

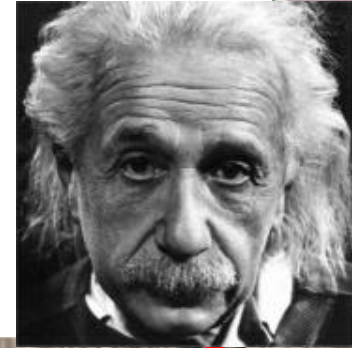
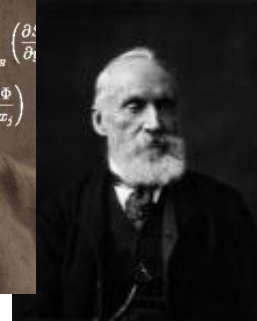
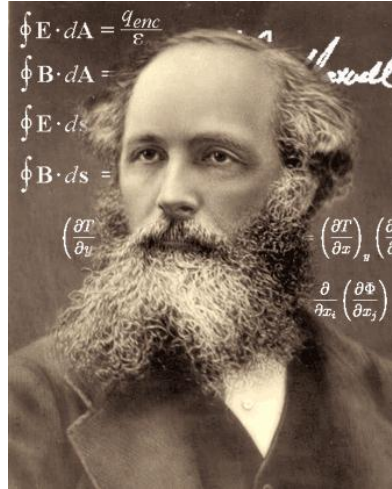
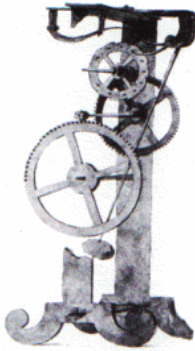


# Does Anybody Really Know What Time It Is?

- What time is it?
- What is time? Does it exist?
- Can we reverse, or even stop, time?
- Can we travel in time?
- How old is the universe?
- When will the universe end?

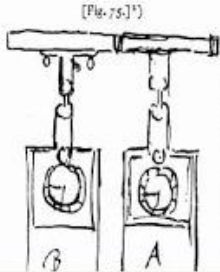
“You must remember this, a kiss is still a kiss, a sigh is just a sigh. The fundamental things apply, as time goes by ...” (By Herman Hupfeld) in *Casablanca*

# History of Time



Huygens' V. 3 clocks

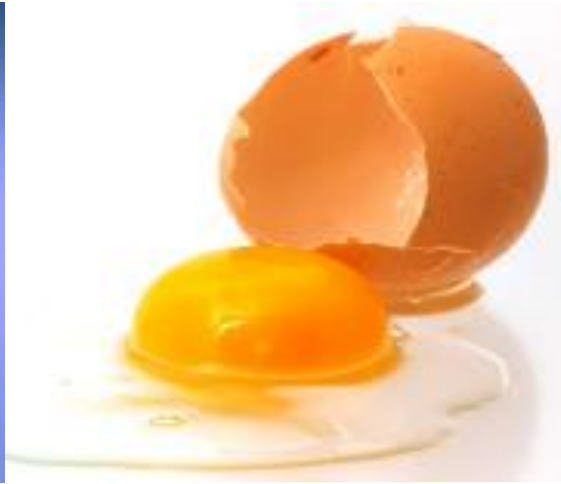
1665.



22 febr. 1665.  
Diebus 4 aut 5 horologiorum duorum novorum in quibus carentulae [Fig. 75], miram concordiam observaveram, ita ut ne minimo quidem excessu alterum ab altero superaretur. sed consonarent semper reciprocaiones utriusque perpendiculari. unde cum parvo spacio sympathie quatero afficeretur caperem ne simul inaevel femihora

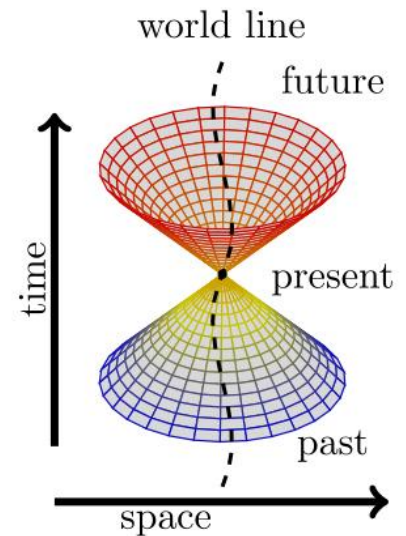


# The Arrow of Time



Past ... Present ... Future

- Macroscopic vs microscopic
- 2<sup>nd</sup> Law of Thermodynamics
- Entropy and Disorder



