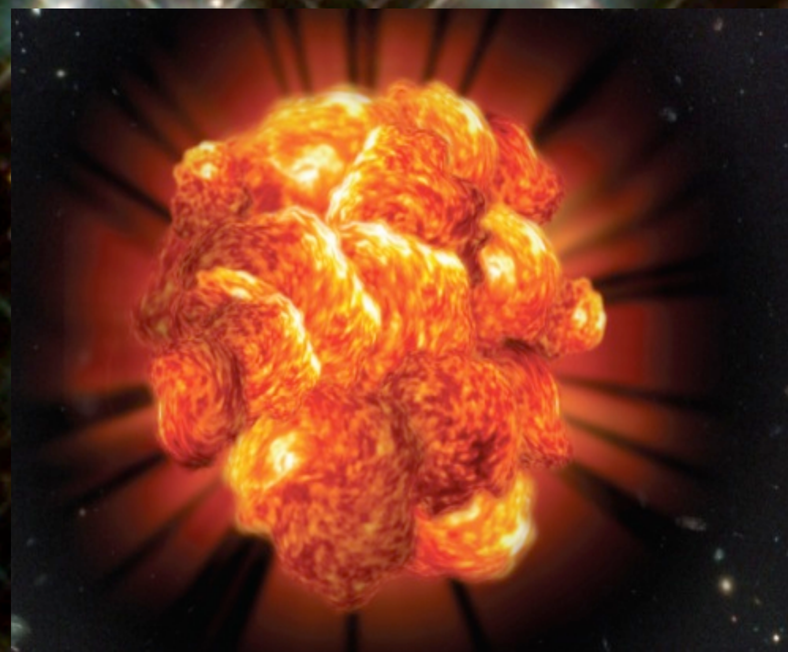
Pair-Instability Explosions:

do they happen in natre?



Avishay Gal-Yam,

Weizmann Institute

Stockholm 2011

The Core-Collapse Spectrum

Lower mass limit unclear:

<7..11 solar; stable C/O core

M: 7-11 M: 8-16 M: 17-25 M: 25-30 M: 40-50 M: 50-150 M> 150

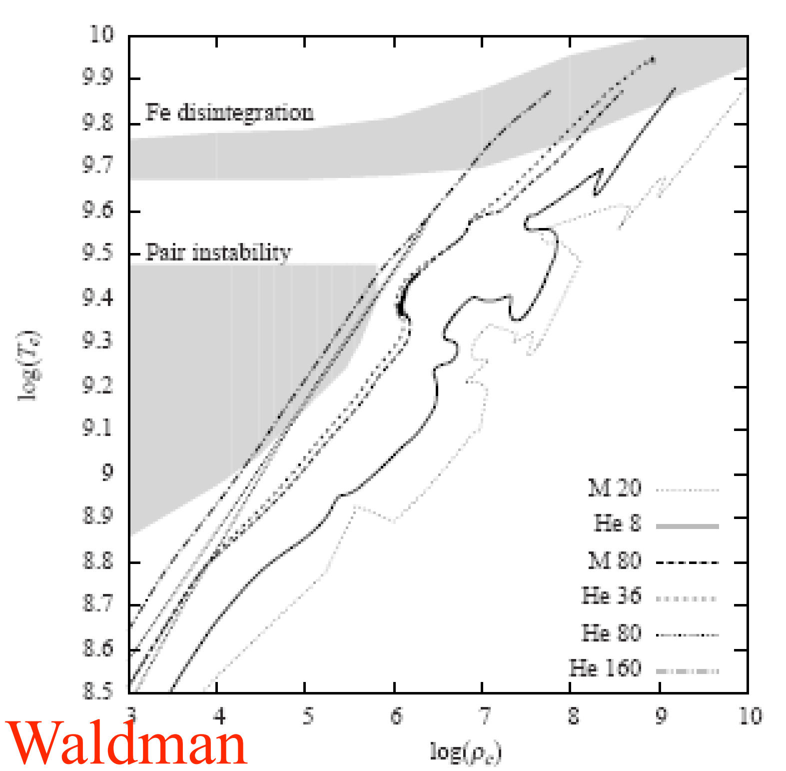
Pair Instability Supernovae (PISNE)

(Shaviv & Rakavi 1967; Barkat, Rakavi & Sack 1967 ; Heger & Woosley 2002; Waldman 2008 …)

* Helium cores above ~50 solar masses become pair unstable

* In these low-density high-T cores, $\gamma\gamma \rightarrow e^+e^-$ wins over oxygen ignition, heat is converted to mass and implosion follows

* Inertial oxygen ignition leads to explosion and full disruption



* "This is a uniquely calculable process" (Heger & Woosley 2002); "this is a trivial calculation" (Barkat 2009); "Pretty neat homework problem" (Gal-Yam 1996)

"Smoking gun":

Core mass > 50 solar

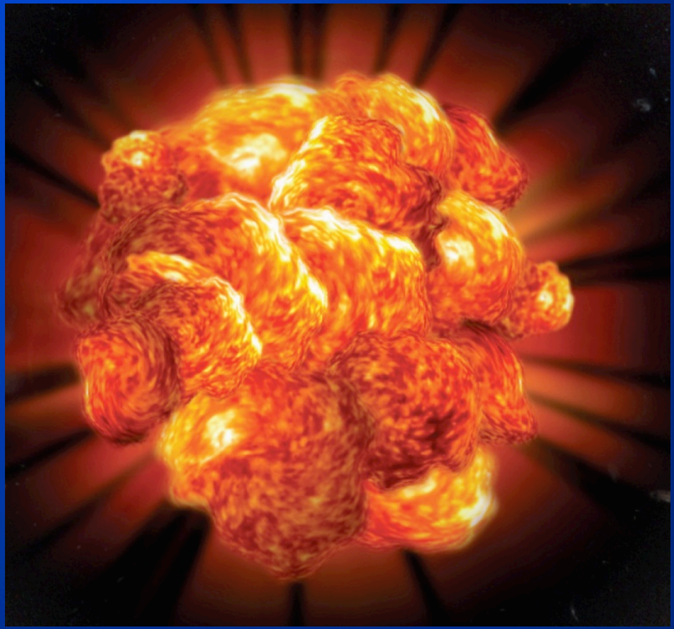
Pair Instability Supernovae (PISNE)

* Helium cores above the threshold robustly explode

* PISNe care not for metallicity, but for mass loss

* PISNe progenitors seem not to exist in our Galaxy – require M > 140 solar - (though transitional pulsational events might)

* At early Universe, M~1000 stars may have existed



SN 2007bi=SNF20070406-008

(PTF "dry run")

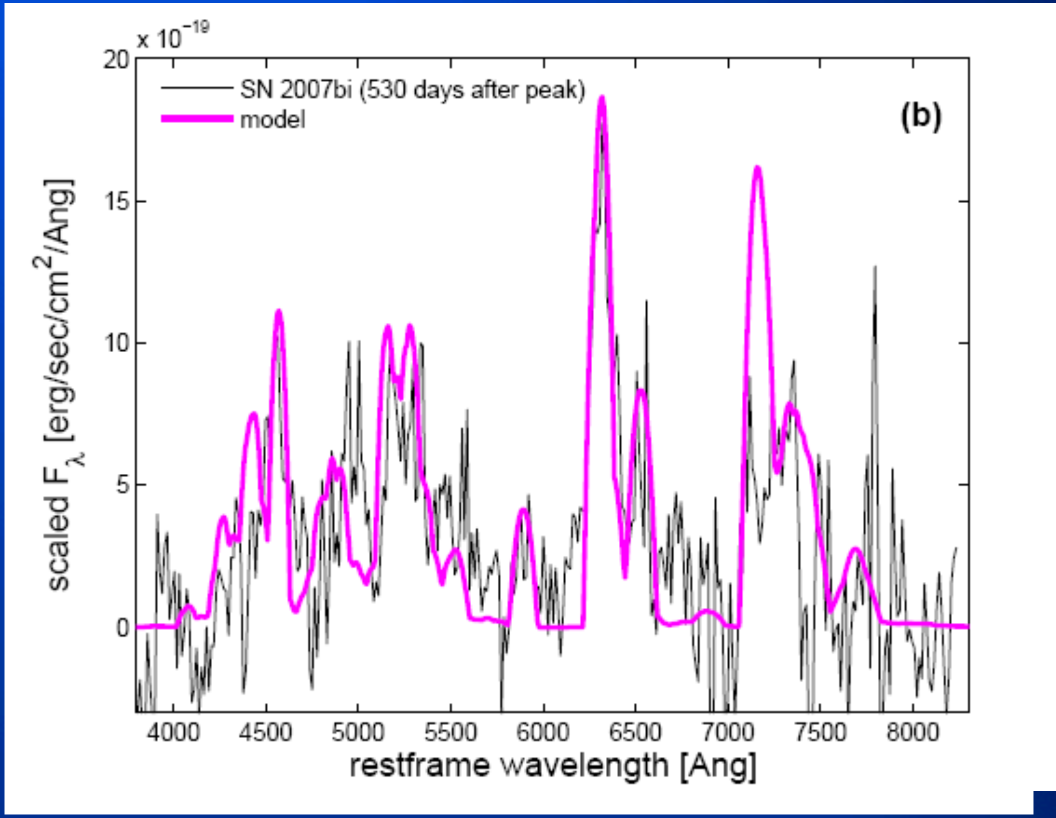
* Type Ic SN (no H, He). No interaction, no dust, v=12000 km/s

* Luminous peak (-21.3), slow rise (~77 days), ^{56}Co decay

* ejected mass ~100 solar, E_k~1e53, 4-11 solar masses of ^{56}Ni (87A)

* Well-fit by models (Kasen)

