Testing the Expansion History of the Universe with TeV Photons

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A low level of extragalactic background light as revealed by γ-rays from blazars

Nature 440:1018 (2006)

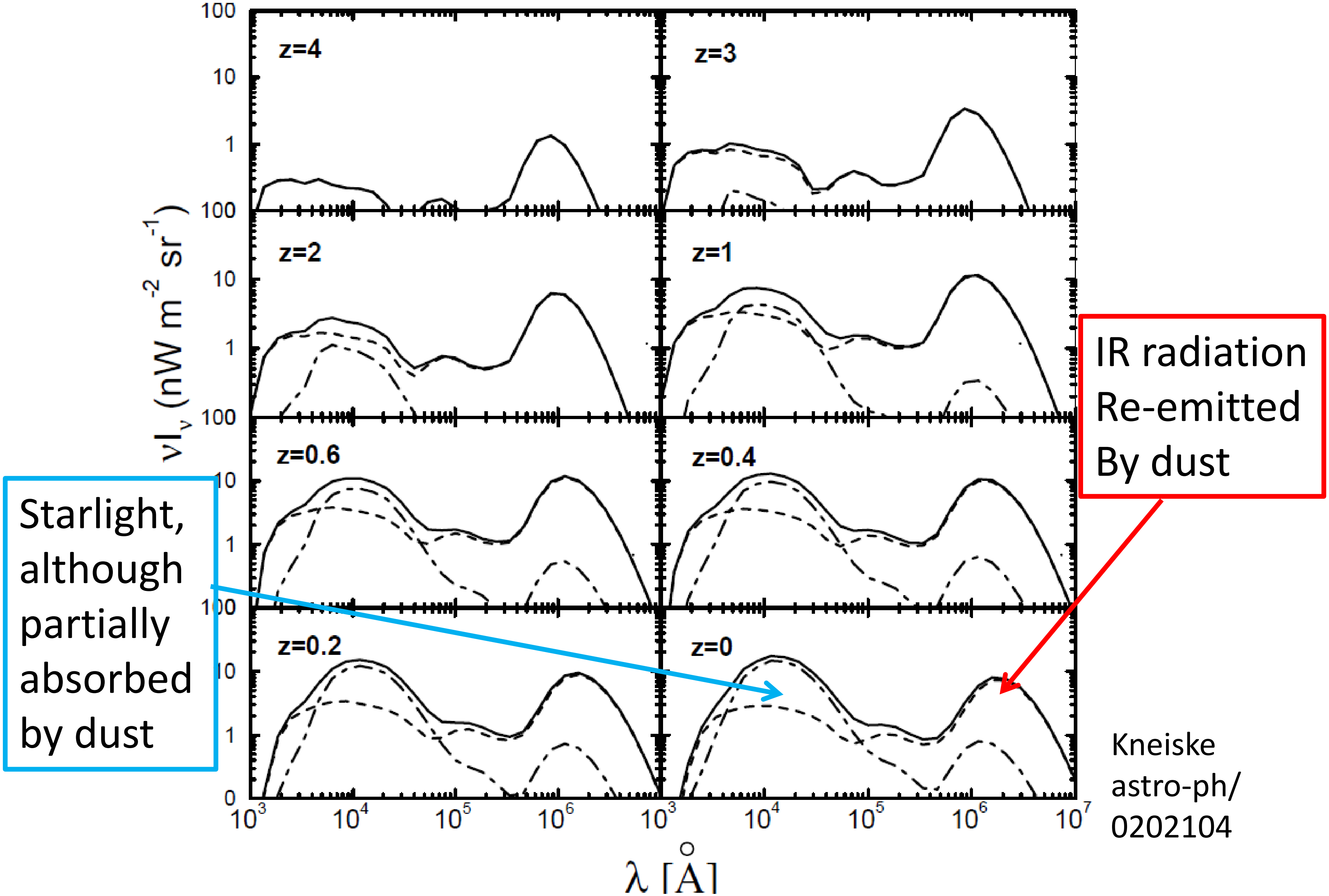
Quasar 3C279
Z=0.536

Very-High-Energy Gamma Rays from a Distant Quasar: How Transparent Is the Universe?

The MAGIC Collaboration*

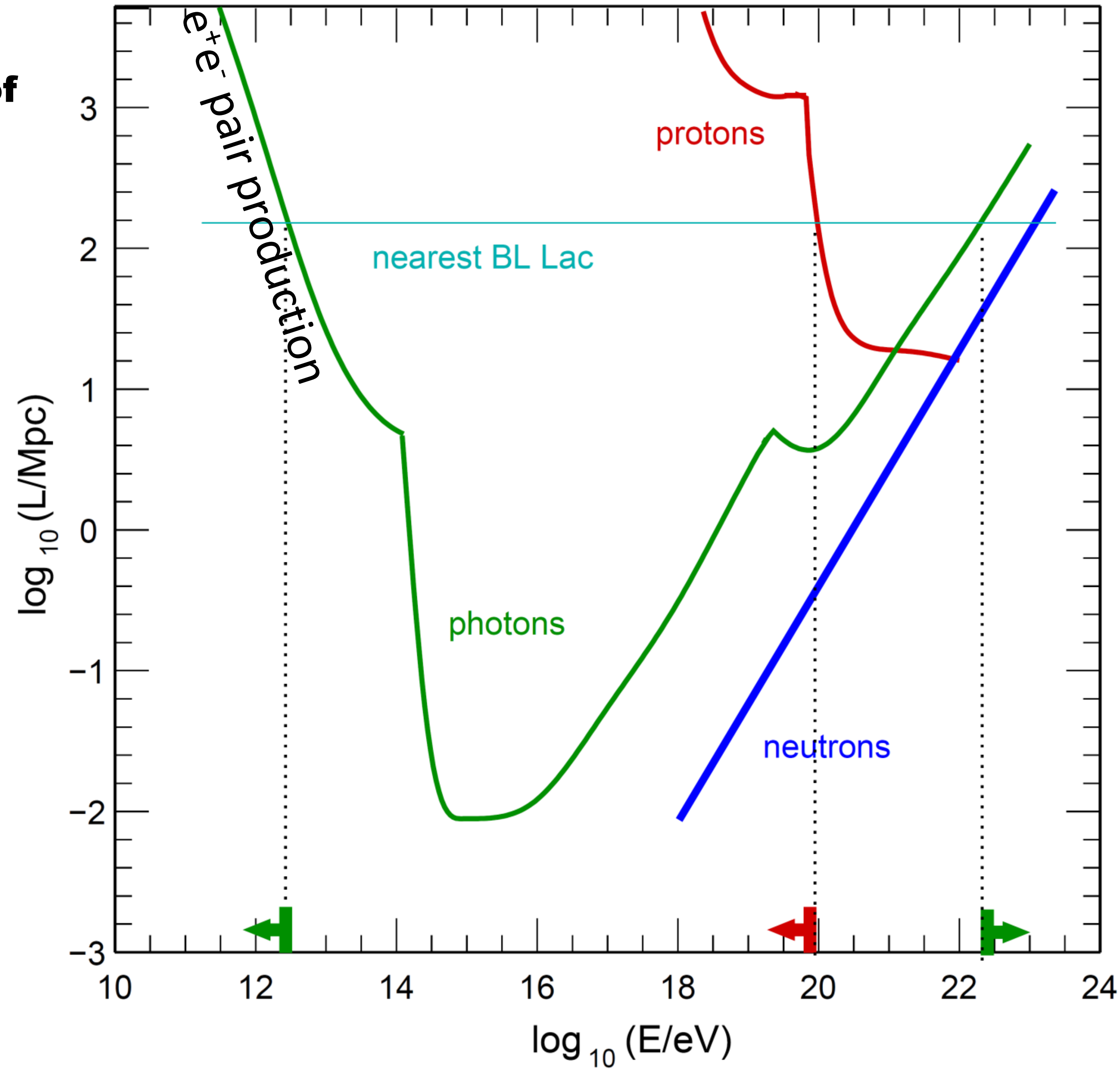
Science **320**, 1752 (2008); DOI: 10.1126/science.1157087

