IAUS 331 : « SN 1987A, 30 years later »
Booklet of abstracts

The GeV Gamma-Ray Emission Detected by Fermi-LAT Adjacent to SNR Kesteven 41

(IAU GRANTEE)

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Hadronic emission from supernova remnant (SNR)-molecular cloud (MC) association systems has been widely regarded as a probe of the shock-accelerated cosmic-ray protons. We here report on the detection of a gamma-ray emission source with a significance of 24 sigma in 0.2-300 GeV, projected to lie to the northwest of the thermal composite SNR Kesteven 41, using 5.6 years of Fermi-Large Area Telescope (LAT) observation data. The 3 sigma error circle, 0.09° in radius, covers the 1720 MHz OH maser and is essentially consistent with the location of the V_LSR ~ -50 km/s MC with which the SNR interacts. The source emission has an exponential cutoff power-law spectrum with a photon index of 1.9±0.1 and a cutoff energy of 4.0±0.9 GeV, and the corresponding 0.2-300 GeV luminosity is ~1.3×10^{36} erg/s at a distance of 12 kpc. While the inverse Compton scattering scenario would lead to a difficulty in the electron energy budget, the source emission can naturally be explained by the hadronic interaction between the relativistic protons accelerated by the shock of SNR Kesteven 41 and the adjacent northwestern MC. In addition, we present a list of Galactic thermal composite SNRs detected at GeV gamma-ray energies and recent research on GeV gamma-ray emission from SNR-MC systems.

The role of the diffusive protons in the gamma-ray emission of SNR RX J1713.7-3946

(IAU GRANTEE)

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RX J1713.7-3946 is a prototype in the gamma-ray-bright supernova remnants (SNRs) and is in continuing debates on its hadronic versus leptonic origin of the gamma-ray emission. We explore the role played by the diffusive relativistic protons that escape from the SNR shock wave in the gamma-ray emission, apart from the high energy particles' emission from the inside of the SNR. In the scenario that the SNR shock propagates in a clumpy molecular cavity, we consider that the gamma-ray emission from the inside of the SNR may either arise from the IC scattering or from the interaction between the trapped energetic protons and the shocked clumps. The dominant origin between them depends on the electron-to-proton number ratio. The surrounding molecular cavity wall is considered to also produce gamma-ray emission due to the "illumination" by the diffusive protons that escaped from the shock wave during the expansion history. We simplify the algorithm for Li & Chen's (2010) "accumulative diffusion" model for diffusive escaping protons. This two-zone model is fit to the broad-band spectrum of the SNR that incorporates the updated 5-yr Fermi data, with application of the MCMC method. The broad-band spectrum can be well explained by this two-zone model, in which the gamma-ray emission from the inside governs the TeV band, while the outer emission component substantially contributes to the GeV gamma-rays. The two-zone model can also explain the TeV gamma-ray radial brightness profile that significantly stretches beyond the nonthermal X-ray emitting region.

Linking 3D CCSN simulations with observations

(IAU GRANTEE)

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The exact details of the explosion mechanism of core-collapse supernovae (CCSNe) are still an open big question in stellar astrophysics. To help constraining the CCSN explosion mechanism rich information obtained from modern multi-wavelength observations from young CCSN remnants must be exploited. However, there is currently still a missing gap between computer models of CCSNe and what we can observe from the aftermath of these violent explosions due to high demand of computing power for realistic simulations. I will report recent progress to bridge the gap between 3D CCSN simulations and observations, and discuss what we can learn from these studies.

Single versus binary star progenitors of Type IIb supernovae

(IAU GRANTEE)

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Stripped-envelope supernovae (SNe) represent a challenge to our understanding of massive star evolution. Wind mass loss and binary interactions are the leading candidates to explain observations. In this work, we focus on a class of SNe known as Type IIb SNe. These initially exhibit strong Hydrogen spectral lines which weaken and disappear over time and are thought to arise from progenitors that have retained a small amount of their Hydrogen envelope. They are also the only class of stripped-envelope SNe with several identified progenitors and are thus powerful tools for testing our understanding of massive stellar evolution. To identify the evolutionary pathways to Type IIb SNe we model a large population of solar-metallicity single and binary star sequences covering a broad parameter space. First we look for those sequences that satisfy observational constraints for detected progenitors of Type IIb SNe at core-collapse. We find that while single star models cannot satisfy all constraints, binary star models can. We also derive the parameter space and properties of progenitors (and companions) of Type IIb SNe based solely on their residual hydrogen envelope.

The diversity of GRBs and their supernovae: GRB-SN, kilonovae and SN-less GRBs

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Observing the supernovae (SNe) associated to the different types of gamma-ray bursts (GRBs) is one of the few means to study their progenitors. In the past years, it has become clear that the GRB-like events are more heterogeneous than previously thought. There is a clear difference between the long GRBs, which are produced by the collapse of a very massive stars and are normally associated with broad lined Ic supernovae and short bursts, that occur when two compact objects merge and that, at least in some cases, can produce an associated kilonova. Moreover, the SNe associated with different sub-types of long GRBs are also seen to differ, especially those associated with ultra-long duration GRBs. To address this issue in a systematic way we started in 2010 an observing programme at the 10.4m GTC telescope. In this talk I will present the results of our observational programme, including the detection of 12 new GRB-SNe, and will discuss them in the context of all known GRB-SNe. Highlights of our sample are the discovery of the first SN associated with a hyper-energetic burst (130427A), the study of the SN associated with a shock-breakout GRB (GRB 140606A) or the SN associated to the peculiar ultra-long GRB 101225A at z=0.85. The sample includes also the follow-up of several short GRBs in search for kilonovae emissions (GRB 130603B and GRB 160821B are important examples). I will also present new, unpublished photometric and spectroscopic observations of the SNe of GRB 150518A and 150818A.

Investigating the origin of the X-ray emission from SN 1987A

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We present the results of a detailed comparison between our 3-D MHD simulation of SN 1987A and the X-ray data obtained in the framework of the large campaign of observations of this unique source. We adopt a forward modeling approach which allows us to directly synthesize from the model high- and low-resolution X-ray spectra, together with images in different energy bands. We fold the synthetic observables through the Chandra and XMM instrumental response and directly compare models and actual data. We find that our simulations (which describe the evolution from the very aftermath of the SN explosion to the present age) provide a very good fit to the data, by reproducing X-ray fluxes, spectral features, and morphology of SN 1987a at different evolutionary stages. We therefore obtain a deep insight on the physical origin of the observed emission, by revealing the contribution of shocked surrounding medium, dense clumps of the circumstellar ring, and ejecta to the total emission. We finally provide predictions for future observations (to be performed with the forthcoming Athena X-ray telescope) showing the growing contribution of the ejecta X-ray emission.

Evolution and explosions of stars leading to type IIP or IIb supernovae through MESA and SNEC

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We analyze observed light curves of core collapse supernovae, using our models of evolution and explosion of massive stars first with Modules for Experiments in Stellar Astrophysics and then via Supernova Explosion Code. We consider stars that retain large hydrogen envelopes as well as those with mostly stripped hydrogen envelope prior to their explosion, such as the well-observed supernovae SN 2013ej and SN 2011dh. We note that both the mass and the mass loss rate of the progenitor star are key variables that affect the analysis apart from local and host galaxy extinctions, energy of the explosions, size of the star etc. There is relevant high resolution optical and X-ray data both in their pre- and post- explosion phases for these cases. We investigate whether very large mass loss rates (enhanced with respect to the predictions of the Dutch scheme) are required a year or so prior to the explosion, as claimed recently or if nearly steady mass loss rates measured by Chandra X-ray data (but for 15-400 years prior to explosion for SN 2013ej, Chakraborti et al 2016 and consistent with the Dutch scheme), would suffice. As the progenitors of stripped envelope SNe are known to have lost substantial mass during their evolution, we investigate with hydrodynamic models the effects of mass and mass loss and explosion kinetic energy variations on the light curves of type IIb SNe, e.g. SN 2011dh.

Synergy SKA-CTA: supernova remnants as cosmic accelerators

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Supernova remnants (SNRs) are thought to be one of the most important sites where cosmic rays are accelerated with high efficiency and in a wide range of energies. A good test for this hypothesis will be represented by the data jointly collected by next-generation gamma-ray and radio observatories. Radio is currently the most important band to study SNRs, since almost all known Galactic SNRs are radio emitters and about 50% of them are not detected in other bands. Radio emission is fundamental to explore the SNR environment and to shed light on the physical processes involved. Spatial variations of the radio spectral index are hints of interaction with molecular clouds and in general are tracers of the particle acceleration efficiency. Polarimetry reveals the orientation and degree of order of the magnetic field showing the presence of turbulences in the plasma, usually connected to acceleration sites. Radio emission provides then important information on the position and efficiency of the particle acceleration mechanism, supplying independent checks of those high-energy phenomena detectable in X- and gamma-rays. Some examples of observations that we obtained with the state-of-the-art radio facilities will be provided along with the problems we are facing in achieving a complete characterization of SNRs in the Galactic plane, problems that we expect to significantly reduce when the SKA and its pathfinder become fully operational.

Understanding X-ray and gamma-ray emission of RX J1713.7-3946

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RX J1713.7-3946 is the brightest TeV supernova remnant, so it is an important test case for cosmic-ray acceleration. The gamma rays can be easily correlated with the X-ray emission which is dominated by synchrotron emission from accelerated electrons. The absence of ambient thermal X-ray emission (together with only moderate absorption) indicates that the gas is tenuous. There are also indications from CO observations that dense gas is geometrically correlated with X-ray emission, but no proof of directly shocked molecular gas. Since a Central Compact Object sits at the center of the remnant, the mainstream view is that the SNR develops into the wind of its high-mass progenitor and now reaches the shell of denser gas around. The new Fermi data, together with the HESS data, show that the gamma-ray spectrum is hard below 10 GeV, then flat up to a cutoff at a few TeV. This can be explained as Inverse Compton emission, but the break above 10 GeV, as well as the relatively narrow X-ray filaments, are difficult to explain as electron cooling because the X to gamma ray ratio is modest, implying a low magnetic field. Models explaining the gamma rays as hadronic emission remain largely ad-hoc. I will discuss RX J1713.7-3946 in view of recent developments (proper motions, X and gamma-ray geometry) with particular emphasis on leptonic models.

Discovery of Titanium-K Lines in the Northeastern Jet of Cassiopeia A

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Spatial distribution and the amount of ^{44}Ti produced between a compact object and ejecta (i.e. mass cut) reflect the physical condition of supernova explosion and constrain the explosion models. The gamma-ray lines associated with ^{44}Ti decay were detected from the young supernova remnant (SNR) Cassiopeia A with the Compton Observatory. Since then Cassiopeia A has been a prime target for the gamma-ray satellites. Recently, the NuSTAR satellite has reported maps of 68/78 keV lines, which are produced when ^{44}Ti decays into ^{44}Sc by electron capture, demonstrating the spatial distribution of the synthesized ^{44}Ti for the first time. Interestingly, the spatial distribution markedly differs from that of Fe K lines measured with the Chandra X-ray Observatory. Here we report the first detection of Ti K lines in the northeastern jet region of Cassiopeia A with Chandra. We estimate titanium mass as ~10^{-5} solar mass, which indicates that the Ti-K lines should be emitted by stable titanium. We discuss nucleosynthesis in the jet region based on our measurement of the abundances of intermediate and heavy mass elements.

