Title: Physics beyond the Horizon

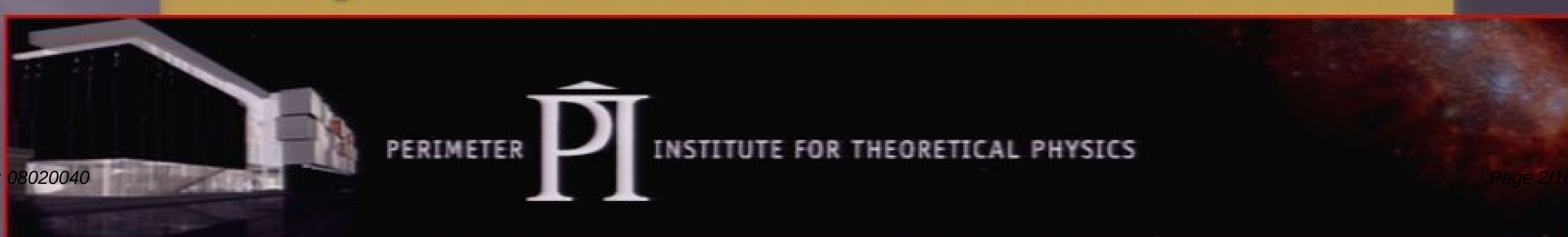
Date: Feb 20, 2008 02:00 PM

URL: http://pirsa.org/08020040

Abstract: The history of human knowledge is often highlighted by our efforts to explore beyond our apparent horizon. In this talk, I will describe how this challenge has now evolved into our quest to understand the physics at/beyond the cosmological horizon, some twenty orders of magnitude above Columbus\' original goal. I then recount how the study of physics on the horizon scale has led to the successful development of inflationary cosmology, and how we can use the Integrated Sachs-Wolfe effect in the Cosmic Microwave Background to probe cosmological physics, such as late-time inflation, the nature of gravity, and primordial non-gaussianity on the horizon scale.

PHYSICS BEYOND THE HORIZON

Niayesh Afshordi



Perimeter Institute Observatory

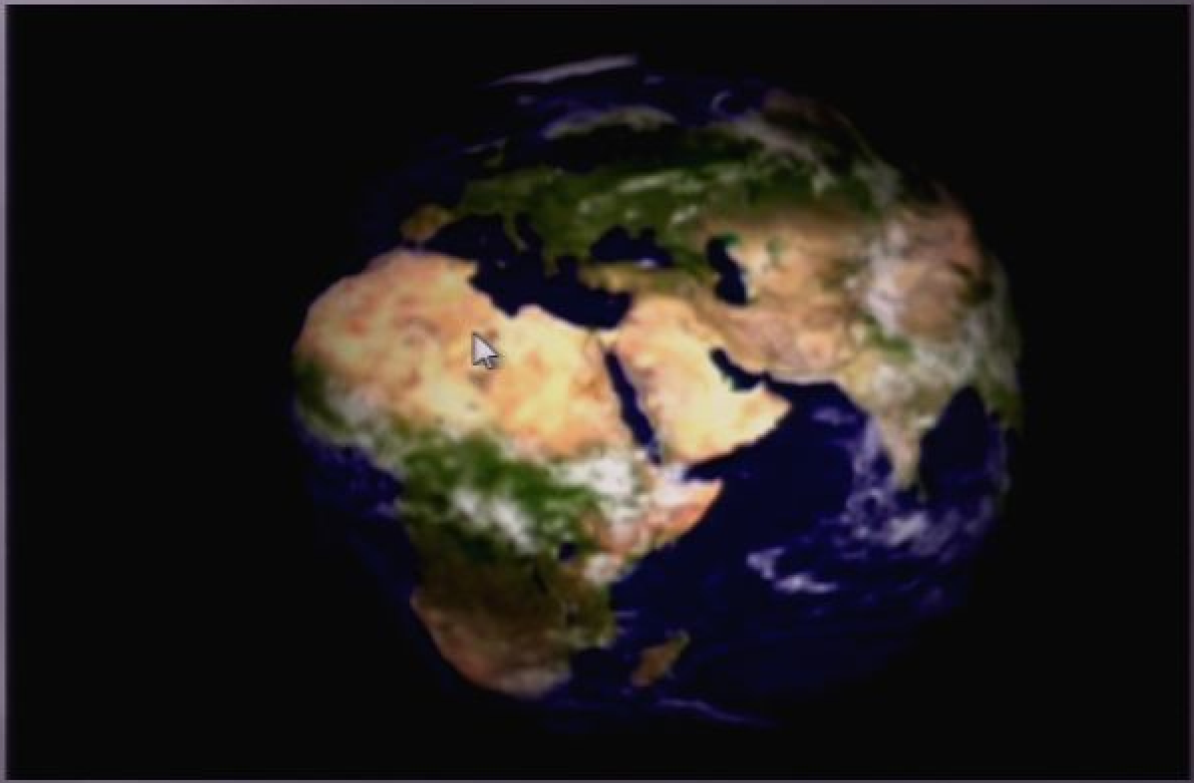
where Stars meet Strings

Perimeter Institute Observatory: the construction ☺

Cosmography vs Cartography

Ptolemy's 150 AD World Map, 10^9 cm

Cosmography vs Cartography



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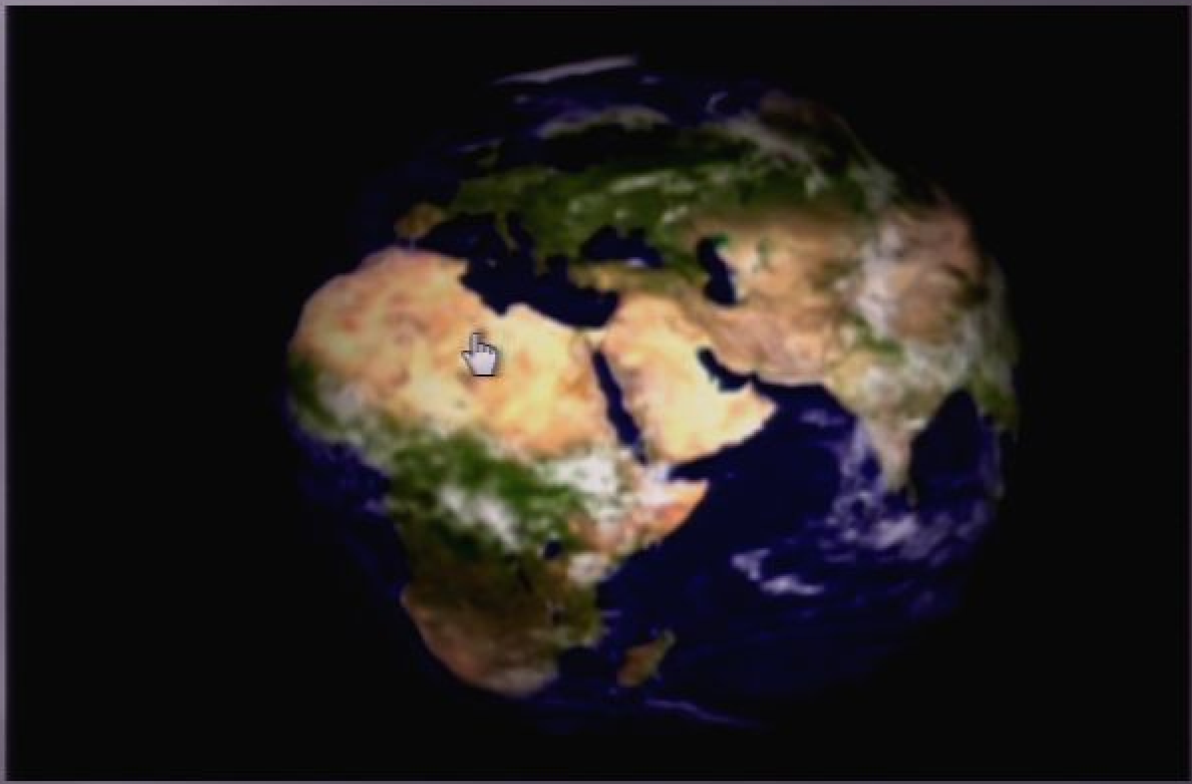

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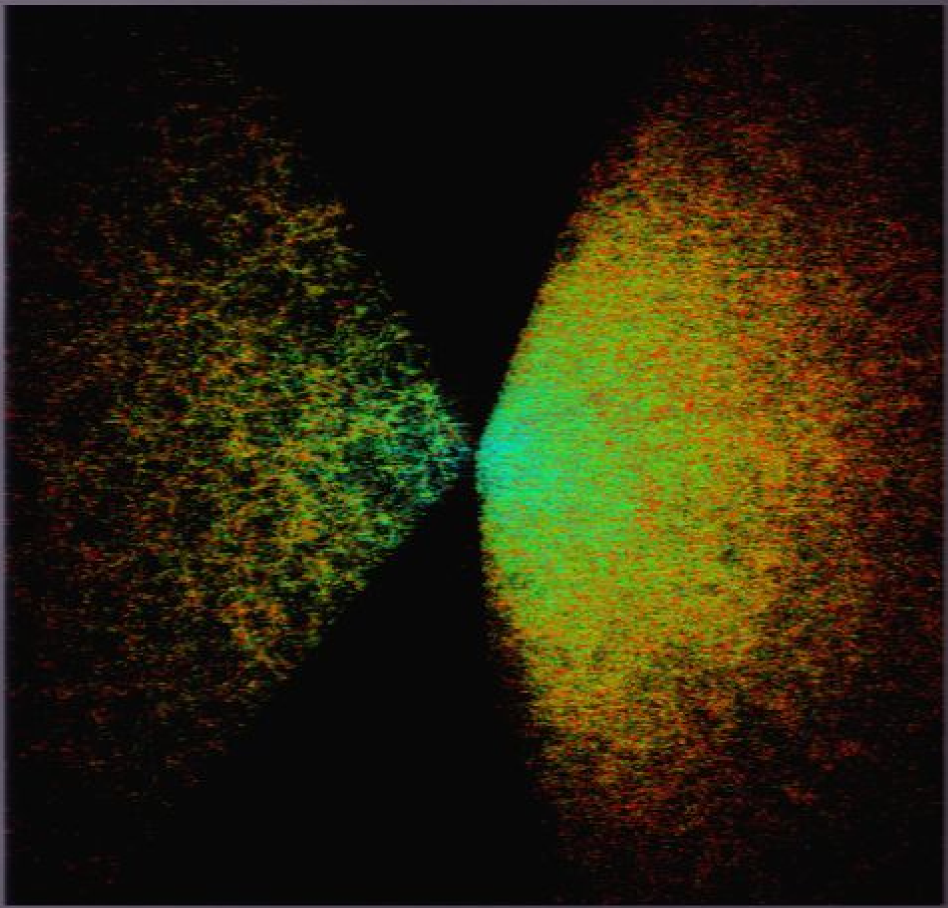

Sloan Digital Sky Survey: 1 Gpc ~ 10^{28} cm (due to Mike Blanton)

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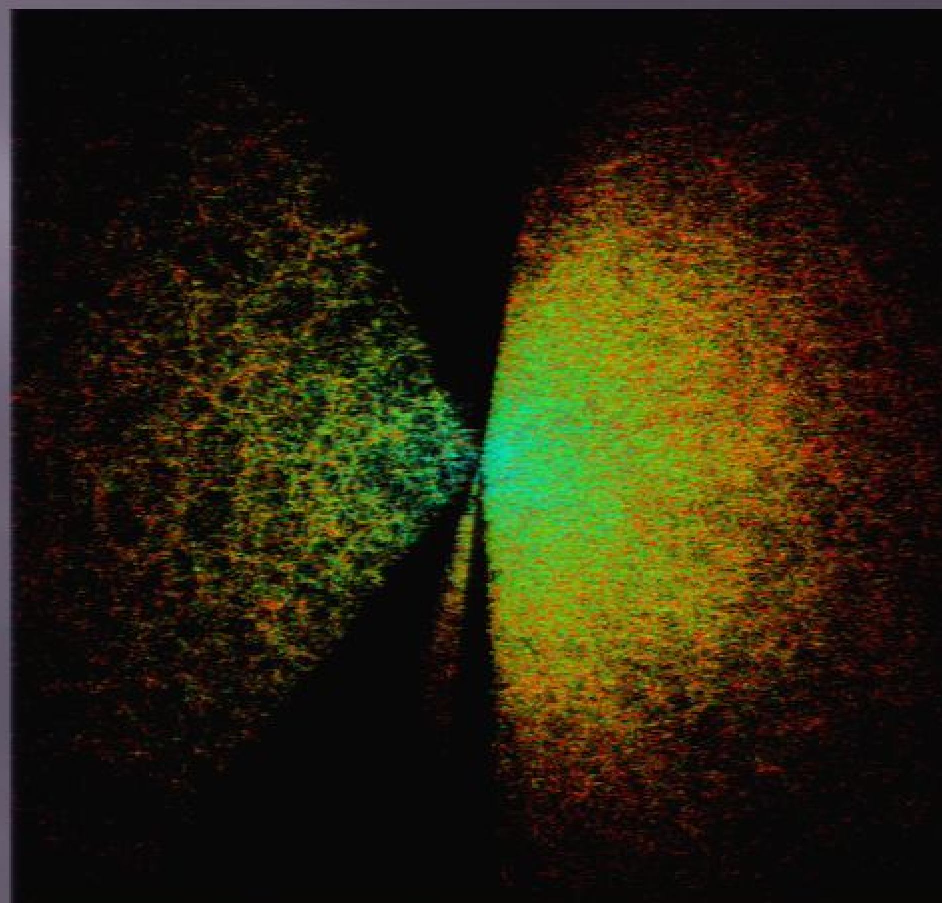

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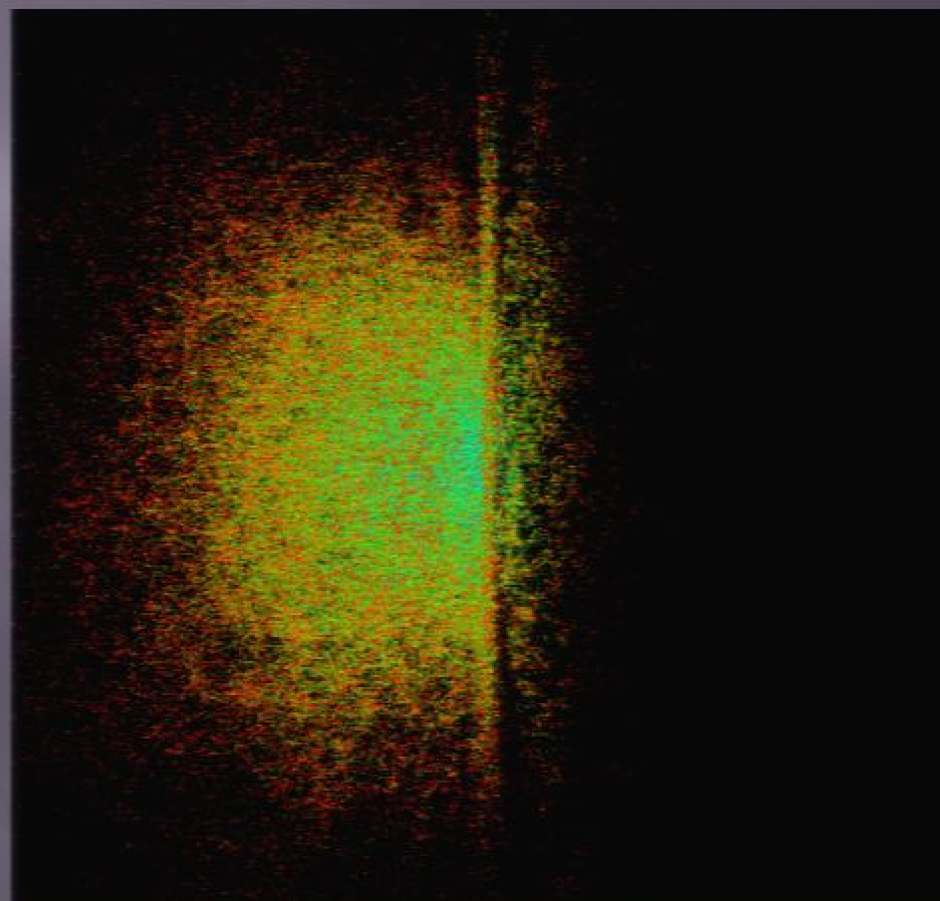

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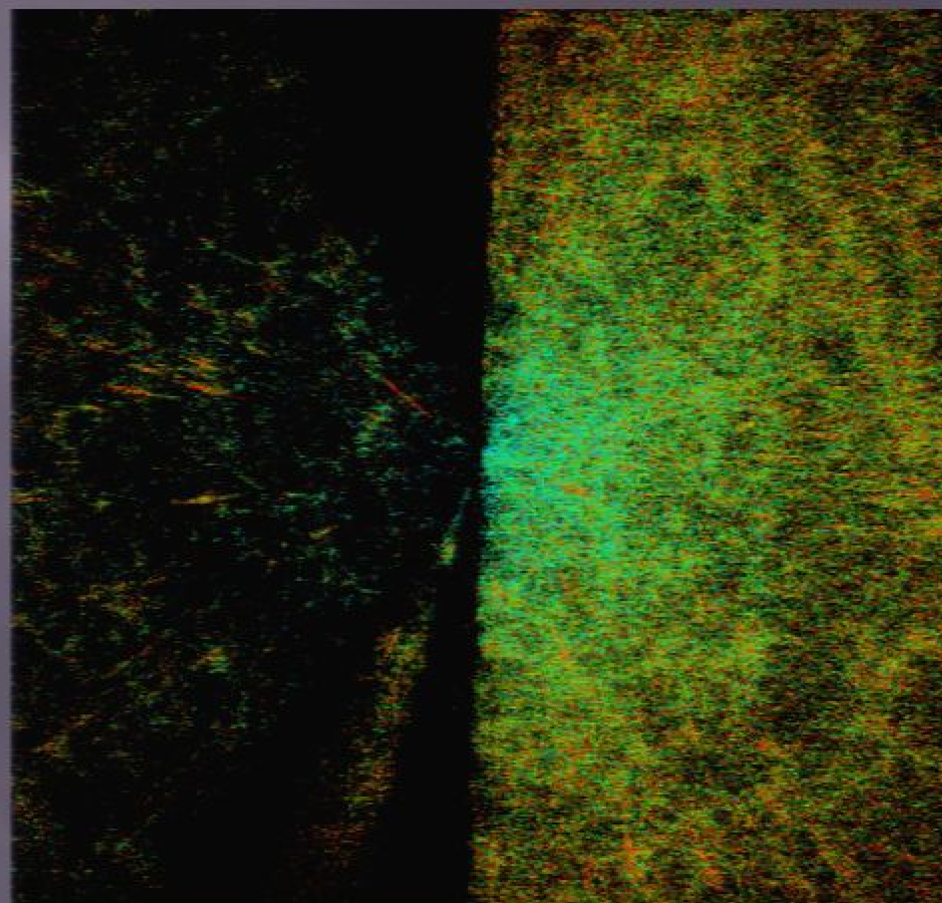

