Host Galaxies of Type Ia Supernovae:
Indirect Clues to SN Progenitors

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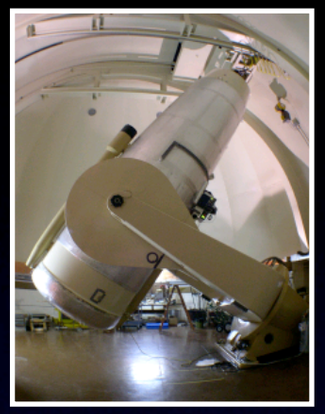
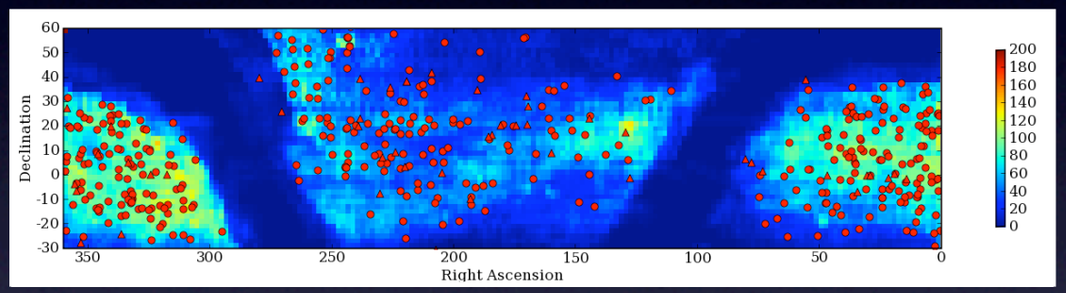
Outline

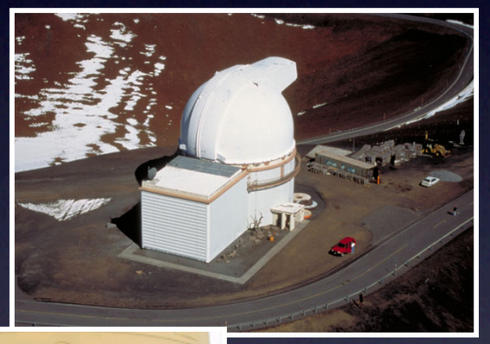
- Motivation: Standardizing the Standard Candle
- SN Ia Host Galaxy Studies To-Date
- SNe Ia from Low-Metallicity Progenitors
- Hostless (?) SNe Ia

SNfactory Overview

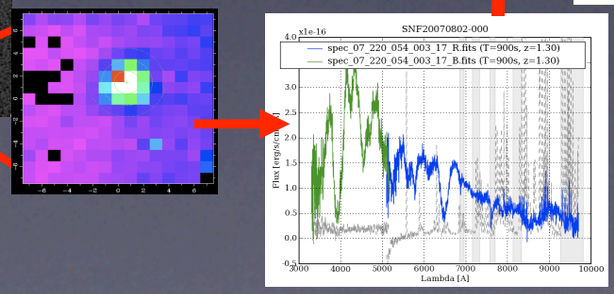


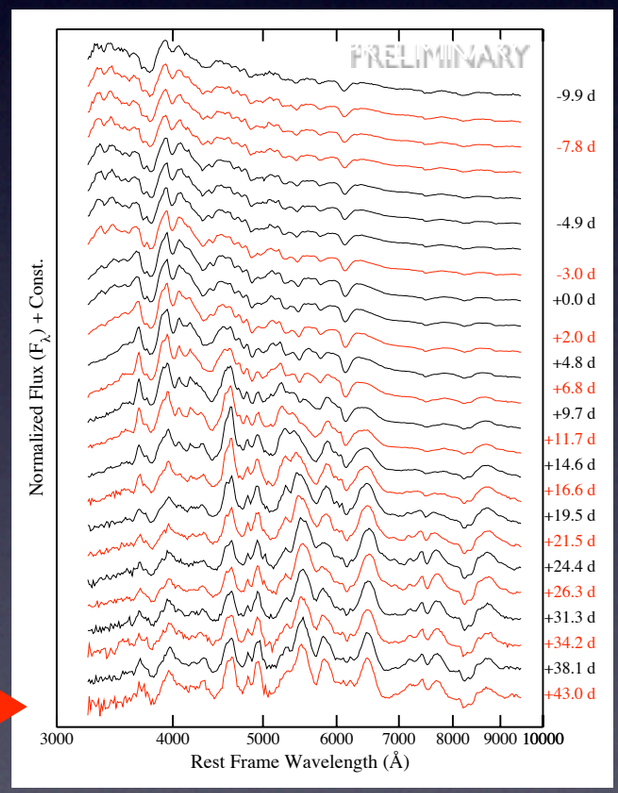
- Untargeted wide-field search w/ QUEST camera on Palomar 48-in
- Discovered over 1000 SNe, over 600 spectroscopically typed:
  - 396 SNe Ia discovered by SNf ("demographics" sample)
  - 185 SNe Ia with well-sampled LCs ("cosmology" sample)





- Followup with SuperNova Integral Field Spectrograph (SNIFS) on University of Hawaii 2.2m (UH88)
  - Flux calibrated spectral time series with 2-3 day cadence
  - Can synthesize light curves from SN SED in ANY band without need to perform K-corrections



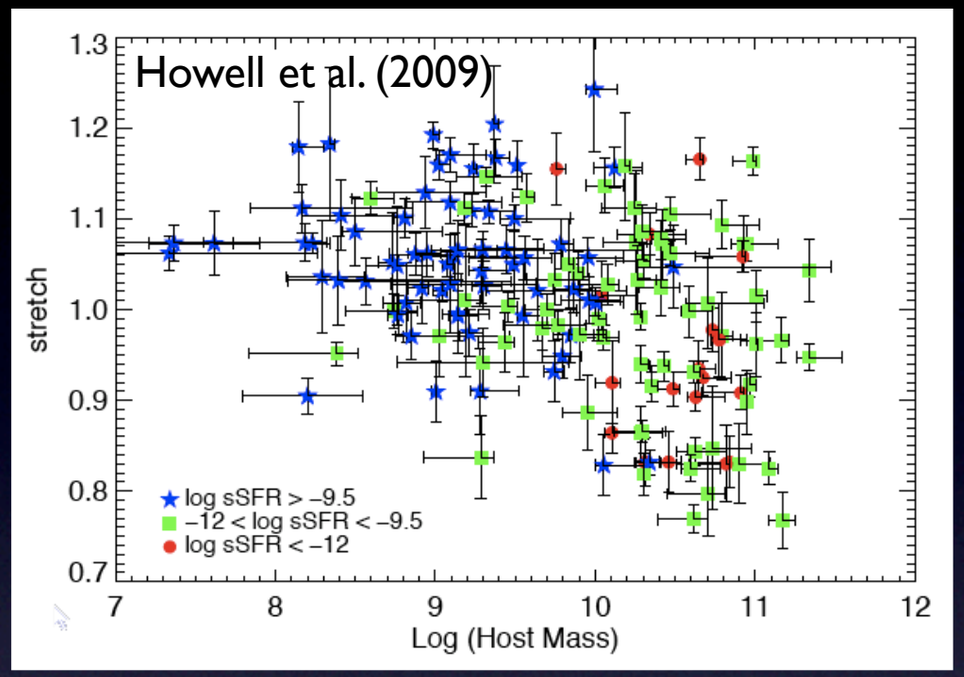


Motivation: Calibrating SNe Ia for Cosmology

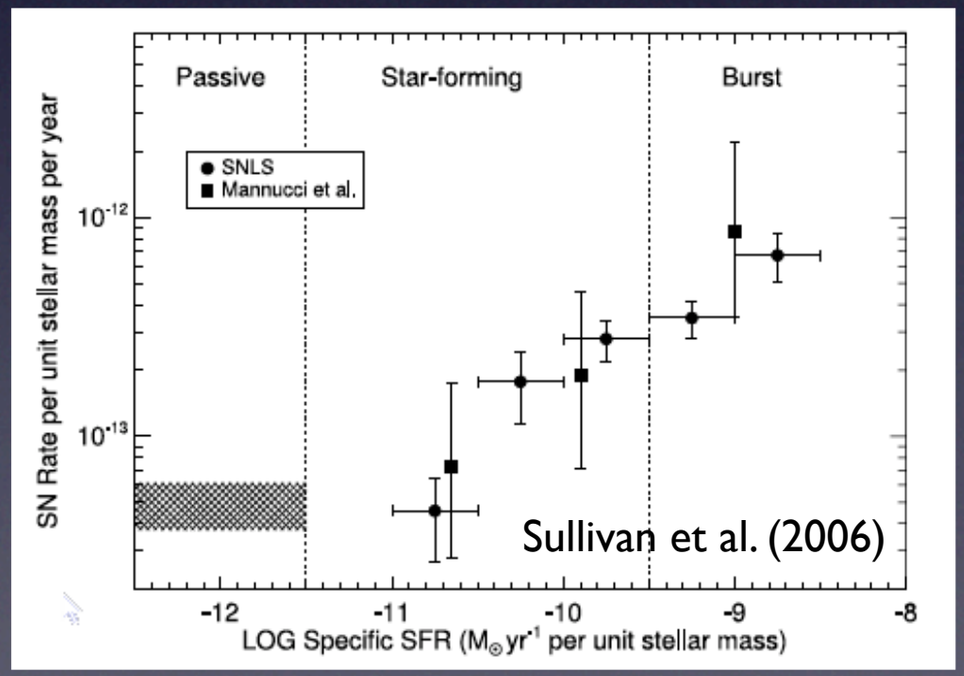
- SNe Ia have raw brightness dispersion of ~ 0.4 mag, correctable w/ light curve parameters to ~0.15 mag
- **SNfactory**: spectral time series may reveal more about cause of dispersion (i.e. what part of SED drives it), or means to correct for it (Bailey et al. 2009)
- **The Concern: Is dispersion progenitor-driven?**
- **The Future**: high-volume SN searches and photometric followup at high-redshift
  - Will evolving progenitor environments derail empirical SN Ia calibrations by introducing systematic biases?
- **Approach**: study SN Ia environments at low-z for clues

Host Galaxies of SNe Ia - Early Results

- SN Ia stretch correlates with galaxy mass
  - product of SN progenitor age?
  - correctable* from SN light curve

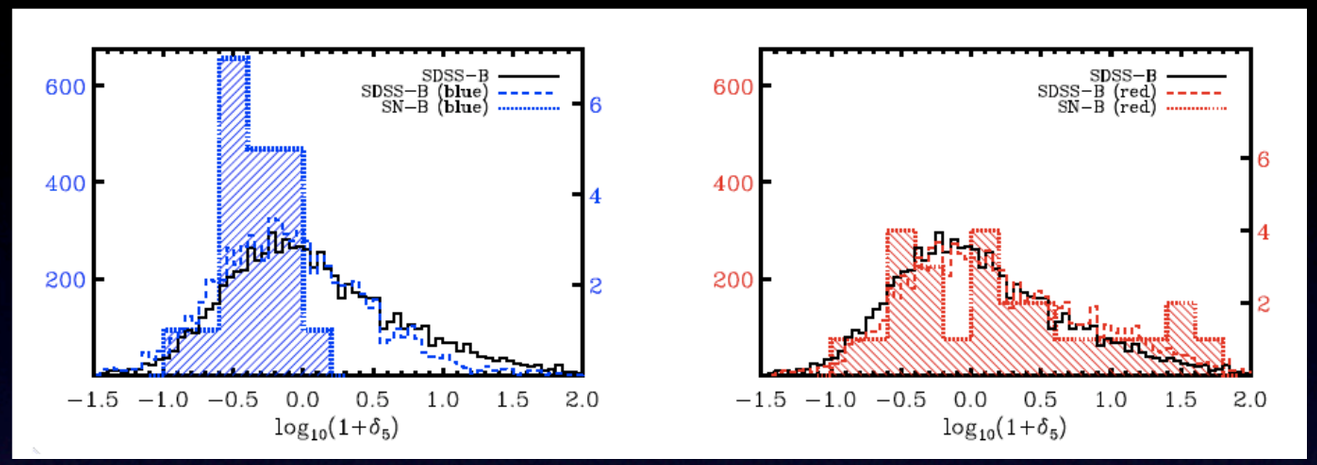


- SN Ia rates related to host mass and star-formation rate
  - two distinct progenitor channels? - "A+B" model (Scannapieco & Bildsten 2005)

