AS1001:Extra-Galactic Astronomy

Lecture 10: Revision & Hot Topics

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Exam Format

- Answer one question from each course
- Four questions: total out of 100

- Galaxies & Cosmology: Exam on Lectures 1 to 9

Lecture 1: Distances

- Standard Candles:

$$F = \frac{L}{4\pi d^2} \qquad m_1 - m_2 = -2.5 \log_{10} \frac{F_1}{F_2}$$

$$m - M = 5 \log_{10} d(pc) - 5$$

- Period-Luminosity relation / Cepheid variables
  - •DON'T: remember formula
  - •DO: understand calibration; importance of Cepheids
  - •Calculate *d* given *P*, *m*
  - •Calculate *m* given *d*, *P*

Lecture 2: Galaxy Morphology

- Hubble tuning fork; why not evolutionary sequence
- Galaxy types: Ellipticals, Spirals, Irregulars
- Main features of each type. Components
- Why are ellipticals red?
- Understand: young & hot = blue
  old & cool = red
  i.e., $B_\nu(T_*)$; $L \sim T^4$ (Ron's course)

Lecture 3: Galaxy Fundamentals

- $m = M + 5\log_{10} d(Mpc) + 25$
- How many stars? Assume $F_G = n_* F_*$
  F_* = "Average star"
  Use: $m_1 - m_2 = -2.5\log_{10}\frac{F_1}{F_2}$
- Formation scenarios. Observations for & against
- Space density of galaxies: what d and V can we see if we observe $m = 14$ and we know $M = -20$
- How far apart are galaxies?
- How are galaxies clustered? Soap suds, galaxies found on the bubble surfaces: filaments & voids

- Mass to Light ratios: $$\frac{\mathbf{M}}{L} = X \frac{\mathbf{M}_{\otimes}}{L_{\otimes}}$$

  $X = 1$ for Sun; $X \sim 10$ for a galaxy
  Galaxy M/L ratios indicate dark matter
- Average density of Universe

Lecture 4: Galaxy Spectra

- Continuum; Absorption lines; Emission lines
- 4000A break: blanket effect of absorption in stellar atmospheres. Strong in ellipticals, weaker in spirals, absent in irregulars.
- Absorption lines: metals in stellar atmospheres => old stars => ellipticals, spiral bulges
- Emission lines: hot gas ionized by hot stars => young stars => spiral disks, irregulars
- Radial velocities: $$\frac{v}{c} = \frac{\lambda - \lambda_0}{\lambda_0}$$

Lecture 5: Dark Matter

- Virial Equilibrium: Rotation = Gravity
  => circular orbits: $v = \sqrt{\frac{GM}{R}}$
- Calculate galactic masses given v and r
- Rotation curves: stars trace mass => $v \sim 1/r^{0.5}$
  Observe: v = constant => additional mass
- v = const => $\rho \sim 1/r^2$ => spherical isothermal halo
- Dark matter in galaxy clusters: galaxies moving too fast to stay bound
- Conclusion: 90% of the Universe is made up of dark matter… OR we have wrong theory of gravity

Lecture 6: Orientation, Black Holes

- Orientation: $$\cos i = \frac{\text{Observed minor axis}}{\text{Observed major axis}} = \frac{b}{a}$$
- Line of sight velocity: $$v_{\text{obs}} = v_{\text{rot}} \sin i$$

- Black Holes: so massive & compact light cannot escape. Be able to derive Schwarzschild radius: kinetic energy = gravitational energy: $r_S = 2Gm/c^2$
- SMBHs: observe large speeds at some given distance: derive mass: $M = v^2 r / G$
- Hawking radiation, virtual pairs. Primordial BHs evaporating now. $M=5M_\odot$ evaporate in $\sim 10^{62}$yrs

Lecture 6: Quasars

- $\sim 10^5$ times more luminous than normal galaxies
- Broad emission lines => rapid rotation
- Seen at large redshift
- Emit strongly in X-rays
- Spectrum: power law (non-thermal), Synchrotron radiation: relativistic electrons spiraling in **B**-field
- QSO model + unification scheme for Quasars, Blazars, and Radio galaxies
- QSOs in the Universe: $z > 0.3$ => common in early Universe then died out

