Nuclear supernovae with Gaia

Seppo Mattila

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

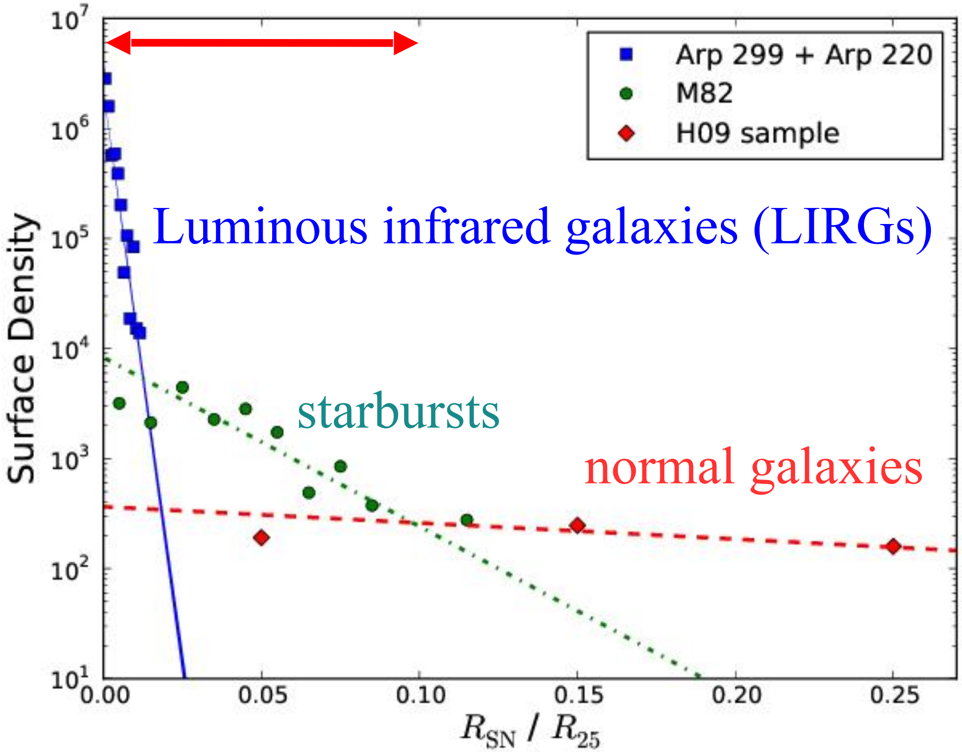
Thomas Reynolds, Tuomas Kangas (Turku), Erkki Kankare, Rubina Kotak (QUB),
Stuart Ryder (AAO), Miguel Perez-Torres (IAA-CSIC), Cristina Romero-Canizales (PUC),
Nadia Blagorodnova (IoA->Caltech), Morgan Fraser, Simon Hodgkin (IoA) *and others*

Gaia Science Alerts Workshop 2015, 12th Nov. 2015

Background

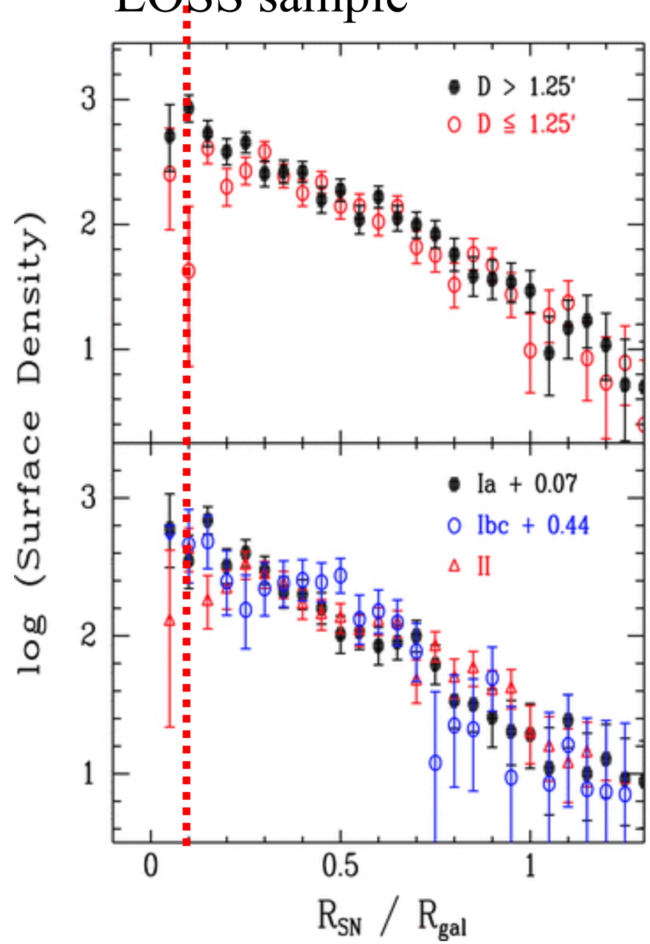
Occurrence of SNe in nuclear environments

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



Herrero-Illana+2012

LOSS sample



Leaman+2011;
Li+2011

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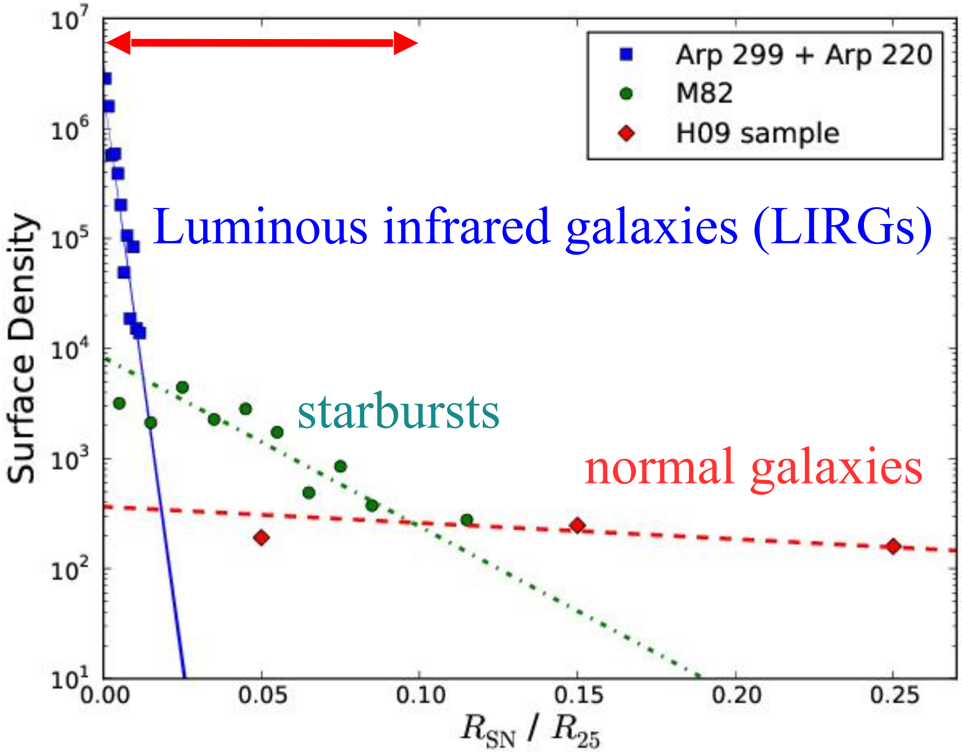

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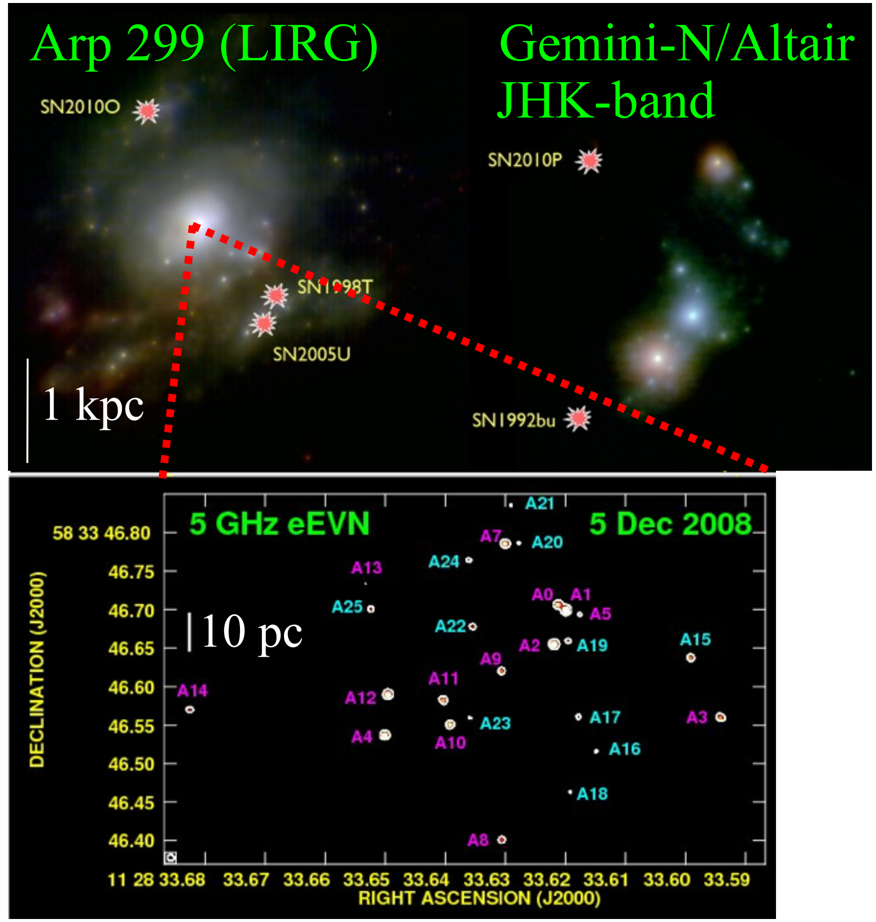
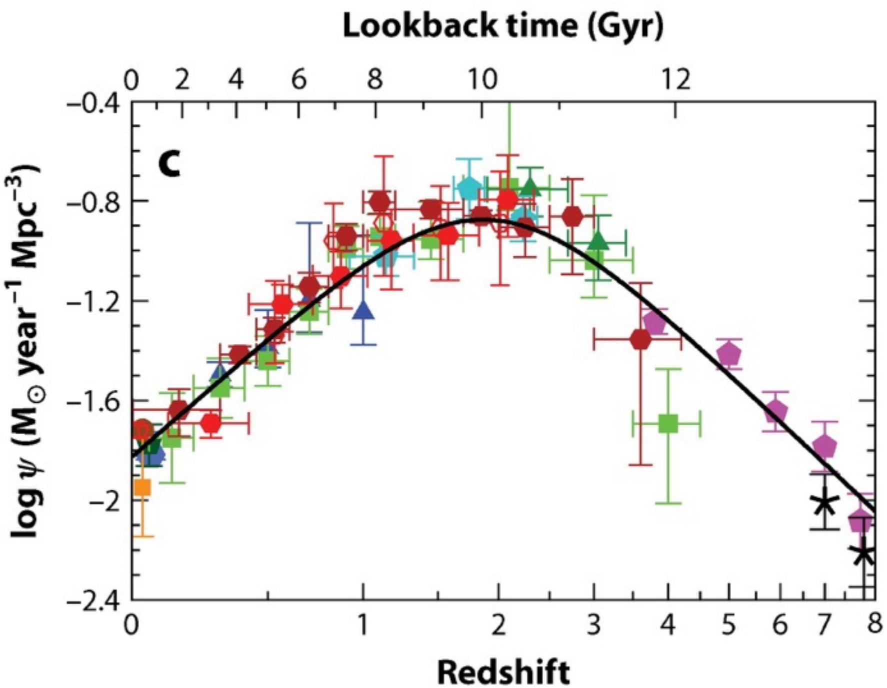


