Observational Summary
or: A Theorist Looks at Observations

Richard Easther

How Did I Get *This* Job?

1. Eiichiro Komatsu could not come...
2. I started in particle physics and gravity: $\Omega_k \equiv 0$ or ~0.7
    - Planck, string and GUT scale physics
3. 2006: I was compiling HEALPIX and likelihood code
    - Worrying about convergence statistics for MCMC
4. 2010: $\Omega_k = -0.0023$ (-0.0058,+0.0054)
    - My interests are much the same; but the world is different
    - And I am not giving a retirement speech!

Look For Features...

"Happy families are all alike;
every unhappy family is
unhappy in its own way"

Leo Tolstoy

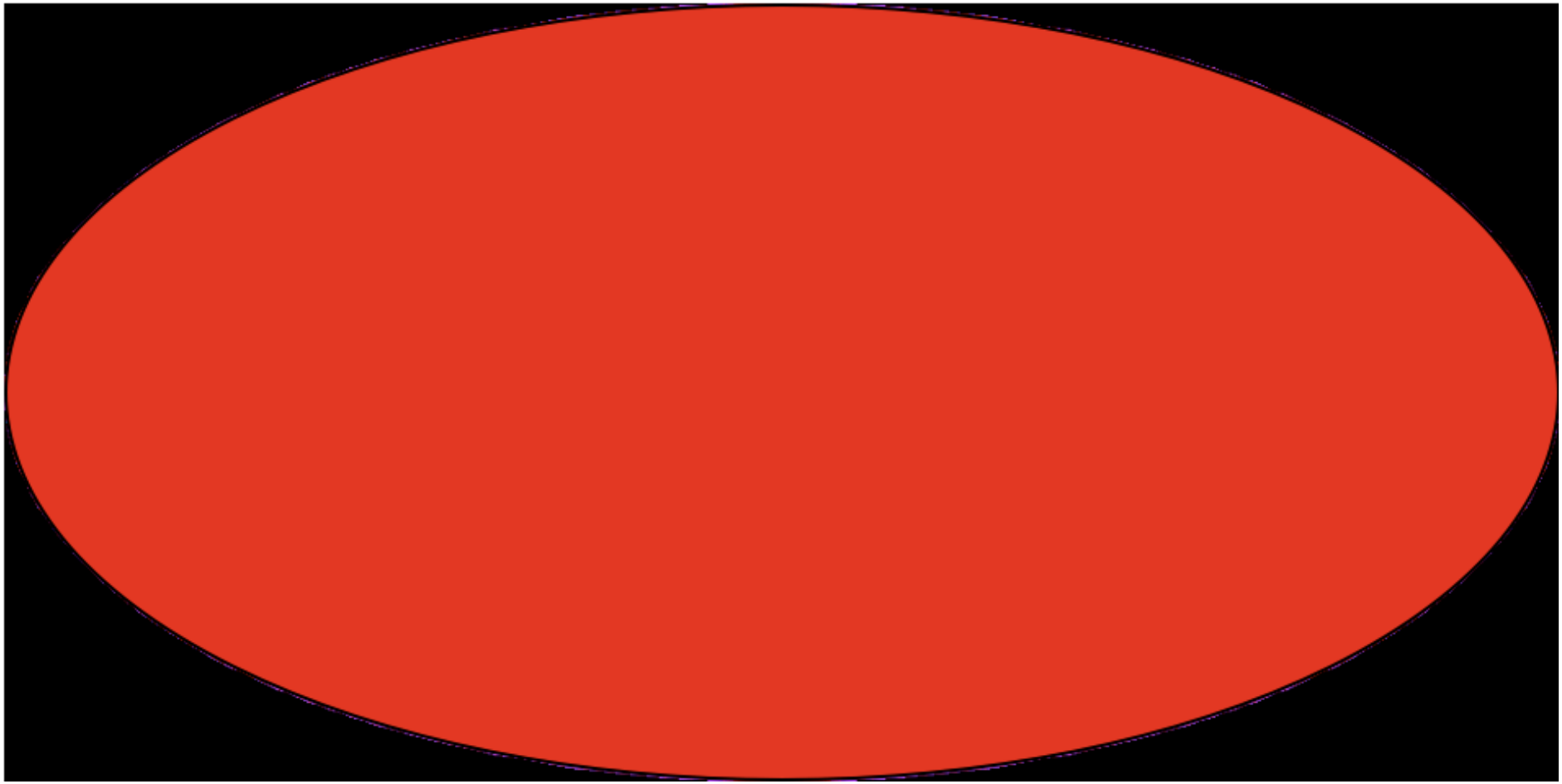
Look For Features...

"Smooth universes are all alike;
every lumpy universe is lumpy
in its own way"

not Leo Tolstoy

Primordial Features...