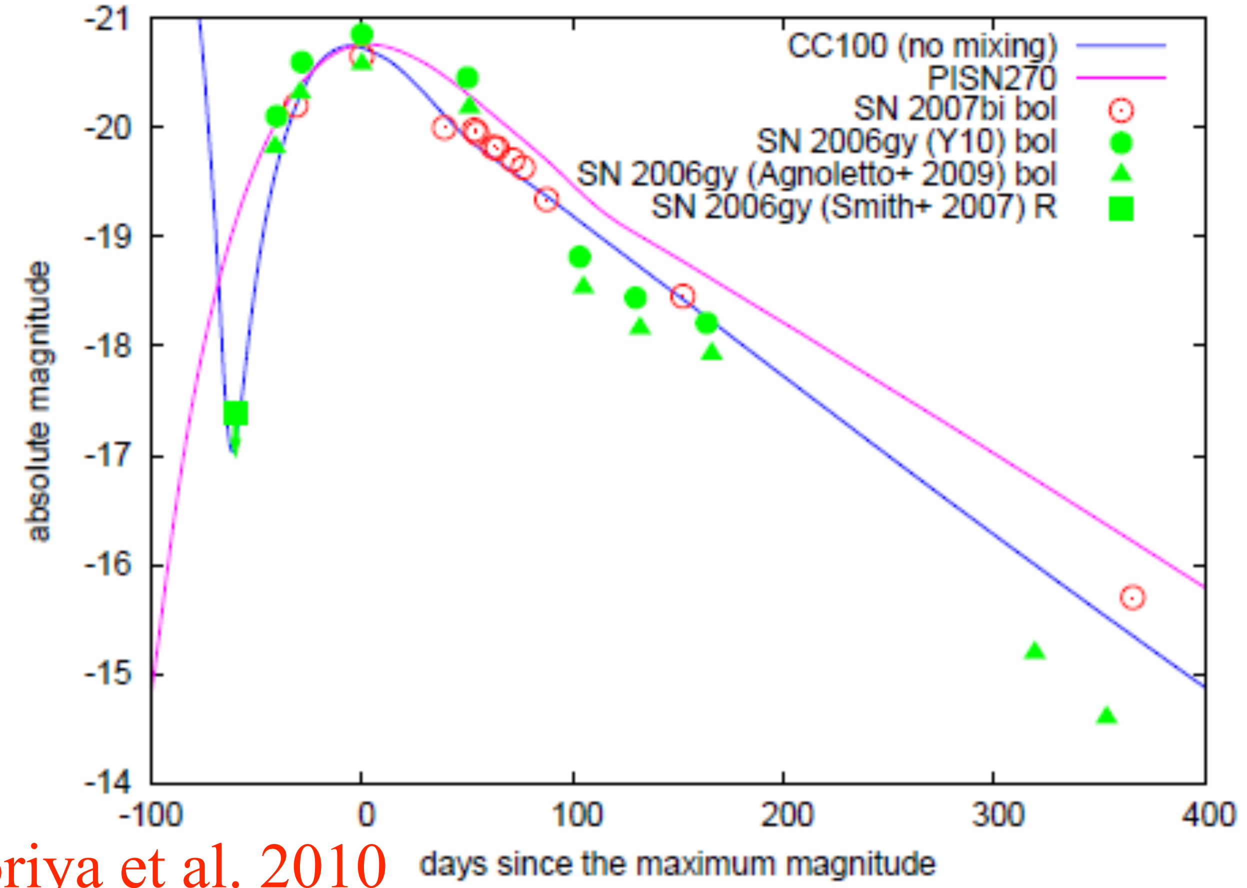
* Nebular spectra: 4-6 solar mass of ^{56}Ni; >50 solar total (Direct comparison with 98bw; Mazzali models)



Core mass > 50 robustly established;

Gal-Yam et al. 2009, Nature, 462, 624

Alternative model?



Moriya et al. 2010

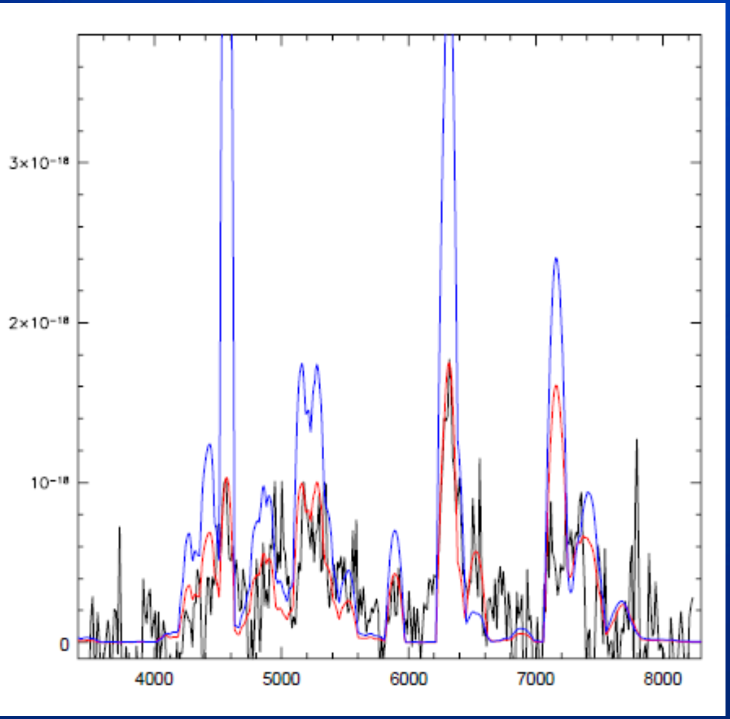
Alternative model?

TABLE 1
THE AMOUNT OF ELEMENTS CONTAINED IN THE EJECTA

^{12}C	^{16}O	^{20}Ne	^{24}Mg	^{28}Si	^{32}S	^{36}Ar	^{40}Ca	^{56}Ni
1.4	18.7	1.4	1.5	5.1	2.7	0.5	0.4	6.1

NOTE. — Units: $M_\odot$

Moriya et al. 2010



Same amount of ^{56}Ni within a smaller total ejecta mass: emission lines too strong.

CC model cannot explain SN 2007bi spectra

Implications for mass loss

Table 1. The range of MS mass for PI and CC SN models appropriate for SN 2007bi deduced from the mass range of the CO core and the surface He abundance. The ratio of the probability of explosion as a PI SN to explosion as a CC SN for SN 2007bi, $r_{PI/CC}$, is also listed (see Section 4).

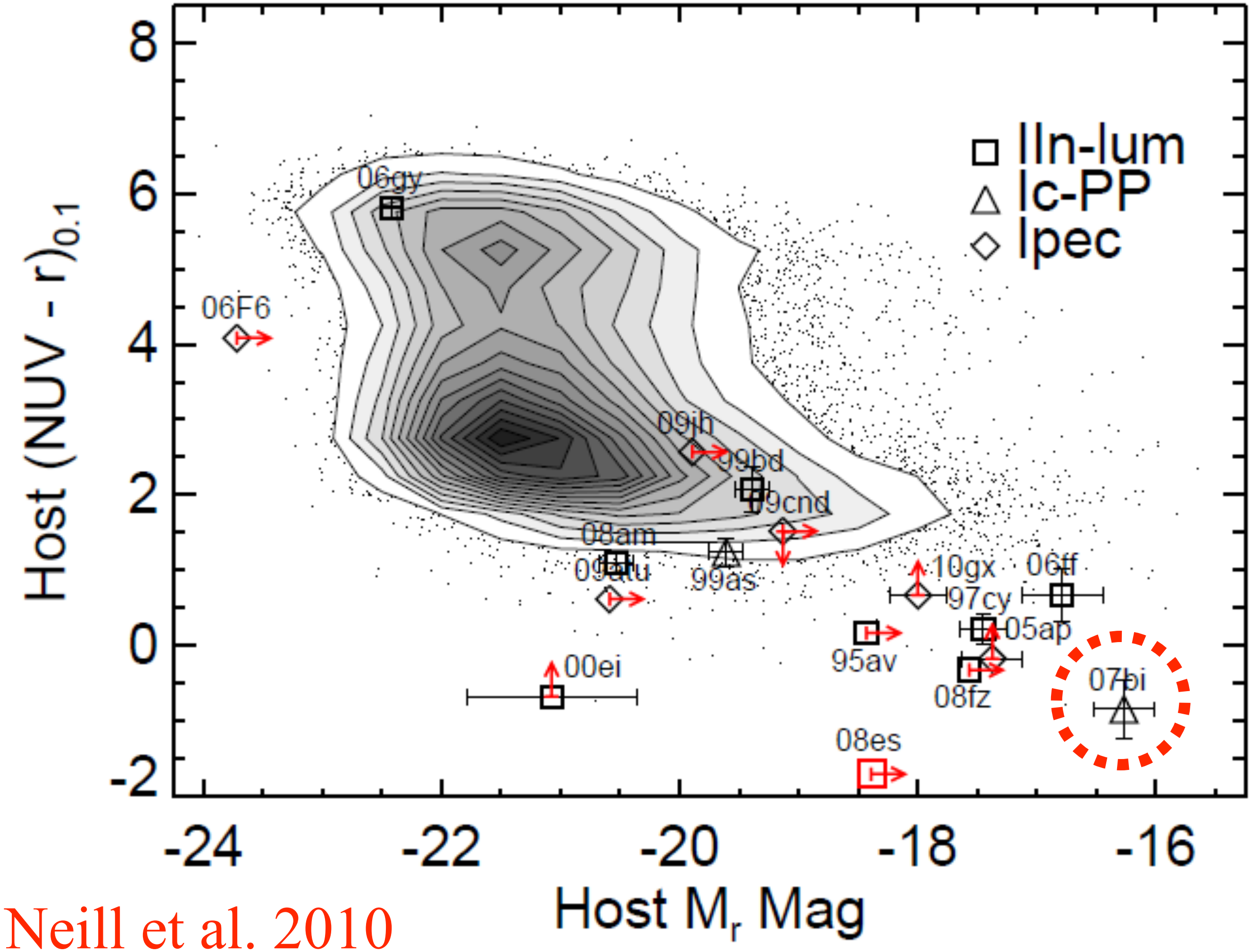
Condition	PI SN ($M_\odot$)	CC SN ($M_\odot$)	$r_{PI/CC}$
	Case A		
$M(He) \leqslant 0.5M_\odot$	–	110 – 120	0
$M(He) \leqslant 1.5M_\odot$ or $Y_s \leqslant 0.5$	515 – 575	110 – 280	0.024
	Case B		
$M(He) \leqslant 0.5M_\odot$	–	110 – 115	0
$M(He) \leqslant 1.5M_\odot$ or $Y_s \leqslant 0.5$	–	110 – 500	0
	Case C		
$M(He) \leqslant 0.5M_\odot$	–	–	–
$M(He) \leqslant 1.5M_\odot$ or $Y_s \leqslant 0.5$	310 – 350	135 – 170	0.19

Yoshida & Umeda 2011

If CC model ruled out, either we have found stars with initial mass > 500 solar, or standard mass loss theory needs to be revised

