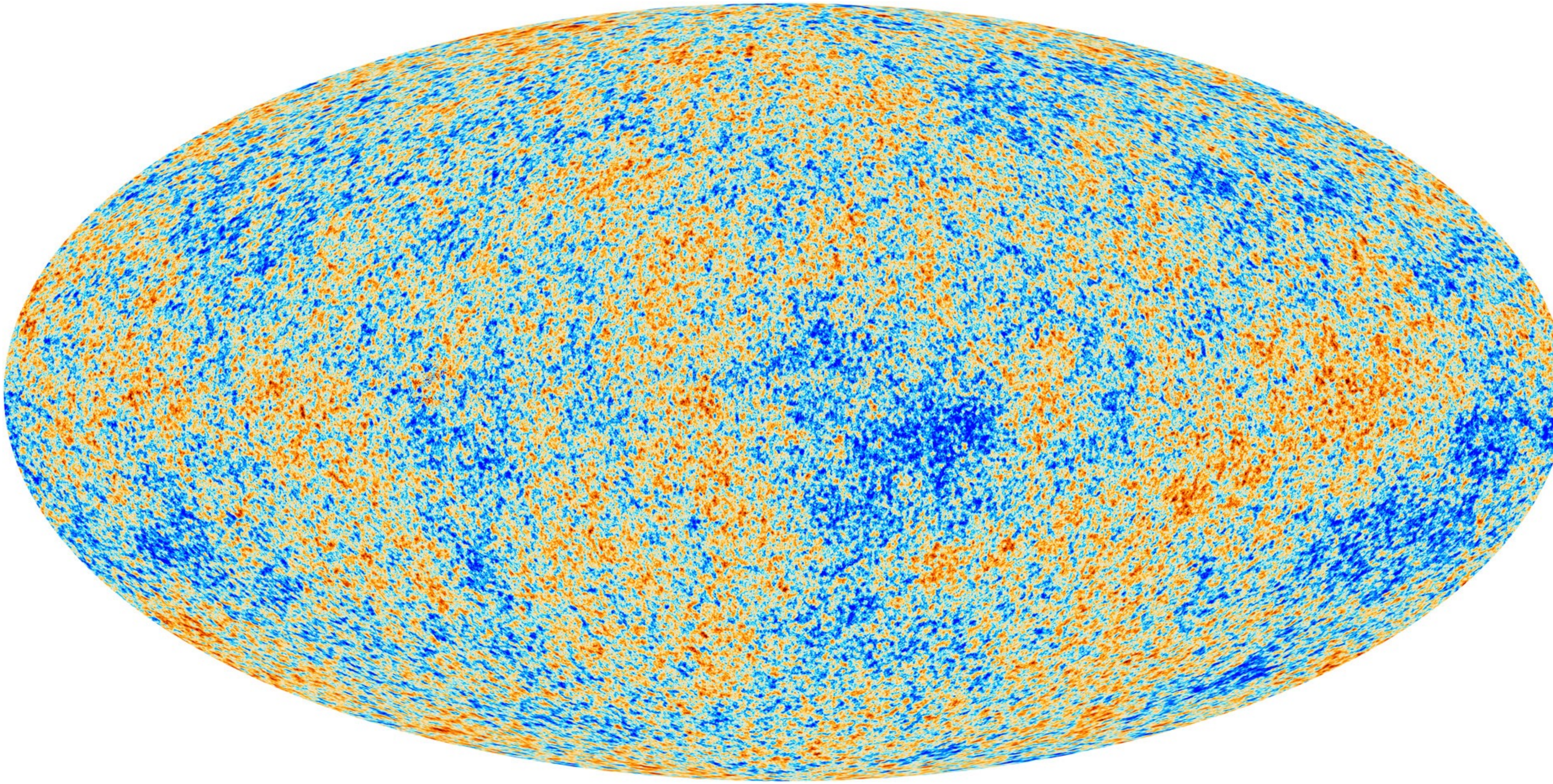
Fundamental Physics and the Cosmic Microwave Background

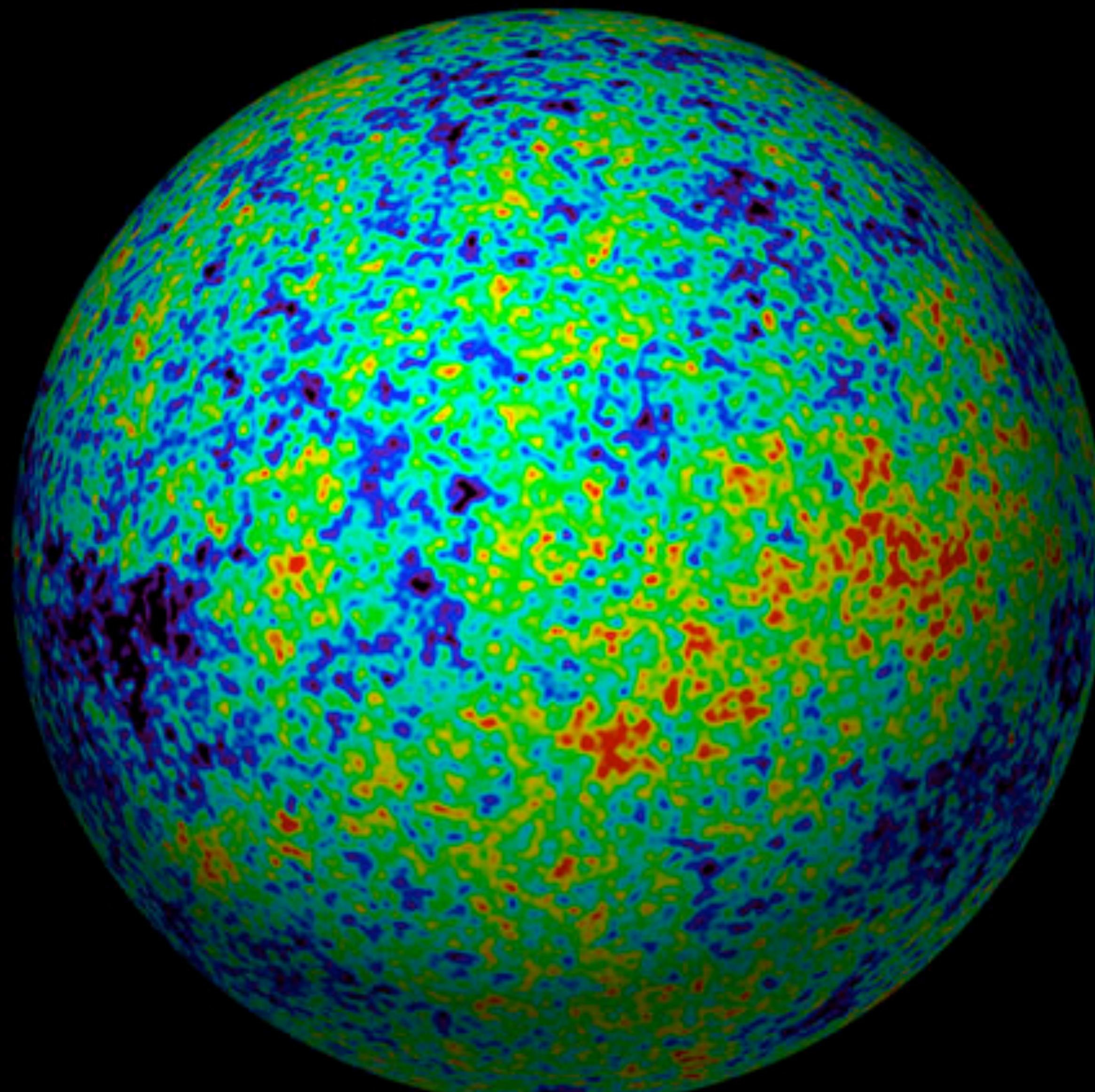
Arthur Kosowsky
University of Pittsburgh

I. Our Universe

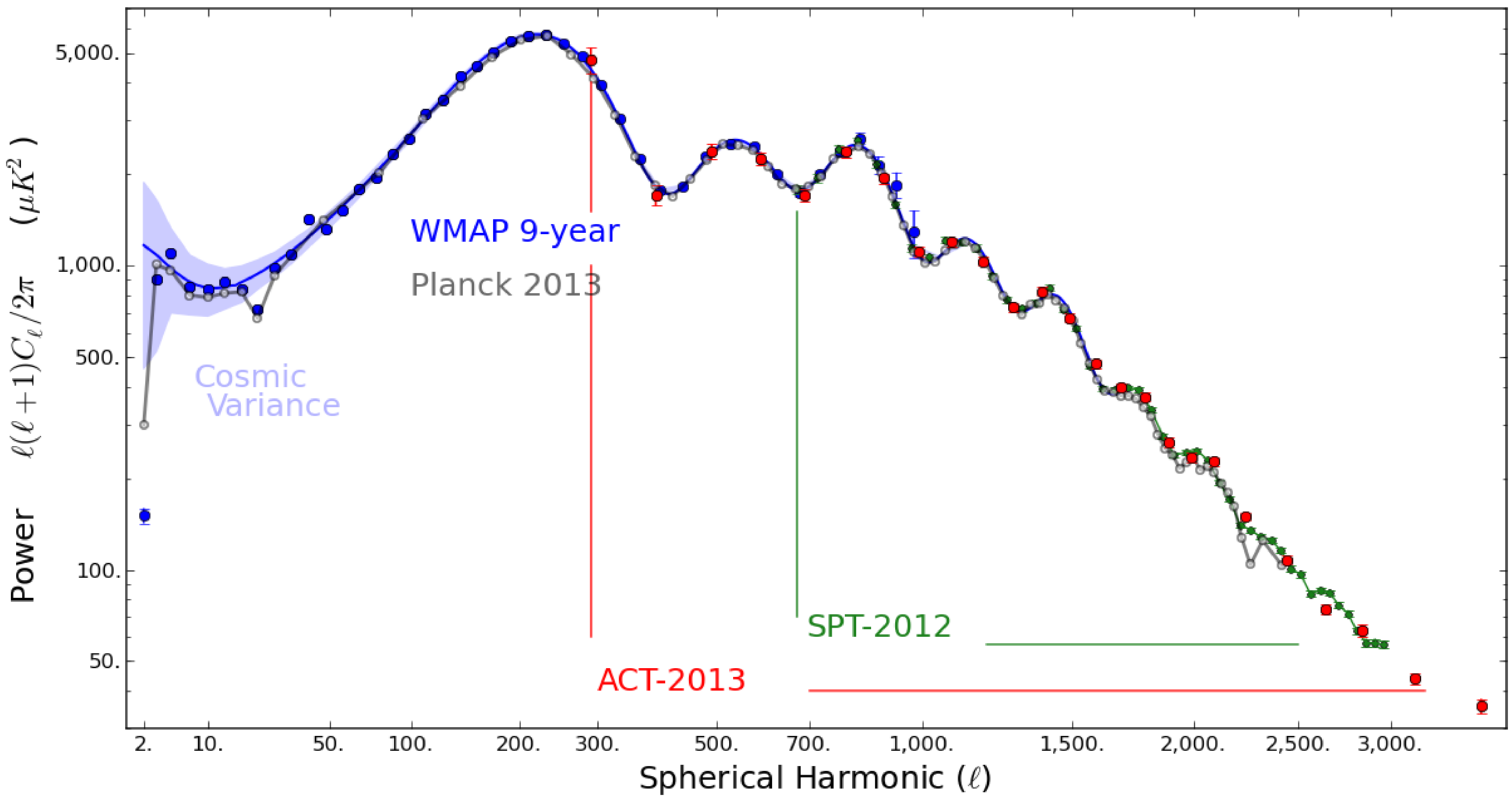


Planck 2013

Microwave background is mostly an image of density and velocity of primordial plasma in a spherical slice through the universe at age 370,000 years



