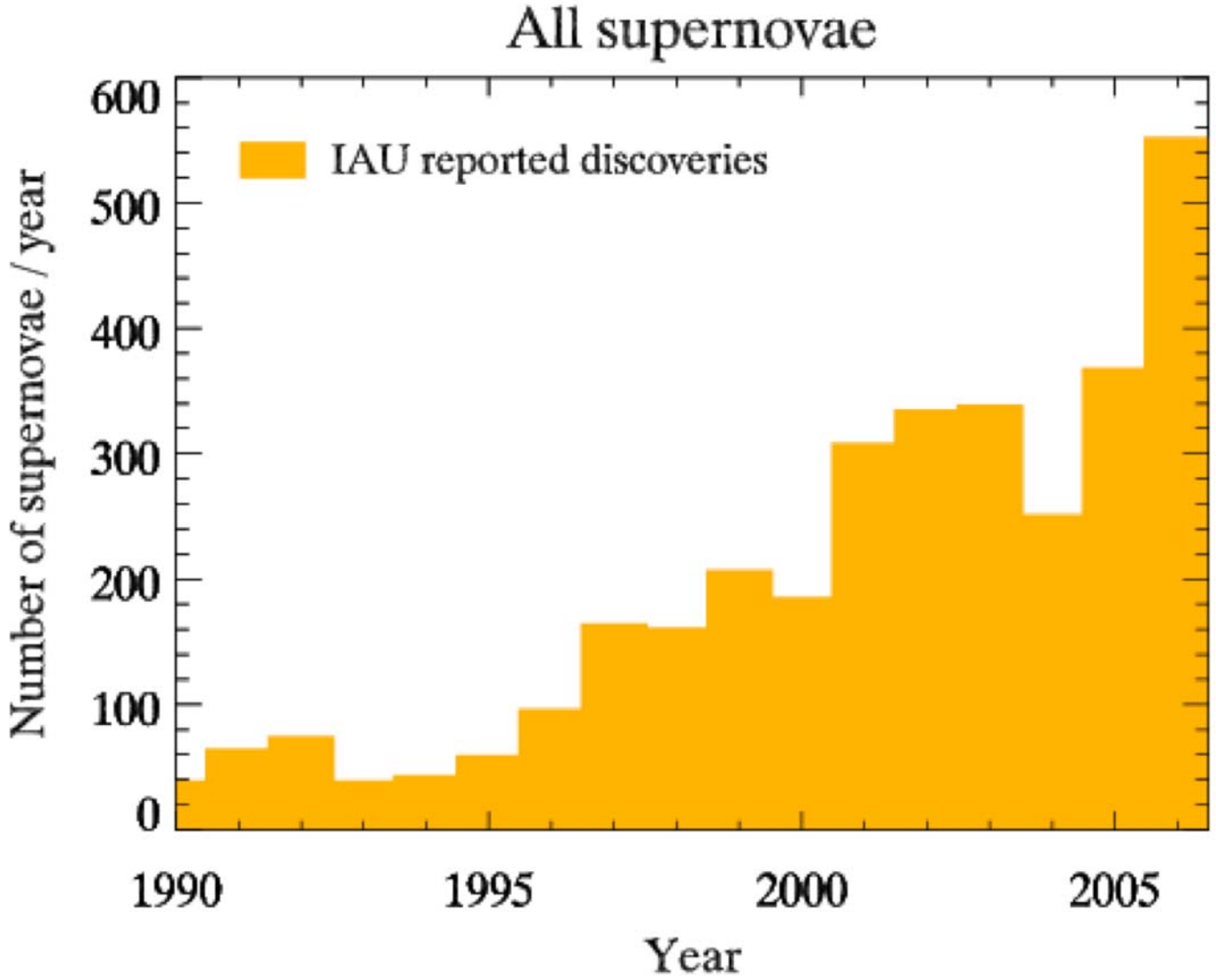
# Supernovae by the 1000s

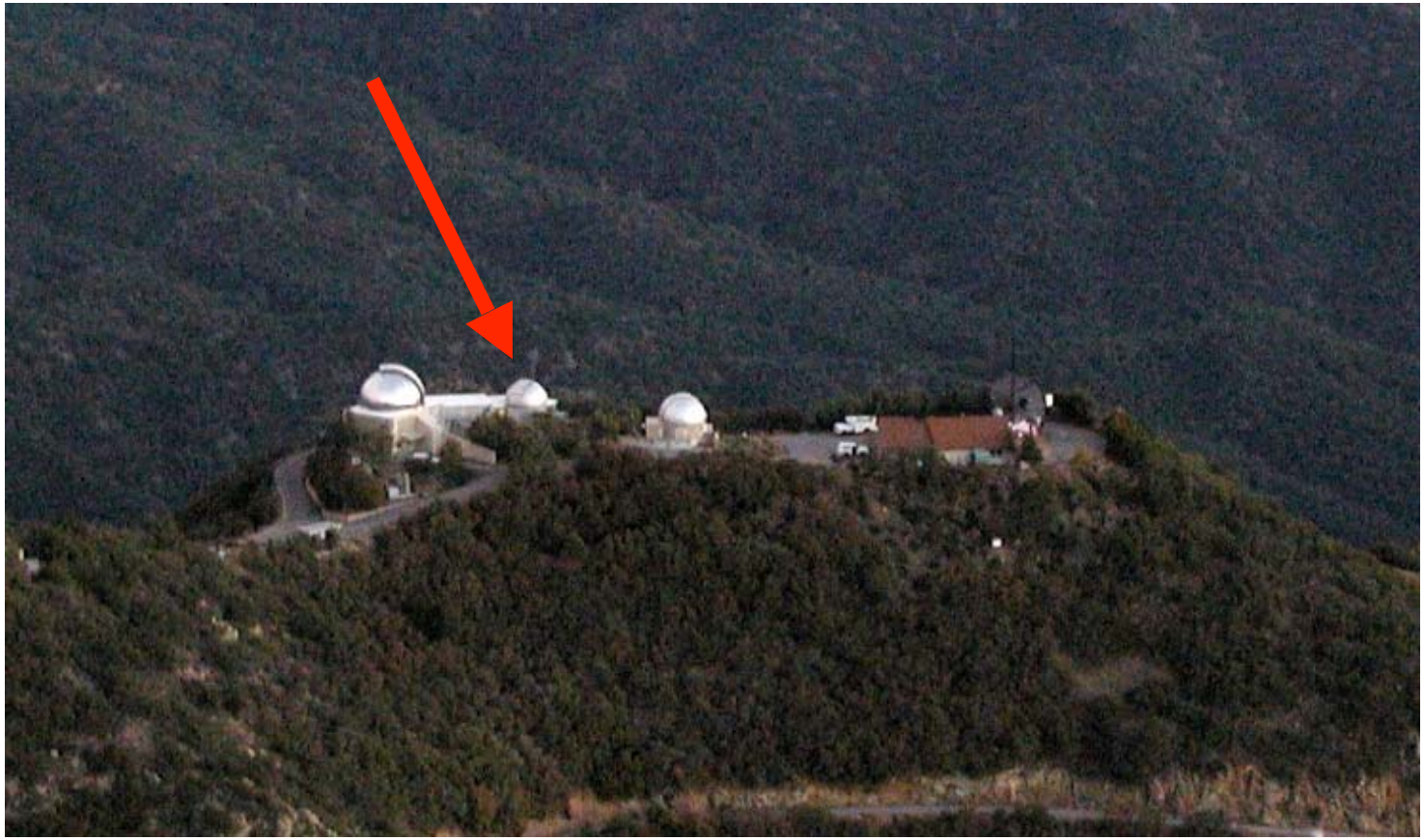
4081 SNe since 1006 (~60% since 2000)



