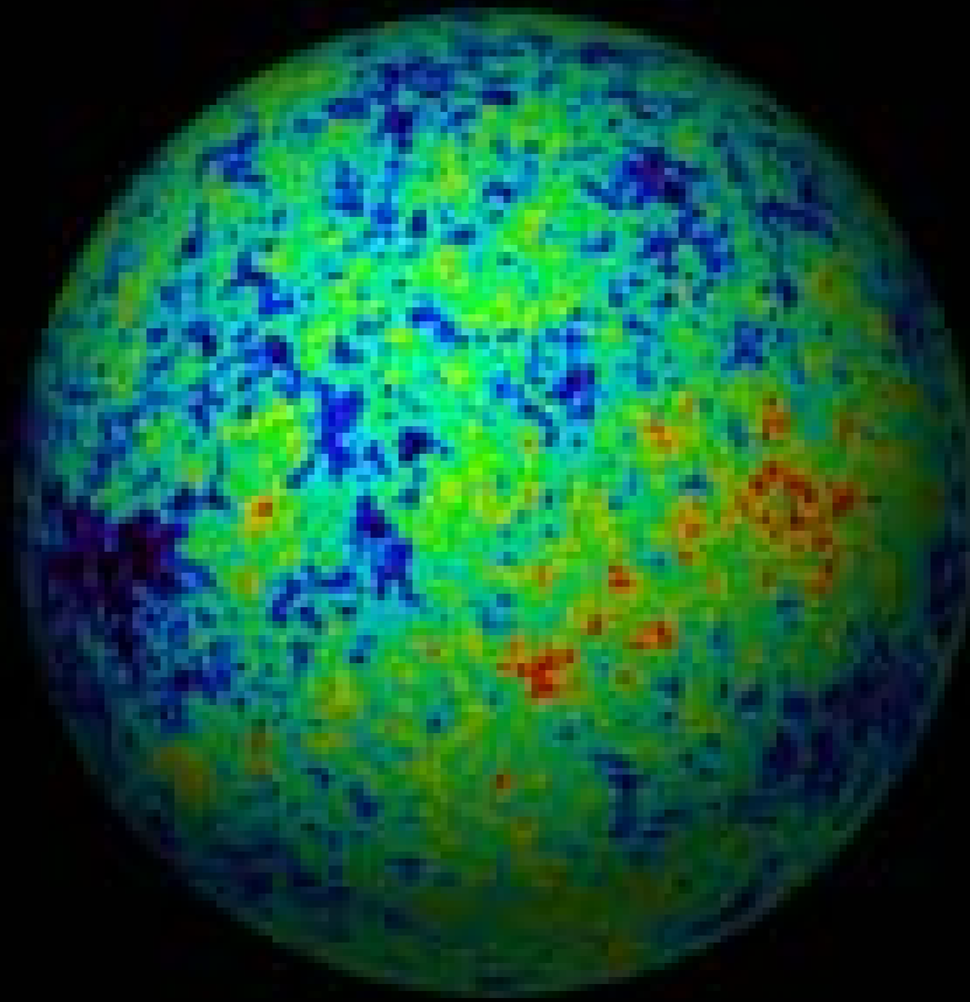
NS102 Lecture 15



Open: Island In The Sun – Weezer
Close: Einstein – Artichoke

GnatSigh News
(all the news that fits)

- **Website** http://home.fnal.gov/~rocky/NS102/
- **Exam next Tuesday**
  - **Don't memorize any equations!**
  - **Review sessions in KPTC**

    Sun: 5:30-6:30 pm & Mon: 5:30-6:30 pm
- **Final Exam**
  - **10:30-12:30 Thursday 9 June**
- **Please see me after class:**
  - **Sabahat A., Emily K., Elise M., Vanessa T.**

Lab this week: The Hubble constant

Lab next week (last one): Big Bang Nucleosynthesis

Artichoke

26 Scientists Volume One Anning – Malthus

CD List price: ~~$17.92~~
CD Baby Price: $12.97 Add to cart

IN STOCK. ORDER NOW. Will ship within 24 hours!

Indie pop concept record of scientist biographies -- one for every letter of the alphabet -- in the tradition of the Beatles, Pixies, Breeders, Beck, Cake, the Fall, the Talking Heads, Wire, and Robyn Hitchcock.

TRACKS

PLAY ALL SONGS lo-fi: dial-up
PLAY ALL SONGS hi-fi: broadband

1. Albert Einstein
2. Mary Anning
3. Luther Burbank
4. William Thomson Kelvin
5. Galileo Galilei
6. Werner Heisenberg
7. Thomas Robert Malthus
8. Charles Robert Darwin
9. Marie Curie
10. Joseph Lister
11. Richard Buckminster Fuller
12. Jan Ingenhousz
13. Thomas Jefferson

(Click a song name to hear it in lo-fi MP3. Need help?)

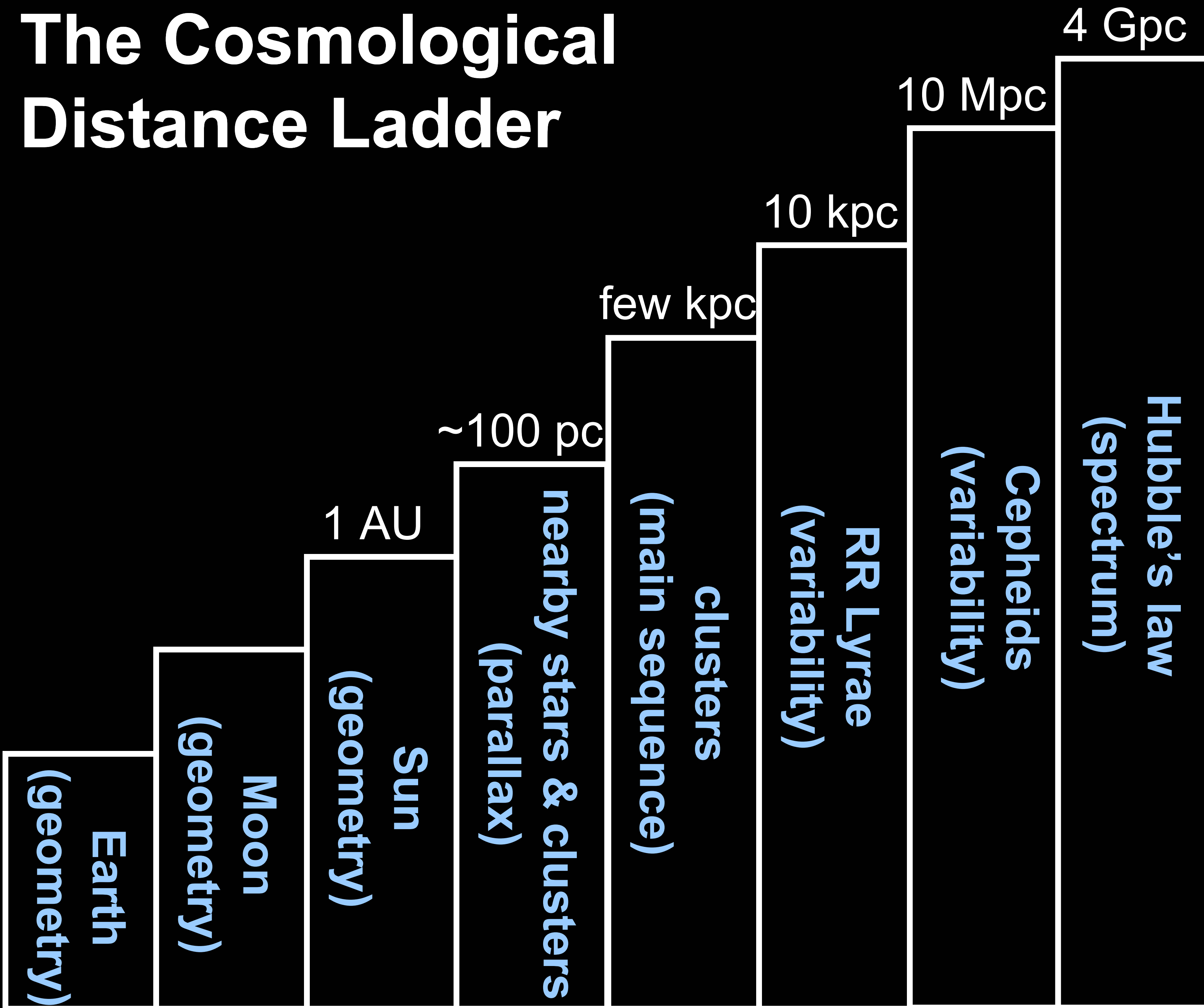
NOTES

On Sunday we celebrated the release of Artichoke's "26 Scientists Volume One Anning – Malthus" with a waffle brunch followed by a living room concert. Friends from all over LA were here -- kids banging on drums, men in leather and rubber smiling through the porch windows -- and the accoustics of the living room improved greatly by all those bodies.

Sometimes I daydream that Terry Gross, host of NPR's "Fresh Air," is asking me how and why I began writing 26 loosely biographical songs about scientists, one for every letter of the alphabet. "Well, Terry," I reply as if we were old chums, "it was a bit of a songwriting stunt. The abecedarium, as the A to Z structure is called, has long been a popular device in kid's books, as well as with one of my favorite artists, Edward Gorey. These days when I sit down to write a song -- starting with some rhythmic grunting and a little semi-melodious wailing -- I ask myself, 'Is this a scientist song?' About half the time it is, in which case it's research time. Did you know that when Isaac Newton died, he was a virgin who had neglected to write a will? And that all his furniture was covered with dark red velvet? Can't wait to work that into Volume Two." Before she can tell me how amusing this all is, and how great the songs are, my daydream ends abruptly. There's a telephone in my hand, but Terry Gross is gone and I'm on hold with a credit card company.

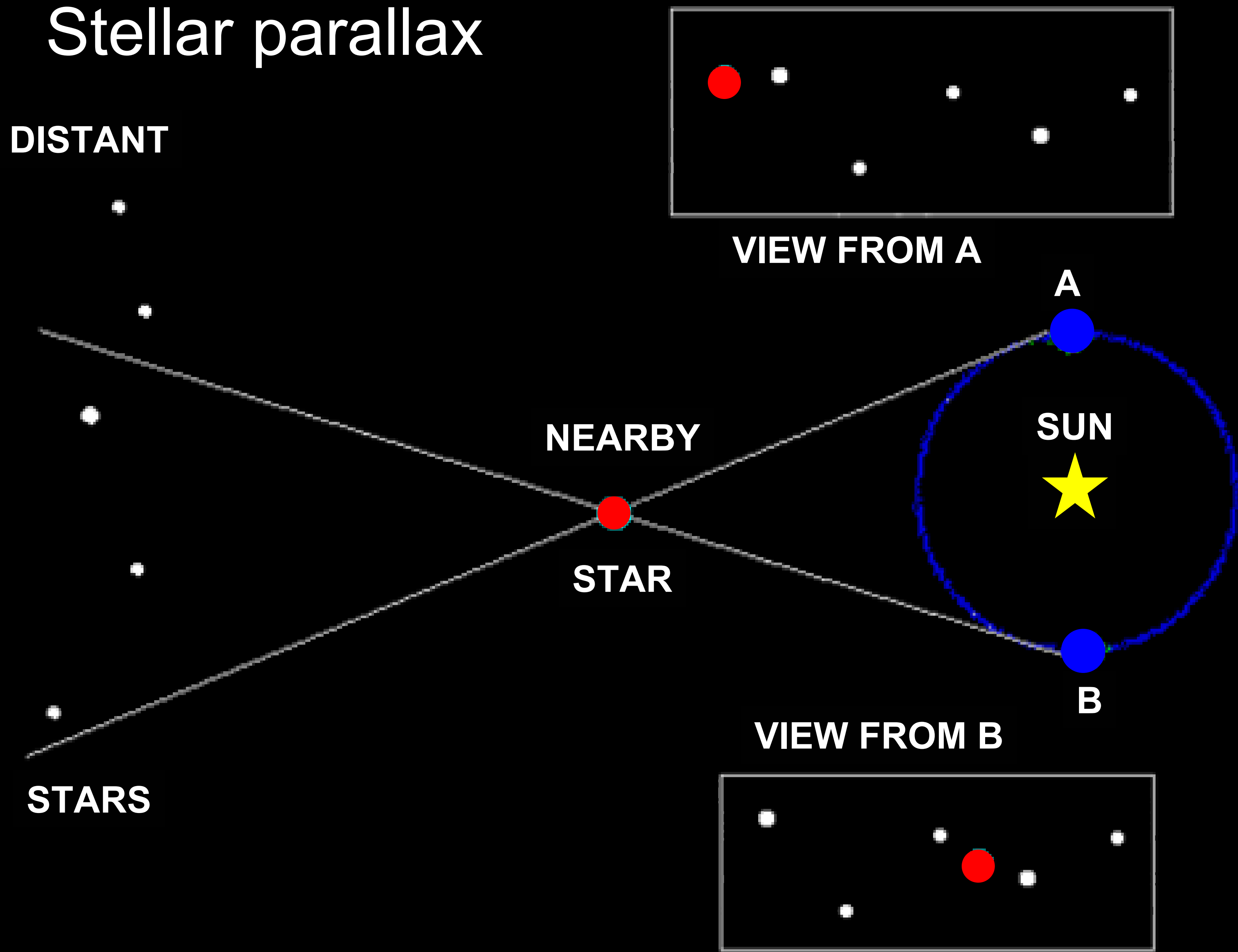
Ten years ago I bought a guitar in Pittsburgh. It came with a free ice cube tray. I already knew how

The Cosmological Distance Ladder



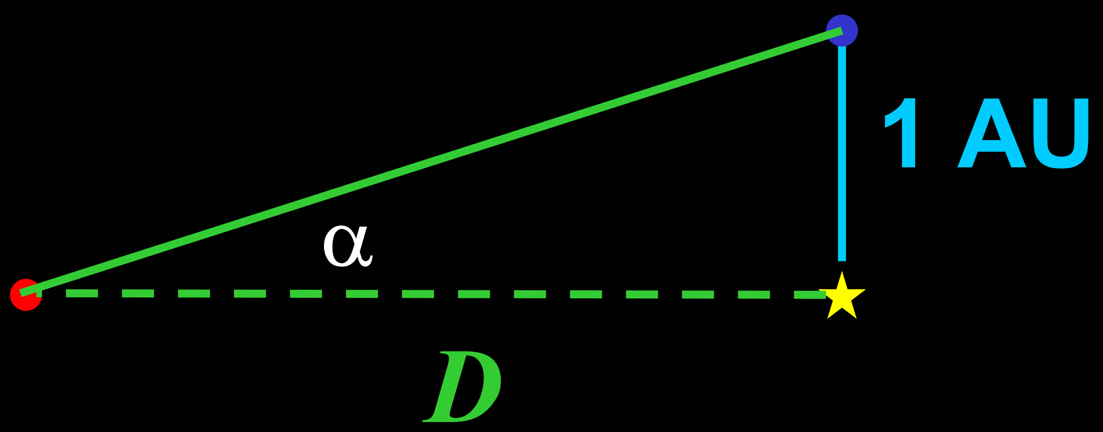
They move
They have different apparent brightness
They have different colors
They change in brightness
They (galaxies) are redshifted

Stellar parallax



$$\frac{D}{200{,}000\ \text{AU}} = \frac{\text{seconds}}{\alpha}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\alpha}$$



For light: $$m_1 - m_2 = -2.5\log\left(I_1 / I_2\right)$$

"–" means smaller *m* is brighter!

