

Observing the Origin of the Universe

by

Ned Wright (UCLA)

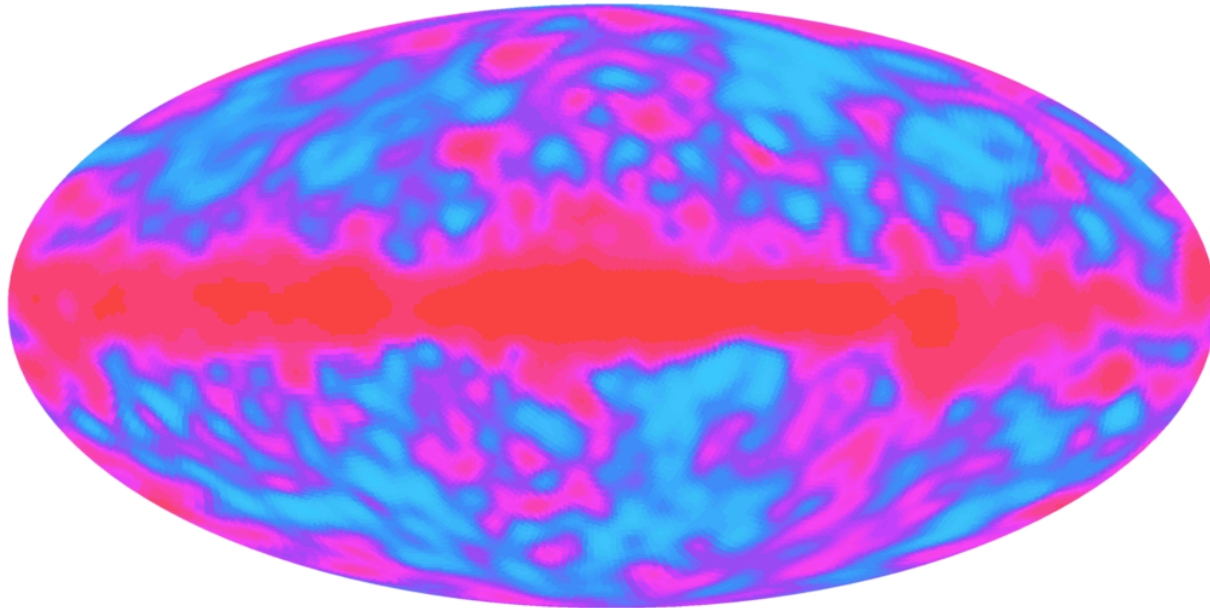
- <http://www.astro.ucla.edu/~wright/intro.html>
- <http://www.astro.ucla.edu/~wright/cosmolog.htm>
- <http://www.astro.ucla.edu/~wright/CMB-DT.html>
- <http://map.gsfc.nasa.gov>

A Big Media Splash in 1992:

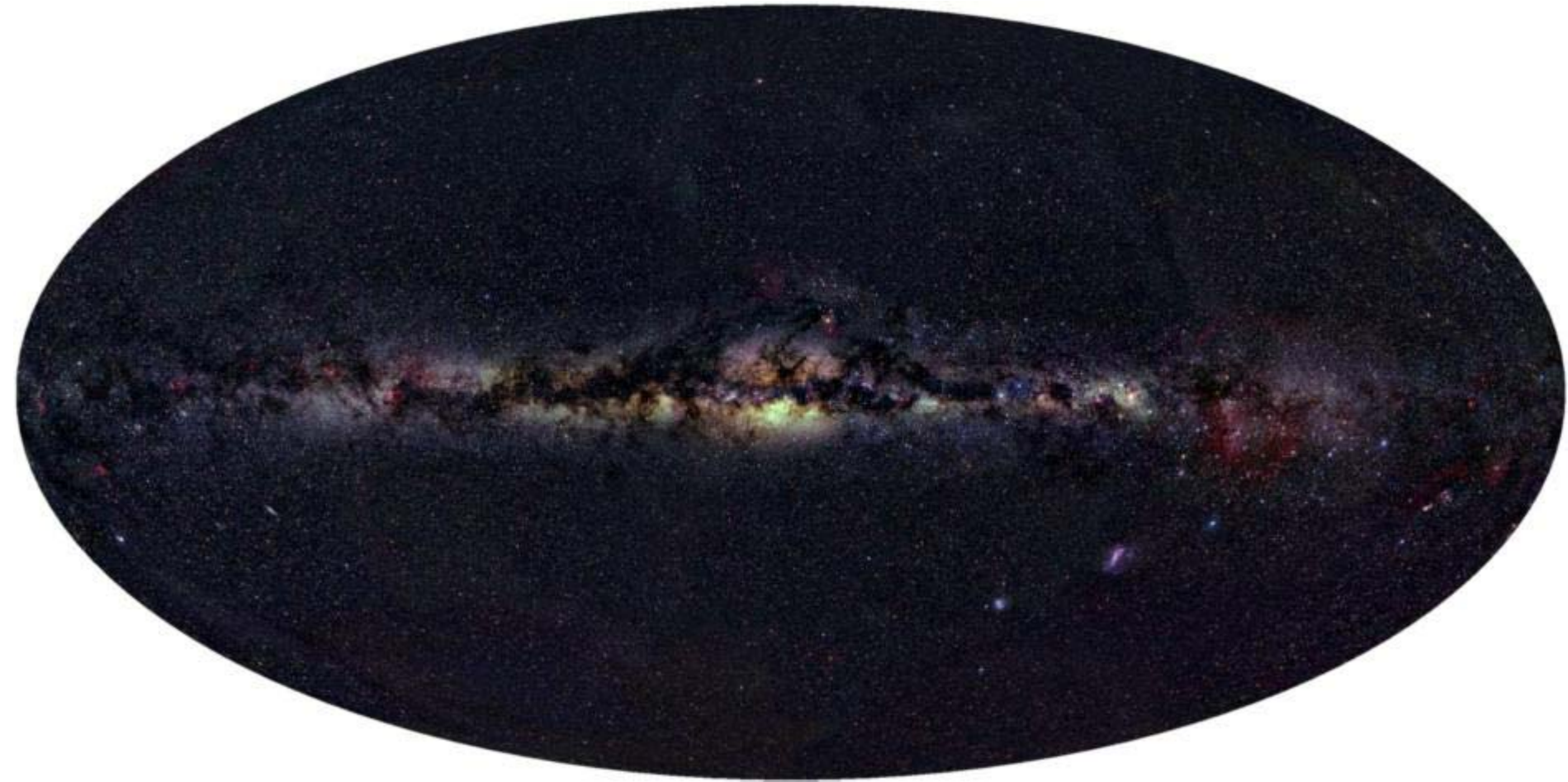
THE TIMES

25 April 1992

Prof. Stephen Hawking of Cambridge University, not usually noted for overstatement, said: “It is the discovery of the century, if not of all time.”

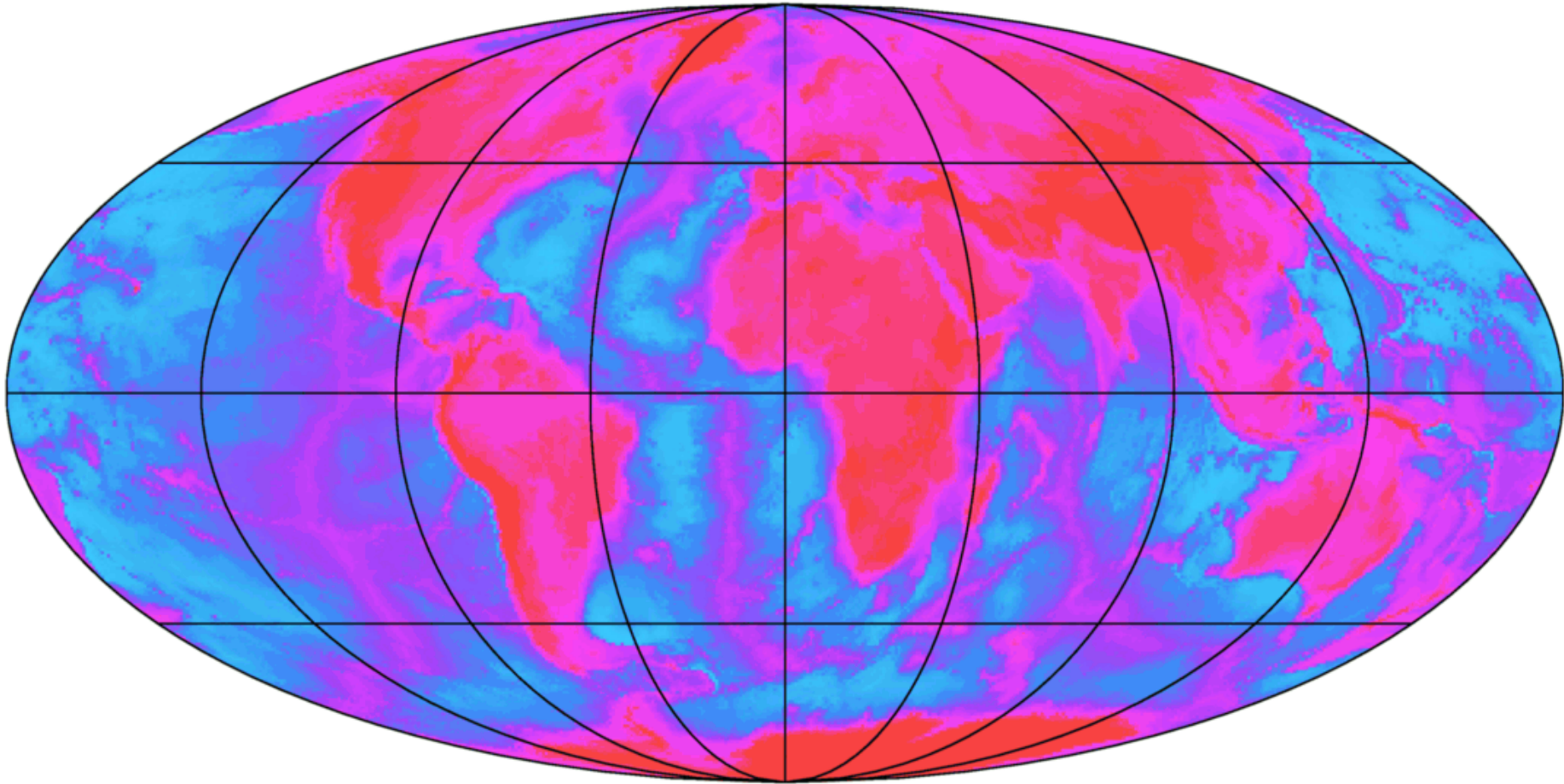


The oval is an all-sky map in galactic coordinates:



An equal area projection:

EARTH



Color Means Temperature

- Red areas are 30 μK hotter than average and the blue areas are 30 μK colder than average.
- As on the Earth map, color also maps into gravitational potential, with **red=high** and **blue=low**.

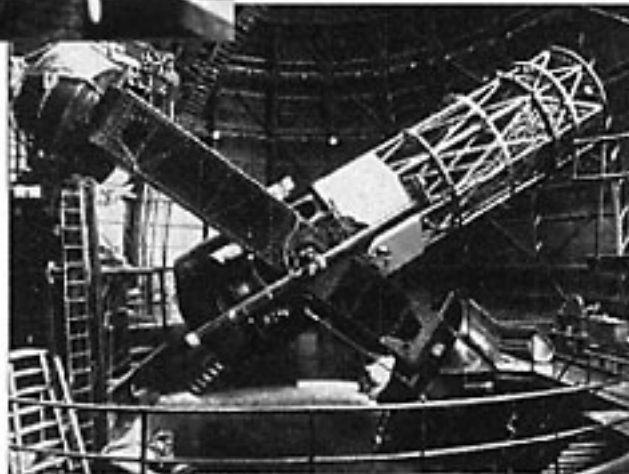
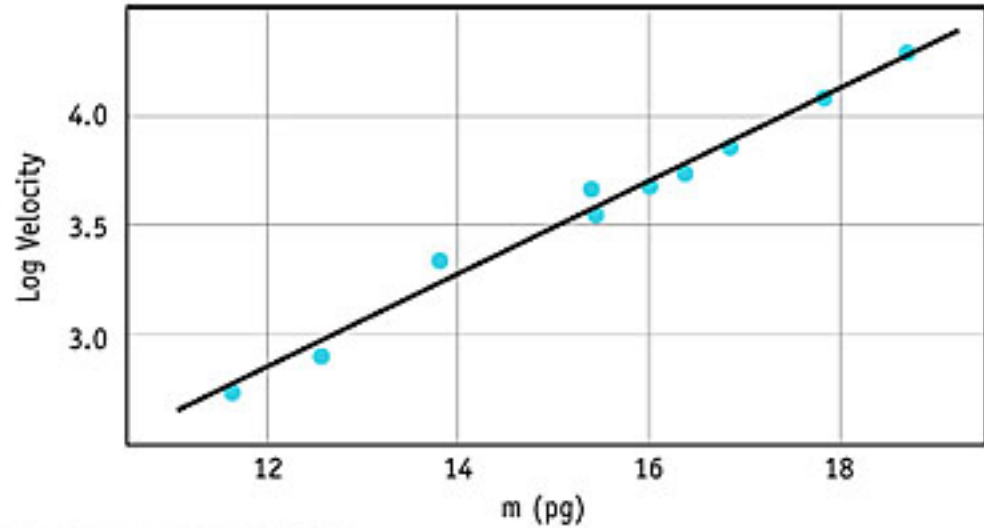
But really, what have we learned since 1905?

- Expansion of the Universe in 1929
- The Universe is homogeneous & isotropic.
- Dark matter in 1932
- Cosmic Microwave Background in 1964
- Accelerating Expansion in 1998

Discovery of the Expanding Universe



Edwin Hubble



Mt. Wilson
100 Inch
Telescope

Linear v vs D law does not distort



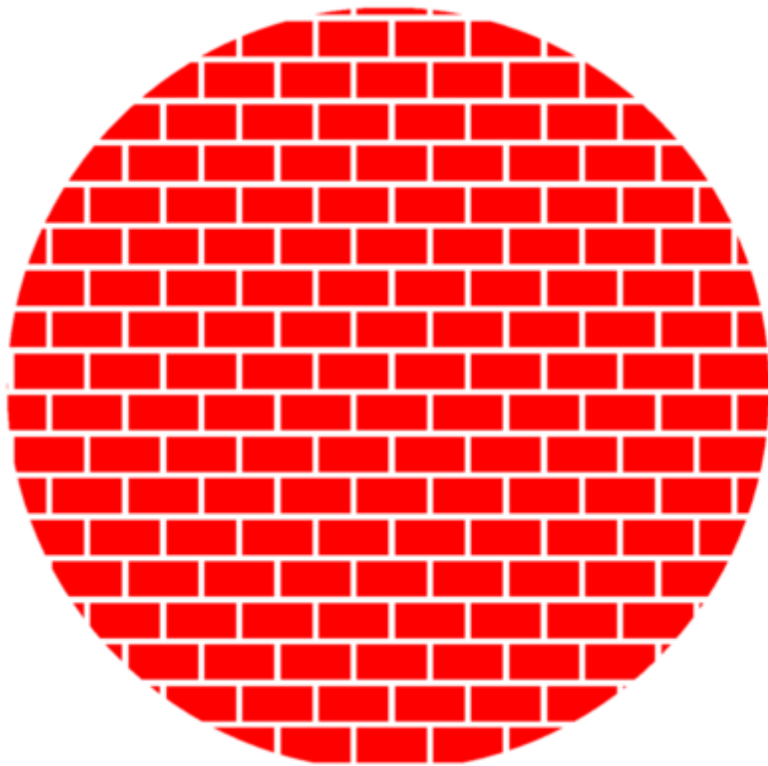
$$v \propto D^0$$

$$v \propto D^1$$

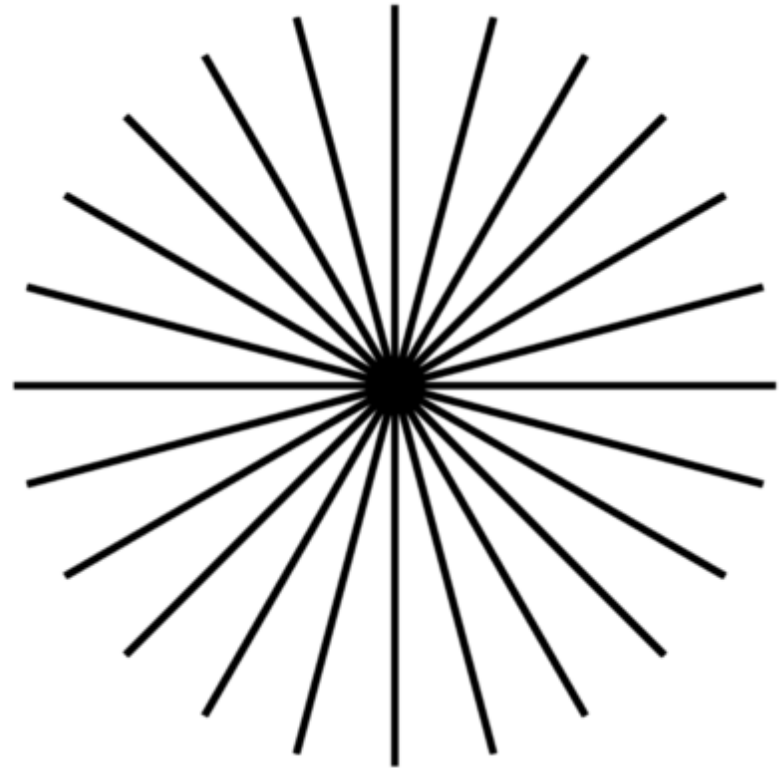
$$v \propto D^2$$

The Cosmological Principle

- The Universe is homogeneous and isotropic



Not isotropic



Not homogeneous

On the CN non-discovery

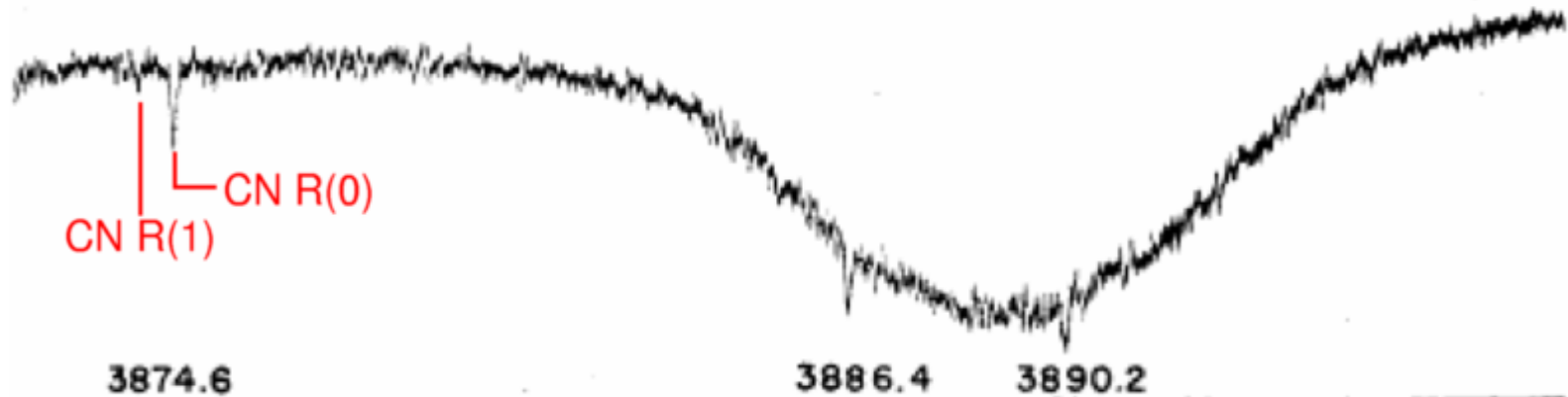


Plate 3 of Adams (1941, ApJ, 93, 11-23) reporting McKellar's work

Herzberg (1950) in *Spectra of Diatomic Molecules*, p 496:

“From the intensity ratio of the lines with $K=0$ and $K=1$ a rotational temperature of 2.3° K follows, which has of course only a **very restricted meaning.**”

There went Herzberg's [second] Nobel Prize.

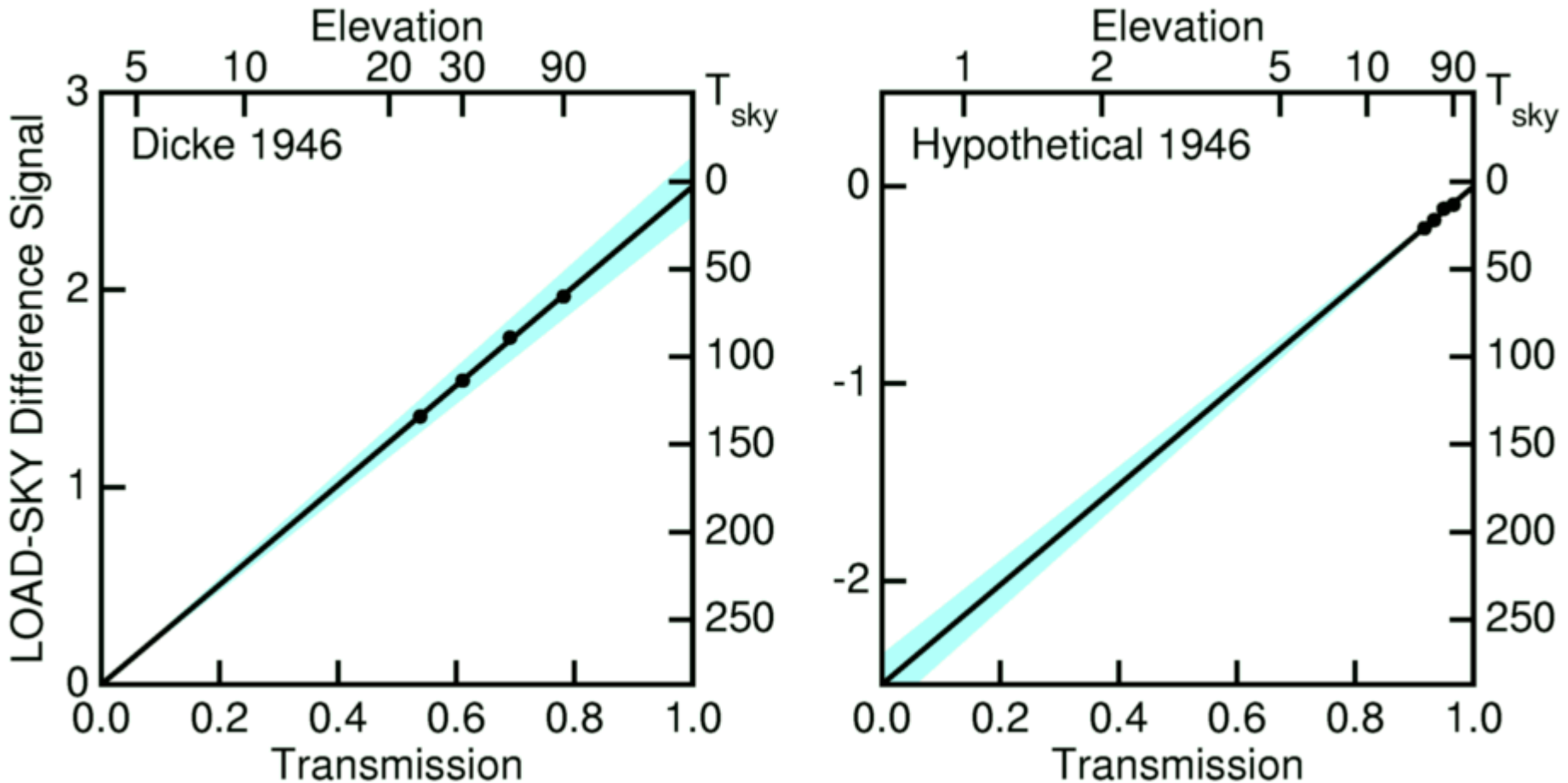
Bob Dicke missed the Nobel Prize

- Dicke *et al.* (1946) gave $T_0 < 20$ K.
- Dicke, Peebles, Roll & Wilkinson (1965) were trying to measure T_0 when scooped by Penzias & Wilson (1965).



