Supernovae

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- Supernovae (Photometric and Spectroscopic Evolution, Rates)
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1.1 ICRANet participants

- Carlo Luciano Bianco
- Letizia Caito
- Luca Izzo
- Massimo Della Valle

1.2 Past collaborators

- John Danziger (INAF-Trieste)
- Roberto Gilmozzi (ESO, Garching, Munchen)
- Mario Livio (STScI, Baltimore)
- Piero Madau (Santa Cruz, California University)
- Nino Panagia (STScI, Baltimore)
- Saul Perlmutter (Lawrence Berkeley National Laboratory, University of California)
- Sumner Starrfield (Arizona State University)
- Robert Williams (STScI, Baltimore)

1.3 Ongoing collaborations

- Lorenzo Amati (INAF-Bologna)
- Guido Chincarini (Bicocca University, Milano) and the SWIFT team
- Filippo Frontera (Ferrara University)
- Roberto Gilmozzi (ESO, Garching, Munchen)
- Filippo Mannucci (INAF-Arcetri, Firenze)
- Dani Maoz (Tel-Aviv University)
- Francesca Matteucci (Trieste University, Trieste)
- Ken Nomoto (University of Tokyo)
- Nino Panagia (STScI, Baltimore)
- Andrea Pastorello (Queen's University, Belfast)
- Martin Henze (MPE-Garching)
- Evan Scannapieco (Arizona State University)
- Robert Williams (STScI, Baltimore)
- Bruno Leibundgut (ESO)
- Adam Riess (STScI & Hopkins University)
- Martin Henze (Max-Planck)
- Enrico Cappellaroc (INAF-Padova)
- Massimo Turatto (INAF-Padova)

1.4 Sabatical Visits, 2005-2010

- European Southern Observatory, Munchen (2005)
- STScI, Baltimore, (2005)
- KAVLI Institute, Santa Barbara (2006, 2007)
- Tokyo University (2006)
- Dark Cosmology Center, Niels Bohr Institute, Copenhagen (2007)

- Aspen Center for Physics (2007)
- Queen's University, Belfast (2007)
- European Southern Observatory, Munchen (2008-2009)

1.5 Students

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- Husne Dereli (IRAP PhD, Turky)

2 Brief description

My research field concern the study of several classes of transient phenomena such as: supernovae, gamma-ray bursts and novae .

Gamma-ray bursts and their Afterglows. My interest in this area started in 2000 when I became member of the SWIFT follow-up team. Most efforts were (and still are) devoted to the study of the connection between Supernovae and GRBs. Currently, I'm PI of a VLT proposal *A spectroscopic study of the Supernova/GRB connection* aimed at following the spectroscopic evolution of nearby SN-GRB associations. This project is carried out in collaboration with other members of SWIFT follow-up team. I point out 4 highlights from this programme, occurred in 2008/2011: i) the discovery of a transition object (SN 2008D/XRF 080109) between GRBs and standard Core-Collapse SNe; ii) the detection of a GRB-SN at z=0.53 and iii) the discovery of GRB 090423 at z=8.1 that is the farthest GRB ever (spectroscopically) confirmed; iv) the discovery and the follow-up of a new case of association between GRBs and SNe, i.e. GRB100316D/SN 2010bh, which takes advantage of the performances of X-shooter at VLT.

Supernovae. Photometric and the spectroscopic study of all types of SNe (Ia, Ib/c, II-linear, II-plateau) near maximum light and at late stages and their theoretical modeling. The observations at maximum provide us with the necessary data for using SNe (Ia and II) as standard candles. The observations at later stages allow one to discriminate among different energy sources (i.e. radioactive decay, pulsar, light-echo), to model the mechanisms of the explosion, and to shed light on the nature of the progenitor (In collaboration with N. Panagia and the Padova and Belfast SN groups.)

Supernovae at high z. The study of Supernovae has been extended to objects at high-z. The search for SNe at high z is twofold important. On the one hand the evolution of the SN rate with redshift contains unique information on the star formation history of the universe, the IMF of stars and the nature of the progenitors in Type Ia events. On the other hand SNeI-a at $z \sim 1 - 1.5$ are valuable tracers of cosmological models . Both aspects are currently investigated both on observational and theoretical grounds. We currently have an ESO proposal at VLT, "SN rate at high redshift and the composition of the universe" (PI B.Leibundgut in collaboration with P. Rosati, D. Maoz. S. Blondin, M. Postman and A. Riess) which has been awarded with 40h at VLT.

