Dark energy

Carlo Baccigalupi, SISSA

Outline

- Fighting against a cosmological constant
- Parametrizing cosmic acceleration
- current bounds on dark energy
- “Classic” dark energy effects
- “Modern” effects from dark energy: the promise of lensing
- Future dark energy probes

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

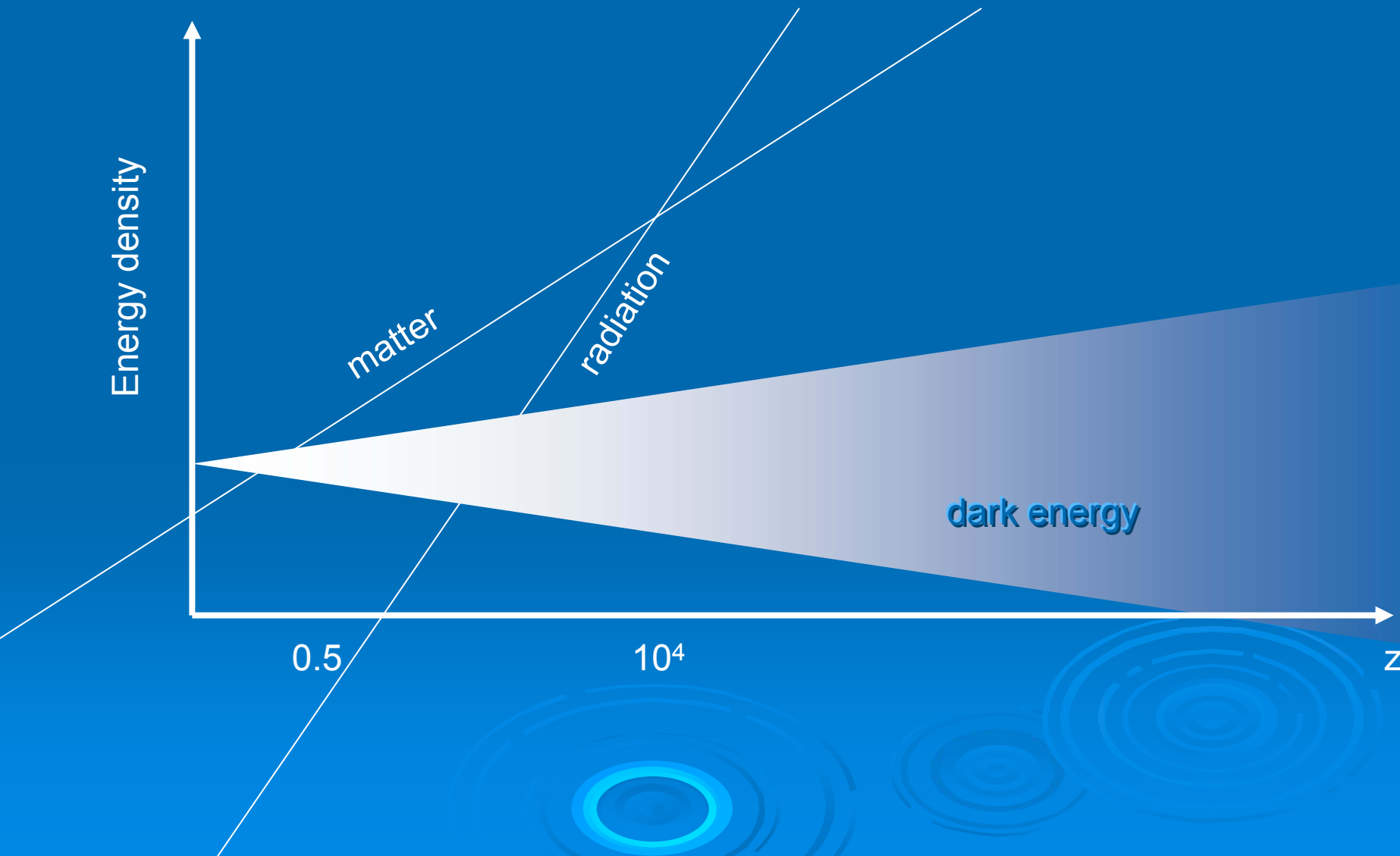
$$|\Lambda - V|/M^4_{Planck} = 10^{-123}$$

