Gravity Wave Fossils

signatures of tensor modes in pre-reionization 21 cm structure

Kiyoshi Wesley Masui

with: Ue-Li Pen

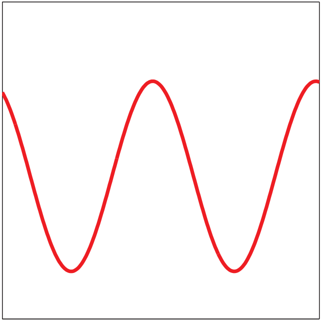
CITA@25: May 13, 2010

Motivation

- Primordial tensors (gravity waves) are hard to detect: current constraint is $r < 0.24$ (WMAP), near future $r \sim 0.01$ (B-modes).
- Inflation makes very specific predictions for the tensor power spectrum, $n_T = r/8$.
- There is an abundance of information in the pre-reionization 21 cm signal if it could be mapped.
- How would you look for tensors?

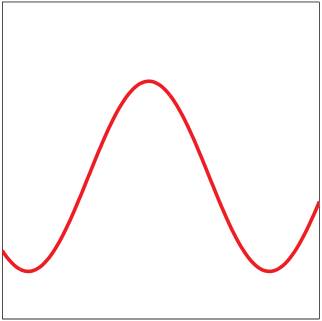
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$



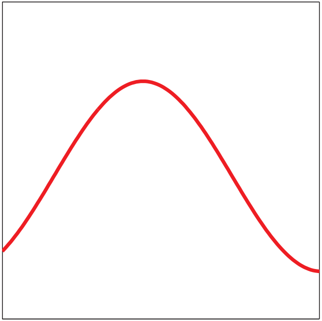
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$



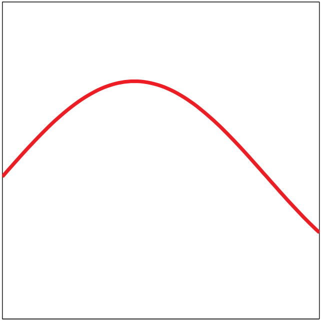
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$



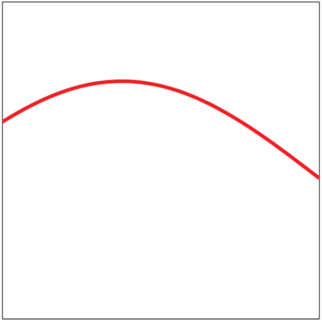
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$



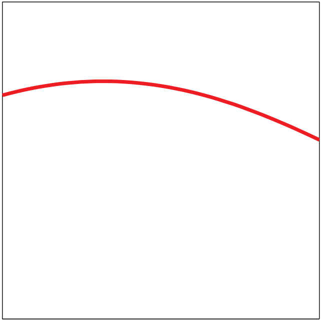
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$



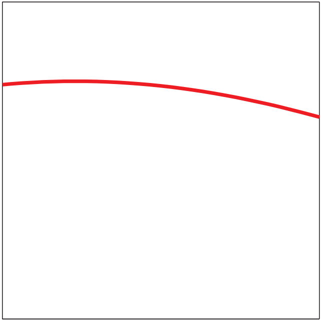
Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$

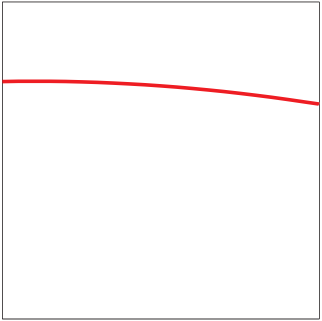


Gravity Wave Fossils

- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$

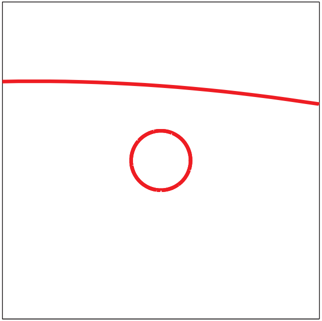


Gravity Wave Fossils



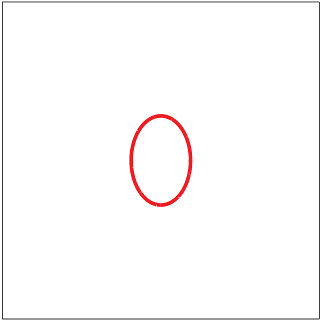
- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$
- $k_T \ll aH$

Gravity Wave Fossils



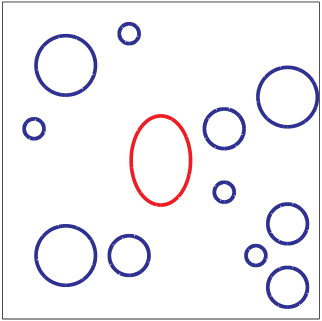
- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij}) dx^i dx^j \right]$
- $k_T \ll aH$
- $\tilde{x}^\alpha = (x^\alpha - \frac{1}{2} h_{\alpha\beta} x^\beta)$

Gravity Wave Fossils



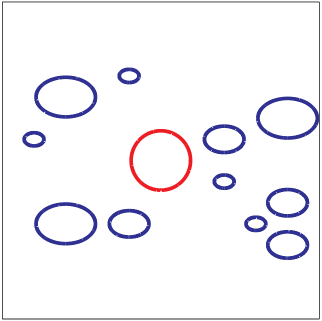
- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$
- $k_T \ll aH$
- $\tilde{x}^\alpha = (x^\alpha - \frac{1}{2} h_{\alpha\beta} x^\beta)$
- $$ds^2 = a^2 \left[-d\eta^2 + \delta_{ij} d\tilde{x}^i d\tilde{x}^j - \frac{\tilde{x}^c}{2}(h_{\beta c,\alpha} + h_{\alpha c,\beta}) d\tilde{x}^\alpha d\tilde{x}^\beta\right]$$