Intensity of Venus vs. Sirius

Venus $m_{♀} = -4$

Sirius $m_S = -1.5$

$$m_{♀} - m_S = -2.5 \log(I_{♀}/I_S)$$

$$-4 - (-1.5) = -2.5 \log(I_{♀}/I_S)$$

$$\cancel{-}2.5 = \cancel{-}2.5 \log(I_{♀}/I_S)$$

$$1 = \log(I_{♀}/I_S)$$

$$10^1 = 10 = I_{♀}/I_S$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

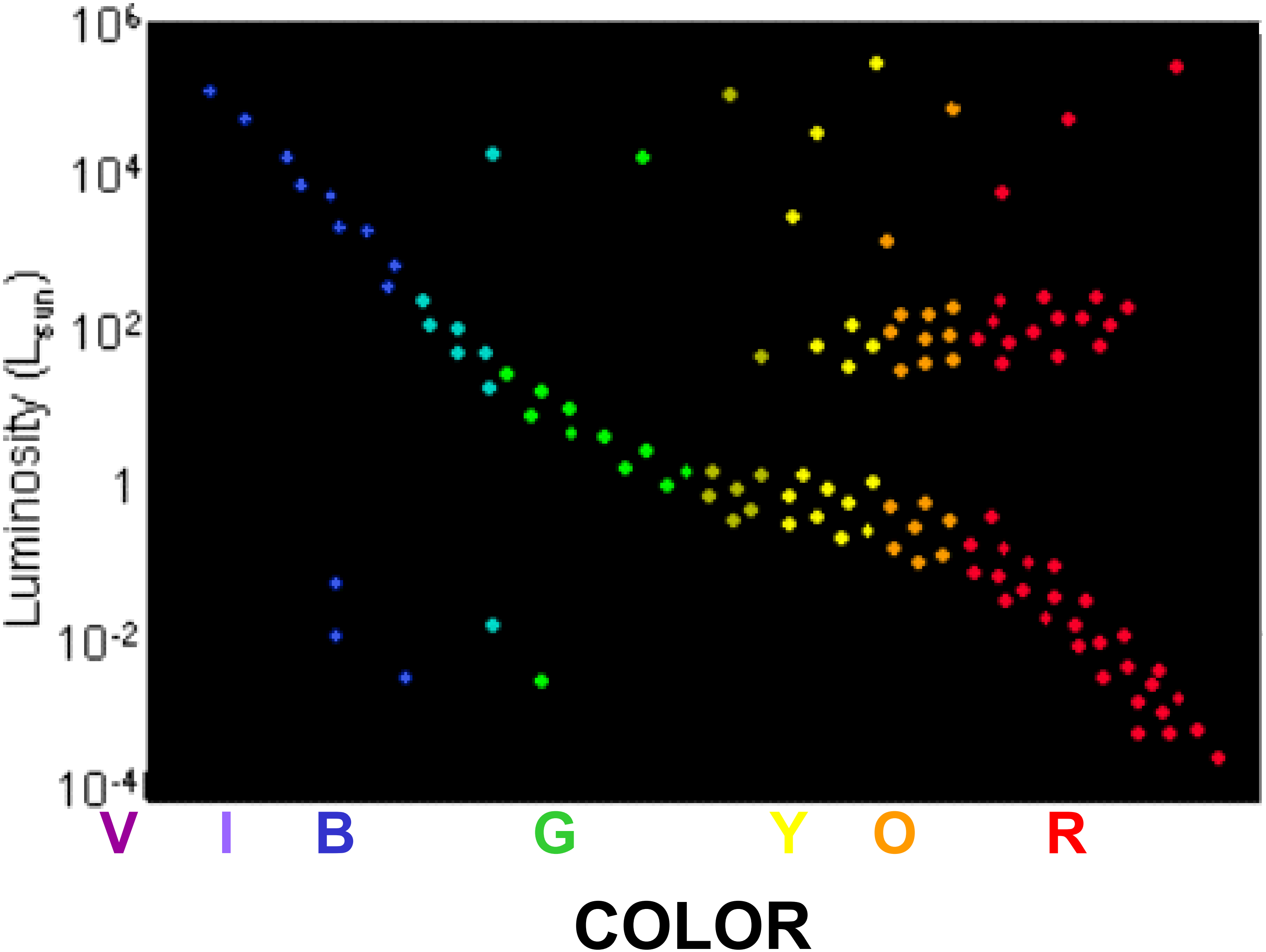
$$I = \frac{L}{4\pi R^2}$$

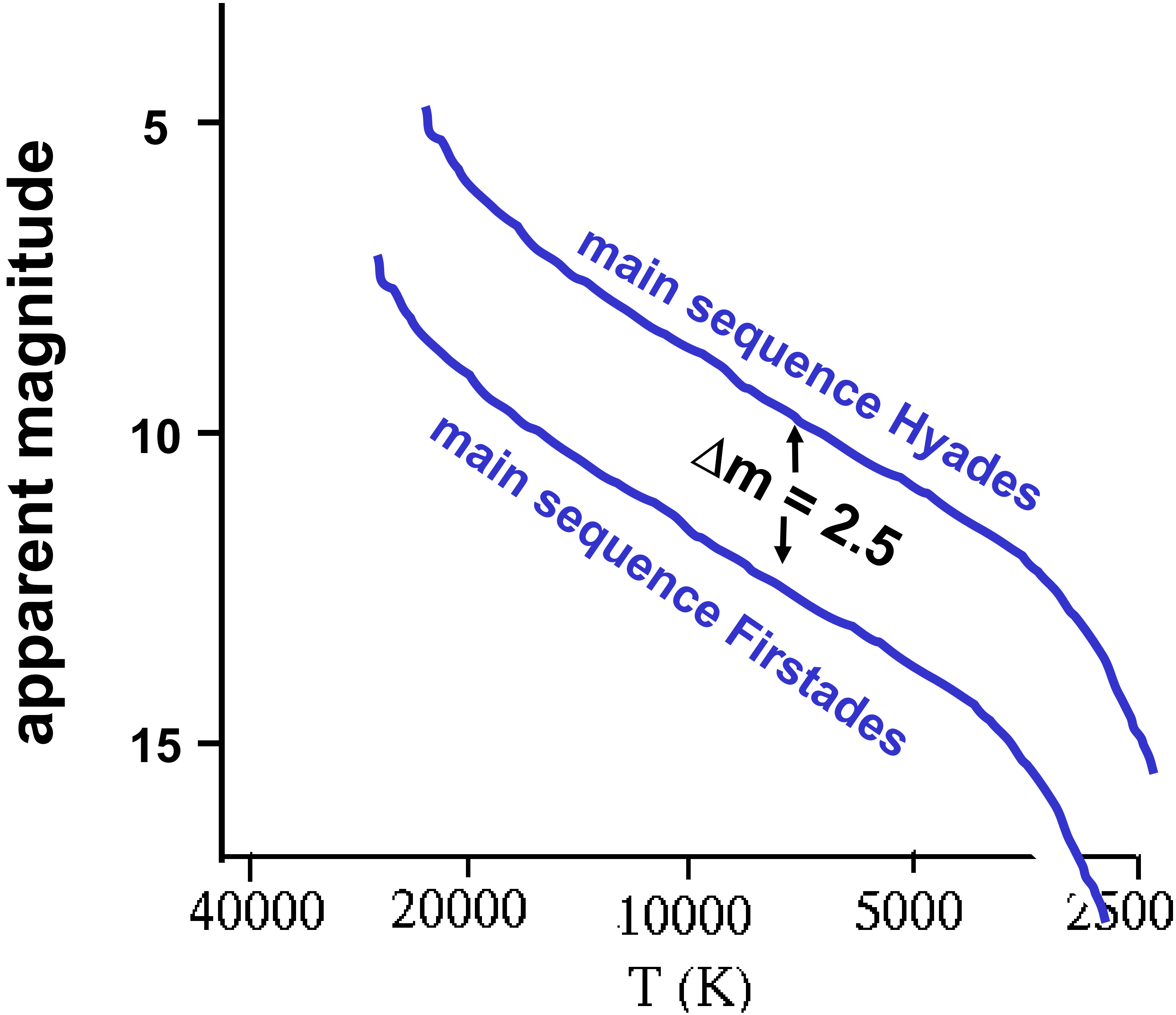
$$-26.8 - m = -2.5\log\left(0.137 \text{ watts cm}^{-2}/I\right)$$

Measured

star	parallax (")	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard's star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000

Schematic Hertzsprung-Russell Diagram





apparent magnitude
5
10
15
main sequence Hyades
main sequence Firstades
Δm = 2.5
40000
20000
10000
5000
2500
T (K)

$$m_H - m_F = -2.5\log\left(I_H / I_F\right)$$

$$-2.5 = -2.5\log\left(I_H / I_F\right)$$

$$1 = \log\left(I_H / I_F\right)$$

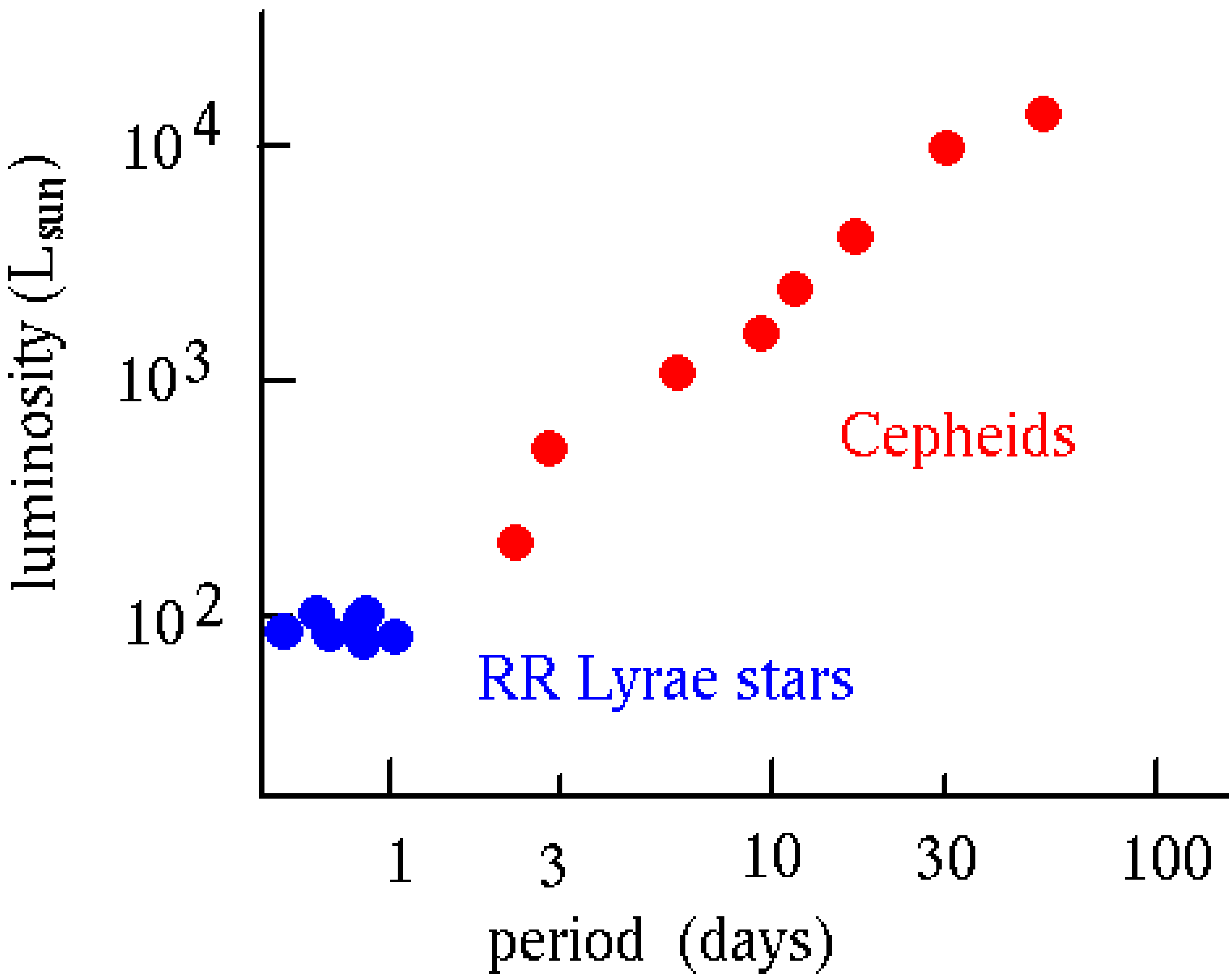
$$10 = I_H / I_F$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_F = \frac{\text{Luminosity}_F}{4\pi R_F^2}$$

$$\frac{I_H}{I_F} = \frac{R_F^2}{R_H^2} \qquad 10 = \frac{R_F^2}{R_H^2} \qquad 3 = \frac{R_F}{R_H}$$

Distances to other clusters

- Construct H-R diagram for cluster
- Measure Δm compared to HR diagram for Hyades
- Compute distance in terms of distance to Hyades
- How far can you go?
- Say most distant open observable cluster is Lastades



luminosity (L_{sun})
10^4
10^3
10^2
Cepheids
RR Lyrae stars
1
3
10
30
100
period (days)

- Main sequence stars are not extremely bright… we need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

- RR Lyrae stars found in distant clusters we know the distance to via H-R fitting.

- RR Lyrae stars are identified because their light output changes regularly on a time scale of half to one day.

- They are brighter than the sun by about a factor of 100 and are standard candles. Can see farther away and use as standard candle.

Cepheids as distance indicators

For cepheids of known distance

- Measure apparent magnitude of the cepheids

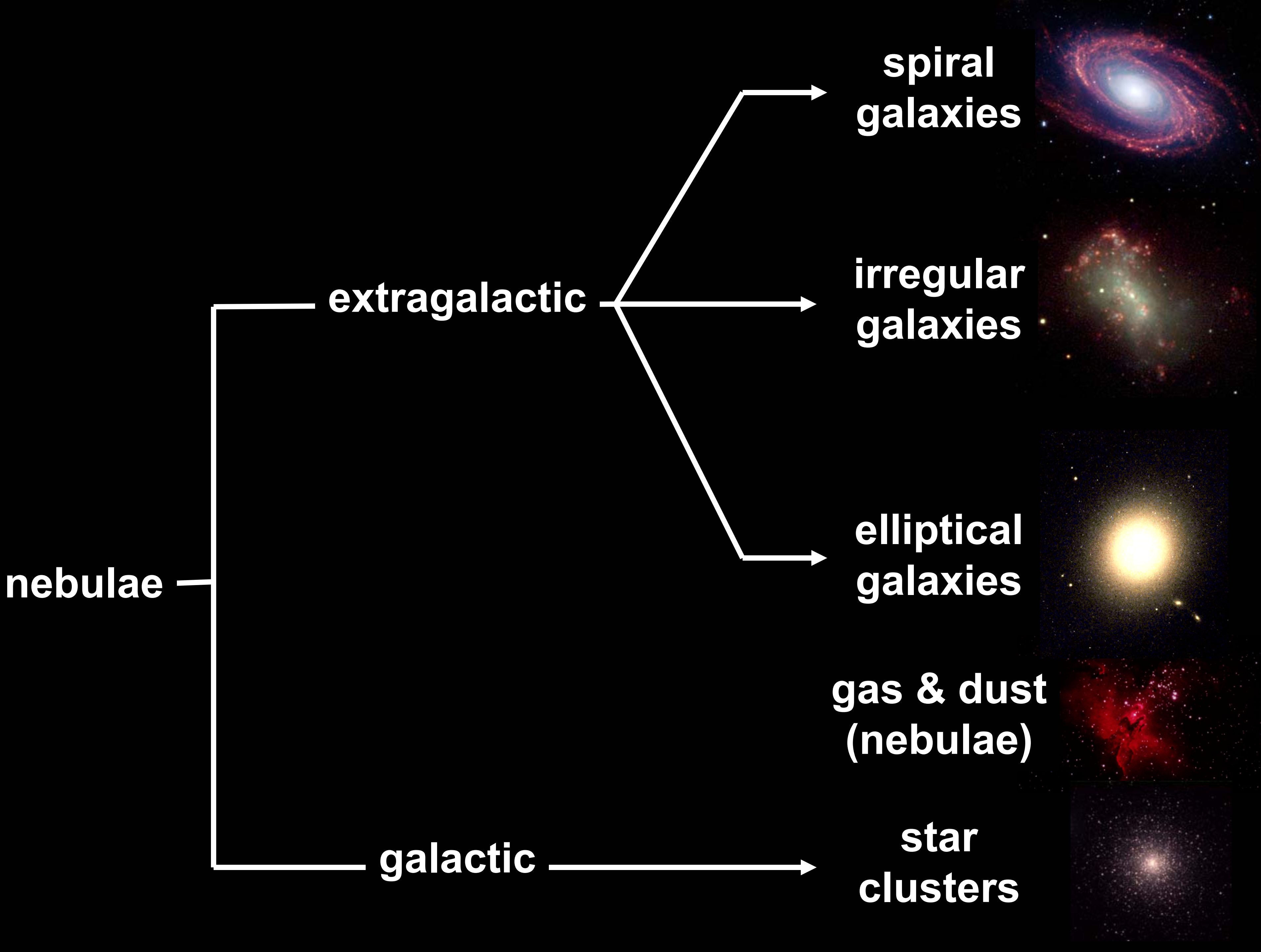
$$I = \frac{L}{4\pi R^2} \quad \rightarrow \textbf{know } L$$

- Measure period of the cepheids
- Calibrate (if know period know L)

For cepheids of unknown distance

- Measure period….know L
- Measure apparent magnitude

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \textbf{know } R$$


nebulae
extragalactic
galactic
spiral galaxies
irregular galaxies
elliptical galaxies
gas & dust (nebulae)
star clusters

Talking points in the Great Debate

1. Rotation of M101
2. Variable stars
3. Stars or gas
4. Spatial distribution & velocity

Doppler Shift

$$\lambda_0 = c\Delta t = \text{ rest wavelength}$$

$$\lambda = c\,\Delta t \pm \text{v}\,\Delta t = \text{ detected wavelength}$$

$$c\,\Delta t = \lambda_0 \quad \Rightarrow \quad \lambda = \lambda_0 \pm \text{v}\,\Delta t$$

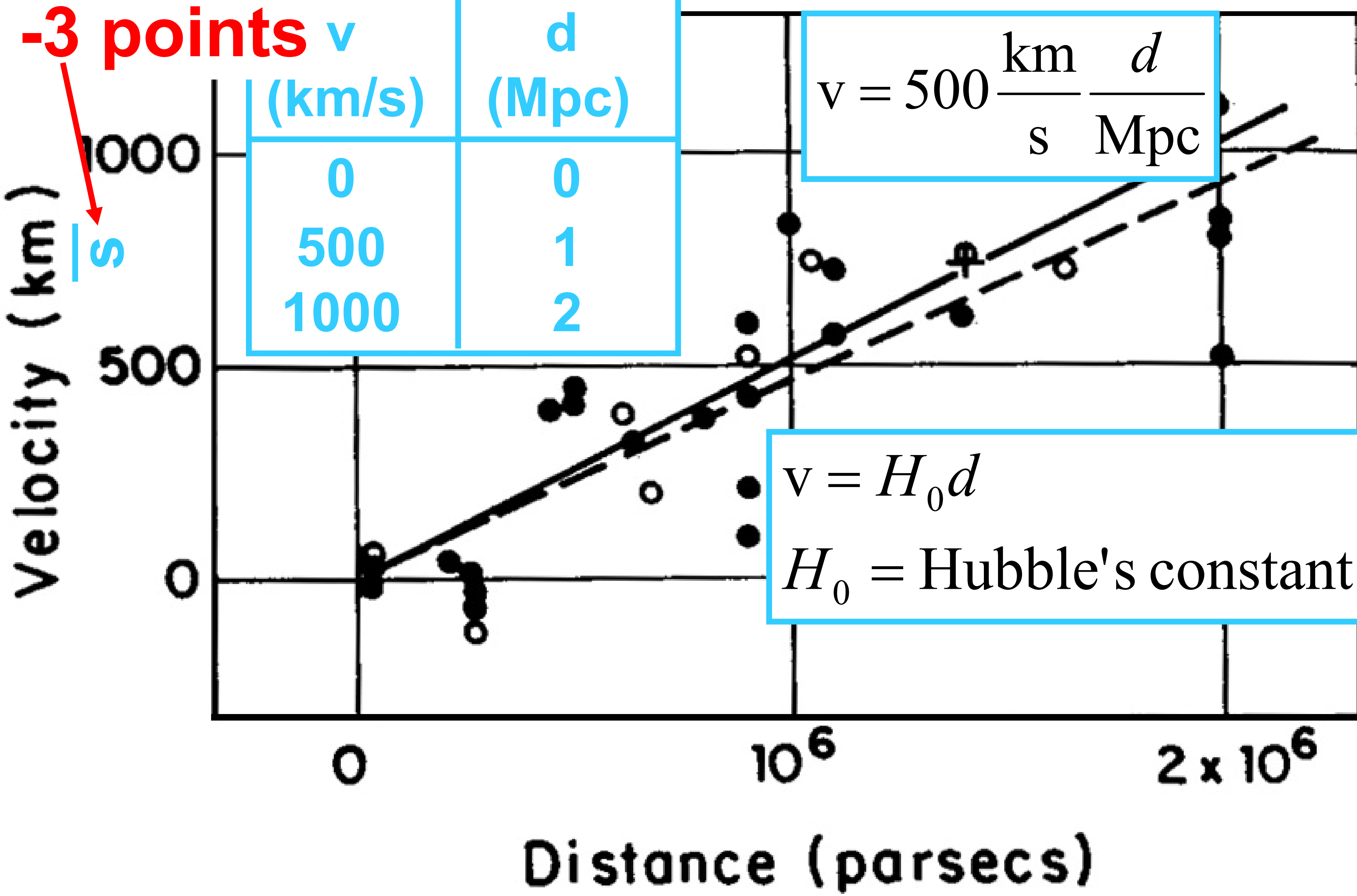
$$\Delta t = \frac{\lambda_0}{c} \quad \Rightarrow \quad \lambda = \lambda_0 \pm \frac{\text{v}}{c}\lambda_0$$

$$\boxed{\lambda = \lambda_0\left(1 \pm \frac{\text{v}}{c}\right)}$$

$+ \rightarrow$ receding (longer λ)

$- \rightarrow$ approaching (shorter λ)