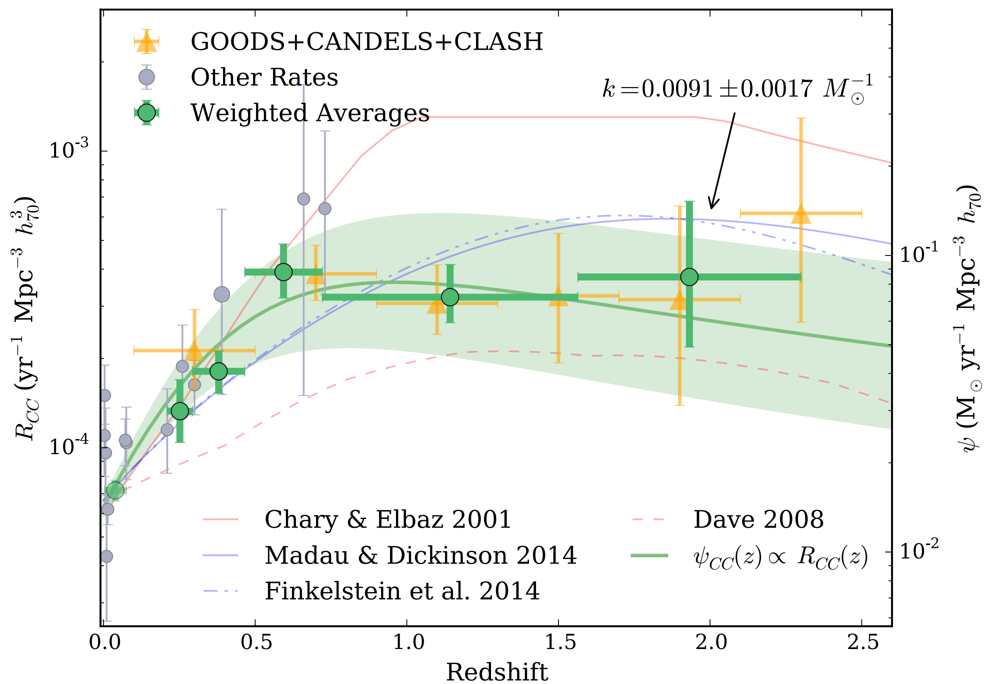
Perez-Torres+2009

Detailed comparison between cosmic SNR and SFH

- Consistent picture of SFH available from UV, optical and IR up to z ~ 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



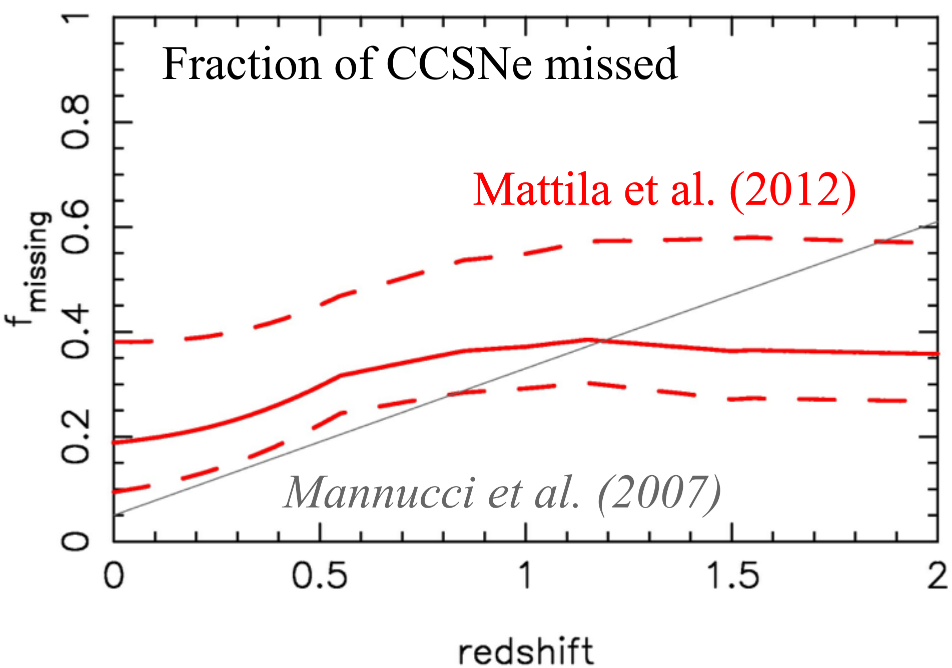
Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

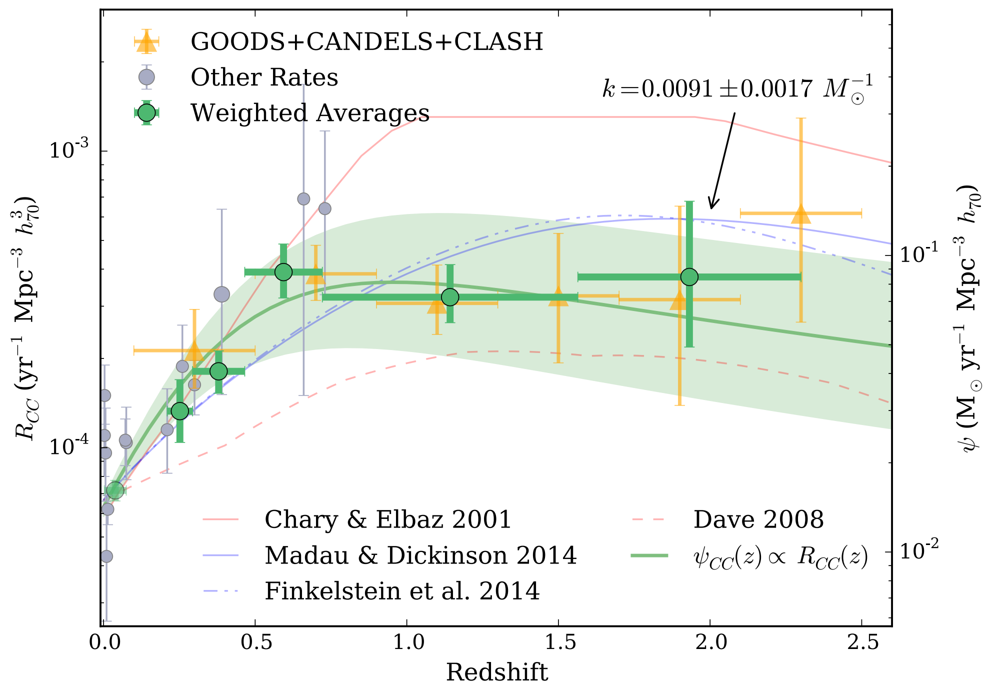


Strolger+2015

Detailed comparison between cosmic SNR and SFH

- Consistent picture of SFH available from UV, optical and IR up to z ~ 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 ?

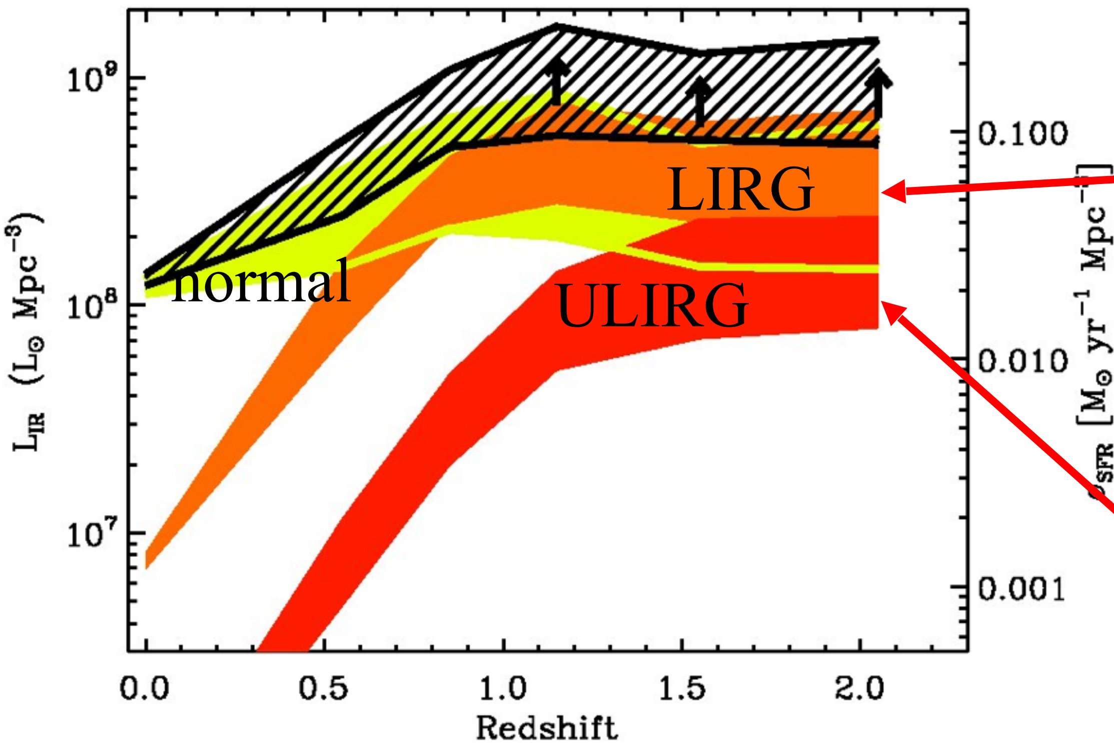




Strolger+2015

Existence of "dark" SNe in U/LIRGs

- (Ultra)luminous IR galaxies locally rare but at z ~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

