Explosive Ideas about Massive Stars - from Observations to Modeling

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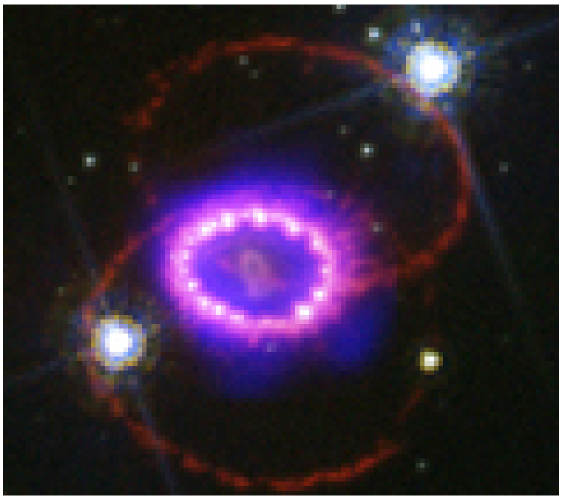

Book of Abstracts

Contents

Posters and refreshments / 289

A shallow water analog for asymmetric core-collapse, and neutron star kick/spin

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Massive stars end their life with the gravitational collapse of their core and the formation of a neutron star. Their explosion as a supernova depends on the revival of a spherical accretion shock, located in the inner 200km and stalled during a few hundred milliseconds. Numerical simulations suggest that an asymmetric explosion is induced by a hydrodynamical instability named SASI. Its non radial character is able to influence the kick and the spin of the resulting neutron star. The SWASI experiment is a simple shallow water analog of SASI, where the role of acoustic waves and shocks is played by surface waves and hydraulic jumps. Distances in the experiment are scaled down by a factor one million, and time is slower by a factor one hundred. This experiment is designed to illustrate the asymmetric nature of core-collapse supernova.

SN 1987A / 293

Circumstellar gas around SN 1987A

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The structure of the circumstellar medium around SN 1987A poses a challenge to our understanding of mass loss from massive stars. I will review what is known about the three rings around the supernova, as well as other gas close to it. I will also discuss how the rings have been excited, and what we can learn from them about the supernova shock breakout and the ejecta/ring interaction. I will also highlight the elemental abundances in the rings.

Posters and refreshments / 294

Early UV emission from SNe

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We derive a simple approximate model describing the early, up to a few days, UV/optical supernova emission, which is produced by the expansion of the outer hundredth solar mass of the shock-heated envelope, following the shock breakout and preceding the optical emission driven by radioactive decay. Our model includes an approximate description of the time dependence of the opacity (due mainly to recombination), and of the deviation of the emitted spectrum from a black body spectrum. For He envelopes, neglecting the effect of recombination may lead to an underestimate of the luminosity by more than an order of magnitude. We also show that the relative extinction at different wavelengths may be inferred from the light-curves at these wave-lengths, removing the uncertainty in the estimate of progenitor radius due to reddening (but not the uncertainty in E/M due to uncertainty in absolute extinction). For core collapse SN, the characteristics of the early UV/O emission constrain the radius of the progenitor star, its envelope composition, and the ratio of the ejecta energy to its mass, E/M. For SN Ia, the characteristics of the emission may allow one to distinguish between a pure deflagration explosion and a delayed detonation (DDT) explosion, and to constrain the detonation and deflagration velocities for DDT explosion. The early UV/O observations of the type Ib SN2008D and of the type IIp SNLS-04D2dc are consistent with our model predictions. For SN2008D we find progenitor radius to be approximately 10ˆ11 cm, and an indication that the He envelope contains a significant C/O fraction.

Posters and refreshments / 296

Understanding Neutrino-Driven Supernova Explosions: the Antesonic Condition

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The mechanism of core-collapse supernovae is unknown. Despite considerable effort, most simulations of supernovae are not successful, and it has proven difficult to revive the stalled accretion shock, particularly for more massive stellar progenitors. Although it is known that the stalled accretion shock turns into explosion when the neutrino luminosity from the collapsed core exceeds a critical value (L_crit) (the "neutrino mechanism"), the physics of L_crit, as well as its dependence on the properties of the proto-neutron star (PNS) and changes to the heating/cooling mechanisms has never been systematically explored.

We quantify the deep connection between the solution space of steady-state isothermal accretion flows with bounding shocks and the neutrino mechanism. In particular, we show that there is a maximum, critical sound speed above which it is impossible to maintain accretion with a standoff shock, because the shock jump conditions cannot be satisfied. The physics of this critical sound speed is general and does not depend on a specific heating mechanism. We show that if c_Tˆ2/v_escˆ2 >= 3/16 = 0.1875 explosion results - the "antesonic" condition. We generalize this result to the more complete supernova problem, where the critical condition for explosion can be written as c_Sˆ2/v_escˆ2 = 0.19 over a broad range in accretion rate and microphysics. Other criteria proposed in the supernova literature fail to capture the physics of L_crit.

In addition, we explore effects of collective neutrino oscillations on L_crit.

Posters and refreshments / 297

Gamma-Ray Emission from Composite Supernova Remnants

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As a pulsar wind nebula evolves inside its host supernova remnant, its gamma-ray emission becomes increasingly brighter due to the buildup of energetic particles injected by its pulsar. When the SNR reverse shock collides with the PWN, the resulting increase in the magnetic field results in rapid synchrotron losses, modifying the particle spectrum of the nebula. Gamma-ray observations of composite SNRs thus provide a probe of the underlying particle spectra that can be compared with models for the evolution of these systems. In addition, particles accelerated at the forward shock can produce gamma-ray emission through inverse Compton scattering or the decay of pions from proton-proton collisions either within the SNR shell or with dense material in surrounding molecular clouds. Here I report on recent gamma-ray studies of several composite SNRs, and discuss the implications of the gamma-ray results in the context of models of their broadband spectra.

Explosion mechanism / 298

On the Mechanism of Core-Collapse Supernova Explosions

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Core-collapse supernovae are a puzzle that has taxed theorists and computational science for half a century. Such explosions are the source of many of the heavy elements in the Universe and the birthplace of neutron stars and stellar-mass black holes. However, determining the mechanism of explosion remains the key goal of theory. Recently, using sophisticated numerical tools and platforms, theorists have been able to conduct multi-dimensional simulations with some physical fidelity that have provided insight into the phenonoma that attend stellar death and explosion. The core of the emerging theoretical synthesis is the centrality of spatial dimension in the context of hydrodynamic instability and asphericity. In this talk, I will review the state of the field and the contending explosion models. In the process, I will highlight the computational astrophysics that has been applied to date, and that may be necessary in the future to credibly unravel this mystery.

SN 1987A, cont'd / 299

Spectroscopic modeling of SN 1987A and other Type II SNe

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Core-collapse SNe offer unique opportunities to look inside massive stars. By calculating the deposition and degradation of gamma-rays and positrons, solving the equations for statistical and thermal equilibrium, and considering the effects of multi-line radiative transfer, we produce model spectra that can be compared with observations. We apply our model to interpret the spectrum of SN 1987A at an age of 8 and 19 years, finding a powering of ~1.5E-4 Msun of 44Ti in the iron/silicon core to satisfactorily reproduce most of the observed lines. We compare models with local and non-local positron deposition, and find better agreement assuming local trapping. The cold and neutral ejecta produce strong Fe I lines. We also see that radiative transfer effects still play a crucial role for the spectral formation even many years after explosion. One outstanding problem is, however, to explain the weak Fe II 26 mu line observed by Spitzer. I also briefly discuss current work on modeling other Type IIP SNe in the 200-600 day range.

