Dark Matter Ultracompact Minihalos & the Early Universe

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Outline

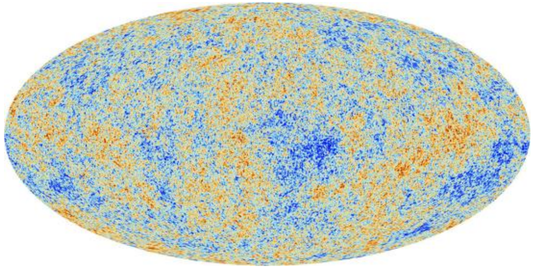
Based on three recent papers:

- ➔ Clark, Lewis & Scott 2015a (arXiv: 1509.02938, MNRAS accepted)
- ➔ Clark, Lewis & Scott 2015b (arXiv: 1509.02941, MNRAS accepted)
- ➔ Adams, Aslanyan, Bringmann, Clark, Easter, Lewis, Price & Scott (will appear on the arXiv today!)

- The primordial Universe
- ‘Ultracompact’ dark matter halos
- Constraining abundance of rare objects
- Implications on the properties of the early Universe

Primordial Fluctuations

Small fluctuations in the density of the early Universe seeded structure formation.



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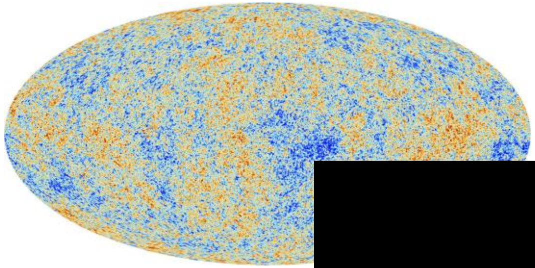

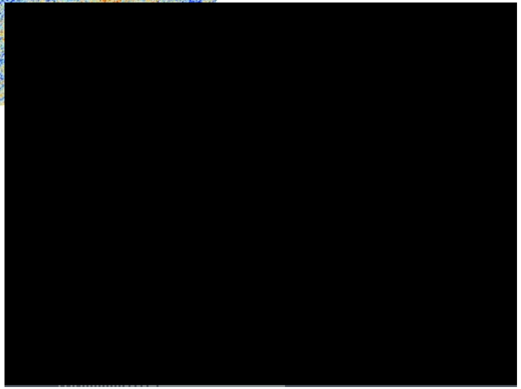

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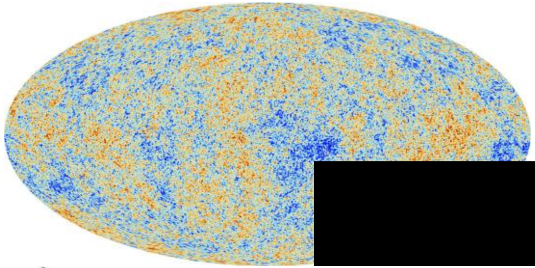

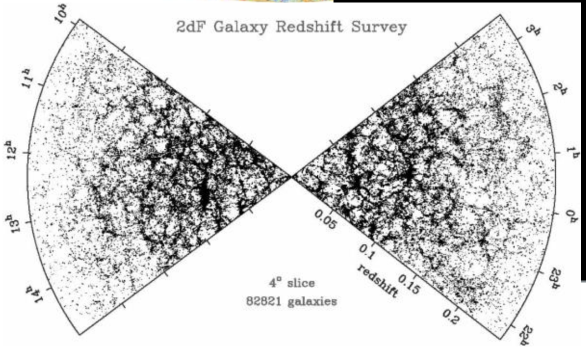

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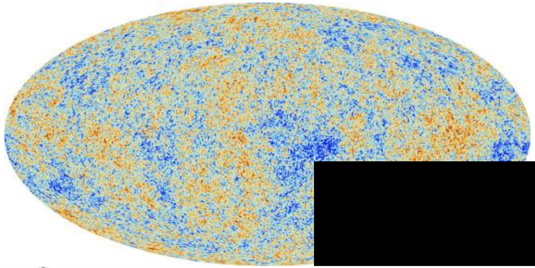

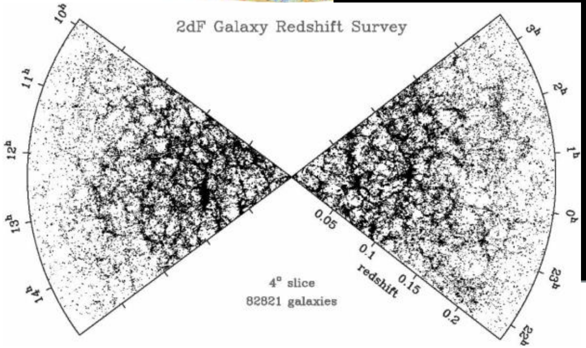

The initial perturbations appear to have:

- Gaussian-distributed amplitudes:

$$\mathrm{pdf}(\delta) = \frac{1}{\sqrt{2\pi\sigma^2_{\chi,H}(z_\mathrm{X}, R)}} \exp\left(-\frac{\delta^2}{2\sigma^2_{\chi,H}(z_\mathrm{X}, R)^2}\right)$$

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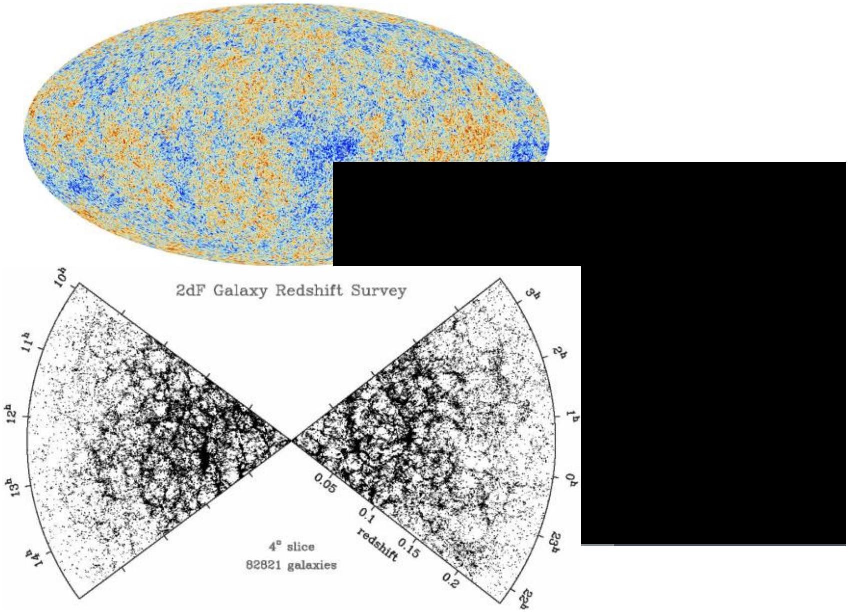

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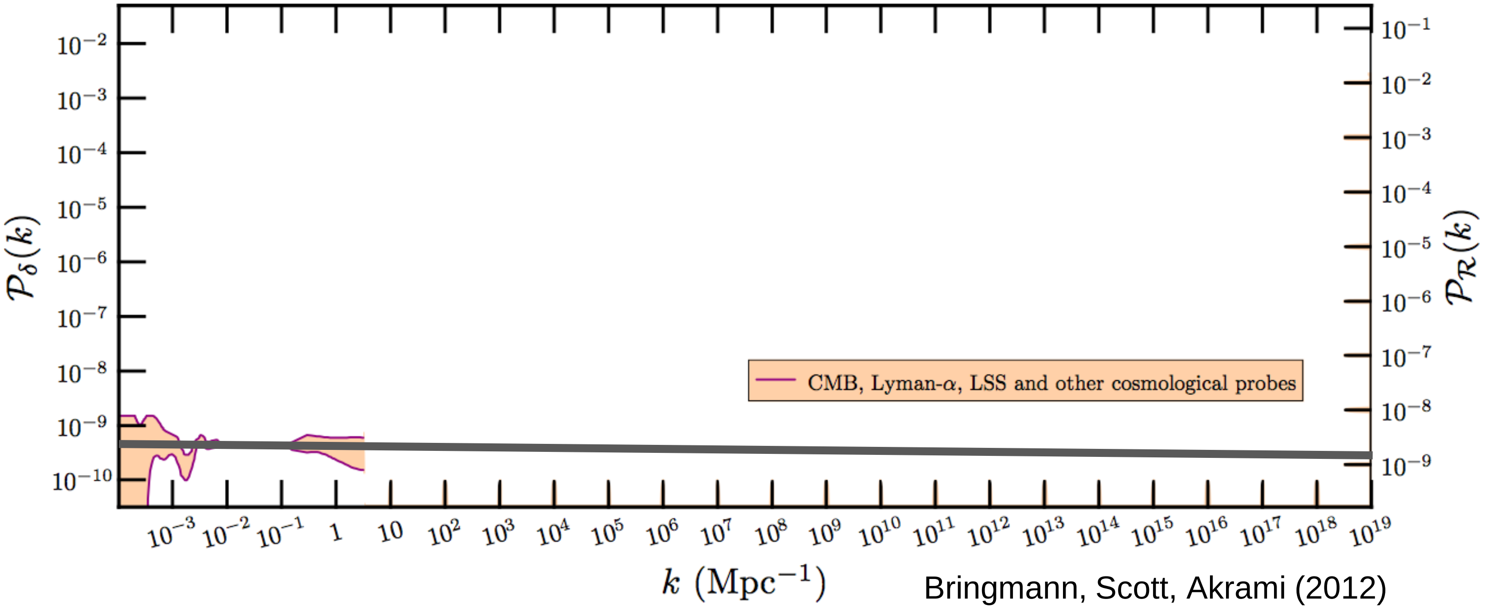
- *about* the same **power** on all scales, characterised by a spectral index: $n_s \approx 1$

$$\mathcal{P}_\delta(k) \propto k^{n_s - 1}$$

Primordial Fluctuations



Bringmann, Scott, Akrami (2012)