Lecture 7: Development of Cosmology

- Copernican Principle: nothing special about us
- Olber's Paradox: why is sky dark at night? Because the Universe has finite age. Cannot see light from objects more distant than ~15 billion light years
- Modern Cosmology: Einstein (GR), Hubble (H_0)
- GR Tests: Precession of Mercury's orbit
  Gravitational Lensing
  Slowing of clocks in gravitational field
- Einstein's blunder: GR predicts dynamic universe. Einstein added cosmological constant, Λ, to make Universe static. Hubble's observation's changed this

Lecture 8: Universal Expansion

- Hubble observed expanding Universe $v = H_0 \, d$
- Does not violate Copernican Principle: all galaxies see other galaxies moving away
- HST Key Project: $H_0 = 72$ km/s/Mpc
- Age of Universe ~ $1/H_0$ = 13Gyr (more accurate calculation yields ~15Gyr). All consistent with ages of globular clusters, etc.
- Peculiar velocities: $V_{RADIAL} = V_{RECESSIONAL} \pm V_{PECULIAR}$

Lecture 9: Hot Big Bang

- Cosmological Principle:

  THE UNIVERSE IS ISOTROPIC AND HOMOGENEOUS

- Evidence: Hubble Deep Fields, Large scale surveys, uniformity of cosmic microwave background radiation
- Re-collapse or eternal expansion: derive critical density

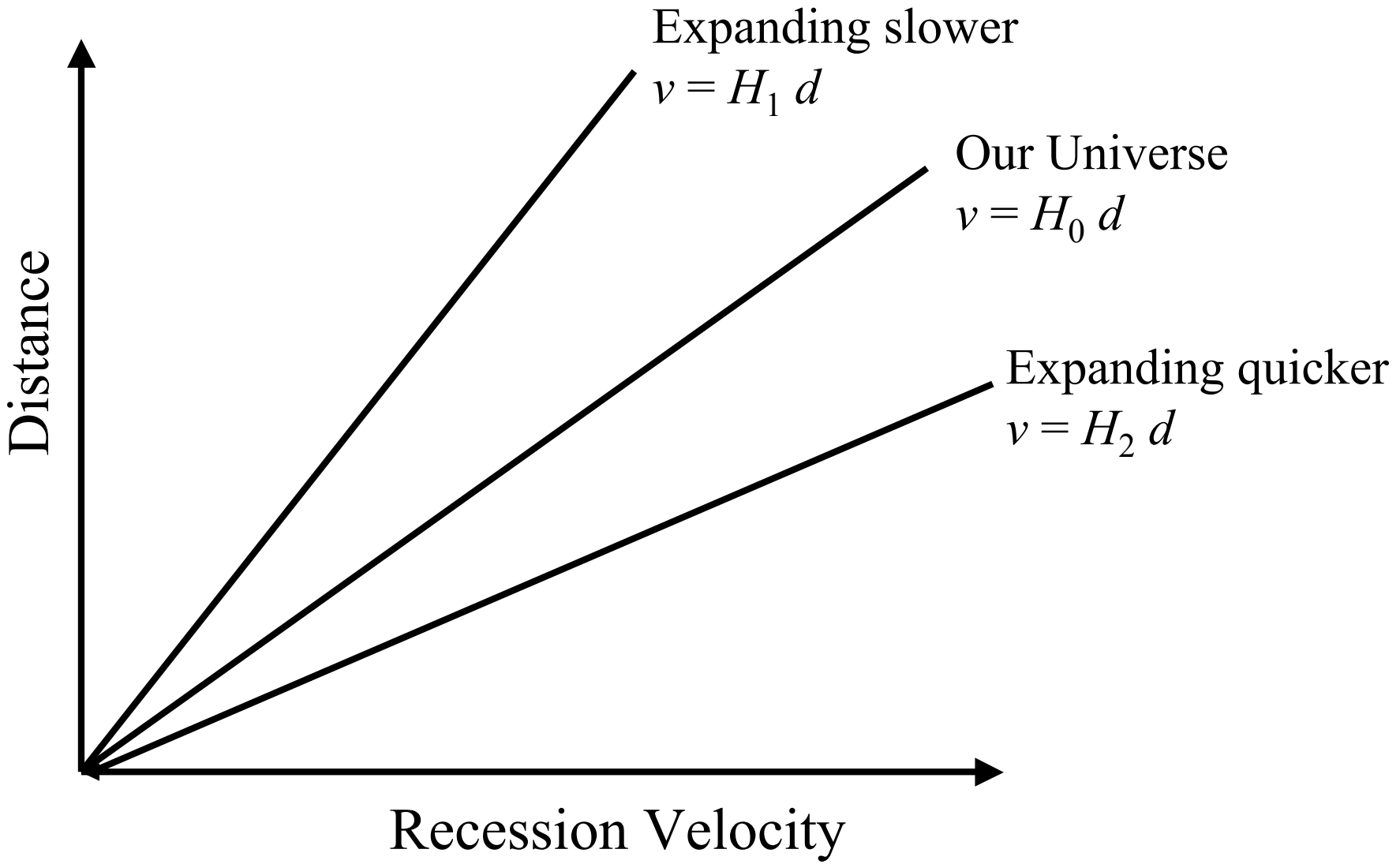
$$\rho_{\text{CRITICAL}} = 3H_o^2 / 8\pi G$$

