# Peering into the Big bang : the new microwave map of the Universe

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TYPESET USING LaTeX, FoilTeX, LyX, Ppower4

# Outline

- The expanding Universe; millions of galaxies
- The Big Bang and Cosmic Background Radiation
- Formation of galaxies
- New technology
  - ⋆ Hubble Space Telescope
  - ⋆ WMAP
- The new synthesis
- Summary
  - ⋆ Epilogue : Related big questions (Dark matter, cosmological constant ...)

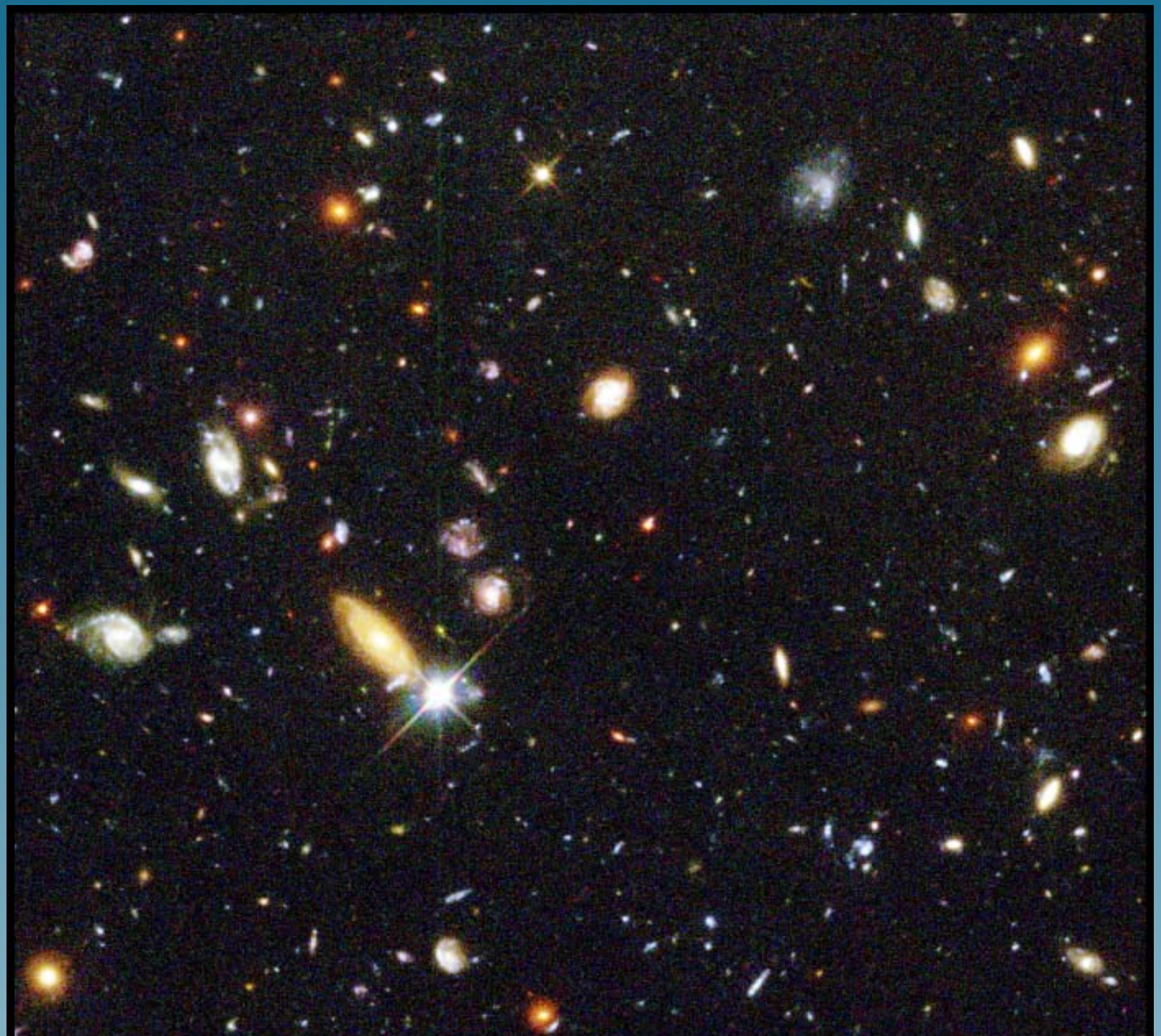
# Cosmography - I

Before the advent of large telescopes the Milky Way was our Universe.

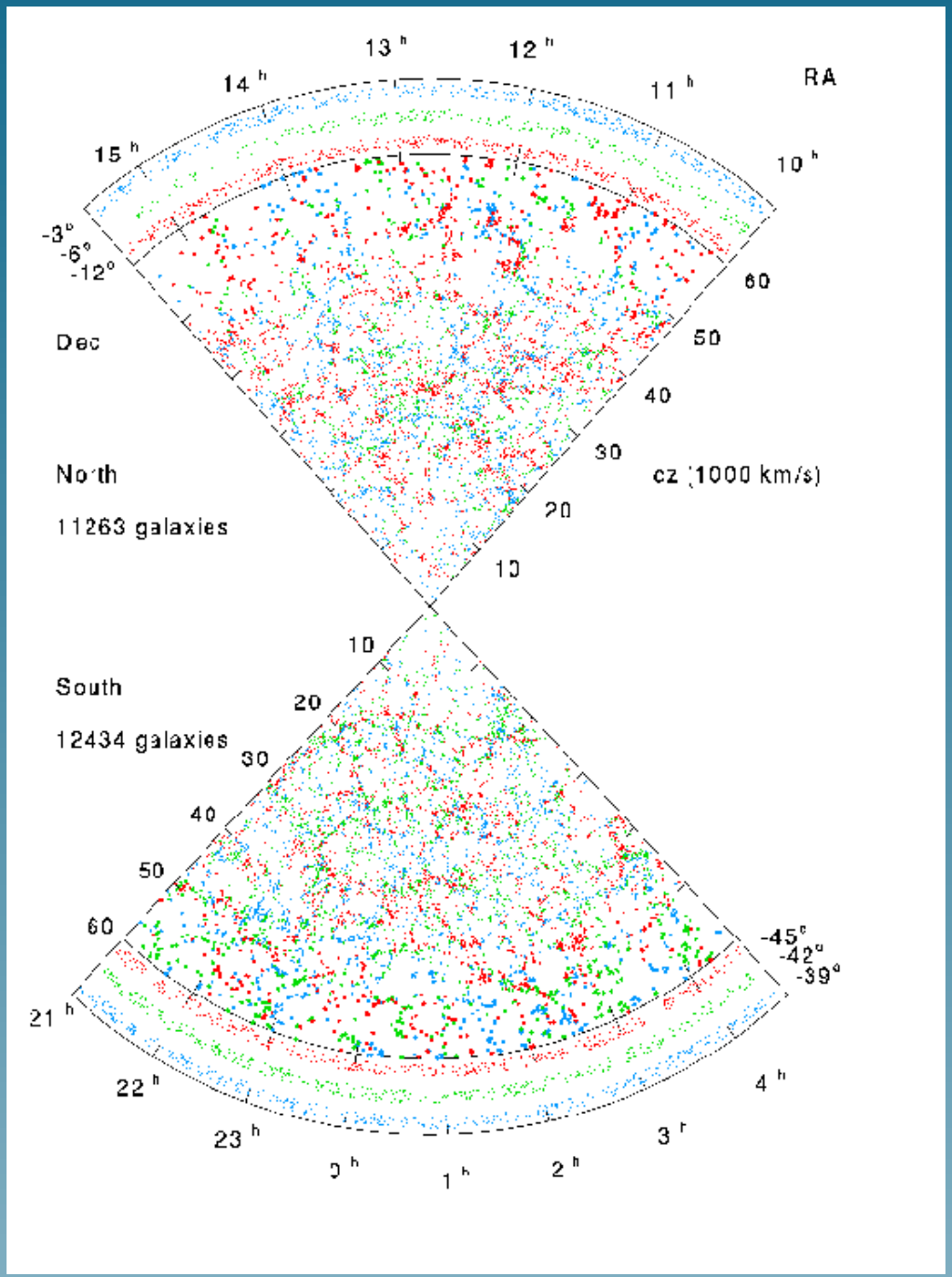
# Island universes

Nebulae in our Milky Way could not be distinguished from Galaxies.

Immanuel Kant conjectured that some of the nebulae could be “island universes” similar to our own.

