Nuclear supernovae with Gaia

Seppo Mattila

University of Turku, Finland
+ Clare Hall & IoA, Univ. of Cambridge

Thomas Reynolds, Tuomas Kangas (Turku), Erkki Kankare, Rubina Kotak (QUB), Stuart Ryder (AAO), Miguel Perez-Torres (IAA-CSIC), Cristina Romero-Canizales (PUC), Nadia Blagorodnova (IoA->Caltech), Morgan Fraser, Simon Hodgkin (IoA) and others

Gaia Science Alerts Workshop 2015, 12th Nov. 2015
Background
Occurrence of SNe in nuclear environments

SNe within the nuclear regions of galaxies (especially in starbursts and LIRGs) neglected by most searches

Herrero-Illana+2012

Leaman+2011; Li+2011
Occurrence of SNe in nuclear environments

SNe within the nuclear regions of galaxies (especially in starbursts and LIRGs) neglected by most searches

Herrero-Illana+2012

Perez-Torres+2009
**Detailed comparison between cosmic SNR and SFH**

- Consistent picture of SFH available from UV, optical and IR up to $z \sim 8$
- Detailed comparison between CCSN rates and cosmic SF history can provide a useful consistency check and information on the mass range for CCSN progenitors

---


Strolger+2015
Detailed comparison between cosmic SNR and SFH

- Consistent picture of SFH available from UV, optical and IR up to $z \sim 8$
- Detailed comparison between CCSN rates and cosmic SF history can provide a useful consistency check and information on the mass range for CCSN progenitors
- Systematic uncertainties in the CCSN rates significant at all redshifts
- Fraction of CCSNe “missed” in the nuclear regions of U/LIRGs as a function of $z$?
Existence of “dark” SNe in U/LIRGs

- (Ultra)luminous IR galaxies locally rare but at $z \sim 1-2$ dominate the star formation
- Stars forming rapidly during a few x 100 Myr starburst episodes
- Large numbers of massive short lived stars exploding as CCSNe
- Missed by surveys due to large extinctions and concentration to nuclear regions

LIRGs: $10^{11} L_\odot < L_{\text{IR}} < 10^{12} L_\odot$
SFR a few x 10-100 $M_\odot$ yr$^{-1}$
a few x 0.1-1 CCSNe yr$^{-1}$

ULIRGs: $10^{12} L_\odot < L_{\text{IR}} < 10^{13} L_\odot$
SFR a few x 100-1000 $M_\odot$ yr$^{-1}$
a few x 1-10 CCSNe yr$^{-1}$

Magnelli+2009,2011
Adaptive Optics detection and study of SNe in LIRGs
NOT/NOTCam K-band (natural seeing)
Arp 299 (LIRG)
Gemini-N/Altair JHK-band (Adaptive Optics)
it is the region that is most likely to contain new SNe (IC 694 accounts for most of the infrared emission in Arp 299, rate for past...i.e., much smaller than the synthesized interferometric beam. And A25, based on a positional coincidence with the peak of...i.e., forming activity, as indicated by...infrared wavelengths. Yet, Arp 299 hosts recent and intense star-forming activity, as indicated by...26 compact components to be detected above 5 rms (see Fig. (a) through (c)). The attained o...emotion (see Appendix 5). Since optical and near-infrared observations are likely to...inhibiting the variability of their compact ra...s some of the luminous infrared galaxy Arp 299-A on 8 April 2008 and 7.3 (A1) and between 1.0 (A13) and 7.7 (A1) times the...over 2 epochs, to directly detect recently exploded core-collapse supernovae by means of the variability of their compact ra...the 5 GHz radio emission (see Appendix 5). Since optical and near-infrared observations are likely to...and source detection and techniques for flux density extrac...detection of five compact sources (A15, A18, A22, A23, A24), one of which (A0) was identified as a young SN.

Baseline Array (VLBA) observations carried out during 2002 and 2003 resulted in the detection of five compact sources (A0, A1, A13, A18, and A24), based on a positional coincidence with the peak of the 5 GHz radio emission (see Appendix 5). Since optical and near-infrared observations are likely to

We used the electronic European VLBI Network (e-EVN) and Very Long Baseline Array (VLBA) observations to detect recently exploded core-collapse supernovae by means of the variability of their compact radio emission.