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

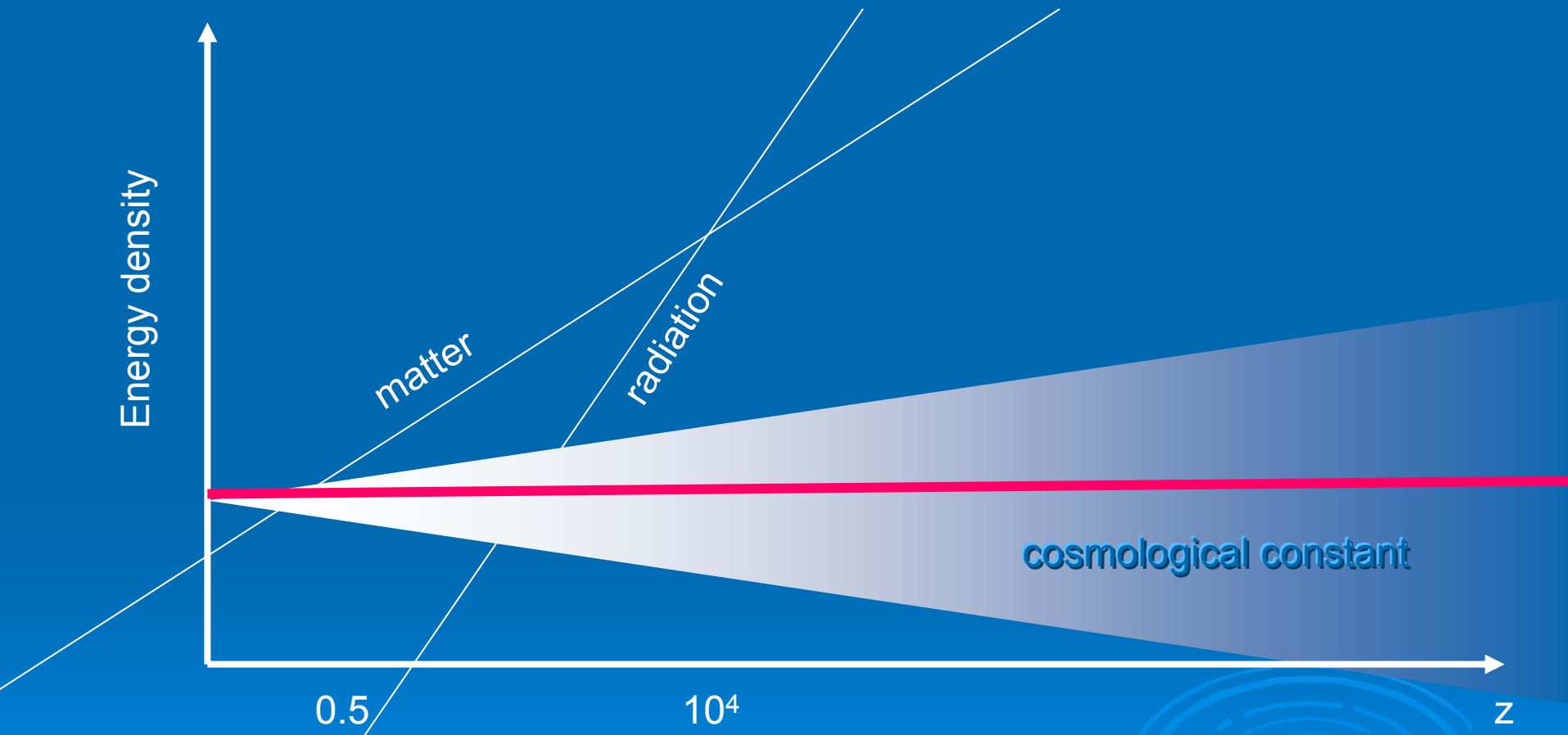
$(\text{Boh?})^2$

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

Dark energy

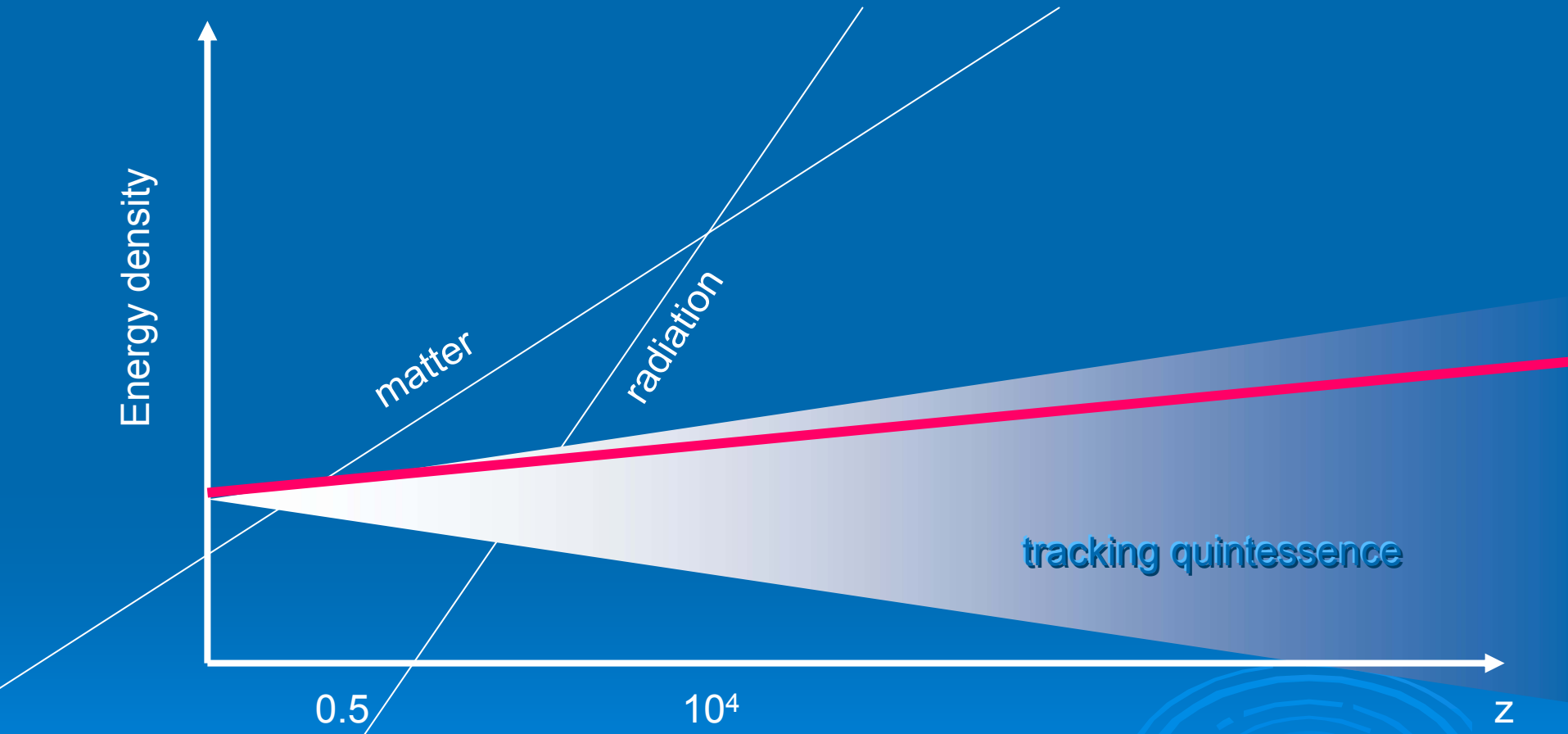


Dark energy



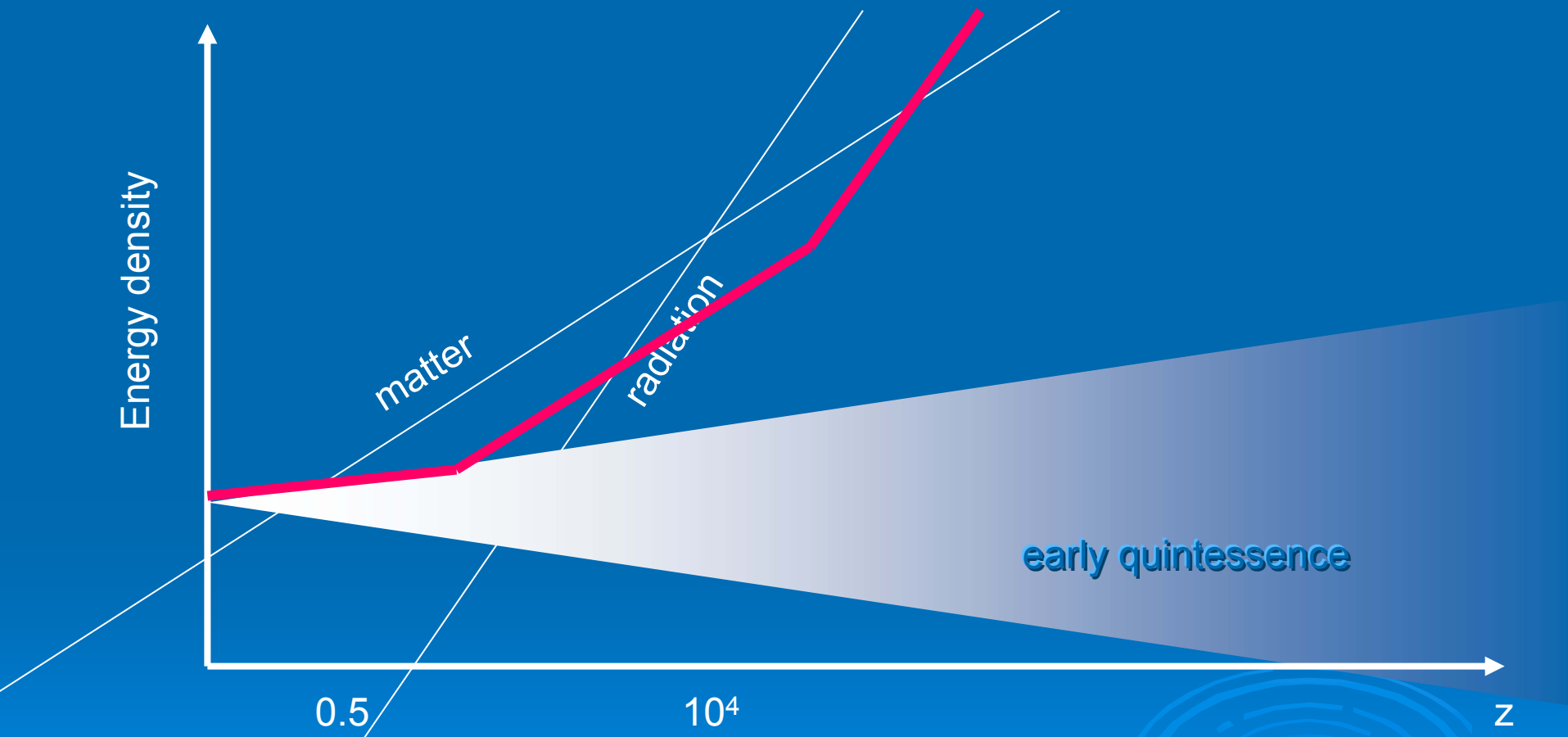
Einstein 1916

Dark energy



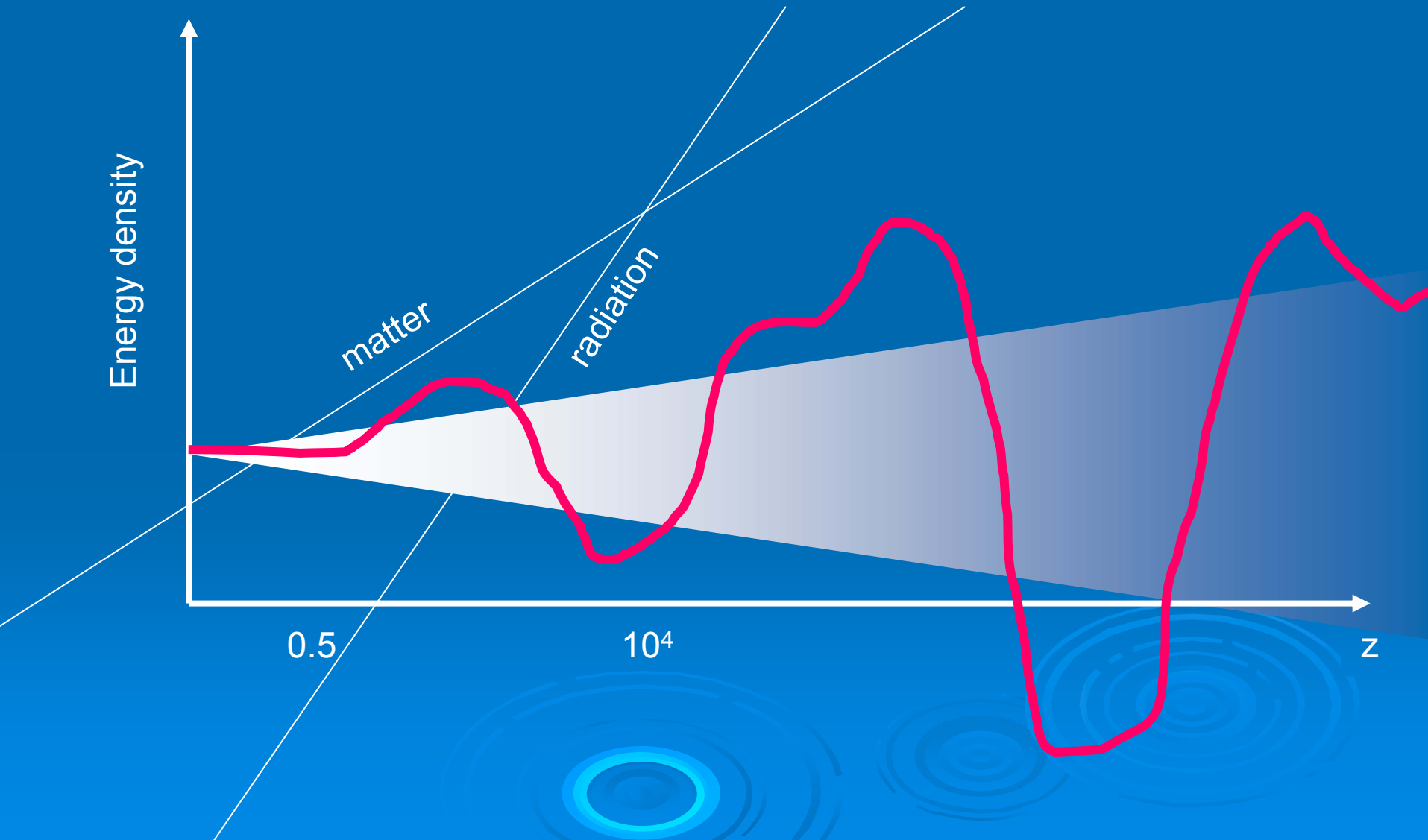
Ratra & Peebles, 1988

Dark energy