Search for obscured Supernovae. The "true" value of the SN rate is considerably underestimated because of extinction. This problem can be partially solved by observing in the infrared. We have started two NIR SN searches in ultra-luminous galaxies, the former at NTT and TNG the latter with HST-NICMOS (In collaboration with F. Mannucci, R. Maiolino and G. Cresci).

Search for environmental effects on the properties of type Ia SNe. This is a long-term project (in collaboration with F. Mannucci, Nino Panagia, R. Gilmozzi and F. Matteucci) aimed at throwing light on the still unknown origin of the progenitors of type Ia Supernovae. Our results have been reported in 10 papers so far published (since 2005), see items 5 and 8.

Novae. The systematic study of extragalactic novae in galaxies of different Hubble types has shown, that nova frequency (number of nova outburst per year) depends on the Hubble type of the parent galaxy. In particular, we find that spiral galaxies are more prolific nova producers, by a factor about 4, in units of K-band luminosity, than ellipticals and S0's. We show that this result could be explained by assuming that novae in late– and early–type galaxies originate from two different classes of progenitors. This result has been recently confirmed by X-ray monitoring of Super-Soft sources observed in M31 (see item 2 and 3).

The use of the maximum magnitude *vs.* rate of decline relationship, calibrated on the nova population of M31 and LMC, has allowed us to re-define the distance scale from the Local Group up to Fornax cluster and to measure the Hubble constant. The distance moduli so derived compare very well (i.e. within 0.2 mags) with those obtained via Cepheids, thus demonstrating that classical novae are indeed good distance indicators perfectly suitable to calibrate the absolute magnitude at maximum of type Ia occurred in early type galaxies. In collaboration with R. Gilmozzi we have explored the possibility to use nova stars as standard candles for measuring the cosmological parameters, with an Extremely Large Telescope (40m). High resolution spectroscopic observations carried out with Bob Williams, Elena Mason and A. Ederoclite on a sample of galactic Novae have shown the existence of stationary material, coming from the secondary star, around the circumburst area. Implications for Nova (and possibly SN-Ia) progenitors are under investigations.

Cosmological Parameters with GRBs. Observations of SNe-Ia in the range of redshift $z \approx 0.3 \div 1.3$ (Perlmutter et al. 1998; 1999; Riess et al. 1998; 2004; Schmidt et al. 1998) have shown that their peaks magnitude appear (at $z \sim 0.5$) dimmer than expected by ~ 0.2 mag. This result has been taken as evidence for the existence of a "cosmic jerk", then suggesting that the Universe may accelerate its expansion. On the other hands the cosmological interpretation rely on the lack of evolutionary effects on progenitors of type Ia SNe. Recent results on SNe-Ia progenitors, which imply the existence of two different classes of progenitors for SNe-Ia (Della Valle & Panagia 2003,

Della Valle et al. 2005, Mannucci et al. 2005, 2006, 2007, Sullivan et al. 2006, Aubourg et al. 2007) occuring in different environments and at different redshift, may cast some doubts on this assumption. In addition recent versions of the Hubble diagramm for SNe-Ia (e.g. Wood-Vasey et al. 2006) display peculiar distributions of the residuals, which are also suggestive for the presence of systematics. This situation calls for an independent measurement of the cosmological parameters besides the one obtained via SNe-Ia. We show that GRBs can be used to measure Ω_M (see Amati et al. 2008; Della Valle & Amati 2008).

3 Publications 2012

1. *Supernovae and Gamma-Ray Bursts: 10 Years of Observations*, Della Valle, M. 2012 Proceedings of the Twelfth Marcel Grossmann Meeting on General Relativity, edited by Thibault Damour, Robert T. Jantzen and Remo Ruffini. Singapore: World Scientific, 2012, p.261

In this paper I have shortly reviewed the observational status of the Supernova and Gamma-ray bursts connection, including some of the most recent cases: such as GRB 081007/SN 2008hw at z=0.53 and SN 2008D associated with GRB 080109, a borderline object that may link GRBs with "standard" core-collapse events.

2. *Monitoring AGNs and transient sources with the Wide Field X-ray Telescope*, Paolillo et al. 2012, Memorie della Societa Astronomica Italiana Supplement, v.19, p.264 (2012)

The Wide Field X-ray Telescope (WFXT) is a proposed mission concept with a high survey speed, due to the combination of large field of view (FOV), effective area and sharp PSF across the whole FOV. A mission such as WFXT will detect a large number of variable and transient X-ray sources during its operating lifetime. We present estimates of the WFXT capabilities in the time domain, allowing to study variability of thousand of AGNs with significant detail, as well as to constrain the rates and properties of hundreds of X-ray Flashes/faint GRBs, Tidal Disruption Events, ULXs, Type-I bursts etc. The planned WFXT extragalactic surveys would thus allow to trace variable and transient X-ray populations over cosmological volumes.