# How Old is the Universe?

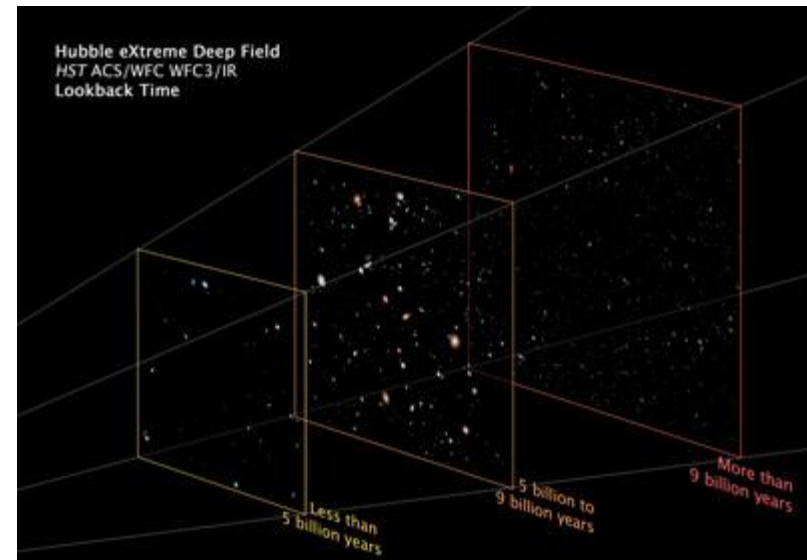
(just look up!)

- Measurements
  - White Dwarfs
  - Star Clusters
  - Chemical Elements
- Cosmological Models
  - Based on General Relativity
  - Supported by recent observations



# Lookback Times

From Earth to	Time
Moon	1.3 s
Sun	8.3 min
Jupiter	35-52 min
Pluto	5+ hours
Nearest Star (Proxima Centauri)	4.2 yr
Orion Nebula	1500 yrs
Across Milky Way	100, 000 yr
Andromeda	2.5 million yrs = 2.5 Myr
Hubble Ultra Deep Field	13 billion yrs = 13 Gyr



<http://hubblesite.org/newscenter/archive/releases/2012/37/image/>

# Albert Einstein

- **General Relativity - 1915**

- Curvature of spacetime tells bodies how to move
- Bodies tell spacetime how to curve

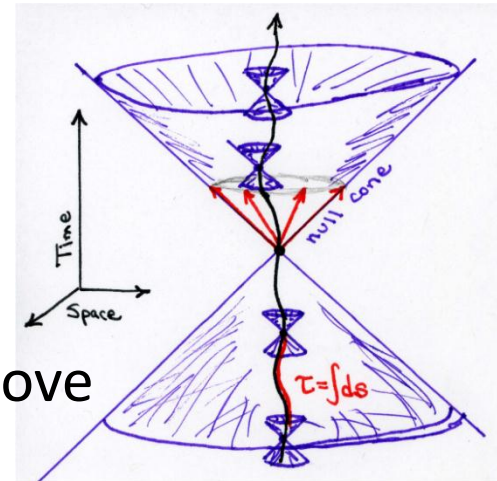
- **GPS - Relativistic Time Corrections**

- Gravitation: + 46 ms/day (faster)
- Time dilation: - 7 ms/day (slower)
- Total: + 39 ms/day faster

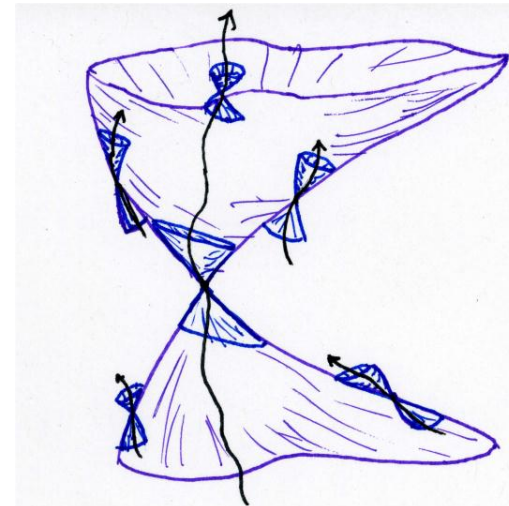
.... Off 12 km/day!

