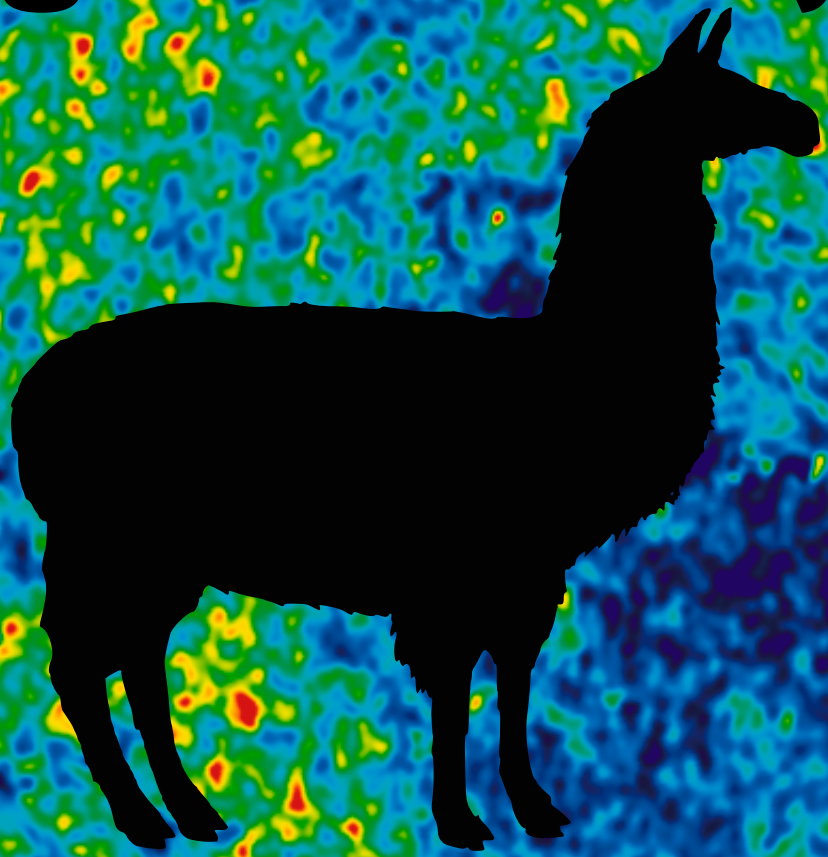
More results from the Atacama Cosmology Telescope

Kevin Huffenberger
Department of Physics, University of Miami

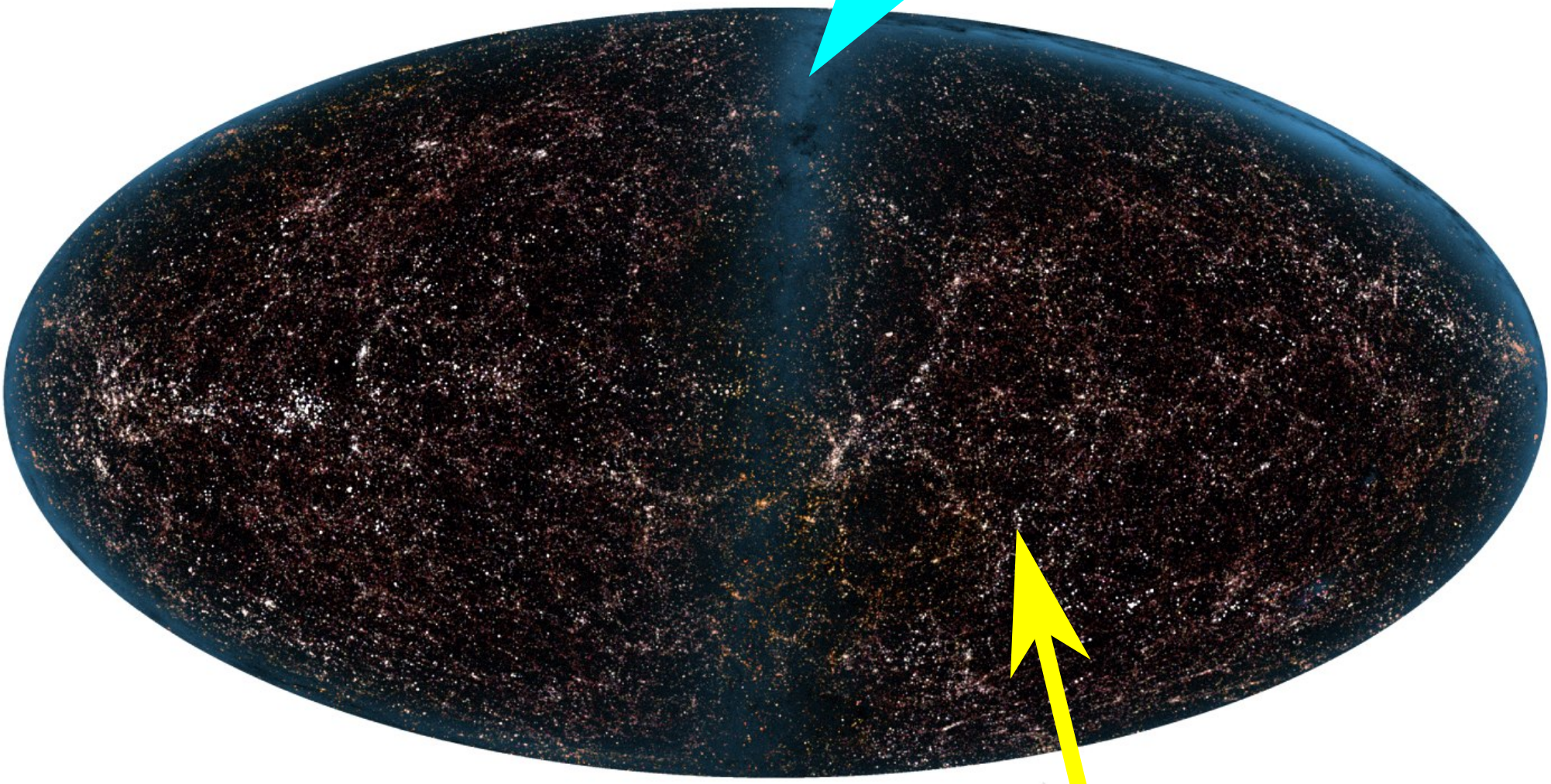
Use CMB to study foreground objects



Large Scale Structure Clusters of Galaxies

Cosmic web

solar system dust

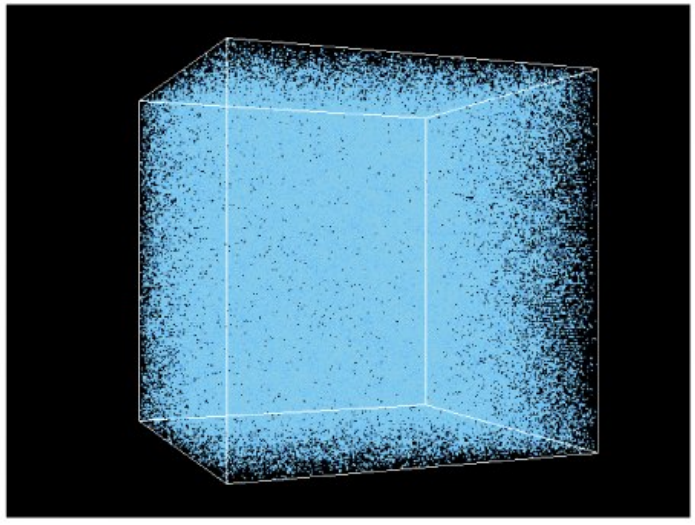


large scale distribution of galaxies

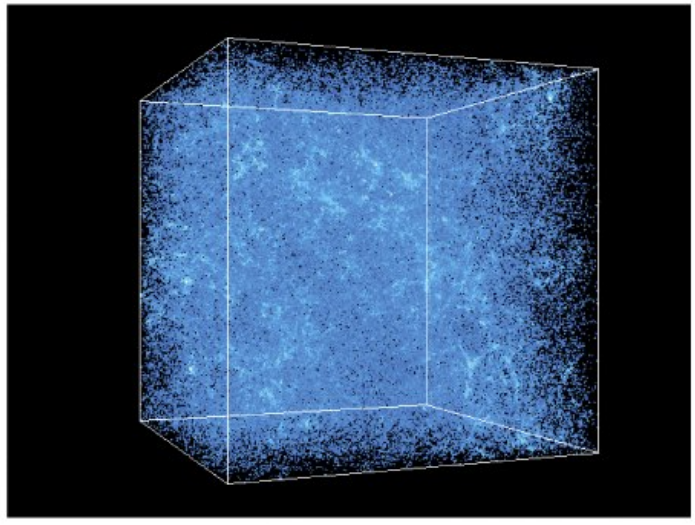
Figure 24-23
Universe, Eighth Edition

2MASS Survey

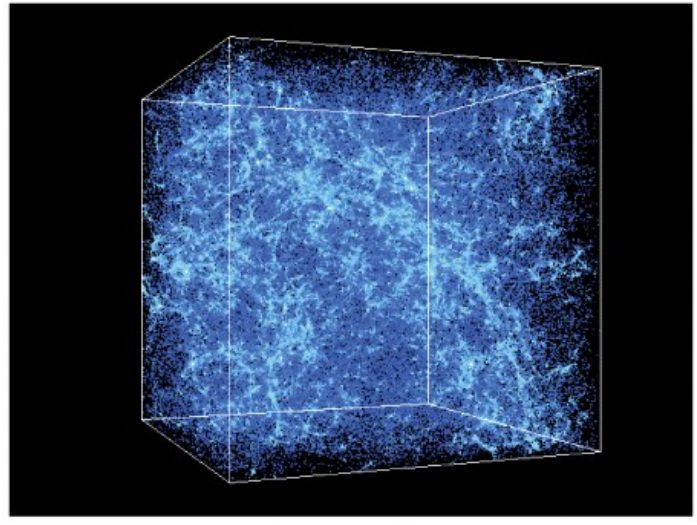
Cosmological matter simulation



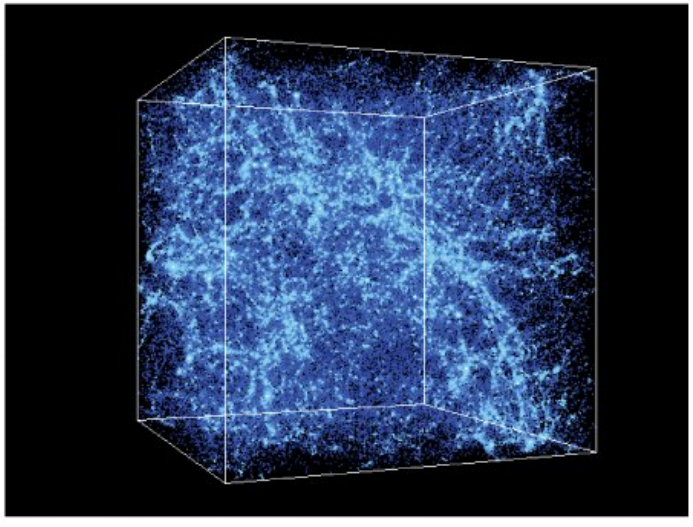
$z = 27.36$ Universe 120 million years old



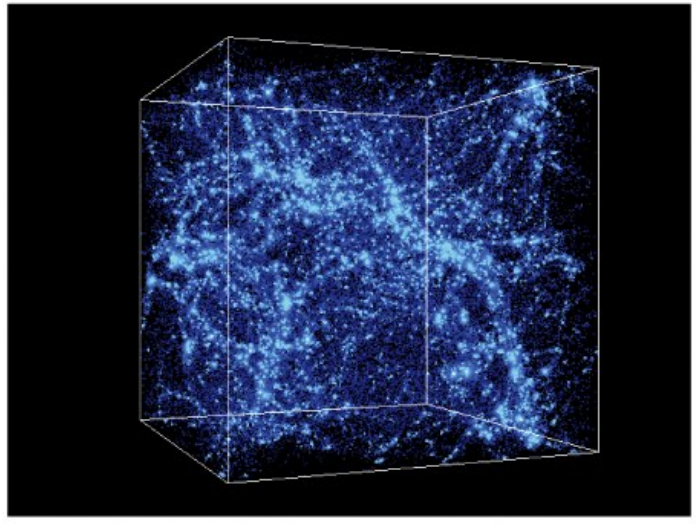
$z = 9.83$ Universe 490 million years old



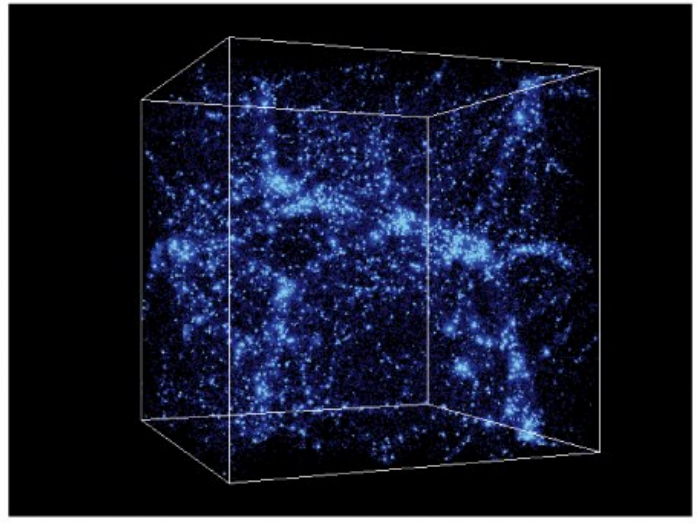
$z = 4.97$ Universe 1.2 billion years old



$z = 2.97$ Universe 2.2 billion years old

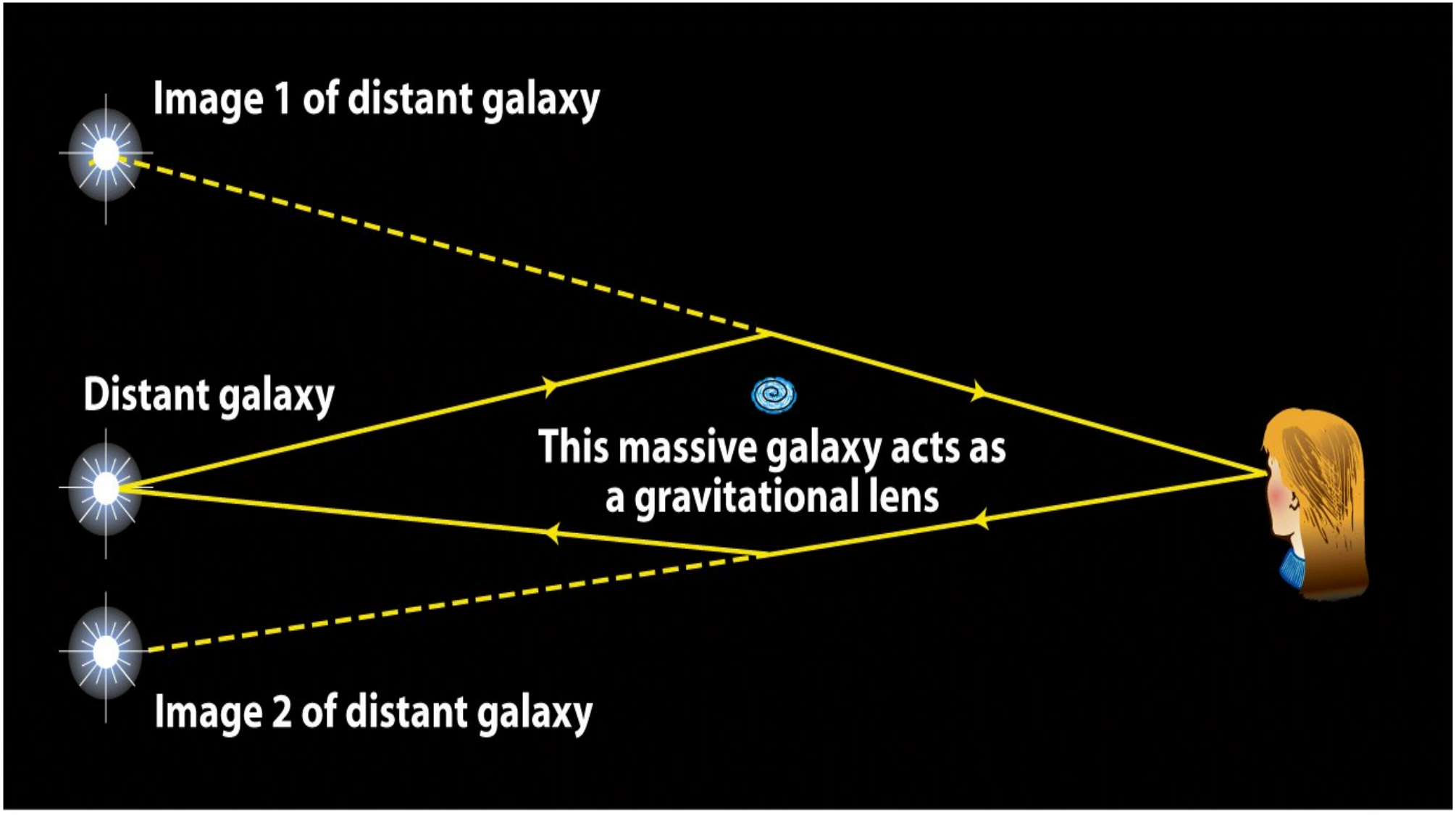


$z = 0.99$ Universe 6.0 billion years old



$z = 0.00$ Universe 13.7 billion years old

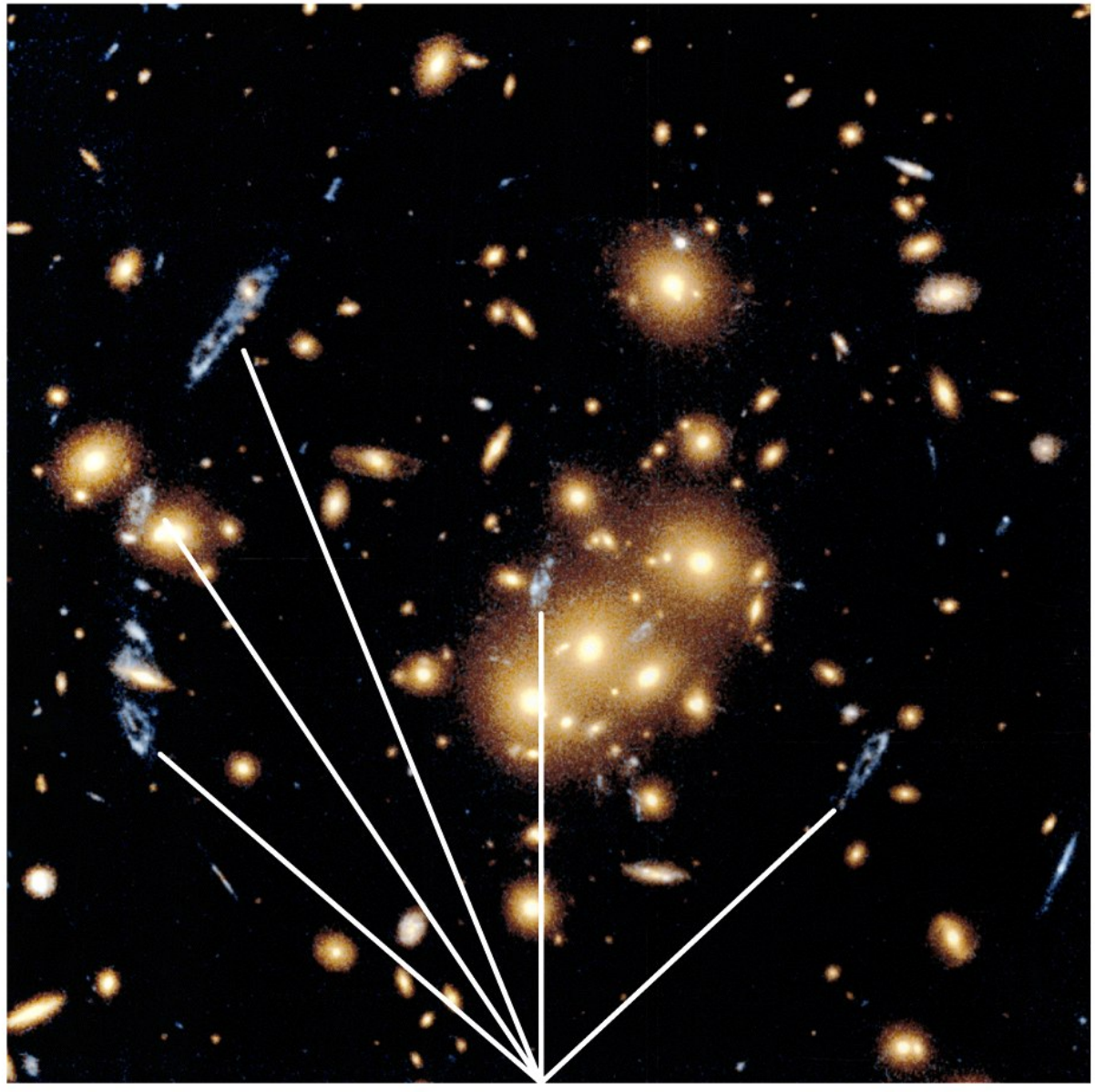
Structure formation → expansion history → dark energy



How gravitational lensing happens

Figure 24-30a
Universe, Eighth Edition

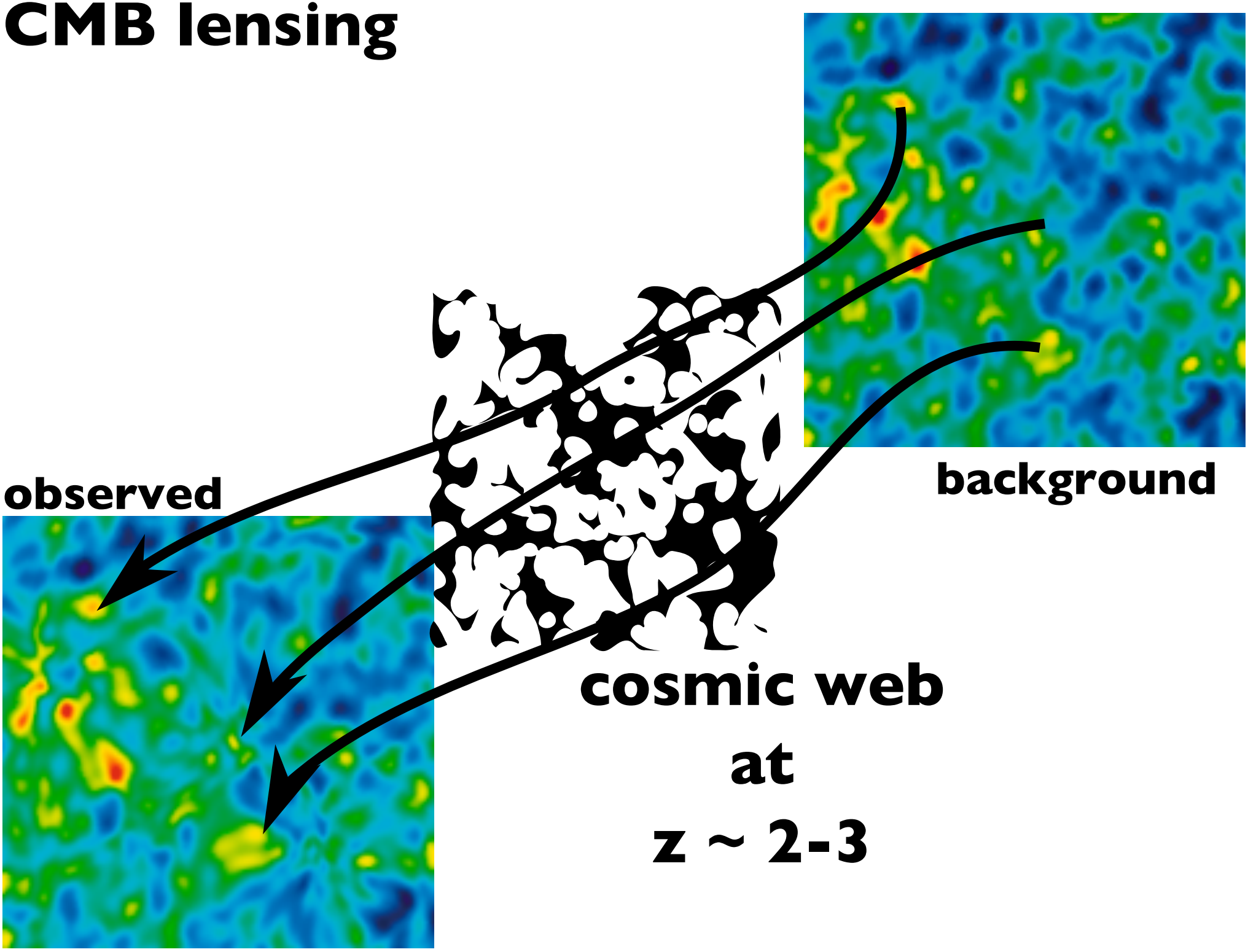
Lensing



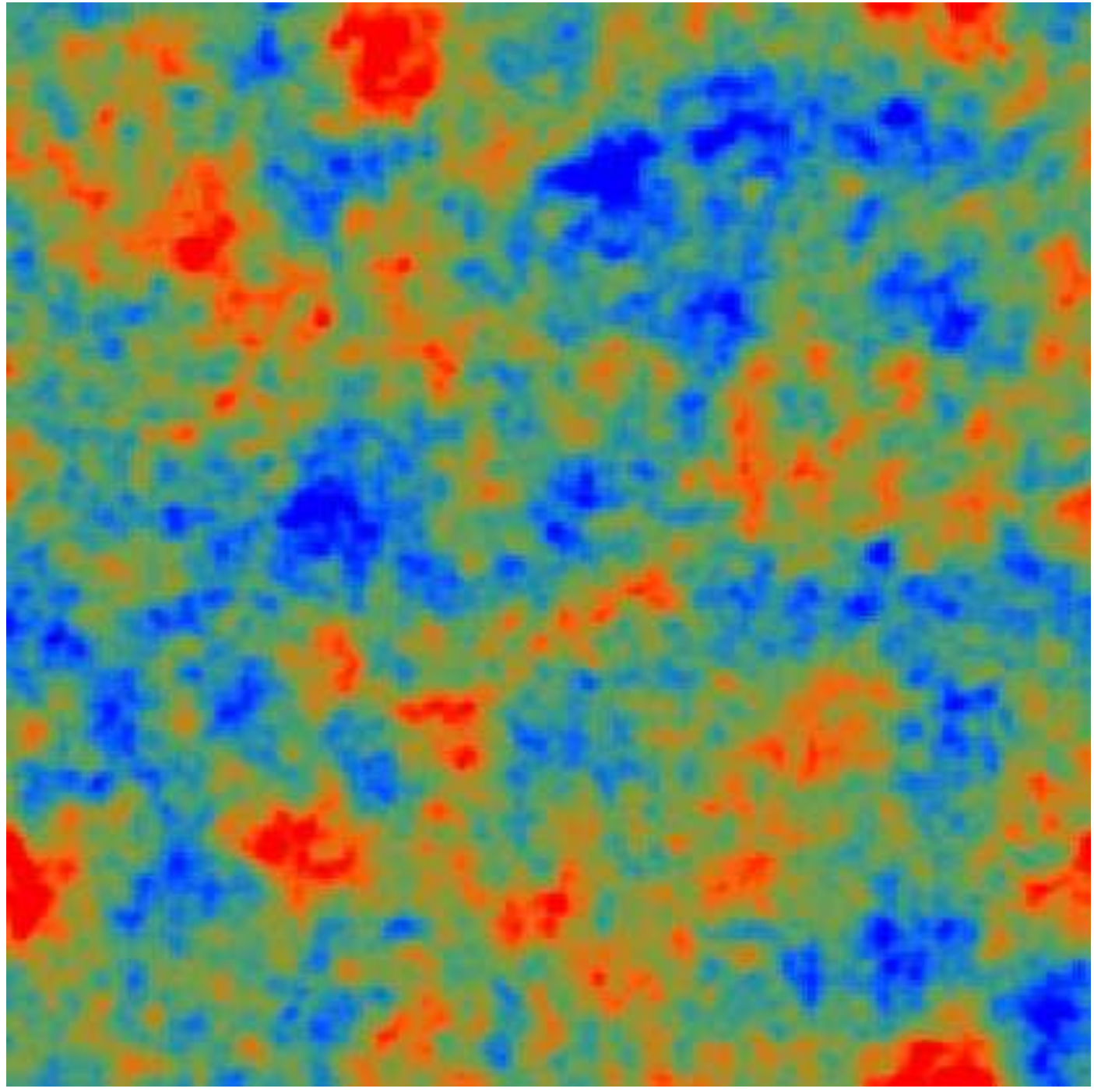
All of these blue arcs are images of the same distant galaxy.

