hi

Lecture 20, 23.03.2017

Cosmology 4, 2 & QM 1

housekeeping

Question about anything?

I'll make a movie for you:

Marie Curie movie anyone?

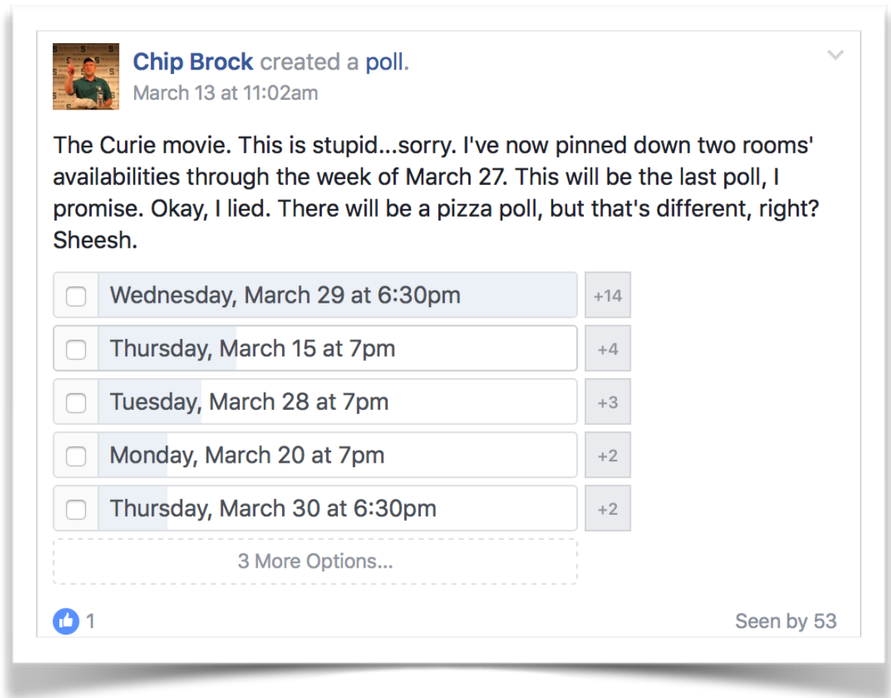
March 29: 6:30pm, BPS 1400

I'll poll for pizza this week

FakeFacebook is due April Fools Day. tee hee

Blog read-reflect project has started.

Did you notice that the homework is in MasteringAstronomy?



Honors Project

has begun. First milestone was last Friday.

Read the Second of two sets of instructions:

`MinervaInstructions2_2017.pdf` in

www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/honors_project_2017/

MasteringAstronomy

free and use of the textbook:

The Essential Cosmic Perspective, Bennett, Megan Donahue, Schneider, Mark Voit

http://www.pearsonmylabandmastering.com/northamerica/masteringastronomy/

Course ID is ISP220SP17

"code" is WSSPCT-SNELL-NAMEN-WEIGH-METIS-NJORD

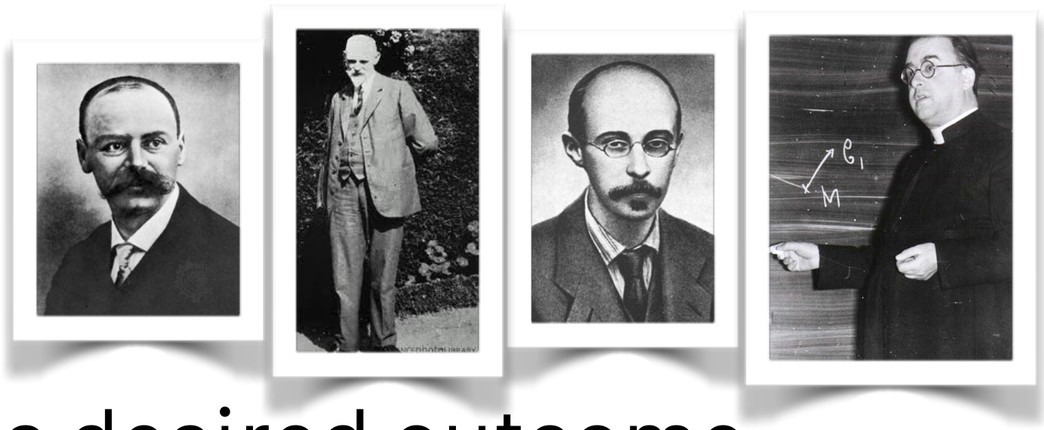
Cosmology 4

Einstein had immediate with GR

nope

…s solutions were the only ones

$$G = T$$



nope

…is cosmology would produce his desired outcome:

a spherical universe

a stable universe

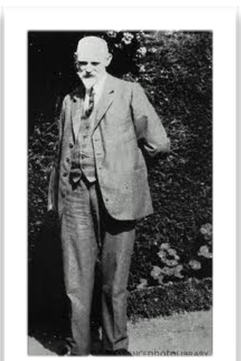
$$G + \Lambda = T$$

"cosmological constant"

nope

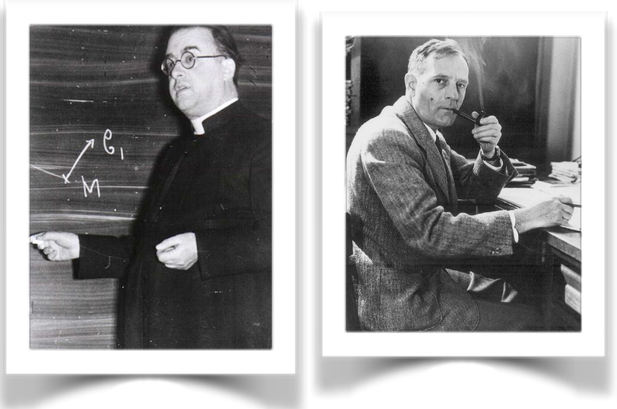
…rely, mass was required in order to create gravity

$$G + \Lambda = 0$$



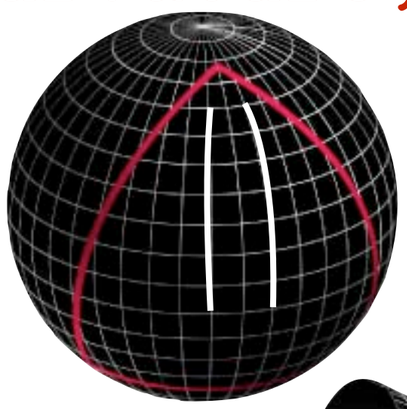
nope

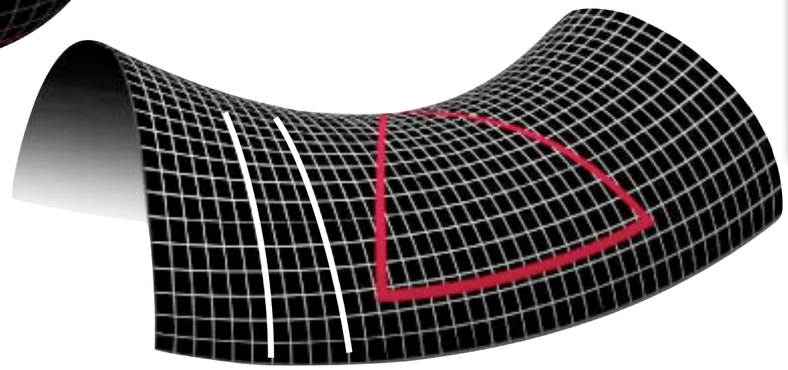
…urely, the universe is stable?



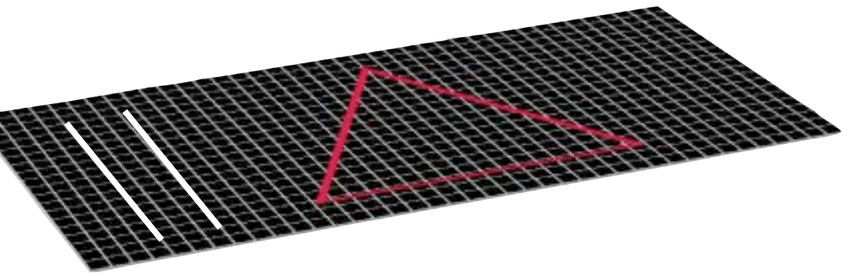
curvature, “k” - hypervolumes

$k = +1$,
positive curvature
finite, unbounded





$k = 0$, no curvature
infinite, unbounded



$k = -1$, negative curvature
infinite, unbounded

is impossible to visualize the negative curvature 3d shape...
it’s like a saddle, or mmm
mmm good
Pringles Potato HyperChips

A mathematical fact:
These 3 are the only geometries that can be both homogeneous and isotropic

Hubble used Leavitt's formulation

Cepheids were everywhere!

were "nebulae" in the Milky Way?

or, is the universe much bigger?

M31, Andromeda

2900 thousand light years

1924: Andromeda is its own galaxy

A famous public argument ended.

The universe became HUGE... **overnight**!

M33, Triangulum

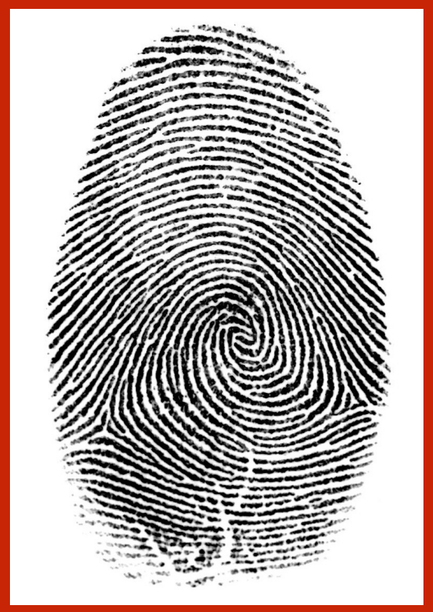
3000 thousand light years

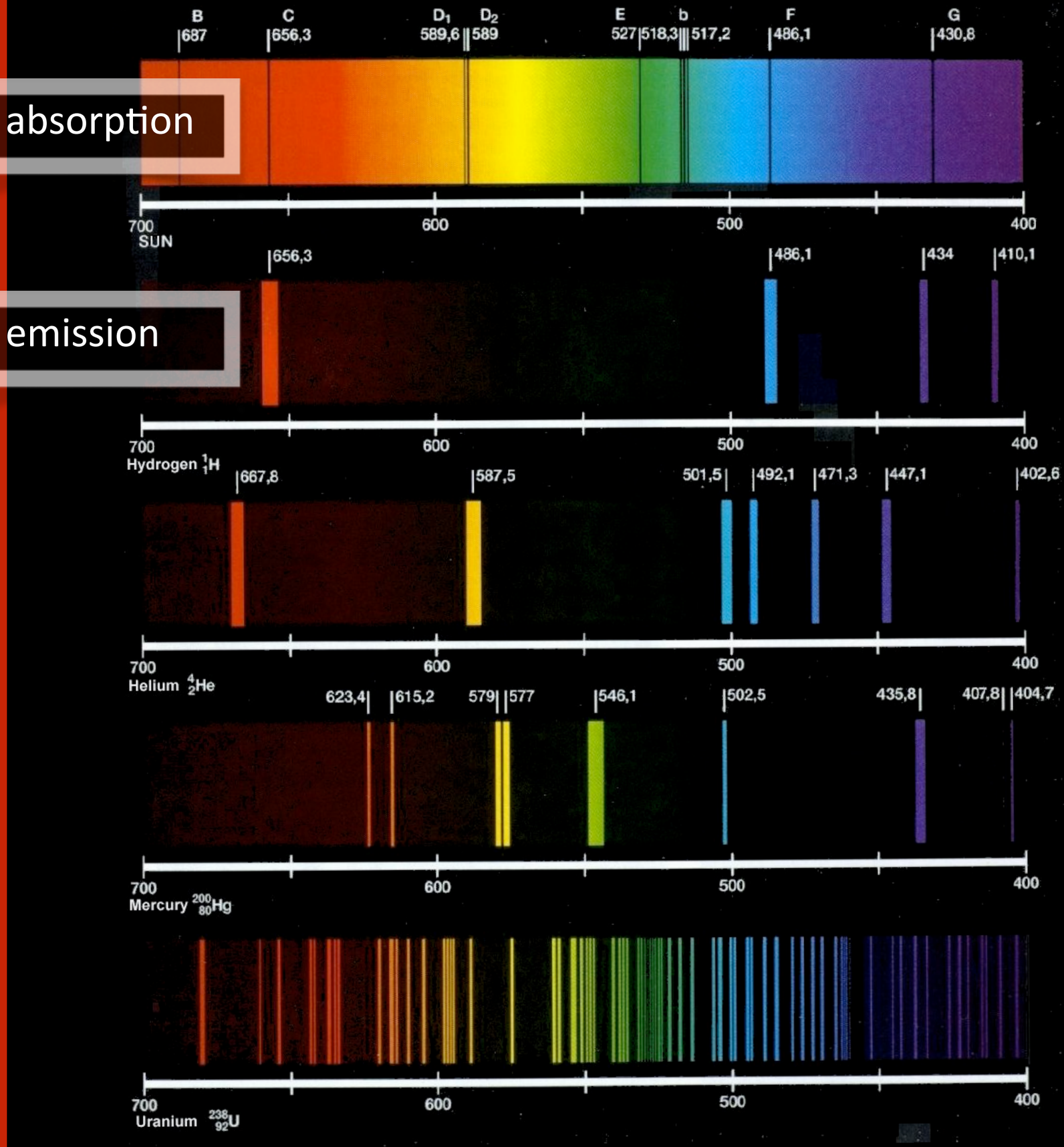
NGC 6822, Barnard's Galaxy

1700 thousand light years

atomic spectra

unique fingerprint of the atomic species





http://www.ruf.rice.edu/~mcannon/Research%20Home/Research%20Home.htm

Hubble used

the finger-print tool of spectroscopy

plus

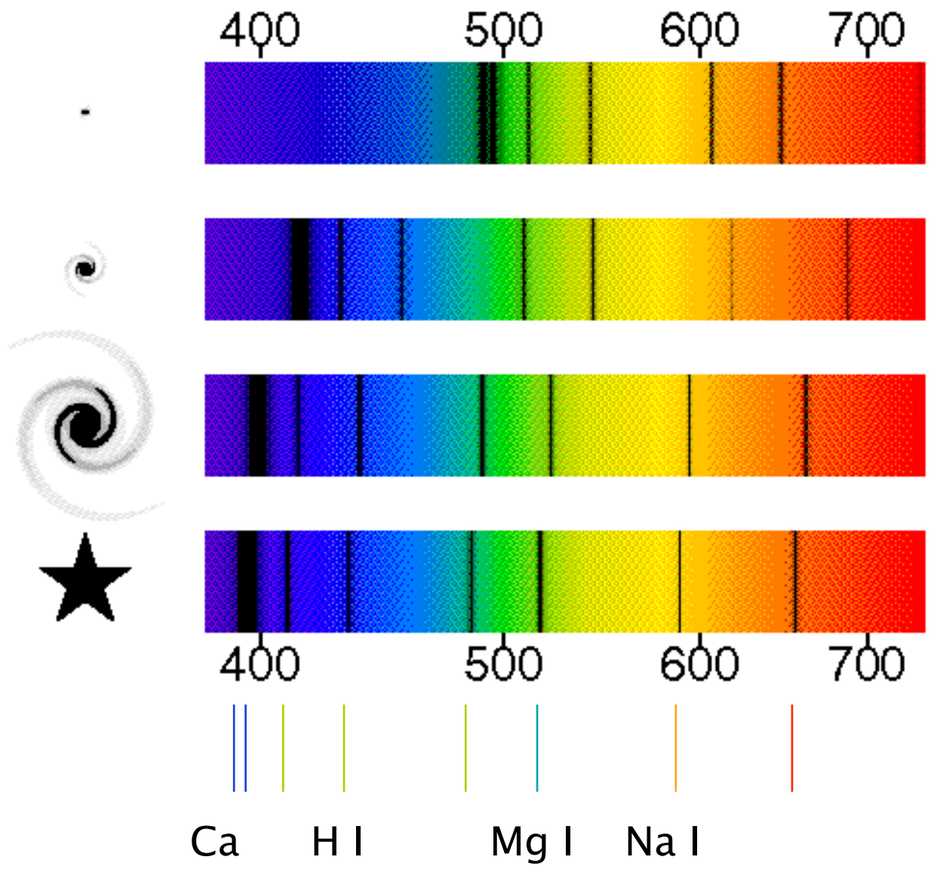
the distance determination tool of Cepheid Variables

