Neutrino Ocillations and Astroparticle Physics (3)

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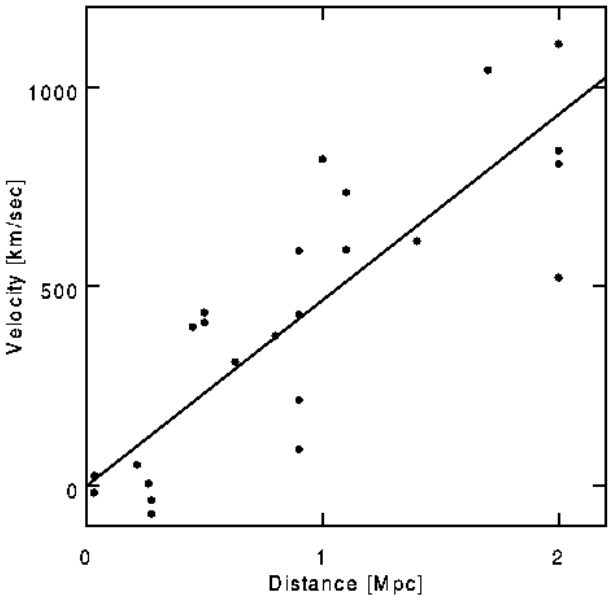
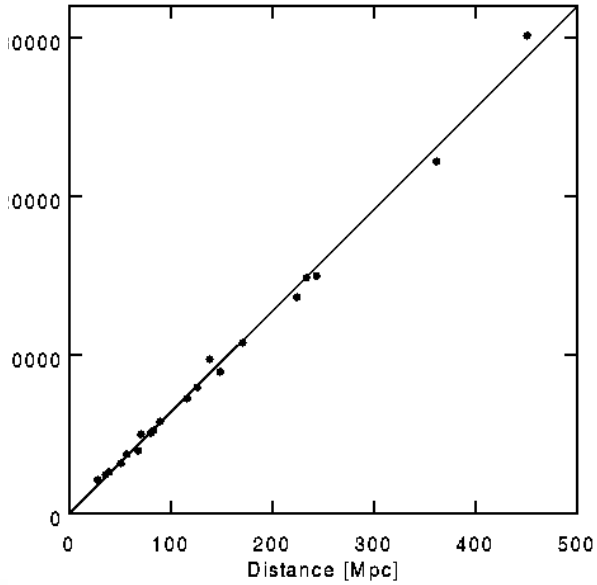
③ Introduction to Cosmology and High Energy Astronomy

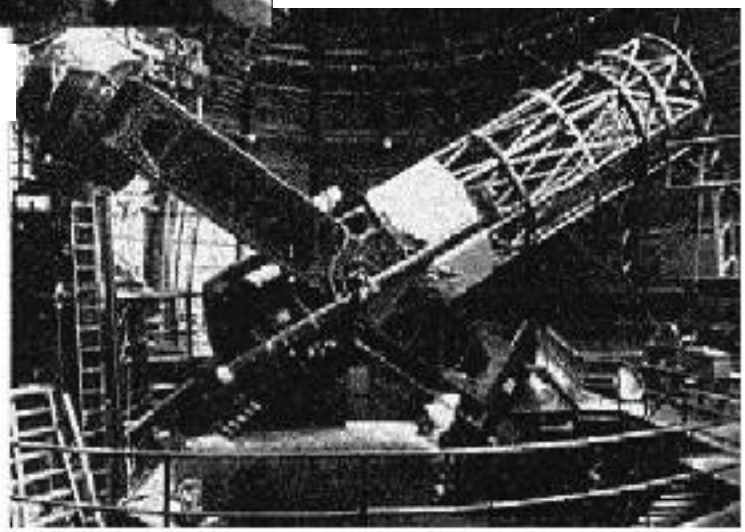
- expansion of the universe
- some astronomy
- some cosmology
- big bang nucleosynthesis
- cosmic microwave background radiation
- SuperNova Type 1a
- Energy composition of universe

Expansion of Universe

Edwin Hubble







Mt. Wilson
100 Inch
Telescope

Velocity of galaxy proportional to distance:

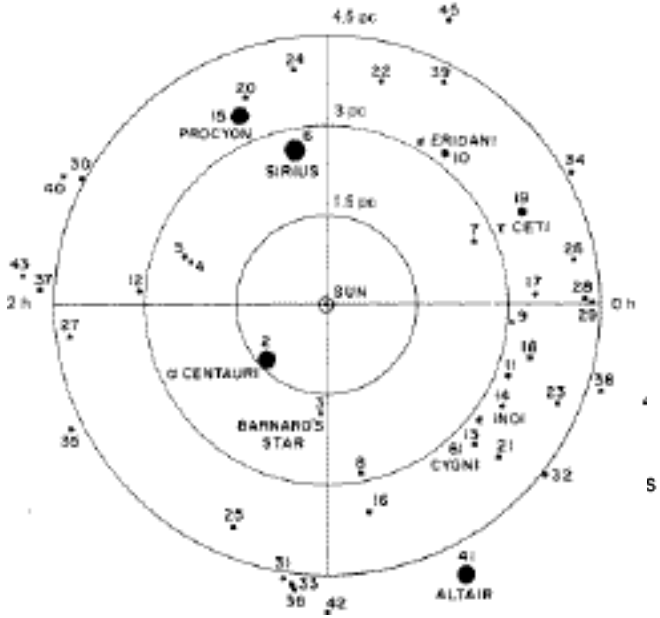
$v = H r$

$H \sim 70$ km/sec / Mpc

Astronomy Scales

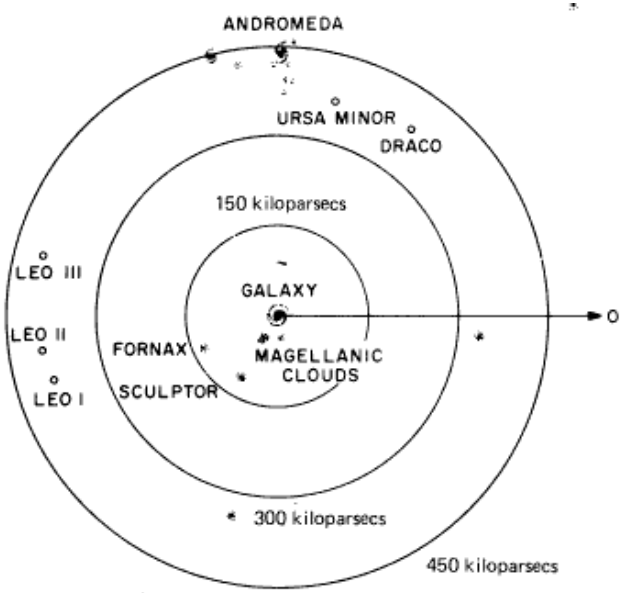
1 pc = 3 light years = 3 10^{16} km

Nearest Stars



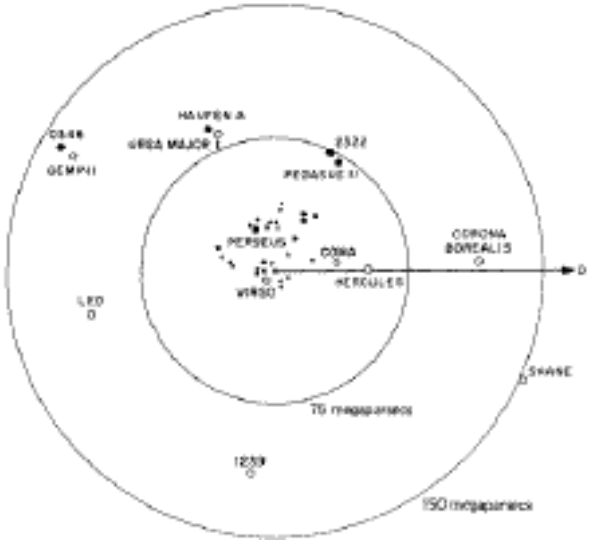
4.5 pc

Nearest Galaxies



450 kpc

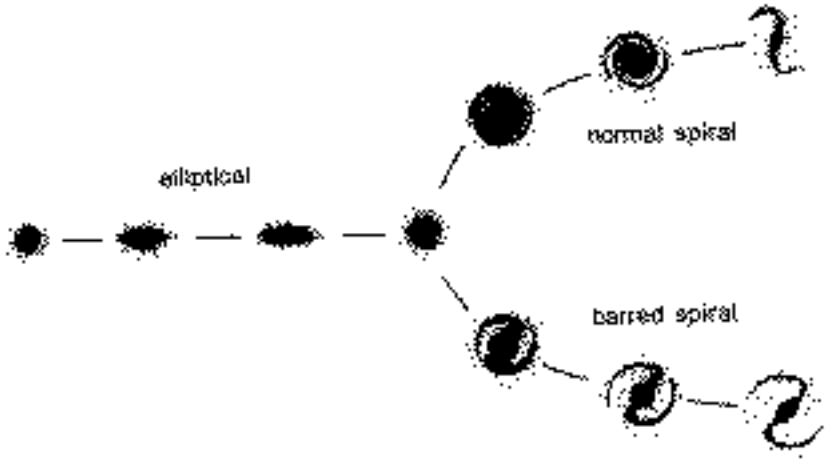
Nearest Galaxy Clusters

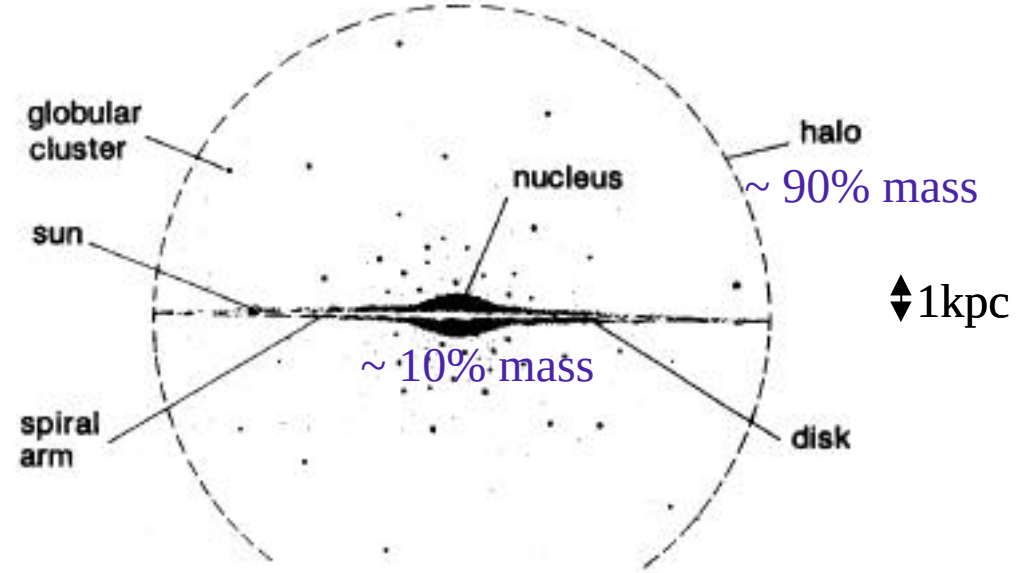


150 Mpc

Galaxies

Spiral (Milky Way)