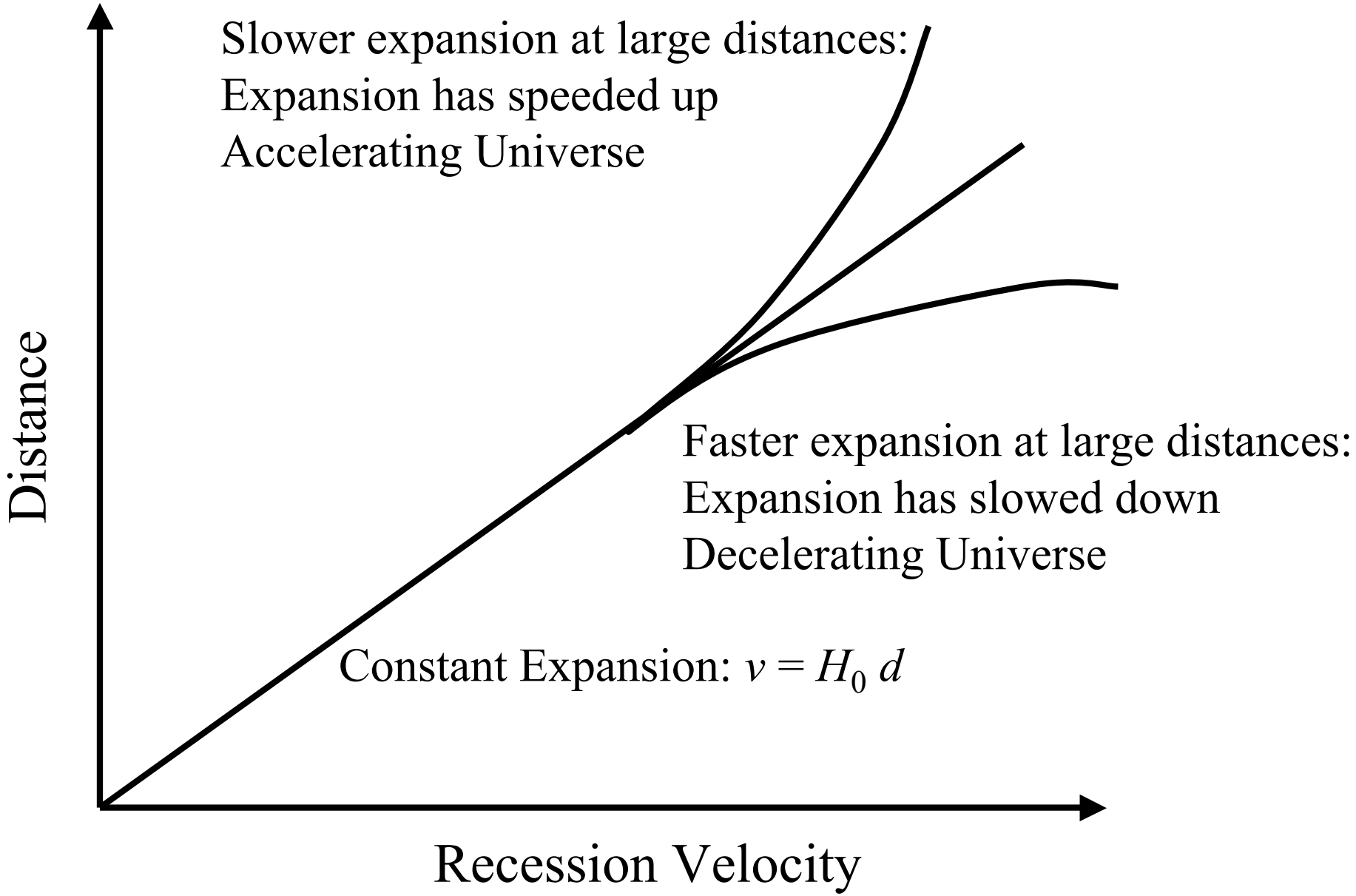
- Density of matter and radiation not enough to close Universe => need DARK energy or a cosmological constant?