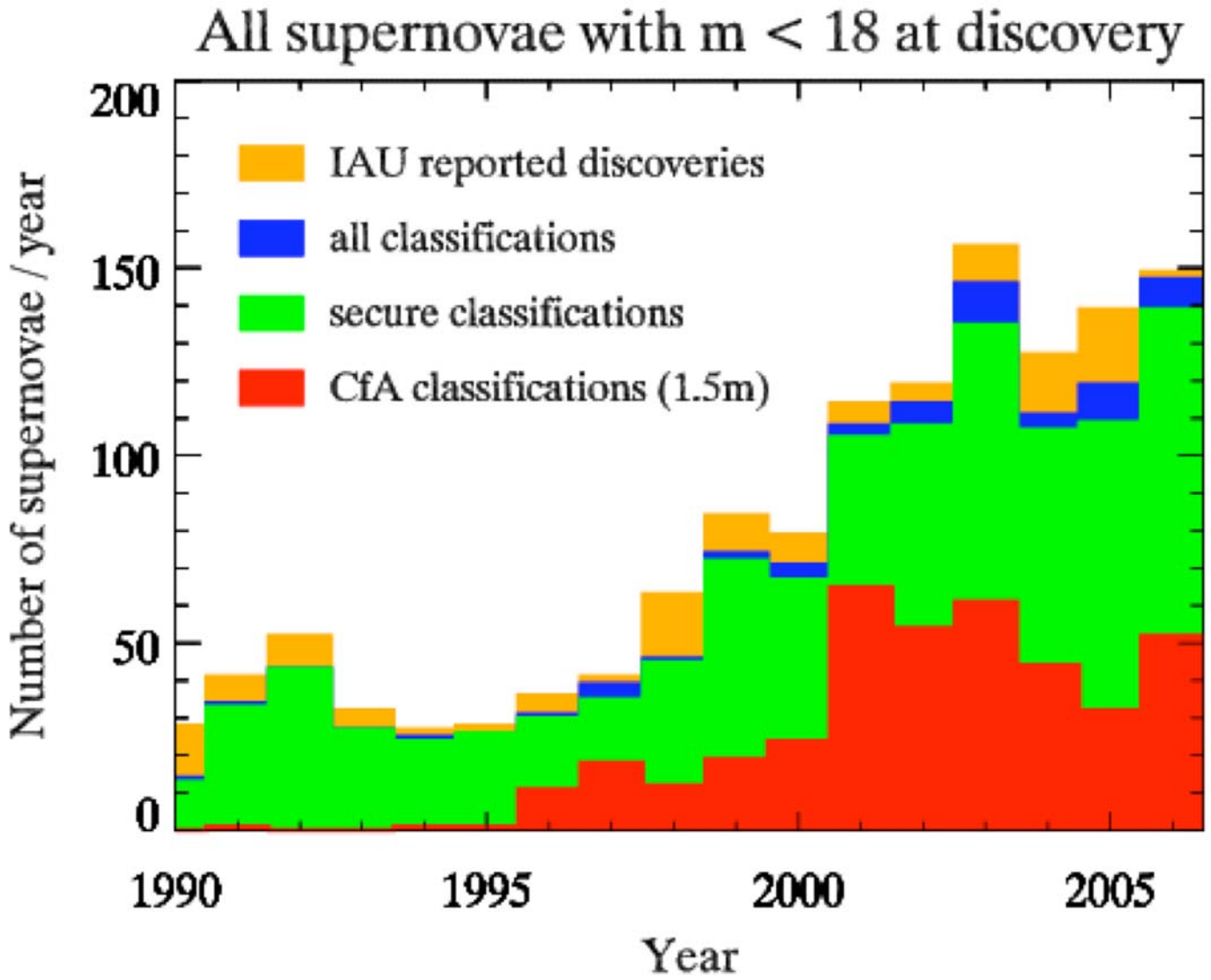

50% discovered
y amateurs

300++ SNe/year
n IAU circulars)

# CfA:
## Following up with light curves

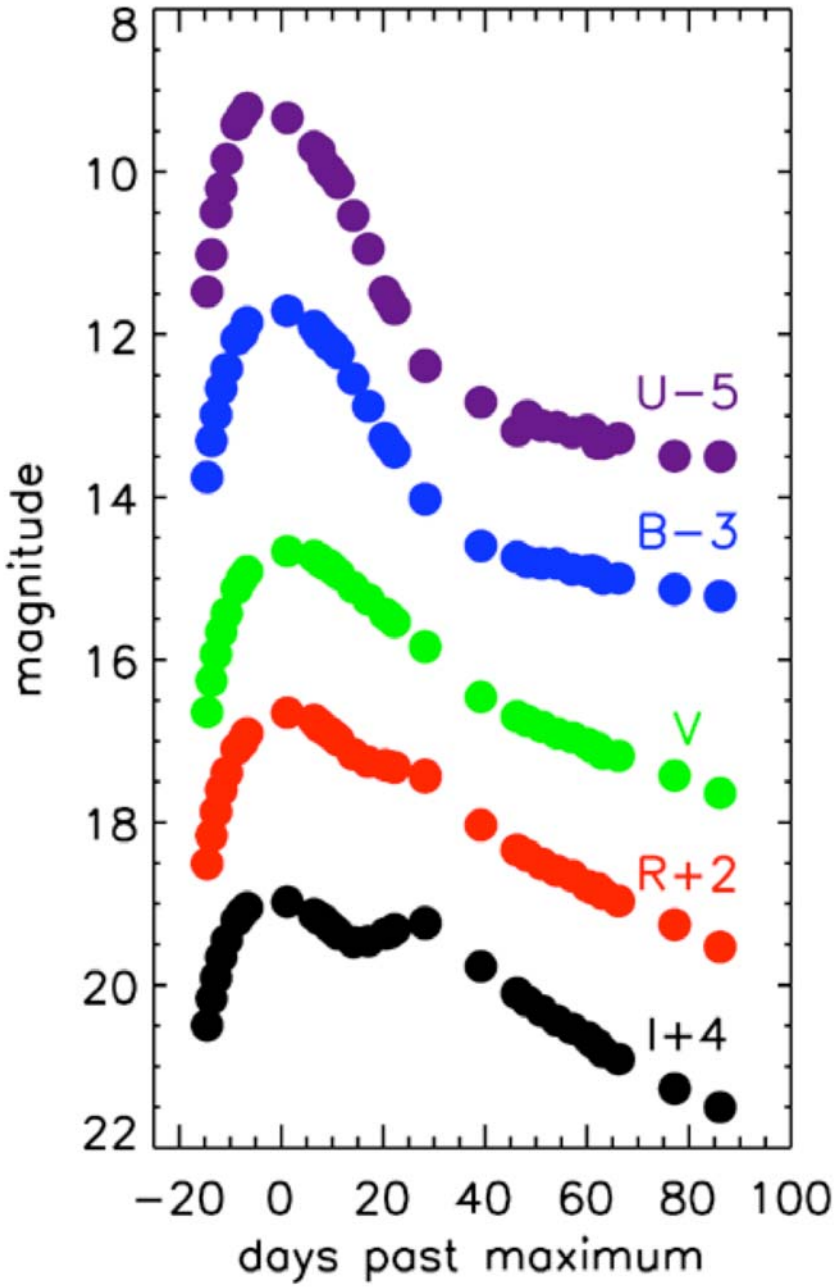


# Supernovae by the 1000s




150 SNe/year
n<18 at discovery)

/3+ classifications
y CfA astronomers

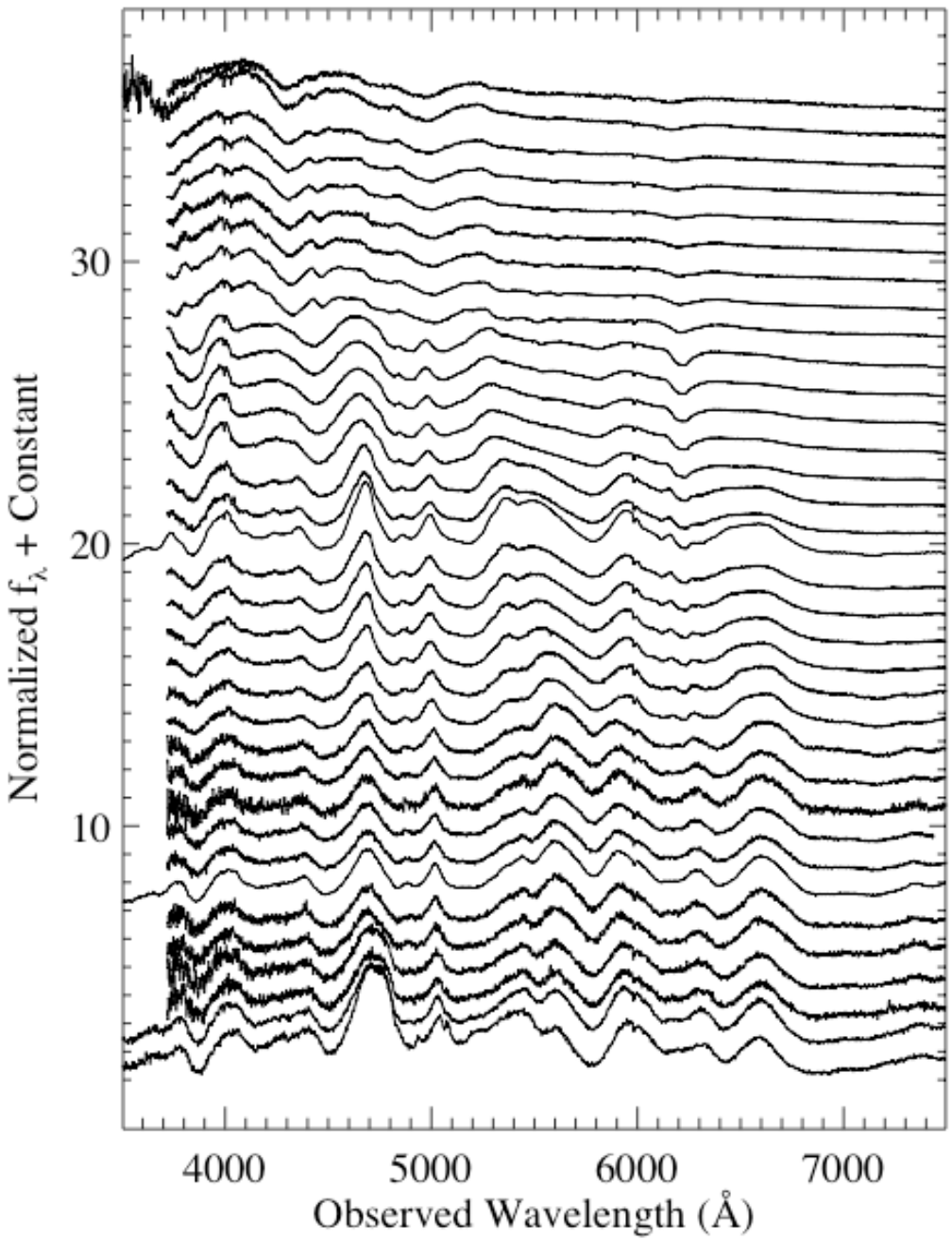



Light Curves: Clues to Luminosity

Most likely related to $^{56}$Ni produced in the explosion

Riess, Press & Kirshner (1995, 1996)

