CMB as a dark energy probe

Carlo Baccigalupi

Outline

- Fighting against a cosmological constant
- Parametrizing cosmic acceleration
- The CMB role in the current dark energy bounds
- “Classic” dark energy effects on CMB
- “Modern” CMB relevance for dark energy: the promise of lensing
- Lensing B modes in CMB polarization
- Future CMB data and dark energy

Fighting the cosmological constant

$$G_{\mu\nu}=8\pi T_{\mu\nu}$$

Fighting the cosmological constant

geometry

$$G_{\mu\nu}+\Lambda g_{\mu\nu}=8\pi T_{\mu\nu}+V g_{\mu\nu}$$

quantum vacuum

Fighting the cosmological constant

Λ:???

Fighting the cosmological constant

Λ:???

$V:M^4_{Planck}$???

Fighting the cosmological constant

Λ:???

$$|\Lambda - V|/M^4_{Planck} \lesssim 10^{-123}$$

V:M^4_{Planck} ???

Fighting the cosmological constant

Λ:???

percent precision

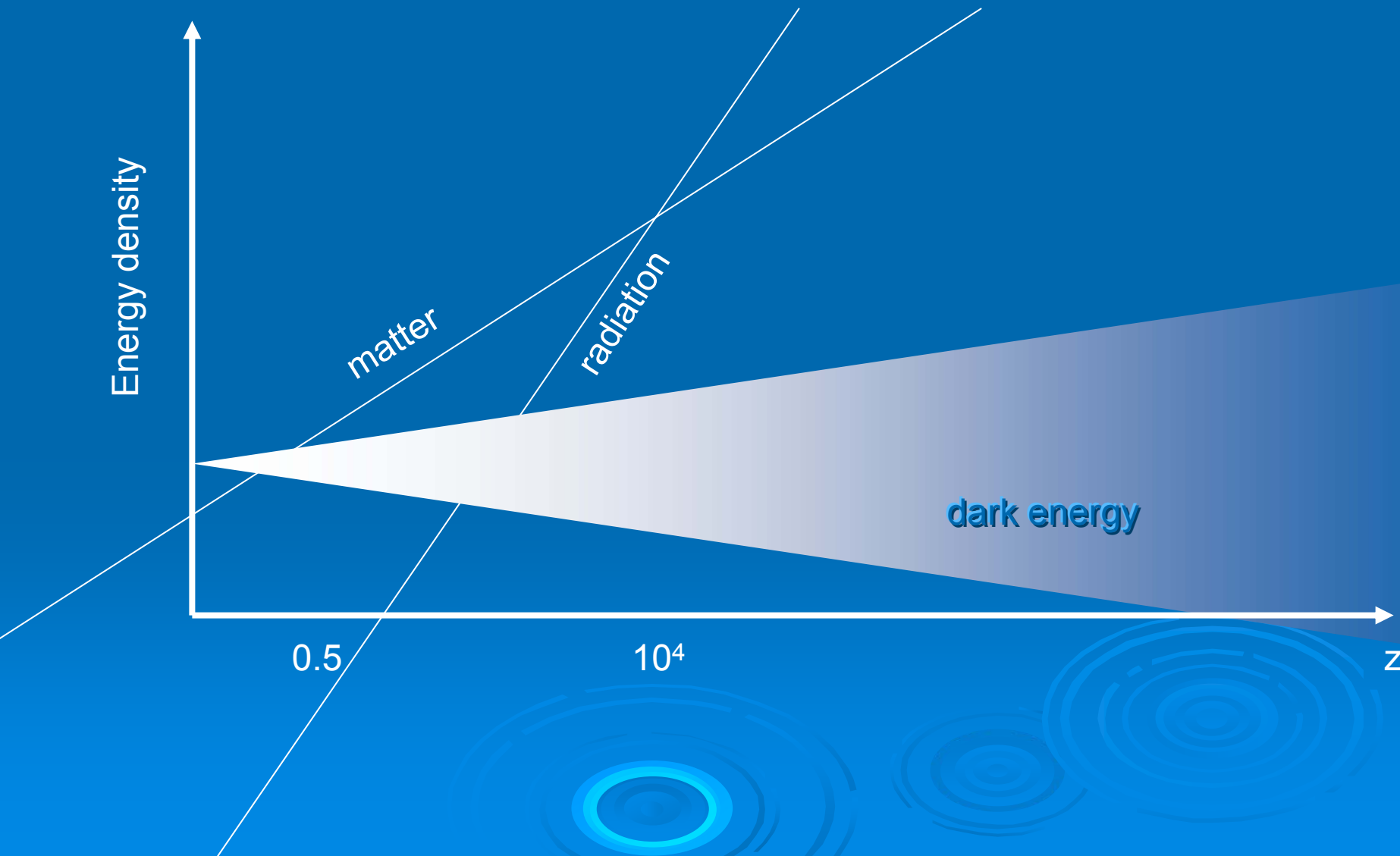
$$|\Lambda - V|/M^4_{Planck} = 10^{-123}$$

$V : M^4_{Planck}$???

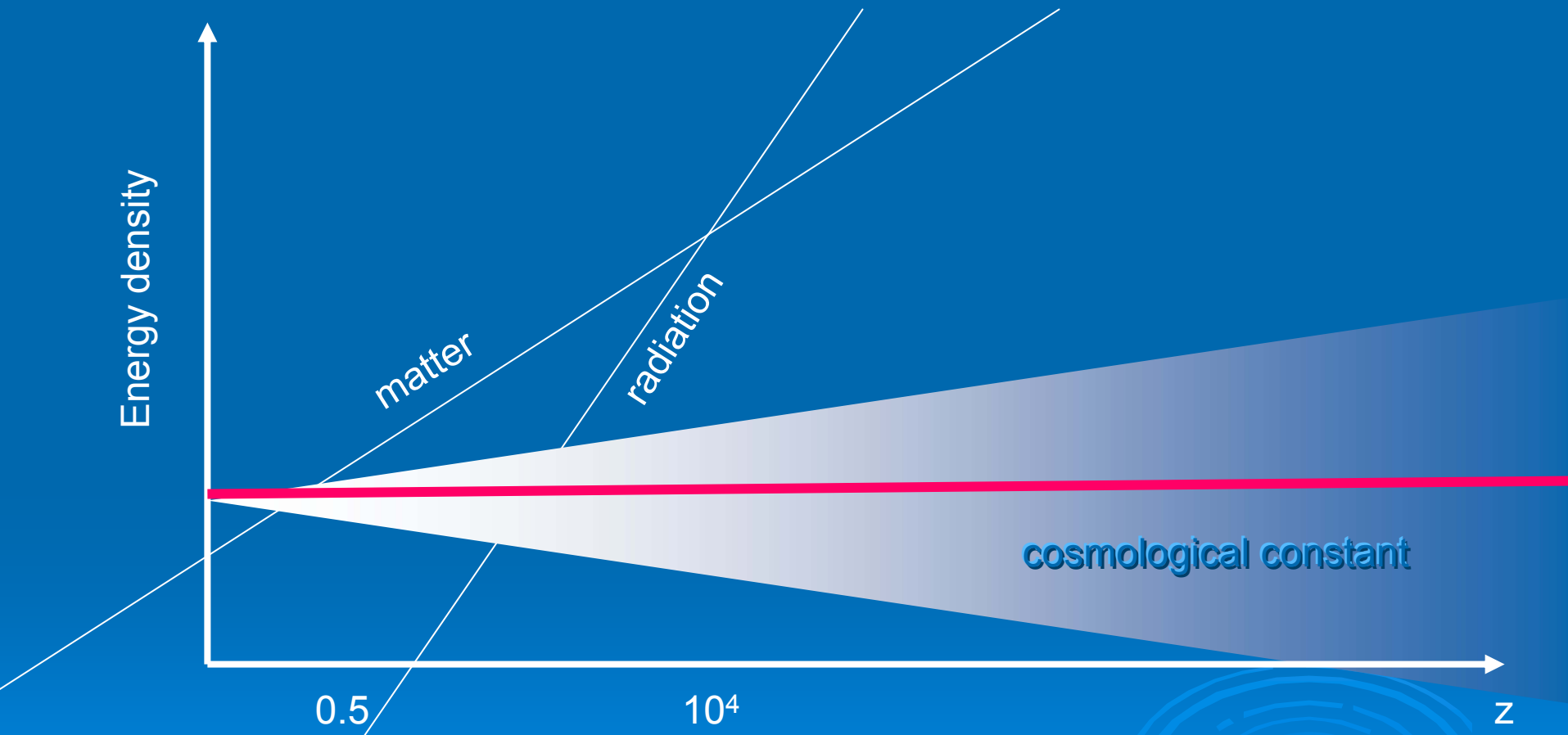
$(\text{Boh?})^2$

- Why so small with respect to any other known energy scale in physics?
- Why comparable to the matter energy density today?

