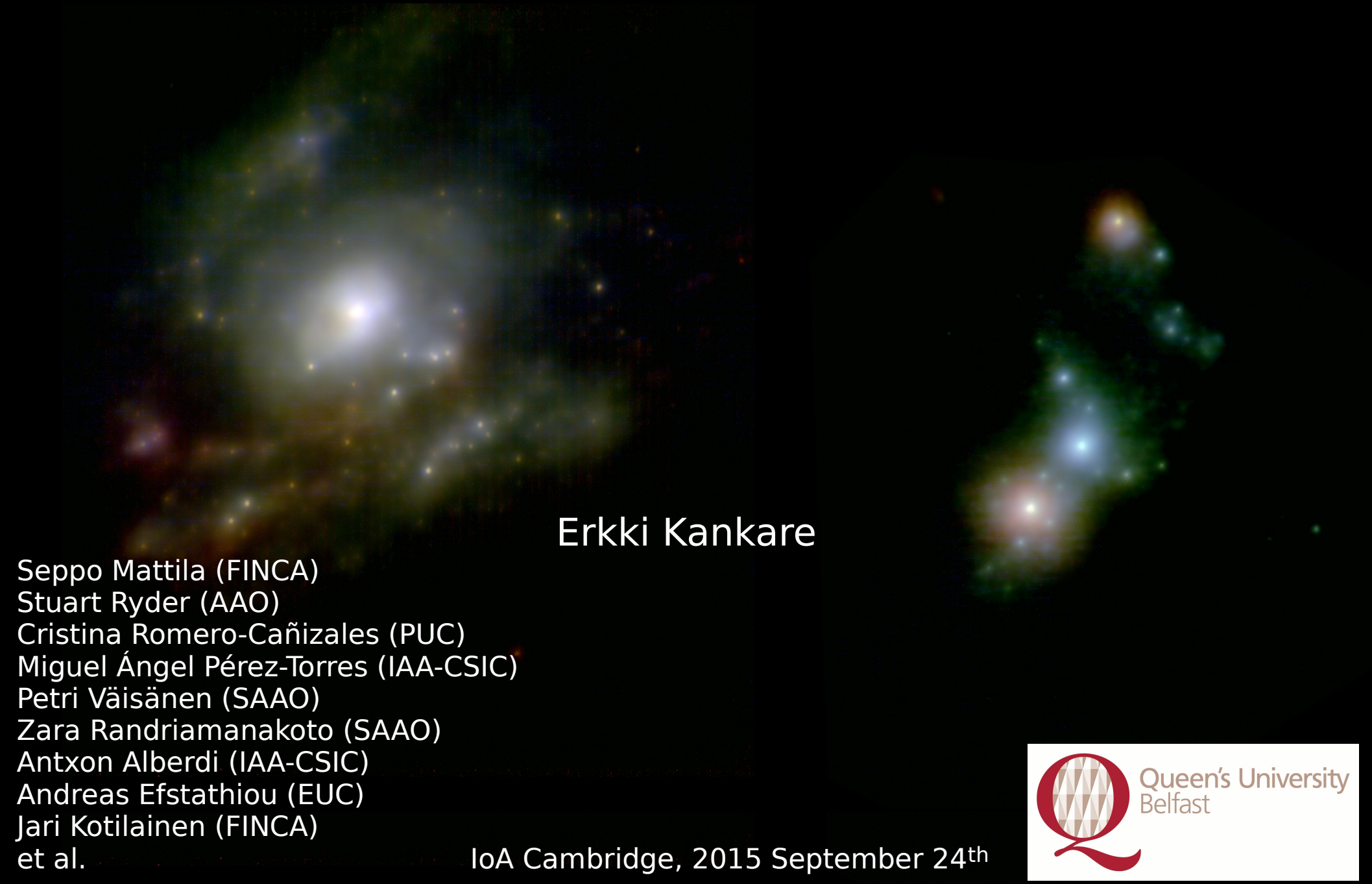
Supernovae in luminous infrared galaxies with Gemini-North ALTAIR/NIRI adaptive optics



Erkki Kankare

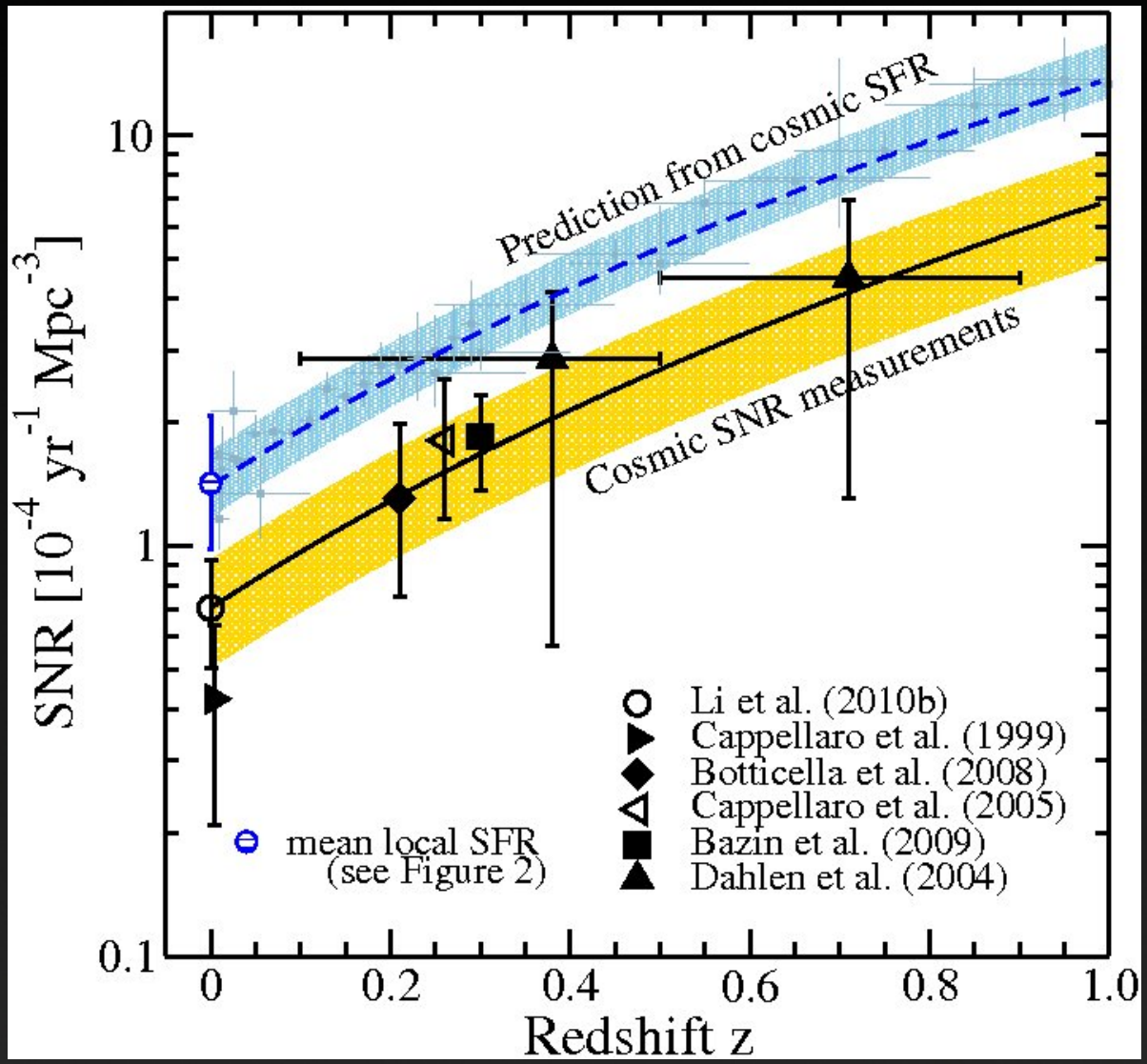
Seppo Mattila (FINCA)
Stuart Ryder (AAO)
Cristina Romero-Cañizales (PUC)
Miguel Ángel Pérez-Torres (IAA-CSIC)
Petri Väisänen (SAAO)
Zara Randriamanakoto (SAAO)
Antxon Alberdi (IAA-CSIC)
Andreas Efstathiou (EUC)
Jari Kotilainen (FINCA)
et al.

Queen's University Belfast

IoA Cambridge, 2015 September 24th

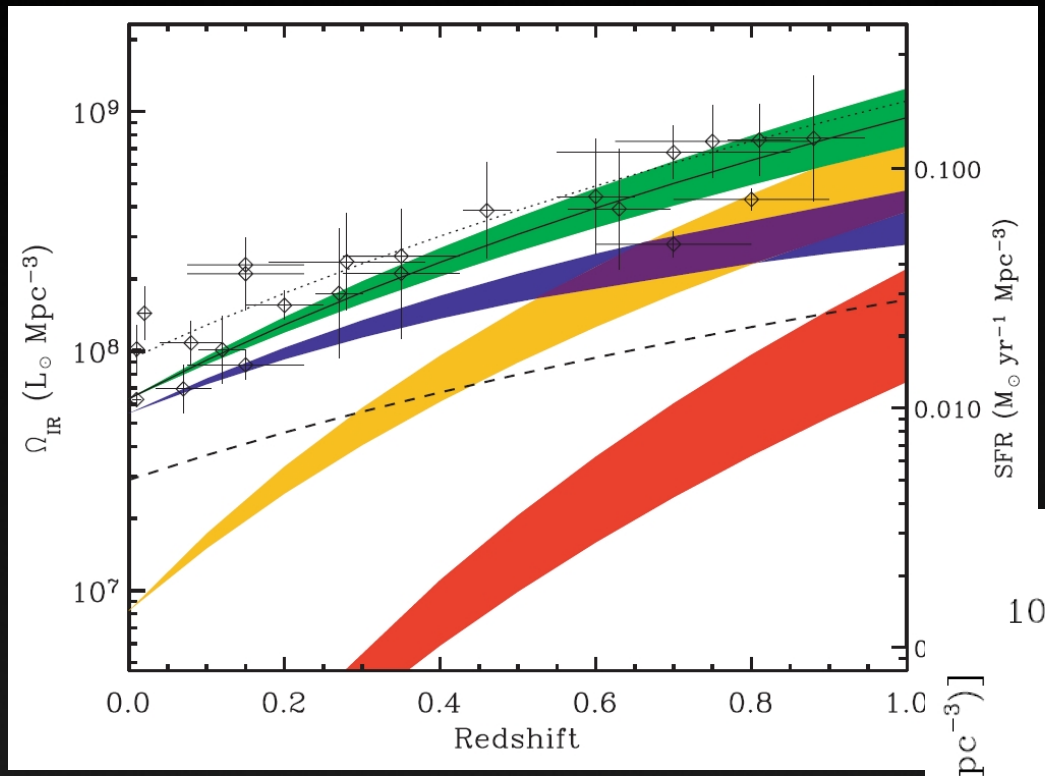
Supernova rates

- Core-collapse supernova rate provides an independent tool to measure star formation
- Horiuchi et al. (2011): 'Supernova Rate Problem' - observed SN rate a factor of ~2 smaller compared to the predicted star formation rate
  - Faint/dark supernovae?
  - Dust extinction?
  - Fundamental problems on our understanding on star formation or SNe?



Horiuchi et al. (2011)

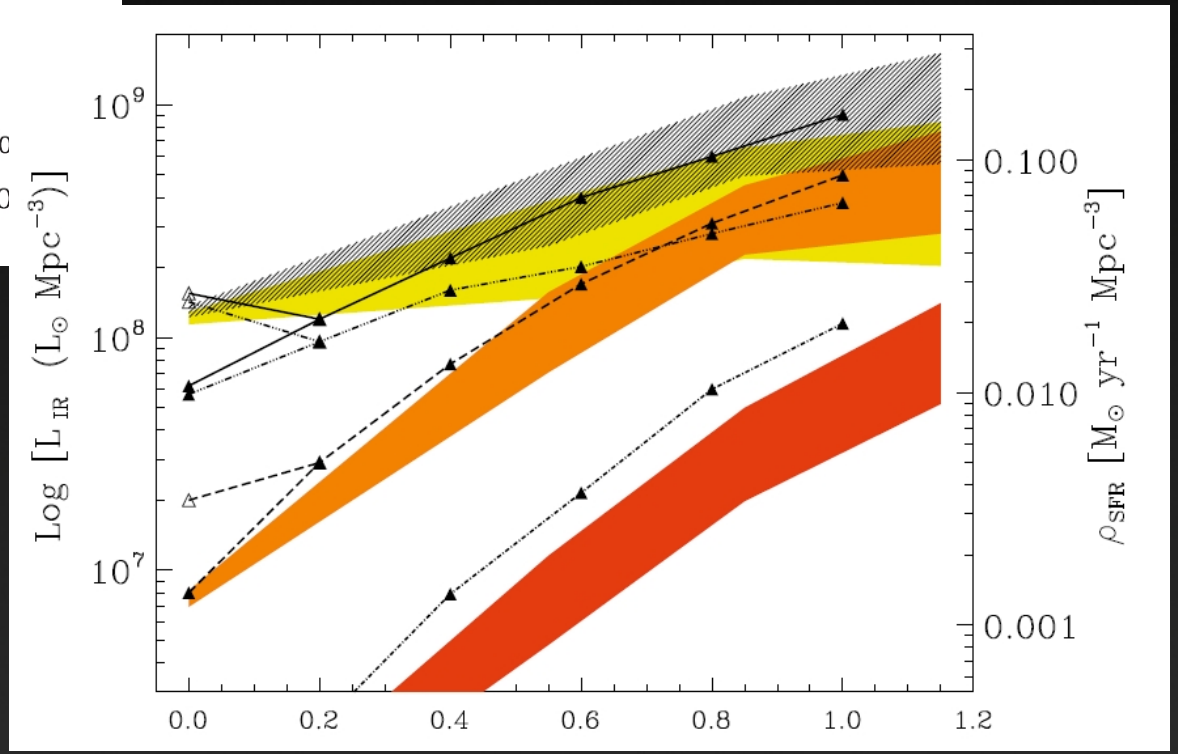
Supernova rates



Le Floc'h et al. (2005)

- Luminous ($L_{IR} > 10^{11}\ L_\odot$) and ultraluminous ($L_{IR} > 10^{12}\ L_\odot$) infrared galaxies (LIRGs and ULIRGs)
- At redshift z~0.7 U/LIRGs become the dominant source of star formation