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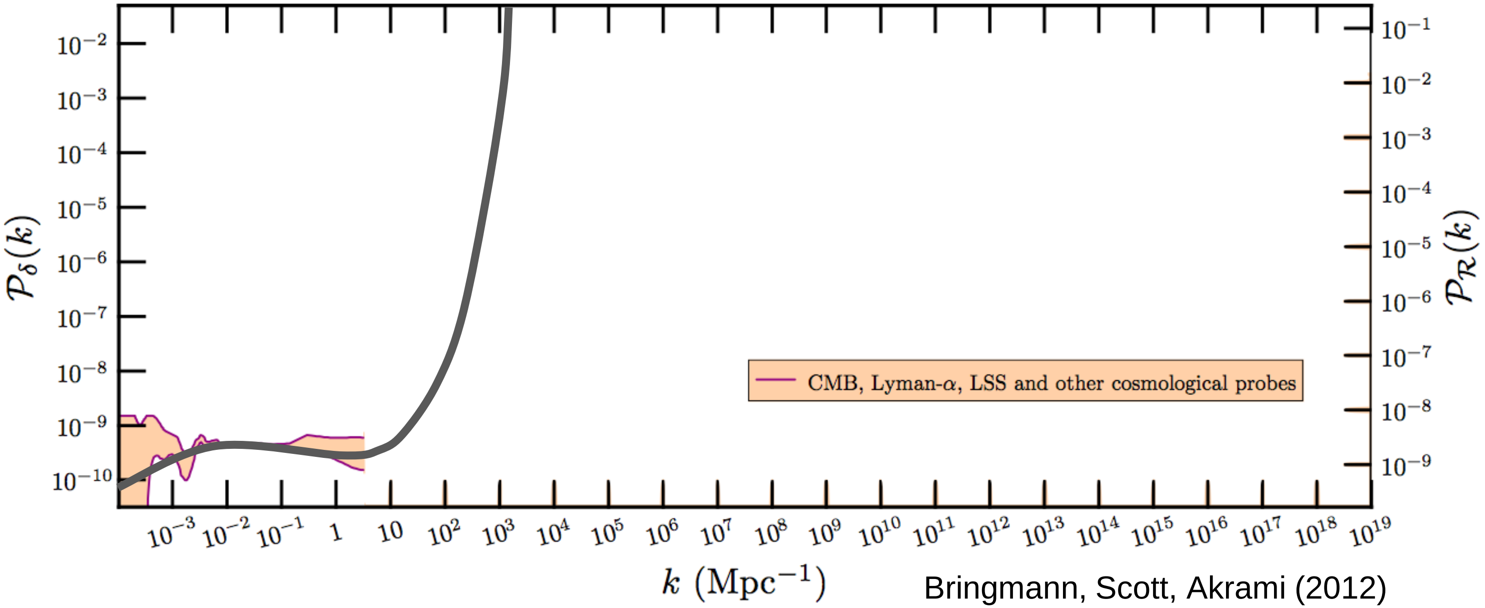

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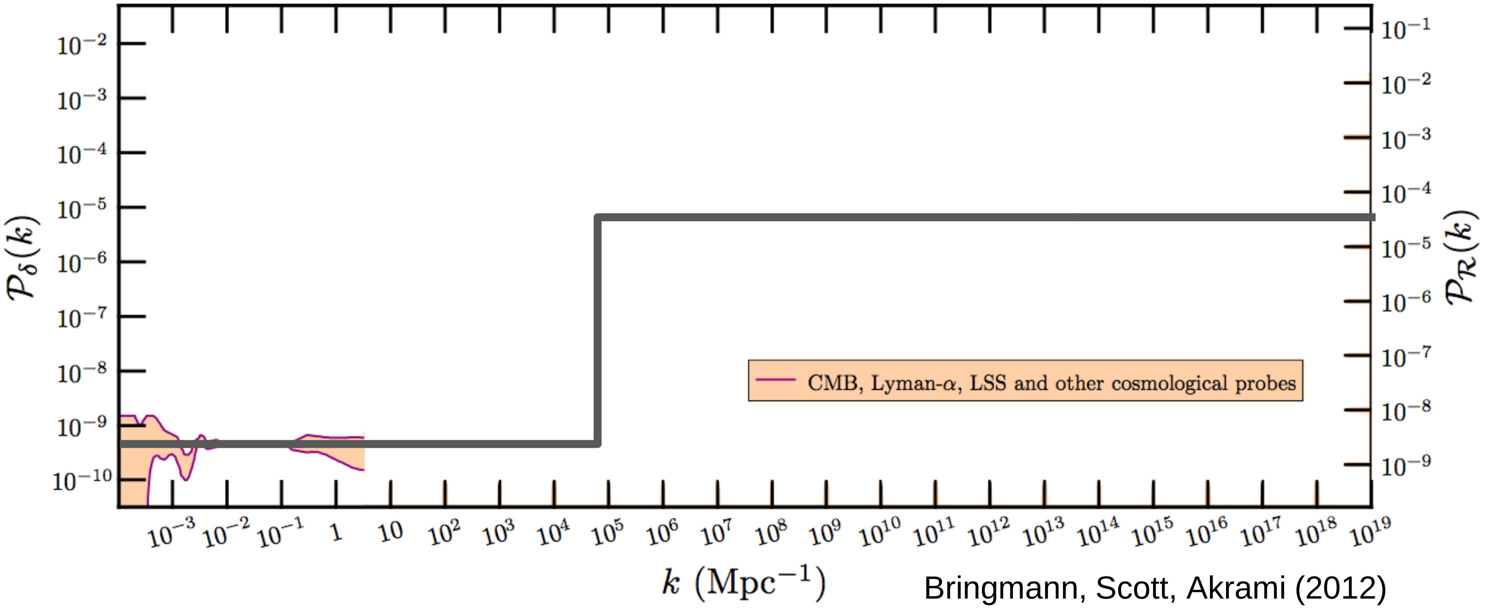

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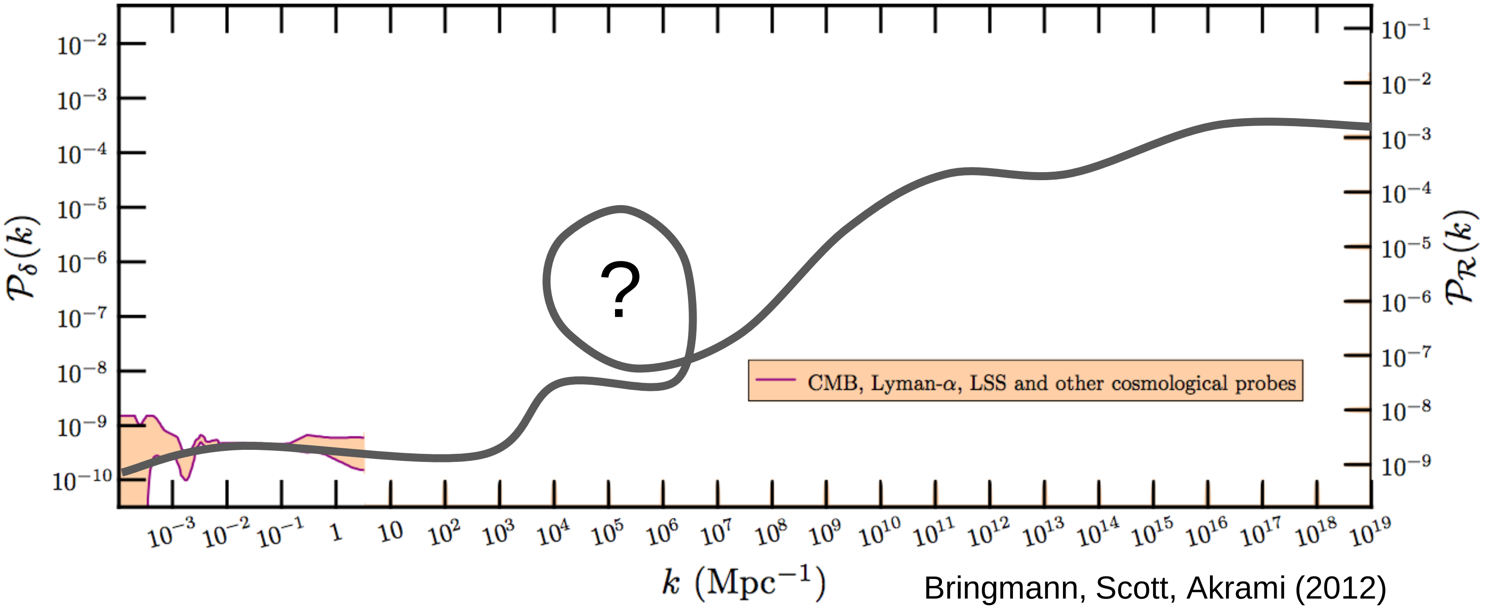

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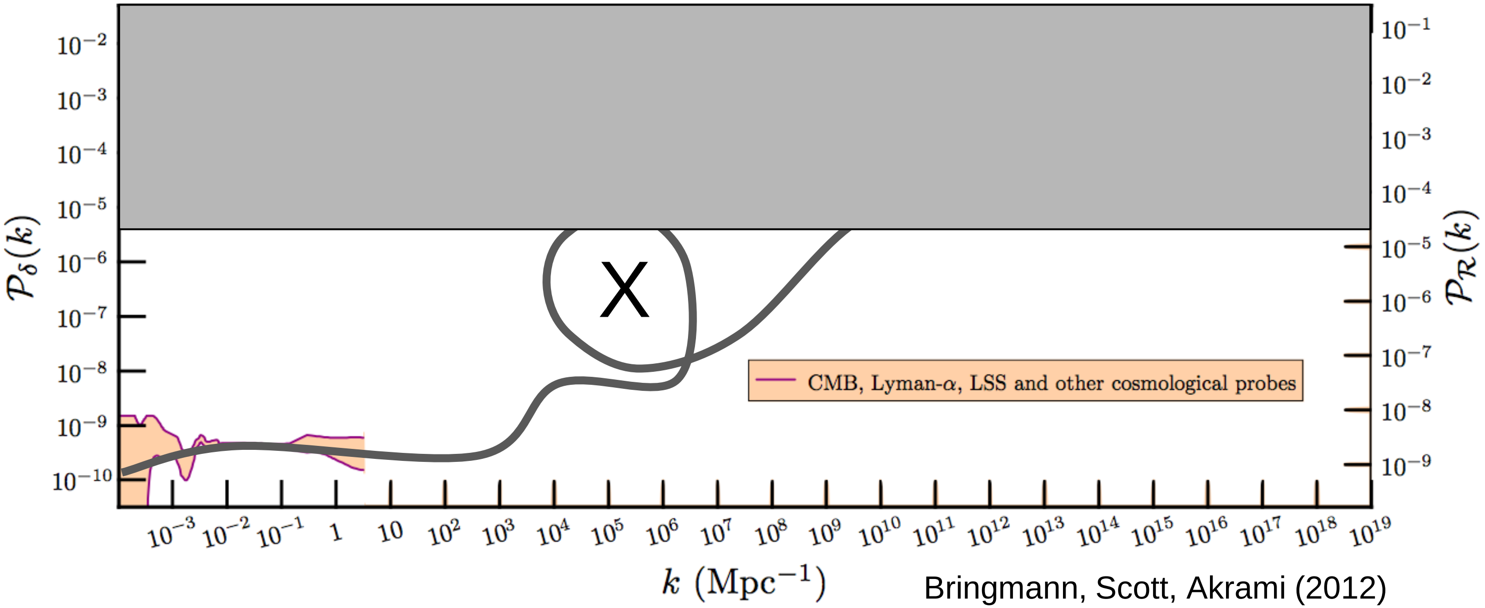

