Binary Companions to Stripped-Envelope Supernovae

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Stellar Thief Is the Surviving Companion to a Supernova

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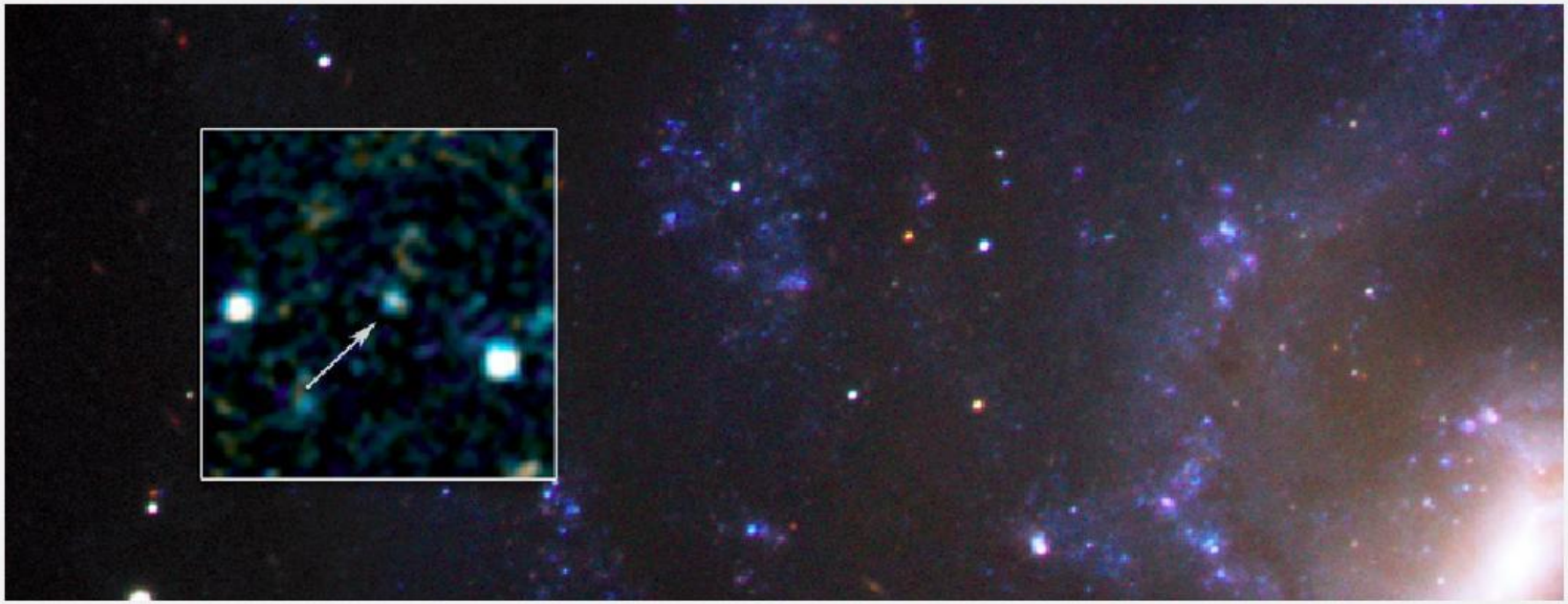


Companion to a supernova is no innocent bystander

In the fading afterglow of a supernova explosion, astronomers using NASA's Hubble Space Telescope have photographed the first image of a surviving companion to a supernova. This is the most compelling evidence that some supernovas originate in double-star systems. The companion to supernova 2001ig's progenitor star was no innocent bystander to the explosion—it siphoned off almost all of the hydrogen

Stripped-envelope supernovae

- Type IIP/L → IIb → Ib → Ic = increase in stripping of H envelope?
- But SNe IIb are spectroscopically distinct from SNe Ib/c of similar age (Liu+ 2016).
- Stripping due to:
  - Stellar winds + eruptive mass-loss?
  - Interaction with a massive binary companion?
  - Combination of both?
- *"Massive stars like company"* – Hugues Sana.
- After explosion, surviving companion most likely to be unevolved, hot main sequence star ⇒ bright in UV.

Famous Type IIb SNe

- SN 1993J: progenitor = K supergiant 13–22 $M_\odot$ (Van Dyk+ 2002); companion = B supergiant (Maund+ 2004).
- SN 2008ax: progenitor = B/A supergiant 4–5 $M_\odot$ (Folatteli+ 2015).
- SN 2011dh: progenitor = YSG 10–19 $M_\odot$ (Van Dyk+ 2013); companion = ??? (Folatelli+ 2014; Maund+ 2015)
- SN 2013df: progenitor = YSG 13–17 $M_\odot$ (Van Dyk+ 2014).
- SN 2016gkg: progenitor = YSG 15–20 $M_\odot$ (Tartaglia+ 2017).