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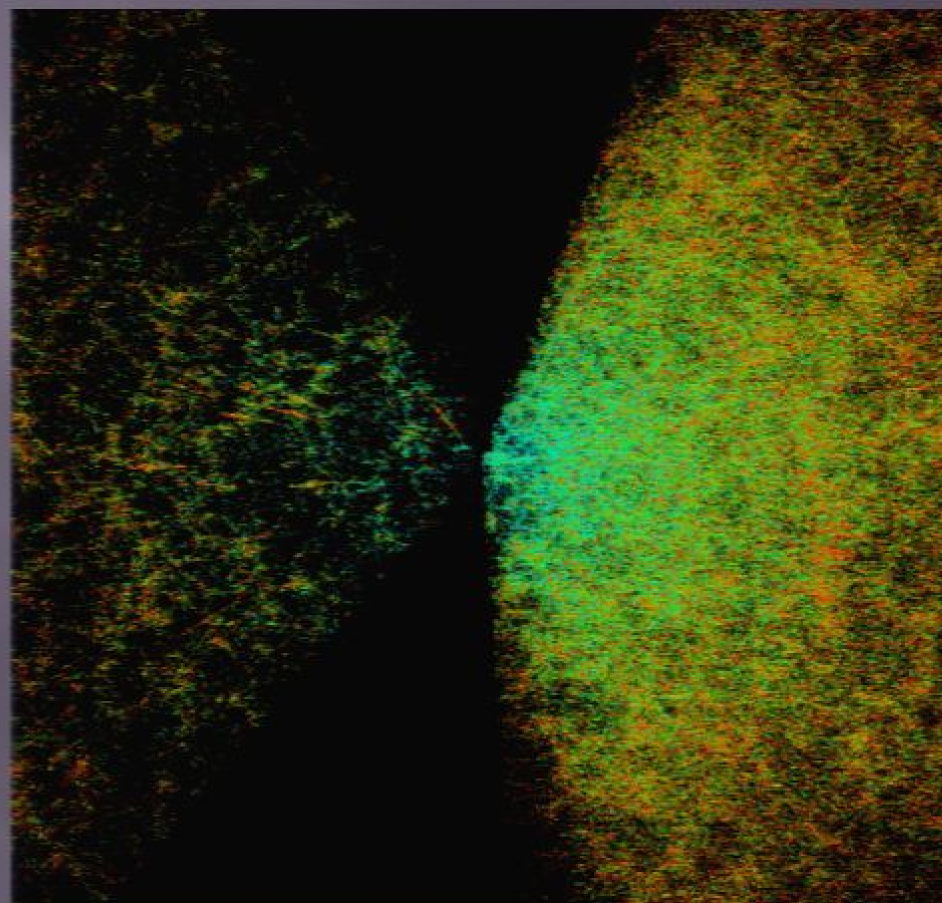

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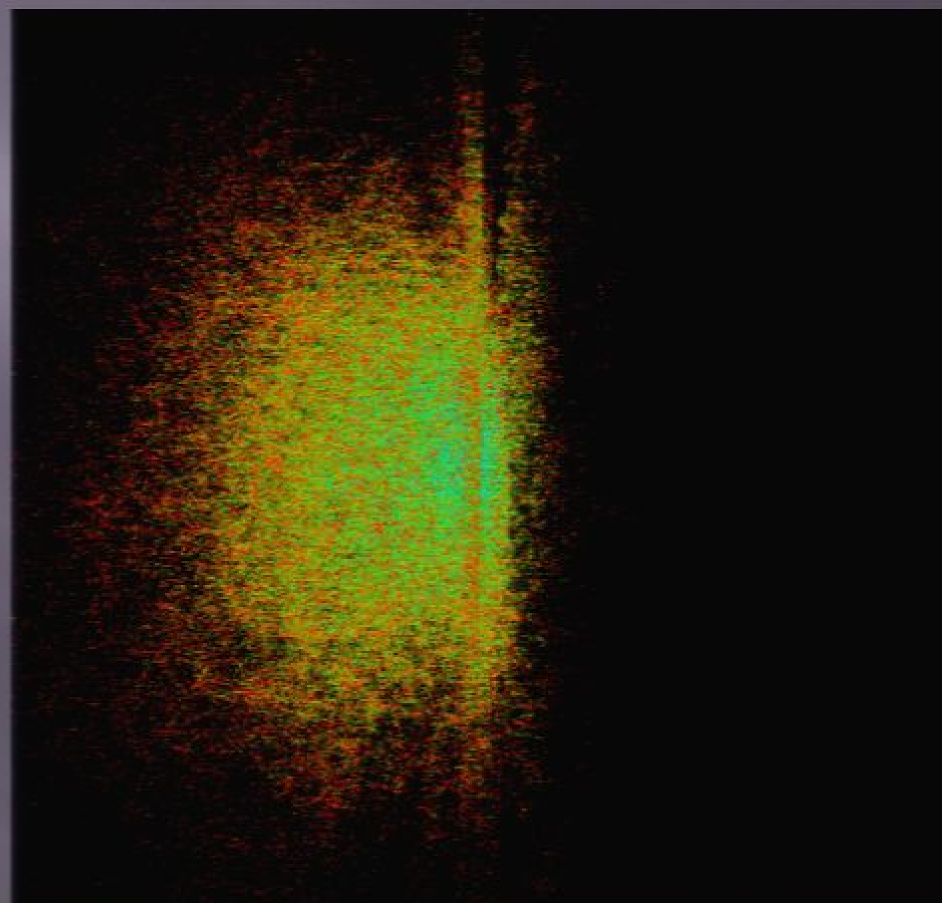

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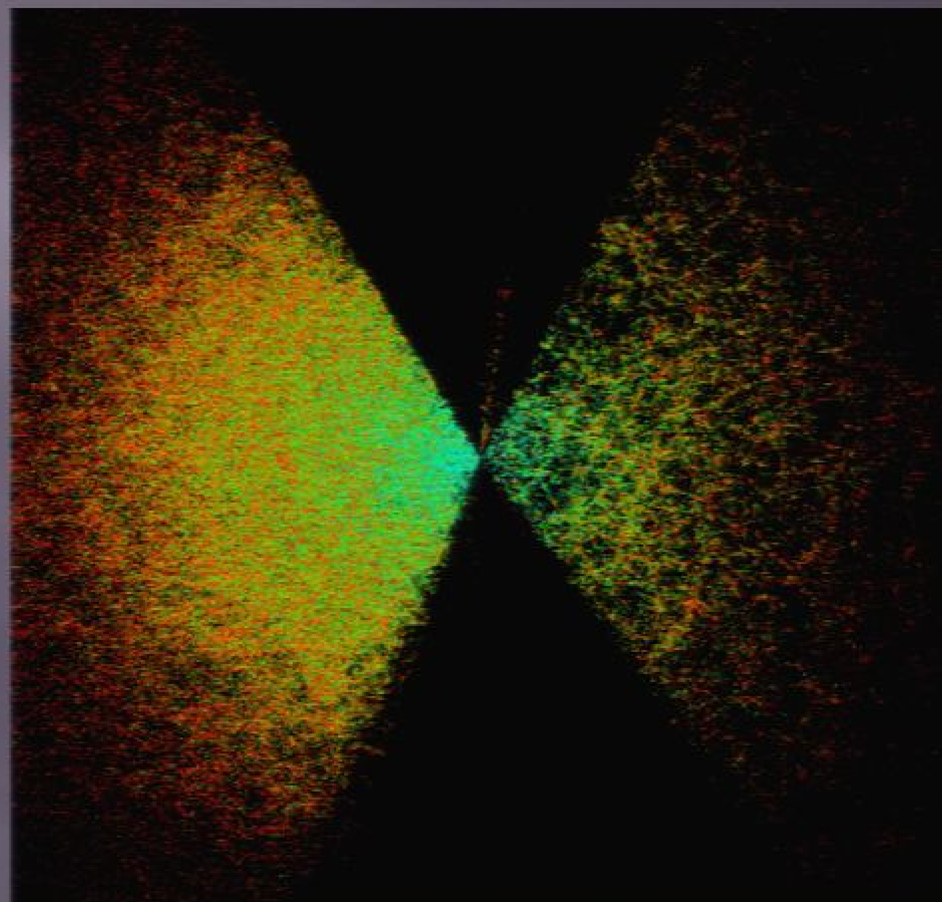

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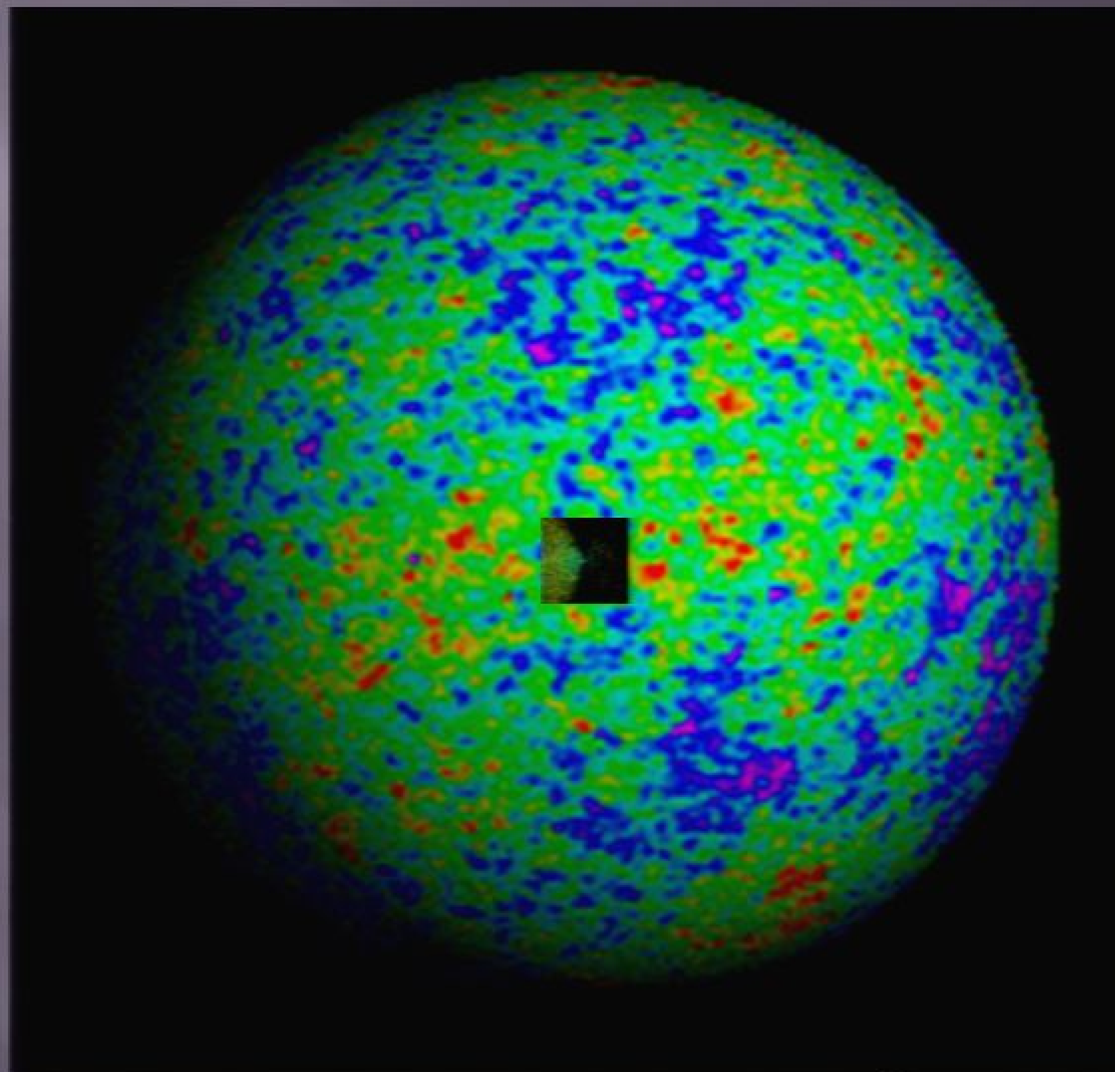

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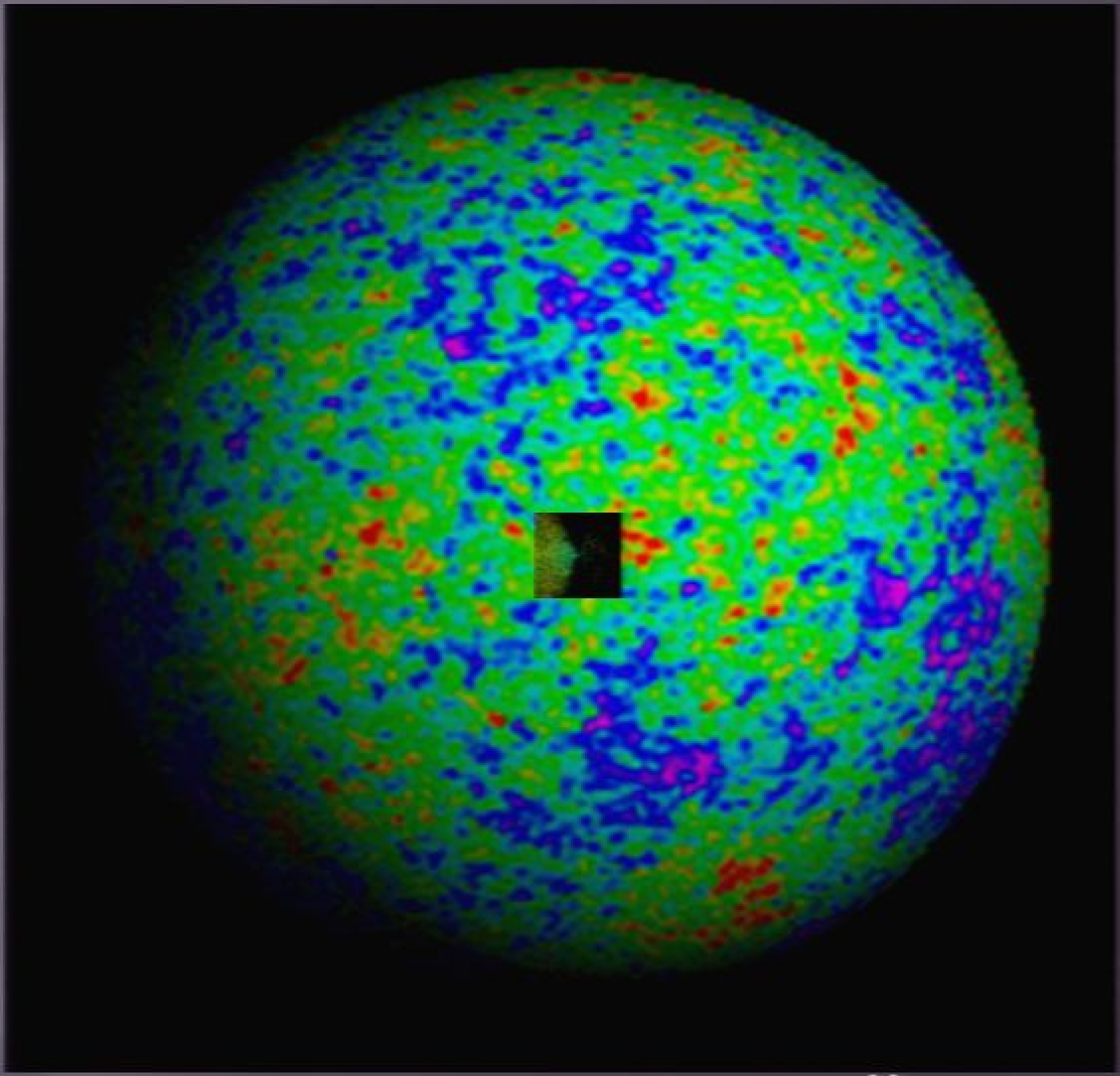

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Our Horizon through time

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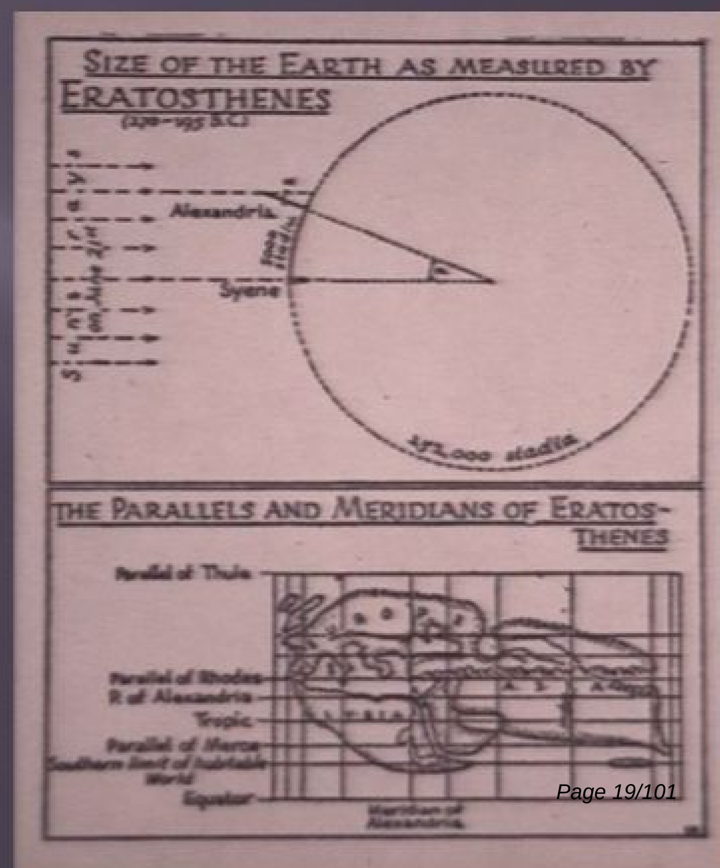

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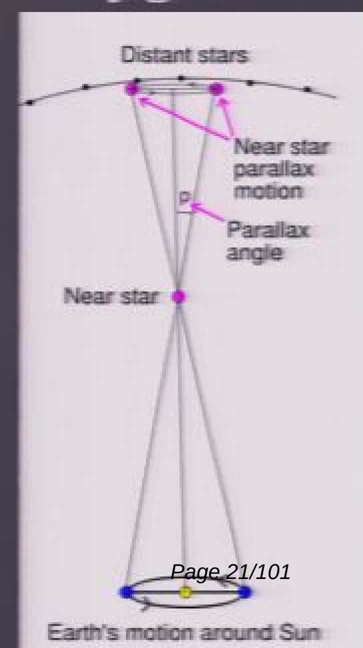