- **Cosmology – 1917**

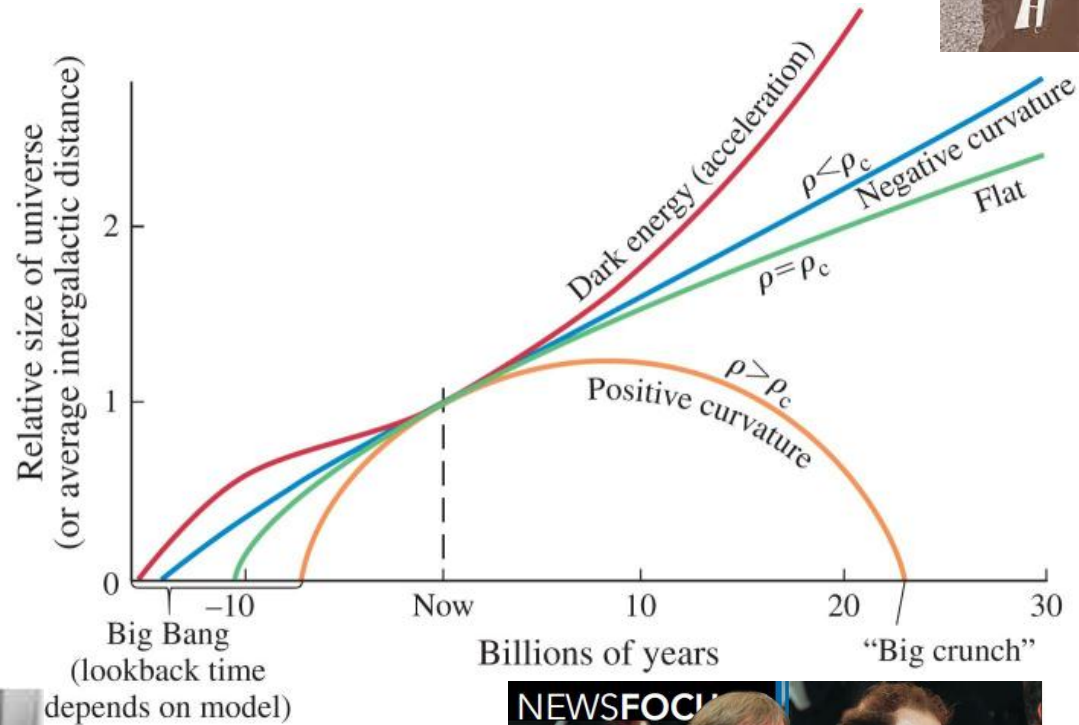
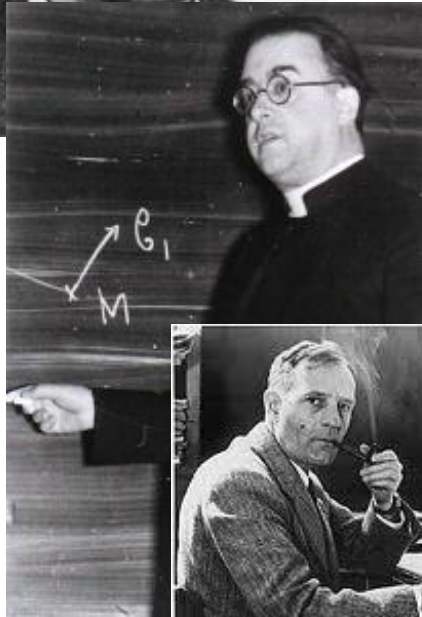
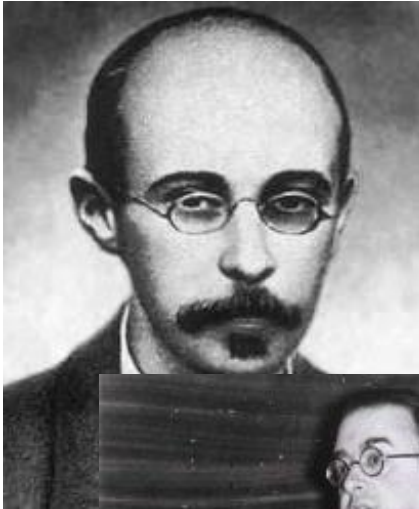
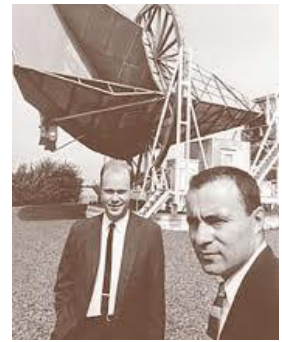
- Cosmological Principle: The universe is the homogeneous and isotropic
  - The universe looks the same from every point
  - The universe looks the same in every direction



$$G_{\alpha\beta} = \frac{8\pi G}{c^4} T_{\alpha\beta}$$



# Cosmological Time – The Expanding Universe





# Lambda-CDM Model

(Standard Big Bang Model)

