An Anthrocentric Universe?

Is Cosmology Consistent?

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Foundations of Cosmology: Mediocrity

cos.mo.log.i.cal prin.ci.ple *n*. the assumption that the universe is, on large scales, homogeneous and isotropic.

me.di.oc.ri.ty prin.ci.ple *n*. the philosophical statement that the there is nothing special about the position of the Earth and by implication the human race. *syn*. Copernican principle.

Fried.man - Rob.ert.son - Walk.er cos.mol.o.gy *n*. the class of 3+1 dimensional space-times where the metric is given by $ds^2=-dt^2+\mathrm{a}[\mathrm{t}]^2 ds_{\mathrm{spatial}}{}^2$ where t is the cosmic time, $a[t]$ is the cosmic scale factor, and ds_{spatial} is the metric of either a 3-sphere, a 3-hyperboloid, or 3-d Euclidean space. Taken as an approximate description of the large scale structure of space-time these (and some of their compactifications) are the only space-times compatible with the cosmological principle.

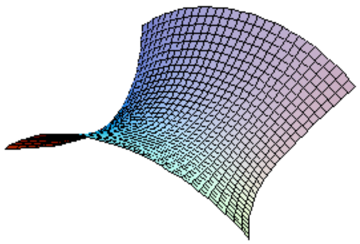
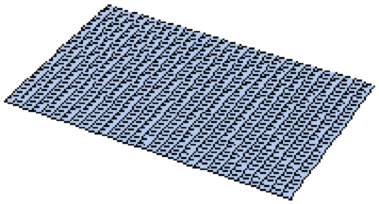
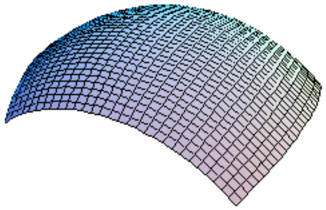
The Cosmological Principle

The reason for the low complexity of the assumed FRW cosmology derived from the assumed symmetries of the universe. These derive from the Cosmological Principle:

Viewed on sufficiently large distance scales, there are no preferred directions or preferred places in the Universe.

which is antecedent of the Copernican principle.

Accepting this principle then requires that the geometry on large scales be homogeneous and isotropic. This leads to a one parameter family of spatial geometries parameterized by the curvature constant, $K=(\Omega_0-1)c^2/H_0^2$, the sign of which determines which of the 3 qualitatively different geometries describes our universe:

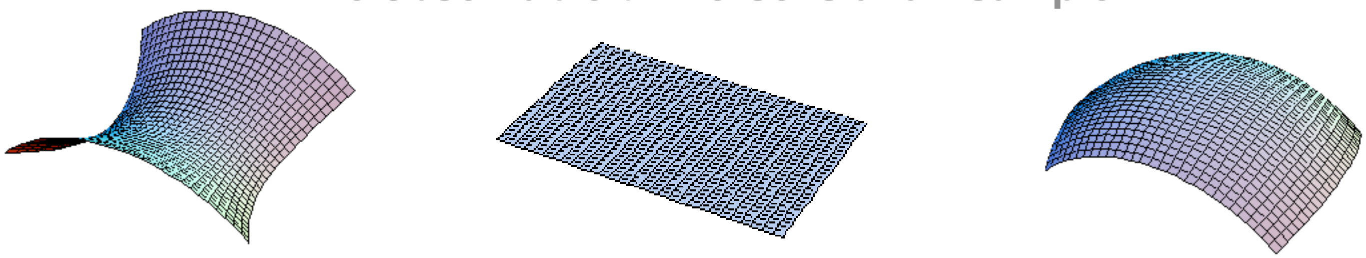




Even with uniform curvature there are a variety of topologies which are allowed. Most non-trivial topologies violate the Cosmological Principle but these are often considered before violations of non-uniformity of the K is! For the tests proposed here the topology, trivial or not, does not matter.

The Cosmological Principle as an Inference Engine

Viewed on sufficiently large distance scales, there are no preferred directions or preferred places in the Universe.

The observable universe is a fair sample.



The Cosmological Principle is a very useful inference tool, allowing one to efficiently combine observations of objects at different times and places to infer properties of the universe as a whole.

Example: The Cosmological Principle and Cosmic Acceleration:

One can use the cosmological principle to compare the velocity gradients [=Hubble parameter] of matter *here and now* with that of the matter *there and then* to infer that there must have been a relative [=tidal] acceleration of [= force on] neighboring parcels of matter. Without the Cosmological Principle we could come to no such conclusion!

The Cosmological Principle as an Inference Engine

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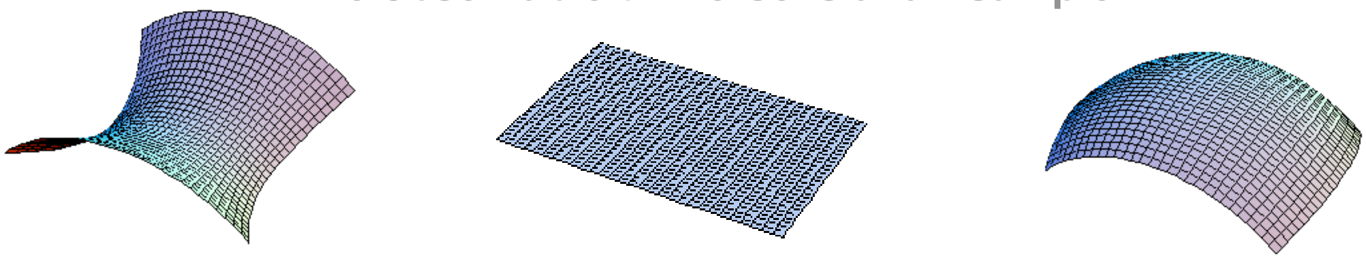


Without the Cosmological Principle it is much more difficult to observationally determine the state of our universe!

... but the universe is homogeneous and isotropic, isn't it?

- It certainly appears to be:
  - CMBR temperature anisotropies as measured by WMAP are very isotropic although there are some hints of anisotropy [Copi *et al.* 2004; Coles *et al.* 2004; Cruz *et al.* 2004; de Oliveira-Costa *et al.* 2004; Eriksen *et al.* 2004; Hansen *et al.* 2004; Jaffe *et al.* 2005; Land *et al.* 2004; Larson *et al.* 2004; Park 2004; Vielva *et al.* 2004]. However this is ***isotropy about us***, *not* isotropy about <u>everyone</u> as the Cosmological Principle requires.
  - Galaxy clustering appears to homogeneous on large scales [Pan *et al.* 2002 ; Yadev *et al.* 2005]. However on large enough scales (~1 Gpc) inhomogeneity and cosmic evolution become difficult to separate.

Cosmological Consistency: *i.e.* testing the Cosmological Principle

- There are many standard cosmological tests
- The usual ones *do not* test the Cosmological Principle!
    - they do tell us which FRW cosmology we live in.
        - *e.g.* the luminosity-distance relation of SNe-Ia.
- A different sort of test would test the cosmological principle itself.
- Let us call this a test of ***Cosmological Consistency***.

