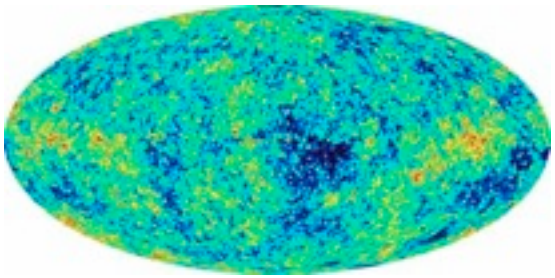
Dark Energy from Supernova Survey

Xiaofeng Wang
Tsinghua University

TMT Forum, Hawaii, July 22-23

Mapping the Expansion Historry of the Universe



CMB: direct probe of quantum fluctuations

Time: 0.003% of the present age of the universe.

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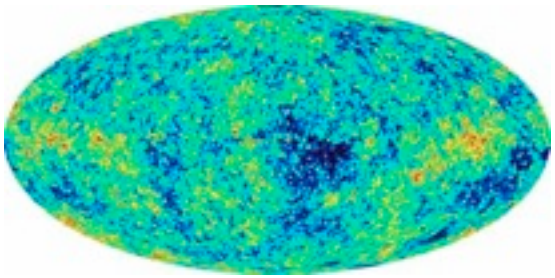

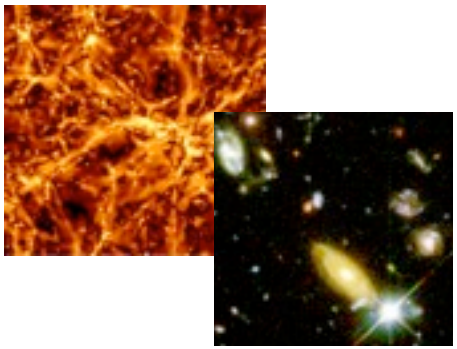

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3D surveys of galaxies and clusters: probes of expansion + growth

Pattern of ripples, clumping in space, growing in time.

BAO, Lensing, Matter power spectrum.

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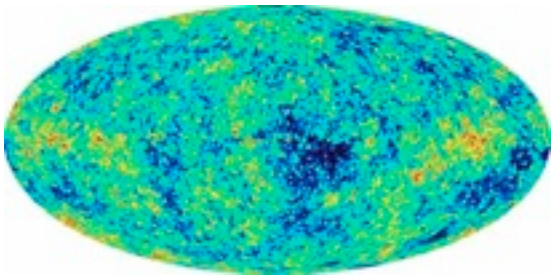

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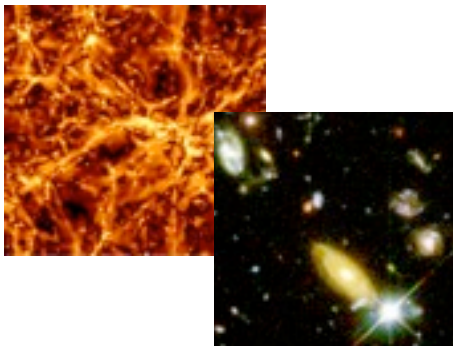


3D surveys of galaxies and clusters: probes of expansion + growth

Pattern of ripples, clumping in space, growing in time.

BAO, Lensing, Matter power spectrum.

Supernovae: direct probe of cosmic expansion

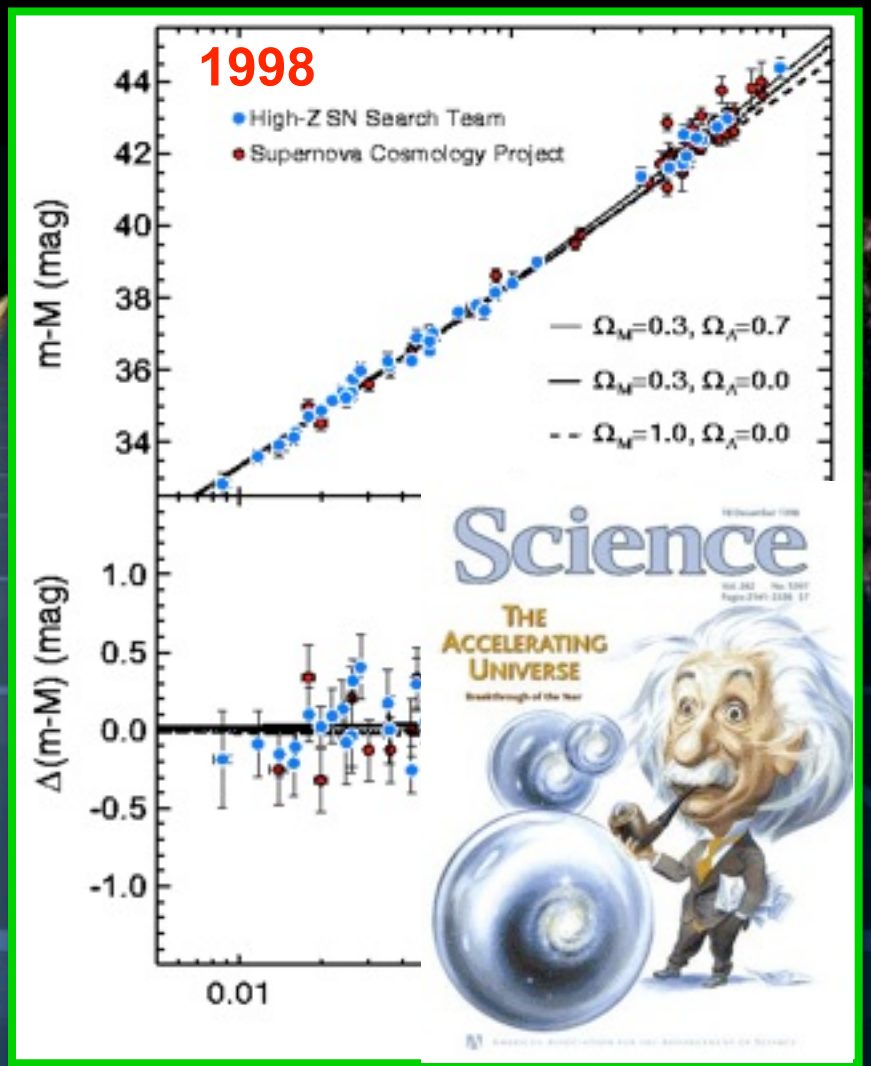
Time: 30-100% of present age of universe

Cosmology in 1998

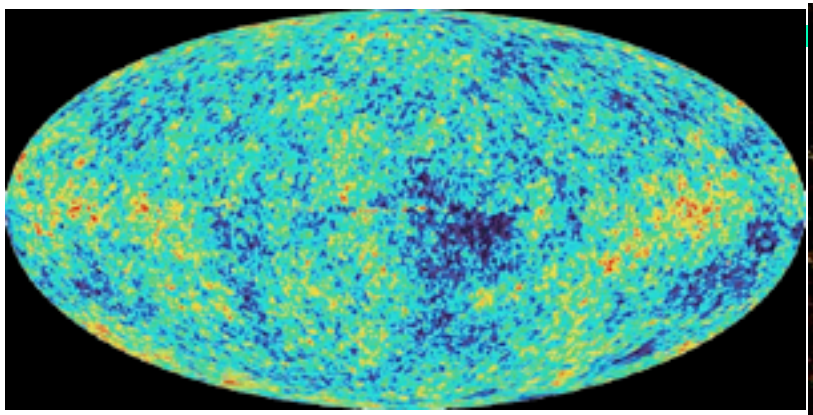
SNe Ia:

- 10^{51} erg
- Uniform

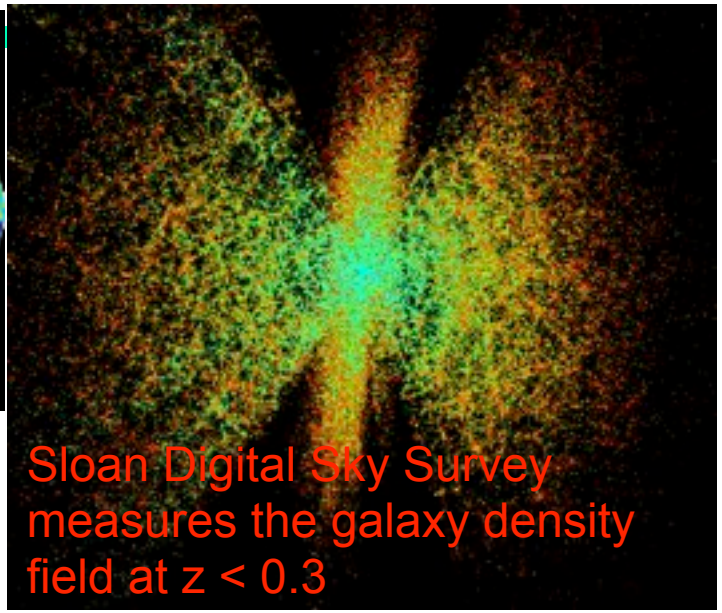
$$r = \sqrt{\frac{L}{4\pi I}}$$



Cosmology in 2004



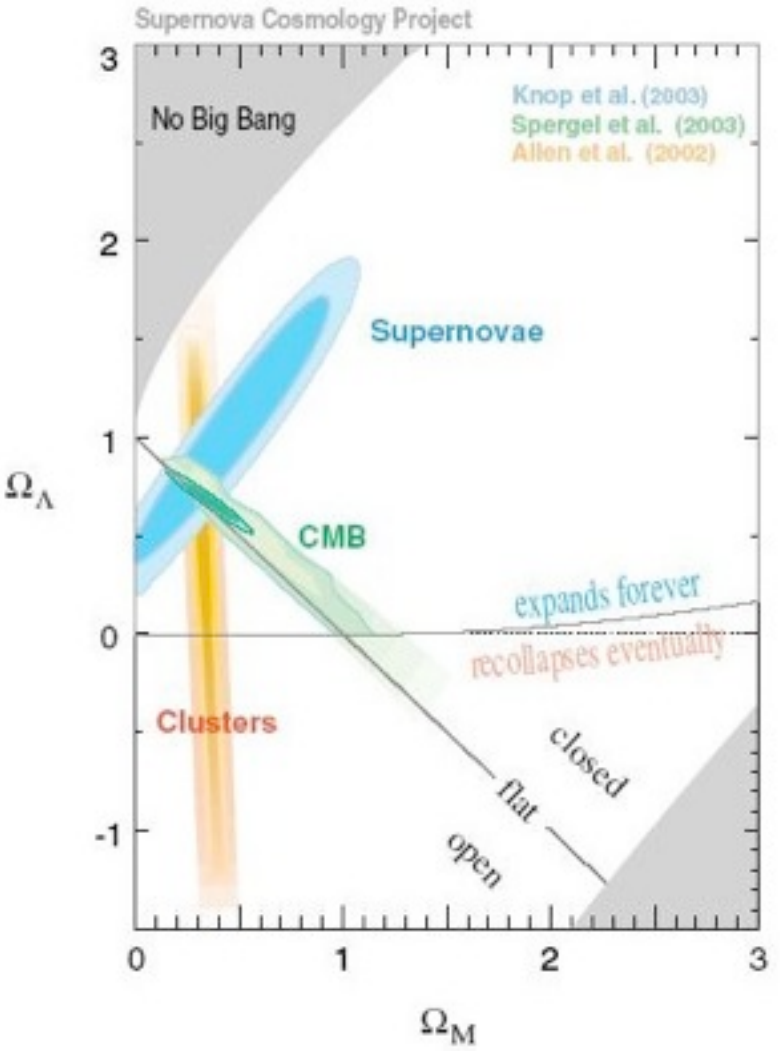
WMAP measures the CMB radiation density field at z=1000



Combine to measure parameters of cosmology to 10%.
We enter the era of precision cosmology.

