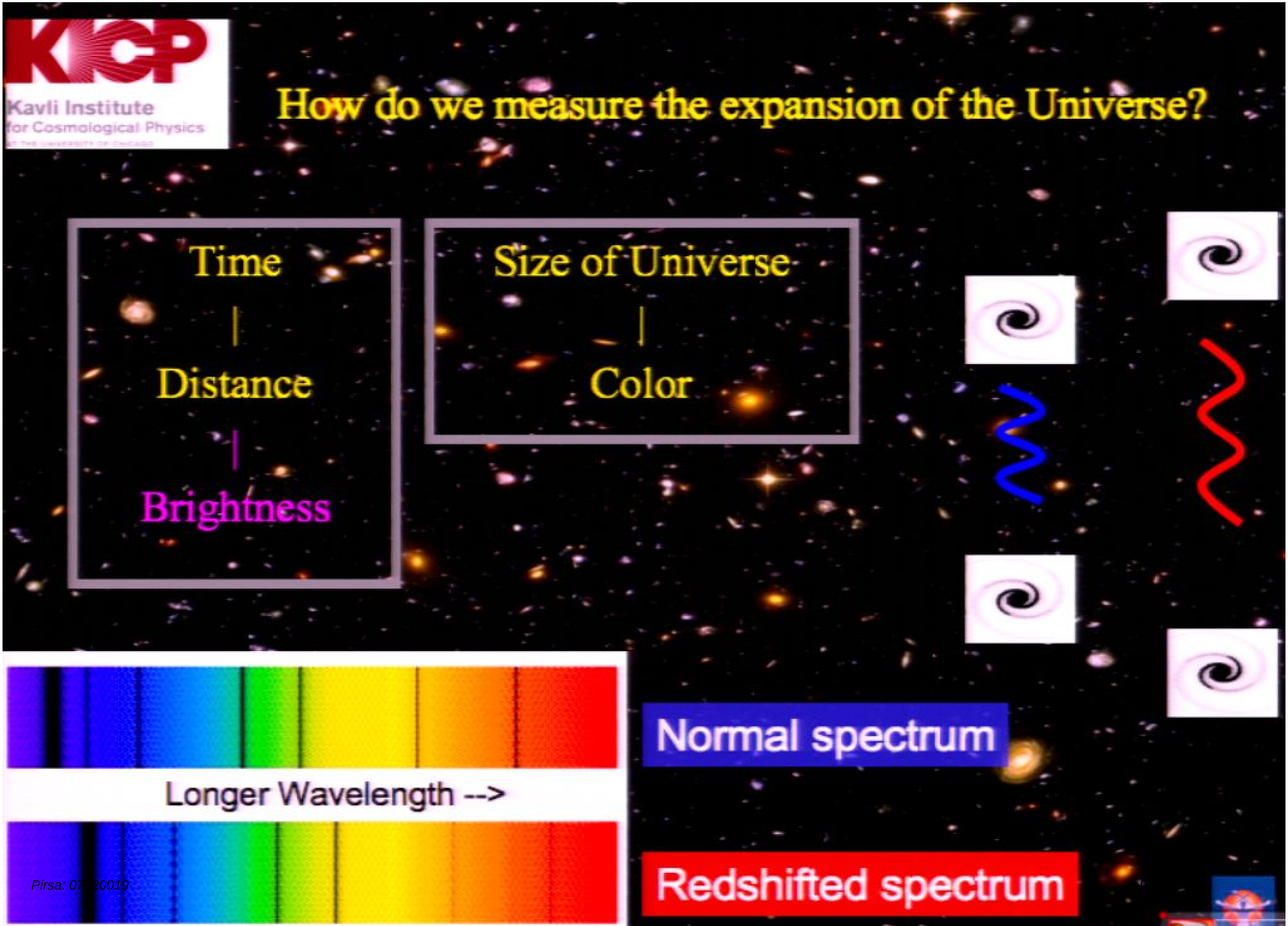
Title: Cosmic Acceleration and Weak Gravitational Lensing

Date: Dec 03, 2007 02:20 PM

URL: http://pirsa.org/07120019

Abstract: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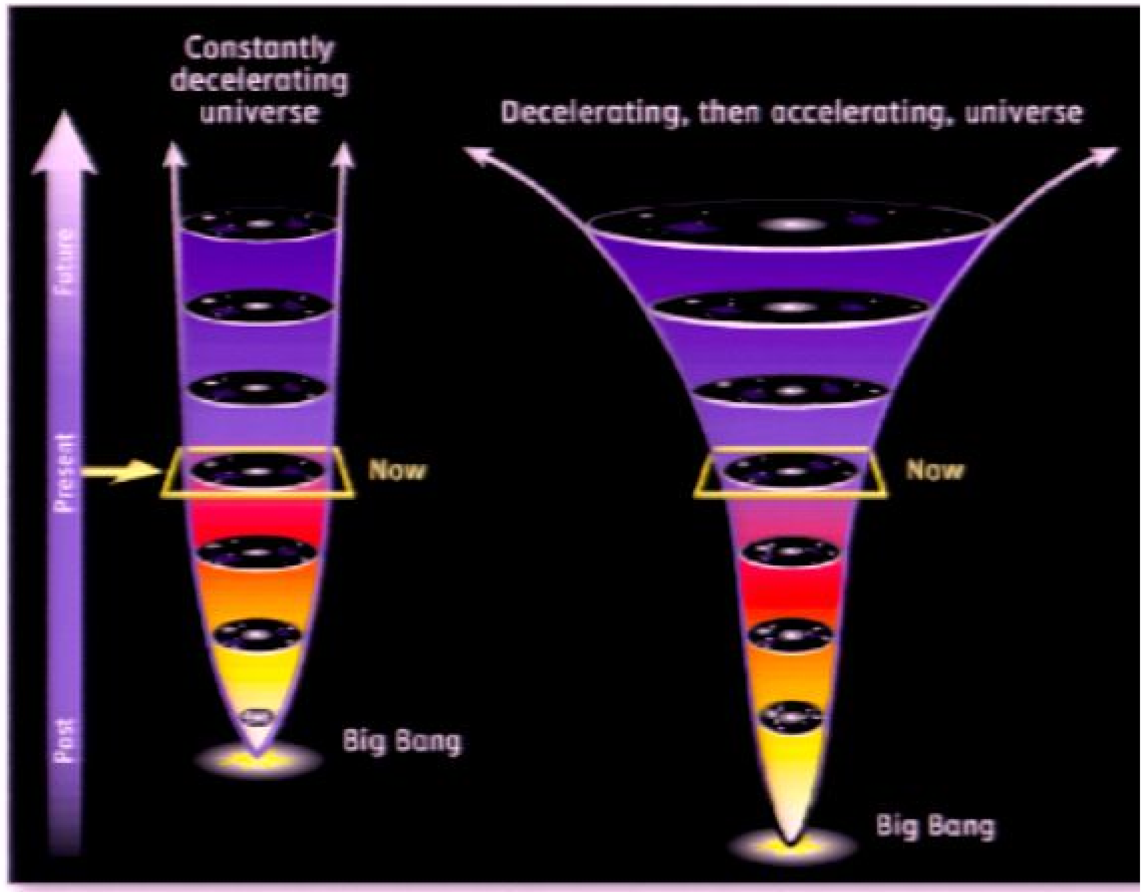
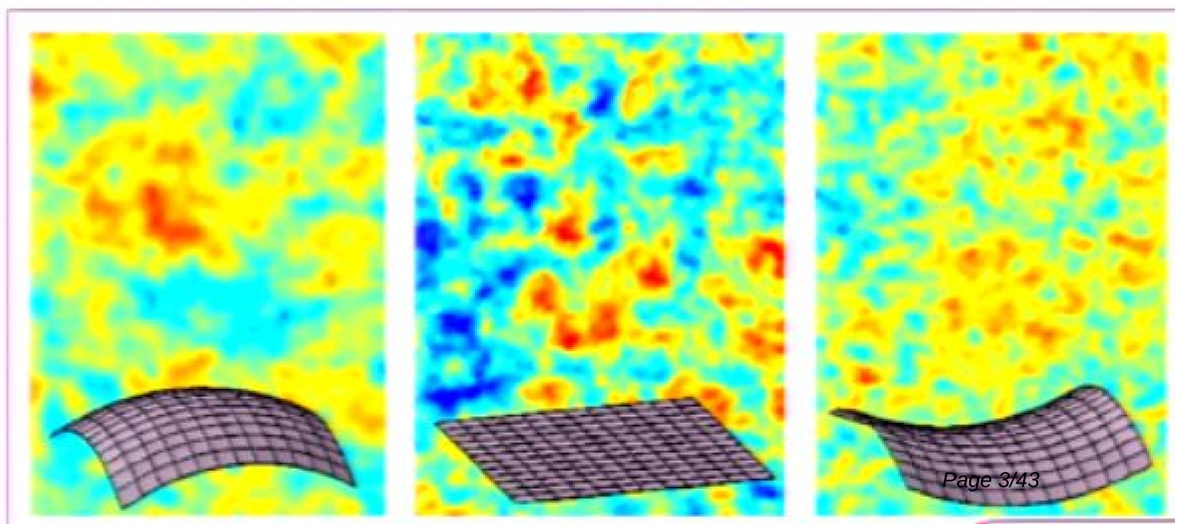
How do we measure the expansion of the Universe?
Time
|
Distance
|
Brightness
Size of Universe
|
Color
Longer Wavelength -->
Normal spectrum
Redshifted spectrum

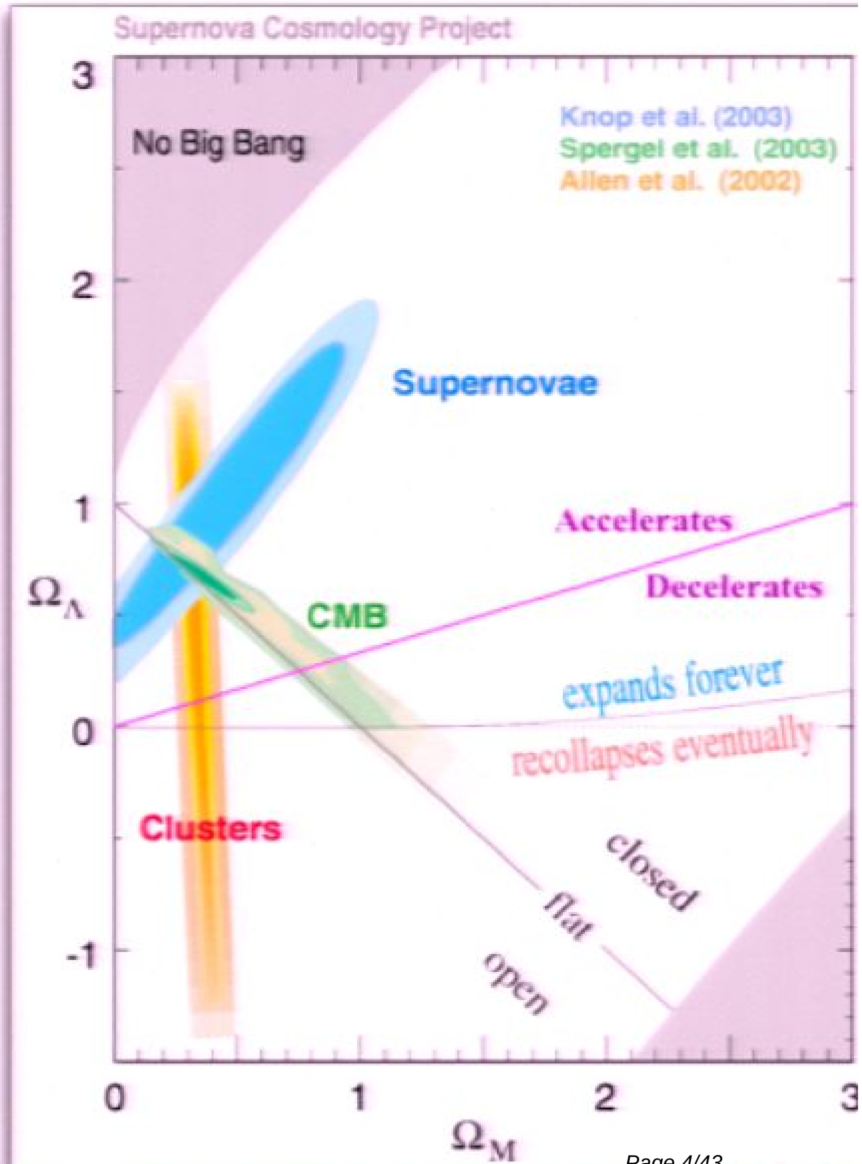
The Accelerating Universe Observed

- Distance/redshift measurements of Type Ia supernovae reveal that the Universe's expansion is **accelerating**!
- Cosmic Microwave Background and other observations imply a **missing energy component**.





The Accelerating Universe Explained?