Cosmological Consistency Tests

Observationally the statistical isotropy of the universe is already well established, most dramatically by the WMAP results. This leaves only radial uniformity to test. Our observational handle on radial uniformity comes only from one number, the curvature constant,

$$K=(\Omega_0-1)c^2/H_0^2,$$

(the sign of **K** determines whether the spatial geometry is flat, spherical, or hyperbolic)

and 2 functions of redshift:

- the angular diameter distance, $D_A[z]$
  - which determines the bolometric luminosity distance by

$$D_L[z]=D_A[z]/(1+z)^2$$

- the Hubble parameter, $H[z]$
  - which is related to the radial comoving distance by

$$D_{co}'[z]=c/H[z]$$

Different Tests - Different Combinations

Examples of how these two functions are related to standard tests

- the apparent luminosity of standard candles

$$l[z] = k[z] \frac{L}{D_A[z]^2}$$

(the "K-correction", $k[z]$, includes $(1+z)^4$ surface brightness dimming and redshift of spectrum into /out of observational band)

- the cosmological volume element ($\propto$ # of objects) per unit redshift per unit solid angle

$$\frac{dV_{\mathrm{co}}}{dz\, d\Omega}[z] = D_{\mathrm{A,co}}[z]^2 D_{\mathrm{R,co}}'[z].$$

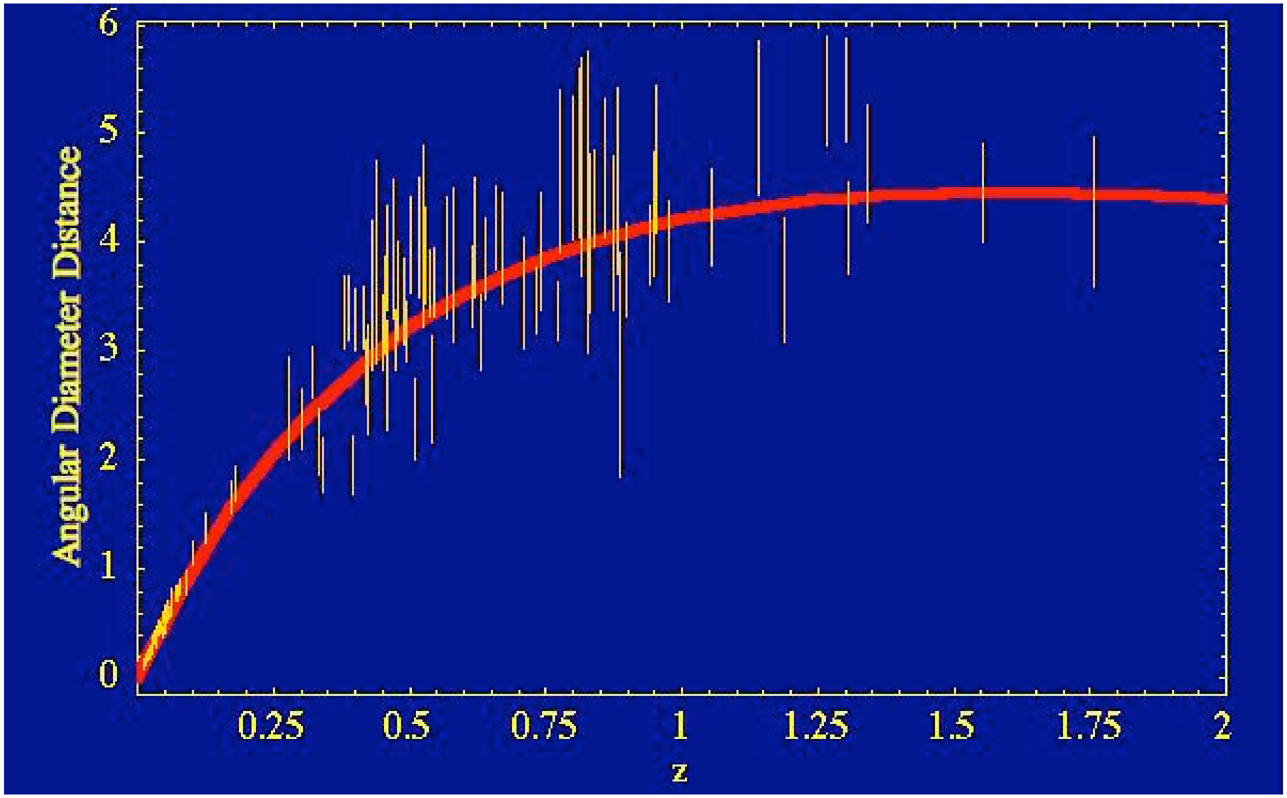
- the Alcock-Paczynski test

$$\frac{\delta z}{\delta\theta}[z] = \frac{D_{\mathrm{A,co}}[z]}{D_{\mathrm{R,co}}'[z]}$$

- N.B. in practice other cosmological dependencies tend to creep into these tests, e.g. the linear growth rate of perturbations, or more complicated things like the star formation rate.

SN-Ia Standard Candle Test

Riess, *et al*. (2004) "*Gold Sample*"



Ly-α Forest Alcock-Paczynski Test

McDonald & Miralda-Escudé (1999) *Measuring the Cosmological Geometry from the Lyα Forest Along Parallel Lines of Sight* Ap.J. **518** 24

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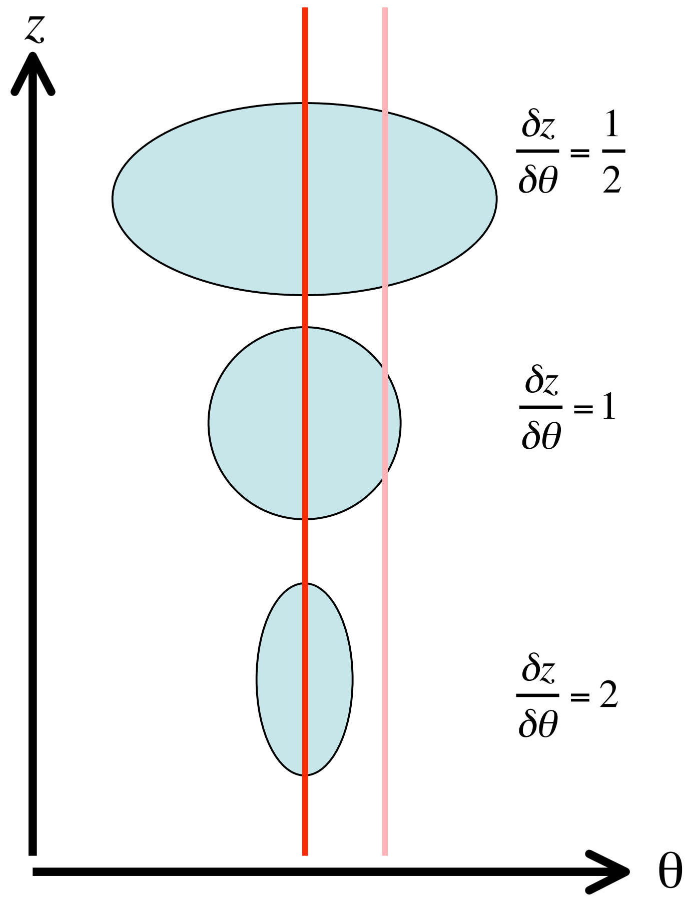

