The Hunt for Dark Energy

Peter Garnavich – University of Notre Dame

… as imagination bodies forth

astronomer's

The forms of things unknown, the ~~poet's~~ pen

Turns them to shapes and gives to airy nothing

A local habitation and a name


Sun Apr 17 04:27:35 MST 2005
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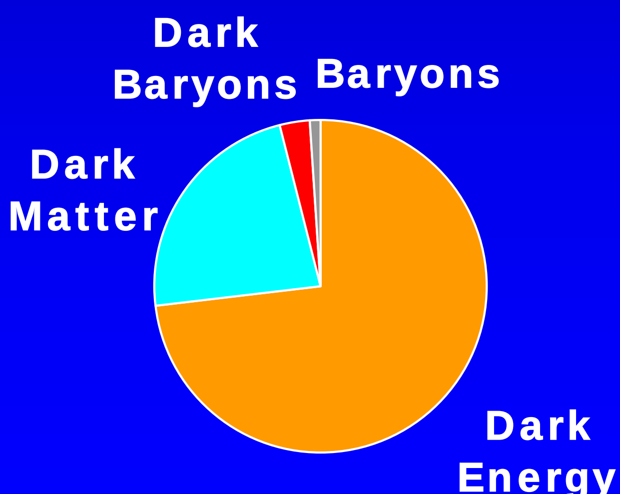
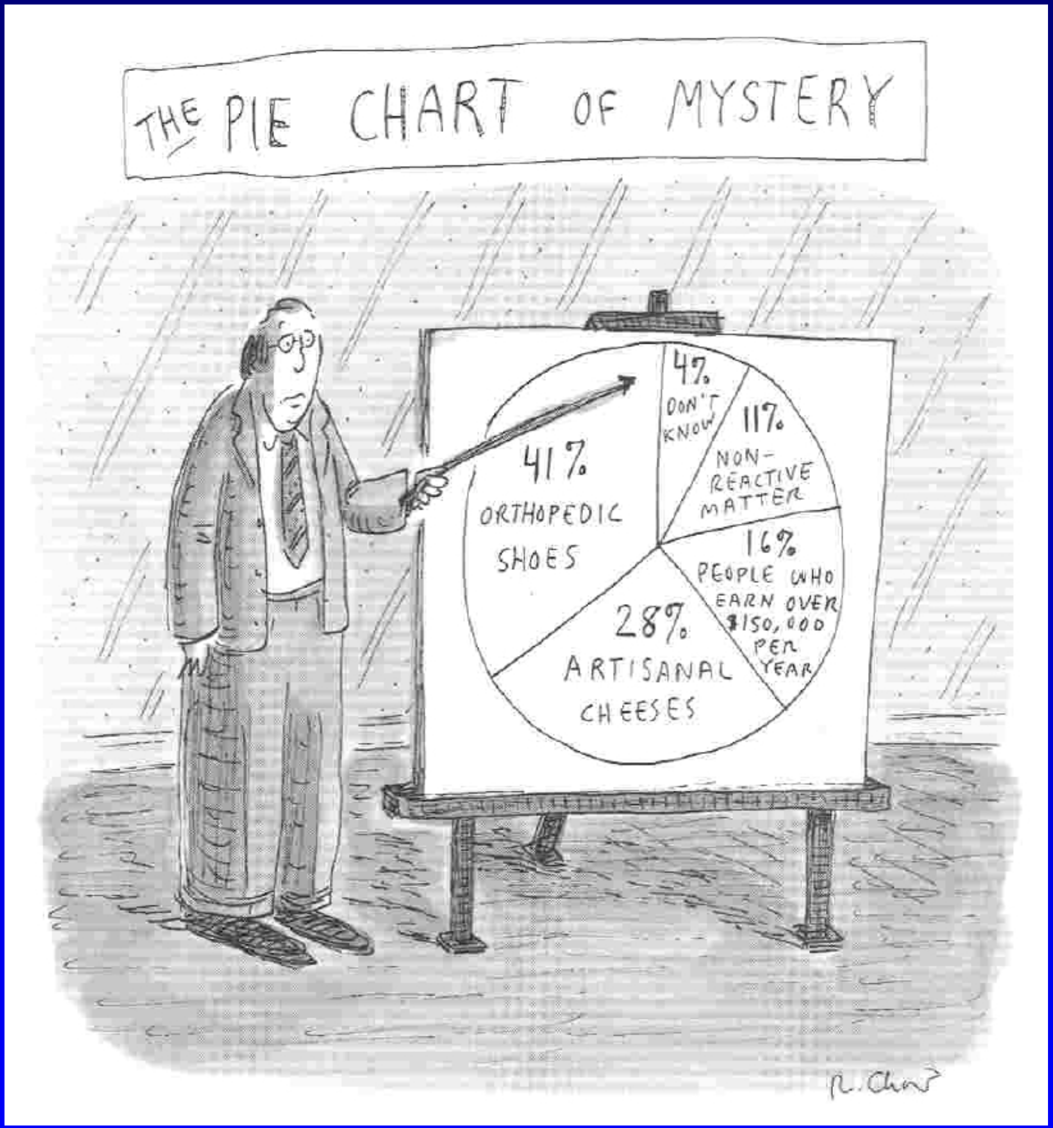
A Very Dark Universe

Ordinary matter makes up a small fraction of the mass/energy.

Dark matter and dark energy dominate.

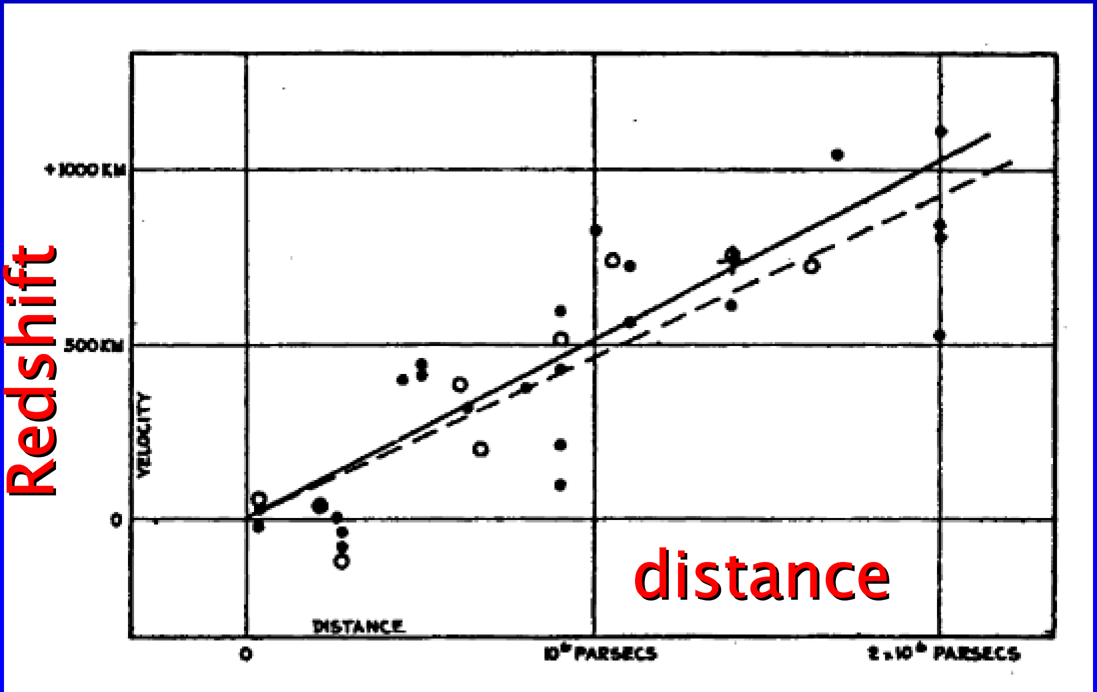




The Universe is Expanding!

1929 Edwin Hubble measured the Doppler shift of nearby galaxies and found a simple relation with their distance –

$$v = cz = H_0 d$$



1+z is the amount the expansion has stretched the initial wavelength of light

past =>

Expansion History ⇔ Matter/Energy Content

Hubble Law: only an approximation that works at small distances from the observer

$$d = cz/H_0$$

- The observed redshift depends on the expansion history of the Universe between emission and detection.
- Expansion history depends on the matter/energy content
- So Distance-redshift relation is a function of matter/energy densities

$$D_L = \frac{c(1+z)}{\mathrm{H}_0} \int_0^z \left[\sum_i \Omega_i (1+\mathrm{z})^{3(1+w)} \right]^{-\frac{1}{2}} \mathrm{dz}$$

Component Density at z=0

Component "Equation of State" => how density varies with redshift.

The Goal: w

Assume the geometry is flat and there are two components:

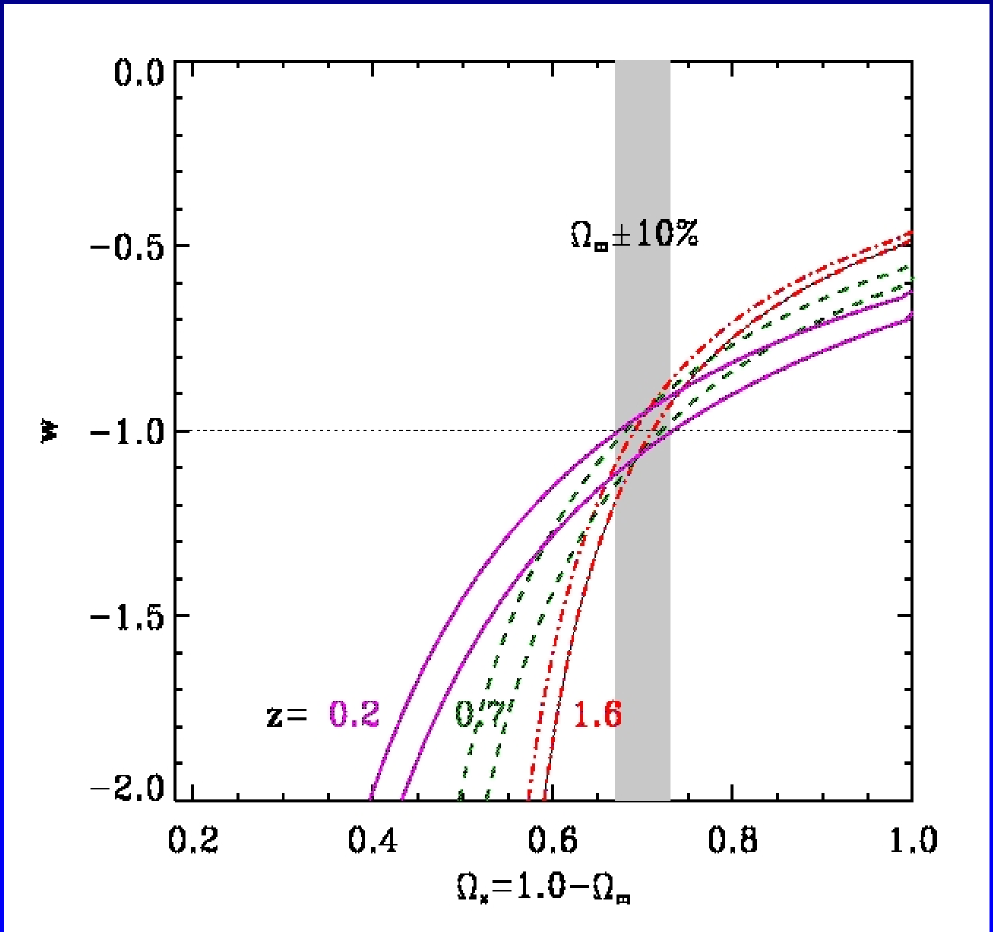
$\Omega_x = 1 - \Omega_m$

w=0 for matter

So there are just two unknowns: Ω_x and w

What is the dark energy?