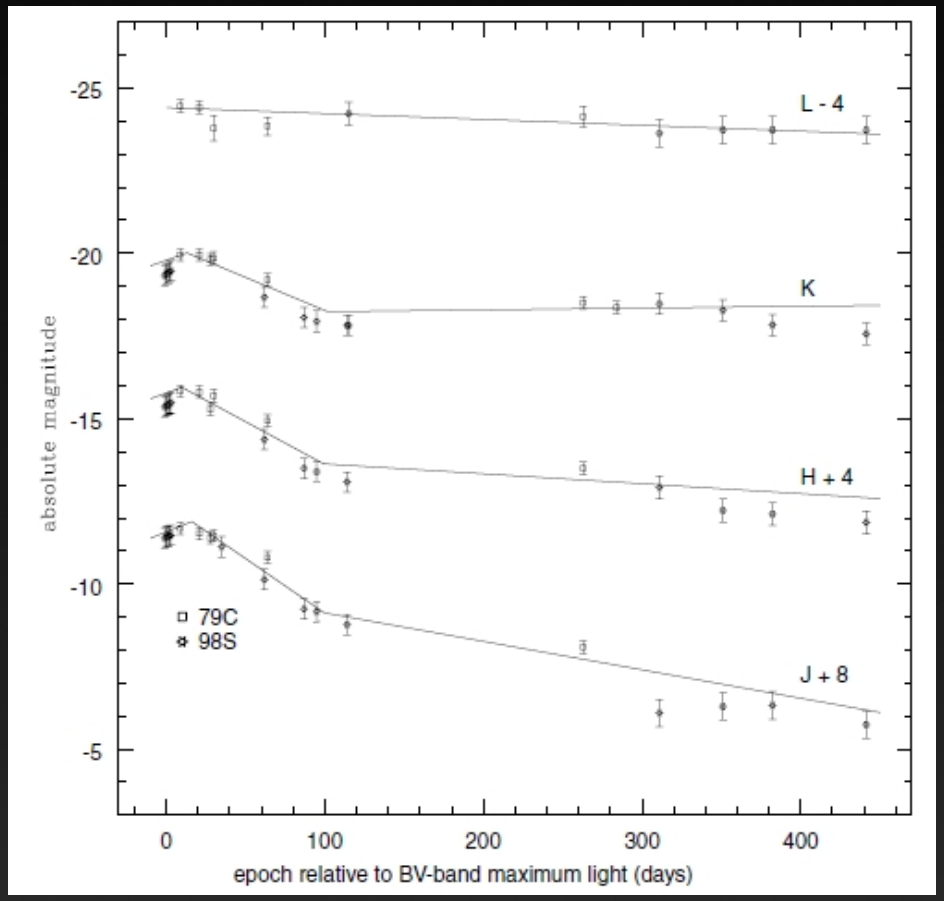
- Dusty, highly obscured galaxies
- High background contrast effect

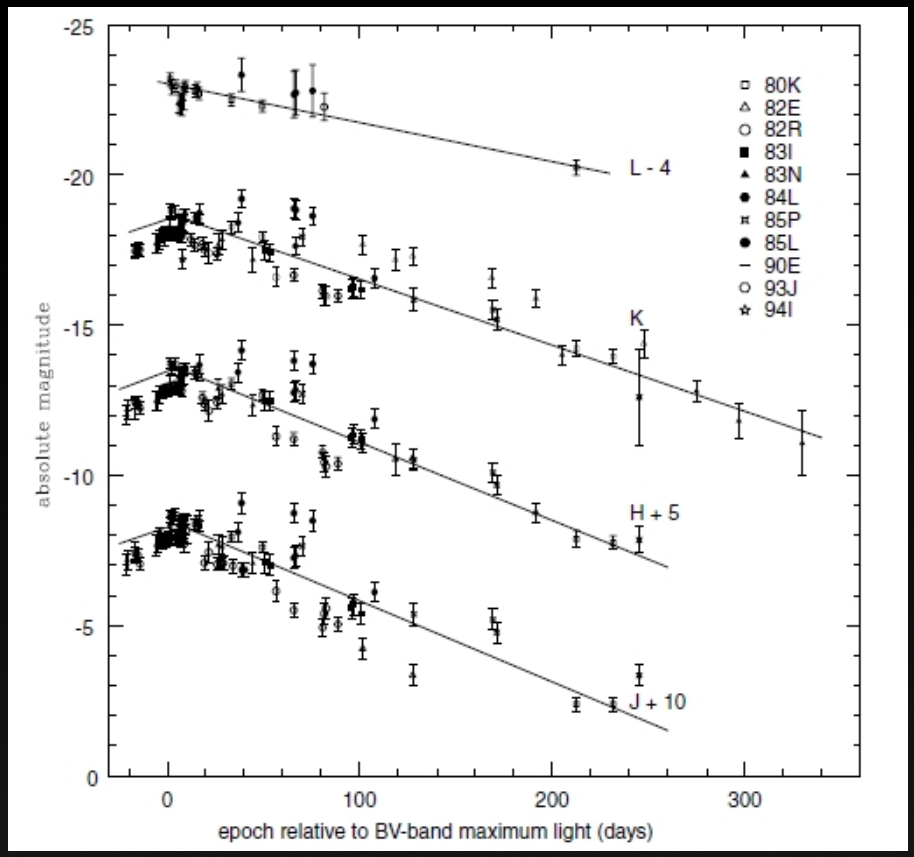


Magnelli et al. (2009)

Near-IR light curve templates

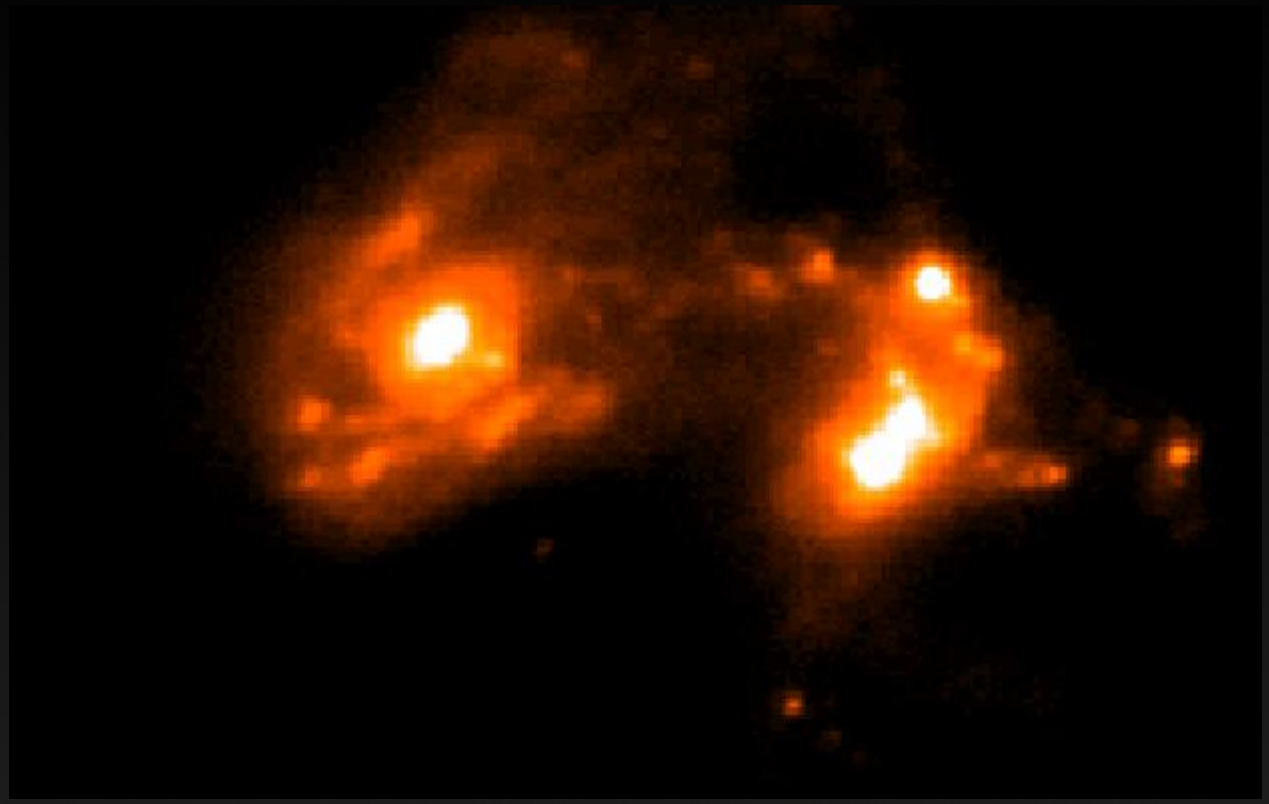
- No optical spectroscopy
- Mattila & Meikle (2001):
  - 'normal' template based on primarily Type Ib/c SNe





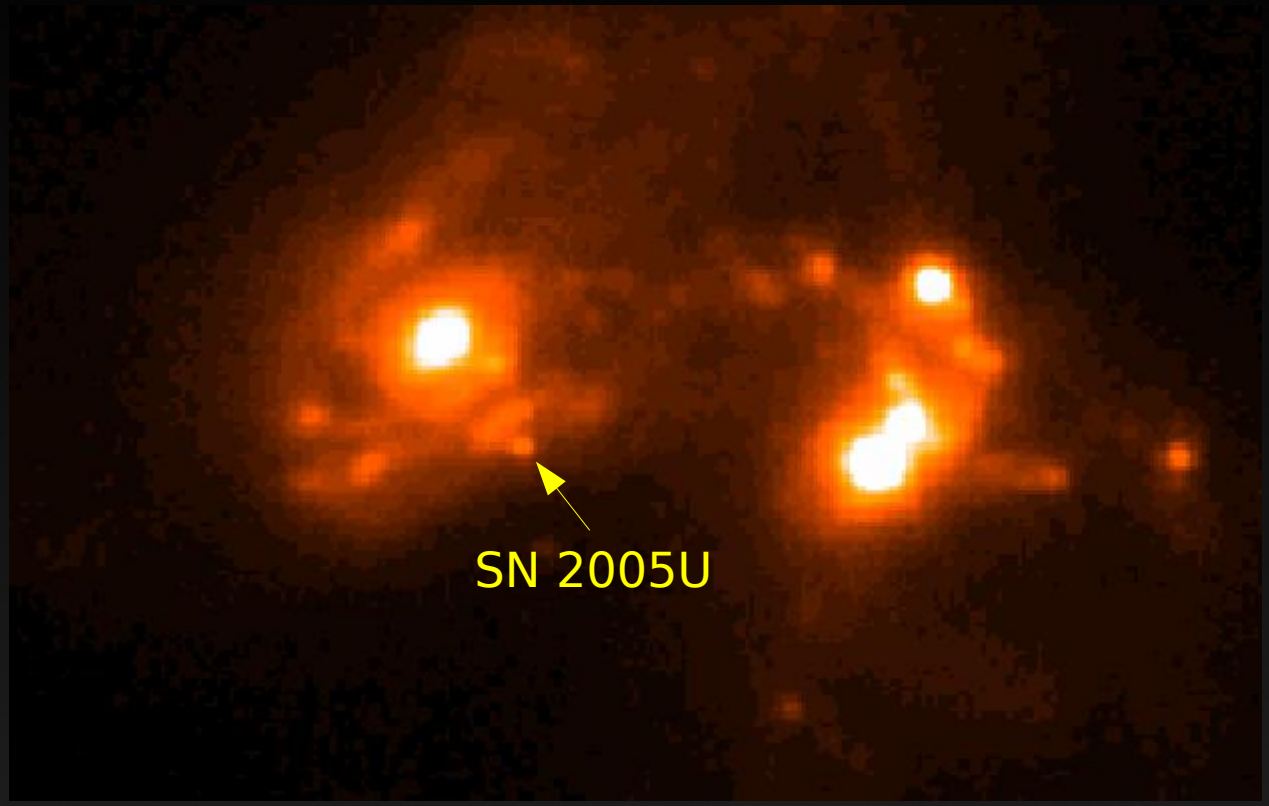
  - 'slowly declining' template based on Type IIn SN 1998S and II-L SN 1979C
- Well sampled light curves of nearby SNe with low line-of-sight extinction, e.g.:
  - IIP SN 1999em (Krisciunas et al. 2009)
  - IIb SN 2011dh (Ergon et al. 2014)
  - Ib SN 2007Y (Stritzinger et al. 2009)

Luminous infrared galaxy Arp 299 @ ~50 Mpc



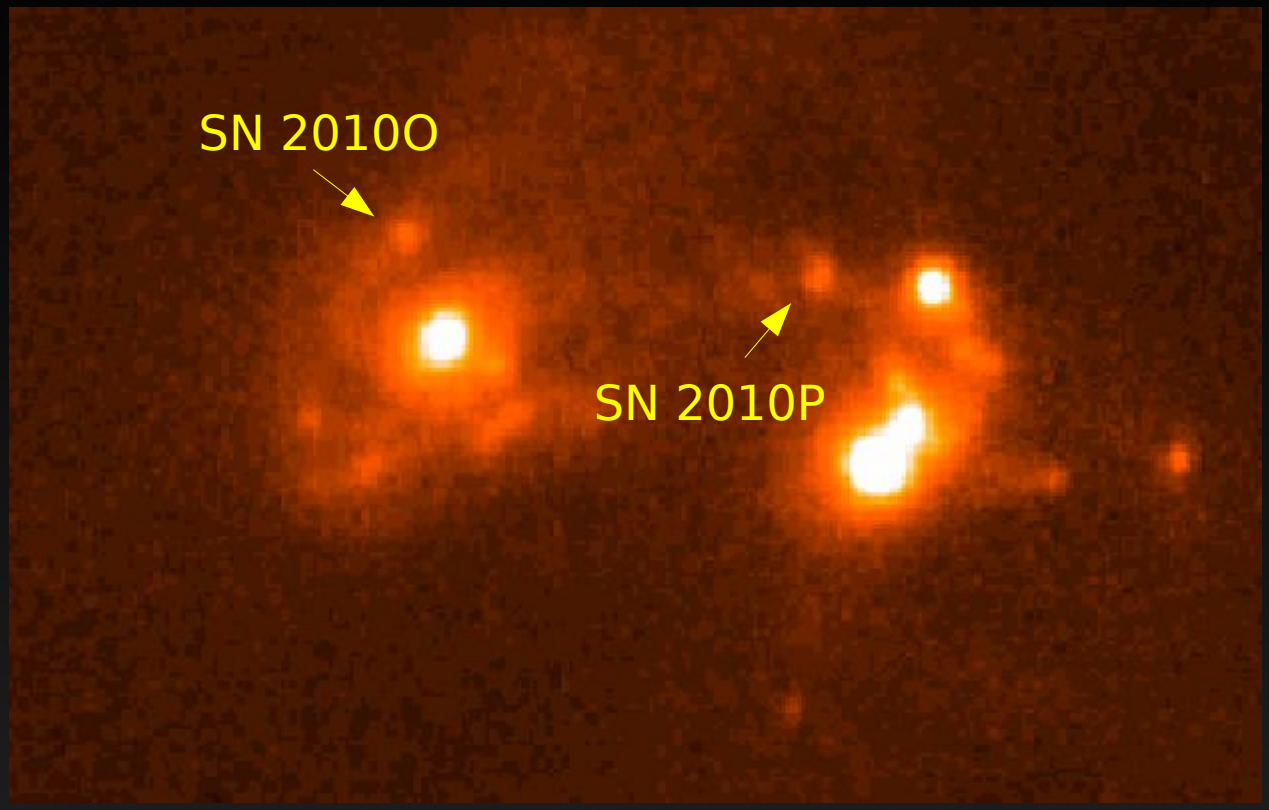
2004 June, WHT/LIRIS, *K*s-band, FWHM ~1“