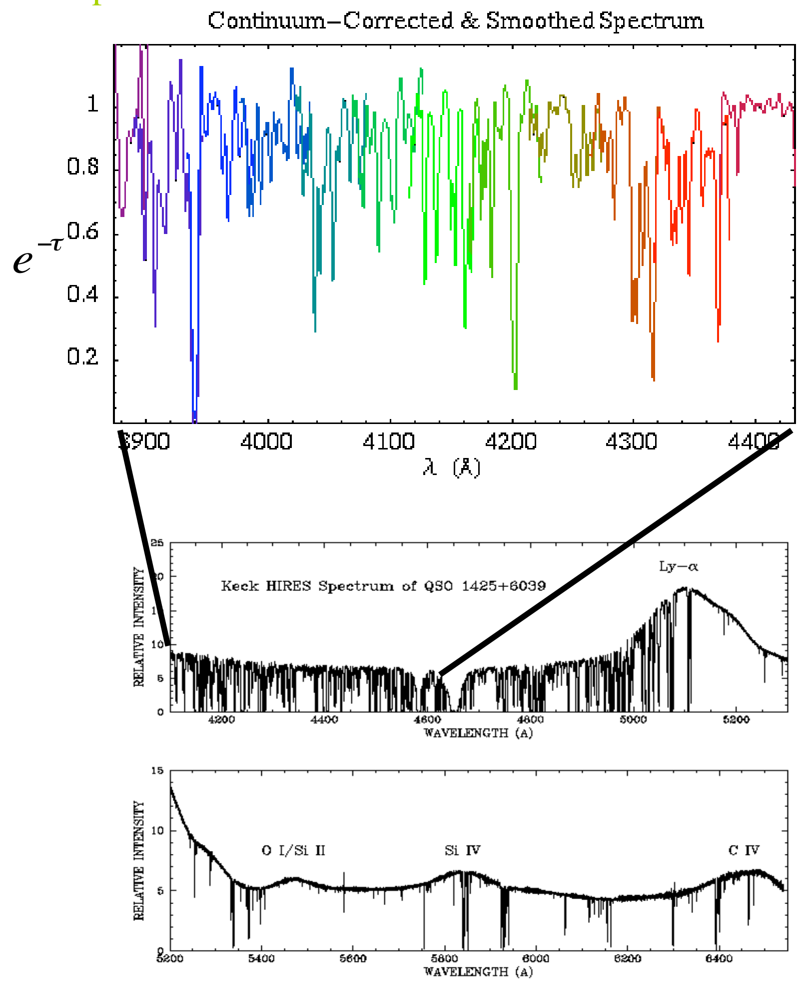

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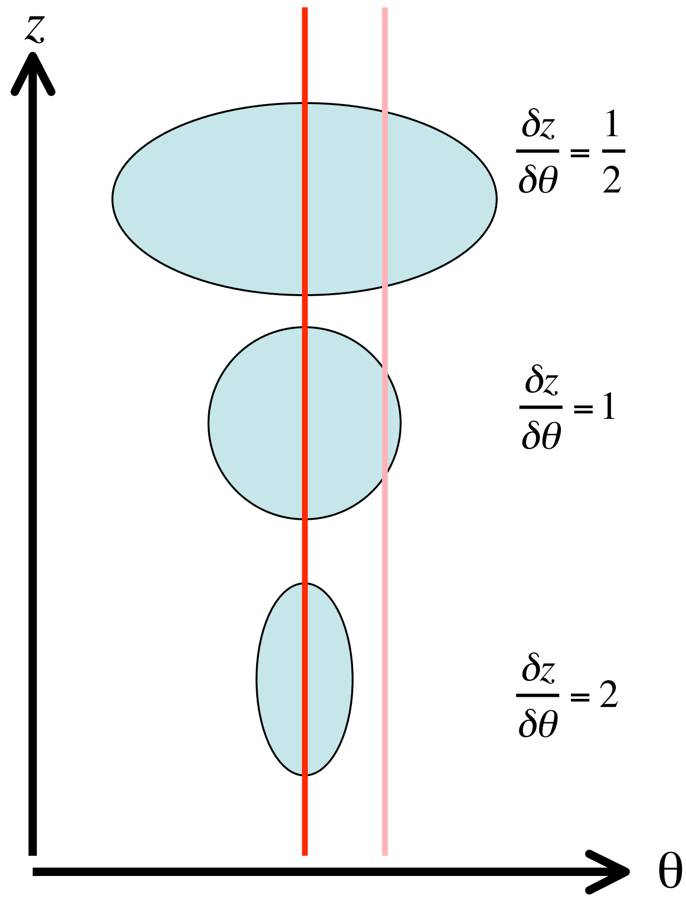

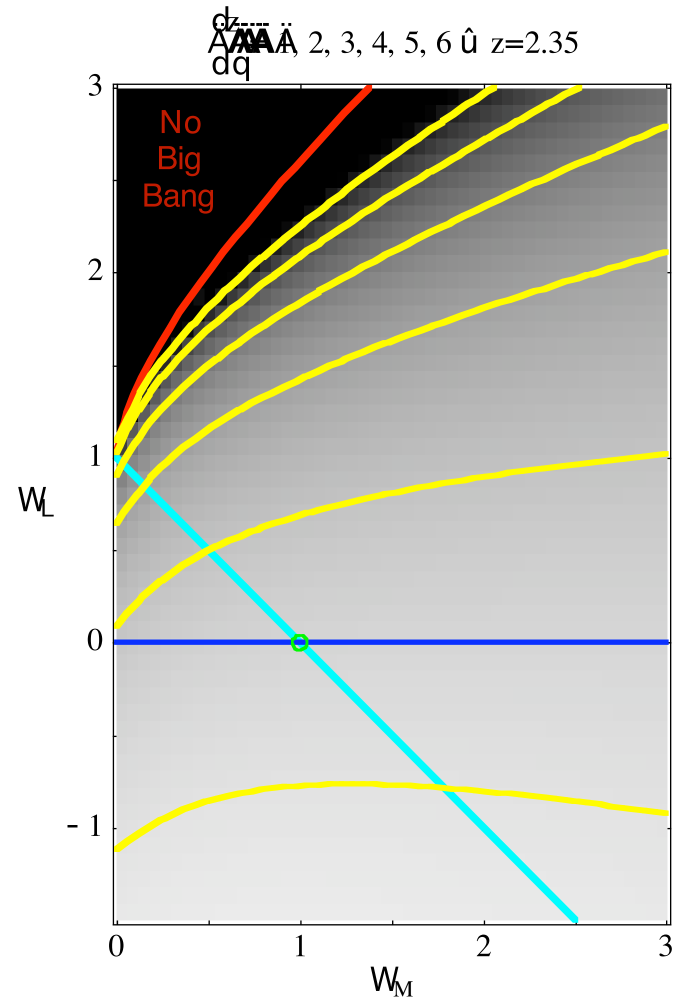

Cosmological Consistency Tests

The cosmological principle requires that **$D_A[z]$** and **$D_{co}[z]$** be related by the ***Cosmological Consistency Relationship***

$$D_{\rm A}[z] = \frac{1+z}{\sqrt{|K|}} S_{{\rm sgn}[K]}[\sqrt{|K|} D_{\rm co}[z]]$$

where $S_\sigma[]$ is one of three functions:

$$S_0[x] = x$$
$$S_{+1}[x] = \sin[x]$$
$$S_{-1}[x] = \sinh[x].$$

This is a direct consequence of the Cosmological Principle.