Don't care. We'll find w and Sean will tell us what the stuff is.



w= −1 => vacuum energy
w= −2/3 => domain walls
w< −1 => phantom energy

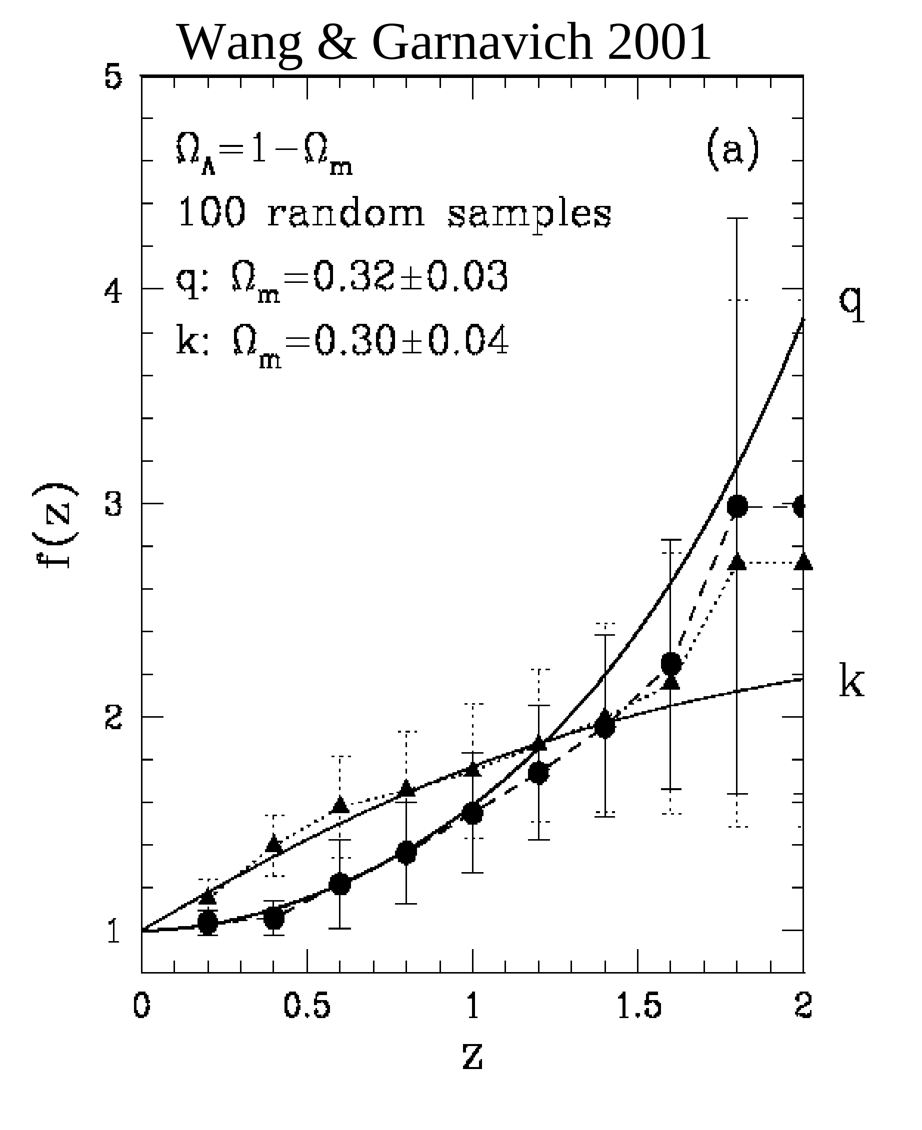
Problem: most general case, w=w(z)

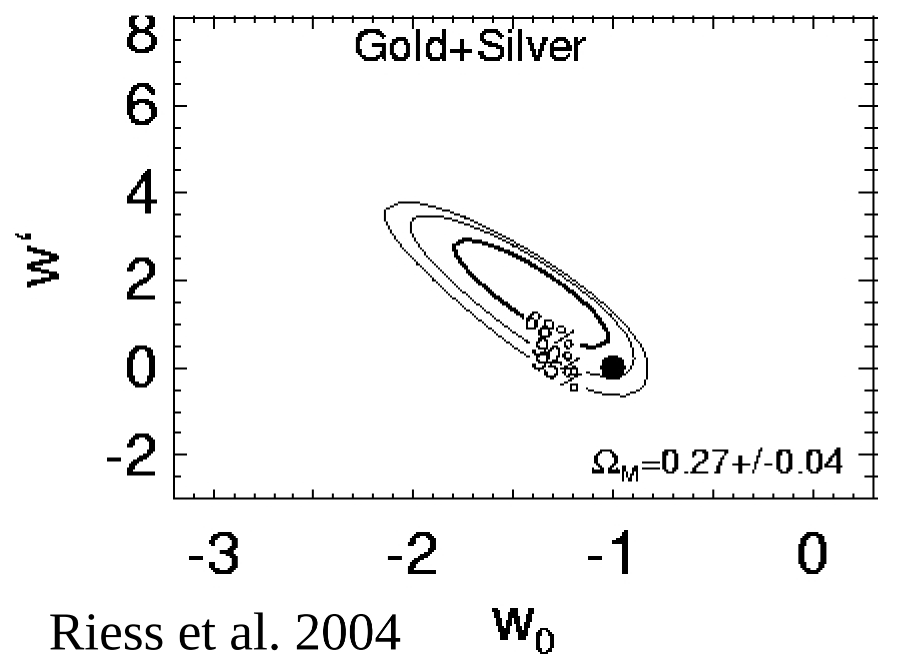
Dynamic Dark Energy

- Many models for dark energy have varying $w=w(z)$
- Really want to reconstruct the dark energy density: $\Omega_x = \Omega_{x0} f(z)$
- Easier is to expand about $z=0$

$$w = w_0 + z w'$$

- Requires distances at $0.2 > z > 2$

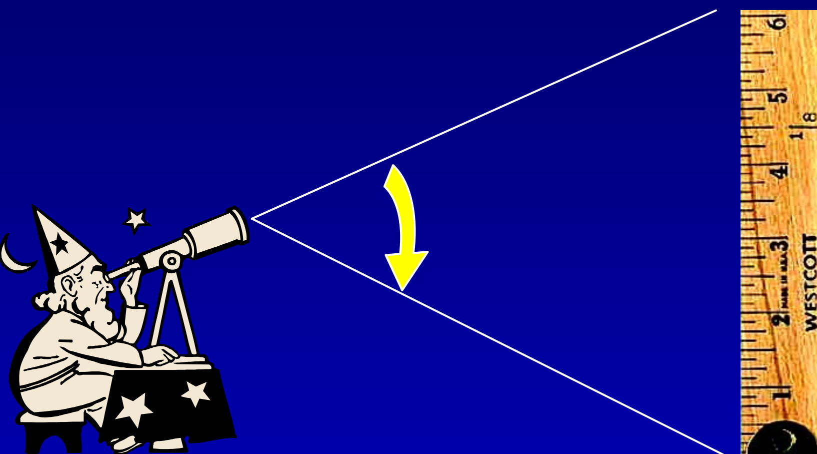


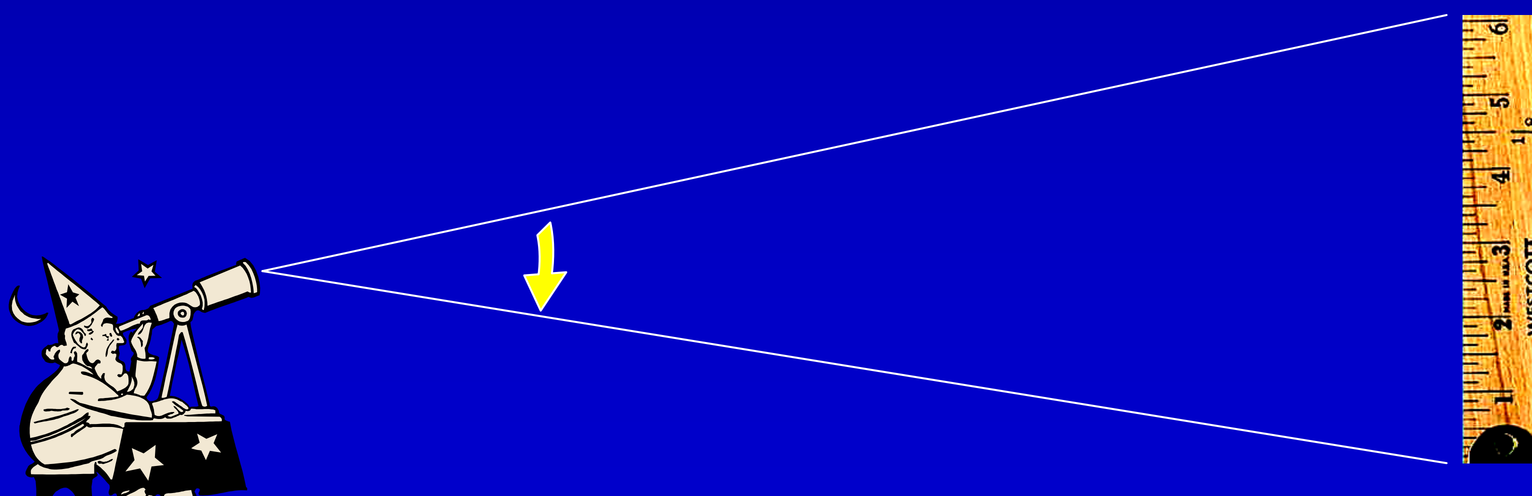


Riess et al. 2004

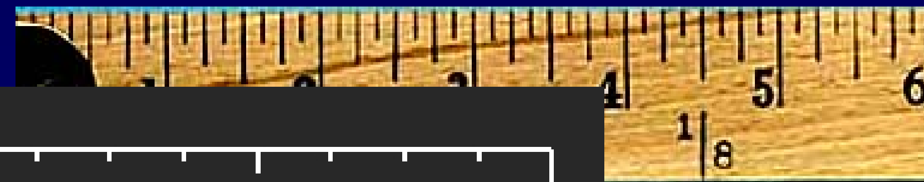
Measuring Distance: Standard Yardsticks

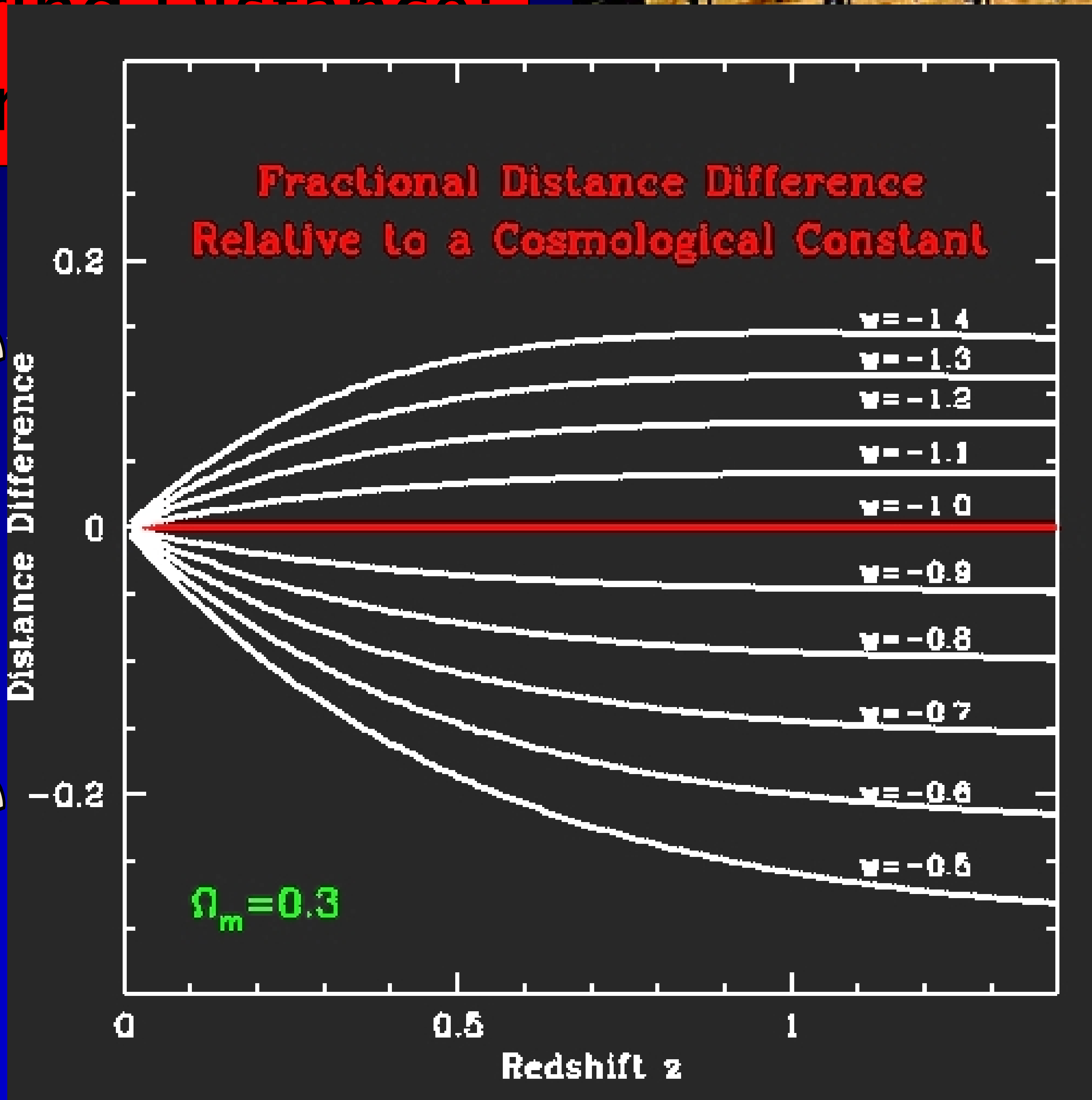
One way to estimate distances: angular size of a standard yardstick





