Title: Lost in the Observational Cosmology Lab: What a Theorist does at NASA

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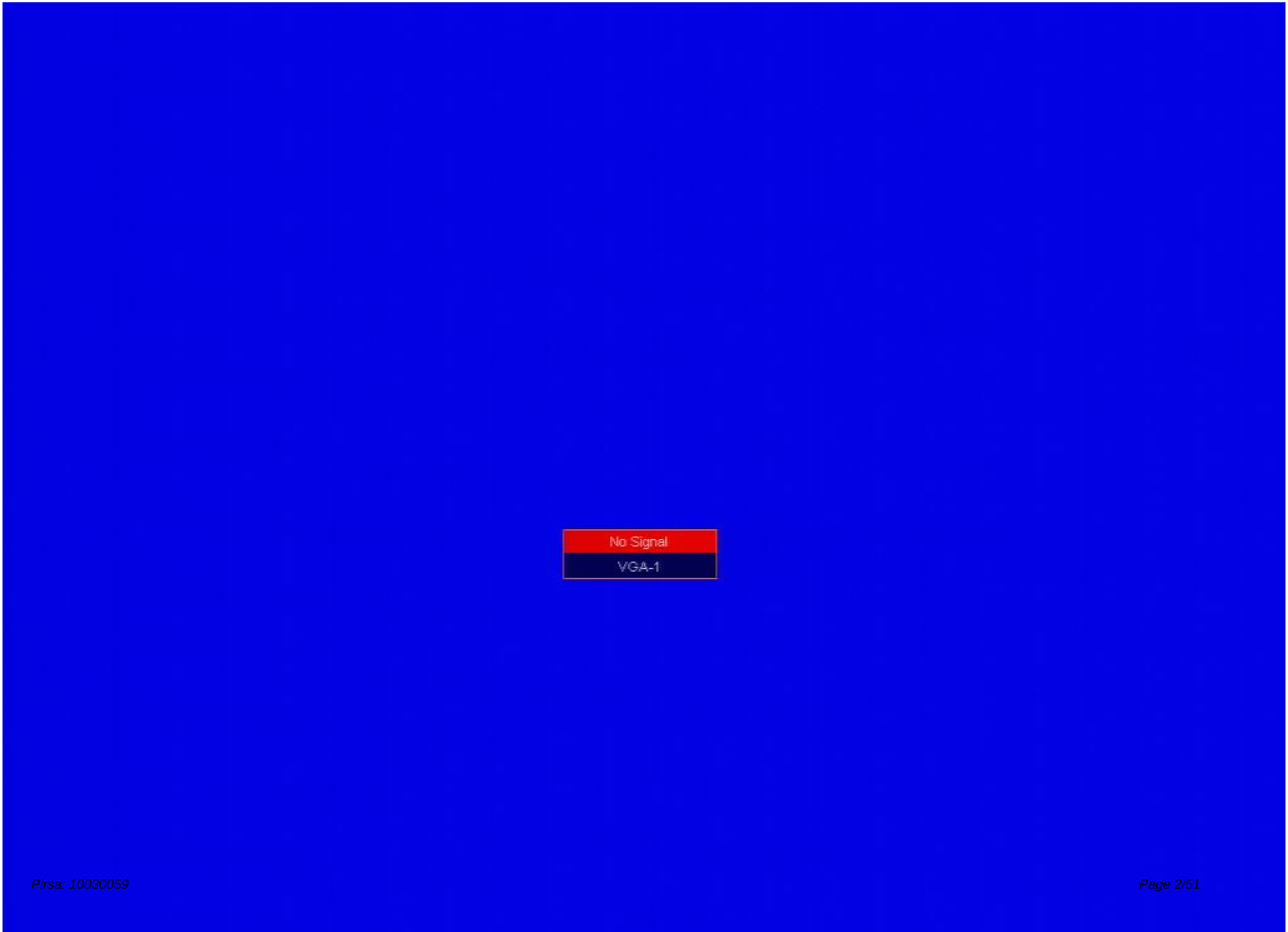
Abstract: While many expect that the best place for a theorist is in an environment where they are surrounded by fellow theorists (e.g. Perimeter Institute), there are significant advantages for the theorist and scientific progress to spend time in a data-oriented environment. Starting in September, I will be a NASA Postdoctoral Program Fellow at Goddard Space Flight Center in Greenbelt, Maryland. In this talk, I will describe the way in which a theorist can contribute to an experimental environment in the field of cosmology. More specifically, I will discuss modified gravity and setting observational priorities for the Joint Dark Energy Mission.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Lost in the Observational Cosmology Lab