Cosmological Consistency Tests

As described, the results of different cosmological tests are inter-related. Some of these relationships are ***axiomatic***, *e.g.*

$$\left(\frac{\delta z}{\delta\theta}[z]\right)\left(\frac{dV}{dz\,d\Omega}\right) = \left(\frac{k[z]\,L}{l[z]}\right)^{\frac{3}{2}}$$

This is basically saying that the volume is given by

Volume = (angular diameter distance)^2 x (radial distance)

Cosmological Consistency Tests

Other relationship depend on the cosmic consistency relation, *e.g.*

$$\frac{\frac{1}{4}\left(\frac{\delta z}{\delta\theta}[z]\right)^{2}\left(\partial_{z}\ln\left[\frac{k[z]\,L}{l[z]}\right]\right)^{2}-1}{\left(\frac{c}{H_{0}}\right)^{2}\frac{k[z]\,L}{l[z]}}=1-\Omega_{0}$$

Which relates observables from an A-P test and a l-z (*e.g.* Sne-Ia) test to

$$\Omega_{0}=\frac{\rho_{\mathrm{b}}+\rho_{\gamma}+\rho_{\mathrm{DM}}+\rho_{\mathrm{DE}}}{\rho_{\mathrm{crit}}}\qquad\qquad \rho_{\mathrm{crit}}\equiv\frac{3}{8\pi\,G}H_{0}^{\;2}$$

This probably isn't quite measurable.

However since the right-hand-side is z-independent one can test cosmic consistency by requiring that one infers the same Ω_0 at each z.

There exist other measures of $\Omega_0[z]$ which one can compare to (*e.g.* Bernstein 2005).

Cosmological Consistency Tests

These tests have not really been made … yet.

¿Cosmological Inconsistency?

- These relations hold no matter how weird the dark energy is!
- Violation of an axiomatic relation probably indicates a measurement error or mis-interpretation of measurements.
- The cosmic consistency relations is a result of assumptions of the FRW (Friedmann-Robertson-Walker Cosmology - one of the fundamental tenets upon which interpretation of cosmological observations is based.
- Violation of cosmic consistency might indicate

1. non-FRW geometry *i.e*. we live in the center of a spherically symmetric but non-homogeneous universe (violation of cosmological Copernican Principle)
2. non-metric theory for propagation of light (post-modern tired light) - as we are in a sense measuring the metric with these tests.
3. Measurement error or a problem with interpretation of measurements.

- As the relations combine different tests, and as it is unlikely that errors in one test would balance errors in another such as to satisfy the relations, this provides a powerful check of all tests involved!
- It is thus worthwhile to compare the AP test at the same redshifts as SNeIa

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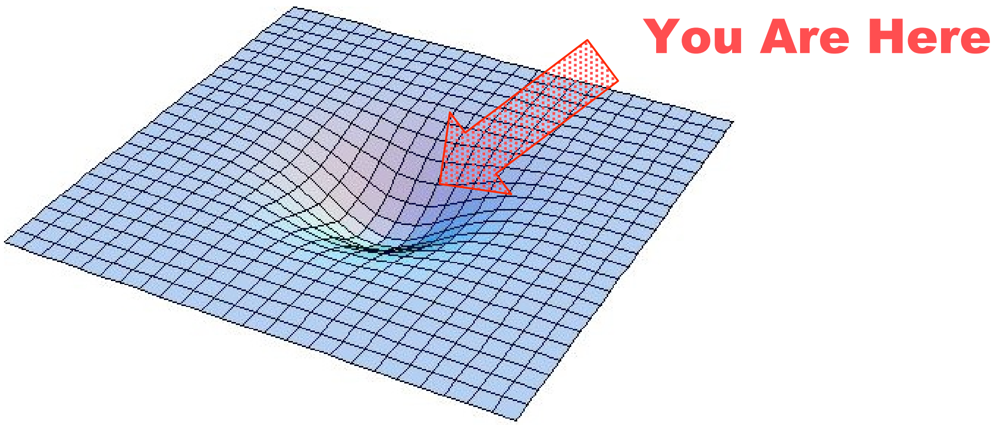
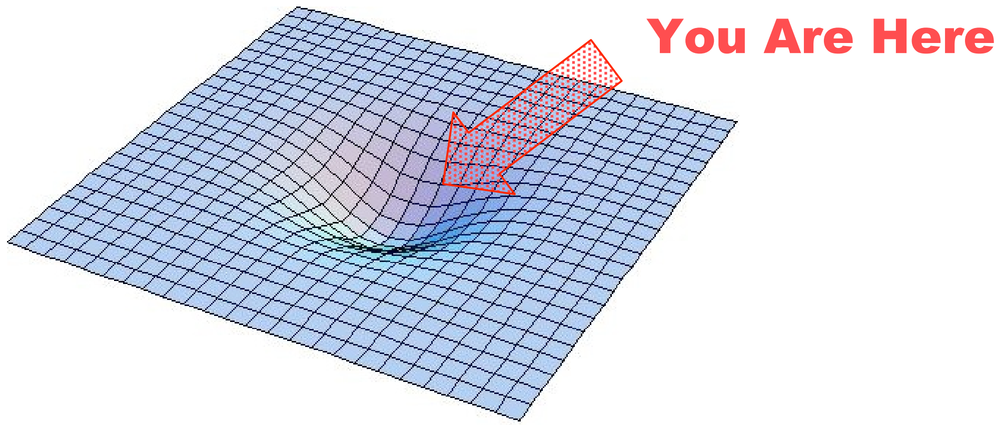
An Anthrocentric Universe