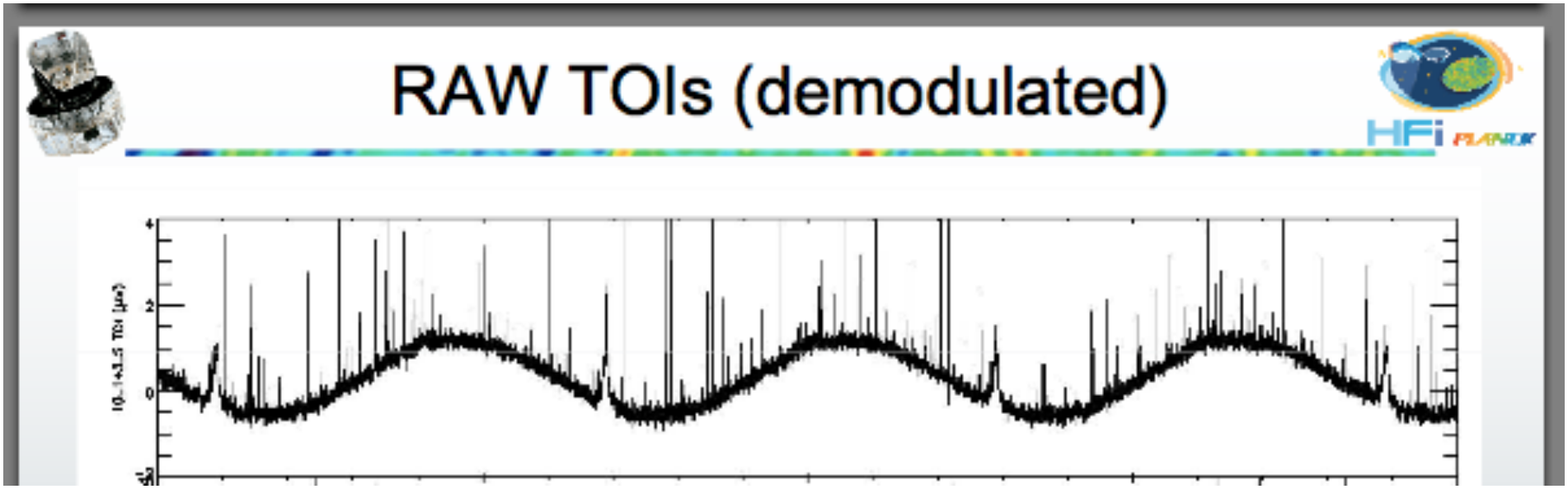
- Universe today is *full* of features...
  - Stars, galaxies, people, planets, halos, voids
- Takes a very special person to see the sky as smooth...
  - Why CMB not immediately seen as astronomical
- Contrast: pre-discovery of pulsars: 23hr56 minute periodicity.
  - US Air Force radar technician: Charles Schisler
- Default is a smooth primordial universe: seeking exceptions



Microwave Sky | 1965 - 2010

Planck Data...

- Time stream data from Bouchet's talk
  - Dipole: sinusoidal modulation across sky during scan
  - Planck detects CMB dipole in real time [how cool is that?]