Nearly the boundary of our Hubble volume



Compilation by M. Halpern

We live in a simple universe

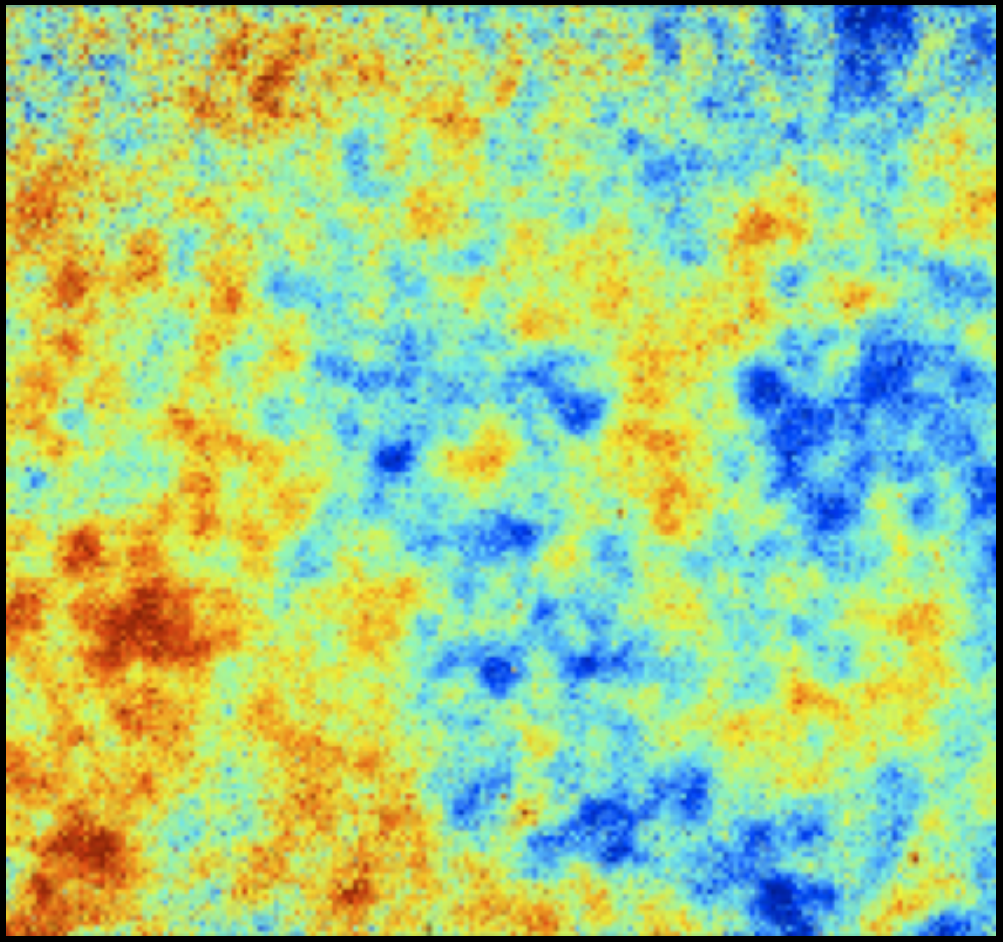
- Statistically isotropic (and homogeneous?)
- Spatially flat: parallel light rays stay parallel
- Ingredients: radiation, neutrinos, baryons, dark matter, dark energy
- Initial adiabatic perturbations: same fractional perturbation in all components
- Power law power spectrum: nearly the same potential perturbation amplitude (at horizon crossing) on all scales
- Structure grows via gravity alone

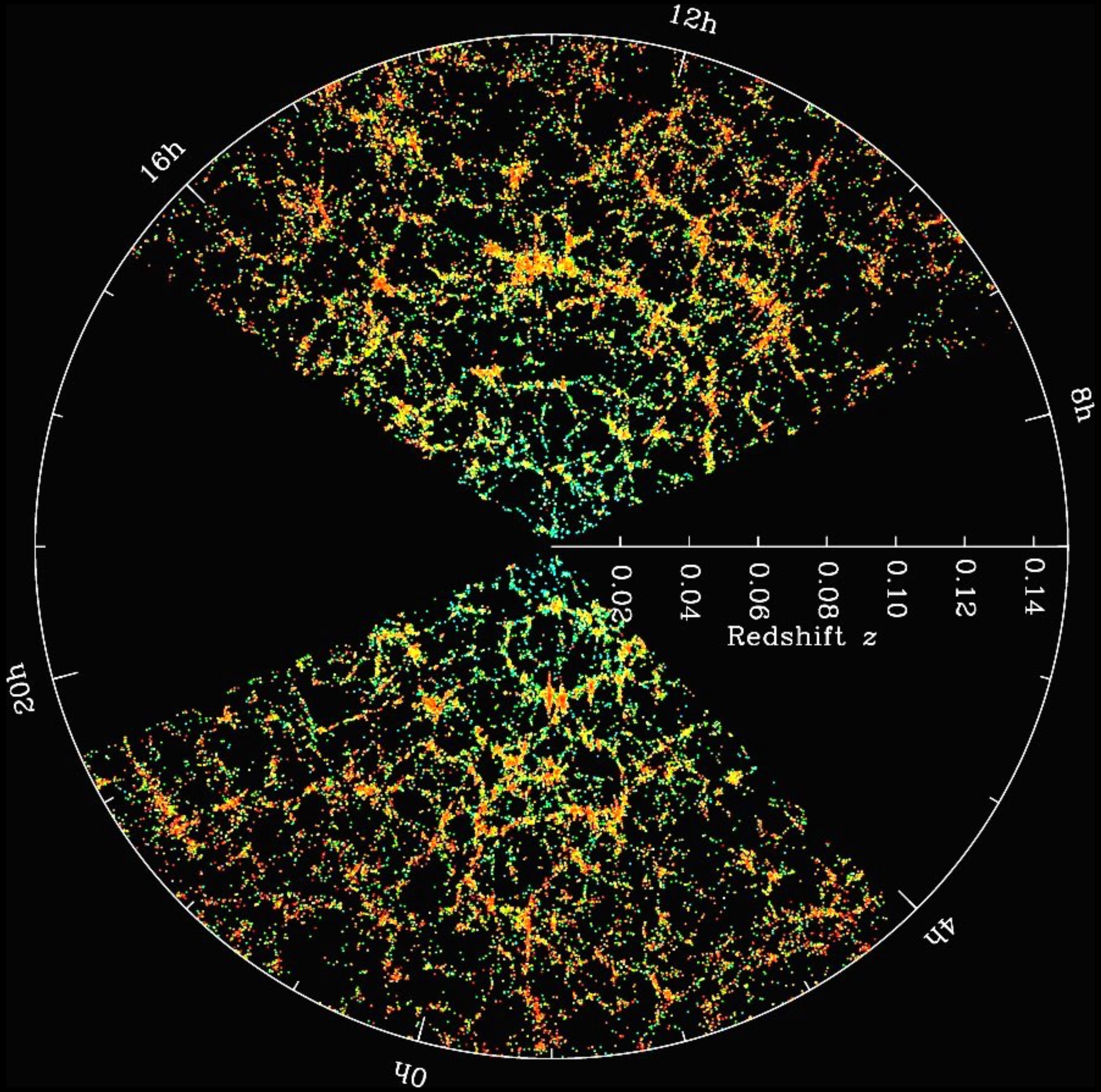
Strongly Constrained:

- NO cosmic strings or defects creating observed structure
- NO explosions creating observed structure
- NO substantial injections of energy during cosmic evolution
- NO significant spatial curvature
- NO nontrivial topology smaller than the Hubble volume
- NO features in primordial perturbation spectrum
- NO evidence for primordial nongaussian perturbations
- NO additional relativistic particles beyond 3 neutrinos

2. Very High Energy Physics

Early-universe inflation is the correct *effective* theory of the observable universe



