

Modern Cosmology: What parts of it should we trust?

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Phoenix Astrocamp
1 June 2008

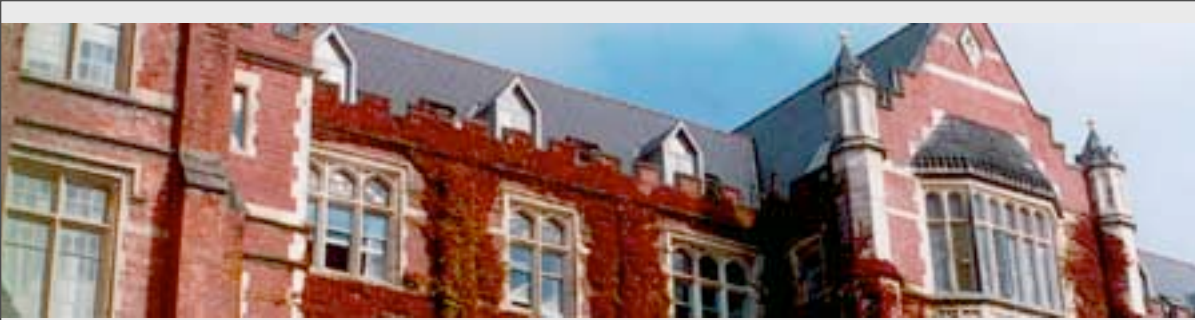




Abstract:

By the time modern cosmology has been filtered through a few reporters and editors, what reaches the general public is often a pale and distorted reflection of what the scientific community actually thinks.

I will present overview of big bang cosmology, carefully distinguishing what we really know for sure (well, almost for sure), from what we can plausibly infer, from what is speculation at the edges of our knowledge.



“There is something fascinating about science. One gets such wholesome returns of conjecture out of such a trifling investment of fact.”

--- Mark Twain



“It is important to keep an open mind; just not so open that your brains fall out”

--- Albert Einstein

What parts of cosmology are rock solid?

Recession of galaxies

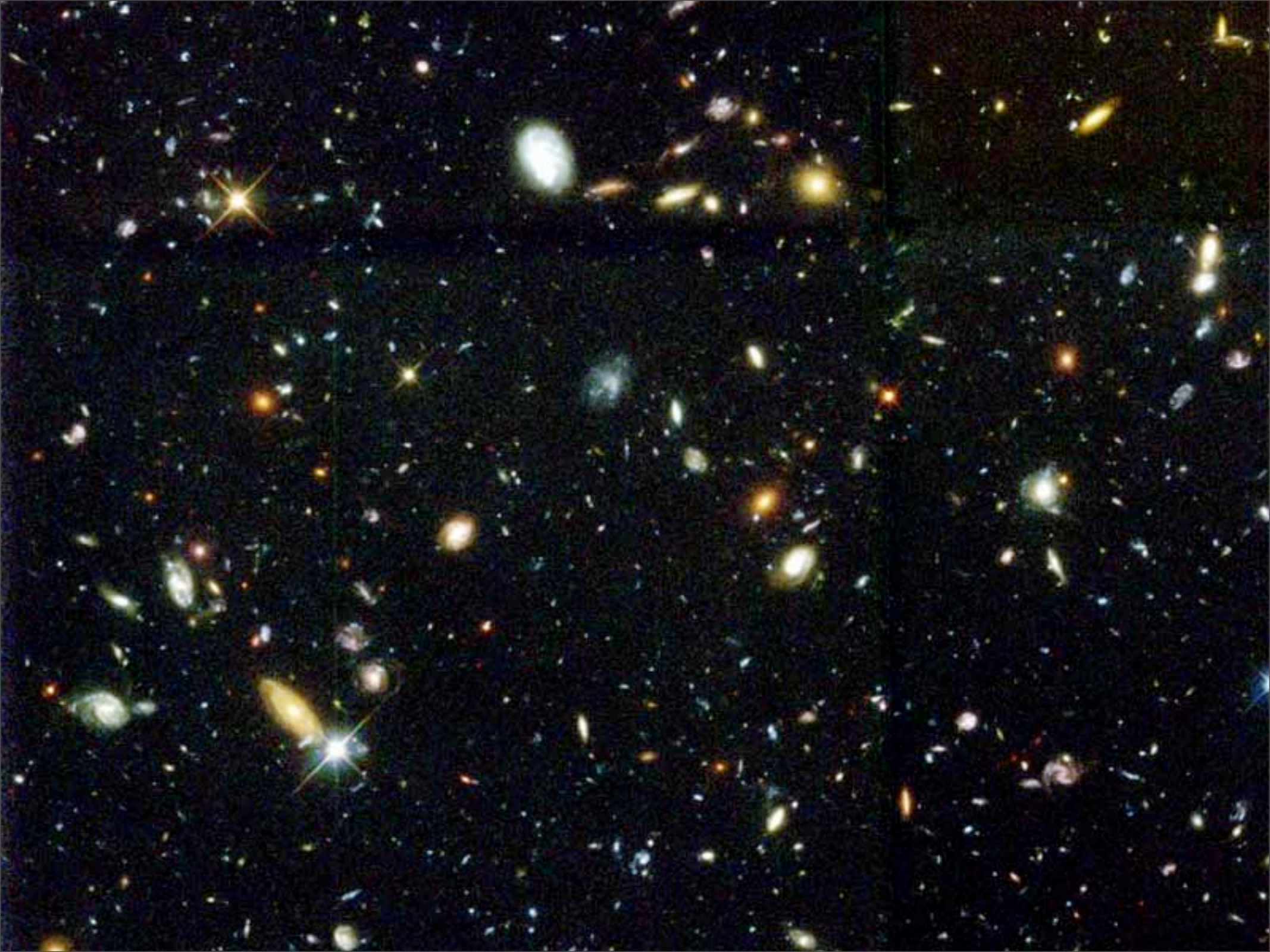
Approximate linear Hubble law

Galactic evolutionary effects

Cosmic Background Radiation

Stellar structure and evolution

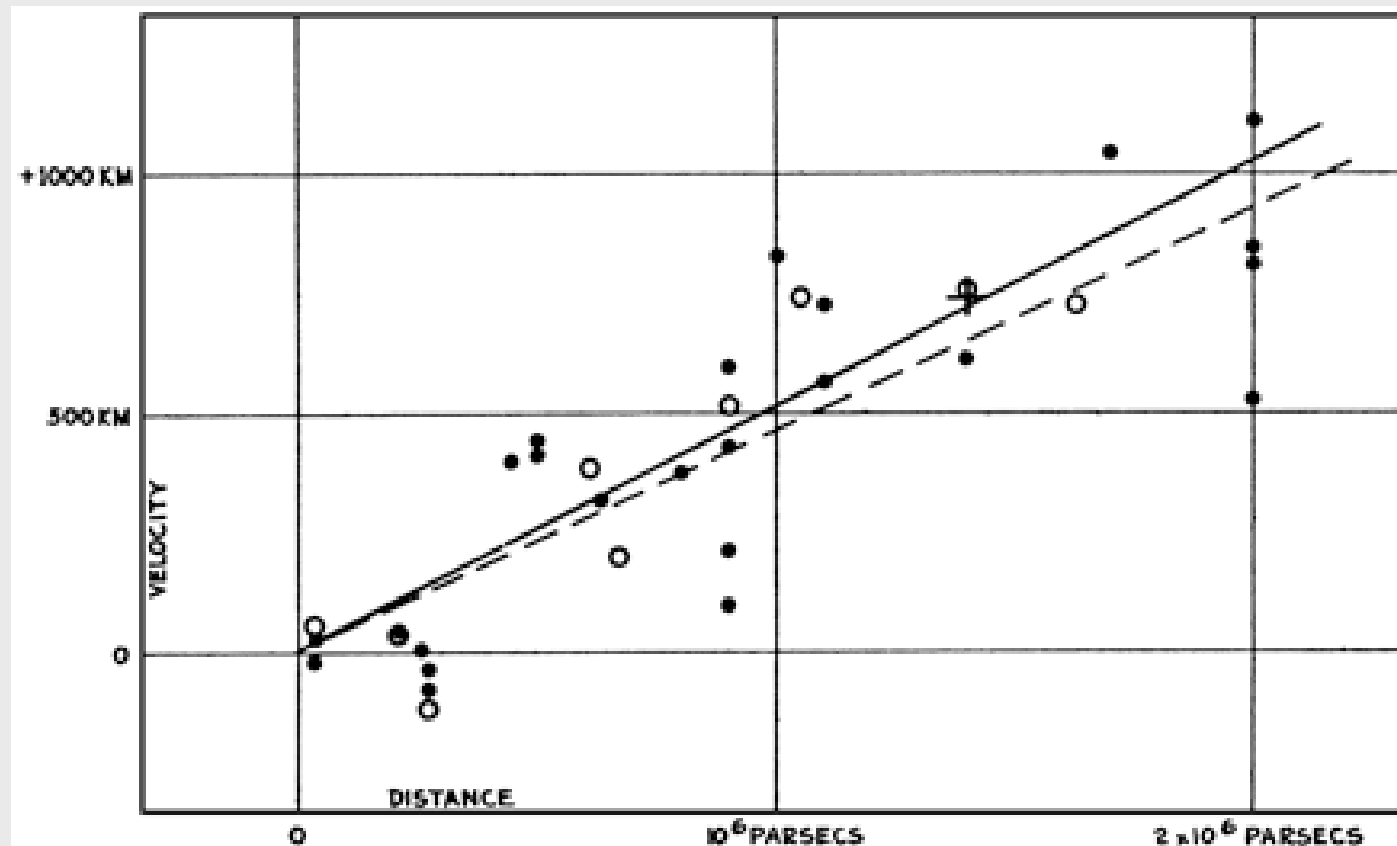
Big bang physics
(at least back to cosmological nucleosynthesis)





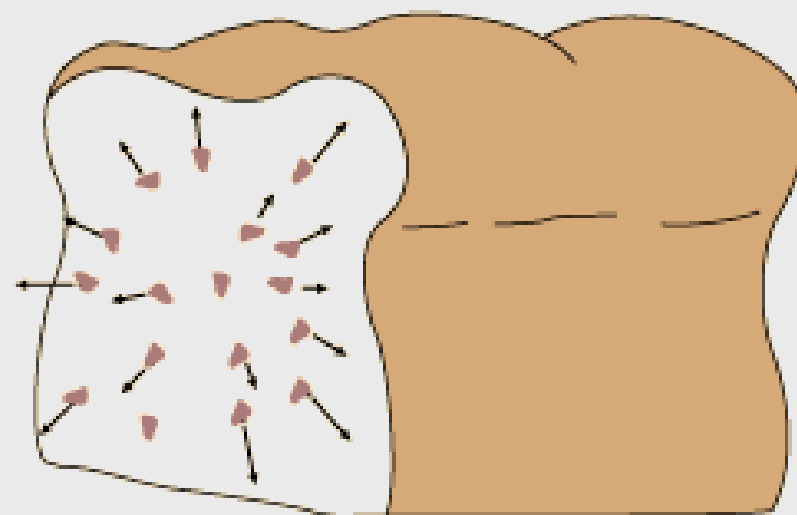
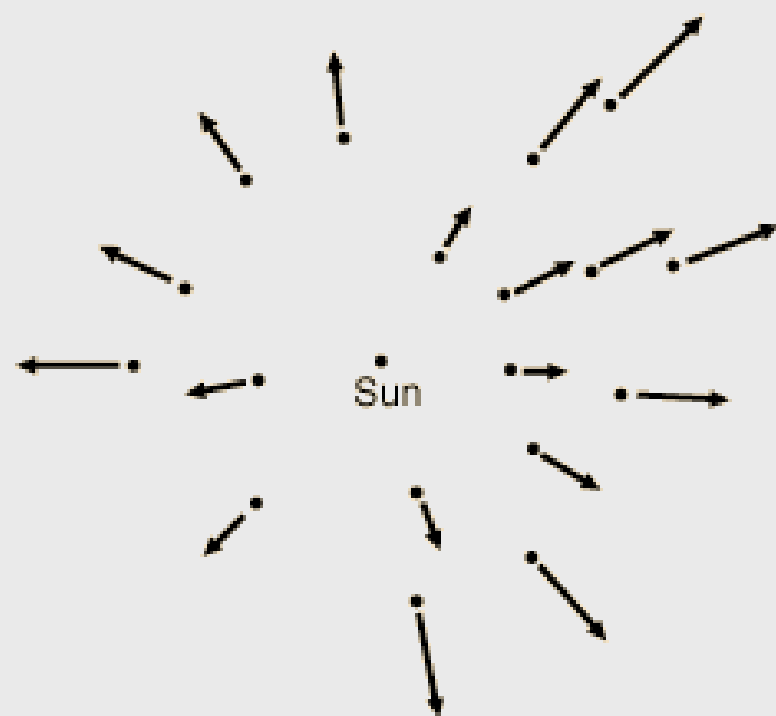
The original Hubble law:

$$v = H_0 d; \quad H_0 \approx 500 \text{ (km/sec)/Mpc.}$$

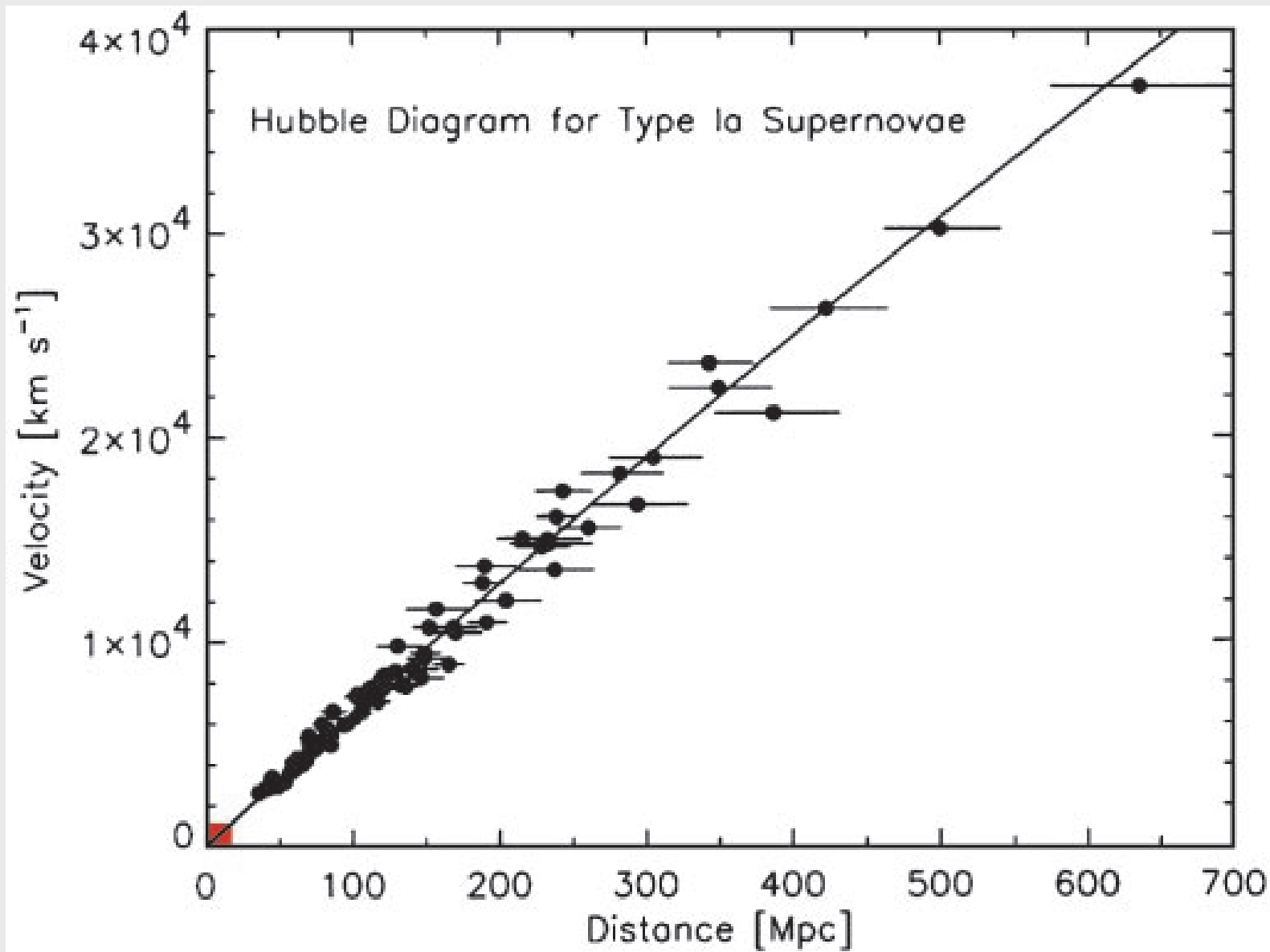


1929

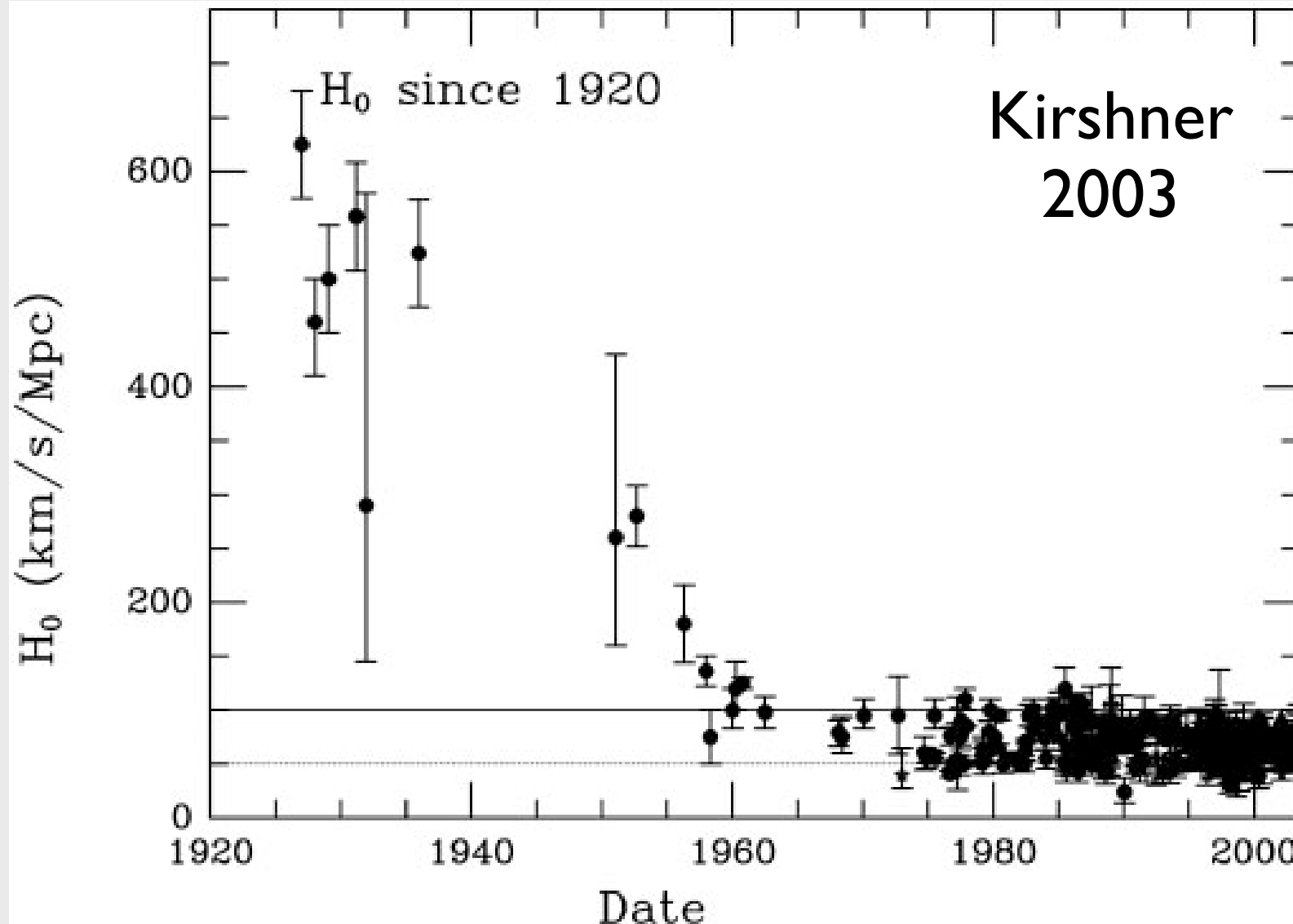
[Hubble, E. P. (1929) *Proc. Natl. Acad. Sci. USA* 15, 168–173]



2003



The Hubble diagram for type Ia supernovae. The scatter about the line corresponds to statistical distance errors of $< 10\%$ per object. The small red region in the lower left marks the span of Hubble's original Hubble diagram from 1929. [Kirshner 2003]

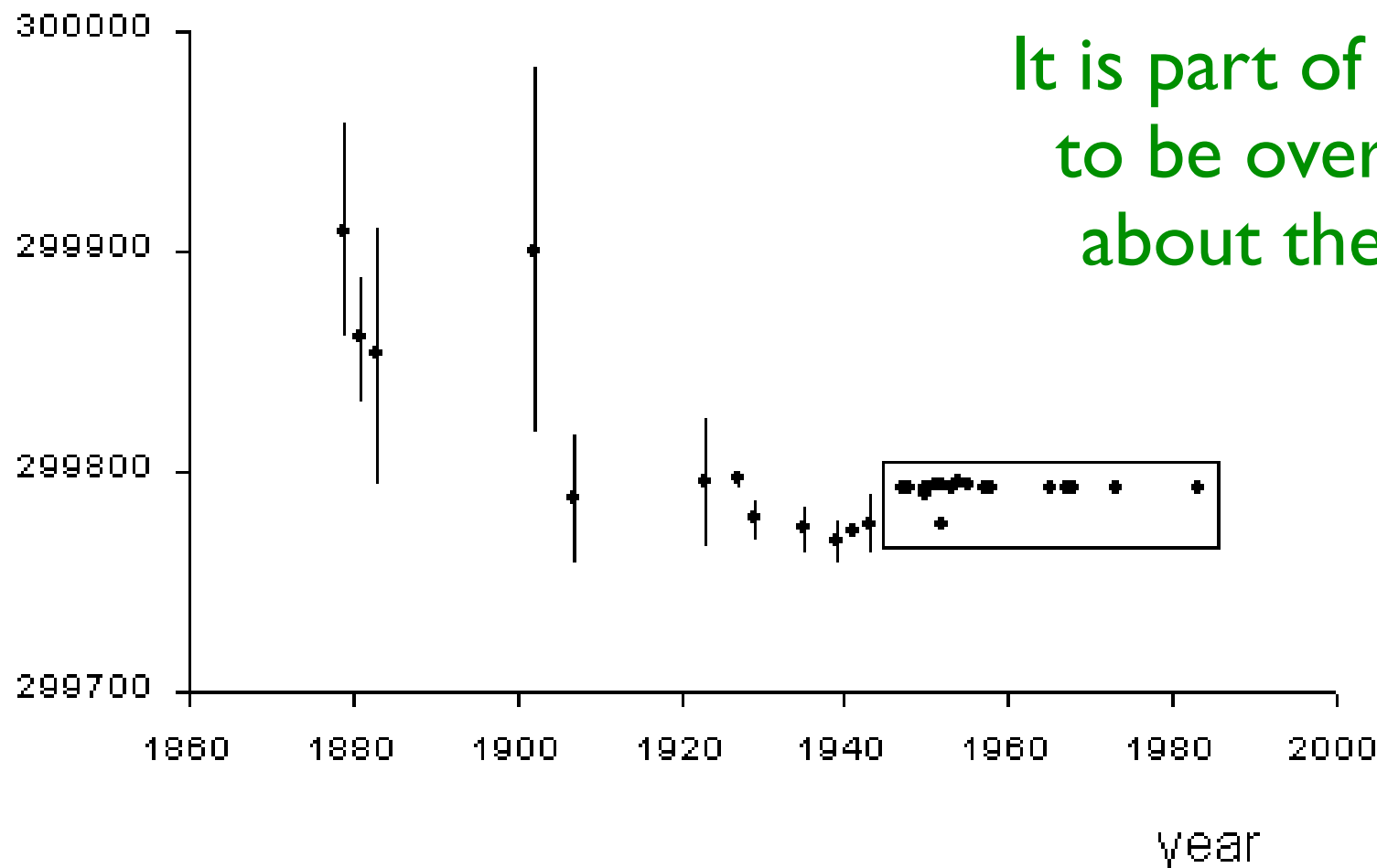


Published values of the Hubble parameter versus time.
At each epoch, the estimated error in the Hubble parameter is small compared with the subsequent changes in its value.
This is a symptom of underestimated systematic errors.