3. *The old nova CP Puppis: a carbon nova and asynchronous polar?* , Bianchini et al. 2012, A&A, 539, 94

CP Pup (Nova Pup 1942) showed outburst and quiescent characteristics indicating a very massive white dwarf, yet the standard spectroscopic dynamical analysis assuming an accretion disk yields an extremely low value for the white dwarf mass. However, some physical parameters and the accretion geometry are still poorly known. The nova was spectroscopically monitored between 1988 and 1996. We analyzed the whole data set in order to redetermine the spectroscopic period and examine its stability. We also looked for chemical anomalies in the spectrum. The average 1996 spectrum yields information on the chemical composition of the binary. We also searched the mean period using the multi-year data set. From the radial velocities of our complete data set we derive the most probable average spectroscopic pe-

riod and tentatively suggest revised ephemeris. However, we demonstrate that the period is intrinsically unstable. We show that a standard accretion disk model does not explain all the spectroscopic features observed nor the variability of the spectroscopic period. We suggest that only interpreting the system as a slightly asynchronous polar would fit the data. The mean optical spectrum of CP Pup shows also an enhanced carbon abundance. Non solar abundances in the accreted material are unexpected and interesting, confirming that the nature of the secondaries of old novae should be studied more in detail. In fact, in CP Pup, as in other novae, the enhanced carbon is an important clue to the pre-outburst evolution, implying that the secondary was heavily polluted with carbon and helium during the common envelope phase of the pre-cataclysmic binary by a relatively massive primary that filled its Roche lobe during the third dredge up on the asymptotic giant branch.

4. *Evidence for Type Ia Supernova Diversity from Ultraviolet Observations with the Hubble Space Telescope*, Wang et al. 2012, ApJ,

We present ultraviolet (UV) spectroscopy and photometry of four Type Ia supernovae (SNe 2004dt, 2004ef, 2005M, and 2005cf) obtained with the UV prism of the Advanced Camera for Surveys on the Hubble Space Telescope. This data set provides unique spectral time series down to 2000 . Significant diversity is seen in the near-maximum-light spectra ($\sim 2000 - 3500\mathring{A}$) for this small sample. The corresponding photometric data, together with archival data from Swift Ultraviolet/Optical Telescope observations, provide further evidence of increased dispersion in the UV emission with respect to the optical. The peak luminosities measured in the uvw1/F250W filter are found to correlate with the B-band light-curve shape parameter $\Delta m15(B)$, but with much larger scatter relative to the correlation in the broadband B band (e.g., $\sim 0.4mag$ versus $\sim 0.2mag$ for those with $0.8mag < \Delta m15(B) < 1.7mag$). SN 2004dt is found as an outlier of this correlation (at $> 3\sigma$), being brighter than normal SNe Ia such as SN 2005cf by $\sim 0.9magand \sim 2.0mag$ in the uvw1/F250W and uvm2/F220W filters, respectively. We show that different progenitor metallicity or line-expansion velocities alone cannot explain such a large discrepancy. Viewing-angle effects, such as due to an asymmetric explosion, may have a significant influence on the flux emitted in the UV region. Detailed modeling is needed to disentangle and quantify the above effects.

5. *The Highly Energetic Expansion of SN 2010bh Associated with GRB 100316D*, Bufano et al. 2012, ApJ, 753, 67

We present the spectroscopic and photometric evolution of the nearby (z = 0.059) spectroscopically confirmed Type Ic supernova, SN 2010bh, associated with the soft, long-duration gamma-ray burst (X-ray flash) GRB 100316D. Intensive follow-up observations of SN 2010bh were performed at the ESO Very Large Telescope (VLT) using the X-shooter and FORS2 instruments. Thanks