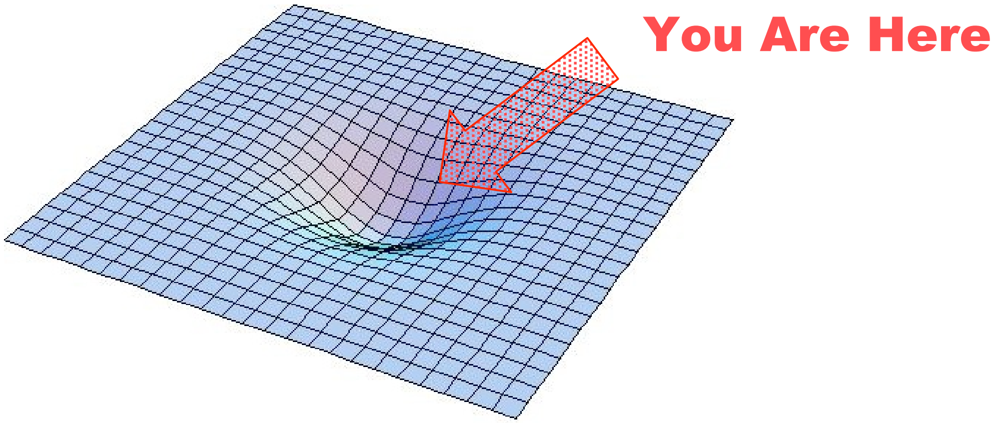
- If we happened to live very near the center of a large spherical homogeneity (an *Anthrocentric Cosmology*) then the universe would
  - appear isotropic about us.
  - the clustering would be anisotropic but, if small enough, this could be confused with redshift space anisotropies.
- There is no compelling observation to reject an Anthrocentric Cosmology out of hand.

An Anthrocentric Universe



- There are major philosophical objections -
  - it certainly is contrary to the trends of modern science.
  - it violates the Cosmological Principle - there are special places in the Universe -
  - worse yet, it violates the Copernican Principle - ***we are at the special place in the observable universe***.

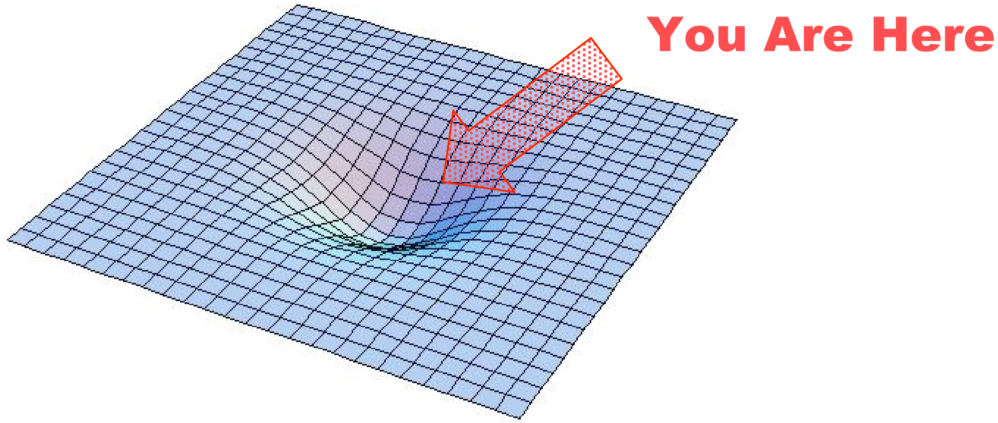
An Anthrocentric Universe



Cons:

- One can exclude the existence of other large inhomogeneities within the surface of last scattering as they would produce a large ISW feature in the CMBR.
- This anthrocentric proposal violates the fair sample clause of the Cosmological Principle if not the entire principle.
- More disturbingly it violates the Copernican Principle of Mediocrity, at least to the extent we are required to live close to the center.
- Normal "cosmological" philosophy would argue that our observational location is extremely unlikely and therefore the model itself is extremely unlikely [barring some anthropic excuse - which I don't think one can make a case for] and/or ruled out.

An Anthrocentric Universe



Pros:

- ***an anthrocentric cosmology may avoid the need for dark energy, or new physics****
- ***it is worth exploring.***

* the new physics may come from the origin of a inhomogeneous universe.

Cosmic Acceleration Lore

• Measurements [Perlmutter *et al*. 1999, Garnavich *et al*. 1999] of the (luminosity) *distance - redshift relation* have been interpreted as a measurement of acceleration of expansion of the universe.

• This in turn has been taken as indicative of either

  • a new form of gravitationally repulsive matter (*e.g*. a cosmological constant) a.k.a. *dark energy*.

  • a modification of the laws of physics (*e.g*. laws of gravity).

The Truth about Cosmic Acceleration

• As indicated by the quantity measured (distance-redshift [=velocity] relation) what is measured *is not acceleration but rather distances and velocities*!

• in physics determinations of *kinematics* (positions [=distances] and velocities) does not determine *dynamics* (accelerations and forces) w/o some other unifying principle (*e.g*. virial equilibrium).

• even a secondary indications of an acceleration universe, the ISW [Integrated Sachs-Wolfe] effect, is a measure of velocity gradients not of acceleration of objects.

• **the data give no direct measurement of unexpected forces!**

Deconstructing Cosmic Acceleration

ac.cel.er.a.tion (*physics*) *n*. the change of velocity with respect to time.

cos.mic ac.cel.er.a.tion *n*. see accelerated expansion of the universe.

ac.cel.er.a.ted ex.pan.sion of the u.ni.verse *n*. phenomena where the cosmic scale factor increases with a positive 2nd derivative with respect to time. In a Friedman-Robertson-Walker cosmology this requires a gravitationally repulsive form of matter (dark energy) and or a cosmological constant [sometimes also considered dark energy].

cos.mic scale fac.tor *n*. see Friedman-Robertson-Walker cosmology.

WYSIWYG Cosmology*: Recipe

Take what we observe as a boundary condition on the universe - see if you get something sensible.

1. Take the observed $D_A[z]$ as the final condition (on our past light cone) for a spherical mass distribution of
   a) Baryons
   b) Dark matter

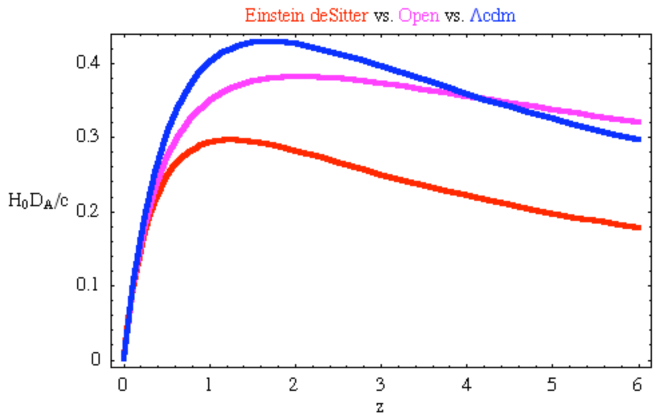
N.B. These are pressureless fluids (dust) so this is the class of Lemaitre-Tolman-Bondi (LTB) solutions.
For low-z phenomena we need not consider the gravity of the photons as dynamically important, however, since we observe the cosmic photons CMBR we must consider them latter.
More generally standard FRW cosmology has a huge number of successful predictions and an Anthrocentric model needs to reproduce all of these successes.