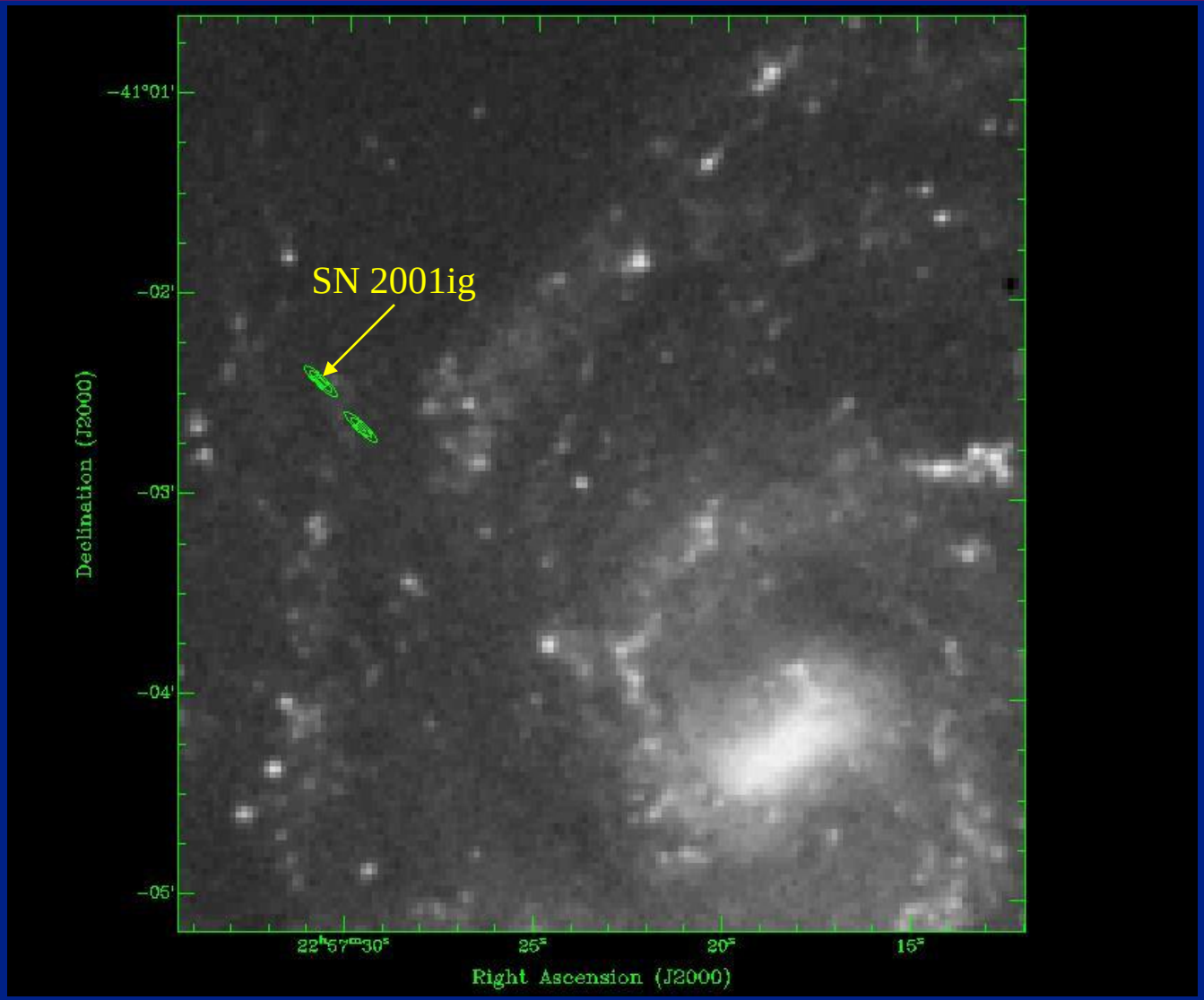
The Type IIb SN 2001ig

- Dec 10.43 2001 UT: discovery by Bob Evans in NGC 7424 (SAB(rs)cd, *D*=11.5 Mpc, δ= –41º).