Posters and refreshments / 300

Why you should not trust NaD absorption from low-resolution spectra to derive extinctions

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Dust extinction is generally the least tractable systematic uncertainty in astronomy, and particularly in supernova science. Often in the past, studies have used the equivalent width of Na I D absorption measured from low-resolution spectra as proxies for extinction, based on tentative correlations that were drawn from limited data sets. We have recently shown, based on 443 low-resolution spectra of 172 Type Ia supernovae for which we have measured the dust extinction as well as the equivalent width of Na I D, that the two barely correlate. I will discuss the causes for this large scatter that effectively prevents one from inferring extinction using this method.

Posters and refreshments / 301

Properties and Spatial Distribution of Dust Emission in the Crab Nebula

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The nature and quantity of dust produced in supernovae (SNe) is still poorly understood. Recent IR observations of freshly-formed dust in supernova remnants

(SNRs) have yielded significantly lower dust masses than predicted by theoretical models and observations high-redshift galaxies. The Crab Nebula's pulsar wind is thought to be sweeping up freshly-formed SN dust along with the SN ejecta. The evidence for this dust was found in the form of an IR bump in the integrated spectrum of the Crab and in extinction against the synchrotron nebula that revealed the presence of dust in the filament cores. We present the first spatially-resolved emission spectra of dust in the Crab Nebula acquired with the Spitzer Space Telescope. The IR spectra are dominated by synchrotron emission and show forbidden line emission from both sides of the expanding nebula, including emission from [S III], [Si II], [Ne II], [Ne III], [Ne V], [Ar III], [Ar V], [Fe II], and [Ni II]. We extrapolated a synchrotron spectral data cube from the Spitzer 3.6 and 4.5 micron images, and subtracted this contribution from our 15-40 micron spectral data to produce a map of the residual continuum emission from dust. The emission appears to be concentrated along the ejecta filaments and is well described by astronomical silicates at an average temperature of 65 K. The estimated mass of dust in the Crab Nebula is 0.008 solar masses.

Surveys now and in future, cont'd / 302

Supernovae in the universe

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In this talk I will review the efforts made to measure the volumetric rates of supernovae, focusing on core collapse supernova, to cosmological distances, z˜1. This includes the recently derived rates from the HST Supernovae Search and the Stockholm Vimos Supernova Search. I will include a discussion on the various issues that have to be address in order to minimize statistical errors when deriving supernova rates, as well as highlighting some of the problems faced when relating supernova rates to star formation rates. I will also give a brief overview of the CANDELS survey, the ongoing HST multi-cycle survey aimed at detecting supernovae to redshift z˜2 by searching in near infrared filters. Finally, I will give some examples on the potential of future telescopes, such as the JWST, to detect supernovae to redshifts well beyond z˜1.

Posters and refreshments / 303

Supernova explosions in interacting binaries

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The presence of a binary companion can have a significant effect on a supernova explosion. Mass transfer affects the evolution of the stars; a massive star may transfer so much mass that it fails to explode as a supernova, whilst conversely an accreting lower-mass star may gain enough material to cause it to explode. Massive stellar cores in close binaries can be spun up by their companions and this may be a source of the rapidly-rotating hypernova explosions that power gamma-ray bursts. Another possible source of gamma-ray bursts in binaries is the deflection of supernova ejecta that are falling back on to a newly-formed black hole. We present some of our recent work on modelling these processes, in order to understand supernovae in interacting binaries and their relation to gamma-ray bursts.

Posters and refreshments / 304

Peculiar Type II Supernovae from Blue Supergiants

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The vast majority of Type II supernovae (SNe) are produced by red supergiants (RSGs), but SN 1987A revealed that blue supergiants (BSGs) can produce members of this class as well, albeit with some peculiar properties. This best studied event revolutionized our understanding of SNe, and linking it to the bulk of Type II events is essential. We present here optical photometry and spectroscopy gathered for SN 2000cb, which is clearly not a standard Type II SN and yet is not a SN 1987A analog. The light curve of SN 2000cb is reminiscent of that of SN 1987A in shape, with a slow rise to a late optical peak, but on substantially different time scales. Spectroscopically, SN 2000cb resembles a normal SN II but with ejecta velocities that far exceed those measured for SN 1987A or normal SNe II, above 18000 km/s for H-alpha at early times. The red colors, high velocities, late photometric peak, and our modeling of this object all point toward a scenario involving the high-energy explosion of a small-radius star, most likely a BSG, producing 0.1 solar masses of Ni-56. Adding a similar object to the sample, SN 2005ci, we derive a rate of about 2% of the core-collapse rate for this loosely defined class of BSG explosions.

Posters and refreshments / 305

Shock Breakout in Dense Wind and Non-Steady Mass Loss

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We investigate the effect of non-steady dense mass loss on the shock breakout in dense wind. We found that the effect of the dense wind from non-steady mass loss can account for two types of interaction-powered luminous supernovae: 06gy-like LSNe which show the narrow emission lines from wind and 08es-like LSNe which do not show them.

SN 1987A, cont'd / 306

Herschel Detects a Massive Dust Reservoir in Supernova 1987A

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We report a surprising detection of the supernova 1987A at far-infrared and submillimetre (submm) wavelengths in 2010. As a part of the Herschel Large and Small Magellanic Cloud surveys (HERITAGE; principal investigator Margaret Meixner), the Herschel Space Observatory scanned the sky in the direction of SN 1987A, and found a faint but clear point source. The source was detected at four wavelength bands from 100 to 350 microns. The smooth spectral energy distribution shows a continuous shape peaking near 200 microns and we conclude that the far-infrared/submm signature is due to thermal dust emission. The estimated dust mass is between 0.5-0.7 solar mass, which is limited by the available elemental mass synthesised in the SN. This new detection by Herschel implies that supernovae can contribute to the overall dust-mass input in the interstellar medium of galaxies.

Posters and refreshments / 307

Role of supernova ejecta clumpiness in the evolution and morphology of the remnants

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During the evolution of SNRs, Rayleigh-Taylor (RT) instability develop at the contact discontinuity between the ejecta and the shocked interstellar medium (ISM). The nonlinear instability evolves, giving rise to a turbulent structure with preferentially radial components, the so-called RT fingers. Current multi-dimensional models of SNRs describe the development of these structures. However they predict an average distance between the contact discontinuity and the forward shock that is much larger than that observed in many young SNRs (e.g SN1006, Tycho's SNR), and they cannot explain the high number of knots observed to protrude ahead of the shock.

There is a growing consensus in the literature that density clumping of ejecta may naturally emerge from supernovae explosions. This early ejecta structure can have important consequences on the development of instability at the contact discontinuity. Here we investigate the role played by the ejecta clumping in the evolution of SNRs through a three-dimensional MHD model describing the expansion of the remnant through a magnetized ISM, including consistently the initial ejecta clumping and the effects on shock dynamics due to back-reaction of accelerated cosmic rays.