His results:

Wavelengths shifted to longer - "**redshifted**"

meaning all of his galaxies seemed to be moving away from us

eg, seemingly, Doppler shifts at work:



http://www.astro.ucla.edu/~wright/doppler.htm

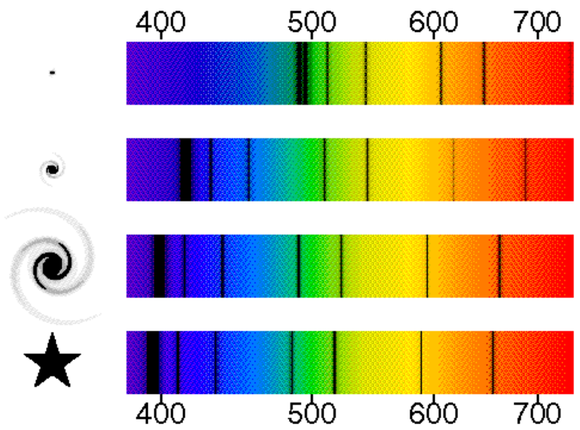
relation alert: **Hubble's Law**

refers to: $$v = rH$$

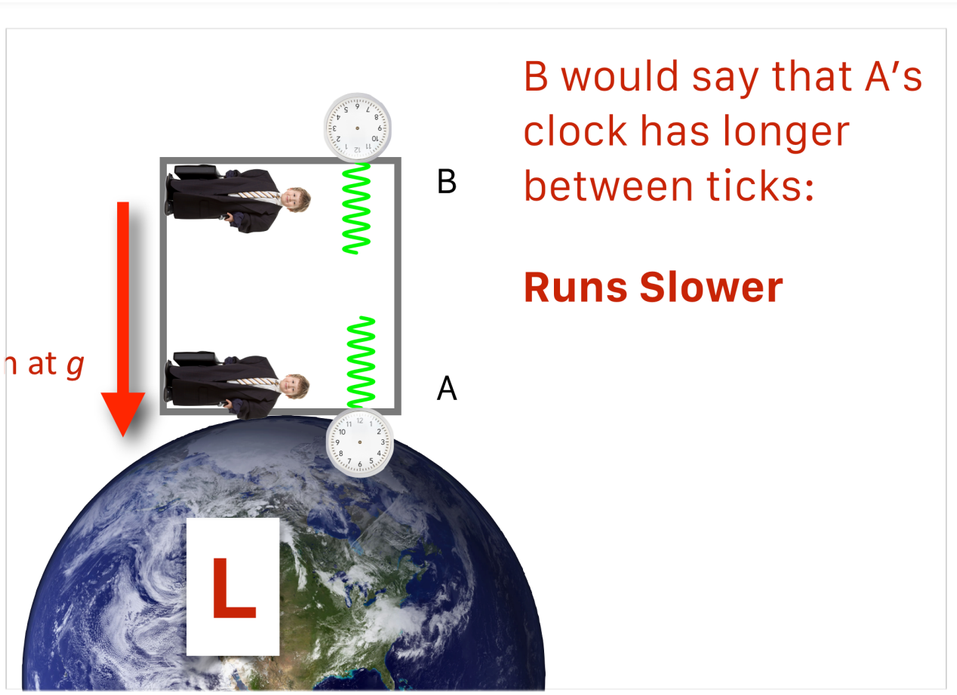
example:

Speed of a galaxy is proportional to the distance away from any point.

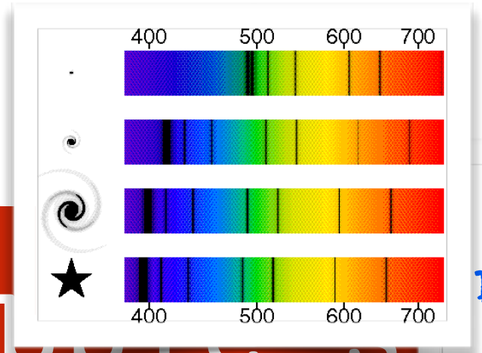
galaxy NGC1832 is 9.57 x 10^{20} km away, so Hubble's Law says it would be moving at v = 2150 km/s



Hubble's observation are not these:



Hubble's



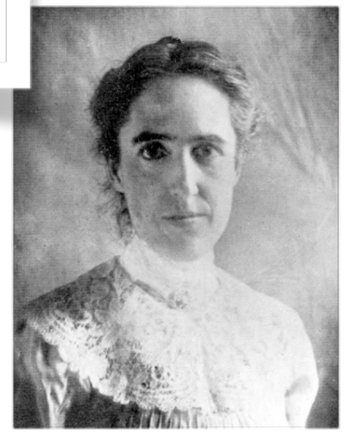
FROM PRESUMED DOPPLER-SHIFTED SPECTRA

HUBBLE'S CONSTANT = 1/T

H: a measure of the time a galaxy has been "traveling"

$$v = rH$$

It's a little tricky... Think Balloons.



FROM LEAVITT'S CEPHEID VARIABLE RELATION

constant of nature:

Hubble “Constant”

value: H_0 = 67.8 +/- 0.9

units: (km/s)/Mpc (1Mpc = 3 x 10^{22}m) so H_0 = 2.26 x 10^{-18} s^{-1}

usage: **fundamental** measurable in experimental cosmology

How old is the universe?

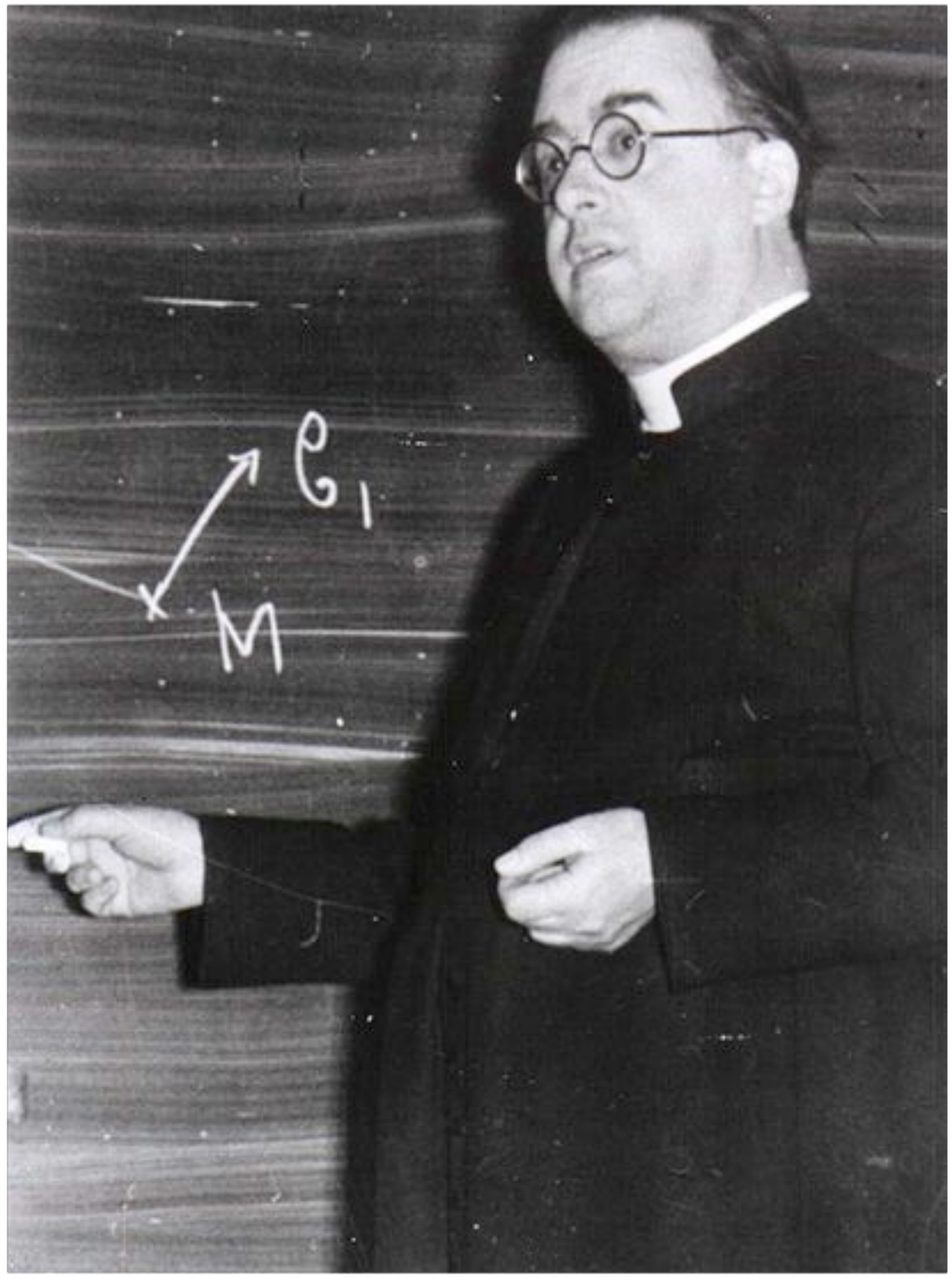
How fast are you expanding from me?

can estimate!

Georges Lemaître (1894-1966)

The father of the Big Bang

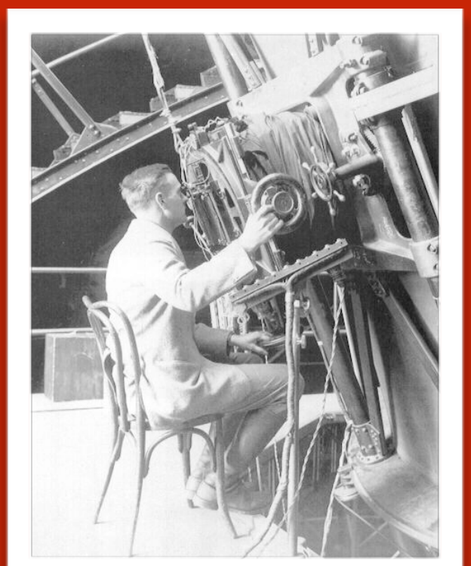
get it?



Lemaître was the first to realize that Hubble had demonstrated:

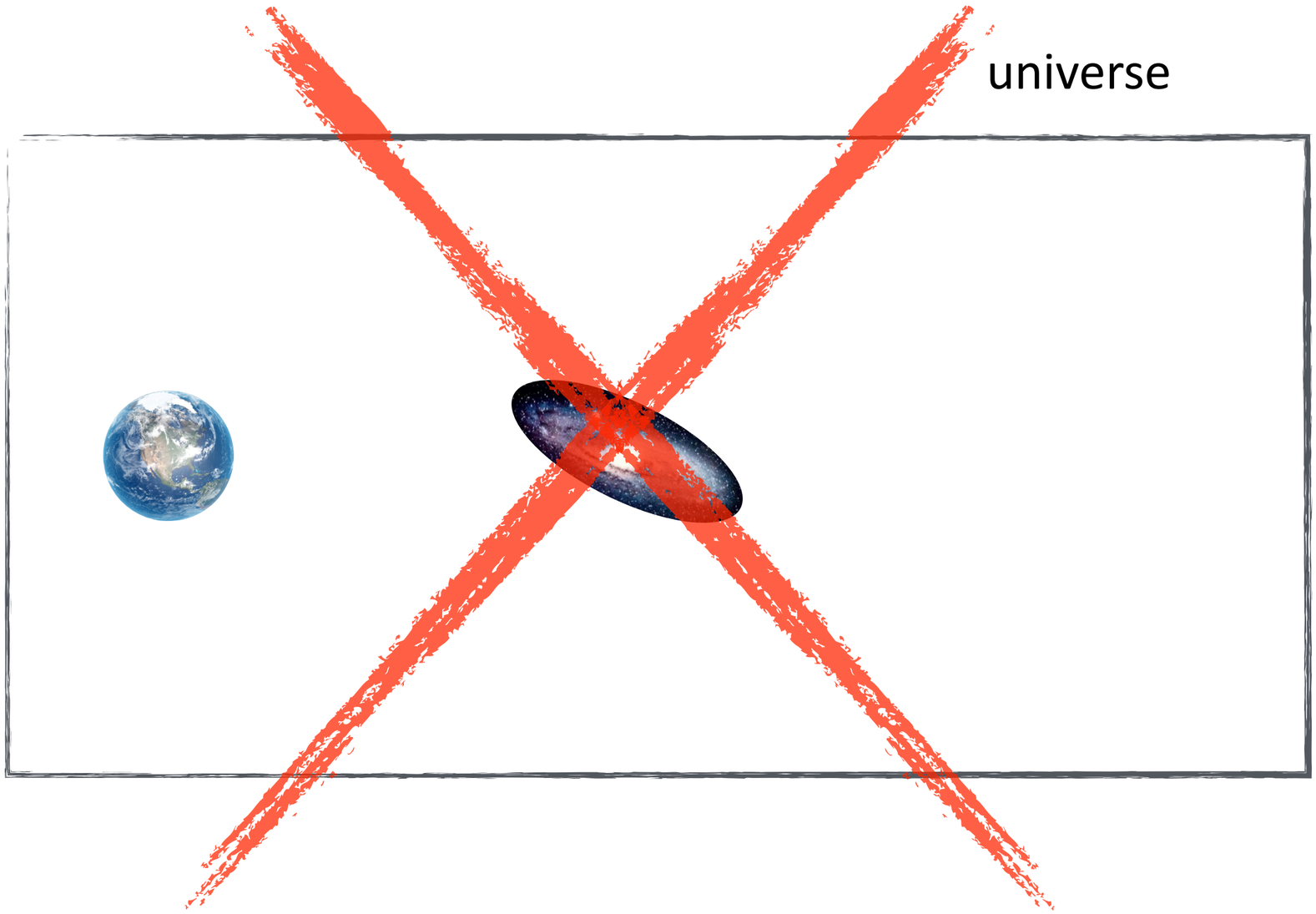
1. spacetime is stretching

The entire kit and caboodle is expanding



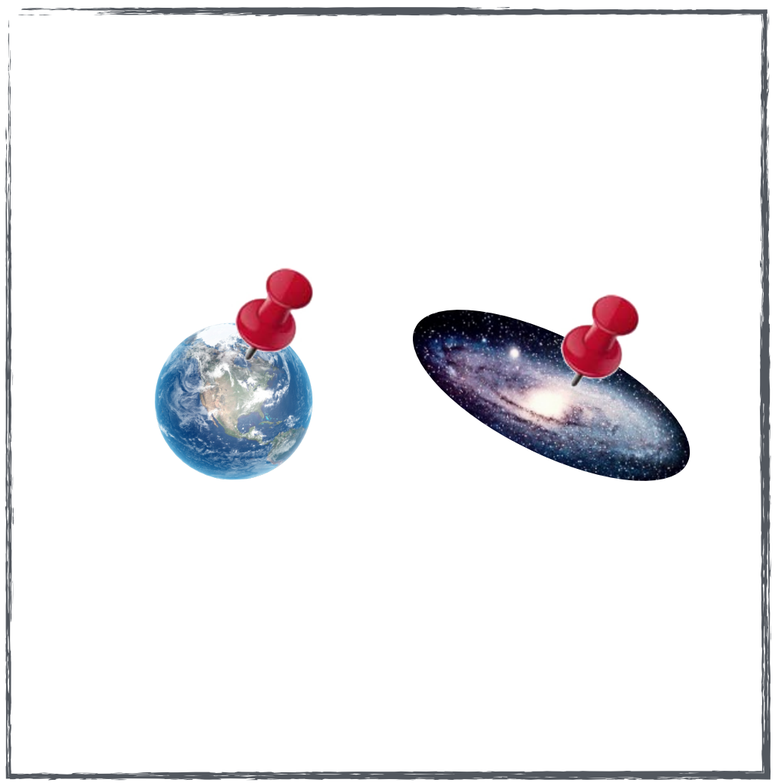
galaxies are not ‘‘moving away’’

inside of the universe



what stretching DOES mean

is complicated!



