Why we need to see the dark matter to understand the dark energy

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overview

Should we be worried if we find a dark matter candidate for which $\Omega_m \neq 0.3$? Probably yes, but maybe it is a sign that the dark energy is not just a cosmological constant…

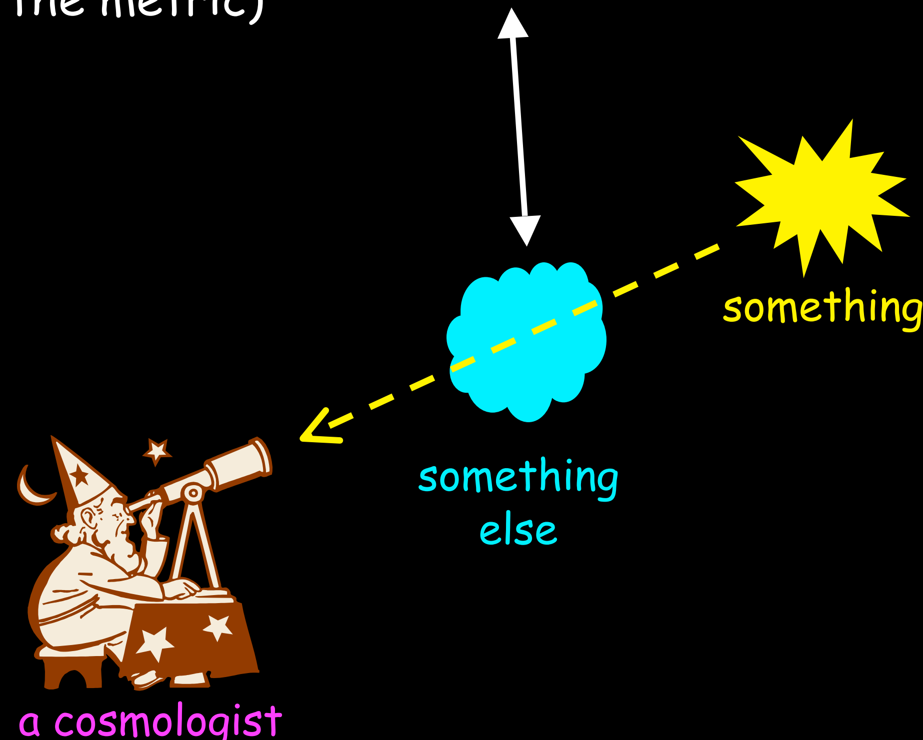
- General Relativity and distances
- measuring dark energy properties
- the Dark Degeneracy and its implications for cosmology

measuring dark things
(in cosmology)

Einstein: $G_{\mu\nu} = 8\pi G T_{\mu\nu}$

(determined by the metric) → geometry

stuff (what is it?) ↕ your favourite theory



Cosmologists observe the geometry of space time

This depends on the total energy momentum tensor

What can we learn?

the universe (0^{th} order)

Assume that the universe is perfectly homogeneous and isotropic (and flat): FLRW metric

$$ds^2 = dt^2 - a(t)^2\, dr^2$$

$T_{\mu\nu}$ must be:

$$T_\mu^\nu = diag(\rho(t), -p(t), -p(t), -p(t))$$

Einstein: $H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho$

probed by distance measurements

$$\dot{\rho} = -3\frac{\dot{a}}{a}(\rho + p)$$

matter: $p = 0$ -> $\rho \sim a^{-3}$

radiation: $p = \rho/3$ -> $\rho \sim a^{-4}$

dark energy: $p = ?$ ($< -\rho/3$)

(define $w = p/\rho$)

-> the only thing to measure is $w(t)$ [or $w(z)$]