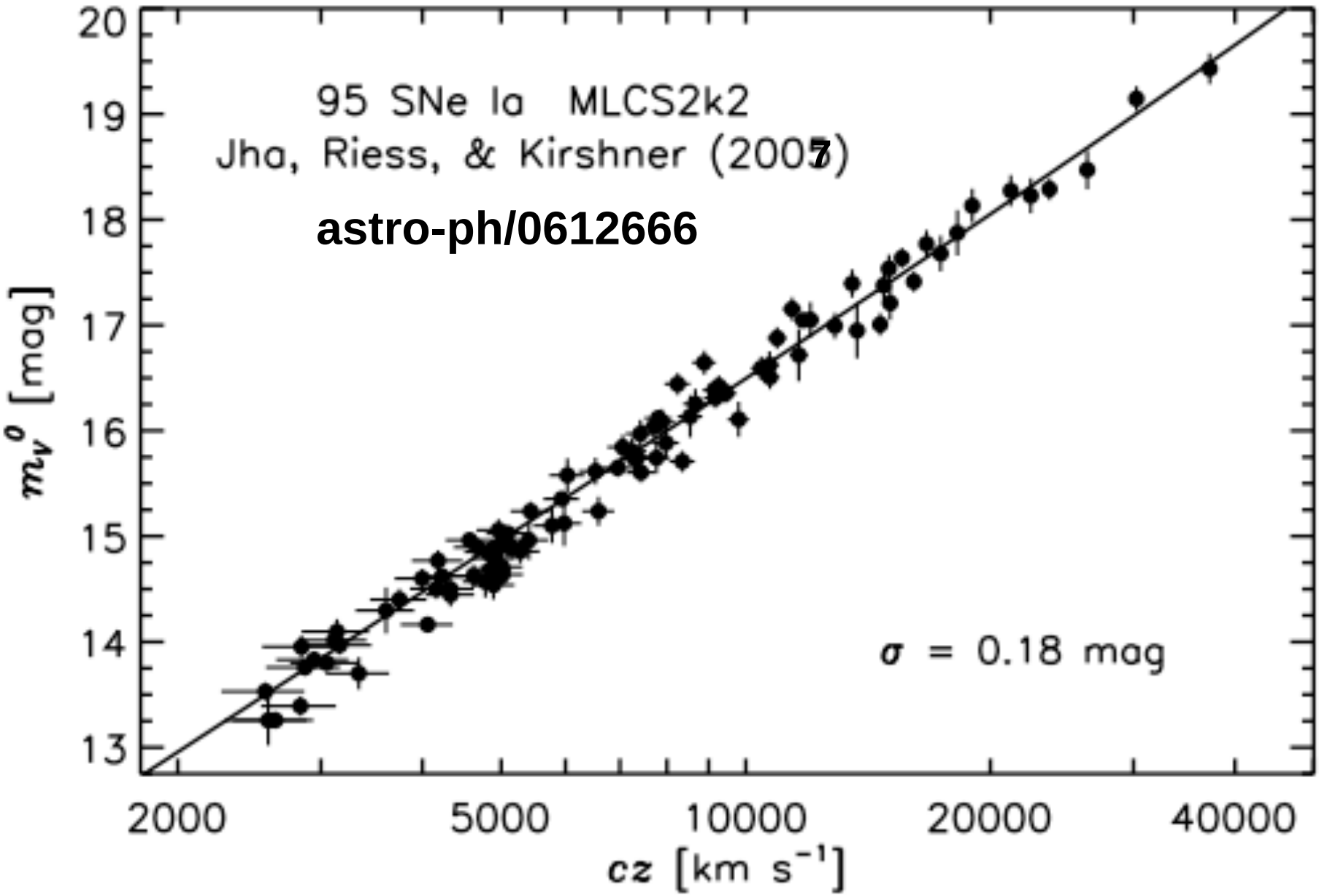
Goal: better distances, determination of extinction by dust



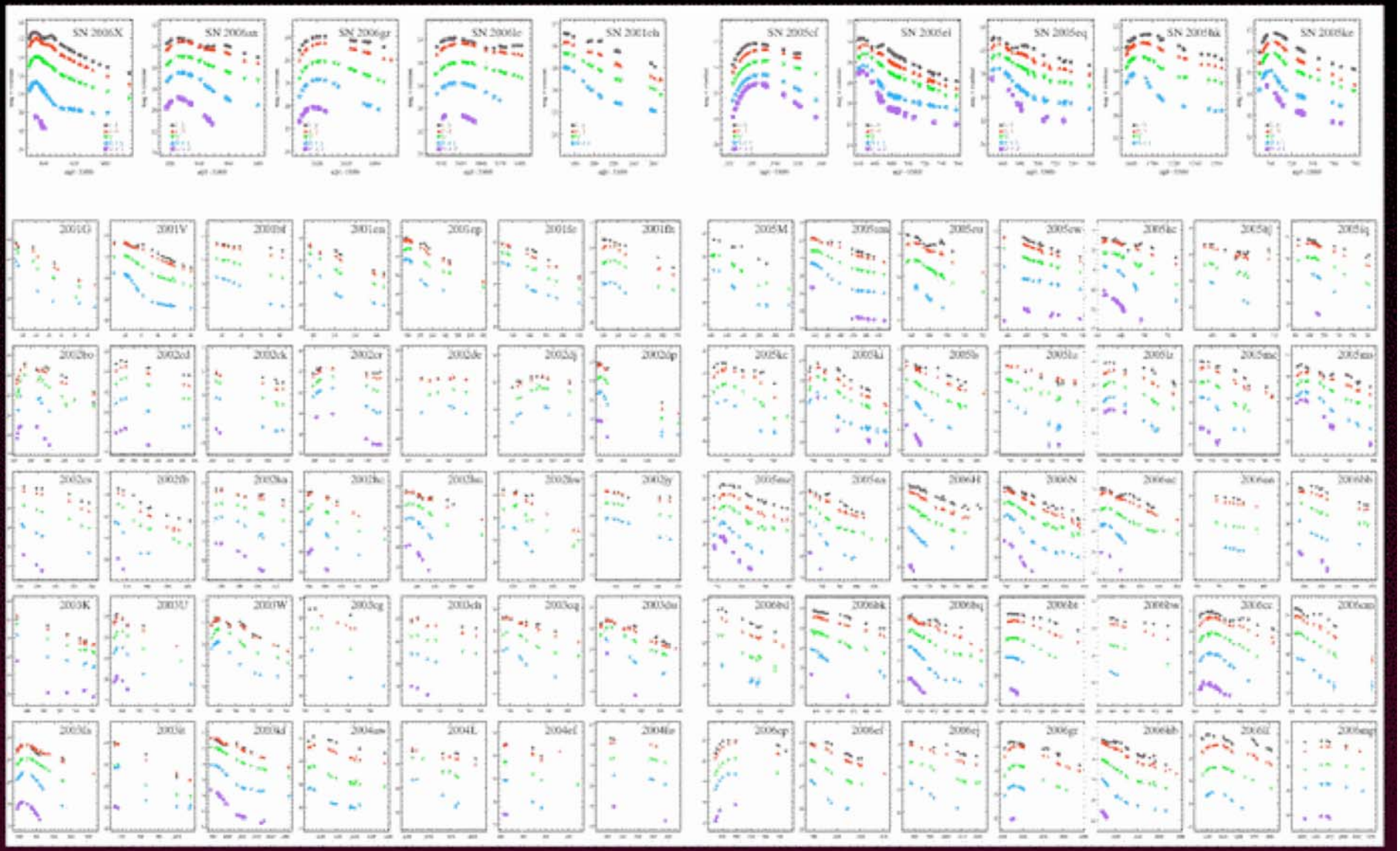

Time series of spectra for a SN Ia

Spectra are similar at a given age, but not identical

Fe seen at late times


95 SNe Ia MLCS2k2
Jha, Riess, & Kirshner (2007)
astro-ph/0612666
$m_v^0$ [mag]
$cz$ [km s$^{-1}$]
$\sigma$ = 0.18 mag
20
19
18
17
16
15
14
13
2000
5000
10000
20000
40000