Supernova 1987A and the Birth of Neutrino Astronomy

(INVITED SPEAKER)
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The historical neutrino observation of SN 1987A occurred close to 30 years after the very discovery of these elusive particles and coincided with the beginnings of neutrino astronomy, the exploration of the neutrino sky in a broad range of energies. Today, another 30 years onward, we will look back at the beginnings of neutrino astronomy, the role of SN 1987A, as well as current developments and an outlook to future directions.

Overview of VHE gamma-ray emission from the SNRs detected by MAGIC

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Up to the knee - at energies approaching 1E+16 eV - the spectrum of the cosmic rays is thought to be dominated by accelerated particles produced in galactic supernova remnants (SNRs). While the charged particles do not give away their source location due to interaction with magnetic fields, already at the acceleration sites there would be detectable emission of very high energy gamma rays which result from various mechanisms. These include leptonic processes caused by energetic electrons or positrons such as inverse Compton upscattering of soft photons or Bremsstrahlung, and hadronic processes such as pion decay induced by collisions between cosmic rays and the ambient medium. Up to the present day, about 20 SNRs have been detected at very high energies, a fair fraction of them (Cas A, IC 443, W51, HESS J1834-087, Gamma Cygni) by the MAGIC telescope system. From studying these objects in the gamma regime, general lessons can be learned about the energetics and acceleration mechanisms at play. In this talk, we give an overview over MAGIC observations of SNRs and discuss the probable origin of the gamma-emission. Additionally, we discuss the general picture of TeV-detected SNRs in the multiwavelength context.

Investigating the region of 3C397 in High Energy Gamma-rays

(IAU GRANTEE)
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Here we investigate 3C397 (G41.1-0.3), a Galactic supernova remnant (SNR) and its surrounding in high energy gamma rays using archival data of Fermi Large Area Telescope (Fermi-LAT). 3C397 is one of the brightest radio SNRs and it is classified as a "mixed-morphology" SNR as the central thermal X-ray emission is enclosed by a radio shell. In many earlier works based on a broadband spectral study of the X-ray emission from 3C397 showed that there is a presence of central X-ray hot spot that suggests the association of any compact object with 3C397 which can be pulsar or pulsar wind nebula. PSR J1906+0722 is a recently discovered gamma-ray pulsar in blind search survey of undefined Fermi-LAT sources by the computing system Einstein@Home. We analyzed 7 years of Fermi-LAT data in the energy range of 100MeV-300GeV for PSR J1906+0722. The off-pulse analysis of the gamma-ray flux from the location of PSR J1906+0722 revealed an excess emission just 0.28 degree away from the pulsar source location which is very close to the radio location of 3C397 and the observed gamma ray emission from this location could be resulting from the interaction between the SNR and its neighboring molecular clouds. To investigate the nature of the high energy gamma rays from 3C397, it is modeled with power-law spectrum and its best-fitting position and the best fitted spectral parameters are estimated. We also investigated the nature of the spectral energy distribution for full phase interval data of PSR J1906+0722. In this presentation, we will give the preliminary results of the gamma-ray analysis of 3C397 and PSR J1906+0722.

Magnetically assisted explosions of weakly magnetized stars

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The explosion mechanism of core-collapse supernovae has not yet been fully understood. Although the neutrino heating is the most promising mechanism, state-of-the-art simulations only show less energetic explosions than what are observed in reality. By carrying out high resolution MHD simulations in 2D axisymmetry, we have recently found that the magnetic fields amplified by the magnetorotational instability (MRI) have a great positive impact on the explosion, even though the progenitors initially possess sub-magnetar-class magnetic flux, provided that they have large angular momenta corresponding to millisecond pulsars (Sawai et al. 2014, 2016). Very recently, we even found that the magnetic fields boost the explosions even in progenitors which neither have a large magnetic flux nor angular momentum. In my presentation, I will show above new findings, and also talk about our new results of r-process nucleosynthesis in MRI driven supernovae.

Properties of X-ray emission of an aspherical shock breakout

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Shock breakout is one of the fast phenomena of a supernova, of which duration corresponds to the light crossing time of the visible region. Since its observable features can reflect the motion and the shape of the shock front, studying the relationship between them would be important for obtaining information on the mechanisms of stellar explosion.
The former studies suggest that the shape of the observed light curve of XRO 080109/SN 2008D implies the asphericity of shock propagation (Suzuki & Shigeyama 2010a, Couch et al. 2011). Furthermore, the power-law feature of the observed X-ray spectrum can be explained by bulk-Compton scattering in the shock with radial velocity of > 30% of the speed of light (Suzuki & Shigeyama 2010b). Though the studies revealed the importance of the observational properties, none of them considers both of the light curve and spectrum, taking bulk-Compton scattering into account. In this study, we investigate the relationship between the properties of the emission and the shock motion, by assuming that the shape of the shock front is like an ellipsoid of revolution. We perform a Monte-Carlo calculation, and found that it might be possible to reproduce both the observed light curve and spectrum of XRO 080109, if the oblateness of the shock front is 0.3, the viewing angle is larger than 30 degrees off the axis of symmetry, and the shock velocity is higher than 50% of the speed of light along the line of sight.

How to form a millisecond magnetar ? Magnetic field amplification in protoneutron stars

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Extremely strong magnetic fields of the order of 1E+15 Gauss are required to explain the properties of magnetars, the most magnetic neutron stars. Such a strong magnetic field is expected to play an important role for the dynamics of core-collapse supernovae, and in the presence of rapid rotation may power superluminous supernovae and hypernovae associated to long gamma-ray bursts. The origin of these strong magnetic fields remains, however, obscure and most likely requires an amplification over many orders of magnitude in the protoneutron star. One of the most promising agents is the magneto-rotational instability (MRI), which can in principle amplify exponentially a weak initial magnetic field to a dynamically relevant strength. I will describe our current understanding of the MRI in protoneutron stars, how it differs to the mostly studied context of accretion disks, and show recent results on the impact of physical conditions specific to protoneutron stars such as neutrino radiation, strong buoyancy effects and large magnetic Prandtl number.

Fermi LAT observations of Supernova Remnants

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The Large Area Telescope (LAT), onboard the Fermi satellite, proved to be, after more than 8 years of data taking, an excellent instrument to detect and study spectra and morphologies of Supernova Remnants (SNRs) from a few hundred MeVs to a few TeVs. SNRs are widely thought to be powerful cosmic-ray accelerators and LAT observations are essential to understand and disentangle the physical processes involving accelerated leptons and hadrons. In this work I will highlight the main results of the first LAT SNR catalog and show the latest LAT results on SNR observations together with multiwavelength data.

Spatio-temporal evolution of the nonresonant Bell's instability in the precursors of young supernova remnant shocks

(IAU GRANTEE)

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Collisionless shocks of shell-type supernova remnants (SNR) are the sites of electromagnetic field generation and cosmic-ray acceleration processes. Diffusive shock acceleration process requires turbulent amplified magnetic fields. Such field can be generated through nonresonant (Bell) instabilities when shock-accelerated cosmic rays (CRs) drift in the shock precursor. Using 2D3V Particle-In-Cell (PIC) simulations we investigate the temporal and spatial development of the nonresonant cosmic-ray-current-driven instability which operates upstream of young SNR shocks and may be responsible for magnetic-field amplification, plasma heating, and hydrodynamical turbulence. Applying of the periodic boundary conditions in the earlier PIC simulations of this instability allowed to investigate only its temporal development. Our current study applies a new realistic setup with open boundaries in the CR drift direction. It allows to investigate both the temporal and the spatial development of the instability. The results of this large-scale high-resolution PIC simulation demonstrate magnetic-field amplification by factor up to 20, as expected on the basis of our earlier studies with periodic simulation boxes. The effects of backreaction on CRs that slow down the initial ambient plasma-to-CR relative drift velocity, limit further growth of the turbulence, and lead to its saturation are also re-confirmed. A detailed spatio-temporal structure of the shock precursor, the evolution of CR distribution, and the microphysics of plasma heating and the saturation processes are also discussed.

Multi-wavelength Characterization of Type Ia Supernova Remnants

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Few Type Ia supernova remnants (SNRs) in the Milky Way are known; however, more than 10 Type Ia SNRs have been identified in the Large Magellanic Cloud (LMC). Due to the small distance to the LMC, 50 kpc, physical properties and stellar environments of SNRs can be well resolved and studied. We use the LMC sample of SNRs to characterize and compare the properties and environments of Type Ia and core-collapse SNRs. More specifically, we examine their optical morphology, nebular spectra (whether Balmer-line dominated or not), X-ray luminosity, and stellar environment. In this poster, we characterize the physical properties of Type Ia SNRs in the LMC so that these properties can be used to identify Type Ia SNRs in nearby but more distant galaxies. A complete sample of Type Ia SNRs in a galaxy will allow us to determine Type Ia supernova rate, while the youngest (Balmer-dominated) SNRs can be used to search for surviving companions of their supernova progenitors.

Morphology studies and resolved spectroscopy of the Vela Jr. Supernova remnant with H.E.S.S.

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Supernova remnants are widely considered to be the origin of Galactic cosmic rays. The Vela Jr. (RX J0852.0-4622) Supernova remnant is one of the prime sources for studies of particle acceleration aiming to test this paradigm due to its strong non-thermal emission across the whole electromagnetic spectrum from radio to very-high-energy (E>100 GeV) gamma-rays, young age and proximity to Earth. Being the largest source in the TeV sky, it is one of a few remnants with well resolved shell-like morphology at very-high-energy gamma-rays. Here we present deep H.E.S.S. observations of Vela Jr. with roughly doubled exposure comparing to previously published results. Strongly improved statistics together with new analysis techniques result in a firm determination of the cut-off in the gamma-ray spectrum and allow the spatially-resolved spectroscopy studies. A revised flux measurement makes Vela Jr. the brightest steady source in the sky above 1 TeV and a smooth connection of the H.E.S.S. spectrum to the spectrum at GeV energies as reported by Fermi/LAT provides an exciting opportunity to recover the present-time parent particle population in both leptonic and hadronic scenarios directly from the gamma-ray data alone. These new observations provide us a deeper insight to the physical processes in Supernova remnants.