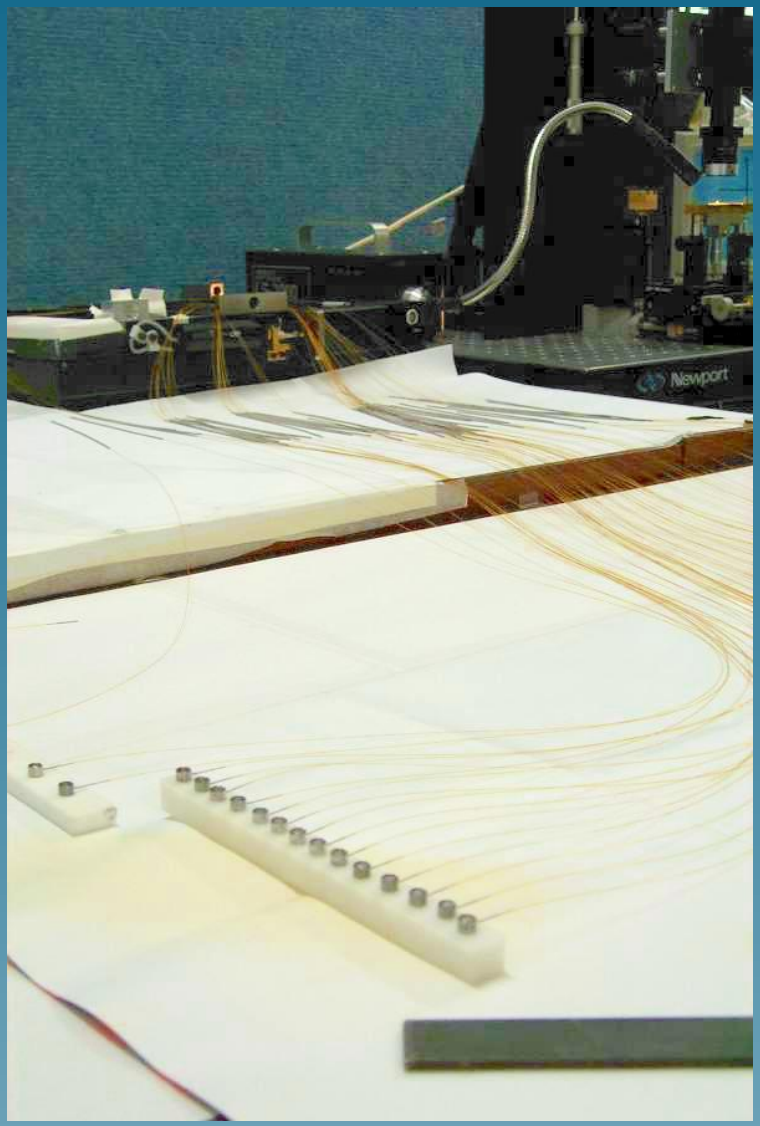


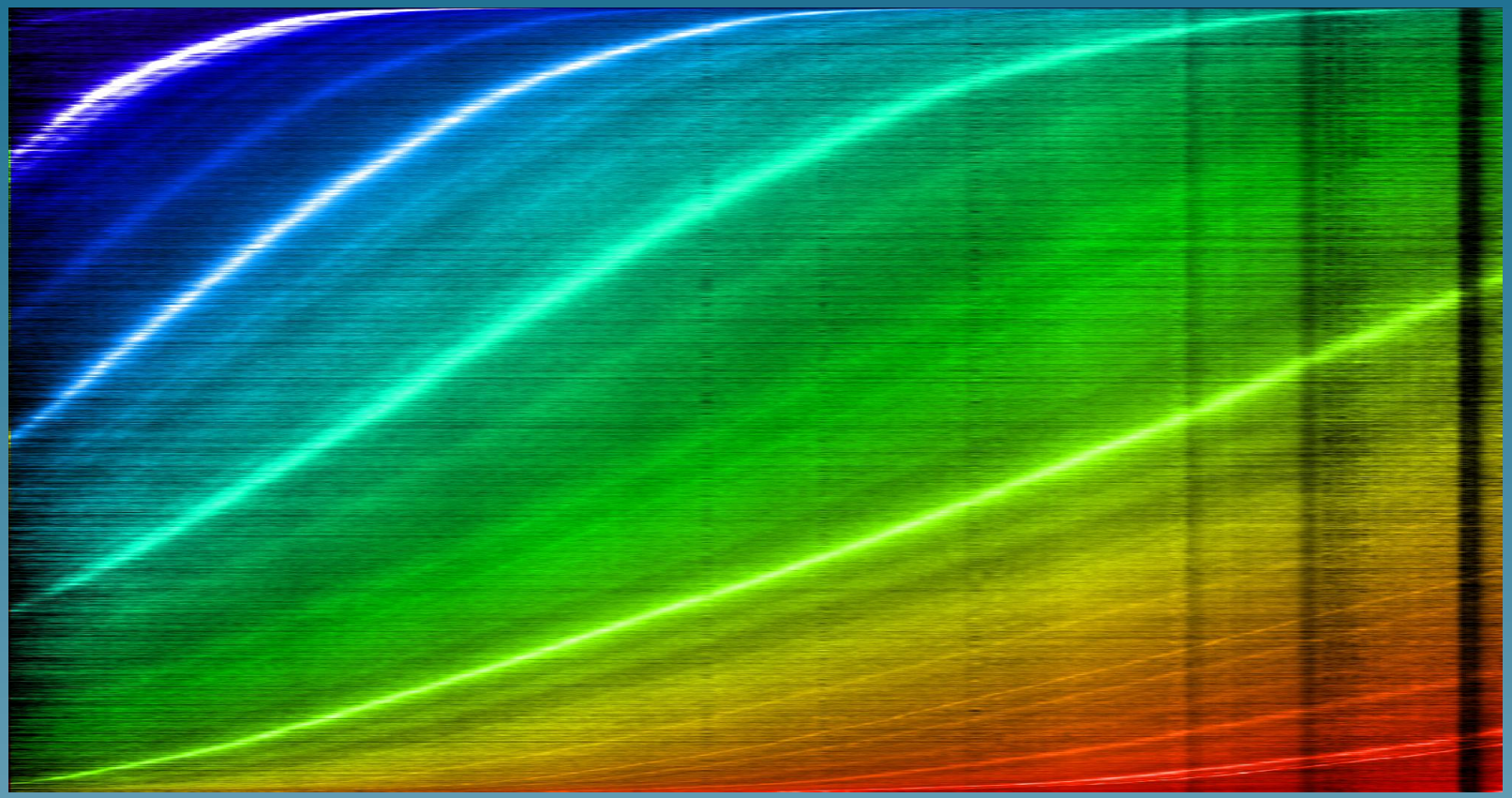
# Galaxy surveys

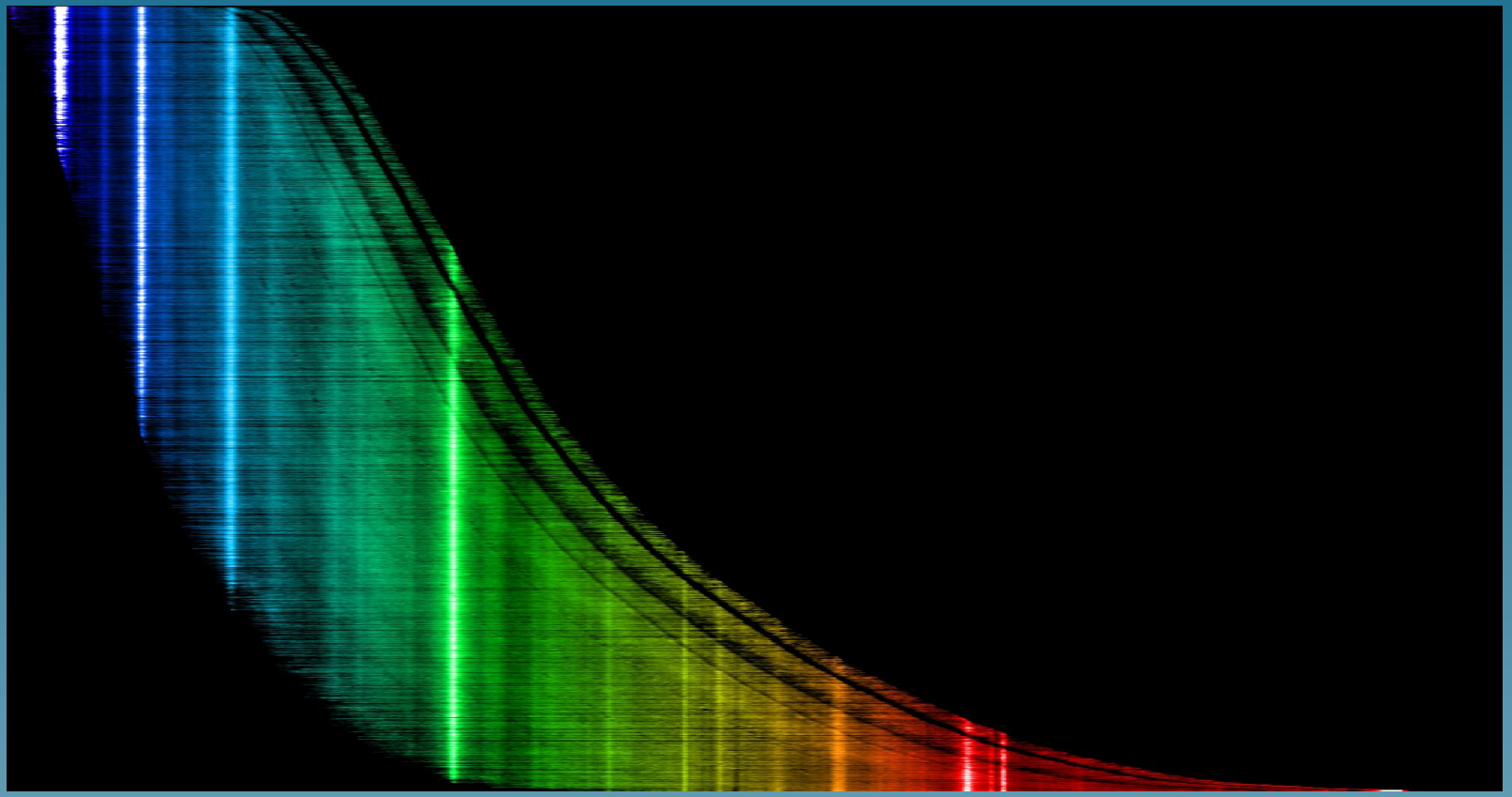

13 h
12 h
14 h
11 h
RA
15 h
10 h
-3°
-6°
-12°
Dec
60
50
40
30
North
cz (1000 km/s)
20
11263 galaxies
10
10
South
20
12434 galaxies
30
40
50
60
-45°
-42°
-39°
21 h
22 h
4 h
23 h
3 h
0 h
1 h
2 h

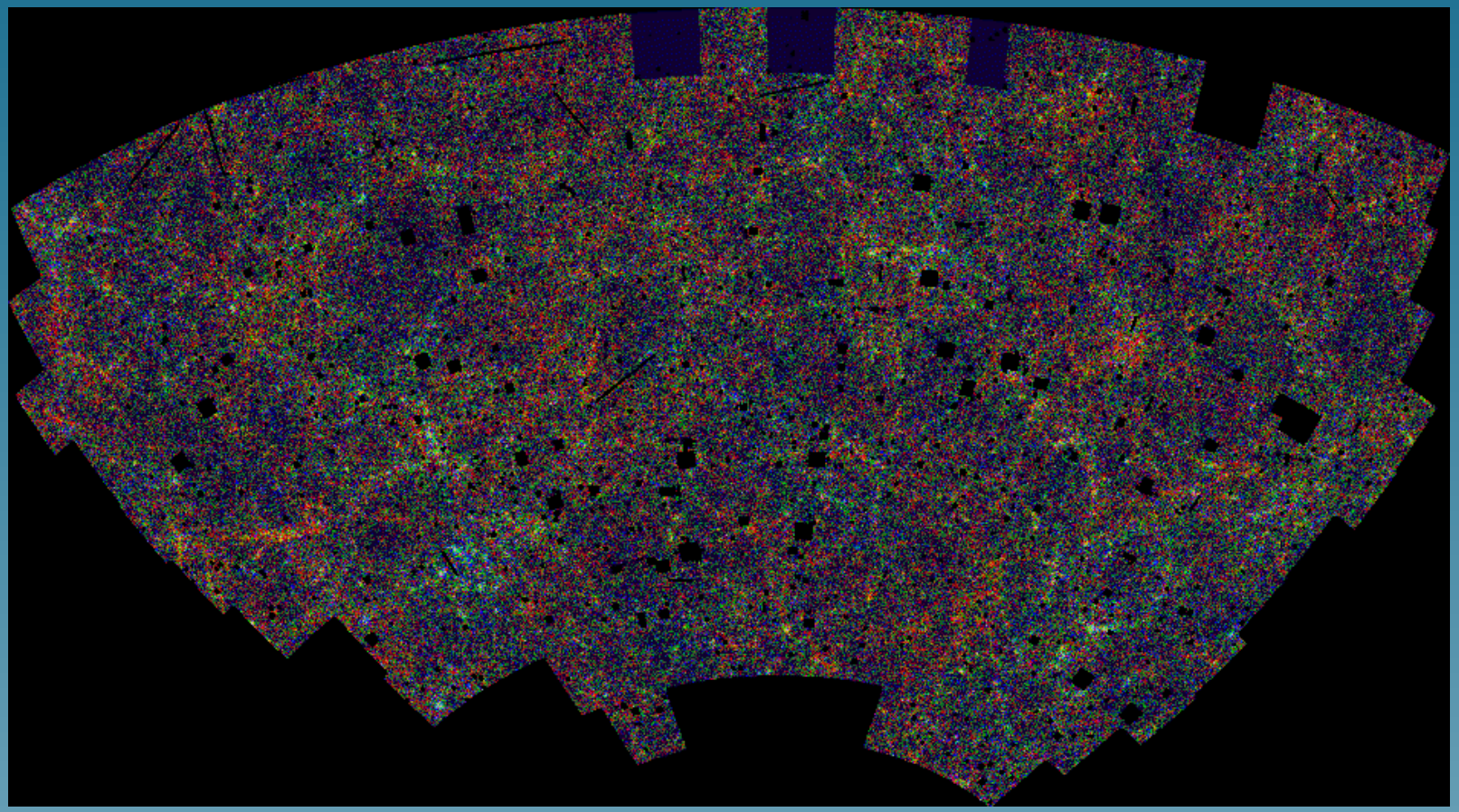
# Galaxy surveys : 2 degree field

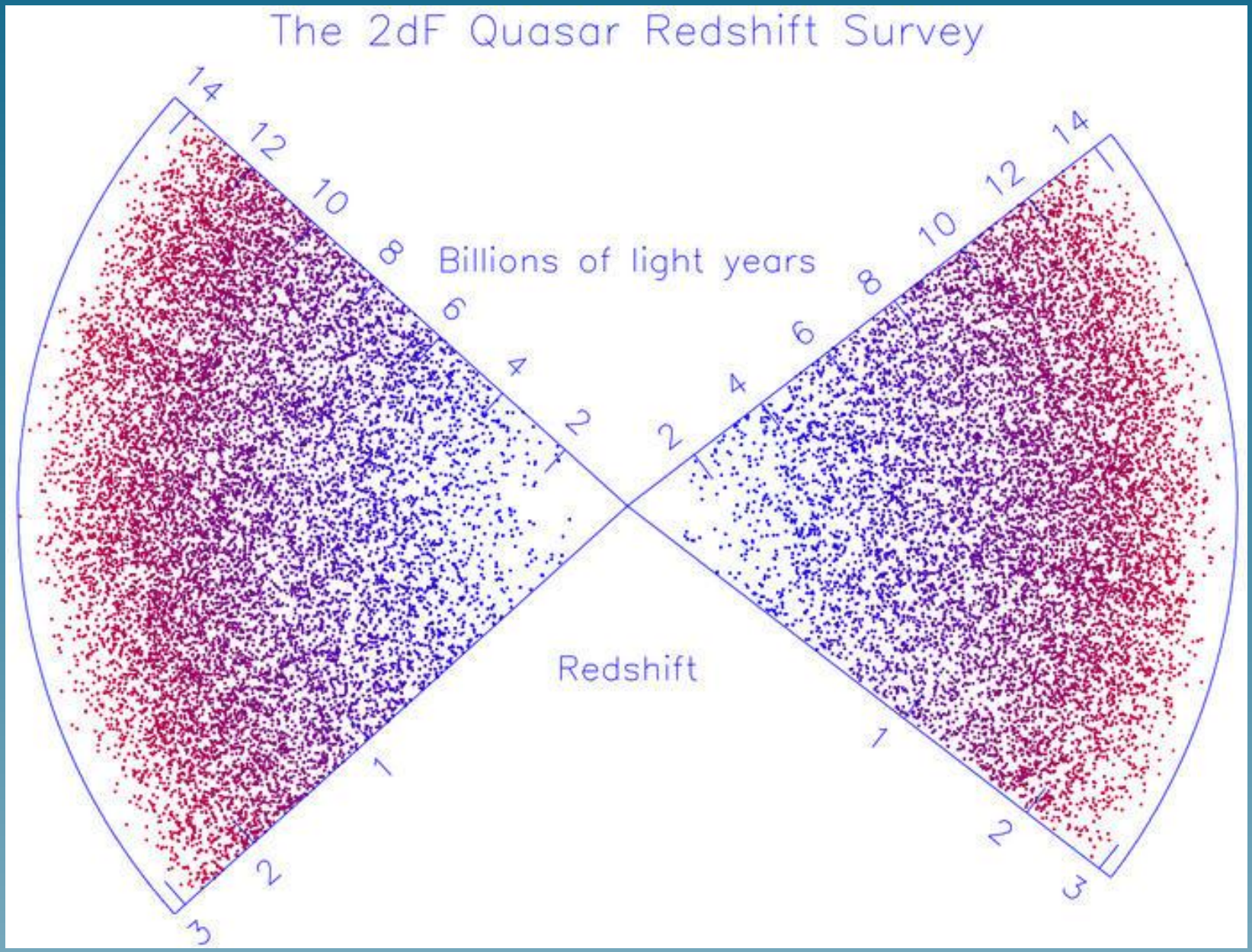
2dF : A joint UK and Australian project. Using the dark skies of Southern Hemisphere.


