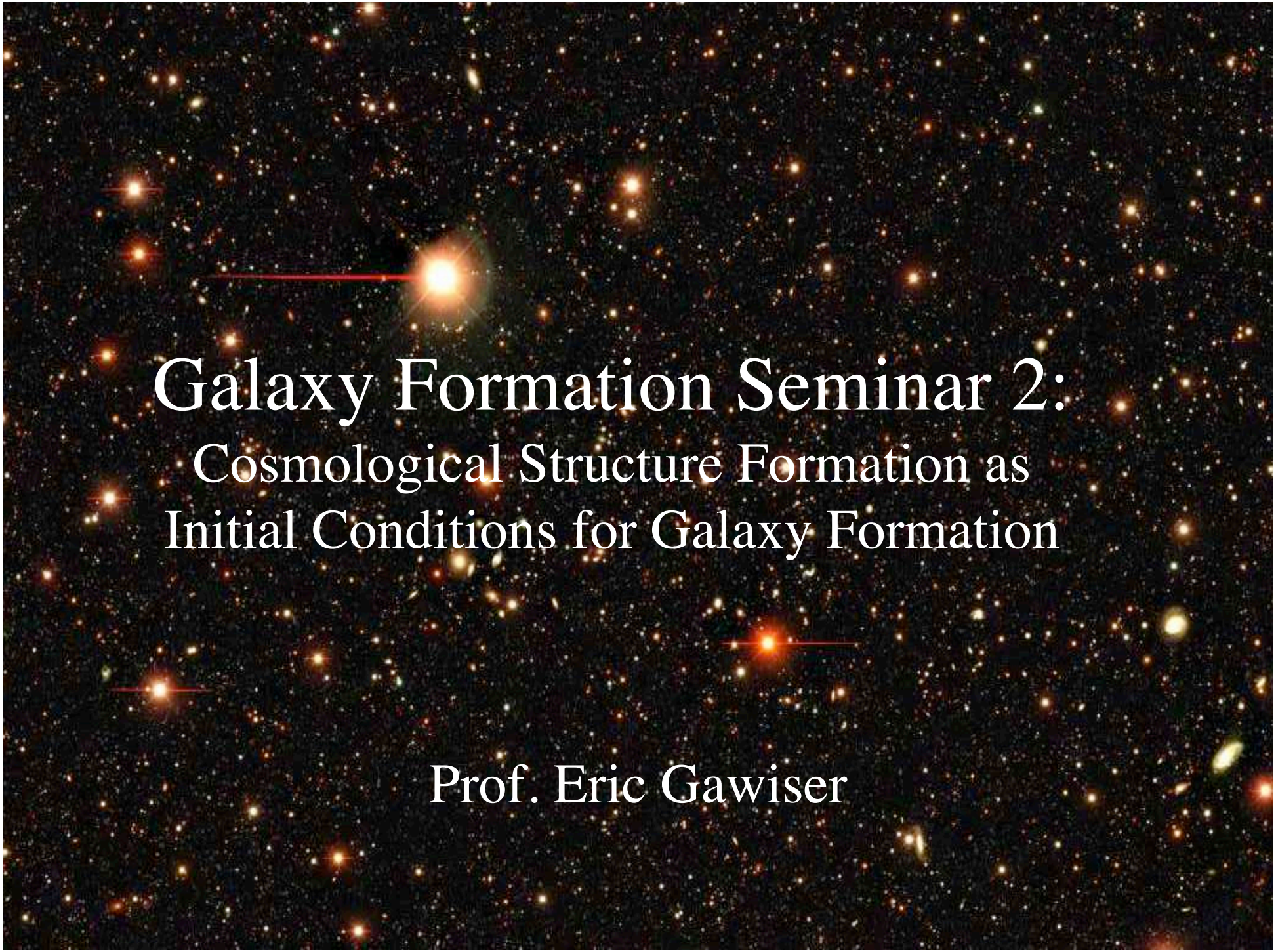
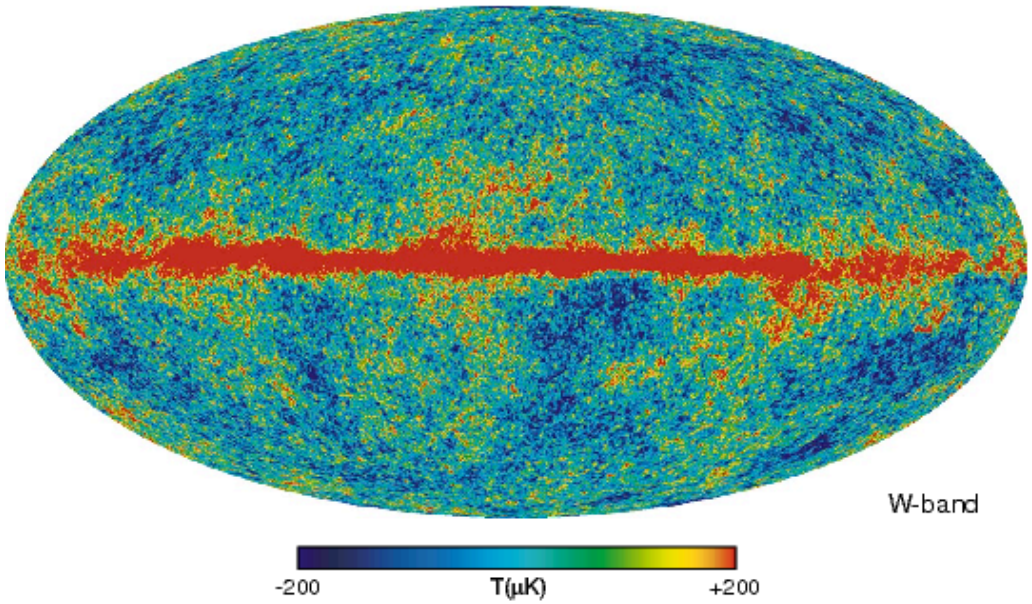