Luminous infrared galaxy Arp 299 @ ~50 Mpc



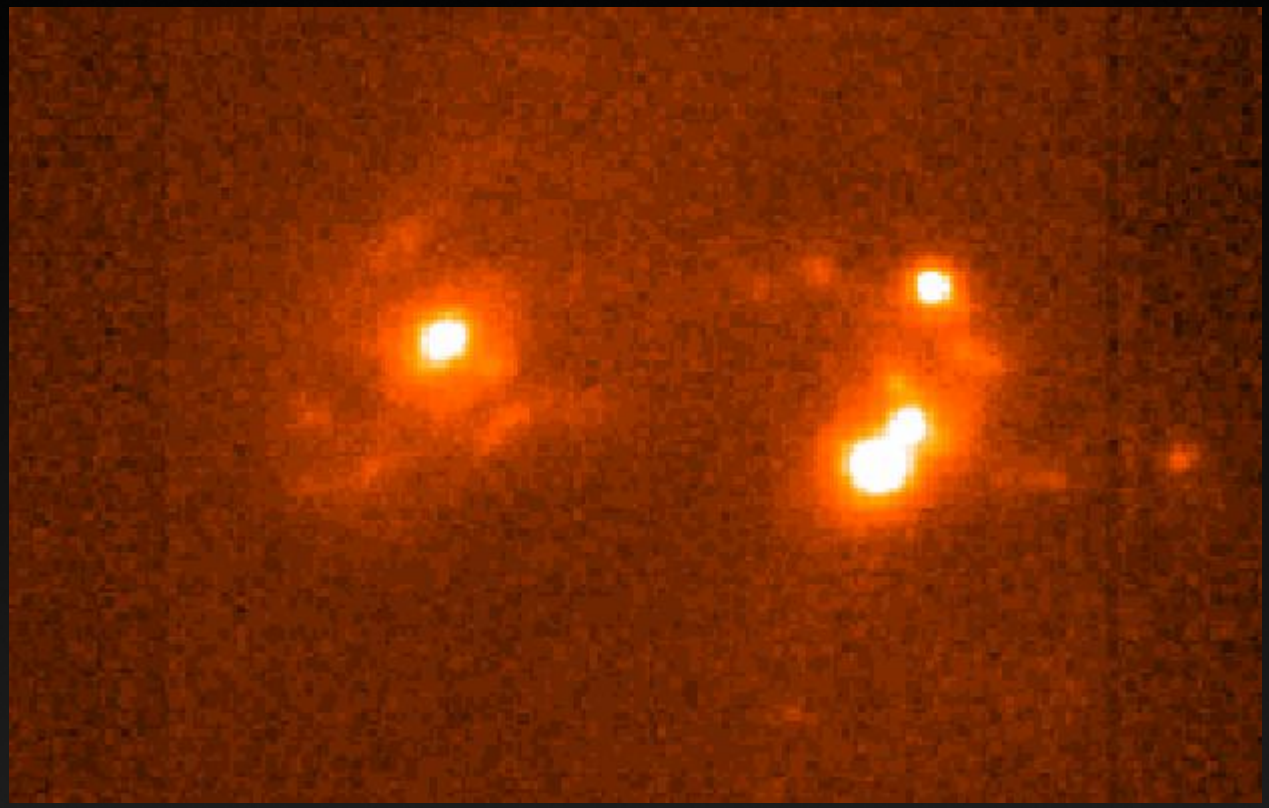
2005 January, WHT/LIRIS, *K*s-band, FWHM ~1“

Luminous infrared galaxy Arp 299 @ ~50 Mpc



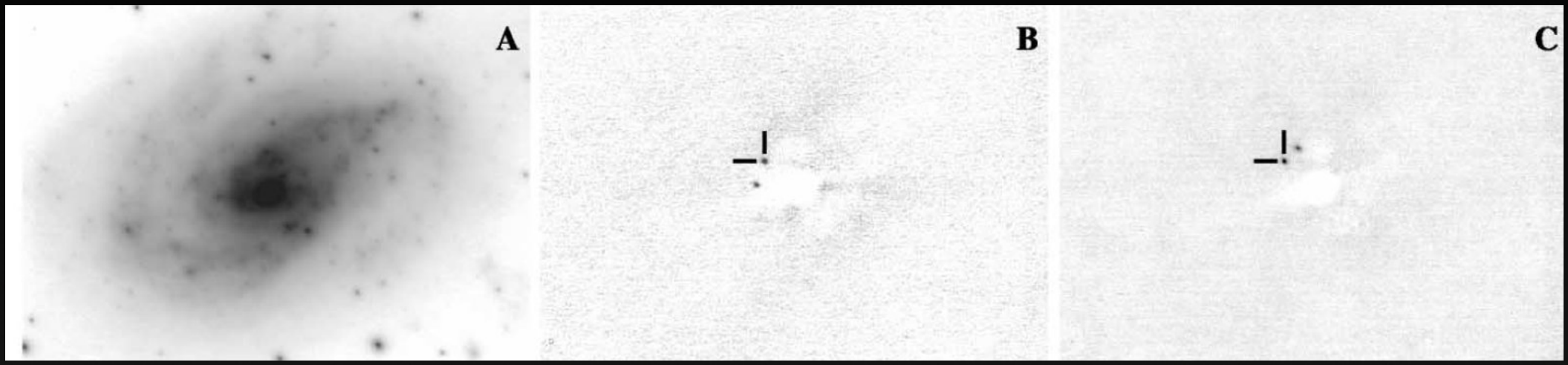
2010 January, NOT/NOTCam, *Ks*-band, FWHM ~1“

Luminous infrared galaxy Arp 299 @ ~50 Mpc



2011 March, NOT/NOTCam, *K*s-band, FWHM ~1“

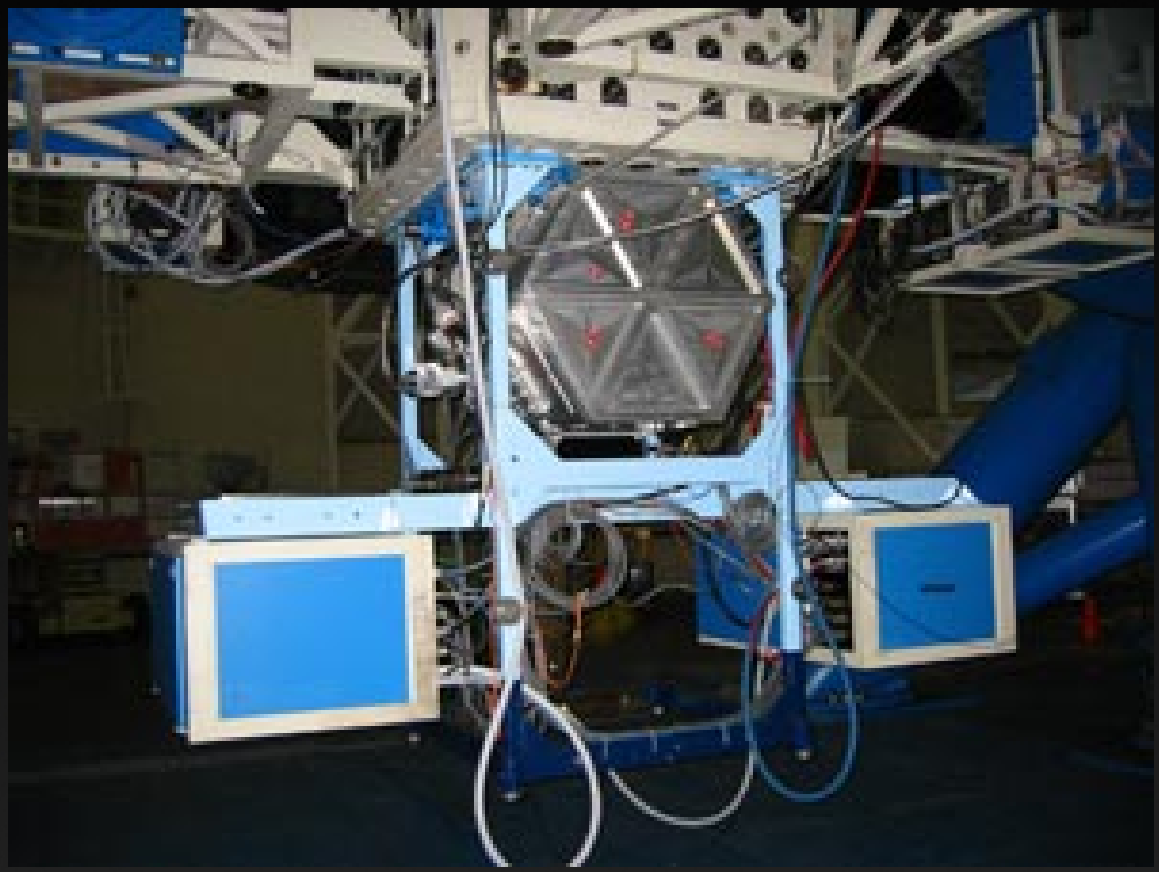
VLT NaCo



- Pioneering work: SN 2004ip in IRAS18293-3414
- Discovered with natural guide star adaptive optics system NaCo at VLT
- Mattila et al. (2007)

Gemini-North ALTAIR/NIRI

- **N**ear **I**nfra**R**ed **I**mager and Spectrograph
- Single-conjugate adaptive optics (AO) system ALTAIR
- *JHK* broad band filters
- 22 arcsec x 22 arcsec
- 0.0219 arcsec/pixel
- FWHM ~ 0.1 arcsec
- Natural guide star (NGS) or laser guide star (LGS) modes
- Survey 2008-2010



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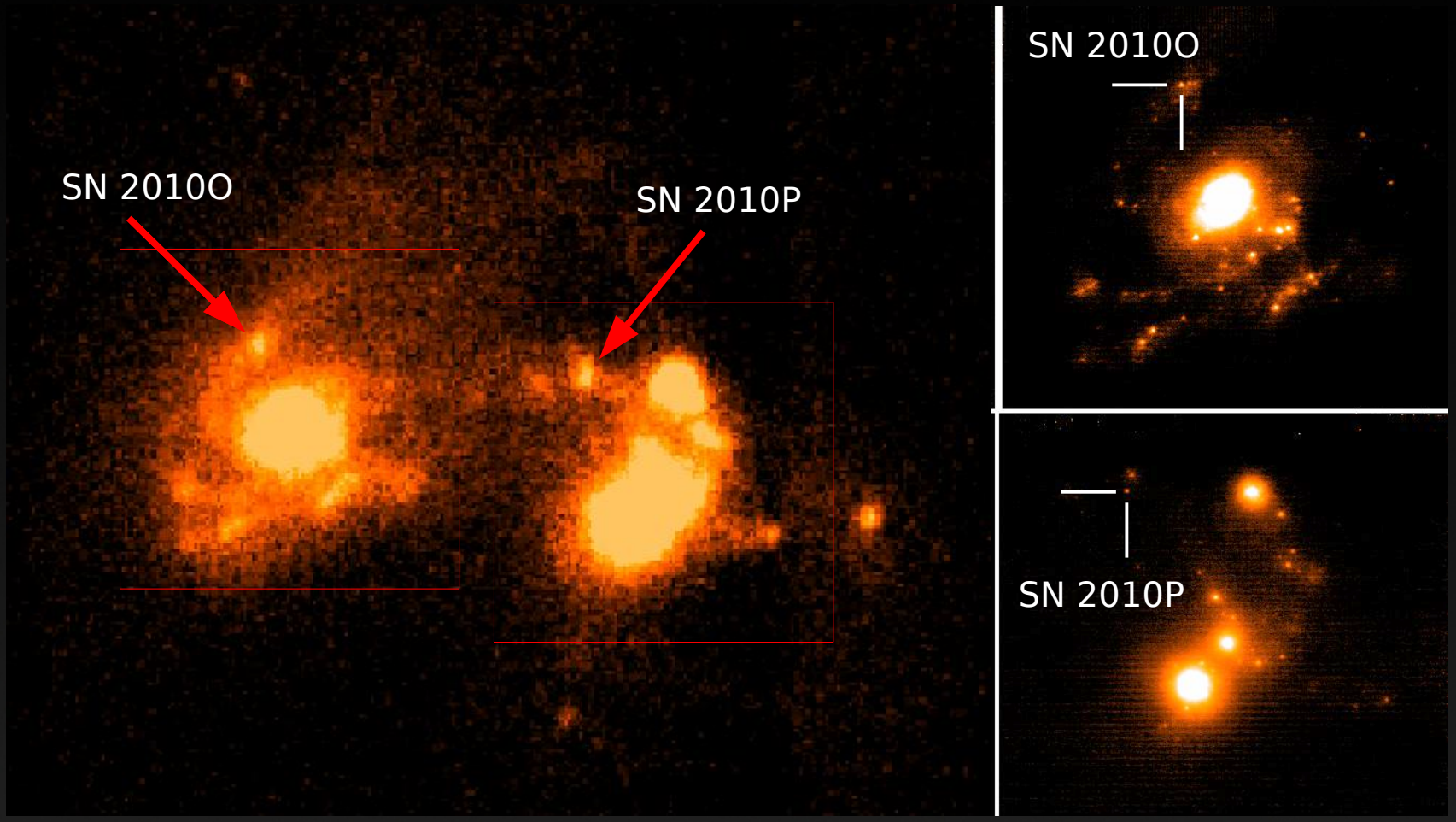
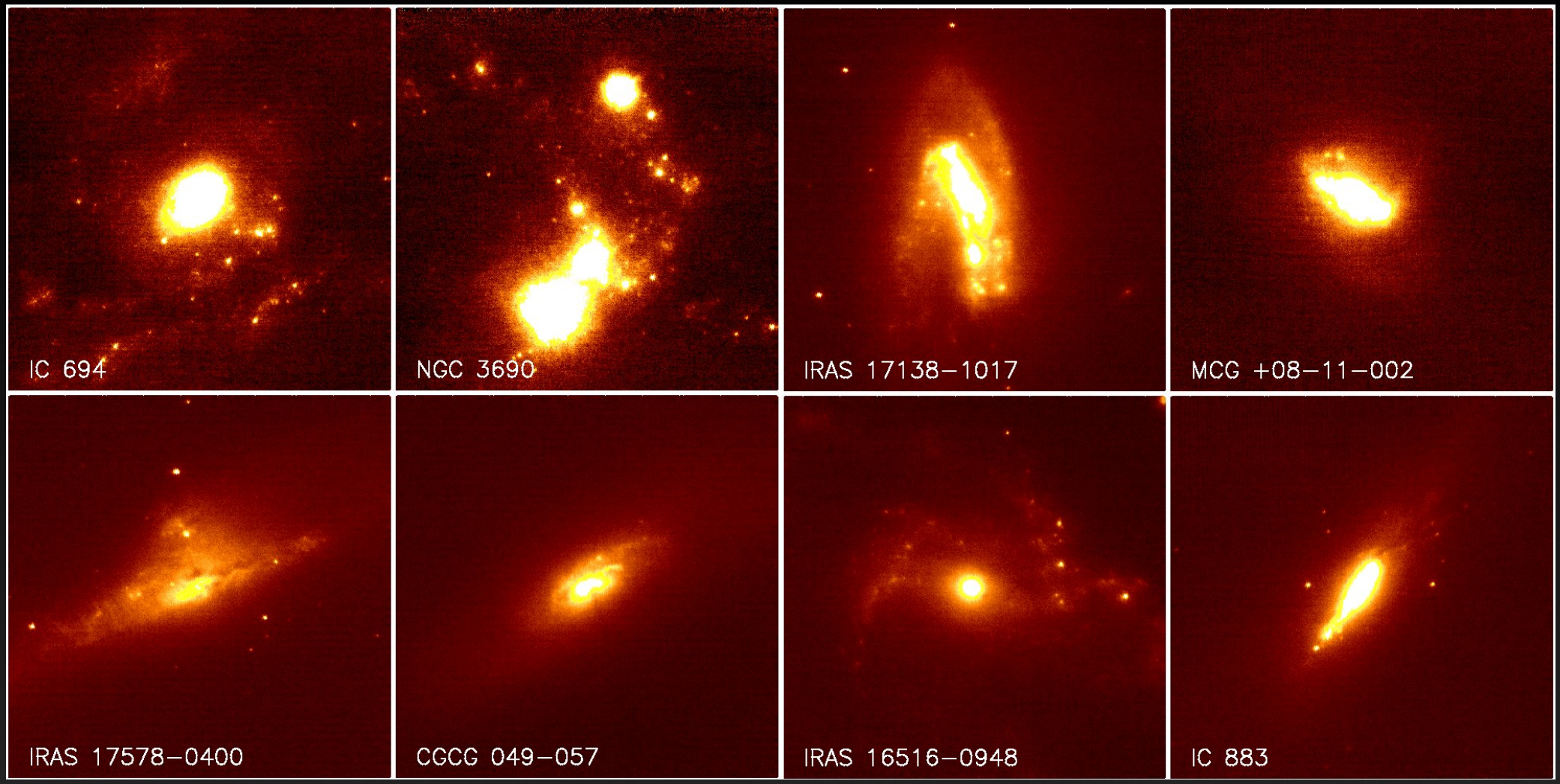
Luminous infrared galaxy Arp 299 @ ~50 Mpc



