

Science

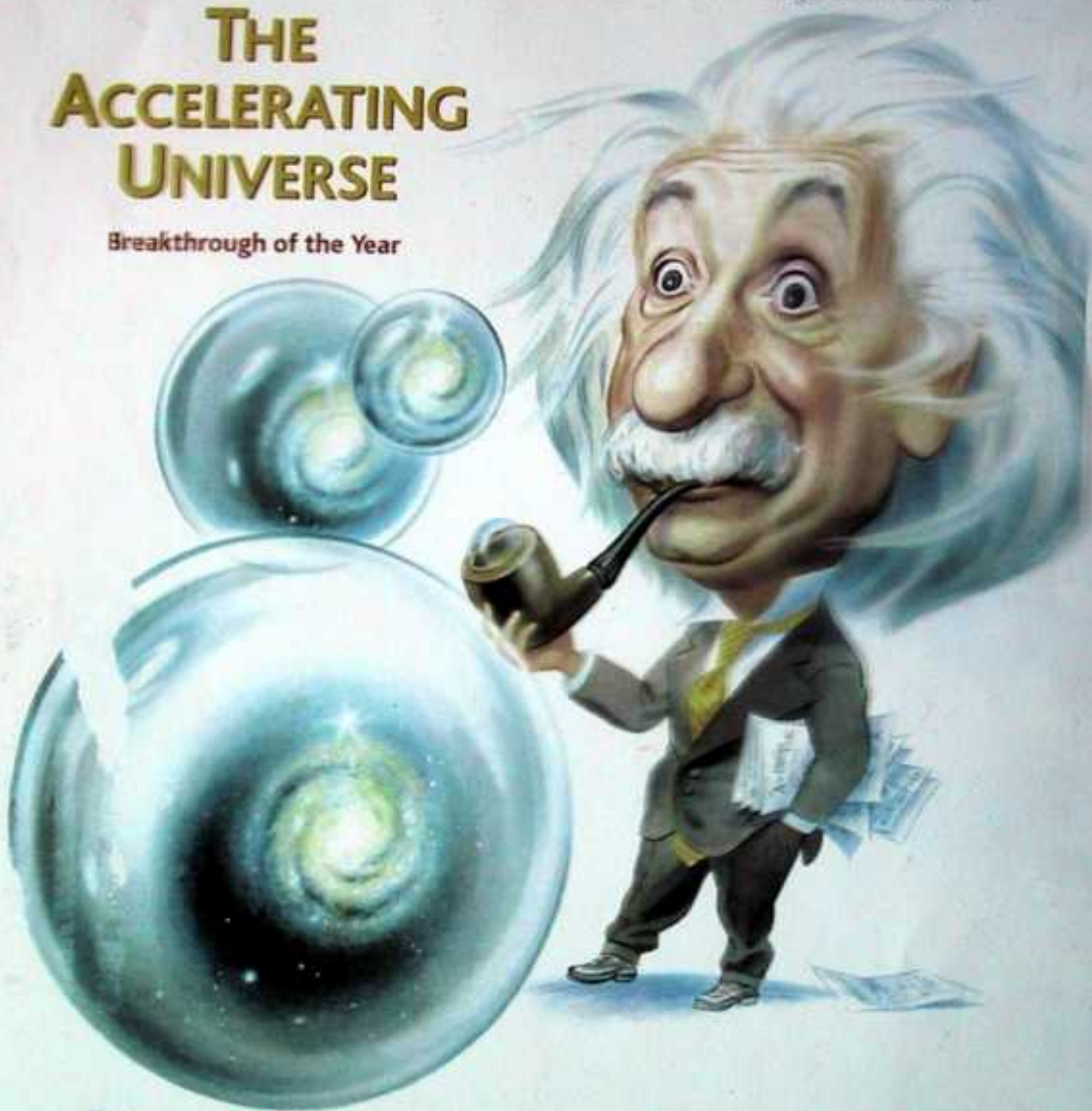
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THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

COSMIC SPEED UP

THE "OLD COSMOLOGY": SEARCH FOR 2 NUMBERS

$$H_0 = (\dot{R}/R)_{\text{today}} = 70 \pm 7 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