* see Peebles & Wilson's *Geraldine Principle*

WYSIWYG Cosmology: General Considerations

The *Dark Energy Phenomena* is roughly speaking that

- at the recession velocity [redshift] where the apparent distances start to "turn over" the turn over is too rapid.



- so the velocity gradients, $H[z]$, which starts to increase less rapidly at small z must be made to increase rapidly at z~0.7.
- recalling that adding more matter causes greater deceleration of the expansion, $H'[z]$, we see that we can do this by placing ourselves in a low density region and then surrounding ourselves with a higher density region [Tomita 2000].

History of A.U.s

- Célérier [2x1999, 3x2000, 2005] Delayed Big Bang Model
- Tomita [2000, 3x2001, 2x2002, 2003] 200 h^{-1} Mpc [off-center] void
  - uses off center observer to explain large scale flows
- Iguchi, Nakamura, Nakao [2002] find void structure from $D_L[z]$
  - ran into "Schwarzschild phenomena"
- Moffat [2x2005]; Alnes, Amarzguioui, Gron [2005]; Boljeko [2005] offshoots of studies related to "accelerated expansion from non-linear clustering"

Lemaitre-Tolman-Bondi Space-Times

The dynamics of spherical dust solutions, can, in comoving synchronous gauge, be be described by Newtonian equations for each spherical mass shell:

$$\ddot{R}[t, M] = -\frac{GM}{R[t, M]^2}$$

R - radius of mass shell determined by area as a function of time
t - proper time as experienced mass shell
M - a specific constant of motion which labels the shell with dimensions of mass

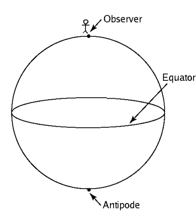
Integrating once we obtain another constant of motion, the "binding energy per unit mass":

$$B[M] = \frac{GM}{R[t, M]} - \frac{1}{2}\dot{R}[t, M]^2$$

M can [almost] be interpreted as the enclosed mass-energy including the rest mass and the gravitational binding energy:

$$dM = \mathrm{Sign}[R'] \sqrt{1 - \frac{2}{c^2} B[M]}\, dM_{\mathrm{rest}}$$

N.B. $\int \mathrm{d}M\, f[\mathrm{M}, B[M]]$, for any function f, gives constants of motion; this includes M_{rest} which must be conserved.
GR gives us the condition: $B[M] \leq 2/c^2$.
GR allows solutions where $\mathrm{B}[M] \to 2/c^2$ and $\mathrm{Sign}[R']$ changes sign (*e.g.* a closed FRW cosmology). A shell at which this occurs we call an *equatorial shell*.

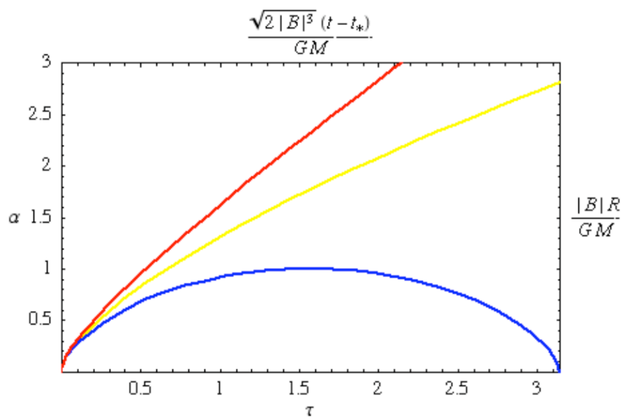


Lemaitre-Tolman-Bondi *cont'd*

Integrating again we obtain the general solution:

$$R[t, M] = \frac{GM}{|B[M]|}\, \alpha_{\mathrm{Sign[B[M]]}}\left[\frac{\sqrt{2}\,(|B[M]|)^{3/2}(t - t_*[M])}{GM}\right]$$

in terms of the dimensionless scale factor for FRW dust cosmologies:



$$\tau = +\sin^{-1}[\sqrt{\alpha_+[\tau]}] - \sqrt{(1-\alpha_+[\tau])\,\alpha_+[\tau]}$$
$$\tau = -\sinh^{-1}[\sqrt{\alpha_-[\tau]}] + \sqrt{(1+\alpha_-[\tau])\,\alpha_-[\tau]}$$

The general solution is characterized by 2 functions $B[M]$ and $t_*[M]$; the latter being the "bang time".

N.B. FRW solutions have a synchronized bang, $t_*[M]=t_i$ and $B[M]\sim M^{2/3}$.

Lemaitre-Tolman-Bondi *versus* Observables

The *dark energy phenomena* in an FRW cosmology characterized by a number Ω_0 and a function, although the function may be chosen in different ways: $D_A[z]$, $D_L[z]$, $V[z]$, $H[z]$, $a[t]$, $w[z]$, … ;

however the LTB models has two functions $B[M]$ and $t_*[M]$., so that a 1 parameter class of LTB solutions will mimic any given dark energy model.

Physically this is to expected since knowing apparent distance vs. velocity does not tell us the mass distribution (although of course the apparent distance is effected by the mass via gravitational magnification).

Since much of the mass is dark we cannot just go out and inventory the mass.

Lensing does not break this degeneracy, which cannot tell if something appears nearer because it is nearer or because it is magnified.

Without the Cosmological Principle inference engine a WYSIWYG cosmology is [at least naively] under-constrained!

Save the Hot Big Bang!