- Within General Relativity (GR), the evidence is explained by lots of ***dark energy***, an invisible, smooth substance with negative pressure
- "Simplest" explanation is Λ or vacuum energy
- Dark energy could have dynamics, e.g. quintessence
- GR requires dark energy but the Standard Model doesn't provide a viable dark energy candidate… *something's gotta give*

What if General Relativity is Wrong?

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- Einstein's equation $G_{\mu\nu} = 8\pi G\, T_{\mu\nu}$,

  provides the Friedmann equation, which links cosmic expansion to cosmic energy + pressure:

$$d^2(\text{Physical Distances}) / dt^2 \sim -(\rho+3p)$$

- Acceleration in GR requires a significant amount of dark energy with $w_{DE} = p_{DE} / \rho_{DE} < -1/3$ … observations consistent with this picture
- But **if GR is wrong**, cosmic expansion could proceed in a different way
- Alternatives include: Extra dimensions, f(R) theories, TeVeS, Quantum Gravity, ???

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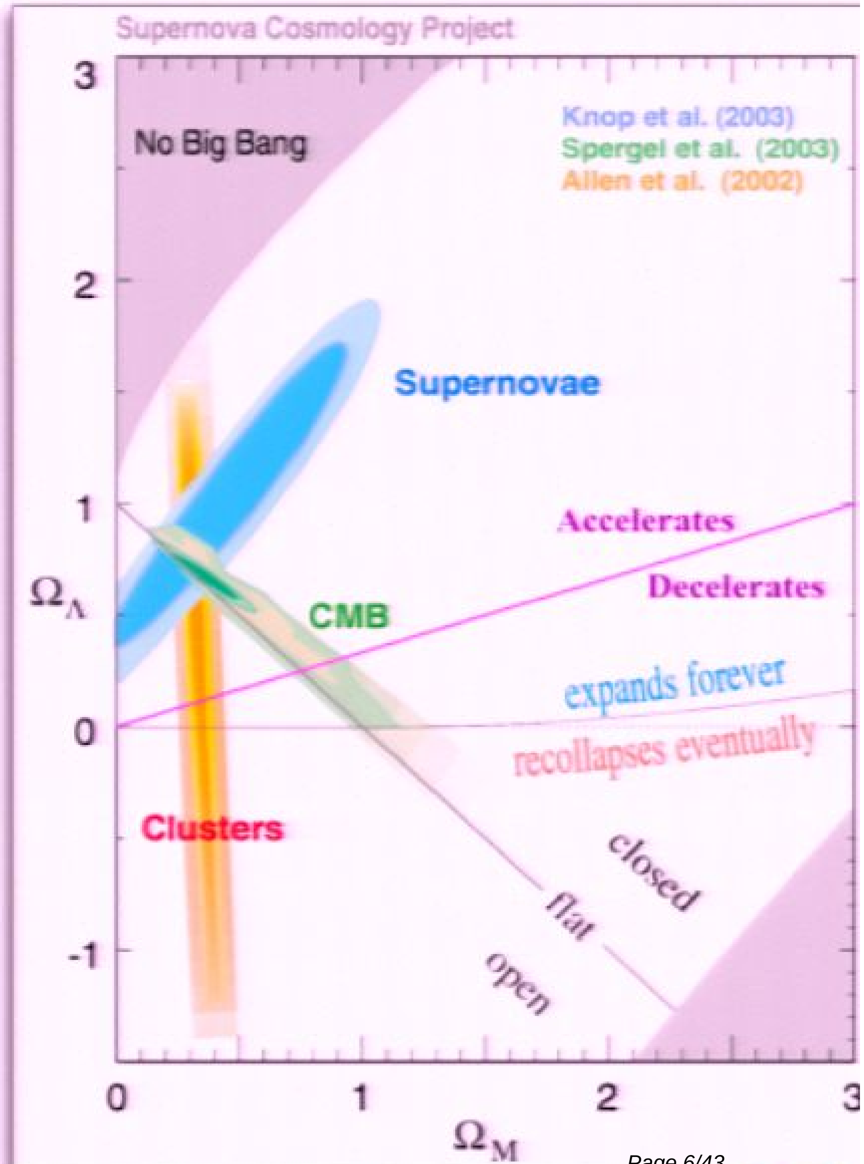

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Des Moines Tribune
General Relativity Falsified!
Americans Charge Across Algerian Beach
Tens of Thousands More on Way


So, is the Universe even accelerating? *I don't know what to believe anymore!*
Des Moines Tribune
General Relativity Falsified!


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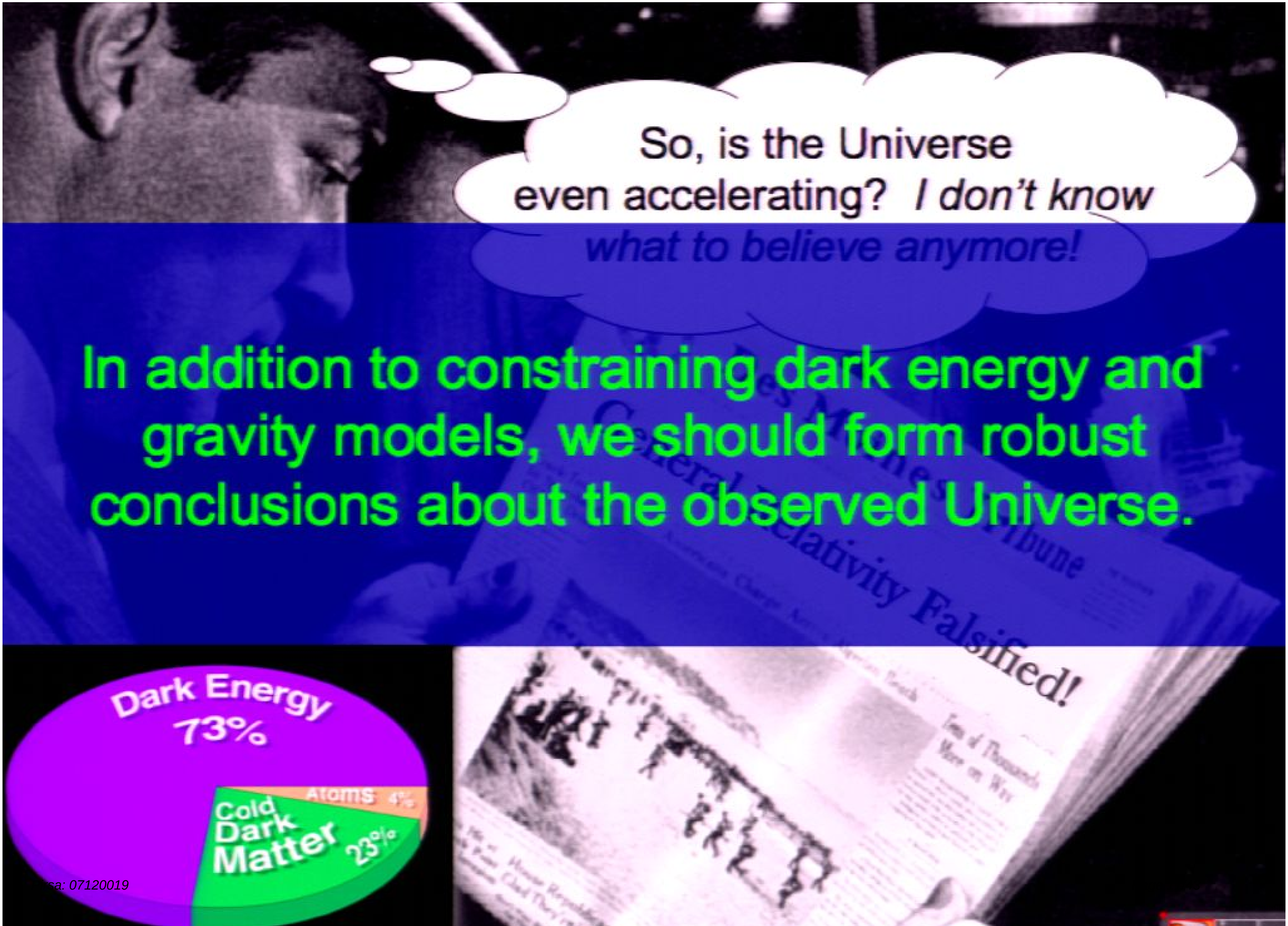
General Relativity Falsified!
Dark Energy 73%
Atoms 4%
Cold Dark Matter 23%
sa: 07120019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In addition to constraining dark energy and gravity models, we should form robust conclusions about the observed Universe.
Relativity Falsified!
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What do We Really Know About Cosmic Acceleration?

(Shapiro & Turner 2006)

Key Assumptions:

- We live on a flat*, homogenous, isotropic spacetime,

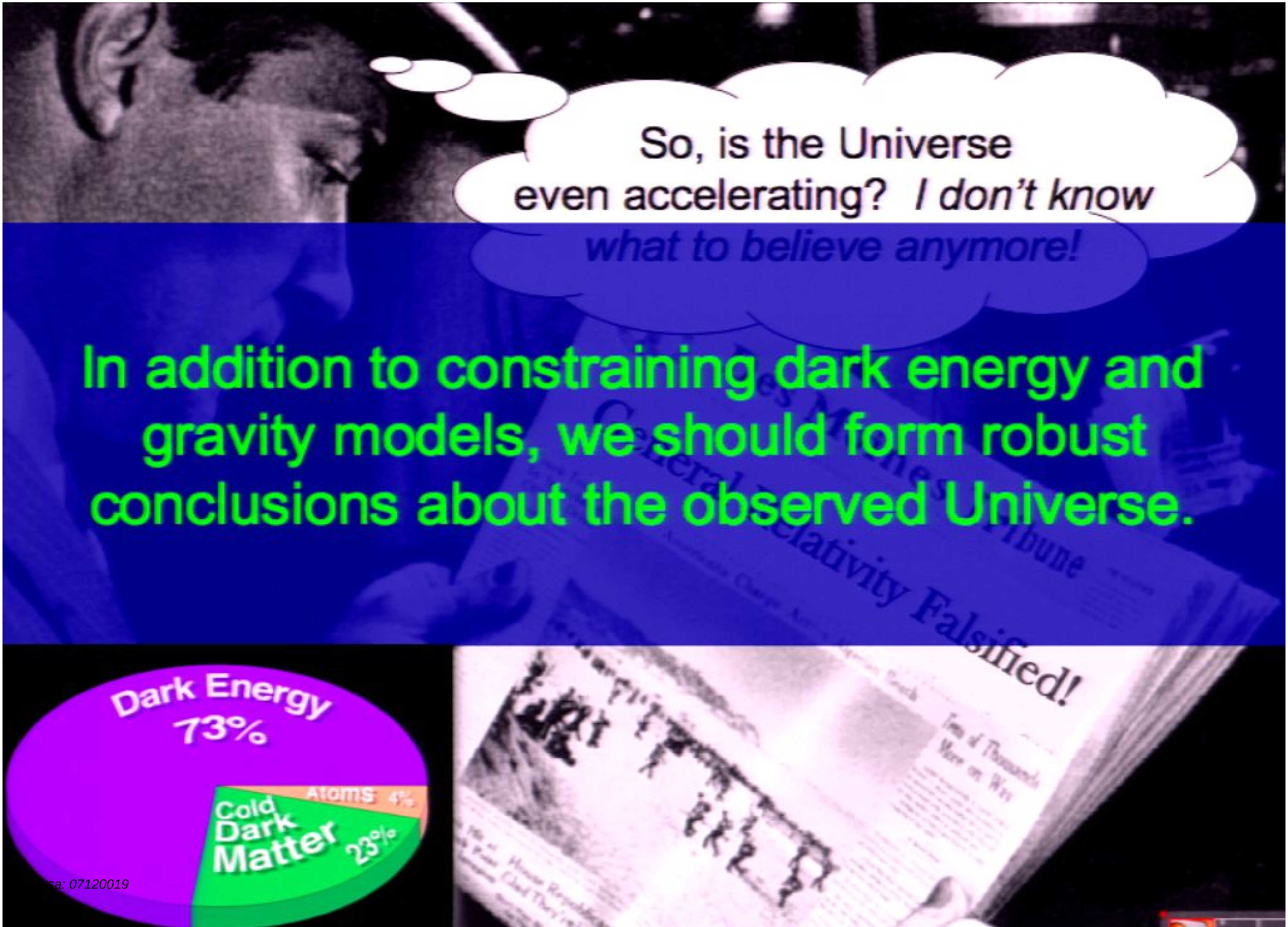
$$ds^2 = -dt^2 + a(t)^2\,(dx^2+dy^2+dz^2) \quad ; \quad a\,(\text{today})=1$$

- Usual geodesic equation holds --> light is redshifted: $a=(1+z)^{-1}$

- Define usual expansion parameters:

$$H(z) = da/dt\,/\,a \qquad \text{<---->} \qquad q(z) = -\,d^2a/dt^2/(aH^2)$$

- Calculate distance/redshift relation directly from q(z), forgoing dynamics (this is "kinematic")
- We can still measure supernova distances (luminosity) and redshifts
- Compare to data:
  Riess et al. Gold set - 157 supernovae with $0.01 < z < 1.76$