In any case, PISNe likely exist at high-z

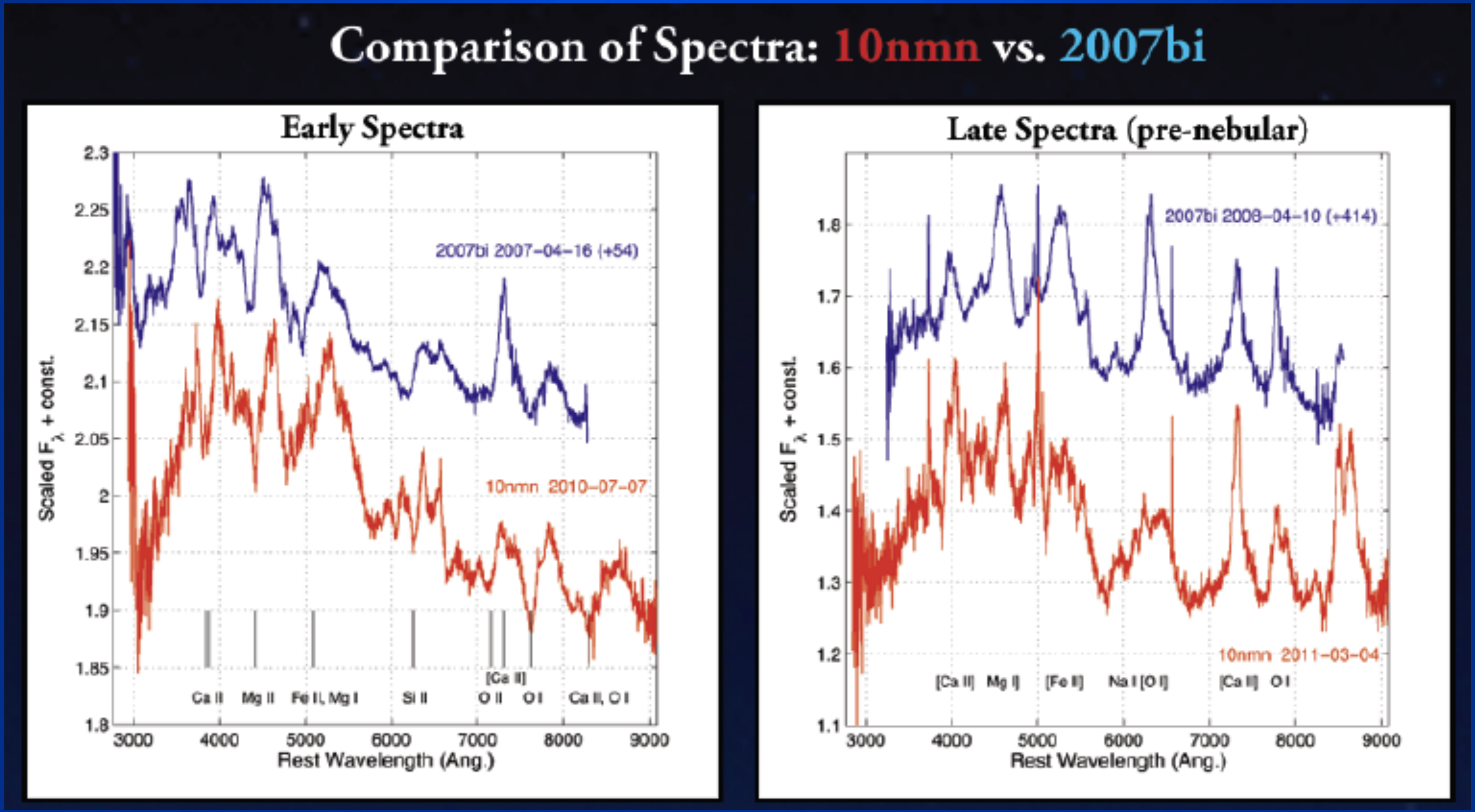
Extreme host



Neill et al. 2010

PTF 10nmn: new results from PTF

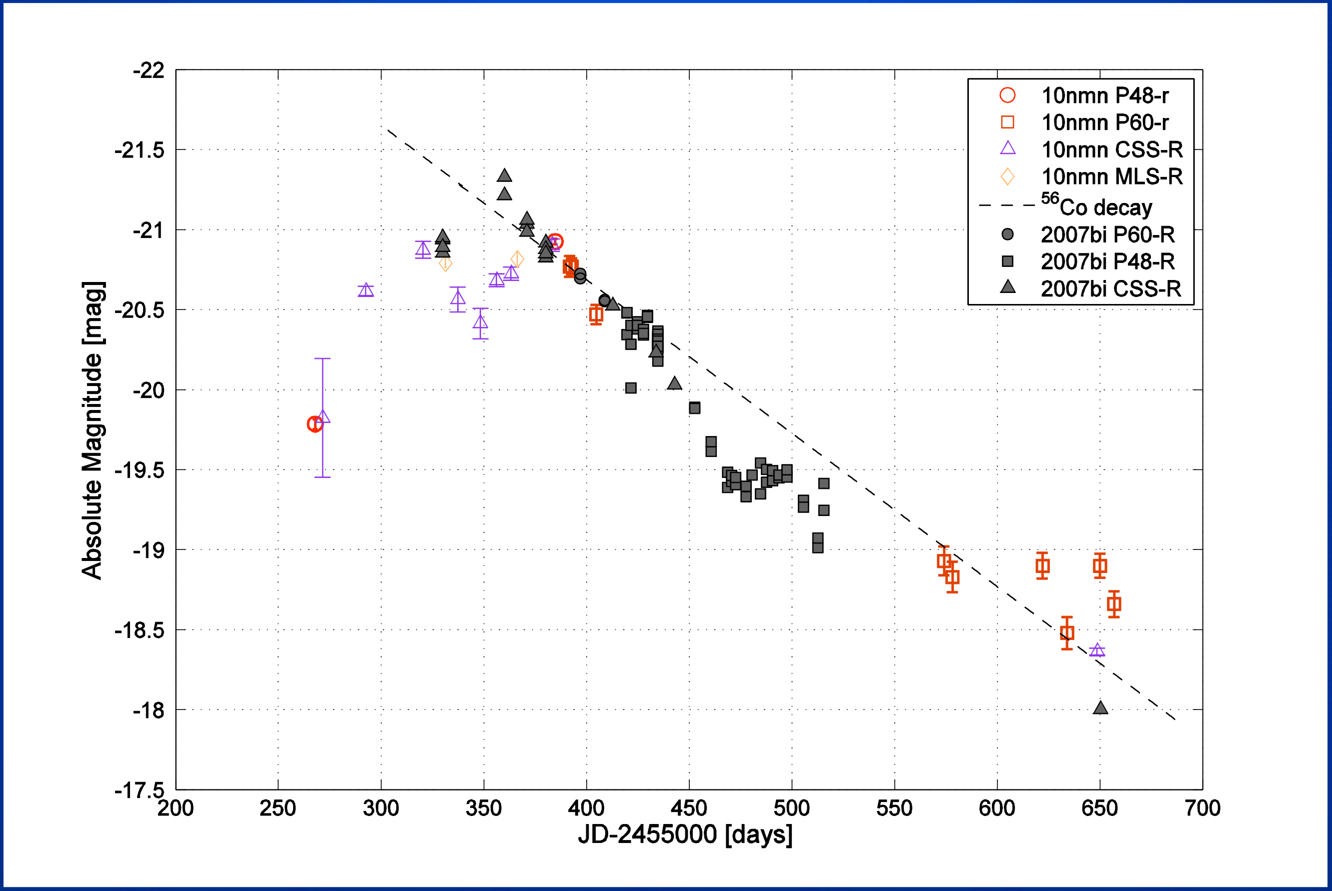
(Yaron)



- SN 2007bi lookalike

PTF 10nmn: new results from PTF

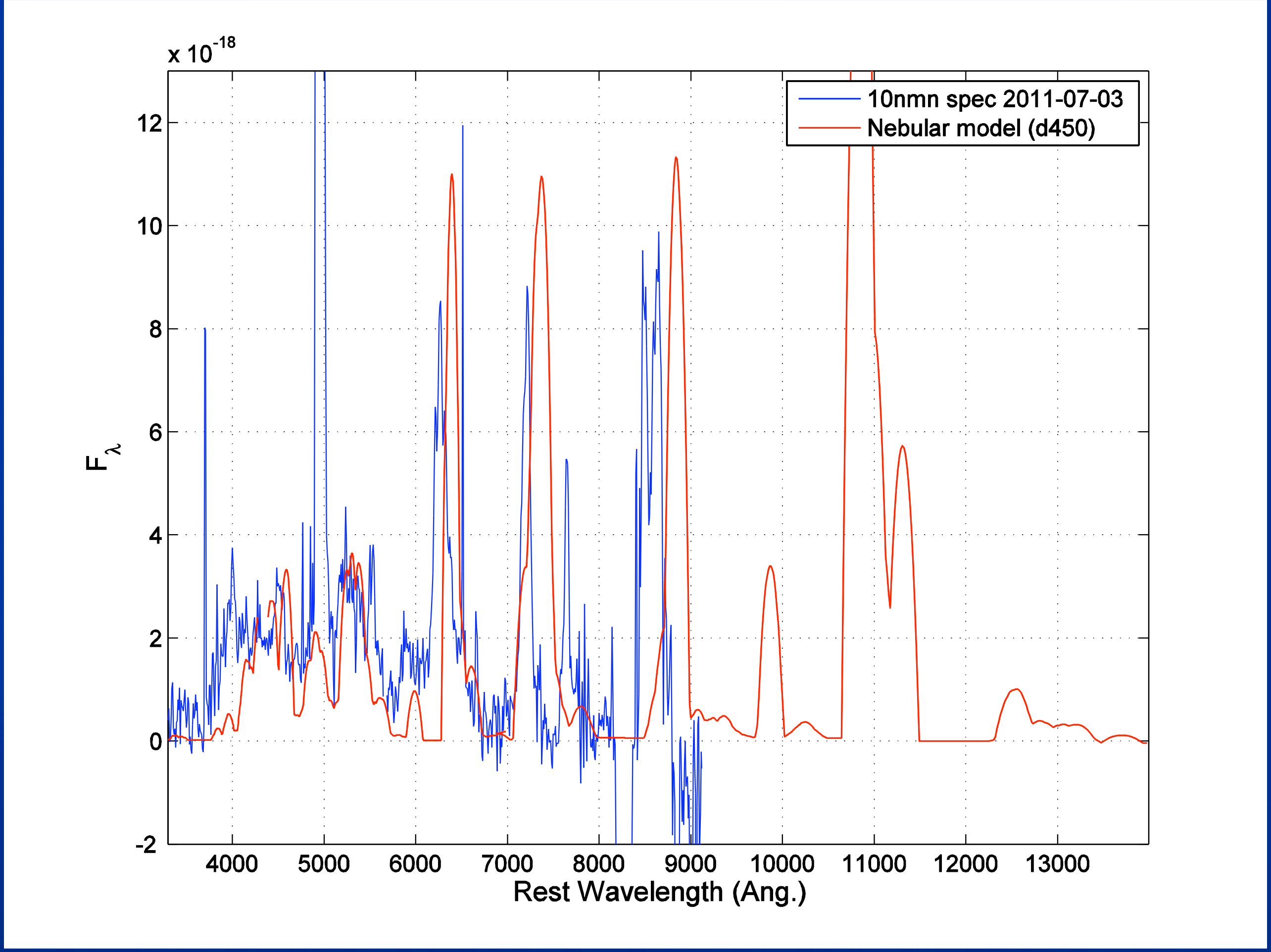
(Yaron)



- Complicated light curve, but slow rise (in favor of PISN)

PTF 10nmn: new results from PTF

(Yaron)



- Nebular spectrum: Ni=5, total=100m lots of C/O (and Ca); IR: an opportunity not to be missed!