Concordance Parameters

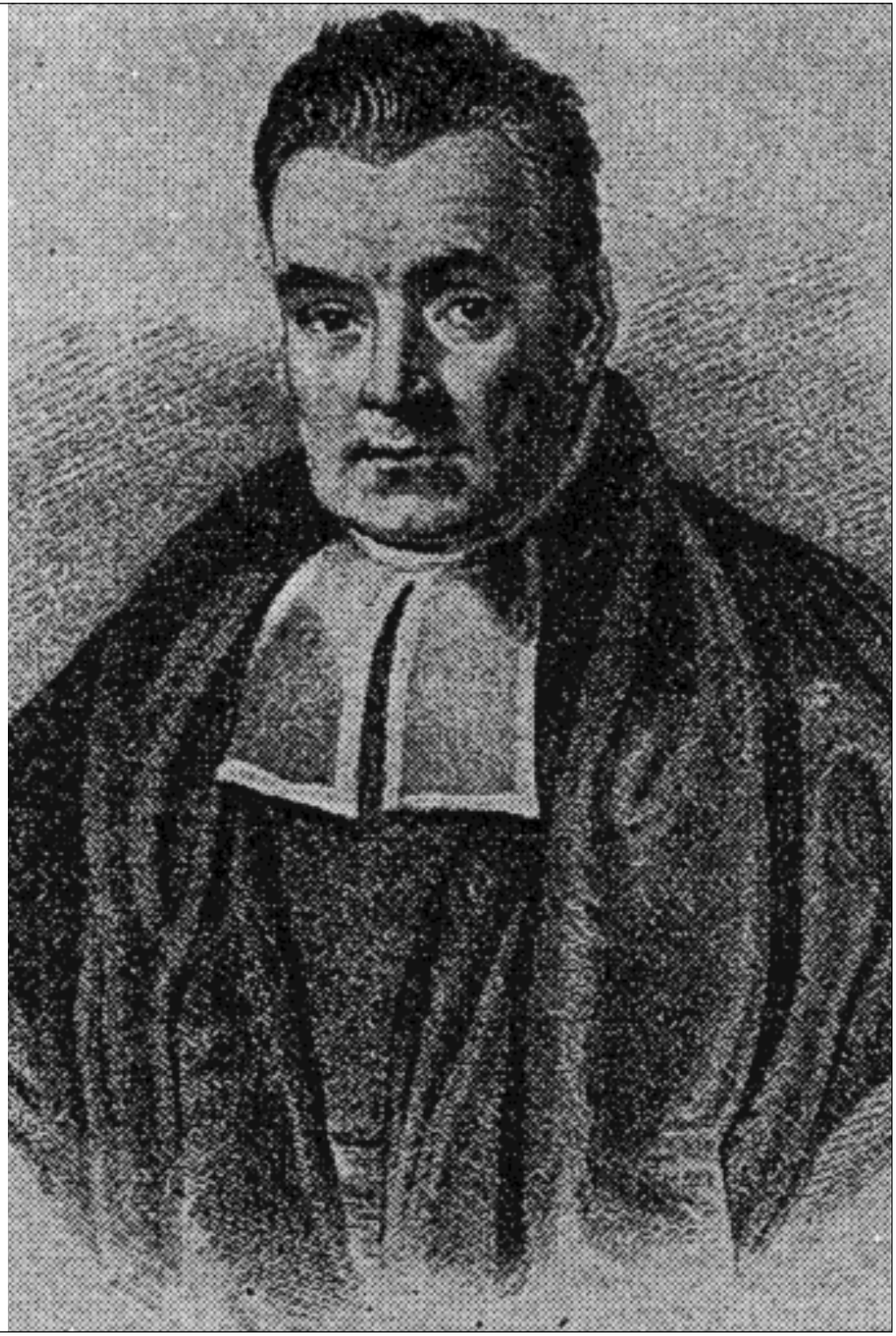
A_{SZ}	Sunyaev-Zeldovich Amplitude	Scattering of photons by hot gas in clusters	Emergent
τ	Reionization	First stars (gastrophysics, nuclear physics)	
h	Hubble's "constant"	When we are looking	Timing
Ω_b	Baryon fraction (Mass known, #??)	Baryogenesis (? - GUT, Electroweak?)	
Ω_{CDM}	Dark matter (Mass ??, #??)	TeV Scale physics?? Supersymmetry? LHC?	Composition
Ω_Λ	Cosmological constant	Quantum Gravity Magic?	
A_s, n_s	Primordial Perturbations	Inflation GUT/string physics?	Primordial

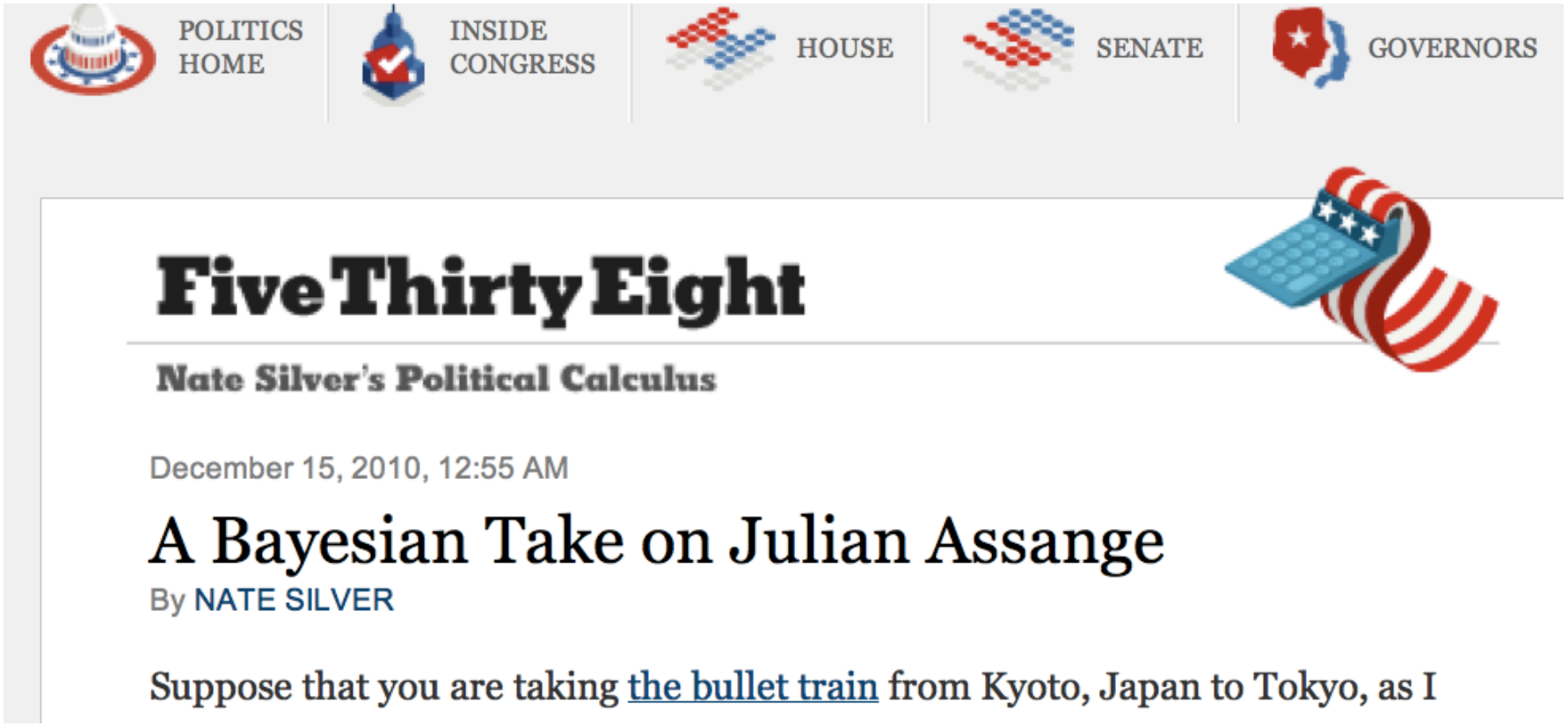
What is a “Feature”?