# Follow-up at FLWO: CfA III



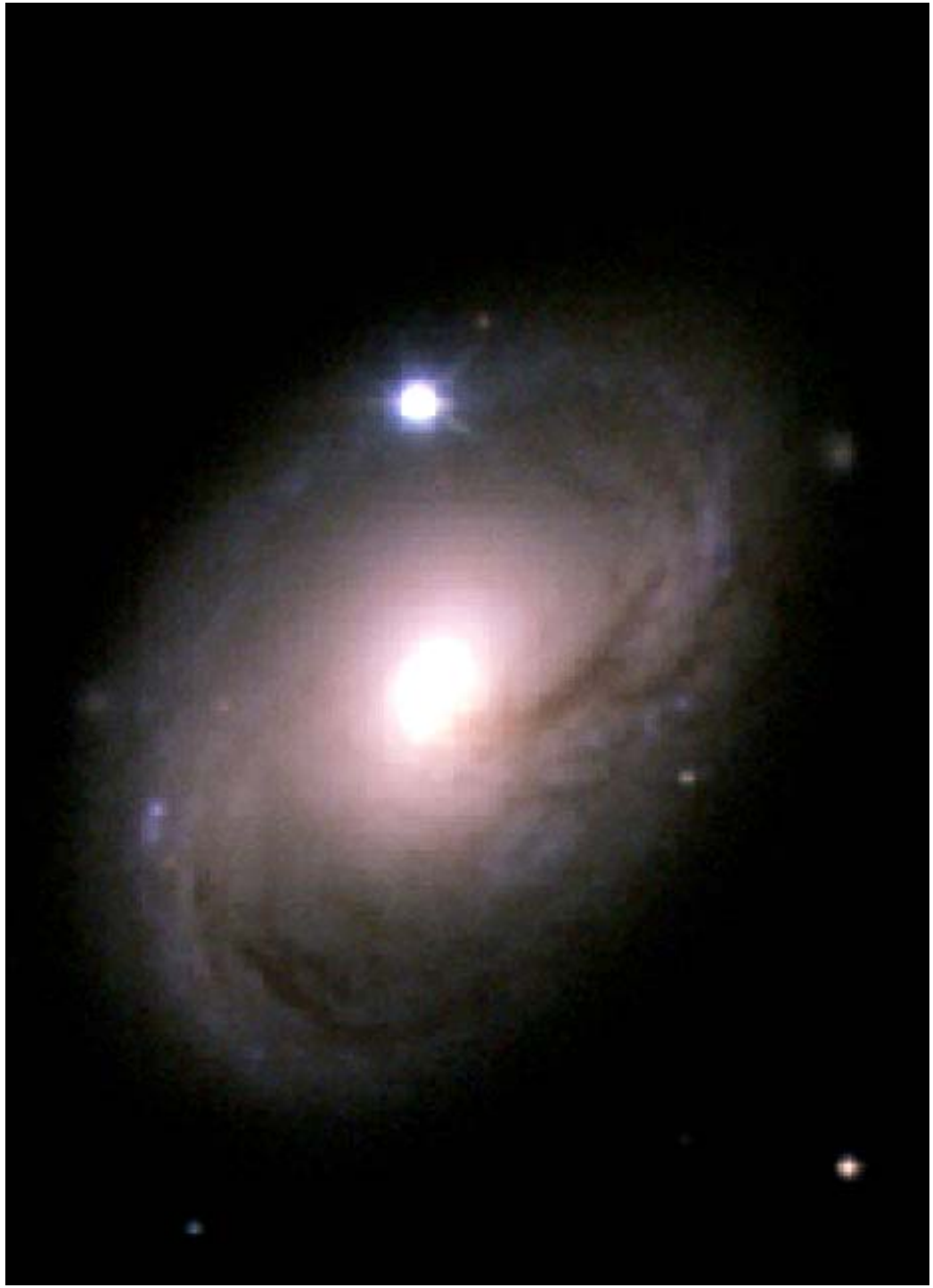
Coming soon: KAIT, Carnegie, SN Factory

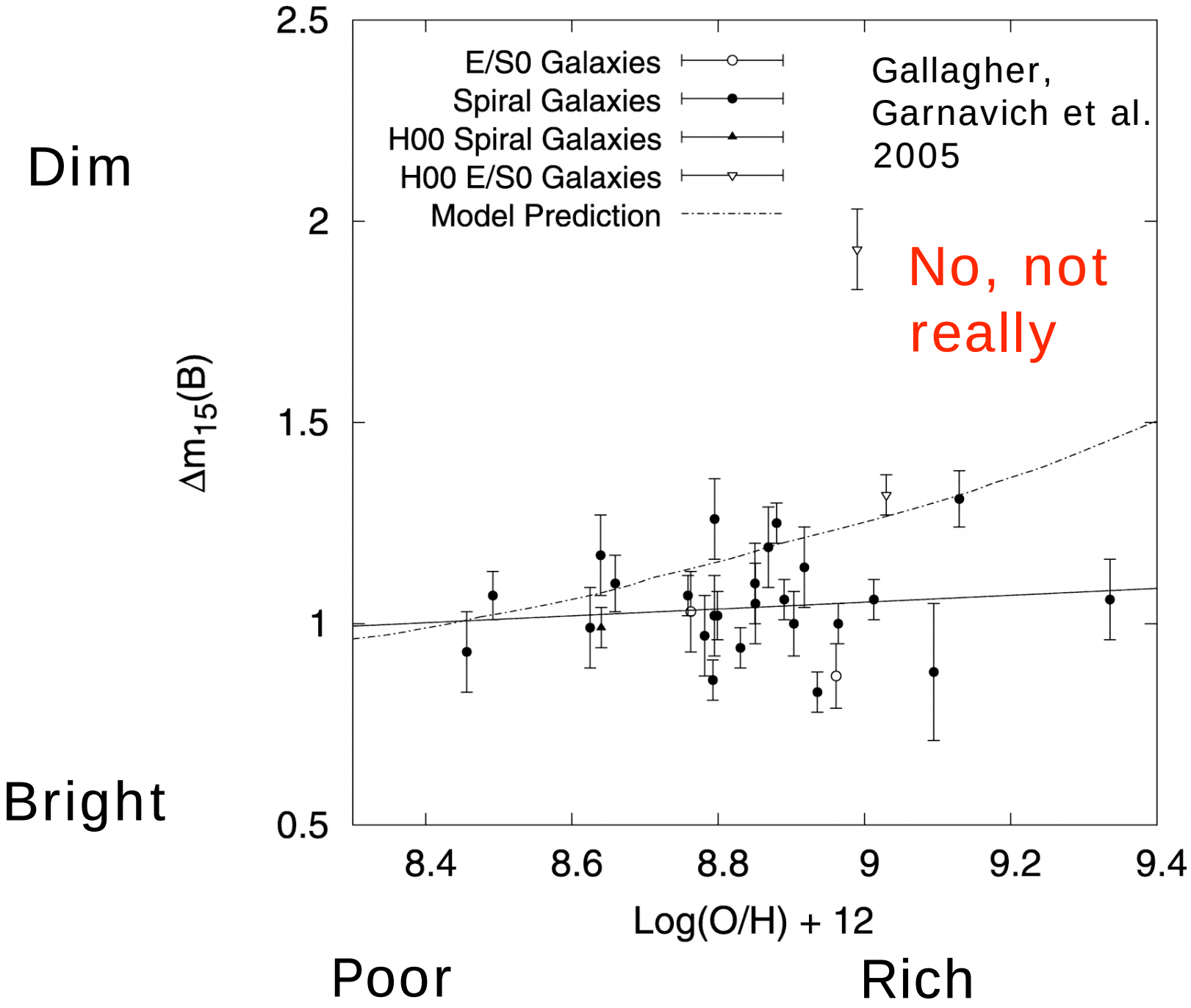
Hicken et al. (2007)

# Chemistry?

Look at galaxy chemistry-- do the SN Ia show the effect predicted?

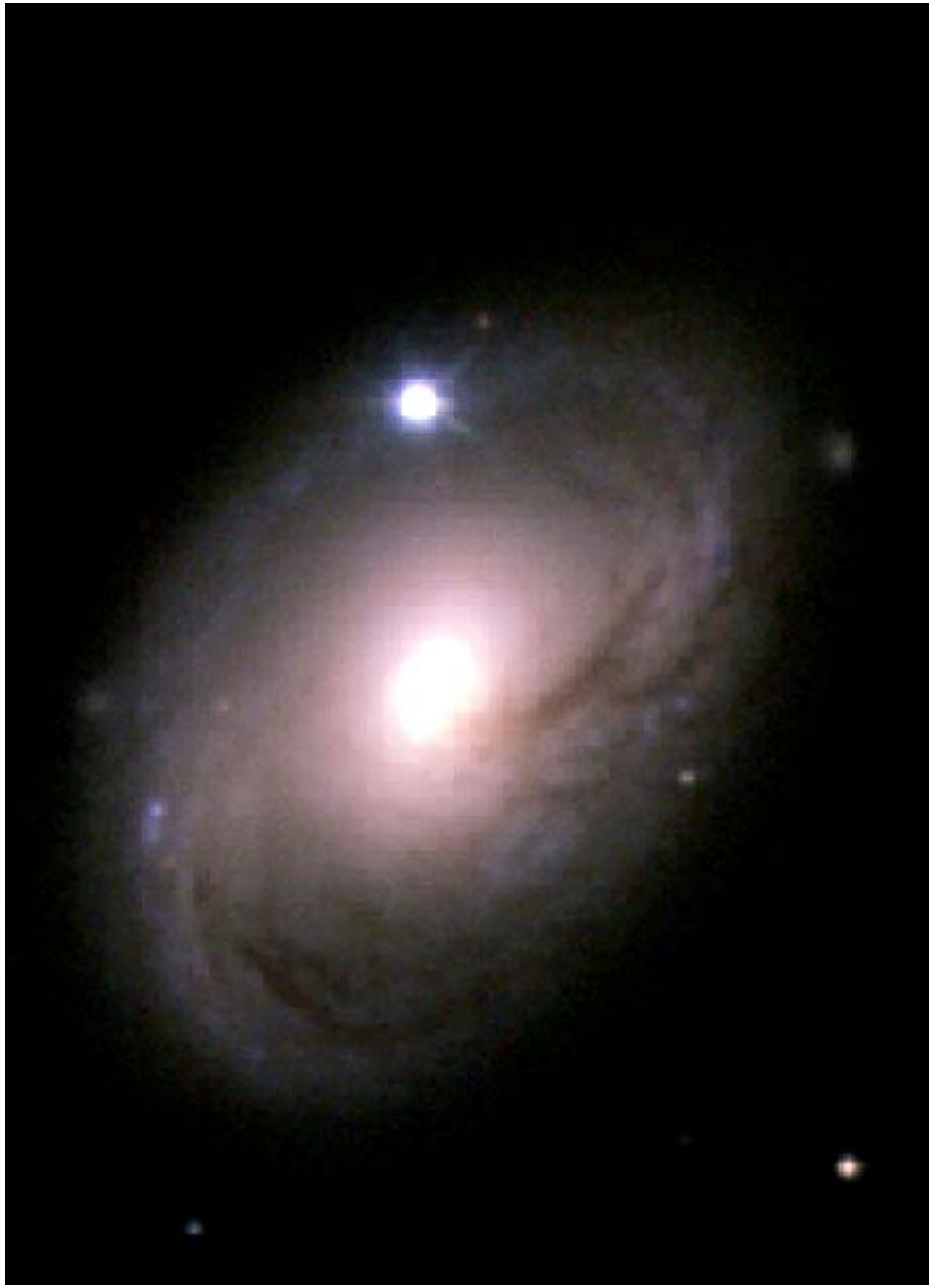
high metallicity => low luminosity?