Characterization of Supernova Remnants in M83

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M83 (NGC 5236), at a distance of 4.61 Mpc, is a large grand-design spiral galaxy with active star formation. A large number of supernova remnant (SNR) candidates have been identified in M83 based on [S II]/H-alpha ratios and/or X-ray emission. The sample of 87 SNR candidates identified by Long et al. (2014), using 790 ks Chandra ACIS observations and complementary optical and radio images, is the most comprehensive. We adopt the optical and X-ray characteristics of Type Ia SNRs in the Large Magellanic Cloud (LMC; see poster by Ou et al. in this conference), and use them to assess the nature of SNRs in M83. We use archival Hubble Space Telescope (HST) H-alpha, [S II], and [O III] images to examine the shell morphology, nebular line ratios, and interstellar environments of the SNR candidates in M83, and HST broadband continuum images to study their underlying stellar population. These nebular properties and stellar environments are compared with those of Type Ia SNRs in the LMC in order to differentiate between Type Ia and core-collapse SNR candidates in M83. We analyze the relative frequencies and spatial distributions of Type Ia and core-collapse SNRs in M83, and present the results in this poster.

ALMA observations of Molecules in Supernova 1987A

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Supernova (SN) 1987A has provided a unique opportunity to study how SN ejecta evolve in 30 years time scale. We report our ALMA spectral observations of SN 1987A, taken in 2014, 2015 and 2016, with detections of we CO, 28SiO, HCO+ and SO, with weaker lines of 29SiO. We find a dip in the SiO line profiles, suggesting that the ejecta morphology is likely elongated. The difference of the CO and SiO line profiles is consistent with hydrodynamic simulations, which show that Rayleigh-Taylor instabilities causes mixing of gas, with heavier elements much more disturbed, making more elongated structure. Using 28SiO and its isotopologues, Si isotope ratios were estimated for the first time in SN 1987A. The estimated ratios appear to be consistent with theoretical predictions of inefficient formation of neutron rich atoms at lower metallicity, such as the Large Magellanic Cloud (about half a solar metallicity). The deduced large HCO+ mass and small SiS mass, which are inconsistent to the predictions of chemical model, might be explained by some mixing of elements immediately after the explosion. The mixing might have made some hydrogen from the envelope to sink into carbon and oxygen-rich zone during early days after the explosion, enabling the formation of a substantial mass of HCO+. Oxygen atoms may penetrate into silicon and sulphur zone, suppressing formation of SiS. Our ALMA observations open up a new window to investigate chemistry, dynamics and explosive-nucleosynthesis in supernovae.

Ultraviolet Extinction of a Few Supernova Remnants

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Supernova is one of the major contributors to interstellar dust, and the supernova-produced dust may be different from AGB stars due to its violent activity in the explosion. In order to understand the characteristics of supernova-produced dust, ultraviolet (UV) extinction is determined to a few supernova remnants which are optically very thin, because UV band is very sensitive to interstellar extinction and the UV band extinction is important to constrain the properties of sub-um-sized dust grains. In combination of the data from the UV photometric survey (GALEX) and from the optical spectroscopic surveys (RAVE and LAMOST), the extinction in the GALEX/NUV and GALEX/FUV bands relative to the selective extinction E(B-V) are determined to a few supernova remnants, which is compared with the average extinction over the entire sky. In addition, the relation of intrinsic stellar color indexes with the GALEX/NUV and GALEX/FUV bands are determined with stellar effective temperature. The dust model will be constructed to explain the derived UV extinction law.

Cosmic ray astroparticle physics: current status and future perspectives

(INVITED SPEAKER)

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The data we are receiving from galactic cosmic rays are reaching an unprecedented precision, over very wide energy ranges. Nevertheless, many problems are still open, while new ones seem to appear when data happen to be redundant. We will discuss some paths to possible progress in the theoretical modeling and experimental exploration of the galactic cosmic radiation.

The infancy of supernova remnants: evolving a supernova into its remnant in 3D

(IAU GRANTEE)
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Recently, first neutrino-driven supernova explosions have been obtained in three-dimensional, self-consistent, first-principle simulations, these models are still not always exploding robustly and, in general, the explosions are not sufficiently energetic. To constrain the explosion mechanism, and the related uncertainties, it is thus very helpful to consider observational constraints: pulsar kicks, progenitor association and supernova remnants (SNR). Recent observations of asymmetries in the supernova ejecta of Cas A(high ratio of ^{44}Ti/^{56}Ni emission, optical light echoes, jet-like features in the X-ray and optical ejecta, and spatially resolved X-ray emission) are very promising, to compare to long-term simulations of the explosion. In addition three-dimensional observations of SN87A are becoming more constraining on the geometry of the ejected material during the explosion. In this talk I will discuss our efforts to model the late time evolution of a 3D supernova explosion, where we include the effects of beta decay which inflates the structures dominated by ^{56}Ni. We tentatively compare to observations and show that the structures we find in the simulations depend sensitively on the quantities plotted.

Spatial distribution of different subtypes of Core-Collapse and Thermonuclear Supernovae in the galaxies

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We investigate the distribution of different types of SNe along the radius and in height above the galactic plane in spiral galaxies. We find out that a significant fraction of CCSNe is not detected in the central parts of the galaxies even by modern CCD search programs. Comparing the radial distributions of subtypes of CCSNe we reveal higher concentration of SNe Ib, Ic and IIn to the centers of the galaxies, while SNe IIP and IIn show similar and more flat distribution. We estimate the scale hight of SNe above the galactic plane and find out that it is smaller for SNe Ibc than for type II SNe.

MUSE Integral Field Observation of the Oxygen-rich SNR 1E0102

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We have observed the Oxygen-rich SNR 1E0102.2-7219 with the integral field spectrograph WiFeS at Siding Spring Observatory and discovered sulphur-rich ejecta for the first time. Follow-up deep DDT observations with MUSE on the VLT (8100s on source) reaching down to a noise level of ~3 x 10^{-20} erg/s/cm²/A/arcsec² lead to the additional discovery of fast moving hydrogen, argon, and chlorine. These detections challenge the interpretation that the progenitor of 1E0102 was a compact core of a Wolf-Rayet star that had shed its entire envelope. In addition to the detection of the products of oxygen-burning, this unprecedented sharp (0.2" spaxel size at ~0.7" seeing) and deep MUSE view of an Oxygen-rich SNR in the Magellanic Clouds contains further exciting discoveries, including [Fe XIV] and [Fe XI] emission we associate with the forward shock and O I and Ne I recombination plausibly associated with the explosion center. We will present this exciting data set and discuss its implications with respect to the explosion mechanism and nucleosynthesis of the associated supernova.

Incidence of stellar rotation on the explosion mechanism of massive stars

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We address the issue of the pulsar spin-up or down by hydrodynamic instabilities during the collapse of a rotating massive star. The impact of stellar rotation on core-collapse supernovae has been mostly investigated considering rapidly-rotating cases so far, related to bipolar explosions. Here we focus on the effect of slower rotation, where the centrifugal force is minor, which can affect the spiral modes of the Standing Accretion Shock Instability (SASI) and of the corotation instability, known as low-T/|W|. Using numerical simulations of a simplified setup in cylindrical coordinates, we show that the amplitude of the SASI spiral mode increases only if the ratio of the shock to the neutron star radii is large enough. A corotation instability develops at large rotation rates and impacts the dynamics more dramatically, leading to a strong one-armed spiral mode. Non-axisymmetric modes are able to redistribute angular momentum radially and affect the pulsar spin at birth. We perform a systematic study of the relationship between the core rotation period and the initial pulsar spin. Stellar rotation rates for which pulsars are spun up or down by SASI are estimated. Rapidly spinning progenitors are modestly spun down, less than ~40%, even in the presence of a corotation instability. Given the observational constraints on pulsar spin periods at birth, this suggests that rapid rotation might not play a significant hydrodynamic role in the core-collapse mechanism when magnetic fields are ignored.

325 MHz and 610 MHz Radio Counterparts of SNR G353.6-0.7 a.k.a. HESS J1731-347

(IAU GRANTEE)
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HESS J1731-347 a.k.a. SNR G353.6-0.7 is one of the five known shell-type Supernova Remnants (SNRs) emitting in the Very High Energy (VHE, Energy > 0.1 TeV) gamma-ray domain. We observed this TeV SNR with the Giant Metrewave Radio Telescope (GMRT) in 1390, 610 and 325 MHz bands. We discover the 325 and 610 MHz radio counterparts of the SNR HESS J1731-347 with the GMRT. Various filaments of the SNR are clearly seen in the 325 and 610 MHz bands. However, the peak in gamma-ray emission comes from the filament which is most faint in radio and the brightest filaments in radio correspond to faint emission in gamma-ray. We explain this anti-correlation in terms of a possible leptonic scenario of the VHE emission. We determine the spectral indices of the bright individual filaments, which were detected in both 610 and 325 MHz bands. Our values are largely consistent with the non-thermal radio emission.

X-ray Synchrotron Polarization from Turbulent Plasmas in Supernova Remnants

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Over the last two decades in the era of precision X-ray astronomy, the evidence for turbulent/convective mixing of heavy elements in core collapse supernovae has been witnessed via high resolution X-ray imaging of their remnants. As the supernova remnants (SNRs) age, they become efficient cosmic ray accelerators at their outer shell shocks. The current paradigm for shock acceleration theory favors turbulent field environs in the proximity of these shocks, turbulence driven by current instabilities involving energetic ions. Yet imaging in optical or X-rays is not yet capable of discerning such turbulence. With the imminent prospect of dedicated X-ray polarimeters becoming a reality, the possibility looms of probing turbulence on scales that couple to the super-TeV electrons that emit X-rays. This paper presents X-ray polarization signatures from energetic electrons moving in simulated MHD turbulence of varying levels of "chaos." The emission volumes are finite spherical slabs that represent the active regions of young SNR shells. Signal measures for various distant observer perspectives are obtained, and energy dependence of the synchrotron polarization is computed. We find, as expected, that the turbulent field energy must be quite limited relative to that of the total field in order for the X-ray polarization degree to be as strong as the radio measures obtained in some remnants. Results are presented for angular resolution apertures pertinent to the planned IXPE, PRAXyS and XIPE polarimeters.

The impact of reverberation on pulsars of low spin-down power: A rotationally-powered magnetar nebula around Swift 1834.9-0846

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A wind nebula, generating extended X-ray emission, was recently detected surrounding Swift 1834.9-0846. This is the first magnetar for which such a wind nebula was found. Soon after this discovery, claims were made arguing that such a nebula could only be produced by an transfer of magnetic energy into particle acceleration, thus being different in nature to all others pulsar wind nebulae (PWNe) known. Here, we investigate whether there is a plausible scenario where the PWN can be sustained without the need of advocating for additional sources of energy other than rotational. We do this by using a detailed radiative and dynamical code that studies the evolution of the nebula and its particle population in time. We find new effects related to the reverberation processes in nebulae of pulsars of low spin-down power, the most important of which is the appearance of adiabatic heating being increasingly dominant over the escape of particles as reverberation goes by. We show that Swift 1834.9-0846's nebula can be explained as being rotationally-powered, as all other known PWNe are, if it is currently being compressed by the environment. The need of reverberation naturally explains why this is the only magnetar nebula detected, and provides estimates for Swift 1834.9-0846's age.

