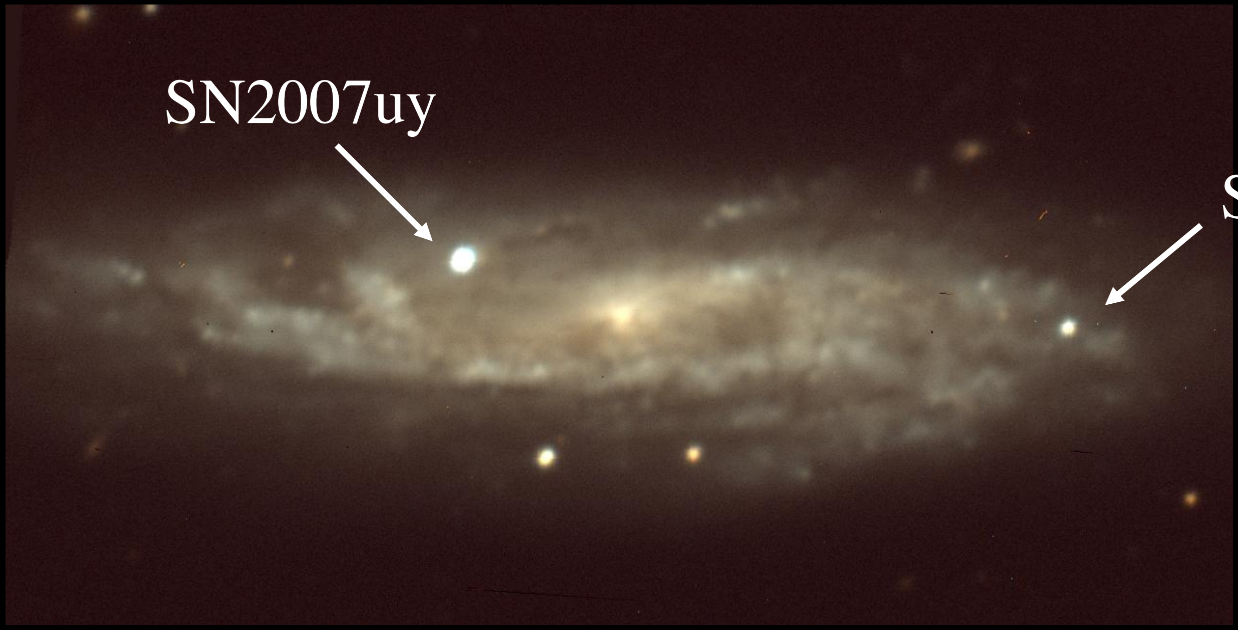
Differences Among SN-GRBs, SN Ic-bl and SN Ic



Modjaz+09 (Credit: D. Perley, J. Bloom, M . Modjaz, Gemini/NOAO)

Maryam Modjaz
(New York University)

Fellow Stellar Death Detectives

t

- **Harvard-CfA: Bob Kirshner**

  H. Marion, M. Hicken, S. Blondin, P. Challis, M. Wood-Vasey, A. Friedman
- K. Z. Stanek (Ohio State), J. L. Prieto (Carnegie-Princeton), T. Matheson (NOAO), L. Kewley (Hawaii), P. Garnavich (Notre Dame), J. Greene (Princeton)
- **UC Berkeley: Alex Filippenko, Josh Bloom**, N. Butler, R. Chornock, R. Foley, A. West, D. Kocevski, W. Li, A. Miller, M. Ganeshalingam, D. Perley, D. Poznanski, J. Silvermann, N. Smith, D. Starr, P. Kelly
- **PTF:** Avishay Gal-Yam, Iair Arcavi, +PTF team
- **NYU:**

Federica Bianco

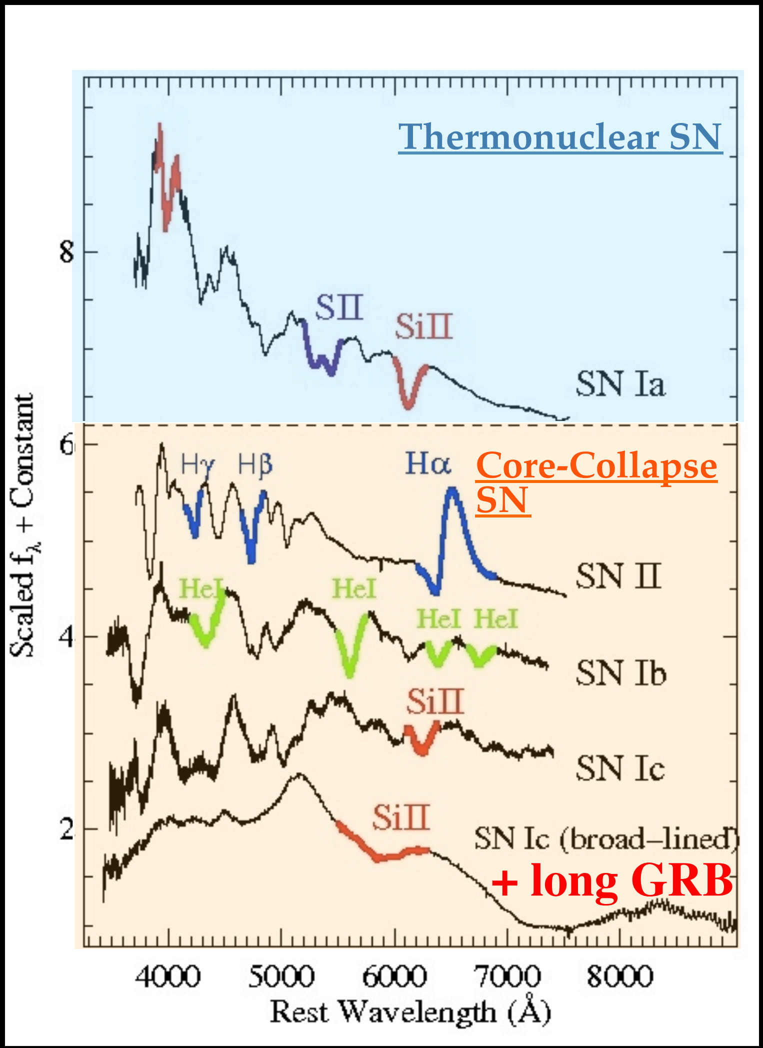
Yuqian Liu

David Fierroz

Or Graur

SN ZOO

- **Spectra:** Type I (without H) and Type II (with H)



+Hydrogen-rich SNe (SN IIL, IIn, IIb)

+ Exploding Zoo:
Superluminous SNe (SLSN)

See S. Smartt's & L. Dessart's talks

Broad lines:large expansion velocities (~30,000 kms^{-1})

large $E_{kinetic}$(10^{52} erg)

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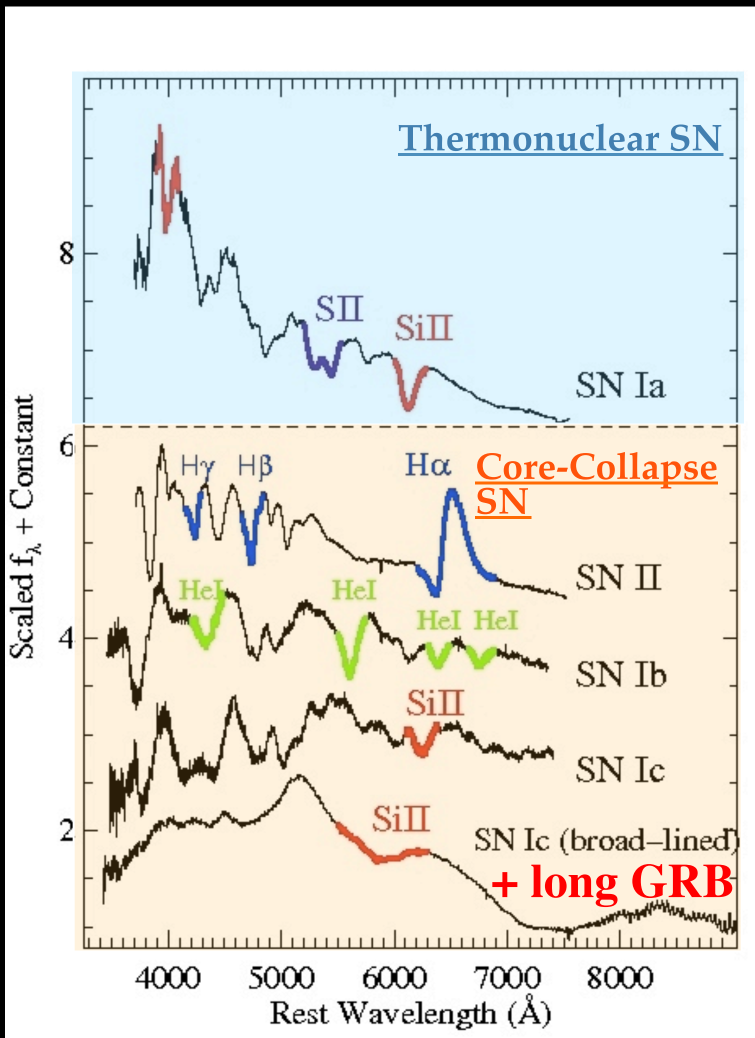
SN ZOO

- **Spectra:** Type I (without H) and Type II (with H)



+Hydrogen-rich SNe (SN IIL, IIn, IIb)

+ Exploding Zoo:
Superluminous SNe (SLSN)

Stripped-Envelope SN

See S. Smartt's & L. Dessart's talks

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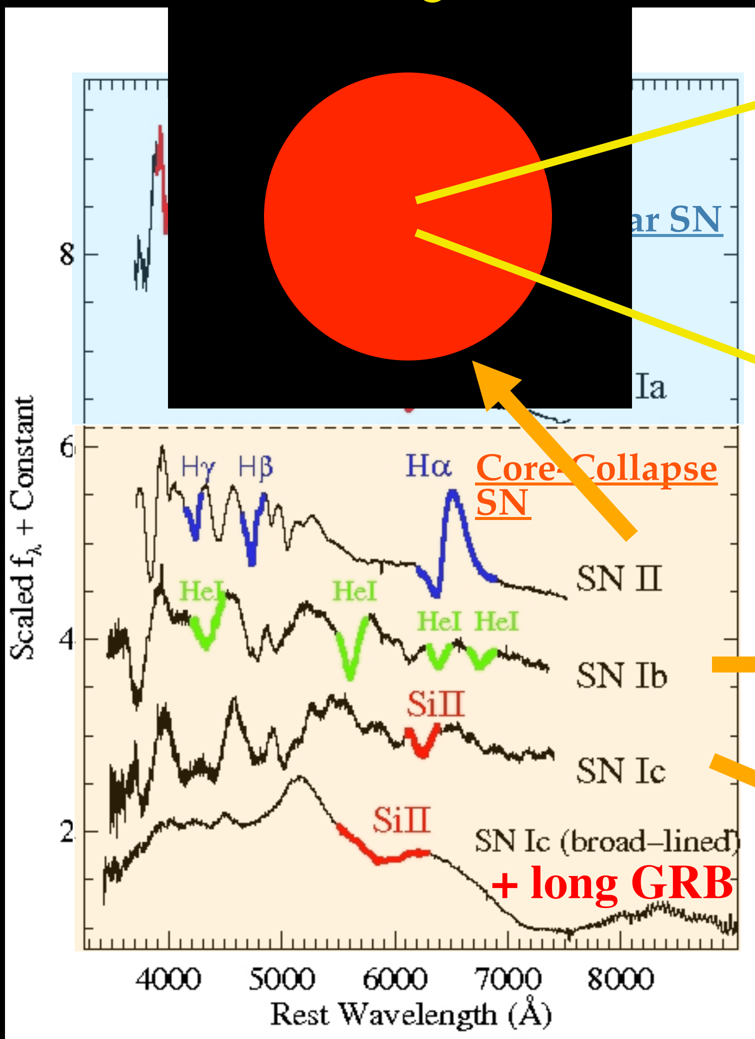
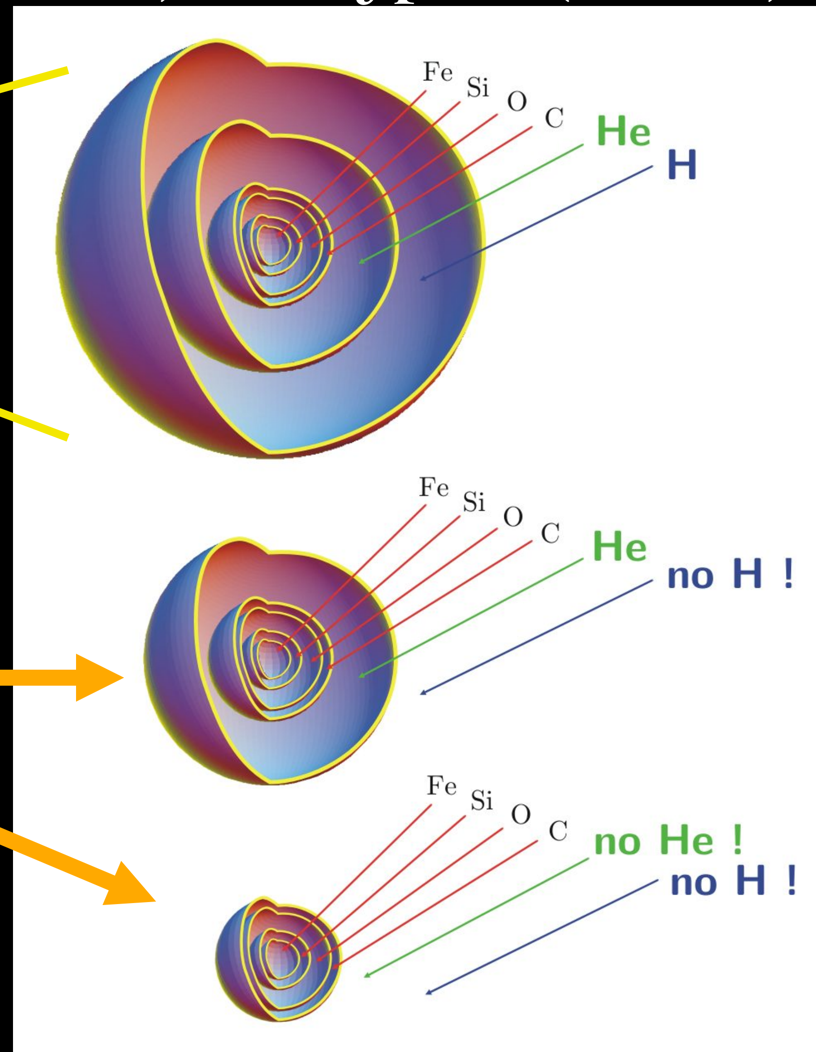
SN ZOO