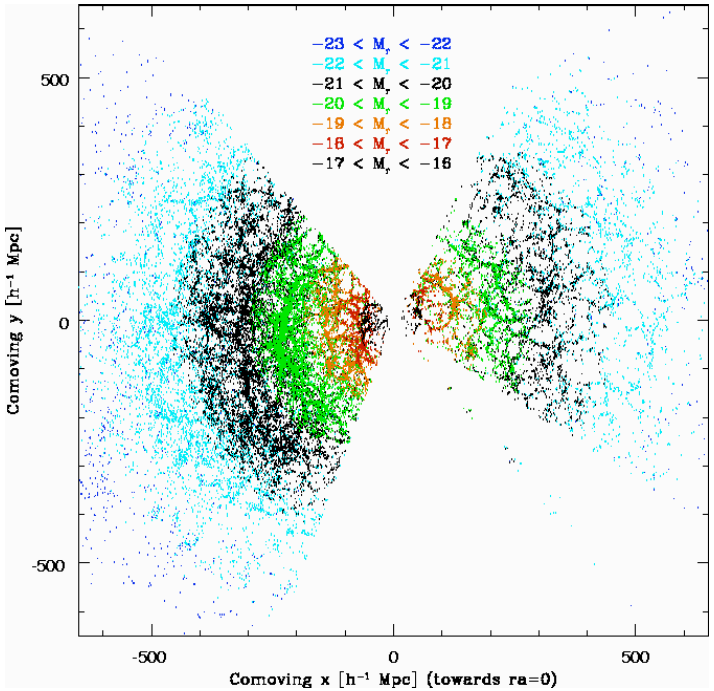