Measuring Distance: Standar





<−1/3
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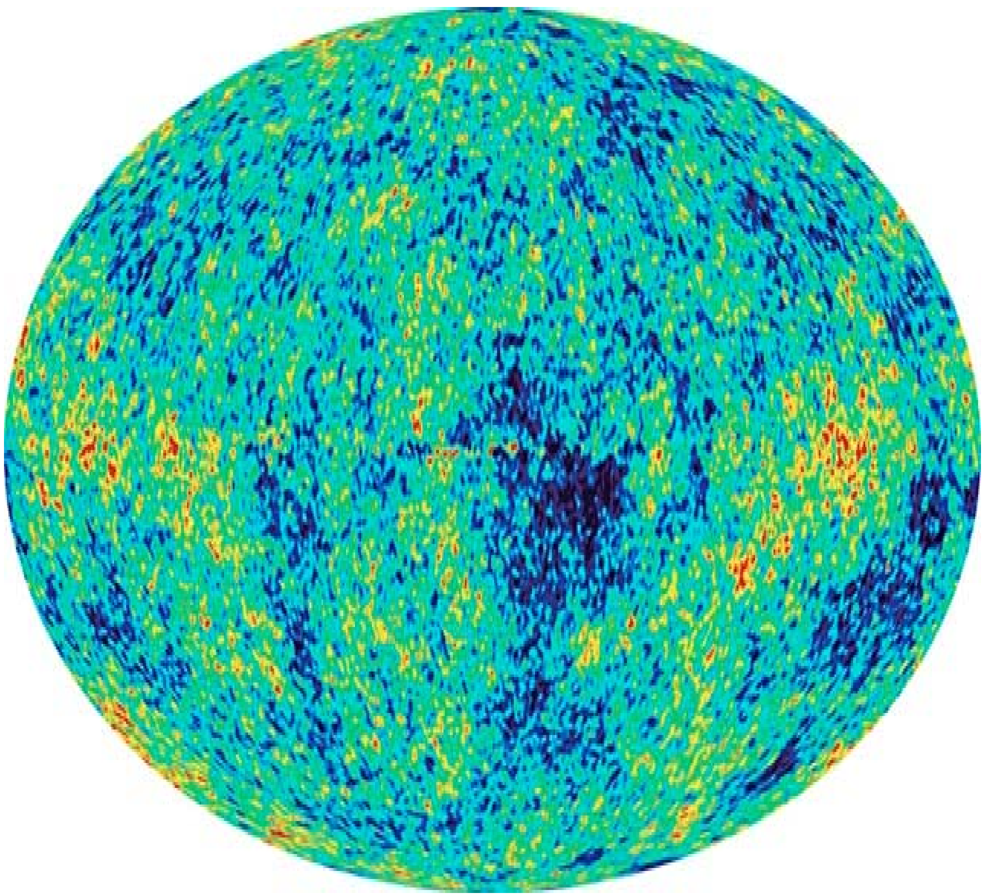
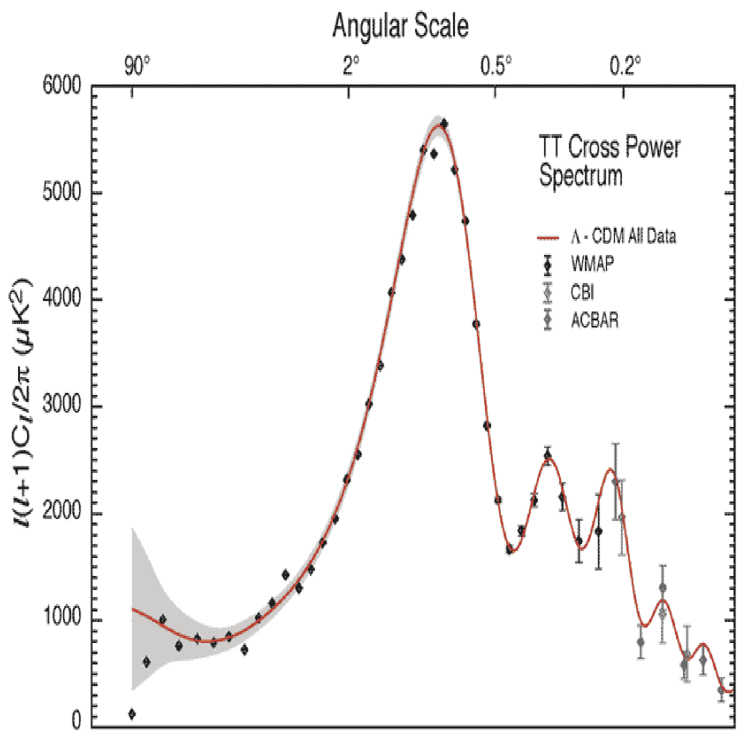
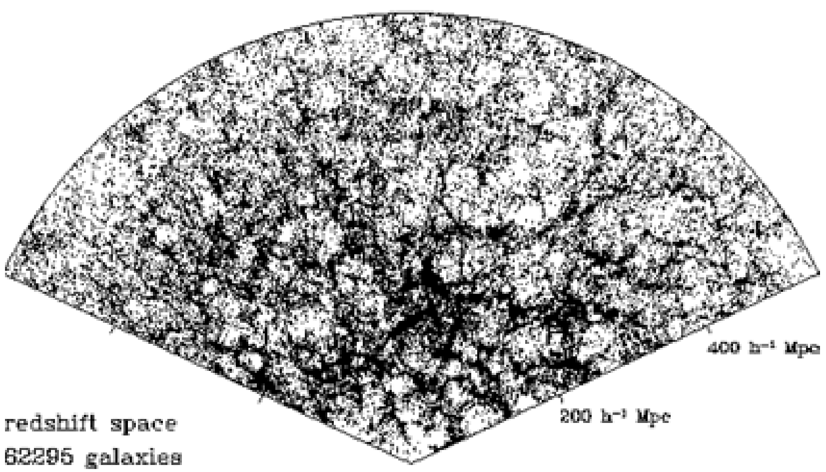
Few Standard Yardsticks

CMB anisotropies define a length scale which is imprinted on the large-scale structure.

“Baryon oscillations” measured as a function of z can constrain w.







Standard Candles

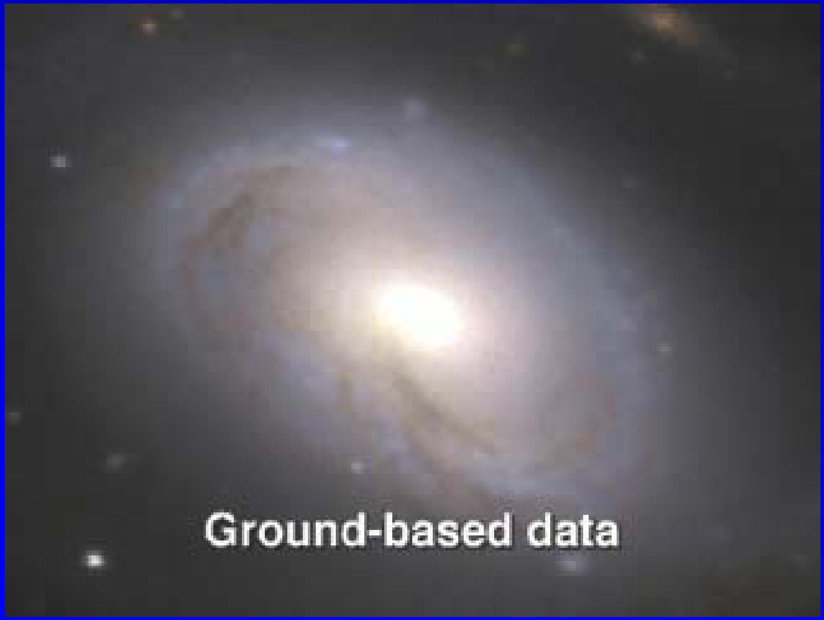
The relative brightness of street lights is a clue to their distance:

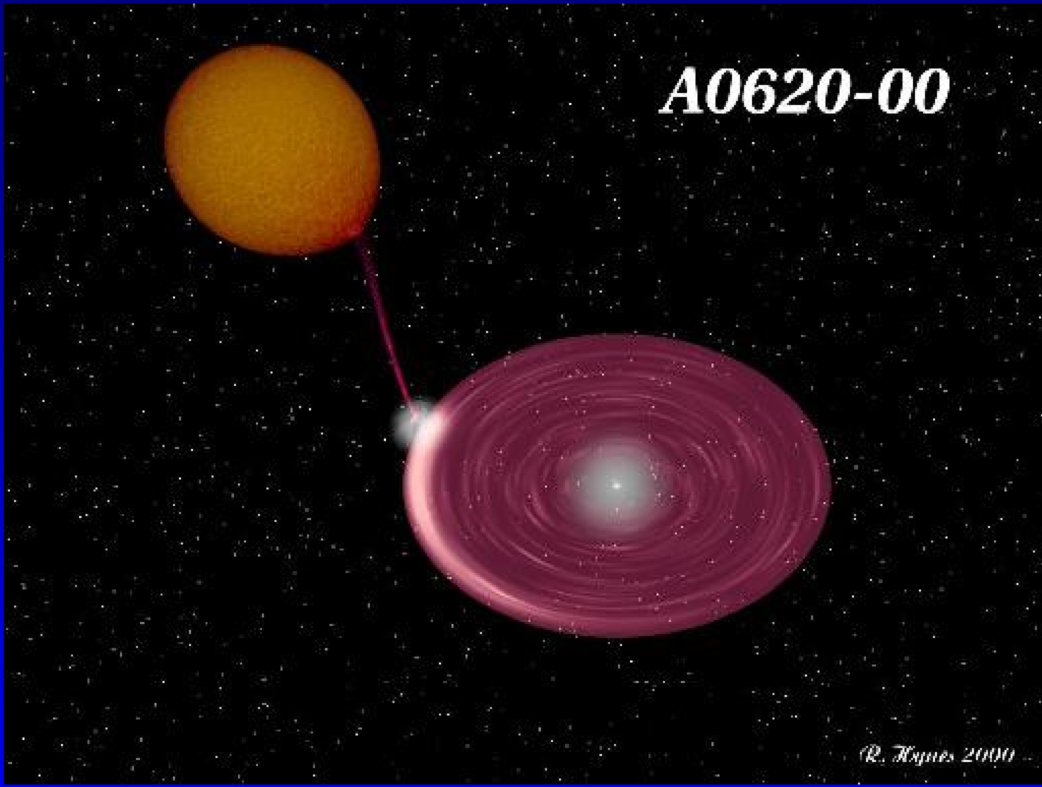
The Inverse-Square law

A light bulb twice as far as an <u>identical</u> bulb will appear 4 times fainter

Supernovae as "Standard Candles"

Type Ia SN: detonation or deflagration of a white dwarf near the 1.4 M_{sun} limit.



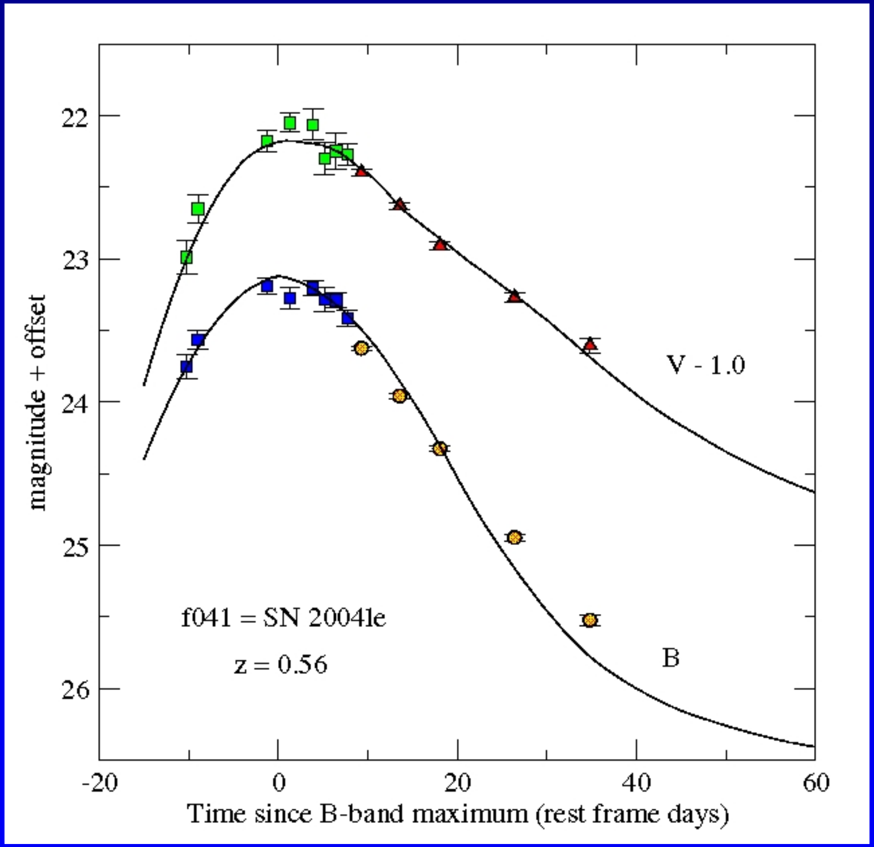


Type Ia events are bright– 10 billion times the Sun

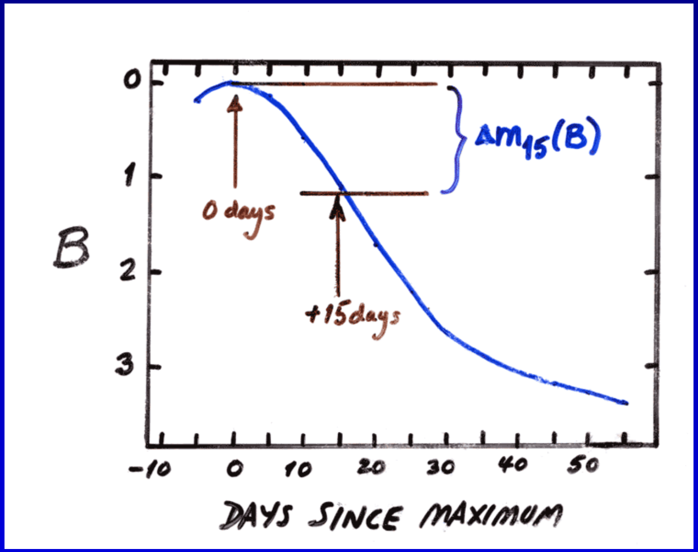
But are they standard?

