UH88/SNIFS and Gemini/GMOS IFU spectroscopy of nearby core-collapse supernova sites

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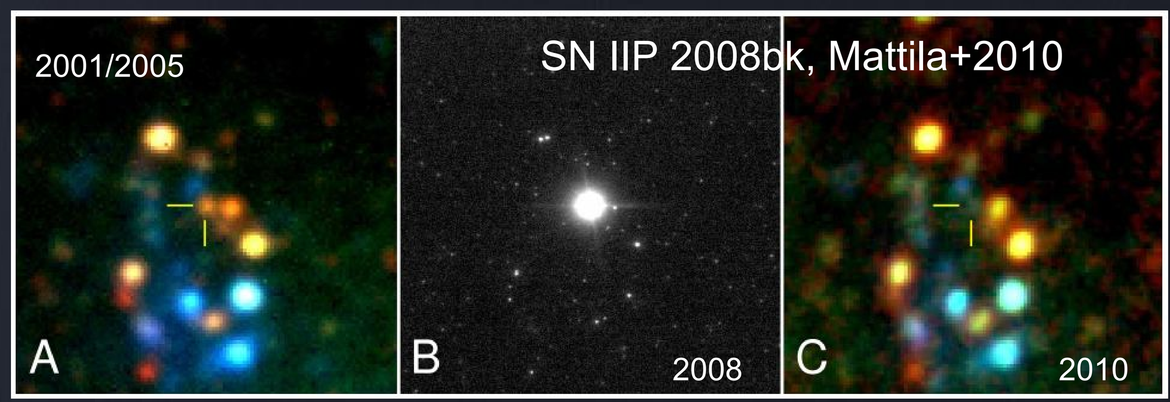
We present the results of our integral field spectroscopic study of 27 nearby type Ic/Ib/II-L/II-P supernova explosion sites done with UH88/SNIFS and Gemini/GMOS, provided via NAOJ and Subaru. Employing the technique of IFS enables us to observe the stellar populations present at the explosion site spatially and spectrally. The physical properties of the parent stellar population of the SN progenitor such as age and metallicity were derived from its spectrum, which in turn give age and metallicity estimate of the coeval SN progenitor. With this method we were able to constrain the metallicity and initial mass of the SN progenitors and compare it to theoretical predictions. We found indications that both single massive progenitor and binary sub-WR progenitor channels may be at play in producing SNe Ib/c, and some of the type II SN progenitors may have been as massive as Ib/c progenitors.

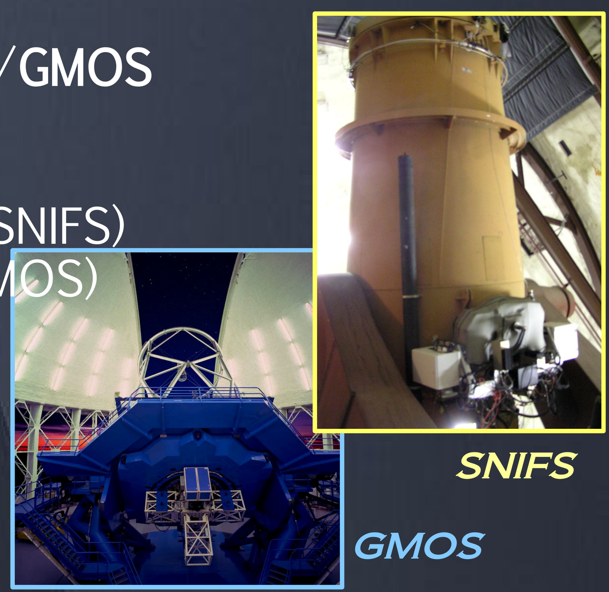
Hunting down the progenitors of CCSNe

- *What kind of massive star explodes as a particular type of SN?*
- Mass & metallicity: two of the most important parameters in progenitor star evolution
- It is still necessary to confront model predictions with more observational data
- From direct detection (and nondetection) → SN II-P progenitors are RSG stars of ~8-17 $M_\odot$ (Smartt+09); few II-L/IIb/IIn progenitor detections up to now
- No Ib/c progenitor detection so far ... are they really WR stars >25 $M_\odot$? Or lower-mass binaries?
- Direct detection: powerful but difficult to increase statistics → alternative strategy: study the immediate SN environment & parent stellar population