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PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

BIG Cosmology Questions

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- Why did cosmic acceleration begin shortly after the onset of structure formation?
- Can both questions be addressed simultaneously?

Outline

- Goddard Space Flight Center (GSFC) and WMAP

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1. Goddard Space Flight Center, COBE and WMAP
2. Cosmic Acceleration

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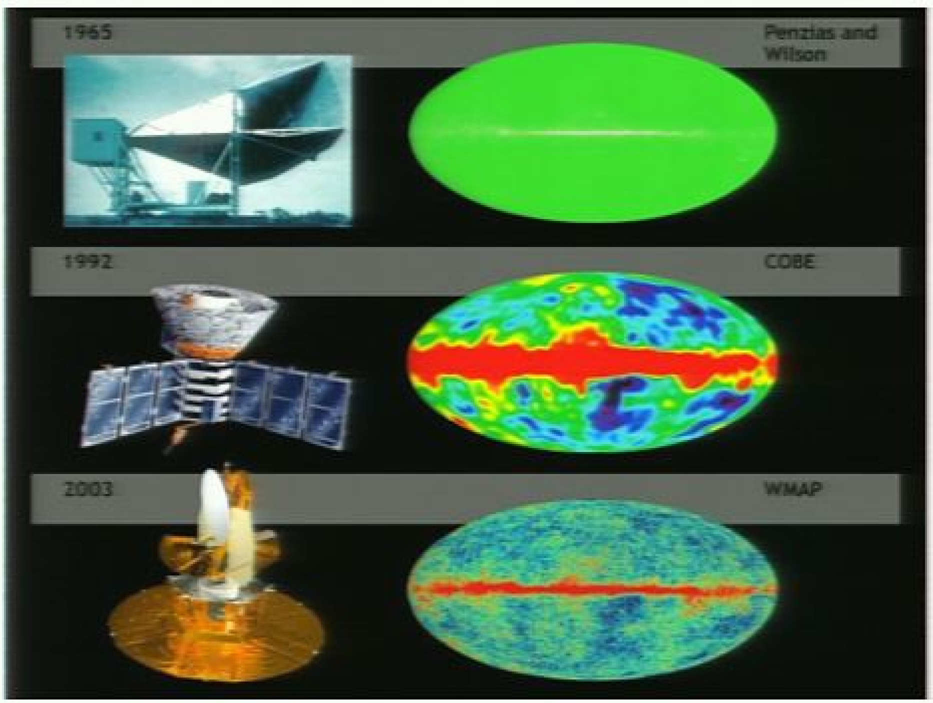
2. Cosmic Acceleration
3. Joint Dark Energy Mission & Observational Priorities
4. Modified Gravity & Weak Lensing

- NASA's Astrophysics Science Division
  - → Observational Cosmology Lab
  - → Hubble Space Telescope Operations
  - → James Webb Telescope Construction & Operations
  - → Weather & Global Warming Observations
  - → Cosmic Background Explorer (COBE)
  - → Wilkinson Microwave Anisotropy Probe (WMAP)
  - → Solar and Lunar Astrophysics (SOHO, SDO, LRO)
- Earth Science, heliophysics and solar system science

COBE and WMAP



- CMB discovery was a very fortunate accident
- A lot of information is encoded:
  - *Almost* isotropic universe (COBE)
  - Anisotropies tell us about curvature and structure formation (WMAP)

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$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- Adding a constant leaves a lot of questions unanswered ...

