Max-Planck-Institut für Astrophysik

MPE

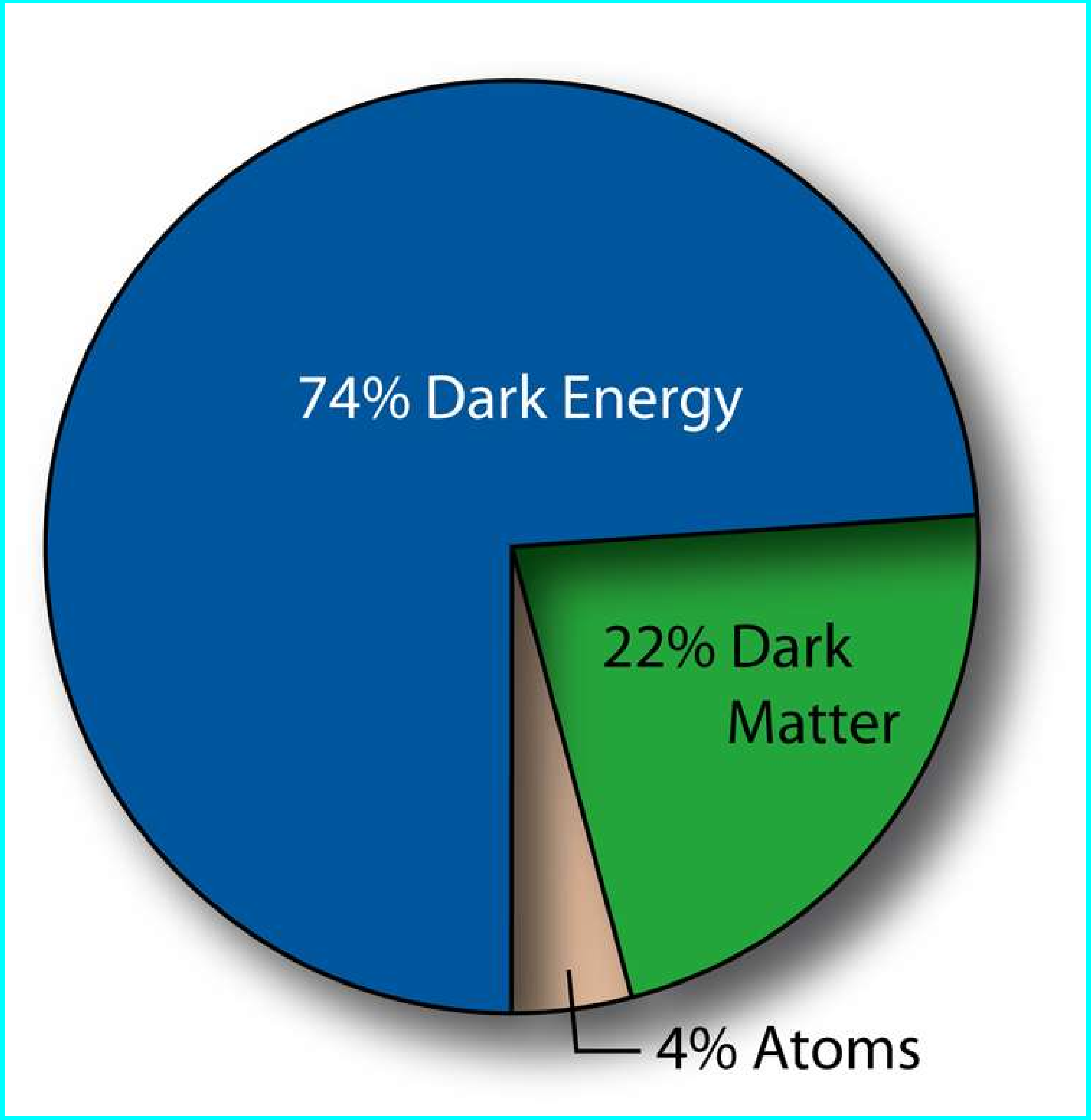
Advisor-Seminar Astrophysik, TUM, Sommersemester 2006

The Dark Universe

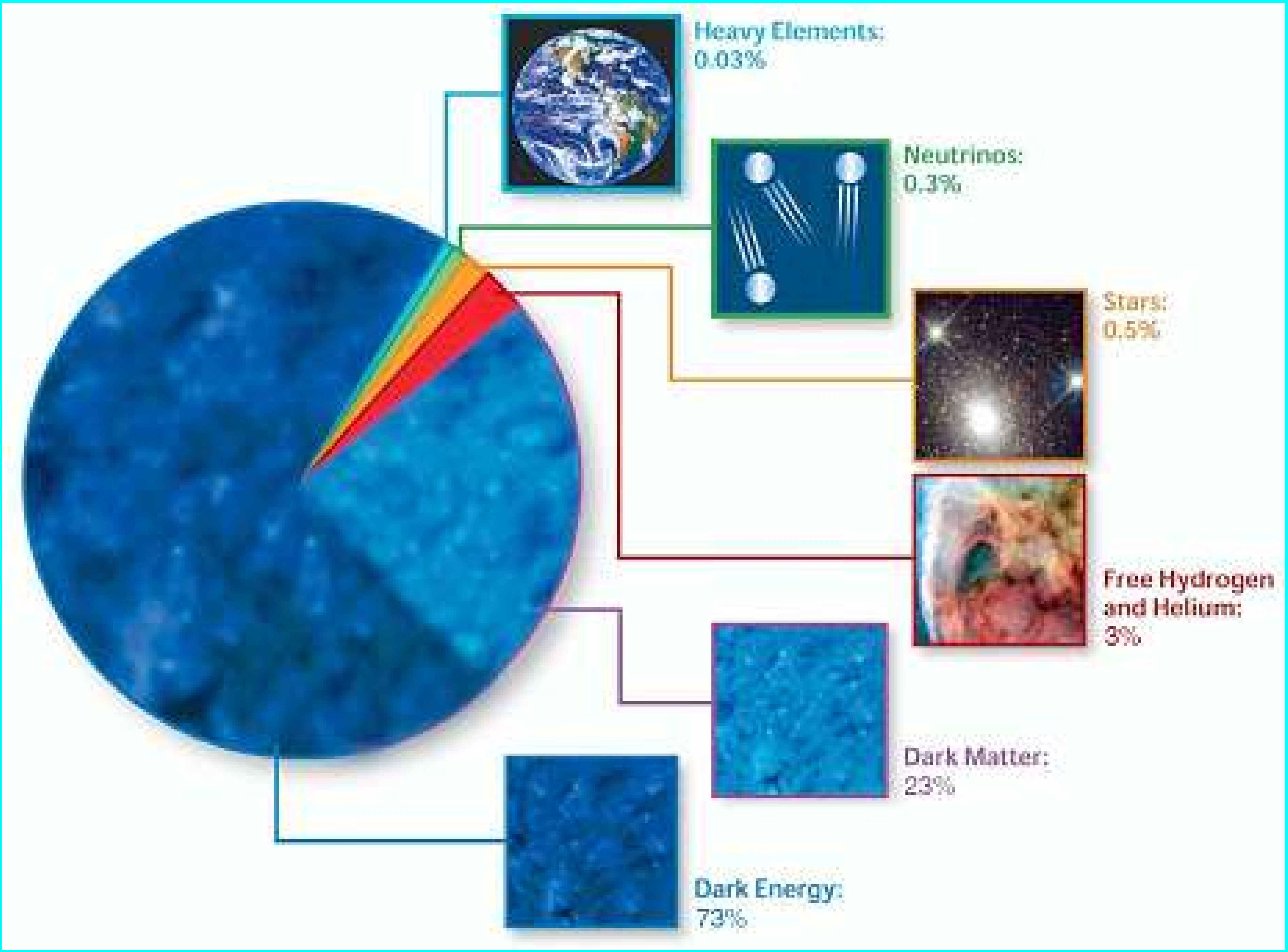
Questions

- How did the universe evolve?
- What does the universe consist of?
- How can we explore the past of the universe by observations?
- How can we model the evolution of the universe?
- How can we learn about invisible objects and processes in the universe?