Extragalactic Background Light

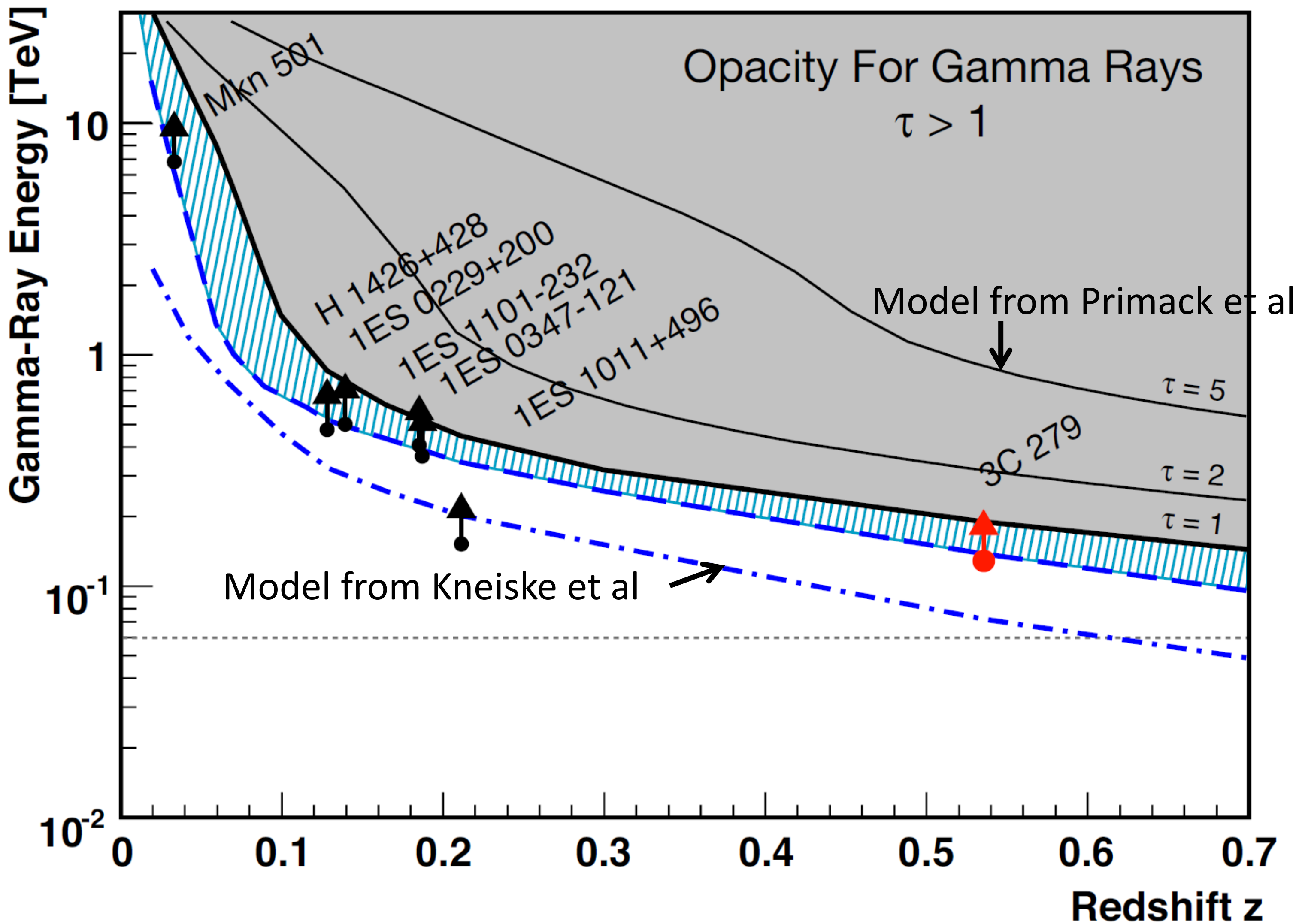


Kneiske astro-ph/ 0202104

Transparency of Universe at different wavelengths



Gamma Ray Horizon



MAGIC COLLABORATION arXiv:0807.2822

Frieman Robertson Walker Model

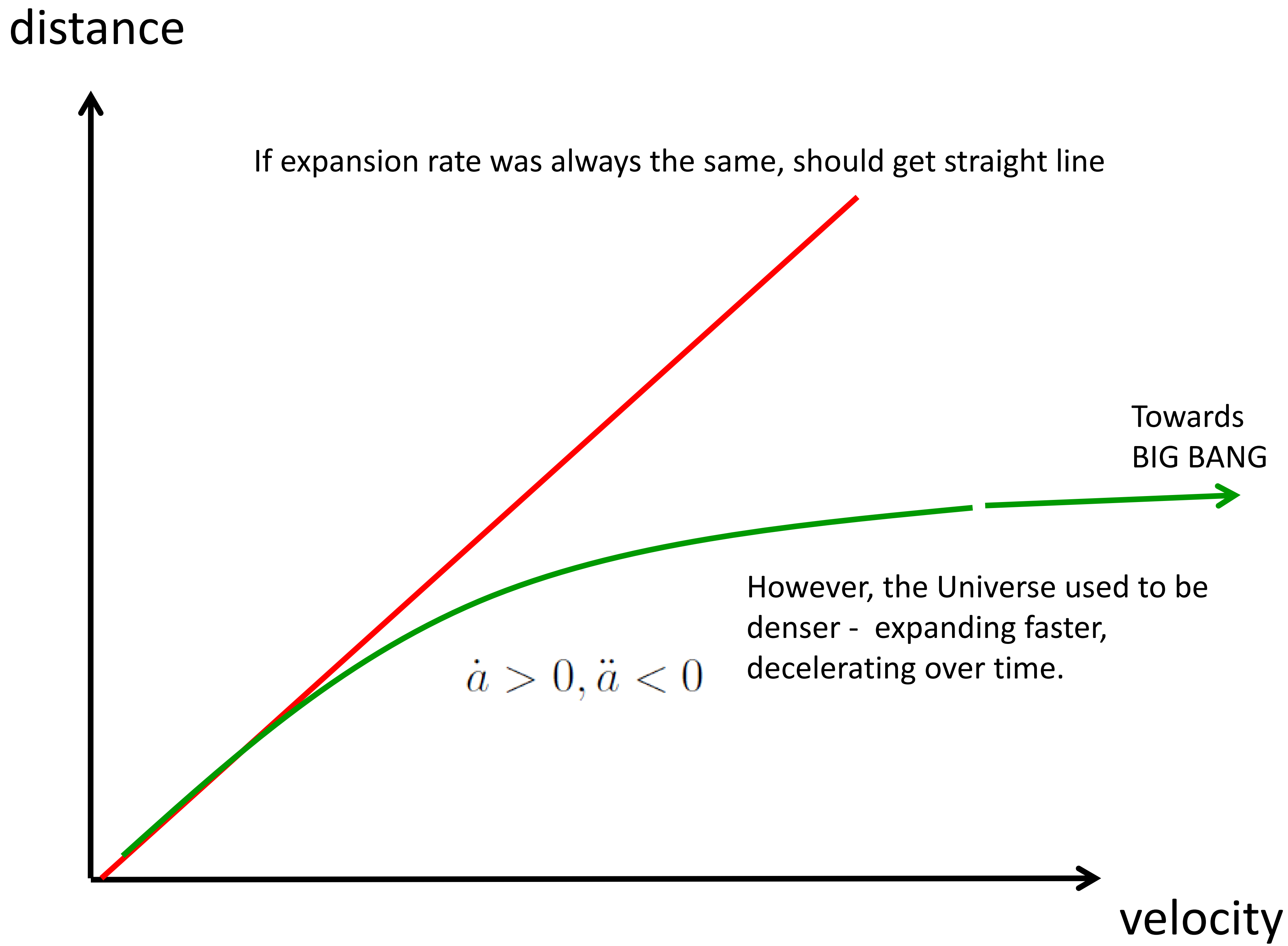
Assume Isotropic/homogeneous Universe i.e. Robertson Walker Metric

