

Einstein and the Accelerating Expansion of the Universe

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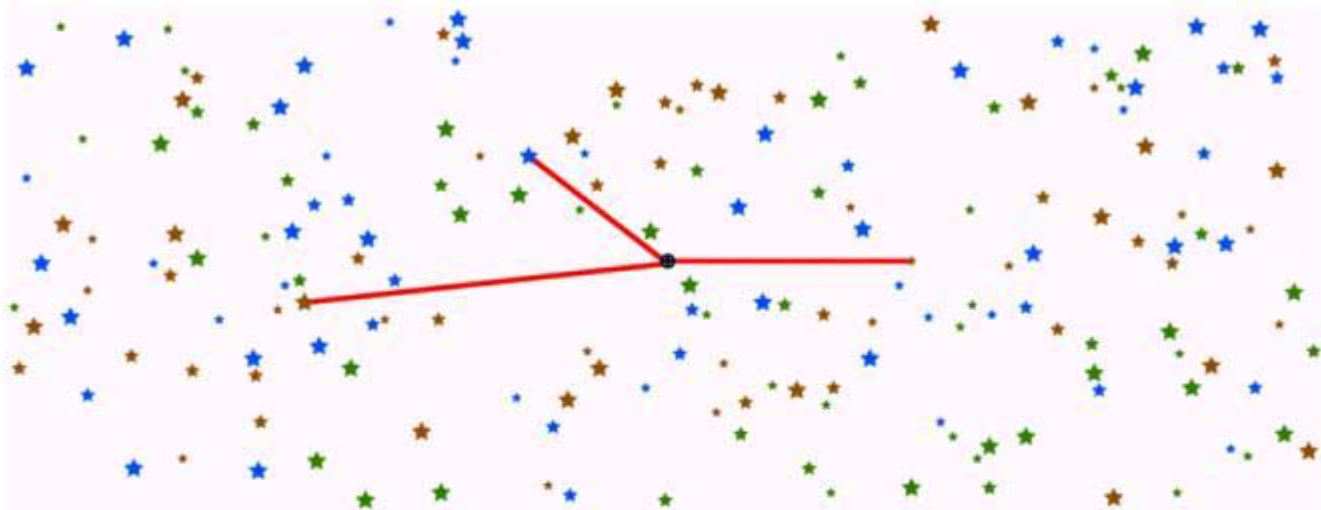
13 March 2005

Cosmology is an Observational Science

- We can't do experiments on the Universe.
- We can't change the initial conditions and see what happens.
- But we can observe what the Universe is like.
- And we can study what past, present and future conditions of the Universe are compatible with our observations and the same laws of physics that apply in our laboratories.

Only One Fact in 1917

1) The sky is dark at night. And Einstein ignored it.



In a homogeneous unchanging Universe every line of sight will end on a star. So why is the night sky not as bright as the surface of a star? The **Cosmic Infrared Background** is what remains after this Olbers' paradox is resolved.

General Relativity & Cosmology

- General relativity allows a consistent calculation of the effects of gravity in a uniform distribution of galaxies that fills the entire Universe.
- But Einstein thought the Universe was static, and a static uniform distribution of galaxies that filled the entire Universe would be unstable to collapsing into clumps.
- So Einstein added a new constant to his equation for gravity: the cosmological constant, Λ .