- >~8 M$_\odot$ ... e I (without H) and Type II (with H)





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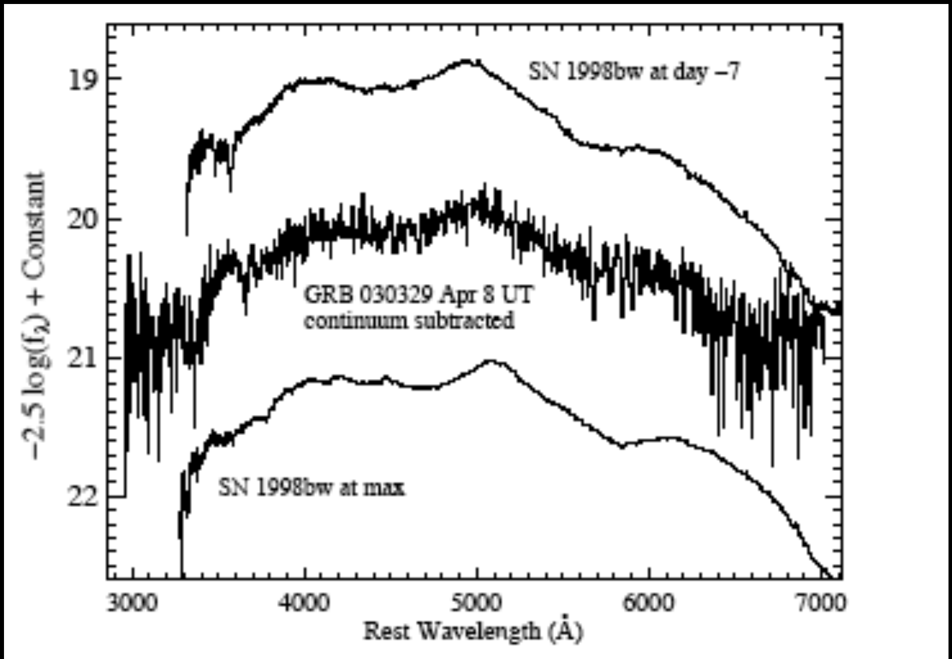
SN-GRB Connection

1998-2013: ~dozen of solid SN-GRBs with **Spectroscopic IDs:** **broad-lined SN Ic**

(0.0085 < z < 0.6)



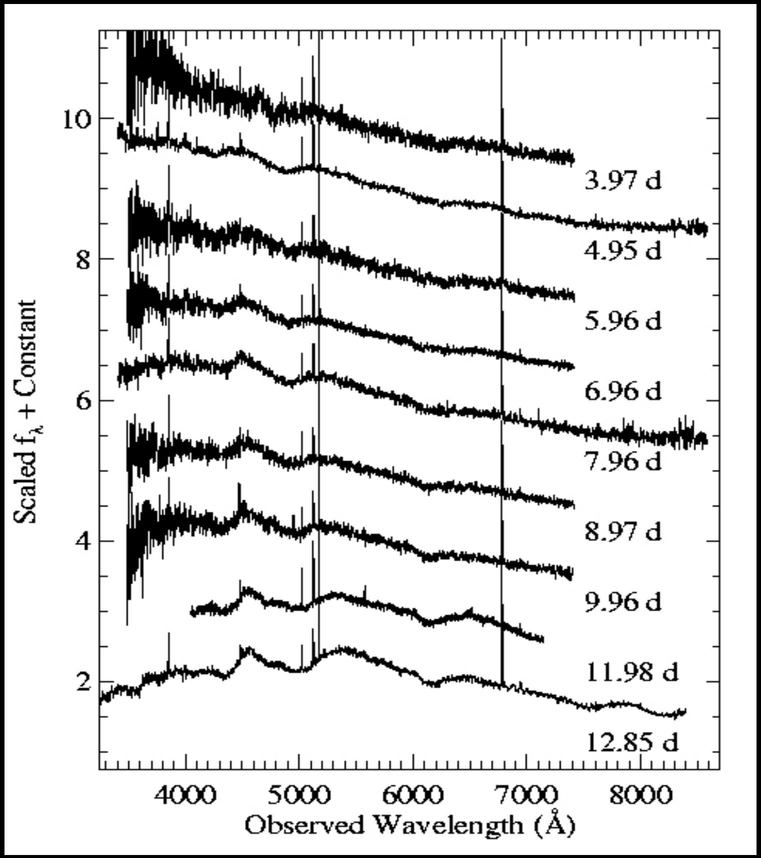
Stanek et al. (2003), Matheson et al. (2003), see also Hjorth et al. (2003)

see Reviews: Woosley & Bloom (2006), Hjoerth & Bloom (2011), Modjaz (2011)

SN-GRB Connection

1998-2013: ~dozen of solid SN-GRBs with **Spectroscopic IDs: broad-lined SN Ic**

(0.0085 < z < 0.6)



Modjaz et al. (2006)

SN-GRB Connection

1998-2013: ~dozen of solid SN-GRBs with Spectroscopic IDs: broad-lined SN Ic
(0.0085 < z < 0.6)

- Most recent SN-GRBs: Similar SN Ic-bl for huge range of GRB luminosities (5 orders)

• Many (~45/60) broad-lined SN Ic have NO observed GRB

• Probably not off-axis GRBs (e.g., Soderberg et al. 2006)

-> Successful GRBs need special conditions

GRB*	SN	Redshift
1) 980425	**1998bw**	**0.0085**
2) 030329	**2003dh**	**0.1685**
3) 031203	**2003lw**	**0.1006**
4) 050525A	2005nc	0.606
5) 060218	**2006aj**	**0.0335**
6) 081007	2008hw	0.5295
7) 091127	2009nz	0.490
8) 100316D	**2010bh**	**0.0593**
9) 101219B	2010ma	0.55
10) 120422A	2012bz	0.283
11) 130427A	2013cq	0.3399

GRB	SN	Redshift
111211A	?	0.478
120714B	2012eb	0.398
130702A	2013dx	0.145

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UNDERSTANDING SNe Ic WITH AND WITHOUT GRBs

- **Focus on Stripped SNe with and without GRBs to elucidate conditions and progenitors of different types of explosions**
- **2-thronged approach:**
  1) **<u>Explosion properties:</u> spectra & light curves**
  2) **<u>Host galaxies:</u> metallicities at SN & GRB sites & SF conditions**

"Large" data-sets: robust statistical analysis
constraints on SN-GRB central engine & progenitors

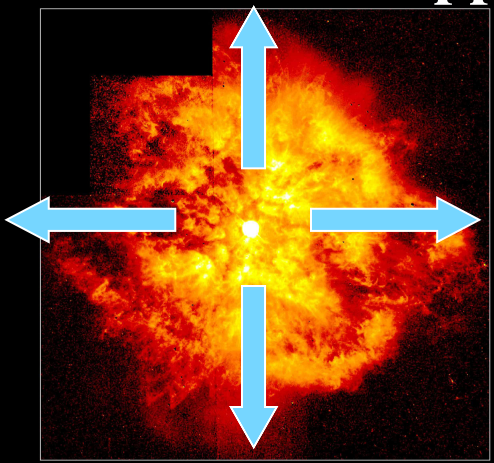
UNDERSTANDING SNe Ic WITH AND WITHOUT GRBs

- **Focus on Stripped SNe with and without GRBs to elucidate conditions and progenitors of different types of explosions**
- **2-thronged approach:**
  1) **Explosion properties: spectra & light curves**
  2) **Host galaxies: metallicities at SN & GRBs sites & SF conditions**

CONCLUSIONS: SN Ic-bl (with and without GRBs) are different from SN Ic -> different progenitors

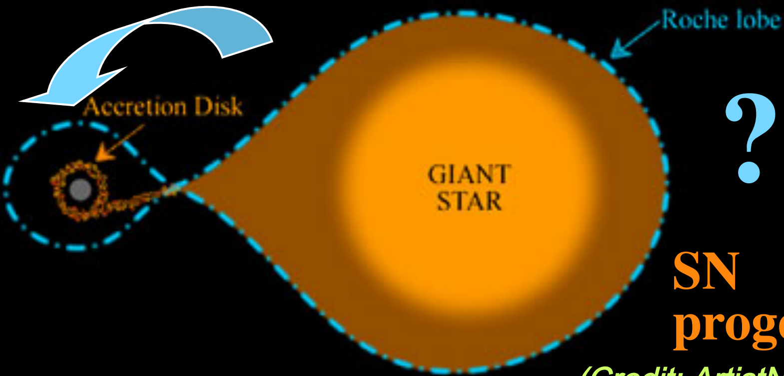
Stellar Forensics: Hunt For Progenitors

Stripped SN & SN-GRB progenitors:



(Credit: Hubble/ NASA)

or



?

SN progenitor

(Credit: ArtistNASA)

Single massive (> 30 $M_\odot$) Wolf-Rayet stars with metallicity-dependent winds (or eruptions) (e.g., Woosley et al. 1995, Maeder & Conti 2004, but see Smith & Owocki)

He stars (8-40 $M_\odot$) in binaries, runaway binaries (e.g,. Podsiadlowski +04)

-> Binaries are common: ~70% interacting! (Sana, deMink et al. 2012)

See P. Podsiadlowski's talk

Importance of Stripped SN & GRB progenitors!

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Stellar Forensics: Hunt For Progenitors

Direct Study:

NO progenitor detections for ~10 SN Ib, Ic, Ic-bl (e.g. Smartt09)

->not conclusive (Bibby+12, Yoon+12)

-> Need for more indirect, statistical studies!