Dim
Bright
2.5
2
1.5
1
0.5
$\Delta m_{15}(B)$
E/S0 Galaxies
Spiral Galaxies
H00 Spiral Galaxies
H00 E/S0 Galaxies
Model Prediction
Gallagher, Garnavich et al. 2005
No, not really
8.4
8.6
8.8
9
9.2
9.4
Log(O/H) + 12
Poor
Rich

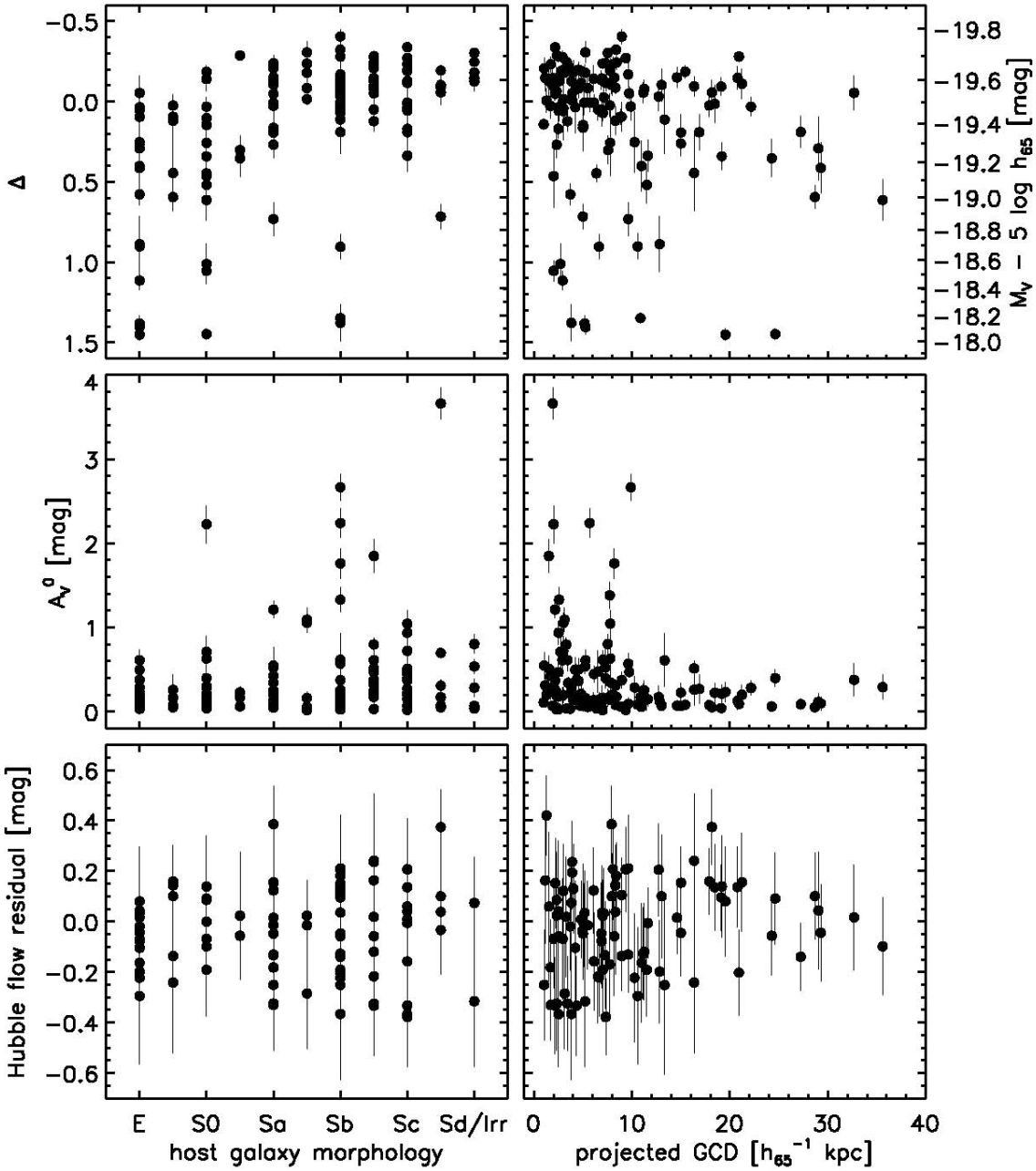
# Age?

Look at galaxy morphology-- SN Ia found in sprials (both old and young stars) and in ellipticals (where most of the stars are old)



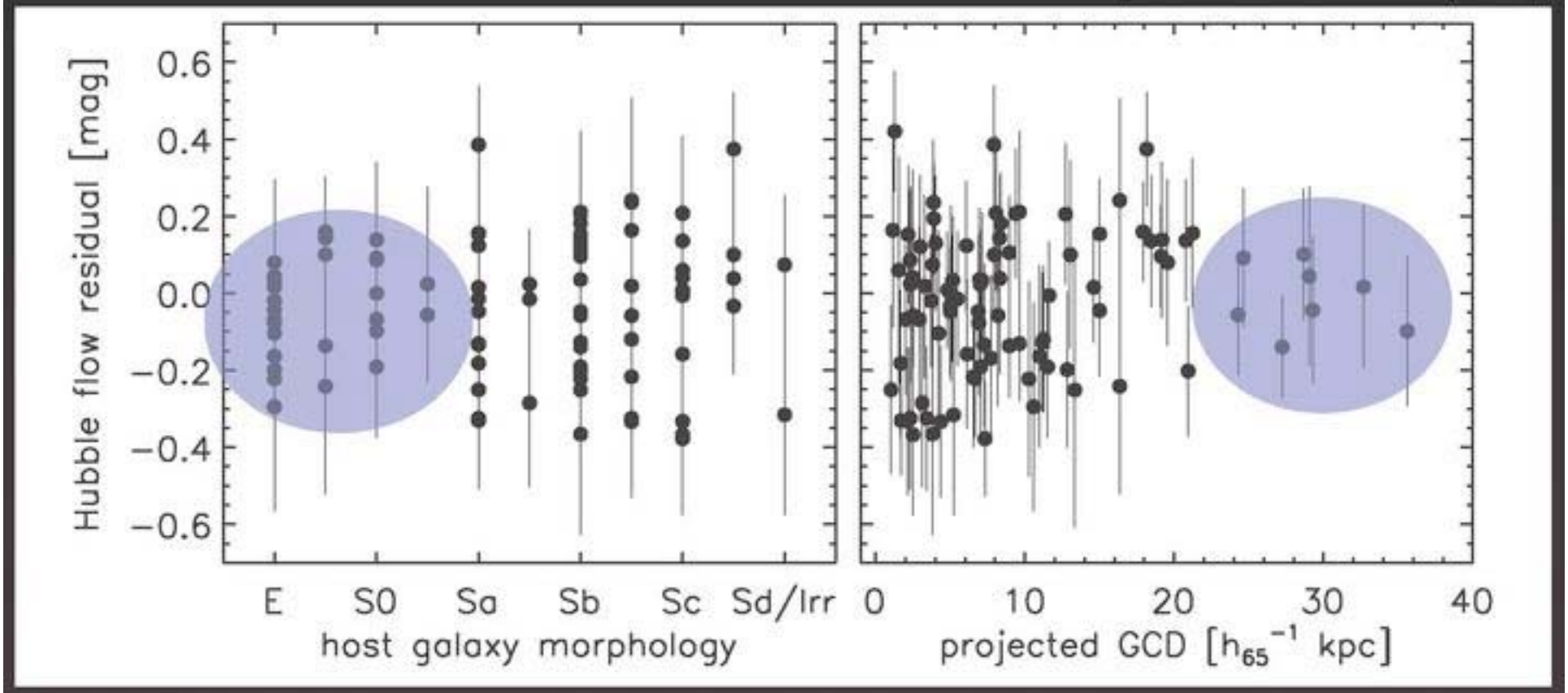
There are **real** systematic differences between the supernovae in spirals and ellipticals

At the present level of precision, MLCS2K2 copes well with these effects



# Sharpening our precision tools

Jha, Riess, & Kirshner (2006)