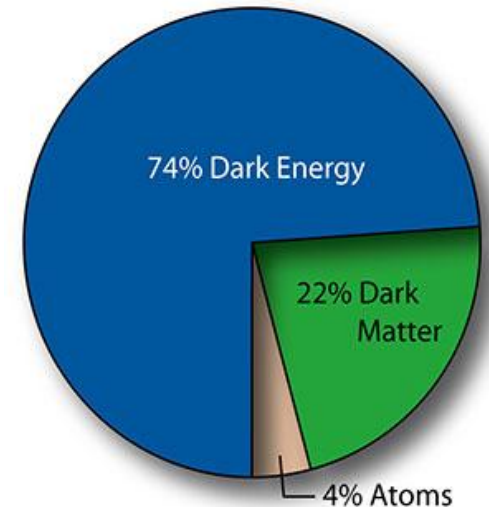
$$H^2 + \frac{\kappa}{a^2} = \frac{8\pi G}{3} \rho(a)$$

expansion rate      curvature of space      energy density

**Rate<sup>2</sup> = Radiation + Matter + Dark Energy - Curvature**

$$\frac{H^2}{H_0^2} = \Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda.$$

- 1965 – CMB – radiation
- 1980's – Dark Matter
- 1992 – COBE
- 1998 – Dark energy ~ 73%
- 2000 – BOOMERang – Flat Universe
- 2001 – 2dfGRS galaxy survey – Matter ~ 25%



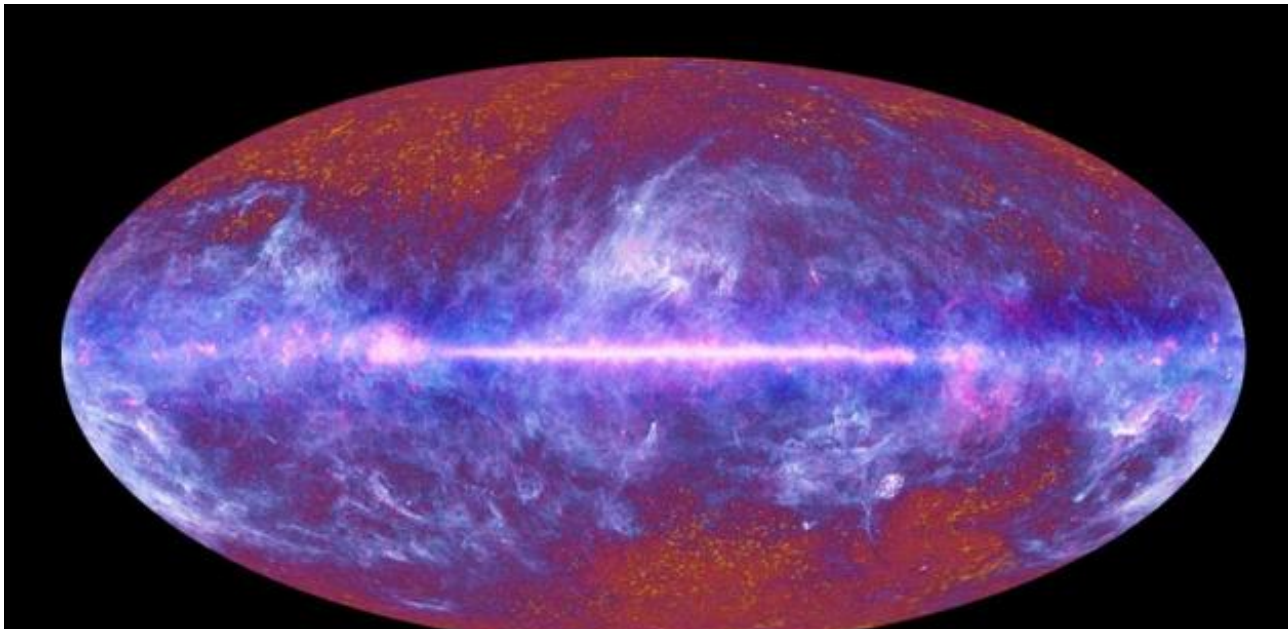
# Age of the Universe

## Latest Results

### Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Final Maps and Results - 2012

C. L. Bennett, D. Larson, J. L. Weiland, N. Jarosik, G. Hinshaw, N. Odegard, K. M. Smith, R. S. Hill, B. Gold, M. Halpern, E. Komatsu, M. R. Nolta, L. Page, D. N. Spergel, E. Wollack, J. Dunkley, A. Kogut, M. Limon, S. S. Meyer, G. S. Tucker, E. L. Wright (Submitted on 20 Dec 2012 (v1), **last revised 30 Jan 2013** (this version, v2)) <http://arxiv.org/abs/1212.5225>