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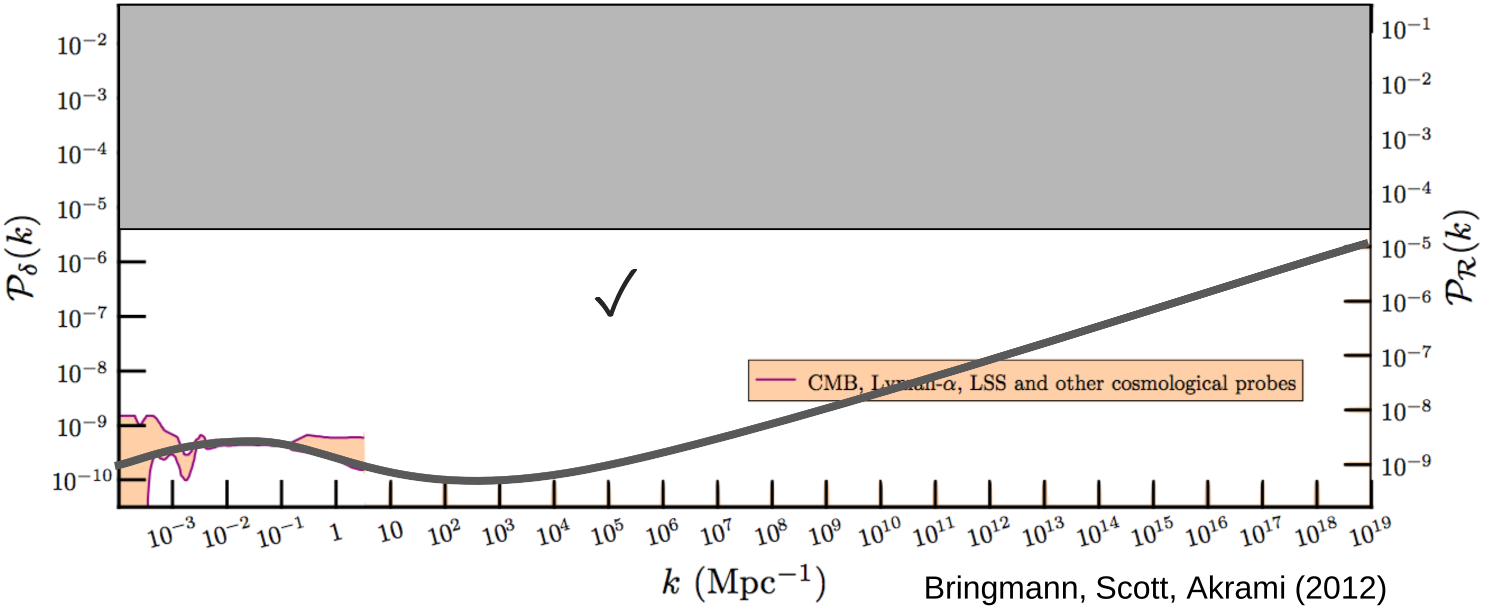

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Ultracompact Minihalos

Requirements for formation

- A fluctuation of amplitude $10^{-3} < \delta < 0.3$

- Isolated formation (seeded well before matter-radiation equality) - providing purely radial infall

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Properties

- Extremely dense dark matter halo: an *Ultracompact Minihalo* (UCMH)

- $\boldsymbol{\rho} \propto r^{-2.25}$ compared to standard $\boldsymbol{\rho} \propto r^{-1}$

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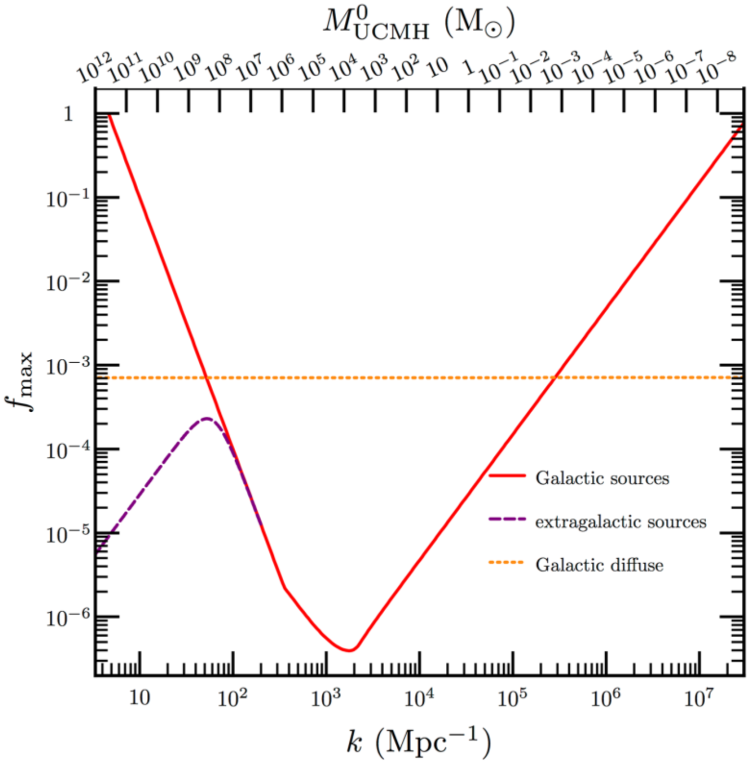
UCMHs are *very* useful

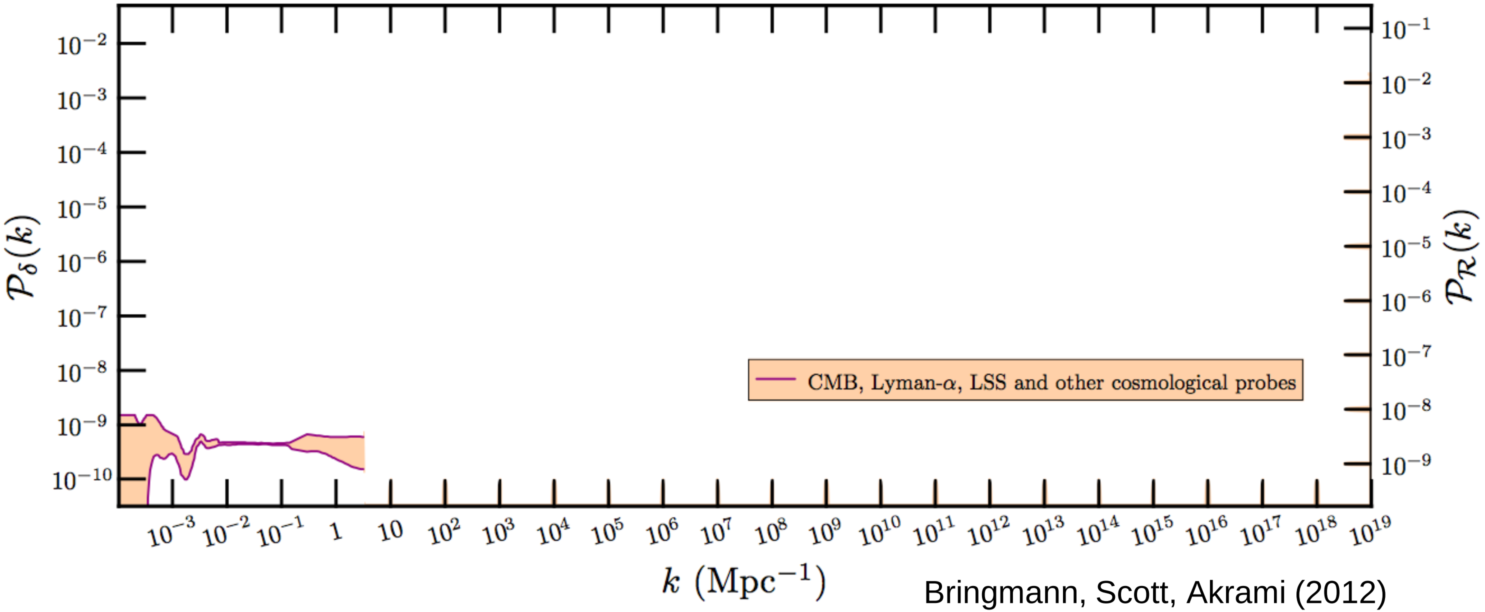
- Persist through to present day
- Mass maps to scale.
  Abundance maps to primordial power.
- Much more likely to form than PBHs
- Very good indirect DM detection targets

Constraining UCMHs

Gamma-ray Sources



Implied Constraints on the Early Universe



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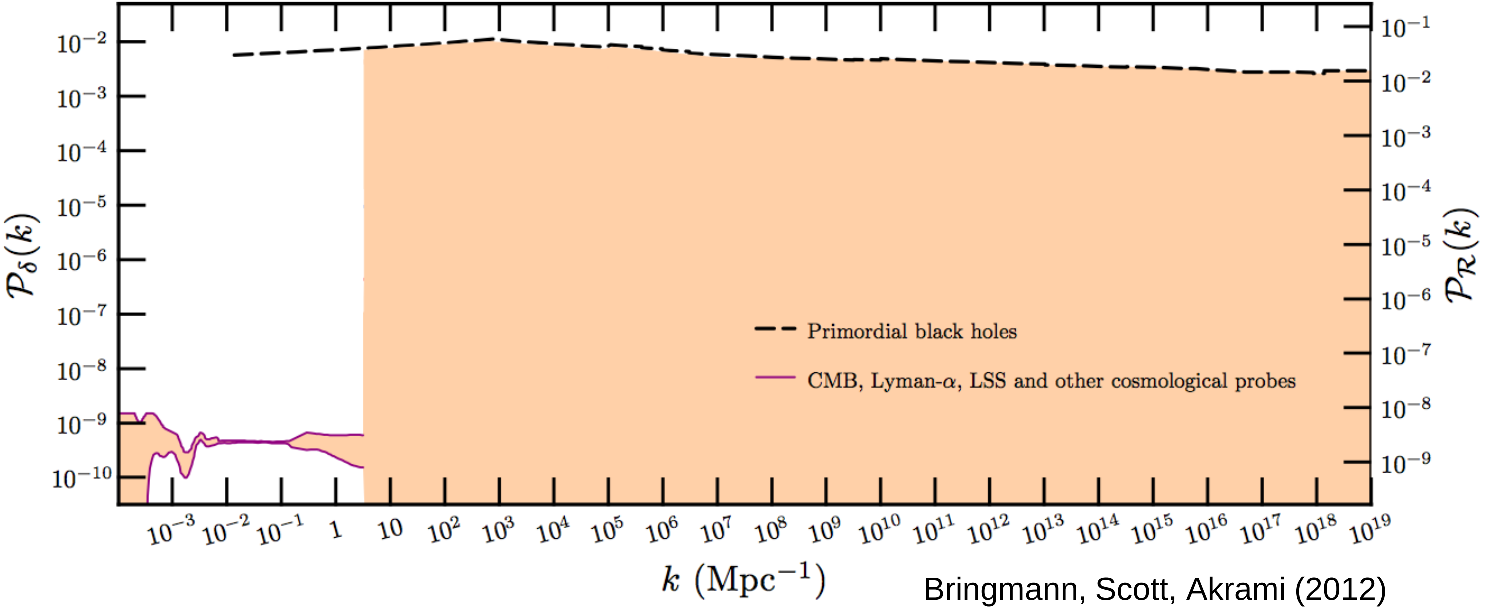