Galaxy Formation Seminar 2:
Cosmological Structure Formation as Initial Conditions for Galaxy Formation

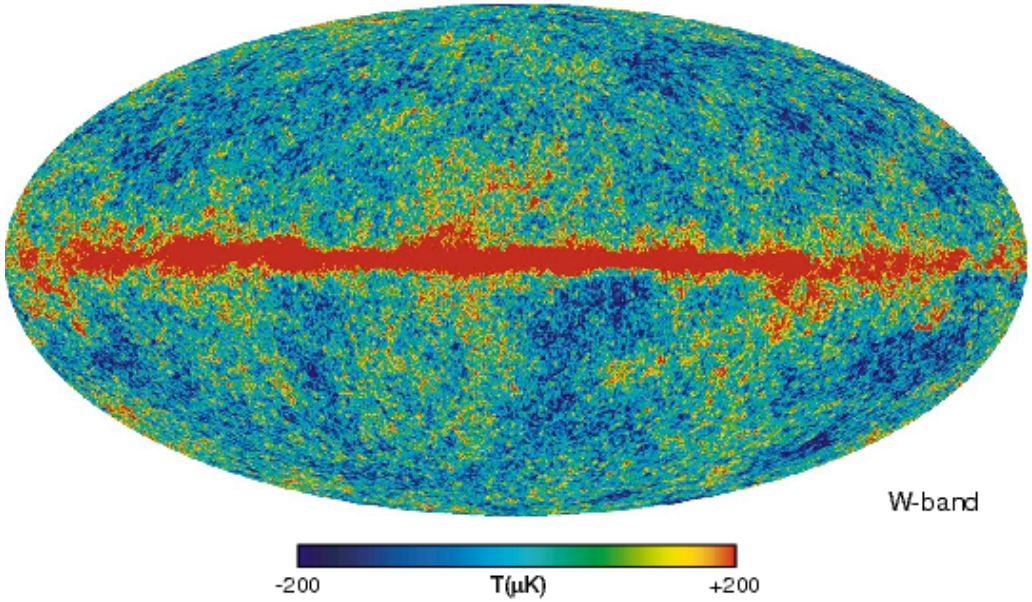
Prof. Eric Gawiser

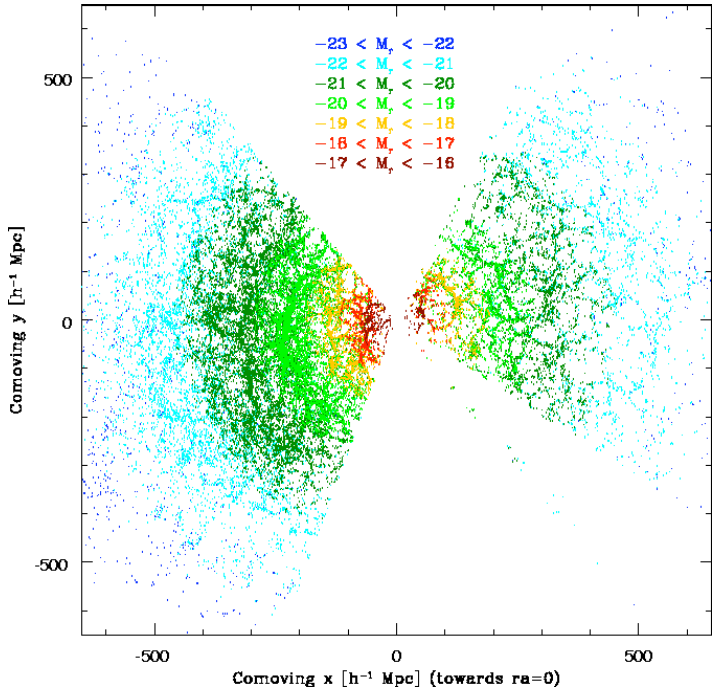
Cosmic Microwave Background anisotropy and Large-scale structure

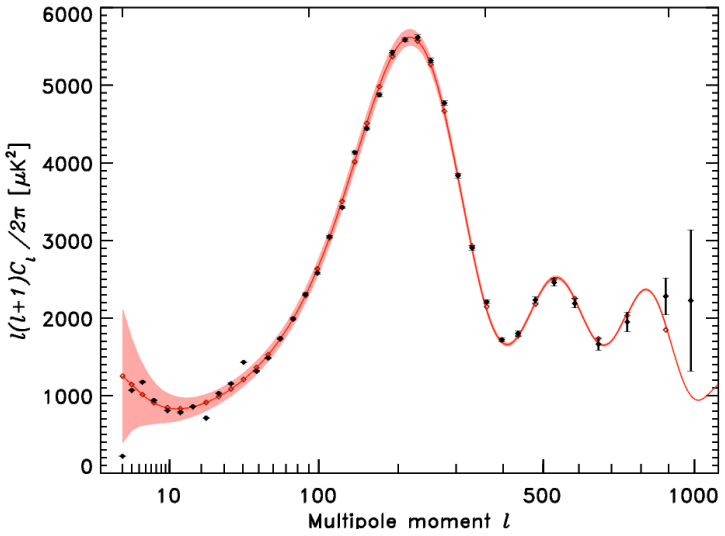


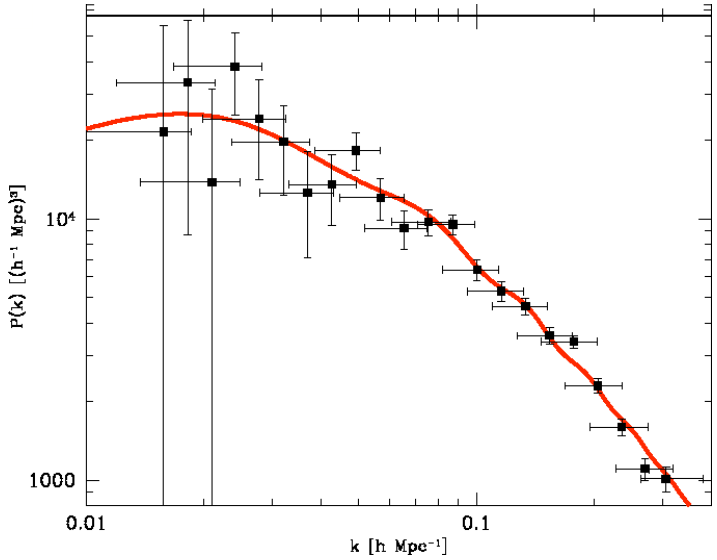


Cosmic Microwave Background anisotropy and Large-scale structure both show baryon acoustic oscillations