The Old, The New and the Coincidence

1. The measured value of the Cosmological Constant is 120 orders of magnitude too small

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The Old, The New and the Coincidence

1. The measured value of the Cosmological Constant is 120 orders of magnitude too small
2. The value of the Cosmological constant isn't zero!
3. Coincidence problem: structure formation and dark energy dominance happened around the same time

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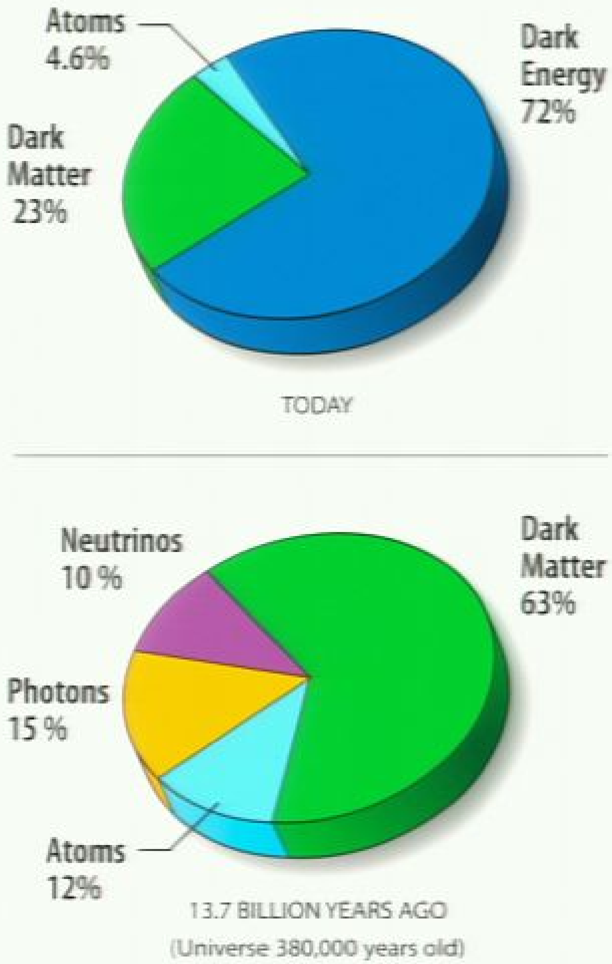
Only known solution: Landscape +Anthropics*



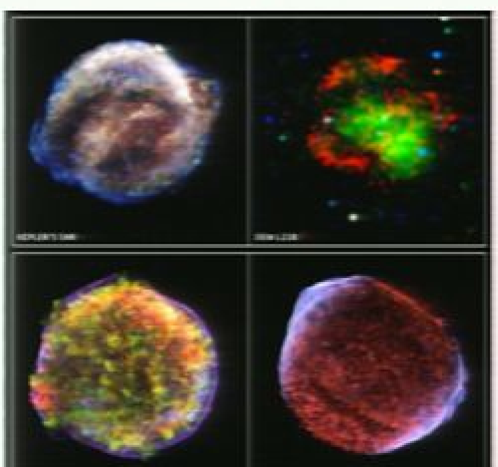
- Joint effort between NASA and the Department of Energy
- Understanding the mysterious "dark energy"
- Space-based wide-field telescope
- Final decision in April/May 2010

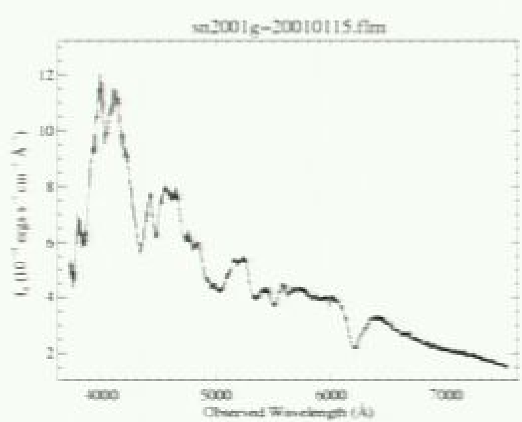
Scoping out The Mystery

1. Type Ia Supernovae
2. Baryon Acoustic Oscillations (BAO)
3. Weak Gravitational Lensing

Exploding Stars Are So 1998

- Violent explosion of a white dwarf star
- All pretty much look exactly the same (consistent peak luminosity)
  - →Astronomer's dream: Standard Candle
- Standard candles are important for measuring distances → discovering cosmic acceleration! (at $z < 0.9$)