Gravity Wave Fossils



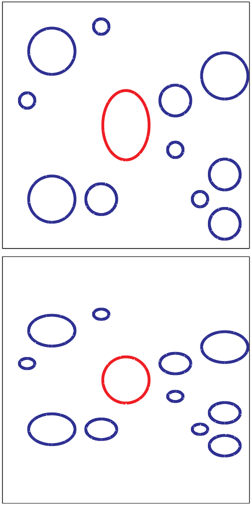
- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$
- $k_T \ll aH$
- $\tilde{x}^\alpha = (x^\alpha - \frac{1}{2}h_{\alpha\beta}x^\beta)$
- $$ds^2 = a^2 \left[-d\eta^2 + \delta_{ij}d\tilde{x}^i d\tilde{x}^j - \frac{\tilde{x}^c}{2}(h_{\beta c,\alpha} + h_{\alpha c,\beta})d\tilde{x}^\alpha d\tilde{x}^\beta\right]$$
- $\tilde{P}(\vec{k}) = \tilde{P}(k)$

Gravity Wave Fossils



- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$
- $k_T \ll aH$
- $\tilde{x}^\alpha = (x^\alpha - \frac{1}{2}h_{\alpha\beta}x^\beta)$
- $$ds^2 = a^2 \left[-d\eta^2 + \delta_{ij}d\tilde{x}^i d\tilde{x}^j - \frac{\tilde{x}^c}{2}(h_{\beta c,\alpha} + h_{\alpha c,\beta})d\tilde{x}^\alpha d\tilde{x}^\beta\right]$$
- $\tilde{P}(\vec{k}) = \tilde{P}(k)$
- $$P(\vec{k}) = \tilde{P}(k) - \frac{k_i k_j h_{ij}}{2k}\frac{d\tilde{P}}{dk} + O(\frac{k_T}{k}h_{ij}) + O({h_{ij}}^2)$$

Gravity Wave Fossils



- $ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right]$
- $k_T \ll aH$
- $\tilde{x}^\alpha = (x^\alpha - \frac{1}{2}h_{\alpha\beta}x^\beta)$
- $$ds^2 = a^2 \Big[-d\eta^2 + \delta_{ij}d\tilde{x}^i d\tilde{x}^j - \frac{\tilde{x}^c}{2}(h_{\beta c,\alpha} + h_{\alpha c,\beta})d\tilde{x}^\alpha d\tilde{x}^\beta\Big]$$
- $\tilde{P}(\vec{k}) = \tilde{P}(k)$
- $$P(\vec{k}) = \tilde{P}(k) - \frac{k_i k_j h_{ij}}{2k}\frac{d\tilde{P}}{dk} + O(\frac{k_T}{k}h_{ij}) + O({h_{ij}}^2)$$
- Gravity wave decays.
- Geodesic equation is trivial original coordinates.
- Anisotropy becomes observable.

Gravity Wave Fossils

$$P(\vec{k}) = \tilde{P}(k) - \frac{k_i k_j h_{ij}}{2k}\frac{d\tilde{P}}{dk} + O(\frac{k_T}{k} h_{ij}) + O({h_{ij}}^2)$$

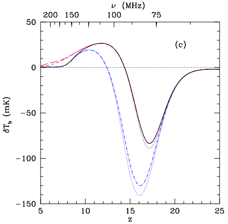
- Looking for a local anisotropy in the *scalar* power spectrum.
- Tensor modes can be reconstructed by measuring scalar power spectrum patch by patch $h_{ij} \sim \langle \delta_{,i}\delta_{,j} \rangle_{\delta}$.
- Can then verify that h_{ij} is transverse and traceless.
- However, effect is minute, so you need many scalar modes.

Why is this bigger than other effects

- Normally tensor modes decay rapidly once they enter the horizon.
- The fossils are permanent.
- Simultaneously probe a range of scales for the tensor power spectrum.
- May allow the measurement of the tensor spectral tilt n_T.
- Test the inflation consistency relation.

Forecasts

Furlanetto, Peng and Briggs, 2006



SKA will try to detect the 21 cm line at redshift 15 with 10 km baselines.

$$r_{min} = \frac{32\pi^2}{A_s k_{max}^3} \left(\frac{6}{V V_H} \right)^{1/2}$$

$$r_{min} = 7.3 \left(\frac{1.2\, h/\mathrm{Mpc}}{k_{max}} \right)^3 \left[\frac{200\, (\mathrm{Gpc}/h)^3}{V} \frac{3.3\, (\mathrm{Gpc}/h)^3}{V_H} \right]^{1/2}$$

To test the consistency relation:

$$k_{max} \sim 40\, h/\mathrm{Mpc} \left[\frac{200\, (\mathrm{Gpc}/h)^3}{V} \left(\frac{0.1}{r} \right)^2 \right]^{1/3}$$

Conclusions

- New effect for detecting primordial tensor modes.
- Very powerful for measuring r with low frequency arrays ($z \sim 15$).
- Only chance we have of measuring n_T, but r needs to cooperate.