Newport



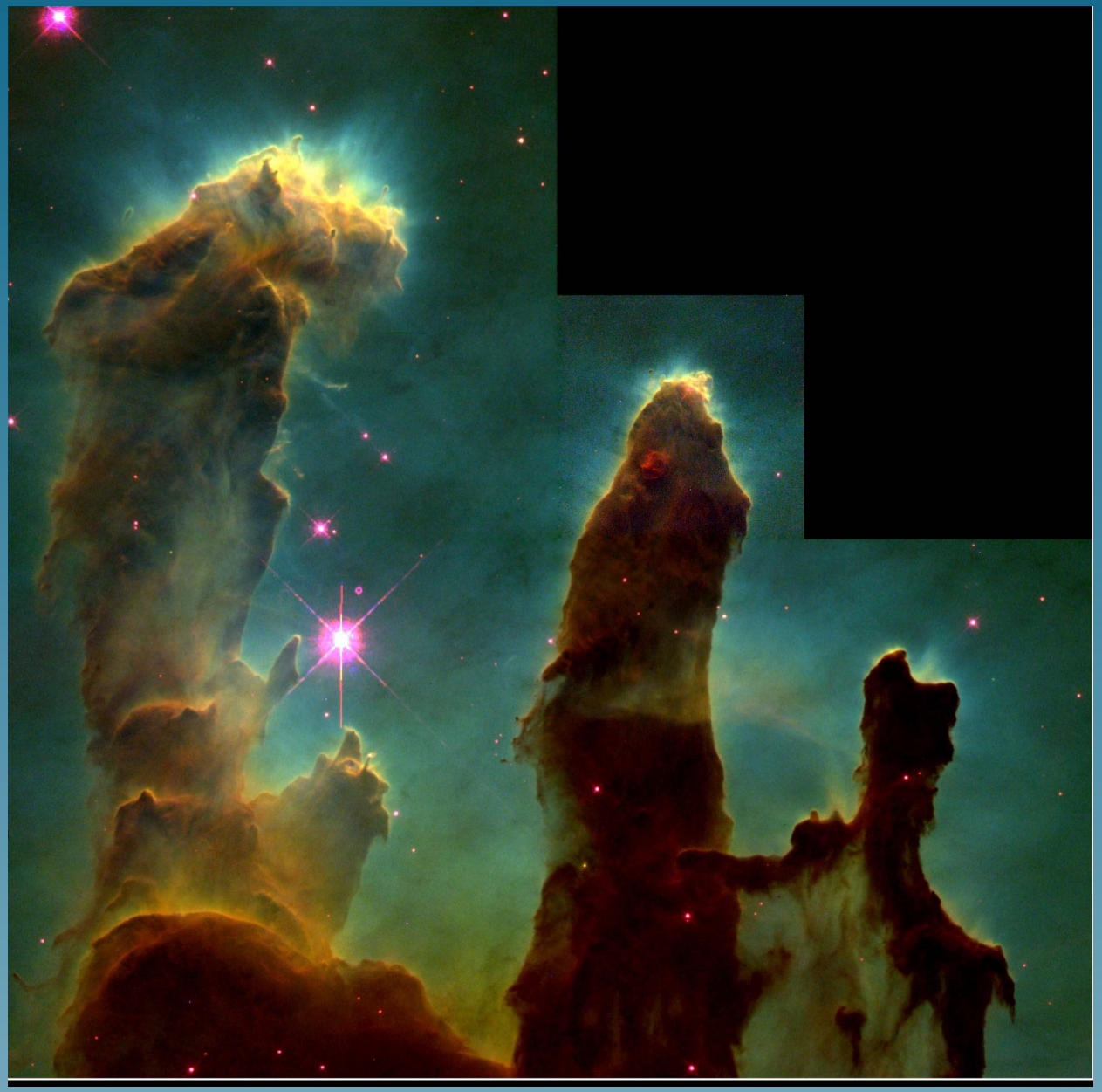





The 2dF Quasar Redshift Survey
Billions of light years
Redshift
14
12
10
8
6
4
2
1
2
3

# star formation cloud

The Eagle nebula M16



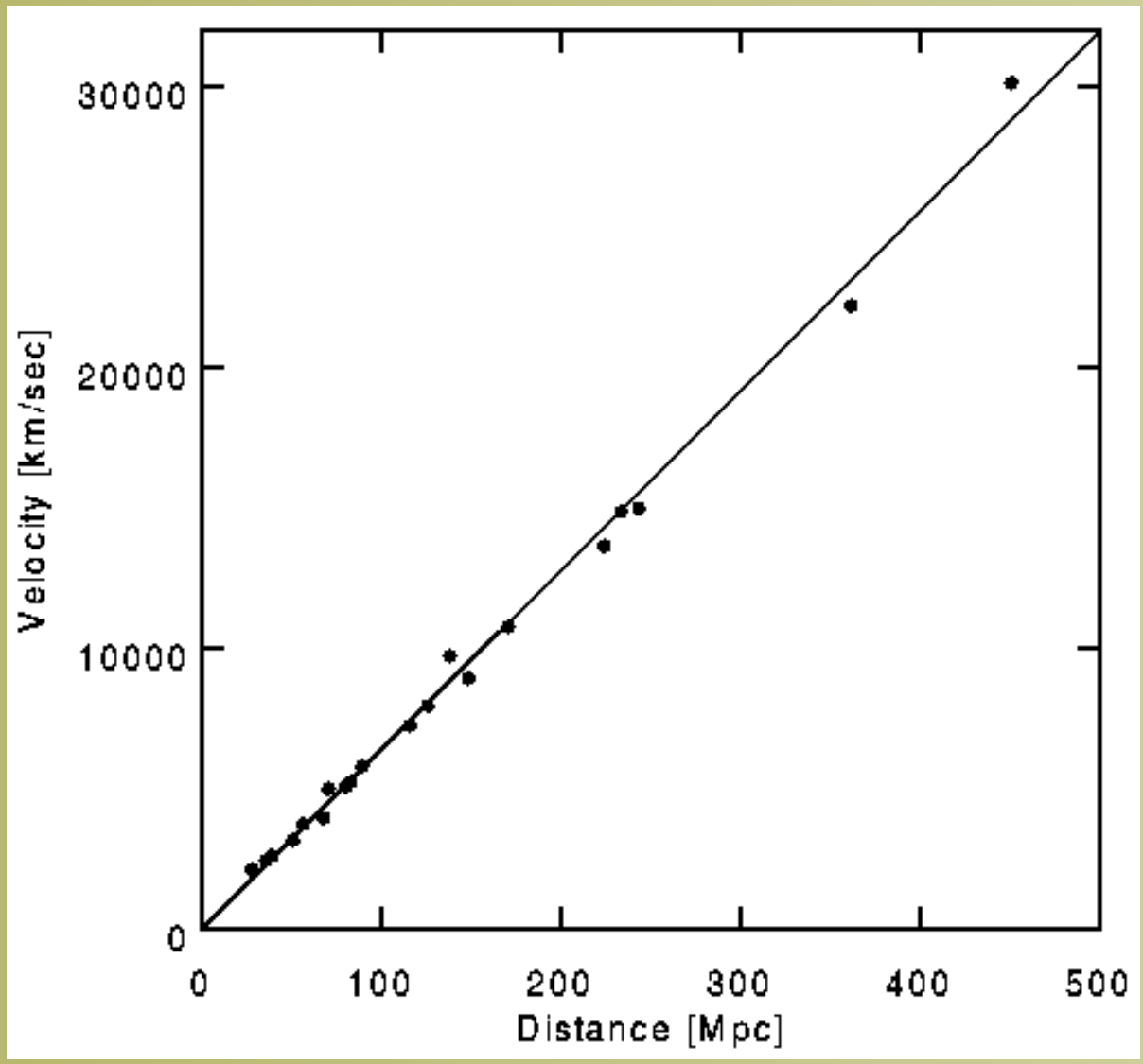
# Details ...