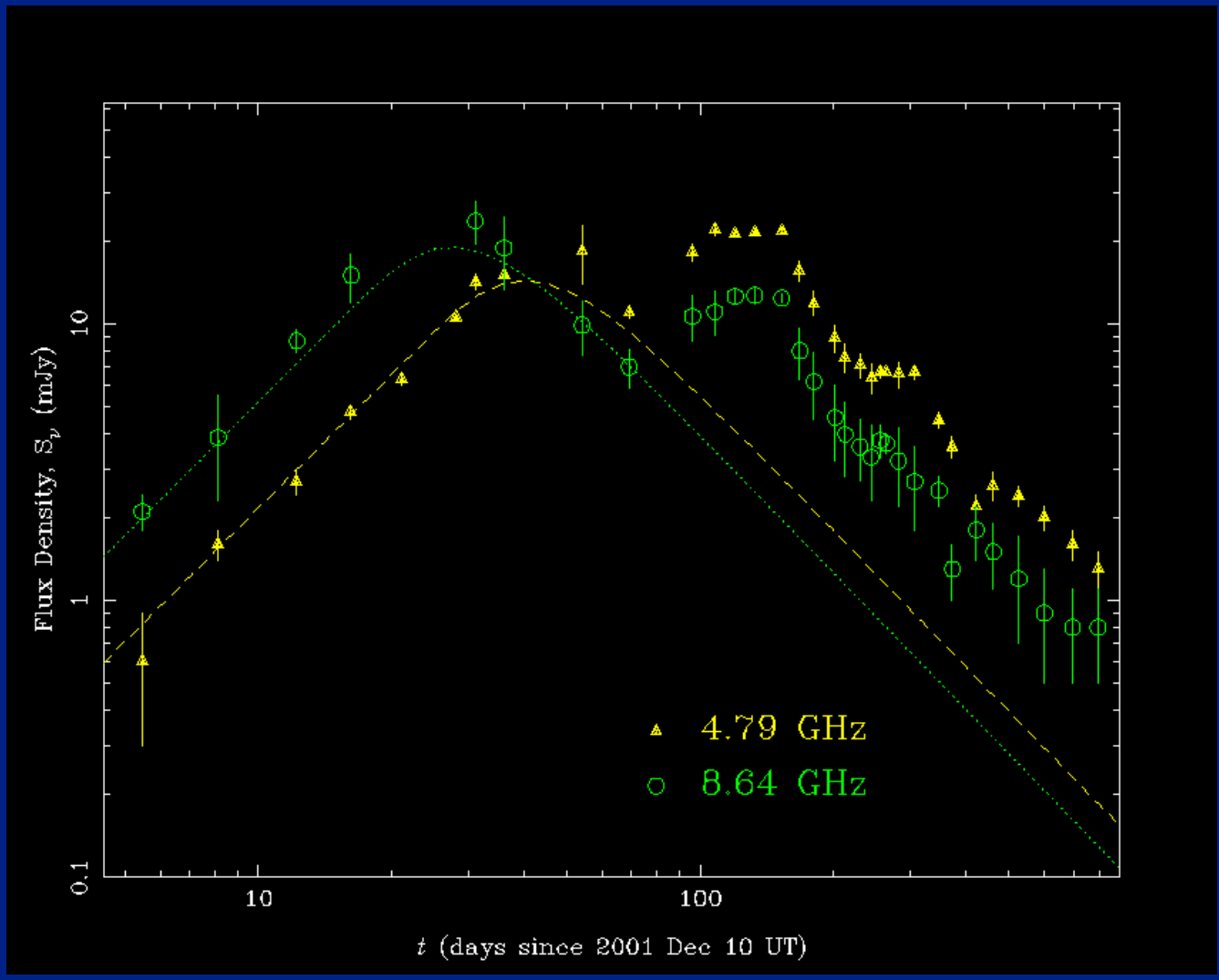
The Type IIb SN 2001ig

- Early spectroscopy (Magellan, NTT) suggested similarities with SN 1987K and SN 1993J (Type IIb).
- Dec 15 UT: Detected with ATCA at 8.6 GHz.
- May 2002: Detected with ACIS-S/*Chandra*.
- No optical light curve data.
- 12 optical spectra (Silverman+ 2009) + 3 epochs of spectropolarimetry (Maund+ 2007) in first year.
- Early HST UV spectra (Ben-Ami+ 2015) : Type Ia-like reverse fluorescence features $\Rightarrow$ high ^{56}Ni mass, compact progenitor.