- One definition
  - Anything not explained by concordance cosmology?
  - But that may (one day) include e.g. neutrino physics / Y_{He}
- Feature / background is a matter of perspective
  - Symmetry: argues for pure Harrison-Zel’dovich spectrum?
  - Slow roll inflation prefers $n_s \neq 1$ (to give us a clock)
  - Brings us to priors

Someone (oddly) not invited...

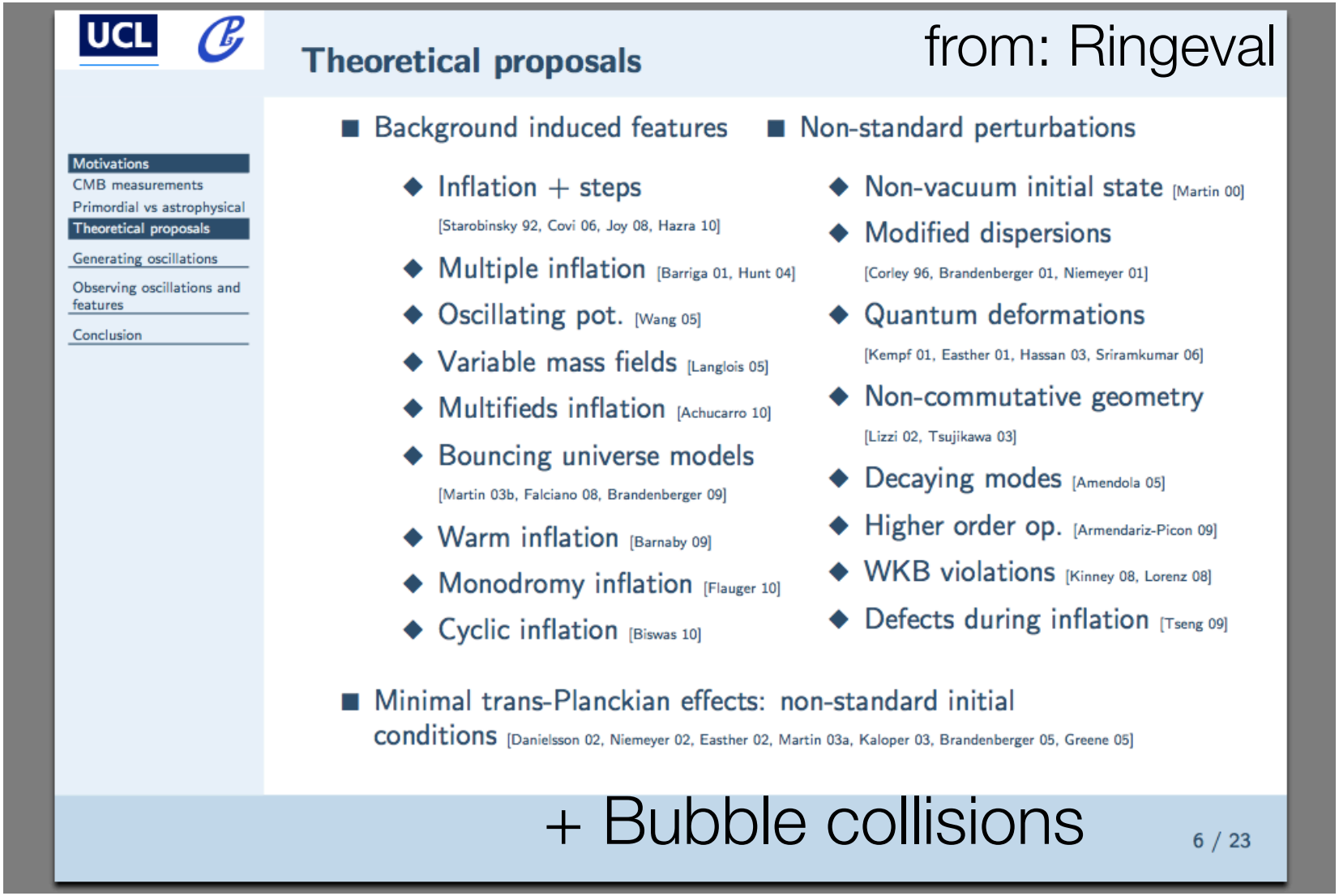
- Reverend Bayes...
  - n_s fitted in WMAP1
  - Question of model selection
- Not clear this image is Bayes
  - Got it from Wikipedia
  - Misidentification not just for astronomy