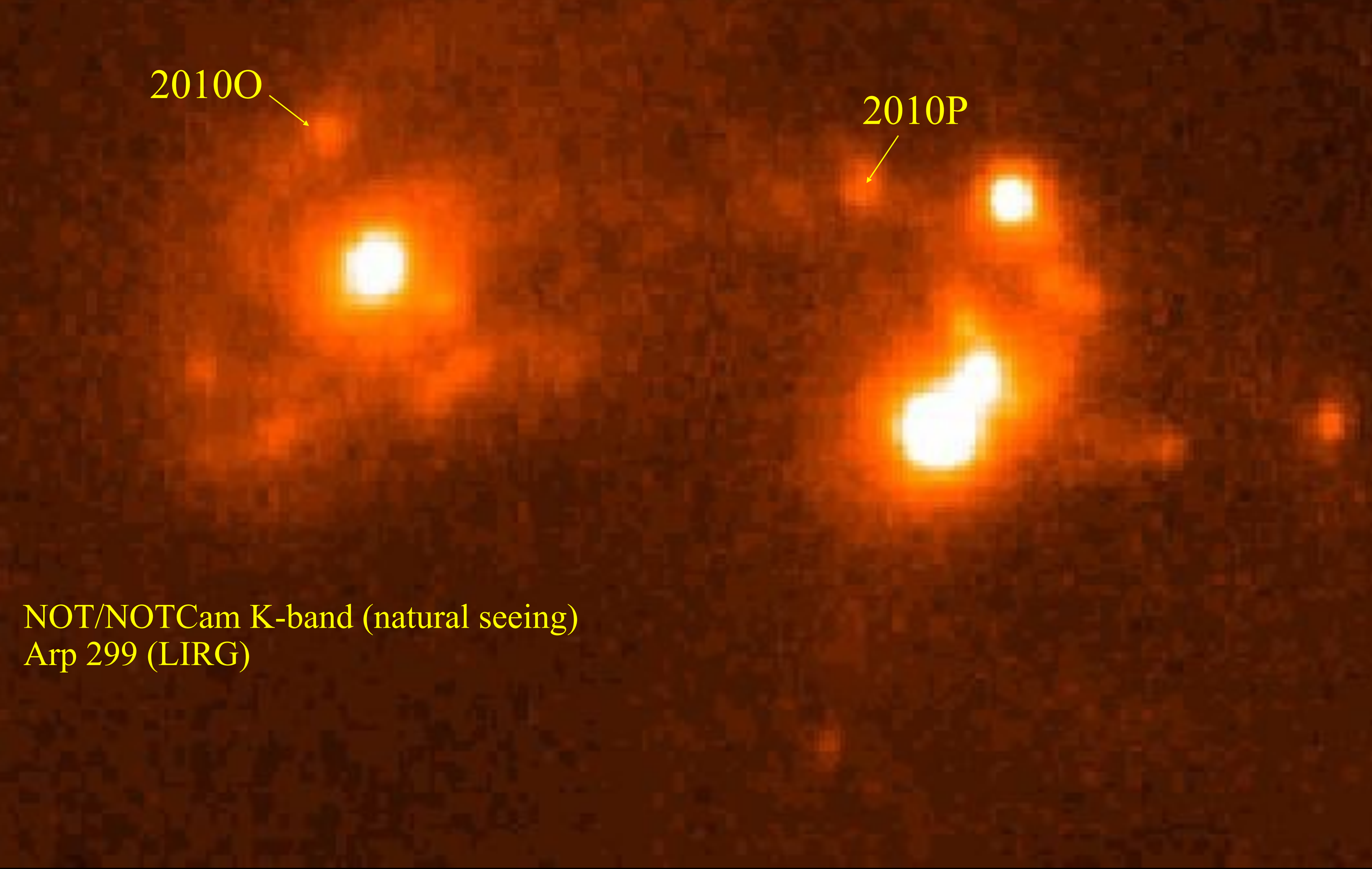


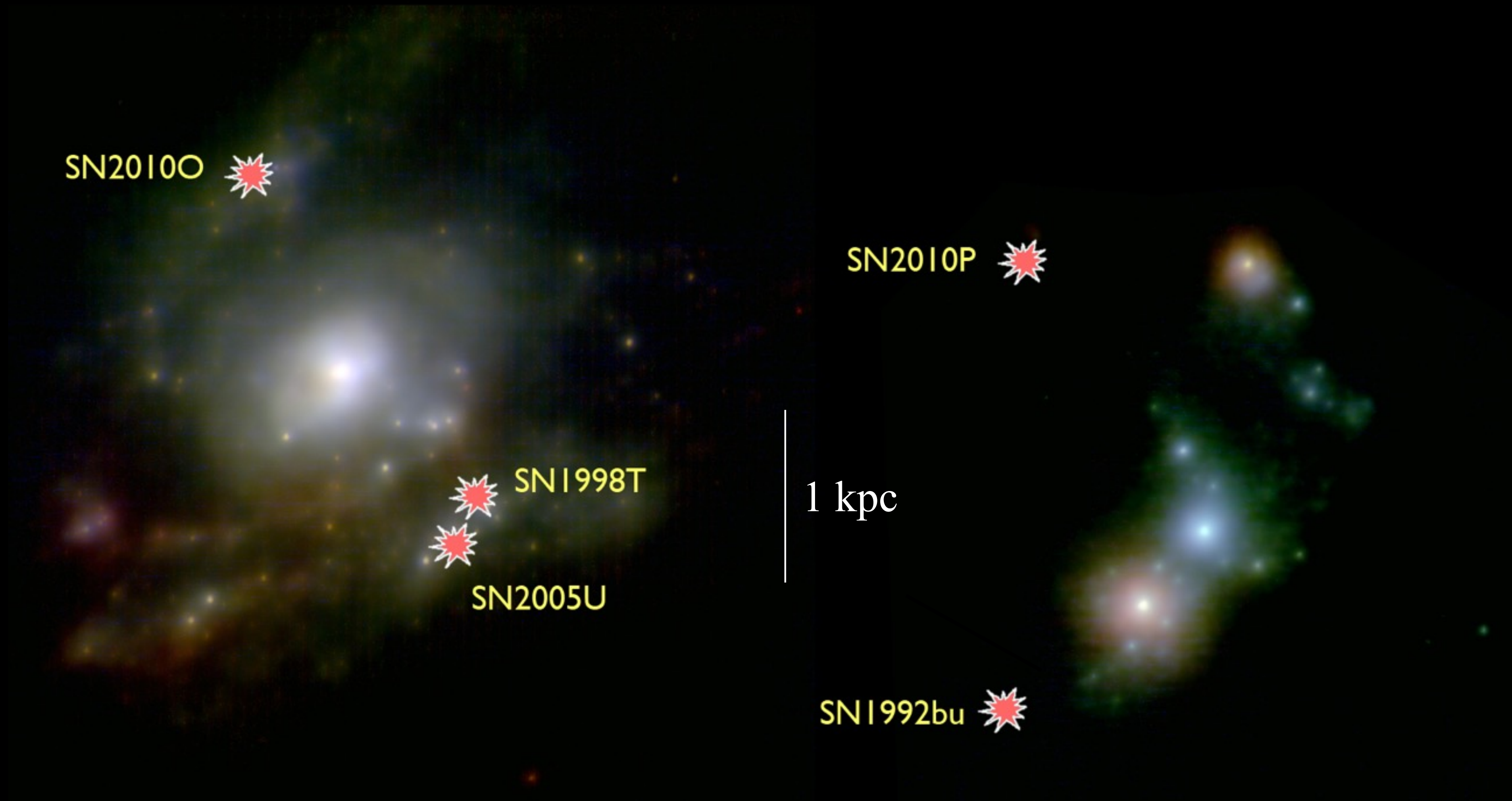
Magnelli+2009,2011

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

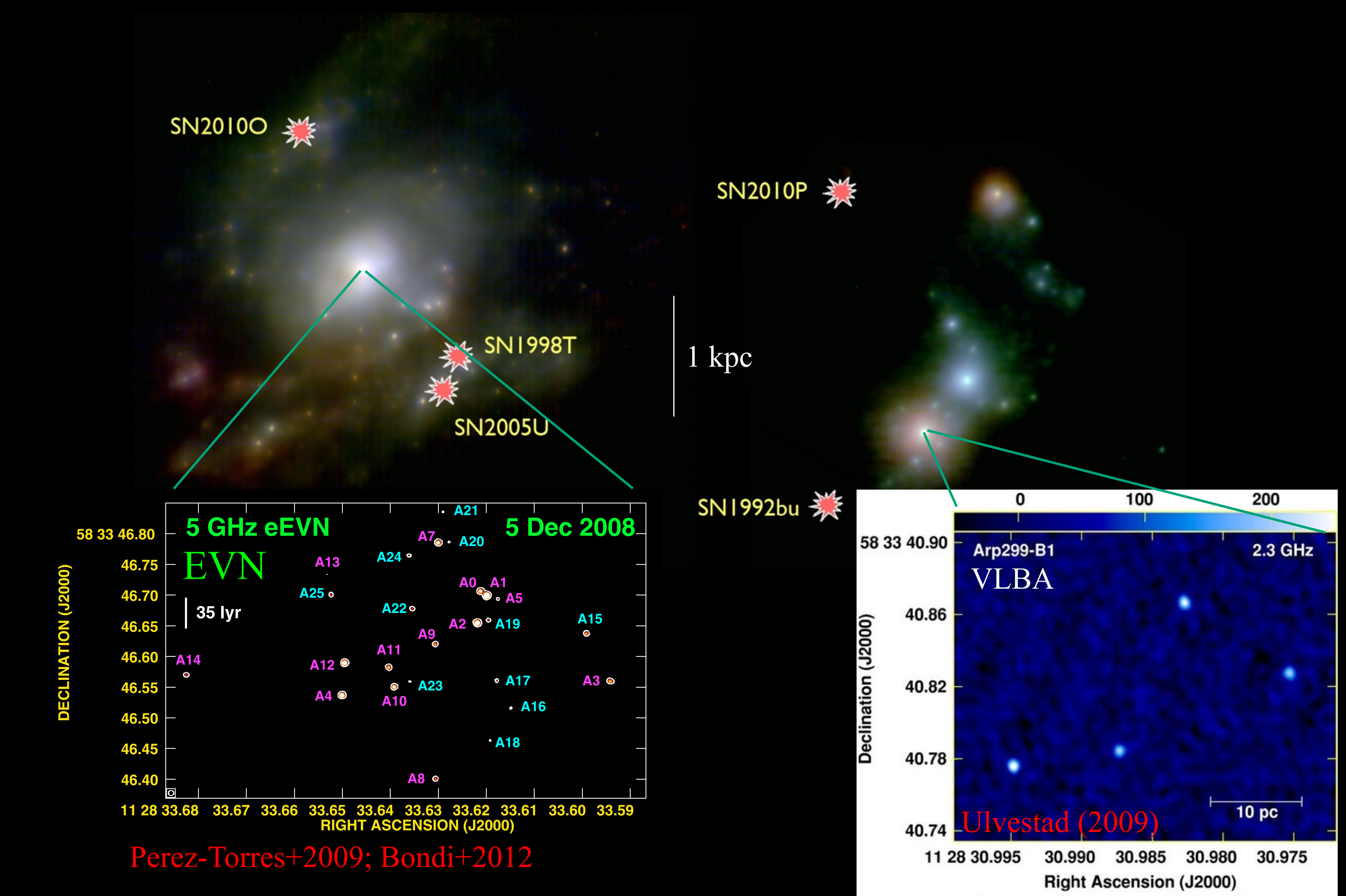
ULIRGs: $10^{12} L_\odot < L_{IR} < 10^{13} L_\odot$
SFR a few x 100-1000 $M_\odot$ yr^{-1}
a few x 1-10 CCSNe yr^{-1}

Adaptive Optics detection and study of SNe in LIRGs


2010O
2010P
NOT/NOTCam K-band (natural seeing)
Arp 299 (LIRG)



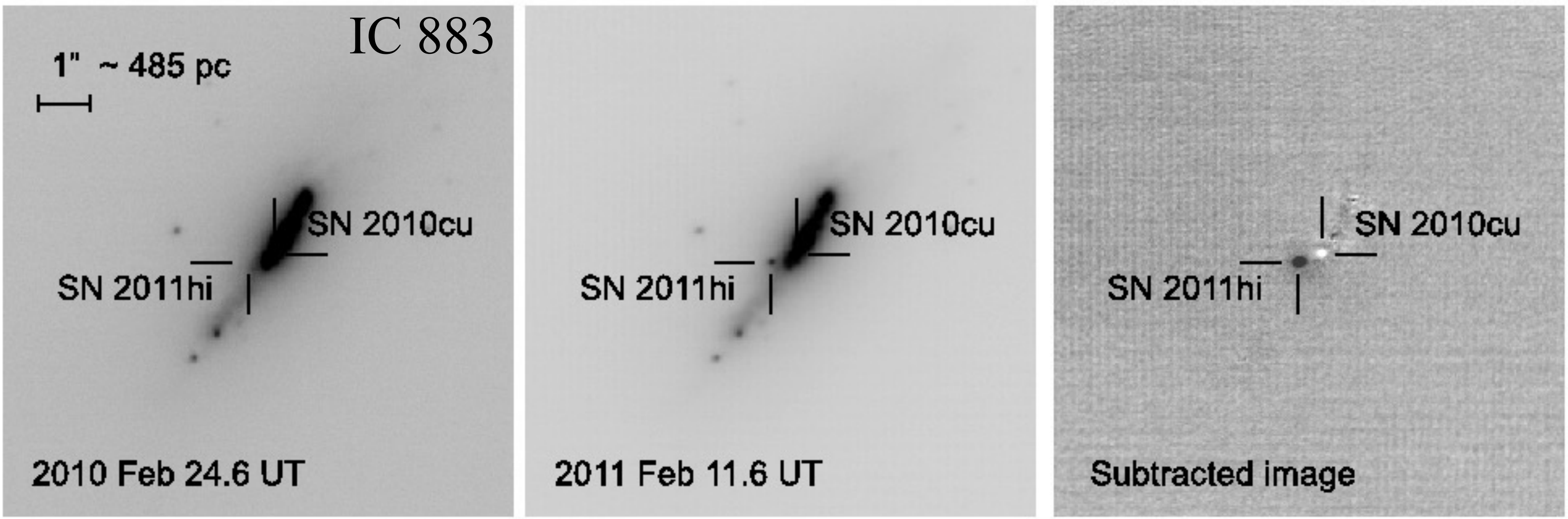
Gemini-N/Altair JHK-band (Adaptive Optics)