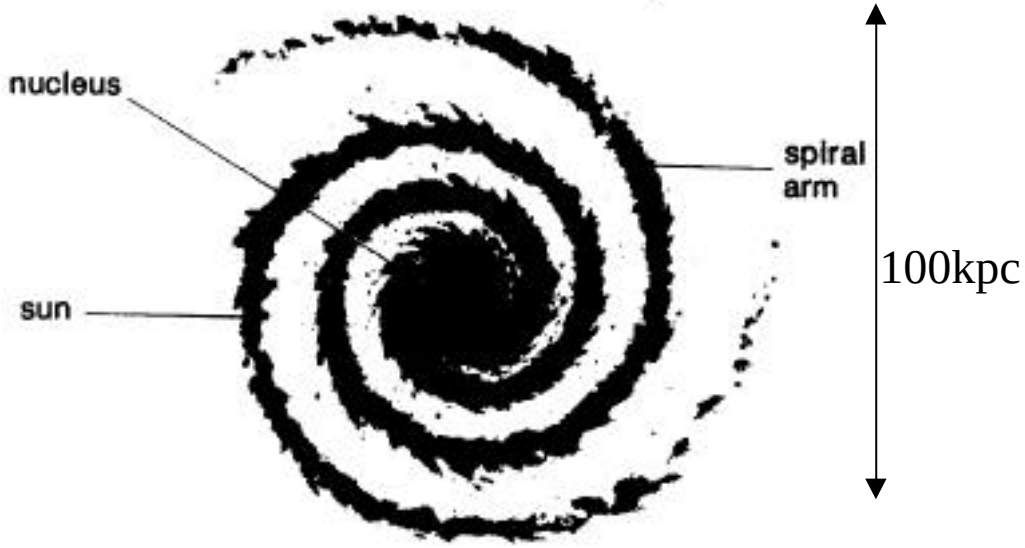




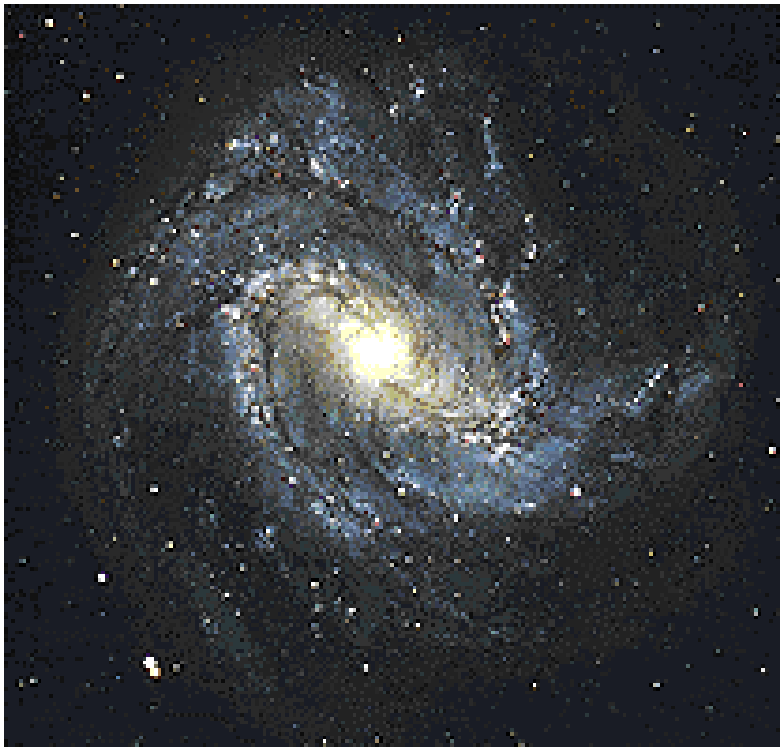
Solar Mass: $M_{\grave{u}} = 2\ 10^{33}g$

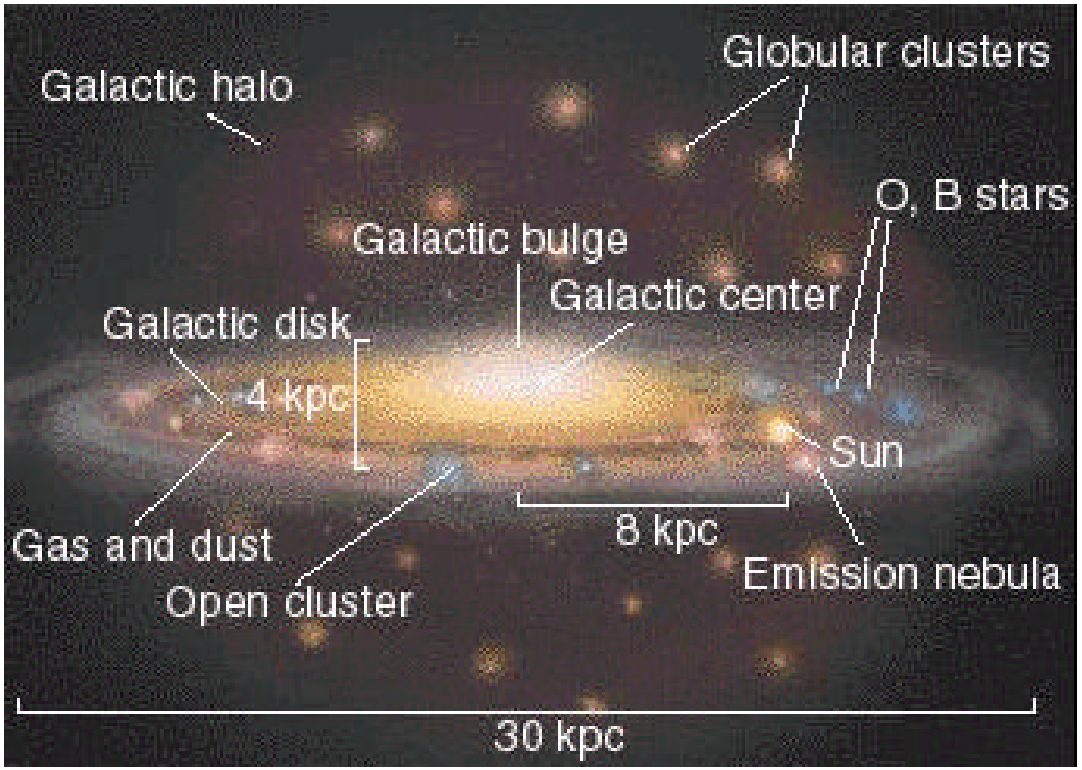
Typical stars mass 1-10 $M_{\grave{u}}$

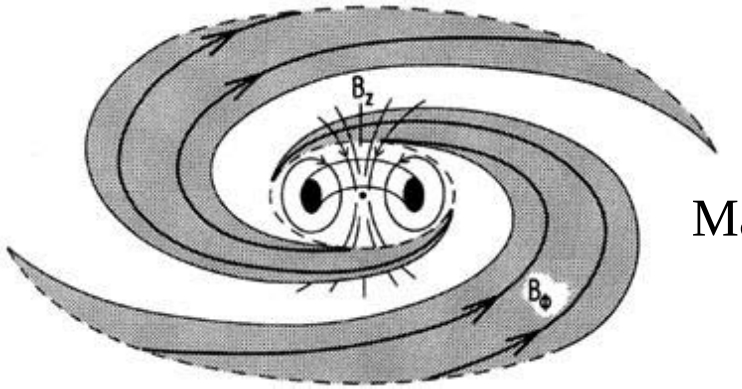
Typical Galaxies 10^6 - 10^{12} $M_{\grave{u}}$