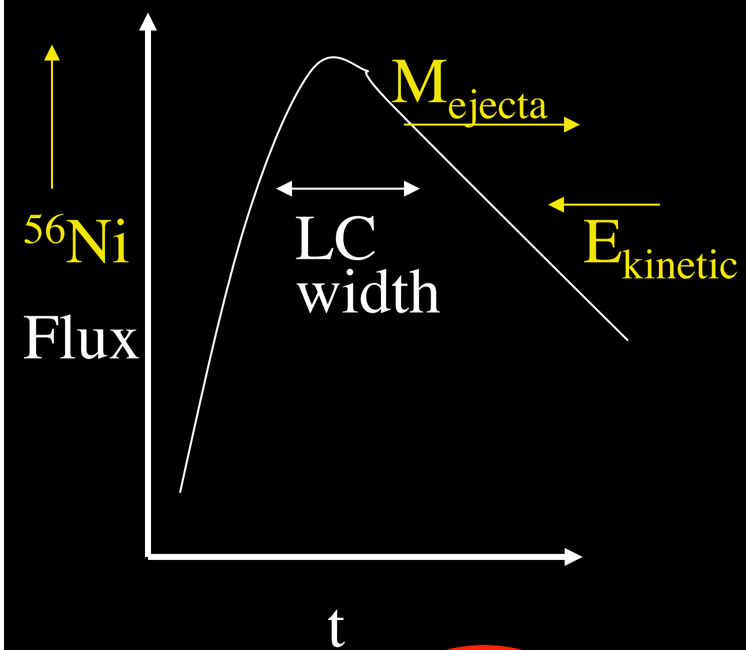
1) From Explosion Properties:

- Optical & NIR light curves & spectra (Drout+11, Cano+13, Bianco, Modjaz et al. in prep)
- (SN Shock breakout & Envelope-Cooling [e.g, Campana+06, Soderberg+08, Modjaz+09, Arcavi+11, etc]) -> R. Sari's talk

Light curves

“Arnett-Model”:
Type SN I (no H):

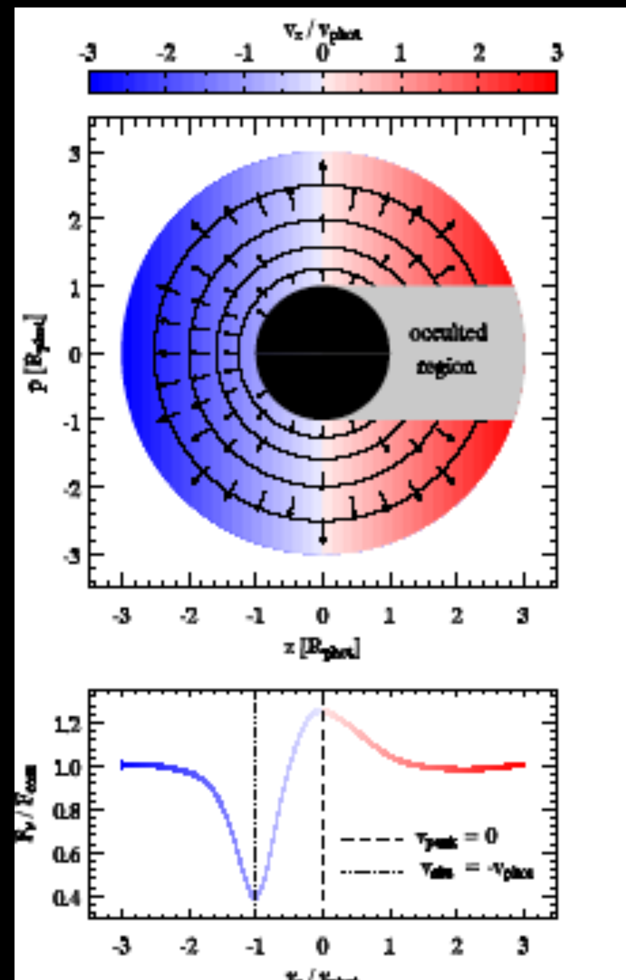
$$^{56}Ni \xrightarrow[6.6d]{\gamma} {}^{56}Co \xrightarrow[78d]{\gamma} {}^{56}Fe$$



LC width ∝ M_{ejecta} $E_{kinetic}^{-3}$

Spectra

See C. Fryer’s & L. Dessart’s talks



P Cygni: Blue absorption, Red emission

Credit: S. Blondin

velocity ∝ $M_{ejecta}^{-1/2}$ $E_{kinetic}^{1/2}$

From Light curves (no spectra)

Drout+11 : 25 SN Ib, Ic, Ic-bl with Palomar 60

SN Type	$M_{V_{peak}}$ (mag)	$M_{R_{peak}}$ (mag)	M_{Ni} ($M_\odot$)
SNe Ib	-17.6 ± 0.9	-17.9 ± 0.9	0.20 ± 0.16
SNe Ic	-18.0 ± 0.5	-18.3 ± 0.6	0.24 ± 0.15
SNe Ic-BL	-18.3 ± 0.8	-19.0 ± 1.1	0.58 ± 0.55
3 Engine-driven SNe	-18.9 ± 0.3	-18.9 ± 0.4	0.40 ± 0.18

(i) Median ejecta masses:

(a) Ib: $M_{ej} \sim 3.9\,M_\odot$
(b) Ic: $M_{ej} \sim 3.4\,M_\odot$
(c) Ic-BL: $M_{ej} \sim 3.9\,M_\odot$
(d) GRB/XRF: $M_{ej} \sim 6.0\,M_\odot$.

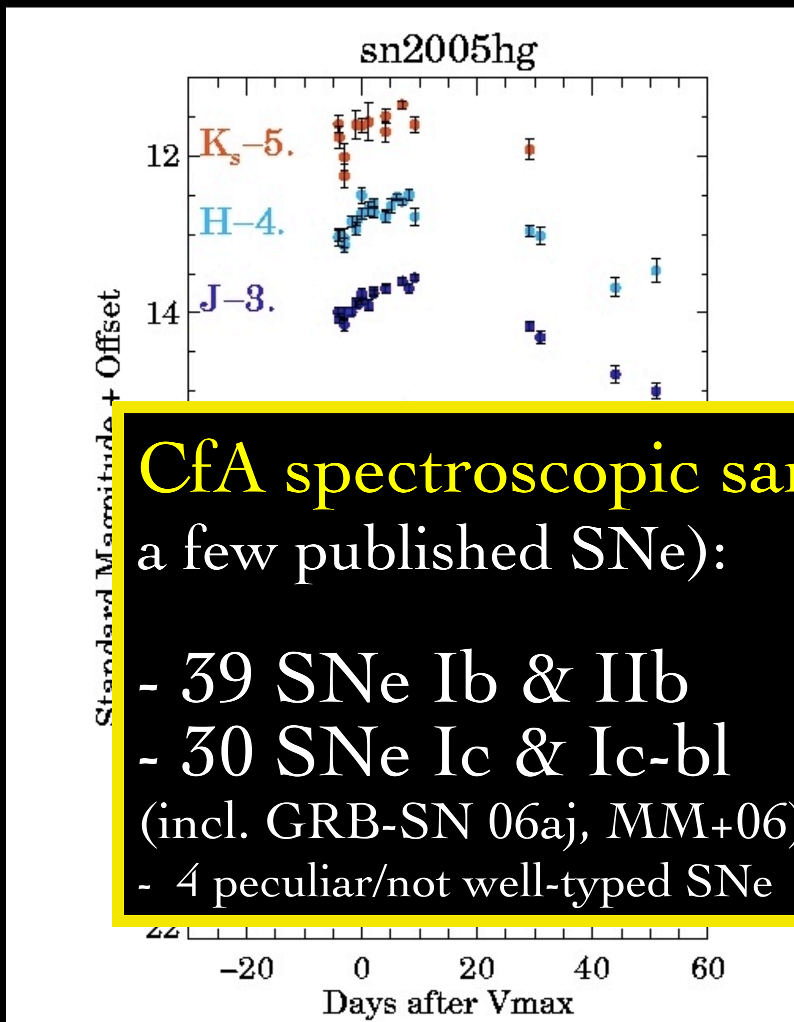
(ii) Median nickel masses:

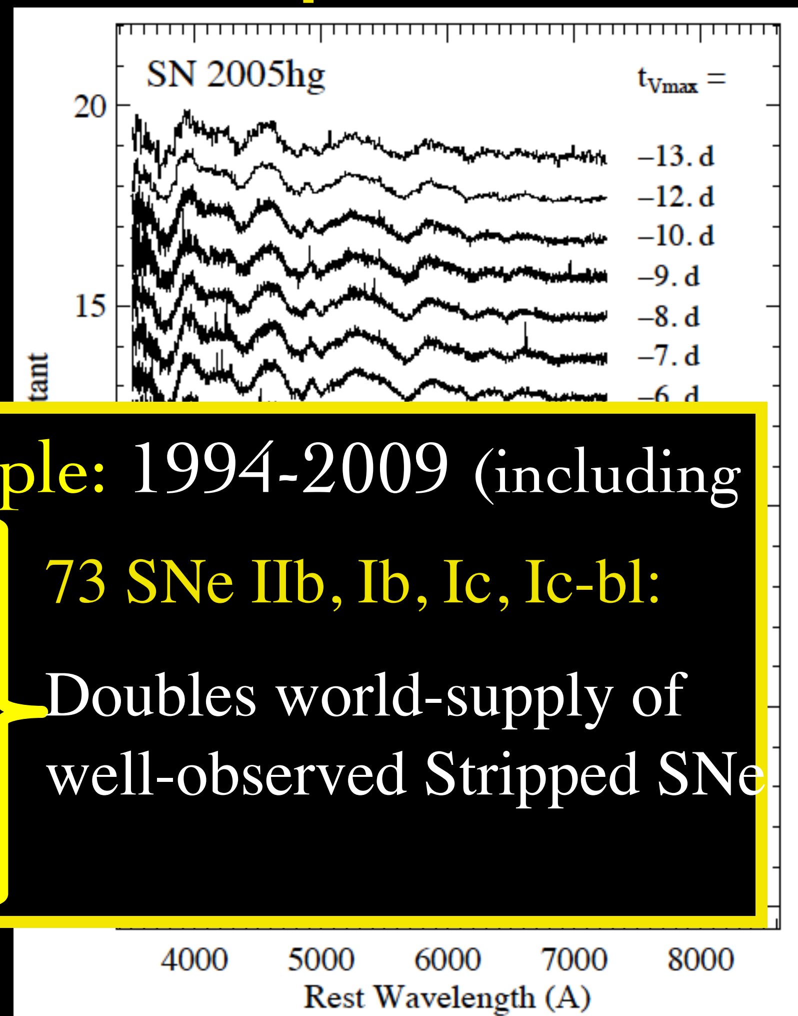
(a) Ib and Ic: $M_{Ni} \sim 0.15$–$0.18\,M_\odot$
(b) Ic-BL: $M_{Ni} \sim 0.25\,M_\odot$
(c) GRB/XRF: $M_{Ni} \sim 0.3$–$0.35\,M_\odot$.

Cano+13: literature data (20 GRB/XRFs, 19 Ib, 13 Ic, 9 SN Ic-bl)

SN Ic-bl & GRBs: larger peak mag (i.e., ^{56}Ni mass) than SN Ic by factors of 2-3

CfA Stipped SN Sample: Extensive LC & Spectra





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CfA spectroscopic sample: 1994-2009 (including a few published SNe):

- 39 SNe Ib & IIb
- 30 SNe Ic & Ic-bl

(incl. GRB-SN 06aj, MM+06)

- 4 peculiar/not well-typed SNe

73 SNe IIb, Ib, Ic, Ic-bl:

Doubles world-supply of well-observed Stripped SNe

Stellar Forensics: From Explosions

CfA Stripped SN sample of spectra & light curves:

--> Ejecta masses for SN Ib and SN Ic a) the same

b) low ("~2" M_{sun})!

From literature SN-GRB & GRBs: **higher** (~2x) average M_{ej} (Cano+13)

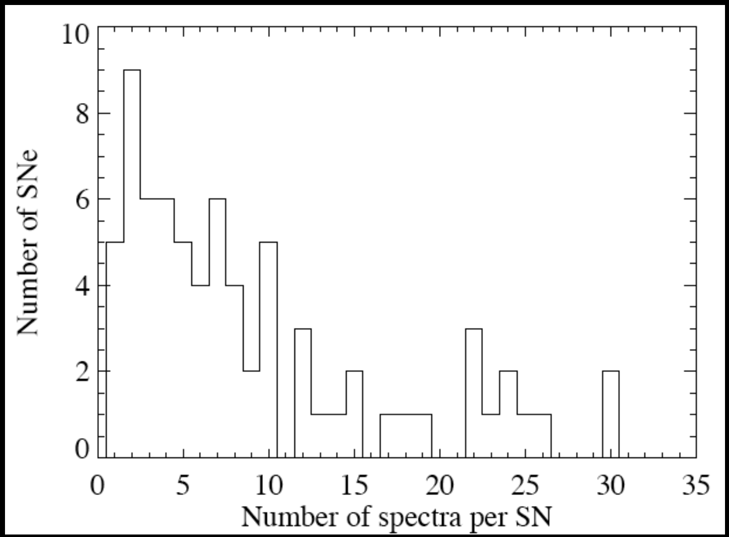
-> binaries!?