# Local neighbourhood

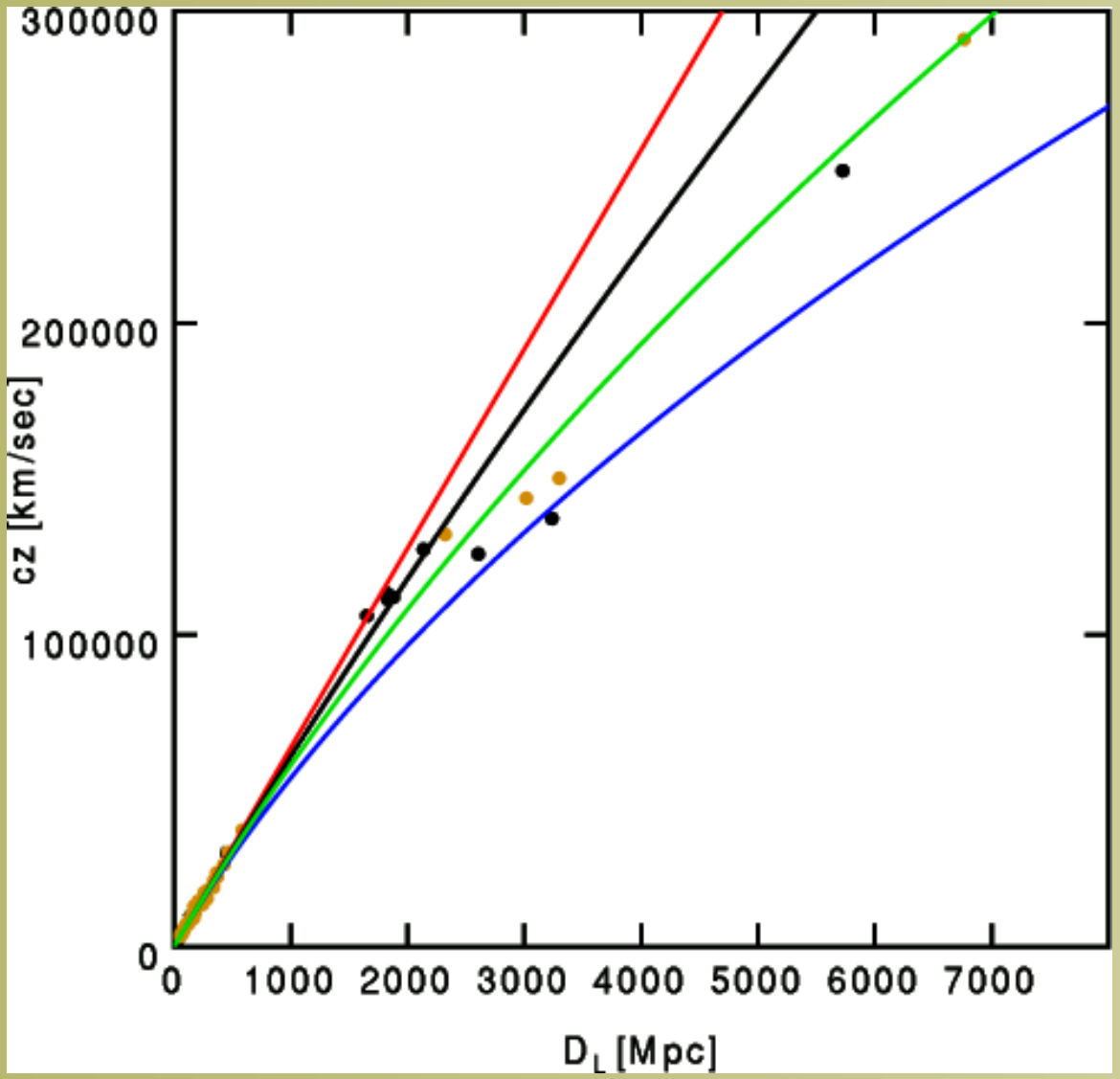
Andromaeda picture
Local nbhd schematic

# The Big Bang

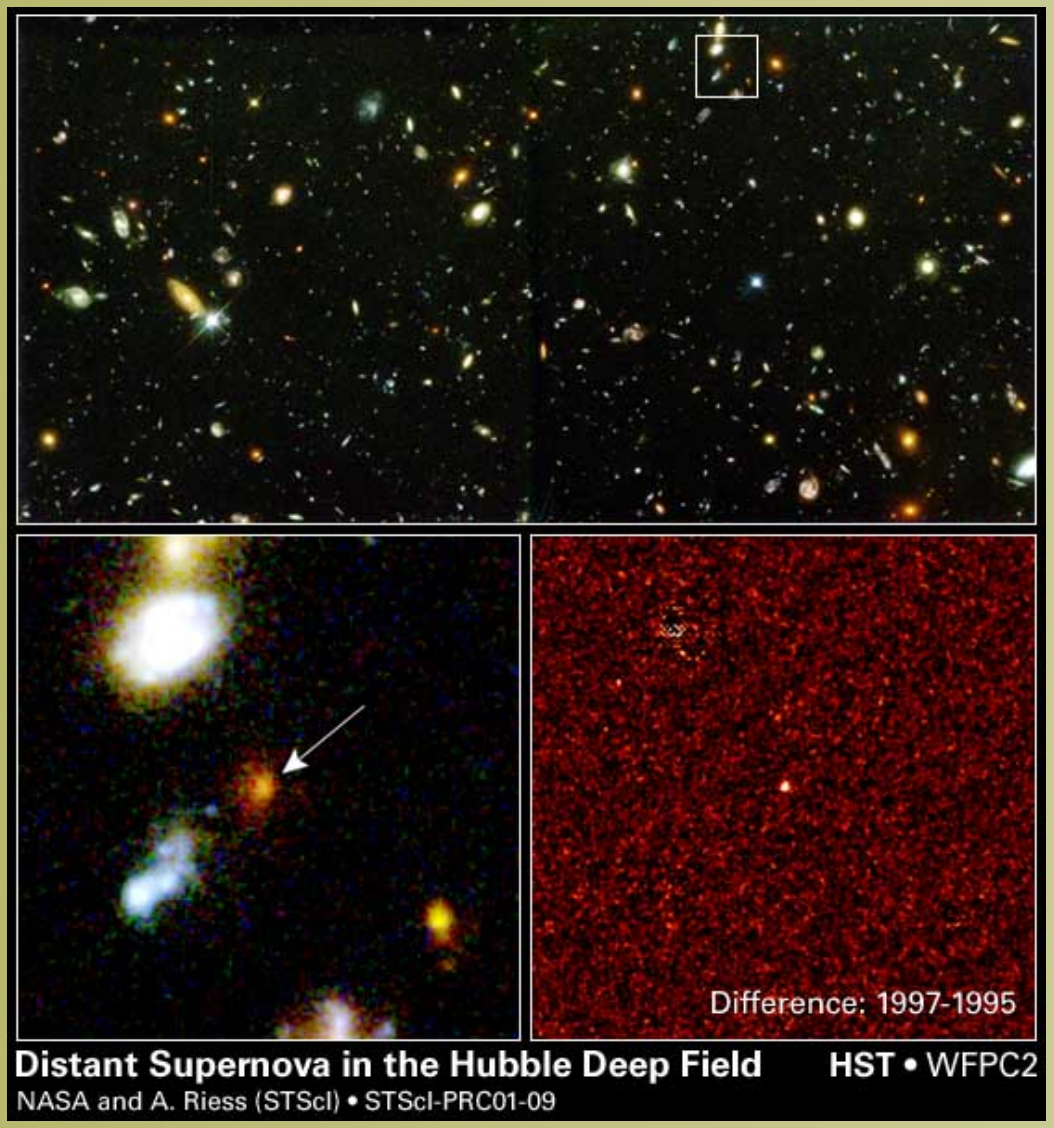
For most galaxies, the Hydrogen spectrum is shifted into the red. Independent measurements of distances to galaxies and their redshifts revealed a pattern. Edwin Hubble drew a line through this plot.


30000
20000
10000
0
Velocity [km/sec]
0
100
200
300
400
500
Distance [Mpc]

# Modern Hubble plot



# A blast from the remote past




*Show movie*

# The Cosmic Expansion

Extrapolated sequence backwards in time

| | | |
|---|---|---|
| • Ionised Hydrogen | 1 eV | $10^4$ K |
| • Free neutrons and protons | 1 MeV | $10^{10}$ K |
| • Quark-Gluon plasma | 1 GeV | $10^{13}$ K |
| • Electroweak scale | 100 GeV | $10^{15}$ K |
| • Quantum Gravity | | $10^{19}$ GeV |

Neutral H formation $\sim 10^5$years after the Big Bang

Relic radiation $10^4$ K then; 3 K now

Alpher, Bethe and Gamow (1942)

# Gravity = curved space-time

General Relativity the theory of the space-time metric

$$ds^2 = dt^2 - R(t)^2\{\frac{dr^2}{1+kr^2} + r^2 d\theta^2 + r^2 \sin^2 d\phi^2\}$$

$k = 0$ for flat Universe; $k = \pm 1$ for constant positive or negative curvature

$R(t)$ the Scale factor ... A. A. Friedmann

# Equation for $R$

$$\left(\frac{1}{R}\frac{dR}{dt}\right)^2 + \frac{k}{R^2} = \frac{8\pi}{3}G\rho$$

Equation of state $p = p(\rho)$ required

Radiation dominated Universe :

$p = \frac{1}{3}\rho \Rightarrow R(t) \propto t^{1/2}$

Matter dominated Universe :

$p = 0 \Rightarrow R(t) \propto t^{2/3}$

# Book keeping of Cosmic contents

$$H^2 + \frac{k}{R^2} - \Lambda = \frac{8\pi G}{3}\rho$$

where ρ =Total energy

another way of writing ...

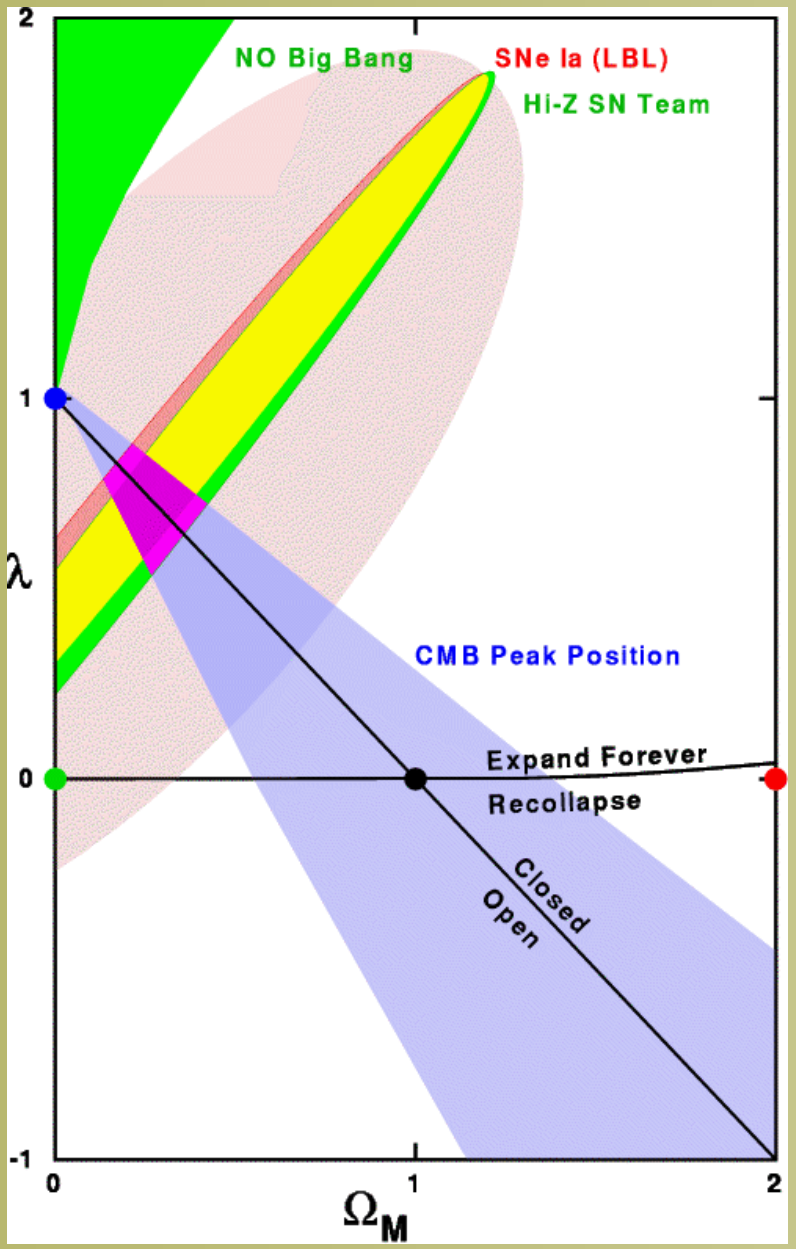
$$1 + \frac{k}{H^2 R^2} = \Omega_\Lambda + \Omega_\rho$$

- ✔ Today LHS seems to be $1$
  - ✔ So in the curvature term, $k = 0$

# Current best fit to data

- ✔ $\Lambda$ term seems to dominate, $\Omega_\Lambda = 0.7$
- ✔ But most of ρ is not baryons! Let $\Omega_\rho = \Omega_{DM} + \Omega_B$
  - ✔ Baryons contribute only $\Omega_B = 0.03$
  - ✔ $\Omega_{DM} = 0.27$ So much is the “Dark Matter”

How do we know all this?


NO Big Bang
SNe Ia (LBL)
Hi-Z SN Team
CMB Peak Position
Expand Forever
Recollapse
Closed
Open
λ
$\Omega_M$
2
1
0
-1
0
1
2

# Cosmography : main features

Current parameters of the Universe :

- Expansion rate $71 \pm 4$ (km/s)/MegaParsec
- Size of the visible Universe $3$ GigaParsec
- Age of the Universe $13.7 \pm 2$ GigaYears
- Age at decoupling $380 \pm 7 \times 10^3$ Year

How do we know all this?

# Dark Matter and Dark Energy

What can Dark Matter be?

It could have been neutrinos, but that would be too light ...

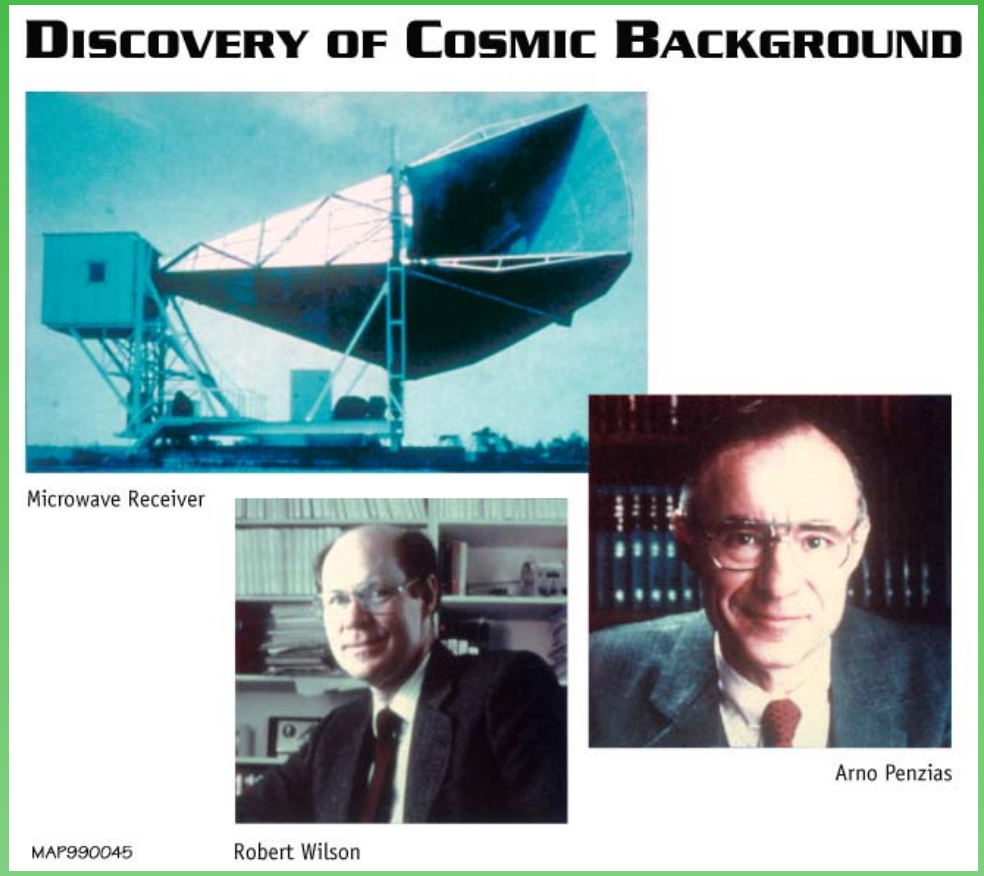
All other particles thoroughly searched at High Energy acceperators

Signature of new physics? Supersymmetry?

# Cosmography - II

# A bug in communication link

A noisy communication link in 1965




Nearby, in Princeton Dicke, Roll, Peebles and Wilkinson were building the antenna required to detect the radiation.