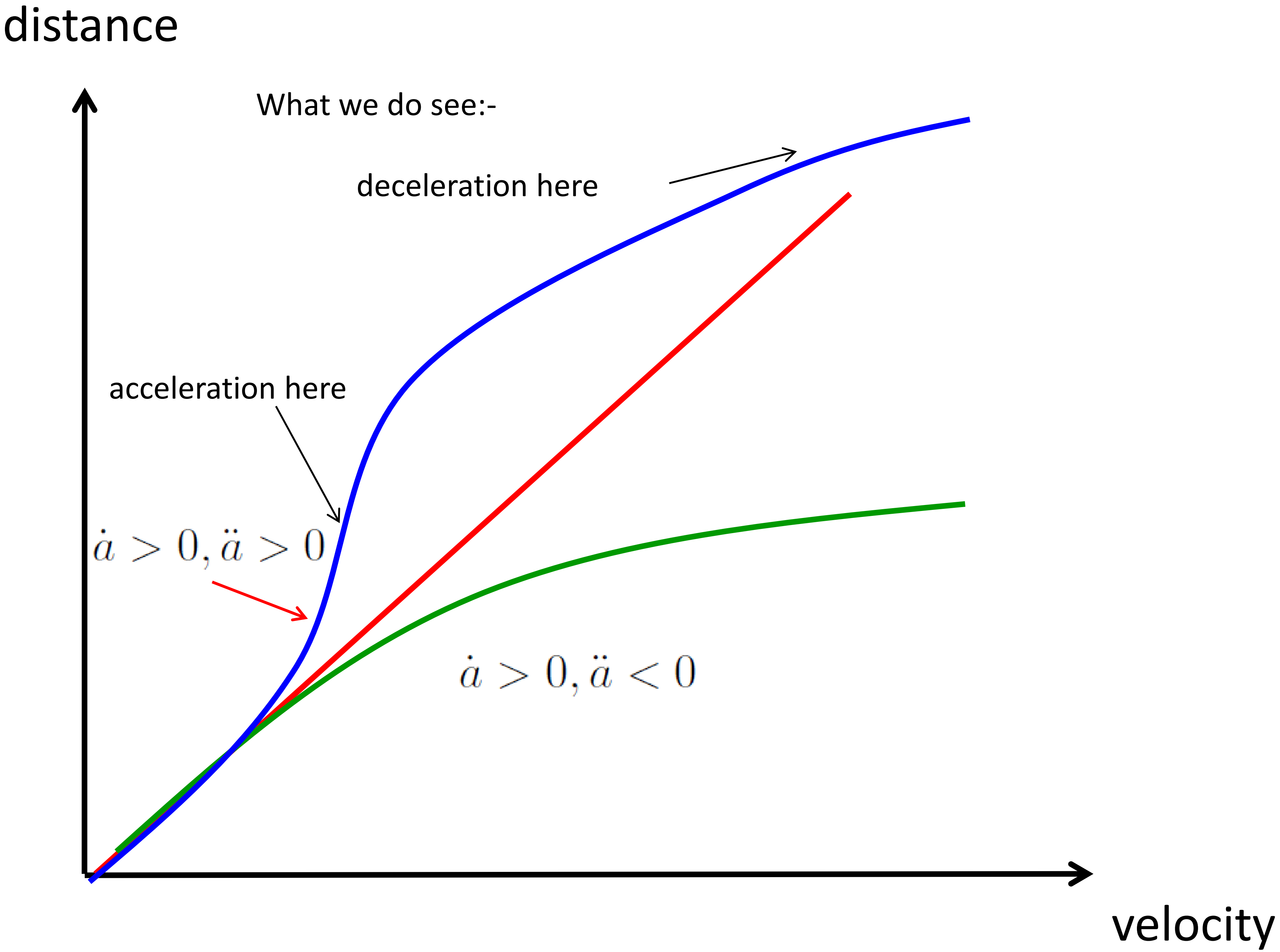
$$ds^2 = -c^2 dt^2 + a^2(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2\right)$$