Bianco, Modjaz et al, in prep

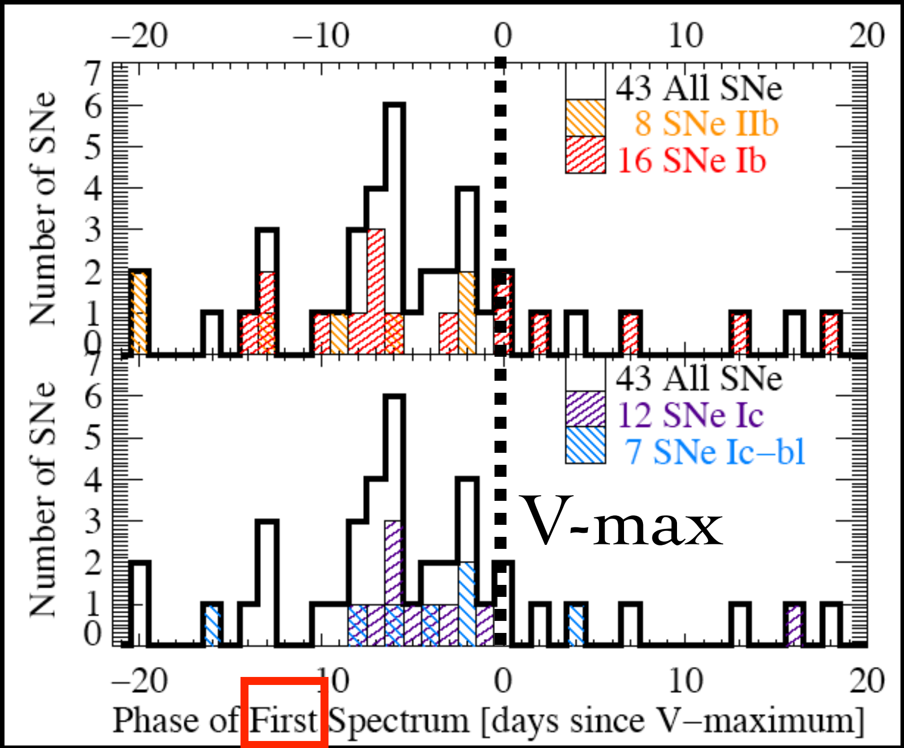
Modjaz et al. 2014: extensive Spectroscopic Data

- SN relatively nearby (<cz>~ 4100 km/s)
- 43 of 73 SNe have measured date of max

Many Spectra: Total of 645, $<N_{spec}>$= 10 spec/SN -> important for SN classification & progenitor nature



Many Early Spectra (before max)



Modjaz et al. (2014, AJ, in press)

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Mean Spectra: Typical SN

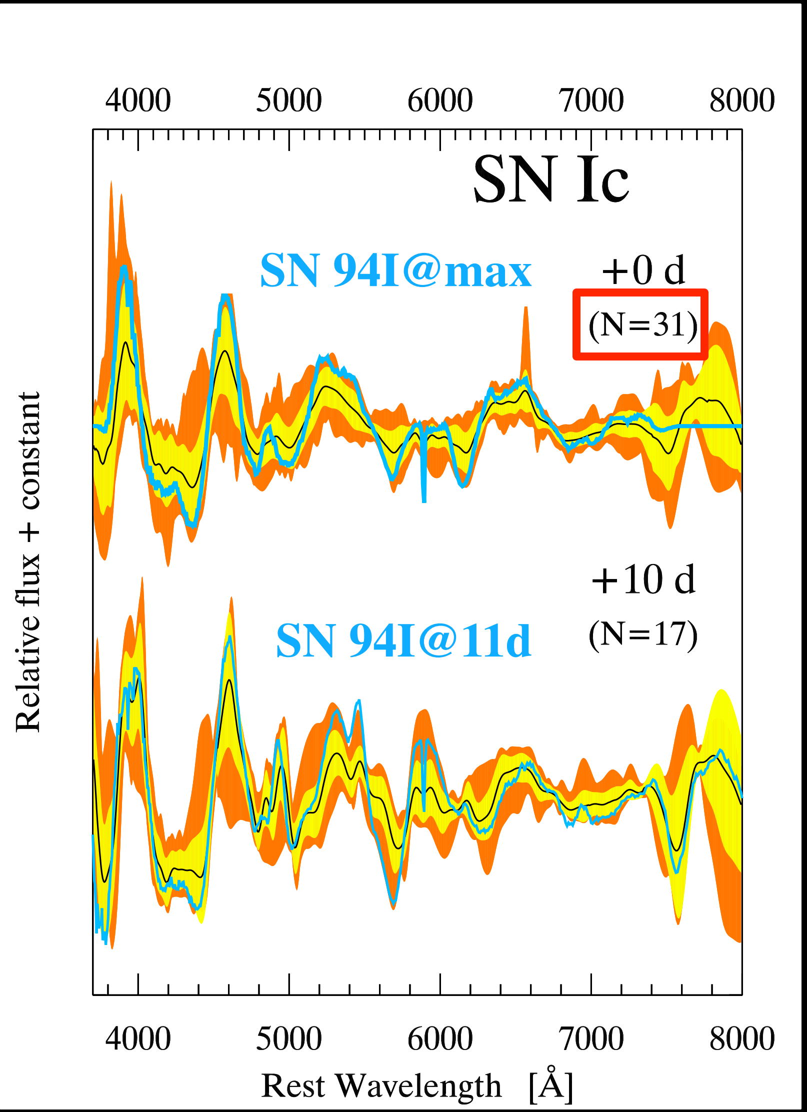
SNIDified (S. Blondin & Tonry 2007): continuum removed

std dev
max dev

Line widths:

- **SN Ic @ +0d: ~7000-15,000 km/s**

- **SN94I is NOT a typical SN Ic**



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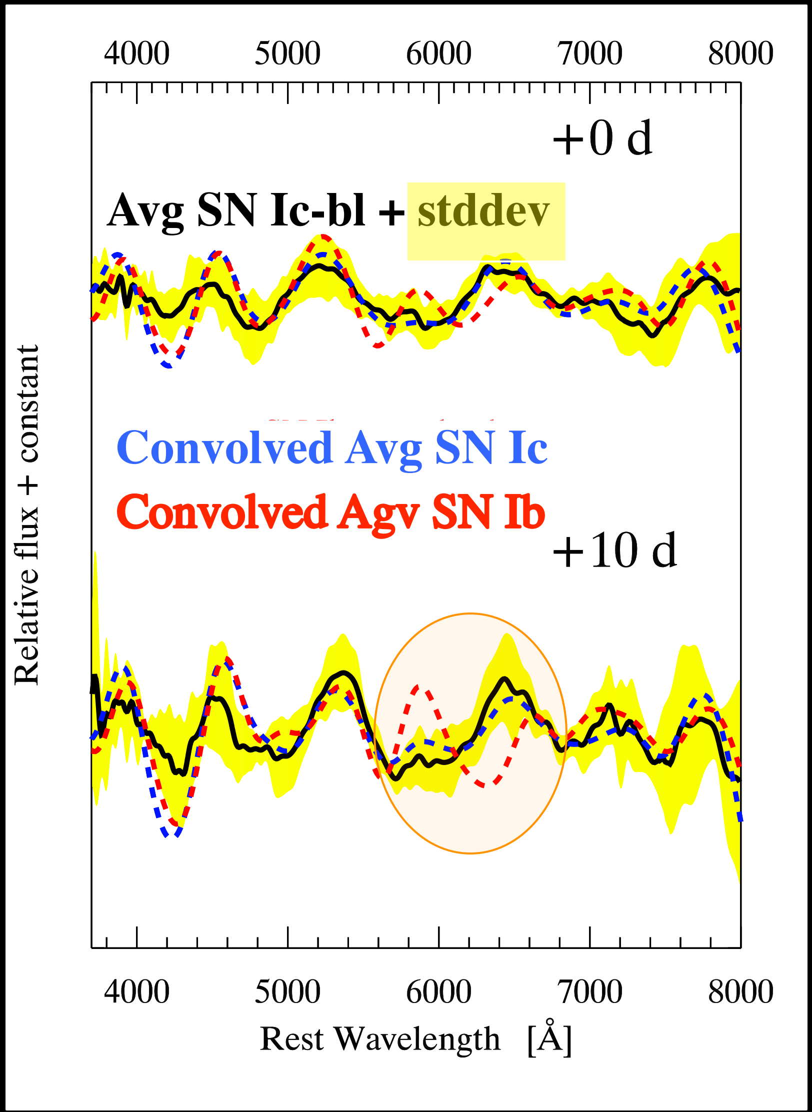
Modjaz et al. (in prep)

SN Ic-bl are NOT hiding Helium

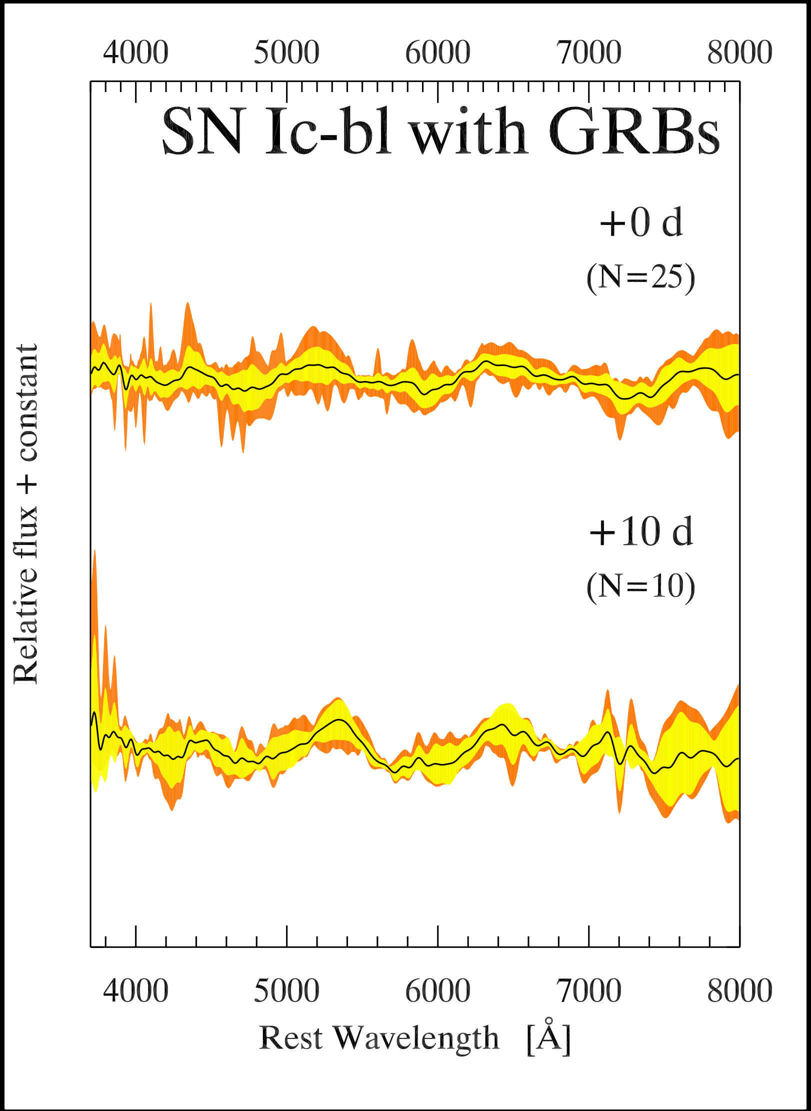
SN Ic convolved with ~15,000 km/s Gaussian + blueshifted by 3000 km/s =~ **SN Ic-bl**



-> **SN Ic-bl** spectra: most likely no smeared-out Helium !

SN Ic-bl with and without GRBs

SN Ic-bl with GRBs: broader spectra than SN Ic-bl without observed GRBs



Reasons:

- **choked, lower energy jet in SN Ic-bl?**
- **viewing angle effect?**
- **Implications for “donut magnetars”**