Speed of light since 1880:

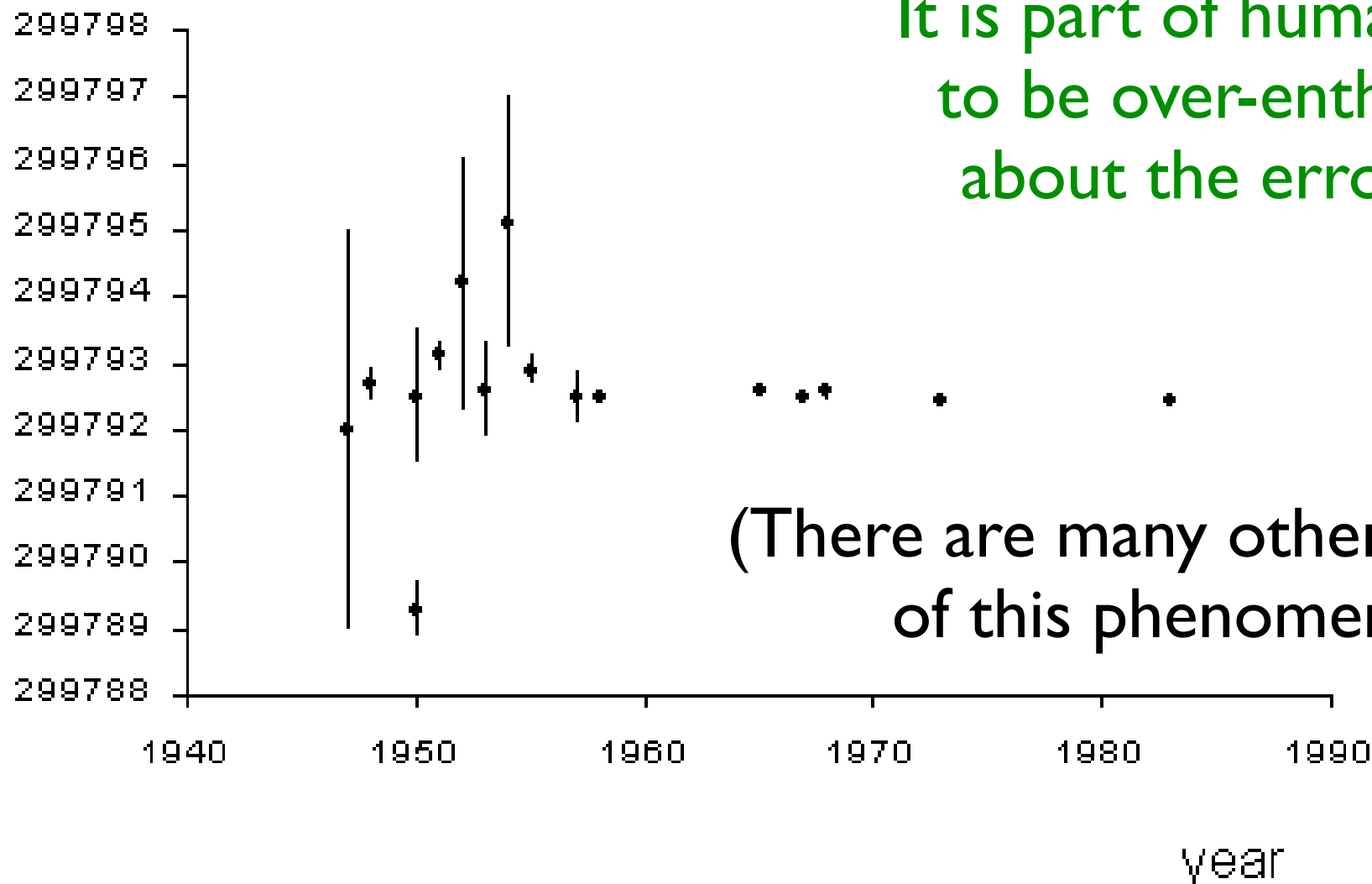
Speed (km/s)



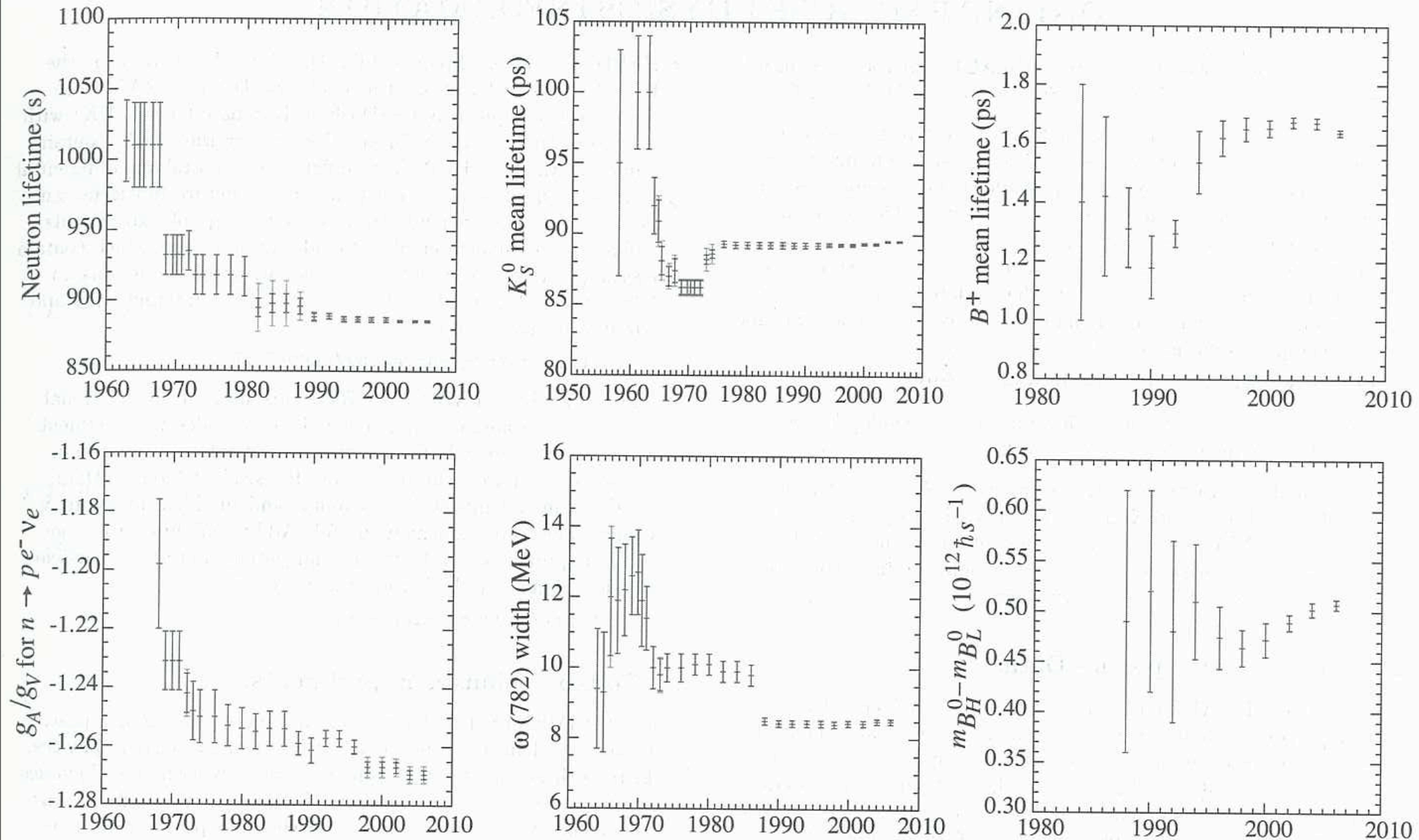


Speed of light since 1940:

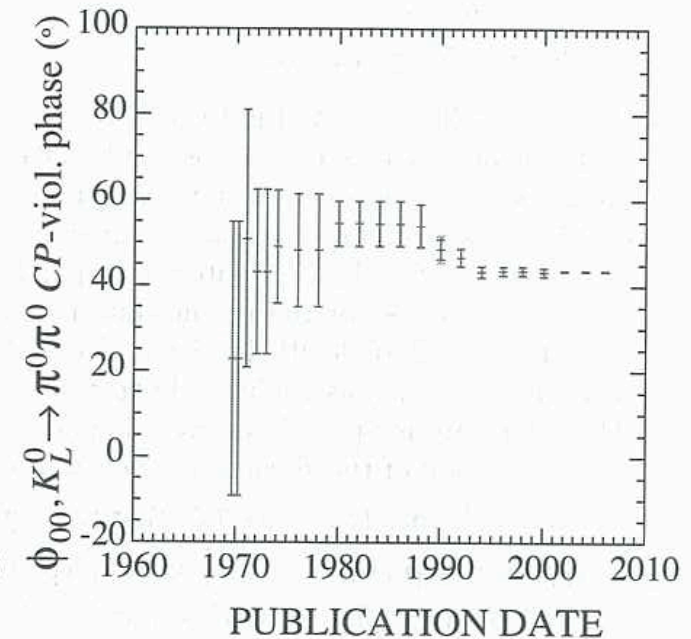
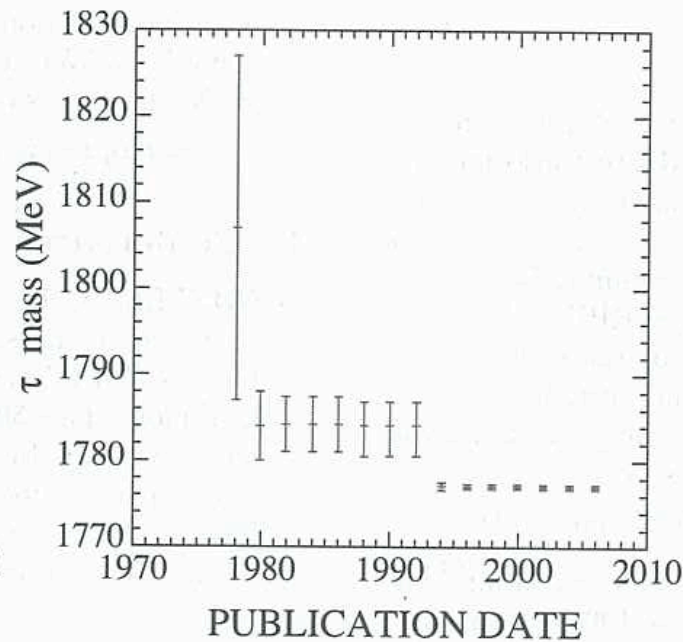
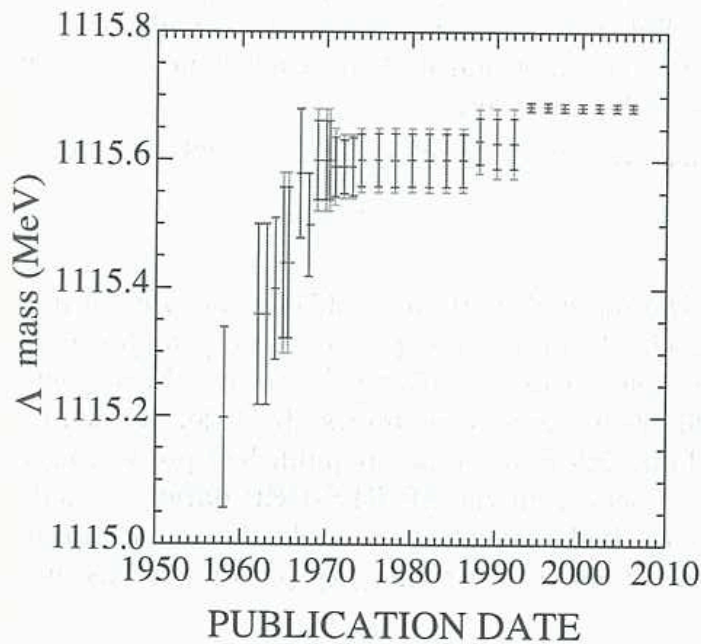
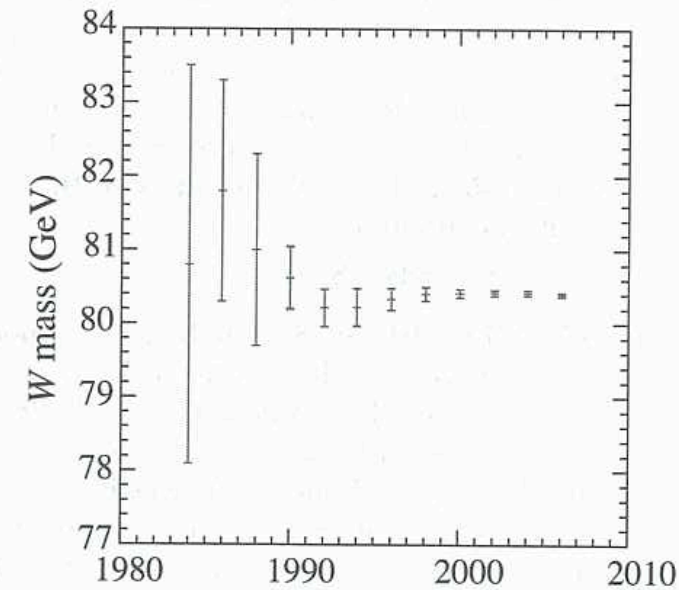
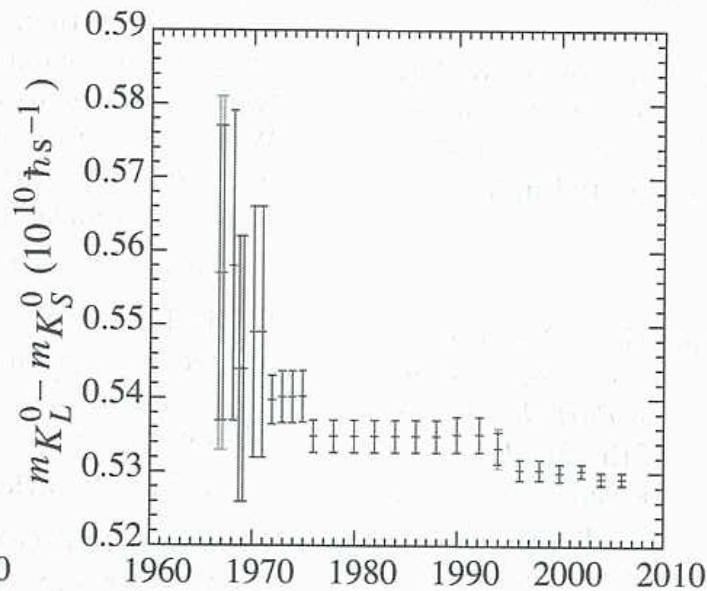
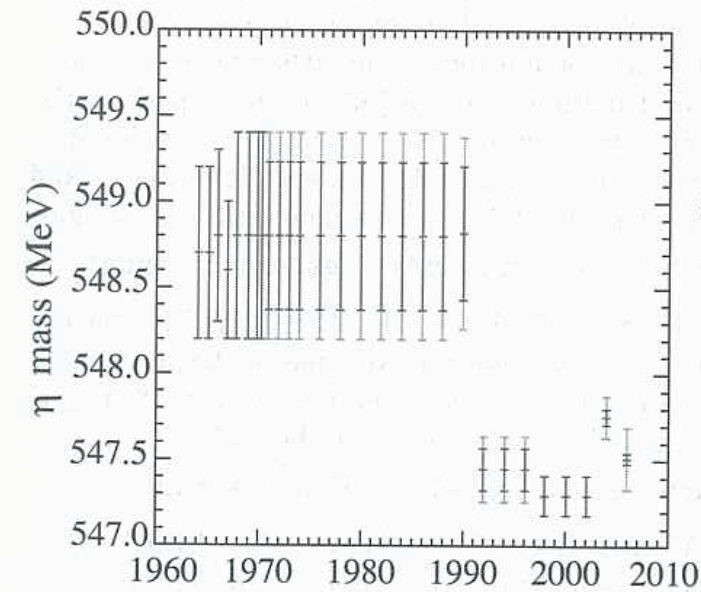
Speed (km/s)