We can plot CMB angular power spectrum C_l in terms of the spatial dark matter power spectrum P(k) by inverting

$$C_l = \sum_k W_l(k) P_p(k)$$

$$\left\langle \left| \delta_{\vec{k}} \right|^2 \right\rangle = P_p(k)$$

(Figure from Tegmark & Zaldarriaga 2002)

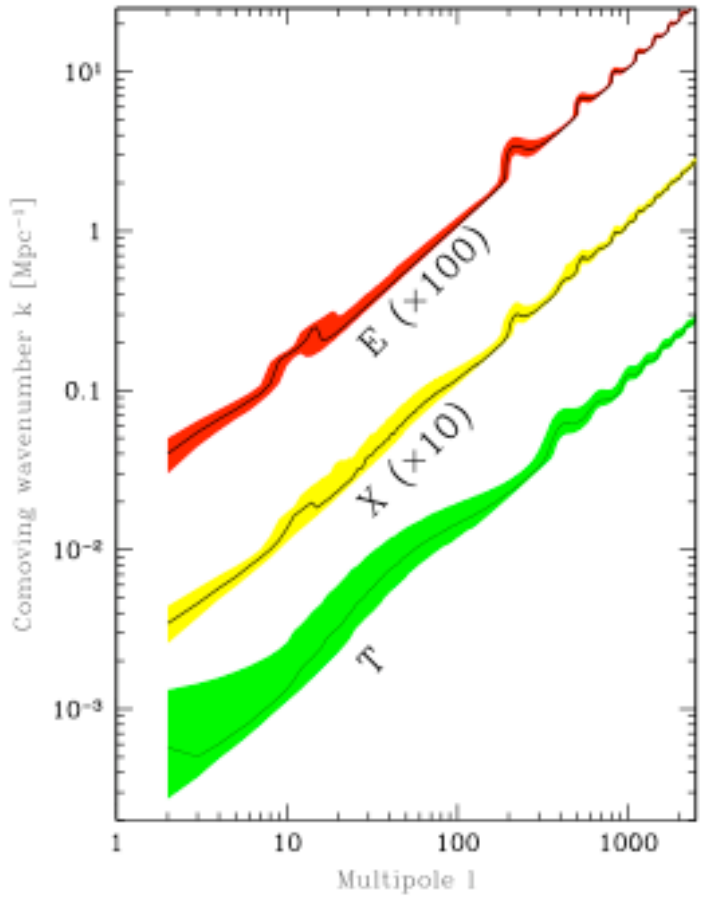
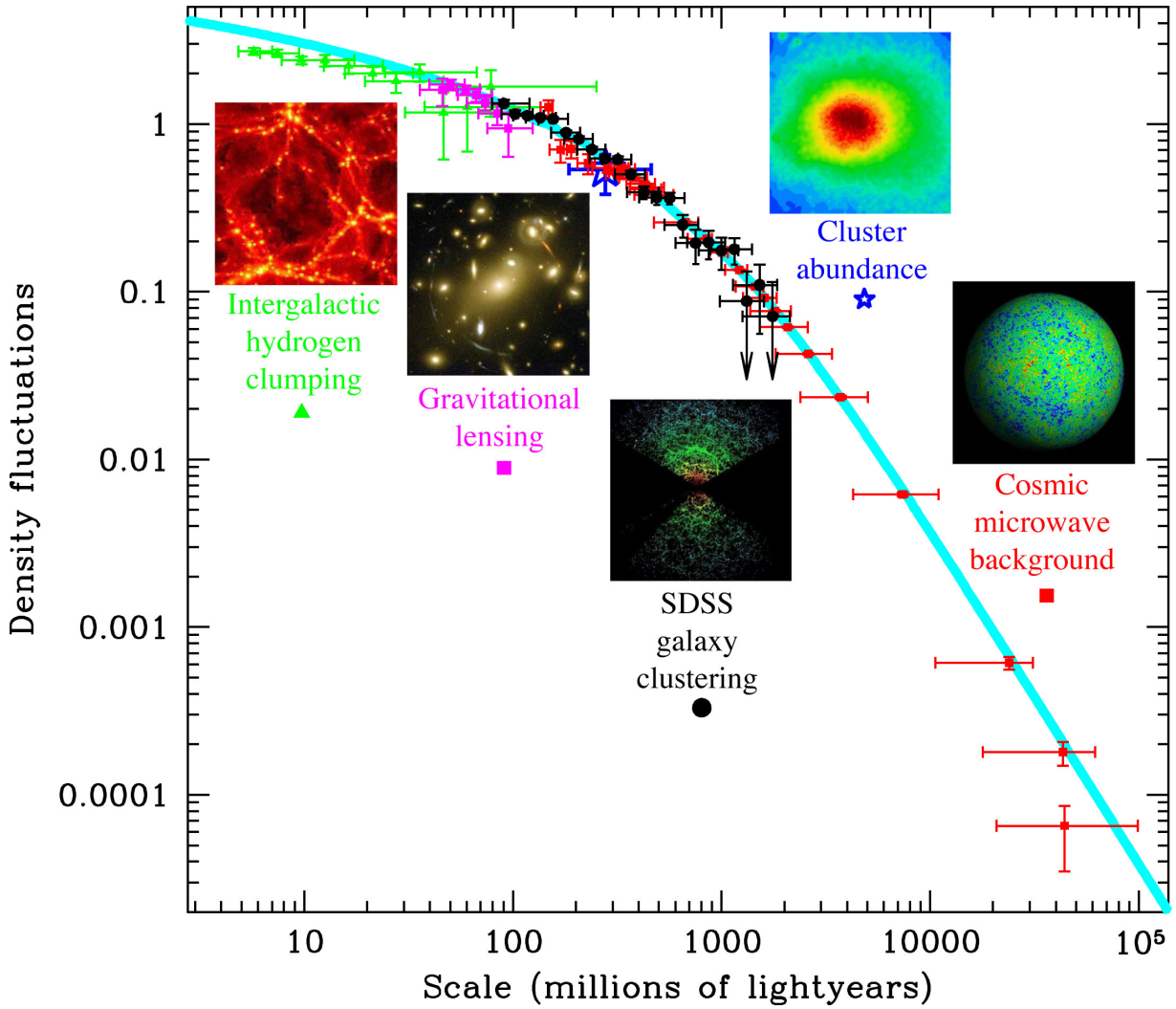