Milky Way Galaxy

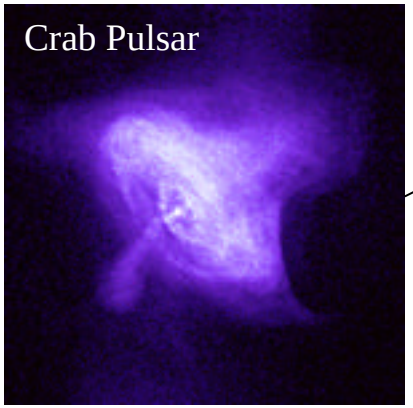


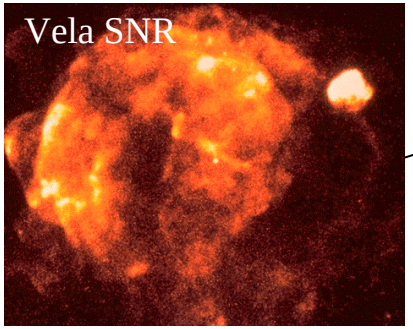


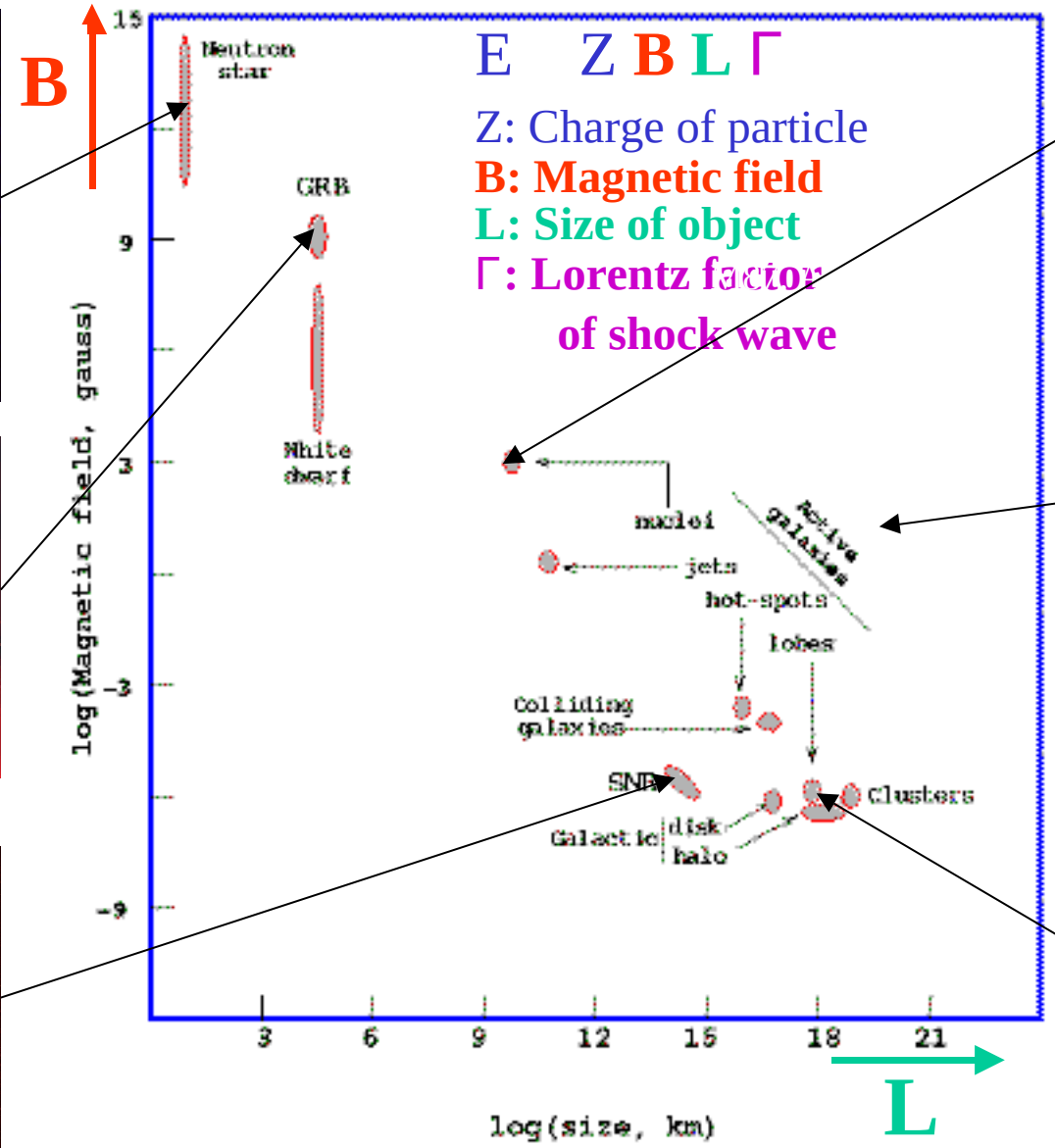


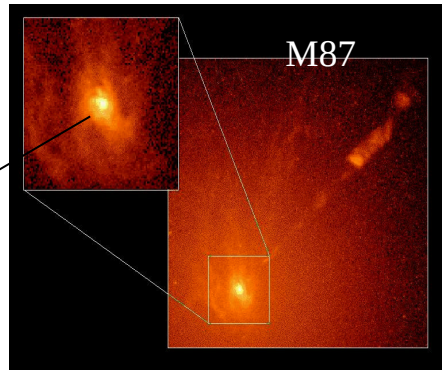
Magnetic field
few μG

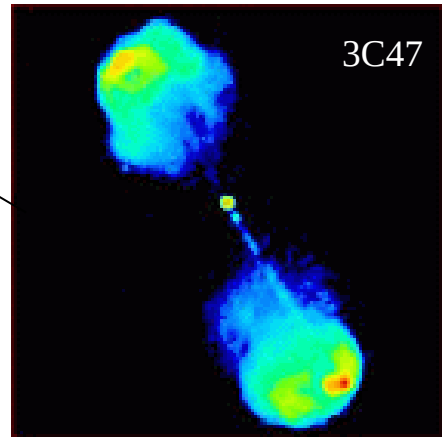
Cosmic Accelerators: Hillas Plot





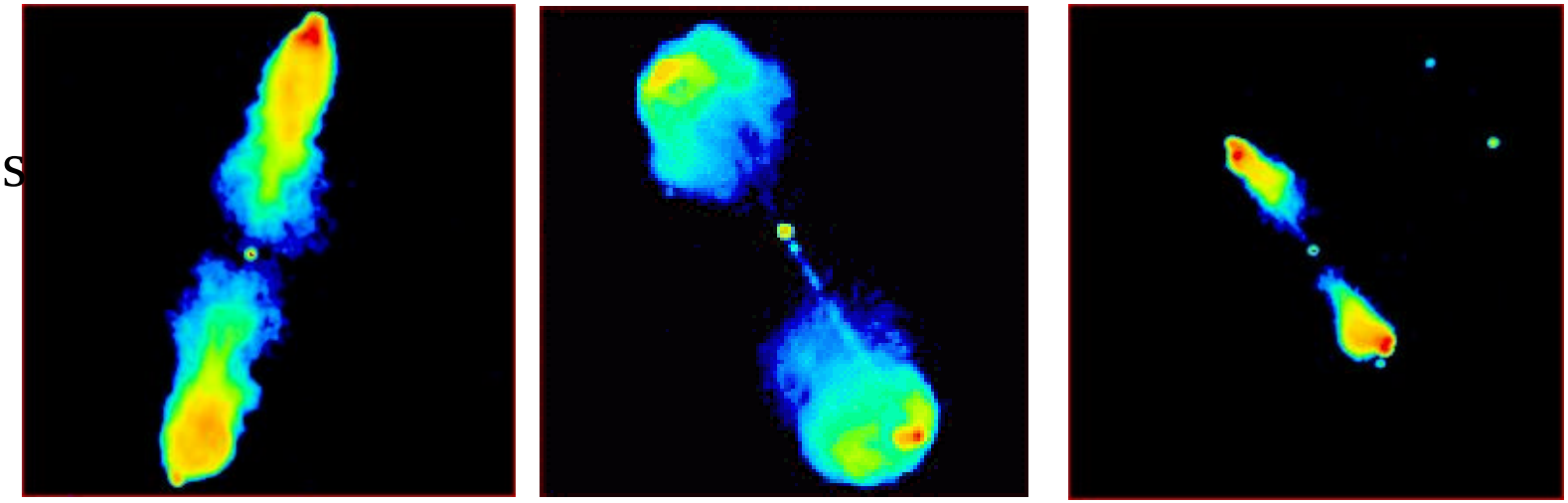




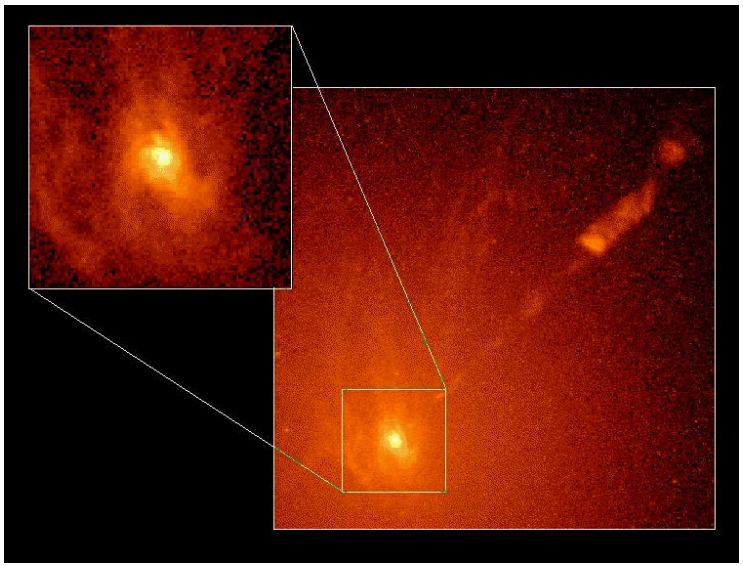


Active Galactic Nuclei

Radio Images

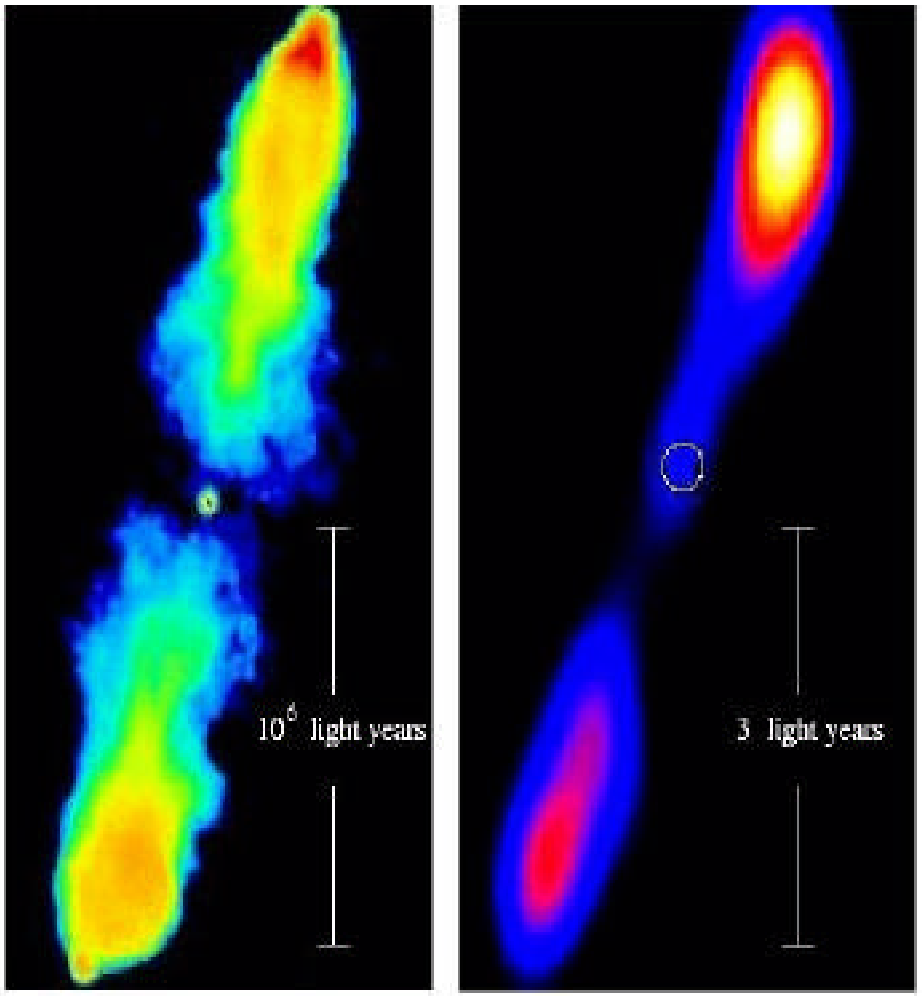


Visible light

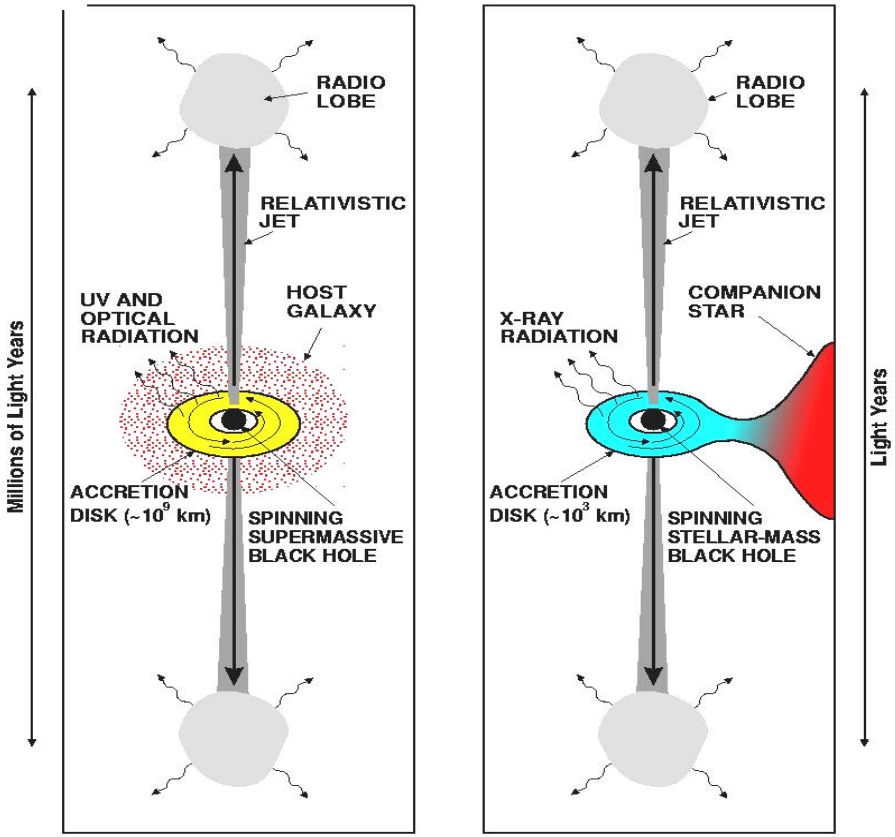


QUASARS & MICROQUASARS

QUASAR **MICROQUASAR**



QUASAR **MICROQUASAR**

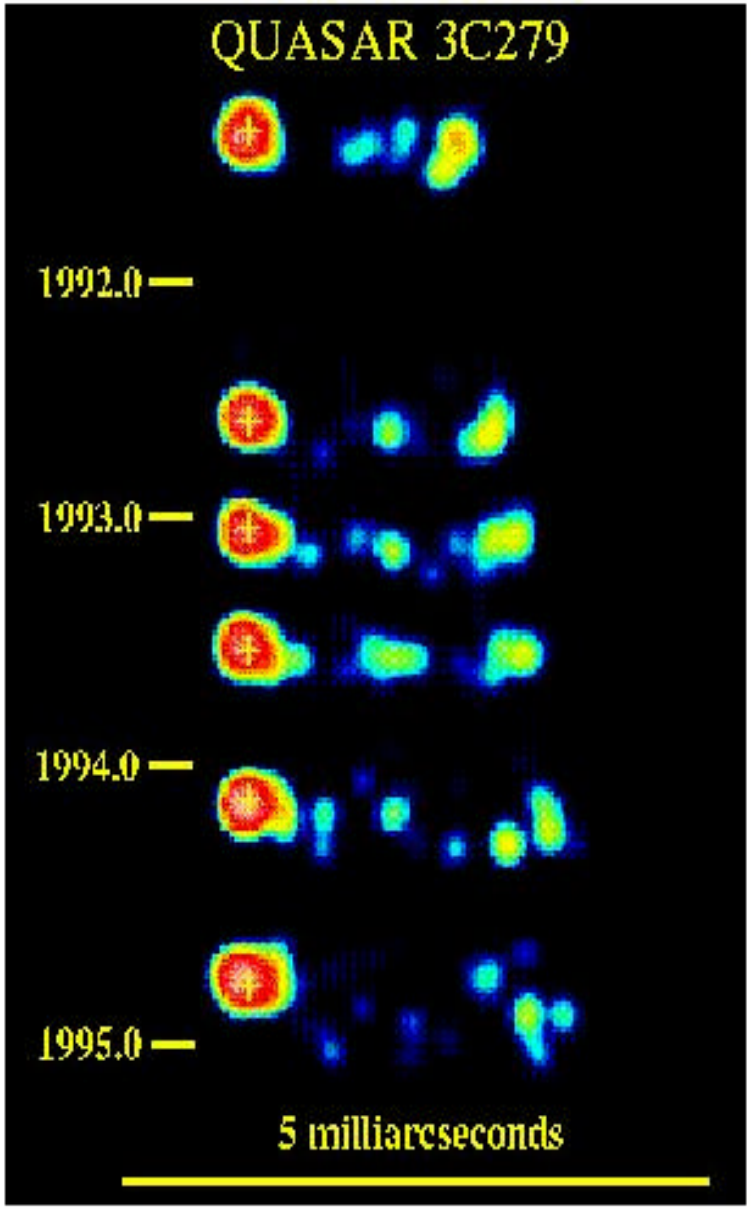