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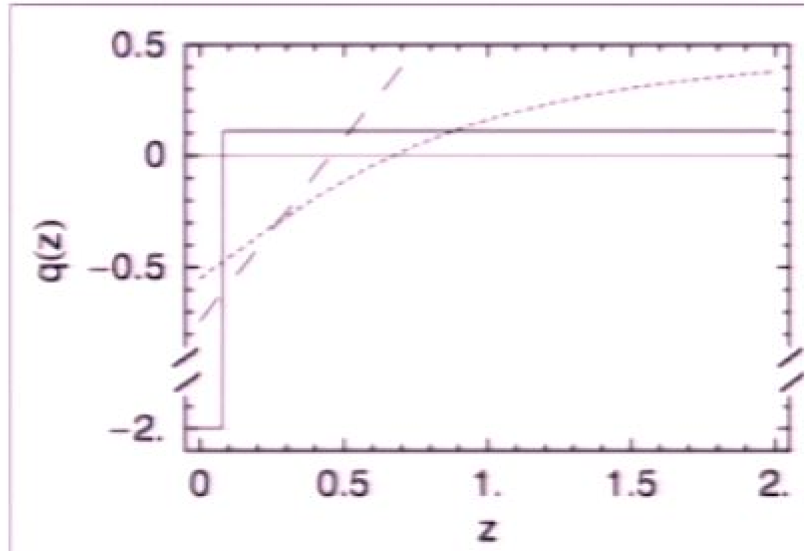
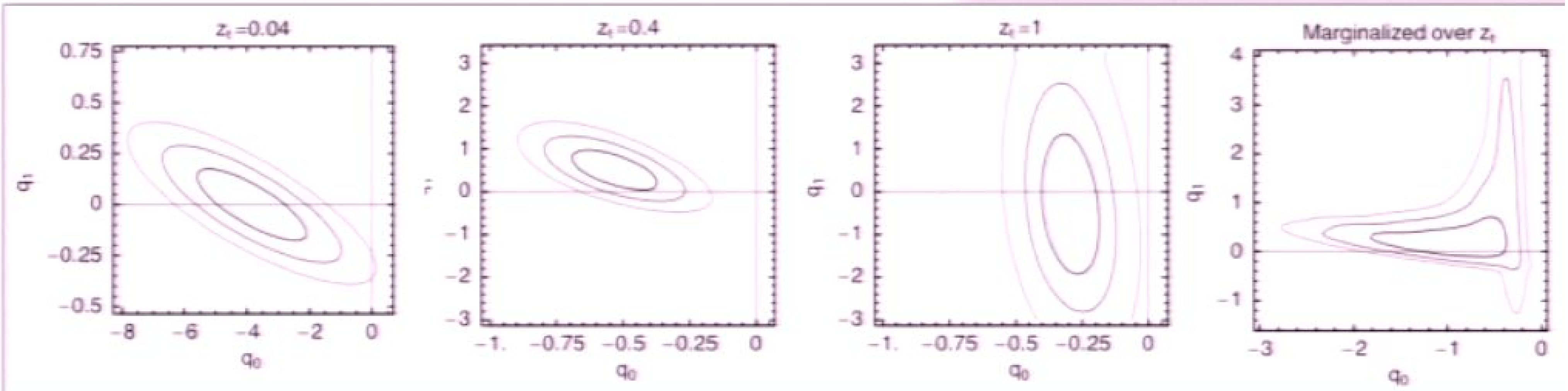
Did the Universe ever really accelerate/decelerate?



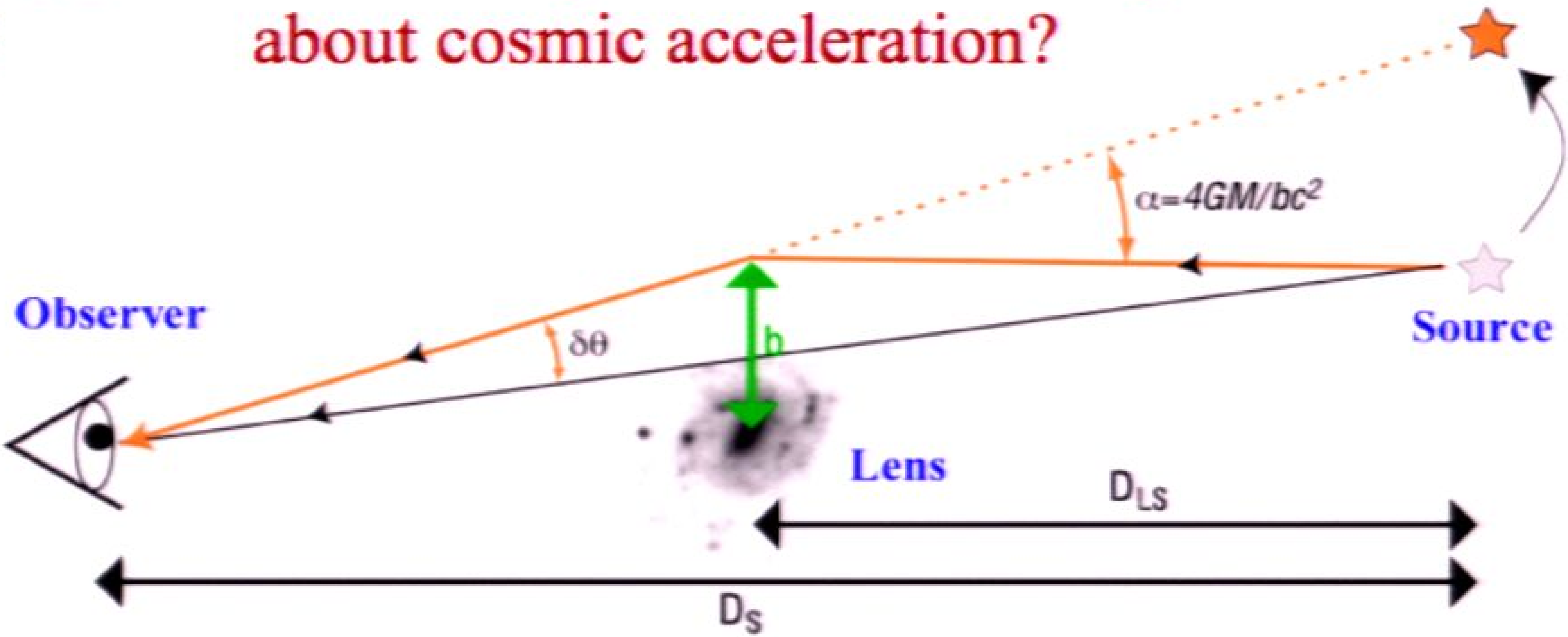
- A linear q(z) model says yes, *but do we believe it?*
- A 2-zone model: $q(z) = q_0\ (z<z_t)$
  $= q_1\ (z>z_t)$

  says probably…
- These models fit the data as well as ΛCDM.



- Which features are real? Which are just due to the model?
- Using *principle components*, we argue that acceleration is real (5σ) and probably not constant.

What can gravitational lensing tell us about cosmic acceleration?



Dark energy changes the distance ratios between sources, lenses, and observers

Dark energy interferes with structure formation (slows the clumping of matter, fewer massive structures form)

By observing sources at multiple redshifts, we can isolate distance information and turn lensing into a kinematic probe

OR, include structure information and test alternate gravity theories

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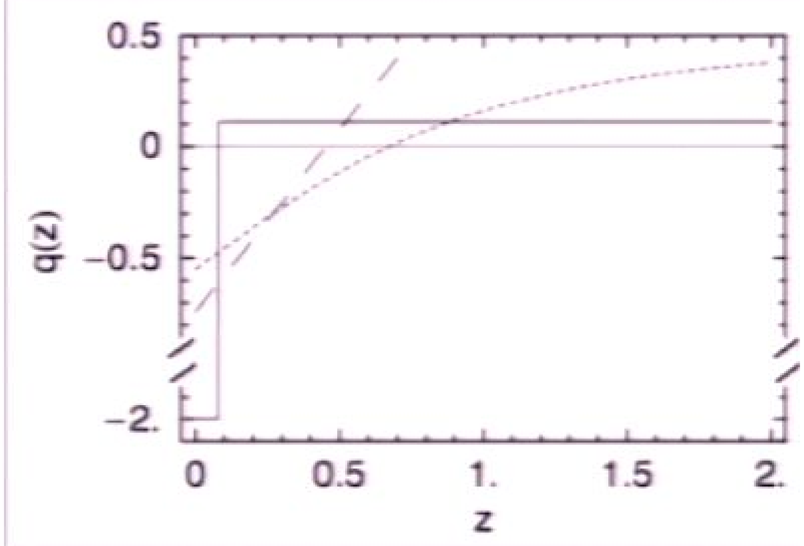

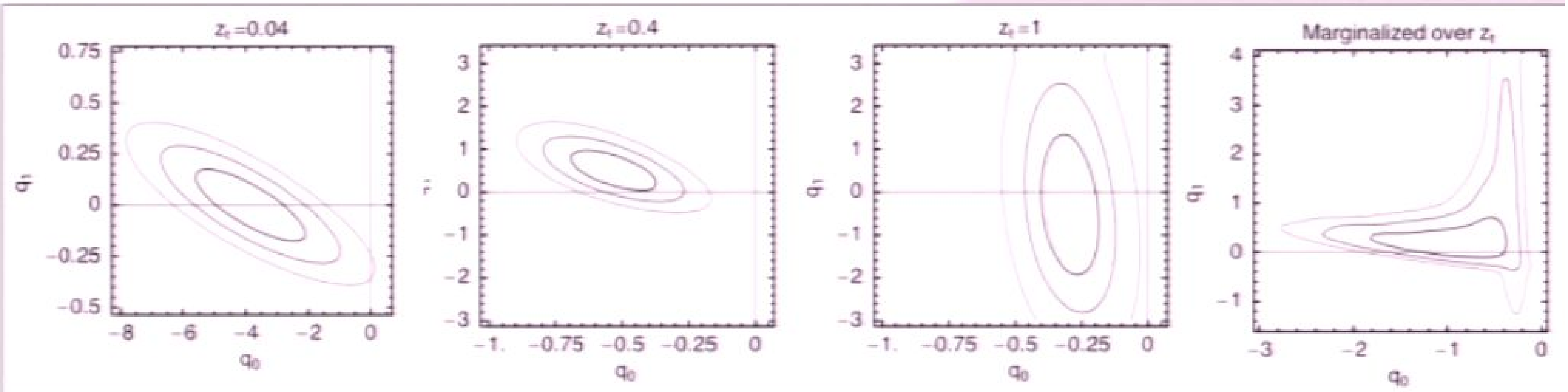

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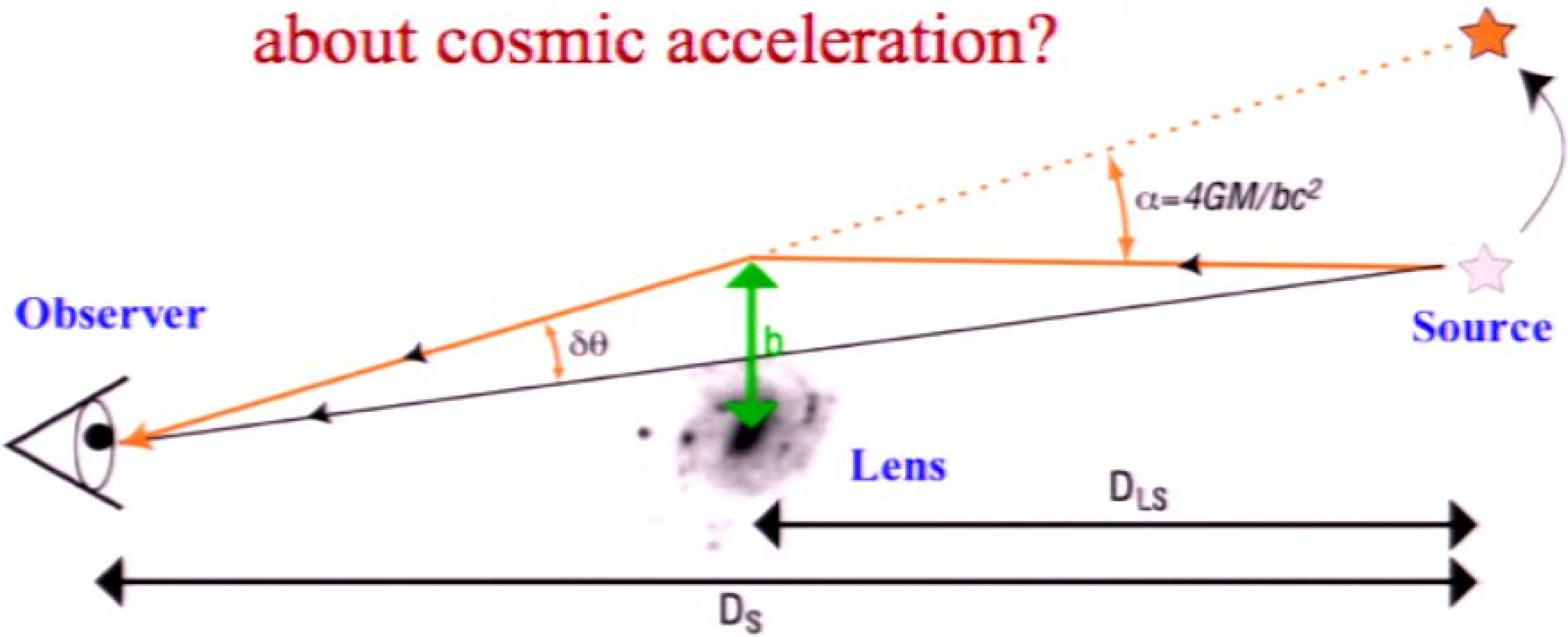