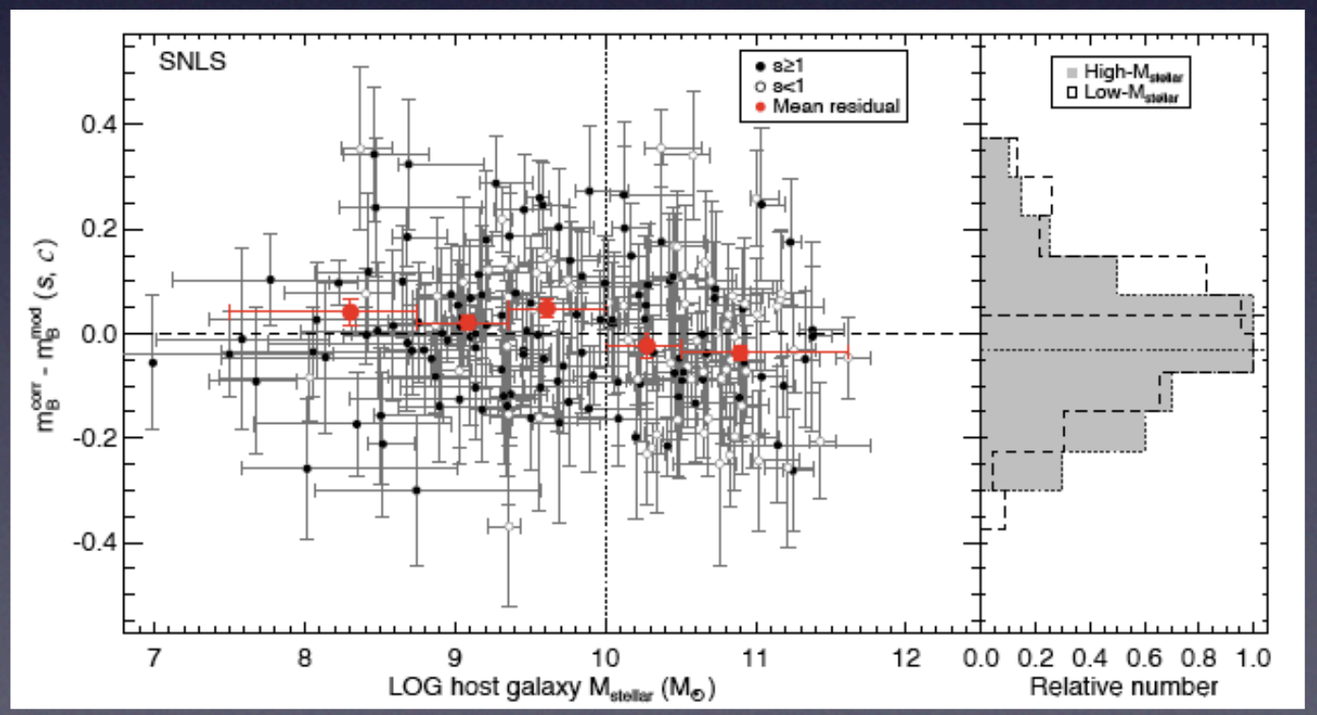


Some Unsettling Recent Results...

- Cooper et al. (2009) found a lack of SNe Ia in star-forming galaxies in high-density regions
  - maximum metallicity for "prompt" SNe Ia?

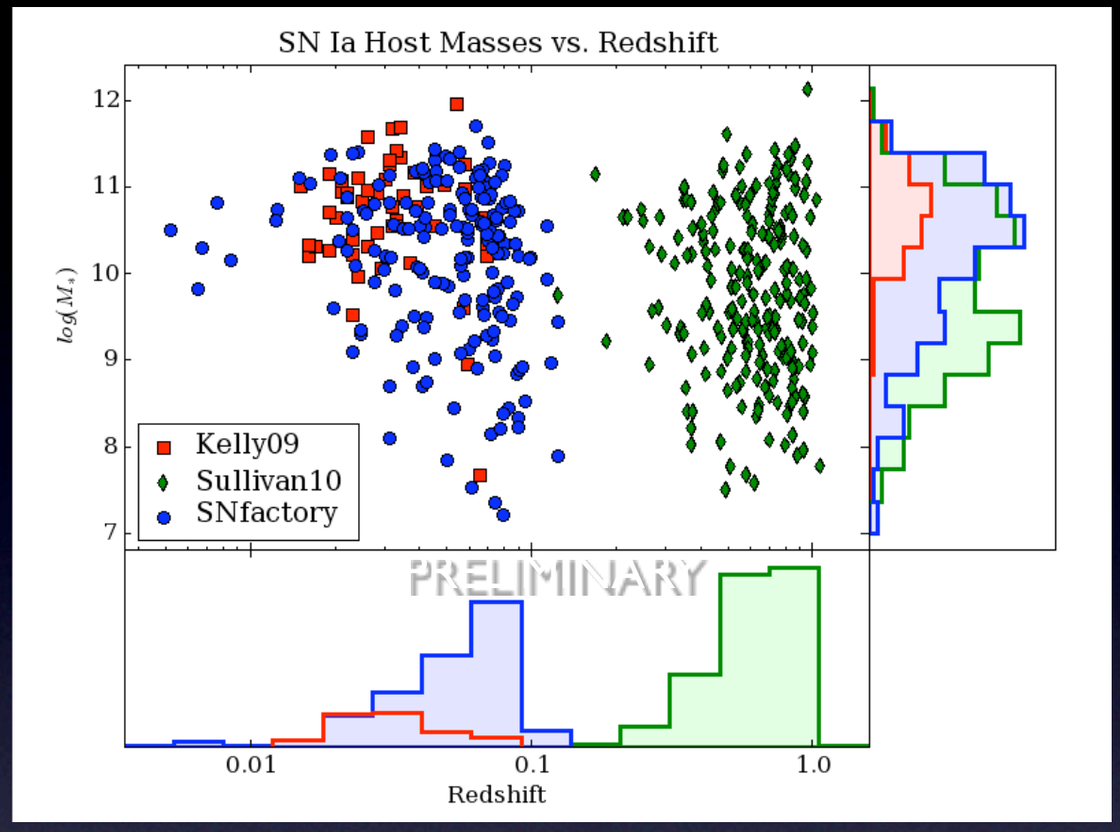


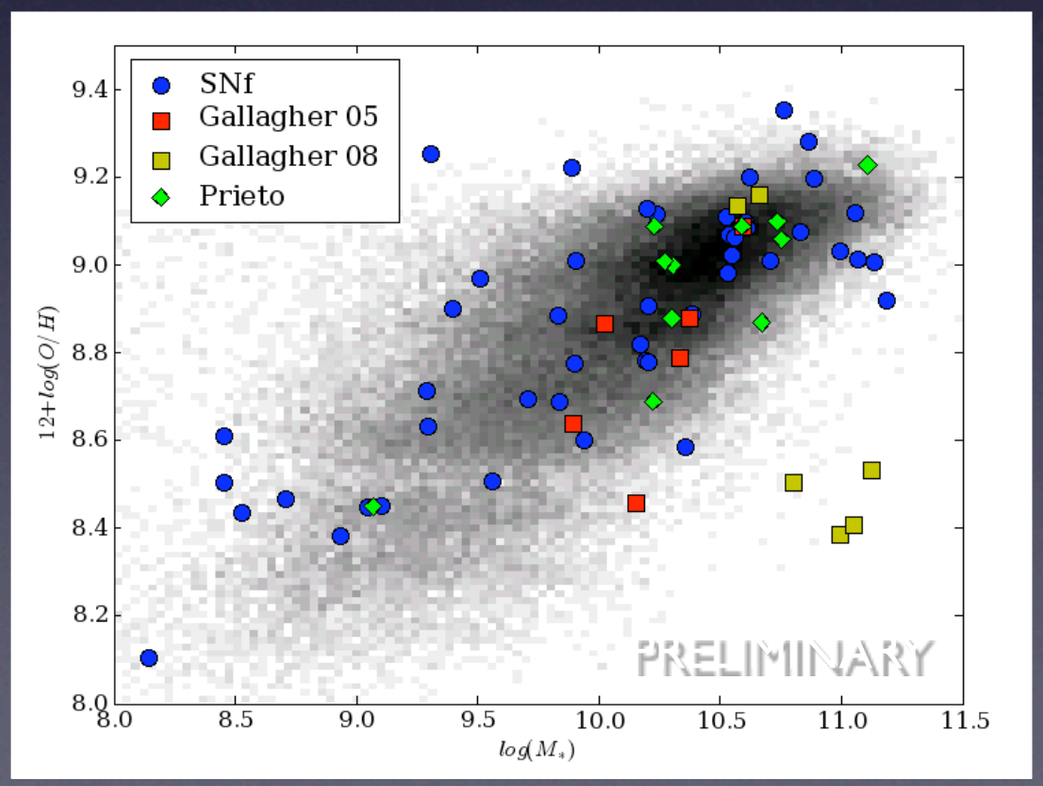
- Kelly et al. (2009) found >2σ dependence of *corrected brightness* on host galaxy mass
- Sullivan et al. (2010) found *corrected brightnesses* SNe Ia in low-mass hosts exceeds those in high-mass hosts by 0.08 mag at 4σ



SNfactory's Input...

- SNfactory sample of 185 SN Ia hosts spans similar mass range of high-z (SNLS)
- Multiband data on hand (from SDSS) for ~1/2 our sample, applied for time to observe remaining 1/2

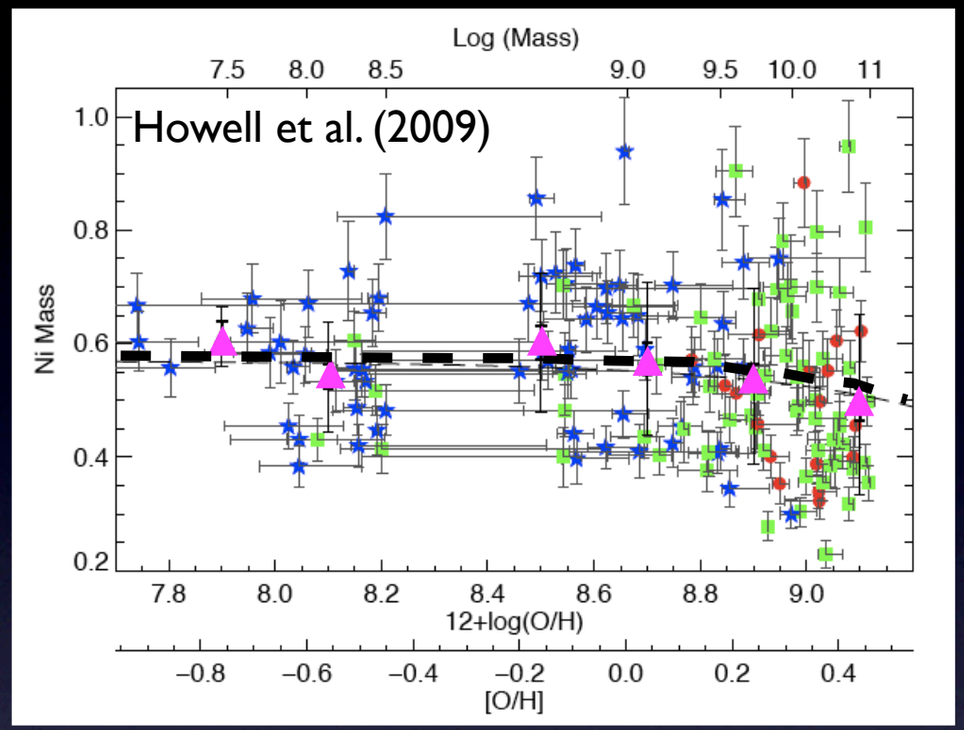


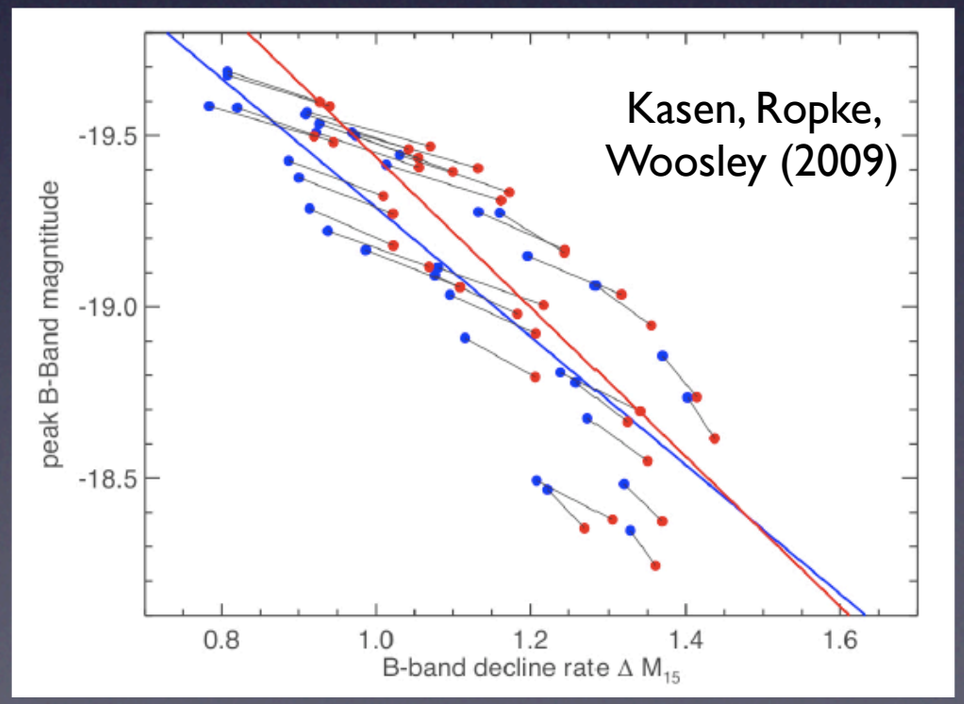


- Spectroscopically-measured SN Ia host metallicities scarce (17 total in Hubble Flow)
- SNfactory has 70+ spec. Z's on hand for SNe in our 1st cosmology sample, more proposed to observe in fall