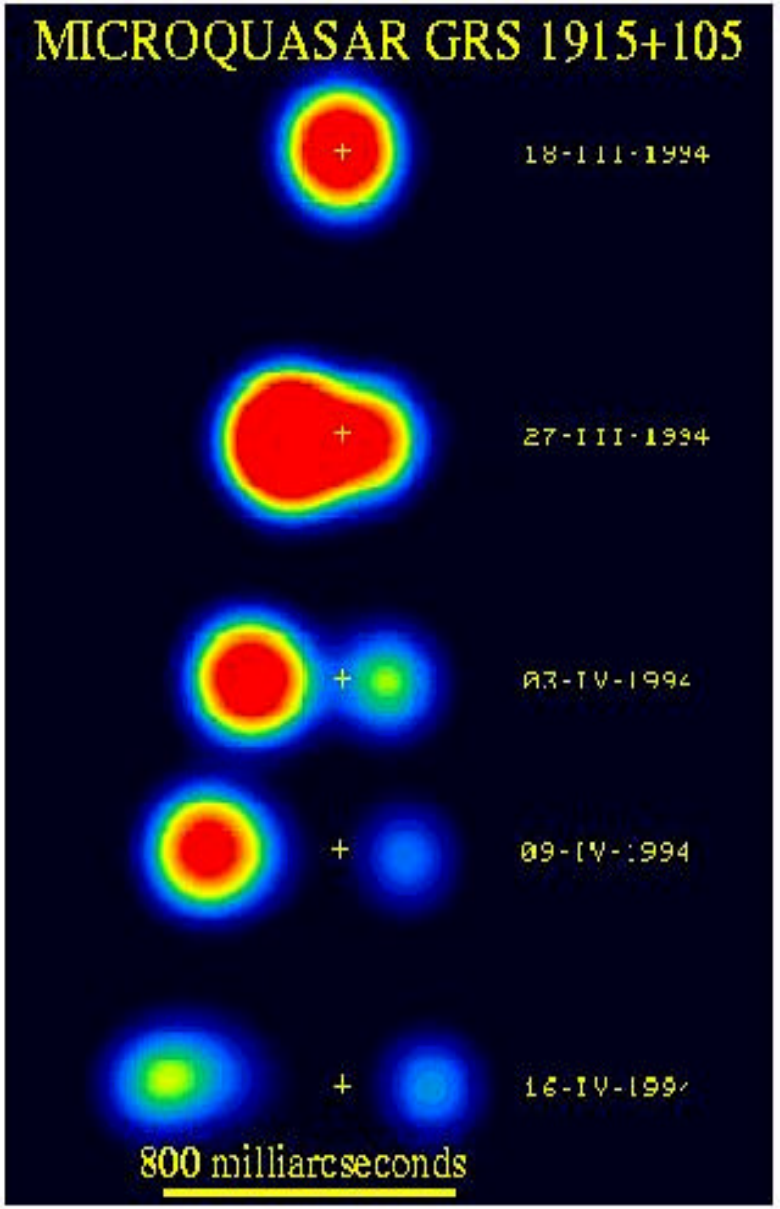
Central black hole

10^8- 10^9 $M_\odot$ **10^2- 10^5 $M_\odot$**

distant galaxies **local galaxy**

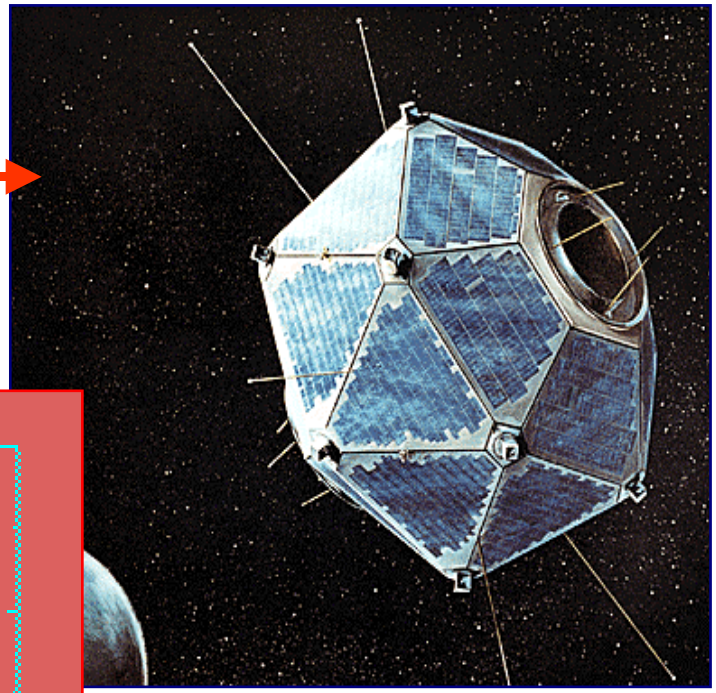
QUASARS & MICROQUASARS

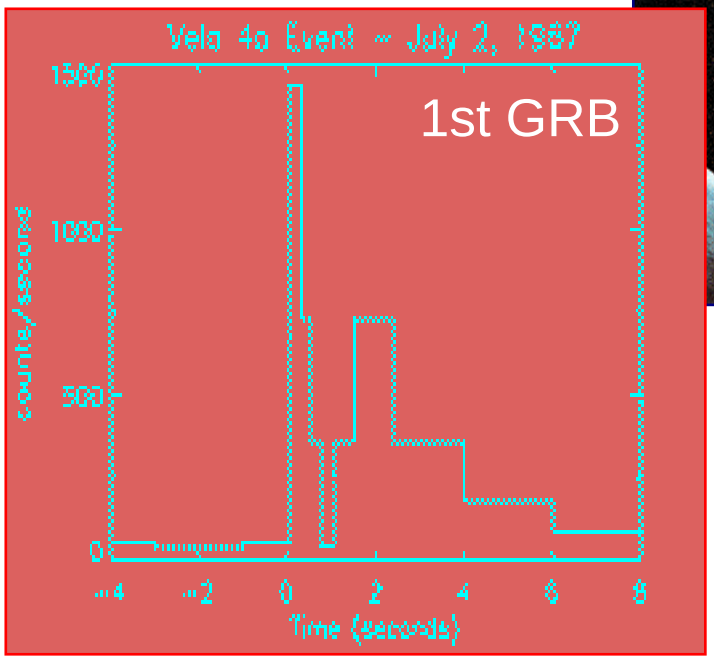




Gamma-Ray Burst Story

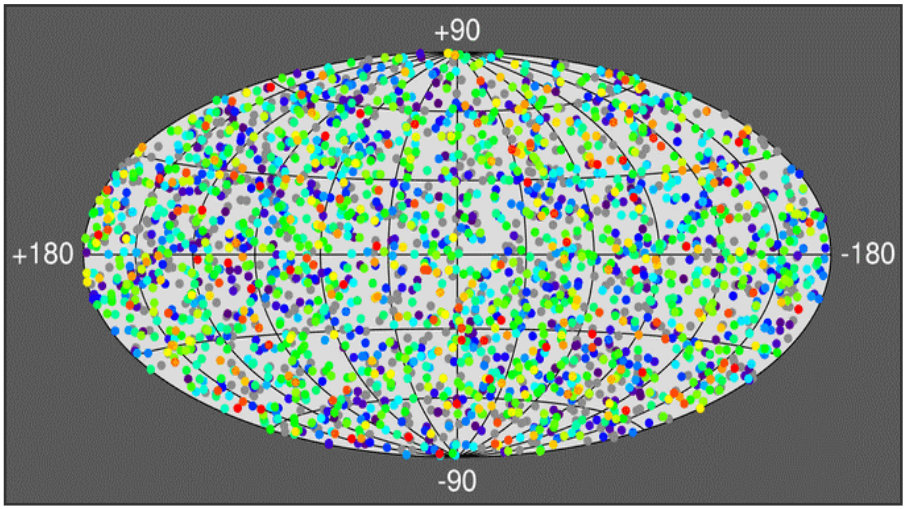
Gamma Ray Burst were first detected by the Vela satellites that were developed in the sixties to monitor nuclear test ban treaties.

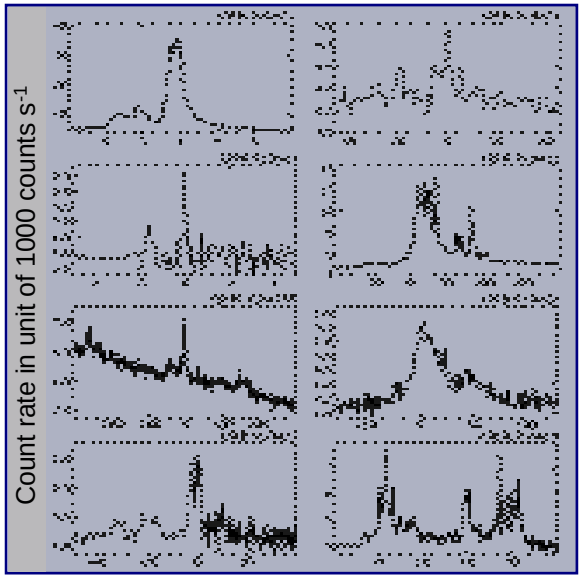




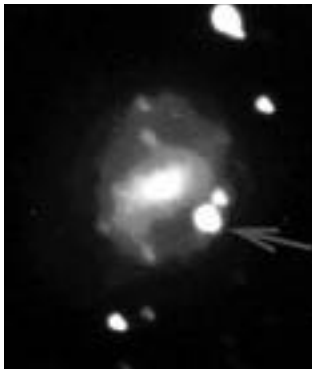
Gamma Ray Bursts : present knowledge

~1-2 / day, duration 10ms - 100s,
isotropic distribution in sky,
at extra galactic distances.