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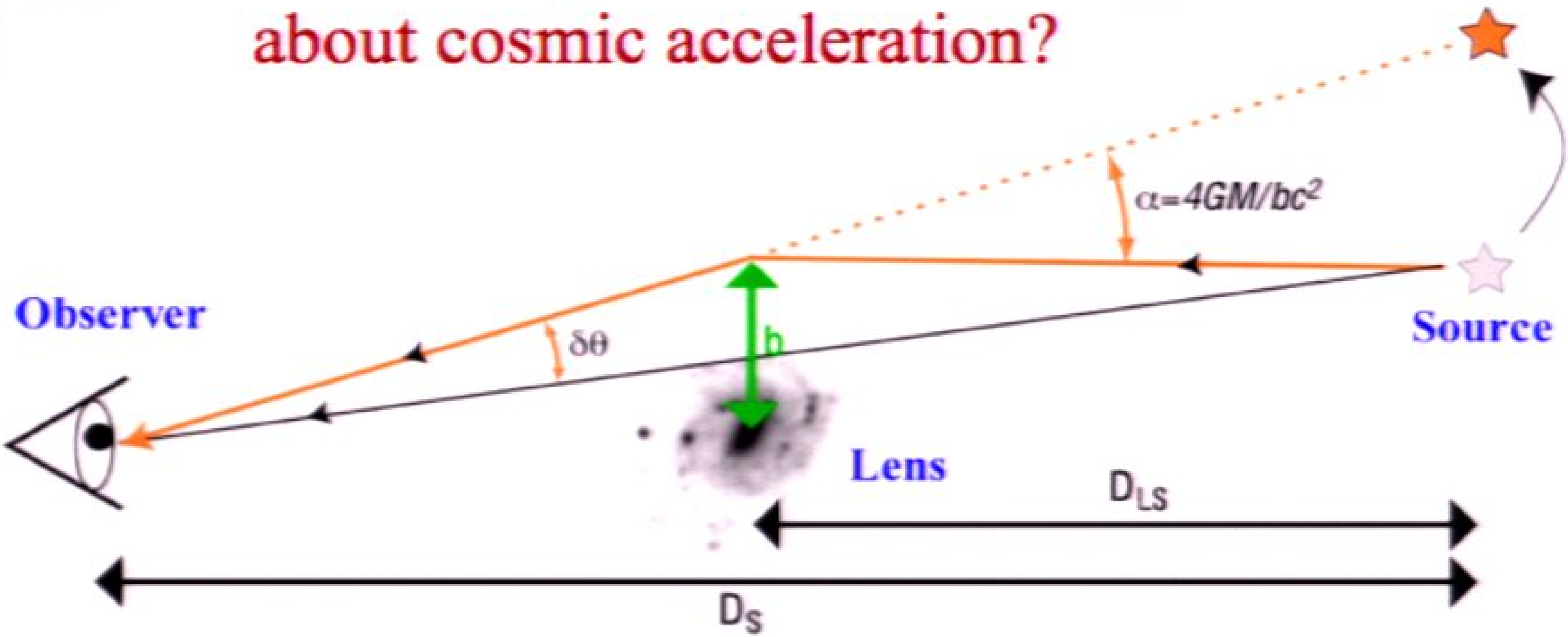

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Work in Progress

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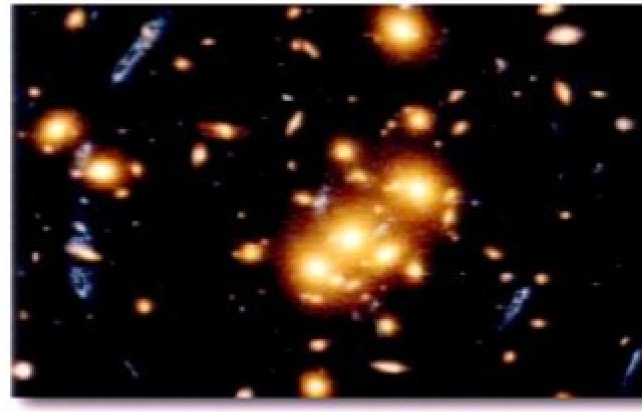
Gravitationl Lensing: Strong vs. Weak

Strong Lensing



Gravitationl Lensing: Strong vs. Weak

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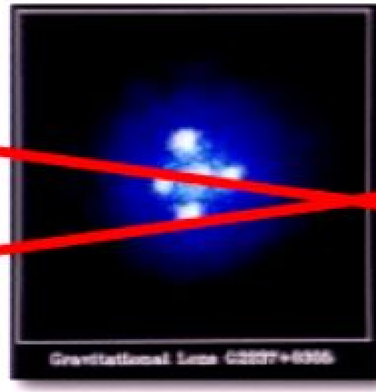
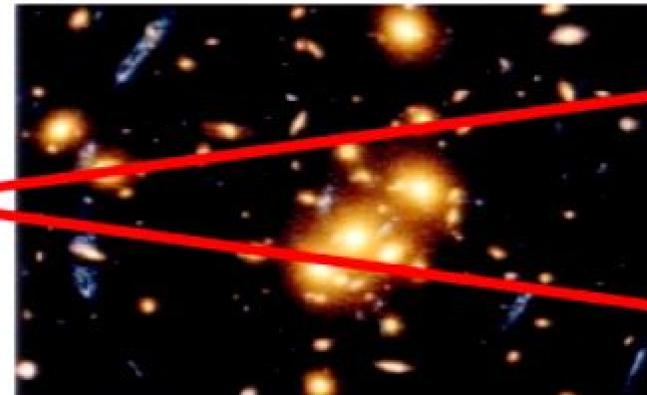
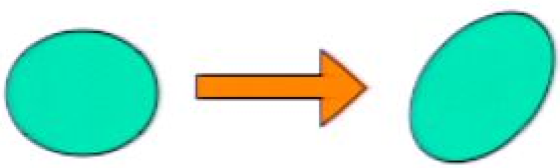
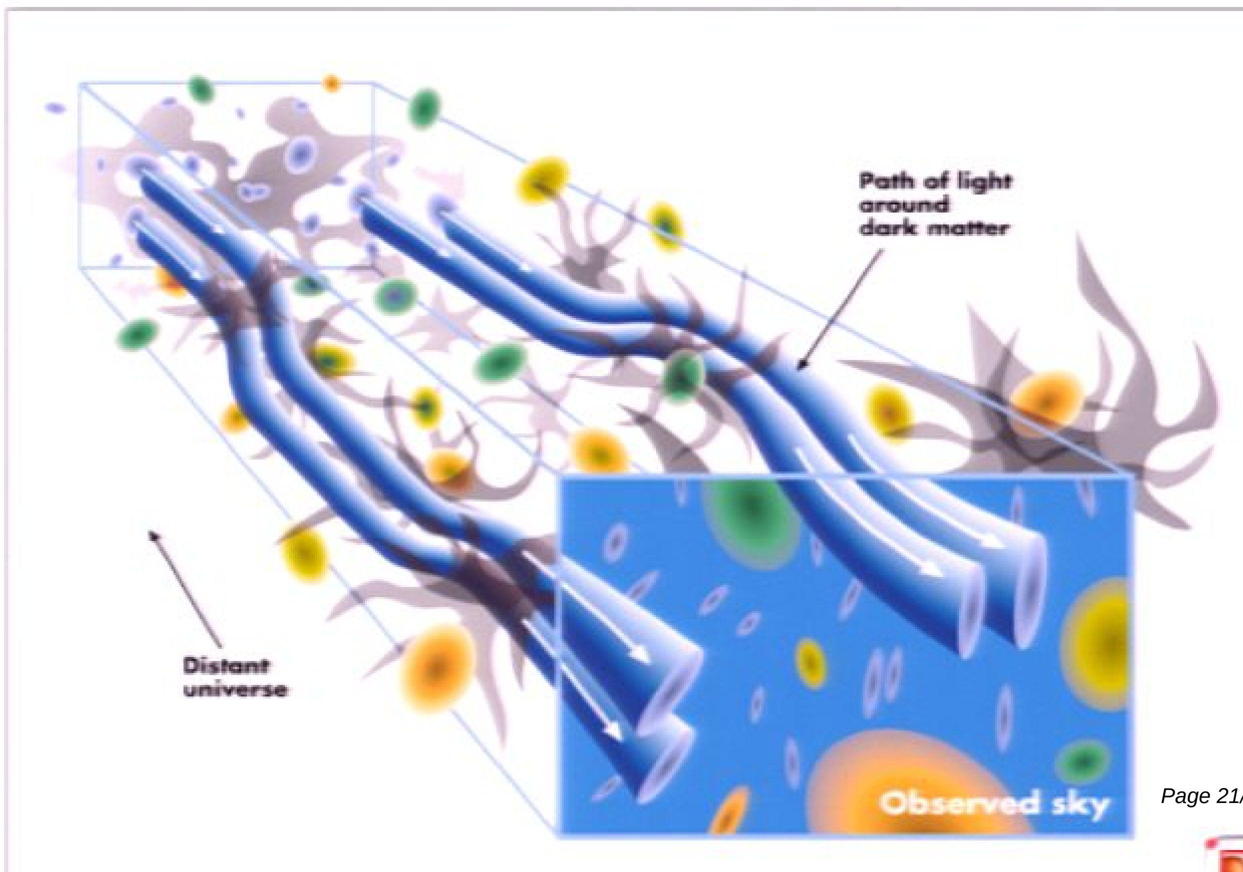






Weak Lensing



- Weak lensing provides a **direct probe** of the Universe's TOTAL matter distribution

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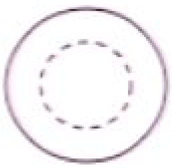
Calculating the Shear Power Spectrum

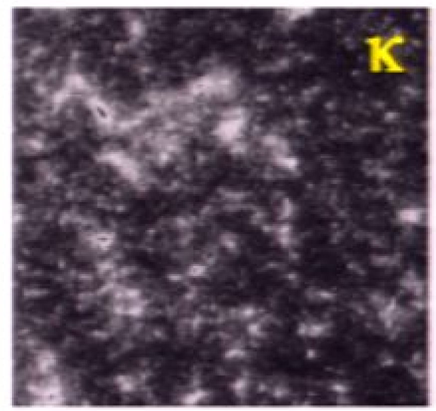
Jain et al. 2000

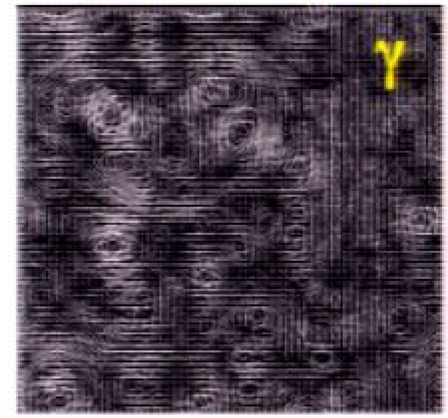
Distortion tensor $\psi_{ij} = \begin{bmatrix} \kappa + \gamma_1 & \gamma_2 + \omega \\ \gamma_2 - \omega & \kappa - \gamma_1 \end{bmatrix}$



κ = convergence   γ = shear

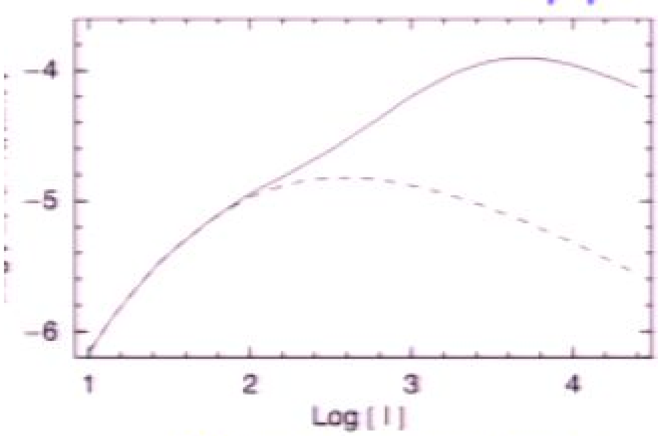
ω = rotation





Distortion is essentially a distance-weighted projection of the mass density, i.e. a direct trace

