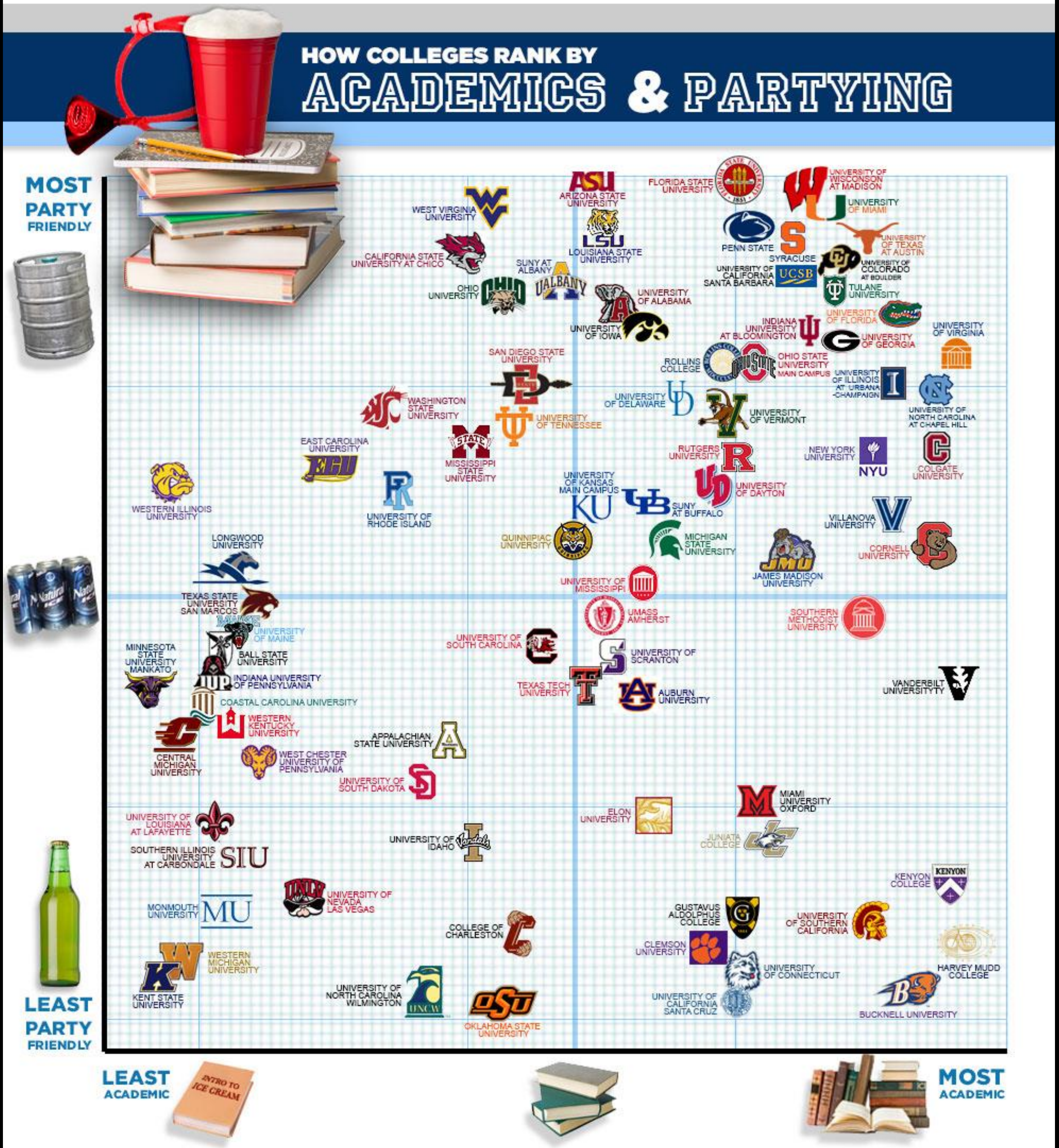
Observational summary

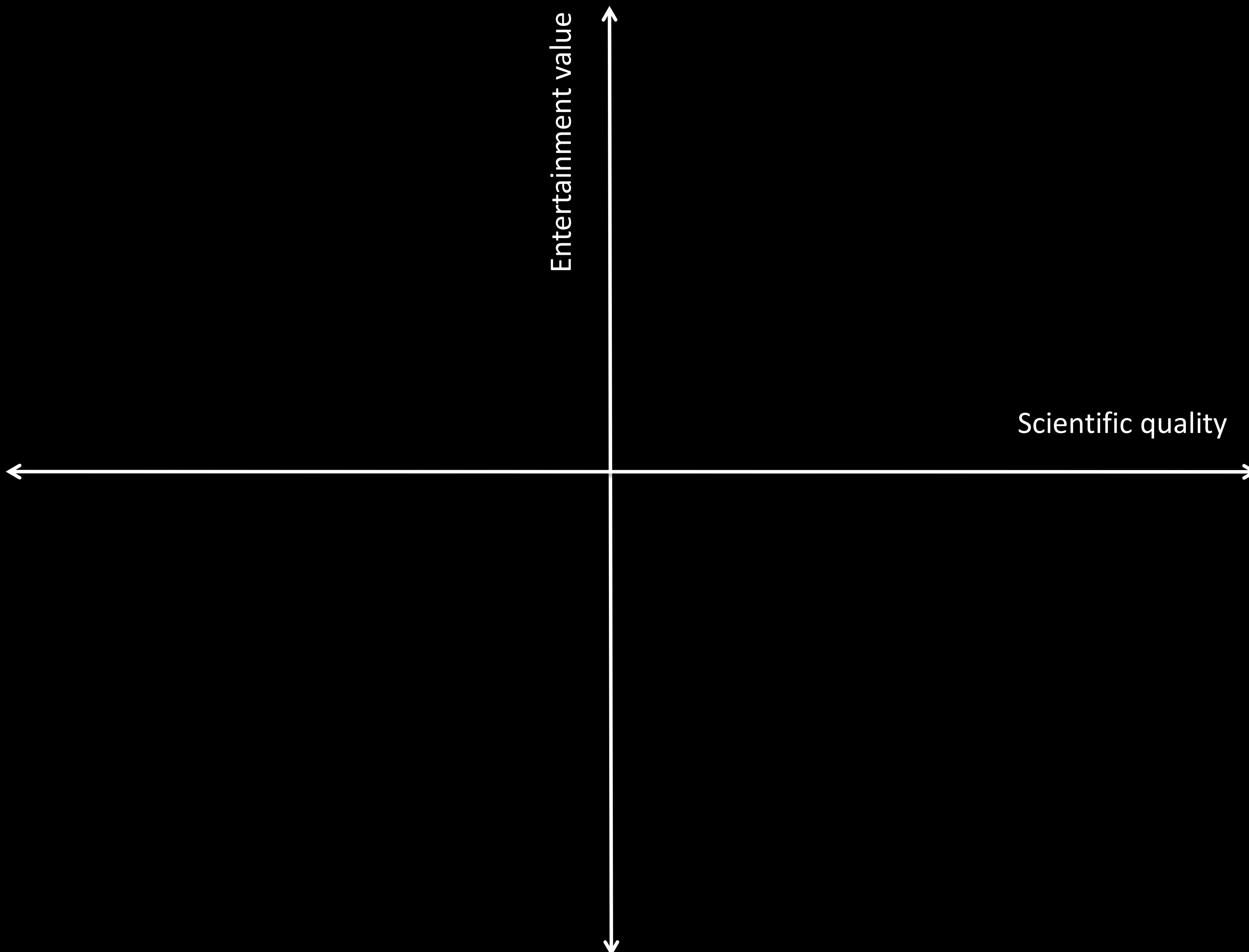
Andy Howell

Las Cumbres Observatory
Global Telescope Network

University of California
Santa Barbara

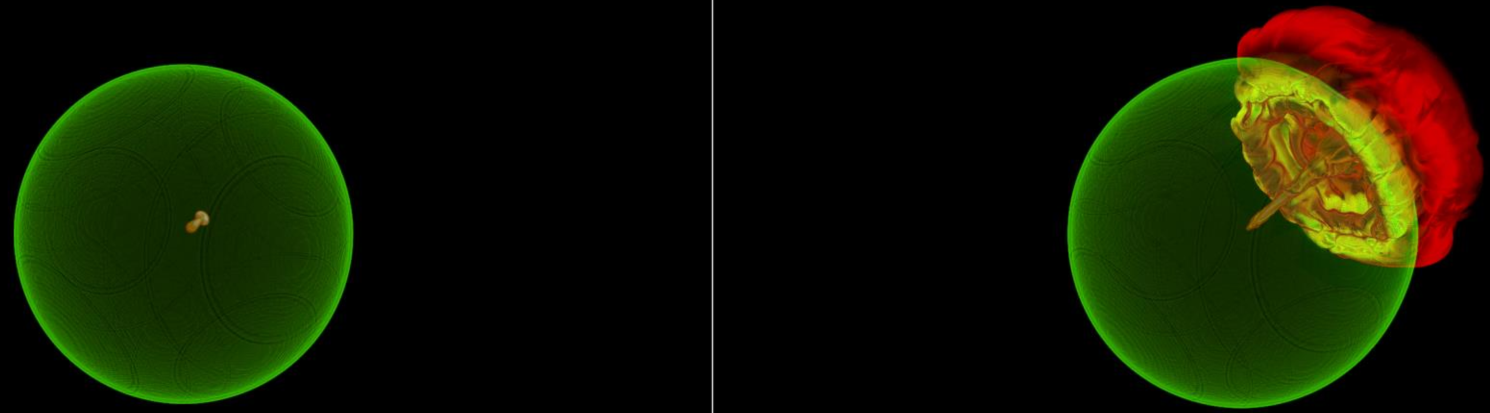
LCOGT.net


HOW COLLEGES RANK BY
ACADEMICS & PARTYING
MOST PARTY FRIENDLY
LEAST PARTY FRIENDLY
LEAST ACADEMIC
MOST ACADEMIC
INTRO TO ICE CREAM
WEST VIRGINIA UNIVERSITY
ARIZONA STATE UNIVERSITY
FLORIDA STATE UNIVERSITY
UNIVERSITY OF WISCONSON AT MADISON
UNIVERSITY OF MIAMI
LOUISIANA STATE UNIVERSITY
PENN STATE
SYRACUSE
UNIVERSITY OF TEXAS AT AUSTIN
CALIFORNIA STATE UNIVERSITY AT CHICO
SUNY AT ALBANY
UNIVERSITY OF CALIFORNIA SANTA BARBARA
UNIVERSITY OF COLORADO AT BOULDER
OHIO UNIVERSITY
UNIVERSITY OF ALABAMA
TULANE UNIVERSITY
UNIVERSITY OF IOWA
INDIANA UNIVERSITY AT BLOOMINGTON
UNIVERSITY OF FLORIDA
UNIVERSITY OF GEORGIA
UNIVERSITY OF VIRGINIA
SAN DIEGO STATE UNIVERSITY
ROLLINS COLLEGE
OHIO STATE UNIVERSITY MAIN CAMPUS
UNIVERSITY OF ILLINOIS AT URBANA -CHAMPAIGN
WASHINGTON STATE UNIVERSITY
UNIVERSITY OF DELAWARE
UNIVERSITY OF TENNESSEE
UNIVERSITY OF VERMONT
UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
EAST CAROLINA UNIVERSITY
MISSISSIPPI STATE UNIVERSITY
RUTGERS UNIVERSITY
NEW YORK UNIVERSITY
NYU
COLGATE UNIVERSITY
WESTERN ILLINOIS UNIVERSITY
UNIVERSITY OF RHODE ISLAND
UNIVERSITY OF KANSAS MAIN CAMPUS
SUNY AT BUFFALO
UNIVERSITY OF DAYTON
VILLANOVA UNIVERSITY
LONGWOOD UNIVERSITY
QUINNIPIAC UNIVERSITY
MICHIGAN STATE UNIVERSITY
JAMES MADISON UNIVERSITY
CORNELL UNIVERSITY
UNIVERSITY OF MISSISSIPPI
TEXAS STATE UNIVERSITY SAN MARCOS
UMASS AMHERST
SOUTHERN METHODIST UNIVERSITY
UNIVERSITY OF MAINE
MINNESOTA STATE UNIVERSITY MANKATO
BALL STATE UNIVERSITY
UNIVERSITY OF SOUTH CAROLINA
UNIVERSITY OF SCRANTON
INDIANA UNIVERSITY OF PENNSYLVANIA
TEXAS TECH UNIVERSITY
AUBURN UNIVERSITY
VANDERBILT UNIVERSITTY
COASTAL CAROLINA UNIVERSITY
WESTERN KENTUCKY UNIVERSITY
CENTRAL MICHIGAN UNIVERSITY
APPALACHIAN STATE UNIVERSITY
WEST CHESTER UNIVERSITY OF PENNSYLVANIA
UNIVERSITY OF SOUTH DAKOTA
MIAMI UNIVERSITY OXFORD
UNIVERSITY OF LOUISIANA AT LAFAYETTE
ELON UNIVERSITY
JUNIATA COLLEGE
UNIVERSITY OF IDAHO
SOUTHERN ILLINOIS UNIVERSITY AT CARBONDALE
KENYON COLLEGE
UNIVERSITY OF NEVADA LAS VEGAS
MONMOUTH UNIVERSITY
GUSTAVUS ALDOLPHUS COLLEGE
UNIVERSITY OF SOUTHERN CALIFORNIA
COLLEGE OF CHARLESTON
CLEMSON UNIVERSITY
WESTERN MICHIGAN UNIVERSITY
UNIVERSITY OF CONNECTICUT
HARVEY MUDD COLLEGE
KENT STATE UNIVERSITY
UNIVERSITY OF NORTH CAROLINA WILMINGTON
UNIVERSITY OF CALIFORNIA SANTA CRUZ
BUCKNELL UNIVERSITY
OKLAHOMA STATE UNIVERSITY


Entertainment value
Scientific quality

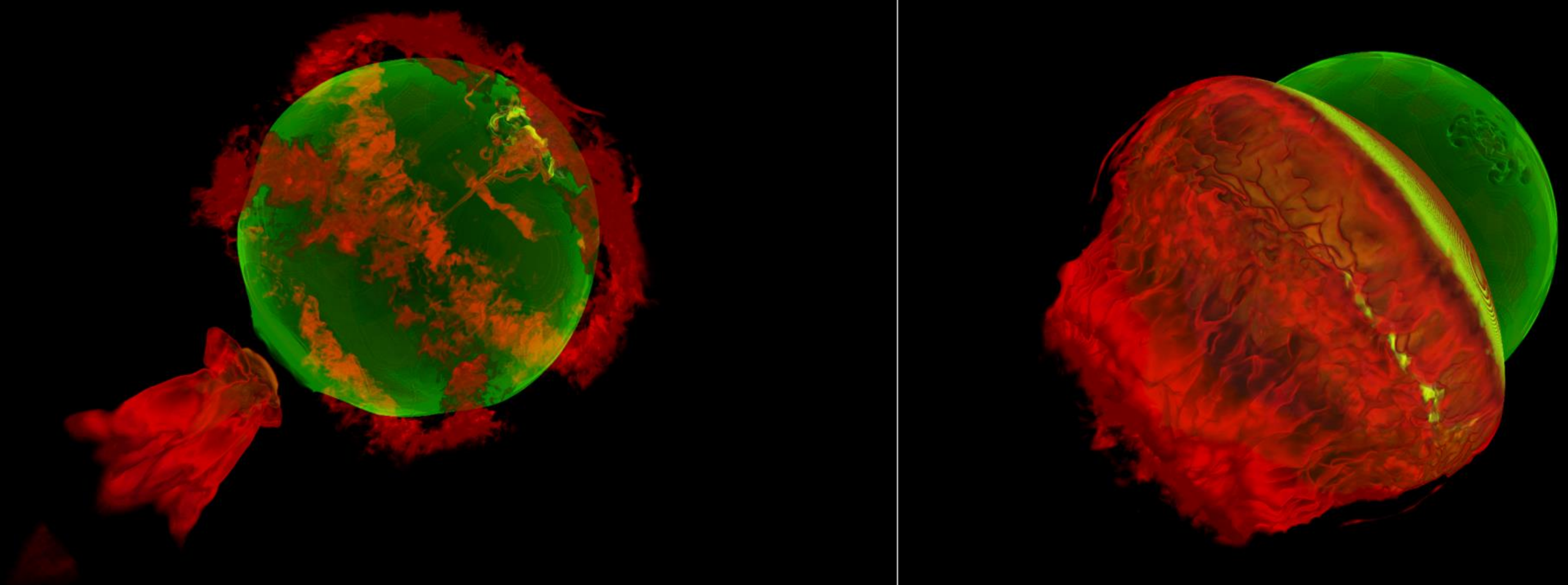
Rene Magritte: The Treachery of Images

The famous pipe. How people reproached me for it! And yet, could you stuff my pipe? No, it's just a representation, is it not? So if I had written on my picture "This is a pipe", I'd have been lying!



This is not a supernova.

Theorists are dirty, filthy liars.



sne Ia

wind, RLOF,
merger,
collision

CO
WD

- RG
- MS
- He WD
- CO WD
- M dwarf

Compared to when I was a grad student, things are less “certain” but healthier scientifically.

Circumstellar material

Image credit: BJ Fulton (LCOGT / iPTF)

Or Graur

Summary: multiwavelength observations of SN 2011fe argue against a single-degenerate progenitor.