SN 1987A, cont'd / 308

Supernova 1987A in Radio

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Being the brightest supernova since the invention of modern telescopes, SN 1987A has been intensively studied over the last two decades and it exhibited a highly unusual evolution. At radio frequencies, the initial outburst peaked on day 4 then followed by a rapid decay. The radio emission re-emerged around mid-1990, marking the birth of a radio remnant. Monitoring observations with the Australia Telescope Compact Array indicate an initial remnant expansion rate over 0.1c, then slowed down to 4000km/s before 1992 and stayed nearly constant. Over the past 12 years, the radio flux has been increasing exponentially with a progressively flattening spectrum. The radio remnant is now bright enough that allows the first VLBI detection recently, which shows evidence of small-scale structure < 0.2", but still no sign of any compact object at the center.

Explosion mechanism / 309

Newtonian and Relativistic Shock Breakouts

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Observations of SNe light at early times can open a window to a wealth of information on the progenitor system and the explosion itself. I will present the theoretical expectation of that emission, starting at the shock breakout, through the planar phase and into at the spherical phase, until recombination and/or radioactive decay start playing a role. I will discuss separately Newtonian breakout and relativistic breakout. The former take place in regular core-collapse SNe while the latter is expected in white dwarf explosions (e.g., type Ia and .Ia SNe, AIC), extremely energetic SNe (e.g., SN2005ap, SN2007bi) and GRB-SN. I will show that both types of

breakouts, when spherical, have characteristic signatures, which can be identified, and discuss the detectability of the breakout emission from various types of SNe.

What we can learn from SN spectra and light curves / 310

Type IIn supernovae: What can we learn from spectra and light curves

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Type IIn supernovae (SN IIn) is highly diverse and badly understood class with a common feature: they show narrow emission lines indicative of a dense circumstellar matter (CSM). The narrow emission lines could originate either from the undisturbed circumstellar gas excited by
X-ray/ultraviolet radiation or from shocked circumstellar clouds. In most SNe IIn the total luminosity is fully powered by the SN/CSM interaction. The origin of the dense CSM is likely very much different and could be related either with a heavy wind or with a violent ejection of massive shell. The wide range of the ambient density is manifested in enormous range of SNe IIn luminosity: from -14 mag (2008S) to -22.5 mag (2008es). The current comprehension of physics behind the light curves and spectra of different SNe IIn is reviewed and challenging problems that impede our understanding of this category of SNe are emphasised.

Posters and refreshments / 312

The Type II supernovae 2006V and 2006au: two SN 1987A-like objects

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Supernova 1987A revealed that a blue supergiant (BSG) can end its life as a core-collapse supernova (SN). Such objects show peculiar properties distinguishing them from ordinary Type IIP SNe, whose progenitors are believed to be red supergiants. A similarity among 1987A-like events include a long rise to maximum and peak luminosities which are fainter than Type IIP SNe and mainly powered by radioactivity.

We investigate two core-collapse SNe that exhibit properties similar to SN 1987A. Optical and near-infrared light curves and optical spectroscopy of SNe 2006V and 2006au, obtained through the course of the Carnegie Supernova Project, are presented.These observation are compared to SN 1987A, and are also used to estimate parameters of their respective progenitor stars. We apply a semi-analytic model to determine the main physical properties of these objects.

Both SNe and in particular SN 2006V have light curves following the profile exhibited by SN 1987A, with its characteristic slow rise time. In the first 20 days of the observation, SN 2006au also present a peculiar slightly decreasing phase (or almost flat, depending on the filters), which is the signature of the photospheric cooling

phase that ensues shock-wave breakout. Both SNe are brighter than SN 1987A and the colors indicate these objects to be even strongly bluer, suggesting higher temperatures. We consistently find higher temperatures by fitting a black body on the spectral energy distributions. The spectra are consistent with typical Type II spectra and with the spectra of SN 1987A, but the expansion velocities are higher, especially for SN 2006au.

These properties suggest a scenario involving BSG progenitors as for SN 1987A, but larger explosion energies, which we consistently find when we apply the semi-analytic model. The characteristic compactness that would be required by this kind of progenitor is confirmed by the radius estimation of SN 2006V and SN 2006au (respectively 55 and 80 solar radii). We also present an upper limit for the Ni mass synthesized in both SNe (0.11 solar massesfor SN 2006V and 0.075 solar masses for SN 2006au).

Posters and refreshments / 313

New insights on the long GRBs-SNe association

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According the Collapsar model long GRBs (LGRBs) arise during the collapse of a massive star and involve the emergence of a relativistic jet through the envelope of the exploding star.
This model naturally explains the links between LGRBs and SNe, such as the the association of half a dozen LGRBs with broad-line Ic SNe.
However, a closer look at this association reveals that four out of the six bursts differ form ordinary LGRBs:
They are less luminous, have a smooth lighcurve and their spectra show no evident for a high energy tail.
The nature of these low luminosity GRBs is puzzling, and it is interesting to see whether they originate in the same way as LGRBs.
We examine the propagation of a relativistic jet inside a stellar envelope, and find that the jets involved in low luminosity GRBs are not powerful enough to break out of their progenitors.
This implies that their gamma-ray emission must be generated by a different mechanism than that of luminous LGRBs.
The high rate of the low luminosity GRBs indicates that jets that are generated following a core collapse, have a higher chance of being buried rather than breaking out.
This puts the GRB-SN connection in a new light where typical SNe engines can only generate low luminosity GRBs while only the most powerful ones can generate LGRBs.

Posters and refreshments / 314

Impact of electro-weak processes in type II supernovae collapse

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A complete description of the core-collapse supernova mechanism requires an appropriate treatment of both the hydrodynamics and the microphysics.

Indeed, despite the crucial role played by hydrodynamics (e.g. hydrodynamical instabilities, rotation, convection or General Relativistic effects), to produce type II supernovae explosions, the influence of nuclear physics inputs on the outcome of the simulations is far from being unimportant.

Using our spherically symmetric (1D) Newtonian hydro code [1], we evaluate the impact of the temperature dependence of the nuclear symmetry energy [2] during the core-collapse and early post-bounce phase. We found a systematic reduction of the deleptonization during collapse for different electron capture rates [3,4] and a shift of the position of the formation of the shock outwards of a significative amount.

We also plan to investigate such microphysics effects in the General Relativity framework [5,6,7].

We believe that the introduction of such a temperature dependence in multidimensional simulations should be considered.

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Posters and refreshments / 315

Clumpiness and Density Diagnostics in Supernova Ejecta From Forbidden Line Profiles

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Constraining the structure and asymmetries within supernova (SN) ejecta is of great importance to understanding the explosion mechanism and for constructing better models of SN feedback mechanisms. SN forbidden line profiles at later times, when the ejecta is optically thin in the continuum, provide a potential diagnostic of

densities and the distribution of individual ionic species throughout the proto-remnant. Further, asymmetries in the line shape can be used to understand density and/or compositional inhomogeneities within the ejecta. This is because in forbidden lines, the scaling of the emissivity with density changes at a characteristic critical" density that is set primarily by atomic constants. As a result, the evolution of total line flux has the potential to give a direct measure of absolute density within the ejecta. We will present models of forbidden lines in SN ejecta and examine the effect of local density variations (clumps") on their profile shape, and examine how the total line flux varies with time in relation to optical depth in the line and age of a SN.

Supernova Progenitors / 317

Peculiar supernovae and their progenitors

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A number of supernovae has been discovered in recent times
showing weird observed
properties. A few of them are extremely sub-luminous, others
are among the brightest
stellar explosions ever observed. In this review I present
photometric and
spectroscopic data of some of the most astonishing unusual
transients, and outline
what we currently know on the nature of their progenitor stars.