Hubble's Discovery Paper - 1929

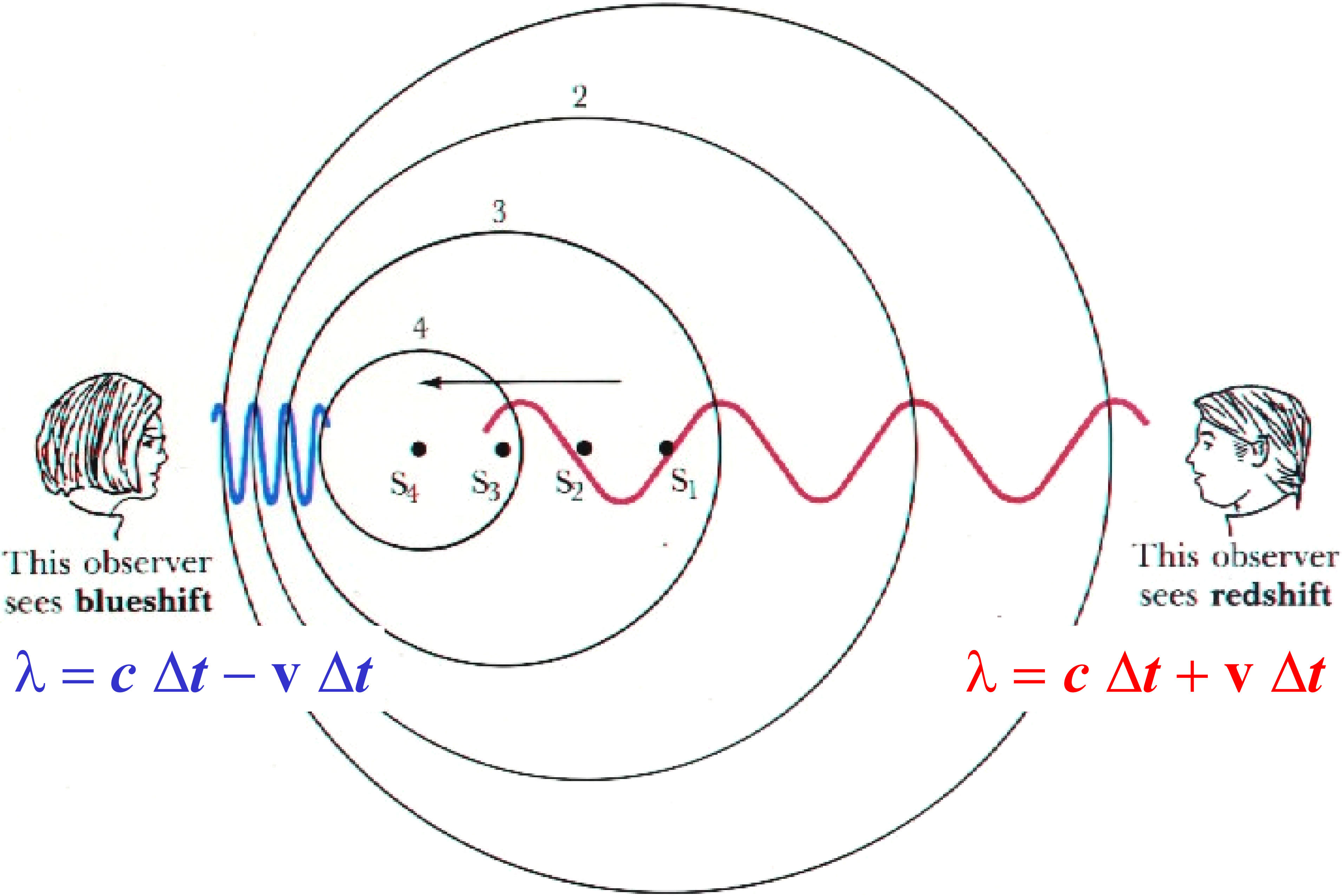


v (km/s)	d (Mpc)
0	0
500	1
1000	2

$$v = 500 \frac{\text{km}}{\text{s}} \frac{d}{\text{Mpc}}$$

$$v = H_0 d$$

$$H_0 = \text{Hubble's constant}$$



$$\lambda = c\,\Delta t - v\,\Delta t$$

$$\lambda = c\,\Delta t + v\,\Delta t$$

We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe
  (no center)
- no special set of points
  (no edge)

The expansion of the universe is

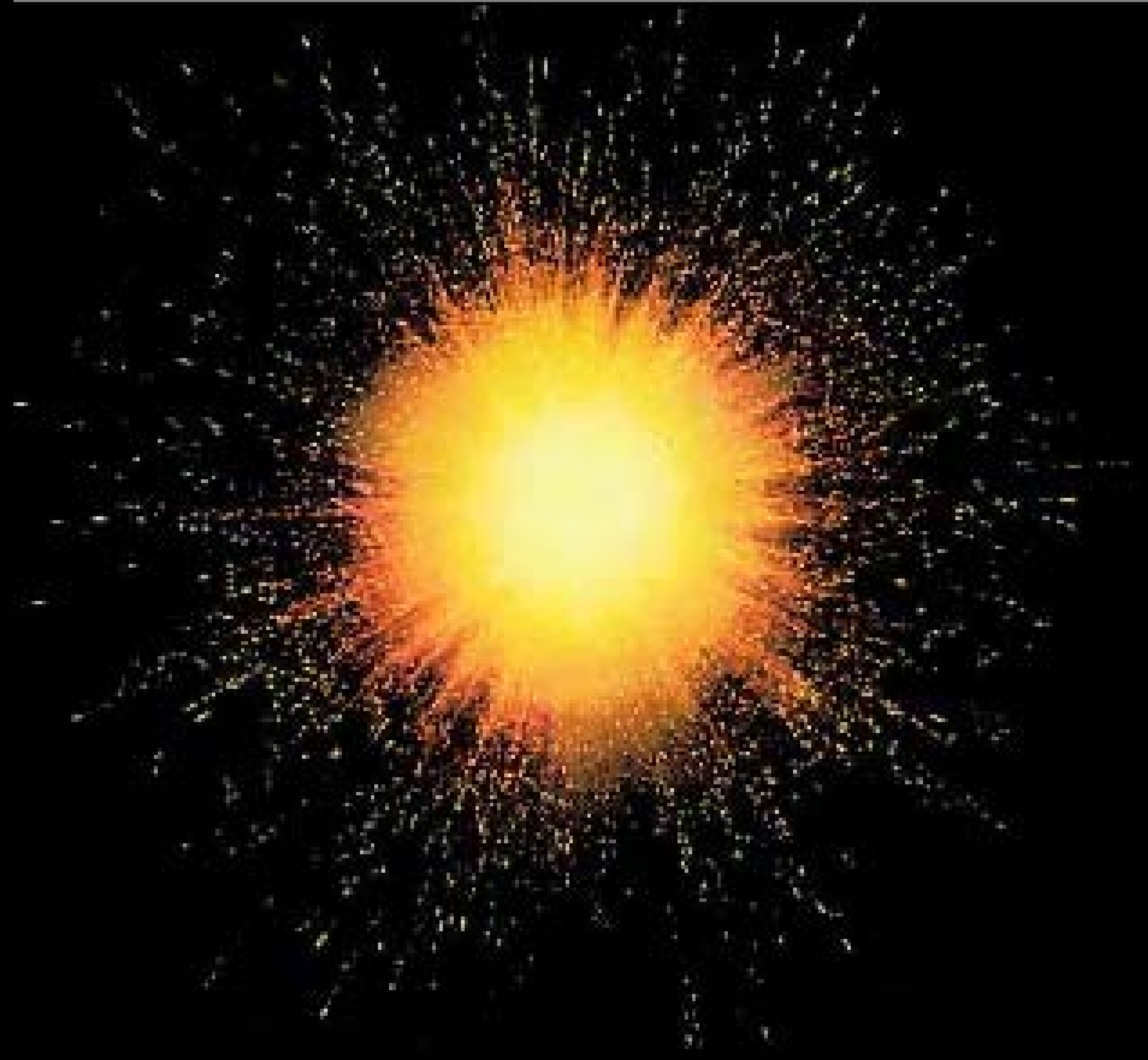
an explosion *of* space

not

an explosion *into* space

The universe does not expand *into* anything!

This is not the big bang!



The age of the elements

- Elements come in different isotopes
  (same # of protons, different number of neutrons)
- Many isotopes are radioactive — they decay
- If start with $N(0)$ nuclei, after a time t, the number will be

$$N(t) = N(0)\, 2^{-t/\tau_{1/2}}$$

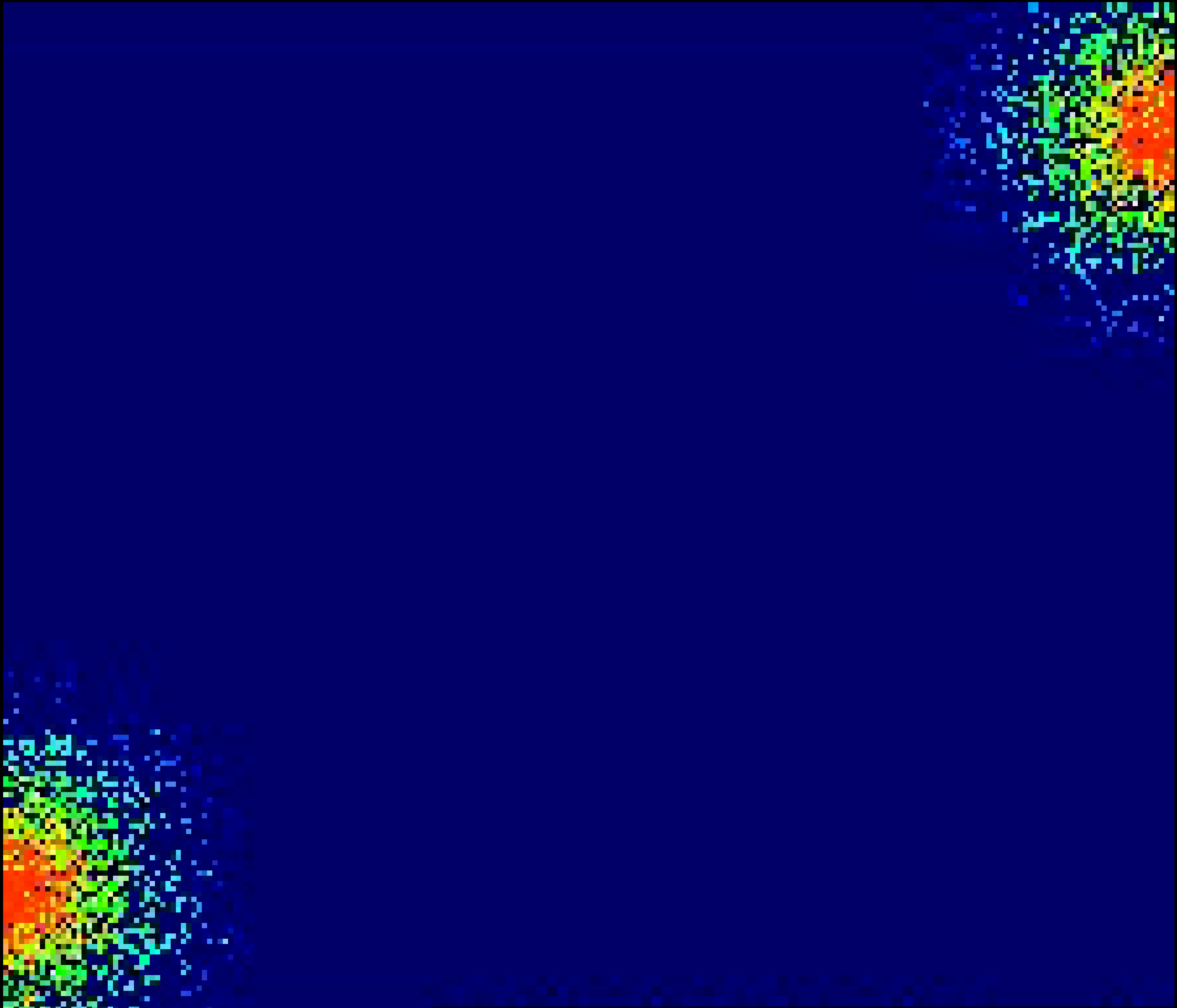
$\tau_{1/2}$ is the half-life

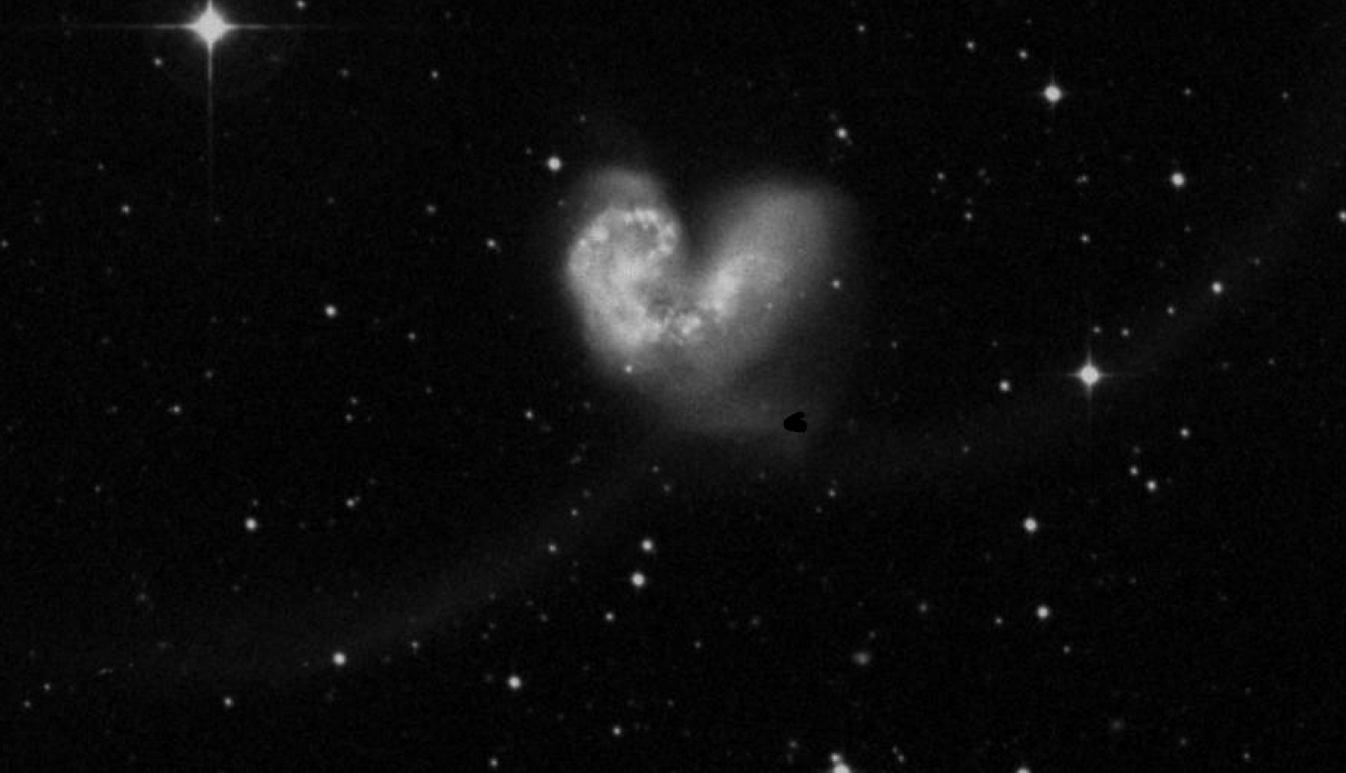
Can use radioactive isotopes to date objects
Radio dating …. nucleocosmochronology

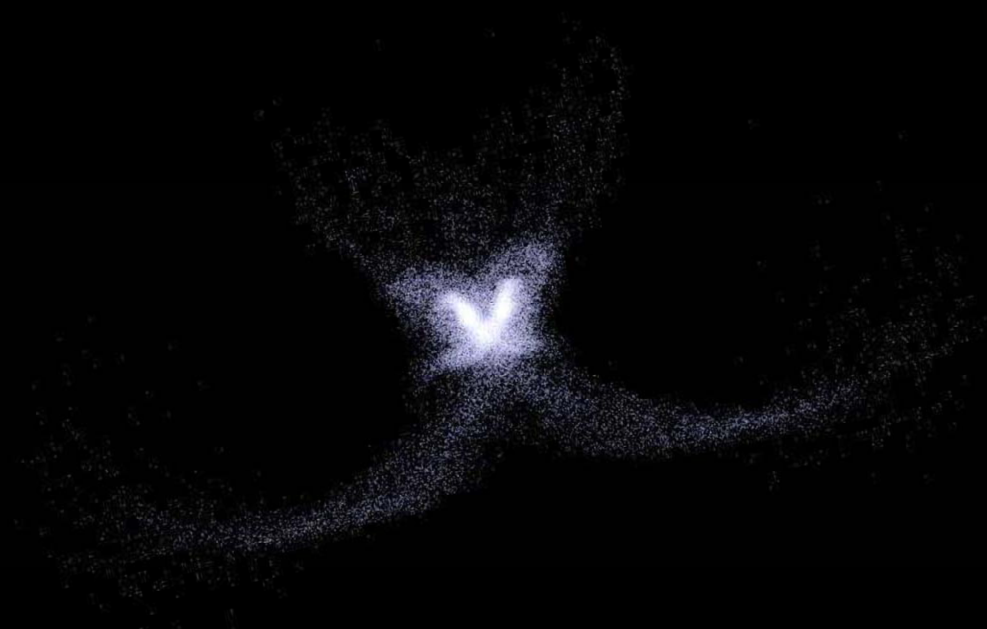
blueshift = 300 km s^{-1}
distance = 0.65 Mpc

$$300\,\frac{\text{km}}{\text{sec}}\times\frac{3\times10^{7}\text{sec}}{\text{yr}}\times\frac{1\text{Mpc}}{3\times10^{19}\text{km}}$$