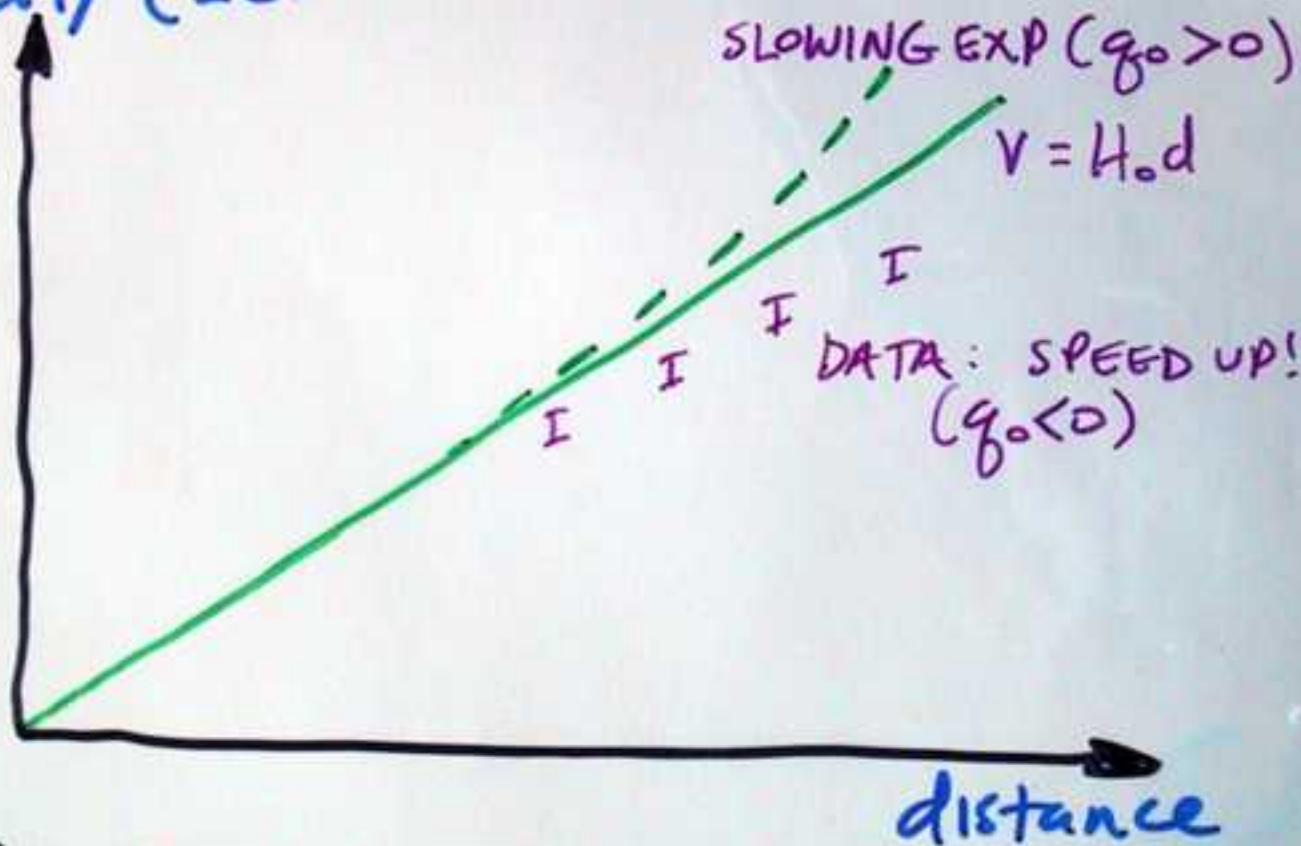
$$q_0 = \left(-\frac{\ddot{R}/R}{H^2} \right)_{\text{today}} = \frac{\Omega_0}{2} (1 + 3P) = -0.66 \pm 0.1$$

Friedmann Eqⁿ

$$= \frac{1}{2} \text{ for } \Omega_0 = \Omega_m = 1$$
$$= \frac{1}{6} \text{ for } \Omega_0 = \Omega_m = \frac{1}{3}$$

LOOKING BACK W/THE HUBBLE DIAGRAM

velocity ($\approx c$)



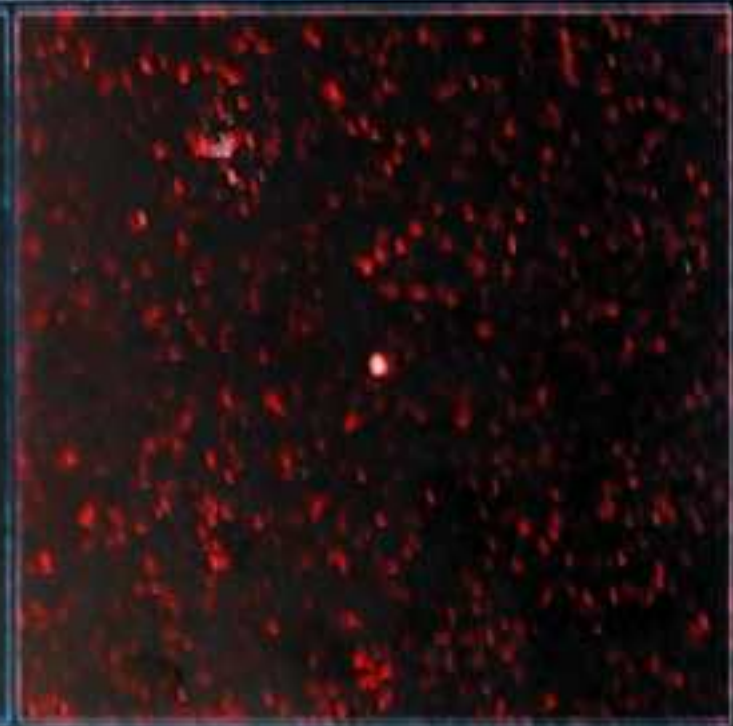
IT'S ALL ABOUT MEASURING DIST. W/ STD CANDLES

- measuring "v" (actually z) easy
- distance hard - std candles

$$(1+z) r(z) = d_L \equiv \left(\frac{L}{4\pi F} \right)^{1/2}$$



Type Ia Supernova (SNIa):
Thermonuclear explosion of
1-4 M_{\odot} white dwarf
≈ "std bomb"

