A Verification of the Expansion of Space

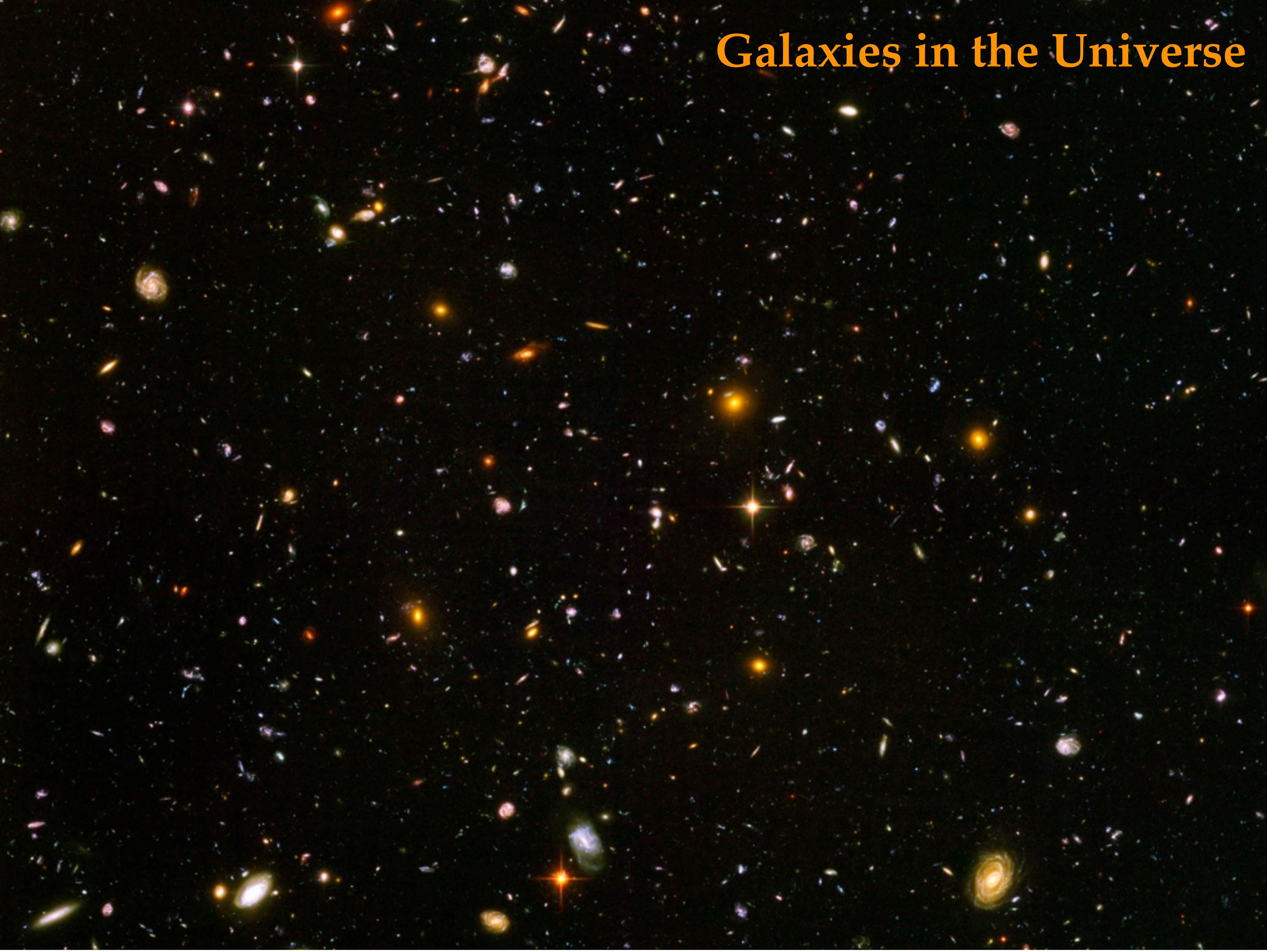
Andrew R. Zentner

University of Pittsburgh

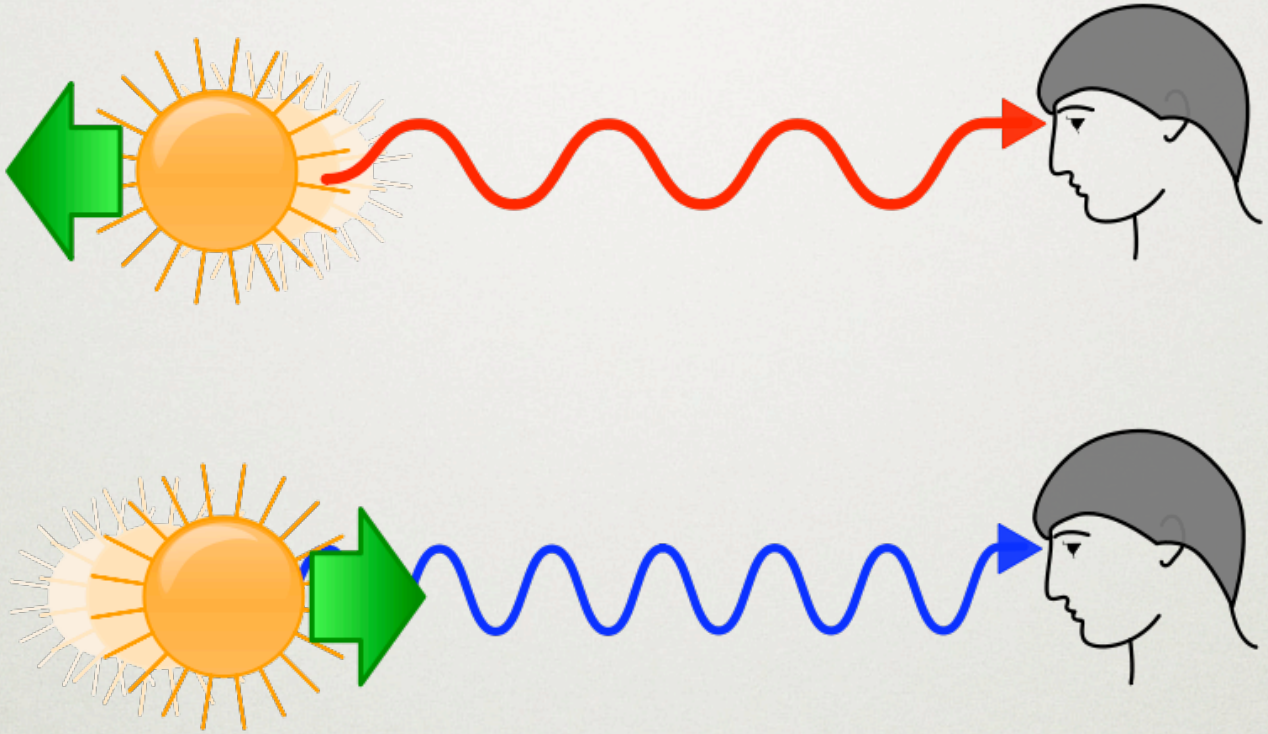
CONTENTS

Andromeda: A Galaxy Like Ours

Galaxies in the Universe

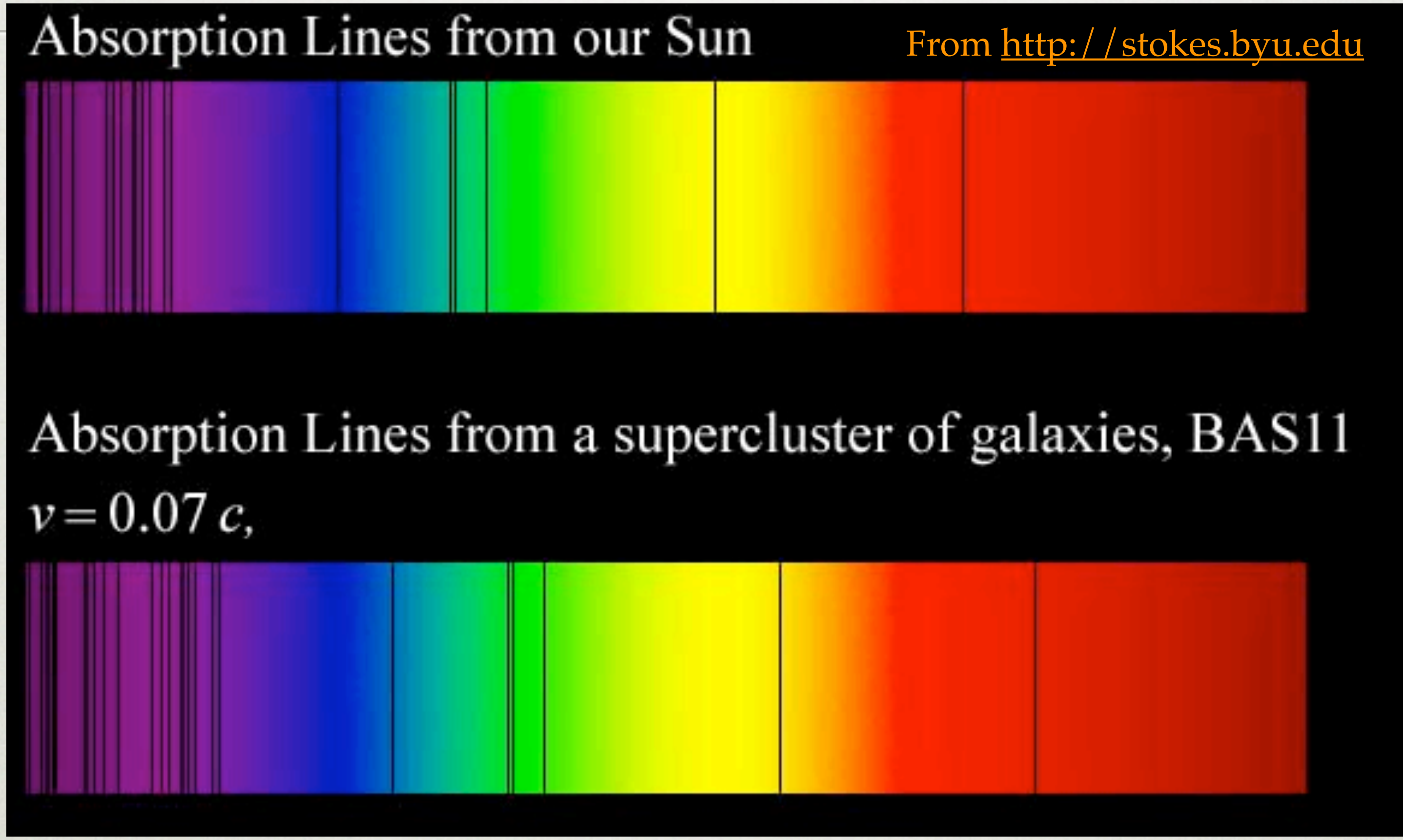


The Doppler Shift & Cosmic Redshifts



- "Redshift" describes the stretching of electromagnetic wavelengths from receding sources

The Expanding Universe

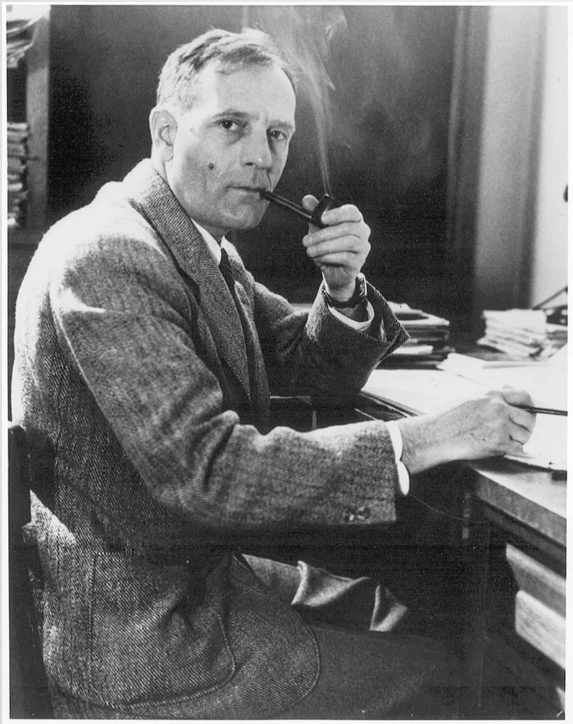


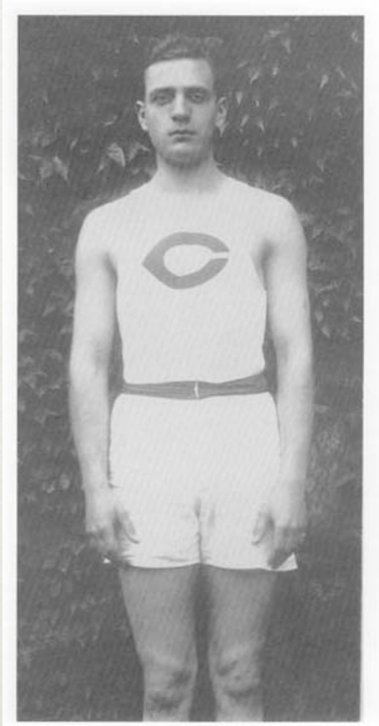
- We measure the redshifts of objects via characteristic patterns in electromagnetic spectra
- The amount of redshift gives the object's speed, in this case, 47 million miles per hour

The Expanding Universe

- A colleague of Edwin Hubble's, Vesto Slipher, measured the redshifts of many galaxies, and found something surprising...
- Almost all galaxies (Andromeda is an exception), appear to have REDSHIFTS, or shifts to longer wavelengths (in contrast to blueshifts)
- This was startling because the implication is that most galaxies are moving away from ours!

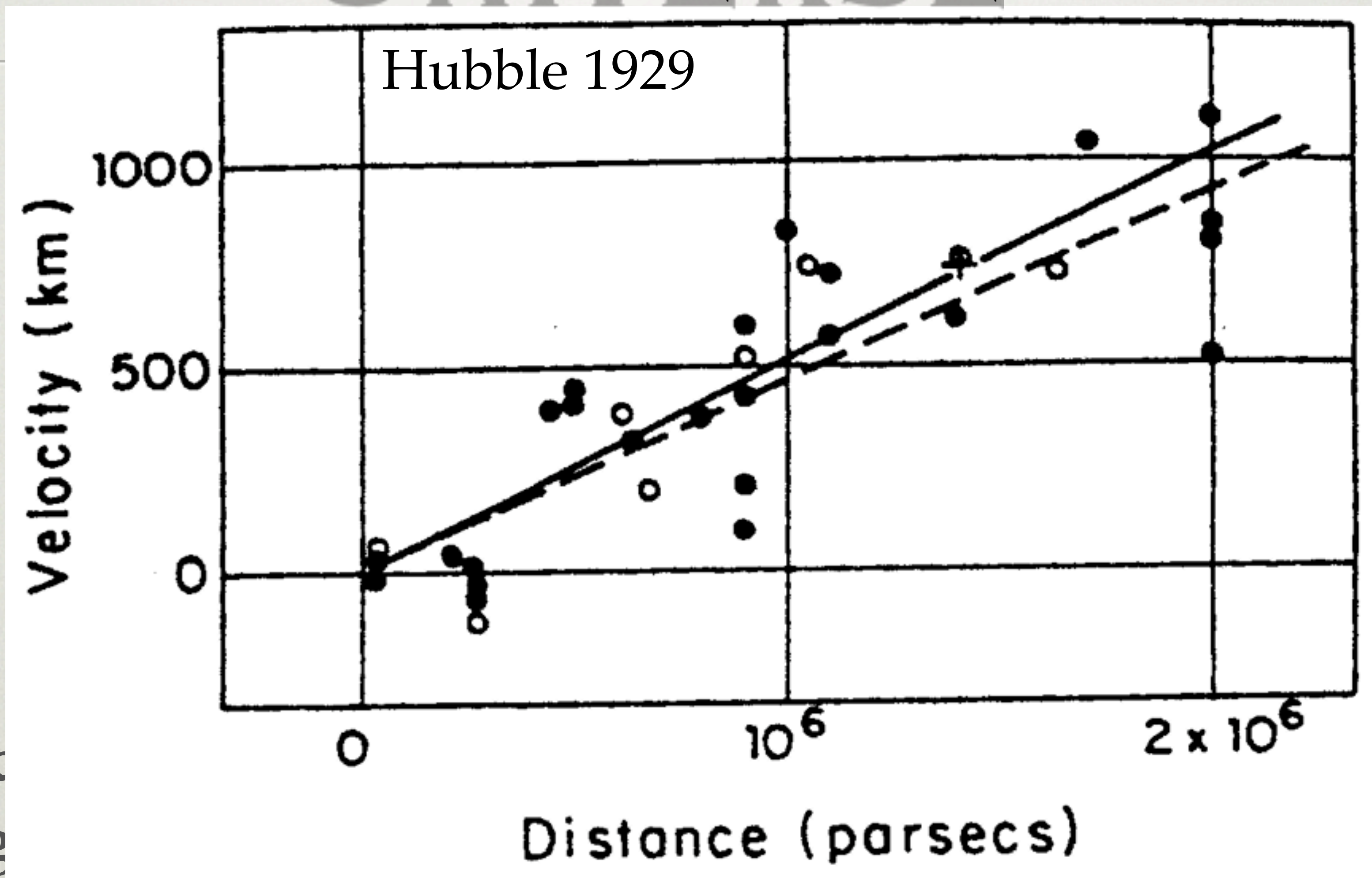
The Expanding Universe





- Edwin Hubble made a plot of the distance to galaxies against the velocities that galaxies were receding
- Galaxies recede at a speed proportional to their distance
- Today the Hubble expansion rate is 22 (km/s) for every million light years of distance