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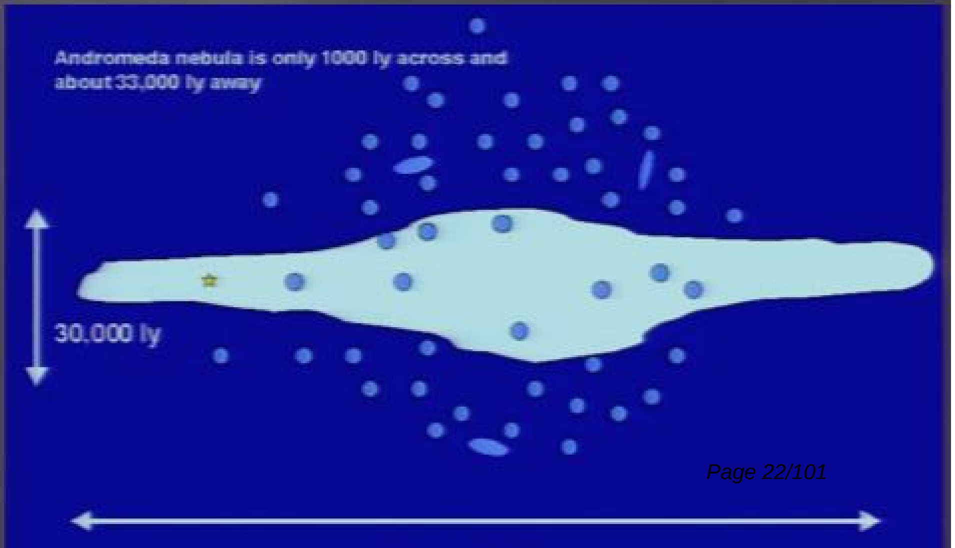

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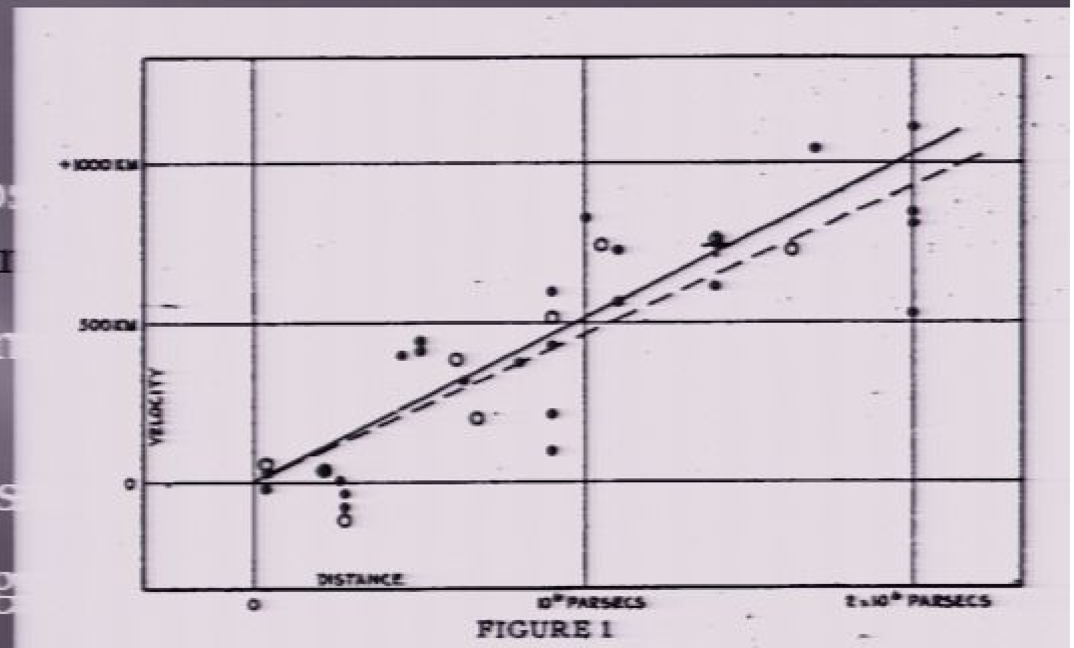

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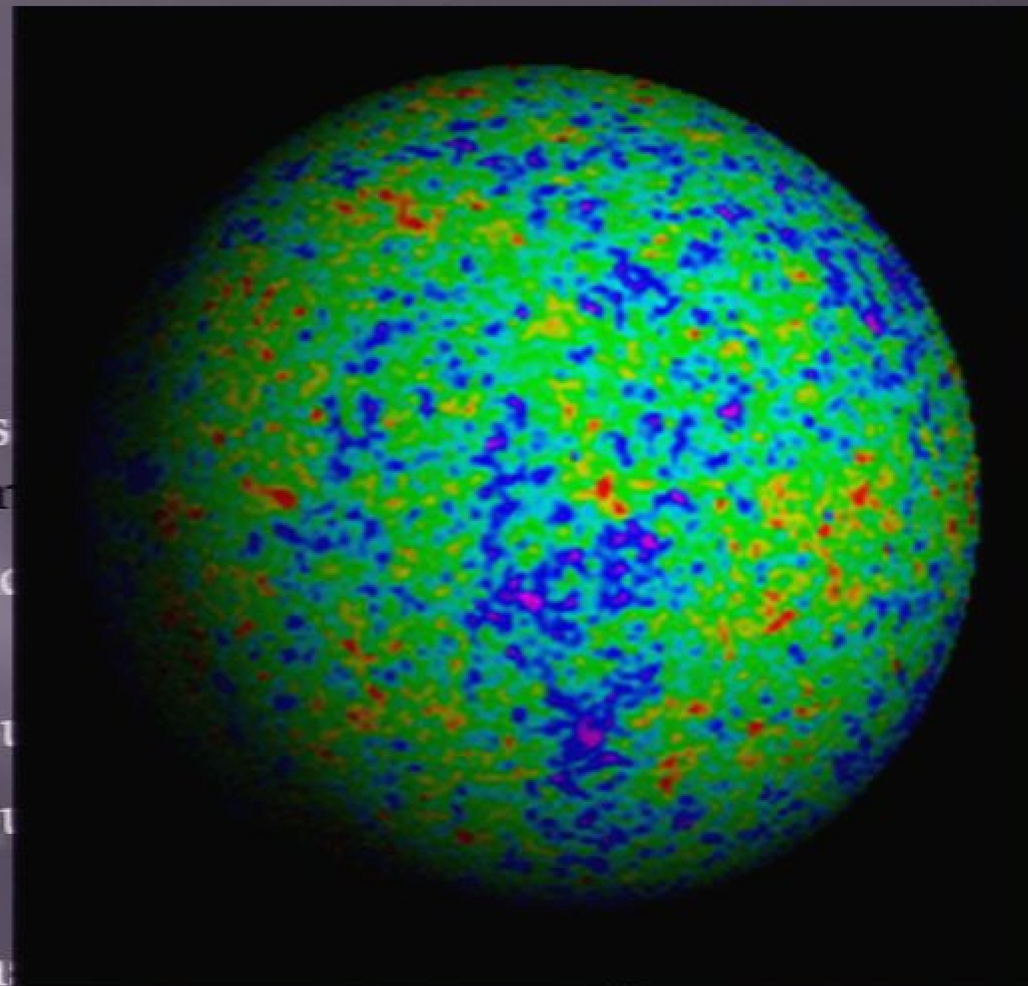

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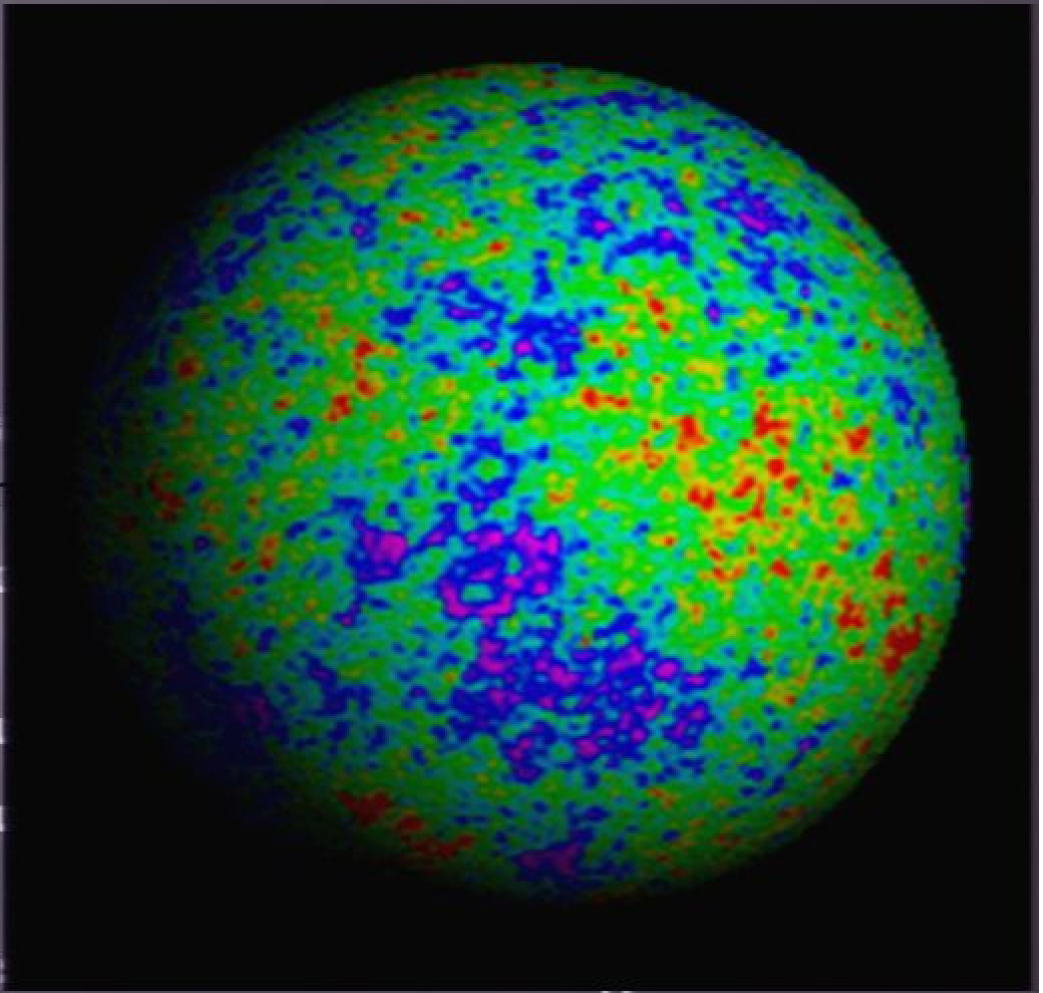

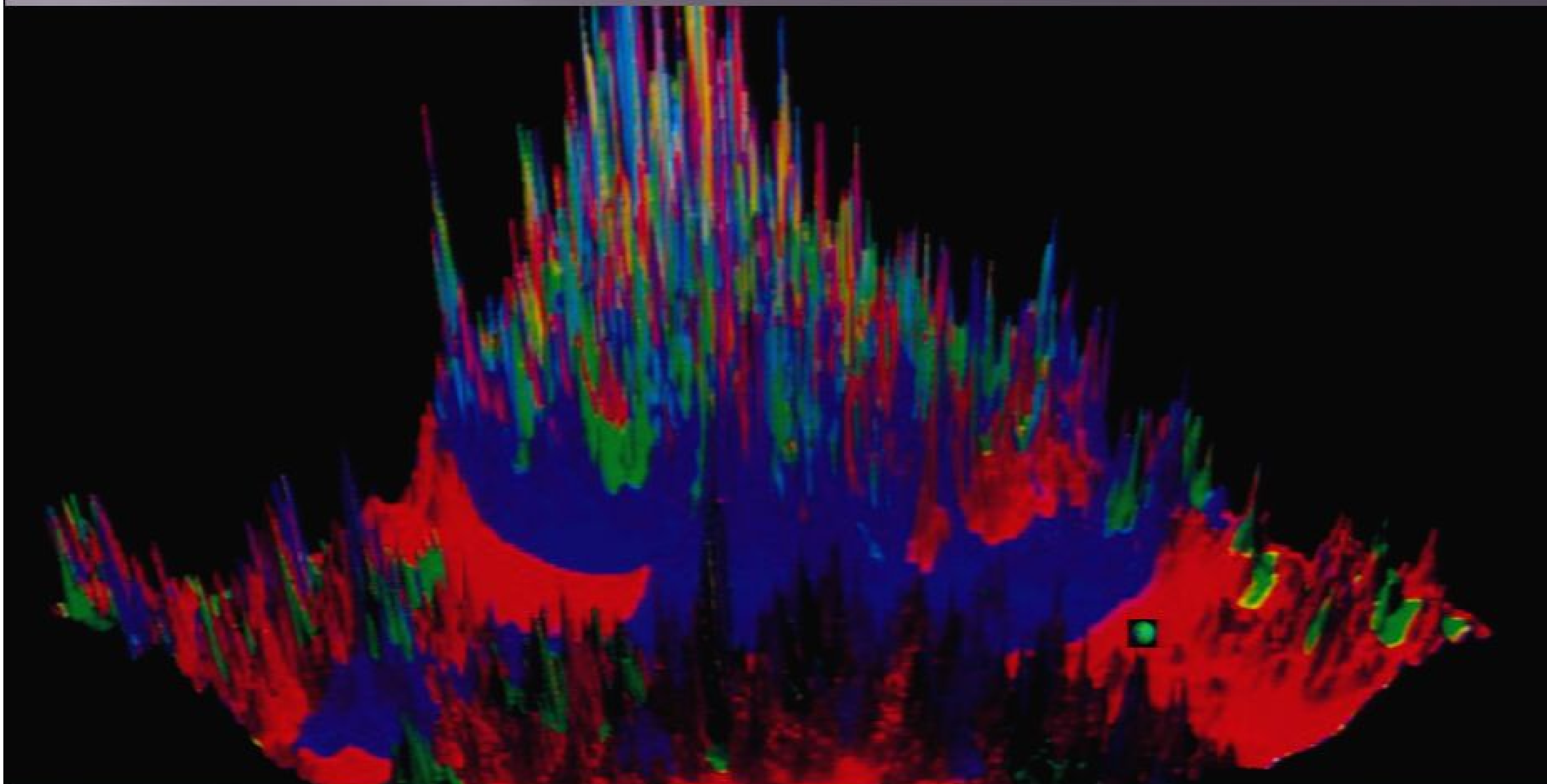

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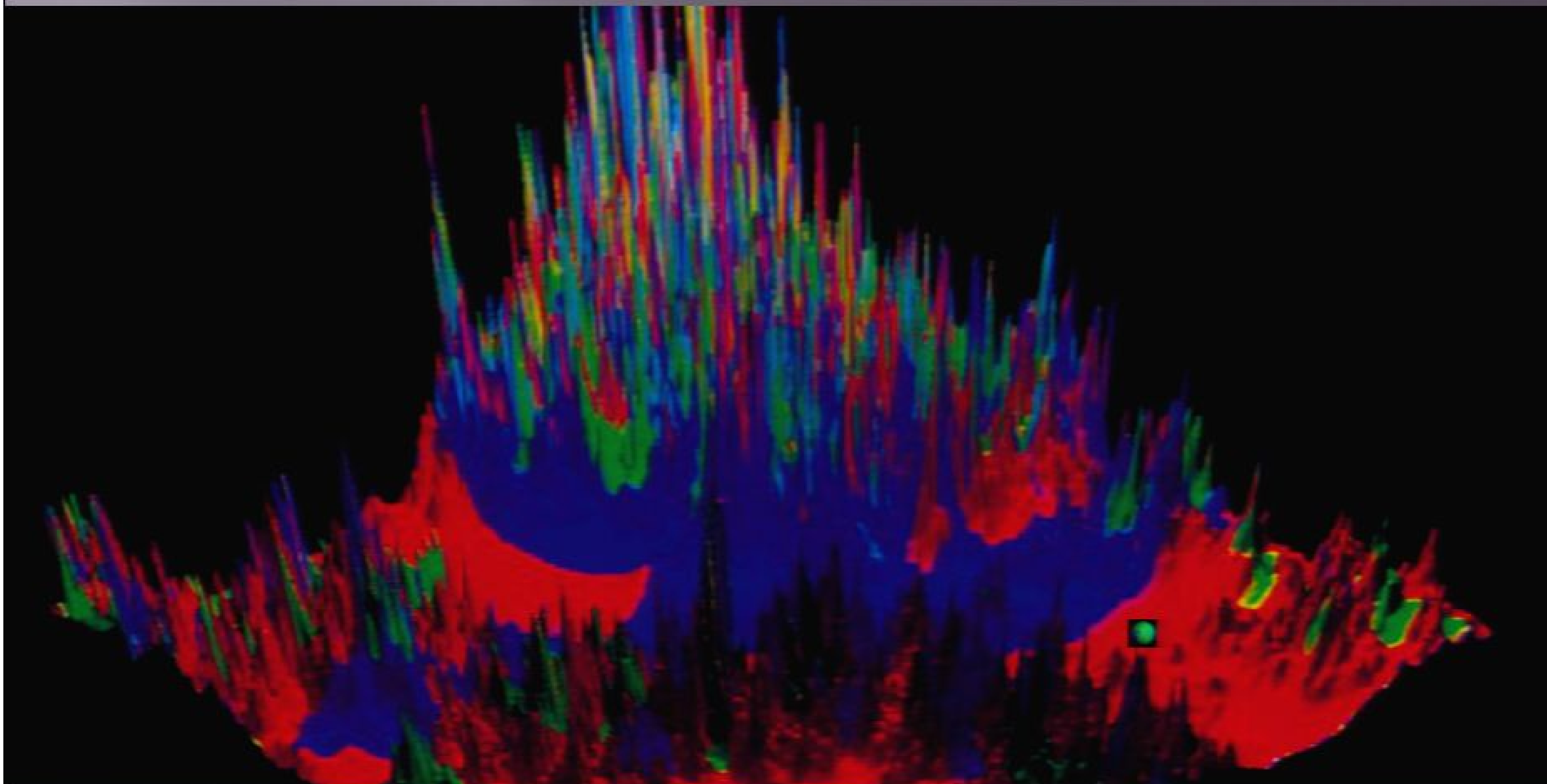