$$=\frac{1\ \text{Mpc}}{3\ \text{Gyr}}\Rightarrow 0.65\ \text{Mpc in 2 Gyr}$$

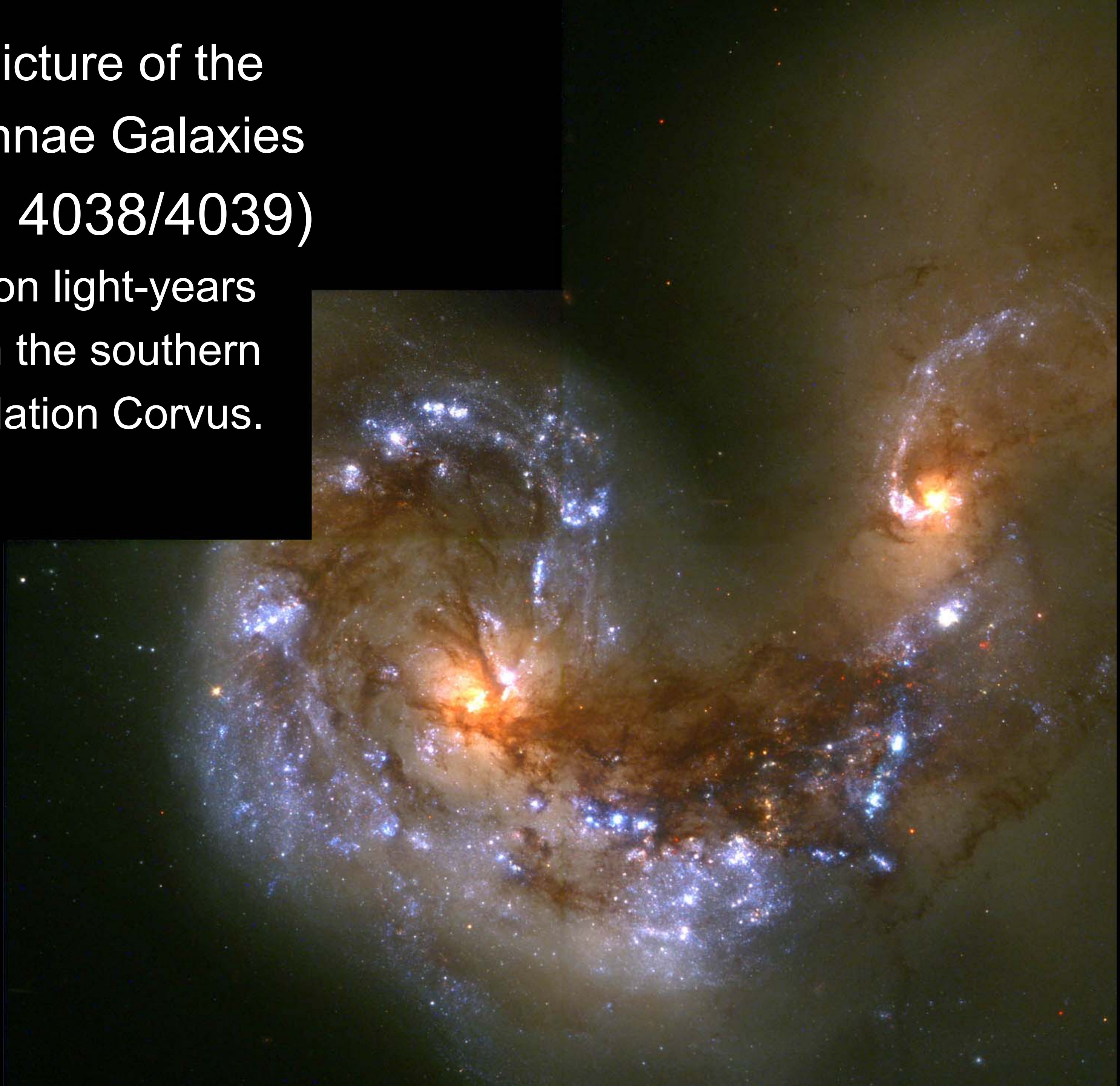




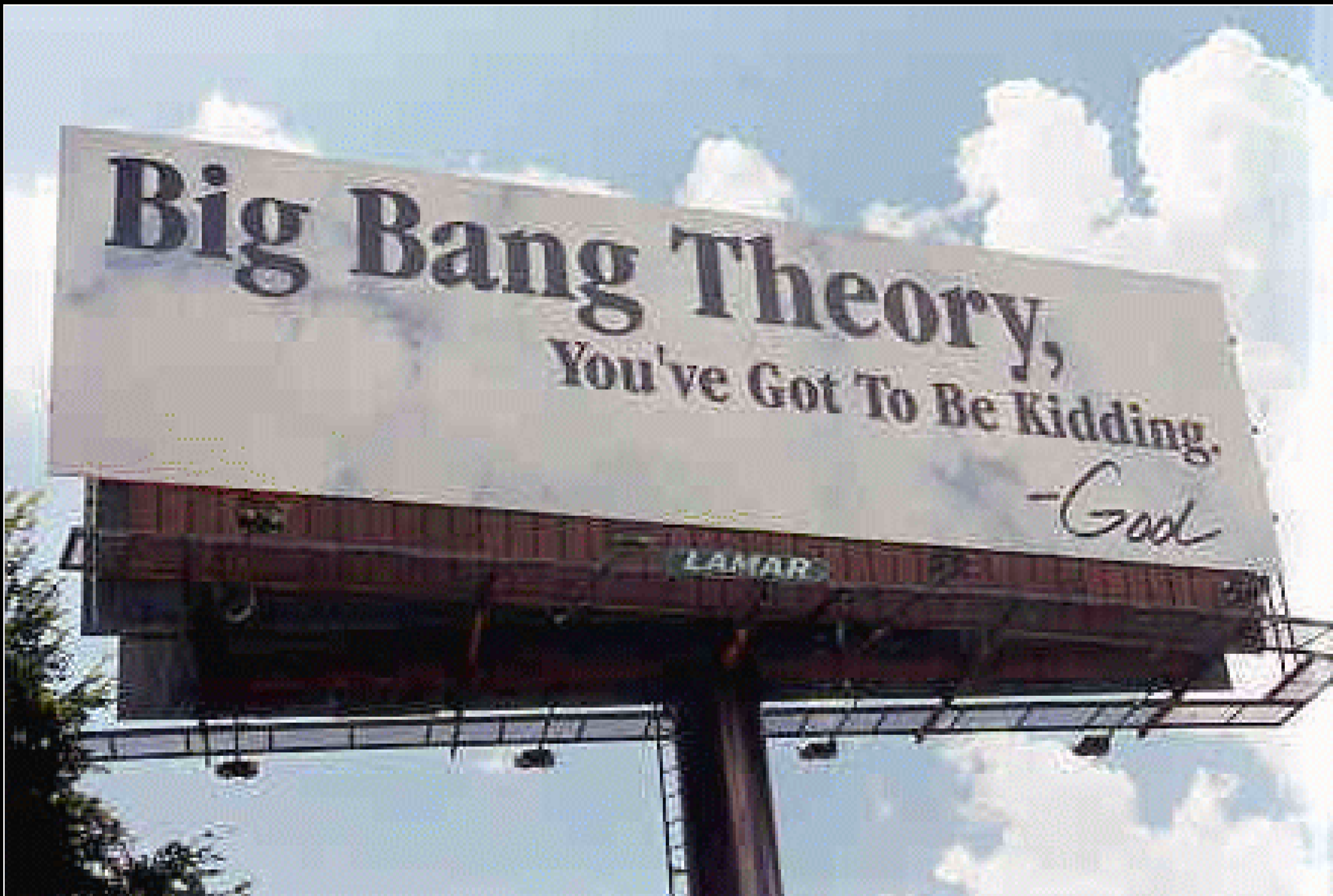


HST Picture of the Antennnae Galaxies (NGC 4038/4039)

63 million light-years away in the southern constellation Corvus.



The Big Bang

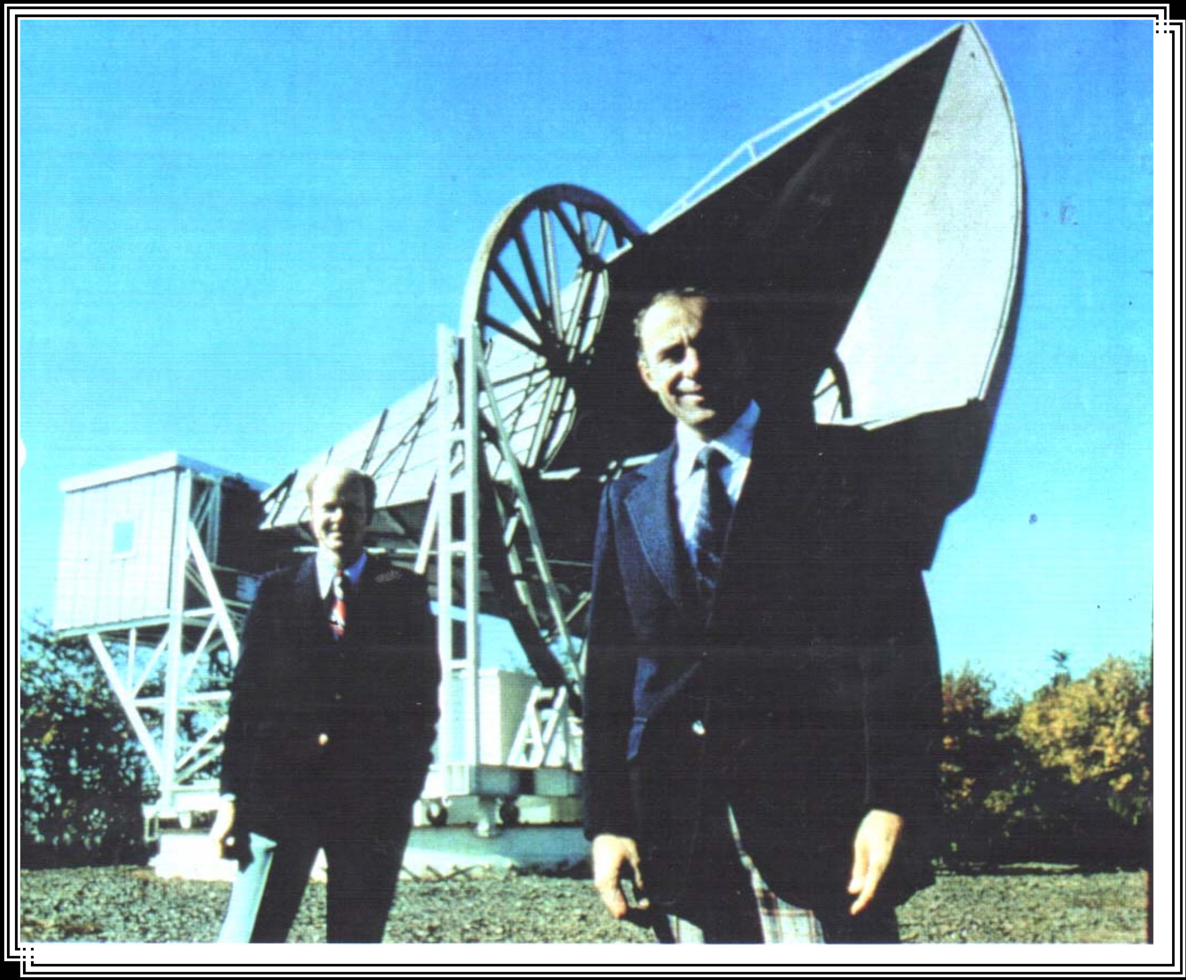


Space expands.

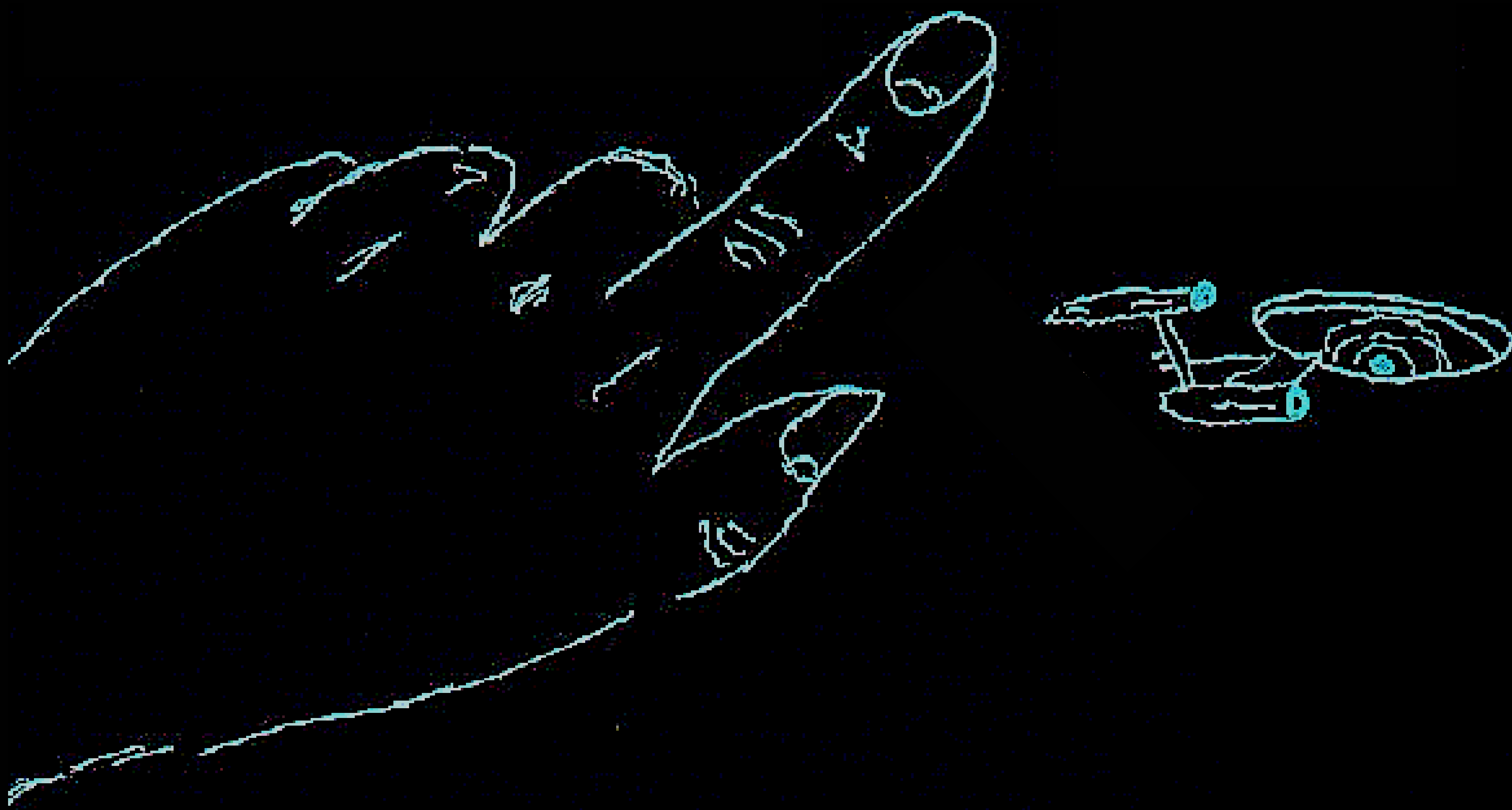
Edwin Hubble
1929

The universe
is radiant.