Wavelength	Constraints	Source
Optical (*HST*)	- Red-giants, most He-star donors excluded.	Li+ 11
Optical (ground)	- No nova detected during decade before explsion. - Main-sequence donors ruled out by lack of hydrogen stripped from donor ($M_H < 0.001\ M_\odot$).	Li+ 11 Shappee+ 13
Radio	- No circumstellar wind from giant donor. - Deeper limits: rapidly-accreting WDs, symbiotic binaries, and recurrent novae excluded.	Horesh+ 12 Chomiuk+ 12
X-ray	- No super-soft X-ray source with $L_X > (4\text{-}25) \times 10^{36}$ erg/s. - Symbiotic binaries, Roche-lobe overflowing subgiants, and main-sequence donors excluded. CSM < 150 cm^{-3}.	Li+ 11 Margutti+ 12
UV	- Main-sequence donors with radius $R > R_\odot$ excluded.	Brown+ 12
He II λ4686 Å	- No super-soft X-ray source with $L_X > 3 \times 10^{37}$ erg/s within 10^5 years before explosion, if ISM density > 5 cm^{-3}. - No rapidly-accreting WD with wind that can produce 2 - 6 pc cavities in ISM density of ~1 cm^{-3}.	Graur+ 14

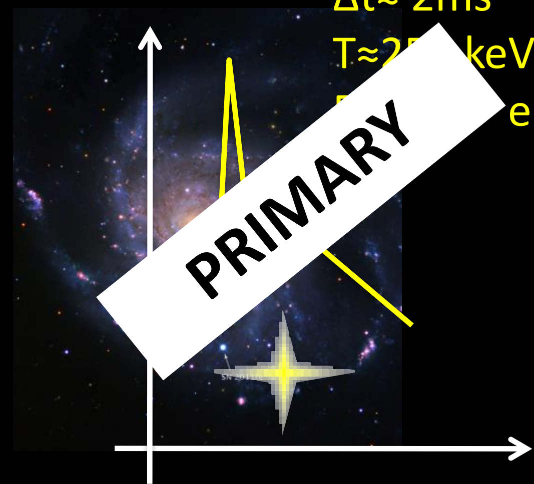
Margutti

Summary

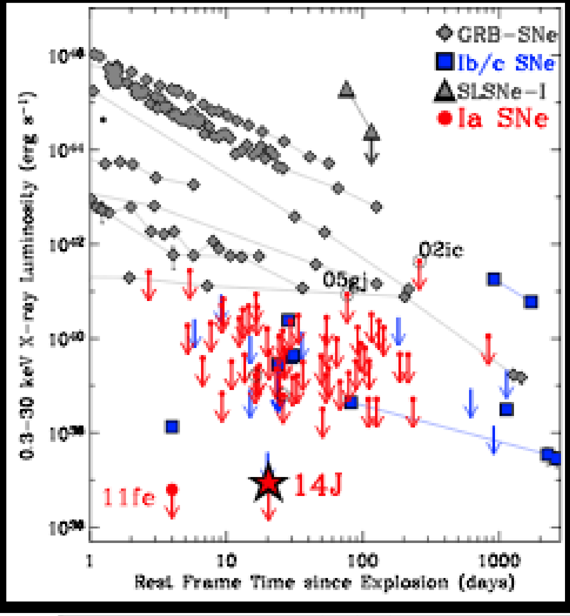
Pre-SN X-ray emission

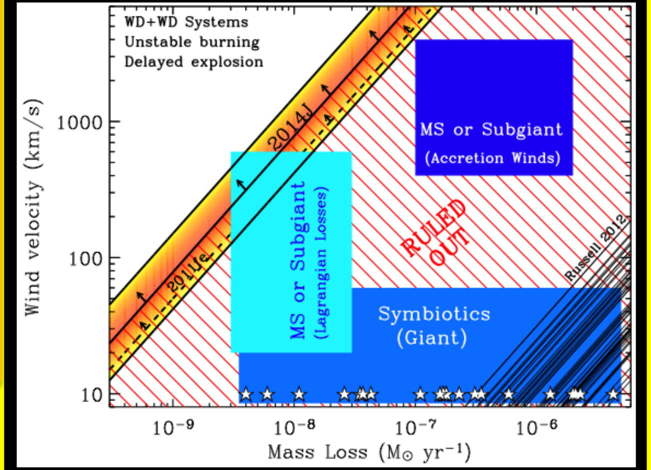
Shock Break Out

Δt≈ 2ms
T≈2 keV
erg

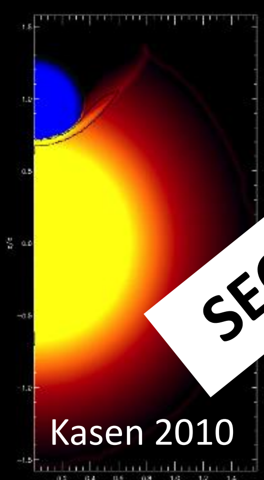


Shock interaction with the ambient medium





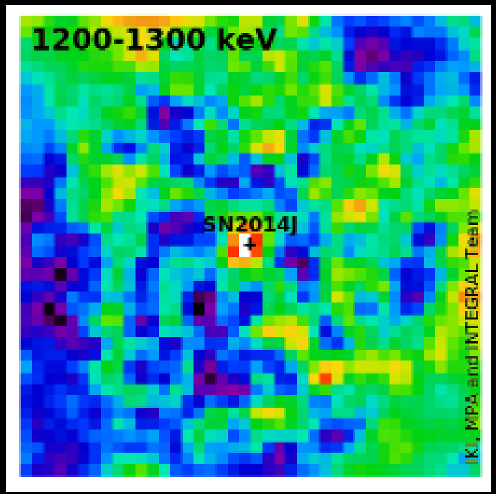
Shock Interaction w. companion



Δt≈ hrs
(@ T
T
6-47 erg
10^{44} erg/s

SECONDARY

Gamma-rays from nuclear decay



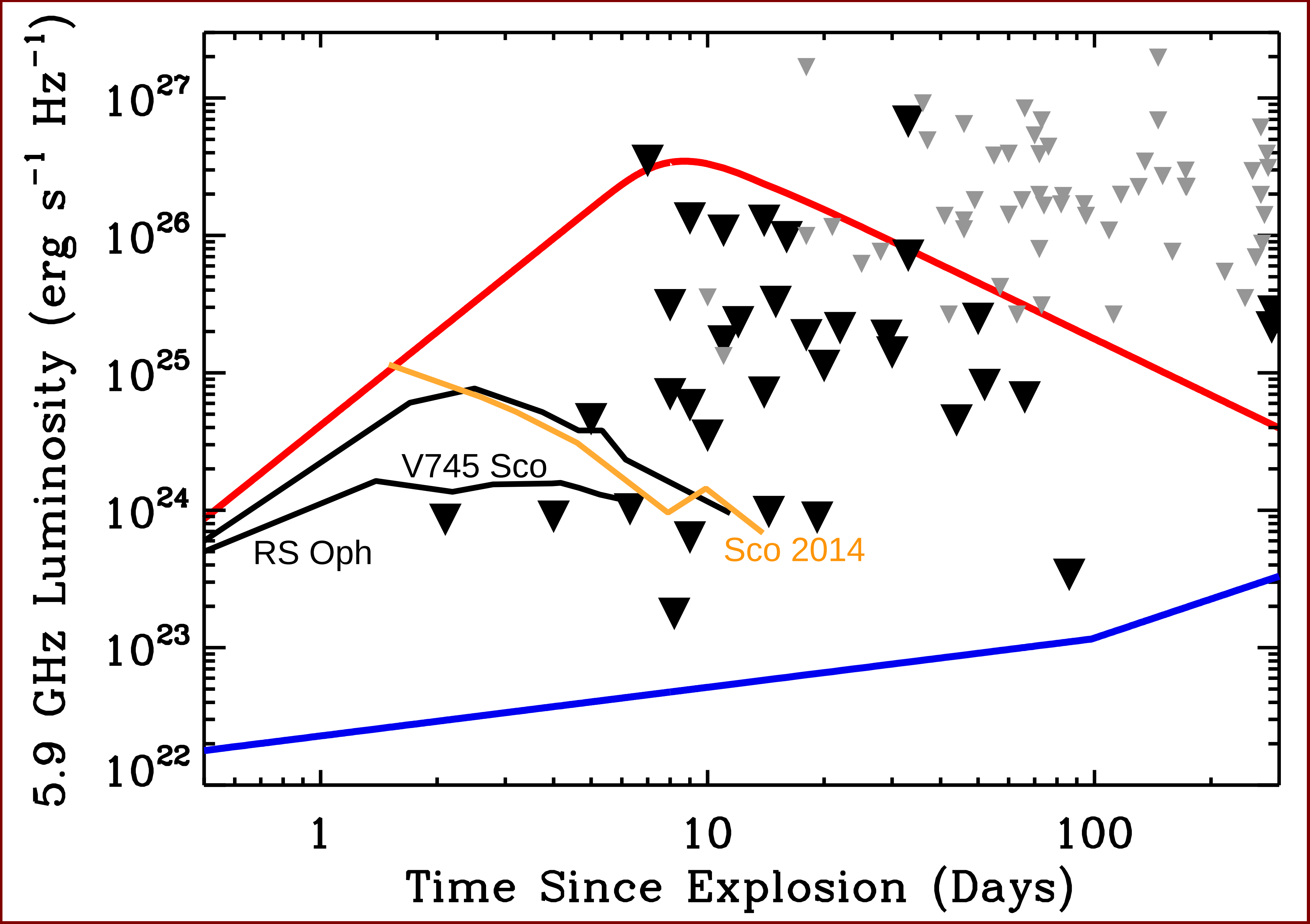
Churazov +14

(1) Unsteady mass loss

(2) Multiple epochs of deep observations

Radio constraints

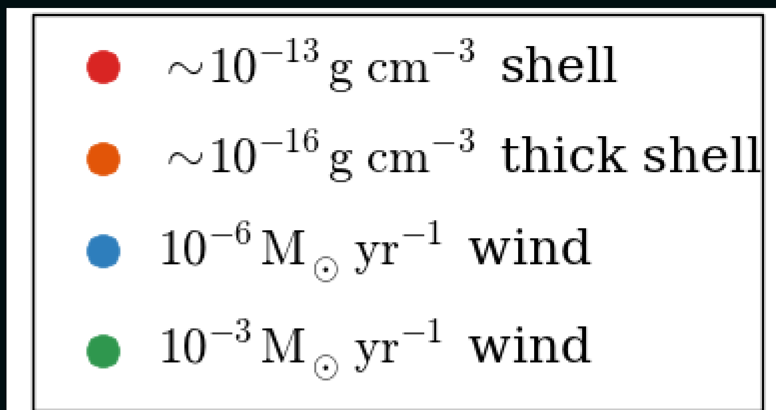
Chomiuk

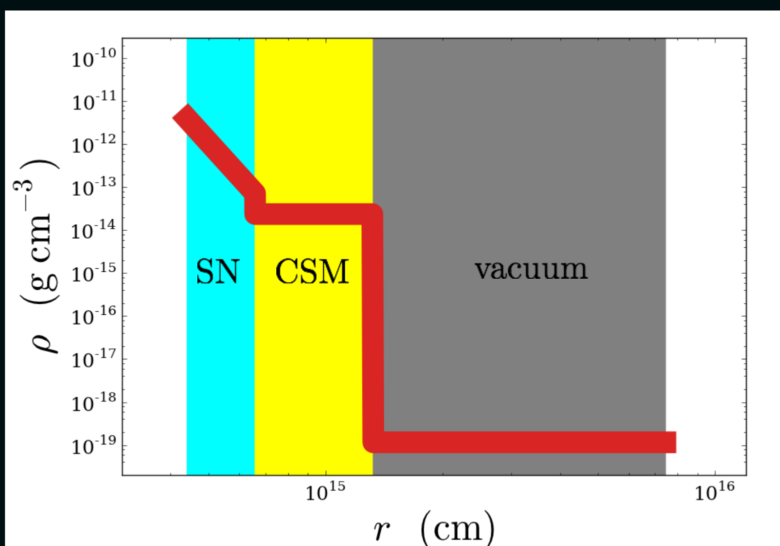


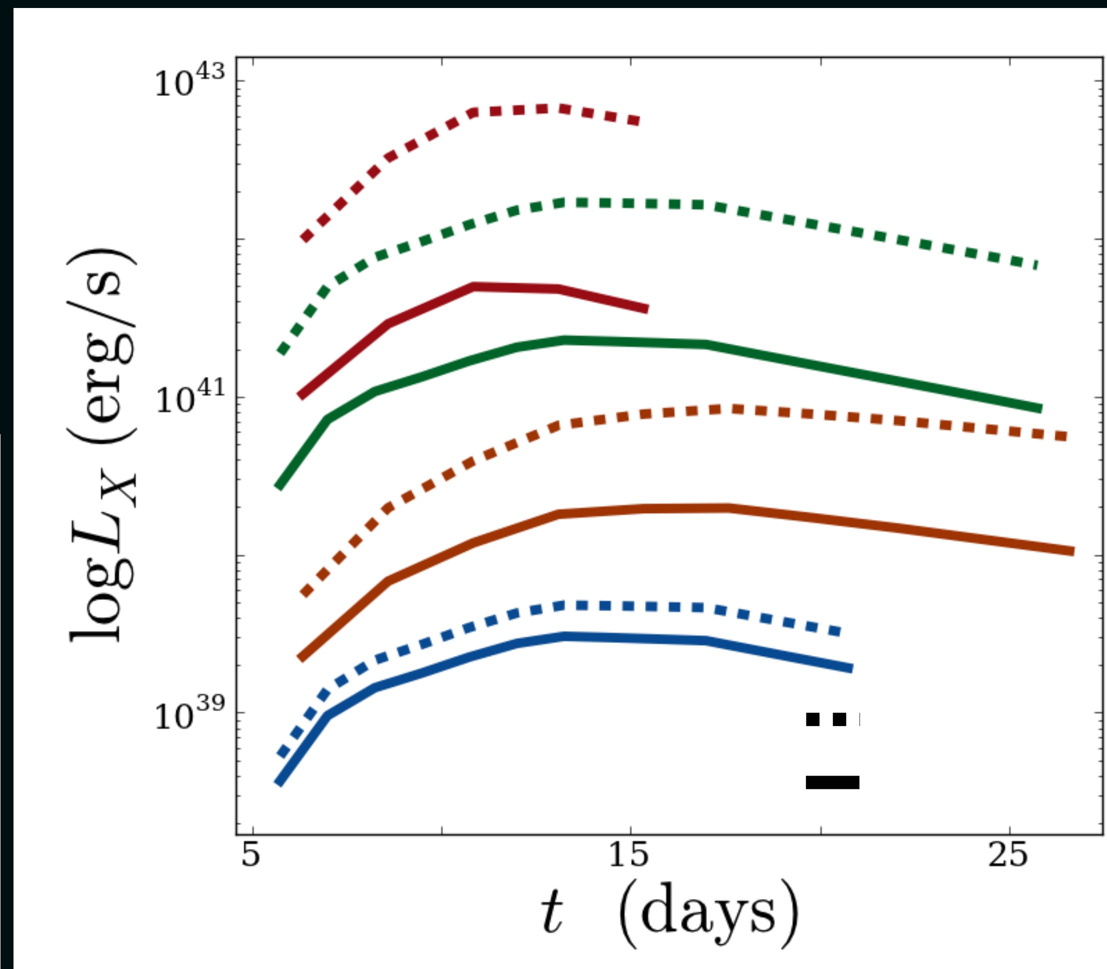
csm interaction models

model suite → observables

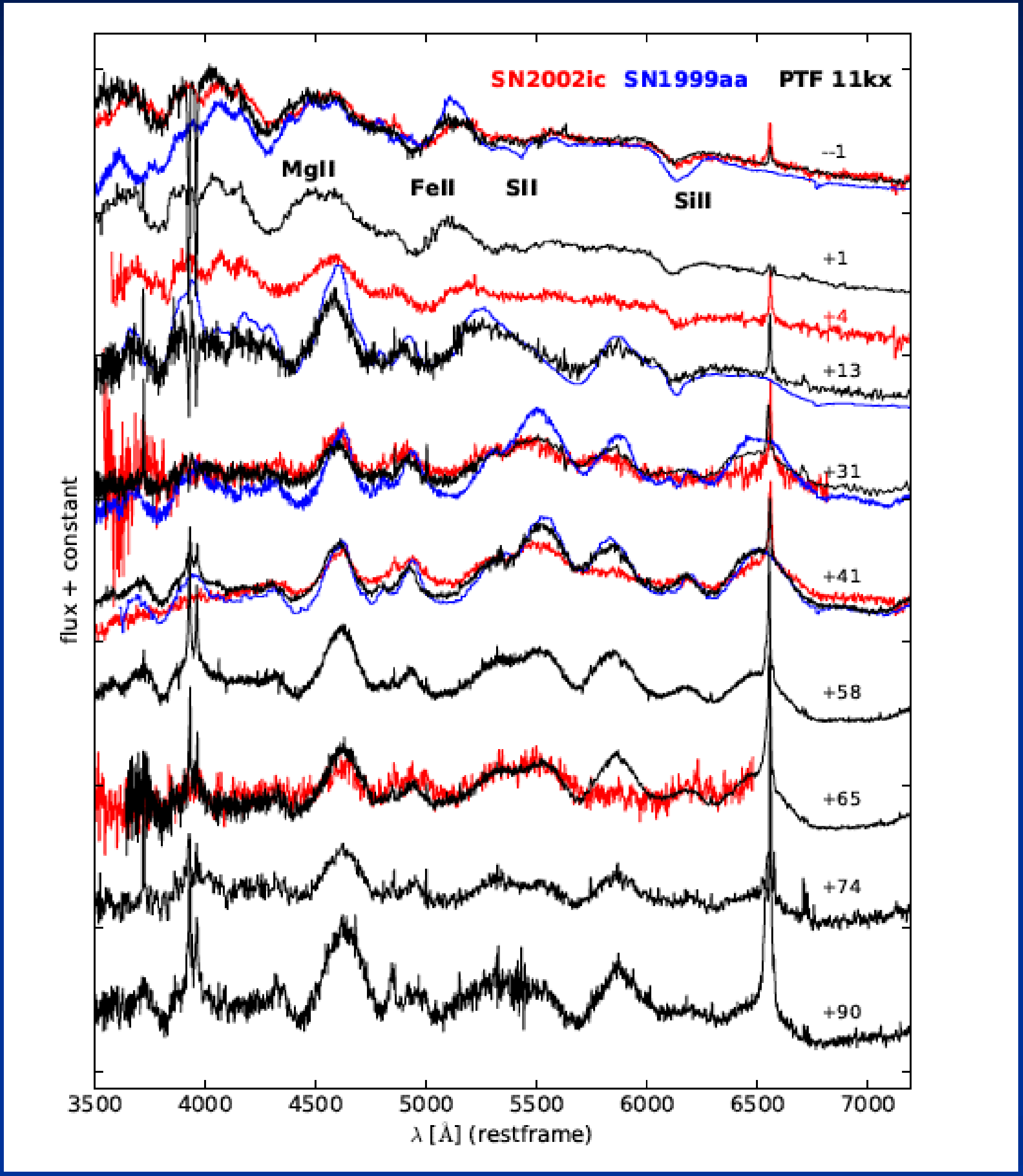
- degeneracies
- detectability
- plausability