PTF 10nmn: new results from PTF

(Yaron)

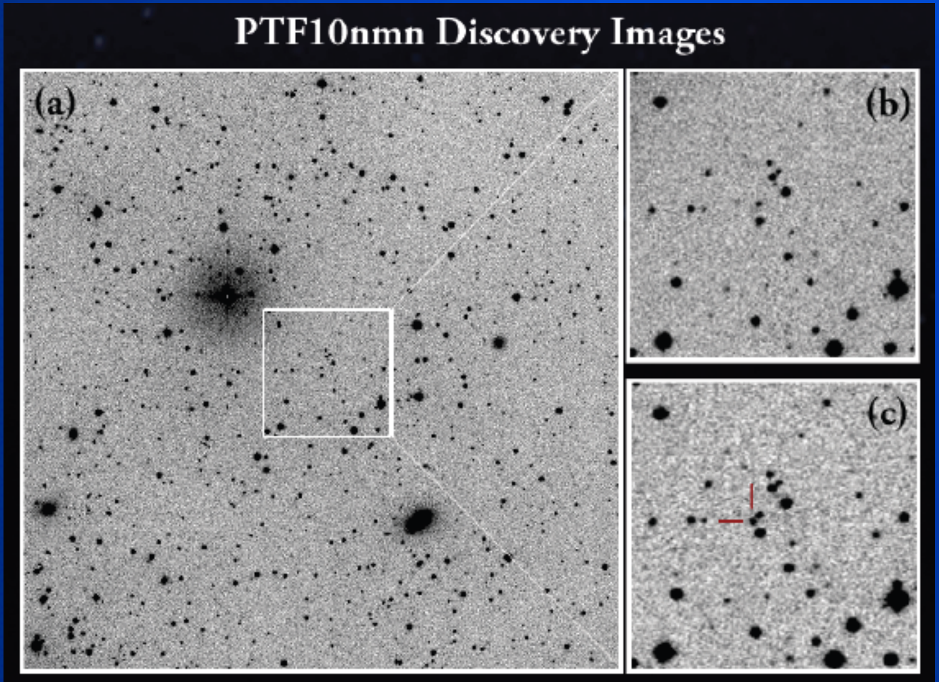


Fig. 1 - R-band Images from the PTF survey telescope - Palomar's 48-inch (P48). (a) Co-added pre-explosion reference image. (b) A Zoom-in of the 2009 Jun 01 image. (c) Discovery image of PTF10nmn on Mar 12 2010 (at apparent magnitude m_R~19.4).

- Host: another dwarf (< LMC)

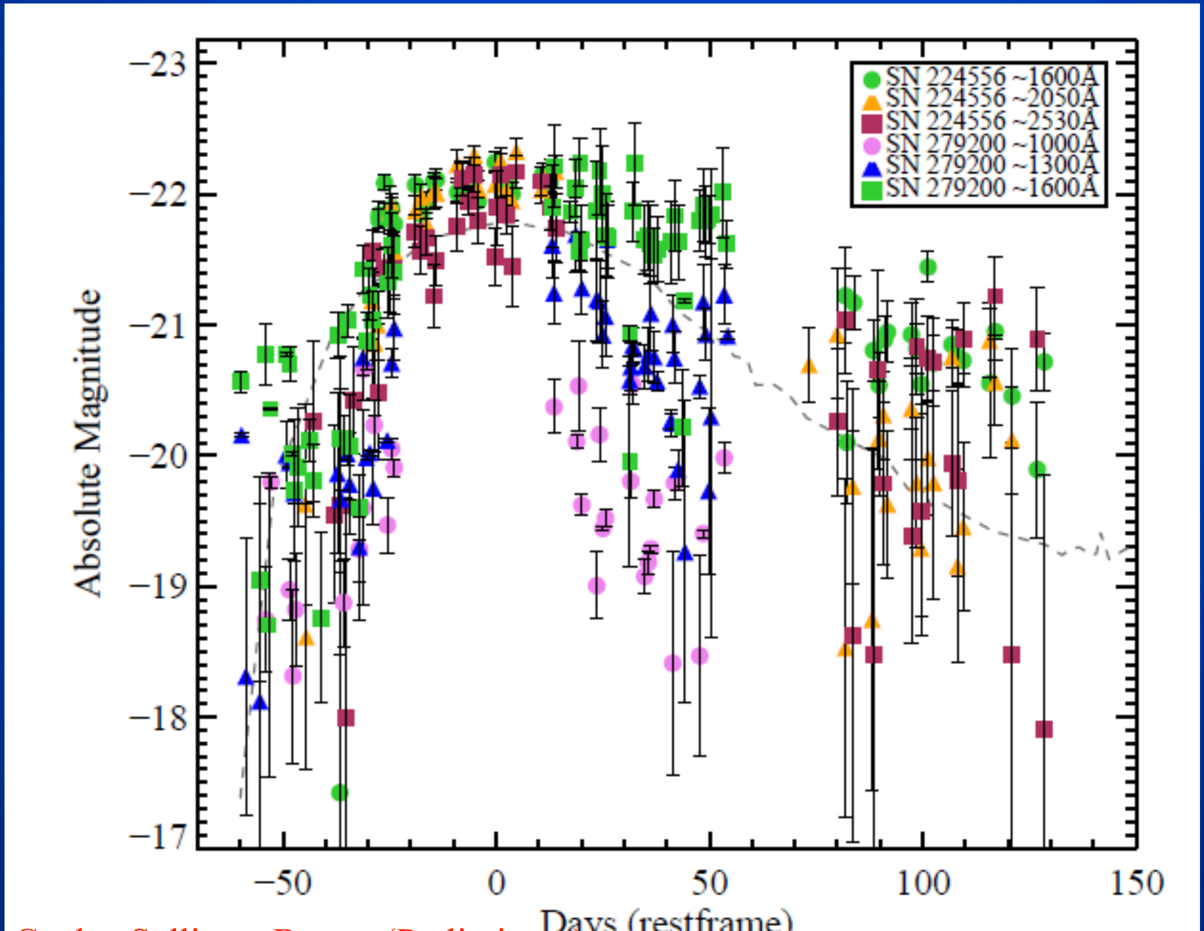
PTF 10nmn: new results from PTF

(Yaron)

- Rate at low-z is about ~1 per year, these are ~5 times rarer than Quimbies (roughly): truly at top of the IMF

PISNe at high redshift
(Cooke)

- PISNe are also detected at high redshifts (Cooke; PS1)



Cooke, Sullivan, Barton (Preliminary)

PISNe at high redshift

(Cooke)

- PISNe are also detected at high redshifts
- They are also rare there
- At the top of the IMF also at high-z

Implications

(Gal-Yam et al. 2009)

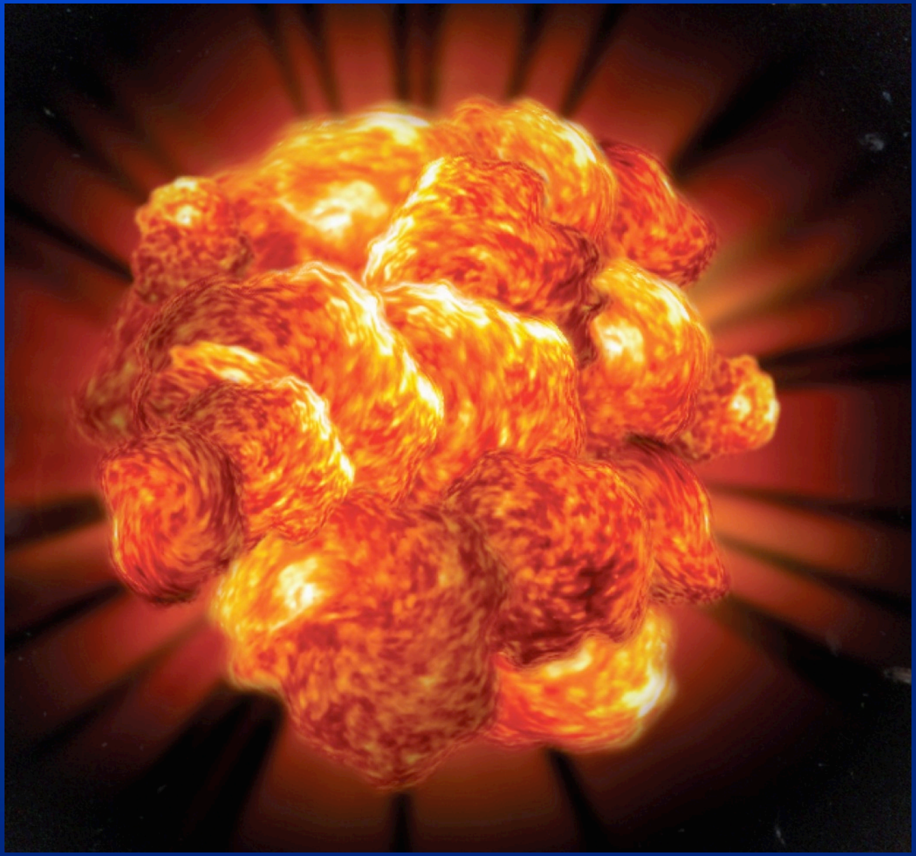
* A helium core ~100 solar detected at Z ~ SMC

•Many mass loss models are wrong (c.f Langer models)