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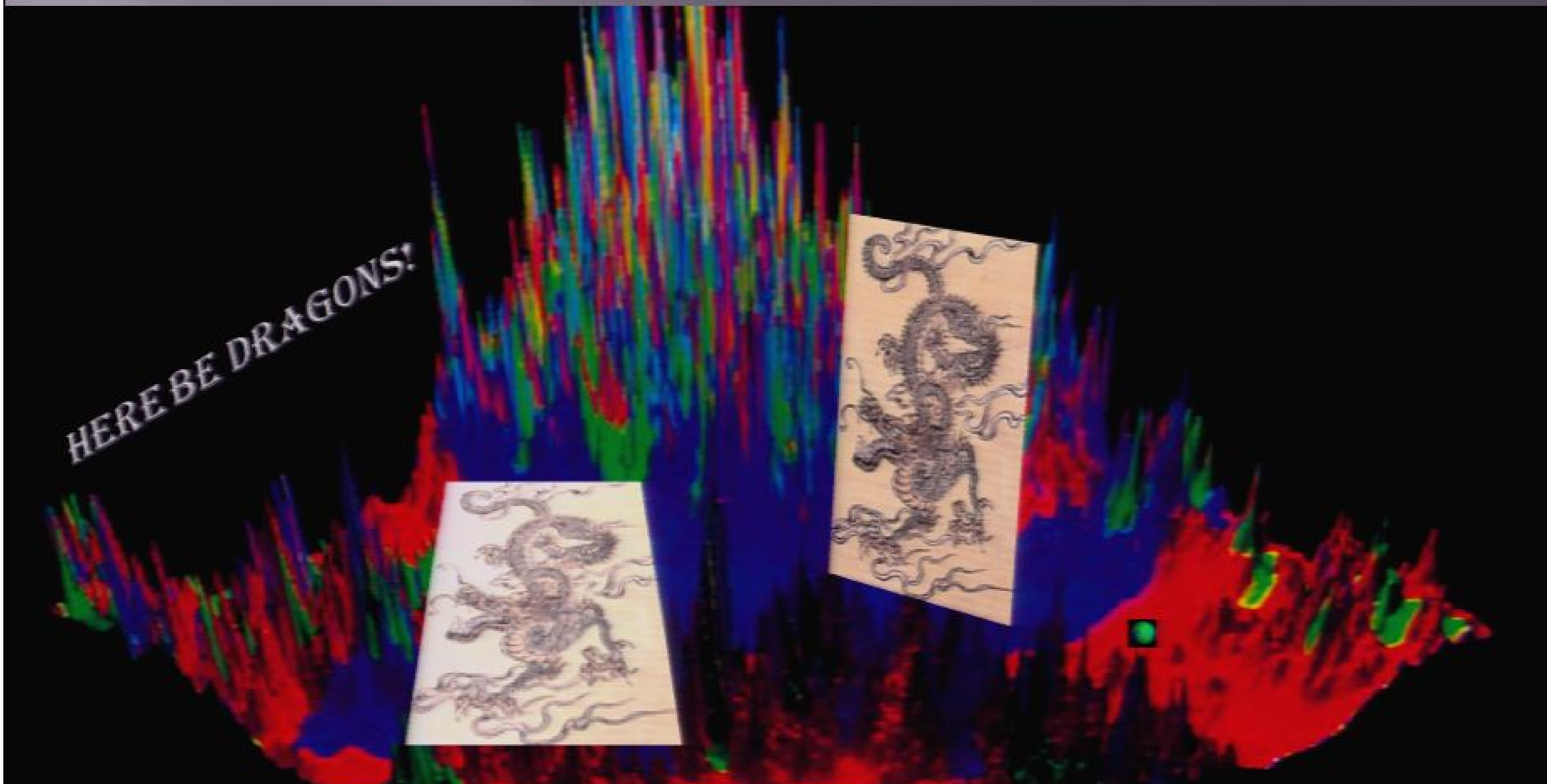

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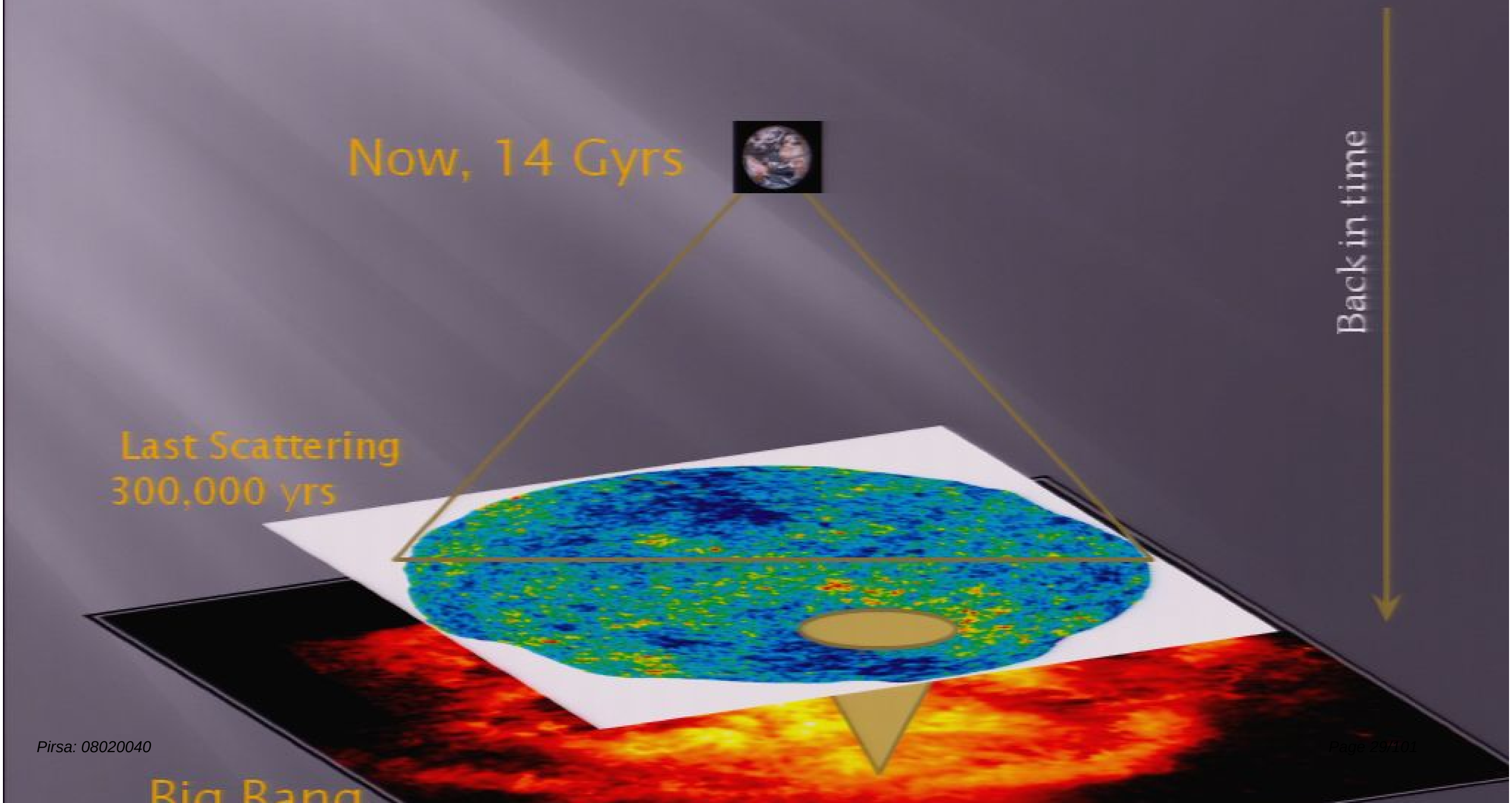
Horizon Problem

- At last scattering, causal horizon is much smaller than horizon today.



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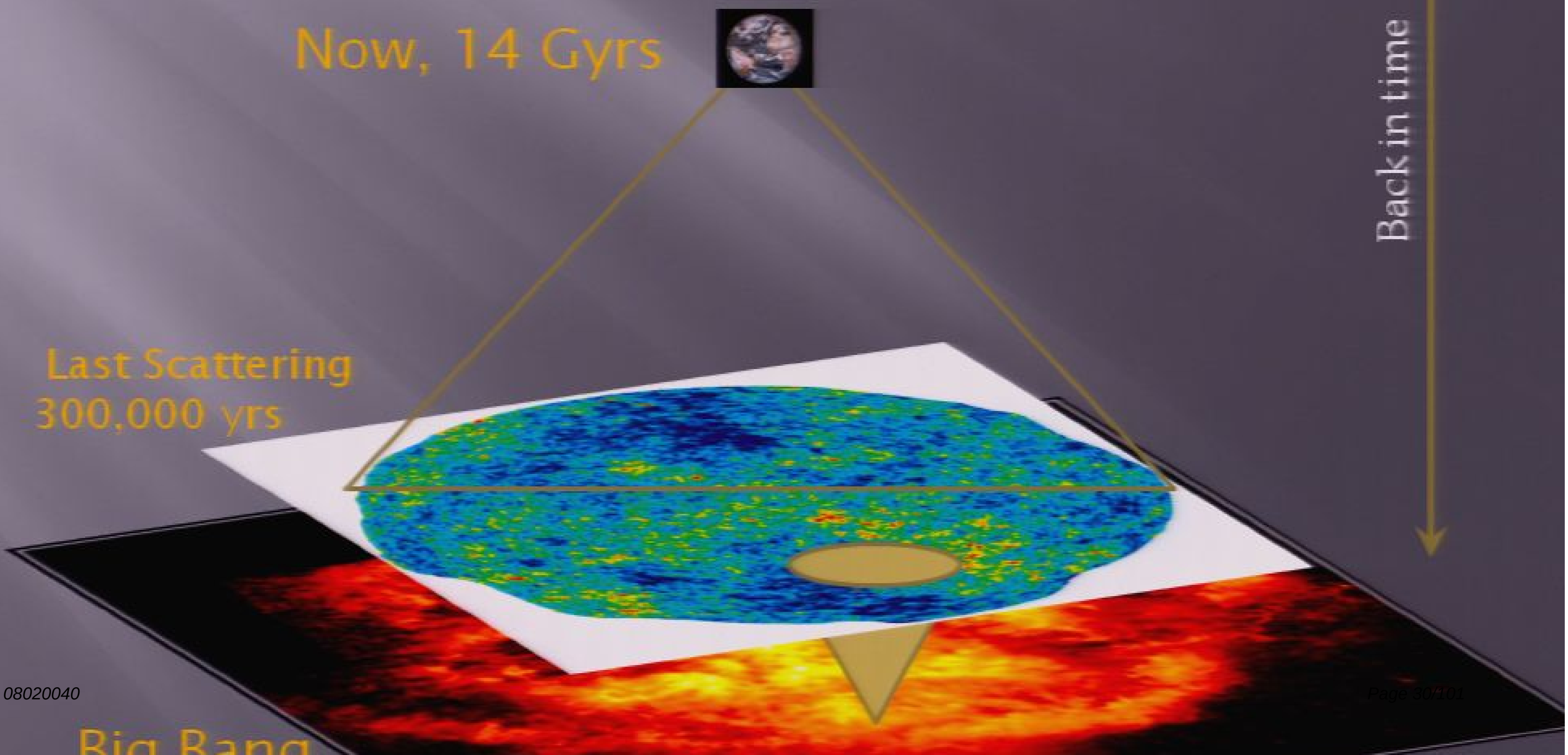
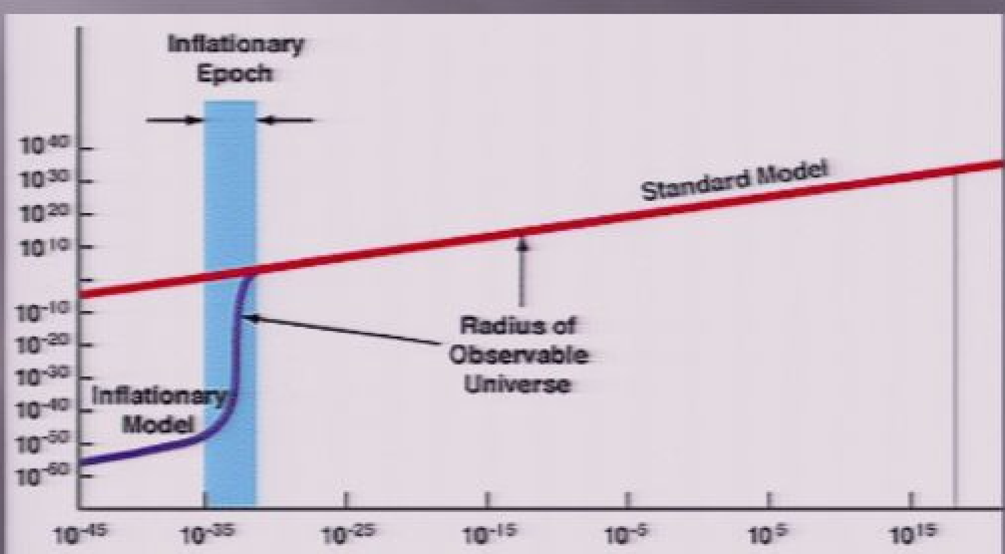
- So, why is CMB isotropic to 1 part in 10^5?



Inflation *(Guth 1981)*

- A period of exponential expansion can inflate the causal horizon ($a \propto e^{Ht}$)
- 60 e-foldings of inflation solves the horizon problem



Time

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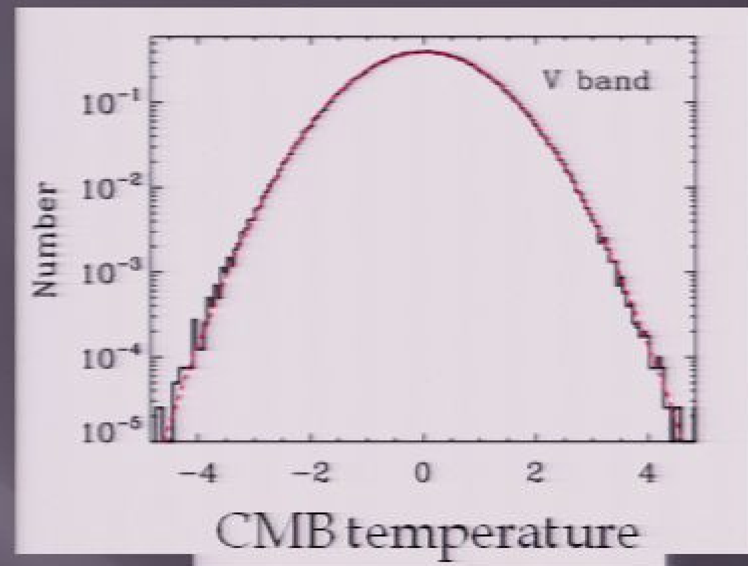

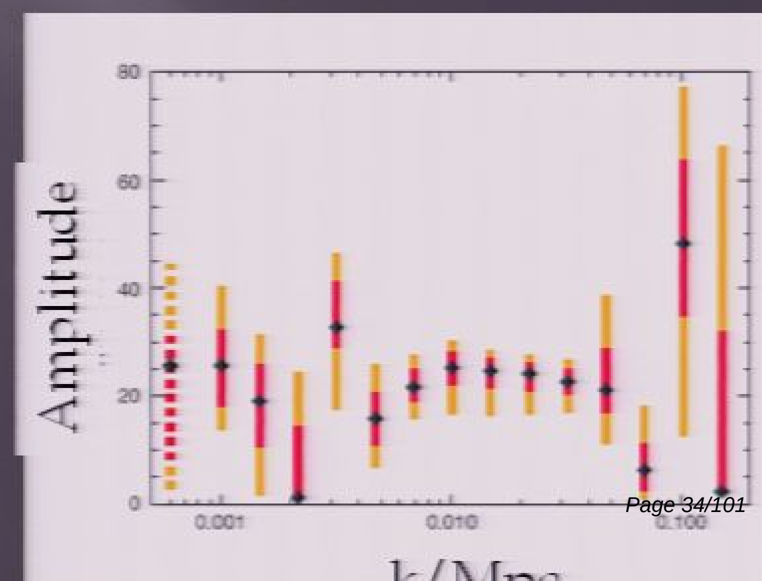

Spergel et al. 2007

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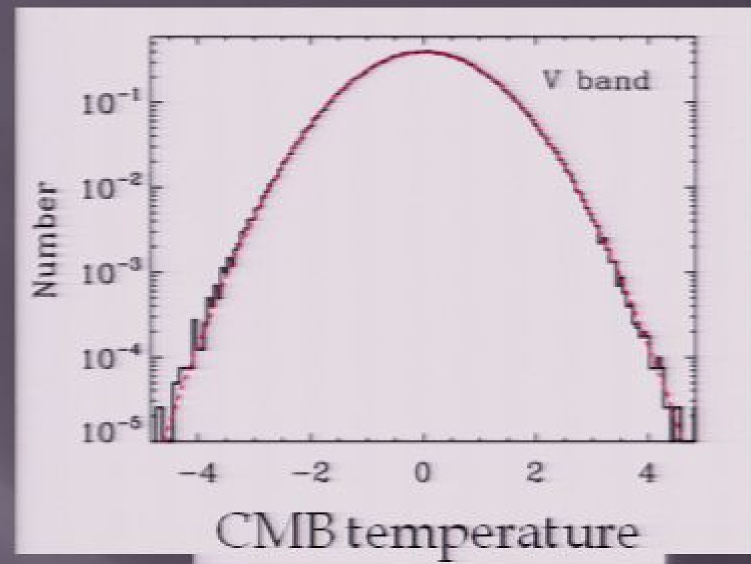