Pre-explosion

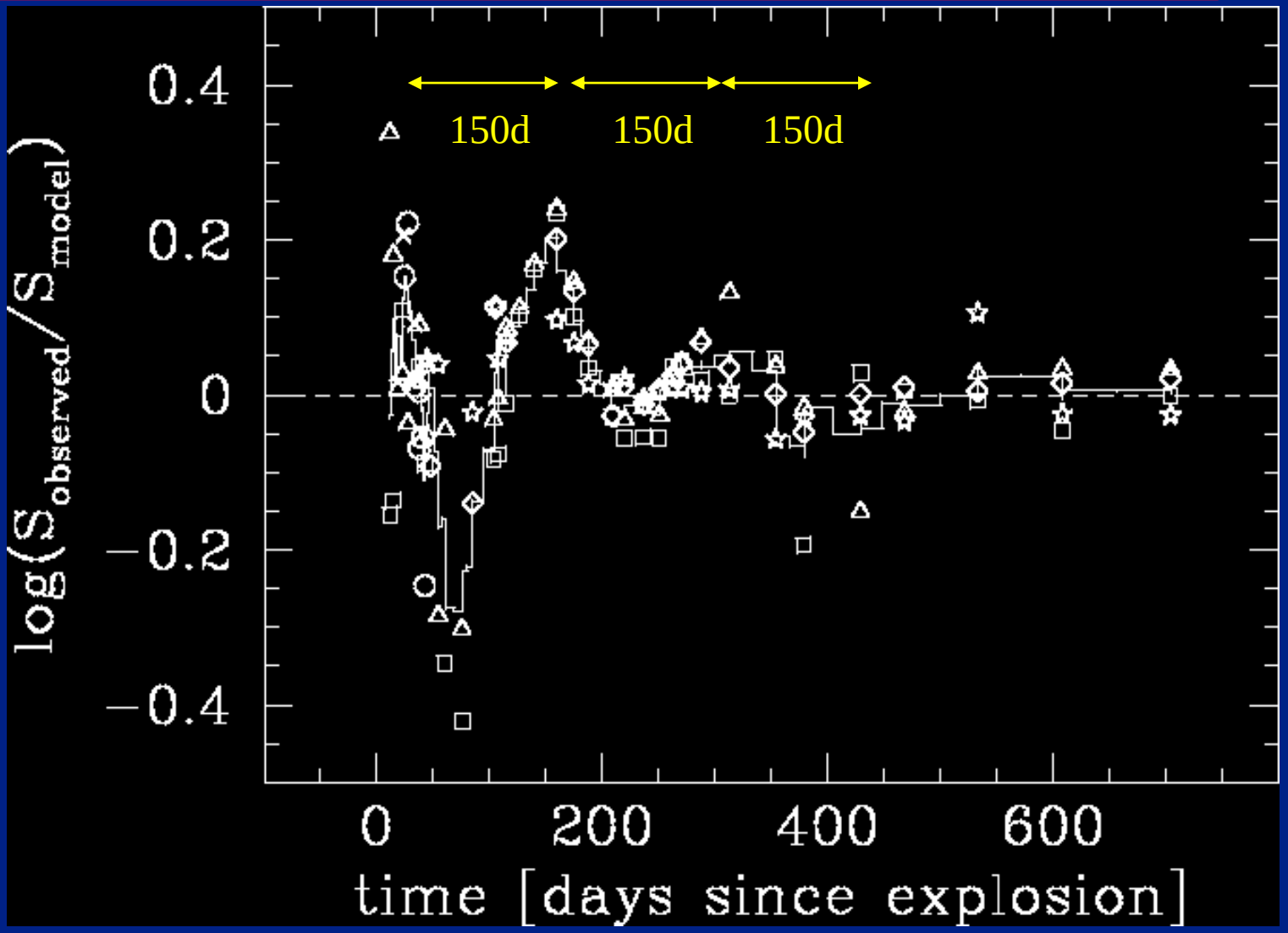


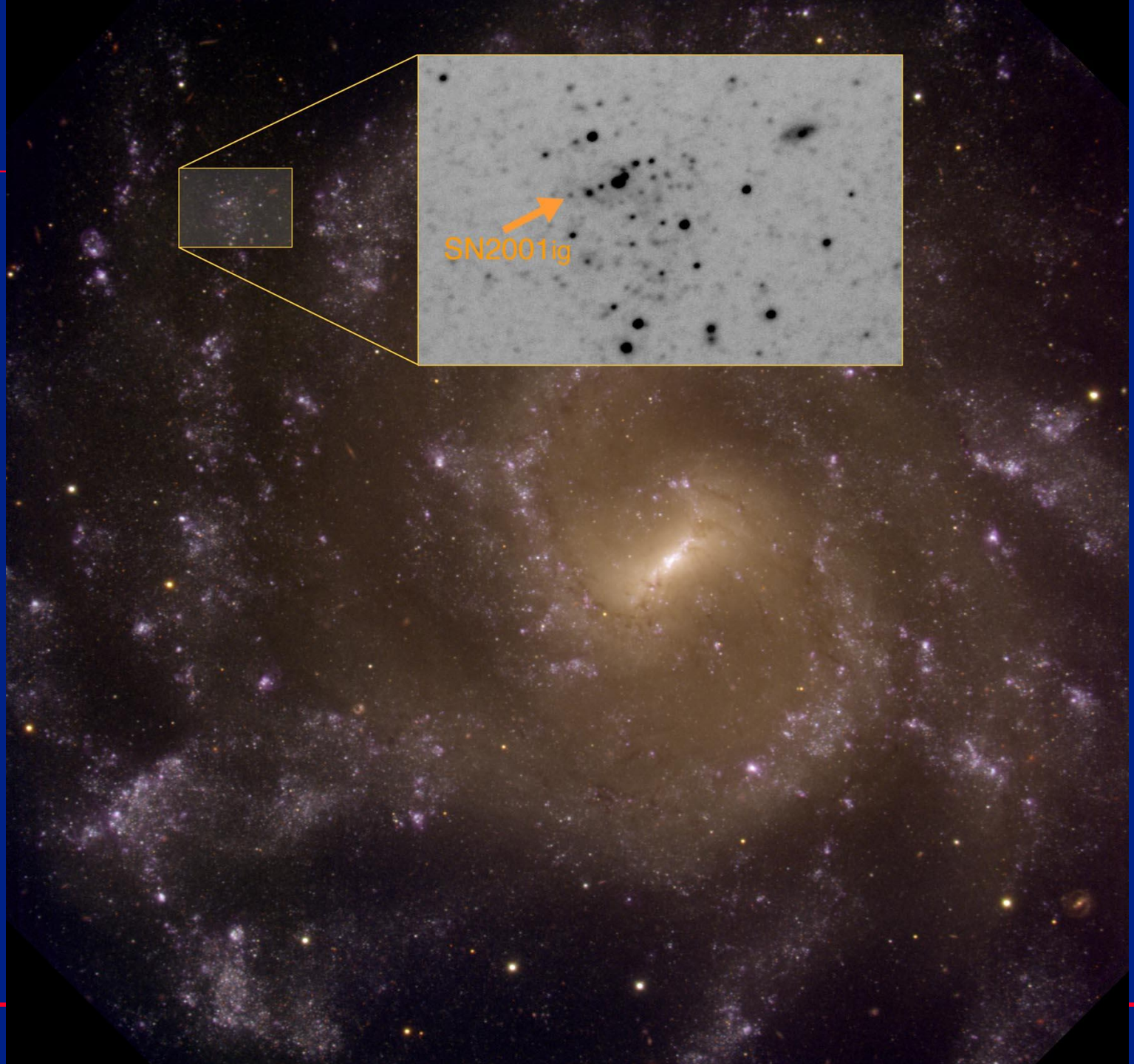
Radio “light curve”