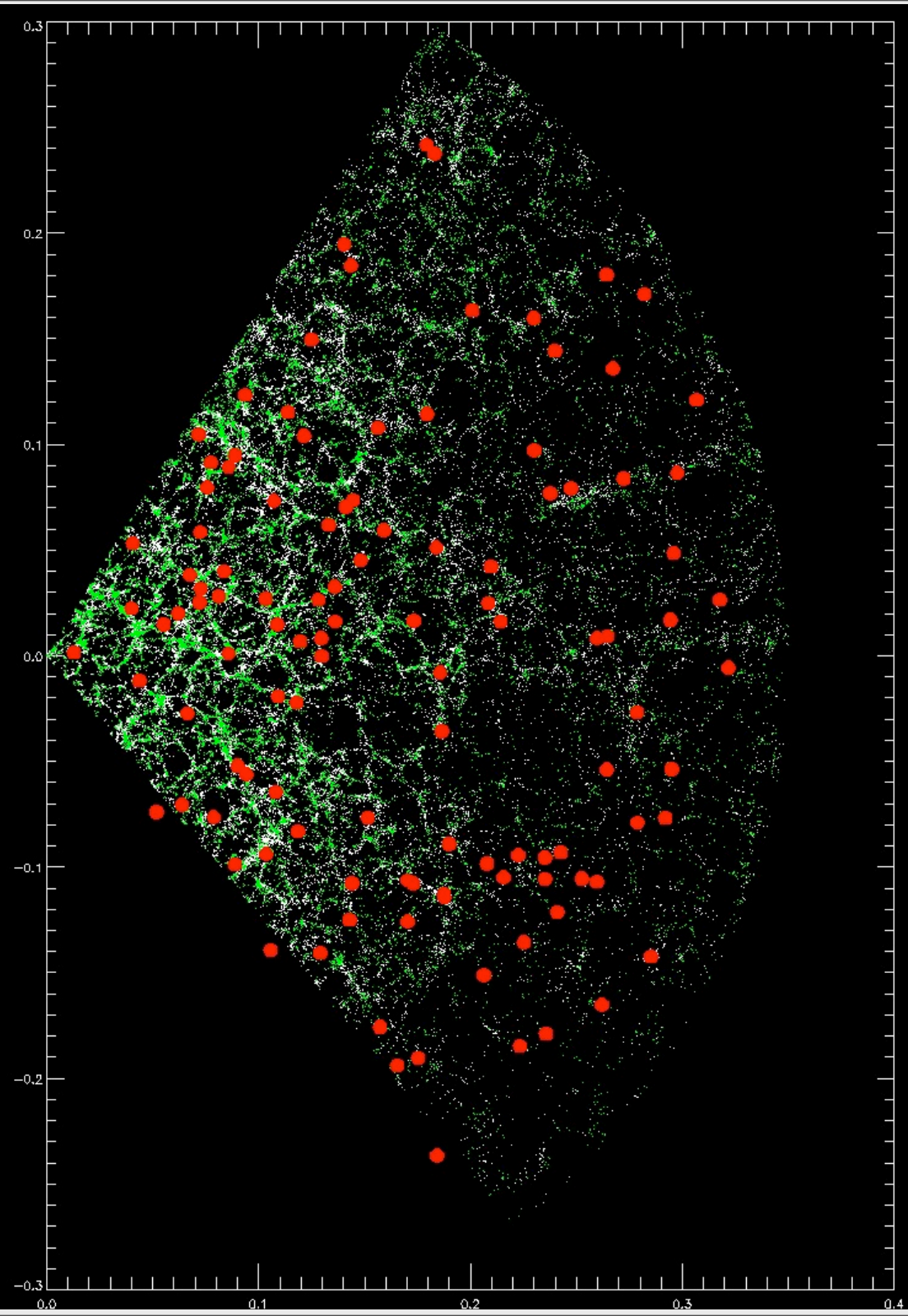
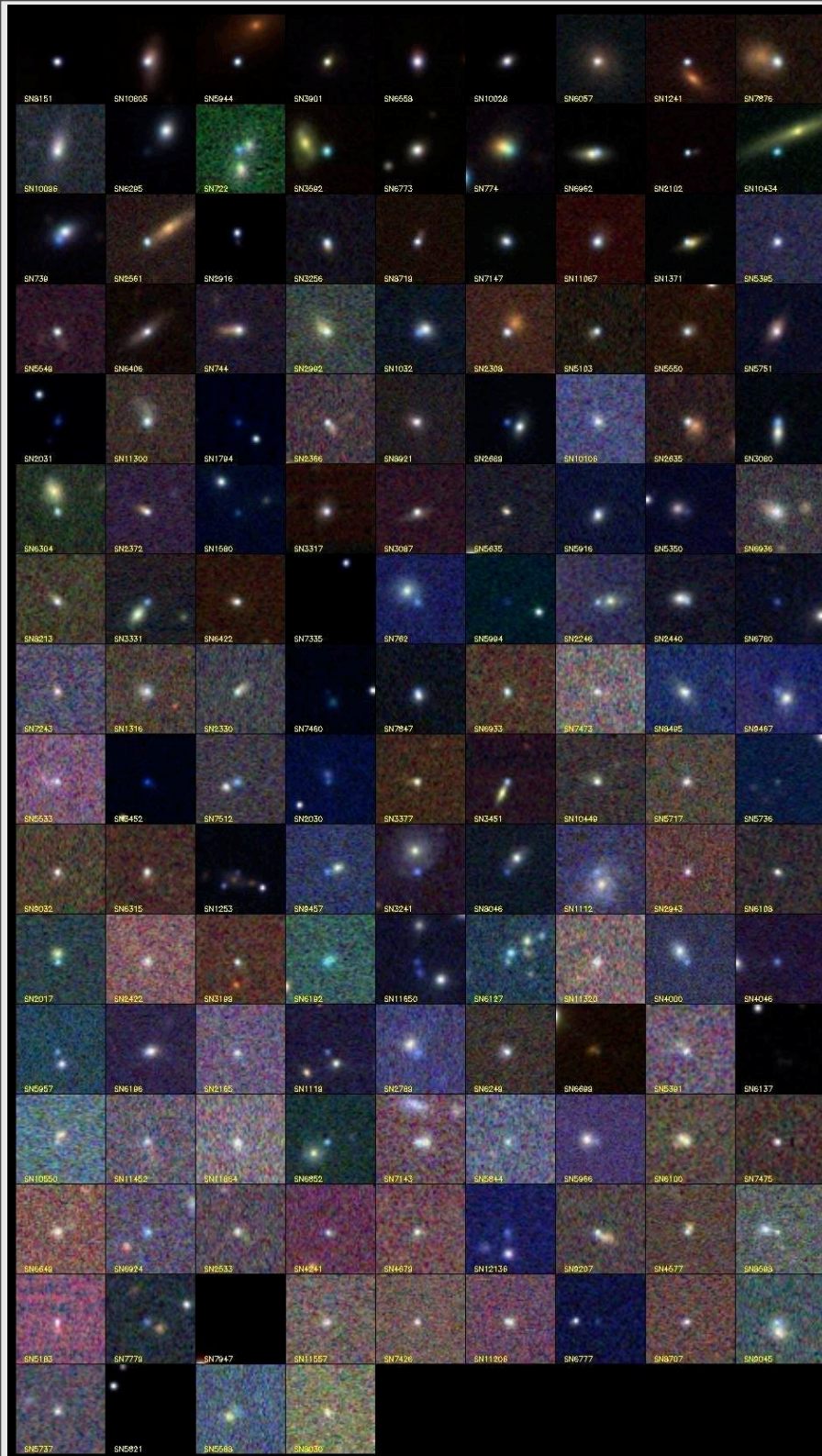


Selected measurements from particle physics:



Selected measurements from particle physics:







Preponderance of evidence:

The universe is accelerating.

But (based on supernova data alone),
this acceleration is not established
“beyond reasonable doubt”.

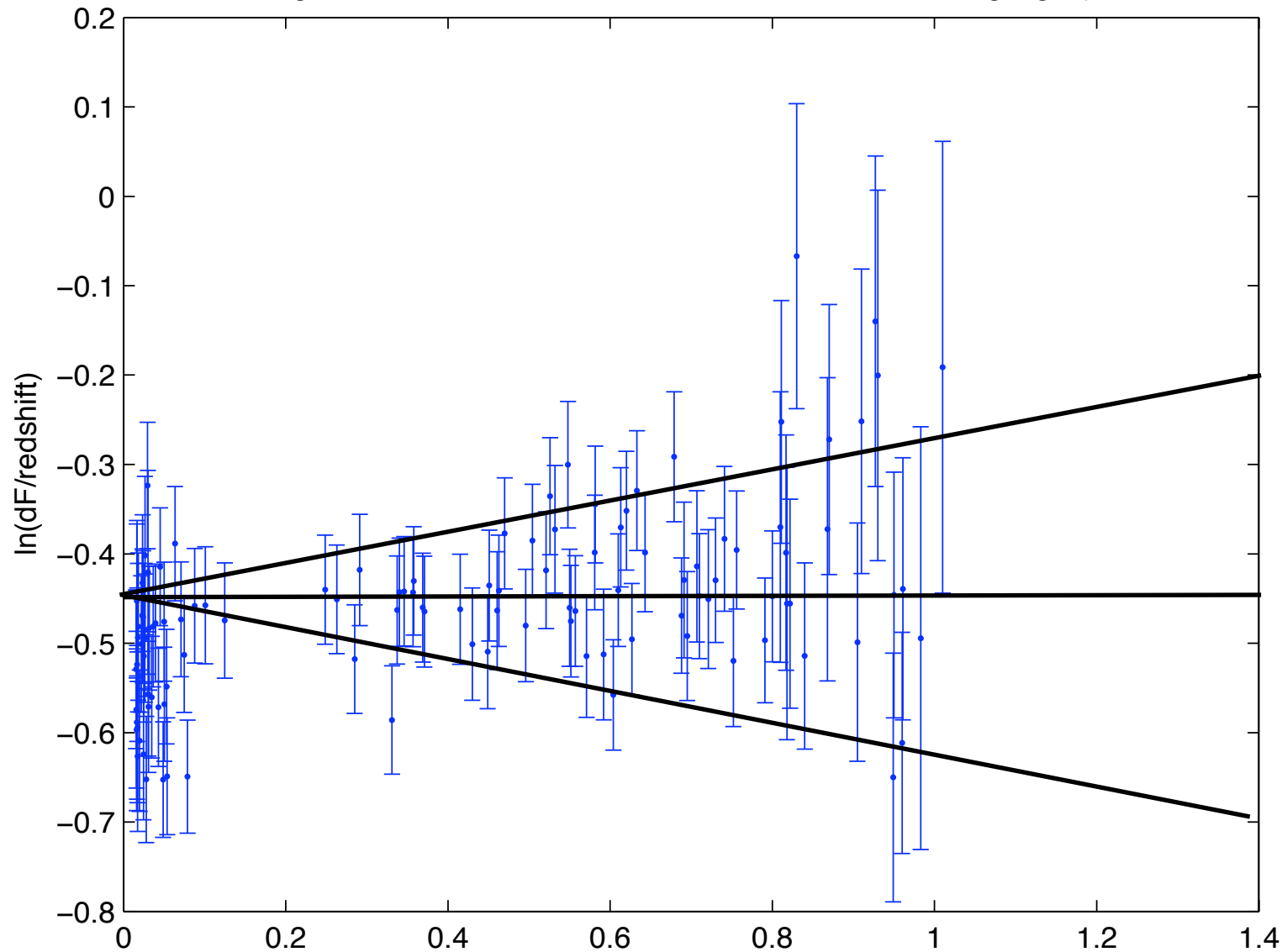
There are an awful lot of subtleties hiding in the
woodwork of the statistical analyses...

Antidote to excessive statistical sophistication:



Antidote:

Logarithmic Photon flux distance versus z-redshift using legacy05



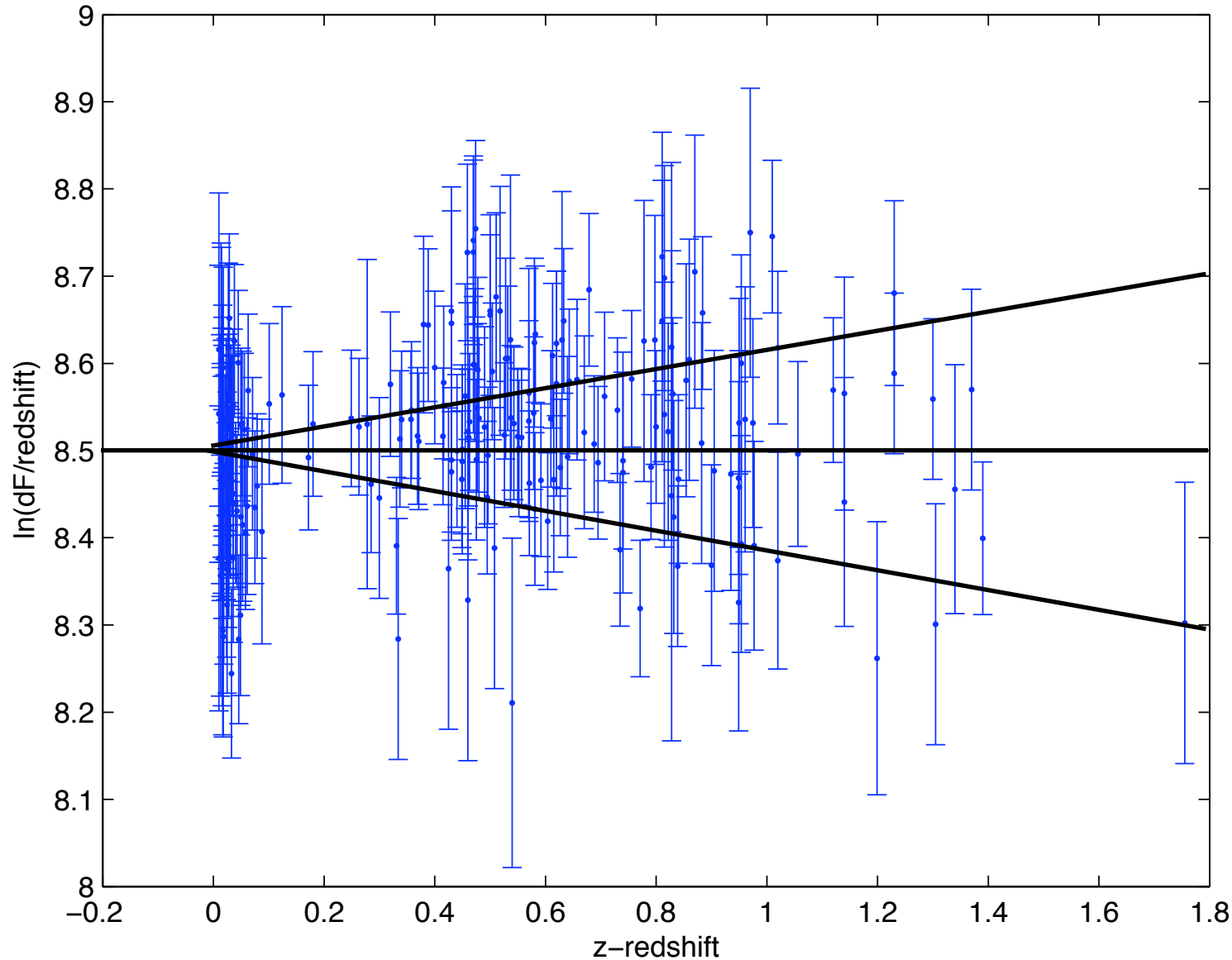
(statistical
uncertainties
only)

legacy 05



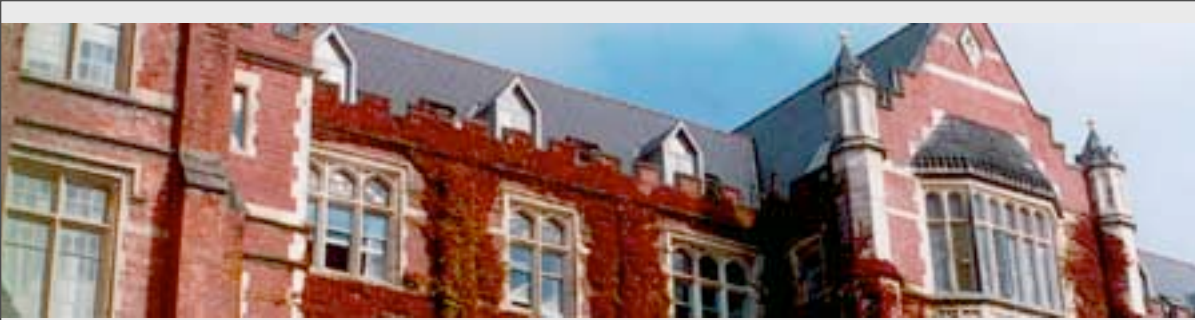
Antidote:

Logarithmic Photon flux distance versus z-redshift using gold06



(statistical
uncertainties
only)

gold 06



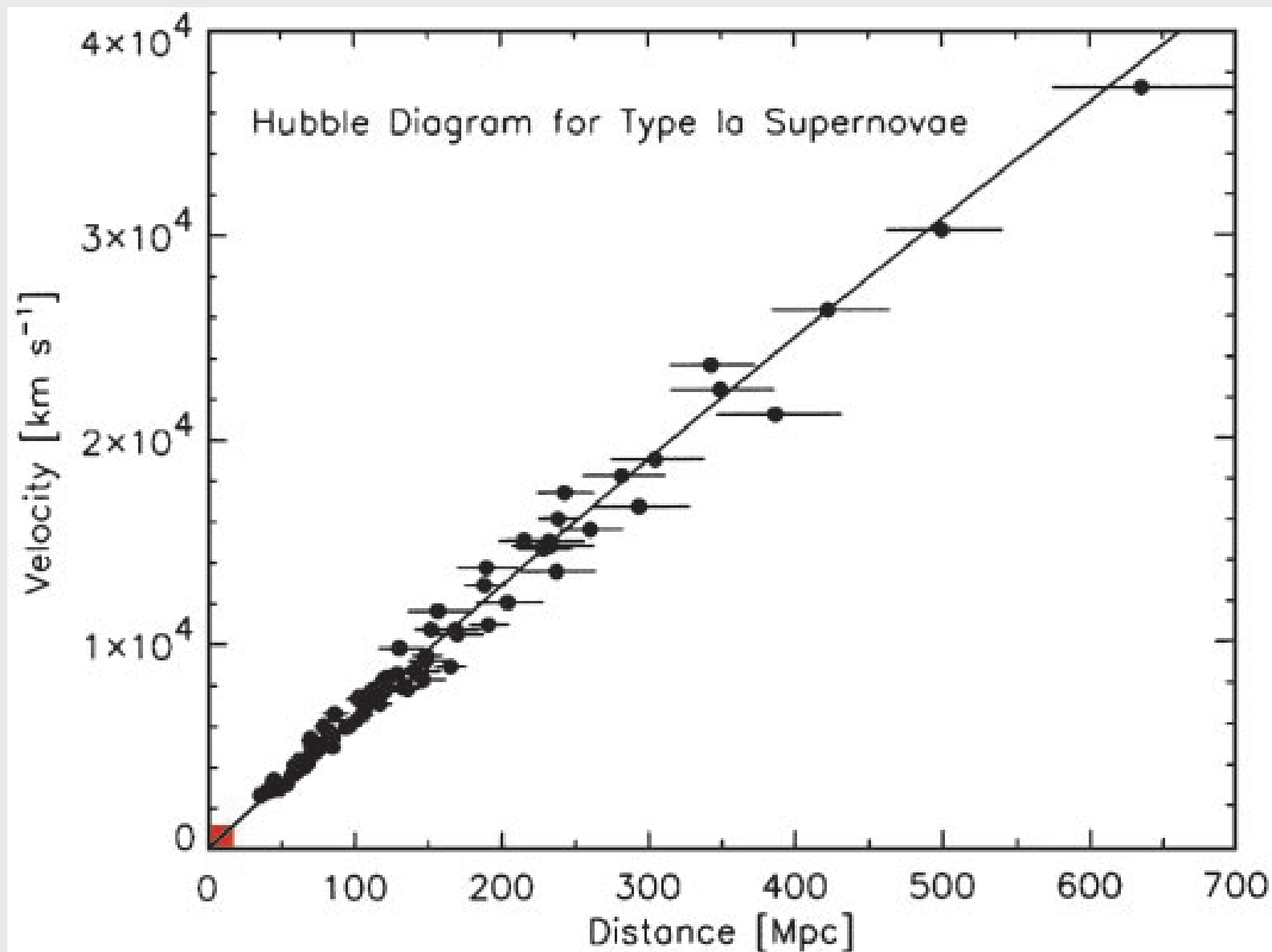
- * The fact that there is no overwhelmingly obvious visual trend in these graphs tells you that extracting the deceleration parameter will at best be a very tricky and uncertain process.
- * However, the leading linear term in the Hubble law,

$$d = \frac{c z}{H_0} + \mathcal{O}(z^2),$$

is certainly well supported
by the supernova data.



2003





- * Some parts of cosmology are already precision science.
- * Cosmological distance determinations, however, are not yet precision science.

“Precision cosmology? Not just yet.”



Puzzle:

The cosmic background radiation is very smooth.

The distribution of galaxies is very lumpy.

But is the geometry of spacetime very lumpy?
Or is it very smooth?

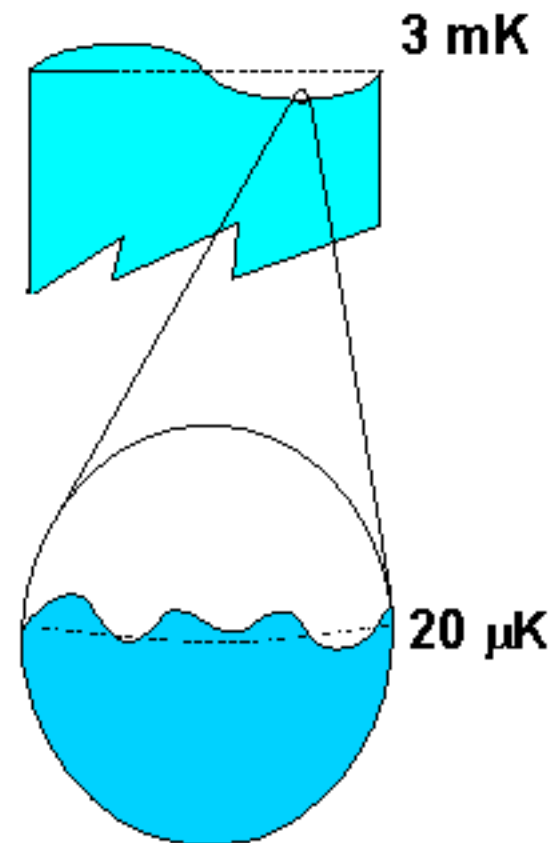
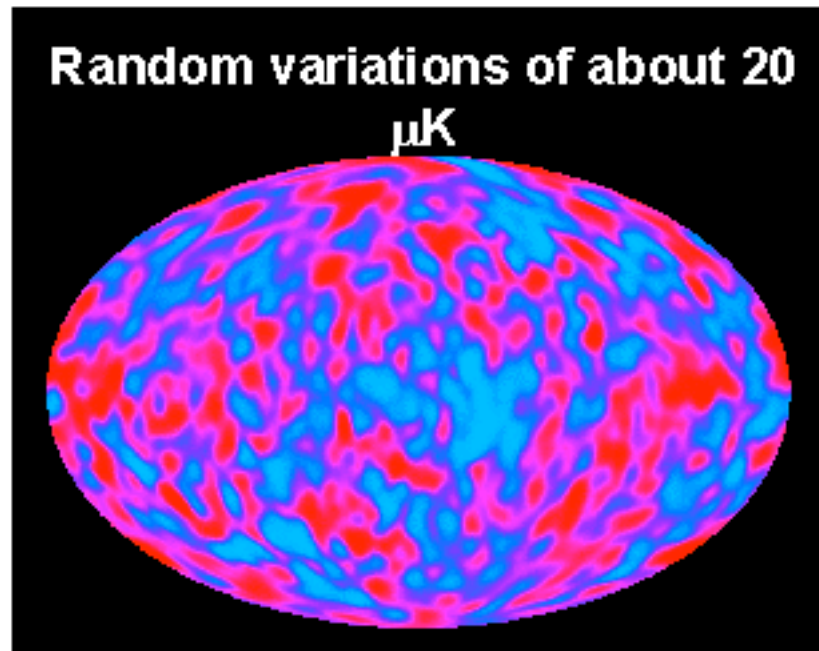
CBR: $z \sim 1088$

Galaxies: $z \sim 0$ to 6



CMB:
CBR:

EVEN SMALLER VARIATIONS IN T_{CBR}



homogeneous to about one in a million



but
large
density
fluctuations!