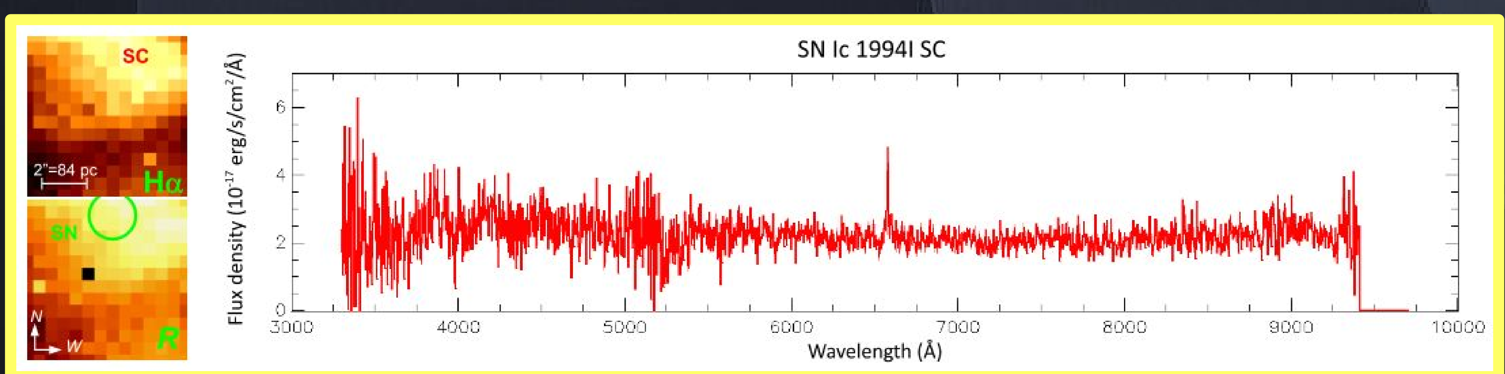
IFU spectroscopy of nearby SN sites

- Observations using 2.2m UH88/**SNIFS** and 8.1m Gemini/**GMOS** at Mauna Kea in 2010-2011
- Coverage:
  330-970 nm @ R~1000, 6.4"x6.4" FoV @ 0.4"/spaxel (SNIFS)
  400-680 nm @ R~1700, 5"x3.5" FoV @ 0.2"/spaxel (GMOS)
- Data reduction & analysis using IRAF
- With integral field spectroscopy: probing the immediate SN environment spatially and spectrally
- Minimizing contamination & proxy usage, as opposed to conventional slit spectroscopy