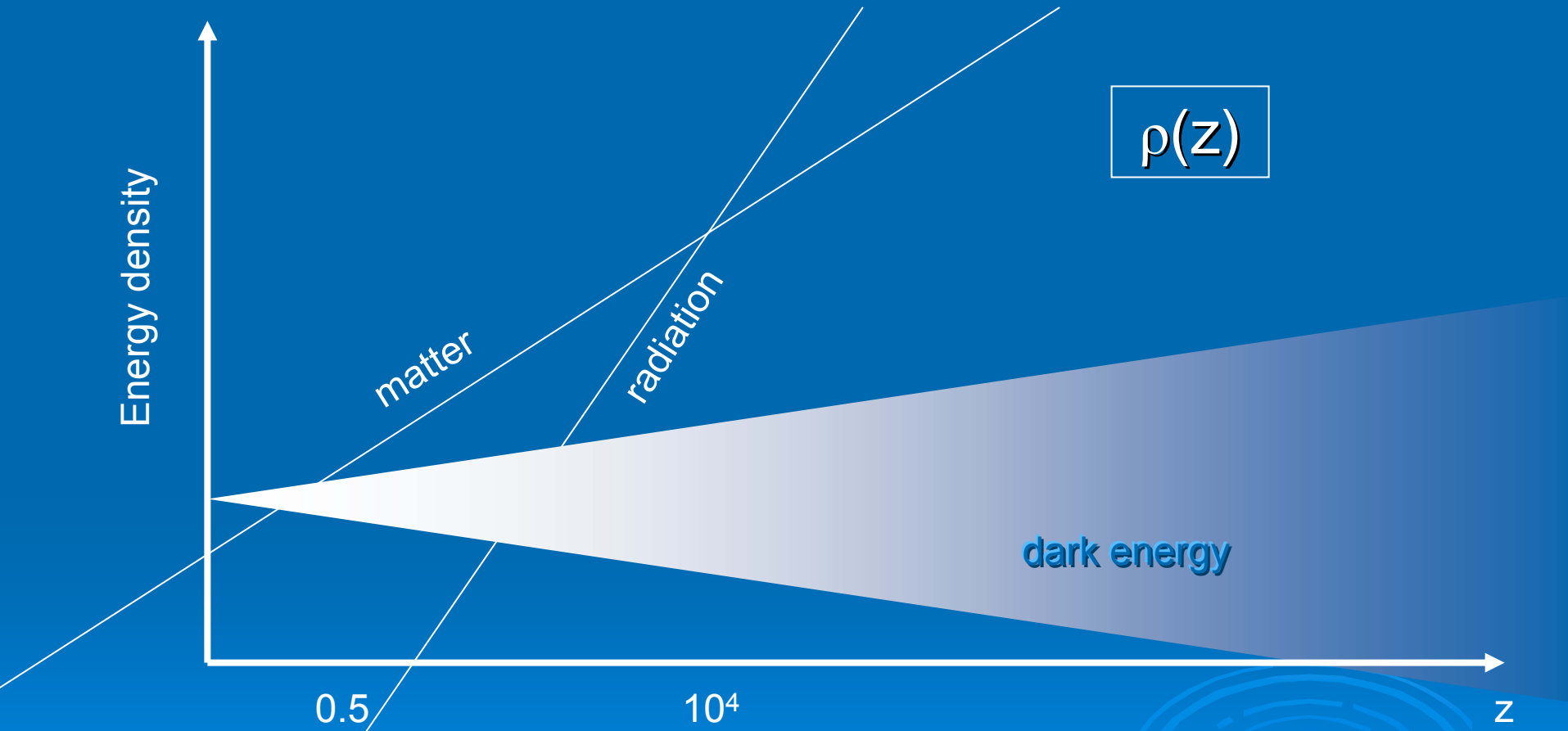


Wetterich 1988

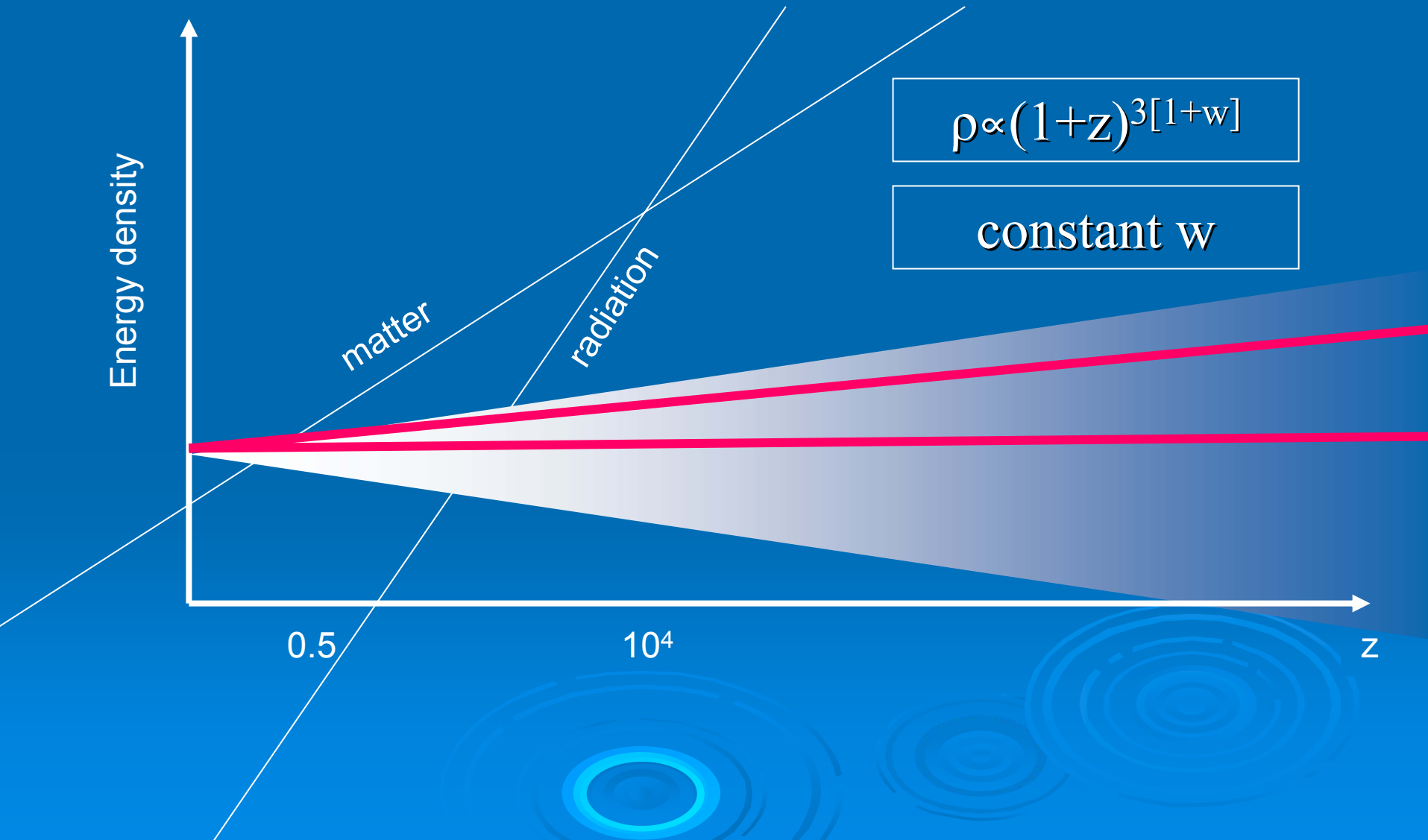
Dark energy



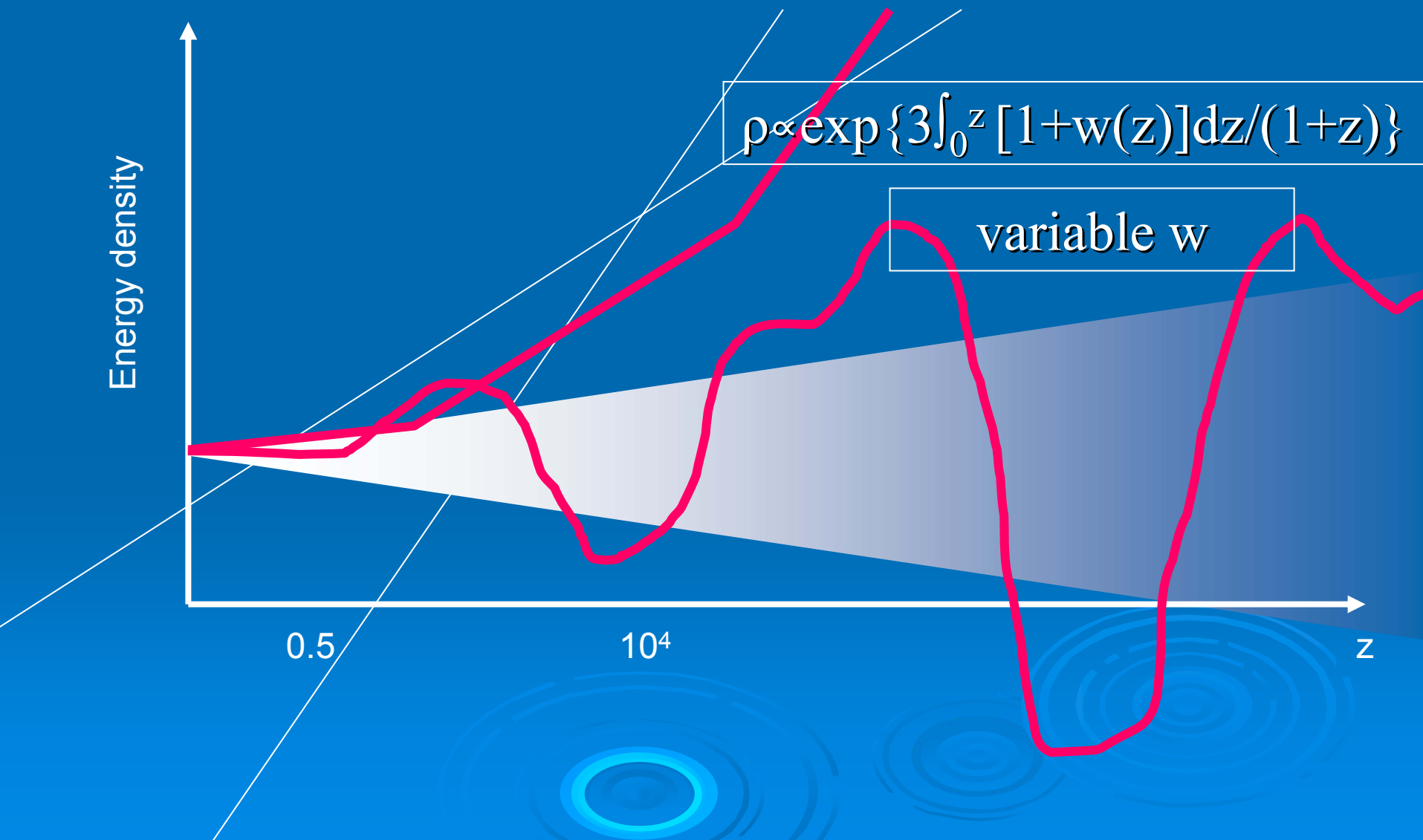
Parametrizing cosmic acceleration is …



…parametrizing cosmic density

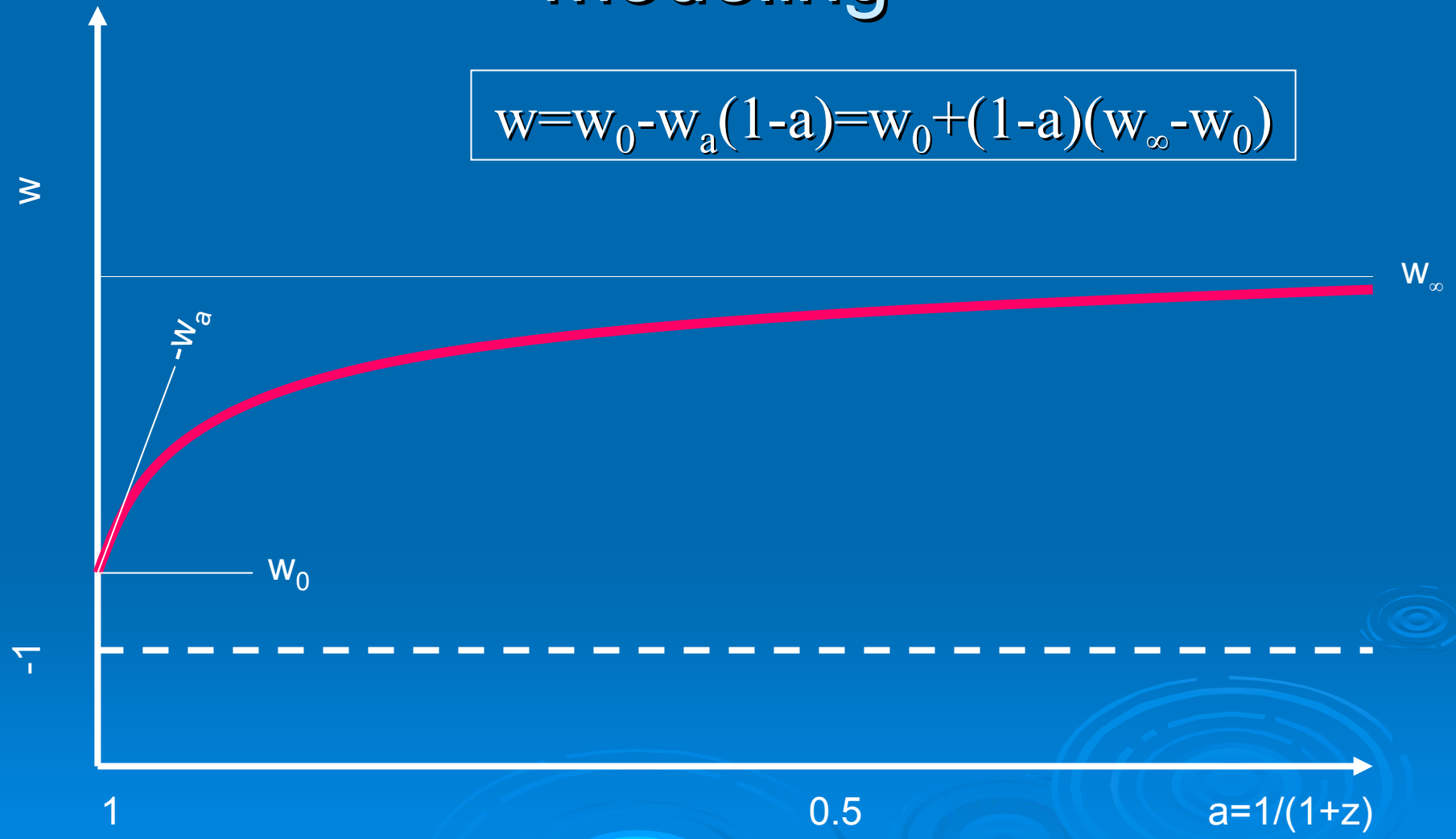


Parametrizing cosmic density



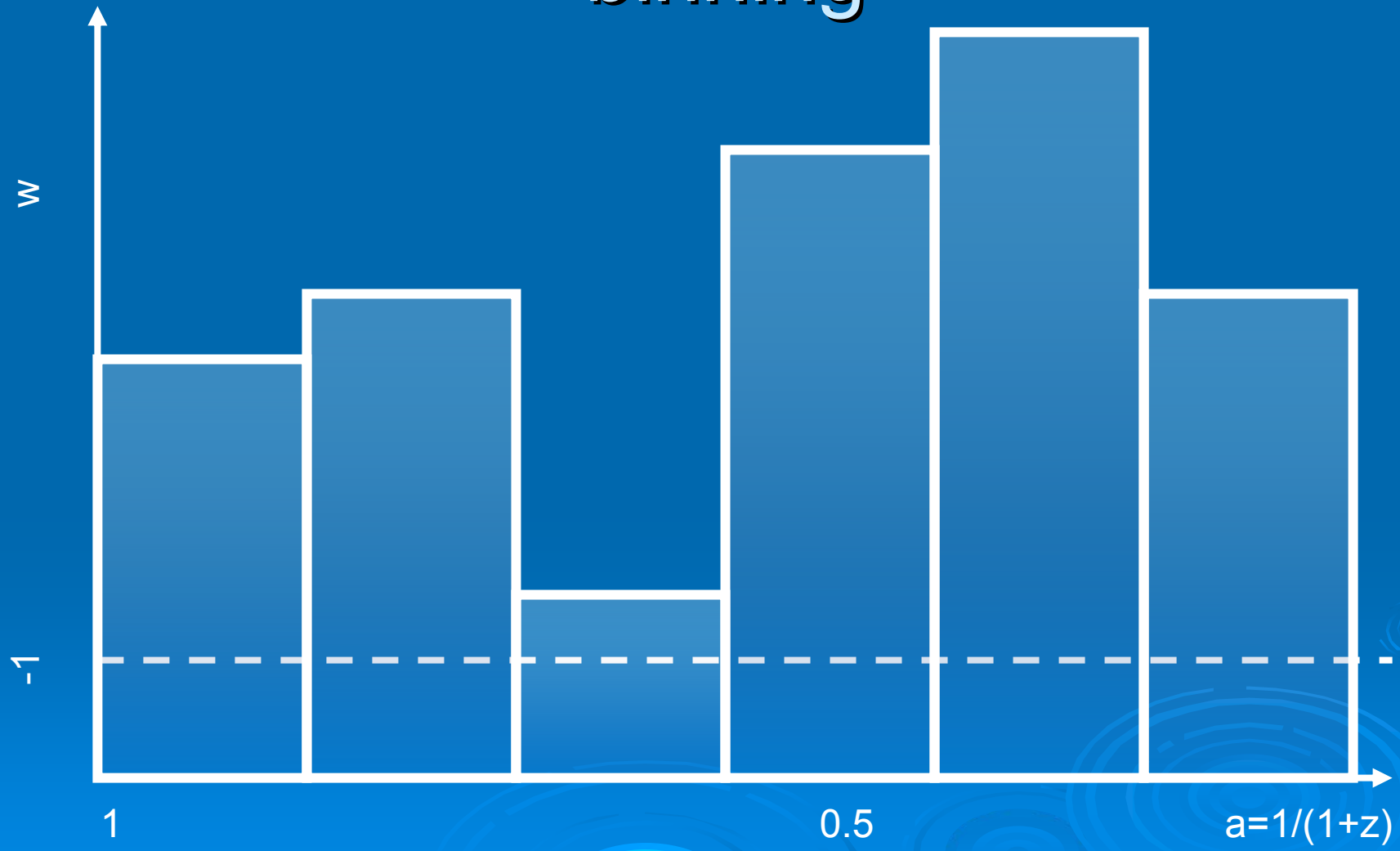
Parametrizing cosmic acceleration: modeling