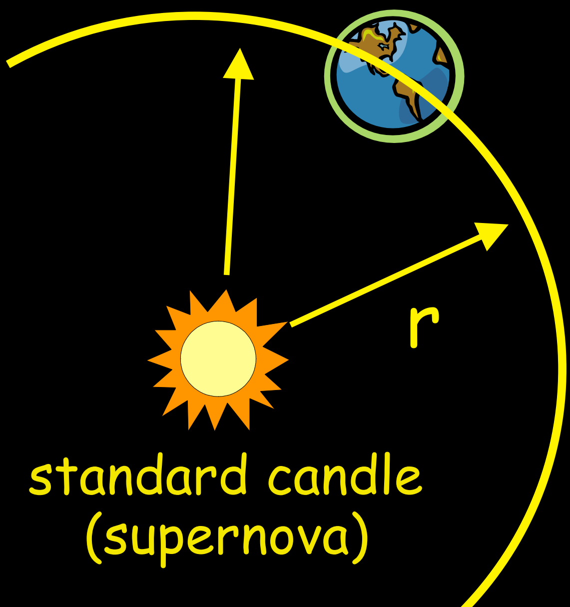
distances in the universe

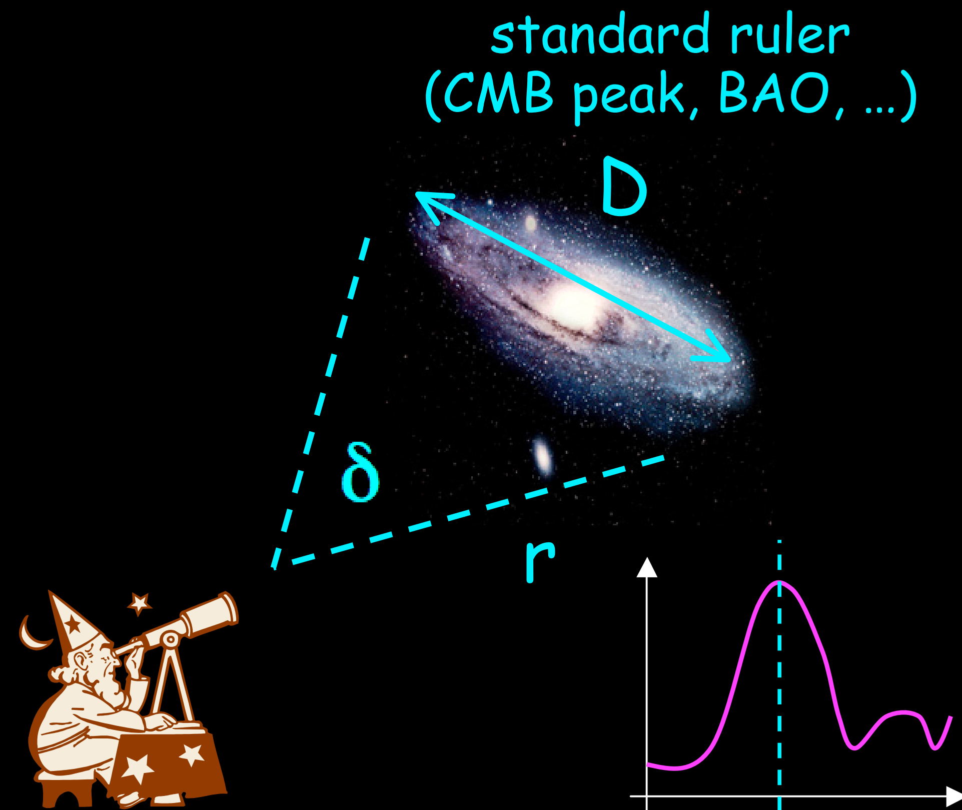
$$r = \int \frac{dt}{a(t)} = \int \frac{dt}{da}\frac{da}{dz}\frac{dz}{a} = \int_0^z \frac{dz'}{H(z')}$$

($1+z = a_0/a$)