Dark energy

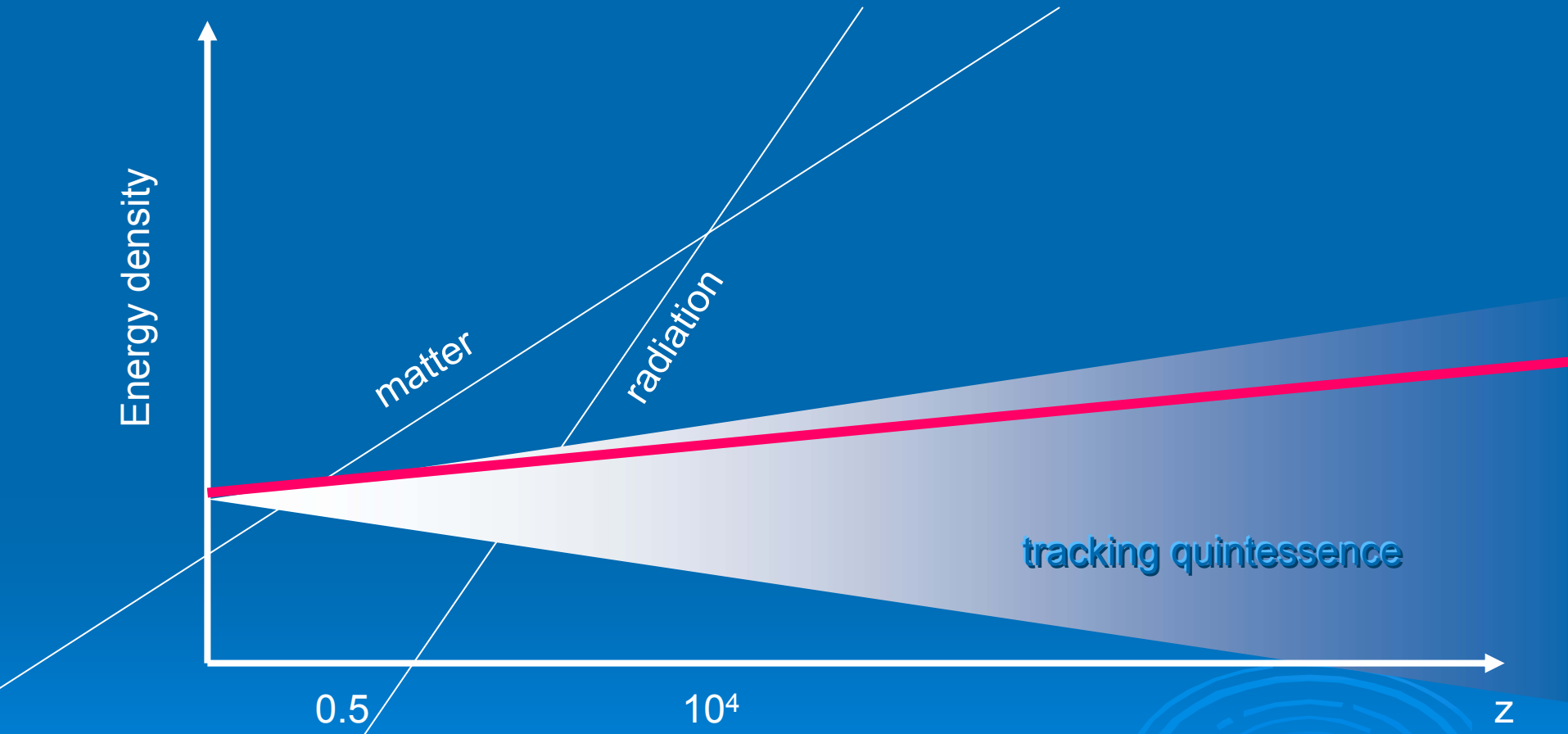


Dark energy



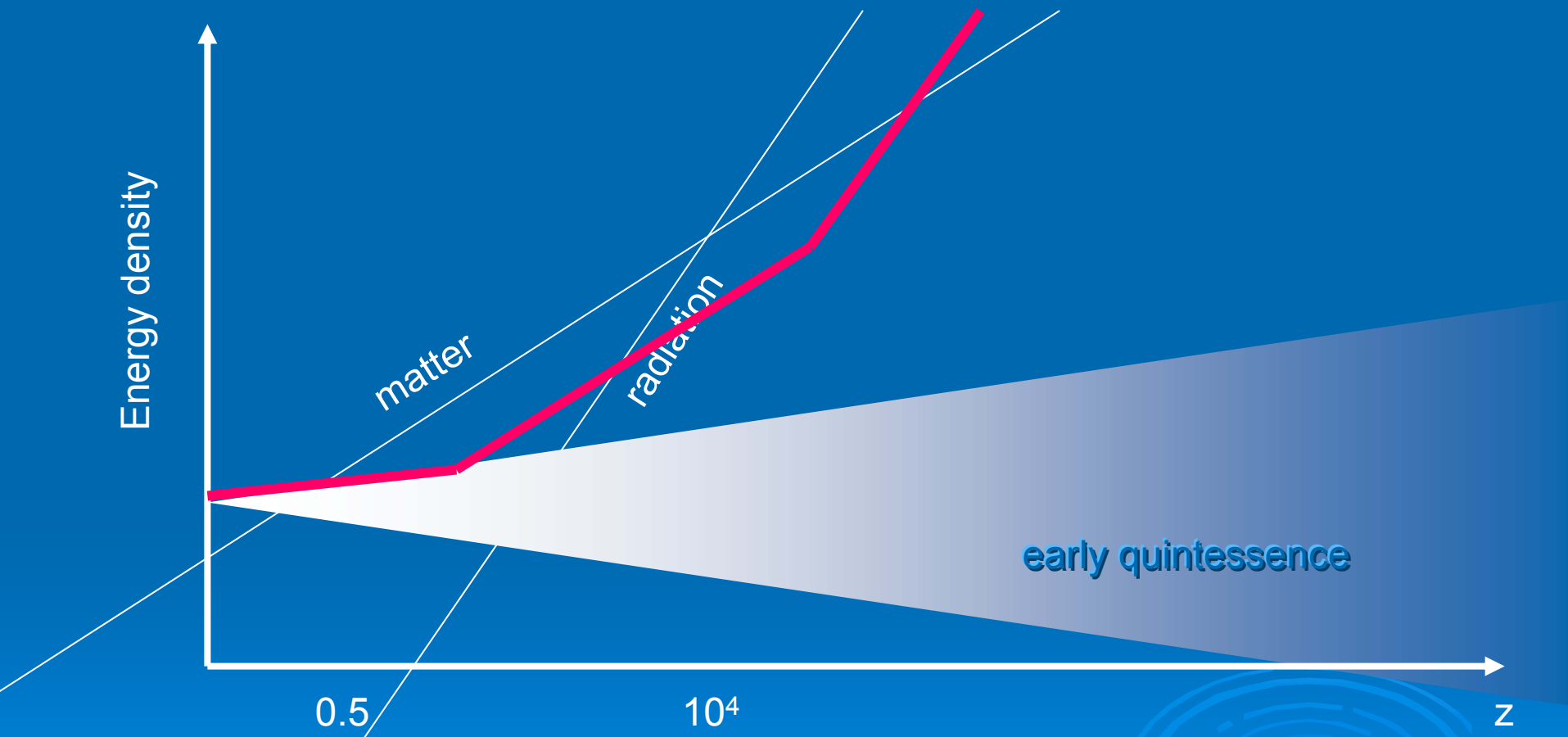
Einstein 1916

Dark energy



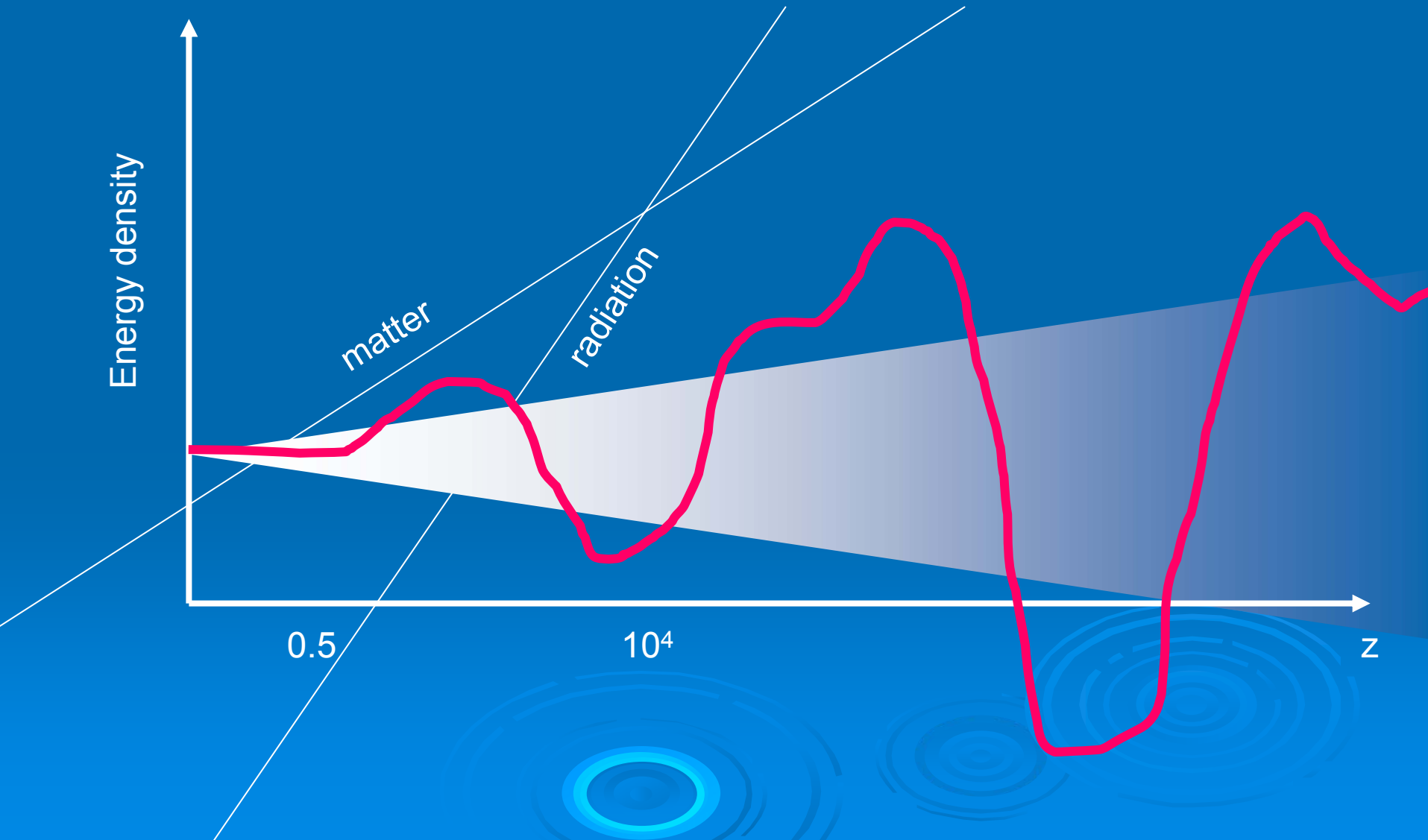
Ratra & Peebles, 1988

Dark energy

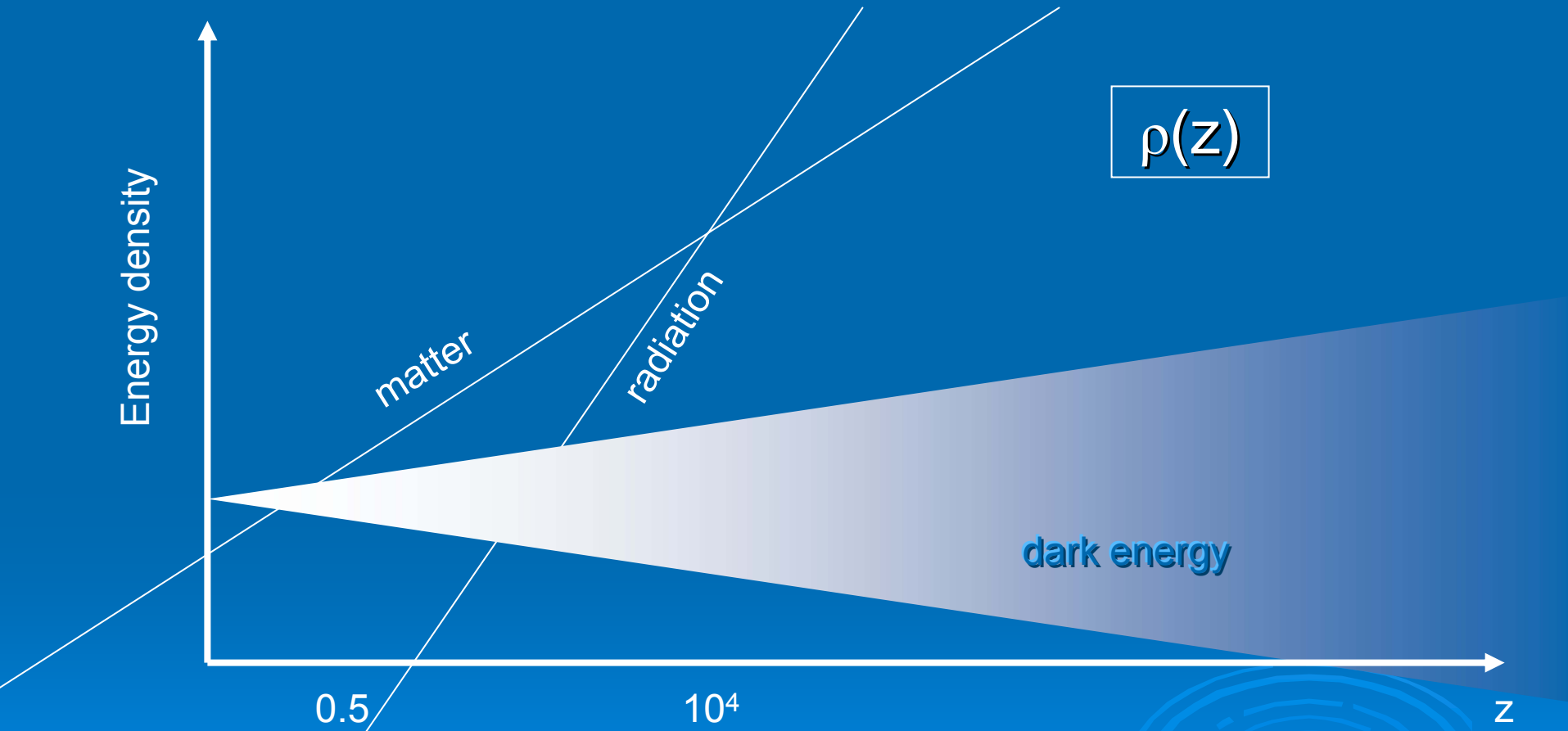


Wetterich 1988

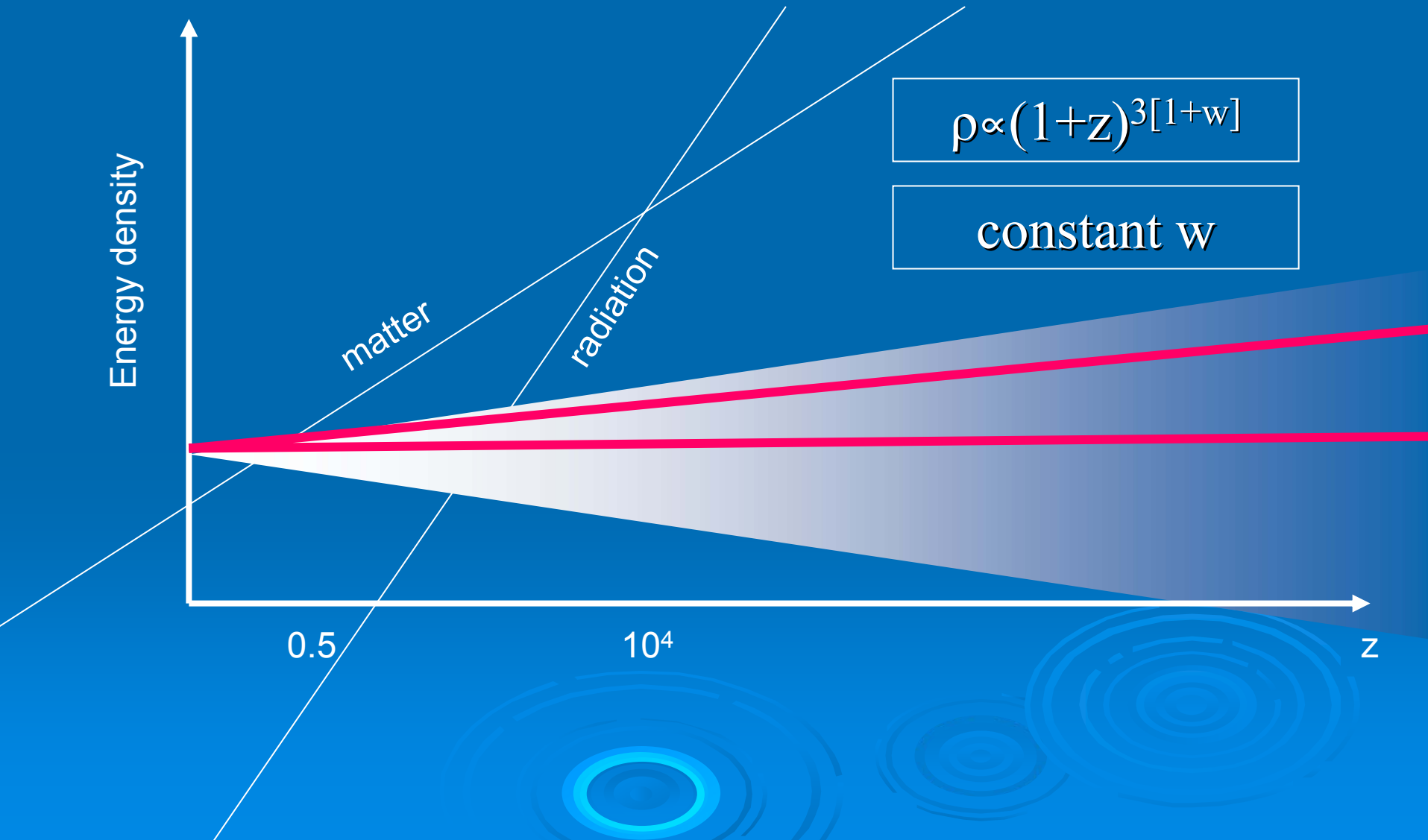
Dark energy



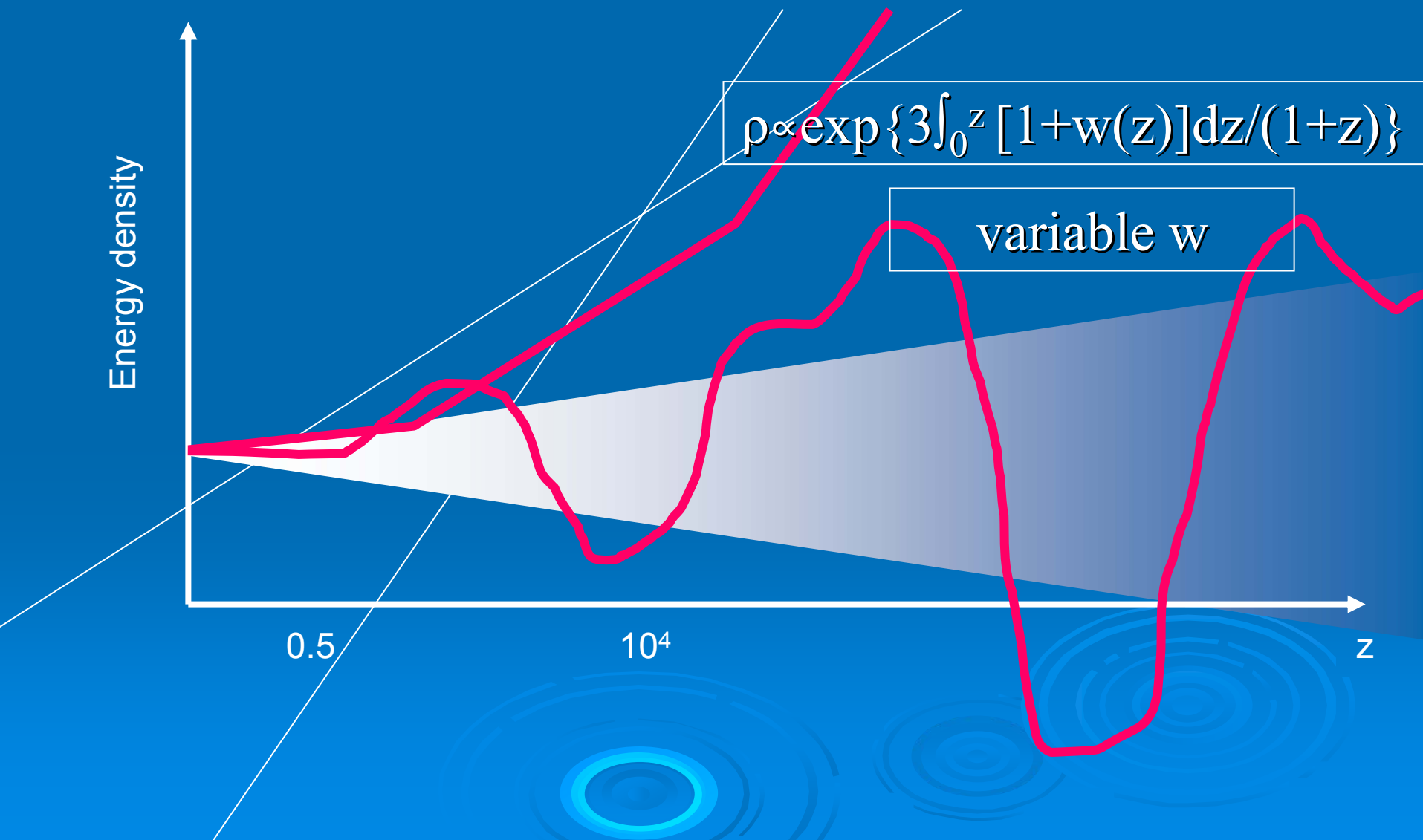
Parametrizing cosmic acceleration is …



…parametrizing cosmic density

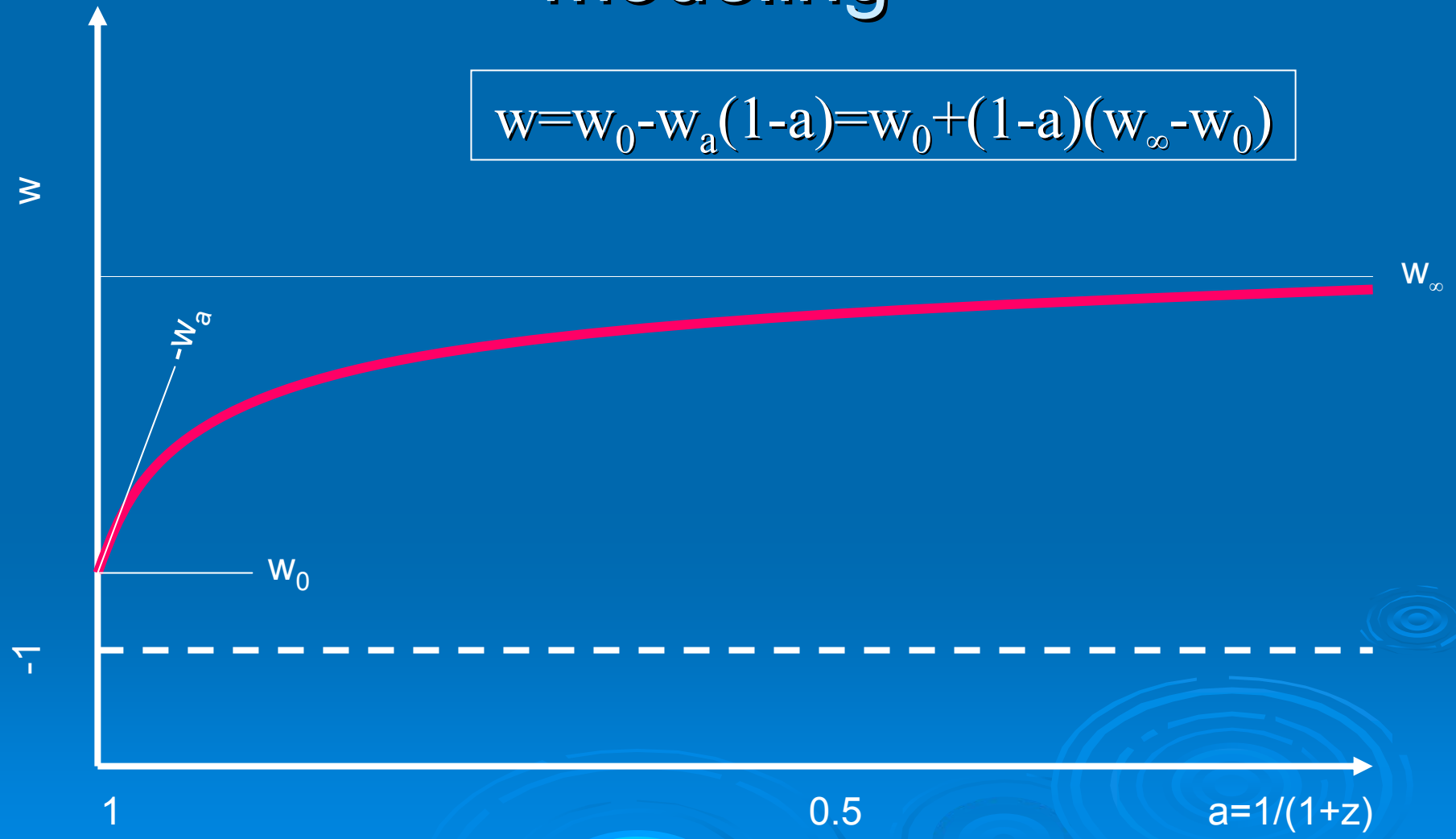


Parametrizing cosmic density



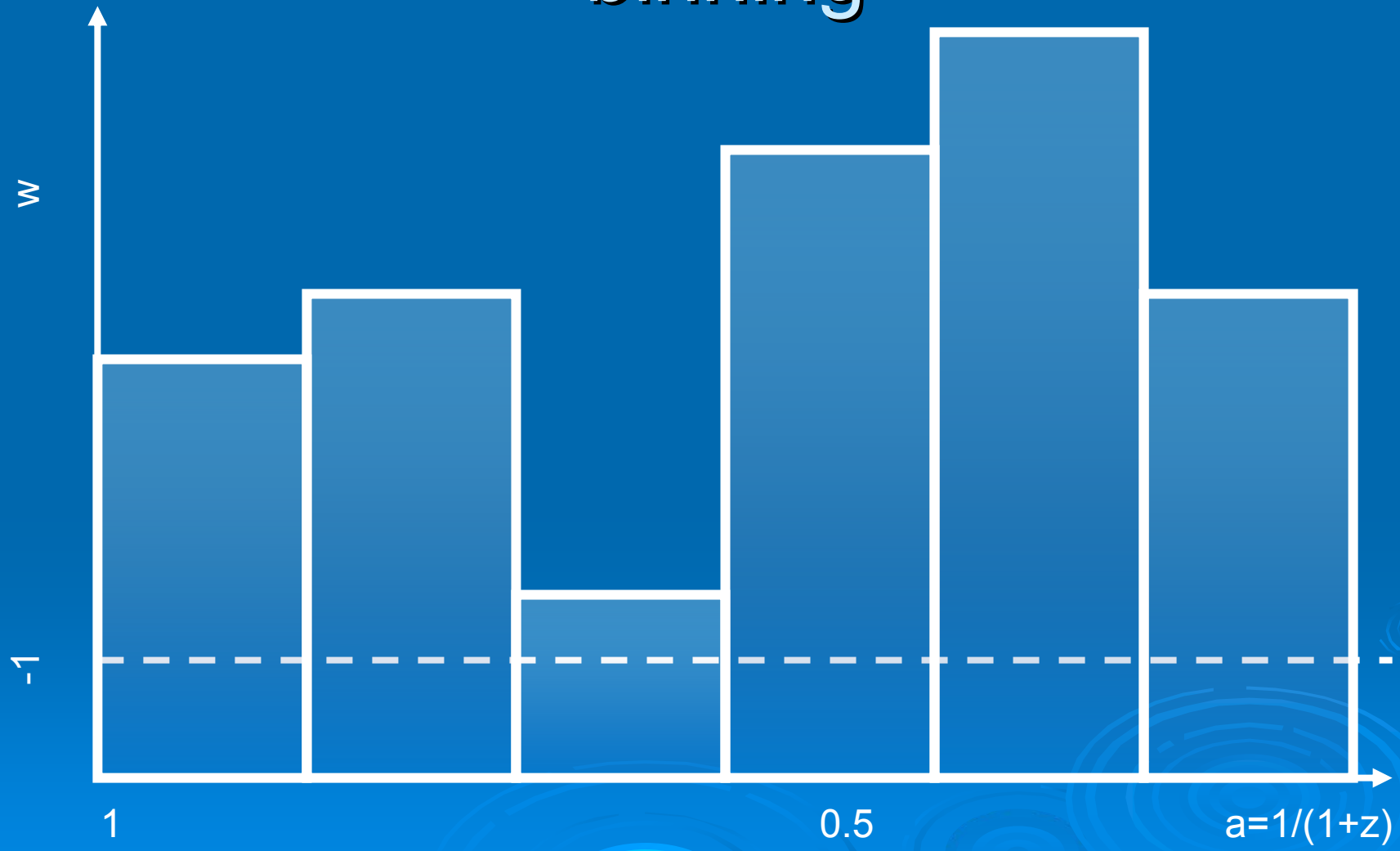
Parametrizing cosmic acceleration: modeling

$$w=w_0-w_a(1-a)=w_0+(1-a)(w_\infty-w_0)$$



Chevallier & Polarski 2001, Linder 2003