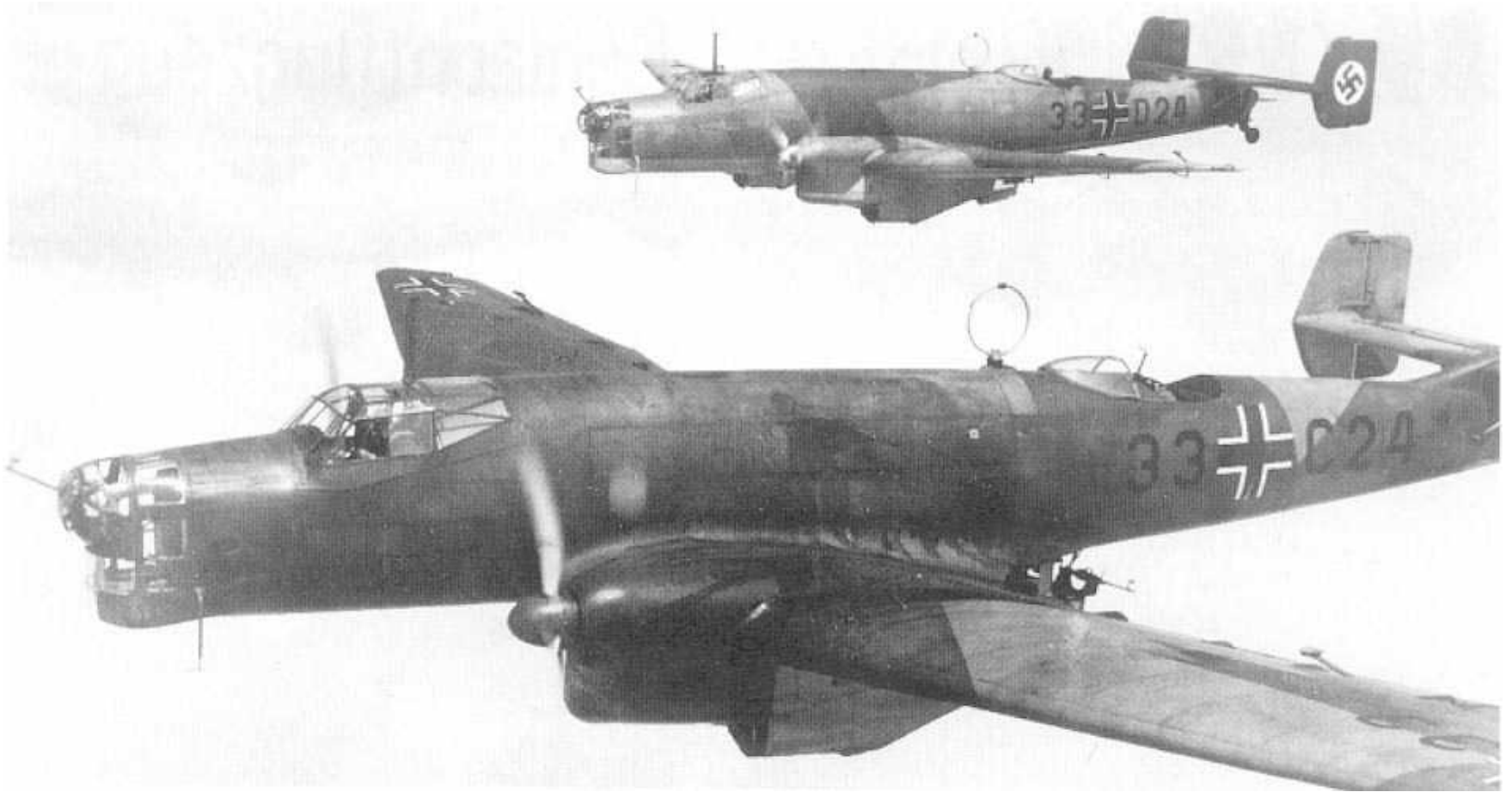
Fig. 1. Early 1.5 cm microwave radiometer atop a Radiation Laboratory building at M.I.T. Measurements are being made by (left to right) E. Beringer, R. Kyle, A. Vane, and R. H. Dicke. Dicke is shaking the “shaggy dog” — a piece of absorbing material used as a 295 K calibration source.

CMB Measurable in 1940's

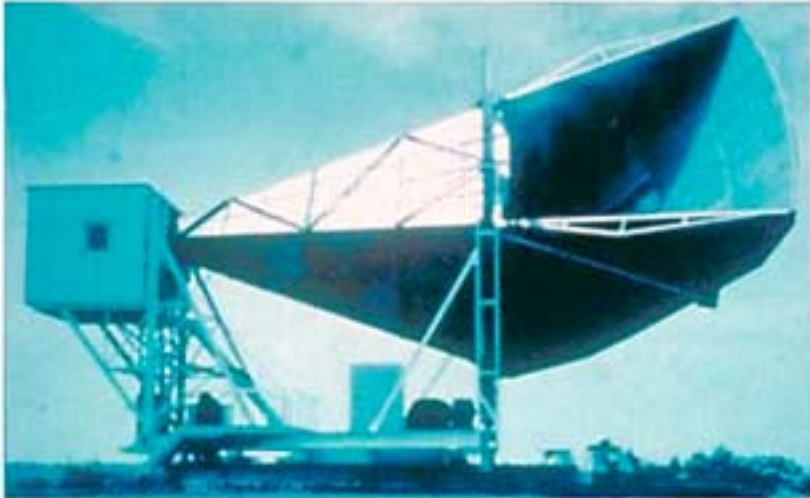


- Dicke used a room temperature reference load so there was a large difference at the zenith and a 3% calibration uncertainty was a 10 K uncertainty in T_0 .

But Dicke was distracted by WW II



Discovery of the Cosmic Microwave Background



Microwave Receiver



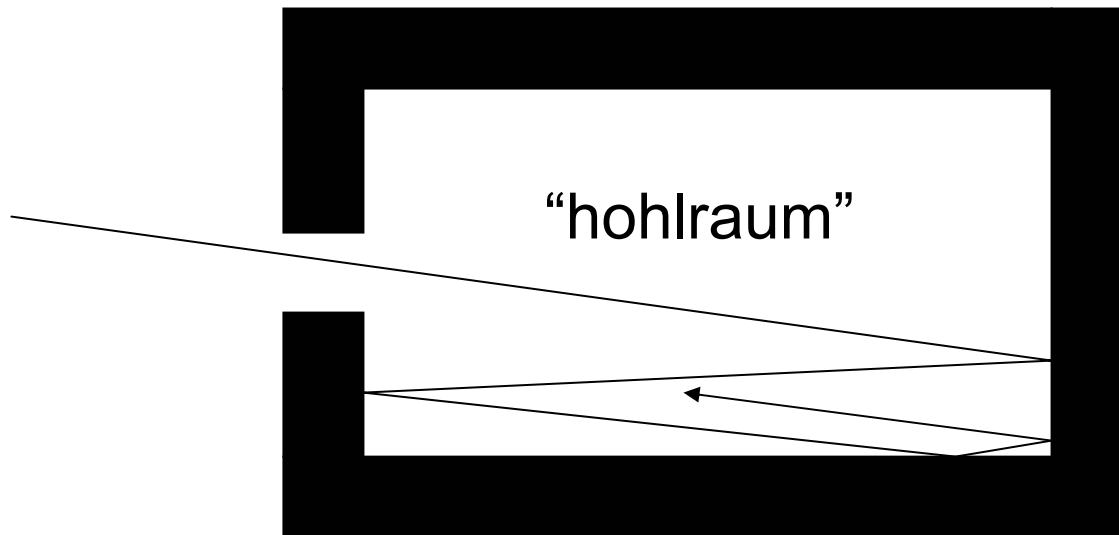
Arno Penzias



Robert Wilson

CMB Spectrum is a Blackbody

- A blackbody is an opaque, non-reflective, isothermal body.
- The best laboratory blackbodies use cavities with small entrances so light is almost trapped inside, giving very small reflections.



Personal History: my FIRAS breadboard at MIT

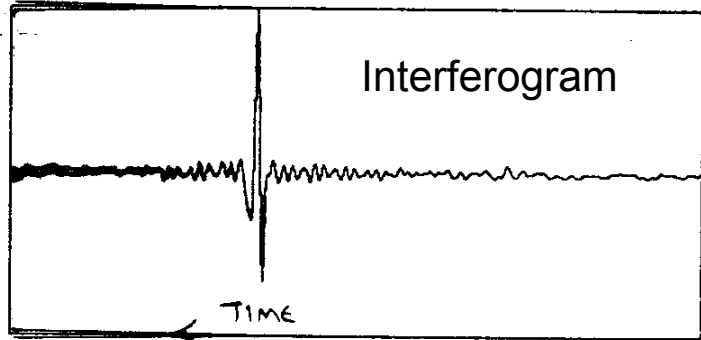
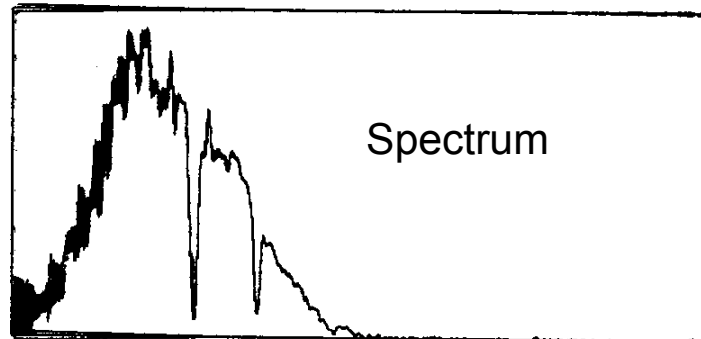
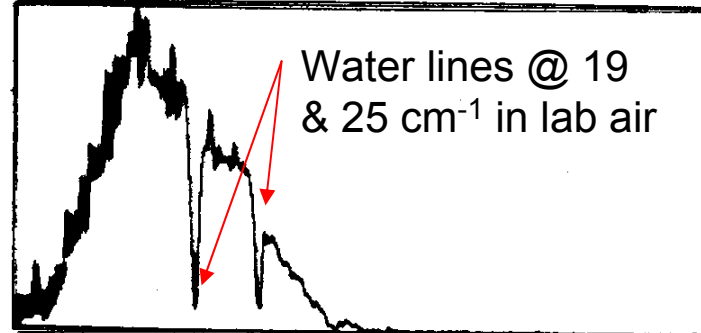
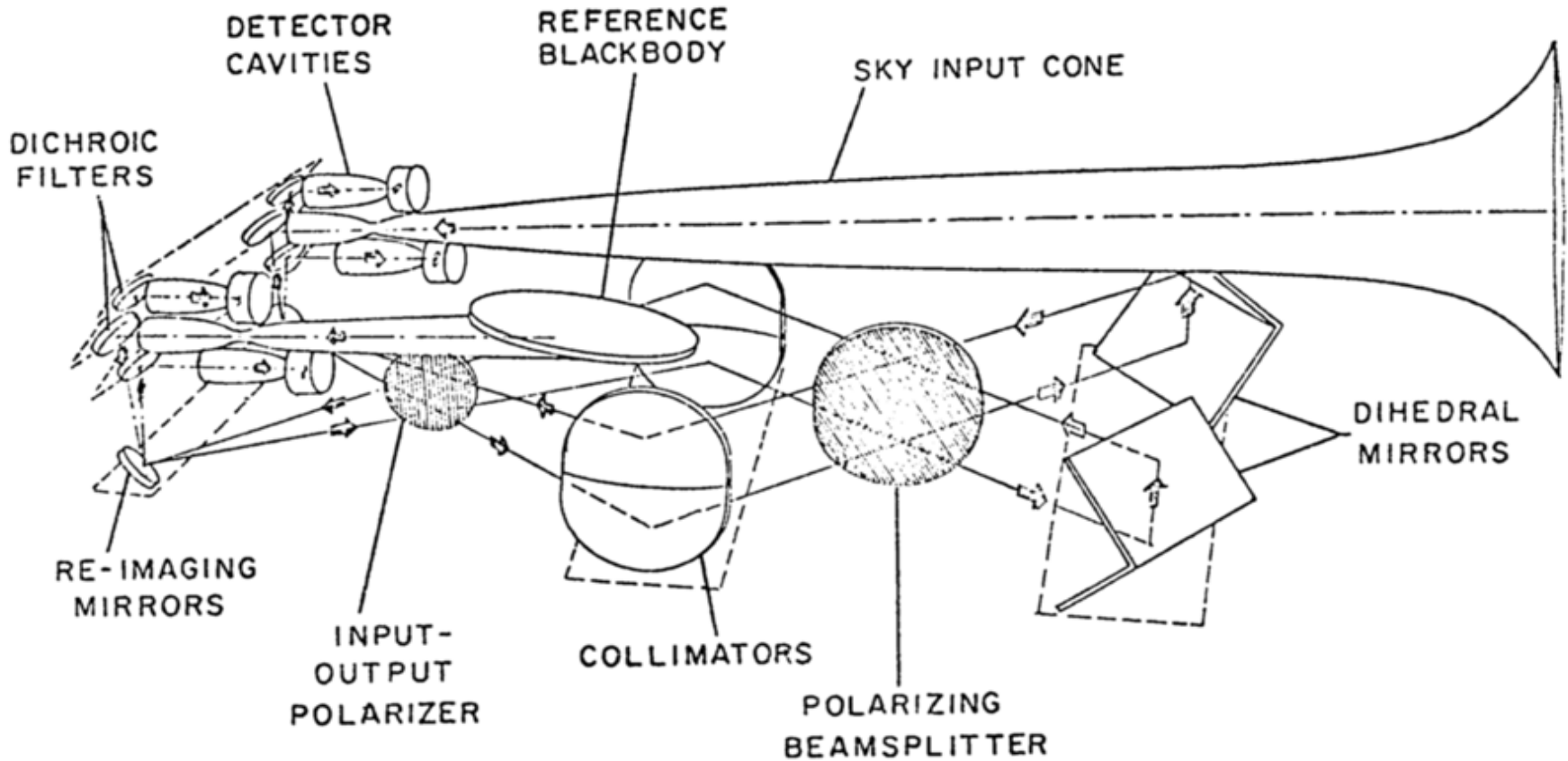
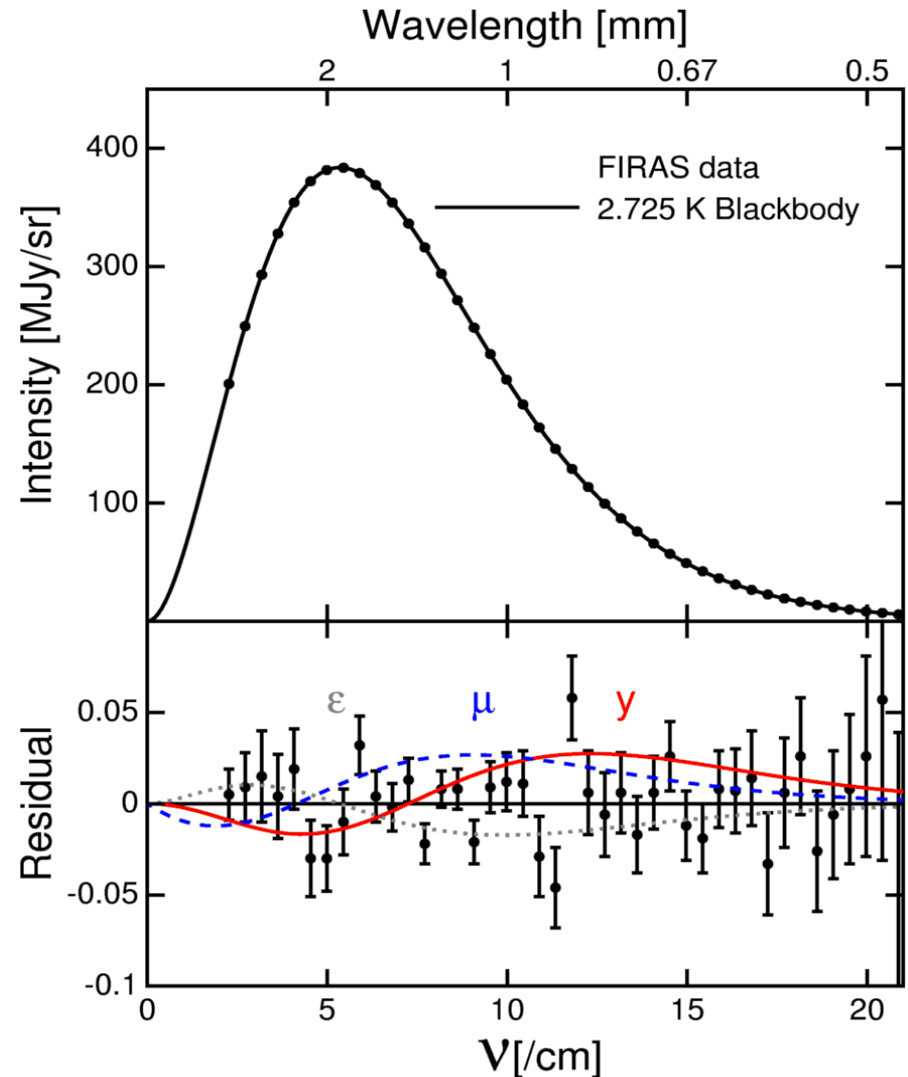


Diagram of FIRAS



Spectrum is Very Black

- Residuals in lower panel are what FIRAS measured: Sky-Blackbody
- RMS residual 50 parts per million
- Energy from hot electrons into CMB < 60 parts per million

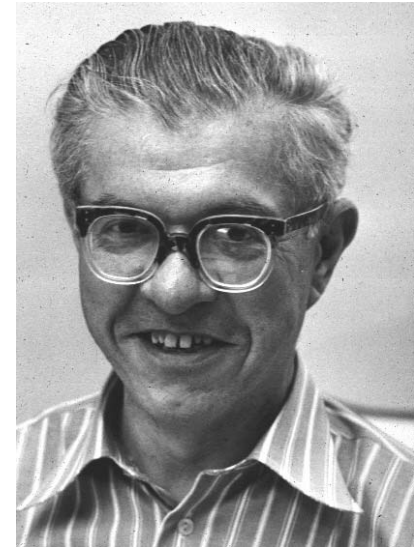


CMB Disproved the Steady State

- A blackbody spectrum comes from an opaque, isothermal source.
- The Universe now is transparent, not opaque.
- The Universe now has a wide range of temperatures.
- Therefore, the Universe must have evolved from an opaque, isothermal state into its present condition, which contradicts the Steady State hypothesis.

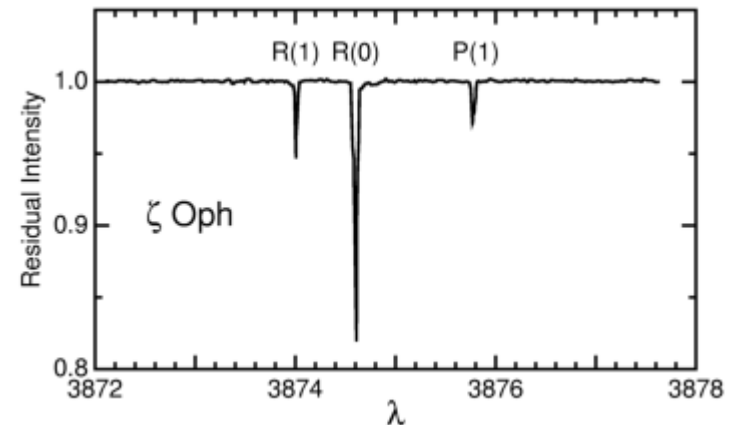
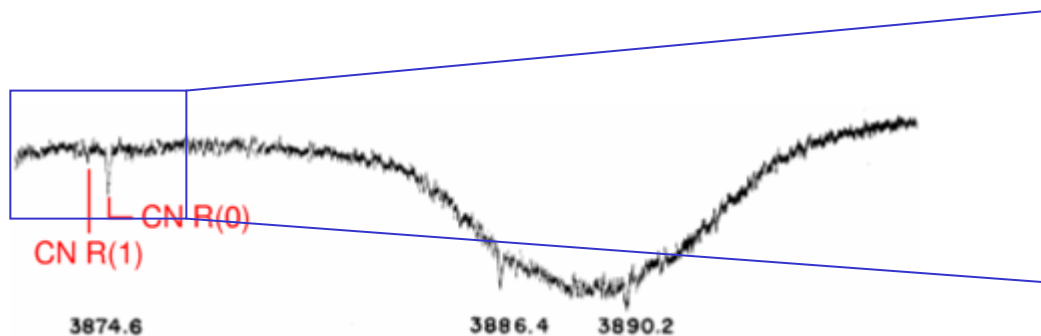
Fred Hoyle missed the Nobel Prize

- Hoyle (1950), reviewing a book by Gamow & Critchfield: “[the Big Bang model] would lead to a temperature of the radiation at present maintained throughout the whole of space much greater than McKellar's determination for some regions within the Galaxy.”
- This book implied $T_0 = 11$ K. Gamow in 1956 *Scientific American* implied 6 K. Alpher & Herman explicitly gave 5 K or 1 K in 1949 *Phys Rev*.
- Nobody followed this up!



CN followup after Penzias & Wilson

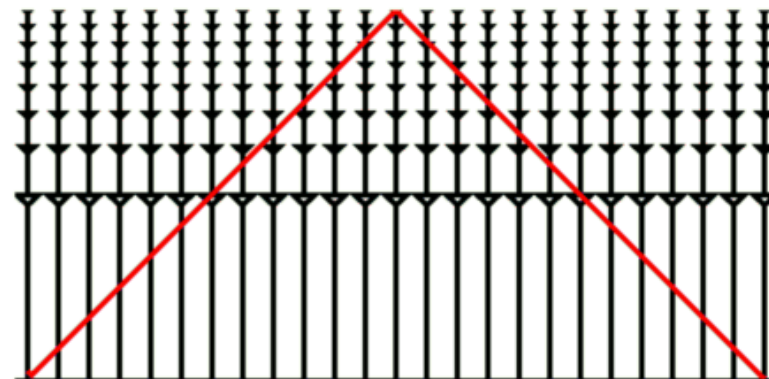
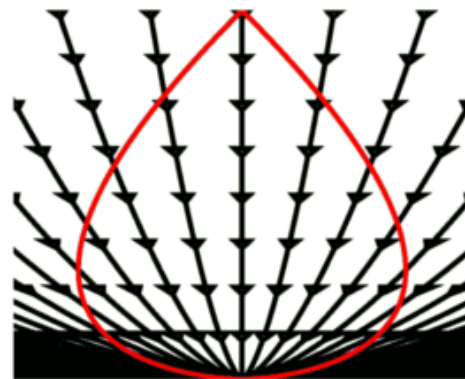
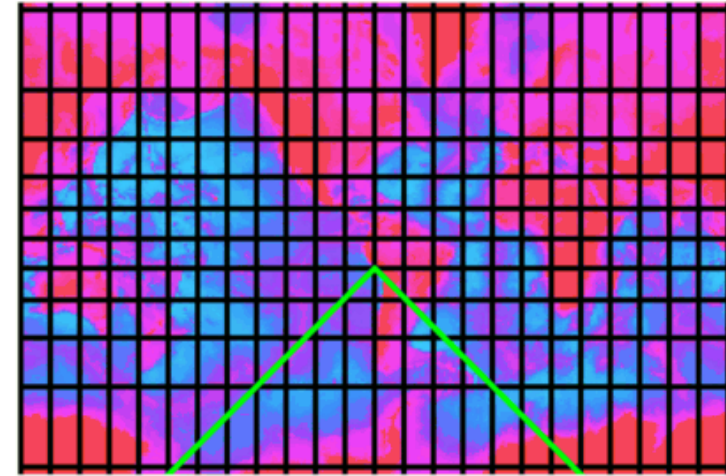
- Reworking and reobserving the CN lines gave 2.78 ± 0.10 K at 2.64 mm. (Thaddeus, 1972, ARAA, 10, 305-334)
- By 1993, 2.73 ± 0.03 K (Roth, Meyer & Hawkins* 1993)



(*) was at LLNL (UCLA PhD's)

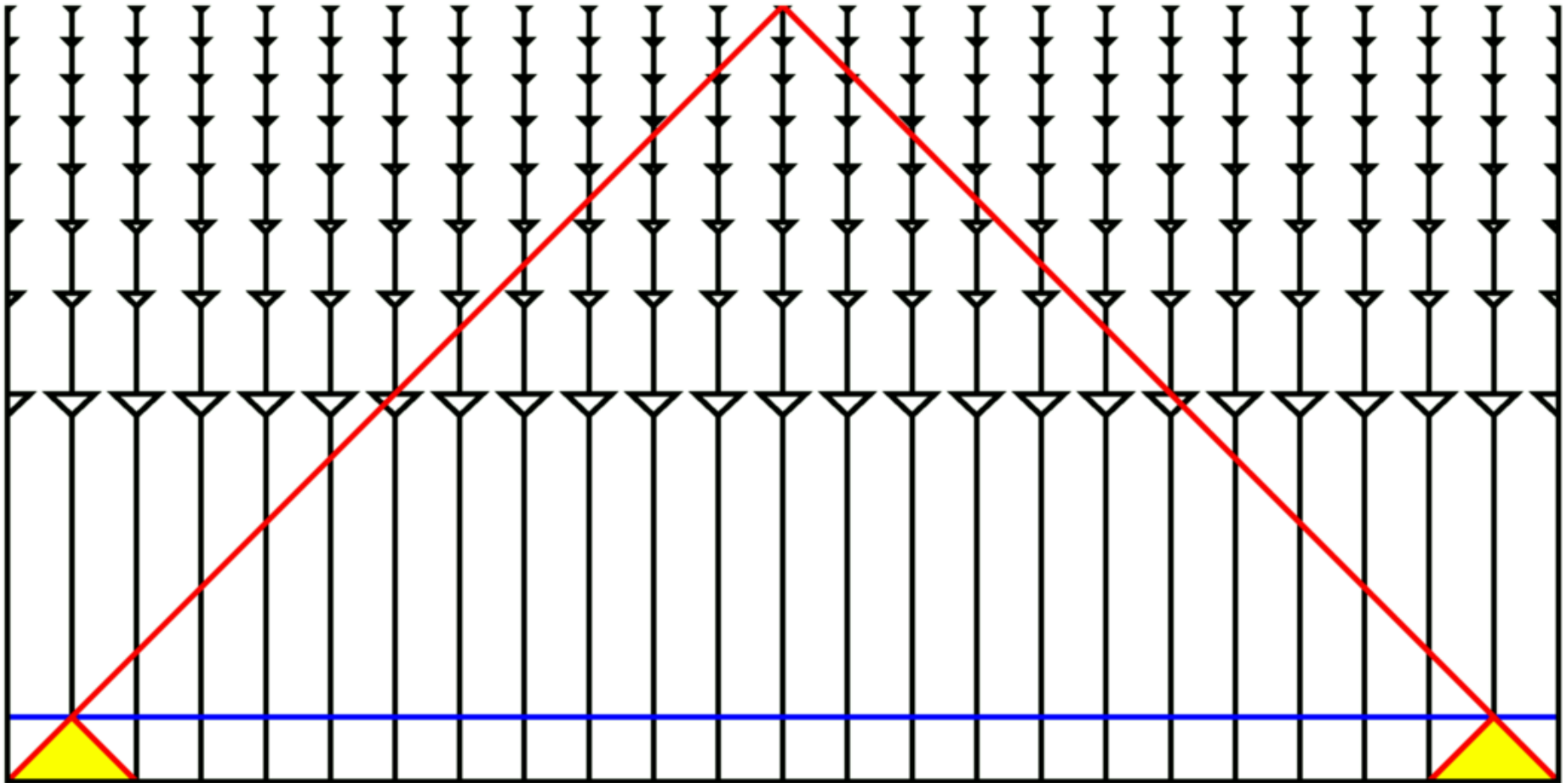
“Normal” vs Conformal ST Diagram

- Constant SE course is a curve on the globe but a straight line on the conformal Mercator map.
- Constant speed-of-light is a curve on the “normal” space-time diagram but a straight line on the conformal diagram.