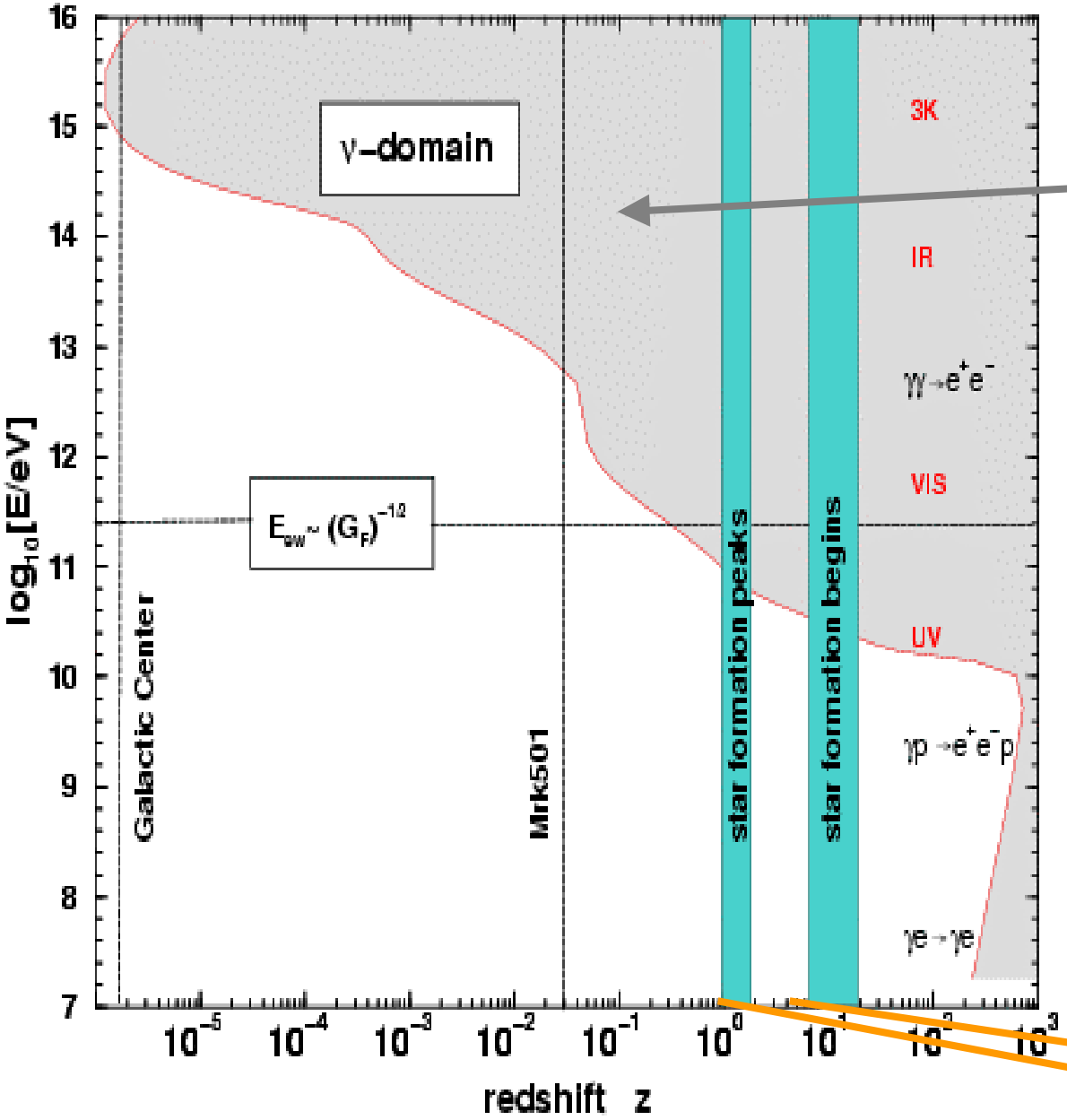


Now evidence
of GRB association
with supernova



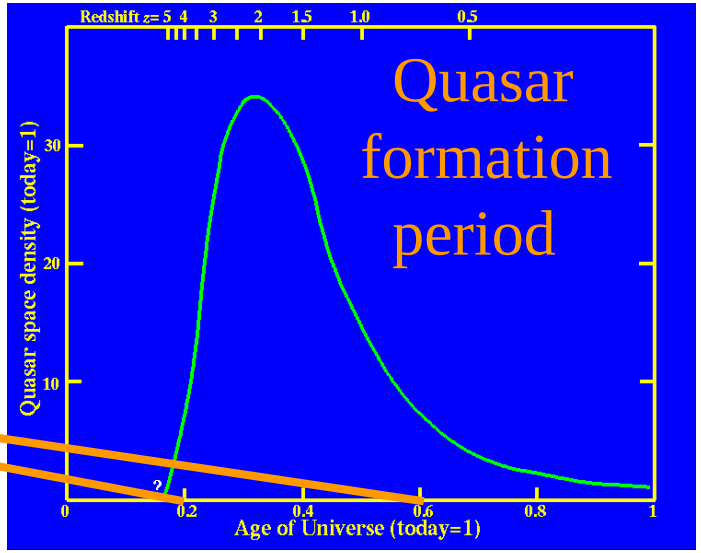
ANTARES will dump all data in ± 100 secs of gamma ray burst warning signal

Multi-Messengers to see Whole Universe



Distant universe
invisible in
high energy photons

need neutrinos



Evolution of the Universe

Consider a particle on surface of sphere which expands with universe:

r : radius of sphere ρ : mass density in universe

Mass inside sphere is: $(4\pi/3)\, r^3 \rho$

Potential energy of particle: $-(4\pi/3) r^3 \rho\, G/r$

Kinetic energy: $\dot{r}^2/2$

so total energy: $\dot{r}^2/2 - (4\pi/3) r^3 \rho\, G/r = E$

Sphere evolves with time, write $r(t) = a(t)\, x$

remember $H = v/r = \dot{a}/a$

Then get Freidmann equation: $H^2 = (8\pi/3)\, G\, \rho - K/a^2$

where $K = -2E$

Evolution of universe depends on value of K

if $K < 0$, energy $E > 0$ expansion continues for ever

if $K > 0$, energy $E < 0$ eventually universe contracts

$K = 0$ critical value

Matter Density and Curvature of the Universe

Freidmann eqn: $H^2 = (8\pi/3)\, G\, \rho - K/a^2$

With K = 0

Freidmann equation: $H^2 = (8\pi/3)\, G\, \rho$

define critical density: $\rho_c = (3/8\pi)H^2/G$

define density fraction: $\Omega = \rho / \rho_c$

Same K comes into the spatial line element in General Relativity:

$$d\ell^2 = \frac{dr^2}{1 - Kr^2/a^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2)$$

If K = 0, geometry is Euclidean - flat, if K ≠ 0, geometry curved

equivalently if $\Omega = 0$ universe is flat

$\Omega > 0$ curvature positive, universe is closed

$\Omega < 0$ curvature negative, universe is open

Cosmological Constant

Einstein did not know about the expansion of the universe and add a ad-hoc term to make universe static

Freidmann equation becomes:

$$H^2 = (8\pi/3)\, G\, \rho - K/a^2 + \Lambda/3$$

where Λ is cosmological constant

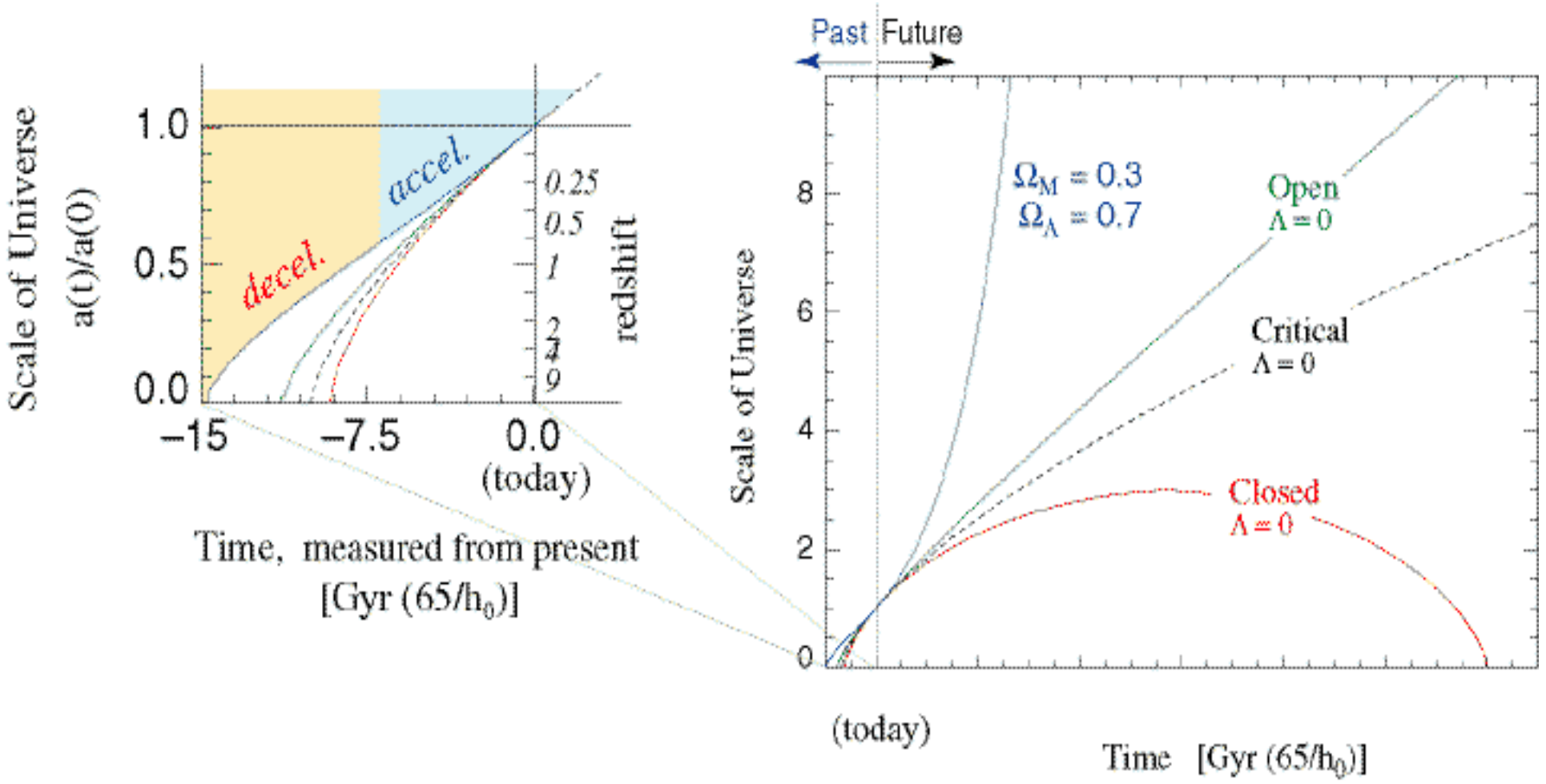
Theory no longer needs it, but experiment seems to indicate its presence