– **Confirms dark energy (!)**

A concordance LCDM model

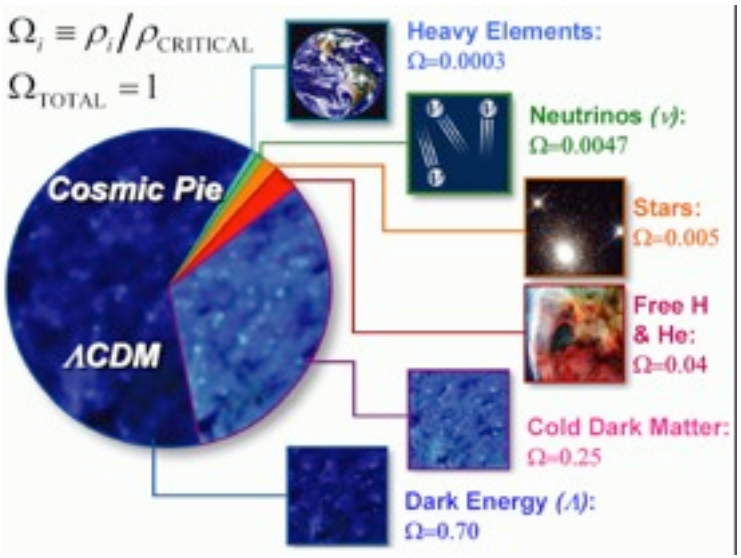


Multi-probe concordance : CMB, + SN, clusters, galaxies redshift surveys, Weak Lensing, …

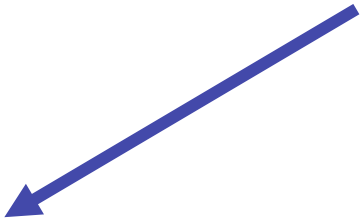
➔ Concordance LCDM model with

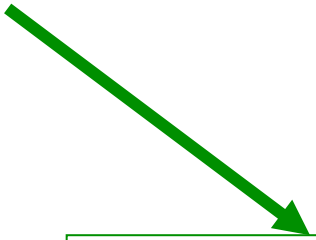
Cold Dark Matter

and Cosmological constant (or DE)



What is the Dark Energy?





New form of « field/ matter? »

Quintessence?

Unified Dark Matter?

Cosmological Constant???

Modified Gravity/ GR ?

- Non minimal Couplings?
- Extra-Dimensions?
- Anisotropy/ inhomogeneity effects?
- Negative energy?
- ….

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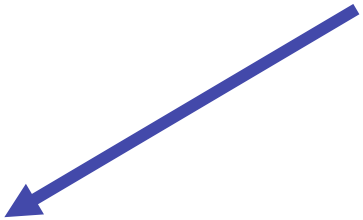

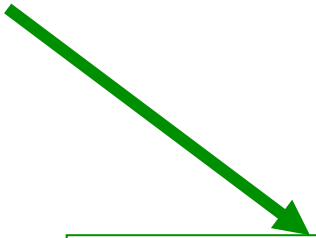

New form of « field/ matter? »
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Cosmological Constant???

$w = -1$

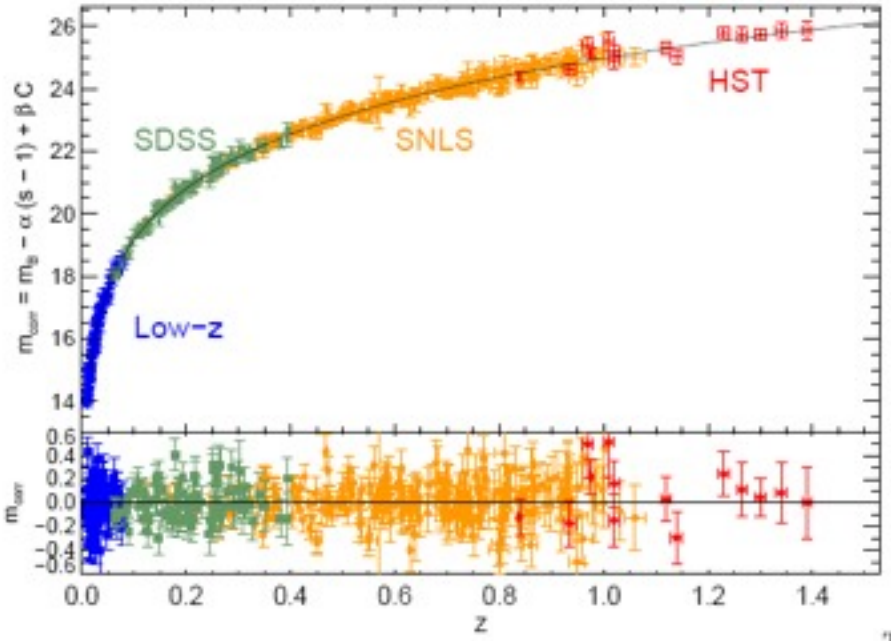
Modified Gravity/ GR ?

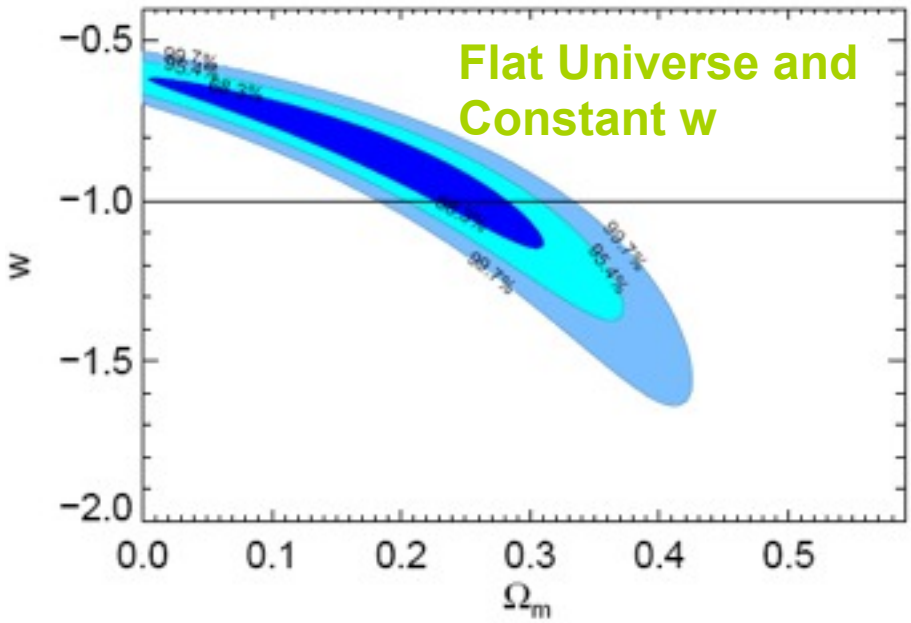
- Non minimal Couplings?
- Extra-Dimensions?
- Anisotropy/ inhomogeneity effects?
- Negative energy?
- ….

How to distinguish them?
- equation of state $w(z) = p/r$
- structures growth factor
- ???

Dark Energy from SNe Ia

Conley et al. Jan 2011





high-quality joint sample of 472 SNe

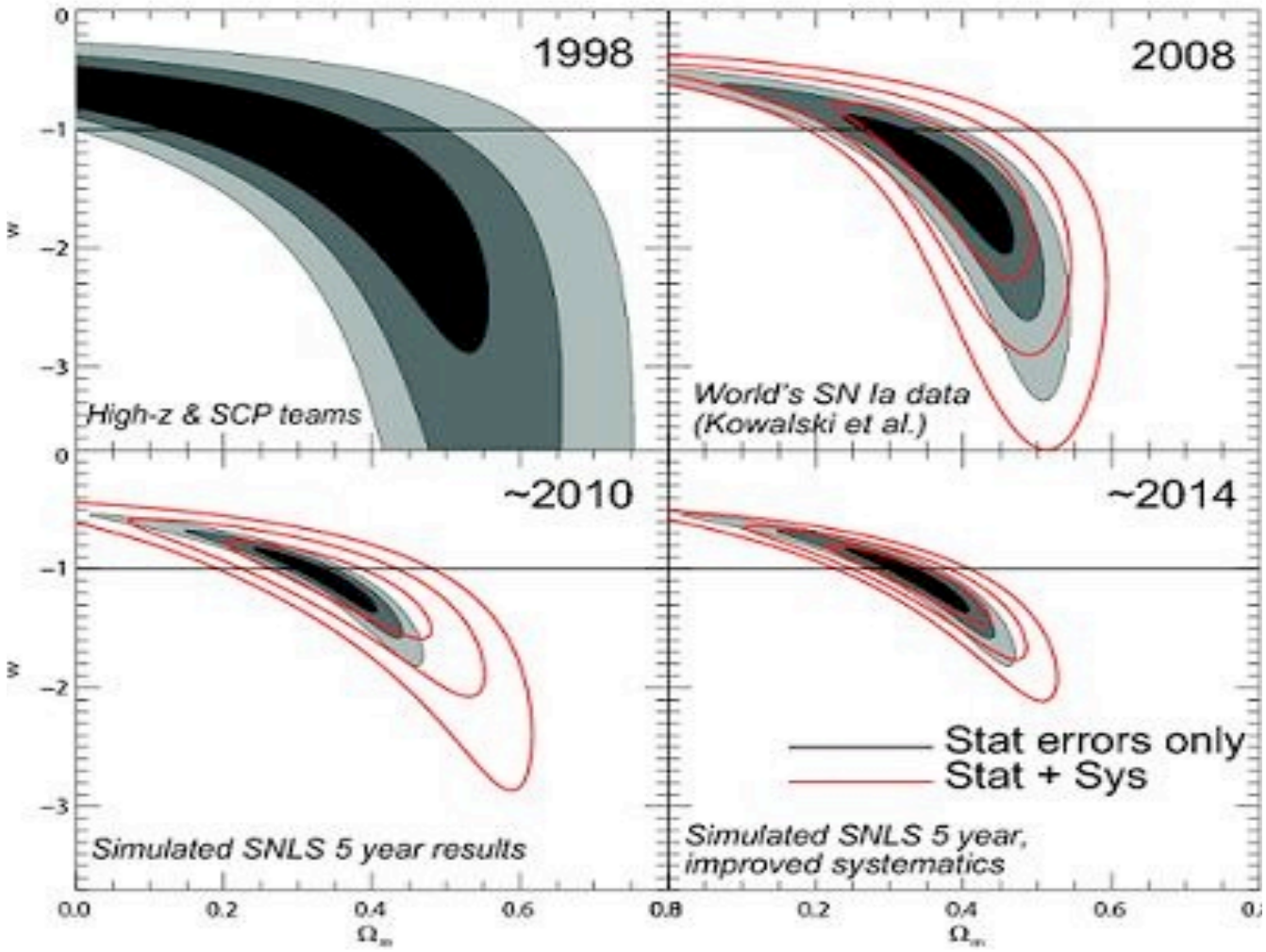
123 low-z, 93 SDSS, 242 SNLS, and 14 *HST*

Table 6: Results from SN-only fits

Uncertainties	Ω_m	w	α	β
Marginalization fits				
Stat Only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	$1.45^{+0.12}_{-0.10}$	$3.16^{+0.10}_{-0.09}$
Stat plus Sys	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$	$1.43^{+0.12}_{-0.10}$	$3.26^{+0.12}_{-0.10}$

SN Ia: still provides best single constraint on EoS to date

Dark Energy from SNe Ia

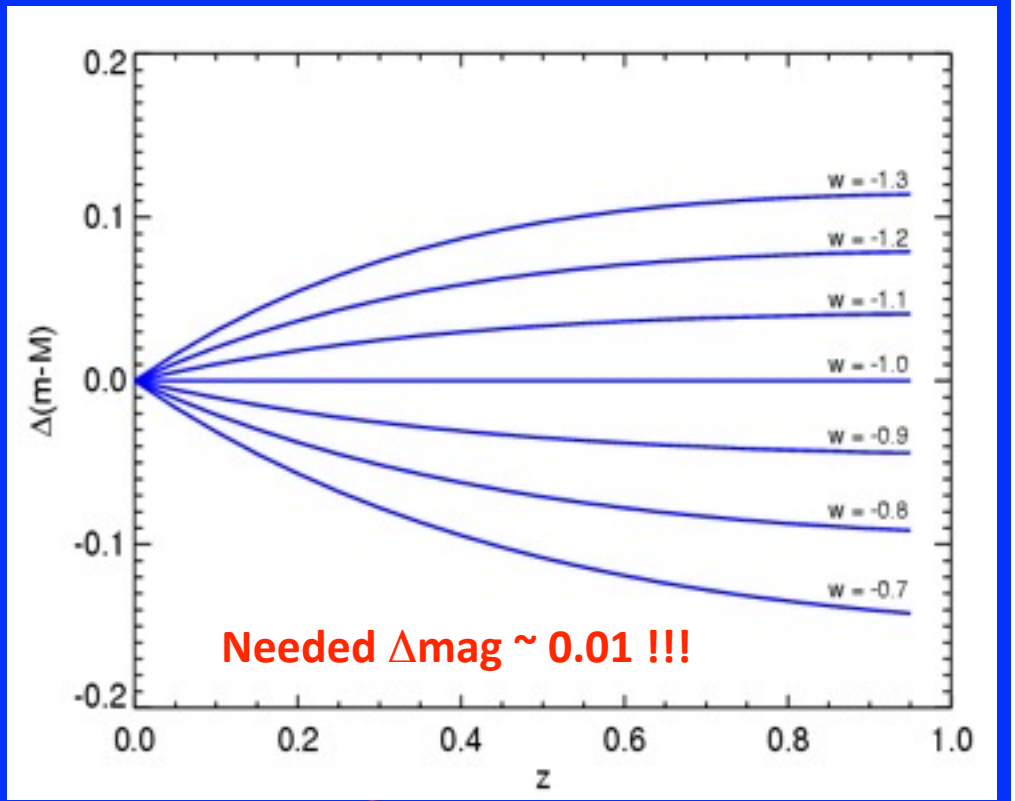


Howell (2010)

Probing Dark Energy with Supernovae

$$\rho(z) = \rho_0 \exp\left(\int 3\frac{w(z)+1}{1+z}dz\right)$$

Equ. of State $$w = \frac{p}{\rho}$$



Measurement ingredients:

- Low-z SNe
- High-z SNe
- ∀ Ω_M prior or constraint -> BAO

δw (w=-1) ~ 2.5 δm

How to improve DE measurement from supernovae

Program: PTF, KAIT, CTF

- Different classes of SNIa, average magnitude may depend on environment, redshift …
- May have impact on precision cosmological parameter determination
- Precision aim for 1% : many issues need to be solved

Best studied with SN spectroscopy!