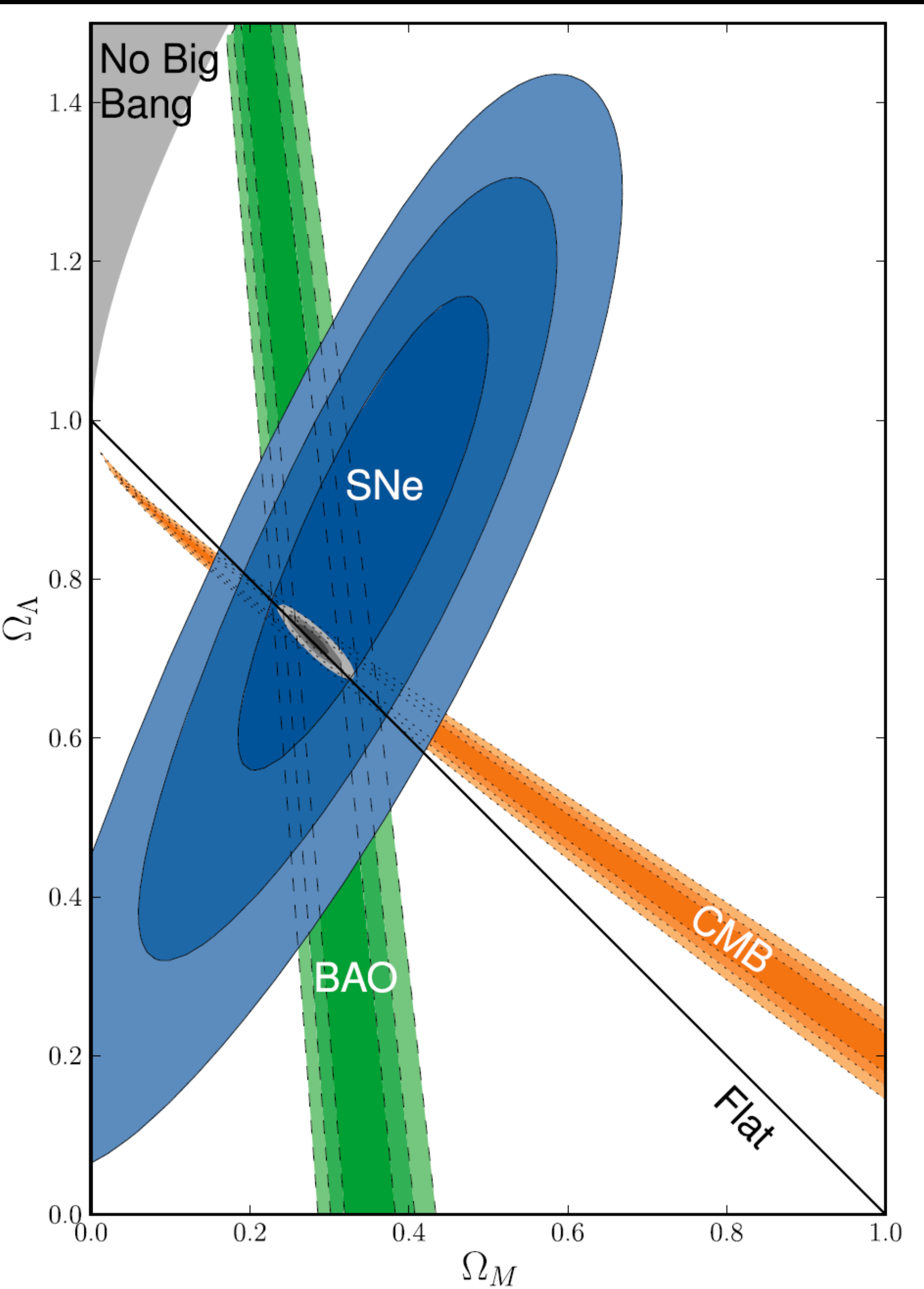
Comoving coordinate

Leads to Friedman equation

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

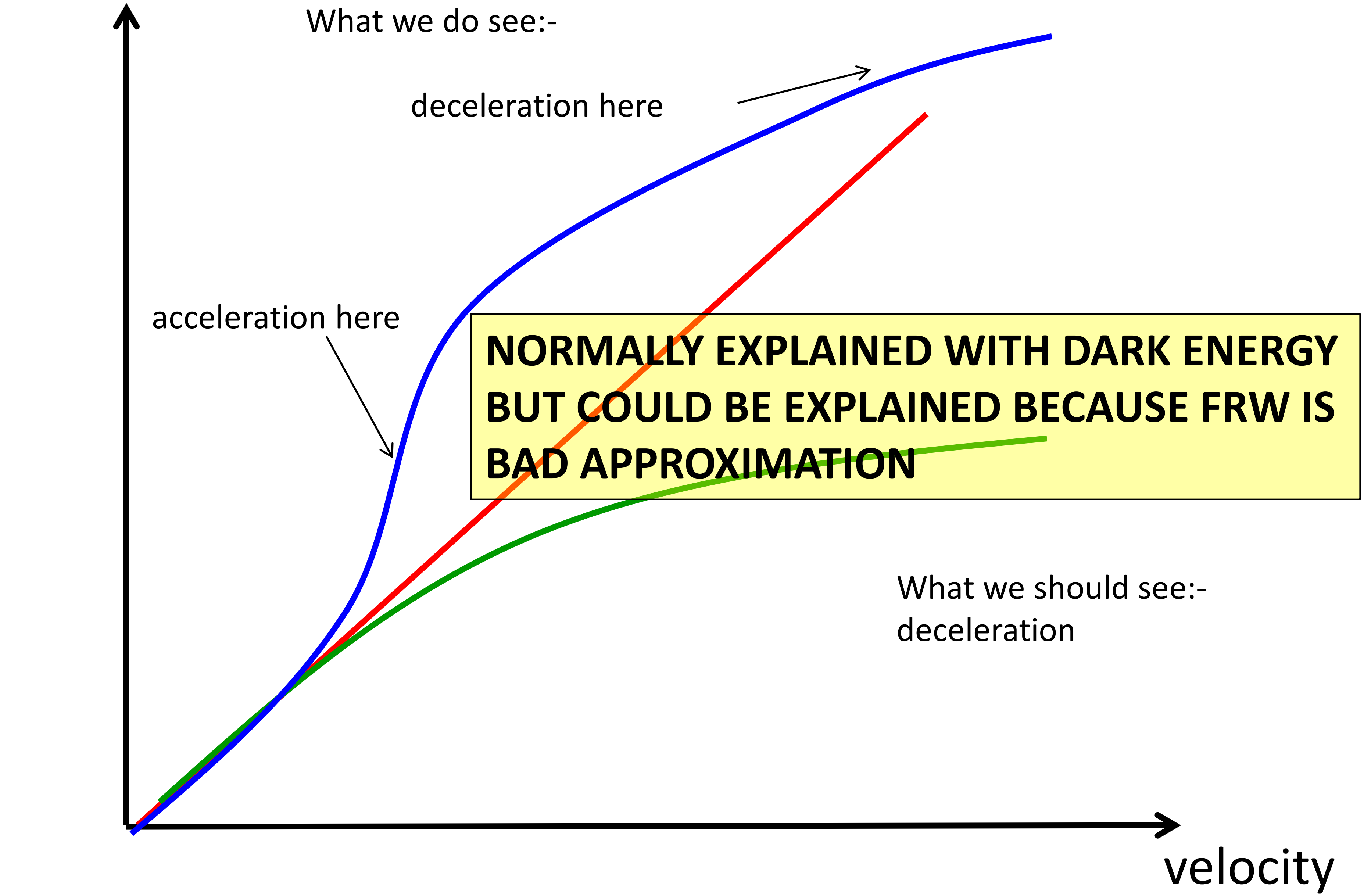

distance
If expansion rate was always the same, should get straight line
Towards BIG BANG
However, the Universe used to be denser - expanding faster, decelerating over time.
$\dot{a} > 0, \ddot{a} < 0$
velocity


distance
What we do see:-
deceleration here
acceleration here
$\dot{a} > 0, \ddot{a} > 0$
$\dot{a} > 0, \ddot{a} < 0$
velocity


No Big Bang
SNe
BAO
CMB
Flat
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Ω_Λ
Ω_M


Dark Energy 73%
Cold Dark Matter 23%
Atoms 4%

Basic Issue with Expansion History



Evolution of a Spherical Void

We assume spherical void and use Lemaitre-Tolman-Bondi metric

$$ds^2 = -dt^2 + S^2(r,t)dr^2 + R^2(r,t)(d\theta^2 + sin^2\theta d\phi^2)$$

$$S^2(r,t) = \frac{R'^2(r,t)}{1 + 2E(r)}$$

curvature

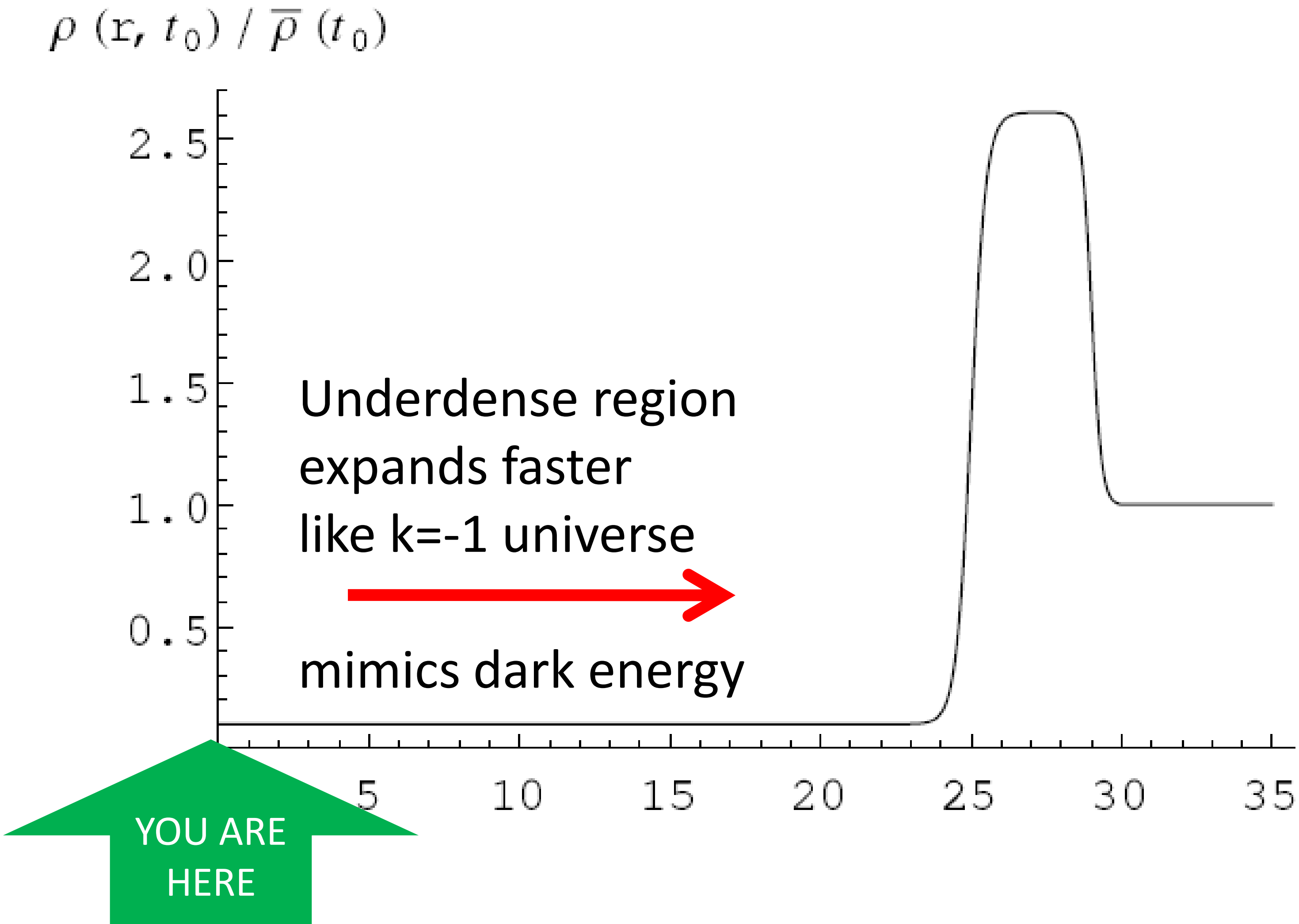
'Friedman' equation for Lemaitre-Tolman Bondi metric