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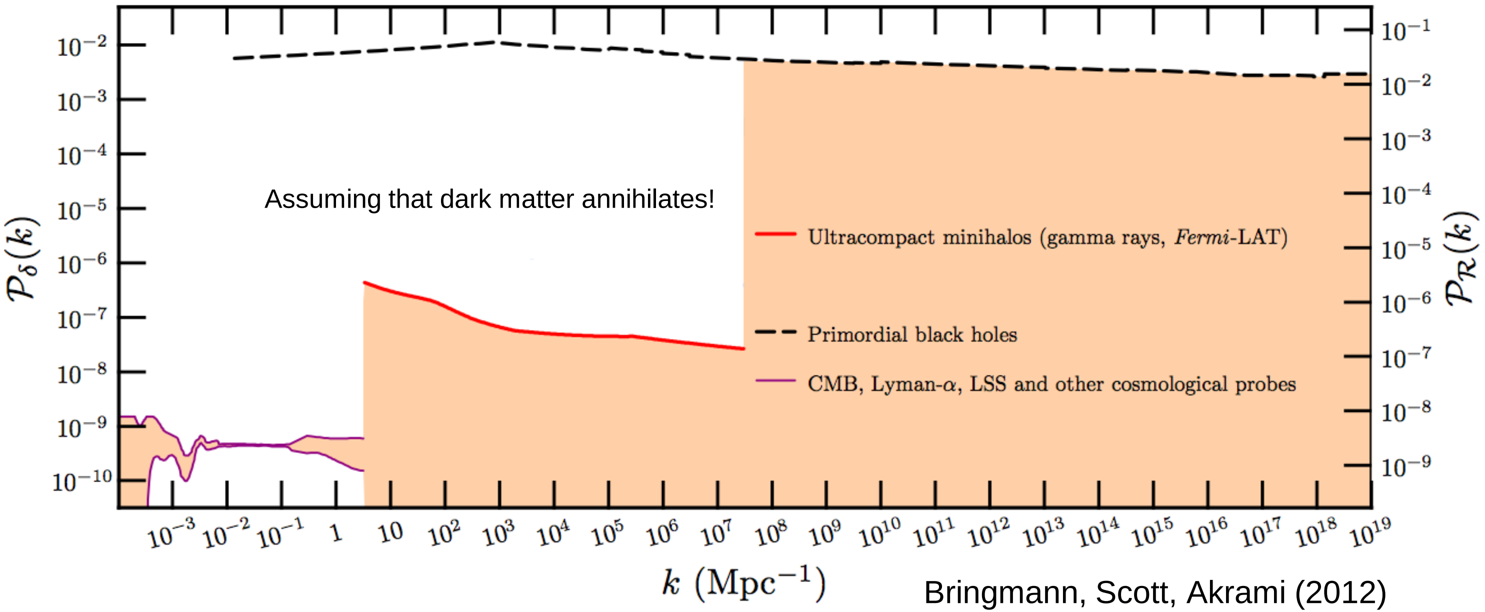

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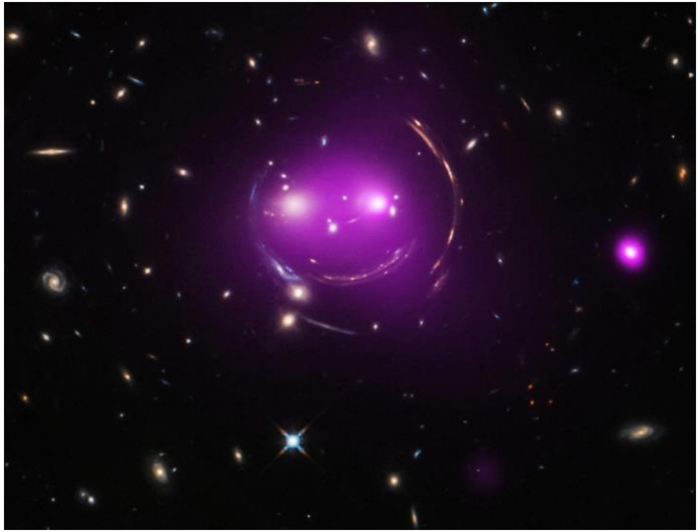
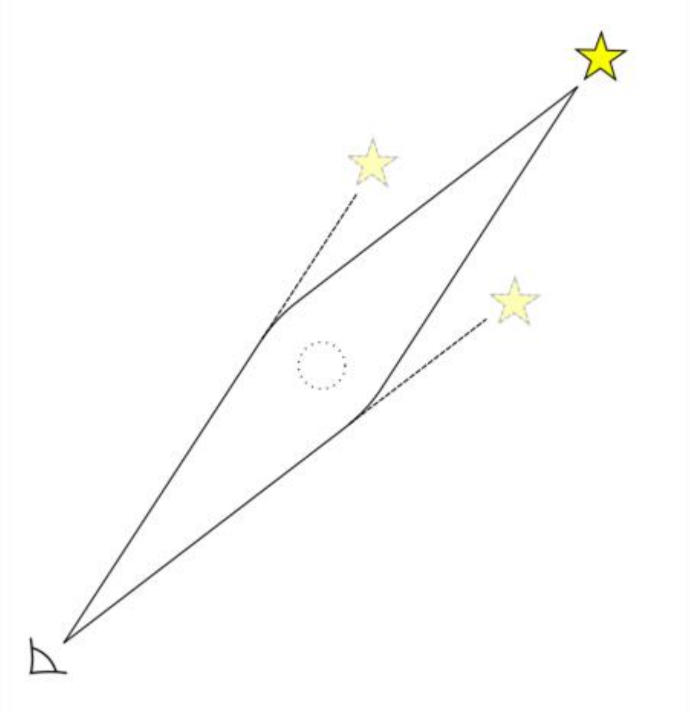
Gravitational Lensing

- Least ‘sensitive’: Strong Lensing





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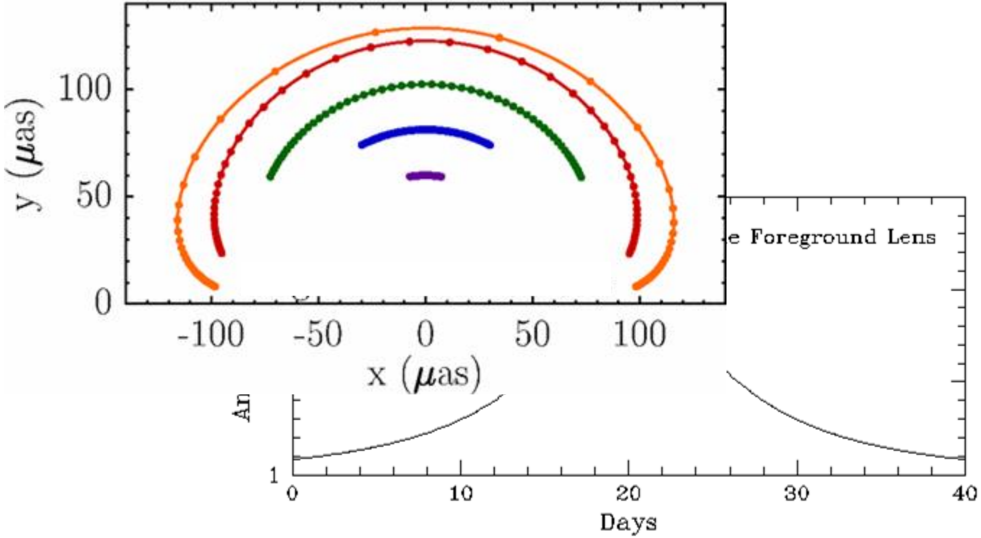

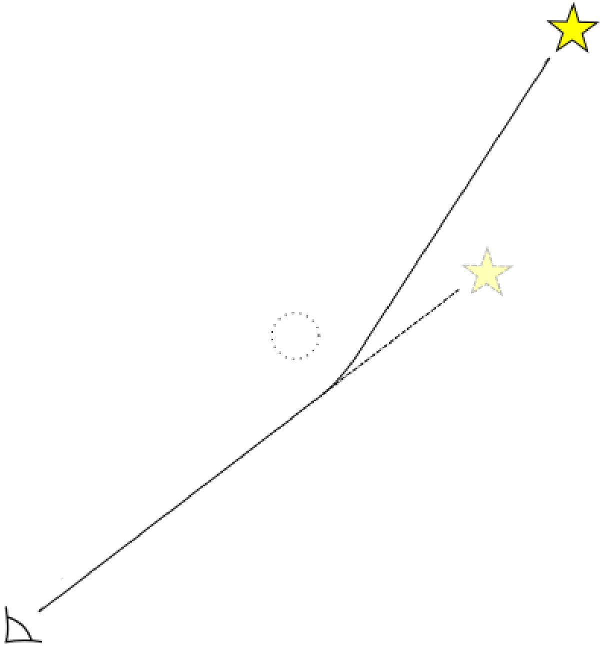

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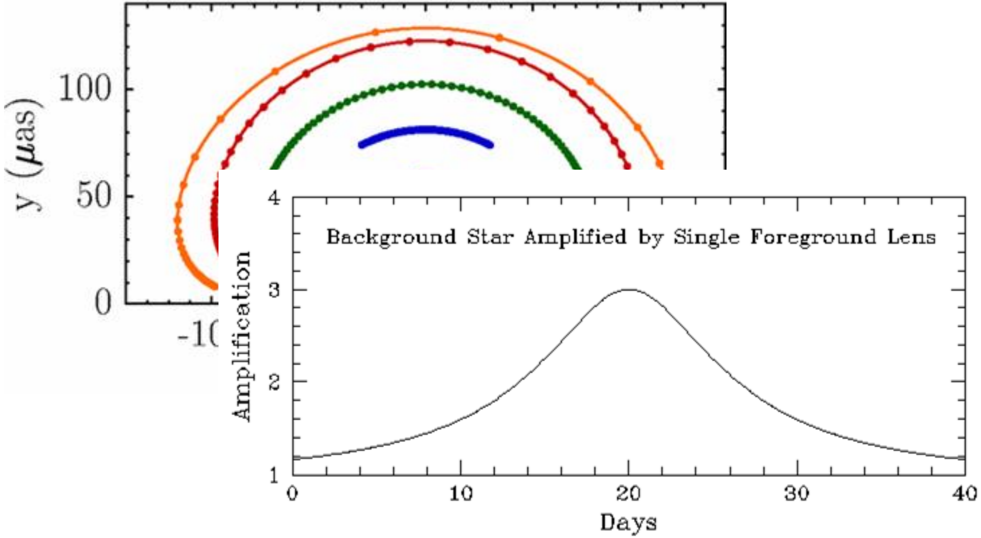