to the detailed temporal coverage and the extended wavelength range ($3000 - 24800\mathring{A}$), we obtained an unprecedentedly rich spectral sequence among the hypernovae, making SN 2010bh one of the best studied representatives of this SN class. We find that SN 2010bh has a more rapid rise to maximum brightness (8.0 ± 1.0 rest-frame days) and a fainter absolute peak luminosity ($Lbol \sim 31042ergs - 1$) than previously observed SN events associated with GRBs. Our estimate of the ejected 56Ni mass is $0.12 \pm 0.02 M_{\odot}$. From the broad spectral features, we measure expansion velocities up to 47,000 km s-1, higher than those of SNe 1998bw (GRB 980425) and 2006aj (GRB 060218). Helium absorption lines He I 5876 and He I 1.083 μm, blueshifted by $\sim 20,000 - 30,000kms - 1$ and $\sim 28,000 - 38,000kms - 1$, respectively, may be present in the optical spectra. However, the lack of coverage of the He I 2.058 μm line prevents us from confirming such identifications. The nebular spectrum, taken at $\sim$ 186 days after the explosion, shows a broad but faint [O I] emission at 6340Å. The light curve shape and photospheric expansion velocities of SN 2010bh suggest that we witnessed a highly energetic explosion with a small ejected mass (E k 1052 erg and Mej $\sim 3 M_{\odot}$). The observed properties of SN 2010bh further extend the heterogeneity of the class of GRB SNe.

6. *Metallicity effects on cosmic Type Ib/c supernovae and gamma-ray burst ratesD*, Grieco et al. 2012, MNRAS, 423, 3049

Type Ib/c supernovae (SNe Ib/c) are likely to be associated with long gamma-ray bursts (GRBs), and therefore it is important to compare the SN rate in galaxies with the GRB rate. To do this we computed SN Ib/c rates in galaxies of different morphological types (ellipticals, spirals and irregulars) by assuming different histories of star formation and different SN Ib/c progenitors. We included some recent suggestions about the dependence of the minimum mass of single Wolf-Rayet (WR) stars on the stellar metallicity and therefore on galactic chemical evolution. We adopted several cosmic star formation rates (i.e. relative to a comoving unitary volume of the Universe) as a function of cosmic time, either observationally or theoretically derived, including the one computed with our galaxy models. We then computed the cosmic SN Ib/c rates. Our results show that the predicted SN Ib/c rates in spirals and irregulars can reproduce well the present observed rates if both single WR stars and massive binary systems are taken into account as SN Ib/c progenitors. The metallicity effects on the minimum mass for single WR stars are evident mainly in the early phases of galaxy evolution and do not influence substantially the predicted local Type Ib/c rates. We reached the following conclusions. (i) The ratio cosmic GRB rate /cosmic Type Ib/c rate varies in the range 10-2-10-4 in the whole redshift range, thus suggesting that only a small fraction of all SNe Ib/c gives rise to GRBs. (ii) The metallicity dependence of SN Ib/c progenitors produces lower cosmic SN Ib/c rates at early times, for any chosen cosmic star formation rate. (iii) Different the-

oretical cosmic star formation rates, computed under different scenarios of galaxy formation, produce SN Ib/c cosmic rates that differ mainly at very high redshifts. However, it is difficult to draw firm conclusions on the high-redshift trend because of the large uncertainties in the data. (iv) GRBs can be important tracers of star formation at high redshifts if their luminosity function does not vary with redshift, and they can help in discriminating among galaxy formation models.

7. *M31N 2008-05d: a M 31 disk nova with a dipping supersoft X-ray lightcurve*, Henze et al. 2012, A&A, 544, 44

Classical novae (CNe) represent a major class of supersoft X-ray sources (SSSs) in the central region of our neighbouring galaxy M 31. Significantly different SSS properties of CNe in the M 31 bulge and disk wereindicated by recent X-ray population studies, which however considered only a small number of disk novae. We initiated a target of opportunity (ToO) program with XMM-Newton to observe the SSS phases of CNe in the disk of M 31 and improve the database for further population studies. We analysed two XMM-Newton ToO observations triggered in Aug. 2011 and Jan. 2012, respectively, and extracted X-ray spectra and light curves. Results: We report the discovery of an X-ray counterpart to the M 31 disk nova M31N 2008-05d. The X-ray spectrum of the object allows us to classify it as a SSS parametrised by a blackbody temperature of 32 ± 6 eV. More than three years after the nova outburst, the X-ray light curve of the SSS exhibits irregular, broad dip features. These dips affect primarily the very soft part of the X-ray spectrum, which might indicate absorption effects. Dipping SSS light curves are rarely observed in M 31 novae. As well as providing an unparalleled statistical sample, the M 31 population of novae with SSS counterparts produces frequent discoveries of unusual objects, thereby underlining the importance of regular monitoring.

