International Summer School of Science Bakuriani, 2012

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Energy Sources of the Luminous Universe

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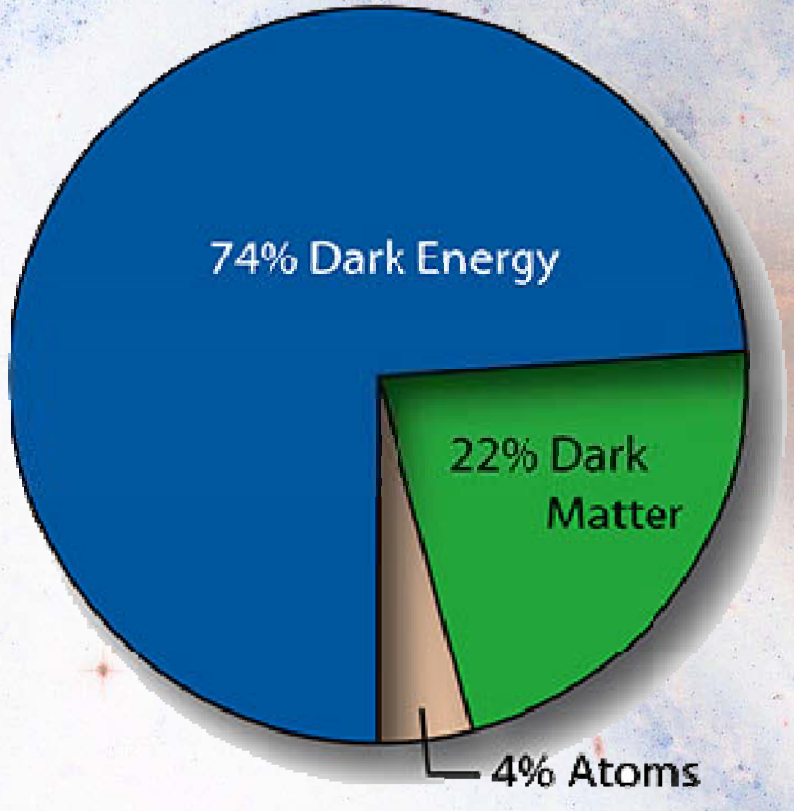
Composition of the Universe

Wilkinson MAP data (cosmological observation)



4% Atoms =

3.5% Interstellar Matter

(Hydrogen, Helium, neutrino)