Figure 24-31
Universe, Eighth Edition

CMB lensing

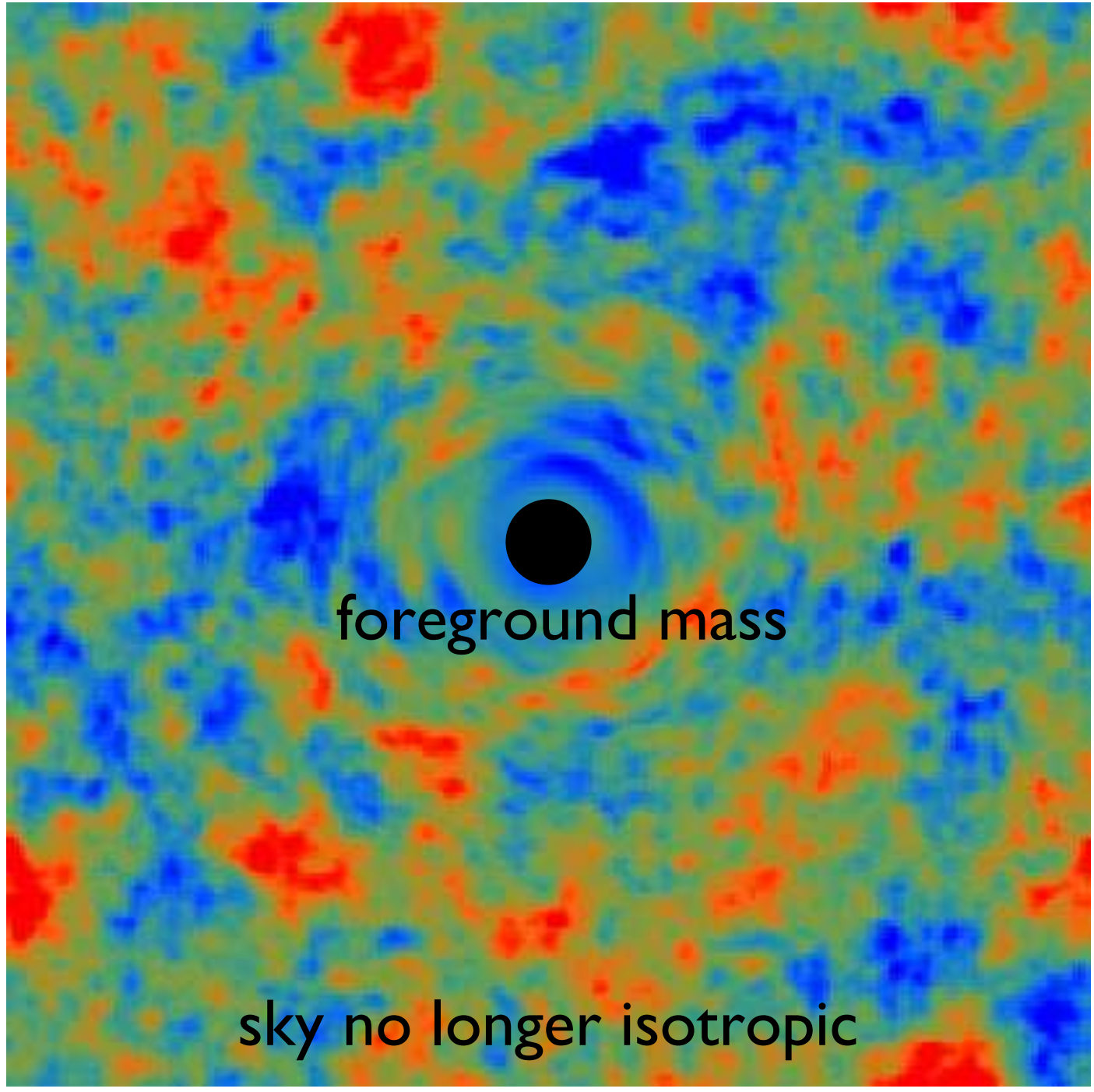


CMB (Hu & Okamoto 2001)

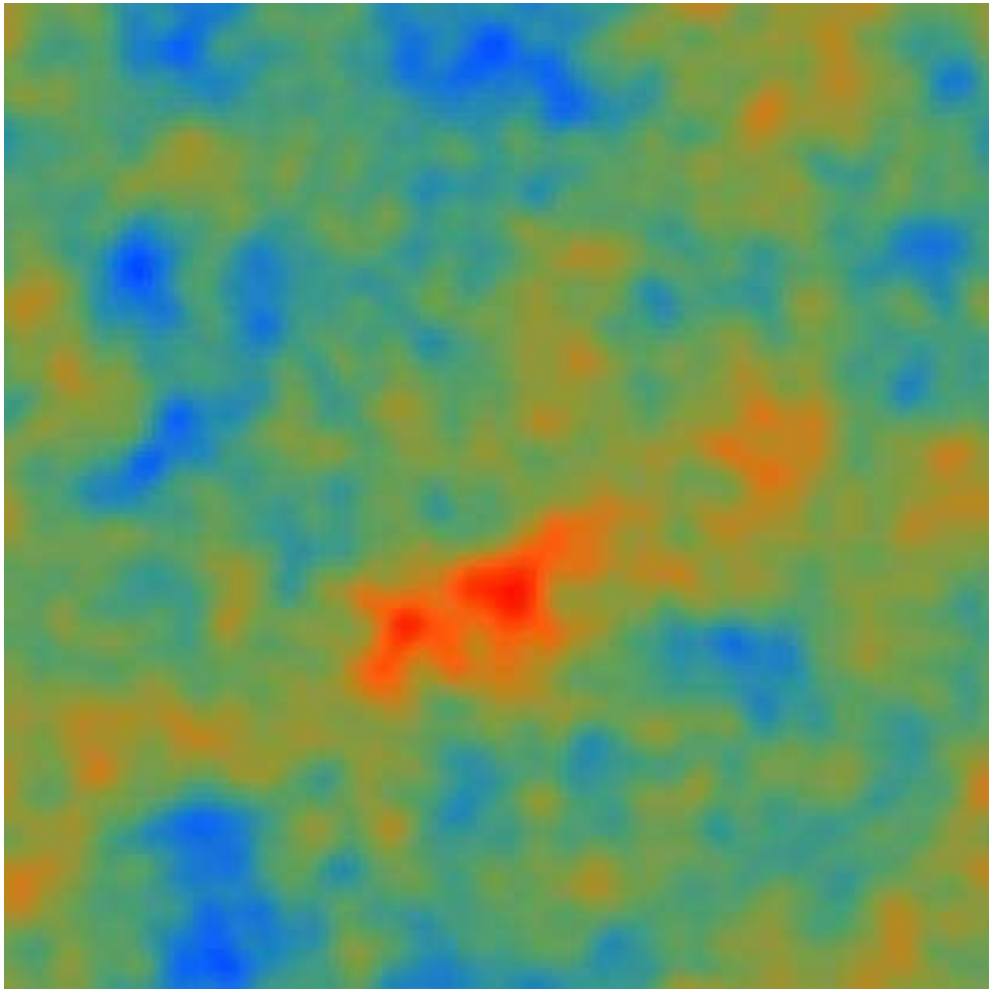


CMB lensed

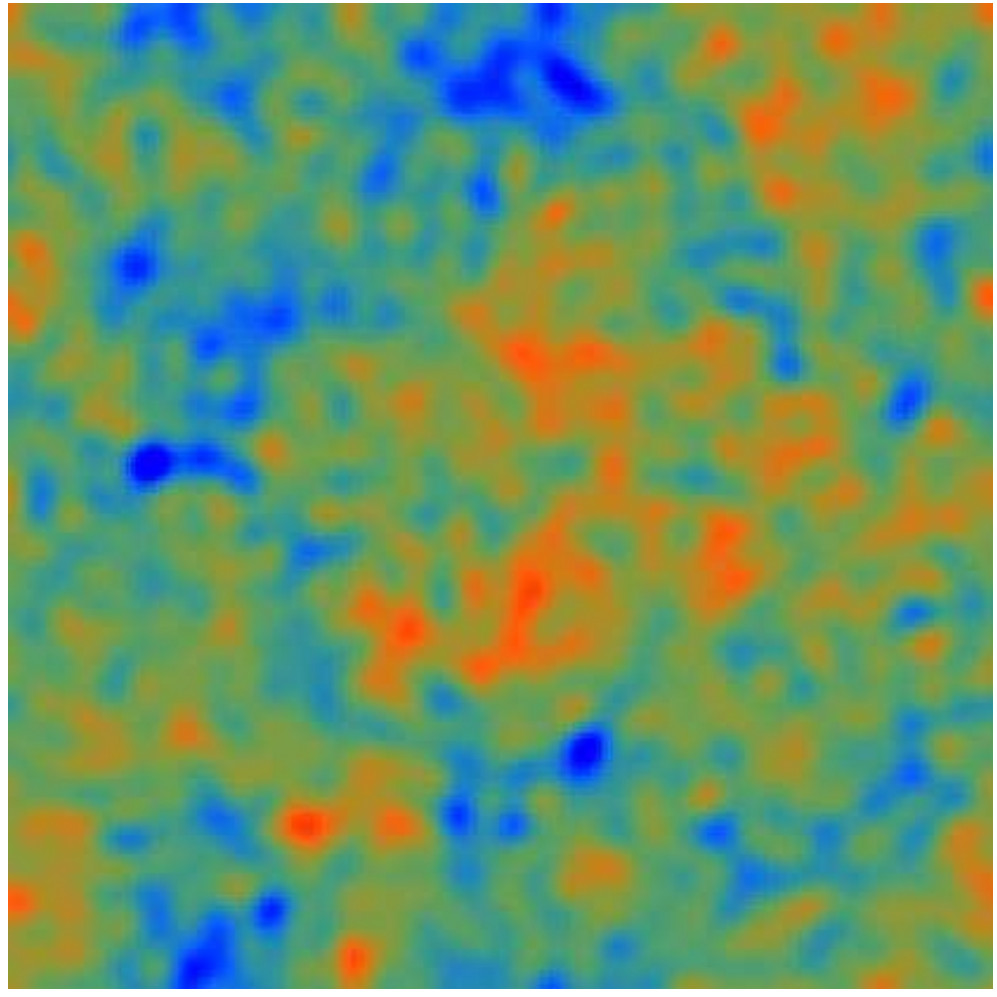
(Hu & Okamoto 2001)



CMB lensing mass reconstruction



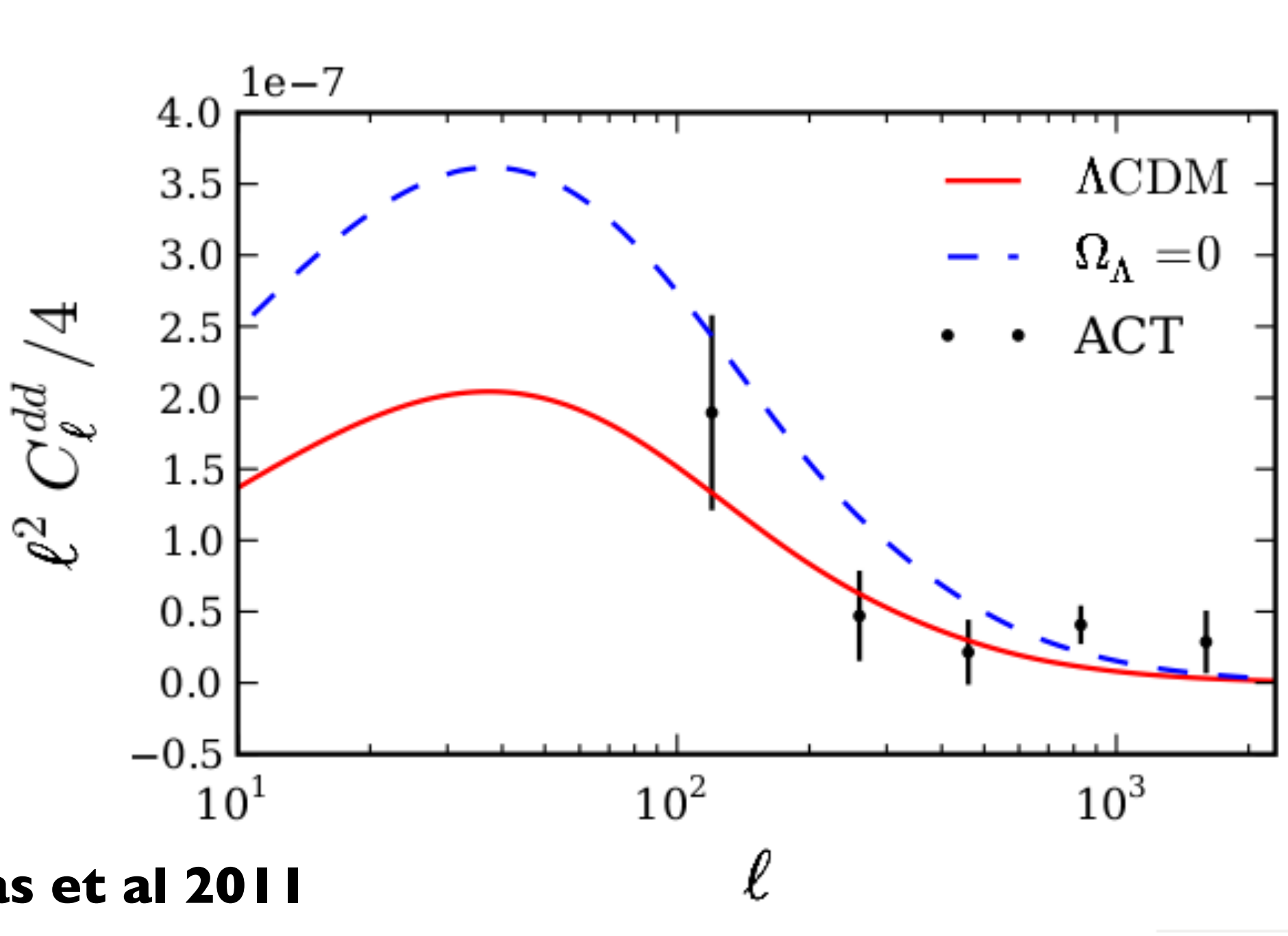
Integrated density



Using CMB T

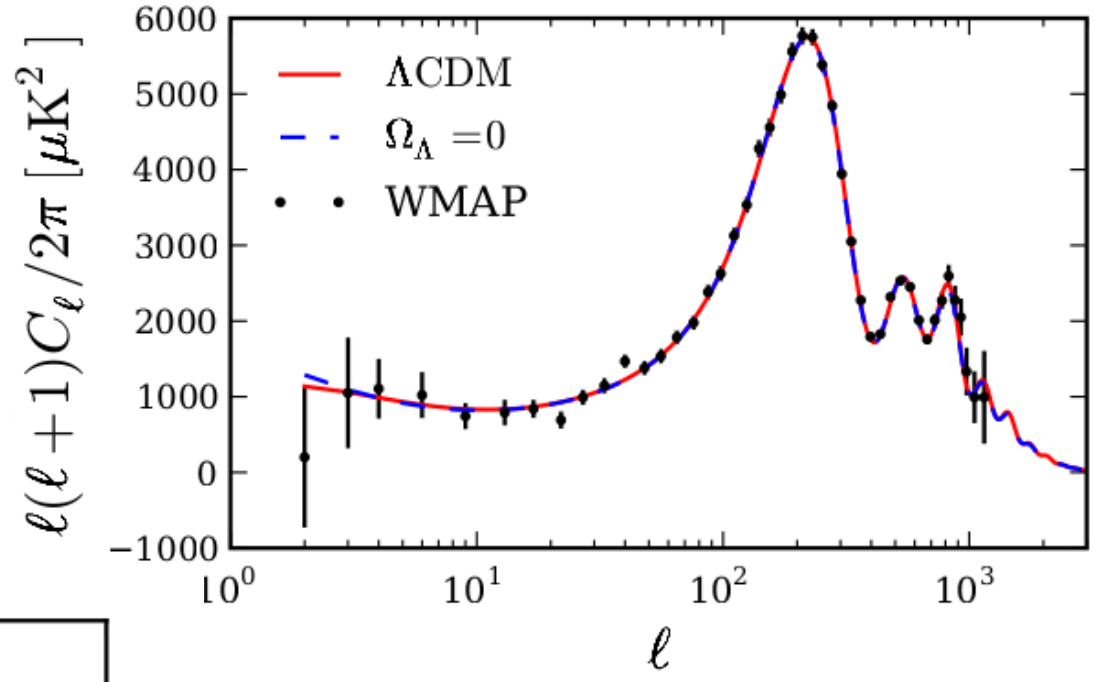
(Hu & Okamoto 2001)

ACT CMB-lensing results

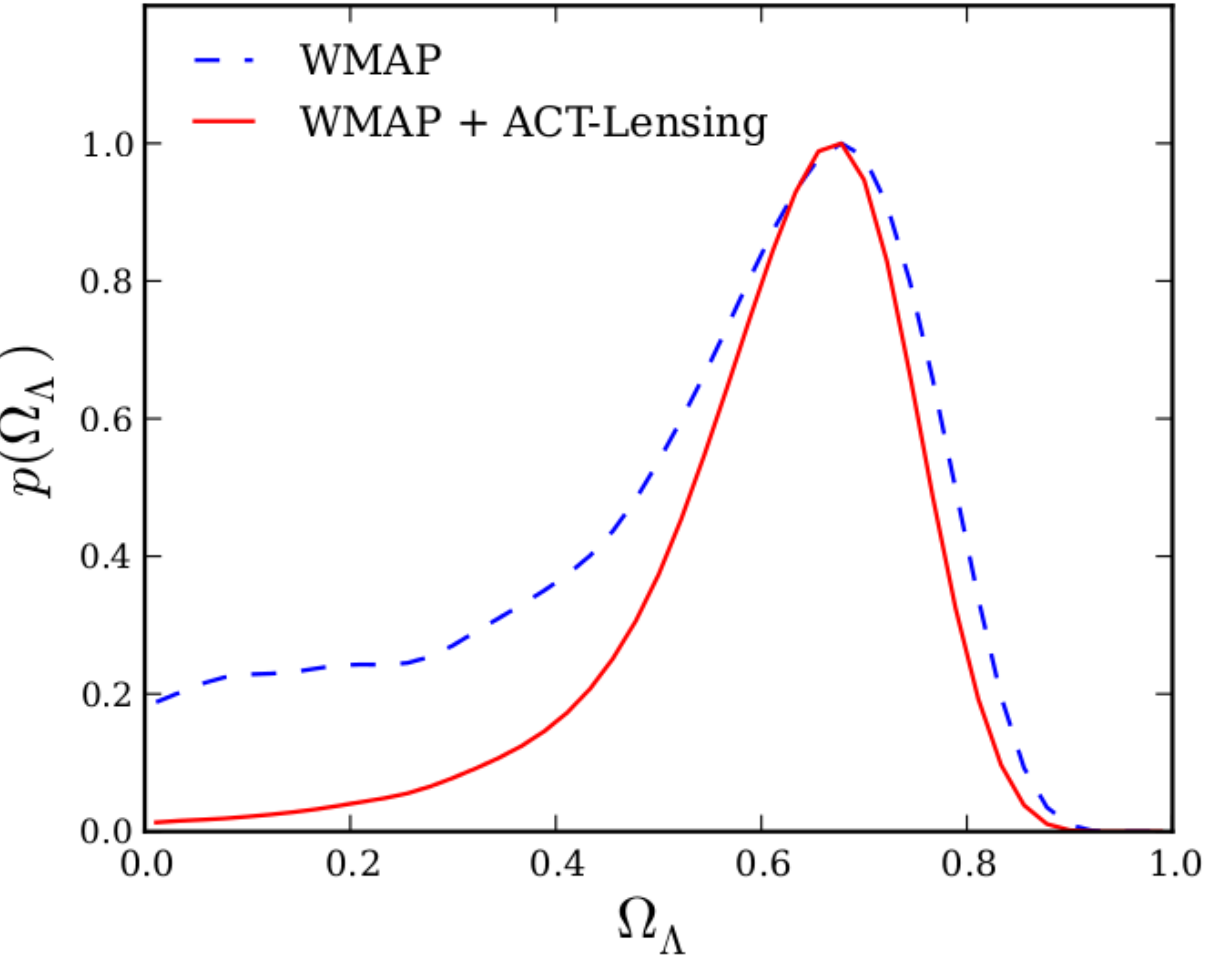


Das et al 2011

ACT CMB-lensing result

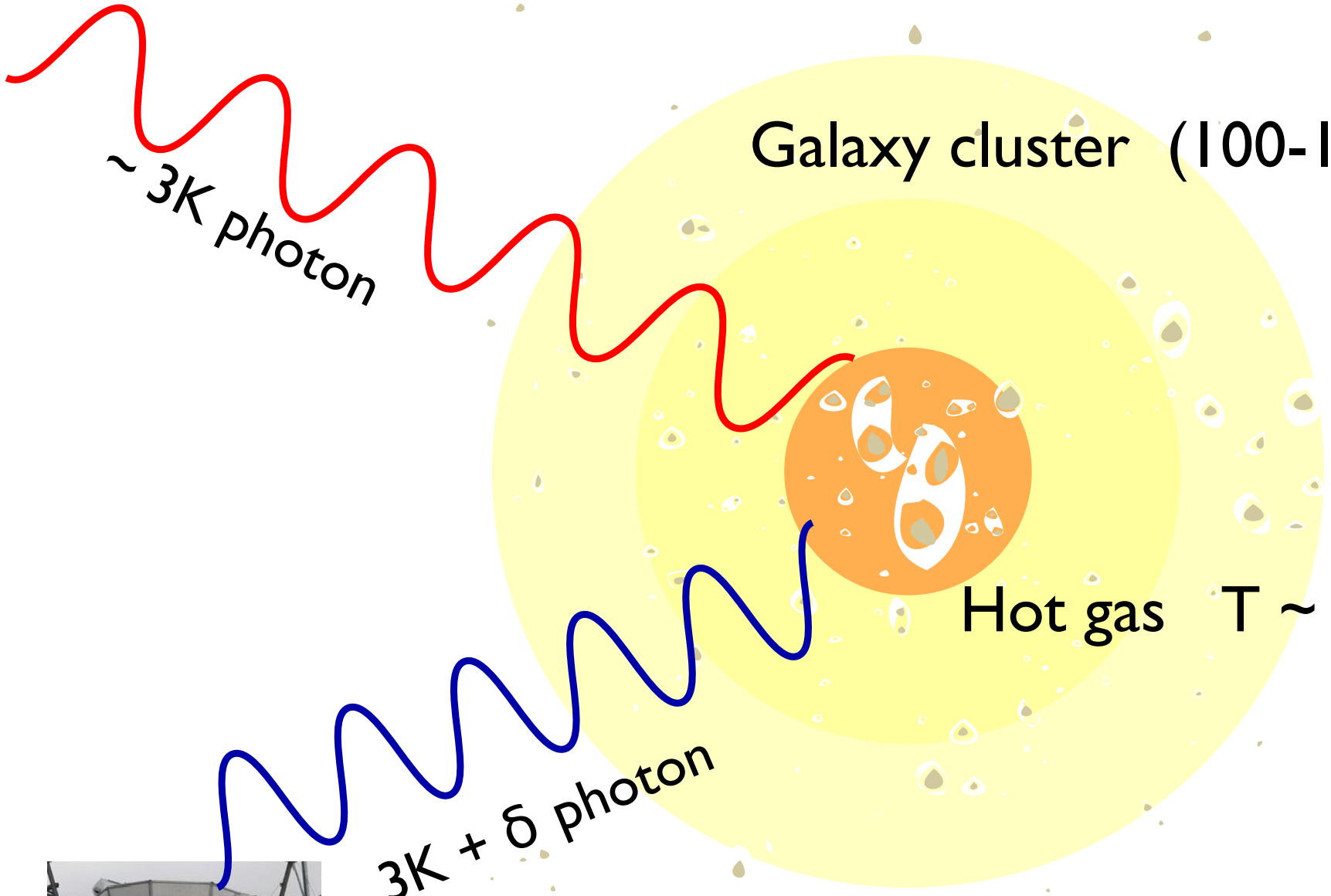


Sherwin et al 2011

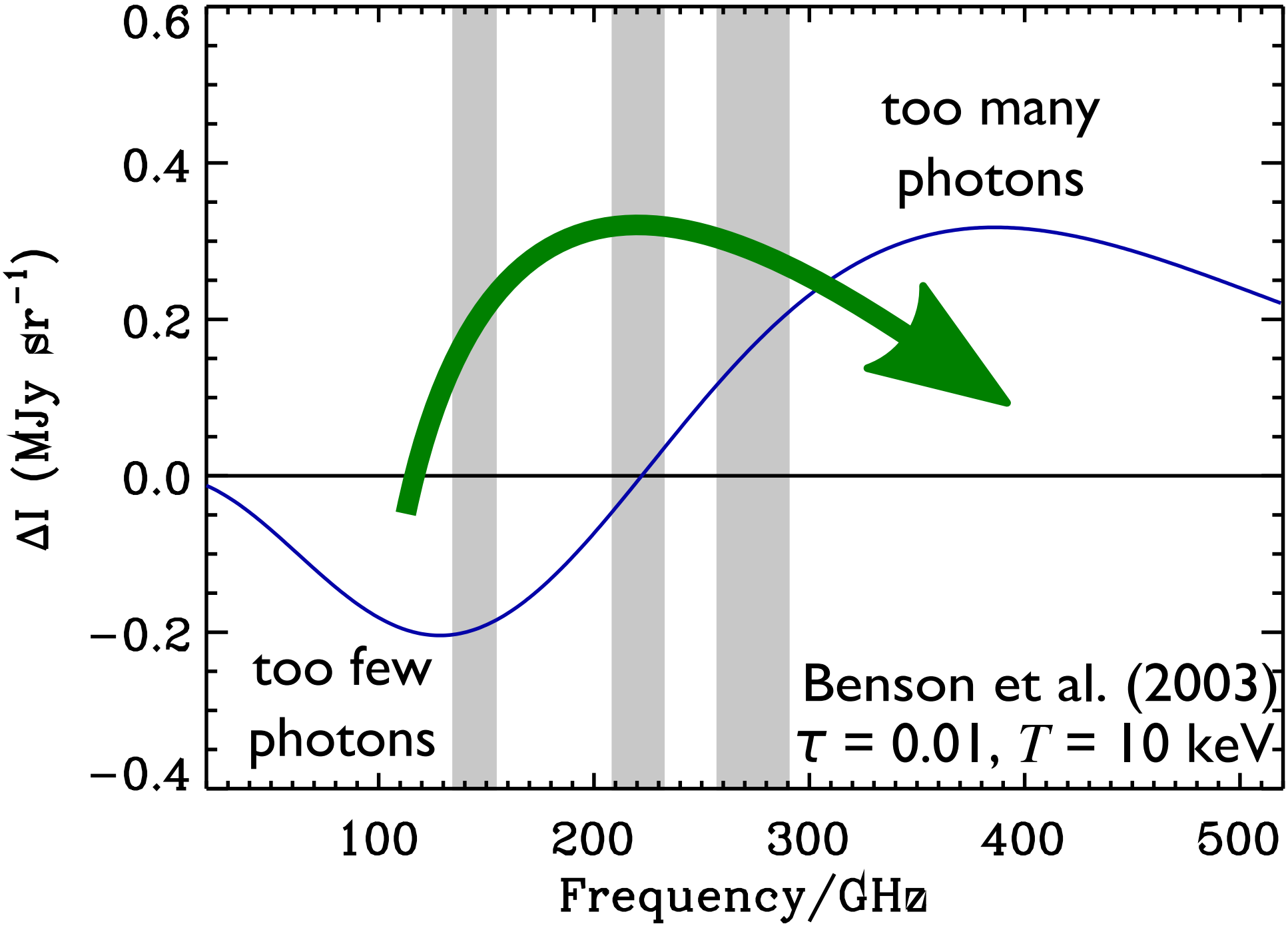


3.2σ evidence for Dark Energy from CMB alone (w/out SN)