High-Z SNe Now and Future

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- **Programs: SNLS, ESSENCE, DES**

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Waiting for thousands of SNIa from LSST and **space programs** (WFIRST in US/ EUCLID(?) in Europe)

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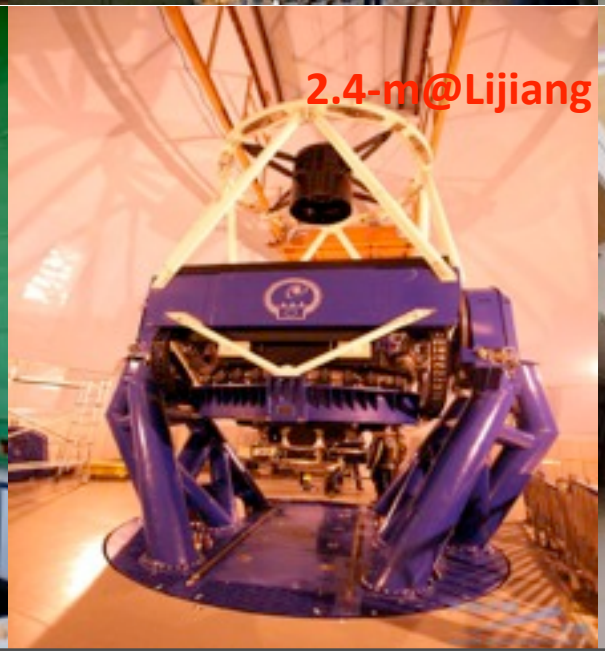
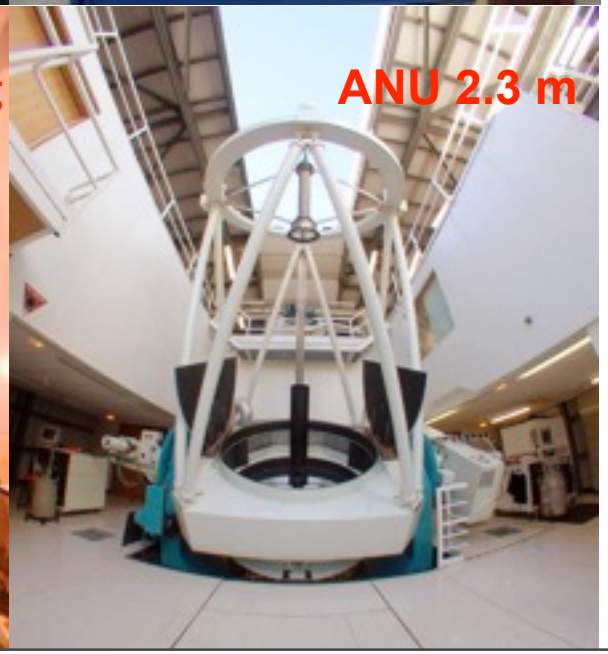
Or … **KDUST** project

Chinese Transient Factory (CTF)





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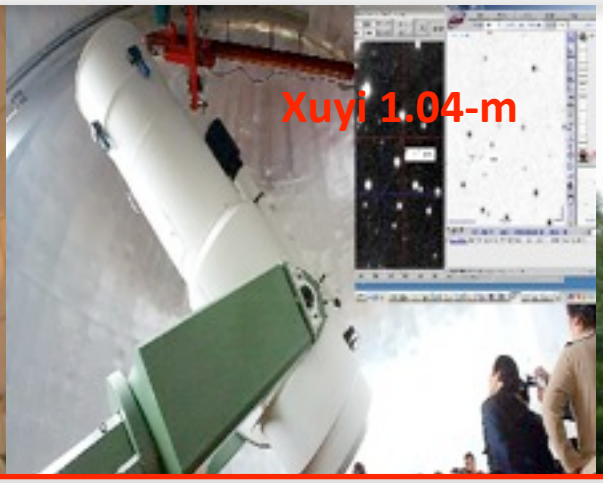
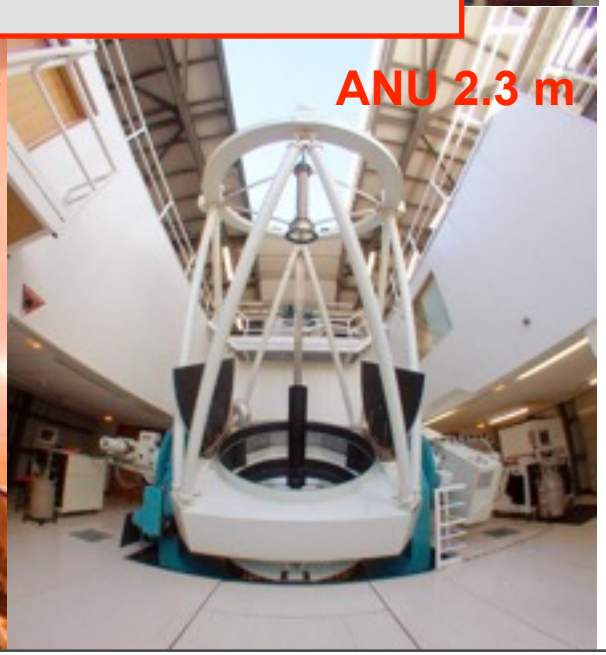
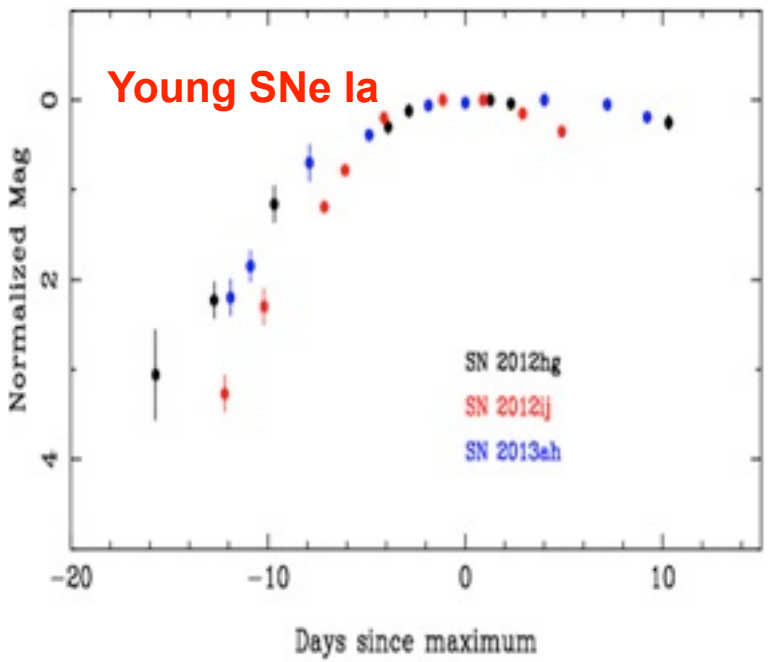


CTF（Supernova、Nova, and AGN etc）

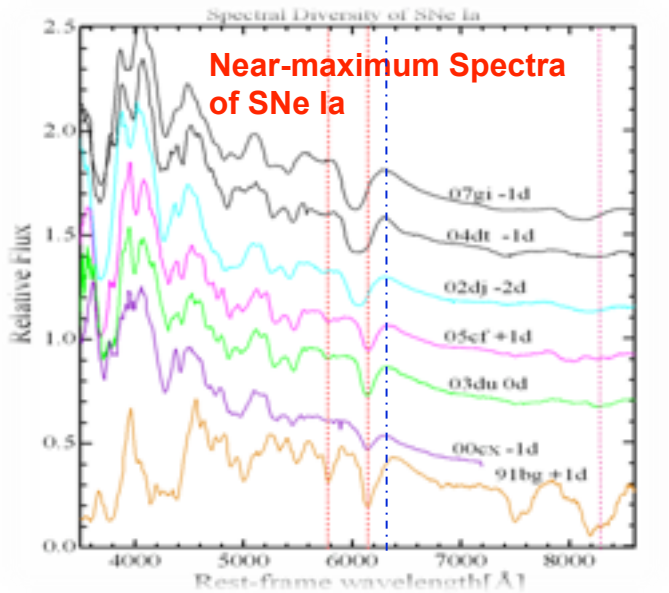


Sky Survey from CTF

Tsinghua-NAOC Transient Survey(TNTS)

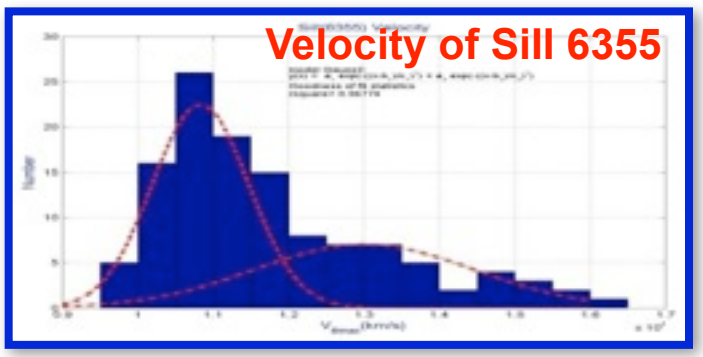


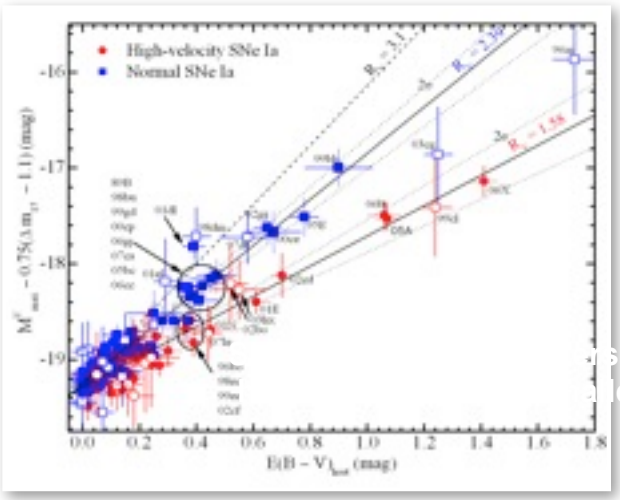
Spectral Diversity of SNe Ia



Problem： Rv changes，how to find out more uniform subsample for cosmological purpose？

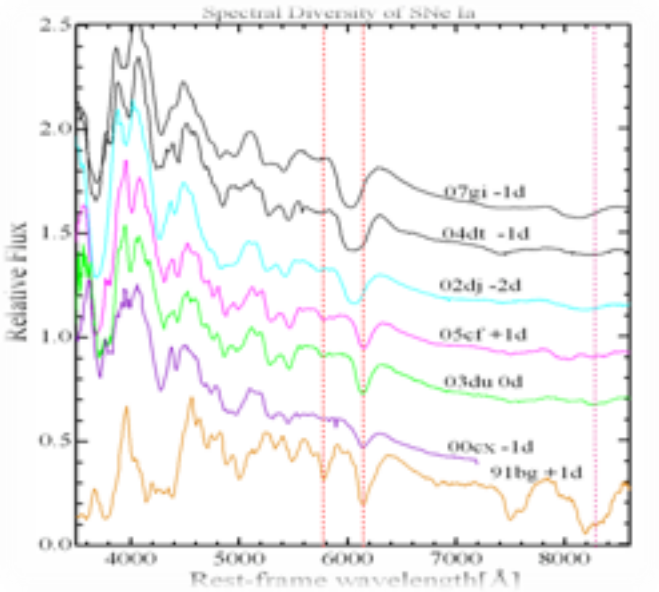
Our findings： blueshift of Si II 6355 absorption is related to photometric properties of SNe Ia such as color and/or Rv.