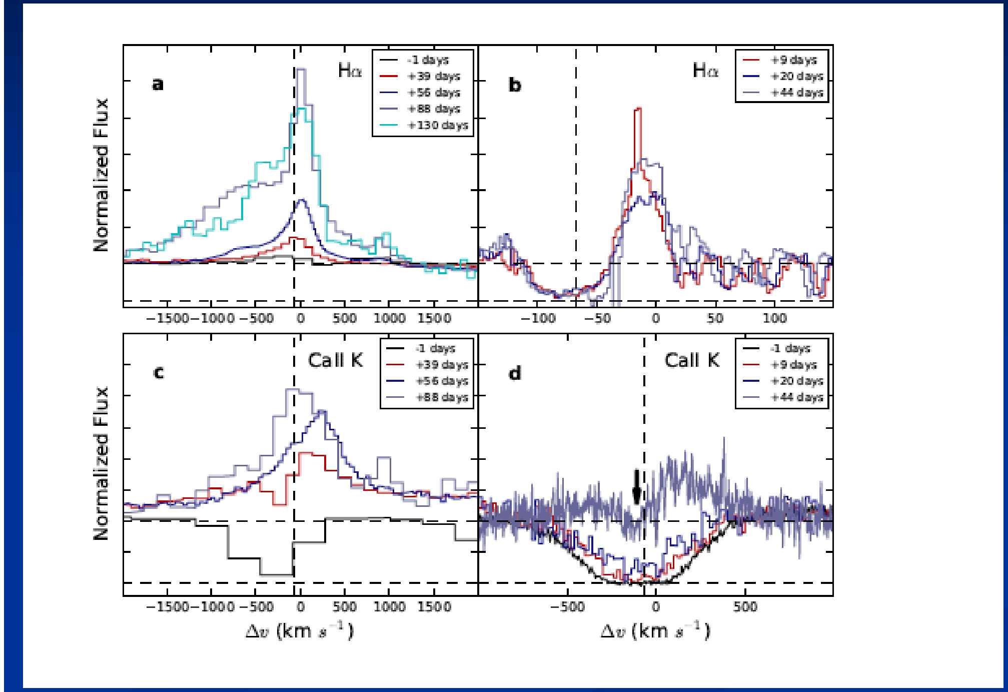






Ia-CSM

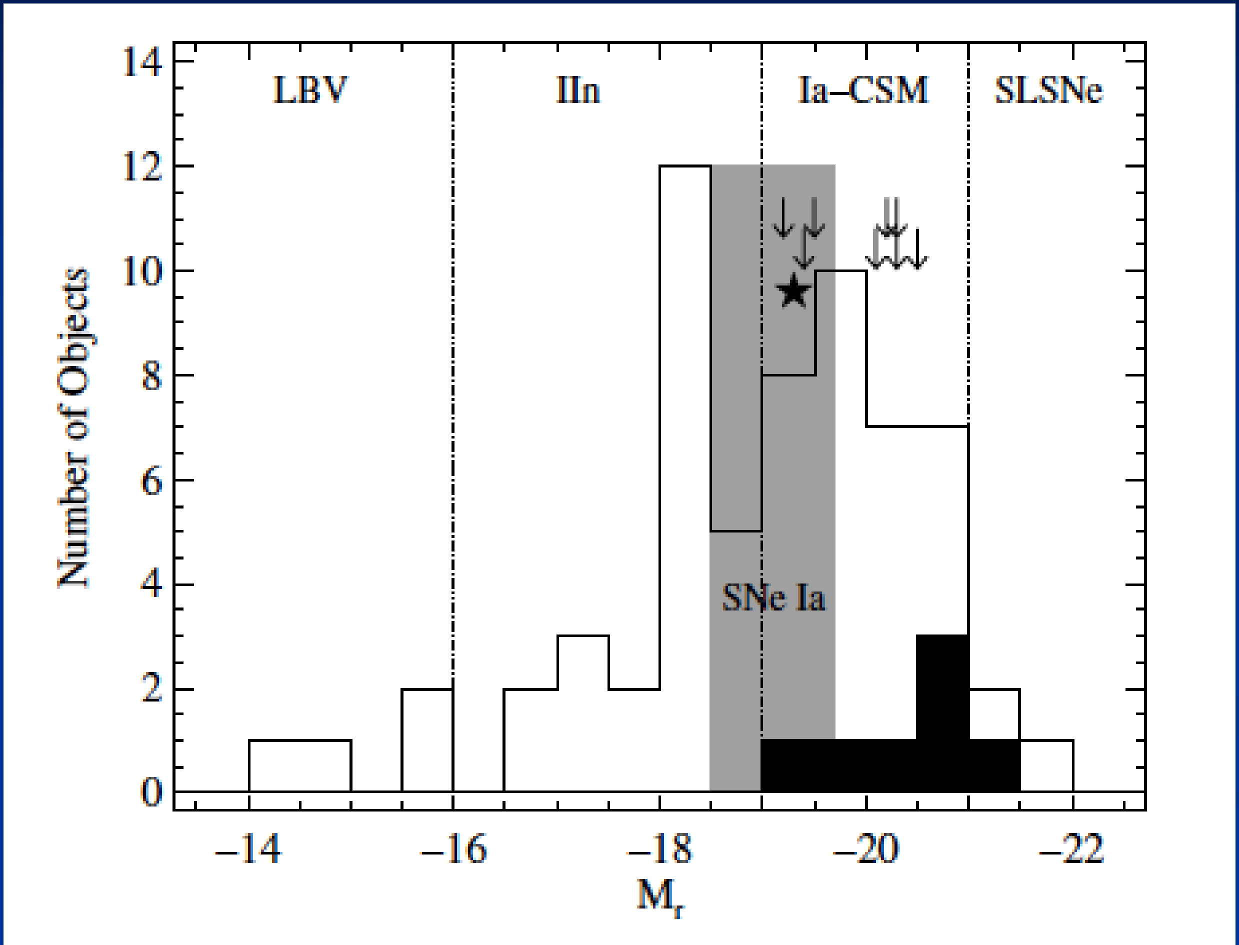




11kx directly relates the 2002ic and 2005gj SNe to Ia's and measures a size for the CSM.

Dilday *et al* (2012)

Ia-CSM



Silverman et al (2013) identifies a group of them in the LOSS and PTF datasets.

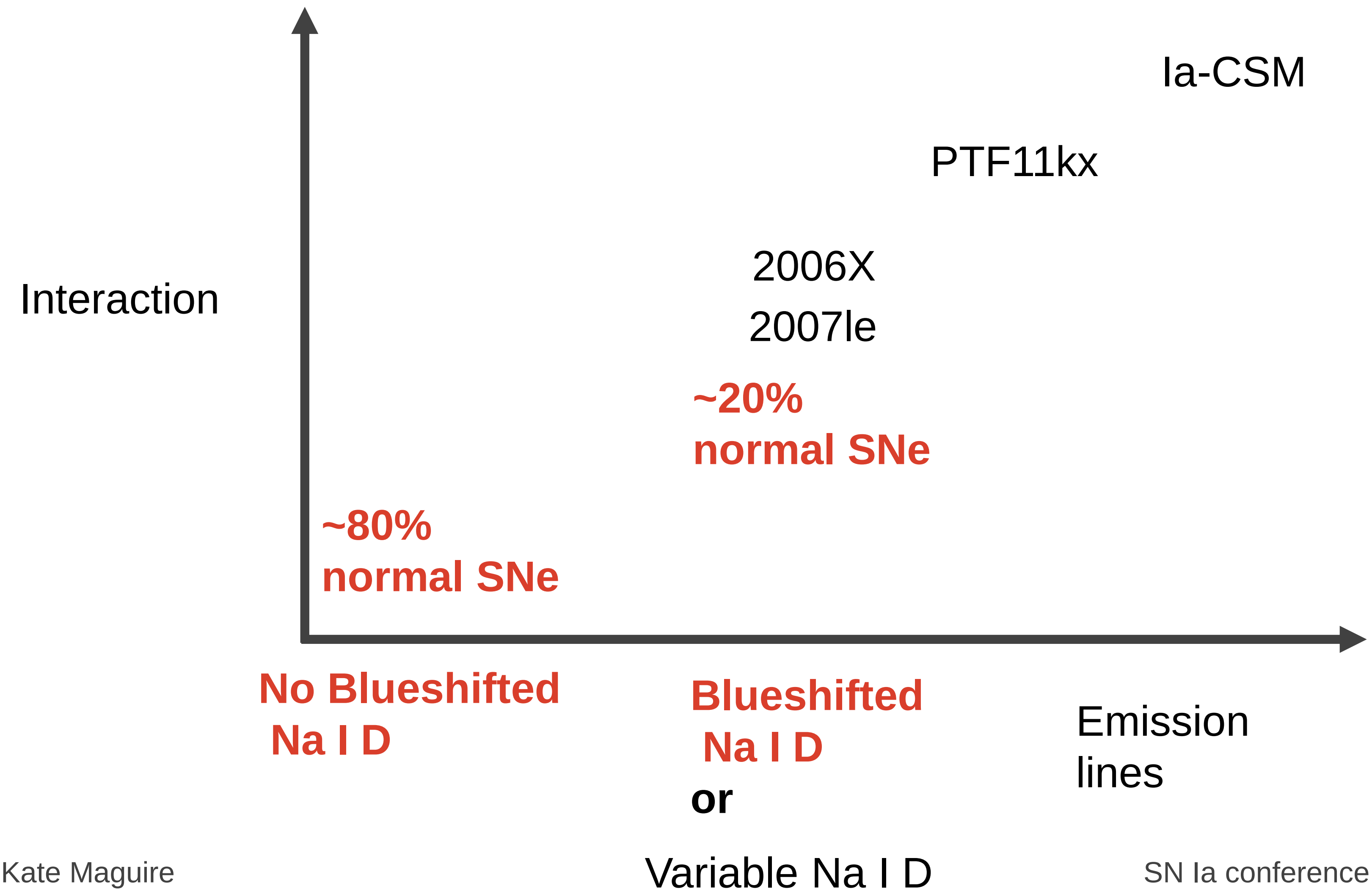
H-alpha to H-beta ratio is large, weak He I lines, slightly brighter than a SN Ia.

Rates are low (1%-ish), but it might be biased by how we have identified them.

What if the CSM was 3 times farther away.... See Harris' talk.

Late-time observations!!!

CSM interaction strength



Dust / reddening

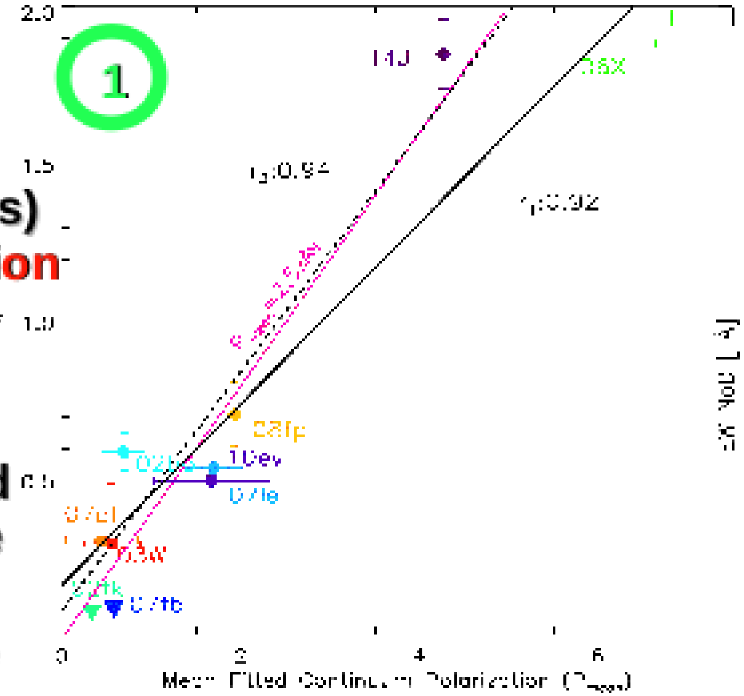
1 **Dust that reddens = Dust that polarizes**

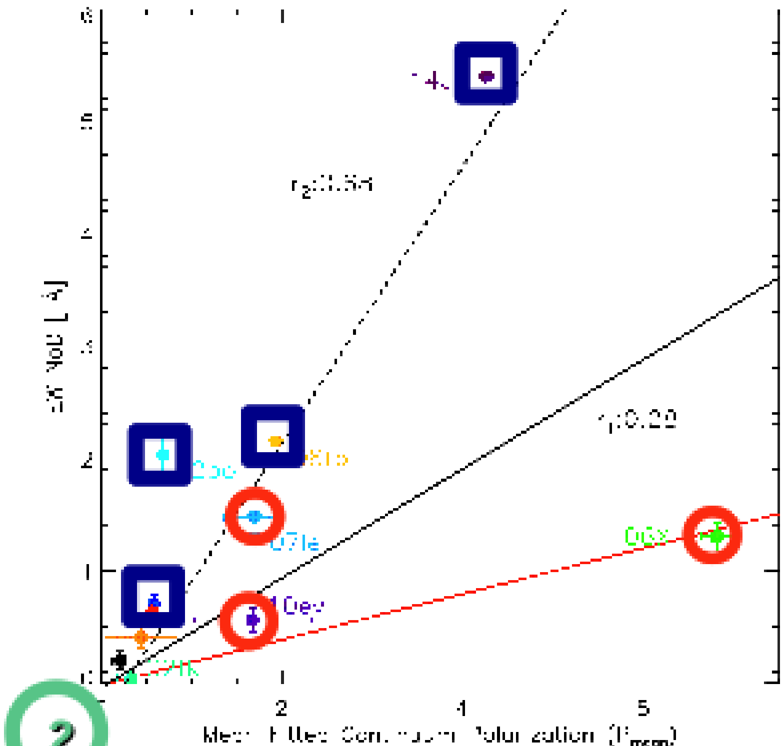
Av has proved to be IS (DIBs)
Observed Pol→ IS polarization

2

Scatter seen in N(Na) vs Av (Phillips2013) is reproduced in our EW Na vs Pol sample

Do Blueshifted-Na Ia's have different dust/gas balance?

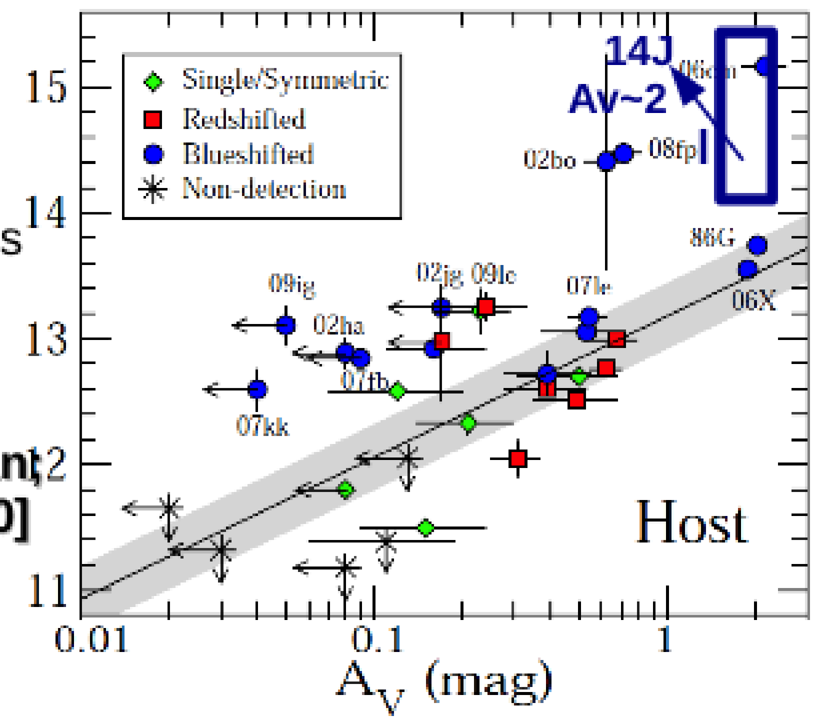




Model of dust absorption/desorption by Soker2014 lets Na(gas) to be released from dust (as in comets near Sun) without sublimating it ➔ Na variability
Model predicts dust grains @ 1pc from explosion

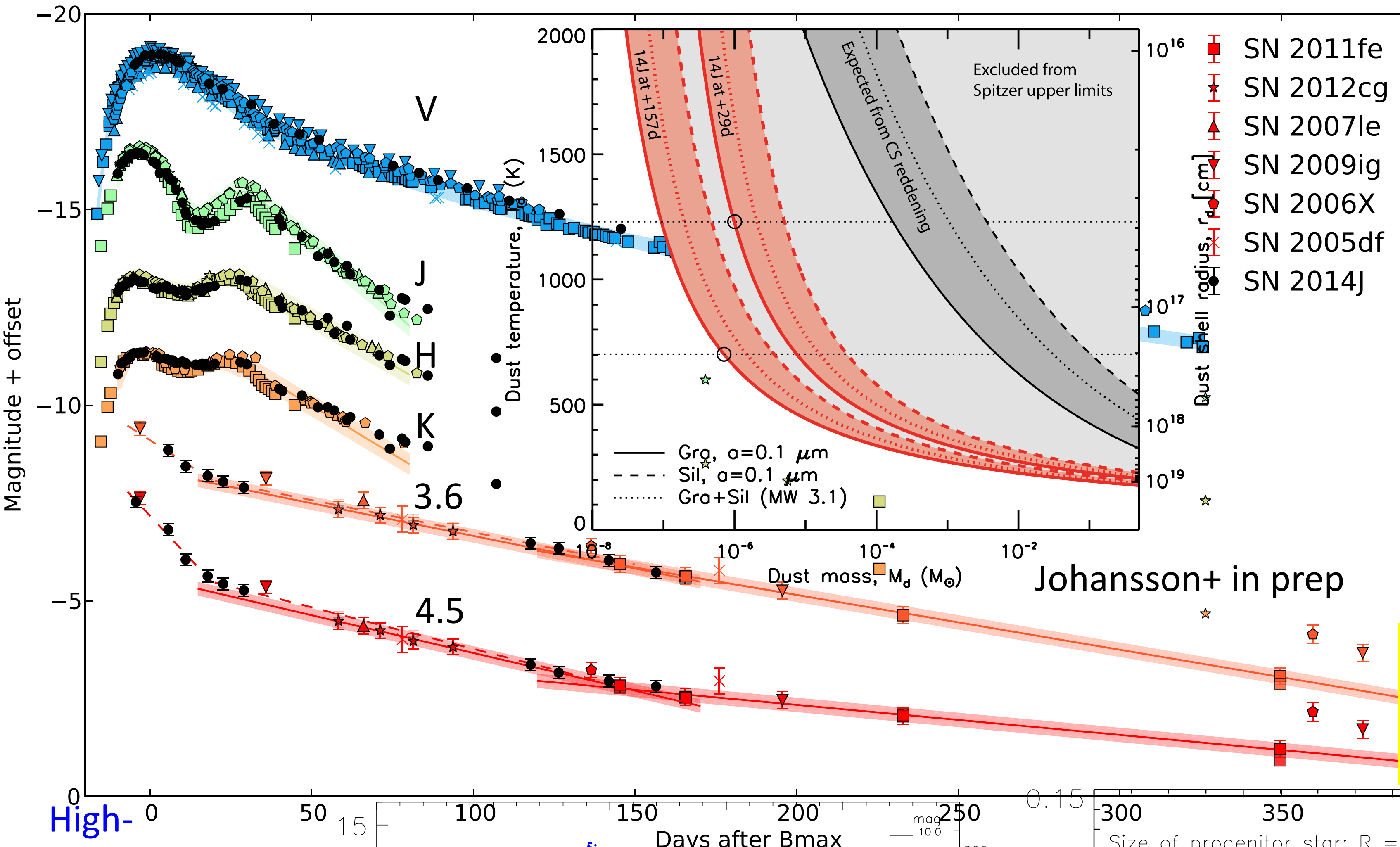
It is possible to find signs of the progenitor at large distances from the explosion (pc scale) ➔ CSM?ISM?distant CSM?