Detections of Thermal X-Ray Emission and Proper Motions in RX J1713.7-3946

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We report the first detections of thermal X-ray line emission and proper motions in the supernova remnant (SNR) RX J1713.7-3946, the prototype of the small class of synchrotron dominated SNRs. Using Suzaku and deep XMM-Newton observations, we have extracted X-ray spectra from the central portion of the remnant, finding clear line features at 1 keV and 1.35 keV. These lines can be best explained as Ne Ly-alpha and Mg He-alpha from a thermal emission component. Since the abundance ratios of metals to Fe are much higher than solar values in the thermal component, we attribute the thermal emission to reverse-shocked SN ejecta. The measured Mg/Ne, Si/Ne, and Fe/Ne ratios of 2.0-2.6, 1.5-2.0, and <0.05 solar suggest that the progenitor star of RX J1713.7-3946 was a relatively low-mass star (<~20 Msun), consistent with a previous inference based on the effect of stellar winds of the progenitor star on the surrounding medium. Since the mean blastwave speed of ~6000 km/s (the radius of 9.6 pc divided by the age of 1600 yr) is relatively fast compared with other core-collapse SNRs, we propose that RX J1713.7-3946 is a result of a Type Ib/c supernova whose progenitor was a member of an interacting binary. We will also present expansion measurements in the south-east region of the remnant, using XMM-Newton observations on a 13 yr time interval.

Jets in supernovae and SNRs

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I will review the jet feedback mechanism (JFM) for exploding core collapse supernovae, and present new results. In particular, I will present the role of jets in shaping some supernova remnants (SNRs). The kinetic energy of the jets that is required to inflate `ears' in some SNRs is compatible with the expectation from the jittering-jets model. I will argue that `ears' in SNRs support the JFM to explode massive stars.

Are supernova remnants in the Galaxy and star-forming regions sources of high-energy neutrinos?

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Recent detection of high-energy cosmic neutrinos by the IceCube Neutrino Observatory has opened the first non-electromagnetic channel to study astrophysical sources, including supernova remnants (SNRs). Indeed, long-held view is that SNRs accelerate cosmic rays to 1 PeV energy and perhaps higher. Thus 20 TeV - 2 PeV cosmic neutrinos detected by IceCube can be directly put to test cosmic-ray acceleration in SNRs. In this talk we focus on angular correlation of cosmic neutrinos with SNRs in the Milky Way which have been detected by very high-energy (VHE) gamma rays, as well as with star-forming regions and starburst galaxies to search for an answer to the origin of high-energy neutrinos related to SNRs. We also model VHE gamma-ray data using cosmic-ray interactions with gas surrounding SNRs and explore if high-energy neutrinos detected by IceCube can be produced in the same process.

3D Supernova Explosion Models for the Production and Distribution of ^{44}Ti and ^{56}Ni in Cassiopeia A

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The spatial and velocity distributions of nuclear species synthesized in the innermost regions of core-collapse supernovae (SNe) can yield important clues about explosion asymmetries and the operation of the still disputed explosion mechanism. Recent observations of radioactive ^{44}Ti with high-energy satellite telescopes (NuSTAR, INTEGRAL) have measured gamma-ray line details, which provide direct evidence of large-scale explosion asymmetries in Supernova 1987A, and in Cassiopeia A (Cas A) even by mapping of the spatial brightness distribution (NuSTAR). Here, we discuss three-dimensional (3D) simulations of neutrino-driven explosions which can explain basic properties of the production and anisotropic ejection of radioactive nuclei in these stellar explosions.

The Type IIb Supernova 2016gkg and Its Remarkable Blue Progenitor

(IAU GRANTEE)
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The progenitor stars of Type IIb supernovae (SNe IIb) – whose spectra exhibit strong hydrogen P-Cygni profiles at early times and rapidly evolve to be helium-dominated – are thought to explode as the end points of binary star systems where the primary star has been stripped by a companion. The exact end stage of this primary star is poorly constrained, and only a few examples have been identified from pre-explosion imaging. These examples span a range of luminosities and temperatures from red to blue supergiants, which correlates with the variety in their supernova explosions. I will discuss the Type IIb supernova 2016gkg and its progenitor star identified in pre-explosion Hubble Space Telescope imaging. The star was very blue and luminous, consistent with the progenitor of the SN IIb 2008ax. Also like SN 2008ax, the optical spectrum of SN 2016gkg evolved rapidly in Halpha, pointing to the explosion of a heavily-stripped star. I will discuss modeling of the early-time SN 2016gkg light curve, which constrains the explosion date and radius of the progenitor star and is consistent with pre-explosion imaging. Finally, I will detail ongoing efforts to observe the optical evolution of SN 2016gkg with particular focus on asymmetries and abundances in the ejecta and the potential for interaction with circumstellar matter.

The SNR-CR connection: a modern prospective

(INVITED SPEAKER)

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After one century from the discovery of cosmic rays by Victor Hess, the origin of these particle is still puzzling the astrophysical community. During the past forty years a complex theoretical picture has been built up, based on the idea that supernova remnants (SNRs) should be the main factories of Galactic cosmic rays. The key mechanism of this so called "supernova remnant paradigm" is the diffusive particle acceleration which occurs around shocks produced by the expansion of SNRs. In this talk I will review the basic features of particle acceleration theory around shocks, with special attention on the role of magnetic field amplification induced by the back reaction of accelerated particles themselves. Then I will focus on the theoretical predictions on non-thermal radiation emitted by SNRs with emphasis on X-ray and gamma-ray emission, comparing them with recent observations by satellites as well as by Cherenkov telescopes, showing how multiwavelength spectra can be used to estimate the shock dynamical properties and the efficiency of CR acceleration. Finally I will comment on the role of cosmic rays in the galactic evolution through the generation of galactic winds. Such winds could be able to subtract gas from the Galactic plane, hence lowering the star formation rate and polluting the intergalactic medium.

Multimessenger predictions from 3D Core-Collapse Supernova Models

(INVITED SPEAKER)

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Based on three-dimensional core-collapse supernova simulations, I will review the signatures of gravitational-wave and neutrino emission. I will also discuss how we can extract the information of the yet-uncertain mechanisms of explosion by analyzing the multi-messenger signals.

Constraints on the progenitors from radio and X-ray observations of core collapse supernovae

(INVITED SPEAKER)

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It is extremely difficult to get direct information of the supernovae progenitor star, and for a few known cases they are limited to very nearby supernovae. Circumstellar interaction of the supernova ejecta with the surrounding wind expelled from the progenitor star towards end stages of its evolution provide a unique way to have a handle on the behaviour of the late time evolution of the supernova progenitor star. In this talk I will review our current understanding of the supernovae exploding in dense environments with inputs from radio and X-ray bands.

Observational Constraints on the Supernova Engine

(INVITED SPEAKER)

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SN 1987A marked a renaissance in our understanding of the supernova engine driven by the wealth of data provided by this single supernova event. Observations of SN 1987A both provided direct confirmation of the core-collapse engine (e.g. neutrinos) and discovered new evidence leading theory to explore convection mechanisms and asymmetries that have ultimately led to our current paradigm for this supernova engine. Since 1987A, observations and theoretical predictions have both expanded tremendously, allowing theorists to home in on increasingly detailed aspects of the supernova engine. I will review aspects of the observational data that have confirmed and placed constraints on the supernova engine as well as list some of the outstanding issues comparing the supernova engine to data.

Massive Stars explosions

(INVITED SPEAKER)

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Massive stars are expected to end their lives as core-collapse supernovae. Wide-field surveys have discovered several new types of stellar transients that may be related to rarer events such as pair-instability supernovae. Despite discovering an increasing number of supernovae, their explosion mechanisms are still debated. I will review our knowledge on massive-star supernovae from an observational point of view, including core-collapse supernovae and rarer events like superluminous supernovae. I will also discuss how future surveys will help reveal their nature.

Supernova lessons from low- and high-energy neutrinos

(INVITED SPEAKER)

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Neutrinos are key particles in core-collapse supernovae. Neutrinos can be direct probes of the still uncertain and fascinating supernova mechanism. Characteristic predictions of the expected neutrino signal from the burst as well as detection perspectives of MeV-TeV neutrinos from the stellar collapse will be reviewed.

Fermi acceleration under control: eta Carinae

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We have compared data obtained with the Fermi Large Area Telescope on two passages of eta Carinae at periastron and with the expectation of hydrodynamic simulations including particle acceleration. Two emission components can be distinguished. The low energy component cuts-off below 10 GeV and its flux, modulated by the orbital motion, varies by a factor less than 2. Short term variability occurs at periastron. The flux of the high energy component varies by a factor 3-4 but differently during the two periastrons. The variability observed at low energy, including some details of them, and these observed at high energy during the first half of the observations, match the prediction of the simulation. Diffuse shock acceleration provides a convincing match to the observations and new diagnostic tools to probe the geometry and energetics of the system. Eta Carinae is bright enough to be detected by IceCube observing for many years. Orbital modulations of the high-energy component can be distinguished from these of photo absorption by the four large size telescopes of the Cherenkov Telescope Array to be placed in the southern hemisphere.

Disentangling the hadronic from the leptonic emission in the composite SNR G326.3-1.8

(IAU GRANTEE)

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Supernova remnants (SNRs), pulsar wind nebulae (PWNe) and pulsars are the usual suspects to accelerate the bulk of cosmic rays in our Galaxy. In those objects the gamma-ray emission allows us to probe the population of high-energy particles and in particular the population of accelerated hadrons radiating through the pion-decay mechanism. Those Galactic accelerators are most of the time studied as independent objects, even if, in the case of some core-collapse supernovae, the shell-like SNR, the PWN and the pulsar are in fact present in the same object. In the case of composite SNRs, both the SNR shell and the PWN are bright enough to be observed in the same source. Understanding the nature of the gamma-ray emission in such objects can be challenging for sources of small angular extension. Previous studies of the composite SNR G326.3-1.8 (radius=0.3°) revealed bright and extended gamma-ray emission but its origin remained uncertain. With the recent Pass8 Fermi-LAT data that provide an increased acceptance and angular resolution, we investigate the detailed morphology of this composite SNR in order to distinguish the SNR from the PWN contribution. In particular, we take advantage of the new possibility to filter events based on their angular reconstruction quality (PSF types). Disentangling the different components is crucial to clearly model the spectral properties of the source and to understand its nature.