Parametrizing cosmic acceleration: binning

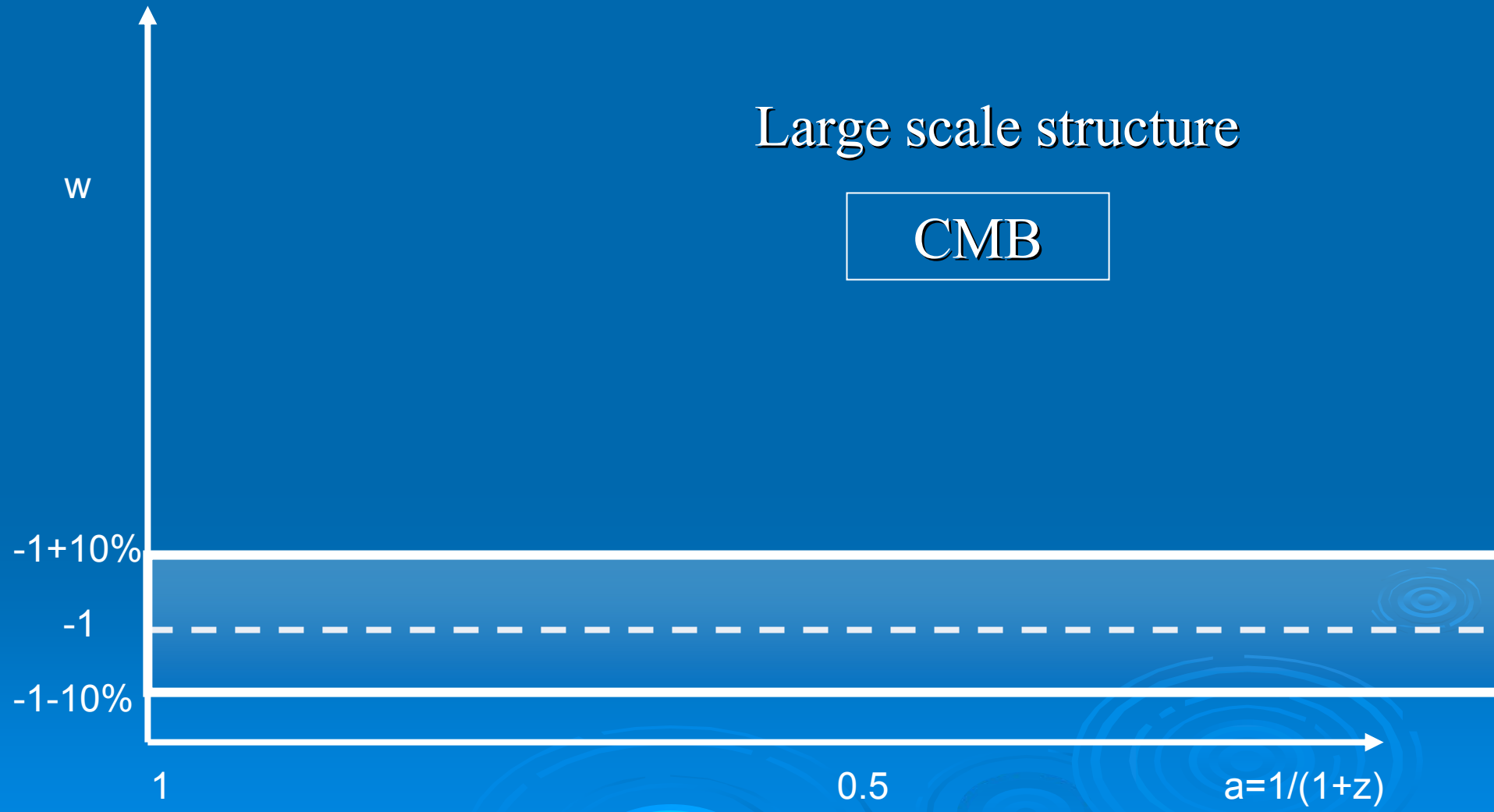


Crittenden & Pogosian 2006, Dick et al. 2006

Parametrizing cosmic acceleration: binning versus modeling

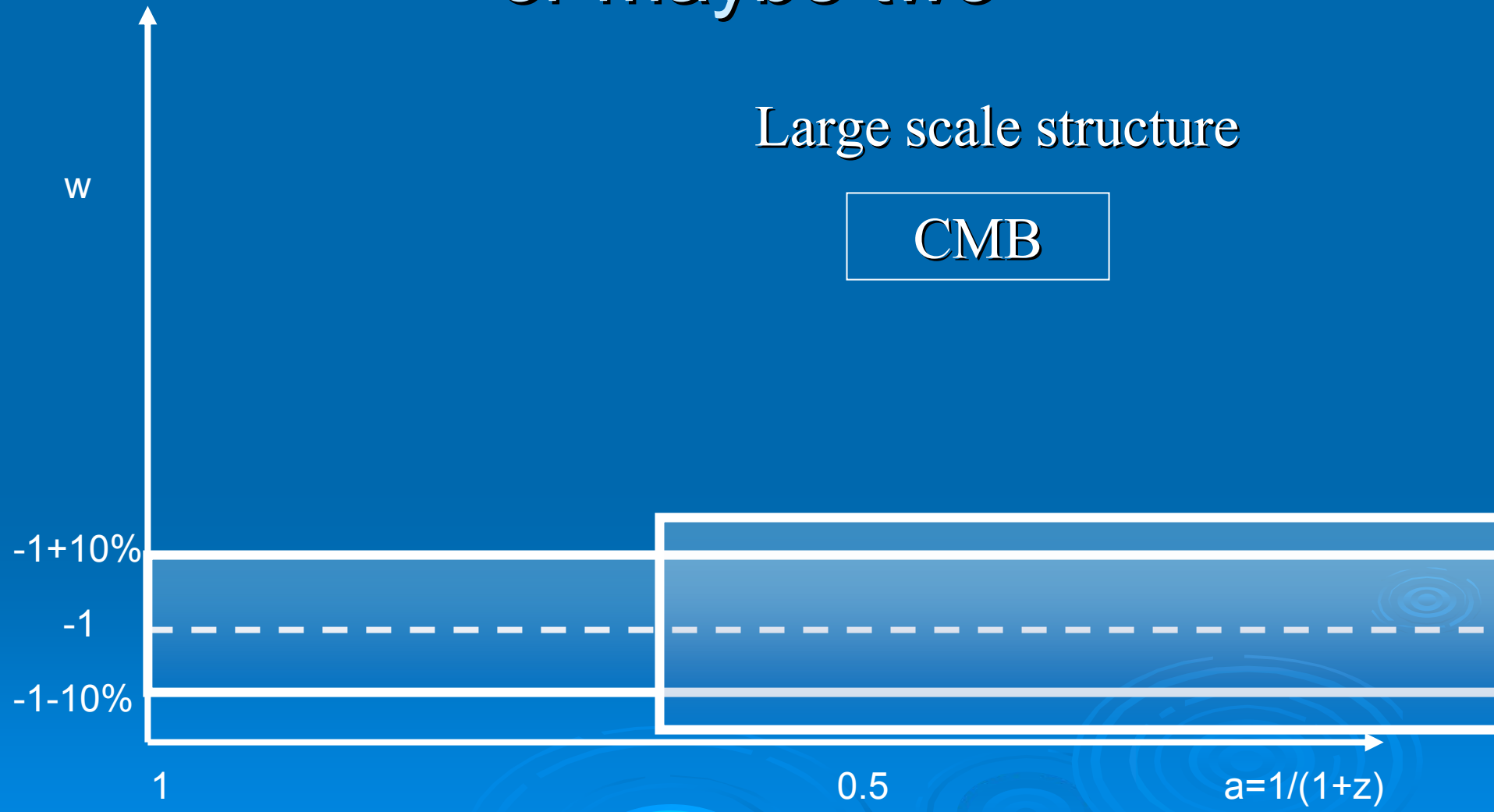
- Binning: model independent ☺, many parameters ☹
- Modeling: always a bias ☹, but a minimal model exists ☺, made by w_0 and its first time derivative
- Sticking with one particular model in between may be inconvenient, better relating that to one of the two approaches above

Present cosmological bounds: one bin



See Spergel et al., 2006, and references therein

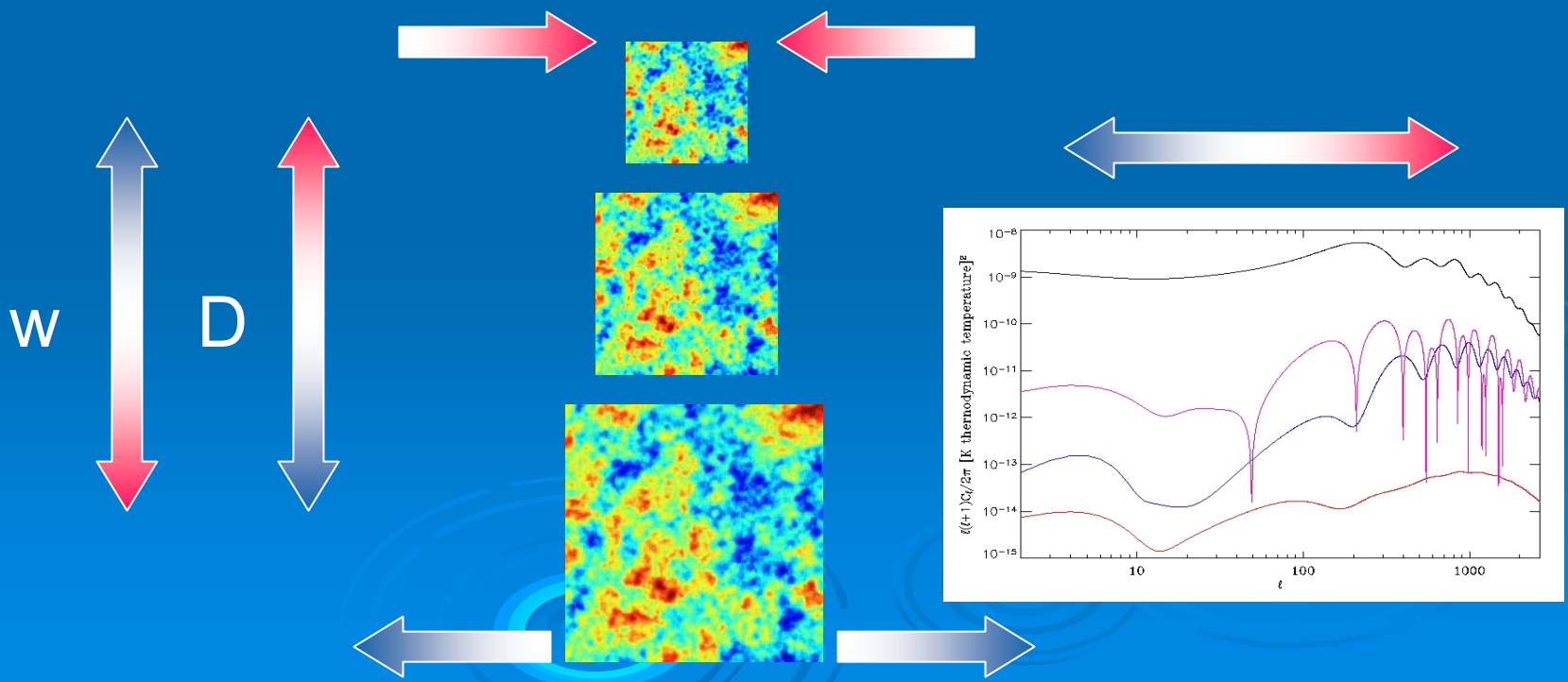
Present cosmological bounds: one bin, or maybe two