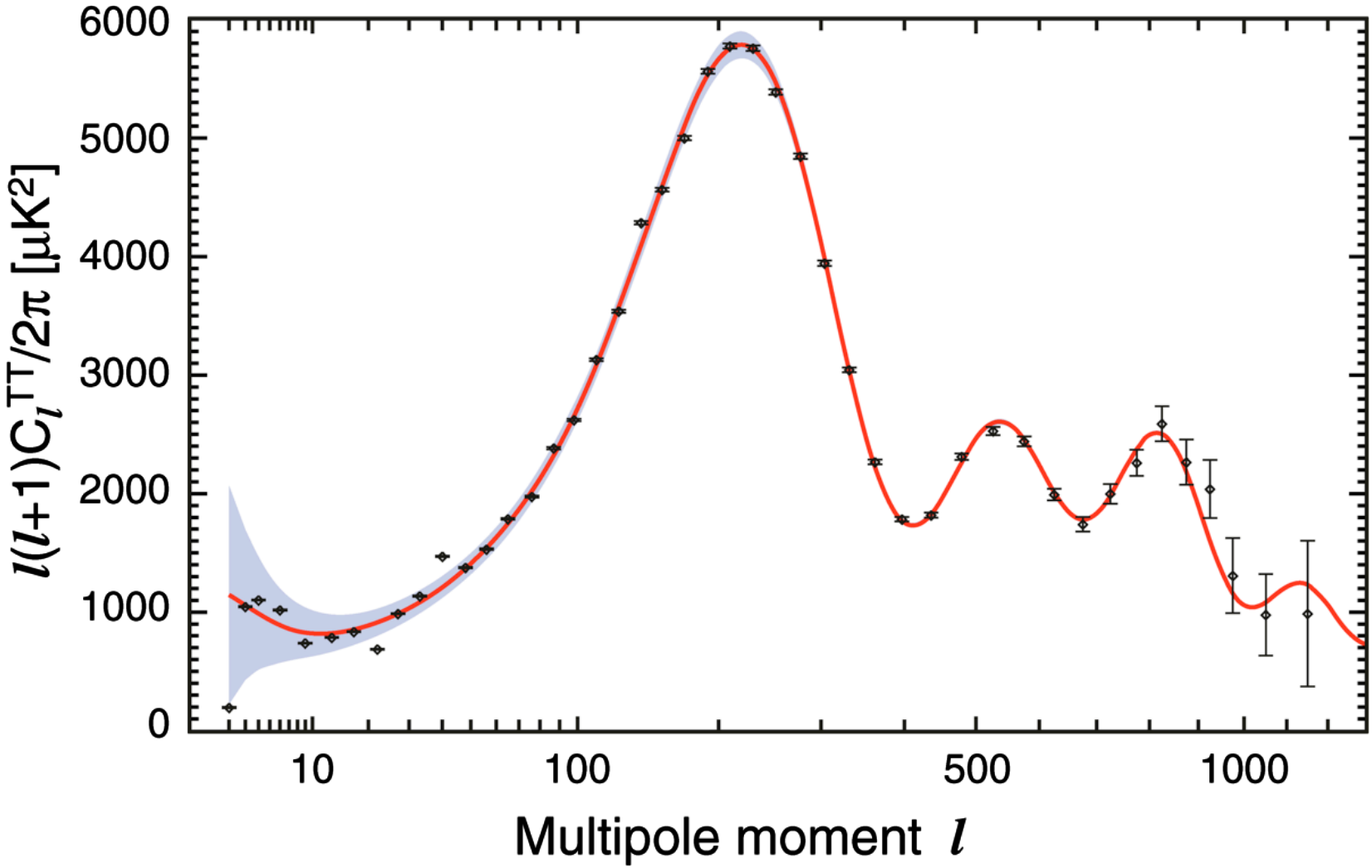
Another thing we missed...