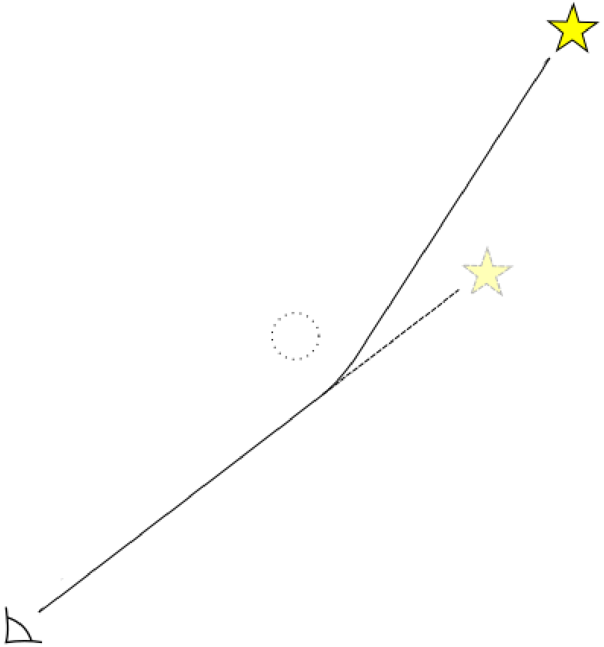

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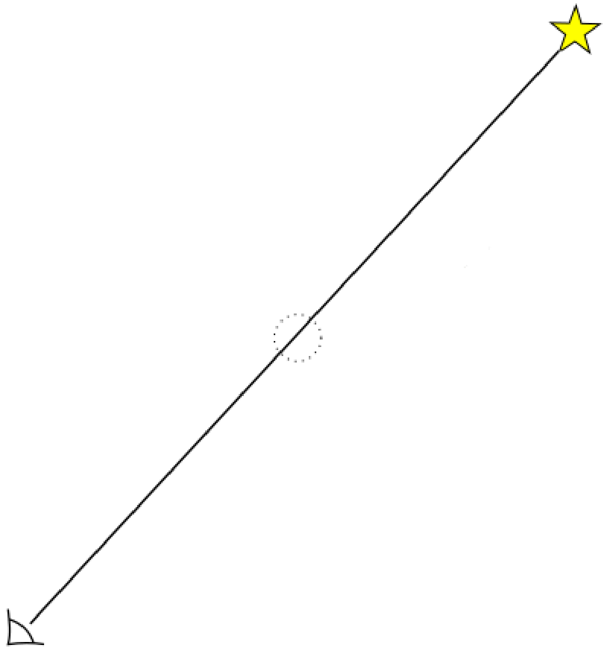
- Negligible deflection: Time-delay microlensing

$$\tau = \frac{1}{c}\int_C ds - \frac{2}{c^3}\int_C \varphi(r)ds$$

Light travel time



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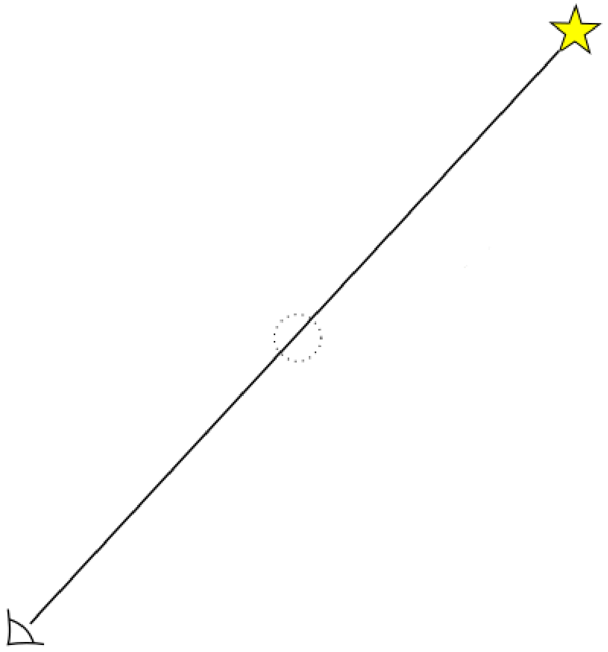

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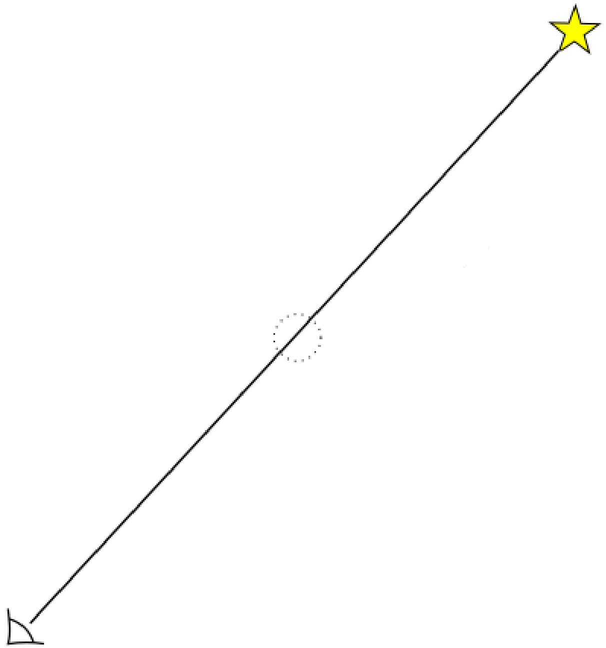
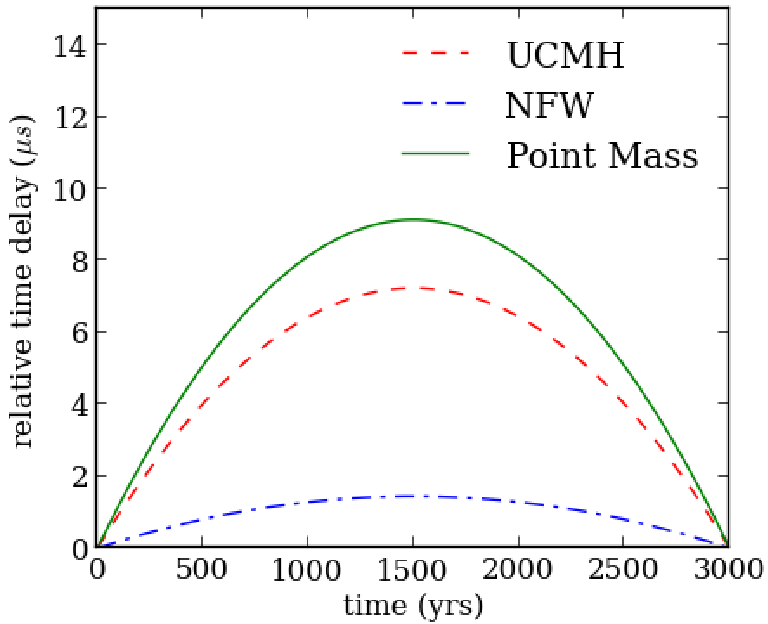
Newtonian gravitational potential



Pulsar Timing

Single lensing event



Clark et al. (2015), arXiv: 1509.02938

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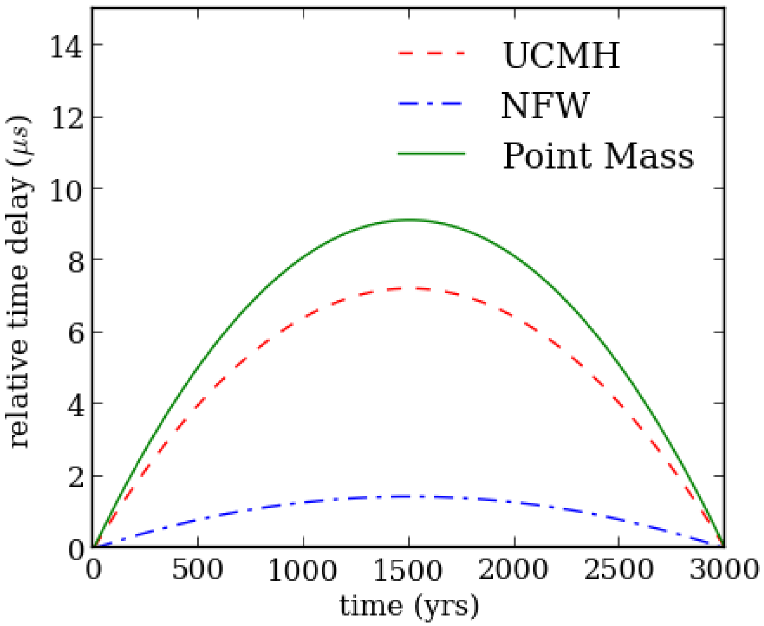
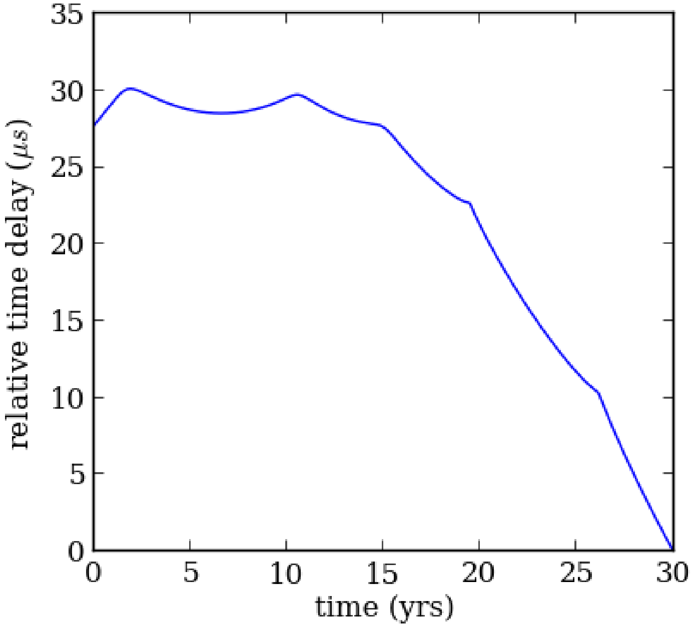