Effect of Λ term was unexpected

Newtonian Gravity



Einstein wanted shorter range gravity

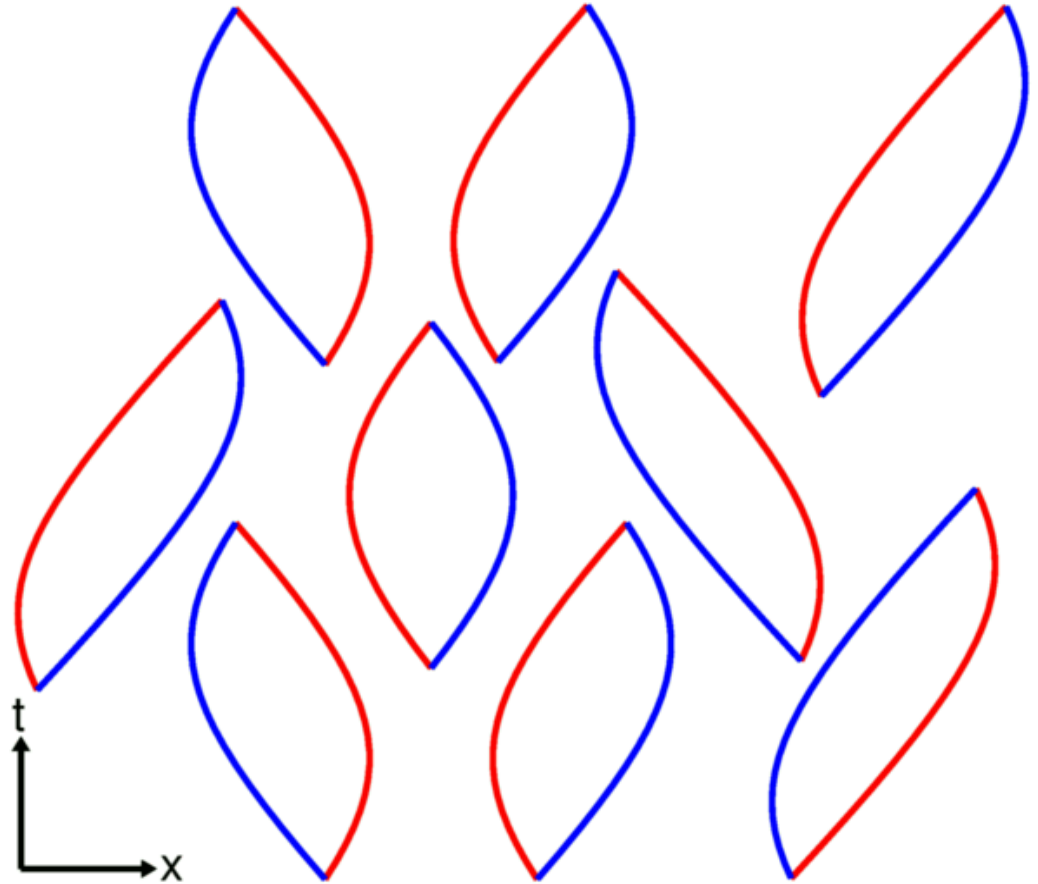


Einstein found a long range repulsion

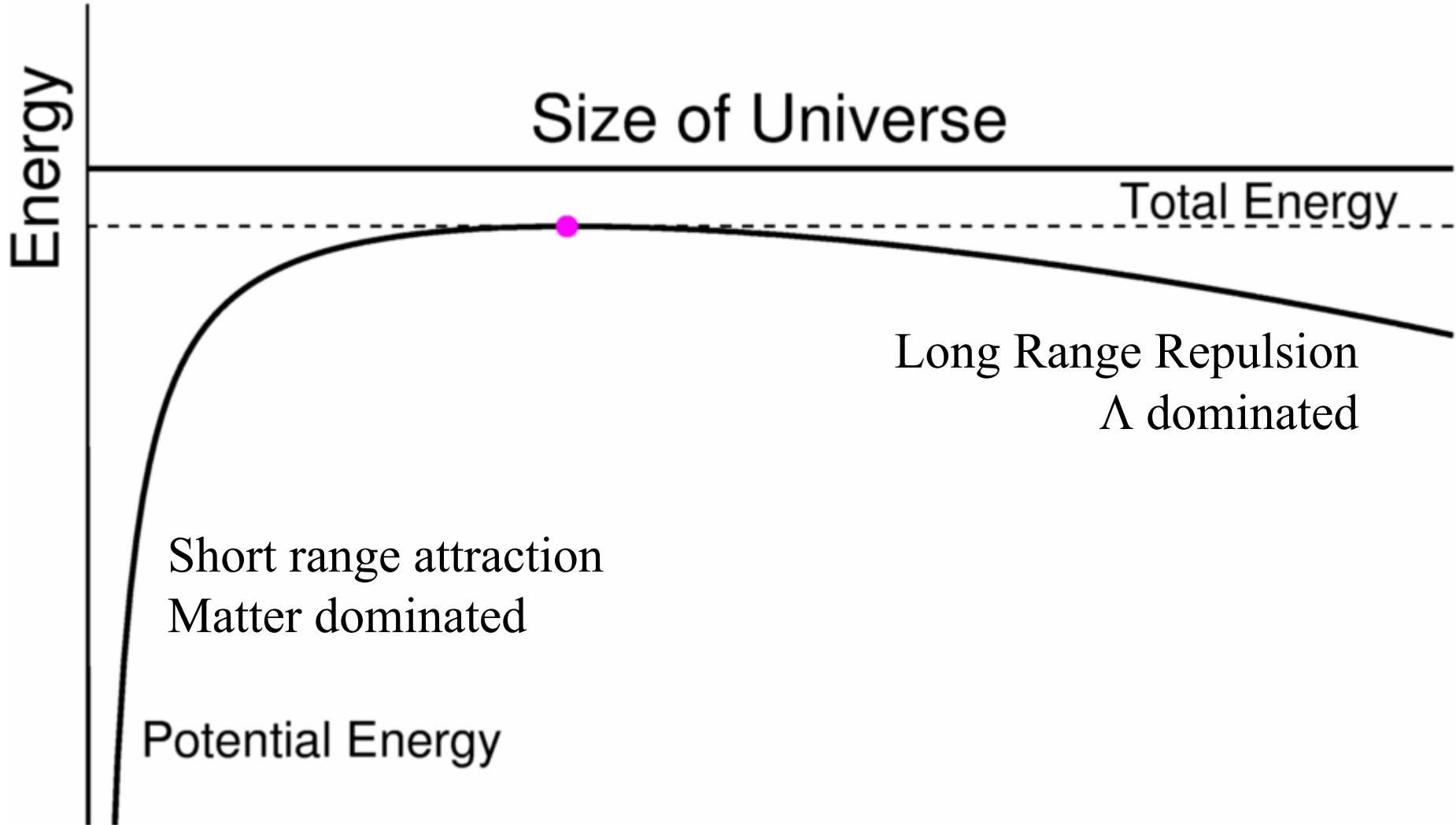


Source of Cosmological Constant

- A vacuum energy density is equivalent to Einstein's cosmological constant: Λ
- Quantum fluctuations could lead to a vacuum energy density.



Represent Force by Slope



- This is quite a good analogy for cosmological models.

Other models based on GR

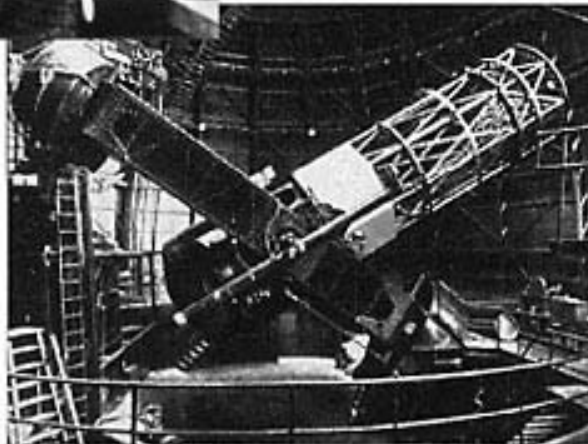
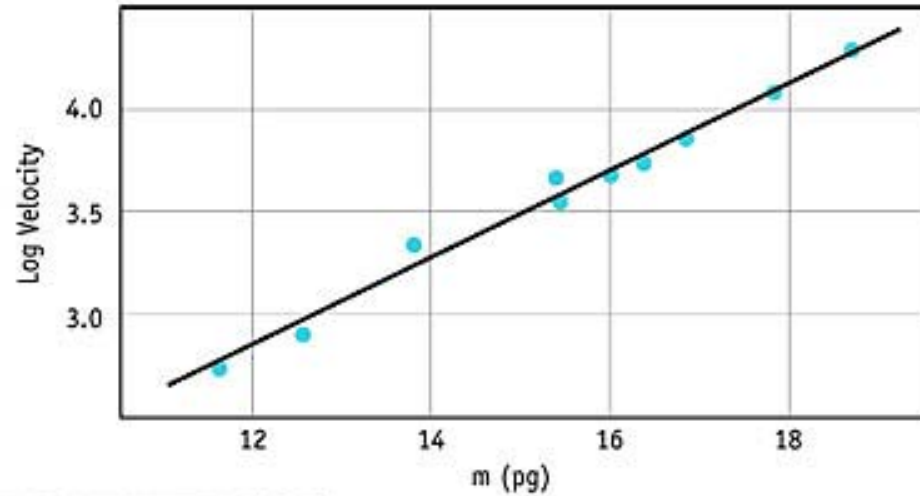
- Einstein had a very special combination of matter, Λ and total energy to give a static Universe. But this model is only metastable. If perturbed, it would either collapse or expand forever.
- de Sitter considered a model with no matter, only Λ . This model had an exponentially accelerating expansion.
- Friedmann considered models with matter that expanded from a singularity of infinite density.

New Data

DISCOVERY OF EXPANDING UNIVERSE



Edwin Hubble



Mt. Wilson
100 Inch
Telescope



Hubble Law: $v = HD$

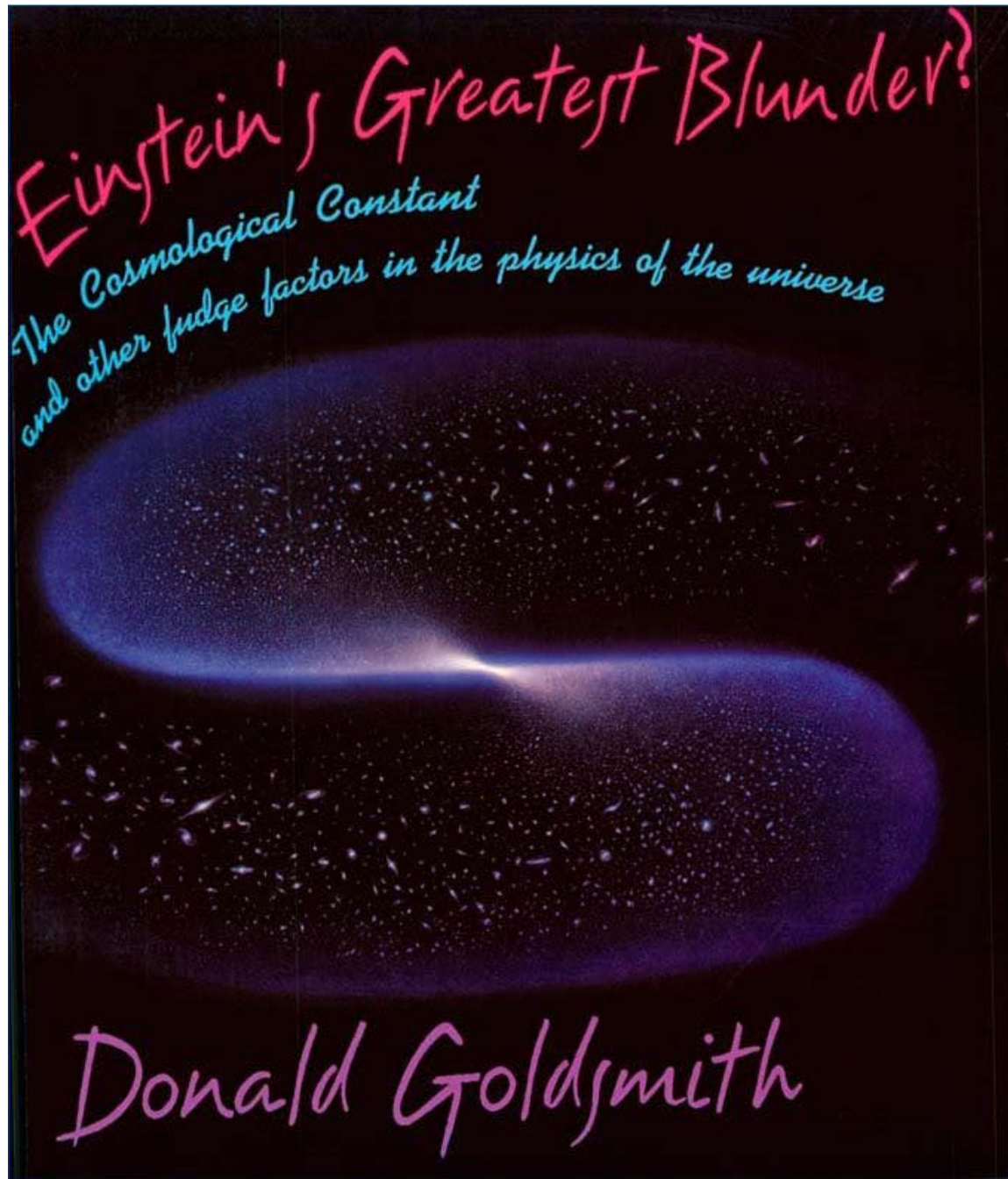
- Hubble found a recession velocity proportional to the distance.
 - Einstein static fails, de Sitter & Friedmann pass
- Hubble also found that the distribution of galaxies was homogeneous [the same in all places] and isotropic [the same in all directions].
 - Einstein static, de Sitter & Friedmann all pass