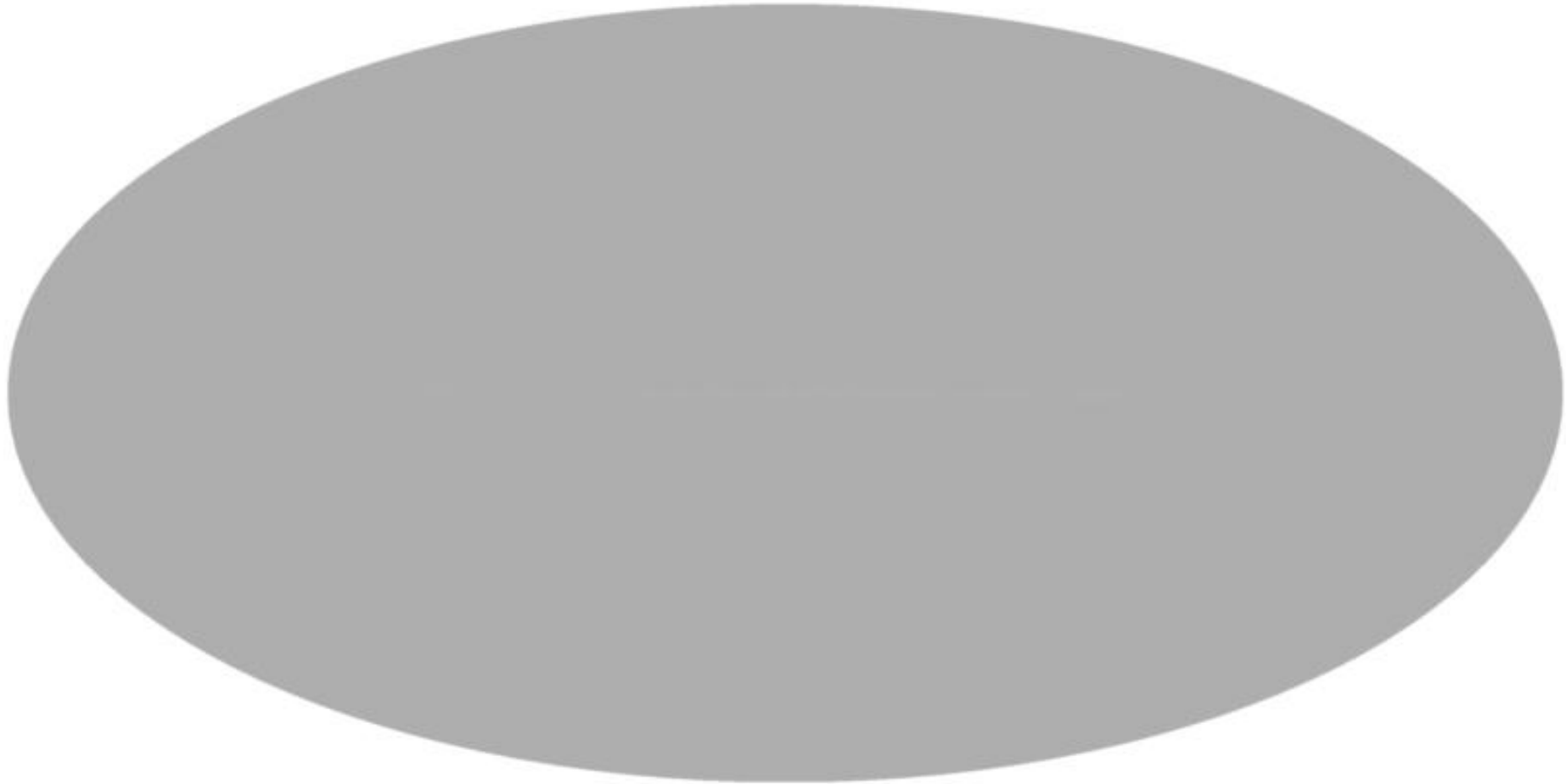


Horizon Problem

Regions seen on left and right of sky can only be influenced by the yellow areas in their past lightcones. These are disjoint, so why is the CMB T the same in both?

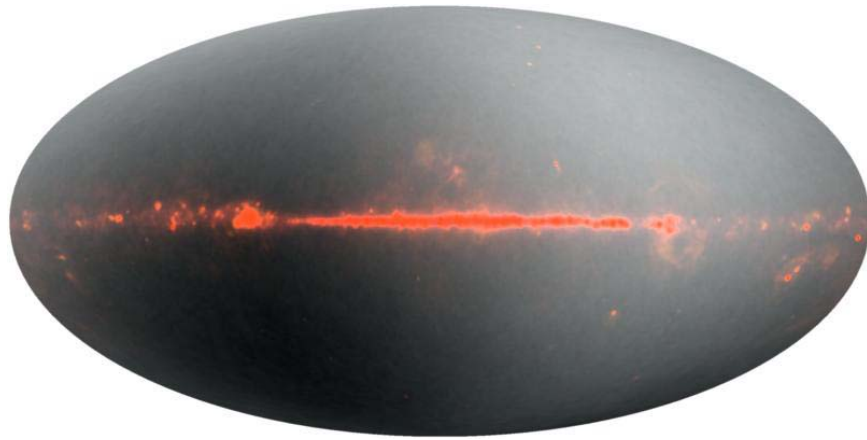


True Contrast CMB Sky



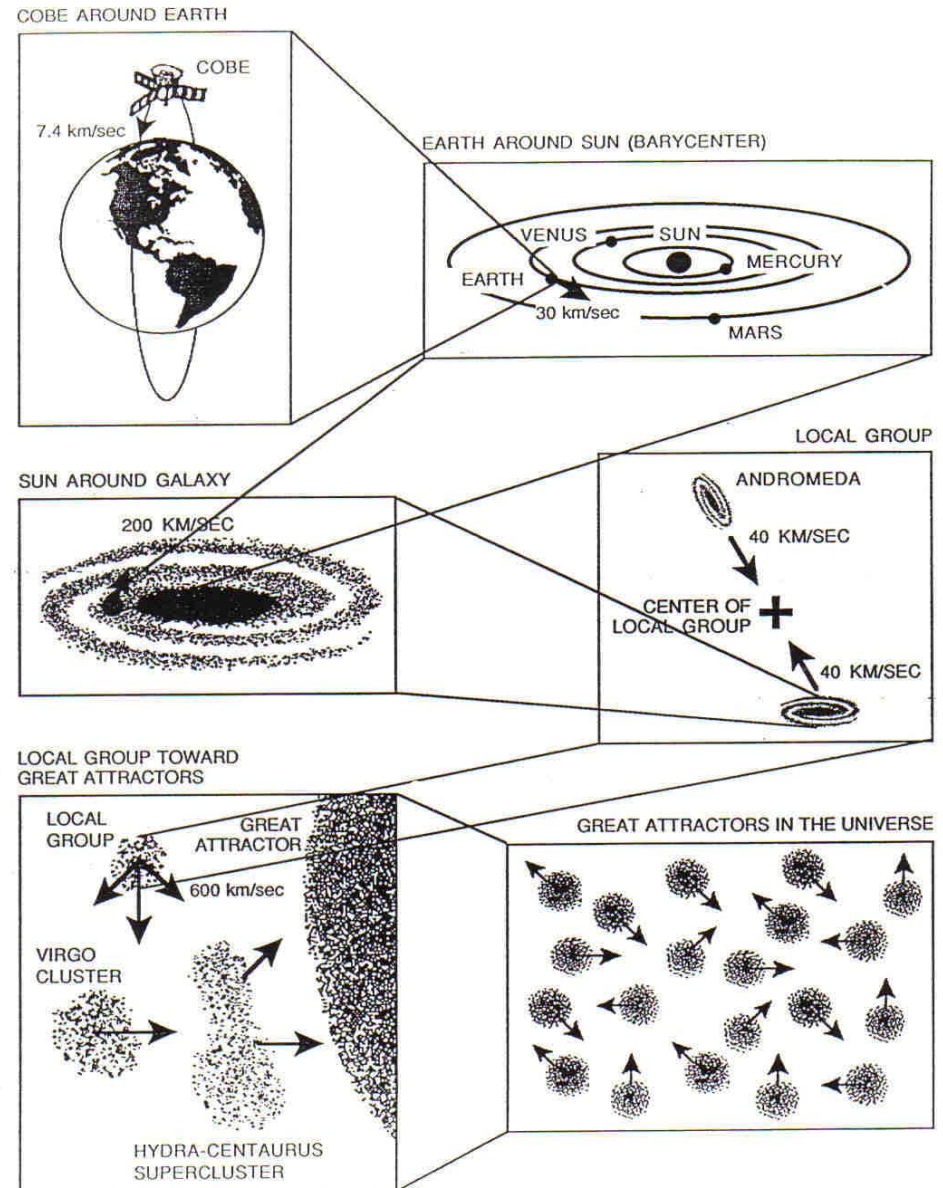
33, 41 & 94 GHz as RGB, 0-4 K scale

Enhanced Contrast:

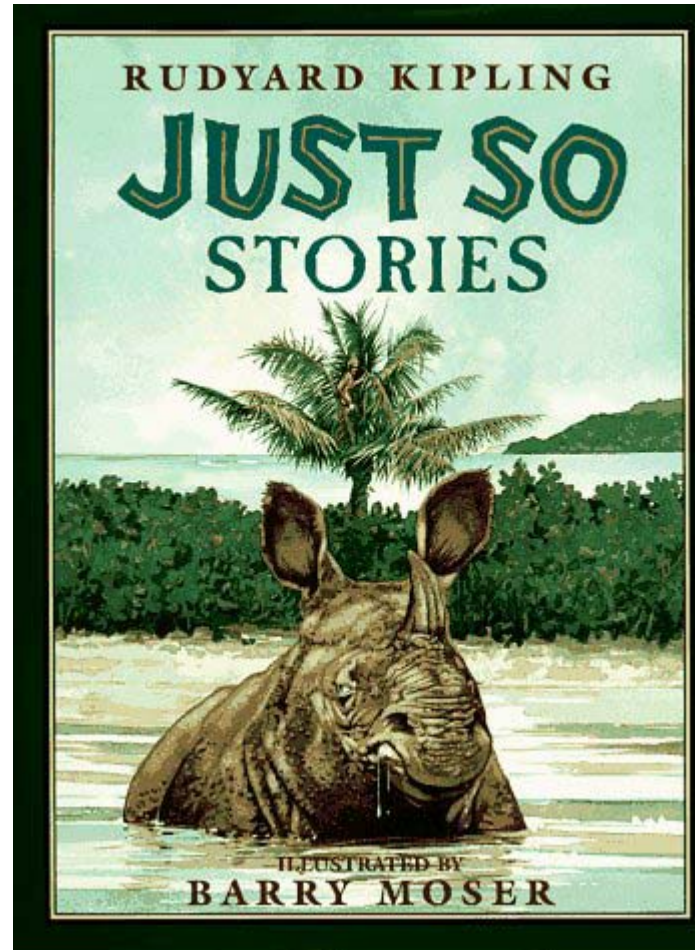


- Conklin 1969 - 2σ
- Henry 1971 - 3σ
- Corey & Wilkinson 1976 - 4σ
- Smoot *et al.* 1977 - 6σ

VELOCITY COMPONENTS OF THE OBSERVED CMB DIPOLE

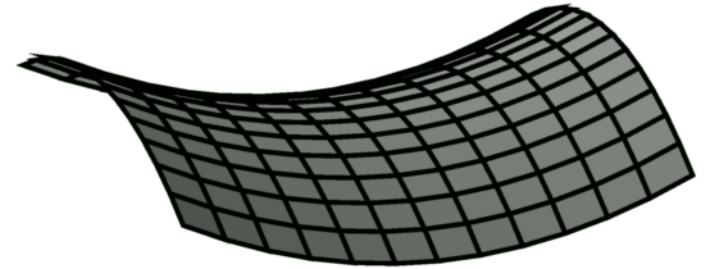
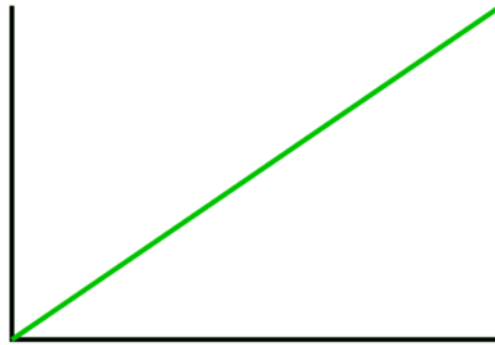


Just So?

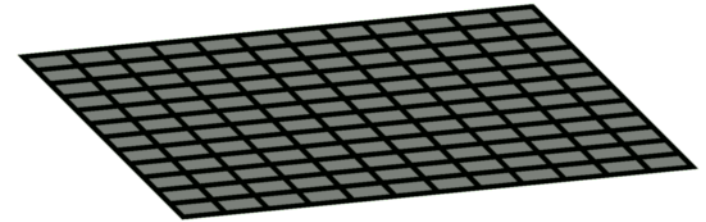
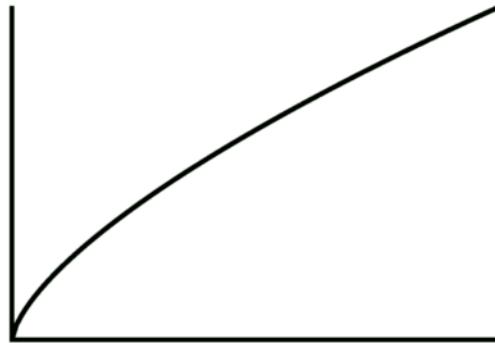


Geometry, Density, Destiny

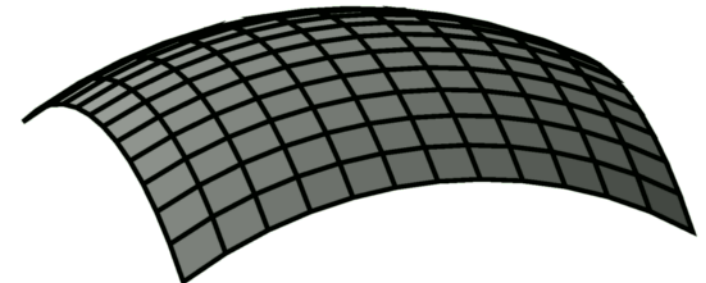
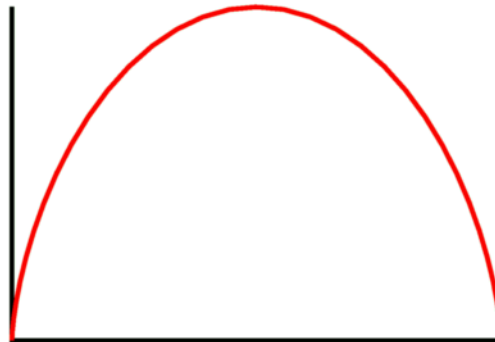
Density $<$ critical,
negative curvature,
expand forever



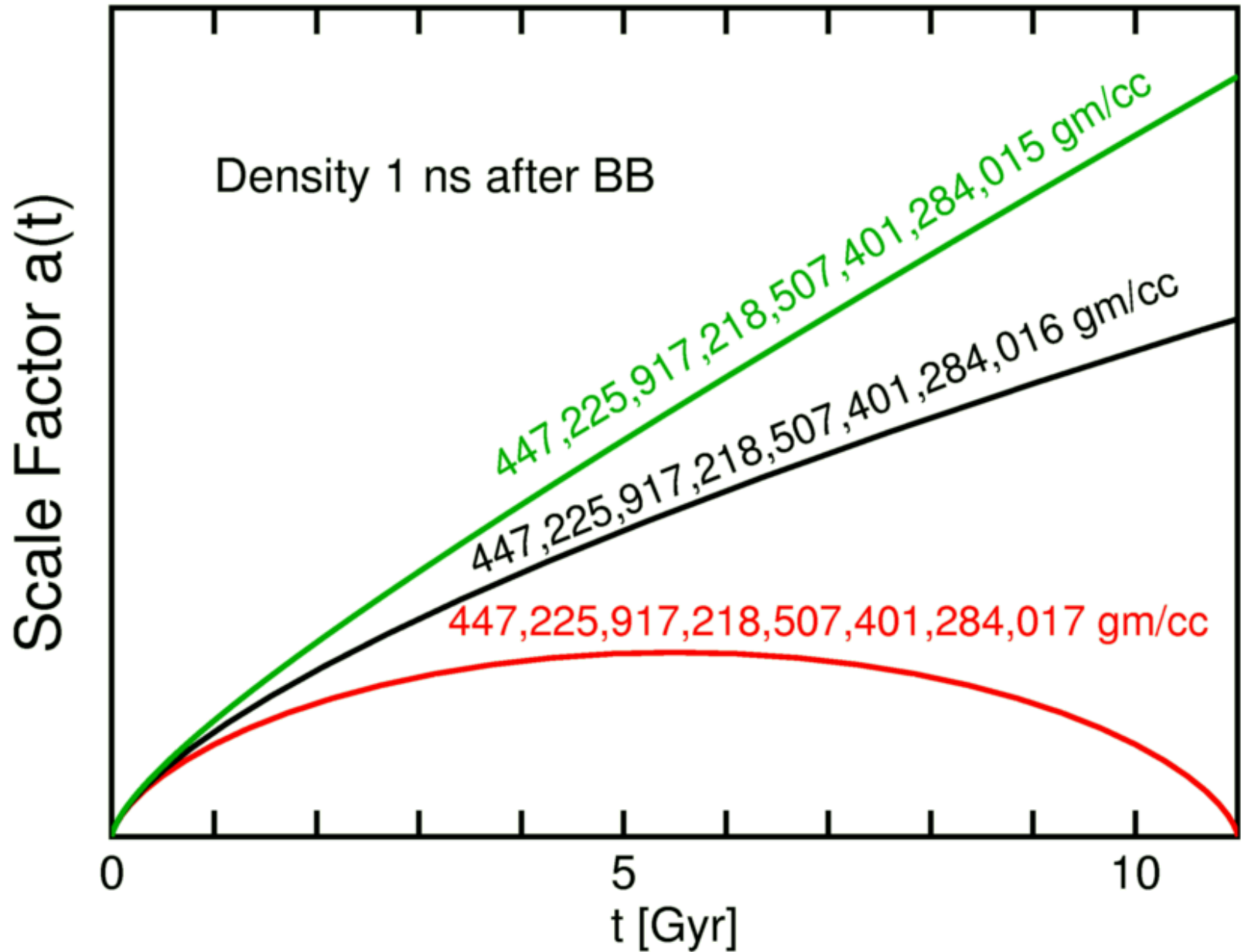
Density = critical,
zero curvature,
expand forever



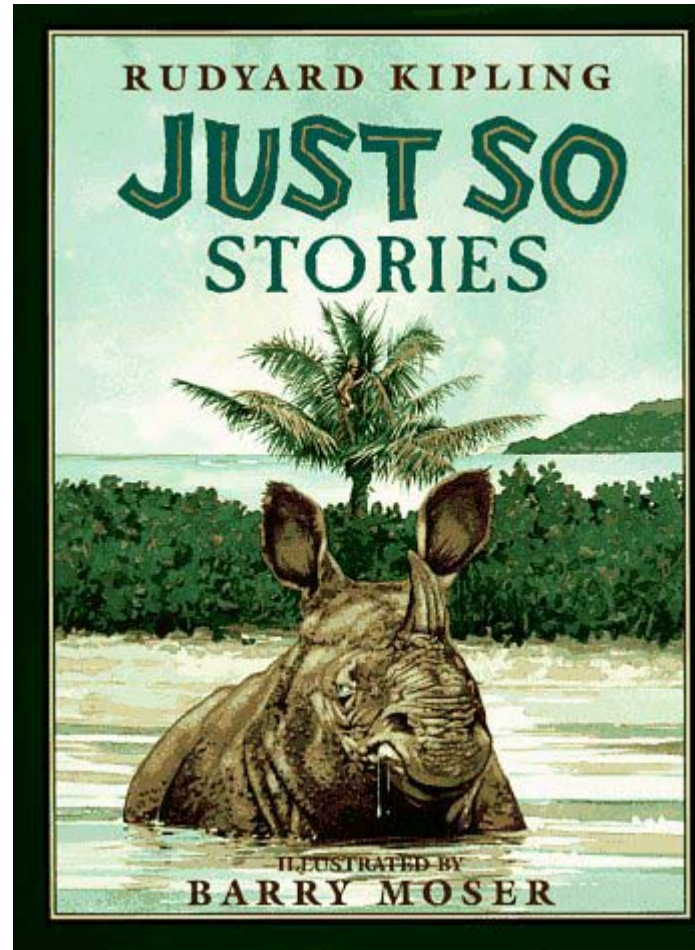
Density $>$ critical,
positive curvature,
recollapse



Density must be fine-tuned

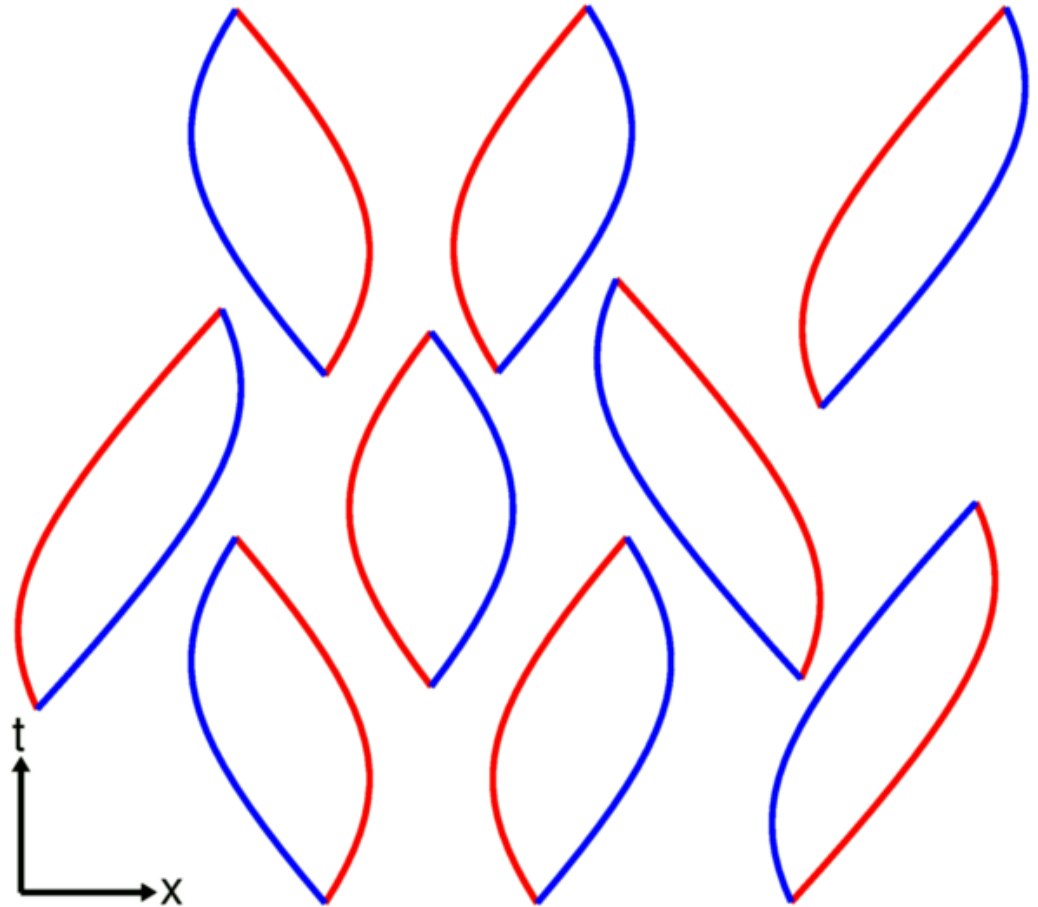


Just So?