# Galaxy formation

Before there was anything, there was nothing, right?

*So where did everything come from?*

*-BC cartoon*

From homogeneous plasma

... to clumps of cold matter

# Theory

Needed input : fluctuations in the matter density, $\frac{\delta\rho}{\rho}$ at a time $t_1$

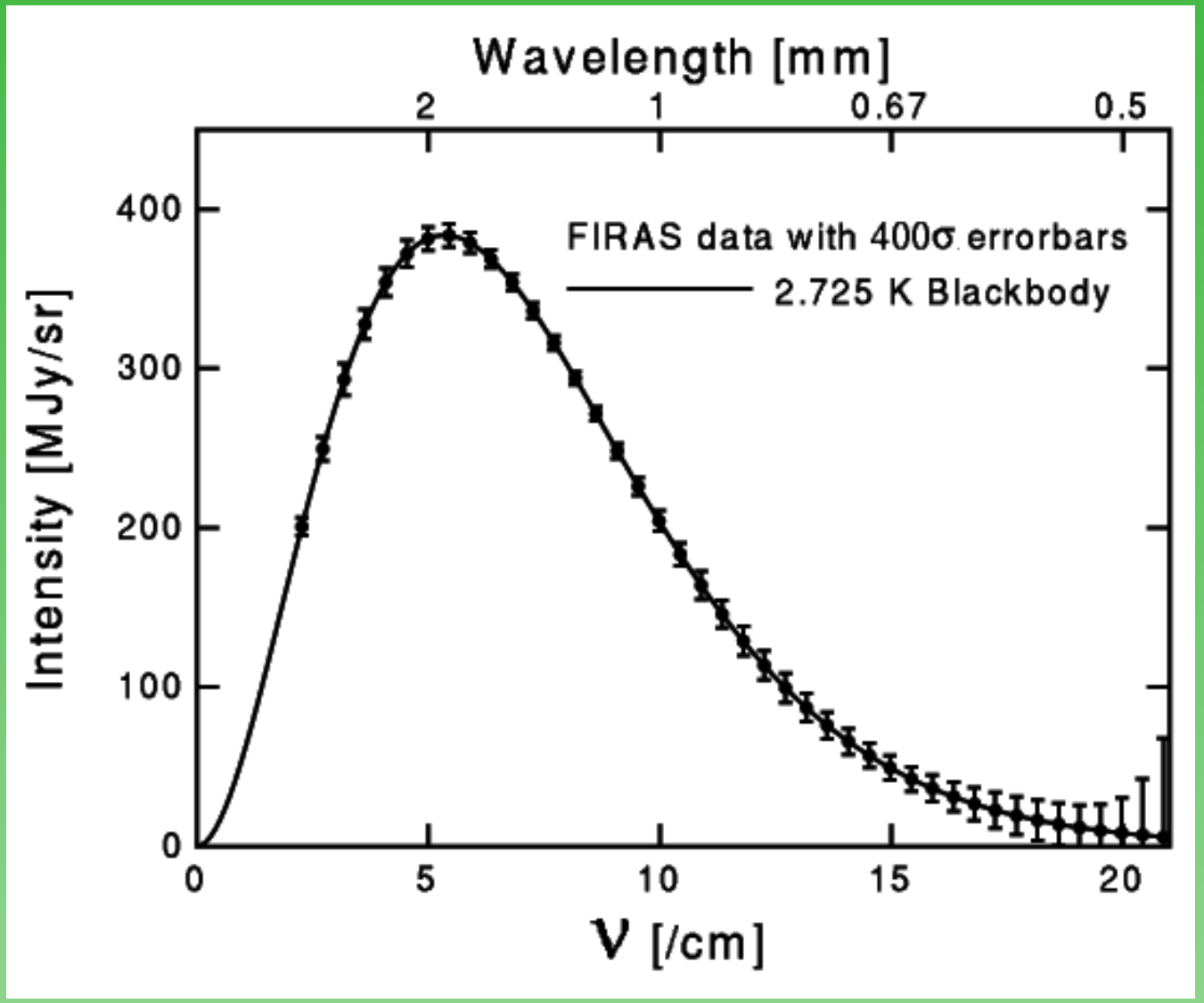
- Matter : Perturbations grow proportional to scale factor $R(t)$
- Radiation : No growth in perturbations

At present epoch perurbations are large, $\sim O(1)$

$$\left[\frac{\delta\rho}{\rho}\right]_{eq} \sim \frac{R_{equality}}{R_0} \sim 10^{-4}$$

Imprints on the decoupled radiation

# COBE and friends 1992-95



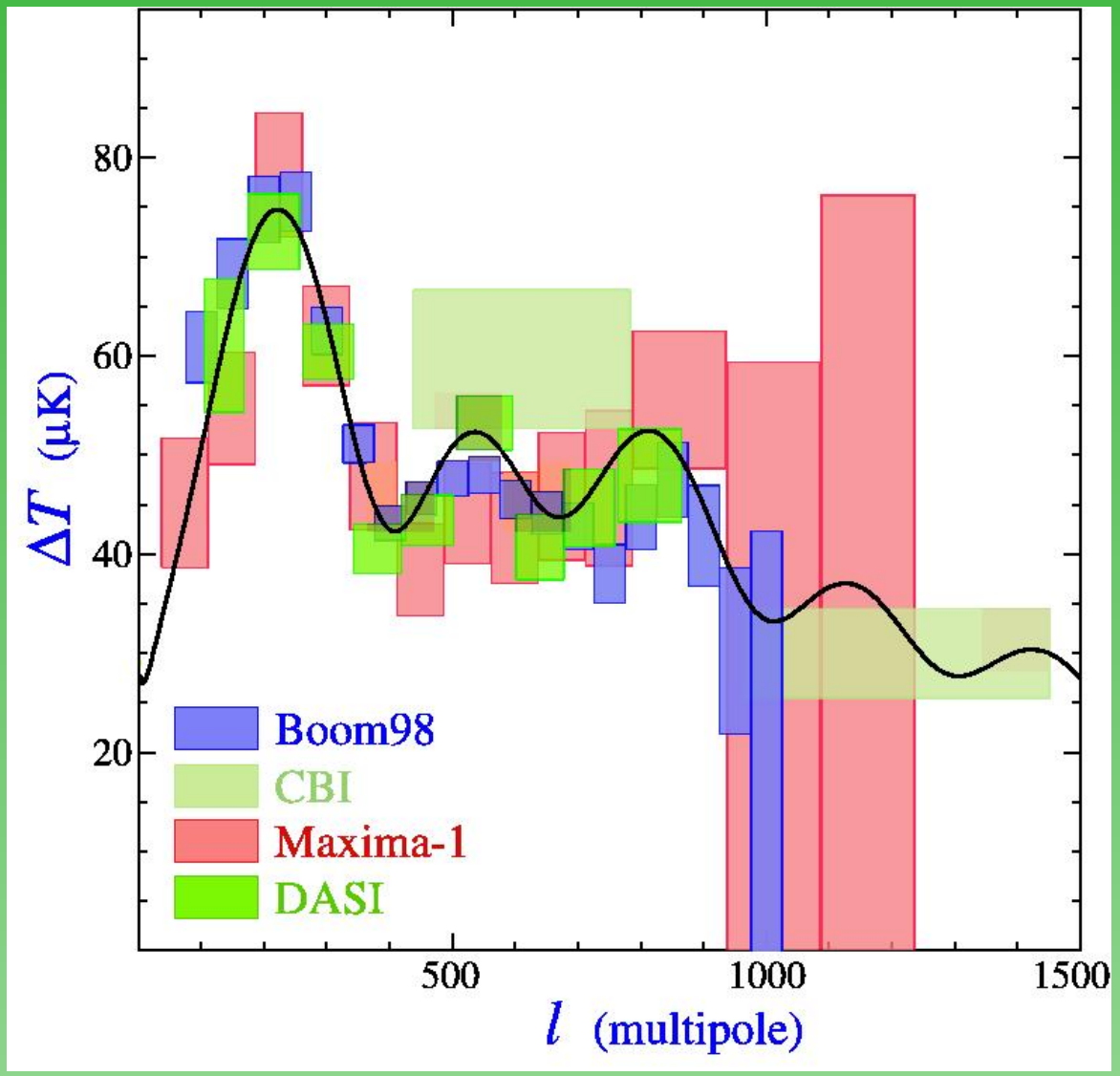
# Power spectrum estimation

The sky can be described in terms of spherical harmonics

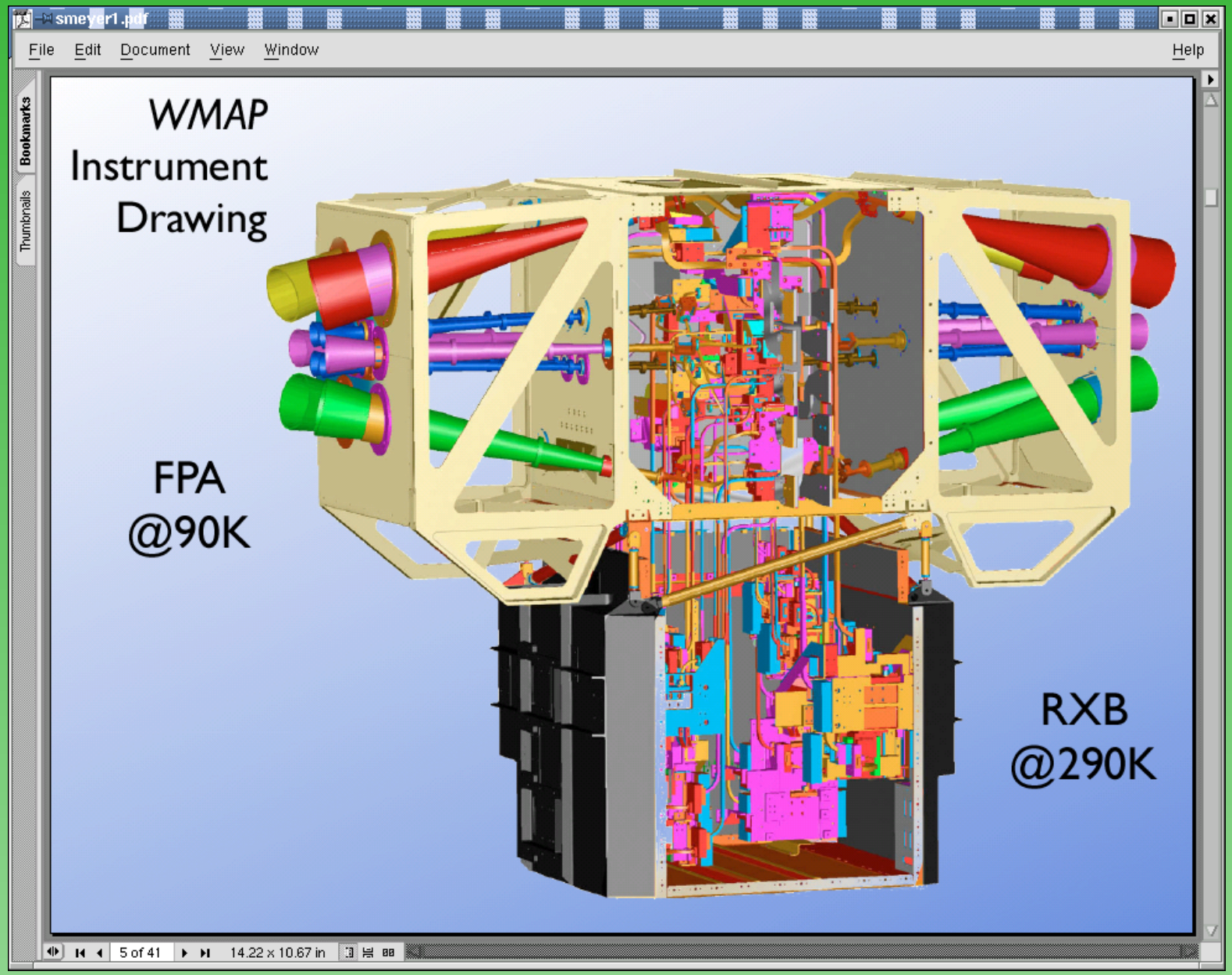
$$\Delta T(\mathbf{n}) = \sum a_{lm} Y_{lm}(\mathbf{n})$$