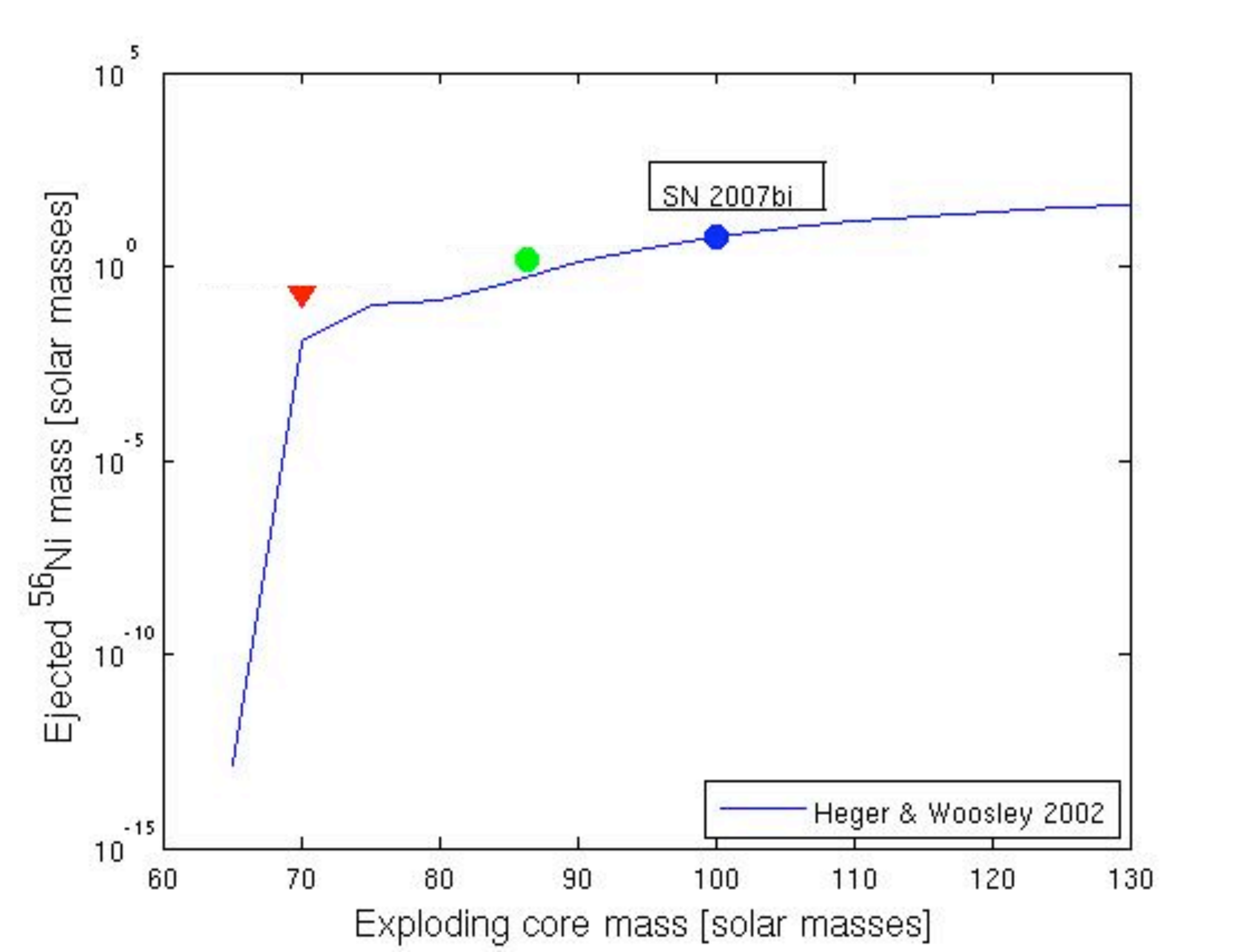
* PISNe happen locally, Universally, SN models are ~ok

* Dwarfs have stars above Galactic limit (>200 solar, probably)

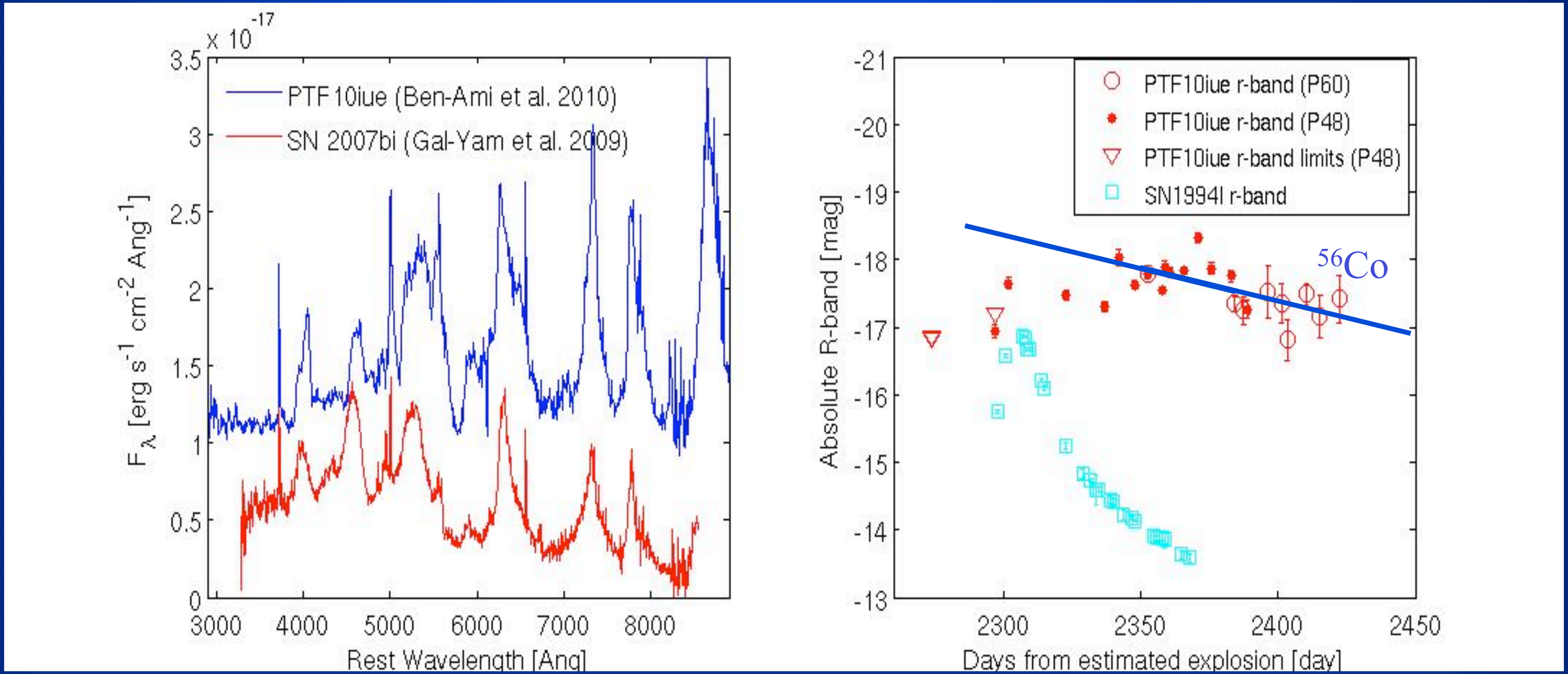
* Hydrogen efficiently removed (pulsations?)



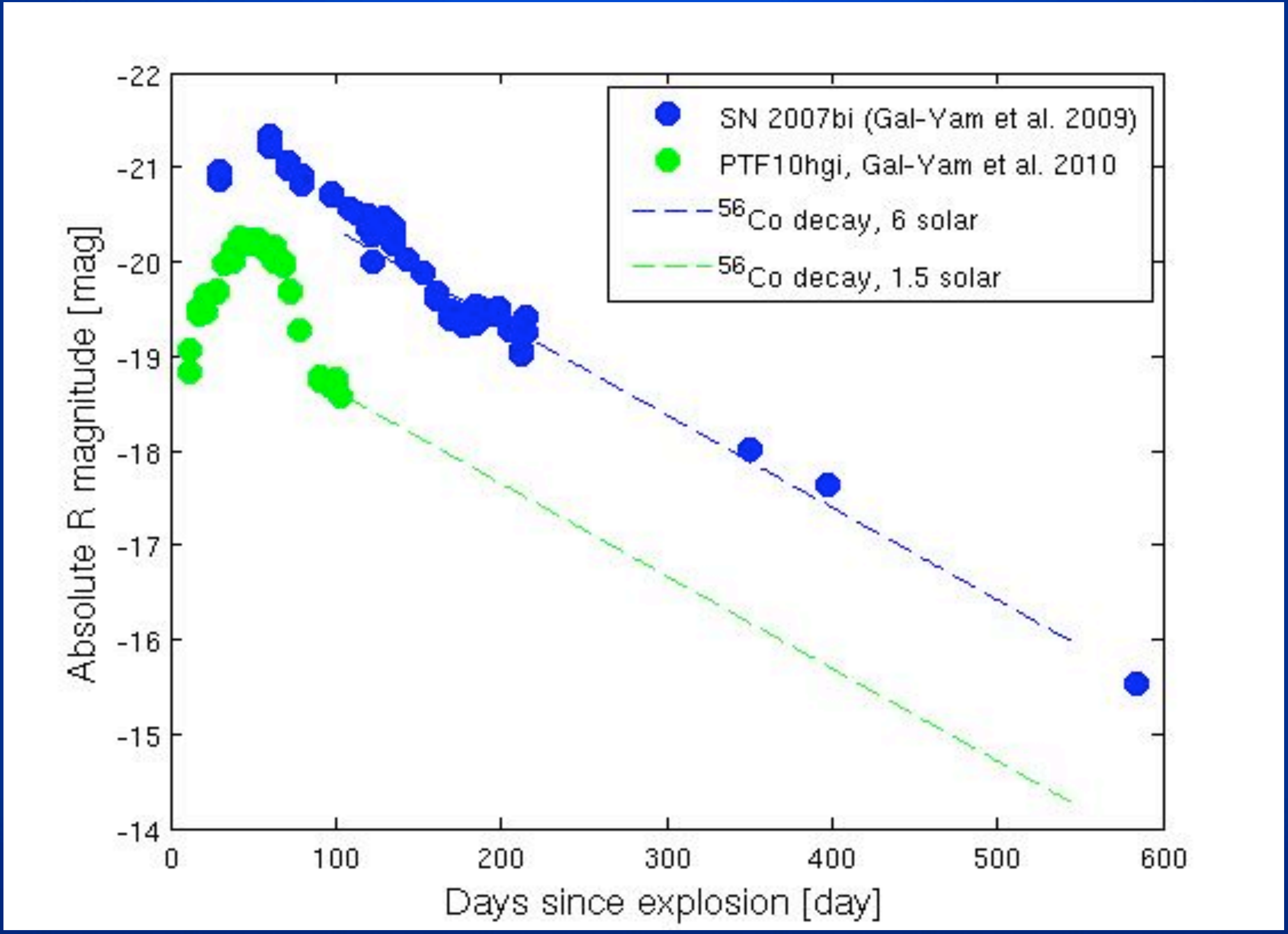
Implications (observational)