Type Ia Supernovae – Not Standard Candles

Brightness correlated with light curve decline rate

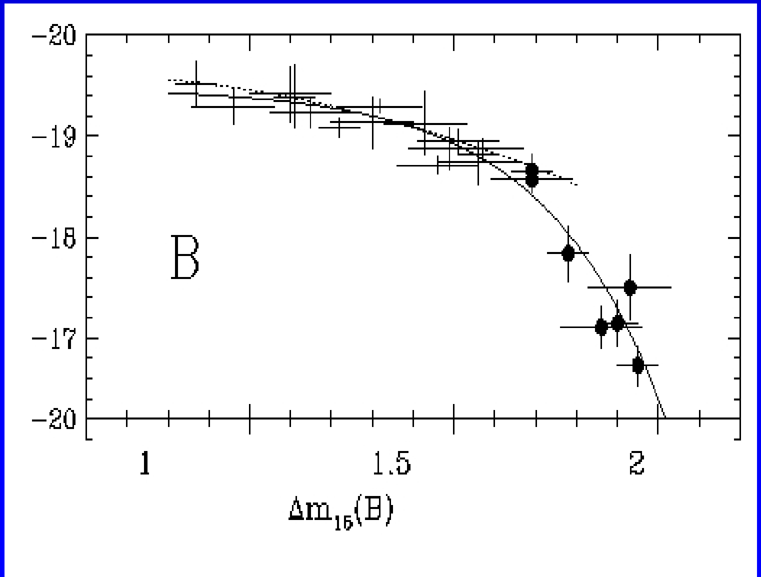


Krisciunas et al (2005)



Phillips 1993

Log Brightness



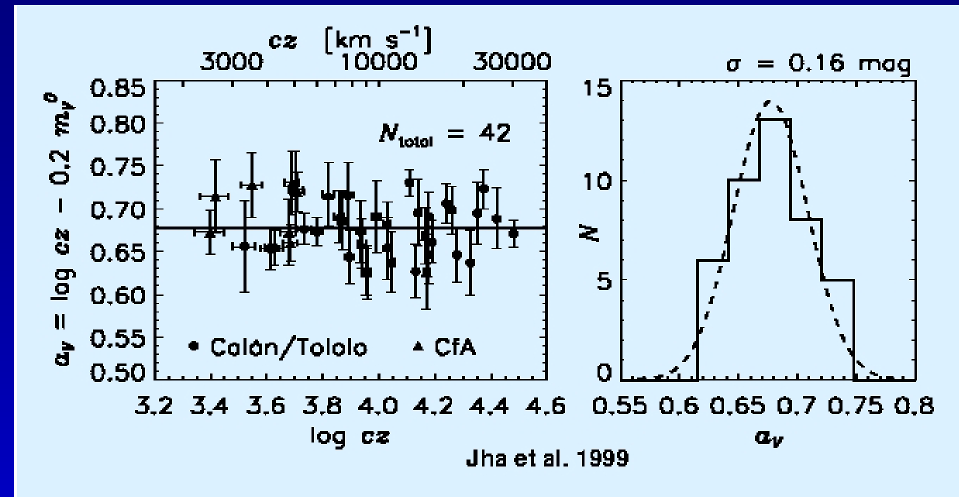
“It’s empirical”

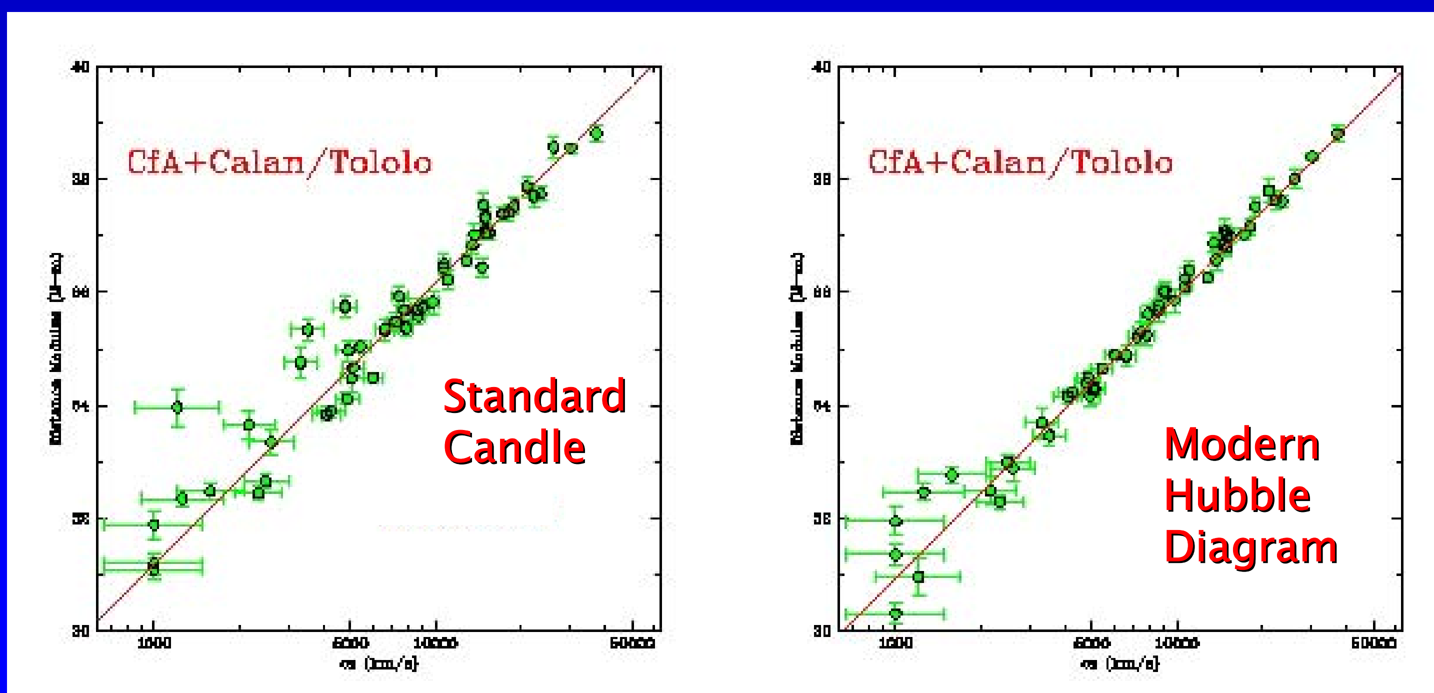
Supernovae are Calibrate-able Distance Indicators

Mass of ^{56}Ni produced =>peak luminosity and decline rate.

Colors are repeatable so dust absorption can be estimated

Correctable to 0.15 mag scatter!



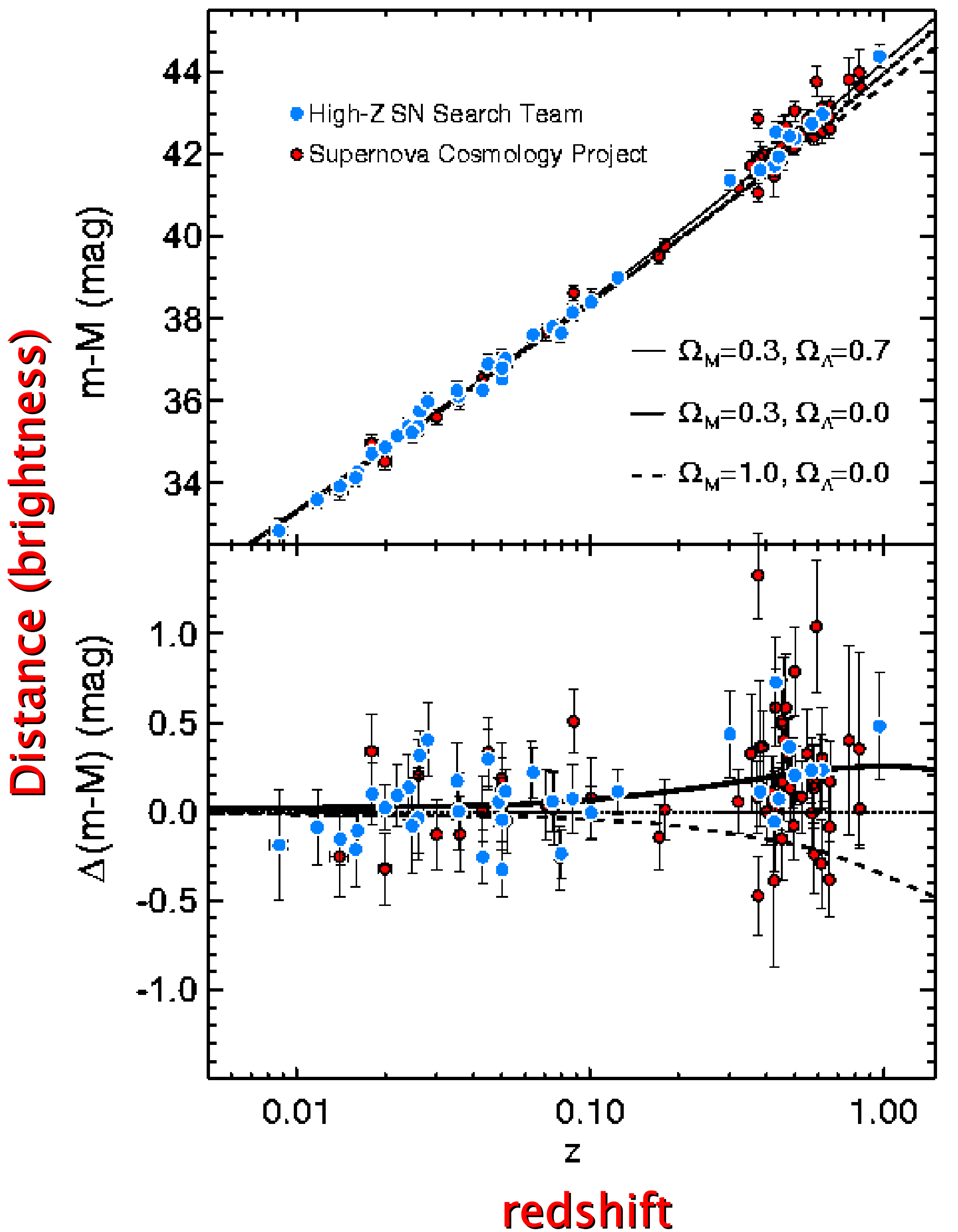


Type Ia Supernova: First to Map Expansion History

1998: Two teams searched for SN Ia ~ 5 billion light years away

Found them fainter than expected from deceleration => acceleration!