A. Synchronize Bang

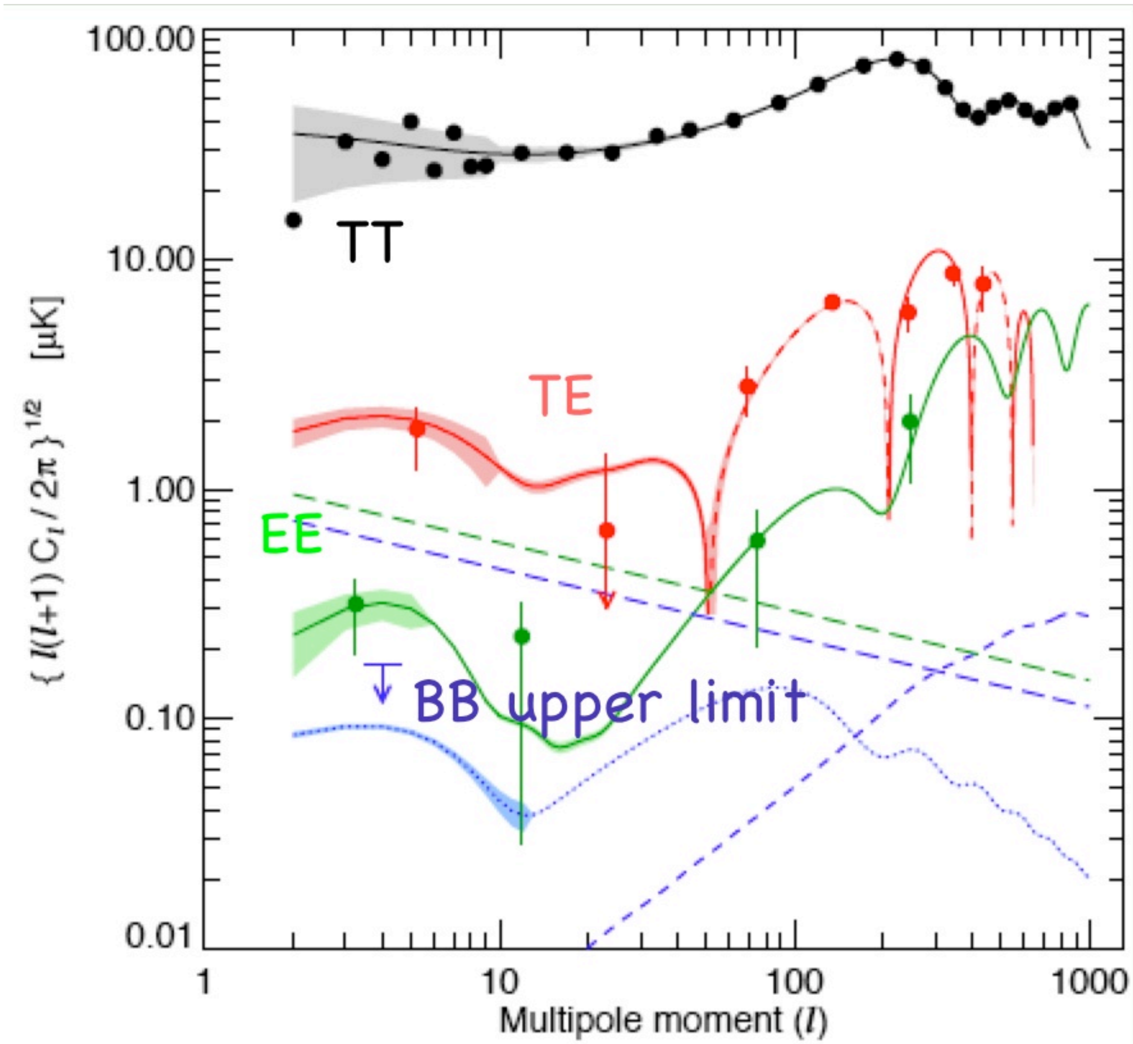
To break the degeneracy I suggest that one synchronizing the bang $t_*[M]=t_\mathrm{i}$.

- These are the two equivalent manifestations of a synchronized bang:
  1. the initial conditions consist of only growing modes.
  2. the initial expansion rate is everywhere isotropic (preserve BBN).

B. Keep It Simple Stupid

- Make the initial photon/baryon/dark matter/neutrino ratio uniform.
  1. This will preserve homogeneous Big Bang Nucleosynthesis.
  2. Compatible with CMBR.

Can the CMBR Really Work?



Can the CMBR Really Work?

CMBR anisotropies provide us with one of the most exquisitely detailed pictures of the standard hot big bang universe. It has issued in the present era of *precision cosmology*.

Q Can one really alter the basic FRW cosmological model w/o altering drastically altering the CMBR?

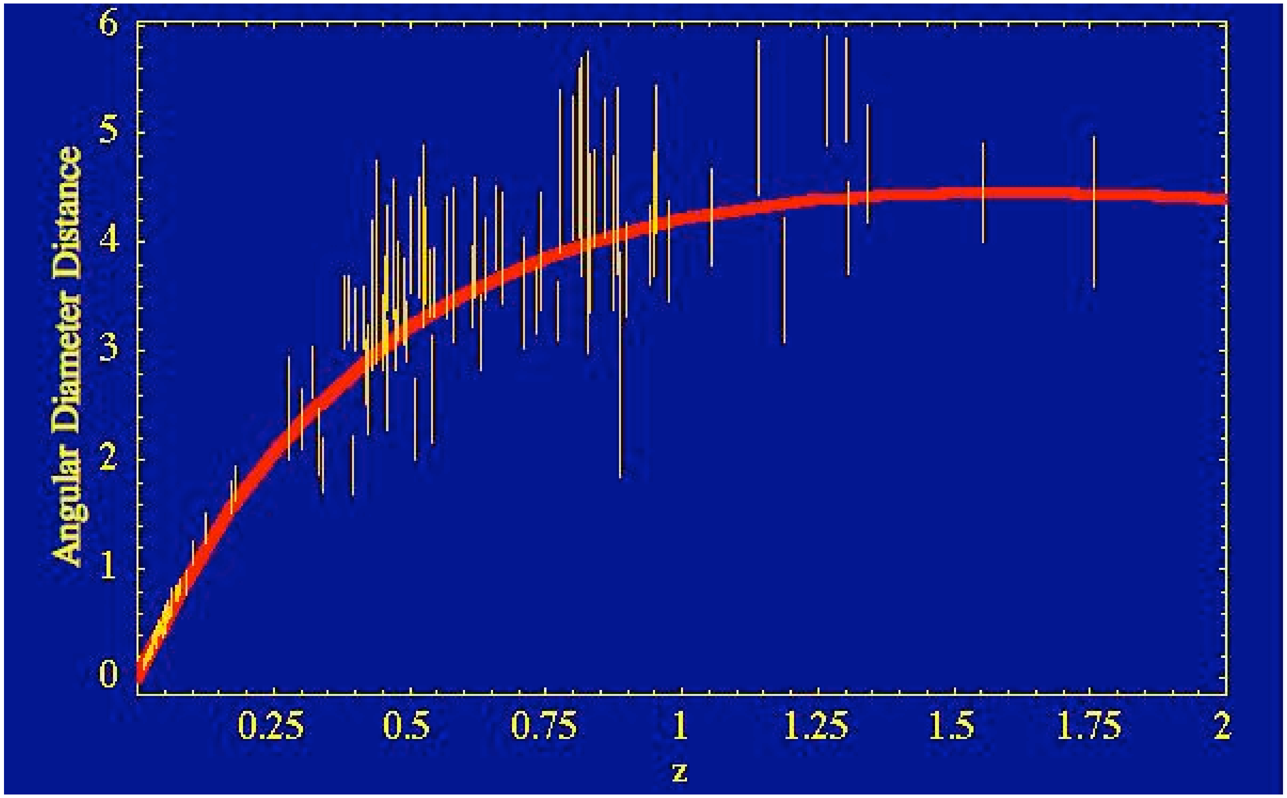
A Yes!

- Most the the CMBR predictions (acoustic peaks, etc.) are features of the [growing mode] adiabatic initial fluctuations in a dark matter + baryon + photon + neutrino cosmology.
  - A synchronize bang Anthrocentric Universe can accommodate this.
- Some large angle features depend on late time ISW and reheating and this certainly must be looked at more closely.
- Sitting at the center removes the anisotropic ISW features of a large void.