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



Chevallier & Polarski 2001, Linder 2003

Parametrizing cosmic acceleration: binning

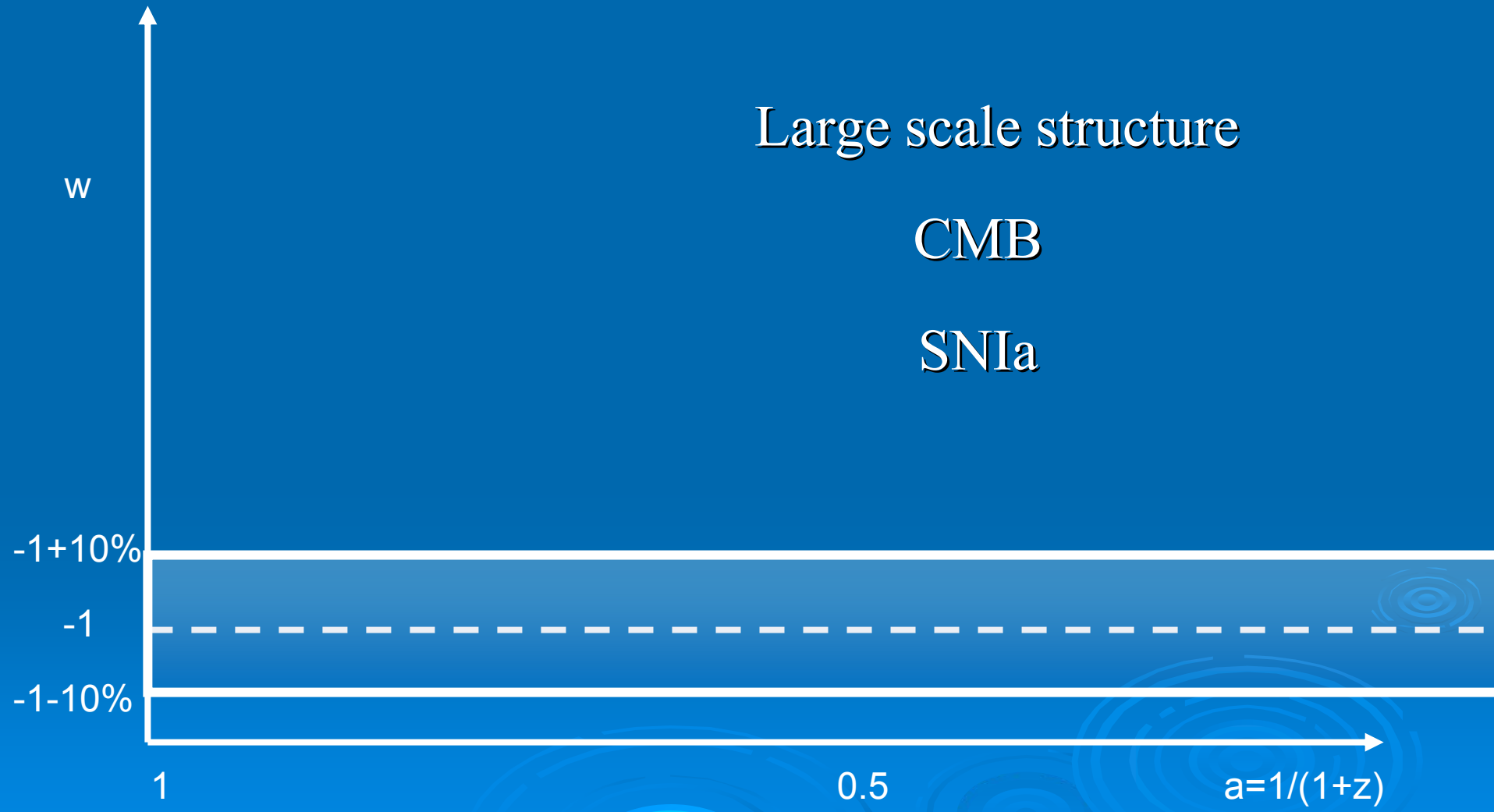


Crittenden & Pogosian 2006, Dick et al. 2006

Parametrizing cosmic acceleration: binning versus modeling

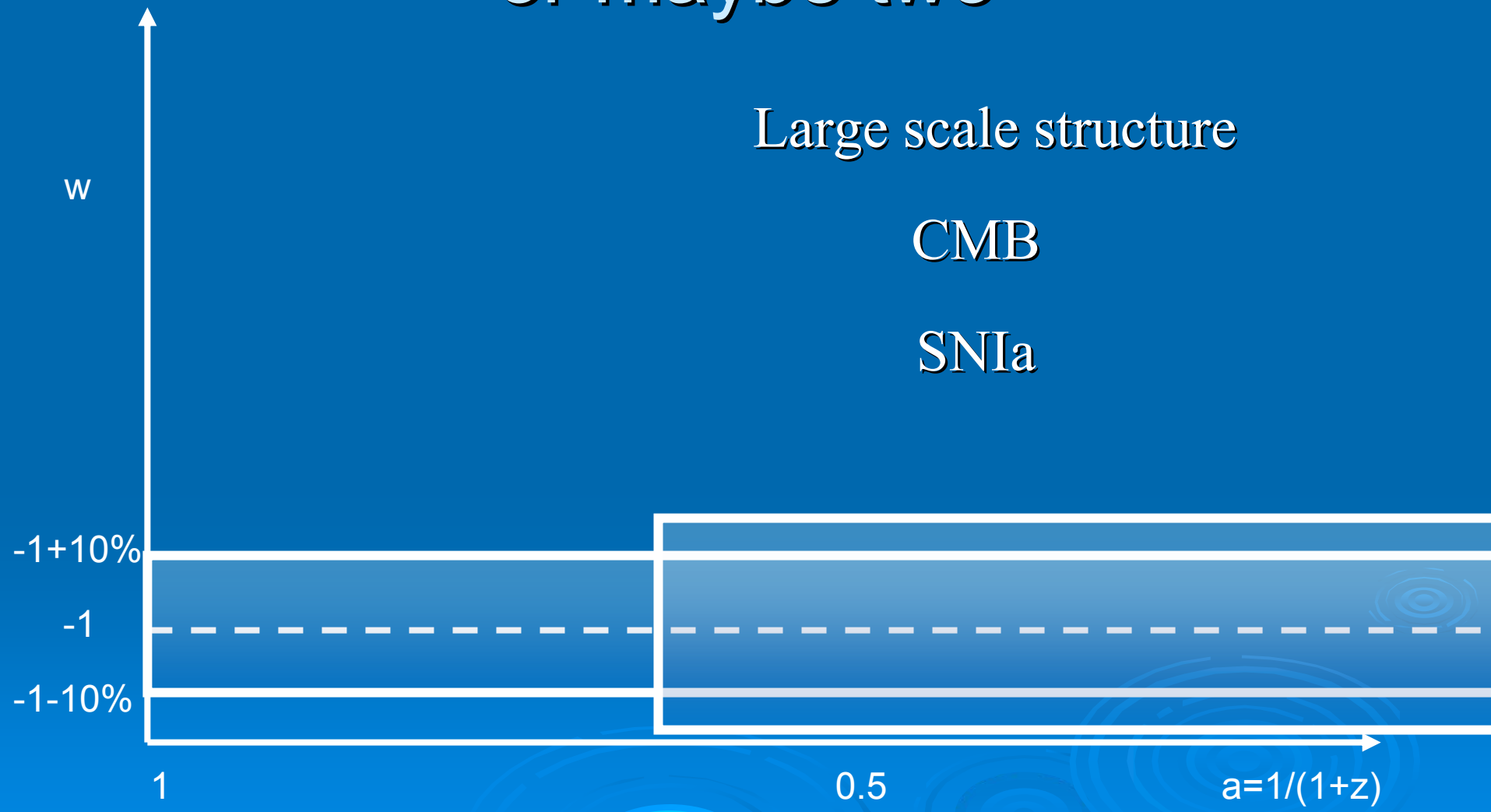
- Binning: model independent ☺, many parameters ☹
- Modeling: always a bias ☹, but a minimal model exists ☺, made by w_0 and its first time derivative
- Sticking with one particular model in between may be inconvenient, better relating that to one of the two approaches above

Present cosmological bounds: one bin



See Spergel et al., 2006, and references therein

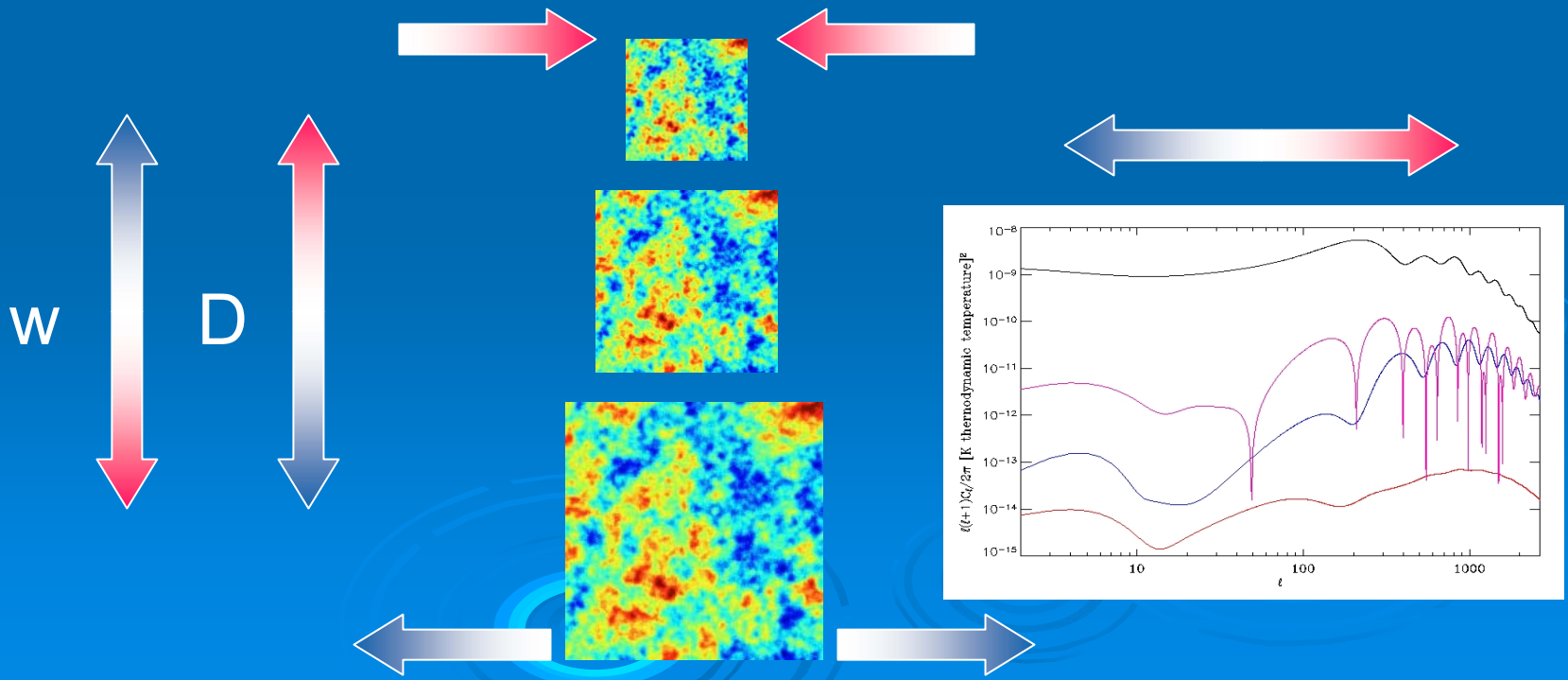
Present cosmological bounds: one bin, or maybe two



Seljak et al. 2005

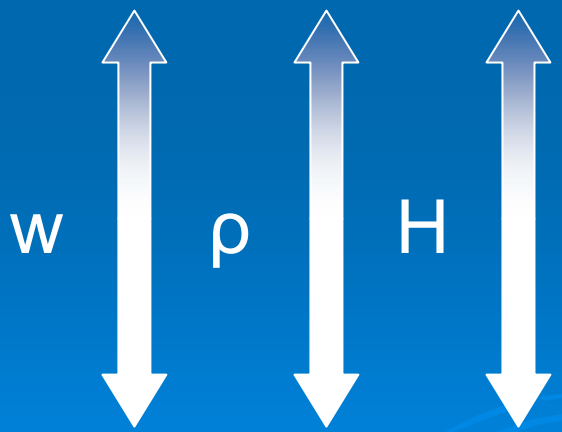
“Classic” dark energy effects: projection

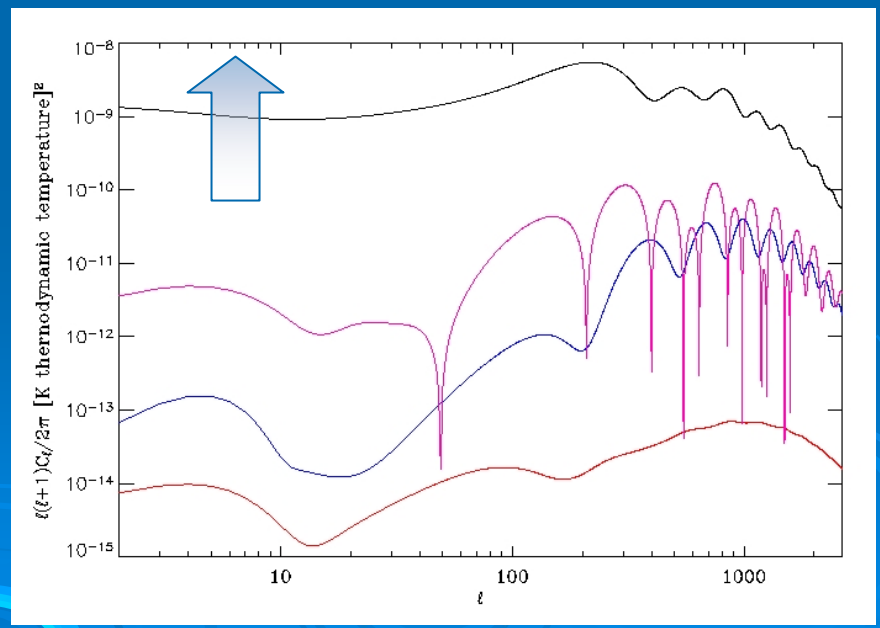
$$D = H_0^{-1} \int_0^z \frac{dz}{[\Sigma_i \Omega_i (1+z)^{3(1+w_i)}]^{1/2}}$$



“Classic” dark energy effects: growth of perturbations

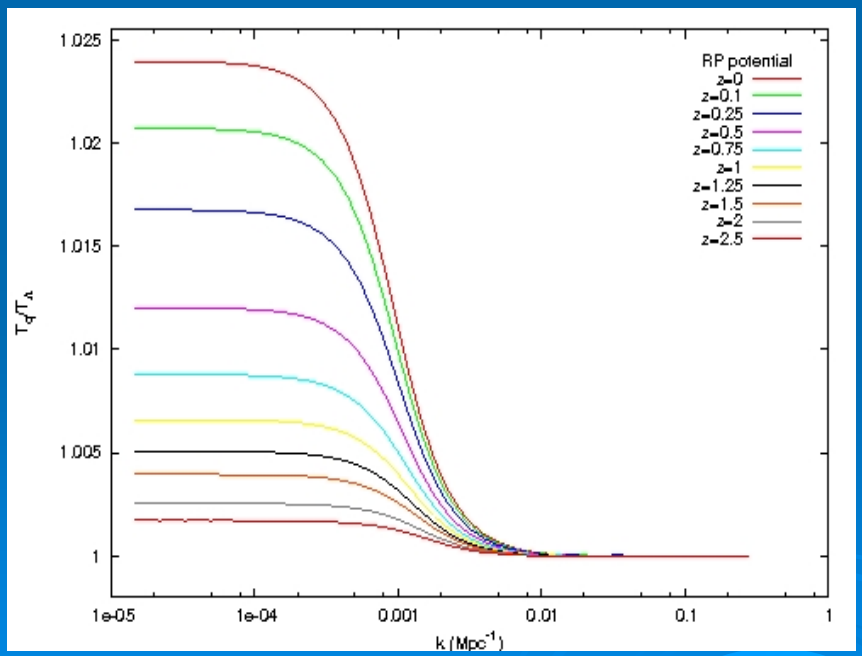
Cosmological friction for cosmological perturbations∝H