Population of lenses



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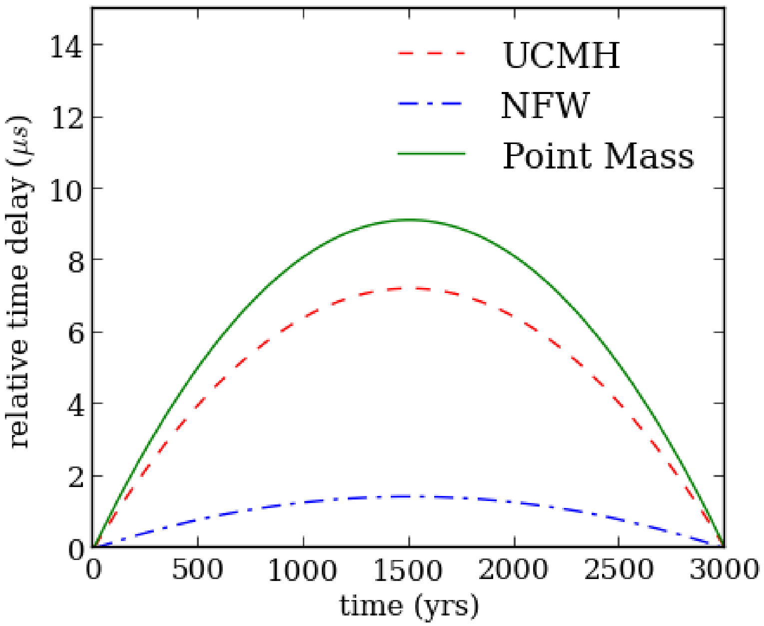

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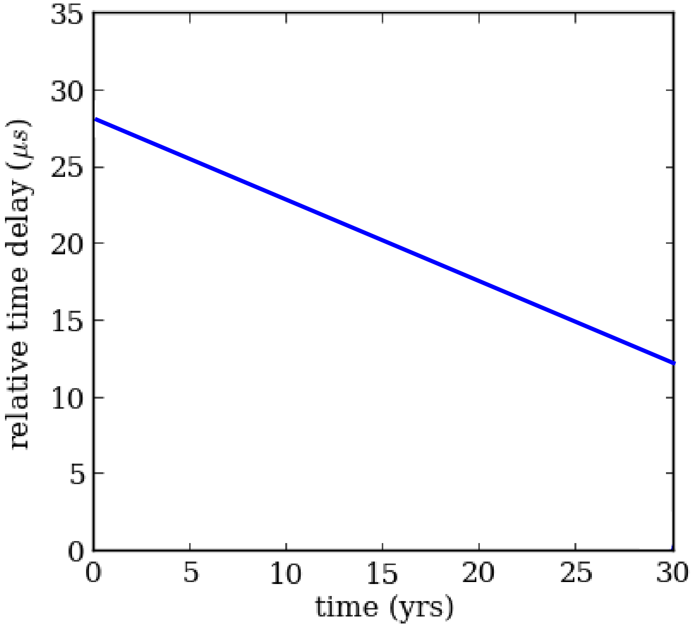

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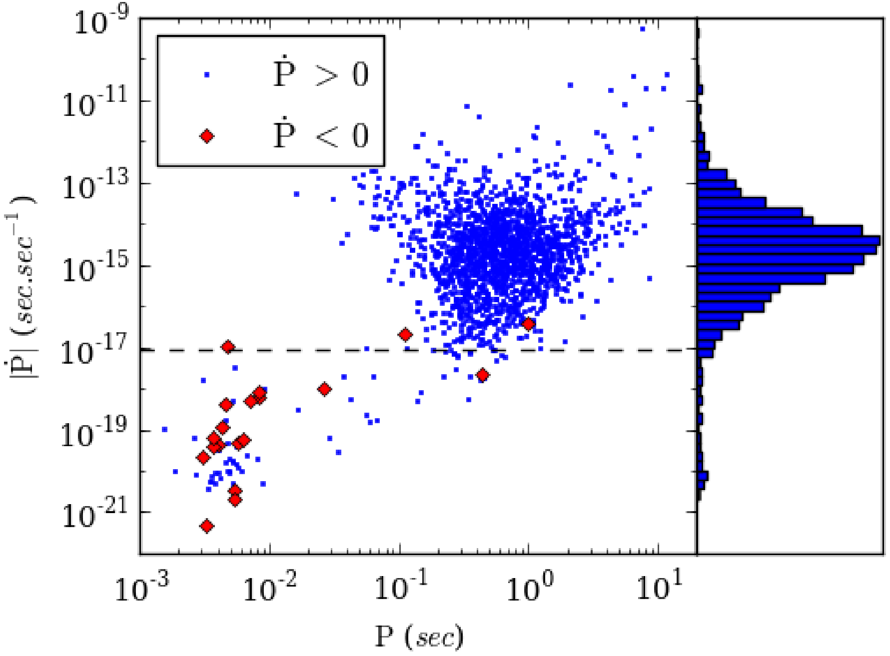

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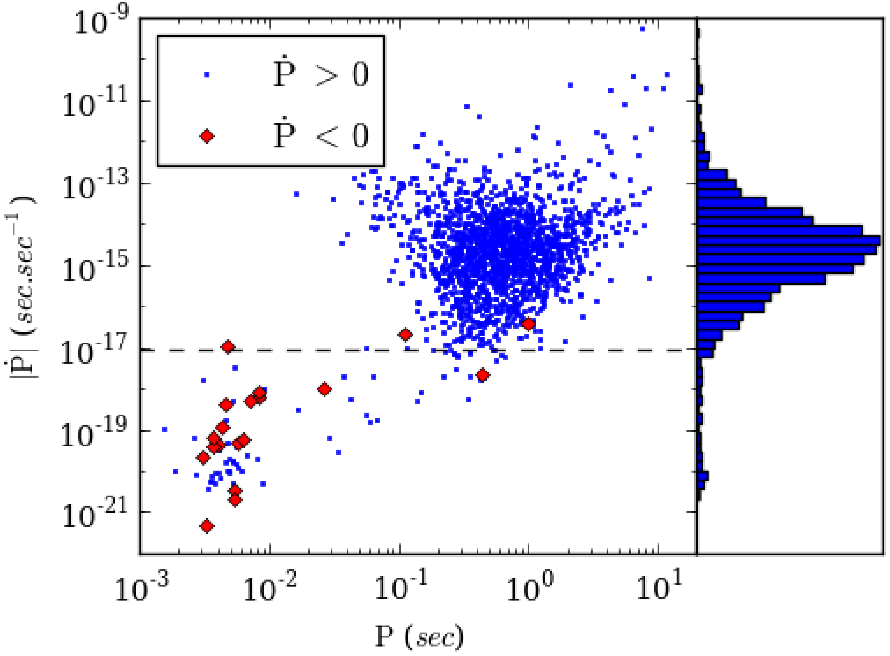