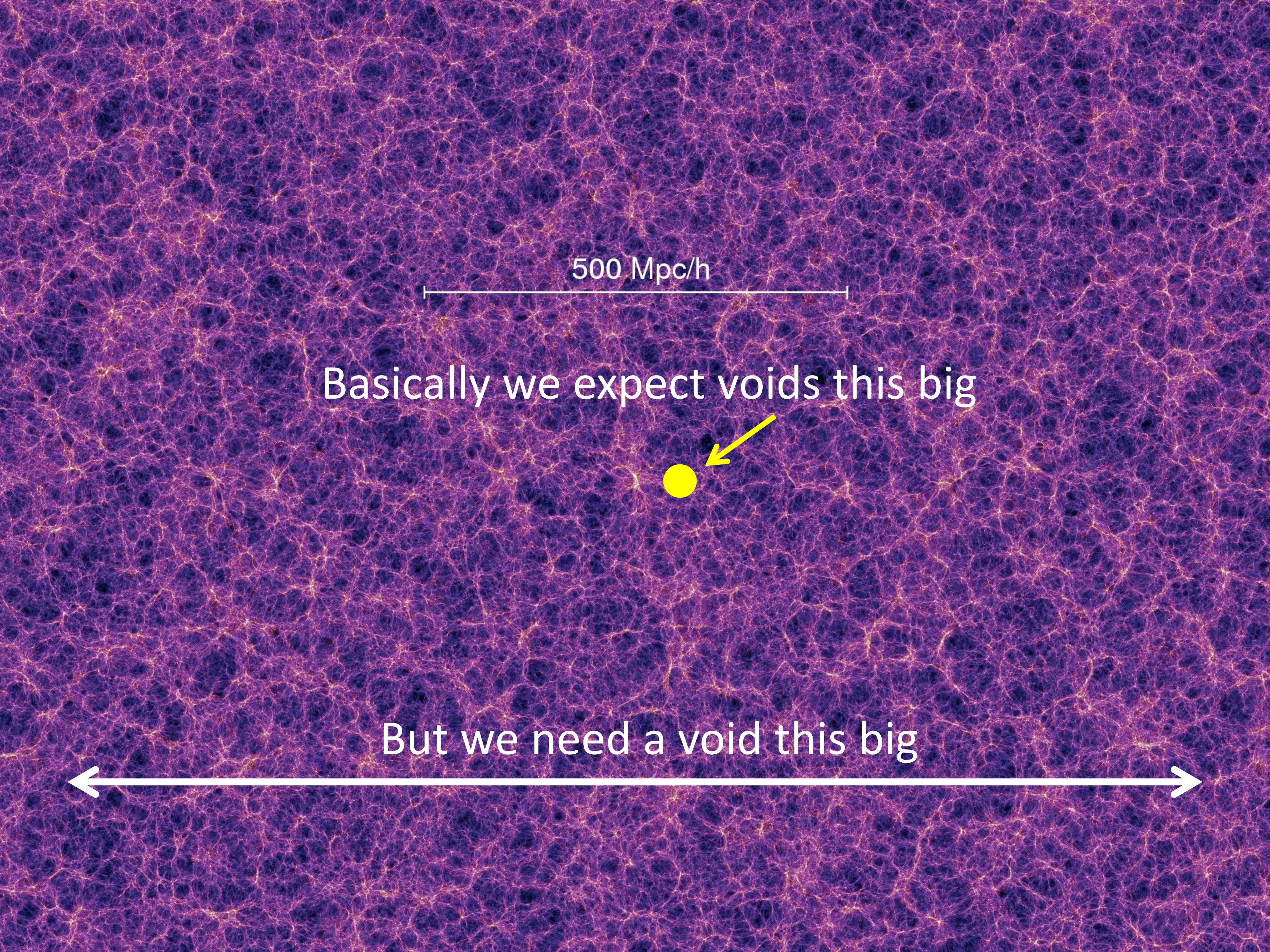
$$\frac{1}{2}\dot{R}^2 - \frac{GM(r)}{R(r,t)} - \frac{1}{3}\Lambda R^2 = E(r)$$

$$E(r) = \frac{1}{2}\frac{H_{\mathrm{LTB}}^2 a_{\mathrm{LTB}}^2}{c^2}\left(r^2 - \frac{3}{4\pi}\frac{M(r)}{a_{\mathrm{LTB}}^3 r \bar{\rho}(t_{\mathrm{LTB}})}\right)$$