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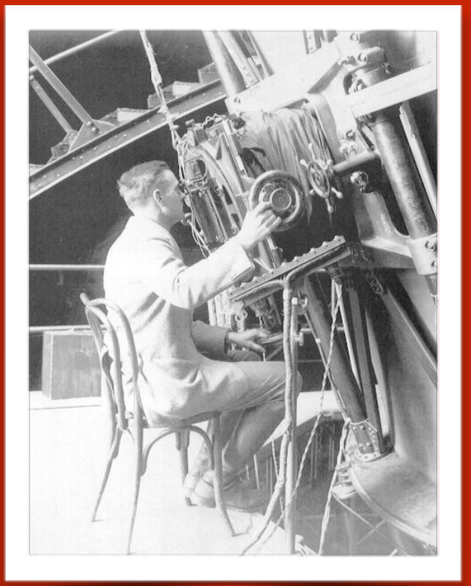


1. spacetime is stretching

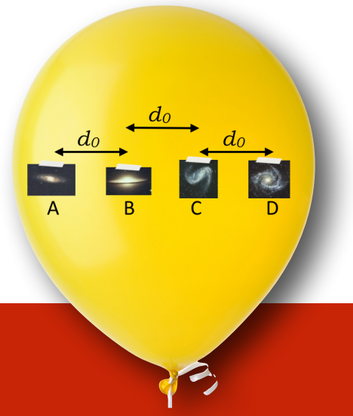
The entire kit and caboodle is expanding

2. But then he realized that the current Universe could have come from something smaller

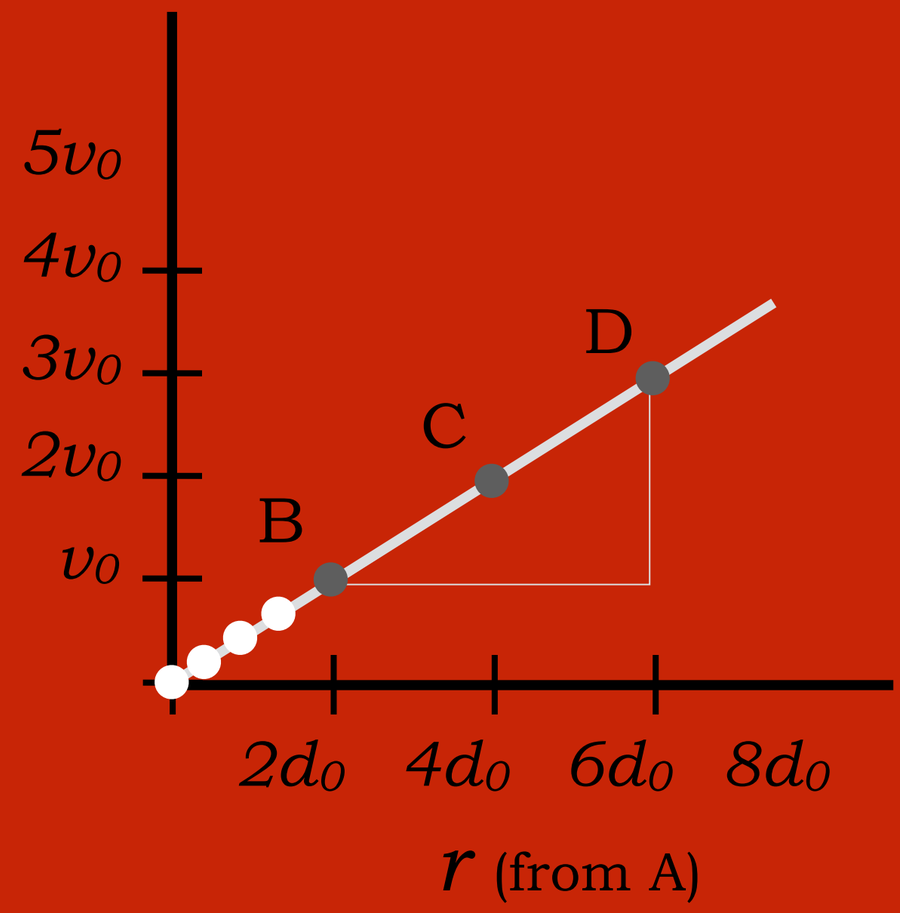
and still smaller

and still smaller

until.



blink



> We can compare space-time to an open, conic cup...The bottom of the cup is the origin of atomic disintegration; it is the first instant at the bottom of space-time, the now which has no yesterday because, yesterday, there was no space.

George Lemaitre, The Primeval Atom

Lemaître envisioned

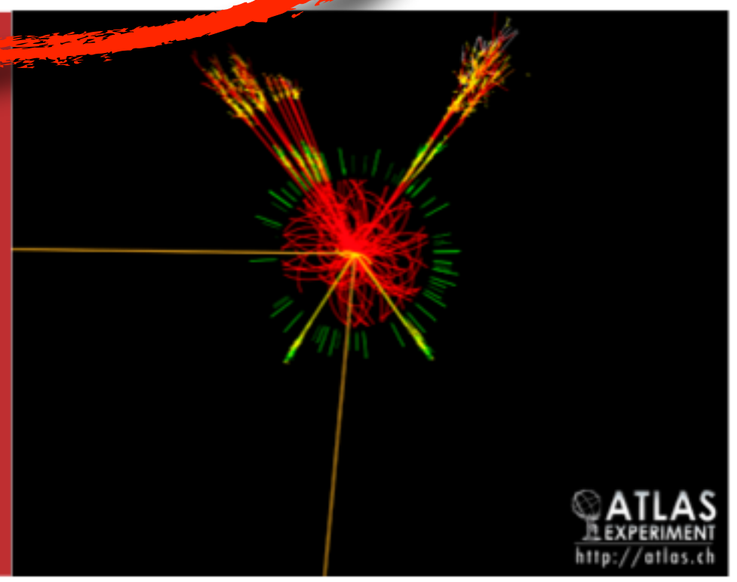
A “primeval atom”

it was the heady times of quantum mechanics and early nuclear physics

He envisioned a fissioning of a big, big nucleus

QUARKS, SPACETIME, and the BIG BANG

spring term 2012



A simulated Higgs Boson event as it might appear inside of the ATLAS detector at the Large Hadron Collider.

think about this.

a Catholic Priest-Theoretical Physicist

envisioning the beginning of the Universe...a "creation story"?

Sir Arthur Eddington states that, philosophically, the notion of the beginning of the present order of Nature is repugnant...I would rather be inclined to think that the present state of quantum theory suggests a beginning of the world very different from the present order of Nature.

“

Lemaître: Nature

comment May 9, 1931

Was his theology in the way of his science?

No.

He was explicit in his separation of the science and his faith

And, the respect that his colleagues held for him

did not result in accusations of him pushing his religion into Cosmology

undercut

Lemaître had been very careful

to not mix religion and science

Imagine his panic

when 1951 “Study Week” the Pious XIII made a statement:

> . . . contemporary science, with one sweep back across the centuries, has succeeded in bearing witness to the august instant of the primordial Fiat Lux, which along with the matter there burst forth from nothing a sea of light and radiation . . . Thus, with that concreteness which is characteristic of physical proofs, modern science has confirmed the contingency of the universe and also the well-founded deduction to the epoch when the world came forth from the hands of the creator.

Pious XIII, Un'Ora,1951

Whoa. Lemaître was stunned.

Science and religion to him: two completely different paths

As far as I can see, such a theory remains entirely outside any metaphysical or religious question. It leaves the materialist free to deny any transcendent Being. [1]

We may speak of this event as of a beginning. I do not say a creation.
Physically it is a beginning in the sense that if something happened before, it has no observable influence on the behavior of our universe, as any feature of matter before this beginning has been completely lost by the extreme contraction at the theoretical zero.
Any preexistence of the universe has a metaphysical character. Physically, everything happens as if the theoretical zero was really a beginning.
The question if it was really a beginning or rather a creation, something started from nothing, is a philosophical question which cannot be settled by physical or astronomical considerations. [2]

[1] Solvay Conference 1958

[2] quoted in: Godart and Heller, Cosmology of Lemaître, 67

Lemaître

WWII was hard on Belgium

after the war, Lemaître did not go back to first-principle cosmology

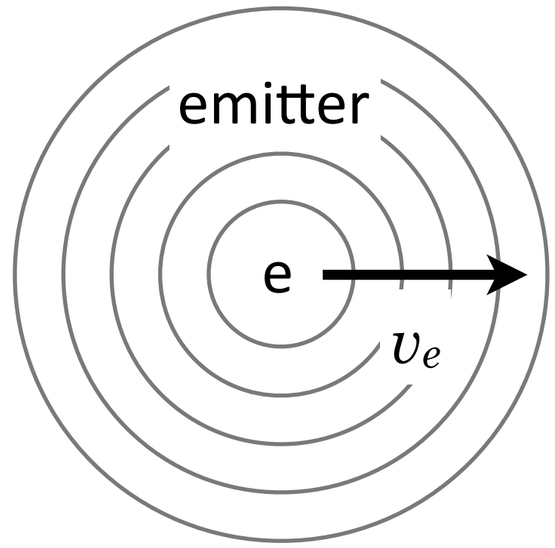
but he pioneered scientific computing on cosmological parameters before anyone in the 1950’s

Like Copernicus

Within days of his death, Lemaître learned of Penzias and Wilson’s discovery of the cosmic microwave background consistent with the Big Bang

June 20, 1966

red shift…5¢ version



"Relativistic Doppler shift"

$$z \equiv \frac{\Delta\lambda}{\lambda_e} = \frac{\lambda_O - \lambda_e}{\lambda_e}$$

z measures the stretchiness of space

z is called the "redshift"

related to the recession velocity:

$$z = \sqrt{\frac{1+\beta}{1-\beta}} - 1 \qquad \beta = \frac{v_e}{v}$$

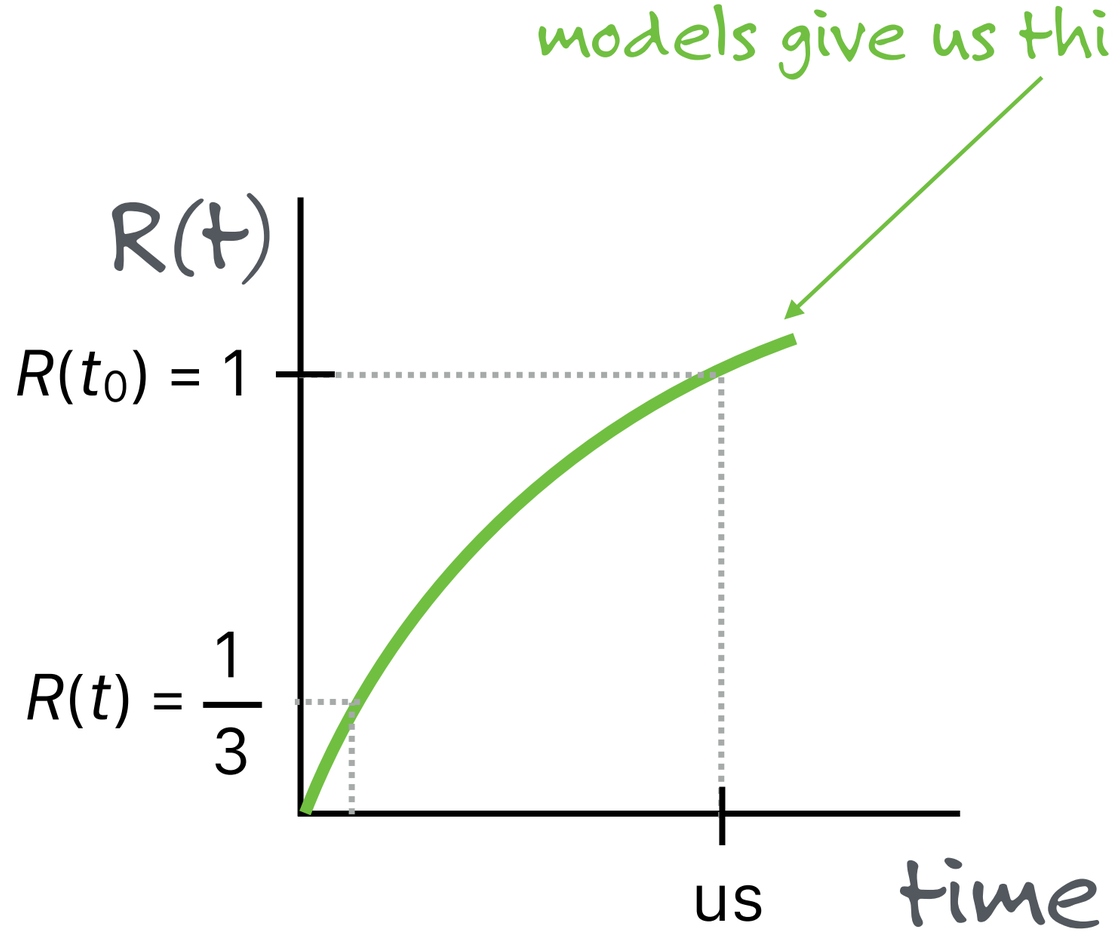
s t r e t c h i n e s s

$$z \equiv \frac{\Delta\lambda}{\lambda_e} = \frac{\lambda_O - \lambda_e}{\lambda_e}$$