Theoretical SN Ia Progenitor Metallicity Effects

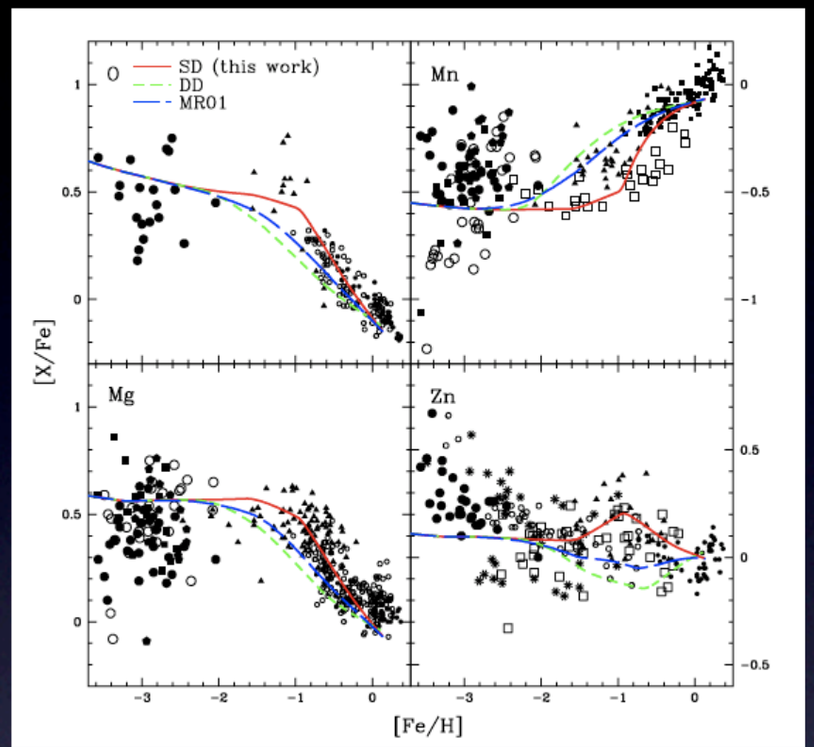
- Timmes, Browns, & Truran 2003
  - metal-rich stars generate more ^{22}Ne which decreases mass of ^{56}Ni produced in SN
  - Howell et al. (2009) with SNLS data and Neill et al. (2009) with low-z data show TBT03 agrees qualitatively with trends in data, but with much scatter
- Kasen et al. (2009) include TBT03 effect in simulation, find it changes slope and zeropoint of stretch-luminosity relation

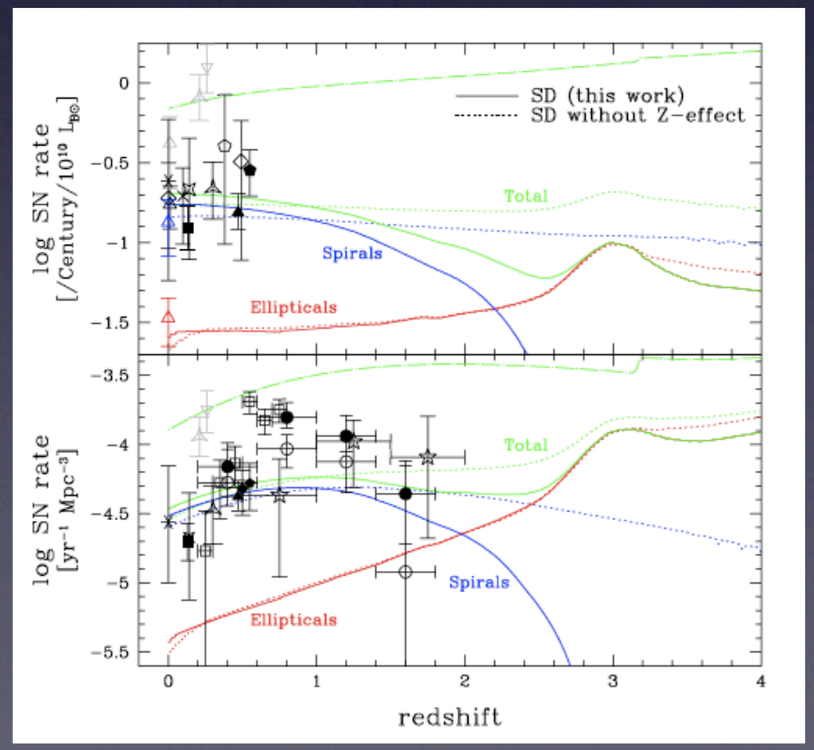




Theoretical SN Ia Progenitor Metallicity Effects

- Kobayashi & Nomoto (2009) model WD accretion in single-degenerate (SD) channel, find minimum strength of wind (powered by Fe opacity) needed to prevent CE phase
  - predicts low-metallicity inhibition of SNe Ia
- matches Galactic chemical enrichment very well
- produces declining SN Ia rate at high redshift - important in predicting expected yields of future high-z surveys
- with low-Z cutoff, reduces concern about SN Ia evolutionary effects





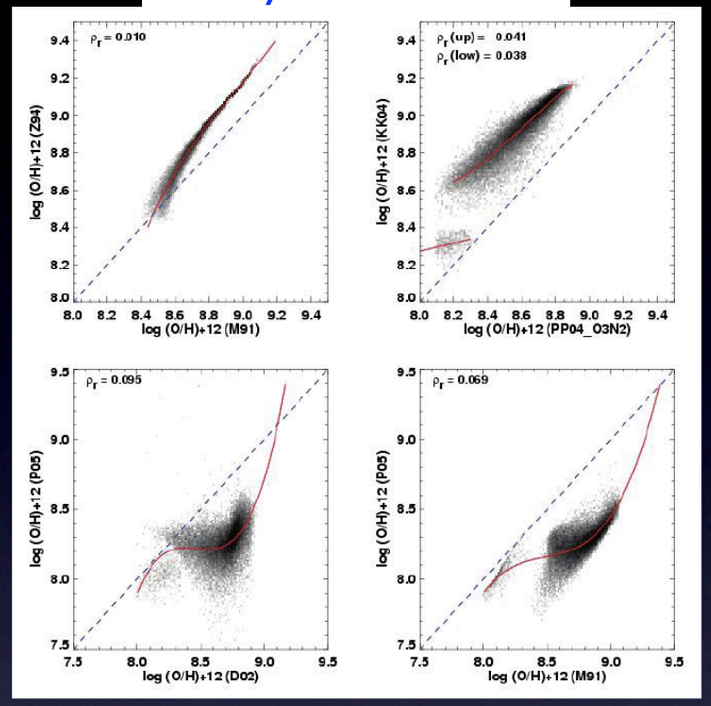
KN Cutoff - has anyone approached it?

- Cutoff is from deficient Fe opacity at [Fe/H] ≈ -1.1
- Most galaxy abundances in terms of $12+\log(O/H)_{gas}$
- Conversion requires:
  - solar abundance - $12 + \log(O/H)_{\odot} = 8.69$
  - Oxygen enrichment:
    - KN08 (arxiv): assume Milky Way $[O/Fe]_{MW} = 0.3$
    - KN09 (ApJ): dwarf galaxies may be lower - $[O/Fe]_{dwarf} = 0.0$
- Two possible values:
  - $12 + \log(O/H) = 7.9$ (KN08 - Galactic enrichment)
  - $12 + \log(O/H) = 7.6$ (KN09 - dwarf enrichment)

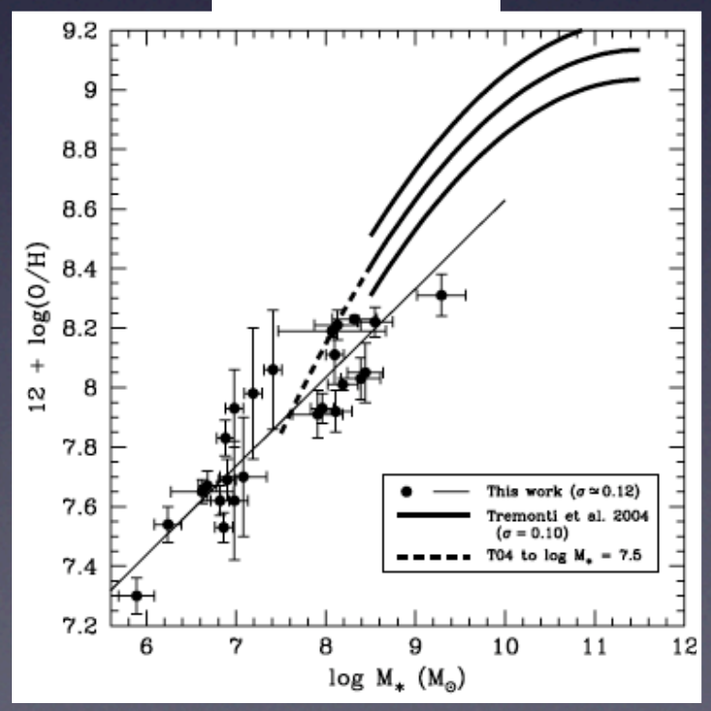
KN Cutoff - has anyone approached it?

- Metallicity in star-forming galaxies measured using strong emission-line techniques:
  - Different methods disagree
  - Absolute scale uncertain
- When spectroscopic Z unavailable, most authors use mass-metallicity (MZ) relations (e.g. Tremonti et al. 2004, Lee et al. 2006)
  - MZ relation has intrinsic dispersion of ~0.1 dex at solar O/H, up to 0.3 dex at low Z
  - MZ relation at low Z doesn't appear to line up with higher Z

Kewley & Ellison 2008



Lee et al. 2006



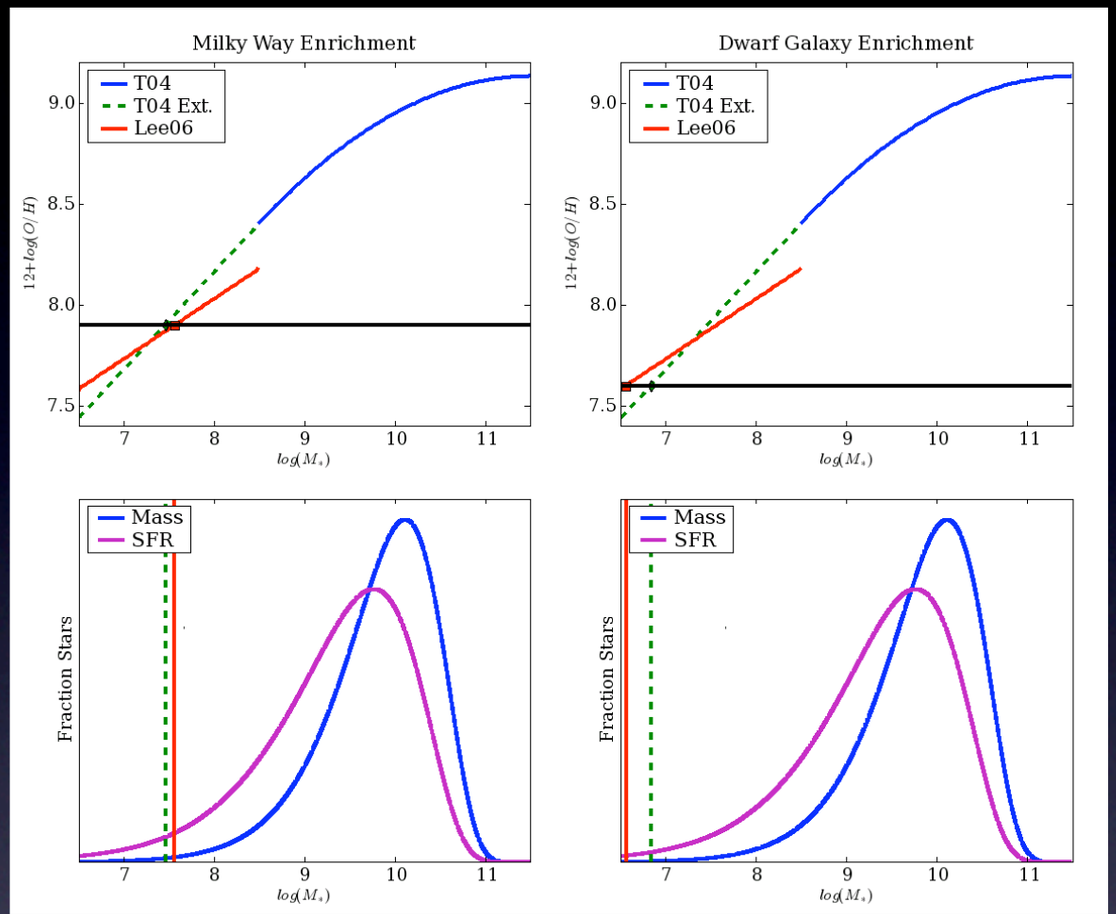
KN Cutoff - has anyone approached it?