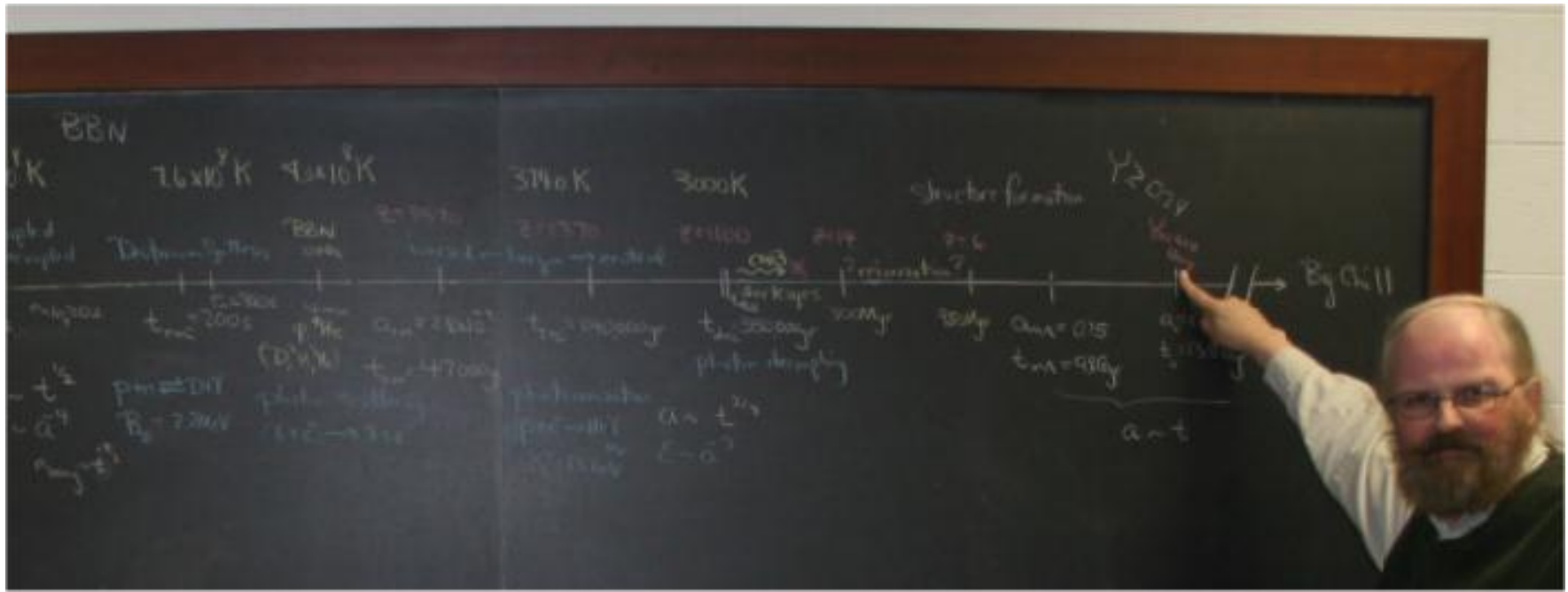
- ... **13.77 billion years old** to within a half percent.
- ... the curvature of space is within 0.4% of "flat".
- ...ordinary atoms make up only 4.6% of the universe.
- ...dark matter is 24.0%
- ...dark energy makes up 71.4% of the universe



# Do We Know What Time Is?

## Frontiers in Time

- What happened before time began?
- Is time continuous or discrete?
- What is time like inside a black hole?
- Can we travel in time?
- Why do we only remember the past?