NOT/NOTCam,
Ks-band, FWHM ~1“

Gemini/ALTAIR/NIRI,
K-band, FWHM ~0.1”

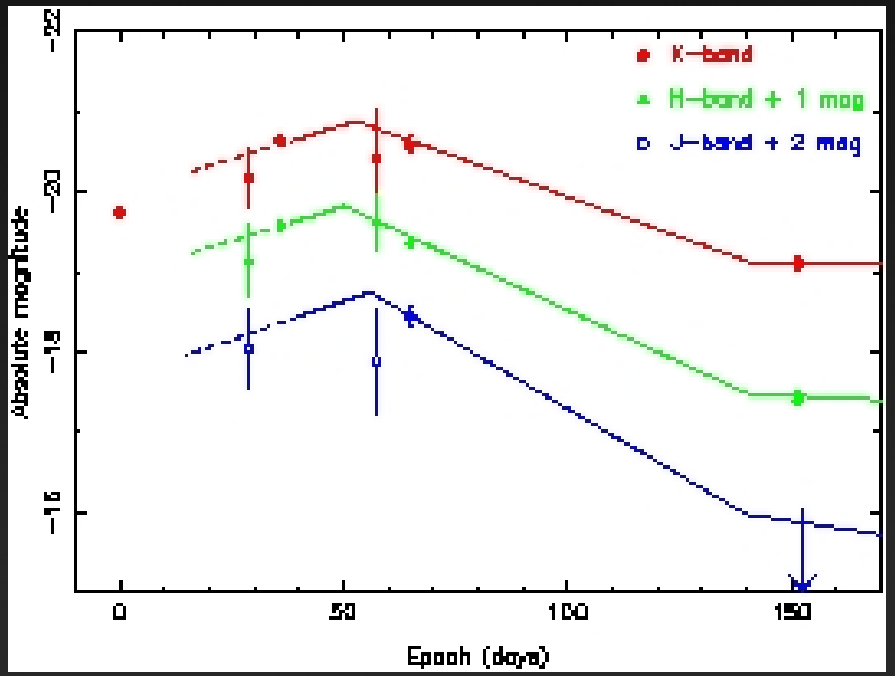
Gemini-North ALTAIR/NIRI LIRG SN programme

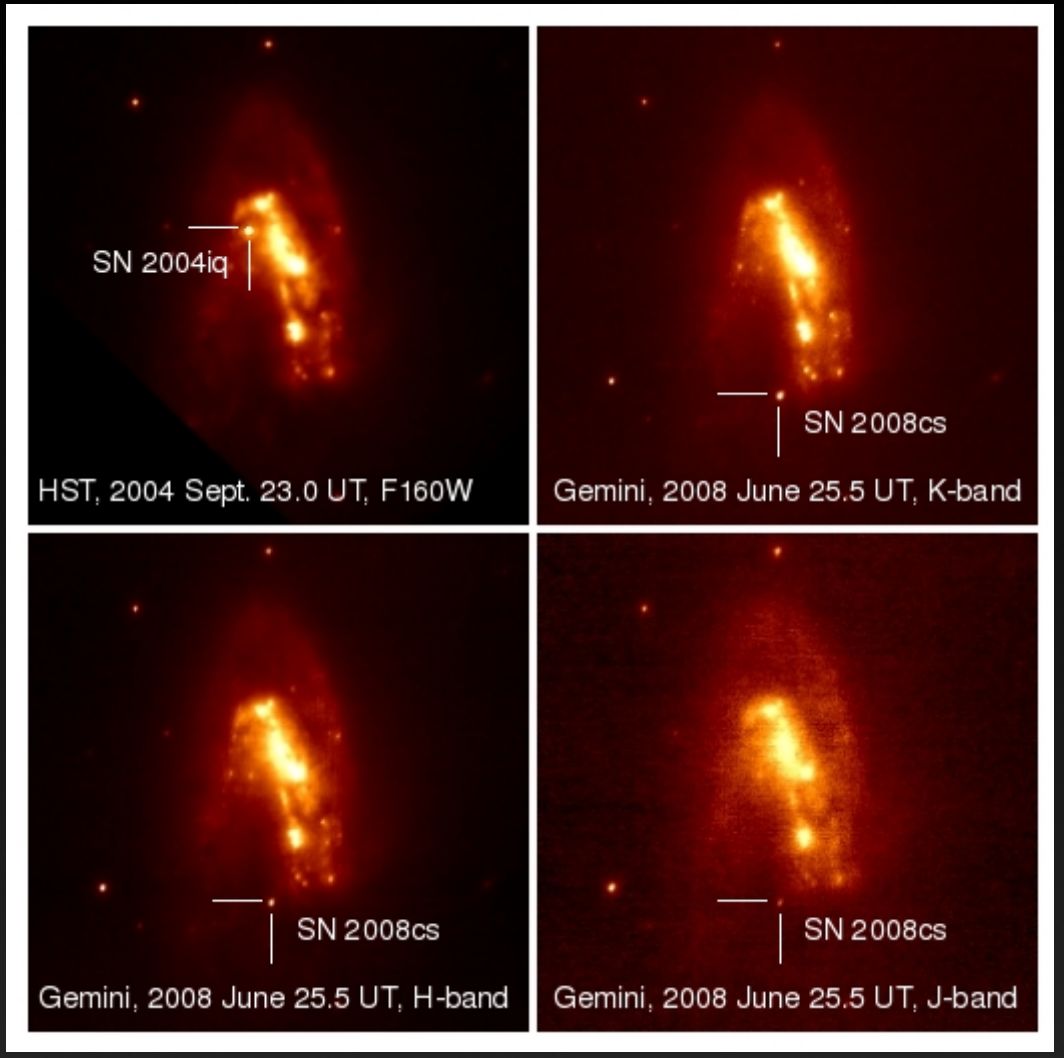


- Sample of 8 LIRGs
  - < 100 Mpc
  - SN rate ~ 1 yr^{-1} in each LIRG

SN 2004iq & SN 2008cs in IRAS 17138-1017

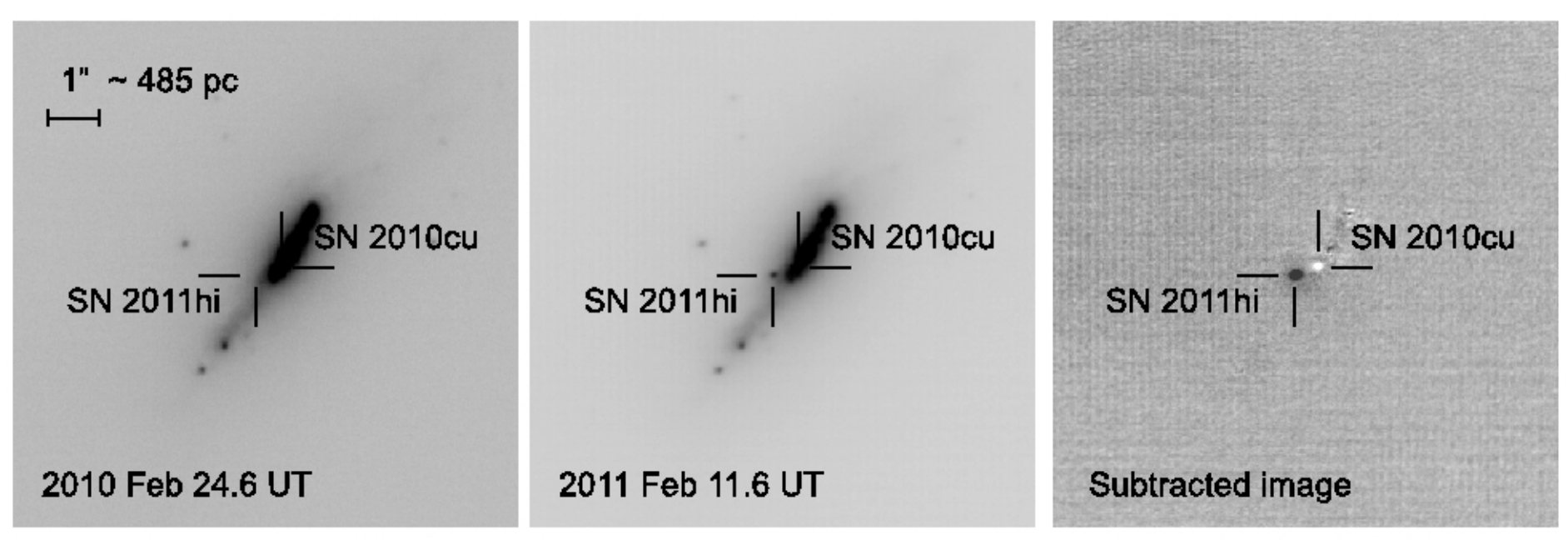
- SN 2004iq: SN in HST archive images
  - Host galaxy extinction of $A_V \sim$ 0-4 mag?
  - Very likely a CCSN
- SN 2008cs: First LGS SN discovery
  - Total line-of-sight extinction of $A_V \sim$ 18 mag
  - Type IIn/L





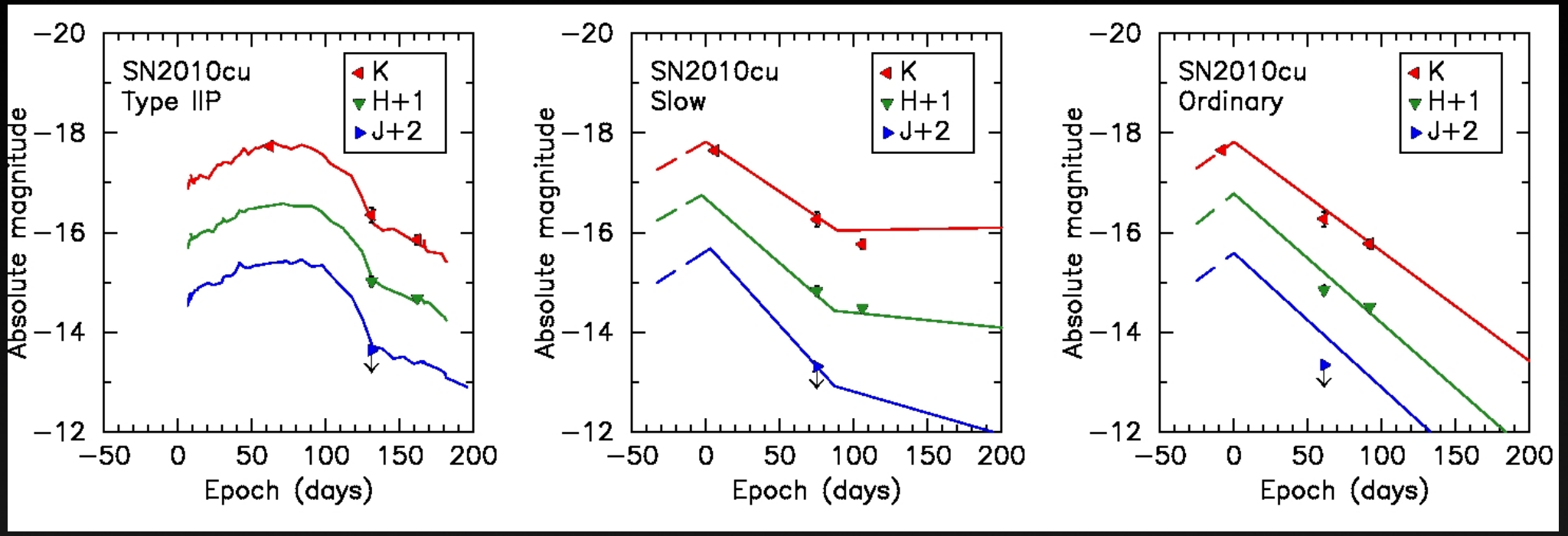
- Expected SN rate of IRAS 17138-1017 ~0.7 SNe yr^{-1}
- Kankare et al. (2008), ApJ, 689, L97

