Searching for Inflationary Gravitational Waves with CMB and Large Scale Structure

Christopher Hirata – CIFAR April 2012

See Esfandiar Alizadeh & Christopher Hirata
arXiv 1201.5374

Inflationary gravitational waves

- Inflation gives at least 2 types of primordial perturbations.

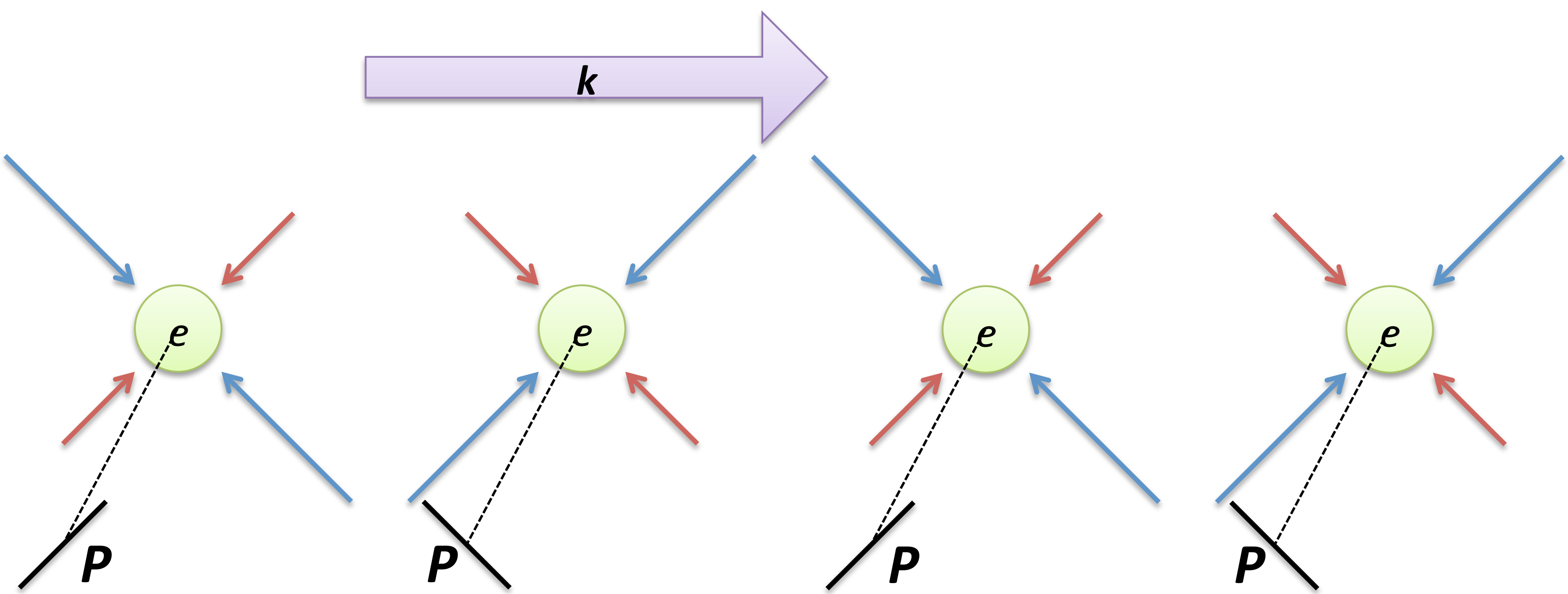
$$ds^2 = a^2(\eta)\left\{-d\eta^2 + [1+2\zeta(\mathbf{x})]\delta_{ij}dx^i dx^j + 2h_{ij}^{\mathrm{TT}}(\mathbf{x})dx^i dx^j\right\} + O(\eta^2)$$