Inflation to the rescue!

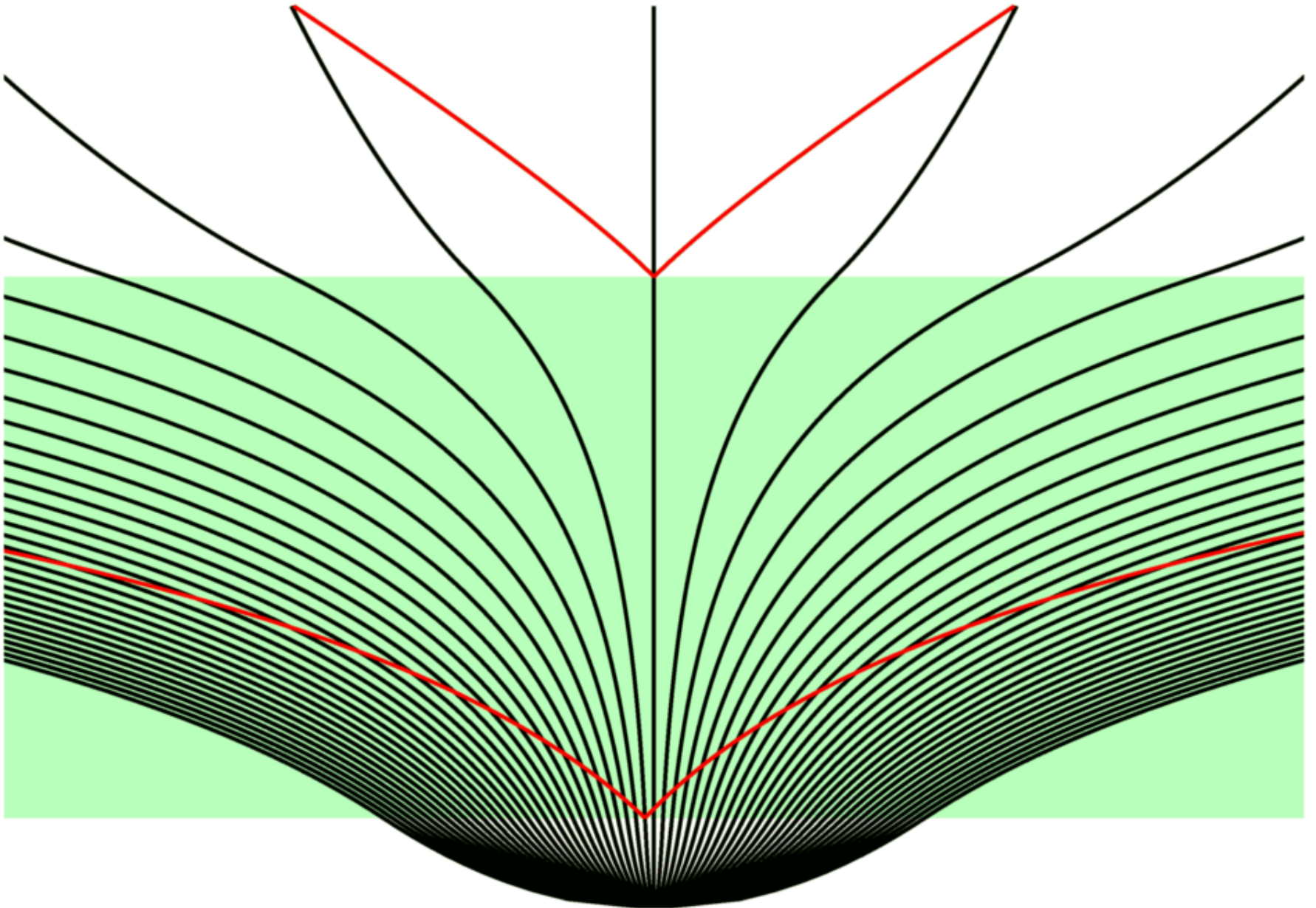
- A vacuum energy density is equivalent to Einstein's cosmological constant: Λ
- Quantum fluctuations could lead to a vacuum energy density.



Vacuum Energy is Repulsive

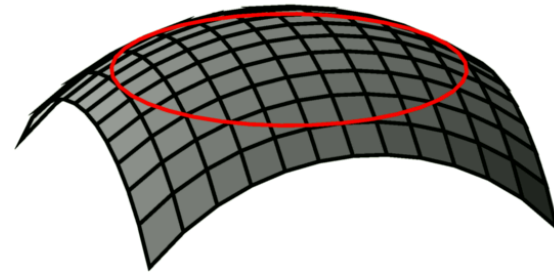
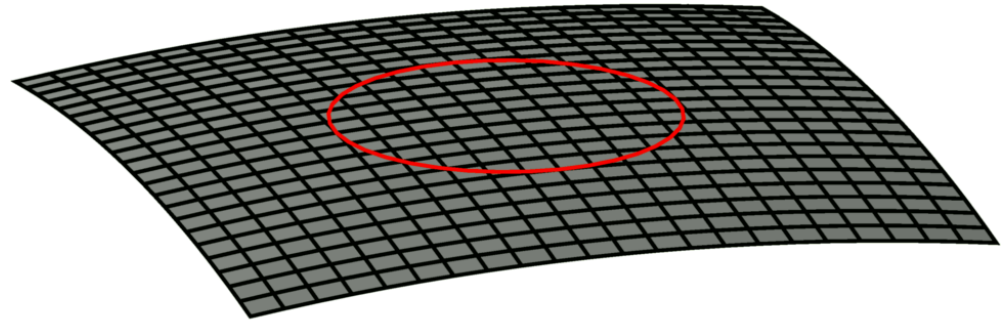
- In General Relativity energy has gravitational effects.
- A pressurized volume has energy, PV .
- Vacuum energy density must have a negative pressure, $P = -\rho c^2$.
- If $P = -\rho c^2$ the stress-energy tensor of the vacuum is Lorentz invariant so you cannot measure your velocity relative to the vacuum.
- Net gravity from positive vacuum energy density plus negative pressure is repulsive.

Repulsion leads to exponential growth



Solving Horizon & Flatness-Oldness

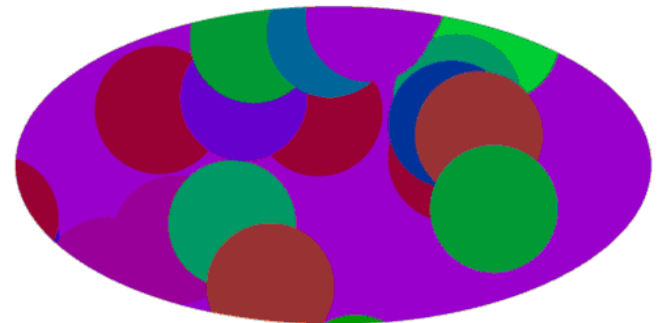
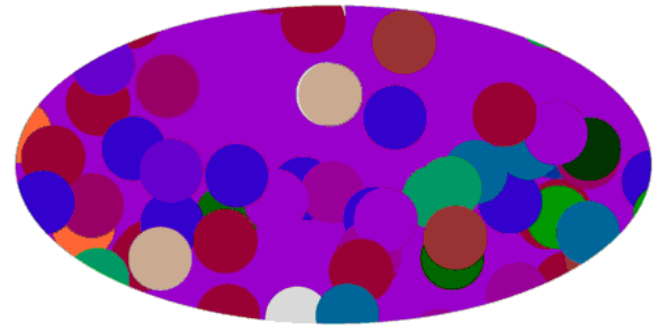
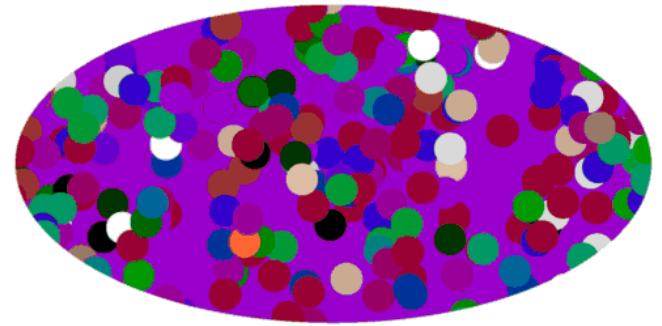
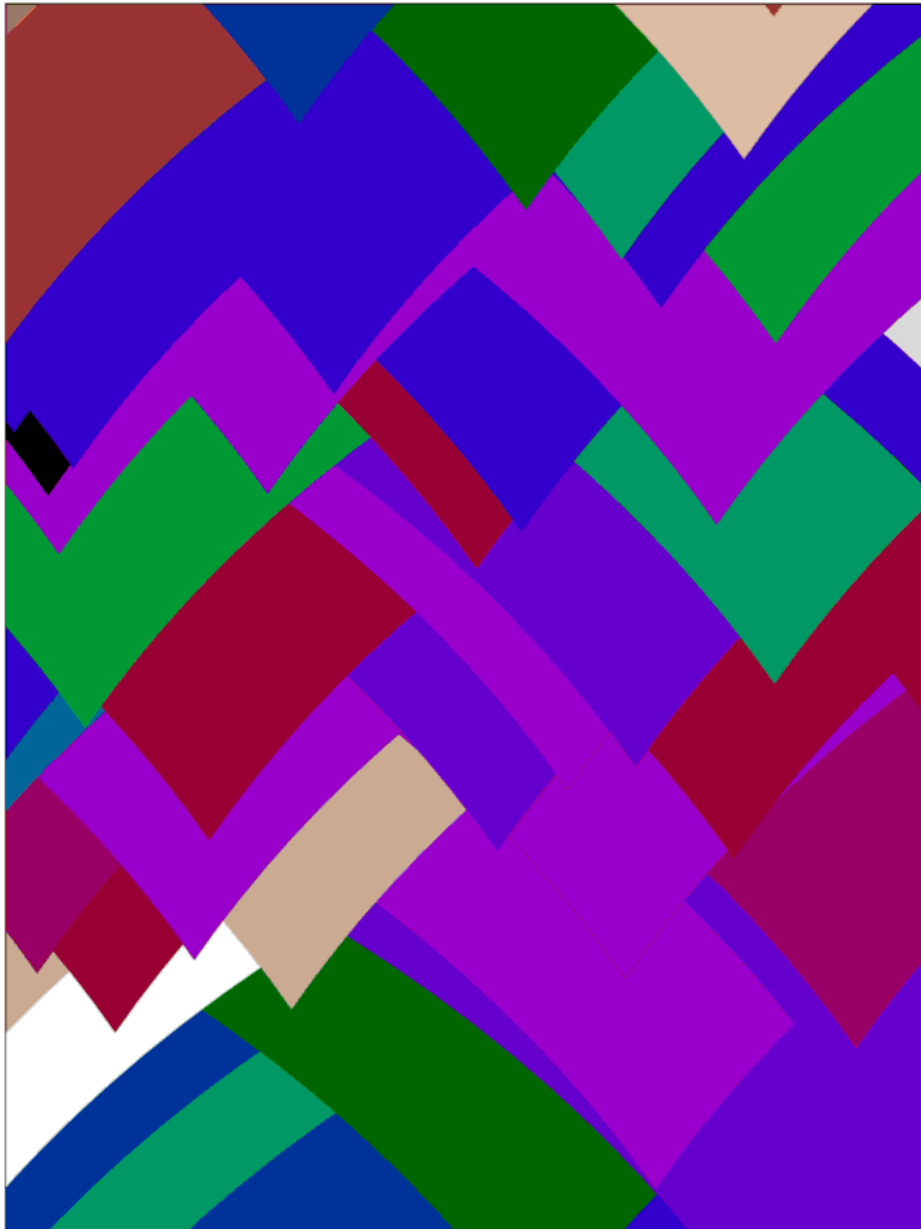
- A small patch grows to be bigger than the observable Universe. $T = \text{const}$ is explained.
- Whatever the curvature of the patch may be, it will look flat. $\text{Density} = \text{critical}$ is explained.



Inflationary Scenario

- The exponential growth during the period when there was a non-zero vacuum energy is called “inflation”.
- Inflation “postdicts” solutions to the flatness-oldness and horizon problems.
- It also solves the “monopole” problem.
- Does it predict anything that we can test?

Quantum Fluctuations Get Very Big



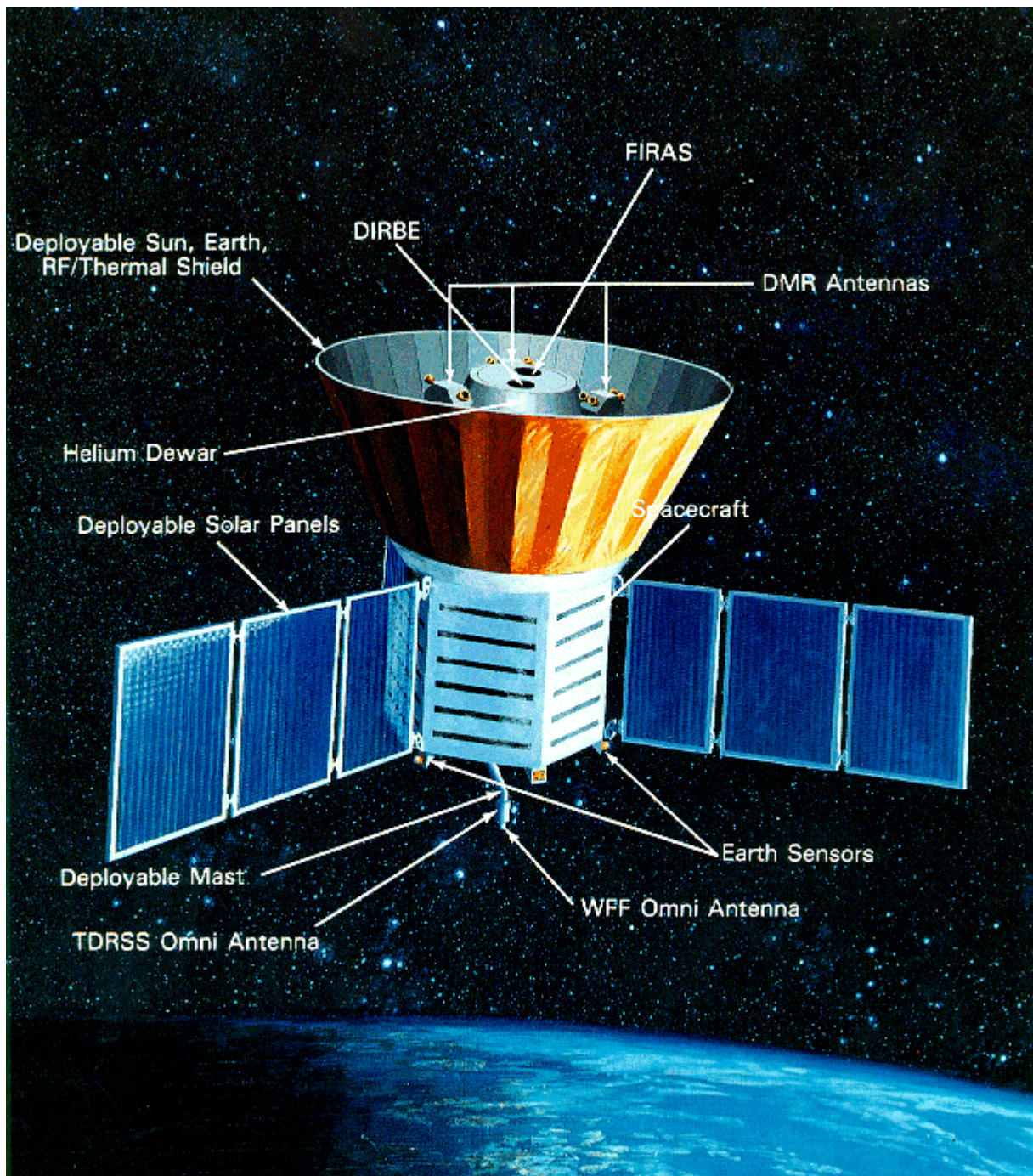
Quantum Fluctuations get Very Big

- QFs occur uniformly throughout space-time.
- Their future light-cones expand beyond the observable Universe.
- New QFs continue to add small-scale structure.

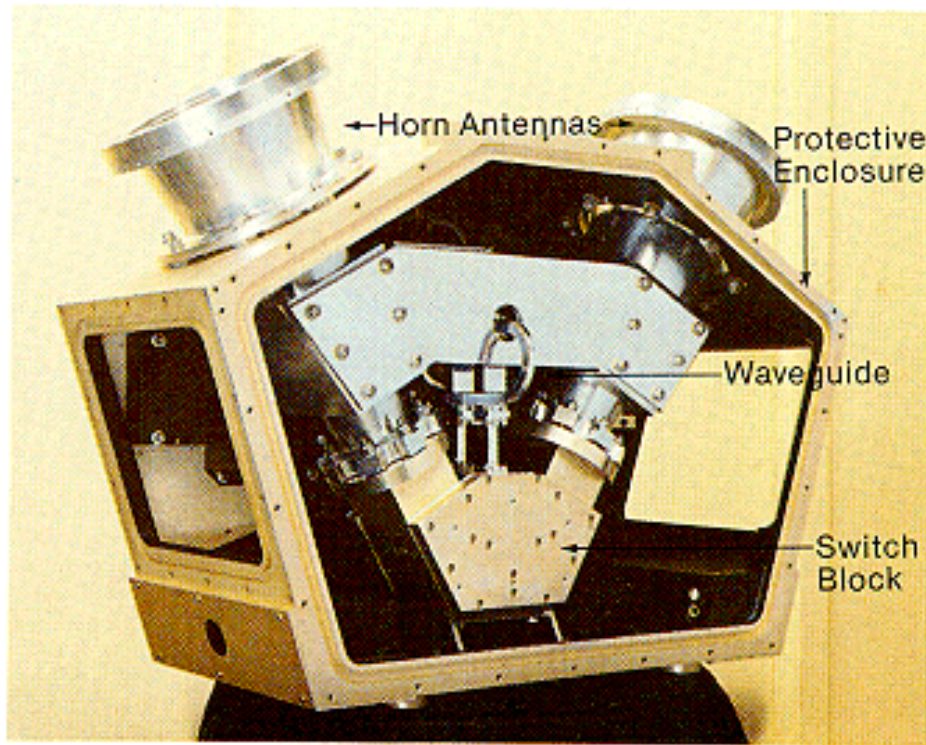


COBE Science Working Group

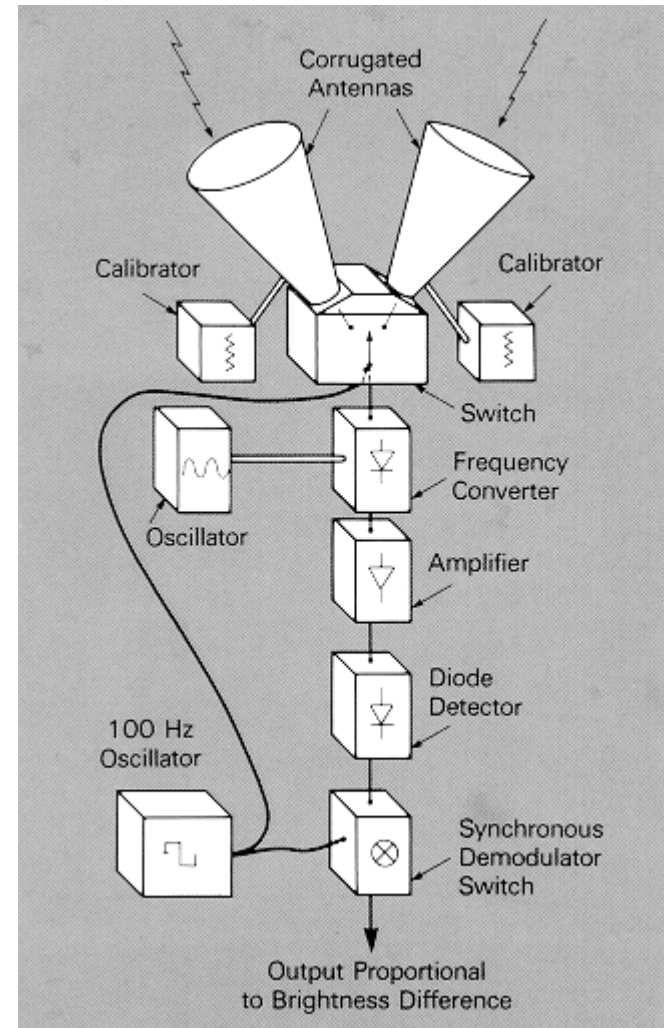




Differential Microwave Radiometers



The 9.6 mm DMR receiver partially assembled. Corrugated cones are antennas.



Personal History: Anisotropy

From: BONNIE::WRIGHT

"Ned Wright - (213)825-5755" 17-AUG-19

91 19:18:36.02

To: 6938::CBSWG

CC: WRIGHT

Subj: DMR

COBE SWG only:

8/17/91

I have analyzed the preliminary 1 year DMR maps by making a linear combination to give a "no galaxy" map. The results are presented here, and are quite consistent with unbiased CDM. There is probably a real quadrupole in the data.

From: BONNIE::WRIGHT

"Ned Wright - (213)825-5755" 6-OCT-1991 23:37:13.50

To: 6955::BENNETT

CC: WRIGHT

Subj: DMR

Chuck,

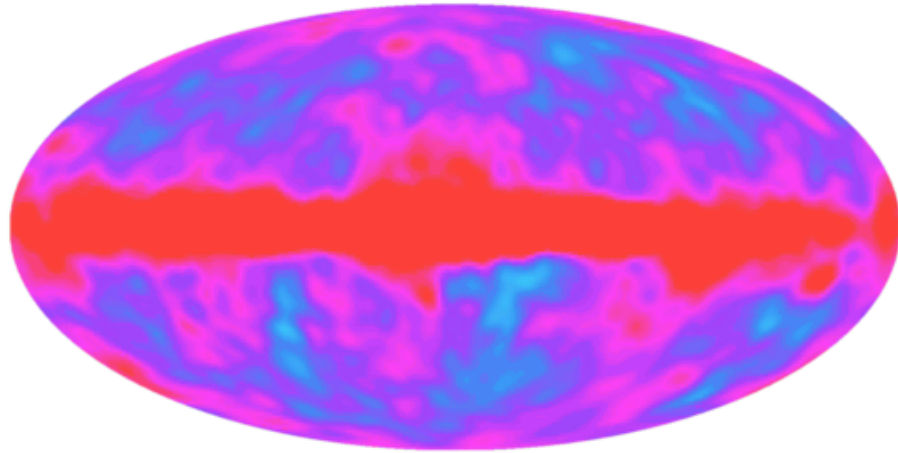
10/6/91

I have been working on the new 1 year maps. I include a bunch on analyses following this message. It looks like a 10 sigma detection of an Harrison-Zeldovich spectrum with an amplitude corresponding to a quadrupole of 15 microK. The "No Galaxy" map is noisier but agrees with the 53A+B.