Life in Anthrocentric Cosmologies

A. Different kinds of redshift
   1. By expansion at a given position
   2. Change in photon energy of photon
B. Photon-to- Baryon ratio although initially uniform can vary with time
   1. BBN n_b/n_γ should match CMBR value (not local value)
C. Expansion is not isotropic
   1. growth of perturbations not isotropic (not a universal growth factor)
   2. objects at intermediate redshift are not statistically round
D. Schwarzschild phenomena: for simple void models, at max. of $D_A[z]$ we know that $GM=1/2\ c^2 D_A$.
   1. this is avoided if the max. is beyond the equator *i.e*. for high enough density at large z.
   2. Fixing $D_A[z]$ to the data one also may be forced to certain values of Ω_0 which may not be acceptable! However this requires find the peak of $D_A[z]$.

Weighing the Universe



In all LTB models (including FRW models) at the peak of $D_A[z]$ we know that

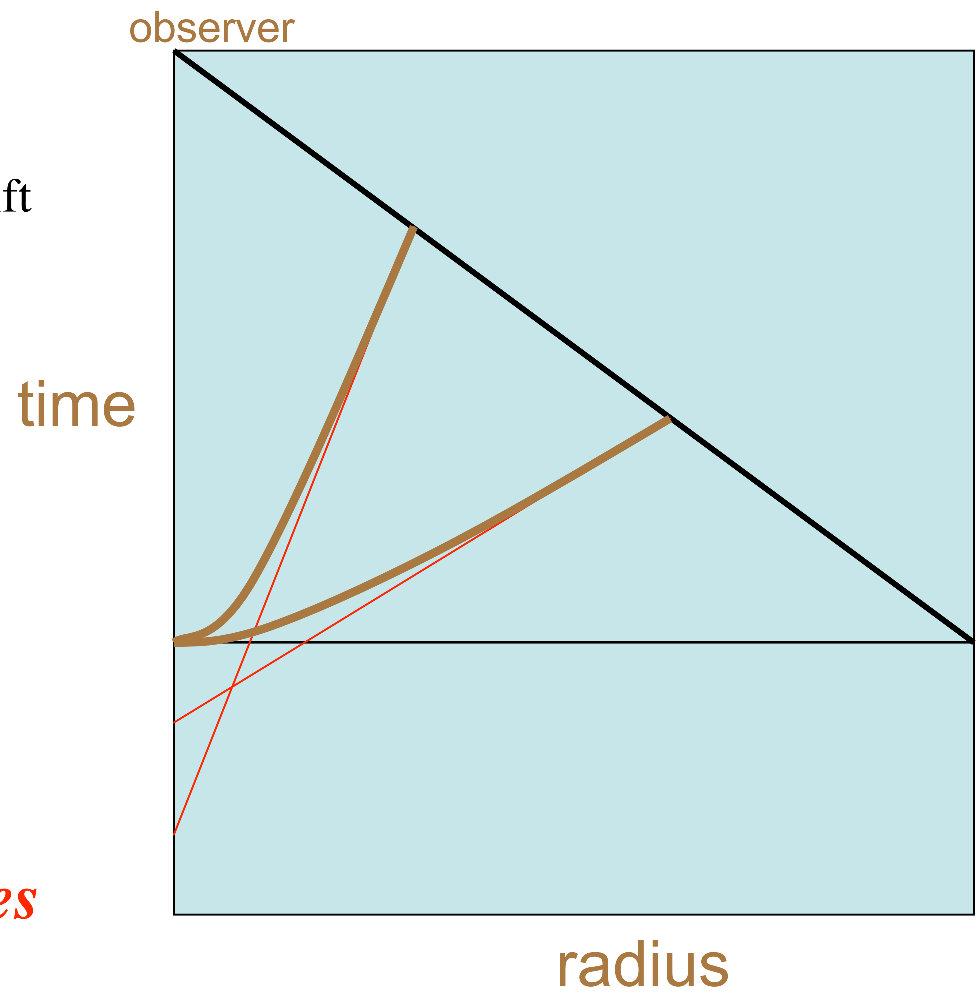
$$M = 1/2\ c^2 D_A / G$$

By measuring the peak we have weighed the universe!

Building An Anthrocentric Universe

Given a $D_A[z]$

1. start w/ Minkowski space
2. put matter at apparent distance
3. give velocity according to redshift
4. crank up mass so that all matter meet at origin at desired time in past
5. while adjusting velocity to compensate for gravitational redshift
6. while adjusting "distance" to compensate for gravitational lensing magnification



Any $D_A[z]$ can be reproduces in this way!

Mathematically You Need to Solve a set of ODE's

TensorManifoldsLemaitreTolmanBondi.nb

This leads us to define some simpler dimensionless variables

$$\frac{d\ln[R_{lc}]}{d\ln[1+z]}\Big|_{FRW} \equiv \mathrm{Sign}[R'] \sqrt{\frac{\alpha_{lc}\,(1+2\,\varphi)}{\mp 2\,\varphi\,(1\mp\alpha_{lc})}} - 1.$$

$$\Delta \equiv \frac{\frac{d\ln[R_{lc}]}{d\ln[1+z]}}{\frac{d\ln[R_{lc}]}{d\ln[1+z]}\Big|_{FRW}} - 1$$

$$T \equiv \frac{\tau_{\pm}[\alpha_{lc}]}{\alpha_{lc}^{3/2}\sqrt{1\mp\alpha_{lc}}}$$

Note that in a true FRW universe

$$\frac{d\ln[R_{lc}]}{d\ln[1+z]} = \frac{d\ln[R_{lc}]}{d\ln[1+z]}\Big|_{FRW}$$

Also note that for the bound case $T \in (1, \infty)$ and for the unbound case $T \in (0, 1)$, both approaching unity as $\alpha_{lc} \to 0$ at early times. In terms of these variables the ODE's simplify considerably

$$\frac{d\ln[\varphi]}{d\ln[1+z]}\Big|_{\xi=0} = 2\left(\frac{d\ln[R_{lc}]}{d\ln[1+z]}\Big|_{FRW} + 1\right)\left(1 - \frac{\Delta\,T}{2-(3\mp 2\,\alpha_{lc})\,T}\right) .$$

$$\frac{d\ln[\alpha_{lc}]}{d\ln[1+z]}\Big|_{\xi=0} = \frac{d\ln[R_{lc}]}{d\ln[1+z]} - \left(\frac{d\ln[R_{lc}]}{d\ln[1+z]}\Big|_{FRW} + 1\right)\left(1 + \frac{2\,\Delta}{2-(3\mp 2\,\alpha_{lc}+\Delta)\,T}\right)\left(1 - \frac{\Delta\,T}{(2-(3\mp 2\,\alpha_{lc})\,T)}\right)$$

150%

Summary

• ***On the largest scales the cosmological principle is assumed rather than tested.***

• ***Tests of cosmological consistency are possible in the forseeable future.***

• ***Breaking the cosmological principle w/ an Anthrocentric Universe may explain the accelerating universe phenomena.***

• ***Such a model is consistent with many of the successes of standard FRW cosmology.***

• ***It is premature to say that an Anthrocentric model is really viable - but this should be explored (dark energy is a G$ industry).***

The next time someone accuses you of

“*thinking the whole universe is centered around you*”

you might reply

“*That just might be true*”.