The Expanding Universe



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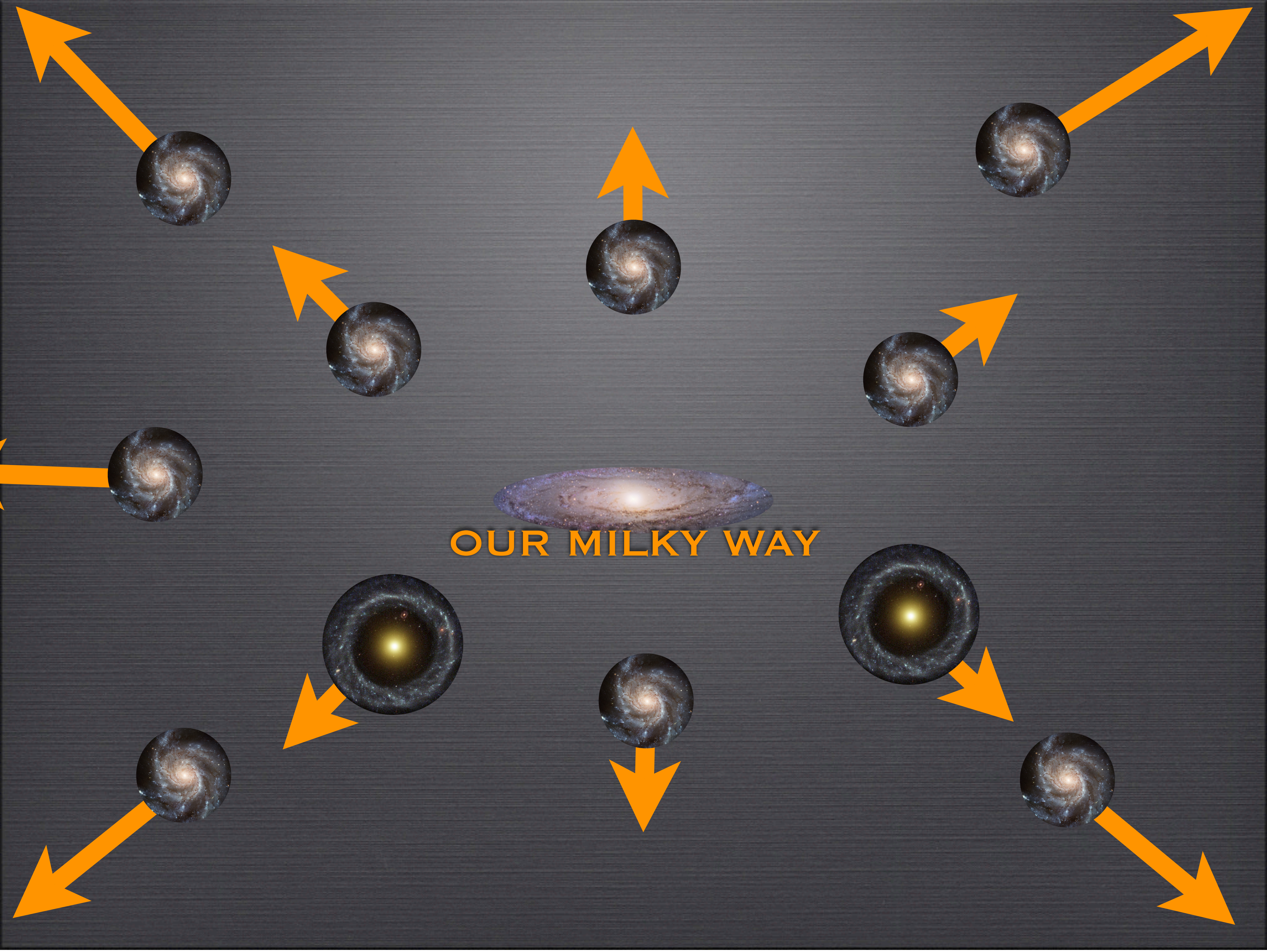
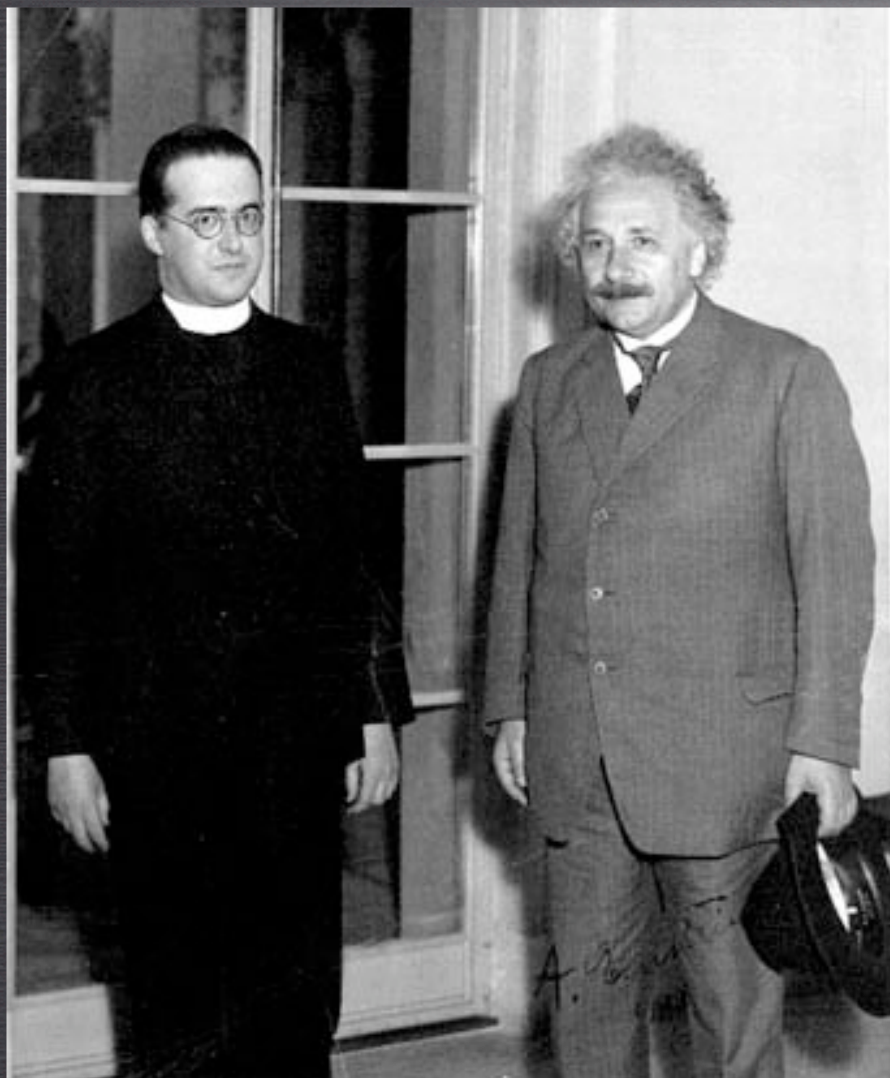
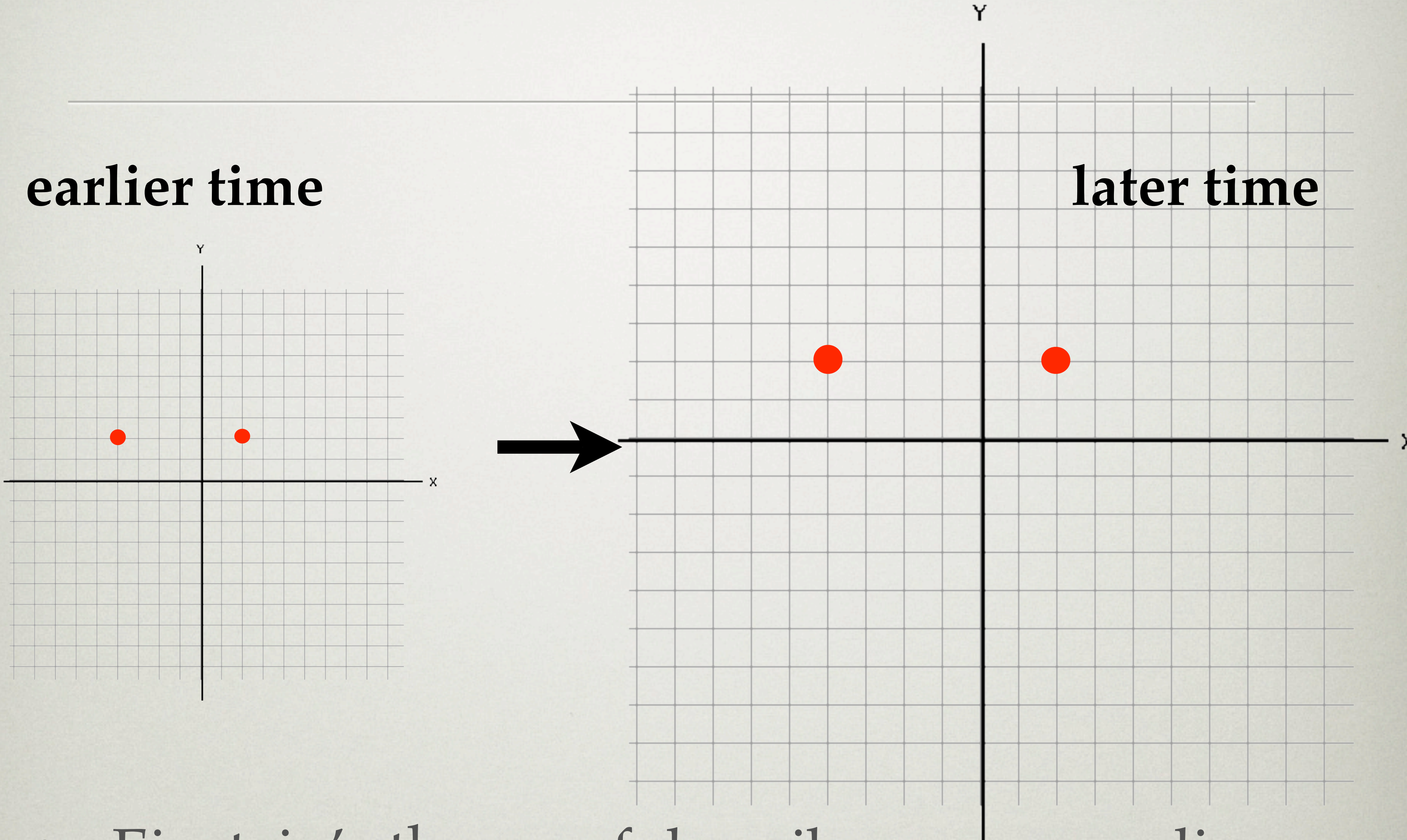

OUR MILKY WAY

The Expanding Universe

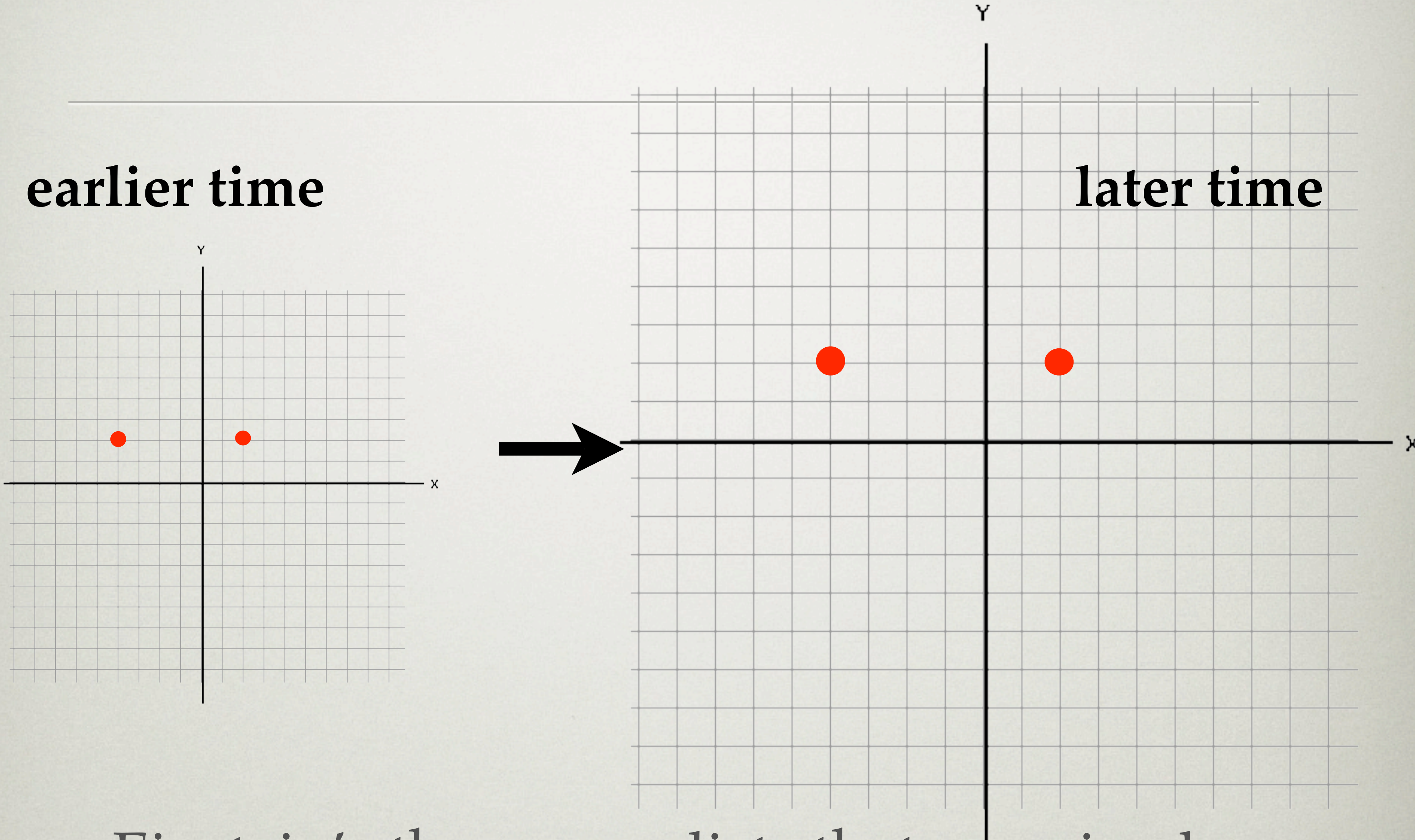


The Expanding Universe



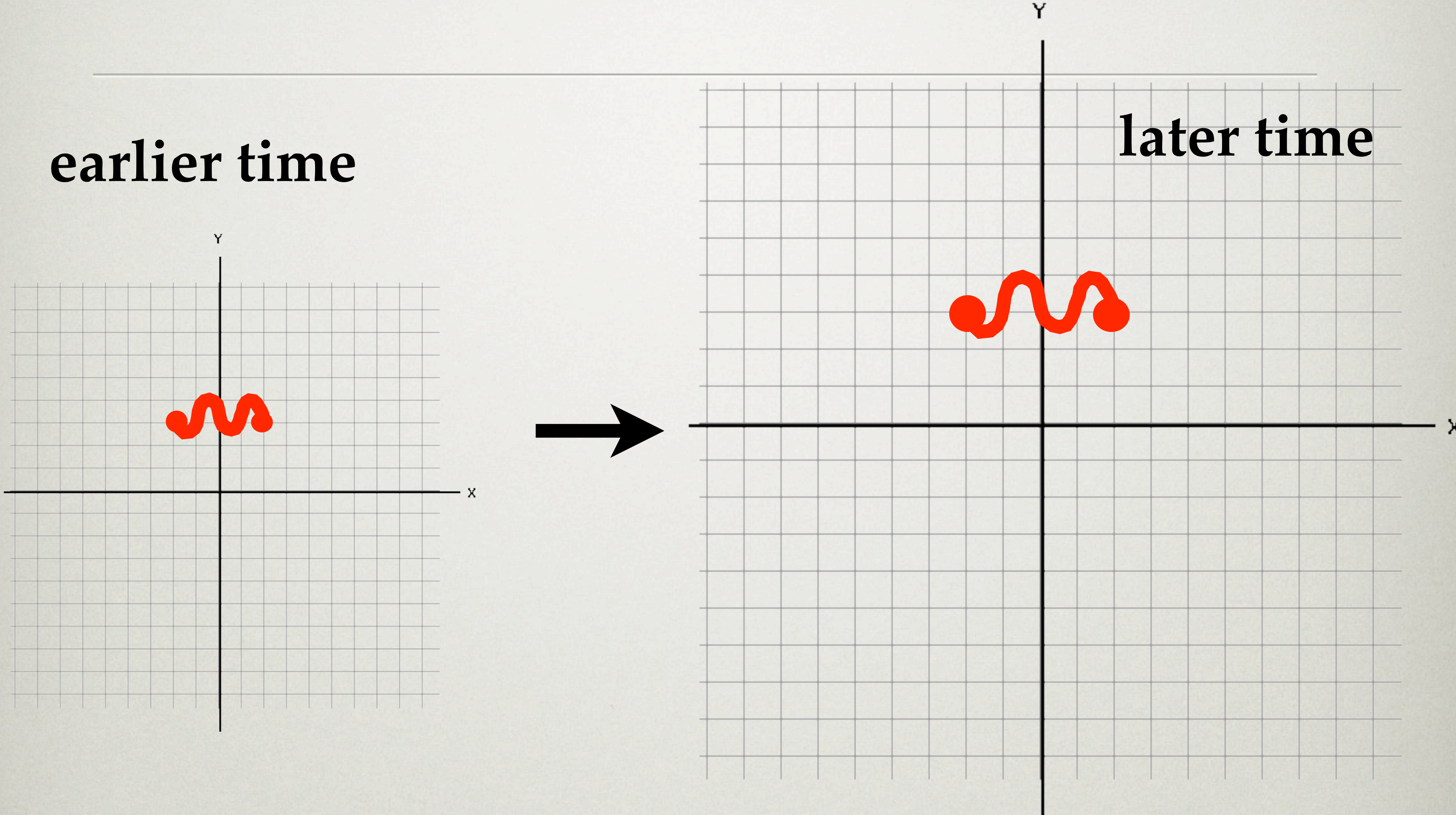
- Einstein's theory of describes an expanding Universe