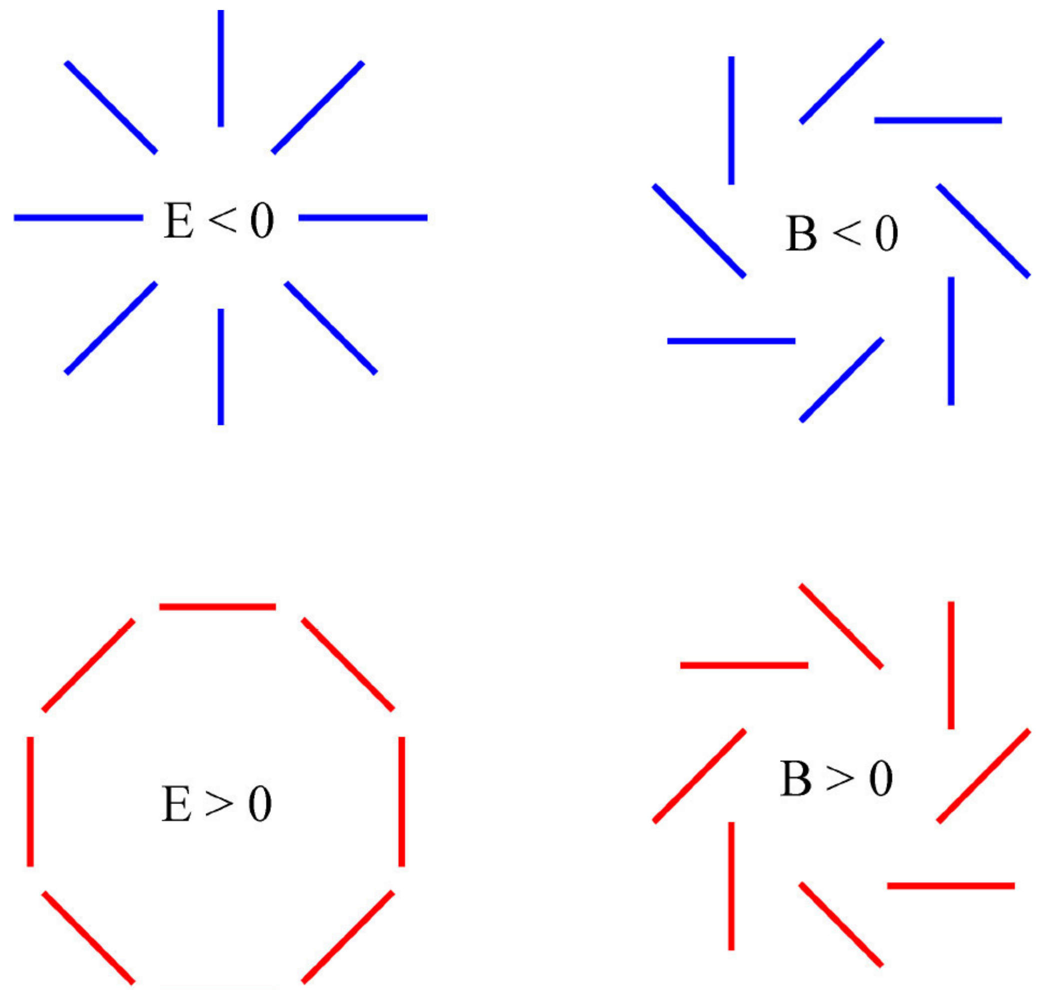


The Inflation Paradigm

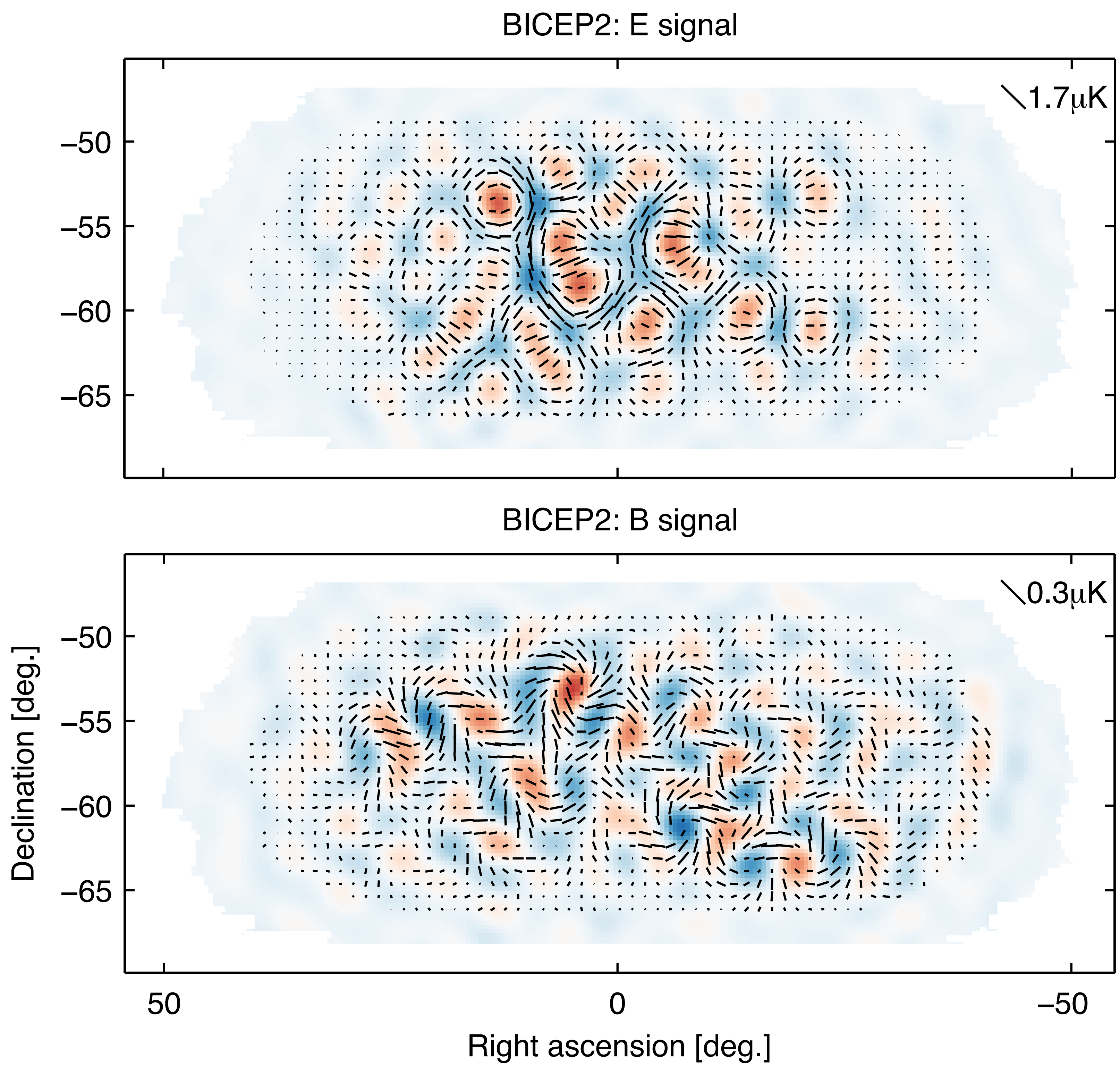
- Exponential expansion during initial 10^{-35} seconds
- Energy scale: 0.01 x Planck energy
- At least e^{60} expansion factor
- Quantum fluctuations seed primordial gaussian density perturbations
- Power spectrum $P(k) = Ak^{n}$, $n < 1$

Did this really happen?