Conventional to treat it as another contribution to the density fraction

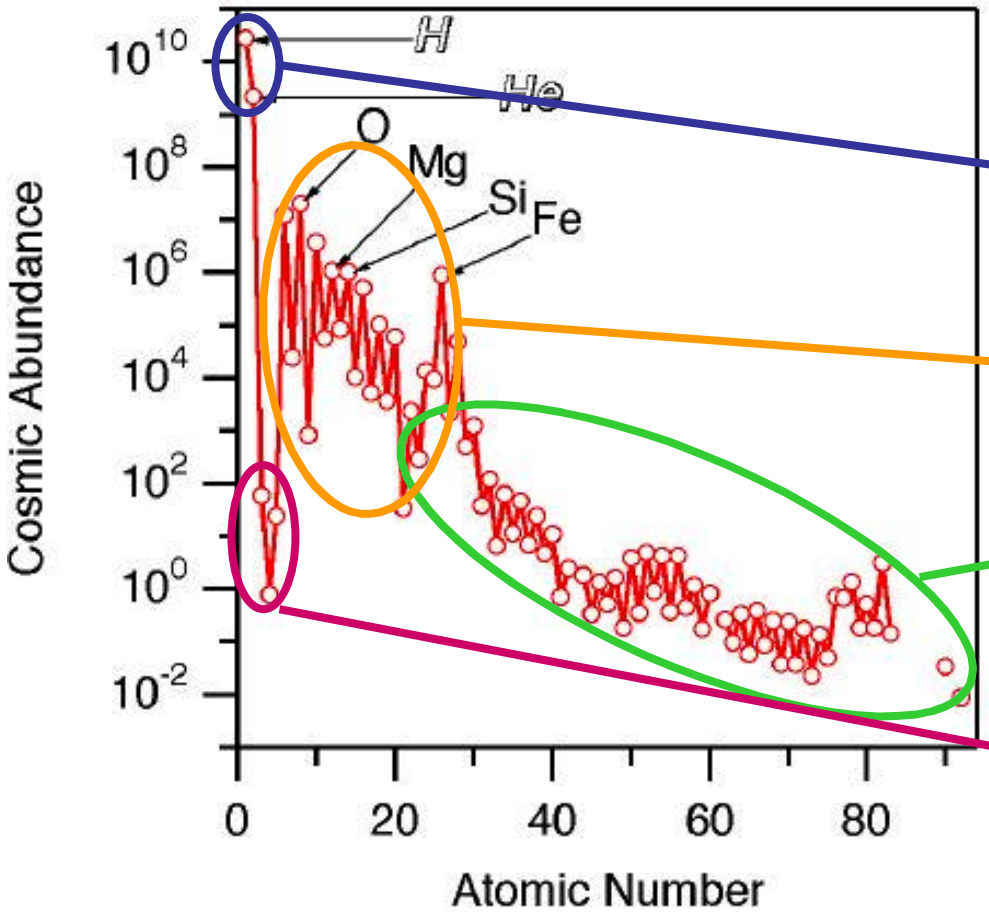
$$\rho(t) = \rho_{matter}(t) + \rho_{\Lambda}$$

$$\Omega = \Omega_{matter} + \Omega_{\Lambda}$$

Future of Universe



Origin of Elements



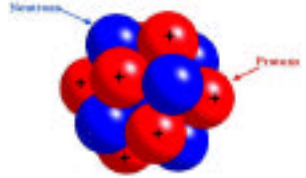
formed in:

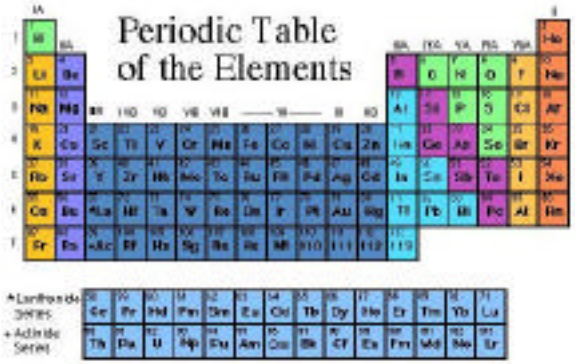
Big Bang Nucleo-synthesis

Hot Stars

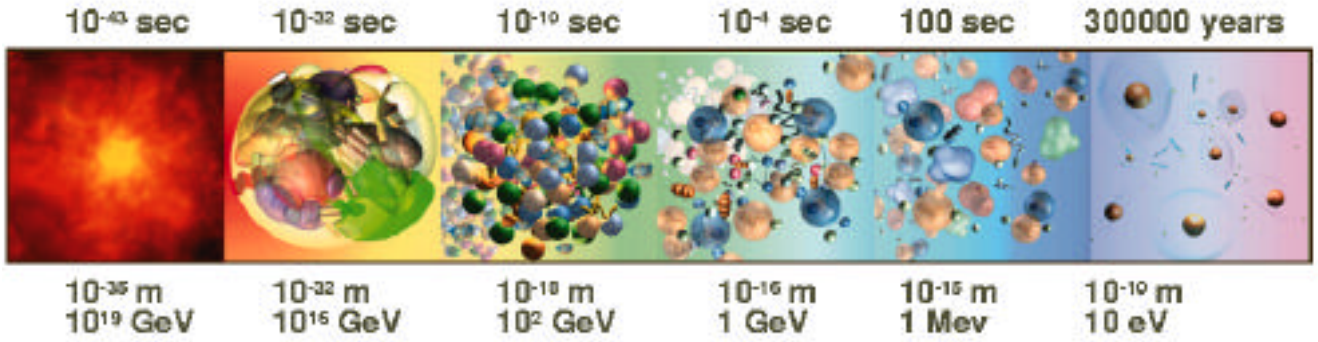
Supernova Explosions

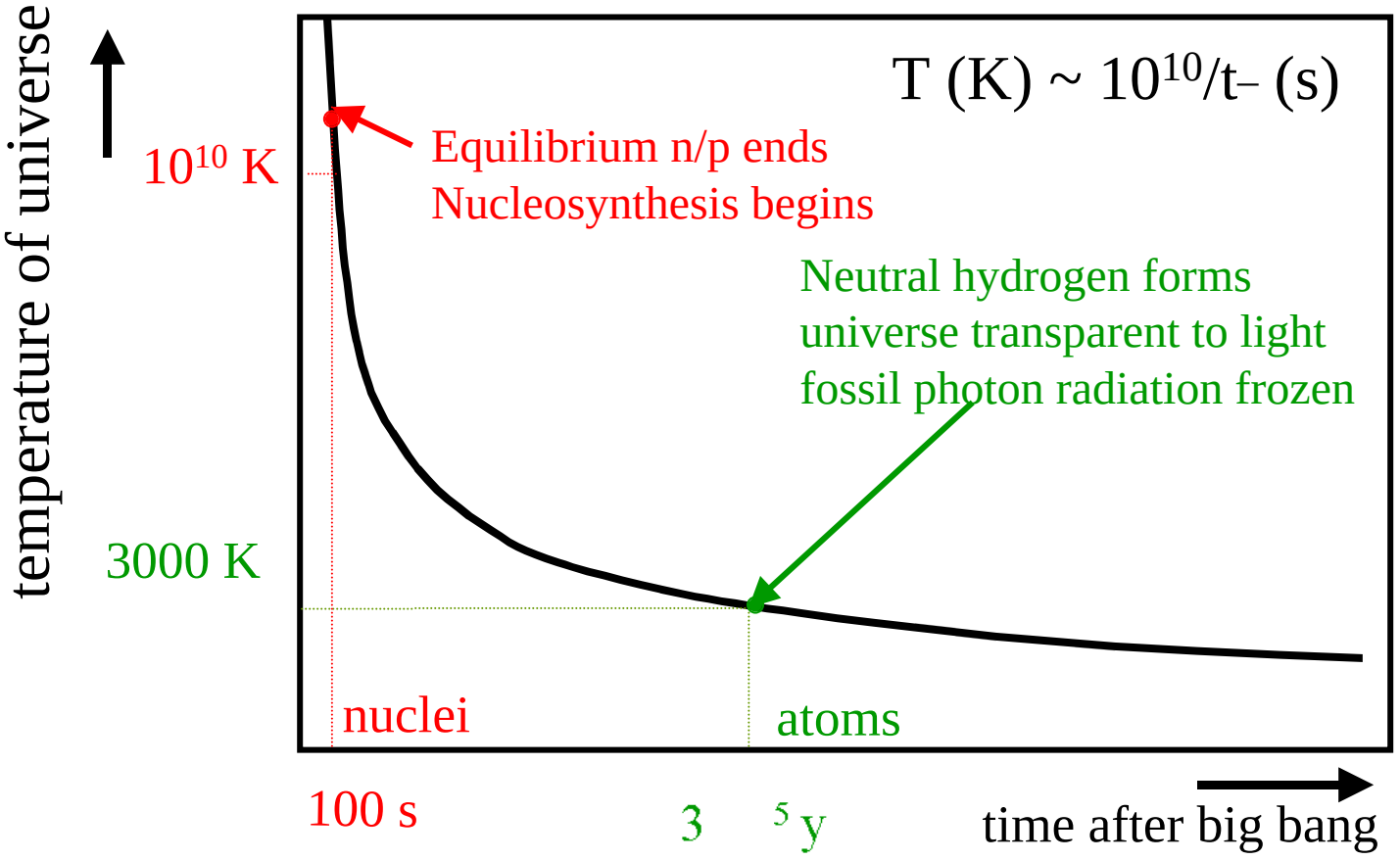
Cosmic Ray Interactions



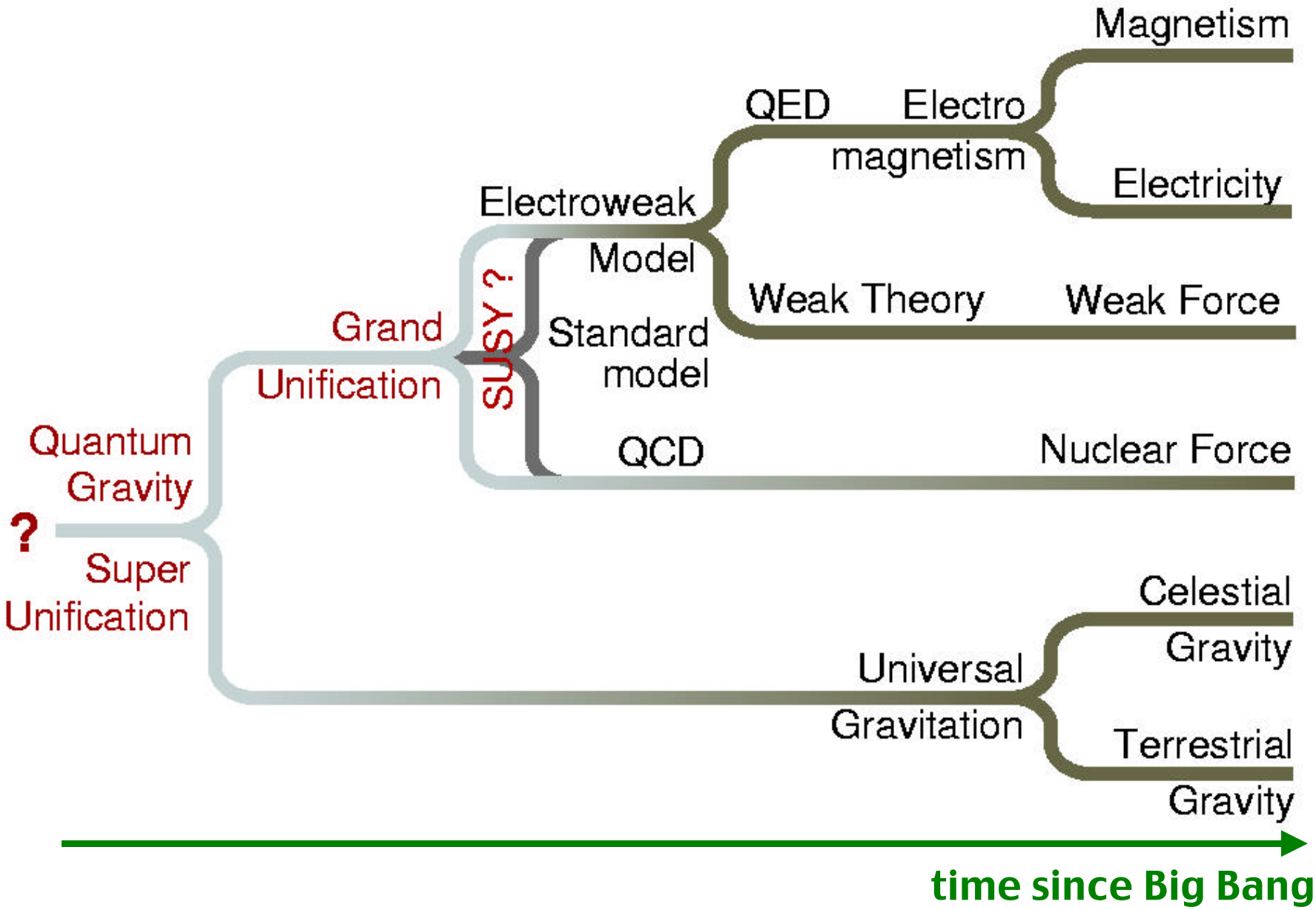


Big Bang


10⁻⁴³ sec
10⁻³² sec
10⁻¹⁰ sec
10⁻⁴ sec
100 sec
300000 years
10⁻³⁵ m
10¹⁹ GeV
10⁻³² m
10¹⁵ GeV
10⁻¹⁰ m
10² GeV
10⁻¹⁶ m
1 GeV
10⁻¹⁵ m
1 Mev
10⁻¹⁰ m
10 eV