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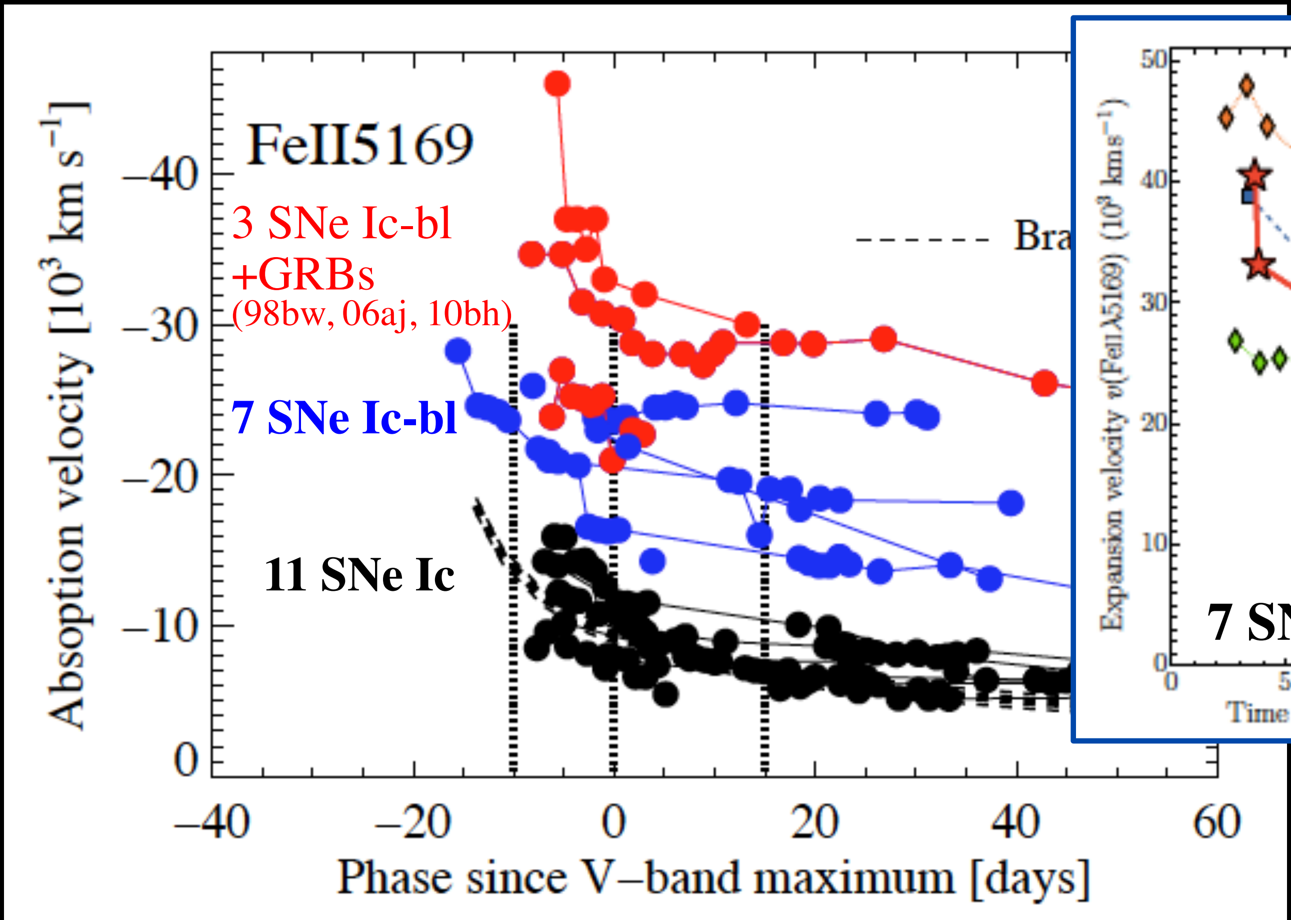
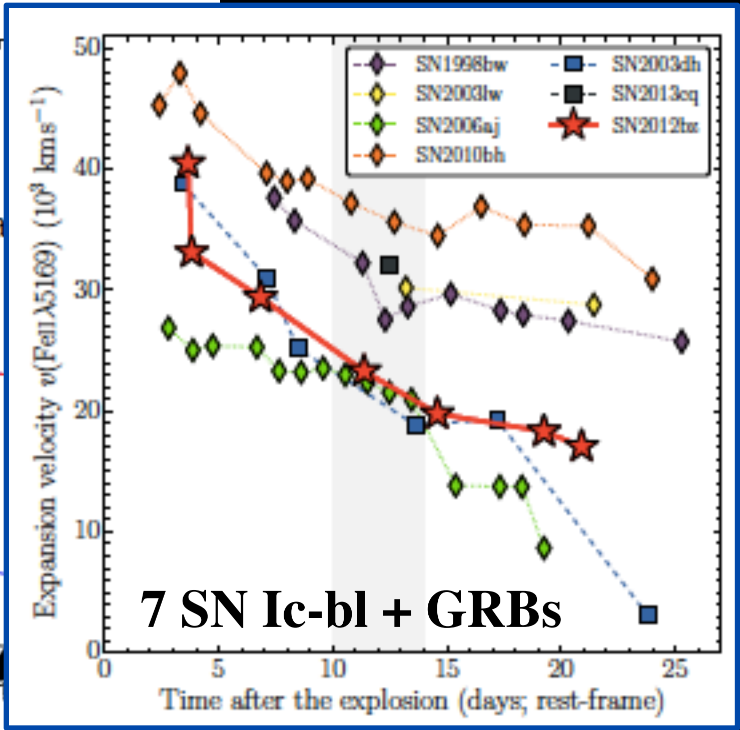
SN Ic-bl with and without GRBs

Modjaz et al. (in prep)

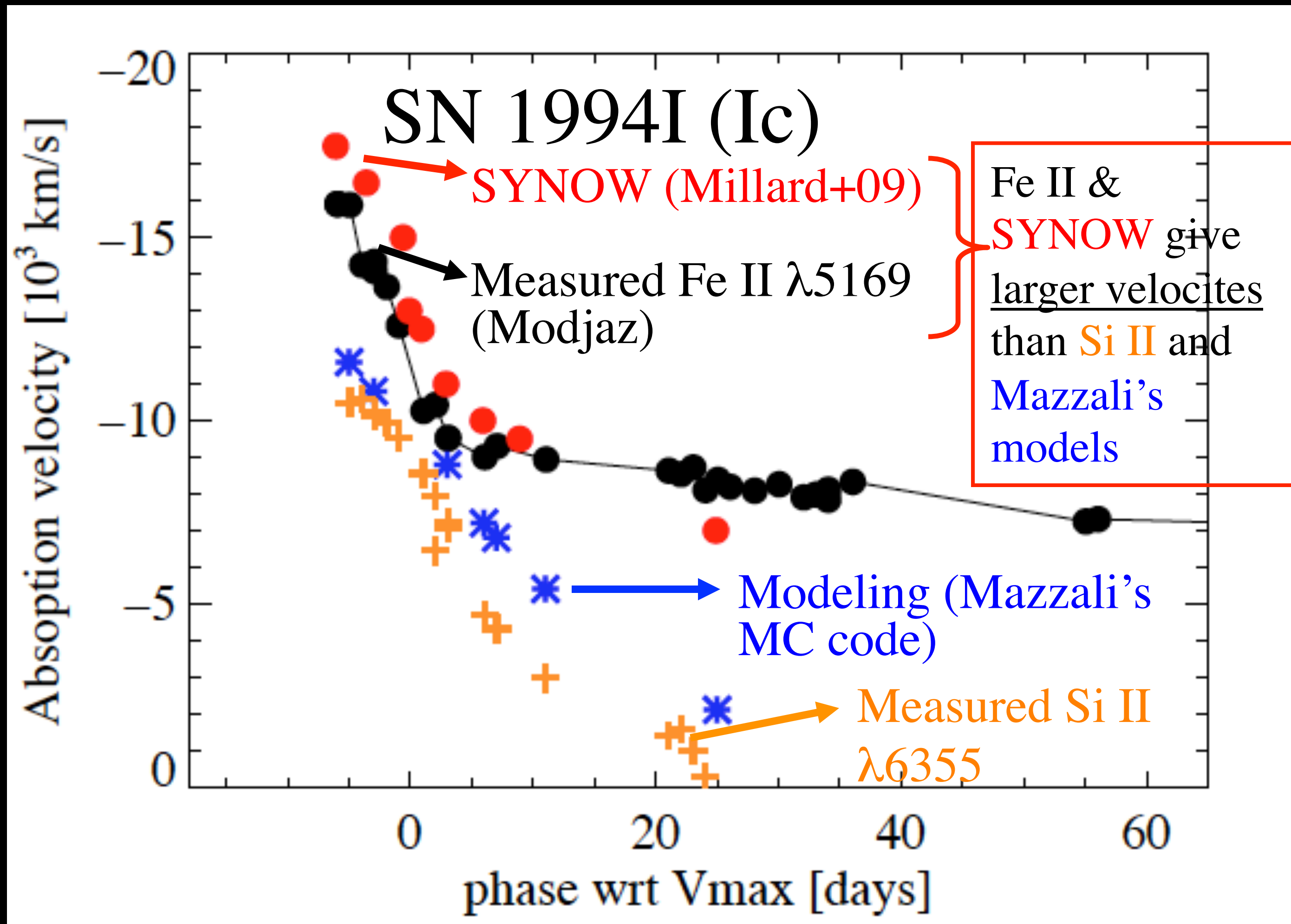
Schulze+14 (astro-ph)

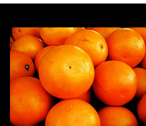




Caveat: blending for SNe Ic-bl!

"Velocity" depends on Method



Compare  to  :

Choose the same method when comparing velocities of SNe !

Stellar Forensics: Environmental Clues

Direct Study:

NO progenitor detections for ~10 SN Ib, Ic, Ic-bl (e.g. Smartt09)

->not conclusive (Bibby+12, Yoon+12)

Statistical Study:

Differentiate between GRB, and Stripped SN progenitor models via observations of environments & host galaxies

3 Methods:

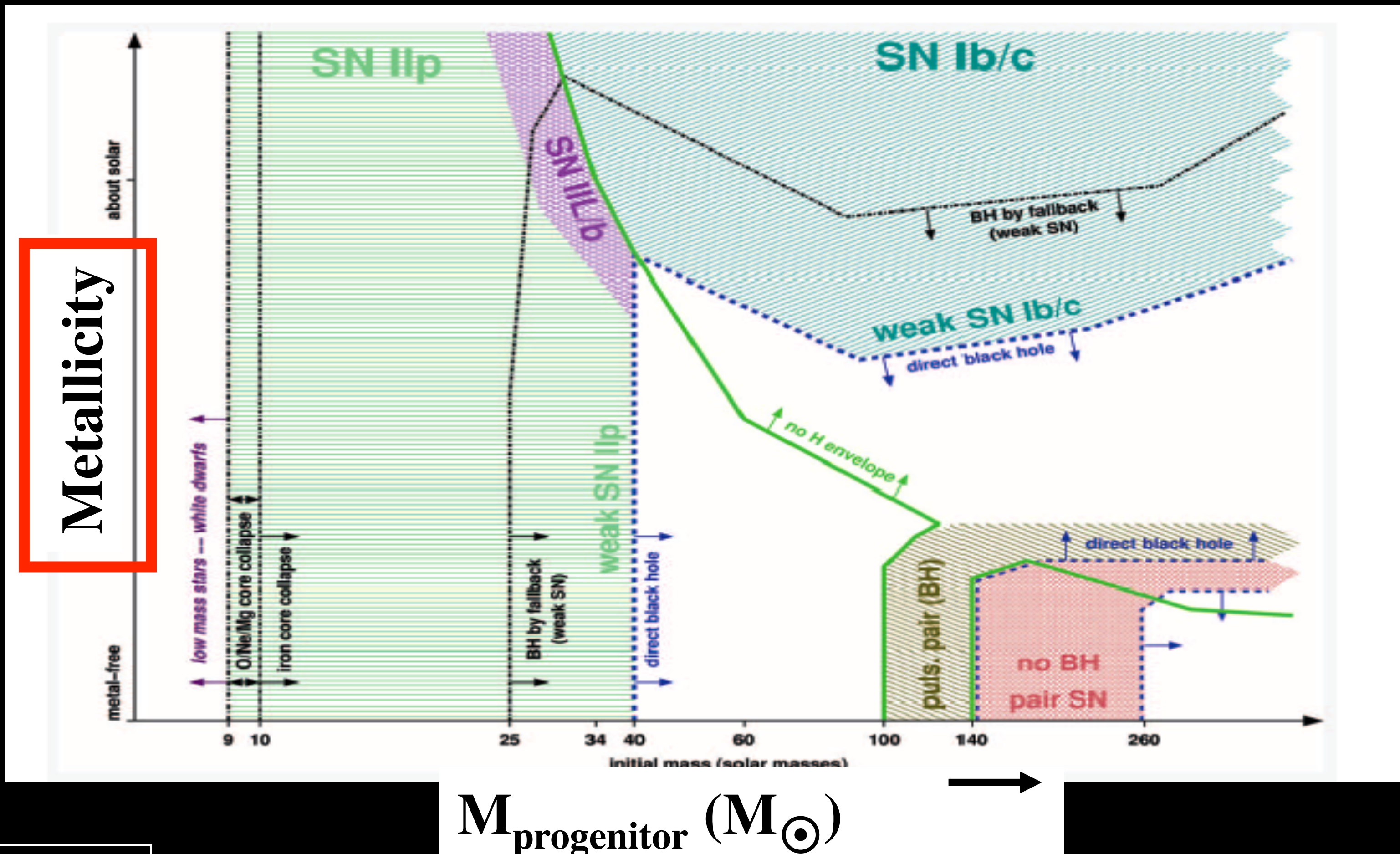
- Proximity to HII regions & Brightest Blue regions
- Measured metallicity
- Host galaxy SF conditions

Star's Mass & Metallicity is important

- Massive stars at different Z: different amount of
  - mass loss
  - core angular momentum (e.g. for both GRB collapsar and magnetar model **[Woosley (1993), MacFadyen & Woosley (1999), Yoon & Langer (2005)]**)

See S.-C. Yoon's talk

Star's Mass & Metallicity is important



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See S.-C. Yoon's talk

THEORY: Heger et al (2003)

[also O' Connor & Ott (2011), Dessart, O' Connor & Ott +12]