Arno Penzias
Robert Wilson
1965

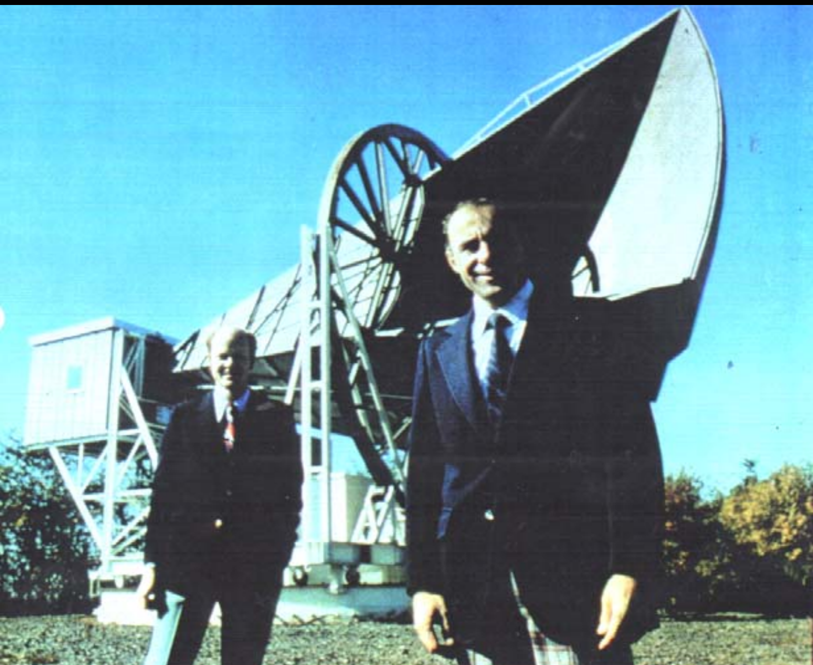


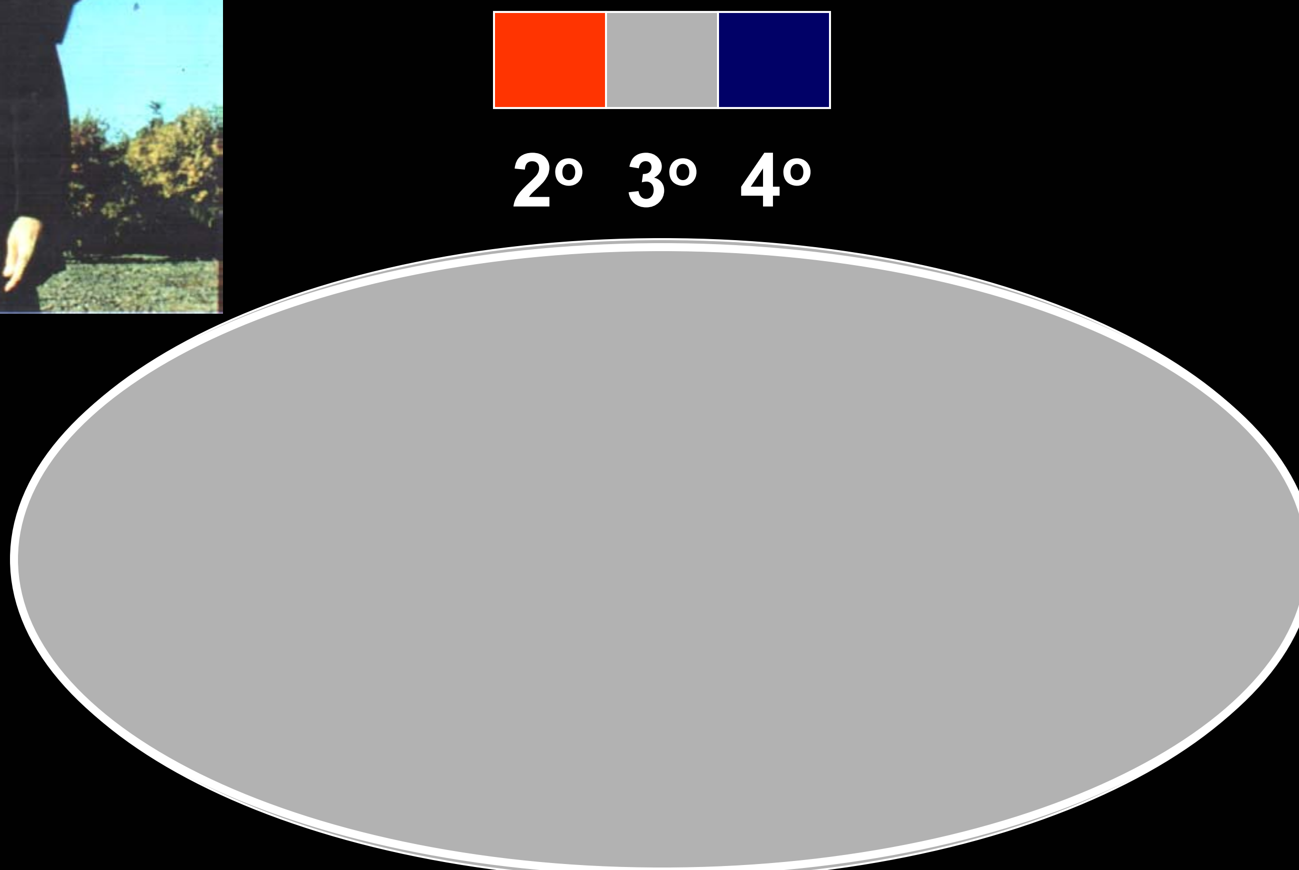
Cosmic background radiation



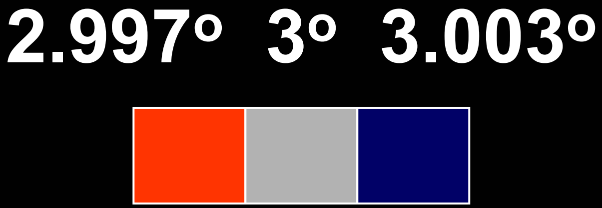
$T = 3K = -454^{o}$ F

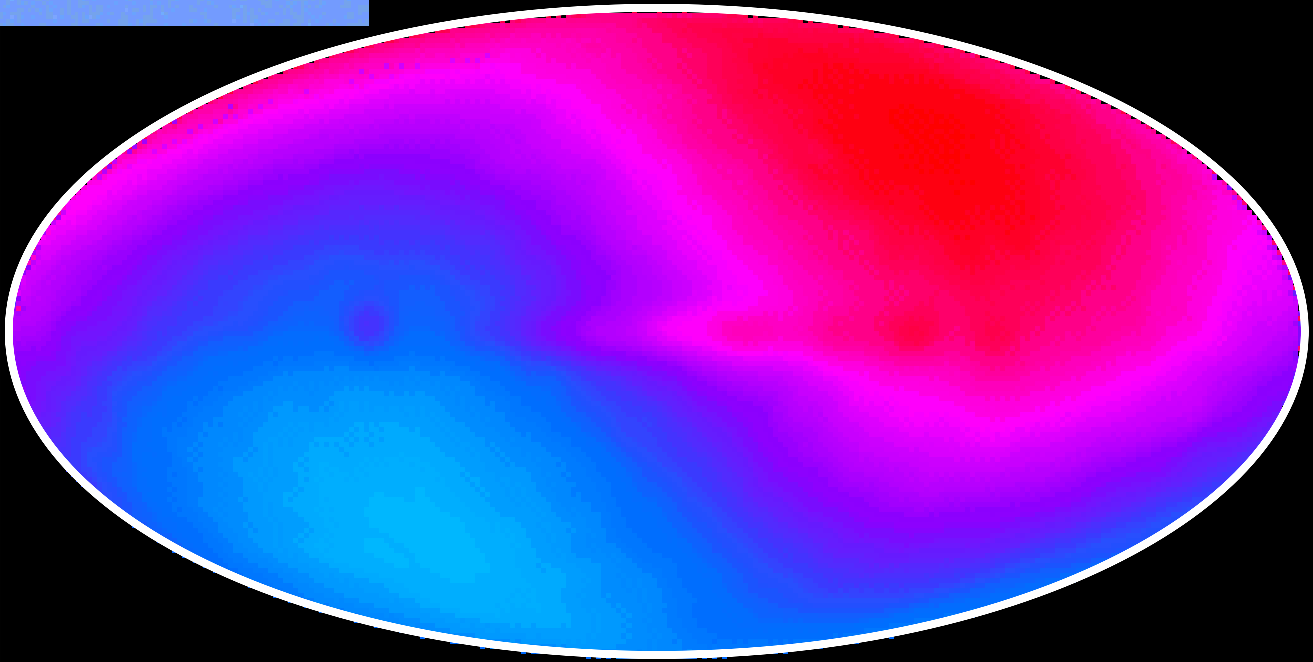
Cosmic Radiation ca. 1960s



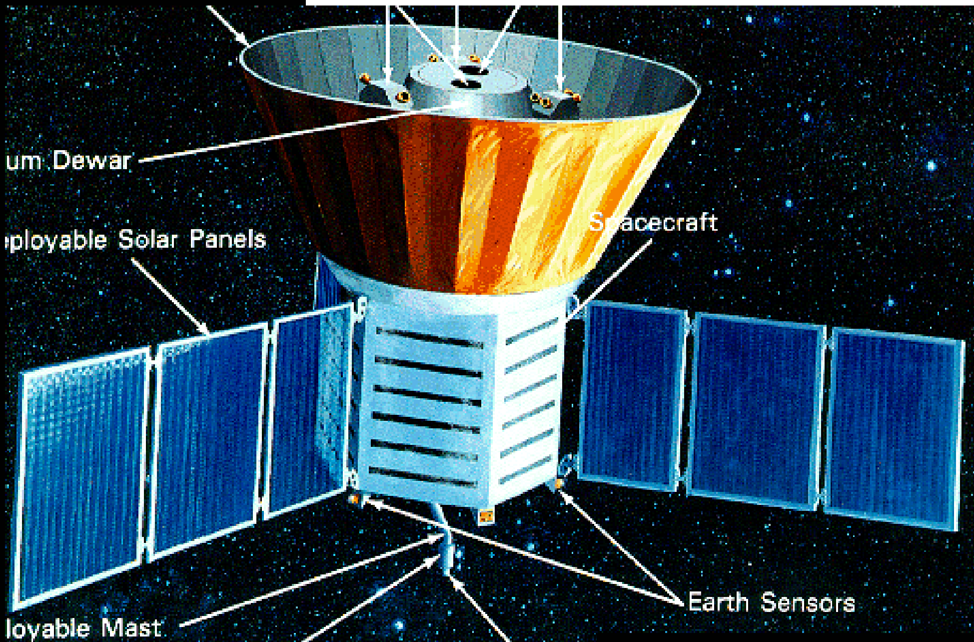


Cosmic Radiation ca. 1975



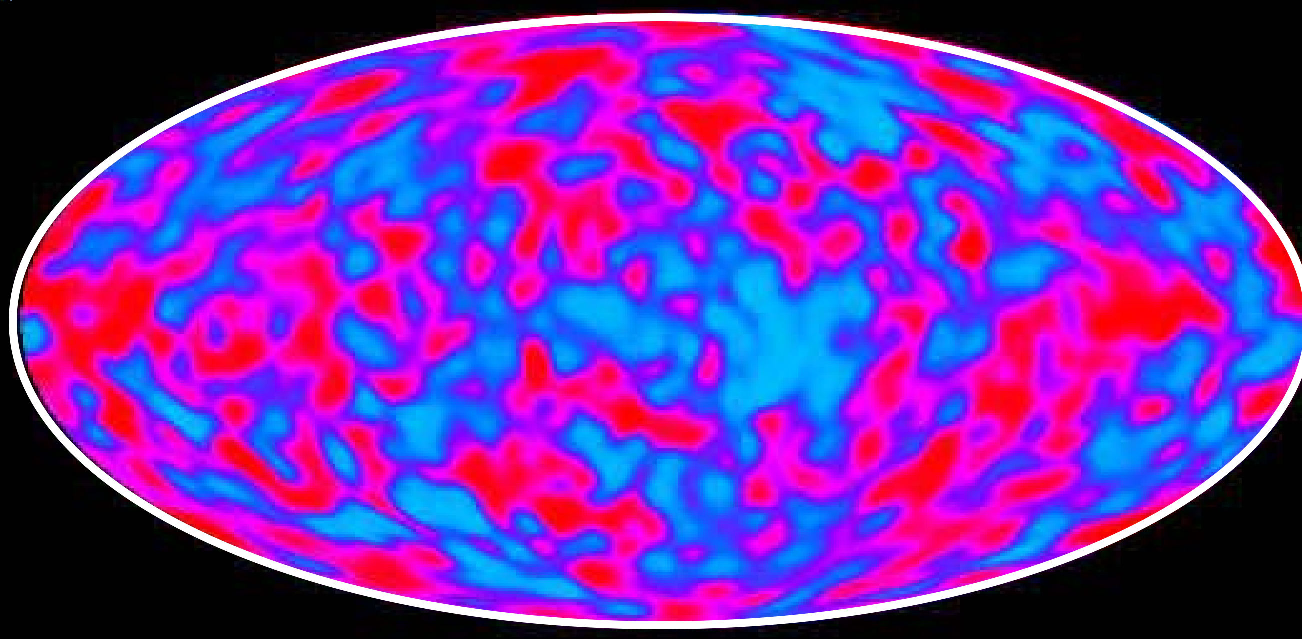


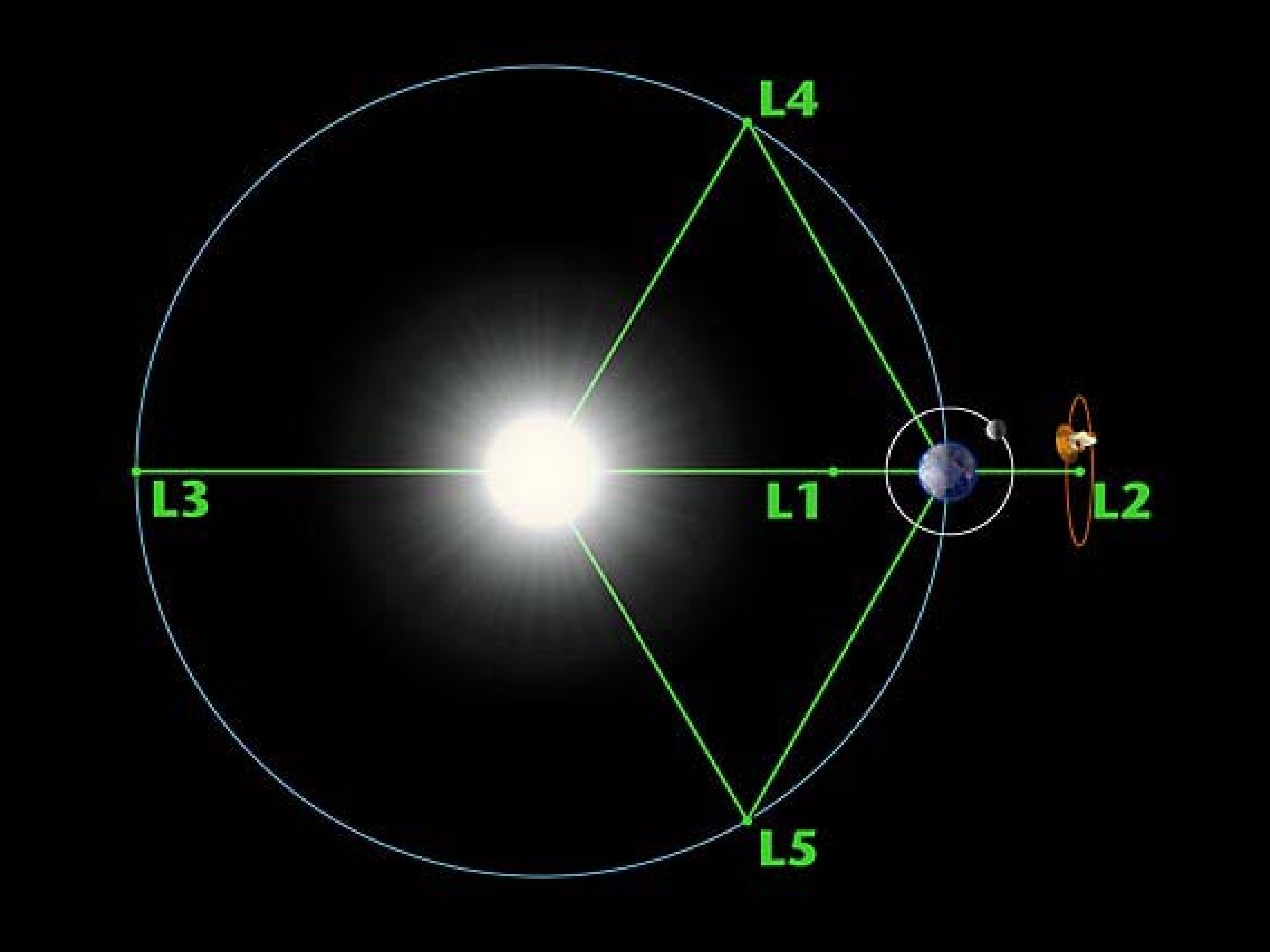
Cosmic Radiation 1992



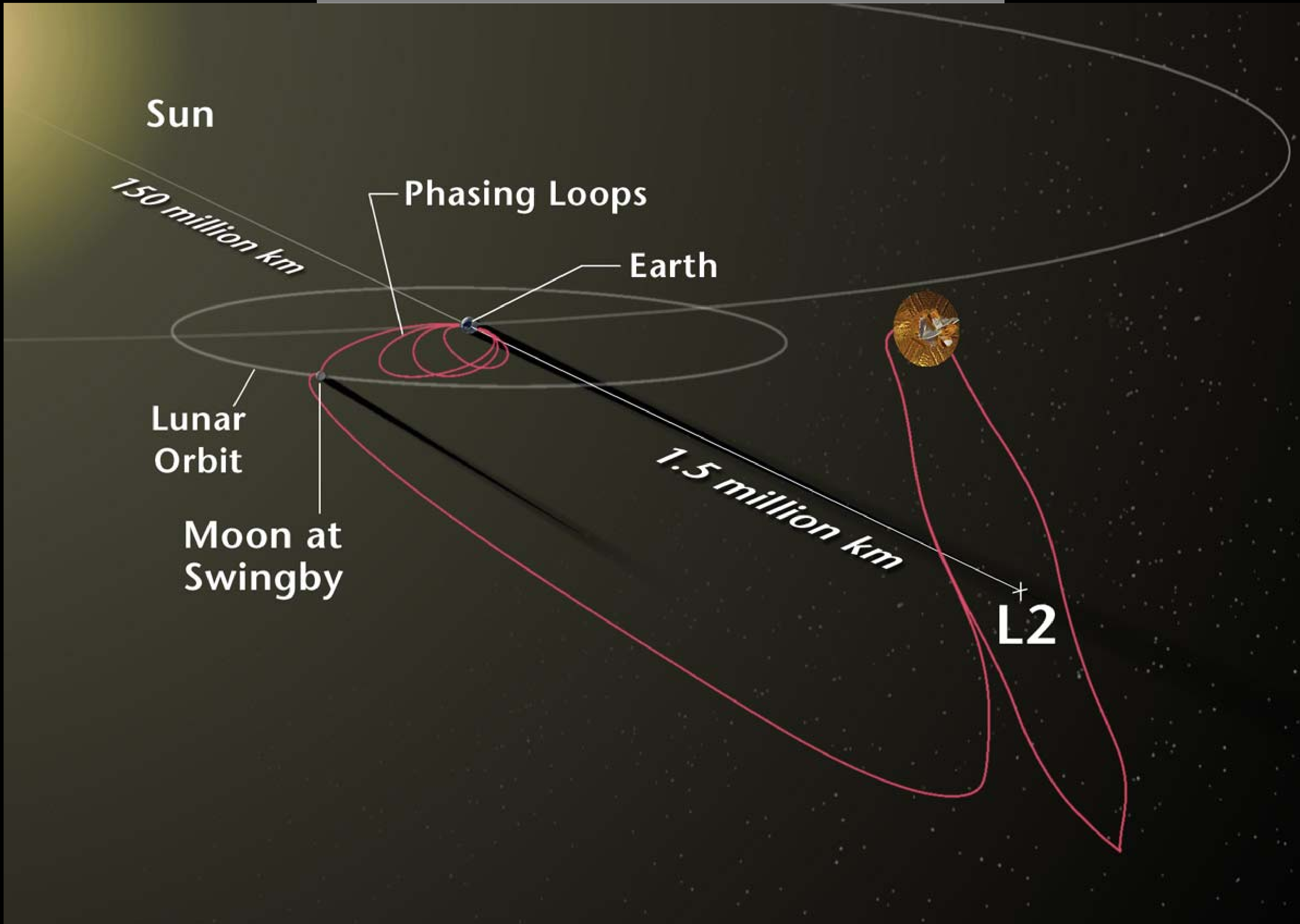
COBE

2.99997° 3° 3.00003°

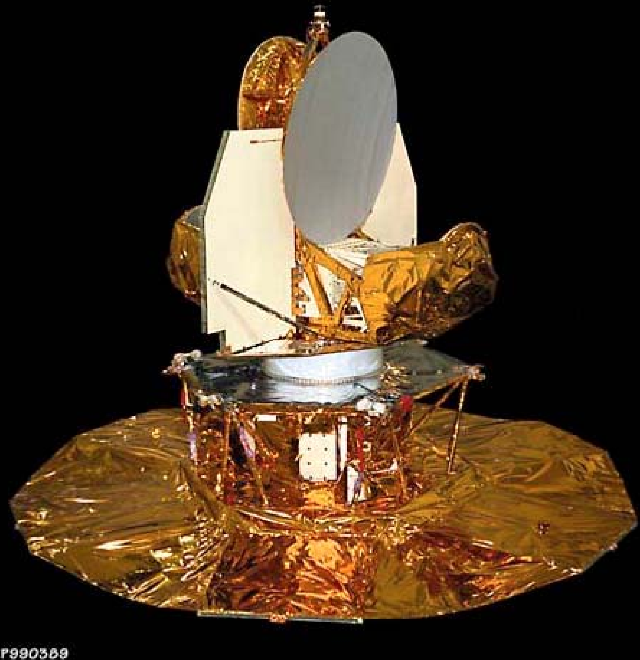



L4
L3
L1
L2
L5

The voyage to L2

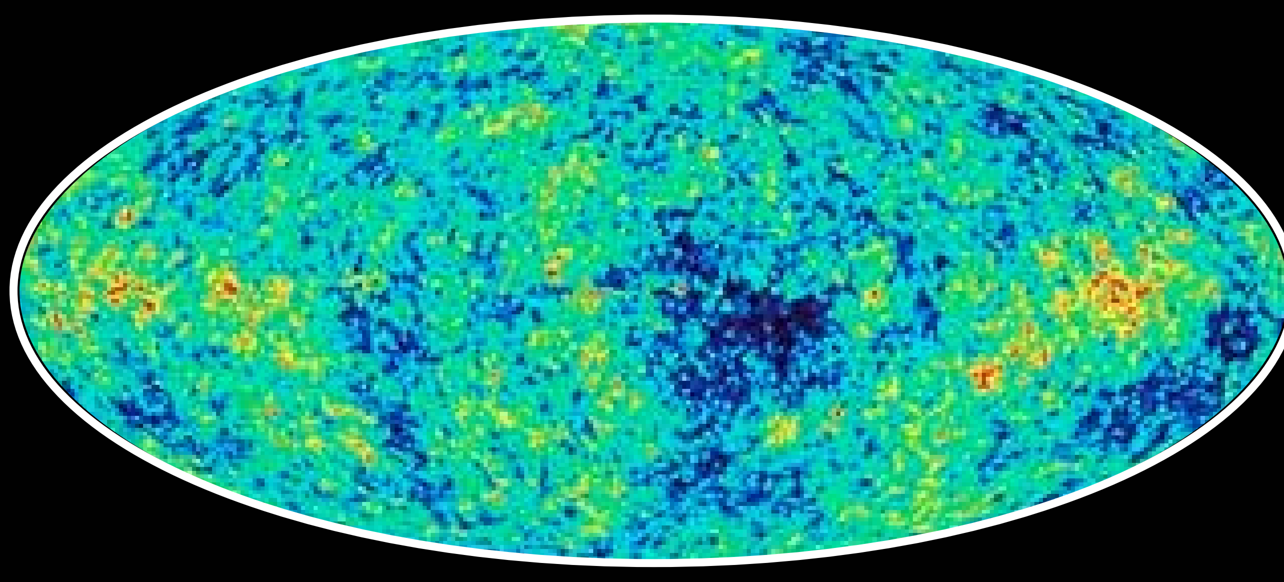


Cosmic Radiation 2005



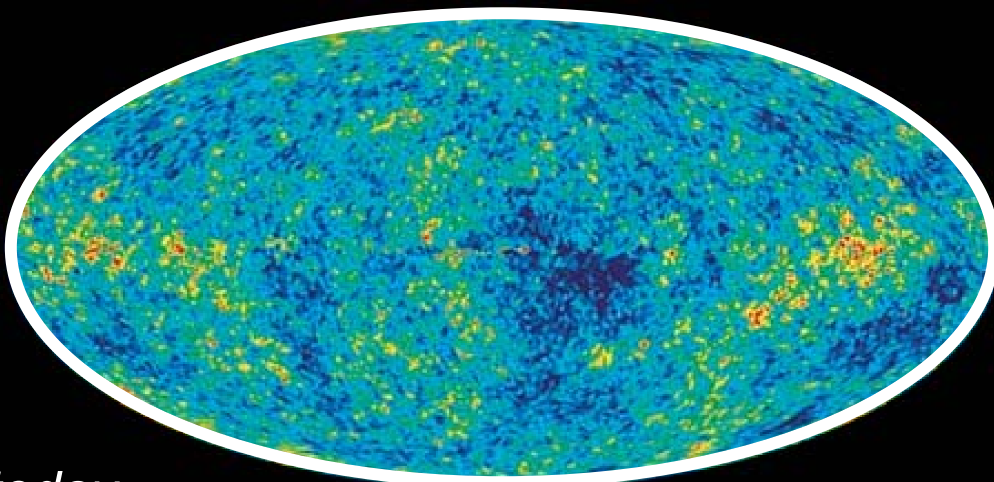
WMAP

2.99997° 3° 3.00003°

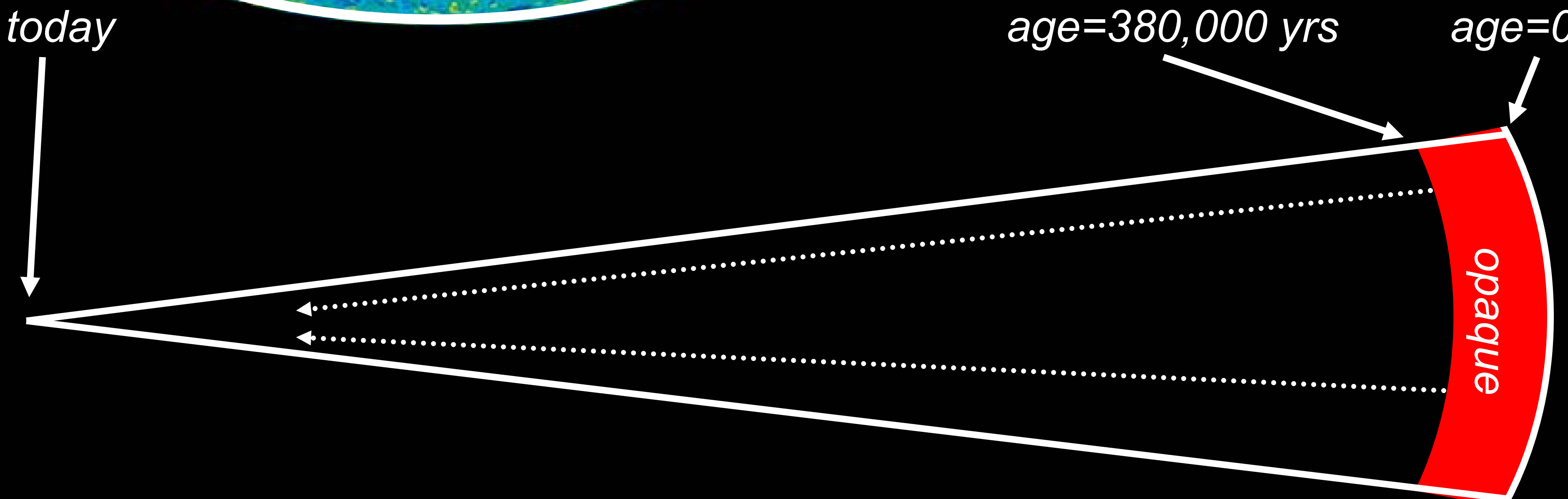


The newborn universe

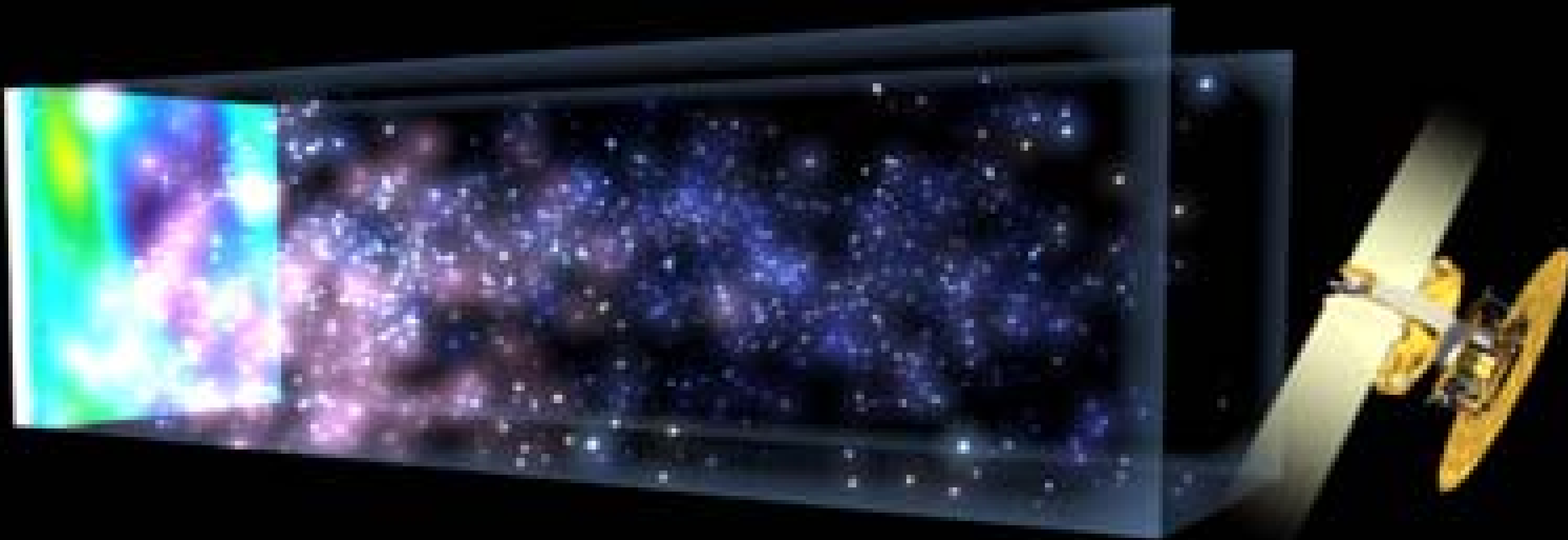
Looking out in space is looking back in time.



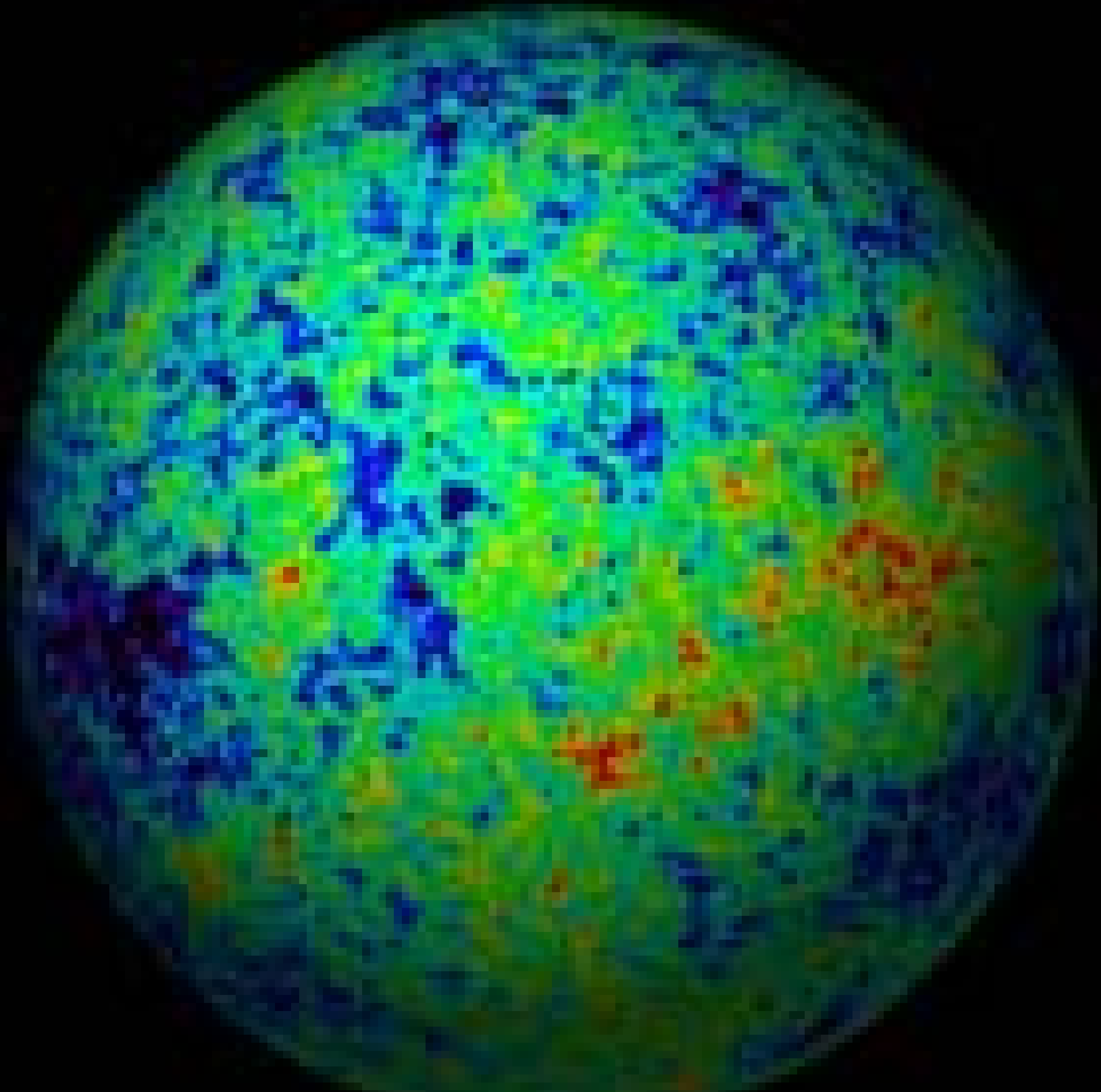
CBR: a snapshot of the universe 380,000 AB



The Last Scattering Surface



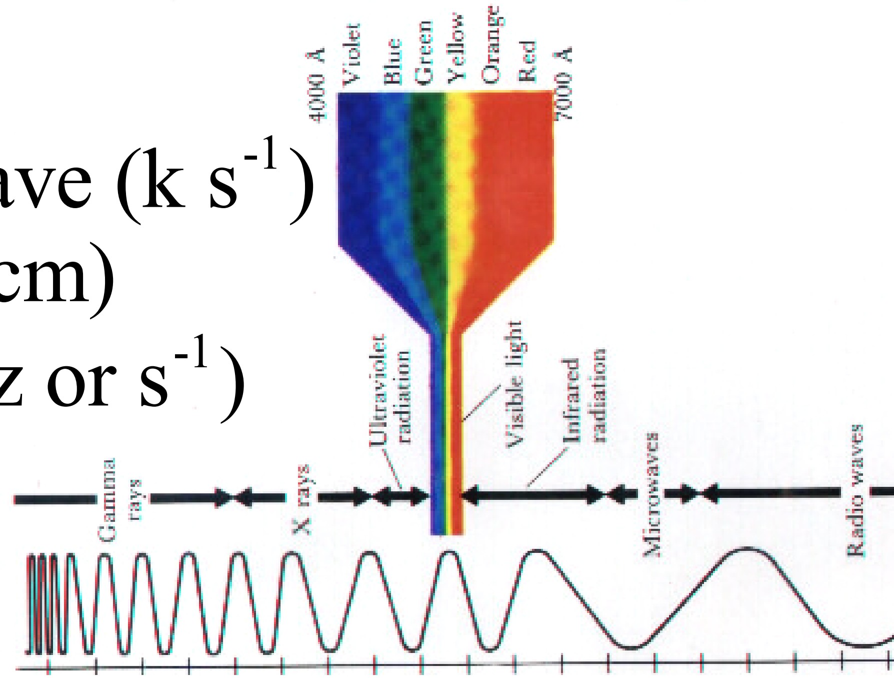
The Last Scattering Surface



Facts about light

1. Light is a wave

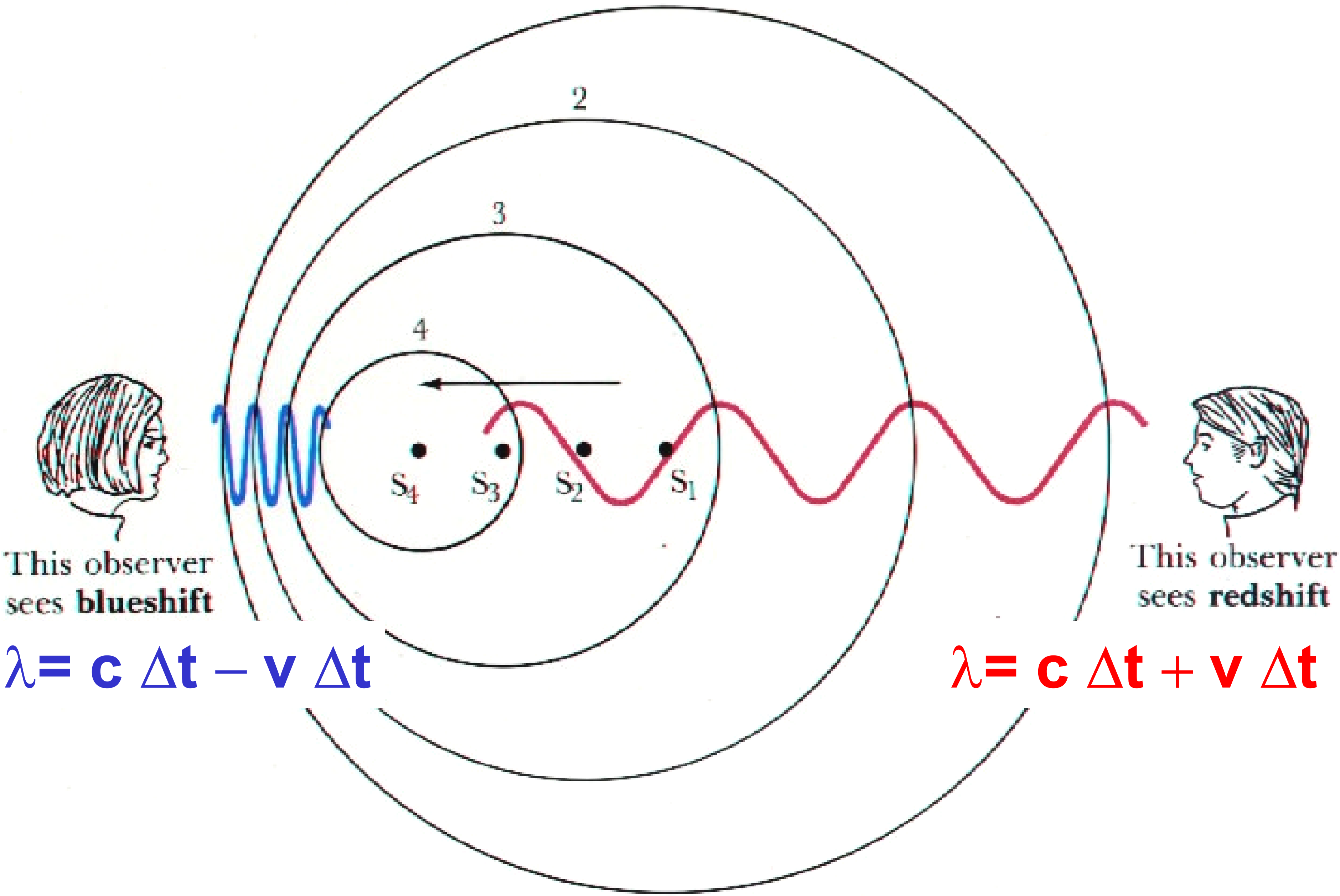
$$c = \lambda \nu \quad \begin{cases} c = \text{ velocity of wave (k s}^{-1}\text{)} \\ \lambda = \text{ wavelength (cm)} \\ \nu = \text{ frequency (Hz or s}^{-1}\text{)} \end{cases}$$



2. The wavelength is quantized