Models vs Olbers Paradox

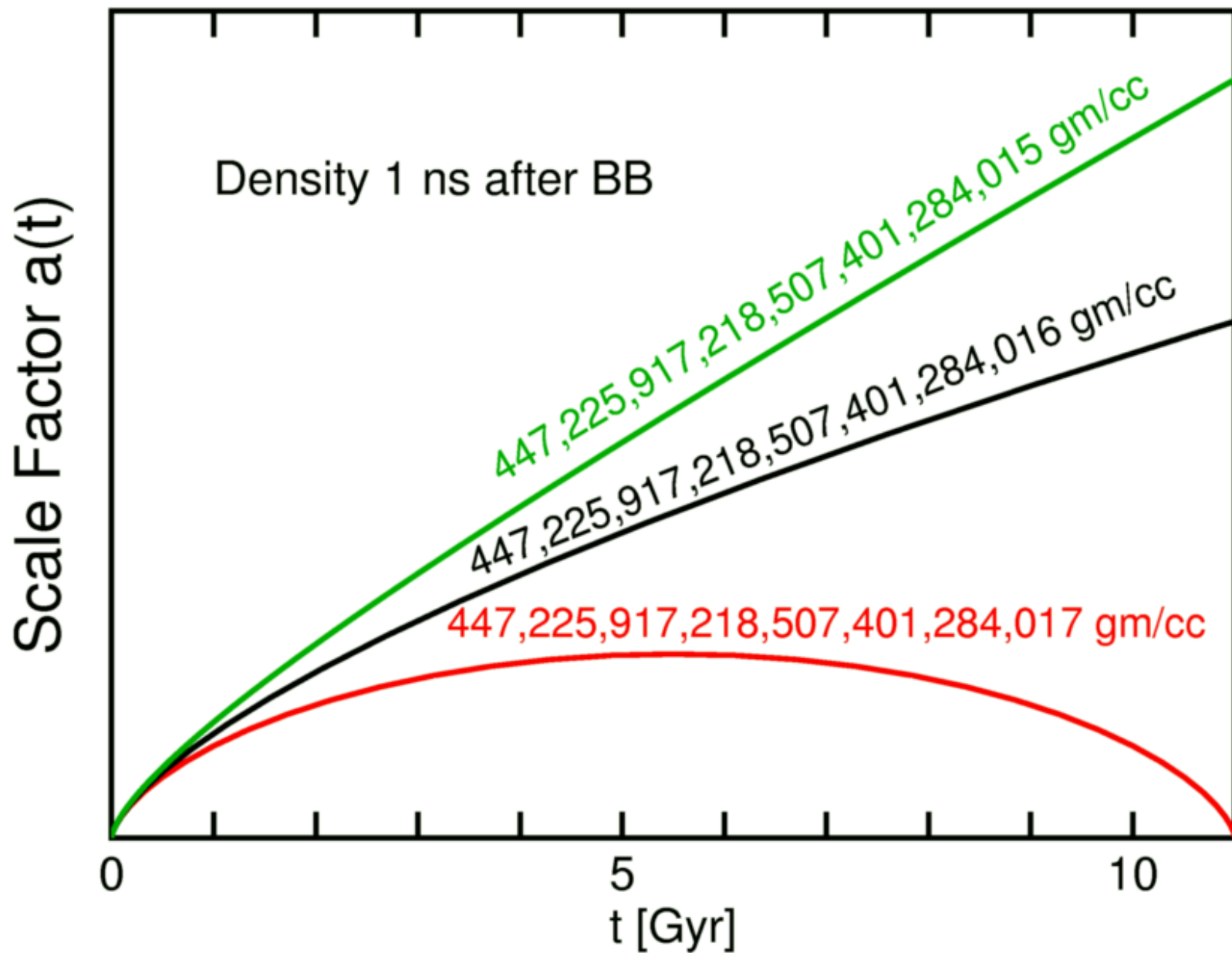
- A static Universe filled with light-emitting stars cannot be static. It will fill up with photons and gradually get brighter.
- Einstein's static model will fill up with light until the night sky is as bright as the surface of a star.
- Expanding de Sitter & Friedmann models are consistent with a dark night sky.

Λ Was Demoted

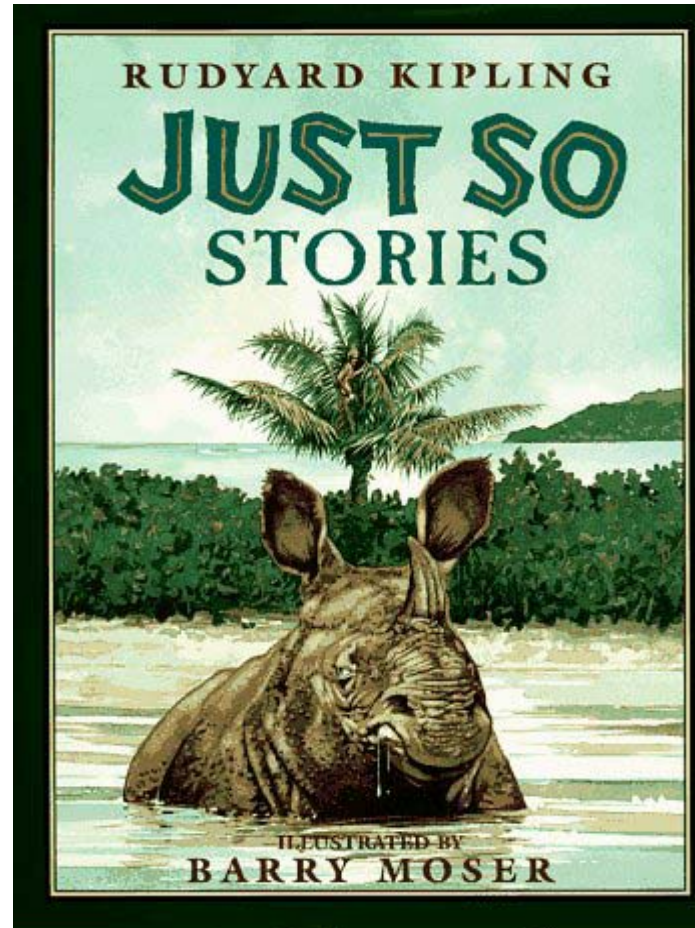
- Expanding models with or without matter and/or Λ are possible.
- But matter is needed – we are here.
- Λ was not needed so it was deprecated.