Posters and refreshments / 318

The "Swan Song" of the Pulsar Wind Nebulae

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Bamba et al. (2010) used deep X-ray observations, with Chandra and Suzaku, to estimate the sizes of faint and old Pulsar Wind Nebulae (PWNe). They found a steady increase in size with the nebular age, up to ages of about 10ˆ5 yr. Their conclusion was that these PWNe keep expanding up to large ages, in apparent contradiction with the idea that a reverse shock from the associated supernova remnant squeezes the PWN before the beginning of the Sedov phase. As a consequence, in order to allow X-ray emitting electrons to reach large distances from the pulsar without being burnt by synchrotron losses, they infer a very weak nebular magnetic field and/or that these electrons are diffusing out efficiently.

I propose a different scenario, in which the observed trend arises from the combination of objects expanding under a wide range of ambient densities. Older PWNe re-brighten considerably near the time at which they are compressed by the reverse shock, and this represents for many of them the last chance to become detectable. But the time at which this phase takes place also depends on the

ambient medium density, and it can be shown that the observed trend is naturally reproduced, by assuming reasonable values for the supernova and pulsar initial conditions.

Using this scenario, also the correlation found by Mattana et al. (2009) between the X-ray PWN flux and the pulsar spin-down luminosity can be reproduced. It should be noticed that they also used a sample containing several aged PWNe, with characteristic ages up to 10ˆ5 yr. A related effect is that, since right before the PWN compression phase the nebular magnetic field is very low, the X-ray emitting electrons suffer negligible synchrotron losses and then they build up a flatter energy distribution, therefore justifying the positive correlation, discovered by Gotthelf (2003) and confirmed by Li et al. (2008), between X-ray luminosity and X-ray photon index.

Finally, I will discuss the statistical properties of the TeV emission in old PWNe.

Posters and refreshments / 319

Axisymmetric Supernova Simulation with Spectral Neutrino Transfer

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Core-collapse supernovae are violent explosion of massive stars at their end of life. The standard model of the supernova
explosion is so-called "delayed explosion scenario", in which the neutrino heating plays an important role. In order to
investigate whether this model works properly, we must solve raditation hydodynamic equations incorporating the neutrino
radiative transfer with detailed
microphysics.

By performing axisymmetric hydrodynamic simulations of core-collapse supernovae with a spectral neutrino transport based on
the isotropic diffusion source approximation scheme, we support the assumption that the neutrino-heating mechanism aided by
the standing accretion shock instability and convection can initiate an explosion of 13 M_sun and 15 M_sun stars. In this poster,
we show our recent works of multi-dimensional simulations.

Posters and refreshments / 320

Locations of SNe Ib/c: comparison with locations of WR stars, local metallicities and stellar ages.

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Stripped-envelope core-collapse SNe are supposed to result from the explosions of stars that have lost their outer hydrogen layers but the exact nature of their progenitor and (possible) companion stars remains unknown. By comparing their locations to those of WR stars we show that they are indeed compatible. Furthermore, SN Ib locations are more closely related to those of WN stars, while those of SNe Ic to those of WC stars, as expected by theory. Based on spectra obtained at 20 explosion sites, there is a possible trend for SNe Ic to occur at slightly more metal-rich environments than SNe Ib (by 0.08 dex). By placing limits to the ages of the youngest stars in the explosion regions (under the assumption of instantaneous star formation) and comparing with the lifetimes of single massive stars, we conclude that a fraction of these explosions is the outcome of binary evolution.

Posters and refreshments / 321

Infrared and X-ray Spectroscopy of the Kes 75 Supernova Remnant Shell: Characterizing the Dust and Gas Properties

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We present deep Chandra observations and Spitzer Space Telescope infrared (IR) spectroscopy of the shell in the composite supernova remnant (SNR) Kes 75. The remnant is composed of a central pulsar wind nebula (PWN) and a bright partial shell in the South that is visible at radio, IR, and X-ray wavelengths. The X-ray emission from the shell is dominated by a two-component thermal model with temperatures of ˜0.2 and ˜2 keV. While previous studies suggest that the hot component may originate from reverse-shocked SN ejecta, our new analysis shows no definite evidence for enhanced abundances. The IR spectrum of the shell is dominated by continuum emission from dust with little, or no line emission. The X-ray and IR emission in the shell are spatially correlated and the modeling of the IR spectrum shows that the dust is heated to a temperature of ˜ 140 K by a relatively dense, hot plasma. The total mass of the hot dust component is 0.008 solar masses, while the dust-to-gas ratio in this region is approximately the Galactic value, indicating that no significant dust destruction has occurred in the shell. The comparison of the X-ray and IR data suggests that the emission may originate from an interaction of the SN blast wave with clumpy circumstellar medium (CSM).

Circumstellar interaction / 322

Theory of Circumstellar Interaction

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Recent ideas related to supernova interaction with their surroundings will be discussed. Attention will be given to the case of very dense surroundings.

Surveys now and in future, cont'd / 323

Gravitational Radiation from Core Collapse Supernovae

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The only means to get direct and immediate information about the engine of core collapse supernovae is from observations of neutrinos emitted by the forming neutron star, and through gravitational waves. The latter are emitted when the explosion involves time-dependent asphericities because of rotation, magnetic fields, non-radial flow, and anisotropic neutrino emission. In my talk I will review the current status of the efforts to predict the gravitational wave signal of core collapse supernovae, particularly addressing the results of some recent 3D studies.

Posters and refreshments / 324

Intensive Follow-up of the Type Ib/c SN 2010as

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We present a detailed study of the Type Ib/c SN 2010as based on optical and near-infrared imaging and spectroscopy, plus radio observations. The data span from about two weeks before to about 150 days after maximum light. SN colors and spectra indicate this object suffered considerable reddening by dust. Intermediate resolution X-Shooter spectra cover the time of maximum light and show multi-component interstellar absorption lines. Pre-maximum spectra show large velocity variations in Ca II and probable H lines. We use the multi-band data to derive physical parameters for the progenitor object and explosion process.

Posters and refreshments / 325

Explosive nucleosynthesis in neutrino-driven, zero-metal supernovae

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We examine explosive nucleosynthesis during neutrino-driven, aspherical supernova (SN) explosion
aided by standing accretion shock instability, based on two-dimensional hydrodynamic simulations
of the explosion of 15-40$M_\odot$ stars with zero metallicity.
The magnitude and asymmetry of the explosion energy are estimated with the simulations,
for a given set of neutrino luminosities and temperatures.
By post-processing calculations with a large nuclear reaction network,
we have evaluated abundances and masses of ejecta from the aspherical SNe.
We find that the evaluated abundance patterns are similar to those observed in
extremely metal poor stars (Cayrel et al. 2004, Lai et al. 2008),
as shown in the spherical models of Tominaga et al. (2007) and Heger \& Woosley (2008) and
in the two-dimensional models of Joggerst et al. (2010),
although in their models, the explosion is manually and spherically initiated by
means of a thermal bomb or a piston.
Sc and Co, which are underproduced in the two-dimensional models of Joggerst et al.
(2010), are appropriately produced in our models.
Hypernovae may not be required to reproduce the observed abundance patterns.
No models in our simulations, however, can reproduce large [C,N,O/Mg] (> 1) observed
in two hyper metal-poor stars.