< γ γ >



Shear power spectrum

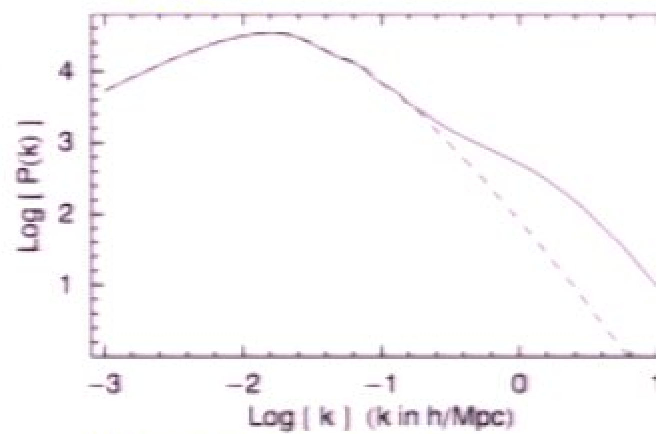
$$P_{\gamma\gamma}(l) \sim \int d\chi \; P_{\delta\delta}(k;\chi)\, W(\chi)$$

$$k = l/\chi$$

$$<\varepsilon\varepsilon> \sim <\gamma\gamma> + \varepsilon_0^2/n_{gal}$$

Elipticity

< δ δ >



Mass power spectrum

Weak Lensing Progress

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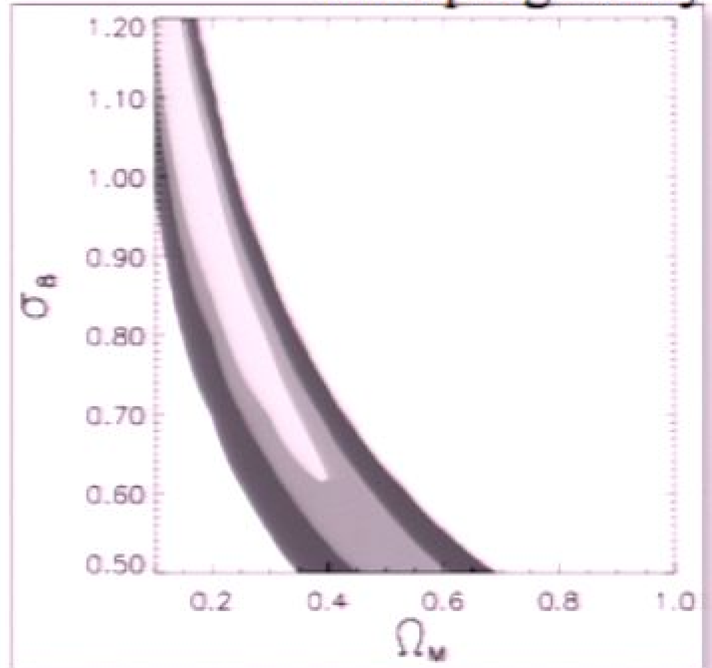
Preliminary WL results are consistent with each other and with other probes, e.g. show that $\Omega_M < 1$

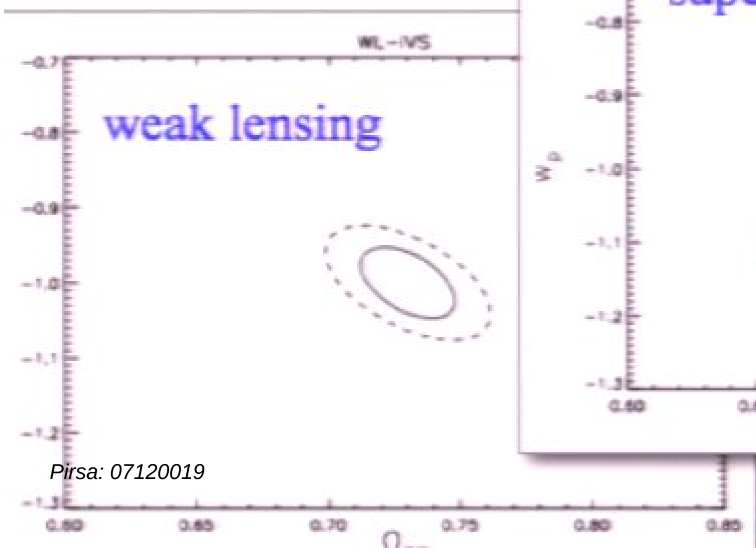
Starting to get results from **tomography**

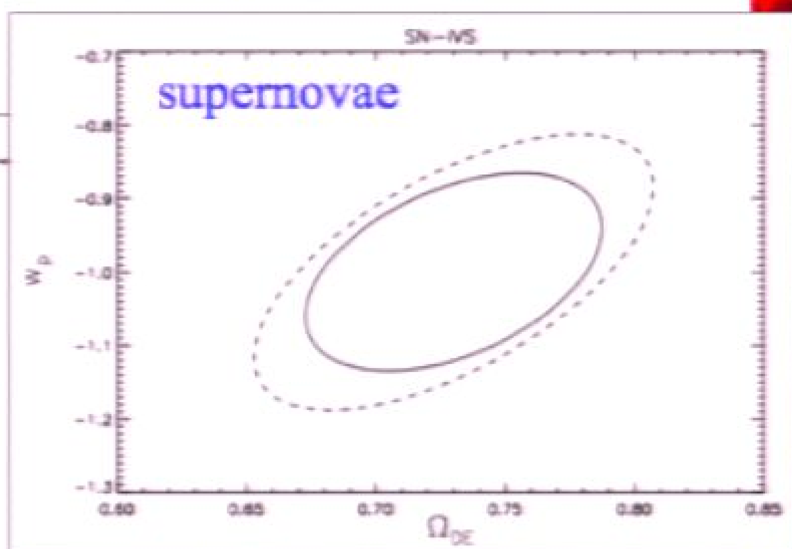
- Watch redshift evolution of structure formation
- Distance information needed for dark energy constraints

Theorists must answer future high-precision experiments with high-accuracy predictions!

100 sq-deg survey







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Theory Systematics in Weak Lensing

Theory Systematics in Weak Lensing

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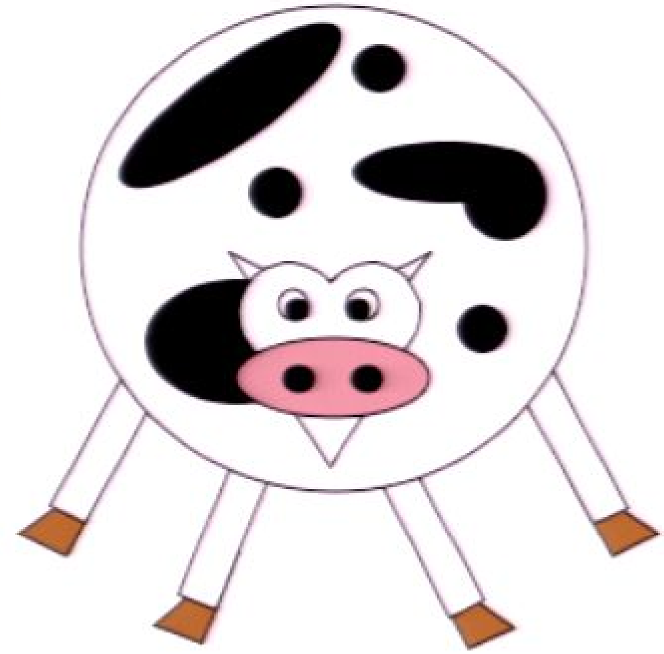
Refining our weak lensing "spherical cow":

- Intrinsic alignments
- Source clustering
- Non-Gaussianity
- **Computational approximations**



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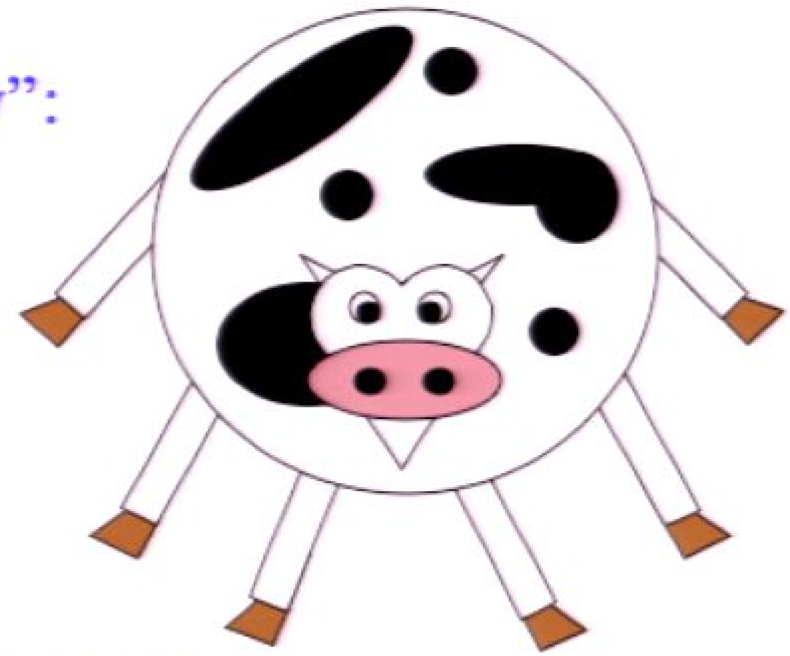
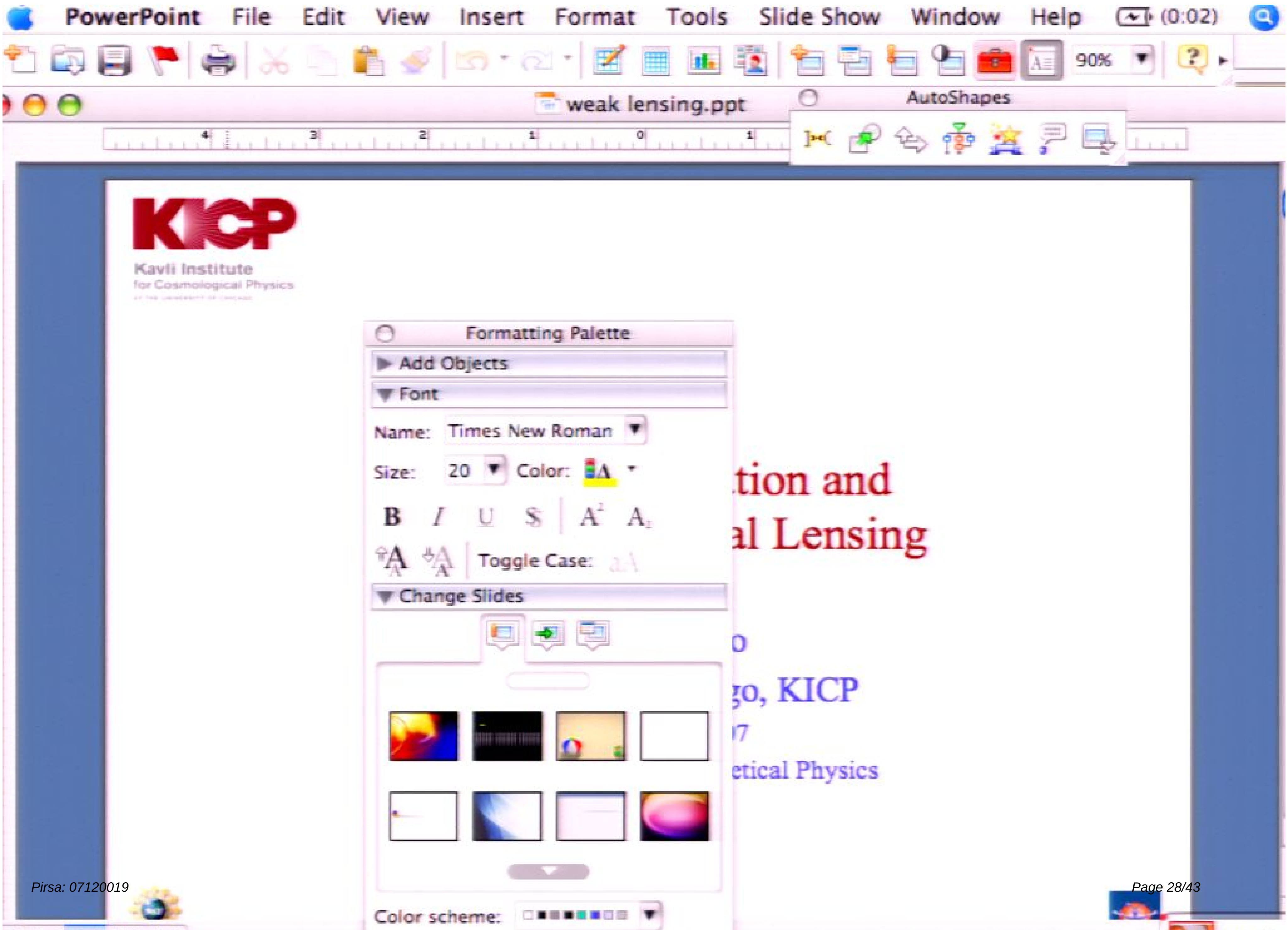