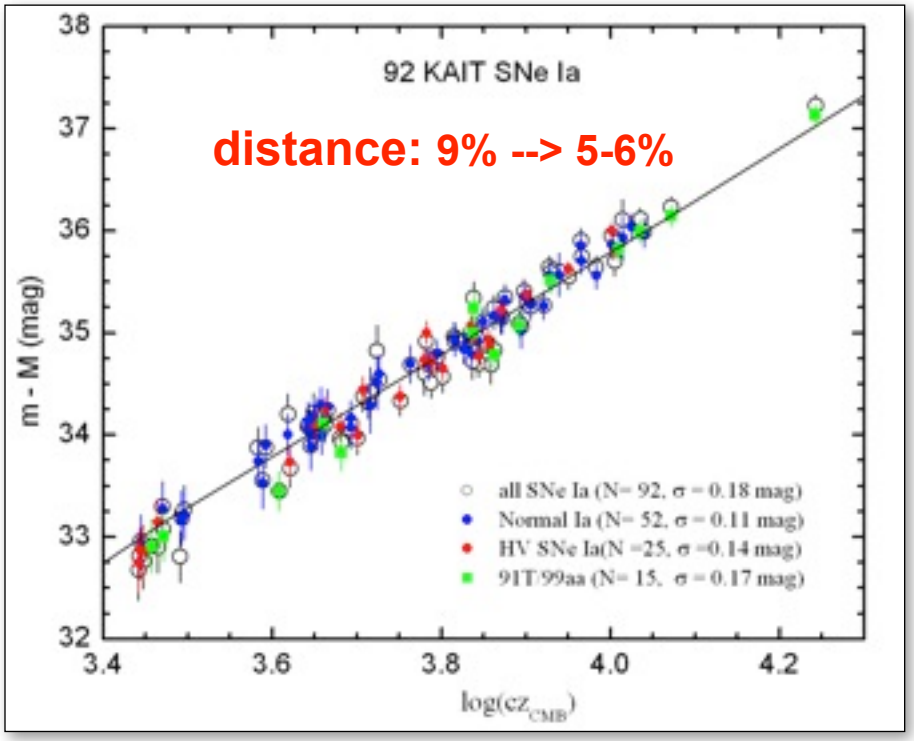




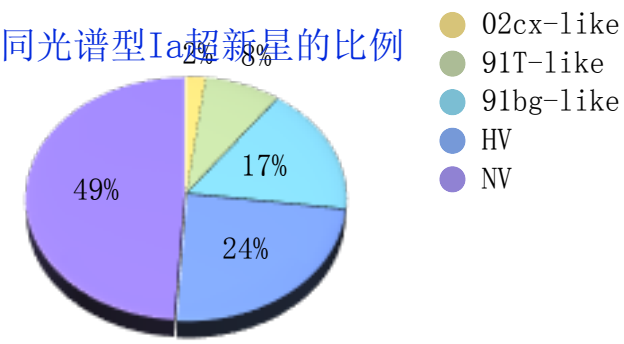
Wang et al. 2009, ApJ, 699, L139

More Uniform Subsmple of SNe Ia

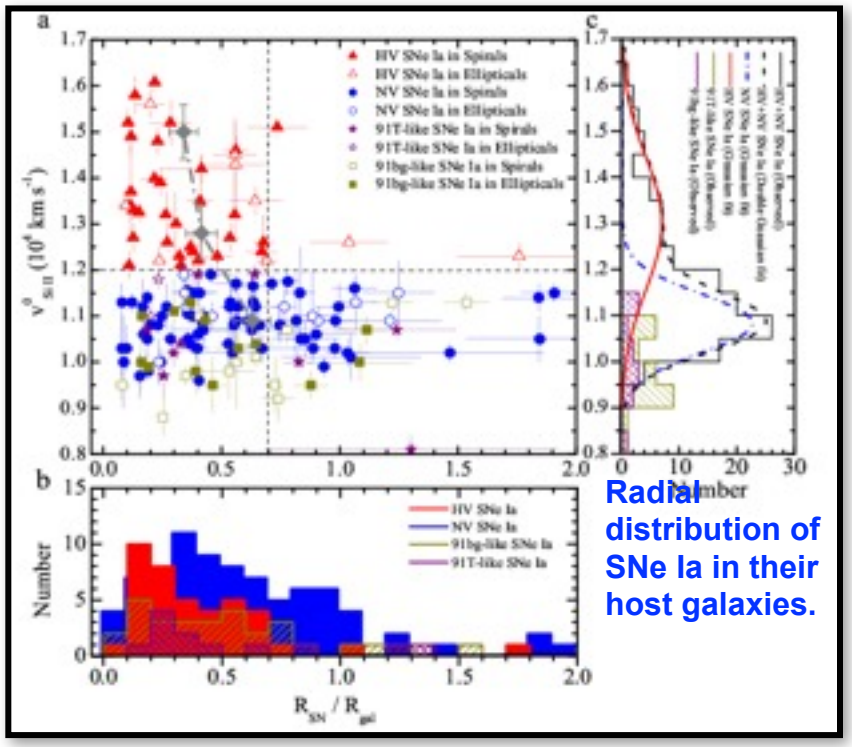




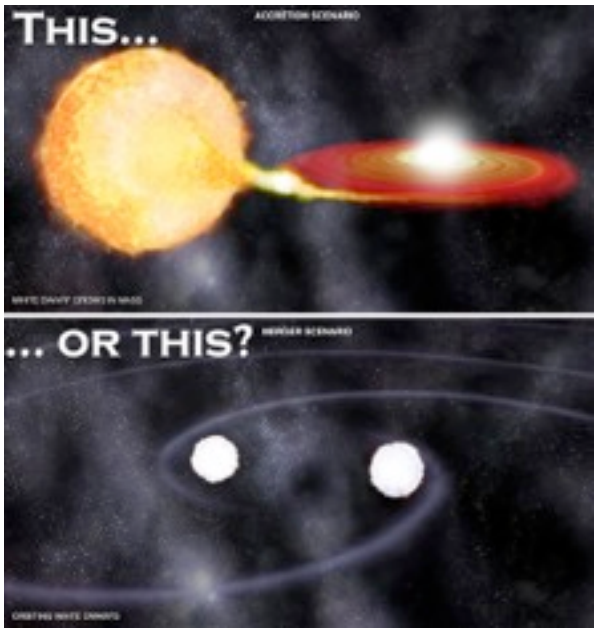
不同光谱型Ia超新星的比例



Two populations of Type Ia SNe Ia



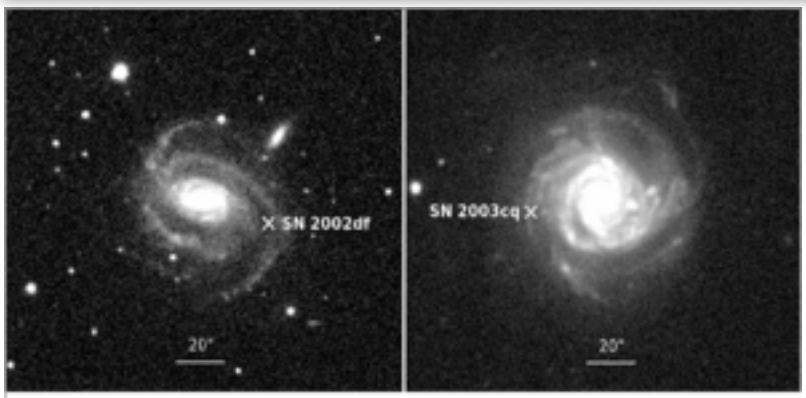
Radial distribution of SNe Ia in their host galaxies.



VS

And

Wang, X.-F., et al.
Science , 2013, 340 , 170-173



Implications 1：**Accretion model and merger model perhaps co-exist for SNe Ia.**

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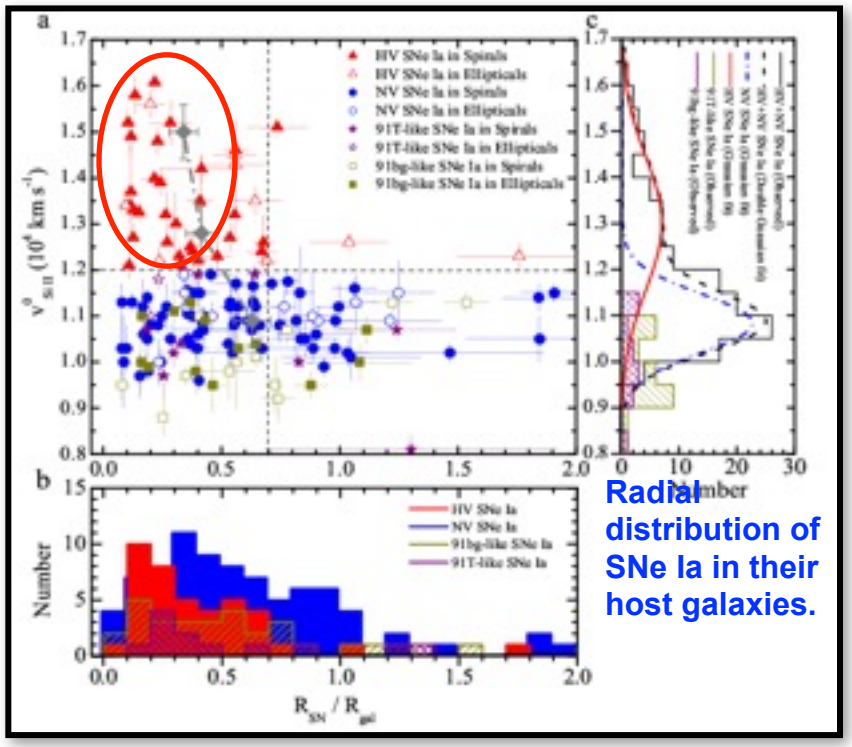

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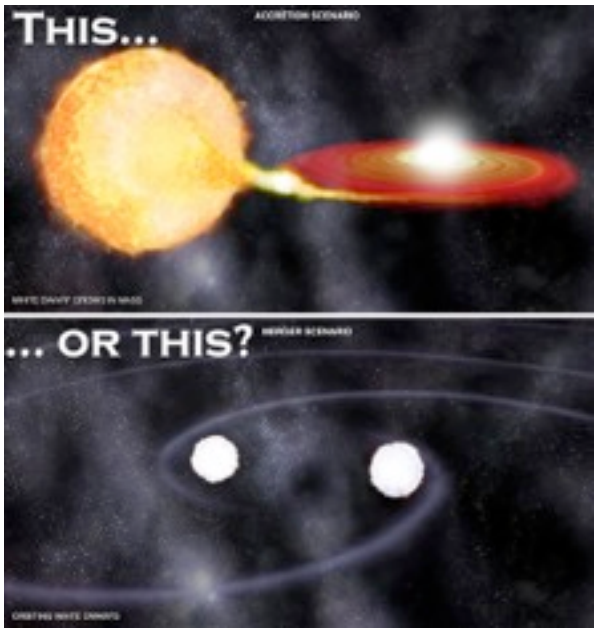

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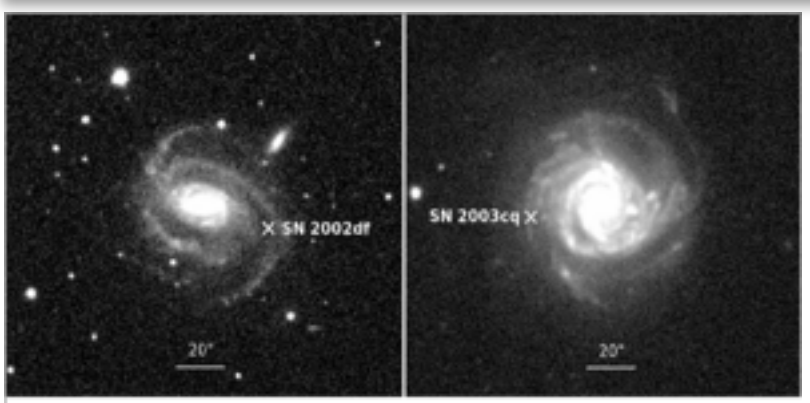