8. *U Scorpii 2010 outburst: a new understanding of the binary accretion disk and the secondary star*, Mason et al. 2012, A&A, 544, 149

We present optical and near-infrared (NIR) spectroscopic observations of U Sco 2010 outburst. From the analysis of lines profiles we identify a broad and a narrow component and show that the latter originates from the re-forming accretion disk. We show that the accretion resumes shortly after the outburst, on day +8, roughly when the super-soft (SSS) X-ray phase starts. Consequently U Sco SSS phase is fueled (in part or fully) by accretion and should not be used to estimate mrem, the mass of accreted material which has not been ejected during the outburst. In addition, most of the He emission lines, and the He ii lies in particular, form in the accretion flow/disk within the binary and are optically thick, thus preventing an accurate abundance determination. A late spectrum taken in quiescence and during eclipse shows Ca II H&K, the G-band and Mg ib absorption from the secondary star. However, no other significant secondary star features have been observed at

longer wavelengths and in the NIR band.

9. *The optical SN 2012bz associated with the long GRB 120422A*, Melandri et al. 2012, A&A, 574, 82

The association of Type Ic supernovae (SNe) with long-duration gamma-ray bursts (GRBs) is well established. We endeavor, through accurate ground-based observational campaigns, to characterize these SNe at increasingly high redshifts. We obtained a series of optical photometric and spectroscopic observations of the Type Ic SN 2012bz associated with the Swift long-duration GRB 120422A (redshift z = 0.283) using the 3.6-m TNG and the 8.2-m VLT telescopes during the time interval between 4 and 36 days after the burst. The peak times of the light curves of SN 2012bz in various optical filters differ, with the B-band and i'-band light curves reaching maximum at 9 and 23 rest-frame days, respectively. The bolometric light curve has been derived from individual bands photometric measurements, but no correction for the unknown contribution in the near-infrared (probably around 10-15%) has been applied. Therefore, the present light curve should be considered as a lower limit to the actual UV-optical-IR bolometric light curve. This pseudo-bolometric curve reaches its maximum $(Mbol = -18.56 \pm 0.06) at 13 \pm 1$ rest-frame days; it is similar in shape and luminosity to the bolometric light curves of the SNe associated with $z < 0.2$ GRBs and more luminous than those of SNe associated with X-ray flashes (XRFs). A comparison with the model generated for the bolometric light curve of SN 2003dh suggests that SN 2012bz produced only about 15% less 56Ni than SN 2003dh, about 0.35 Msun. Similarly the VLT spectra of SN 2012bz, after correction for Galactic extinction and for the contribution of the host galaxy, suggest comparable explosion parameters with those observed in SN 2003dh (EK 3.510^{5}2 erg, Mej $\sim 7 M_\odot$) and a similar progenitor mass ($\sim 25 - 40 M_\odot$). GRB 120422A is consistent with the Epeak - Eiso and the EX,iso - E,iso - Epeak relations. GRB 120422A / SN 2012bz shows the GRB-SN connection at the highest redshift so far accurately monitored both photometrically and spectroscopically.

10. *Supersoft X-rays reveal a classical nova in the M 31 globular cluster Bol 126*, Henze et al. 2012, A&A, submitted, 2012arXiv1211.4736H

Classical novae (CNe) represent the main class of supersoft X-ray sources (SSSs) in the central region of our neighbouring galaxy M 31. Only three confirmed novae and three SSSs have been discovered in globular clusters (GCs) of any galaxy so far, of which one nova and two SSSs (including the nova) were found in M 31 GCs. To study the SSS state of CNe we carried out a high-cadence X-ray monitoring of the M 31 central area with XMM-Newton and Chandra. We analysed X-ray and optical data of a new transient X-ray source in the M 31 GC Bol 126, discovered serendipitously in Swift observations. Our optical data set was based on regular M 31 monitoring programmes from five different small telescopes. Additionally, we made use of Pan-STARRS 1

data obtained during the PAndromeda survey. Our observations reveal that the X-ray source in Bol 126 is the third SSS in an M 31 GC and can be confirmed as the second CN in the M 31 GC system. This nova is named M31N 2010-10f. Its properties in the X-ray and optical regimes agree with a massive white dwarf ($M(WD) > 1.3M_{\odot}$) in the binary system. Incorporating the data on previously found (suspected) novae in M 31 GCs we used our high-cadence X-ray monitoring observations to estimate a tentative nova rate in the M 31 GC system of 0.05 /yr/GC. An optical estimate, based on the recent 10.5-year WeCAPP survey, gives a lower nova rate, which is compatible with the X-ray rate on the 95% confidence level. There is growing evidence that the nova rate in GCs is higher than expected from primordial binary formation and under conditions as in the field. Dynamical binary formation and/or additional accretion from the intracluster medium are possible scenarios for an increased nova rate, but observational confirmation for this enhancement has been absent, so far. Regular X-ray monitoring observations of M 31 provide a promising strategy to find these novae.