Visible Emission Spectrum

3. Doppler shift



$\lambda = c\,\Delta t - v\,\Delta t$

$\lambda = c\,\Delta t + v\,\Delta t$

4. Light is a particle

- **Particles of light are "photons"**
- **Photons have energy**

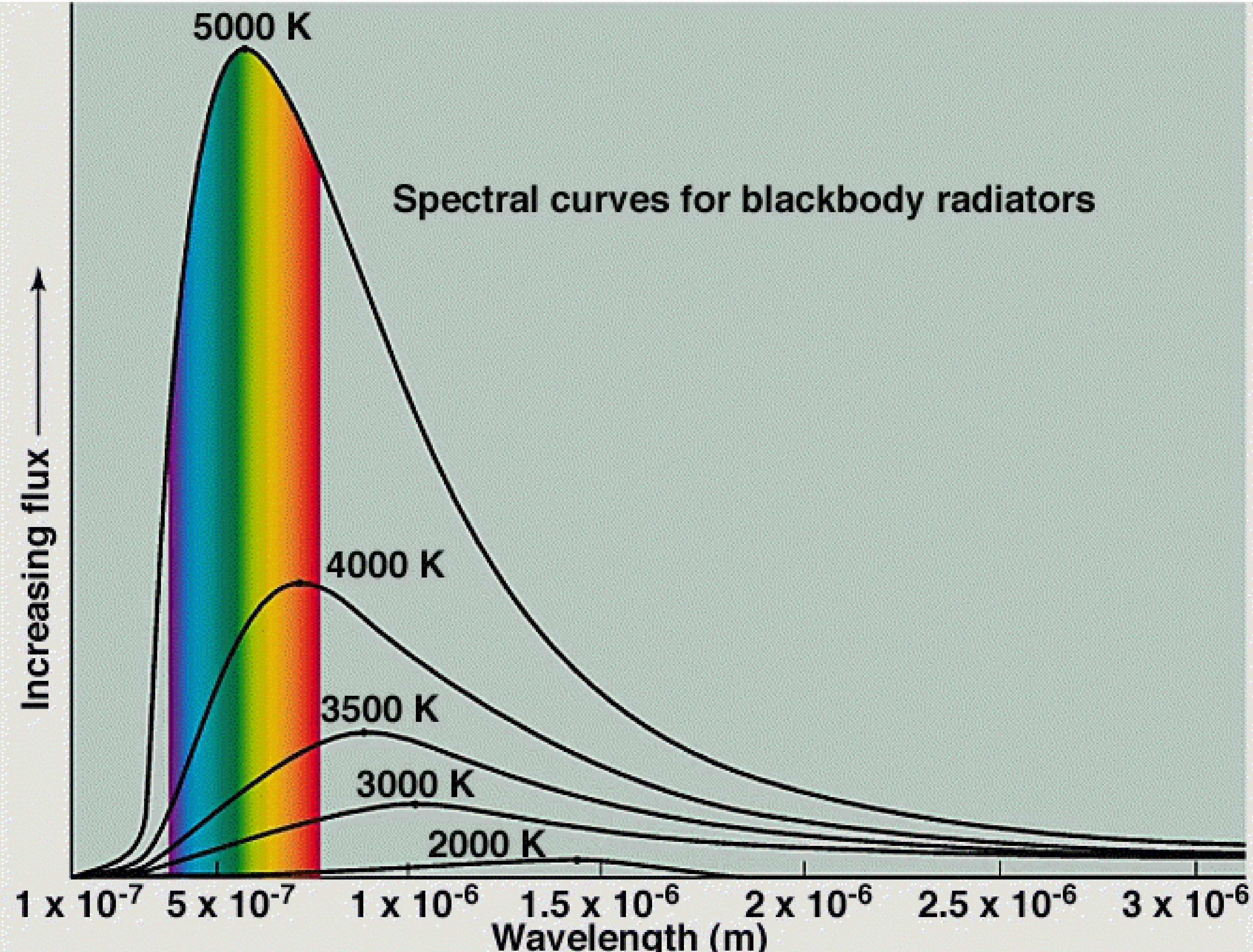
$$E_\gamma = h\nu = hc/\lambda \quad h = \text{Planck's constant}$$

$$\text{(unit of the quantum)}$$

- **Temperature is a measure of energy of the photons**

$$\langle E_\gamma \rangle = h \langle \nu \rangle = k_B T \quad k_B = \text{Boltzmann's constant}$$

$$\langle \cdots \rangle = \text{ average}$$



Spectral curves for blackbody radiators
5000 K
4000 K
3500 K
3000 K
2000 K
Increasing flux
1 x 10^-7
5 x 10^-7
1 x 10^-6
1.5 x 10^-6
2 x 10^-6
2.5 x 10^-6
3 x 10^-6
Wavelength (m)

4. Light is a particle

- **Particles of light are "photons"**
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$$E_\gamma = h\nu = hc/\lambda \quad h = \text{Planck's constant}$$

$$\text{(unit of the quantum)}$$

- **Temperature is a measure of energy of the photons**

$$\left\langle E_\gamma \right\rangle = h\left\langle \nu \right\rangle = k_B T \quad k_B = \text{Boltzmann's constant}$$

$$\left\langle \cdots \right\rangle = \text{ average}$$

- **If wavelength stretched, E decreases, T decreases**

Energy of photons decrease

- **Where does the energy go?**
- **What about conservation of energy?**

Conservation of Energy?