Supernova Cosmology

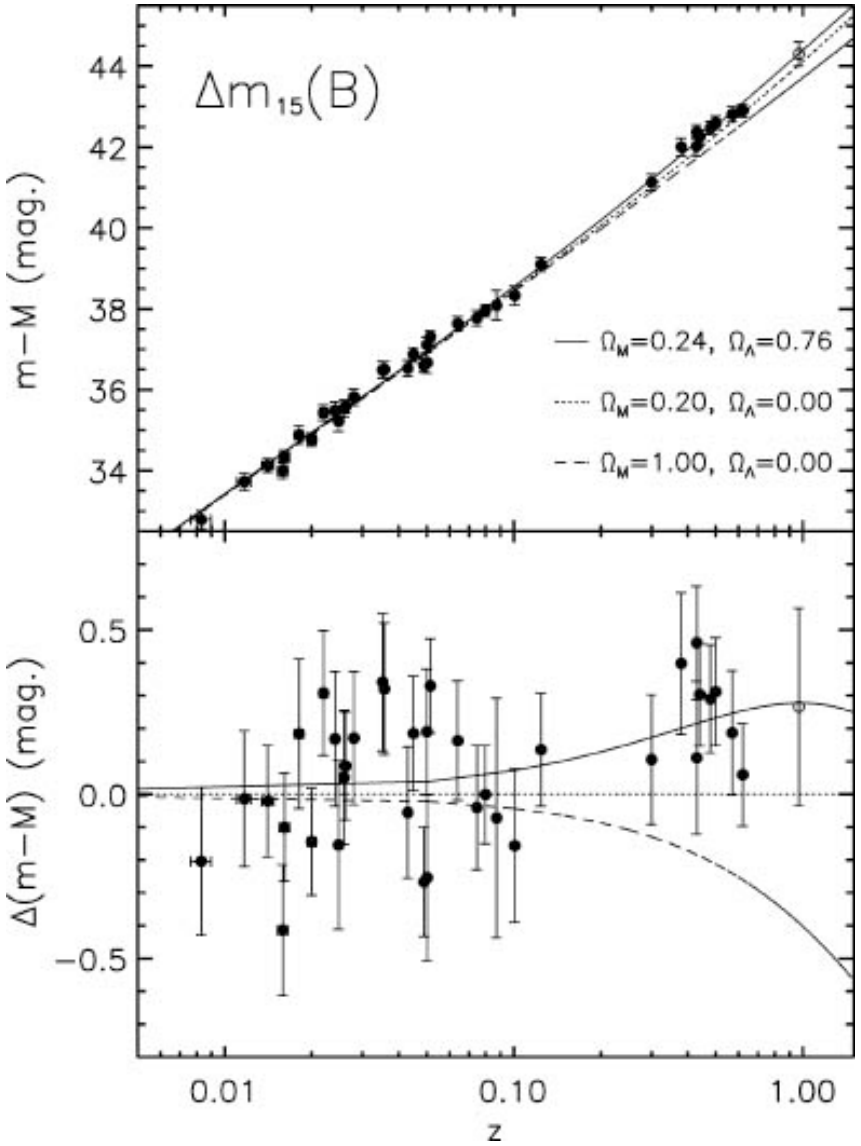
- SN Ia as standard candles: same maximum *L*
- Search lots of galaxies for SN Ia: very bright
- Probe galaxies at VERY large distances
- Do distant galaxies have the same distance/velocity relationship as the Hubble Law?
- Has the rate of expansion changed?