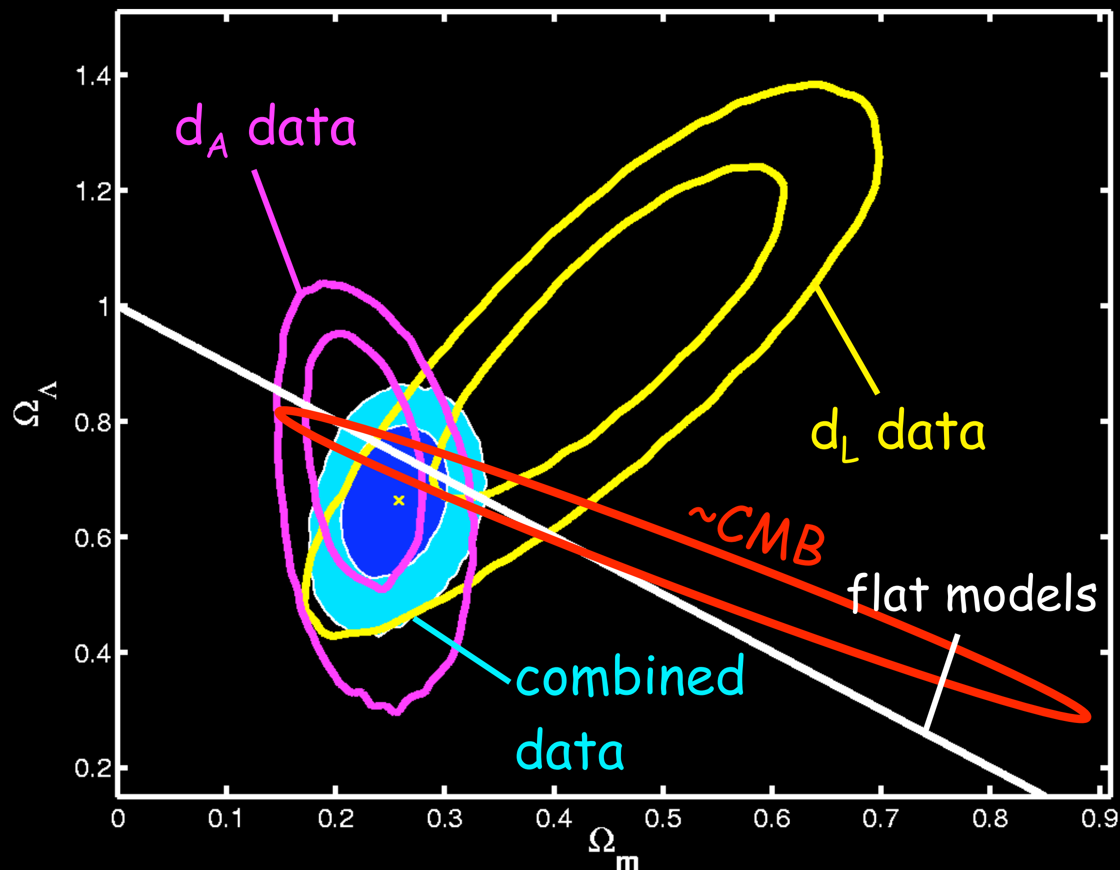
$$d_L(z) = (1+z)r(z)$$

$$d_A(z) = r(z)/(1+z)$$





the concordance (ΛCDM) model



- assume that there is dark matter and a cosmological constant
- never mind 40 orders of magnitude wrt the SUSY breaking scale
- all current data sets agree with this model
- Λ=0 ruled out a very high confidence

(B.A. Bassett & MK, ApJ **607**, 661 (2004); PRD **69**, 101305R (2004); astro-ph/0406013)

back to the dark energy

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measuring $w_{DE}(z)$

Assuming that we have dark matter (p=0) and dark energy with a free w(z) we find:

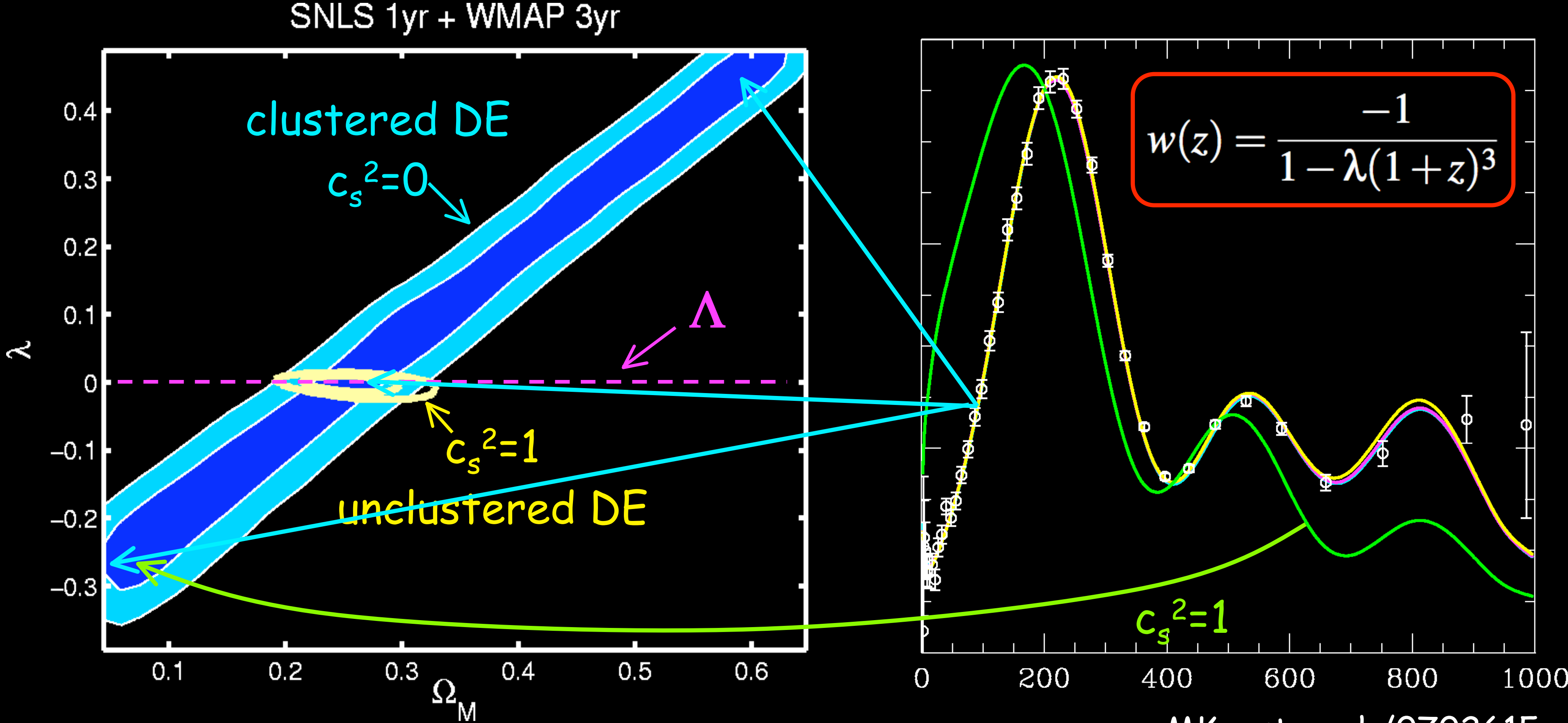
$$w(z) = \frac{H(z)^2 - \frac{2}{3}H(z)H'(z)(1+z)}{H_0^2\Omega_m(1+z)^3 - H(z)^2}$$

- So how precisely do we know Ω_m? From measurements of the expansion rate?
- Given H(z) we get a w(z) for ***every*** choice of Ω_m!
- but for FLRW $ds^2 = -dt^2 + a(t)^2\, dx^2$ so H(t) is all we can know, and we cannot measure Ω_m!

➜ Dark Degeneracy

surely the CMB will help?

We all know that Planck will measure $\Omega_m h^2$ to 1% or so?!



MK, astro-ph/0702615

(Perturbations in the dark energy can be very important)

conclusions

- homogeneous case: w(z) <-> H(z)
- (the cosmological constant is by far the best model)
- cosmology alone cannot separately measure different dark contributions
- cosmology alone cannot prove that the dark energy is Λ
- an unknown Ω_m introduces a degeneracy with w(z)
- conversely, we can always choose a dark energy to accommodate (nearly) any Ω_m !
- couplings between dark matter and dark energy introduce new degeneracies (ie are immeasurable with cosmology alone)
- all this remains true even if we take perturbations into account (requiring typically $c_s^2 \ll 1$ for the DE)
- limits tend to be extremely model dependent, so be careful when using simple expressions (e.g. CMB peak positions)