Distance error = 0.15/sqrt(N) if no systematic error



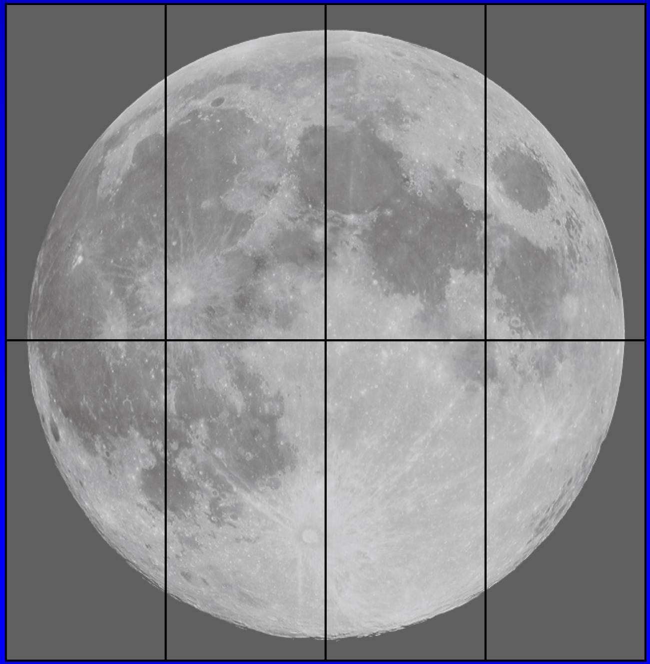
ESSENCE – aka the “w” project

Equation of State: SupErNova trace Cosmic Expansion

Aspen 2002

Essence of ESSENCE

- CTIO 4m
- Mosaic CCD: ½ deg per image
- R=23.5 in 200sec (+I-band)
- SNIa out to z~0.75
- 7 square deg / full night
- Read out ~100 sec => sucks



8K x 8K
MOSAIC
CCD Camera

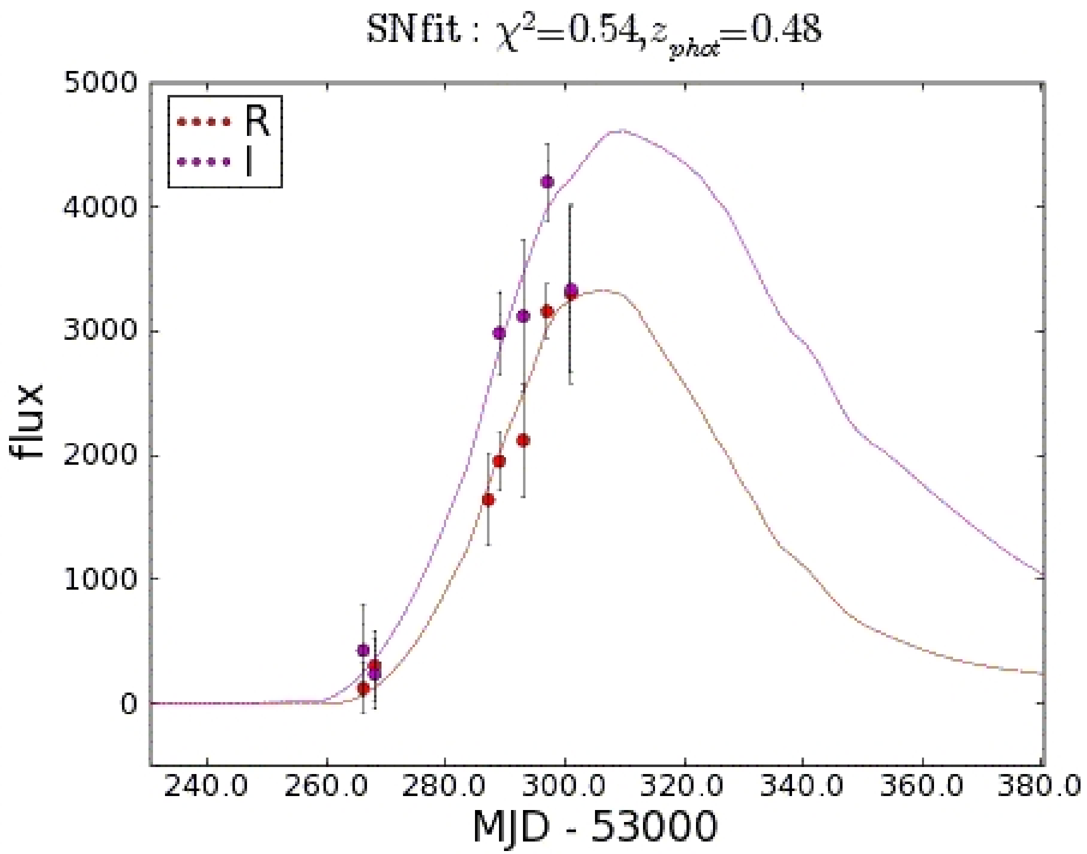
CTIO 4m

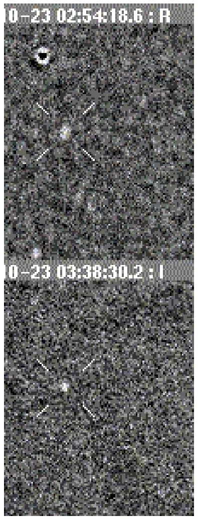
Event Info

ID	
RAaverage	
DECaverage	
Ninside	
R mag (53301.121050)	
R avg offset	
I mag (53301.151740)	
I avg offset	
R−I:	

Spectroscopy Info

Spec. status	
Spec. prio	
Spec. Tel	
Spec. Date	
Spec. Type	
Spec. Comment	



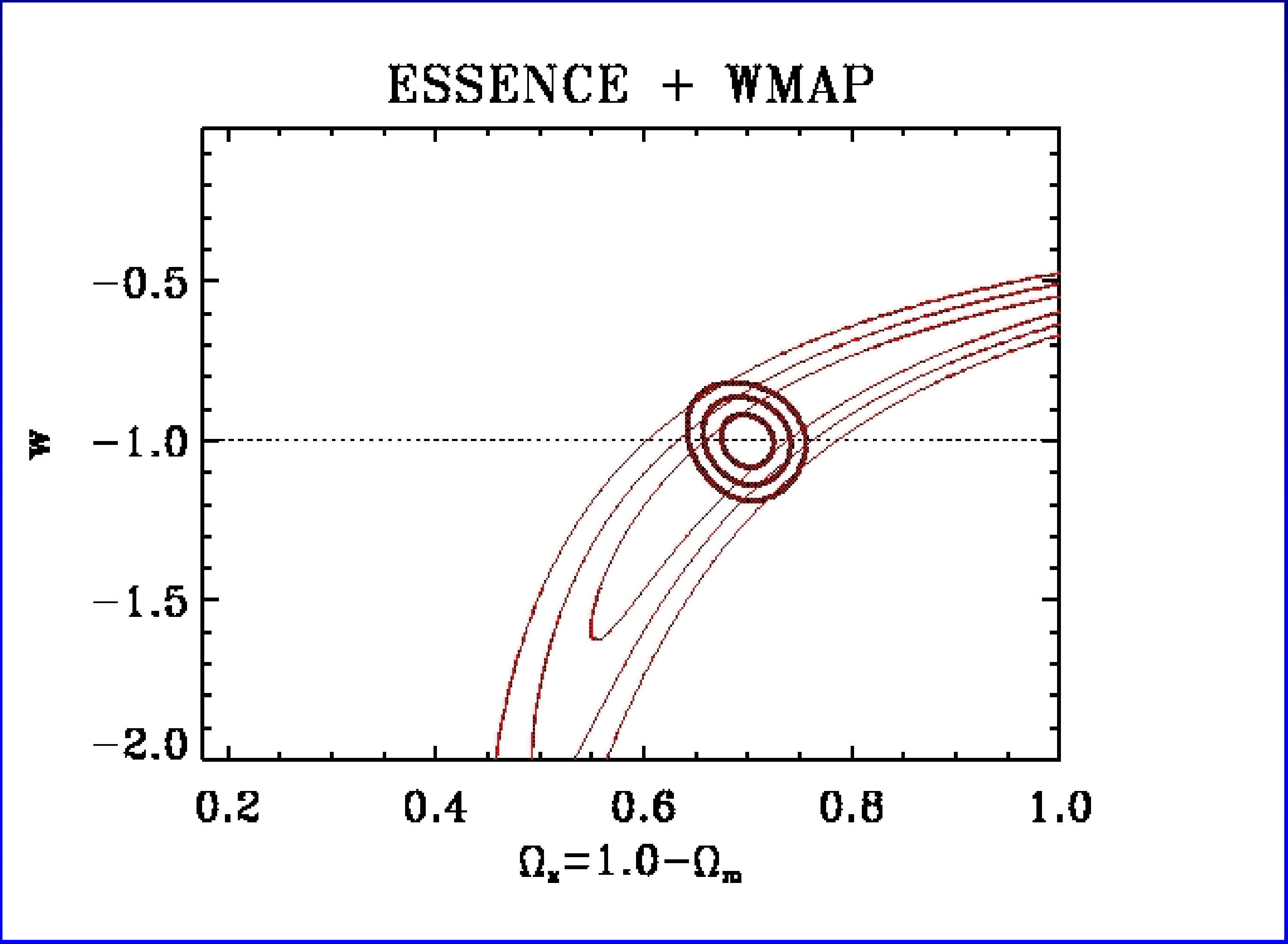


Fit Parameters

CHI2	0.54
TMAX	53305.48
RMAX	22.63
IMAX	22.19
ZPHOT	0.48
DILATION	2.19

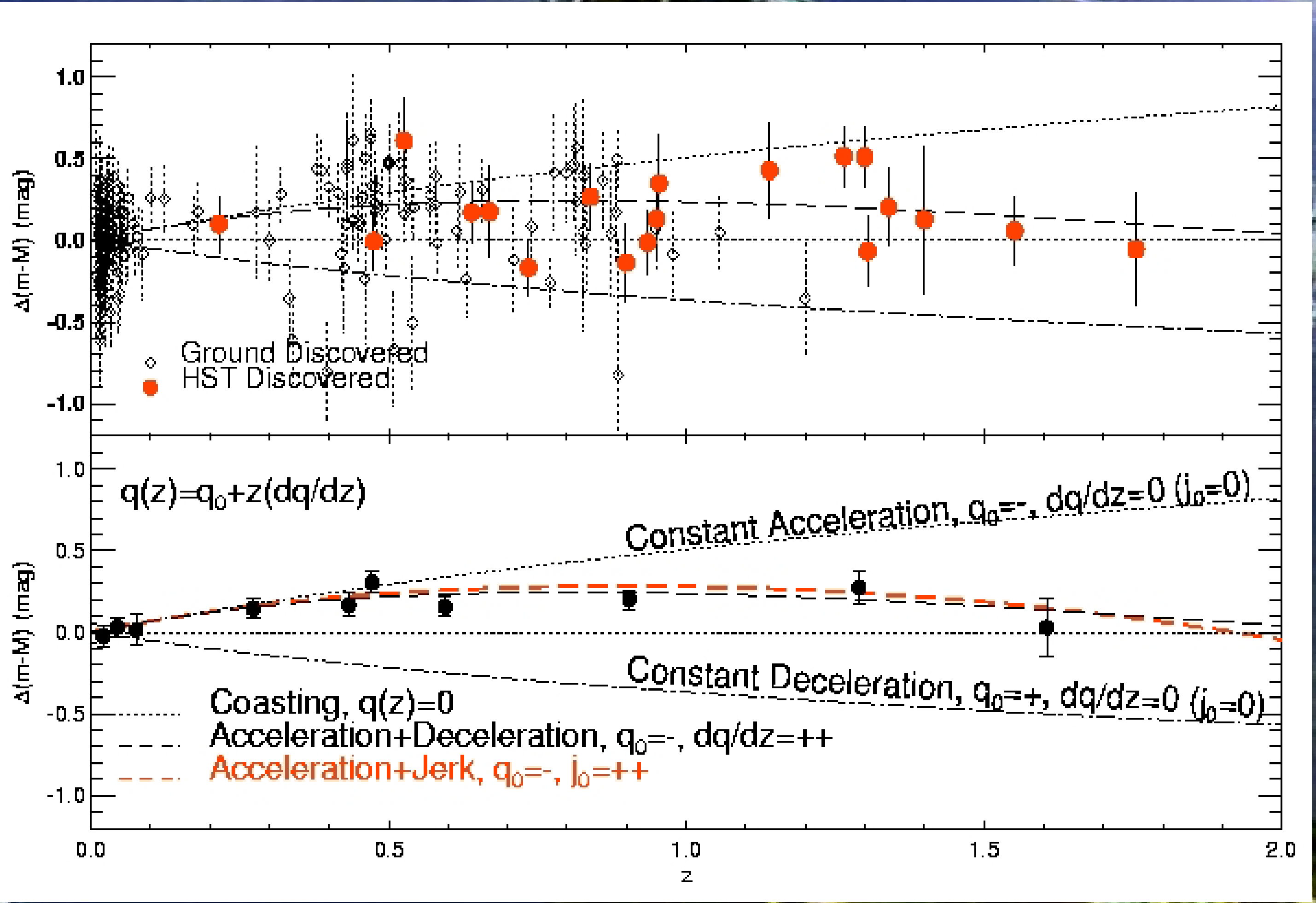
Goals:

- ~200 SNIa $0.2 < z < 0.8$
- Single Filter/Detector System to limit systematics
- Reliable limit on w to ~10%