The dark side of the universe

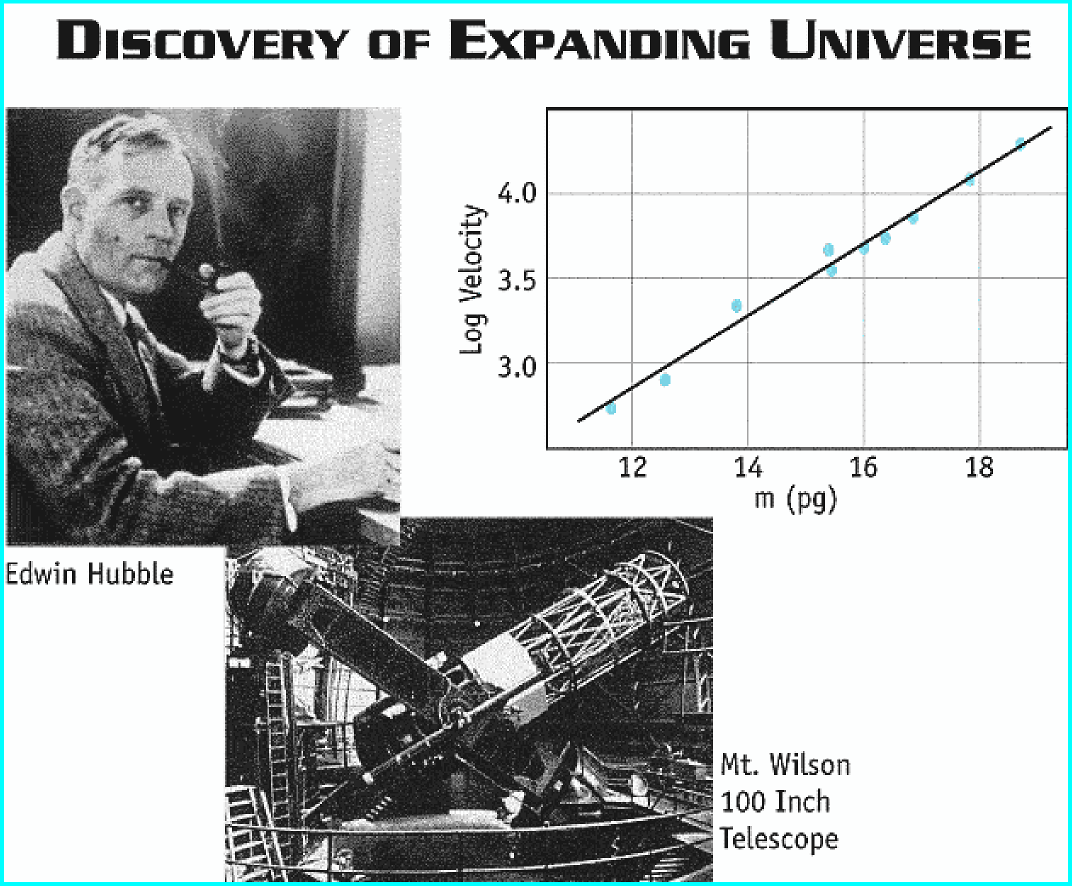


The dark side of the universe

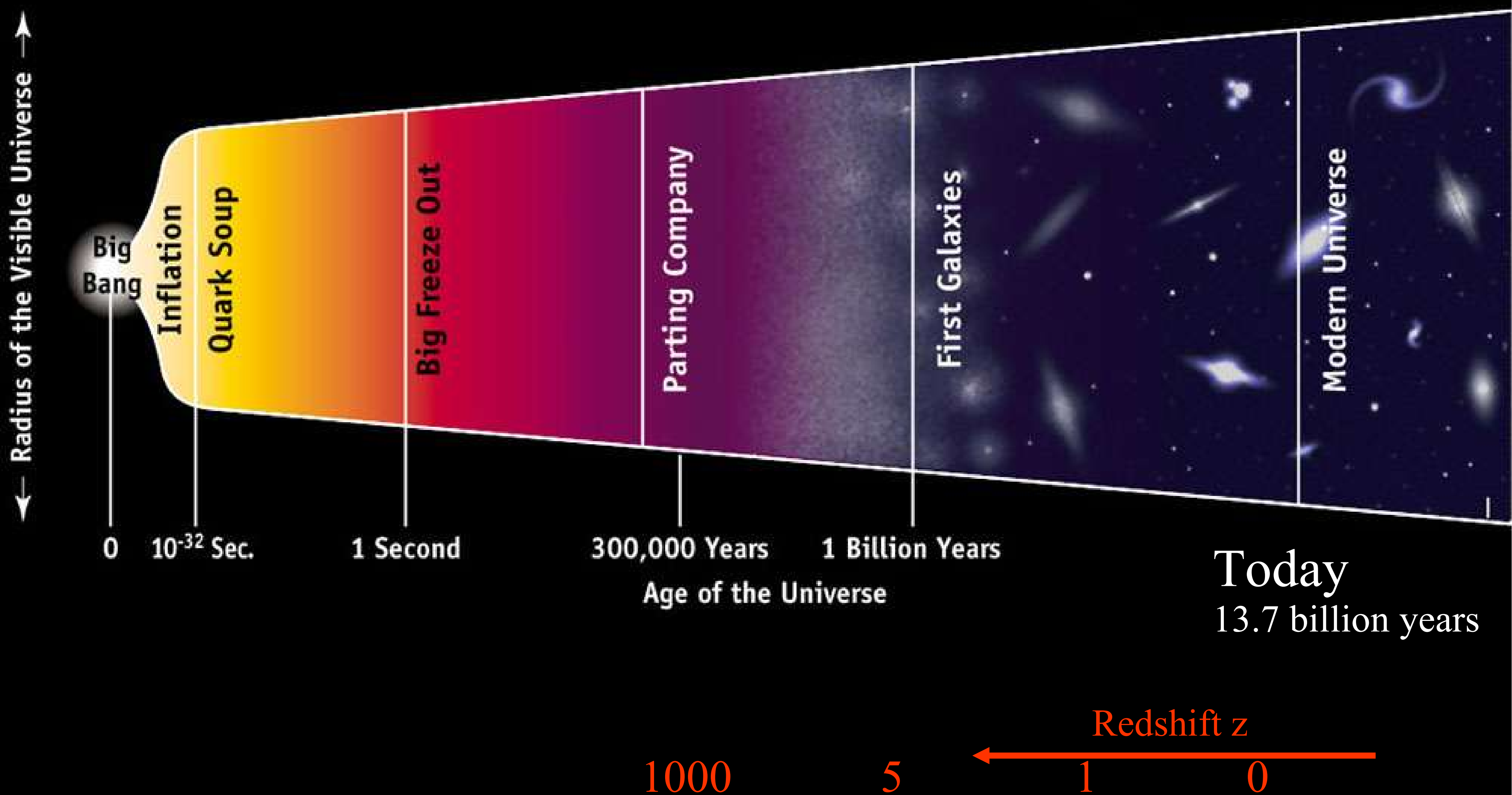


Big Bang cosmology

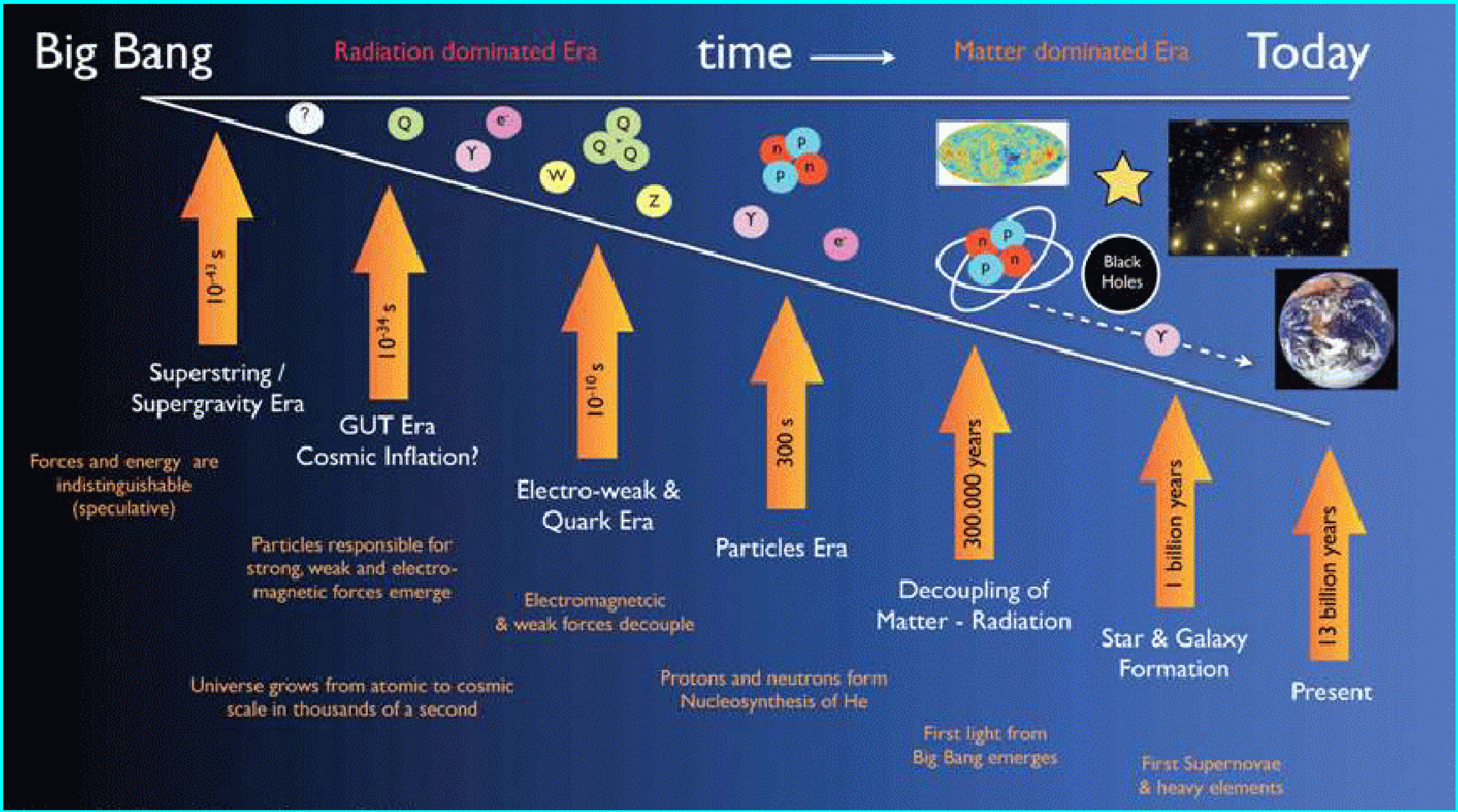
- The universe expands: Hubble flow
- It started out very hot: Cosmic microwave background
- Upon cooling, the fundamental forces, particles, and light chemical elements “froze out”