Classical physics: $$\frac{dE}{dt} = 0 \quad \Rightarrow \quad E = \text{constant}$$

energy, momentum, mass

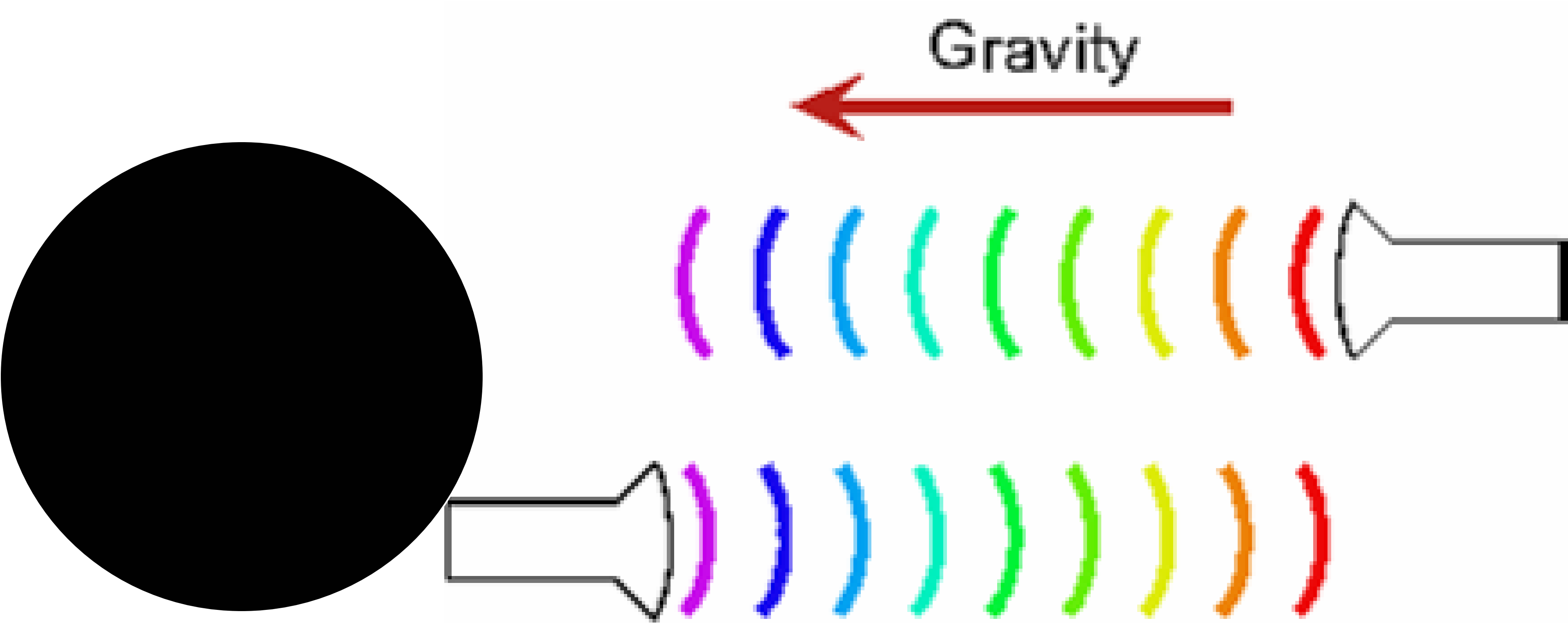
Special relativity:
($E = mc^2$ and all that) $$\frac{dT^{\mu\nu}}{dx^{\mu}} = 0$$

space and time

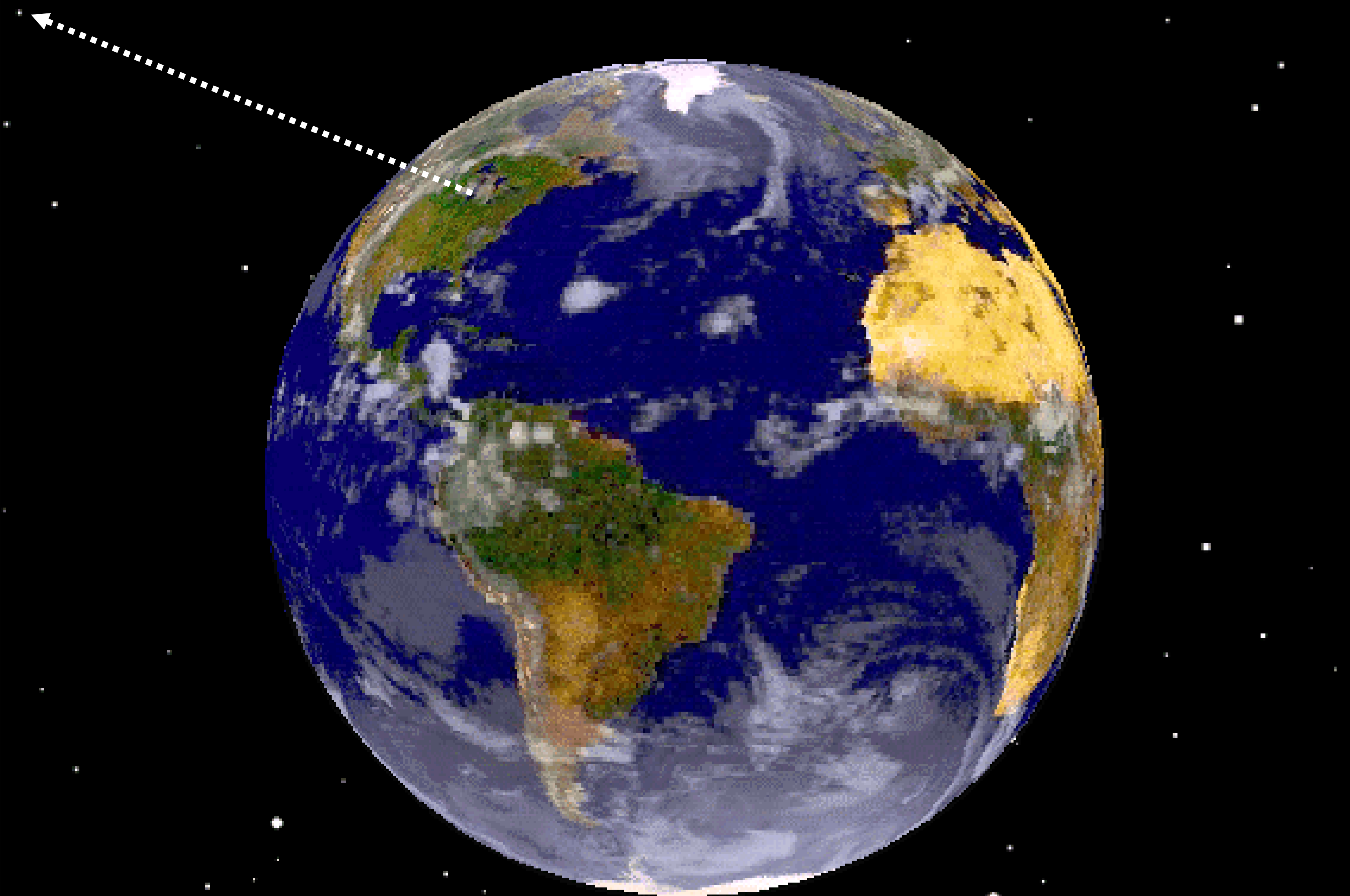
General relativity:
(gravity) $$\frac{dT^{\mu\nu}}{dx^{\mu}} + \Gamma^{\mu}_{\mu\alpha} T^{\alpha\nu} + \Gamma^{\nu}_{\mu\alpha} T^{\mu\alpha} = 0$$

gravity

Gravitational redshift



Gravitational redshift

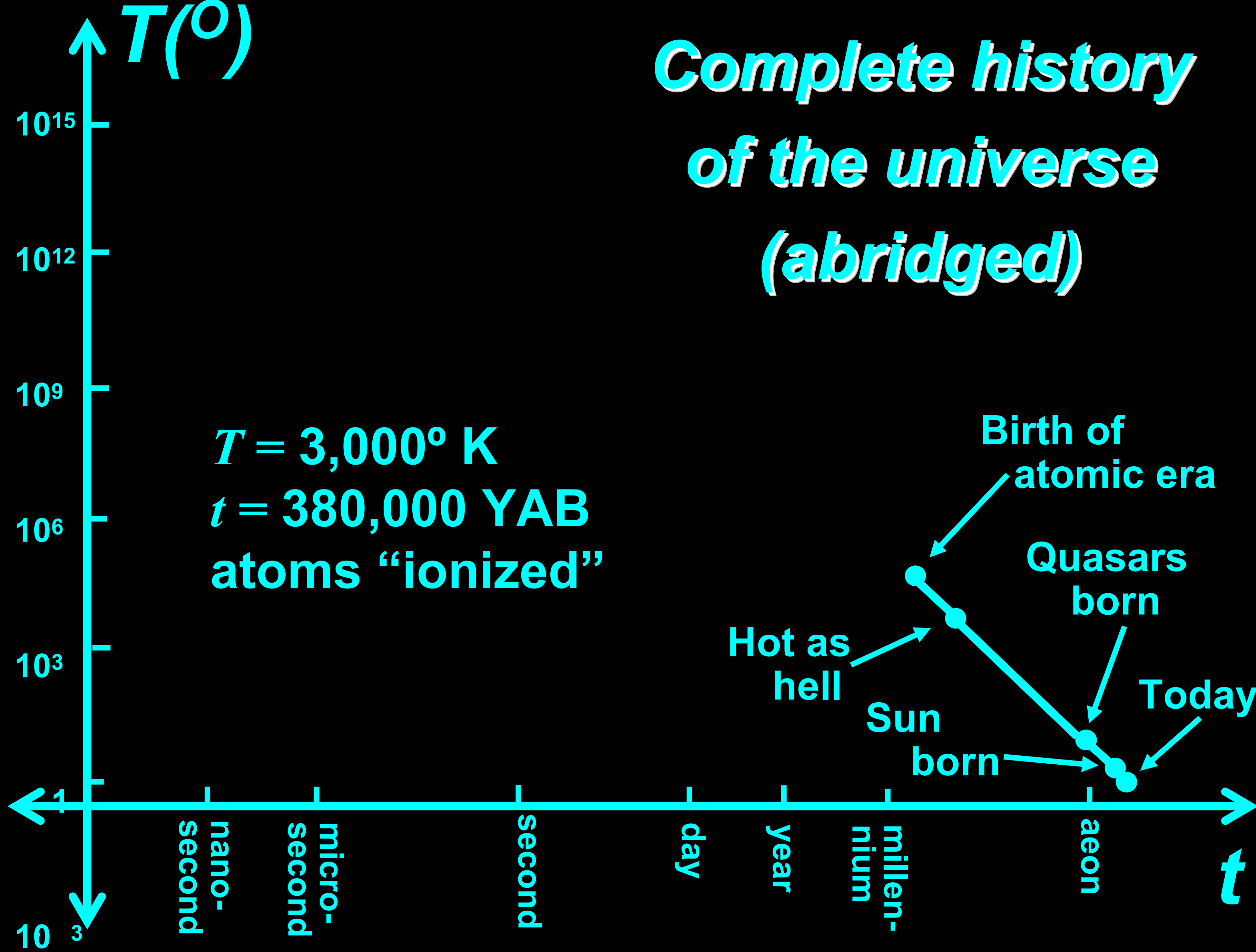


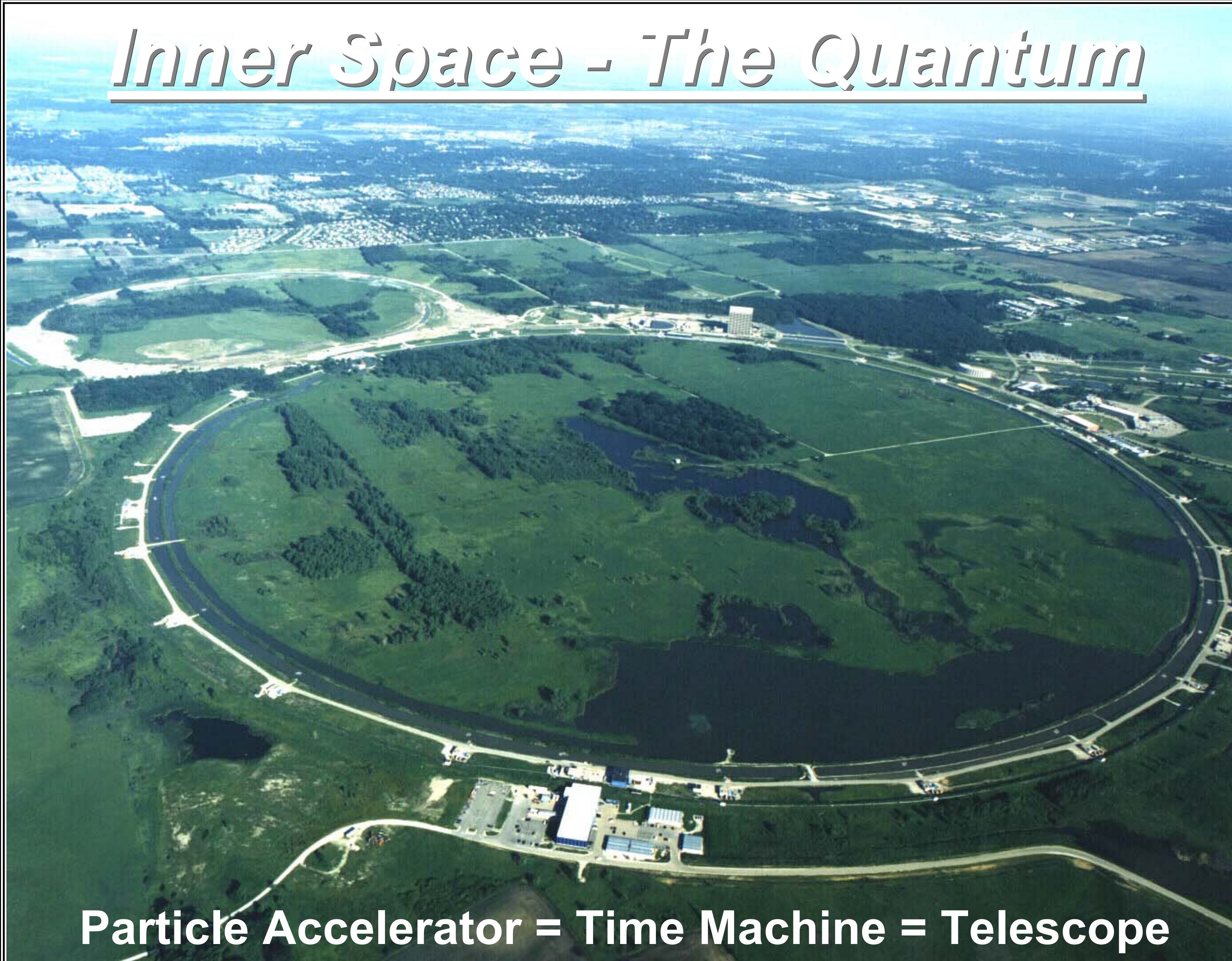
Cosmological Weather Report

- Today T=3K
- Yesterday was hotter!
- Tomorrow will be colder!

Possible future of the universe

Complete history of the universe (abridged)



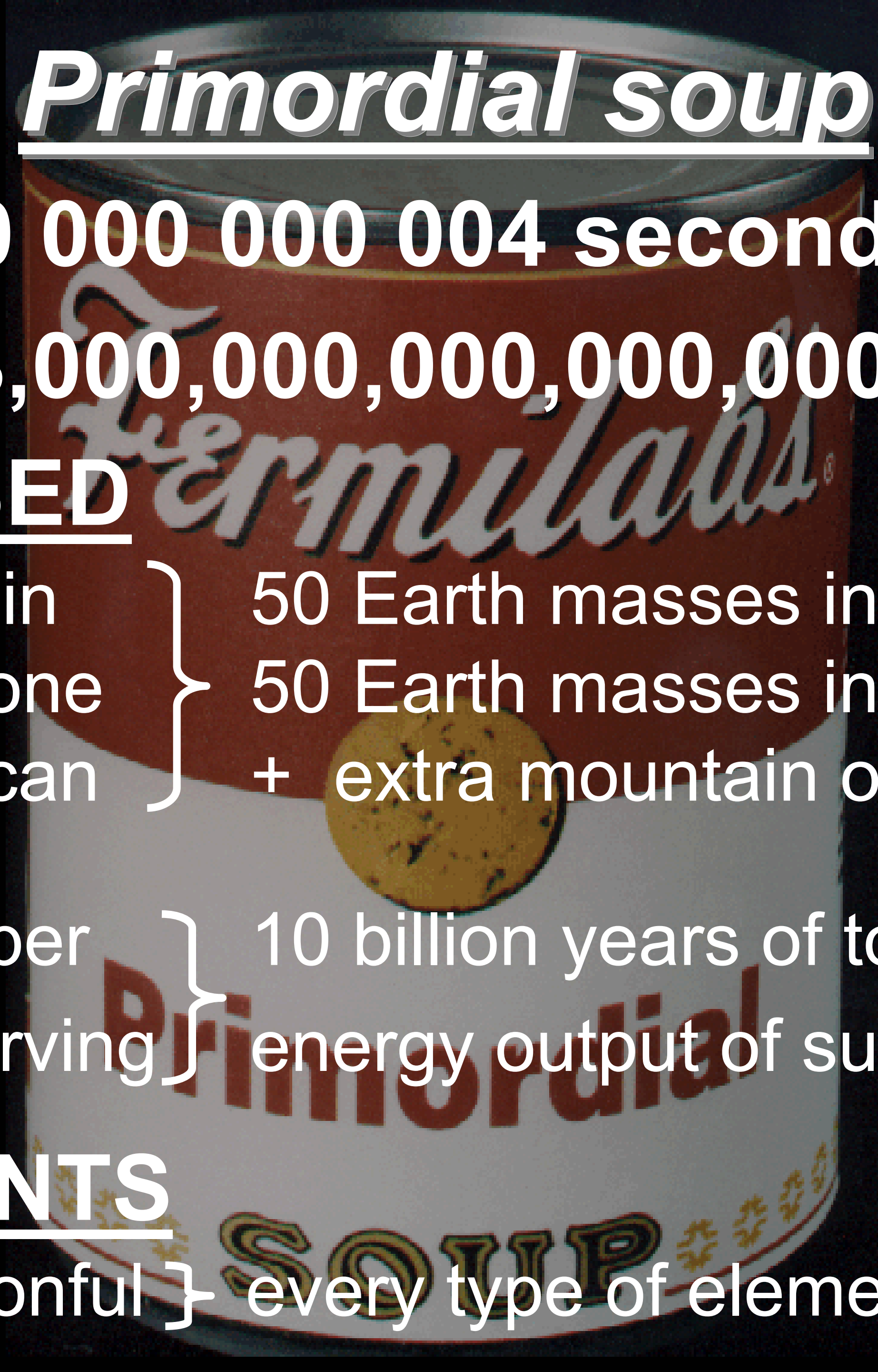

Inner Space - The Quantum
Particle Accelerator = Time Machine = Telescope


Fermilab's
Primordial
SOUP

Primordial soup

0.000 000 000 004 seconds AB

3,000,000,000,000,000°



CONDENSED

in one can } 50 Earth masses in matter
50 Earth masses in antimatter
\+ extra mountain of matter