Source	Lowest Z	Spectroscopic / Mass-Based	Method
Hamuy 2000	8.46	Spec	Lick Indices
Gallagher 2005	8.49	Spec	Kewley & Dopita 2002
Gallagher 2008	8.34	Spec	SSP-matching
Prieto 2008	8.23	Spec	Tremonti 2004 Bayesian Method
Neill 2009	8.65	Mass	Tremonti 2004 MZ
KN08 - MW O/Fe	7.9		
Howell 2009	~7.7	Mass	Lee 2006 MZ
Sullivan 2010	~7.7	Mass	High-z MZ
SNfactory	**~7.7**	Mass*	Lee 2006 MZ
KN09 - Dwarf O/Fe	7.6		

***SNfactory ideal for host spectroscopic metallicities**

How many SNe might we expect below KN cutoff?

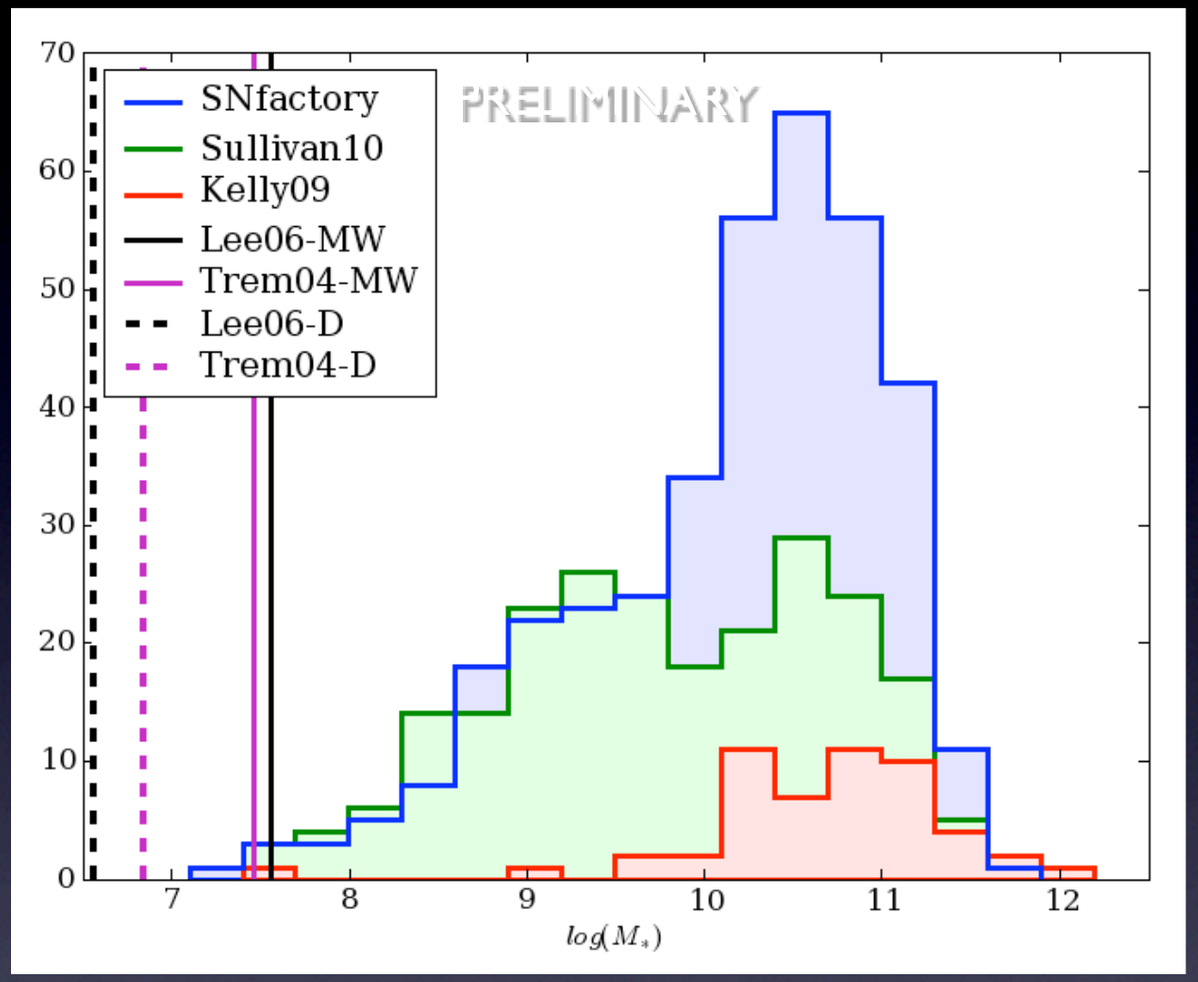
- Determine host mass corresponding to cutoff using M-Z relation
- Measure fraction of all stellar mass in galaxies of mass lower than cutoff
- Similarly, measure fraction of cosmic star-formation rate below mass cutoff

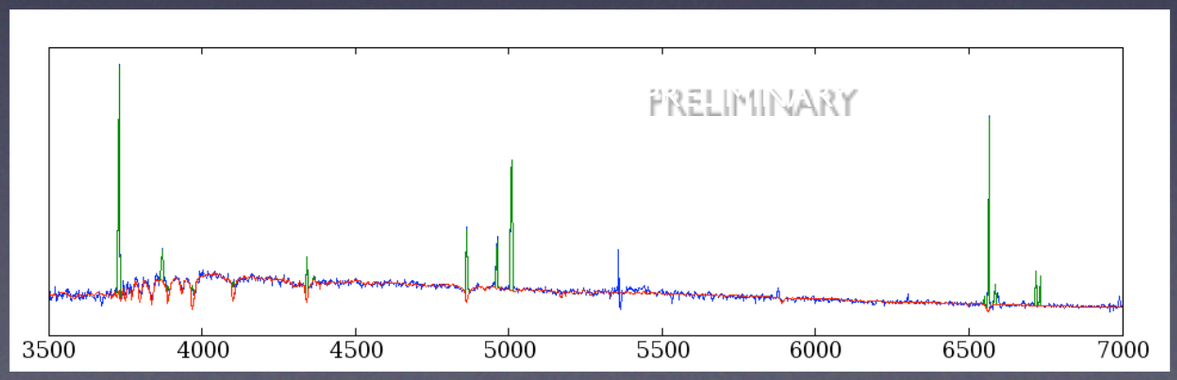


Enrichment	M-Z Relation	Cutoff M*	Fraction M*	Fraction SFR
MW	Tremonti 2004	7.46	0.36%	3.37%
[O/Fe] = 0.3	Lee et al. 2006	7.56	0.45%	3.91%
Dwarf	Tremonti 2004	6.84	0.09%	1.33%
[O/Fe] = 0.0	Lee et al. 2006	6.56	0.05%	0.88%

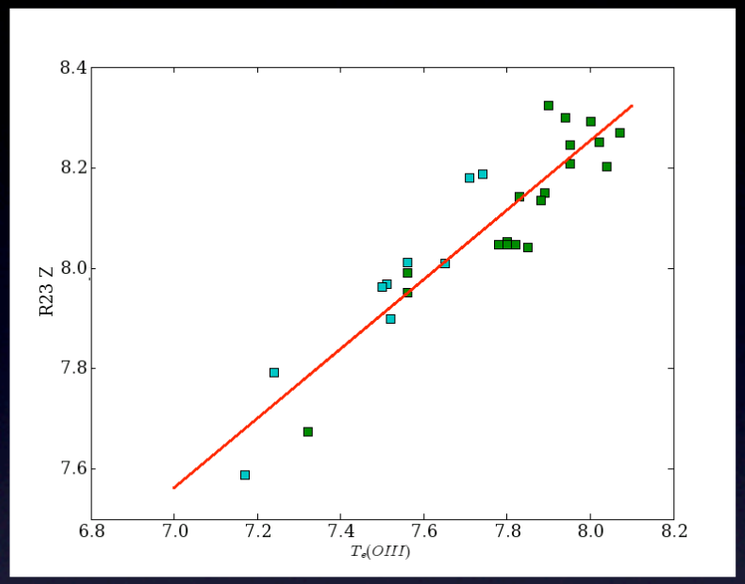
SNfactory Data

- SNfactory hosts extend to low mass - best chance to test KN09 theory
- Extensive host spectroscopy program - 38 total nights on Lick, Keck, CTIO, SOAR, 300+ host spectra obtained
- Measure metallicity for star-forming hosts using emission line strengths
- Host masses using deep photometry from SNIFS and LRIS (obtained during spec. target acquisition)



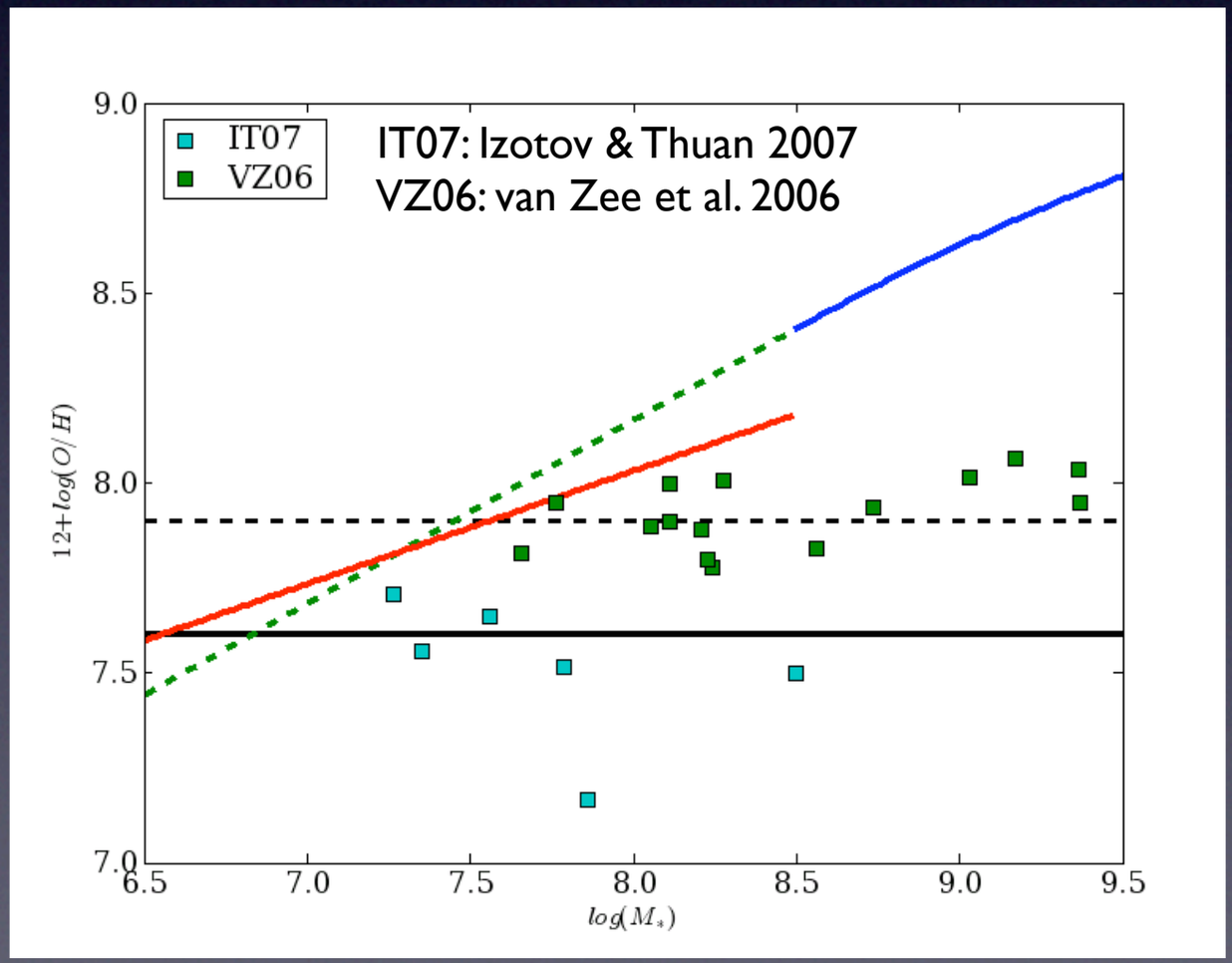


Choosing the right calibration...