Linking SNe and SNRs. Time-dependent injection in SN 1987A and gamma-ray emission of IC 443

(IAU GRANTEE)
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The acceleration times of the highest-energy particles which are responsible for the gamma-rays in young and middle-age supernova remnants (SNRs) are comparable with the SNR age. If the number of particles starting acceleration was varying during early times after the supernova explosion then this variation should be reflected in the shape of the gamma-ray spectrum. In order to analyse this effect, we consider detailed observations of the time variation of the radio spectral index in SN1987A. By using these observations and the solution of the non-stationary equation for the diffusive shock particle acceleration, we reconstruct the time evolution of the particle injection efficiency (fraction of particles to be accelerated) in SN1987A. The extracted dependence is then applied to derive the particle momentum distribution after the time-dependent acceleration till the age of IC443. Having the particle distribution, we model the gamma-ray spectrum of this SNR. We show that the break in the proton spectrum around 50 GeV needed to explain the gamma-ray emission from IC443 is a natural consequence of the early variation of the cosmic ray injection. The very good correspondence between the observed radio index evolution in SN1987A and gamma-ray spectrum of IC443 demonstrate that the very-high energy gamma-rays originate from particles which began acceleration during the first months after the supernova explosion. We conclude that the measurements of the radio index variation in supernovae are quite important to understand the physics of particle injection in the diffusive shock particle acceleration and that the shape of the hadronic gamma-ray spectrum in SNRs critically depends on the temporal variation of the cosmic ray injection process in the immediate post explosion phases.

High-resolution observations of dust in SN1987A

(IAU GRANTEE)
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The dust produced by supernovae is an important topic for understanding supernova physics and the chemical evolution of galaxies. Recent ALMA observations of SN 1987A have allowed us to peer into the inner ejecta to the cool dust, with spatial resolution from 0.3" at ~300 GHz down to 0.09" at ~680 GHz - an improvement over the previous 300 GHz Cycle 0 observations at 0.69". Comparison of the dust location and morphology with other multiwavelength emission presents an interesting picture of the role dust plays in the ejecta. The mm-FIR SED is compared to radiative models to study the dust composition 30 years after the initial explosion. Fits to the ring emission also probe the drift of the center of the system over time.

High quality sampling of SNRs in the radio band

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Synchrotron radio emission is a critical tracer of particle acceleration processes in supernova remnant (SNRs) shocks, directly tracing the energy spectra of the relativistic electrons accelerated by the blast wave. High-resolution and high-sensitivity studies of the radio emitting plasma in SNRs play a key role in assessing the spectral and spatial characteristics of the emission, as they permit the recognition of distinct components in the source and the analysis of the influence that the ambient inhomogeneities have in acceleration mechanisms at the SN shock front. In this talk, all these fundamental aspects together with the role of SNRs as the presumed sources of Galactic cosmic rays will be discussed for a sample of well-known objects on the basis of deep radio imaging coupled with a multi-wavelength coverage up to gamma-rays.

Balmer-dominated shocks in Tycho's SNR: omnipresence of CRs

(IAU GRANTEE)
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We present wide-field, highly spatially and spectrally resolved optical observations of shock filaments in the northeastern (NE) rim of Tycho's supernova remnant (SNR) in order to investigate and reliably isolate the signal of possible cosmic ray (CR) acceleration. Alongside observations in high-energy bands, optical wavelengths also shed light on acceleration of hadronic component of CRs in SNRs. Spectra of Balmer-dominated shocks (BDSs), typically observed around Type Ia SNRs, show the presence of strong two-component Halpha lines: a narrow (FWHM ~ 10 km/s) and a broad component (FWHM ~ 1000 km/s), both originating downstream of the shock in radiative decays of hydrogen atoms that either have been excited in the shock or have undergone charge exchange reactions with the post-shock protons, respectively. CRs affect the Halpha-line parameters: heating the cold neutrals in the interstellar medium results in broadening of the narrow Halpha-line beyond 20 km/s, the maximally allowed thermal broadening, but also reduces the broad Halpha-line width due to energy being removed from the protons in the post-shock region. For the first time we show that the width of the narrow Halpha line being much larger than 20 km/s is not an effect of differential projection and limited spatial resolution, nor a spurious result of a broad-neutral precursor and the associated intermediate (FWHM ~ 100 km/s) line component. Perhaps most importantly, we show that the CR-induced narrow line broadening extends across the entire NE rim, implying that CR acceleration is ubiquitous and its relation to locally varying shock conditions can now be investigated. In addition to the narrow line, we find significant (Bayesian) evidence for the theoretically suggested intermediate component in 24% of the shock, and quantify its parameters as well.

High-resolution spectral imaging of Supernova Remnants IC443 and W44 at 22 GHz with the Sardinia Radio Telescope

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Galactic Supernova Remnants (SNRs) are commonly identified as extended radio sources with steep spectra. To date, a multi-wavelenght coverage (ranging from radio to ultra-high-energies) of a part of these SNRs has been provided. The nature of the high-energy emission is still debated and the co-spatiality study of the radio and gamma-ray emissions could represent a crucial test for disentangling the two basic possible scenarios represented by leptonic (Inverse Compton and bremsstrahlung emission) and hadronic models (π^0 mesons decay emission). Radio emission is expected up to 20-50 GHz, but even for the most interesting and bright objects, high-resolution images at frequencies above 5 GHz in the confused regions of the Galactic Plane are lacking and not easily achievable. In fact, interferometric imaging synthesis of large structures (> 1°) at high-frequencies becomes unfeasible. In the framework of the Astronomical Validation and Early Science activities of the Sardinia Radio Telescope (SRT, www.srt.inaf.it), we performed 22 GHz imaging observations of SNR W44 and IC443. Thanks to the single-dish imaging performances of SRT and innovative ad hoc imaging techniques, we obtained maps that provide a detailed structure of the remnants. We use the high-frequency radio studies of SNRs to better characterize the spatial-resolved spectra and search for possible spectral steepening or breaks in selected SNR regions, assessing the high-energy tail of the region-dependent electron distribution.

Radioactive decay of GRB-SNe at late-times

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We compare the light curves of a sample of more than a dozen Type Ic SNe, including normal Ic's, Ic-bl, the SNe of LGRBs and peculiar Type Ic's. We find that when the early light curve is used to estimate the ^{56}Ni production of the SNe, and the light curves of the SNe are normalized by their Ni production, with the exception of the peculiar Type Ic SNe, the light curves lie on top of one another with remarkable regularity, showing a scatter of less than 25% at late times (between 60 and 150 days rest frame). Thus the 56Ni estimated from the early light curve accurately predicts the amount of ^{56}Co seen decaying in the late-time light curve. While we are studying a very wide range of SNe Ic energies and subtypes (from relatively low velocity explosions to broad lined to GRB-SNe), the excellent scaling between the late-time light curves implies that in spite of the great energy of their relativistic jets and high kinetic energies, the light curves of these supernovae are powered primarily, if not entirely, by the radioactive decay cascade of ^{56}Ni.

Upper limits on gamma-ray emission from SNe serendipitously observed with H.E.S.S.

(IAU GRANTEE)
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Supernovae remnants (SNRs) have been proven to be able to accelerate cosmic rays (CR) up to ~ 10^{14} eV. There is however no observational evidence so far that they can accelerate particles up to the "knee" of the CR spectrum at 10^{15} eV (= 1 PeV). From the point of view of energetics, supernovae (SNe) and their remnants are the best candidates to be the sources for cosmic rays. Some models indicate that particles with PeV energies are accelerated in the first year(s) after the explosion. This requires collisionless shocks moving through a dense circumstellar medium, as this gives rise to the particles being accelerated to higher energies (see e.g. Katz et al. 2011, Marcowith et al. 2014). Very-high-energy (VHE) gamma-ray emission will be produced by proton-proton interactions. The current generation of Air Shower Cherenkov Telescopes like the High Energy Stereoscopic System (H.E.S.S.) may be able to detect them (see e.g. Cardillo et al. 2015). Within that context we searched for young SNe in nearby galaxies serendipitously observed by the H.E.S.S telescopes, and this within a year after the outburst. Data collected between December 2003 and March 2015 were considered and compared to recent extragalactic SNe catalogues. Nine type-II SNe were selected and analysed. No significant emission from these SNe has been found, and upper limits to their VHE emission are reported.

SNRs interacting with molecular clouds, a tracer of hadron acceleration at the SN shocks

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Extensive observational evidence shows that supernova remnants (SNRs) are potent particle accelerators in our Galaxy. However, the connection between these sources and the production of Galactic cosmic rays particles (mostly protons and ions) with energies up to 10^{15}-10^{16} eV/nucleon has still many intriguing aspects. Gamma-ray emission detected in correlation with molecular clouds (MCs) interacting with SNRs is an effective tool to illuminate the presence of hadronic emission provided by the decay of π^0 mesons produced after the collision of protons accelerated at the SN shock fronts with dense ambient gas. In this talk, observational evidence of new cases of SNRs/MCs associations correlated with emission in the GeV and TeV gamma-ray domains, are presented. The new results, along with the modeling of the spectral energy distribution of the gamma-ray photons were used to test the presence of hadronic acceleration in SNRs.

Unveiling the structure of the progenitors of type-IIP Supernovae through Multiwaveband observations

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Observational evidence from archival, pre-explosion images, suggests that progenitors of type-IIP SNe (SNe-IIP) have 8 < M < 15 M_sun. However, the post-explosion temporal evolution of the event suggests that even in this mass range, the stellar evolutionary paths, the ensuing mass loss, and the eventual interaction of the supernova shock with the resulting CSM can show considerable diversity. Here we present the results from our program on multi-waveband (mainly optical) observations of SNe-IIP. Mass loss in their progenitors, with a massive and extended H-envelopes, is seen to occur via both strong stellar winds, or episodic mass ejections. Moreover, some type-IIP SNe also show unusually steep decline, characteristic of type-IIL (e.g. SN-IIP 2013ej). Our early and late-time spectrophotometry of these events shows CSM- shock interaction to varying degree among progenitors of comparable mass. Combined with X-ray data, our findings suggest that SNe-IIP progenitors can lose mass via strong stellar winds (e.g. SN2013ej, and SN2014cx), have episodic mass loss (SN2011ja), or have negligible mass loss (SN2012aw, SN2013ab).

Outbursts of evolved massive stars: SN 2015bh and its relatives

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Massive stars in the final phases of their lives are rather unstable and frequently expel large amounts of material. Some of these eruptions can be almost as bright as a core-collapse (CC-) SN and resemble CSM-powered Type IIn SNe, infact the distinction between those "impostors" and "real" CC-SNe is not always easy. SN 2015bh in NGC 2770 is one of those interesting examples. It experienced frequent, short-term variabilities for at least 21 years and finally erupted or exploded in a bright event in May 2015 with a peak magnitude of -17.5, preceeded by a less luminous precurser in the months prior to that. Its spectra are consistent with an LBV in outburst before May 2015 and before a complex double P-Cygni profile appears during the main event. During the entire span of pre-explosion observations were always situated red wards of LBVs in outburst in the HR diagram, at a similar temperature than the Eta Car great eruption but at slightly lower luminosities. A very similar event was SN 2009ip and possibly SNhunt 248 while the short-term outbursts of the SN 2000ch impostor seems to mimic the decade-long outburst phase of SN 2015bh. Whether any of these events survive the following "main event" can currently not be answered securely. If it did survive, this might be an attractive way to shed the outer envelope and create a Wolf-Rayet star in only a matter of decades. Future large-scale high-cadence surveys might detect many more of these curious events.