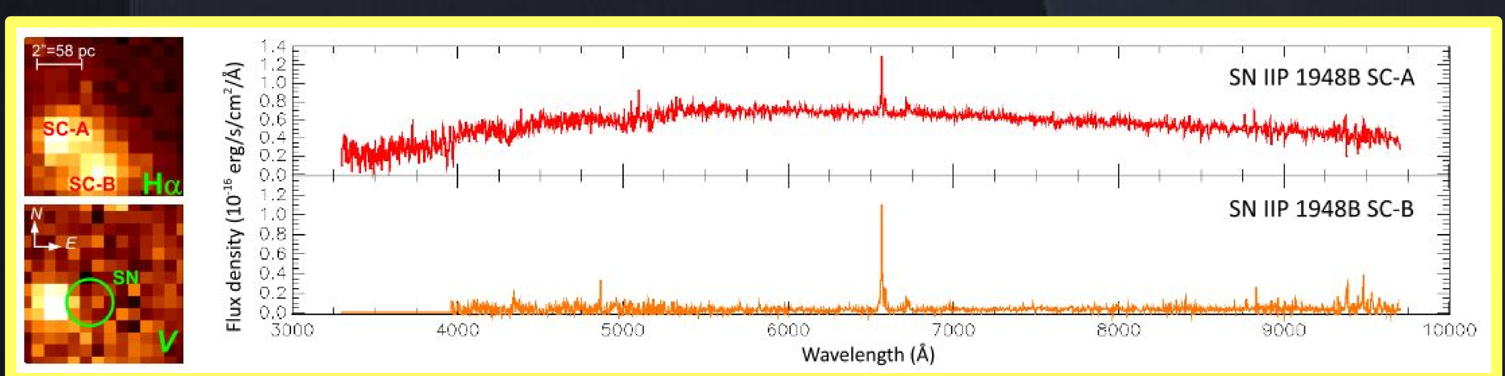


- Using IFS, we detect SN progenitor parent stellar population
- Extract the spectrum of the parent population from IFU datacube
- Compare parent population spectrum with SSP models (Starburst99; Leitherer+99) → age from age indicators such as Hα / CaT equivalent widths
- Metallicity is derived by strong-line method (Pettini & Pagel 2004)
- Derive SN progenitor age & metallicity from the parent population
- Progenitor star age (lifetime) → initial (ZAMS) mass via Padova stellar evolution models (Bressan+93)

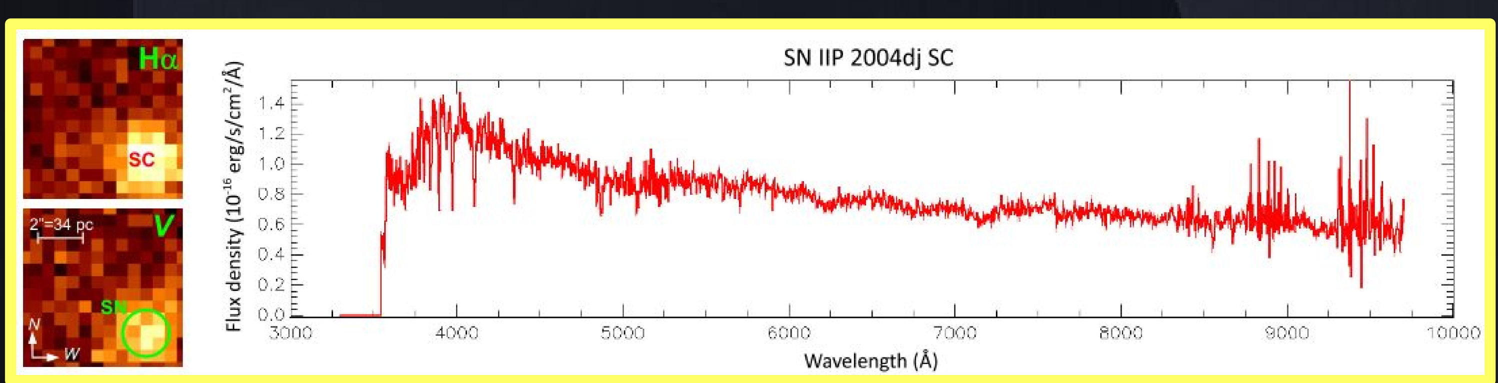
Looking into the explosion sites, spatially & spectrally