Seljak et al. 2005

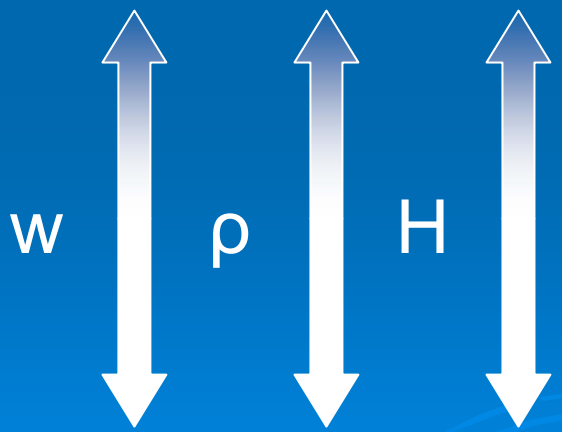
“Classic” dark energy effects on CMB: projection

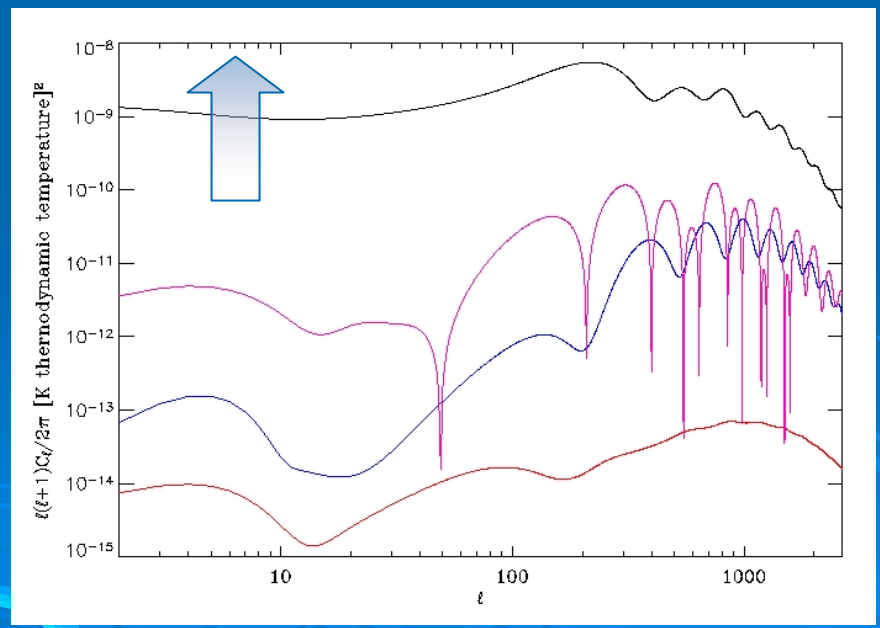
$$D = H_0^{-1} \int_0^z \frac{dz}{[\Sigma_i \Omega_i (1+z)^{3(1+w_i)}]^{1/2}}$$



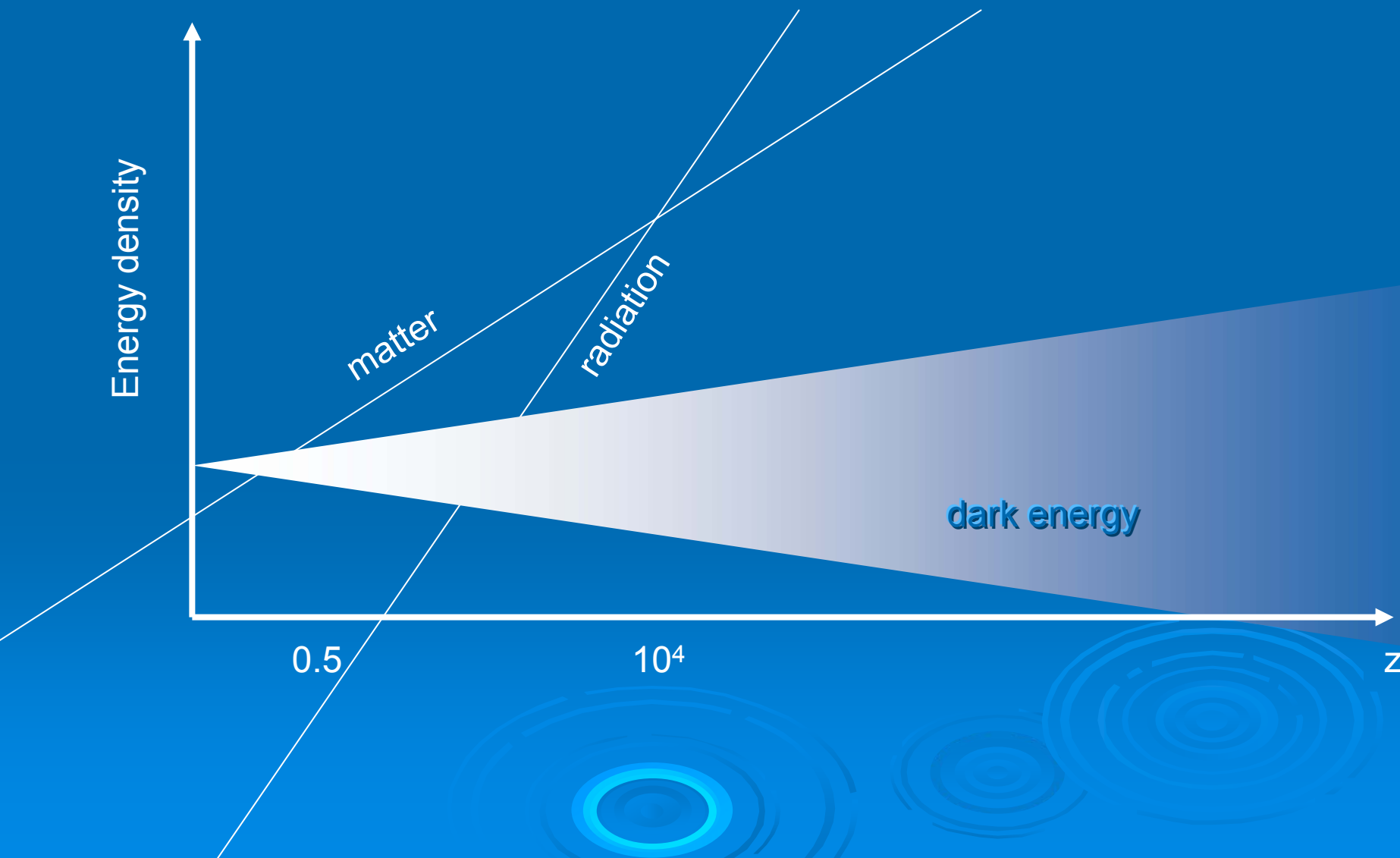
“Classic” dark energy effects on CMB: integrated Sachs-Wolfe

Cosmological friction for cosmological perturbations∝H





The “modern” era



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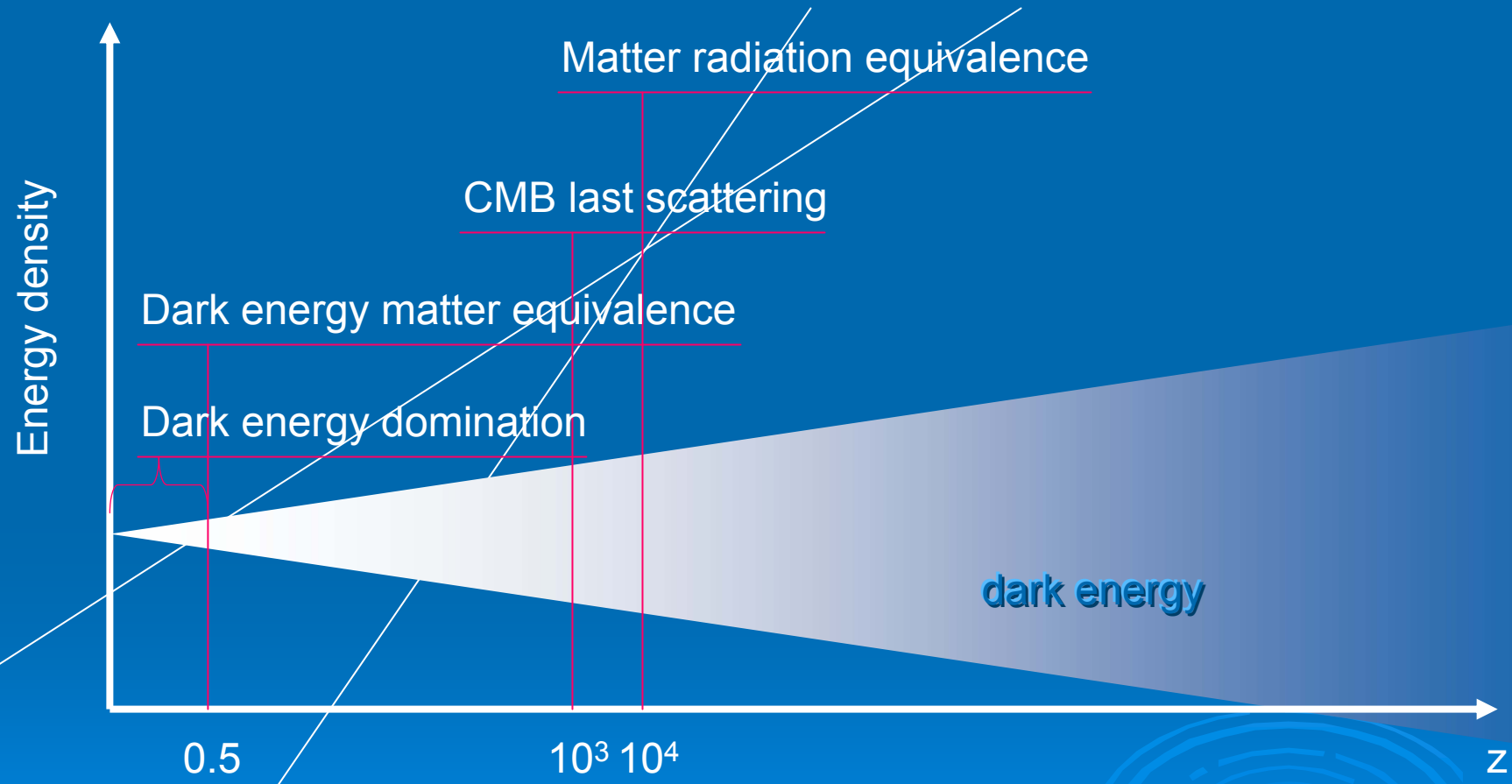

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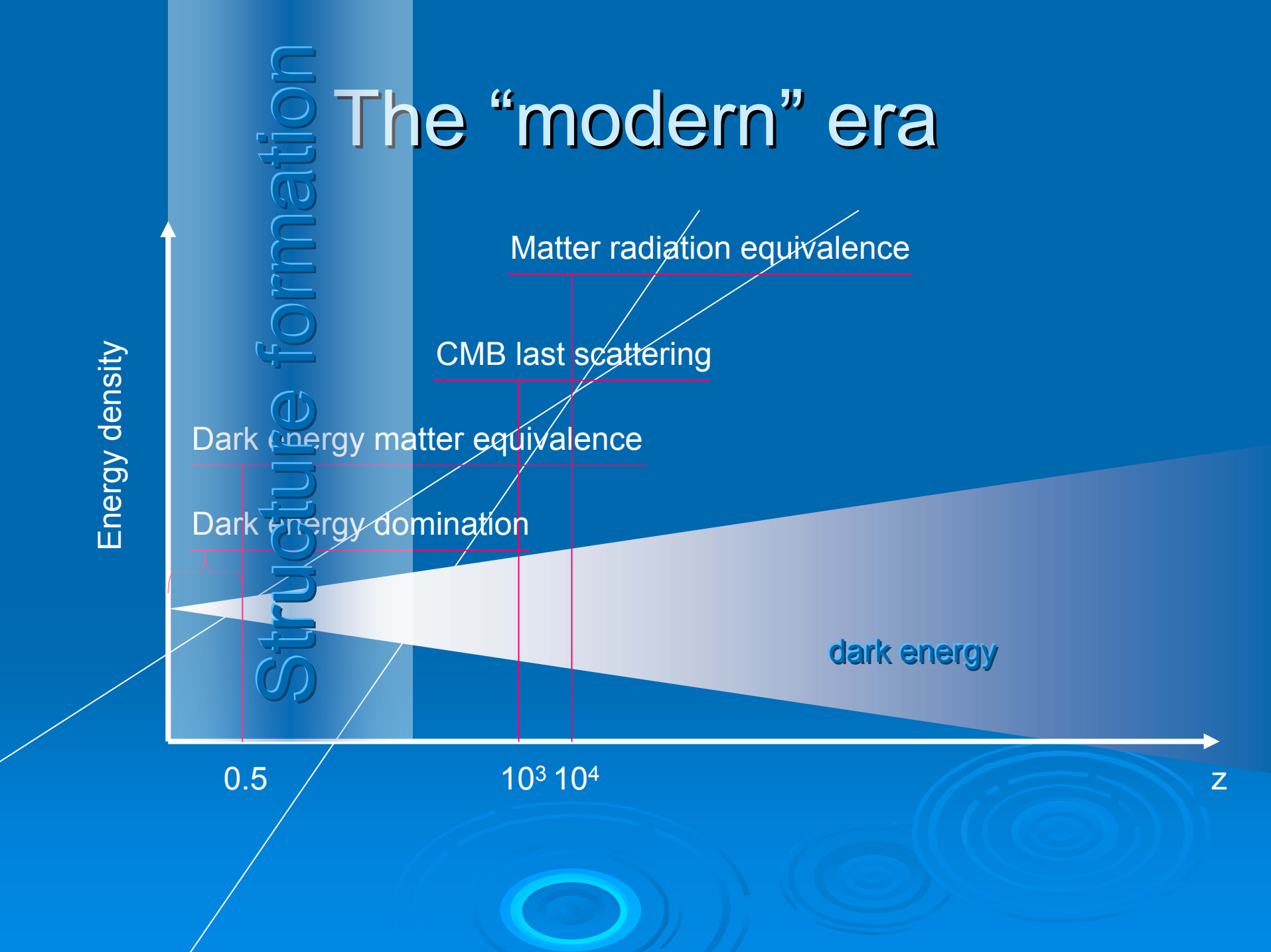

The “modern” era: study the signatures of structure formation on the CMB

- Beat cosmic variance by predicting the ISW effect from local and observed structures
- Study lensed CMB

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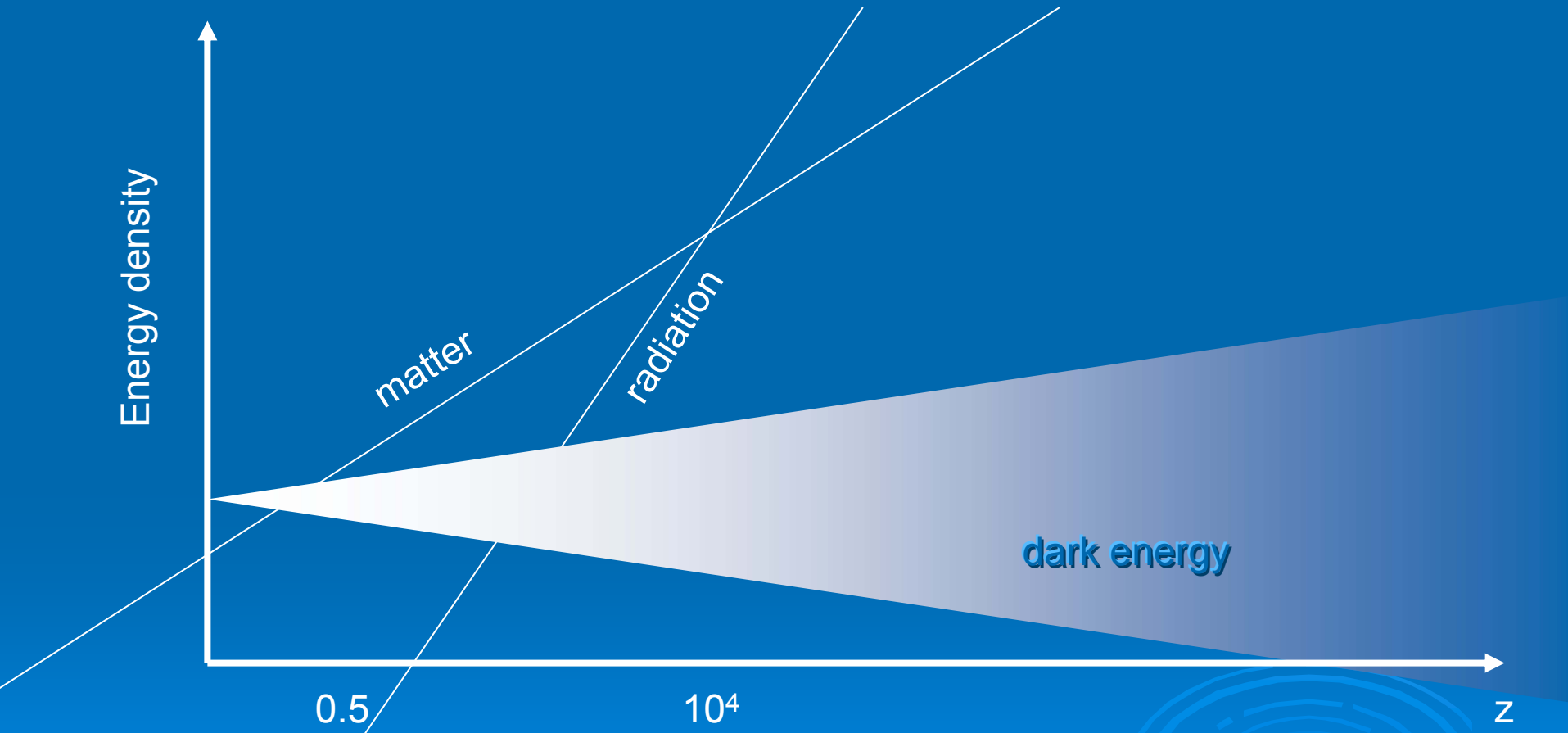
The promise of lensing