Our polarimetric constraints on dust from donor★ wind aligned due to Bfield, plus time constancy of the Pmean; Place the polarizing dust at a minimum distance [0.2-20] pc. We cannot exclude a progenitor connection, although the tight relation with IS extinction points towars and IS origin



Paula Zelaya

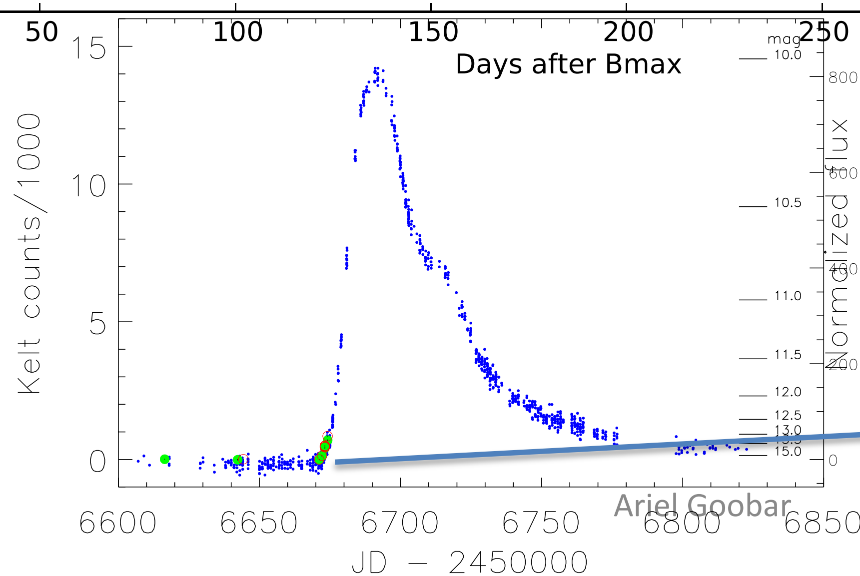
Ariel Goobar

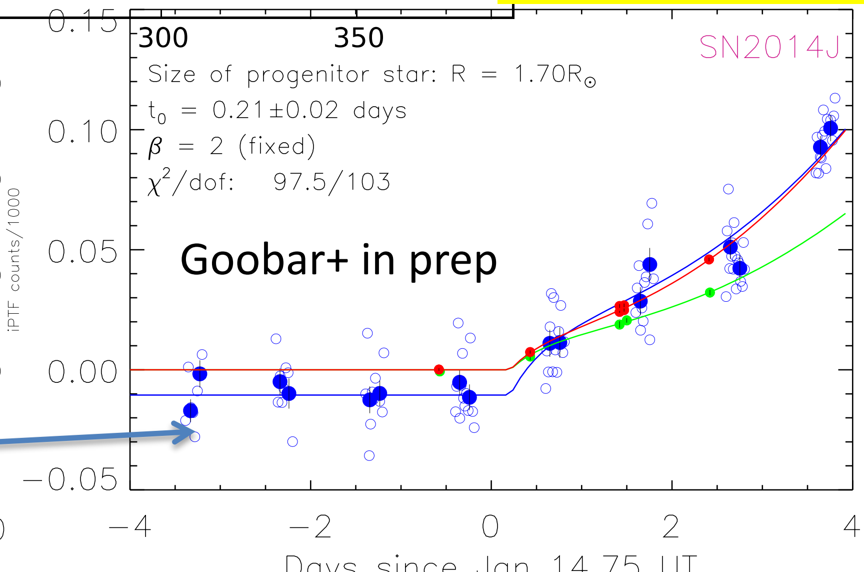


WD size + t^2 excluded at 90% CL

High-cadence KELT data

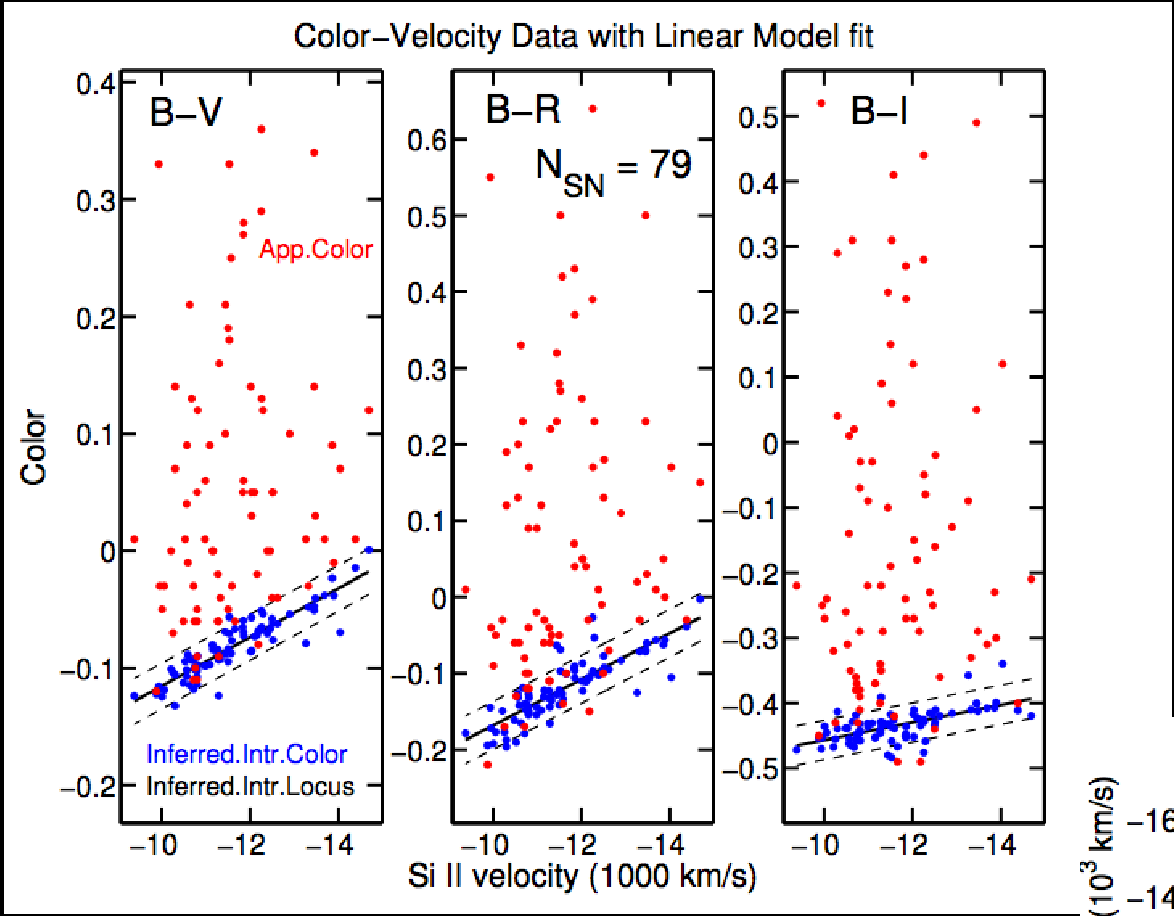
iPTF narrow-band obs.

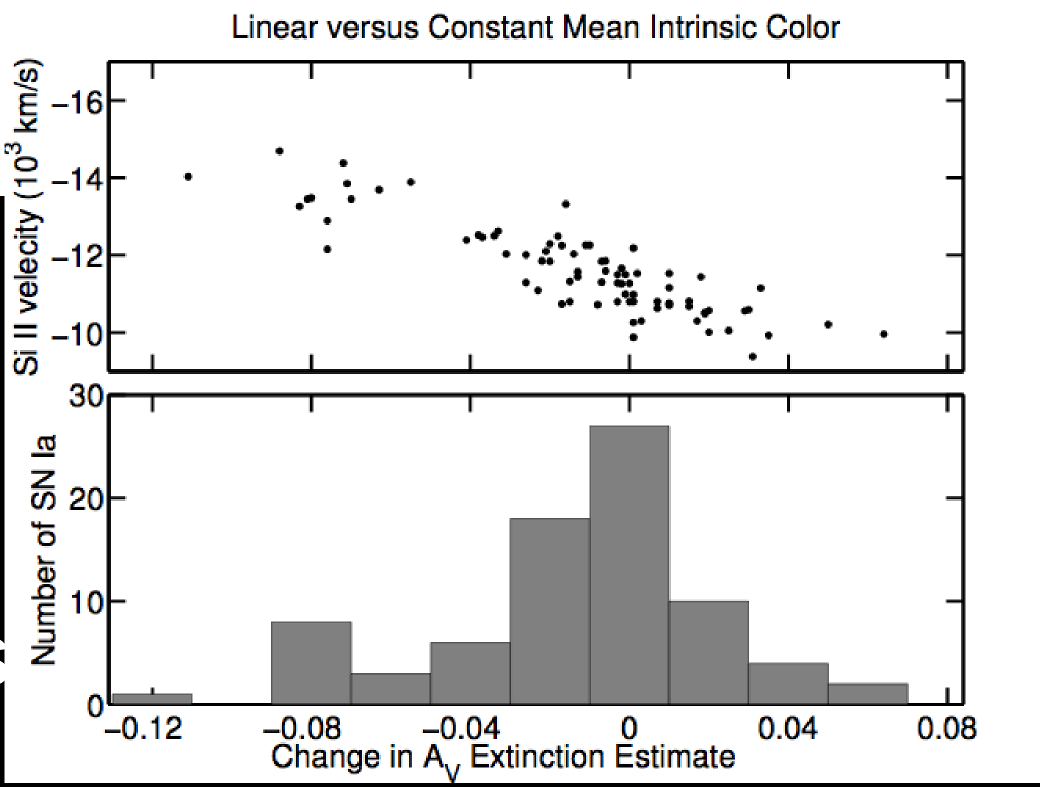




Mandel, Foley & Kirshner 2014 (arxiv:1402.7079)

Statistical model for SN Ia Intrinsic Colors vs. Ejecta Velocity





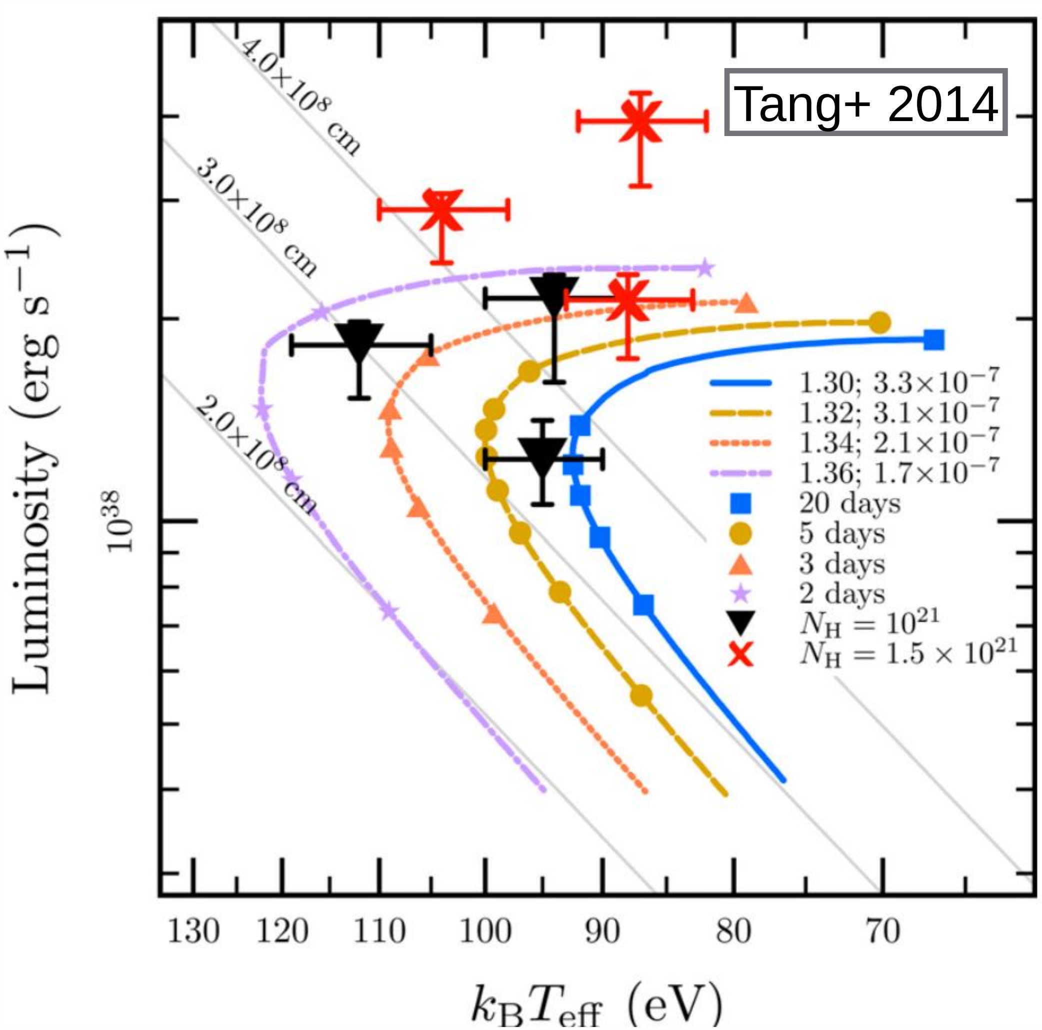
Velocity-dependent systematic correction in dust reddening & extinction A_V estimates

Binaries

Bill Wolf

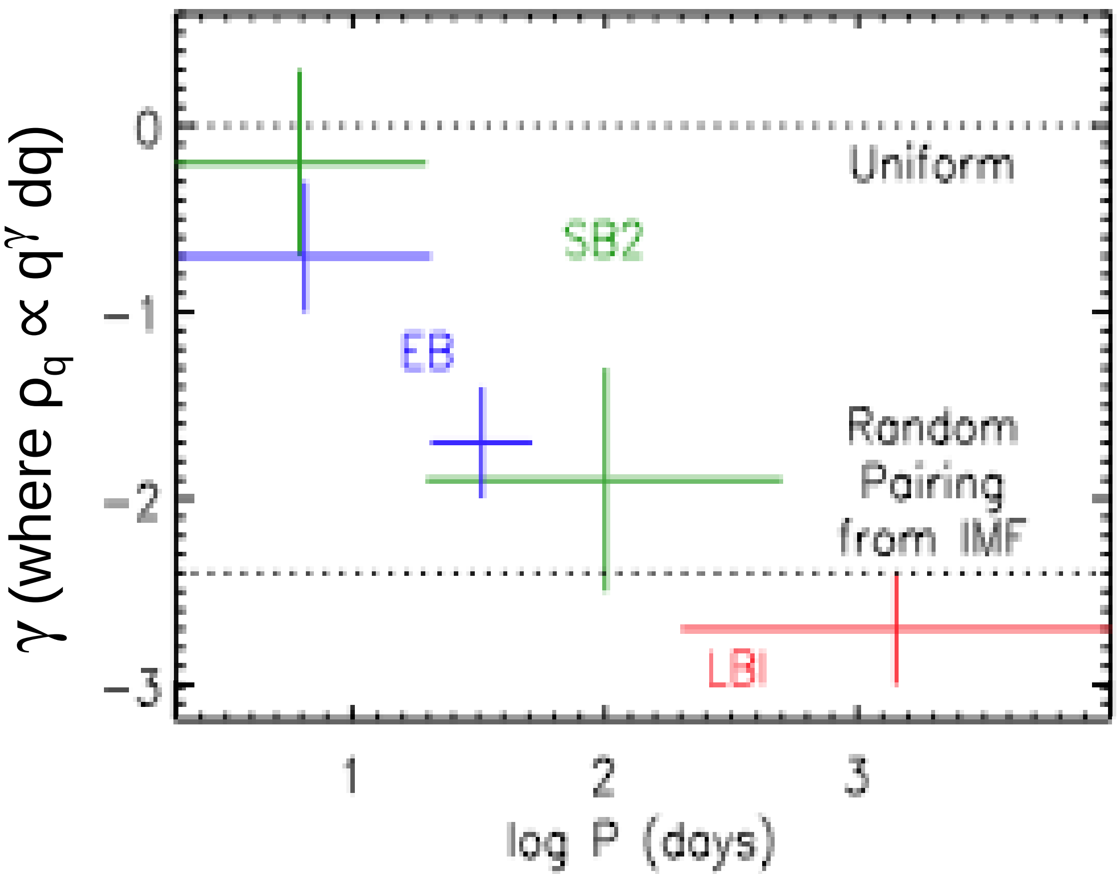
RX J0045.4+4154 (Formerly Known As PTF 09hsd)

- 1 Year Recurrence Time (shortest known to date)
- Mass constrained to > 1.30 $M_\odot$
- X-ray observations and supersoft source modeling estimate M_{WD} ~ 1.32-1.34 $M_\odot$
- Goes off again in next few months
- If SD channel works, objects like this should exist



Black/Red points: Data
Tracks: MESA Simulations

Close MS binaries coevolved (uniform ρ_q, i.e. $\gamma = 0$), while components in slightly wider binaries formed independently via random pairings from the IMF ($\gamma = -2.4$)

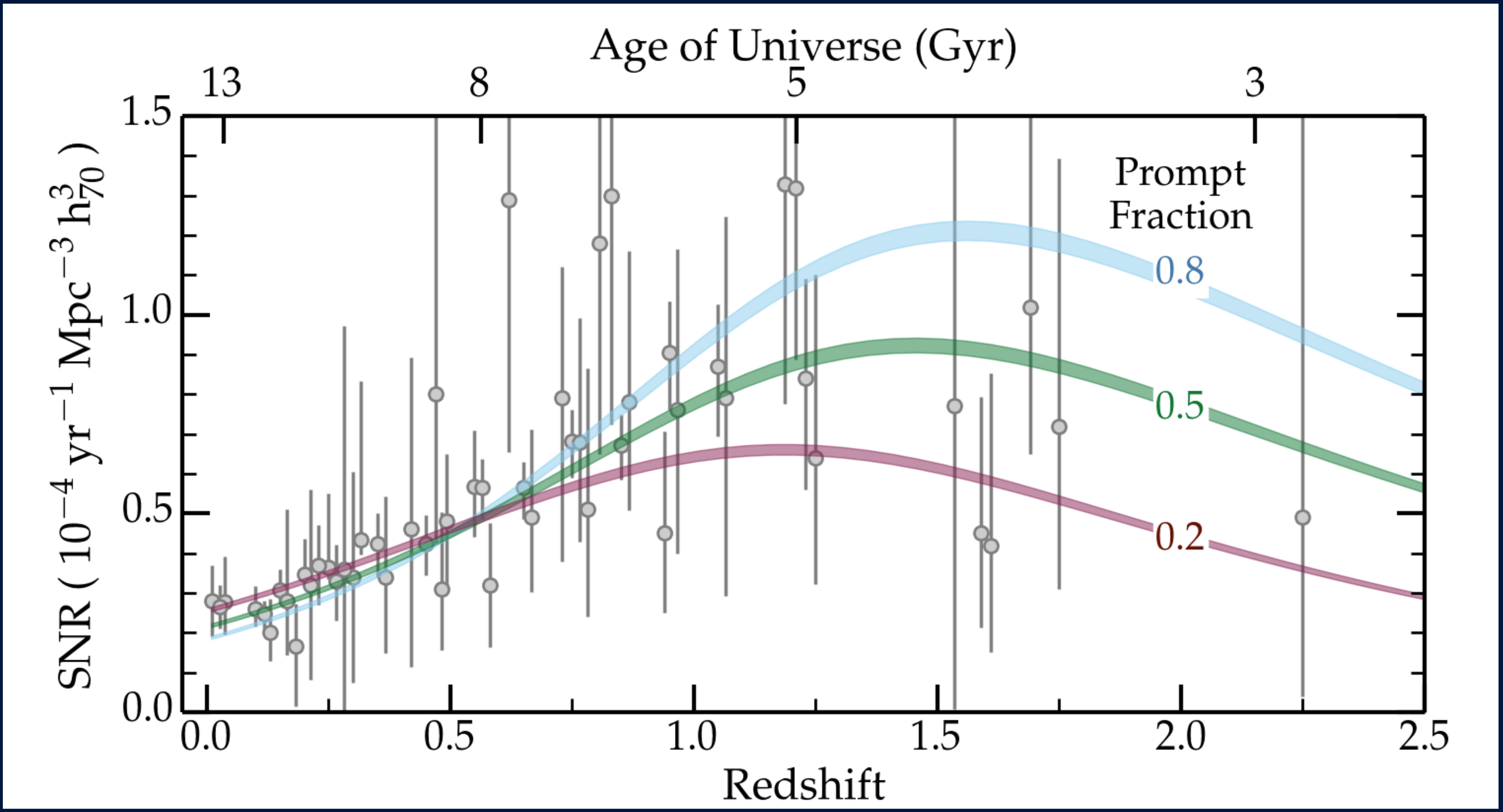


After accounting for this observed correlation in binary population synthesis, we expect **≈5×** more sub-M_{Ch} double-detonation DD and **≈20×** more symbiotic (WD+RG) SD than originally predicted.