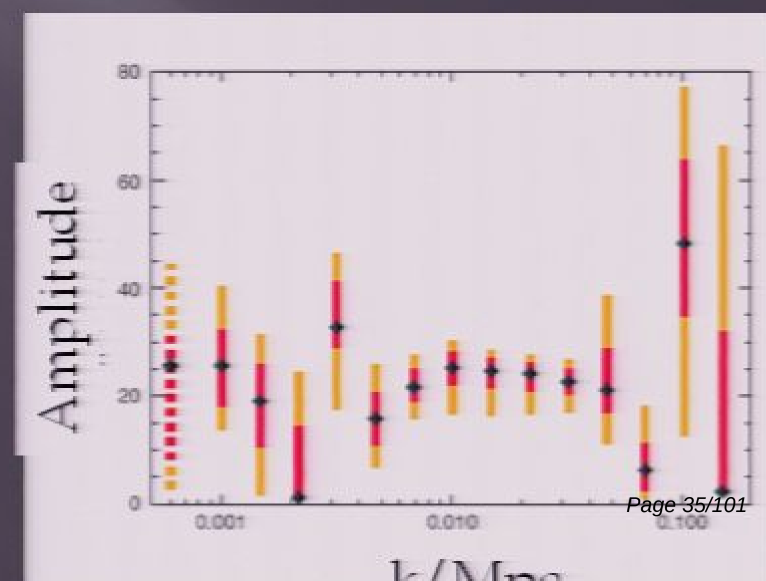

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Different Horizons

- Inflationary horizon: how far light travels since Big Bang

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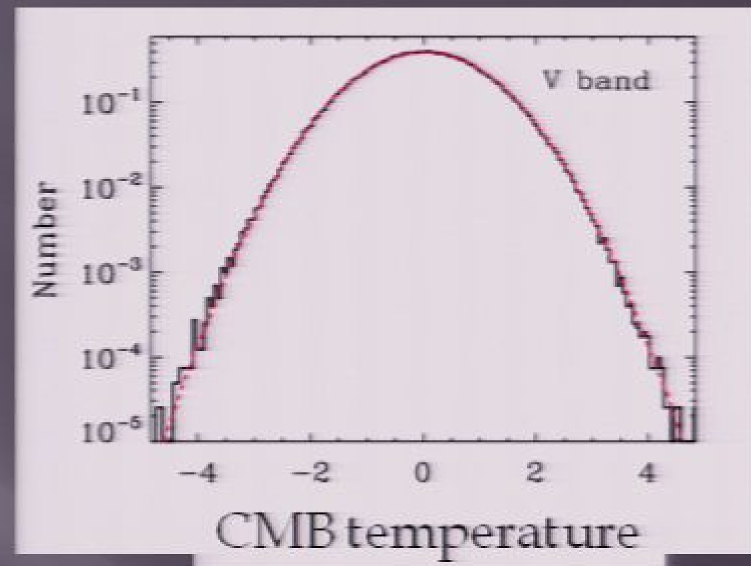

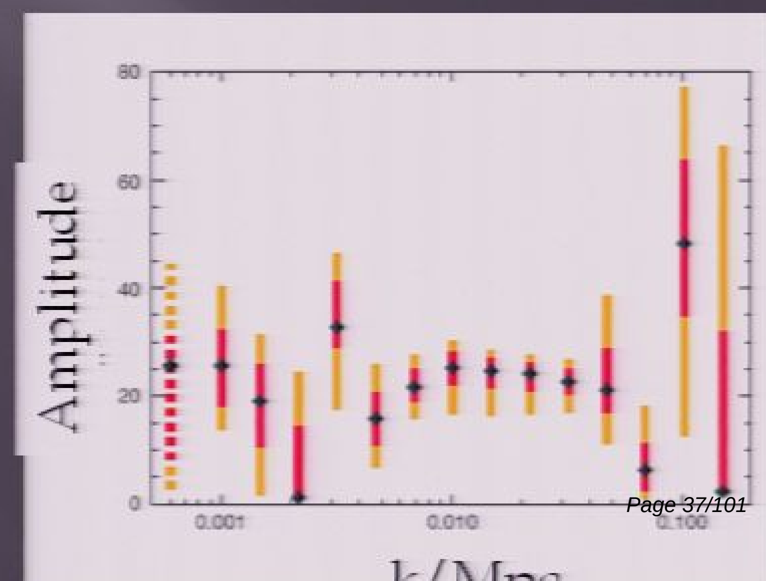

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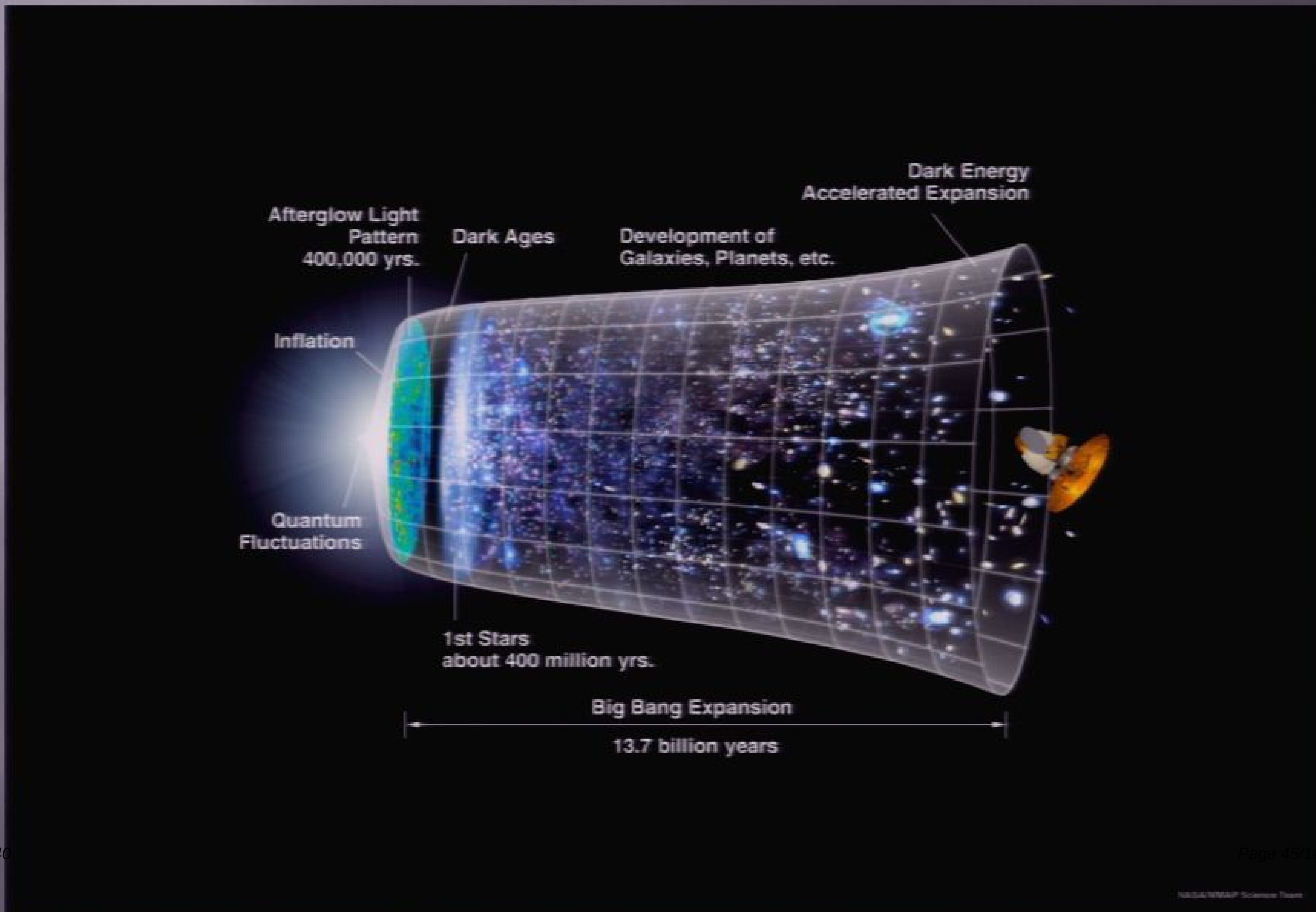
Physics beyond the Horizon:

- Cosmic acceleration and the ISW effect
- Gravity on Horizon scale
- Statistics on Horizon scale

Cosmic Timeline: Dark Energy Domination



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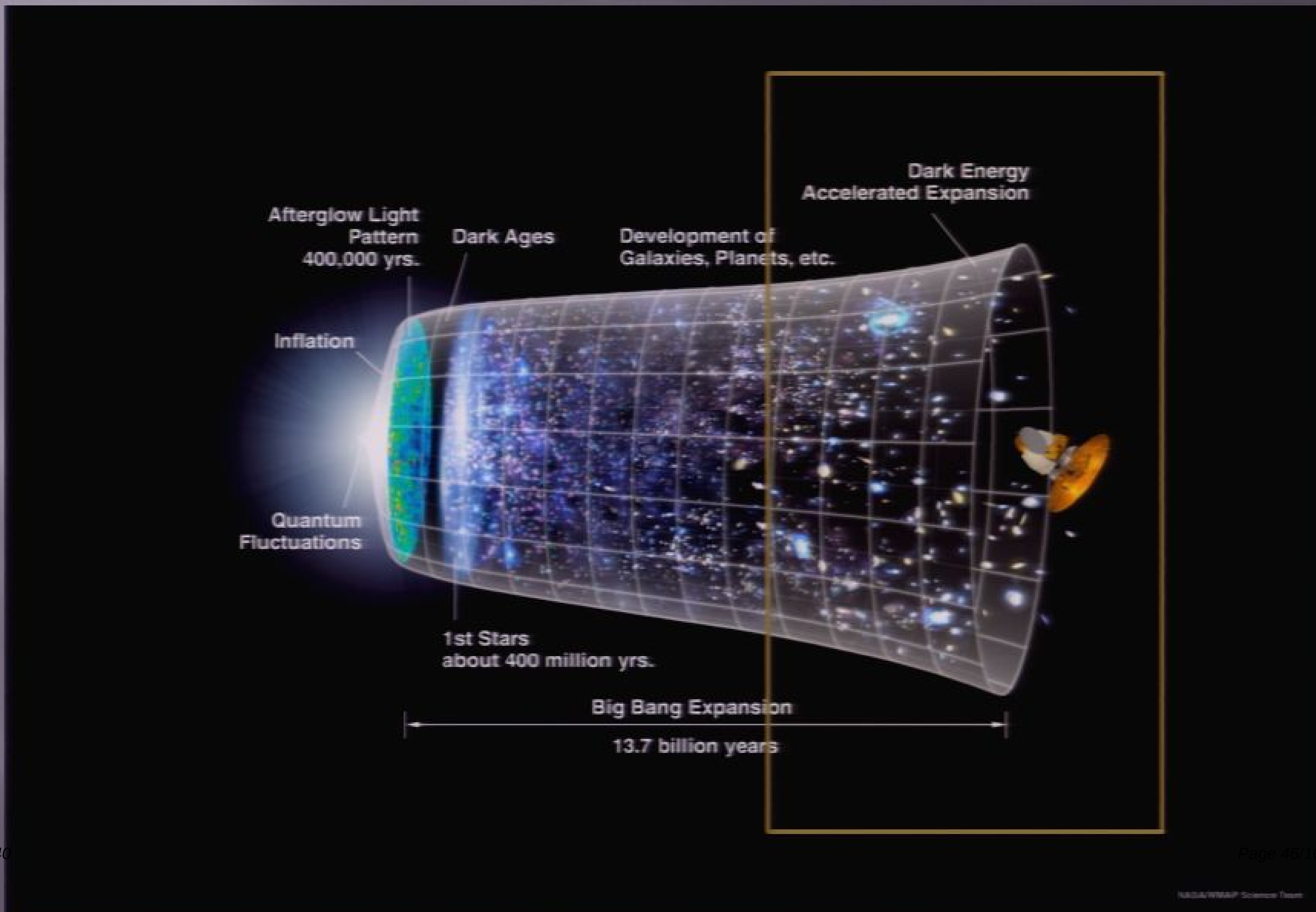
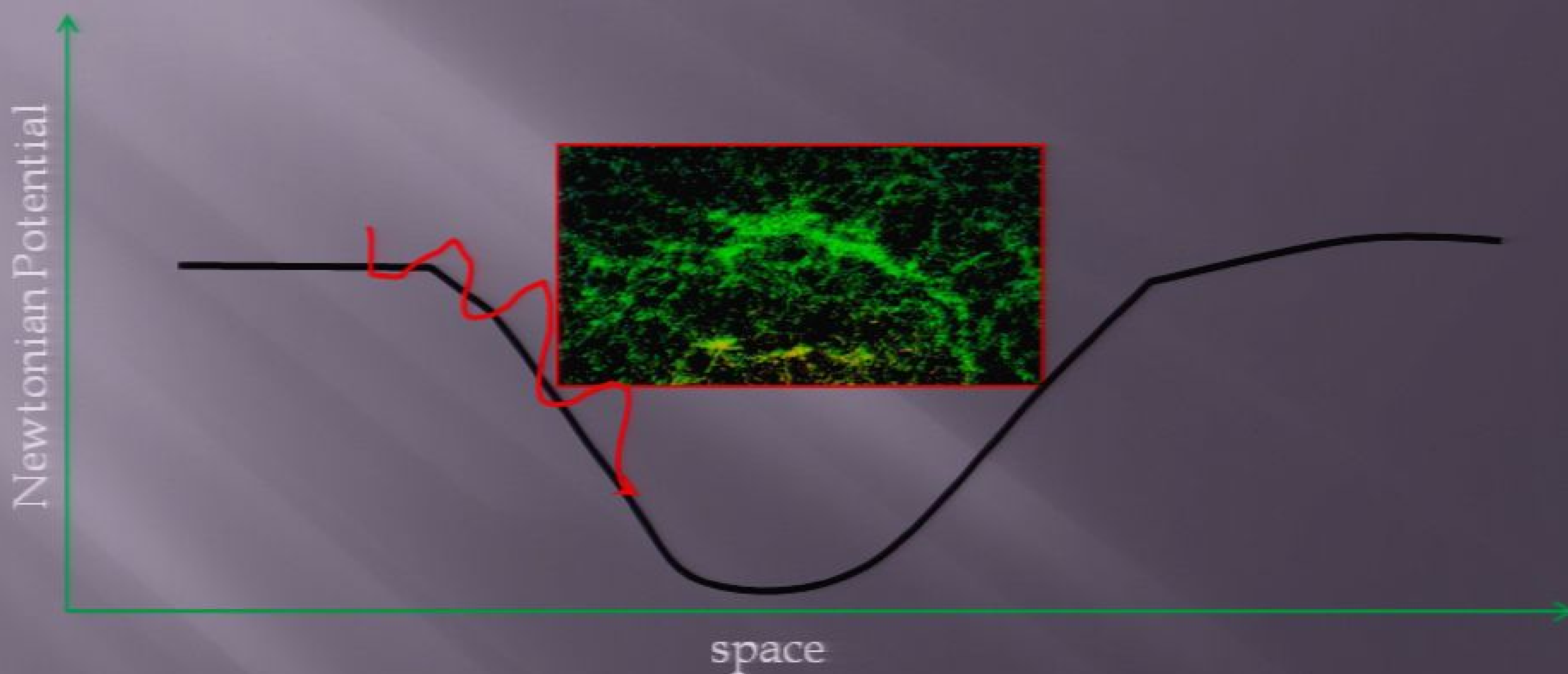


Integrated Sachs-Wolfe (ISW) effect



- Accelerated Expansion results in decay of Newtonian potential
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$$\delta T = 2T \int \dot{\Phi} \, dt$$

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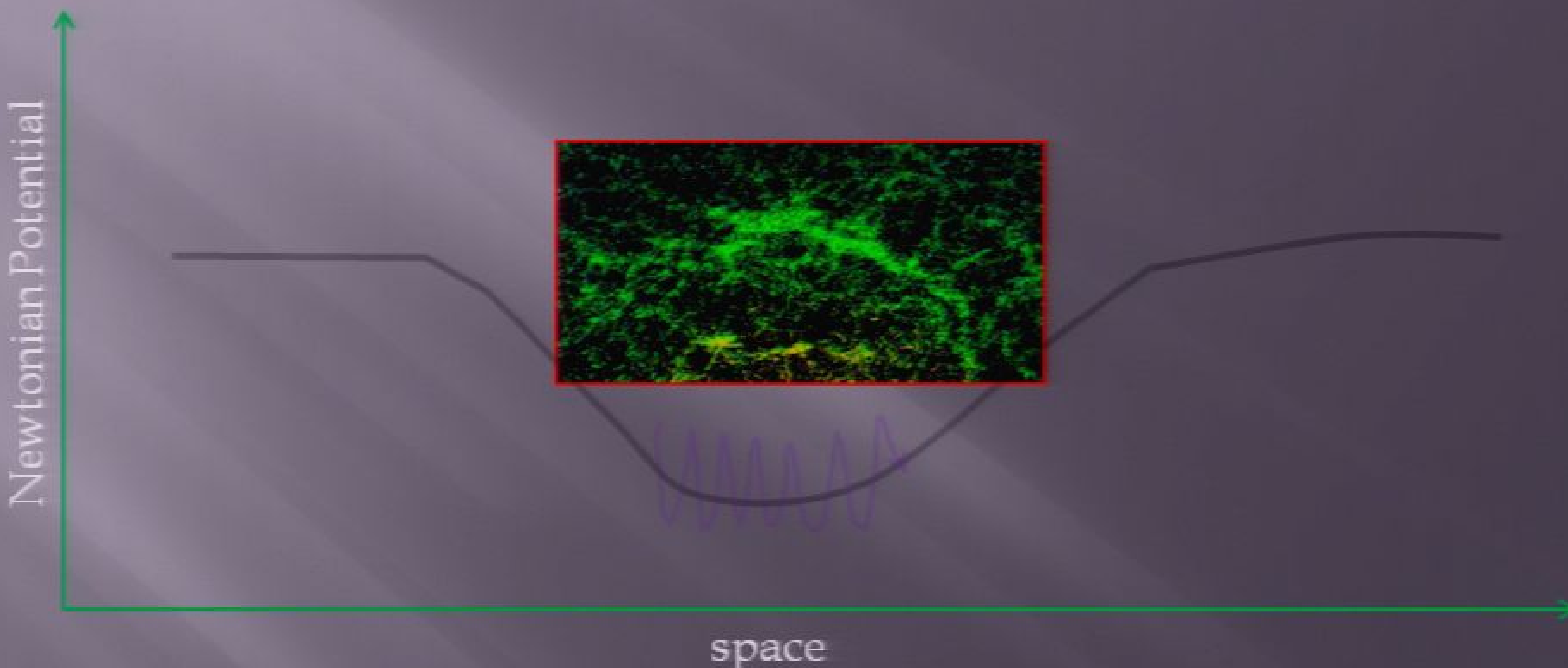