SN2010O
SN2010P
SN1998T
SN2005U
SN1992bu
1 kpc
5 GHz eEVN
5 Dec 2008
EVN
35 lyr
A0 A1 A2 A3 A4 A5 A7 A8 A9 A10 A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21 A22 A23 A24 A25
58 33 46.80
46.75
46.70
46.65
46.60
46.55
46.50
46.45
46.40
DECLINATION (J2000)
11 28 33.68 33.67 33.66 33.65 33.64 33.63 33.62 33.61 33.60 33.59
RIGHT ASCENSION (J2000)
Perez-Torres+2009; Bondi+2012
0 100 200
Arp299-B1
2.3 GHz
VLBA
58 33 40.90
40.86
40.82
40.78
40.74
Declination (J2000)
10 pc
Ulvestad (2009)
11 28 30.995 30.990 30.985 30.980 30.975
Right Ascension (J2000)

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



Kankare,SM+2008,2012,2014; Ryder,SM+2014; Romero-Canizales+2014

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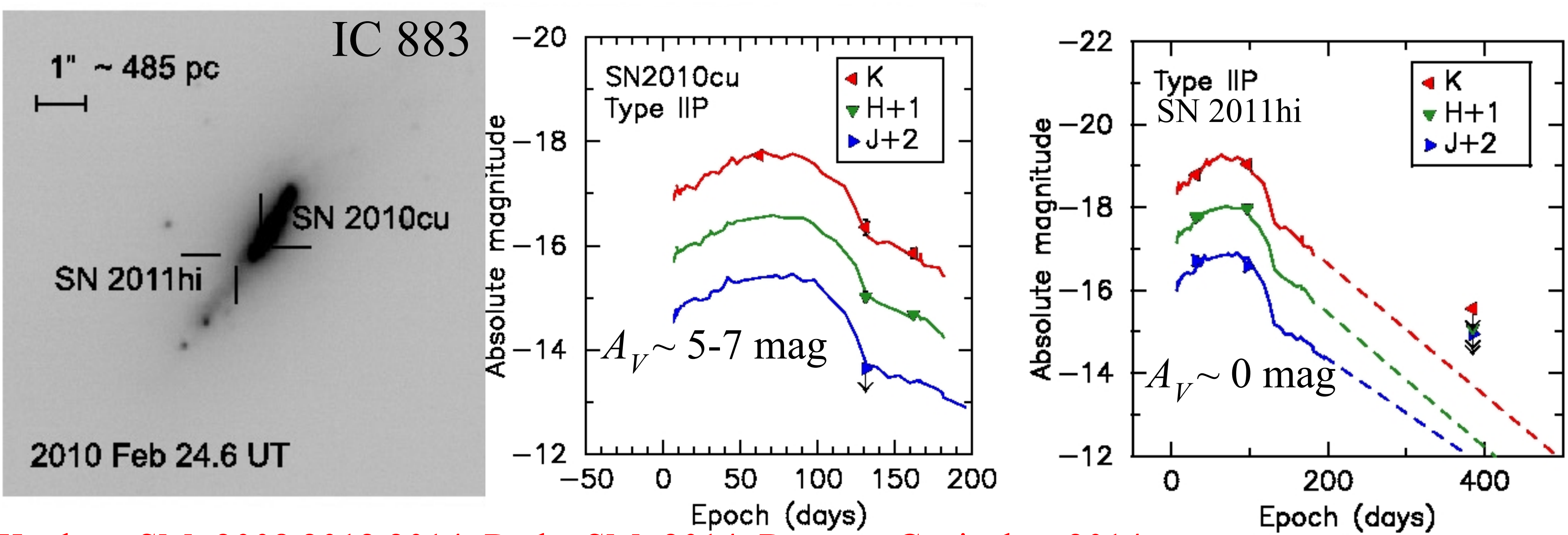

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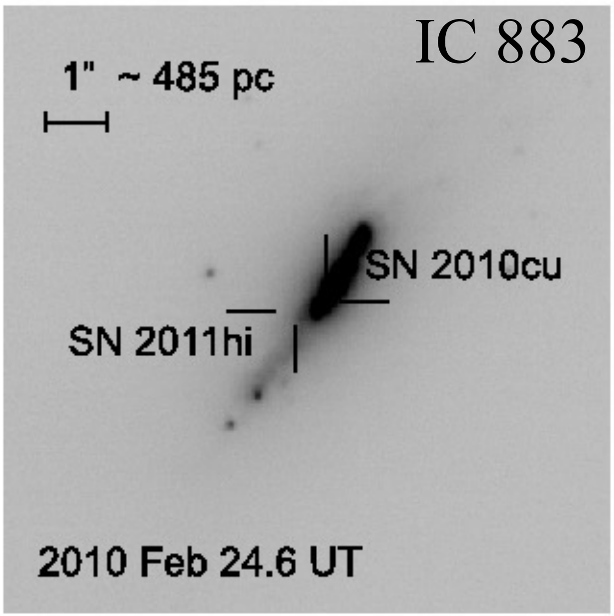
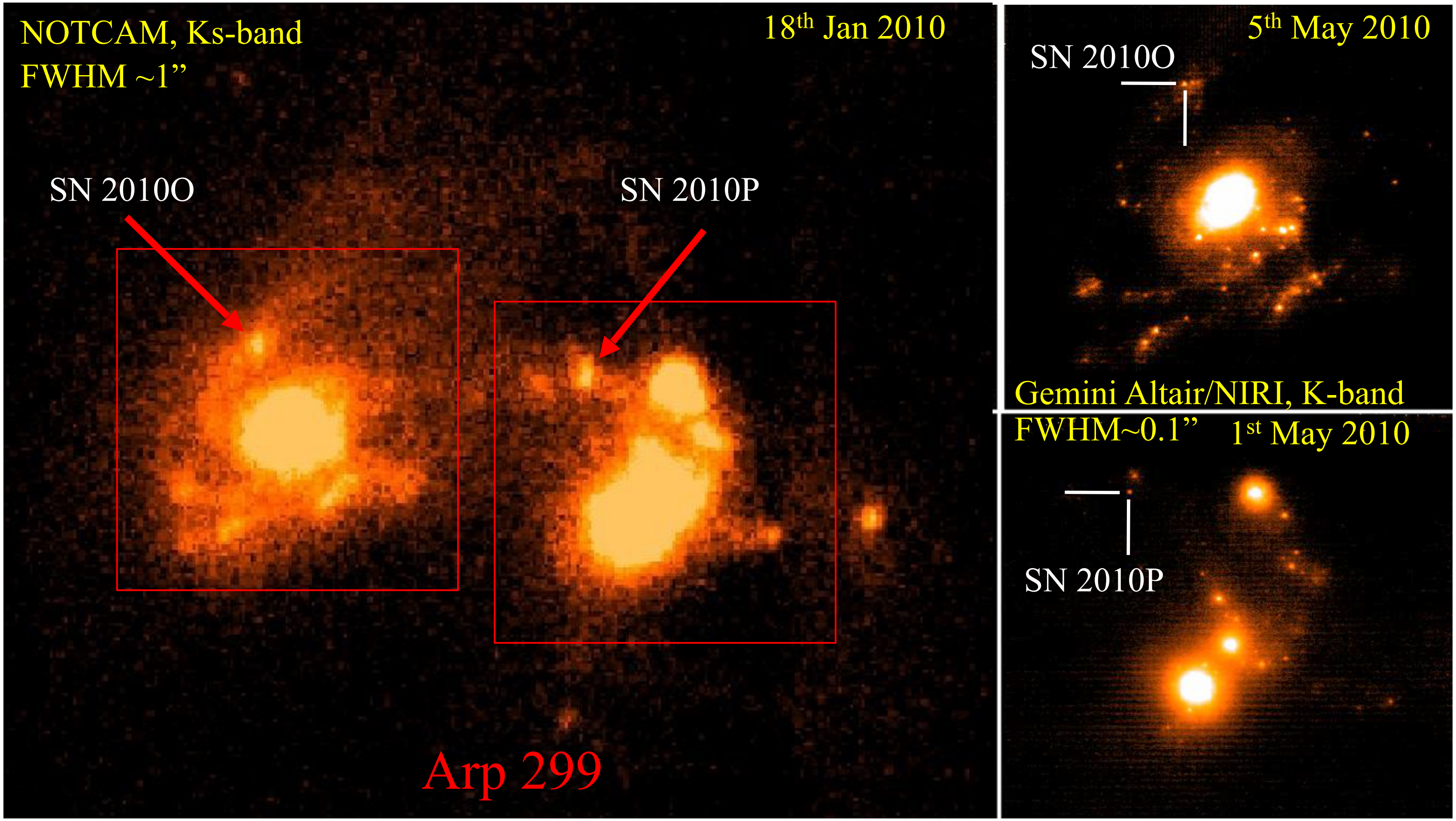
- Use SN NIR light curves and colours to find the likely SN types and extinctions
- Detect SNe within a few hundred pc to kpc nuclear regions with A_V up to 18 mag



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

Kankare,SM+2008,2012,2014; Ryder,SM+2014; Romero-Canizales+2014

SN follow-up in (circum)nuclear regions

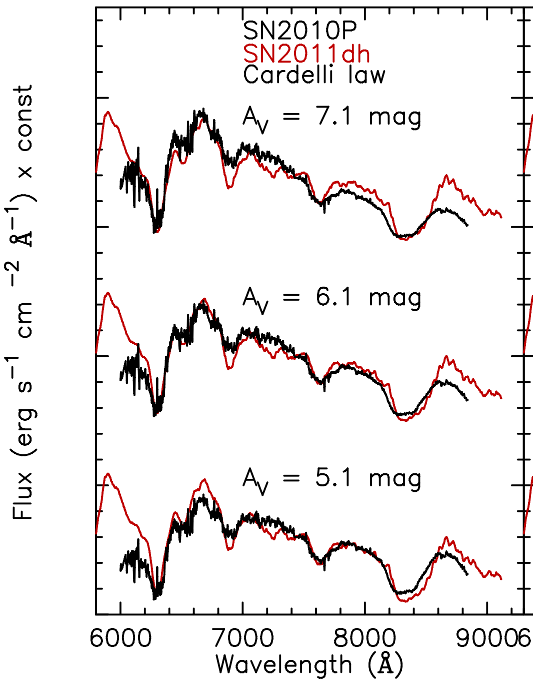


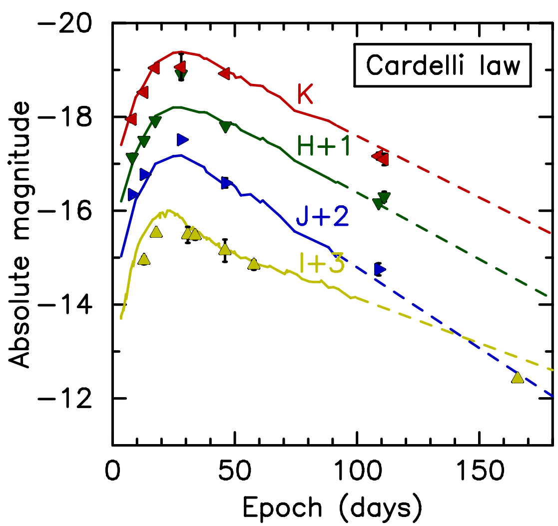
SN 2010O an amateur discovery, SN 2010P discovered in Ks-band with the Nordic Optical Telescope (NOT) at ~1” from the nucleus C'