Perez-Torres et al. (2009) and Bondi et al. (2012)
Detection and study of nuclear SNe at NIR with AO

- Monitored a sample of LIRGs with Gemini-N+ALTAIR/NIRI with LGS AO
- In the near-IR K-band extinction strongly reduced and AO provides a 0.1” resolution
- Investigate the properties and rates of SNe in the nuclear regions of LIRGs
- SN detection and accurate photometry from AO imaging using image subtraction

Detection and study of nuclear SNe at NIR with AO

- Monitored a sample of LIRGs with Gemini-N+ALTAIR/NIRI with LGS AO
- In the near-IR K-band extinction strongly reduced and AO provides a 0.1” resolution
- Investigate the properties and rates of SNe in the nuclear regions of LIRGs
- SN detection and accurate photometry from AO imaging using image subtraction
- Use SN NIR light curves and colours to find the likely SN types and extinctions

Detection and study of nuclear SNe at NIR with AO

- Monitored a sample of LIRGs with Gemini-N+ALTAIR/NIRI with LGS AO
- In the near-IR K-band extinction strongly reduced and AO provides a 0.1” resolution
- Investigate the properties and rates of SNe in the nuclear regions of LIRGs
- SN detection and accurate photometry from AO imaging using image subtraction
- Use SN NIR light curves and colours to find the likely SN types and extinctions
- Detect SNe within a few hundred pc to kpc nuclear regions with A_V up to 18 mag

<table>
<thead>
<tr>
<th>Supernova</th>
<th>LIRG Host</th>
<th>Extinction A_V (mag)</th>
<th>Projected distance (pc)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN 2004iq</td>
<td>IRAS 17138-1017</td>
<td>0–4</td>
<td>700</td>
<td>?</td>
</tr>
<tr>
<td>SN 2008cs</td>
<td>IRAS 17138-1017</td>
<td>17–19</td>
<td>1500</td>
<td>IIn/L</td>
</tr>
<tr>
<td>SN 2010O</td>
<td>IC 694 (Arp 299)</td>
<td>2</td>
<td>1100</td>
<td>Ib</td>
</tr>
<tr>
<td>SN 2010P</td>
<td>NGC 3690 (Arp 299)</td>
<td>7</td>
<td>1200</td>
<td>IIb</td>
</tr>
<tr>
<td>SN 2010cu</td>
<td>IC 883</td>
<td>0–1</td>
<td>200</td>
<td>II-P?</td>
</tr>
<tr>
<td>SN 2011hi</td>
<td>IC 883</td>
<td>5–7</td>
<td>360</td>
<td>II-P?</td>
</tr>
</tbody>
</table>

SN follow-up in (circum)nuclear regions
SN 2010O an amateur discovery, SN 2010P discovered in Ks-band with the Nordic Optical Telescope (NOT) at ~1” from the nucleus C'
SN 2010P: heavily obscured SN in Arp 299

- Near-IR photometry from Gemini-N, NOT
- Deep optical spectrum from Gemini-N
- Similar to the Type IIb SN 2011dh but $A_V \sim 7$
- Radio follow-up from eMERLIN, VLA, EVN
- The most slowly evolving Type IIb radio SN

Kankare, SM+2014; Romero-Canizales+2014
PESSTO follow-up of SN 2013fc

- SN2013fc classified by PESSTO as SN IIn on 2013-08-30 (ATel 5338)
- 3.5” (1.4 kpc) offset from the nucleus of the LIRG ESO 154-10 (d~80 Mpc)
PESSTO follow-up of SN 2013fc

- SN2013fc classified by PESSTO as SN IIn on 2013-08-30 (ATel 5338)
- 3.5” (1.4 kpc) offset from the nucleus of the LIRG ESO 154-10 (d~80 Mpc)
- Red continuum and very strong Na I D indicating a large extinction $A_V = 2.9$
PESSTO follow-up of SN 2013fc

- SN2013fc classified by PESSTO as SN IIn on 2013-08-30 (ATel 5338)
- 3.5” (1.4 kpc) offset from the nucleus of the LIRG ESO 154-10 (d~80 Mpc)
- Red continuum and very strong Na I D indicating a large extinction $A_V = 2.9$
- High res. spectra reveal the origin of the narrow lines in the host galaxy

Kangas,SM+2015
PESSTO follow-up of SN 2013fc

- SN2013fc classified by PESSTO as SN IIn on 2013-08-30 (ATel 5338)
- 3.5” (1.4 kpc) offset from the nucleus of the LIRG ESO 154-10 (d~80 Mpc)
- Red continuum and very strong Na I D indicating a large extinction $A_V = 2.9$
- High res. spectra reveal the origin of the narrow lines in the host galaxy
- Photometrically and spectroscopically similar to SN 1998S (IIn) and 1979C (II-L)
PESSTO follow-up of SN 2013fc