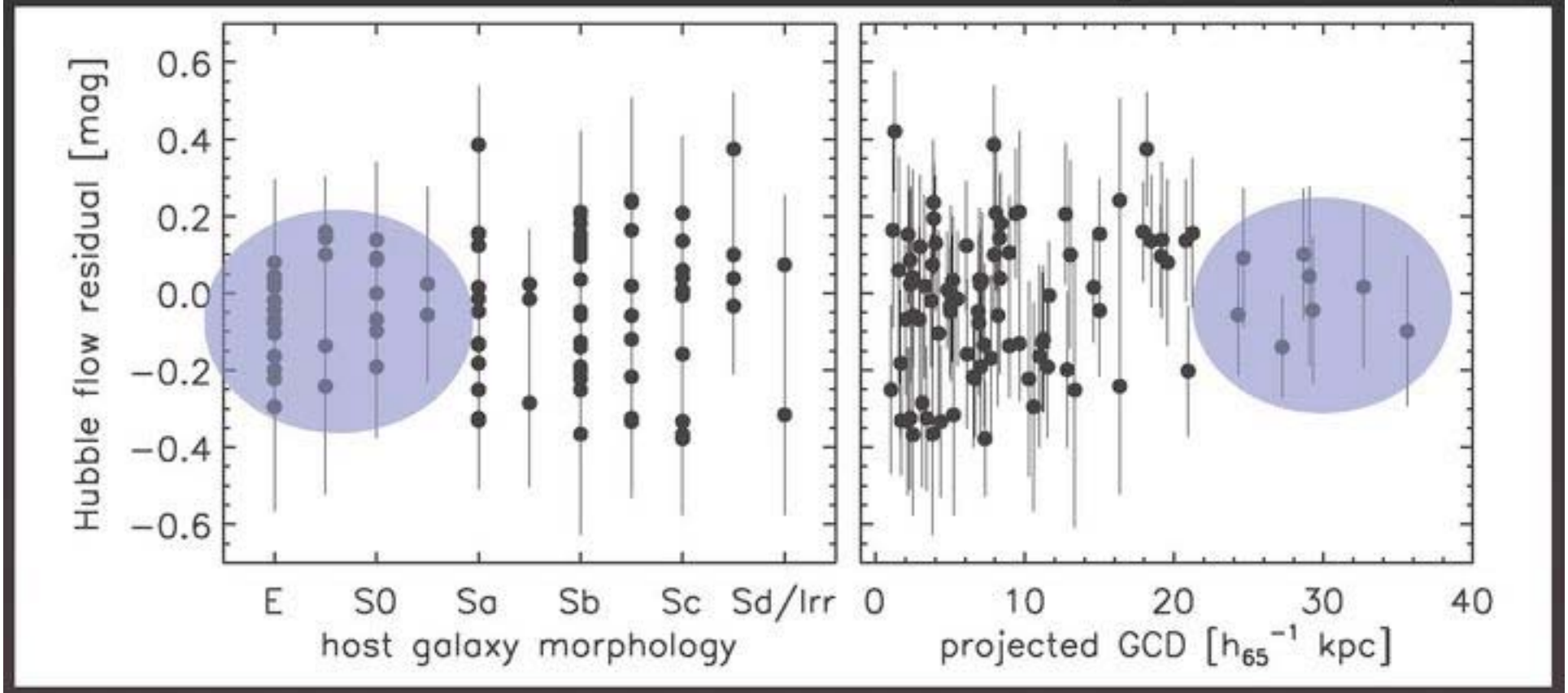

*Are we battling the fog of dust?*

Intrinsic dispersion of subsamples could be much lower: 3% distances?

→ *we need more nearby objects!*

# Sharpening our precision tools

Jha, Riess, & Kirshner (2006)

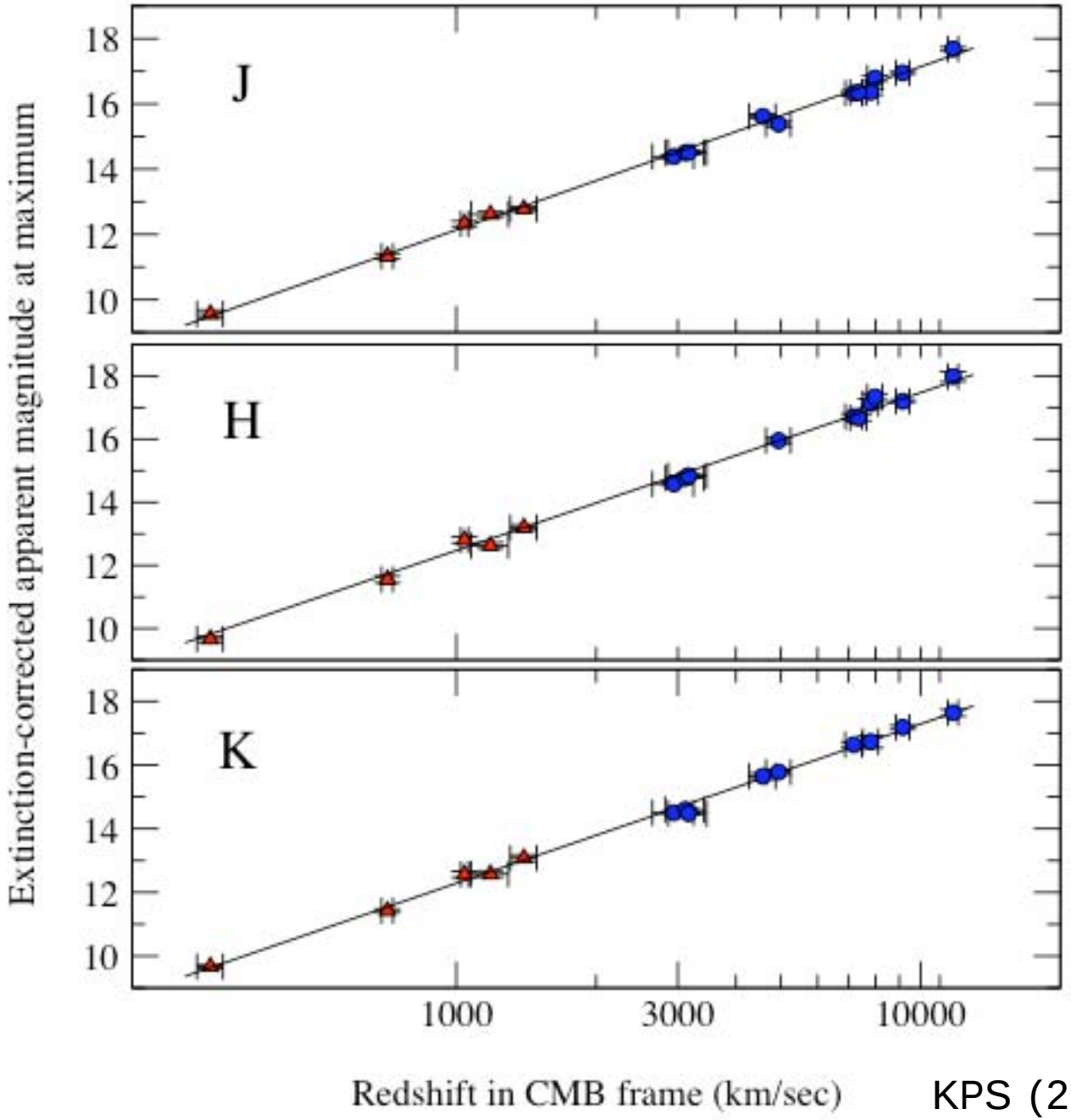



*Are we battling the fog of dust?*

Intrinsic dispersion of subsamples could be much lower: 3% distances?