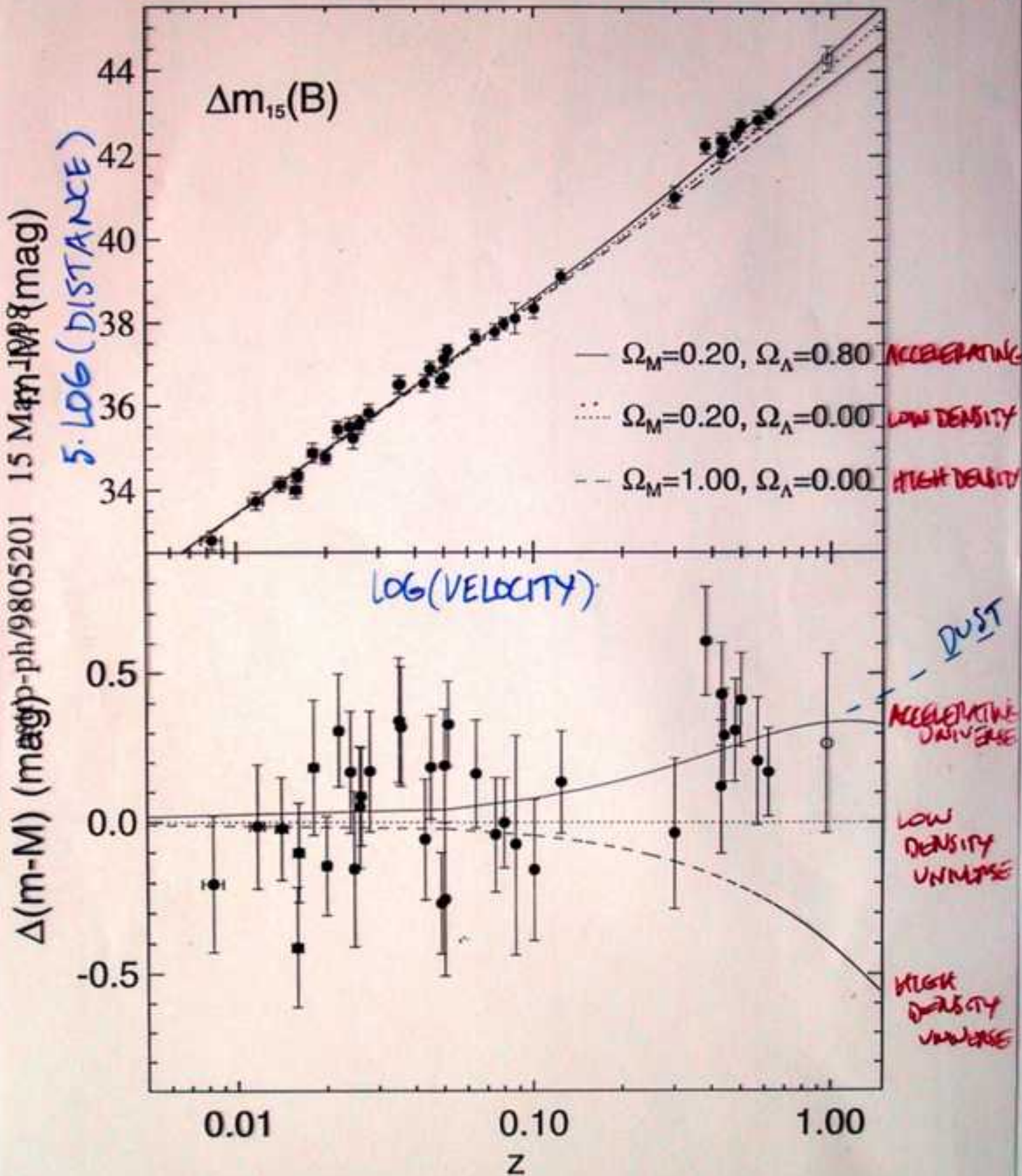


Distant Supernova in the Hubble Deep Field
Hubble Space Telescope • WFPC2

NASA and A. Riess (STScI) • STScI-PRC01-09

Extragalactic astrophysics

A. RIESS et al 98