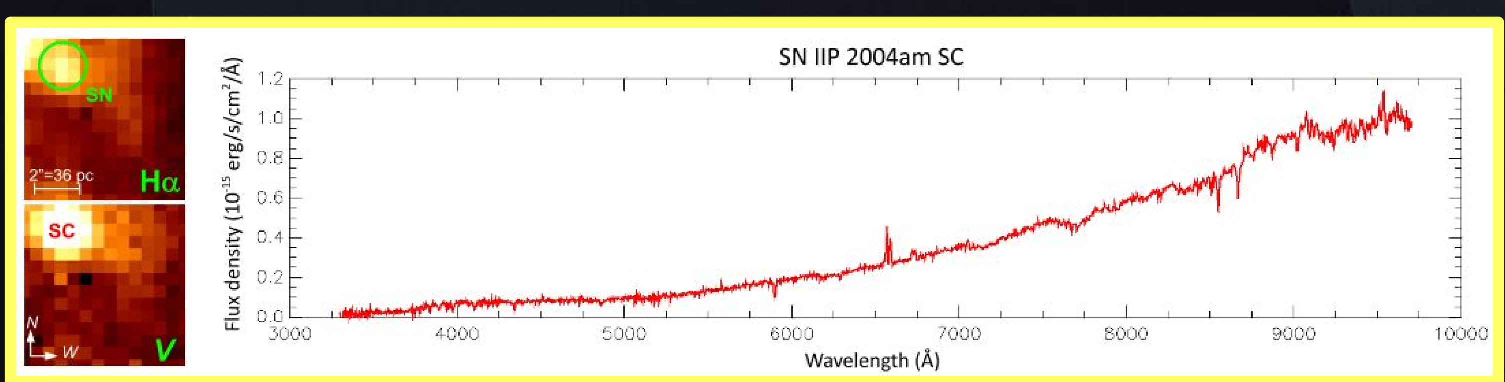
SC: 11.0 Myr, 0.83 $Z_\odot$: → 17.9 $M_\odot$ progenitor — Nomoto+94: 15 $M_\odot$ binary progenitor



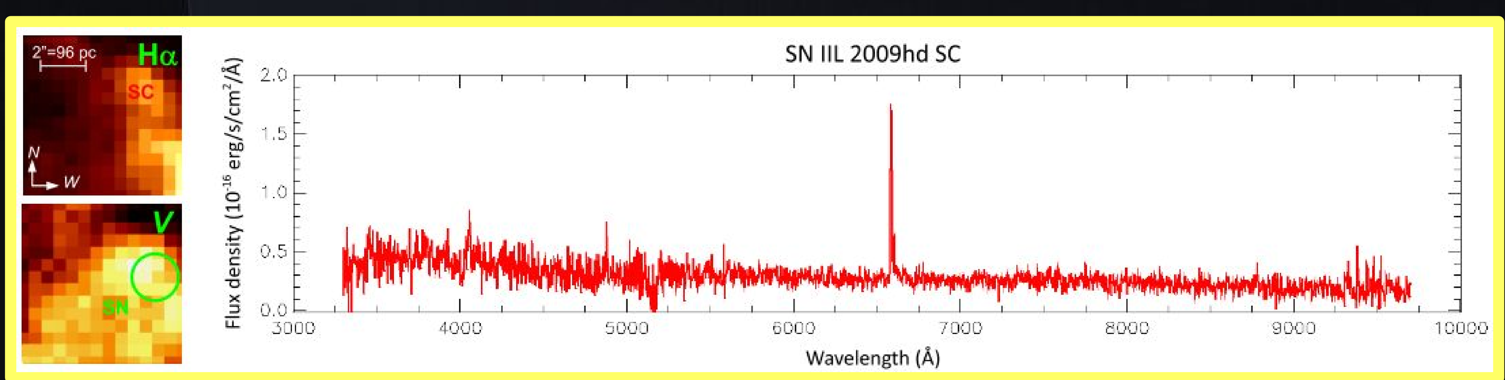
SC-A: 13.4 Myr, 0.83 $Z_\odot$: → 14.9 $M_\odot$ progenitor