Turbulent magnetic reconnection and particle acceleration at nonrelativistic shocks of young supernova remnants

(IAU GRANTEE)
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Particle heating and acceleration, and the effects of spontaneous turbulent magnetic reconnection at high Mach number perpendicular nonrelativistic collisionless shocks for parameters that are applicable to conditions at young supernova remnants are studied with two-dimensional fully kinetic Particle-In-Cell (PIC) simulations. These unprecedented high-resolution large-scale simulations sample a representative portion of the shock surface to fully account for time-dependent effects of the cyclic shock reformation. The physics of strong shocks is governed by ion reflection that leads to the formation of magnetic filaments in the shock ramp, resulting from Weibel-type instabilities, and to electrostatic Buneman modes in the shock foot. Merging magnetic filaments can also trigger spontaneous turbulent magnetic reconnection in the shock transition. We discuss the nonlinear shock structure and particle energization processes with the emphasis on the dynamics of electron heating and pre-acceleration needed for their injection into diffusive shock acceleration. On this line we study physical and numerical parameter space to find conditions providing the most efficient acceleration. The importance of turbulent magnetic reconnection processes is scrutinized. Relevance of our results to the physics of fully three-dimensional systems is discussed.

The Progenitors of Core-Collapse Supernovae

(INVITED SPEAKER)
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Ideally, we would like to know how stars of different initial masses and metallicities explode at the end of their evolution. A good way to constrain our understanding of the fate of stars is to compare the observed properties of supernova progenitors to predictions of stellar evolution models. These predictions rely on our understanding of the combined effects of various processes: mass loss, convection, rotation, magnetic fields and binary interactions. In this talk, I will start by presenting what we know about these processes and their impact on the evolution of massive stars. I will then talk about some of the key uncertainties affecting these predictions: convective boundary mixing, evolution at the boundary between massive and intermediate-mass stars, combined effects of mass loss, rotation and binarity to remove the hydrogen- and possibly the helium-rich layers. Finally, I will conclude and discuss the next steps needed to further improve stellar evolution models and their predictions.

CSI in Supernova Remnants

(INVITED SPEAKER)
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Supernovae (SNe) explode in environments that have been significantly modified by the SN progenitors. For core-collapse SNe, the massive progenitors ionize the ambient interstellar medium (ISM) via UV radiation and sweep the ambient ISM via fast stellar wind during the main sequence phase, replenish the surroundings with stellar material via slow winds during the luminous blue variable (LBV) or red supergiant (RSG) phase, and sweep up the circumstellar medium (CSM) via fast wind during the WR phase. If a massive progenitor was in a close binary system, the binary interaction may cause mass ejection in certain preferred direction, such as the orbital plane, and even bipolar outflow/jet. As a massive star finally explodes, the SN ejecta interact first with the CSM that was injected and shaped by the star itself. As the newly formed supernova remnant (SNR) expands further, it encounters interstellar structures that were shaped by the progenitor from earlier and earlier times. Therefore, the structure and evolution of a SNR is largely dependent on the initial mass and binarity of the SN progenitor. The Large Magellanic Cloud (LMC) has an excellent sample of over 50 confirmed SNRs that are well resolved by Hubble Space Telescope, Chandra X-ray Observatory, and Spitzer Space Telescope. These multi-wavelength observations allow us to conduct stellar forensics in SNR and understand the wide variety of morphologies and physical properties of SNRs observed.

Explosion and Nucleosynthesis of Massive and Very Massive Stars

(INVITED SPEAKER)
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Single stars more massive than about eight times the mass of the sun are generally thought to undergo a violent death - their core collapsing and making a neutron star or a black hole, whereas the outer layers may be ejected in a violent explosion - the supernovae. Some of the most massive stars may undergo an even more dramatic event, a complete disruption by thermonuclear burning - pair-instability supernovae that can be as impressive as the counterpart of up to one hundred Type Ia supernovae going off at the same time in the same spot. Those stars that make black holes may do so early during the collapse or only after some time, due to material falling back after the original explosions, and the material falling back could, if endowed with sufficient angular momentum, still induce a powerful explosion, at least for some of them. But even if a neutron star is formed, the resulting explosion energy could vary dramatically, depending on progenitor, and, in particular, if rotation is involved and some of the rotational energy can be tabbed efficiently. All of these different outcomes account for quite a variety of observational consequences. A focus of this talk will be to discussion different explosion models and their impact on expected nucleosynthesis.

Supernova remnants dynamics

(INVITED SPEAKER)

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Supernova remnants are the site of a number of physical processes (shock-heating, non-equilibrium ionization, hydrodynamic instabilities, particle acceleration, magnetic field amplification...). Their related emission processes provide us with a large set of observational data. Supernova remnants are the result of the interaction of high-velocity material ejected by the supernova explosion with the medium surrounding the progenitor star. This interaction gives rise to a double-shock structure that lasts for hundreds of years, with a forward shock and a reverse shock compressing and heating to tens million of degrees the surrounding medium and the ejecta, respectively. It is mostly in this phase that young supernova remnants provide information on their explosion mechanism through spectro-imaging observations of the ejected nucleosynthesis products and their dynamics, notably in the X-ray domain. I will review these observations and their implications for our current understanding of the dynamics of supernova remnants. I will conclude on the prospects with future facilities.

Bridging the gap between SNe and their remnants through multi-dimensional hydrodynamic modeling

(INVITED SPEAKER)

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Supernova remnants (SNRs) are diffuse extended sources often characterized by a rather complex morphology and a highly non-uniform distribution of ejecta. General consensus is that such a morphology in young SNRs reflects, on one hand, pristine structures and features of the progenitor supernova (SN) explosion and, on the other hand, the early interaction of the SN blast wave with the inhomogeneous circumstellar medium (CSM) formed in the latest stages of the progenitor's evolution. Thus multi-wavelength observations of SNRs may encode information about the physical properties of both the interacting ejecta and the shocked CSM. Deciphering the observations might open the possibility to reconstruct the ejecta structures soon after the SN explosion and the structure and geometry of the medium immediately surrounding the progenitor star. This requires accurate and detailed numerical models which describe the evolution from the SN explosion to the remnant development and which connect the emission properties of the remnants to the progenitor SNe. Here we show how multi-dimensional SN-SNR hydrodynamic models have been very effective in deciphering observations of SNR Cassiopeia A and SN 1987A, thus unveiling the average structure of ejecta in the immediate aftermath of the SN explosion and constraining the 3D pre-supernova structure and geometry of the environment surrounding the progenitor SN.

Bringing the High Energy Sky into Focus: NuSTAR's View of Supernova Remnants

(INVITED SPEAKER)
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Understanding the origin of supernova explosions remains one of the outstanding problems in astrophysics. This is true of both explosions resulting from the collapse of a massive star as well as the thermonuclear explosions (Type Ia) that are commonly used as “standard candles” in cosmology. X-ray and gamma-rays produced promptly during these explosions as well as those produced in the decay of radioactive elements found in supernova remnants can be used to study the energetics of the explosion. I will provide an overview of recent high energy X-ray observations of supernovae and supernova remnants using the Nuclear Spectroscopic Telescope Array (NuSTAR). The NuSTAR Small Explorer (SMEX) mission, launched June 13, 2012, is the first focusing high-energy X-ray telescope in orbit. Covering the hard X-ray band from 3–79 keV, NuSTAR provides more than a 100-fold improvement in sensitivity, more than a 10-fold improvement in angular resolution and source positioning capability, and significantly improved spectral resolution compared to previous instruments that have operated in this band. This has enabled a unique set of observation tools for studying supernovae and the ejecta left behind by the explosions. I will review recent results from NuSTAR and place them in the context of theoretical models.

The Radio Remnant of Supernova 1987A - A Broader View

(INVITED SPEAKER)
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Supernova remnants (SNRs) are powerful particle accelerators. As a supernova (SN) blast wave propagates through the circumstellar medium (CSM), electrons and protons scattered across the shock gain energy by entrapment in the magnetic field. The accelerated particles generate further magnetic field fluctuations and local amplification, leading to cosmic ray production. The wealth of data from SNR 1987A is providing a template of the SN-CSM interaction, and an important guide to the radio detection and identification of core collapse SNe based on their spectral properties. Thirty years after the explosion, radio observations of Supernova 1987A span from 70 MHz to 700 GHz. We review extensive observing campaigns with the Australia Telescope Compact Array (ATCA), the Atacama Large Millimeter/submillimeter Array (ALMA), the Australian Long Baseline Array, the Parkes Observatory, and the Murchison Widefield Array. Observations across the radio spectrum indicate rapid changes in the remnant morphology, while there is a decrease of the flux density increase rate. Current ATCA and ALMA observations show that the SNR has entered a new evolutionary phase, as the shock propagates beyond the highly dense circumstellar torus created by the progenitor star and the ejecta has cooled sufficiently for it to produce copious quantities of dust and molecules.

SN 1987A at 30 years

(INVITED SPEAKER)
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The most important recent developments of the ring collision and the ejecta structure during the last 10 years in different wavelength ranges will be reviewed. The increasing flux from the ring reached a peak at about 7000 days and is now decreasing. At the same time new spots are seen outside the ring. The ejecta is showing a highly asymmetric structure, and is together with Cas A, the only supernova where we can obtain three dimensional information, which has made possible direct comparisons with explosion models. The energy input to the core is still dominated by radioactive decay of ^{44}Ti, while the envelope receives most of its energy from thermalized X-rays from the ring collision. It is now clear that the supernova is entering the remnant phase. Recent observations of molecules and dust in both the NIR and radio gives complementary information about the cool inner ejecta. Finally, limits on the compact object will be discussed.

SN 1987A: The Supernova of a Lifetime

(INVITED SPEAKER)
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Supernova 1987A was full of surprises in 1987 and has continued to surprise and delight astronomers for the past 30 years. An ongoing series of observations from space, first with the International Ultraviolet Explorer satellite, and, after its launch in 1990, with the Hubble Space Telescope have revealed important aspects of the evolution of the star that exploded, the circumstellar matter lost by that star in the tens of thousands of years before the explosion, and the intricate interaction between the expanding debris and the circumstellar surround. This talk will recount some of those surprises and sketch the physical changes that are occurring now as SN 1987A morphs gradually into a supernova remnant. While radioactive decay of nuclides produced in the first seconds of the explosion have powered the emission from the debris, there has been a shift to emission that is powered by the conversion of kinetic energy into radiation as the supernova becomes a supernova remnant. I will show the latest images from a long series of observations with the Hubble Space Telescope and place new limits on the emission from a point source at the center of SNR 1987A.

Now and the Future of Broadband SNR Models

(INVITED SPEAKER)
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Confronted by observational data of ever increasing quality and quantity, the ability of a SNR model to explain rich multi-wavelength emission properties is no longer a luxury but a necessity. In this talk, I will review the current status of modern broadband modeling of young to dynamically evolved SNRs and what we have learnt so far. Then I will elaborate on my vision for the future prospects of this field, especially focusing on the importance of synergy with state-of-the-art developments in progenitor star and supernova researches as well as with future ground-based and space observatories.