scalar - adiabatic ***tensor***

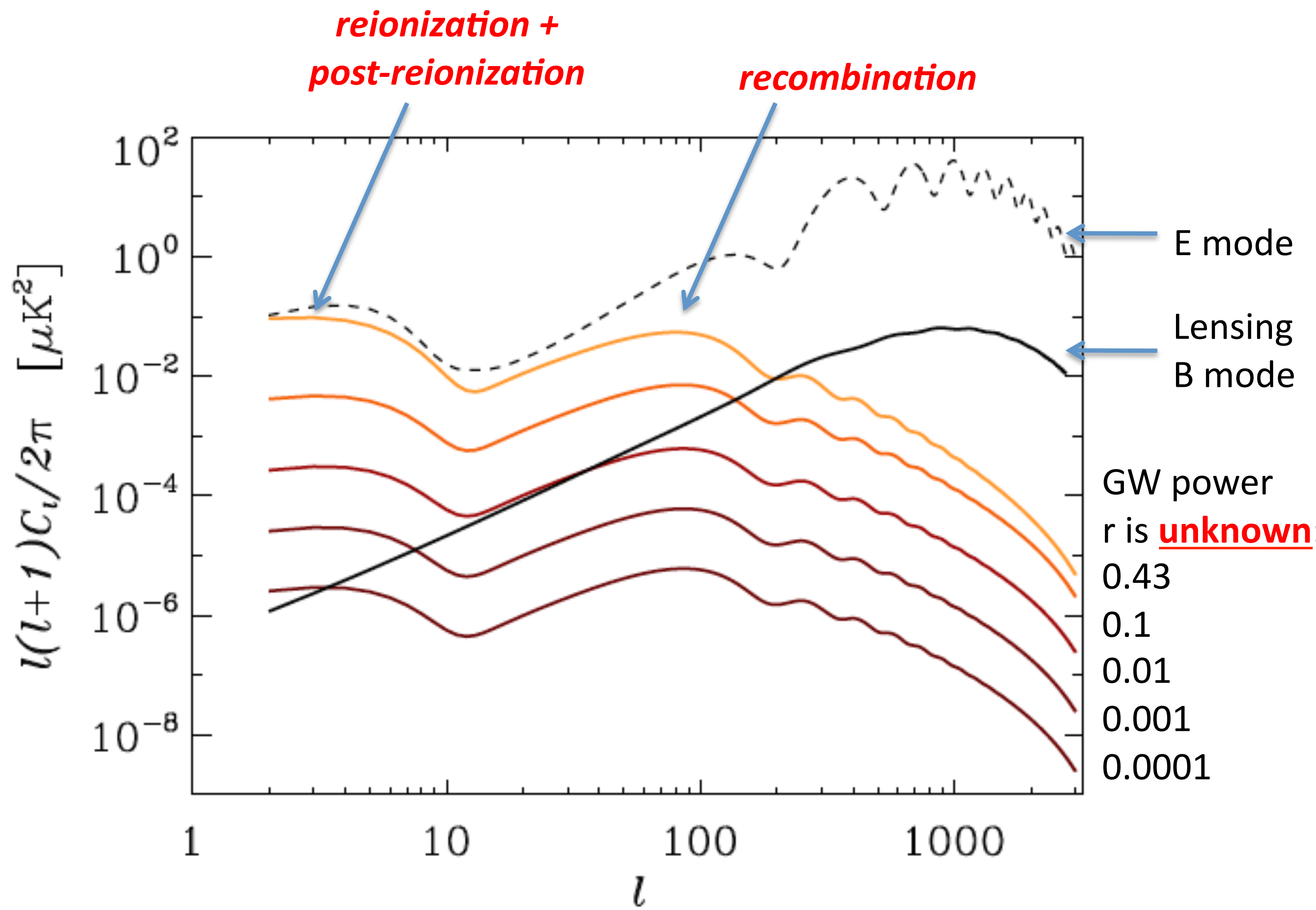
- Pulled out of the vacuum, literally.
- [Can add anything else but get these from minimal scalar field.]
- Scalar perturbations → discovered, routinely used ...
- Tensor perturbations (GW): $P_h(k)$ → Hubble rate & energy density during inflation!

The B mode

- Polarization due to GW-induced quadrupole Thomson scattering off of electrons.
- Search for "B mode" polarization in CMB – wrong parity to be due to density perturbations.