Varying Hubble Laws




Slower expansion at large distances:
Expansion has speeded up
Accelerating Universe
Faster expansion at large distances:
Expansion has slowed down
Decelerating Universe
Constant Expansion: $v = H_0\, d$
Distance
Recession Velocity

Accelerating Universe: Λ's Back?



Observations of distant SNe show departures from Hubble Law. Indicates Universe is ACCELERATING!

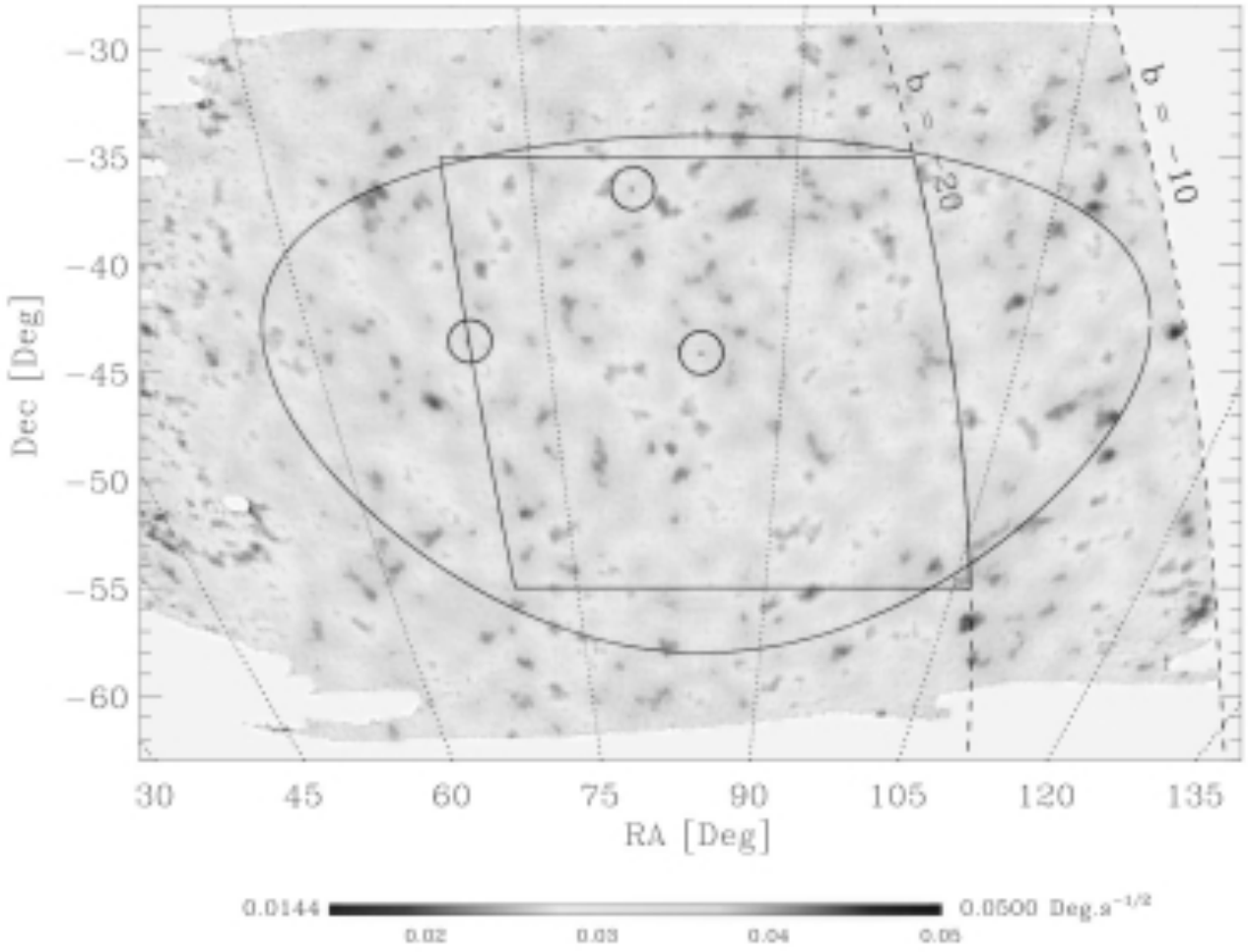
Need cosmological constant or DARK ENERGY to accelerate Universe