Polarization: The New Frontier



Geometric decomposition: density perturbations make only E-mode

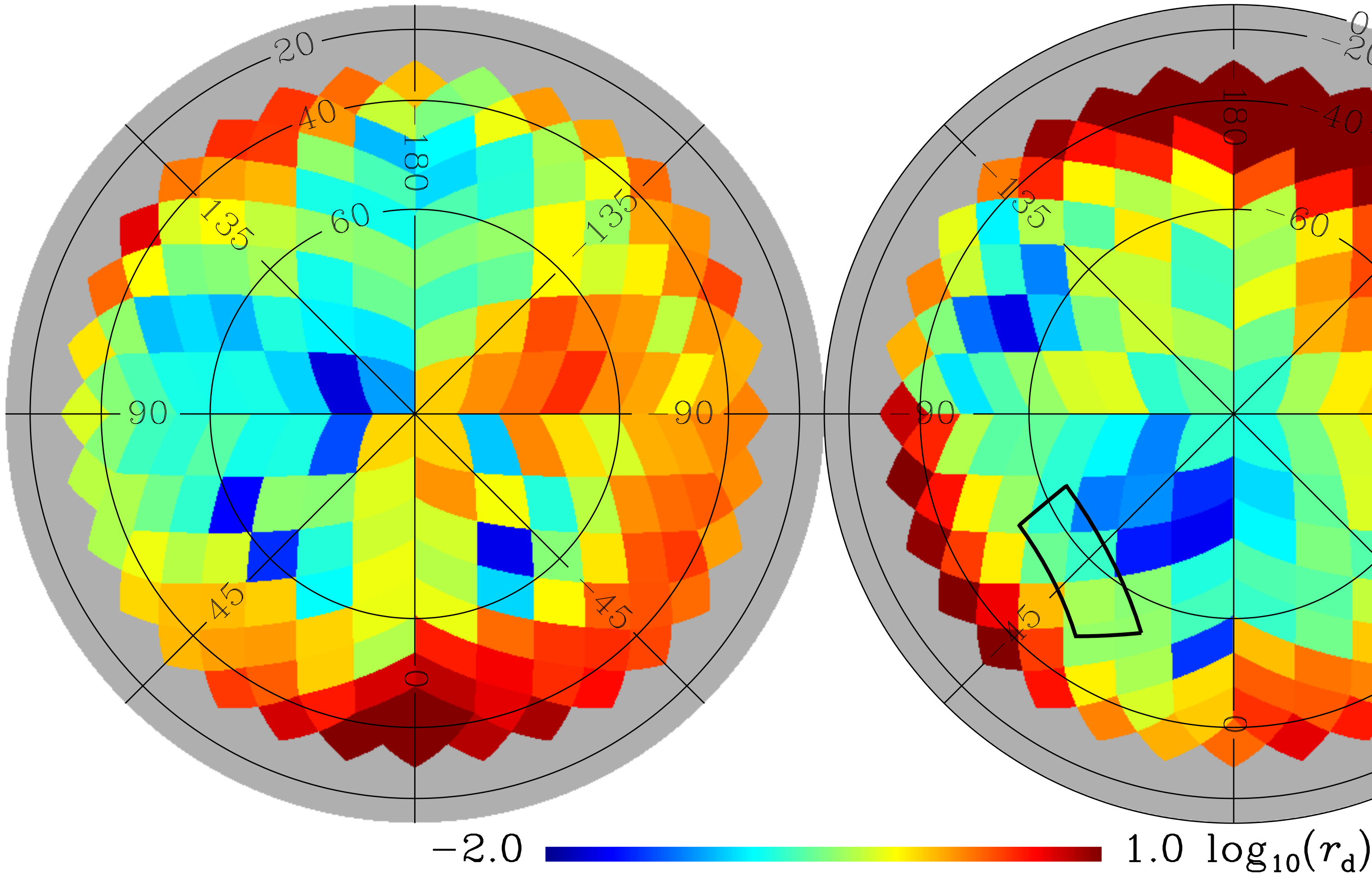


5 parts in 10^7
of mean intensity

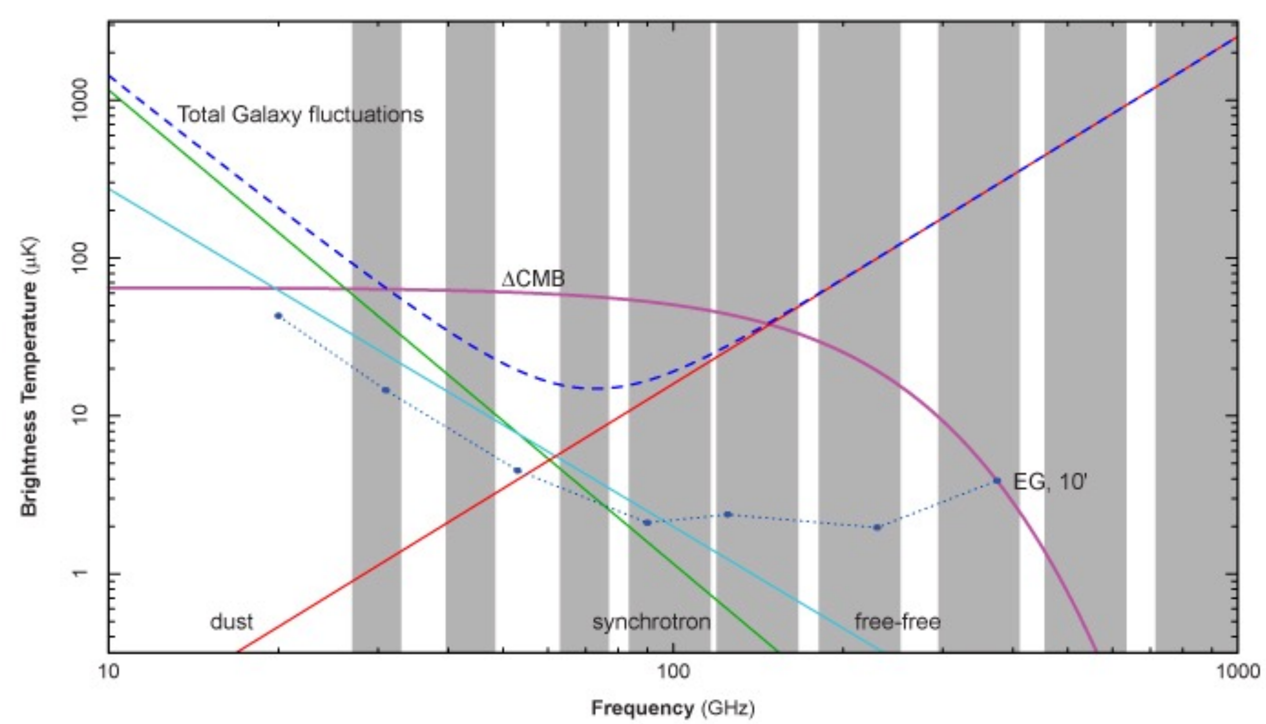
1 part in 10^7
of mean intensity

BICEP2 Collaboration, 2014

Planck Collaboration: Dust polarization at high latitudes



Planck Collaboration 2014



The Chase is On for Inflation B-mode Polarization

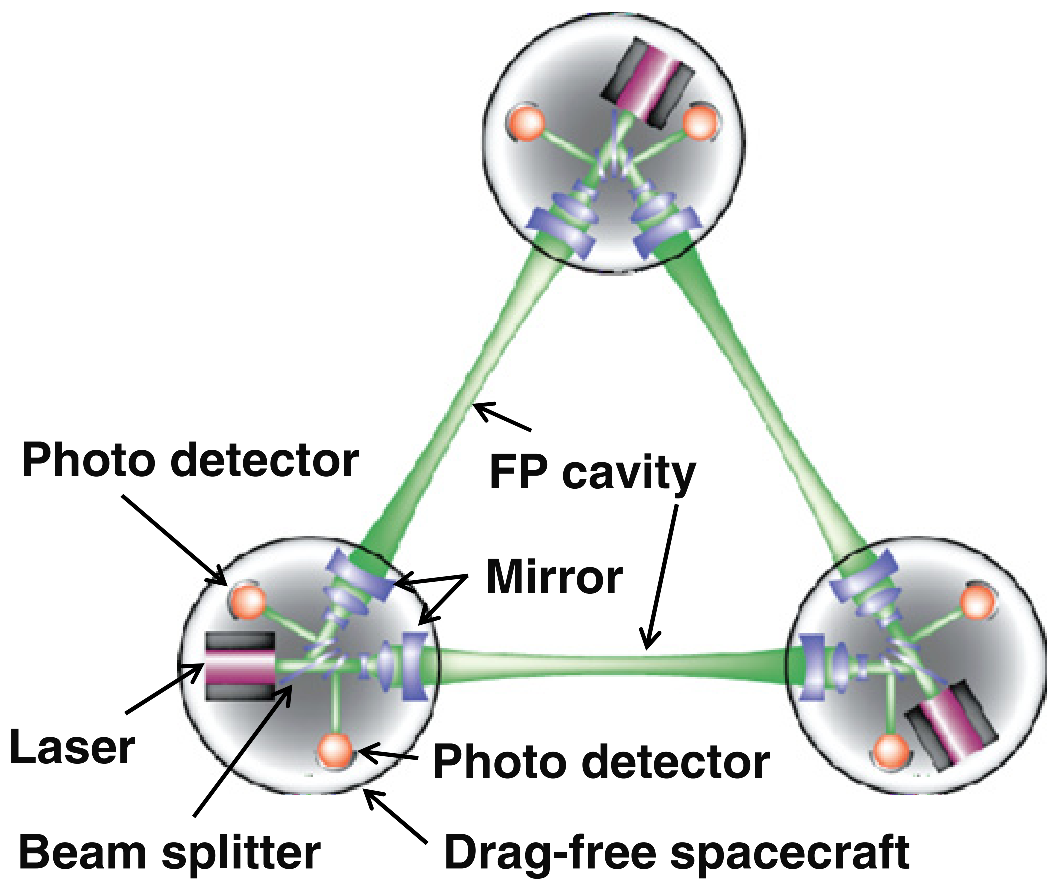
Ground: BICEP3, POLARBEAR, CLASS, ACT, SPT

Balloon: SPIDER, EBEX

Satellite Proposals: PIXIE (NASA), CORE (ESA), LITEBIRD (JAXA)

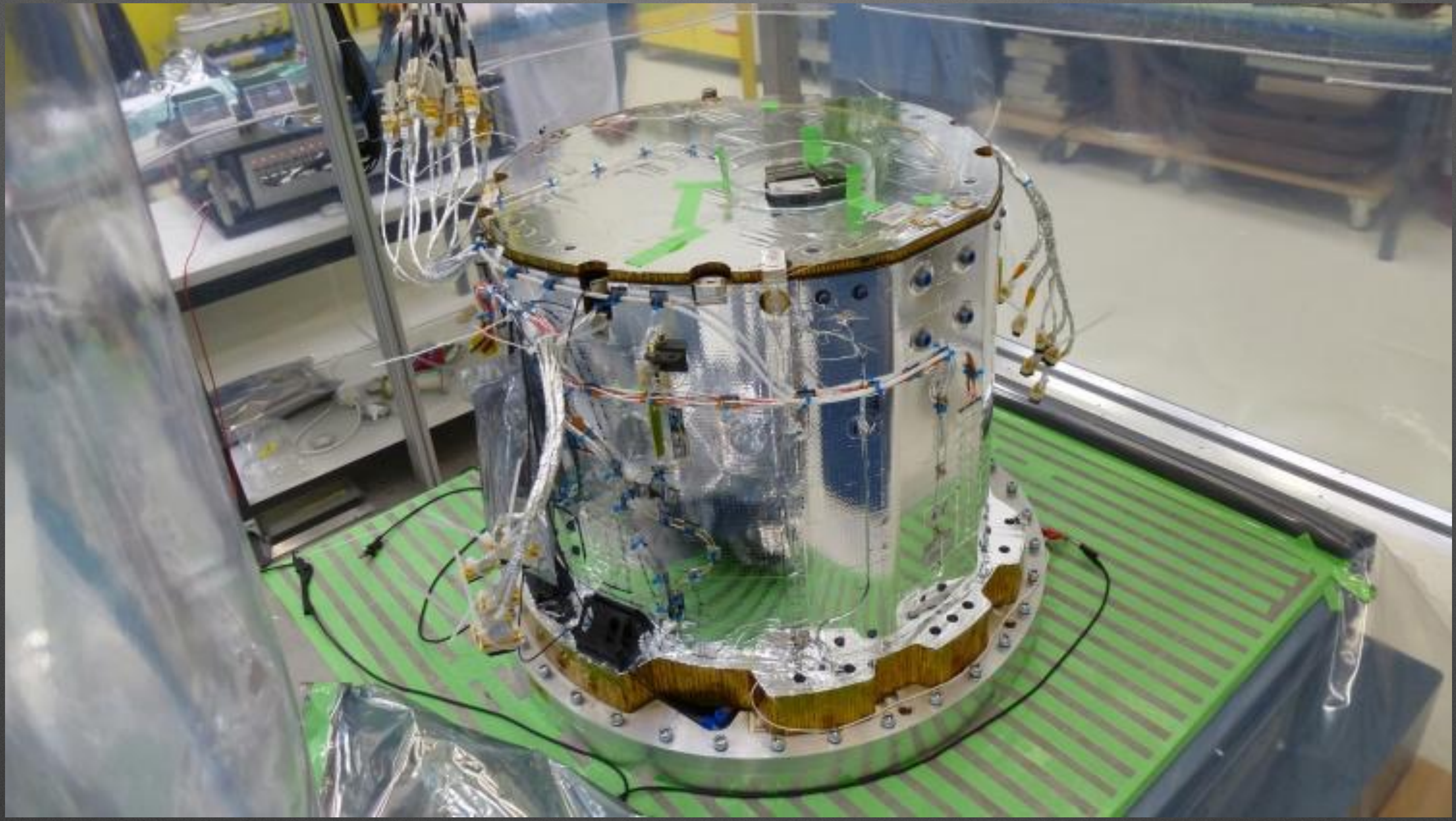
If tensor signal detected in B-mode polarization, inflation predicts it should exist at solar system wavelengths

Potentially observable at frequencies above 0.1 Hz ?