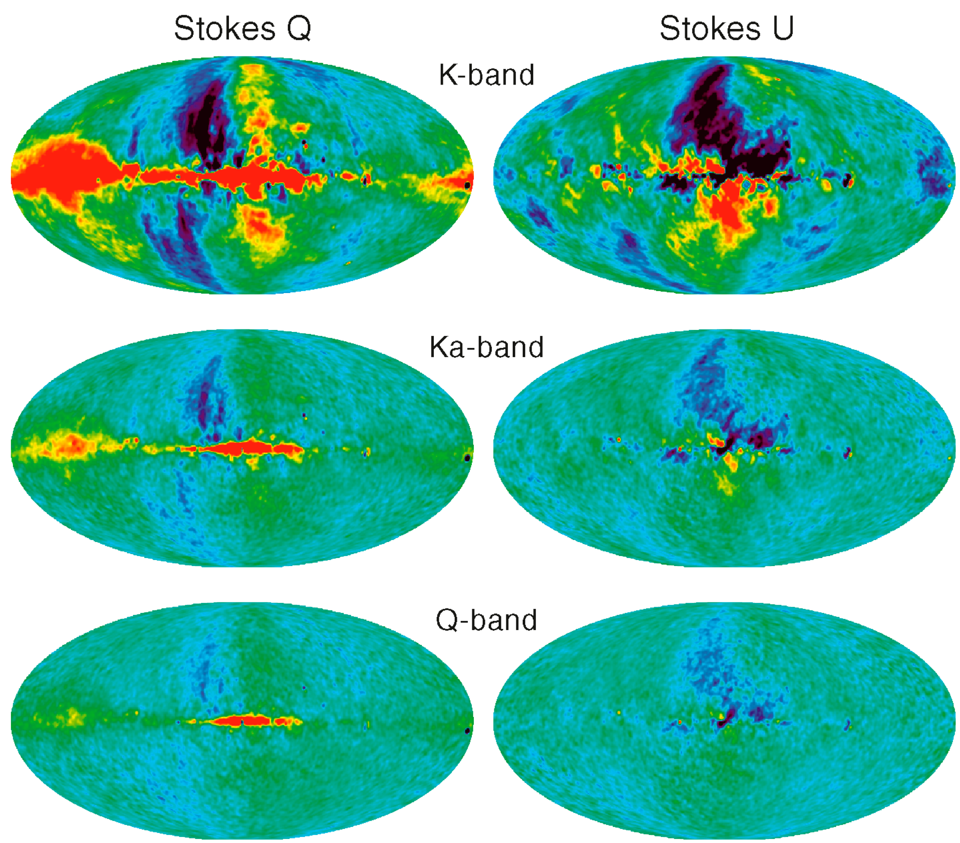
The GW Windows



Smith et al 2008

But: Foregrounds!

- Can look for the recombination peak in cleanest parts of sky
  - Strategy for current generation of ground-based polarimeters.
  - If r is large (≥ several x 10^{-2}) then this seems a likely route to a first detection.
- Want to confirm it with the reionization peak. But no clean sky available at ℓ~4.
  - Remember Heisenberg: $\Delta\ell\ \Delta\theta > 1/4\pi$.
  - Solvable? I think so, but would like to have more ways to confirm a GW detection.