- Nonlinear Matter Power Spectrum + Baryons
- ????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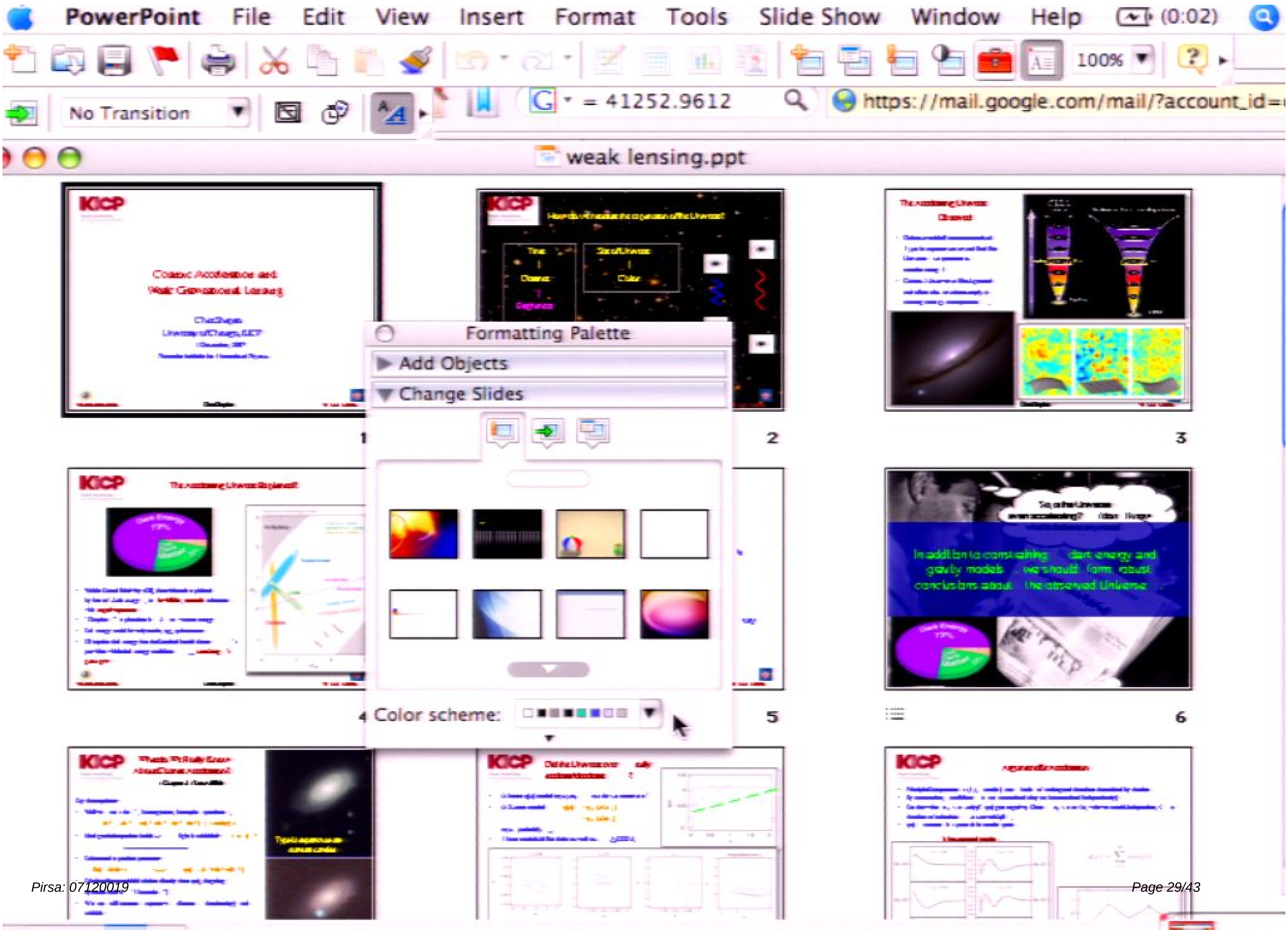
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Formatting Palette
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1
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4
5
6

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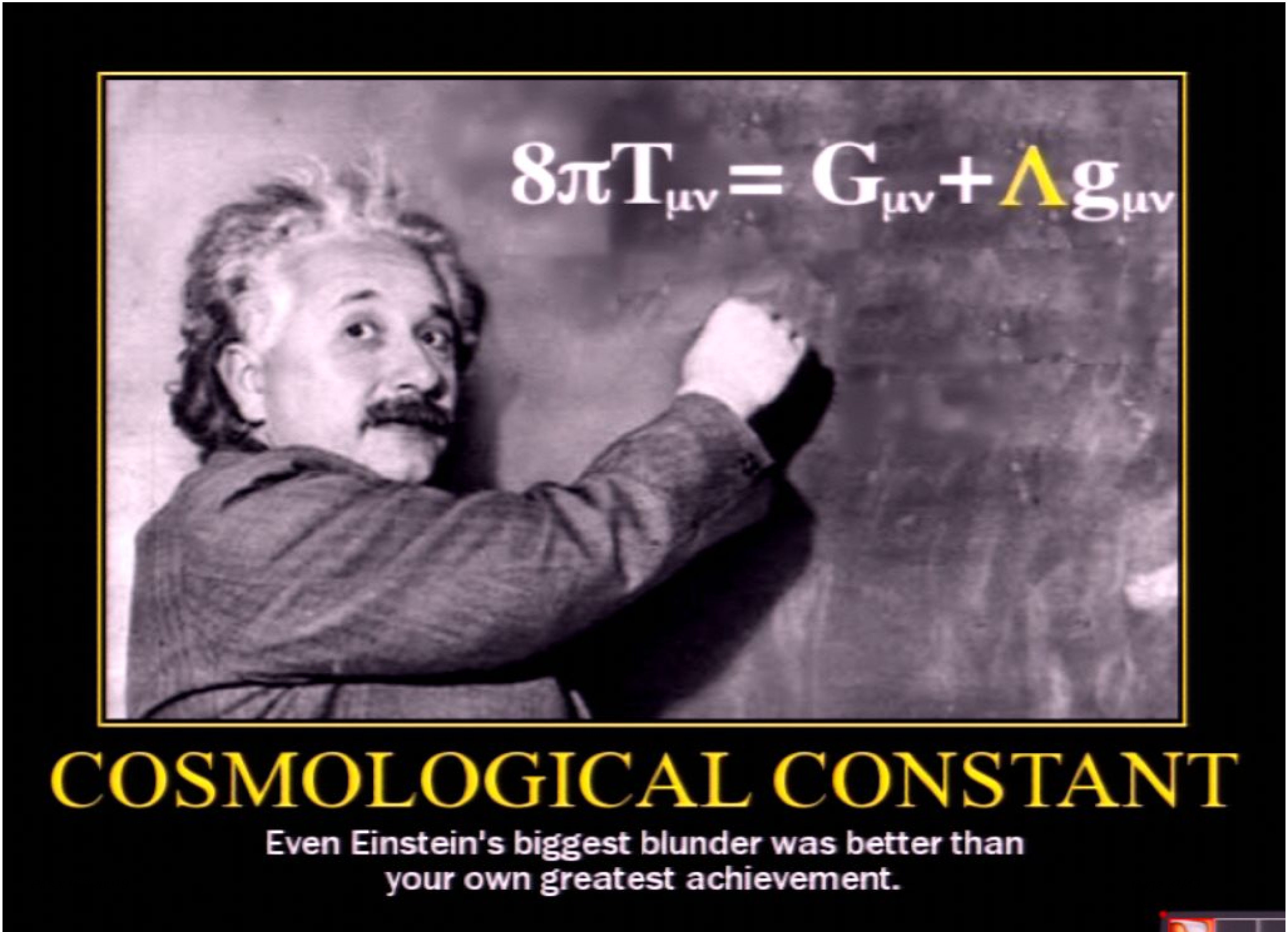
Summary

- The possibility of gravity modification requires us to take a hard look at "what we know" in cosmology.
- Weak lensing's dependence on multiple gravitational effects make it a powerful probe of dark energy and gravity models.
- For future weak lensing surveys to be fully effective, theorists must remain vigilant.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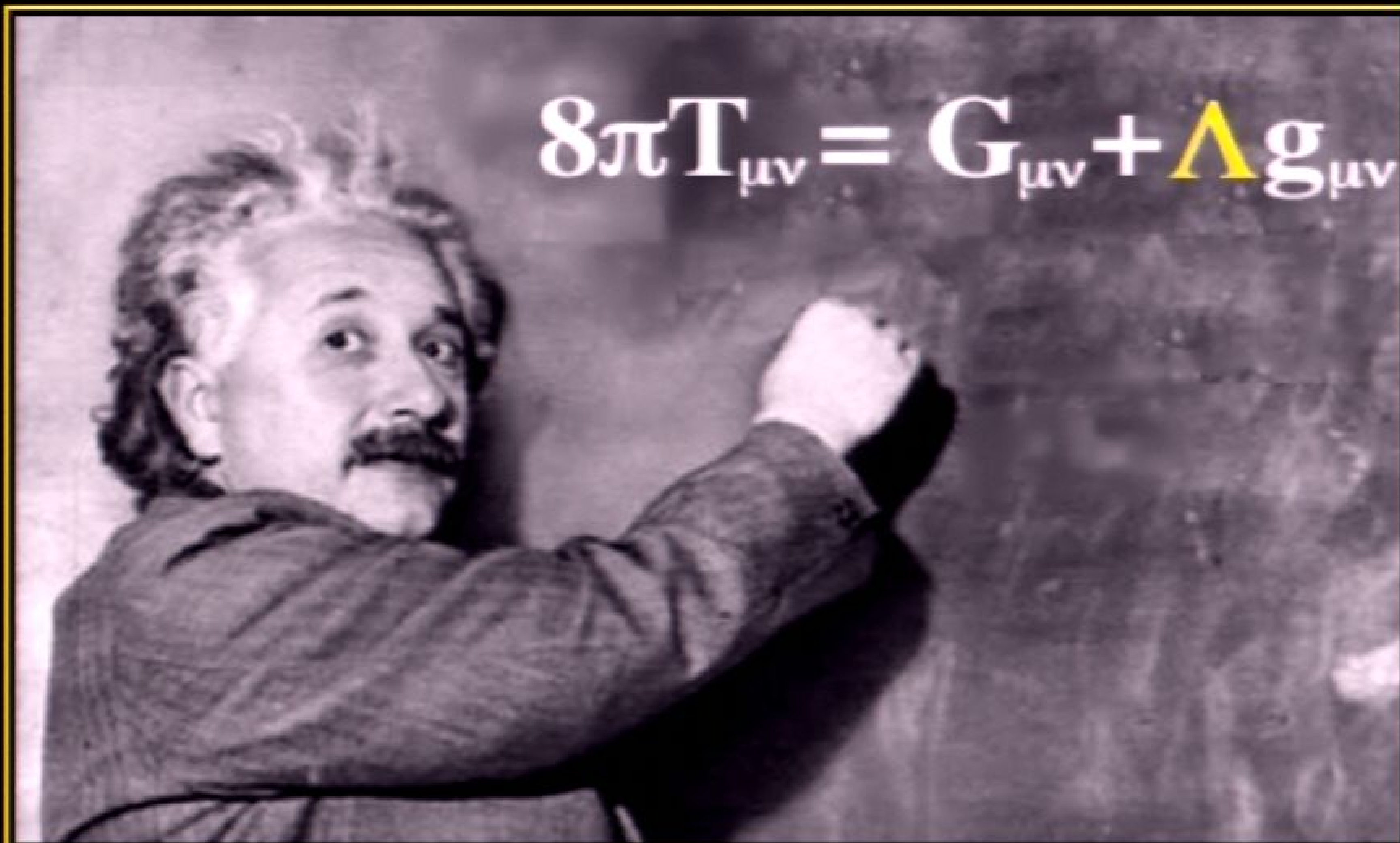
COSMOLOGICAL CONSTANT
Even Einstein's biggest blunder was better than your own greatest achievement.