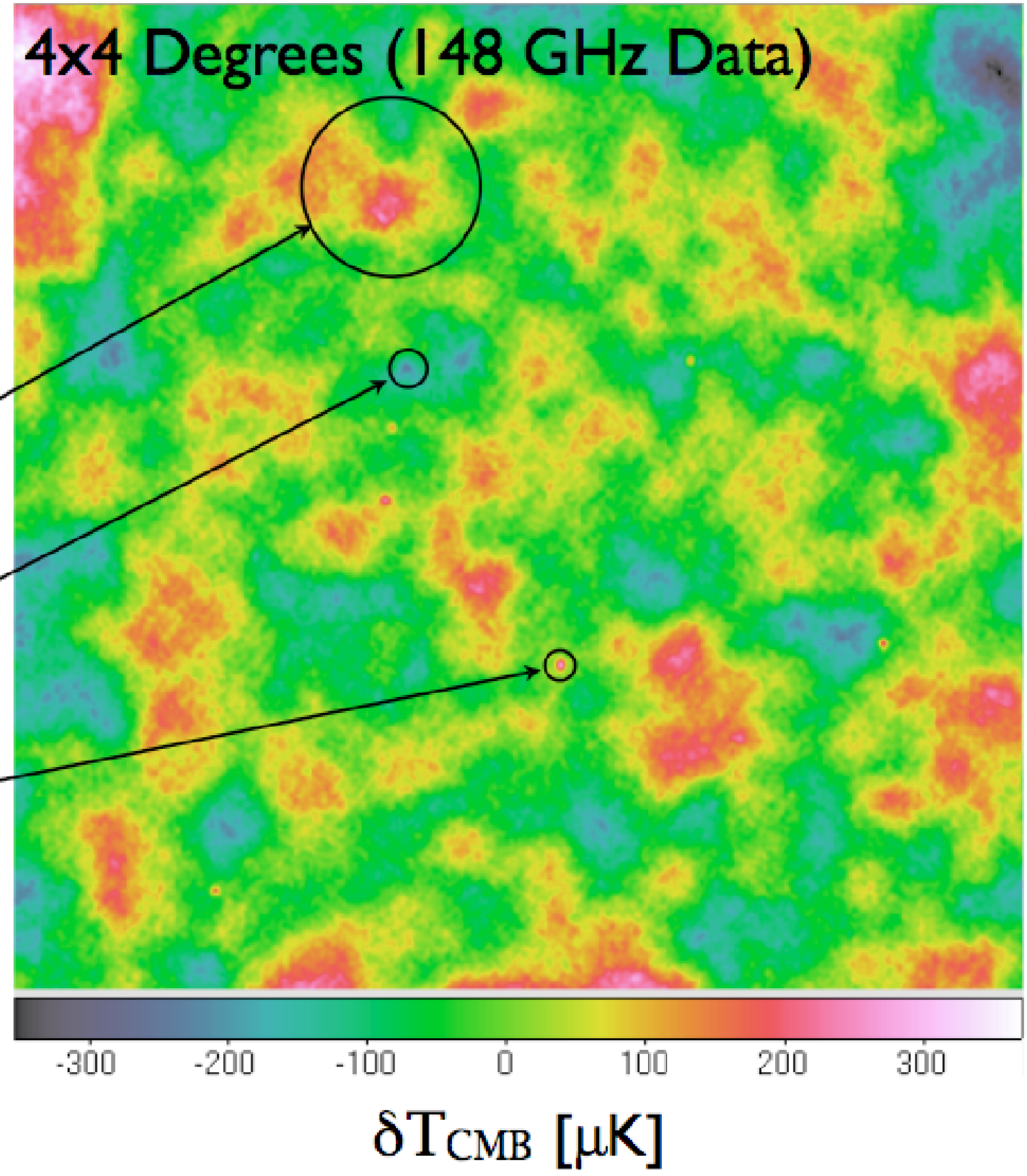
Sunyaev-Zeldovich effect



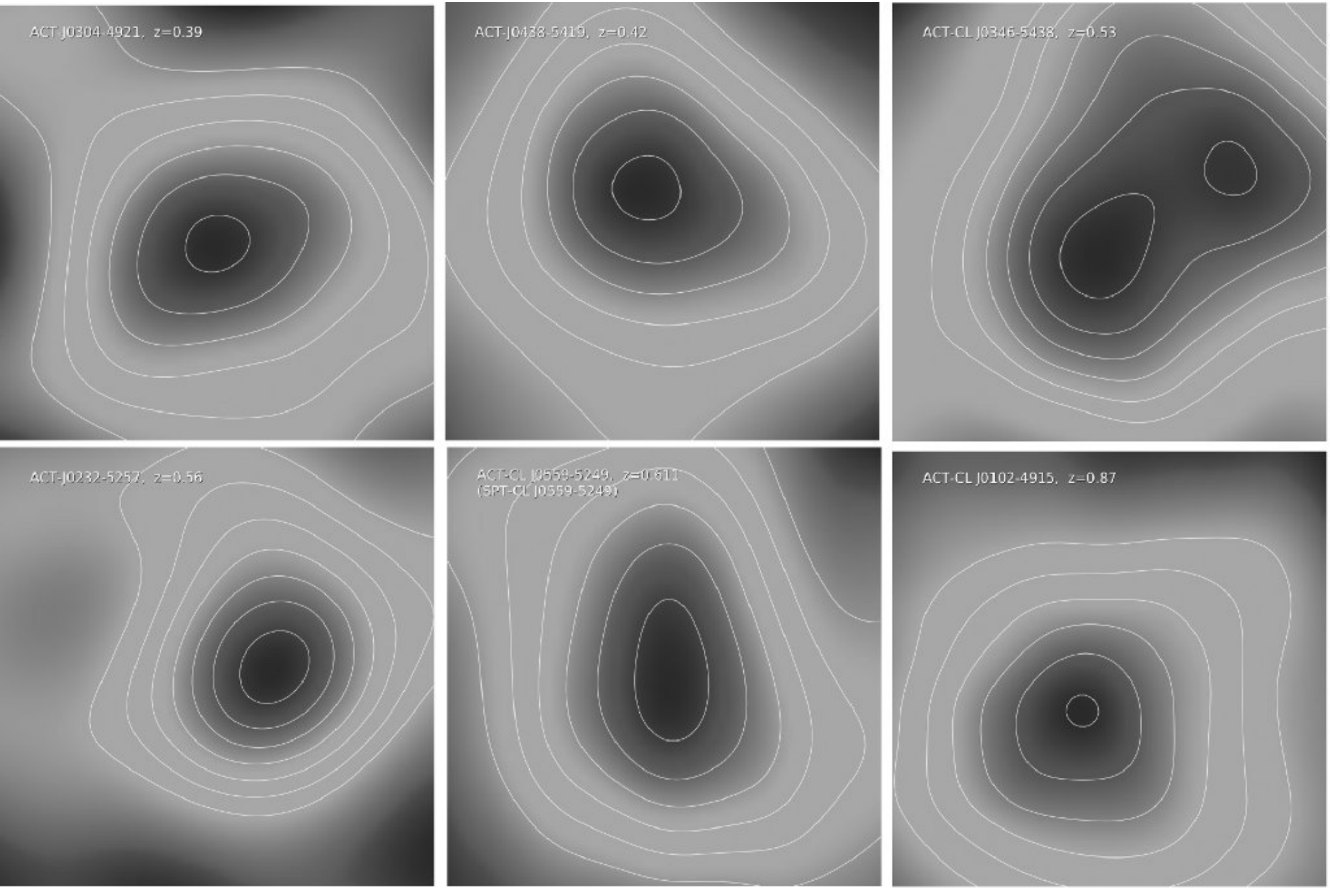
SZ distorts CMB blackbody



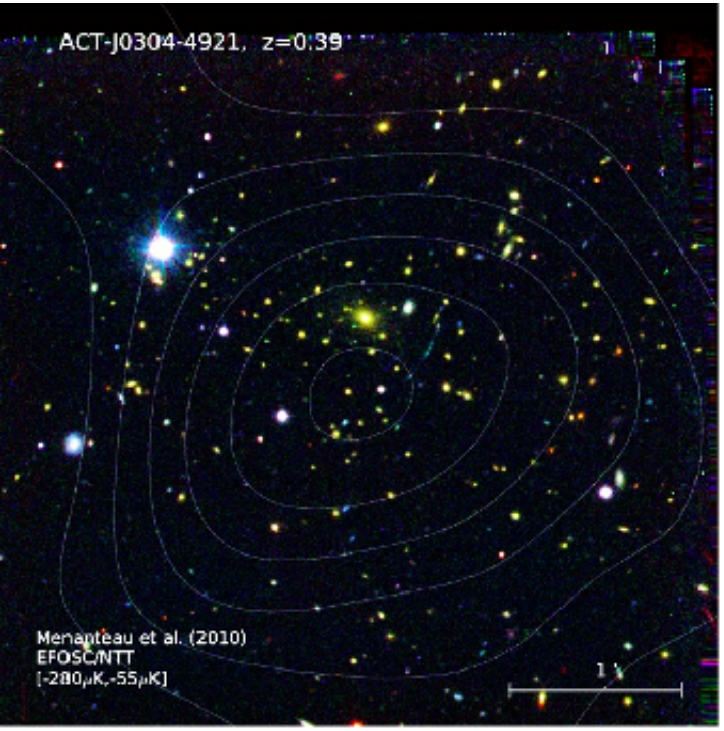
ACT Map

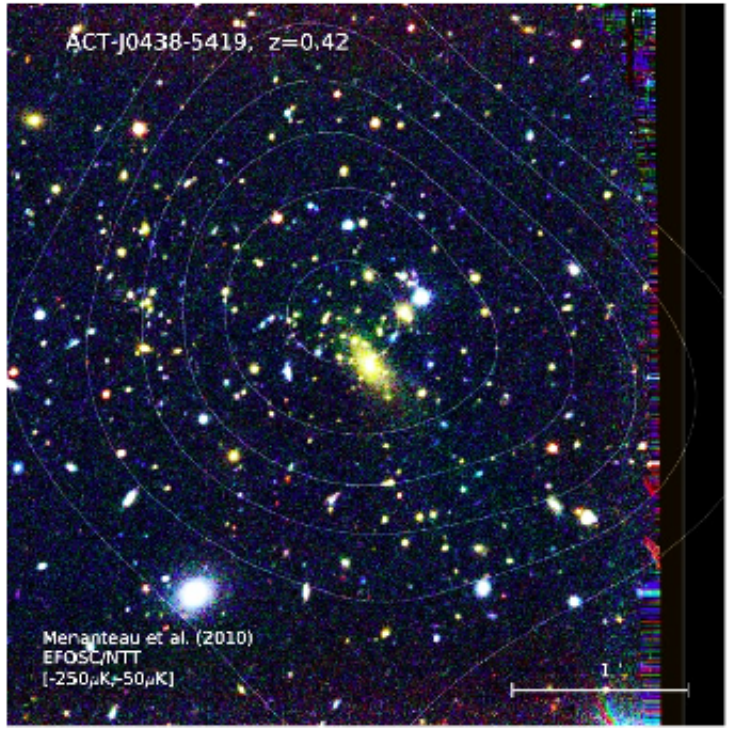

4x4 Degrees (148 GHz Data)
CMB fluctuation
Cluster
Active Galactic Nucleus
-300
-200
-100
0
100
200
300
δTCMB [μK]

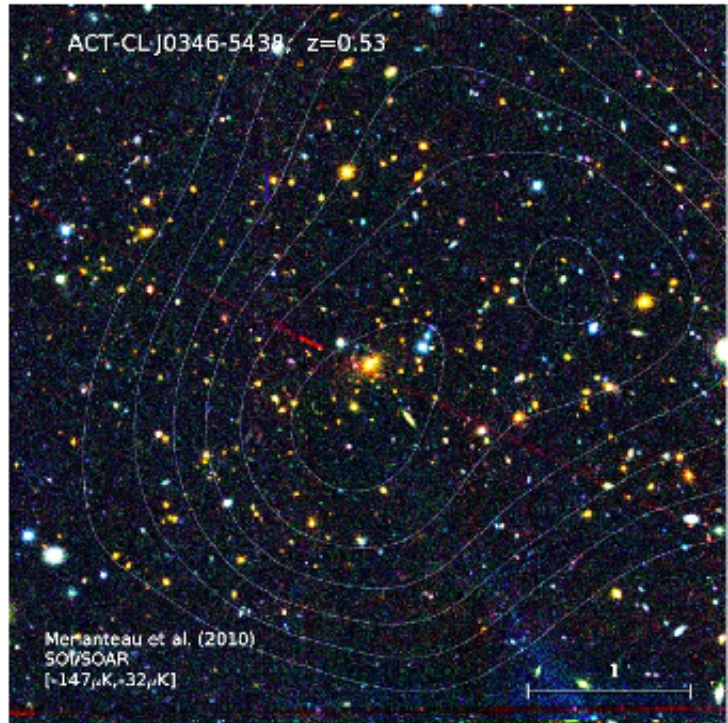
ACT identified galaxy clusters

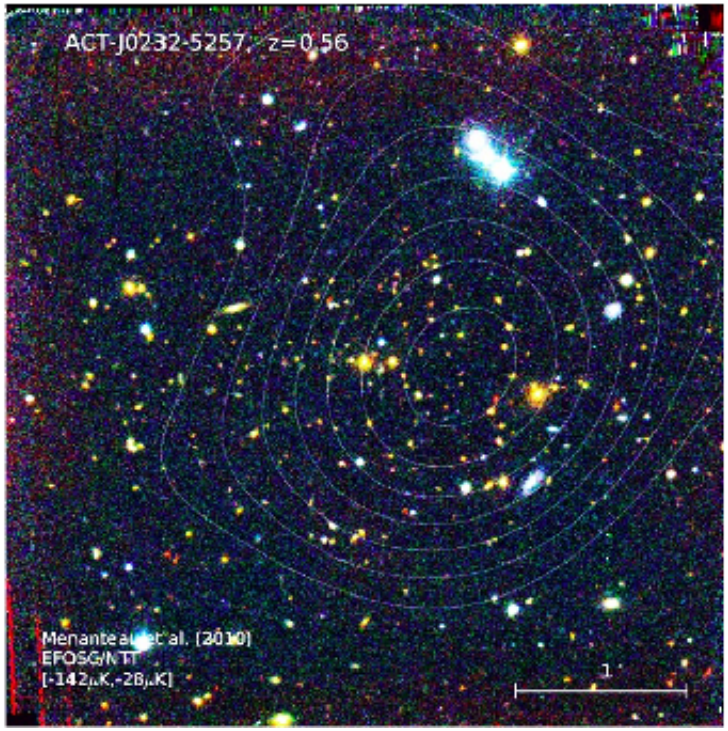


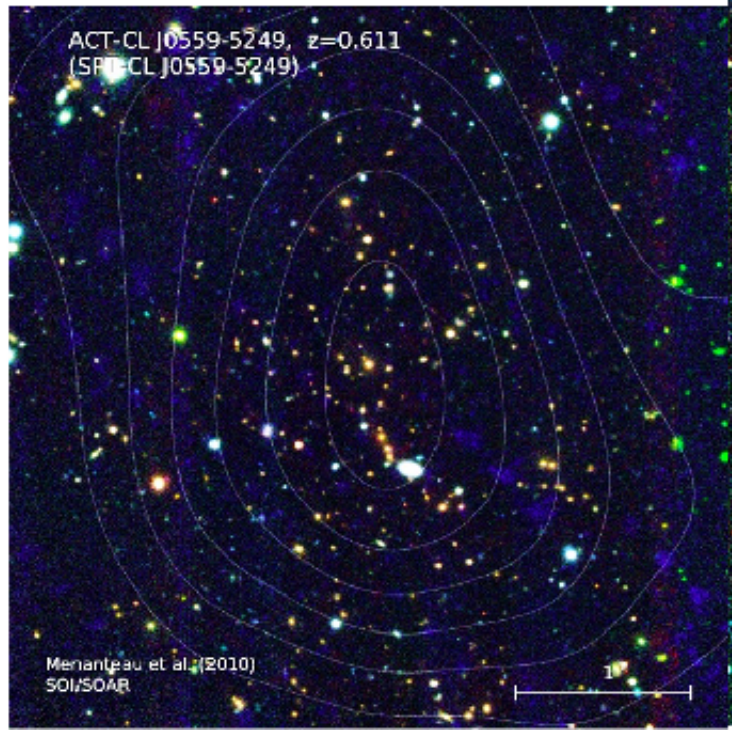
ACT identified galaxy clusters

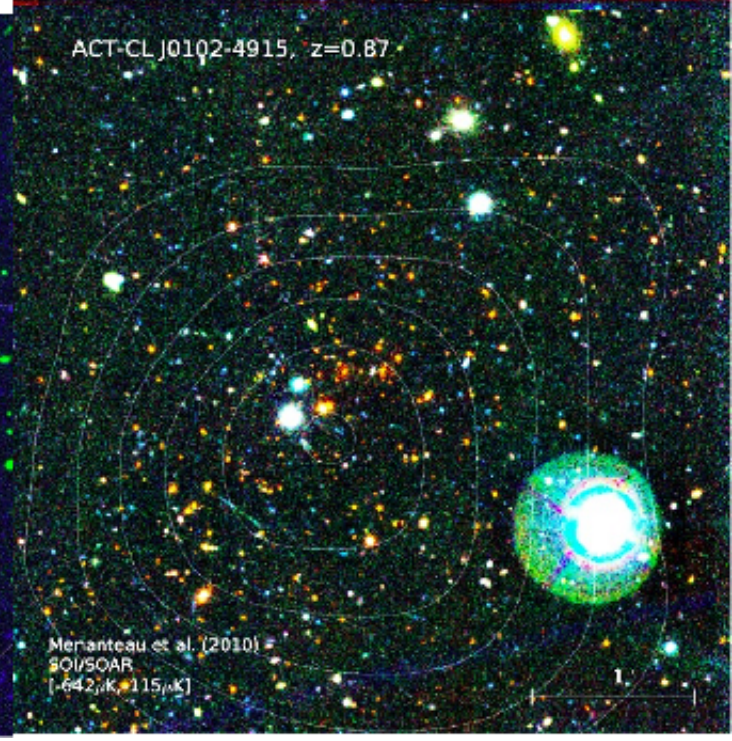




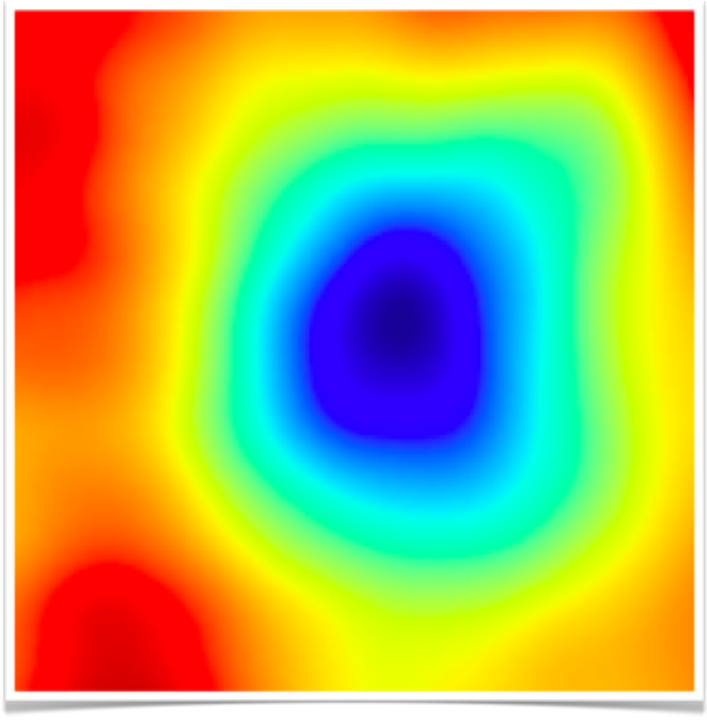




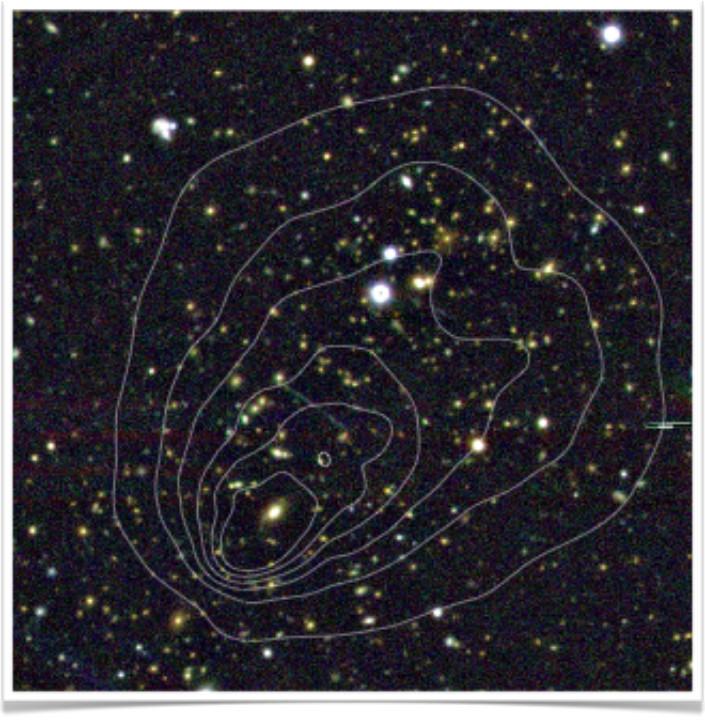




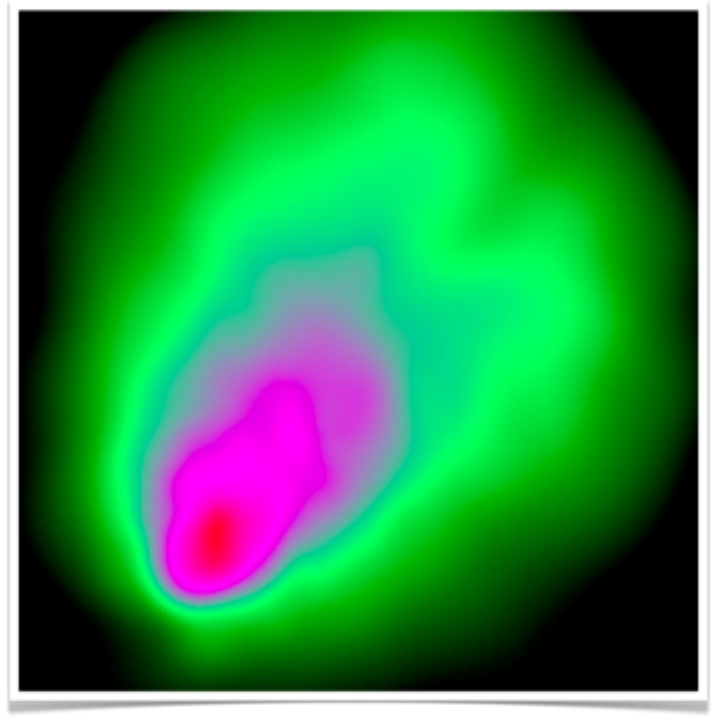
Exceptional galaxy cluster "El Gordo"



SZ



Optical

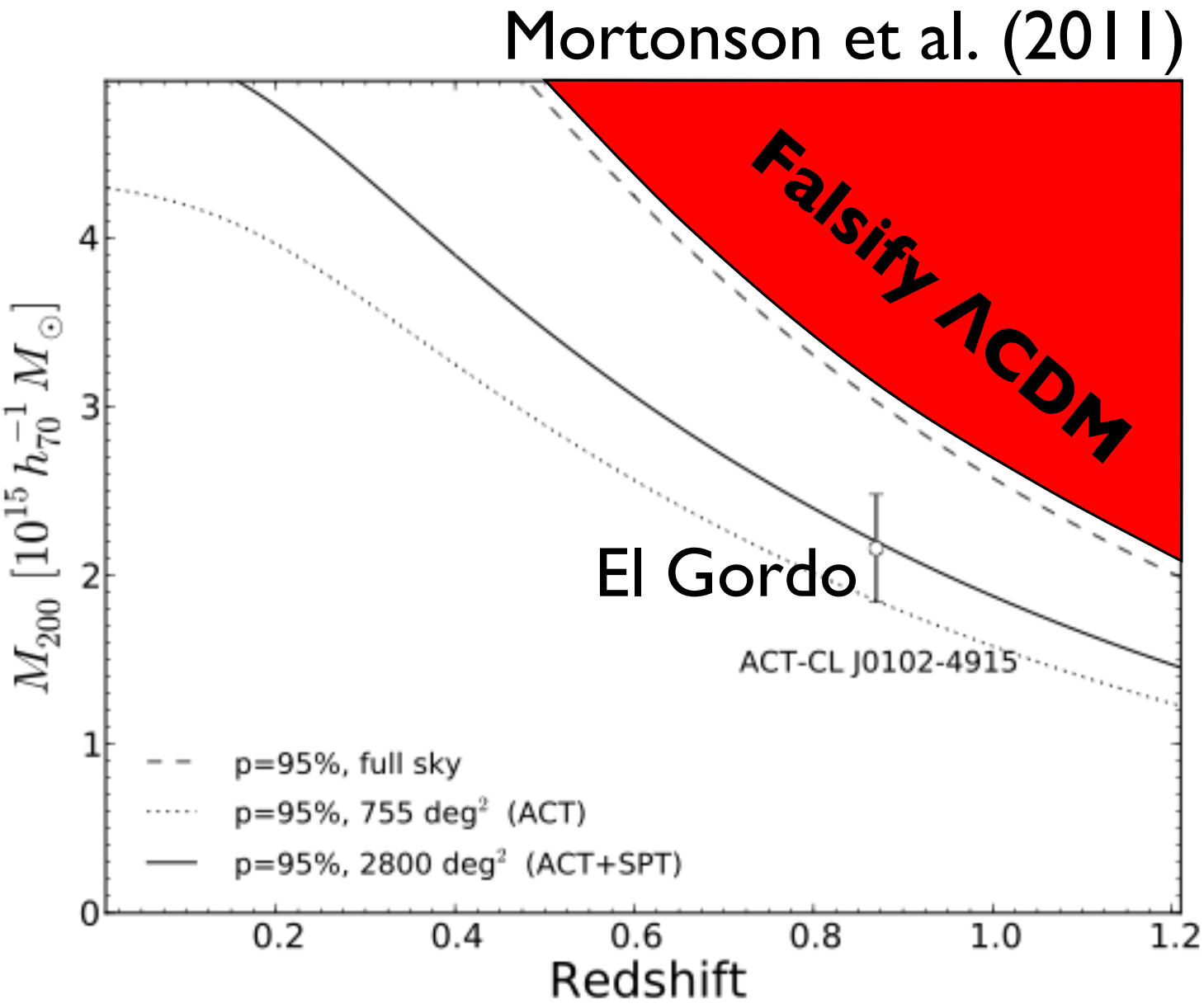


X-ray

z = 0.87, M ~ 2 x 10^{15} Msun

Highest T, Most massive at z>0.6

How rare is such a cluster?