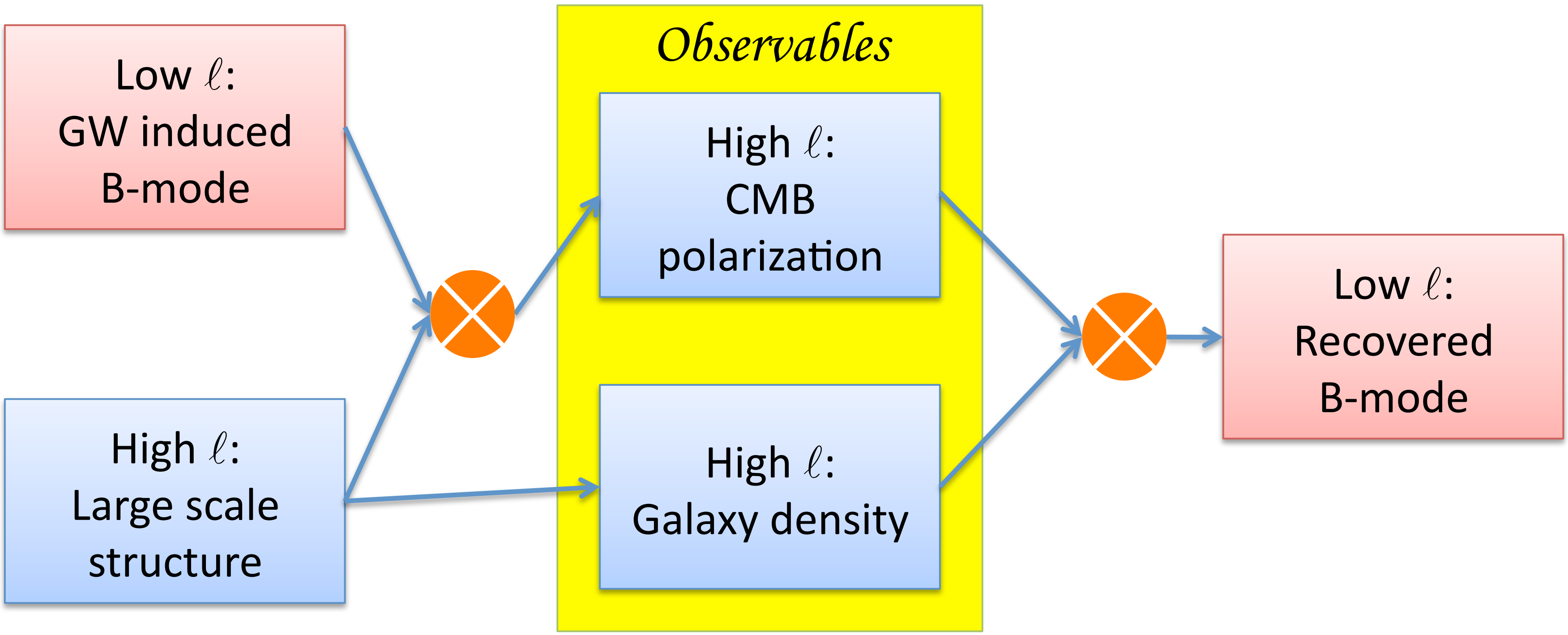


WMAP-7
Jarosik et al 2011

The 3rd GW Window?

- All post reionization density perturbations modulate the low-ℓ B mode.
- This leads to a high-ℓ polarization signature from IGWs reaching to all scales.
- But very faint (few nK) – no hope of detecting the signal directly! Need an overlapping tracer of large scale structure to "demodulate."
- Arcminute scale (ℓ ~ few x 10^3) is particularly attractive.
  - ✓ Get below "noise" from primary CMB.
  - ✓ Resolvable with SZ telescopes, although **not** at present sensitivity.
  - ✓ Hemisphere scale galaxy surveys could actually probe large scale structure at this ℓ (e.g. LSST), although still some time in the future.

In a Cartoon



Big Advantages:

- Avoid smooth low ℓ foregrounds – the low ℓ CMB is never used.
- Cosmological signal is obtained via a cross-correlation – more robust.

Big Disadvantage:

- LSS projected to z ~ few has $\delta\rho/\rho_{2D}$<<1 – need more sensitivity. (In raw sensitivity, this method will never beat direct measurement of low ℓ.)