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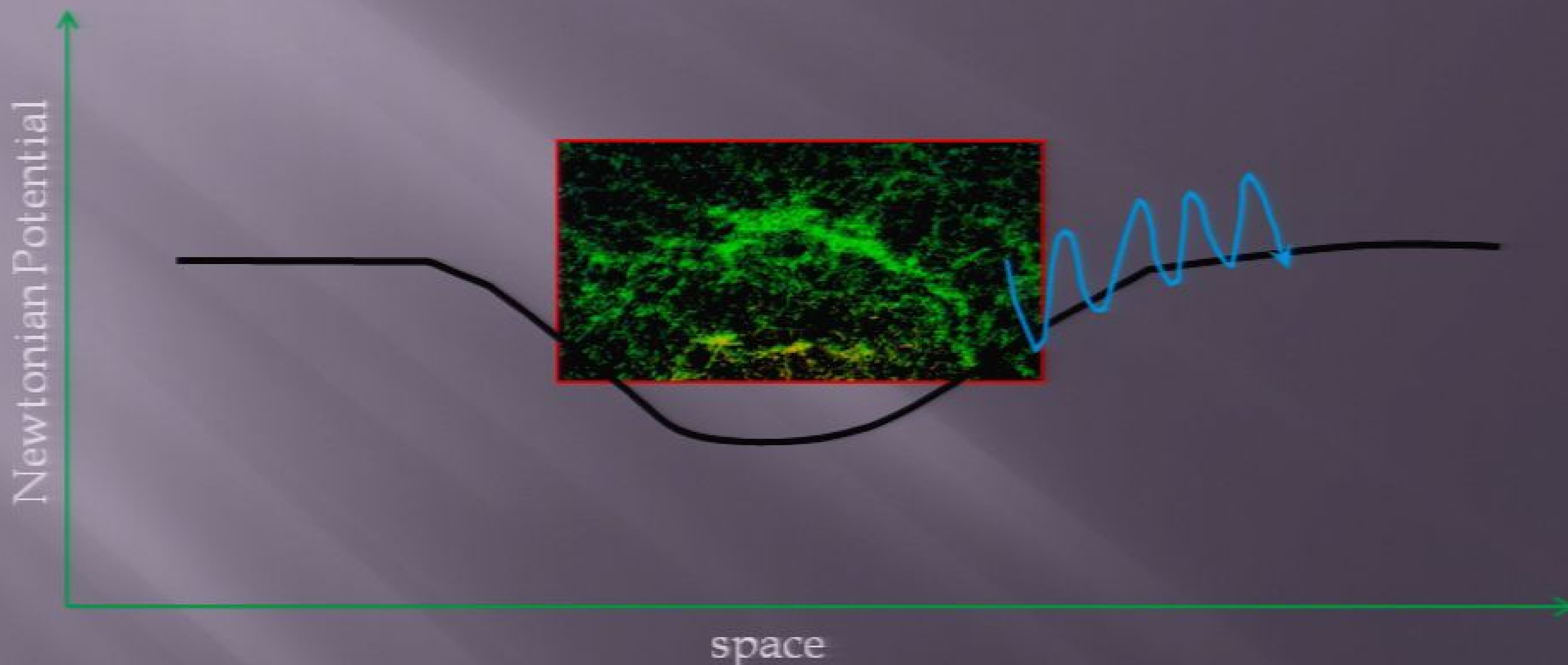

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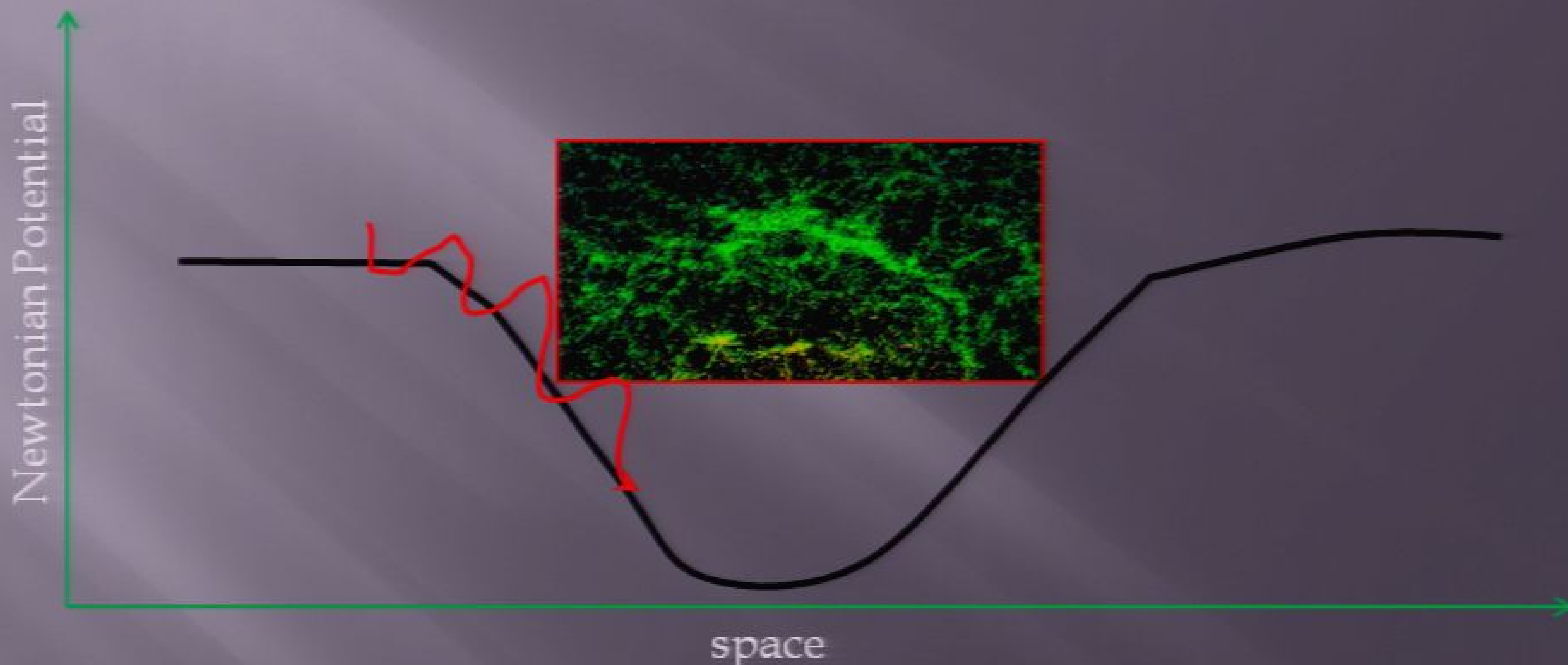

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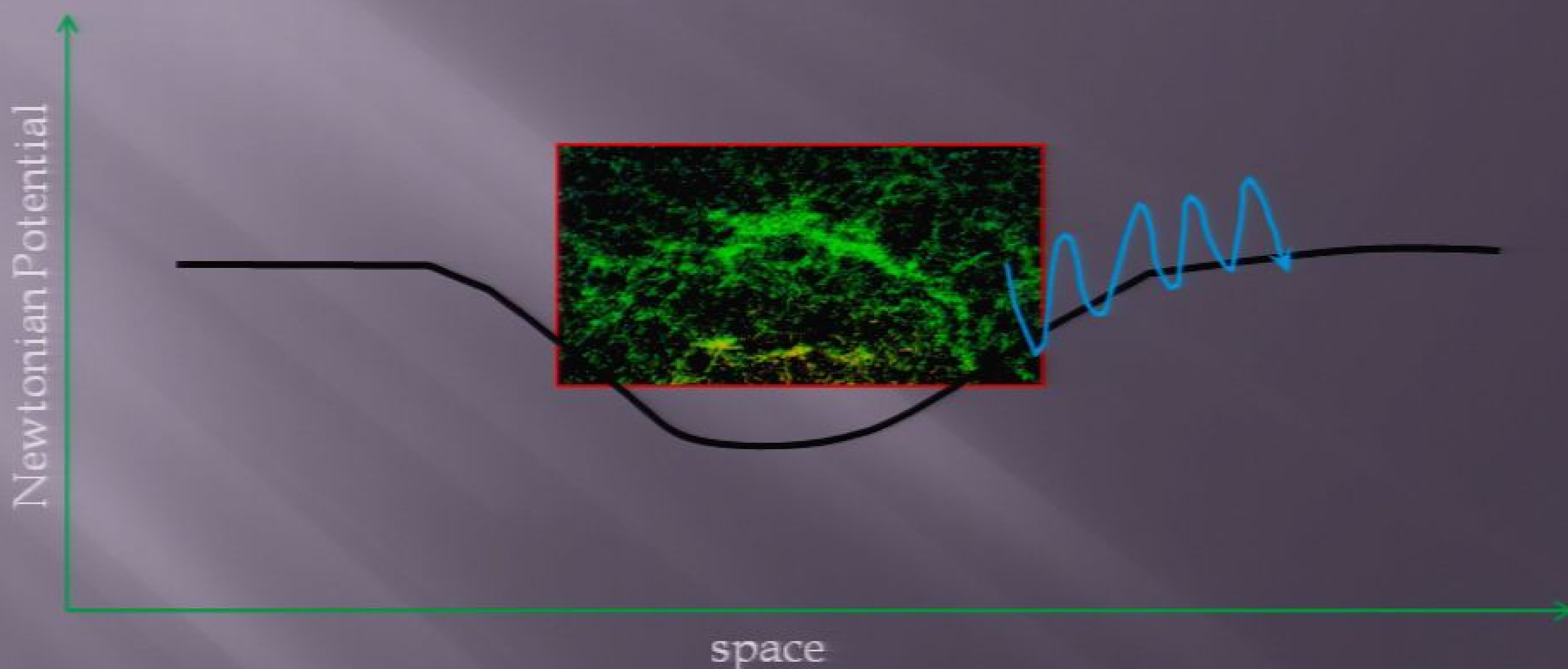

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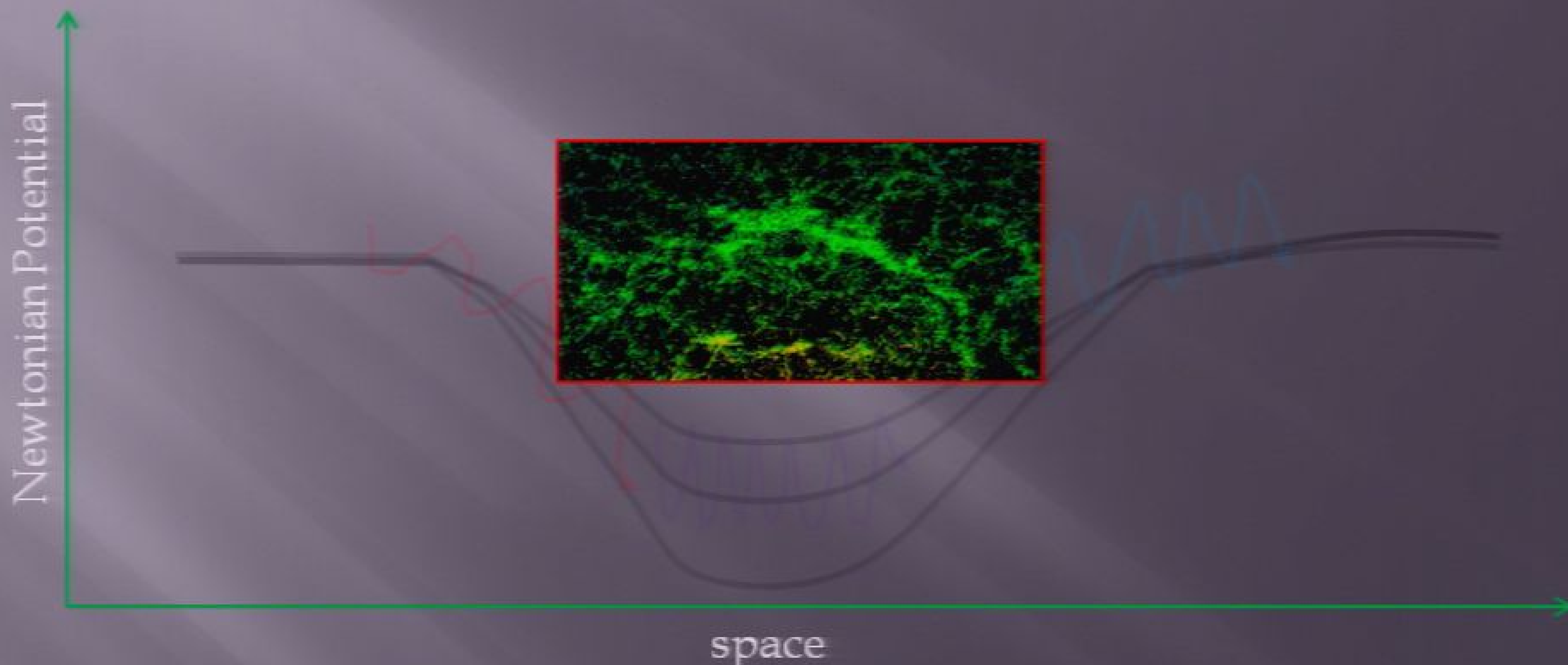

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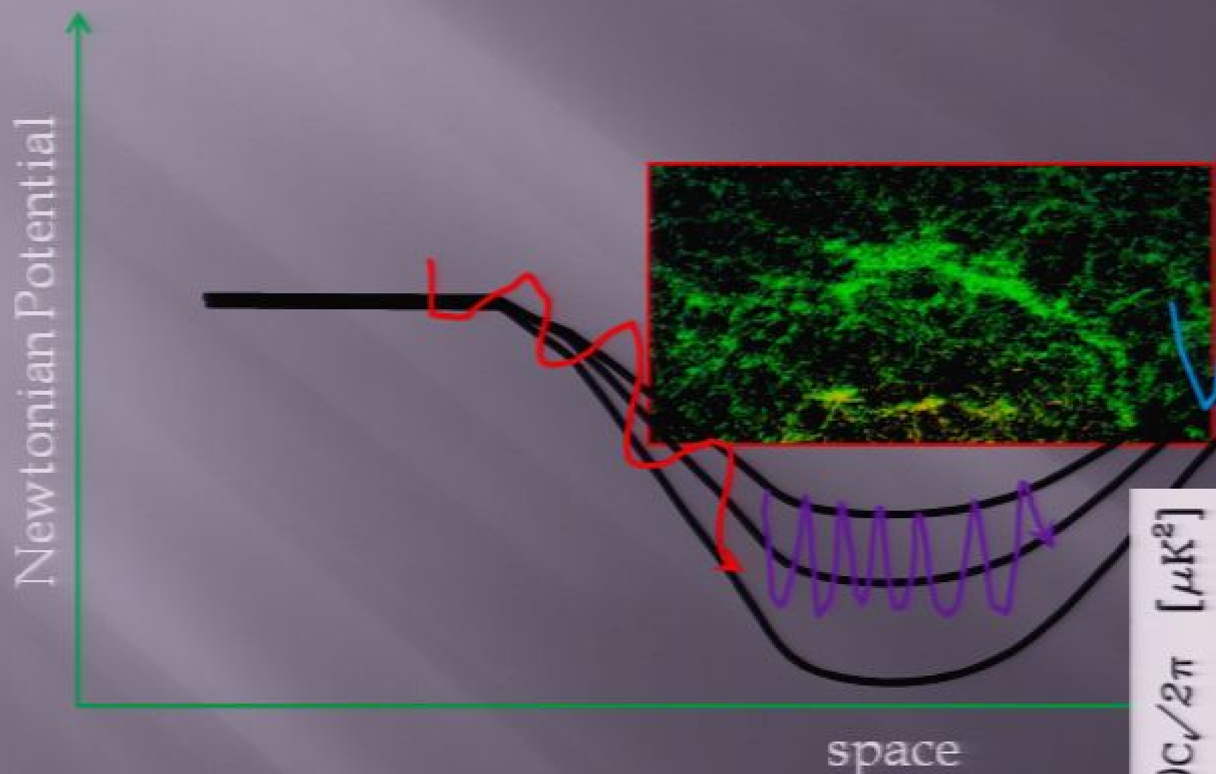

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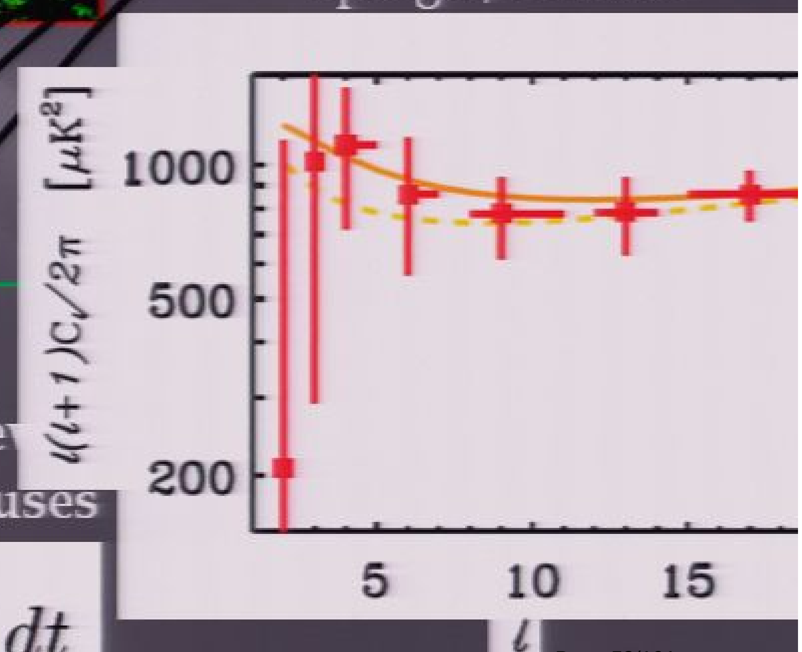

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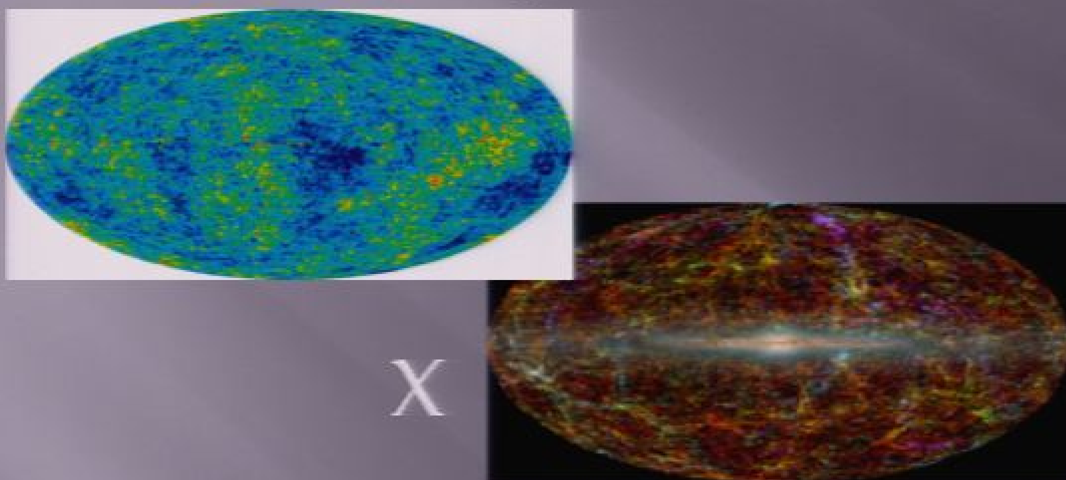
ISW in Cross-Correlation

Cosmic Microwave Background



Galaxies

- Cross-correlating CMB with Galaxy distribution extracts the ISW signal from primary anisotropies