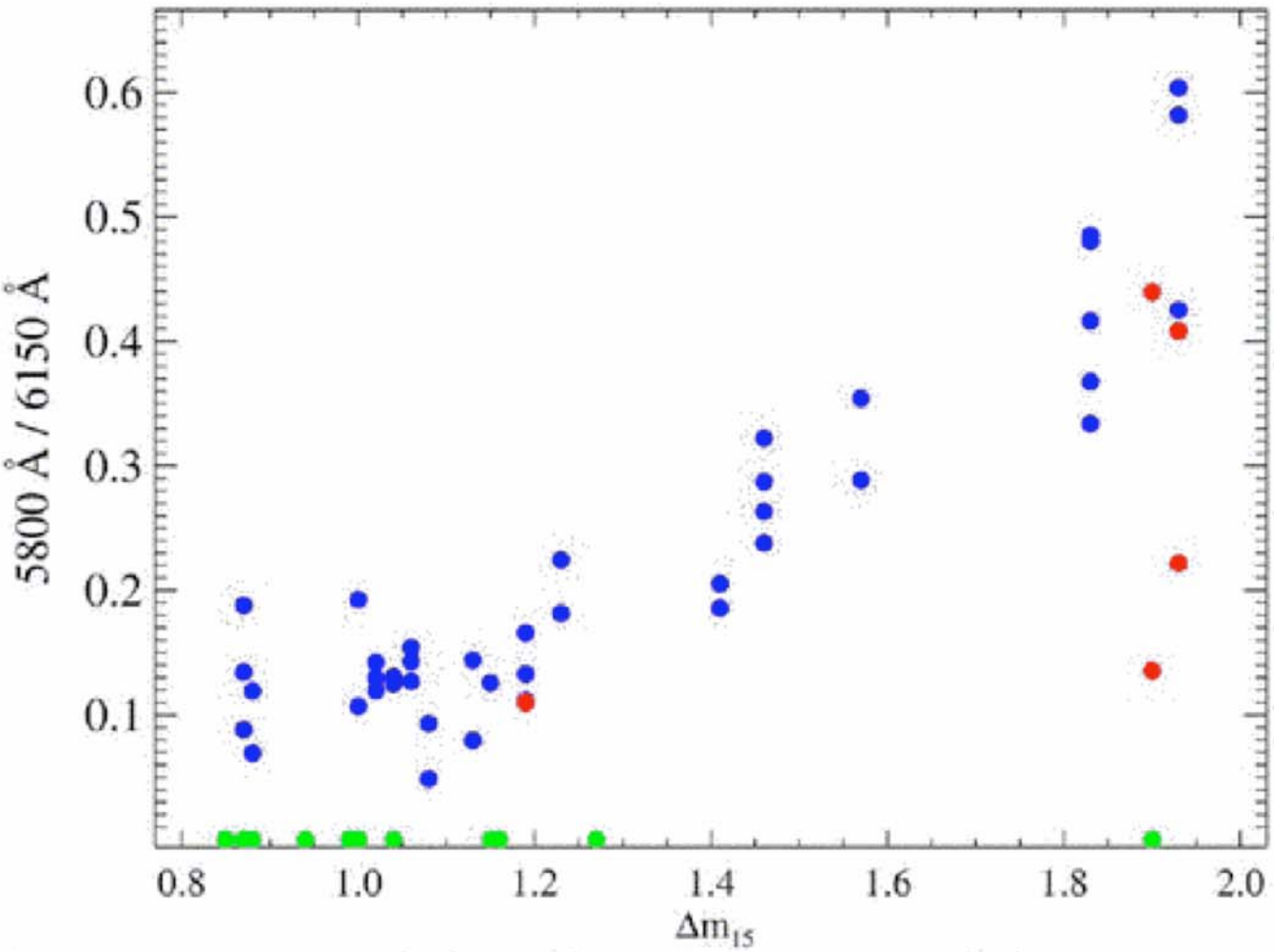
→ *we need more nearby objects!*

# Infrared Hubble Diagrams

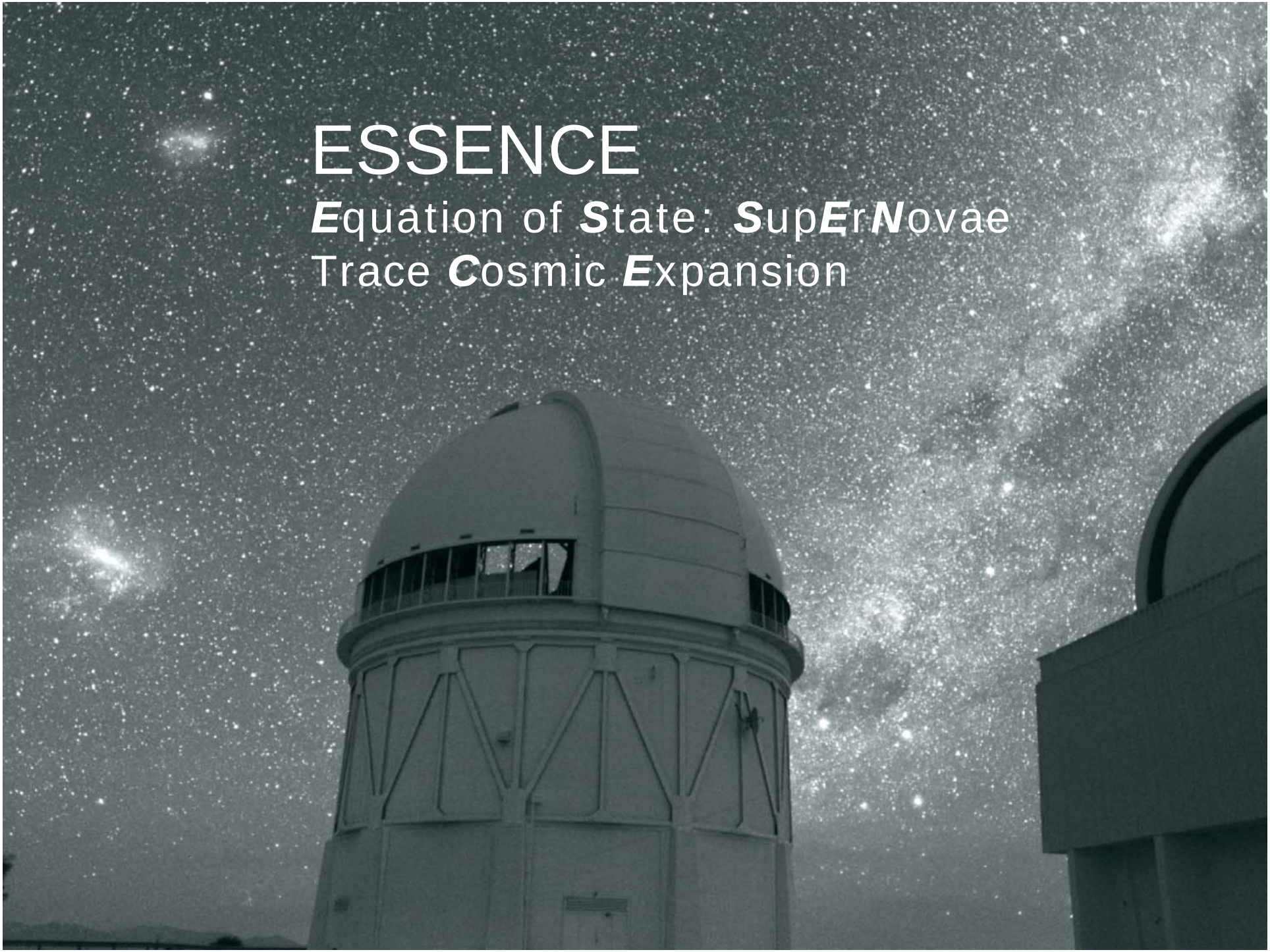



KPS (2004)

# Strength of 5800Å Feature




cf. Nugent et al. 1995, Garnavich et al. 2004, Bongard et al. 2006


ESSENCE
*E*quation of *S*tate: *S*up*E*r*N*ovae
Trace *C*osmic *E*xpansion

# The ESSENCE Survey

- Determine the properties of dark energy-- $\Lambda$ or not?
- 6-year project on CTIO 4m telescope in Chile; 12 sq. deg.
- Half of the night, every 2nd night, for 3 months!
- Same-night detection of supernovae
- Goal is 200 SNeIa, $0.2<z<0.8$
- Data and SNeIa public real-time

# ESSENCE Survey Team

| | | | |
|---|---|---|---|
| Claudio Aguilera | CTIO/NOAO | **Bruno Leibundgut** | ESO |
| Andy Becker | Univ. of Washington | Weidong Li | UC Berkeley |
| **Stéphane Blondin** | Harvard/CfA | **Thomas Matheson** | NOAO |
| **Peter Challis** | Harvard/CfA | Gajus Miknaitis | Fermilab |
| Ryan Chornock | UC Berkeley | Jose Prieto | OSU |
| Alejandro Clocchiatti | Univ. Católica de Chile | Armin Rest | NOAO/CTIO |
| Ricardo Covarrubias | Univ. of Washington | **Adam Riess** | STScI/JHU |
| Tamara Davis | Dark Cosmology Center | **Brian Schmidt** | ANU/Stromo/SSO |
| Alex Filippenko | UC Berkeley | **Chris Smith** | CTIO/NOAO |
| Arti Garg | Harvard University | Jesper Sollerman | Stockholm Obs. |
| **Peter Garnavich** | Notre Dame University | Jason Spyromilio | ESO |
| **Malcolm Hicken** | Harvard University | Christopher Stubbs | Harvard University |
| **Saurabh Jha** | SLAC/KIPAC | Nicholas Suntzeff | Texas A&M |
| **Robert Kirshner** | Harvard/CfA | John Tonry | Univ. of Hawaii |
| Kevin Krisciunas | Texas A&M | **Michael Wood-Vasey** | Harvard/CfA |

# Thinking about dark energy:

R(t), the cosmic scale factor

- R"~ **-**$(\rho + 3P)$, so you expect **deceleration** when P is negligible or when P is positive.
- But, P does not have to be positive! The cosmological constant has negative P.
- If $P<-1/3\rho$, R" >0-- you get **acceleration!**

# The Equation of State: w

For dark energy

$\rho = R^{-3(1+w)}$; $w = P/\rho$

Regular matter: $w = 0$; $\rho = R^{-3}$

Radiation $w = 1/3$, $\rho = R^{-4}$

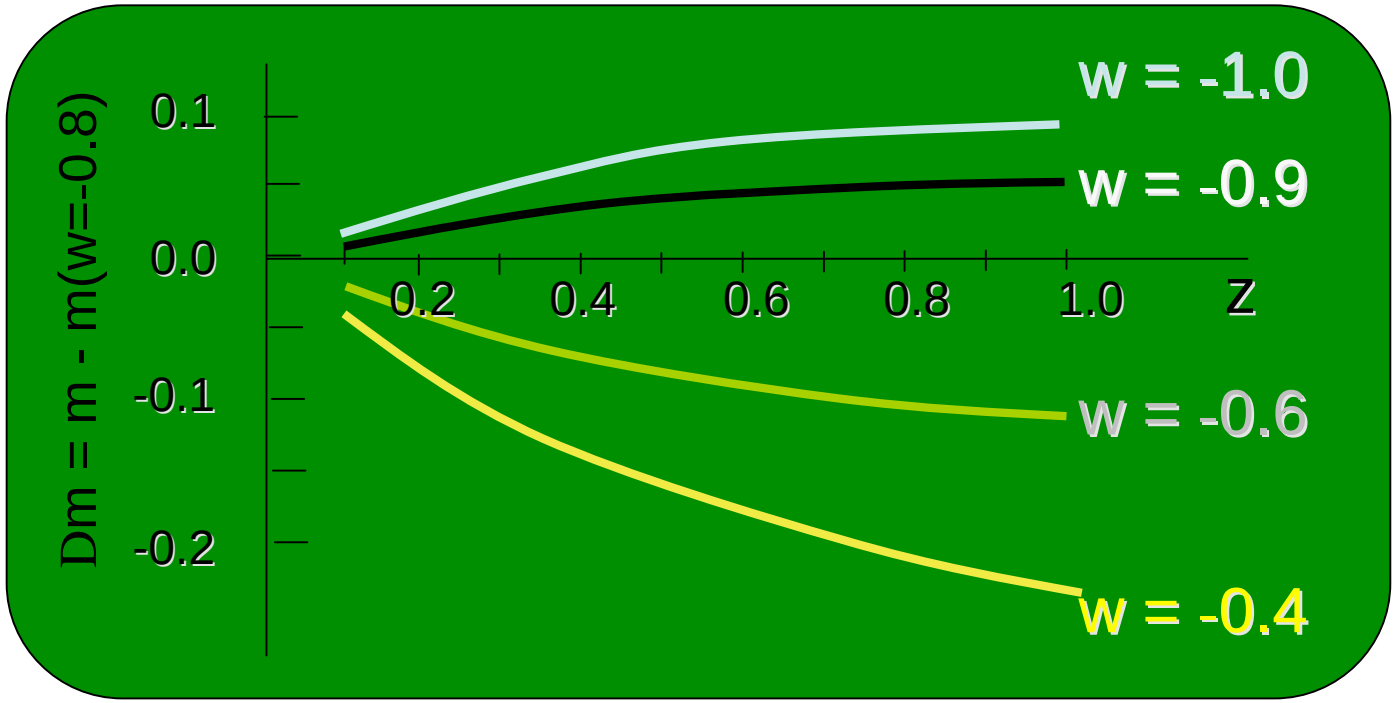
**Cosmological Constant $\rho = R^{0} \Rightarrow w = -1$**