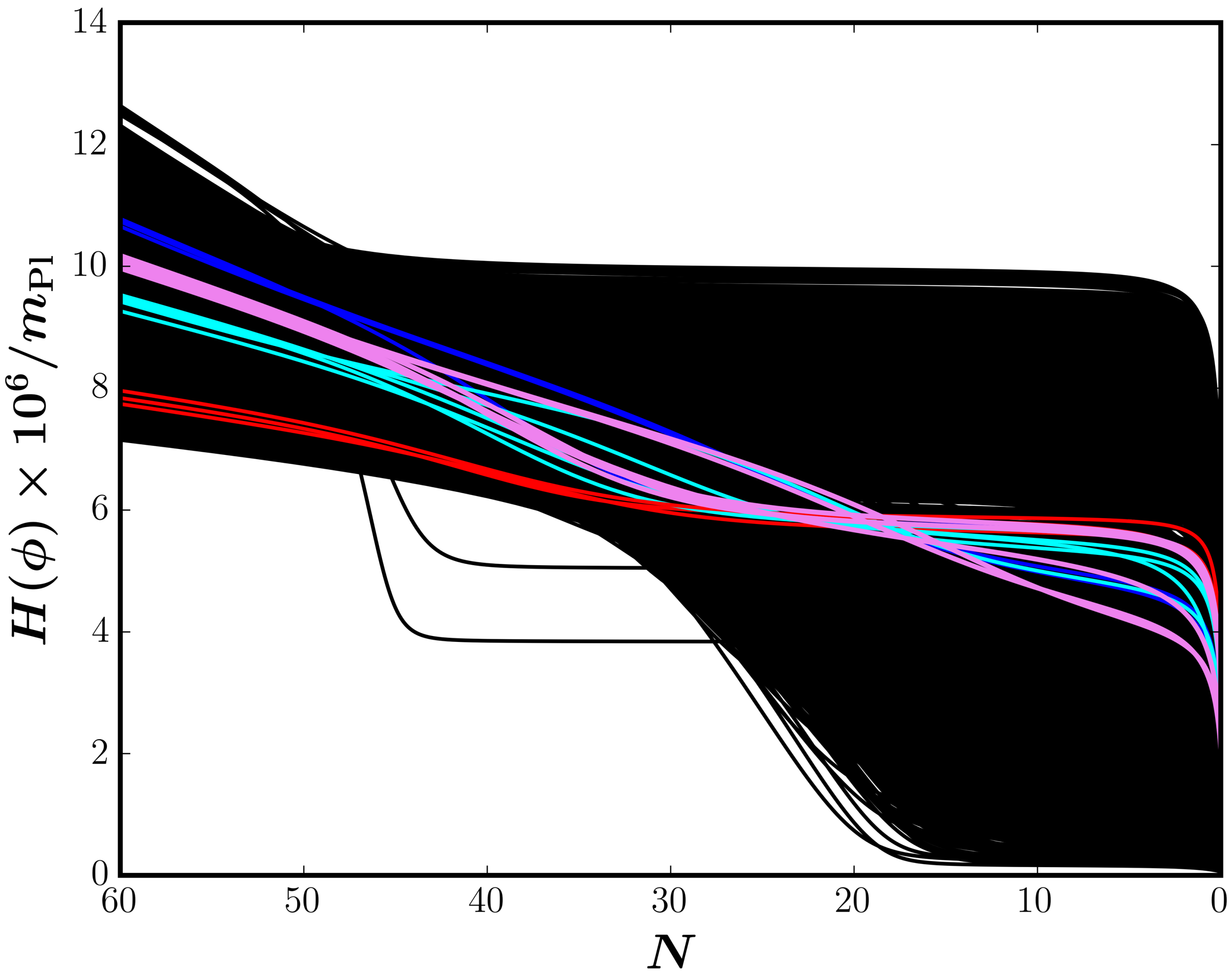


DECIGO concept,
JAXA

Fabry-Perot
Michelson interferometer
Arm length 1000 km

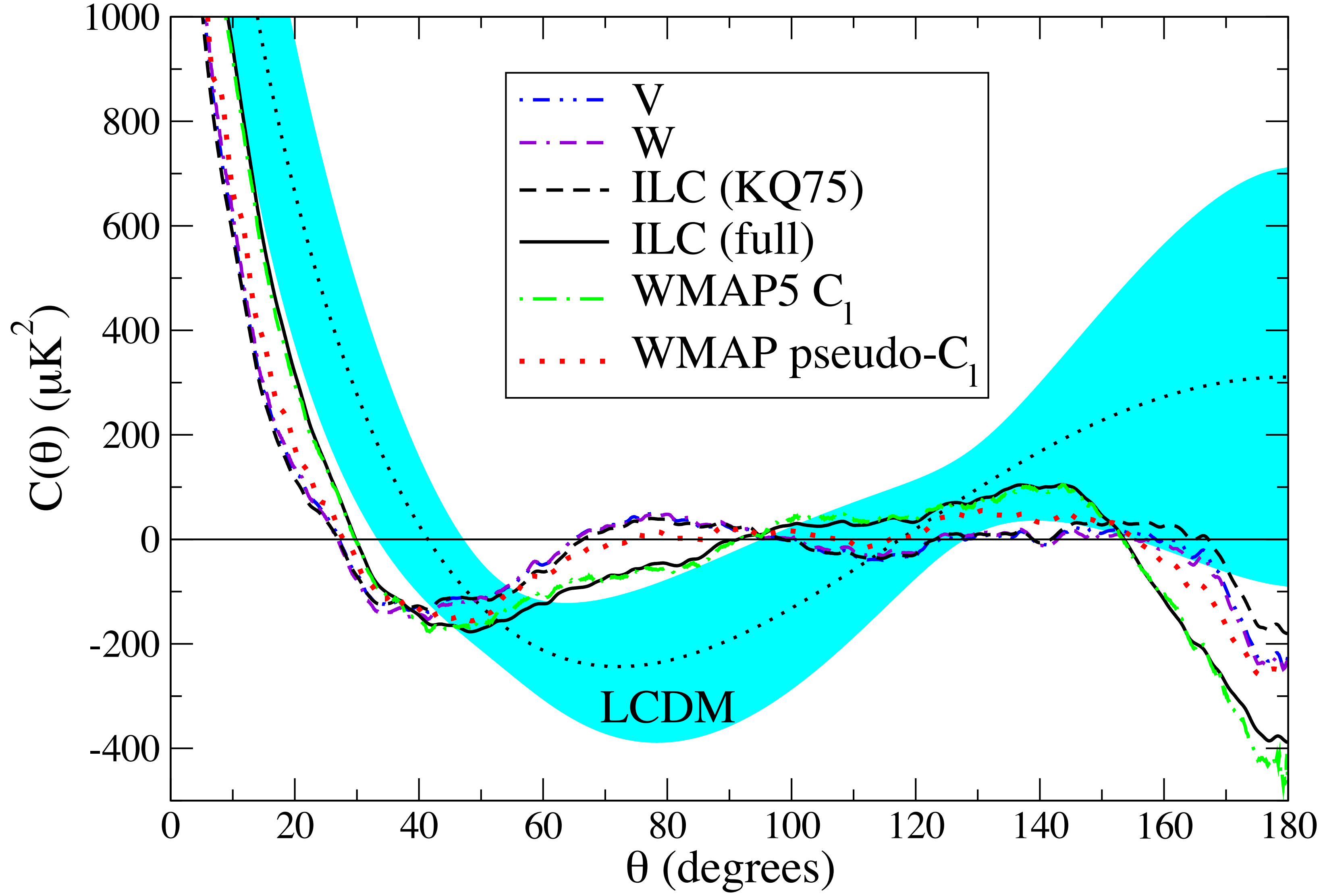


LISA Pathfinder mission: ESA launch 2015



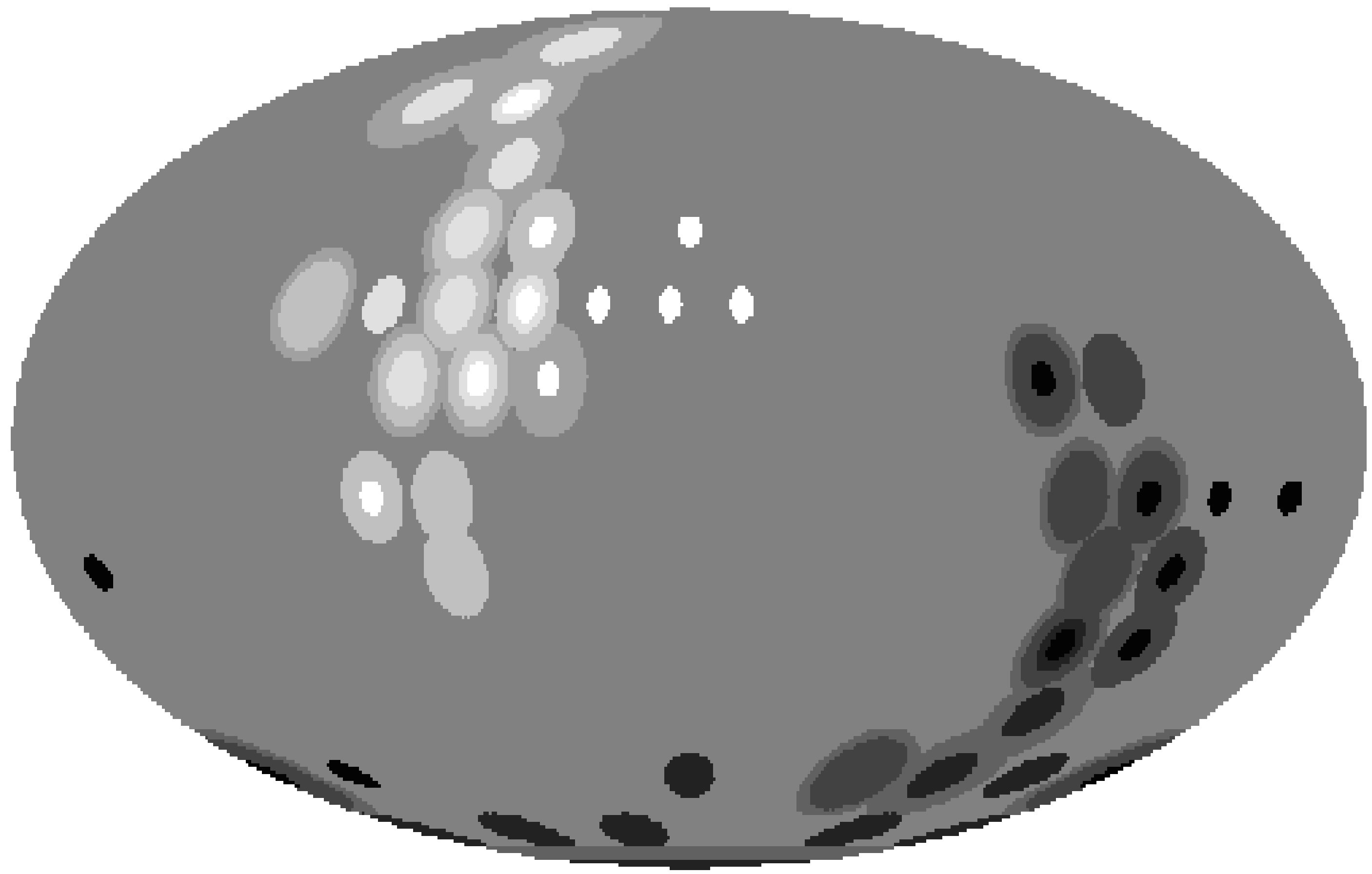
Determine expansion history during inflation ?

J. Caligiuri et al. 2015



Copi, Huterer, Schwarz and Starkman 2009

Lack of correlations in the microwave sky at large angles: few parts in 10^4 chance in standard inflation



Hansen, Banday, and Gorski 2004

Half of the sky has 6% larger fluctuations than the other half, between 2 and 3 sigma significance

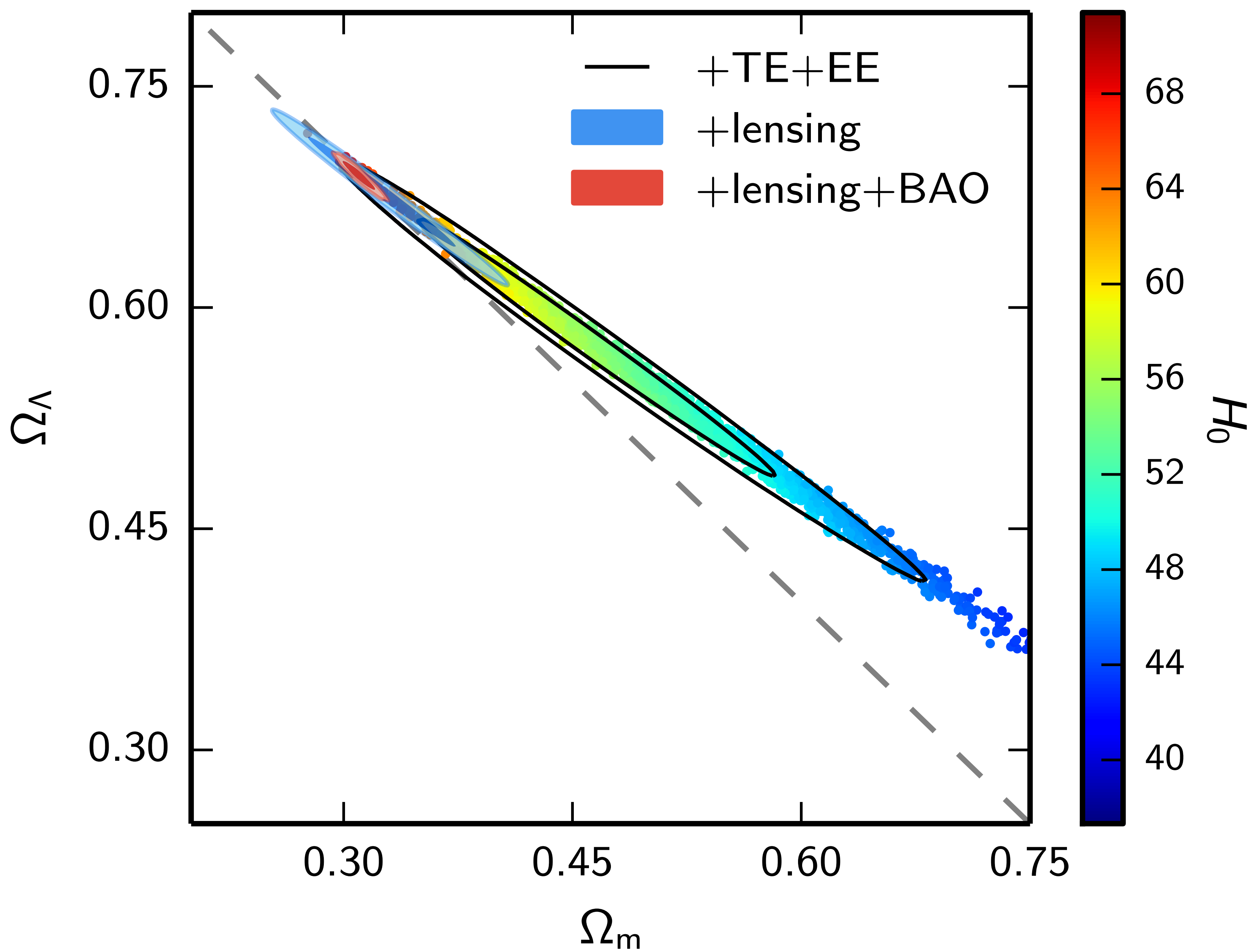
Polarization sky gives mostly independent sampling of primordial perturbations at last scattering

A. Yoho, S. Aiola et al. 2015;
S. Aiola, B. Wang, and A. Kosowsky in preparation 2015

New physics at inflation scale?