$$\ldots \quad z + 1 = \frac{\lambda_0}{\lambda_e} = \frac{R(t_0)}{R(t)}$$

$\underbrace{\qquad\qquad}$

measurable

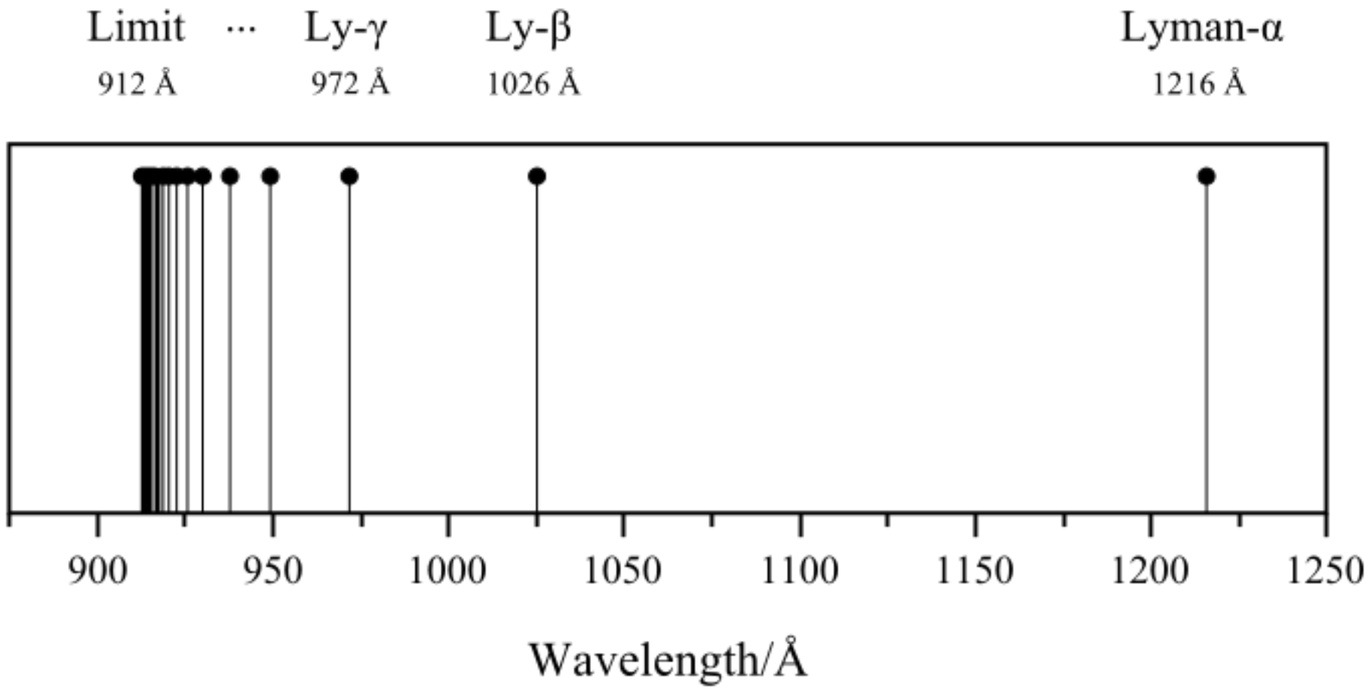


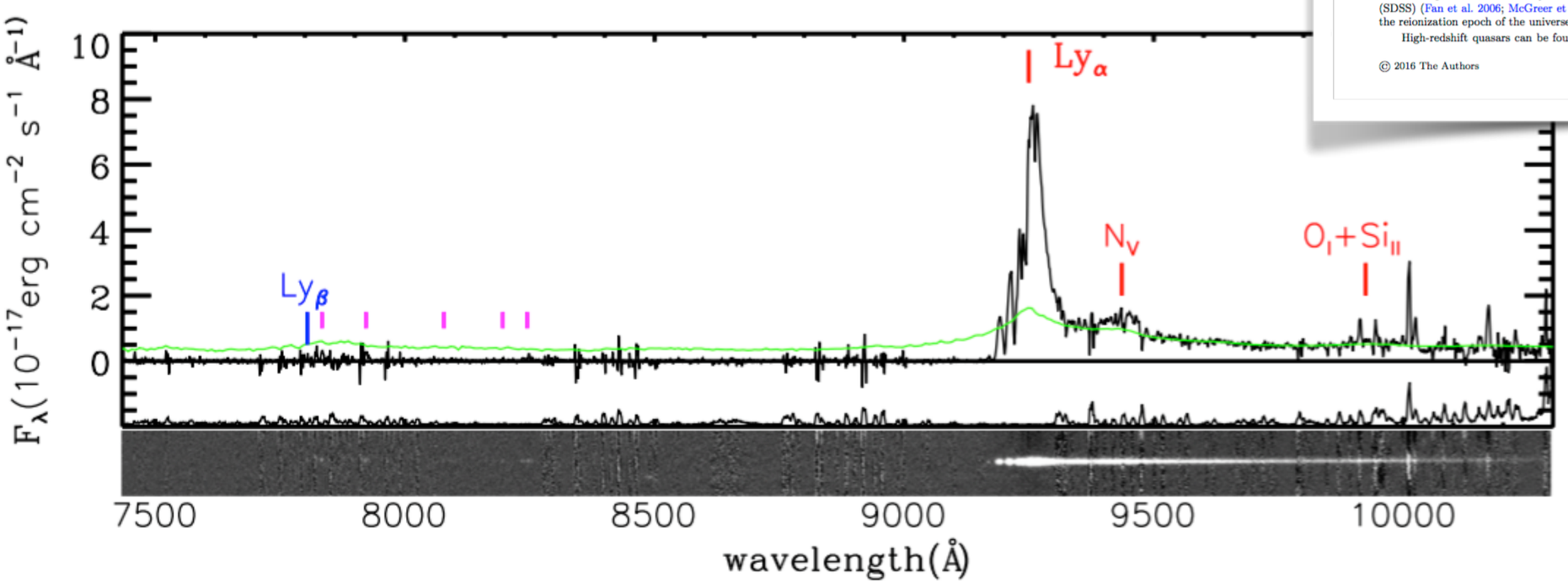
suppose light from a galaxy is observed
@ wavelength 4 times emitted

we'd say: it has a "redshift of 3"

example

J006.1240+39.2219





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A Quasar Discovered at redshift 6.6 from Pan-STARRS1

Ji-Jia Tang[1,2],Tomotsugu Goto[3], Youichi Ohyama[2], Wen-Ping Chen[4], Fabian Walter[5], Bram Venemans[5], Kenneth C. Chambers[6], Eduardo Bañados[7,†], Roberto Decarli[5], Xiaohui Fan[8], Emanuele Farina[5], Chiara Mazzucchelli[5], Nick Kaiser[6], Eugene A. Magnier[6], and PS1 collaboration et al.
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[2]Institute of Astronomy and Astrophysics, Academia Sinica, No.1, Sec. 4, Roosevelt Rd., Taipei 10617, Taiwan
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[6]Institute for Astronomy, University of Hawaii at Manoa, Honolulu, HI 96822, USA
[7]Carnegie Observatories, 813 Santa Barbara Street, Pasadena, California, 91101 USA
[8]Steward Observatory, University of Arizona, Tucson, AZ 85721, USA
†Carnegie-Princeton Fellow

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT
Luminous high-redshift quasars can be used to probe of the intergalactic medium (IGM) in the early universe because their UV light is absorbed by the neutral hydrogen along the line of sight. They help us to measure the neutral hydrogen fraction of the high-z universe, shedding light on the end of reionization epoch. In this paper, we present a discovery of a new quasar (PSO J006.1240+39.2219) at redshift z 6.61±0.02 from Panoramic Survey Telescope & Rapid Response System 1. Including this quasar, there are nine quasars above $z > 6.5$ up to date. The estimated continuum brightness is M_{1450}=−25.96 ± 0.08. PSO J006.1240+39.2219 has a strong Ly α emission compared with typical low-redshift quasars, but the measured near-zone region size is R_{NZ} 3.2 ± 1.1 proper megaparsecs, which is consistent with other quasars at z~6.

Key words: quasar — cosmic reionization

1 INTRODUCTION

Quasars or quasi-stellar objects (QSOs) are supermassive black holes (SMBHs) with accretion disks in the center of a galaxy. They are amongst the most luminous observable objects after the epoch of recombination at $z \sim 1100$. High-redshift ($z \geq 6.0$) quasars are, thus, a powerful tool to probe the early universe. A quasar's spectrum can be used to estimate the mass of SMBH (e.g. De Rosa et al. 2014; Mortlock et al. 2011; Morganson et al. 2012; Venemans et al. 2015), which constrains the evolution and formation model of SMBH within a timescale of <1 Gyr (Li et al. 2007; Tanaka & Haiman 2009). The Gunn-Peterson (GP) (Gunn & Peterson 1965) troughs in the spectrum can constrain the neutral hydrogen (H i) fraction in the early universe (Becker et al. 2001; Fan et al. 2002; Fan 2006; Goto 2006; Bolton et al. 2011; Goto et al. 2011). The GP troughs observed in the $z \sim 6$ quasars discovered by Sloan Digital Sky Survey (SDSS) (Fan et al. 2006; McGreer et al. 2006) suggest that the reionization epoch of the universe ends around $z \sim 6$.

High-redshift quasars can be found by a red color, tween two adjacent broad bands caused by the strong intergalactic medium (IGM) absorption on the blue side of the redshifted Ly α emission (1216Å at rest frame). The number of quasars we can find is limited by the survey area and depth. After decades of searching, more than 100 quasars are found between $5.7 < z < 6.5$ from various kind of surveys (e.g. Bañados et al. 2016; Mortlock 2016). Most of them are i-dropouts which are very red in $i-z$ color. To search for quasar above $z > 6.5$, z-dropouts are needed because the Ly α line is redshifted to wavelength $\lambda \geq 9000$Å. Several surveys covering wavelength ~ 1 μm have been dedicated to search for them and only eight are found in previous work. The highest redshift quasar at z 7.085 was found by Mortlock et al. (2011) using UK infrared Telescope Infrared Deep Sky Survey (UKIDSS; Lawrence et al. (2007)). Venemans et al. (2013) discovered three quasars above $z > 6.5$ using Visible and Infrared Survey Telescope for Astronomy (VISTA) Kilodegree Infrared Galaxy (VIKING) survey while Venemans et al. (2015) found another three between $6.5 < z < 6.7$ using the Panoramic Survey Telescope & Rapid Response Sys-

s t r e t c h i n e s s

$$z \equiv \frac{\Delta\lambda}{\lambda_e} = \frac{\lambda_O - \lambda_e}{\lambda_e} \quad \ldots \quad z+1 = \frac{\lambda_0}{\underbrace{\lambda_e}}$$

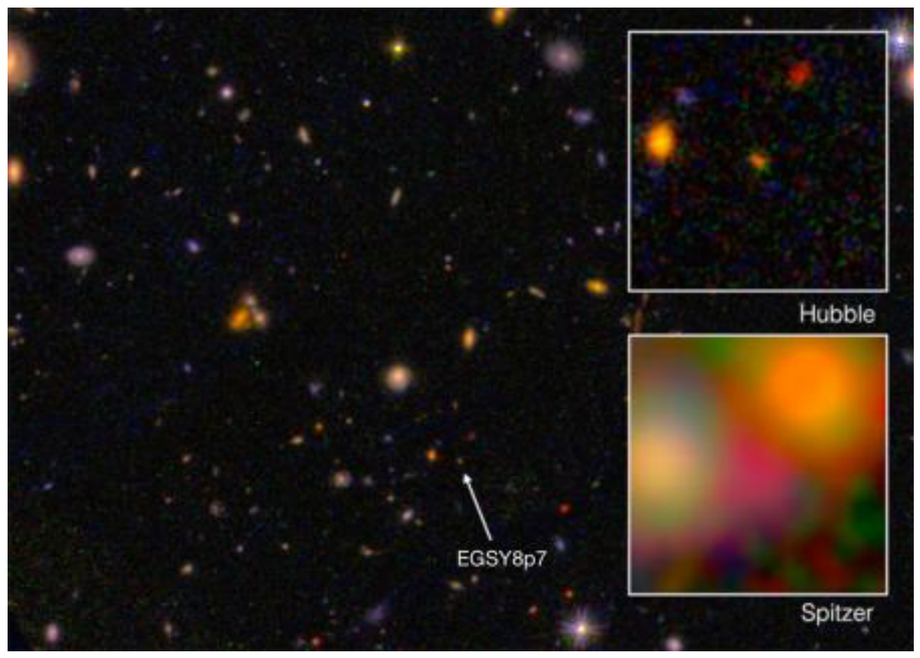
suppose light from a galaxy is observed @ wavelength 4 times emitted

we'd say: it has a "redshift of 3"

The record: last September.

EGS8p7...z = 8.68

Light emitted 13.04 By ago



a big “uh oh”

almost immediately after Hubble’s measurement

original results:

$1 \text{ light year} = c \times 1 \text{ year} = 9.5 \times 10^{15} \text{m}$

H = 160 km/cMly = 1.68 x 10-17 s-1 $\Rightarrow$ $\frac{1}{H} = 2 \times 10^9 \text{years}$