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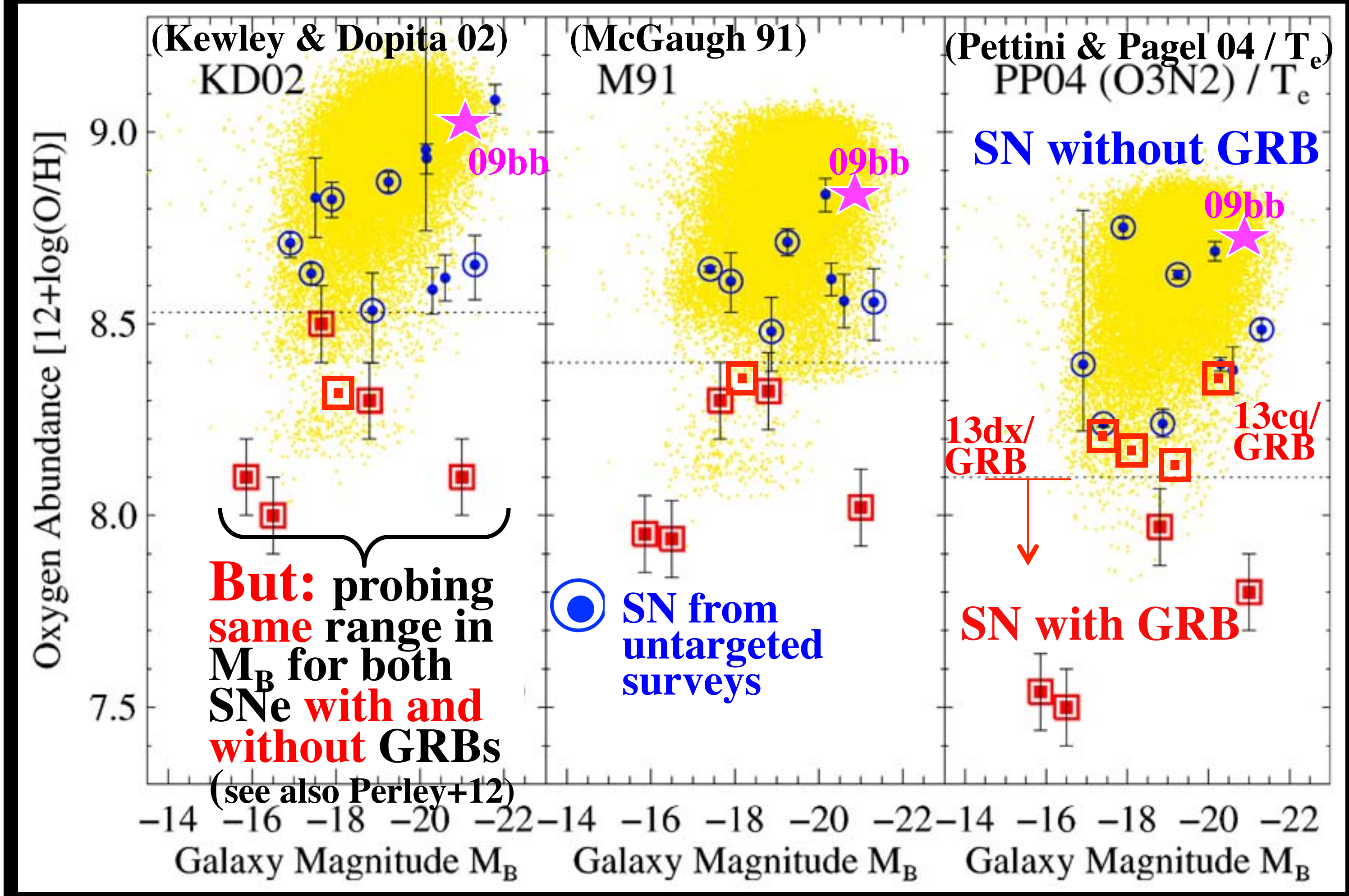
Definition of "Metallicity"

- Metallicity = Oxygen abundance in HII regions from emission lines [$12+\log_{10}(O/H)$]
- Why Oxygen?
  - Most abundant metal in the universe
  - Weakly depleted onto grains
  - Dominant coolant (besides H): strong nebular lines in optical
- Need to be very careful
  - Systematic differences offsets b/w diagnostics (e,g. Kewley & Dopita (2002), Pettini & Pagel (2004), Tremonti et al. 2006
  - Spectra at position of SN or GRB of HII regions to get ~natal Z

Metallicities at the Sites of SN Ic-bl with and without GRBs

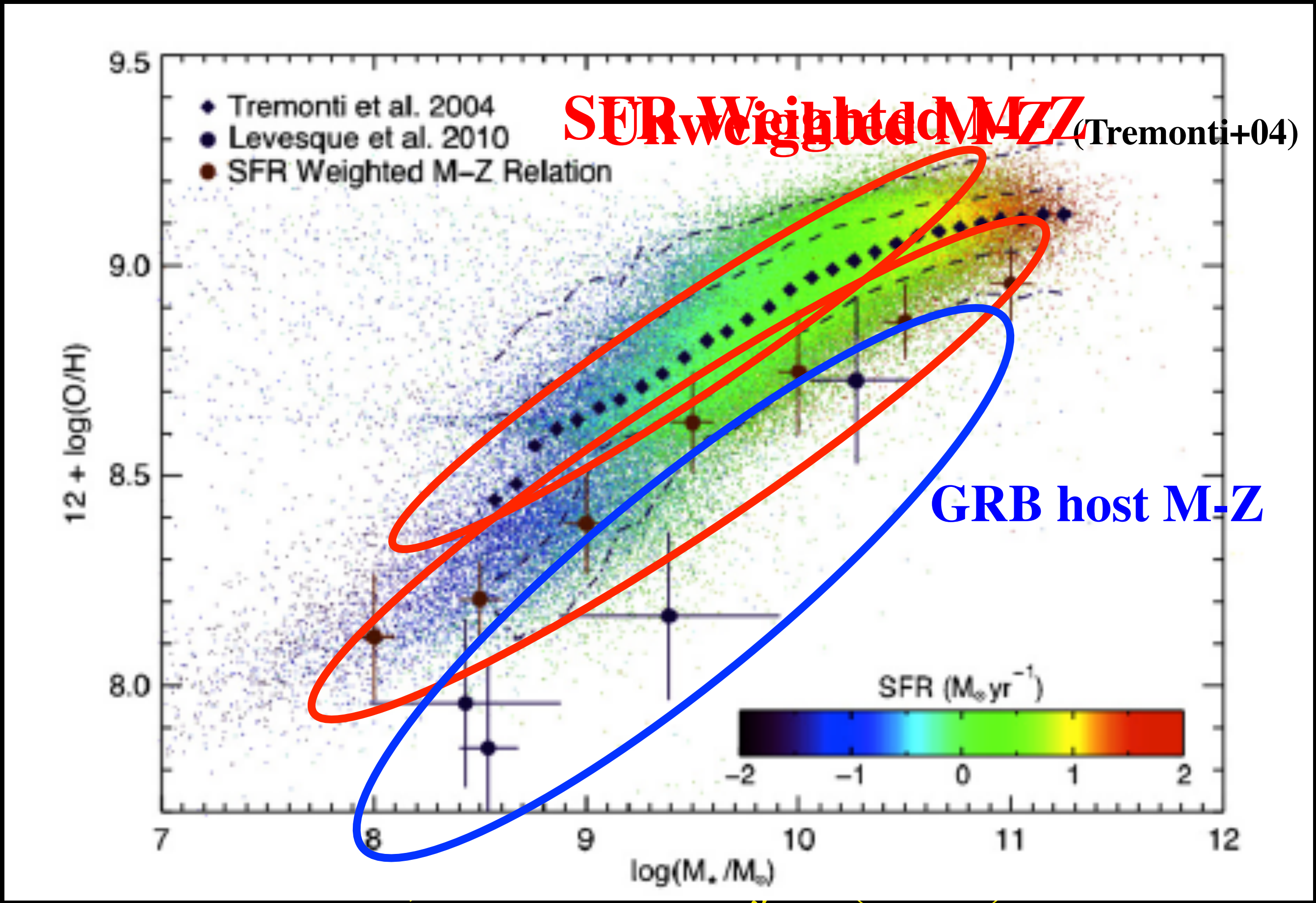


Reason(s):

- Low Z GRB progenitor? (Yoon & Langer 05, Woosley & Heger 06)
- Dust? (Fynbo +10, Perley+10, ..)
- Star formation effect? (Mannucci +10, Koveski & West 11,)

Updated Modjaz et al (2008): For 10bh/100316D: Chornock +11, Starling+ 11, Levesque+11; for 98bw's PP04: Christensen+08, 12bz: Levesque+12, 13cq: Xu+13, 13dx: Kelly+13 SN2009bb: Levesque+10

Metallicity: Causation or Correlation?



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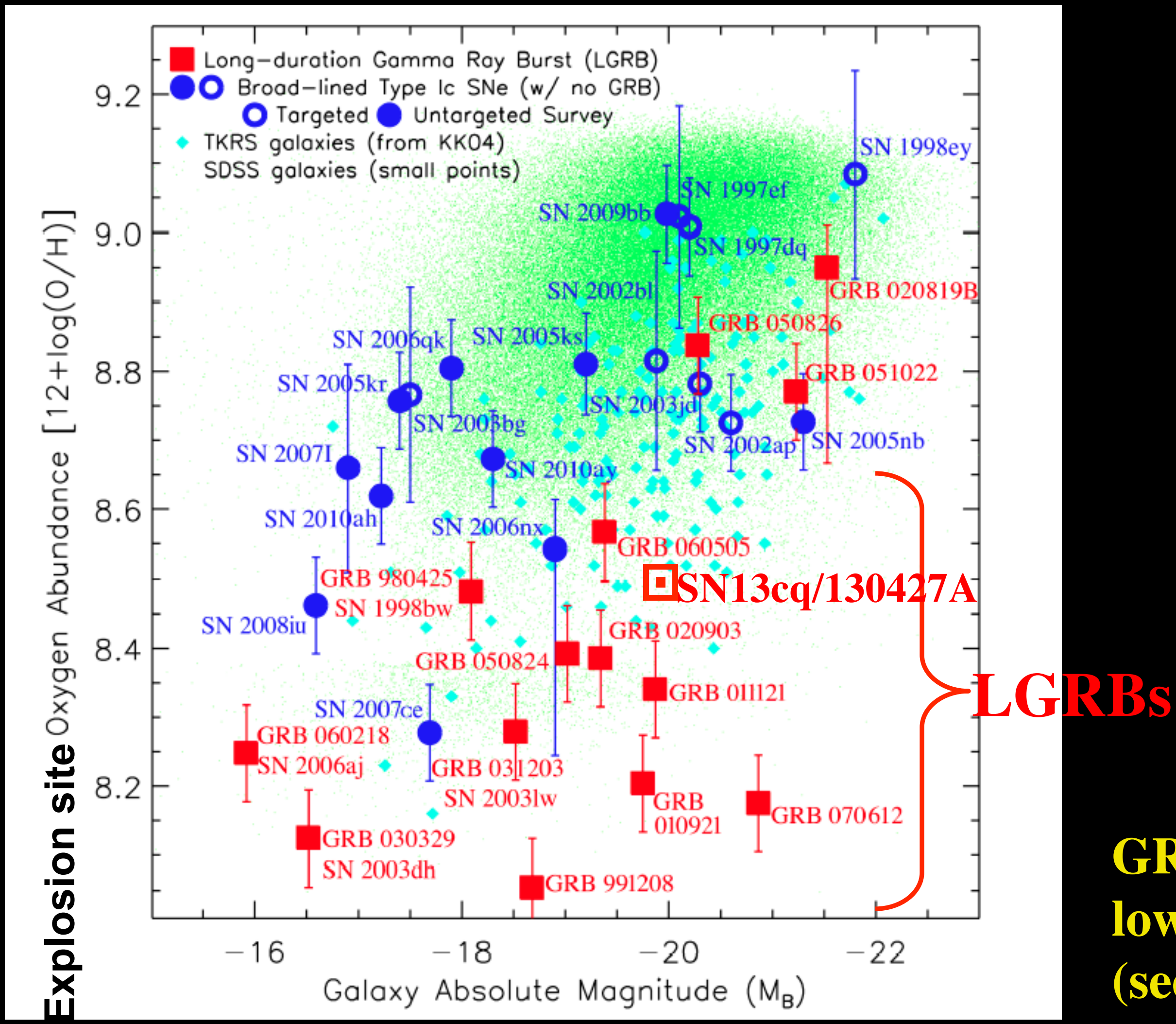
Kocevski & West (2011): SFR weighting not enough to explain GRB host M-Z's offset to low Z (see also Kocevski, West & Modjaz 2009)

Metallicity: Causation or Correlation?