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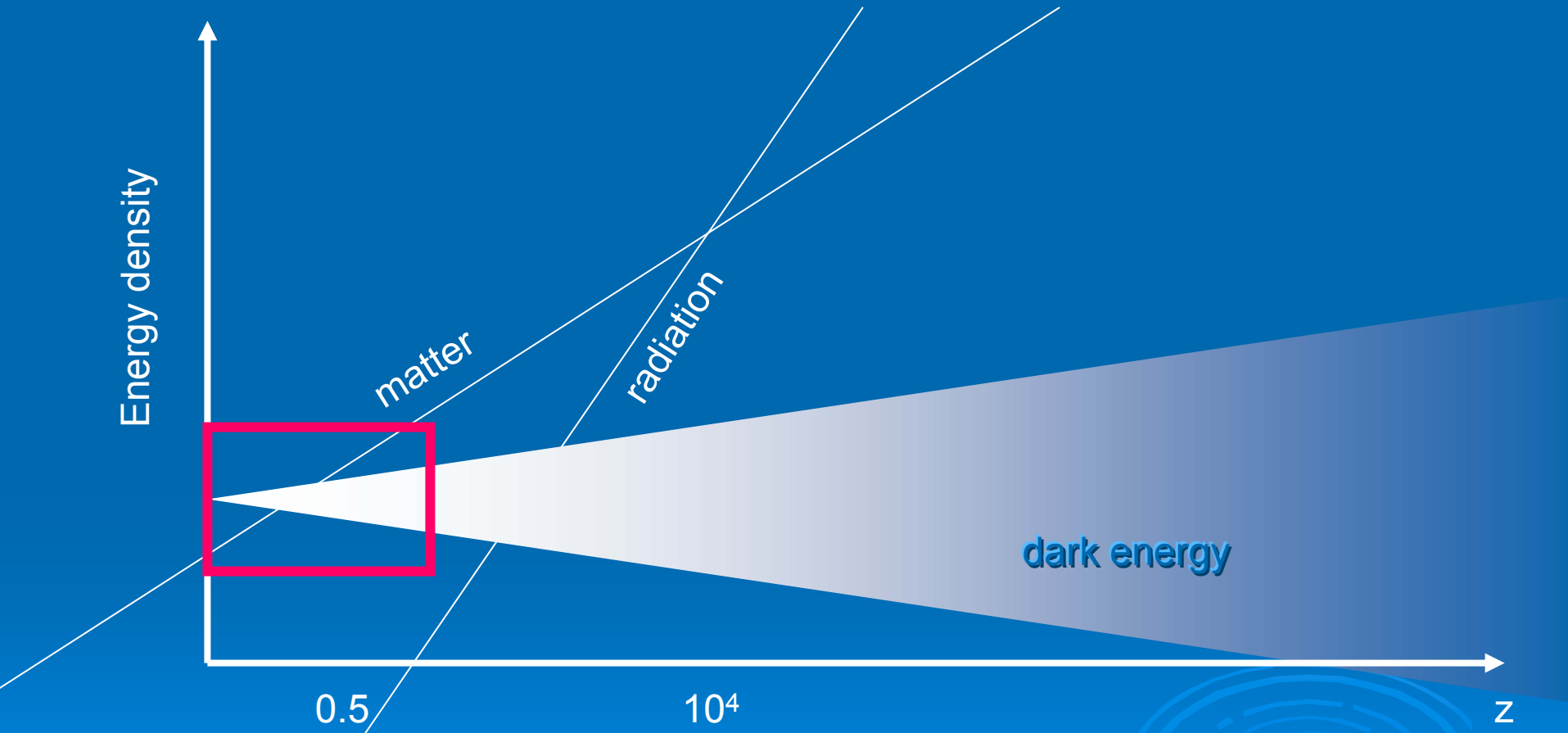

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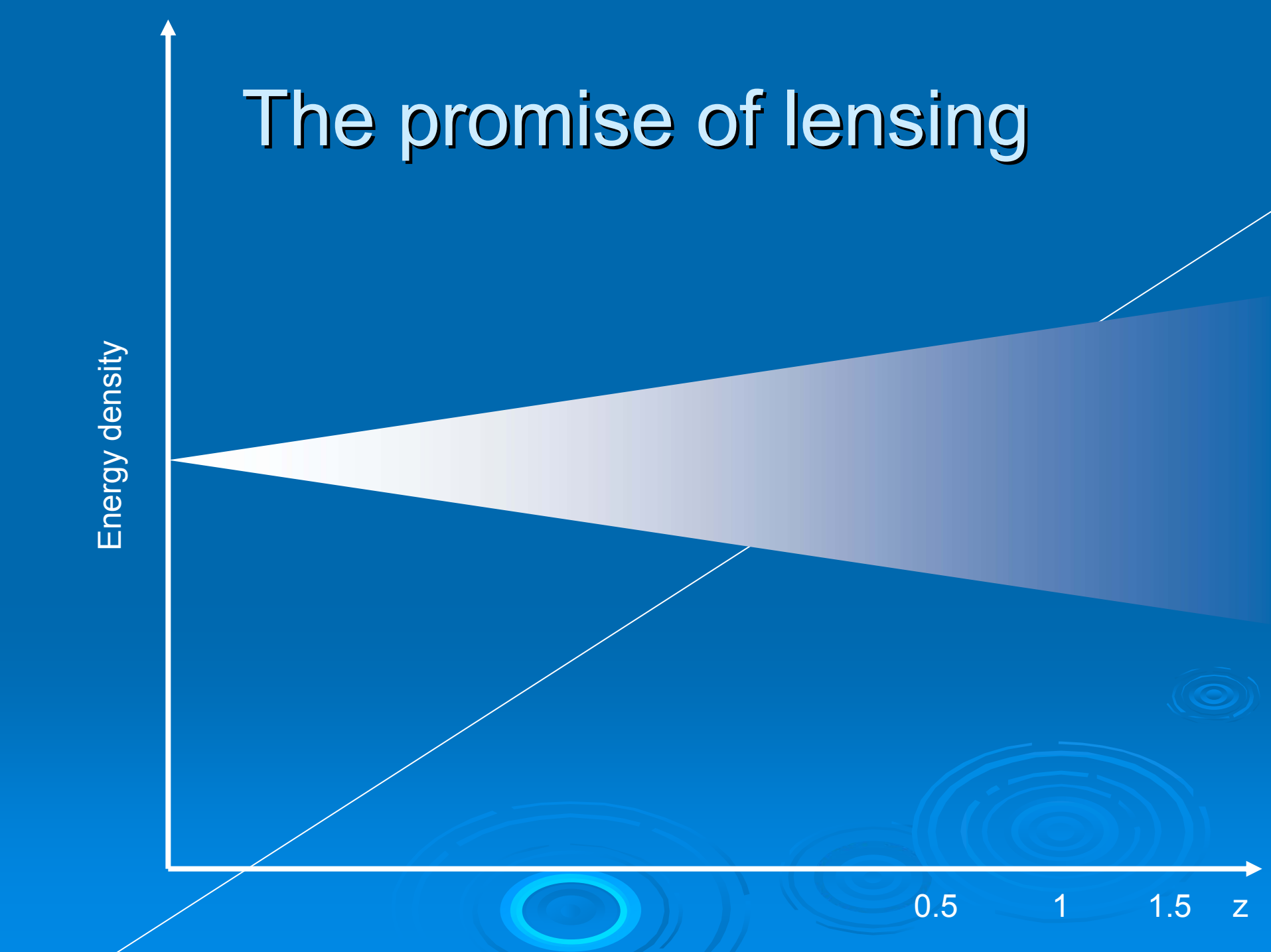

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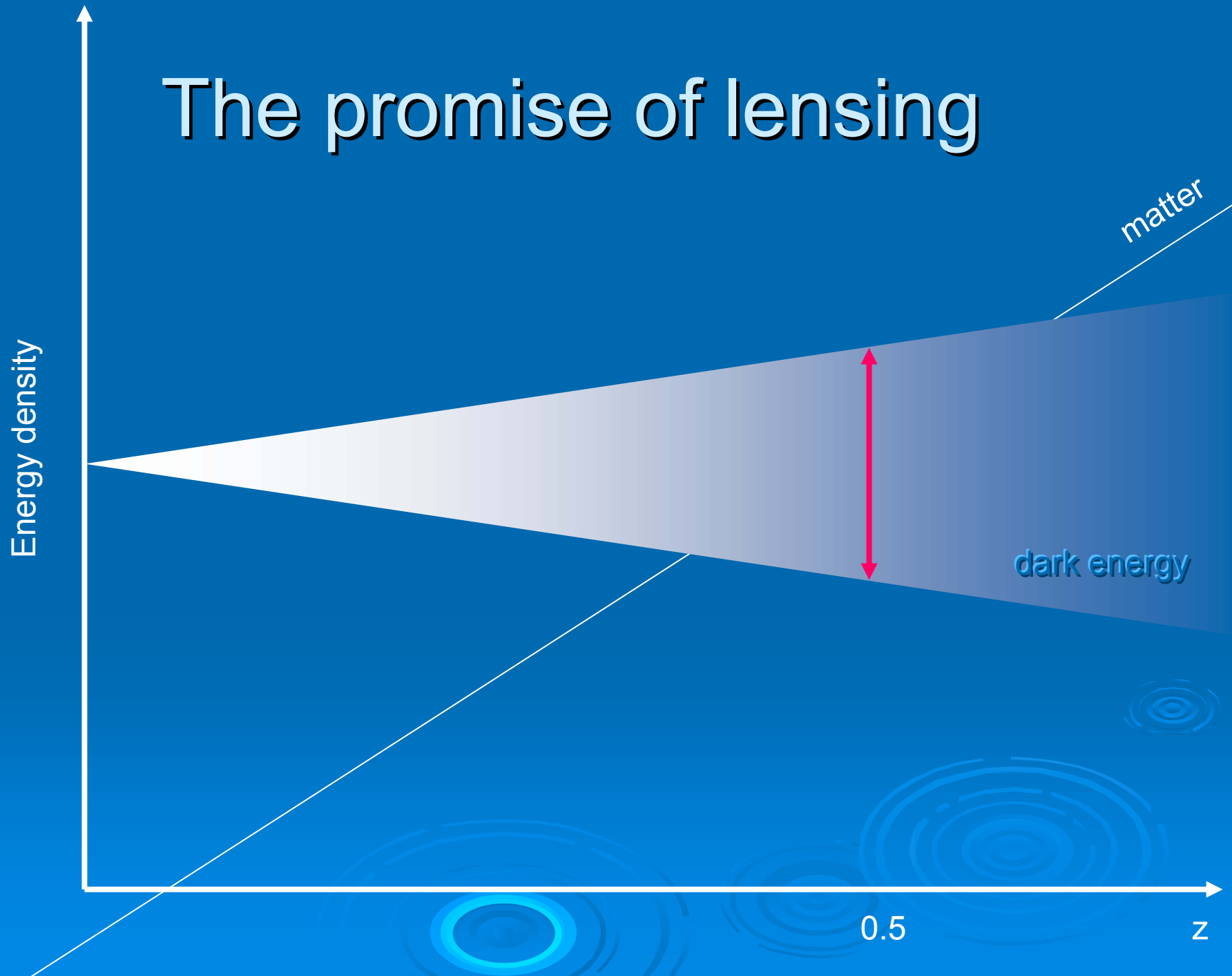
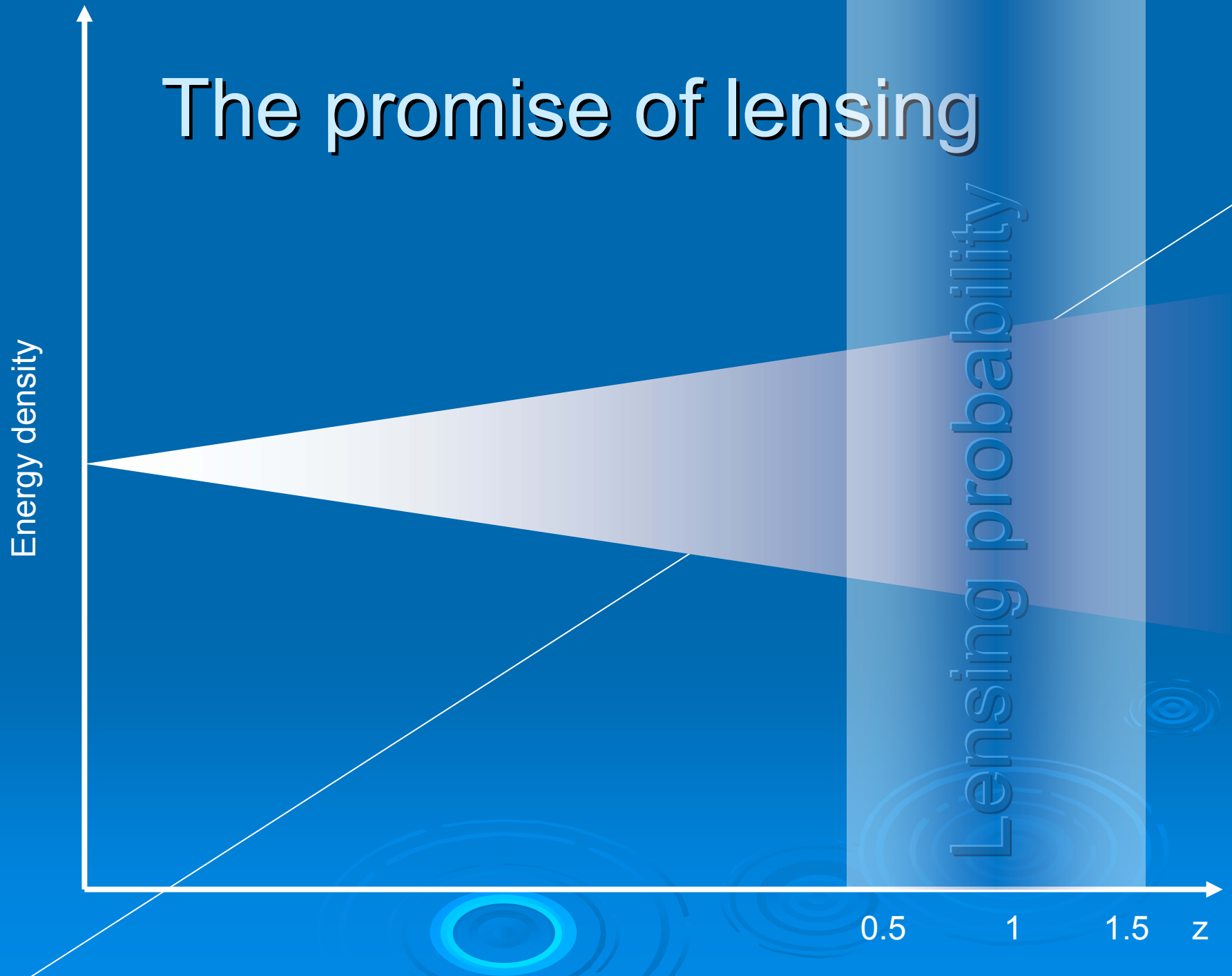