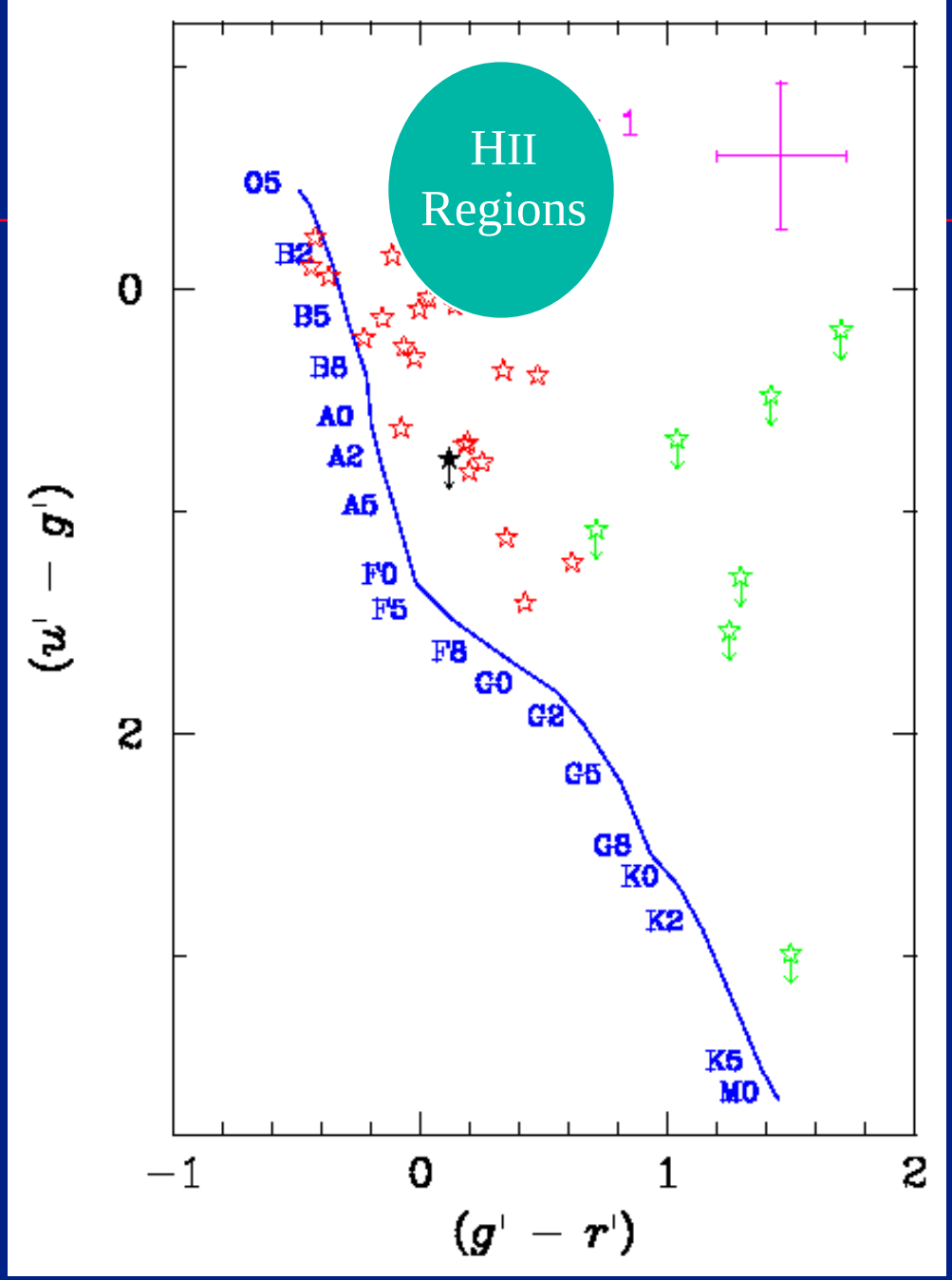


Ryder+ 2004

Episodic mass-loss?

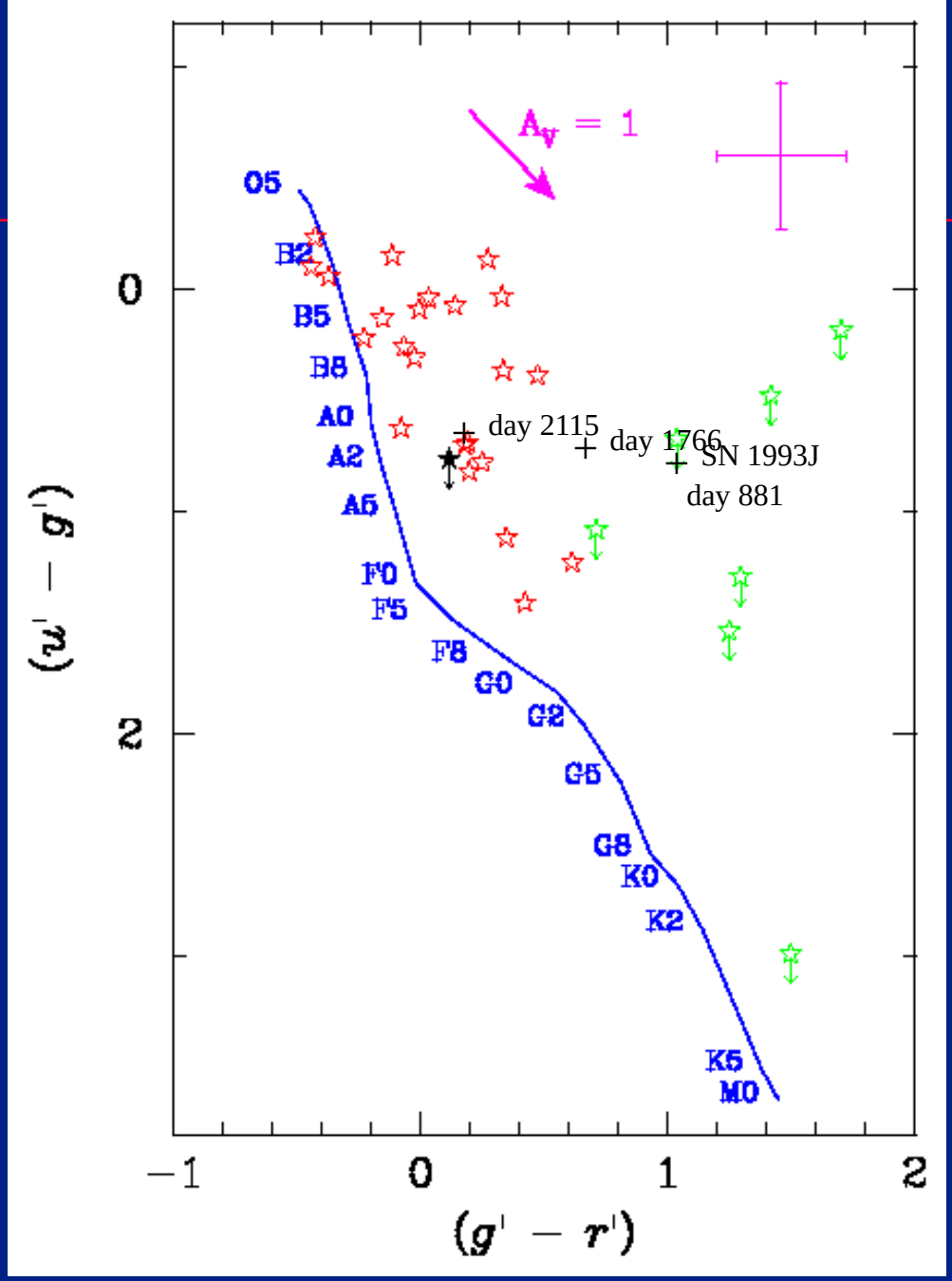



SN2001ig



- HII Region?

Too red in (u' – g')