The Expanding Universe



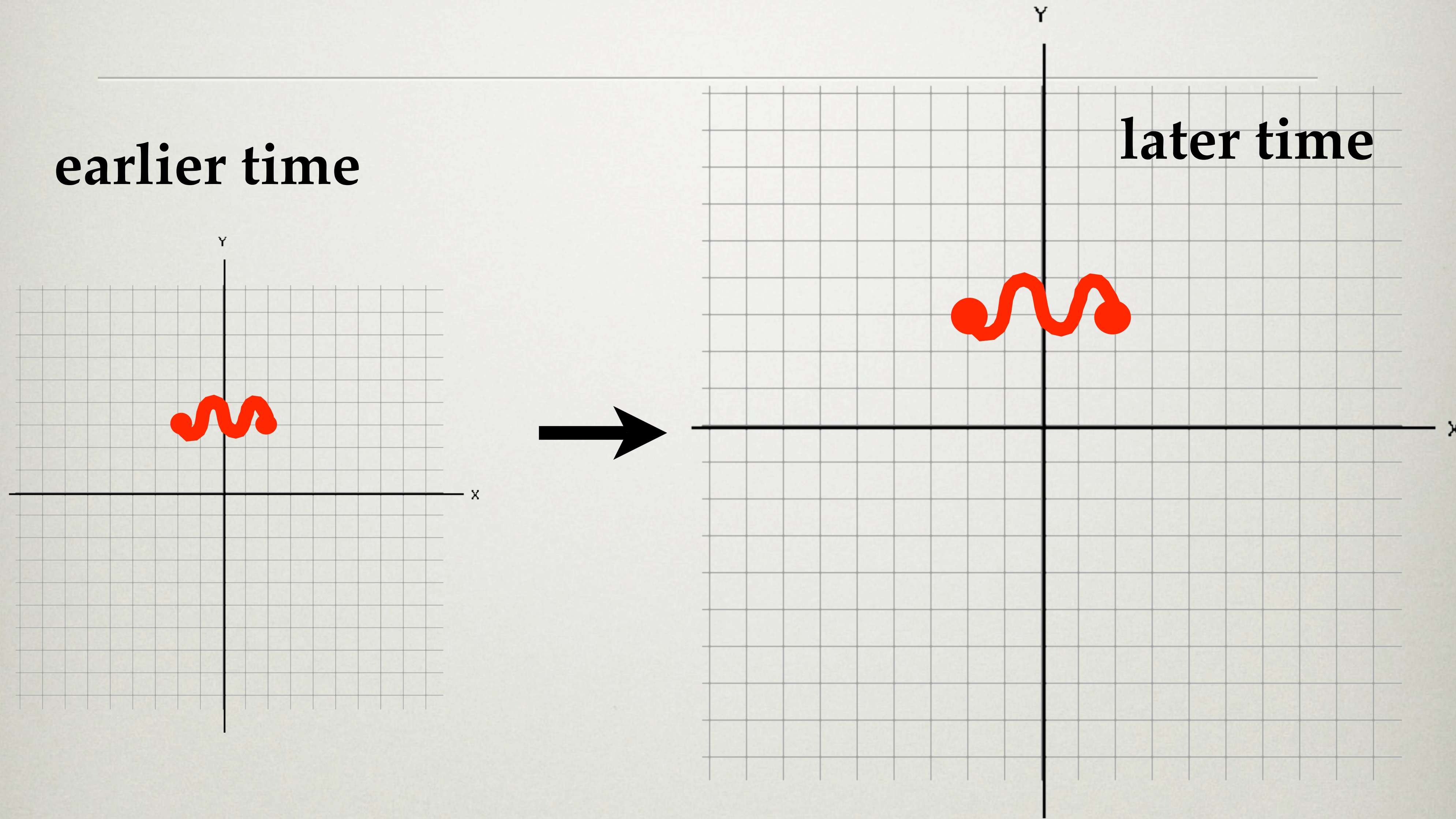
- Einstein's theory predicts that perceived recession speed is proportional do distance

The Expanding Universe



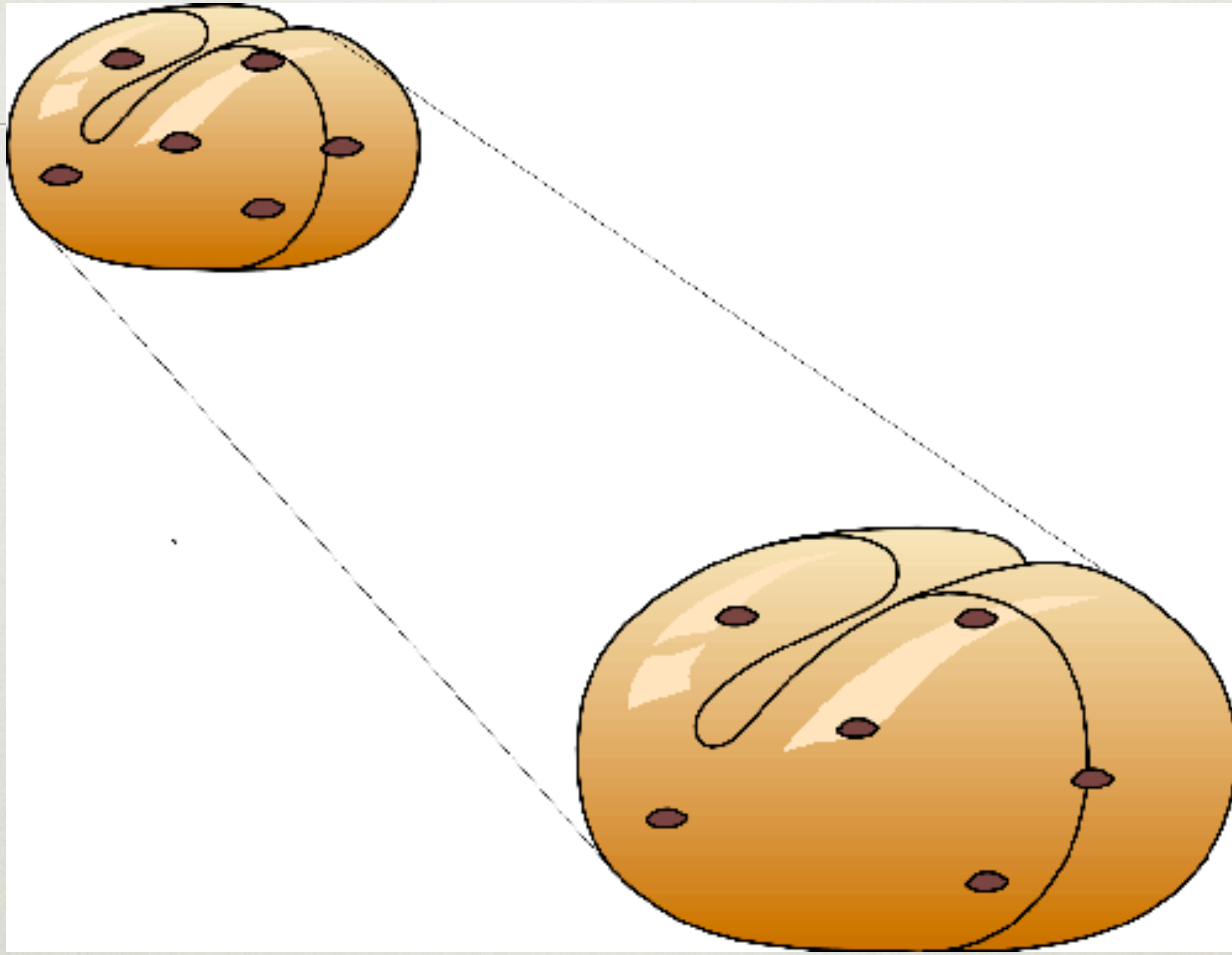
- Wavelengths of light are stretched by the expansion, giving rise to the redshift

The Expanding Universe



- The amount of stretching, or redshift, gives the amount of cosmic expansion

Cosmic Raisin Bread



- **The expansion and measured redshifts require no notion of a "center"**

Big Bang Successes

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1. Predicts the correct abundances of light elements in the Universe: Hydrogen (75%) Helium (24%), Deuterium (0.01%), Lithium (0.00001%)

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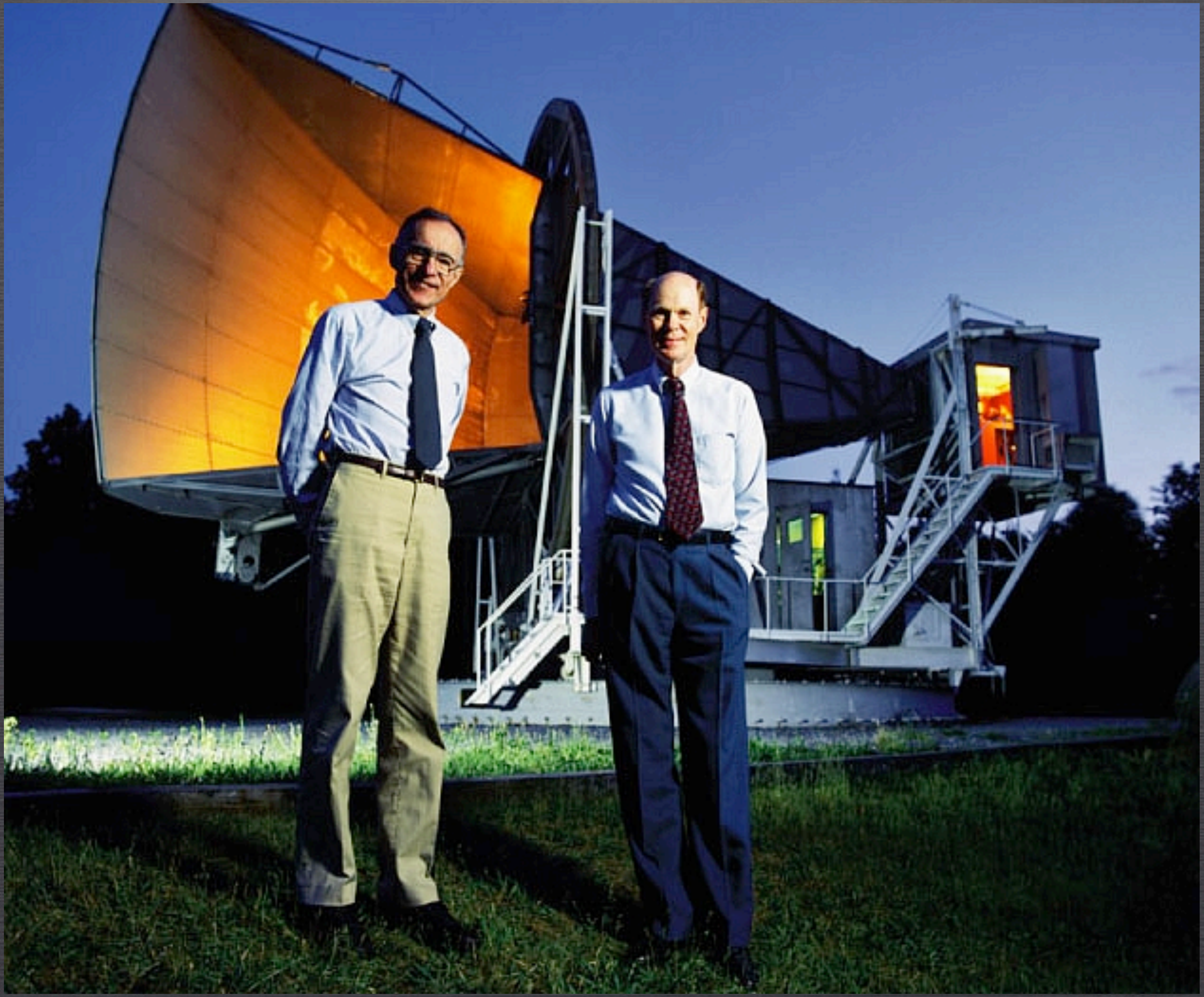
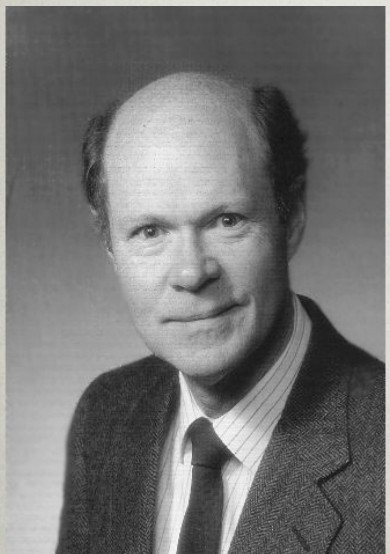
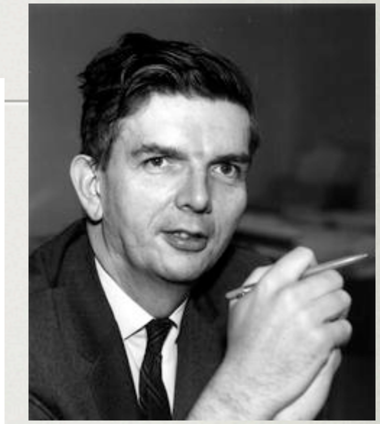
1. Predicts the correct abundances of light elements in the Universe: Hydrogen (75%) Helium (24%), Deuterium (0.01%), Lithium (0.00001%)
2. Predicts the abundances and clustering patterns of galaxies correctly
3. Predicts a nearly uniform "background" of radiation from the early Universe: the 3 K, Cosmic Microwave Background (CMB)

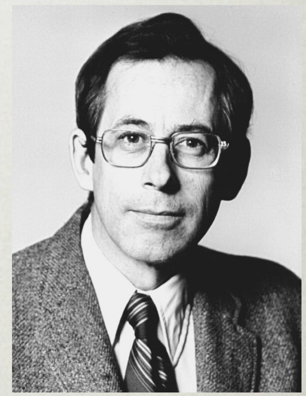
CMB Discoverers: Arno penzias & Robert Wilson

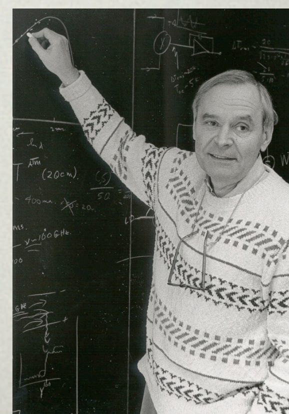


The Cosmic Microwave Background









We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

R. H. Dicke
P. J. E. Peebles
P. G. Roll
D. T. Wilkinson

May 7, 1965
Palmer Physical Laboratory
Princeton, New Jersey

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A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and