The promise of lensing

- By geometry, the lensing cross section is non-zero at intermediate distances between source and observer
- In the case of CMB as a source, the lensing power peaks at about z=1
- Any lensing power in CMB anisotropy must be quite sensitive to the expansion rate at the onset of acceleration

The promise of lensing



How lensing modifies the CMB

- Most relevant on the angular scales subtended by lenses, from the arcminute to the degree
- It makes the CMB non-Gaussian
- It smears acoustic peaks
- It activates a broad peak in the B modes of CMB polarization

Seljak & Zaldarriaga 1997, Spergel & Goldberg 1999, Hu 2000, Giovi et al. 2005

How lensing modifies the CMB

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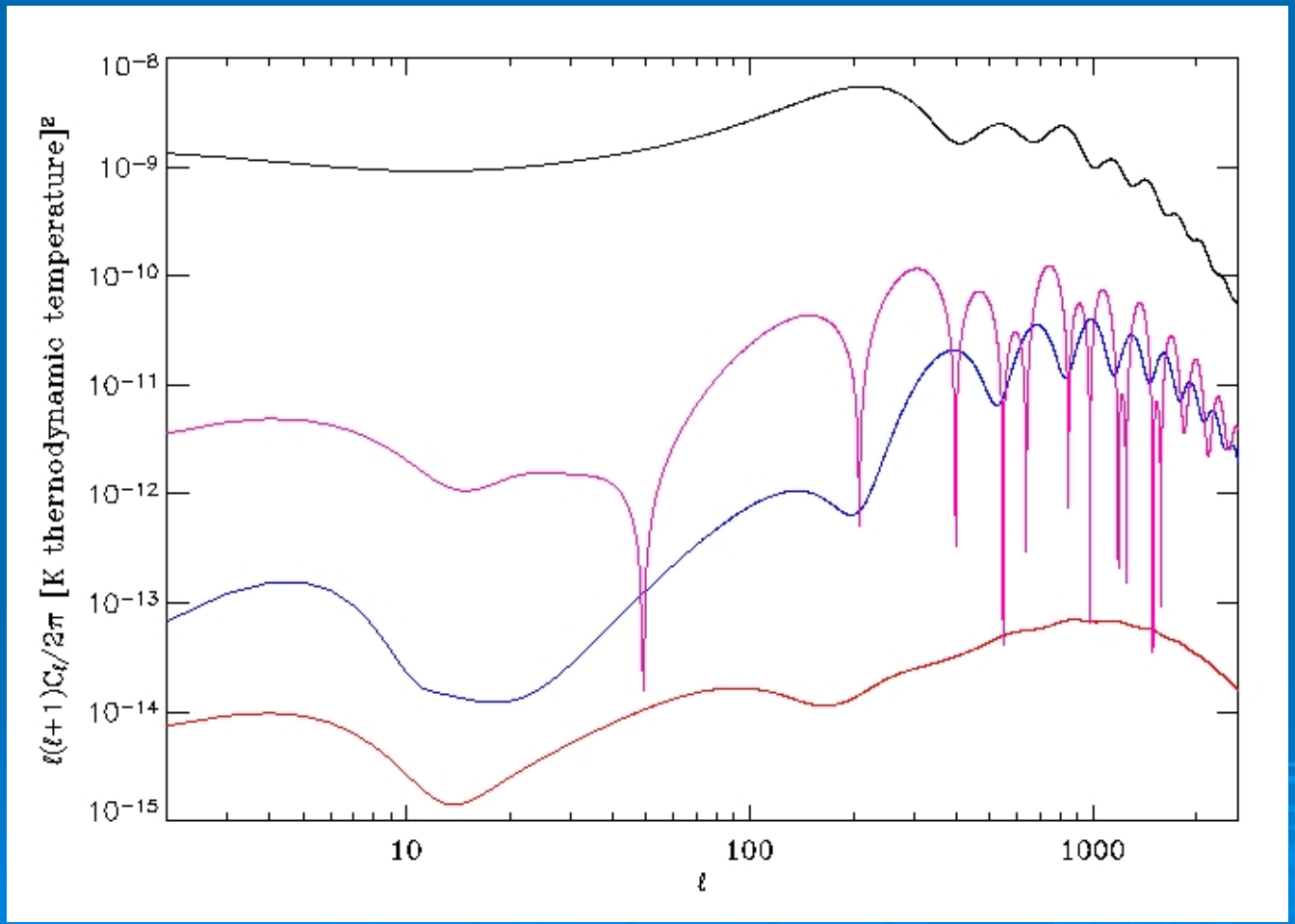
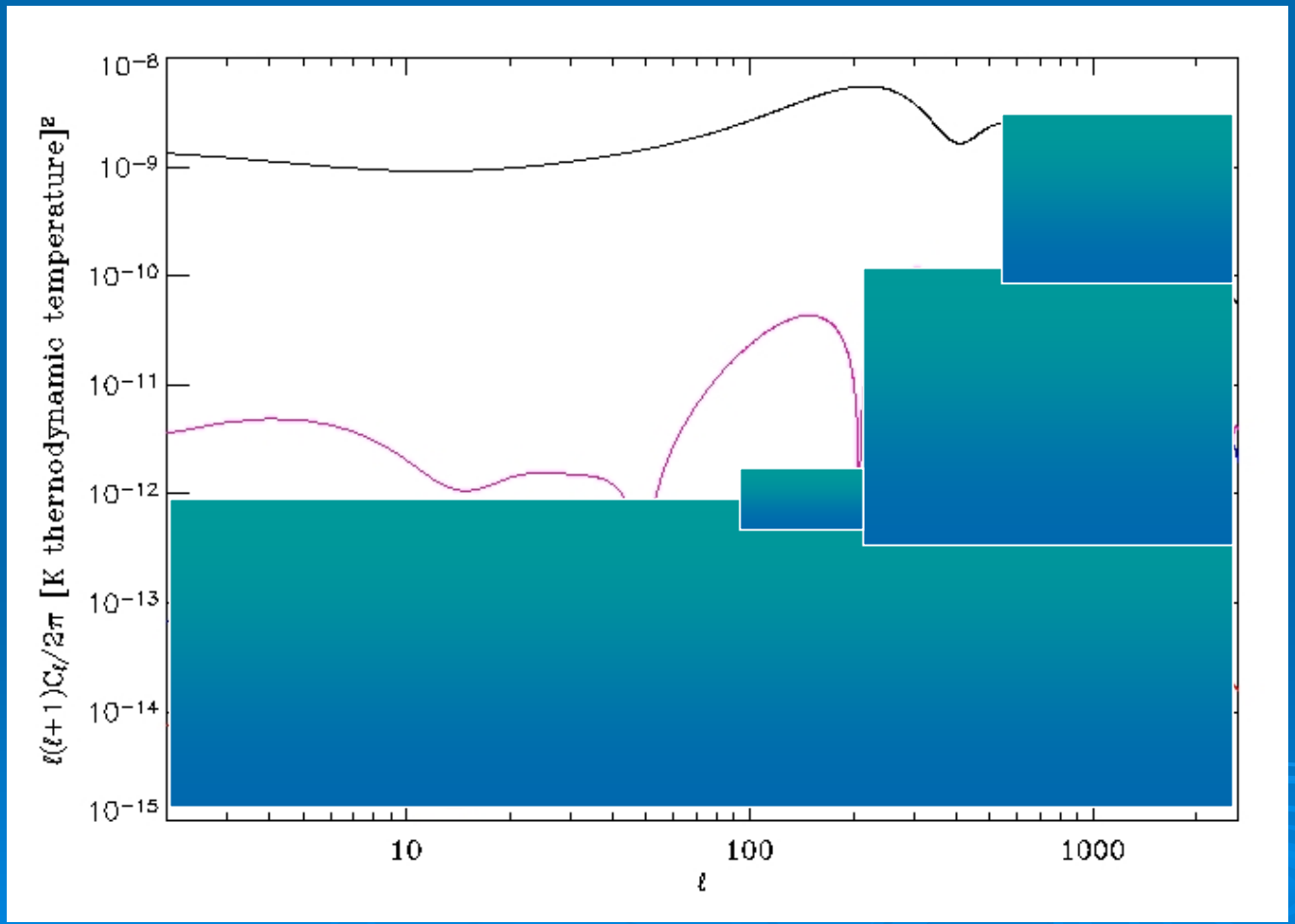
CMB angular power spectrum



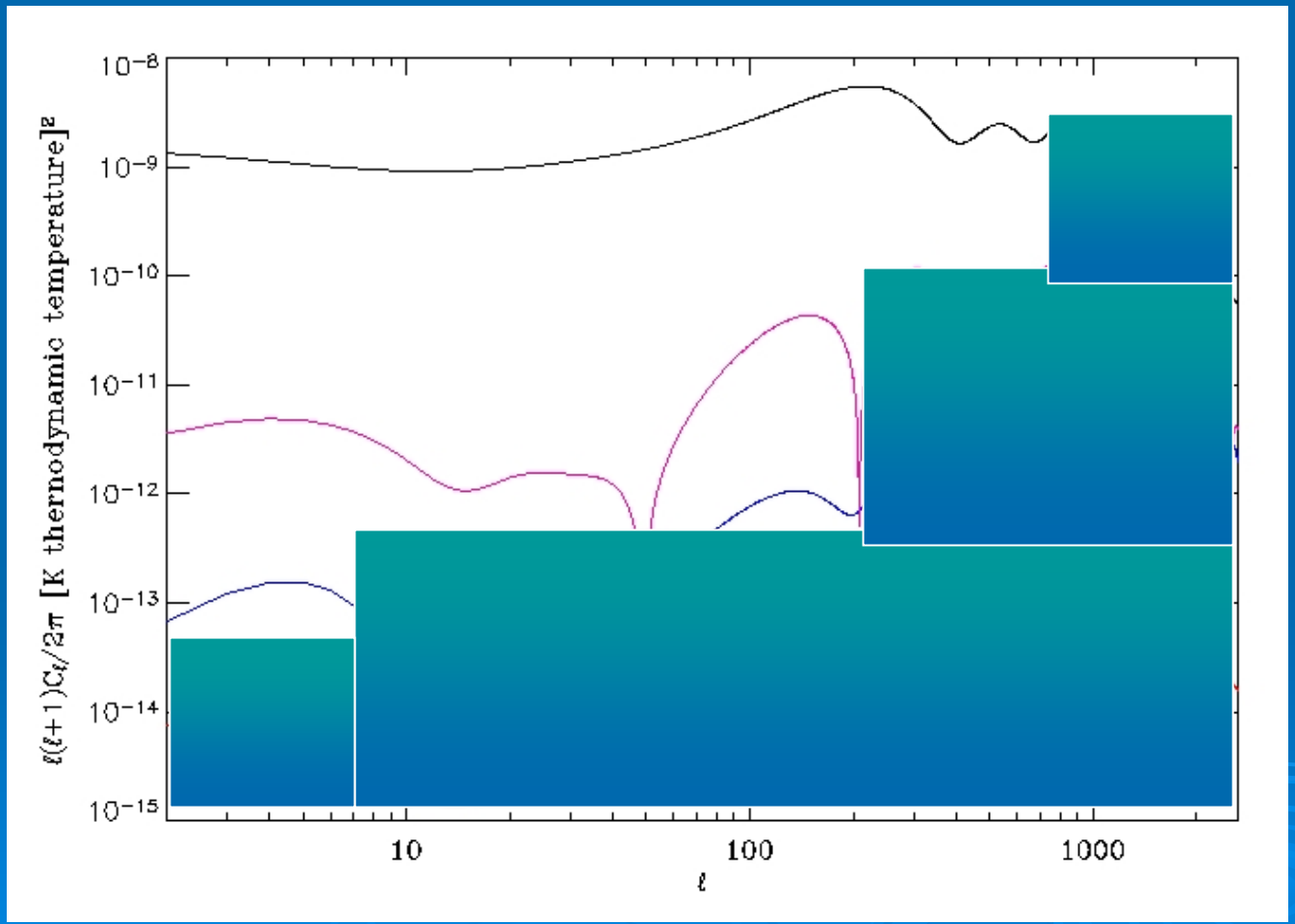
Angle ≈ 200/ℓ degrees

Known CMB angular power spectrum: WMAP first year



Angle ≈ 200/ℓ degrees

Known CMB angular power spectrum: WMAP third year



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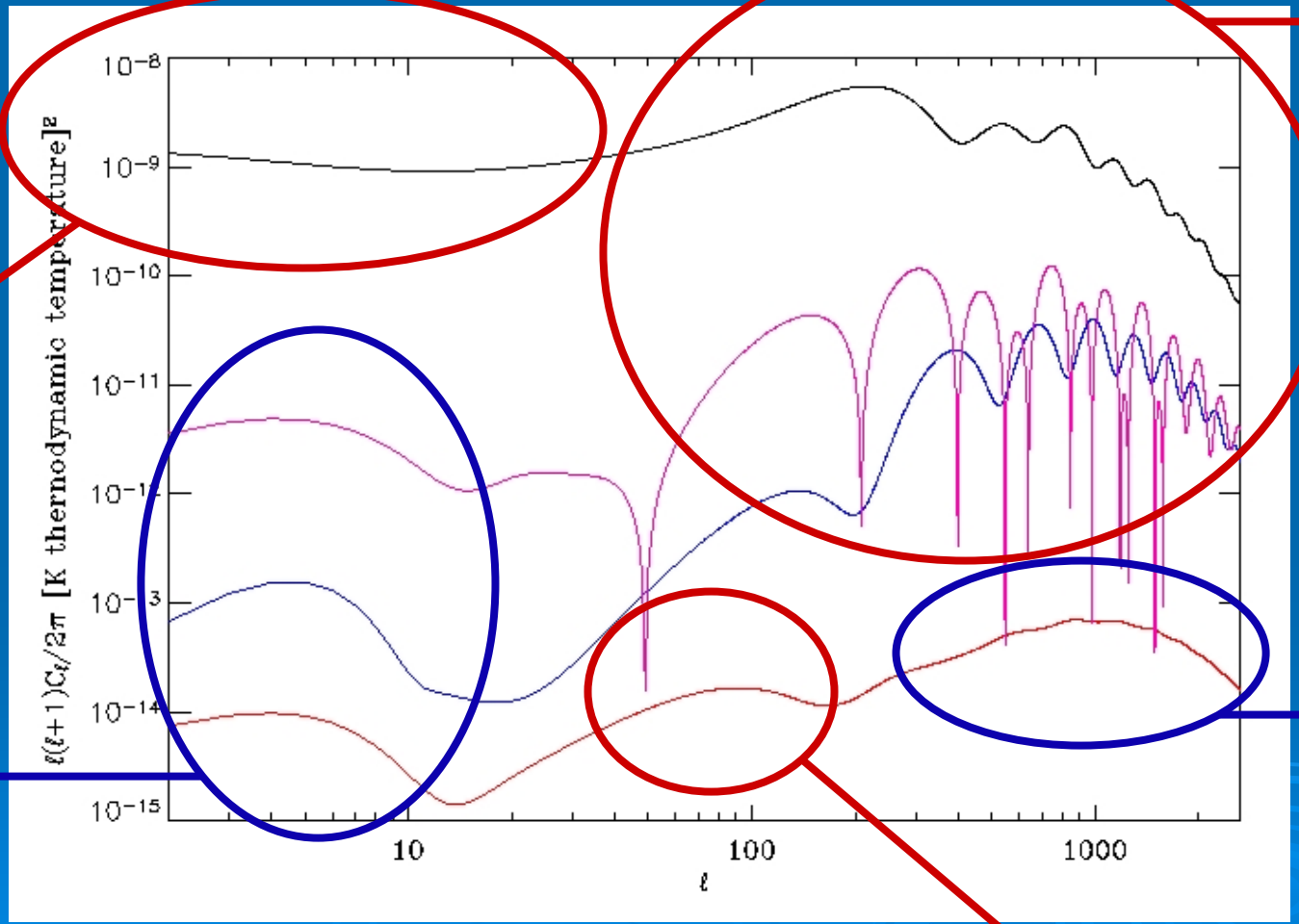
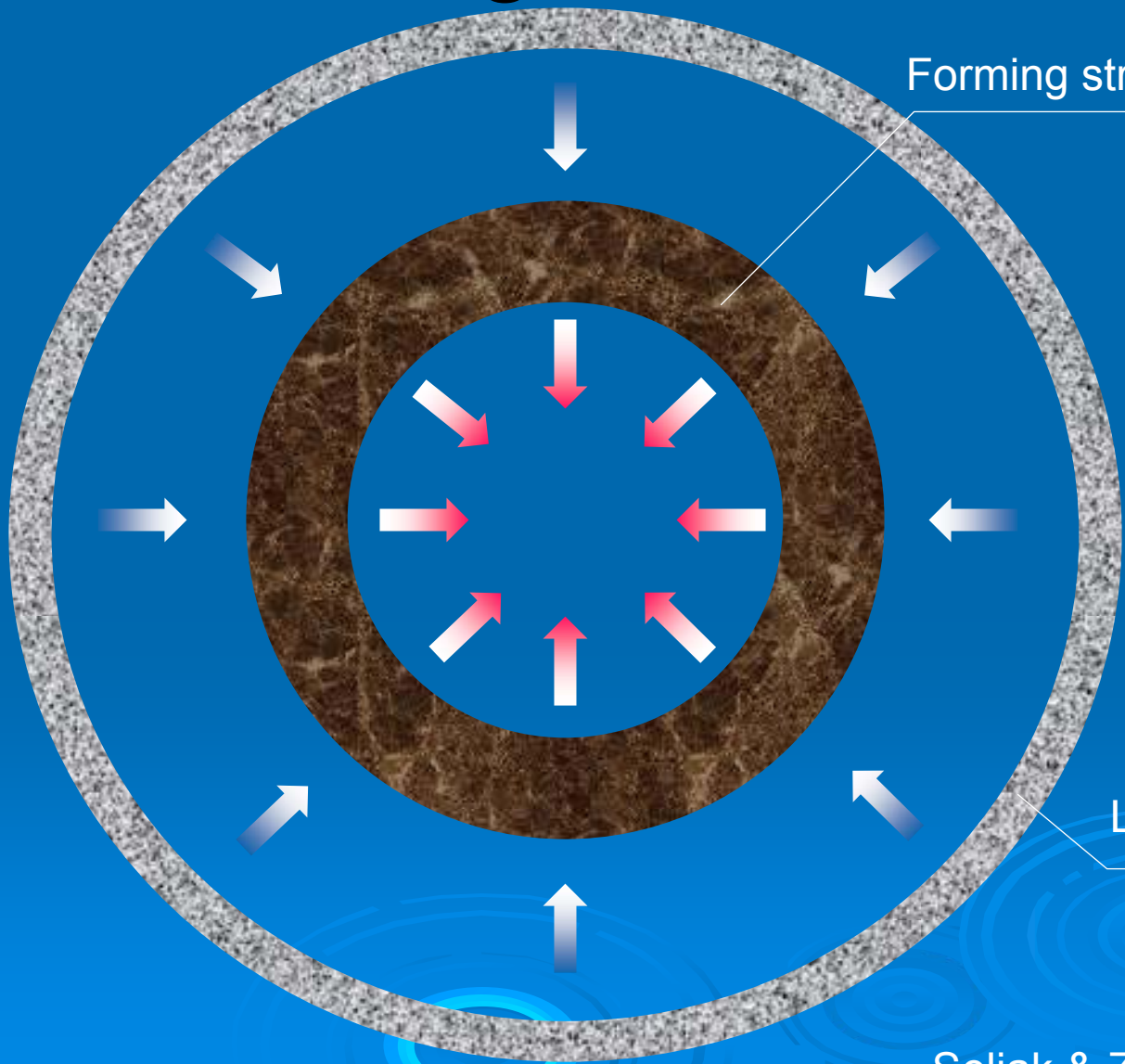
CMB angular power spectrum