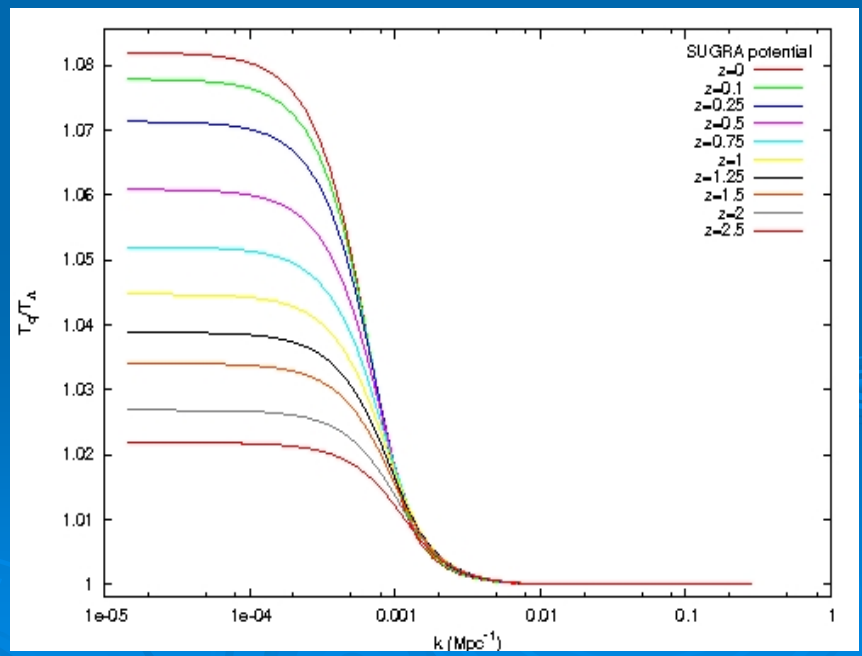




“Classic” dark energy effects: large scale clustering

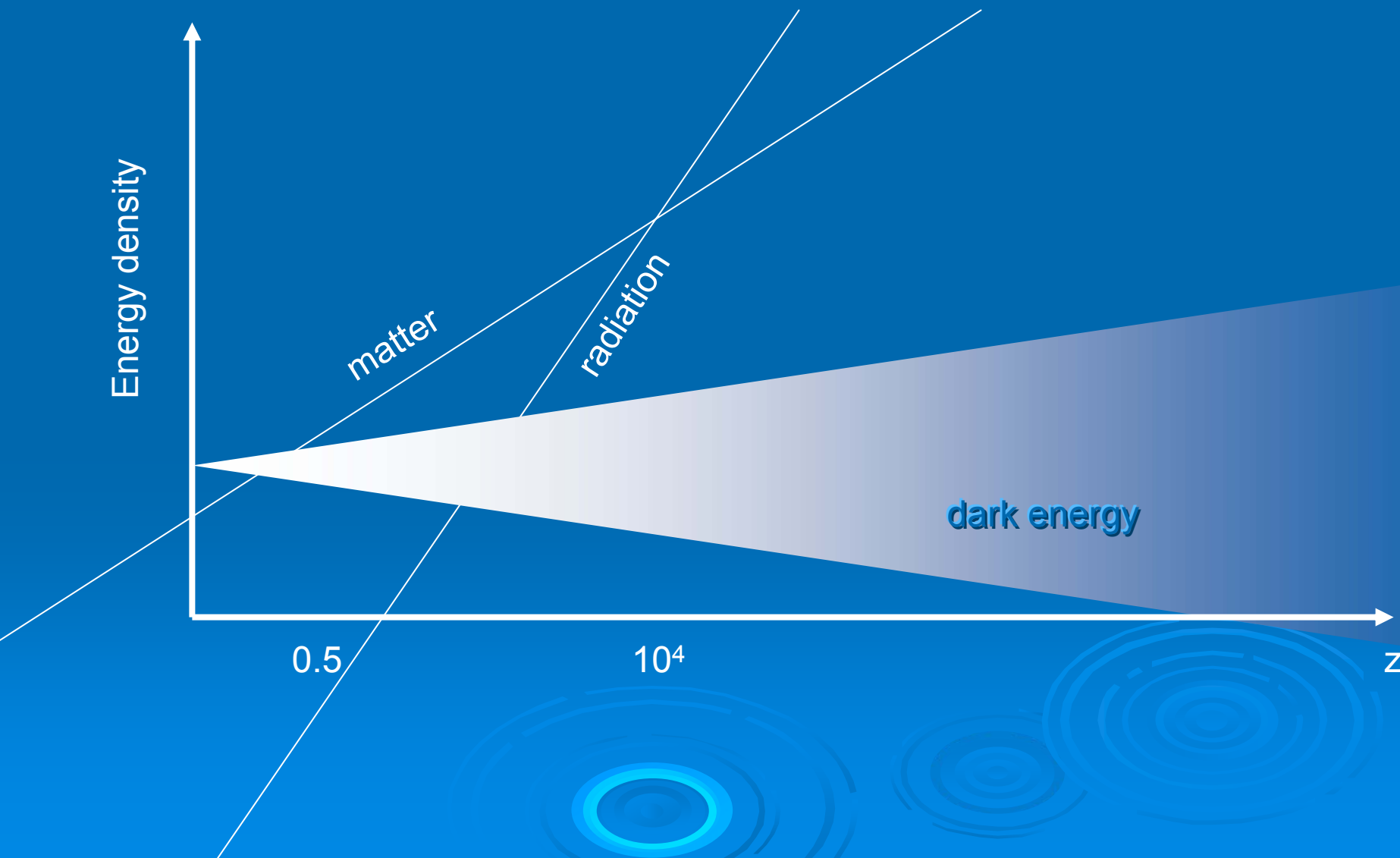
Compton wavelength at present: few hundreds of Mpc



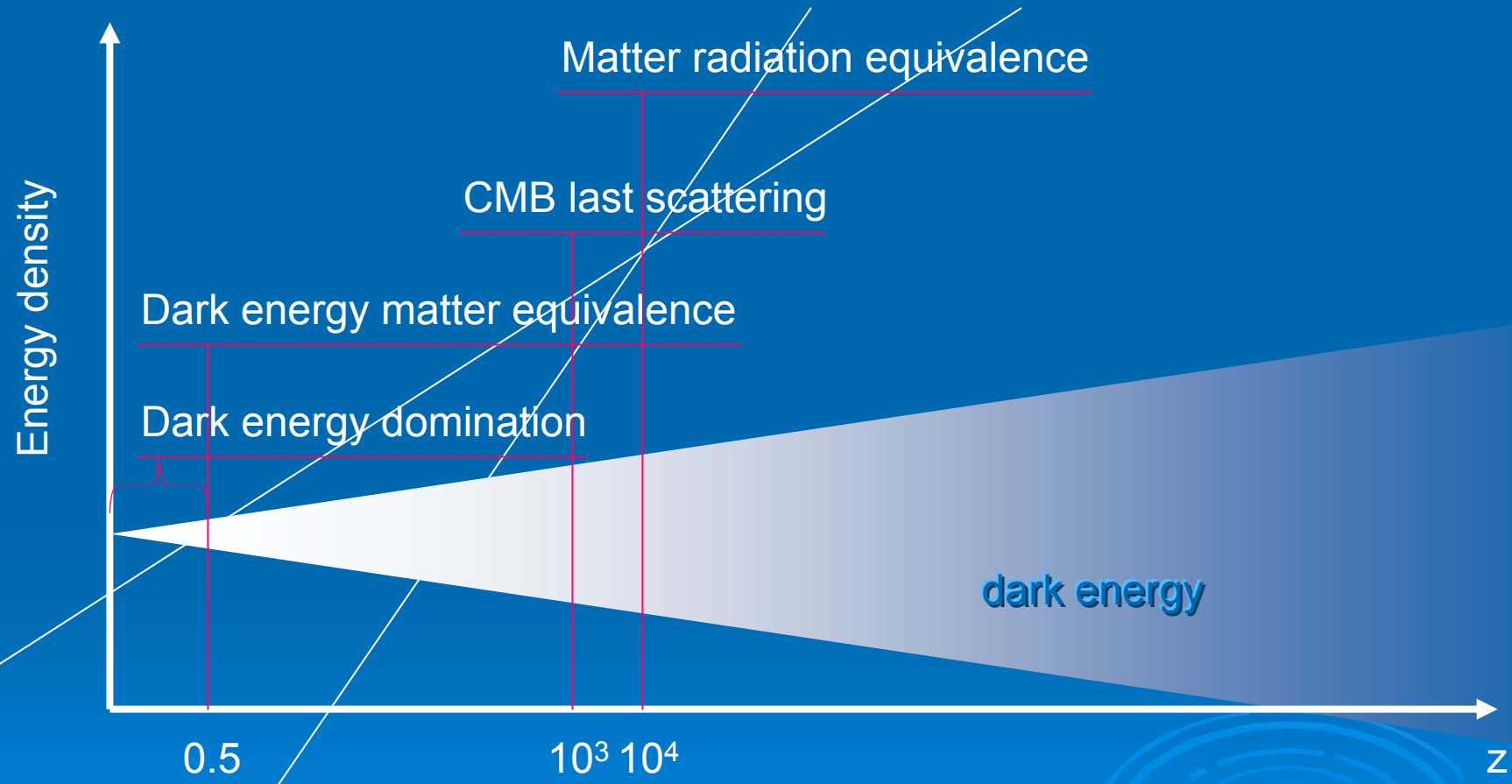


Ma et al. 1999, Montesano, Master degree, 2007, in preparation

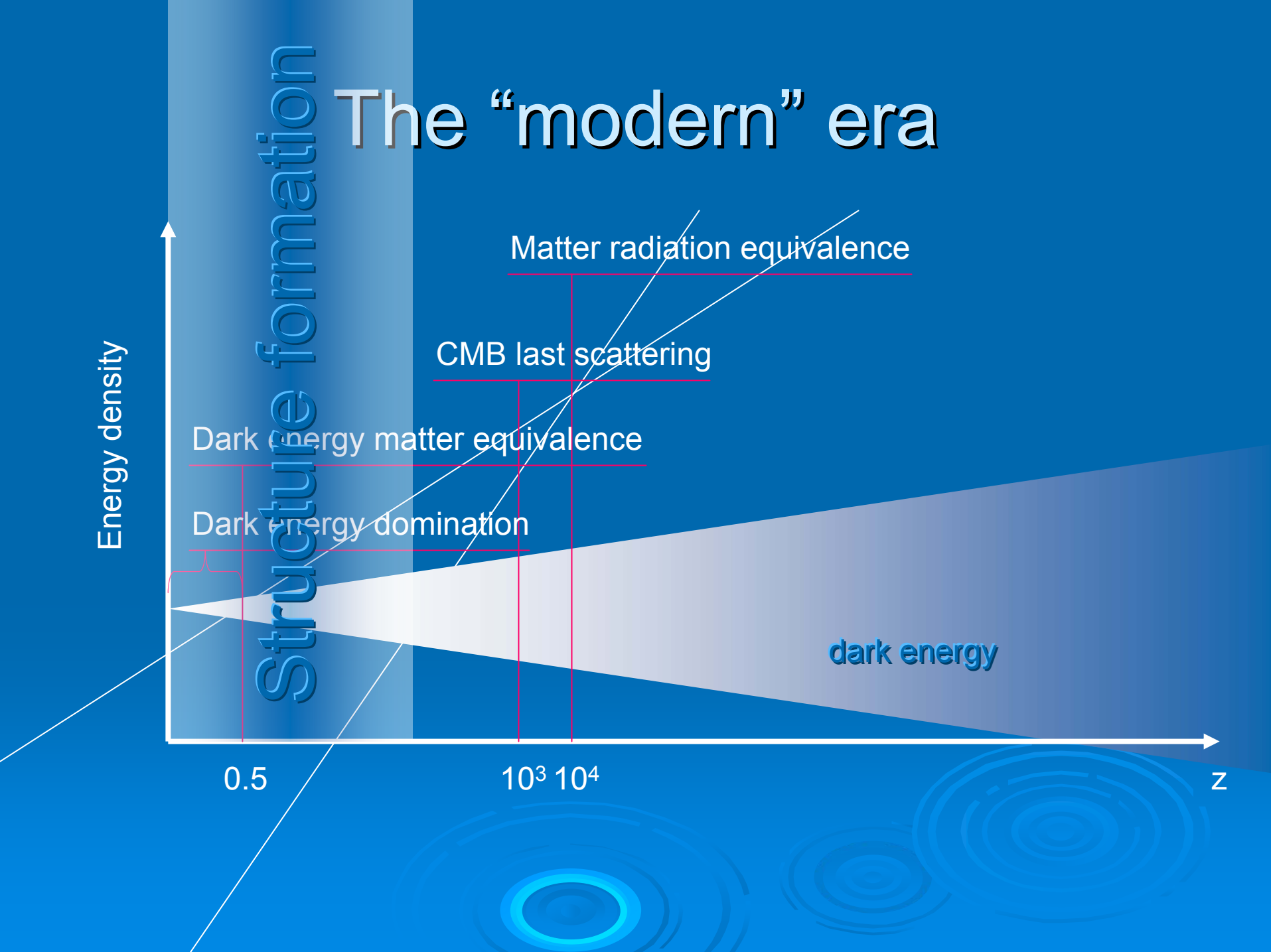
The “modern” era



The “modern” era



The “modern” era



The “modern” era: “slicing” dark energy

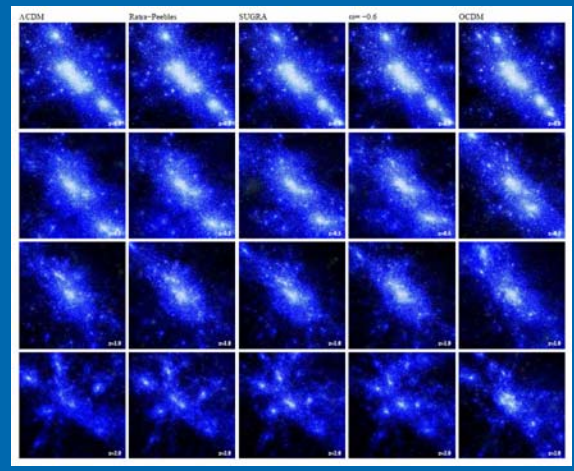
- structure formation in dark energy cosmologies, from galaxy clusters to relevant fractions of the Hubble volume
- Measure H(z) and therefore ρ(z), looking for effects which are sensitive to slices in redshifts
- Baryon acoustic oscillations
- Weak lensing in the optical band from lensing induced ellipticity on background galaxies by lenses at different redshifts
- Complementary weak lensing studies on CMB