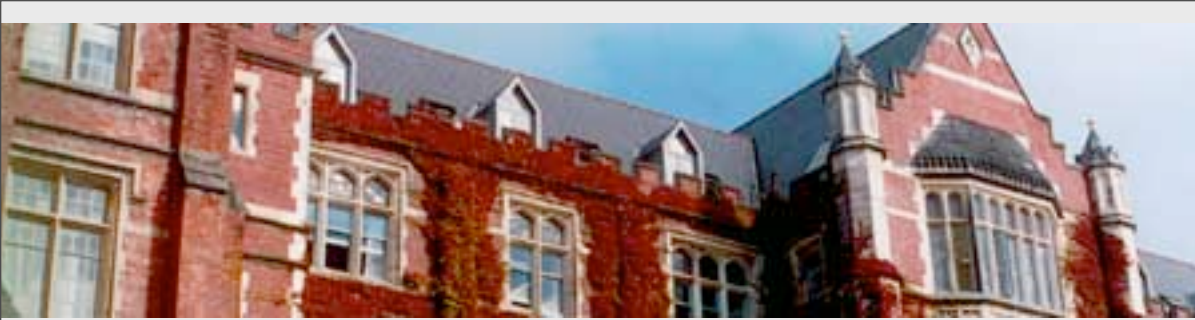


And we have to look past all the lumpy galaxies
to see the smooth background radiation...

And Einstein tells us that lumpy matter should lead
to lumpy spacetime geometry...

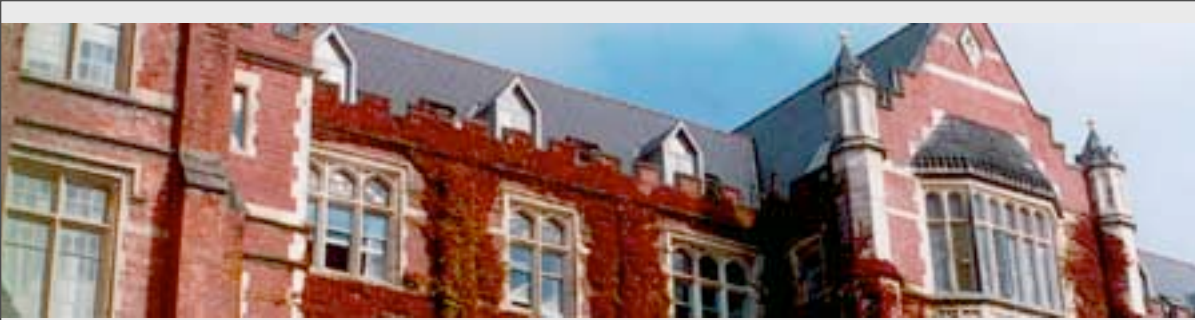
This happens to some extent, but maybe
not as much as we would expect?

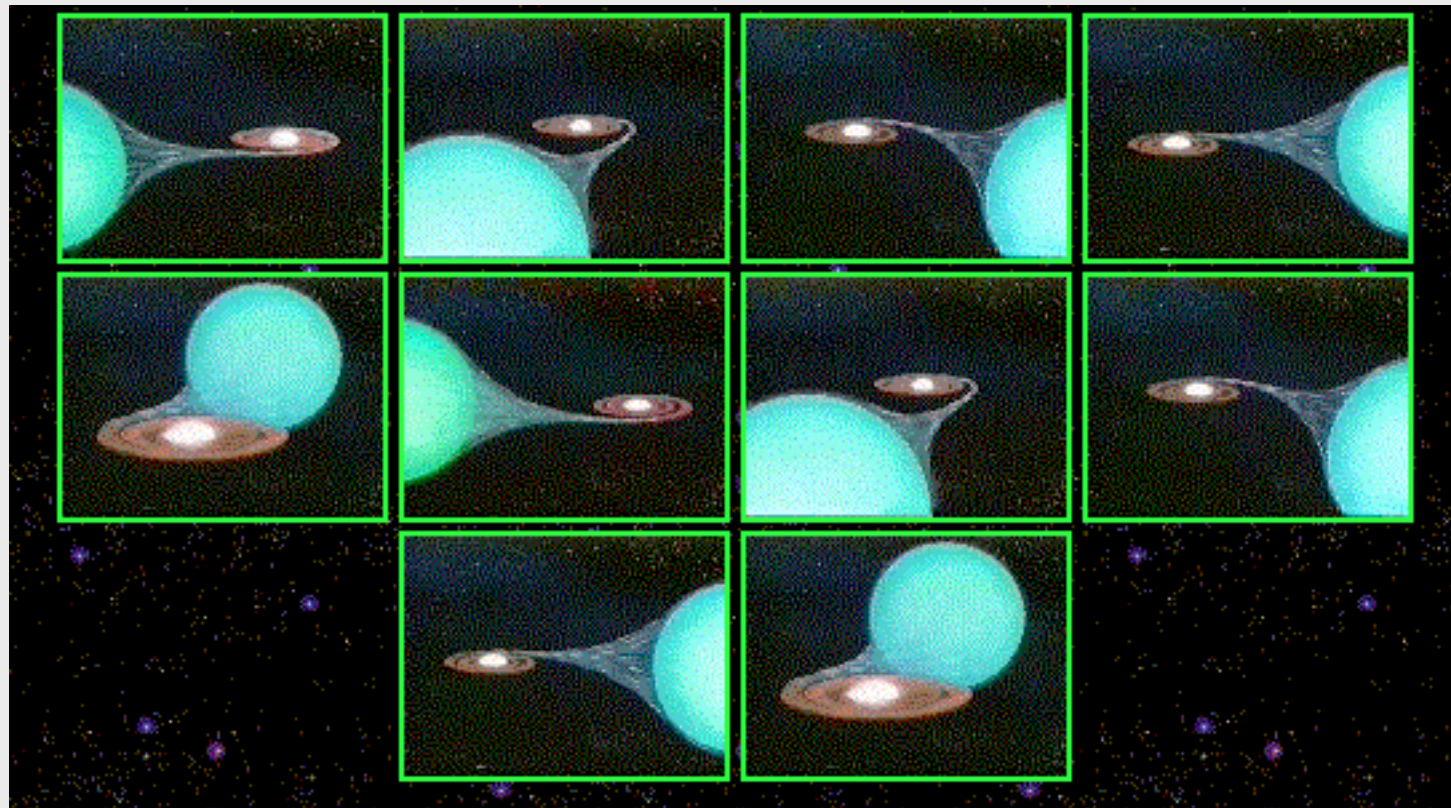
David Wiltshire: U Canterbury --- fractal bubble universe.







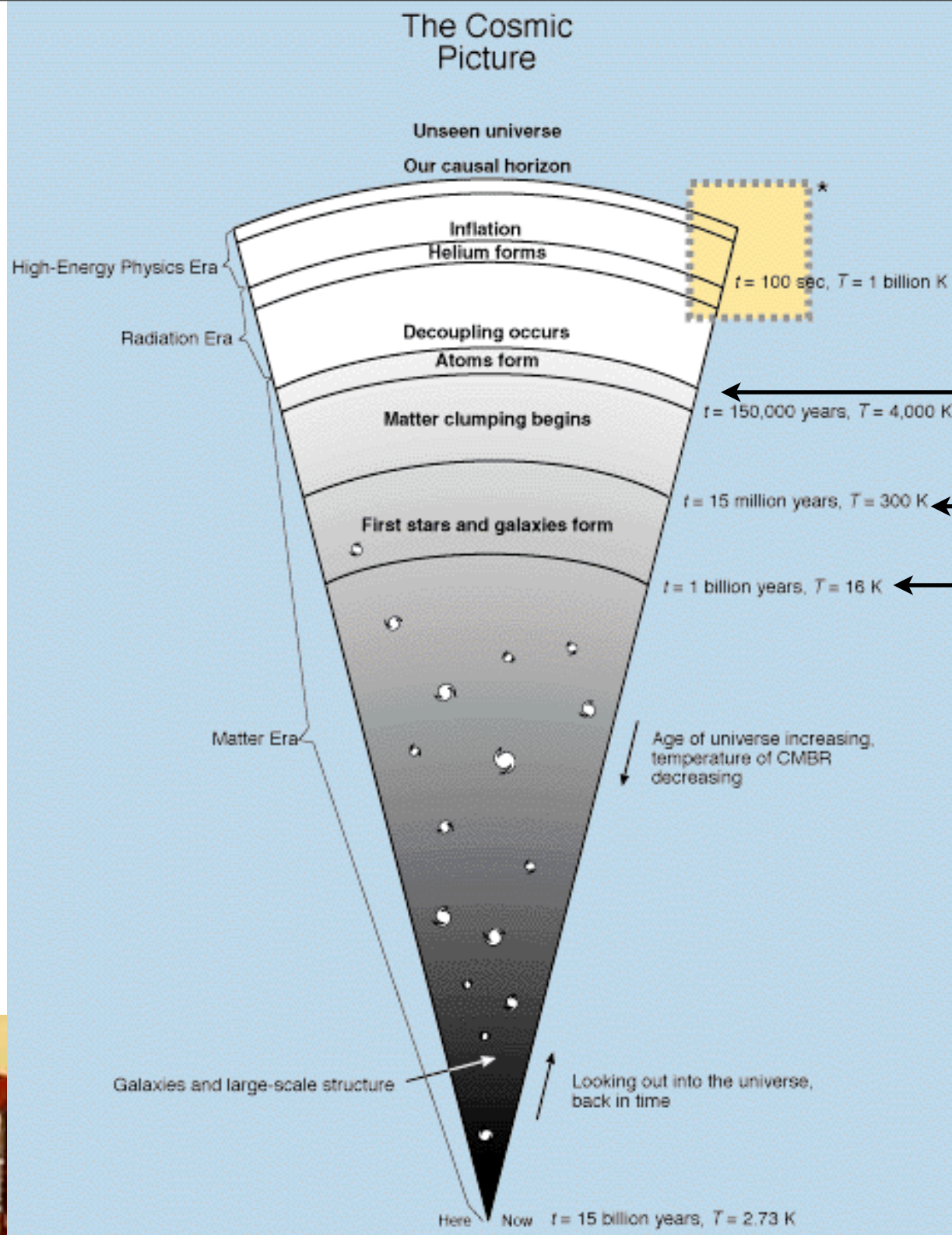




Very good evidence for accretion disks...

Very good evidence for something “dark, heavy, and small”...

The further back we look, the more uncertain we become.



$z \sim 1088$

$z \sim 100$

$z \sim 6$

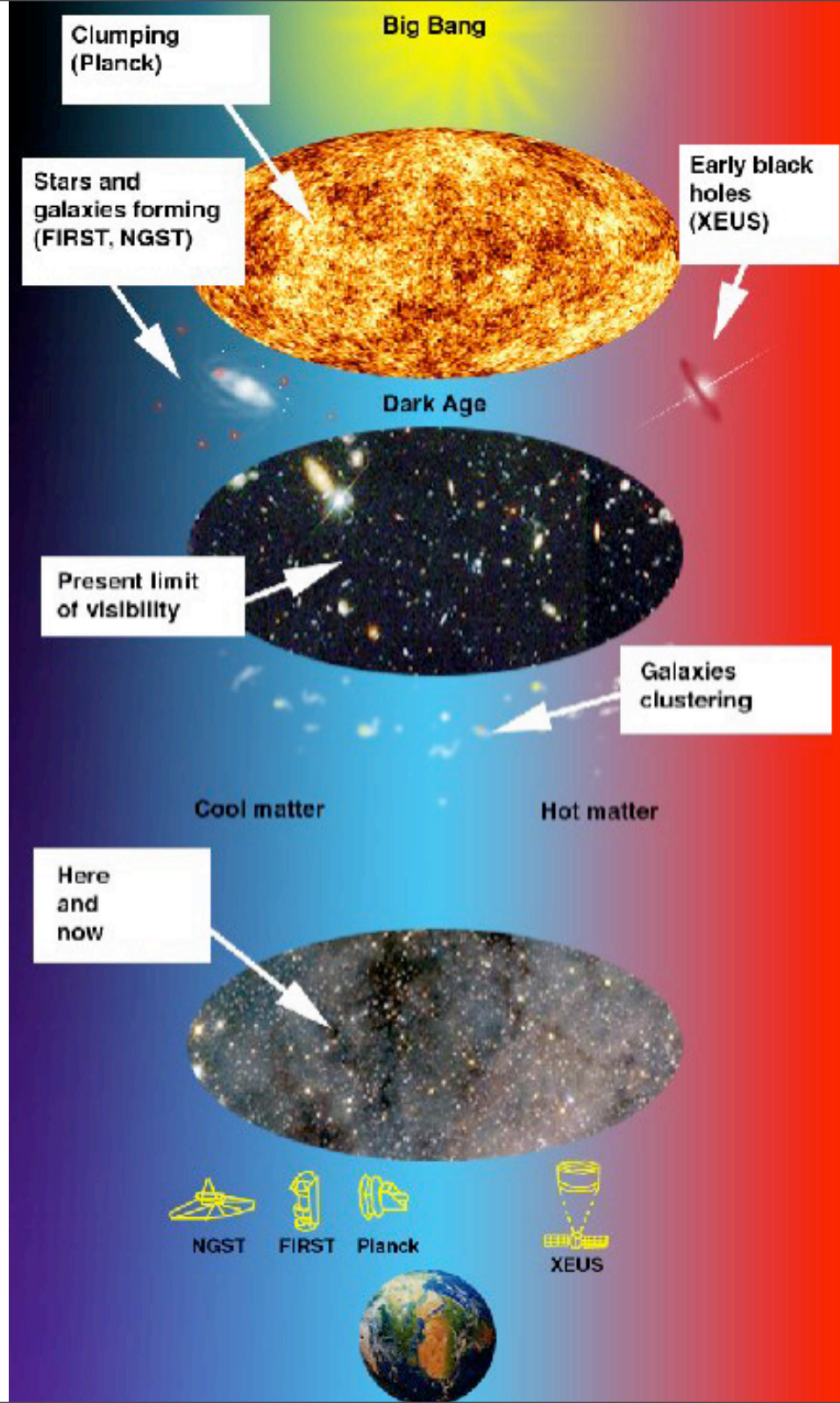


$z = \text{infinity}$

$z \sim 1088$

$z \sim 6$

$z \sim 0 \text{ to } 1$



What parts of cosmology are firm?

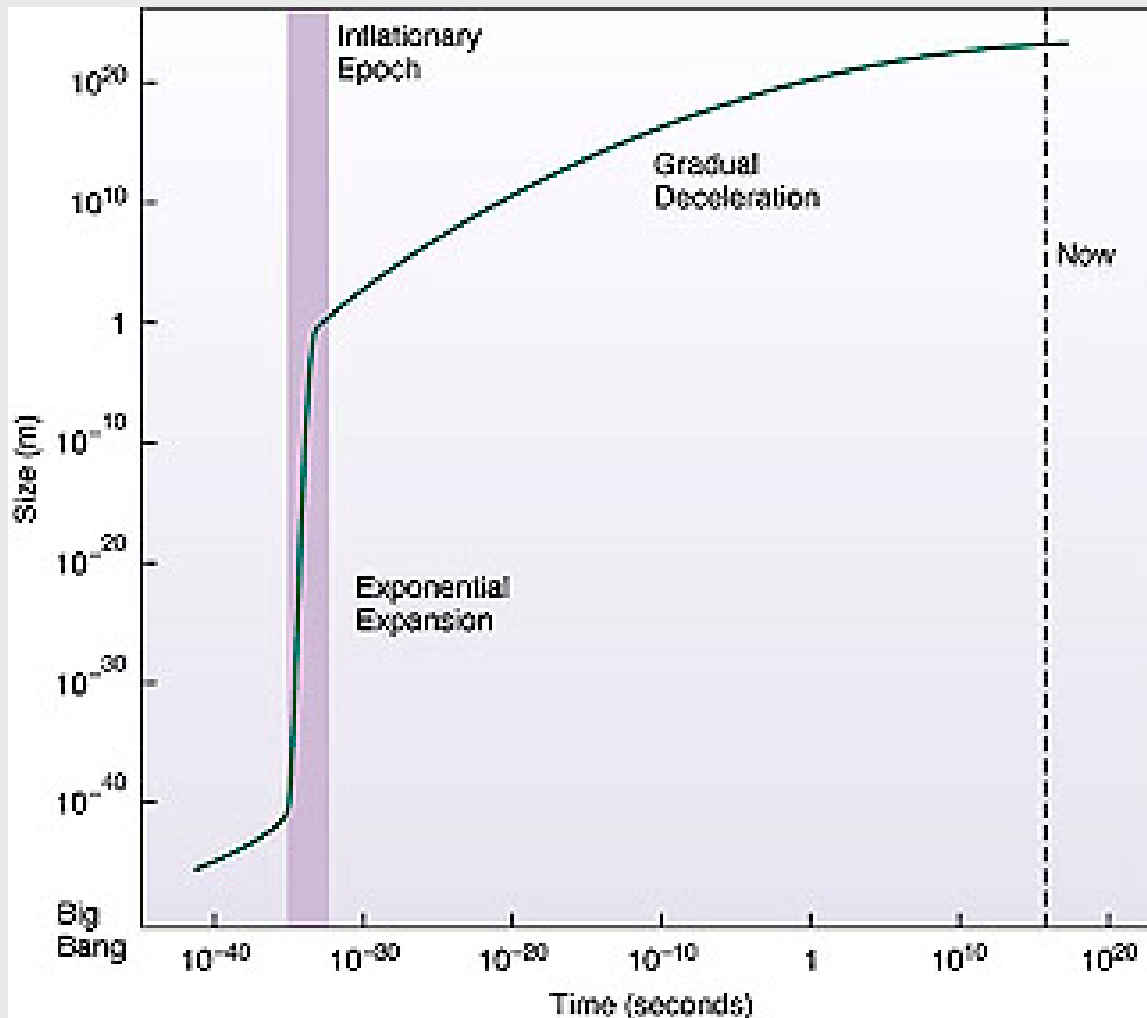
Cosmological inflation

Galaxy-galaxy correlations

Galaxy-CMB correlations

Large-scale structure

Fractal universe?



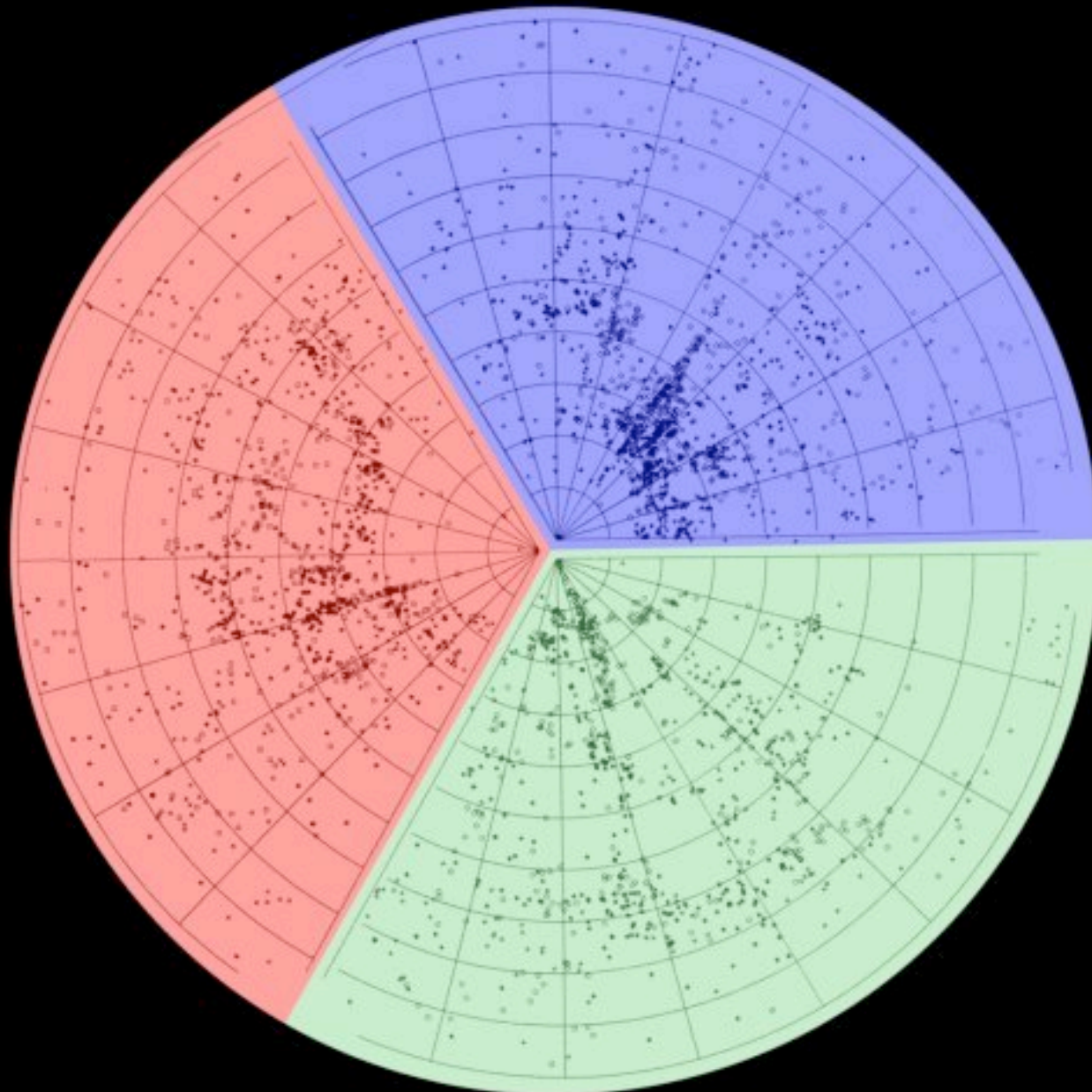
Cosmological
inflation.