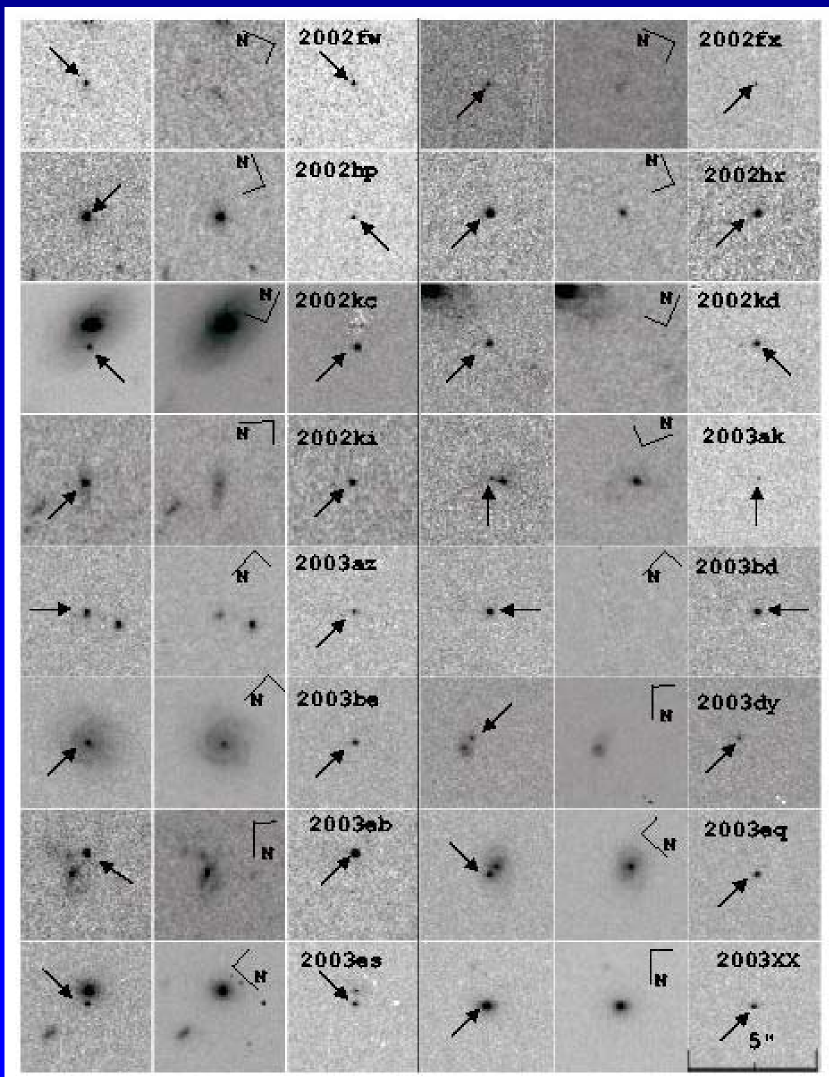
Space, The Final Frontier

- SNIa peak shifted to Infrared at z>1
- Infrared sky background 10000x less in space
- Diffraction limited imaging further reduces background

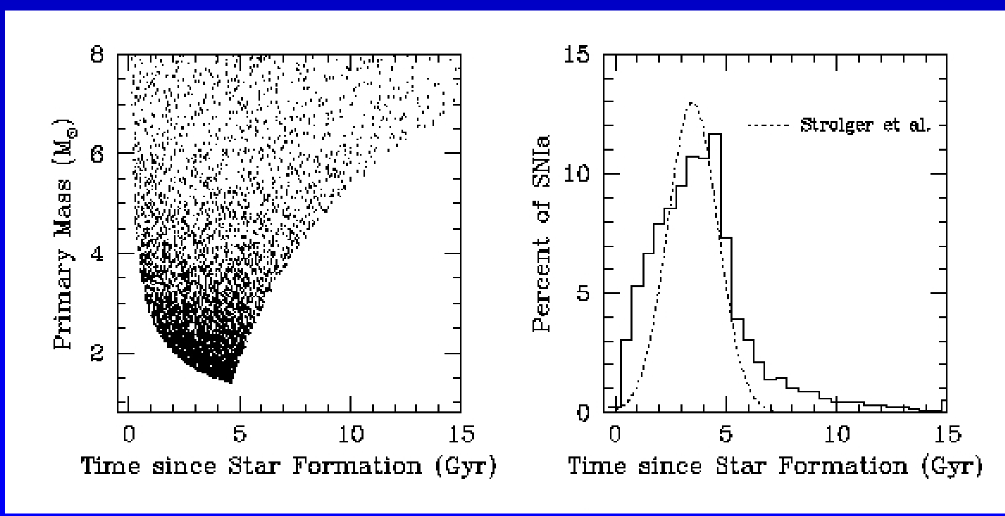


Hubble Telescope – pushing the limit

Great for z>1 SN.
run out of SN at z~1.7



Simple Model of white dwarf + companion says most SNIa blow up 3-4 Gyr after star-formation epoch



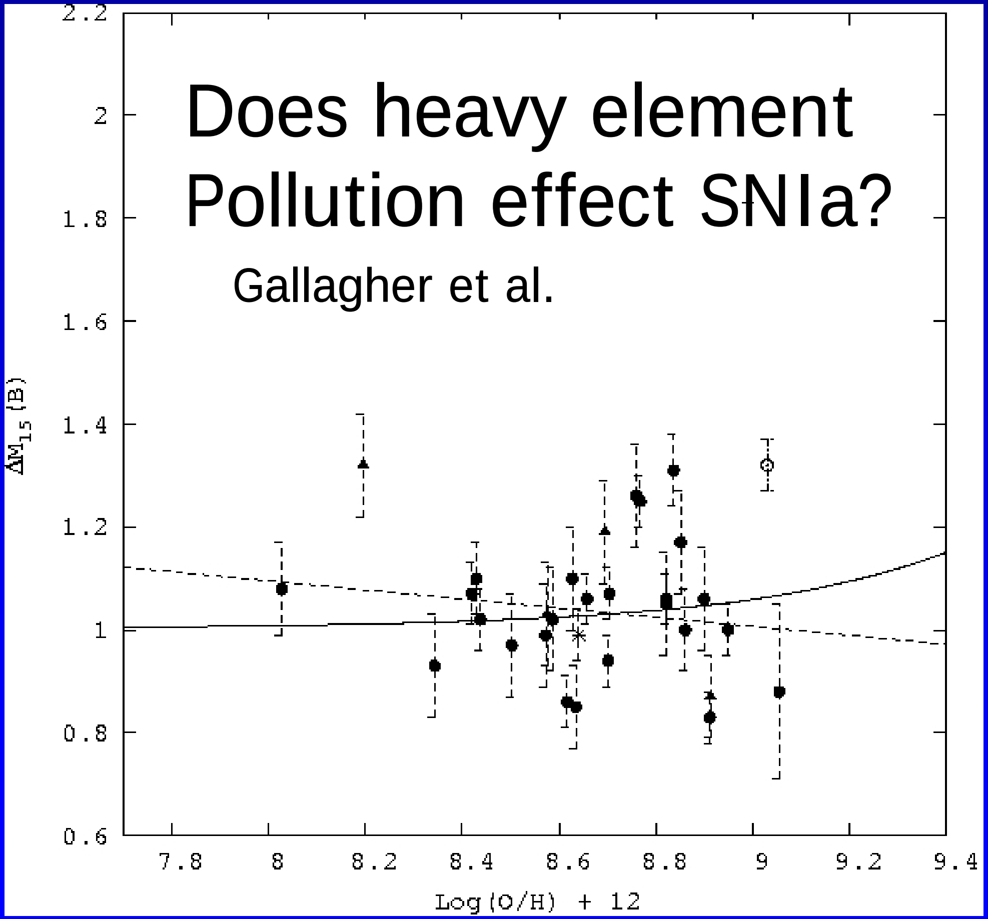
Gallagher et al.

Are SN Ia Good Enough?

Need ~2% luminosity accuracy between 12 Gyr and Now

- Do SN Ia properties vary with cosmic age?
- Do dust properties vary with cosmic age?
- Can detectors be calibrated to <2%?

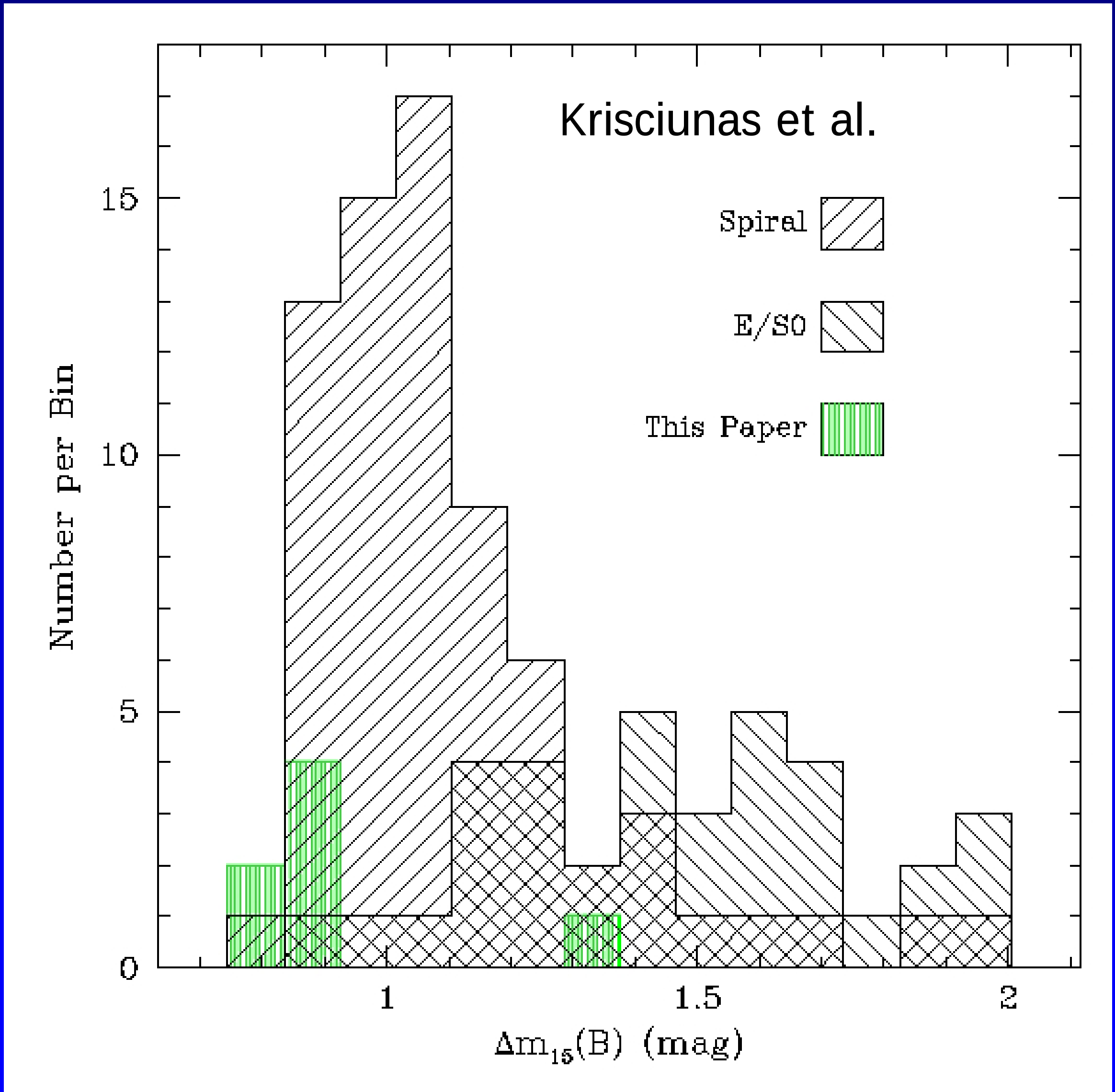
Need to know a 100 watt light bulb from a 98 watt light bulb at a distance of 12 billion light years!