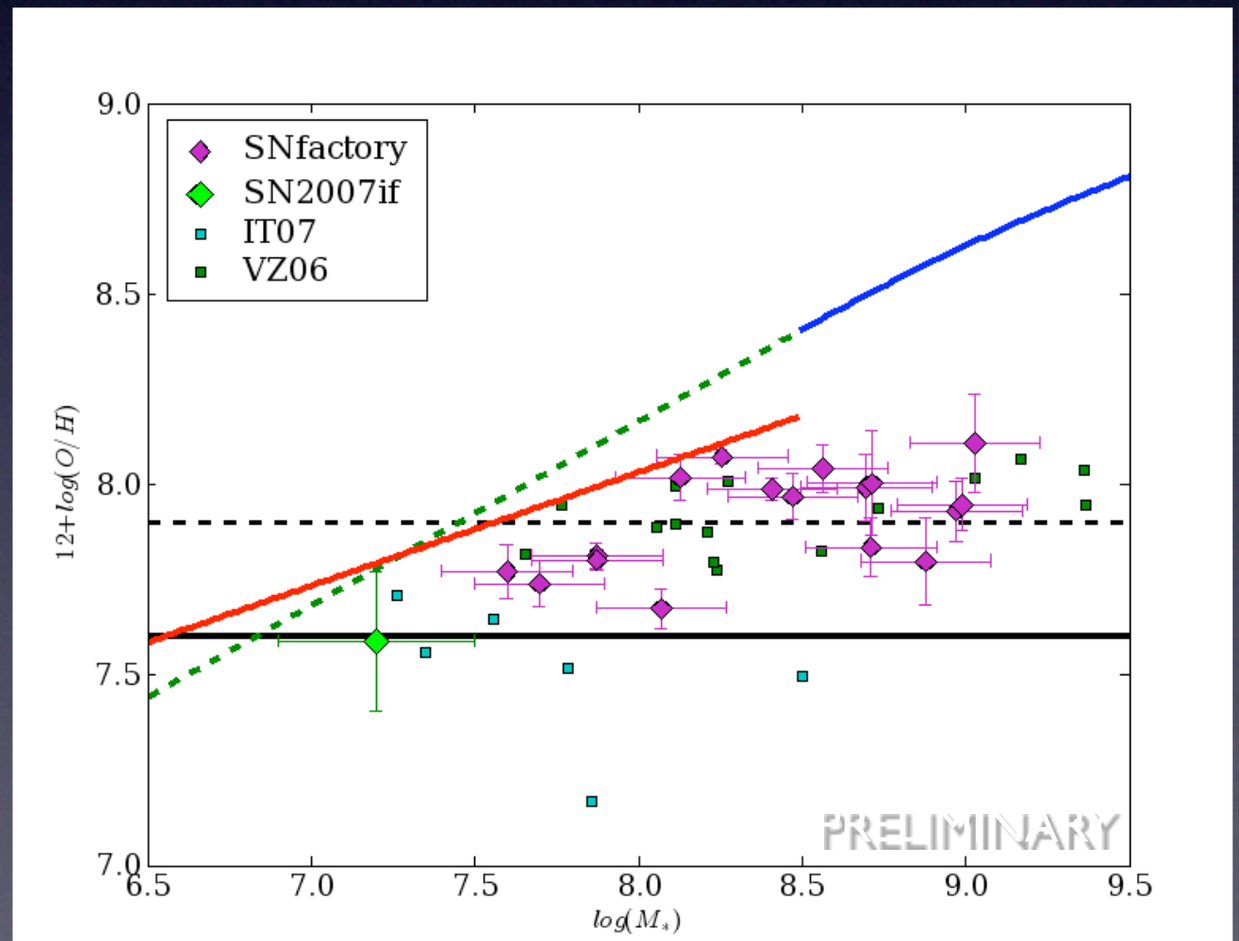
- Classical metallicity technique "R23" not calibrated for low-Z
- Strong-line R23 metallicities for low-Z galaxies correlate strongly with "correct" T_e(OIII) metallicities

- Derive linear conversion
- Convert SN Ia host R23 metallicities
- Effectively setting T_e(Z) to recalibrate lower branch of R23



SNfactory Results

- Final SNfactory host metallicities placed on scale motivated by the most physical metallicity indicator T_e
- Low-Z SNfactory hosts occupy similar region in MZ space as known low-Z samples
- Several SNf hosts lie below the MW-enriched KN08 cutoff
- Only SN2007if lies (slightly) below dwarf-enrichment KN09 cutoff



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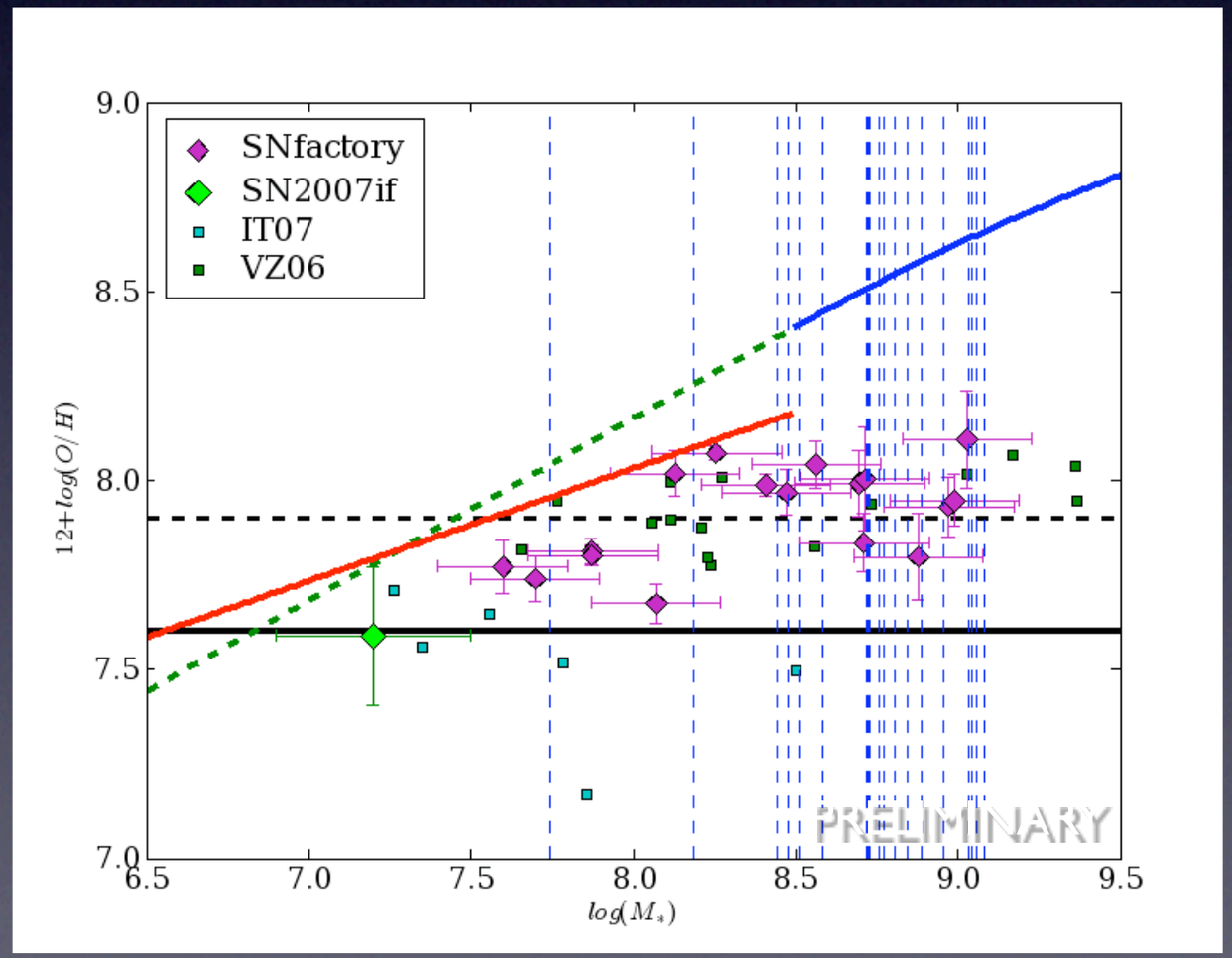
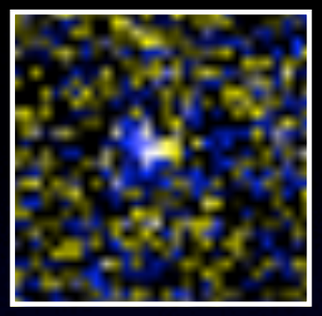
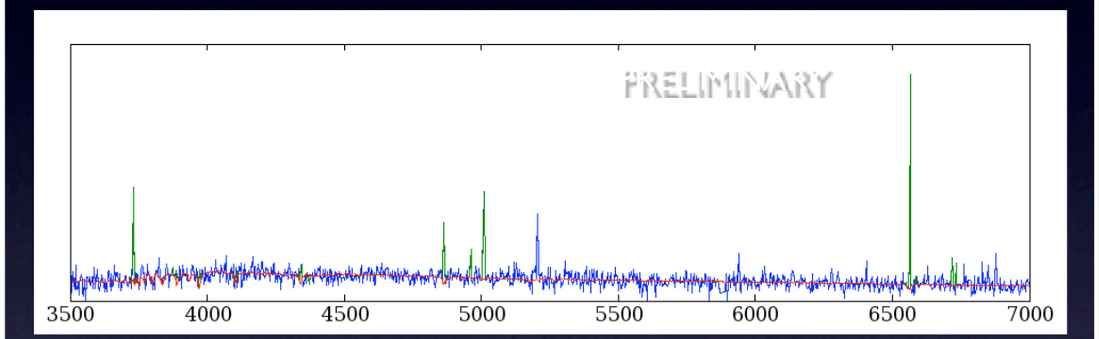
- Several SNf hosts lie below the MW-enriched KN08 cutoff
- Only SN2007if lies (slightly) below dwarf-enrichment KN09 cutoff
- More galaxies still to be observed (blue dashed lines)

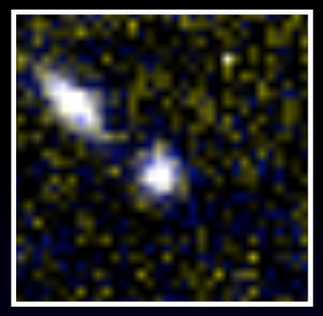


Examples of Ultra-Faint SN Ia Hosts

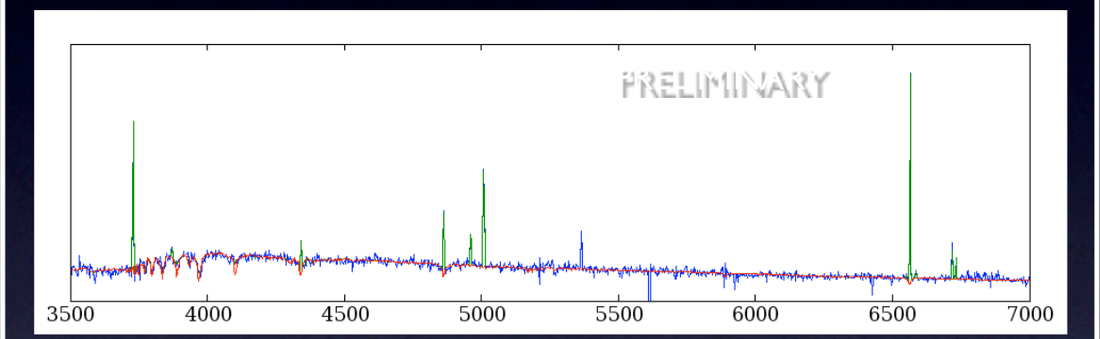


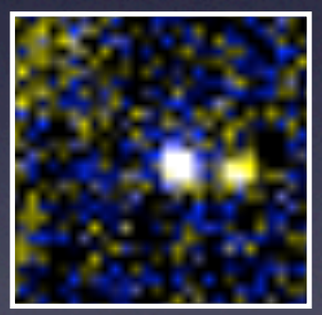
SNF20080510-001
log(M*) = 7.70
12 + log(O/H) = 7.74