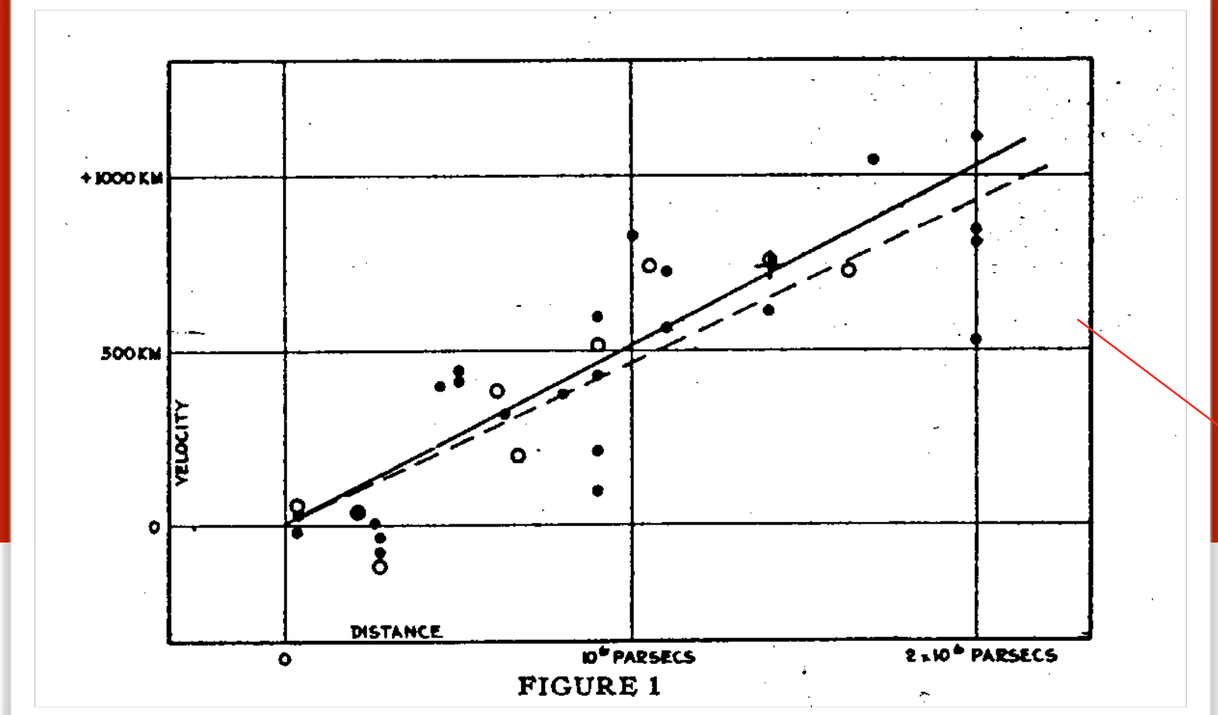
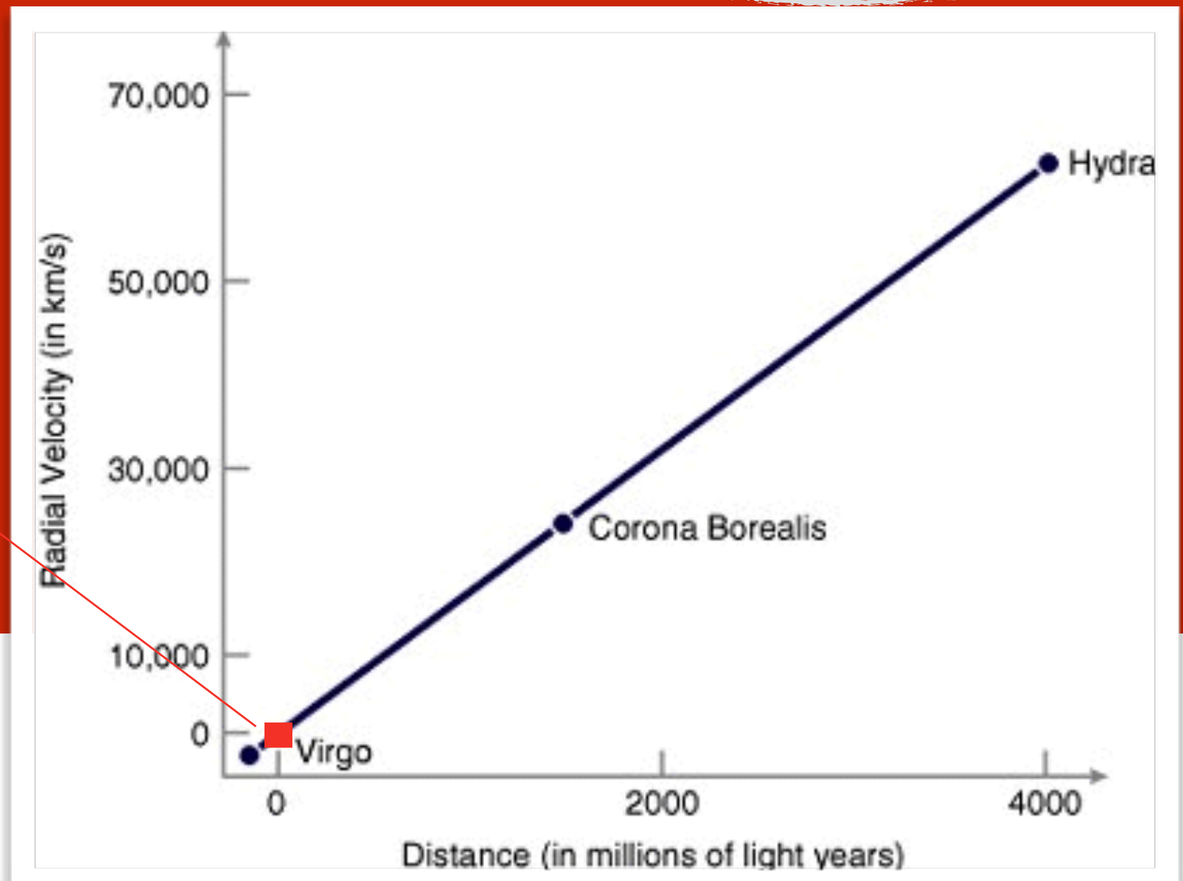


FIGURE 1



oops.

geologists already understood that the Earth was at least 3 By old.

That required some work!

Refinements found a number of assumptions in need of updating

for example...there are 2 kinds of Cepheid Variable stars, and other issues

This is the beginning of quantitative Cosmology.

Measuring the Hubble Constant is an important cottage industry in astronomy

current best result:

$H_0 = 69.3 \pm 0.8$ km/sec/Mpc

$H_0 = 2.25 \times 10^{-18}$ s^{-1}

1 megaparsec (Mpc) = 10^6 parsec = 3.26×10^6 light years = 3.086×10^{16} m

some cautionary comments

The Hubble Constant isn't constant.

$H_0 = 67.8 \pm 0.9$ km/sec/Mpc

$H_0 = 2.26 \times 10^{-18}$ s^{-1}

The subscript "0" means: "Now"

The inverse of the Hubble Constant isn't necessarily

the age of the universe

$H_0^{-1} = 4.42 \times 10^{17}$ s = 14.2 By

(stay tuned)

what do the red shift(S) actually imply? &
what was Lemaître's insight?

not doppler

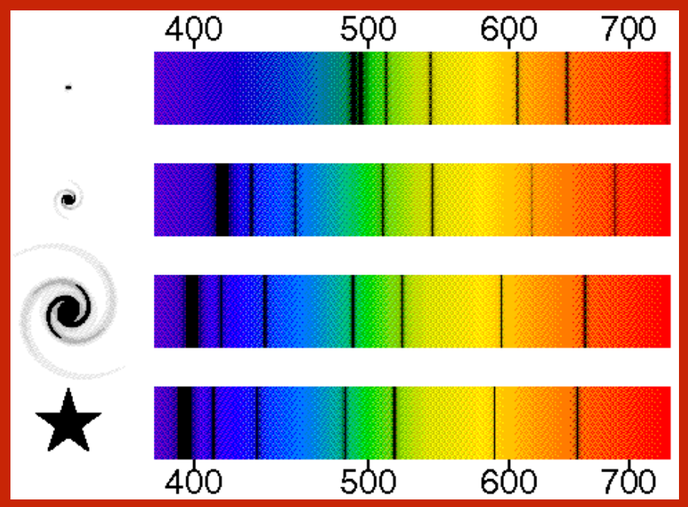
not gravitational

here's **what it is.**

the “red shift”

isn’t a Doppler velocity

it’s geometry

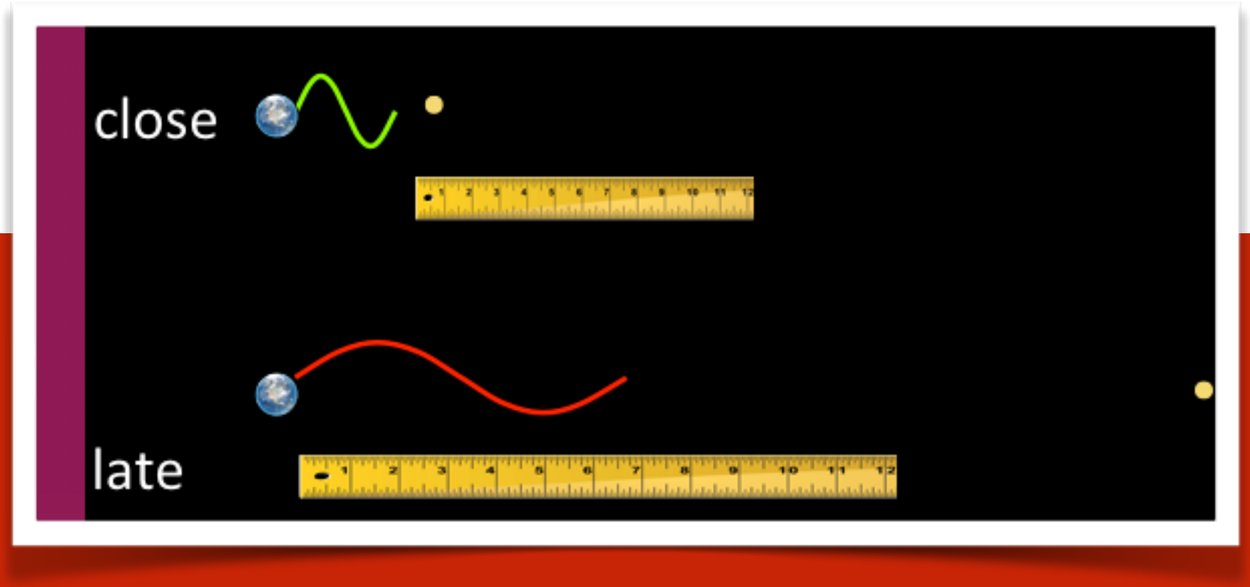


close

late

early

The further away



the more red-shifted its spectrum will be

and the faster it will appear to be receding

the older it will be

and the younger it will appear to be!

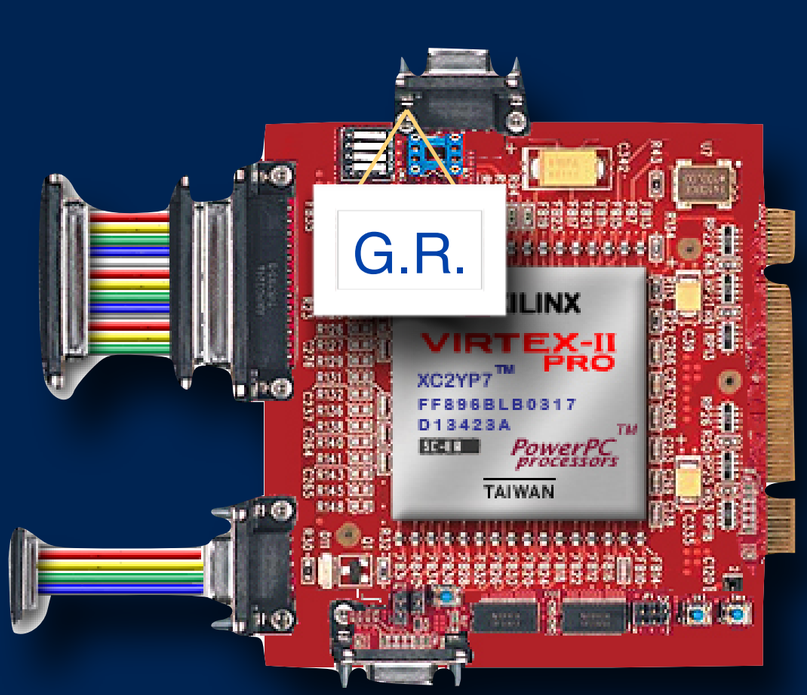
here’s how this is described

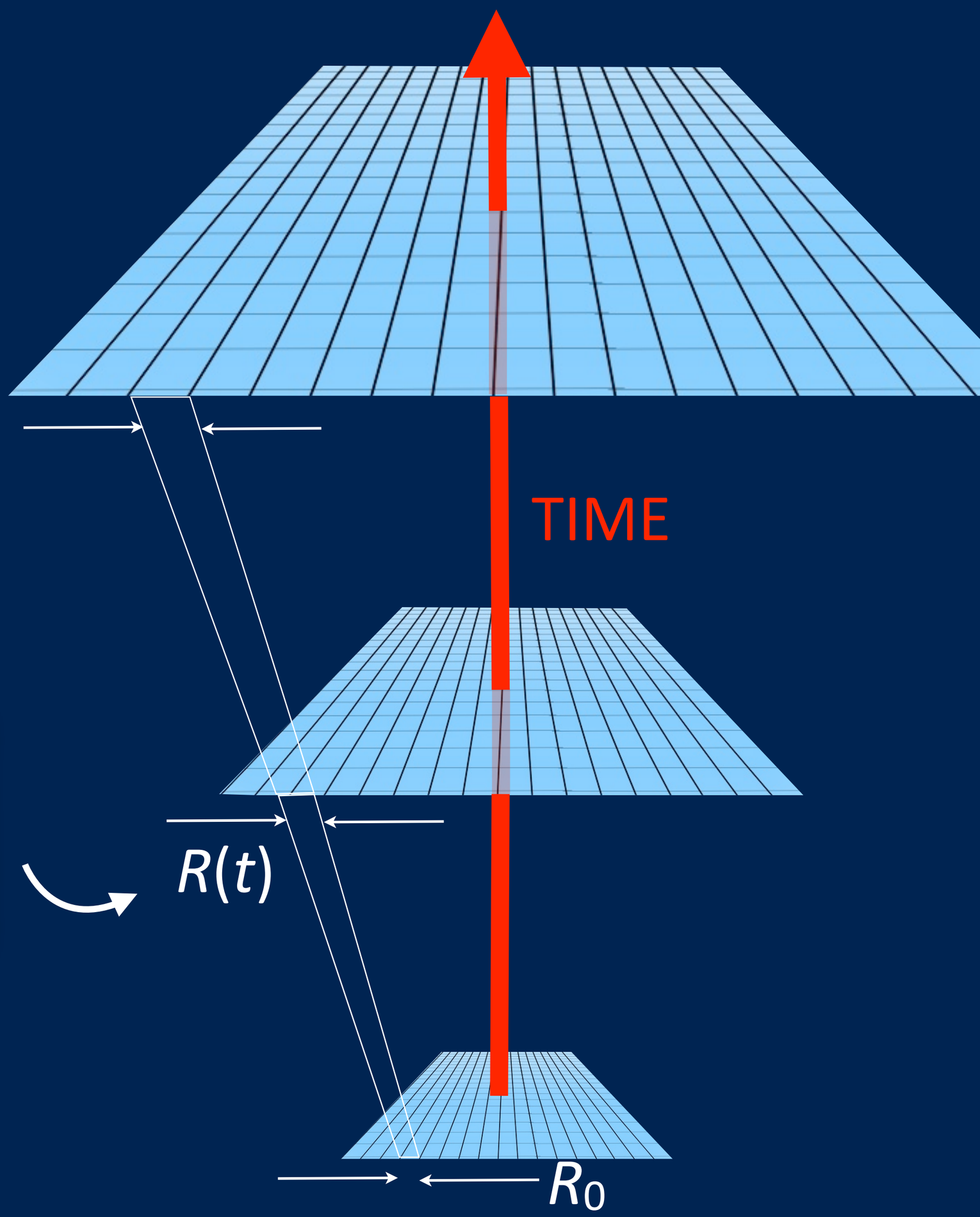
a little technical, but you can do it!