Both SD and DD scenarios may have a t^{-1} delay time distribution with no cutoff.

Maxwell Moe (& Rosanne Di Stefano); Harvard-Smithsonian Center for Astrophysics

Constraints from rates



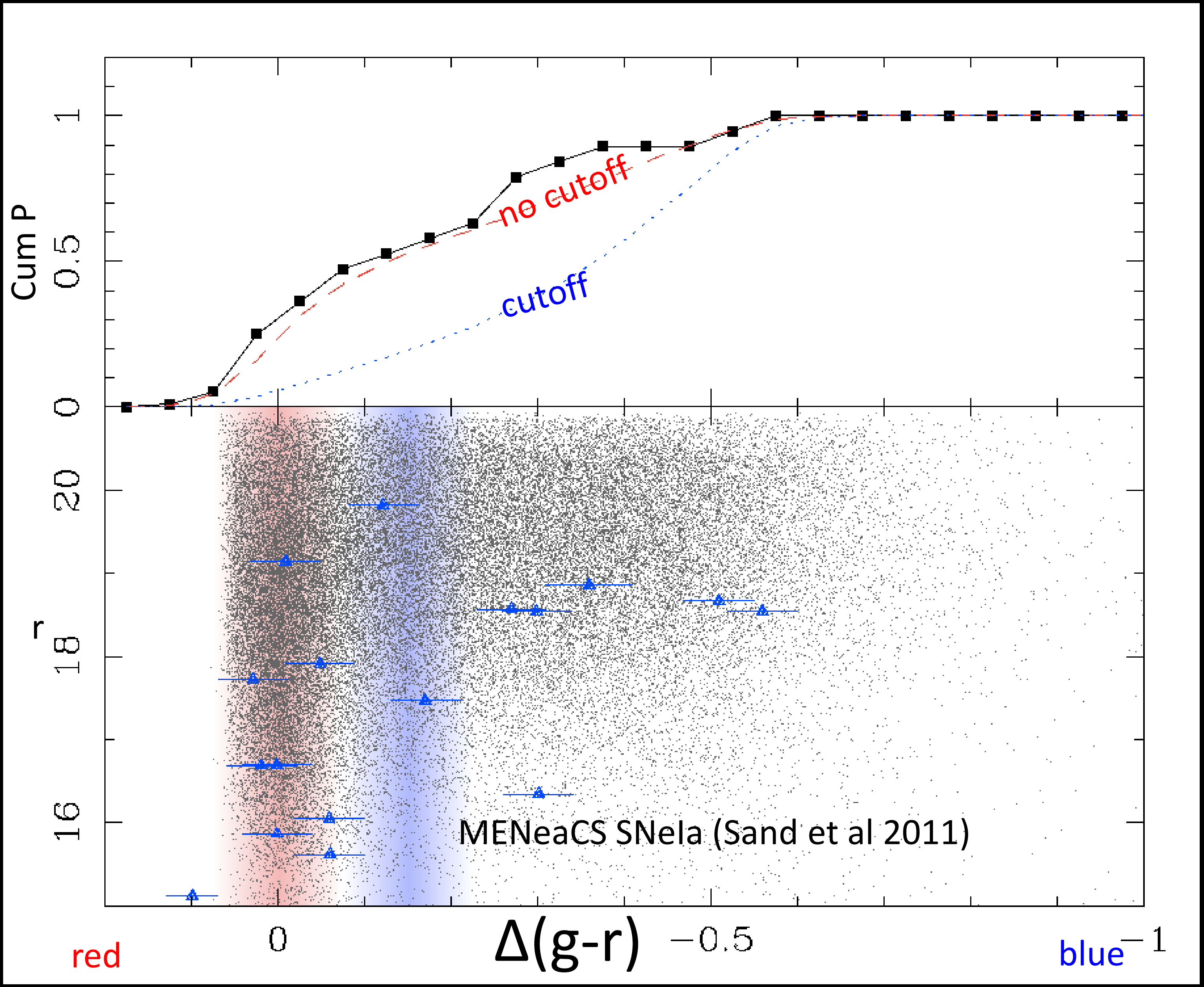
Volumetric rates to z~2.5 require DTD $\propto t^{-1}$ and efficient progenitor pathways

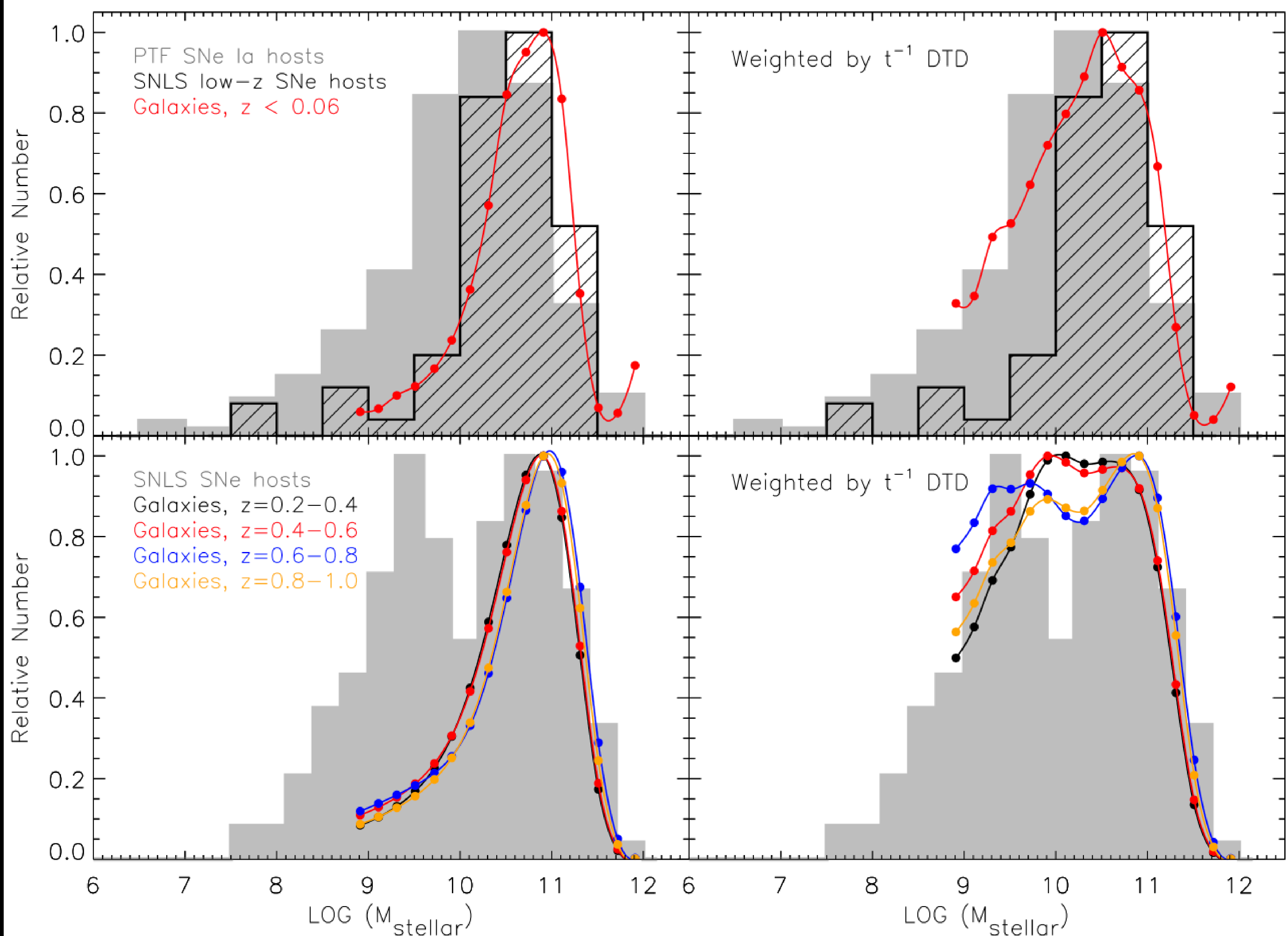
Better constraints on the prompt component can discriminate remaining models

Steve Rodney (JHU)

DTD model with **no** cutoff at t > 2 Gyr favoured. Either SD excluded, or there are large numbers of wide separation binaries (Moe, this meeting).

Chris Pritchet





PTF SNe Ia hosts
SNLS low−z SNe hosts
Galaxies, z < 0.06
Weighted by t^{-1} DTD
SNLS SNe hosts
Galaxies, z=0.2−0.4
Galaxies, z=0.4−0.6
Galaxies, z=0.6−0.8
Galaxies, z=0.8−1.0
Weighted by t^{-1} DTD
Relative Number
LOG ($M_{stellar}$)

Extremes

Class Summary

1. Low Luminosity
2. Low Velocity
3. Low KE/m
4. Sometimes He
5. Similar to Type Ia Supernovae
6. C/O Burning (Lots of Carbon)
7. Not Very Massive Star
8. Spherical Explosion
9. No X-ray/Radio Emission
10. Never Nebular?
11. Strong Forbidden Fe in Some
12. Ca Interior to Fe
13. Produces More Stable Ni (per mass) than SNe Ia
14. Late-Type Hosts
15. Large Variation in ^{56}Ni, Luminosity, Ejecta Mass, Etc
16. Low Ejecta Mass
17. 20-30 per 100 SNe Ia

A C/O White Dwarf that accretes matter from a Helium-Burning Star, resulting in an explosion. At least some of the time, The Explosion Does *Not* Disrupt the White Dwarf.

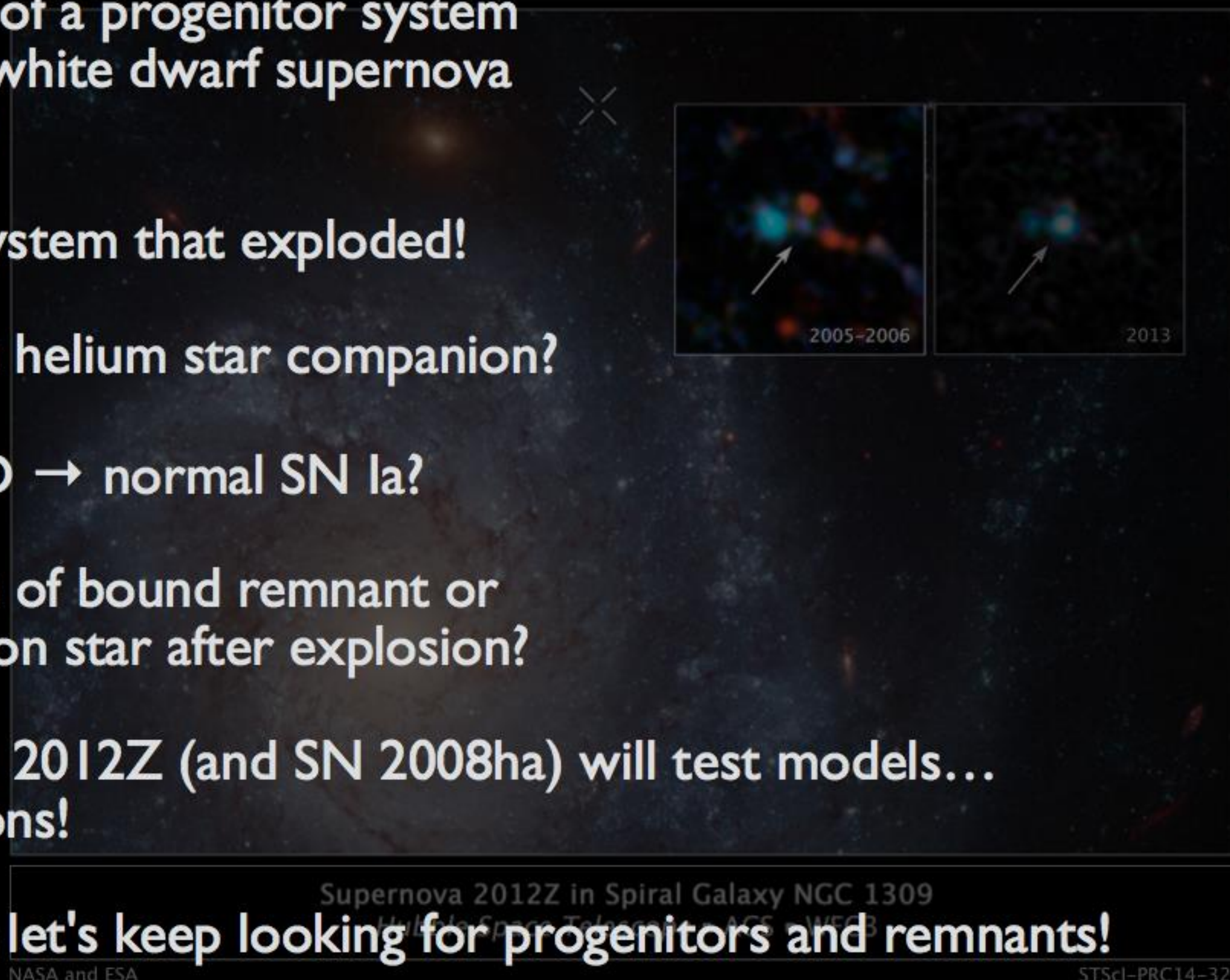
And Are More Common Than SNe Ib

conclusions

Hubble sees 'zombie star' lurking in space: What it is, why it matters

http://www.latimes.com/science/sciencenow/la-sci-sn-nasa-hubble-zombie-star-20140806-story.html

- SN 2012Z: detection of a progenitor system for a thermonuclear, white dwarf supernova in pre-explosion data
- a single degenerate system that exploded!
- M_{Ch} deflagration with helium star companion?
- SD → SN Iax and DD → normal SN Ia?
- SN 2008ha: detection of bound remnant or (disturbed?) companion star after explosion?
- follow-up data on SN 2012Z (and SN 2008ha) will test models… please make predictions!
- future nearby SN Iax; let's keep looking for progenitors and remnants!

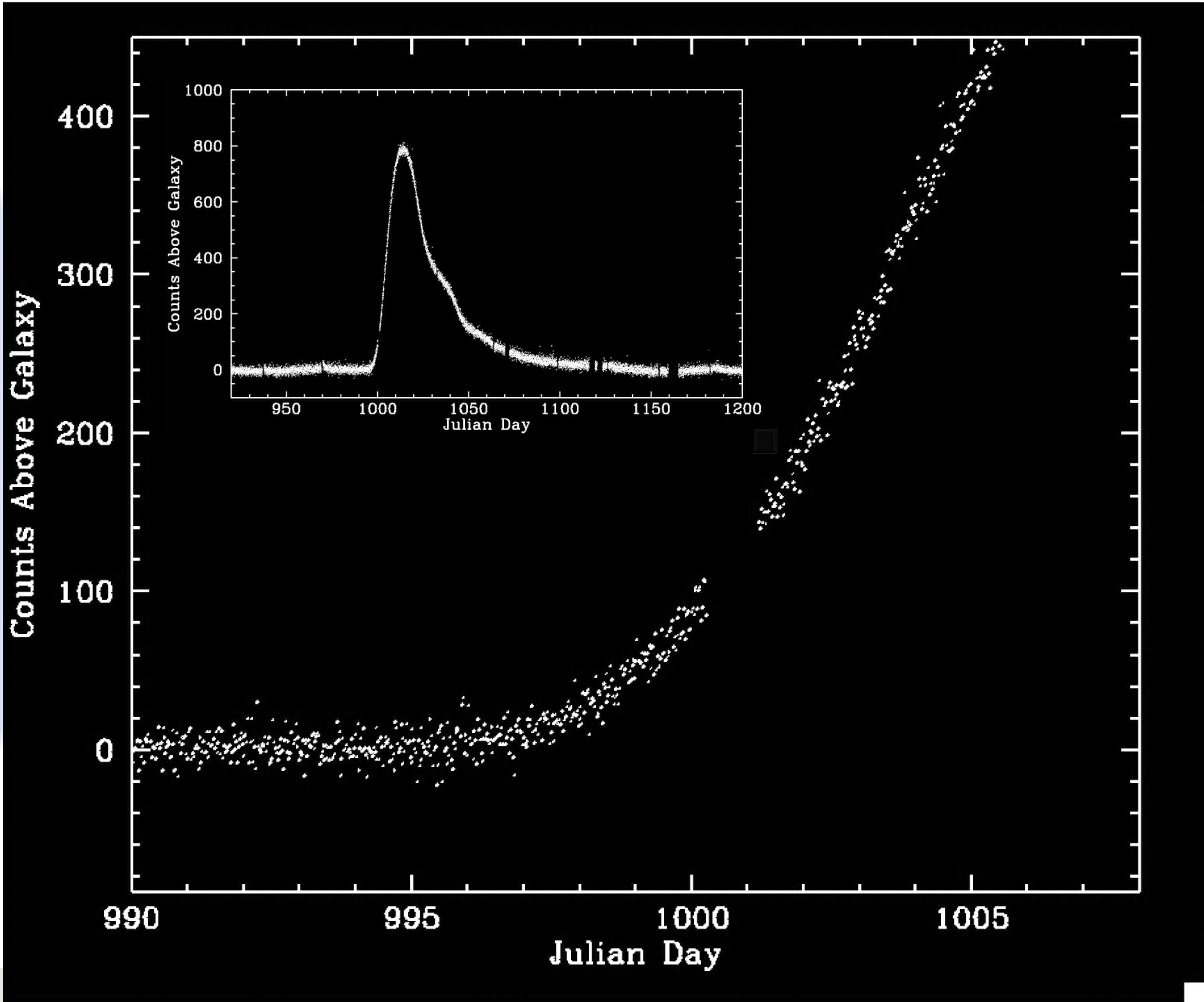


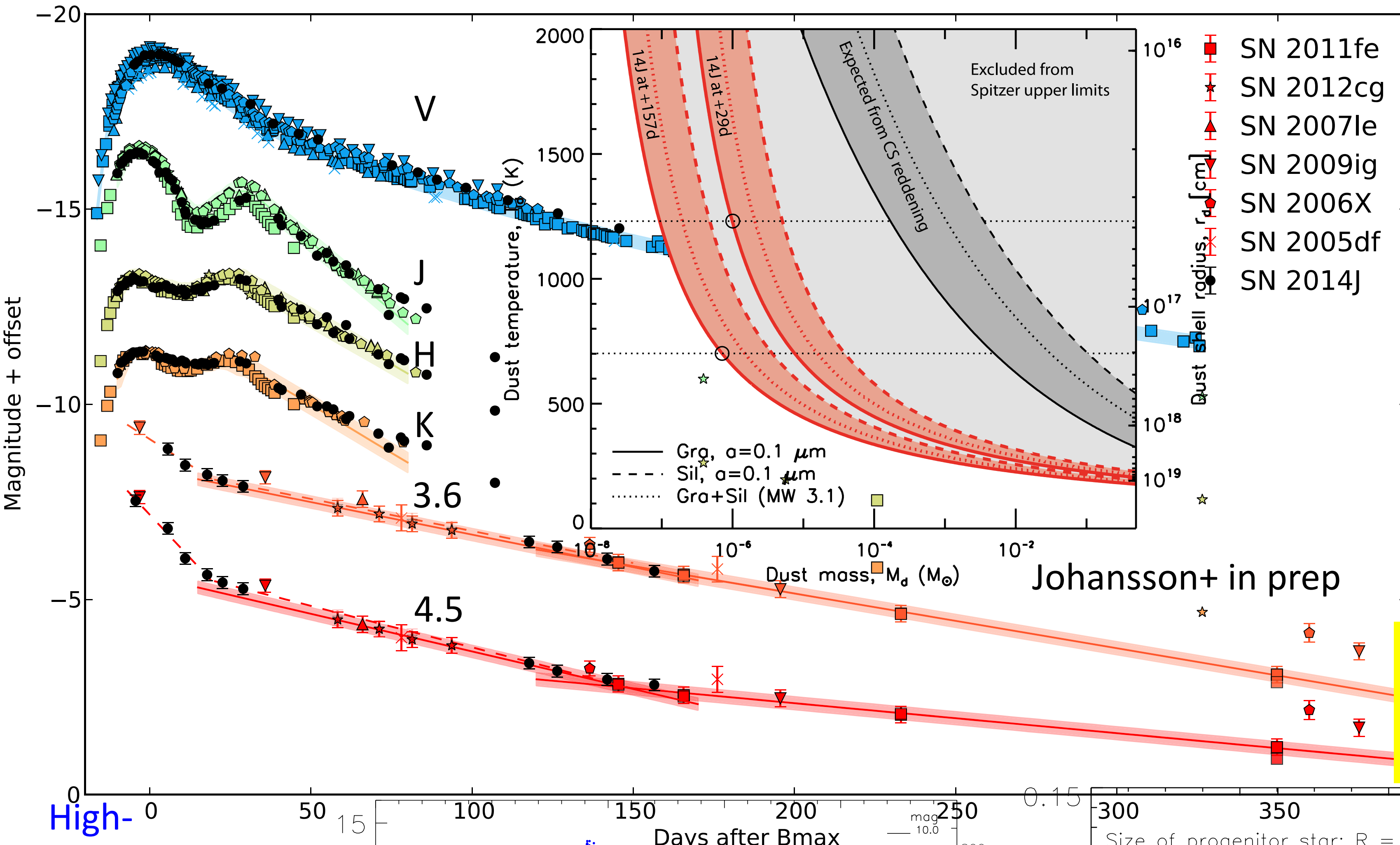
Rise time

Really Nice Light Curves

- 30 Minute Cadence!!!
- Continuous monitoring
- Pre-Explosion
- 4000 Data Points per SN!
- Photometry ~0.01 mag
- Only one Filter