Supernova Remnants and high and very high energy gamma-ray observations

(INVITED SPEAKER)
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Over the past 15 years, the field of high energy and very high energy gamma-rays astrophysics has blossomed. In this period, supernova remnants were established as sources of high-energy gamma-rays. Further detailed study of both populations of SNRs, and of individual objects have revealed a rich phenomenology and provided key insights into the physical nature of supernova remnants and their connection to the populations of galactic cosmic-rays. In this presentation, I will summarize the key results from observations of supernova remnants above 100 MeV and comment on prospects future advances in this area.

e-ASTROGAM : towards a new space mission for gamma-ray astronomy

(INVITED SPEAKER)
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e-ASTROGAM is a gamma-ray observatory recently proposed as a Medium-size mission for the ESA science program. It is dedicated to the observation of the Universe with unprecedented sensitivity in the energy range 0.2 – 100 MeV, extending up to GeV energies, together with a ground-breaking capability for measuring polarization in the MeV range. The e-ASTROGAM payload consists of a single telescope for the simultaneous detection of Compton and pair-producing gamma-ray events. The core mission science addresses three major topics of modern astrophysics: (i) the physics of extreme sources producing relativistic jets and outflows both in our Galaxy and in active galactic nuclei, (ii) the origin and impact of high-energy particles on galaxy evolution, and (iii) the nucleosynthesis and chemical enrichment of the Milky Way. In this talk, I will highlight the expected contributions of e-ASTROGAM to the physics of supernovae and the acceleration of cosmic rays in supernova remnants.

ANTARES and KM3NeT programs for the supernova neutrino detection

(INVITED through OCEVU-LabeX)
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The currently working ANTARES neutrino telescope has capabilities to detect high energy neutrinos produced in astrophysical transient sources. Neutrino alerts are regularly generated to trigger multi-wavelength observatories for special events, such as two or more neutrinos, coincident in time and direction, or single neutrinos of very high energy or with directions compatible with the one of local galaxies. Potential sources include gamma-ray bursts, core-collapse supernovae, and flaring active galactic nuclei. In particular, the neutrino detection together with the multi-wavelength observations may reveal hidden jets in the supernova explosions. Supernovae remnants are currently the most promising acceleration sites of the cosmic rays in our Galaxy. Neutrino emission is expected during the cosmic ray interaction with the surrounding matter. The neutrino telescopes in the Northern hemisphere have excellent visibility to the most of the galactic supernovae remnants. Recent results on the search for point-sources with the ANTARES detector and the prospects for the future KM3NeT detector will be presented. Although ANTARES and KM3NeT detectors are mainly designed for high energy neutrino detection, the MeV neutrino signal from the supernova can be identified as a simultaneous increase of the counting rate of the optical modules in the detector. The noise from the optical background due to K40 decay in the sea water and the bioluminescence can be significantly reduced by using nanosecond coincidences between the nearby placed PMTs. This technique has been tested with the ANTARES storeys consisted of three 10-inch PMTs and is optimized for the KM3NeT telescope where the directional optical modules containing 31 3-inch PMT provides very promising expectations.

Particle accelerators in the Large Magellanic Cloud

(INVITED through OCEVU-LabeX)

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I review the recent progress in gamma-ray observations of the Large Magellanic Cloud using the Fermi Large Area Telescope. The results include the detection of rare and extreme sources, and offer a perspective that usefully complements Milky Way studies on particle acceleration and cosmic ray propagation on large scales. In a second part, I present the current plans and prospects for future observations of the Large Magellanic Cloud at very high photon energies with the Cherenkov Telescope Array.

VHE gamma-rays from the remnants of Galactic core-collapse supernovae

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We now have VHE gamma-ray observations of about two-thirds of the known Galactic SNRs, thanks to a decade of observing with Cherenkov telescope arrays and in particular the coverage of the H.E.S.S. Galactic Plane Survey. These rich datasets allow us to investigate the VHE gamma-ray emission not just from individual remnants or the SNR population as a whole, but also from subsets of that population. In this contribution, we will explore the VHE emission, or in some cases the lack thereof, from the subset of Galactic remnants thought to arise from core-collapse (CC) SNe. We will examine the properties of the VHE emission (or the derived limits, in cases of non-detection) from these remnants and what we can infer about particle acceleration in CC SNRs.

Constraining pulsar birth properties with supernova X-ray observations

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A large fraction of core-collapse supernovae are thought to result in the birth of a rotation-powered pulsar, which is later observable as a radio pulsar up to great ages. The birth properties of these pulsars, and in particular the distribution of their initial rotation periods, are however difficult to infer from studies of the radio pulsar population in our Galaxy. Yet the distributions of their birth properties is an important assumption for scenarios in which ultra-high-energy cosmic rays (UHECRs) originate in very young, extragalactic pulsars with short birth periods and high magnetic fields. Using a model of the very young pulsar wind nebula's dynamical and spectral evolution, with pulsar wind and accelerated particle parameters assumed similar to those inferred from modeling young pulsar wind nebulae (PWNe) in our Galaxy, we show that X-ray observations of supernovae, a few years to decades after the explosion, constitute a favored window to obtain meaningful constraints on the initial spindown luminosity of the newly-formed pulsar. We examine the expected emerging PWN spectral component, taking into account the X-ray opacity of the expanding supernova ejecta, and find that it is typically best detectable in lower-energy X-rays some years after the explosion. We use this framework to assess available X-ray detections of supernovae, as well as upper limits, expanding on the work of Perna et al. (2008). We note that a resulting limit on spindown luminosity corresponds univocally to a limit on the maximum magnetospheric acceleration potential, irrespective of the specific combination of magnetic field and rotation period that achieves it. We use available X-ray observations of supernovae to place constraints on the fraction of newly-born pulsars that may contribute to ultra-high-energy cosmic rays, and derive constraints on the birth period distribution of classical pulsars.

Gamma ray line measurements from supernova explosions

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Gamma ray lines are expected to be emitted in the afterglow of supernova explosions, as radioactive decay of freshly synthesised nuclei occurs. Significant radioactive gamma ray line emission is expected from ^{56}Ni and ^{44}Ti decay, less from longer lived isotopes such as ^{26}Al and ^{60}Fe, and even less from isotopes of elements heavier than iron group elements. Observations have only shown gamma ray line emissions from two core collapse events, Cas A and SN1987A. We will discuss INTEGRAL data from those isotopes, including all line and continuum signatures from these two objects, and the surveys for more supernovae, that have been performed by gamma ray spectrometry.

The origin of gamma rays in RX J1713.7-3946 and the other shell-like SNRs; evidence for the dominant contribution of the hadronic gamma-rays

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It is of crucial importance to test the hadronic process in the VHE gamma-ray production in Galactic young SNRs. We have carried out a detailed study of the interstellar medium in the four shell-like TeV gamma-ray SNRs observed with the H.E.S.S. [RX J1713.7-3946, RX J0852.0-4622, HESS J1731-347, and RCW 86], where we employed sensitive CO and HI observations of the hydrogen gas with the telescopes including NANTEN2, Mopra, and ATCA (Fukui et al. 2012; Fukui 2013; Fukuda et al. 2014; Sano et al. 2017). The accuracy of the hydrogen measurement has been significantly improved (better than 10 %) thanks to the sensitive *Planck* sub-mm data. In this contribution we present that all the four SNRs show good correspondence between the dense hydrogen gas (both in the atomic and molecular forms) and the shell-like VHE gamma-ray emission, while we see possible hints of minor contribution of the leptonic process toward the less dense gas. Based on these results we argue that the hadronic process is dominant in the gamma-ray production, which is consistent with the theoretical picture of the shock-cloud interaction presented by Inoue, Yamazaki, Inutsuka & Fukui (2012) and Gabici & Aharonian (2014). The present study offers a new precise tool to measure the target protons in the CTA era.

Three Dimensional Simulations of Core-Collapse Supernovae in FLASH

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Core-Collapse Supernovae are intrinsically multidimensional. A true understanding of the dynamics and inner workings of the core-collapse supernova central engine requires simulations that assume no spatial symmetries (3D). Spherically symmetric (1D) simulations forbid the development of several key hydrodynamic instabilities like convection and the standing accretion shock. Even axisymmetric (2D) simulations, where these instabilities can develop, have short comings. For example, the nature of turbulence in 2D simulations is fundamentally different than in 3D, with turbulent energy cascading to large scales, leading to the formation of large scale structures behind the shock that encourage shock expansion. In this talk, I will present both 2D and 3D simulations of the core-collapse supernova central engine using an energy-dependent, two-moment, multidimensional neutrino transport scheme that we have developed as part of the FLASH hydrodynamics toolkit. Our 2D simulations survey a series of progenitors and explore some preliminary variations in the neutrino-matter interaction rates. While our suite of 3D simulations explore the impact of resolution, initial progenitor perturbations, and imposed octant symmetry.

Hydrodynamic Simulations of Axisymmetric Supernovae Explosion

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In an aspherical supernova explosion, shock emergence is not simultaneous and non-radial flows develop near the stellar surface. Oblique shock breakouts tend to be easily developed in compact progenitors like stripped-envelop core collapse supernovae. Non-radial flows can alter the observable emission and radiation of a supernova explosion (Matzner et al, 2013; Salbi et al, 2014). These flows limit ejecta speed, change the distribution of matter and heat of the ejecta, suppress the direct breakout flash, and most importantly engender collisions outside the star. We construct a global numerical FLASH hydrodynamic simulation in a two dimensional spherical coordinate, focusing on the non-relativistic, adiabatic limit in a polytropic envelope. The asymmetries were added to the momentum profile of a spherical Sedov explosion. We explore the behavior of non-radial flows outside the star, predict the light curve and color temperature evolution of the SN for different progenitor models, and characterize the sorts of transients resulted from the circumstellar collisions.

Supernova 1986J: a Neutron Star or Black Hole in the Center?

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Supernova 1986J is almost the same age as SN 1987A, but being of Type IIn, is likely to have had a very massive progenitor. Located in the galaxy NGC 891, at a distance of 10 Mpc, it is one of only a handful of supernovae where the radio emission of the expanding ejecta can be resolved using VLBI. We present a new 5-GHz global-VLBI image of supernova 1986J, observed in 2014, and discuss it in detail. SN 1986J is unusual in that a compact synchrotron radio emitting component appeared in the centre of the expanding shell of ejecta about 14 yr after the explosion, which component now dominates the VLBI image. The central component is stationary to within the uncertainties (<1400 km/s) within the shell, which has expanded with $v > 7000$ km/s, and it is marginally resolved with a HWHM radius of $(6.7 \pm 1.5) \times 10^{16}$ cm. Its 5-GHz flux density is still increasing with time, and at present it has a νL_ν luminosity at 5 GHz of $\sim 3 \times 10^{35}$ erg/s, ~15 times that of the Crab Nebula. The central component may be due to a newly formed pulsar wind nebula, or an accreting black hole, or it may be due to interaction of the supernova shock with a highly structured environment left over from a progenitor which was in a close binary system. We discuss the newest observations and the constraints on the nature of the central component

3D dust radiative transfer simulations of SN1987A

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Somewhat surprisingly, copious amounts of cold dust were detected in SN1987A with Herschel and ALMA. We present new radiative transfer simulations of the ejecta of SN1987A, calculated with the state-of-the-art 3D Monte Carlo code SKIRT. The main goal of these simulations is to make detailed estimates of the dust mass at the present epoch, and to quantify in which way clumpiness and geometry affect the dust mass estimates.