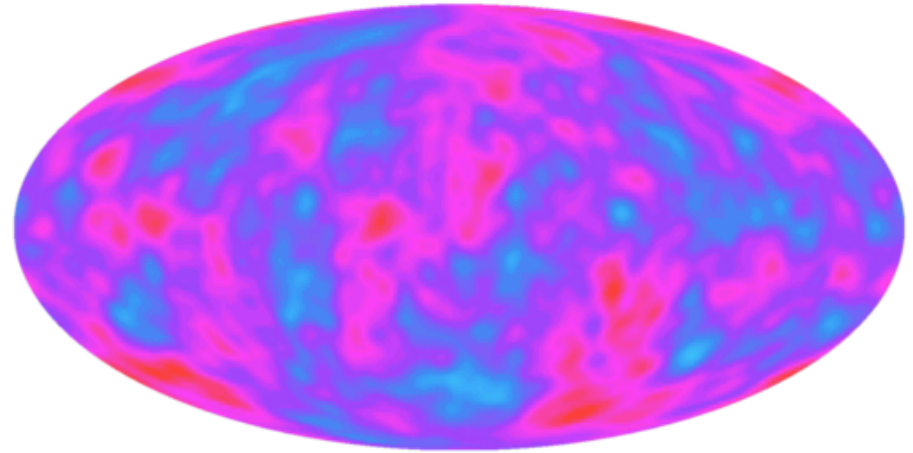
-Ned Wright-

COBE DMR vs EPAS

COBE Data

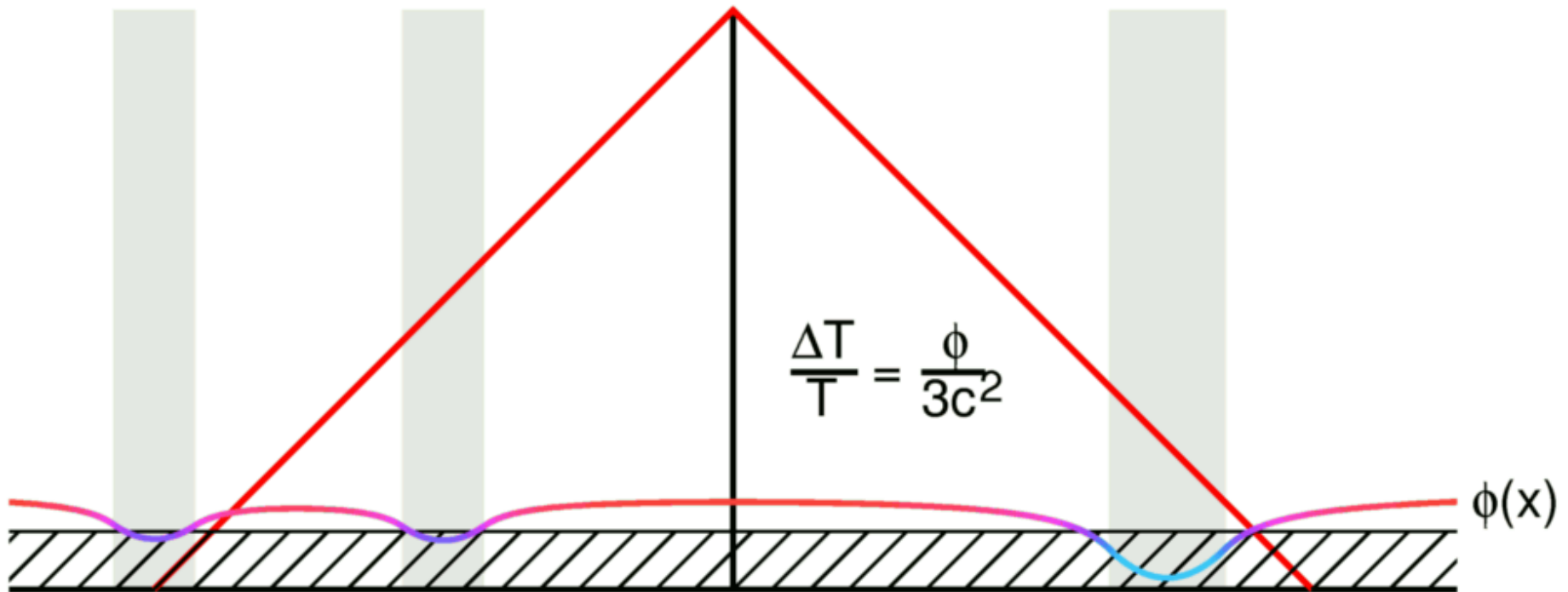


Equal Power on All Scales Model

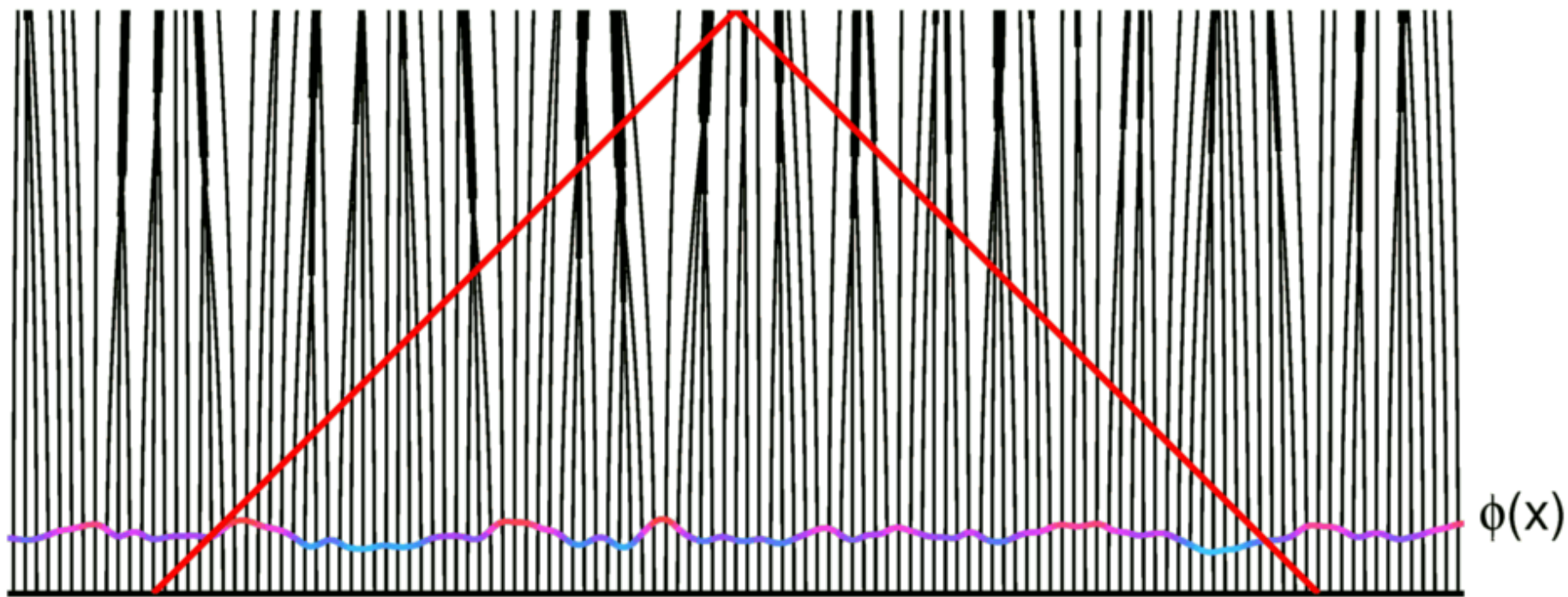


“Chi-by-eye” suggests that the “Equal Power on All Scales” prediction of inflation is correct.

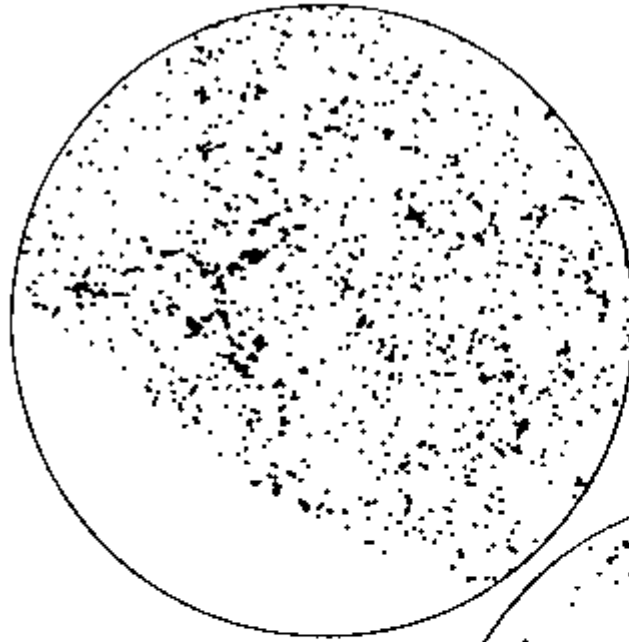
Sachs-Wolfe Effect



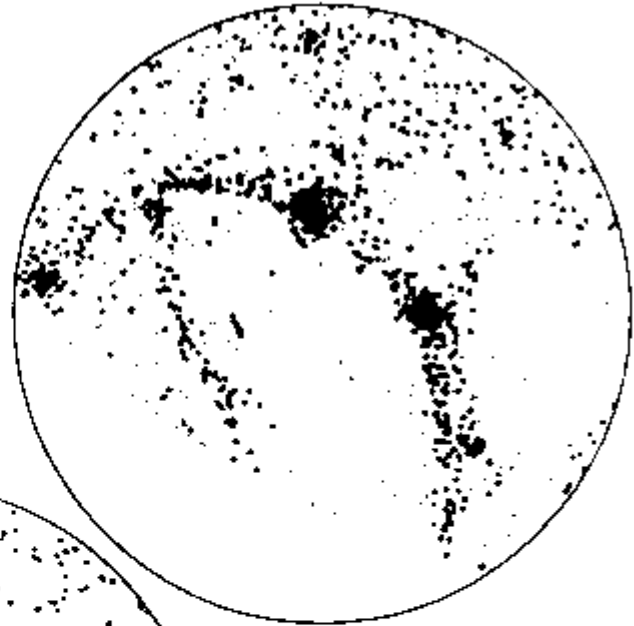
Measured $\Delta\phi$ Leads to Structure



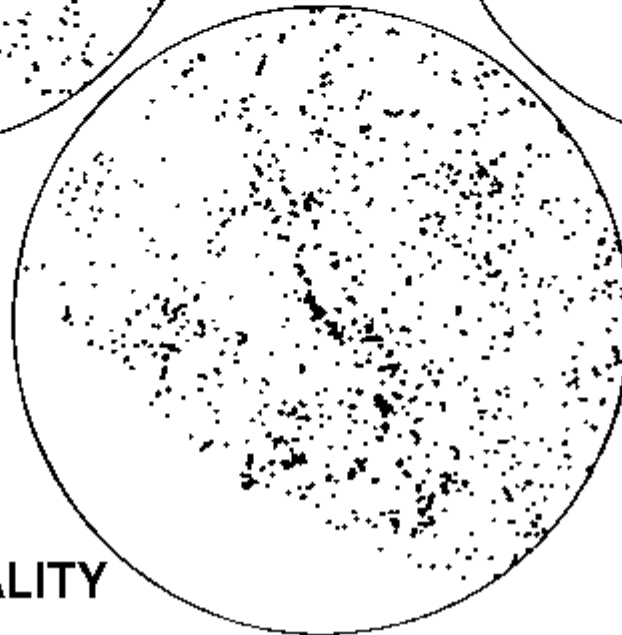
Need Cold Dark Matter



CDM

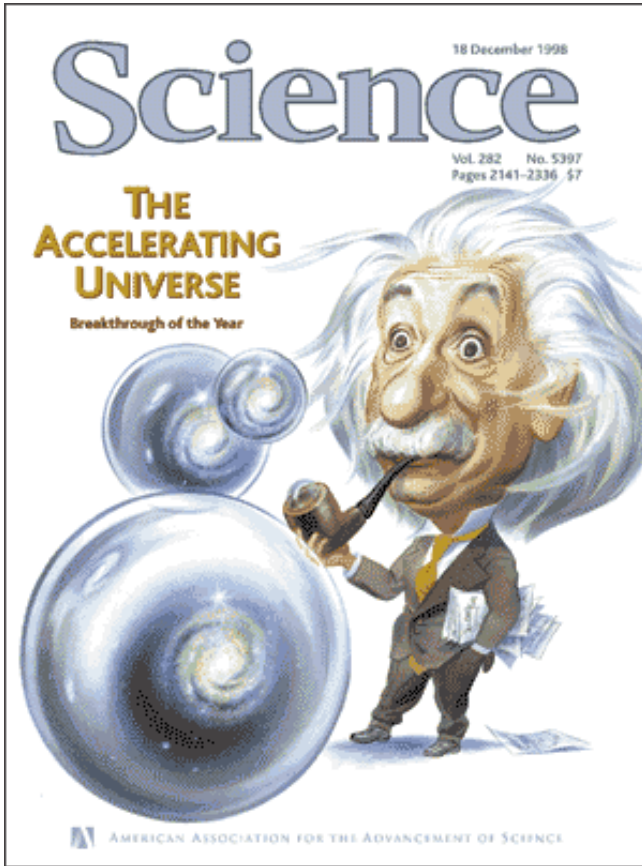


HDM

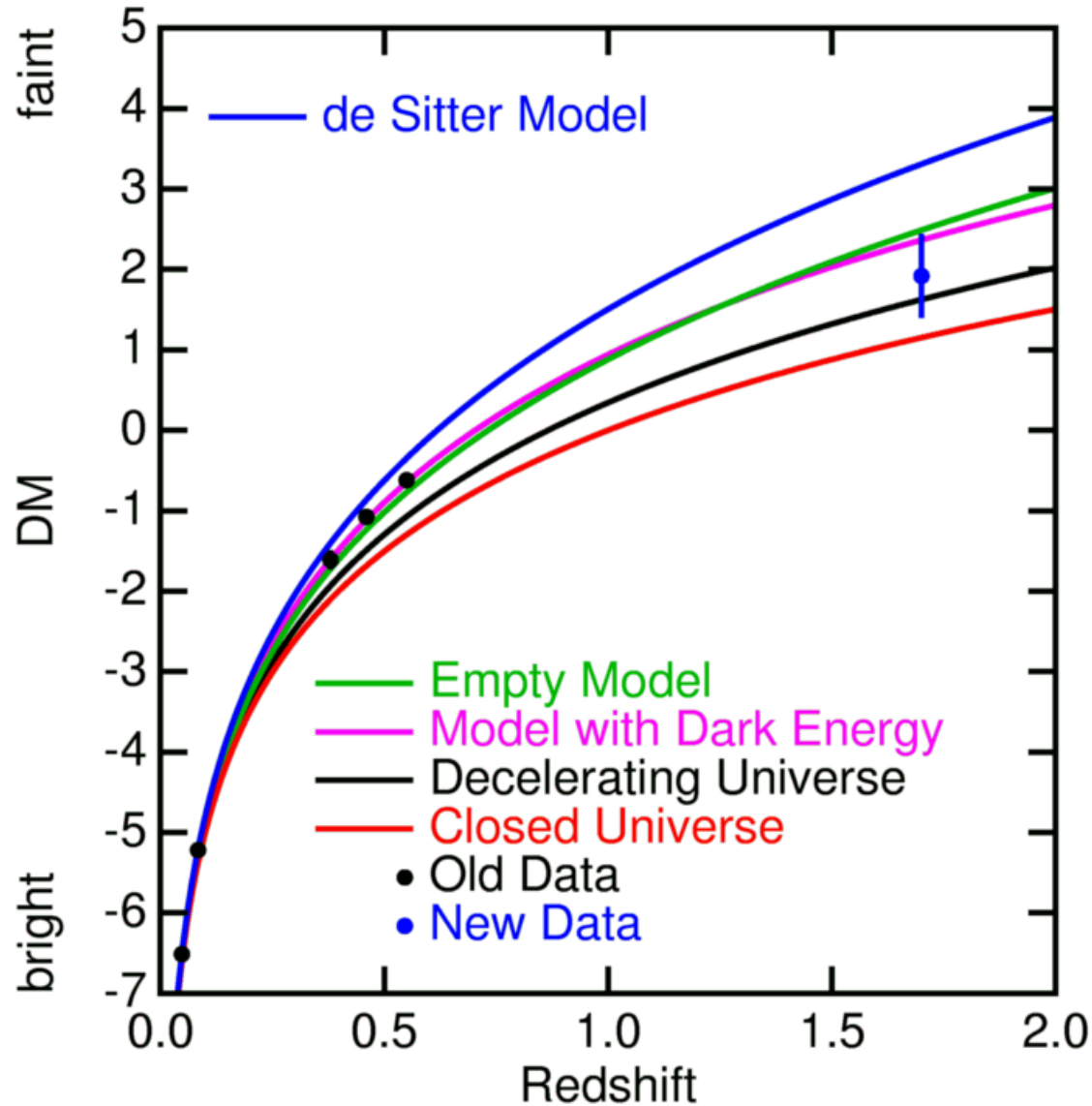


REALITY

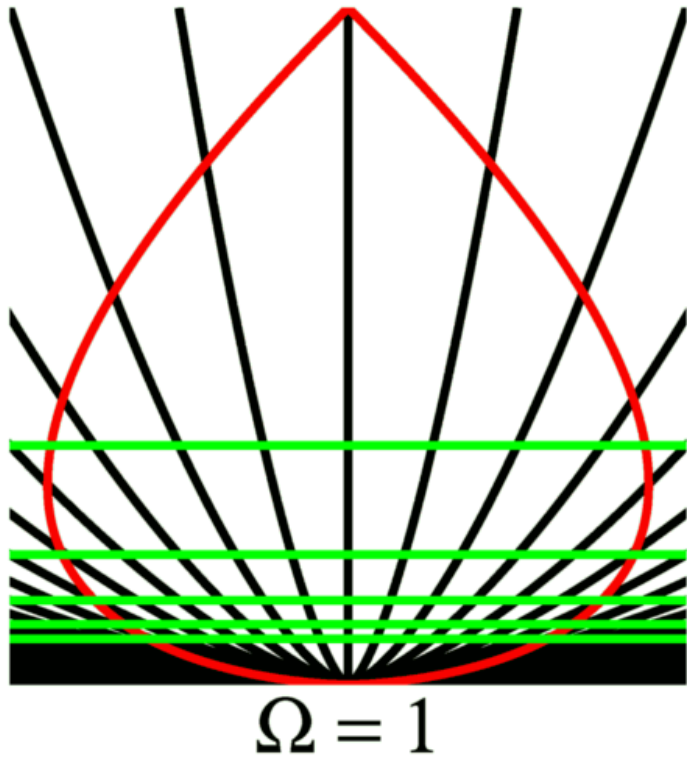
Accelerating Universe: 1998



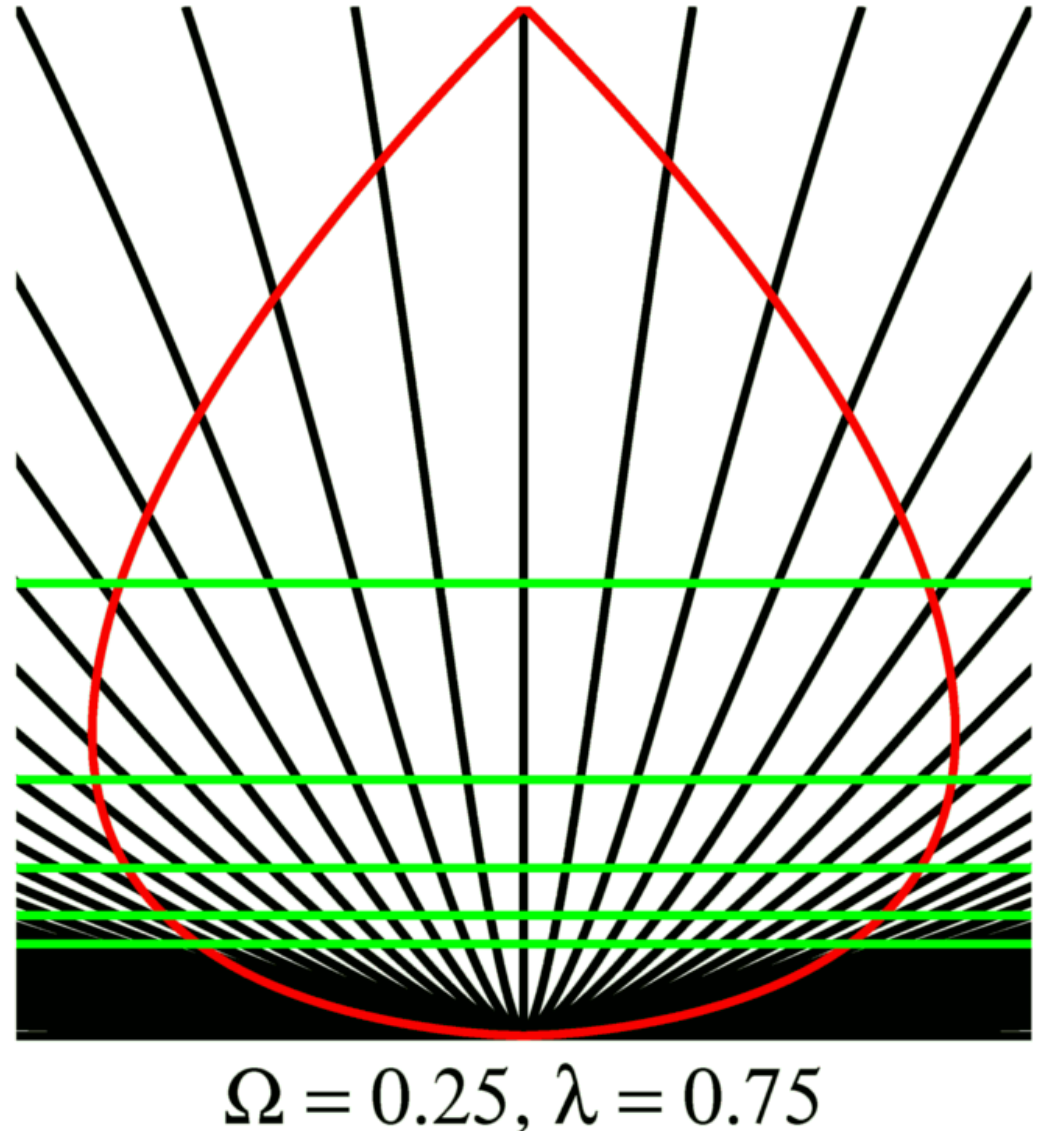
Distant (high z)
supernovae fainter than
Expected



Acceleration causes Faintness



Without CC, Universe is younger, hence light travel time is smaller to any z , so SNe at $z=1$ are closer & thus brighter.



COBE View was Blurry



Sometimes higher resolution...