HOT

per serving } 10 billion years of total energy output of sun

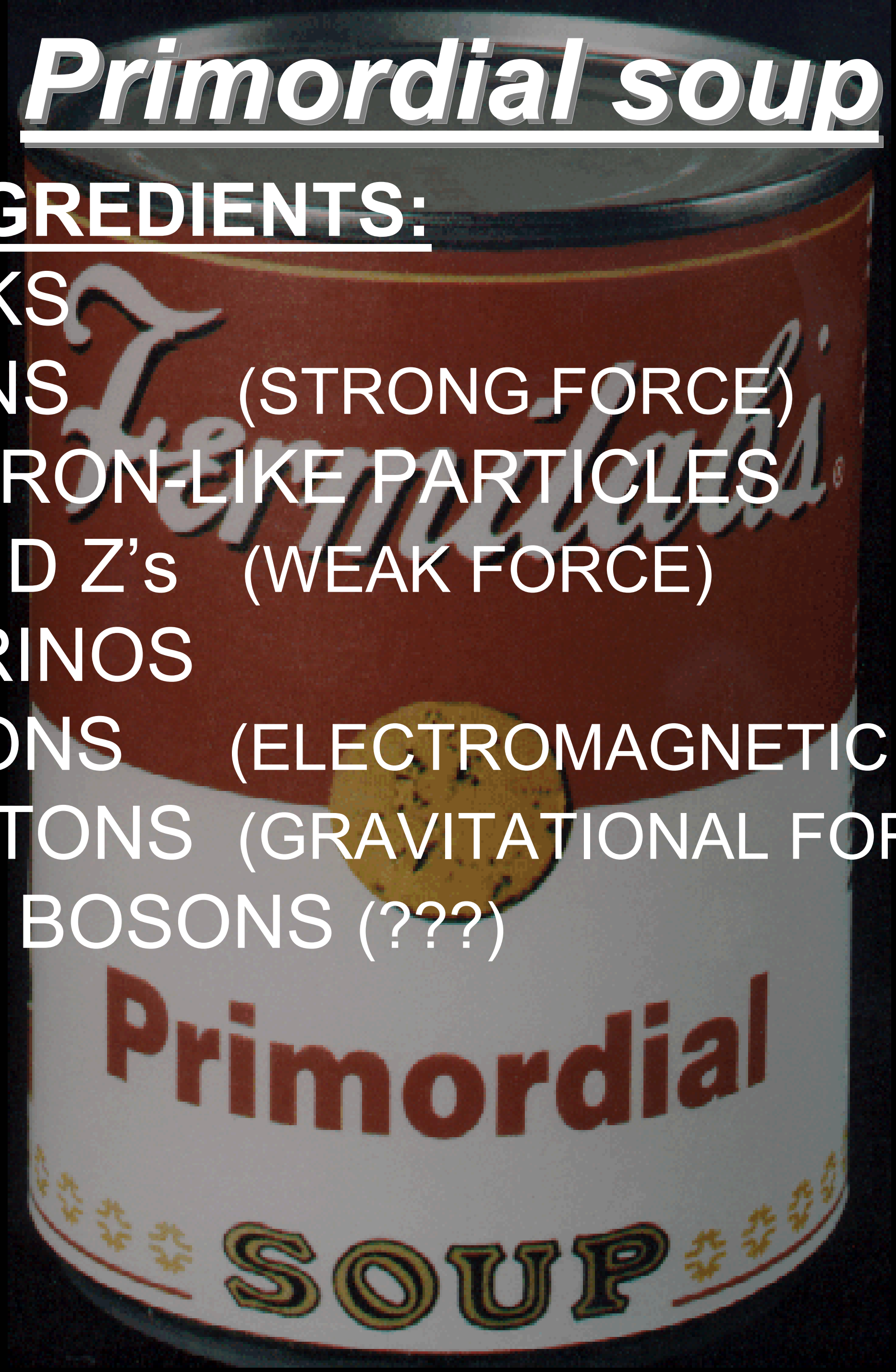
INGREDIENTS

in every spoonful } every type of elementary particle

Primordial soup

KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)



Primordial soup

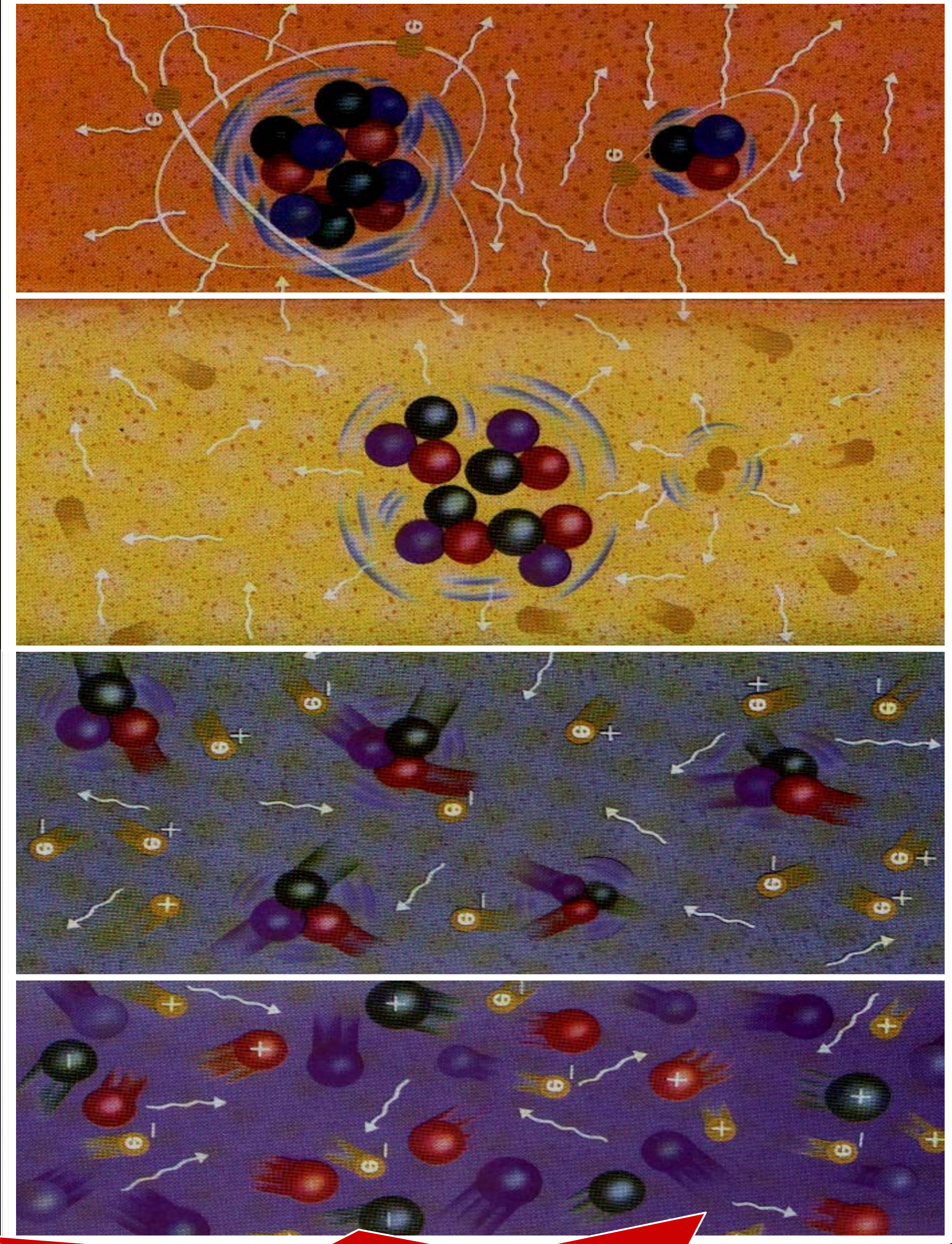
KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)

SECRET INGREDIENT:

DARK MATTER

380,000 years — atoms form



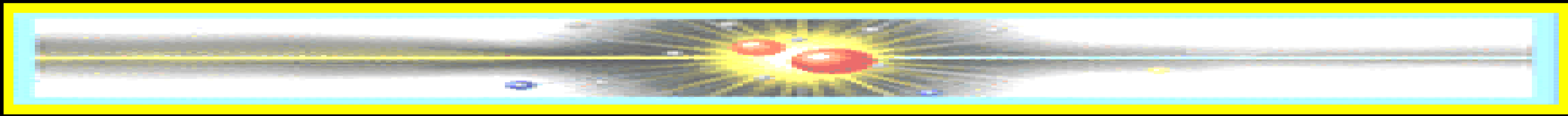
3 minutes — nuclei form

1-micro second — neutrons protons form

4-pico seconds — primordial soup

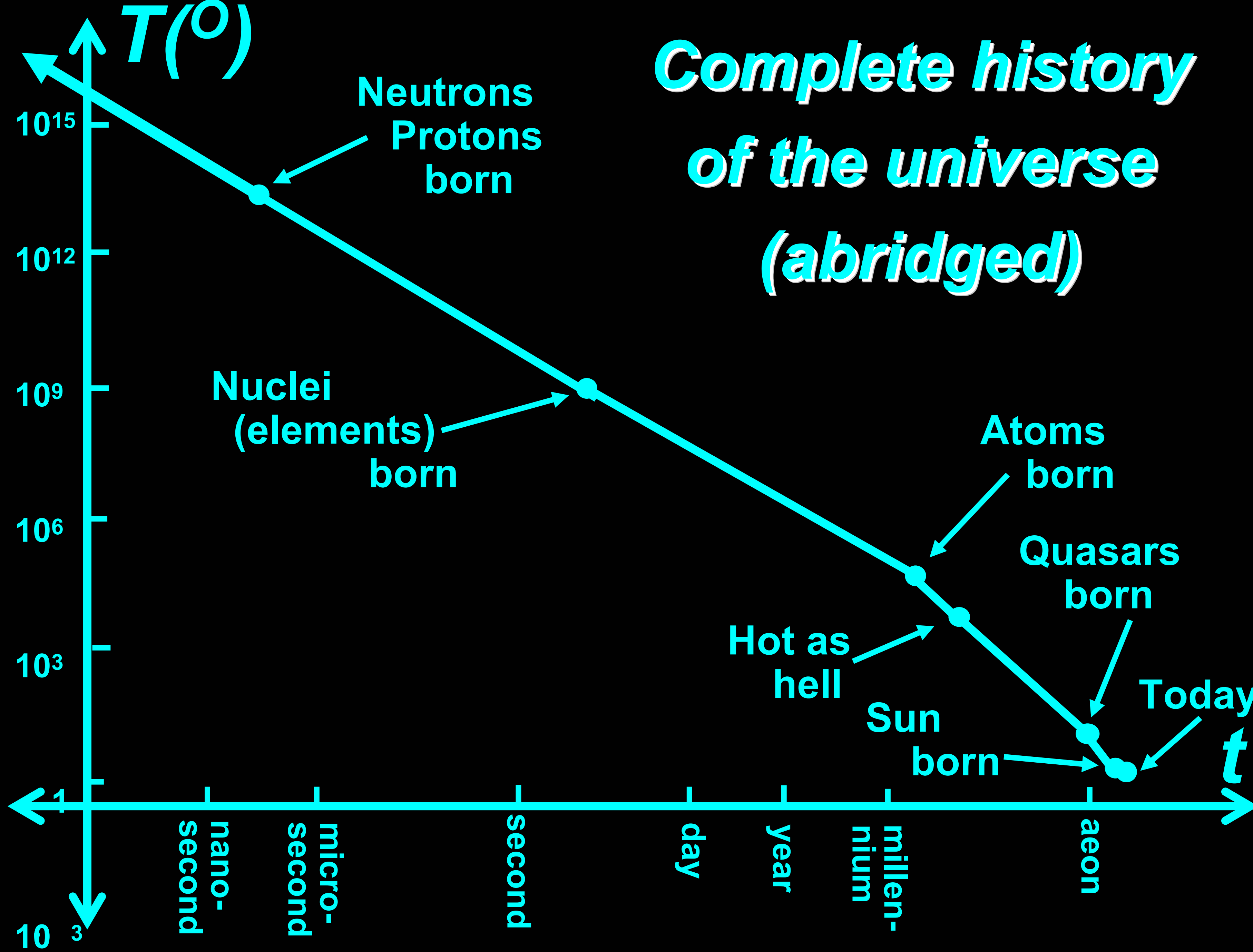
BANG!

EVERYTHING IN THE UNIVERSE

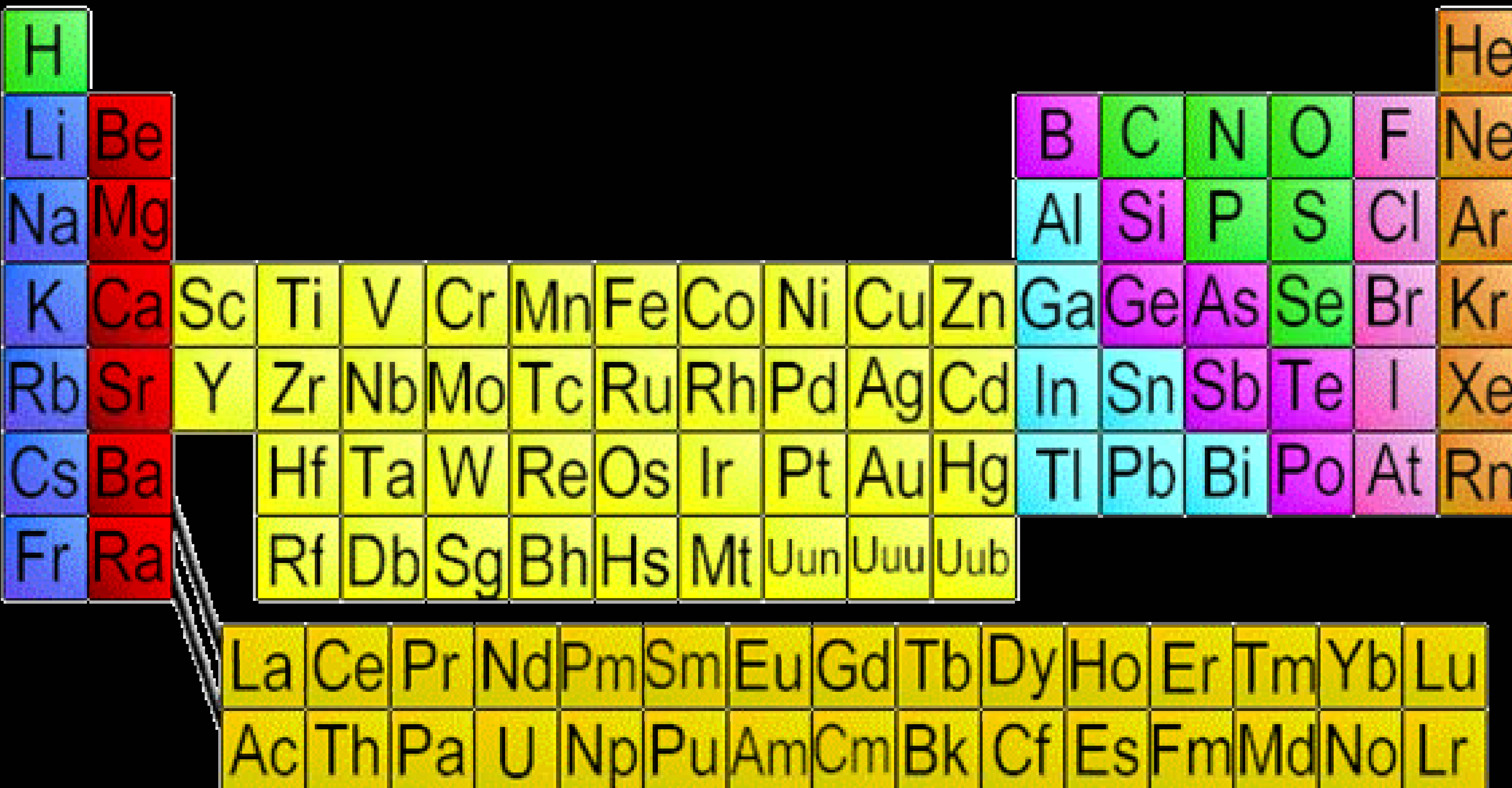


MICROWAVE RADIATION
SUPERCLUSTERS OF GALAXIES
CLUSTERS OF GALAXIES
STARS
PLANETS
PEOPLE
POODLES
PIGEONS
PETUNIAS
POND SCUM
KARL ROVE

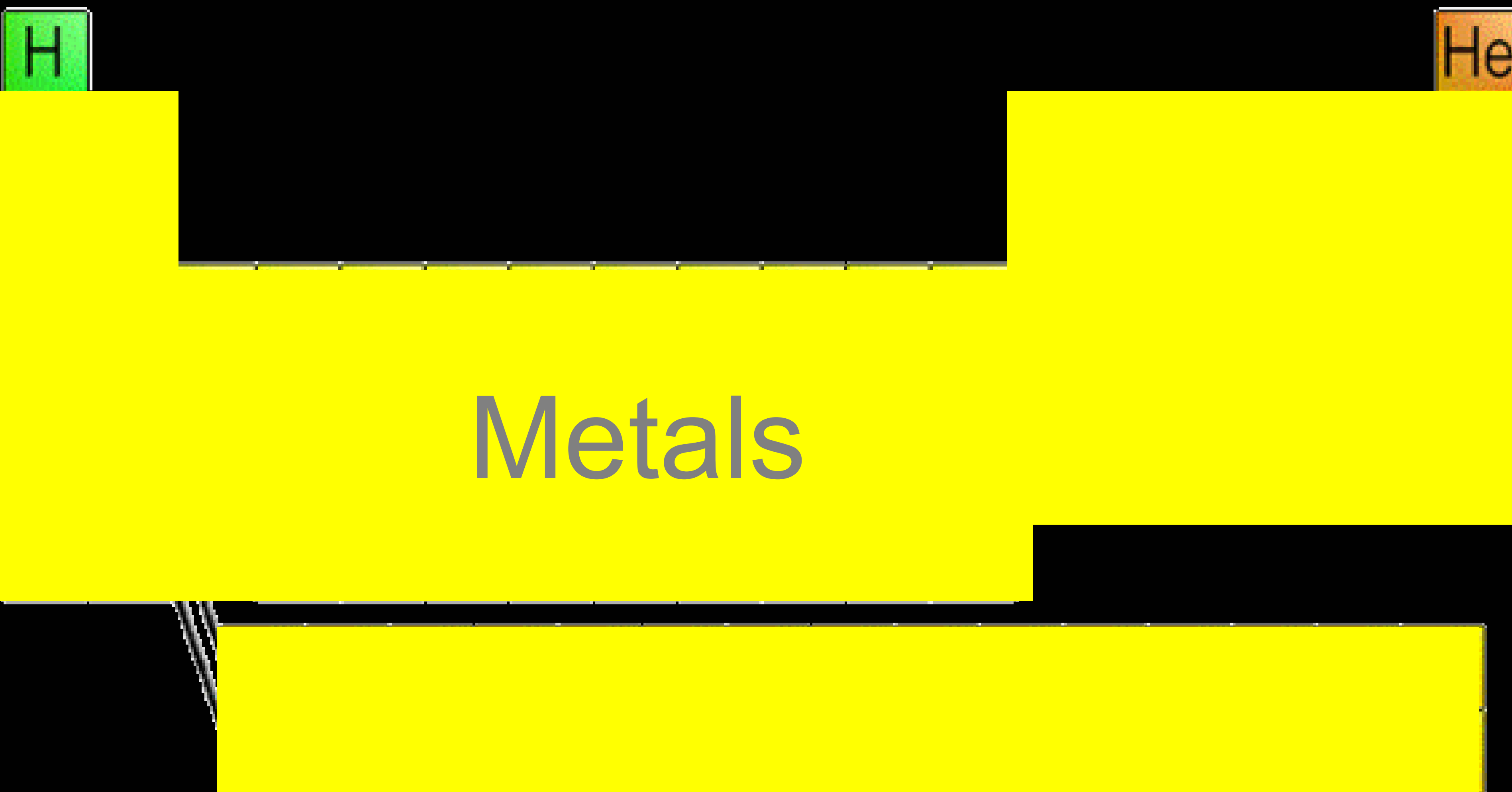
FROM THE PRIMORDIAL SOUP!


Complete history of the universe (abridged)
T(O)
10^{15}
10^{12}
10^{9}
10^{6}
10^{3}
1
10^{3}
Neutrons Protons born
Nuclei (elements) born
Atoms born
Hot as hell
Quasars born
Sun born
Today
t
nano-second
micro-second
second
day
year
millen-nium
aeon

Periodic table - chemist



Periodic table - cosmologist



The Universe today:

73% Hydrogen (10^{-5} ^{2}H-deuterium)
26% Helium (10^{-5} ^{3}He)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} ^{2}H- deuterium)
24% Helium (10^{-5} ^{3}He)
10^{-8}% Lithium

Nucleosynthesis

…the process of assembling nuclei either by nuclear fusion or nuclear fission.