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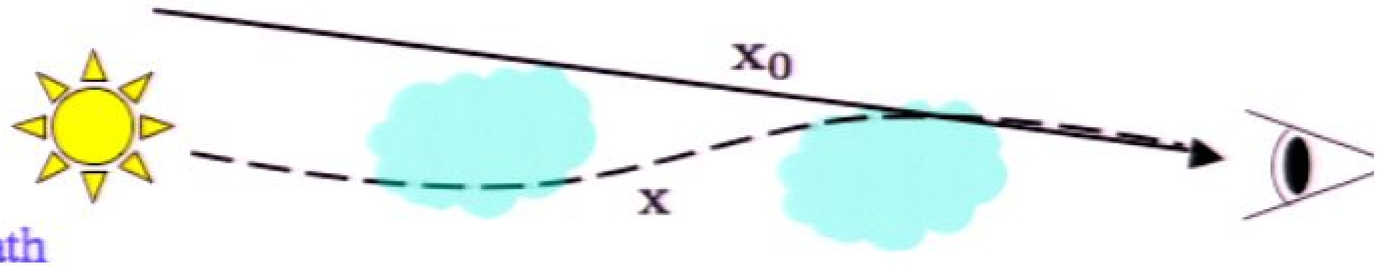
Born Approximation *(Shapiro & Cooray 2006; Cooray & Hu 2002)*



Assumes Φ along true path equals Φ along undeflected path

Correction: (schematically)

$$\mathbf{x} = \mathbf{x_0} + \delta\mathbf{x} \qquad \Phi(\mathbf{x}) = \Phi(\mathbf{x_0}) + \delta x_a \Phi_{,a}(\mathbf{x_0}) + \frac{1}{2}\delta x_a \delta x_b \Phi_{,ab}(\mathbf{x_0}) + O(\Phi^4)$$

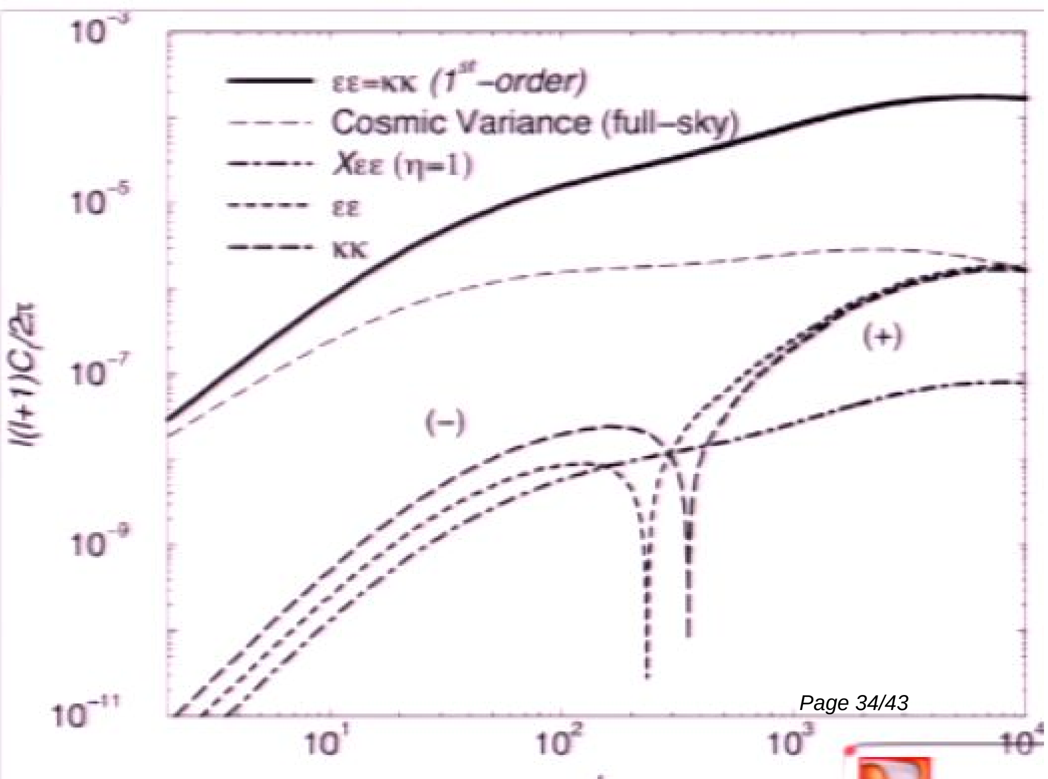
$$<\gamma\gamma> \sim \int <\Phi(\mathbf{x})^2> \sim \int <\Phi(\mathbf{x_0})^2> + \int <\Phi(\mathbf{x_0})^4>$$

(Standard result)

(Do Wick contractions to get in terms of Φ^2)

- This correction is also negligible: Born approximation good for now
- Born/Lens-Lens terms are also small
- Check using simulations:

  Vale & White (2003) find that the Born Approximation works very well for power spectrum; less so for the largest single peaks



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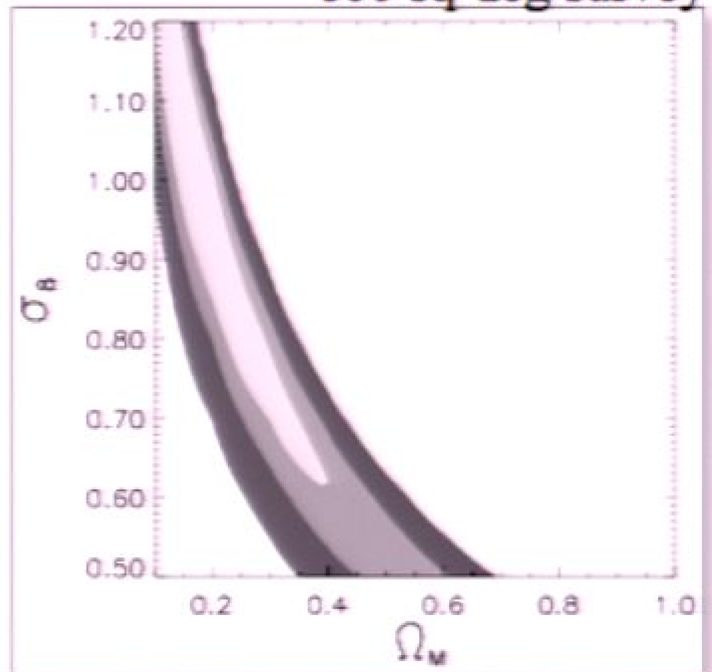

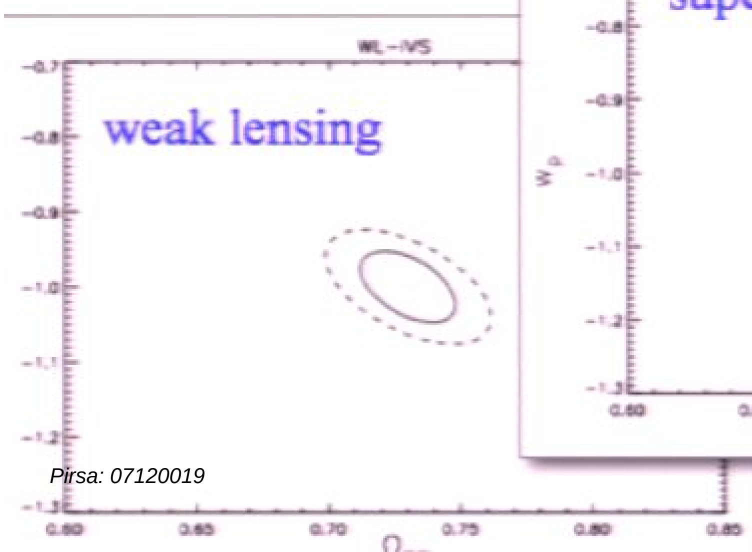

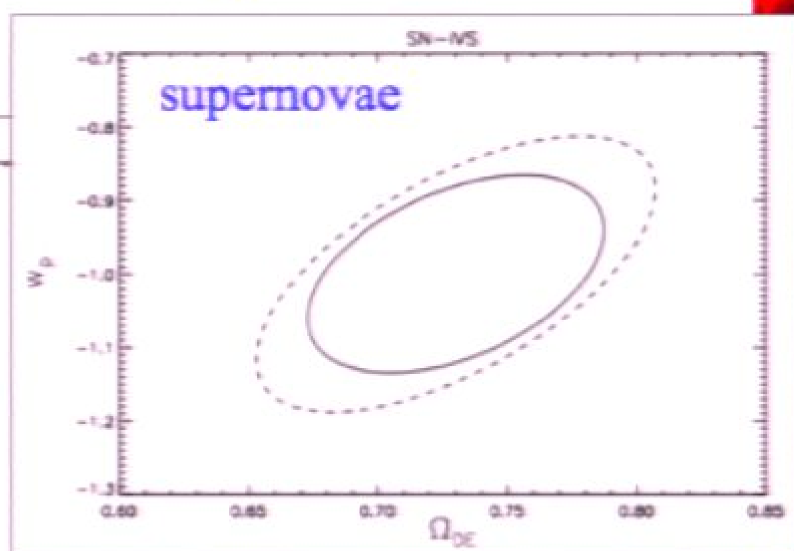

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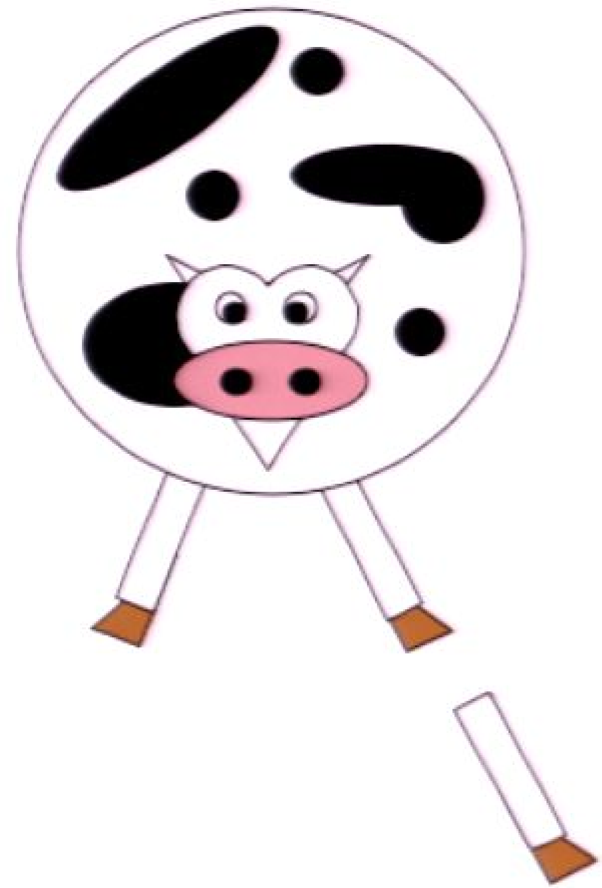

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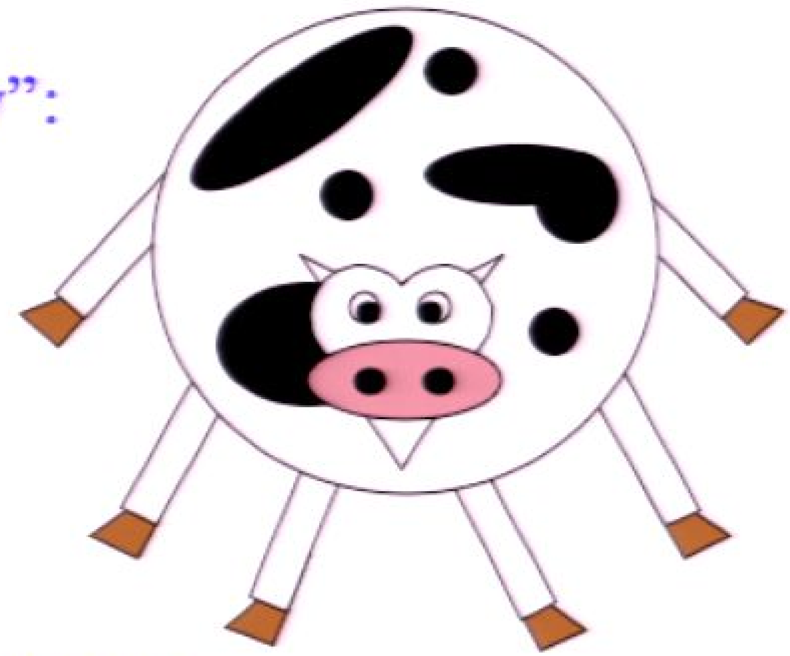

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Lens-Lens Coupling *(Shapiro & Cooray 2006; Cooray & Hu 2002)*