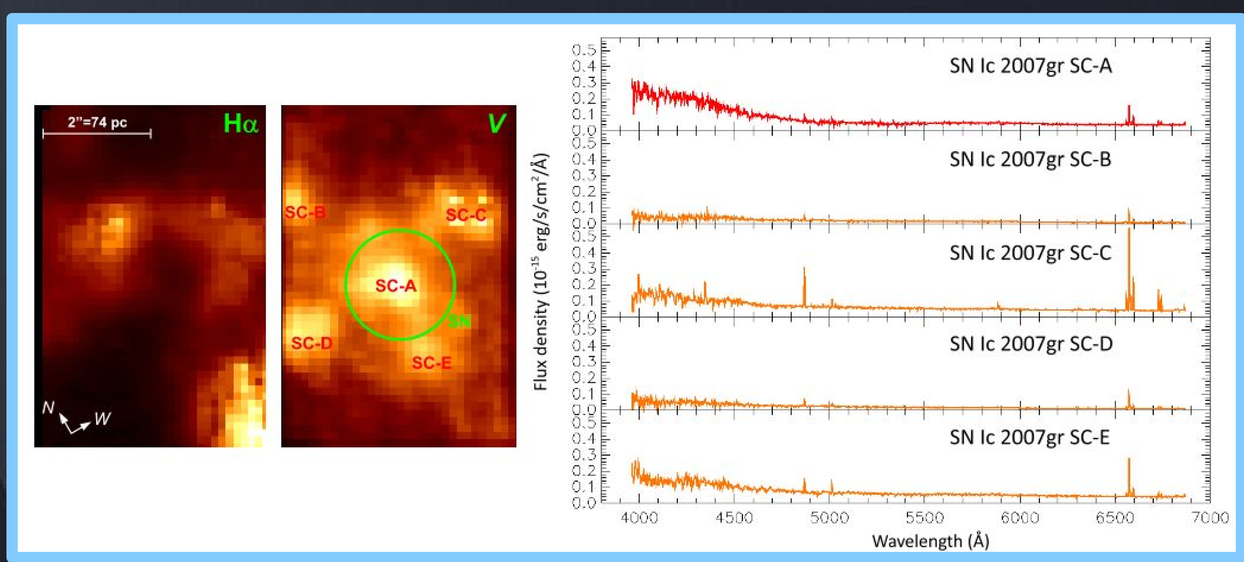
SC: 15.6 Myr, 0.33 $Z_\odot$: → 14.7 $M_\odot$ progenitor — SC age: 10-16 Myr (Vinko+09), 20 Myr (Wang+05), 13.6 Myr (Maiz-Apellanis+04)



SC: 12.8 Myr, 1.35 $Z_\odot$: → 15.8 $M_\odot$ progenitor — SC age: 10-35 Myr (Lancon+08), 30-135 Myr (Smith+06)



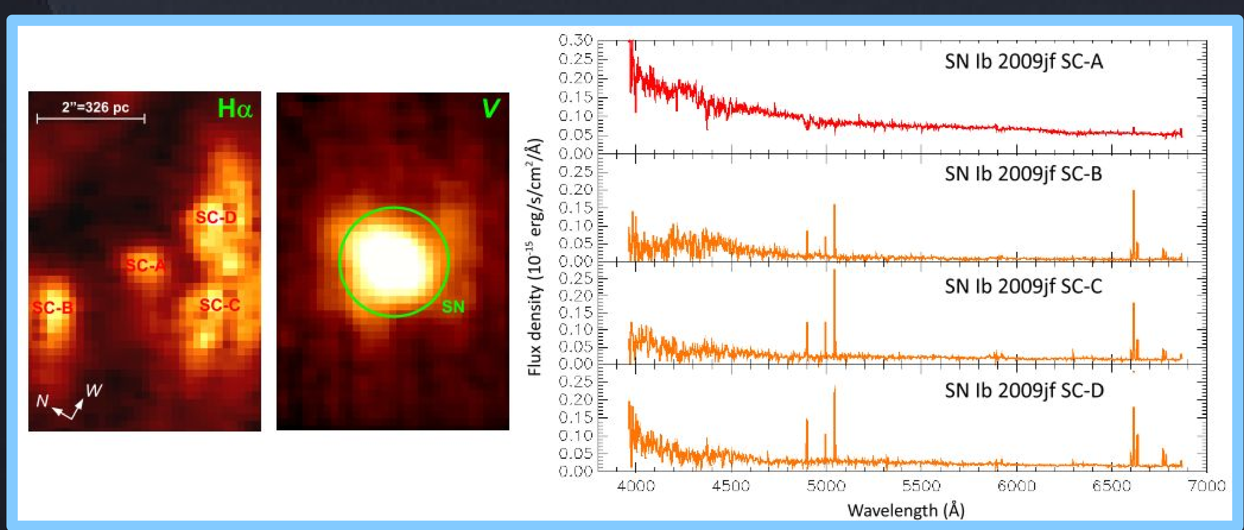
SC: 6.4 Myr, 0.98 $Z_\odot$: → 29.3 $M_\odot$ progenitor — ≲20 $M_\odot$ progenitor (Elias-Rosa+11)



