Adaptive Optics-assisted detection and study of supernovae

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SN 2004ip

VLT/NACO 2004 May 4
VLT/NACO 2004 Sept. 15

1"
Collaborators

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Tomas Dahlen (STScI), Erkki Kankare, Jari Kotilainen (FINCA)
Miguel Perez-Torres (Granada), Andreas Efstathiou (Cyprus)
Cristina Romero-Canizales (PUC), Zara Randriamanakoto (SAAO)
Andres Escala (U. de Chile), Jens Melinder (Stockholm) ...
Supernovae in luminous infrared galaxies (LIRGs)

- U/LIRGs locally rare but at z ~1-2 dominating the star formation
- Stars forming rapidly during a few x 100 Myr starburst episode in LIRGs
- Large numbers of massive short lived (< a few x 10 Myr) stars exploding as CCSNe
- Still mostly undiscovered due to large extinctions and concentration to nuclear regions
- High spatial resolution near-IR imaging required for the detection and study

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**Magnelli et al. (2009, 2011)**

**Väisänen et al. (2008)**

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**The Cosmic Bird**
Supernovae in luminous infrared galaxies (LIRGs)

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**Magnelli et al. (2009, 2011)**

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

- $10^{12}L_\odot < L_{IR} < 10^{13}L_\odot$
  - SFR a few x 100-1000 $M_\odot$ yr$^{-1}$
  - a few x 1-10 CCSNe yr$^{-1}$
Infrared observations and Adaptive Optics techniques reveal hidden “Supernova Factories”

- Monitor samples of nearby (<100 Mpc) starburst dominated LIRGs
- Use AO to provide ~0.1” spatial resolution required for the SN detection and study
- Combined use of near-IR AO and high-res. radio for follow-up studies
- Determine the nature of the SNe and estimate extinctions
- How many SNe are we missing in dusty nuclear regions of LIRGs?

VLT NACO
PI: Mattila/Väisänen

Gemini-South GEMS
PI: Ryder/Bauer

Gemini-North Altair/NIRI
PI: Ryder
**VLT/NACO observations of IRAS 18293-3413**

- Pilot study with NAOS CONICA AO system on ESO VLT in near-IR Ks-band
- Used VIS-WFS, V=15 star 26” away as a **natural guide star (NGS)**
- Uncorrected seeing FWHM ~ 0.5” – 0.9”, am ~1.1 – 1.3
- SR ~ 10 – 30% → FWHM ~ 0.1” ~ 40 pc @ 80 Mpc

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**Non-AO**:
- ESO NTT (SOFI): 1” resolution (400 pc)

**AO**:
- ESO VLT (NACO): 0.1” resolution (40 pc)
Image subtraction for the AO images

Image 1 (FWHM~0.1")

⊗ KERNEL =

Image 2 (FWHM~0.1")

ISIS 2.2: Alard & Lupton (1998)
VLT/NACO reveals SN 2004ip in IRAS 18293-3413
Mattila et al. (2007); Perez-Torres et al. (2007)

- SN 2004ip at 1.4” (500 pc) from the K-band nucleus
- K-band magnitudes consistent with CCSN with $A_V < 40$
- 8.4 GHz VLA detection confirmed the CCSN nature
- First SN to be discovered using AO assisted observations
- Demonstrates the potential of 8-m class telescope + AO in the near-IR
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Perez-Torres et al. (2007); Herrero-Illana et al. in pre.
Gemini-N/ALTAIR reveals SNe 2010cu and 2011hi

*Kankare et al. (2012); Romero-Canizales et al. (2012)*

- Observations with Gemini-N+ALTAIR/NIRI with laser guide star (LGS)
- Two SNe with projected galactocentric distances 0.37” (180 pc) and 0.79” (380 pc)
- The closest SNe yet discovered to a LIRG nucleus in the near-IR
- Accurate SN photometry from follow-up AO imaging using image subtraction

CBETs 2213, 2286, ATel 3245

Subtracted image
Gemini-N/ALTAIR reveals SNe 2010cu and 2011hi

Kankare et al. (2012); Romero-Canizales et al. (2012)

- Likely CCSN types and extinctions from 'template' light curve fitting

\[ A_V \sim 1 \]

\[ A_V = 0 \]

\[ A_V \sim 5-7 \]
Early results from Gemini-S + GeMS/GSAOI

- ESO 440-IG058 observed as a part of the GeMS System Verifications
- Used 3 natural guide stars for tip-tilt + 1 on-detector guide star
- Provides 85”x85” FOV with 0.02”/pixel
- Observe 4 LIRGs in Semester 2013A
- Test PSF uniformity, SN detection by image subtraction, photometry etc.
- Feasibility for SNe at high-z?

Luminous Infrared Galaxy ESO 440-IG058
Gemini South GeMS/GSAOI Jan 2013
S. Ryder (AAO) & the GeMS Team

GeMS Ks-band 160sec NACO Ks-band with NGS
Supernovae as probes of the cosmic star formation

- Correct CCSN rates for the SNe missed due to *obscuration* by dust
- After correction CCSN rates consistent with expectations from the SFRs
- CCSNe provide an *independent* measurement of cosmic star formation history
- Recent HST measurements up to $z \sim 1.3$, E-ELT will provide to $z \sim 4$ (and beyond?)

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![Graph showing supernova rates vs. redshift](image)

- SFR vs. redshift
- Correction methods:
  - All corrections
  - Normal galaxy extinction corrections
  - "Raw" rates

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*Mattila et al. (2012)*

*Mannucci et al. (2007)*

*Dahlen et al. (2012)*
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**Dahlen et al. (2012)**

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**Bouwens et al. (2012)**

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Substantial fraction of CCSNe in U/LIRGs hidden in nuclear regions
High-res. near-IR AO imaging well suited to detect and study
Important for estimating complete CCSN rates as a function of redshift
Valuable for testing methods for AO observations of SNe at high-z