Peter Garnavich
5 Kepler SNe

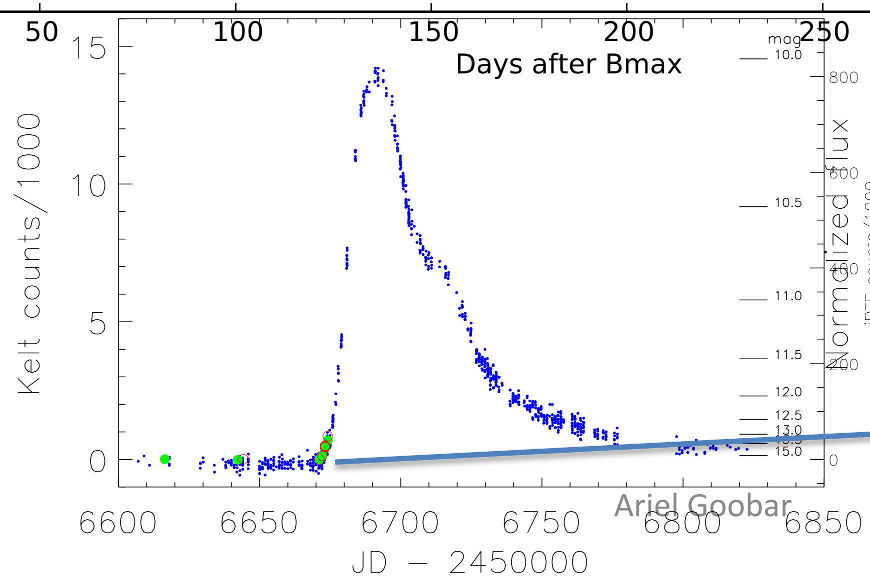


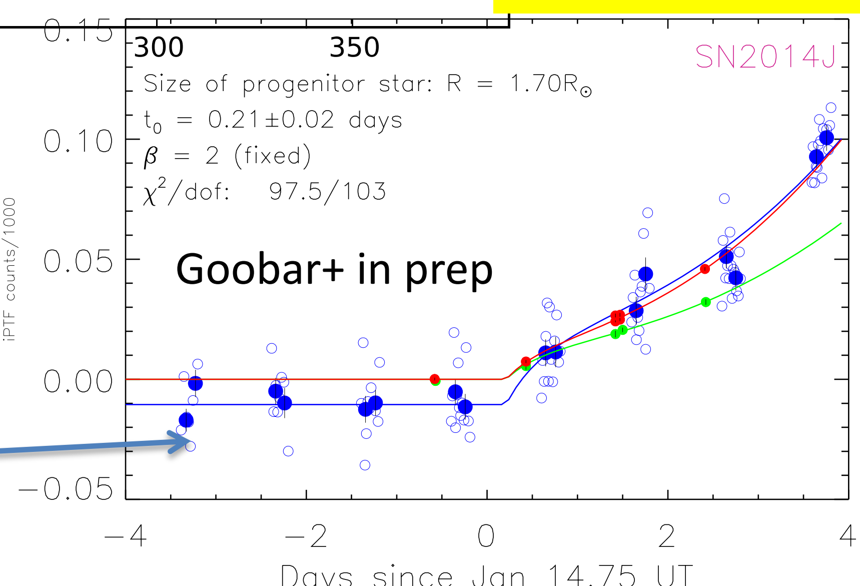


WD size + t^2 excluded at 90% CL

High-cadence KELT data

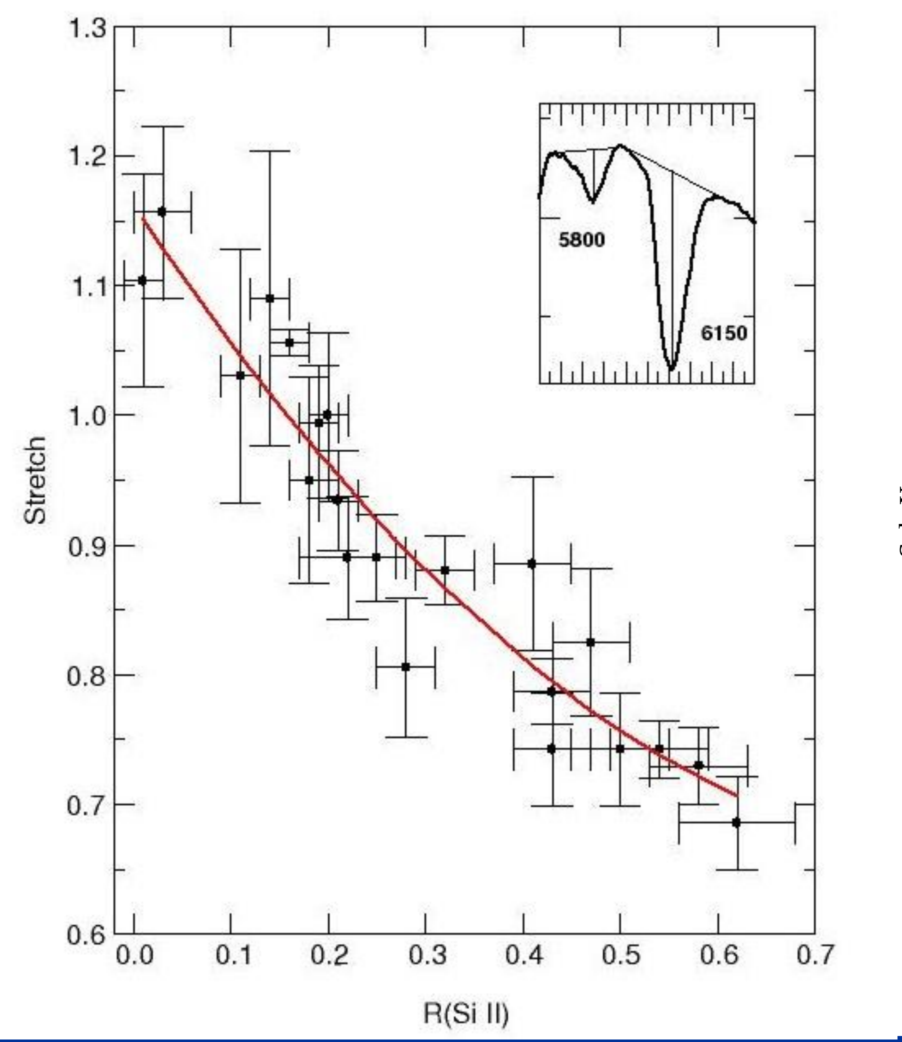
iPTF narrow-band obs.



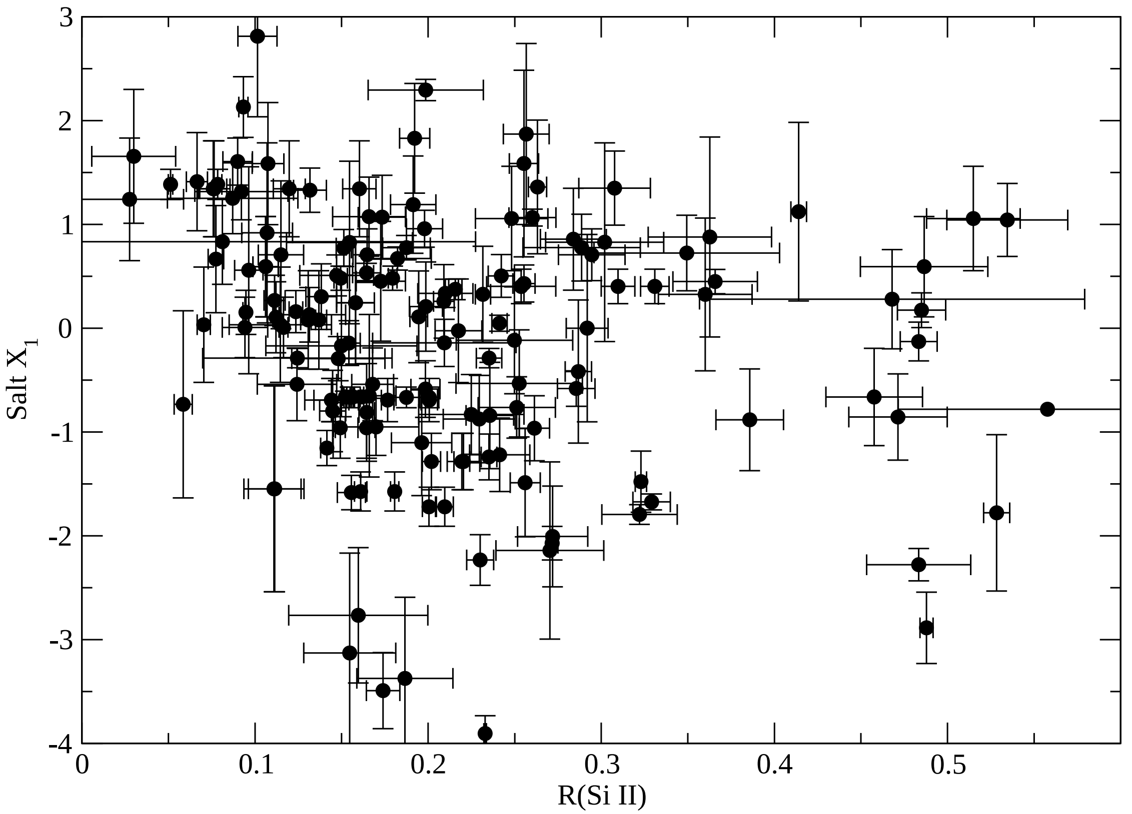


Inferences from data

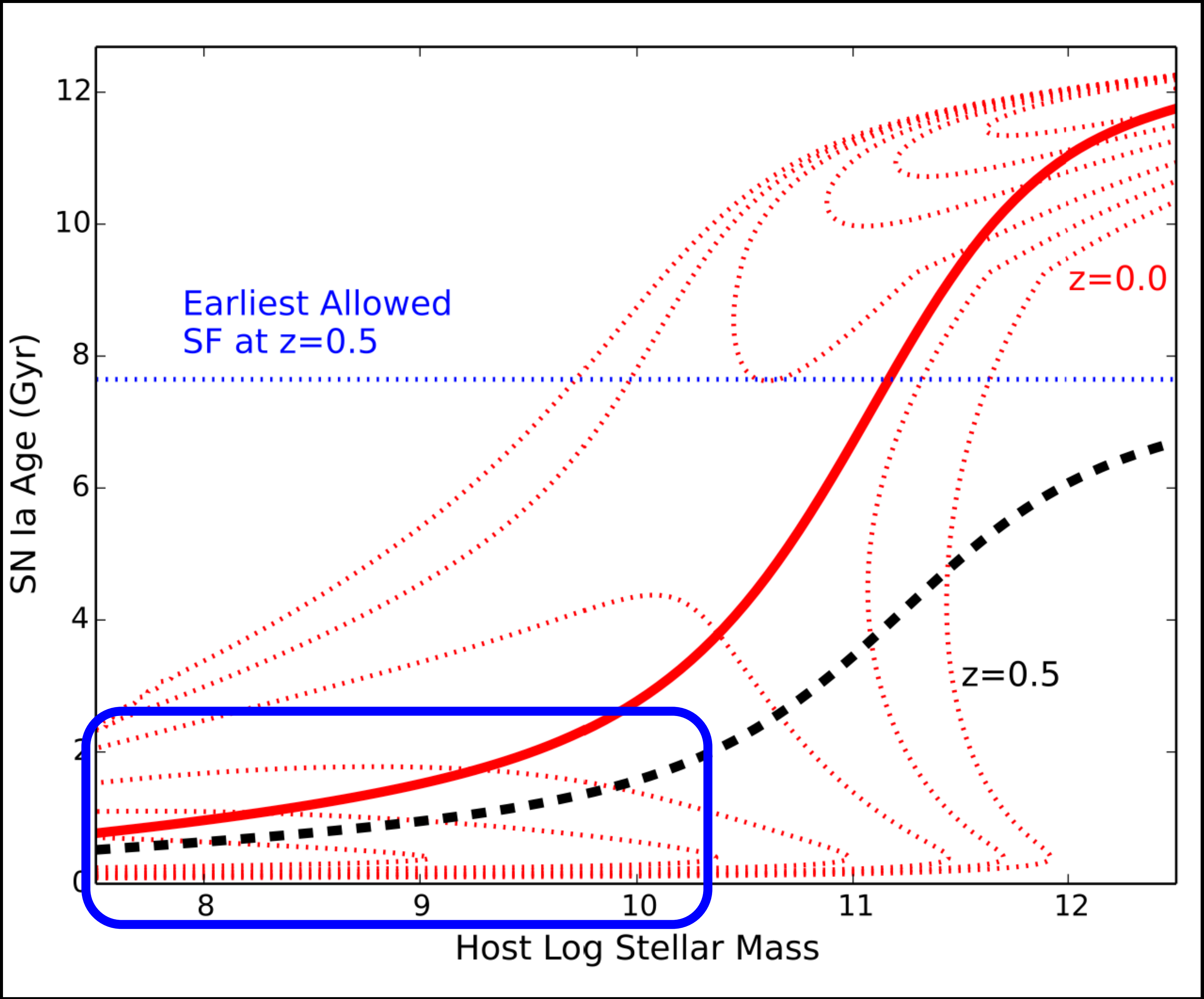
R(SiII)



1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
Stretch
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
R(Si II)
5800
6150



3
2
1
0
-1
-2
-3
-4
Salt X_1
0
0.1
0.2
0.3
0.4
0.5
R(Si II)

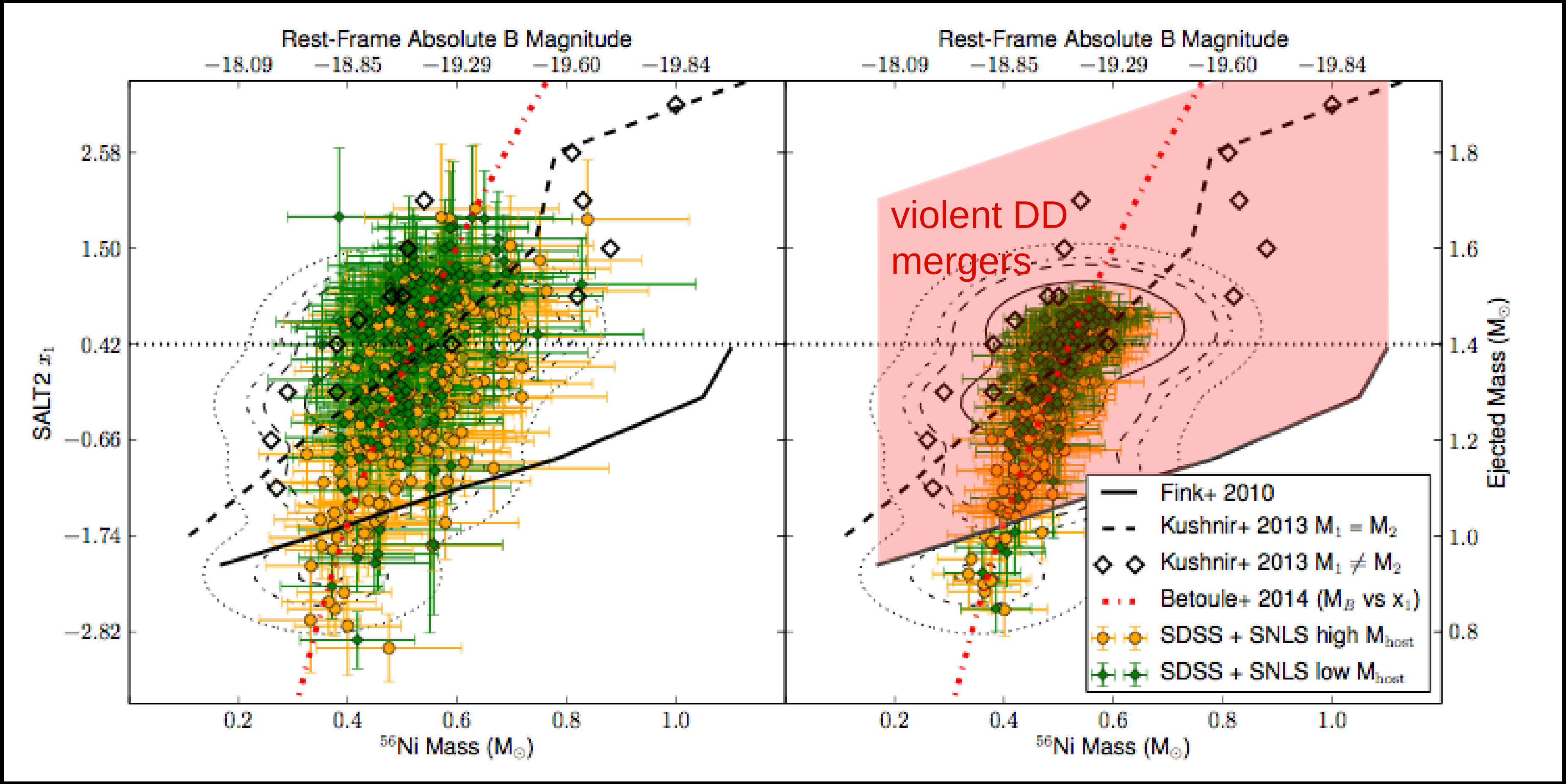


The most homogeneous SN Ia events are in lower mass galaxies

Childress et al. (2014)