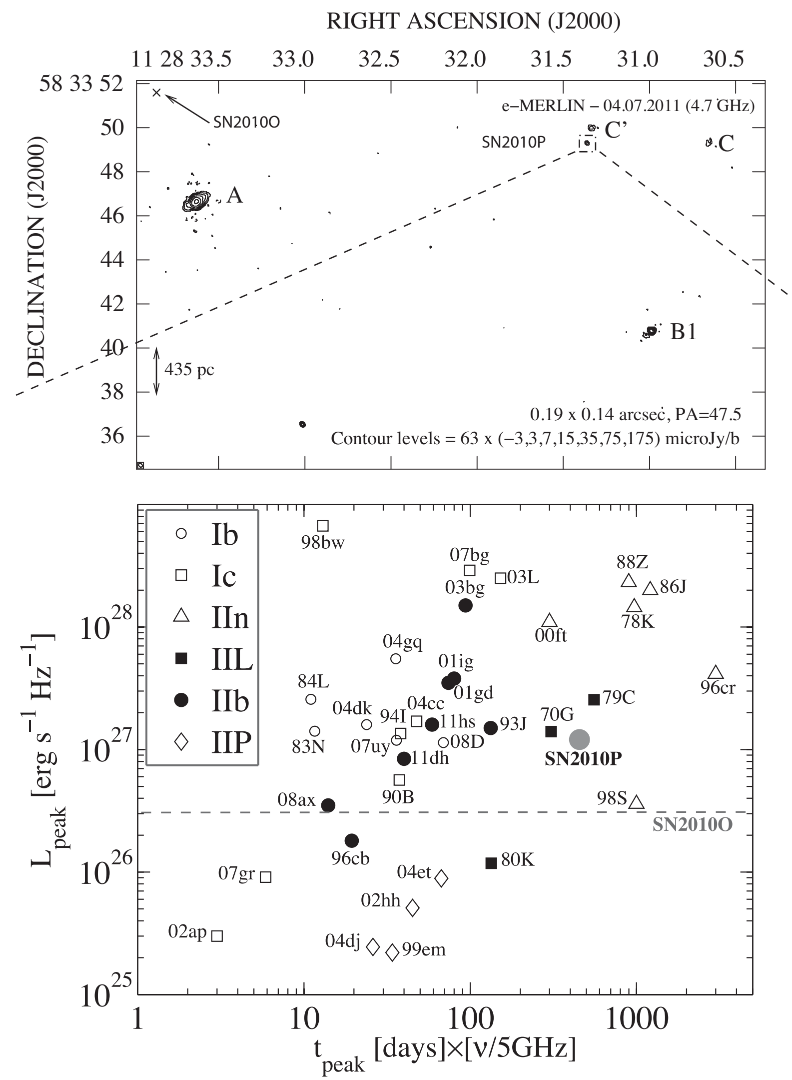
Kankare,SM+2014

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



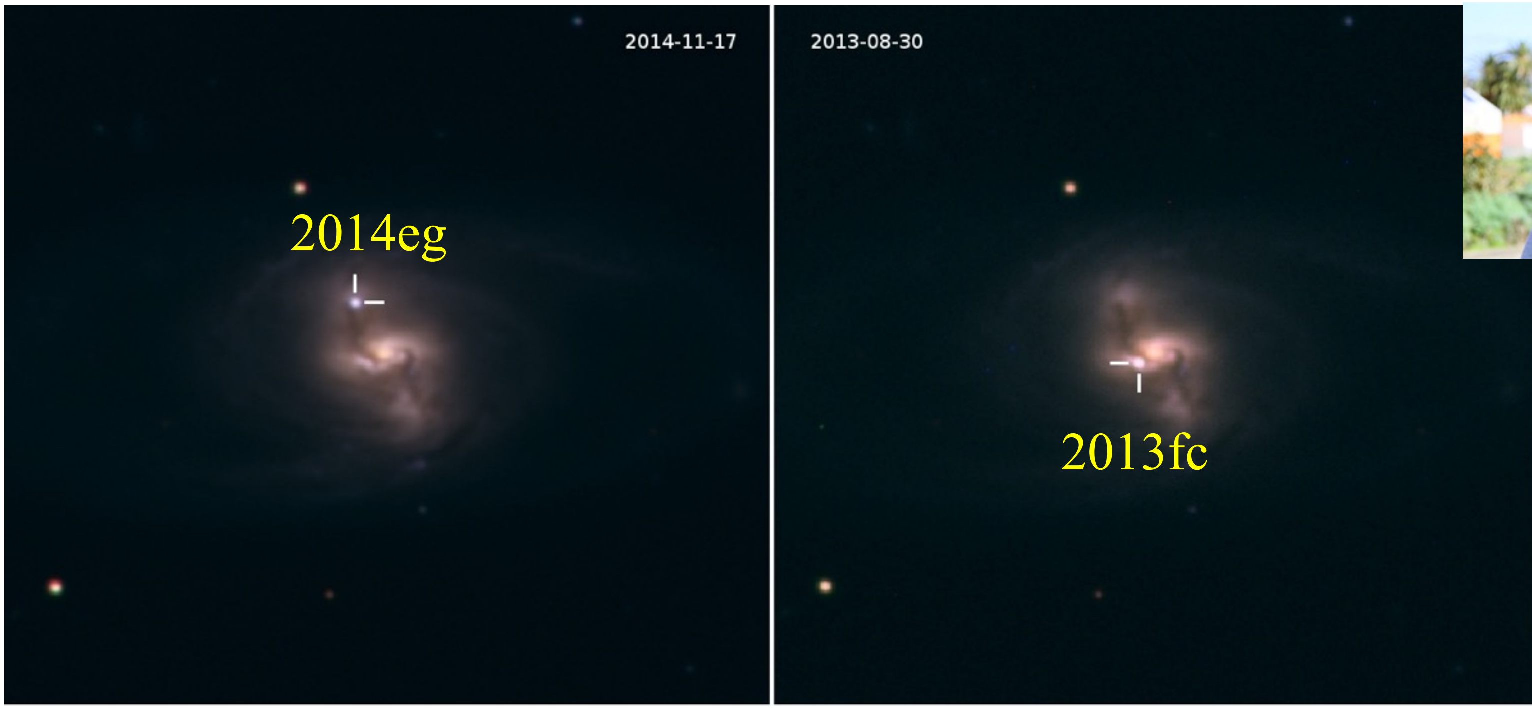




Kankare,SM+2014; Romero-Canizales+2014

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)



Kangas,SM+2015

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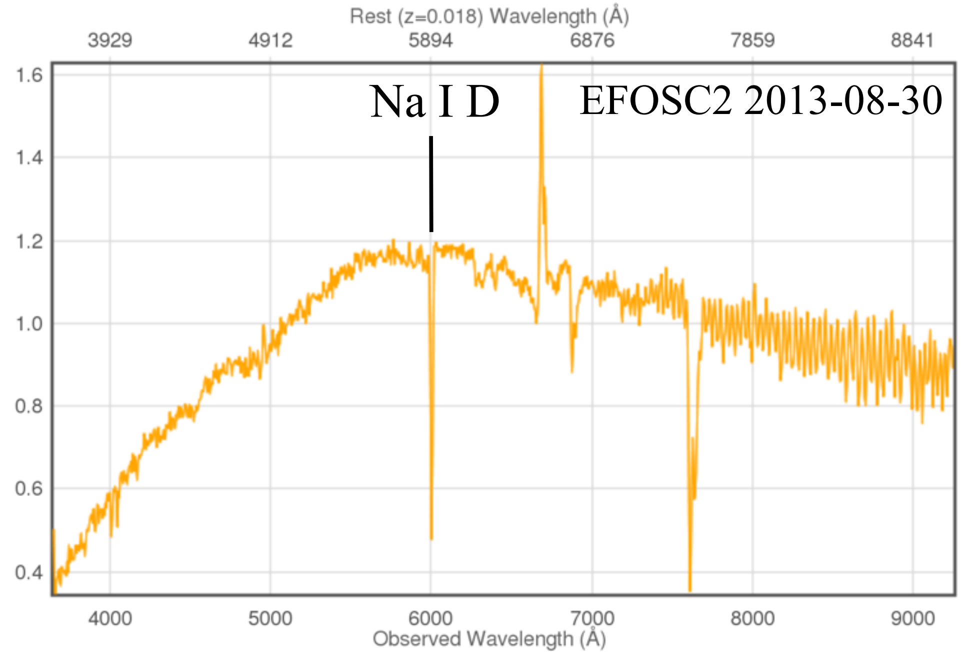

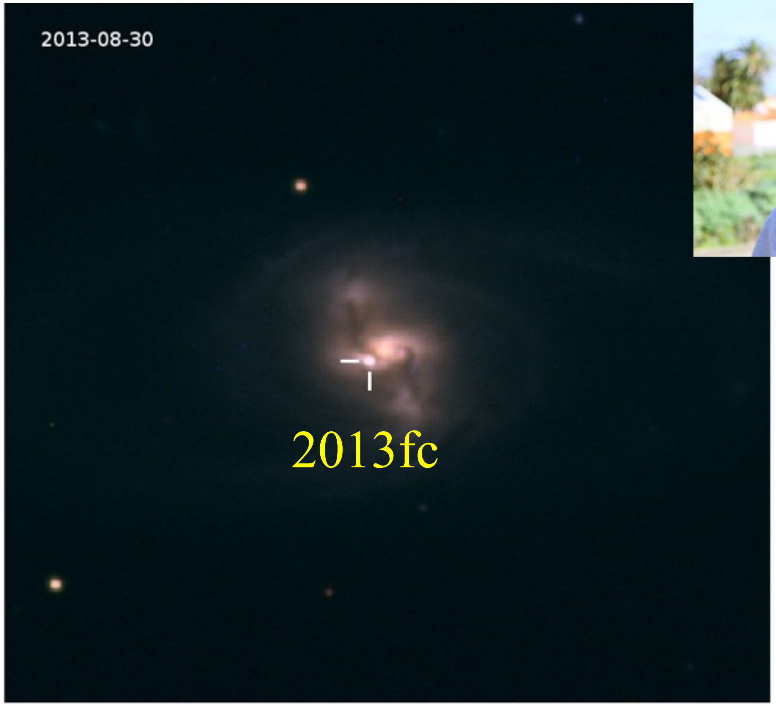

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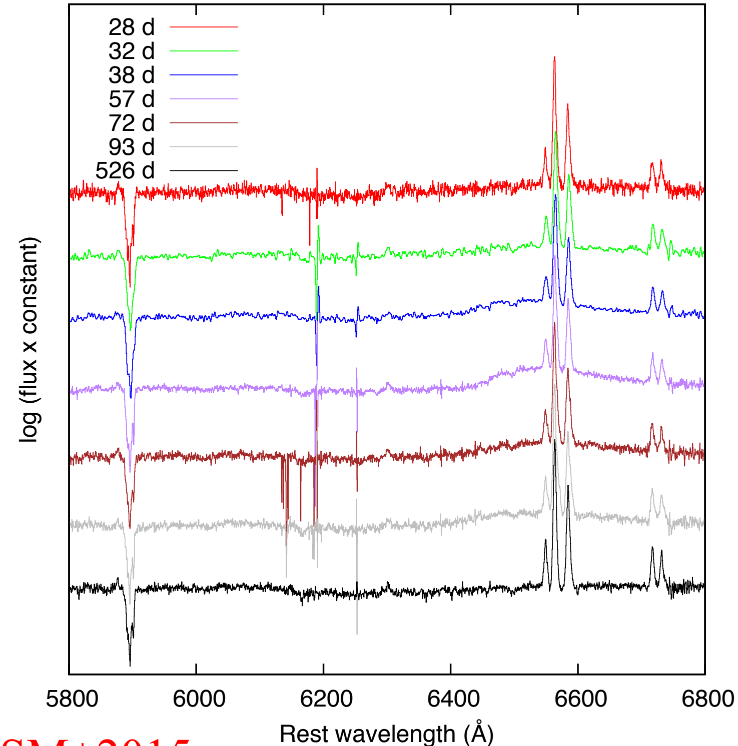