Intensity, Wavelength, and Frequency

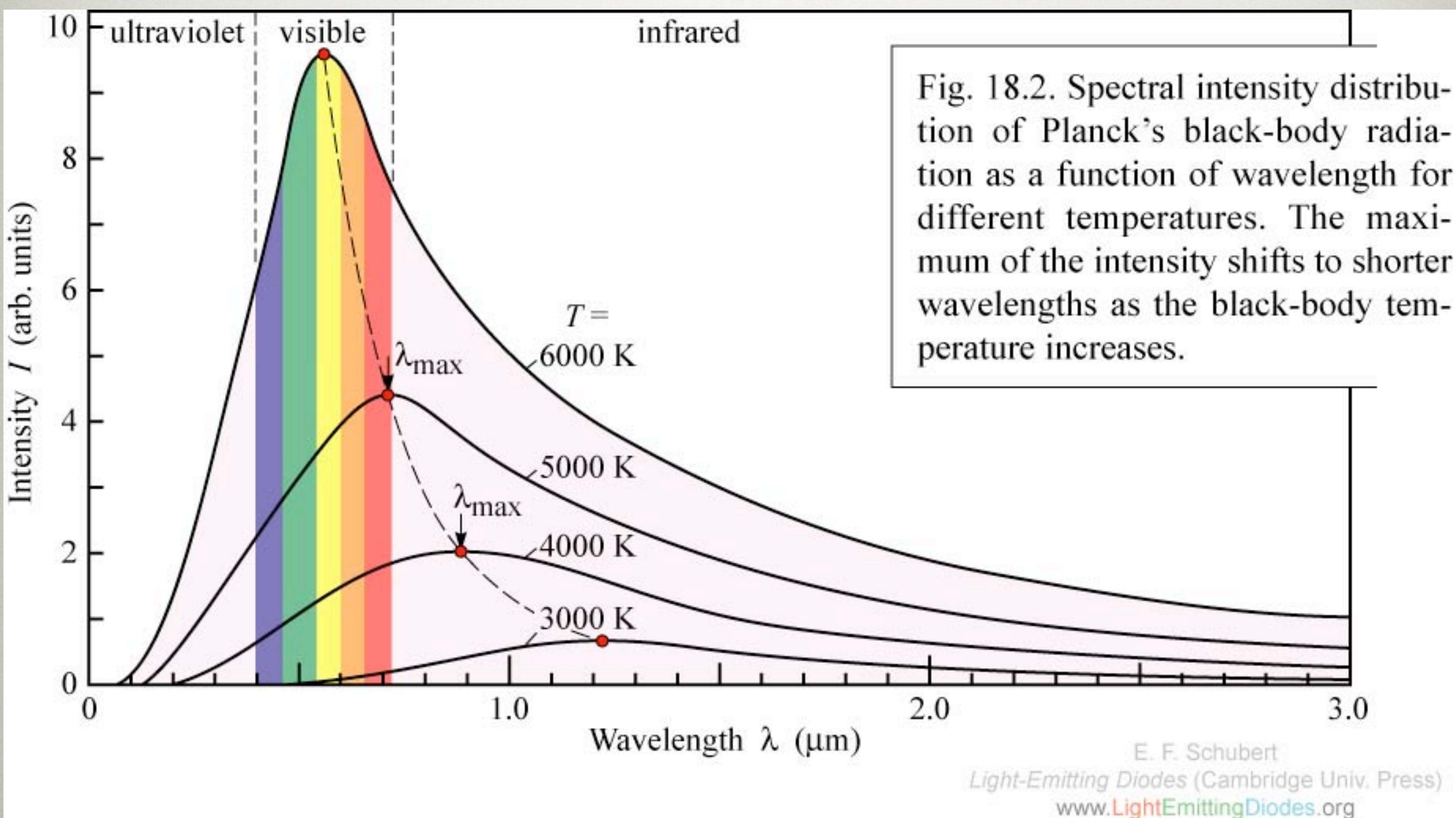
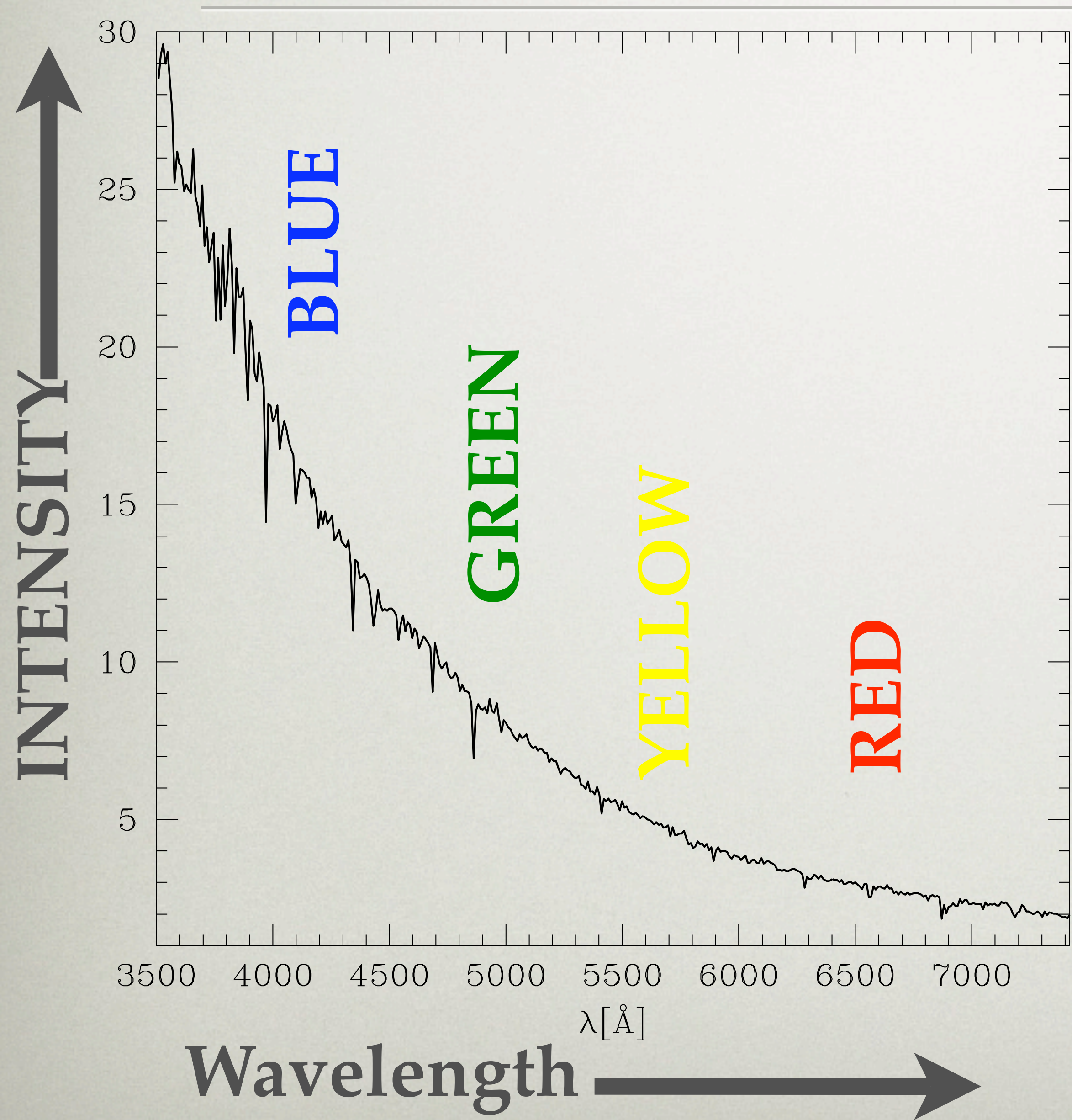


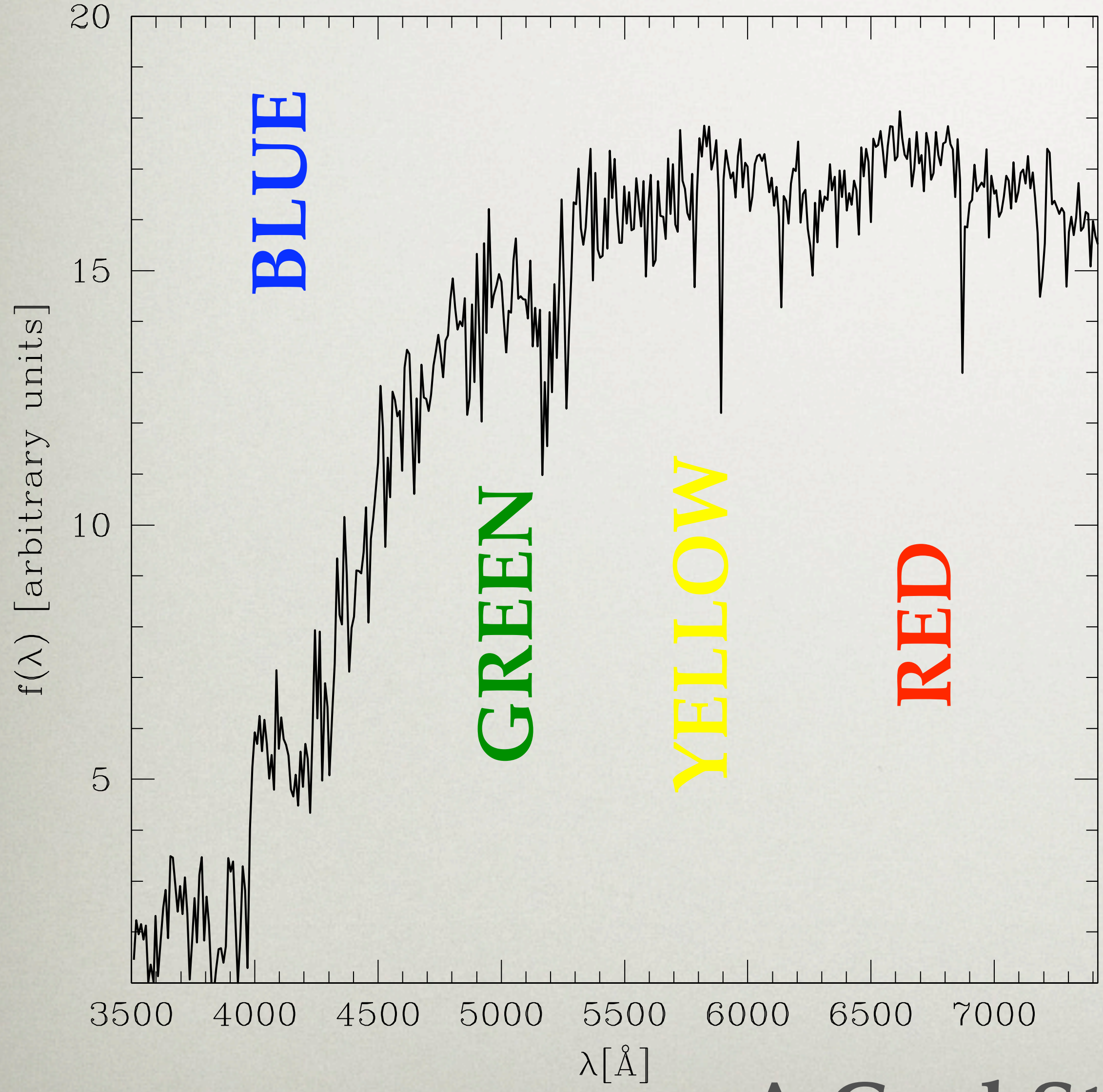
Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

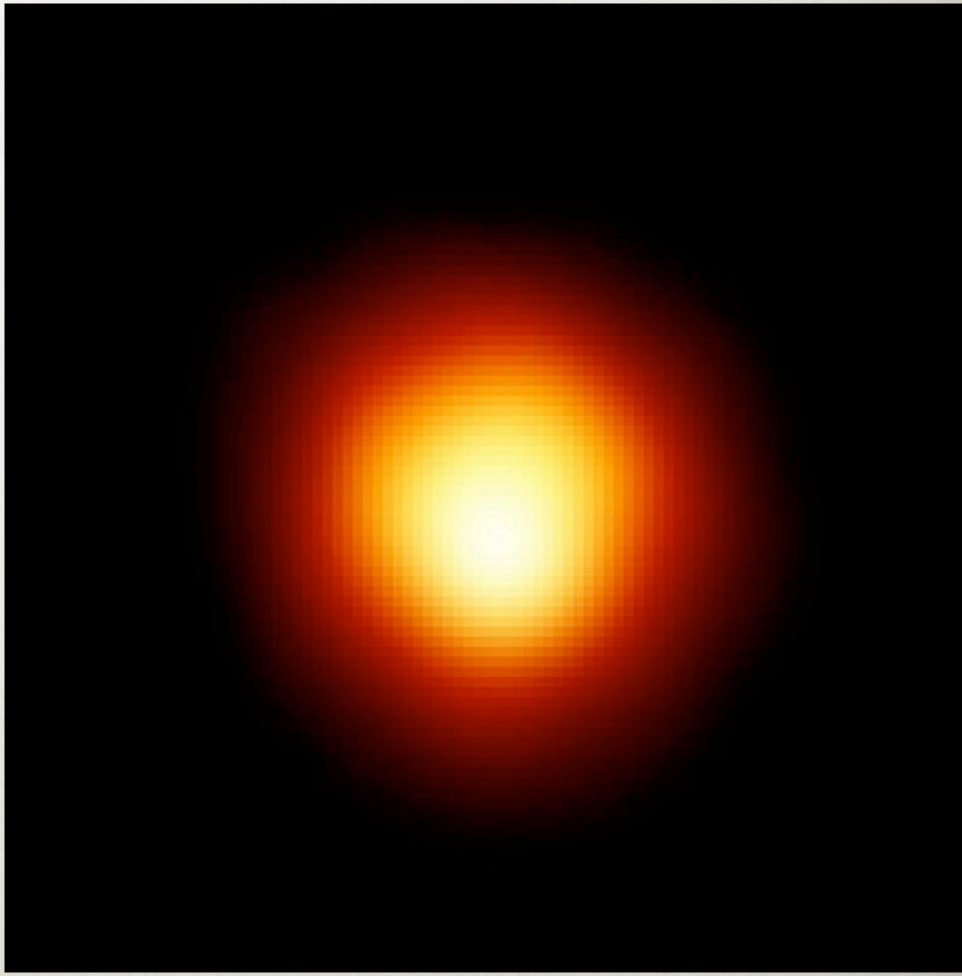
Intensity, Wavelength, and Frequency



- A Hot "O STAR"