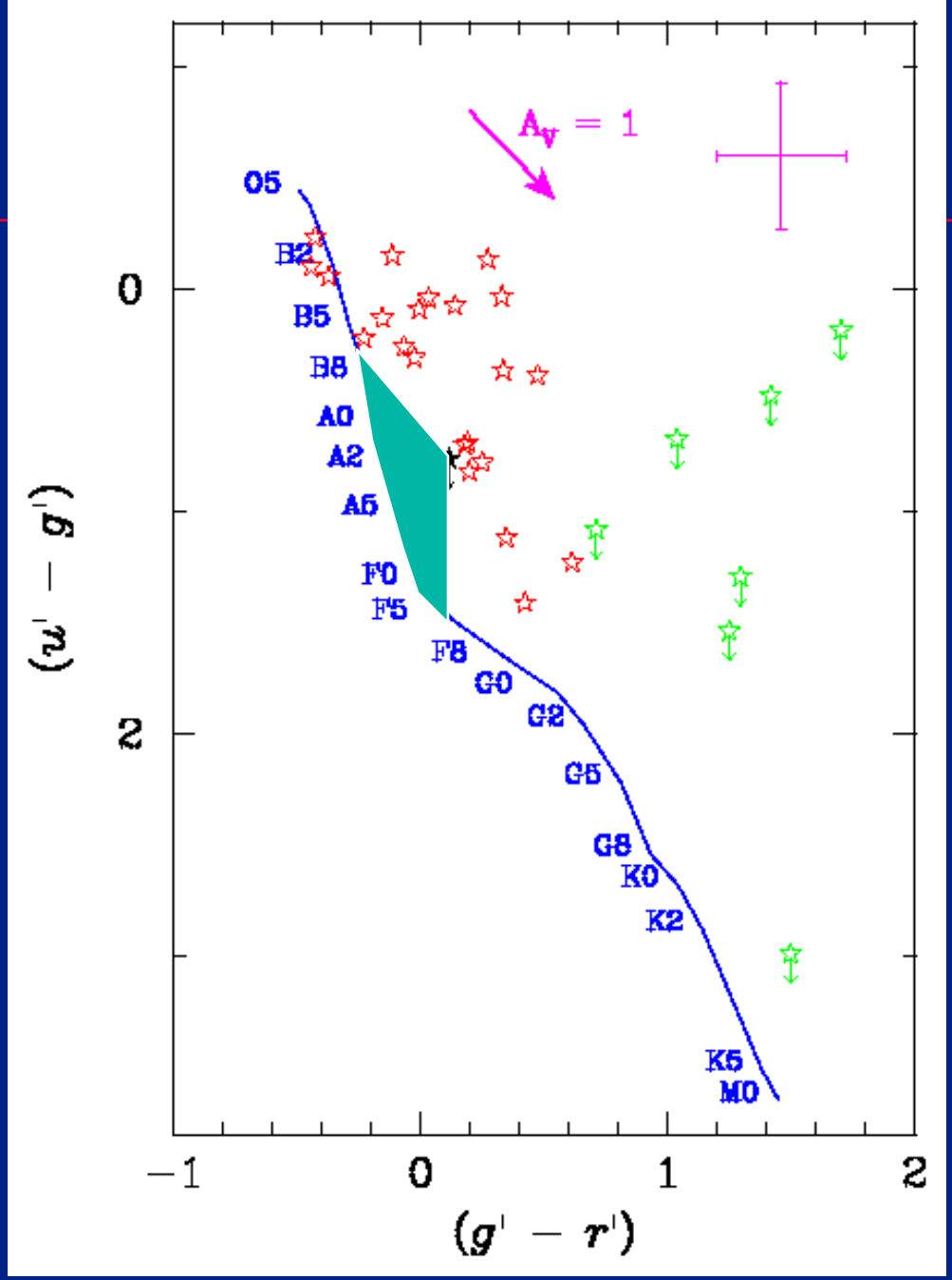


- HII Region?

Too red in (u' – g')

- SNR?

Too blue in (g' – r')



- HII Region?

Too red in $(u' - g')$

- SNR?

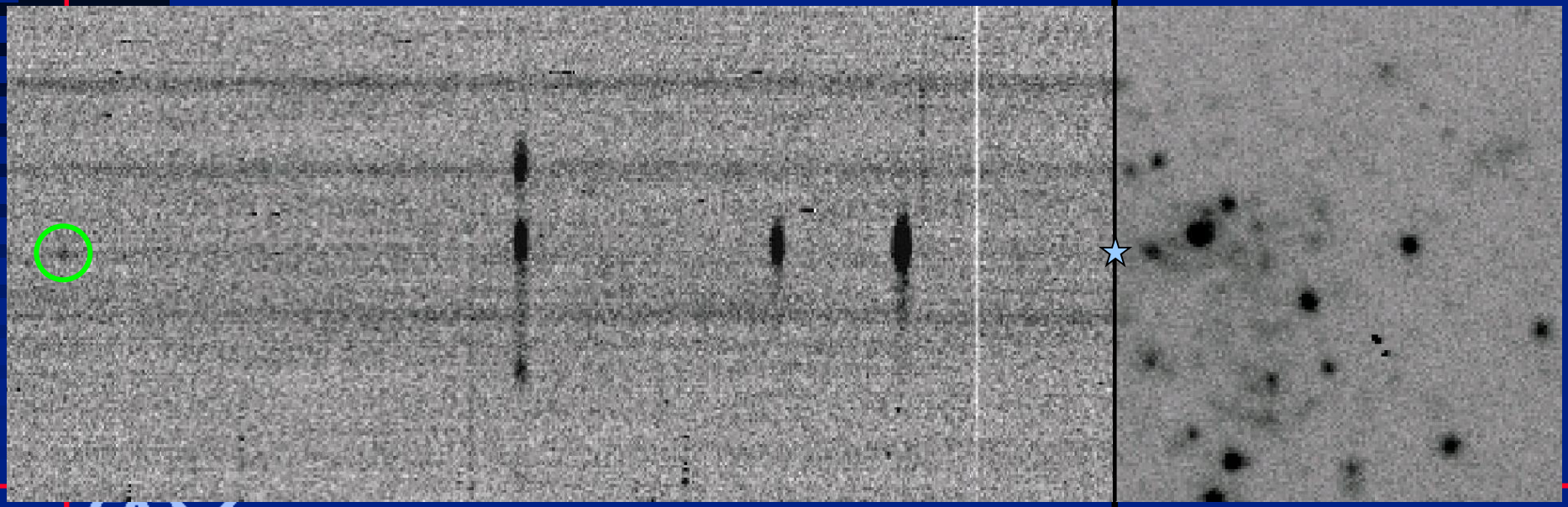
Too blue in $(g' - r')$

- Stellar Companion?
  - B7 → F8
  - $A_V < 1$
  - $\log L/L_\odot \sim 4.5$
  - $M = 10–18\ M_\odot$