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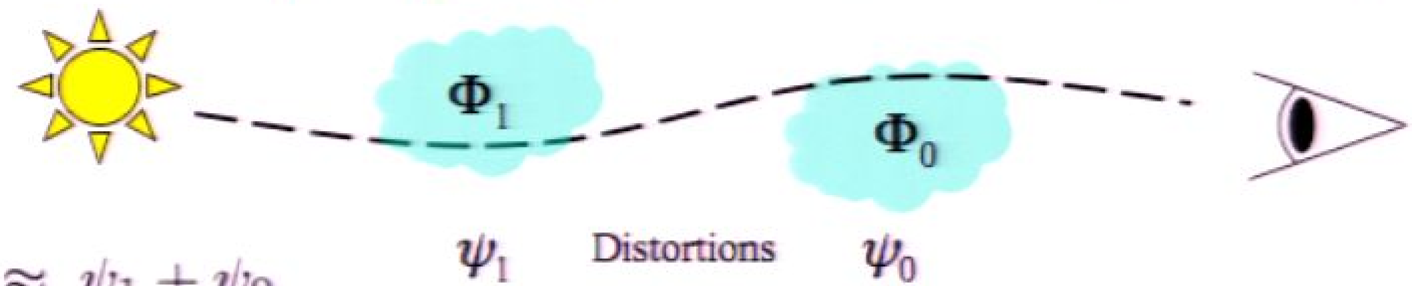
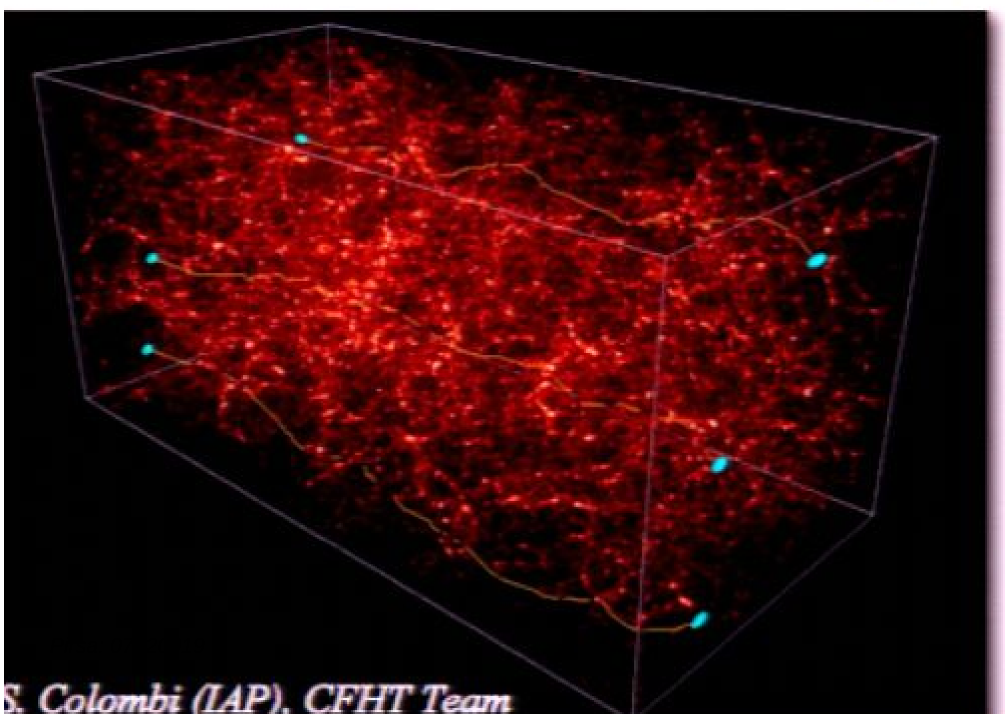


$$\psi \sim \psi_1 + \psi_0\,(1+\psi_1) \approx \psi_1 + \psi_0$$

- Distortion on a ray bundle depends on previous distorions
- Can calculate corrections iteratively: it's negligible.
- Simulation confirms that large, coupled lens events are rare



Vale & White 2003

κ_m	One Event (%)	Two Events (%)	Three Events (%)	Four Events (%)
0.01...	40.8	9.78	1.61	0.19
0.05...	3.46	0.06	0.0005	$<10^{-4}$
0.10...	0.68	0.003	$<10^{-4}$	0
0.15...	0.21	0.0003	0	0
0.20...	0.08	0.0001	0	0
0.25...	0.03	$<10^{-4}$	0	0

Born Approximation *(Shapiro & Cooray 2006; Cooray & Hu 2002)*

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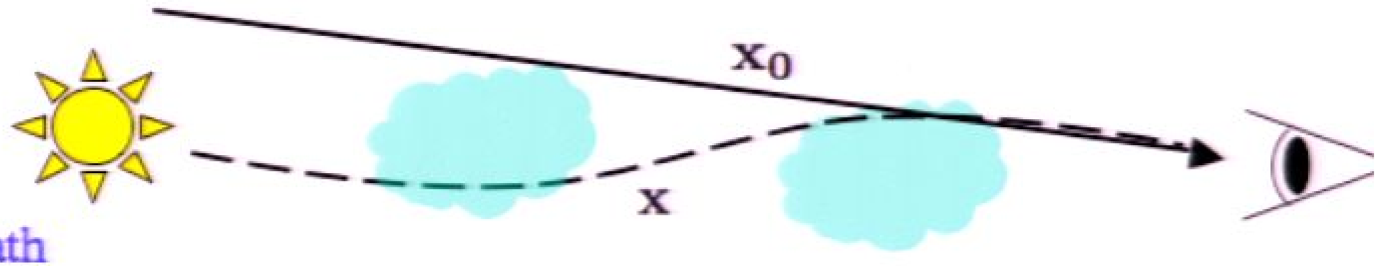


Assumes Φ along true path equals Φ along undeflected path

Correction: (schematically)

$$\mathbf{x} = \mathbf{x_0} + \delta\mathbf{x} \qquad \Phi(\mathbf{x}) = \Phi(\mathbf{x_0}) + \delta x_a \Phi_{,a}(\mathbf{x_0}) + \frac{1}{2}\delta x_a \delta x_b \Phi_{,ab}(\mathbf{x_0}) + O(\Phi^4)$$

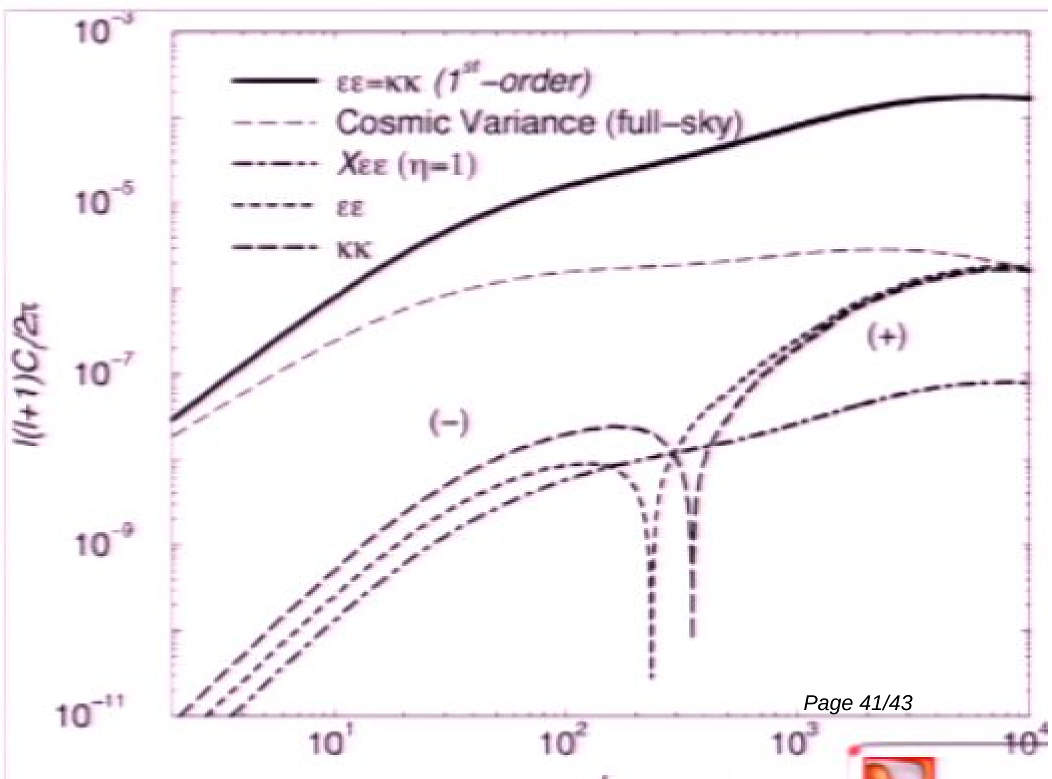
$$<\gamma\gamma> \sim \int <\Phi(\mathbf{x})^2> \sim \int <\Phi(\mathbf{x_0})^2> + \int <\Phi(\mathbf{x_0})^4>$$

(Standard result)

(Do Wick contractions to get in terms of Φ^2)

- This correction is also negligible: Born approximation good for now
- Born/Lens-Lens terms are also small
- Check using simulations:

  Vale & White (2003) find that the Born Approximation works very well for power spectrum; less so for the largest single peaks



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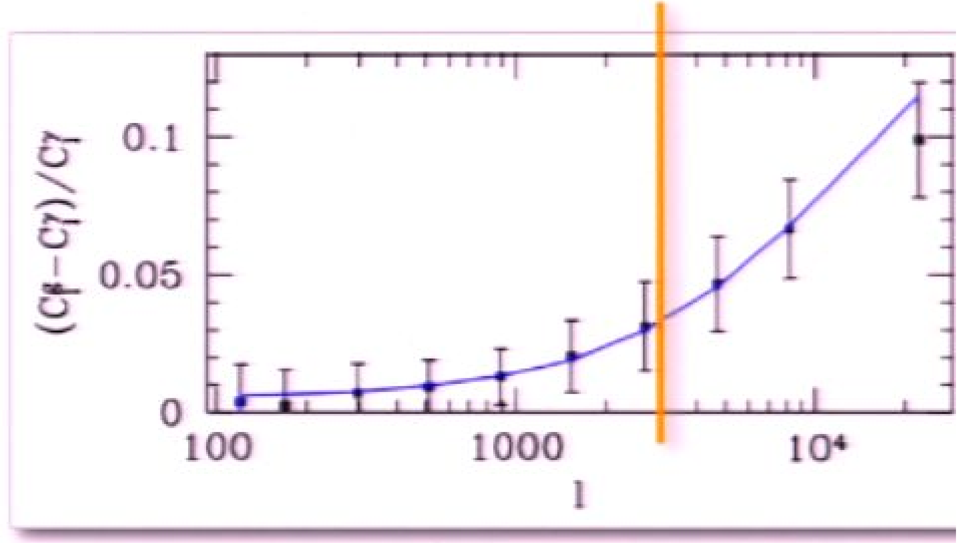
Shear vs. Reduced Shear *(Dodelson, Shapiro, & White 2006)*



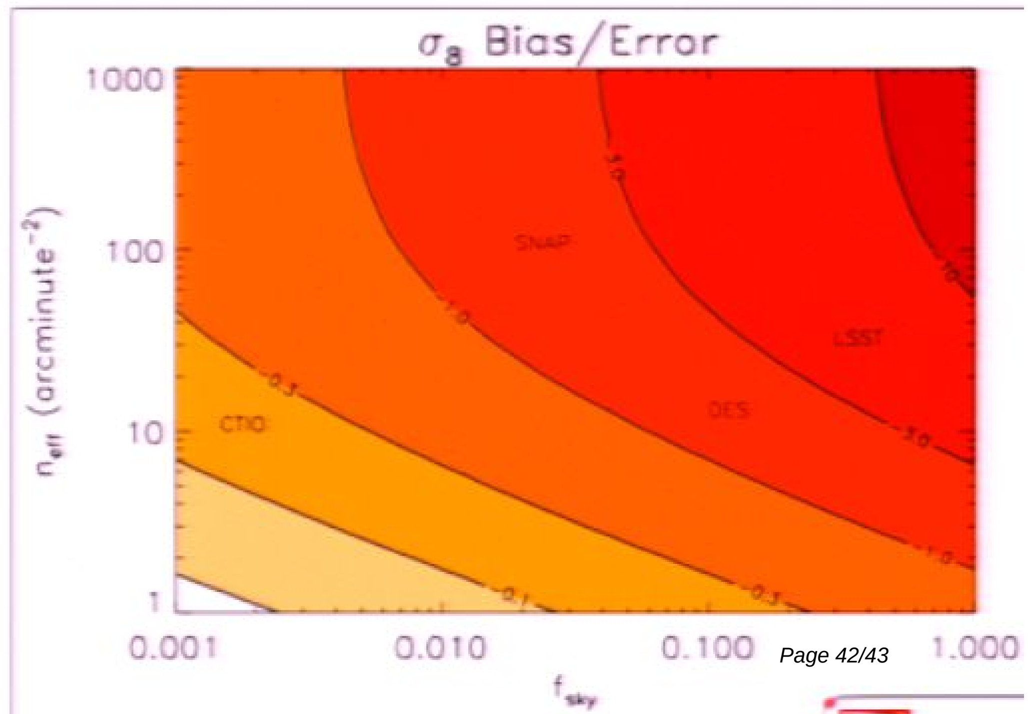
- Observers measure **reduced shear**

$$g = \frac{\gamma}{1-\kappa} \approx \gamma$$

- Can explore this difference with simulations or perturbatively:

$$<gg> = <\gamma\gamma> + <\gamma\gamma\kappa> + O(\Phi^4)$$

- Non-gaussianity makes 3-point term non-vanishing
- Neglecting reduced shear will bias the power spectrum on interesting angular scales by several percent
- This bias can cause surveys to rule out a correct parameter set.



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Summary

- The possibility of gravity modification requires us to take a hard look at "what we know" in cosmology.
- Weak lensing's dependence on multiple gravitational effects make it a powerful probe of dark energy and gravity models.
- For future weak lensing surveys to be fully effective, theorists must remain vigilant.