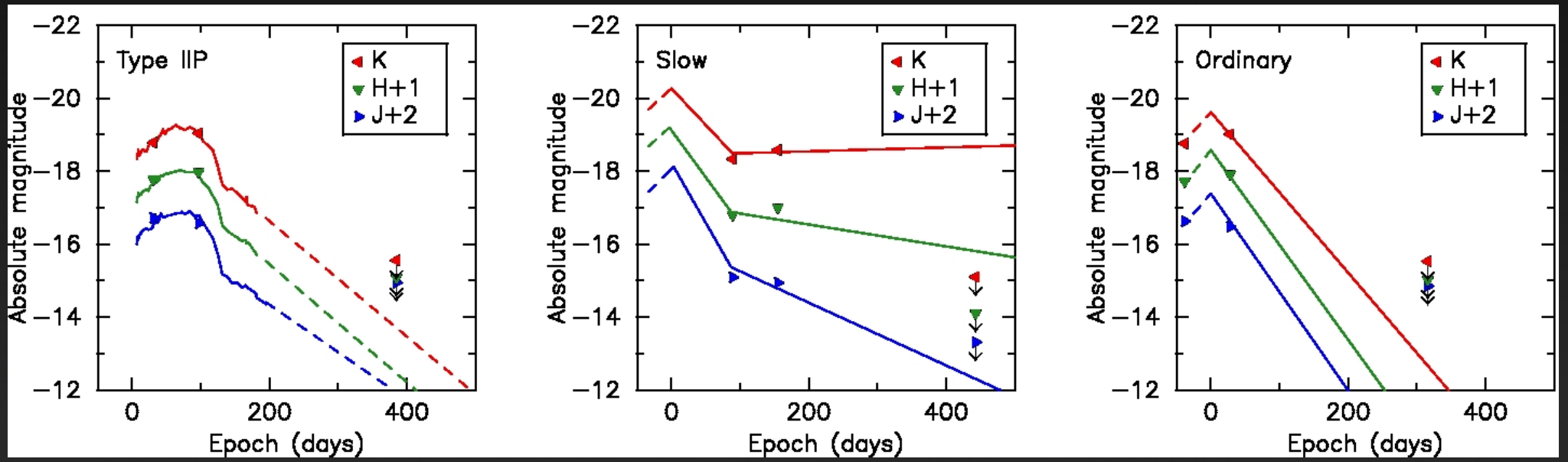
SN 2010cu & SN 2011hi in IC 883



- SN 2010cu at 0.4” (180 pc) and SN 2011hi at 0.8” (380 pc) from the nucleus (projected distance)
- Expected SN rate of IC 883 ~1.3 SNe yr^{-1}
- Kankare et al. (2012), ApJ, 744, L19
- Radio paper on IC 883 with additional ALTAIR/NIRI data, Romero-Cañizales et al. (2012), A&A, 543, A72
  (talk by C. Romero-Cañizales)

SN 2010cu & SN 2011hi in IC 883

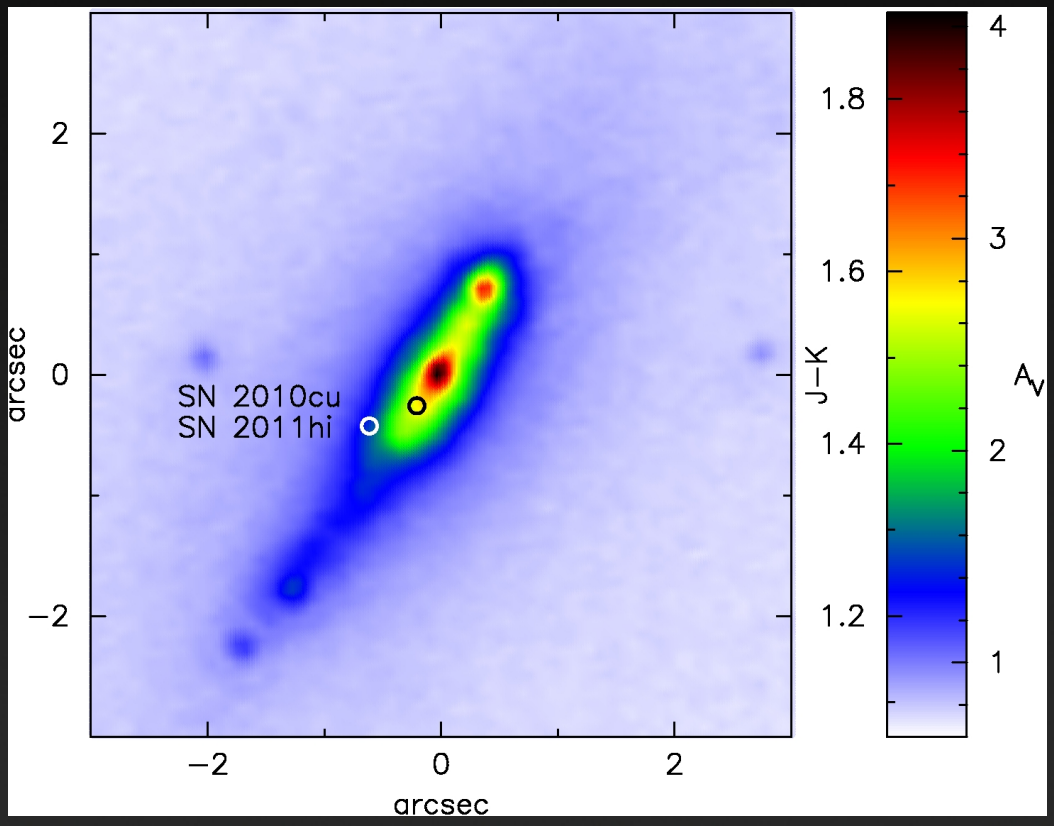




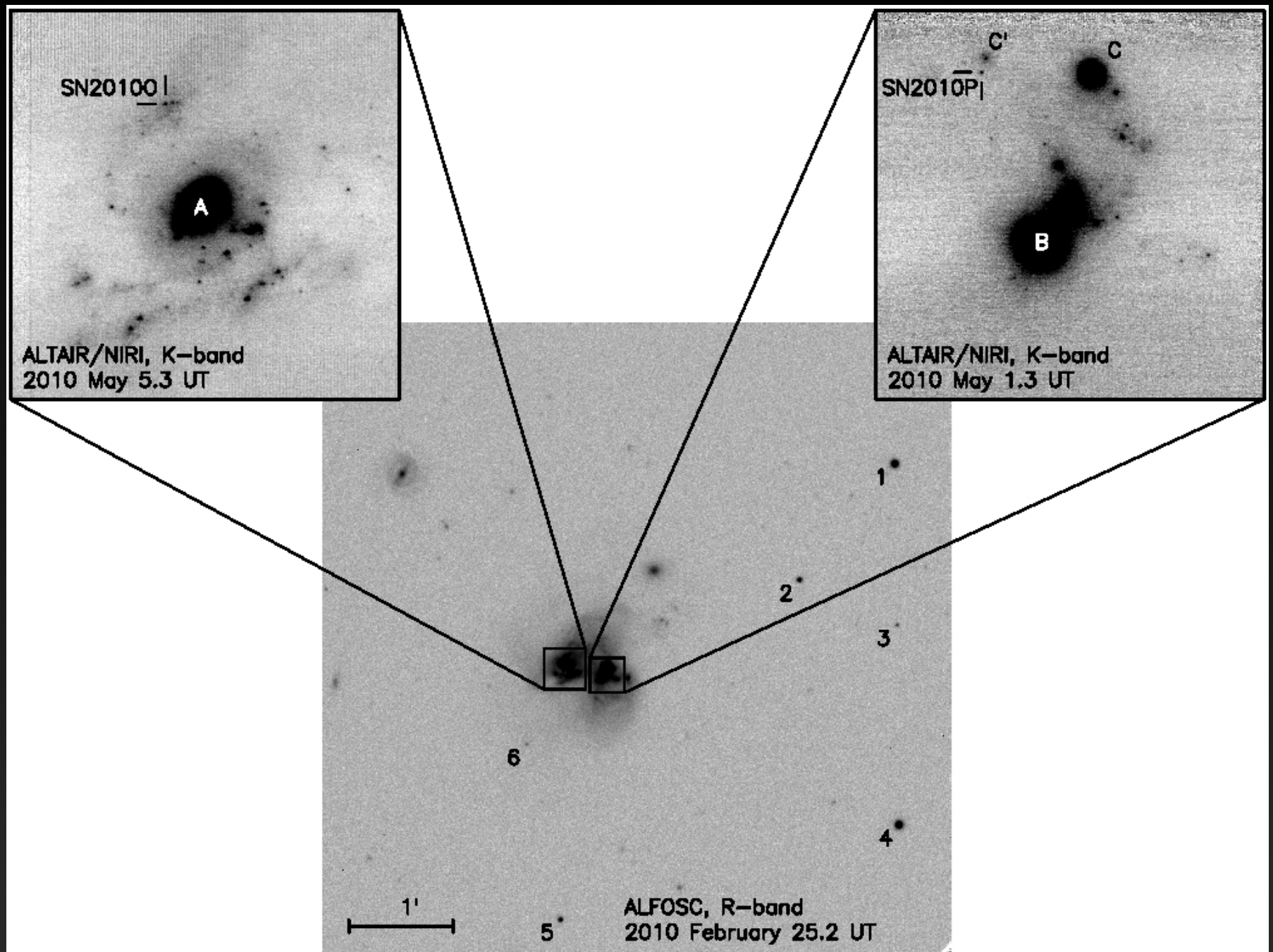
SN 2010cu & SN 2011hi in IC 883

Template	A_V (mag)	t_0 (days)	C (mag)	$\tilde{\chi}^2$	A_V (mag)	t_0 (days)	C (mag)	$\tilde{\chi}^2$
SN 2010cu	Cardelli law				Calzetti law			
ordinary	0.1	-8	+0.80	11	0.1	-8	+0.80	11
slow	0.0	6	+2.20	8.5	0.0	6	+2.20	8.5
IIP	1.3	62	+0.10	1.7	1.0	62	+0.15	1.7
SN 2011hi								
ordinary	6.8	-38	-1.35	5.0	4.7	-38	-1.00	4.4
slow	0.0	89	-0.25	27	0.0	89	-0.25	27
IIP	7.0	31	-1.65	9.4	5.0	31	-1.30	8.8

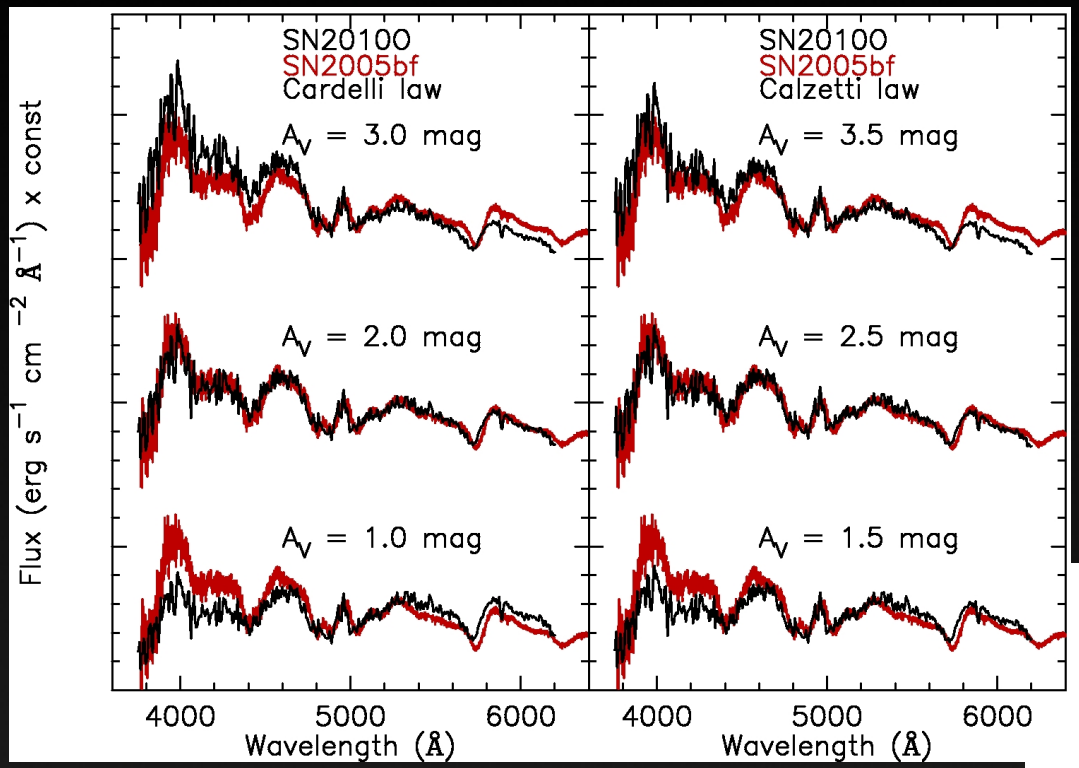
- *J-K HST*/NICMOS archive data colour map
  - Upper limit for the line-of-sight extinction
  - Localized higher extinction possible
- Both SNe most consistent with Type IIP templates
  - SN 2010cu: $A_V \sim 0$ mag
  - SN 2011hi: $A_V \sim$ 5-7 mag