ISW in Cross-Correlation

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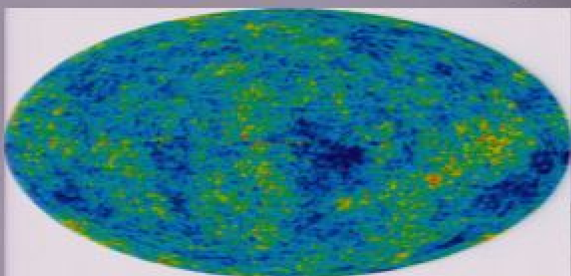

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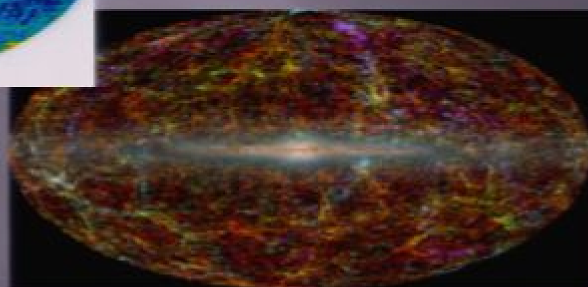

Galaxies

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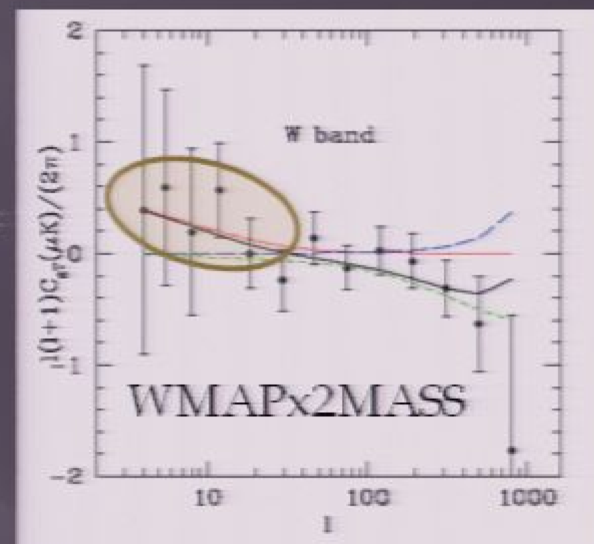
NA, Loh, & Strauss 2004



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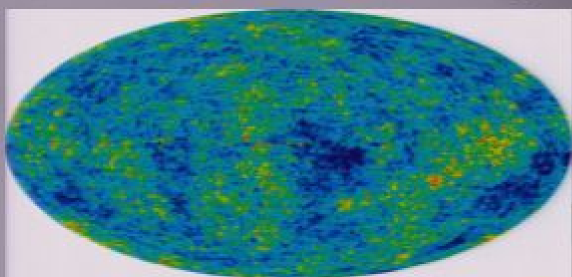

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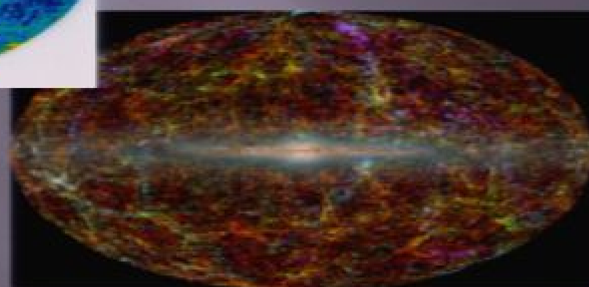

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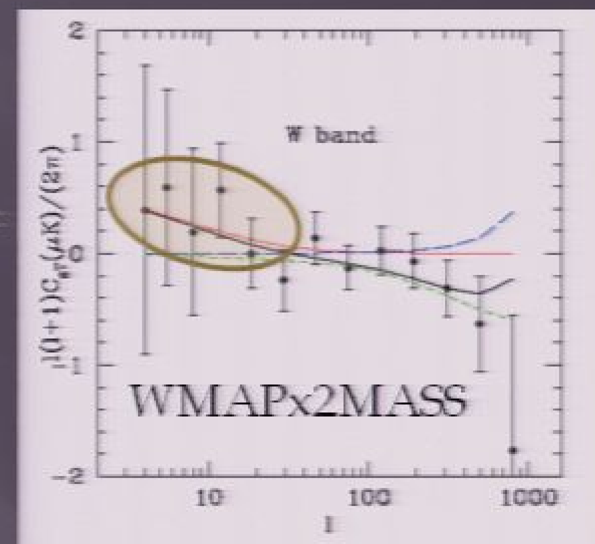

- Cross-correlating CMB with Galaxy distribution extracts the ISW signal from primary anisotropies
- Independent Evidence for Dark Energy

Cosmic Convergence

- Science's No. 1 breakthrough of the year 2003
  → Consistency of different cosmological observations (including ISW effect) as evidence of Dark Energy

Cosmology with the ISW effect

- Not the best probe of conventional DE properties (w,w′,…)

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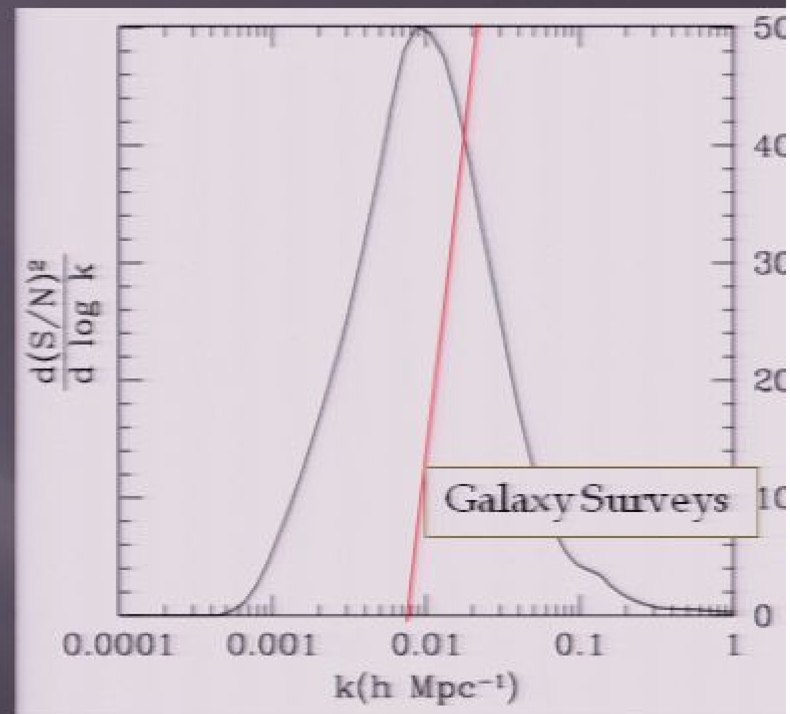

NA 2004

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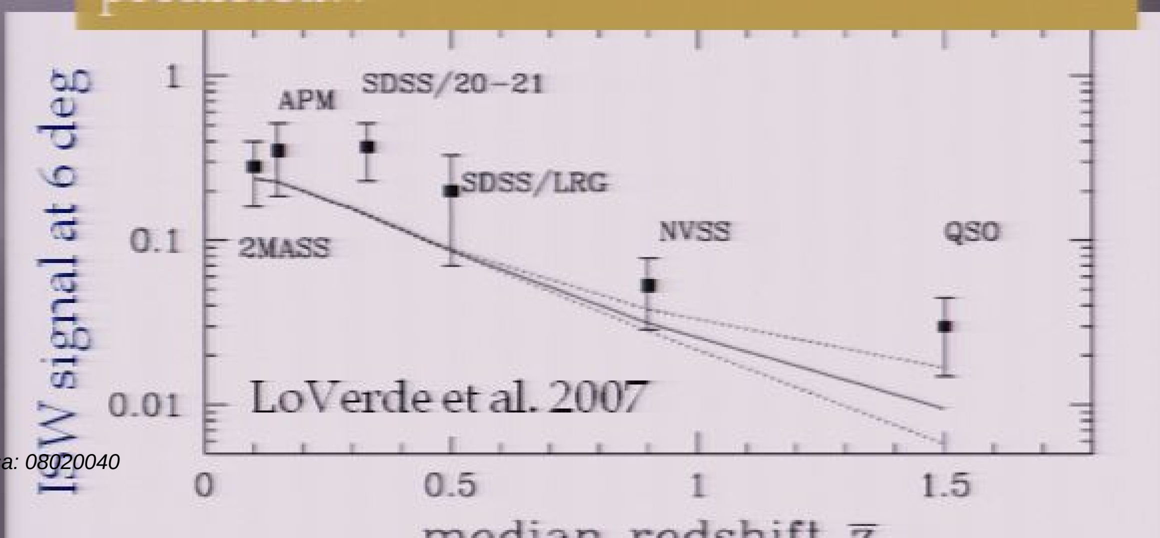
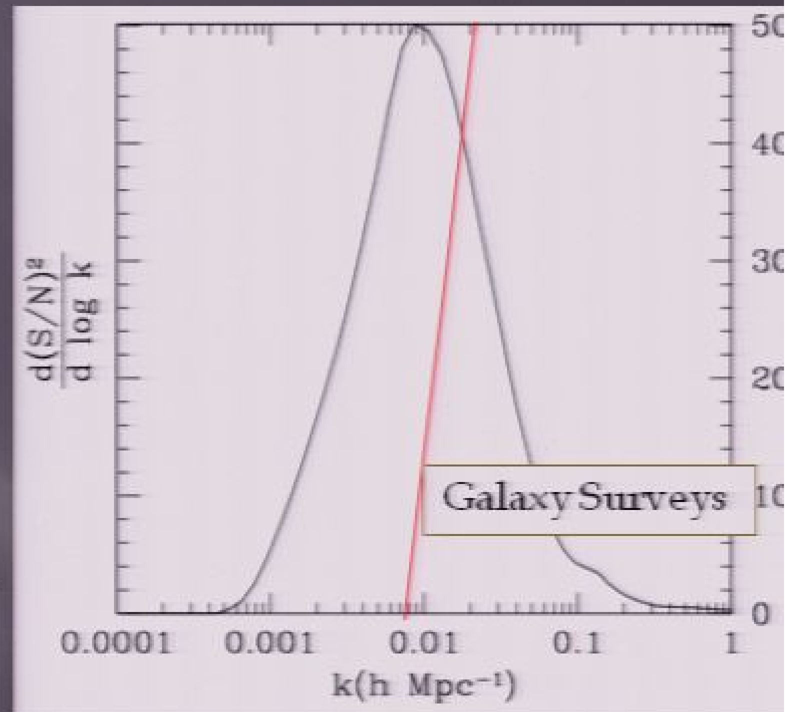
Why are all the observations larger than predicted?!





NA 2004

Gravity on Horizon scale

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- Friedmann Equation

$$\frac{\ddot{a}}{a} = -\frac{4\pi G_F}{3}\rho + 3P$$

Newtonian Gravity

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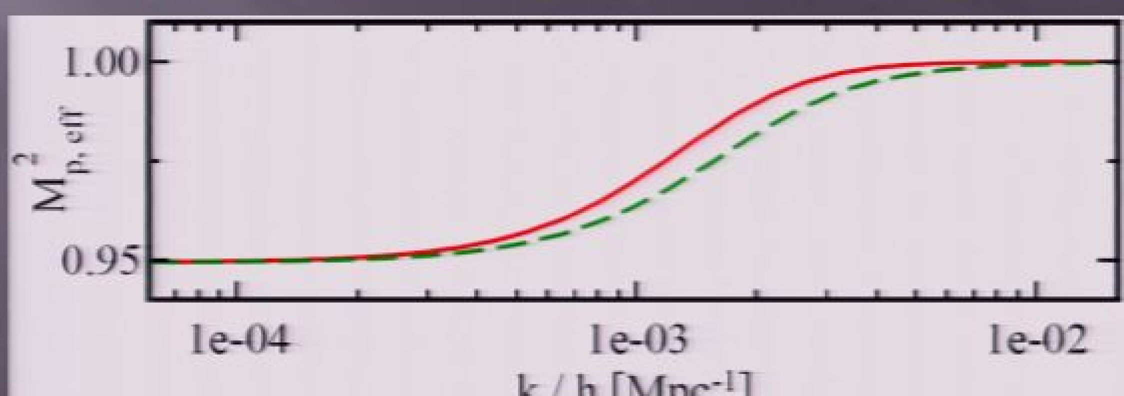

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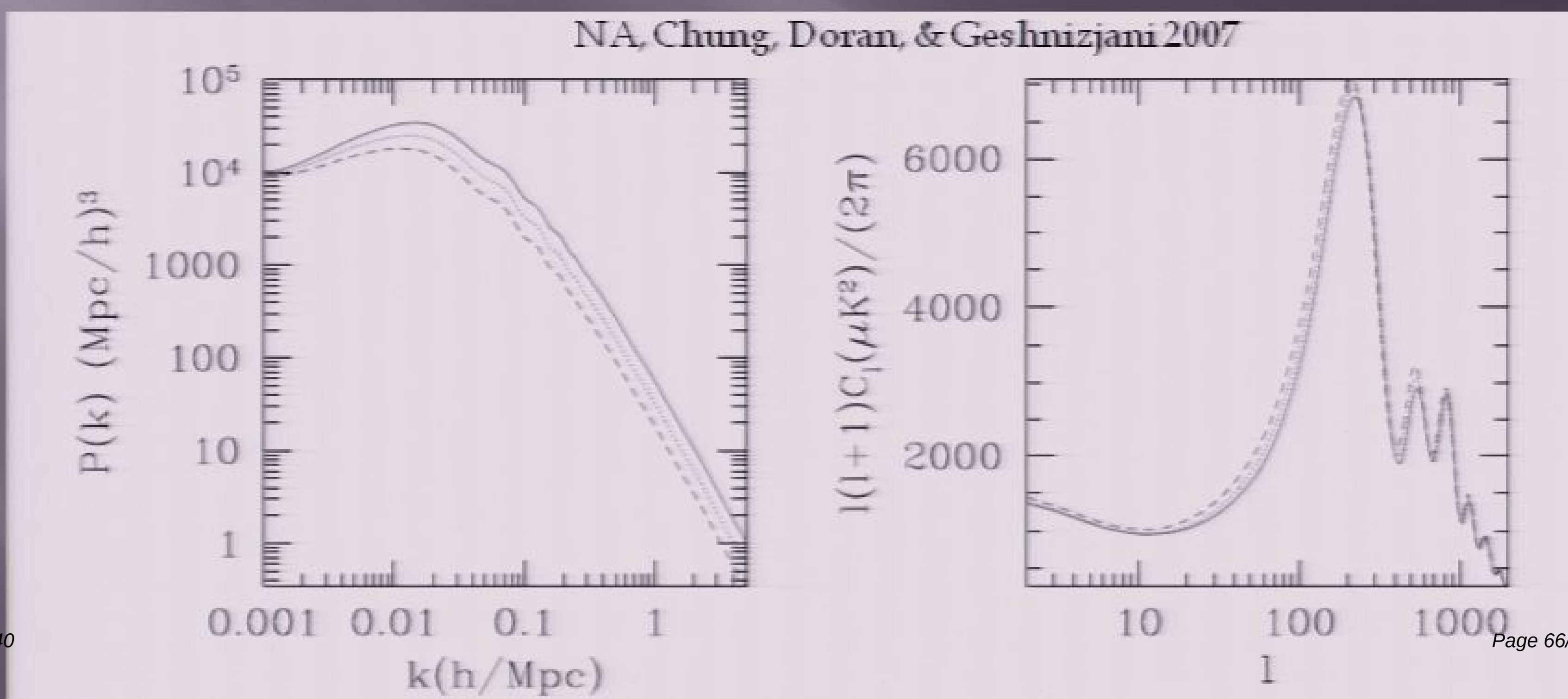

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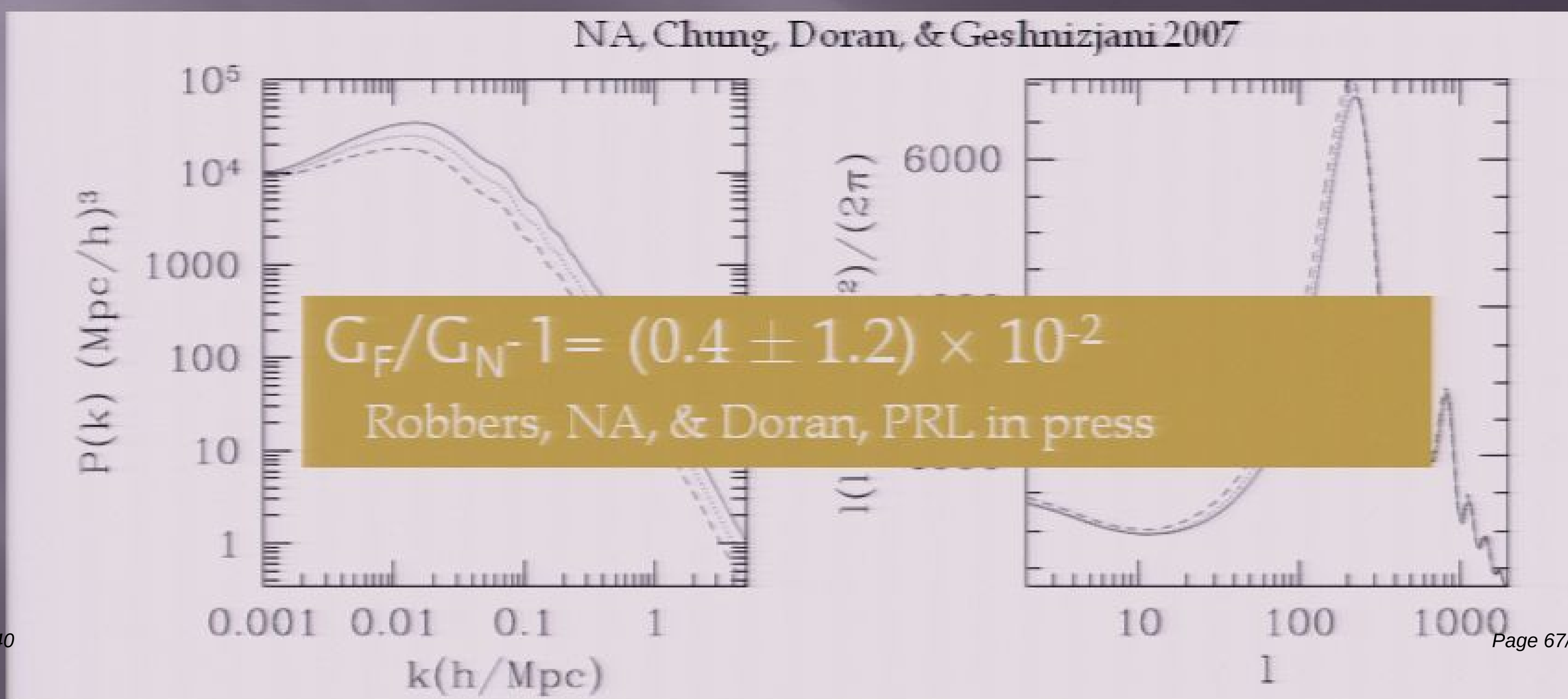

$G_F/G_N - 1 = (0.4 \pm 1.2) \times 10^{-2}$

Robbers, NA, & Doran, PRL in press

Inflationary Statistics

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- Does this rule out single-field inflation?