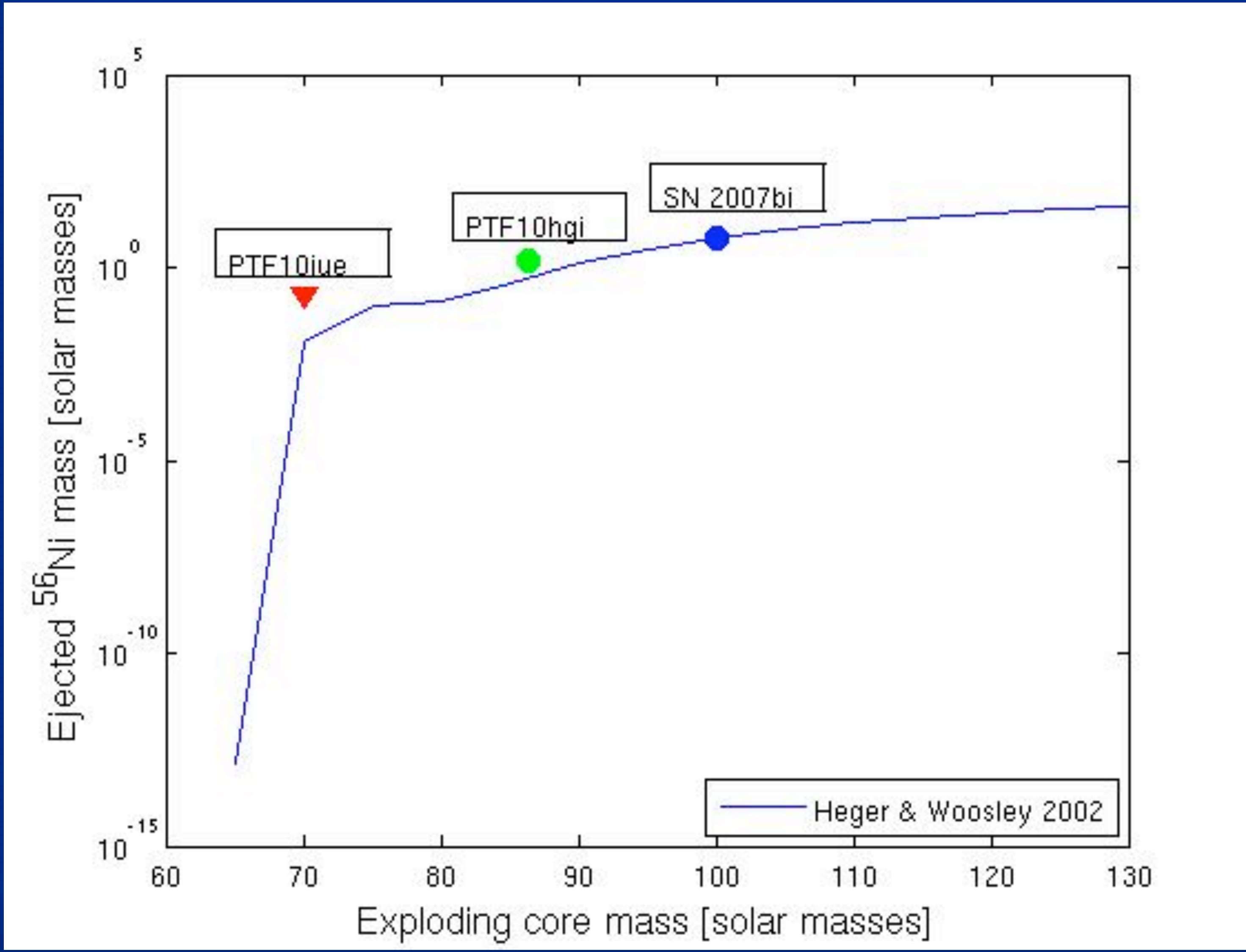
The new plateau (Ben-Ami)



In the middle

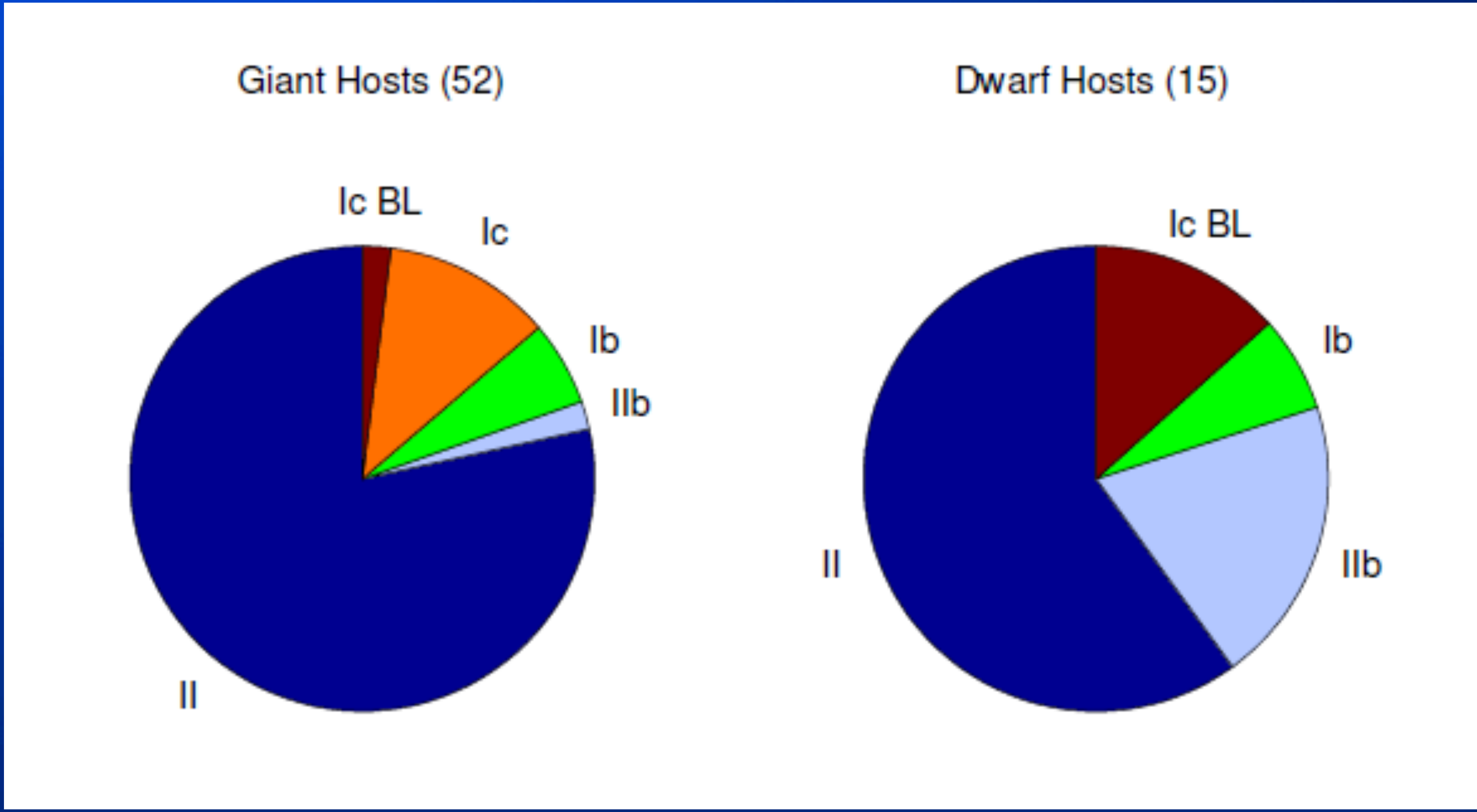


Implications (observational)



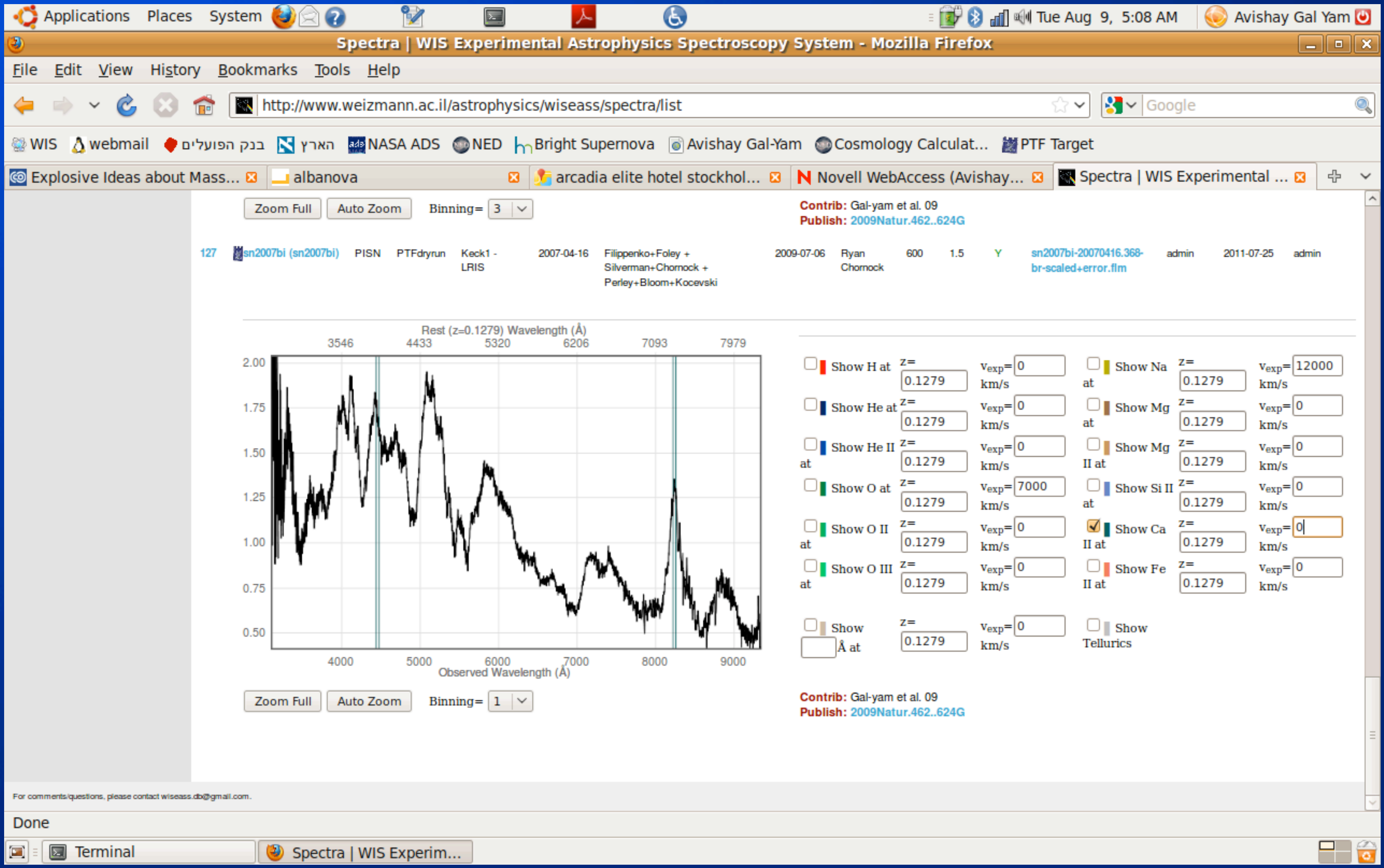
Dwarf and giant galaxies: different populations of massive star explosions