See also:

Gonzalez et al (2012)

$M_{200} \sim 3 \times 10^{14}$

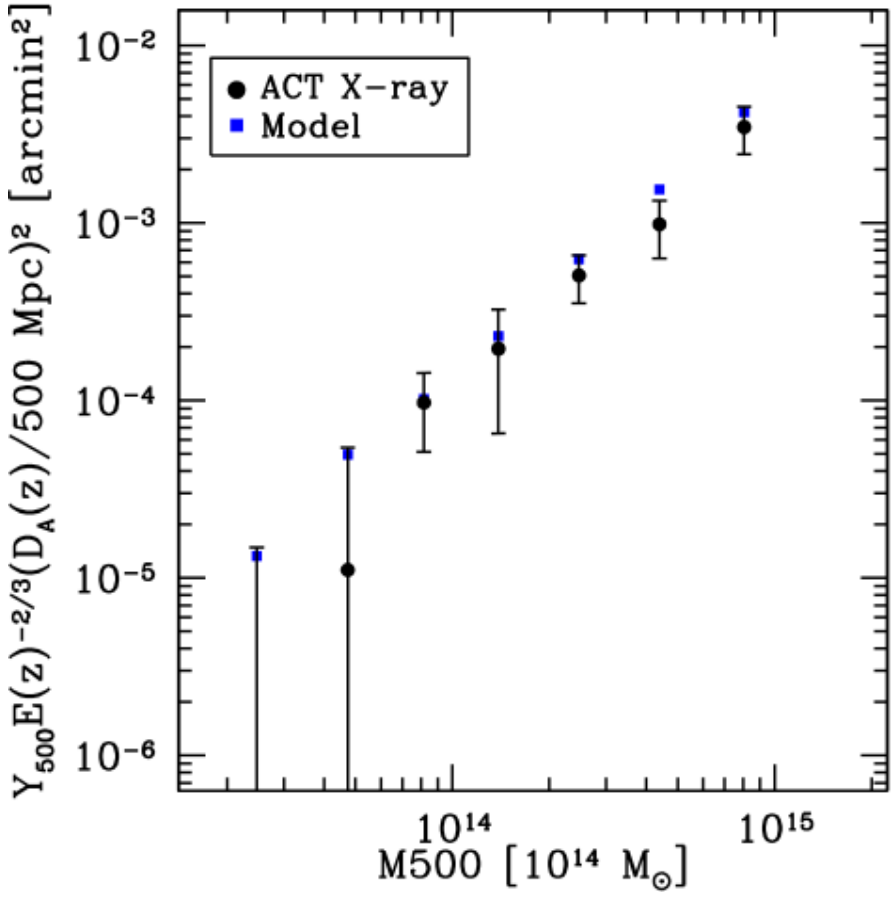
@ z=1.75

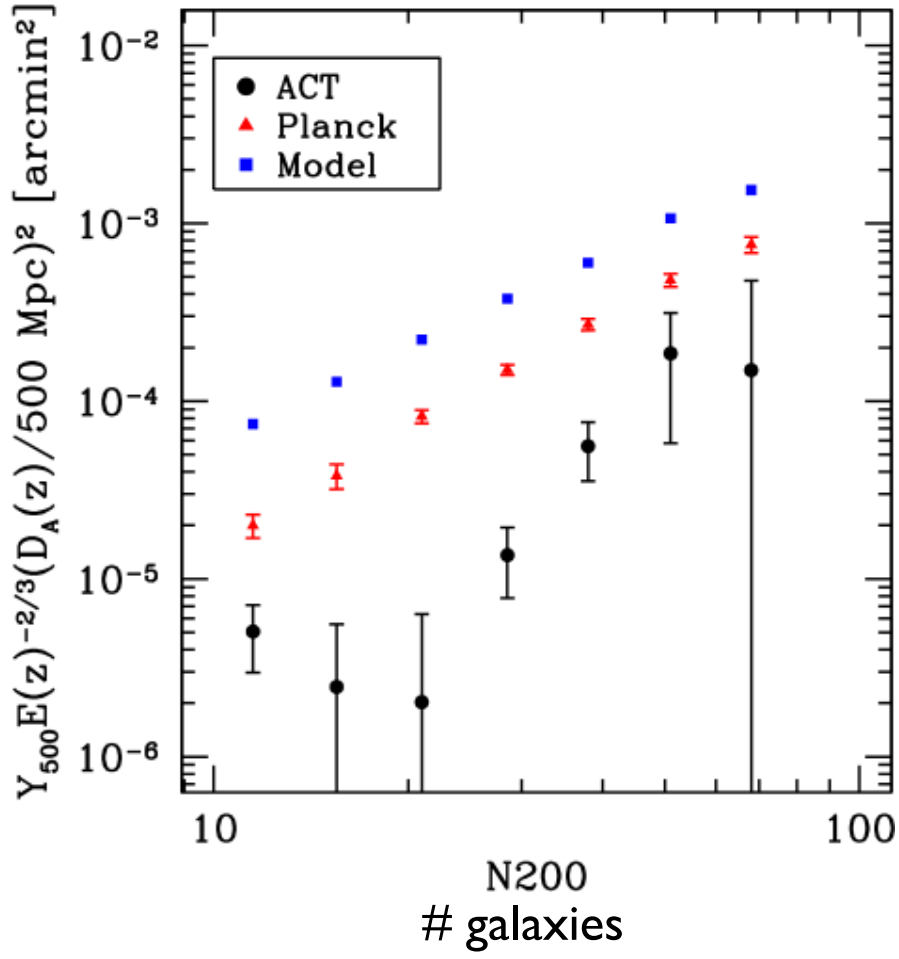
Cluster properties

X-ray selected

Optically selected

SZ intensity





Seghal et al (2012), Hand et al (2012), Sifon et al (2011)

Skewness: Wilson et al (2012)

ACTPol

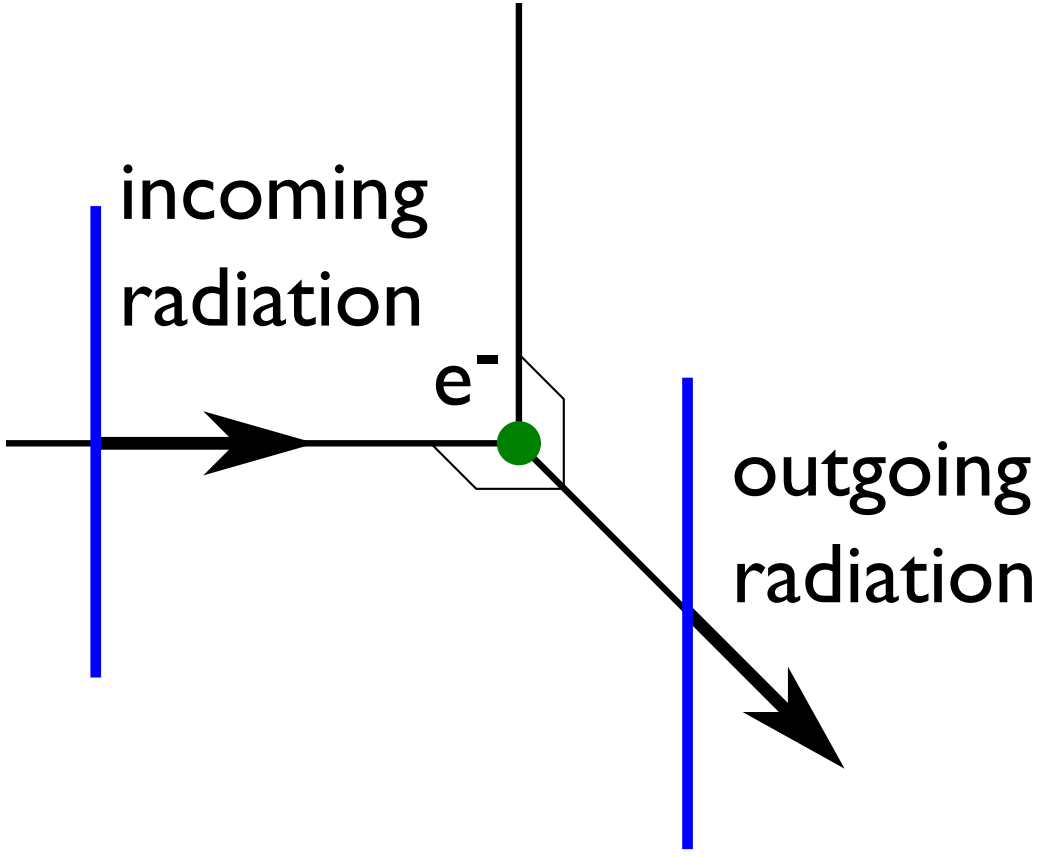
New camera with improved detectors.
Deployment 2012.

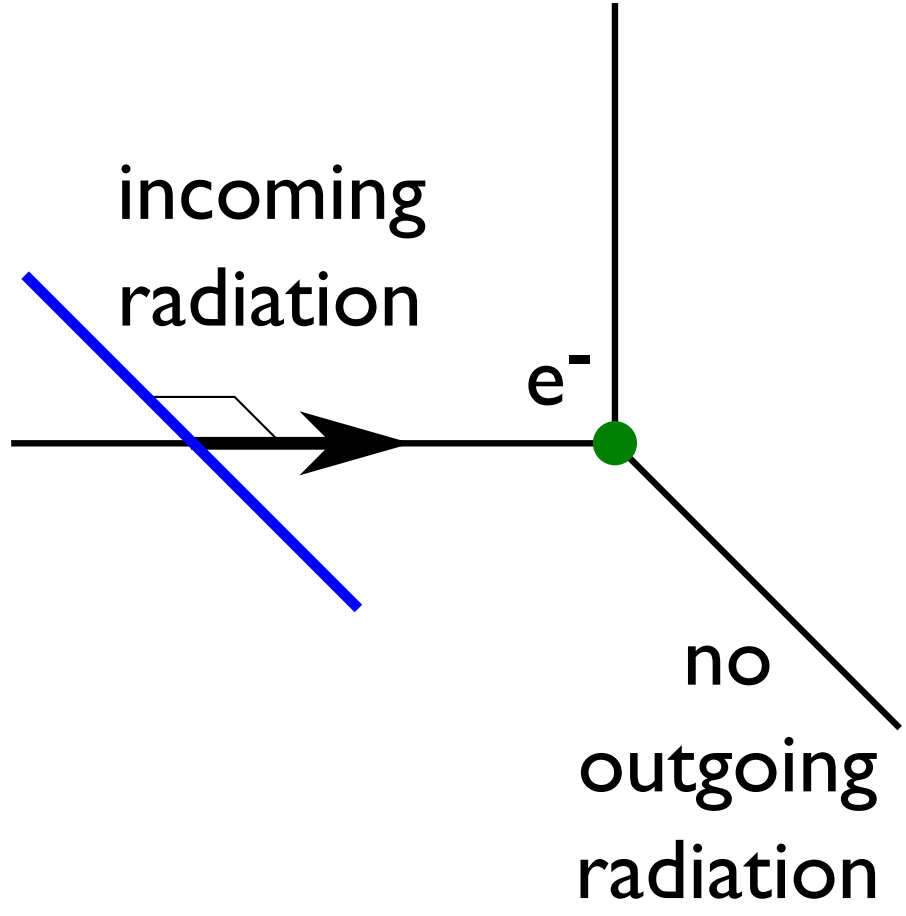
Temperature noise better by ~ 4x
→ improved SZ sensitivity