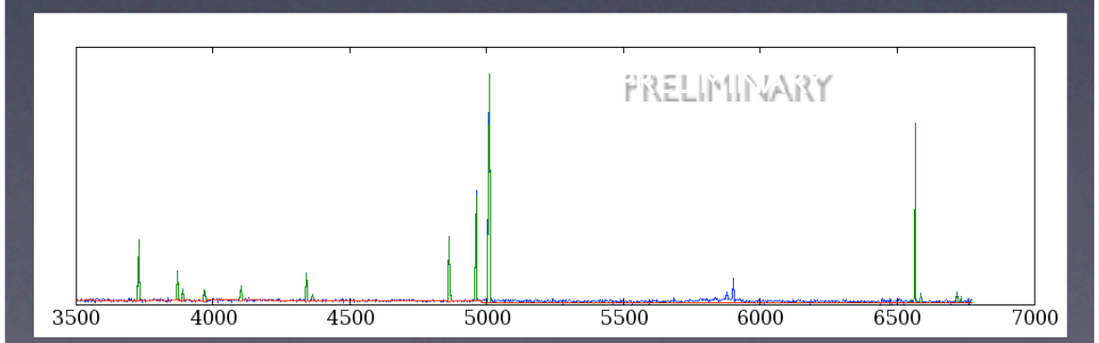


SNF20070424-006
log(M*) = 7.87
12 + log(O/H) = 7.80

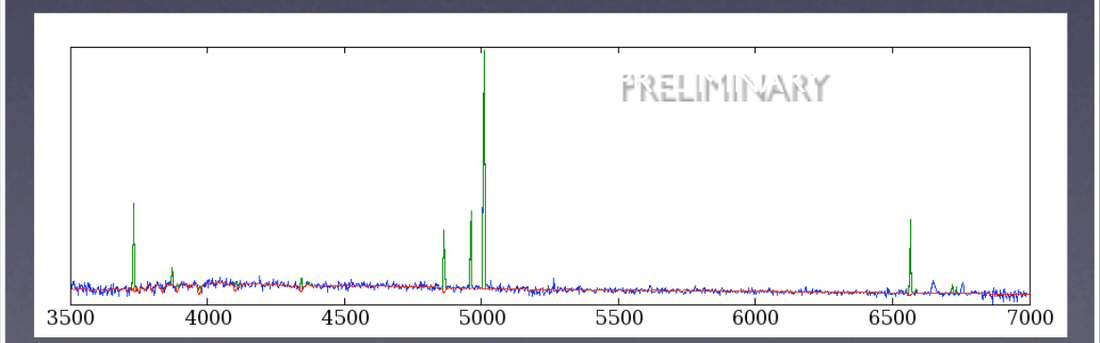




SNF20050824-002
log(M*) = 8.11
12 + log(O/H) = 8.07

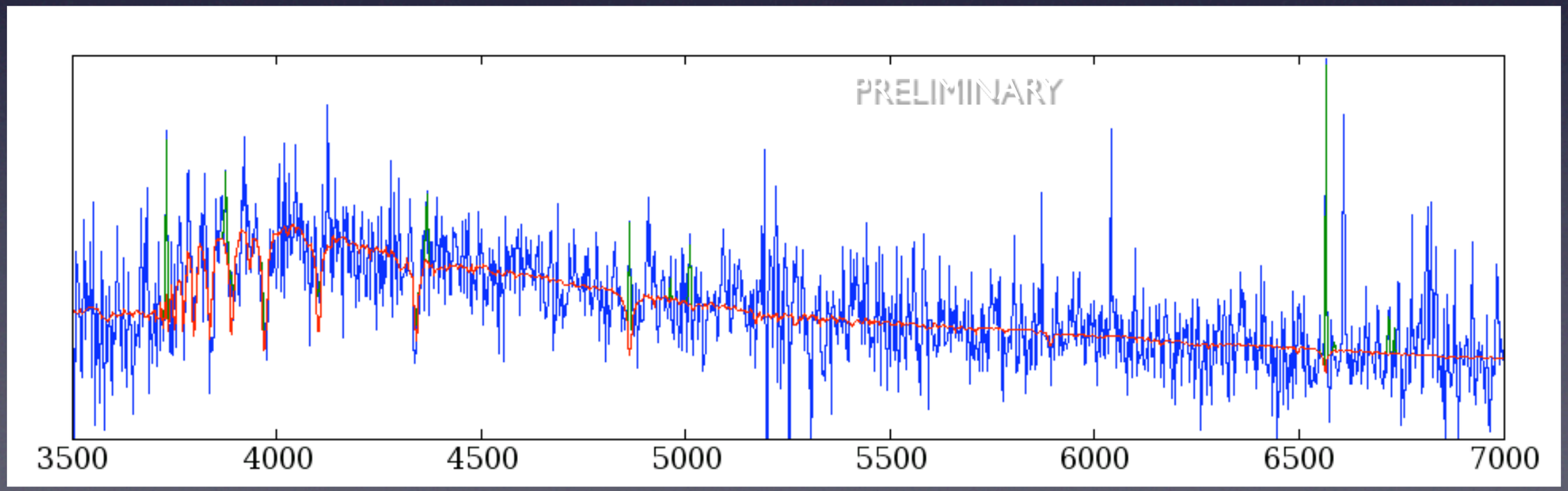


SNF20070331-013
log(M*) = 8.58
12 + log(O/H) = 7.96



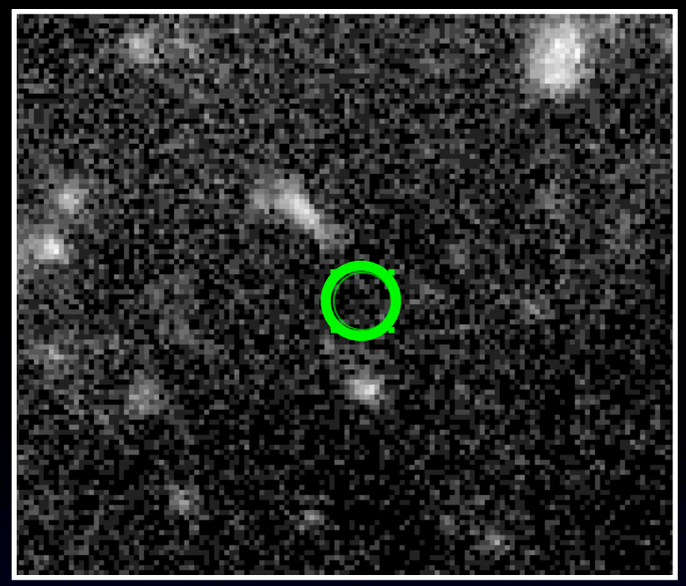
SN2007if (a.k.a. SNF20070825-001)

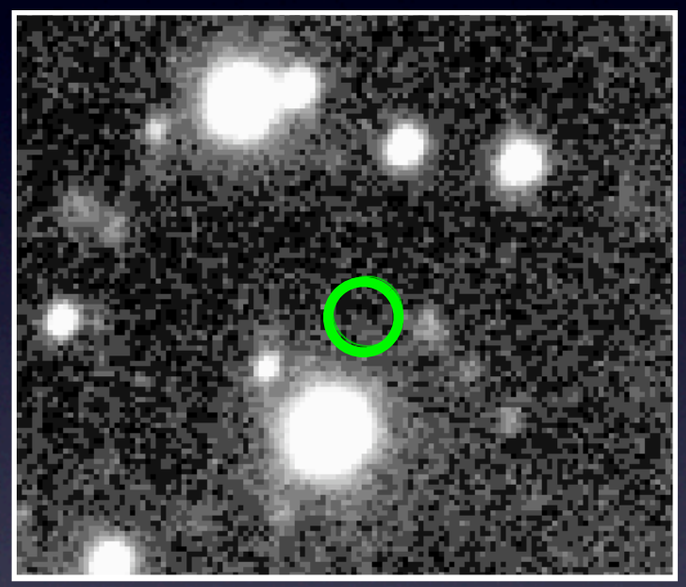
- Super-Chandrasekhar explosion (Scalzo et al. 2010), likely from double-degenerate merger
- Definitively low metallicity host
  - weak OII AND OIII, no NII or SII detected
- Still noisy after 1 hour on Keck!
- m_g = 23.1, M_g = -14.5, log(M*) = 7.19

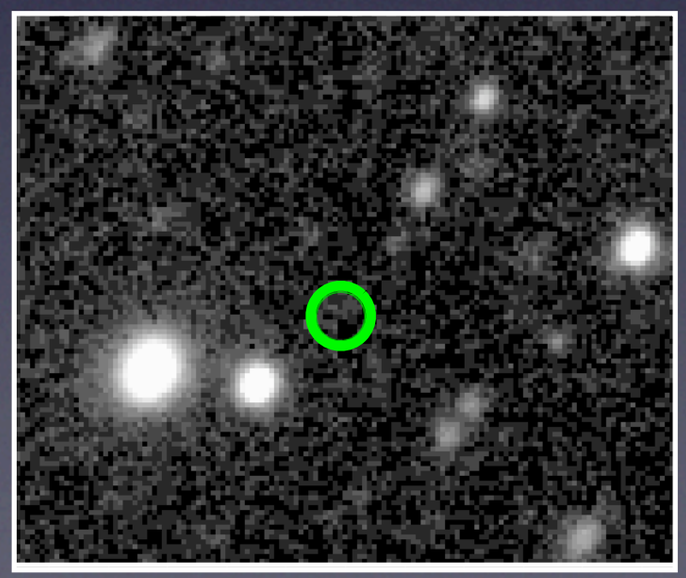


“Hostless” SNe Ia

- Some SNe Ia had multiple faint host candidates in the vicinity...



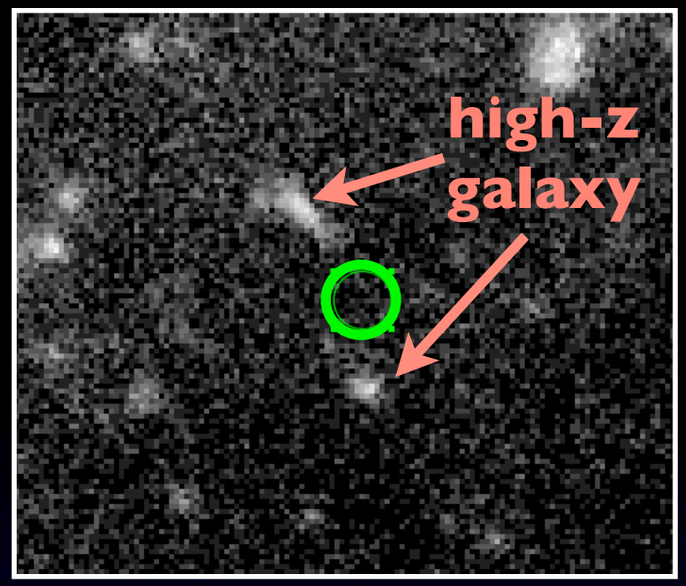


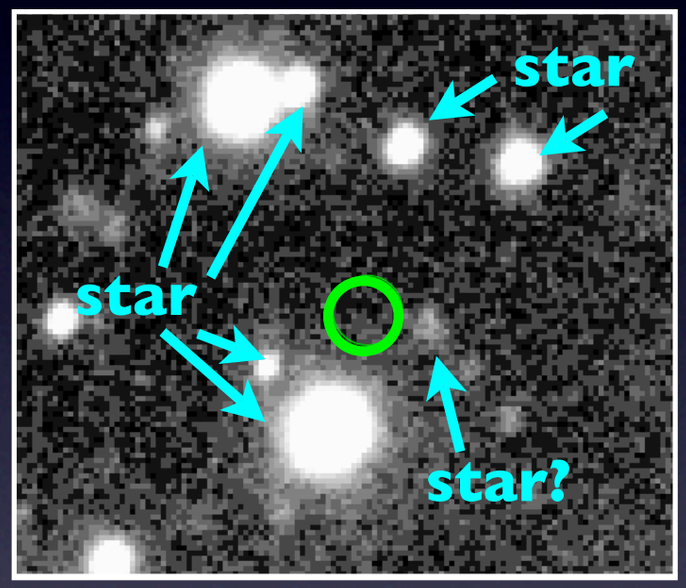


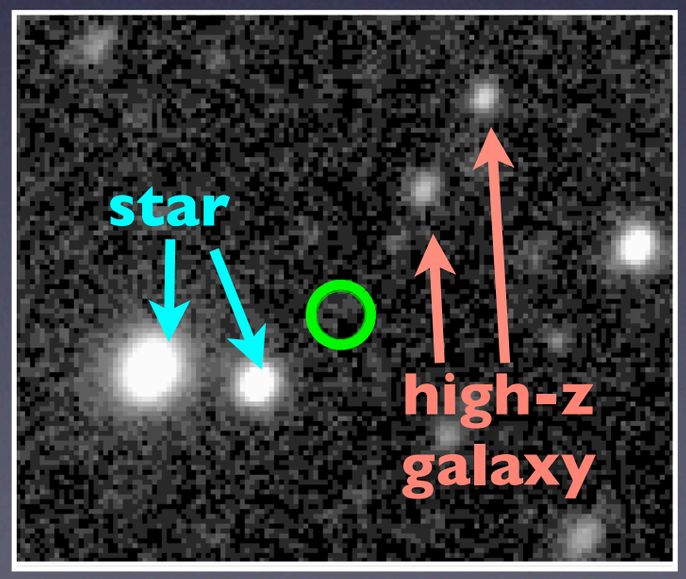
“Hostless” SNe Ia

- Some SNe Ia had multiple faint host candidates in the vicinity...
- ... which turned out to be foreground stars or high-redshift galaxies

WHERE IS THE PARENT STELLAR POPULATION?