Flatness-Oldness Problem: density must be fine-tuned



Just So?



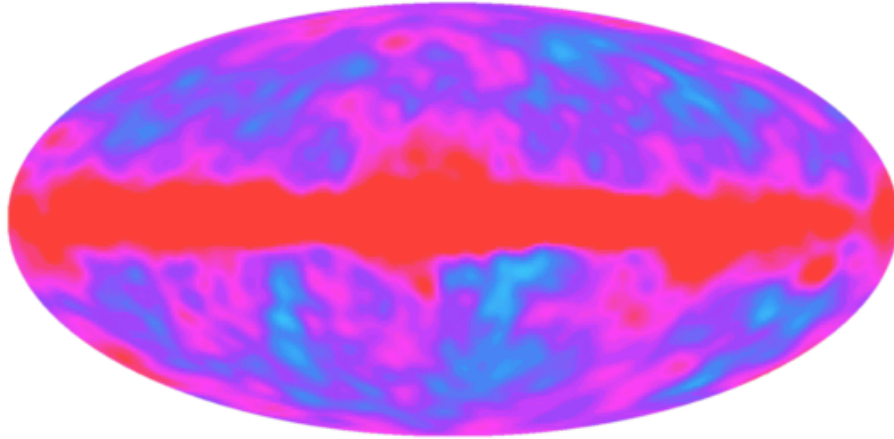
Animated View of Inflation

- Quantum fluctuations occur uniformly throughout space-time.
- Future light cones of fluctuations grow making big circles but new fluctuations continuously replenish the small circles.
- Result is Equal Power on All Scales (EPAS).

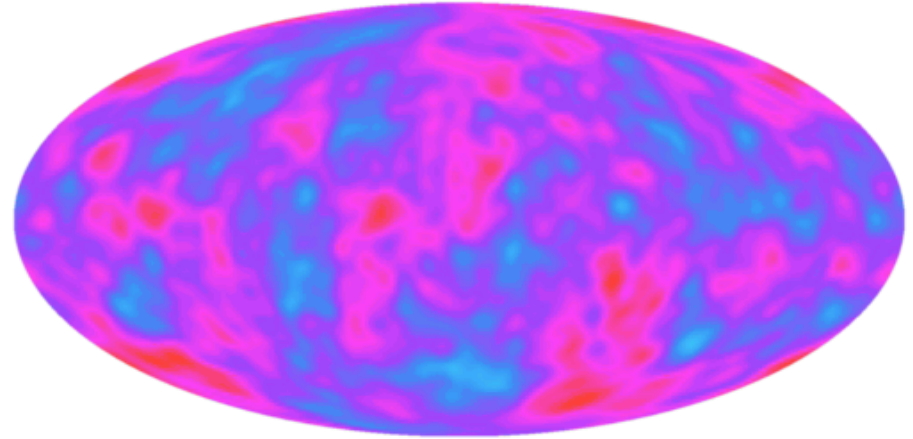


COBE DMR vs EPAS

COBE Data



Equal Power on All Scales Model



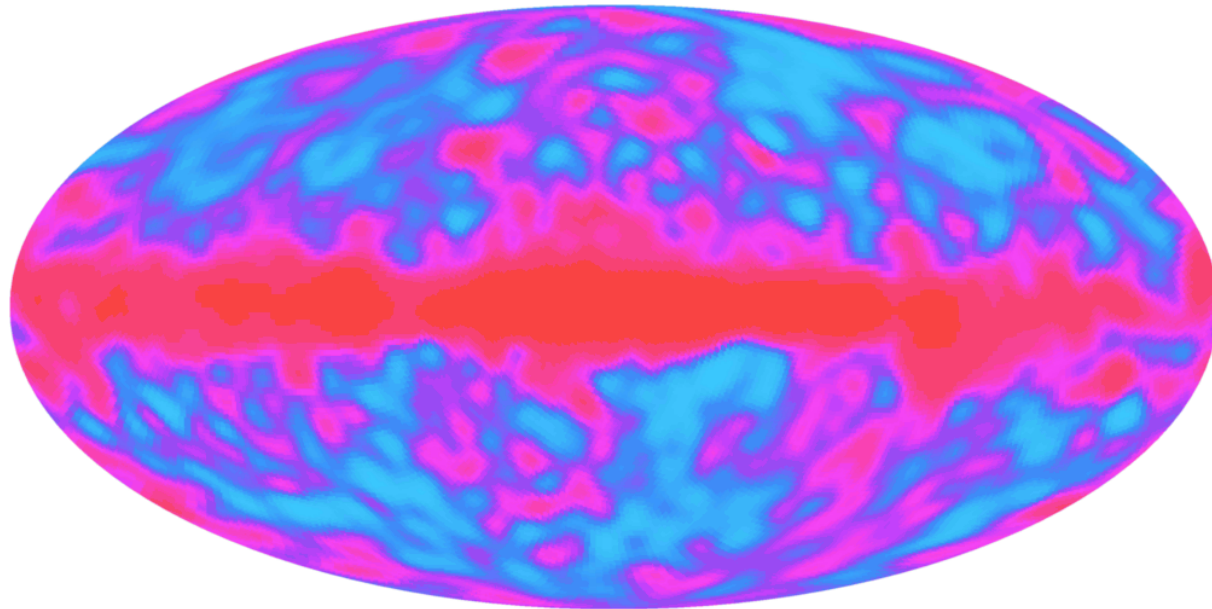
“Chi-by-eye” suggests that the “Equal Power on All Scales” prediction of inflation is correct.

A Big Media Splash in 1992:

THE TIMES

25 April 1992

Prof. Stephen Hawking of Cambridge University, not usually noted for overstatement, said: “It is the discovery of the century, if not of all time.”