Small angular scale CMB polarization

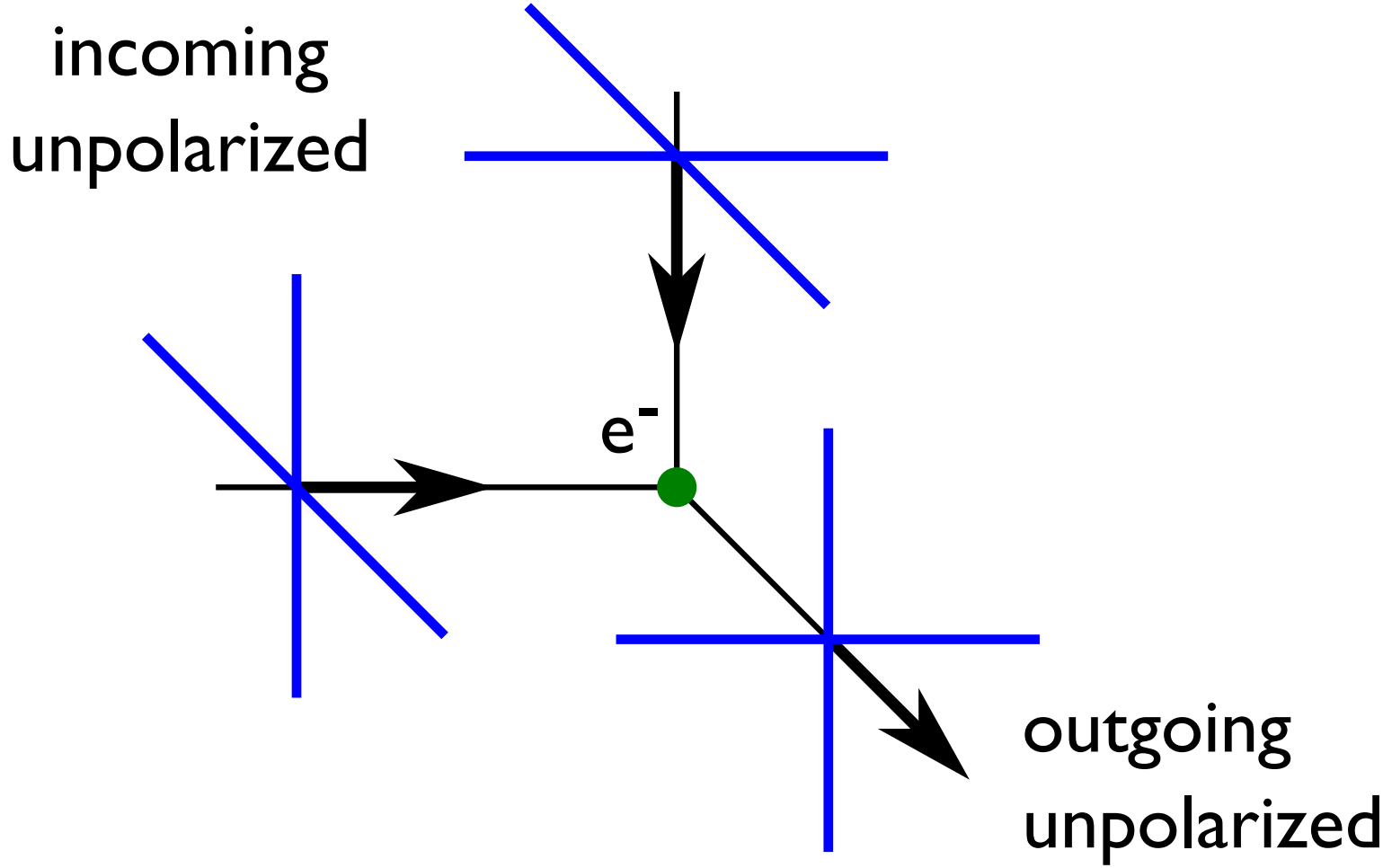
Niemack et al (2010)
arXiv 1006.5049

Polarization in Thomson Scattering

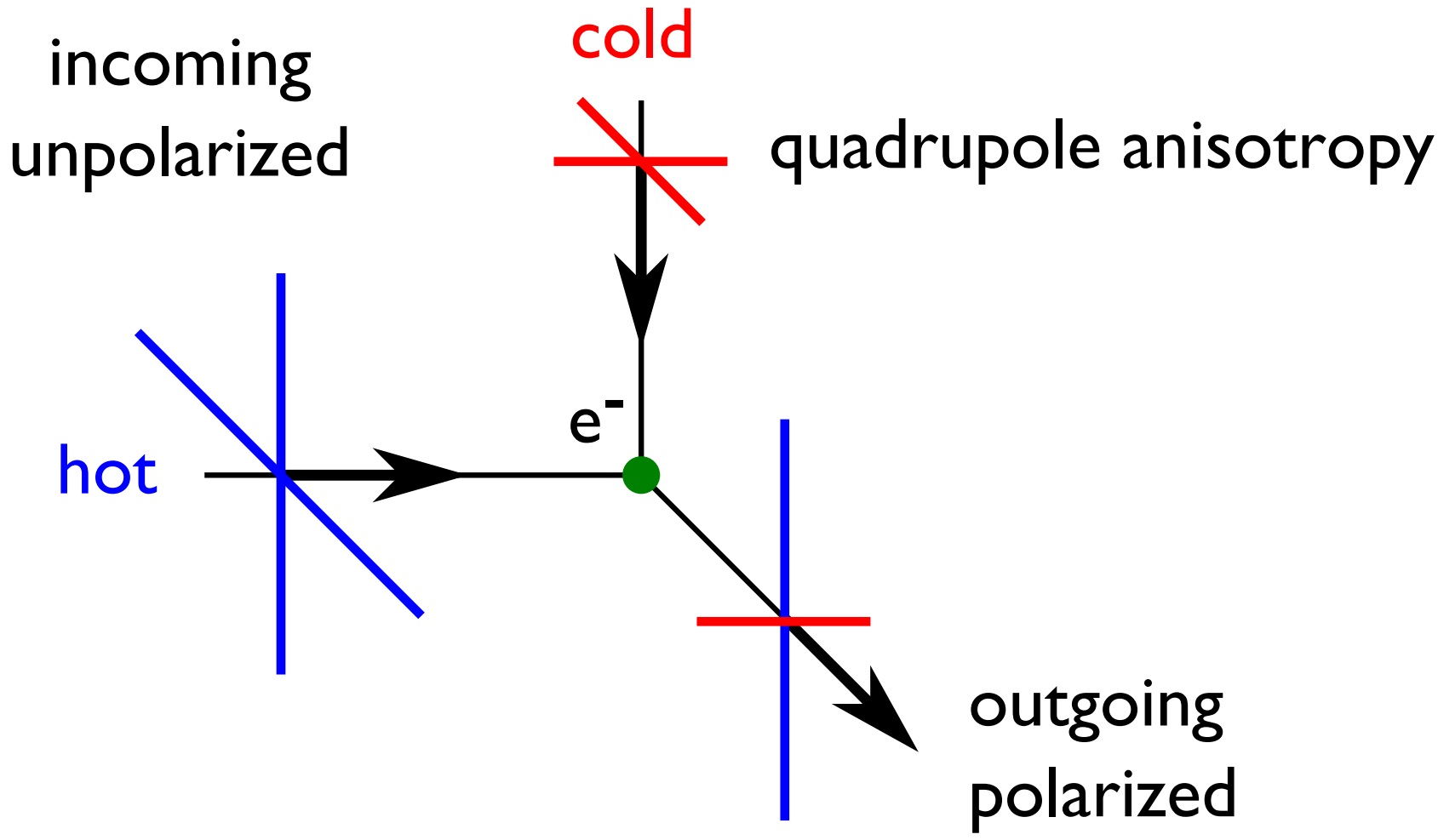




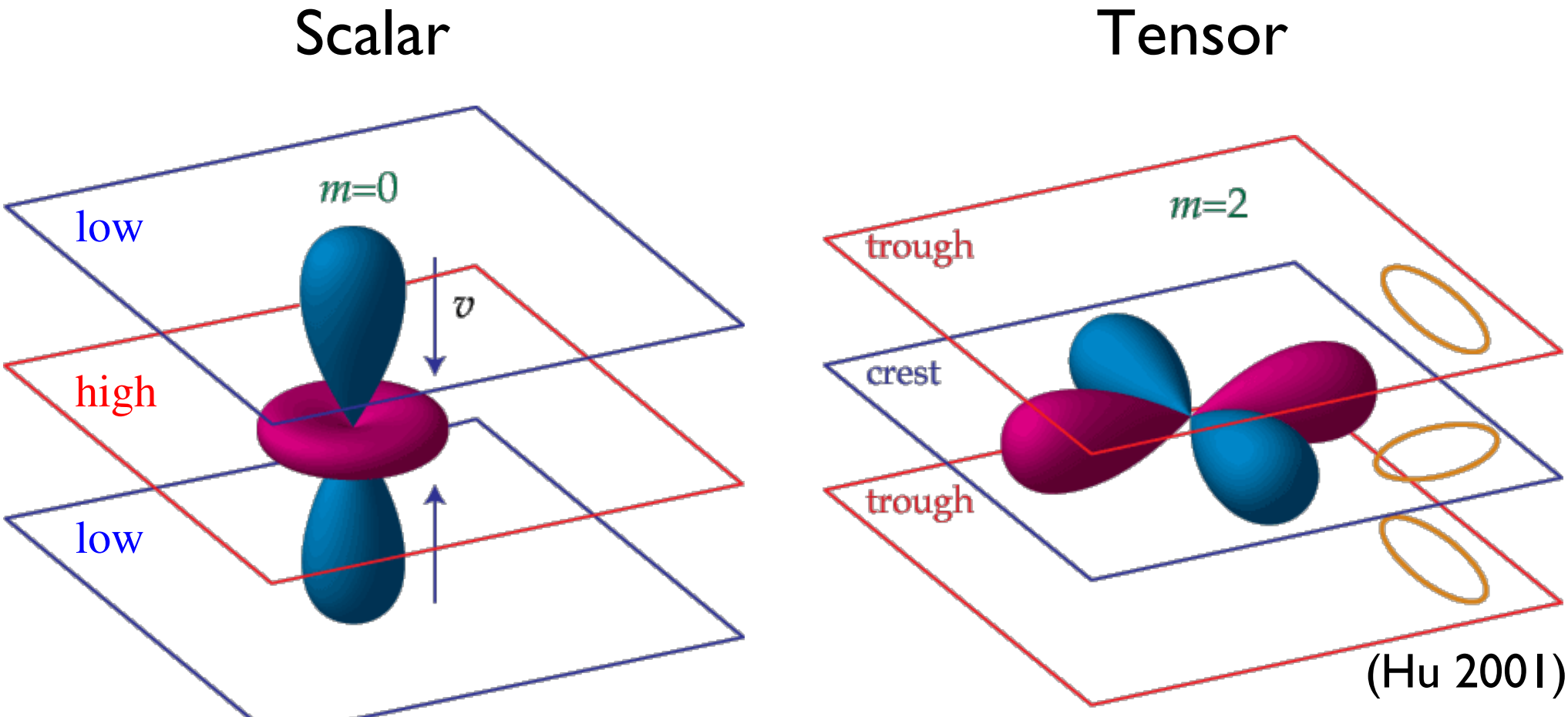
Polarization in Thomson Scattering



Polarization in Thomson Scattering



Perturbations generating quadrupoles

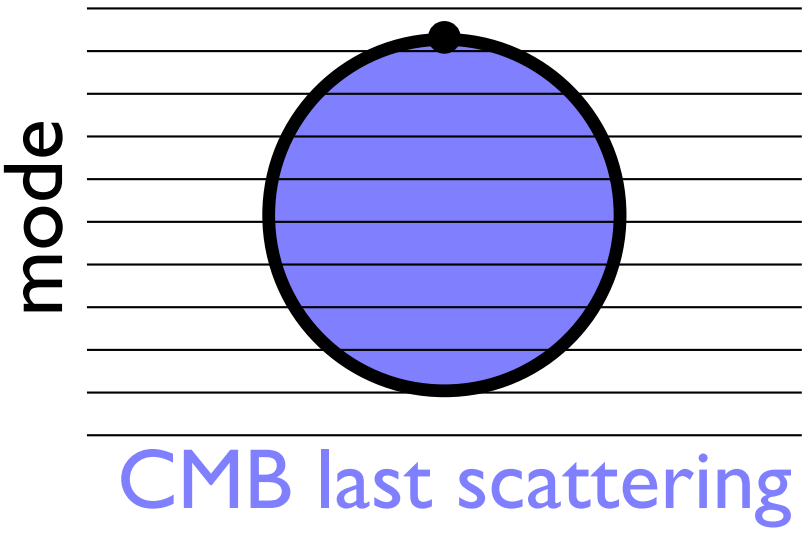


density

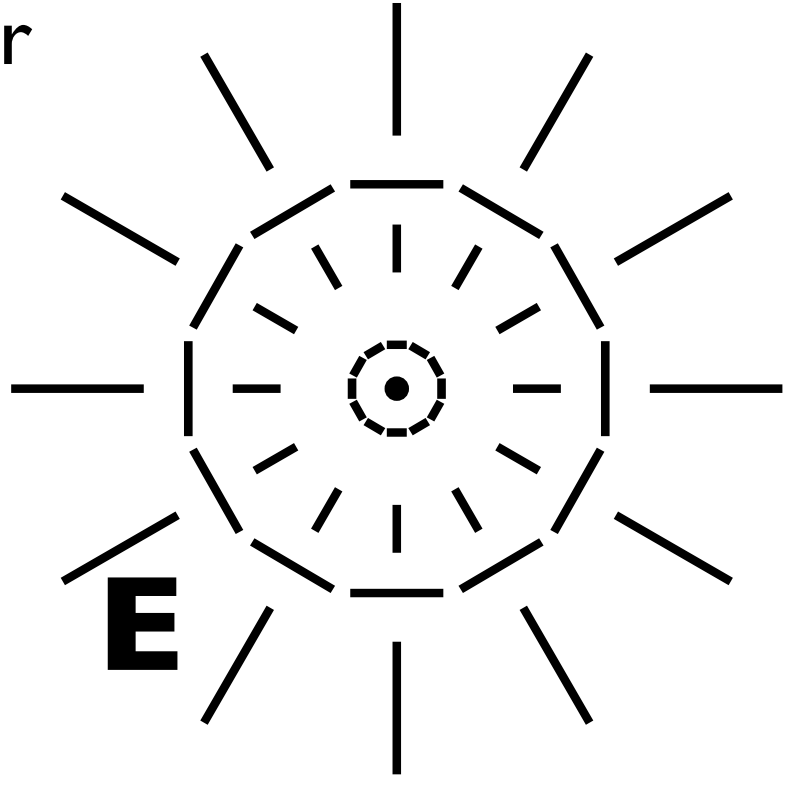
gravity wave

inflation

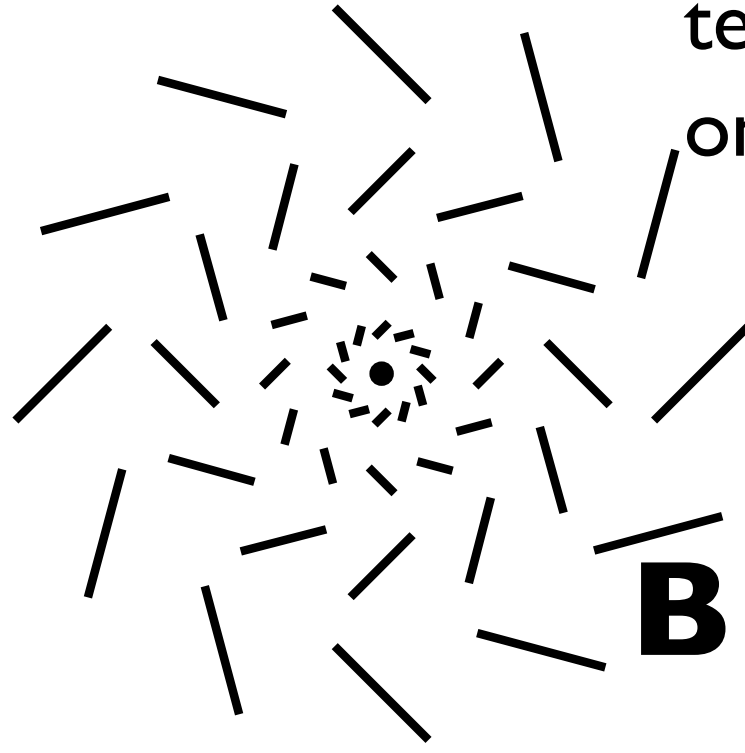
Types of polarization patterns



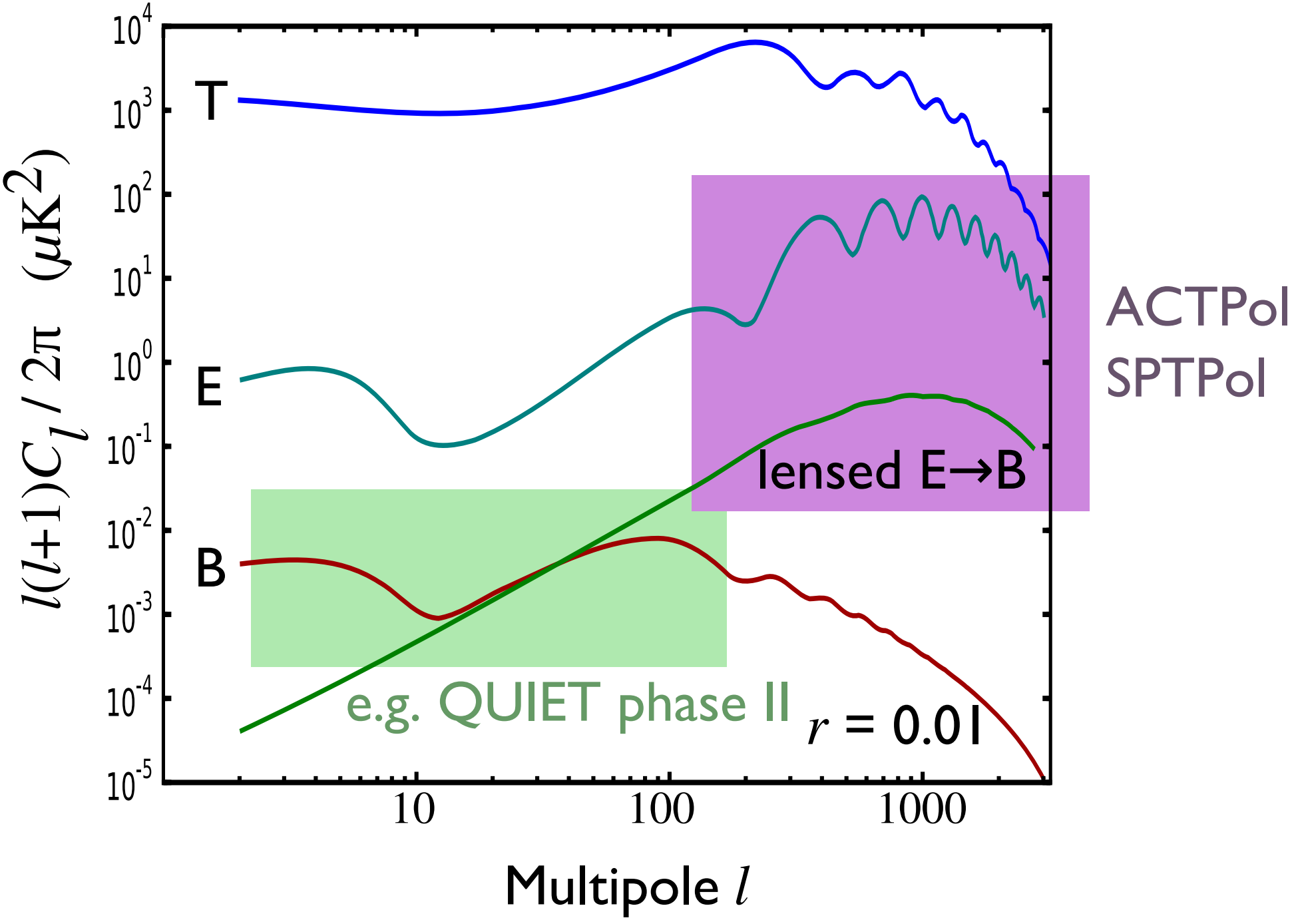
scalar



tensor-only



Power spectrum

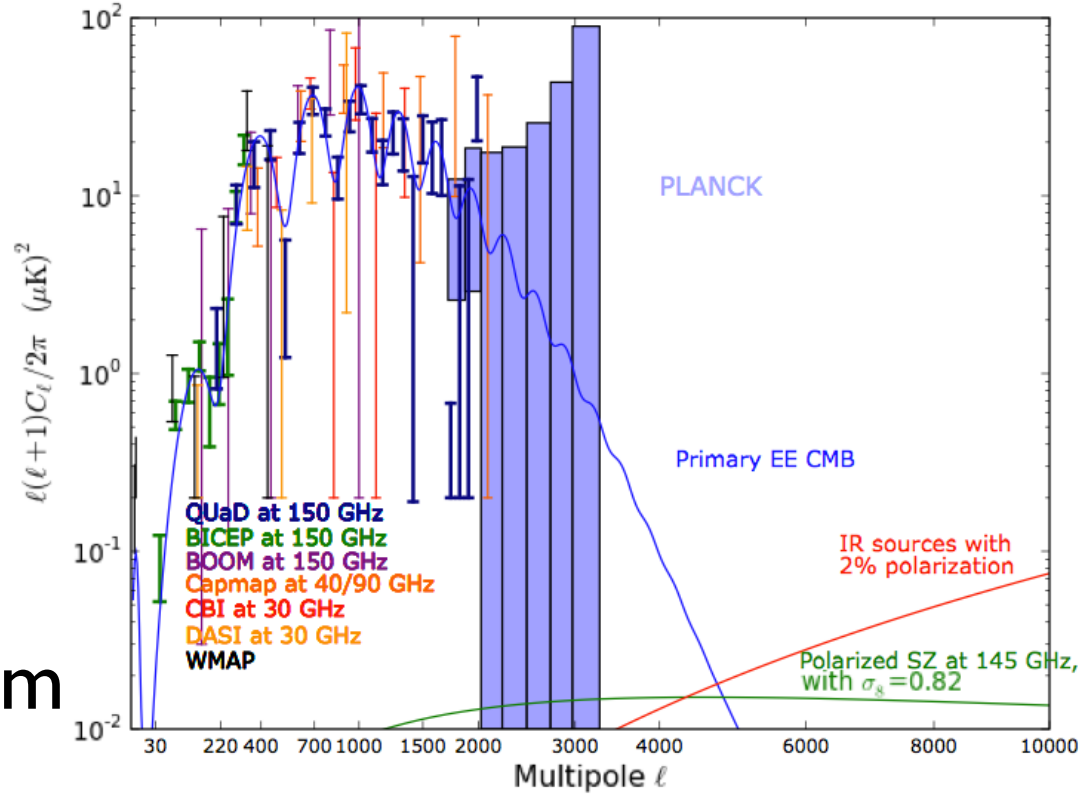


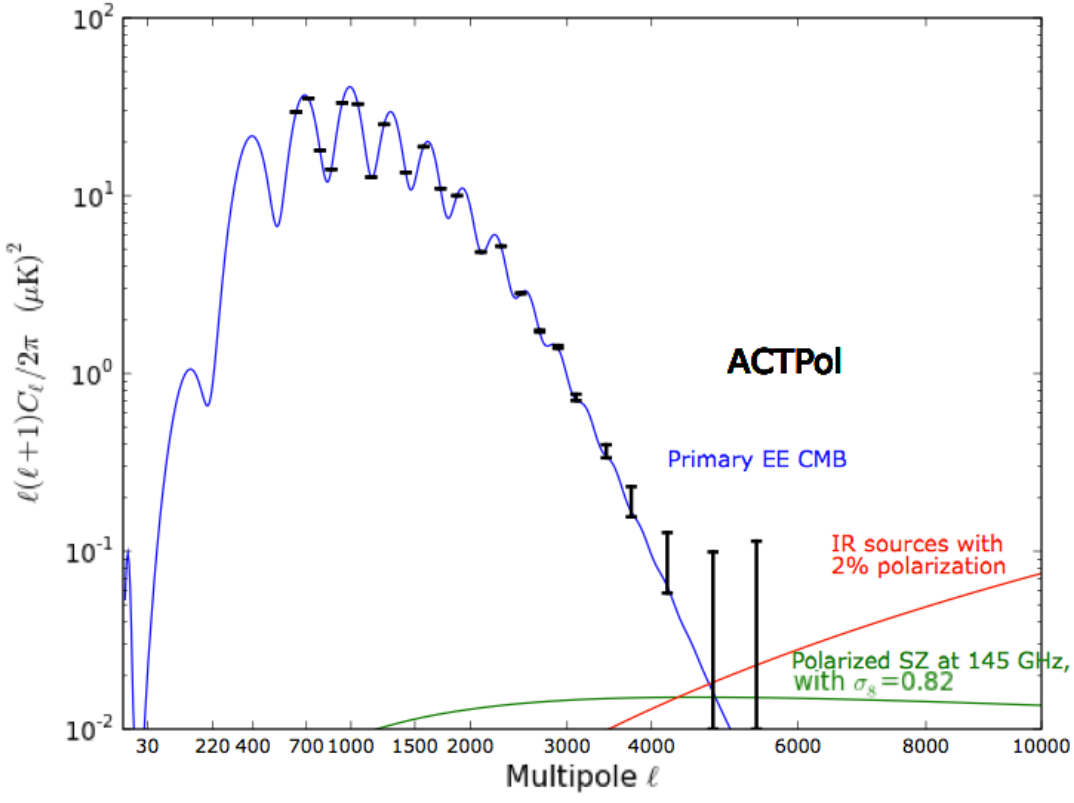
ACTPol Sensitivity

Substantial improvement
on E-mode power spectrum

Detect & Measure lensing
B-modes

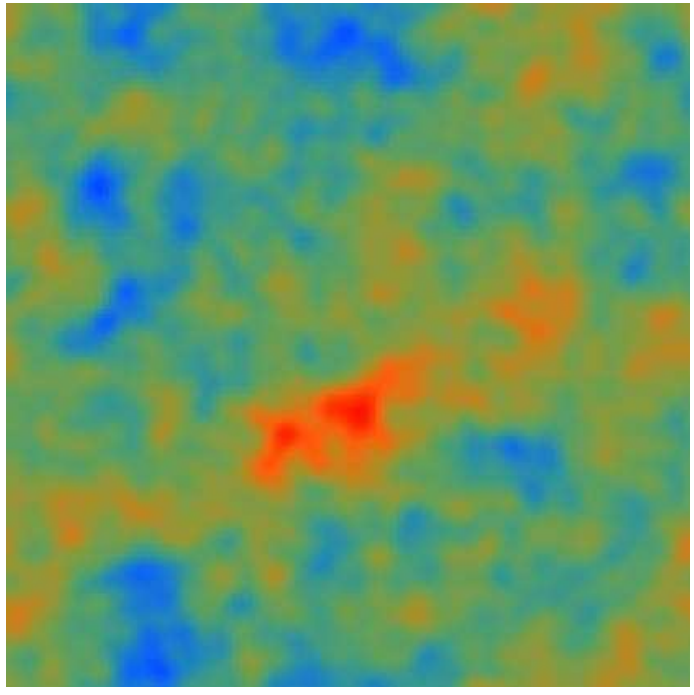
Niemack et al (2010)



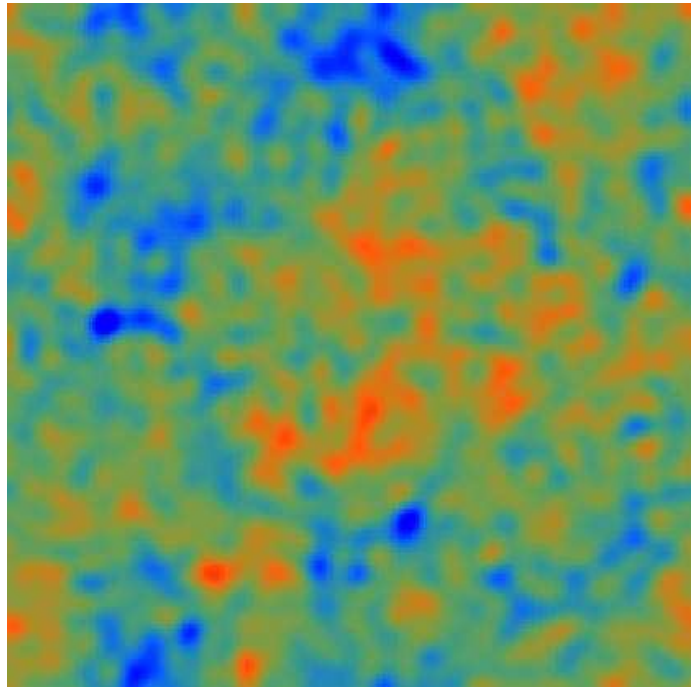


CMB lensing mass reconstruction

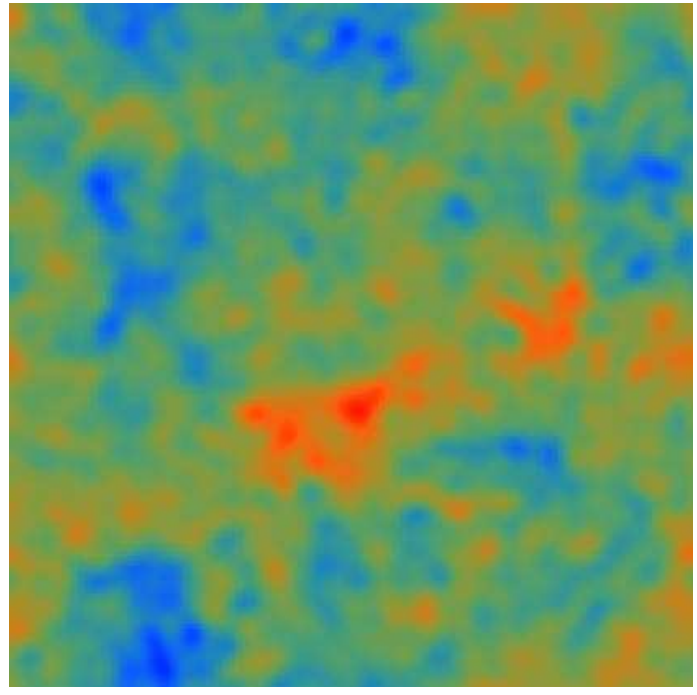
(Hu & Okamoto 2001)



Integrated Density



Using CMB T



Using CMB T, P

ACTPol: $\Sigma m_\nu \sim 0.07$ eV

ACTPol + LRG or Ly α: ~ 0.05 eV

Niemack et al (2010)

Conclusions

With lensing, ACT probes the large scale structure, and gives additional evidence for Dark Energy.

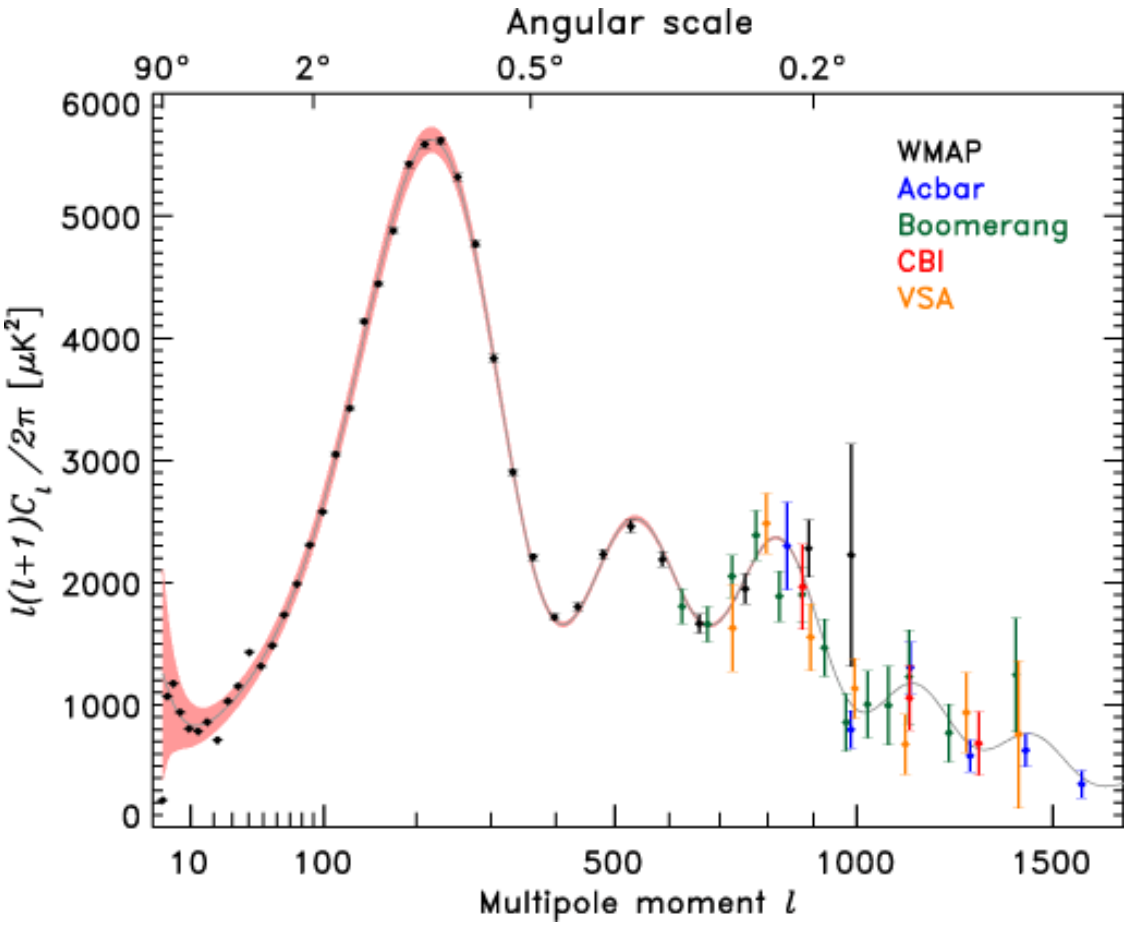
With SZ, ACT is finding massive clusters at high redshift.

ACTPol will measure polarization, opening up new avenues to pursue fundamental physics.

Backup material for questions

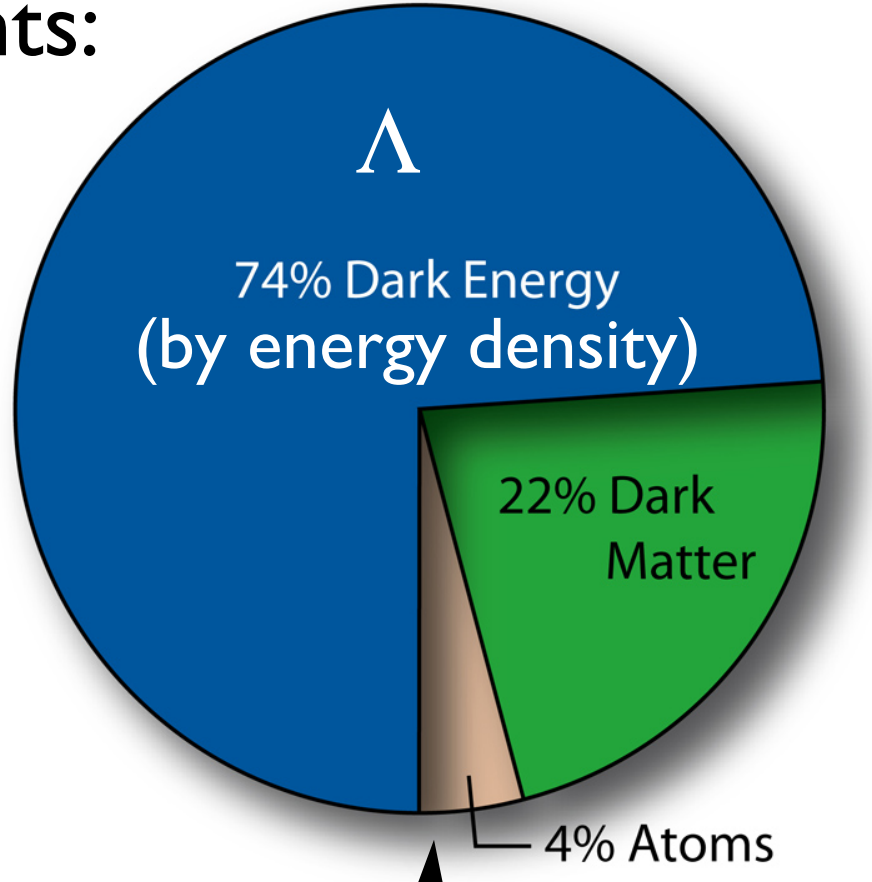
Cosmic Budget

Data:



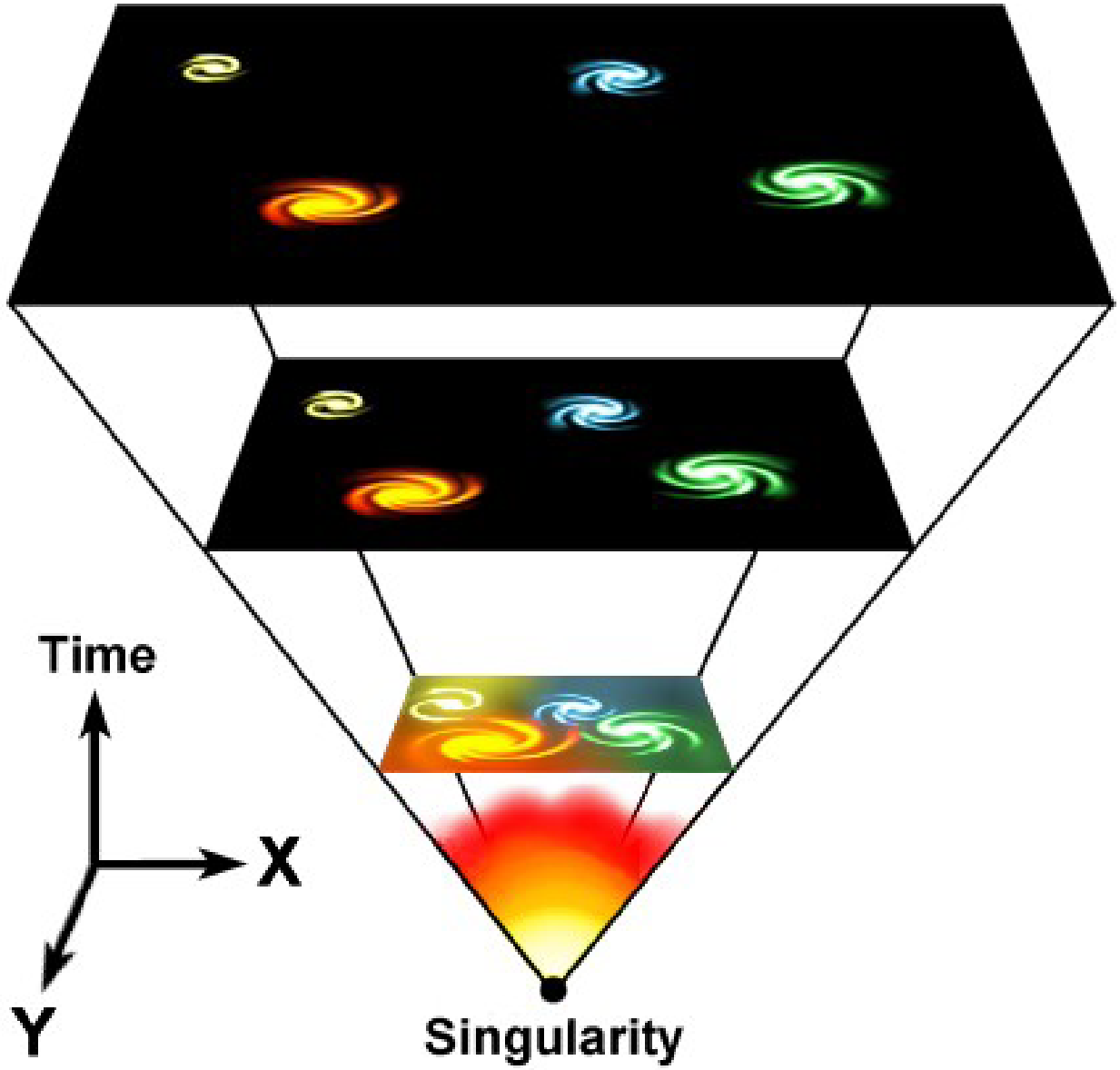
Space-time: flat +/- 2%

Contents:



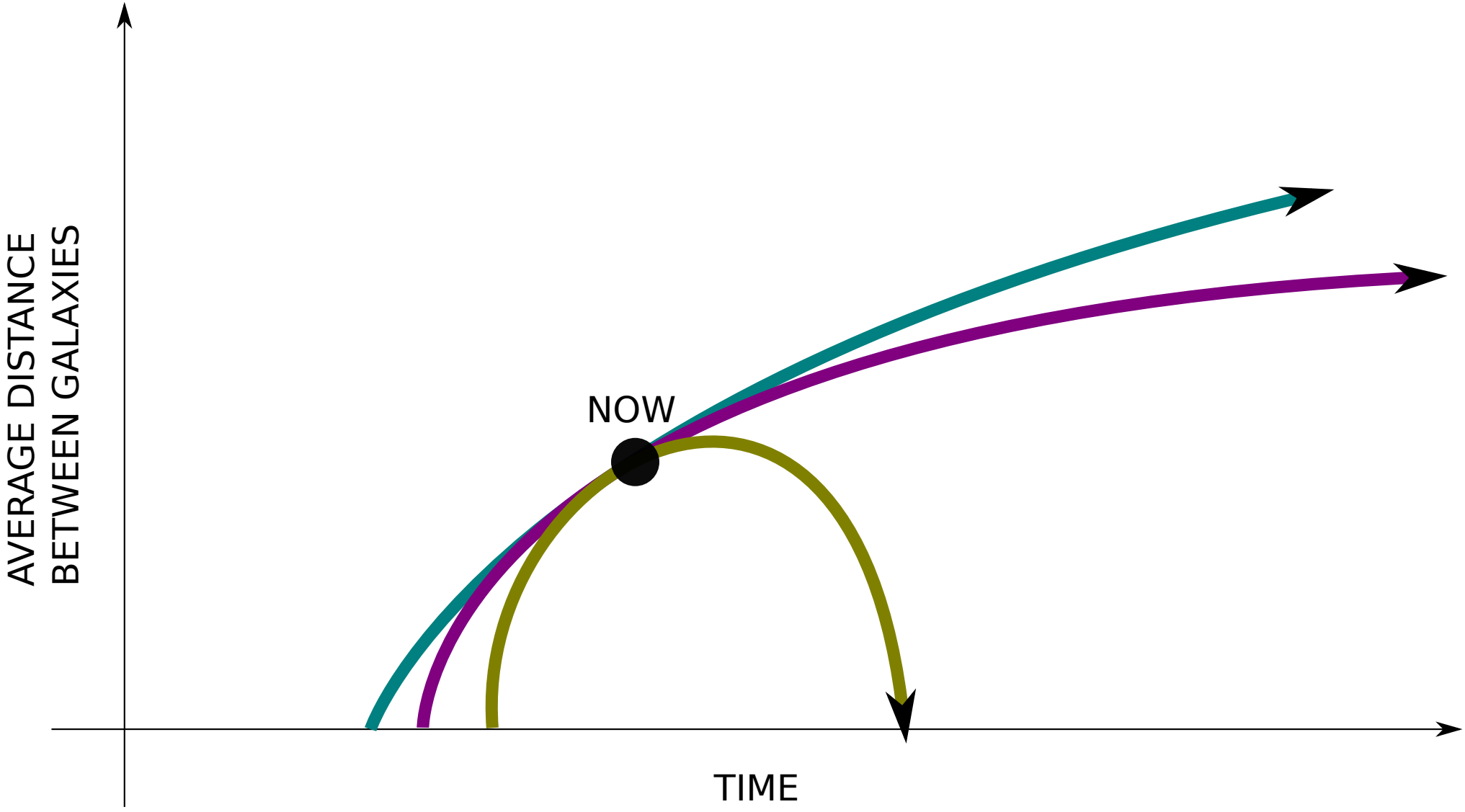
Results:

Expanding universe & the Big Bang



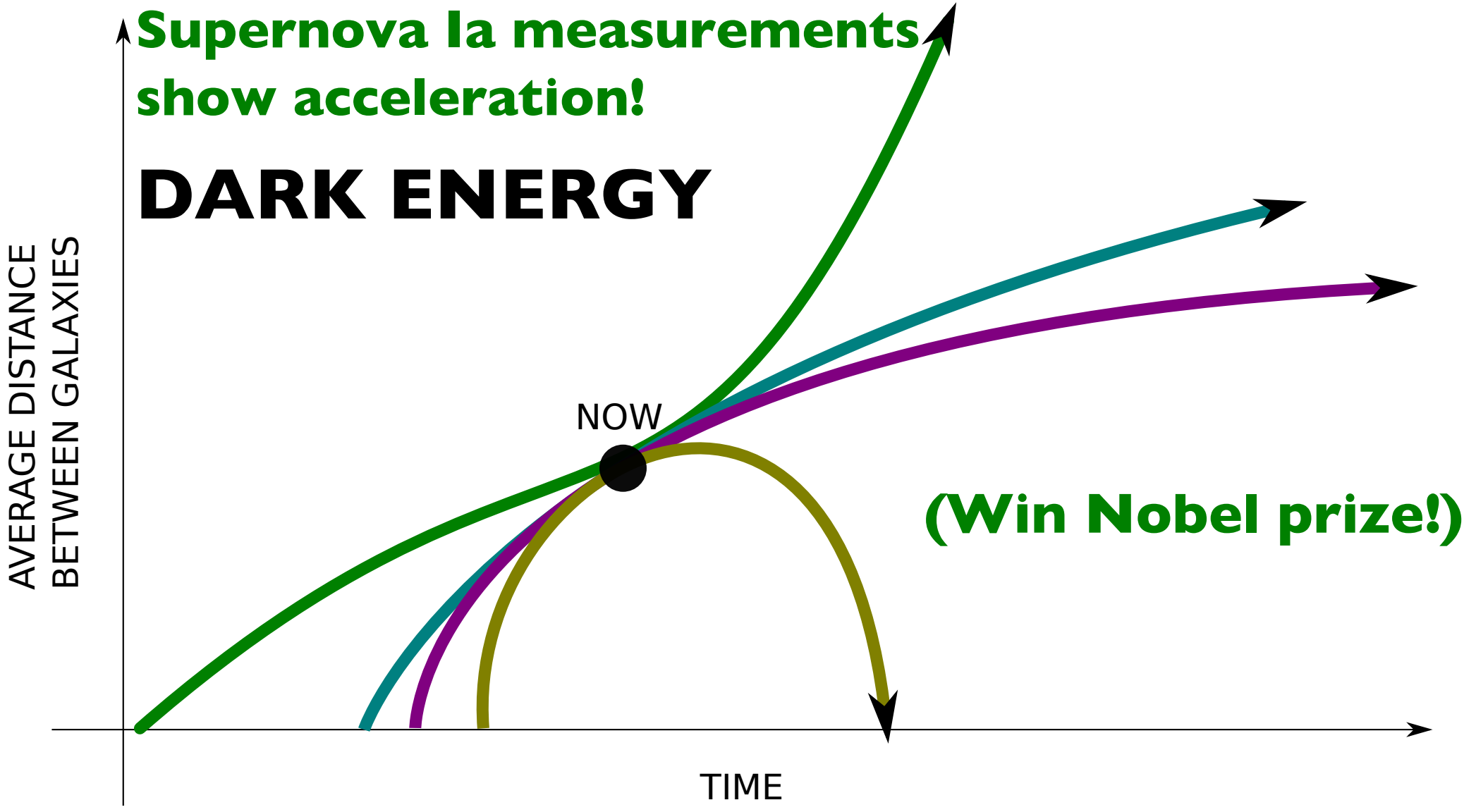
Expansion history/future

... based on Einstein's model for gravity.



Expansion history/future

... based on Einstein's model for gravity.



Type Ia SN indicate expansion is accelerating

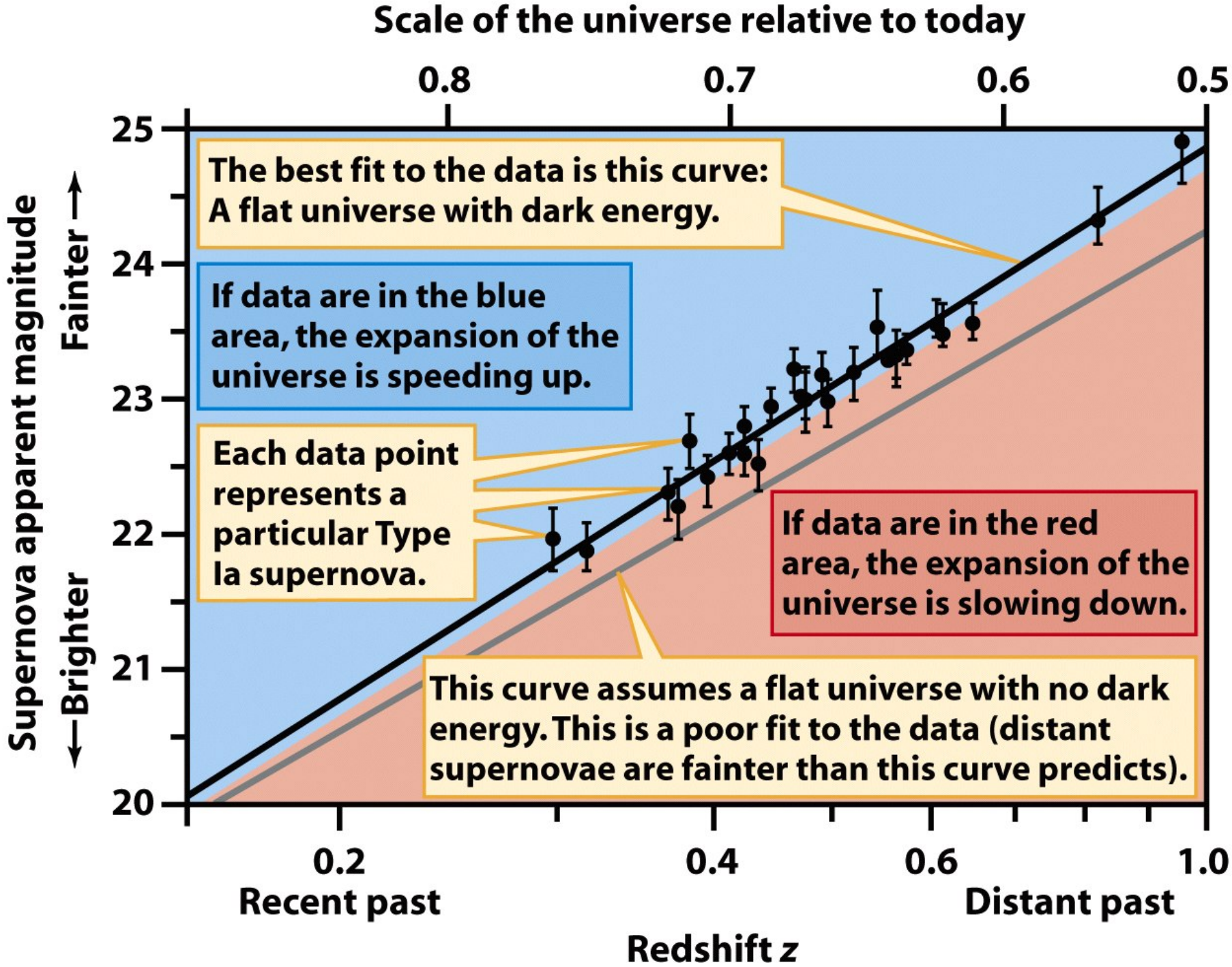


Figure 26-18

Thermal history of the Universe

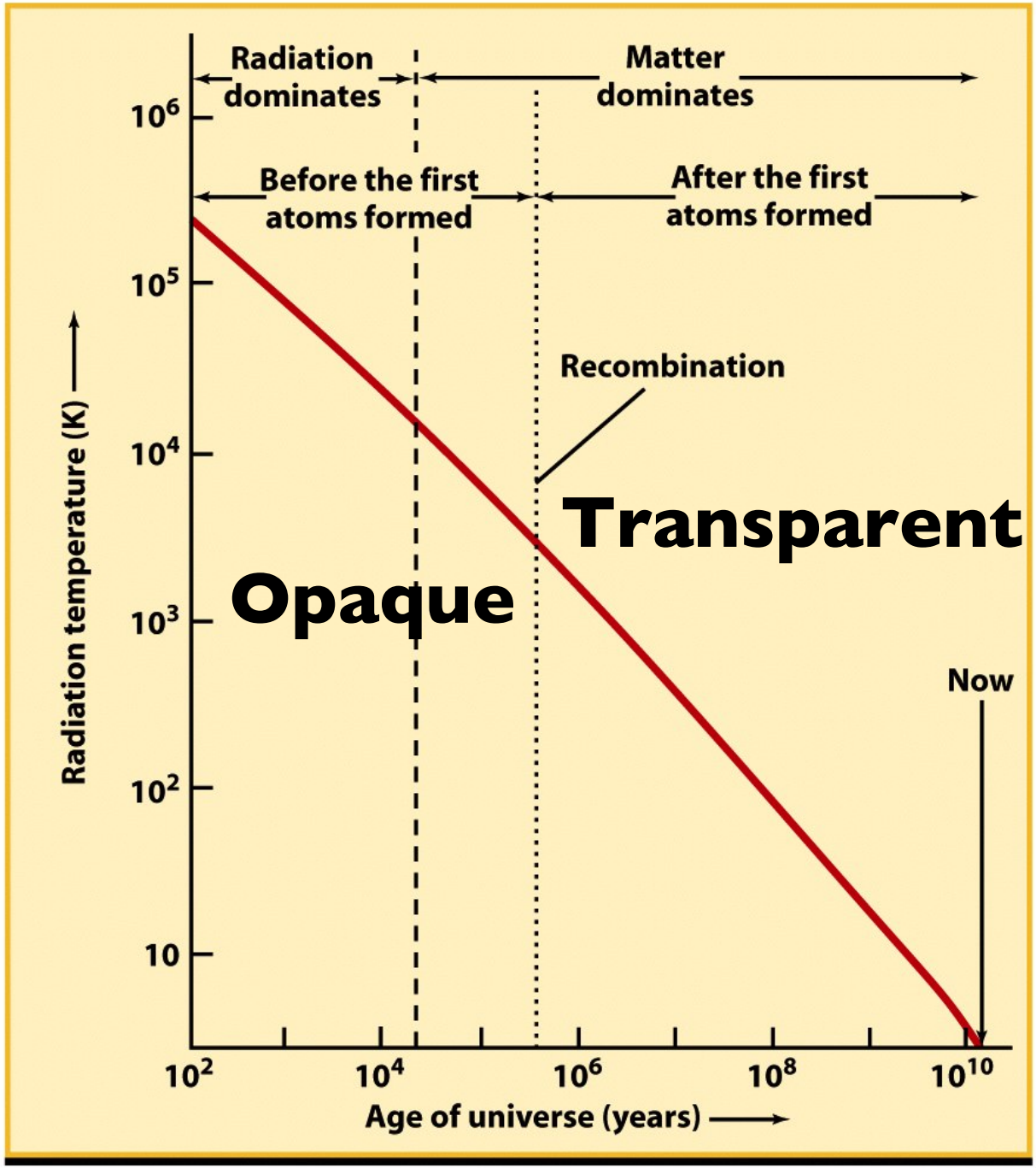


Figure 26-11
Universe, Eighth Edition

Hot, dense objects glow with a specific spectrum

Technical term: "Blackbody radiation"

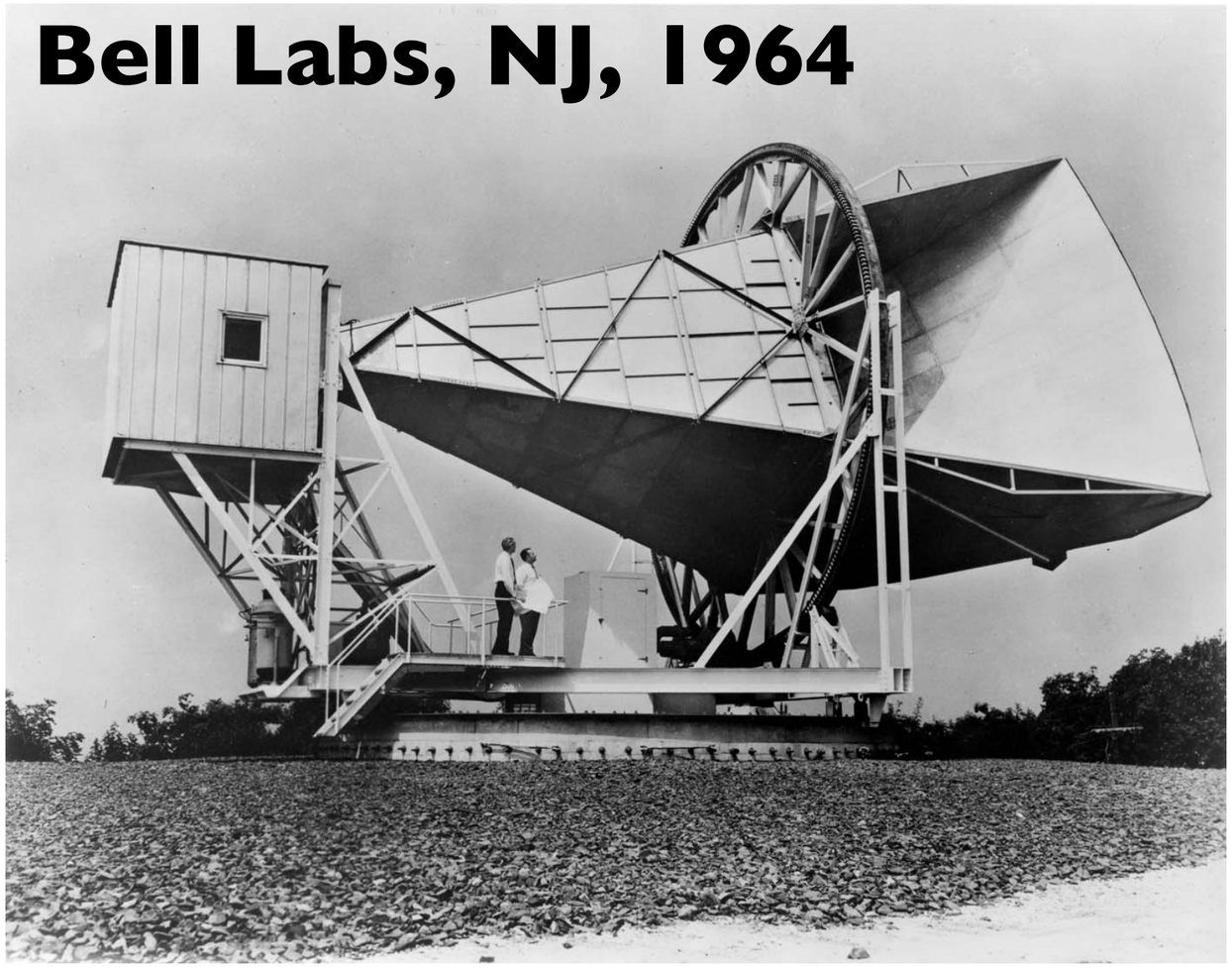
Big Bang's afterglow

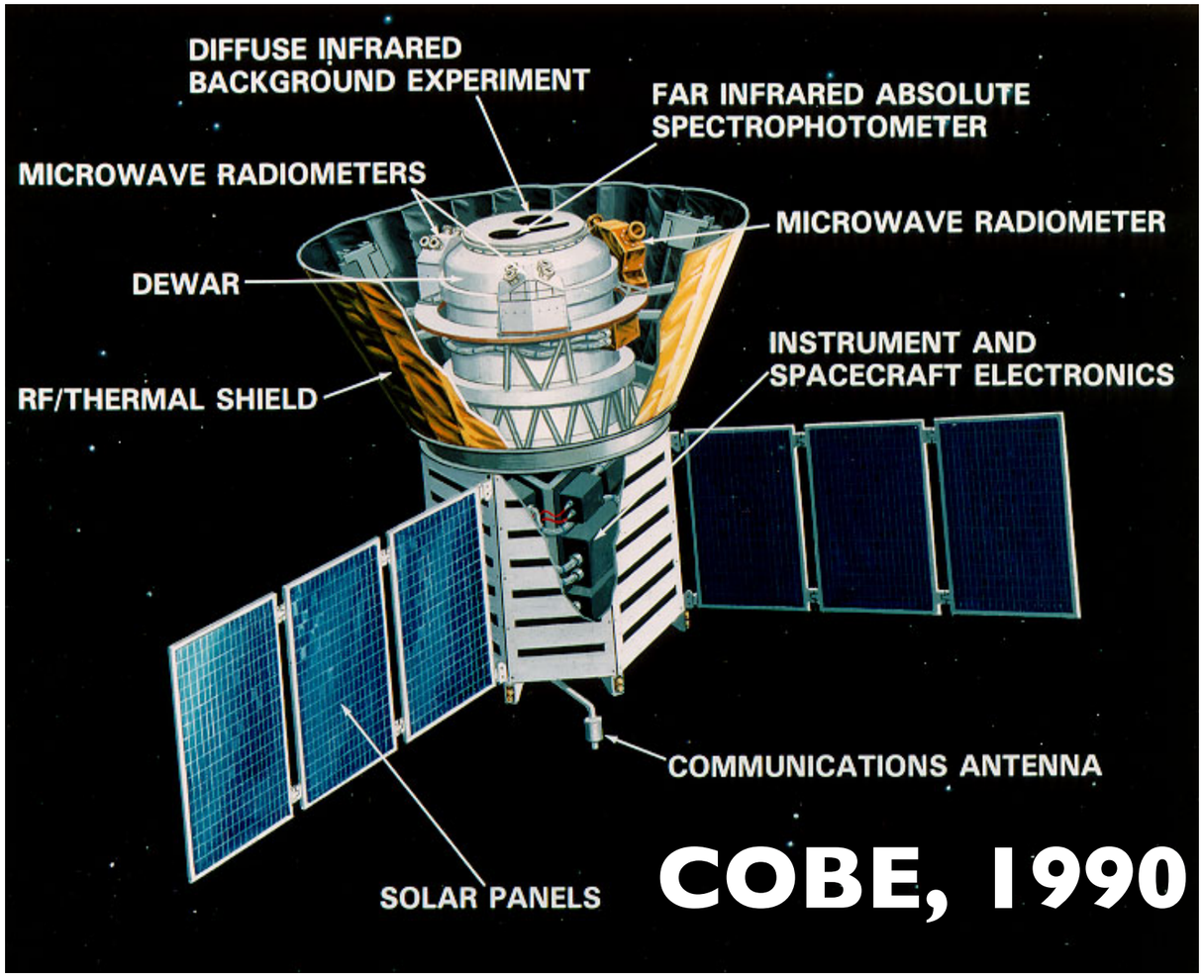
Dense, hot initial state ➡ **Relic Background Radiation**

redshifted to microwaves.