Joint M_{ej}-M_{Ni} distribution

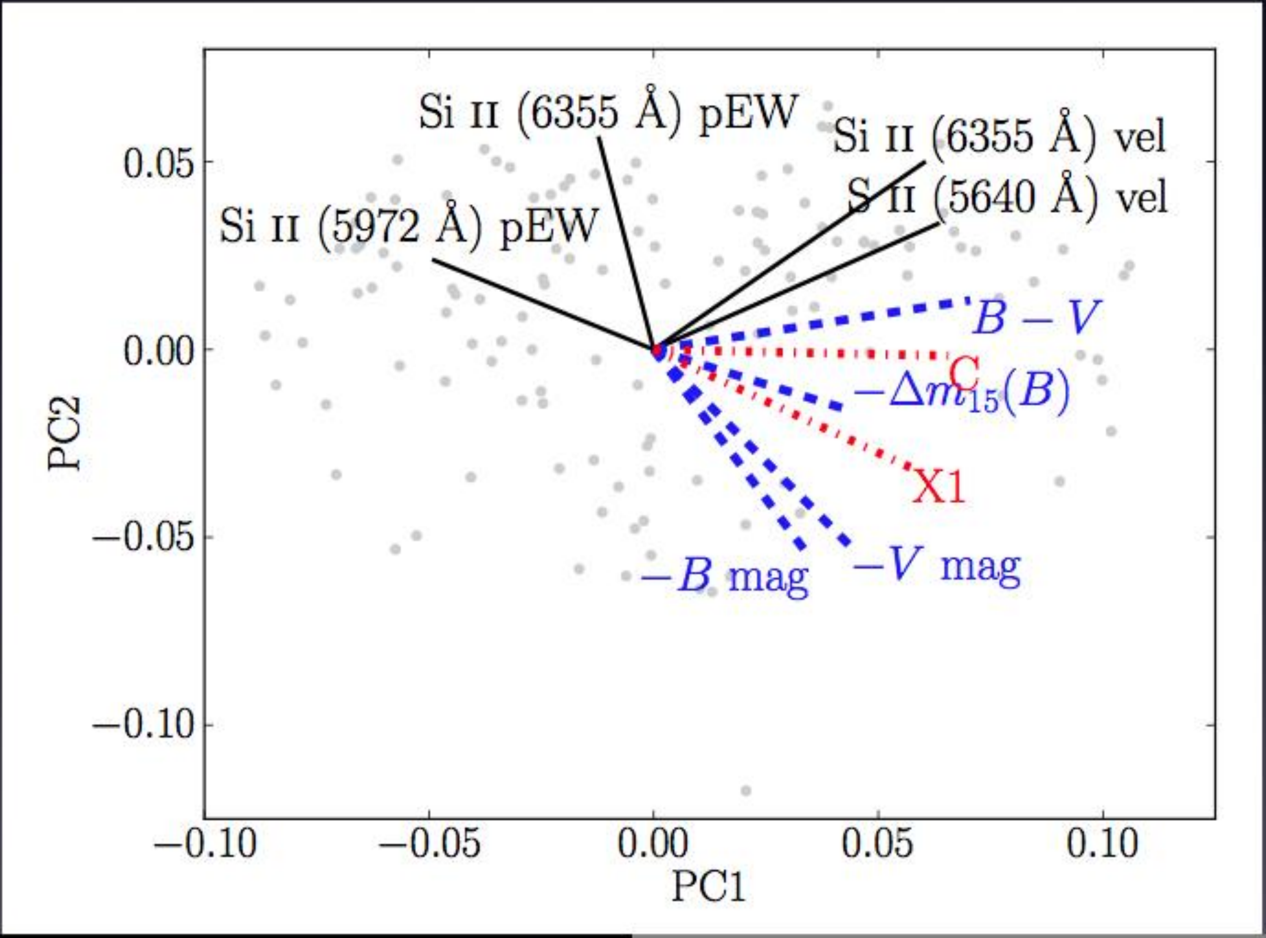
(Richard Scalzo, Ruiter, & Sim, MNRAS in press **arXiv:1408.6601**)



No single channel reproduces this behavior (yet!)

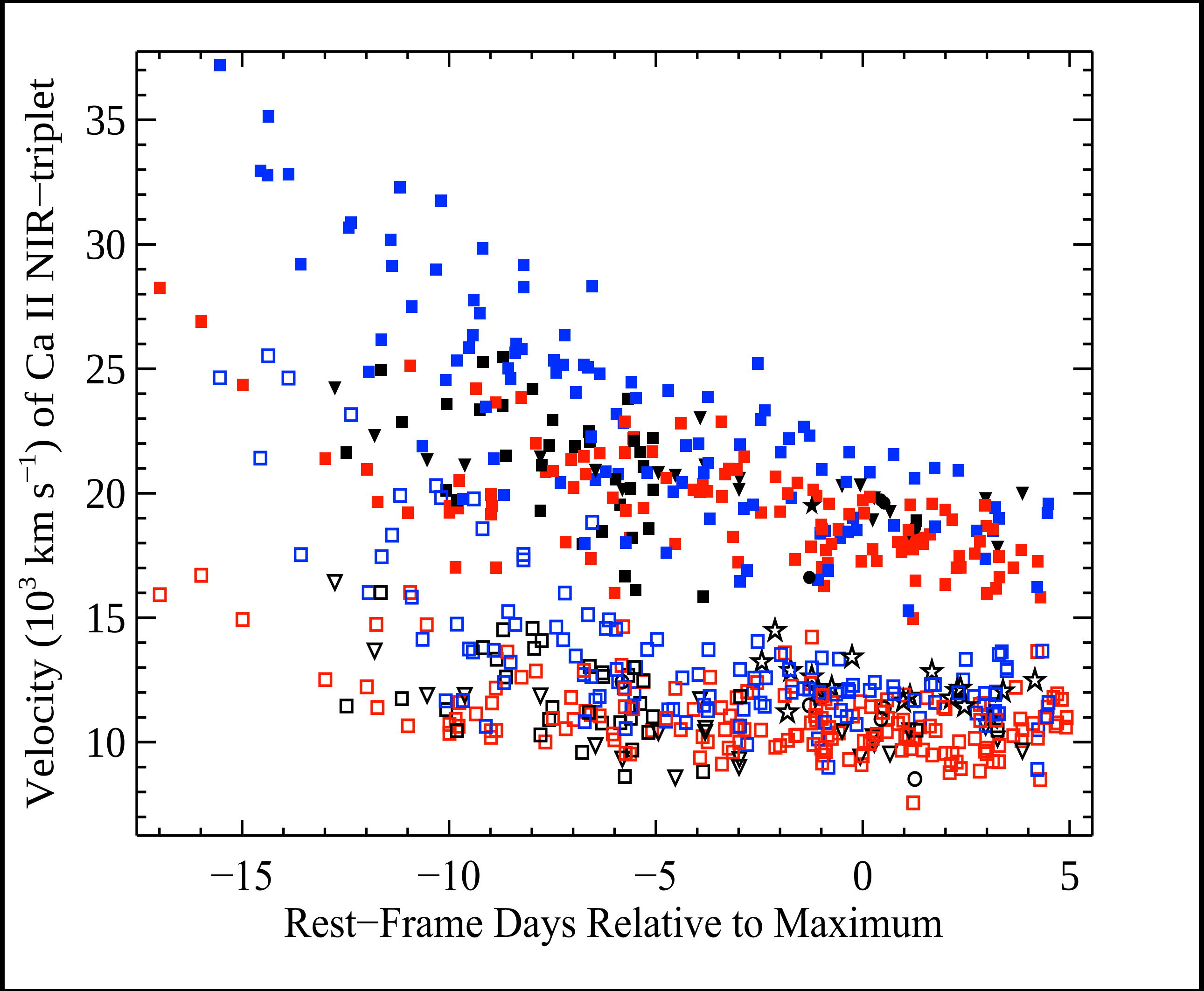
PCA & PLS on SN Ia spectral series

Wrap up of the meaning of the PCs from PCA (projections in the first 2 PCs).
To find these projections we use Partial Least Square (PLS)

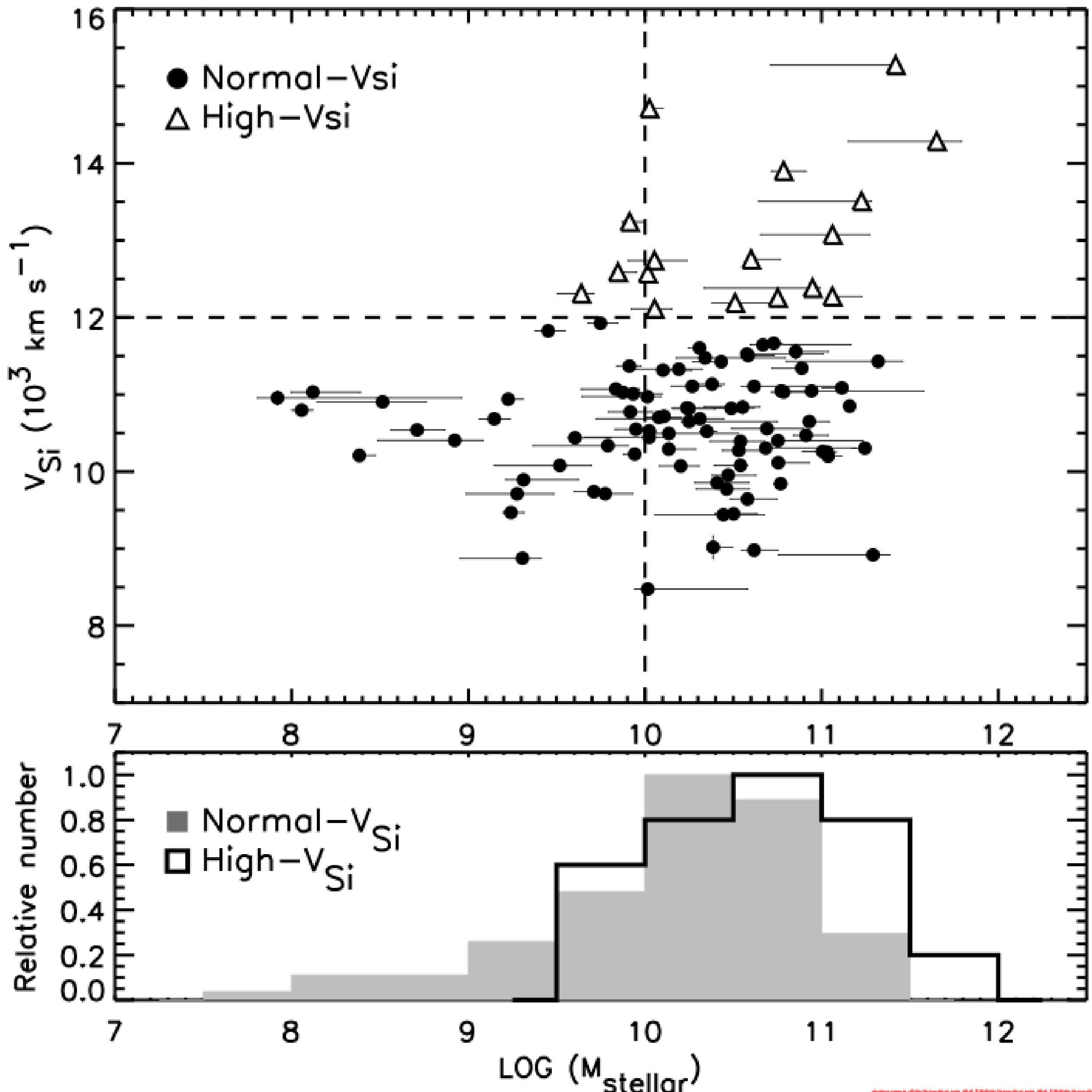


Host galaxy effects

SNe Ia that we put on a Hubble Diagram have HVFs of Ca from just after explosion through ~3 days before maximum brightness (and often longer).



Silicon velocity and host $M_{stellar}$

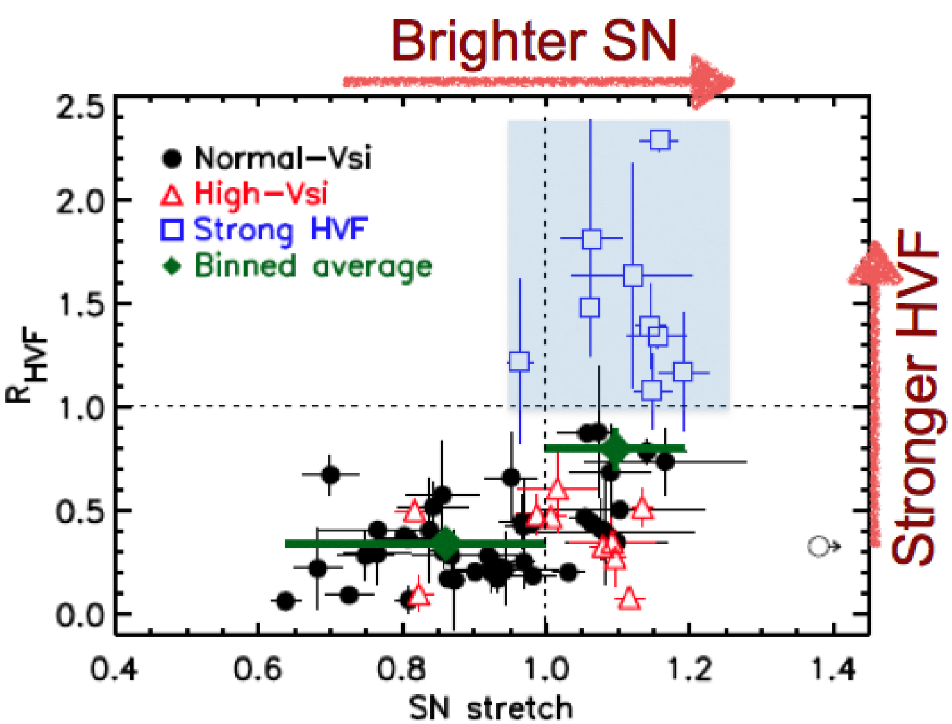


Normal-V_{si}: V_{si} < 12,000 km/s
High-V_{si}: $V_{si} \geq$ 12,000 km/s

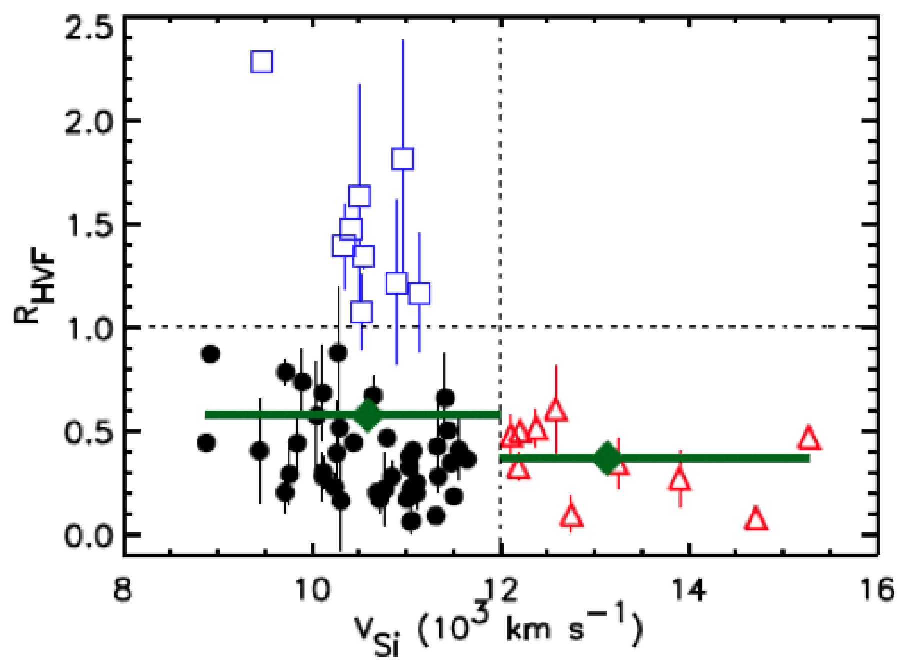
Calcium high-velocity feature (I)

(See also Maguire+ 2014)

R_{HVF} vs Stretch

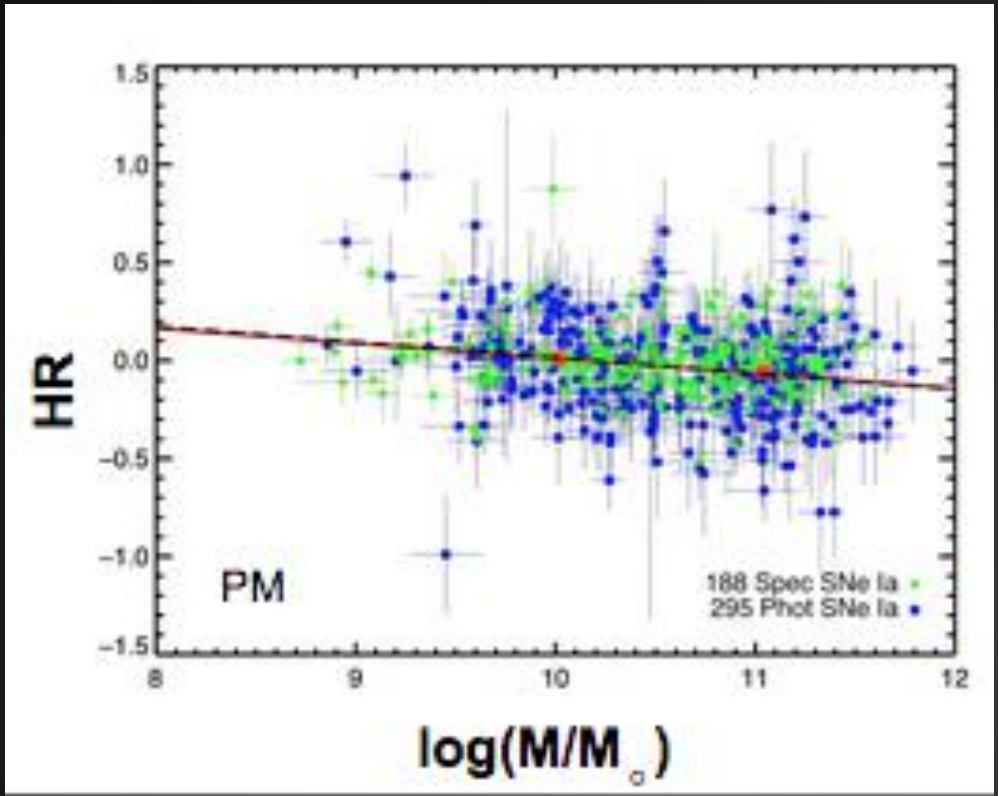


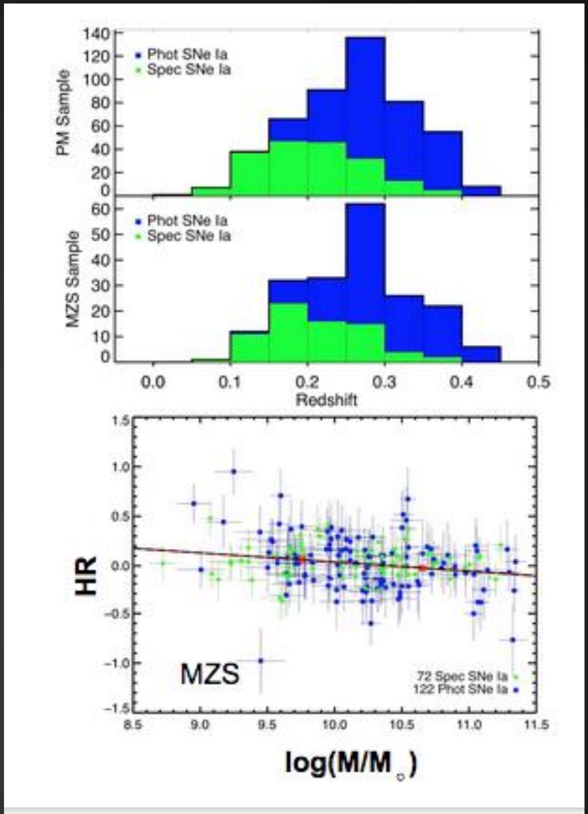
R_{HVF} vs V_{si}



Normal-V_{si}: V_{si} < 12,000 km/s
High-V_{si}: $V_{si} \geq$ 12,000 km/s
Strong Ca II HVF: R_{HVF} > 1