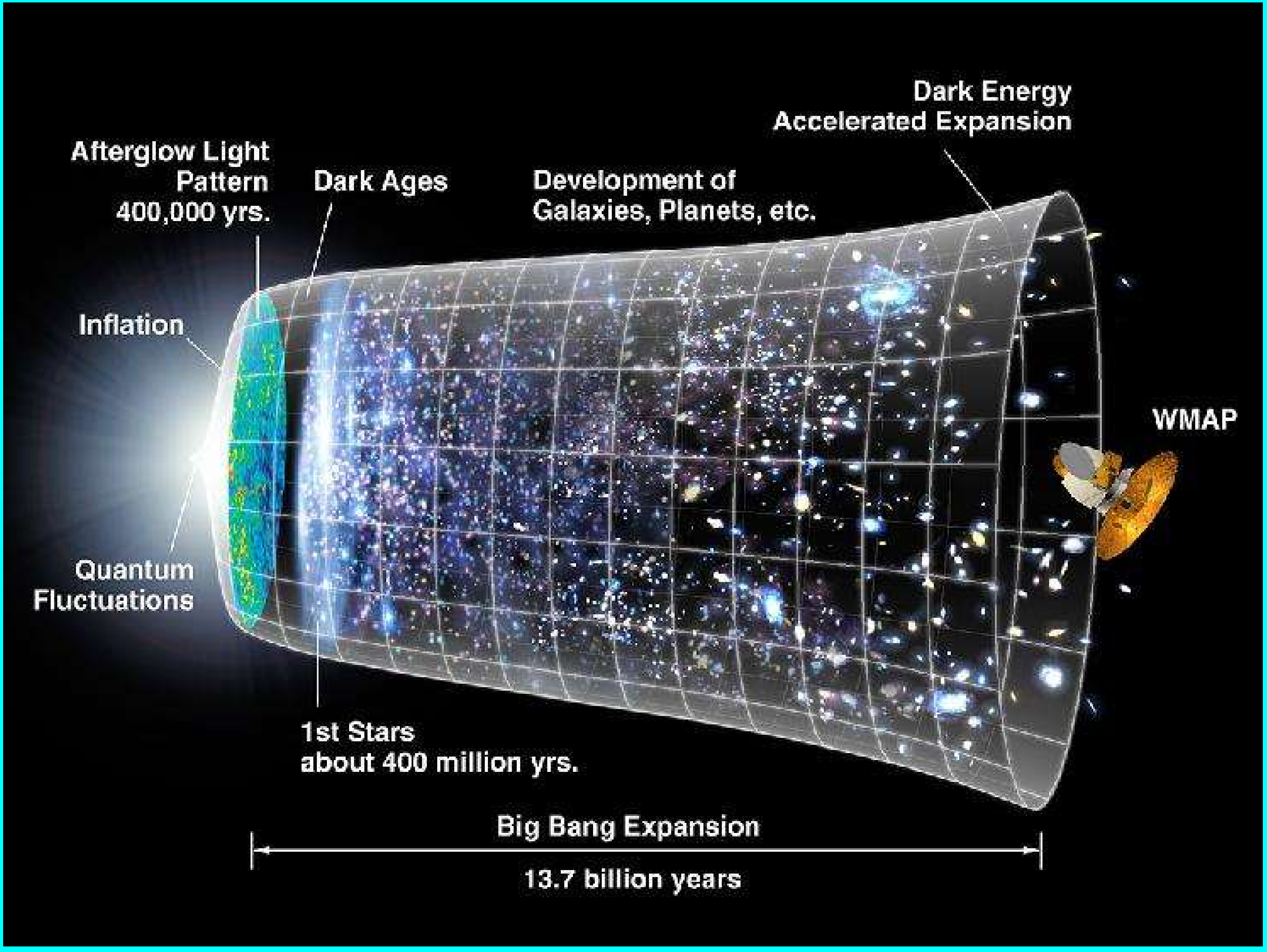
The cosmic time table



The cosmic eras

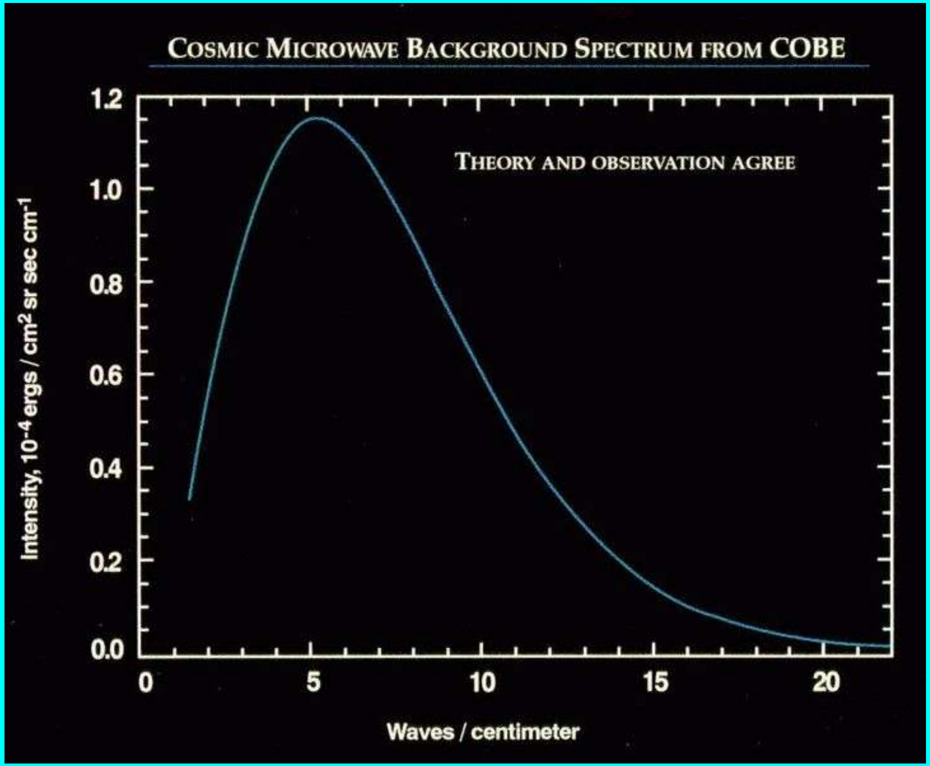


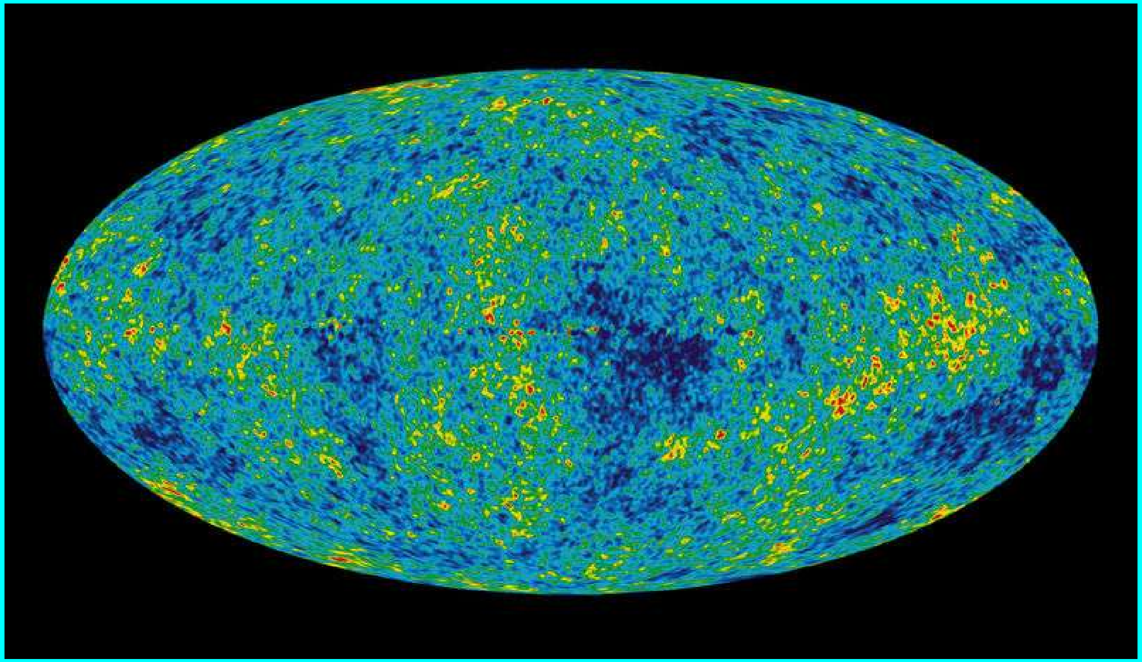
The cosmic microwave background



The cosmic microwave background

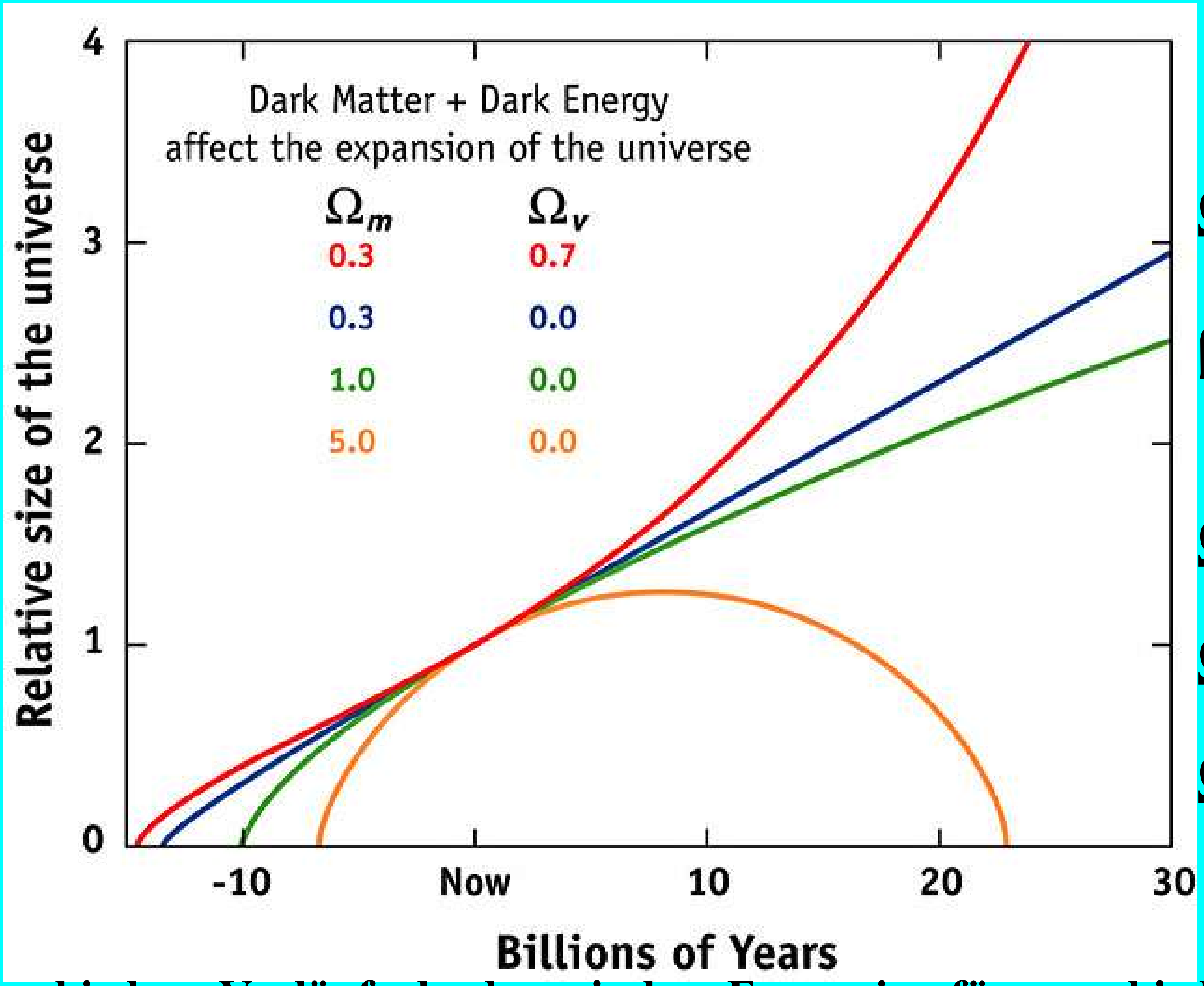
- CMB spectrum is perfect black body
- spatial fluctuations on level 10^{-5}





WMAP measurements

Expansion of the Universe



$\Omega = \rho/\rho_{crit}$

$\rho_{crit} \approx 6\ H/m^3$

$\Omega > 1$ geschlossen

$\Omega = 1$ flach

$\Omega < 1$ offen

Verschiedene Verläufe der kosmischen Expansion für verschiedene Werte für die Energiedichte der Materie (Ω_m bezeichnet die Summe aus Dunkler Materie und normaler Materie) und der Dunklen Energie Ω_Λ (NASA)