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- Low Z GRB progenitor? (Yoon & Langer 05, Woosley & Heger 06)
- Dust? (Fynbo +10, Perley+10, ..)
- ~~Star formation effect? (Mannucci +10, Koveski & West 11,)~~

GRB are systematically at low Z, but not exclusively (see also Levesque+12)

Graham & Fruchter 13

Xu+13 (for 13cq/GRB130427A)

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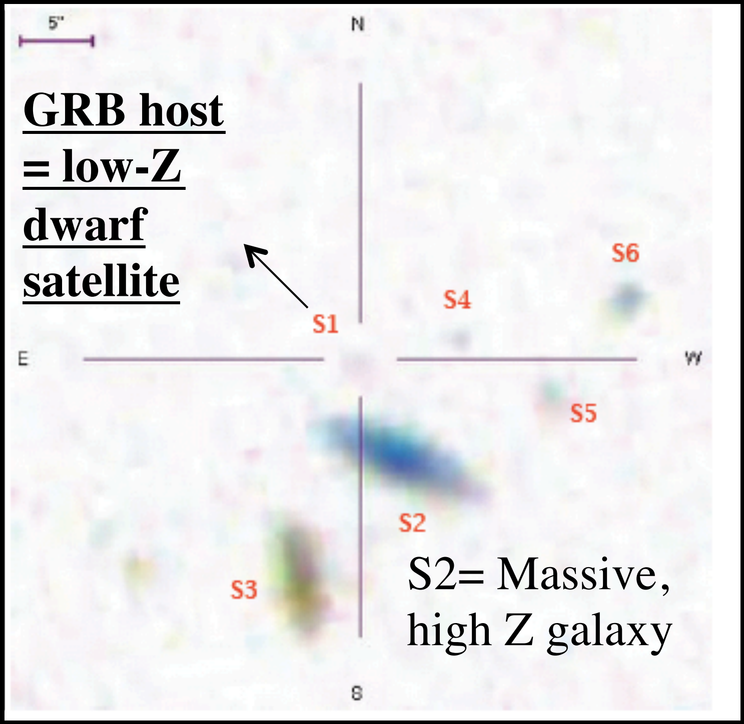
Metallicity: Causation or Correlation?

Word of caution for high-redshift GRB host studies:

Host of SN13dx/GRB130704A



Kelly+13

-> Are the observed high-metallicity “hosts” @higher redshifts really the GRB hosts?

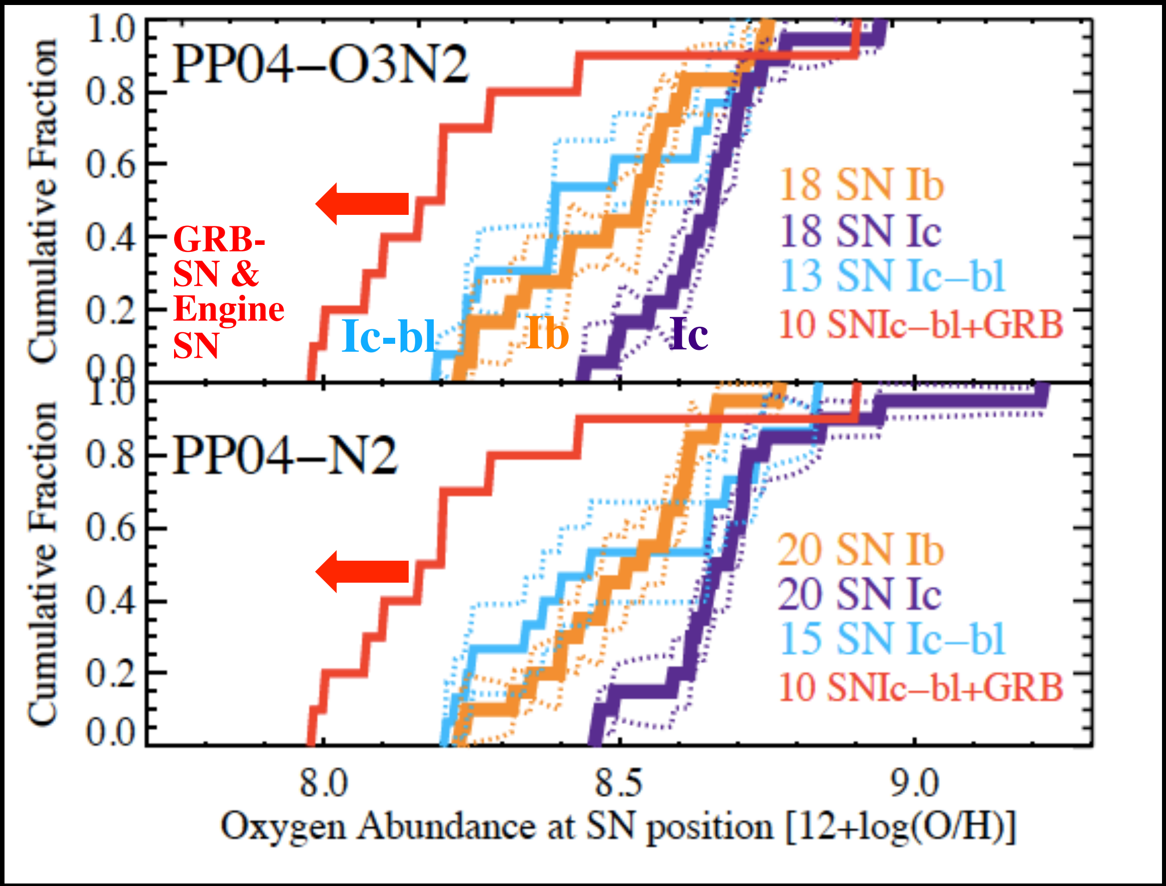
Oxygen abundance @ SN Sites

Meta-analysis:

$Z_{\text{Ic-bl\&GRB}} < Z_{\text{Ic-bl}} < Z_{\text{Ib}} < Z_{\text{Ic}}$

(=Modjaz + 08 &11 & Anderson +10 & Leloudas +11 @SN position

For 10bh/ 100316D:, Levesque+11; for 98bw's PP04: Christensen+08, 12bz: Levesque +12, 13cq: Xu+13, 13dx: Kelly+13 (upper limit)



more metal-rich

Consistent with Arcavi+10, Kelly & Kirshner 12, Kuncaravakti +13, Sanders +12

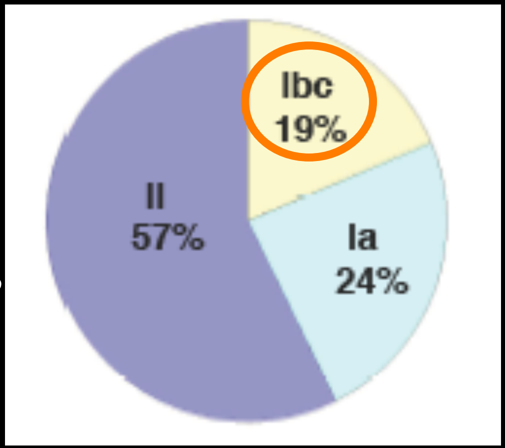
Explosion Rates

- All SN :

~1 SN / (100 years) / (MW-galaxy)

- SN Ib/c:

SN Fractions (Volumetric, from LOSS) in high luminosity, high-*Z* galaxies
(Li et al 2011, Smith et al. 2011)



- SN Ic-bl:

~10% of all SN Ib/c in MW-type galaxies (Guetta & Della Valle 07, Arcavi+11)

but much more common in dwarf (low-L, low-Z) galaxies (up to 50%, Arcavi+11)

- GRB rate: different for low-L and high-L GRBs (Guetta & Della Valle 07)

Kelly, Filippenko, Modjaz, & Kocevski 2014

astro-ph/1401.0729

Sloan Digital Sky Survey ($z < 0.2$)

245 core-collapse SN discovered by galaxy-untargeted surveys, including 17 broad-lined SN Ic (without observed GRBs)

Hubble Space Telescope ($z < 1.2$)