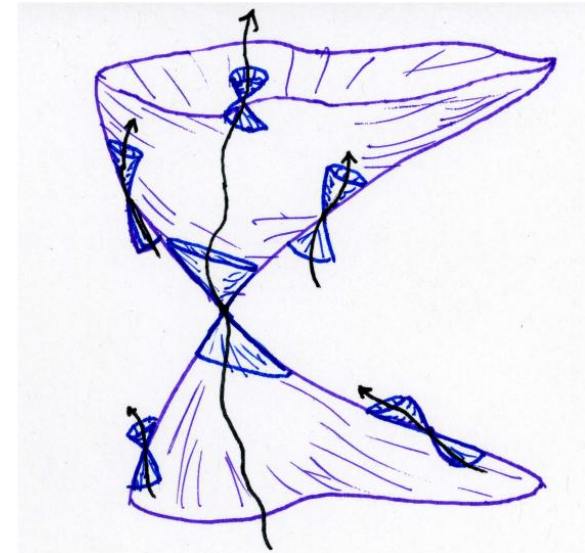
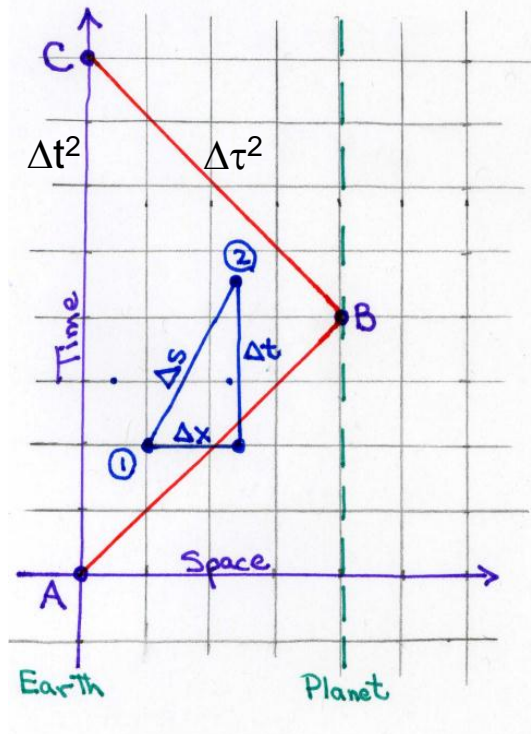
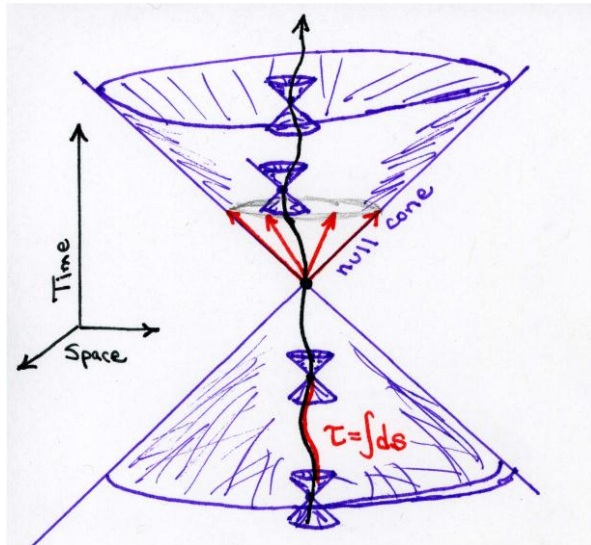