- SN2013fc classified by PESSTO as SN IIn on 2013-08-30 (ATel 5338)
- 3.5” (1.4 kpc) offset from the nucleus of the LIRG ESO 154-10 (d~80 Mpc)
- Red continuum and very strong Na I D indicating a large extinction $A_V = 2.9$
- High res. spectra reveal the origin of the narrow lines in the host galaxy
- Photometrically and spectroscopically similar to SN 1998S (IIn) and 1979C (II-L)

Kangas, SM+2015
Nuclear supernovae with Gaia
Detection and study of nuclear SNe with Gaia

- Gaia able to produce SN detections also within the nuclear regions of galaxies
- Can identify transients with 0.1-0.5 arcsec offset from the host galaxy nucleus
- Of the detected ~1300 SNe yr\(^{-1}\) (m<19) ~200 at nuclear offset <1 arcsec
- In normal galaxies expect the nuclear detections to be dominated by SNe Ia
- In starburst galaxies and LIRGs expect a hidden population of nuclear CCSNe

![Graph showing detection efficiency](image)
Detection of nuclear SNe in LIRGs

- MC simulations by Thomas Reynolds (PhD student, Turku):
  - Sample of ~320 IR bright galaxies and LIRGs (d < 150 Mpc)
  - CCSN rates from galaxy IR luminosities, relative SN rates
  - SN absolute magnitude distributions + template SN light curves
  - Extinctions from smooth exponential distribution of SNe/dust in a spiral disk
  - ‘Missing’ SN fraction similar to the LIRG Arp 299
  - Real cadence of Gaia observations, assume SNe brighter than 19 mag detected

Figure 3. Same as Fig. 1 but for the SNe II. A single average light curve is constructed for the subclasses of SNe II-P, II-L and IIb, while three light curves (fast, average and slow) are for SNe IIn. The fast SN IIn light curve (dash–dotted line) is plotted relative to days since maximum brightness. The right-hand panels show an example fit for each subclass.

II-P

Li+2011

II-L

Riello & Patat 2005

Table 2 lists the data for our template light curves. Only three representative SN Ia light curves are listed, and only parts of the light curves are shown. The entire set of light curves is available electronically (see Supporting Information).

2.3 Photometry of the LF SNe

It is important to collect photometry for every SN in the LF sample to study the light-curve shape and derive the peak absolute magnitude; otherwise, the sample will not be complete. Since our unfiltered survey images are most closely matched to the R band, we use the C⃝ 2011 The Authors, MNRAS 412, 1441–1472 Monthly Notices of the Royal Astronomical Society. C⃝ 2011 RAS.
Detection of nuclear SNe in LIRGs

- MC simulations by Thomas Reynolds (PhD student, Turku):
  - Expected *intrinsic* number of CCSNe $\sim 150$ SNe yr\(^{-1}\)
  - Can detect **240 SNe over 3 yrs** if no SNe missed in nuclear regions
  - Detect $\sim 20$-80 SNe over 3 yrs if similar missing fraction as found in Arp 299
Follow-up spectroscopy for nuclear transients

- Ground-based imaging and spectroscopy crucial to confirm and classify
- Use the 2.5m Nordic Optical Telescope (NOT), La Palma
- Optical imaging and spectroscopy in ToO mode
- Near-IR imaging run once a month
- Nordic Transient Explorer (NTE) instrument will offer simultaneous optical + near-IR spectroscopic and imaging capabilities in early 2018!!
Follow-up spectroscopy for nuclear transients

- Ground-based imaging and spectroscopy crucial to confirm and classify
- Use the 2.5m Nordic Optical Telescope (NOT), La Palma
- Optical imaging and spectroscopy in ToO mode
- Near-IR imaging run once a month
- Nordic Transient Explorer (NTE) instrument will offer simultaneous optical + near-IR spectroscopic and imaging capabilities in early 2018!!
Supernovae in the (circum)nuclear regions of galaxies missed due to searches lacking a sufficient spatial resolution (and extinction)

The rates and properties of nuclear SNe especially in U/LIRGs remained largely unexplored - important for detailed comparison between CCSN rates and cosmic SFR

Near-IR observations using AO correction successfully used for the detection and study of a number of dust obscured nuclear SNe in LIRGs

Gaia has the potential to provide a significant sample of SNe within the unobscured nuclear regions of galaxies over the whole sky but spectral classification and follow-up tricky
More information:
http://www.astro.utu.fi
and facebook
Apply by 29 Jan 2016!