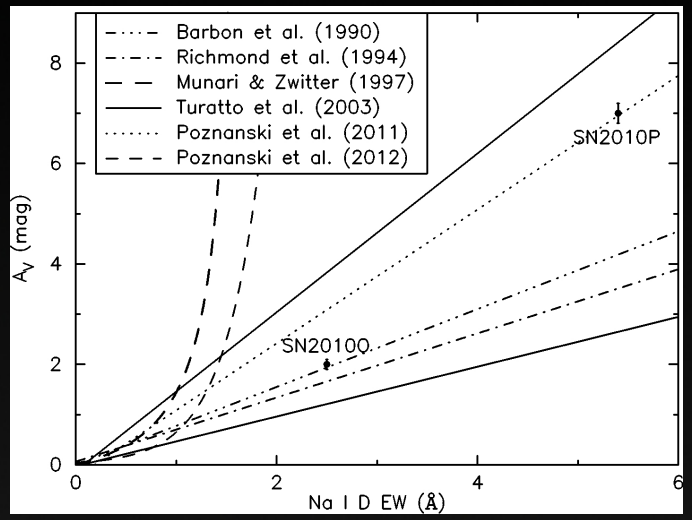


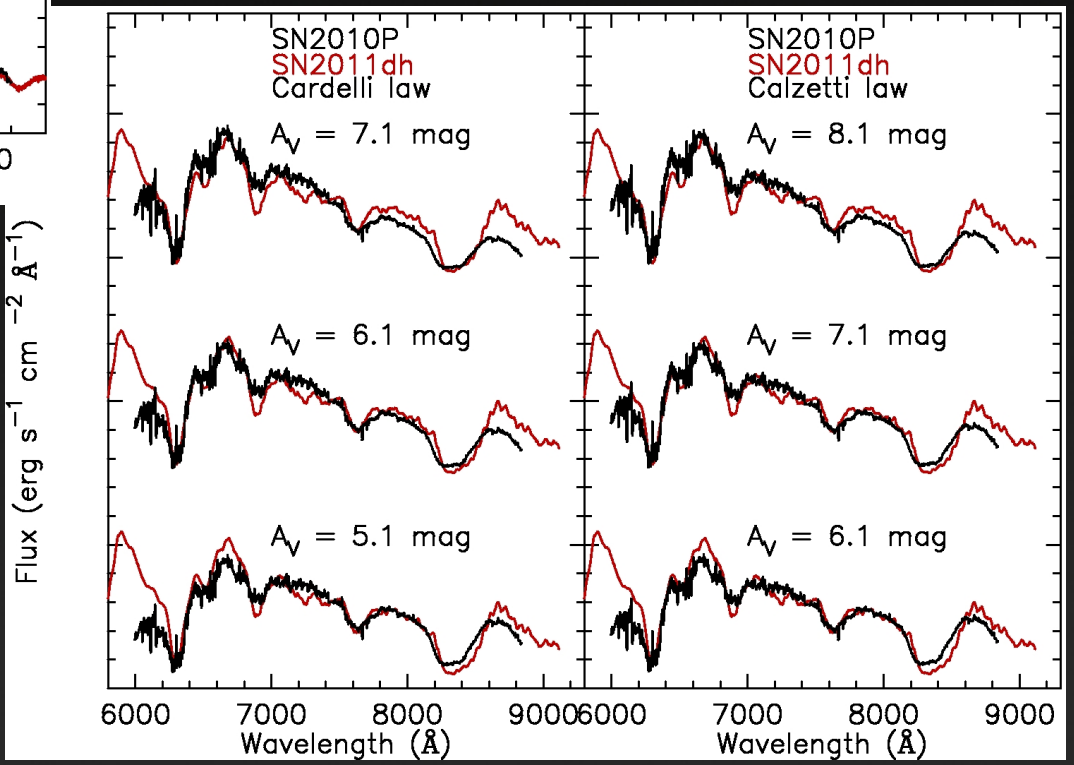
SN 2010O & SN 2010P in Arp299



SN 2010O & SN 2010P in Arp299

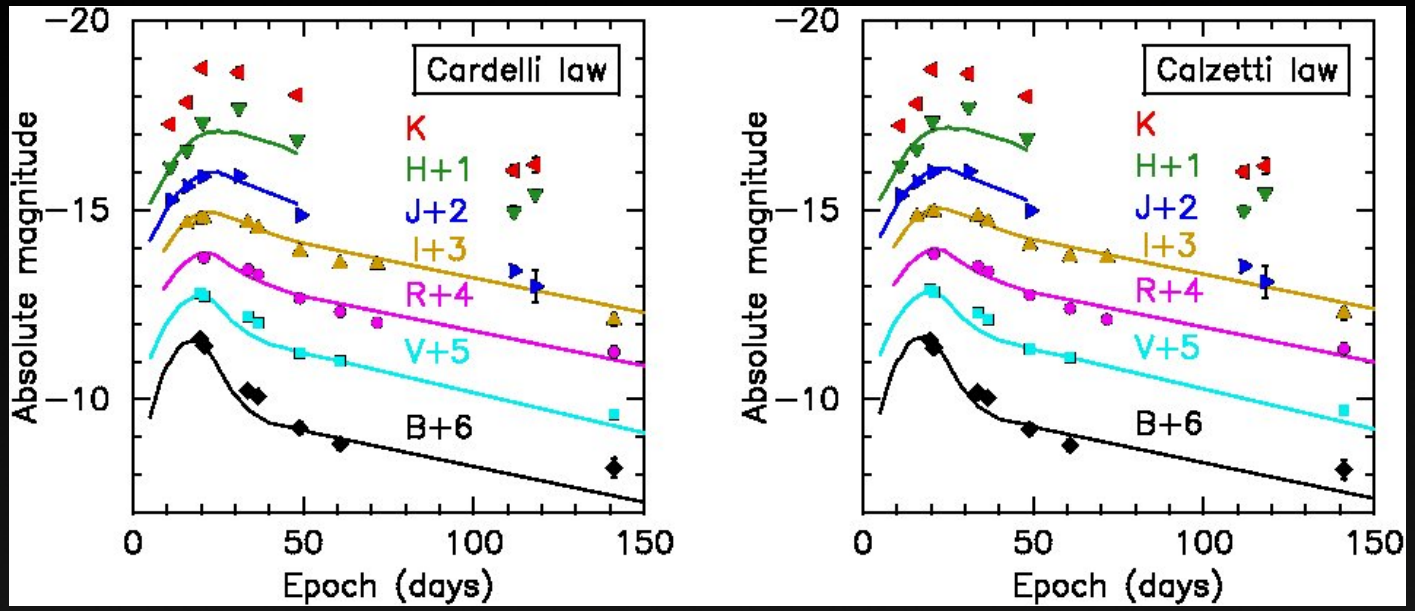




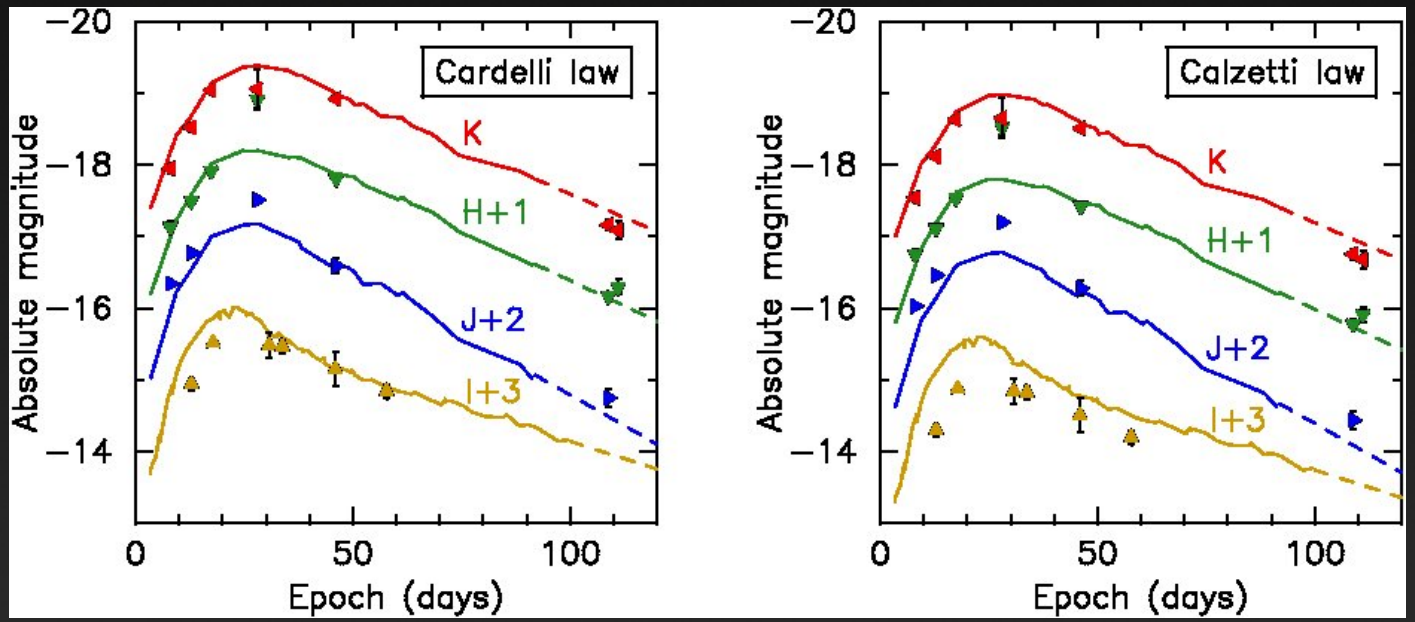


- Low resolution Na I D absorption line a poor proxy of line-of-sight reddening (e.g. Phillips et al. 2013)
- SN 2010O: Type Ib, $A_V \approx 2$ – 2.5 mag
- SN 2010P: Type IIb $A_V \approx 6$ – 7 mag
- Kankare et al. (2014), MNRAS, 440, 1052

SN 2010O & SN 2010P in Arp299



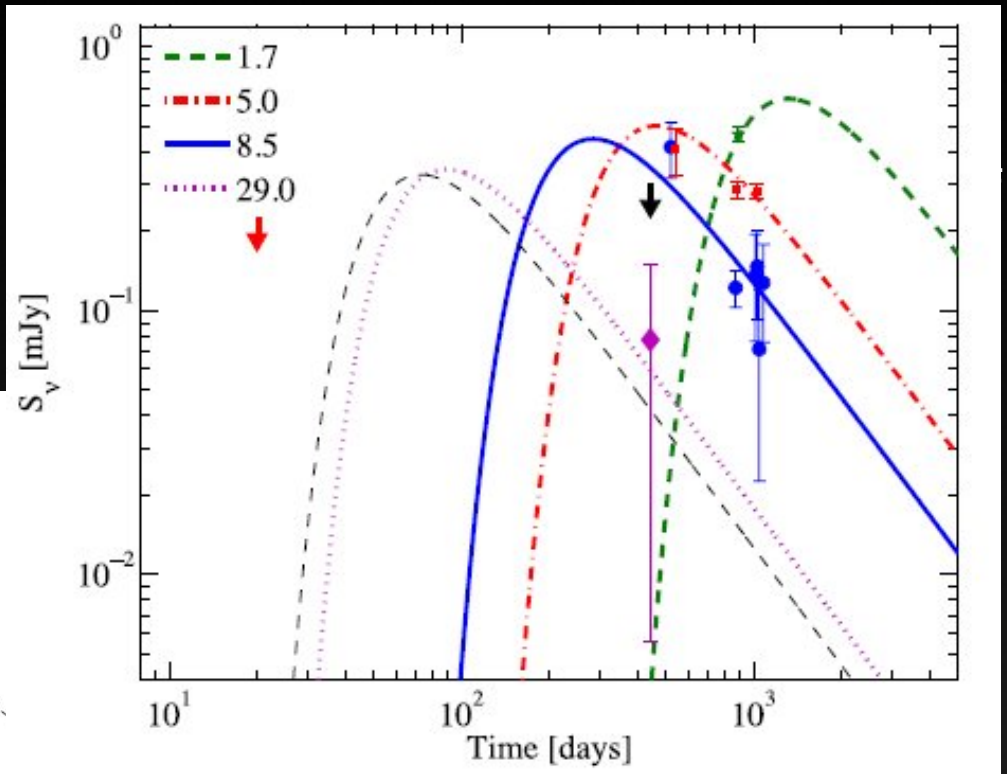
- SN 2010O: $A_V \approx 2$ mag
- Consistent with the spectrum comparison if Cardelli et al. (1989) extinction law adopted

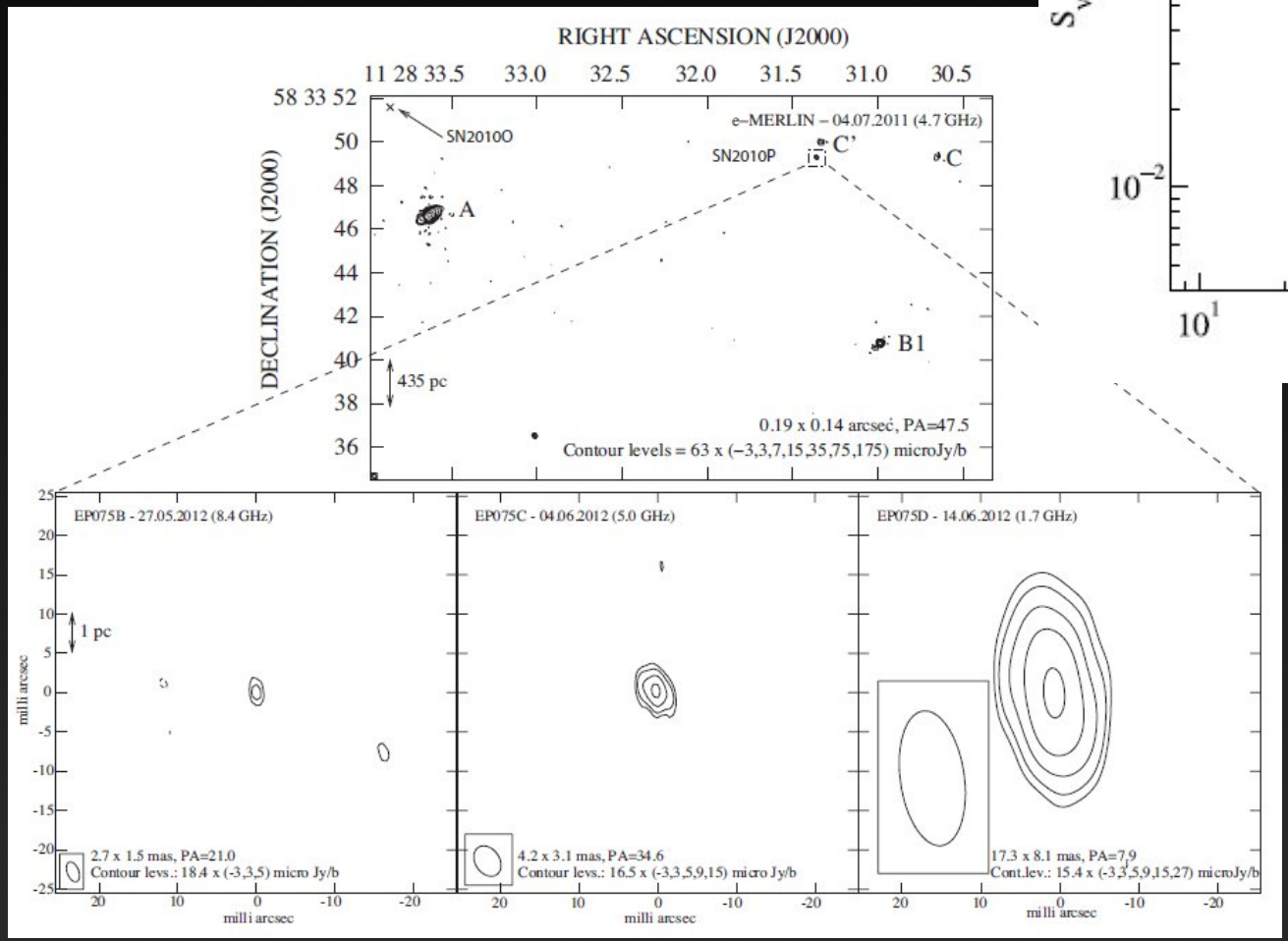


- SN 2010P: $A_V \approx 7$ mag
- Consistent with the spectrum comparison if Calzetti et al. (2000) extinction law adopted
- Different extinction laws present in different components of Arp 299