(Arcavi et al. 2010)

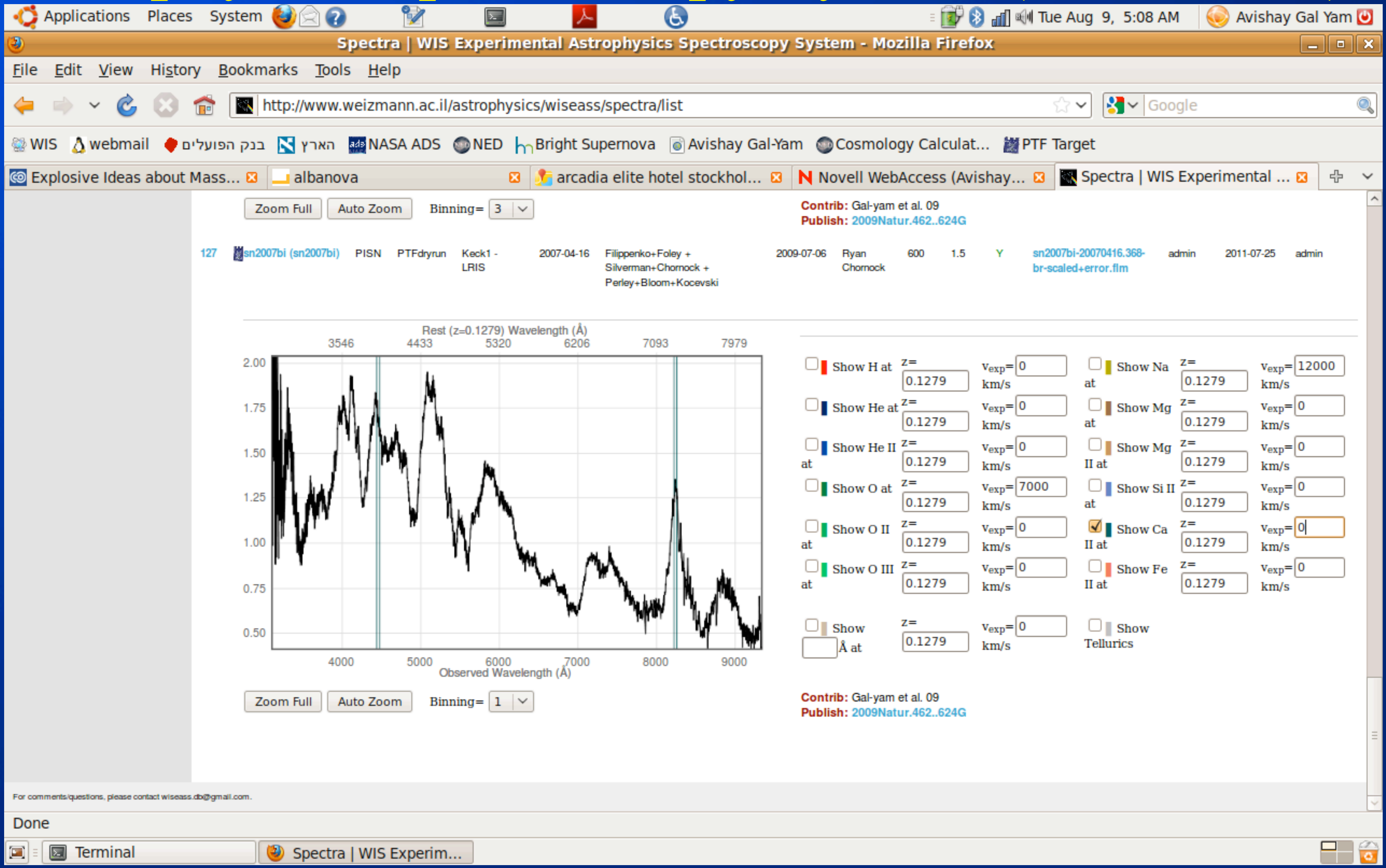


Arcavi et al. 2010, ApJ, 721, 777

And now… something else



The Weizmann Institute of Science Experimental Astrophysics Spectroscopy System (WISEASS)



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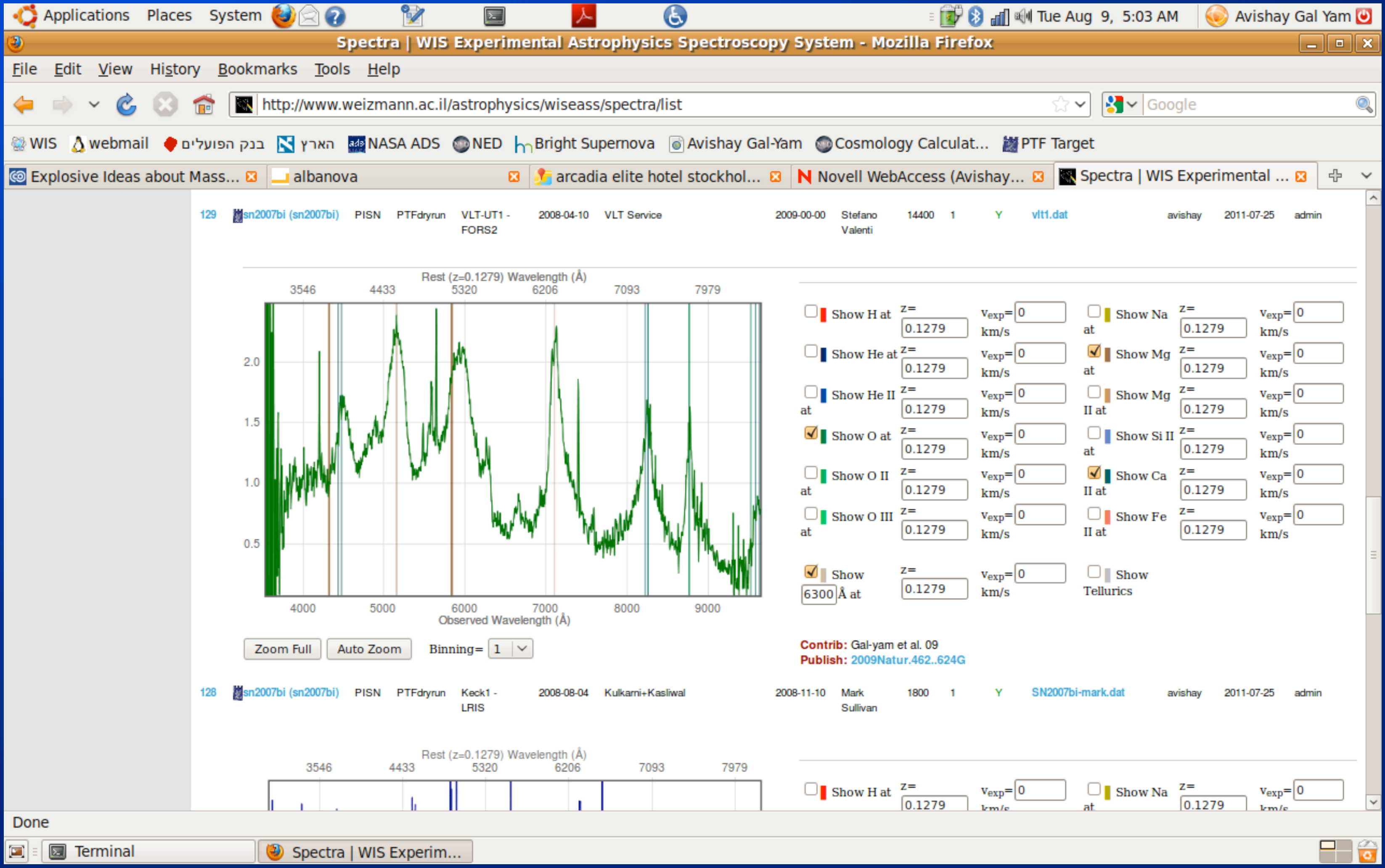