# Talk ends

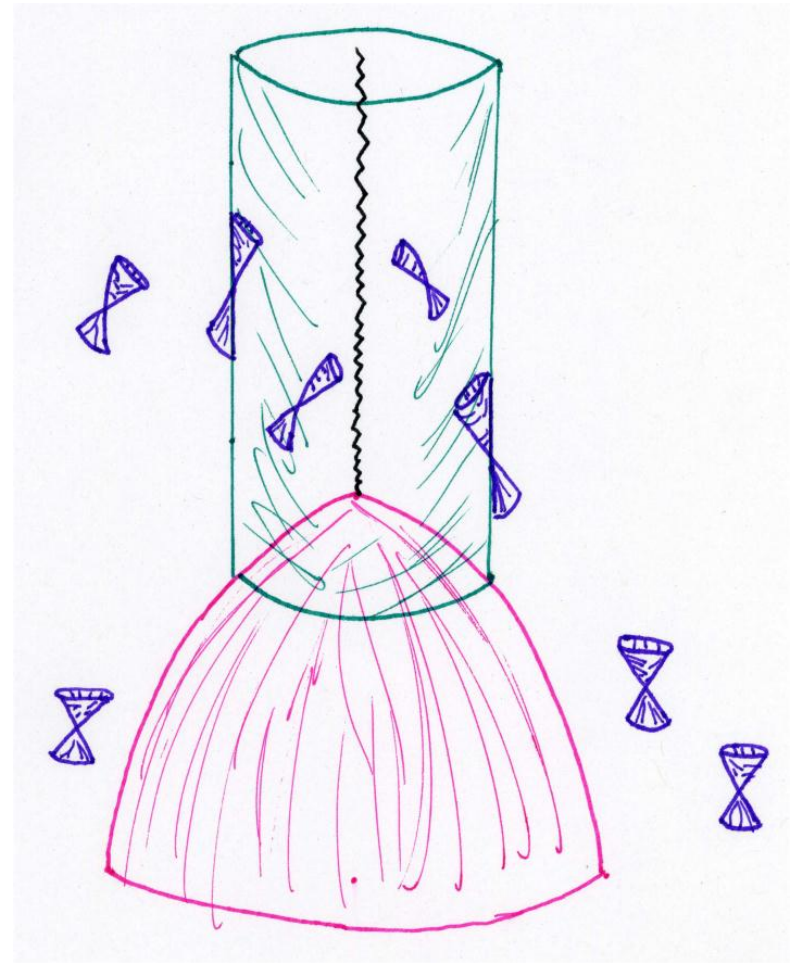
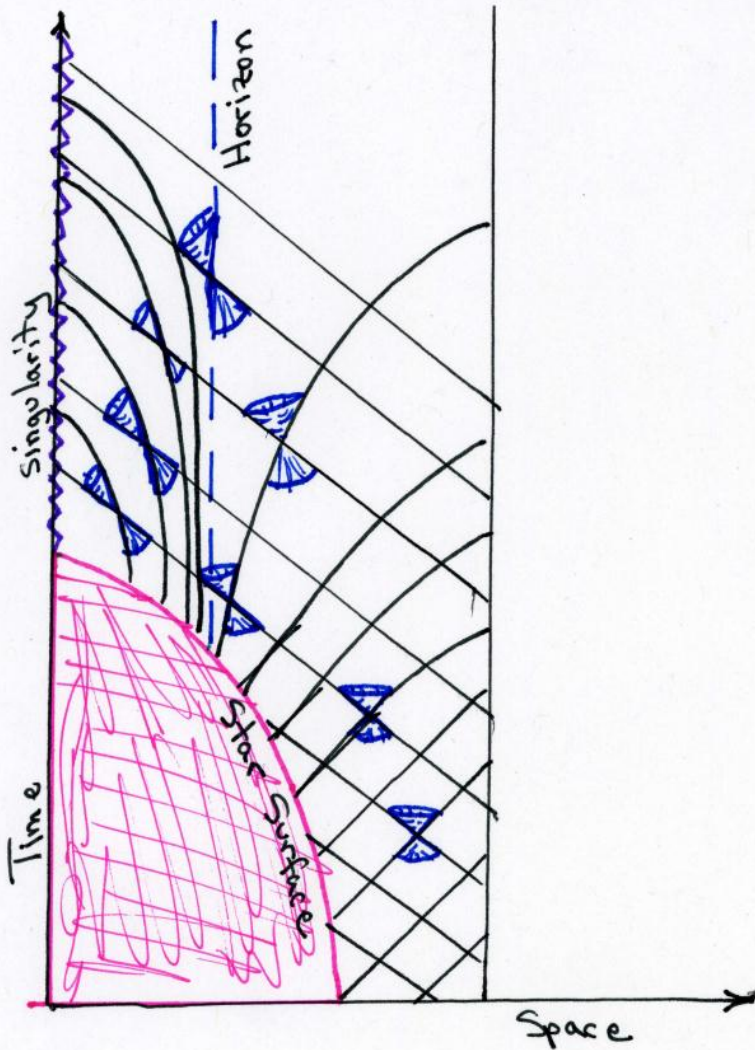
- Next slides are extra