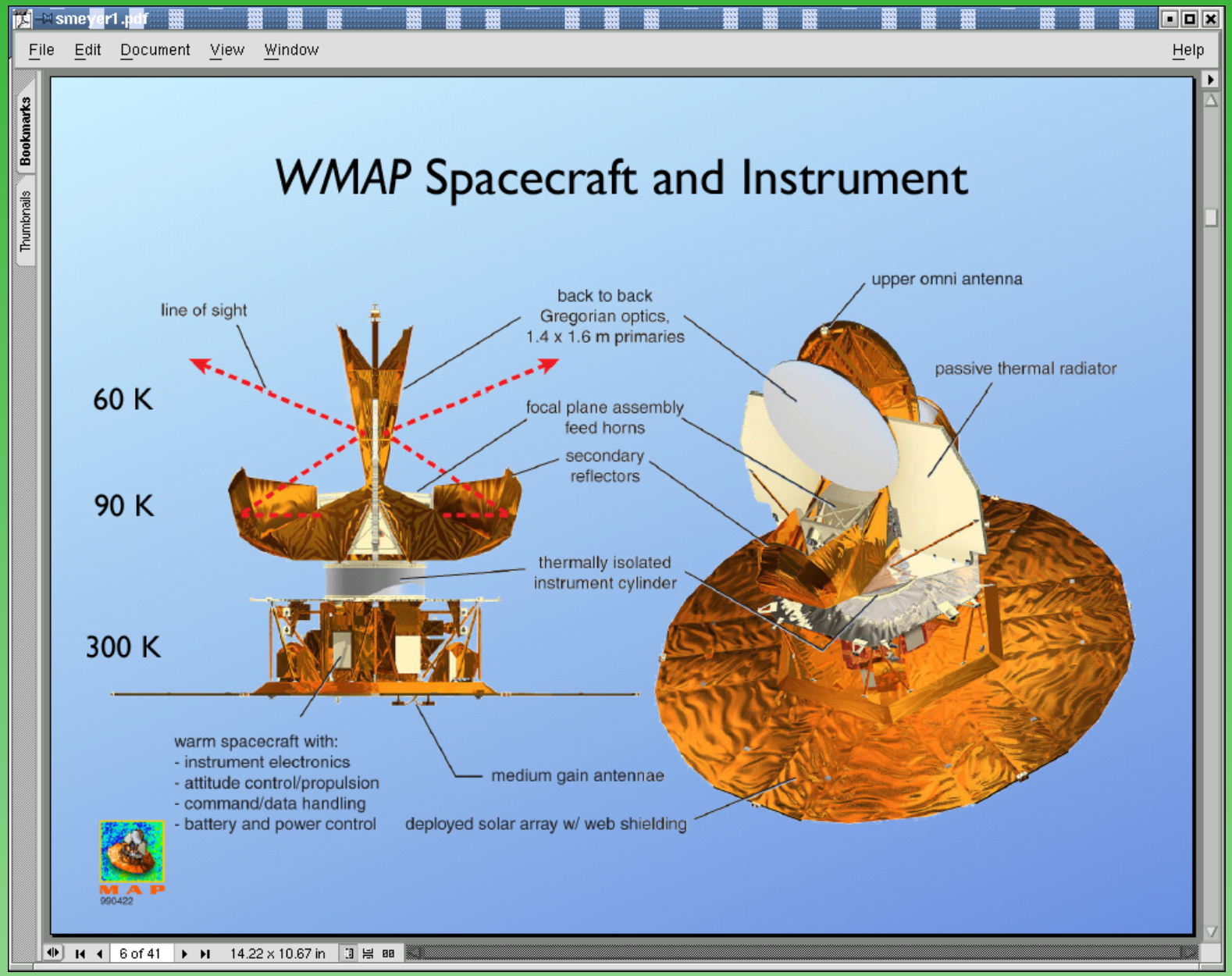
For the CMB we assume $\Delta T(\mathbf{n})$ is Gaussian distributed and define

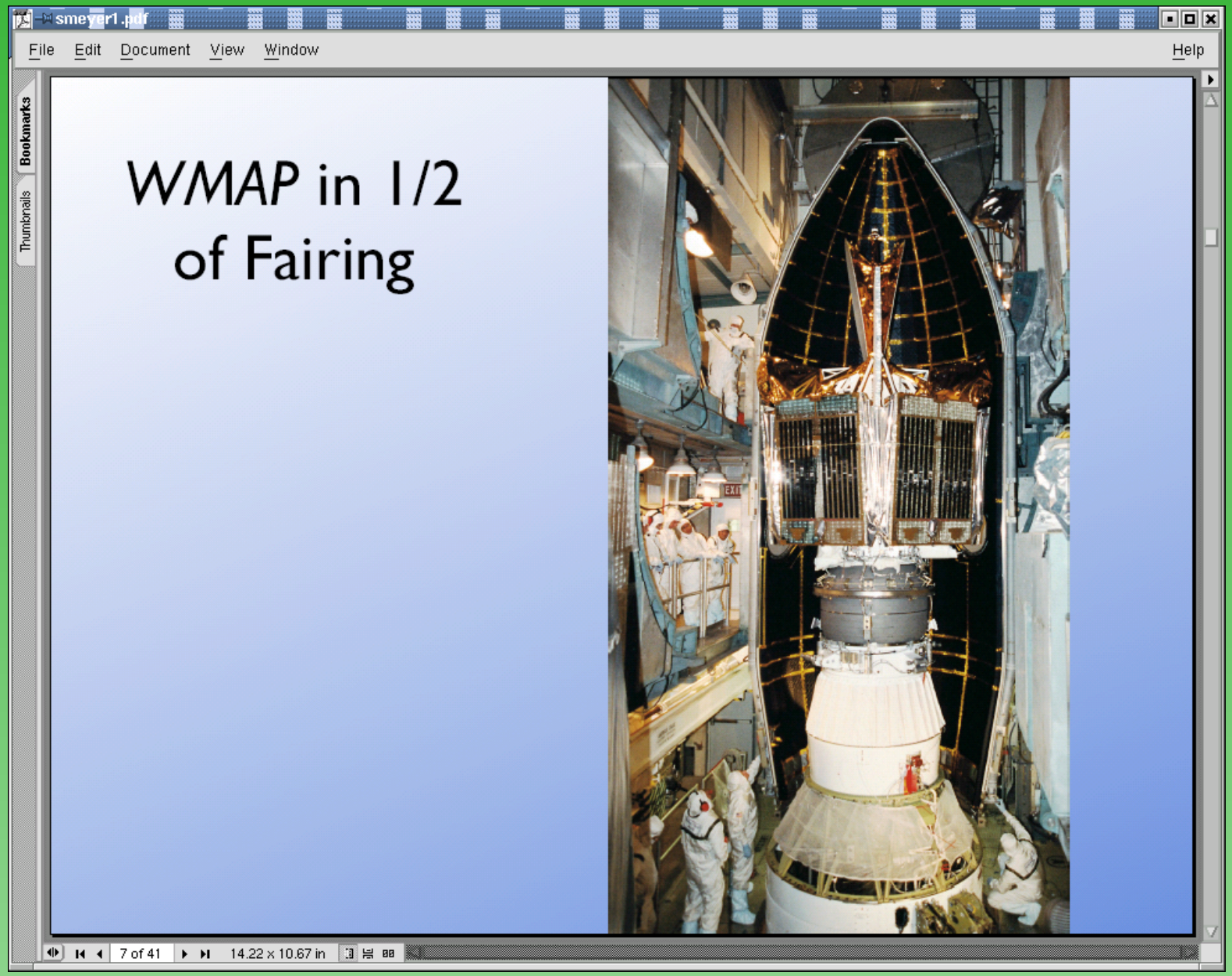
$$C_l \equiv \frac{1}{2l+1} \sum |a_{lm}|^2$$


80
60
40
20
ΔT (μK)
500
1000
1500
l (multipole)
Boom98
CBI
Maxima-1
DASI

# The Wilkinson Microwave Anisotropy Project


smeyer1.pdf
File Edit Document View Window Help
Bookmarks
Thumbnails
WMAP
Instrument
Drawing
FPA
@90K
RXB
@290K
5 of 41
14.22 x 10.67 in


smeyer1.pdf
File Edit Document View Window Help
Bookmarks
Thumbnails
WMAP Spacecraft and Instrument
line of sight
back to back
Gregorian optics,
1.4 x 1.6 m primaries
upper omni antenna
passive thermal radiator
60 K
focal plane assembly
feed horns
secondary
reflectors
90 K
thermally isolated
instrument cylinder
300 K
warm spacecraft with:
- instrument electronics
- attitude control/propulsion
- command/data handling
- battery and power control
medium gain antennae
deployed solar array w/ web shielding
MAP
990422
6 of 41
14.22 x 10.67 in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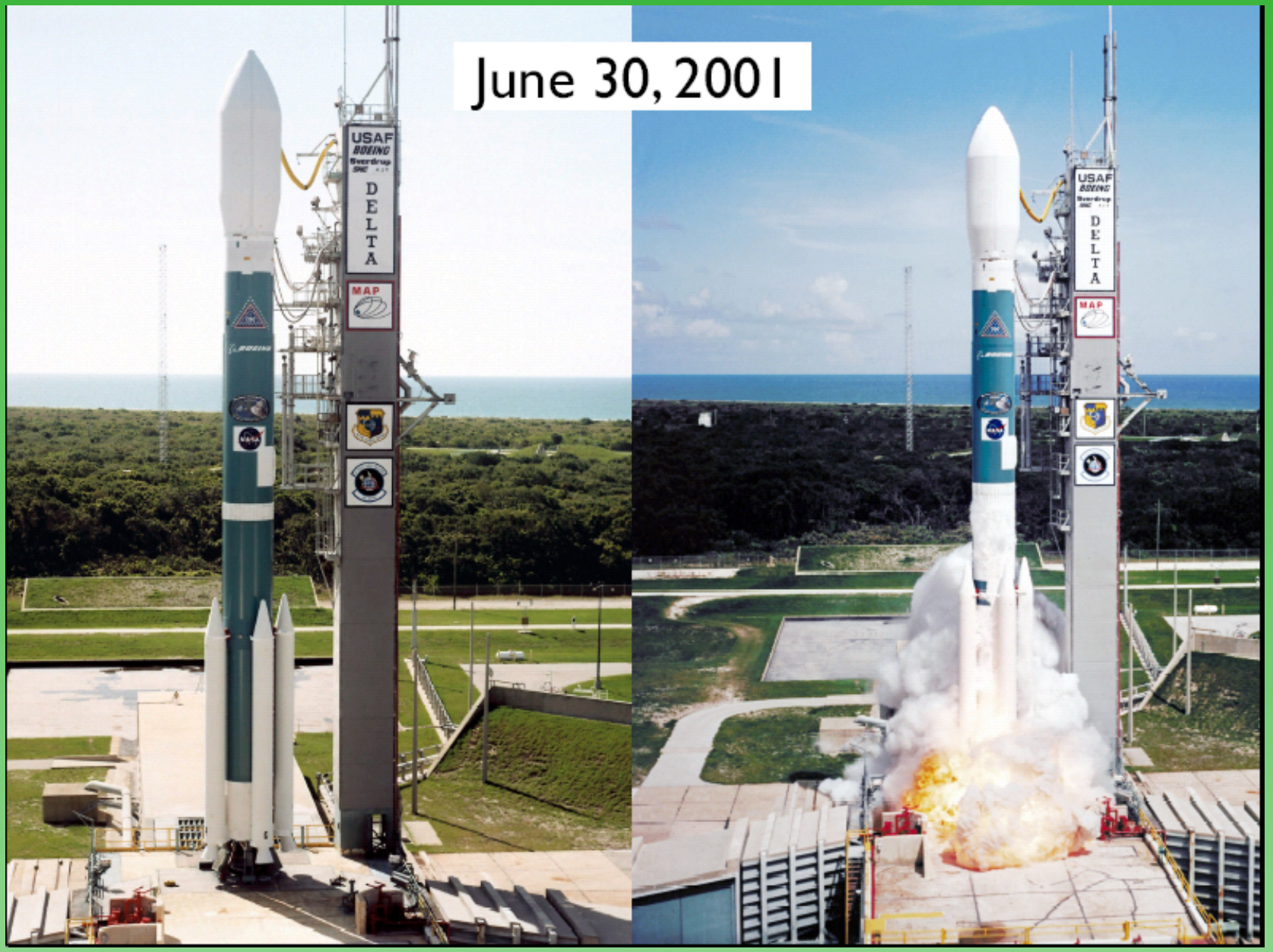
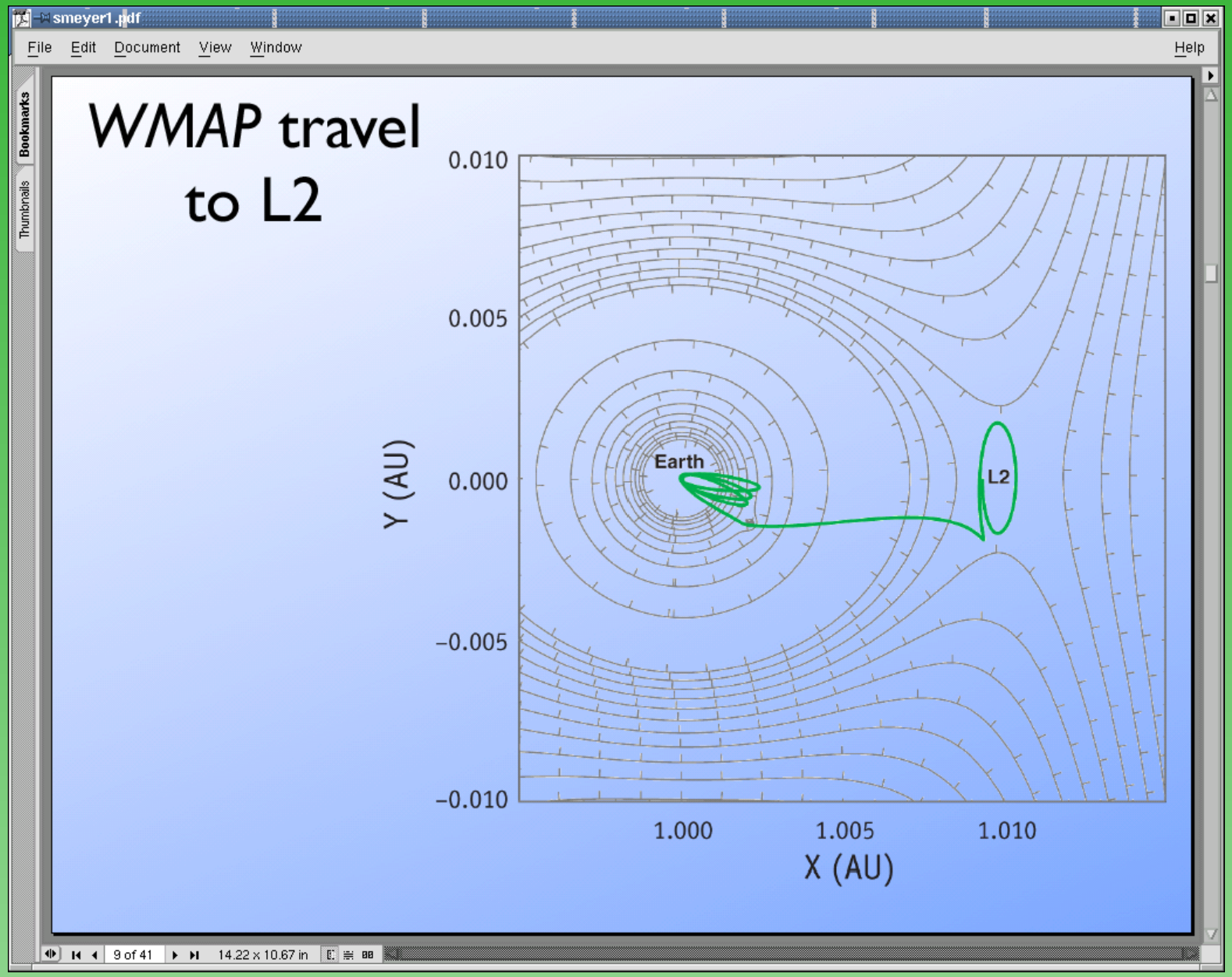
WMAP in 1/2 of Fairing
7 of 41
14.22 x 10.67 in