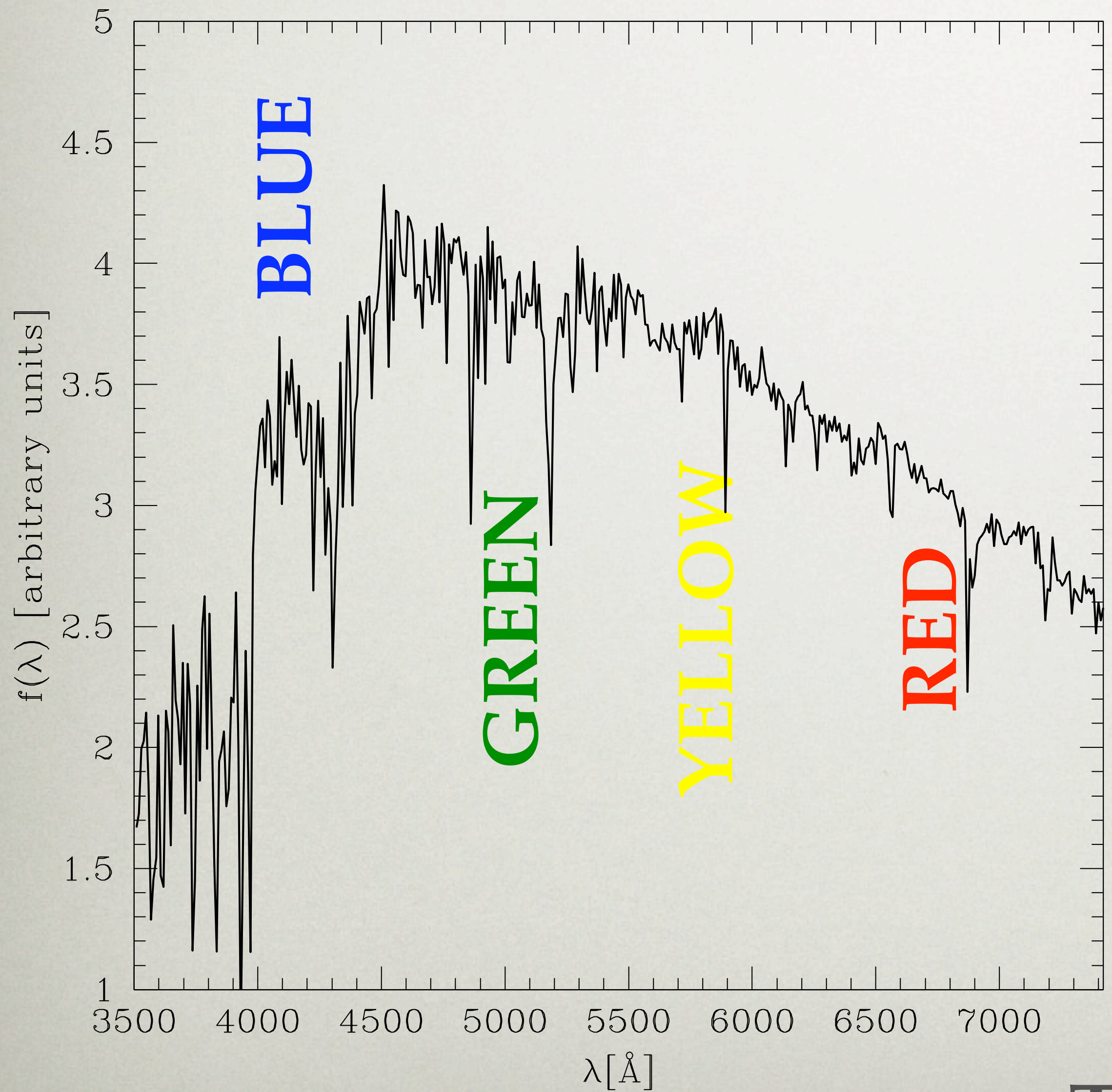
Intensity, Wavelength, and Frequency





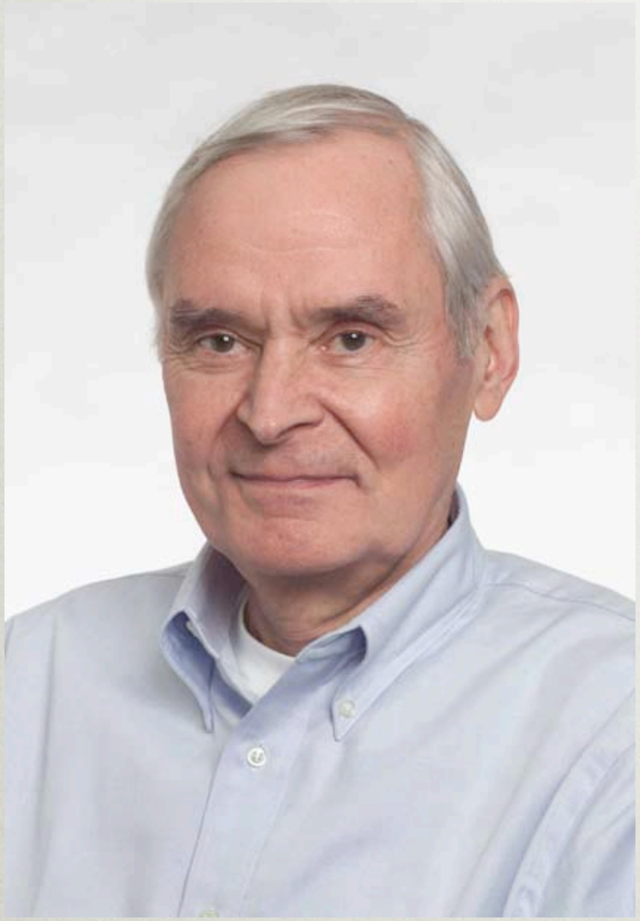
- A Cool Star

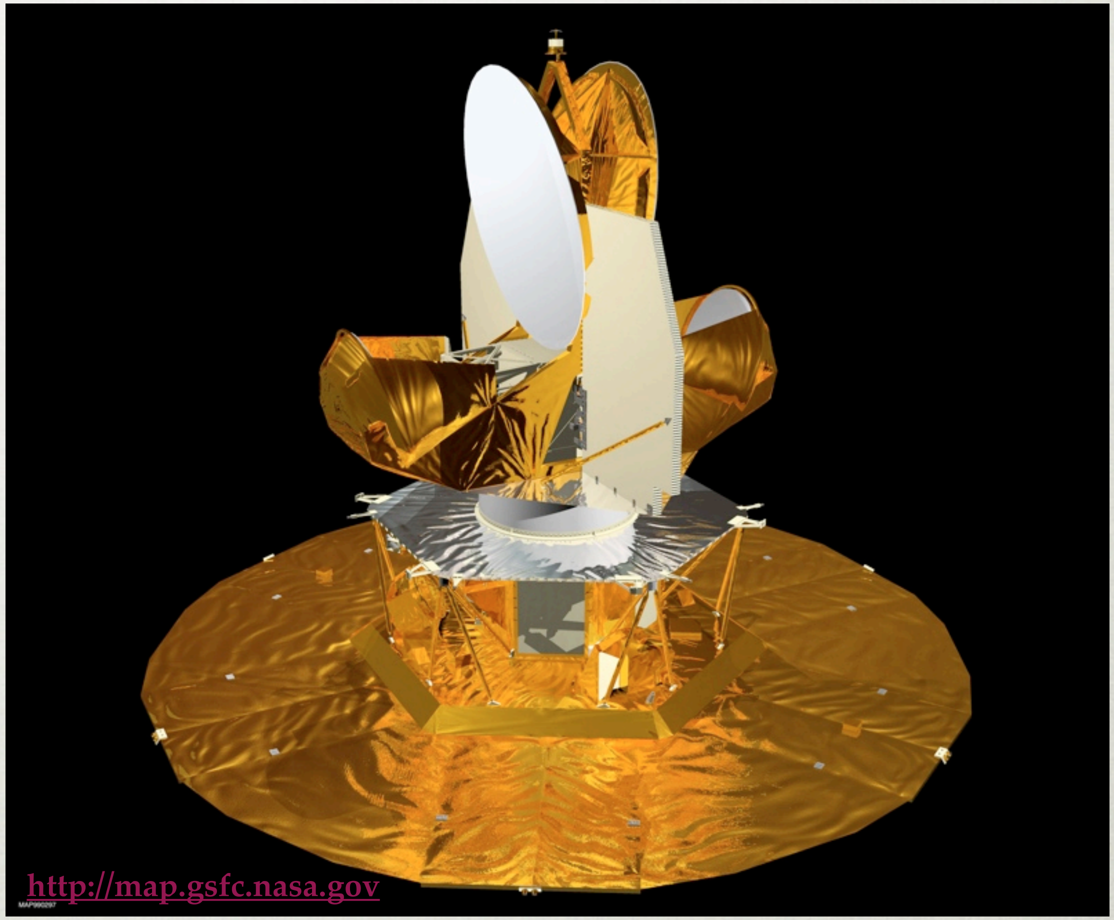
Intensity, Wavelength, and Frequency



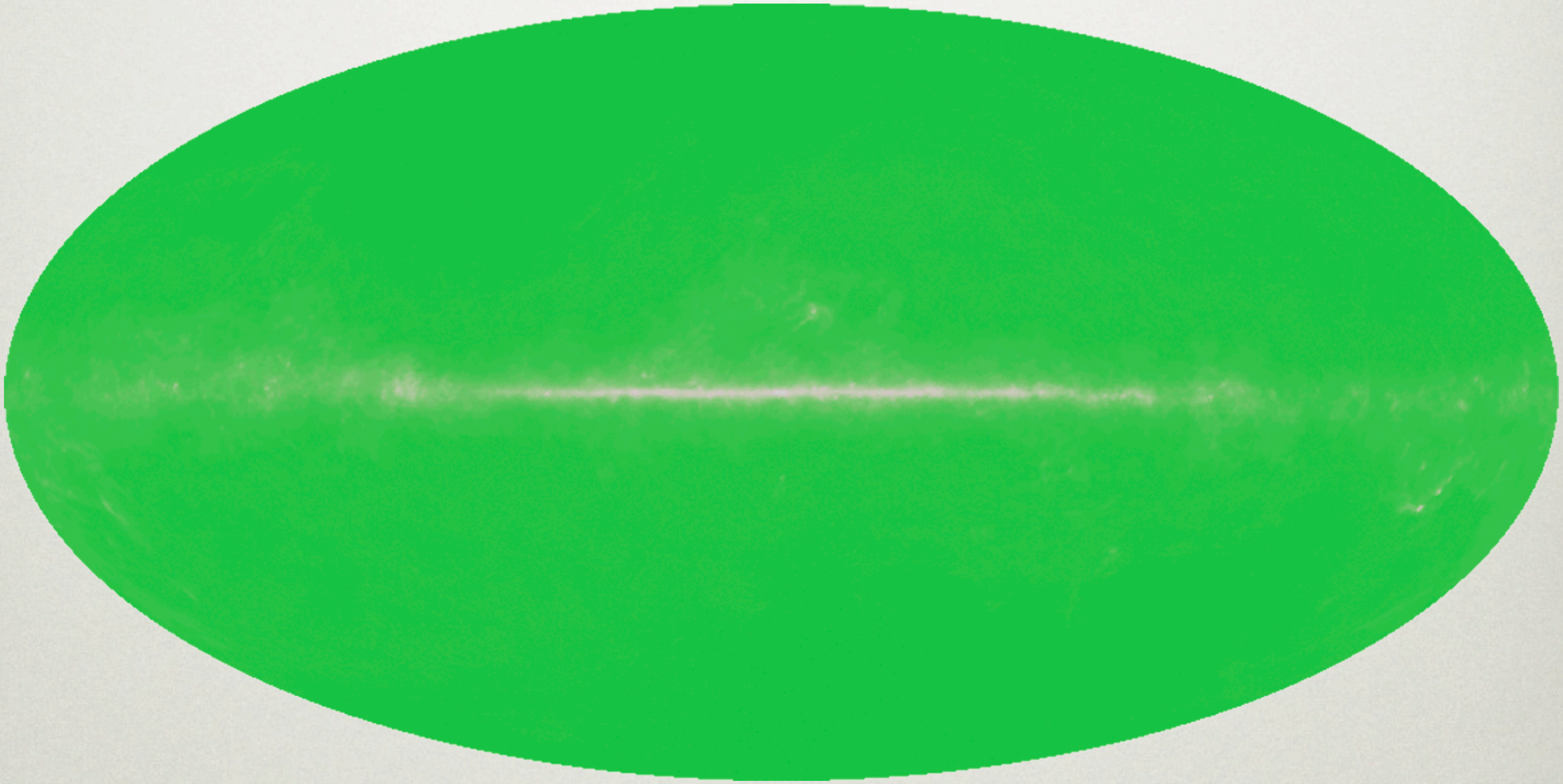
- The Sun

The Wilkinson Microwave Anisotropy Probe





The Cosmic Microwave Background



- A Map of the CMB on the sky is extremely smooth
- The CMB has a thermal spectrum with T=2.726 K = -454.7 °F

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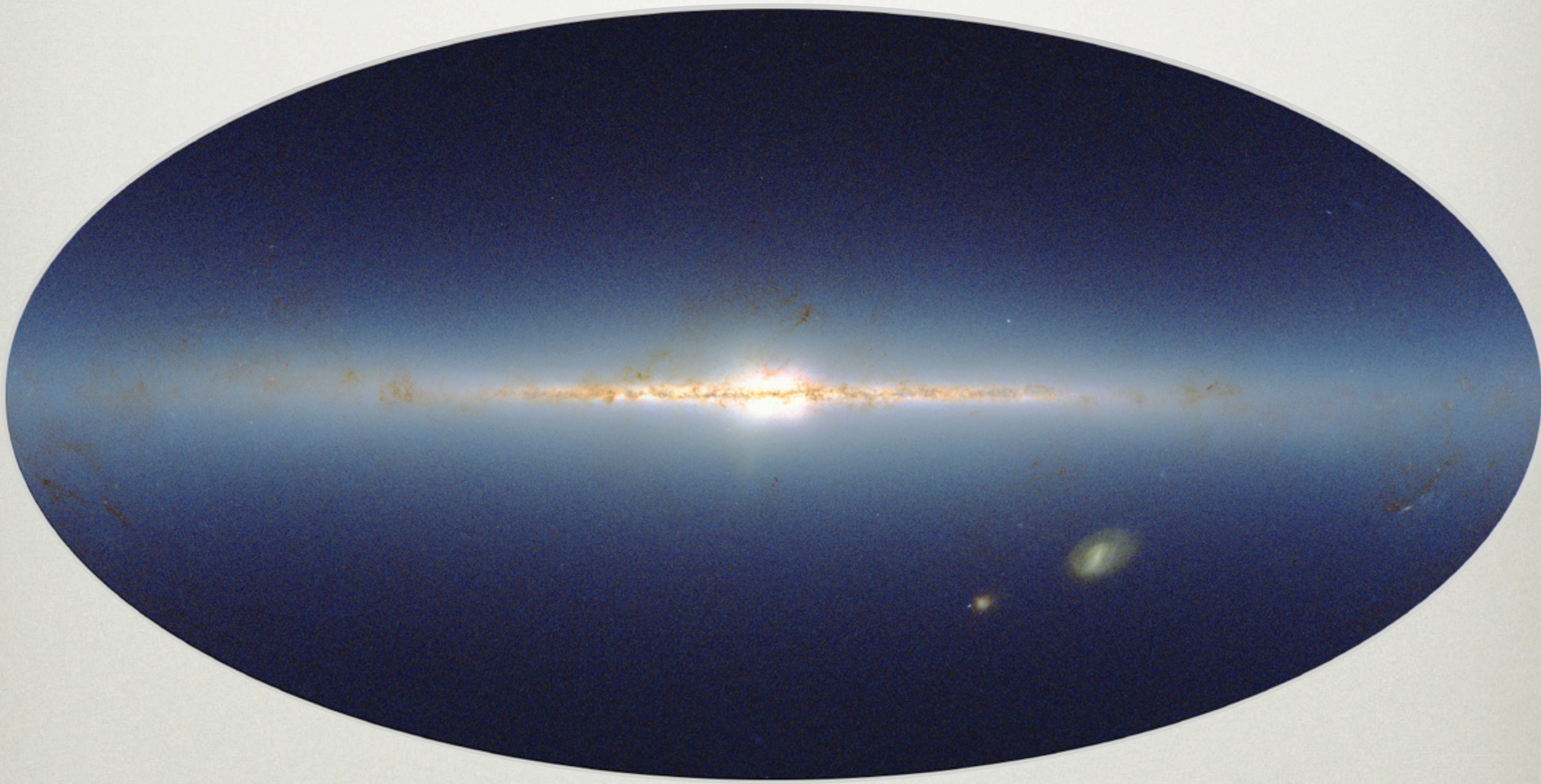

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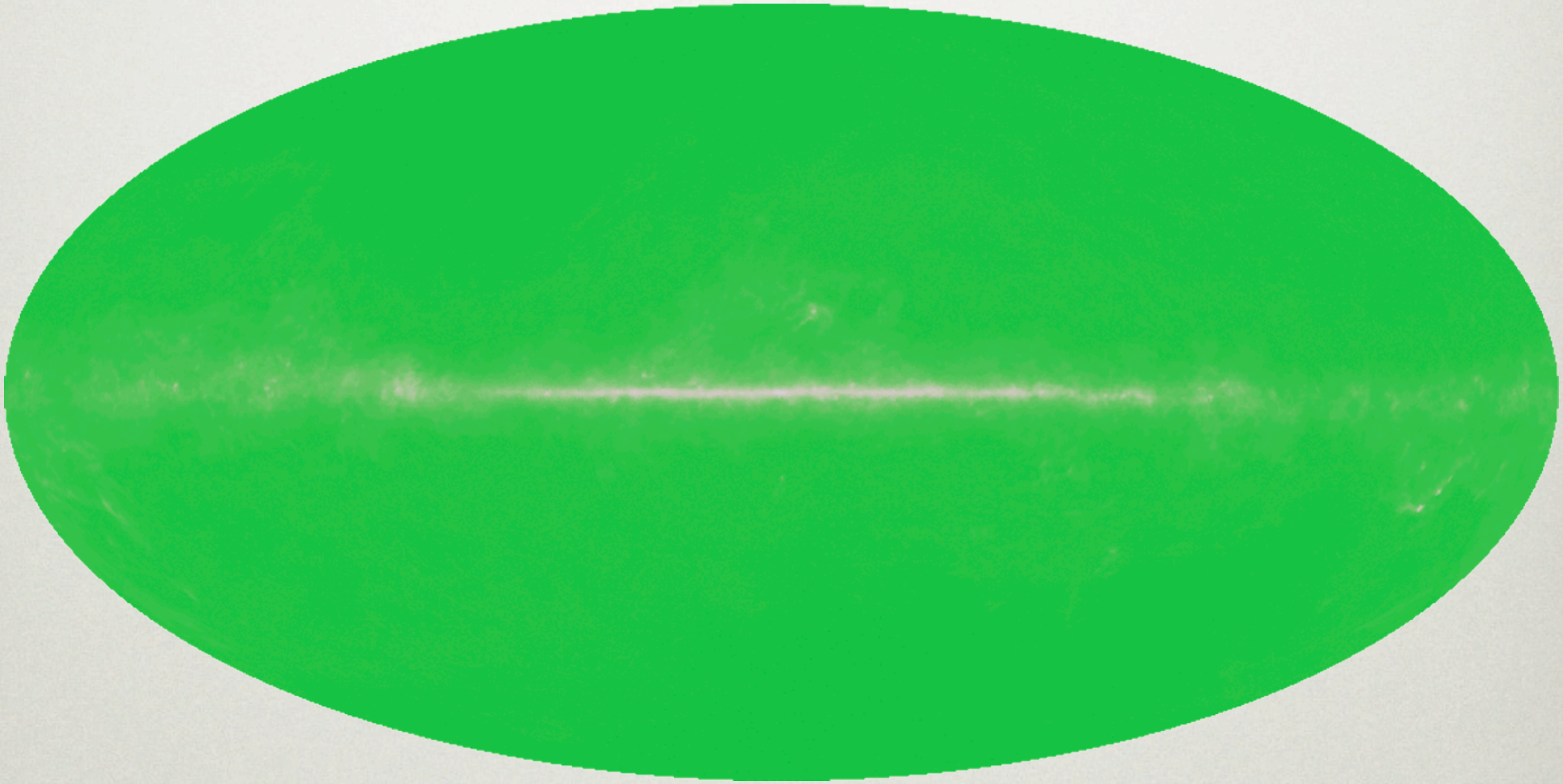

- **Turning up the contrast on the map reveals fluctuations of 1 part in 100,000 or temperature changes of ~ 0.00003 K**