Other possiblities--

w(z) "quintessesnce"

Variations on GR (Dvali et al 2000)

# Measuring the Equation of State

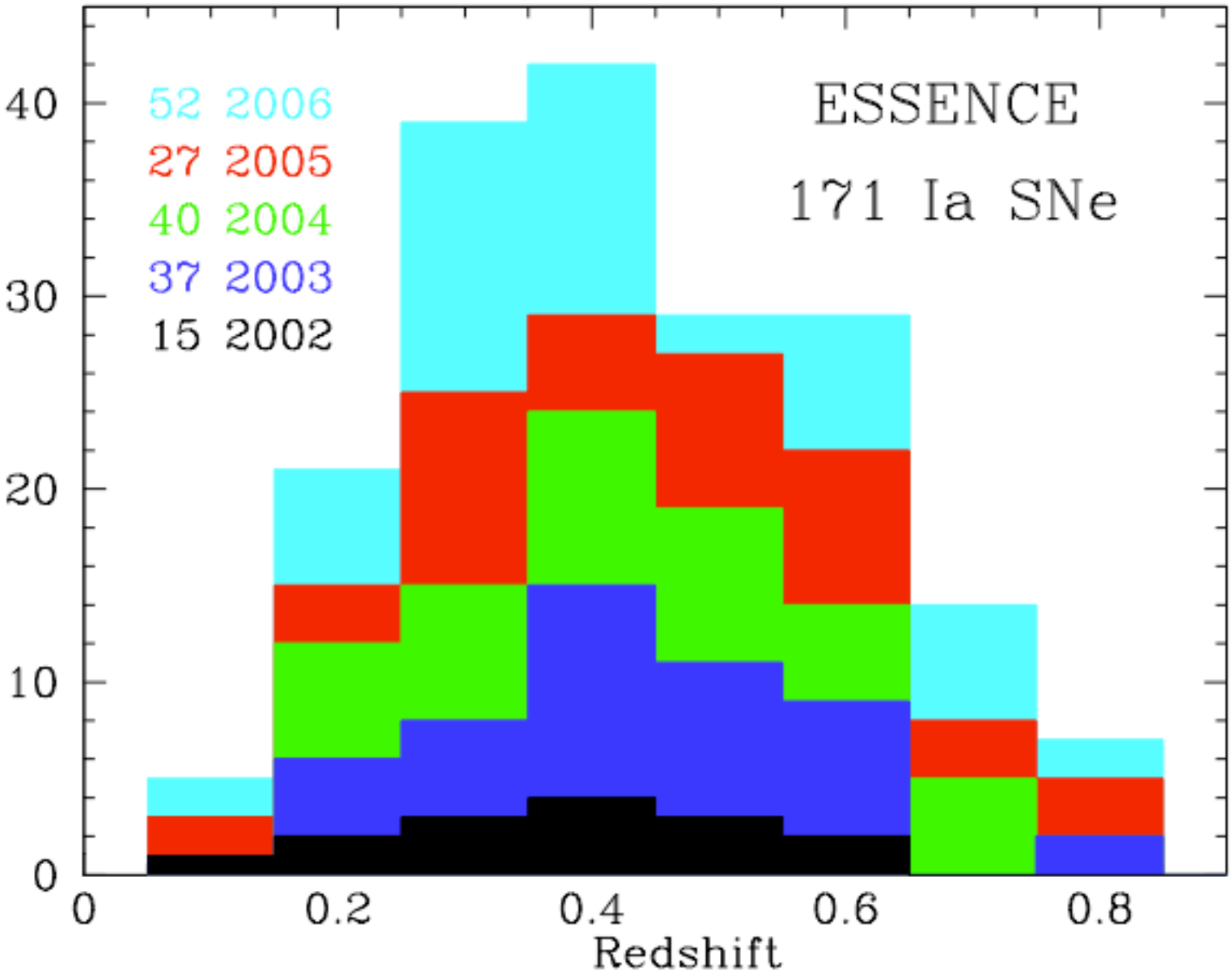



For $\Delta w \sim 0.1$, the difference in apparent SN brightness ~0.05 mag

SN scatter~0.15 mag, $0.15/N^{1/2}$

N~100 => $3\sigma$

Most of the signal by $z \sim 0.4$


52 2006
27 2005
40 2004
37 2003
15 2002
ESSENCE
171 Ia SNe
40
30
20
10
0
0
0.2
0.4
0.6
0.8
Redshift

# ESSENCE Results

Miknatis et al (2007)

**astro-ph/0701043**

Wood-Vesey et al. (2007)

**astro-ph/0701041**

See also SNLS

Astier et al. (2005)

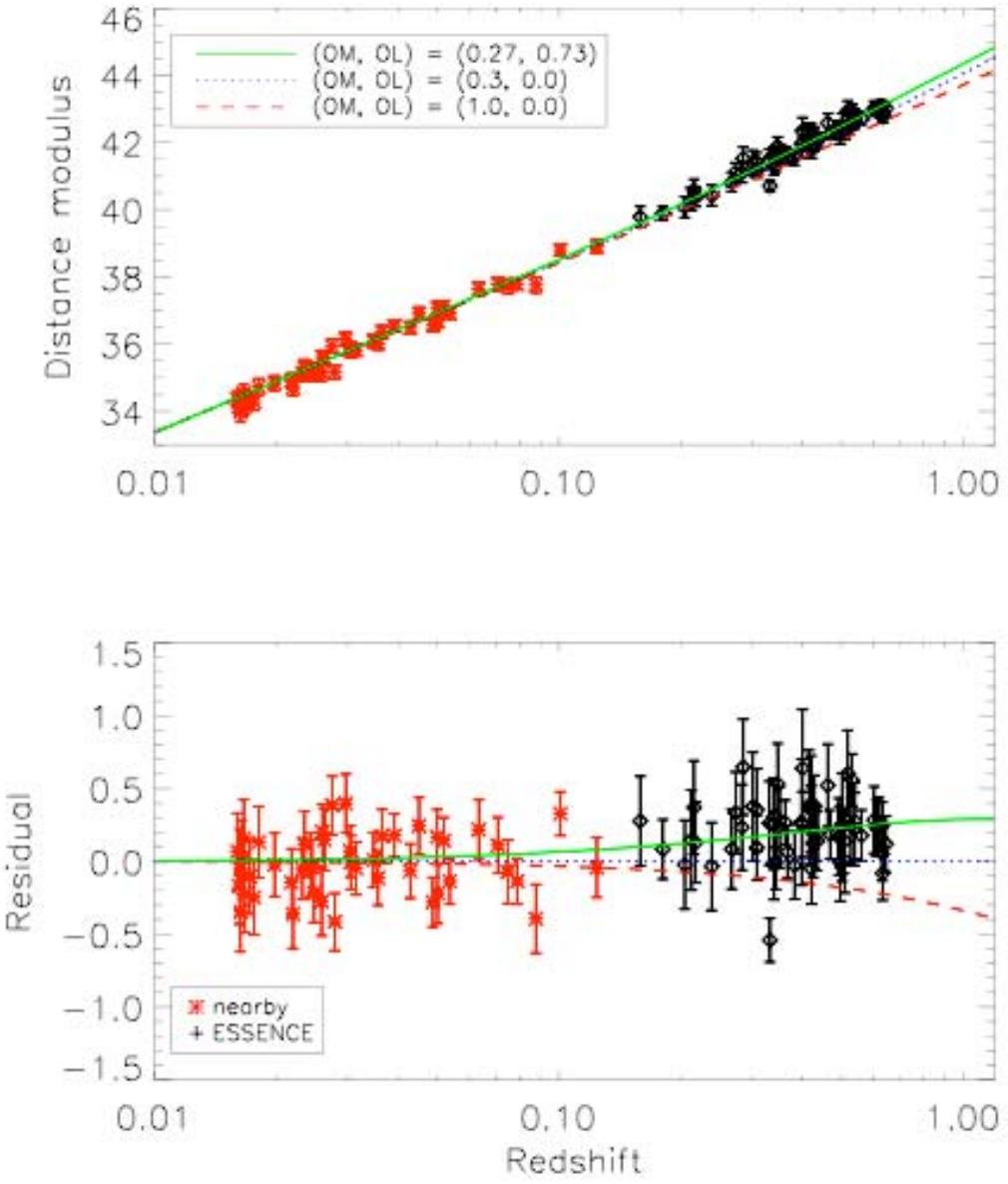



Fig. 8.— Luminosity distance modulus versus redshift for the ESSENCE and nearby SNe Ia for MLCS2k2 with the "glosz" $A_V$ prior. For comparison the overplotted solid line and residuals are for a $(w, \Omega_M, \Omega_\Lambda) = (-1, 0.27, 0.73)$ Universe.