energy/mass/pressure

energy/mass/pressure

$$G = T$$

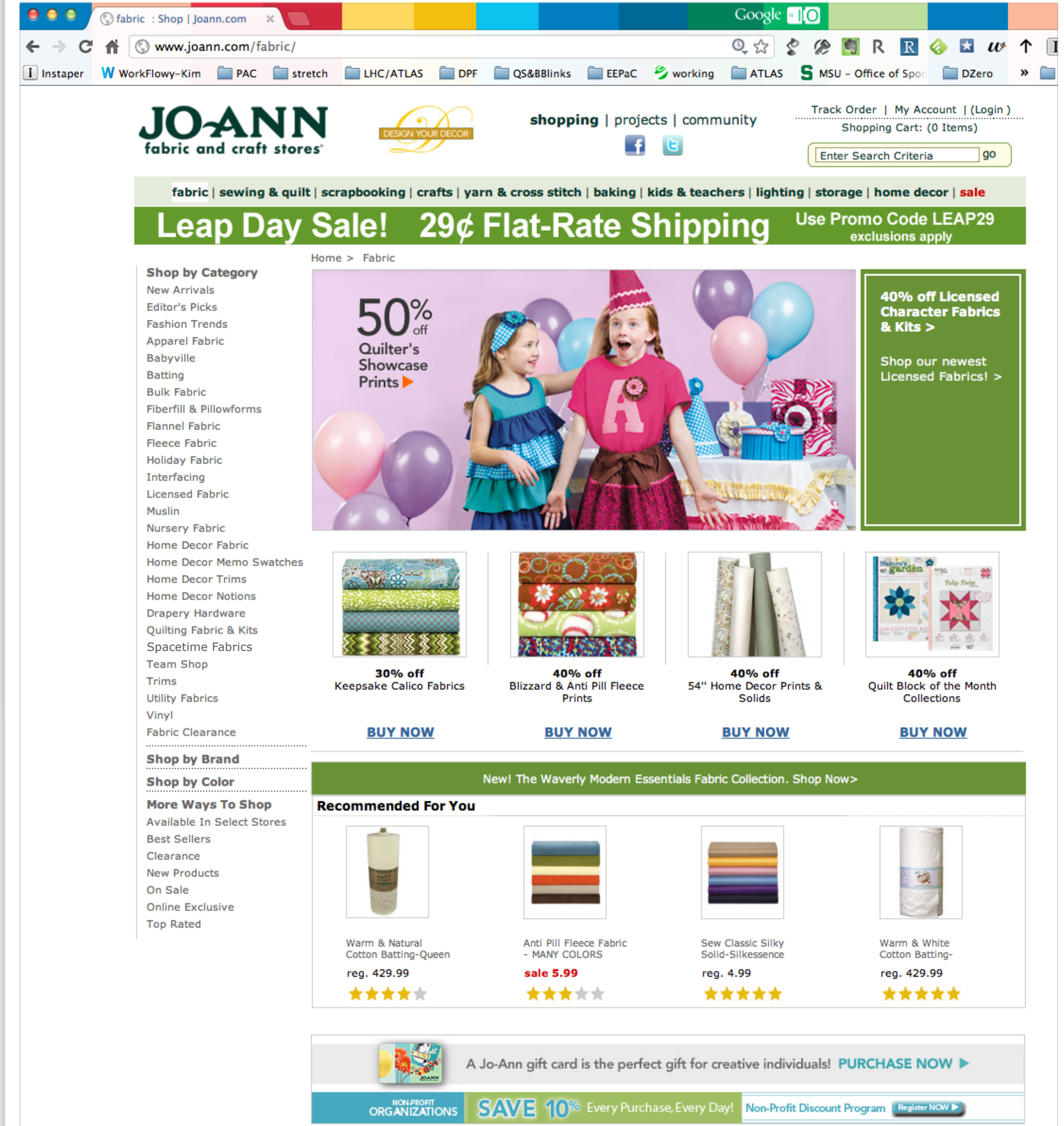




Then a spiritual moment occurs.

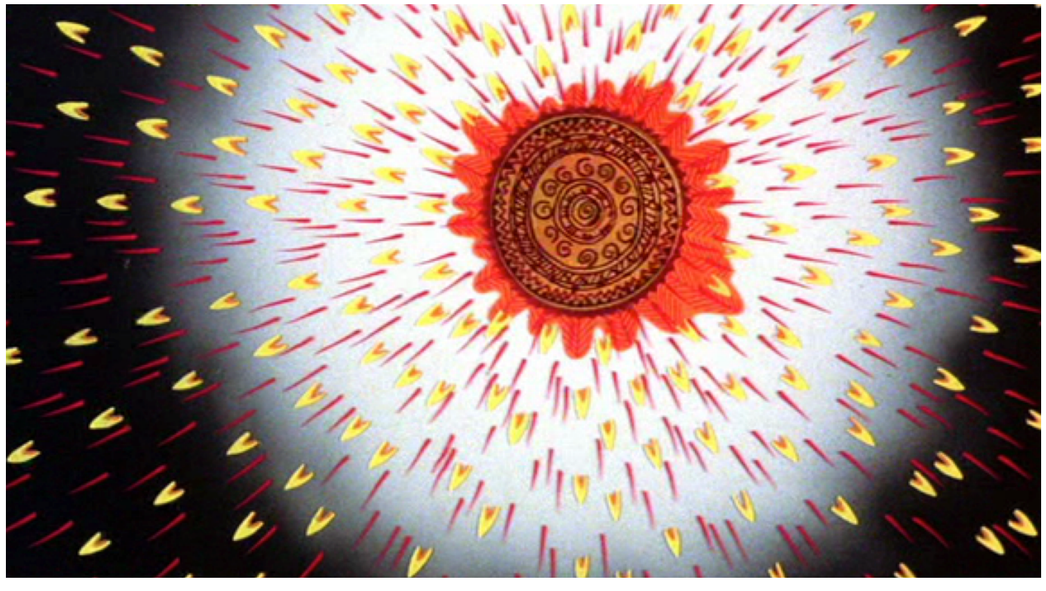
involving spandex.

fabric of spacetime



So, we need 4 deities:

dark specter from power rangers from space



lord firth watership down

Arceus from Pokémon

fujin from Mortal Kombat

universe record-holder

The record: last March.

GN-z11...z = 11.1...so $\beta = 0.986$!

Light emitted 13.4 By ago

wavelength observed now

$$\frac{\lambda_0}{\lambda_e} = 1 + z = 1 + 11.1 = 12.1$$

wavelength emitted then

So the universe has expanded a factor of 12.1 since GN-z11 sent its light our way!

Draft version March 3, 2016
Preprint typeset using LaTeX style emulateapj v. 5/2/11

A REMARKABLY LUMINOUS GALAXY AT Z = 11.1 MEASURED WITH HUBBLE SPACE TELESCOPE GRISM SPECTROSCOPY

P. A. Oesch[1,2], G. Brammer[3], P. G. van Dokkum[1,2], G. D. Illingworth[4], R. J. Bouwens[5], I. Labbé[5], M. Franx[5], I. Momcheva[2,3], M. L. N. Ashby[6], G. G. Fazio[6], V. Gonzalez[7,8], B. Holden[4], D. Magee[4], R. E. Skelton[9], R. Smit[10], L. R. Spitler[11,12], M. Trenti[13], S. P. Willner[6]

Draft version March 3, 2016

ABSTRACT

We present *Hubble* WFC3/IR slitless grism spectra of a remarkably bright $z \gtrsim 10$ galaxy candidate, GN-z11, identified initially from CANDELS/GOODS-N imaging data. A significant spectroscopic continuum break is detected at $\lambda = 1.47 \pm 0.01$ μm. The new grism data, combined with the photometric data, rule out all plausible lower redshift solutions for this source. The only viable solution is that this continuum break is the Lyα break redshifted to $z_{\rm grism} = 11.09^{+0.08}_{-0.12}$, just ~400 Myr after the Big Bang. This observation extends the current spectroscopic frontier by 150 Myr to well before the Planck (instantaneous) cosmic reionization peak at $z \sim 8.8$, demonstrating that galaxy build-up was well underway early in the reionization epoch at $z > 10$. GN-z11 is remarkably and unexpectedly luminous for a galaxy at such an early time: its UV luminosity is 3× larger than L_* measured at $z \sim 6-8$. The *Spitzer* IRAC detections up to 4.5 μm of this galaxy are consistent with a stellar mass of $\sim 10^9$ $M_\odot$. This spectroscopic redshift measurement suggests that the *James Webb Space Telescope* (*JWST*) will be able to similarly and easily confirm such sources at $z > 10$ and characterize their physical properties through detailed spectroscopy. Furthermore, WFIRST, with its wide-field near-IR imaging, would find large numbers of similar galaxies and contribute greatly to *JWST*'s spectroscopy, if it is launched early enough to overlap with *JWST*.

Subject headings: galaxies: high-redshift — galaxies: formation — galaxies: evolution — dark ages, reionization, first stars

1. INTRODUCTION

The first billion years are a crucial epoch in cosmic history. This is when the first stars and galaxies formed and the universe underwent a major phase transition from a neutral to an ionized state. Our understanding of galaxies in this early phase of the universe has been revolutionized over the last few years thanks to the very sensitive WFC3/IR camera onboard the Hubble Space Telescope (*HST*) in combination with ultra-deep *Spitzer*/IRAC imaging. WFC3/IR has pushed the observational horizon of galaxies to the beginning of the cosmic reionization epoch at $z \sim 9-11$, less than 500 Myr from the Big Bang. Several large extragalactic surveys have now resulted in the identification of a large sample of more than 800 galaxies at $z \sim 7-8$ (Bouwens et al. 2015b; McLure et al. 2013; Finkelstein et al. 2015; Bradley et al. 2014; Schmidt et al. 2014) and even a small sample of $z \sim 9-11$ candidates (Oesch et al. 2013, 2014, 2015a; Ellis et al. 2013; Zheng et al. 2012; Coe et al. 2013; Zitrin et al. 2014; Bouwens et al. 2015a; McLeod et al. 2015; Ishigaki et al. 2015; Infante et al. 2015; Kawamata et al. 2015; Calvi et al. 2016).

Spectroscopic confirmations of very high-redshift candidates remain limited, however. The primary spectral feature accessible from the ground for these sources, the Lyα line, is likely attenuated by the surrounding neutral hydrogen for all $z > 6$ galaxies (Schenker et al. 2012; Treu et al. 2013; Pentericci et al. 2014). Therefore, despite the large number of candidates from *HST* imaging, only a handful of galaxies in the epoch of reionization have confirmed redshifts to date (Vanzella et al. 2011; Ono et al. 2012; Shibuya et al. 2012; Finkelstein et al. 2013; Oesch et al. 2015b; Roberts-Borsani et al. 2015; Zitrin et al. 2015).

Given the low success rate of Lyα searches, a viable alternative approach is to search for a spectroscopic confirmation of the UV continuum spectral break (see e.g. Dow-Hygelund et al. 2005; Malhotra et al. 2005; Vanzella et al. 2009; Rhoads et al. 2013; Watson et al. 2015; Pirzkal et al. 2015). This break is expected owing to the near-

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What’s R(t)?

The “scale factor”

the stretchiness of spacetime

The Friedman, Walker, Robertson models

Friedman's and Lemaître's work was expanded on by Howard P Robertson and Arthur G Walker in 1936

They found exact solutions to the Einstein equations, using the Friedman techniques.

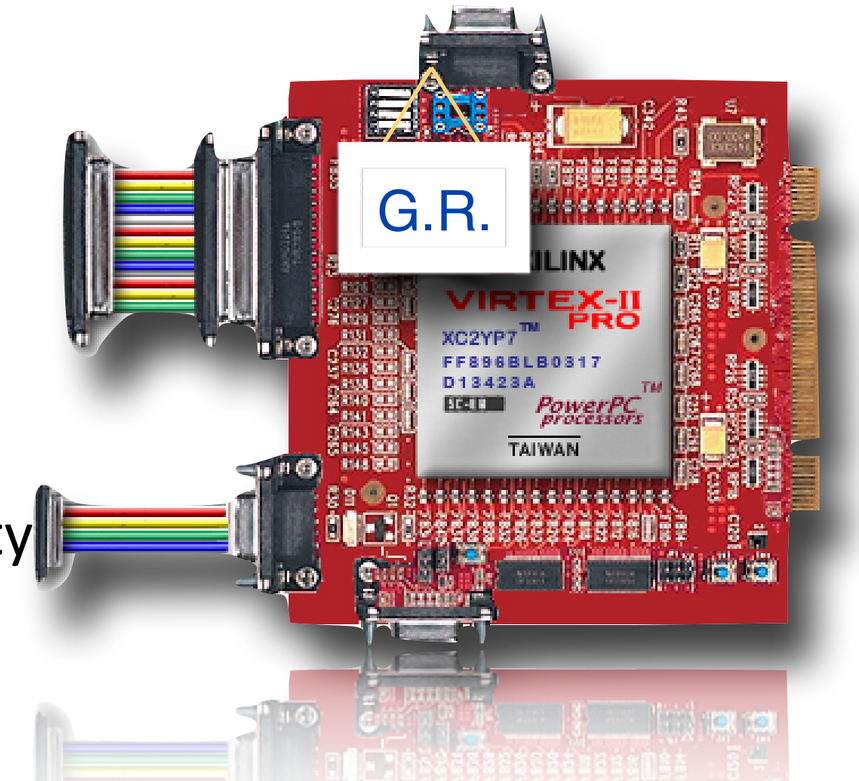
Their model of cosmology is variously called the:

FWR model

FLWR model

Standard Model of Cosmology

$$G + \Lambda = T$$
$$G = T$$



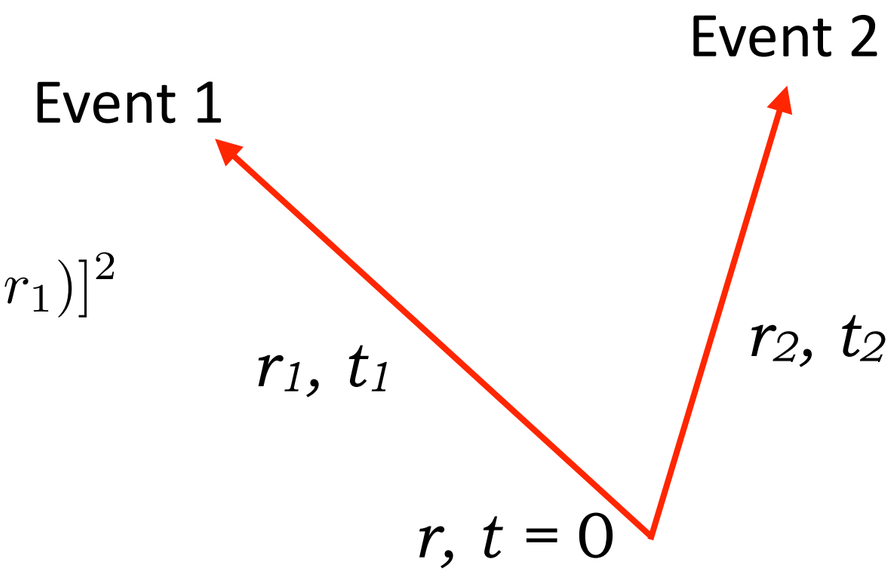
varying assumptions, k, density

the interval again - spacetime separation between two events.