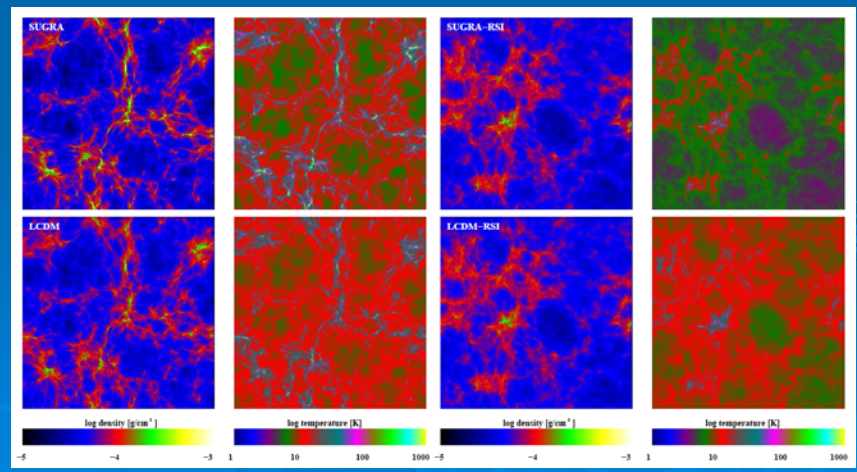
The “modern” era: “slicing” dark energy

- structure formation in dark energy cosmologies, from galaxy clusters to relevant fractions of the Hubble volume
- Measure H(z) and therefore ρ(z), looking for effects which are sensitive to slices in redshifts
- Baryon acoustic oscillations
- Weak lensing in the optical band from lensing induced ellipticity on background galaxies by lenses at different redshifts
- Complementary weak lensing studies on CMB

Structure formation and dark energy

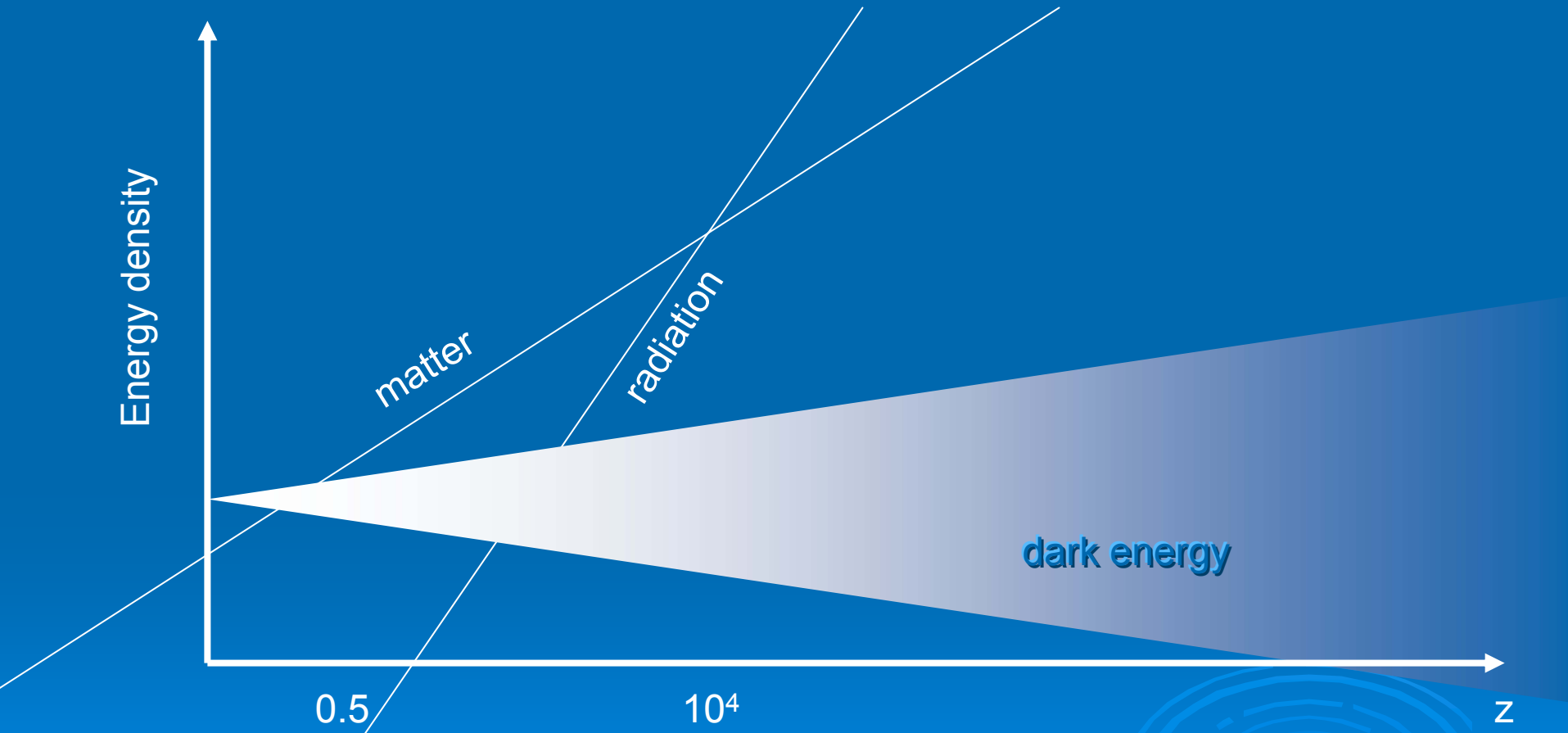
- Linear theory rather well understood
- Dark matter N-body in progress
- Poor knowledge of the gas properties, indication that the dark energy effects are not negligible



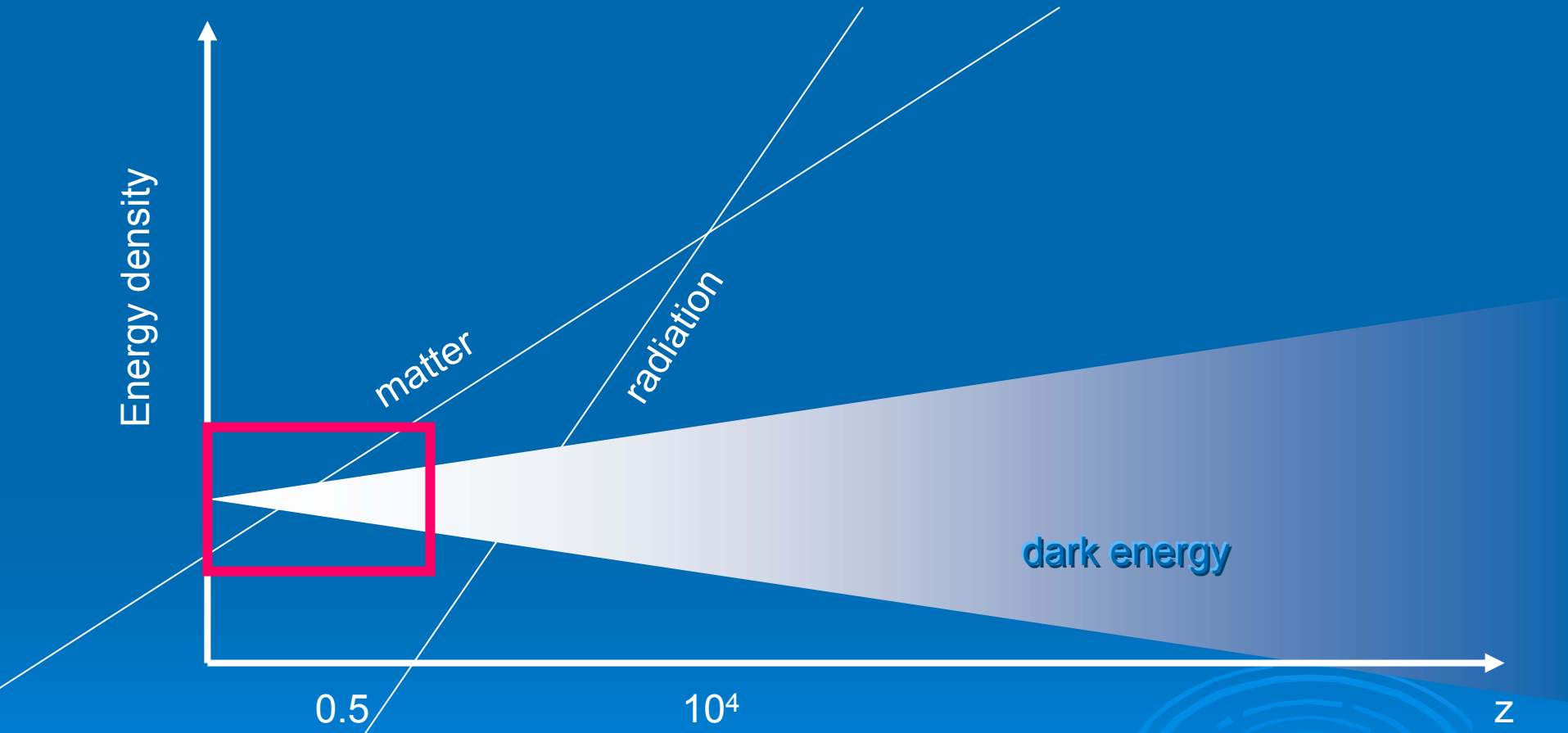


Maio et al. 2007, Mainini, Bonometto 2007, Dolag et al. 2004, Maccio et al. 2003, …