Void Models as Alternatives to Dark Energy

$$\frac{1}{2}\dot{R}^2 - \frac{GM(r)}{R(r,t)} - \frac{1}{3}\Lambda R^2 = E(r)$$



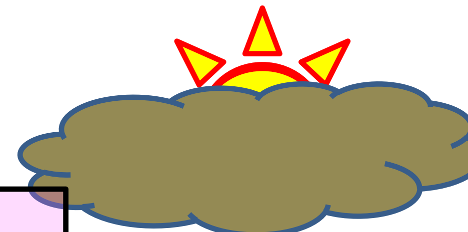

500 Mpc/h
Basically we expect voids this big
But we need a void this big

Pros and Cons of void models

Pros

- can explain supernovae without dark energy

Cons



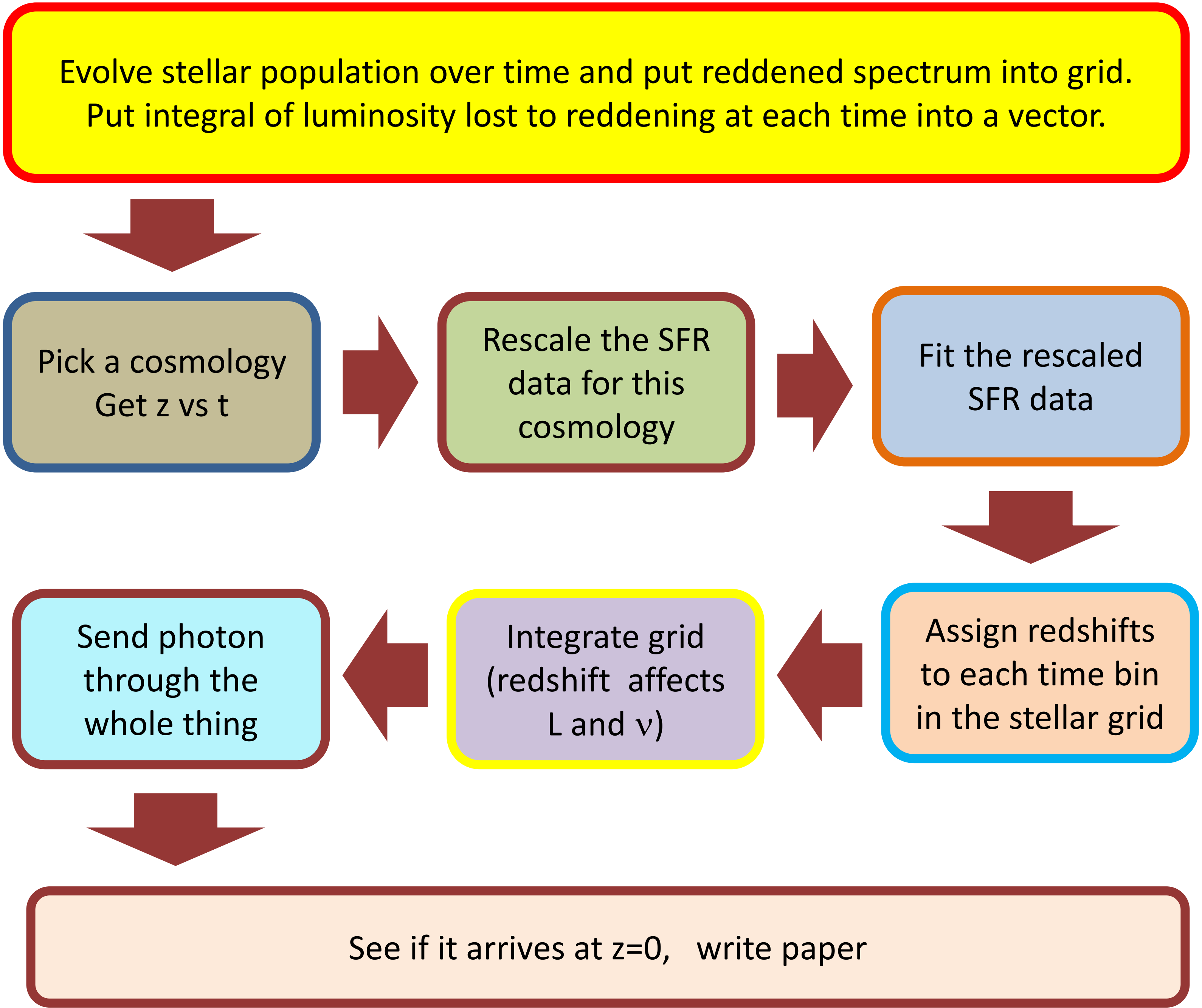
- require complicated power spectra
- need to be near centre of void
- difficult to fit peaks in CMB
- usually still need local value of H to be low

PHILOSOPHICAL / OCCAM'S RAZOR TYPE ARGUMENTS - NEED TO TRY HARDER TO KILL MODEL IN ORDER TO TEST IT

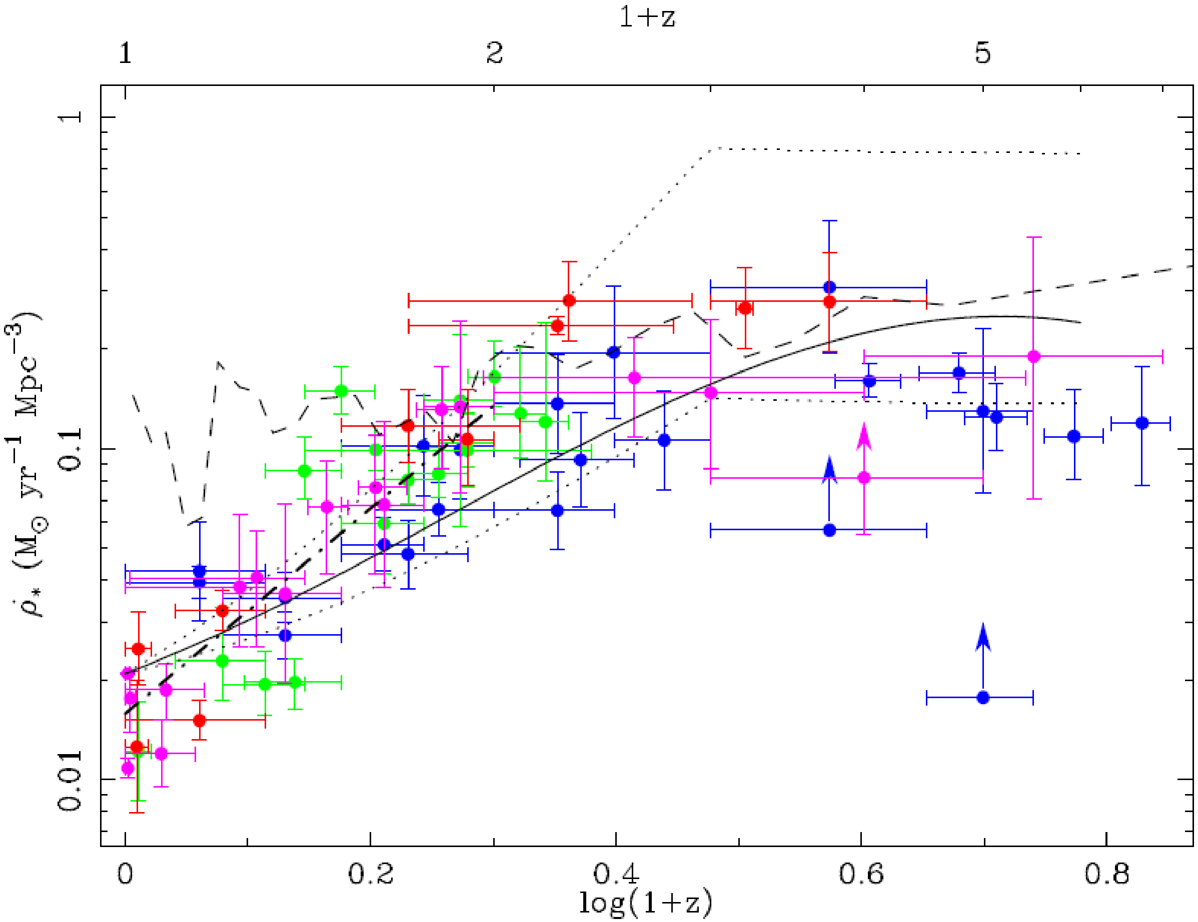
Different cosmologies lead to different extragalactic background light.

Can we use the opacity of the Universe to gamma rays to constrain cosmology?