A.J. in press (astro-ph/9805201)



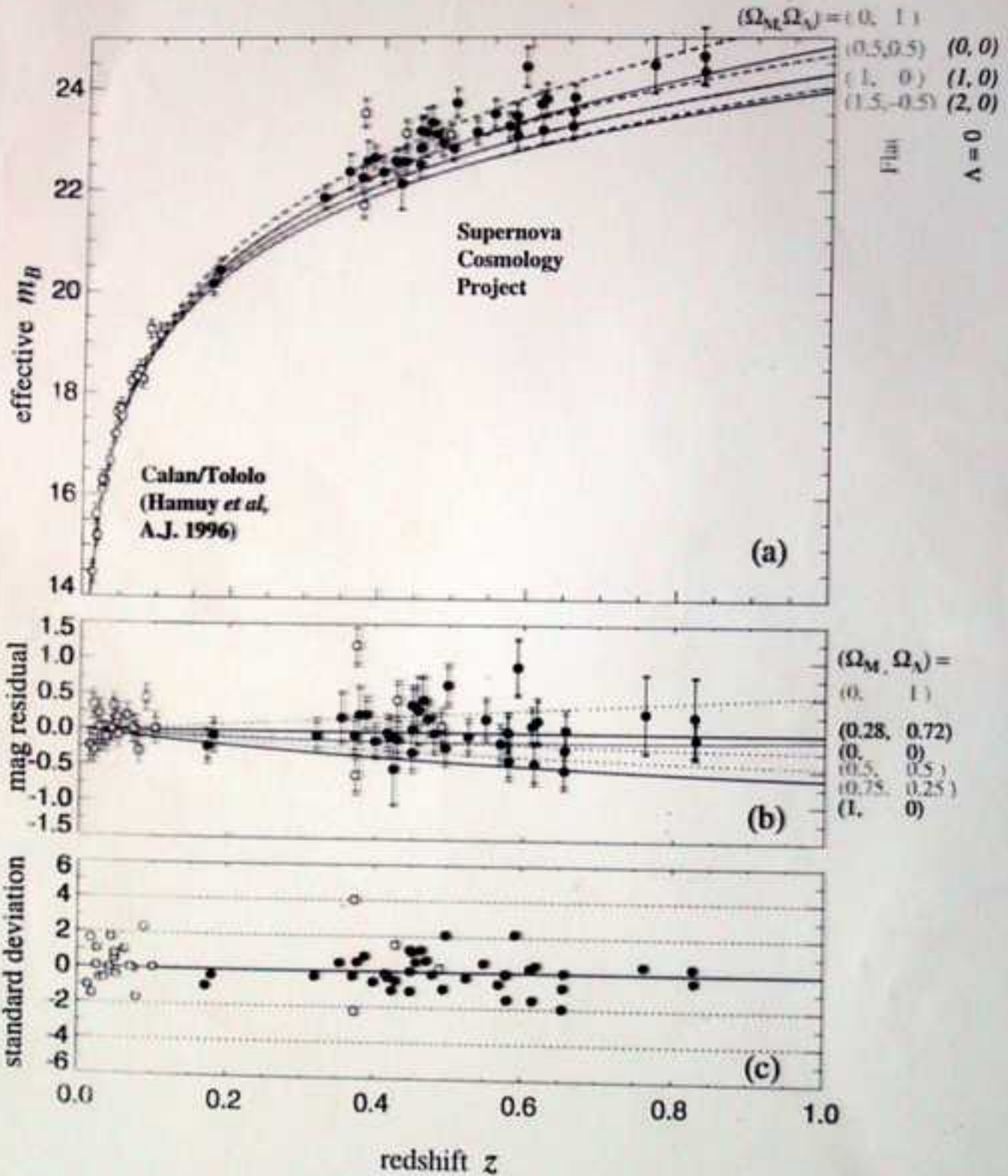


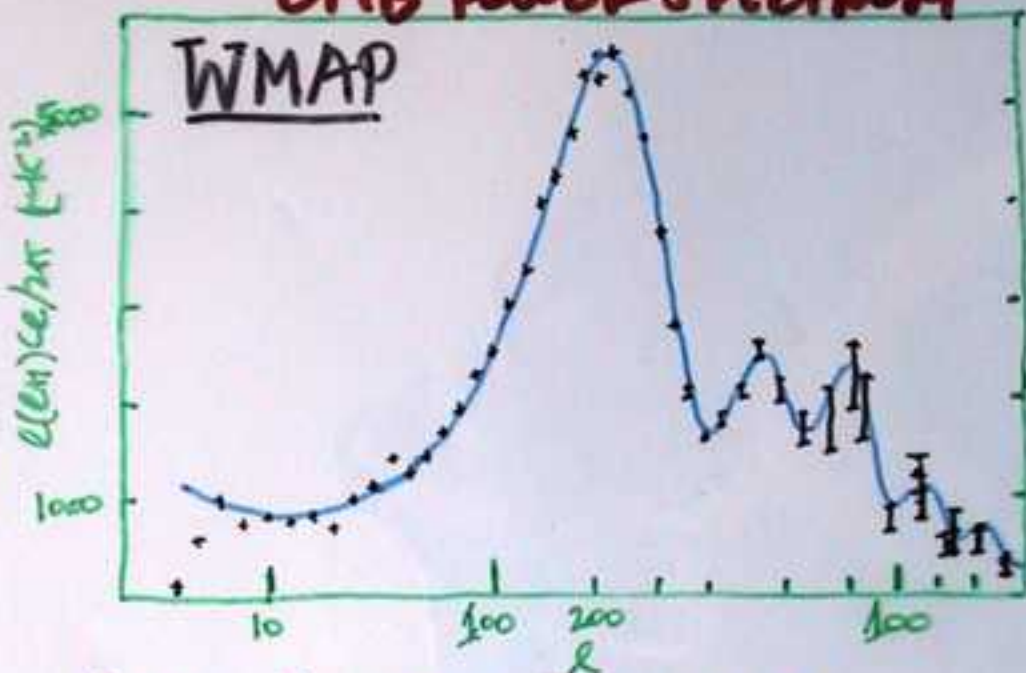
Fig. 2

INDEPENDENT TWO LINES OF EVIDENCE FOR DARK ENERGY

CMB →
"MISSING ENERGY"