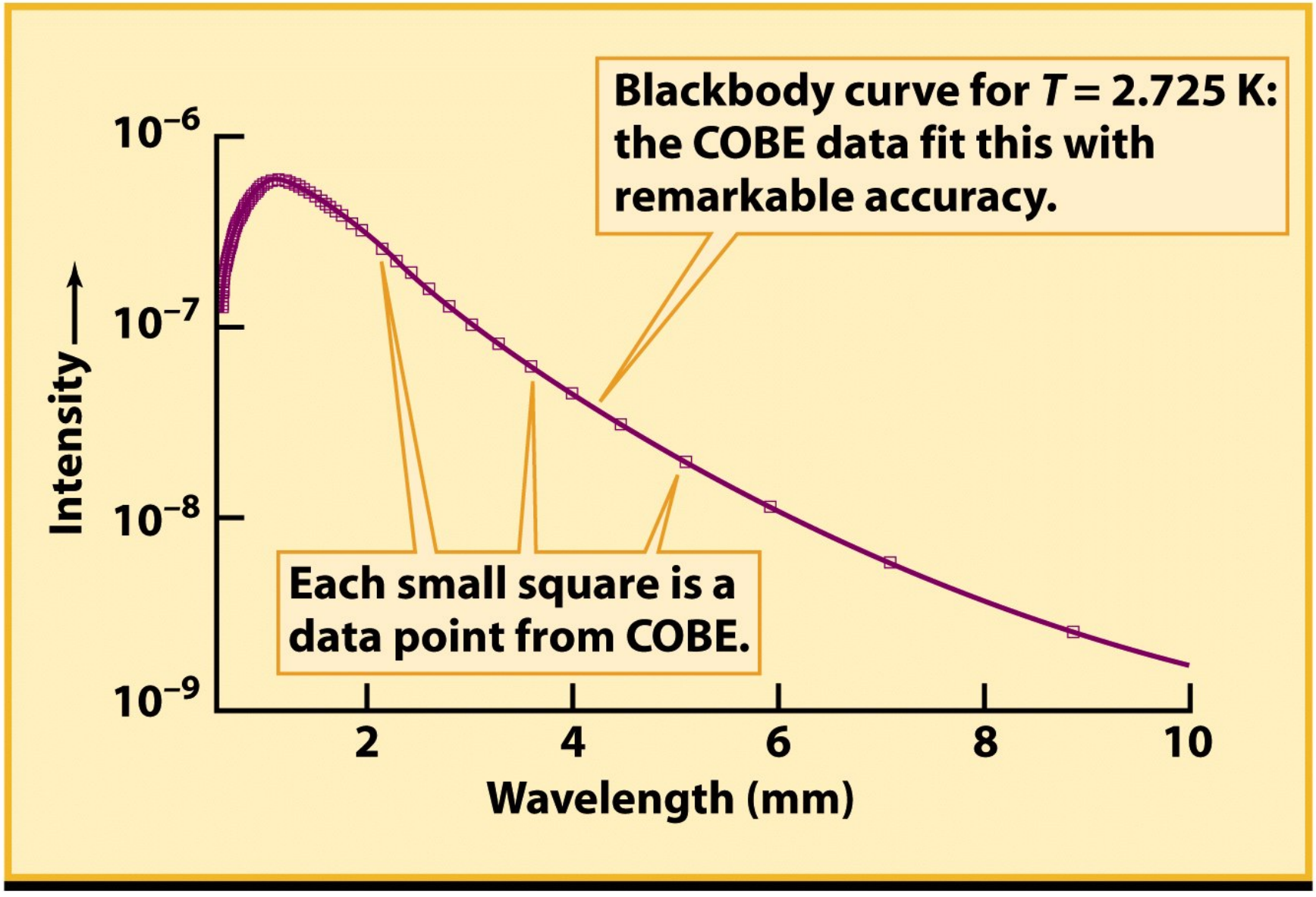
Cold: 3 K above abs. zero

Bell Labs, NJ, 1964





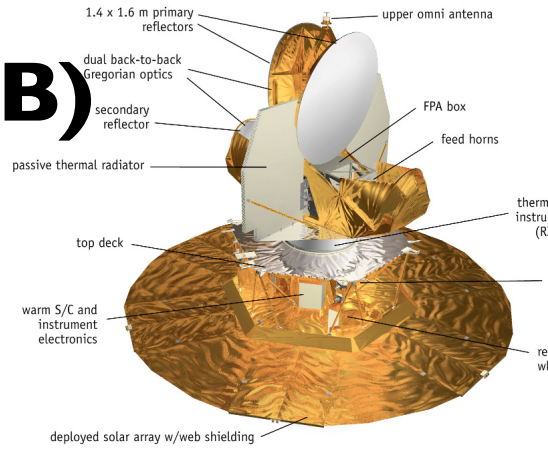
Each resulted in a Nobel prize!



The spectrum of the cosmic microwave background

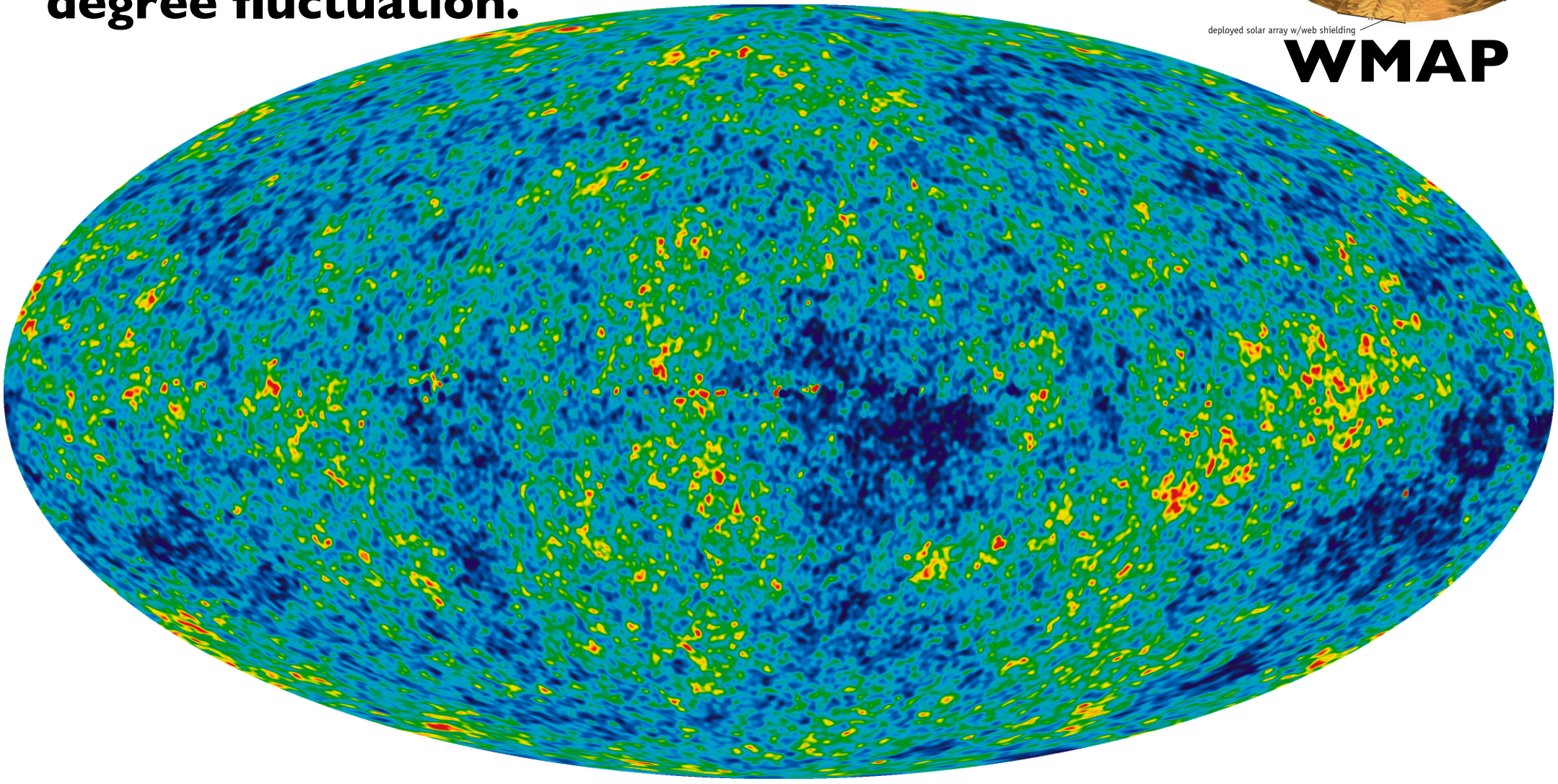
Figure 26-7b
Universe, Eighth Edition

Cosmic Microwave Background (CMB)



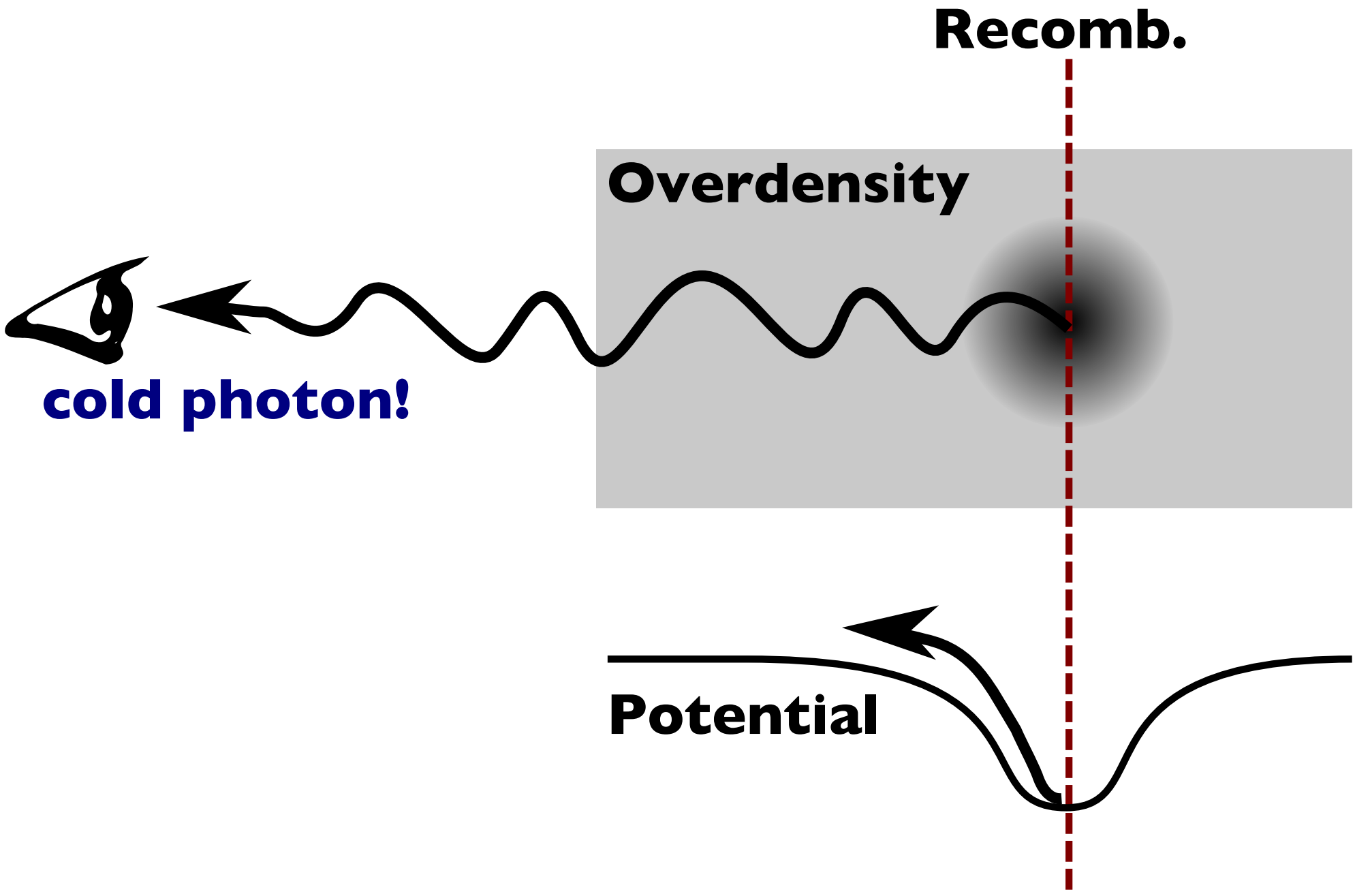
WMAP

Few ten-thousands of a degree fluctuation.

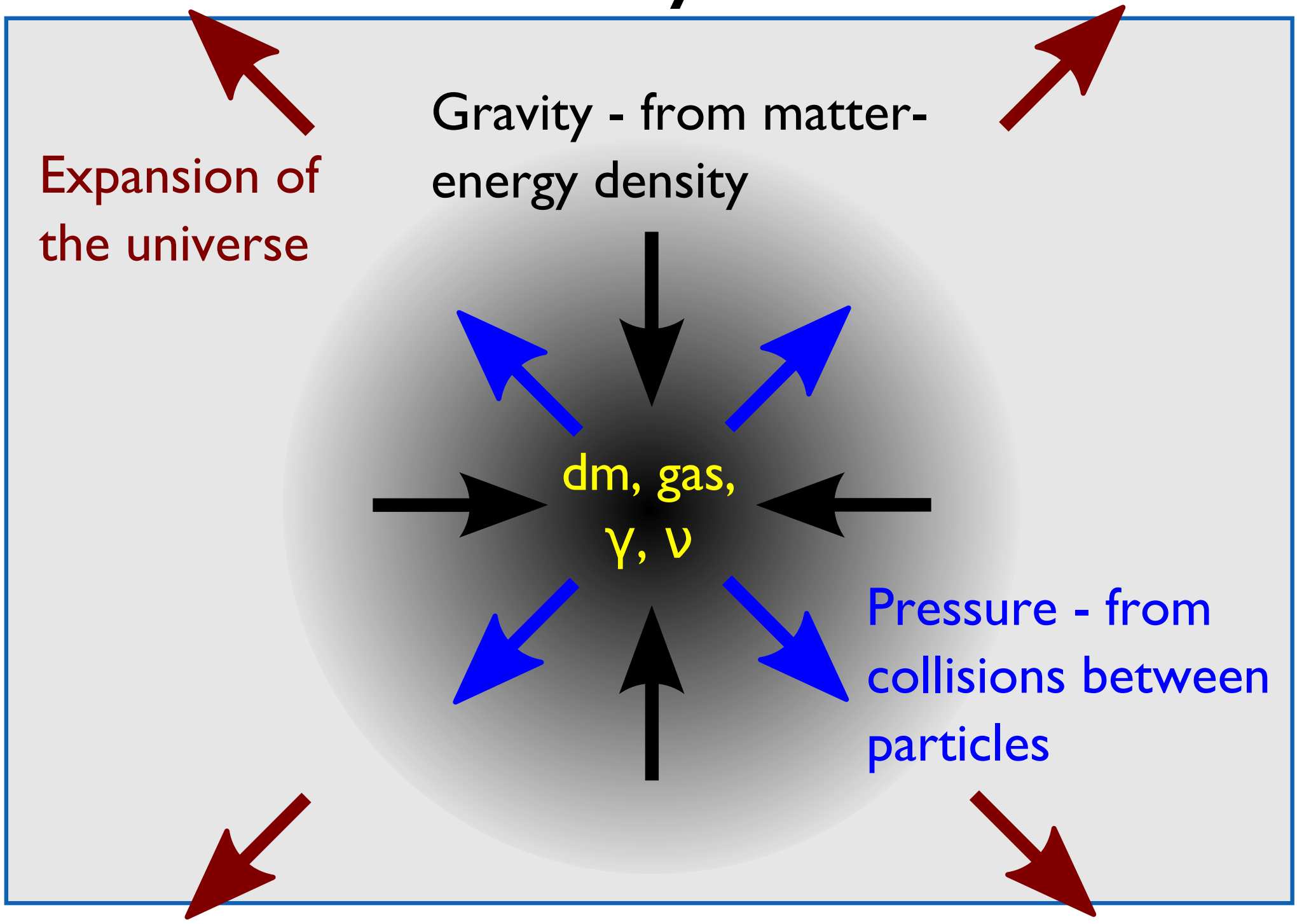


info on grav. potential @ recombination

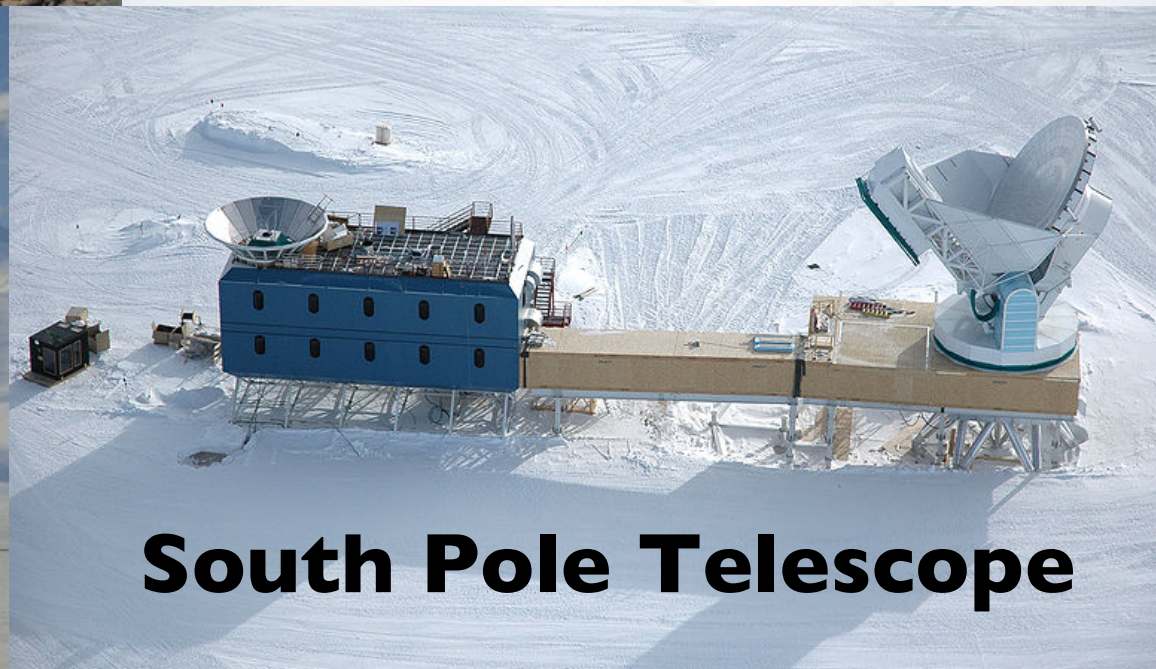
Probing gravitational potential



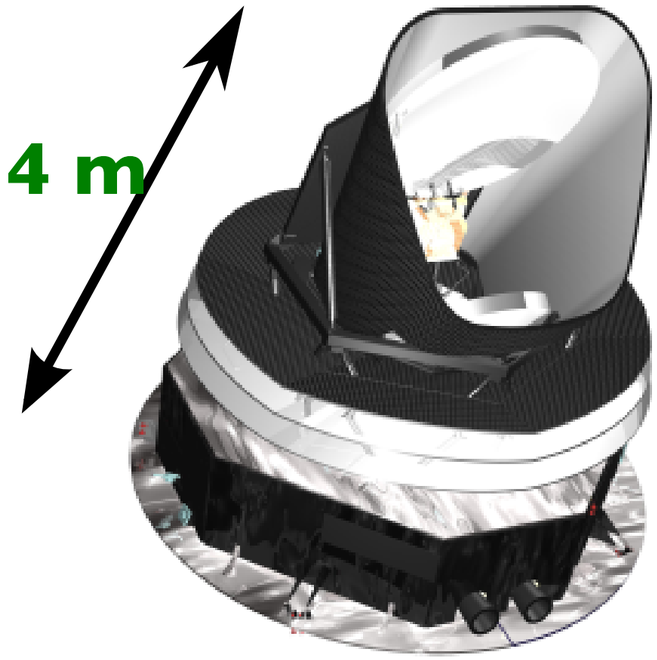
Forces on an overdensity



Ground / balloon based telescopes



Planck



Next generation satellite mission.

All-sky, compared to WMAP:

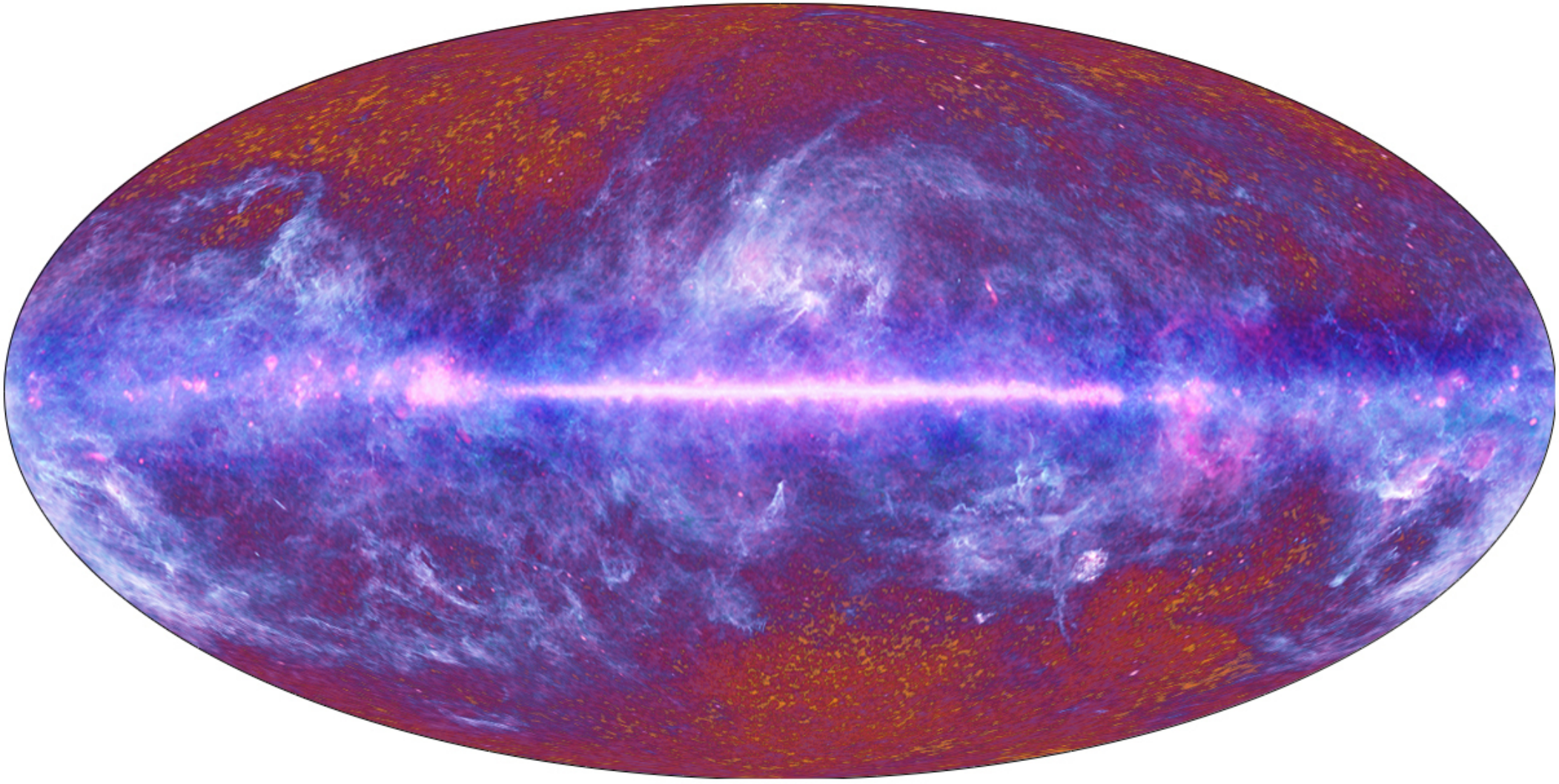
- **Wider frequency coverage.**
- **Lower noise.**
- **Higher resolution.**
- **Better polarization sensitivity.**

ESA/NASA mission, large collaboration.

Launched: May 14, 2009

Data releases: 2011-2013.

Planck's first full-sky image



Cosmology results early 2013

http://irsa.ipac.caltech.edu/

Power spectrum

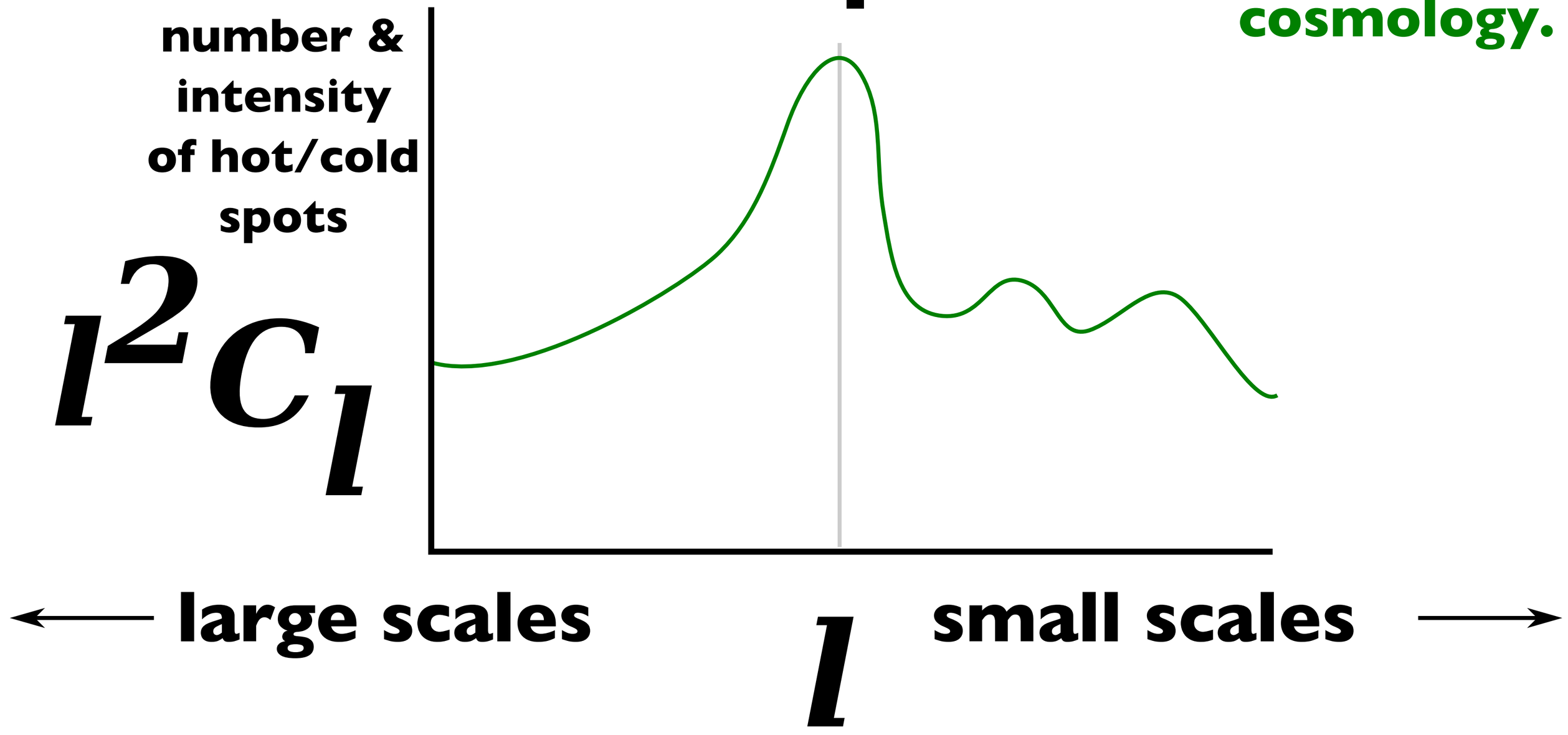
Study two-point correlation function in harmonic space

$$a_{lm} = \int d\Omega \, T(\theta, \phi) Y^*_{lm}(\theta, \phi)$$

$$\langle a_{lm} a^*_{l'm'} \rangle = C_l \delta_{ll'} \delta_{mm'}$$

CMB "power spectrum"

... fundamental tool to understand the implications of CMB measurements for cosmology.