Our exact procedure



Star Formation Rate



Hopkins astro-ph/0407170

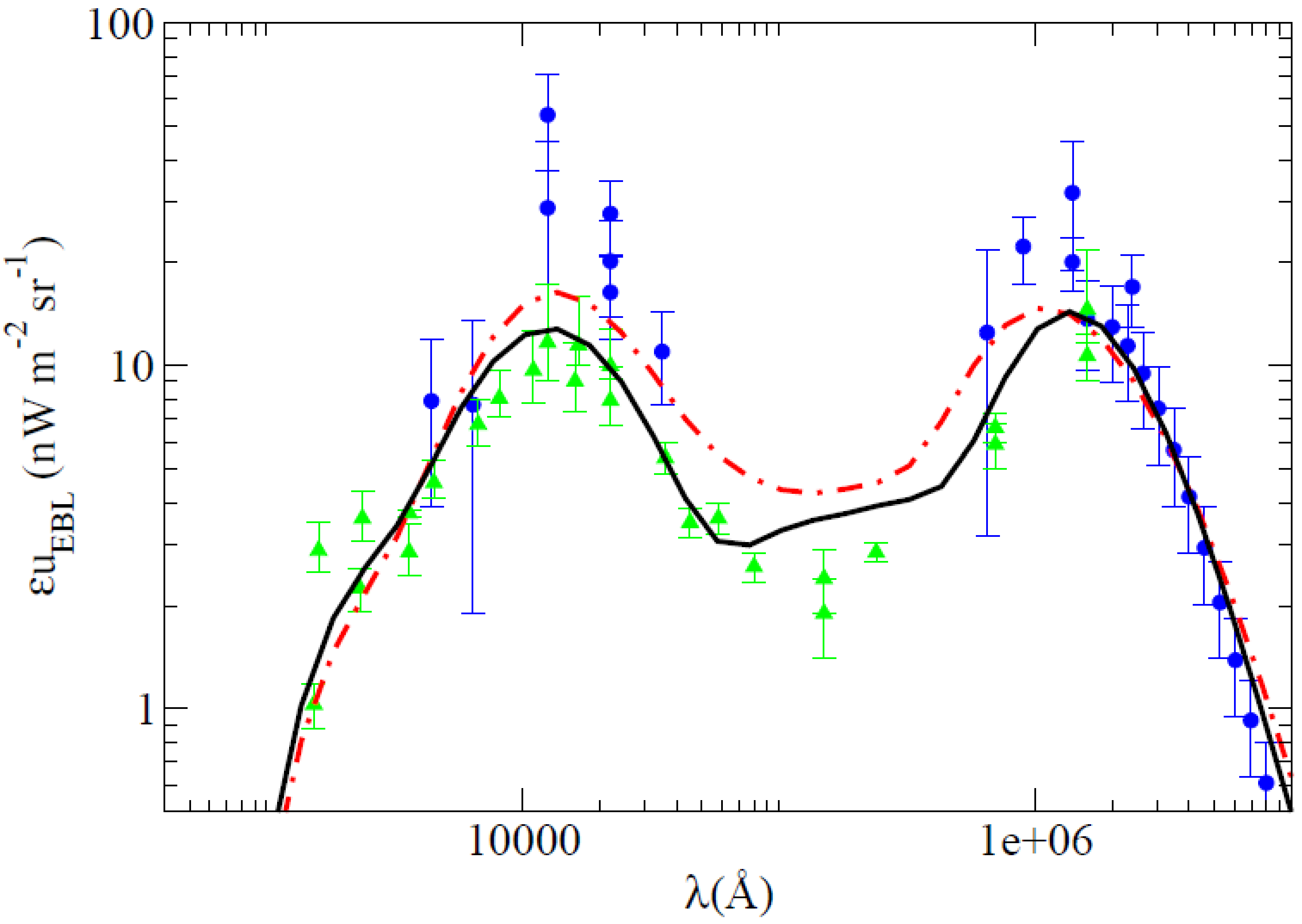
Can be fit with the expression

$$\dot{\rho}_* = \frac{a + bz}{1 + (z/c)^d}$$

$$\dot{\rho}_* \propto \frac{L(z)}{V_c(z, \Delta z)} \propto \frac{D_c^2(z)}{D_c^3(z + \Delta z) - D_c^3(z - \Delta z)}$$

Need to renormalise if you change underlying cosmology.

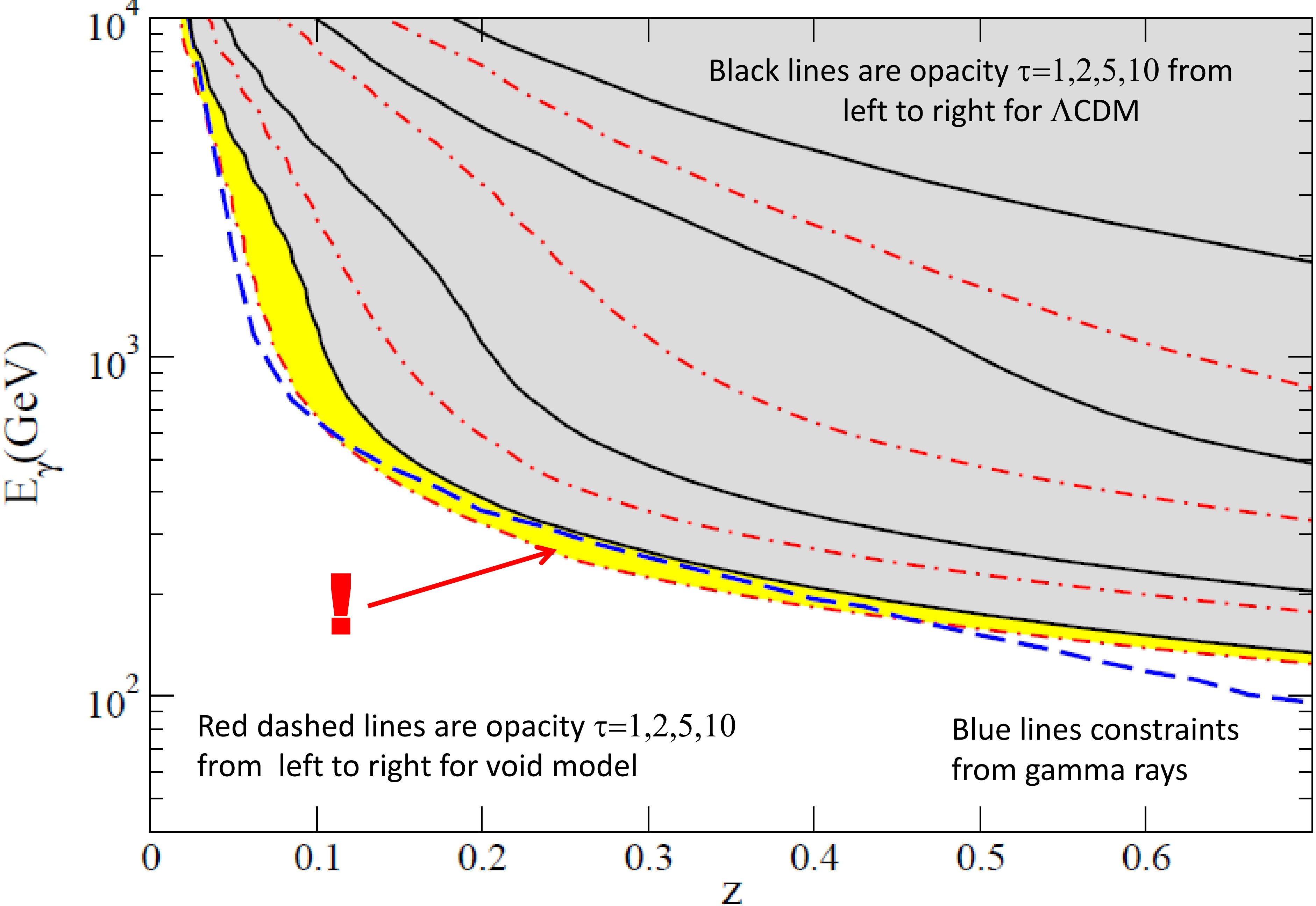
Spectrum produced by our code



Data is from various sources, blue data is observed spectrum, green data is lower limits. Here we haven't fit this spectrum on the left, we just used the star formation rate data.