Cosmic parameters and luminosity distance I

Friedmann cosmology

Assumption:
homogeneous and isotropic universe

Null geodesic in a Friedmann-Robertson-Walker metric:

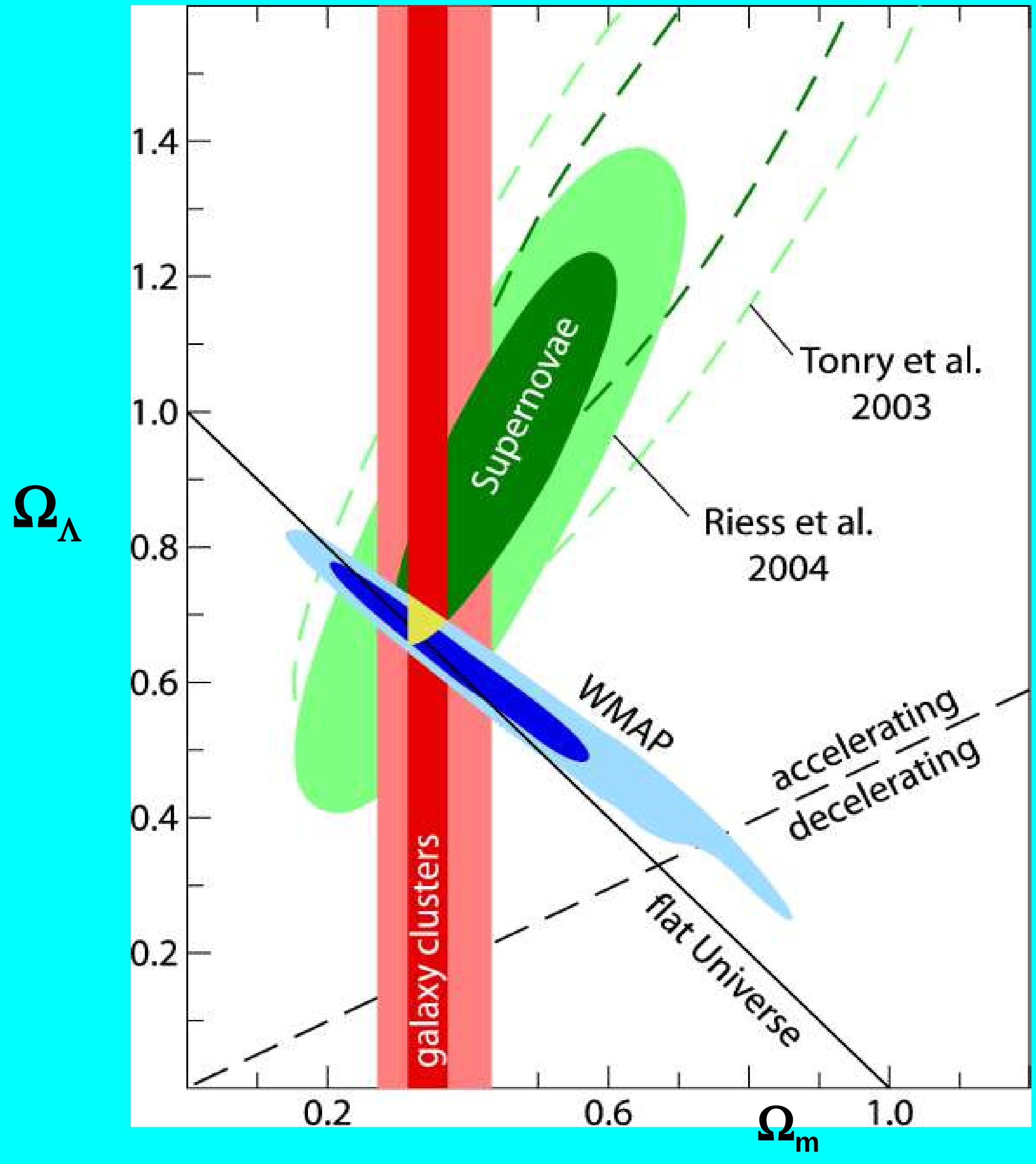
$$D_L = \frac{(1+z)c}{H_0\sqrt{|\Omega_\kappa|}} S\left\{\sqrt{|\Omega_\kappa|}\int_0^z \left[\Omega_\kappa(1+z')^2 + \Omega_M(1+z')^3 + \Omega_\Lambda\right]^{-1/2} dz'\right\}$$

$$\Omega_M = \frac{8\pi G}{3H_0^2}\rho_M$$

$$\Omega_k = -\frac{kc^2}{R^2 H_0^2}$$

$$\Omega_\Lambda = \frac{\Lambda c^2}{3H_0^2}$$

Observational constraints of cosmic parameters



WMAP results from Spergel et al. 2003

REFLEX results from Schuecker et al. 2003 (three weeks before WMAP publication)

Cosmic parameters and luminosity distance II

The equation of state parameter ω

General luminosity distance

$$D_L = \frac{(1+z)c}{H_0\sqrt{|\Omega_\kappa|}} S\left\{ \sqrt{|\Omega_\kappa|} \int_0^z \left[\Omega_\kappa (1+z')^2 + \sum_i \Omega_i (1+z')^{3(1+\omega_i)} \right]^{-1/2} dz' \right\}$$

- **with** $\kappa = 1 - \sum_i \Omega_i$ **and** $\omega_i = \frac{p_i}{\rho_i c^2}$

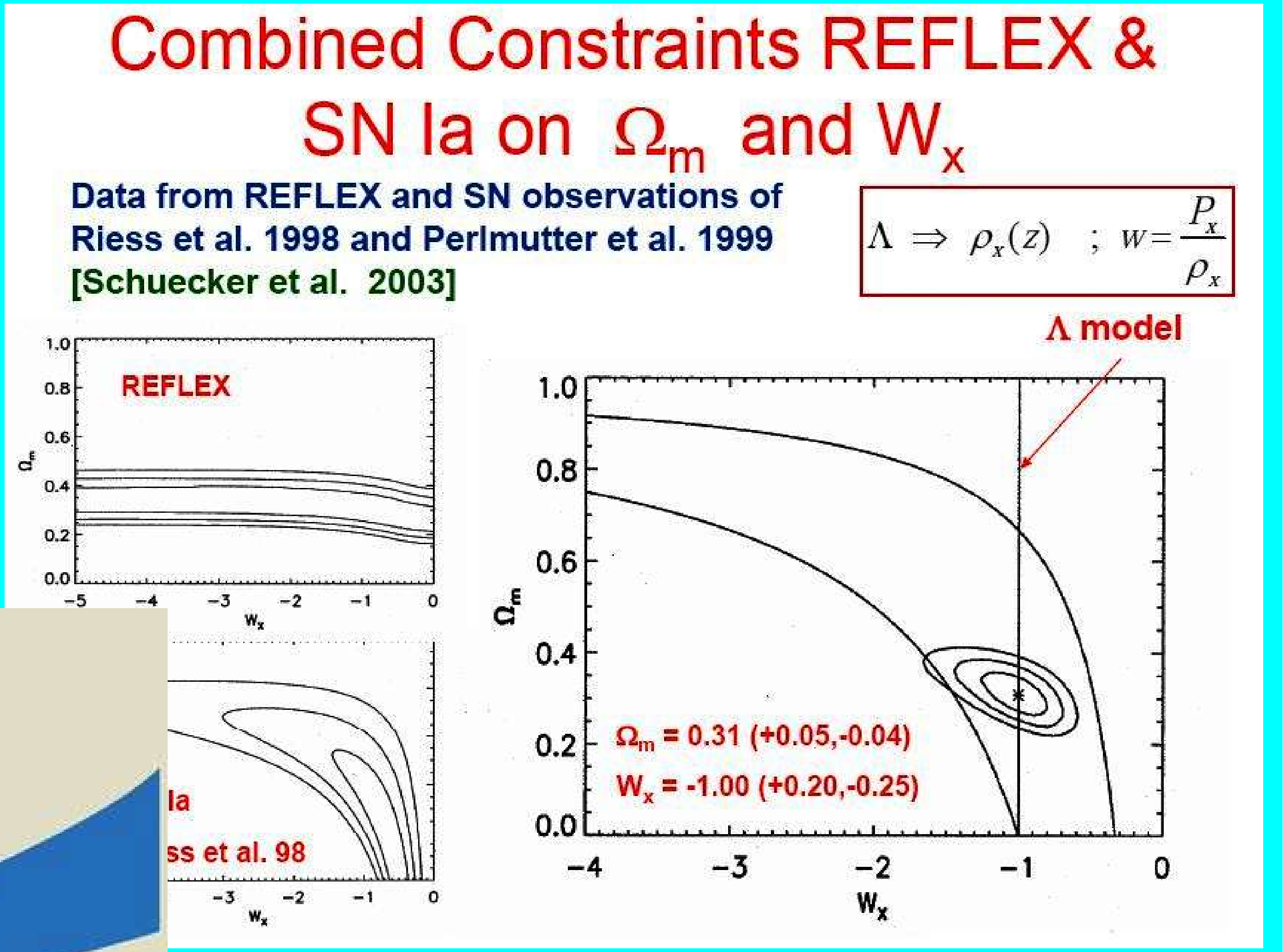
$\omega_M = 0$ (matter)

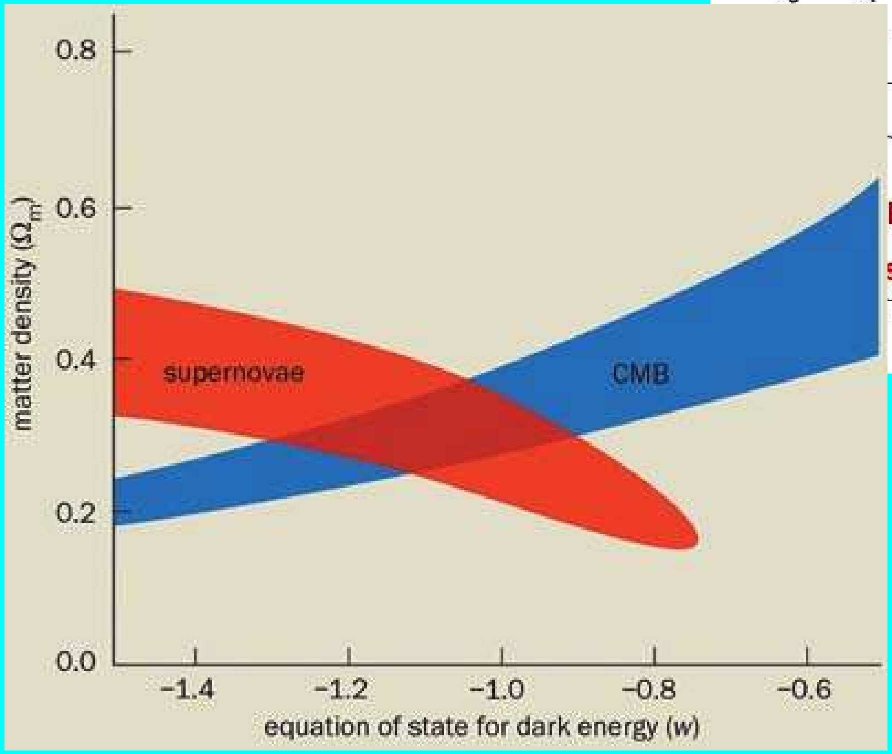
$\omega_R = \frac{1}{3}$ (radiation)