The effect is almost
certainly real.

The cause?

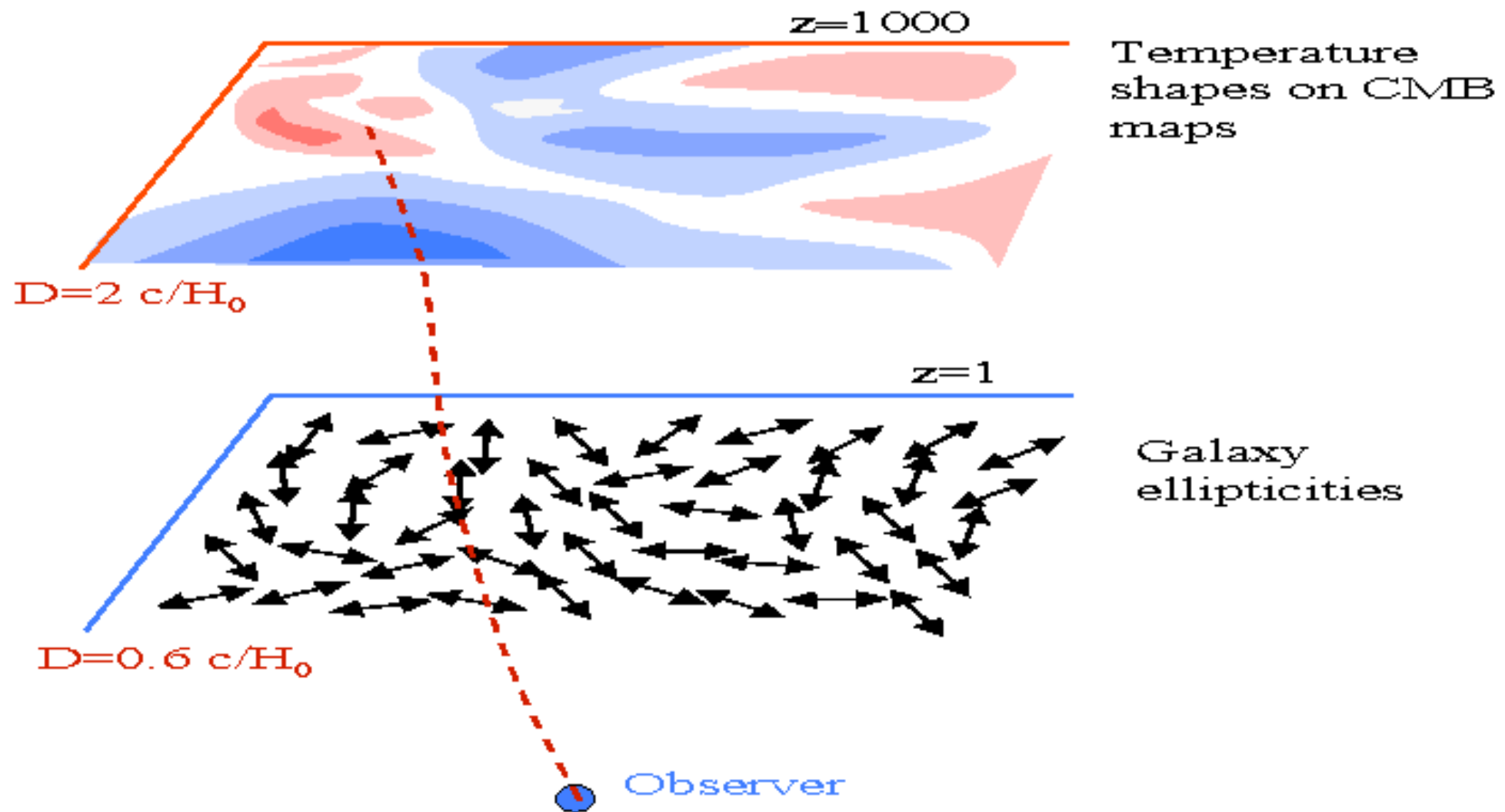


Galaxy-galaxy correlations



Two of these are simulations of galaxy distributions, one is observational data...

Galaxy-CMB shape correlations



Is there a significant amount of correlation?



Structure

Chain of
galaxies





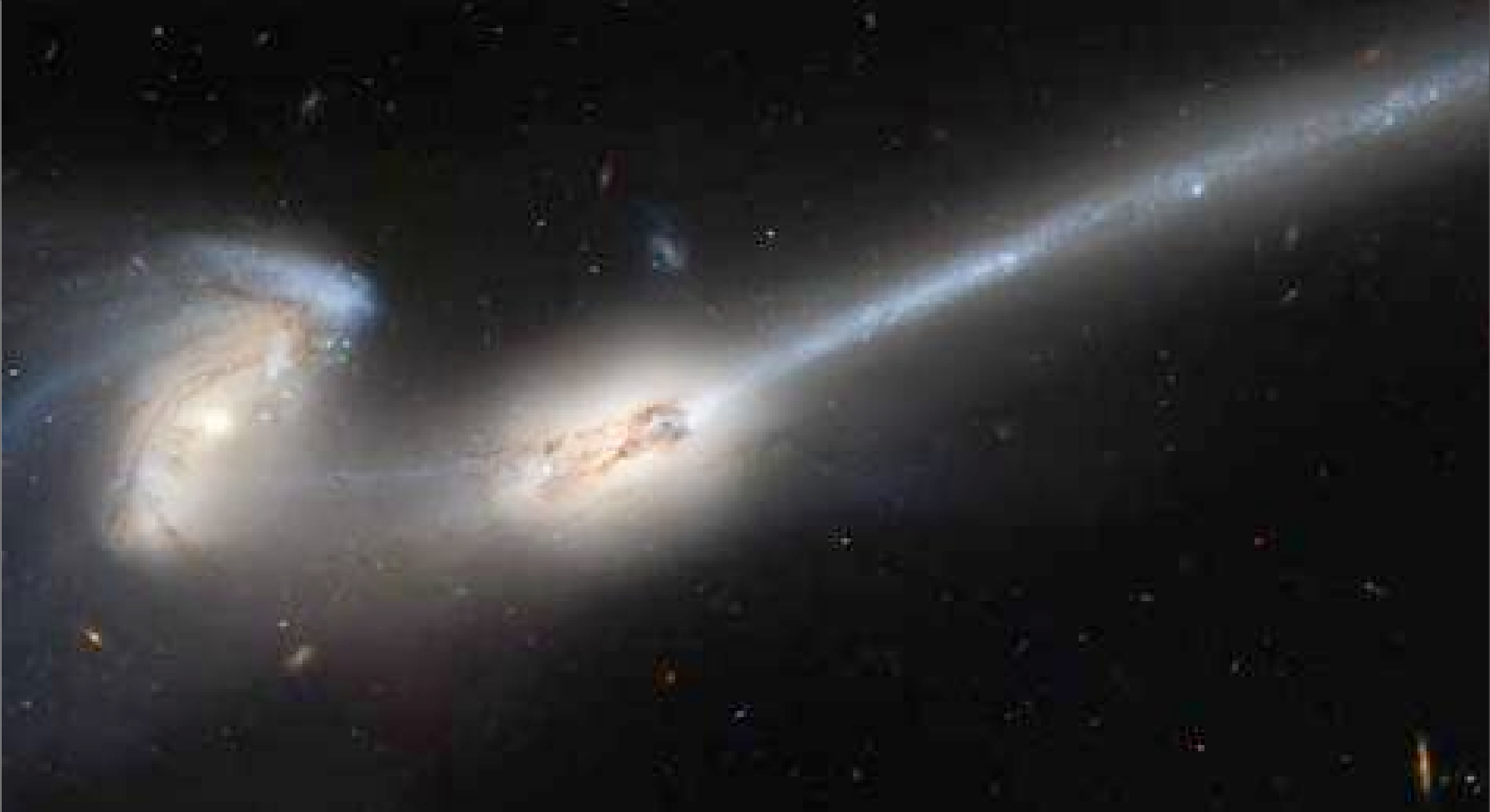
Structure

Tadpole galaxy





Mice



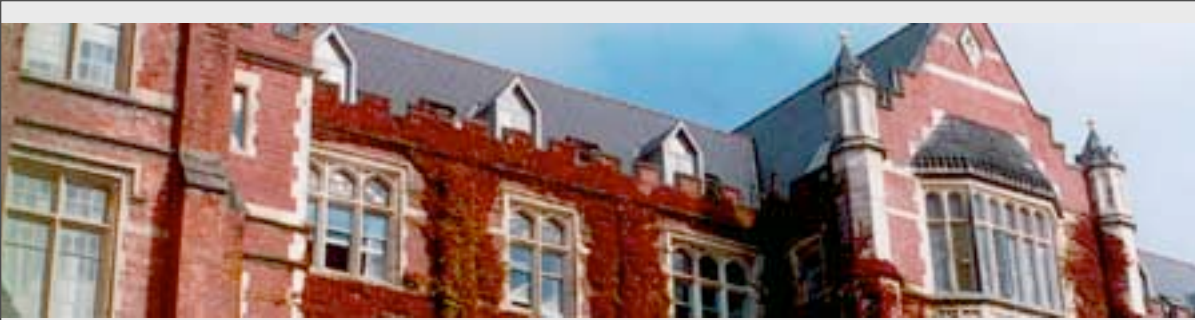
There's more to structure than just galaxies!



Structure



Colliding galaxies --- unhealthy neighborhood.



Where are the bodies buried?

Pioneer anomaly?

Dark matter!

Dark energy?

Overall mass-energy budget!



Pioneer anomaly?



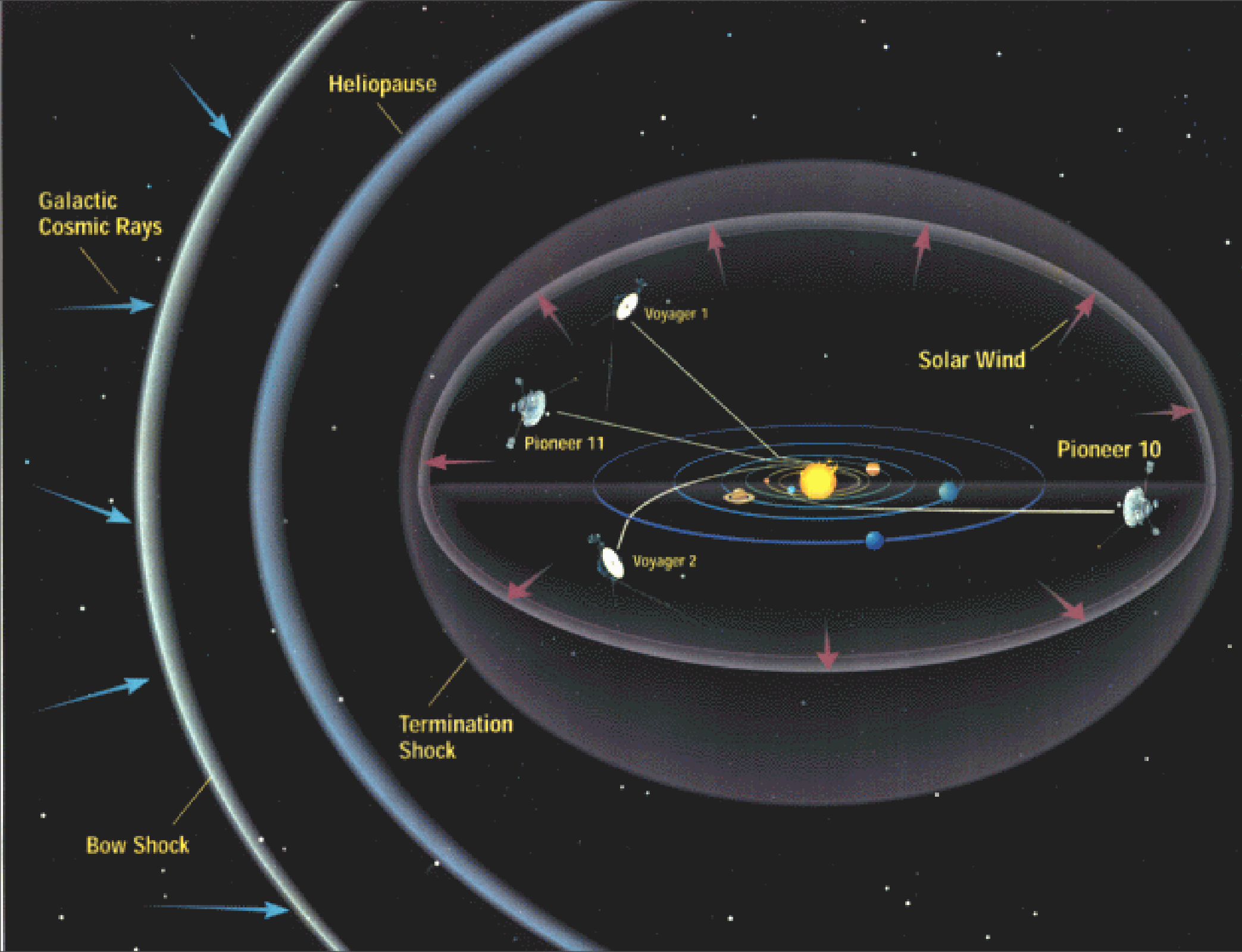
Pioneer 10 and 11,
and Voyager 1 and 2,
have now been
tracked for about 30 years.

They are not quite doing what we expect.

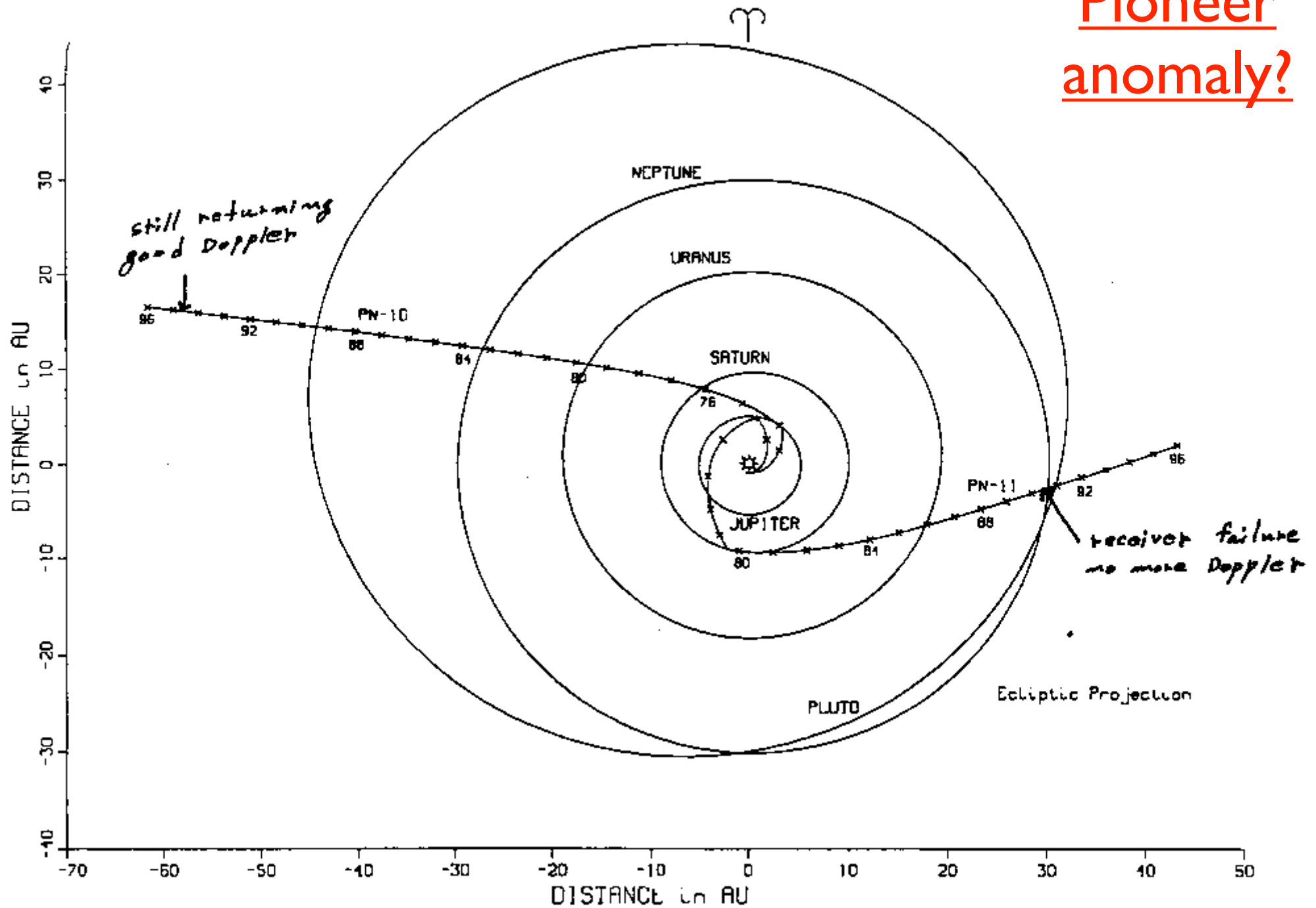
Small “anomalous” acceleration.

Directed toward the Sun.

Magnitude: $a_{\text{anomalous}} \approx c H_0$

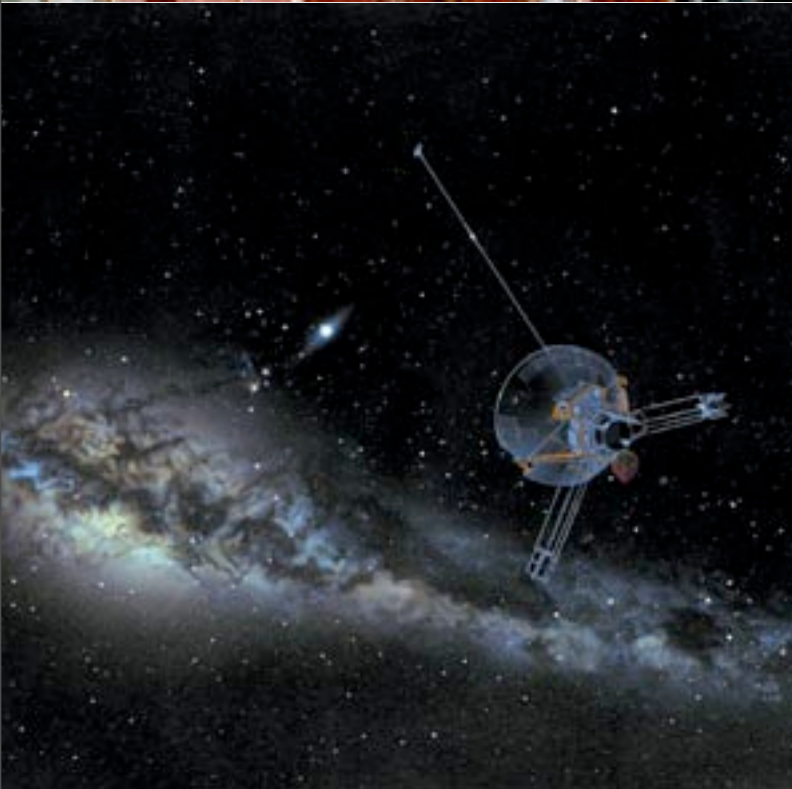


Pioneer anomaly?





Pioneer anomaly?



Say what?

What's the Hubble parameter
doing in solar system physics?

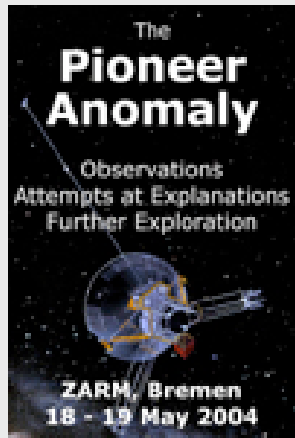
There's no really good model
for what is going on.

It could just be noise: $a_{\text{anomalous}} \approx 10^{-9} \text{ m s}^{-2} \approx 10^{-10} g$

But if it's real, it's just plain weird...



Pioneer anomaly?



People are still very puzzled...

Breakdown of inverse square law
at solar system scales?

$$F = \frac{G m m'}{r^2} + m' a_P + \dots?$$

$$a_P = (8.74 \pm 1.33) \times 10^{-10} m/s^2$$

But it does not seem to affect Uranus, Neptune, Pluto?