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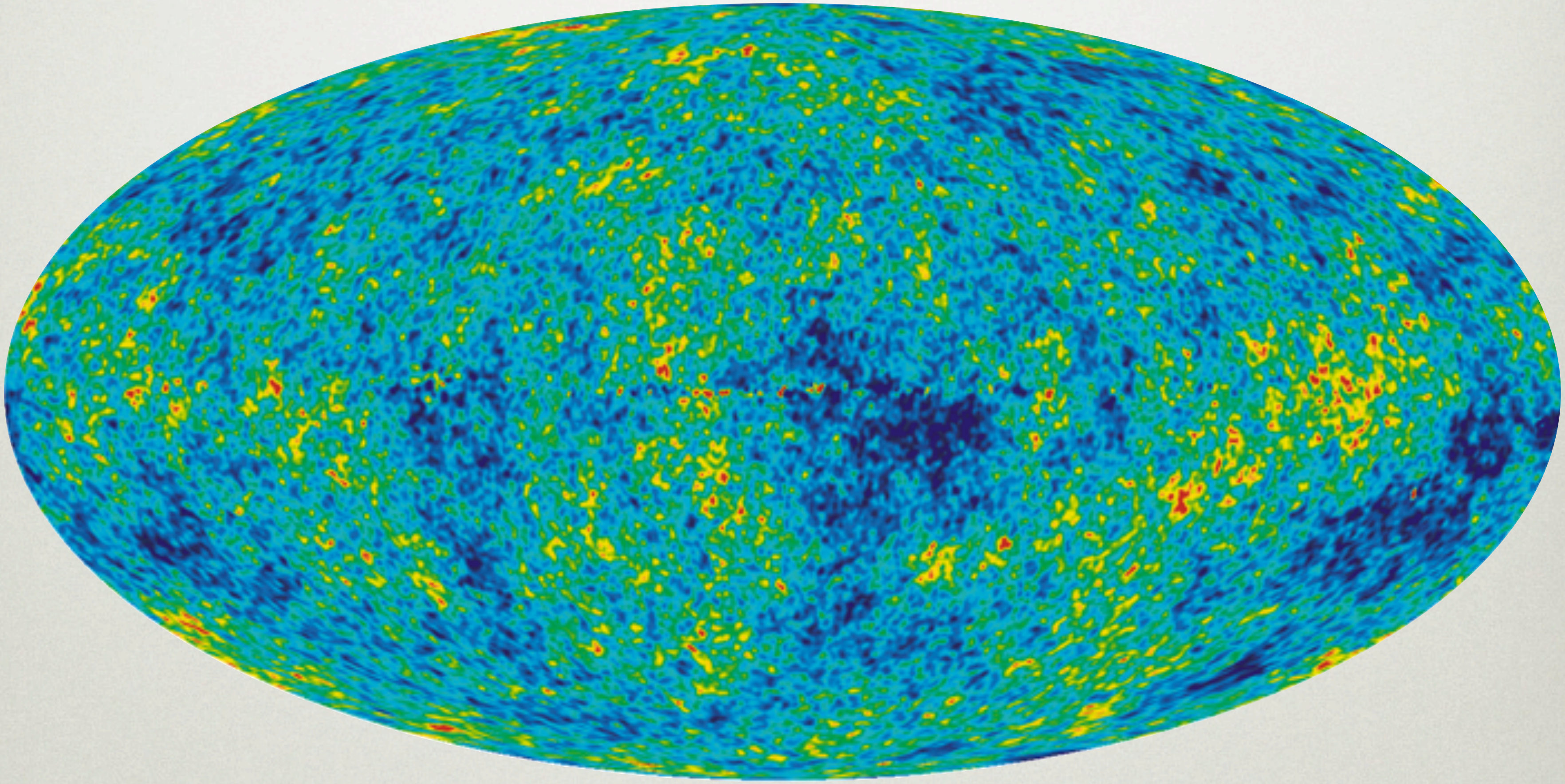

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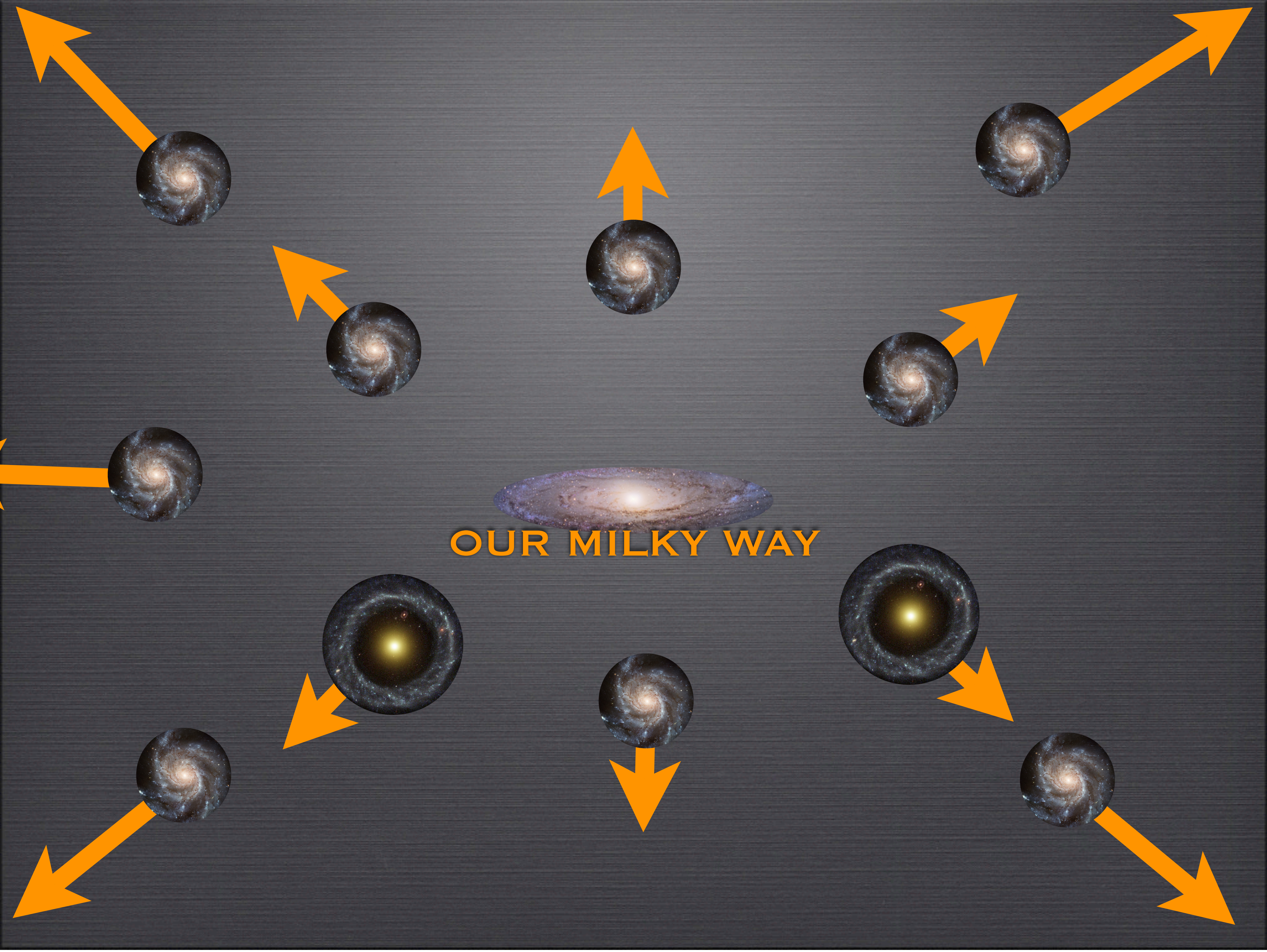
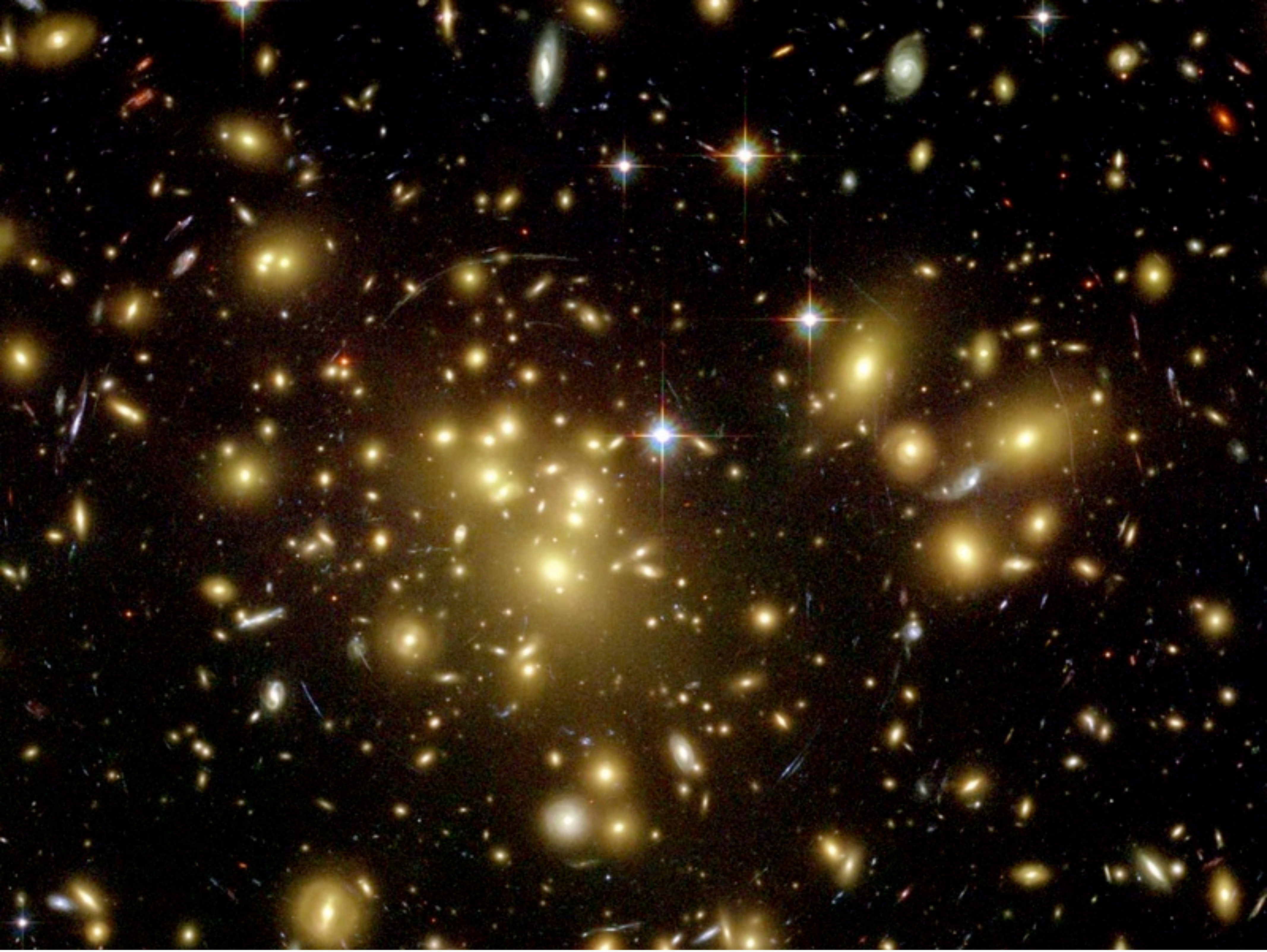

OUR MILKY WAY

Our View

Everyone's View!




Intervening
Galaxy Cluster
CMB Light, Distorted
by Cluster
OUR MILKY WAY

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4. Acquiring energy means boosting frequencies, or increasing wavelengths


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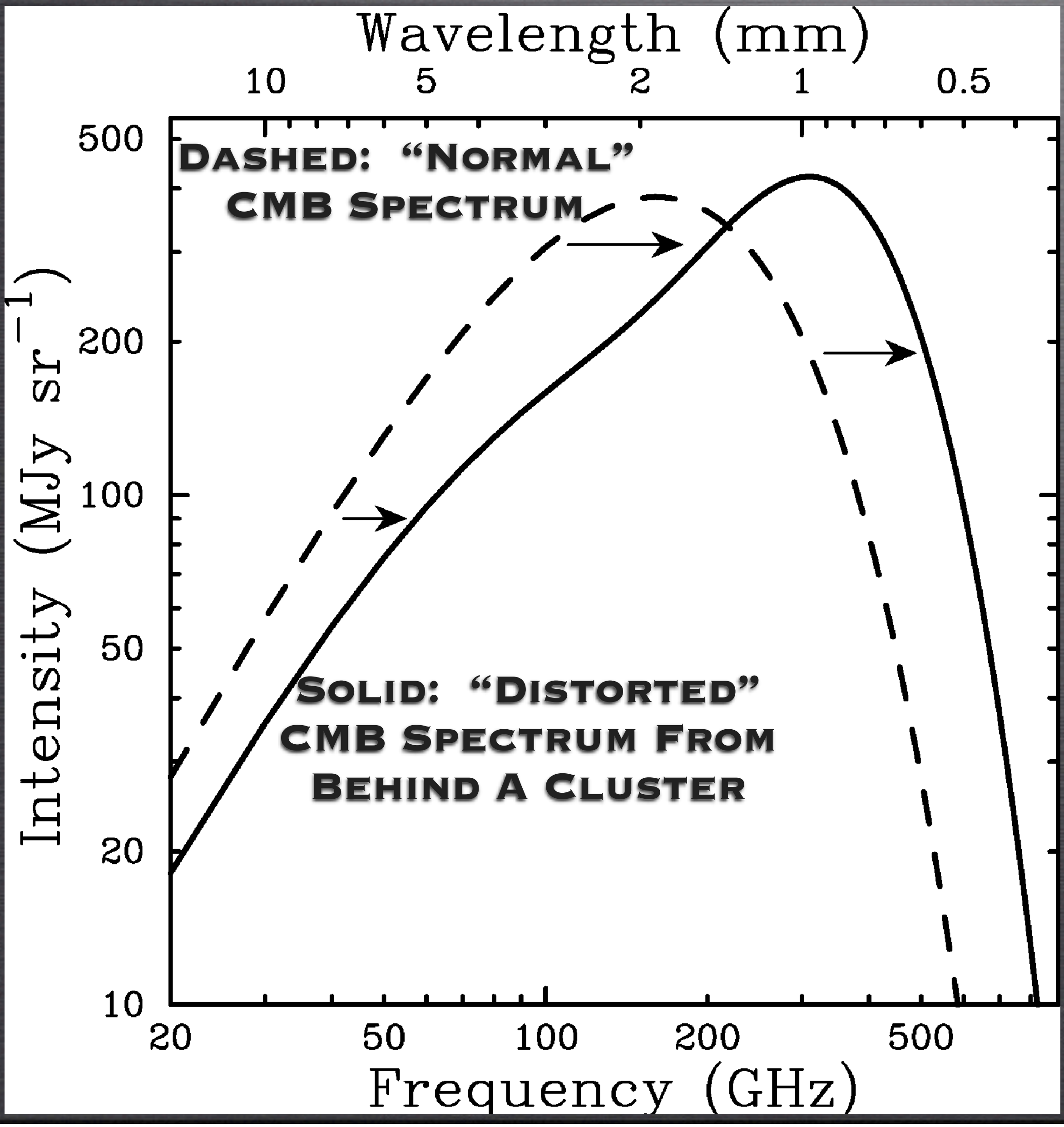
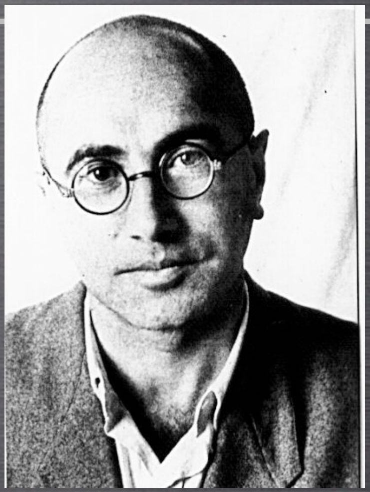
OUR MILKY WAY

The Sunyaev-Zeldovich Effect





Yakov Zeldovich

Rashid Sunyaev

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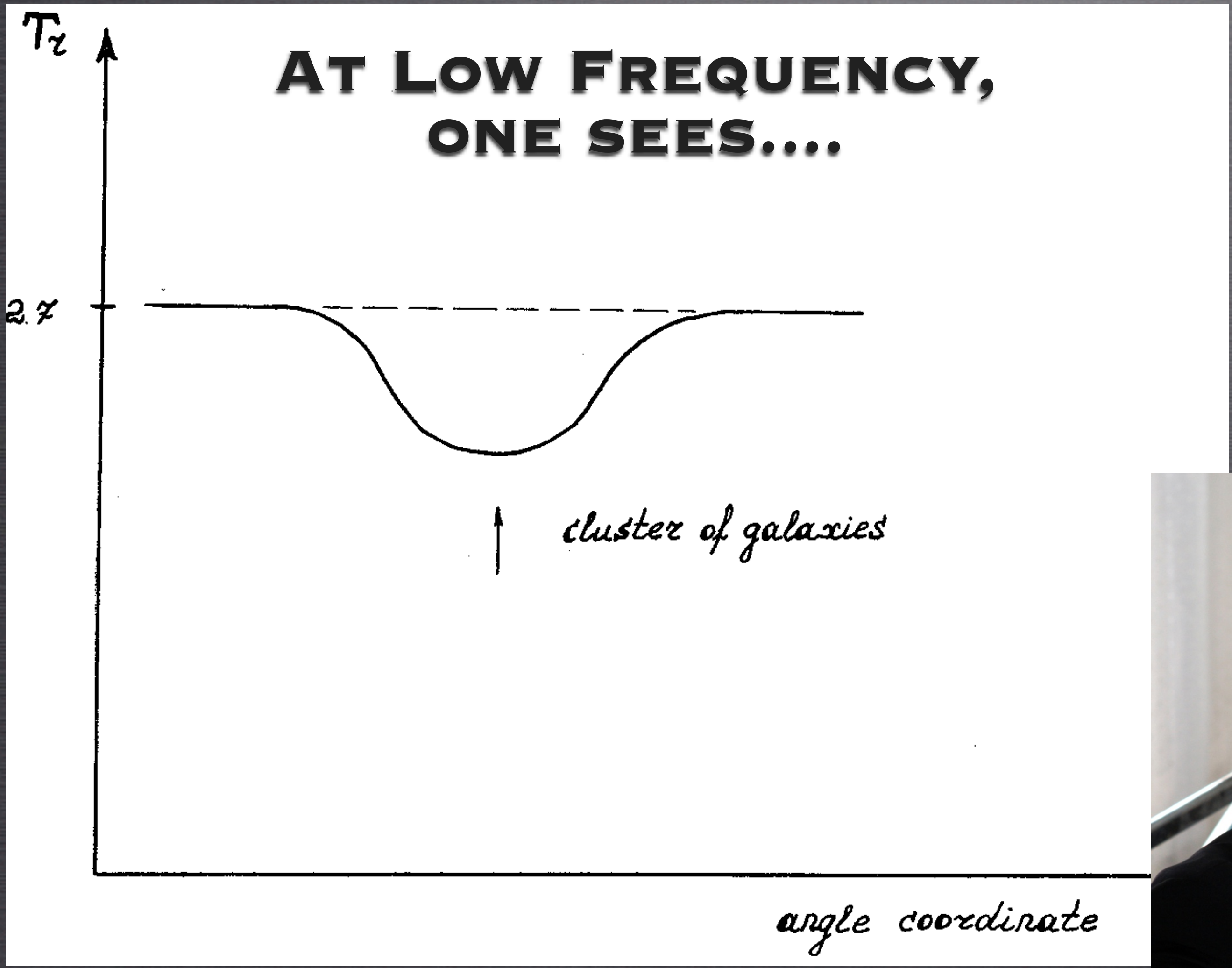