Possible Priors



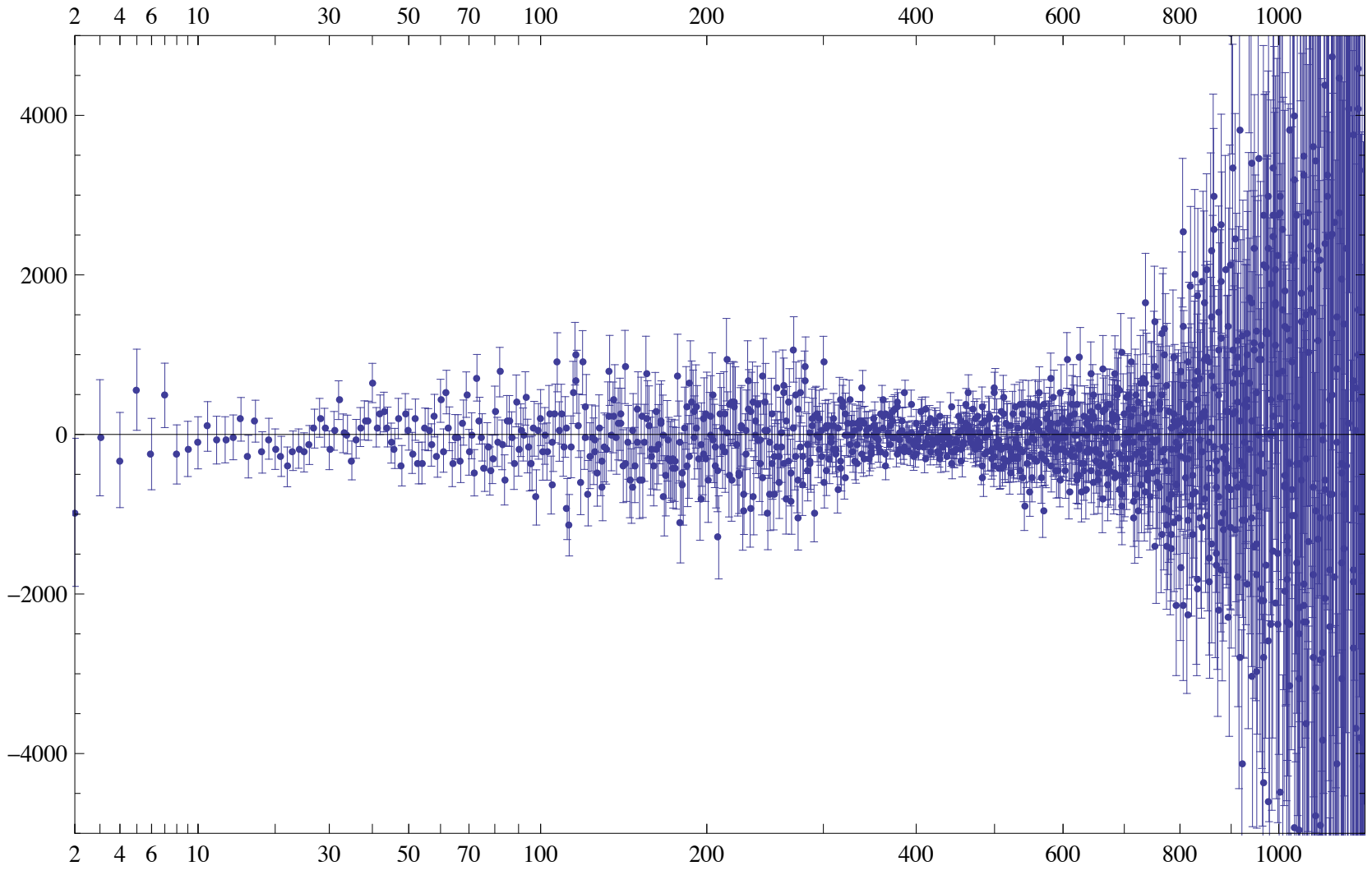
Perhaps the Key Lesson Here...

- We are learning how to think about anomalies / correlations
  - Any dataset will have “features” at some level
  - *Weirdest* universe would a *perfect* fit to CAMB spectrum.
  - Would have no idea how to explain that!
  - Cannot “repeat the experiment” in cosmology
- Could not have this discussion without superb data
  - Concordance cosmology becomes “foreground”
  - Subtract that, see if anything is left over...