Ryder+ 2006

SN 2001ig in 2007

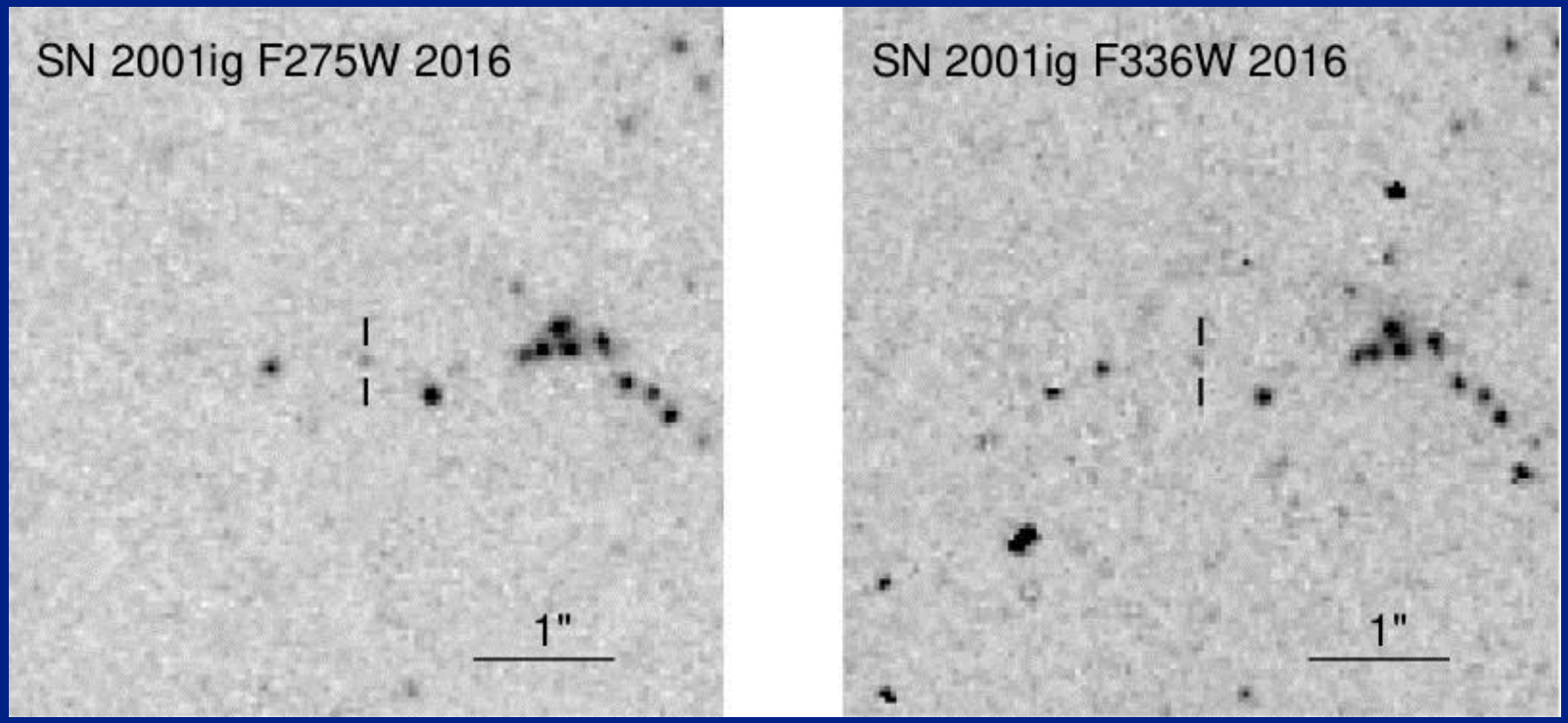
- GMOS + 600V grating + 0.5" slit.
- 5 hrs of <0.5" seeing.



What does He II tell us?

- He II λ4686 ⇒ hard ionising radiation, e.g. AGN, shocks, X-ray binaries, etc.
- Signature of Wolf-Rayet stars?
- Weak, narrow He II seen also in SN 2014C at 1–2 yrs as Type Ib → Type IIn ⇒ delayed interaction with dense shell (as in SN 1996cr and SN 1987A).
- Ongoing/renewed interaction with CSM around SN 2001ig beyond that probed by radio in first 2 years.