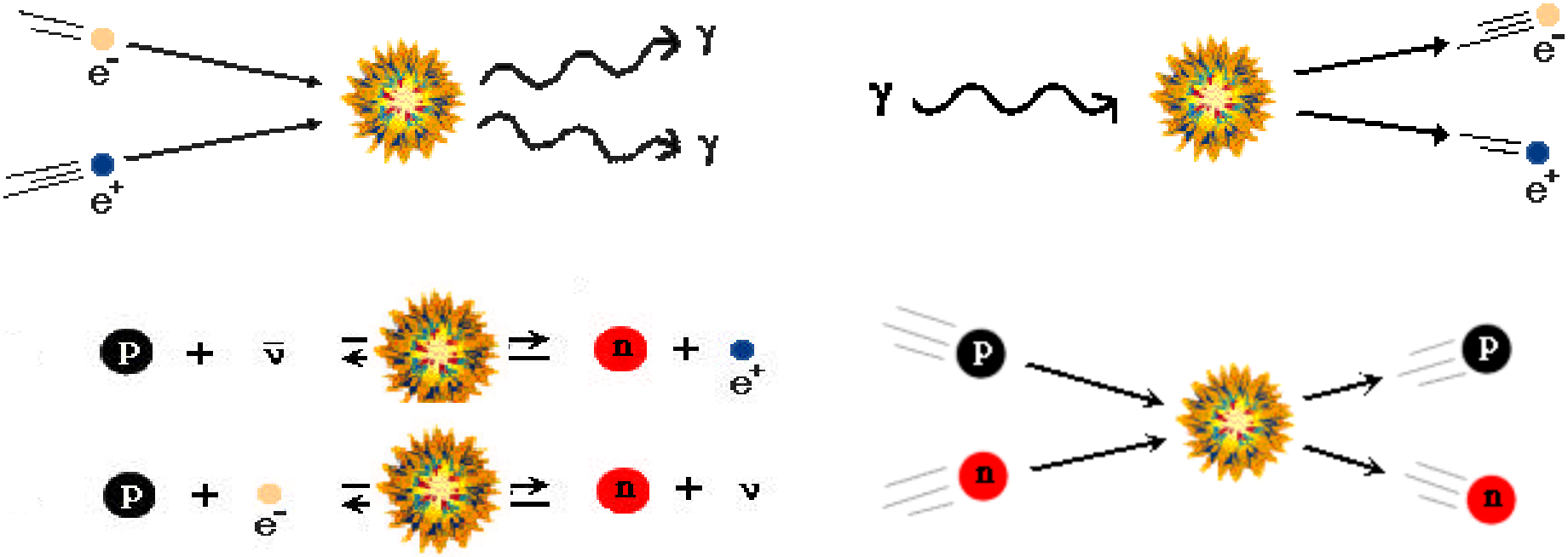

temperature of universe
T (K) ~ 10¹⁰/t– (s)
10¹⁰ K
Equilibrium n/p ends
Nucleosynthesis begins
Neutral hydrogen forms
universe transparent to light
fossil photon radiation frozen
3000 K
nuclei
atoms
100 s
3 ⁵ y
time after big bang

Particle Physics after Big Bang



First Minute after Big Bang

Production rates = Annihilation rates
equilibrium of particles and no nuclei formed

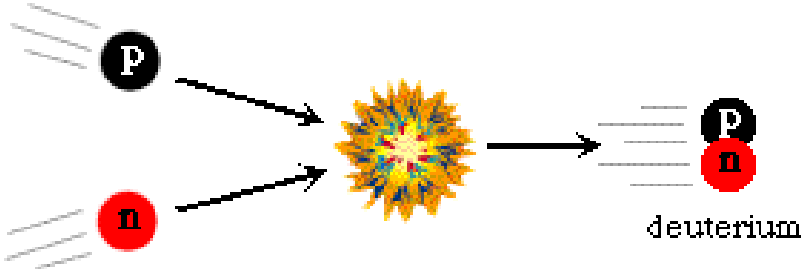


In equilibrium: $\frac{N\ (\text{neutron})}{N\ \ (\text{proton})} = e^{-\Delta m/kT}$ $(\Delta m = 1.3\ \text{MeV})$

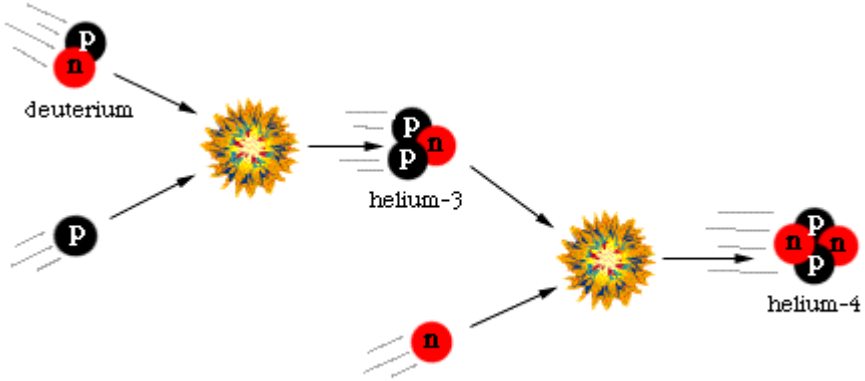
When temperature falls below 10^{10} K (1 MeV) reactions cease

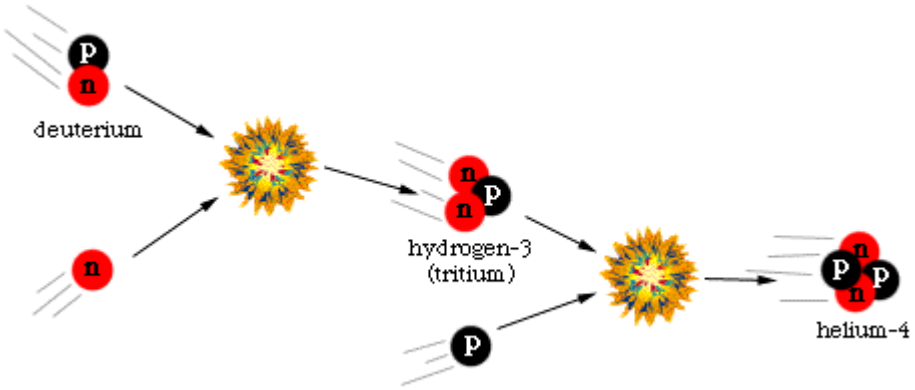
Nucleosynthesis starts

Deuterium necessary to start nucleosynthesis



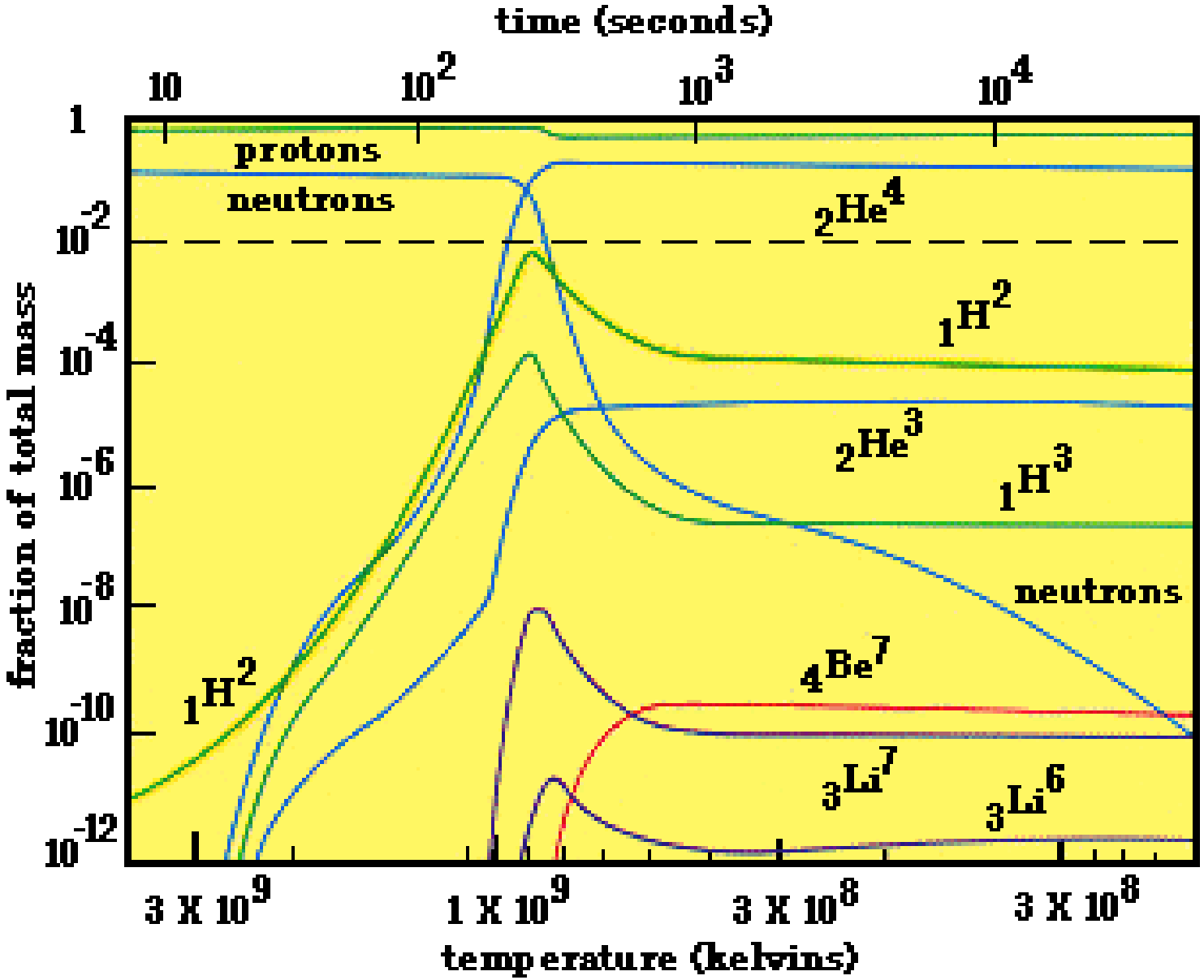
Helium formed from deuterium





(Difficult to continue because no stable mass 5, 8 nuclei)