Explosion mechanism / 326

Hydrodynamics of Core Collapse

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A core-collapse supernova event begins with a nearly spherical hydrodynamic implosion of the core of a massive star and ends with a hydrodynamic explosion as an aspherical shock wave expands through the stellar envelope. The breaking of spherical symmetry is both critical for driving the explosion as well as determining the characteristics of the supernova. The origin of asymmetry may arise in the first few hundred milliseconds after bounce when the nascent shock wave is susceptible to the spherical accretion shock instability, or SASI. We describe the linear and nonlinear growth of both an axisymmetric mode (l=1) and a non-axisymmetric mode (m=1), and argue that this instability is a growing pressure wave driven by the dynamic response of the accretion shock. Using three-dimensional hydrodynamic simulations we show that the non-axisymmetric mode of the SASI dominates the nonlinear evolution at late times.

The supernova - remnant connection / 328

The SN - SNR Connection: Young Galactic CCSN Remnants

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Young and relatively nearby Galactic SNRs offer the possibility of relatively high-resolution investigations of SN ejecta and SNR/CSM interactions. I will present a brief overview of some recent X-ray, optical, and IR results on core-collapse SNRs. My talk will concentrate on work on some on young Galactic collapse SNRs, with an emphasis on the Cas A remnant which has been the focus of several recent Chandra and Hubble Space Telescope observations. In particular, I will present HST images which highlight this remnant's reverse shock emission as well as its high-velocity outermost ejecta arranged in nearly opposing NE and SW ejecta streams or "jets" producing an apparent bipolar asymmetry. I will also discuss possible correlations between the large-scale distribution of ejecta seen in young Galactic SNRs such as Cas A and certain line profiles observed in late-time CCSNe spectra.

Posters and refreshments / 329

A double-peaked 56Ni distribution for SN 2008D

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We present a model for the Type Ib SN 2008D, associated with the X-ray Flash 080109, which assumes a double-peaked 56Ni distribution. This assumption is fundamental to explain the plateau observed in the light curve a few days after the explosion. The presence of this high-velocity radioactive material may be caused by the formation of jets during the explosion. We briefly discuss the alternative scenarios that have been suggested for this supernova.

Posters and refreshments / 330

RCW 86 as cosmic-ray accelerator

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The evidence for supernova remnants as the main sources for Galactic cosmic rays has accumulated over the past decades. However, the physics of the acceleration mechanism is still unclear. In particular, there is a lack of empirical data to test current shock acceleration models.

RCW 86 is an excellent source to test these models, as the shock velocities of the remnant vary by an order of magnitude and parts of the remnant have shown to be

efficient accelerators. I will present our study of this remnant, thereby focusing on differences of the electron and proton temperatures behind the shock fronts and on measuring proper motions of various parts remnant. I will discuss these results in the context of cosmic-ray acceleration models.

Posters and refreshments / 331

The high pre-explosion mass loss rate of SN 2004C

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We present time series radio data of the type Ic supernova SN 2004C taken with the VLA from January 2004 through April 2009 at 4.9 GHz, 8.5 GHz, 15 GHz, and 22 GHz. We also present 3 epochs of Chandra data taken 110, 170, and 1150 days after the initial explosion. We model our radio data for each epoch with a synchrotron self absorbed spectrum, and apply the dynamical model of Chevalier (1998) to infer the properties of the forward shock as well the the mass loss rate of the progenitor star prior to the explosion. We find an abnormally high mass loss rate for the star, $\sim 7 * 10^{-4} M_\sun per yr. We further find that shortly before the explosion, the mass loss rate, while still high, was steadily weakening by a factor of a few in the final decade before the supernova explosion, implying that the rapid changes in the core of the progenitor star were being communicated to the surface and weakening the mass loss rate.

Supernova Progenitors / 332

Do Pair-Production Supernovae exist in nature?

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The theoretical prediction that stars that develop heavy oxygen cores will become pair-unstable and explode has been made many decades ago. Yet, for many years, no examples of such explosions were found, and it was often conjectured that stars massive enough to explode in this manner may only exist at very high redshifts (population III stars). In recent years several luminous supernova explosions have been detected, and some of them have been proposed to result from this mechanism. I will review the theoretical predictions for pair-instability supernovae and confront them with observations, showing that indeed at least one object, SN 2007bi, is a convincing example of a pair-instability supernova. I will describe additional examples recently detected both nearby and in the distant Universe, and comment about the implications for stellar evolution models, the chemical evolution of the Universe, and future detection of the first stars.

Surveys now and in future / 333

Supernovae and Transients with the Pan-STARRS survey

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The Pan-STARRS-1 telescope is a 1.8m survey facility with a 1.4 Gigapix camera, the largest ever built for astronomical use. It has completed 1 year of full science operations. It has mapped most of the northern sky in grizY, is finding near-earth asteroids at fainter magnitudes than before and has discovered more than 2000 supernovae in the Medium Deep Survey fields. These are 11 fields of approximately 7 square degrees each, which are observed in grizY with an average frequency of 3 days. The data provide multi-colour lightcurves and the ability to stack the images over selected periods. I will highlight some new results from PS1, principally the study of ultra-luminous supernovae from redshifts 0.5 - 1.4 and discuss the nature of this population and their host galaxies. We have a focused search for transients with no cataloged host galaxy, or stellar counterpart, and the results of the first year (˜250 objects) will be summarised.

Posters and refreshments / 334

Radio Observations Reveal the Mass Loss Histories of Type Ibc Supernova Progenitor Stars

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We present extensive radio observations of the nearby Type Ibc supernovae (SNe Ibc) 2004cc, 2004dk, and 2004gq spanning $\Delta t \approx 8-1800$ days after explosion. Using a dynamical model developed for synchrotron emission from a slightly decelerated blastwave, we estimate the velocity and energy of the fastest ejecta and the density profile of the circumstellar medium. The blastwaves of all three supernovae are characterized by non-relativistic velocities of $\overline{v} \approx (0.1-25)c$ and associated energies of $E \approx (2-10)\times 10^{47}$ erg, in line with the expectations for a typical homologous explosion. Smooth, stellar wind circumstellar density profiles are indicated by the early radio data and we estimate the progenitor mass loss rates to be $\dot{M} \approx (0.6-13)\times 10^{-5}~\mathrm{M_\odot~yr^{-1}}$ (wind velocity, $v_w = 10^3~\mathrm{km~s^{-1}}$). These properties are consistent with the metallicity-dependent winds observed for Wolf-Rayet stars, the favored progenitors of SNe Ibc including those associated with long-duration gamma-ray bursts. However, at late time, each of these SNe show evidence for abrupt radio variability that we attribute to large density modulations (factor of $\sim 3-6$) at circumstellar radii of $r \approx (1-50)\times 10^{16}$ cm. We infer enhanced mass loss rates that approach or exceed $\dot{M} \sim 10^{-4}~M_\odot~\mathrm{yr}^{-1}$, the saturation limit for Wolf-Rayet line-driven winds. Combining these mass loss rates with those inferred for other radio SNe Ibc (including those associated with nearby gamma-ray bursts) reveals a broad distribution, $\dot{M} \approx 10^{-7}-10^{-2}~\mathrm{M_\odot~yr^{-1}}$, that exceeds the narrow range of mass loss rates measured for local Wolf-Rayet stars. We consider these results in the context of alternative mass loss mechanisms including metallicity-independent continuum-driven winds, hydrodynamic eruptions, and a binary-induced common envelope. Finally we note that our radio observations of SNe 2004cc, 2004dk, and 2004gq point to an apparent synchronization between the progenitor mass loss variations and the explosion that is reminiscent of Type IIn supernovae and supports a link between their progenitors.