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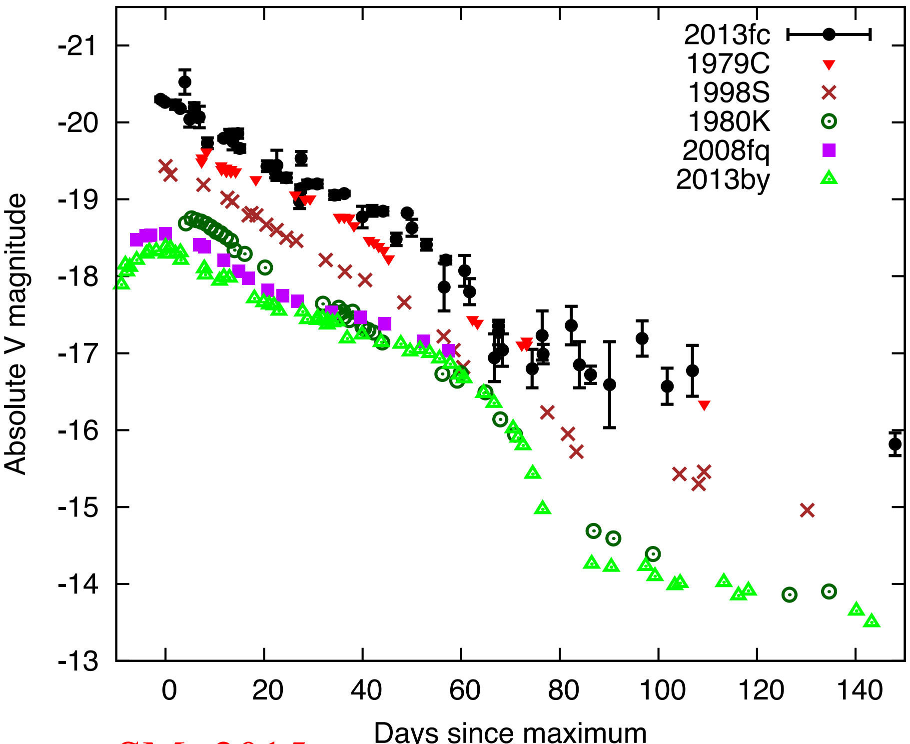
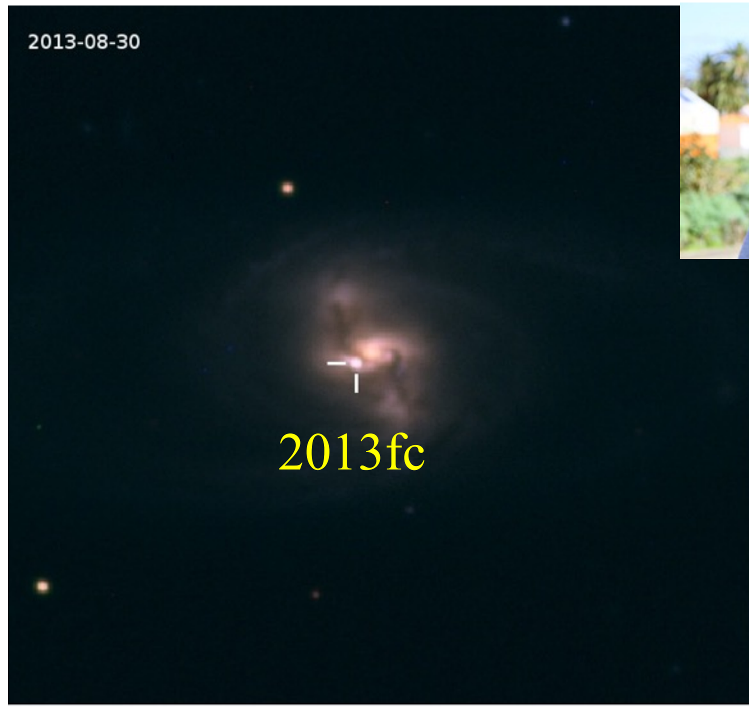
- High res. spectra reveal the origin of the narrow lines in the host galaxy
- Photometrically and spectroscopically similar to SN 1998S (IIn) and 1979C (II-L)





Kangas,SM+2015

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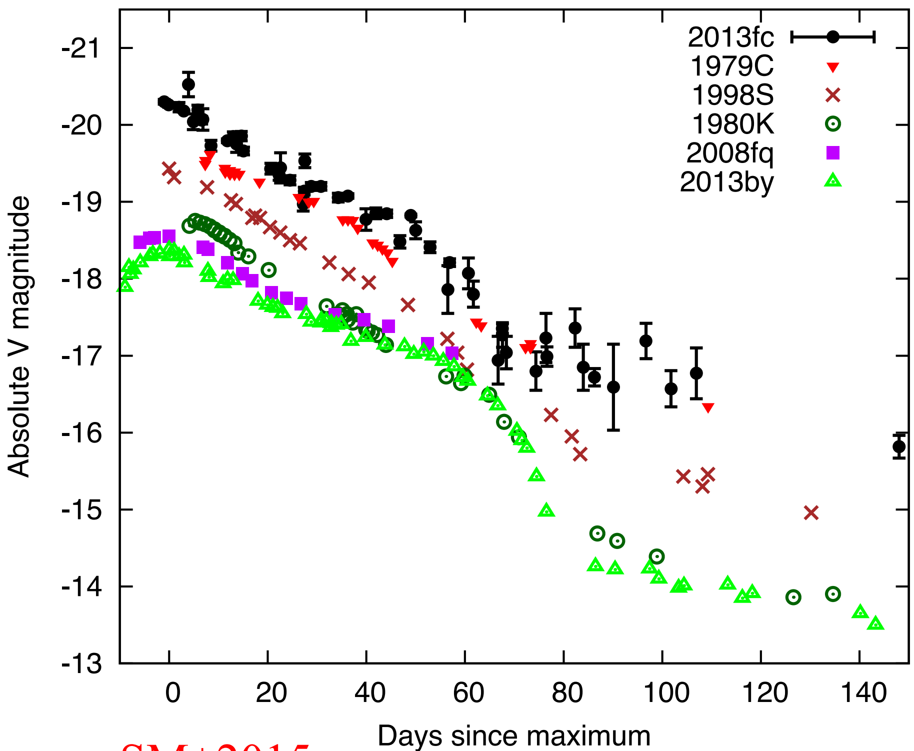
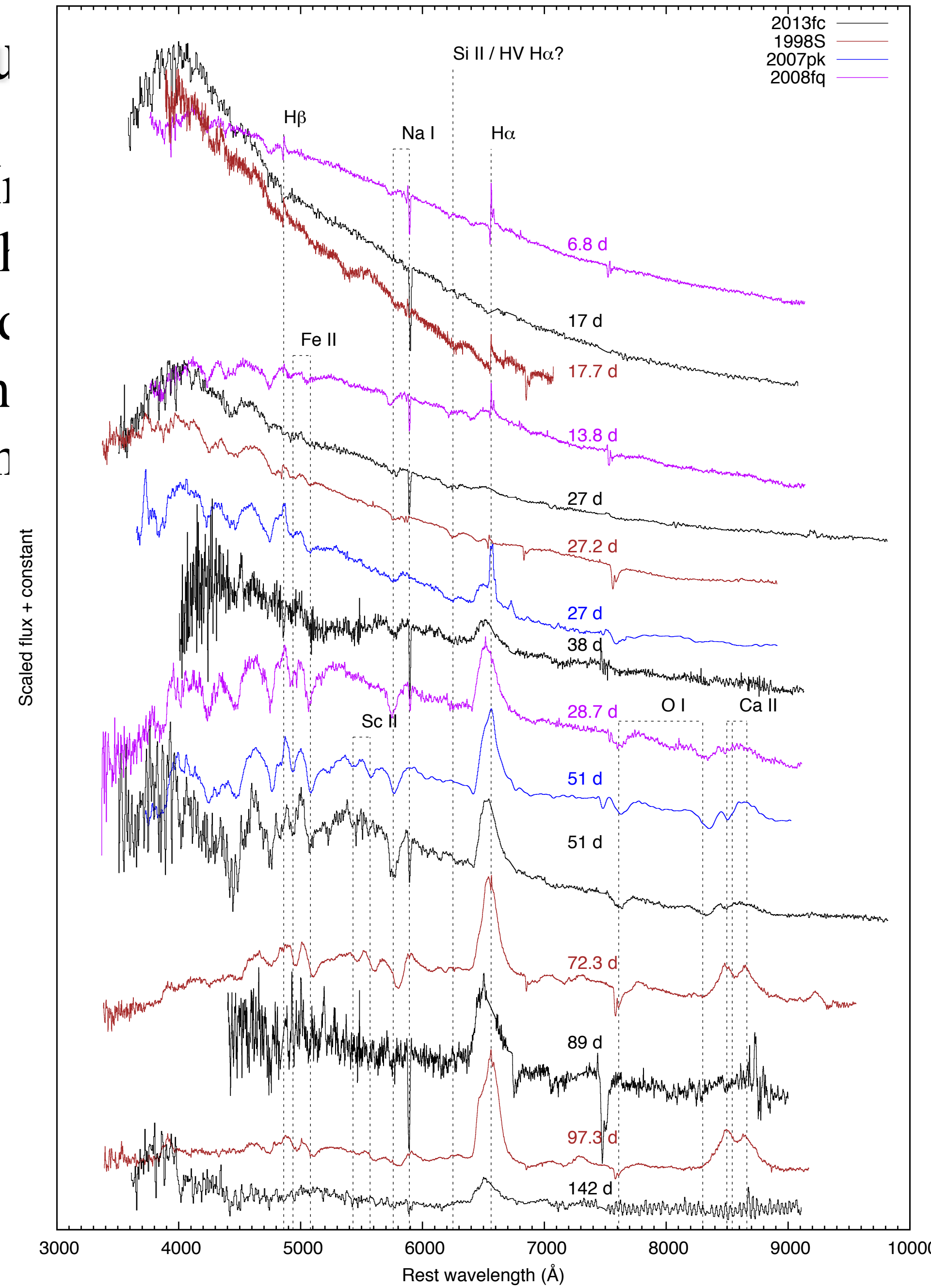