Results

arXiv:1111.4577



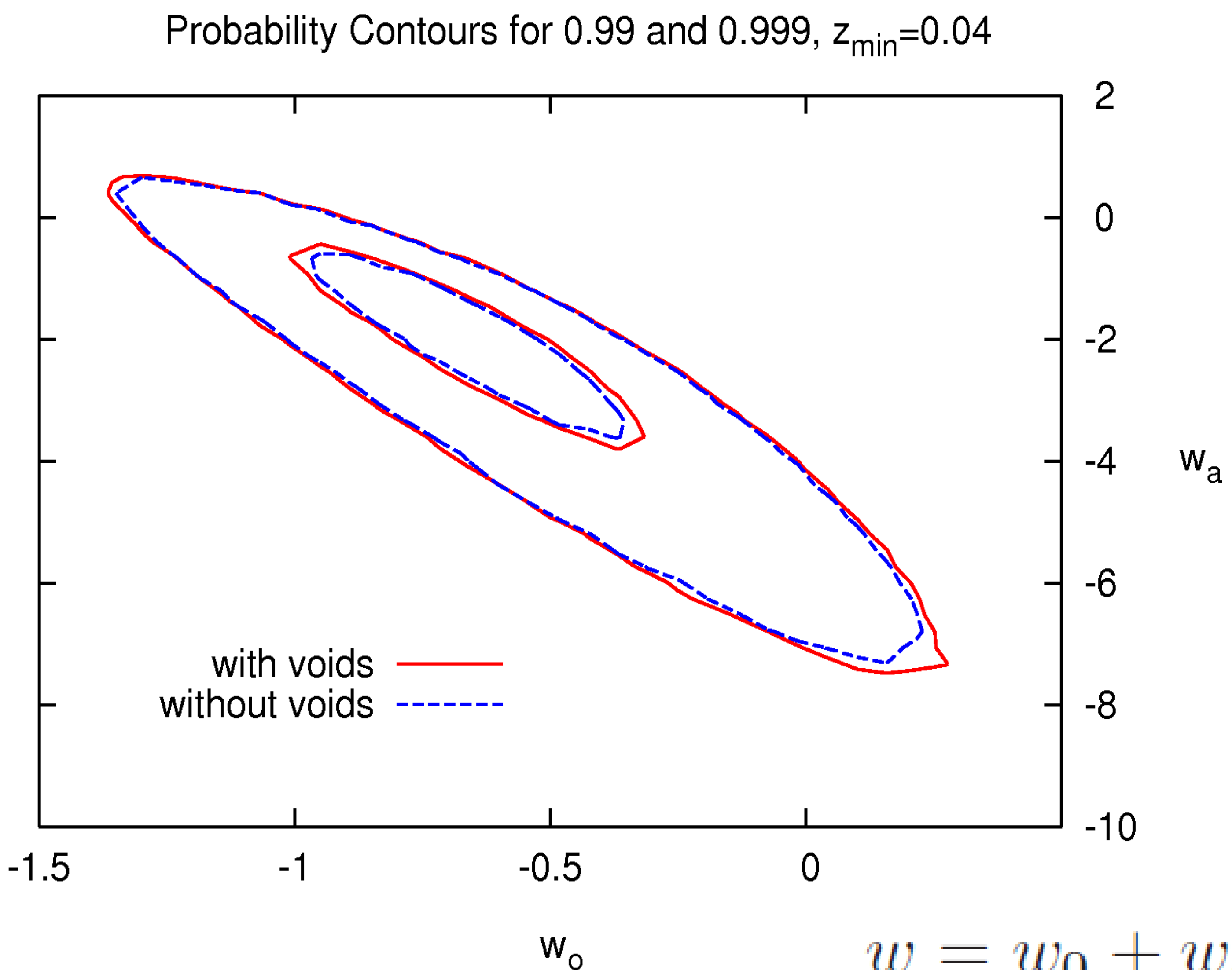
Can do the same thing for any cosmology, not just voids

Consider cosmologies with dark energy equation of states of

$$w = w_0 + w_a \frac{z}{1+z}$$

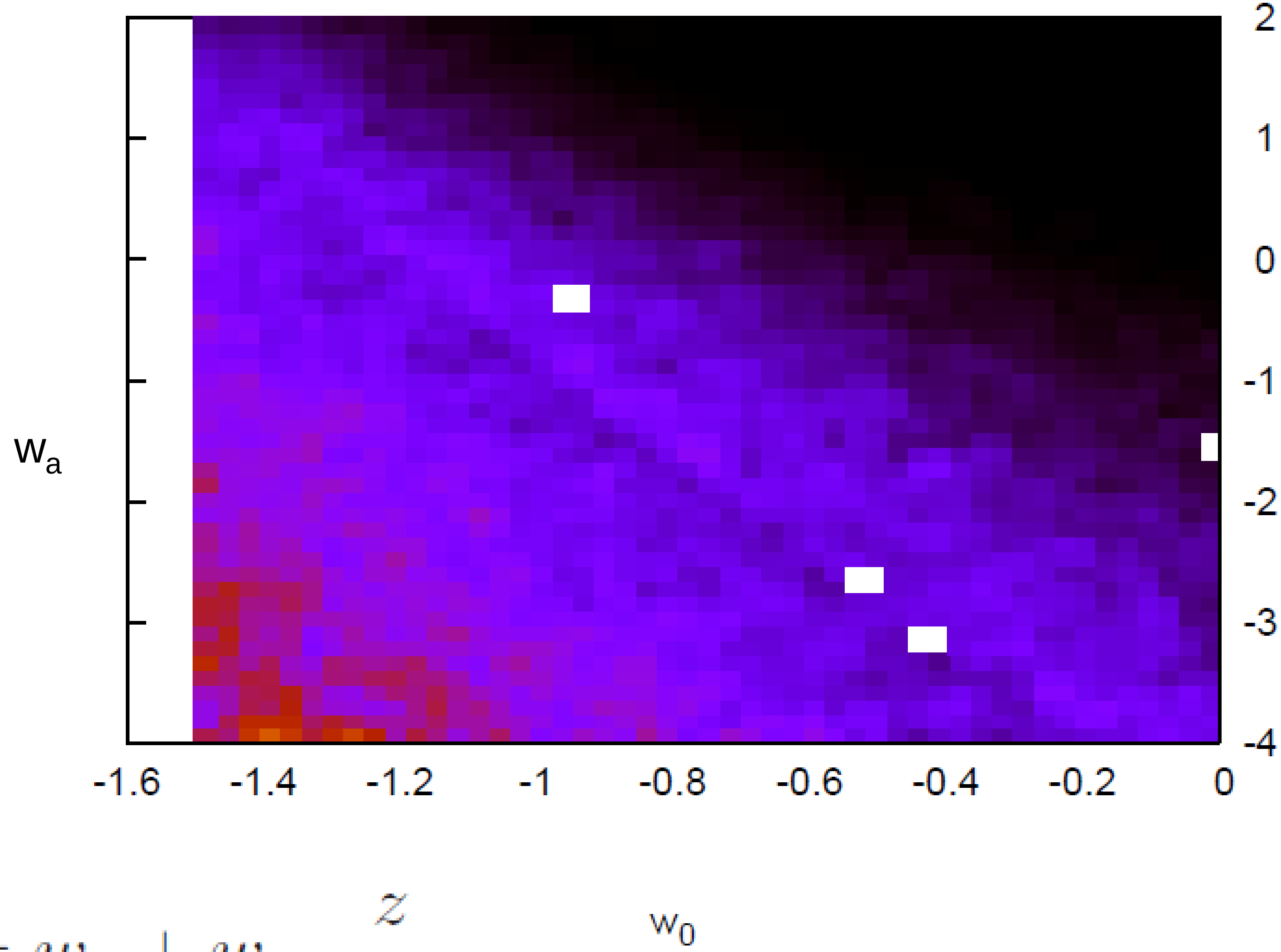
and see how the gamma ray opacity looks for them

Existing constraints on Dark Energy Equation of State.



$$w = w_0 + w_a \frac{z}{1+z}$$

Results



$$w = w_0 + w_a \frac{z}{1+z}$$

Summary

- γ-ray transparency of different cosmologies can tell between them

- Observations of blazars may rule out void models, if we can parametrise errors in our EBL models

- γ-ray transparency can also place constraints on other models of dark energy. I am quite excited about their potential