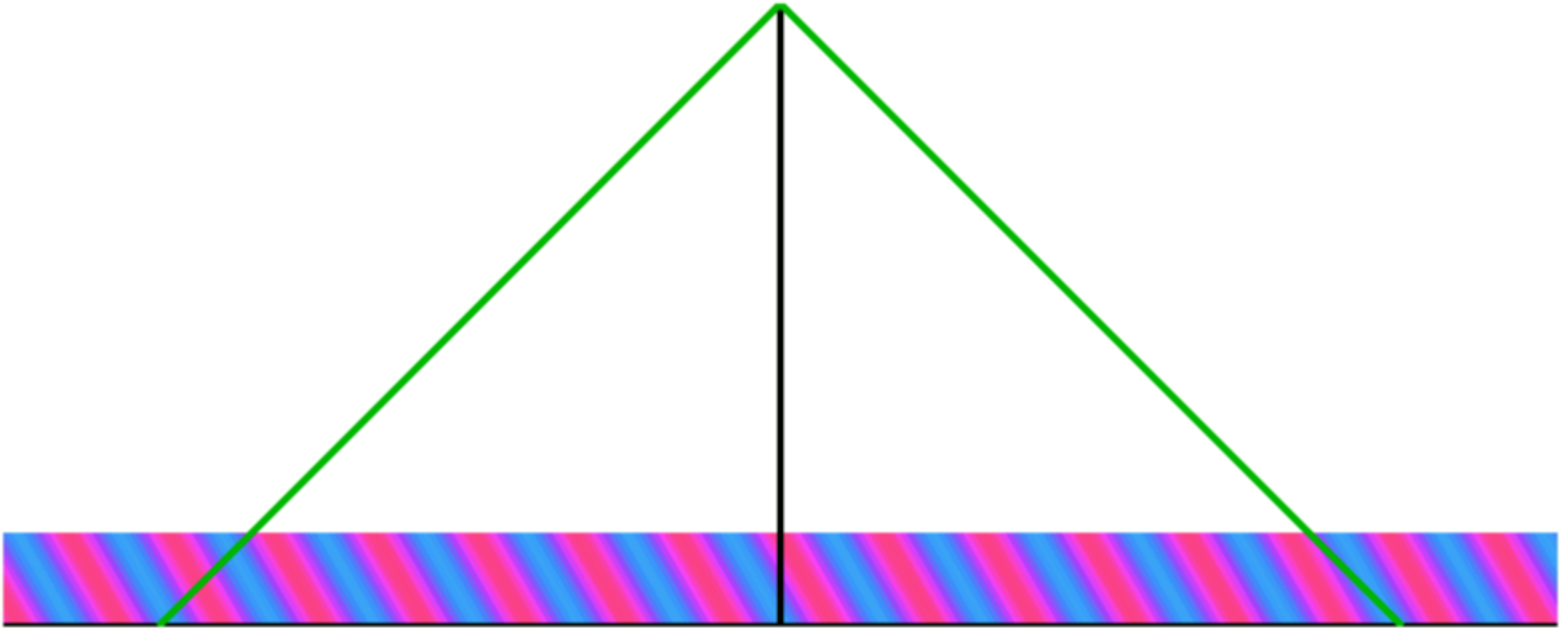


reveals the secret of the Universe

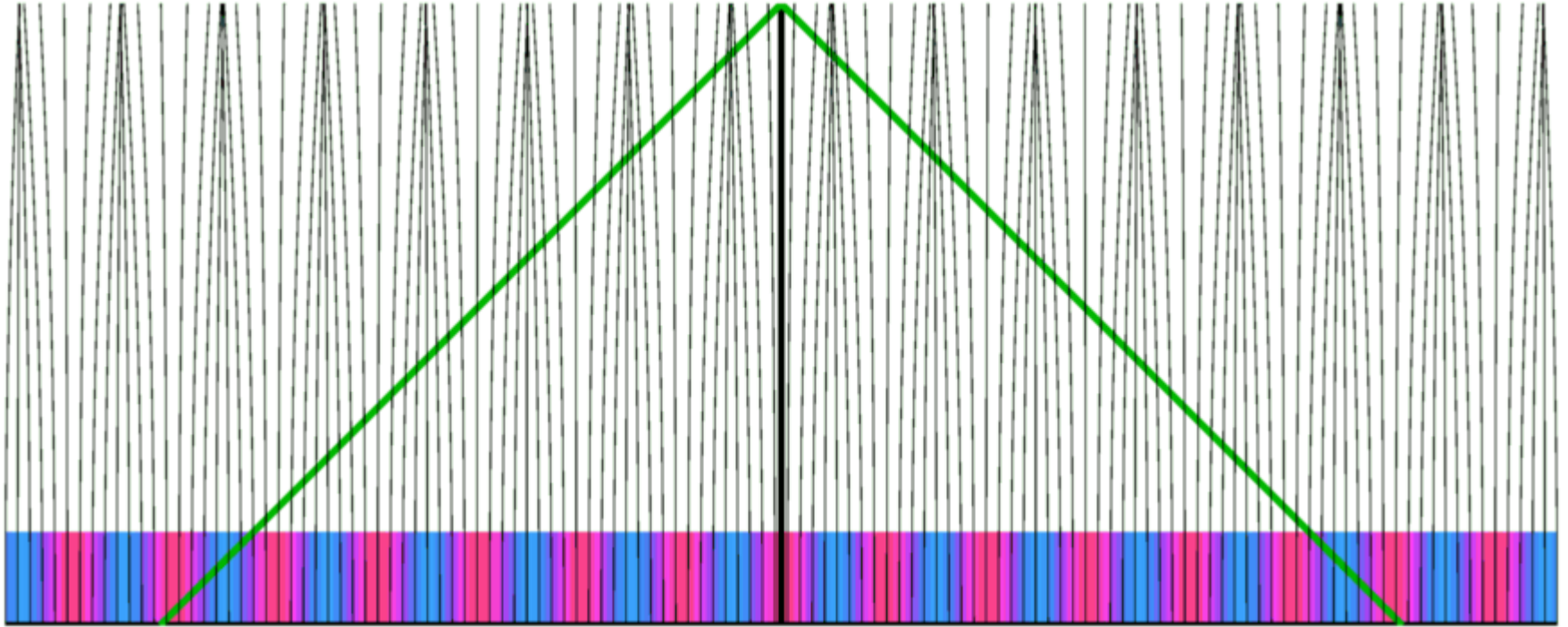
Two Fluids in the Early Universe

- Most of the mass is dark matter
 - 80-90% of the density
 - Zero pressure
 - Sound speed is zero
- The baryon-photon fluid
 - baryons are protons & neutrons = all ordinary matter
 - energy density of the photons is bigger than c^2 times the mass density of baryons
 - Pressure of photons = $u/3 = (1/3)\rho c^2$
 - Sound speed is about $c/\sqrt{3} = 170,000$ km/sec

Traveling Sound Wave: $c_s = c/\sqrt{3}$



Stay at home Dark Matter

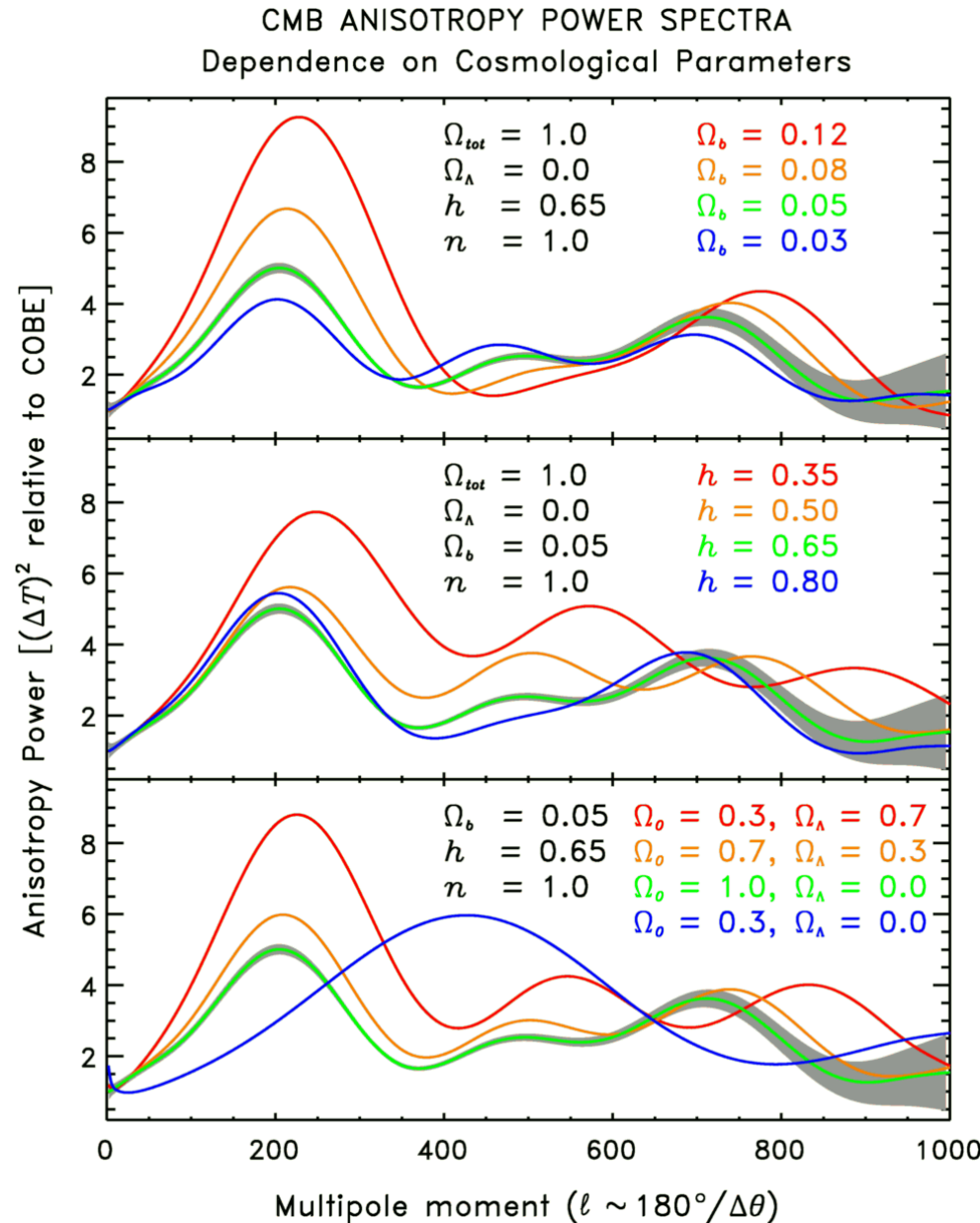


Interference at last scattering

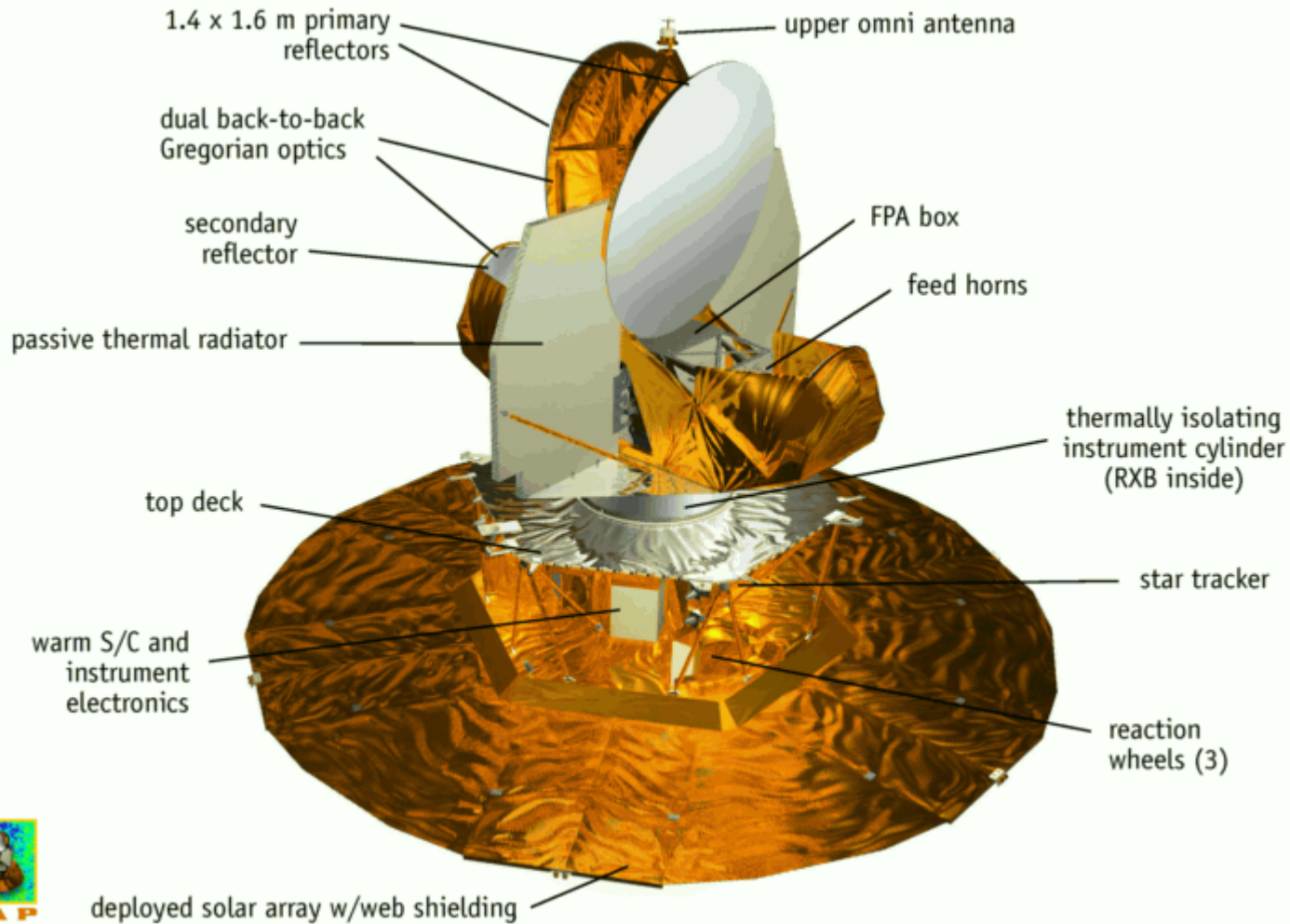
- For the wavelength illustrated [$1/2$ period between the Big Bang and recombination], the denser = hotter effect and potential well = cooler effect have gotten in phase.
- For larger wavelengths they are still out of phase at recombination.

Many parameters to measure

- Careful measurements of the power at various angular scales can determine the Hubble constant, the matter density, the baryon density, and the vacuum density.



A New Cosmology Satellite



WMAP Science Working Group

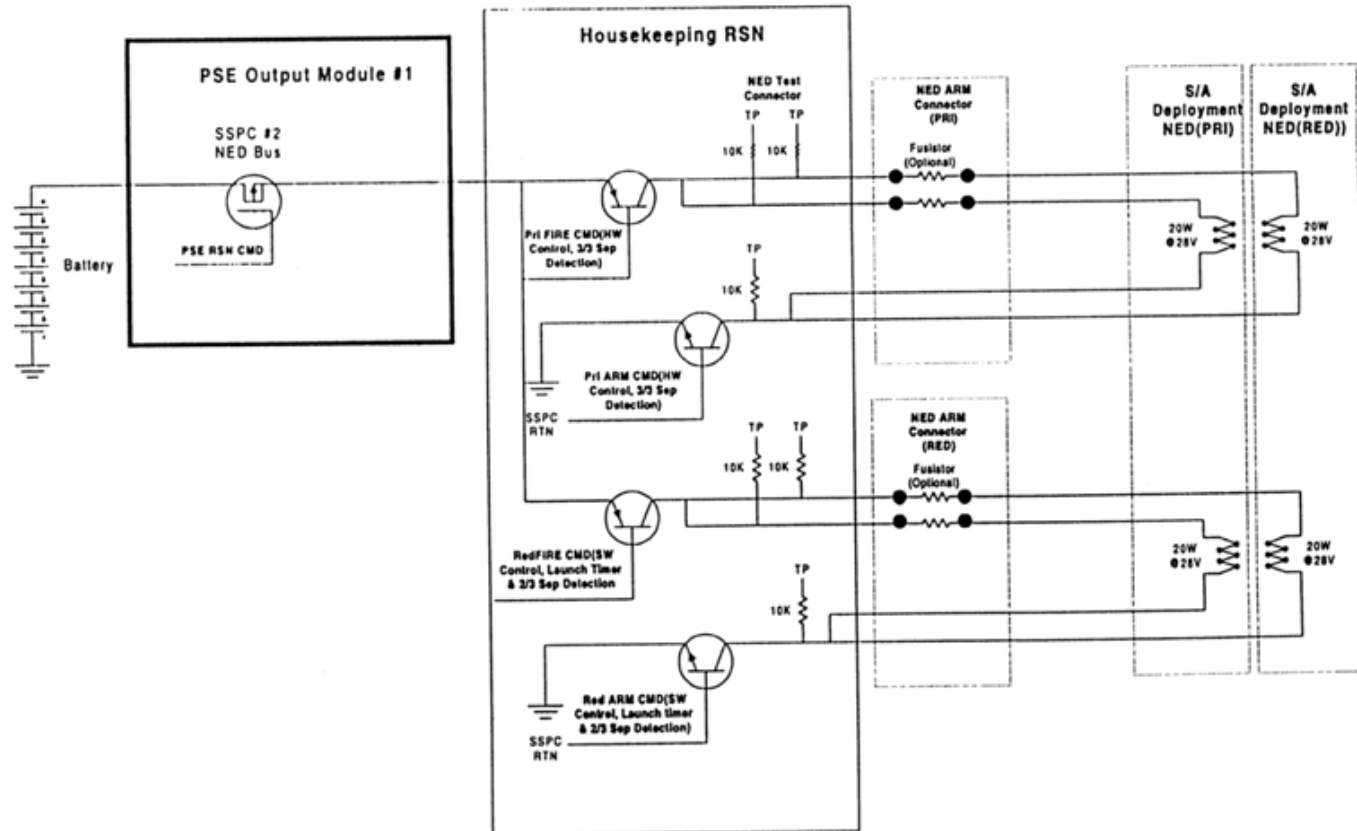


WMAP Status on 30 Jun 2001



and WMAP has a NED Controller!

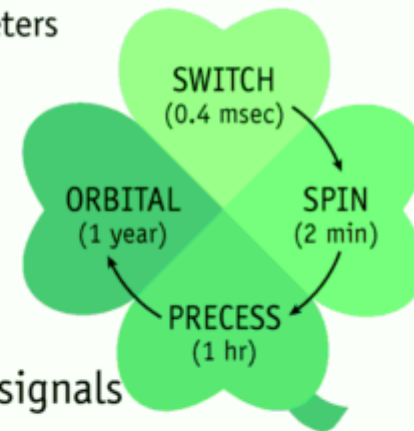
S/A Deployment NED Control



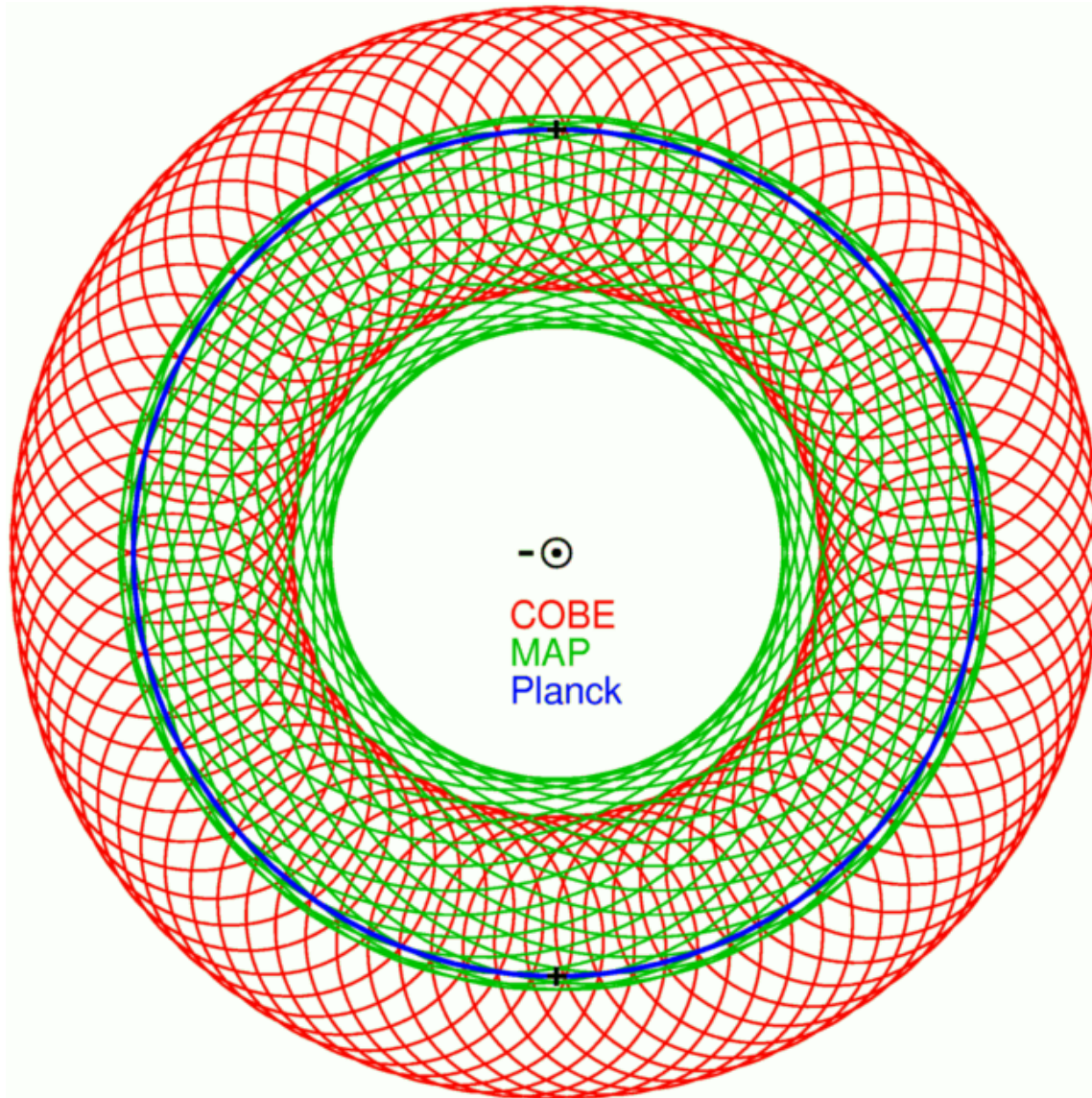
Systematic Error Control

SPIN-SYNCHRONOUS NON-SKY SIGNALS ARE THE LEADING CONCERN

- Minimize sensitivity of experiment to non-sky signals
 - Minimize all observatory changes
 - L2 orbit; constant survey mode operations
 - minimize transmitter time; use make up heater
 - Symmetric, rapidly switched, differential radiometers
 - Rapid sky scanning (30% of sky per hour)
- Multiple modulation periods to isolate & identify systematic effects
- Distinguish cosmic from non-cosmic sky signals
 - 5 frequencies to model and remove galactic signals
 - Minimize stray diffracted signals from Earth, Sun, Moon
 - large edge taper; diffraction shielding
 - L2 orbit