Posters and refreshments / 357

Supernova signatures in the early X-ray emission from GRBs?

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A growing number of long Gamma-Ray Bursts are indisputably associated with core-collapse supernovae, discovered through optical spectroscopy and/or photometry of the GRB afterglow. Three such bursts show evidence of a thermal component in the early X-ray afterglow emission, claimed by some to be a signature of supernova shock breakout. This component could equally be attributed to central engine activity. We examine the X-ray afterglows of all Swift GRBs with associated optical supernovae in search of a thermal X-ray component, comparing these results to those of non-SN-associated GRBs to add to the debate on the origin of this emission.

Circumstellar interaction / 358

Hydrodynamic Interaction and the X-ray emission from Supernovae arising from Massive Stars

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Stellar wind mass-loss and photo-ionization can modify the ambient medium around massive stars during their evolution. Using numerical simulations, we discuss the formation of the circumstellar medium (CSM) around massive stars, and the evolution of supernova shock waves within this medium. The shock-CSM interaction heats up the gas to X-ray emitting temperatures. The output from numerical simulations can be used to compute the X-ray spectra and lightcurves using non-equilibrium ionization calculations. These can be compared directly with observations, allowing us to place strong constraints on the structure and properties of the medium and thereby on the progenitor star, infer the abundances of the ejecta and surrounding medium to reasonable accuracy, and explore the 3D geometry. This is illustrated with examples of specific supernovae.

The supernova - remnant connection / 359

Pulsar Wind Nebulae: what we think and hope to know.

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Pulsar Wind Nebulae (PWNe) are among the best objects where high energy relativistic astrophysics, can be investigated. They are close, well resolved in our observation, and the knowledge derived in their study has a strong impact in many other fields, from AGNs to GRBs. They also behave as a probe of the interior of the surrounding SNR, and their dynamical evolution, can be used to constrain parameters of the SN ejecta, otherwise not accessible. Thanks to a lucky combination of high resolution X-ray imaging (mostly thank to CHANDRA) and the coincidental development of numerical codes to handle the outflow and dynamical properties of relativistic MHD, our understanding of these system have greatly progressed in the last years. I will review how a beautifully coherent picture has developed leading to a now, commonly agreed paradigm, which has branched outside the field of SNRs themselves. I will also present problems, and future possible developments, showing how PWNe continue to provide us with new phenomenology, to challenge established truths.

SN 1987A, cont'd / 360

X-Ray Emission from SNR 1987A

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SN 1987A has been monitored by several X-ray missions such as Chandra, XMM-Newton, ROSAT, Suzaku, and Swift. Now in the phase of young supernova remnant (SNR), X-ray emission from 1987A is dominated by radiation from the shock interacting with dense circumstellar medium. The most extensive X-ray study of SNR 1987A has been performed by Chandra observations for the last 12 years. We review our Chandra observations of SNR 1987A, focusing on its evolution in the soft X-ray light curve, X-ray spectrum, and spatial expansion in the context of the shock interaction with the dense inner ring. We also briefly discuss the latest development in the soft X-ray light curve.

The supernova - remnant connection / 361

Balmer-Dominated Shocks: A 3D View

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The young remnants of supernovae of thermonuclear origin are often surrounded by fast (˜1000 km/s) shocks which are spatially coincident with strong hydrogen emission lines. Typically observed in H-alpha, these two-component lines are direct probes of the physical conditions in the pre- and post-shock gas. In this talk, I begin with a brief review of Balmer-dominated shocks. I will argue why the scientific yields from studying these shocks with high spatial and spectral resolutions are significantly enhanced, and that integral field unit (IFU) spectrographs allow for such studies. Subsequently, I report on an IFU observation of the ˜2000-3000 km/s shocks in the northwestern portion of supernova (SN) 1006. Using models which do not take cosmic ray physics into account, the data is converted into maps of the shock velocity and electron-to-proton temperature ratio; more than 50% of the (Voronoi-)binned data points do not have a corresponding model solution. Additionally, the presence of non-Gaussianity is detected in the broad H-alpha line. Taken together, our results suggest the presence of non-thermal protons in these Balmer-dominated shocks, which we identify as low-energy, hadronic cosmic rays.

What we can learn from SN spectra and light curves / 362

Carnegie Supernova Project Observations of Stripped Core-Collapse Supernovae

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The Carnegie Supernova Project obtained detailed optical (uBgVri) and near-IR (YJHKs) light curves of 35 Type Ib/c and Type IIb supernova. This data set is particularly well-suited to explore color relations over a broad wavelength range, and may offer new ways to accurately estimate host galaxy extinction. I will present the photometric sample and results from an initial analysis of the light curves and spectrophotometry.

Posters and refreshments / 363

Lines and Loops: Polarized Spectra Reveal Three-Dimensional Supernova Structure

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Supernovae of all types are known to be polarized, and many display complex line polarization effects that evolve over time as the supernova evolves. Such behavior reveals details of the clumpy nature of the ejecta, as well as illuminating the characteristics of the circumstellar material lost by the star in its pre-supernova evolution. With the aid of diagnostic tools developed through numerical modeling, polarized supernova spectra have the potential to reveal otherwise inaccessible information about ejecta and surrounding environments.

To illustrate this process, I will present results from a grid of simulated polarized line profiles of core-collapse SNe with circumstellar material, created using a three-dimensional spectropolarimetric radiative transfer code. Taking into account spectropolarimetric line effects helps break the degeneracy between line synthesis models and quantify the asphericities often invoked to explain asymmetric line profiles in total light spectra. In addition, three-dimensional modeling can help interpret the mysterious "q-u loop" phenomenon seen in the polarized line profiles of a variety of recent SNe. I will show simultaneous fits to observed line profiles in total and polarized light, investigate the conditions under which q-u loops arise in these models, and discuss the implications of these simulations for interpretation of the polarized spectra of future supernovae.

Surveys now and in future, cont'd / 364

Surveying The Southern Sky with SkyMapper: Learning about Core Collapse Supernovae

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SkyMapper is a new widefield 1.35m telescope located in Australia dedicated to surveying the southern sky. Its UV optimised 5.7 sq-degree FOV will map the entirety of the southern sky over the next 5 years, and will undertake specific programs to discover and monitor supernovae. In addition to the study of core collapse events directly, SkyMapper offers the ability to study core collapse supernovae through their light echoes, as well as through studies of metal poor stars, whose nucleosynthetic output is dominated by a single event.

What we can learn from SN spectra and light curves / 365

Theory of dust formation in core-collapse supernovae

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Cosmic dust forms in the circumstellar environments of evolved stars with low and high masses because the synthesis of dust requires high gas densities and temperatures. Supernovae are one of these environments and form dust in their ejecta a few months after their explosion. The harsh physical conditions met in the ejecta and the absence of hydrogen hamper the production of complex molecular species as precursors to dust grains. However, dust appears to effectively form in the ejecta implying that efficient pathways to the synthesis of silicates, metal sulphides and amorphous carbon from the gas phase are active. I will review former theories of dust formation in supernovae and present a new approach linking the gas phase to the solid phase in the ejecta. The various routes to dust relevant to supernova environments will be discussed as well as new results on dust clusters synthesis in supernovae with solar metallicity progenitors.