Nonrelativistic perpendicular shocks modeling young supernova remnants through kinetic simulations

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The formation, electromagnetic structure, and the injection of suprathermal particles into diffusive shock acceleration constitute important problems of cosmic-ray astrophysics. We report on recent particle-in-cell studies of high Mach-number nonrelativistic perpendicular shocks in applications to young supernova remnants. We discuss a nonlinear shock structure mediated by magnetic filamentation instabilities, cyclic shock reformation and rippling, and conditions leading to particle heating and efficient electron pre-acceleration at different locations in the turbulent shock transition.

Evidence for a wide electron spectra scatter among different SNR regions from high radio-frequencies observations

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In the framework of the Sardinia Radio Telescope (SRT) Early Science Program, we obtained single-dish high-resolution imaging of the Supernova Remnants IC443 and W44 at 7 GHz. By coupling them with SRT 1.5 GHz maps, we provided accurate spatially-resolved spectral measurements that are clearly highlighting a spread in spectral slope distribution. The observed features range from flat or slightly inverted spectra corresponding to bright radio limbs and filaments, to relatively steep spectra in fainter radio regions. Different theoretical possibilities explaining the above challenging findings are discussed. In particular, we exclude that the observed region-dependent wide spread in spectral slope distribution could be related to absorption processes. Our high-frequency results can be directly related to distinct electron populations in the SNRs including secondary hadronic electrons and resulting from different shocks conditions and/or undergoing different cooling processes. Integrated fluxes associated with the whole SNRs obtained by SRT in comparison with previous results in the literature support the evidence for a slight spectral steepening above 1 GHz for both sources, which is related to primary electrons or more likely secondary hadronic electrons cut-offs.

High-resolution imaging of SNR IC443 and W44 with the Sardinia Radio Telescope at 7 GHz

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We present single-dish imaging of the well-known supernova remnants (SNRs) IC443 and W44 at 1.5 GHz and 7 GHz with the recently commissioned 64-m diameter Sardinia Radio Telescope (SRT). Our images were obtained through on-the-fly mapping techniques, providing antenna beam oversampling, automatic baseline subtraction and radio-frequency interference removal. It results in high-quality maps of the SNRs at 7 GHz, which are usually lacking and not easily achievable through interferometry at this frequency due to the very large SNR structures. SRT continuum maps of our targets are comparable with VLA maps carried out at lower frequencies (at 324 MHz and 1.4 GHz), providing a detailed structure of their complex filamentary morphology. New estimates of the total flux density are given within a 5% error at 1.5 GHz and 7 GHz, in addition to flux measurements in different regions of the SNRs. By coupling the SRT maps at the observed frequencies, we obtained spatially-resolved spectral-indices maps of IC443 and W44. Accurate spectral imaging at such high-radio frequencies are necessary in order to understand the physical properties and better constrain the multi-wavelength scenario (leptonic versus hadronic models). We discuss the physical implications of the observed region-dependent spectral indices for IC443 and W44 and their correlation with the radio and gamma-ray intensity maps obtained with AGILE, Fermi and VERITAS.

H.E.S.S. Observations of the Large Magellanic Cloud

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The Large Magellanic Cloud (LMC) is an irregular satellite galaxy of the Milky Way, which has been observed extensively at Very-High-Energy (VHE) gamma-rays with the H.E.S.S. telescopes. Significant emission from three objects belonging to different source classes was detected: The pulsar wind nebula N 157B, which is powered by the most energetic pulsar known so far, the supernova remnant N 132D, and the super-bubble 30 Dor C. These sources represent the high-energy tip of the VHE gamma-ray source population in the LMC and the first individual cosmic-ray accelerators identified in an external galaxy. The remnant of SN 1987A is still undetected in gamma rays. In this talk we will discuss these sources as possible cosmic-ray accelerators and compare them with similar systems in our Galaxy. We will announce the discovery of a new gamma-ray emitting object in the LMC.

X-raying the evolution of SN 1987A

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We explore the morphological evolution of SN 1987A in X-rays, as observed with the Chandra X-ray Observatory, using a Bayesian multi-scale image reconstruction algorithm. The method allows us to detect changes at small angular scales (~0.25 arcsec) as well as place uncertainties on the magnitudes of the changes. We describe the reconstruction method (LIRA: Low-counts Image Reconstruction and Analysis), and explore the evolution of the inner ring at different passbands using this method. The Bayesian nature of the algorithm allows us to estimate the evolutionary changes directly rather than by comparing reconstructed images at different epochs. Preliminary results are shown in the accompanying figure, which shows the full band Chandra images from Dec 2000 and Jul 2007 in the top row, the reconstruction of the Dec 2000 image at bottom left, and the change from Dec 2000 to Jul 2007 at bottom right.

Constraining magnetic field amplification in SN shocks using radio observations of SNe 2011fe and 2014J

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We modeled the radio non-detection of two Type Ia SNe 2011fe and 2014J considering synchrotron origin of radio emission. This non thermal emission from shock accelerated electrons with power index 3, as inferred from Type Ib/c radio emission, and an assumed value of amplification efficiency of magnetic field $\eta_B = 0.1$, in the shocked region, predicts very low density medium around both the SNe. As synchrotron power is proportional to magnetic field energy density the radio non detection at early and late epoch could lead to constrain η_B in SN shocks. Although the single degenerate channel suggests high density circumbinary medium, there are different mechanisms like nova recurrence, rotation of WD which could result in a cavity around the SN site. On the other hand, merger of two WDs naturally explains the very low density surrounding around the explosion site. With some reasonable assumptions the expected ISM density around both the SNe is ~ 1 cm^{-3}. Considering that the outer part of SN ejecta follows power law density structure, with an index in the range 12 to 14, we found that the null detection of radio emission, around 1.5 and 4 years after the explosion of SNe 2014J and 2011fe, can be explained with the above mentioned particle density when the magnetic field amplification is 0.01. The upper limit on particle density is much lower than 1 cm^{-3} for a higher value of η_B. These are also found to be true in case of a rigidly rotating WD with a MS or RG companion where the WD spins down by losing angular momentum and the surrounding gas attains the interstellar density by the time explosion occurs. Nova recurrence which predicts an immediate low density medium around the SN site is a rather frequent phenomenon, with a period of couple of tens of years, before the star, which is accreting at rate between 3×10^{-8} to 4×10^{-7} M_sun/yr, explodes. Therefore a very fast ejecta, moving with velocity > 50000 km/s for the first couple of weeks, as in the case for SNe 2014J and 2011fe, will interact with this ejected material in less than a month scale for a nova shell velocity = 4000 km/s. Thus one might expect radio emission at early epoch for a considerable strength of magnetic field η_B ~ 0.1. We note the uncertainties involved in various less constrained physical processes, but radio non detection, at early and late epoch, could point towards a low magnification efficiency for magnetic fields in SN shocks.

Les métiers de l'Astrophysique (« When researchers meet students »)

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We propose to present "les métiers de l'astrophysique" to classrooms in schools, colleges and high schools in La Réunion (St Denis, St Gilles, Le Port, Le Tampon, Ilet à Malheur, ...).

Explosions célestes et vestiges de supernova (public conference in French)

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Supernovae (SNe), along with their remnants, are central in many active fields of research as the key sources of cosmic high-energy particles and heavy elements, the privileged sites of cosmic dust formation, and the primary agents of chemical and dynamical evolution of galaxies. Moreover, they are among the rare celestial events visible with the naked eye. Yet, many open issues still need to be deeply explored such as the nature of the SN progenitors and the final stages of stellar evolution, explosion mechanisms and nucleosynthesis, shock acceleration processes and the question of the origin of cosmic rays. SN 1987A, in the Large Magellanic Cloud, the closest SN event witnessed since the invention of the telescope, has been observed in its entire electromagnetic spectrum, and this wealth of information has thus provided much insight into core-collapse SNe. At the occasion of the 30th anniversary of this unique event, I will present our current knowledge on these celestial explosions and their remnants during this public conference.

Cosmic-Ray Lithium Production in the Nova Ejecta

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Traditionally, cosmic-ray (CR) lithium nuclei are assumed to be secondary CRs, which means that they are produced from the interaction between heavier CR nuclei such as carbon and the interstellar gas. However, the recent results reported by AMS-02 show that the spectrum of CR lithium nuclei above ~100 GeV deviates from that predicted from that traditional scenario, and that its spectral behavior is similar to that of helium nuclei, which are primary cosmic-rays (i.e., they are produced directly from sources such as supernova remnants). There are several observational evidences that Galactic nova explosions can produce a significant amount of 7-Be, which can decay into 7-Li within a short time, via the alpha-capture reaction. In this presentation we propose that a nova explosion of a white dwarf followed by a Type Ia supernova that occurred in the vicinity of the Earth can be the origin of cosmic-ray 7-Li nuclei excess observed by AMS-02. The origin of the excess of cosmic-ray protons and helium nuclei will be also discussed.

Measuring Distances to the Galactic Supernova Remnants Using Red Clump Stars

(IAU GRANTEE)
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We carry out a project to measure the distances of Galactic supernova remnants (SNRs). In this project, the red clump stars are used as the standard candle to measure the optical extinction (Av)-distance (d) relation in each direction of Av-known SNRs. Here we present the initial results for SNRs in the first quarter of the Galaxy. We successfully obtain distances for 9 SNRs and upper/lower limits for 29 SNRs, within which, the distances of several SNRs are given by the first time. For previous distance-known SNRs, We find that most our distances are consistent with previous results. In the future, we will extend our work to the whole Galaxy and use the distances to re-calibrate the Sigma-diameter relation and estimate SNRs' other distance-dependent parameters. Then, a statistics study will be employed to understand the evolution of SNRs better.

MHD Simulation of Supernova Remnants

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We present MHD simulations of supernova remnants (SNRs) by taking the stellar wind of progenitor star, Galactic magnetic field and the nearby molecular clouds into consideration. We find that the thickness of shell is not only related to the spatial projection, but also the distribution of surrounding density. For a simplified model, we find the reverse shocks could evolve to secondary shocks after they converge to the explosion site. Our simulation is consistent with the observation of an SNR and predicts that a second shell appears in the well-known one-shell SNR, which is likely proved in our further analysis to archival data. A sample of Galactic SNRs has been selected for following simulations.