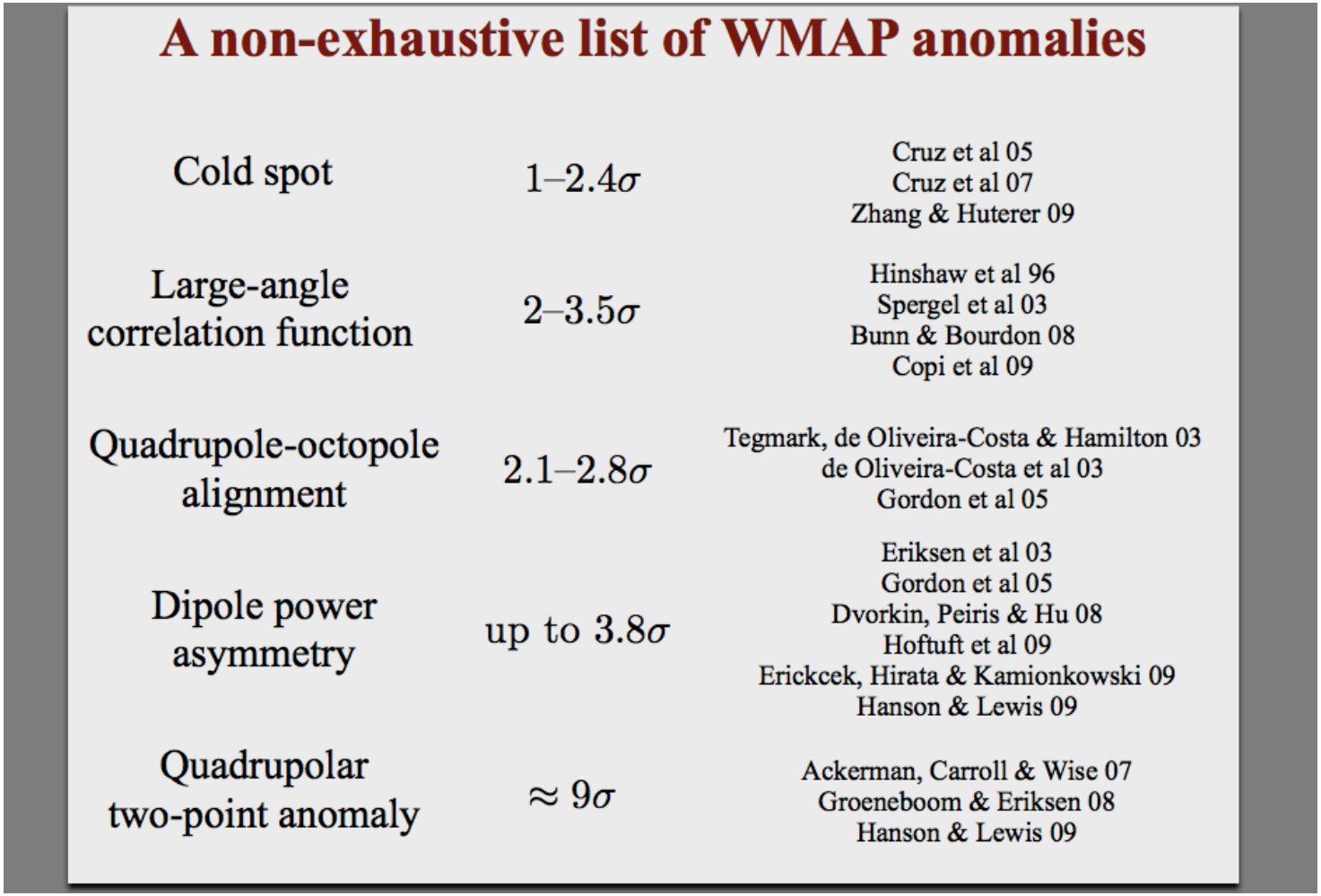
Residuals...

NASA/WMAP



Not much signal left here
(Just 2-point, of course)