SN 1987A, cont'd / 366

X-ray illumination of the ejecta of SN1987A

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I will present the light curve of the ejecta of SN 1987A measured from HST observations spanning the past 17 years. The light curve shows that the flux declined up to around year 2001, but then started to increase, reaching a level more than twice as high in 2010. The declining phase is well modelled by radioactive decay of 44Ti, but a new energy source is needed to explain the late time brightening. I will show that the brightening is due to illumination of the ejecta by X-rays from the circumstellar ring interaction. I will also discuss the observed morphology of the ejecta and how this is affected by the X-ray illumination.

Posters and refreshments / 367

A Blind Search for Radio Transients in M51 and Associated Radio Observations of SN 1994I

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We present radio observations of the type Ic supernova 1994I, reanalyzed as part of a search for radio transients in M51 conducted using archival data from the Very Large Array. The data includes a detailed 4.9 GHz light curve of SN 1994I and three spectra of this object from epochs on April 10, May 4, and August 8, 1994, each spanning frequencies of 1.5-22.5 GHz. We find that the spectra and the light curve are well-fit by a synchrotron self-absorption model, assuming an explosion date of 1994 March 30.0 UT. The radio emission from the SN peaks in the 4.9 GHz band 40 days after the estimated explosion date, reaching a maximum flux of 16.8 mJy. Furthermore, we calculate physical properties of the explosion at the three epochs with full spectra and estimate a pre-explosion mass loss rate of ˜2-5 x 10e-5 solar masses per year, which is consistent with a Wolf-Rayet progenitor for the SN. We also present preliminary results of our survey of radio transient sources in M51. We find no detections in 31 epochs of 10-20 minute duration spanning a period of 6 months, placing a 2-sigma upper limit of 17 per square degree for the source density of transients above 500 microJy.

SN 1987A, cont'd / 368

Hydrogen, Helium, Carbon, and Nitrogen Emission from the SN 1987A Reverse Shock

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In this talk, I will present the most sensitive ultraviolet observations of Supernova 1987A to date. Imaging spectroscopy from the HST-Cosmic Origins Spectrograph show many narrow (FWHM ~ 300 km/s) emission lines from the circumstellar ring, broad (FWHM ˜ 10000-20000 km/s) emission lines from the reverse shock, and ultraviolet continuum emission. The high signal-to-noise (> 40 per resolution element) Ly-alpha velocity profile is dominated by resonant boosting of Ly-alpha photons emitted from the circumstellar ring. The ultraviolet continuum at wavelengths > 1350A can be explained by H I two-photon emission from circumstellar ring gas. We confirm an earlier, tentative detection of N V 1240 emission from the reverse shock and we present the first detections of broad He II 1640, C IV 1550, and N IV] 1486 emission lines from the reverse shock. The helium abundance in the high-velocity material is He/H = 0.14 +/- 0.06. The N V/H-alpha line ratio requires partial ion-electron equilibration (Te≈ 0.14 – 0.35 Tp). We find that the C/N abundance ratio in the gas crossing the reverse shock is significantly lower than that in the circumstellar ring, and possible explanations are discussed.

What we can learn from SN spectra and light curves / 369

Spectroscopic Modeling of Core-Collapse Supernovae

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I will present a new modeling approach that simultaneously computes spectra and light curves and takes into account line blanketing, departures from Local Thermodynamic Equilibrium, time dependent terms in the radiative-transfer, energy, and statistical-equilibrium equations, as well as non-thermal processes associated with radioactive decay. Combined with hydrodynamical inputs of SN ejecta produced with piston-driven explosions of pre-SN red-supergiant, blue-supergiant, or Wolf-Rayet stars, we simulate the photometric, spectroscopic, and spectro-polarimetric evolution from a given time after shock breakout until the nebular phase. This method applies to any SN ejecta in homologous expansion. I will present results for a variety of core-collapse SN types, i.e. including SNe II-peculiar (specifically SN1987A), II-Plateau, Ib, and Ic, focusing on the photospheric phase of their evolution.

SN 1987A, cont'd / 370

The structure of the inner ejecta of SN 1987A

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Observing the inner ejecta of a supernova is possible only in a handful of nearby supernova remnants. SN 1987A is the first modern stellar explosion that has been continuously observed from its beginning to the supernova remnant phase. Twenty years

after the explosion, we are now able to observe the three-dimensional spatially resolved inner ejecta of this supernova.
We have used Integral Field Spectroscopy to image the supernova ejecta and the equatorial ring in several infrared emission lines. The spectral information can be mapped into a radial velocity image revealing the expansion of the ejecta both as projected onto the sky and perpendicular to the sky plane.
The inner ejecta are spatially resolved in a North-South direction and are clearly asymmetric. Like the ring emission, the northern parts of the ejecta are blueshifted, while the material projected to the South of the supernova centre is moving away from us. We argue that the bulk of the ejecta is situated in the same plane as defined by the equatorial ring and does not form a bipolar structure as has been suggested. The exact shape of the ejecta is modelled and we find that an elongated triaxial ellipsoid fits the observations best.
Our observations clearly indicate a non-symmetric explosion mechanism for SN 1987A. The elongation and velocity asymmetries point towards a large-scale spatial non-spherical distribution as predicted in recent explosion models. The orientation of the ejecta in the plane of the equatorial ring argues against a jet-induced explosion through the poles due to stellar rotation.

Supernova Progenitors / 371

Theoretical Paths Leading to Supernovae

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Recent progress in observations have allowed us to now find an overwhelming collection of observational supernova data including a wealth of different classes and marvelous detail in part. But how do they connect with our understanding of the underlying engine, and what stars are responsible for each of them? Theoretical models, on the other hand, also provides a wide variety of model, ranging from electron-capture supernovae at the low-mass end, to core collapse supernova, to gamma-ray burst or hypernovae, to pair instability supernovae for the highest mass stars. In this talk we will give a brief review of the pre-supernova evolution of massive stars and how they connect to different supernova and remnant outcomes. We will give a current overview of the variety of supernova models in this context, and how these theoretical models connect to the progenitor star, in particular the mass, but also other factors like mass loss and rotation of the progenitor star.

Posters and refreshments / 372

Relativistic Explosion Models of Core-Collapse Supernovae

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The collapse of an iron core to a neutron star and the subsequent supernova explosion are among the greatest challenges in computational astrophysics due to the complex interplay of multi-dimensional hydrodynamics, neutrino transport, and strong-field gravity. Due to the compactness of the newly-born proto-neutron star and the occurrence of high velocities (up to ˜0.3c), general relativity plays an important role in the supernova engine. However, it has only recently become possible to conduct multi-dimensional simulations of core-collapse supernovae with both general relativity and sophisticated neutrino transport included. In this poster, we present results from these relativistic explosion simulations, and discuss the implied effects of general relativity on the explosion dynamics as well as on the neutrino and gravitational wave signal from the supernova core.

Supernova Progenitors / 373

Variety of End Points of Massive Stars

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Stars more massive than about 8 times the mass of the Sun end their lives in cataclysmic explosions: supernovae and gamma-ray bursts. In recent years targeted and blind transient surveys have expanded the range of potential outcomes, including potentially non-destructive eruptions on the path to the eventual explosion and highly-luminous events that may require a new range of progenitor or explosion parameters. In this talk I will give an overview of these recent developments spanning the range from transients at intermediate luminosities to gamma-ray bursts.