Universe's contents

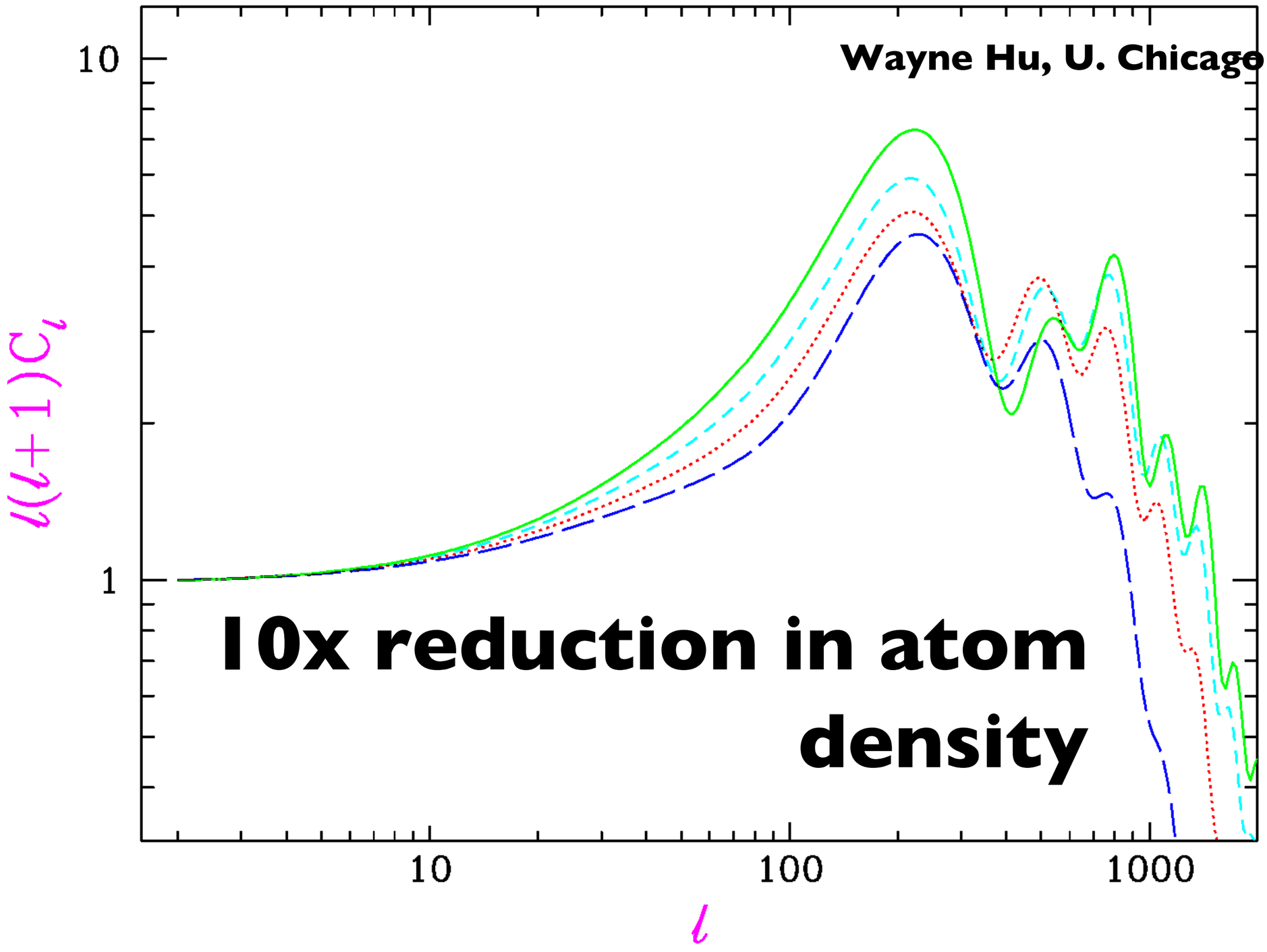
3 components cosmologically relevant:

1. baryons, atoms, "normal matter".

2. cold dark matter, normal gravity, no pressure, no interactions.

3. dark "energy", Λ = Lambda, anti-gravity, cosmological constant, acceleration.

Measuring Universe's contents



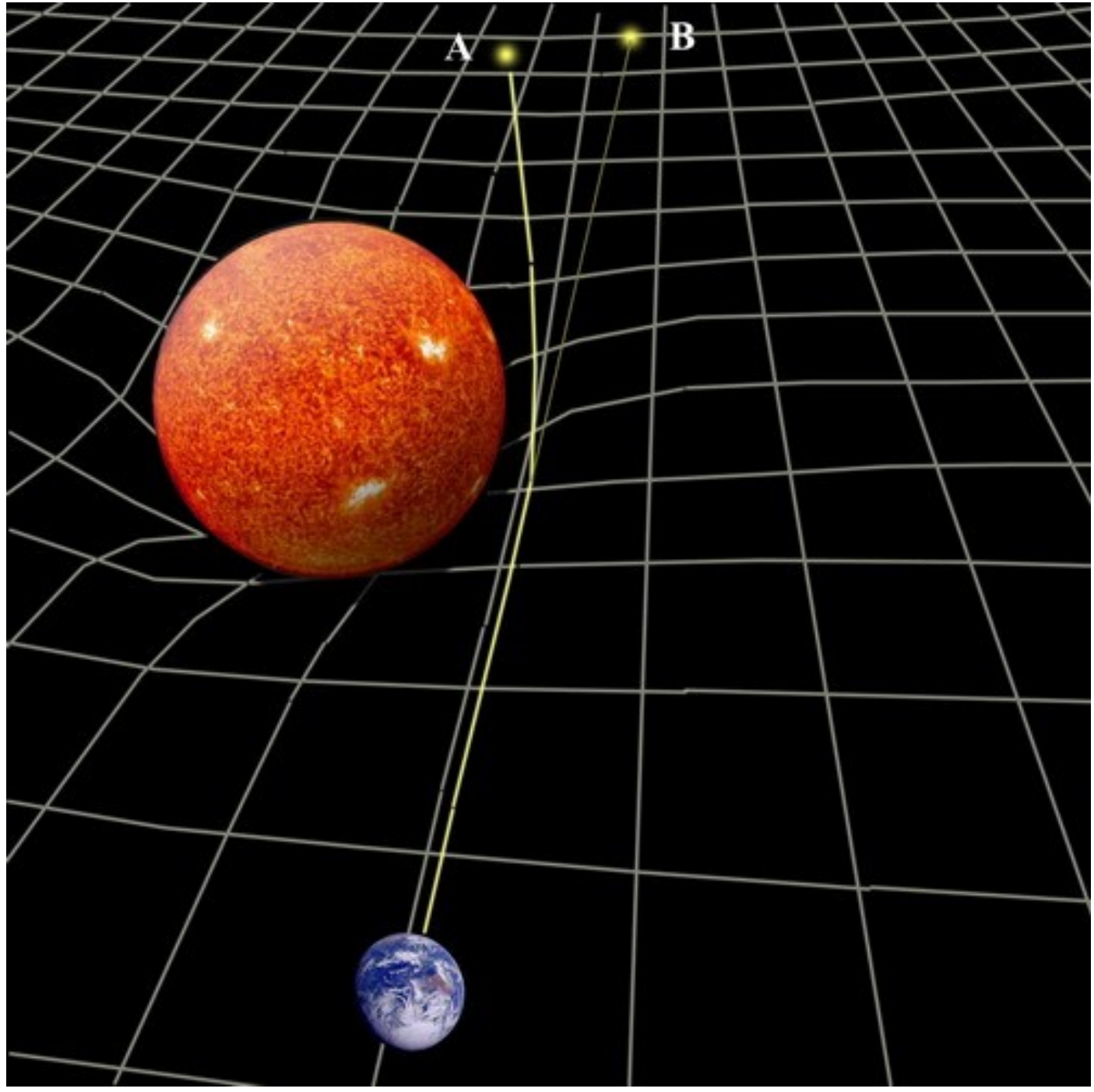
General Relativity: Einstein's theory of gravity

Field equations:

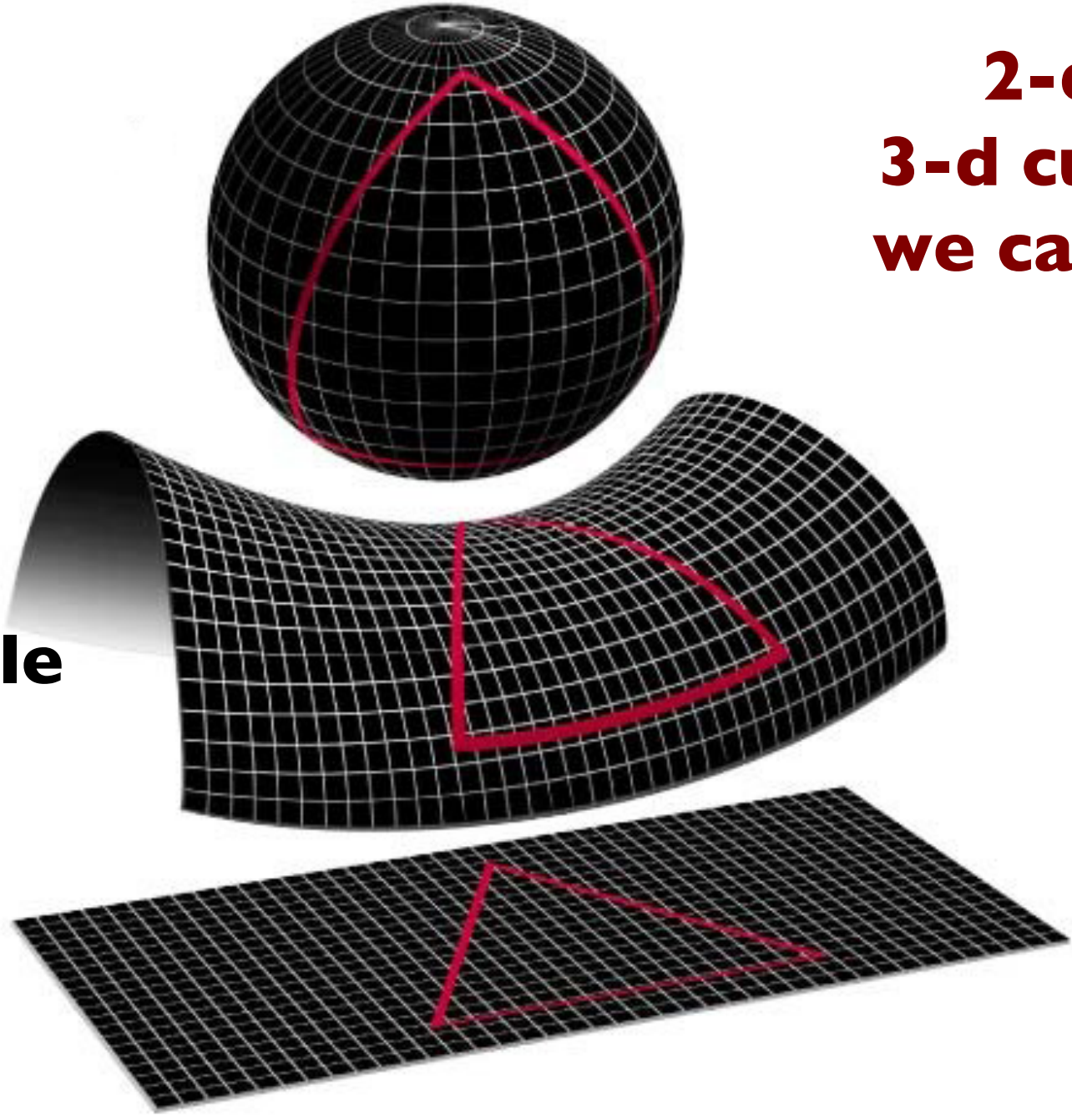
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\left(\begin{array}{c}\text{Curvature}\\ \text{of}\\ \text{space-time}\end{array}\right) = (\text{constant}) \times \left(\begin{array}{c}\text{Matter}\\ \&\\ \text{Energy}\end{array}\right)$$

Gravity = curvature of spacetime.



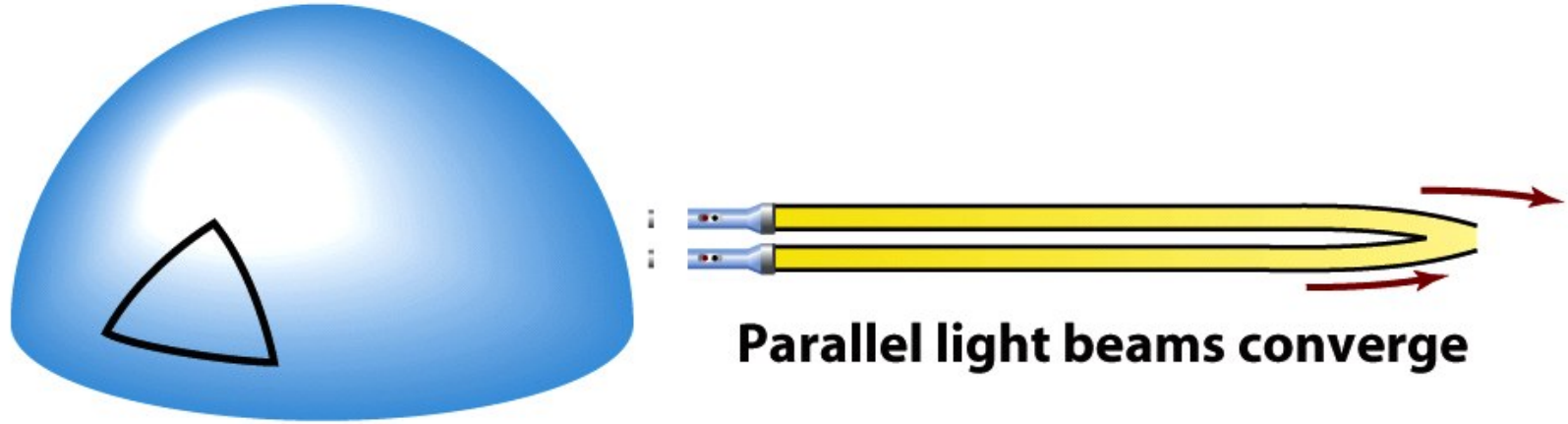
Gravity = curvature of spacetime.



2-d analogs for 3-d curved spaces we can't visualize.

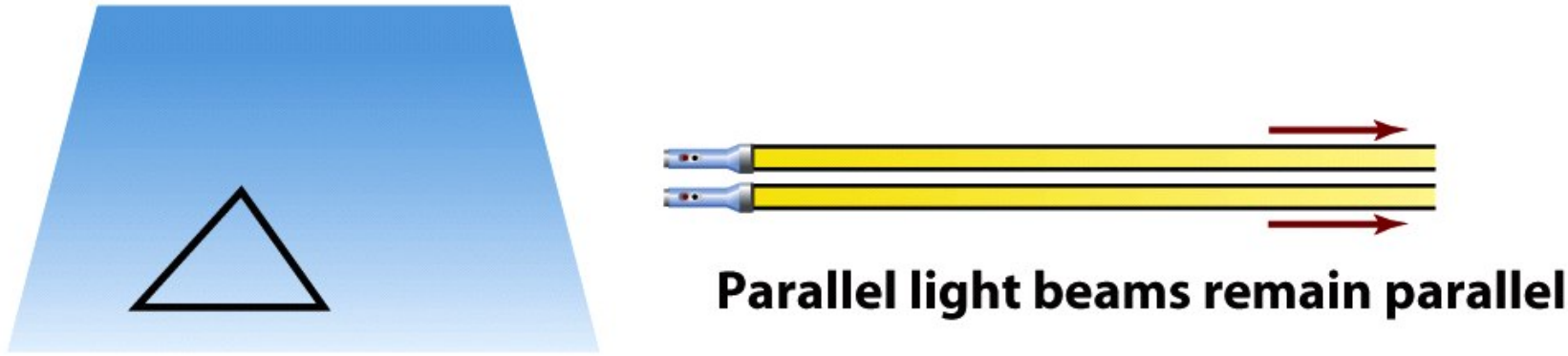
MAP990006

Geometry of the universe



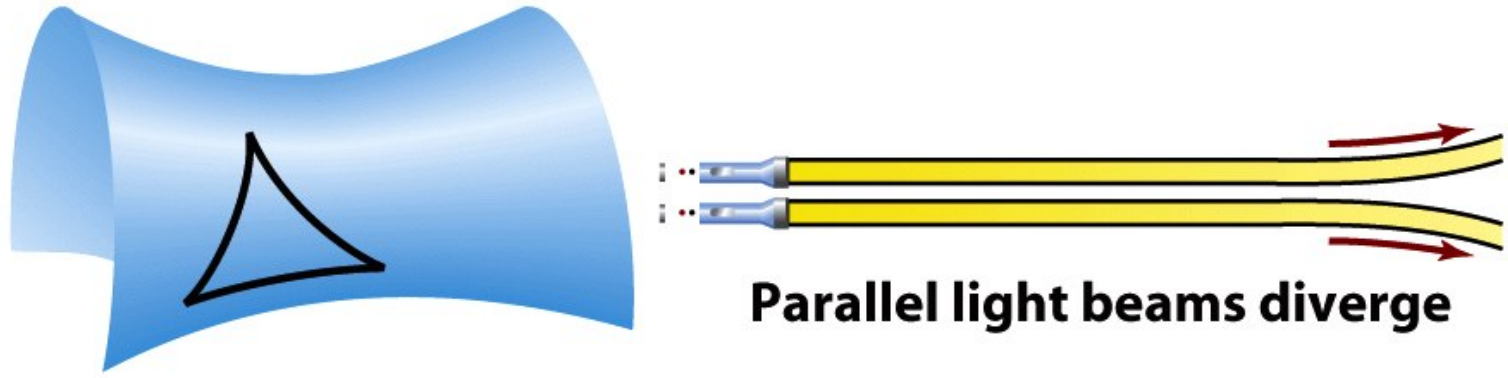
(a) Spherical space

$\rho_0 > \rho_c$, $\Omega_0 > 1$



(b) Flat space

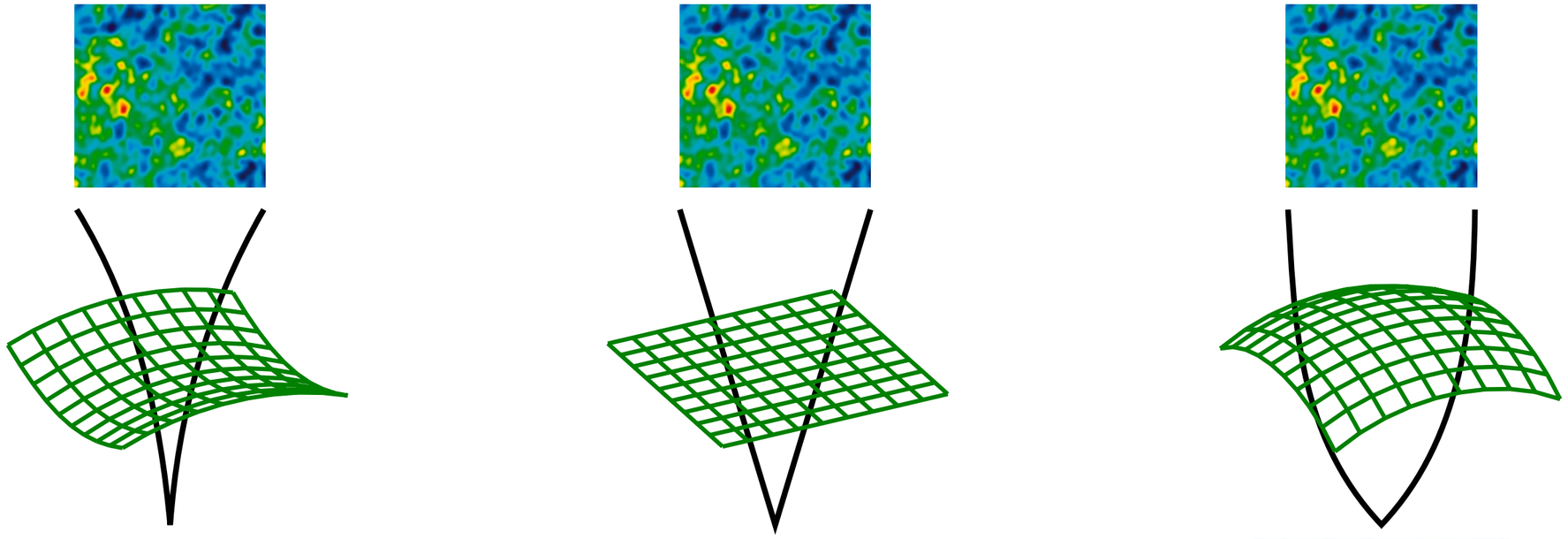
$\rho_0 = \rho_c$, $\Omega_0 = 1$



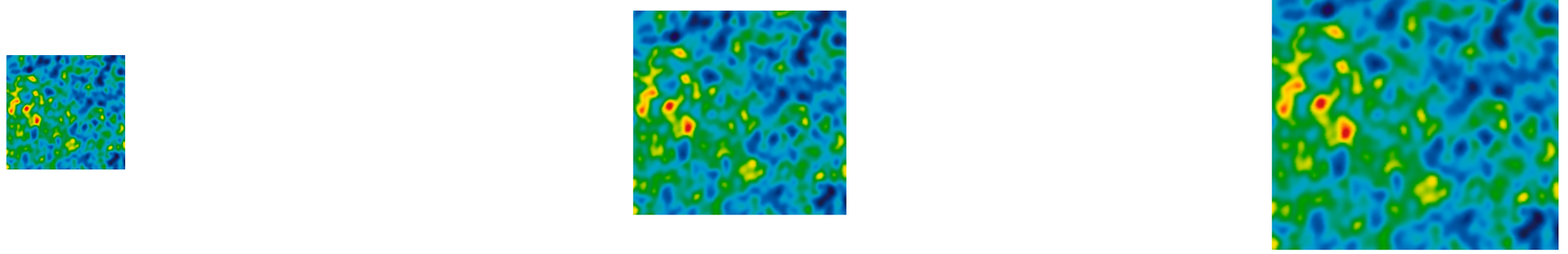
(c) Hyperbolic space

Measuring curvature

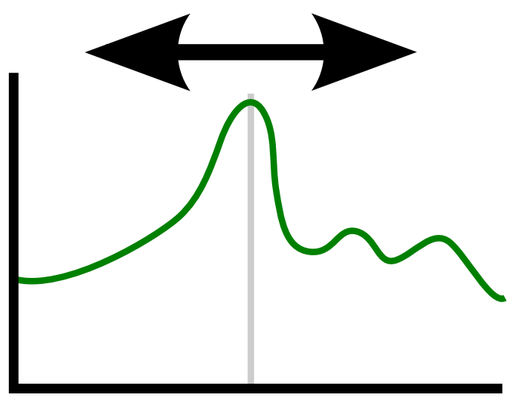
CMB surface



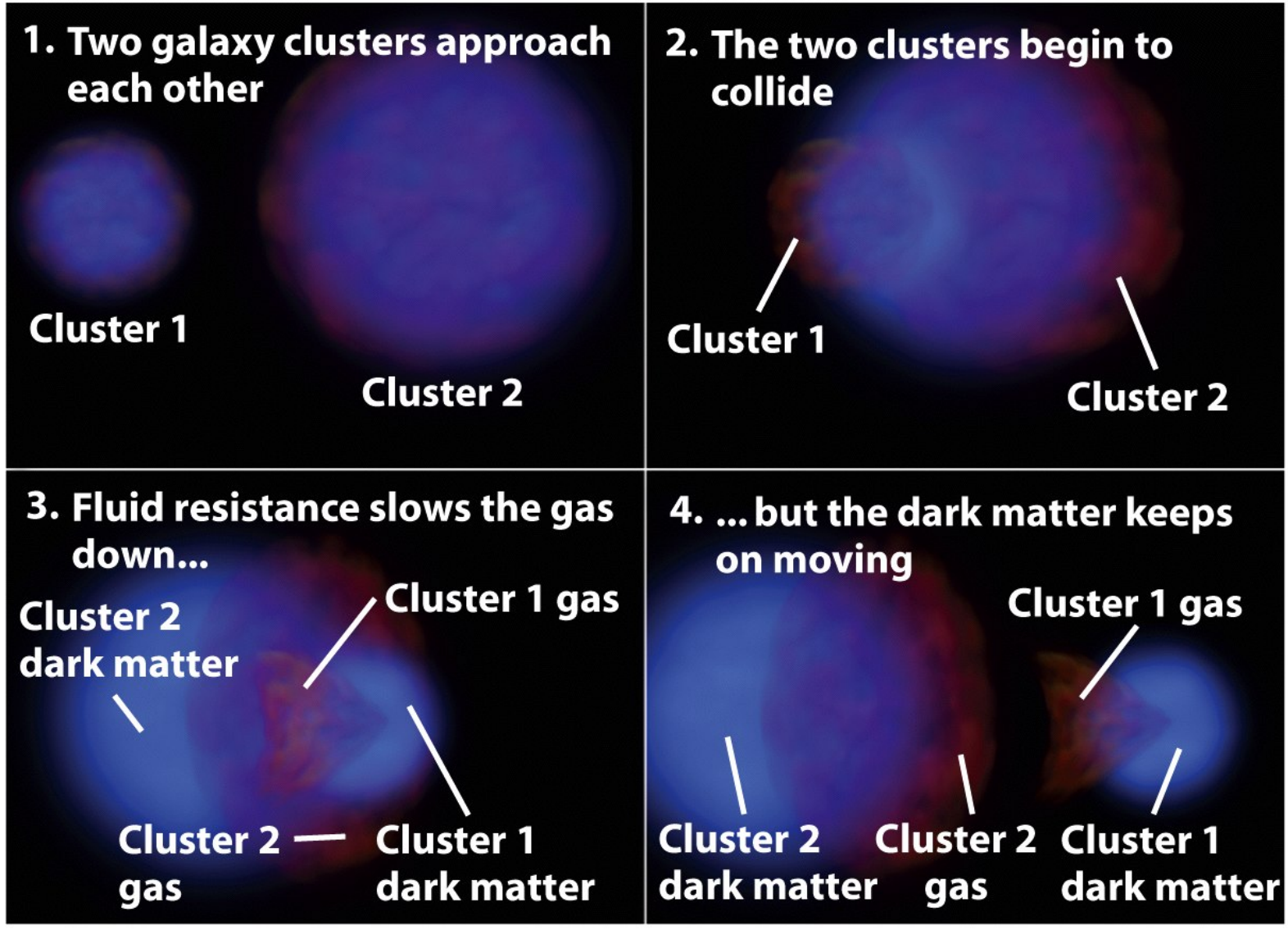
CMB observed



Viewing fixed sized object through curved spacetimes.



Bullet cluster model



A model of how the gas and dark matter in 1E0657-56 could have become separated

Figure 24-32b
Universe, Eighth Edition

ACT measurement of AS0592

ACT-CL J0638-5358, z=0.222
(AS0592)

Menanteau et al. (2010)
MOSAIC/Blanco
[-346 K,-749K]