# How do some physicists see time?

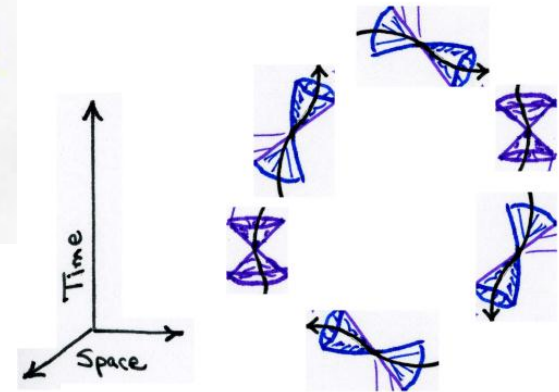
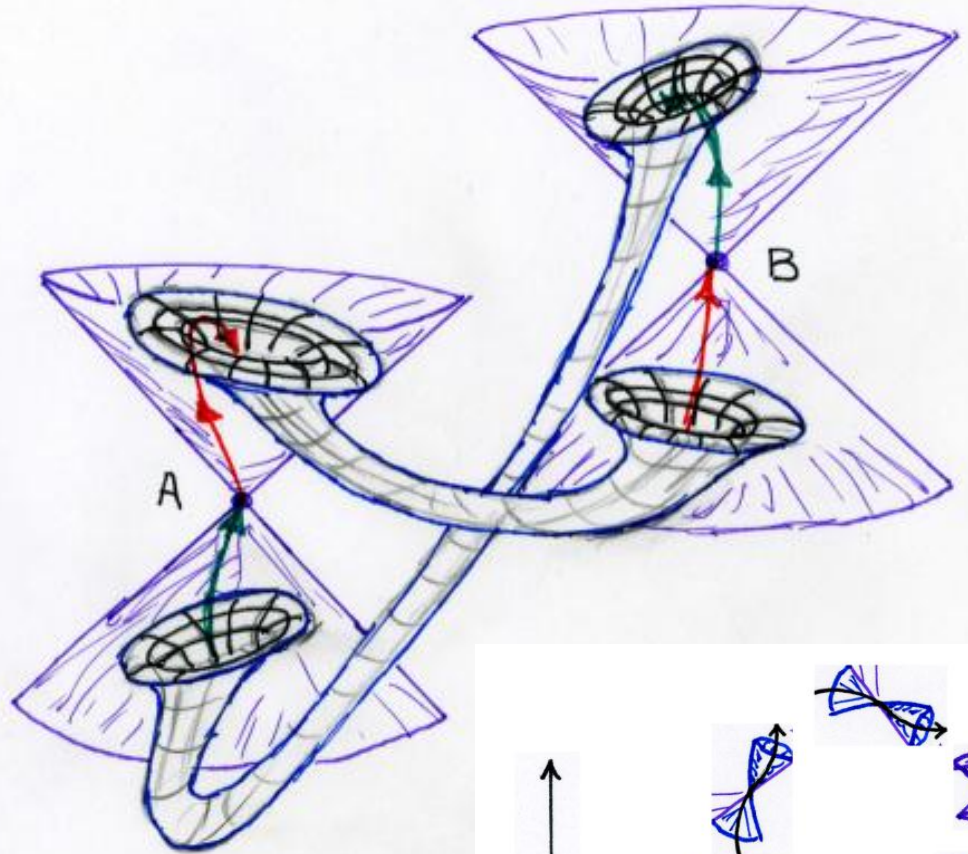
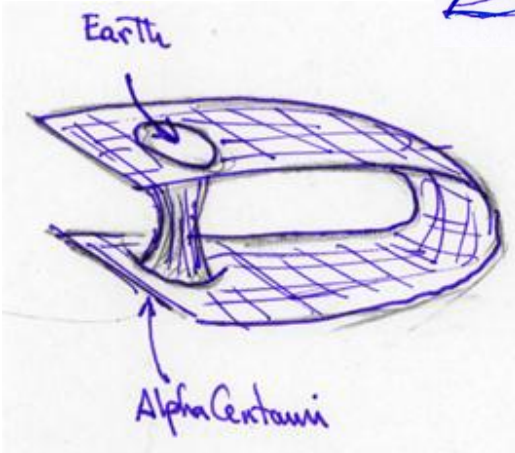
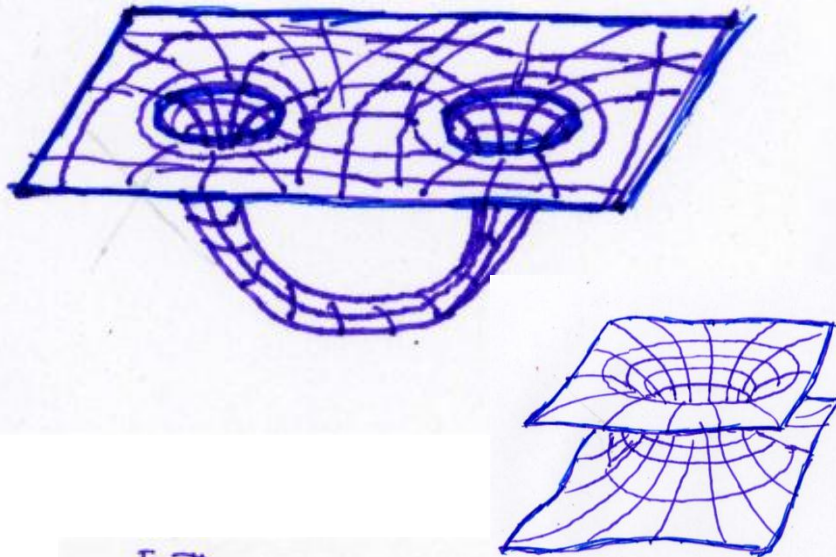
Only if there is time. ☺



# Curved Spacetime: Collapsing Stars



# Wormholes and Time Travel



# Draft of Spoken Thought

When asked "what is time?" words...  
Other questions - No, Age of Univ?  
Answer - rely on history of physics  
from Galileo to Einstein  
Newtonian Mechanics (abstract)  
to Einstein's relative time  
from abstract to atomic clocks  
GPS  
WE KNOW  
Macroscopic - progress Past → Future  
Seen by - puddle → ice  
broken egg → whole egg  
⇒ Arrow of time  
order → disorder/entropy  
Saddle of Universe  
will ~~expanding~~ univ collapse  
What is Age? - Independent measurement  
of Cosmo. models  
Look at Stars - look back in time  
follow light from  
moon, sun, galaxies  
Models based on Einstein's work  
Abstract → GPS  
moving clocks tick slower  
gravity slows time  
Cosmological Principle  
20's - Universe Expanding

Friedmann ~~Model~~ Egn from GR  
Expansion rate depends on amount of stuff  
radiation, matter (atoms/dark), dark energy,  
curvature  
Based on Exptal Evidence  
Latest results (just out) ....  
Frontiers of Time - More questions  
Left Script at home