S–Z Effect

- CMB photons scatter off hot electrons in ICM
- Statistical net gain of energy → CMB spectrum shifted to slightly higher energies → decrement in intensity at Rayleigh–Jean (\( h\nu \ll kT \))

- Amount of decrement → integral of pressure (NT) along line of sight
CMB $\rightarrow 2.728 \pm 0.02$ K

- 0.03% deviations

- Very smooth, but....

- ...there are distortions
Fluctuations on different scales → Angular scale corresponds to spatial scale today → Power spectrum of fluctuations → acoustic peaks in CMB


### TABLE 1

**Power-Law ΛCDM Model Parameters: WMAP Data Only**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean (68% Confidence Range)</th>
<th>Maximum Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baryon density, Ω₀h² ......</td>
<td>0.024 ± 0.001</td>
<td>0.023</td>
</tr>
<tr>
<td>Matter density, Ωₙ₀h² ......</td>
<td>0.14 ± 0.02</td>
<td>0.13</td>
</tr>
<tr>
<td>Hubble constant, h ..........</td>
<td>0.72 ± 0.05</td>
<td>0.68</td>
</tr>
<tr>
<td>Amplitude, A ..............</td>
<td>0.9 ± 0.1</td>
<td>0.78</td>
</tr>
<tr>
<td>Optical depth, τ ..........</td>
<td>0.166 ± 0.076</td>
<td>0.10</td>
</tr>
<tr>
<td>Spectral index, n_s ........</td>
<td>0.99 ± 0.04</td>
<td>0.97</td>
</tr>
<tr>
<td>χ²/ν ........................</td>
<td>1431/1342</td>
<td></td>
</tr>
</tbody>
</table>

**Note.**—Fit to WMAP data only.
Flavors of Structures

- Individual galaxies $\rightarrow$ 0.2–0.5 Mpc
- Galaxy groups $\rightarrow$ 1–2 Mpc
- Clusters of Galaxies $\rightarrow$ 2–4 Mpc
- Superclusters $\rightarrow$ 5–10 Mpc
- Filaments $\rightarrow$ tens of Mpc
200,000 galaxy redshifts $\rightarrow$ 3D map of galaxy distribution traces true baryonic matter distribution

Power spectrum (scales over which galaxies are spatially correlated) reflects matter distribution

Caveats: redshifts reflect deviation from Hubble flow

Variation with morphological type $\rightarrow$ “gastrophysical processes” only act on Mpc-scales

How do we know?

- Redshift surveys (optical): large numbers of galaxies over a large volume
- Wide-field, multi-object spectroscopy to get redshifts
- Emission/absorption line galaxies
Optical Redshift Surveys
Theory → The WHIM
UL-density; LL-dark matter; UR-temp (10^6 K); LR-WHIM

- Shocks convert thermal energy in relativistic electrons
- 10% of low frequency radio background (< 500 MHz)
- Fluctuations on scales of 1' – 1 degree (400 < l < 2000)

Keshet et al. 2004
Optical Redshift Surveys
Large Scale Structure – Filamentary

- How do we know?
  - Redshift surveys (optical): large numbers of galaxies over a large volume

- How big are filaments?
  - Largest length scale is 70–80 Mpc

- What’s going on in the filaments?
  - Galaxy groups line the filaments
  - Giant clusters reside where filaments intersect
Superclusters

The Peculiar Velocity Field and the Great Attractor
- Motions: Earth, Sun, Milky Way, Local Group, Virgo!!!!
  - The observed motion of the Virgo Cluster implies something extremely massive in the direction of the southern Milky Way → The Great Attractor

Observed Superclusters
- There are collections of clusters in the nearby Universe (Perseus–Pisces ridge); usually not spherical (like individual clusters)

Finding the Great Attractor
The Great Attractor

Problem – it's behind the Milky Way in the Zone of Avoidance!!!
Methods of identifying the galaxy distribution behind the Milky Way

- deep optical galaxy searches (using existing sky surveys)
- NIR: 2MASS survey (H,J,K) and DENIS (I,J,K)
- HI surveys
  - unaffected by extinction (ZOA transparent)
  - immediate redshifts/linewidths
  - uniform flux limited sample

**BUT:**
- no early-type galaxies
  - no galaxies with $-250 \leq v \leq 250$ km/s
  - lower detection rate for $|b| \leq 1.5^\circ$ (HI–ZOA)