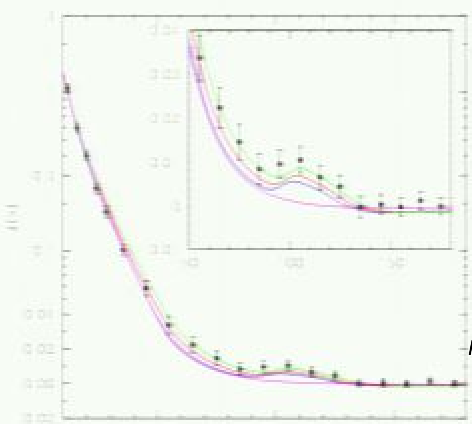


Baryon Music What?

- Spherical sound waves due to primordial overdensities → Baryon Acoustic Oscillations
- WMAP and Planck tell us about sound horizon at time of recombination
- Galaxy clustering ~ sound horizon today

→ Get precise measurement of the expansion rate, H(z)

→ Different systematics than supernovae, better at z>1



The force is not always strong

- Weak lensing is not pretty like strong lensing:

- Observed via statistics of galaxy shapes and their distortions along share line of sight → galaxy shear
- Tells us about gravitational fluctuations, which are highly sensitive to models of gravity
- Paired with BAO → powerful test of GR

Hard Choices

- Instrumentation is costly
- Different observations require different instrumental strengths
- The best BAO/weak lensing system might not be the best supernova survey system
- Before the instrument is built, we plan.
- **This is where a theorist comes in!**

e.g. If we want to look for modified gravity, what is the best way to do it?

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Restating the Problem

- Einstein Equation

$$G_{\mu\nu} = \langle T_{\mu\nu} \rangle$$

space-time curvature:
$(10^{-3}\ \text{eV})^4$

vacuum energy density :
$\geq (100\ \text{GeV})^4$
+ excitations

Gravitational Aether

Afshordi 2008

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$$(8\pi G)^{-1} G_{\mu\nu}[g_{\mu\nu}] = T_{\mu\nu} - \frac{1}{4} T g_{\mu\nu} + \ldots .$$

- The metric is now blind to vacuum energy:

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- [illegible]

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Weak Lensing and Modified Gravity

- Study structure formation:
    1. Effects on the expansion history of the background metric
    2. Evolution of density perturbations
    3. The early-time matter power spectrum

- In the aether: N-body code → angular power spectrum

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Why Do We Care?

(We = theorists of the fundamental physics persuasion)

- What if general relativity is not the correct formulation of the theory of gravity?
- Elegance is nice, but is not empirical in itself
- Modified gravities like gravitational aether are potentially quantum gravity phenomenology

Conclusions

- Cosmic acceleration is a problem
- The Cosmological Constant isn't a solution! It's a problem too ...
- Quantum gravity is a problem and we have no phenomenology for it
- Or do we??
- Gravitational aether is an interesting way of tying both together while neatly divorcing gravity and the vacuum
- The data will tell us what direction to go in

Aether: Observations & Considerations

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- Future CMB/LSS surveys will constrain $G_{mat.}/G_{rad.}$ with 10 times better precision *(Planck/ACT/SPT/SDSS3)*
- Precision tests of gravity: Rotation *(Gravity Probe B)*

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- ***Should we revisit our assumptions for constructing*** *Effective Theories****? (e.g. locality/action)***
- ***Should we re-evaluate our*** *Dark Energy program****?***

JDEM's Transport

Obama's new vision of NASA transport will put it entirely in the hands of private contractors. So, in 2016, JDEM might need to buy a seat on Virgin Galactic like the rest of us.

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