In Special Relativity...which is flat spacetime:

$$\Delta s^2 = (c\Delta t)^2 - (\Delta r)^2$$

$$\Delta s^2 = s_2 - s_1 = [c(t_2 - t_1)]^2 - [(r_2 - r_1)]^2$$



In general:

$$\Delta s^2 = g_{00}(c\Delta t)^2 + g_{11}(\Delta r)^2$$

For FLRW model, a parameterization:

$$\Delta s^2 = (c\Delta t)^2 - \frac{R^2(t)}{\left(1 + \frac{kr^2}{4}\right)^2}(\Delta r)^2$$

a time-dependent scale factor

every point in space receives the same scale factor at each instant of time

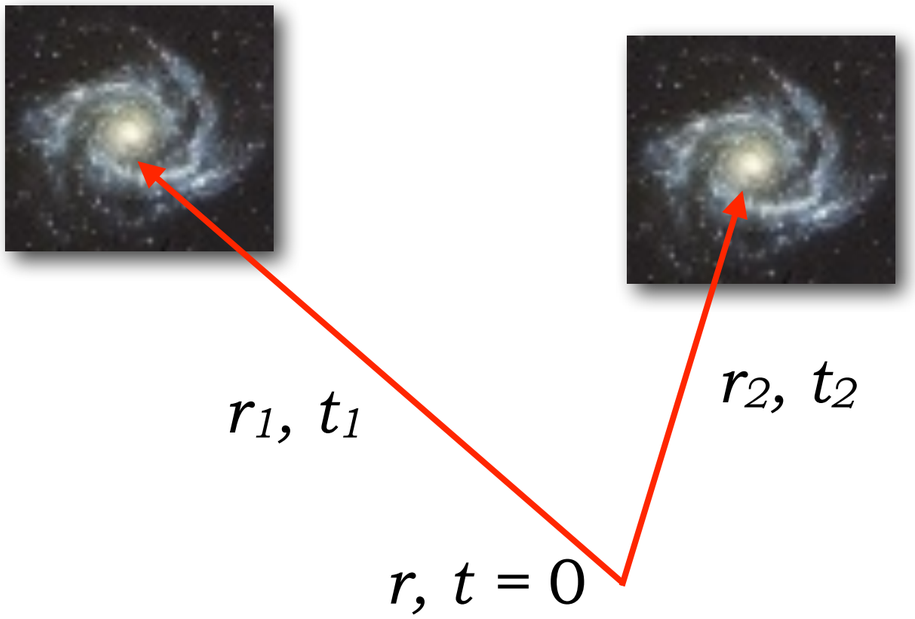
the curvature never changes

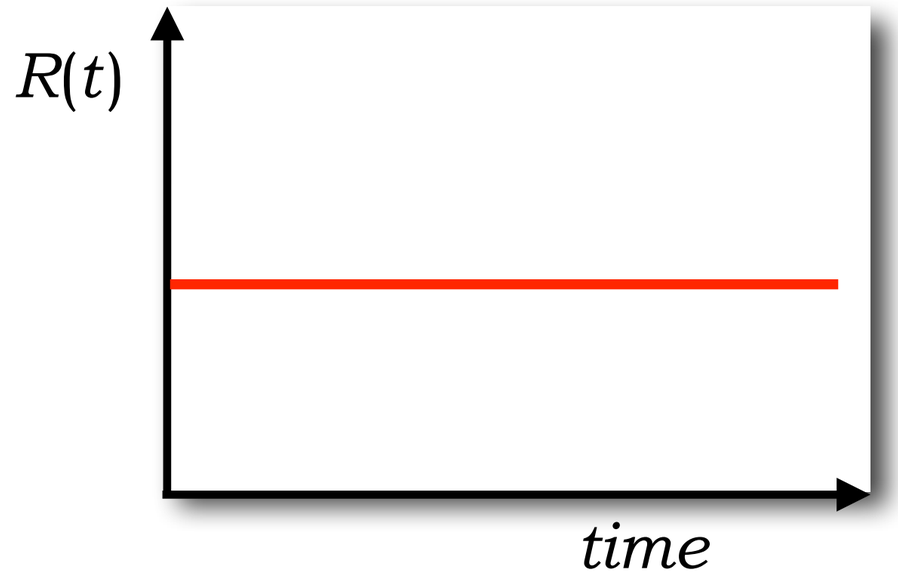
the curvature...

can catalogue the behavior of R

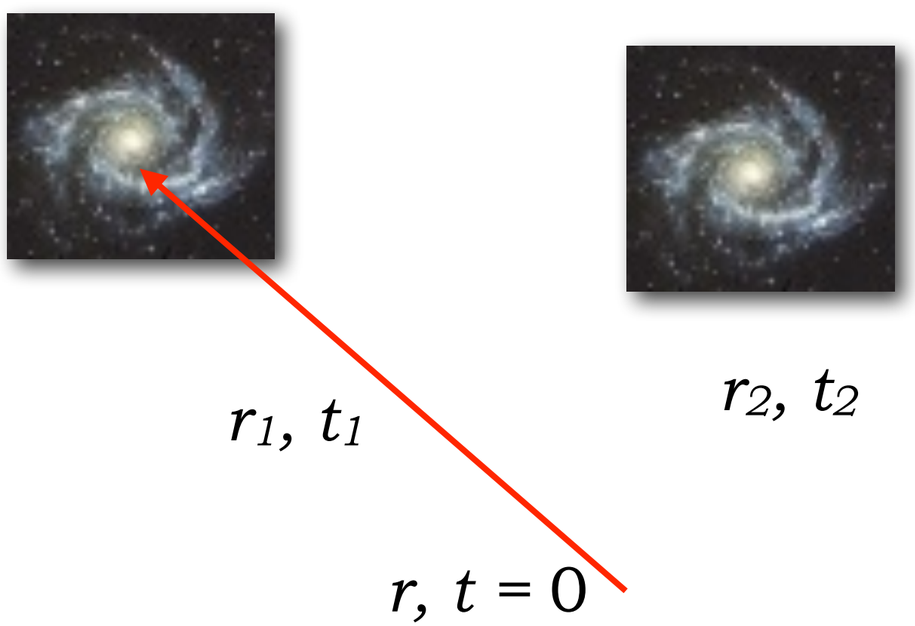
for different choices of the Cosmological Constant and k

Einstein's original model





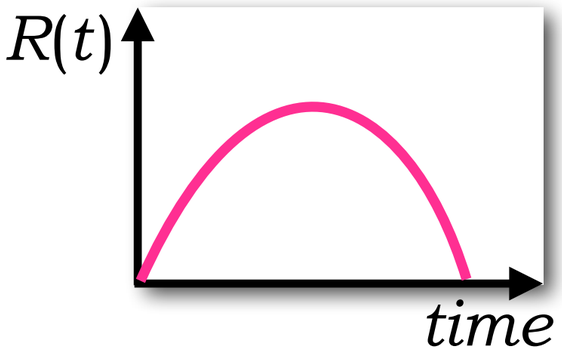
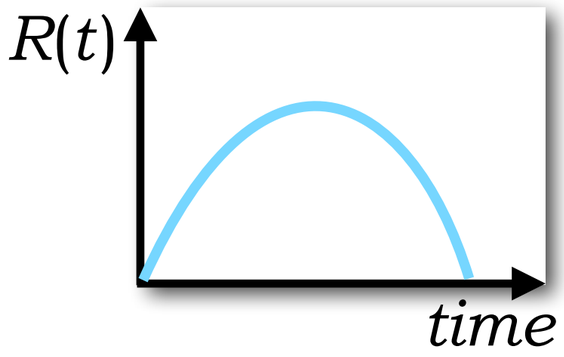
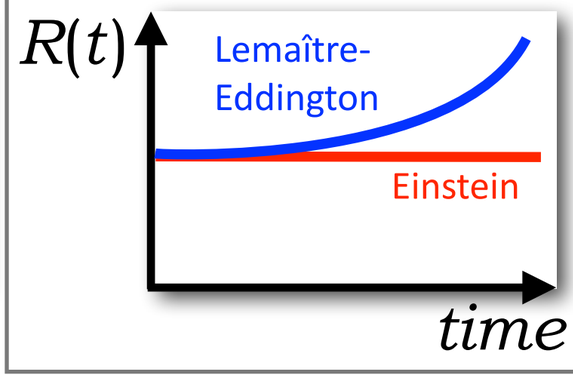
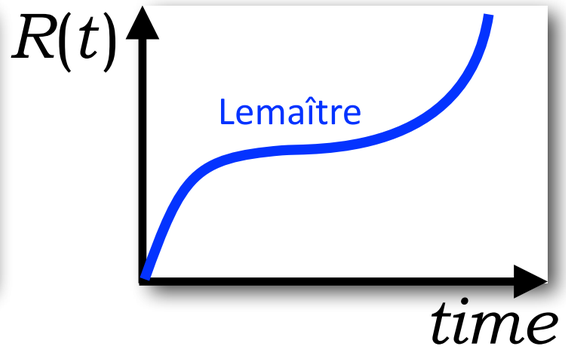
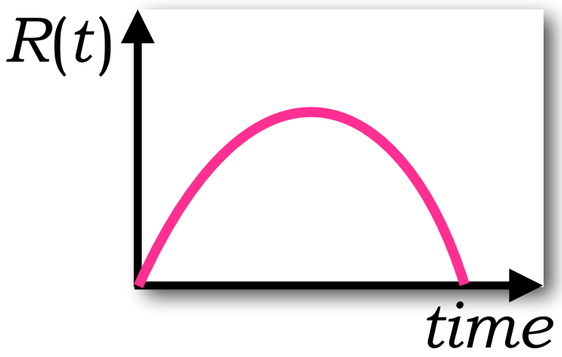
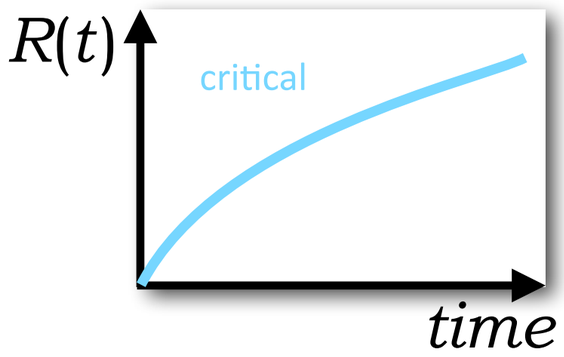
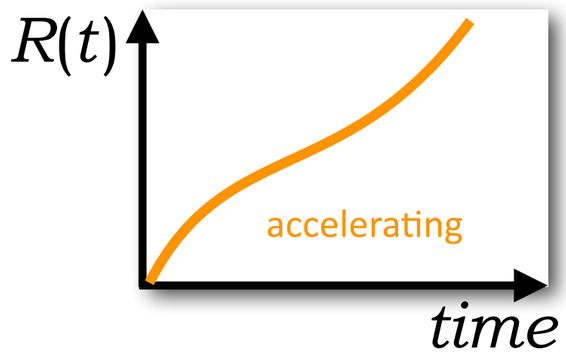
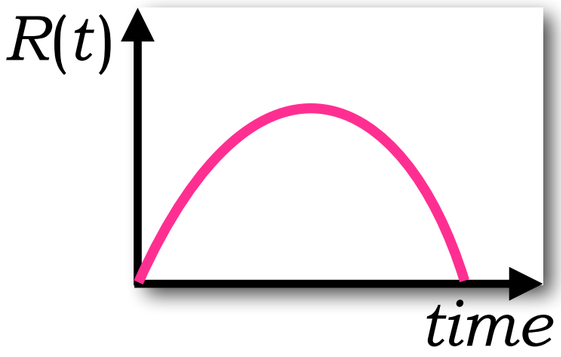
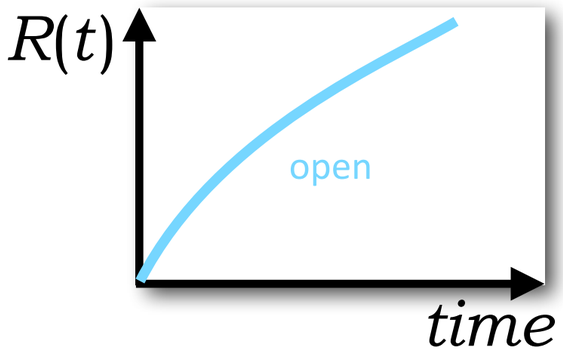
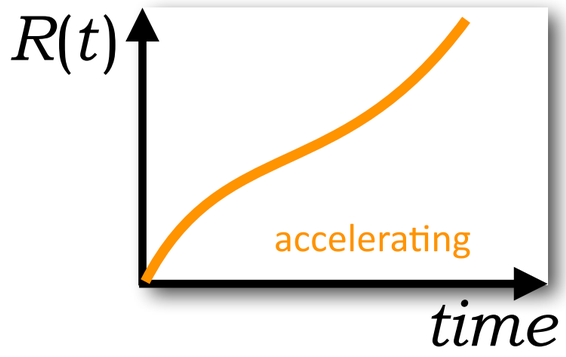
What did Einstein say would be the case?



Static...for which he needed a particular value of the Cosmological Constant

$$\Lambda_E = \frac{4\pi G\rho}{c^2}$$

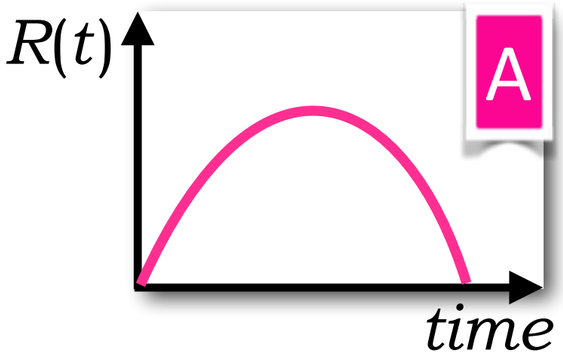
FLRW catalogue of Universes

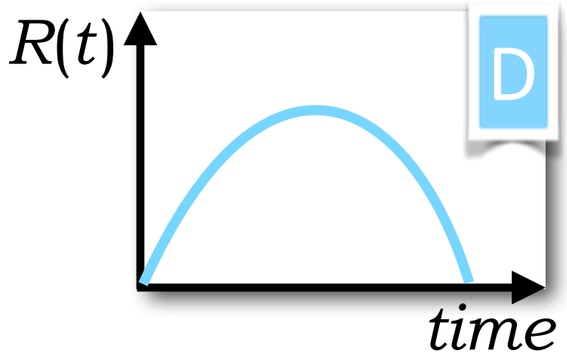
	$\Lambda < 0$	$\Lambda = 0$	$\Lambda > 0$	
			$\Lambda = \Lambda_E$	$\Lambda > \Lambda_E$
$k = +1$				
$k = 0$				
$k = -1$				

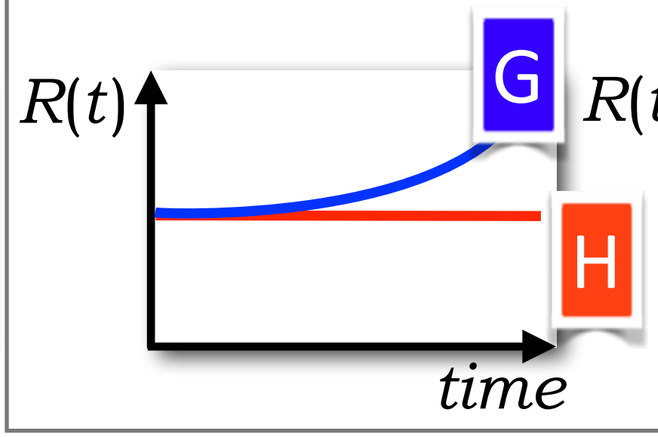
FLRW catalogue of Universes

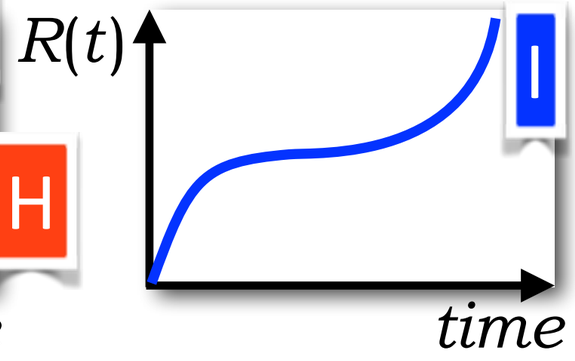
$\Lambda < 0$ | $\Lambda = 0$ | $\Lambda > 0$ | $\Lambda = \Lambda_E$ | $\Lambda > \Lambda_E$