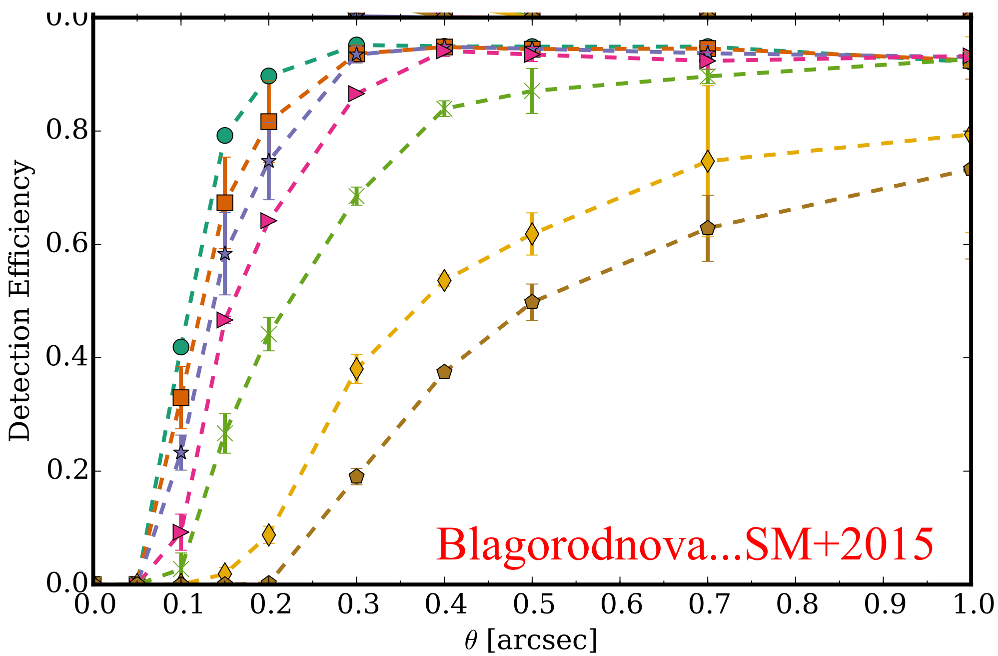


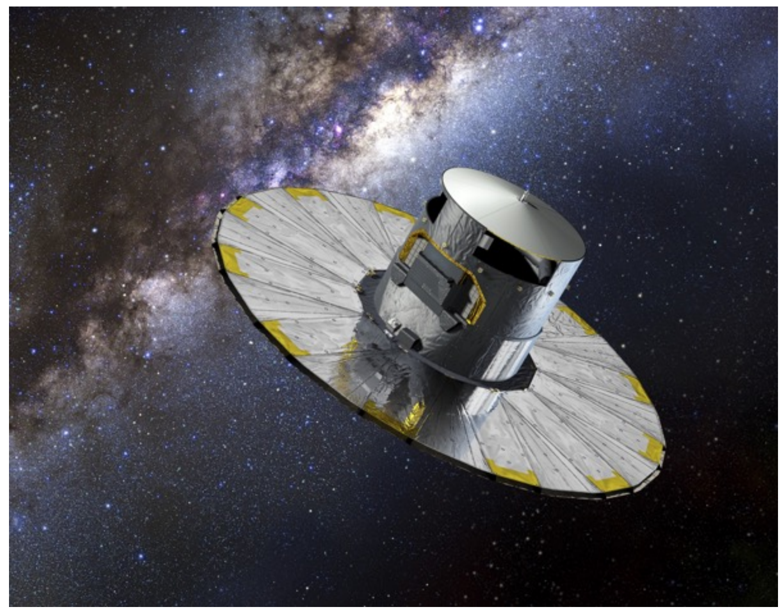
Kangas,SM+2015

Nuclear supernovae with Gaia

Detection and study of nuclear SNe with Gaia

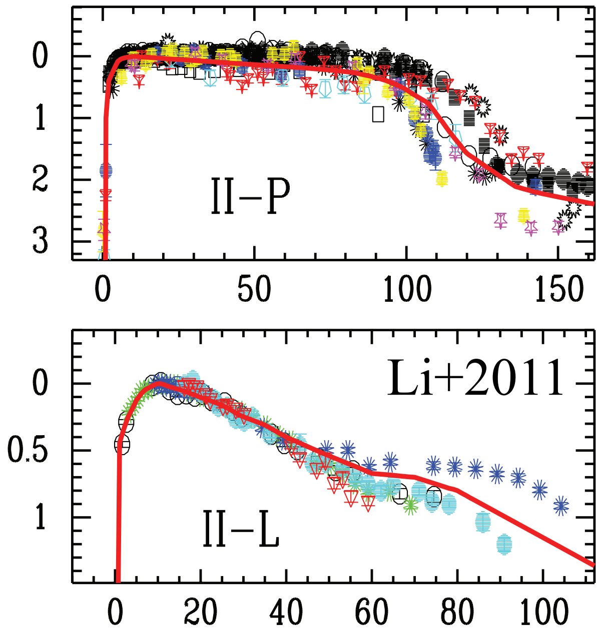
- Gaia able to produce SN detections also within the nuclear regions of galaxies
- Can identify transients with 0.1-0.5 arcsec offset from the host galaxy nucleus
- Of the detected ~1300 SNe yr^{-1} ($m<19$) ~200 at nuclear offset <1 arcsec
- In normal galaxies expect the nuclear detections to be dominated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