SNAP Satellite
SunperNova Acceleration Probe
Probe more distant SNe and test cosmological models…

The Shape of the Universe

- Fluctuations in the CMB indicate the sizes of primordial clumps that formed the first galaxy clusters
- COBE had very coarse resolution ~7 degrees
- Two balloon flights: BOOMERANG, MAXIMA
- Map Universe when it was ~300,000 years old (surface of last scattering of CMB photons)
- Compare observations with cosmological models of structure formation in flat, open, closed Universes

BOOMERANG Results



$\Delta T \sim 10^{-4}$ K

Hot spots ~1 degree: consistent with flat Universe, expand forever

Future Observations

- Very exciting time for cosmology: new satellites
- WMAP: Wilkinson Microwave Anisotropy Probe. Launched 2001, results now being published
- PLANCK surveyor (2007)
- Will map out whole sky in CMBR with high angular resolution
- Era of “precision cosmology”

- Look out for…
- SIRTF: Space Infrared Telescope Facility (August 2003)
- NGST: Next Generation Space Telescope (2007)

Supernova 1987A

- SN Type I: White dwarfs in binary systems
- SN Type II Core collapse of $M_* > 8M_\odot$
- 24 February 1987: Brightest SN in 400 years
- SN Type II in Large Magellanic Cloud, 170 thousand light years from Earth.