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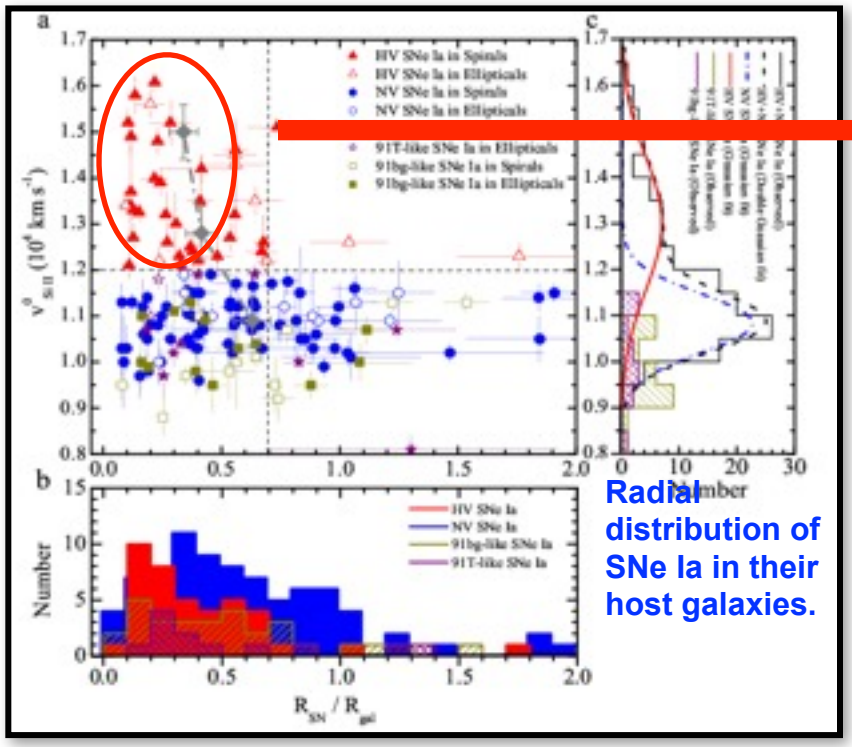

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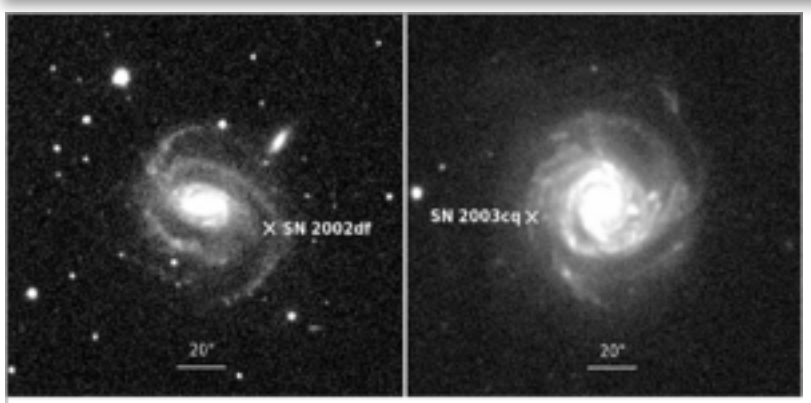

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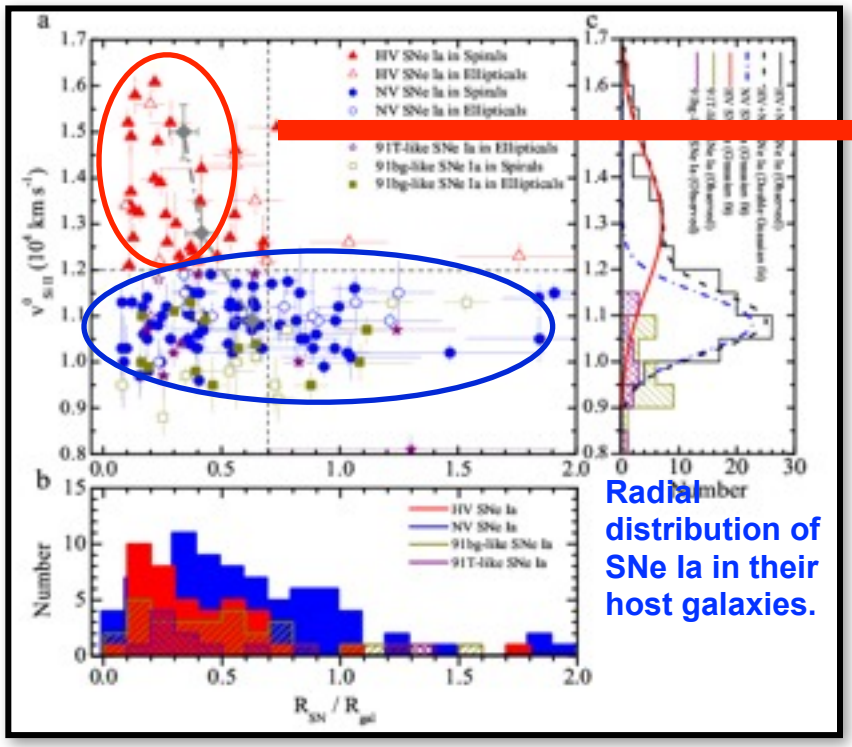

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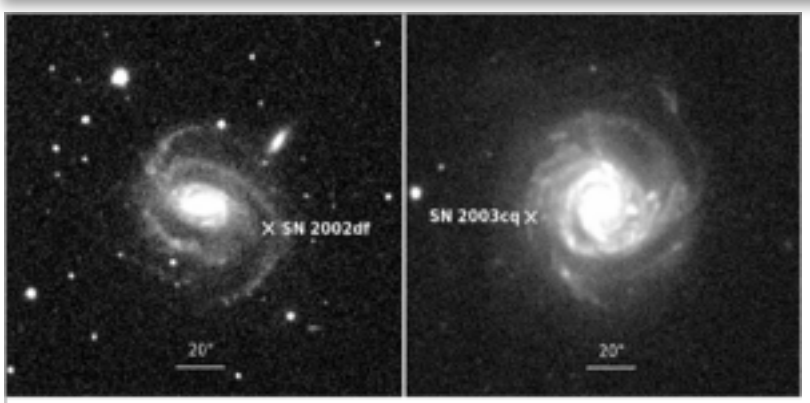

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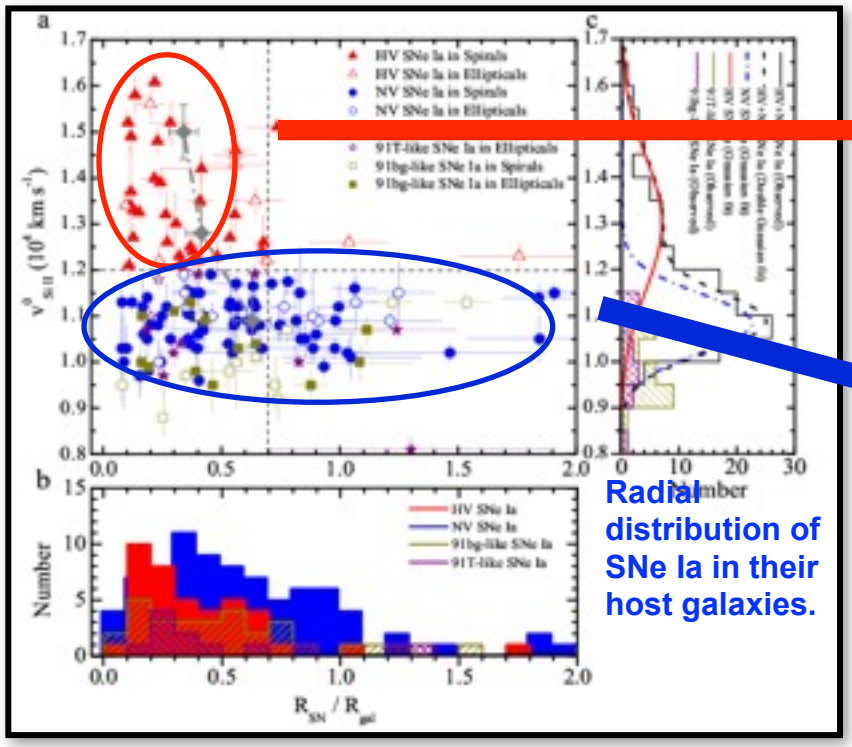

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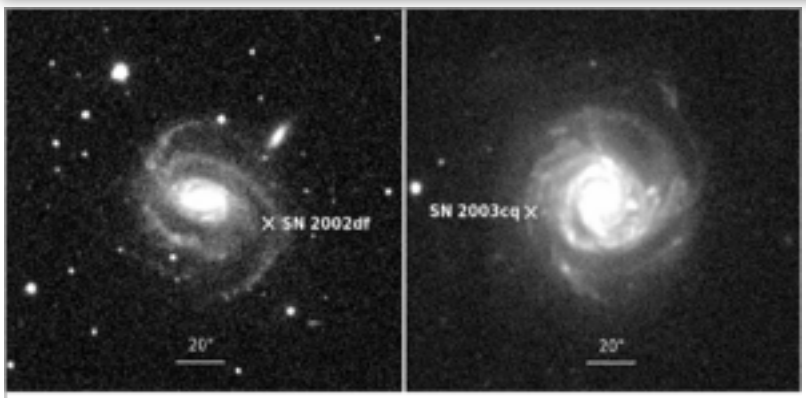

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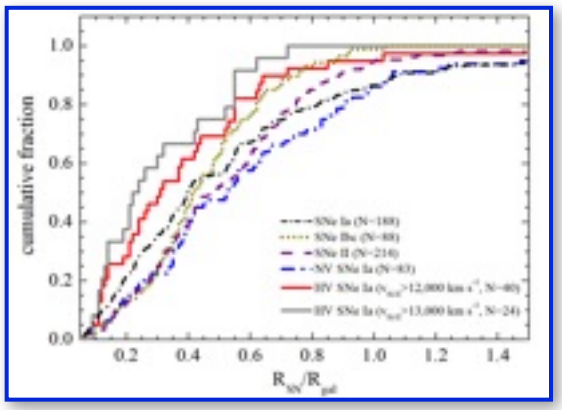
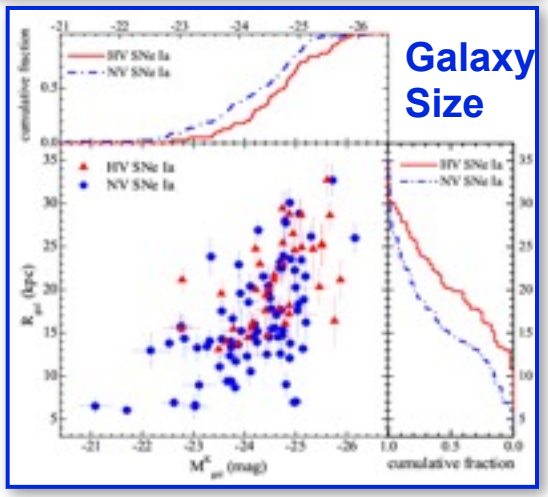
Impact to Cosmology