Rachel C. Wolf: Host Galaxy Environment as a Parameter for SN Ia Standardization





Current Analysis:

- Use sample of of ~480 spectroscopic + photometric SNe Ia from SDSS-SNS (split into two subsets) with BOSS + SDSS host galaxy spectra

- Find 5σ correlation between HR and photometric host mass using PM sample

- Find < 3σ correlation between HR and spectroscopic sSFR & HR and gas-phase metallicity for MZS sample

Further work:

- Consider separate spectroscopic + photometric SNe Ia samples

- Consider age, homogeneity of different host samples

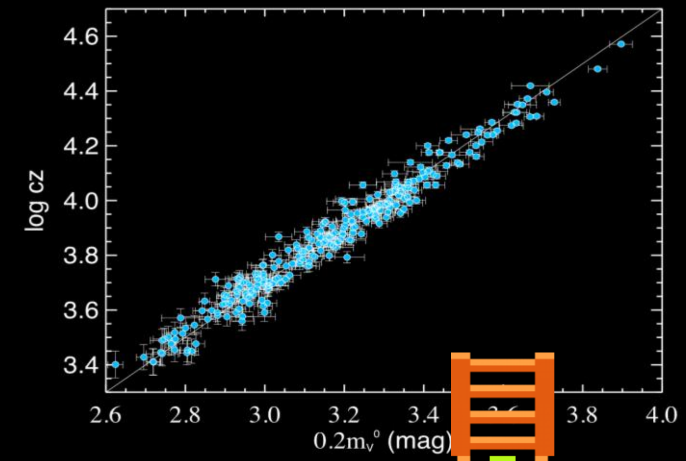
- Consider effects of different mass/metallicity/star-formation rate bins

Cosmology

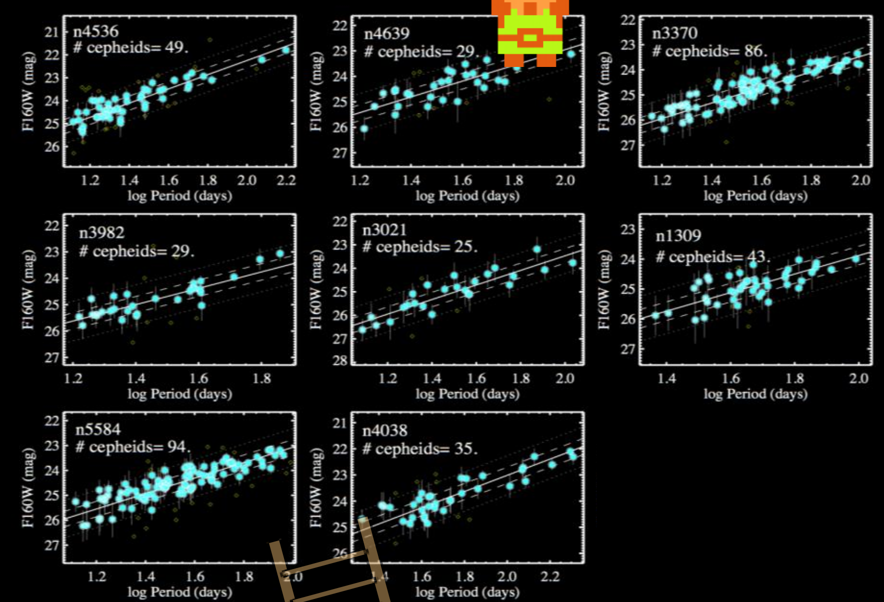
H_0 in 3 Steps*

H_0=73.0[a] +/- 2.4 km/s/Mpc

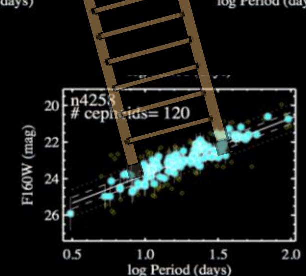
3) SN Ia in Hubble flow



2) HST NIR Cepheid P-L in 8 ideal SN Ia Hosts

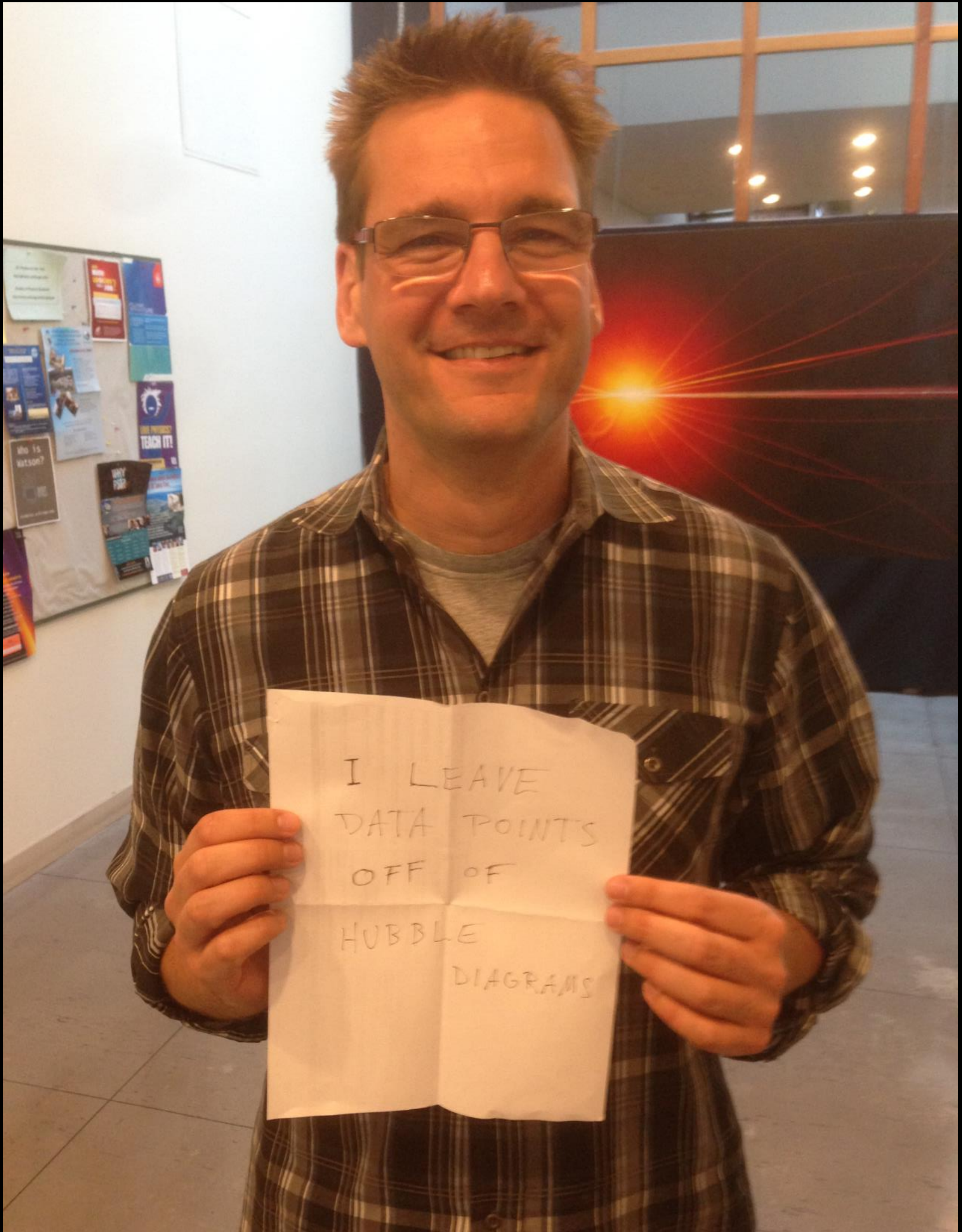


1) HST NIR Cepheid P-L in NGC4258 Anchor (or MW parallax)



*Global regression accounts for data, parameter covariance
[a] updated distance to NGC 4258, Humphreys et al. (2013)

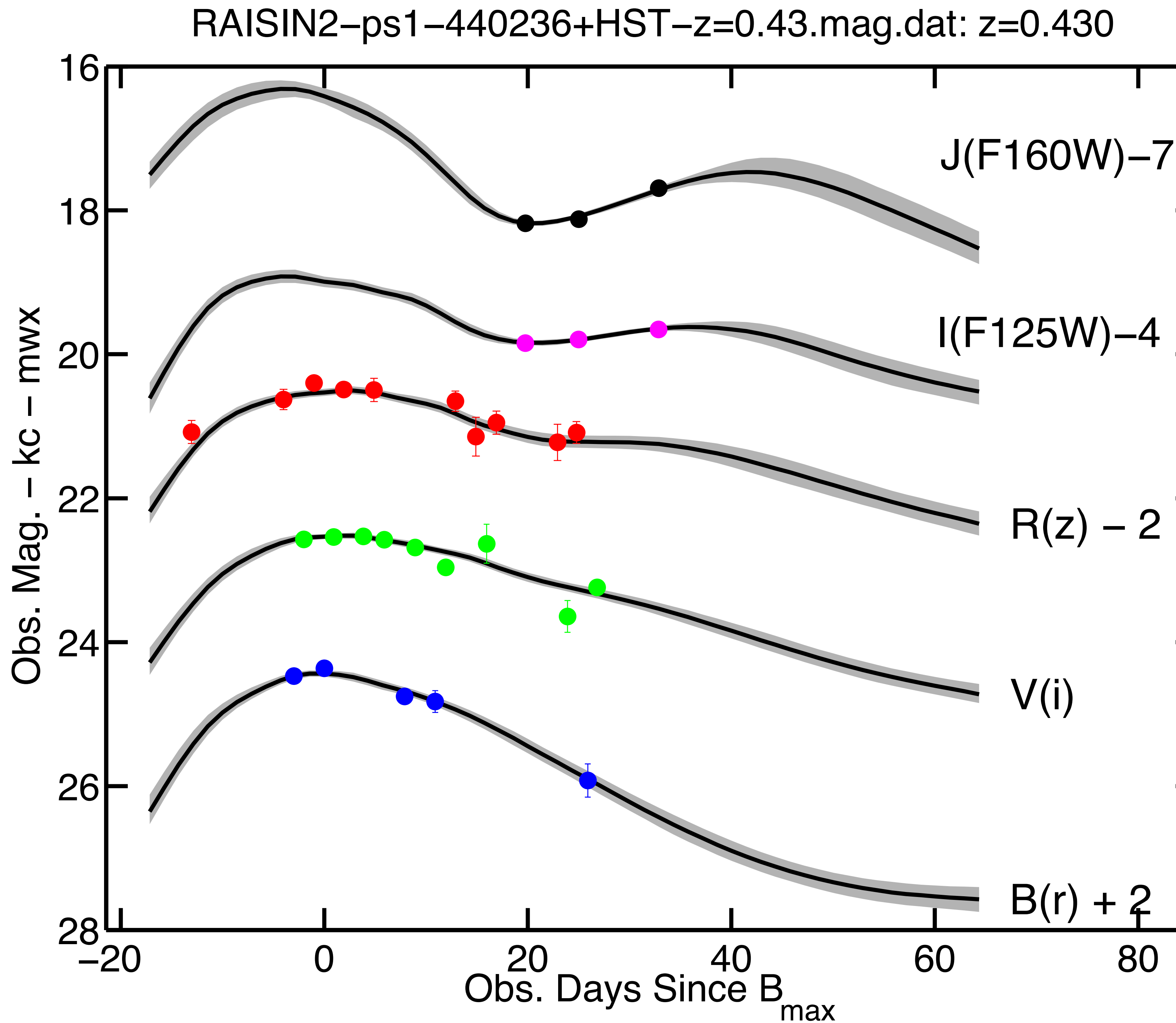

I WATCHED
A MOUSE
EAT MY FOOD
AND DID
NOTHING

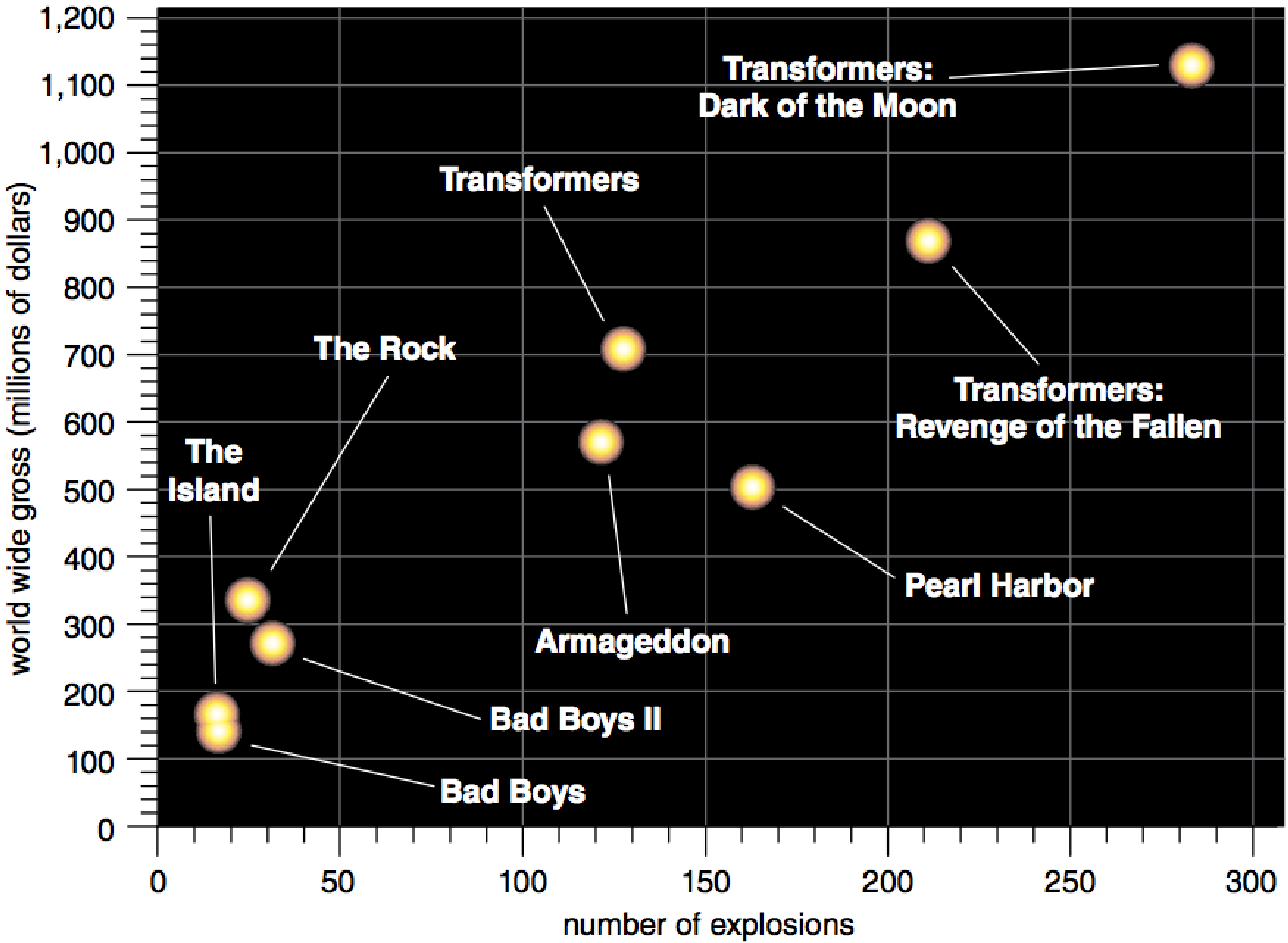

I LEAVE
DATA POINTS
OFF OF
HUBBLE
DIAGRAMS

Most of these systematics should get significantly better in next iterations. Good (optimistic?) SN prediction is that systematic errors will drop with statistical errors

	dw	Plan
Calibration:	0.045	e.g Scolnic - 'Supercal'
SN Color Model:	0.023	better understanding of color. e.g. Kirshner - RAISINS. Patel,Jha,Riess, Scolnic - 'newMLCS'
Host Galaxy Dependance:	0.015	e.g. Thilker/Zheng, Jones - subsample analysis
MW Extinction:	0.013	e.g. Schlafly, Finkbeiner, Green dust maps
Selection Bias:	0.012	More statistics makes easier
Coherent Flows:	0.007	-

SCOLNIC


RAISIN2−ps1−440236+HST−z=0.43.mag.dat: z=0.430
J(F160W)−7
I(F125W)−4
R(z) − 2
V(i)
B(r) + 2
Obs. Mag. − kc − mwx
Obs. Days Since B max
16
18
20
22
24
26
28
−20
0
20
40
60
80


1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
world wide gross (millions of dollars)
0
50
100
150
200
250
300
number of explosions
Transformers: Dark of the Moon
Transformers
Transformers: Revenge of the Fallen
The Rock
The Island
Armageddon
Pearl Harbor
Bad Boys II
Bad Boys

What do observers want from theorists?

DTD for new models like core degenerates

Coherent DTDs from SD models

More spectroscopy

Better radiative transfer comparisons, and more of them

More code to code comparisons for explosion models and nucleosynthesis

Better efficiency of explosions or more systems, new types of explosions?

Better population synthesis (also better understanding mass retention on white dwarfs)

Better understanding of CSM interaction

Better nebular modeling