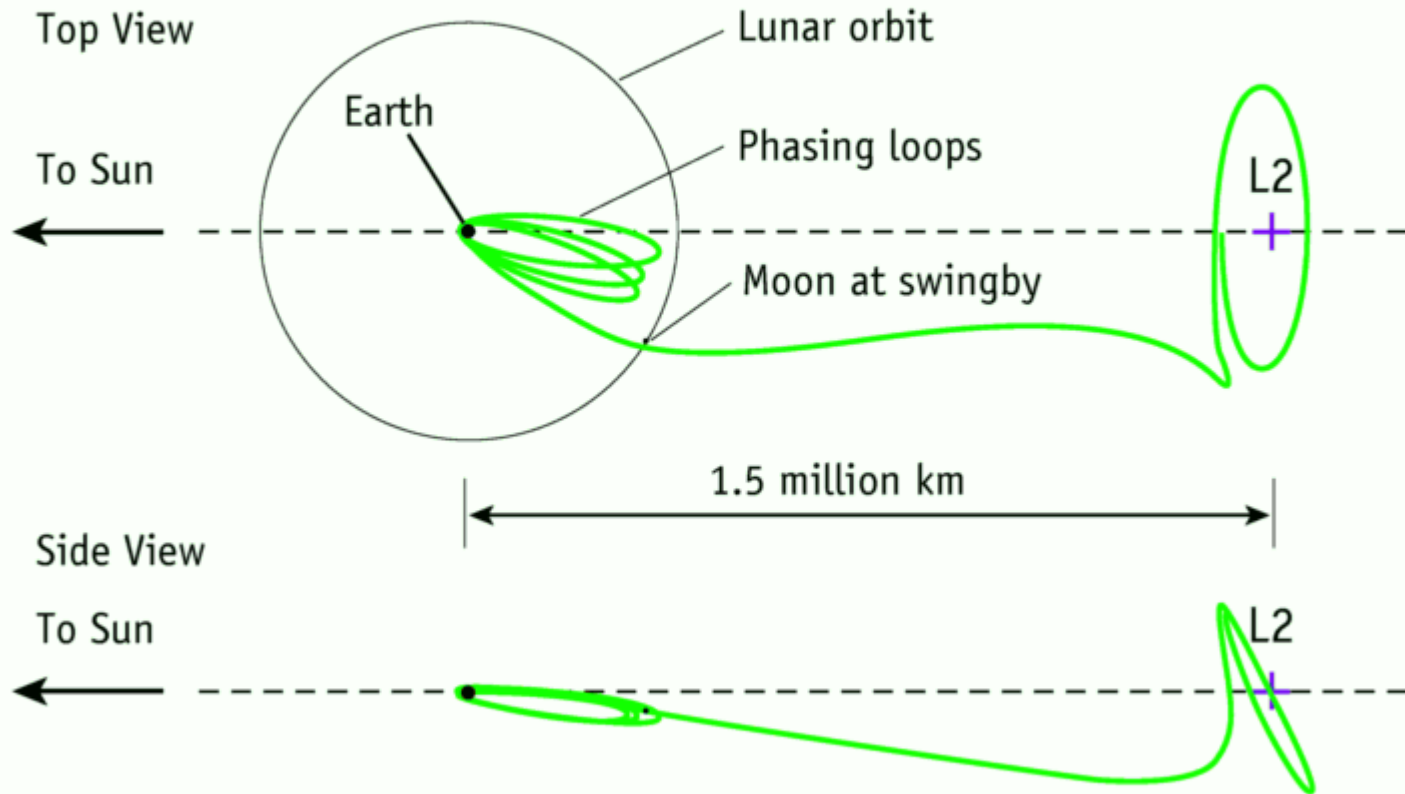


WMAP's Scan Pattern like COBE's

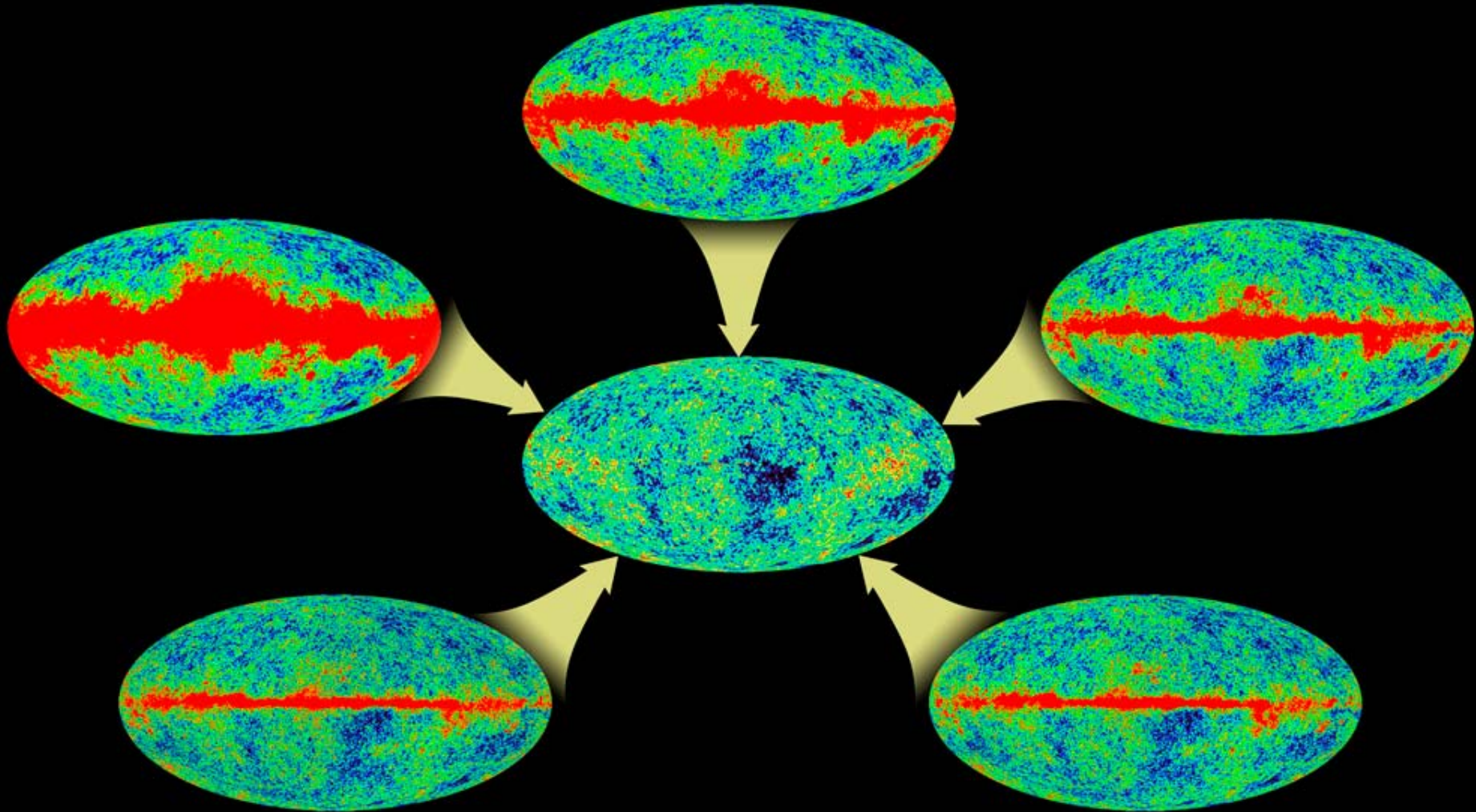


WMAP's Orbit

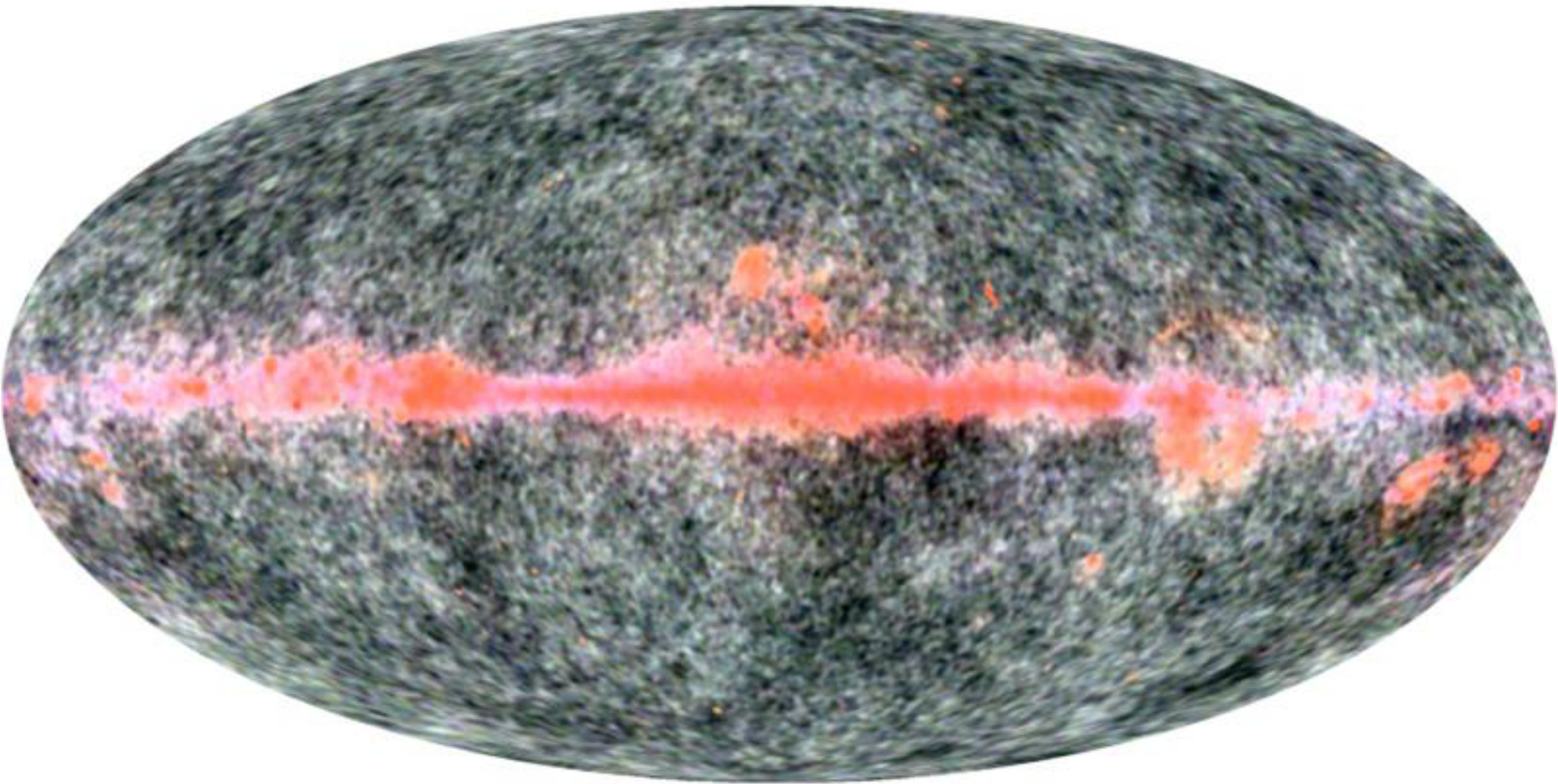
MAP TRAJECTORY TO L2



Combination to remove foreground

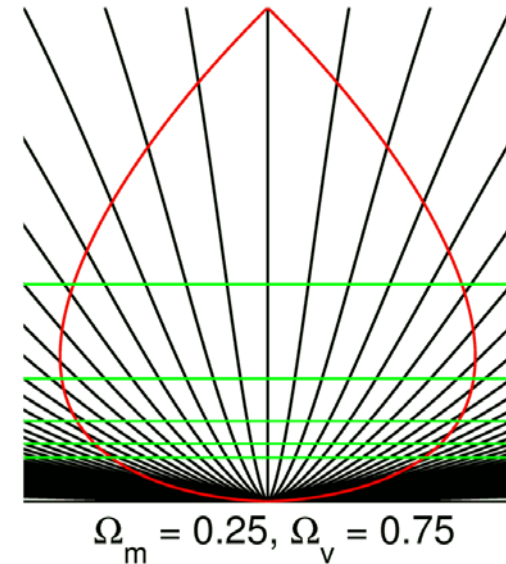
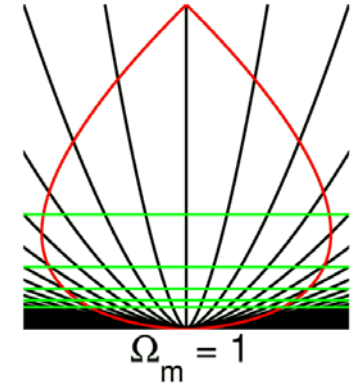
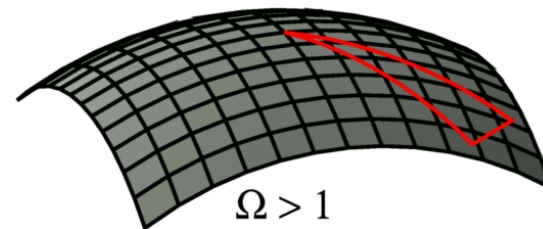
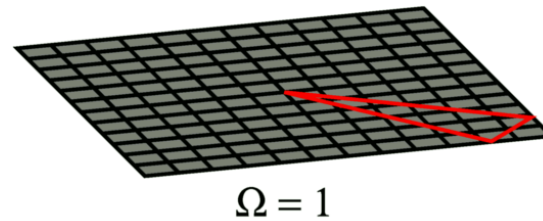
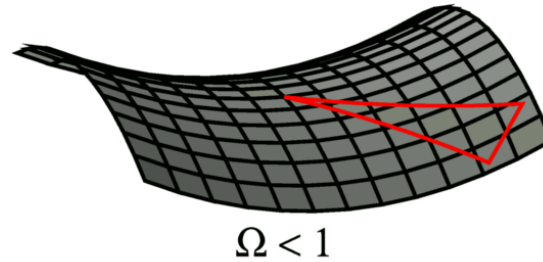


QVW as RGB

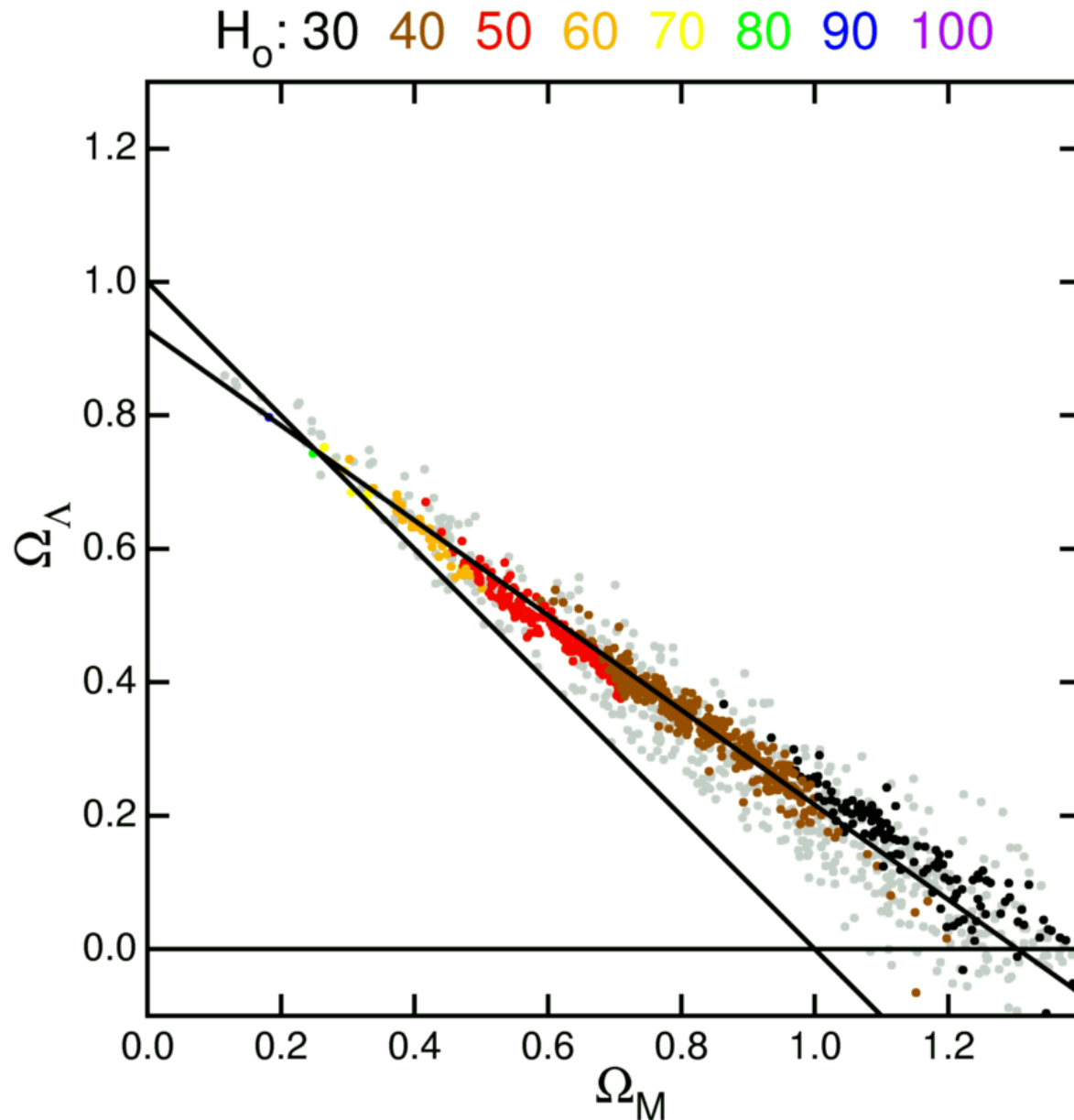


Effects on Peak Position: l_{pk}

- + Open or vacuum dominated Universes give larger distance to last scattering surface
- + High matter density gives smaller wavelength



Results With WMAP

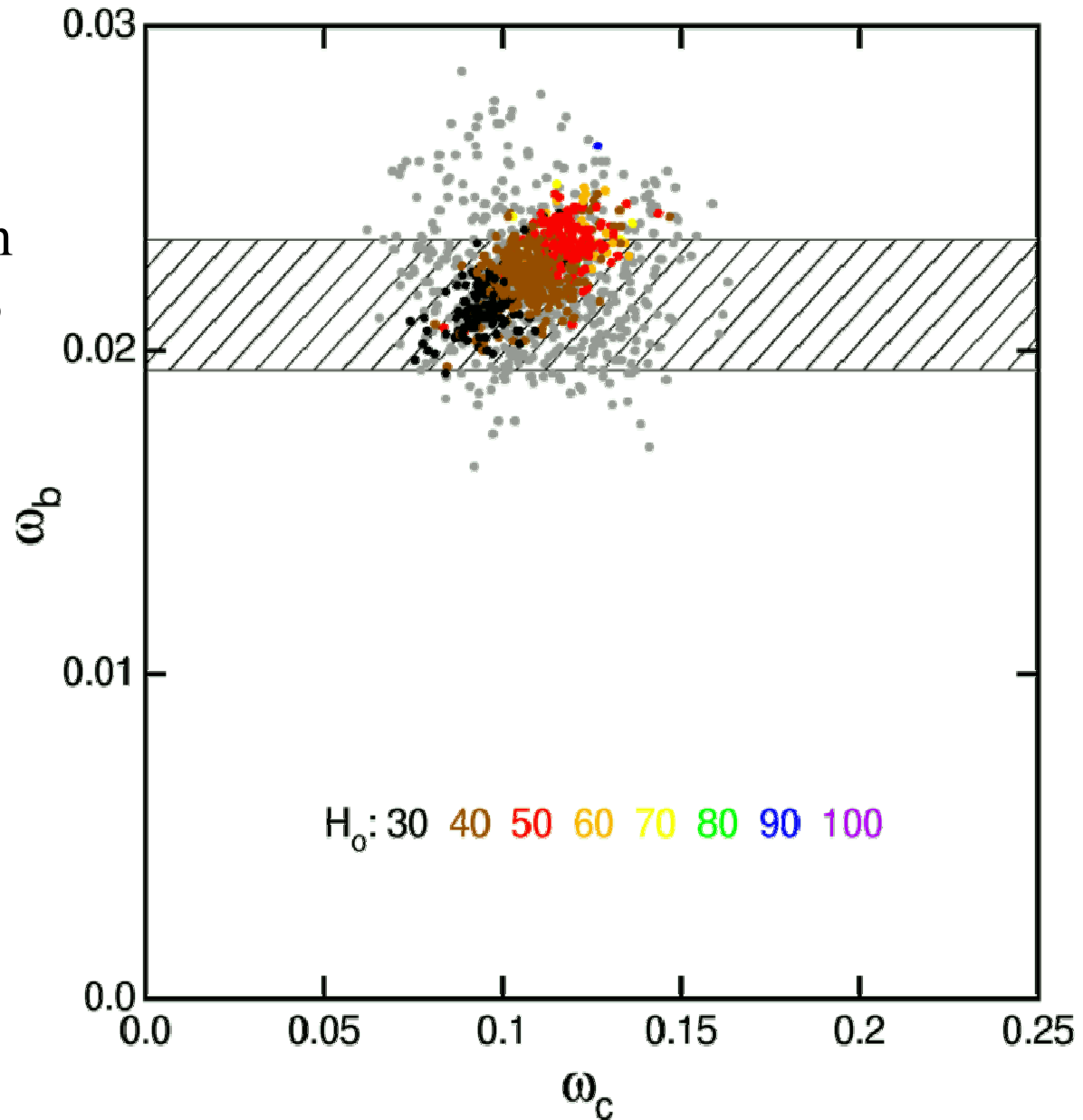


Info from peak & trough heights

- Overall Amplitude of the perturbations
 - Agrees with large scale structure if almost all the dark matter is COLD dark matter
- Primordial power spectrum power law spectral index: $n = 0.99 \pm 0.04$ without running index.
 - EPAS inflationary prediction is $n = 1$
- Baryon/photon and DM/baryon density ratios
 - $\rho_b = 0.42 \text{ yoctograms/m}^3 = 0.42 \times 10^{-30} \text{ gm/cc}$
 - $\rho_{\text{cdm}} = 2.1 \text{ yg/m}^3$ [$\omega \equiv \Omega h^2 = \rho / \{18.8 \text{ yg/m}^3\}$]