Angle ≈ 200/ℓ degrees

Lensing B modes

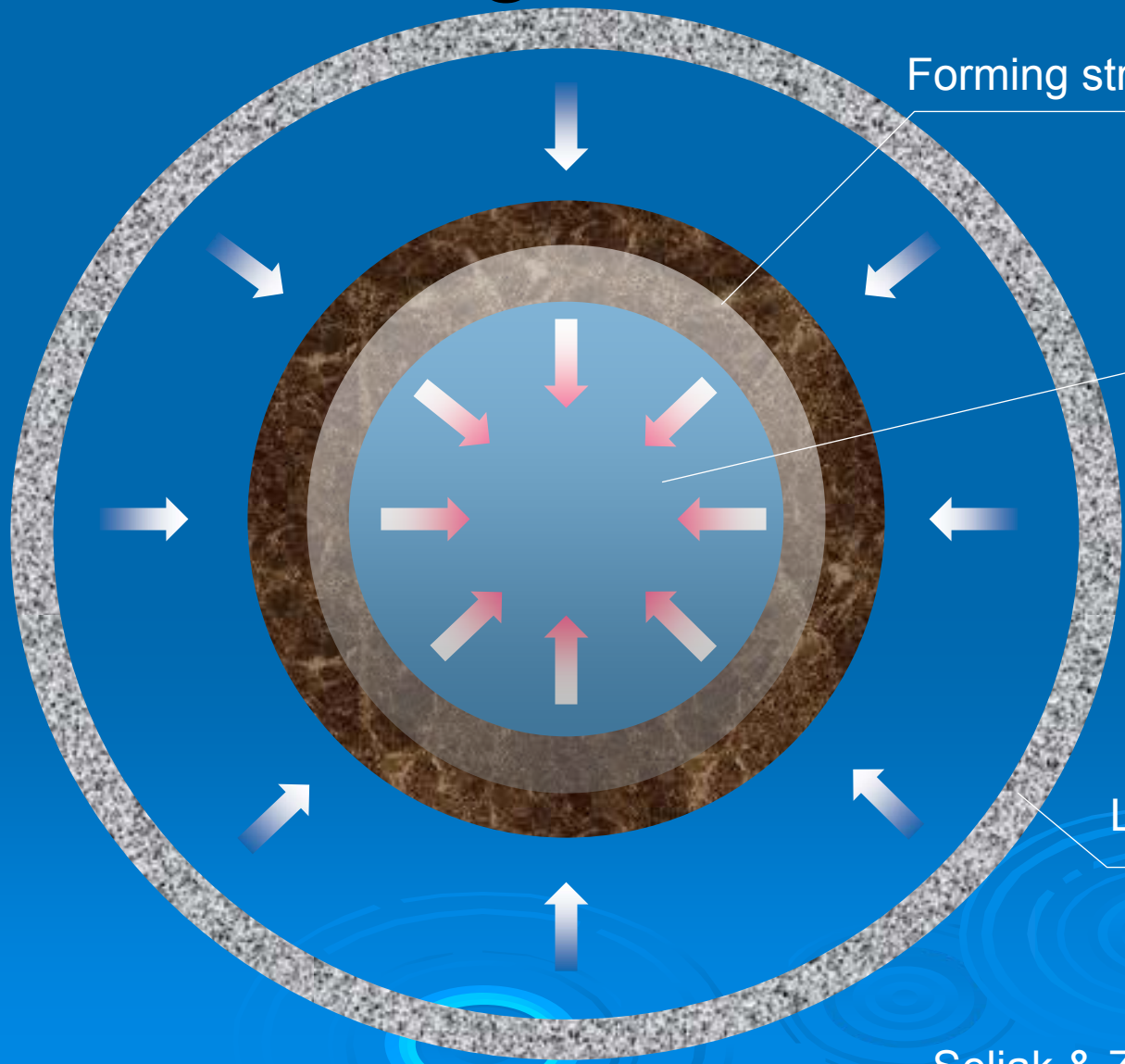
E B



Seljak & Zaldarriaga 1998

Lensing B modes

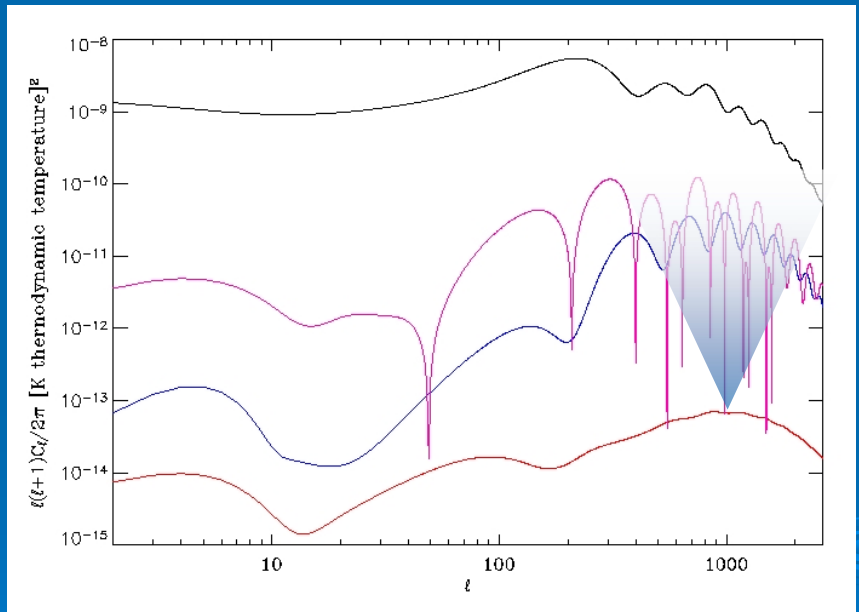
E B



Seljak & Zaldarriaga 1998

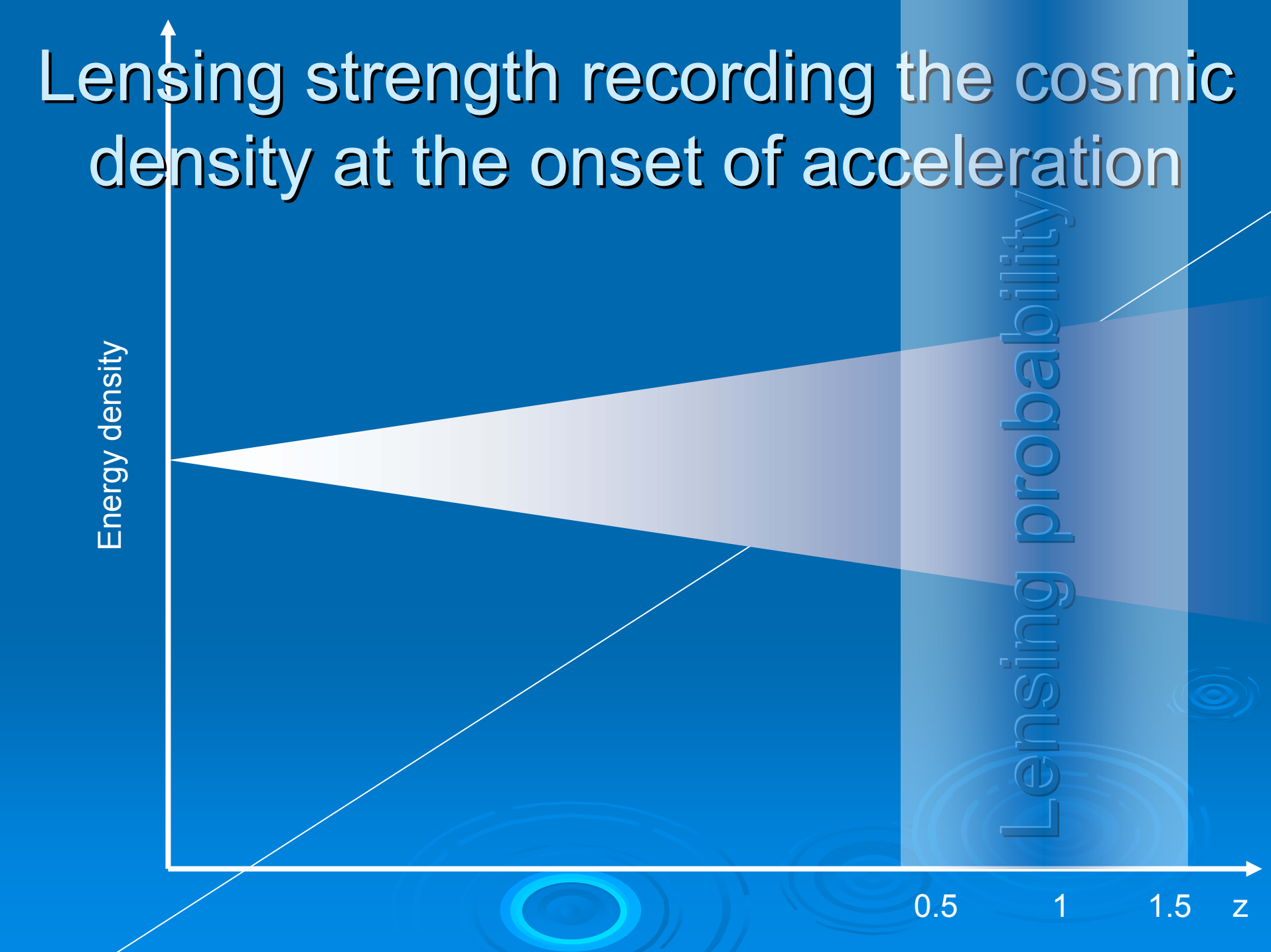
CMB lensing: a science per se

- Lensing is a second order cosmological effect
- Lensing correlates scales
- The lensing pattern is non-Gaussian
- Statistics characterization in progress, preliminary investigations indicate an increase by a factor 3 of the uncertainty from cosmic variance



Smith et al. 2006, Lewis & Challinor 2006, Lewis 2005, …

Lensing strength recording the cosmic density at the onset of acceleration



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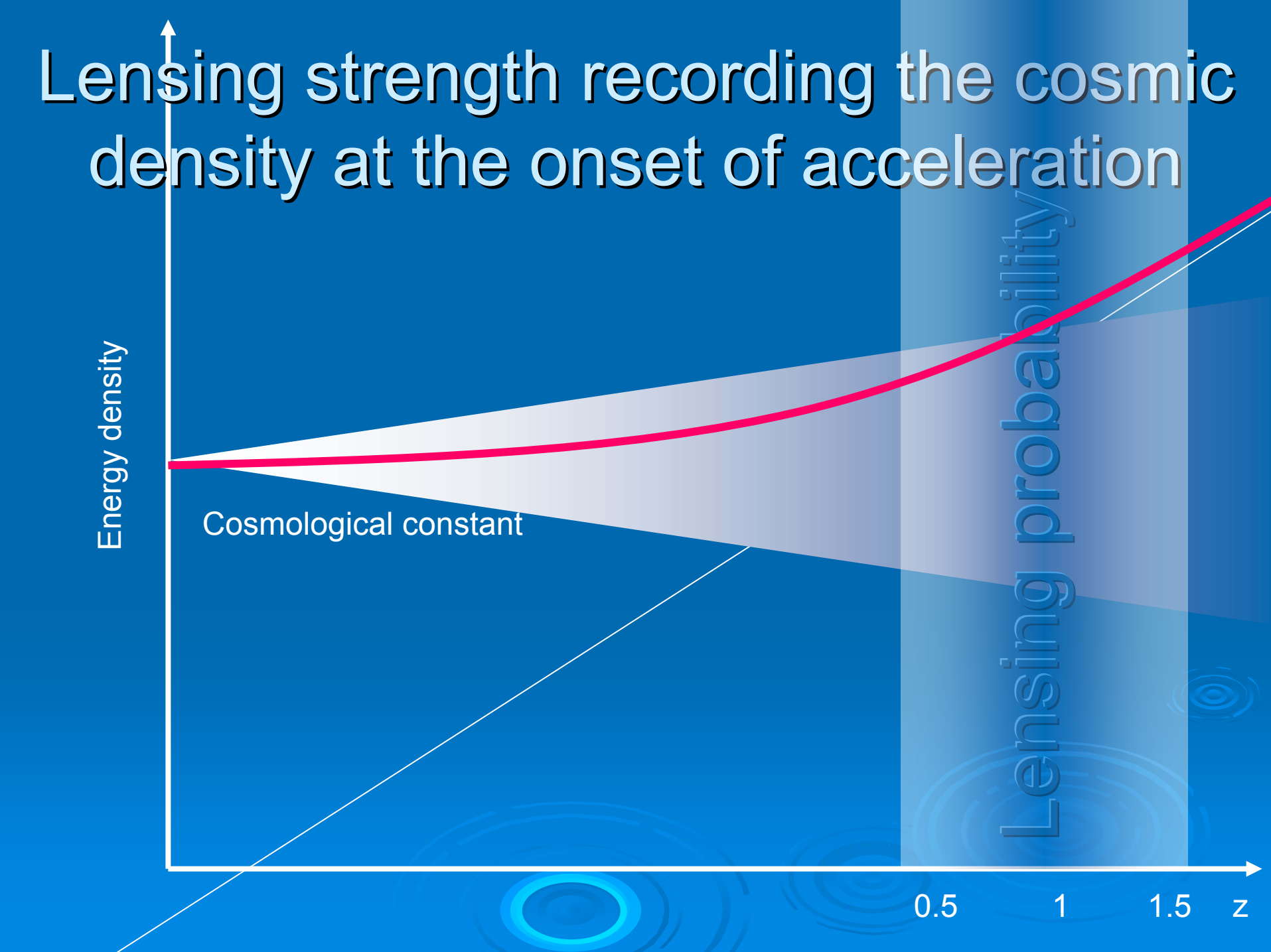