June 30, 2001
USAF
BOEING
DELTA
MAP


smeyer1.pdf
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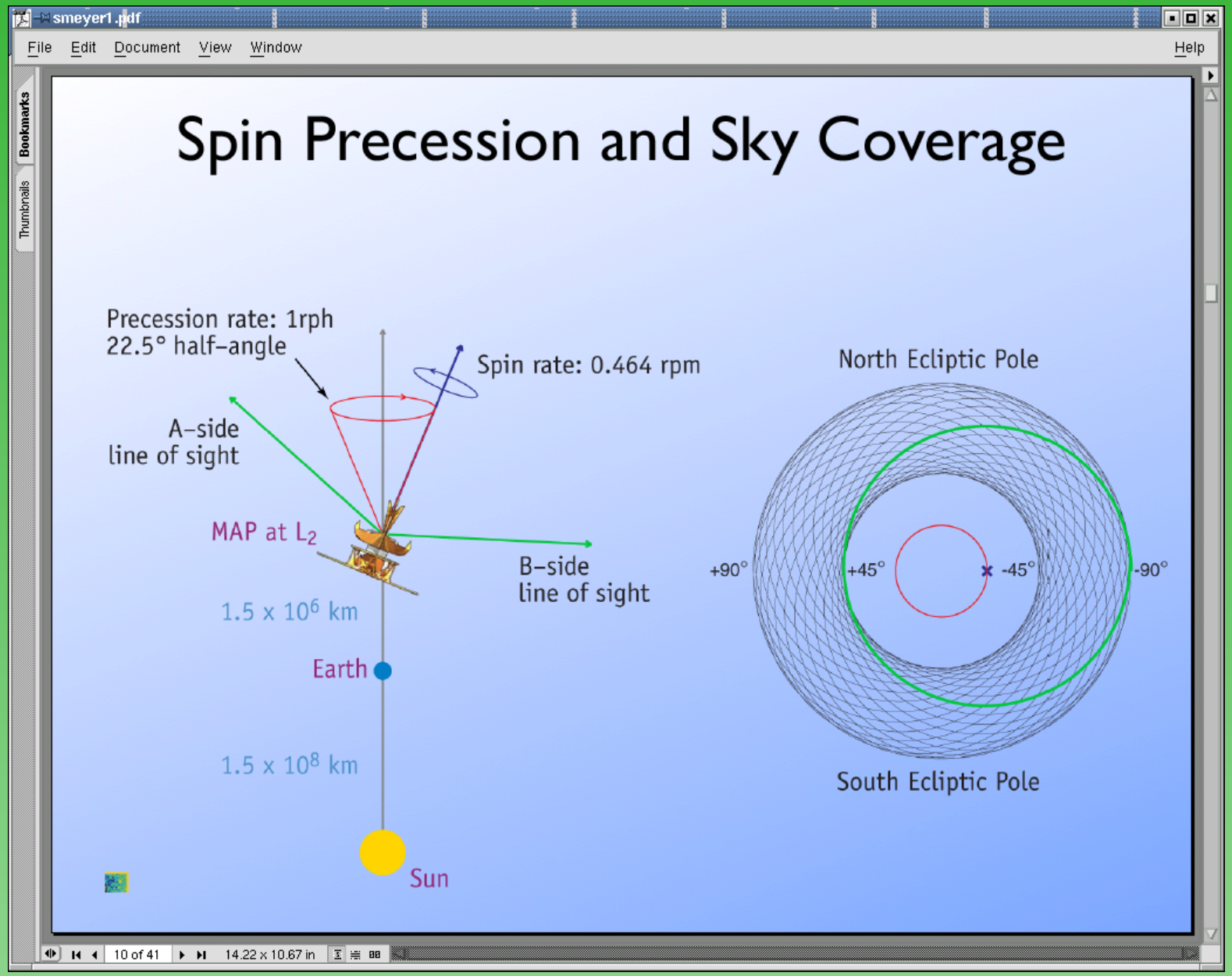
Bookmarks
Thumbnails
WMAP travel to L2
0.010
0.005
0.000
−0.005
−0.010
Y (AU)
Earth
L2
1.000
1.005
1.010
X (AU)
9 of 41
14.22 x 10.67 in


smeyer1.pdf
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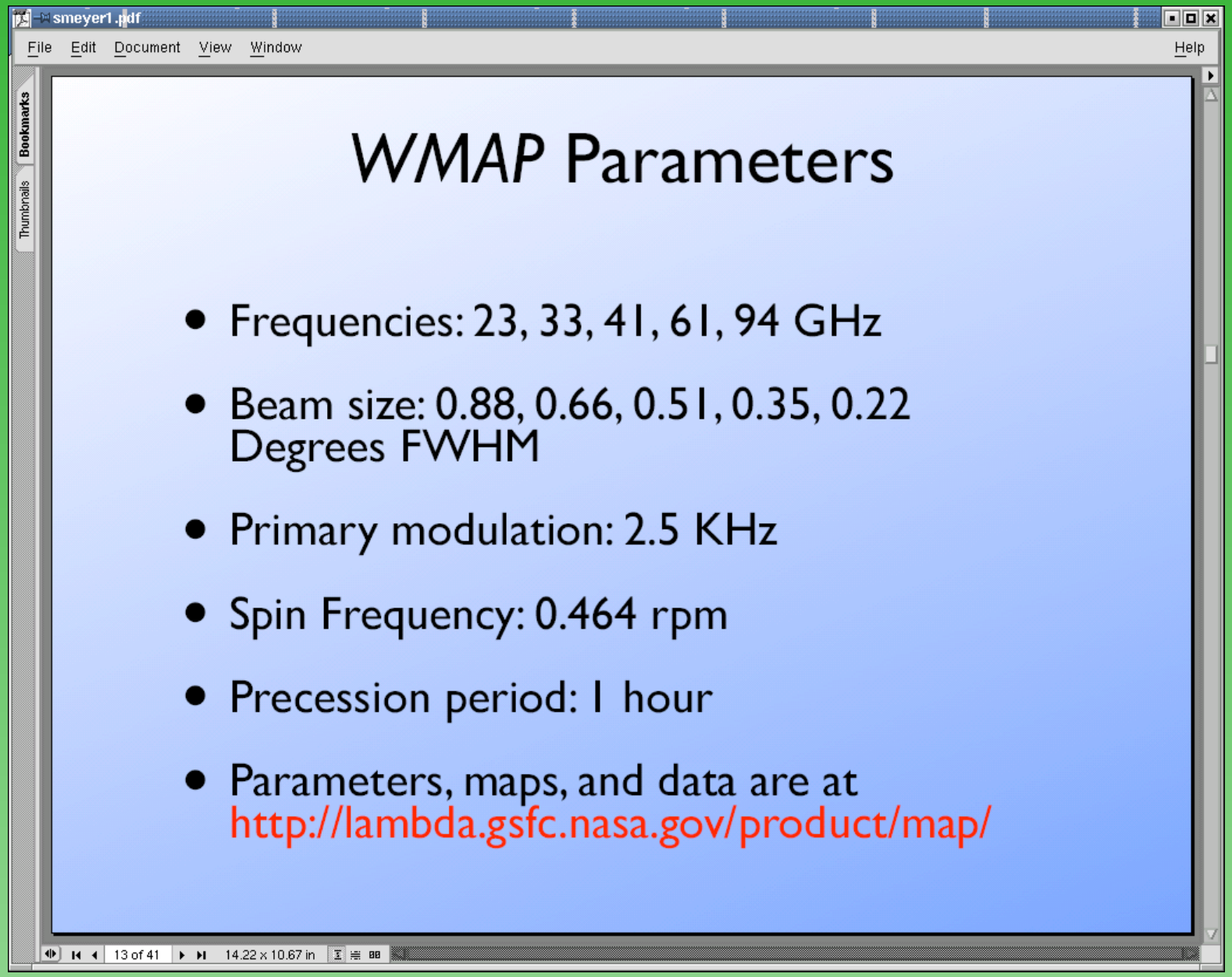
Bookmarks
Thumbnails
Spin Precession and Sky Coverage
Precession rate: 1rph
22.5° half-angle
Spin rate: 0.464 rpm
A-side
line of sight
MAP at L2
B-side
line of sight
1.5 x 10^6 km
Earth
1.5 x 10^8 km
Sun
North Ecliptic Pole
+90°
+45°
-45°
-90°
South Ecliptic Pole
10 of 41
14.22 x 10.67 in


smeyer1.pdf
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Bookmarks
Thumbnails
WMAP Parameters
Frequencies: 23, 33, 41, 61, 94 GHz
Beam size: 0.88, 0.66, 0.51, 0.35, 0.22 Degrees FWHM
Primary modulation: 2.5 KHz
Spin Frequency: 0.464 rpm
Precession period: 1 hour
Parameters, maps, and data are at http://lambda.gsfc.nasa.gov/product/map/
13 of 41
14.22 x 10.67 in

# Power spectrum estimation

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For the CMB we assume $\Delta T(\mathbf{n})$ is Gaussian distributed and define