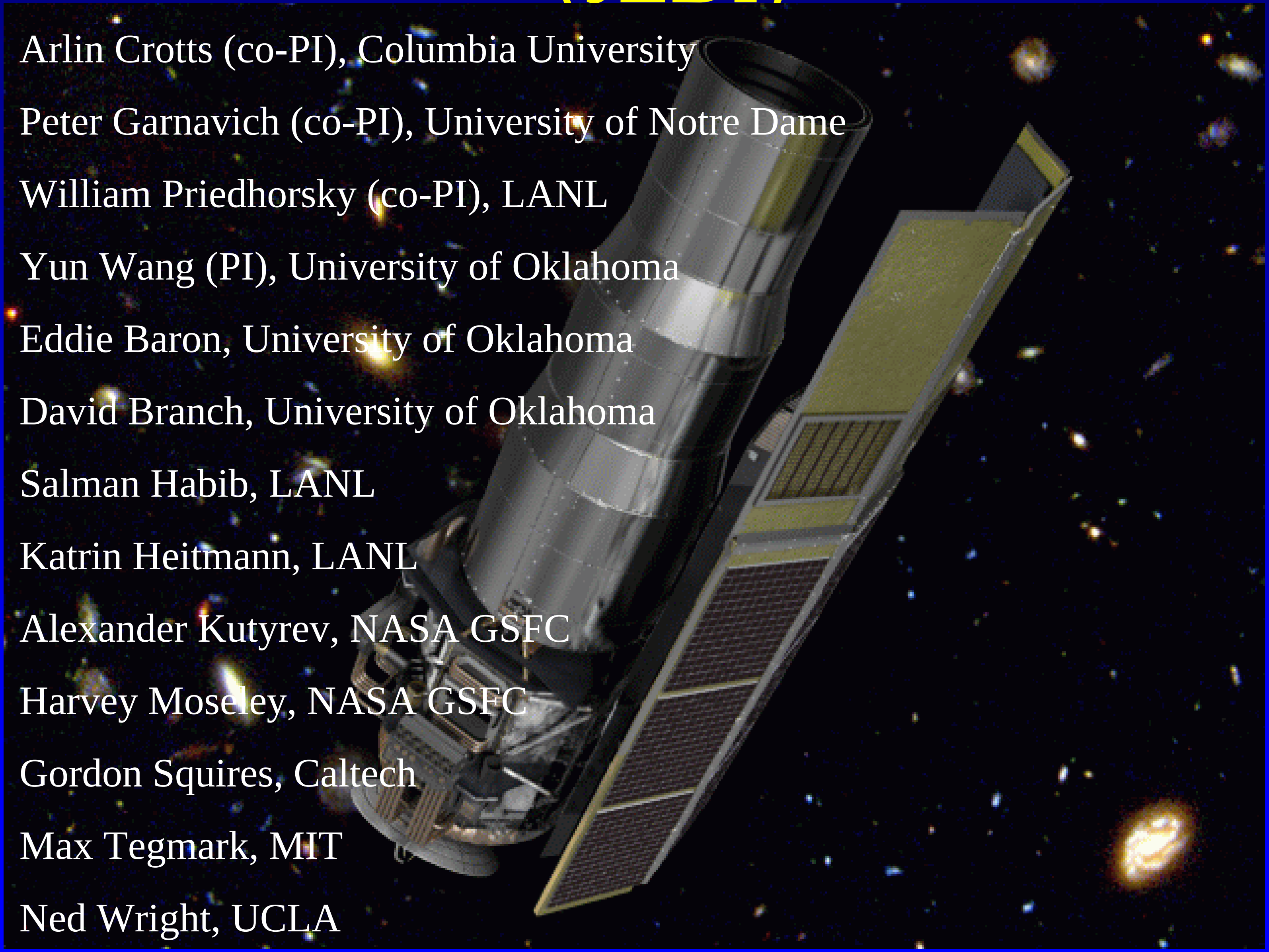
Supernova Surprises

SN selection bias can be subtle.

The highest redshift subset of the HST ESSENCE sample: 6 of 7 supernovae are very slow decliners. Does not match local sample.



Joint Efficient Dark-energy Investigation (JEDI)



Arlin Crotts (co-PI), Columbia University

Peter Garnavich (co-PI), University of Notre Dame

William Priedhorsky (co-PI), LANL

Yun Wang (PI), University of Oklahoma

Eddie Baron, University of Oklahoma

David Branch, University of Oklahoma

Salman Habib, LANL

Katrin Heitmann, LANL

Alexander Kutyrev, NASA GSFC

Harvey Moseley, NASA GSFC

Gordon Squires, Caltech

Max Tegmark, MIT

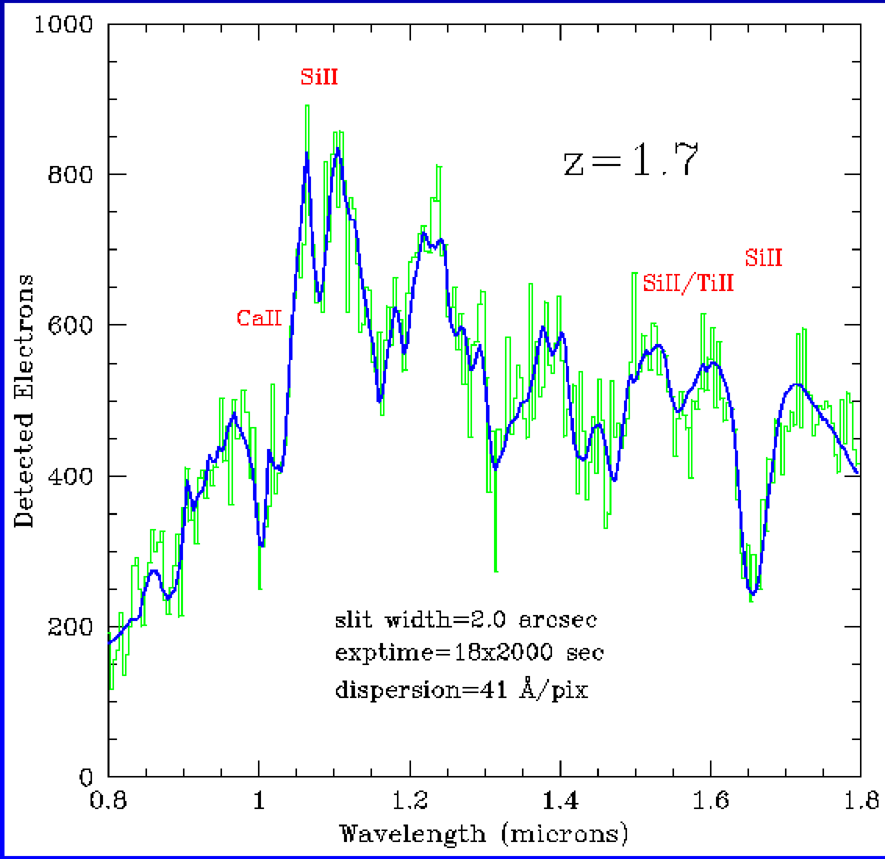
Ned Wright, UCLA

NASA/DOE Dark Energy Space Mission

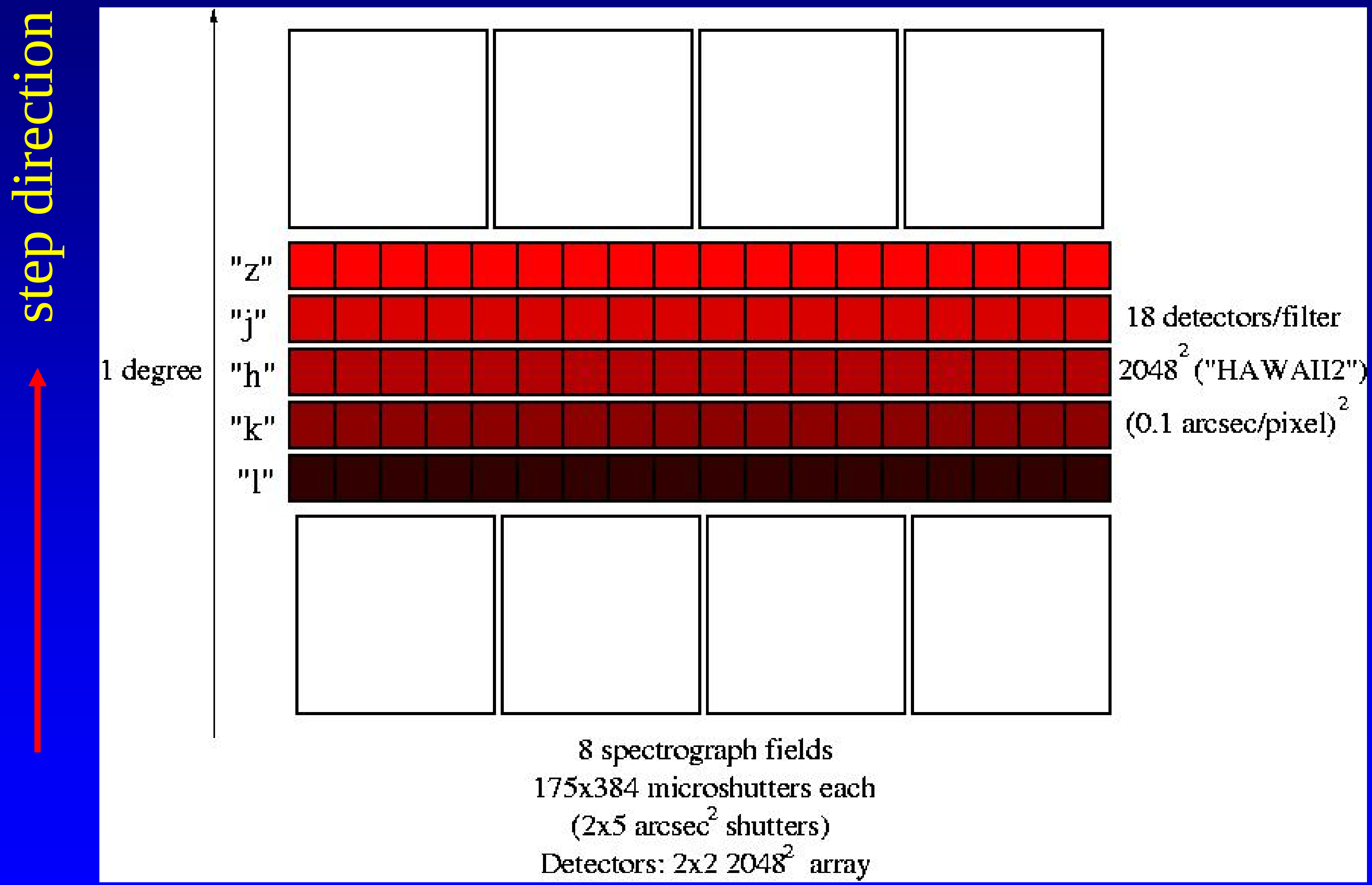
2-m telescope in space: A single spectrum of a type Ia supernova at z~1.7 takes 10 hours!

S/N ~ 10

- JEDI will get ~100 SN spectra simultaneously
- JEDI will measure baryon oscillations over 1000 sqr degrees to z~3
- JEDI will be sensitive out to 3 microns and measure SN in rest-frame IR
- JEDI will measure weak lensing



JEDI focal plane

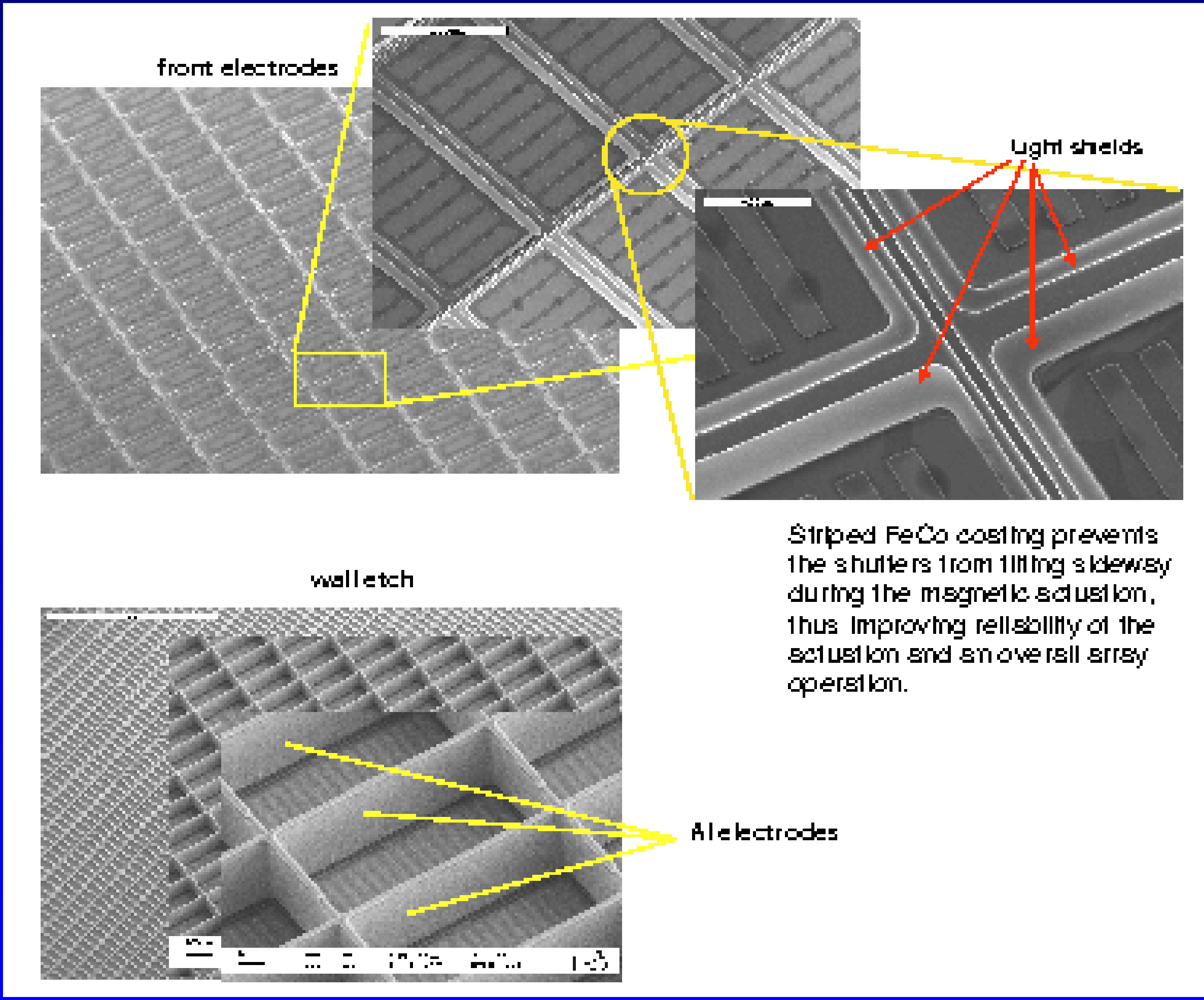


Efficient: Simultaneous Spectra for all SN in 1 deg

Microshutter Arrays:

AAS 205, [5.07] Microshutter Arrays for JWST NIRSpec., S. H. Moseley et al.