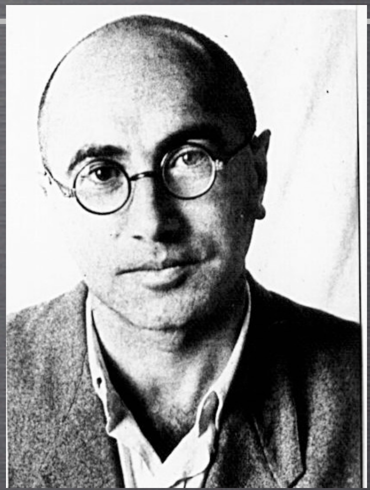

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Rashid Sunyaev


Fast-Moving
Galaxy Cluster
CMB Light, Distorted
by Cluster
OUR MILKY WAY

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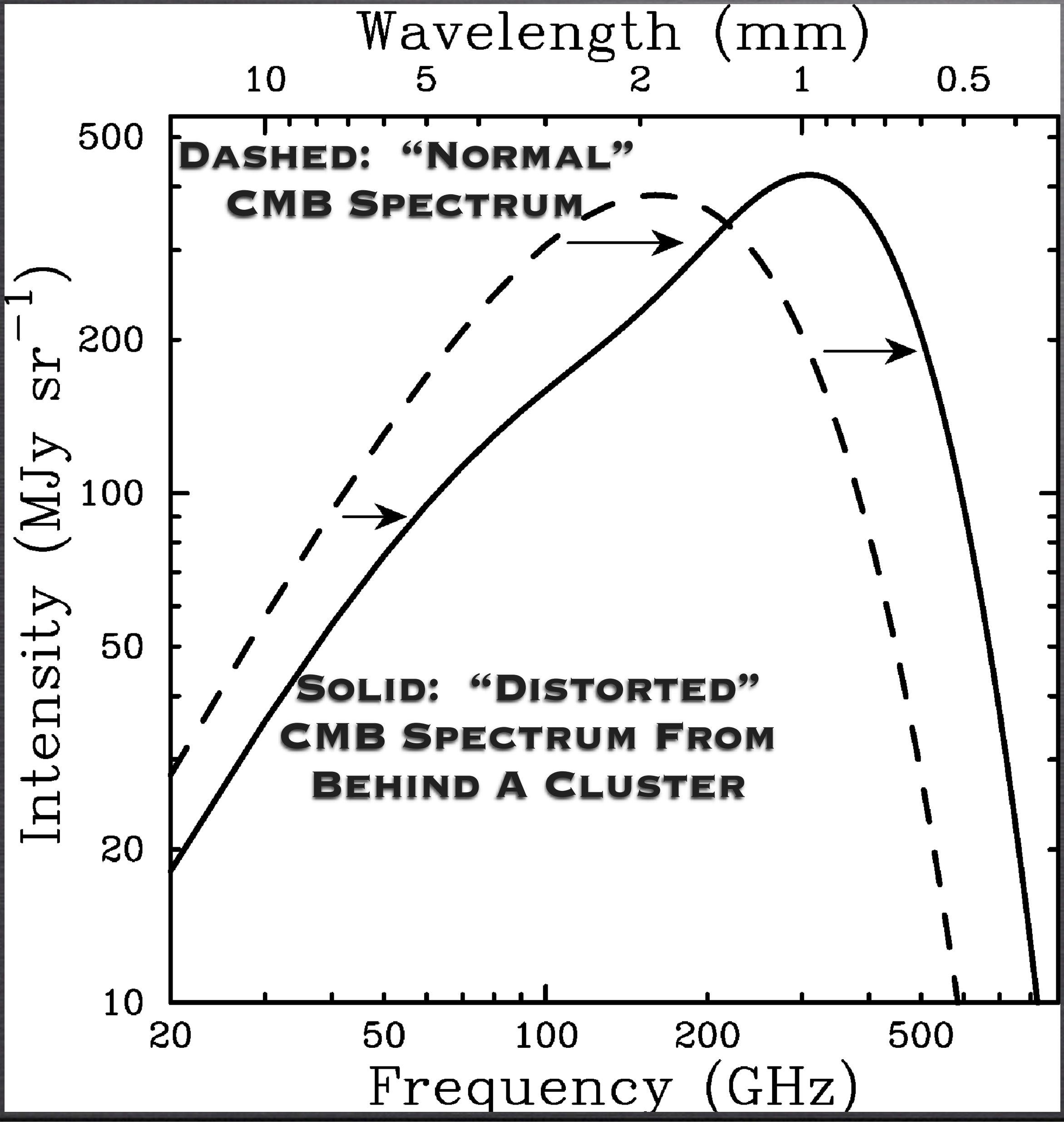

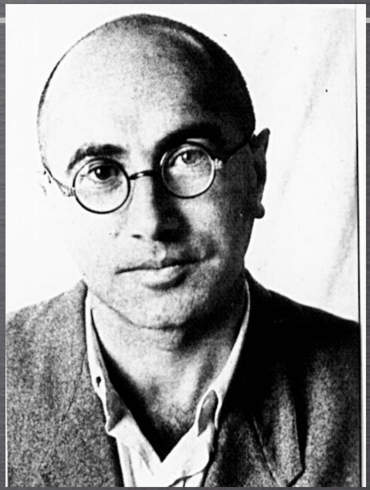

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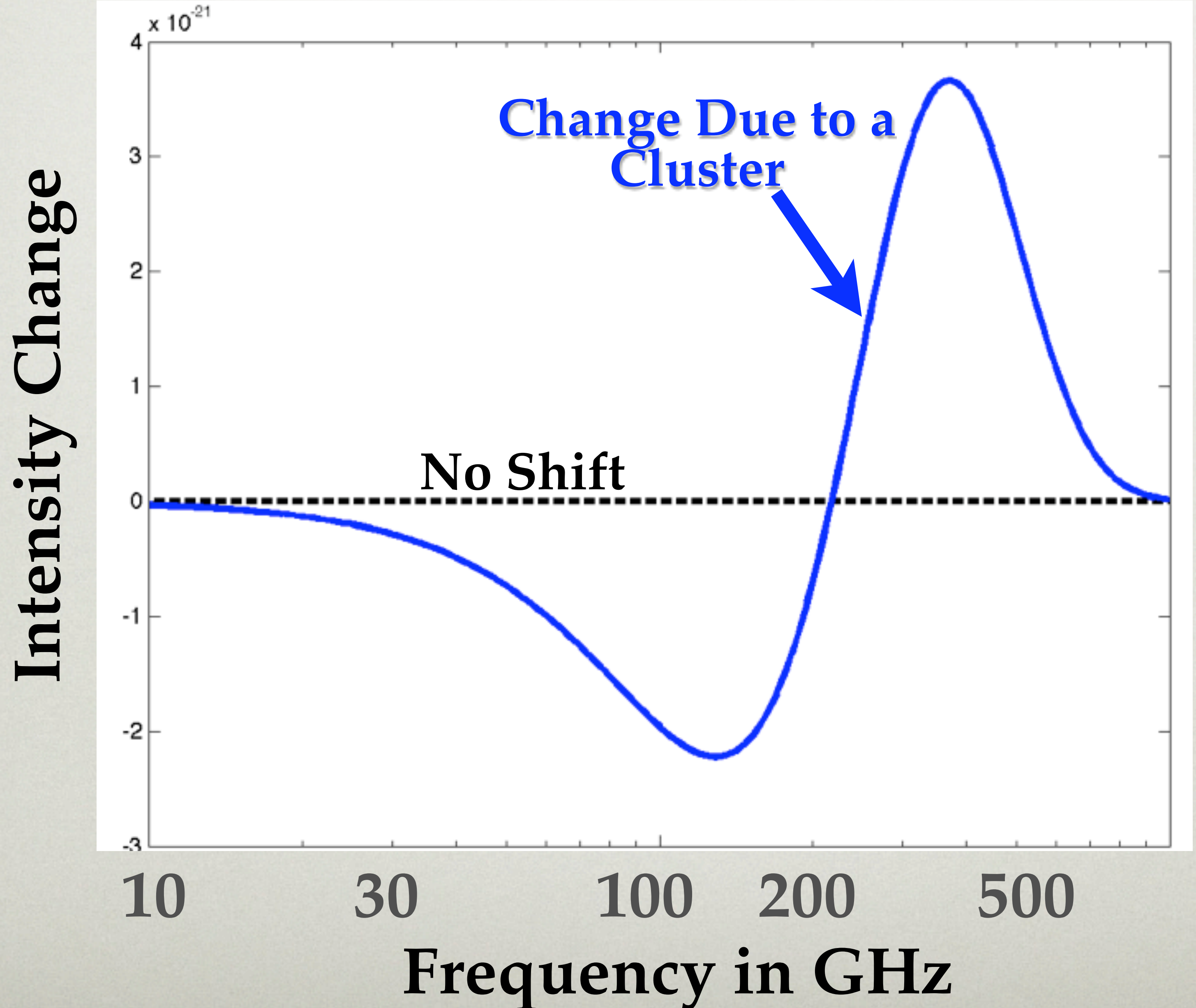

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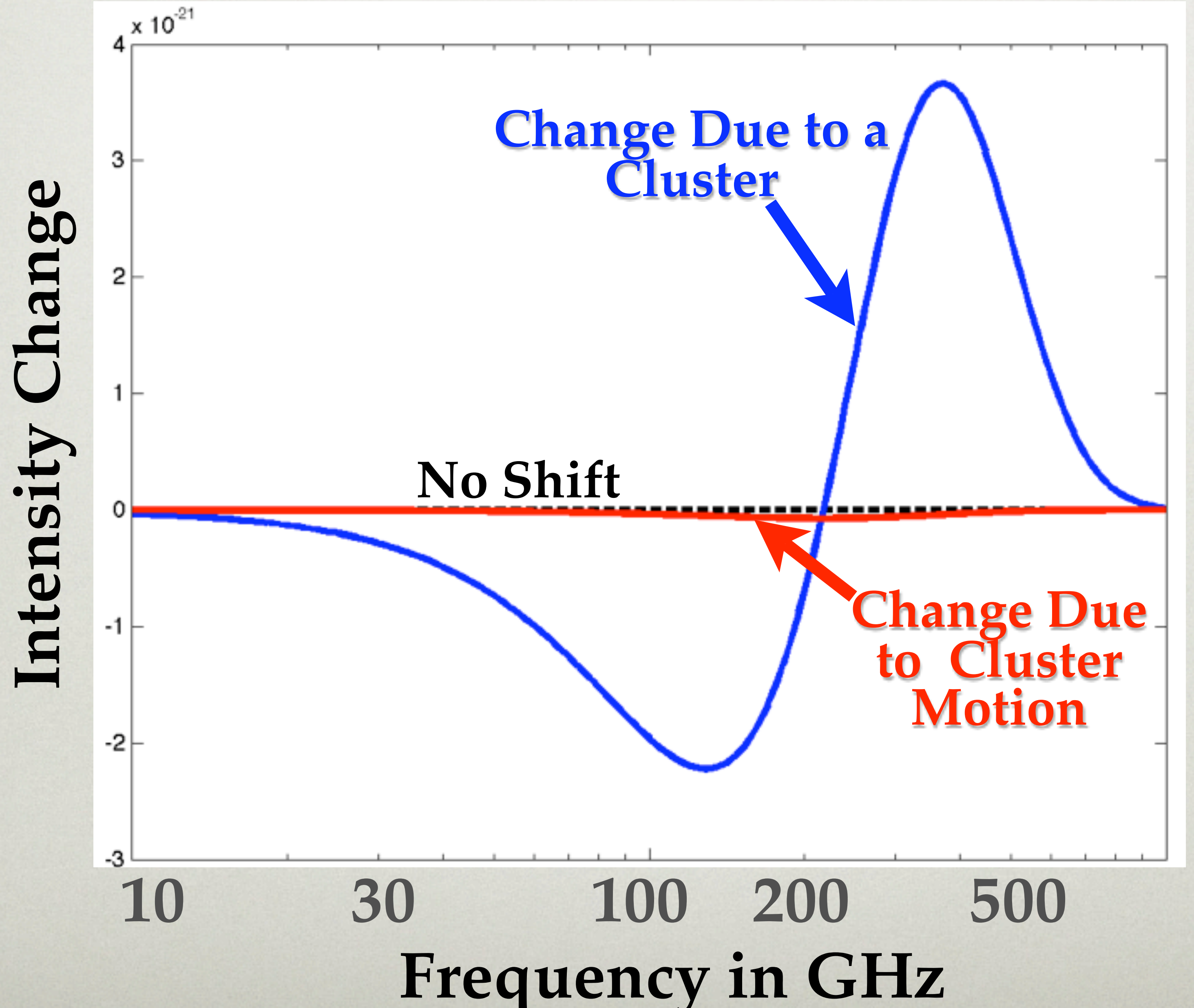

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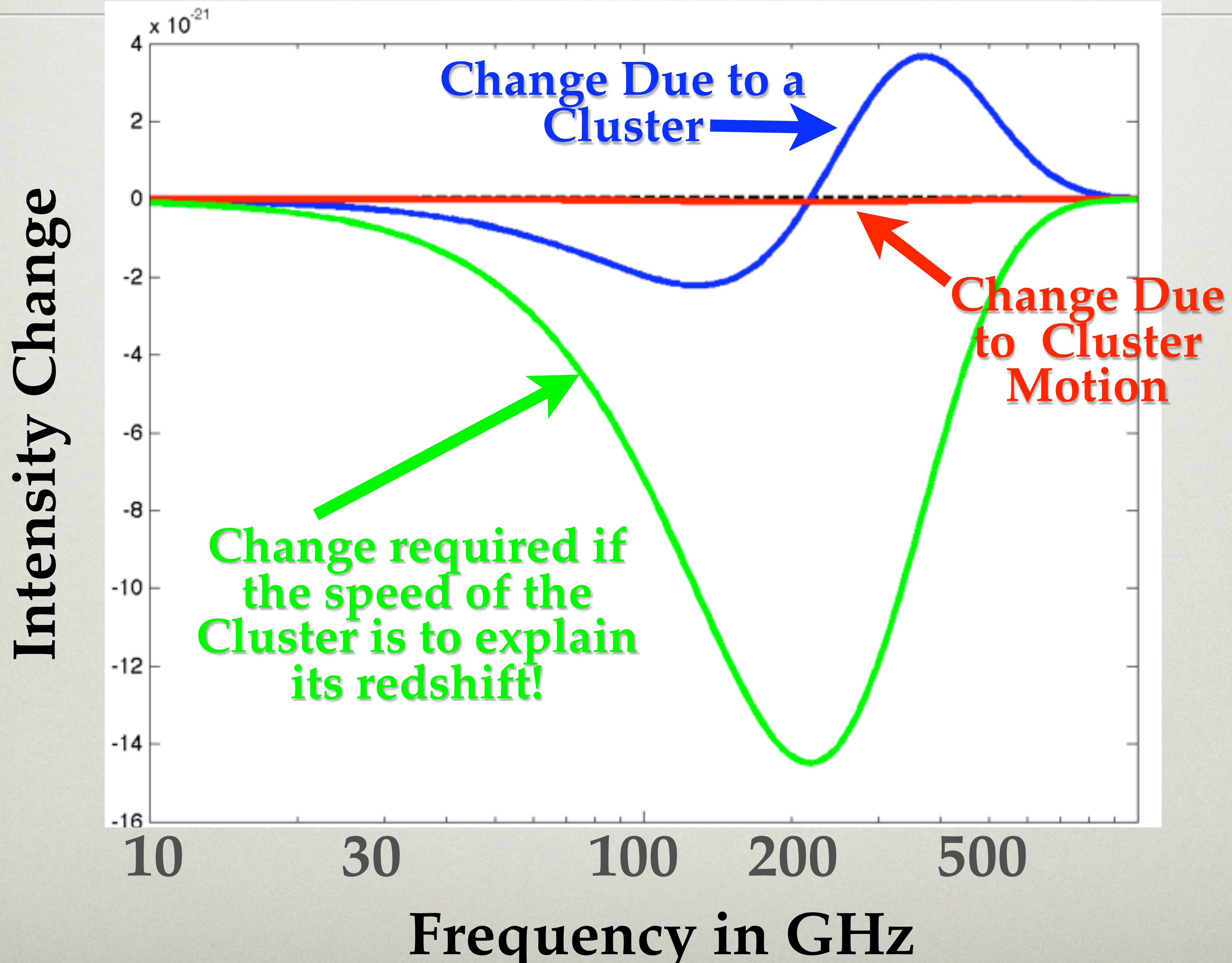