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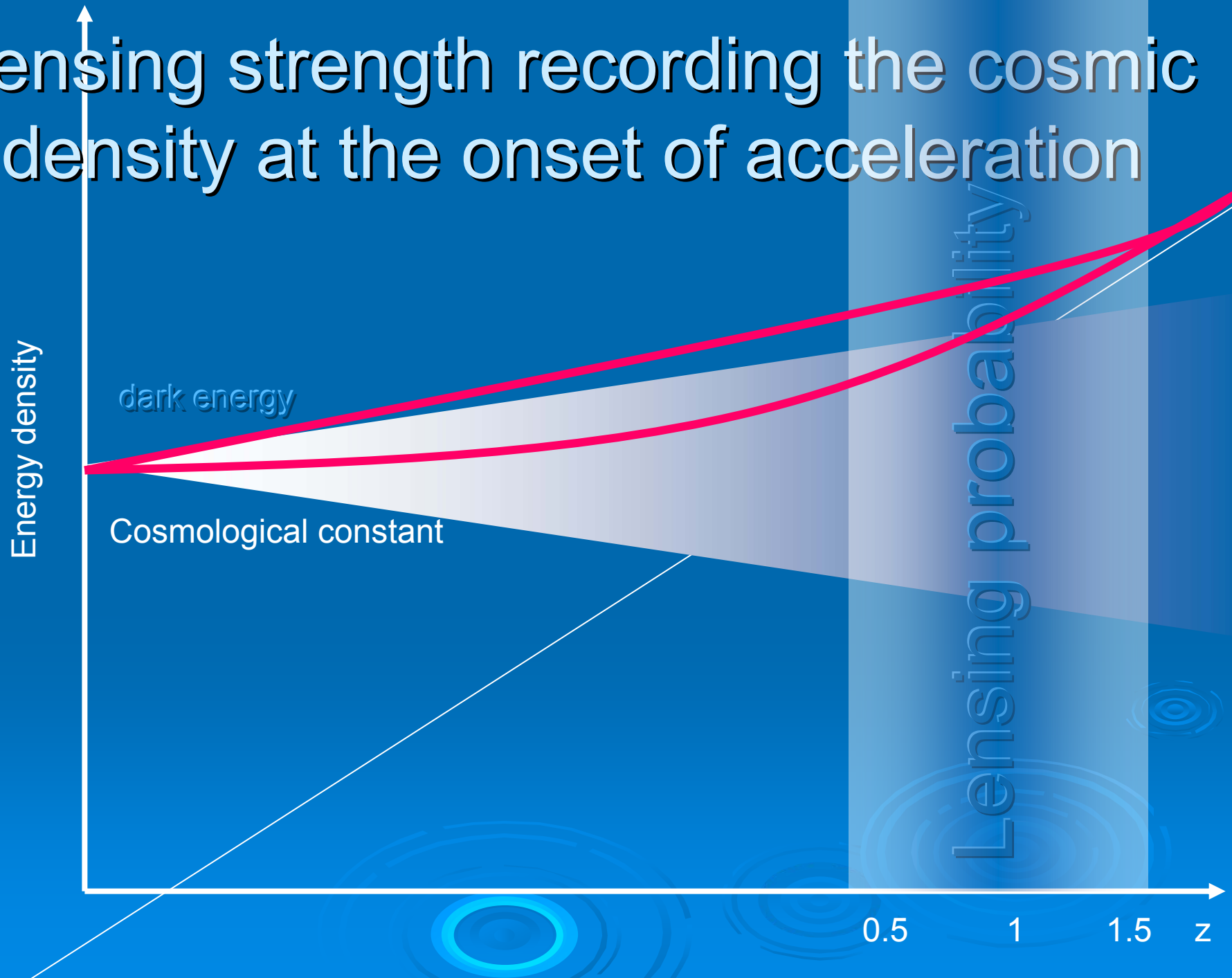
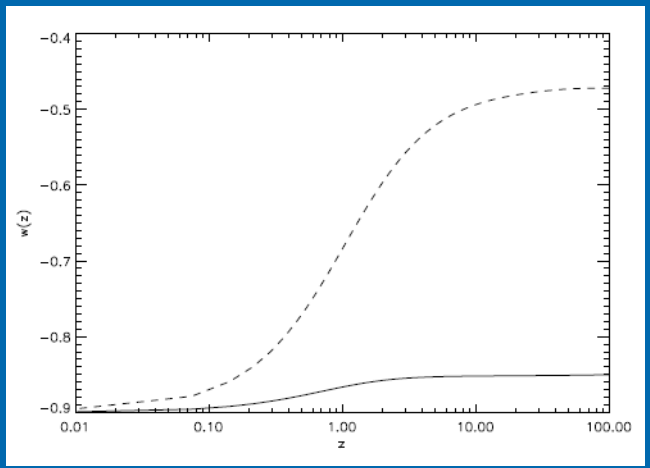


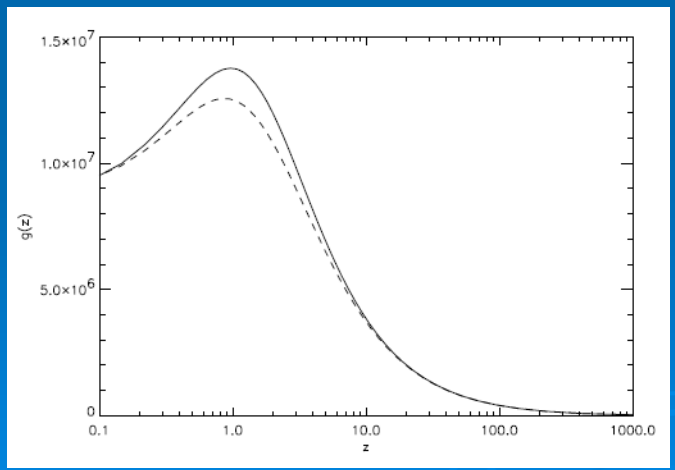
So let's play…

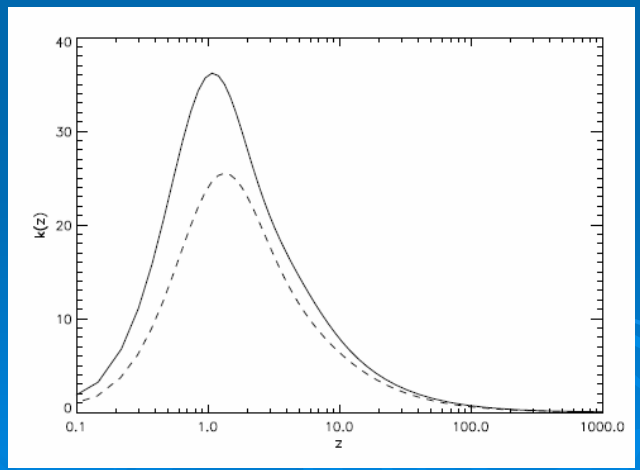
- Upgrade a Boltzmann code for lensing computation in dark energy cosmologies (Acquaviva et al. 2004 experienced doing that with cmbfast, lensing.f has to be substantially changed…)
- Get lensed CMB angular power spectra for different dark energy dynamics
- Look at the amplitude of lensing B modes

Play…

- SUGRA vs. Ratra-Peebles quintessence
- Check structure formation, linear perturbation growth rate, …
- Perturbations and distances affected by geometry coherently…
- Effects sum up in the lensing kernel



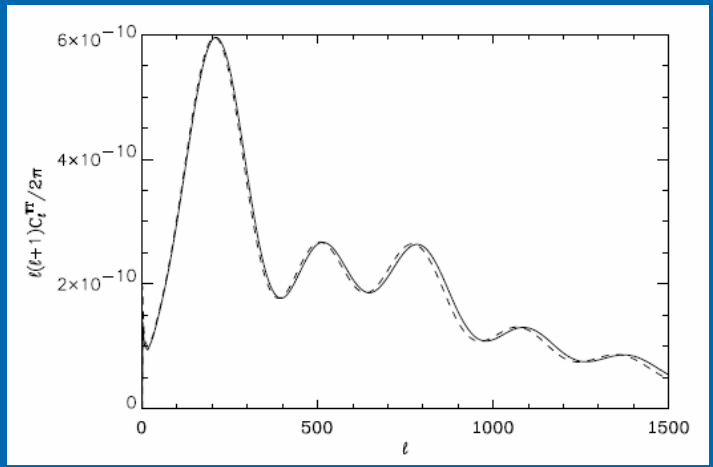


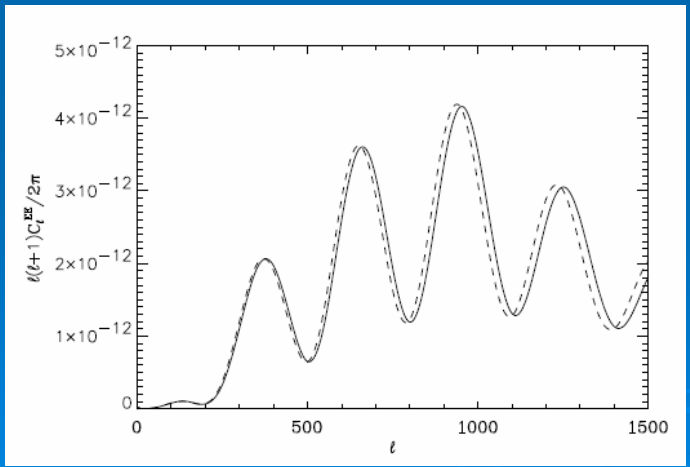


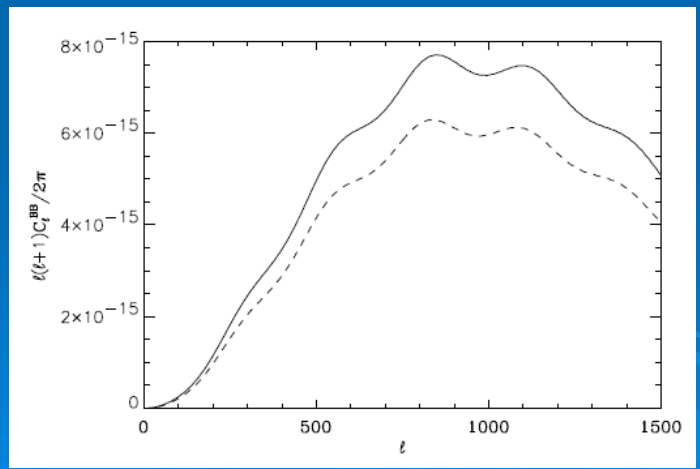
Acquaviva & Baccigalupi 2005

Play…

- TT and EE spectra: slight projection shift
- BB amplitude: reflecting cosmic density at structure formation/onset of acceleration

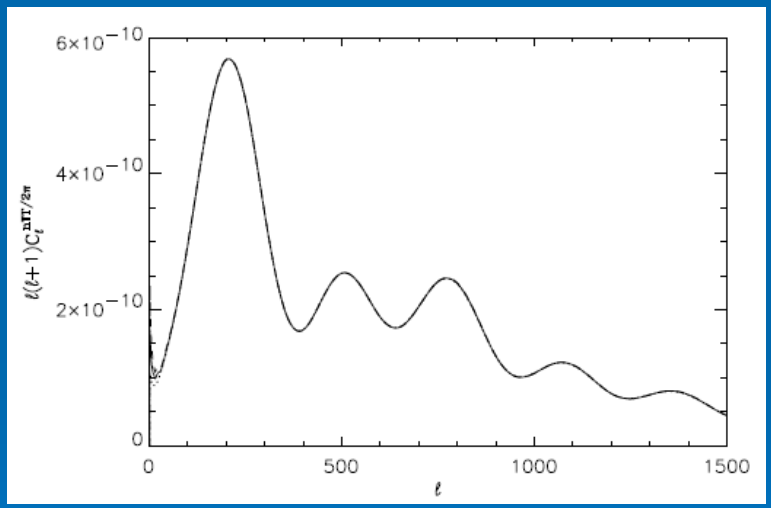


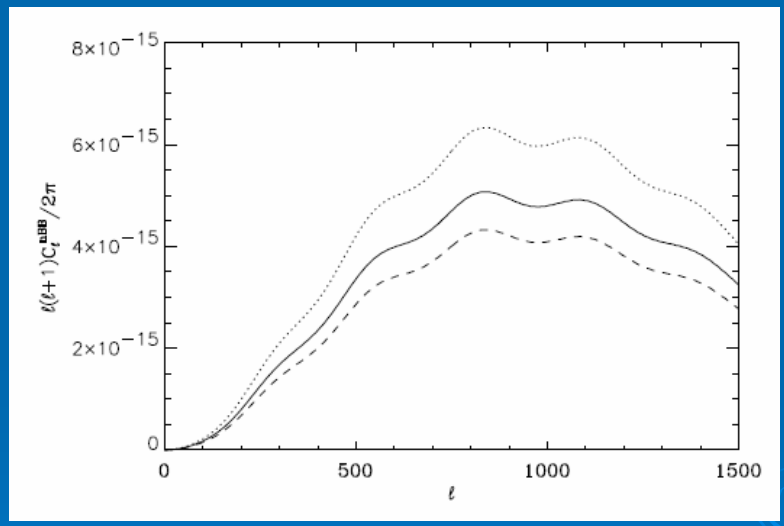




Acquaviva & Baccigalupi 2005

Breaking projection degeneracy





Acquaviva & Baccigalupi 2005

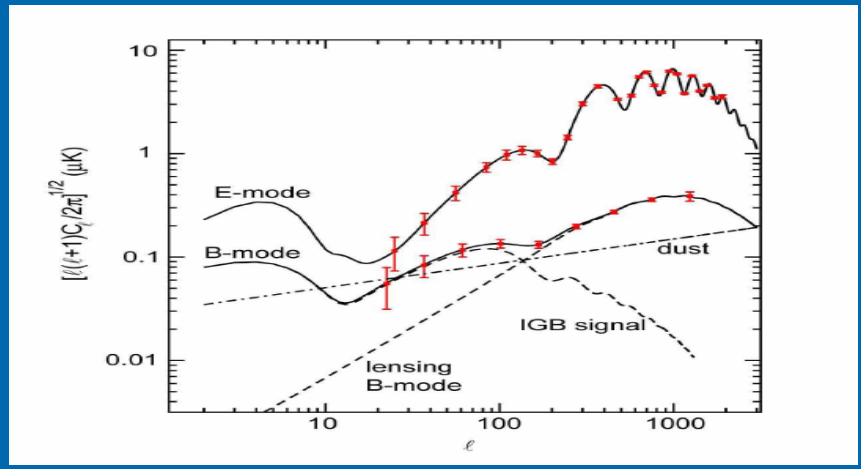
Get serious…

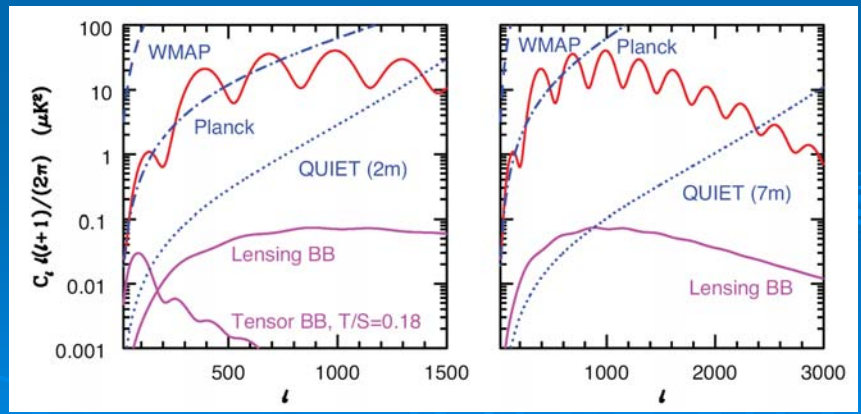
- A Fisher matrix analysis indicates that a 1%-10% measuremtent on both w_0 and w_a is achievable by having lensing B modes measured on a large sky area, few arcminute resolution, micro-K noise
- New relevance for searching B modes in CMB polarization?
- Independent check of the efficiency of the effect ongoing…

Acquaviva & Baccigalupi 2005

Forthcoming B modes hunters

- Planck, marginal, large scale only)
- EBEx, sensitivity ok for lensing B modes, north american flight in fall 2007
- QUIET , sensitivity ok for lensing B modes
- Clover
- Brain
- …
- Complete list available at lambda.gsfc.nasa.gov
- Beyond Einstein, Cosmic Vision…





Conclusions

- CMB lensing sensitivity is at high redshifts
- The CMB is not a probe of the dark energy density redshift average, but can reasonably put two error bars on the dark energy abundance at z=0 and 0.5
- Partner to other probes for constraining the redshift behavior of the dark energy
- You do not know where systematics hit more, so keep it in your toolbox