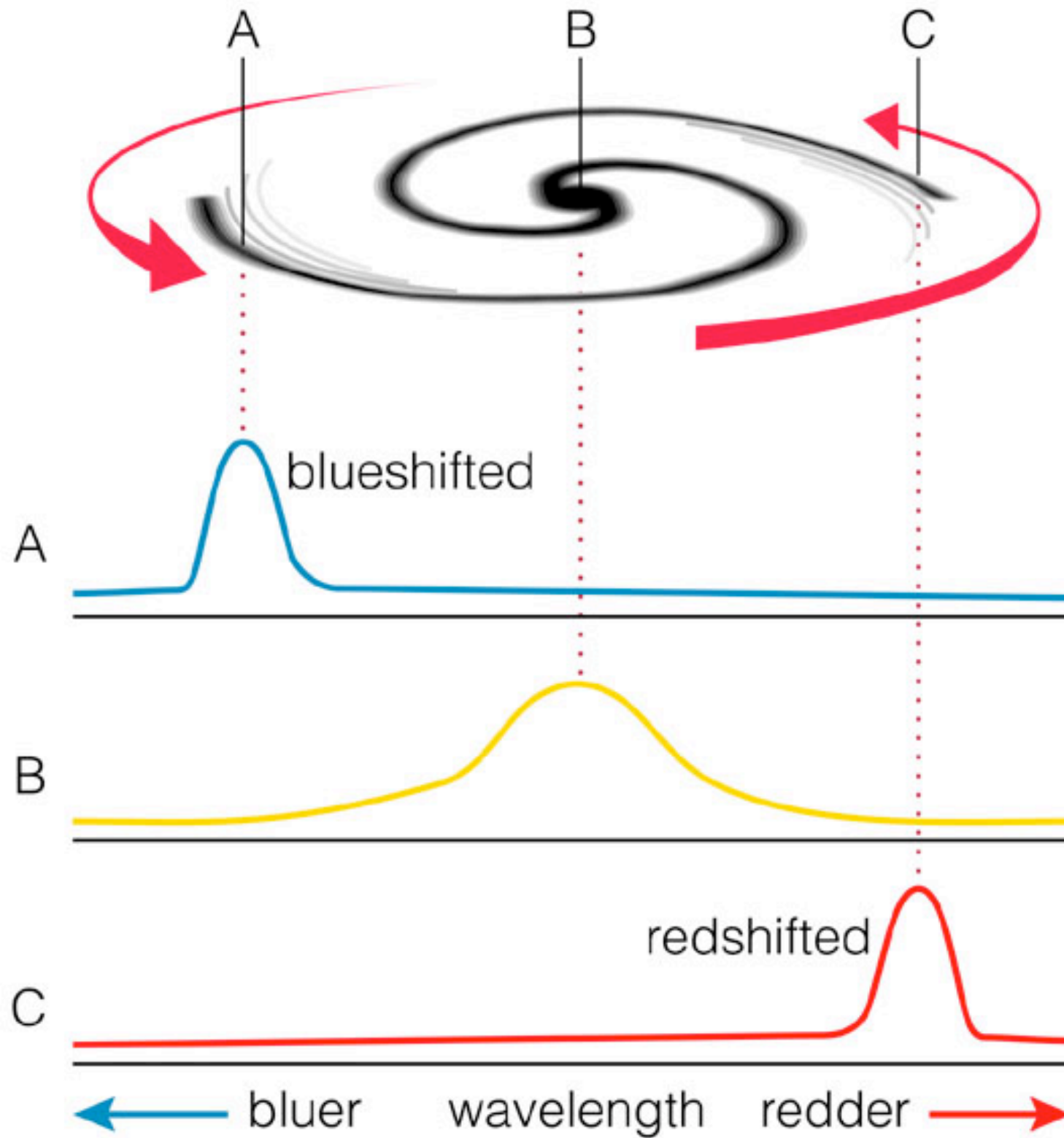
Dark matter?



Andromeda galaxy

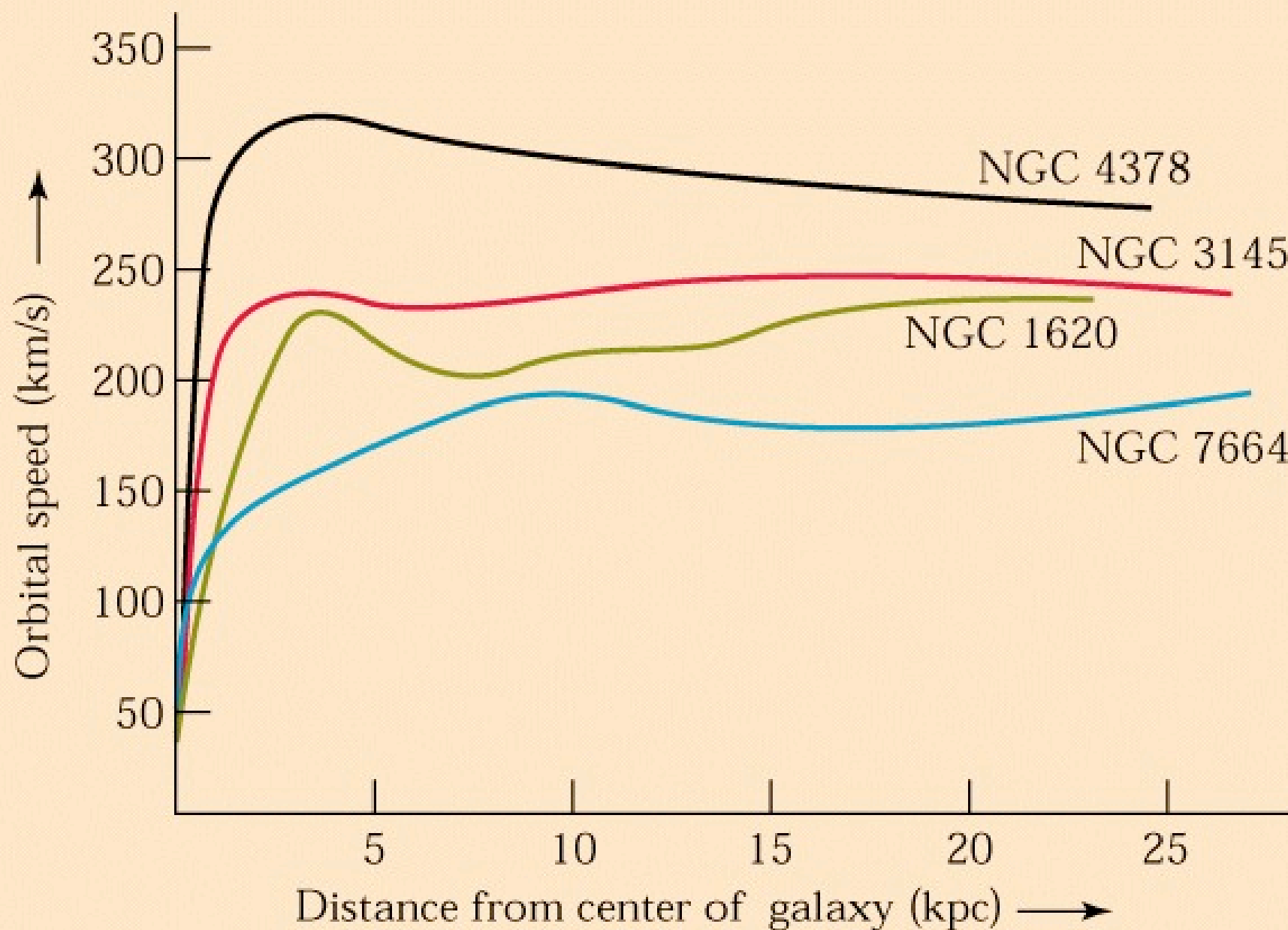
AKA: Galactic
“missing mass”

Buzz phrase:
Galaxy
rotation curves

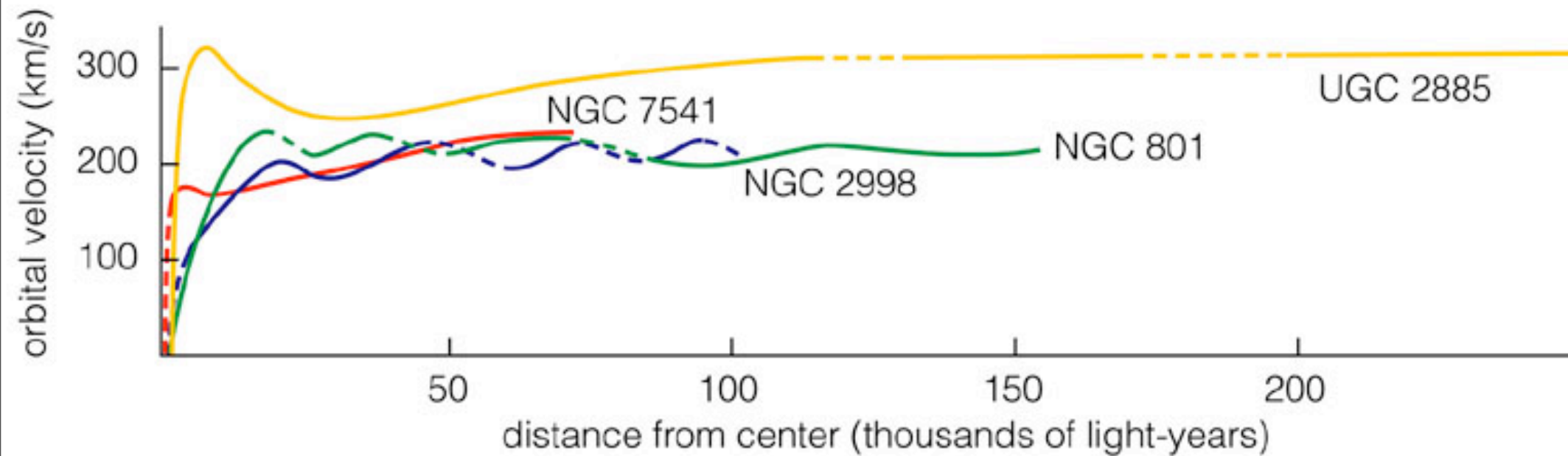




Dark matter?

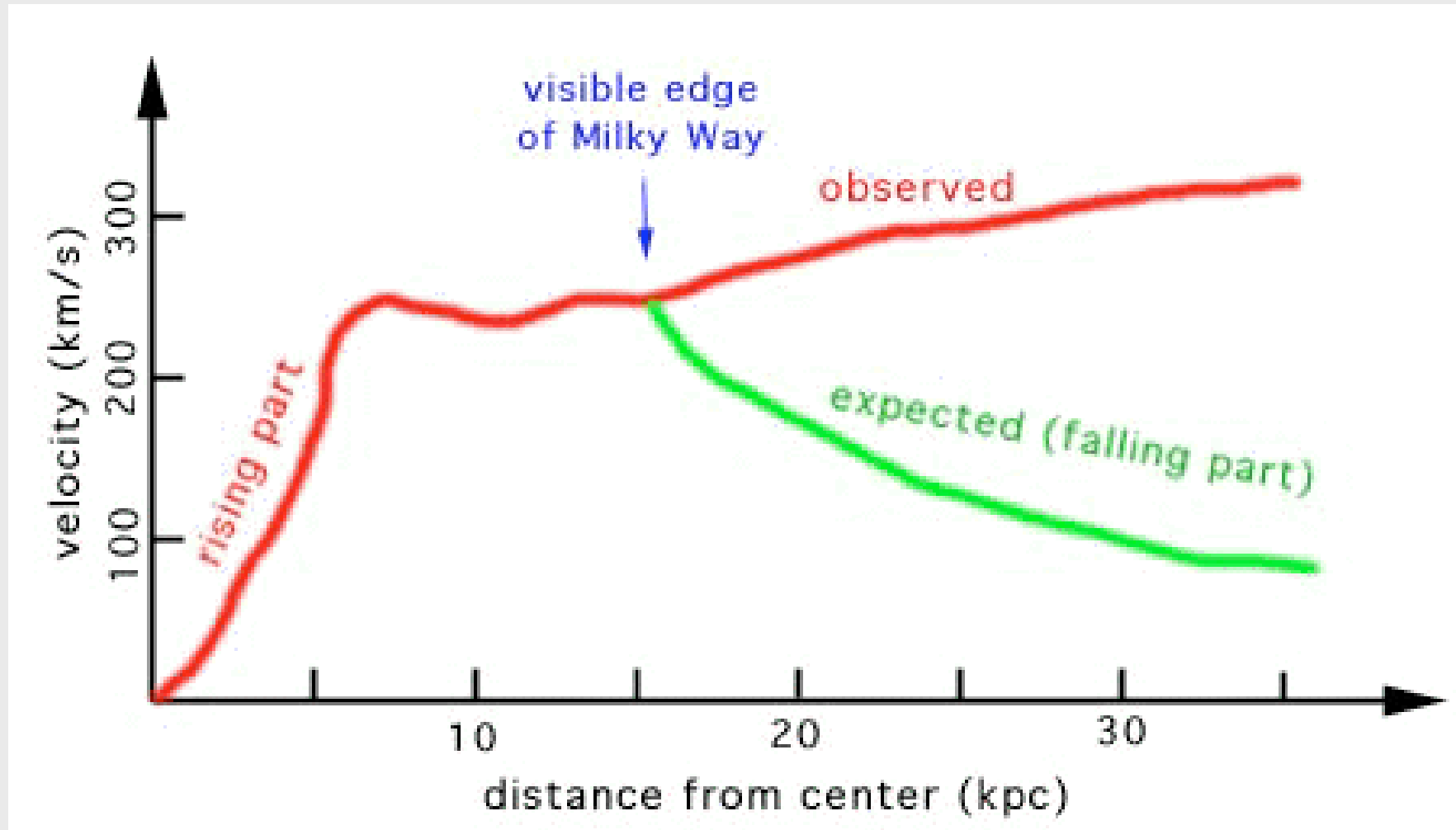


Dark matter?





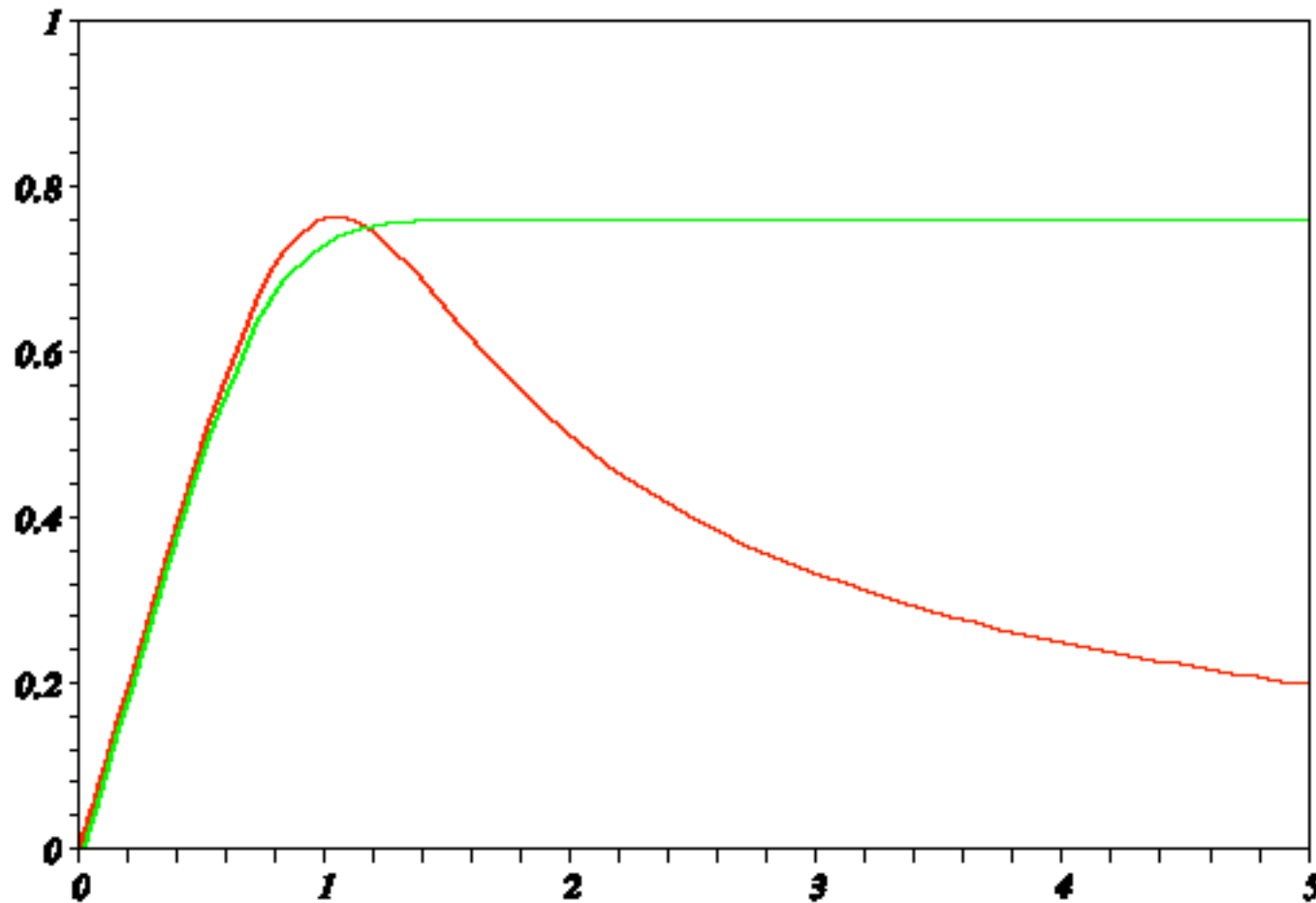
Dark matter?



Our own galaxy --- the Milky way --- shows the same effect.



Dark matter?



Observed:
Approximately
constant

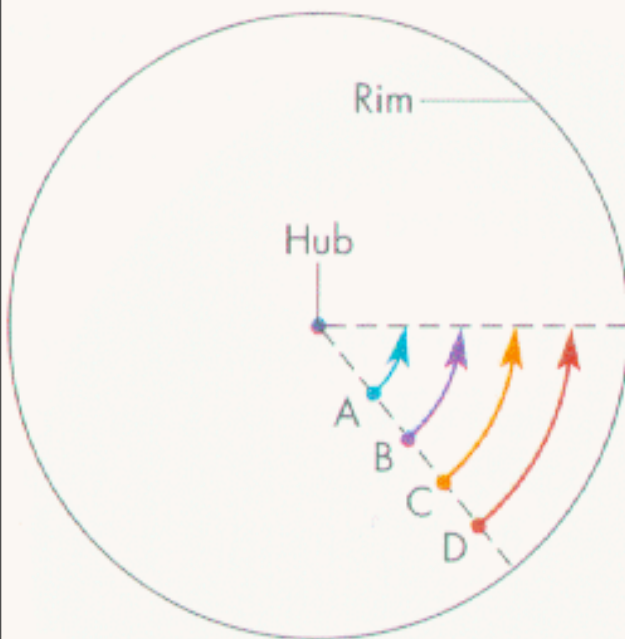
Expected:
Kepler falloff

Schematic galaxy rotation curve

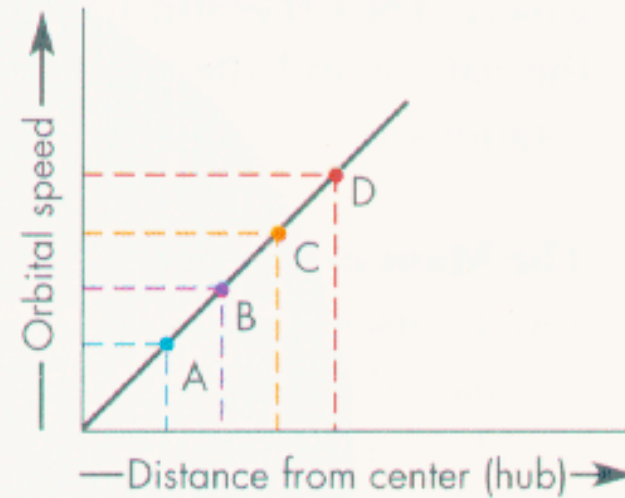
Dark matter?