IMPLICATION

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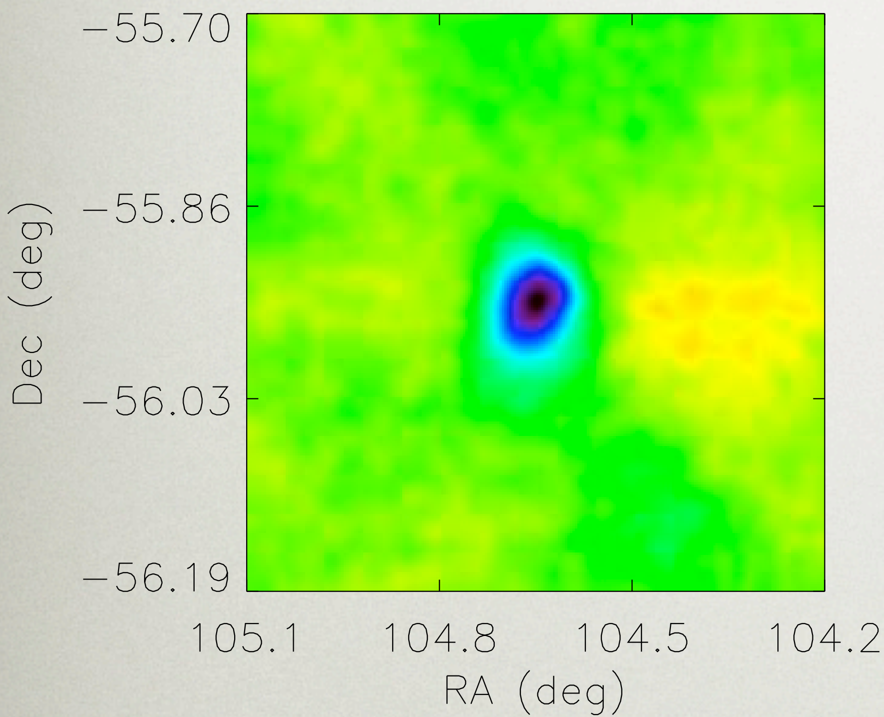
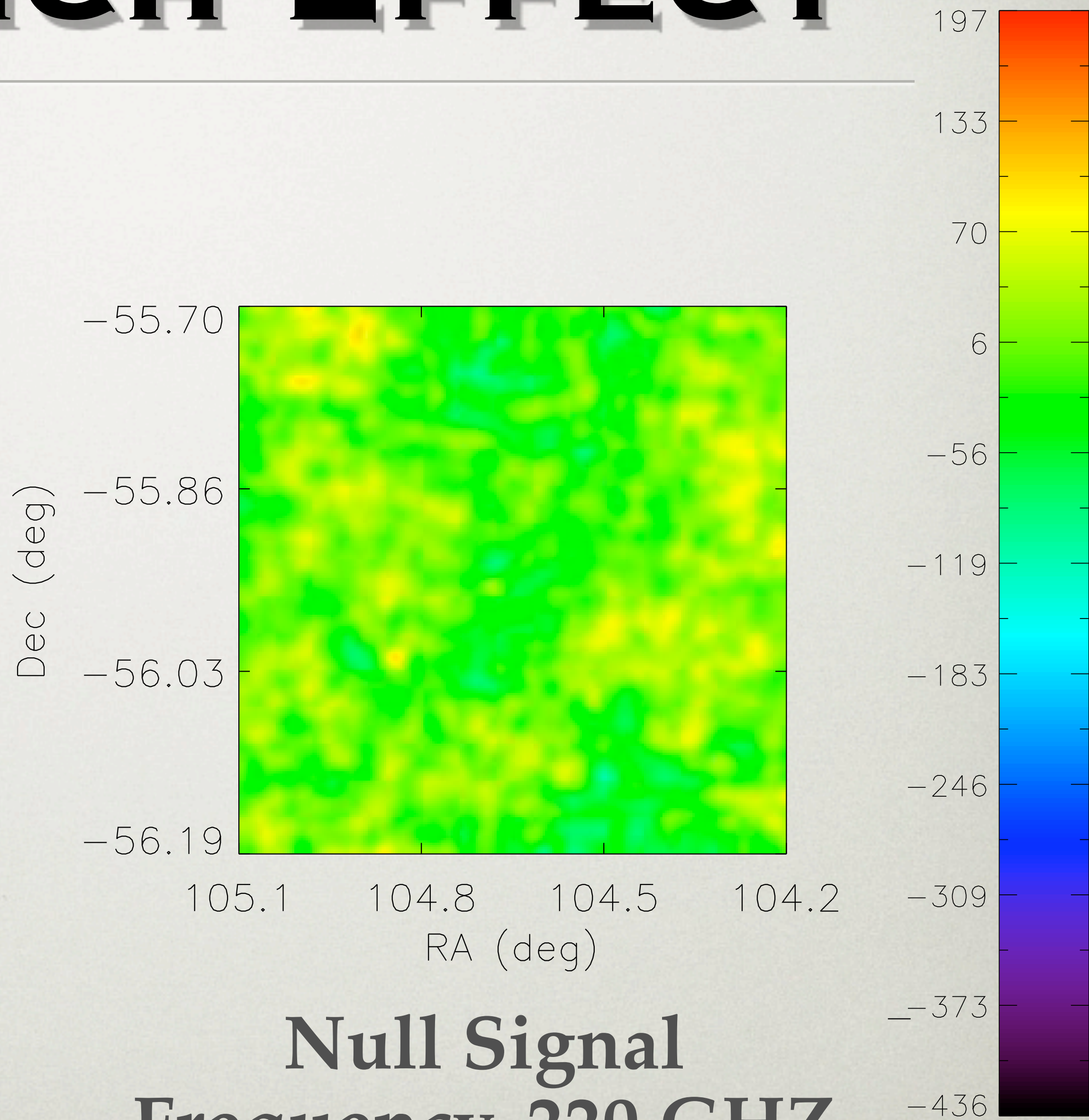
If Galaxy Cluster Velocities explain redshifts, rather than the stretching of space, then there should be a large decrease in the CMB intensity at ALL FREQUENCIES!

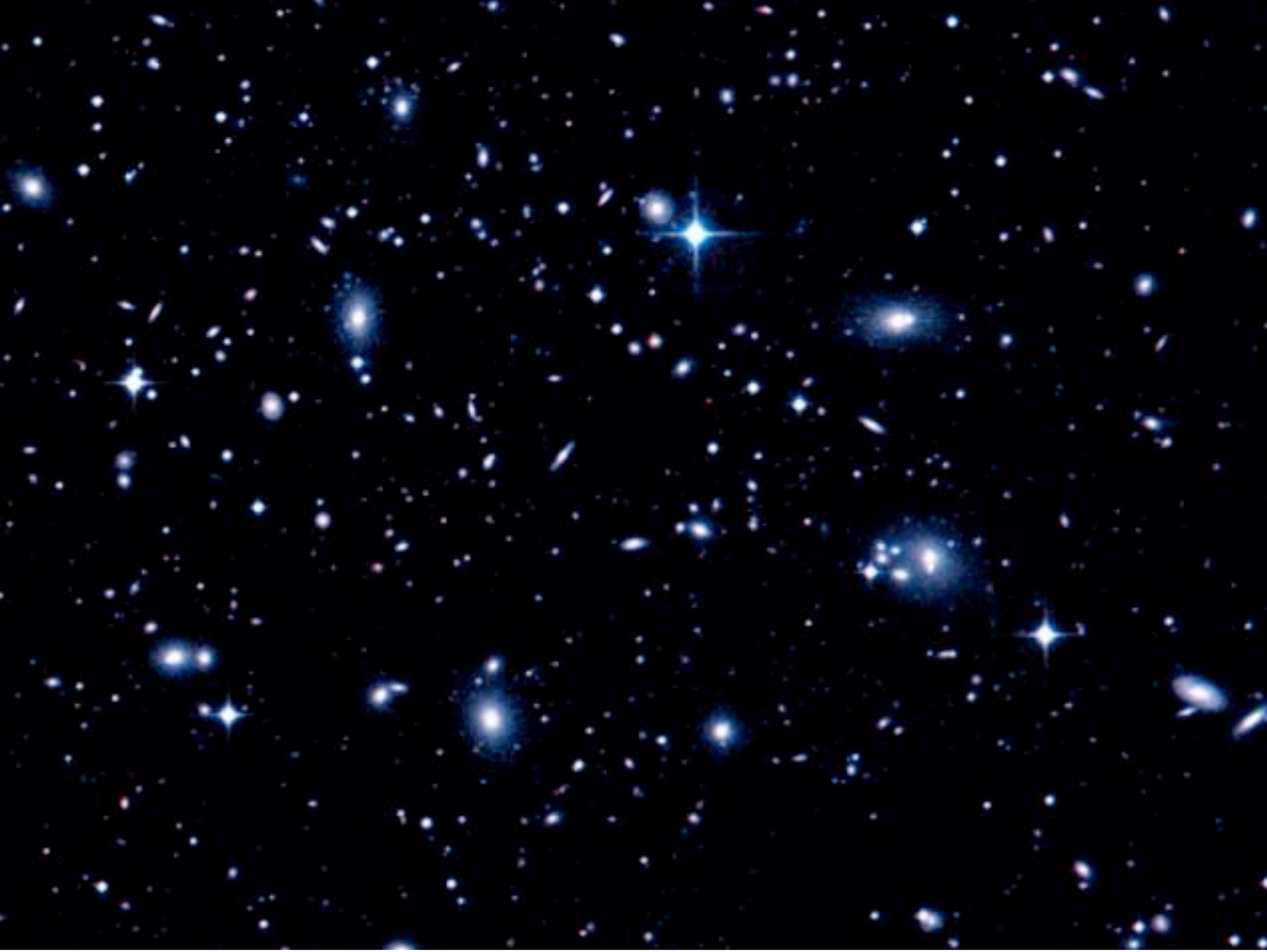
Measured Sunyaev-Zeldovich Effect



Decrement
Frequency, 150 GHZ



Null Signal
Frequency, 220 GHZ



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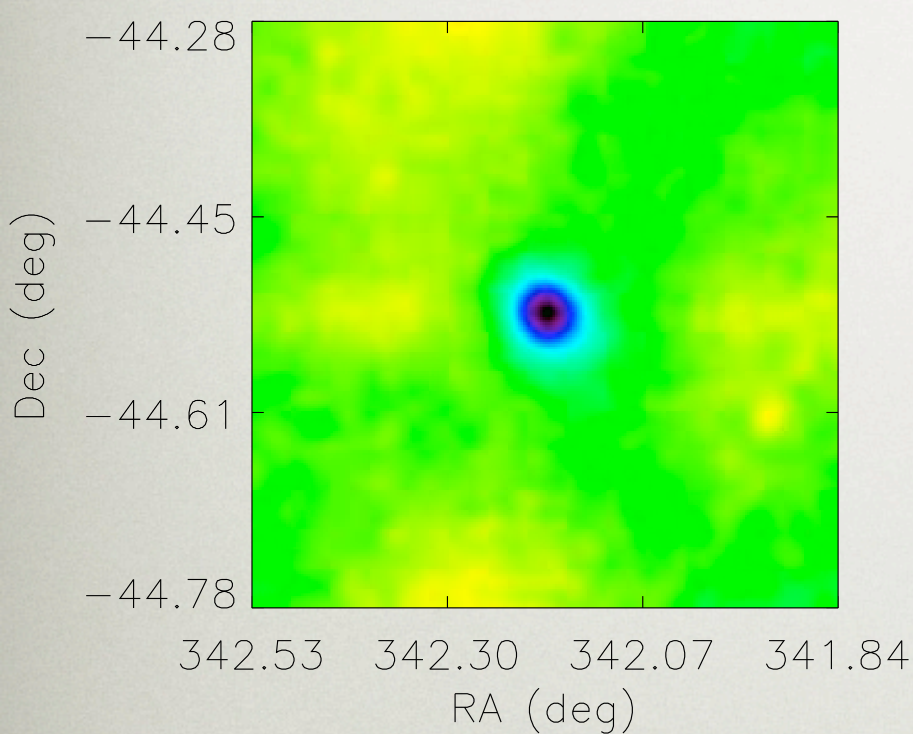

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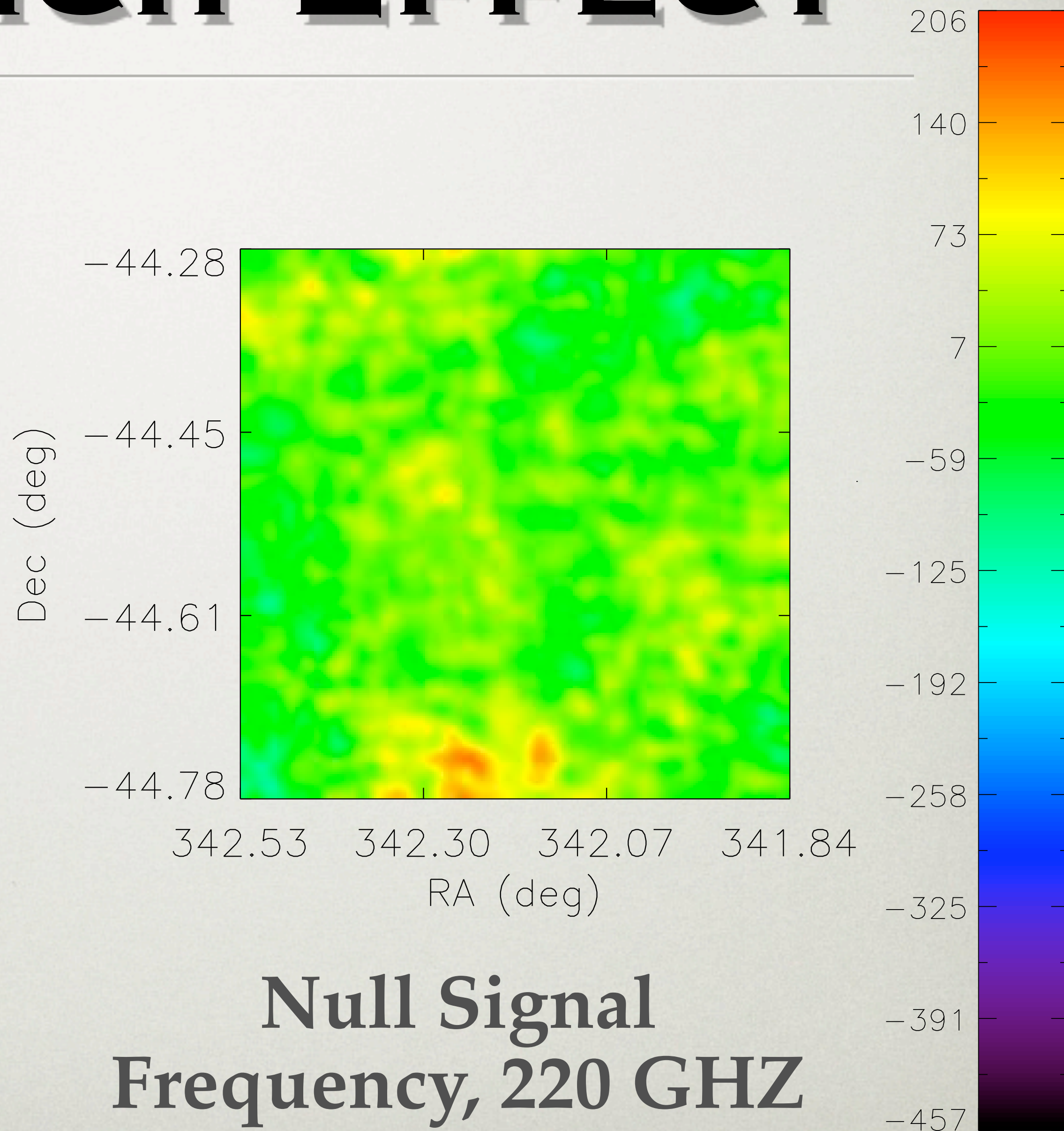

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Summary

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2. We see a “thermal” Sunyaev-Zeldovich distortion of the CMB, so the CMB must be coming from great distances behind the galaxy clusters
3. We see no “kinetic” Sunyaev-Zeldovich distortion, so clusters are also are stationary!
4. Space expands, in order to explain high redshift (Doppler shifted) clusters that do not move!