$k = +1$

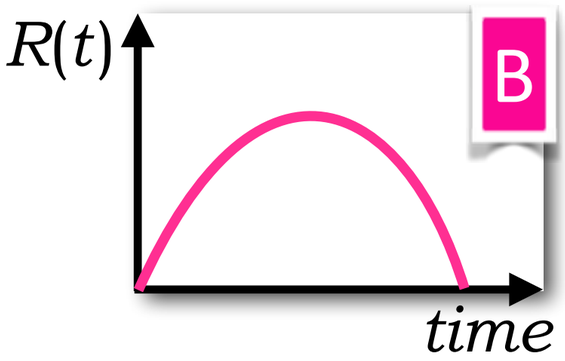


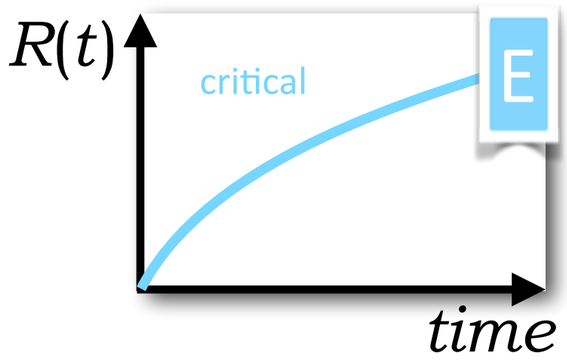


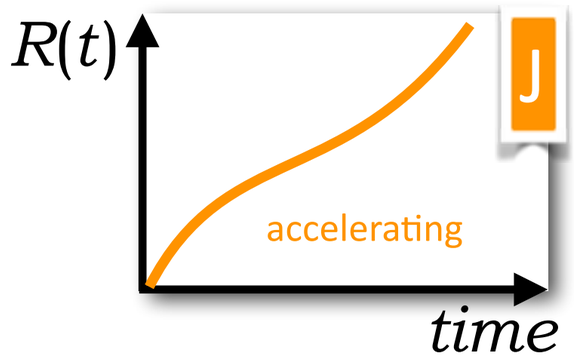




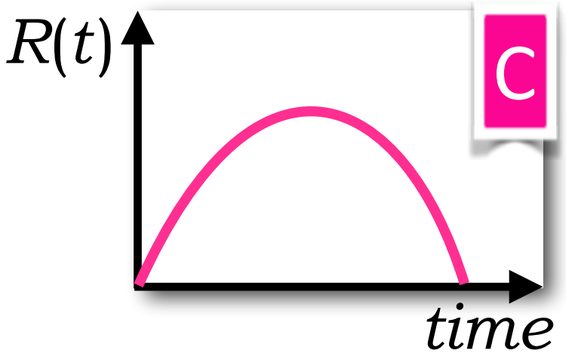
$k = 0$

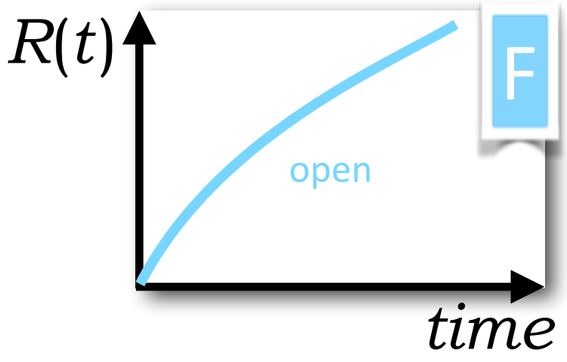


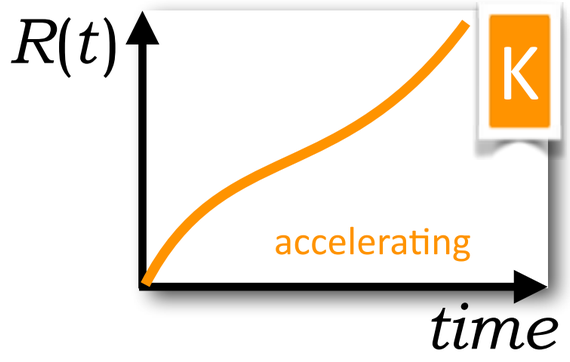




$k = -1$







which one is ours?

that’s the story of the last 3 decades

stay tuned

I see

dead stars

An experiment showing that the universe had a beginning.

Hubble ultra-Deep Field

Hubble Deep Field

radiation era

first
galaxies

first
stars

now

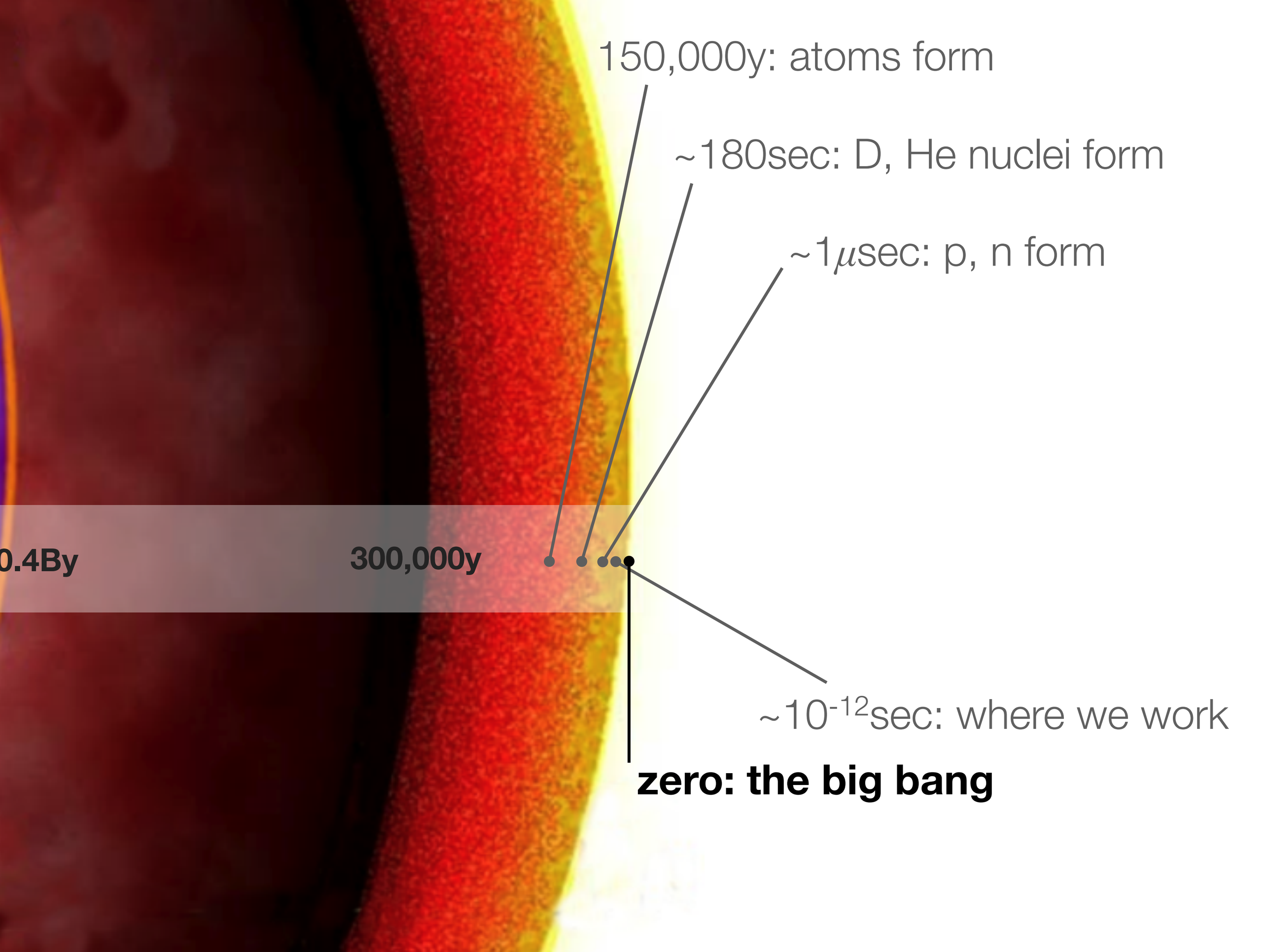
big bang

13.7By

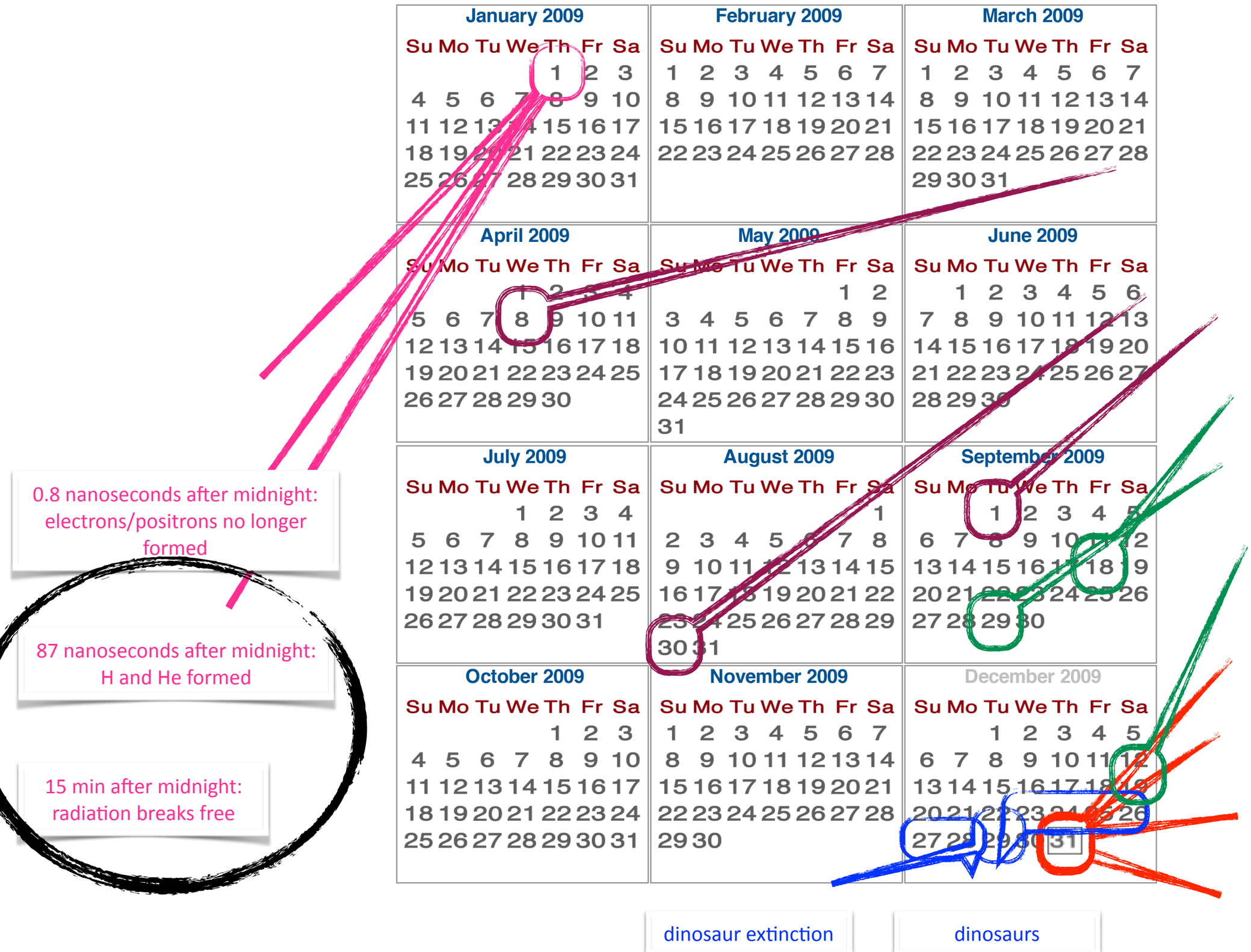
1By

0.2 - 0.4By

370,000y


150,000y: atoms form
~180sec: D, He nuclei form
~1μsec: p, n form
~10-12sec: where we work
zero: the big bang
0.4By
300,000y

our cosmic calendar: 12 months = 13.8 By



0.8 nanoseconds after midnight: electrons/positrons no longer formed

87 nanoseconds after midnight: H and He formed

15 min after midnight: radiation breaks free

Milky Way disk

Sun

Earth

first cells

sponges

first plants

4.5 hr to midnight: early chimps

2.8 hr to midnight: australopithecus

14 min to midnight: neanderthal

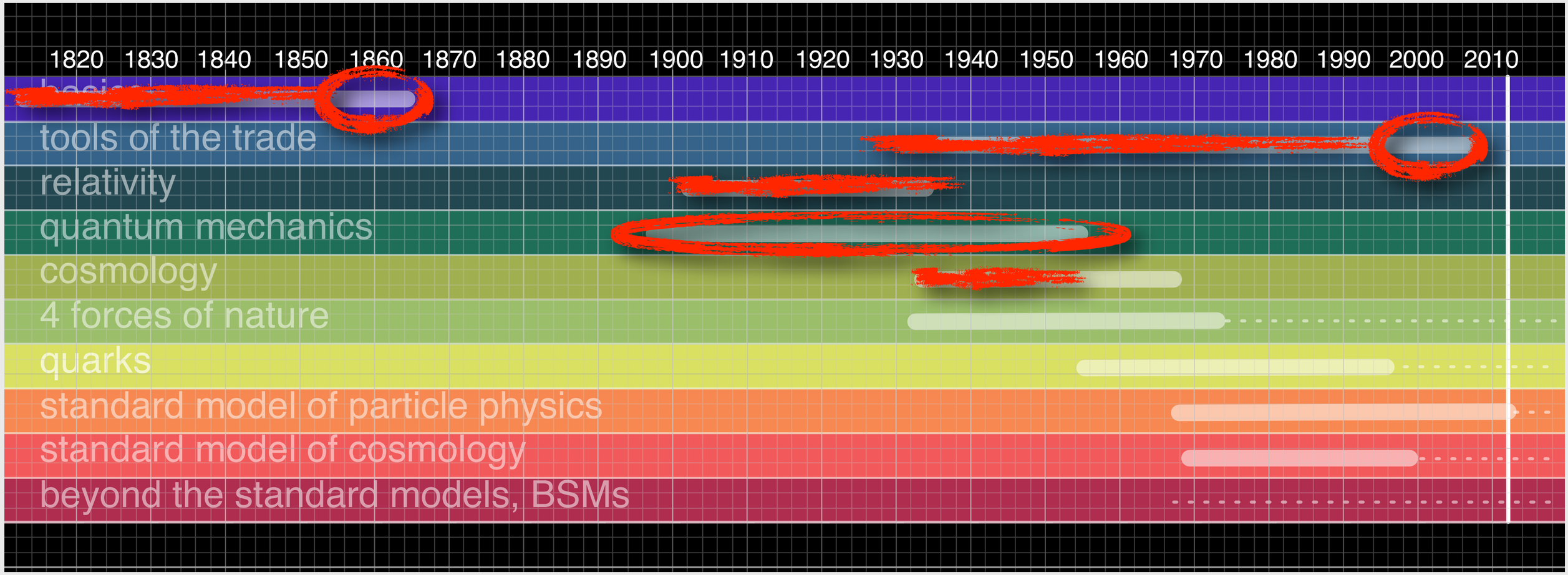
7 min to midnight: homosapiens

dinosaur extinction

dinosaurs

To take the story there

We need quantum mechanics and particle physics


1820 1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
basics
tools of the trade
relativity
quantum mechanics
cosmology
4 forces of nature
quarks
standard model of particle physics
standard model of cosmology
beyond the standard models, BSMs