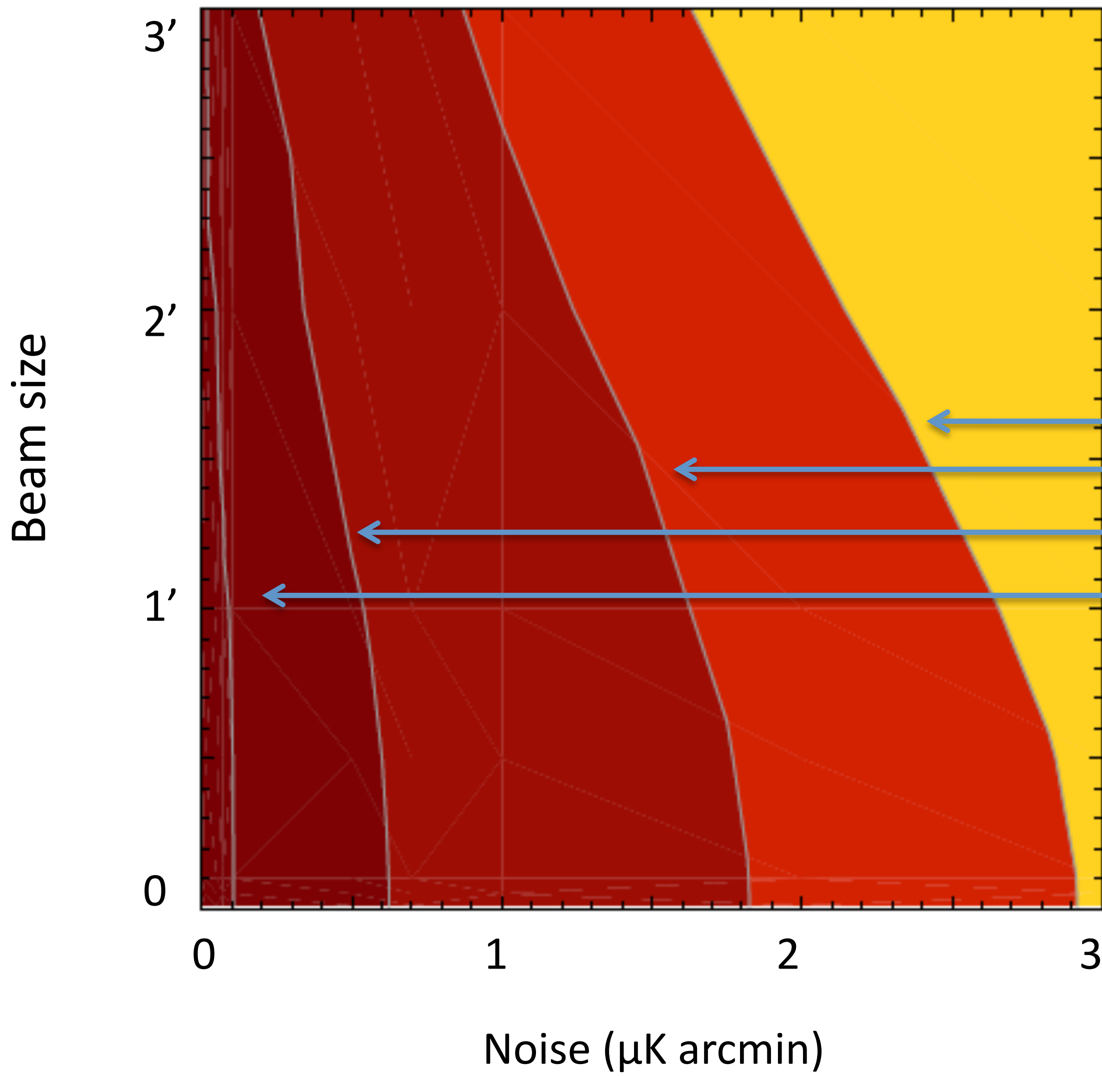
Sensitivity

[or, how crazy is this?]

- Pattern the calculation after the problem of lensing of the CMB [Hu, Seljak & Zaldarriaga … ~10 years ago]
  - It's all the same math except with a few dot products in different places and with the galaxies replacing the primary E-mode.
  - The GW power spectrum is composed of 4-point correlation functions: $P_h(k) = <$ galaxy * P_{CMB} * galaxy * $P_{CMB} >$

- For $\sigma_r = 0.04$, would need the whole sky (minus the galactic plane) to 1 μK arcmin (CMB) and limiting $I_{AB} = 25.6$ (galaxies).
  - This depth for hemisphere scale CMB observations remains futuristic (1—2 orders of magnitude!) but the technology is improving rapidly.
  - LSST will reach this depth (photo-z's will be crude at this magnitude but we don't care).
  - Geometric constraints – all of these are missing the Northern cap.

Sensitivity



σ(r) @ full sky
[with plausible cuts,
a factor of 2—3 worse]

0.1
0.05
0.01
0.001

Alizadeh & Hirata 2012

Some Obvious Questions & Partial Answers

- What if the source galaxies are polarized?
  - They are, but this is not a problem if no Hubble length scale intrinsic alignment of polarization vectors.
- The galaxies don't perfectly trace the electrons, the redshifts are known imprecisely (large photo-z failure rate), etc.
  - True but cannot fake a B-mode signal – protected by parity, much more robust against astrophysics than dark energy studies.
- I→Q,U leakage?
  - This is probably the top systematics concern but there are mitigation strategies.

Summary

- The search for inflationary gravitational waves is fundamental but really hard. If detected, we want to confirm them through as many observational windows as we can.
- CMB × LSS is one way to go about this, and has several key advantages in terms of systematic contamination.
- The sensitivity is beyond current observational capabilities but advances are expected in both CMB and LSS. There are always good reasons to want more!