Radial Distribution





Galaxy Size

Implications 2：

SNe Ia with higher Si II velocities have higher metallicity

Impact to Cosmological Parameters：

- **Ho：73 km s^{-1} Mpc^{-1} →**

  70 km s^{-1} Mpc^{-1}
- **other parameters--> higher Ω_M**

HV：NV=1：2

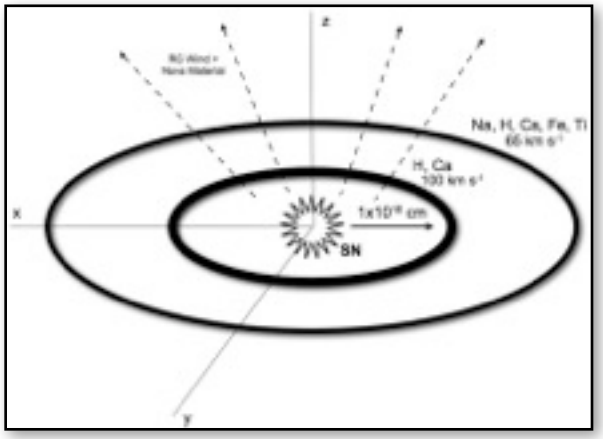
Local Universe

HV：NV< 1：2

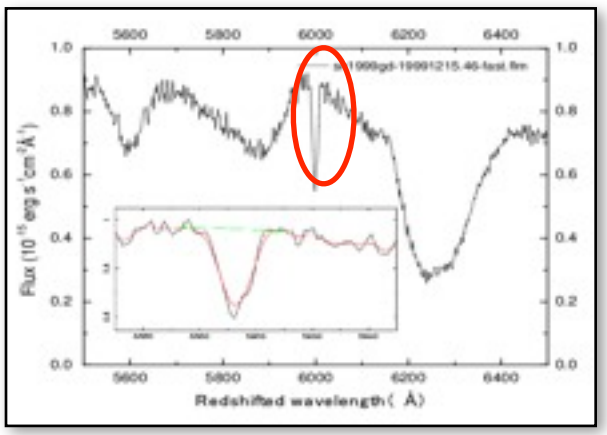
Distant Universe

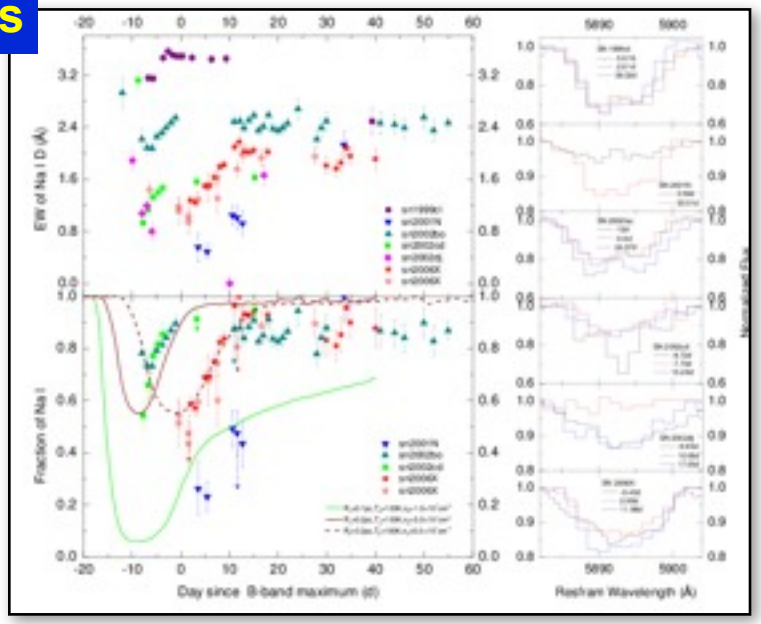
Circumstellar Dust around SNe Ia ?

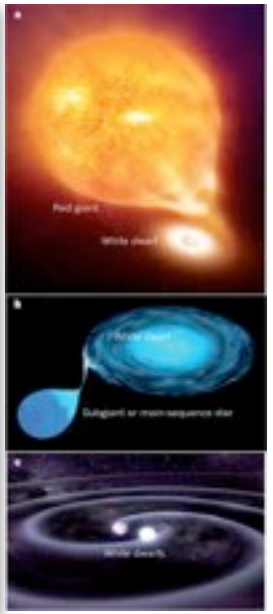
Stellar wind from SN Progenitors



Na I D: 5890 & 5896 Å







Variable Na I D will help distinguish between the SD and DD scenarios of SN Ia Progenitors.

The SN Ia sample with high-resolution spectra is only 3 due to the limit of the telescope and will be greatly enlarged with the coming of TMT.

Chen & Wang, 2013

Direct Identification of SN Ia Progenitor Systems (TMT AO)

Figure 1 | The site of SN 2011fe in Messier 101 as imaged by HST/ACS. The left panel is a full-view colour picture of the face-on spiral galaxy M101 ($18' \times 18'$ field of view) constructed from the three-colour *HST*/ACS images taken at multiple mosaic pointings (from http://hubblesite.org). North is up and east to the left. M101 displays several well-defined spiral arms. With a diameter of 170 thousand light years across, M101 is nearly twice the size of our Milky Way Galaxy, and is estimated to contain at least one trillion stars. The middle panel is a cutout section ($3' \times 3'$) of the left panel, centred on the SN location. SN 2011fe is spatially projected on a prominent spiral arm. The right panel is a section of $2'' \times 2''$ centred on the SN location, which is marked by two circles. The smaller circle has a radius of our 1σ astrometric uncertainty (21 mas), while the bigger circle has a radius of 9 times that. No object is detected at the nominal SN location, or within the 8σ error radius. Two nearby, but unrelated, red sources are labeled as "Star 1" and "Star 2," and are displaced from our nominal SN location by $\sim 9\sigma$, formally excluded as viable candidate objects involved in the progenitor system of SN 2011fe. Credit for the left panel colour picture: NASA, ESA, K. Kuntz (JHU), F. Bresolin (University of Hawaii), J. Trauger (Jet Propulsion Lab), J. Mould (NOAO), Y.-H. Chu (University of Illinois, Urbana), and STScI. *Note: This is a reduced-size figure for arxiv posting.*

Ruling out a luminous red giant Li et al. 2011, nature

Higher-quality Spectra of

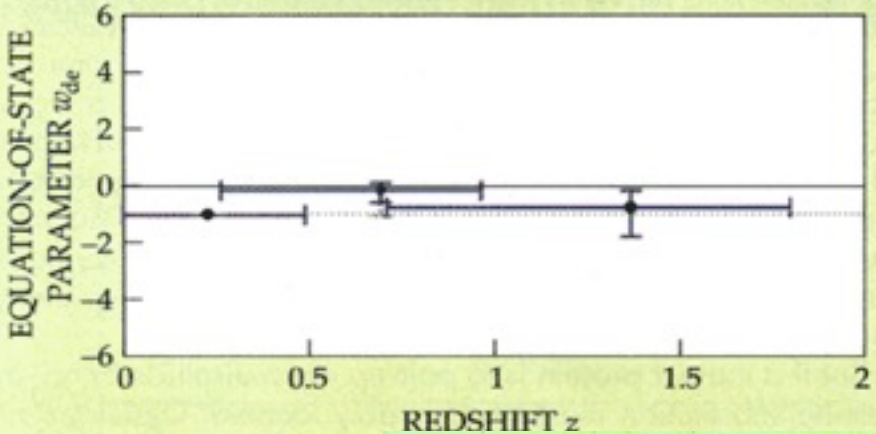


Figure 3. Evolution of w_{de}, the dark energy's ratio of pressure to energy density, as determined from the supernova data. Negative pressure tends to accelerate the cosmic expansion. If the dark energy is the vacuum energy of Einstein's cosmological constant, w_{de} is −1 forever (dotted line). Competing quintessence models let w_{de} change over time. The Higher-Z team concludes, with 98% confidence, that w_{de} was already negative from redshift 1.8 to 1.0, that is, from 10 to 6 billion years ago. (Adapted from ref. 3.)

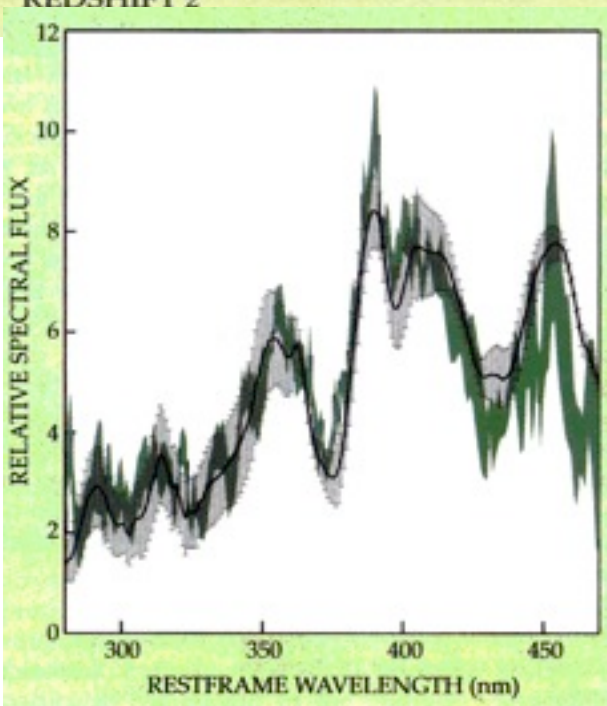
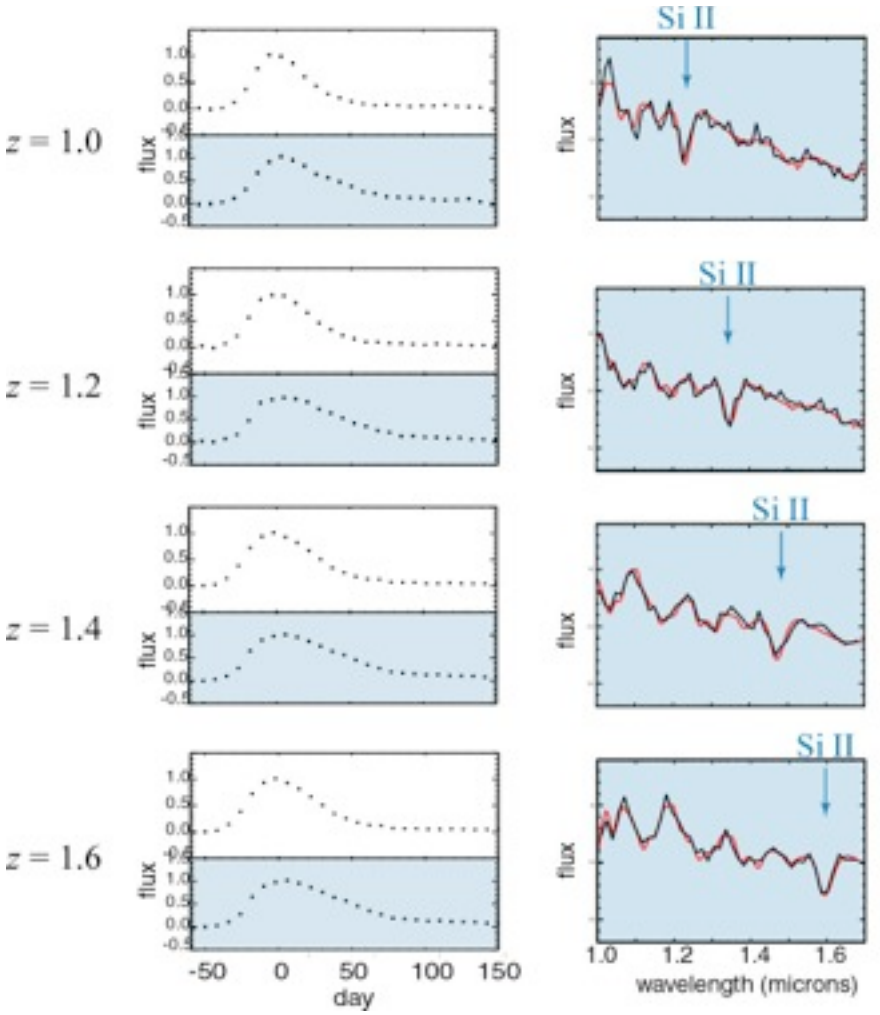


Figure 4. Ancient and recent spectra of type 1a supernovae show no evolutionary change over 10 billion years. The green band is a composite spectrum of the Higher-Z team's 13 best-measured supernovae with redshifts z above 1, transformed into each exploding star's rest frame. The black curve with gray error bars is a template used to verify the type 1a designation for supernovae with redshifts less than 0.1, which would have exploded within the past billion years or so. (Adapted from ref. 3.)