$$\Omega_x = \Omega_0 - \Omega_M = 0.7 \pm 0.04$$

CMB POWER SPECTRUM



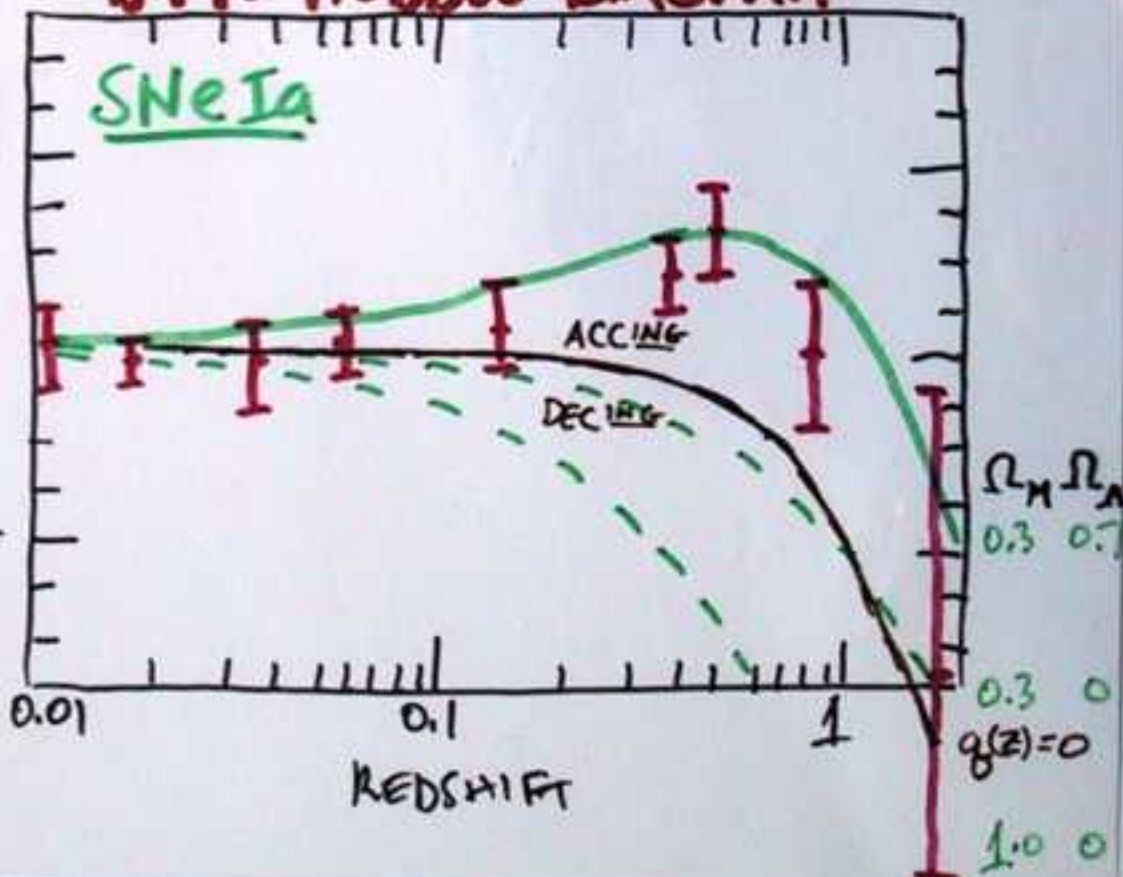
SNeIa

200 SNeIa
astroph/0305008
(Tonry et al)

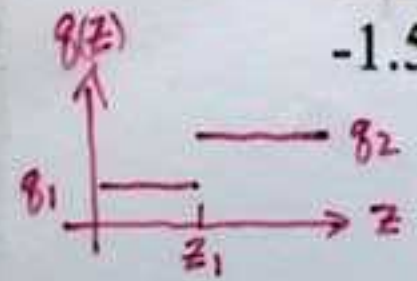
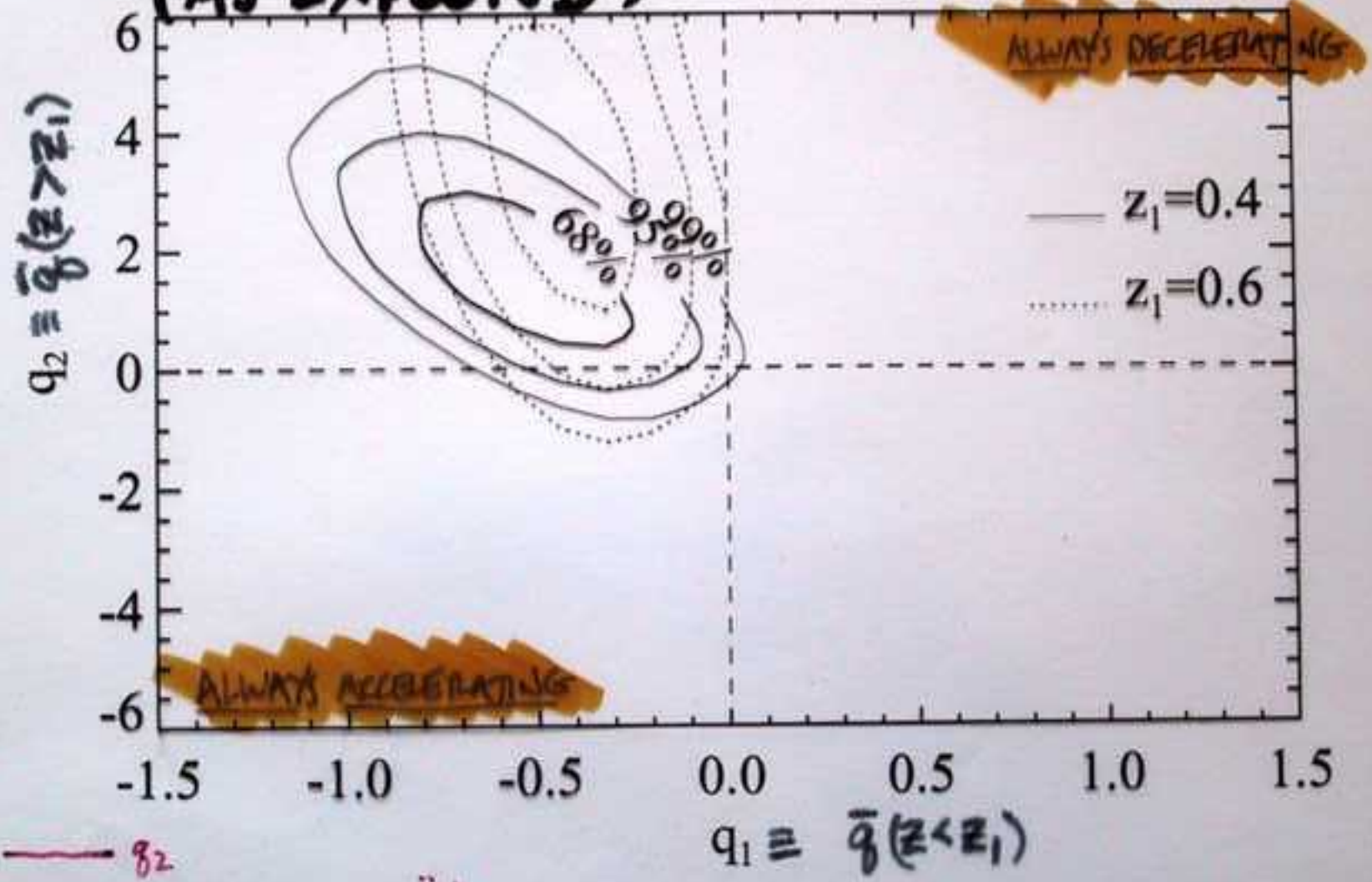
$$\Omega_x = 1.4\Omega_M + 0.35 \pm 0.14 = 0.8 \pm 0.06$$