FIG. 5. The correspondence between ℓ-space and k-space for CMB. For each ℓ, the shaded bands indicates the k-range from the 20th to 80th percentile of the distribution $kW_\ell(k)$ (Figure 4), and the black curve shows the median. From top to bottom, the three bands are for the E-polarization, cross-polarization (X) and unpolarized (T) cases, respectively. To avoid clutter, the E and X bands have been multiplied by 10 and 100, respectively.

Current data trace structure from galactic to cosmological scales



A Standard Model of Cosmology: ΛCDM

Age of universe: 13.8 Gyr

Geometry: flat ($\Omega_{total}=1$)

Dark Energy: 74% ($\Omega_{DE}=0.74$)

Dark Matter: 22% ($\Omega_{DM}=0.22$)

Baryons: 4% ($\Omega_{B}=0.04$)

Primordial power spectrum: n=0.95
(consistent with inflation)

Cosmological Problems and Solutions

- The Horizon Problem: Why is the Universe in thermodynamic equilibrium to one part in 100,000 on apparently super-horizon scales?
- The Flatness Problem: Why is the geometry of the Universe so close to Euclidean?
- The Monopole Problem: Where are the monopoles from GUT-scale symmetry breaking that should be wreaking havoc upon the Universe?
- The Perturbation Problem: Where did the density fluctuations that gave rise to CMB anisotropies and galaxies come from? Why is their spectrum (nearly) scale-invariant?
- The Λ Problem: Why does our Universe appear to have non-zero (but small!) vacuum energy? Why is this just becoming important "today"?

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  No solution from inflation

The Friedmann Equations

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2} \qquad \left(c \equiv 1, k \to 0\right)$$

$$\frac{\ddot{a}}{a} = \frac{-4\pi G}{3}\left(\rho + 3p\right) = \frac{-4\pi G\rho}{3}\left(1 + 3w_{eff}\right) \qquad \left(p \equiv w\rho\right)$$

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$$p = -\frac{dE}{dV} = -\frac{d(\rho a^3)}{d(a^3)} \longrightarrow \rho \propto a^{-3(1+w)}$$

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No preferred scales in DM but non-linear collapse gives distribution of "halos" where galaxies can form -

Small halos collapse first so "bottom-up"

At z>2, galaxy-mass halos rare so most halos have just collapsed

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Dark energy produces cosmological "freeze-out" -

structure formation depressed since $z_{eq} \sim 0.3$