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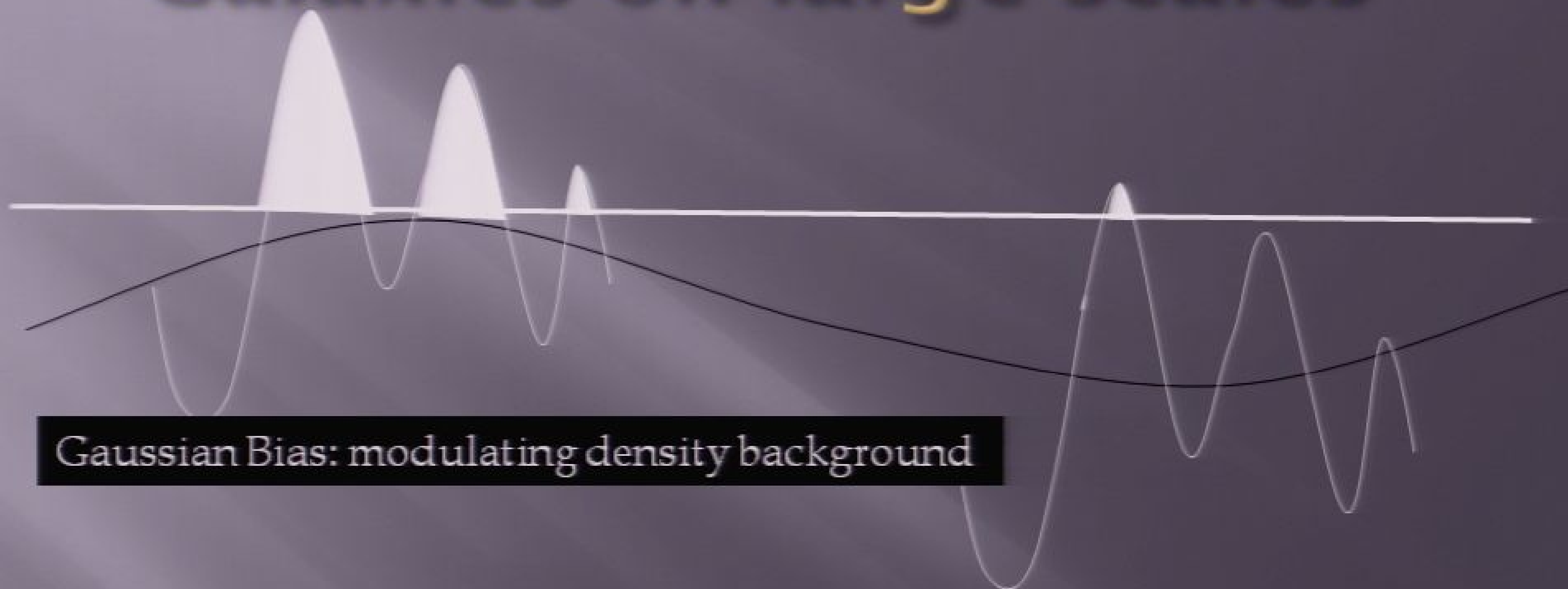
→ Galaxy distribution is much more inhomogeneous on large scales

Galaxies on large scales



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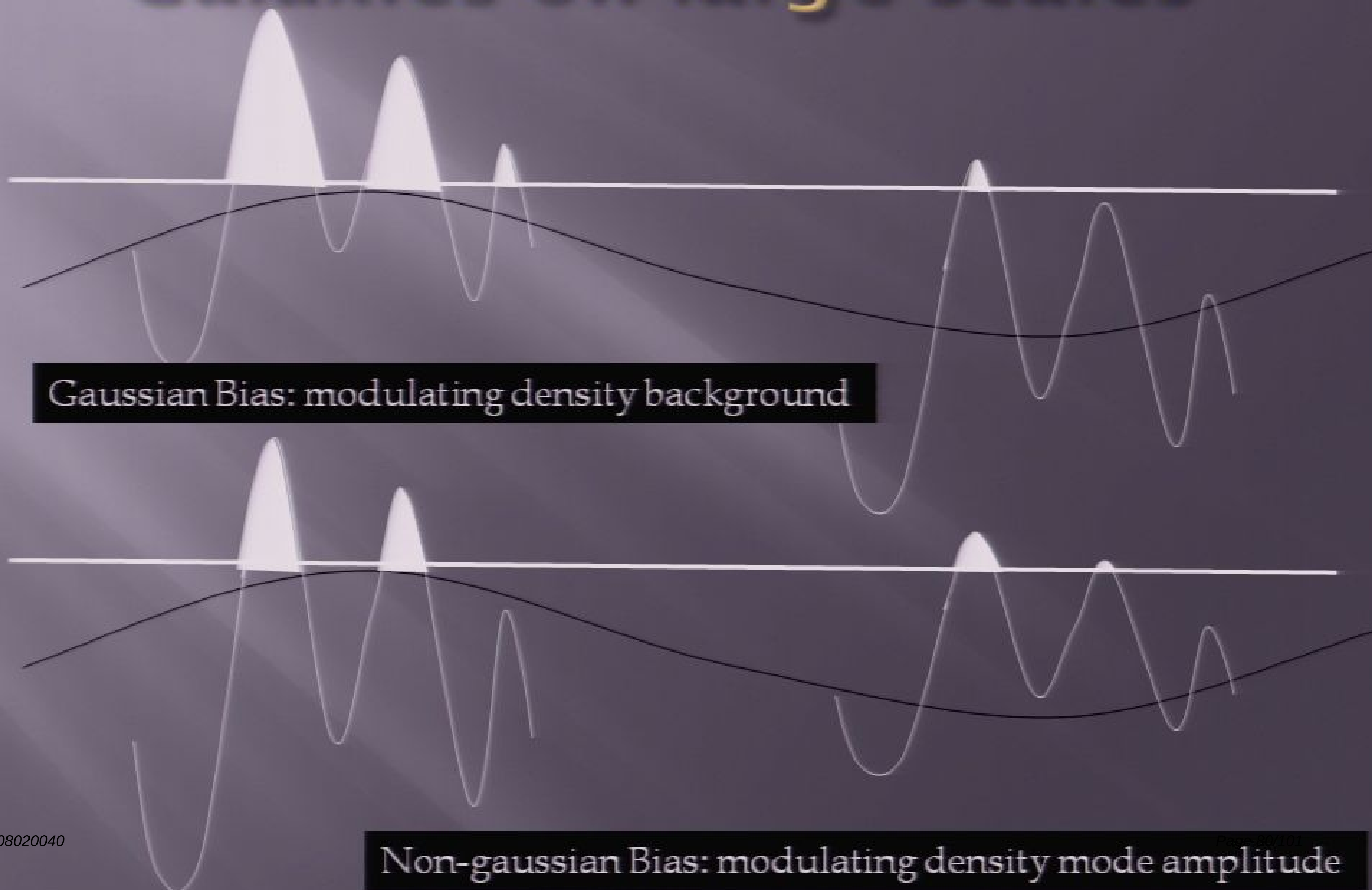

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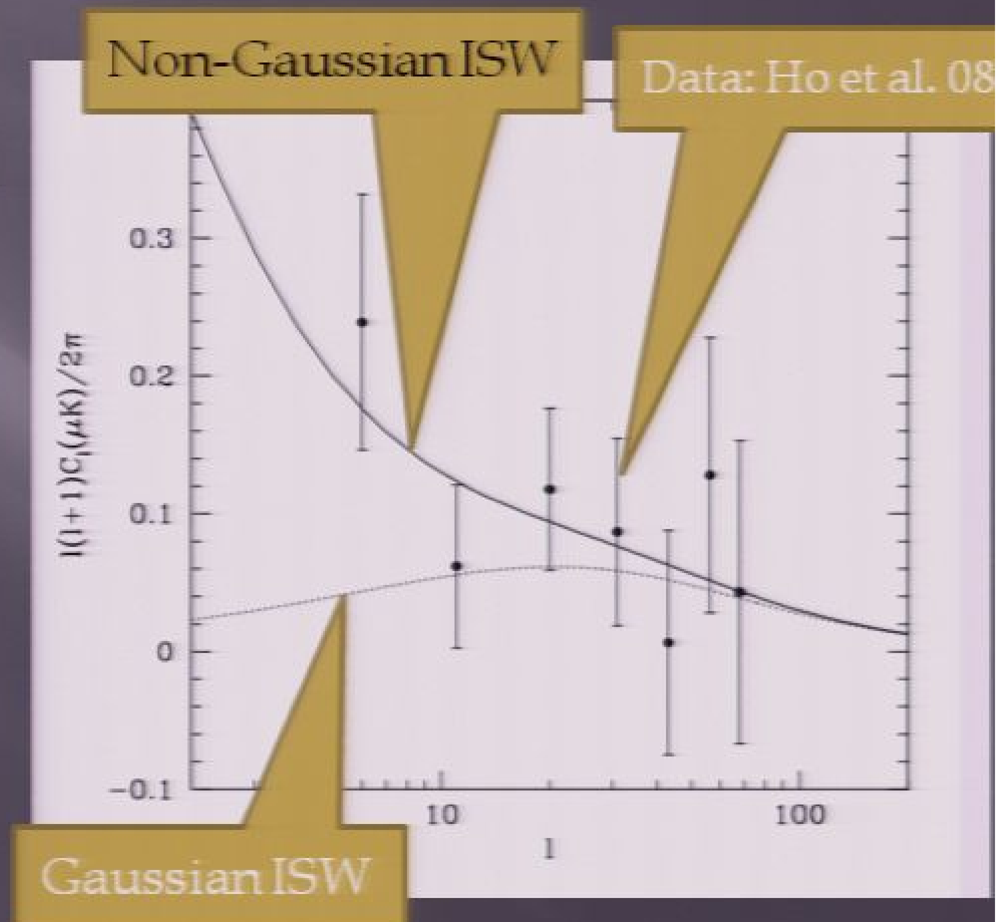

Cross-power spectrum NVSSxCMB
NA & Tolley, in prep.

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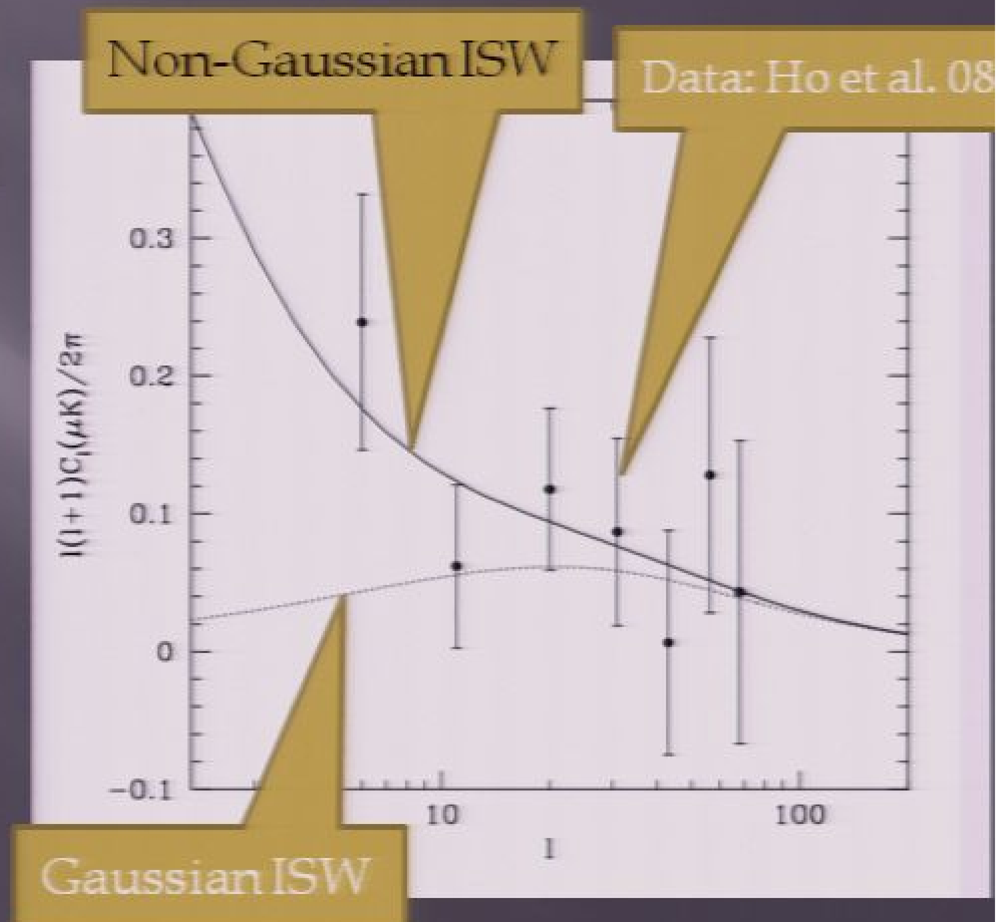

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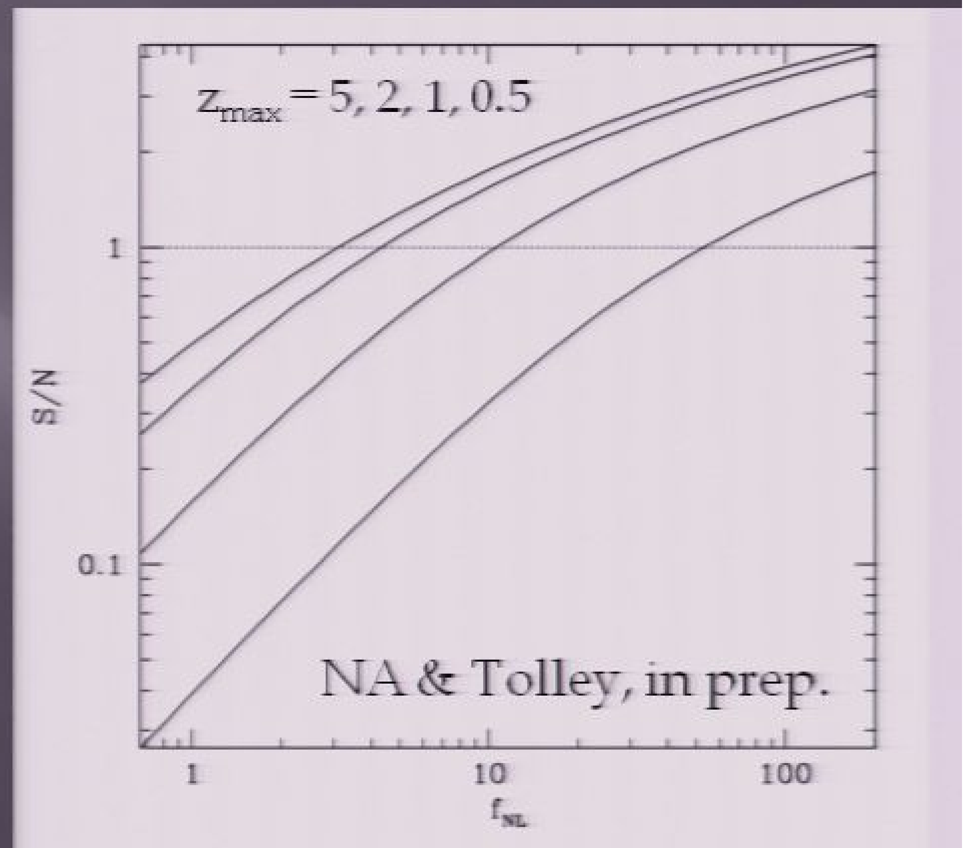

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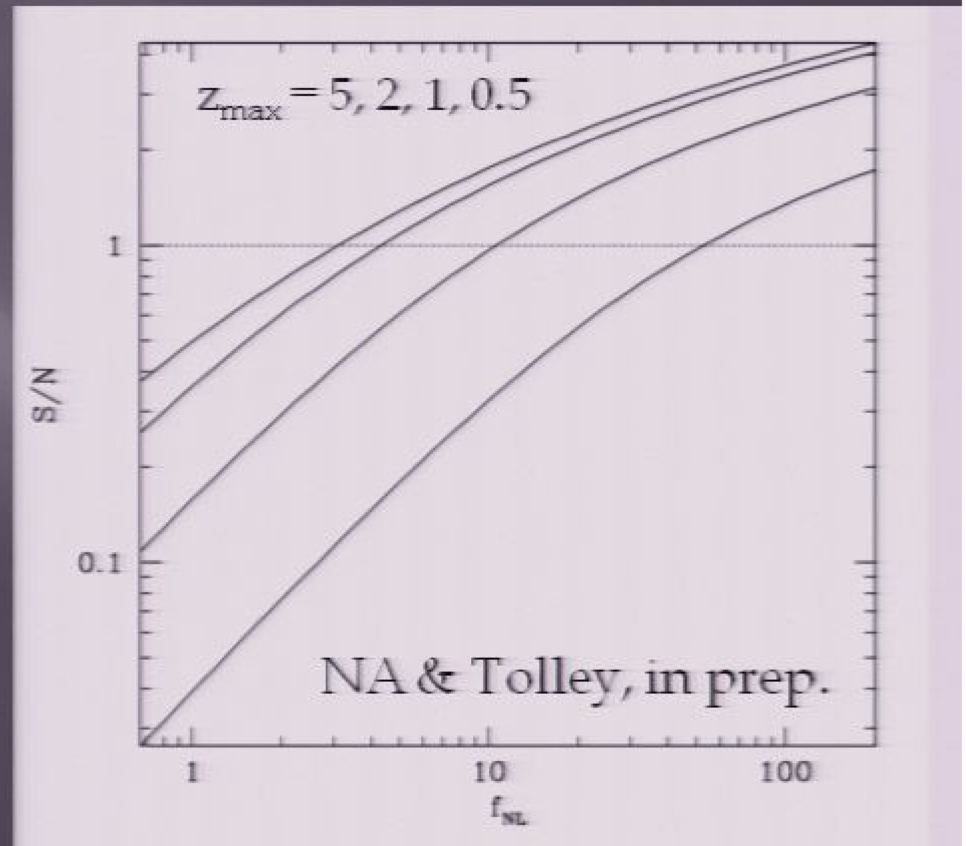
- Similar accuracy for upcoming large scale surveys (in lieu of systematics) ??



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- in correlation with galaxy surveys, probes primordial non-gaussianity (tentative evidence at 2σ level)

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