$\Delta(m-M)$ rel. to $\Omega_0=0$

DIFF. HUBBLE DIAGRAM



EVIDENCE FOR EARLY ($z \approx 1/2$) DECELERATING PHASE FROM SN 1997A (AS EXPECTED)



$$q(z) = -\frac{\ddot{R}/R}{H^2}$$

MST-R155 astro-ph/0105

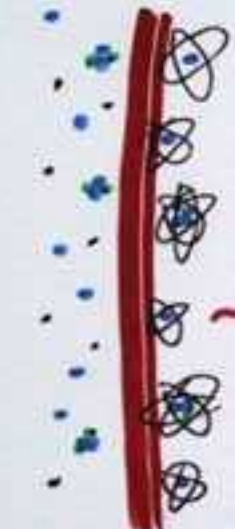
DETECTING DARK ENERGY W/ SACAS-WOLFE EFFECT

R. Scranton et al, astro-ph/0307355

WITH DARK ENERGY
 $(\Omega_M = 1/3, \Omega_{DE} = 2/3)$

$z \sim 0.5$
 EVOLVING
 LARGE-SCALE STRUC.

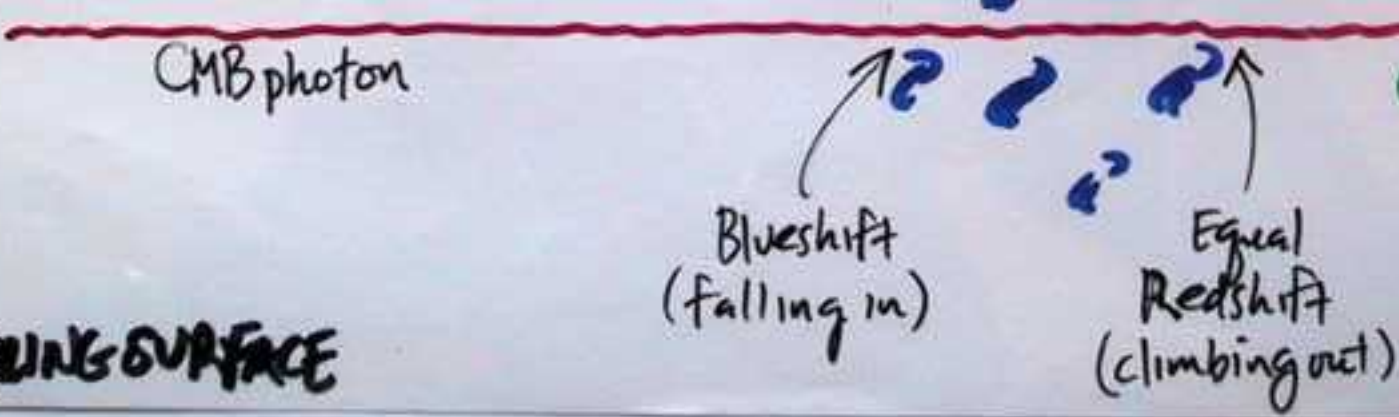
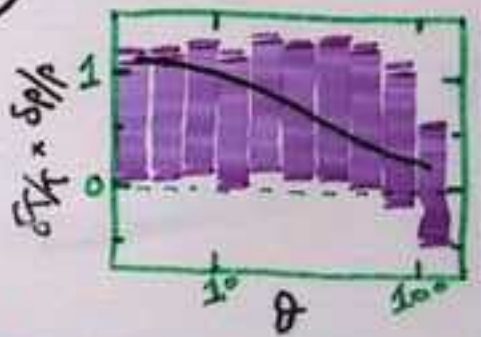
WMAP & SDSS
 ↓
 POSITIVE
 CORRELATION
 BETWEEN
 HOT SPOTS
 & LSS



$z = 1100$
 $t = 400,000$ yrs

W/O DARK ENERGY
 $(\Omega_M = 1, \Omega_{DE} = 0)$

SMALLER (!)
 Redshift
 (climbing out)



LAST-SCATTERING SURFACE

GR ALLOWS FOR REPULSIVE GRAVITY:

SOURCE OF GRAVITY

IN GR :

$$\rho + 3p$$

(SPHERICAL SYMMETRY)

FEATURE NOT A BUG!