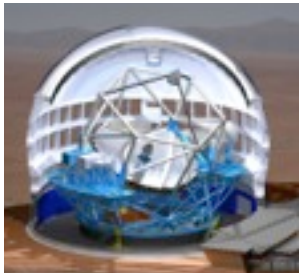
Riess, et al (2007)

TMT Spectroscopy of SNe Ia from LSST or Space Programs

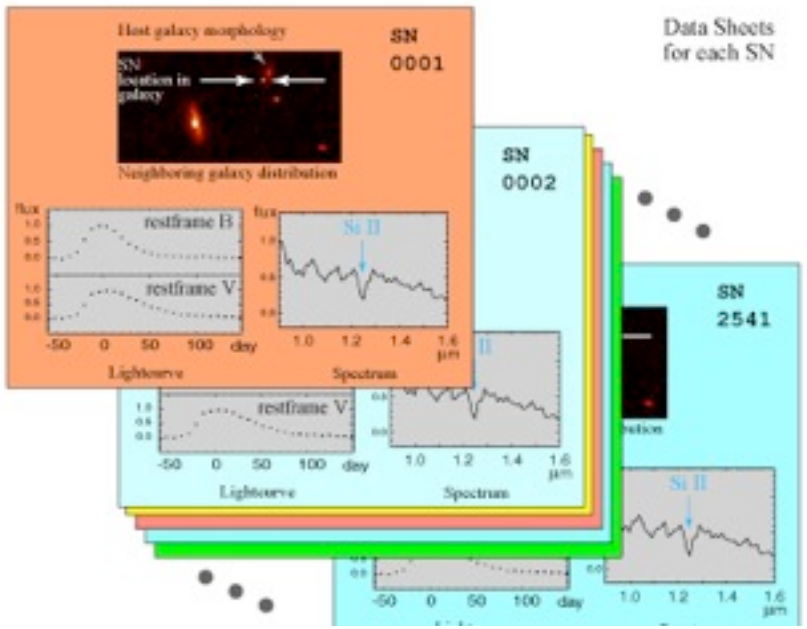


- Multicolor high S/N lightcurves up to z~2

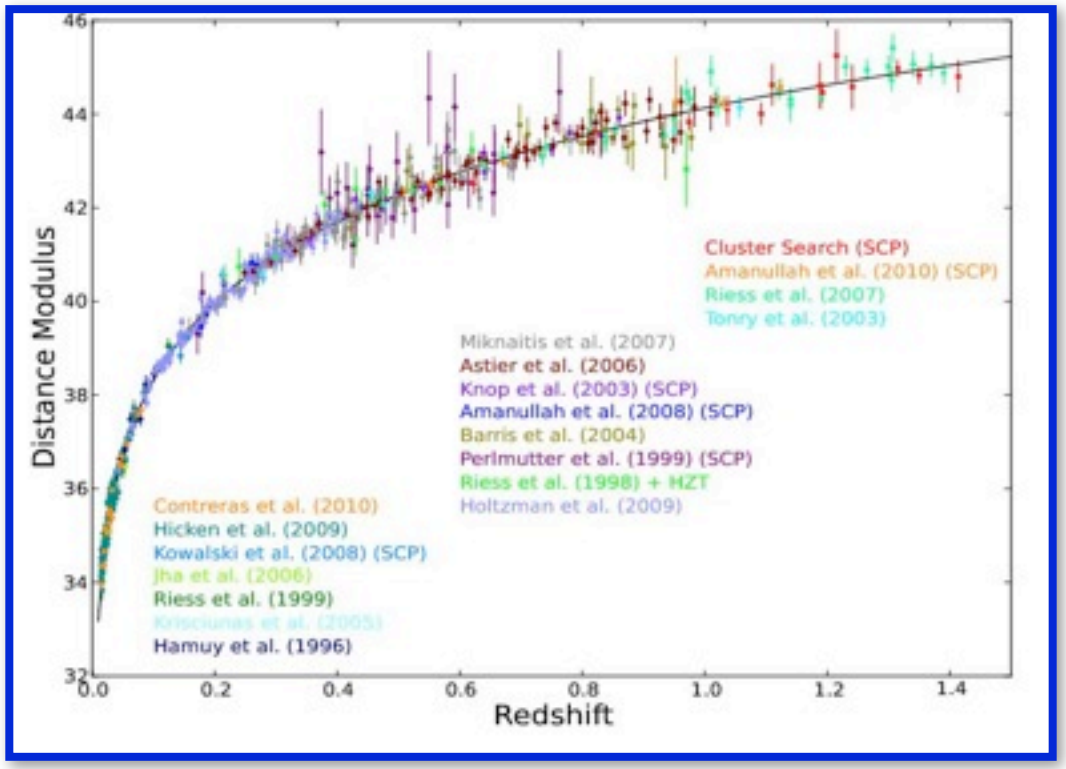
- SN spectral identification up to redshifts z~2



Data Sheets for each SN



Precision Cosmology from Future SN Survey



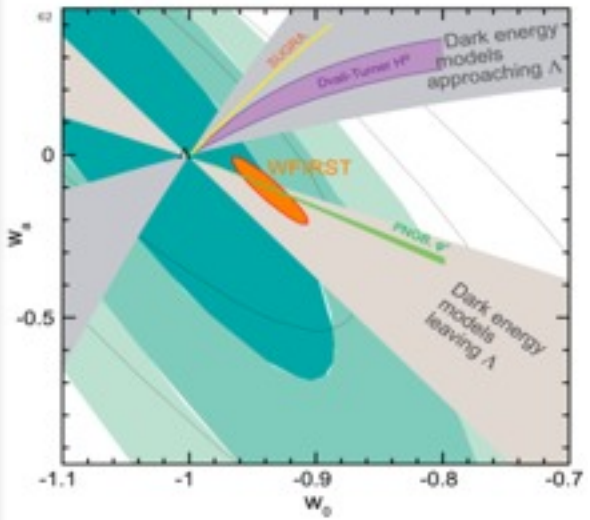
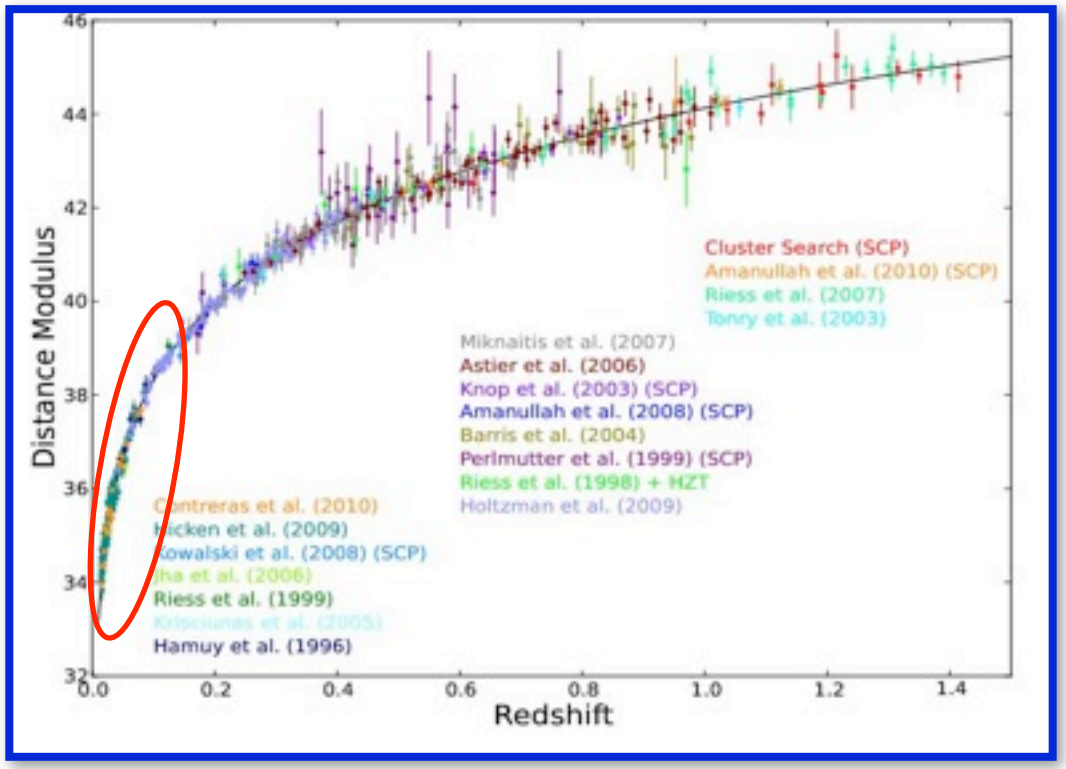
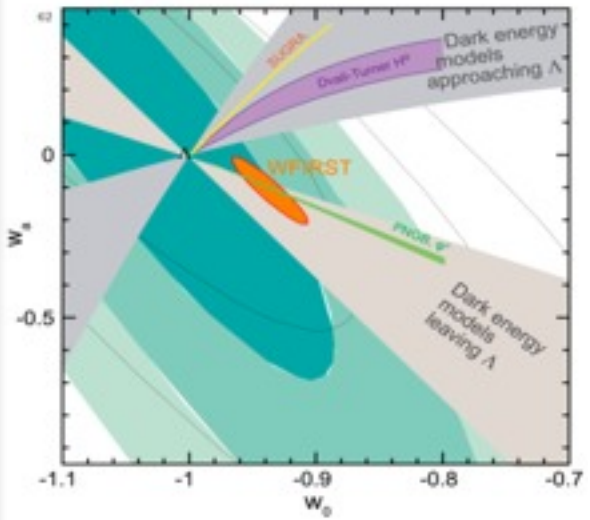


Figure 12: Projected 68% confidence region in the (w_0, w_a) plane for a planned satellite mission (Eric Linder, private communication) compared with the Union2 results. While the existing data cannot constrain a time-dependent w future

Precision Cosmology from Future SN Survey





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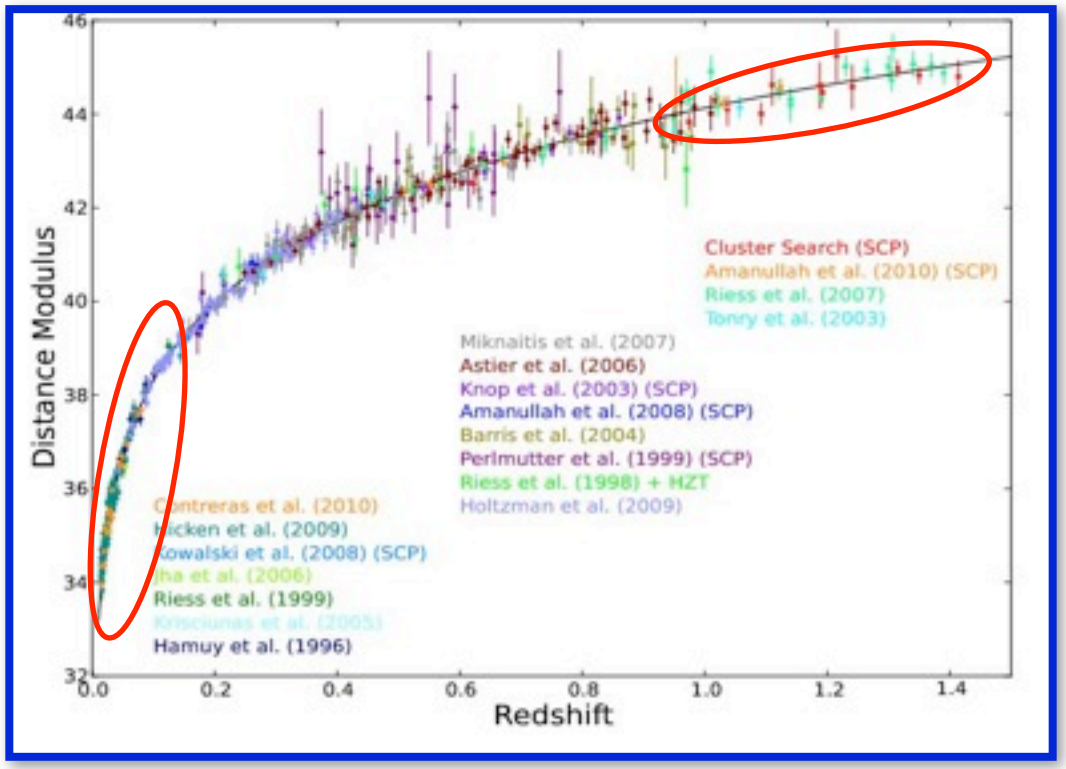