Nucleosynthesis development



helium-4

deuterium

helium-3

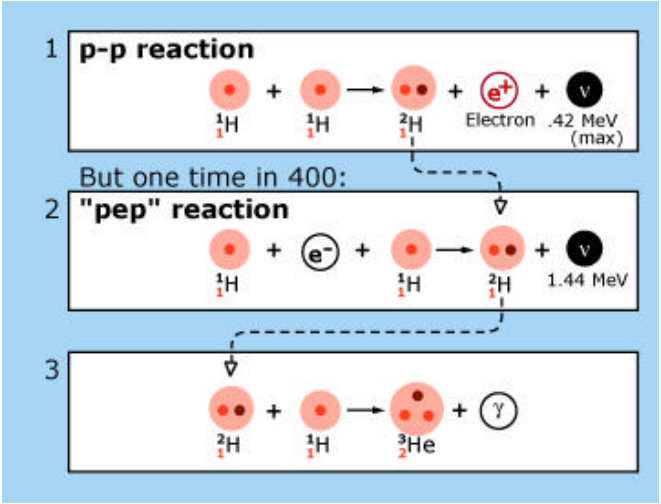
tritium

(free neutrons decay)

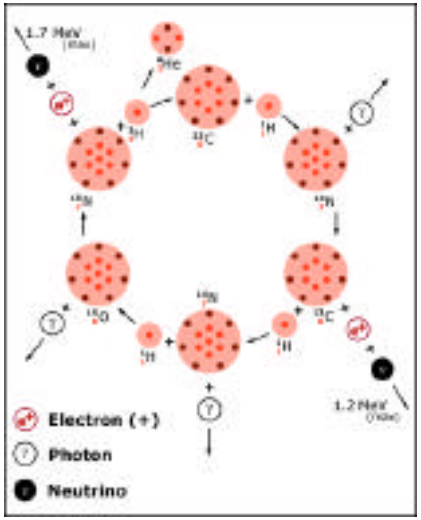
Be, Li low levels

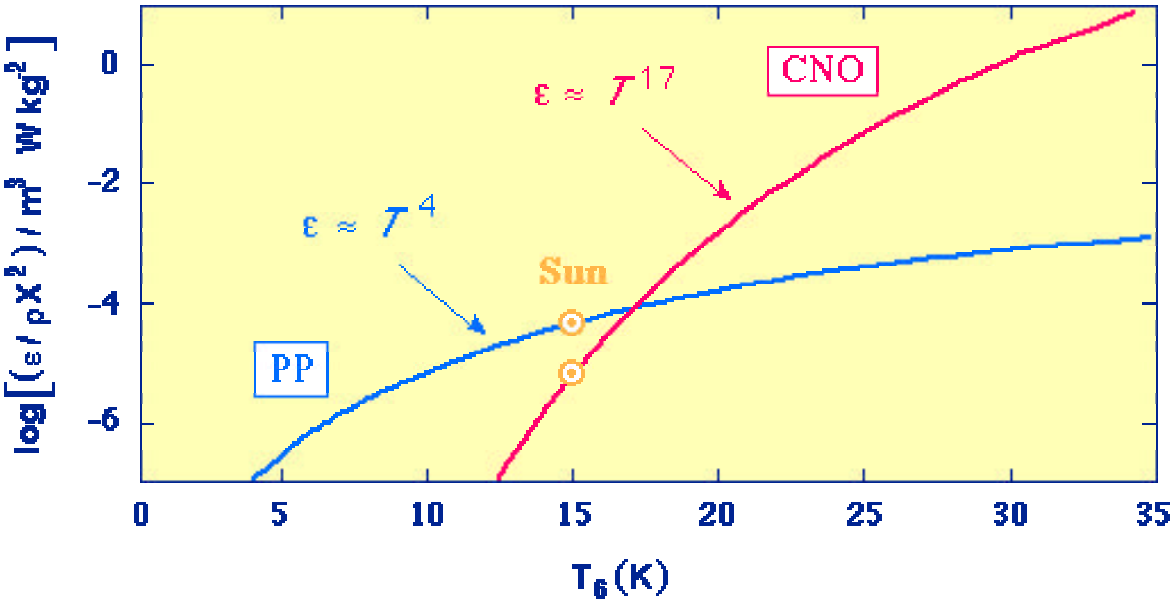
Element Production in Stars

PP cycle : cold stars



CNO cycle : hot stars

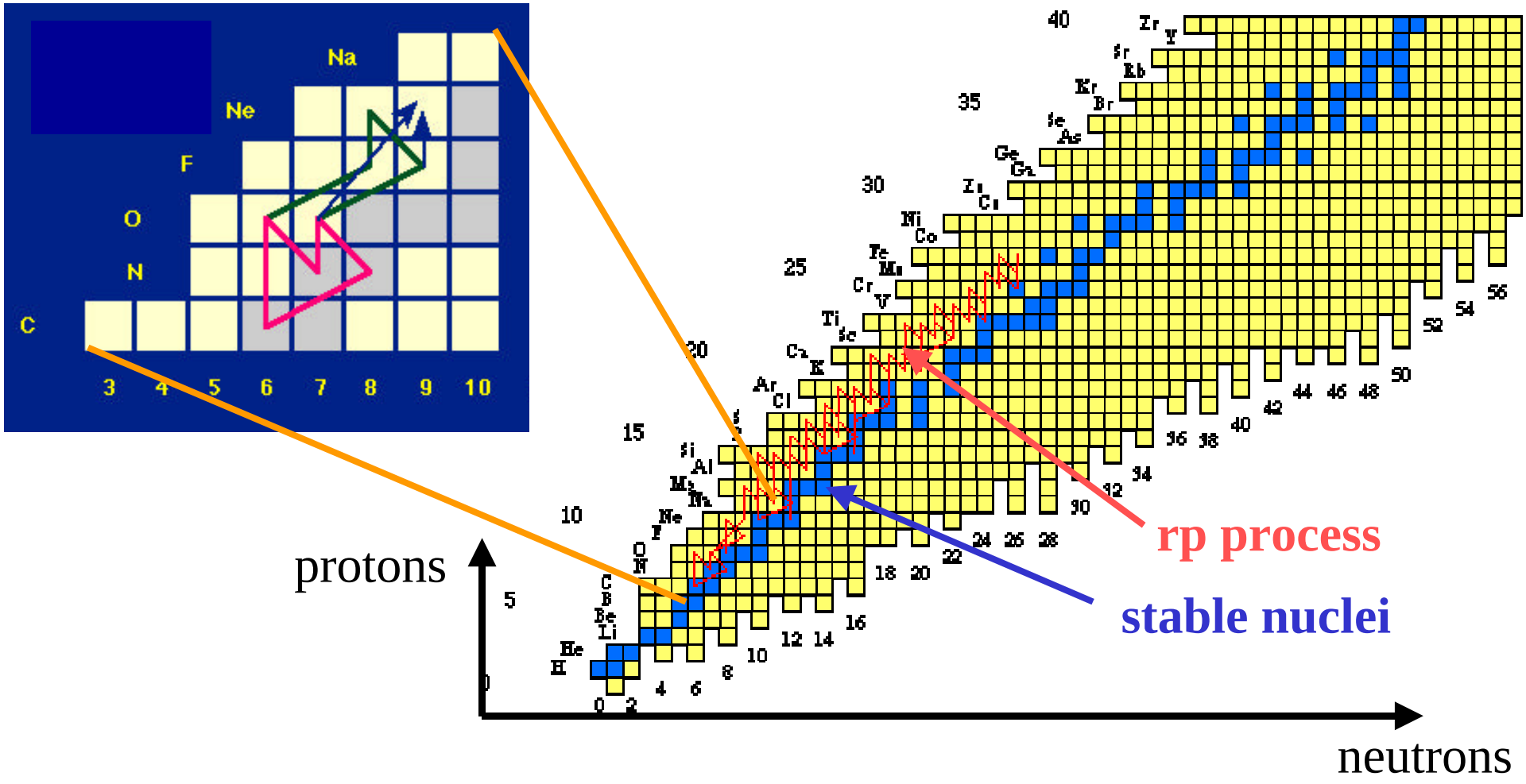




Heavy Element Production in Supernova

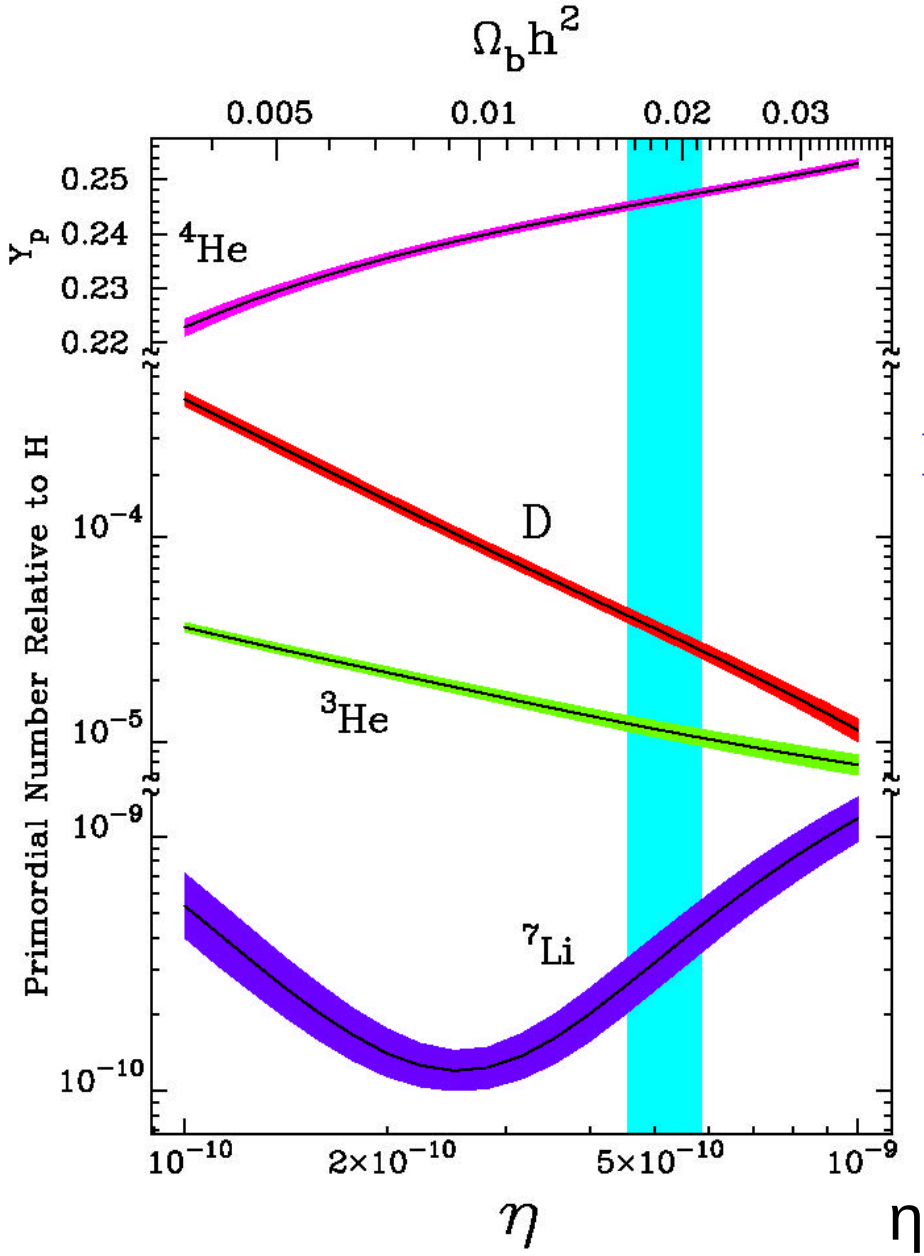
CNO cycle : hot stars

rp process : supernova explosions



Nuclear cross-sections not well known: need accelerator measurements

Nucleosynthesis rate gives baryon density



Measured abundance of He, D
Fraction of baryons < 5%

Must have
non-baryonic particle dark matter

$\eta = N_b/N_\gamma$, baryon number fraction