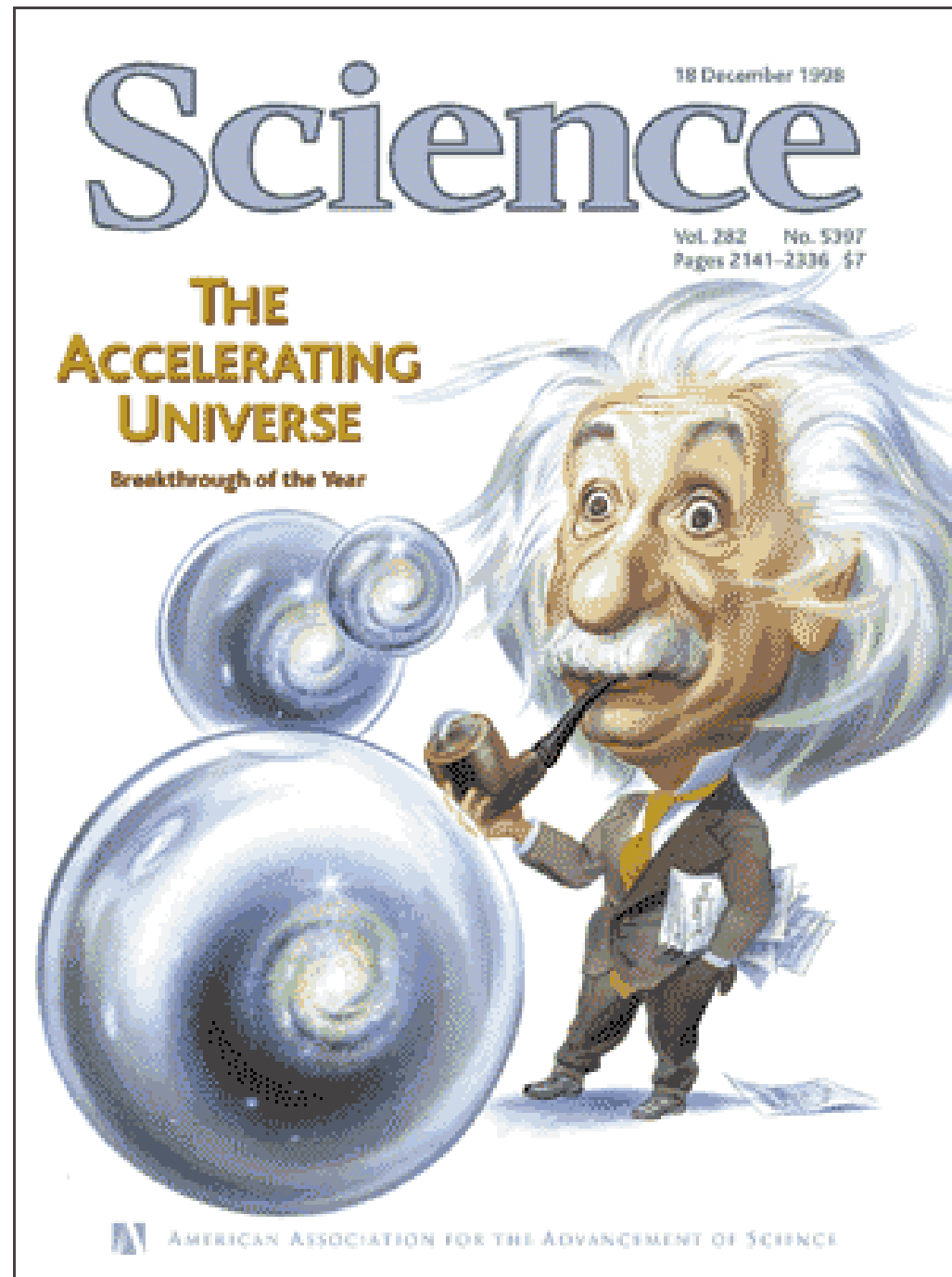


Accelerating Universe: 1998

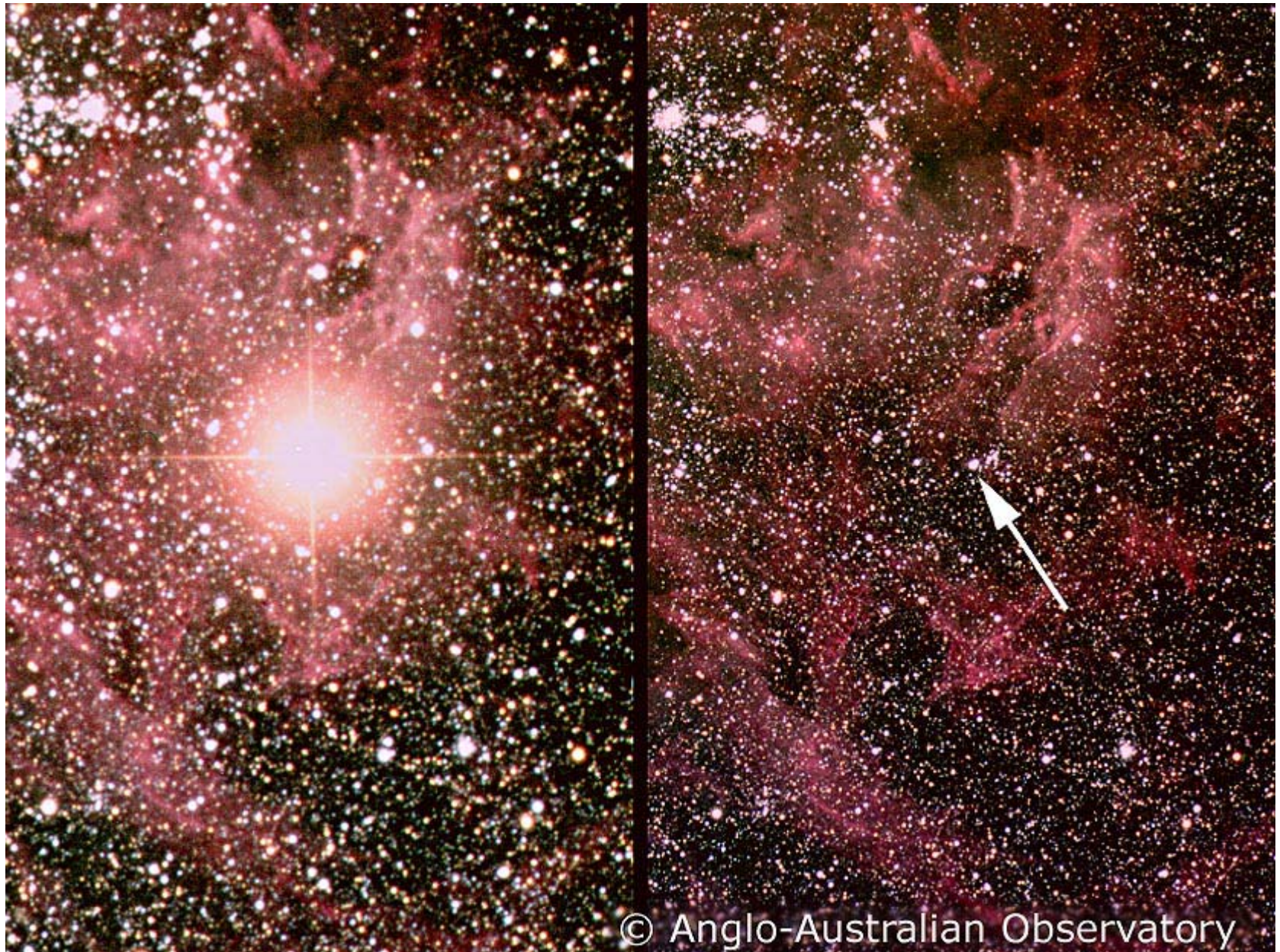
Distant (high z) supernovae fainter than expected.

This was the AAAS discovery of the year in 1998.

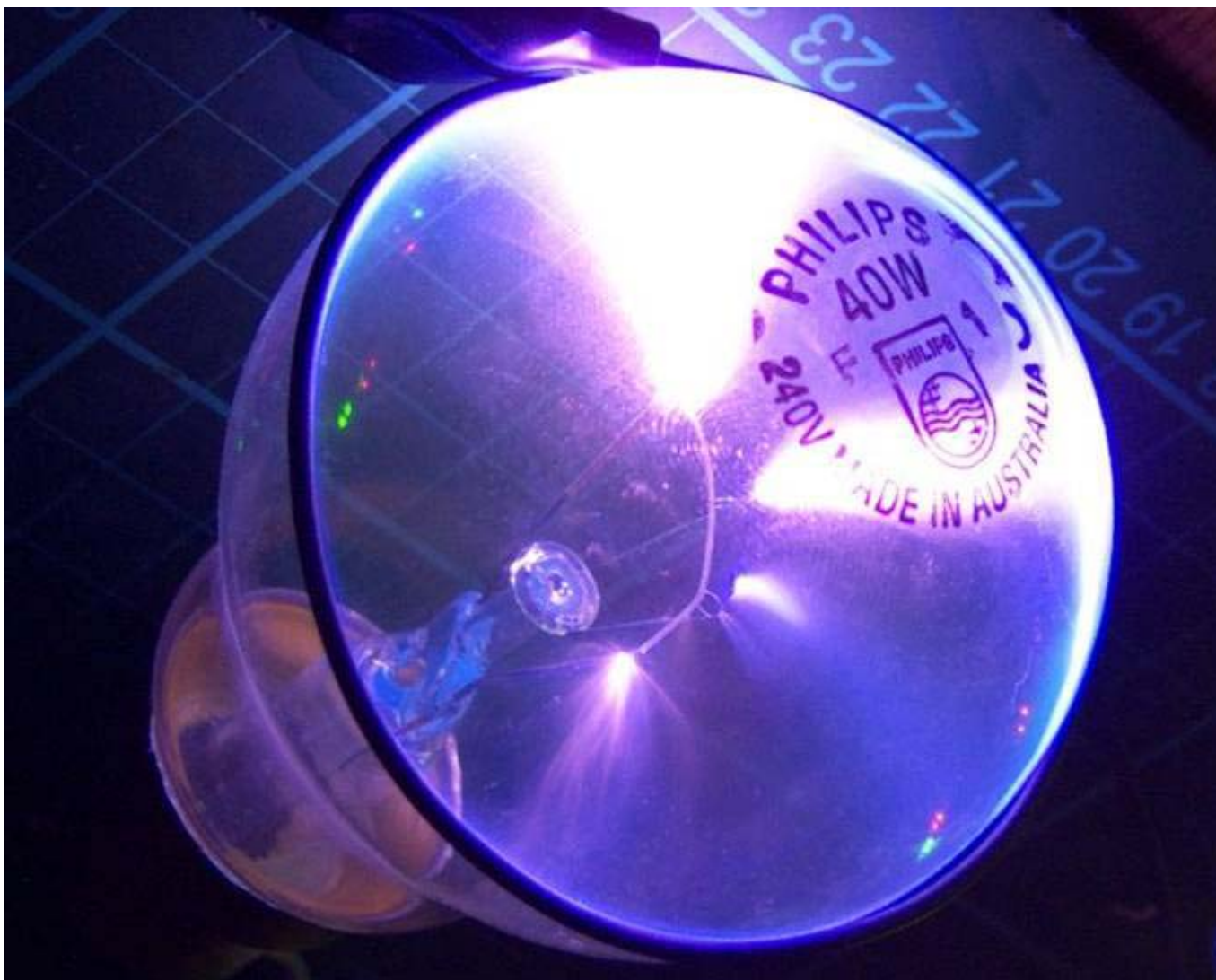
Λ causes acceleration!