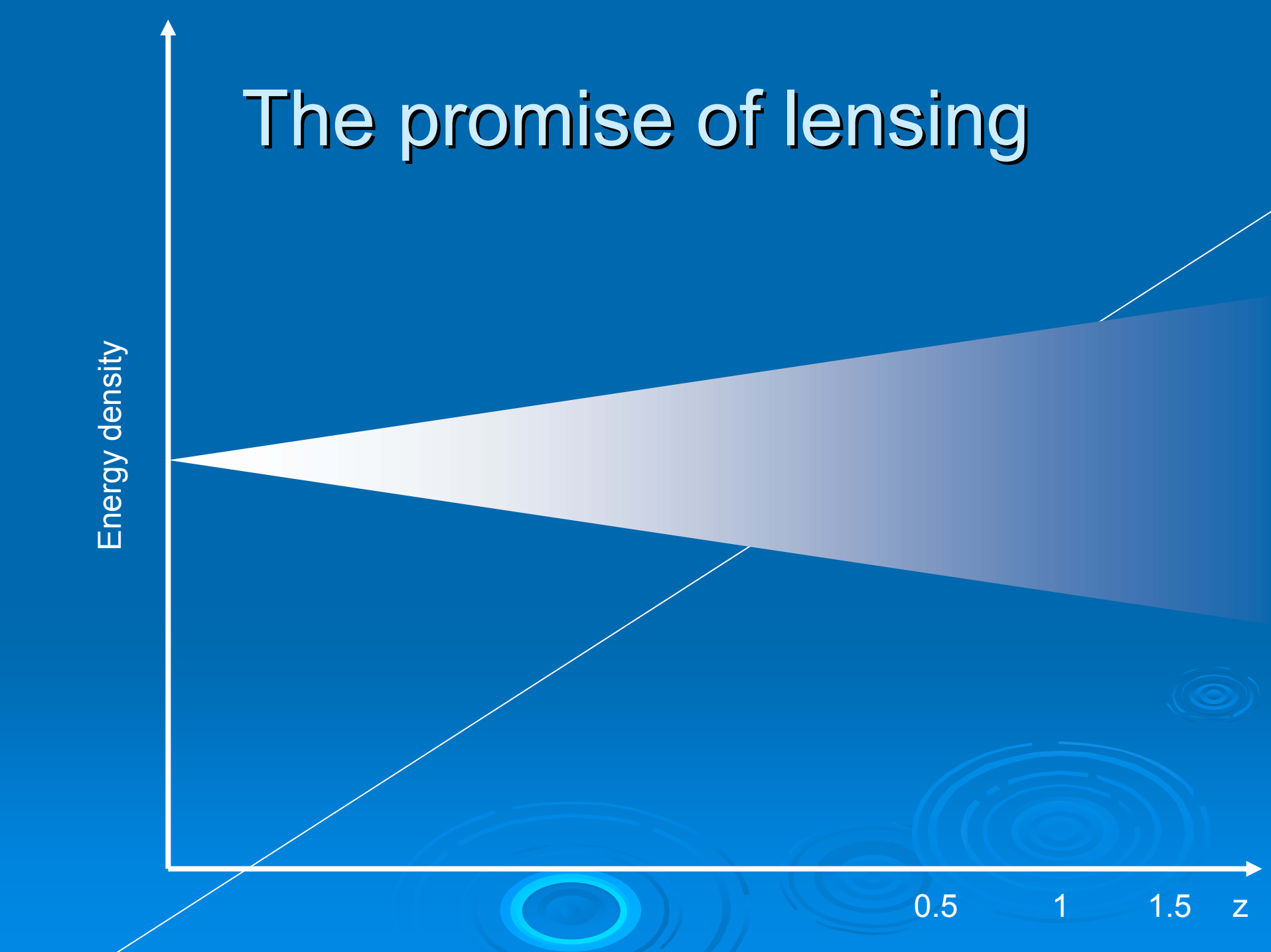
The promise of lensing



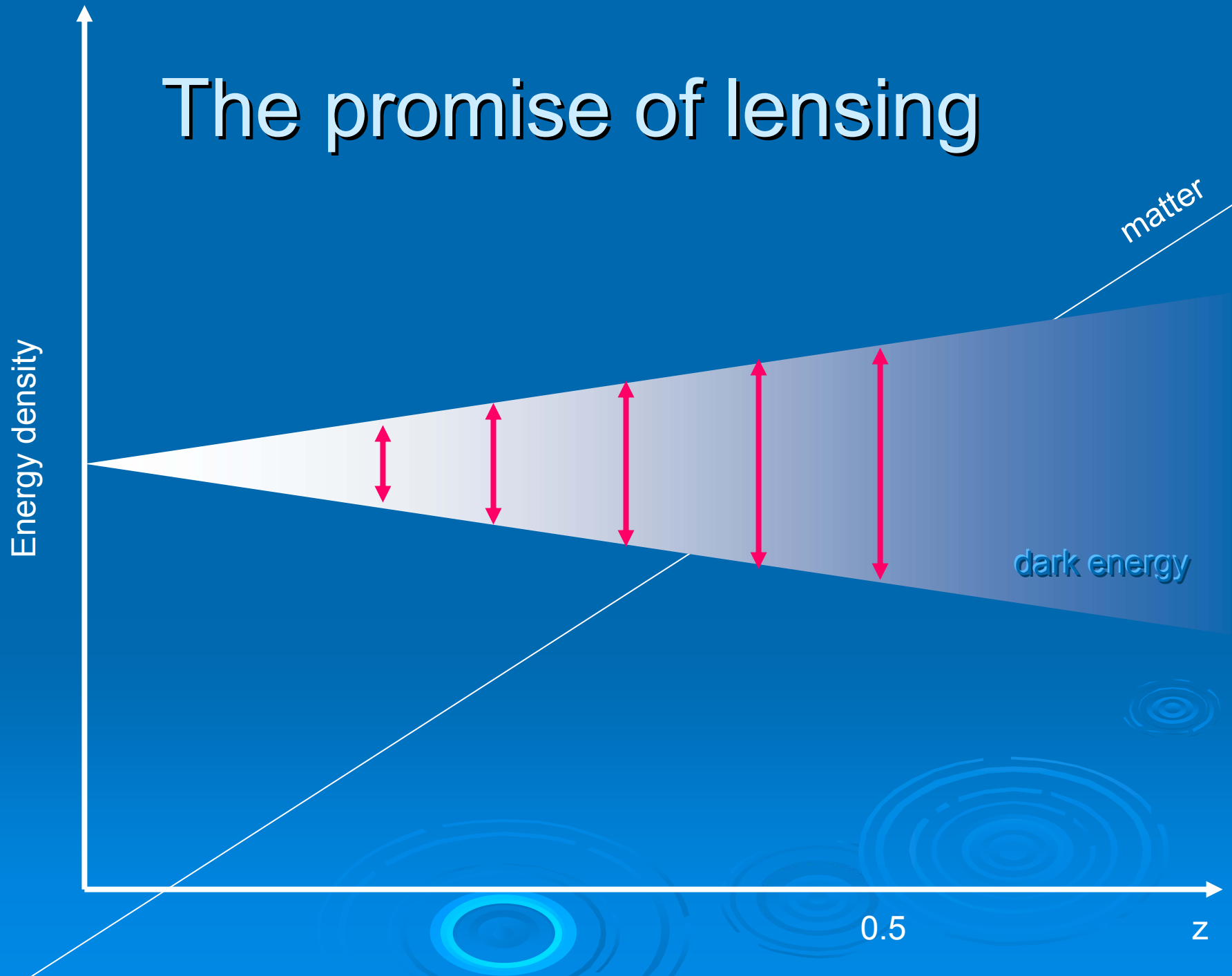
The promise of lensing



The promise of lensing



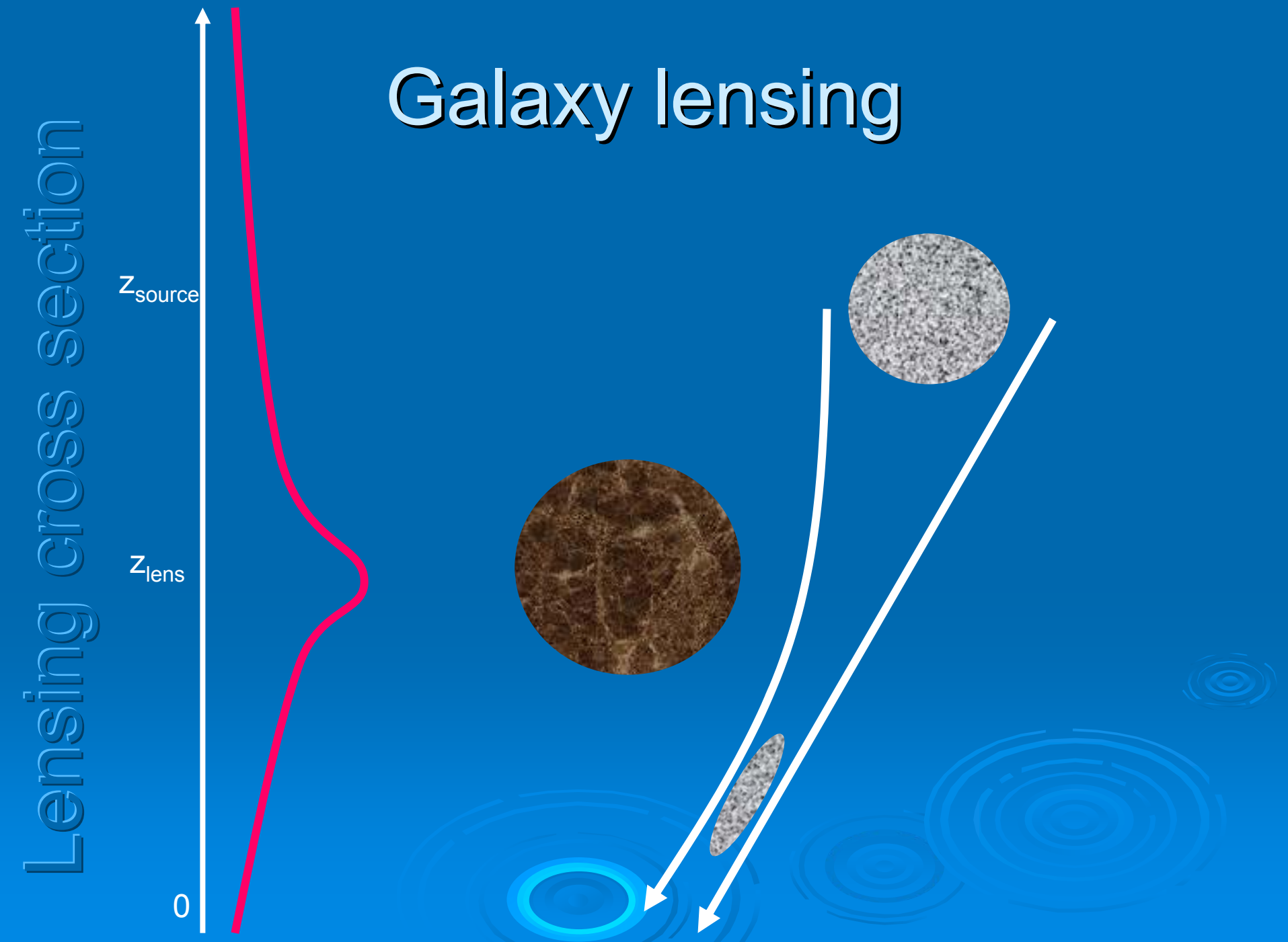
The promise of lensing



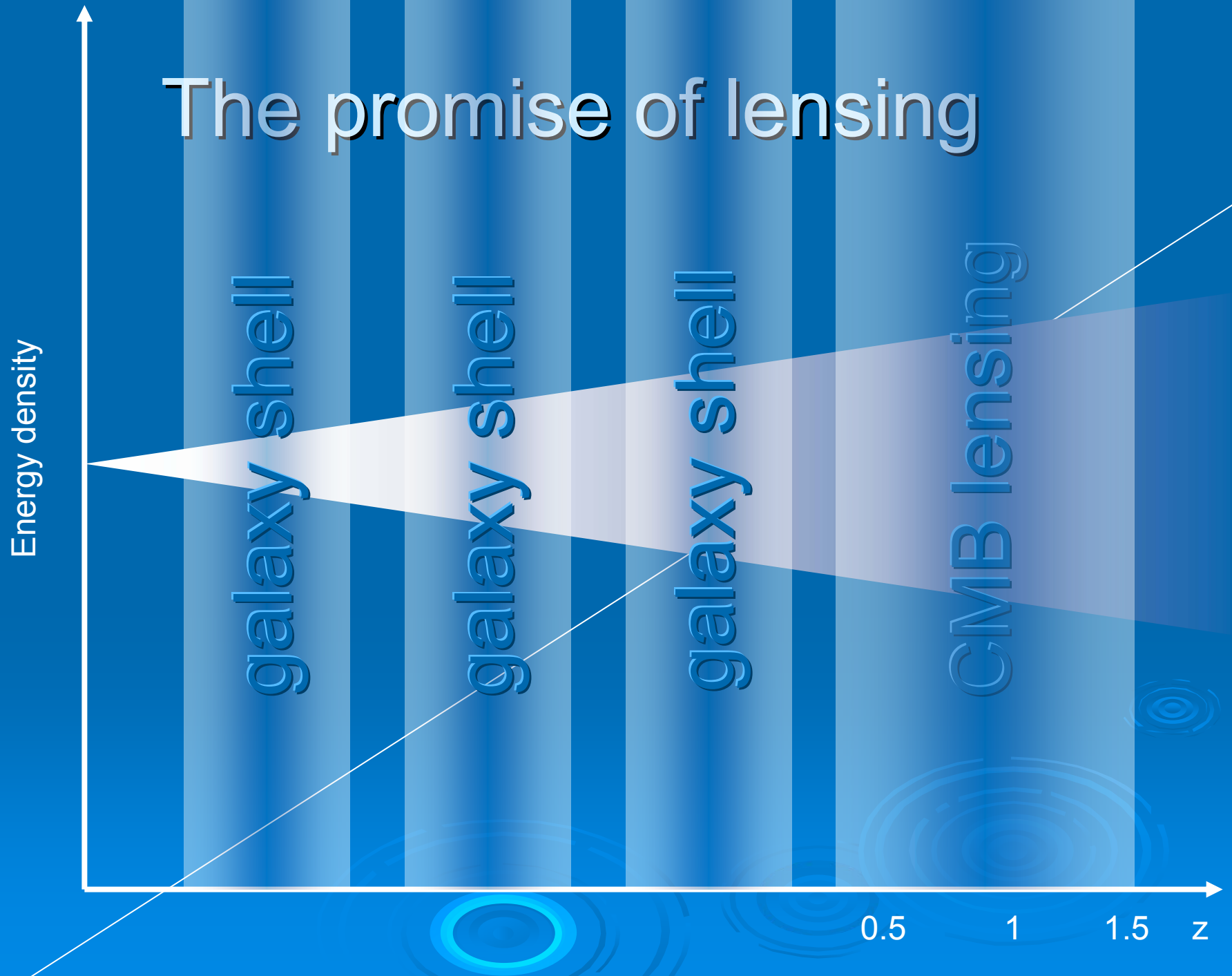
The promise of lensing

- 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

Galaxy lensing

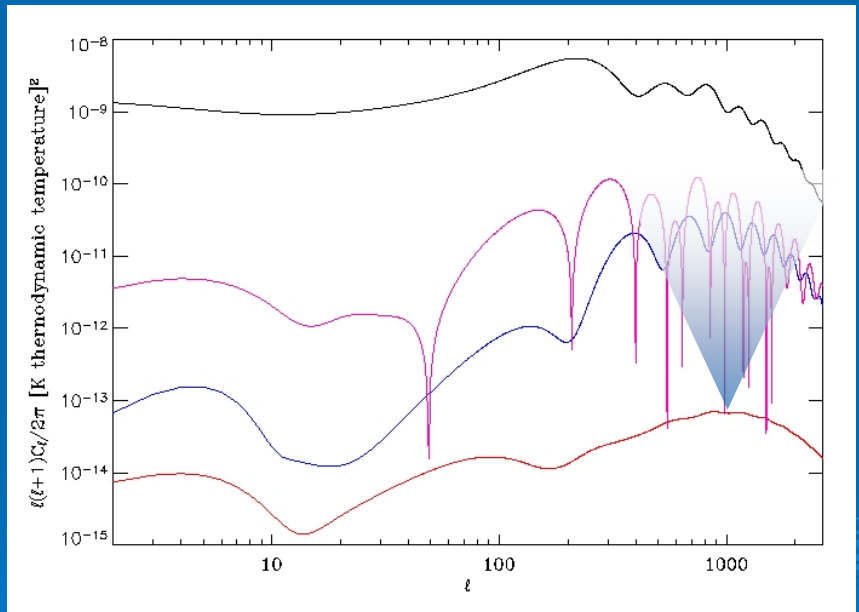


The promise of lensing



CMB lensing: a science per se

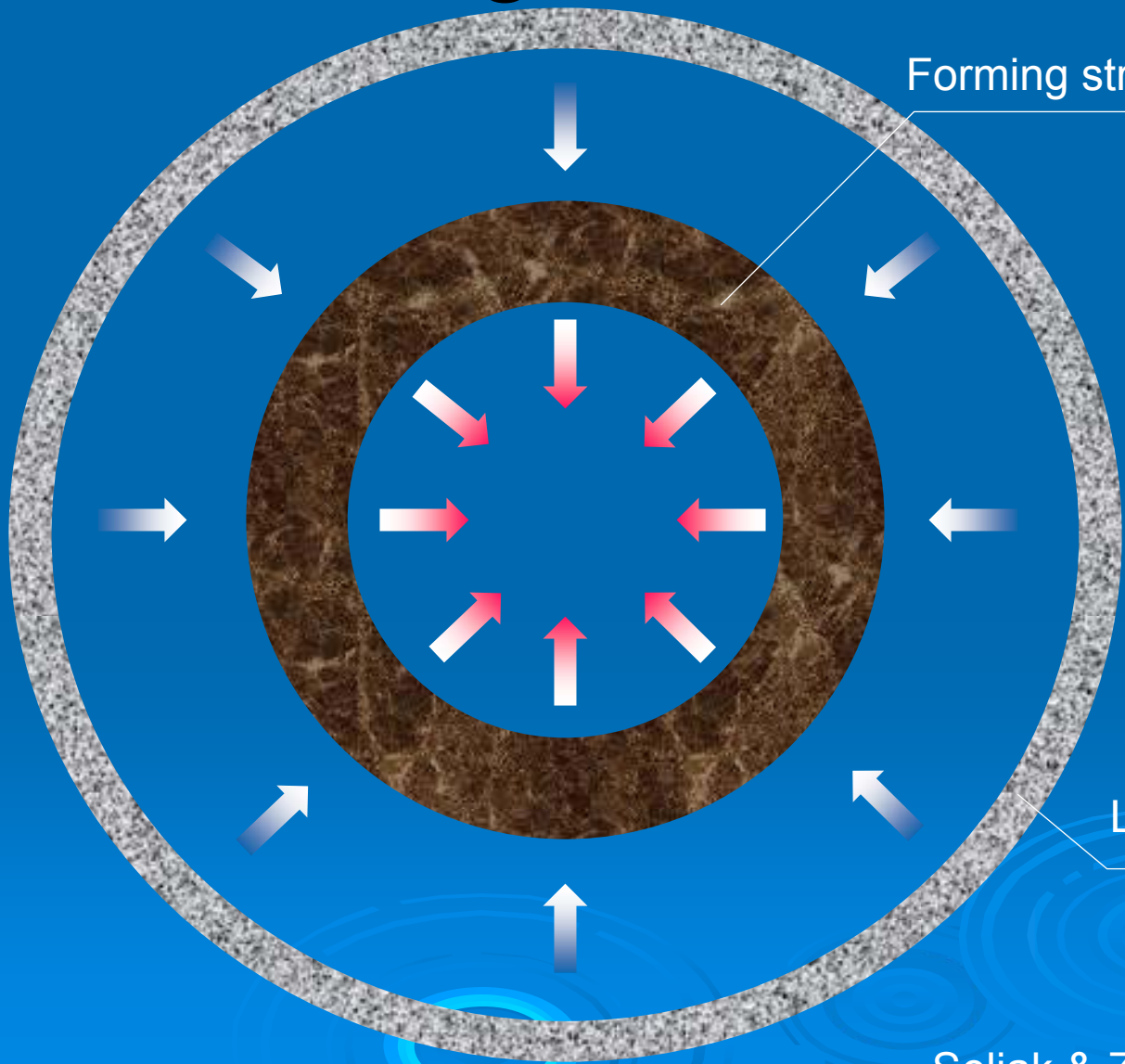
- Lensing is a second order cosmological effect
- Lensing correlates scales
- The lensing pattern is non-Gaussian
- Statistics characterization in progress, preliminary investigations indicate an increase by a factor 3 of the uncertainty from cosmic variance



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

Lensing B modes

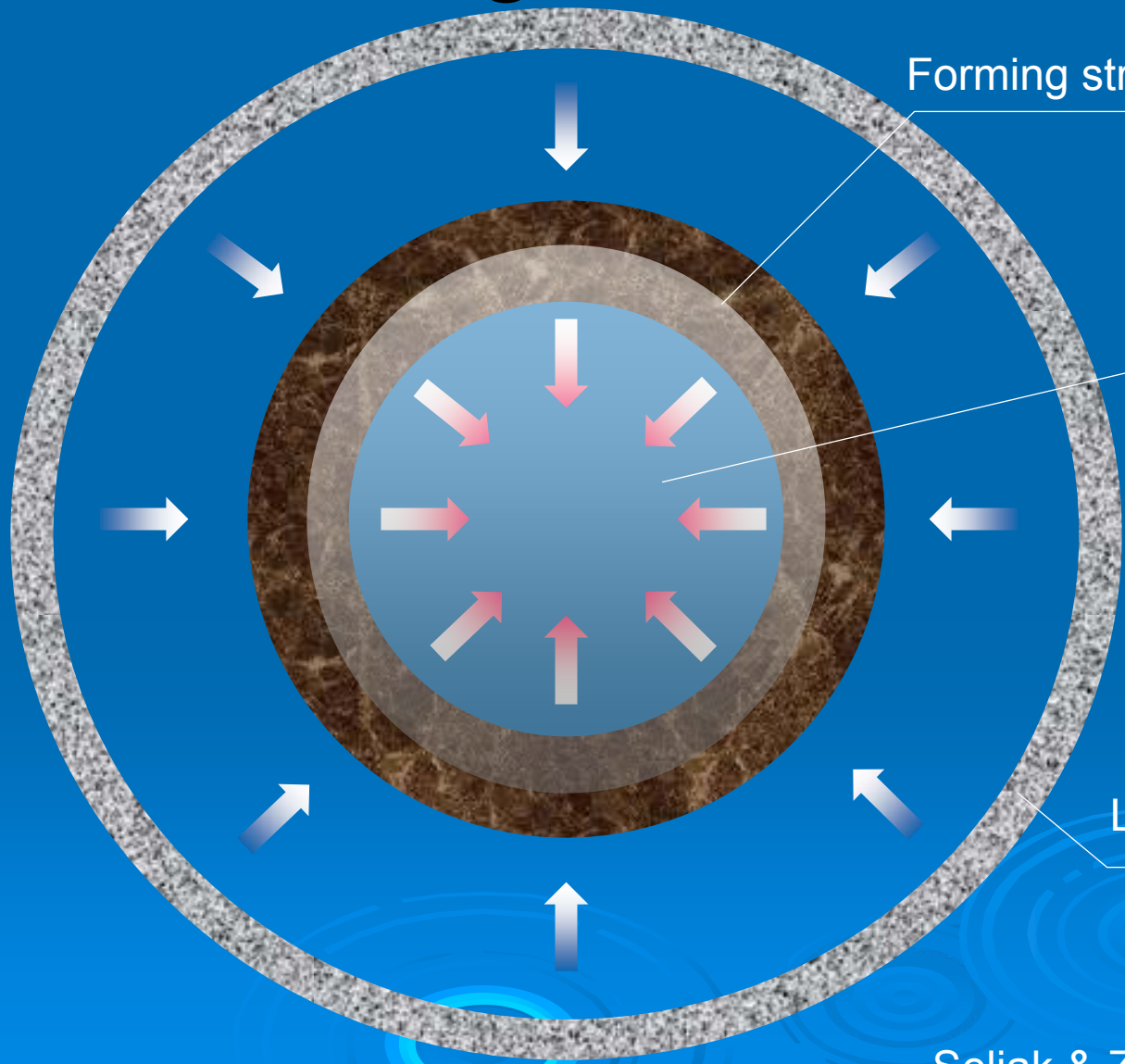
E B



Seljak & Zaldarriaga 1998

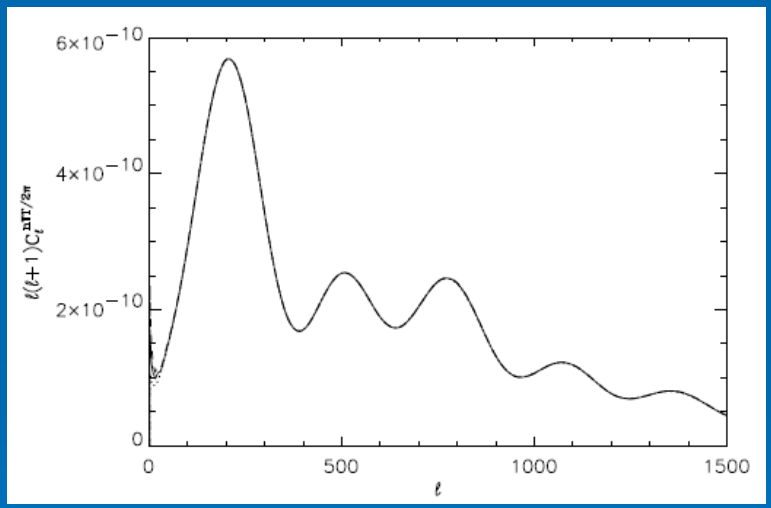
Lensing B modes

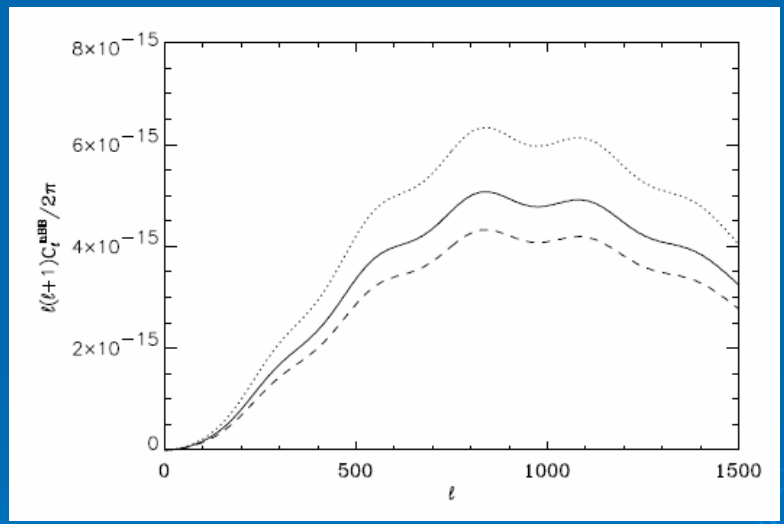
E B



Seljak & Zaldarriaga 1998

Breaking projection degeneracy

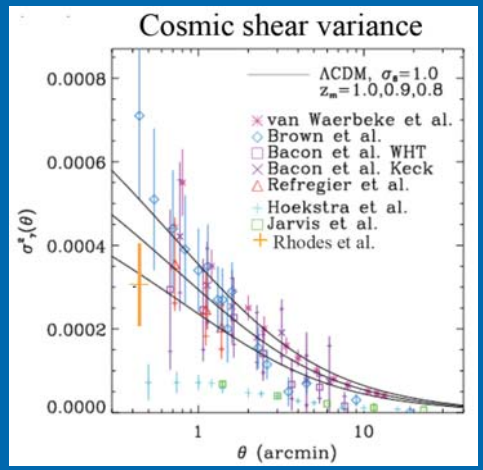


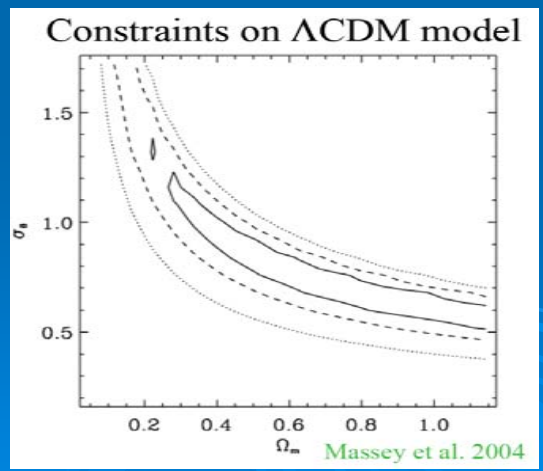