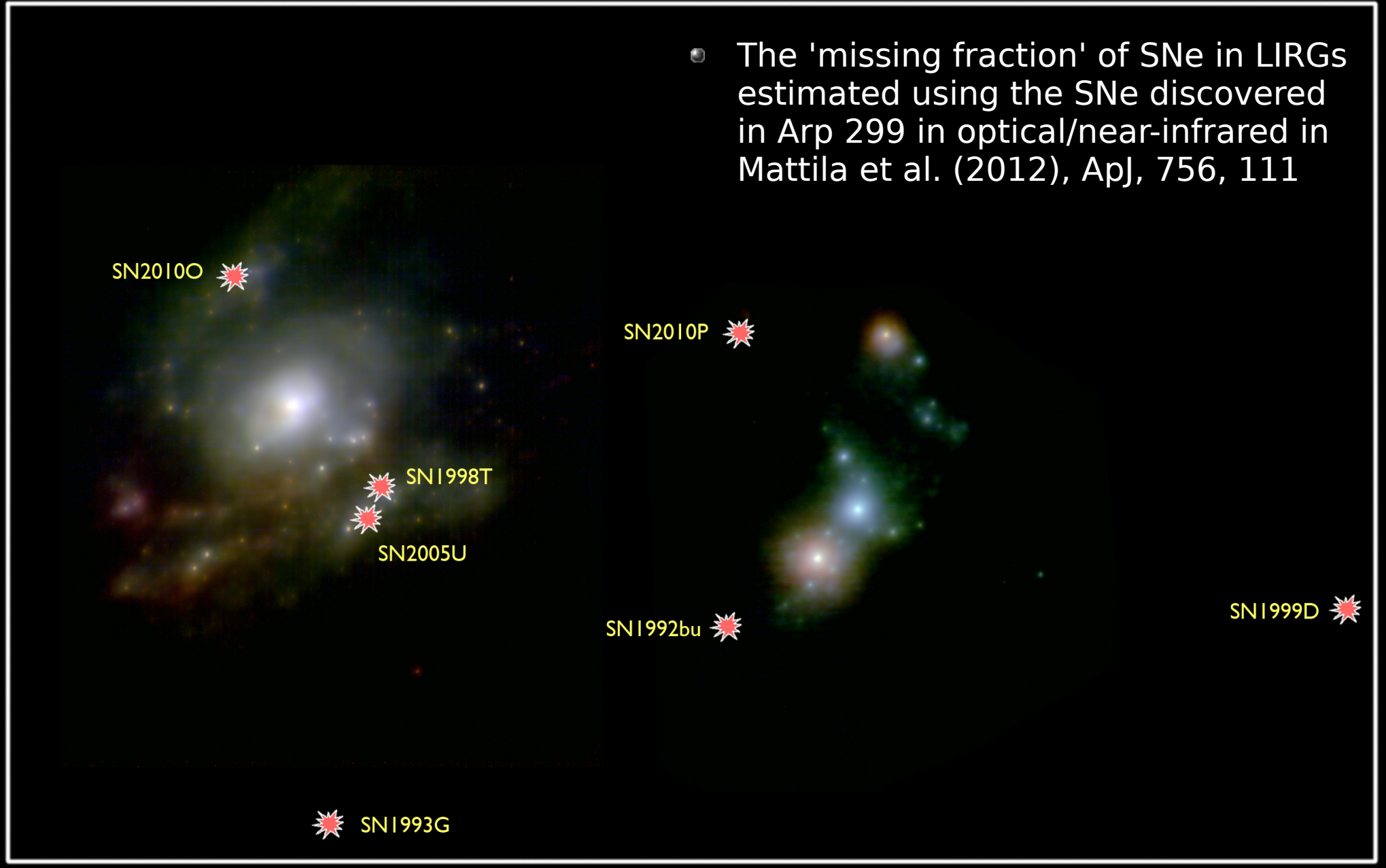
SN 2010O & SN 2010P in Arp299

- Late-time (~400 d) radio detection of SN 2010P excluding the Type Ib nature
- Romero-Cañizales et al. (2014), MNRAS, 440, 1067
- (talk by Cristina Romero-Cañizales)





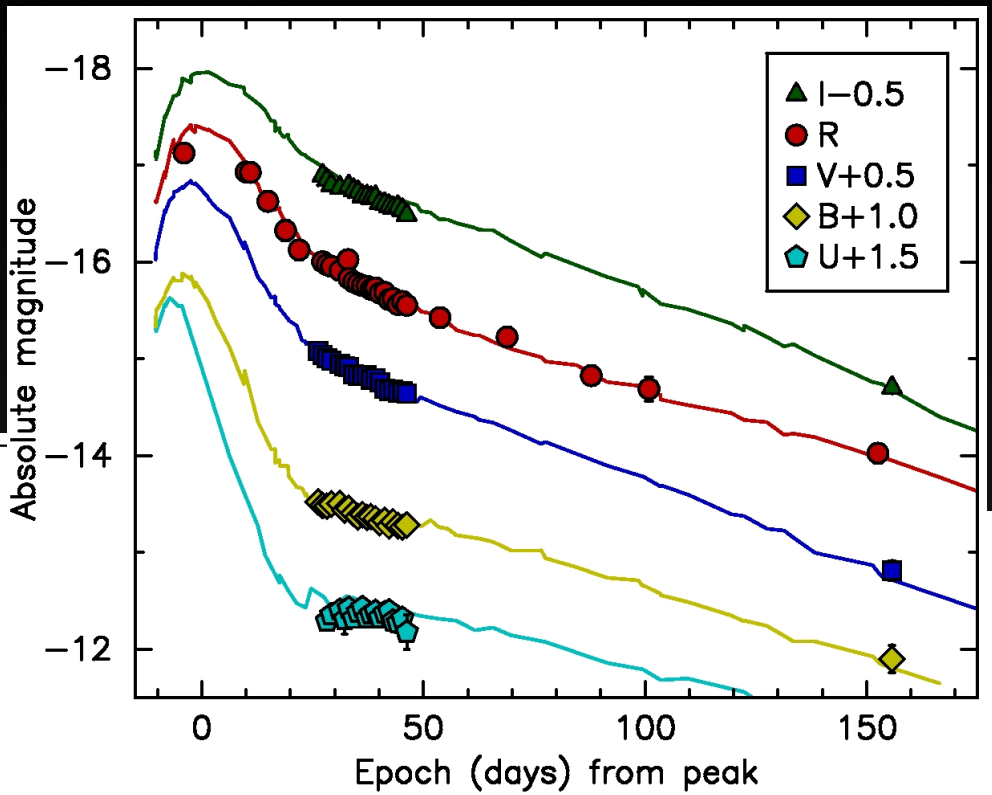
- Radio rise time and progenitor nature relation of Type IIb SNe more complex than previously suggested

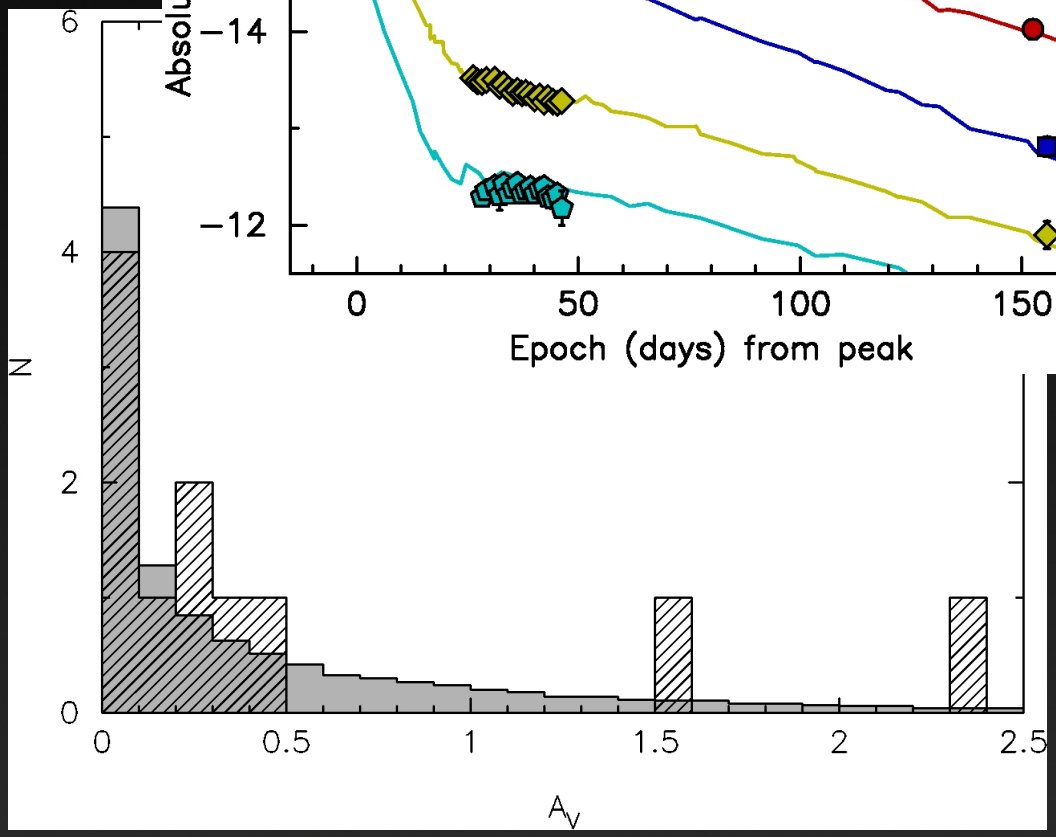


Gemini North, NIRI + ALTAIR - J (blue) + H (green) + K (red)
Stuart Ryder (Australian Astronomical Observatory), Seppo Mattila (Finnish Centre for Astronomy with ESO) and Erkki Kankare (Tuorla Observatory, Finland)

Image Credit: Gemini Observatory / AURA and
Ángel R. López-Sánchez (Australian Astronomical Observatory / Macquarie University)

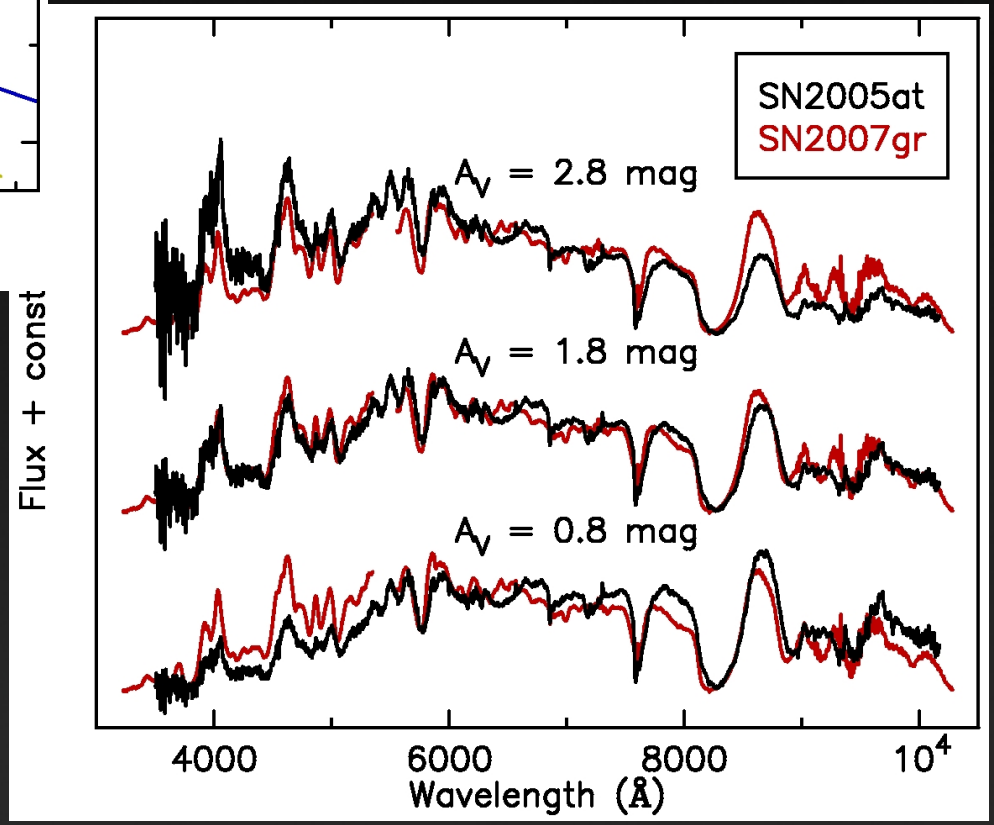
SN 2005at @ ~10 Mpc



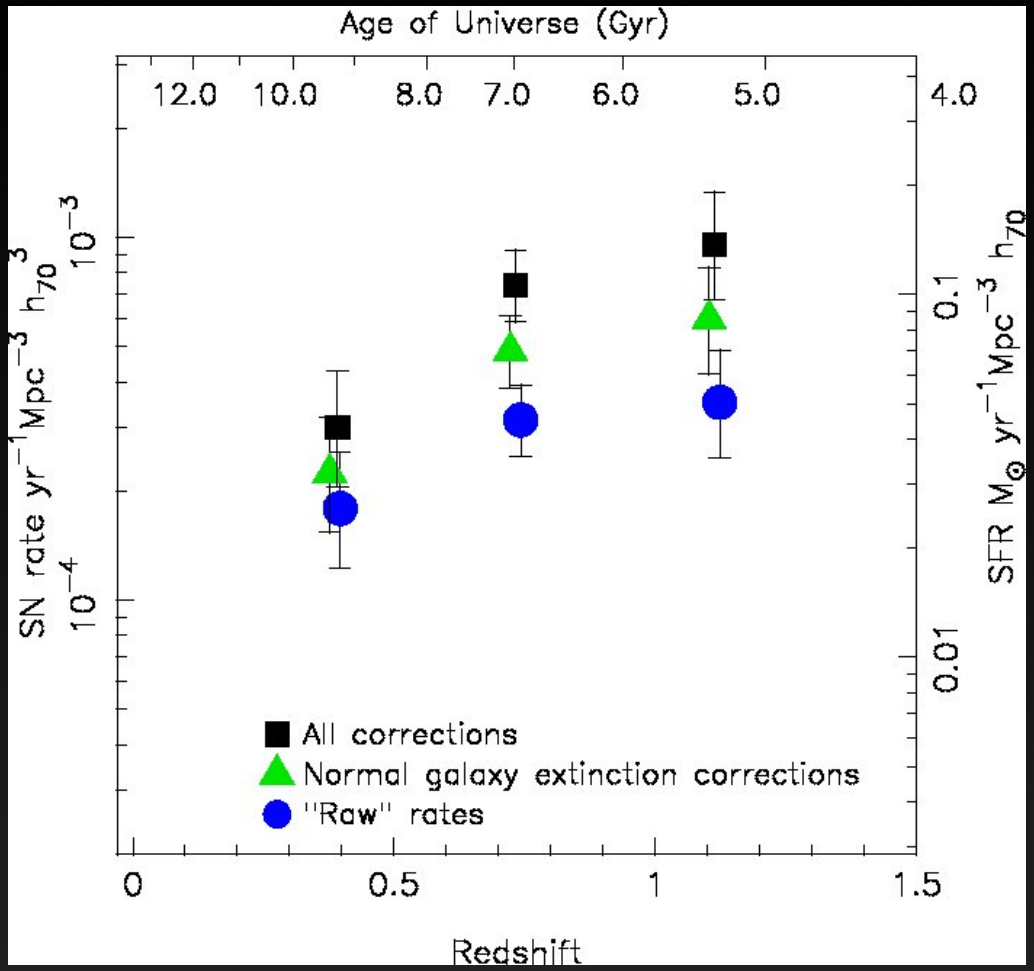


Mattila et al. (2012)

- SN 2005at: in a normal spiral galaxy NGC 6744, SN 2007gr-like Type Ic, $A_V \sim 1.9$ mag
- Kankare et al. (2014), A&A, 572, 75
- Complete the extinction estimates of CCSNe within 12 Mpc at <60° hosts from 2000 to 2011