What we can learn from SN spectra and light curves / 374

Light echoes of core collapse supernovae

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Young Galactic supernova remnants are unique laboratories for supernova physics. Due to their proximity they provide us with the most detailed view of the outcome of a supernova. However, the exact spectroscopic types of their original explosions have been undetermined so far - hindering to link the wealth of multi-wavelength knowledge about their remnants with the diverse population of supernovae.
Light echoes, reflections of the brilliant supernova burst of light by interstellar dust, provide a unique opportunity to re-observe today - with powerful scientific instruments of the 21st century - historic supernova explosions even after hundreds of years and to conclude on their nature. We report on optical light-echo spectroscopy of two Galactic supernovae, in particular the youngest known CC SN Cas A. These observations finally recovered the missing spectroscopic classifications and provide new constraints on explosion models for future studies.

What we can learn from SN spectra and light curves / 375

Stripped core collapse supernovae

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Stripped-envelope core-collapse supernovae (i.e., SNe of Type IIb, Ib, Ic and broad-lined Ic) are supernovae whose massive progenitors have been stripped of progressively larger amounts of their hydrogen and helium envelopes. While the SNe Ic-bl associated with long Gamma Ray Bursts (GRBs) have been studied in detail, the full range of properties of normal or broad-lined SNe is not known, nor their dominant progenitor channel and the productions conditions that lead to different kinds of explosions in massive stars.
Observations of stipped SNe yield vital clues about the explosion properties of massive stars (e.g., explosion geometry) as well as their size and make-up, and set the foundation for excluding contaminants in high-z SN Ia searches and for identifying exotic transients in current and future innovative surveys.

Here I will review observations of a number of intriguing recent events (e.g., SN 2008D, SN 2008ax) as well as the statistical properties of a large sample of stripped SNe, focusing on early-time and late-time optical spectra. I will also briefly mention the most recent results on SN environments, specifically on measured metallities, and what they may tell us about the progenitors of stripped SNe.

Explosion mechanism / 376

The hypernova-GRB connection

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The properties of supernovae associated with GRBs & XRFs, and some other related supernovae are summarized. Discussion includes the possible connection to the unusual supernovae, such as extremely luminous and extremely faint supernovae. The abundance patterns predicted in their nucleosynthesis are compared with those of metal-poor halo stars, DLAs, and other related objects.

Explosion mechanism / 381

Modeling core-collapse explosions

Author: H.-T. Janka[1]

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The talk will review 2D and 3D modeling of core-collapse supernova explosions by the Garching group. It will address the question of the explosion mechanism and the role of relativistic effects, of the neutron star equation of state, and of dimensionality (2D vs. 3D) in this context. Observational consequences of the explosion mechanism will also be discussed.

Supernova Progenitors / 382

The supernova/GRB connection

Author: Jesper Sollerman[1]

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I will make a quick review of the connection between Supernovae and Gamma-Ray Bursts, from an observers perspective. I plan to run through the history of GRBs with a special eye to the SN associations, and try to include also some of the more recent issues and developments.

Explosion mechanism / 383

Radioactivity and nucleosynthesis as probes of explosion models

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Supernovae are observationally characterized by their lightcurves, spectra, late time radioactivities in remnants and their integrated contribution to chemical evolution, witnessed in observations of old stars. We will highlight open questions with respect to nucleosynthesis contributions from core collapse supernovae. While many aspects of intermediate mass (alpha) elements are understood with present supernova models, where the nucleosynthesis calculations are still based on induced explosion mechanisms, the composition of the innermost ejecta depends on a self-consistent treatment of the explosion. This relates to nuclei of the Fe-group, the so-called LEPP nuclei up to Sr-Y-Zr, the understanding of a νp-process, and the options for a weak and/or strong r-process.
We will discuss these aspects with respect to presently existing supernova models and recent investigations in stellar evolution with rotation and s-process contributions from massive stars, specific equations of state which permit explosions via the quark-hadron phase transition, as well as core collaspe events with rotation and strong magnetic fields.

Supernova Progenitors / 384

Core-collapse supernova progenitors

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In the last fifteen years, searches for the progenitors of core-collapse supernovae in archival Hubble Space Telescope images have yielded progenitor candidates for ˜10 nearby supernovae, and upper limits on the luminosity and mass for a further ˜20. In this talk, I discuss recent results from ongoing progenitor searches. In particular, I focus on some of the open questions in progenitor research: whether all faint Type IIP supernovae arise from low (˜8M) progenitors, why we have not detected any high mass red supergiant progenitors thus-far, and whether recent results demonstrate that some stars can in fact explode as yellow supergiants.

What we can learn from SN spectra and light curves / 387

Dust in Core-Collapse Supernovae

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A relatively small number of CCSNe have been observed to exhibit late-time (>100 d) infrared emission from dust over the past 30 years. Since the launch of Spitzer (and now even Herschel), the community has had the capability to probe supernova-associated dust at mid- and far-infrared wavelengths. Combined with ground-based optical and NIR observations, these data have provided strong constraints on the dust properties. The origin and heating mechanism of the dust, however, can be ambiguous. Disentangling the various models of dust formation and heating offers important clues regarding the supernova's circumstellar environment, explosion mechanism, and even progenitor system. Furthermore, the discovery of significant amounts of newly formed SN dust would provide the much sought evidence necessary to confirm SN dust models. In this talk, I will review the various states of dust observed in the supernova environment and will highlight what the community has learned from recent discoveries.

Circumstellar interaction / 388

Unique Progenitor Diagnostics from Radio and X-ray Observations of Supernovae

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For centuries, supernovae have been studied primarily in the visual band thanks to their strong optical emission that dominates the bolometric luminosity on timescales of weeks following the explosion. At the same time, some of the most profound advances in our understanding of supernovae have been made possible through observations at other wavelengths. Here I will review the unique progenitor diagnostics from radio and X-ray follow-up observations of supernovae, including unusual pre-explosion mass loss histories of massive stars nearing dath and unveiling the progenitors of SNe Ia.

Surveys now and in future, cont'd / 391

B. Leibundgut, "Supernova studies in the era of extremely large telescopes"

Author: Bruno Leibundgut[1]

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The next generation of large ground-based telescopes will essentially increase the light-gathering power and the angular resolution. The talk will muse about possible directions
supernova research may take when these telescopes become available. Predicting research a decade into the future is alway risky, but it is possible explore the new parameter space, which
will open with these facilities.

SN 1987A / 392

SINS and SAINTS: 1987A and other Blasts

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The Hubble Space Telescope programs dubbed SINS and SAINTS have been underway since the launch of HST. The angular resolution of HST allows us to image the many different parts of the supernova as it becomes a remnant, and the spectra, especially in the UV, have helped us understand its chemistry and physics. SN 1987A was the best-observed supernova and is now becoming the best-observed supernova remnant.

Some of the highlights include imaging the circumstellar rings, observing the hotspots as they light up, resolving the debris and searching for the stellar remnant, and now tracing how the interaction of the blast wave and the circumstellar ring illuminate the properties of the explosion itself. The Stockholm group, especially Claes Fransson, have been leaders in this work.

SN 1987A provides some useful lessons that can be applied to more distant supernovae where we do not have the benefit of such detailed knowledge.