- Blue supergiant called Sanduleak -69 202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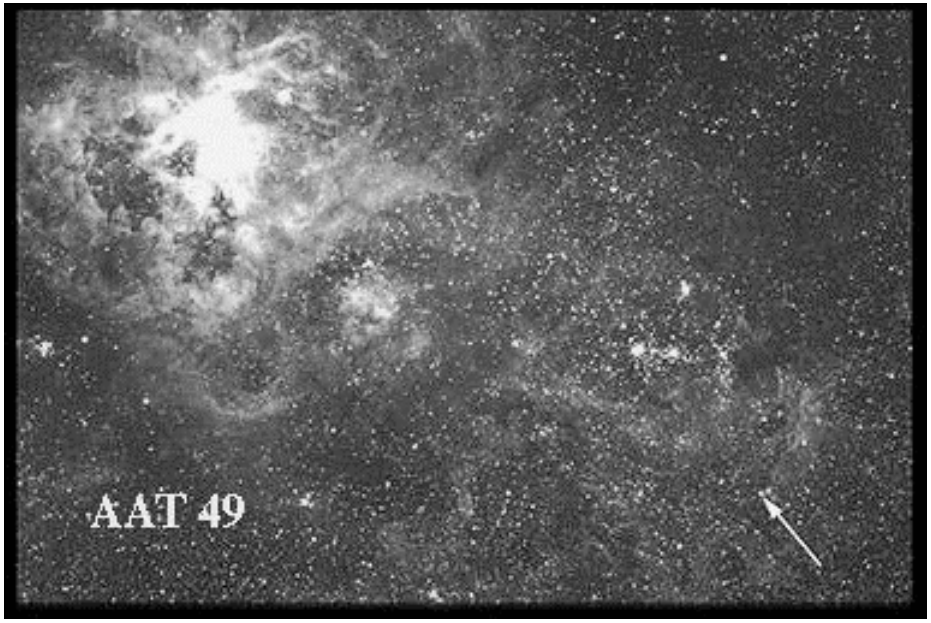
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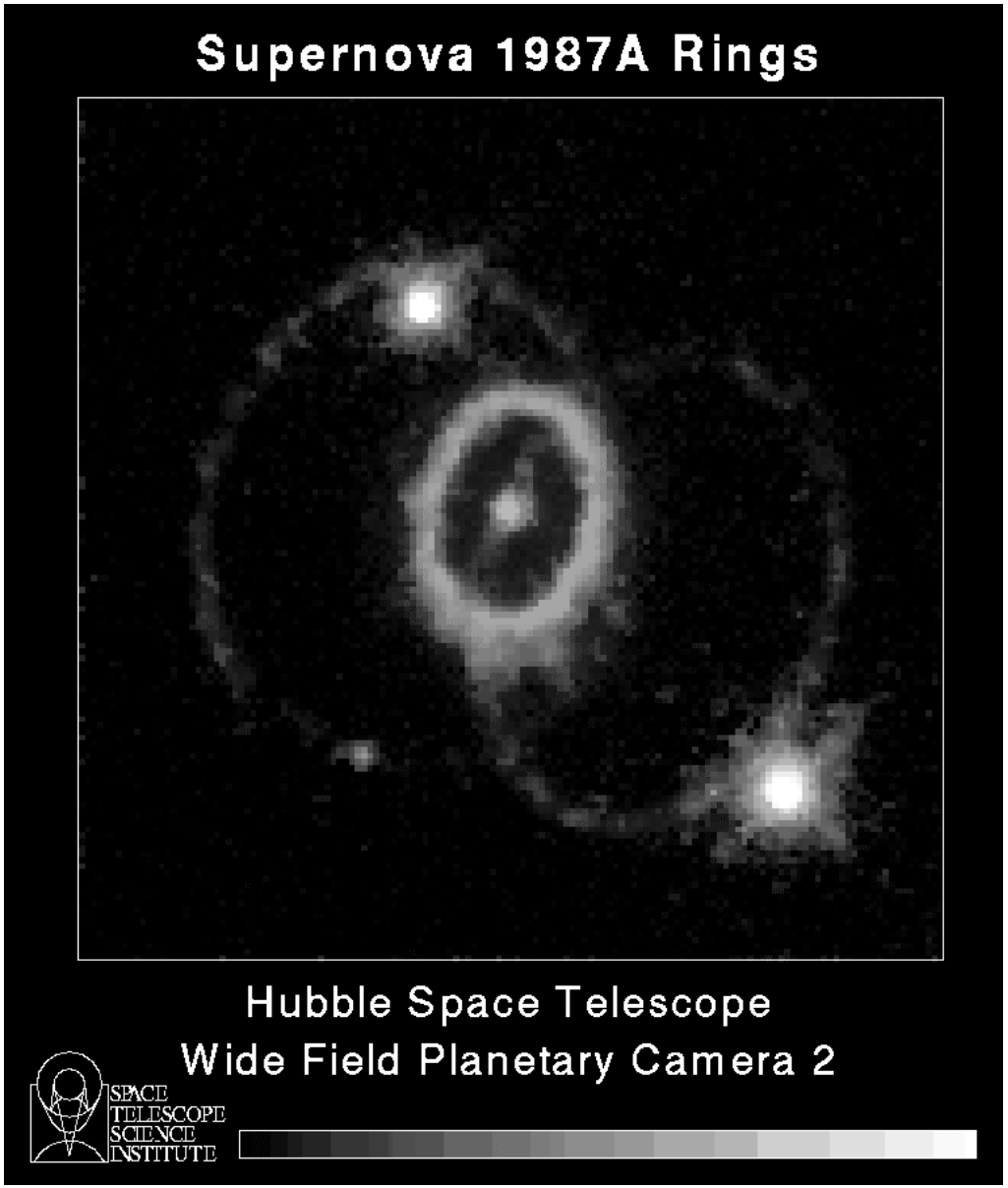
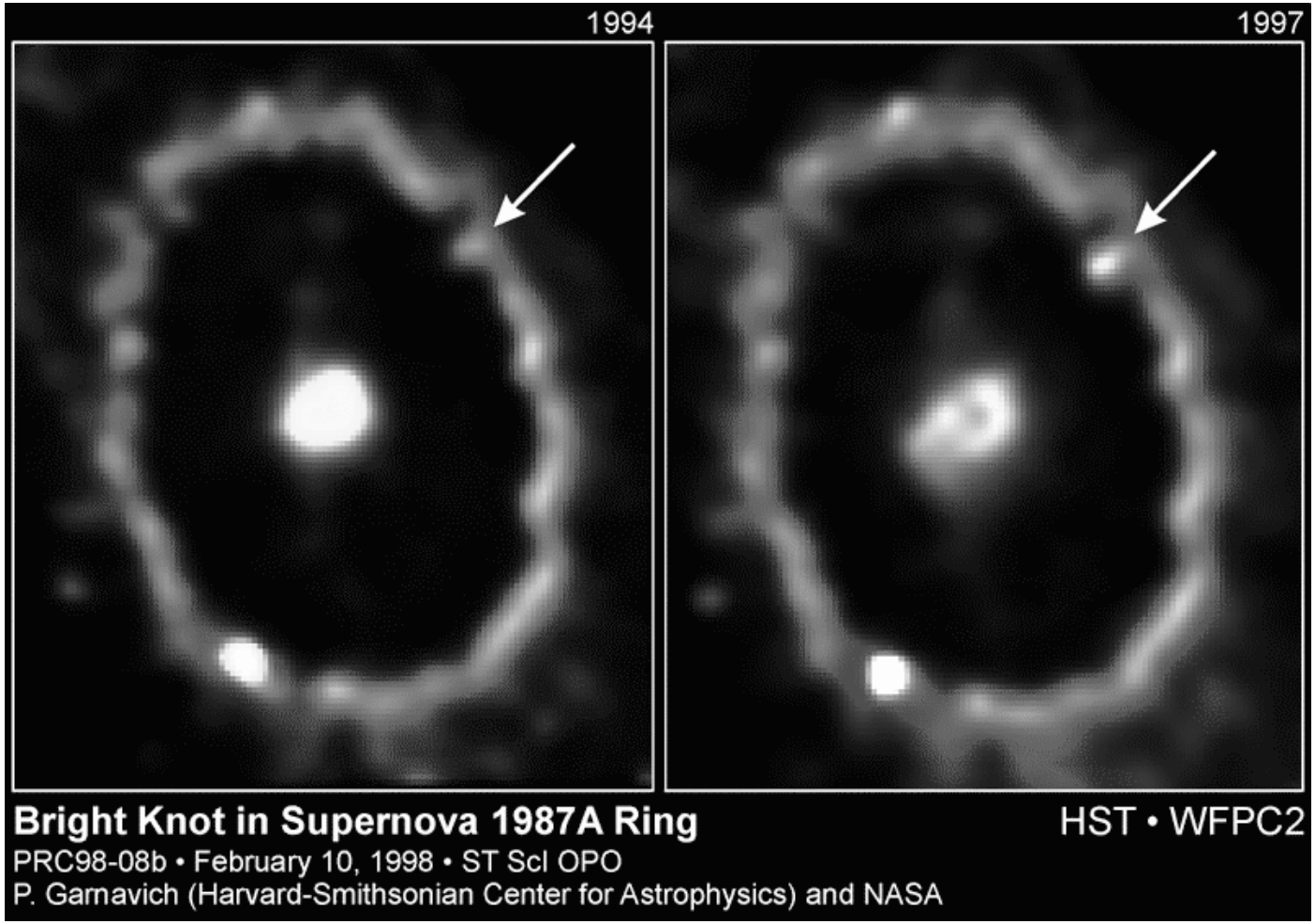
HST View of Supernova 1987A



Central ring from previous mass loss from progenitor star. Ionized by light from SN explosion, glows brightly.

But material from explosion should eventually hit ring and start brightening again…



The ring is starting to brighten again due to SN debris hitting it. Fireworks over next few years…