BLACK HOLES WHEN $p \geq \rho/3$



REPULSIVE GRAVITY WHEN $p < -\rho/3$

QUANTUM VACUUM IS NOT EMPTY!

sea of virtual particles



Whose existence has been detected
(shifting of atomic levels in H)

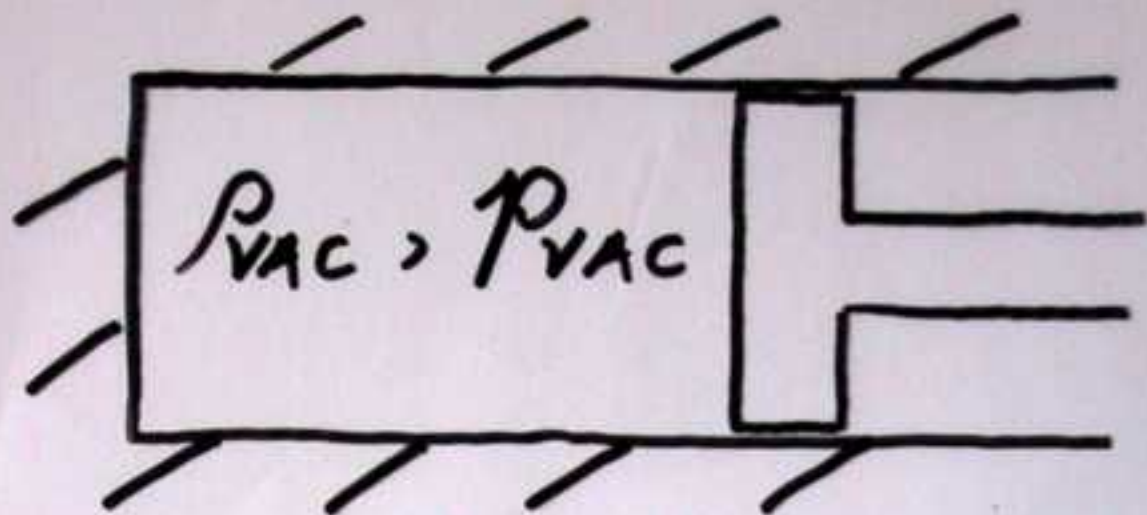
W. Lamb, ca 1950

Quantum vacuum is elastic ($p = -p$)
& its Gravity is Repulsive!

JUST WHAT IS NEEDED -- BUT...
THEORETICAL ESTIMATES OF AMOUNT

10^{55} x what is needed to
explain accelerating Universe

"Houston, we have a problem"



$$dE = -p dV$$

$$P_{vac} dV = -P_{vac} dV \Rightarrow P_{vac} = -P_{vac}$$

DARK ENERGY

MAY BE THE MOST

PROFOUND PROBLEM

IN ALL OF SCIENCE TODAY

WHAT IF

$\Lambda = 0$?

BE CAREFUL WHAT YOU
WISH FOR !!

CALL IT: DARK ENERGY

SOLVING THE DARK ENERGY
PROBLEM WILL REQUIRE
A CRAZY, NEW IDEA!

NB: NOT EVERY CRAZY IDEA IS A SOLUTION

ONLY?

COSMOLOGY IS THE BEST PROBE
OF DARK ENERGY

WEIRD DARK ENERGY or

NEW GRAVITATIONAL PHYSICS?

EINSTEIN'S SURPRISE: NATURAL STATE OF
UNIVERSE IS EXPANSION OR CONTRACTION

NEW SURPRISE: NATURAL STATE OF
"EMPTY UNIVERSE" IS ACCELERATED EXPANSION!

NETWORK OF (FRUSTRATED) TOPOLOGICAL DEFECTS

EG STRING

A. Vilenkin '84
Pen-Spiegel '98



VERY ELASTIC: $\nu = -1/3$

IN GENERAL: $\nu = -N/3$

ROLLING SCALAR FIELD

(aka: decaying cosmological constant,
pseudo Nambu Goldstone boson, quintessence,
not there yet)

Bronstein 1933 (executed by Stalin 1935)