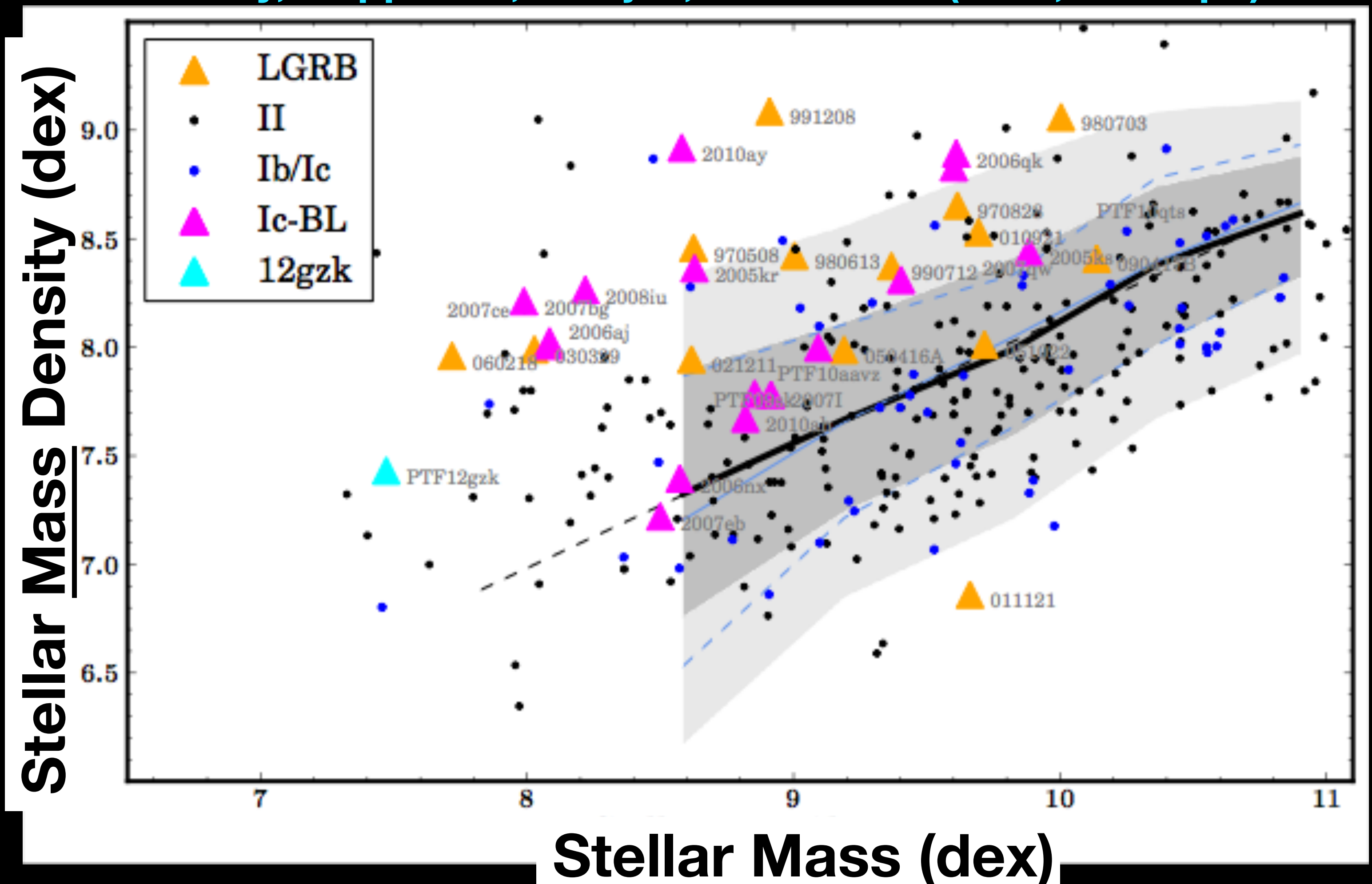
15 optically luminous + obscured LGRBs

Fit galaxy light distributions

z < 0.2 SN Ic-BL and z <1.2 LGRB hosts

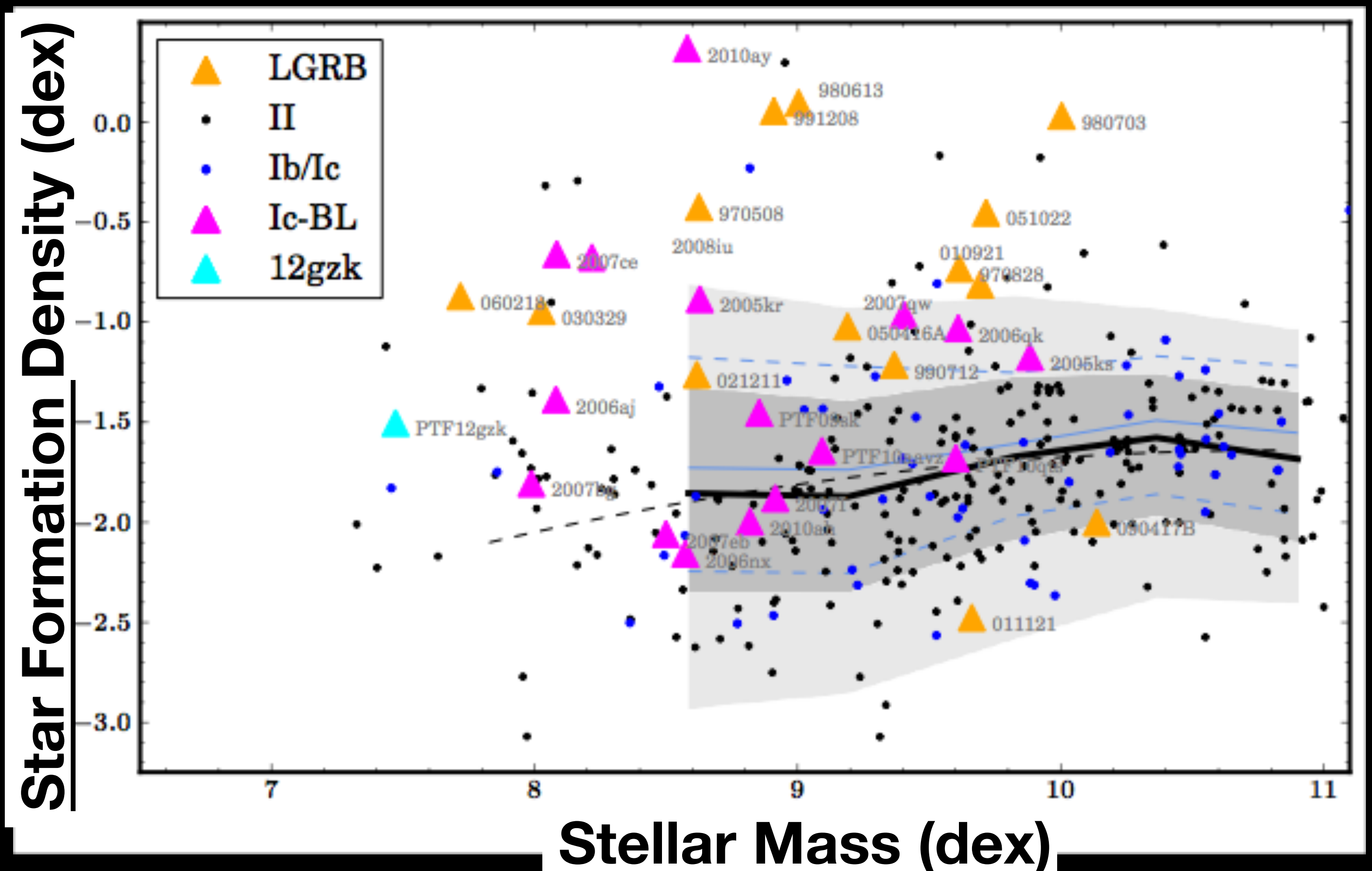
→ high stellar-mass densities

Kelly, Filippenko, Modjaz, & Kocevski (2014, astro-ph)



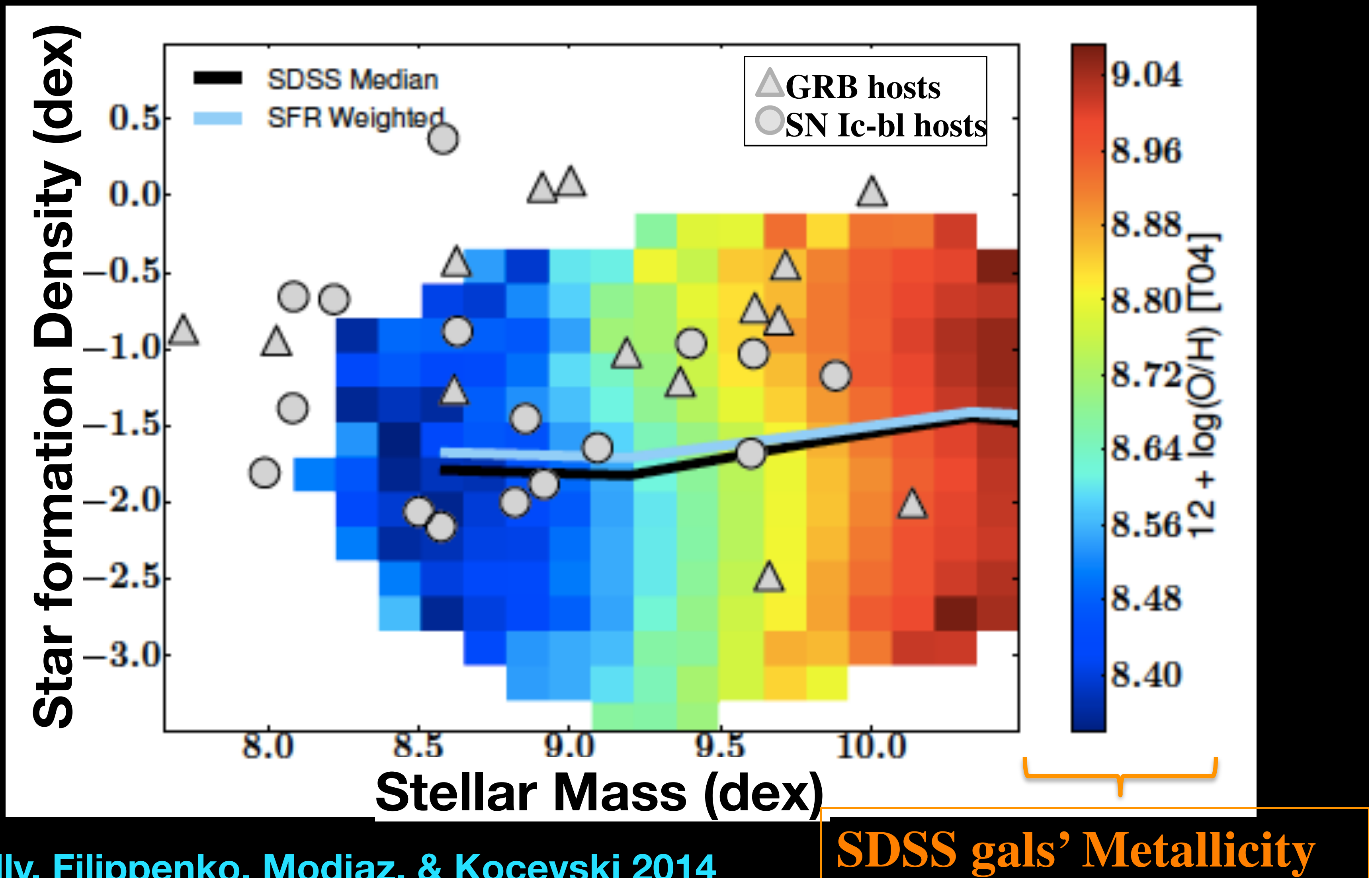
No similar preference among SN II, SN Ib & SN Ic from untargeted galaxies z < 0.2 SN Ic-BL and z <1.2 LGRB hosts

→ **high star-formation densities**



NOT due to high SFR, but small host size (for their stellar masses)

Cannot be explained by a preference for low Z – in addition to low-Z preference for GRBs



Kelly, Filippenko, Modjaz, & Kocevski 2014

Overdense conditions create fast-ejecta progenitors more efficiently

- **Cannot** be explained by a preference for low Z – so additional ingredient for GRBs, besides low Z

- Bound stellar clusters may form more efficiently at high SF densities (e.g., Goddard+ 10)
  - Tight massive binaries in clusters? (eg., Hut+92, v.d. Heuvel & Portegies 13)
  - (Top-heavy IMF? (.g., Kleesen, Spaans & Jappsen 07) but also bottom-heavy IMF (van Dokkum & Conry 10)?)

Kelly, Filippenko, Modjaz, & Kocevski 2014

Palomar Transient Factory (PTF)

PALOMAR TRANSIENT FACTORY

as of Dec 2012 (continues now as iPTF)

Stripped SN host galaxy program: ~1/2 data taken

- Home
- AAS January 2013
- The PTF Team
- Gallery
- Public Papers / Docs
- Education and Public Outreach
- Internal Project TWiki
- Caltech Astronomy

The Palomar Transient Factory (PTF) is a fully-automated, wide-field survey aimed at a systematic exploration of the optical transient sky.

Spectroscopically confirmed supernova discoveries (as of today)
Access public spectra (WISEASS)

All SNe	SNe Ia	SNe Ibc	SNe II
1923	1294	89	467

PTF papers — 57 (list of papers)

Recent News

February 2013: PTF discovers an outburst from a massive star 40days before a supernova explosion (Nature)

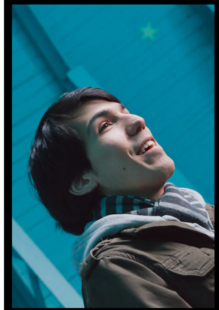
February 2013: The intermediate Palomar Transient Factory (iPTF) begins (Atel #4807)

PTF: Different Galaxies host different CC SNe

Future is now: ~3x more Stripped SN than early 2010

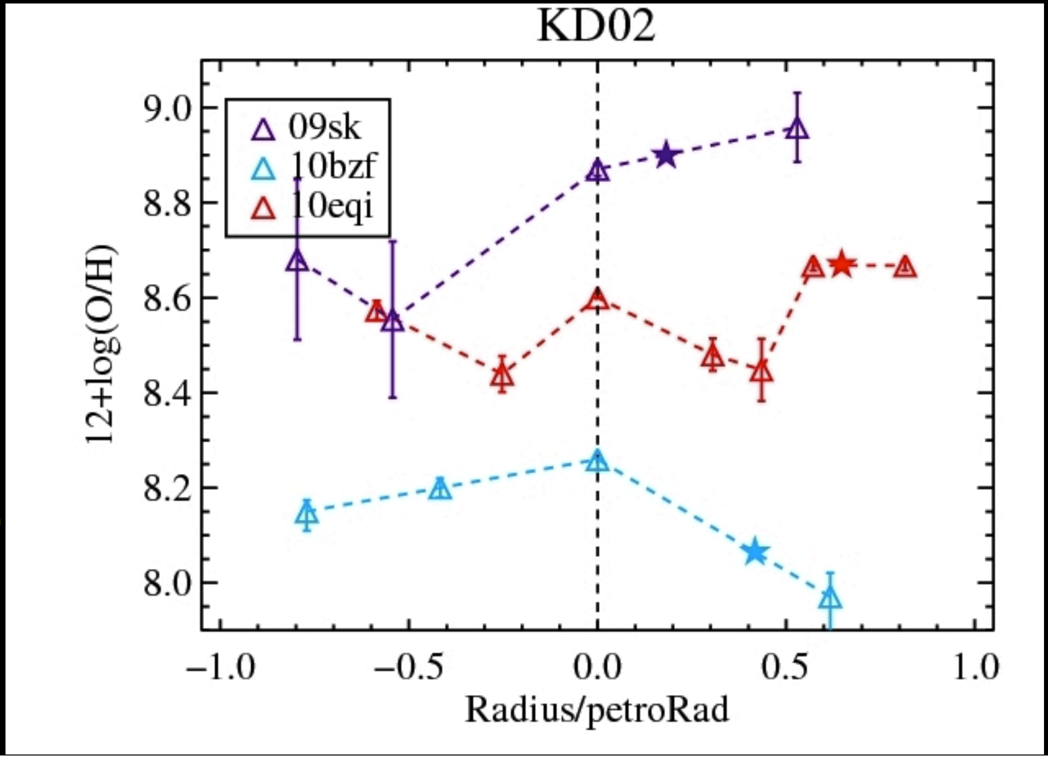
Leading large, unprecedented host galaxy study of 89 PTF Stripped SN from single & homogeneous, galaxy-untargeted survey

Metallicity gradients in PTF Hosts:



Modjaz, Fierroz et al (in prep)

David Fierroz



Conclusions: Stellar Forensics with SN & GRBs

- No Progenitor detections for SN Ib, Ic, Ic-bl, SN-GRBs
  -> NEED for statistical studies of explosion properties & host environments

- Large samples over last ~15 years -> statistics!
- Trends in SN explosion properties & environments as a function of SN subtype: SN-GRB, SN Ic-bl (no GRB), SN Ic
- SN properties:
  - SN Ic-bl + GRBs : highest vels & broadest lines, highest ^{56}Ni masses
- Environmental Properties:
  - SN Ic-bl + GRBs @systematically lower oxygen abundances (but NOT exclusively)
  - SN Ic-bl with and without GRBs in dense SFR galaxies: from binaries?

Maryam Modjaz

Specific questions & Speculations

- Why do SN-GRB look ~the same, when their GRBs have 5 orders of magnitude spread in Eγ ?
- Where are the off-axis GRBs ?
- Why do SN-GRBs show no Helium if SN-GRB progenitor models have ~1-2 Msun of He?
  - NIR spec of SN-GRBs: no He lines
  - SN Ic-bl: no smeared out He
  - Even "hidden" He can't be more than ~0.2 M_{sun} ?

- My Speculation (consistent with most observations):
  - SN Ic-bl with GRBs: high-mass stars in tight binaries @ low Z
  - SN Ic-bl without GRBs: high-mass stars in tight binaries @ less-low Z
  - SN Ic: less-massive stars in less tight binaries @ high Z