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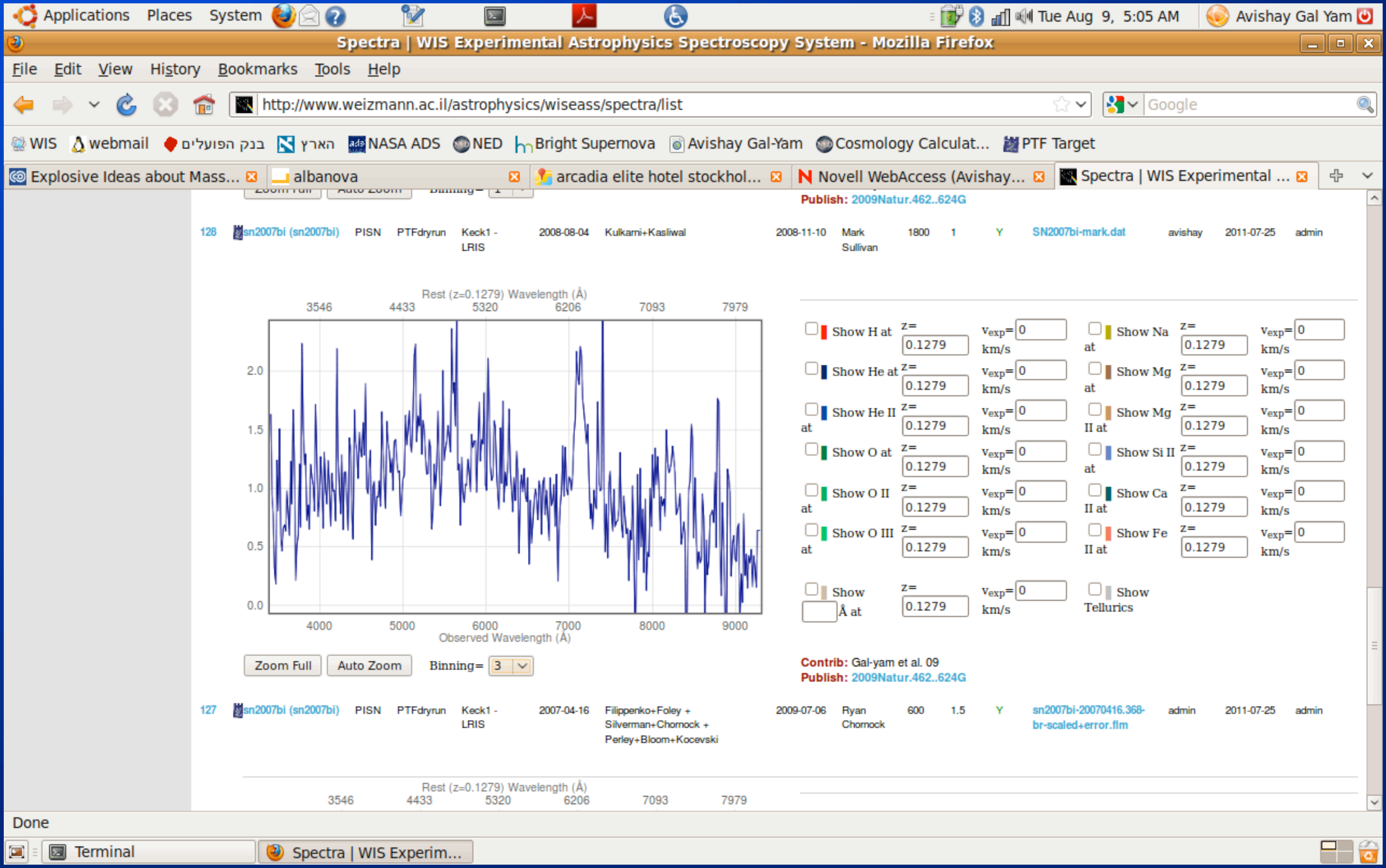

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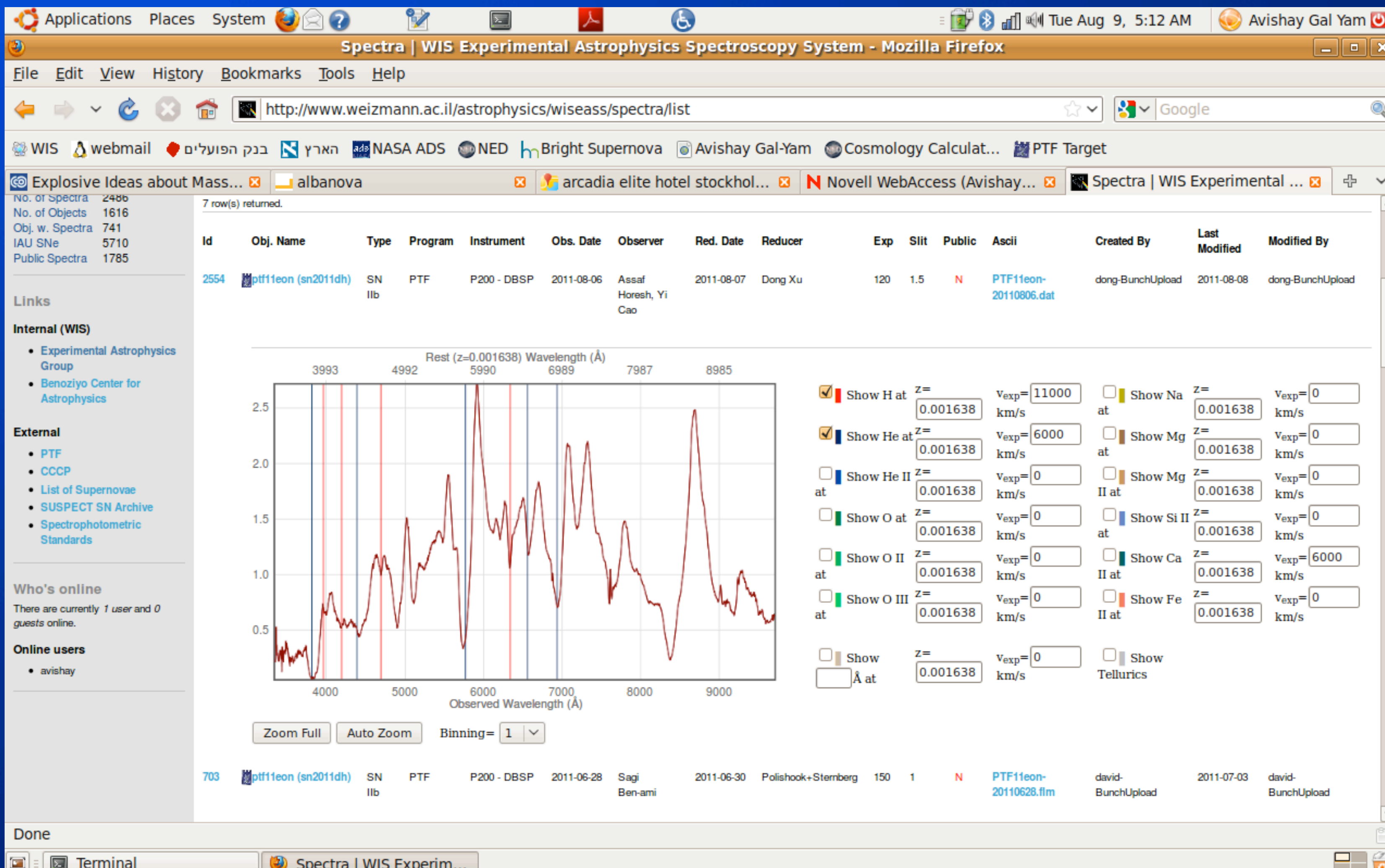

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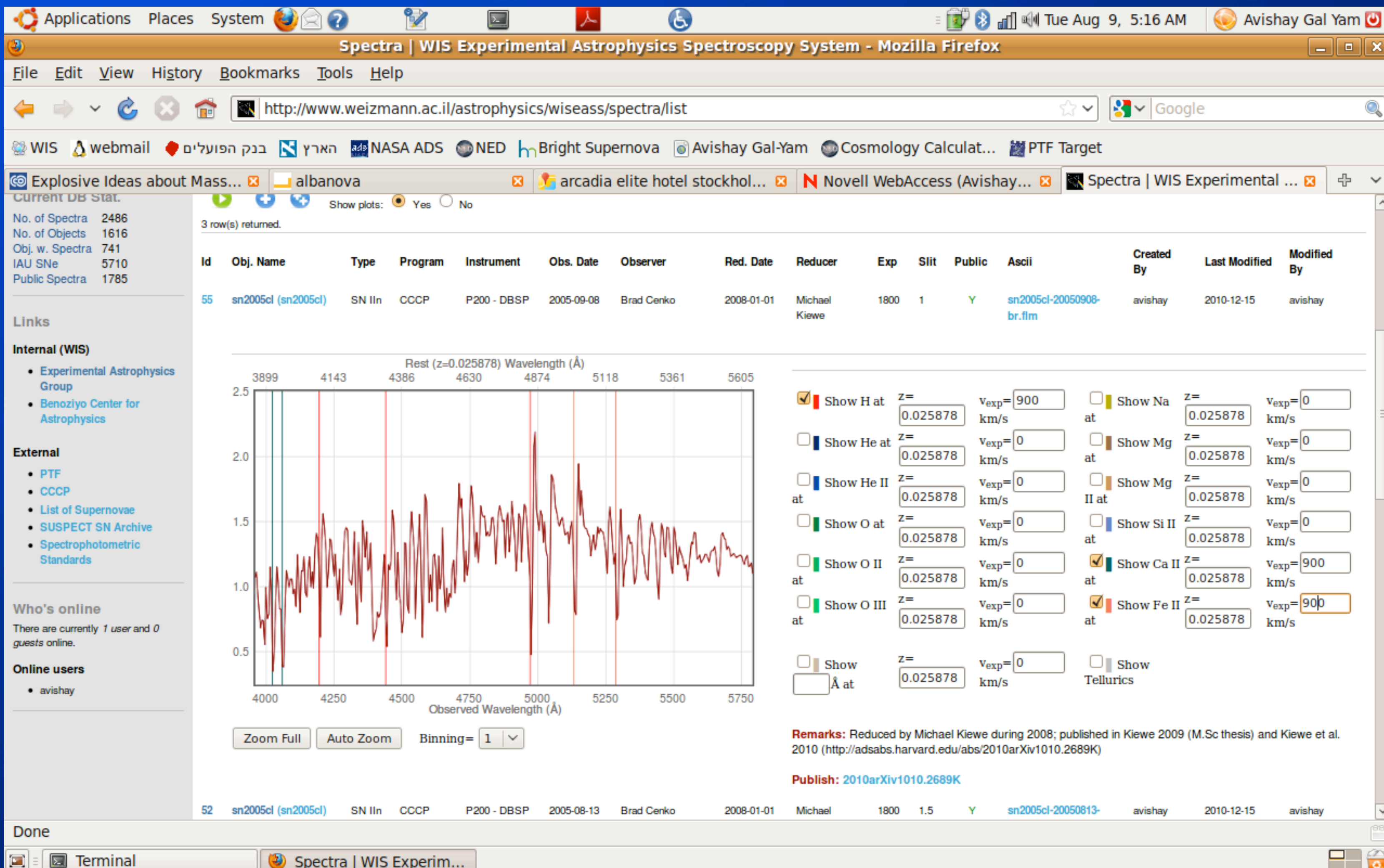

WISEASS:

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Thanks