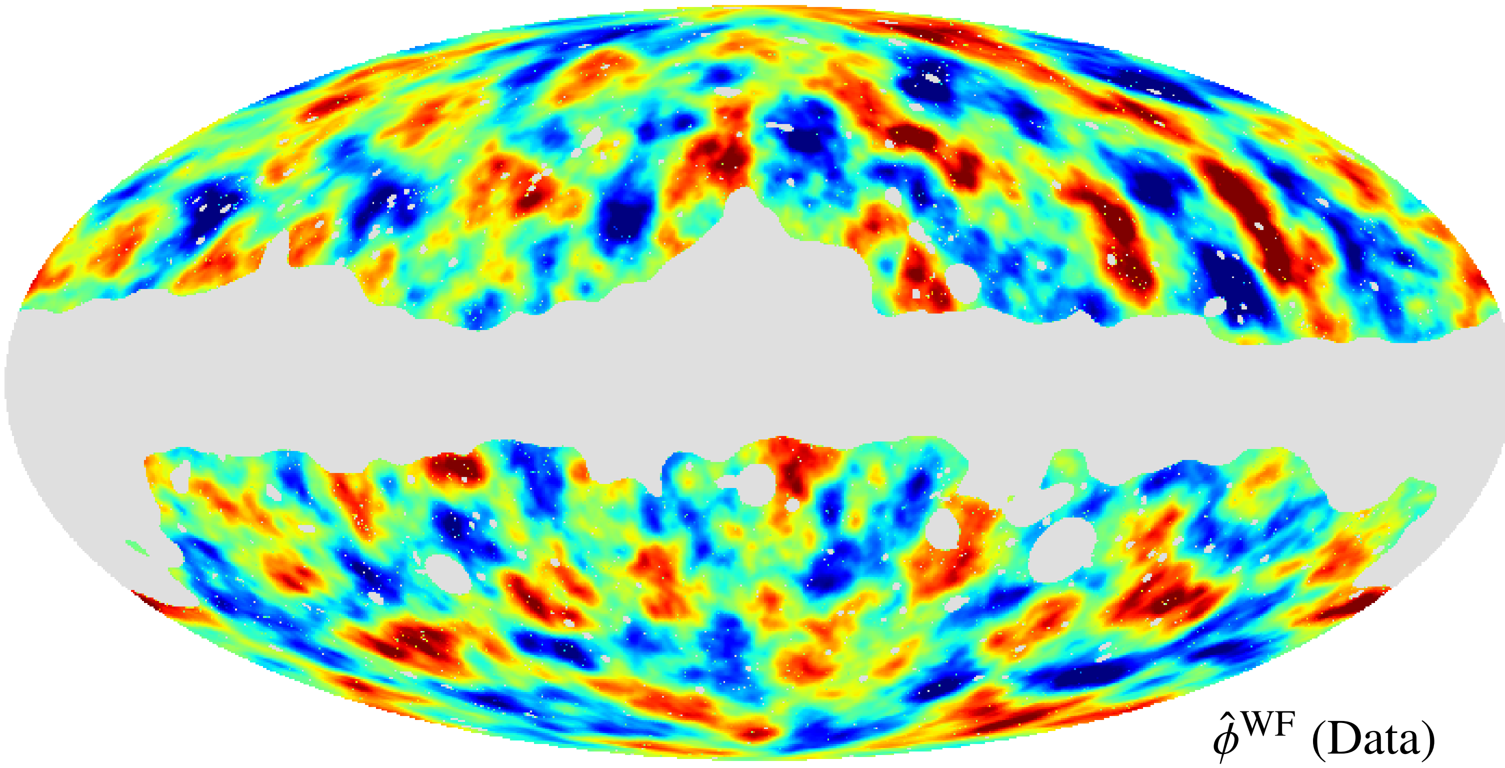
3. Low Energy Physics

Dark Energy from microwave background alone: power spectrum plus gravitational lensing



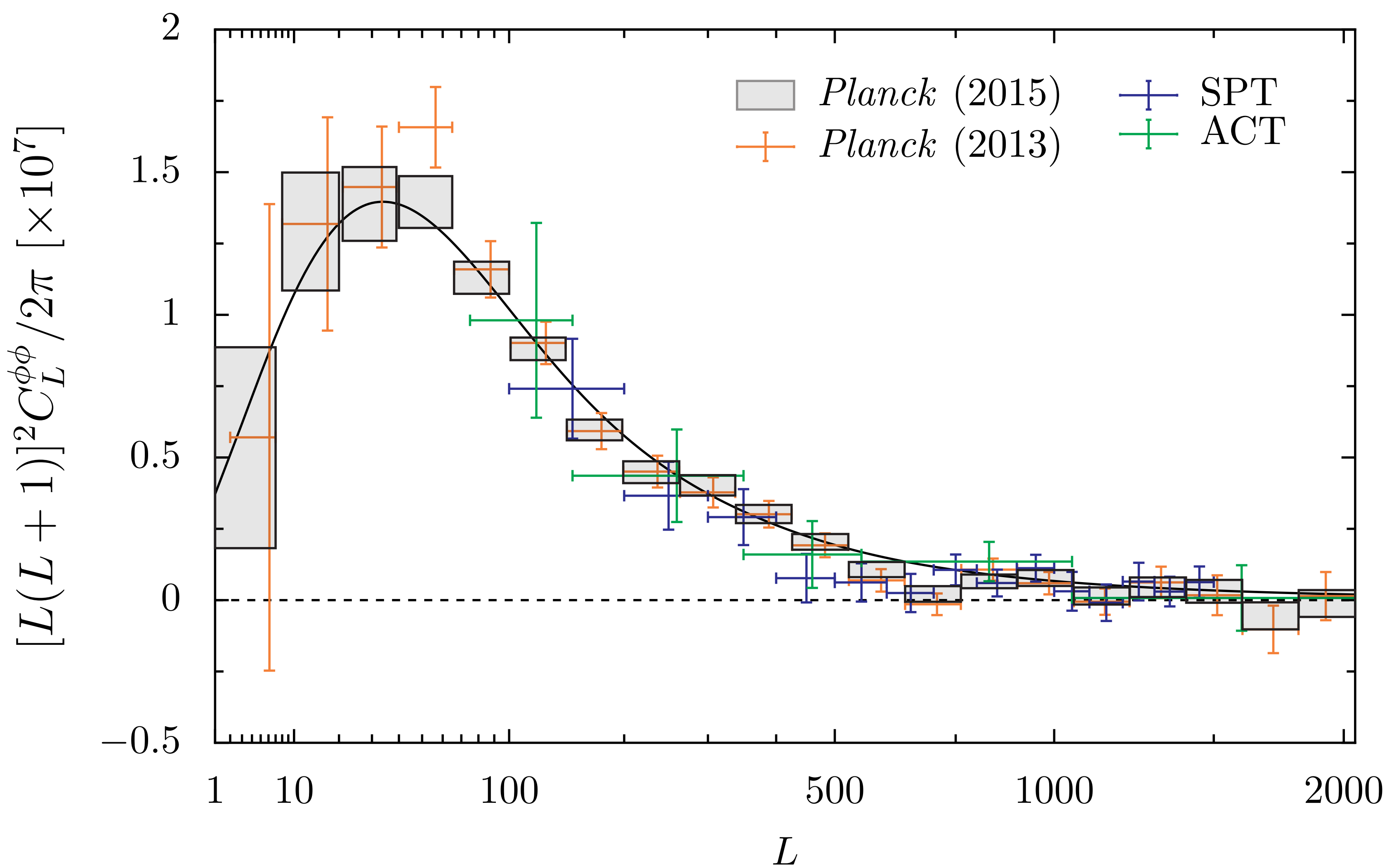
B. Sherwin et al. 2011 (ACT)
van Engelen et al. 2012 (SPT)
Planck XVI 2013
Planck XIII 2015

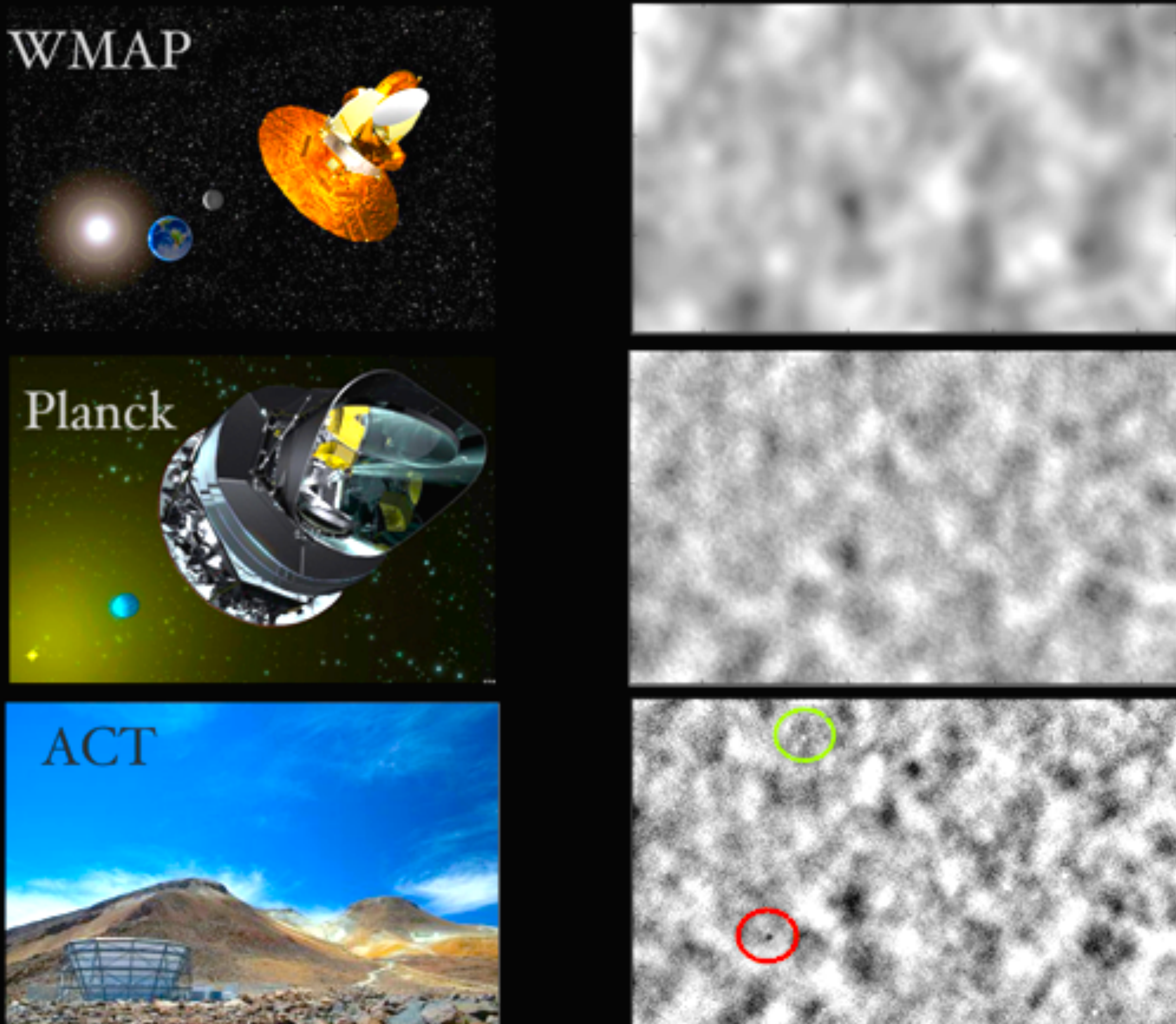
What is dark energy? Test with structure growth