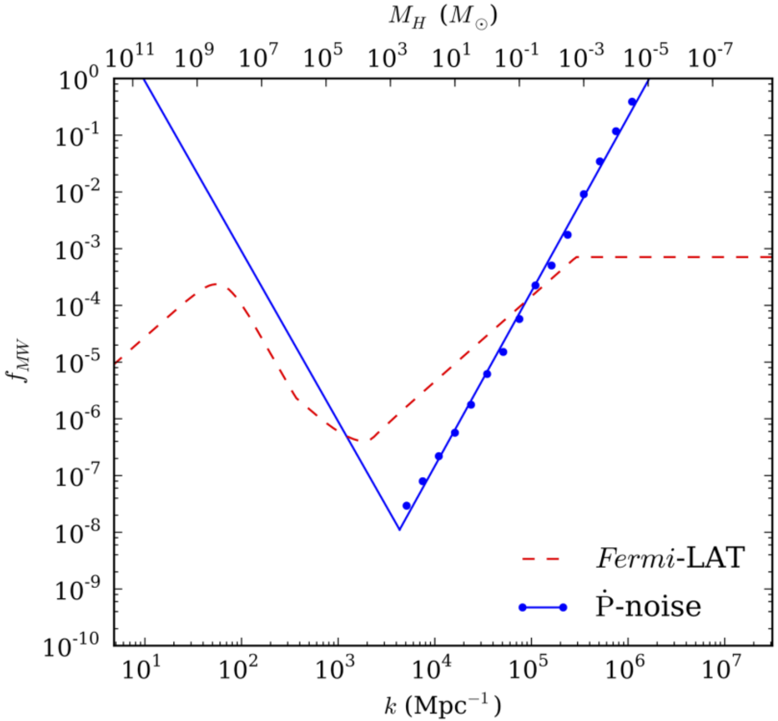

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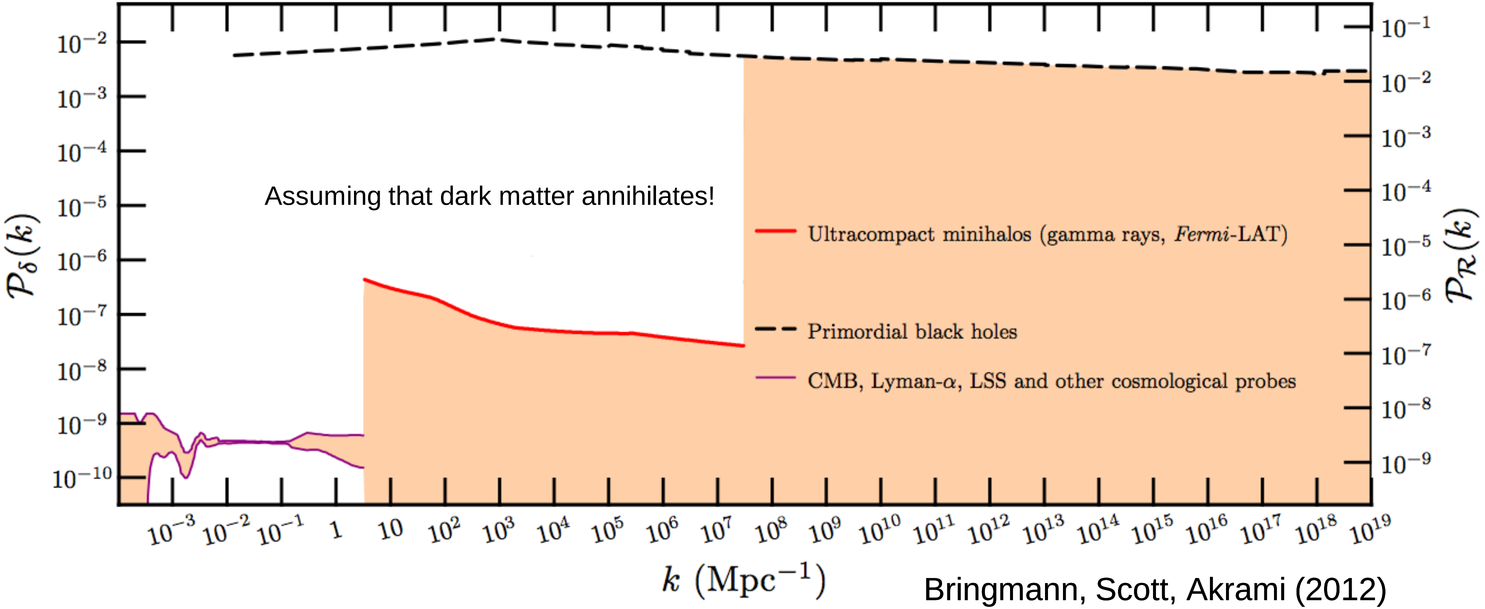

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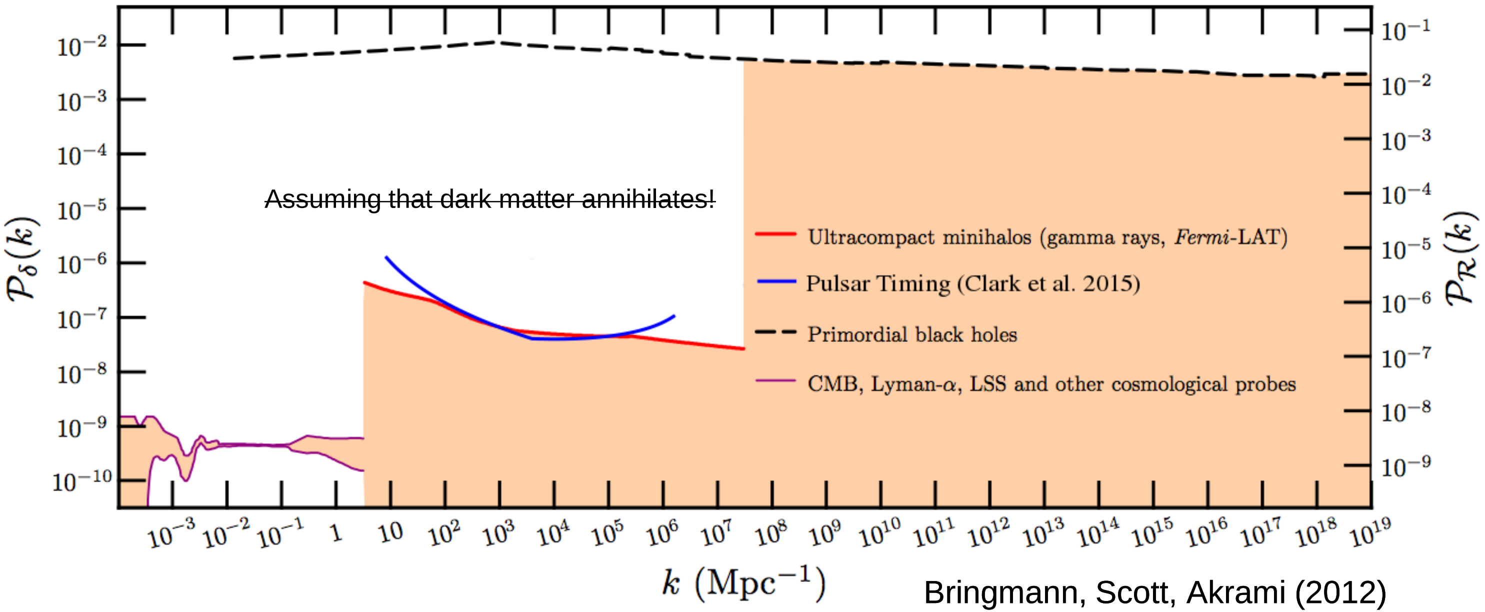

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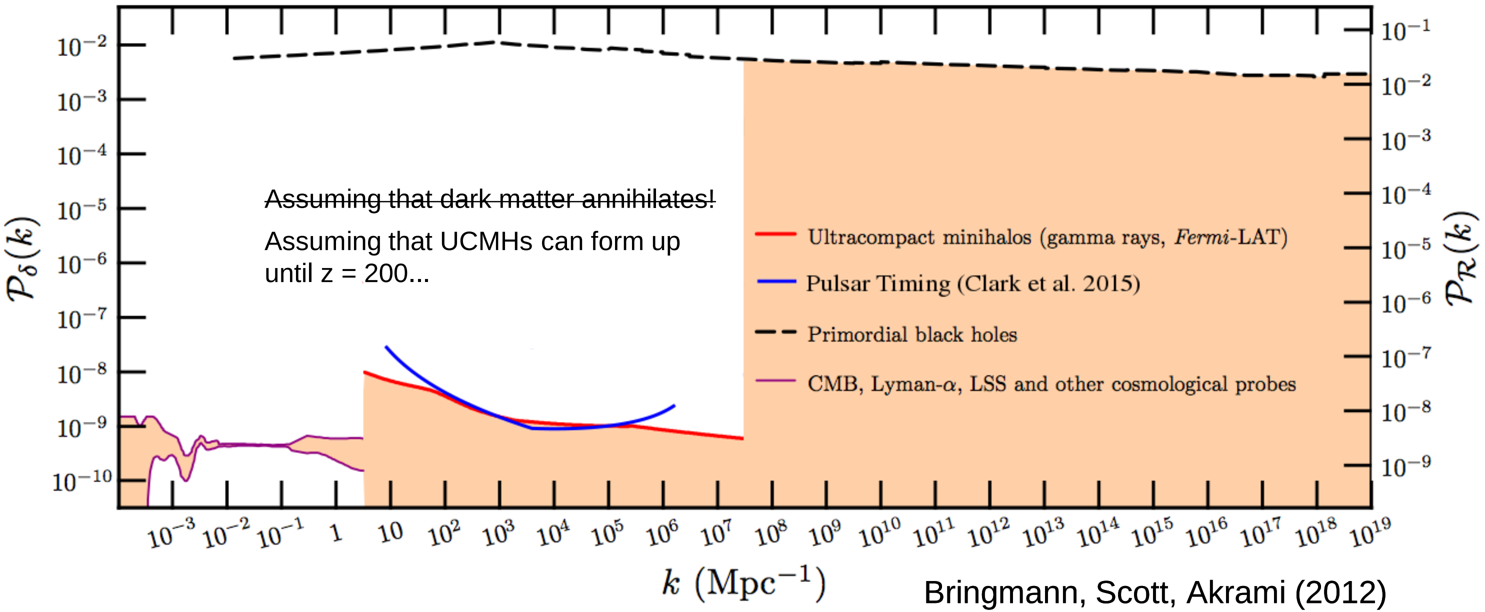

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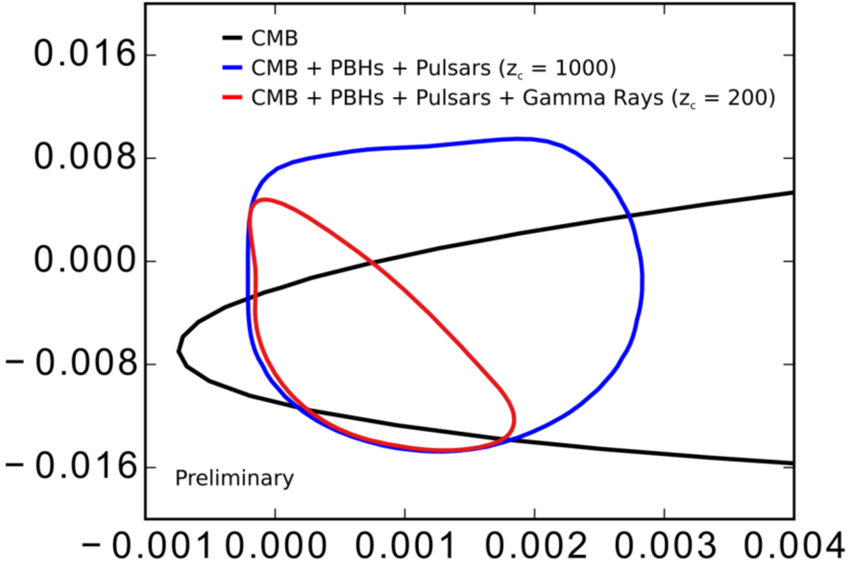
Implied constraints (95% CL)

- Primordial power spectral index, and higher order running



$dn_s/d\ln k$

$d^2n_s/d\ln k^2$

Aslanyan et al. (In prep)