SC-A: 7.8 Myr, 1.12 $Z_\odot$ → 24.4 $M_\odot$
SC-B: 6.7 Myr, 1.35 $Z_\odot$ → 28.3 $M_\odot$
SC-C: 6.4 Myr, 1.20 $Z_\odot$ → 29.3 $M_\odot$
SC-D: 6.4 Myr, 1.35 $Z_\odot$ → 29.1 $M_\odot$
SC-E: 6.8 Myr, 0.85 $Z_\odot$ → 27.9 $M_\odot$

SN 2007gr progenitor @SC-A: 24.4 $M_\odot$

Cluster age: 7 Myr (Crockett+08)
Site metallicity: 0.95 $Z_\odot$ (Modjaz+11)

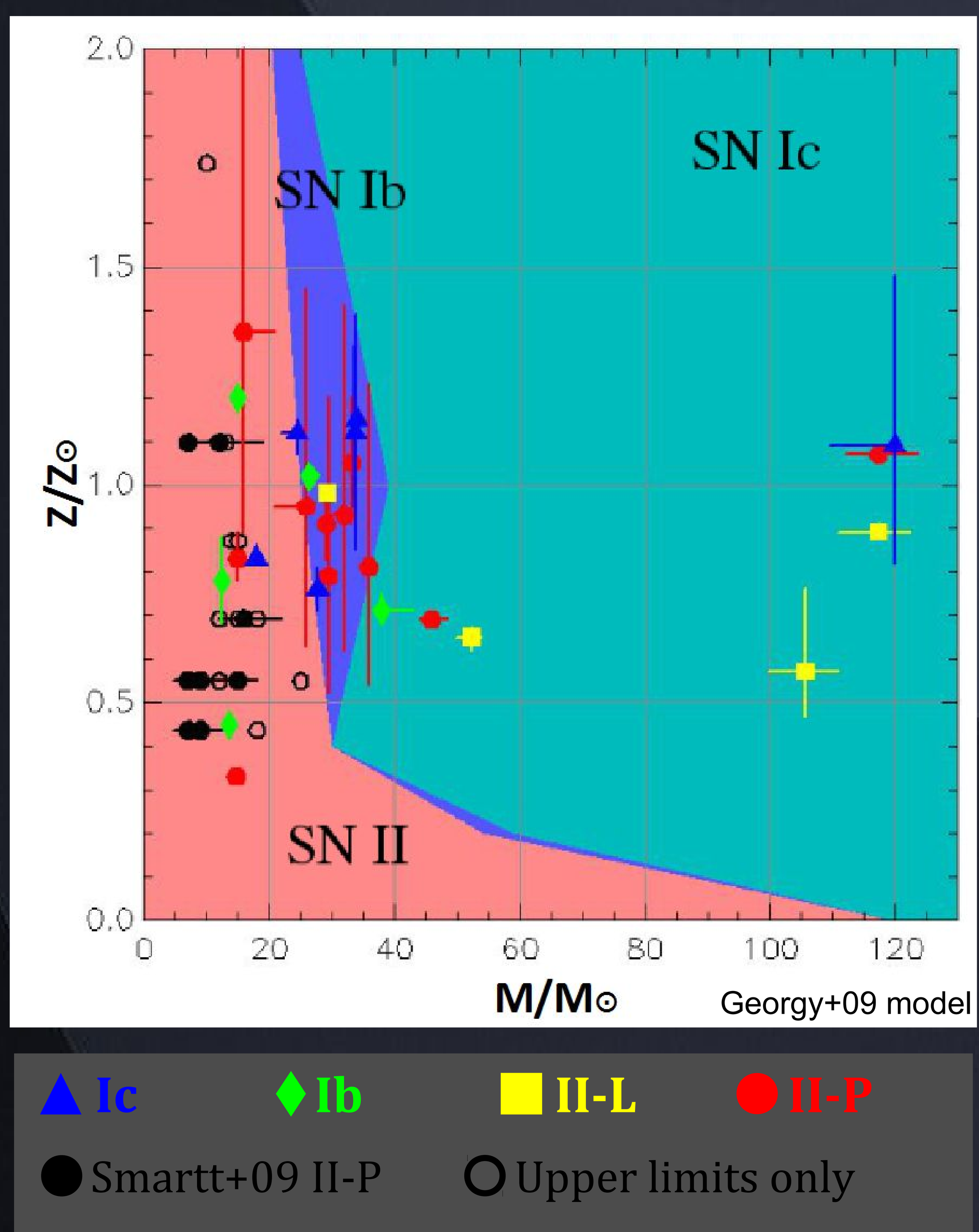


SC-A: 18.2 Myr, 0.78 $Z_\odot$ → 12.4 $M_\odot$
SC-B: 6.0 Myr, 0.66 $Z_\odot$ → 34.7 $M_\odot$
SC-C: 6.4 Myr, 0.63 $Z_\odot$ → 32.2 $M_\odot$
SC-D: 6.3 Myr, 0.81 $Z_\odot$ → 29.7 $M_\odot$

SN 2009jf progenitor @SC-A: 12.4 $M_\odot$

Valenti+09: 25-30 $M_\odot$ progenitor (from SN properties), 8-25 $M_\odot$ (from environment color)

Mass & metallicity of SN progenitors



- On average, SN Ic progenitors are more massive and metal rich than Ib