$\omega_\Lambda = -1$ (cosmological constant)

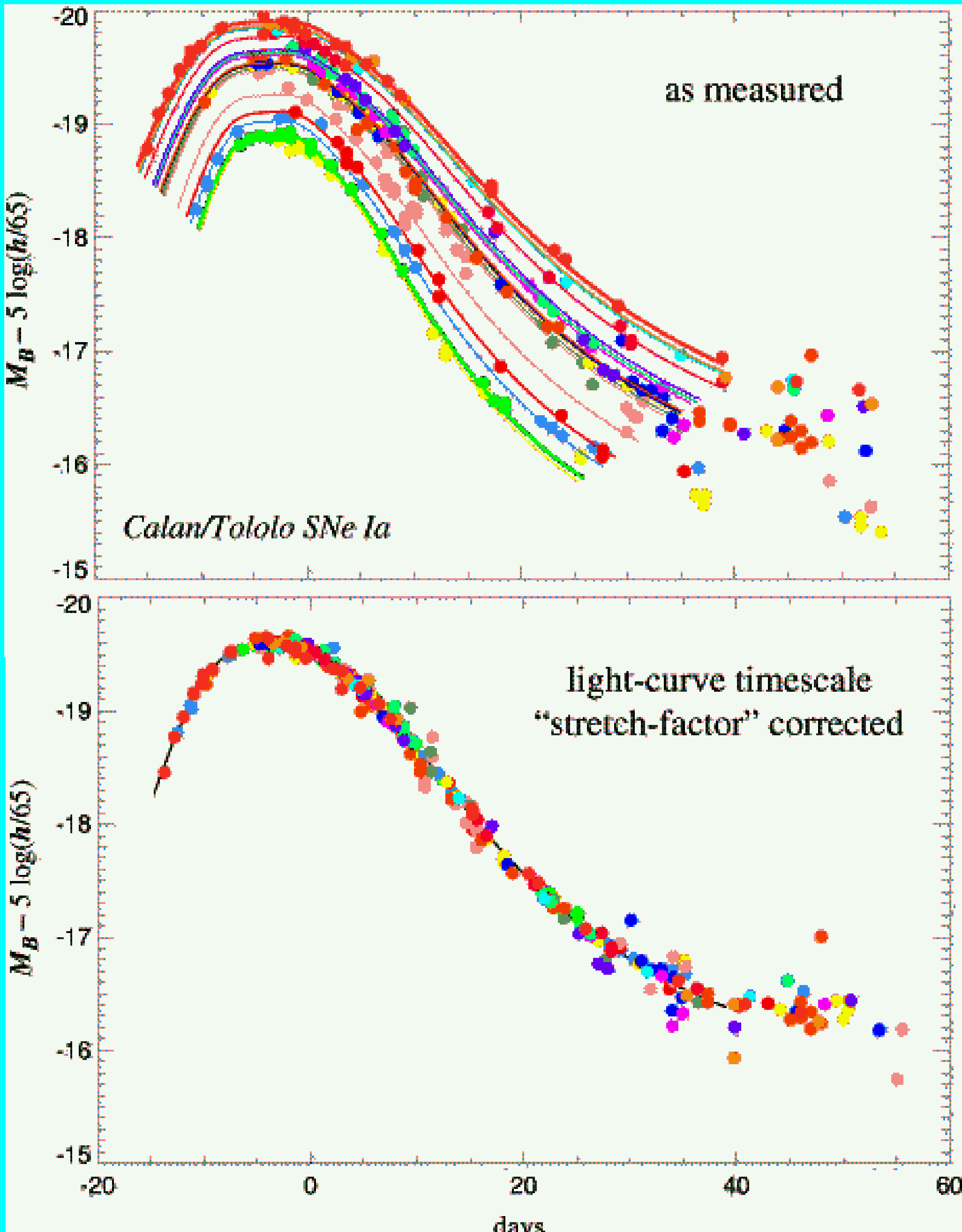
Observational constraints of cosmic parameters

X-ray observations of galaxy clusters and Type Ia supernovae can constrain the "cosmic equation of state"