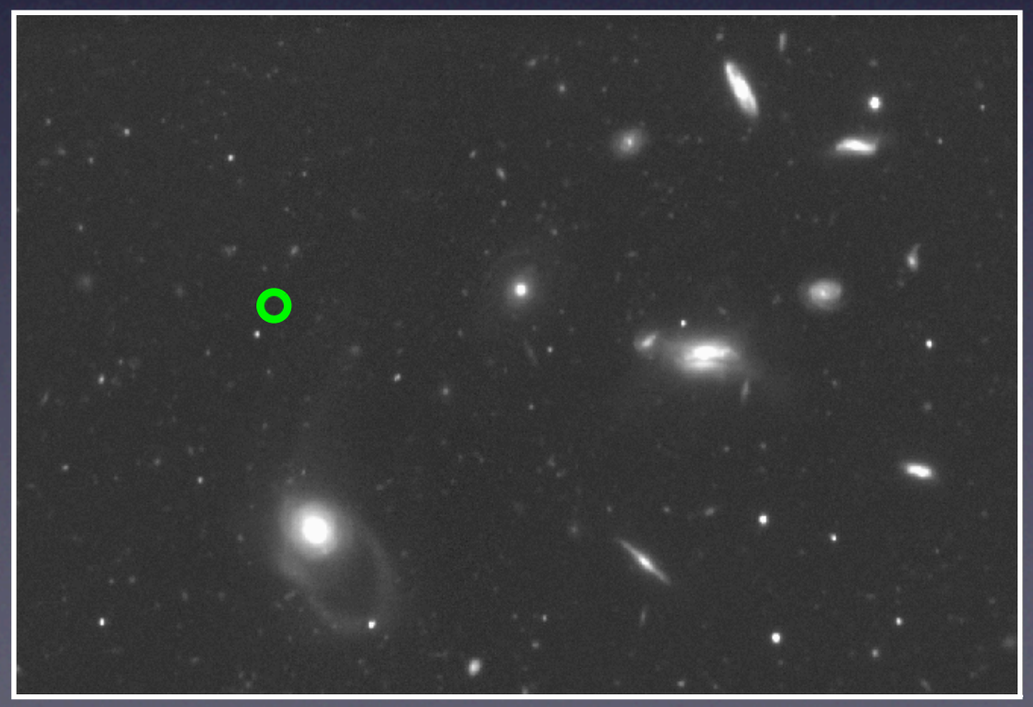


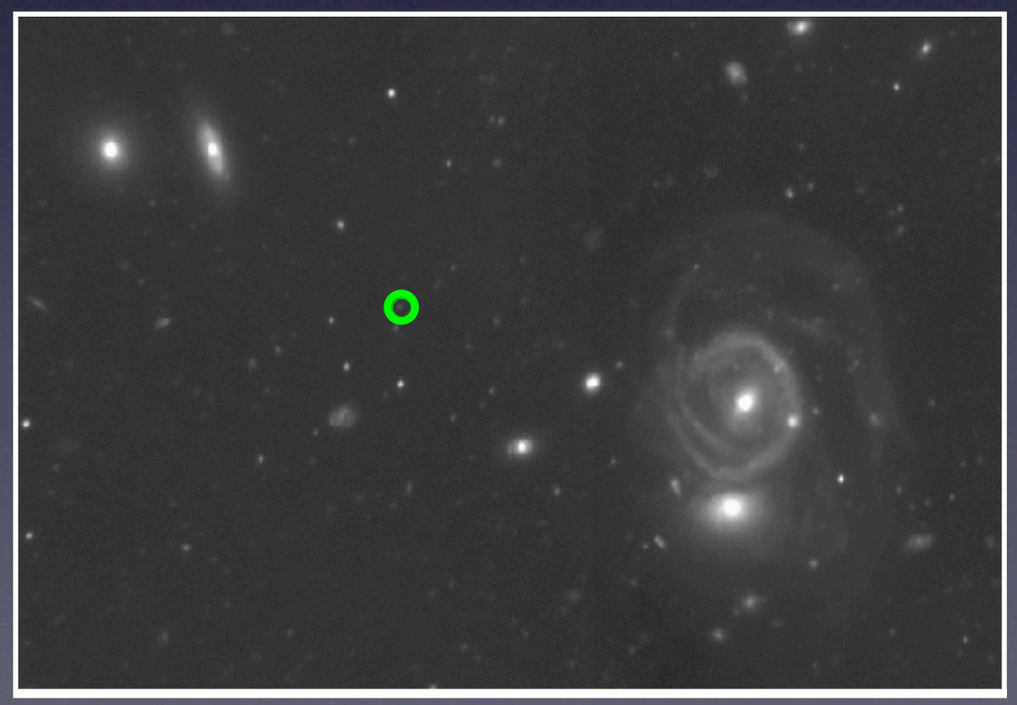
Not-so-hostless (?) SNe Ia

- Some SNe Ia have only false hosts in the immediate vicinity...

Not-so-hostless (?) SNe Ia

- Some SNe Ia have only false hosts in the immediate vicinity...
- ... but interacting galaxy clusters at large distances (at the right redshift!)
- Are these ICM SNe Ia? How far out should we look for host associations?





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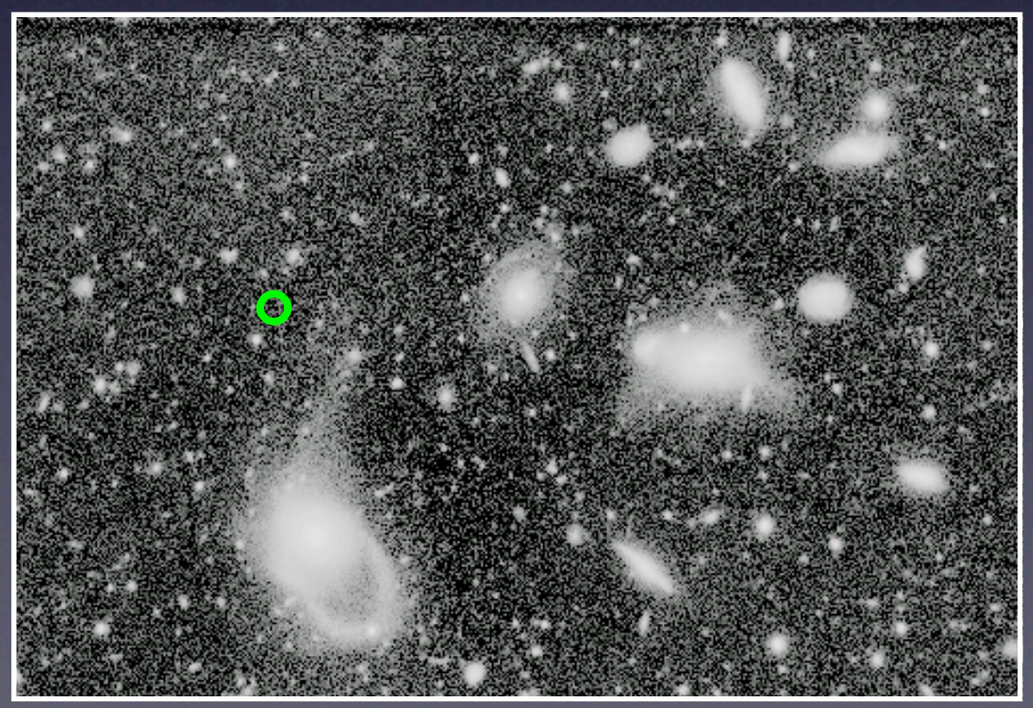

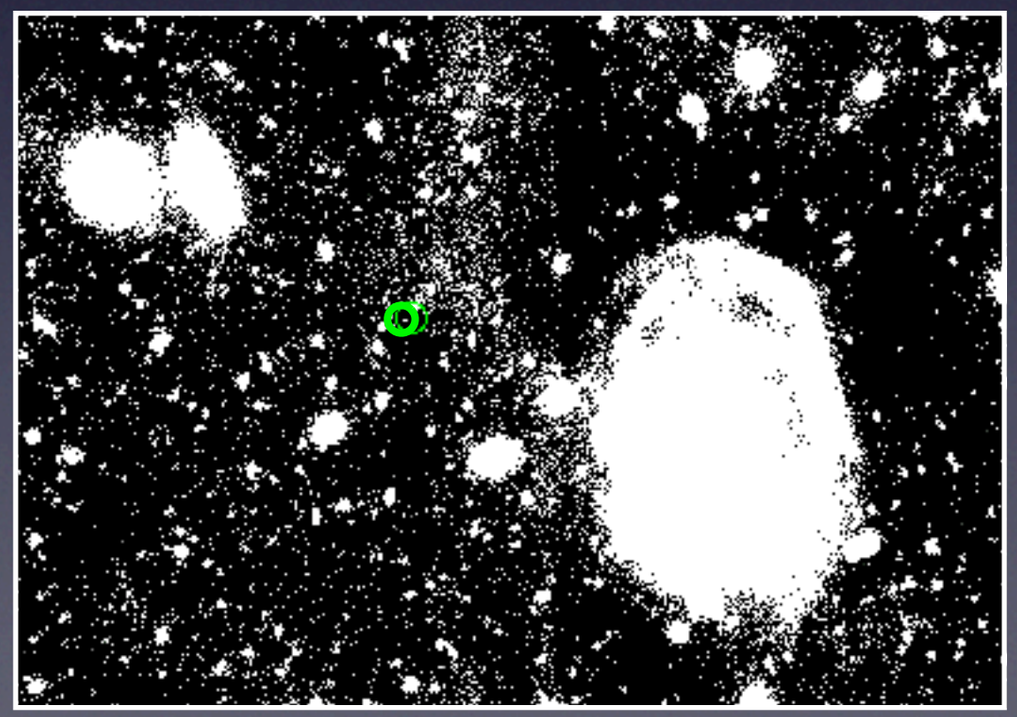

Conclusions

- SN Ia host studies vital for controlling redshift-dependent systematics
- SNfactory host mass and metallicity range poised to contribute to current host phenomena and explore new ones
- We have observed the lowest directly-measured metallicities for SN Ia host galaxies
- SN2007if host has lowest-Z host if sample, is only host below KN09 cutoff (more evidence for DD?)
- Hostless SNe Ia and SNe Ia in interacting environments pose challenge for host-based luminosity corrections

SNfactory Collaboration

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Mike Childress
Hannah Fakhouri
Stu Loken
Peter Nugent
Saul Perlmutter
Karl Runge
Rollin Thomas