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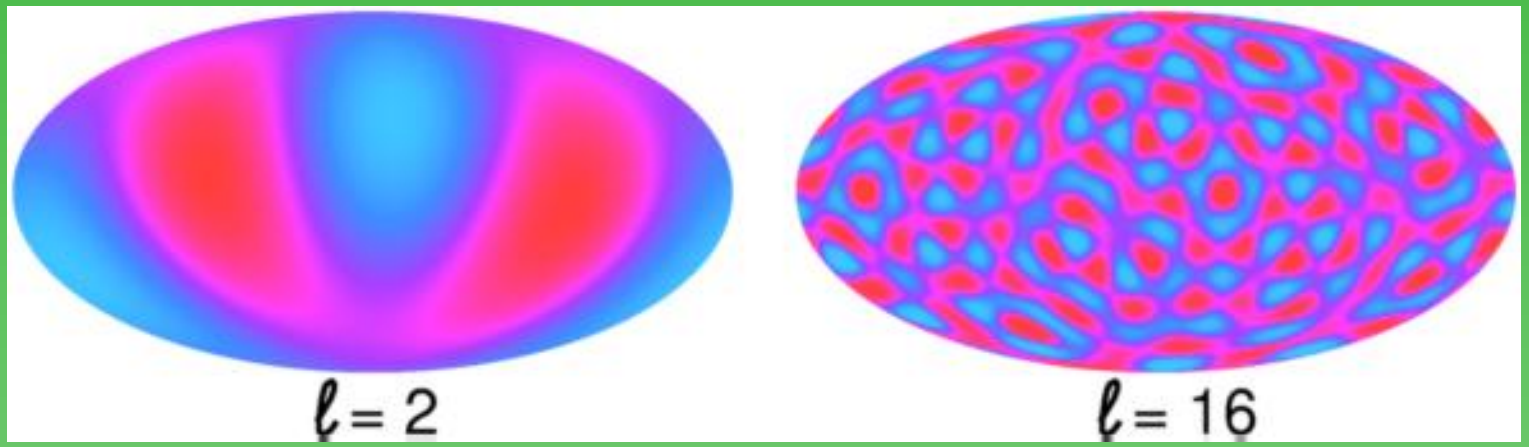
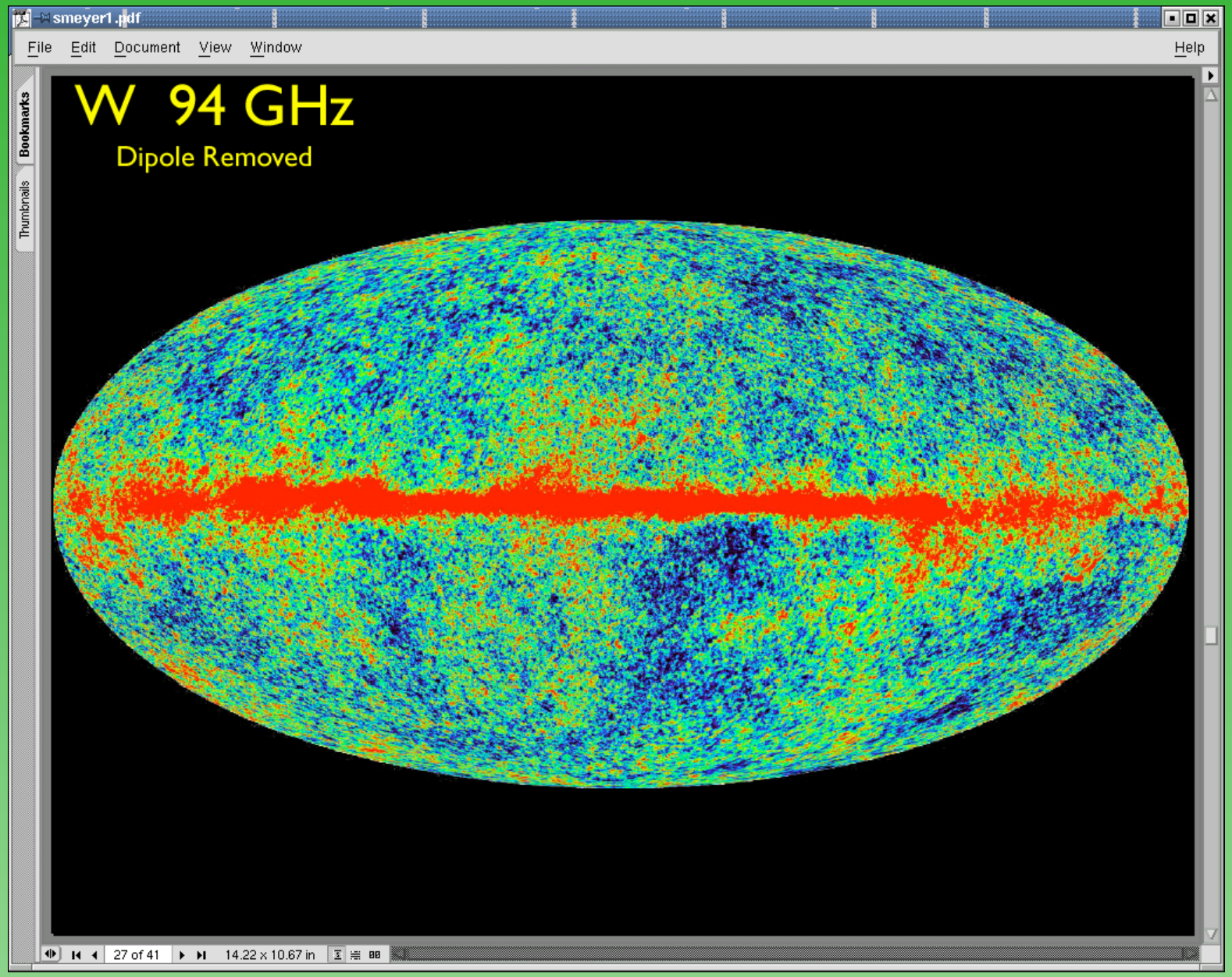
# Spherical harmonics decomposition

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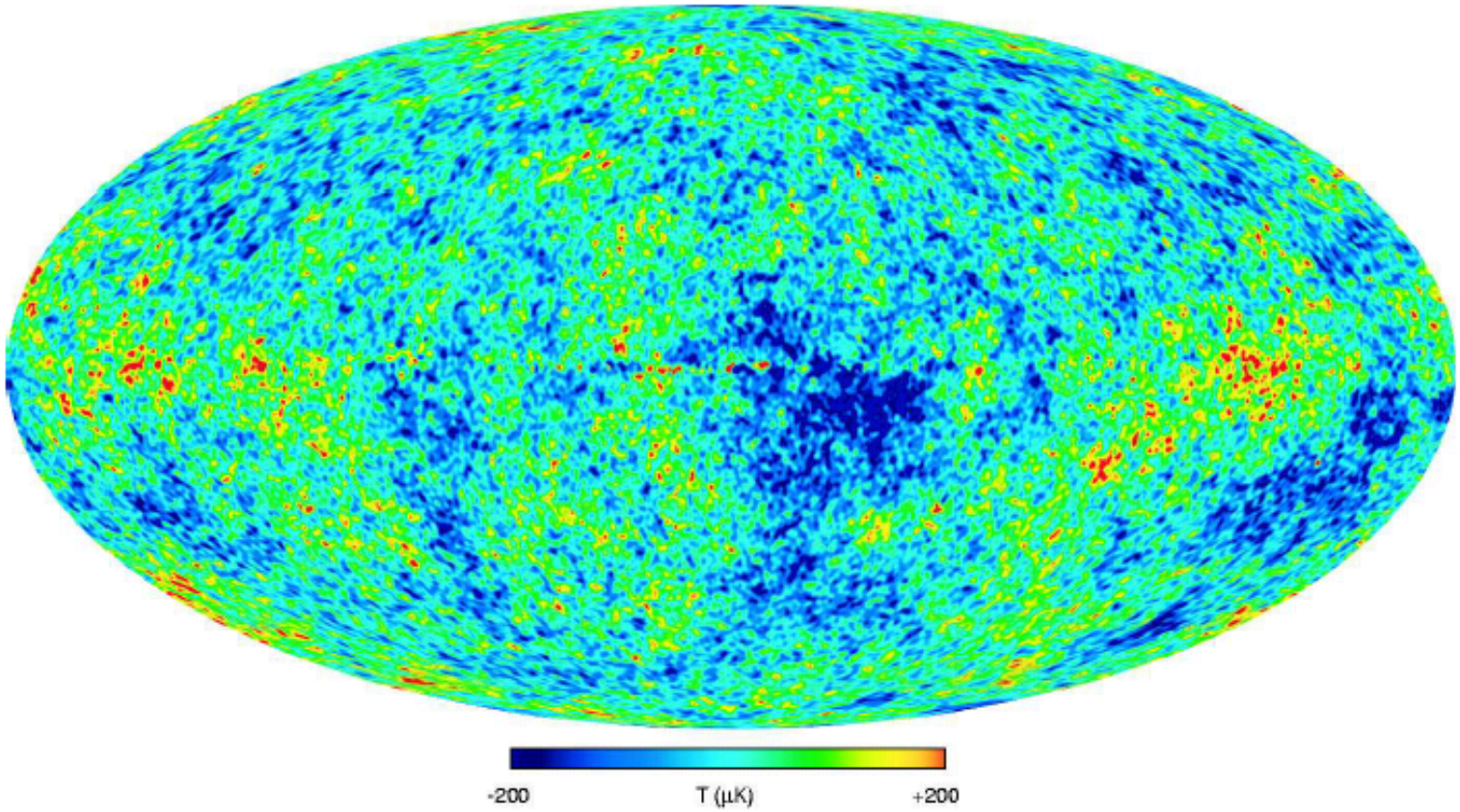
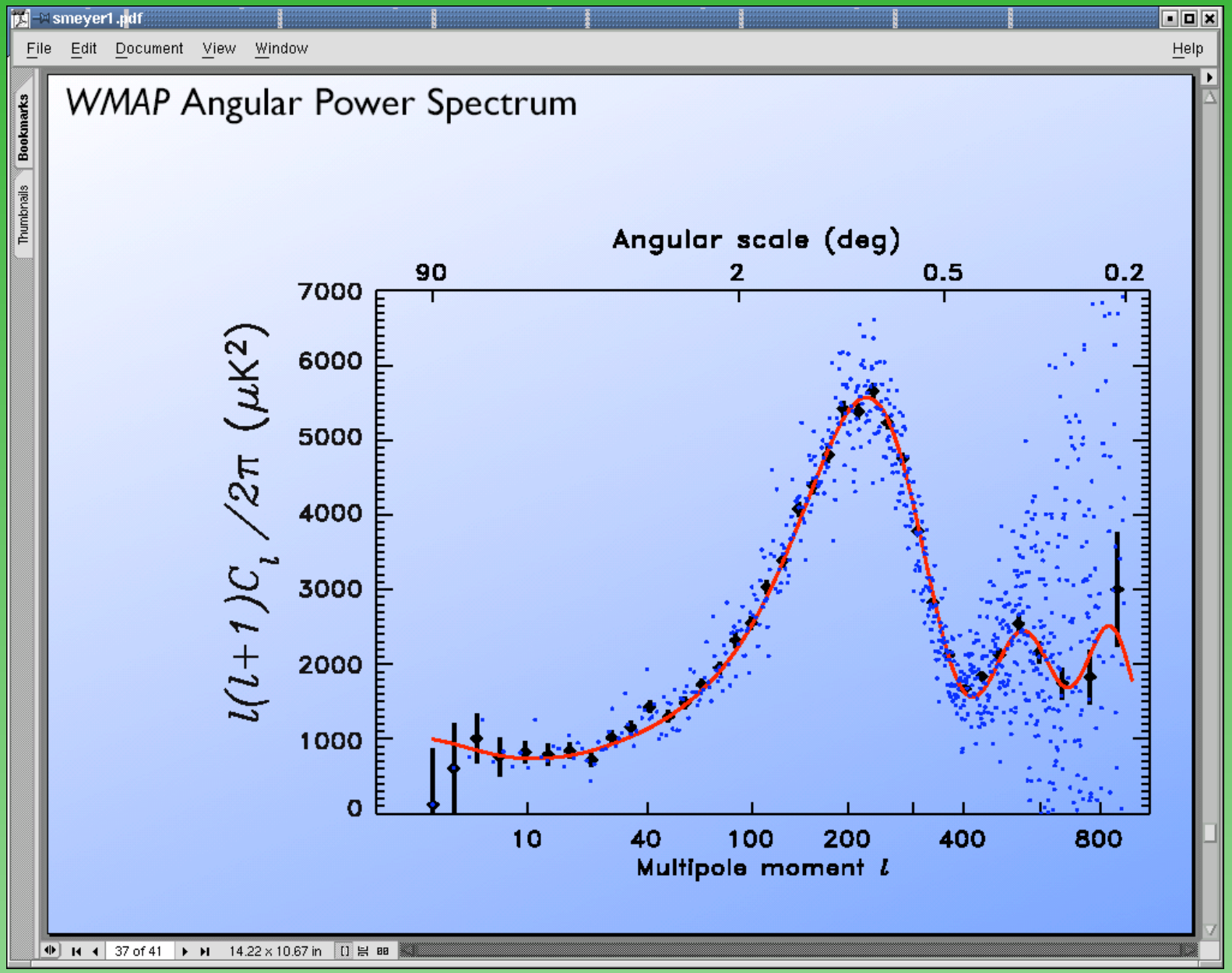
W 94 GHz
Dipole Removed
27 of 41
14.22 x 10.67 in


-200
T (μK)
+200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Bookmarks
Thumbnails
WMAP Angular Power Spectrum
Angular scale (deg)
90
2
0.5
0.2
7000
6000
5000
4000
3000
2000
1000
0
l(l+1)C_l /2π (μK²)
10
40
100
200
400
800
Multipole moment l
37 of 41
14.22 x 10.67 in

# Summary

New questions

- What gave rise to those perturbations? Quantum Mechanics of early Universe?
- What is the unknown form of energy?
- How is the Darm Matter related, if at all, to the baryonic matter?
- Do all these answers fit into a unified theory?

# Sources

Ned Wright www.astro.ucla.edu/~wright/cosmolog.htm

WMAP homepage http://map.gsfc.nasa.gov/