Gravitational lensing probes growth of gravitational potential

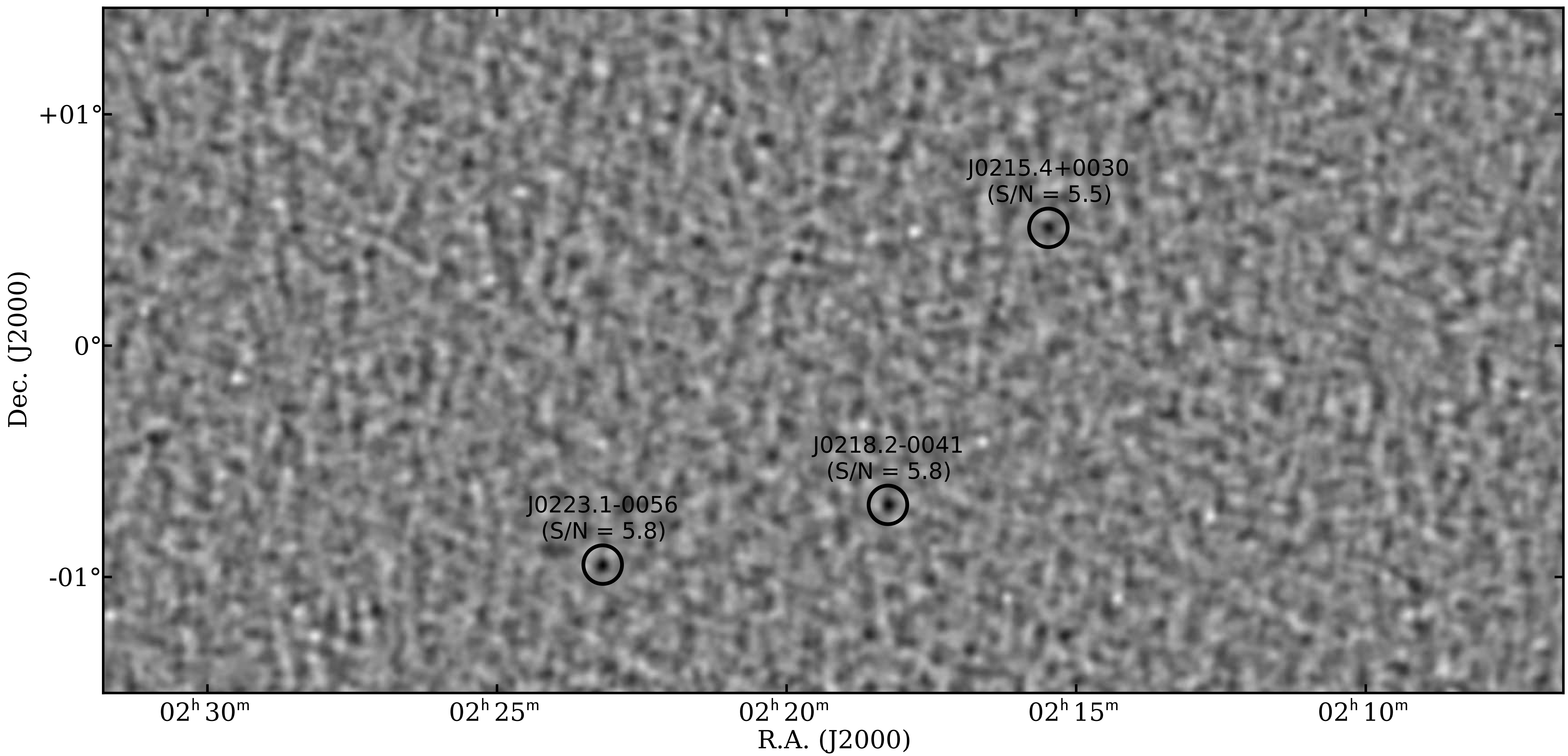
Planck XV 2015





Amir Hajian for ACT

Galaxy Cluster Growth: tSZ

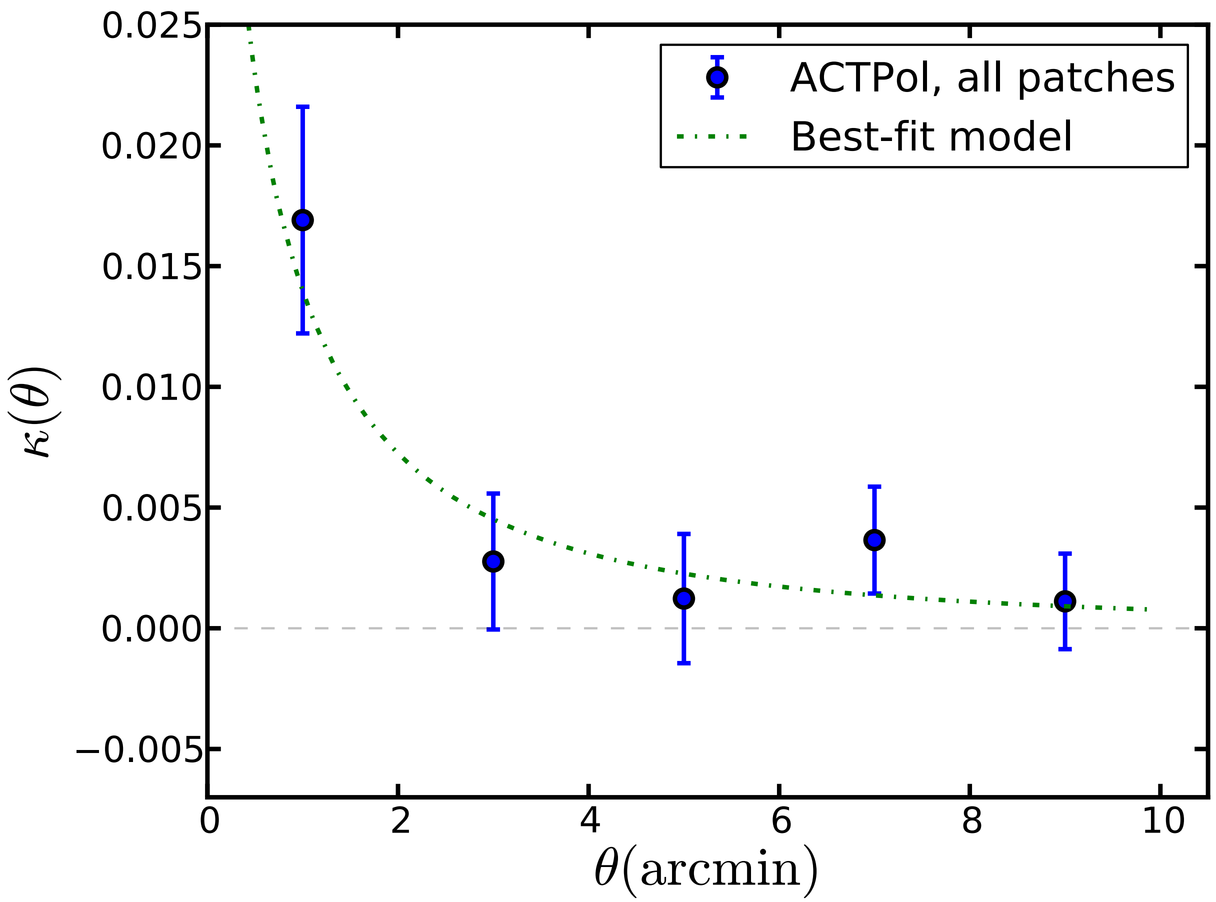


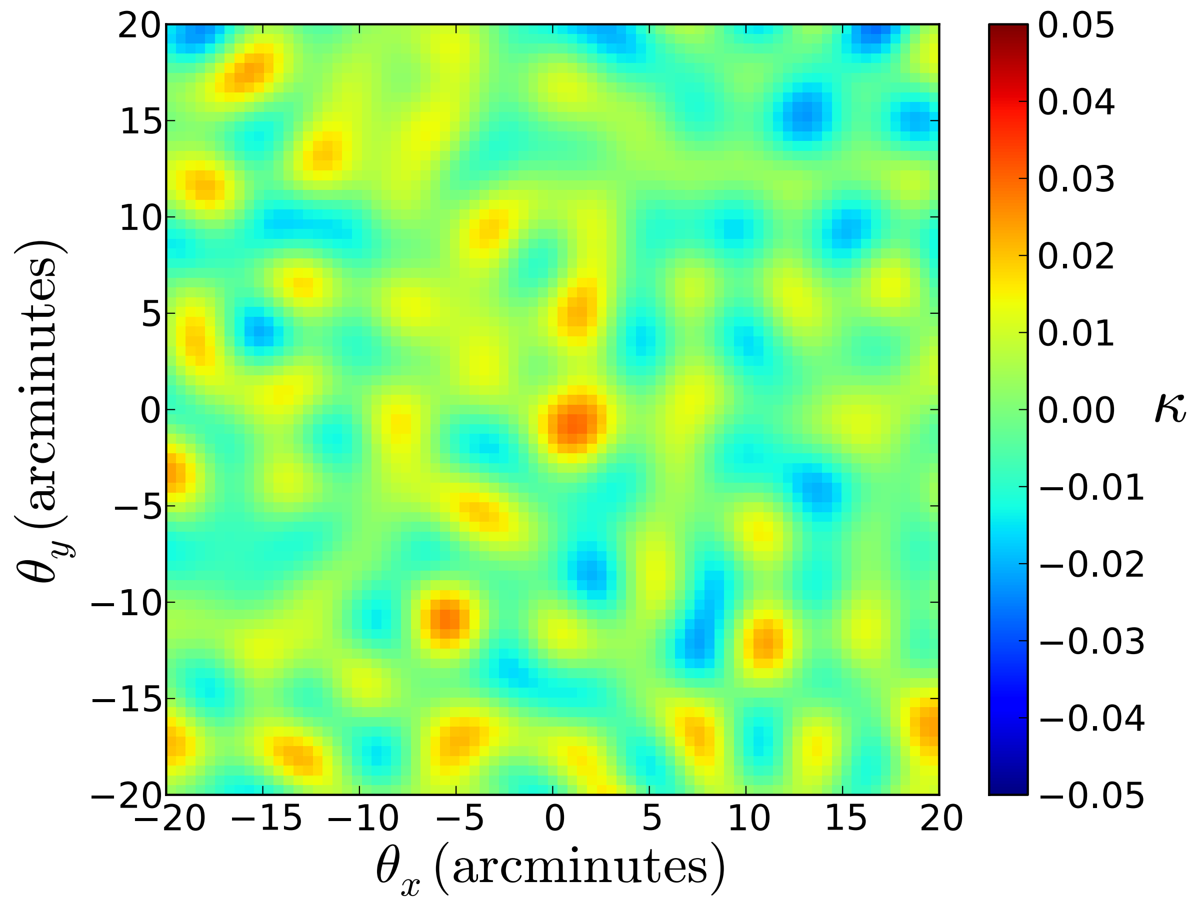
Hasselfield et al. 2013

SPT: Bleem et al. 2015: 409 clusters with S/N > 5

Planck XXIV 2015: 439 clusters with S/N > 6

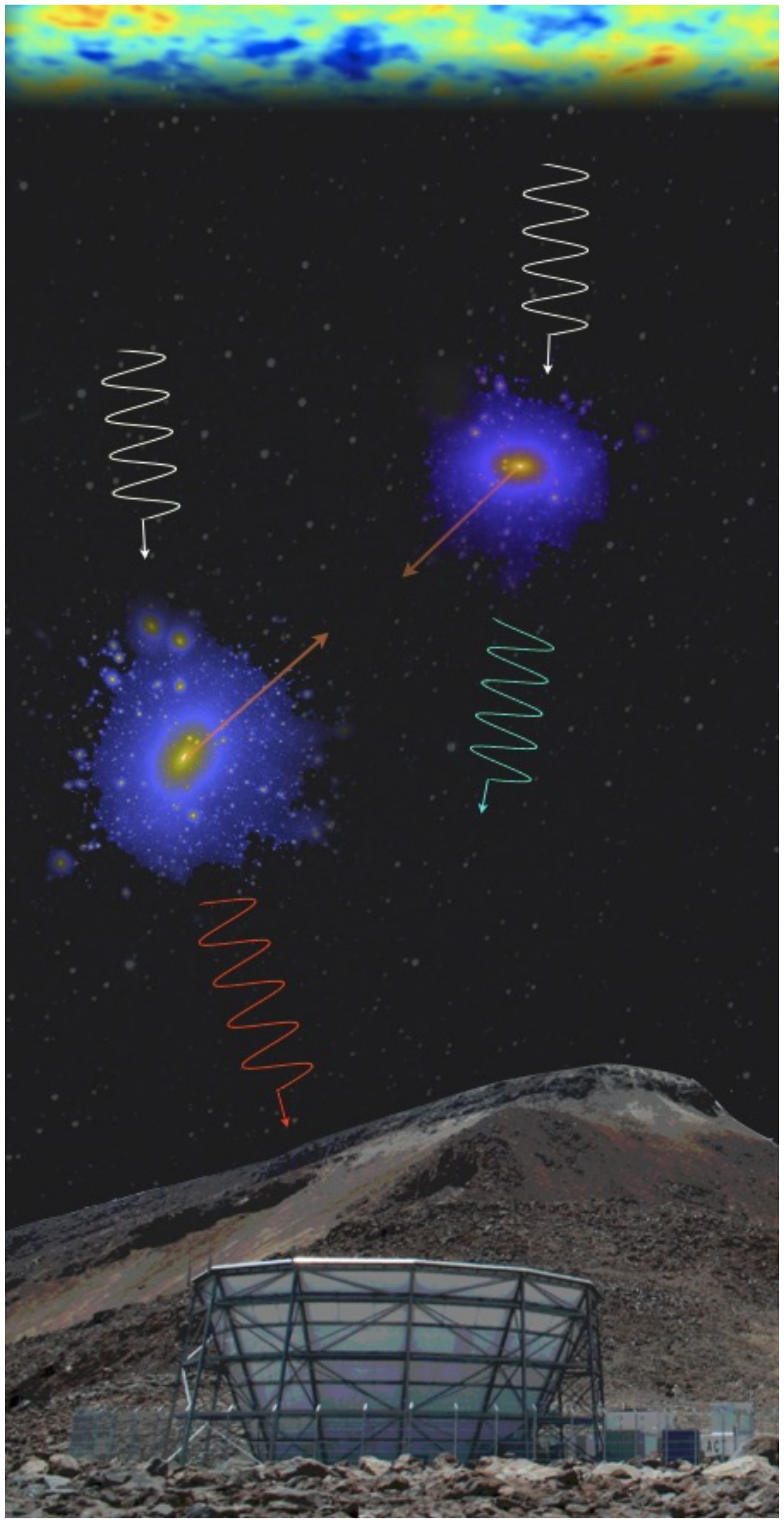
Mean Cluster Masses from Gravitational Lensing

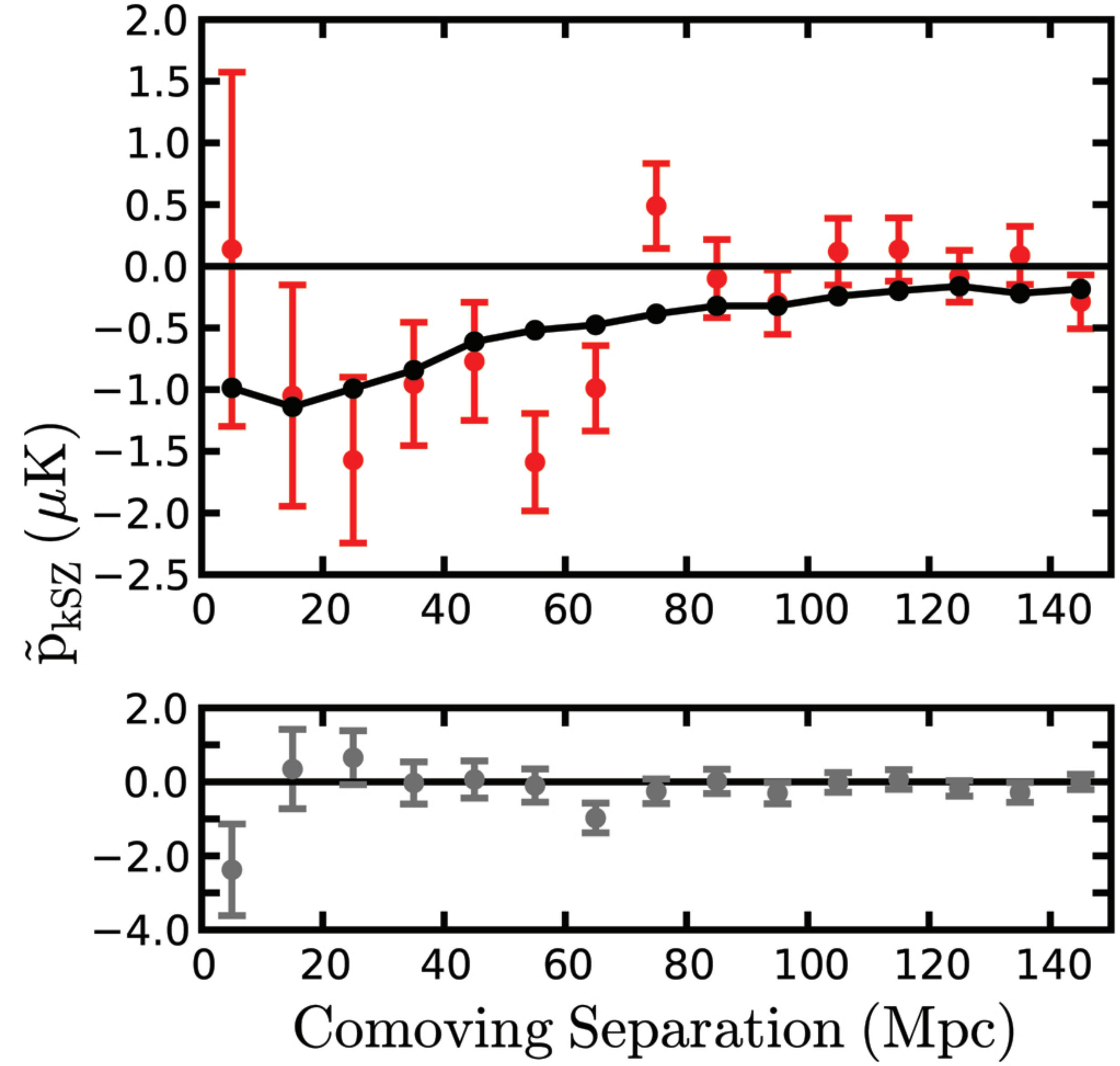




Madhavacheril et al. 2015 (ACT)
Baxter et al. 2015 (SPT)

Evidence for Galaxy Cluster Motions: kSZ