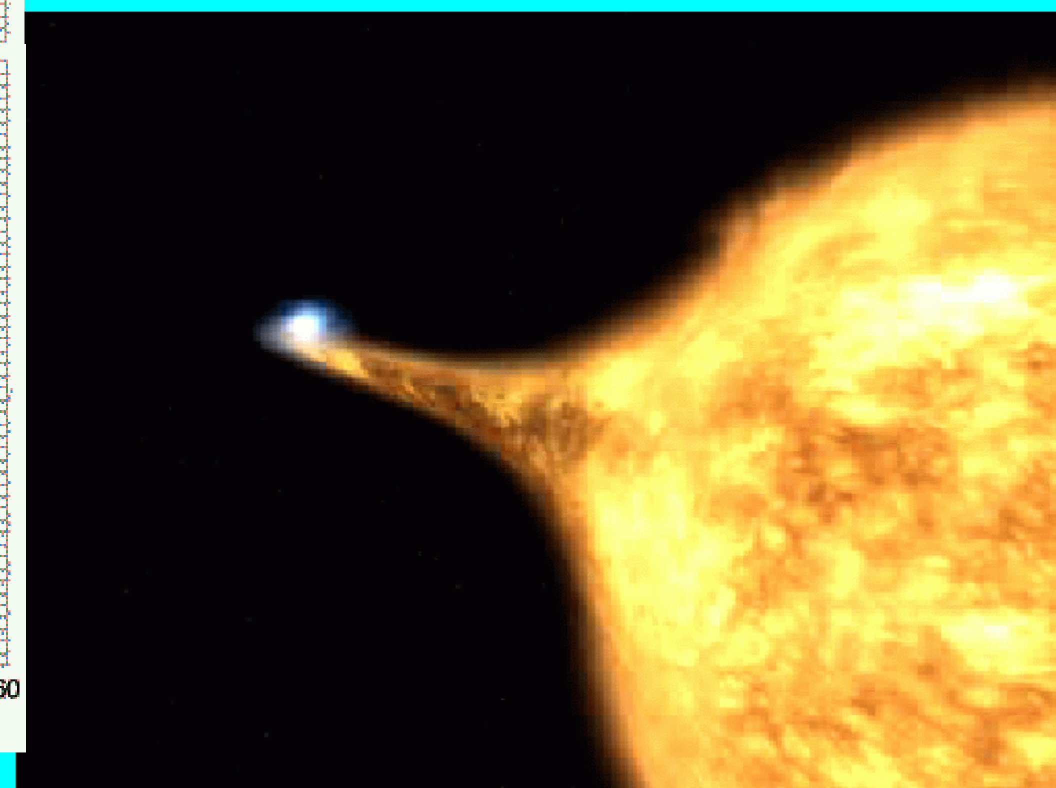




Type Ia supernovae

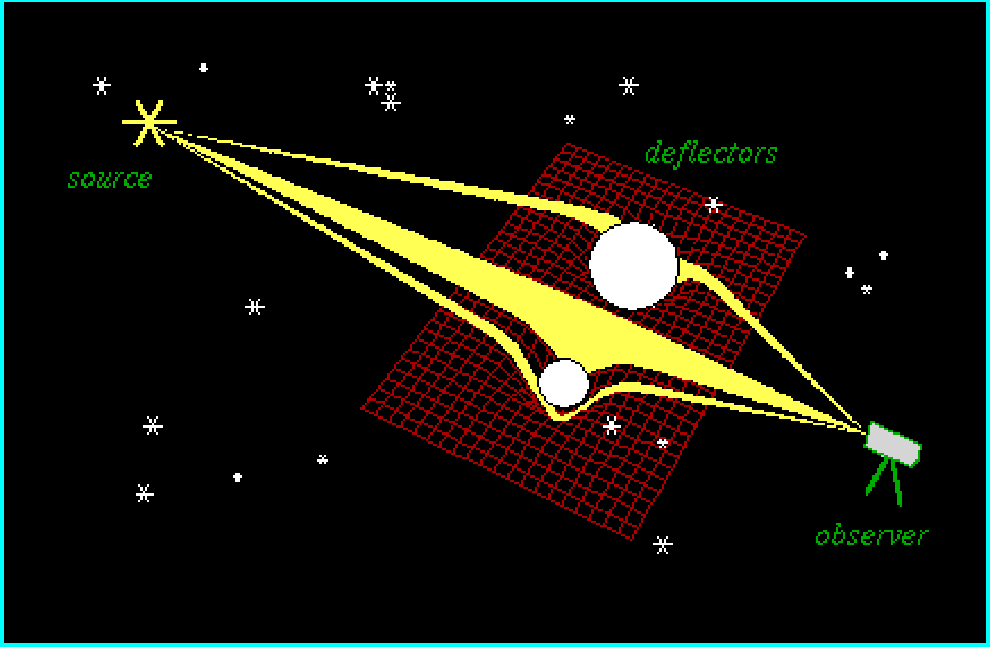


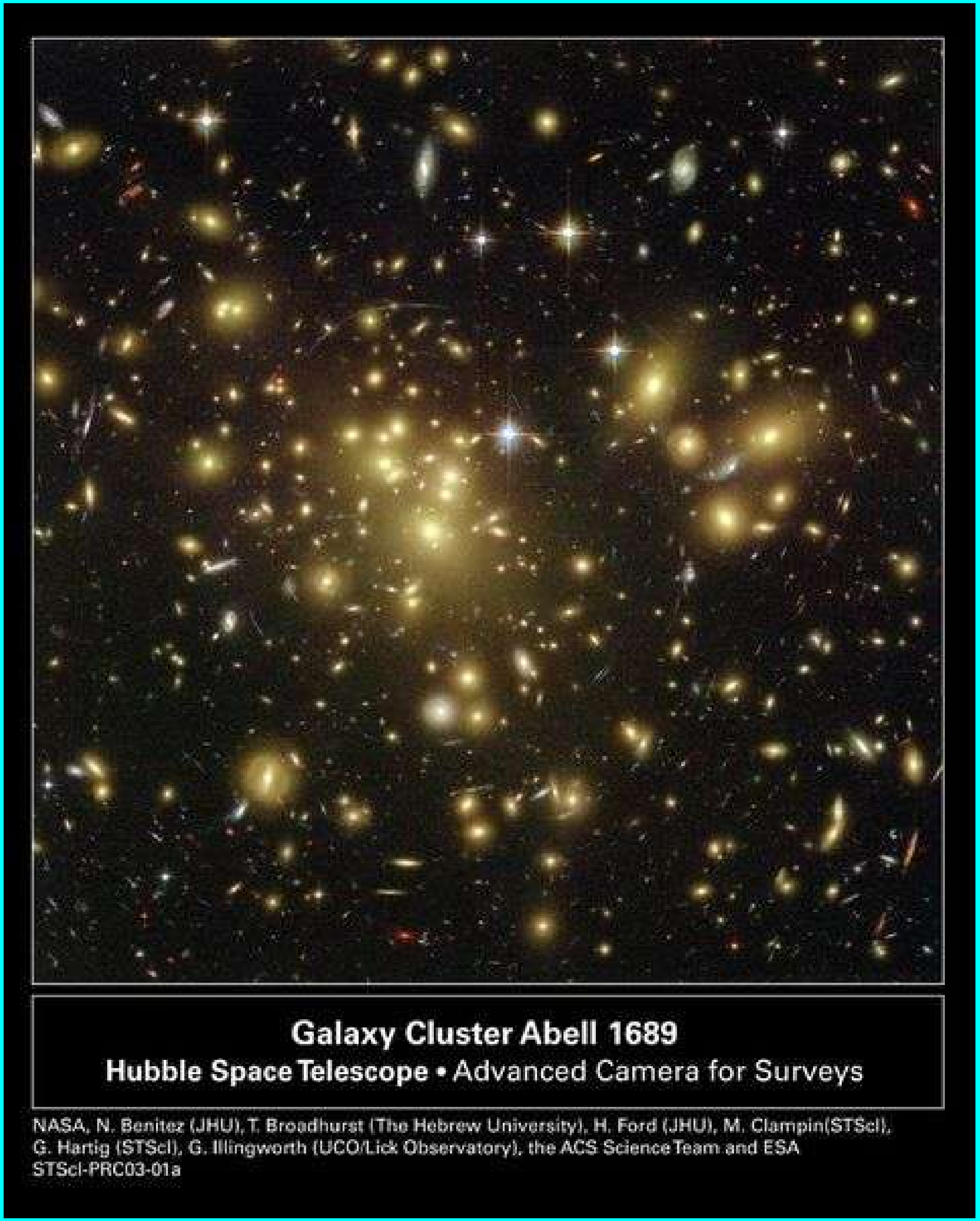
Exploding accreting white dwarfs as "standard candles"



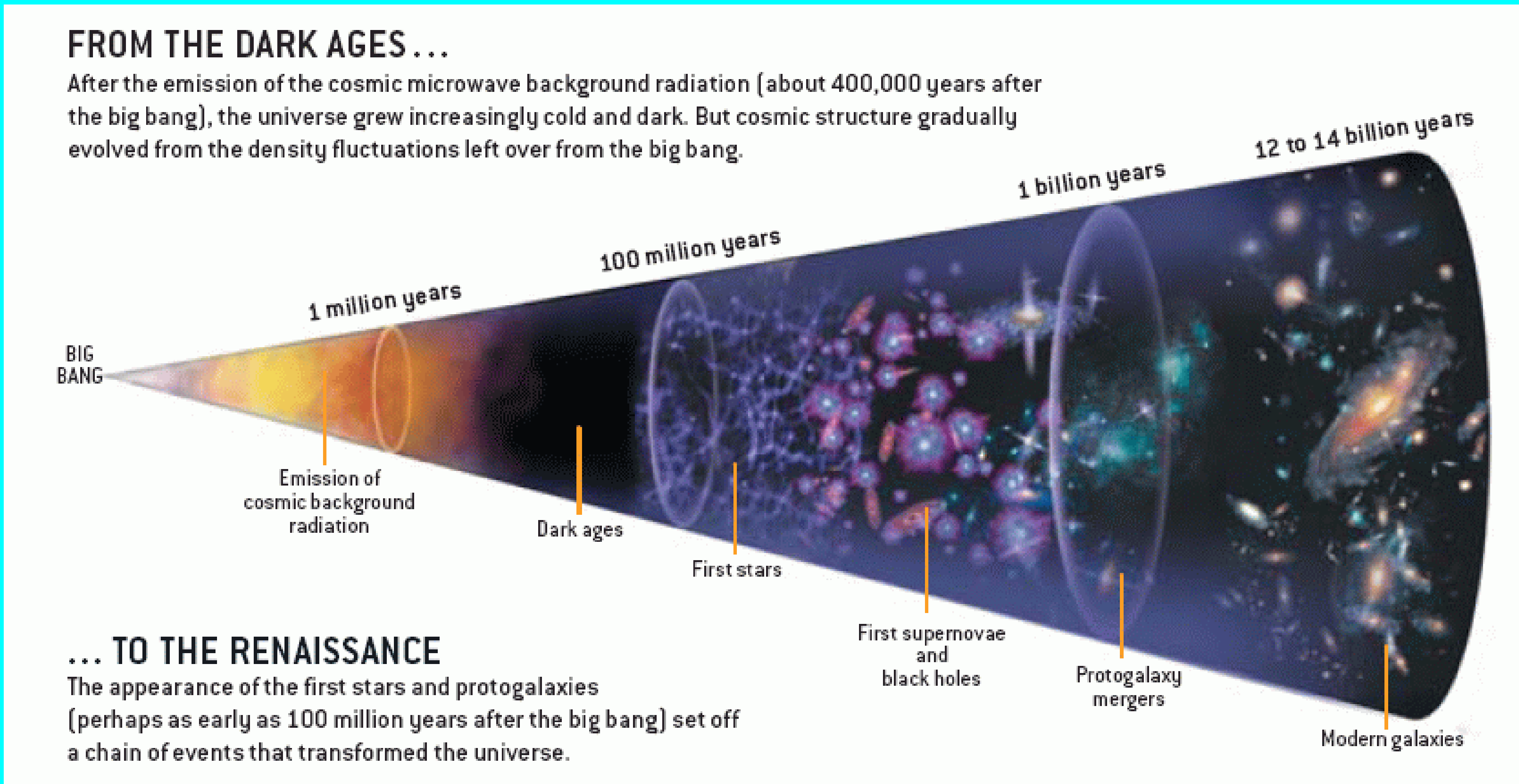
Gravitational Lensing

Weak gravitational lensing by galaxy clusters produces multiple images and arcs for background sources and measures the Dark Matter distribution