HST observes SN 2001ig



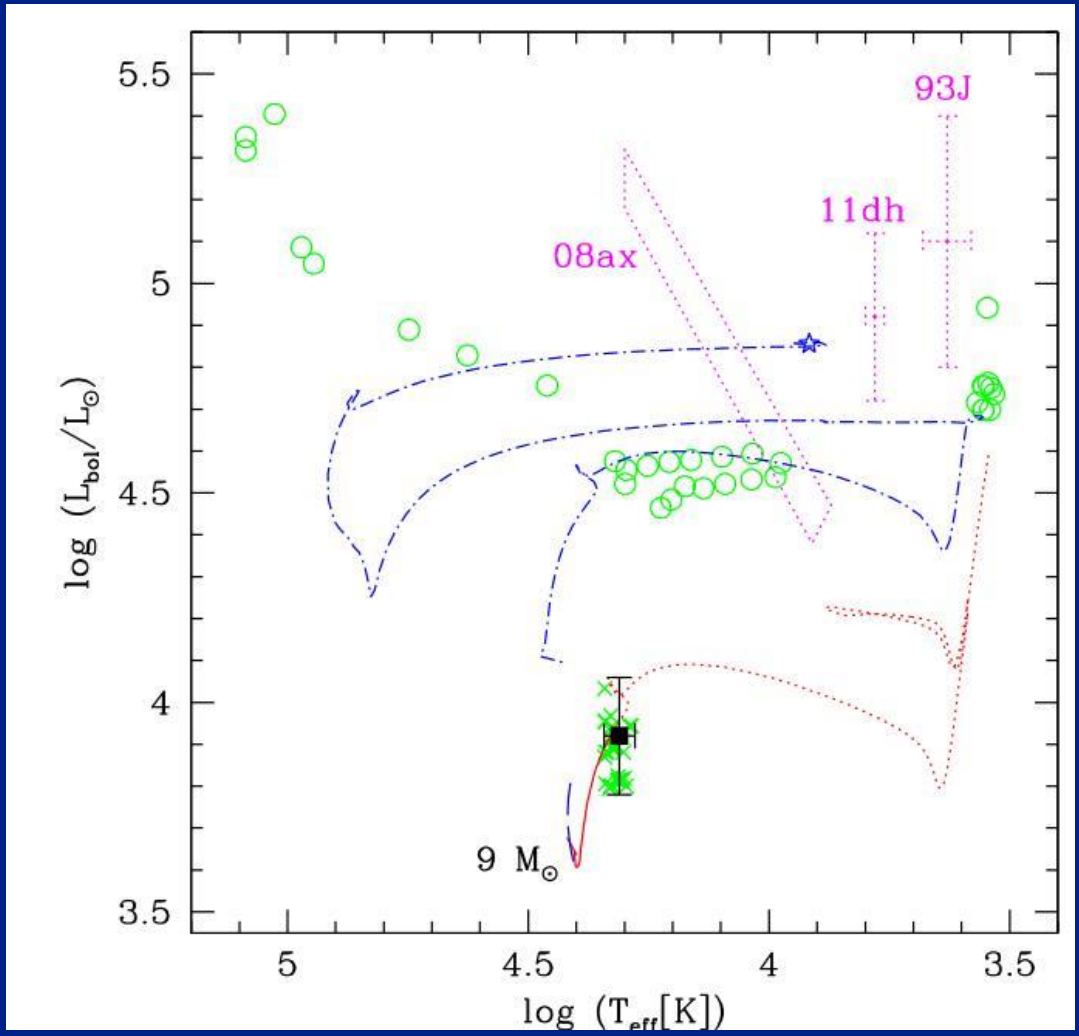
For A_V = 0.06, Z ~0.5 $Z_\odot$, μ = 30.2–30.3:

log ($L_{bol}/L_\odot$) = 3.92 ± 0.14

Early B-type T_{eff} = 19,000 – 22,000 K

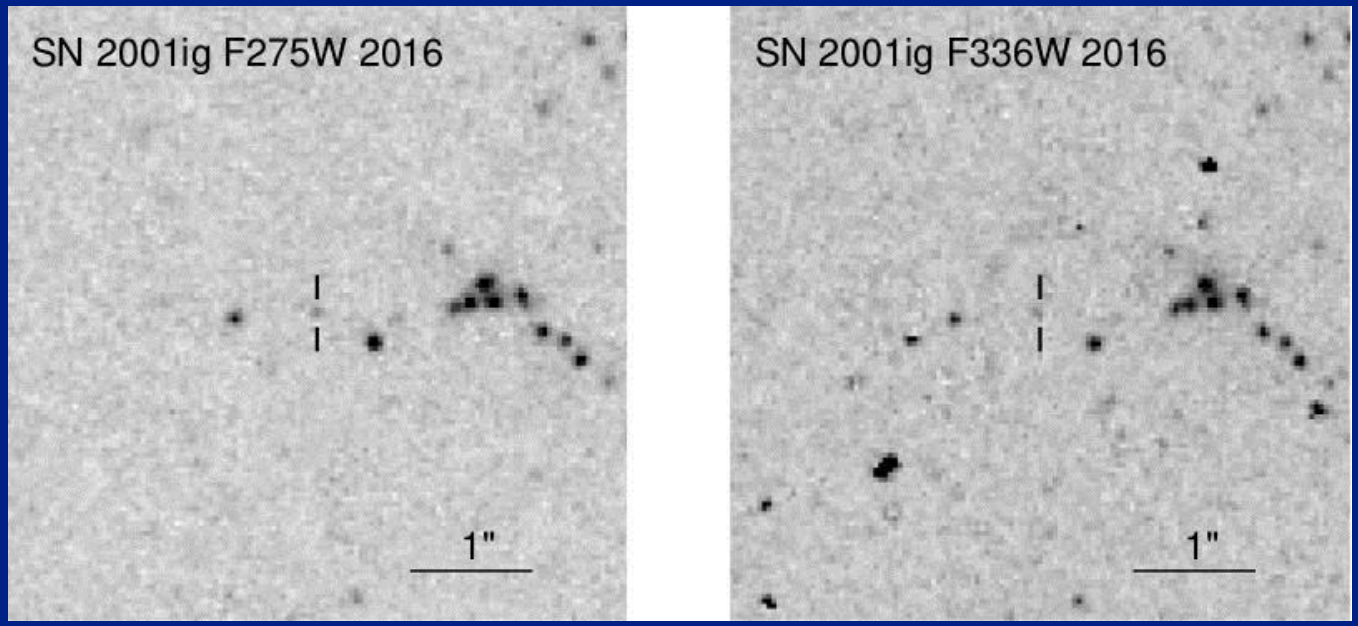
BPASS (Eldridge & Stanway)

- 24 of 12678 Z=0.01 models.
- Primary = 13 $M_\odot$
- Secondary = 9 $M_\odot$ TAMS
- P_{orb} = 400 days
- Final core mass ~3.5 $M_\odot$
- Envelope mass 0.04 $M_\odot$
- Strongly variable mass loss in final <50,000 yrs.



Innocent bystander?

- Unlikely, owing to sparse field in UV + He II detection.
- A single MS B star can account for the source UV luminosity. A cluster would have to be dimmed by dust, not seen by *Spitzer*.



In summary

- Can mass transfer in binary systems account for some/all SESNe? If so, can we still see the companion?
- Clean UV detection of companion to Type IIb SN 2001ig matches a 9 $M_{\odot}$ B-type main sequence star.
- 13 $M_{\odot}$ BPASS primary terminates in same YSG region of HRD as primaries for SN 1993J and SN 2011dh.
- Presence of companions + relatively low primary masses from pre-explosion images weakens case for massive single stars such as LBVs or Wolf-Rayets being the progenitors of most SNe IIb.