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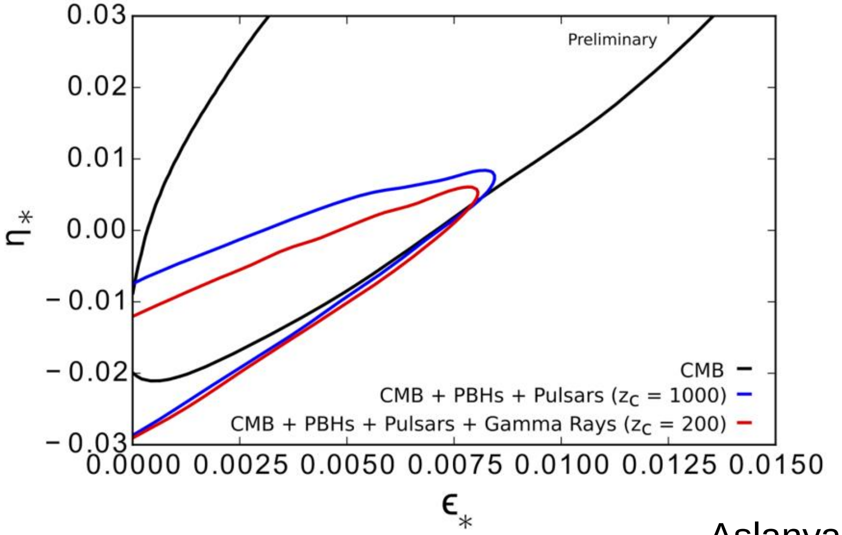
$$\epsilon_* = \frac{M_{\rm Pl}^2}{2}\left(\frac{V'}{V}\right)^2,$$

$$\eta_* = M_{\rm Pl}^2 \frac{V''}{V},$$



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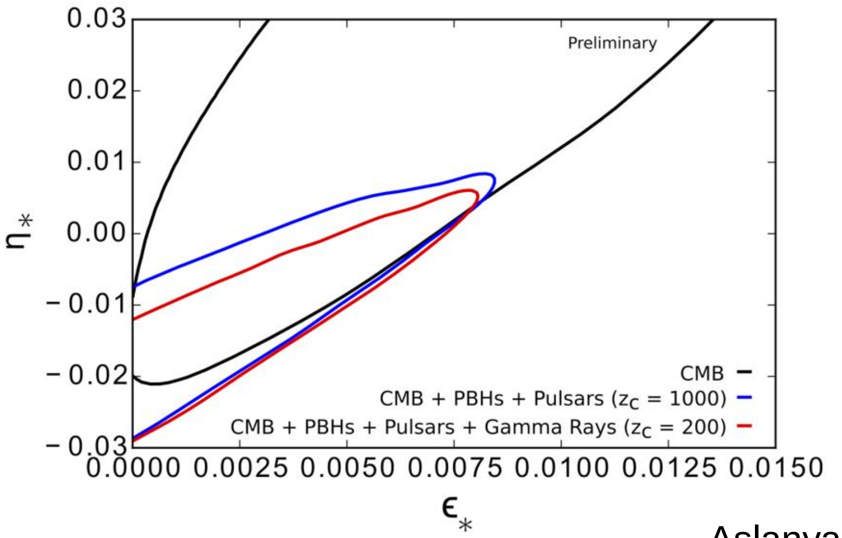
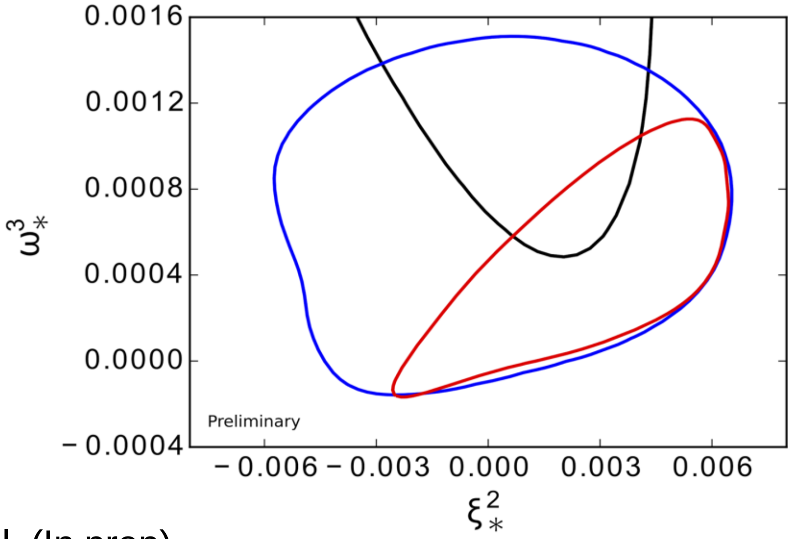
$$\epsilon_* = \frac{M_{\mathrm{Pl}}^2}{2}\left(\frac{V'}{V}\right)^2, \qquad \xi_*^2 = M_{\mathrm{Pl}}^4 \frac{V'V'''}{V^2},$$

$$\eta_* = M_{\mathrm{Pl}}^2 \frac{V''}{V}, \qquad \omega_*^3 = M_{\mathrm{Pl}}^6 \frac{V'^2 V''''}{V^3},$$





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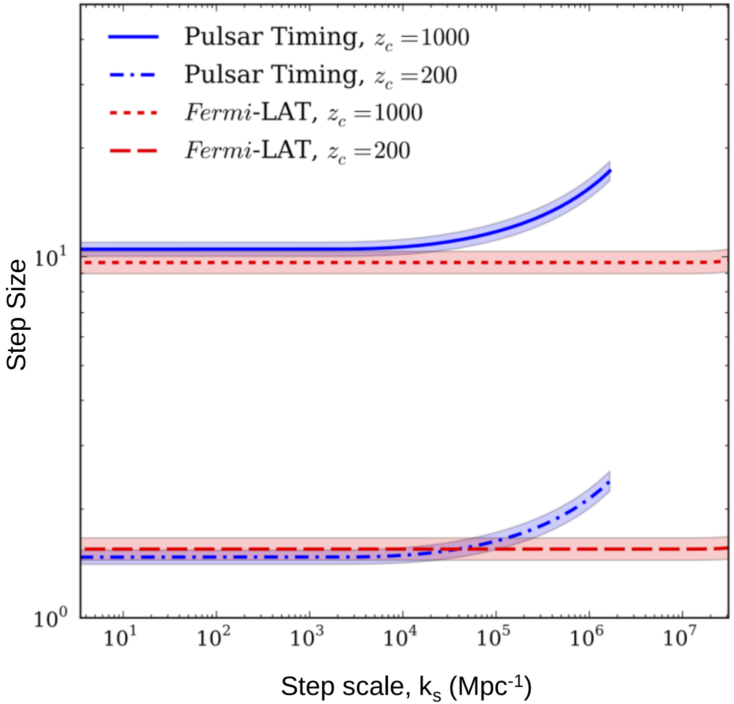

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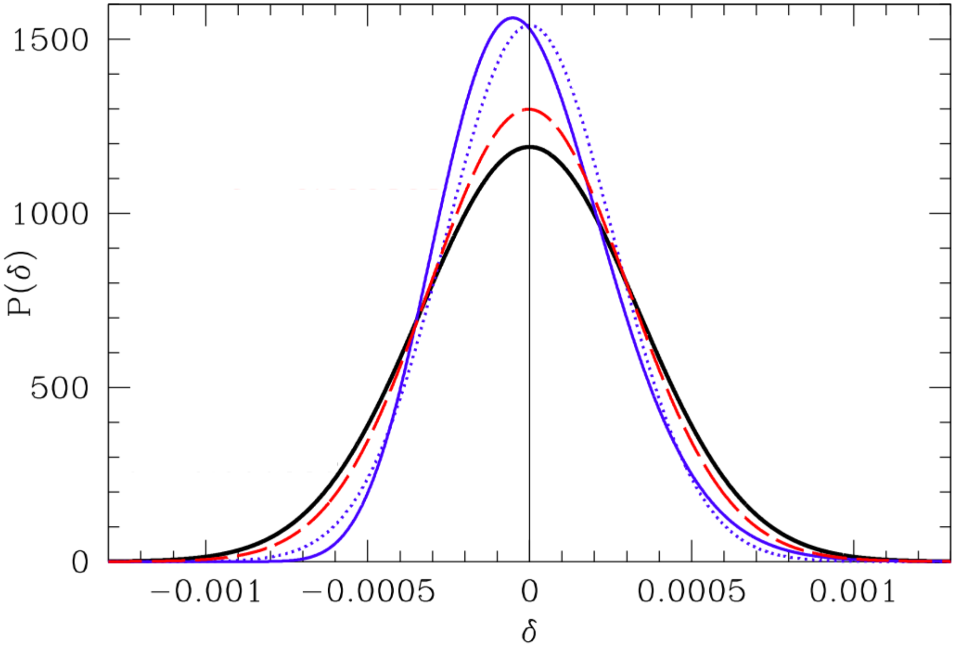
  $f_{NL} < O(10)$ (PBHs)

  $f_{NL} < O(100)$ (UCMHs)



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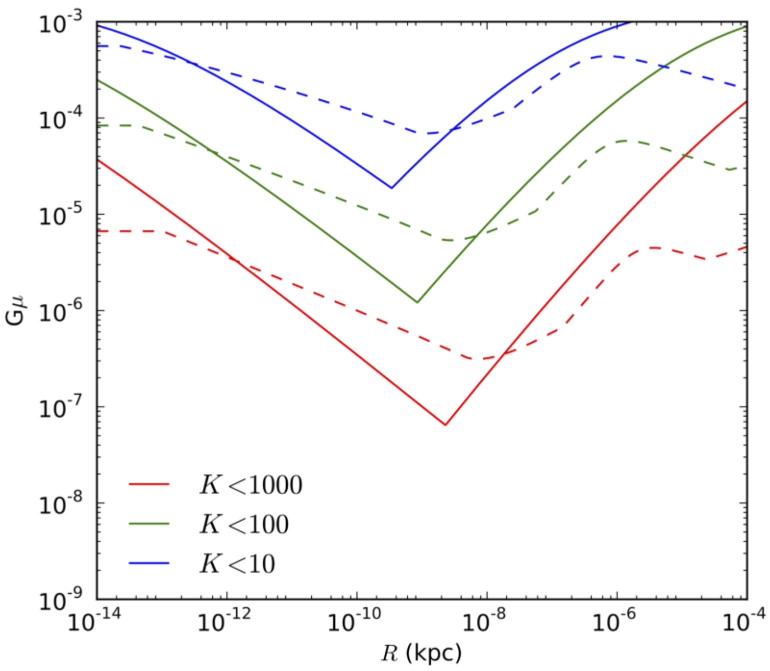
- Cosmic string loop tension:
  $G\mu < 1.7 \times 10^{-7}$ (CMB)
  $G\mu < 6.5 \times 10^{-8}$ (K < 1000)
  $G\mu < 1.5 \times 10^{-6}$ (K < 100)



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Summary

- Should significant additional primordial power be available on small scales, dark matter ‘Ultracompact Minihalos’ would be expected to form.

- UCMHs are fantastic dark matter structures for both indirect detection & lensing.

- These rare objects provide a new avenue of investigation into the early Universe.

- This is all new! More work is needed, and will significantly improve existing results (N-body simulation, improving UCMH & PBH abundance limits, cosmic string loop K-factor).