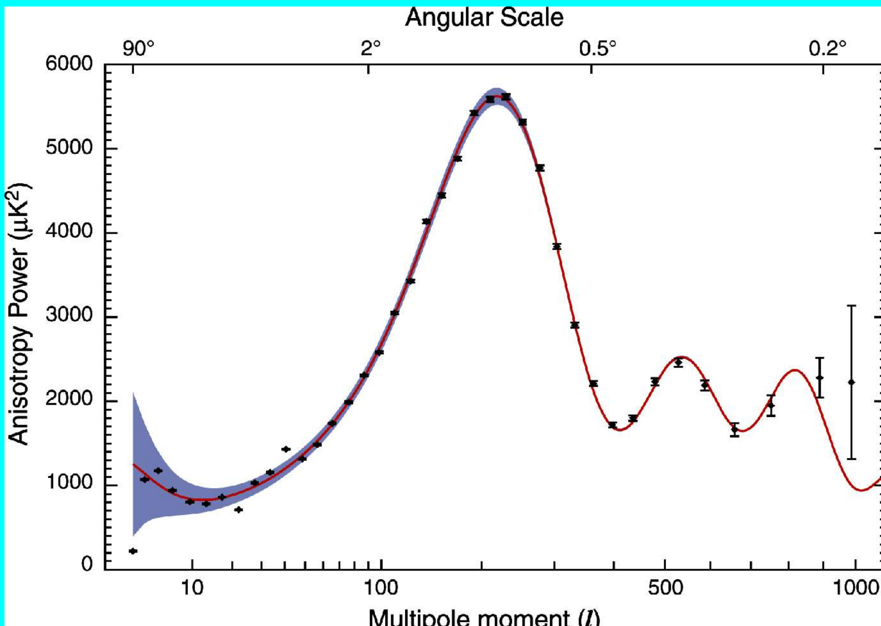


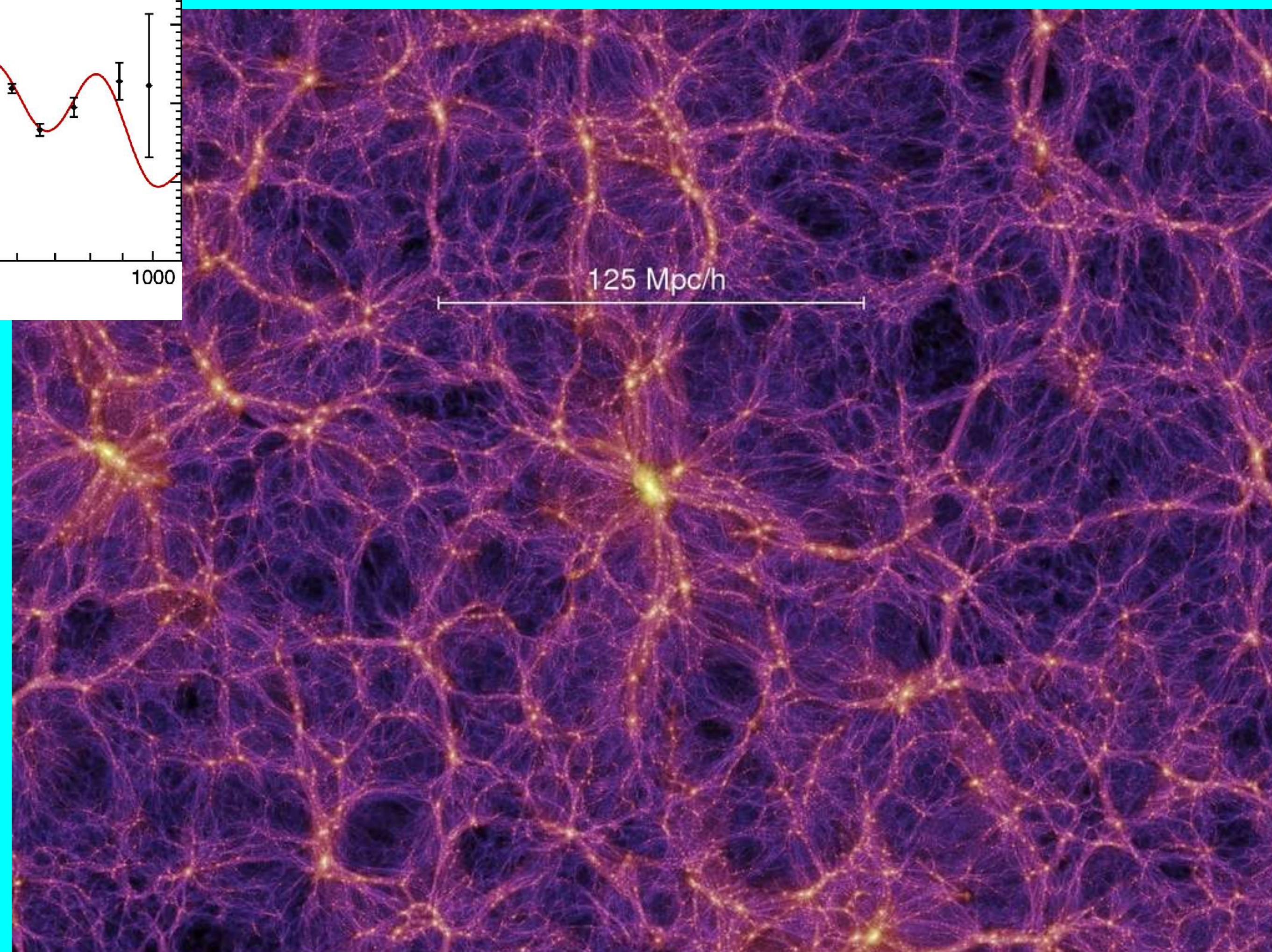


The cosmic structure formation



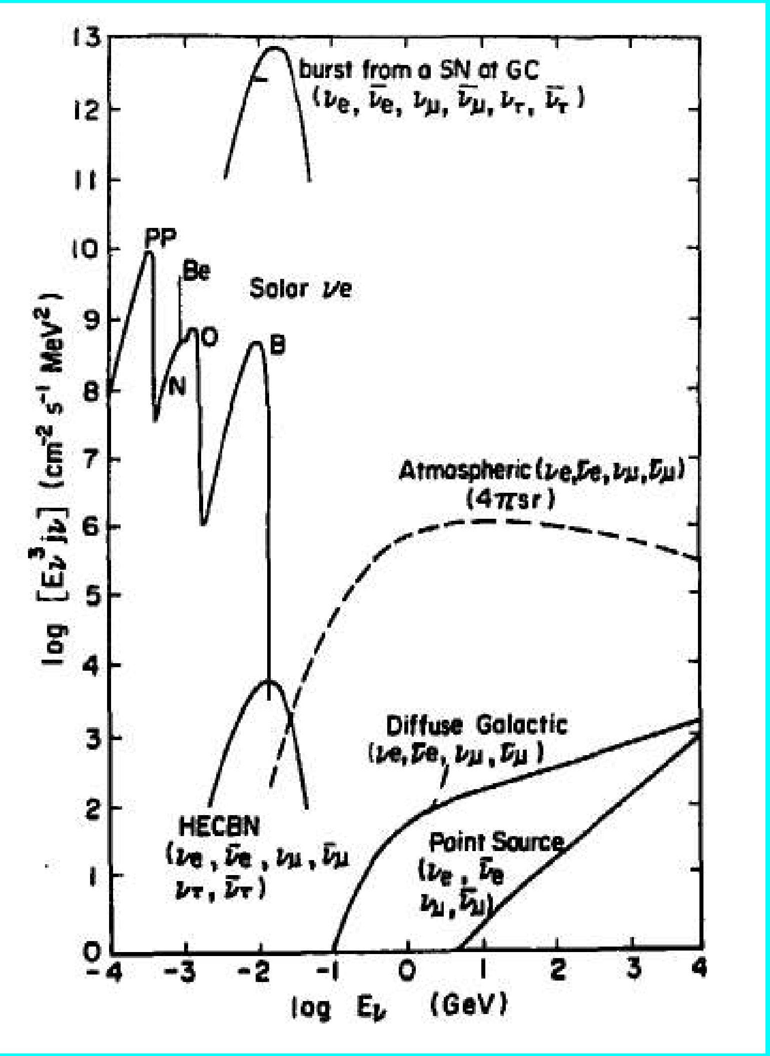
Cosmic structure formation in the computer