Each shutter consists of a shutter blade suspended on a torsion beam (from a support grid) that allows for a rotation of 90°. Each shutter is individually addressable for opening.
All are reset with a magnet.



2D programmable slit mask

The Hunt for Dark Energy

Joint Dark Energy Mission Cost Cap: $600 M

New York City contribution to new Jet Stadium: $600 M

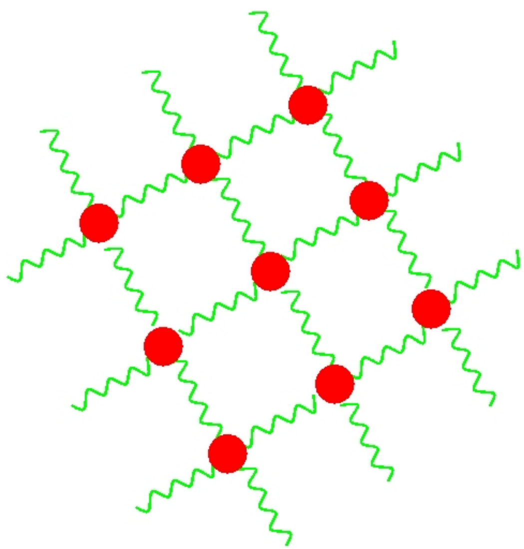
Determining the fate of the Universe: Priceless

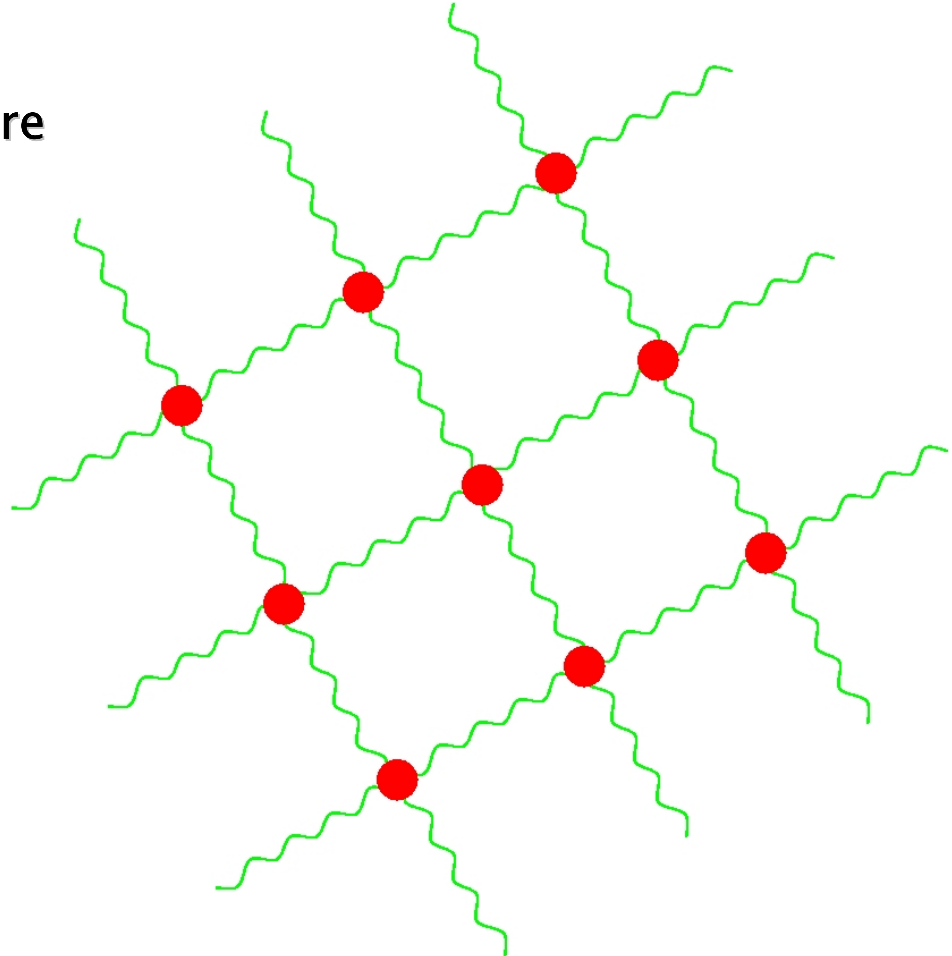
What is Dark Energy?: A Crude Example

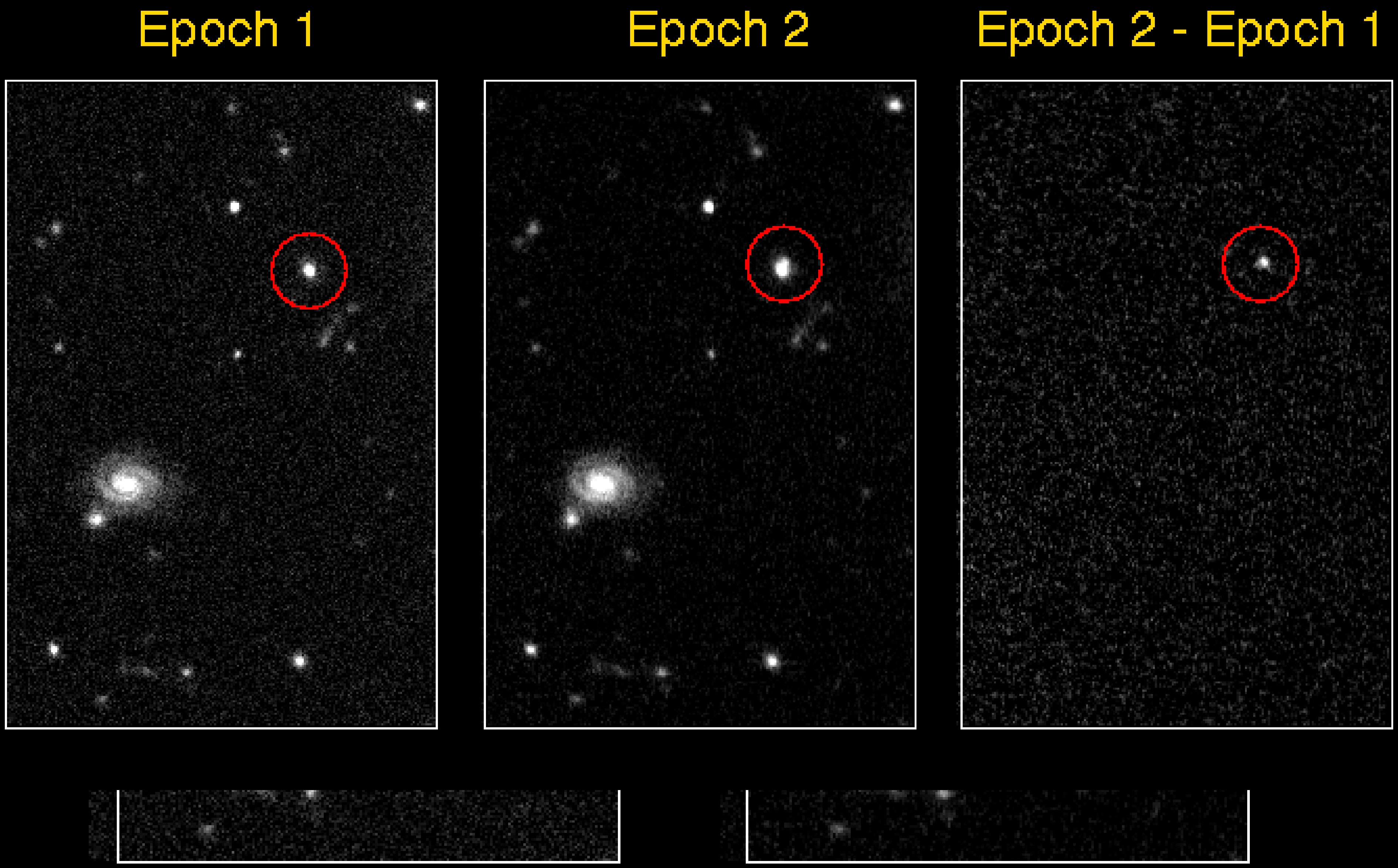
Imagine the universe filled with low mass particles connected with massless springs.

As the universe expands the springs stretch – their energy increases

The mass density decays as $1/a^3$ but the energy density decays more slowly.

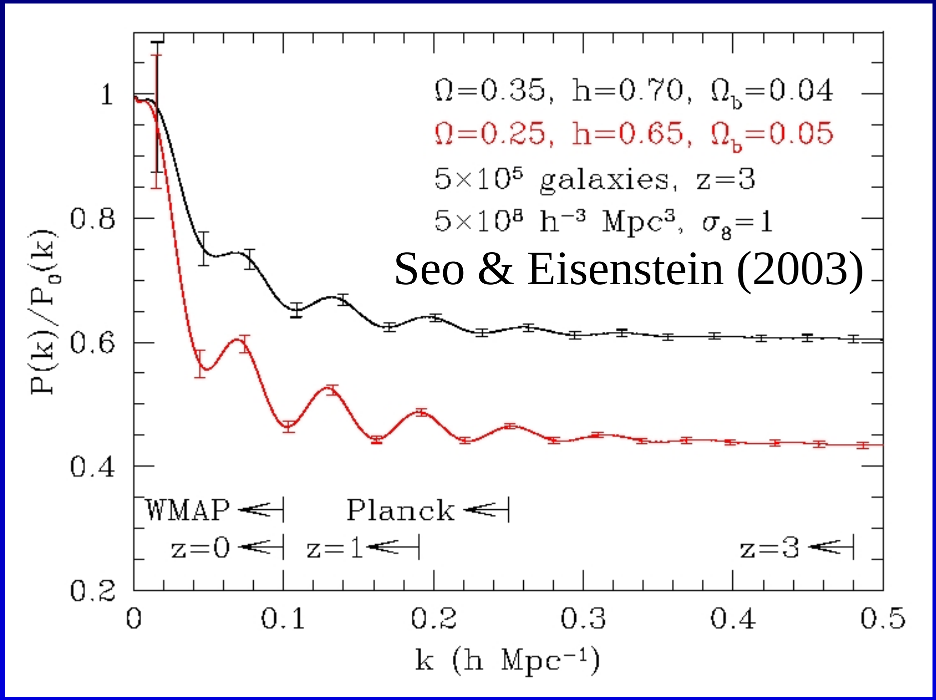




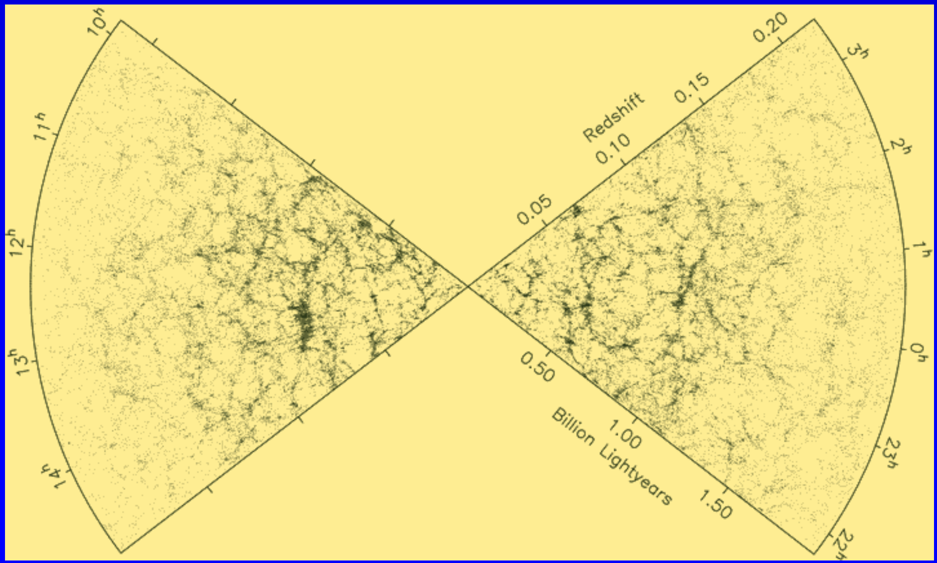

Epoch 1
Epoch 2
Epoch 2 - Epoch 1

Baryon Oscillations out to z~3

JEDI: Measure 10^6 redshifts of galaxies at z~3 while simultaneously taking SNIa data. "SDSS at z=3"



Use the LSS to map angular diameter distance vs z as a Complementary probe of dark energy.



Supernova Classification