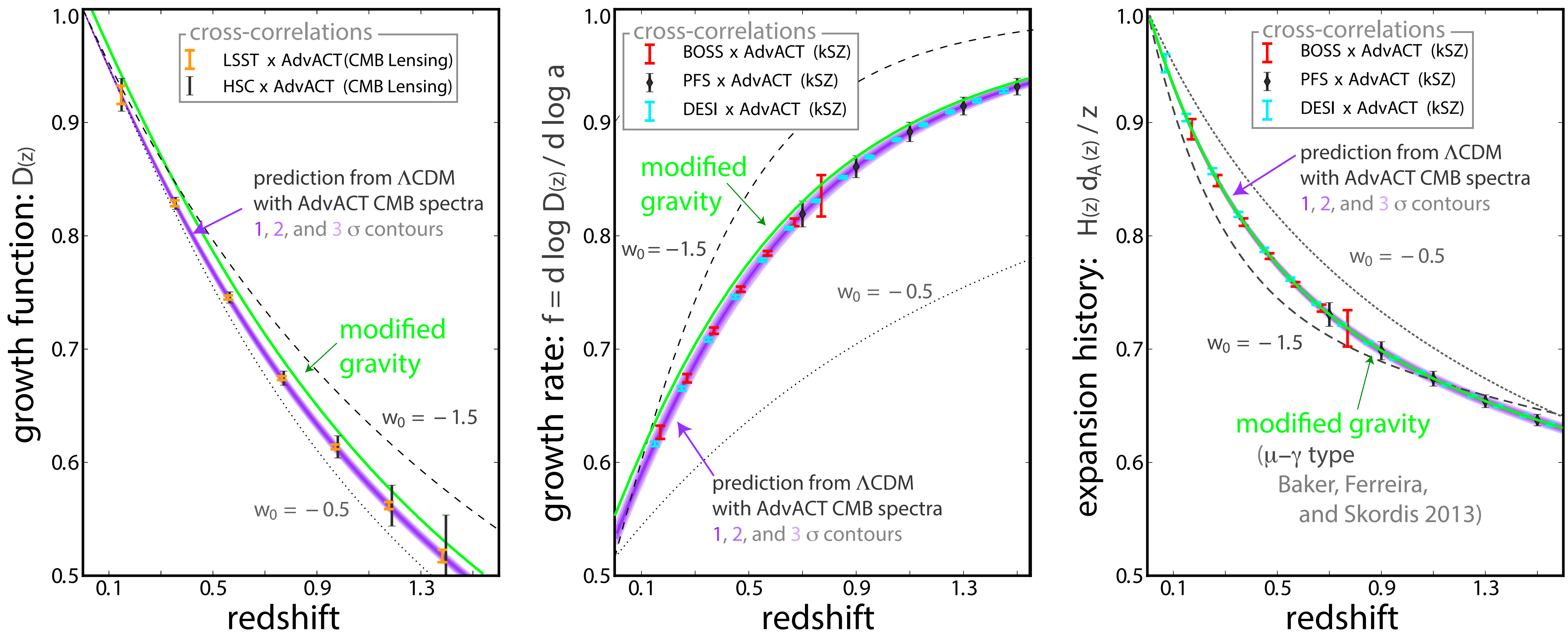


N. Hand et al. 2013

Upcoming microwave background experiments will have increasing sensitivity, multiple frequency bands, and overlap with other surveys

Advanced ACT: 5 frequency bands, half sky coverage

(2016 to 2018)



Probes of gravity from gravitational lensing and thermal and kinematic Sunyaev-Zeldovich effects

Advanced ACT proposal to NSF, 2014
Hlozek et al. in preparation 2015

The past 25 years have been remarkable

The microwave background will continue to probe fundamental physics in novel ways for the next 10 years