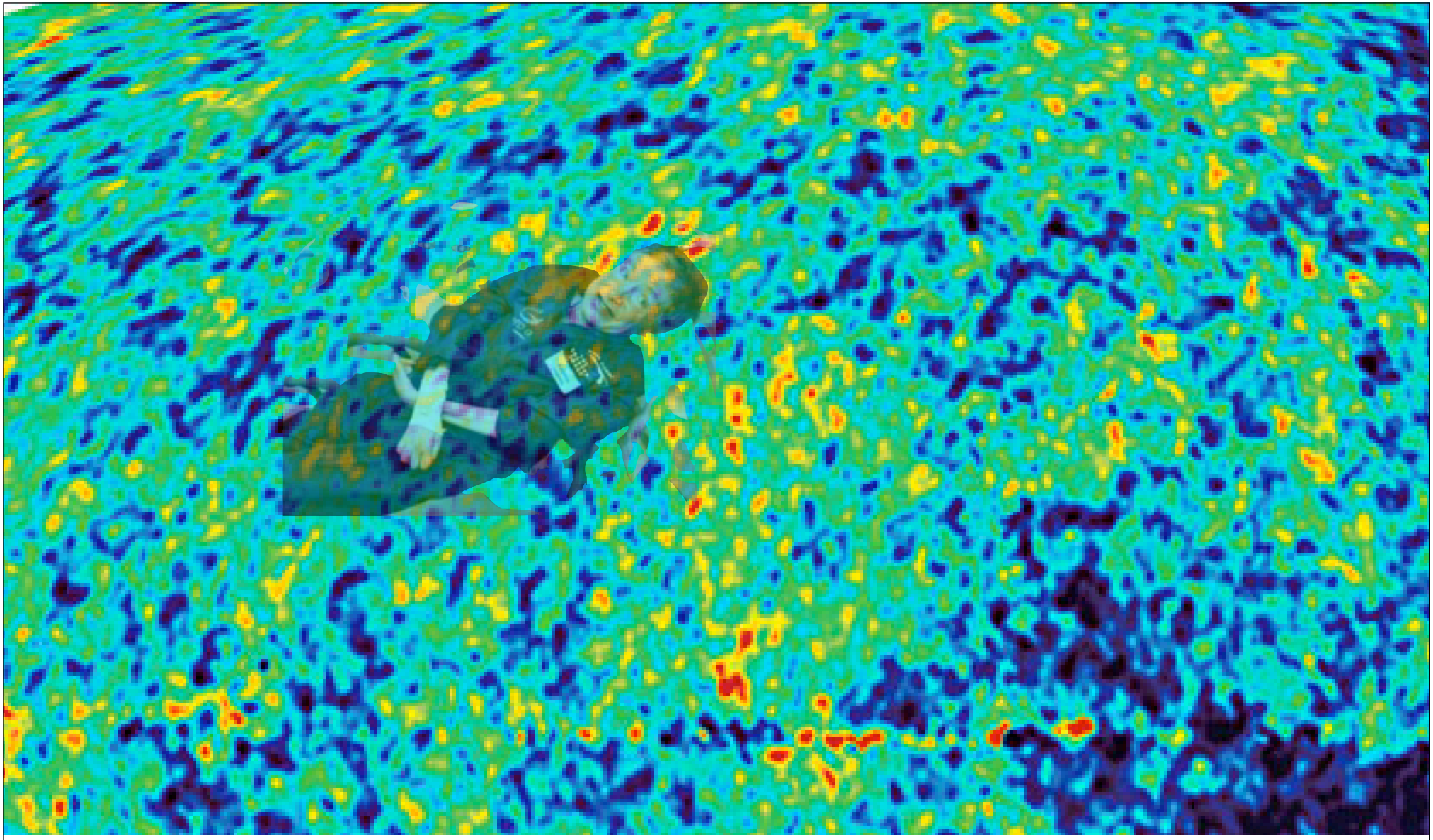
Possible Oddities in Data



Kendrick Smith

Three Possible Outcomes...

- Anomaly is an artifact (quadrupolar 2-point)
- Anomaly is “present” in the sky
  - e.g. cold spot, axis of evil, Penrose circles [Amir Haijan]
  - But not at the level we feel *required* to explain it
- Anomaly is “present” and *needs* to be explained
  - Could be *a posteriori*, but at very high significance
  - Or a prediction of a well-worked out theory
  - So far nothing seen that crosses this threshold



Suppose Planck saw this

A posteriori we can live with...

Position-based anomalies (not k-based)

- High redshift clusters [Hotchkiss, Gordon]
  - Significance (or otherwise) of this result will change quickly
- Bubble collision signatures: [Peiris, and collaborators]
  - NOT claiming a detection
  - Identifying candidate features
  - Confirmed / excluded with better data
  - Calibrated against simulations

“Fourier space” features...

- Anomalies in the power spectrum / 2 point
  - Low -ℓ Cosmic variance limited [WMAP can’t do better]
  - Does not seem to be systematics
  - Will be tested by better polarization data + 3-point
- 3-point function / non-Gaussianity: Yadav, Chen
  - Non-Gaussianity: already bounded at 0.1% level
  - Consistent with zero. (Foreground extraction key)
- Statistical isotropy

Concluding Thoughts...

- Overview idiosyncratic...
  - Apologies to anyone overlooked
  - Split between observations and theory not always clear
- Many thanks to HRI, local organizers [and India!]