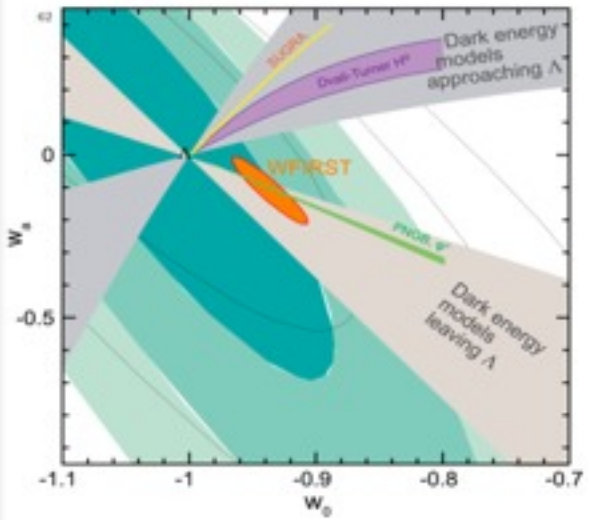

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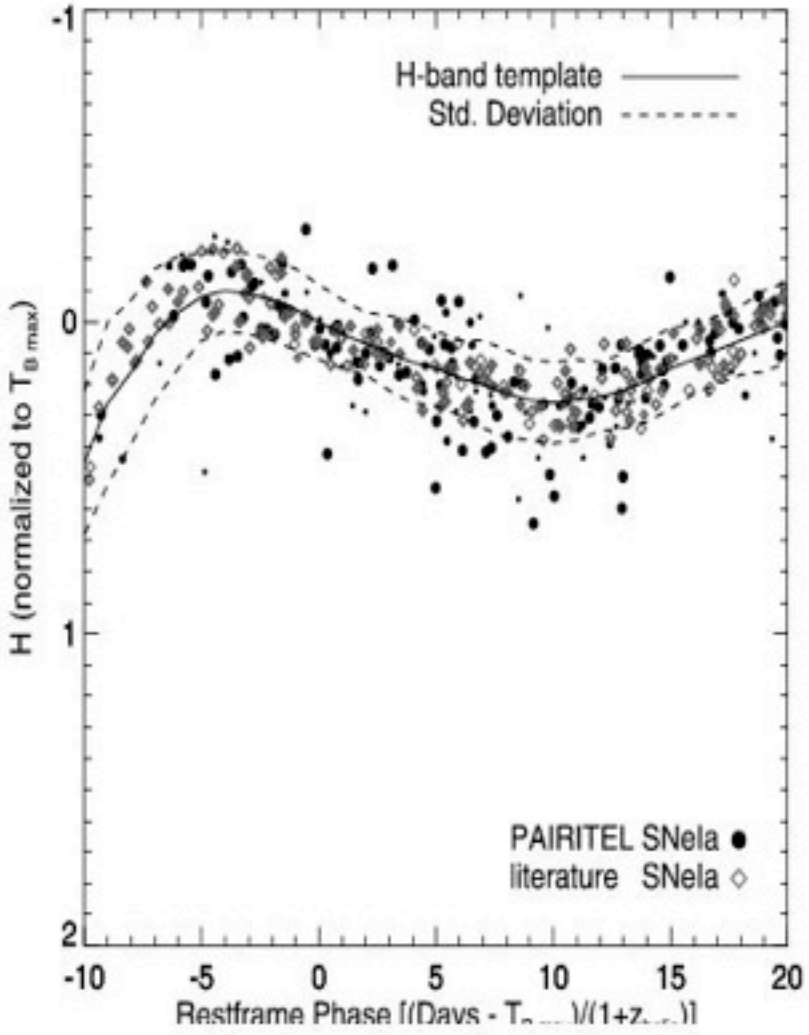
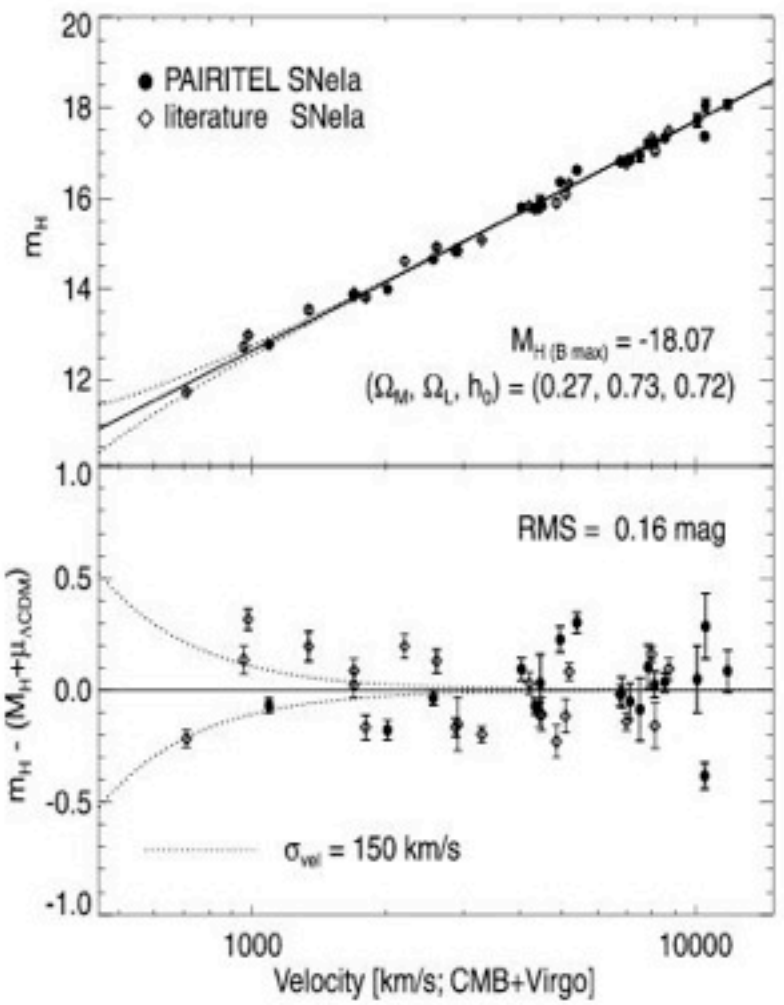
NIR Hubble Diagram of SNe Ia

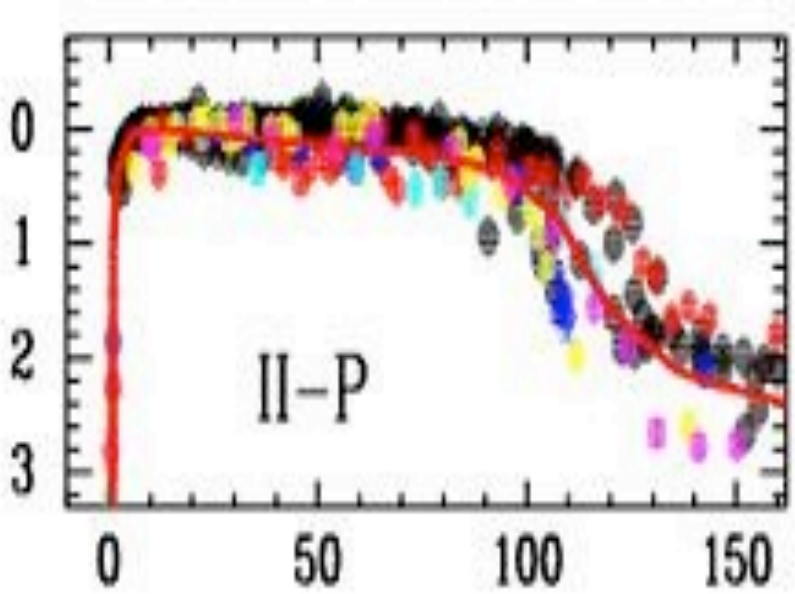


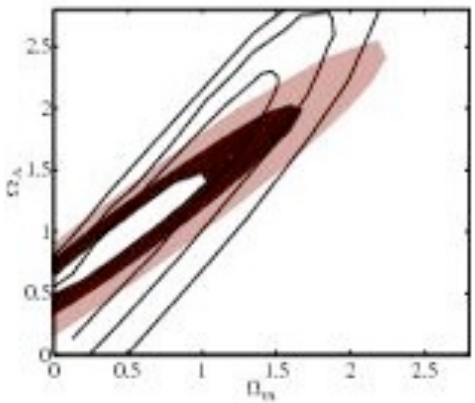


Wood-Vasey et al. 2008

Another choice for cosmology: Type II-P Supernovae?

SNe IIP: Red Supergiant Progenitor



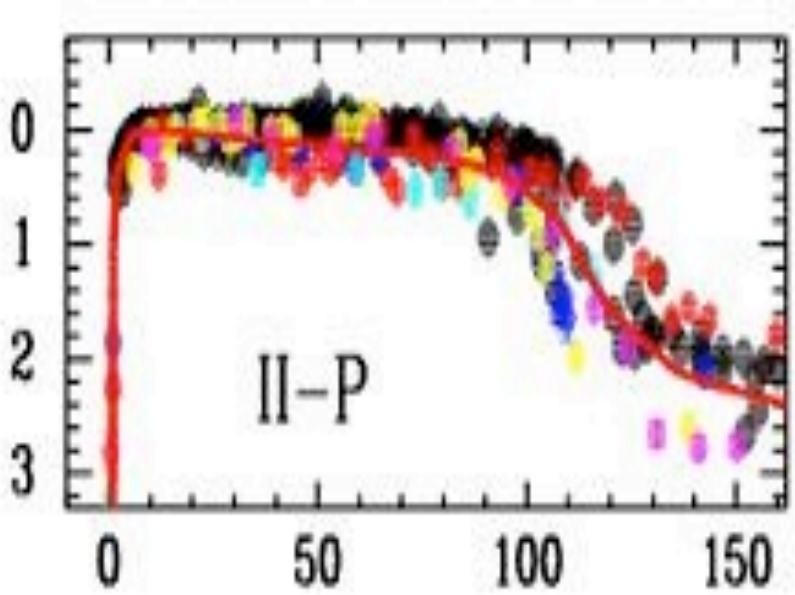


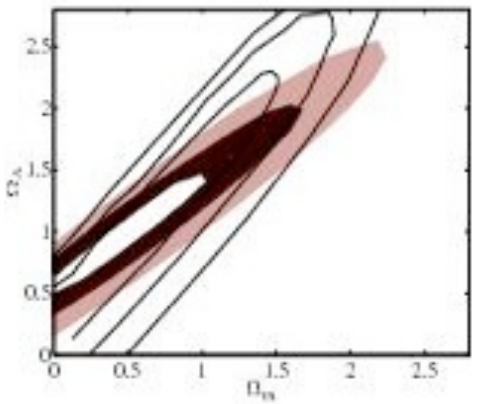
M-S relation for nearby SNe IIP

σ~0.2 mag (10% in distance)

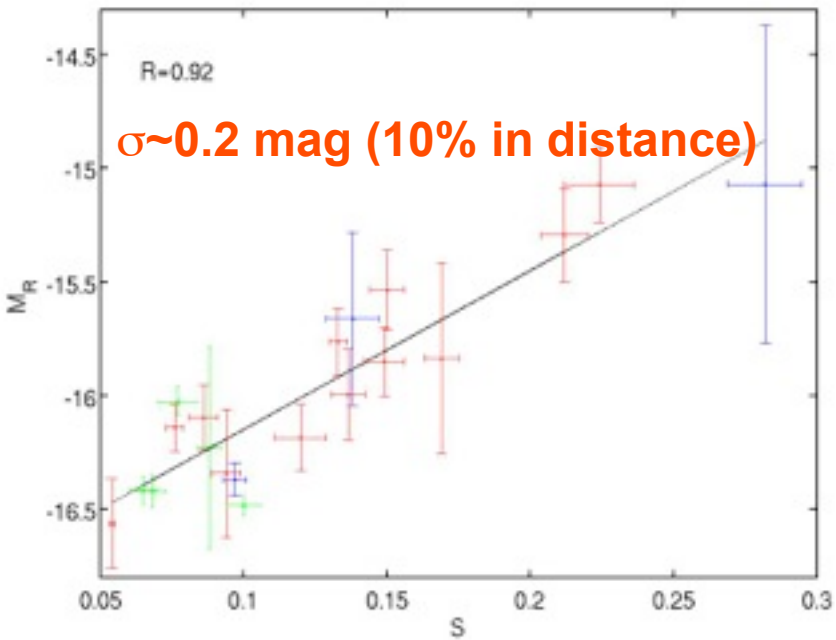
Another choice for cosmology: Type II-P Supernovae?

SNe IIP: Red Supergiant Progenitor





M-S relation for nearby SNe IIP



Summary

- Increasing our physical undertstanding of SN Ia

  -high-resolution spectra

  -high-precision geometry

  -deep imaging of stellar environments of nearby SNe Ia
- Better classifications of next-generation high-z SN Survey

  -near-infared spectra
- NIR Hubble diagram of SNe Ia

  - H/K-band Discovery and followup observations of hundreds of SN Ia between 0.5<z<1 (TMT IRIS)
- SN IIP cosmology at redshifts beyond SNe Ia