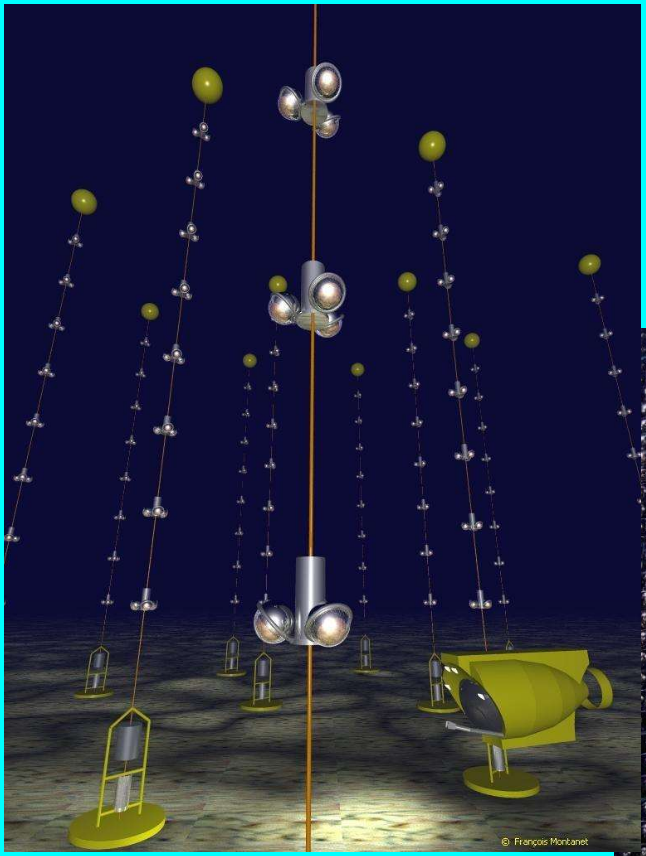


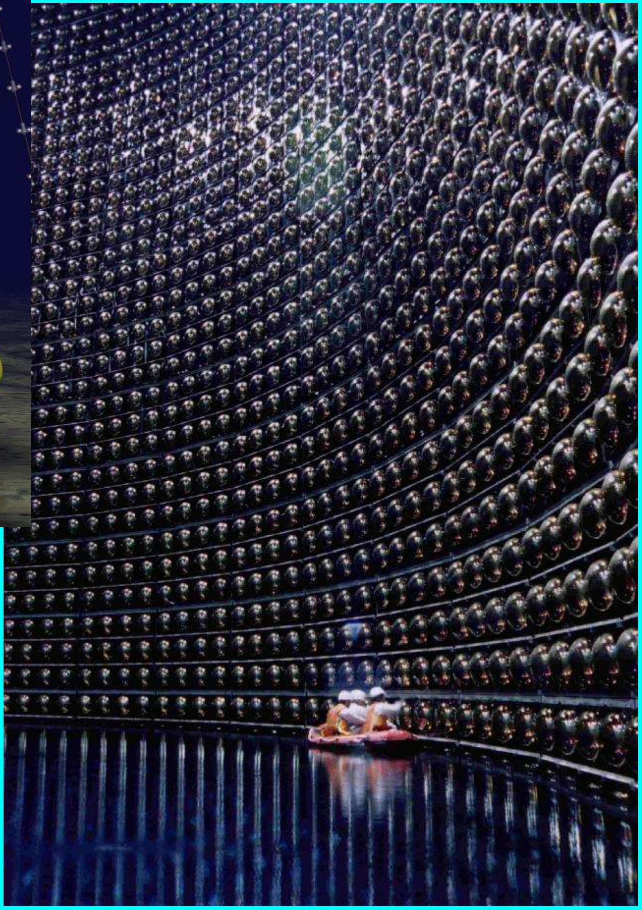


Evolution of clustering of Dark Matter

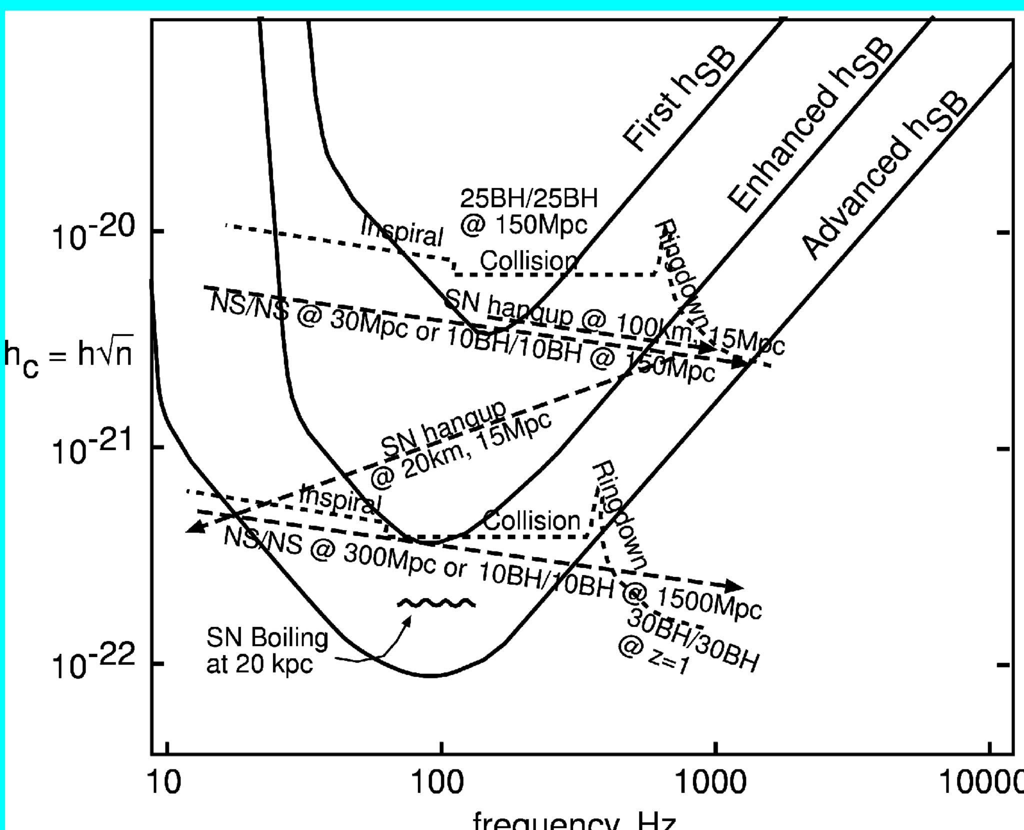
Cosmic neutrino background

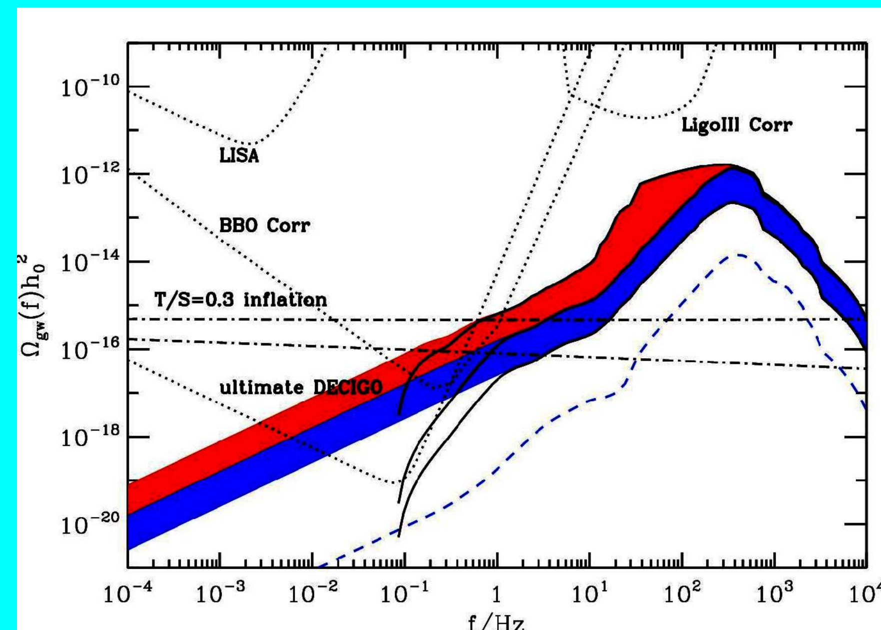




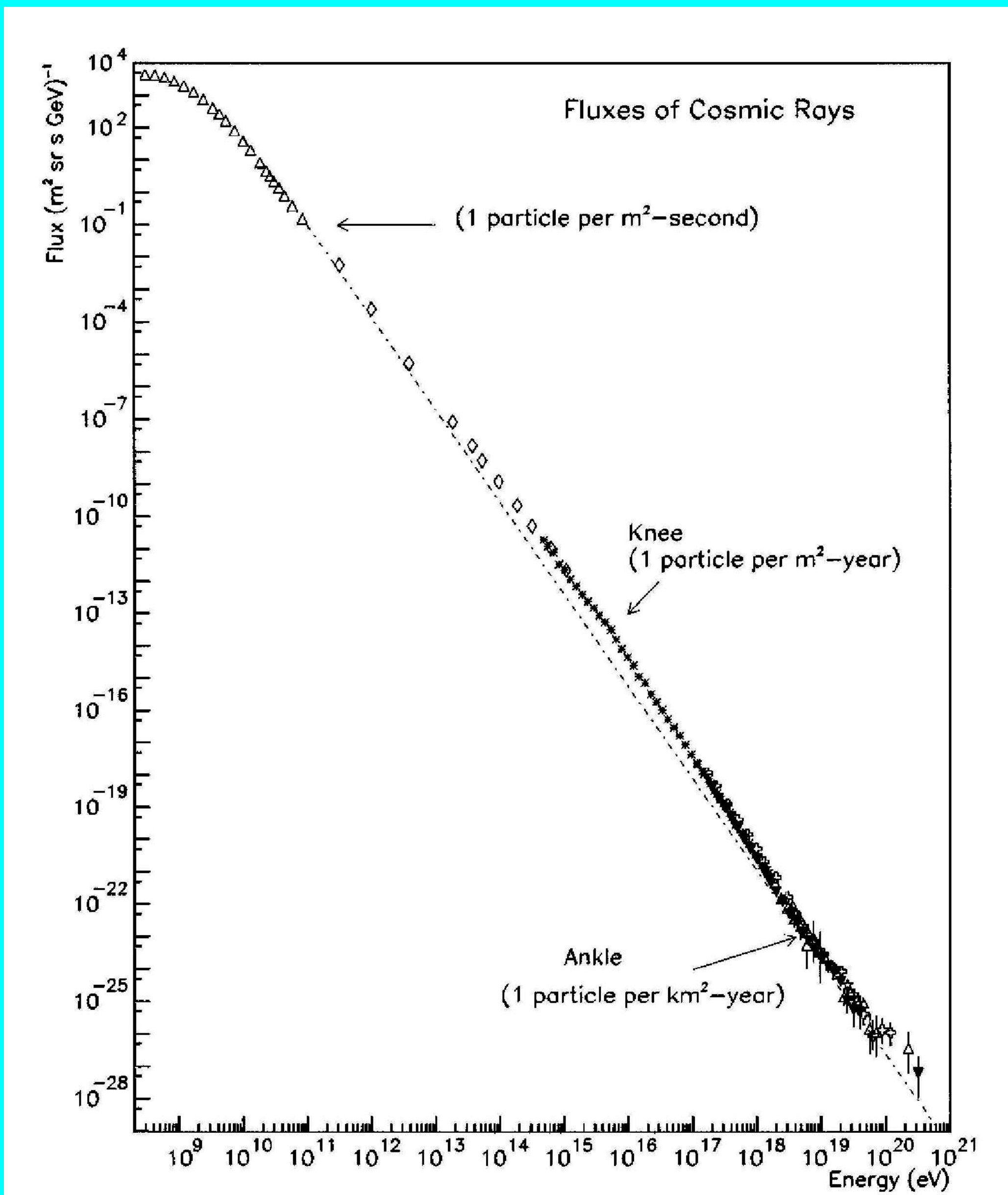


Gravitational wave background

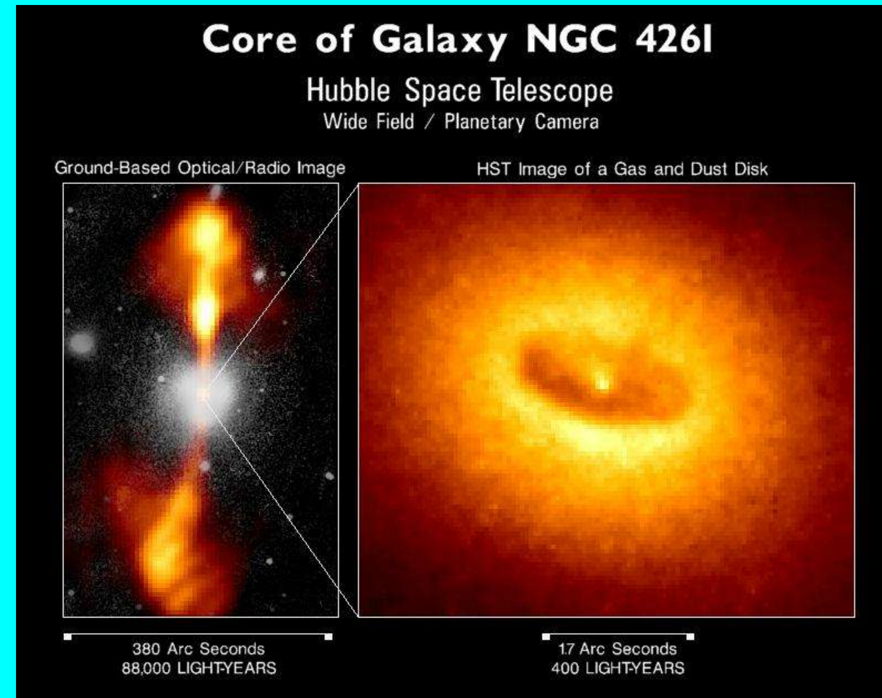




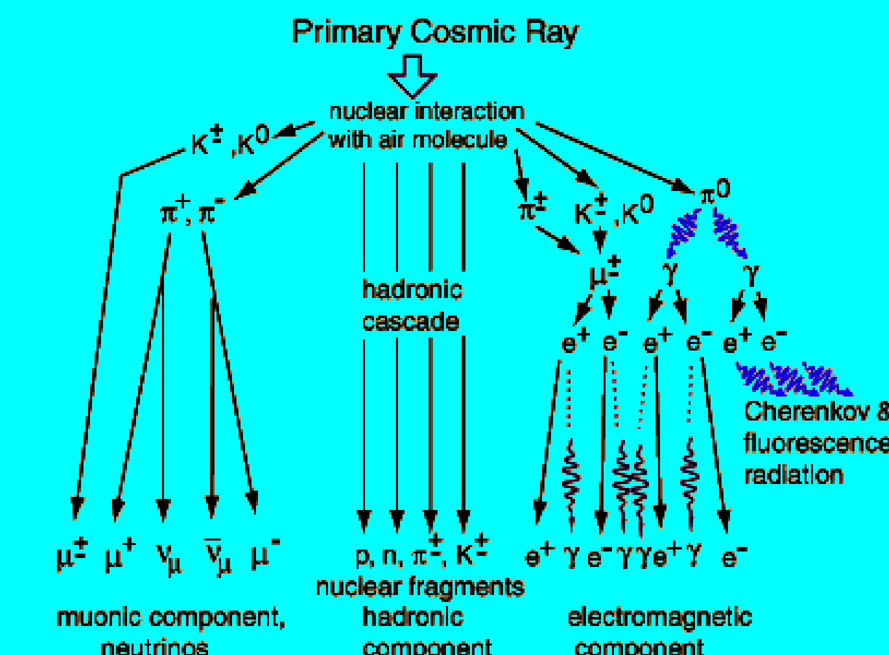
Cosmic Rays



Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Energy (eV)



Core of Galaxy NGC 4261
Hubble Space Telescope
Wide Field / Planetary Camera
Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHT-YEARS
17 Arc Seconds
400 LIGHT-YEARS



Primary Cosmic Ray
nuclear interaction with air molecule
hadronic cascade
Cherenkov & fluorescence radiation
p, n, π±, K± nuclear fragments
muonic component, neutrinos
hadronic component
electromagnetic component