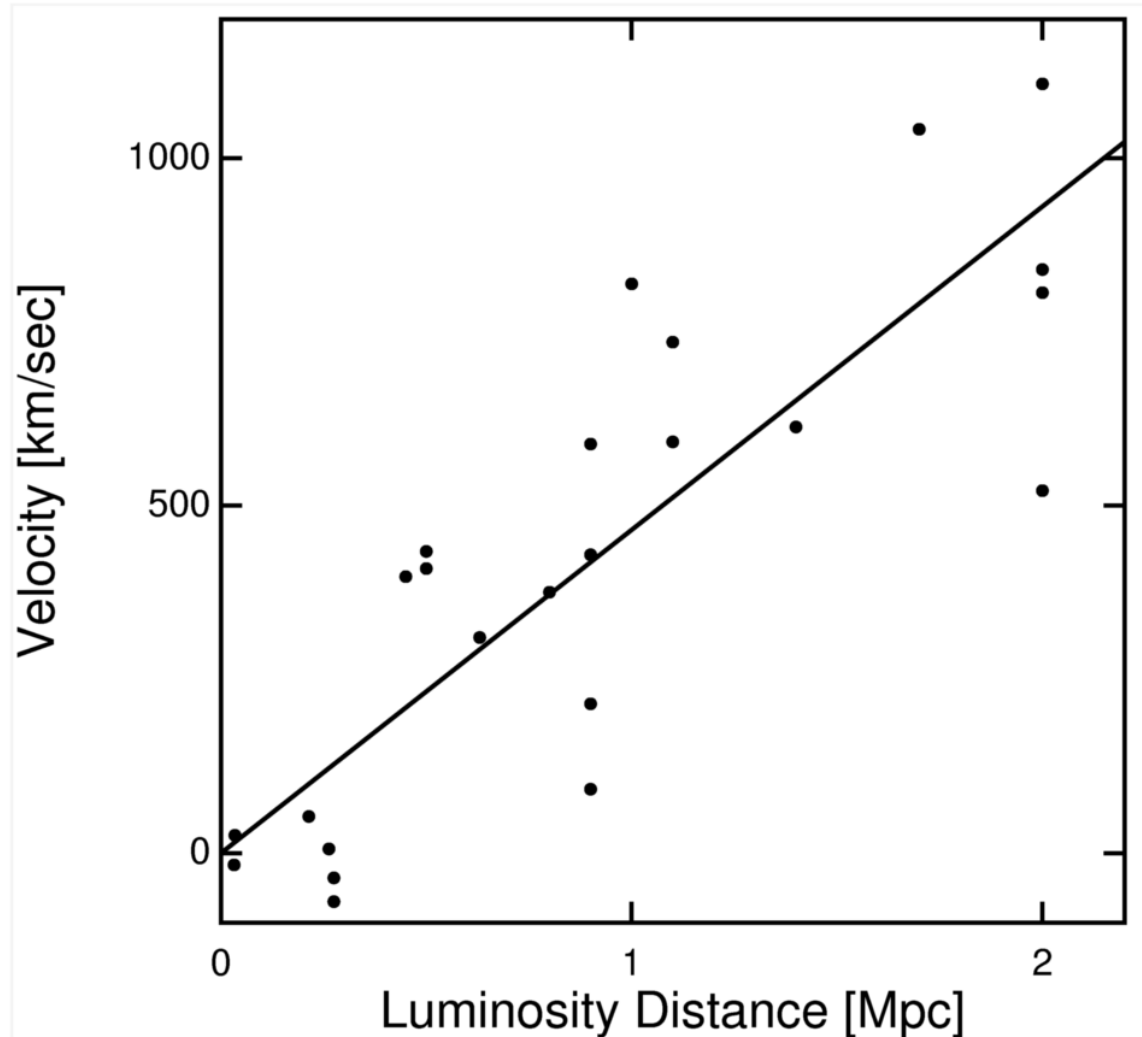
What is a supernova?



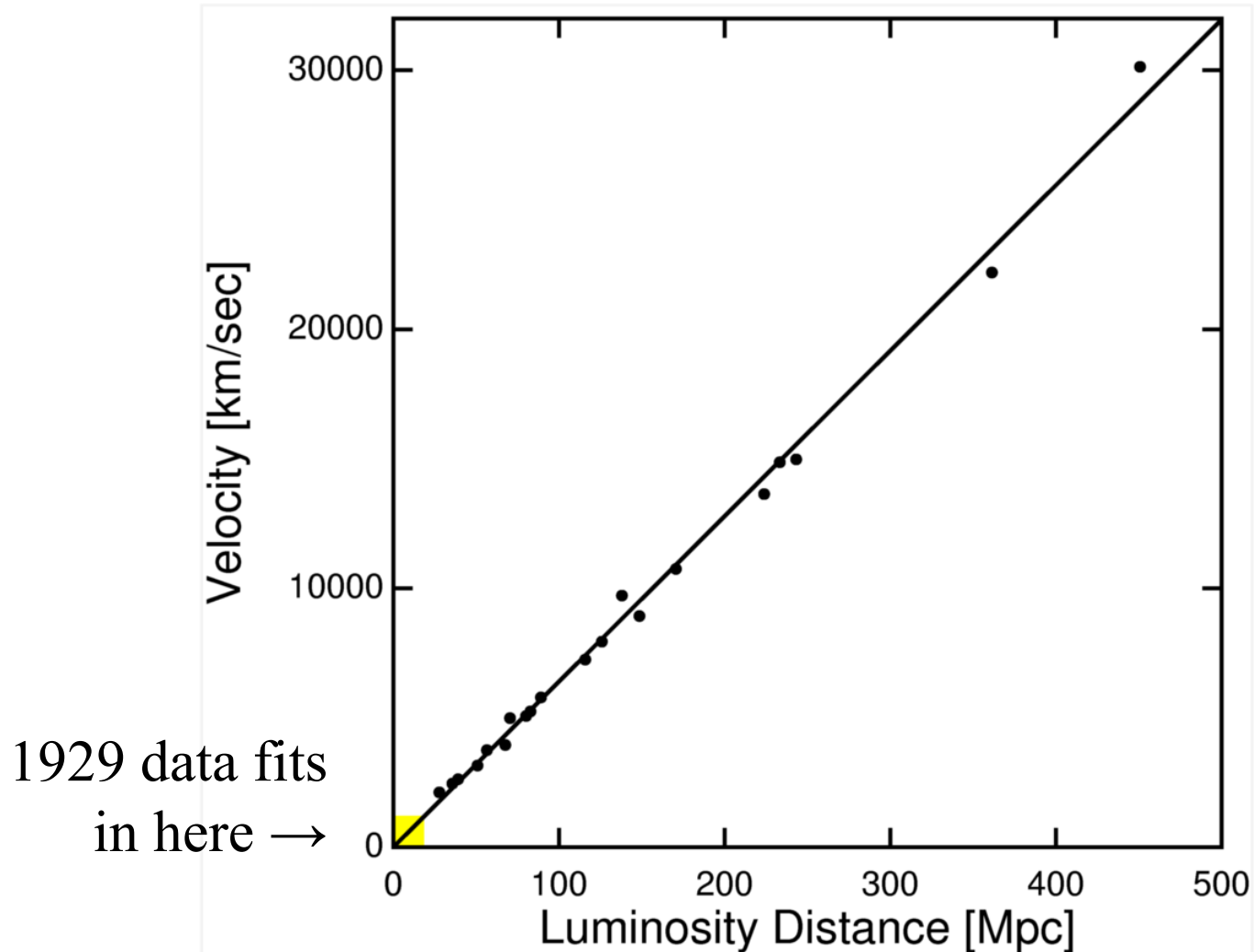
We recently learned how to read the “wattage” label on supernovae:



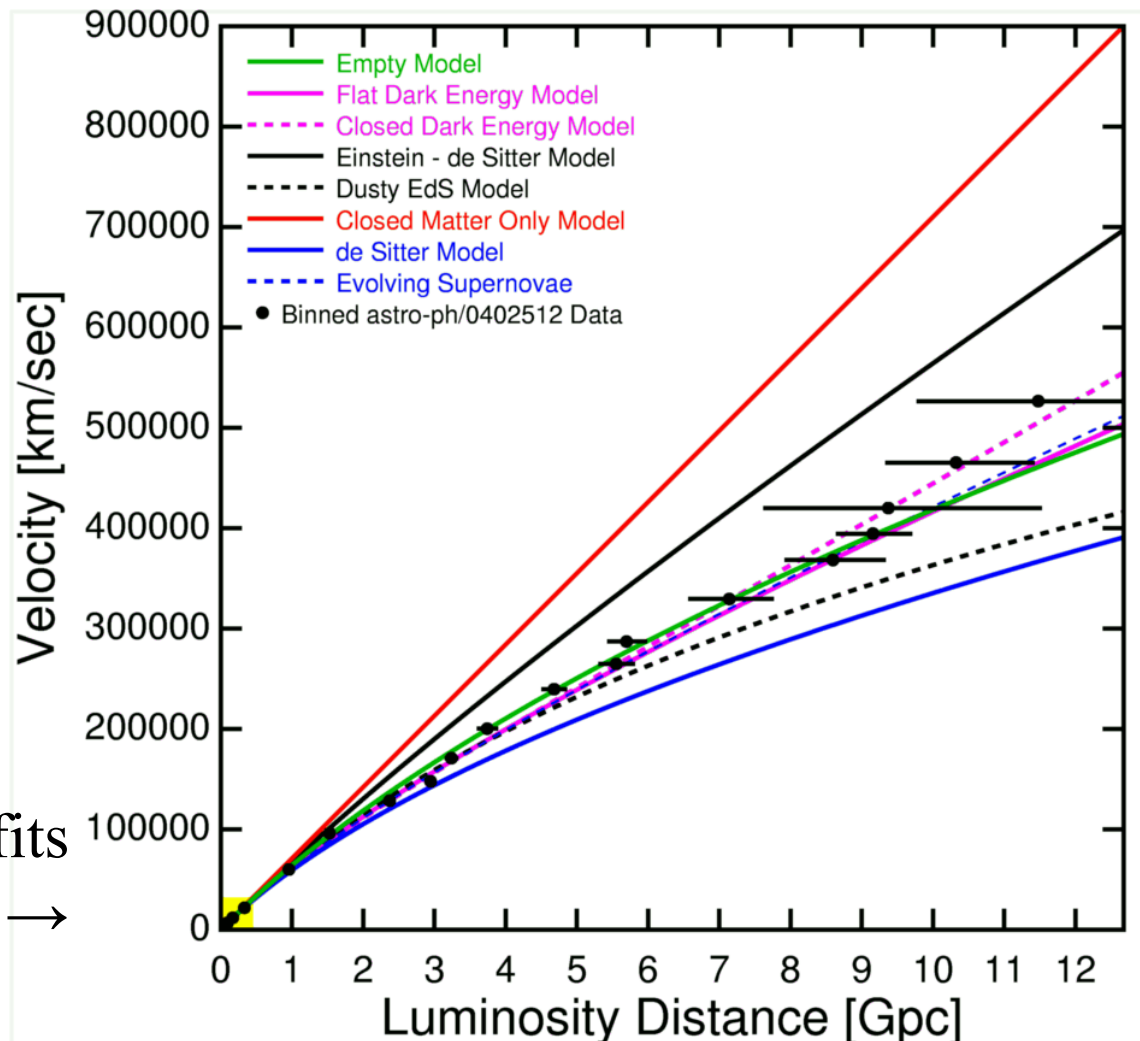
As a result, data on velocity vs distance is now much better! 1929