- Binary (sub-WR mass) progenitors are prevalent in SN Ib/c, in addition to massive (>25 $M_\odot$) single progenitors (similar to the conclusion of Leloudas+11), and possibly more frequent in SN Ib
- Some SN II progenitors may be as massive as single SN Ib/c progenitors, as we estimated that 50% of the sample are possibly contaminants (SN-cluster chance superpositions)

→ Kuncarayakti+13, AJ in press (arXiv 1305.1105, 1306.2106)

References: Bressan et al. 1993. A&AS 100, 647; Crockett et al. 2008. ApJ 672, 99; Elias-Rosa et al. 2011. ApJ 742, 6; Georgy et al. 2009. A&A 502, 611; Lancon et al. 2008. A&A 486, 165; Leitherer et al. 1999. ApJS 123, 3; Leloudas et al. 2011. A&A 530, 95; Maiz-Apellaniz, et al. 2004. ApJ 615, 113; Mattila et al. 2010. arXiv1011.5494; Modjaz et al. 2011. ApJ 731, 4; Pettini & Pagel. 2004. MNRAS 348, L59; Smartt et al. 2009. MNRAS 395, 1409; Smith et al. 2006. MNRAS 370, 513; Valenti et al. 2011. MNRAS 416, 3138; Vinko et al. 2009. ApJ 695, 619; Wang et al. 2005. ApJ 626, 89;