Acquaviva & Baccigalupi 2006

Present lensing

- lensing distortion on CMB is undetected
- Galaxy lensing has been detected and found consistent with the predictions of the concordance model in cosmology

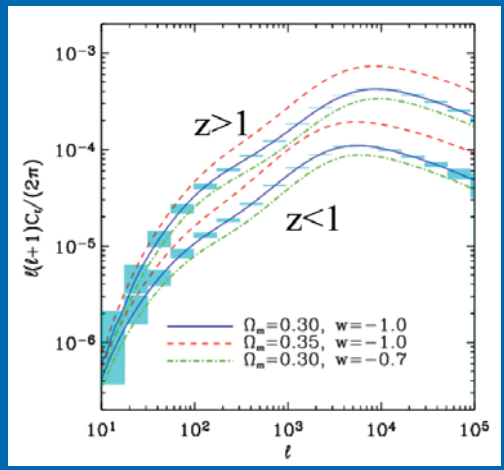


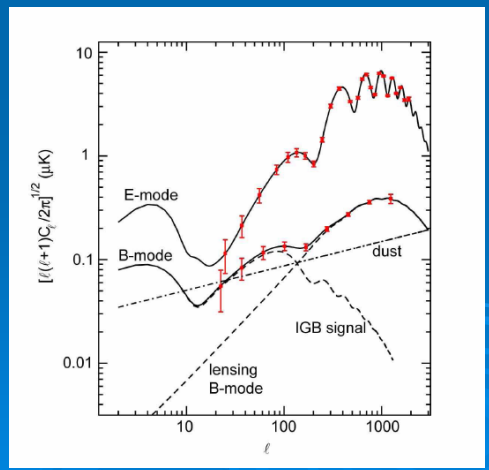


Refregier et al. 2007, DUNE proposal

Future lensing

- DUNE (Dark Universe Explorer) to be proposed in June within the Cosmic Vision Program, able to measure the dark energy abundance in a few bins between z=0 and 1, with percent accuracy
- CMB lensing within reach of the forthcoming detectors





Refregier et al. 2007, DUNE proposal, Oxley et al. 2005 and references, EBEx proposal

Conclusions

- The strong theoretical embarrassement with dark energy is likely to survive the consistency of the redshift average behavior of its energy density with the cosmological constant
- A two decade battle against the cosmological constant is possibly beginning, depending on ESA/NASA funding directions, concrete news within the end of 2007
- The lensing capability of measuring H(z) represents the core of future investigations on dark energy