Hill Schramm Fry 1986

Freeze et al 1987

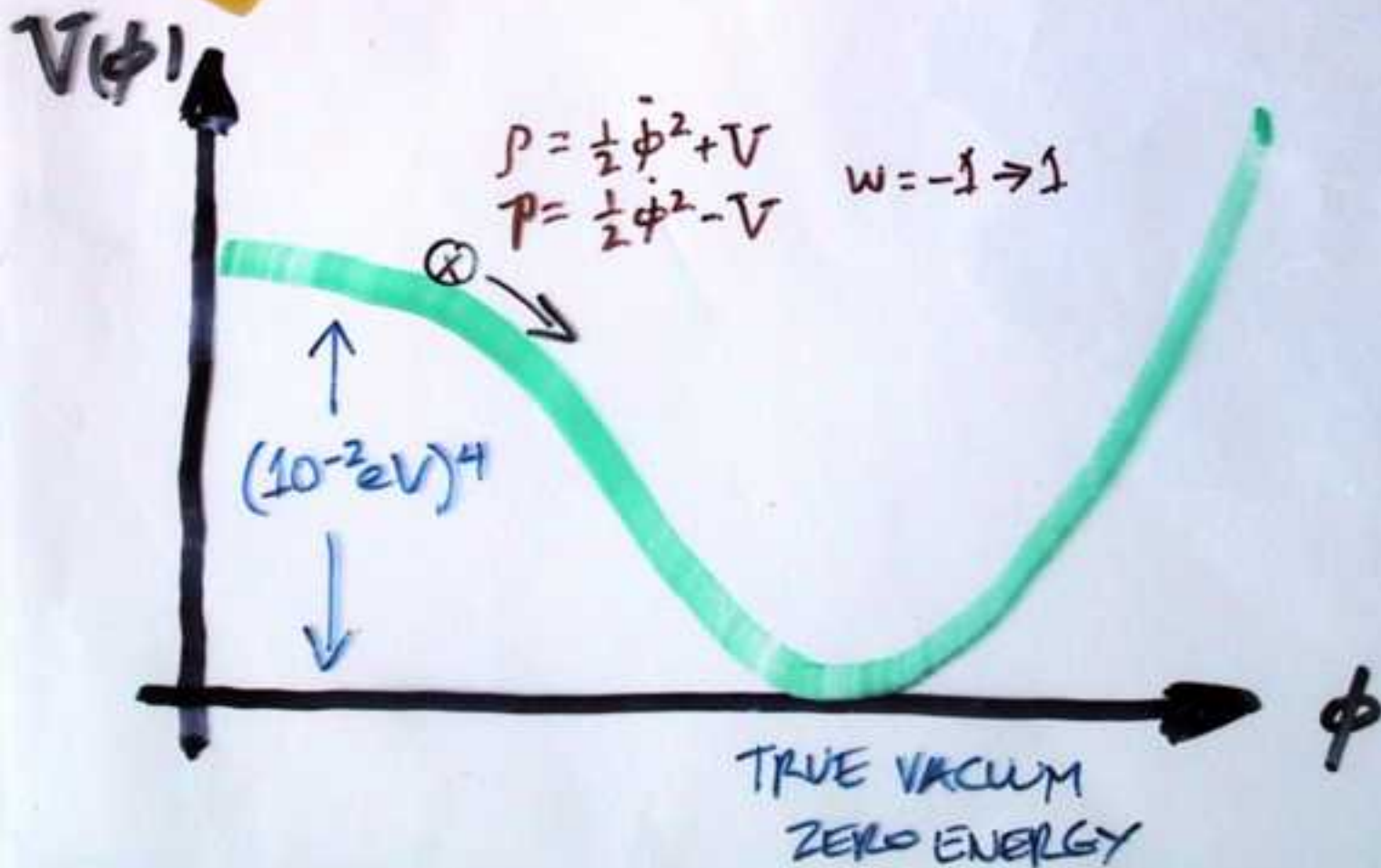
Reza-Peebles 1988

Frieman et al 1995

Caldwell et al 1998

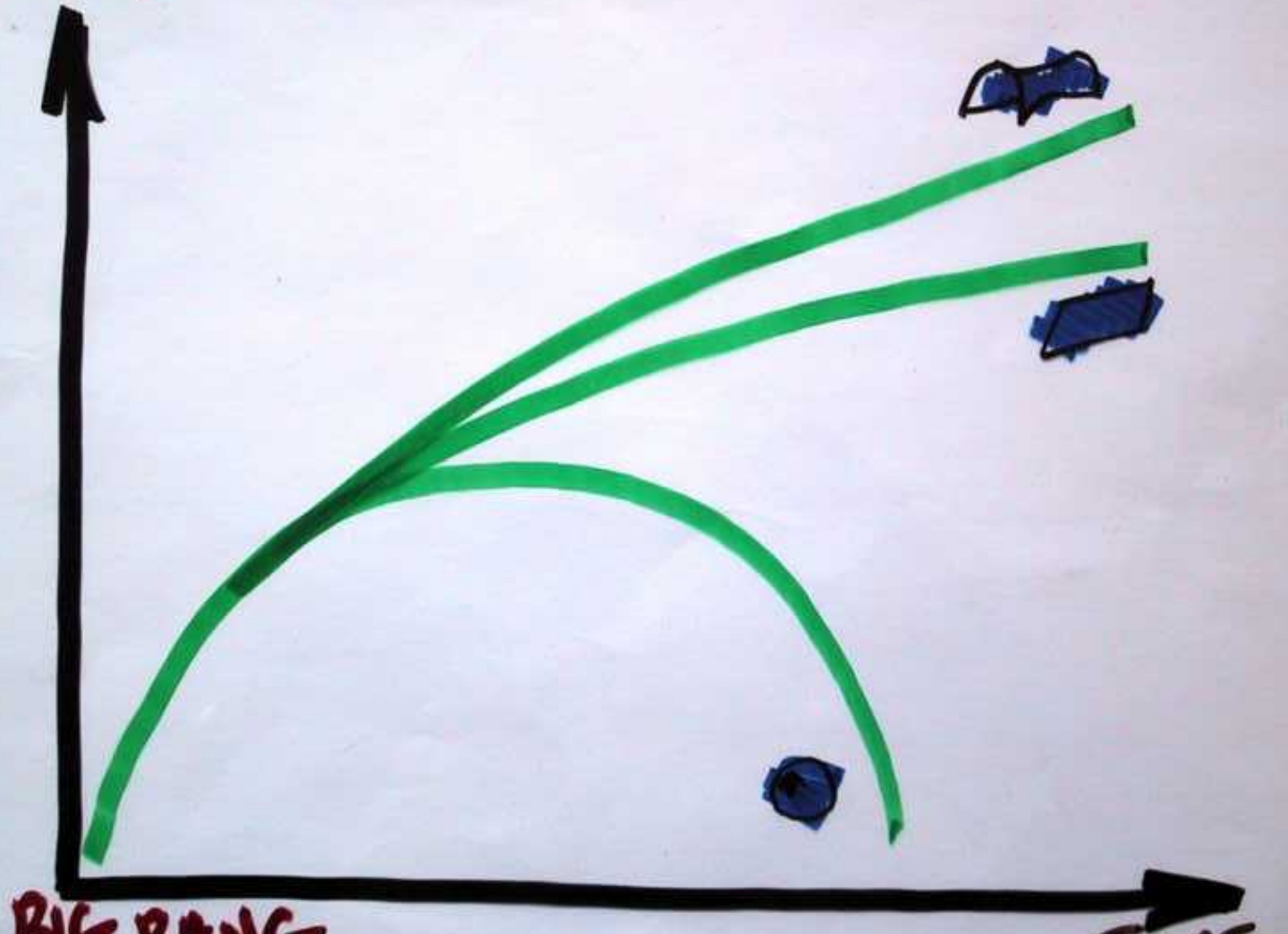
& others

A. GREENSPAN 1998: "... Brief Episodes of Inflation Are Unavoidable."





SIZE



BIG BANG

TIME