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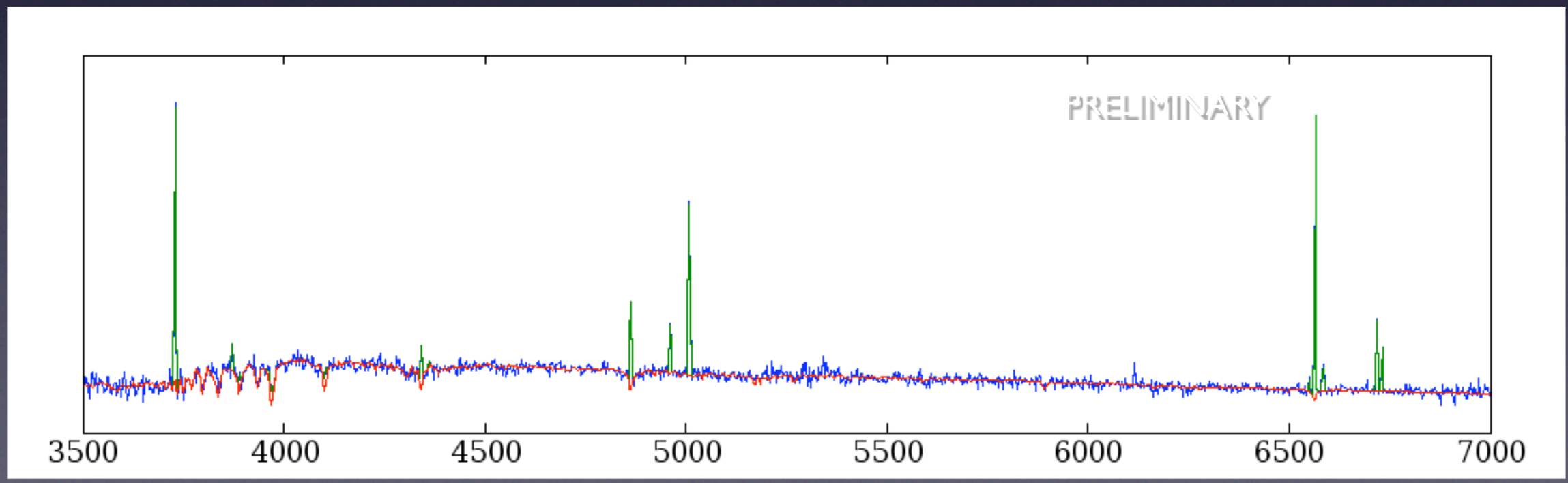
Supplemental Slides

Measuring Emission Line Strengths

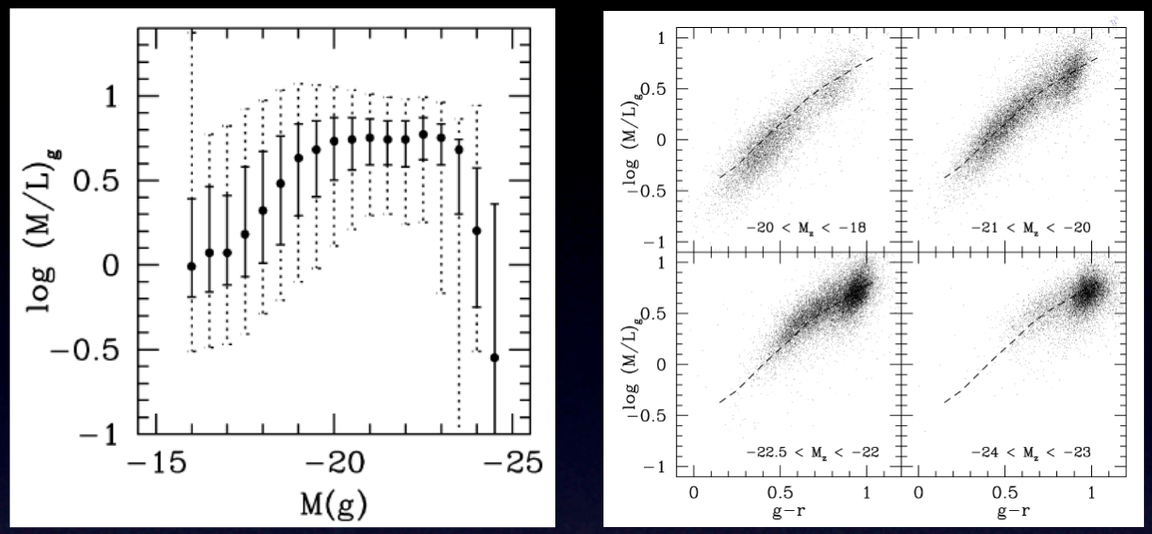
- Emission line fluxes fit using specialized version of IDL line fitting code from SDSS spectroscopic pipeline
- Simultaneously fit emission line profiles AND stellar continuum
  - vital for accounting for stellar absorption
- Background templates from Bruzual & Charlot 2003 (this talk - Z = 0.004), ages ranges from 5Myr to 11 Gyr

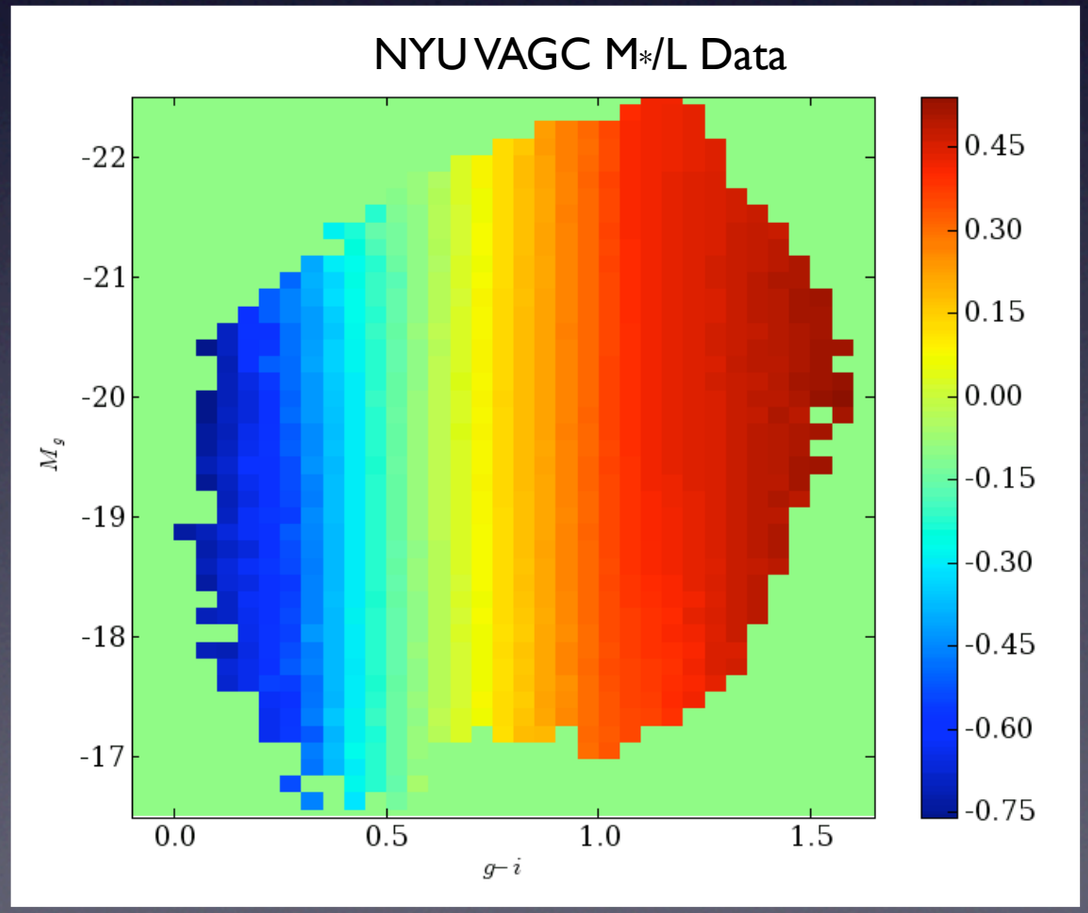


Measuring Host Masses

- Derive mass-to-light ratio from absolute magnitude and color (where available)
- M*/L weak function of M_g, strong function of color
- *g-i* best single color for constraining M*/L (Gallazzi & Bell 2009)
- Use NYU Value Added Galaxy Catalogue to derive M*/L (and its dispersion) in color-magnitude bins
- Can determine host stellar mass to within 0.2 dex
- Multicolor (*ugriz*) better, but not by much!

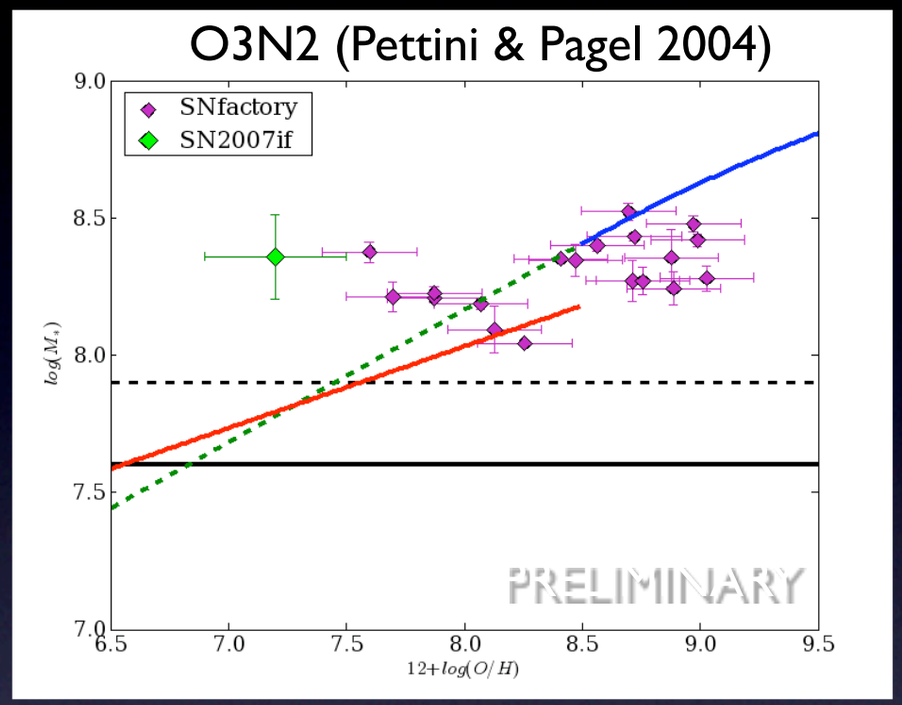
Kauffmann et al. 2003 M*/L

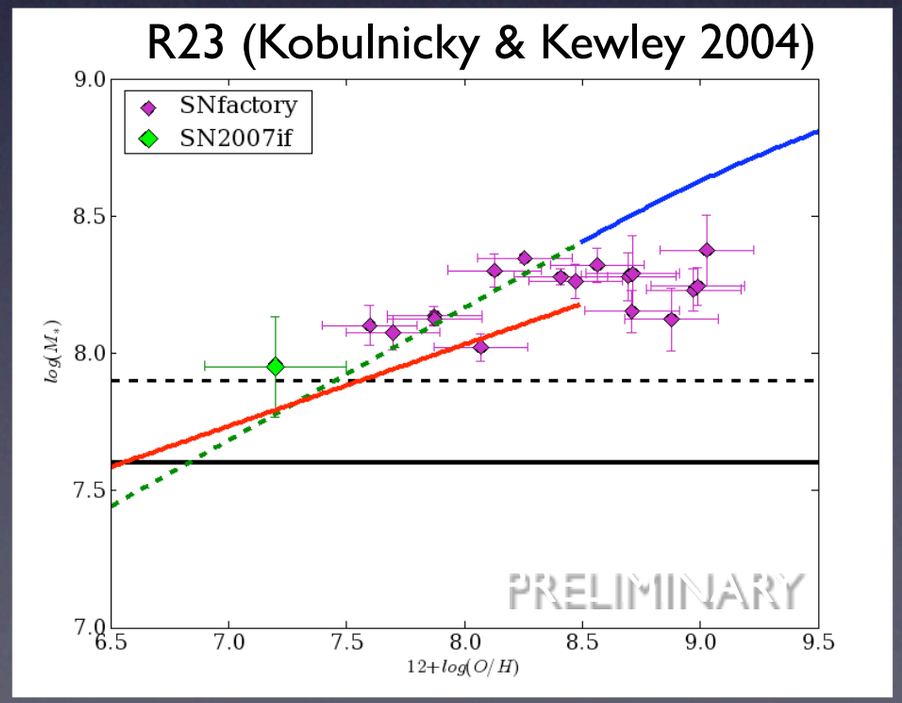




SNfactory Host Metallicities

- Strong-line indicators behave poorly at low metallicity:
  - Nitrogen-sensitive indicators (e.g. O3N2) saturate at low Z due to weak NII
  - Oxygen-sensitive R23 method poorly calibrated at low Z
- SN Ia hosts appear to be above the cutoff ...





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  - Oxygen-sensitive R23 method poorly calibrated at low Z
- SN Ia hosts appear to be above the cutoff ...
  - ... but so do galaxies with low metallicities measured with the "correct" T_e(OIII) method
- STRONG LINE TECHNIQUES NOT ADEQUATE AT LOW METALLICITIES!

IT07: Izotov & Thuan 2007
VZ06: van Zee et al. 2006