As a result, data on velocity vs distance is now much better! 1995



As a result, data on velocity vs distance is now much better! 2004



1995 data fits
in here →

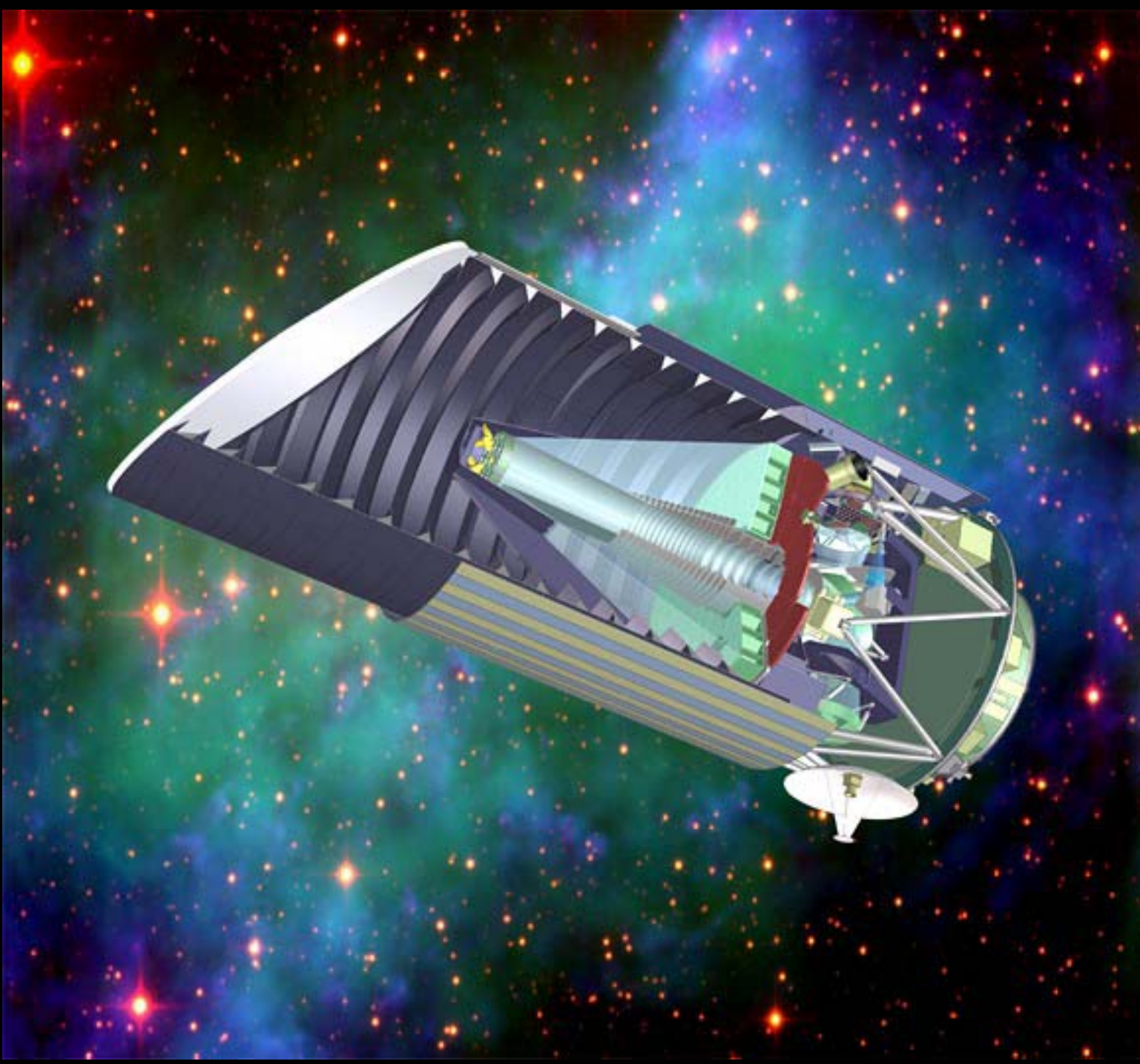
$$v = cz$$

Is Λ really a *CONSTANT*?

- The large Λ during inflation went away.
- Will the small Λ driving the accelerating expansion go away too? Is it the same now as it was 5 billion years ago?
- In order to find out, NASA and the Department of Energy want to build JDEM, the Joint Dark Energy Mission.
- Several groups are proposing JDEM concepts.
- I am on the JDEM Science Definition Team.

JDEM
in 10
years?

NASA
needs
\$\$\$

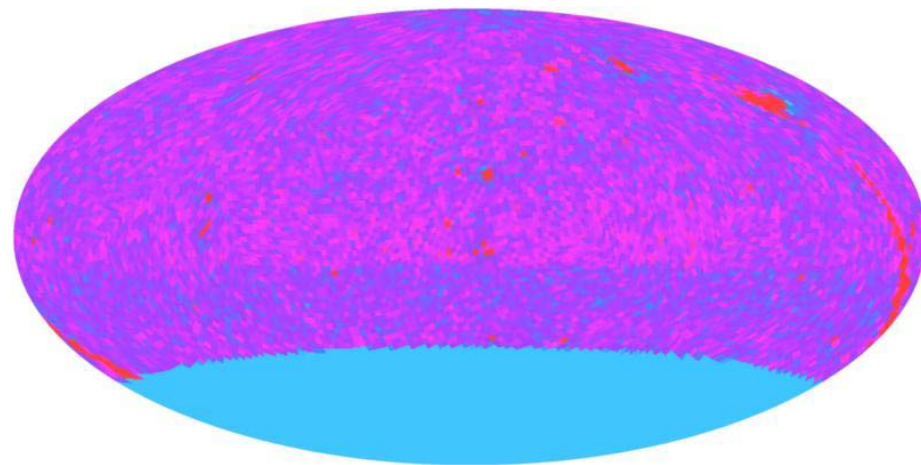
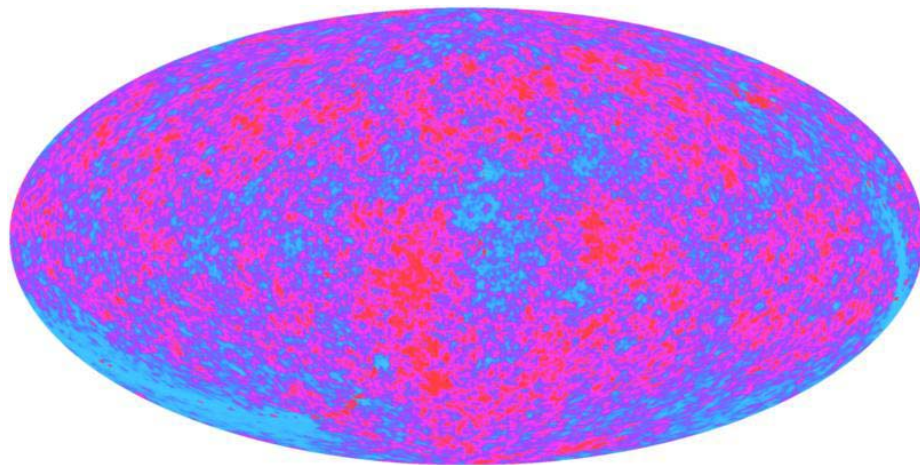


Same Laws of Physics?

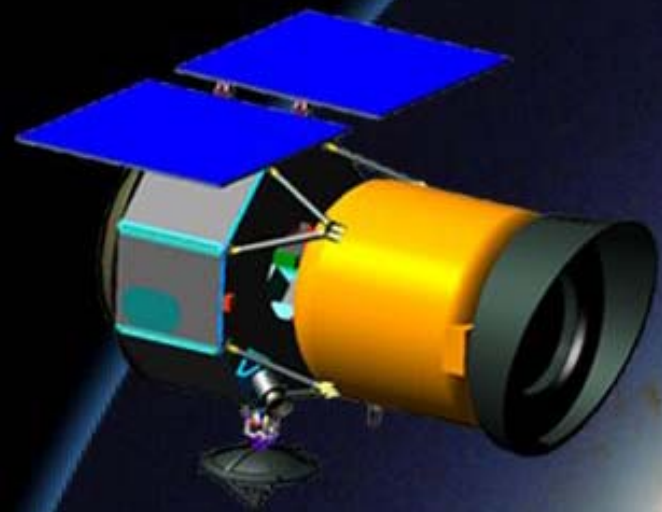
- The cosmological constant Λ is present in space and also in our laboratory.
- But its effects in the laboratory are too small to measure. This is not the best situation.
- Astrophysicists are very eager to confirm the existence of Λ by every possible method.
- Currently there are several independent methods that all agree on the existence of Λ .

Λ Confirmed by CMB & IR maps

- This late Integrated Sachs-Wolfe effect occurs on our past light cone so the CMB ΔT we see is due to structures we also see.
- Correlation between WMAP and large-scale structure seen by:
 - Boughn & Crittenden at 99.7% confidence with hard X-ray background
 - Nolta at 98% confidence with the NRAO VLA Sky Survey
 - Ashfordi at 99.4% with the 2MASS 2 micron all sky survey



WIDE-FIELD INFRARED SURVEY EXPLORER



I am the PI on a MIDEEX called WISE, an all-sky survey in 4 bands from 3.3 to 24 μm . WISE will find and study the closest stars to the Sun, the most luminous galaxies in the Universe, and also map the large-scale structure out to redshift $z=1$, covering the era when the late ISW effect should be generated.

WISE will fly in 2008.

Λ : Blunder or Triumph?

- Einstein invented General Relativity, the best current theory for gravity.
- GR allows a place for Λ , and predicts its gravitational effects.
- Einstein inserted Λ to explain a “fact” about the Universe that was not true. The model he developed was unstable and violated Olber’s Paradox.
- But Λ lives on in the Universe now, during inflation in the very early Universe, and in high energy particle physics.

For More Information

- <http://www.astro.ucla.edu/~wright/cosmolog.htm>
 - Many good books are listed on the Bibliography page of the above Web site
 - http://www.astro.ucla.edu/~wright/cosmo_constant.html
 - http://www.astro.ucla.edu/~wright/sne_cosmology.html
- <http://map.gsfc.nasa.gov>
 - The home page of the WMAP mission to measure the Cosmic Microwave Background sky