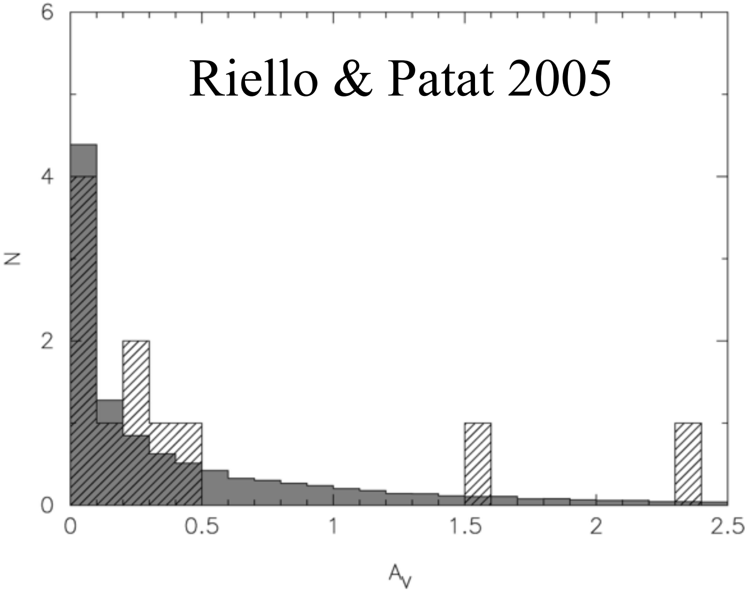


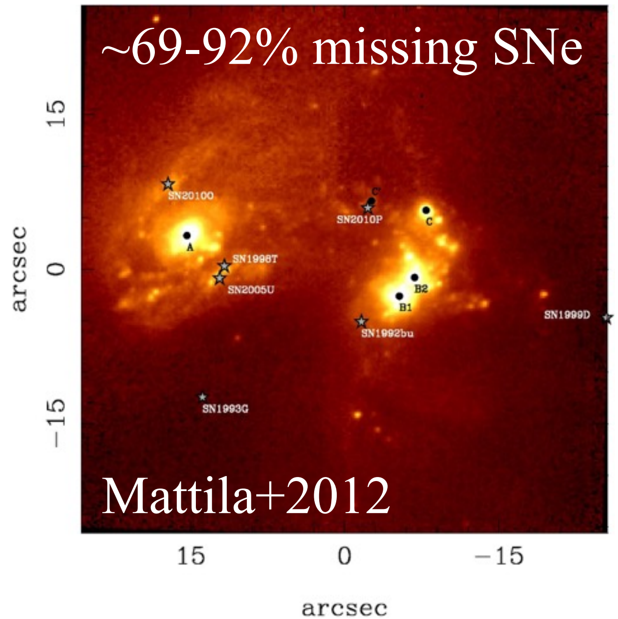


Detection of nuclear SNe in LIRGs

- 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**

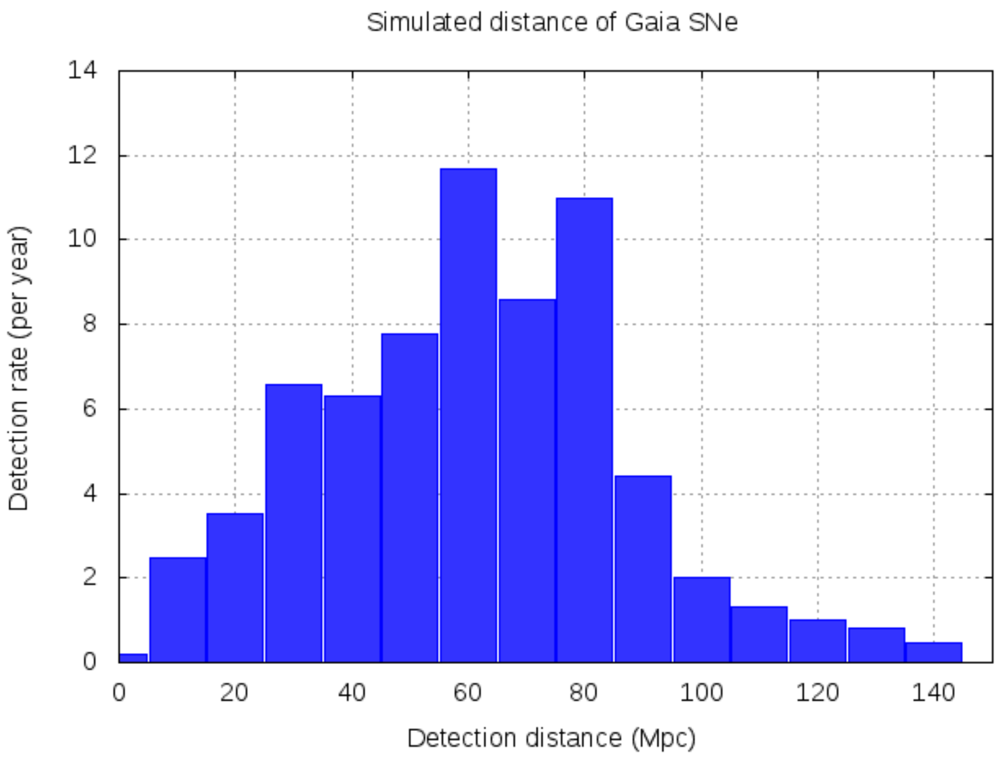


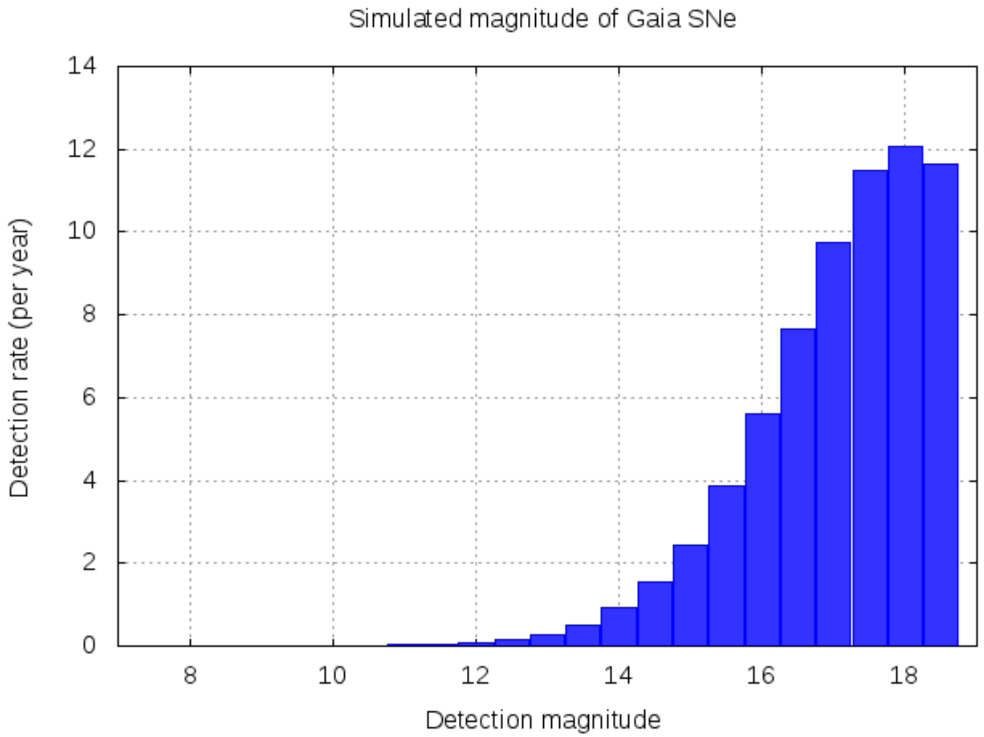




Detection of nuclear SNe in LIRGs

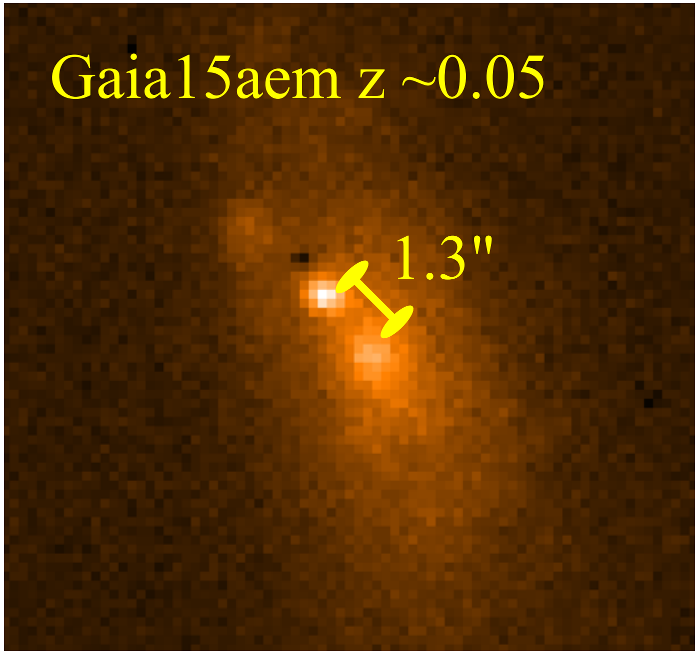
- MC simulations by Thomas Reynolds (PhD student, Turku):
  - Expected *intrinsic* number of CCSNe **~150 SNe yr^{-1}**
  - Can detect **240 SNe over 3 yrs** if no SNe missed in nuclear regions
  - Detect **~20-80 SNe over 3 yrs** if similar missing fraction as found in Arp 299

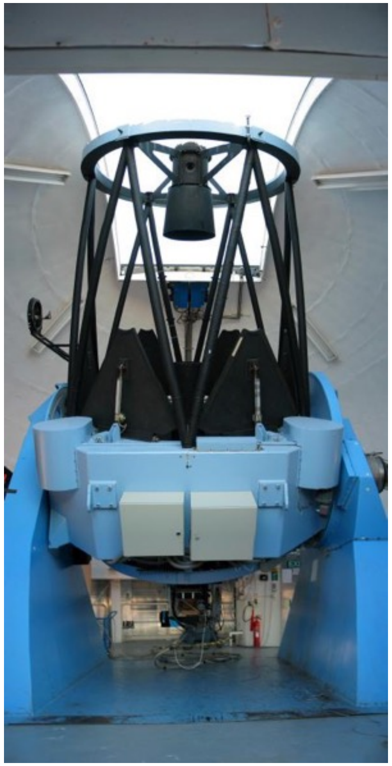




Follow-up spectroscopy for nuclear transients

- 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 !!





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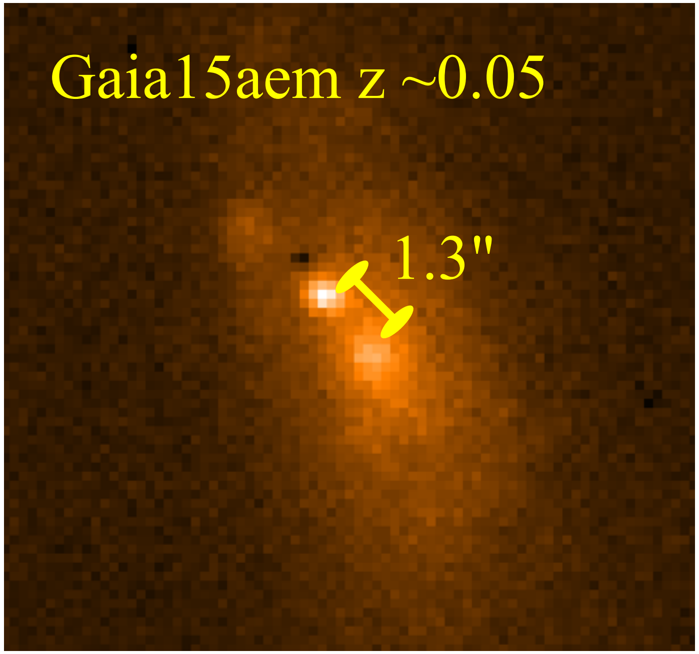
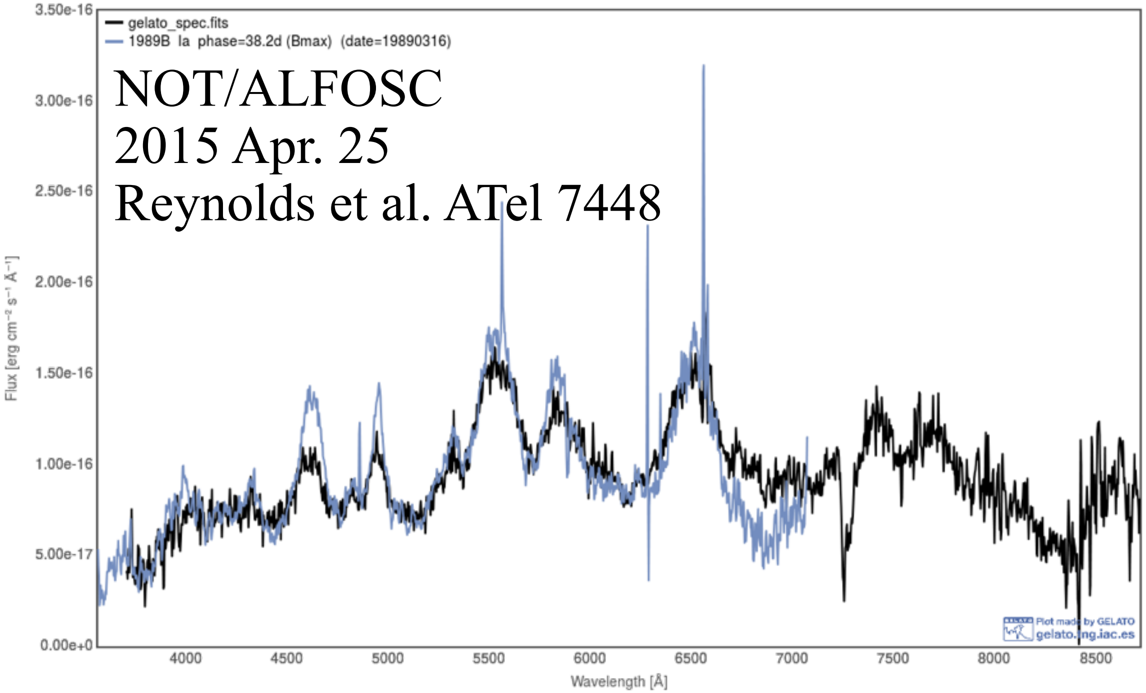
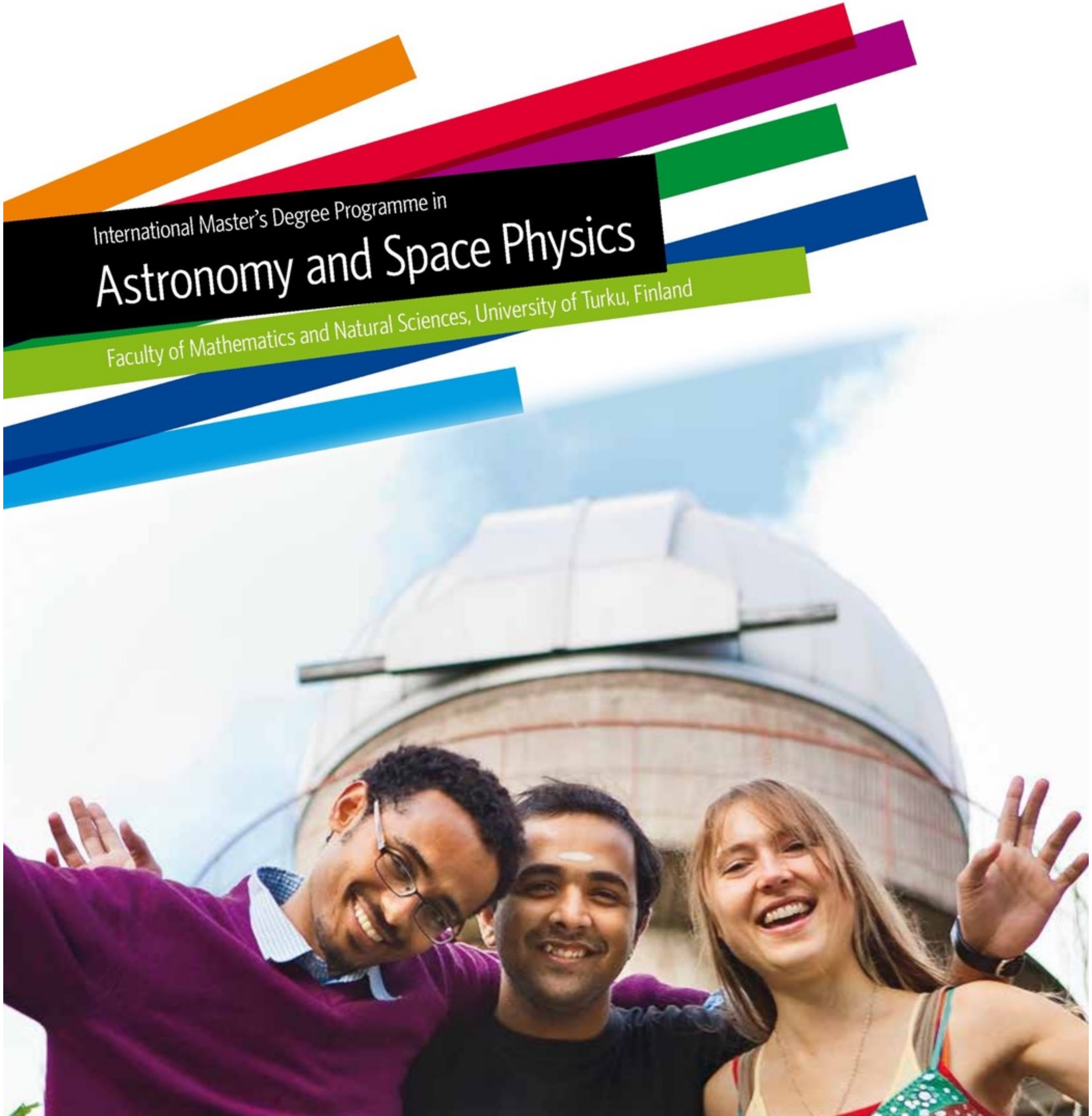




Summary

- 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



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