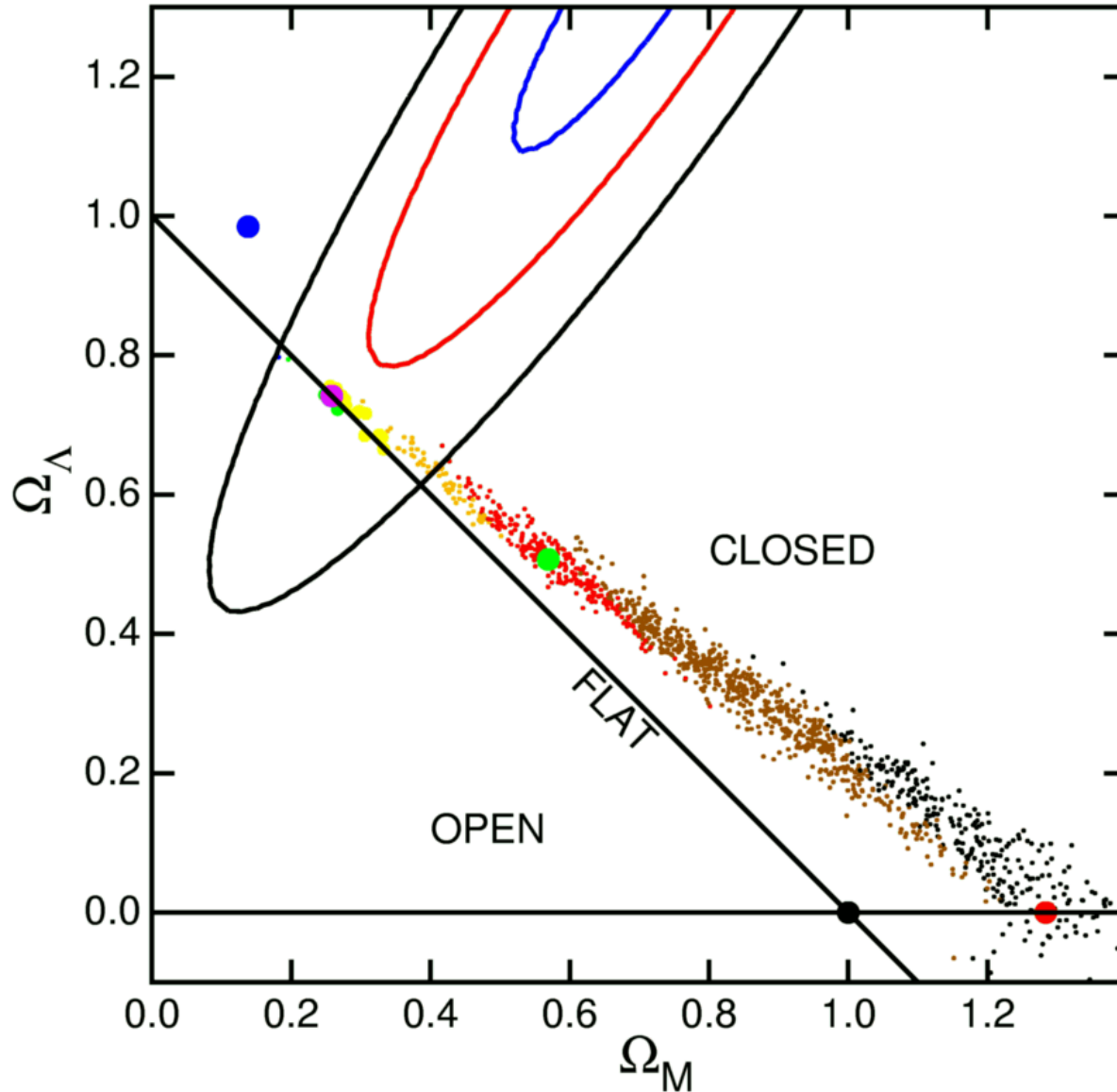
Results With WMAP

Note the new
BBNS value from
astro-ph/0302006

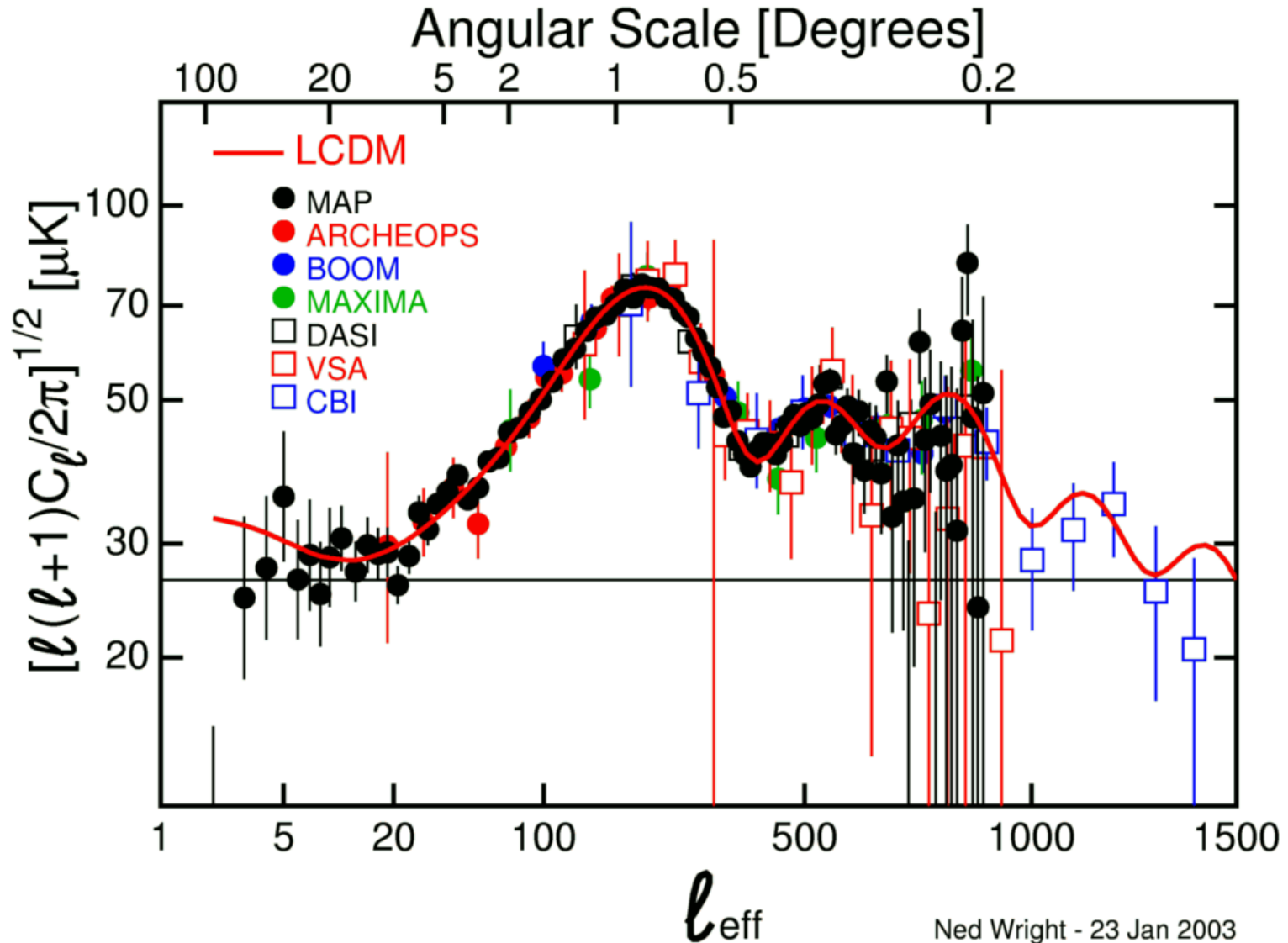


Key to Models

H_0 : 30 40 50 60 70 80 90 100



Λ CDM is a Good Fit

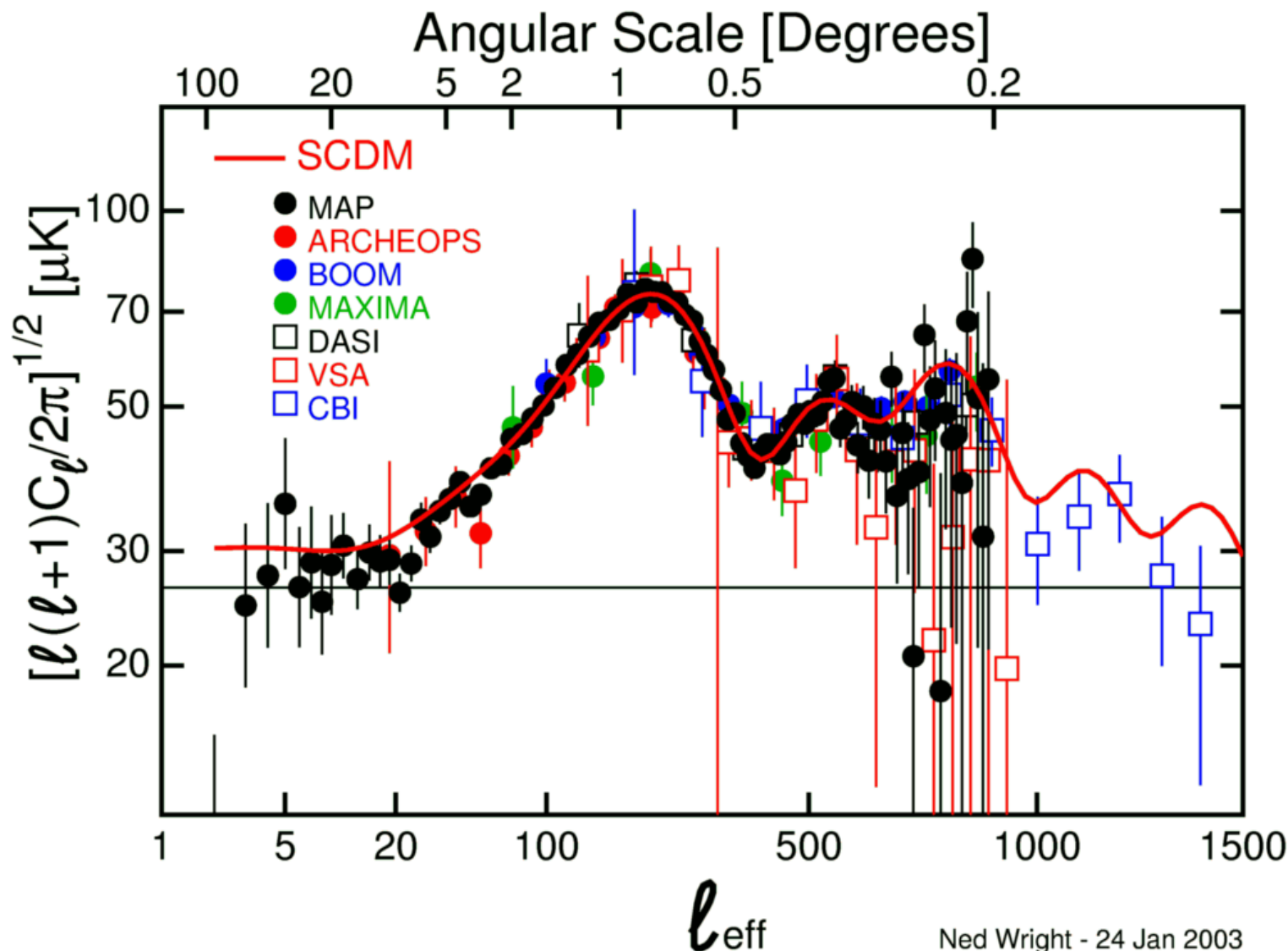


$$H_0 = 71, \Omega_\Lambda = 0.73, \Omega_b h^2 = 0.0224, \Omega_m h^2 = 0.135, \Omega_{\text{tot}} = 1$$

But What Can We SLAY?

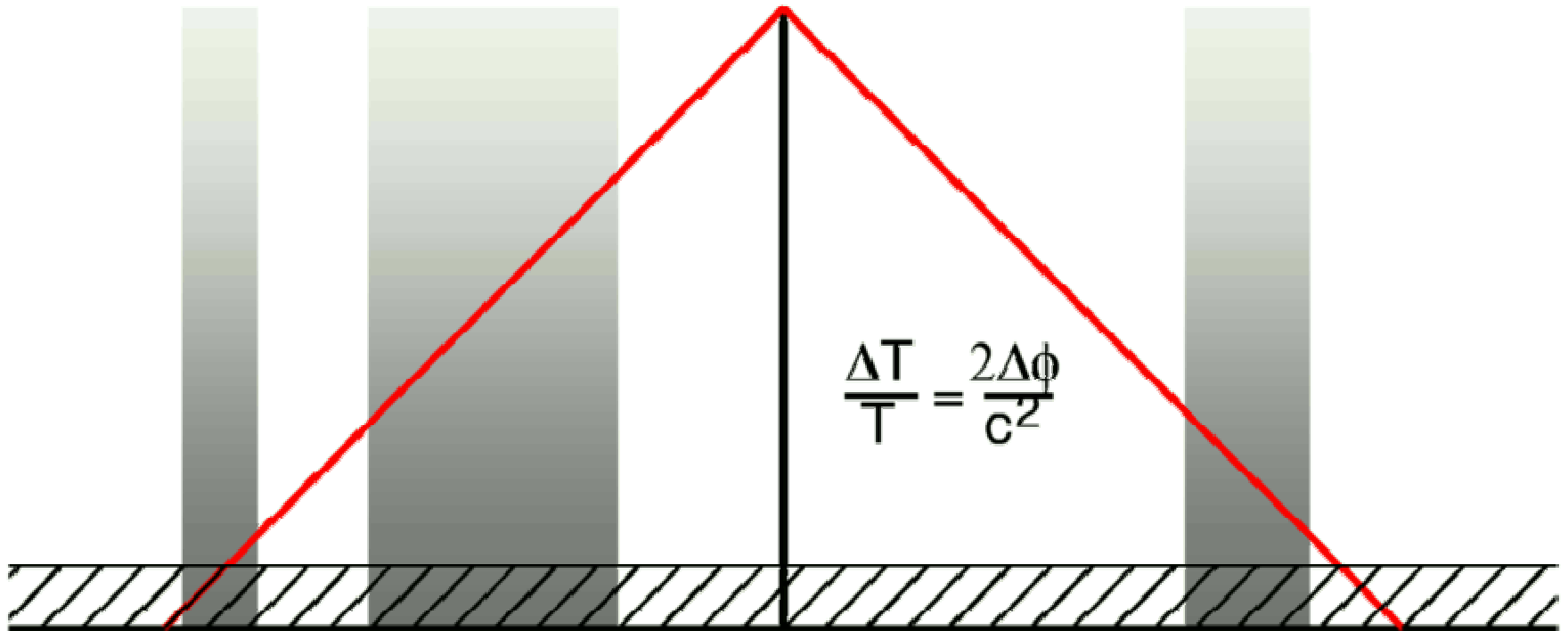


Einstein – de Sitter Model Fails



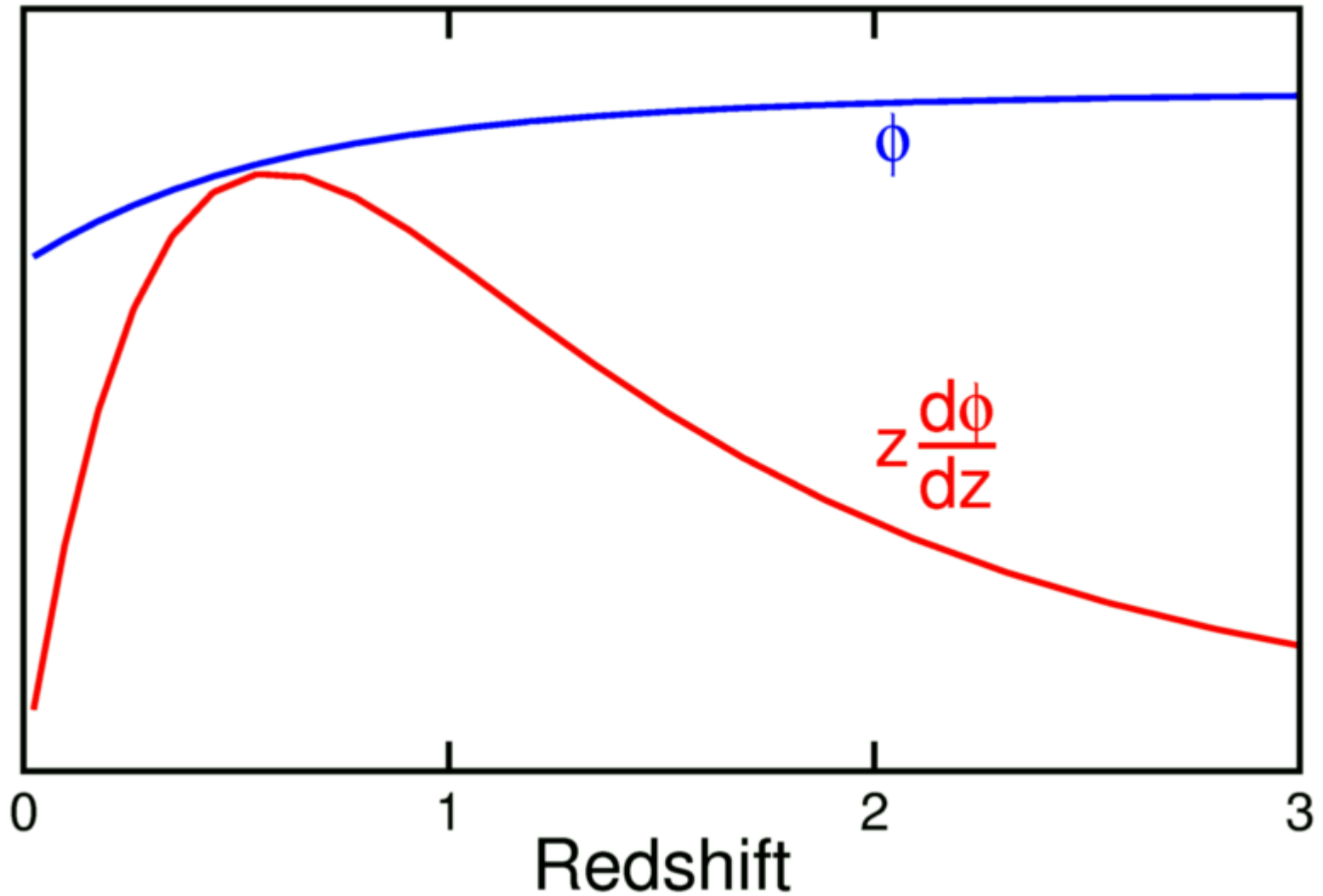
$$H_0 = 50, \Omega_\Lambda = 0, \Omega_b h^2 = 0.0236, \Omega_m h^2 = 0.25, \Omega_{\text{tot}} = 1$$

Late ISW Effect



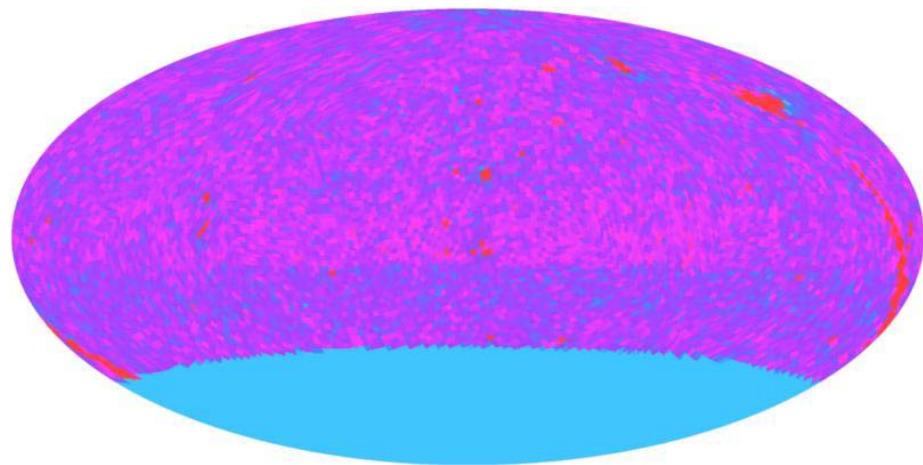
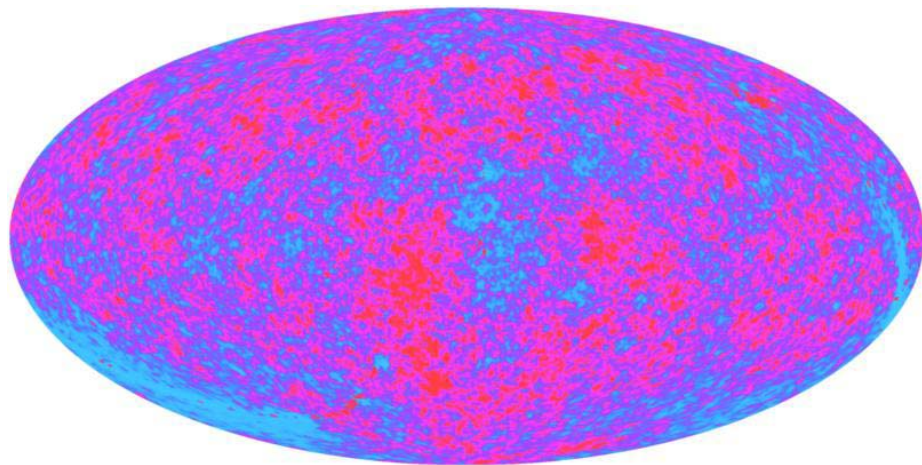
Potential only changes if $\Omega_m \neq 1$ (or in non-linear collapse, but that's another story [Rees-Sciama effect]).

Potential decays at $z \approx 0.6$

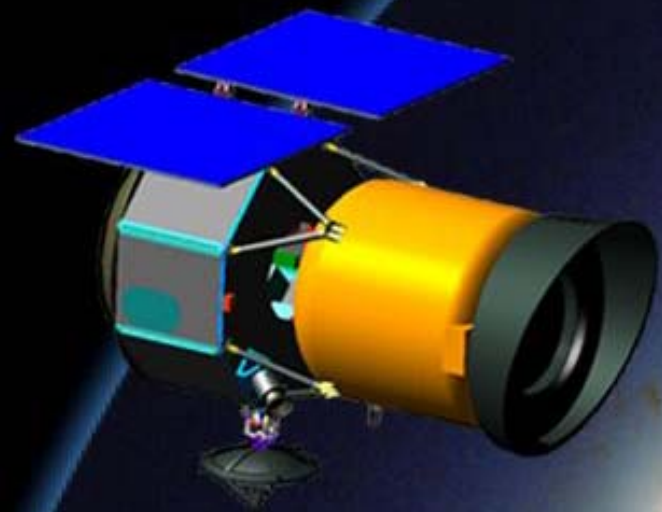


CMB-LSS correlation seen by WMAP

- This late ISW effect occurs on our past light cone so the ΔT we see is due to structures we also see.
- Correlation between WMAP and LSS seen by:
 - Boughn & Crittenden (astro-ph/0305001) at 2.75σ with hard X-ray background and 2.25σ with NVSS
 - Nolta et al. (astro-ph/0305097) at 2σ with NVSS
 - Ashfordi et al (astro-ph/0308260) at 2.5σ with 2MASS



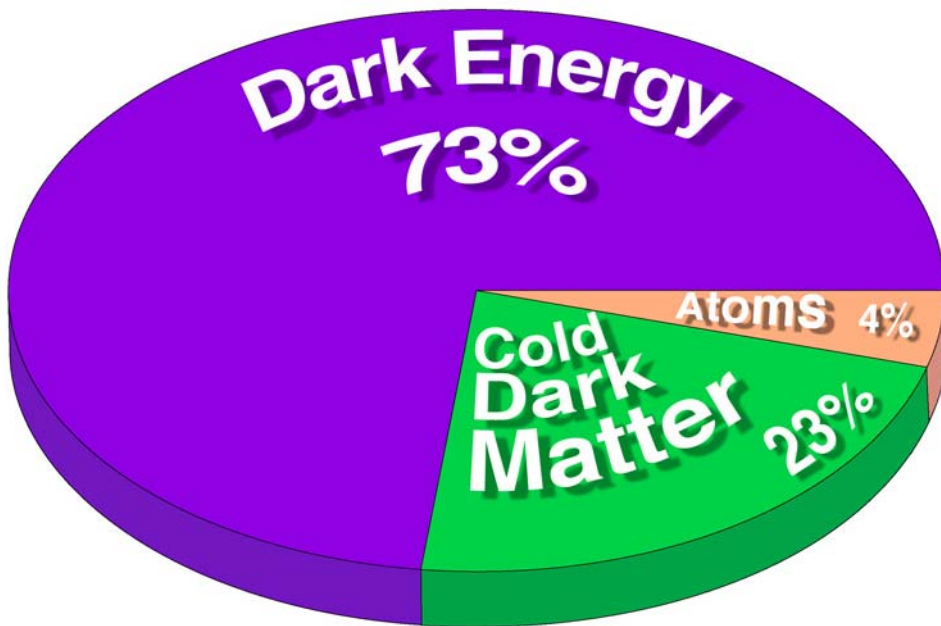
WIDE-FIELD INFRARED SURVEY EXPLORER



I am the PI on a MIDEEX called WISE, an all-sky survey in 4 bands from 3.3 to 24 μm . WISE will find and study the closest stars to the Sun, the most luminous galaxies in the Universe, and also map the large-scale structure out to redshift $z=1$, covering the era when the late ISW effect should be generated.

WISE will fly in 2008.

We (and all of chemistry) are a small minority in the Universe.



Periodic Table of Elements with annotations:

- s-block**: Groups 1 and 2 (IA and IIA).
- d-block**: Groups 3 through 10 (Transition Metals).
- p-block**: Groups 13 through 18 (Non-Metals).
- f-block**: Lanthanide and Actinide series.
- Metals**: Groups 1 through 10.
- Non-Metals**: Groups 13 through 17.
- Phases**: Solid, Liquid, Gas.

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
IA	IIA	Transition Metals										IIIA	IVA	VA	VIA	VIIA	VIIIA			
1	H 1.008	He 4.0026																		
2	Li 6.941	Be 9.0122	Transition Metals										B 10.81	C 12.011	N 14.007	O 15.999	F 18.998	Ne 20.179		
3	Na 22.990	Mg 24.305	Transition Metals										Al 26.982	Si 28.086	P 30.974	S 32.06	Cl 35.453	Ar 39.948		
4	K 39.098	Ca 40.08	Sc 44.956	Ti 47.88	V 50.942	Cr 51.996	Mn 54.938	Fe 55.847	Co 58.933	Ni 58.69	Cu 63.546	Zn 65.39	Ga 69.72	Ge 72.59	As 74.922	Se 78.96	Br 79.904	Kr 83.80		
5	Rb 85.468	Sr 87.62	Y 88.906	Zr 91.224	Nb 92.906	Mo 95.94	Tc (98)	Ru 101.07	Rh 102.91	Pd 106.42	Ag 107.87	Cd 112.41	In 114.82	Sn 118.71	Sb 121.75	Te 127.60	I 126.91	Xe 131.29		
6	Cs 132.91	Ba 137.23	to 71		Hf 178.49	Ta 180.95	W 183.85	Re 186.21	Os 190.2	Ir 192.22	Pt 195.08	Au 196.97	Hg 200.59	Tl 204.38	Pb 207.2	Bi 208.98	Po (209)	At (210)	Rn (222)	
7	Fr (223)	Ra (226.03)	to 103		Unq (261)	Unp (262)	Unh (263)	Uns (264)	Uno (265)	Une (266)	Uun (267)									
																			Phases	
																			Solid	
																			Liquid	
																			Gas	
																			Rare Earth Elements	
																			Lanthanide Series	
																			Actinide Series	

Conclude: Big Cosmic News of 2003



Greenspan Throws Cold Water On Bush Arguments for Tax Cut
Budget Deficits Do Matter, Fed Chairman Says

WASHINGTON, Feb. 12 — Alan Greenspan, the Federal Reserve chairman, today rebuffed many of President Bush's arguments for a big tax rate cut, saying that the economy probably had not yet recovered enough to justify such a move. He also said that the budget deficit would be a major problem in the years ahead.

Mr. Greenspan did not attack the president's plan, but he was cautious in his support. He said that the economy had not yet recovered enough to justify such a move. He also said that the budget deficit would be a major problem in the years ahead.



Tapes of Shuttle's Descent Show Dawning of Disaster

WASHINGTON, Feb. 12 — The first tapes of the shuttle's descent showed the dawning of disaster as the shuttle's main engine began to sputter and the shuttle began to roll over.

TOP U.S. OFFICIALS PRESS CASE LINKING IRAQ TO AL QAEDA

WASHINGTON, Feb. 12 — Senior Bush administration officials today pressed the case for linking Iraq to al Qaeda, with Secretary of State Colin L. Powell and the director of Central Intelligence, George J. Tenet, leading the effort.

France Offering Plan to Expand Iraq Arms Hunt

PARIS, Feb. 12 — France is offering an alternative to the United States plan to expand the hunt for weapons of mass destruction in Iraq, with the offer being made by the French foreign minister.

Congress Agrees to Bar Pentagon From Terror Watch of Americans

WASHINGTON, Feb. 12 — The House of Representatives today agreed to a measure that would bar the Pentagon from conducting surveillance of Americans at home.

France Offering Plan to Expand Iraq Arms Hunt

PARIS, Feb. 12 — France is offering an alternative to the United States plan to expand the hunt for weapons of mass destruction in Iraq, with the offer being made by the French foreign minister.

With Vivid Palette, Mandela Depicts the Jailhouse Years

ROBEN ISLAND, Feb. 12 — The artist Nelson Mandela today unveiled a painting that depicts his years in prison, with the work being shown in a gallery in Johannesburg.

Chicago Leads Oscar Race

CHICAGO, Feb. 12 — The city of Chicago today led the race for the Academy Award for Best Picture, with the film 'Chicago' being the favorite.

Kerry Blue Turtler Is Leader of the Pack

CHICAGO, Feb. 12 — The blue turtler today emerged as the leader of the pack in the race for the Academy Award for Best Picture, with the film 'Chicago' being the favorite.

Cosmos Sits for Early Portrait, Gives Up Secrets

WASHINGTON, Feb. 12 — The mission to Mars today gave up some of its secrets, with the Mars Global Surveyor satellite providing the first detailed images of the planet's surface.

- The Universe is 13.7 ± 0.2 Gyr old
- Hot stars reionized the Universe only 200 Myr after the Big Bang
- We know what the Universe is made of, but most of it is "dark energy" [or "smooth matter. Finding the nature of these dark components gives cosmologists plenty to work on.

Newspaper Circulation	
The New York Times	1,100,000
The Washington Post	600,000
The Wall Street Journal	400,000
The Los Angeles Times	350,000
The Chicago Tribune	300,000
The Dallas Morning News	250,000
The Houston Chronicle	200,000
The San Antonio Express-News	150,000
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The Sacramento Bee	70,000
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