We **do** see this in the galactic core

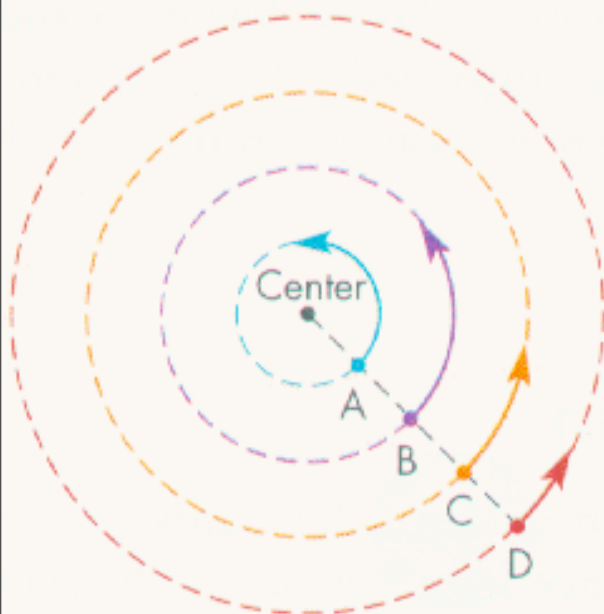
We expect this, **but don't see this**, in the galactic disk



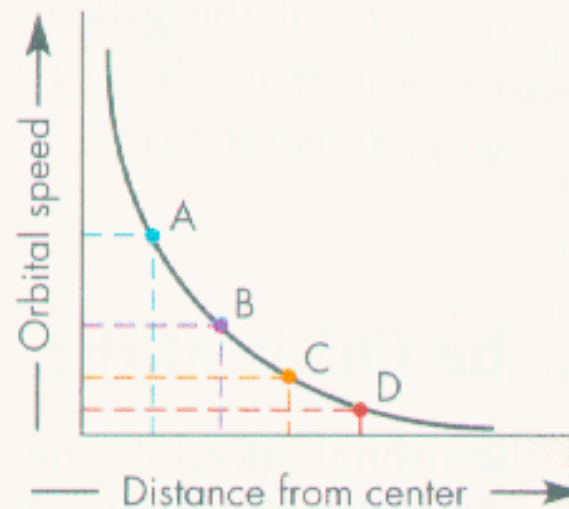
Wheel-like rotation



Rotation curve for wheel-like rotation



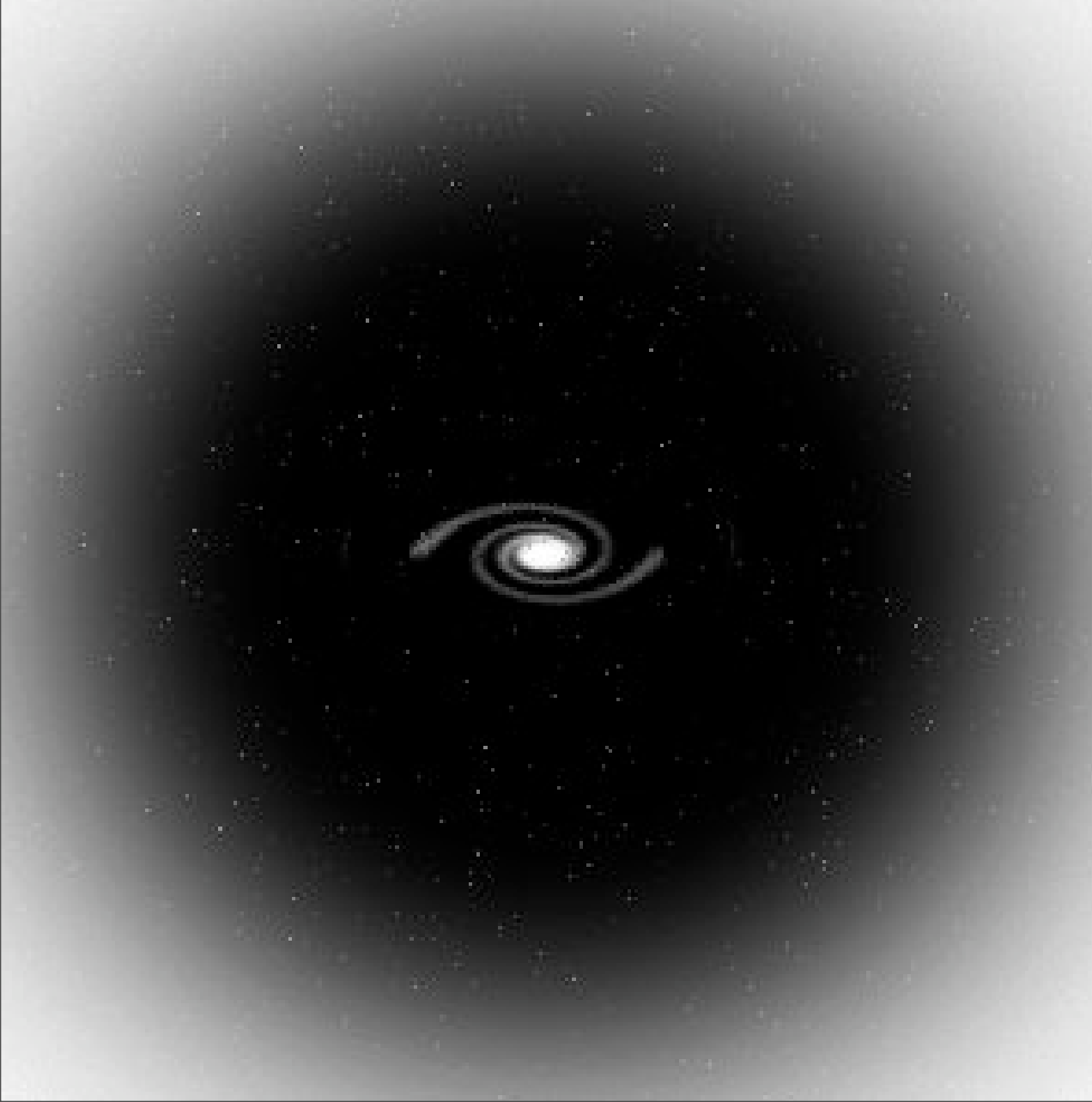
Planet-like rotation



Rotation curve for planet-like rotation



Dark matter?



What a spiral galaxy
“really” looks like....

Density falloff: $1/r^2$

Dark matter halo
out to beyond the
visible disk

But what is the
dark matter?

Nobody knows



Dark matter?

Dark matter makes up about 90% of the mass of typical spiral galaxies

We **only** detect it through its gravitational effects

As yet we have no direct verification of its existence

Possibilities:

Massive neutrinos

Axions

WIMPS

Sparticles

Bose condensates

Other weirdness



Dark matter?

Axion (invisible axion):
mysterious particle beloved
by particle physicists





SUSY:

Particles and Sparticles

Matter particles and their proposed superpartners		Force particles and their proposed superpartners	
Particle Name	Superpartner Particle	Particle Name	Superpartner Particle
Quark	Squark	Graviton*	Gravitino
Neutrino	Sneutrino	W ^{+/-}	Wino ^{+/-}
Electron	Selectron	Z ⁰	Zino
Muon	Smuon	Photon	Photino
Tau	Stau	Gluon	Gluino
		Higgs* boson	Higgsino

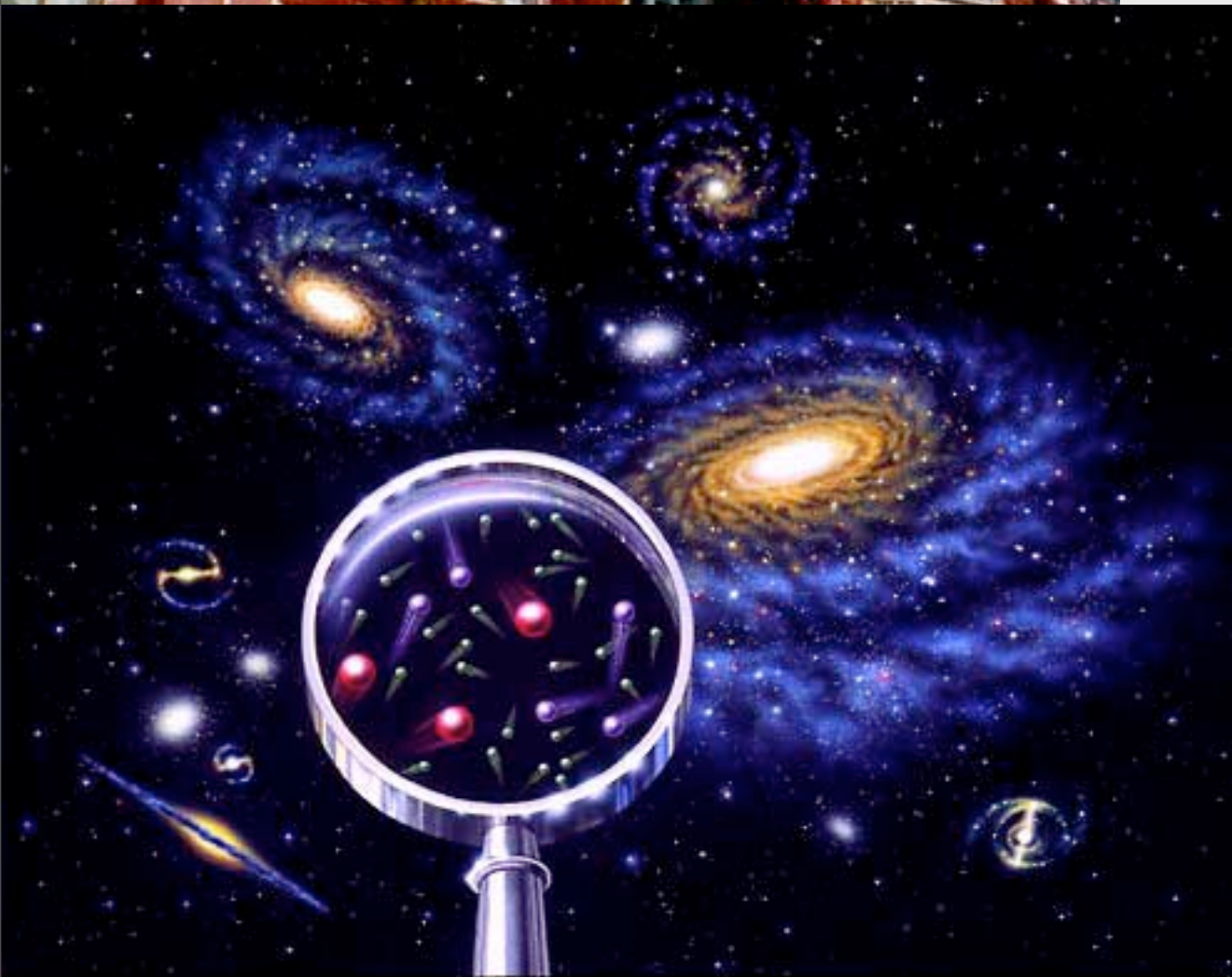
IF
supersymmetry
has anything
to do with
the
“real world”.

Supersymmetry doubles the particle spectrum

The lightest susy-partner is likely to be stable



WIMPS



Weakly interacting massive particles



WIMPS

Suspect Relic	Mass	Origin t, T	Abundance cm^{-3}
Invisible Axion	10^{-5}eV	$10^{-30}\text{sec}, 10^{12}\text{GeV}$	10^9
Light Neutrino	30 eV	1 sec, 1 MeV	100
Photino—Gravitino	keV	$10^{-4}\text{sec}, 100\text{ MeV}$	10
Photino—Sneutrino— Neutralino—Axino— Heavy Neutrino	GeV	$10^{-3}\text{sec}, 10\text{ MeV}$	10^{-5}
Magnetic Monopoles	10^{16}GeV	$10^{-34}\text{sec}, 10^{14}\text{GeV}$	10^{-21}
Pyrgons—Maximons— Newtorites	10^{19}GeV	$10^{-43}\text{sec}, 10^{19}\text{GeV}$	10^{-24}
Quark Nuggets	$\simeq 10^{15}\text{g}$	$10^{-5}\text{sec}, 300\text{ MeV}$	10^{-44}
Primordial Black Holes	$\gtrsim 10^{15}\text{g}$	$\gtrsim 10^{-12}\text{sec}, \lesssim 10^3\text{GeV}$	$\lesssim 10^{-44}$

Table 9.1: WIMP candidates for the dark matter. The cosmic abundance required for closure density is $n_{\text{WIMP}} \simeq 1.05h^2 \times 10^{-5}\text{cm}^{-3}/m_{\text{WIMP}}(\text{GeV})$.

There are many
WIMP candidates

Wimpzilla?



Dark matter?

Really weird possibilities:

MOND: (MOdified Newtonian Dynamics?)

$$F = m a f \left(\frac{a}{a_0} \right); \quad a_0 \approx 10^{-11} g.$$

Breakdown of inverse square law at galactic scales?

$$F = \frac{G m m'}{r^2} + \frac{G m m'}{r r_0} + \dots?$$

$$r_0 \approx 10 \text{ kilo-parsecs}$$

Does not mesh well with the Pioneer anomaly



Dark energy:

AKA: Cosmological constant

AKA: Quintessence

AKA: Accelerating universe



Dark Energy



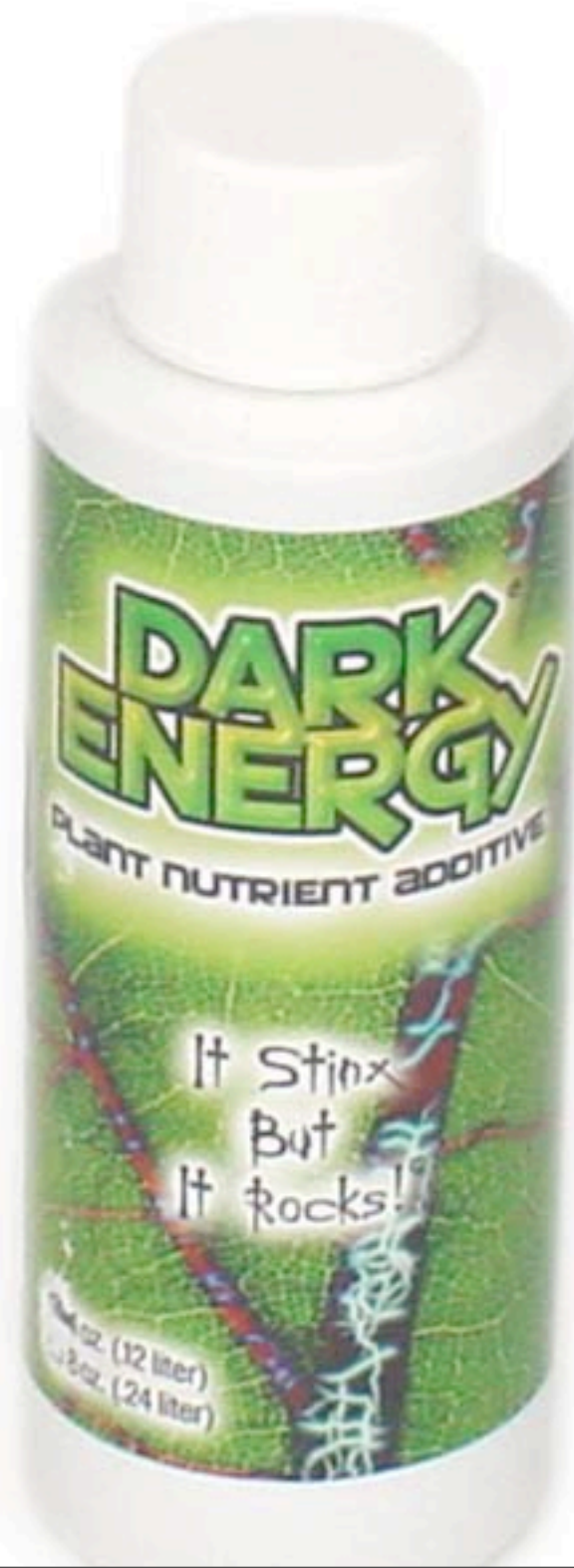
Dark Energy

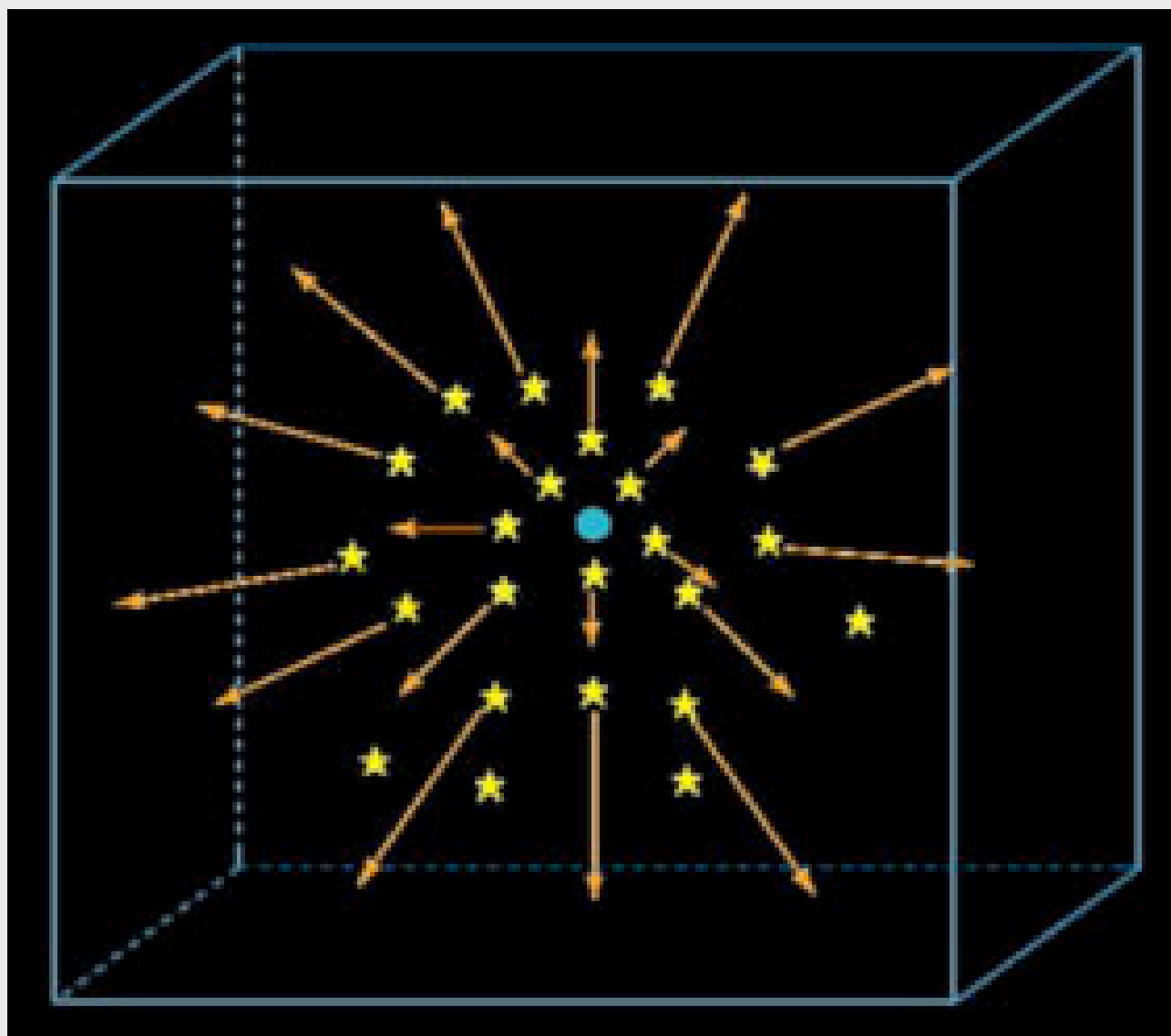


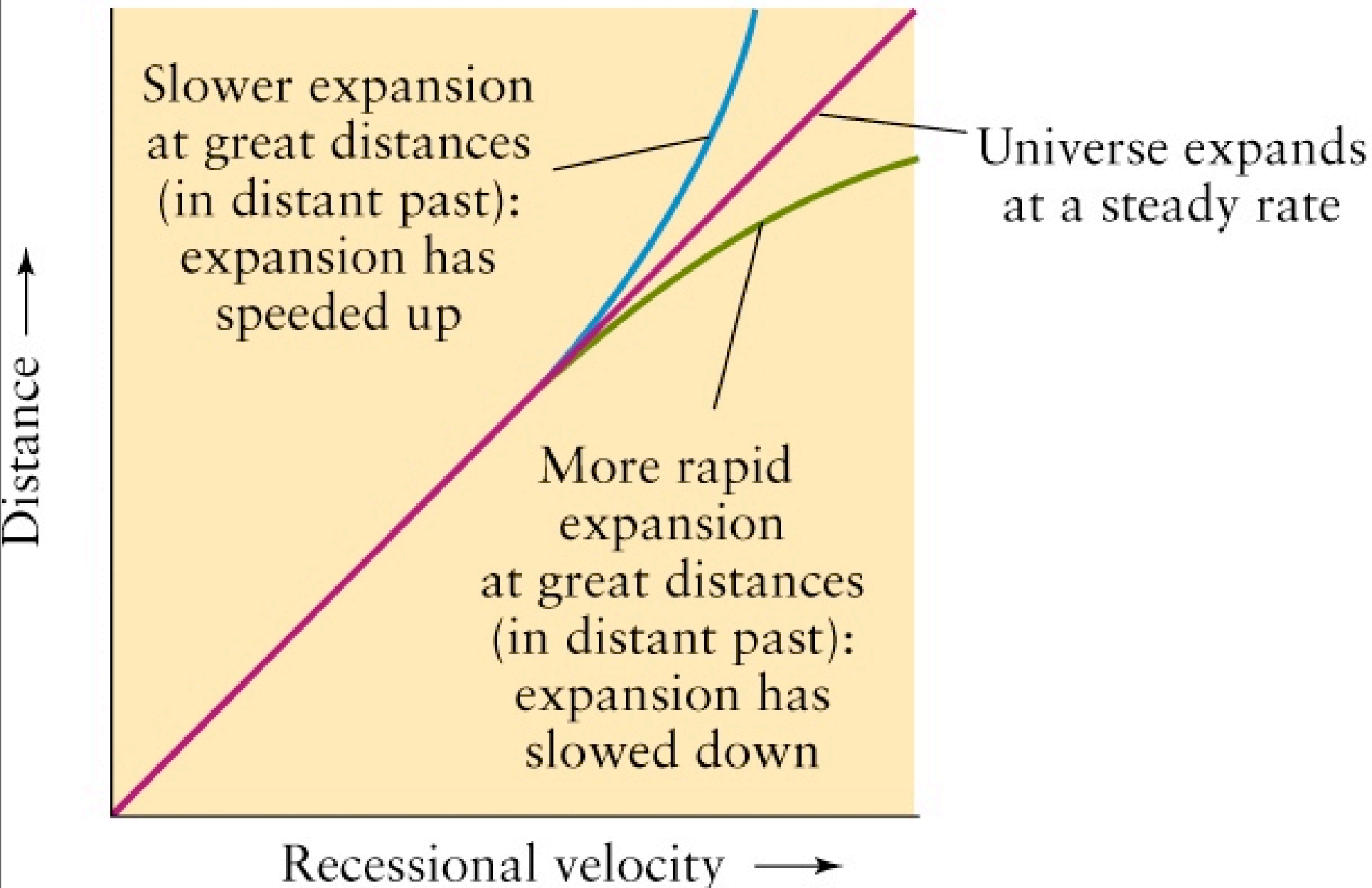
Dark Energy

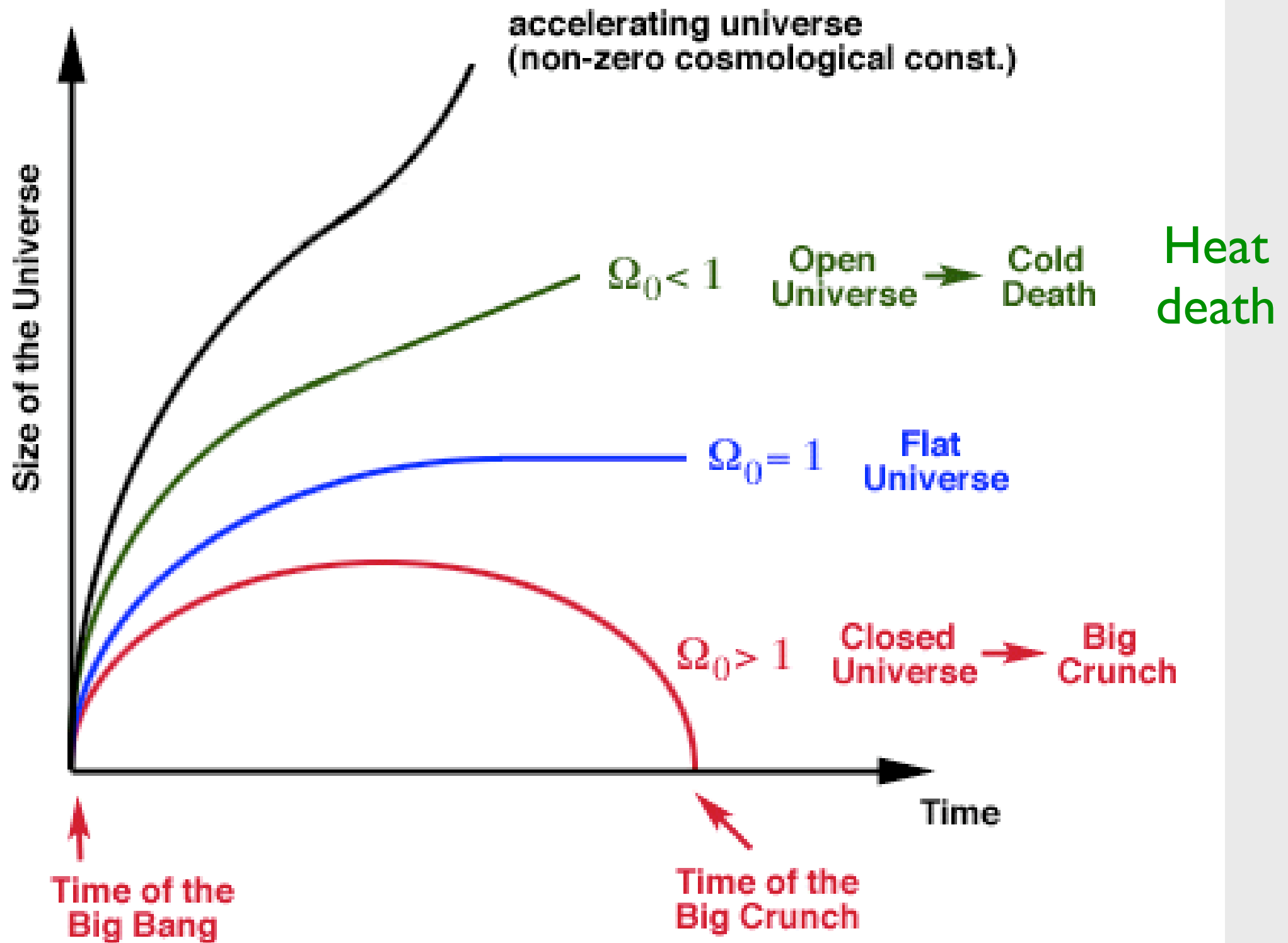


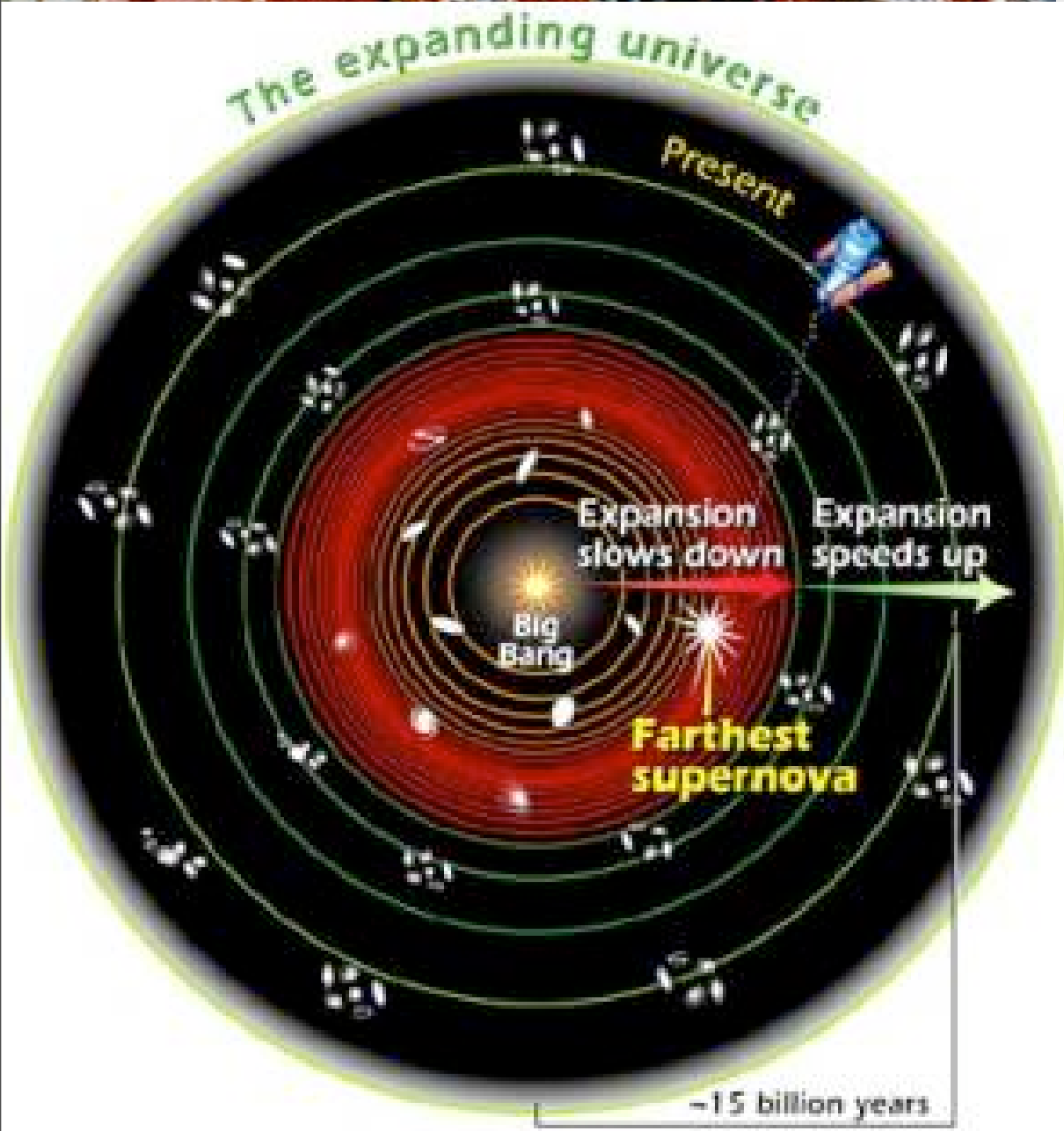
Dark Energy











Dark matter clumps

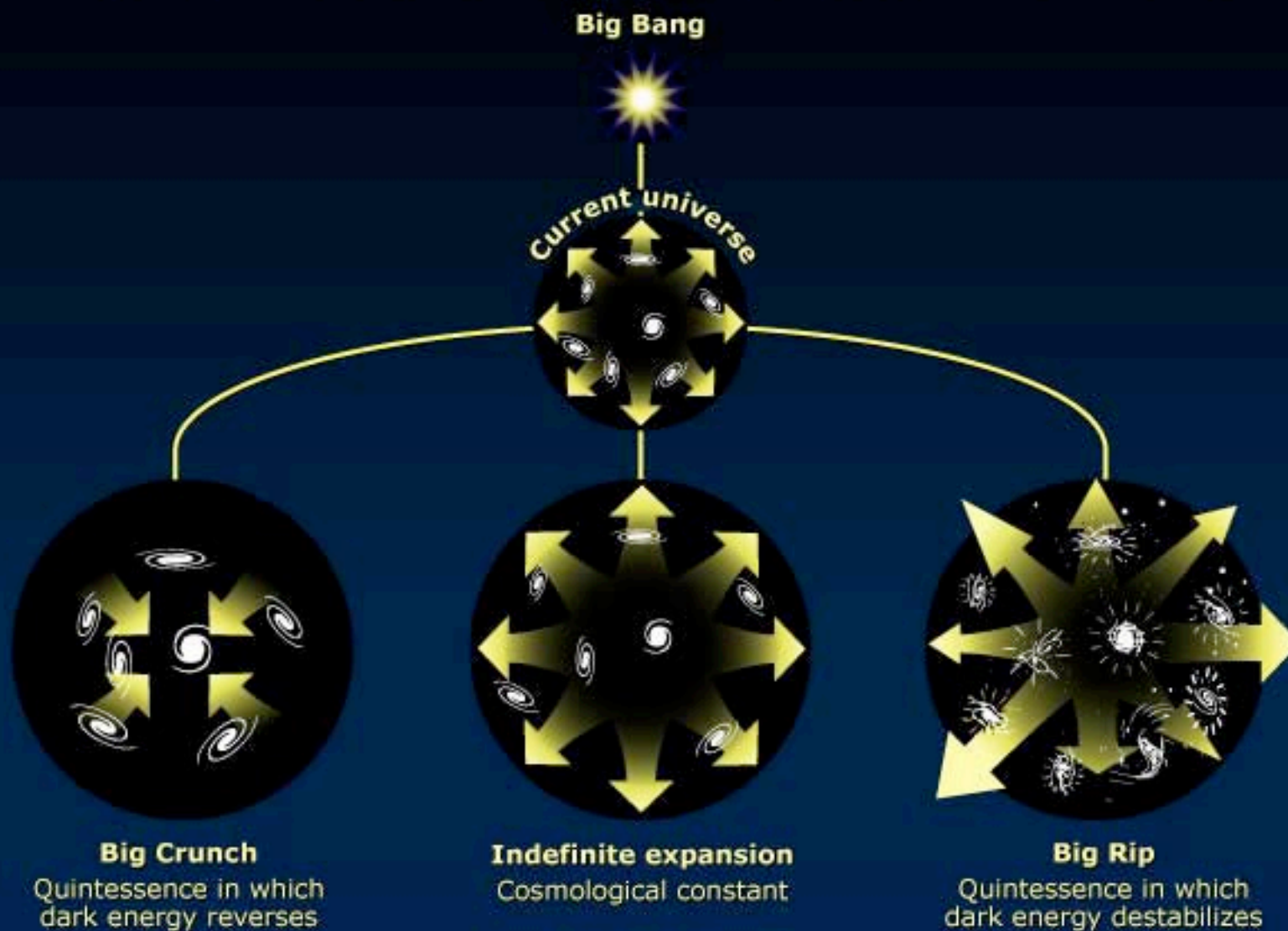
Dark energy does not
clump

(by definition,
not deduction)



Big rip?

Future fates of the dark-energy universe





Dark energy?

Are we living in a large under-dense bubble
in an otherwise simple universe?

Size of bubble: Much bigger than Hubble radius

$$R_H = c/H_0$$

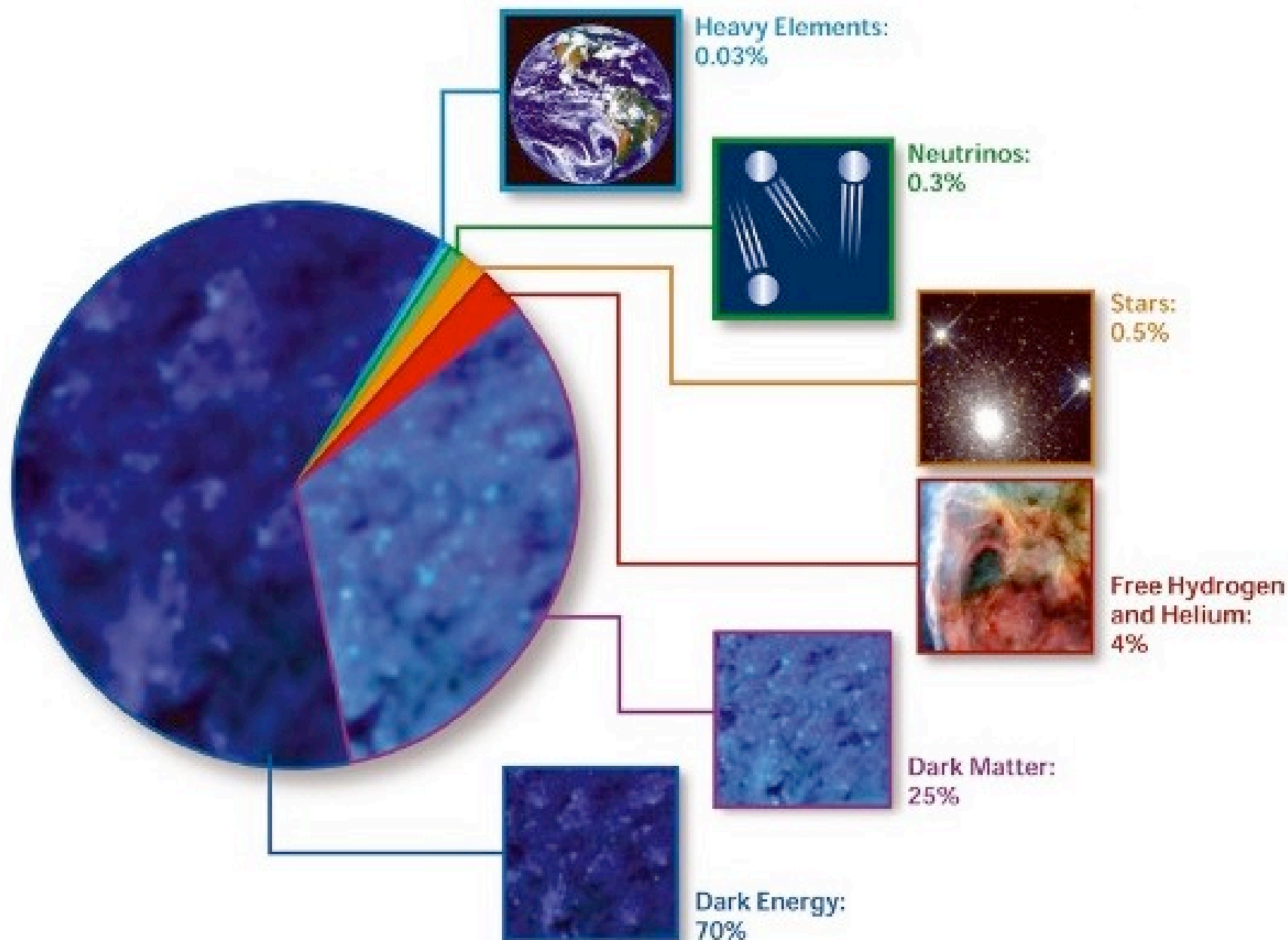
If this idea works it would improve some aspects
of our cosmological picture,
at the cost of giving up large-scale homogeneity.

The universe we see would not be “typical”.

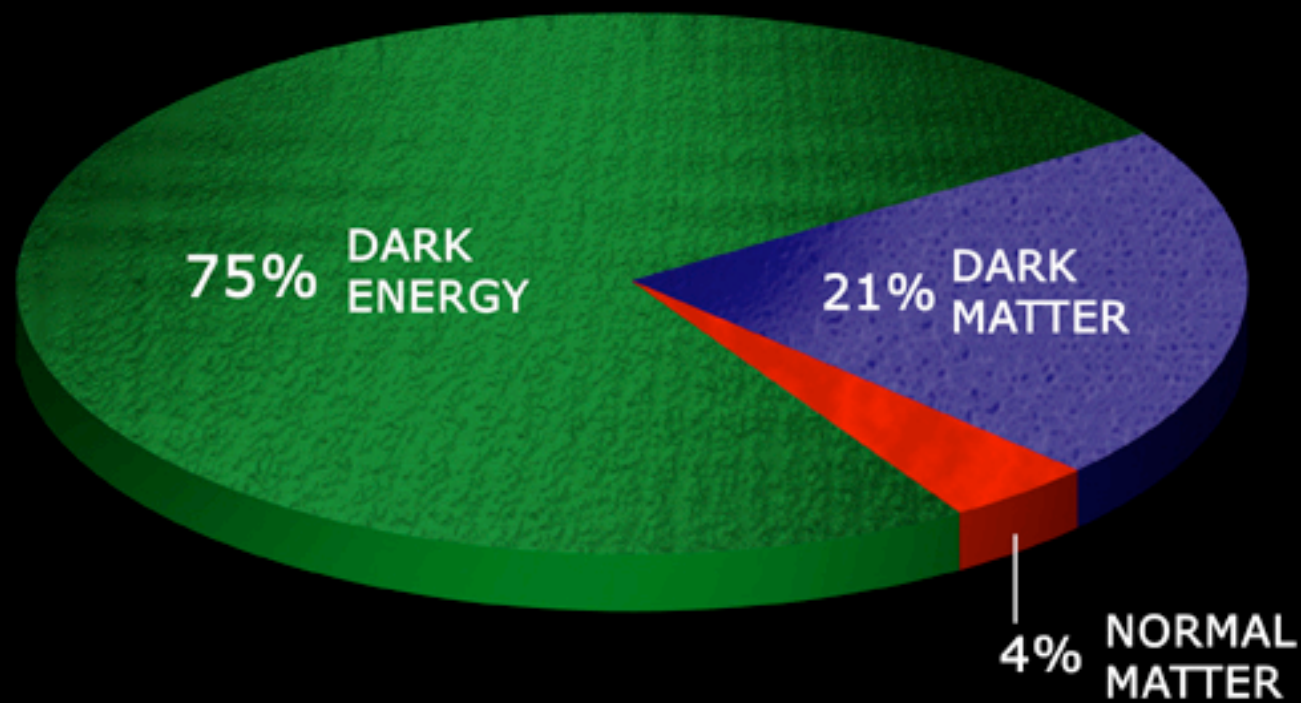
Could get rid of the “dark energy”.



Mass-energy budget?

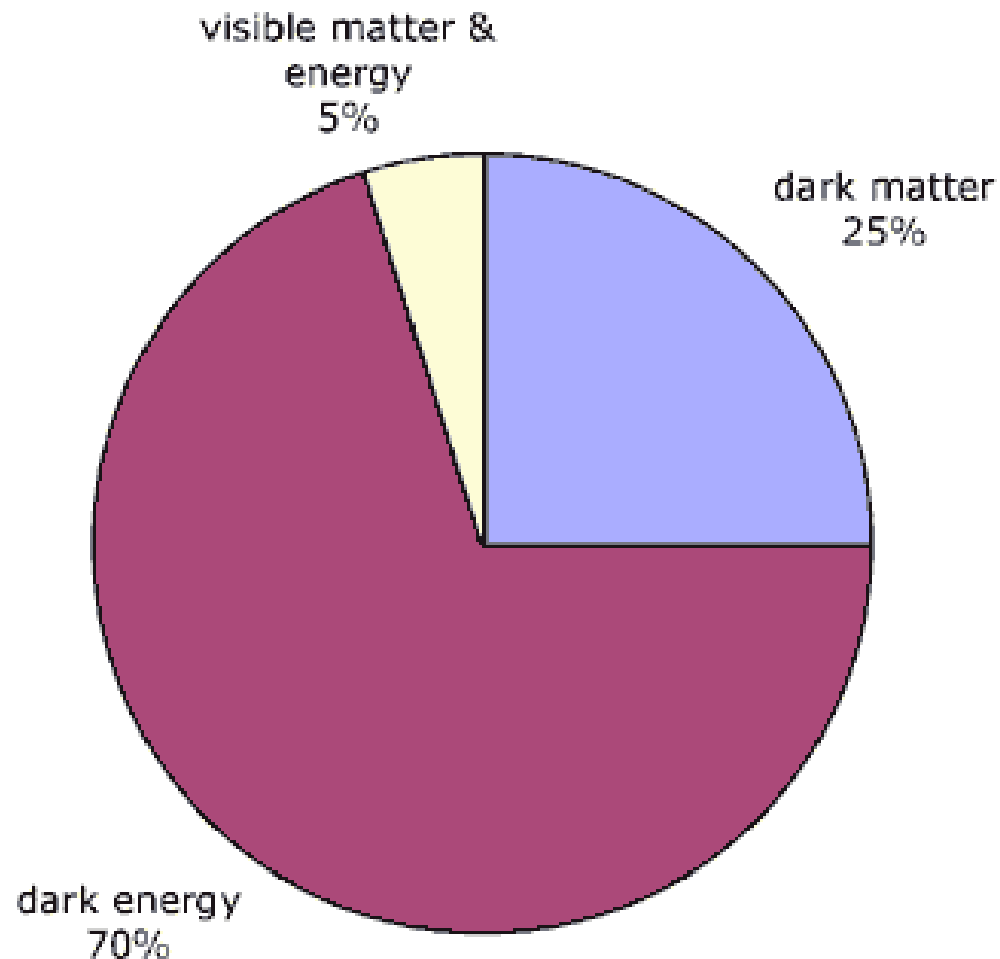


Overall mass-energy budget?





Composition of the Universe, by percent



If you succeed in getting rid of dark energy, we are looking at big changes...



Conclusions:

- 1) The “big bang” is alive and well...
- 2) There is a lot of good high-quality data coming in, this helps keep the theorists on track...
- 3) There is a lot of room for debate at the margins, but the core of the “big bang” is rock solid.

“Sometimes I wonder whether the world is being run by smart people who are putting us on, or by imbeciles who really mean it.”

--- Mark Twain