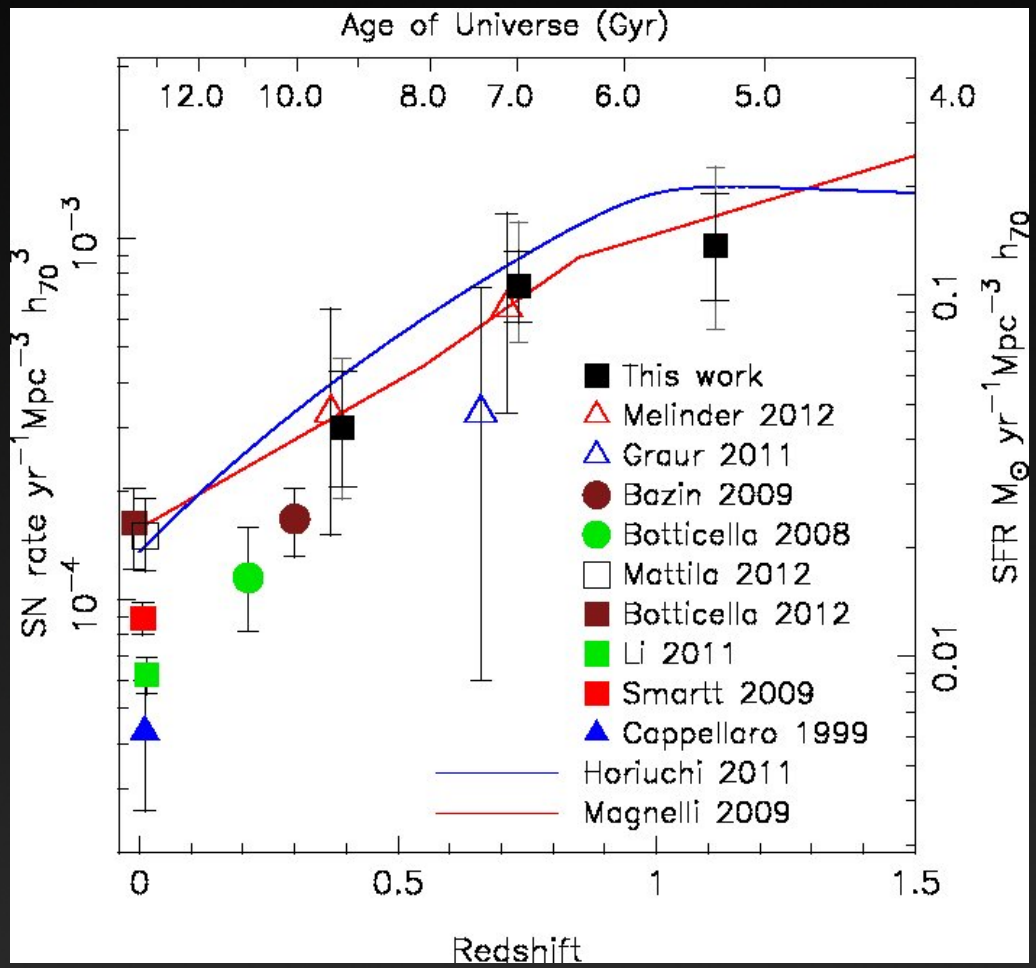


Supernova rates



Dahlen et al. (2012)

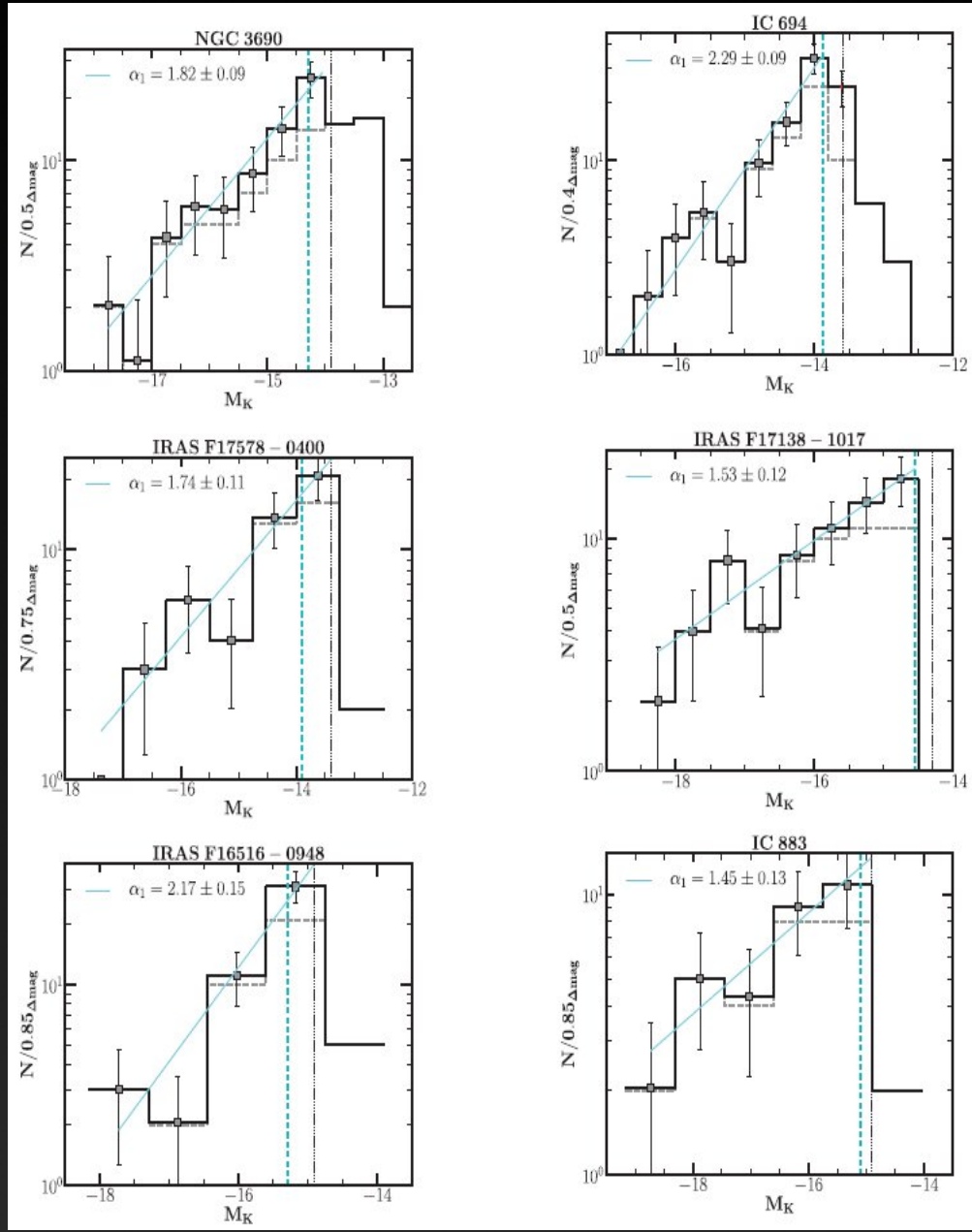
- After extinction and missing fraction corrections no discrepancy between the SN rate and the star formation rate (Melinder et al. 2012, Dahlen et al. 2012)



Dahlen et al. (2012)

Legacy

- Legacy value of the ALTAIR/NIRI data
- High-resolution near-IR images of LIRGs
- Detailed studies of LIRGs
  - Super star cluster population in LIRGs
  - Randriamanakoto et al. (2013, MNRAS, 431, 554)
  - Randriamanakoto et al. (2013, ApJ 775, L38)
  - (talk by Zara Randriamanakoto)



VLT NaCo

- LIRG SN monitoring with VLT/NaCo
- Single-conjugate AO system with a natural guide star
- Discovery example: SN candidate in ESO 440-IG 058
  - Expected SN rate of ~0.7 SNe yr^{-1}
- (talk by Tom Reynolds)

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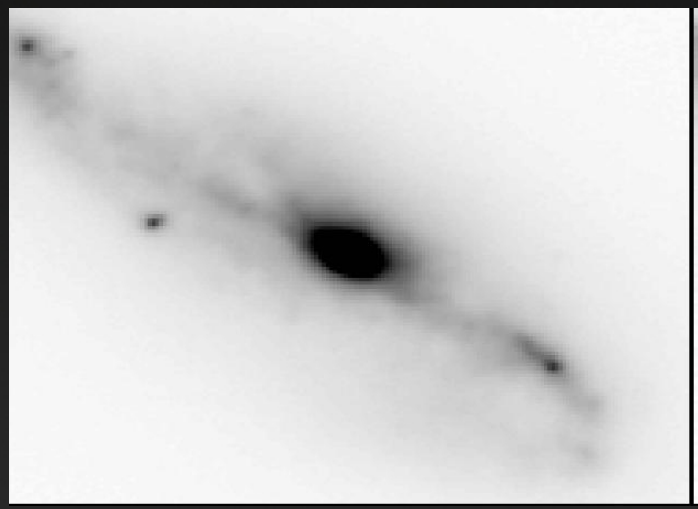
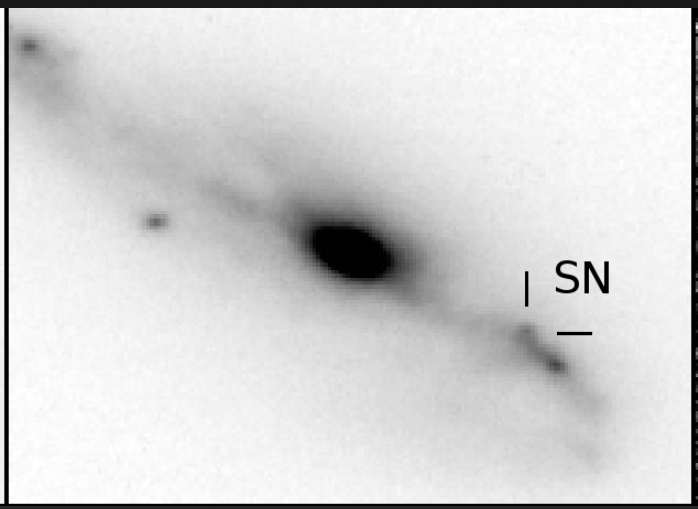
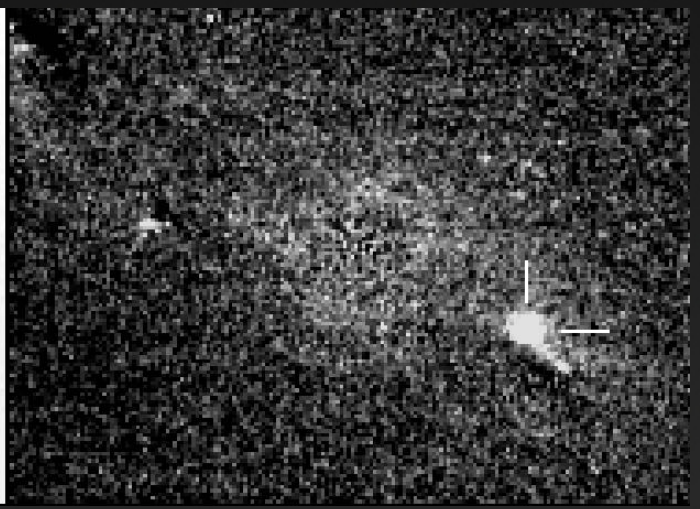


2011 January 22 *K*-band



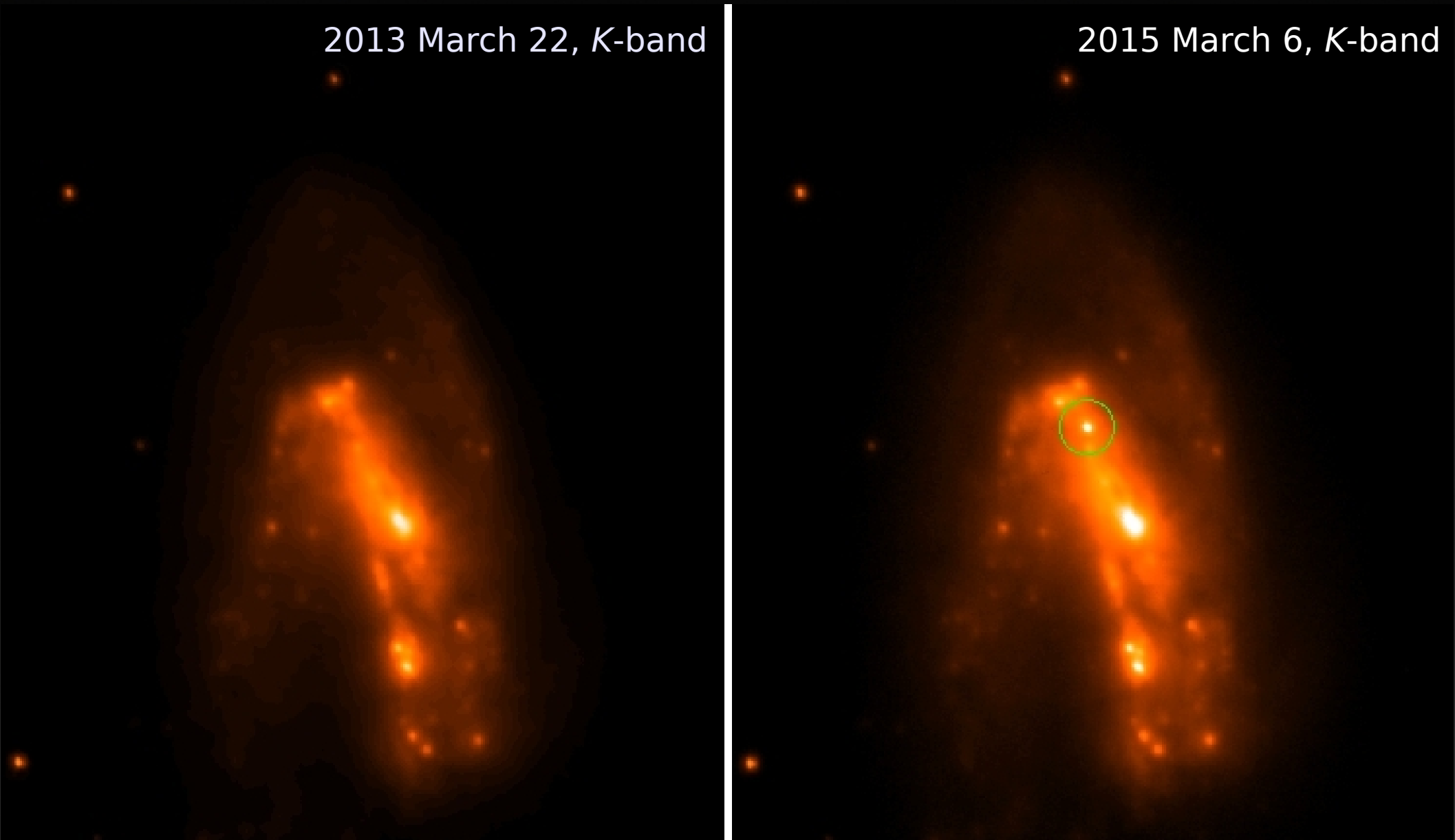
2012 July 18 *K*-band



subtraction

Future

- GeMS/GSAOI – Gemini Multi-conjugate adaptive optics System (talk by Erik Kool)
- Discovery example: yet another SN in IRAS 17138-1017 (Kool et al. in prep)



Summary

- Motivation: SNe in LIRGs
  - SN populations
  - Extinction corrections and missing fractions
  - Ultimately SN rates at low and high redshift
- ALTAIR/NIRI programme
  - 2008-2010
  - Survey sample of 8 LIRGs
  - 6 SNe in total
  - 9 main journal publications to date
- Future
  - Larger sample sizes
  - Next generation AO instruments
  - Increased statistics