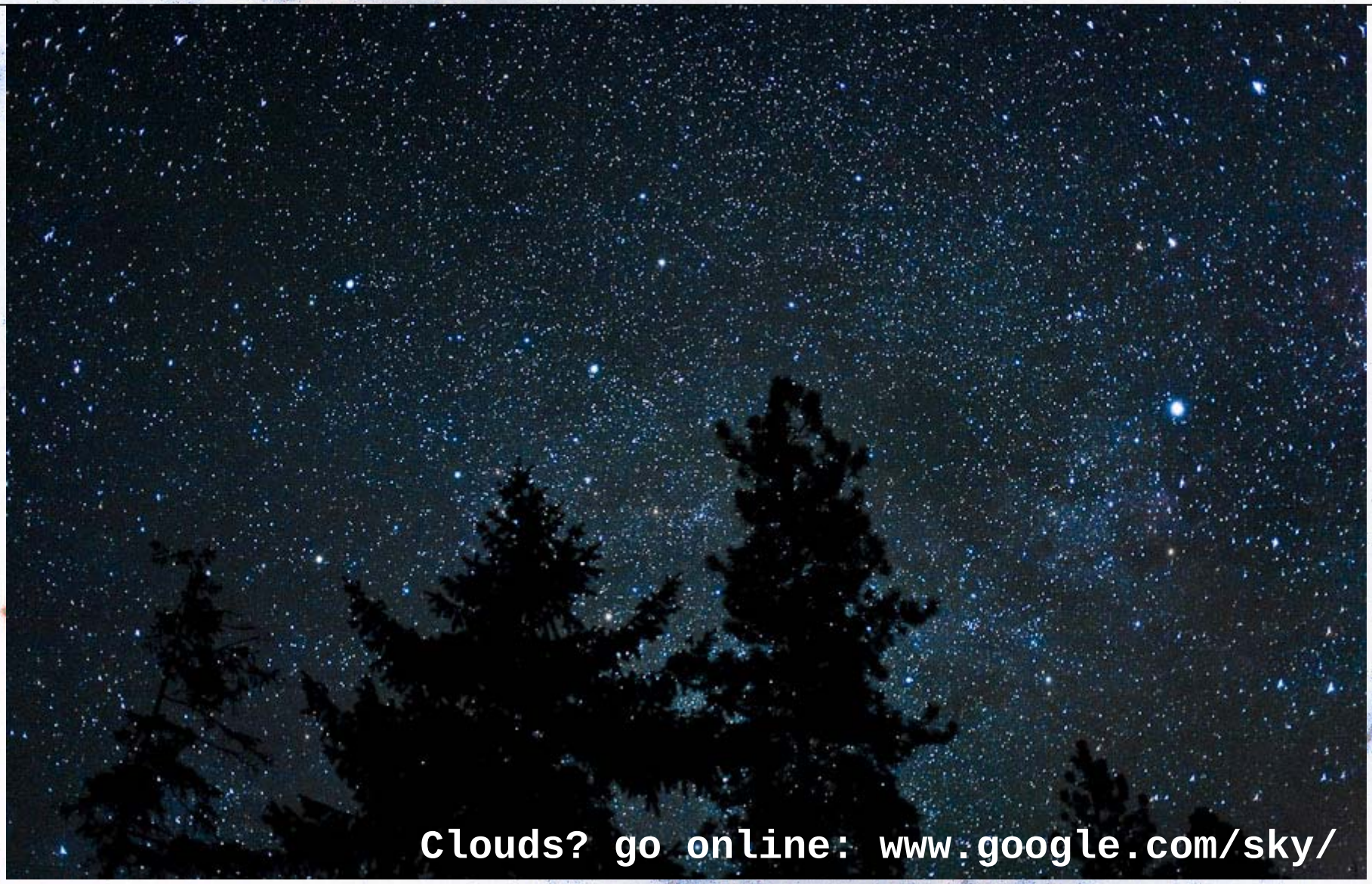
0.5% Luminous matter

(Stars, Galaxies)

Studding the Luminous Universe:

Reconstruct the total picture using only 0.5%

Visible Universe

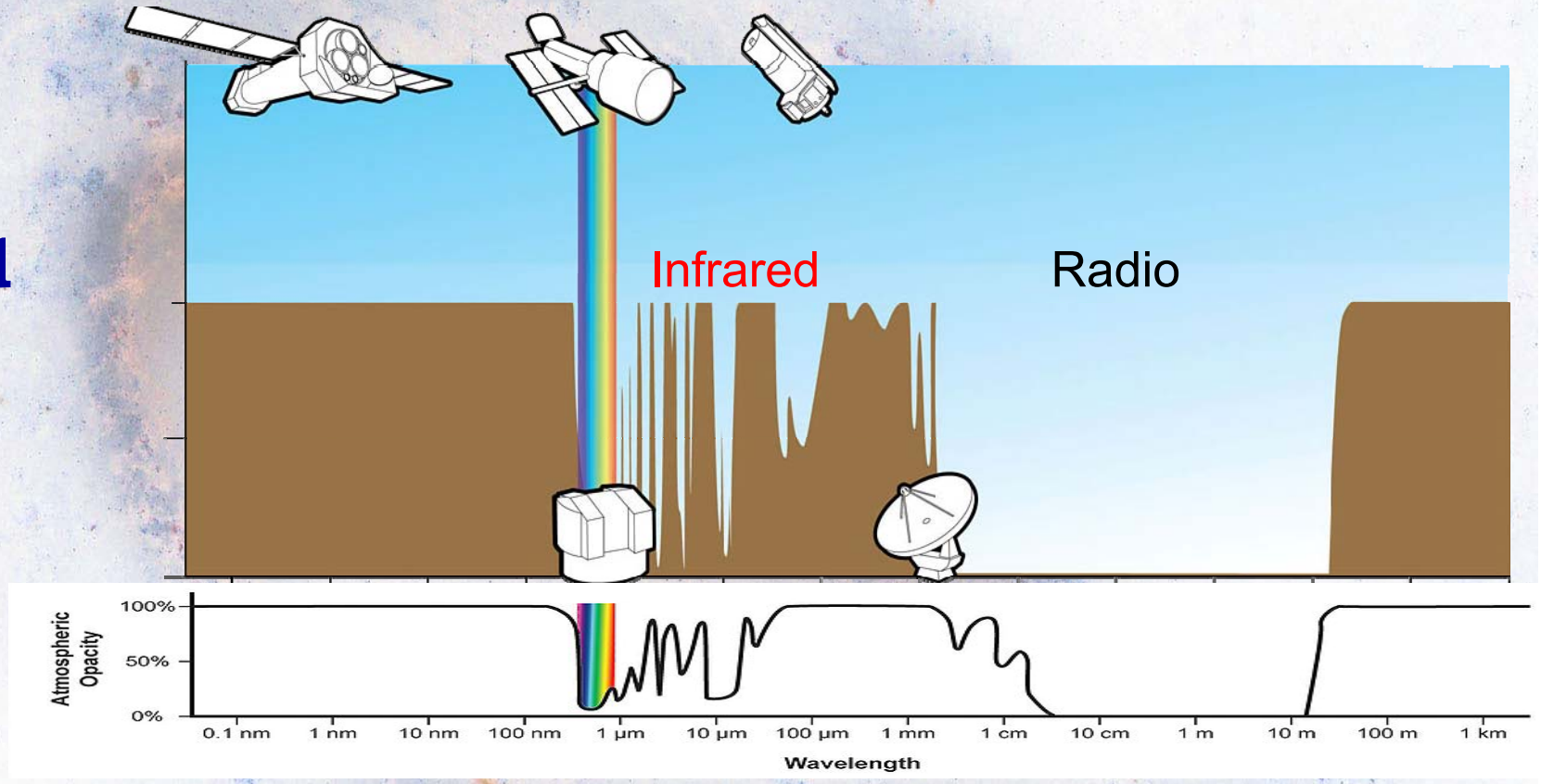


Observing Universe with naked eye

Atmospheric Opacity

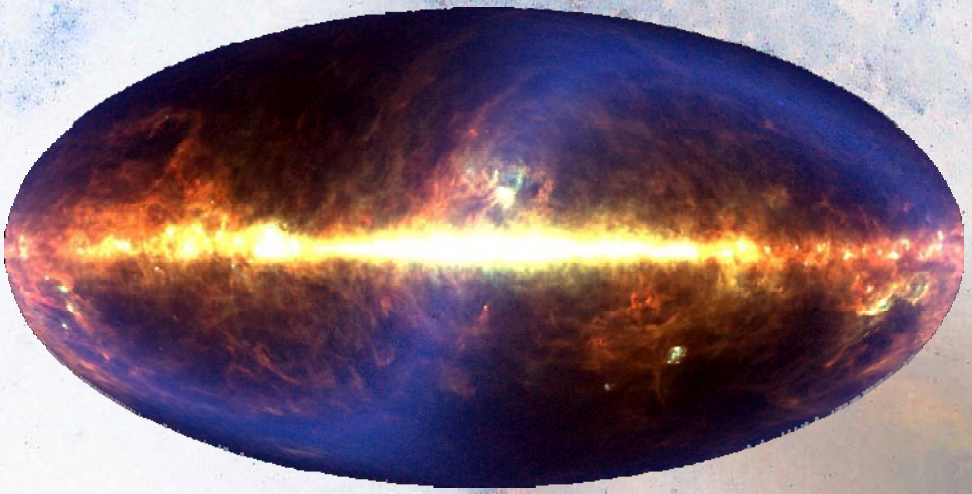
Earth Atmosphere has only few transparent windows to observe the Universe above us:

- **Optical**
- **Infrared**
- **Radio**

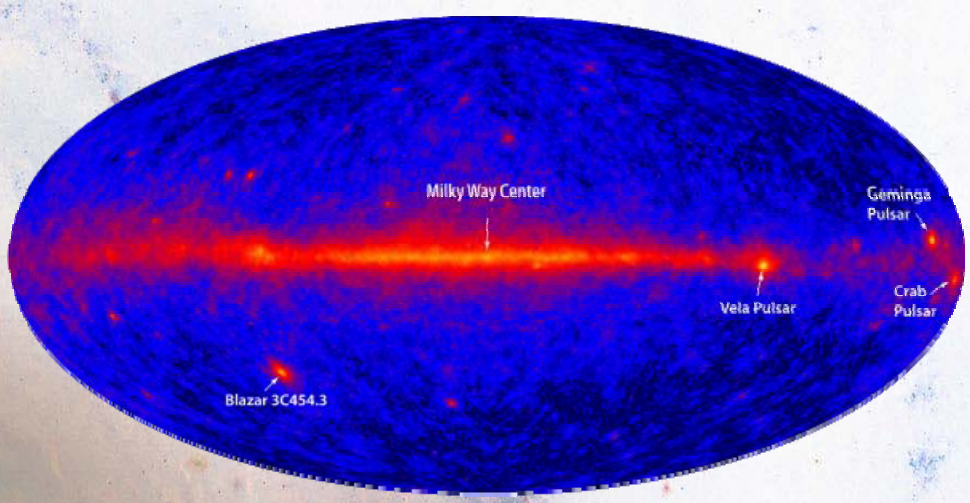


Satellite observations: re-discovery of the Universe

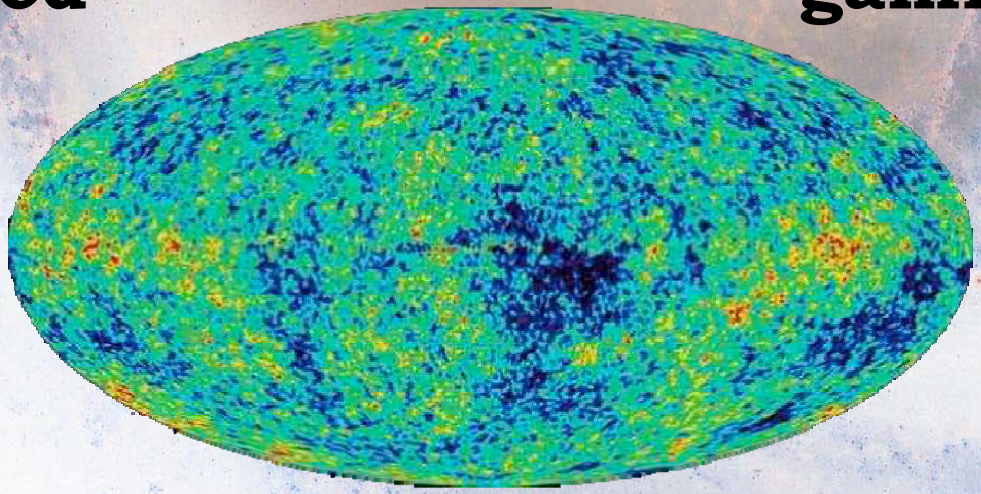
Non-Optical Universe



Infrared



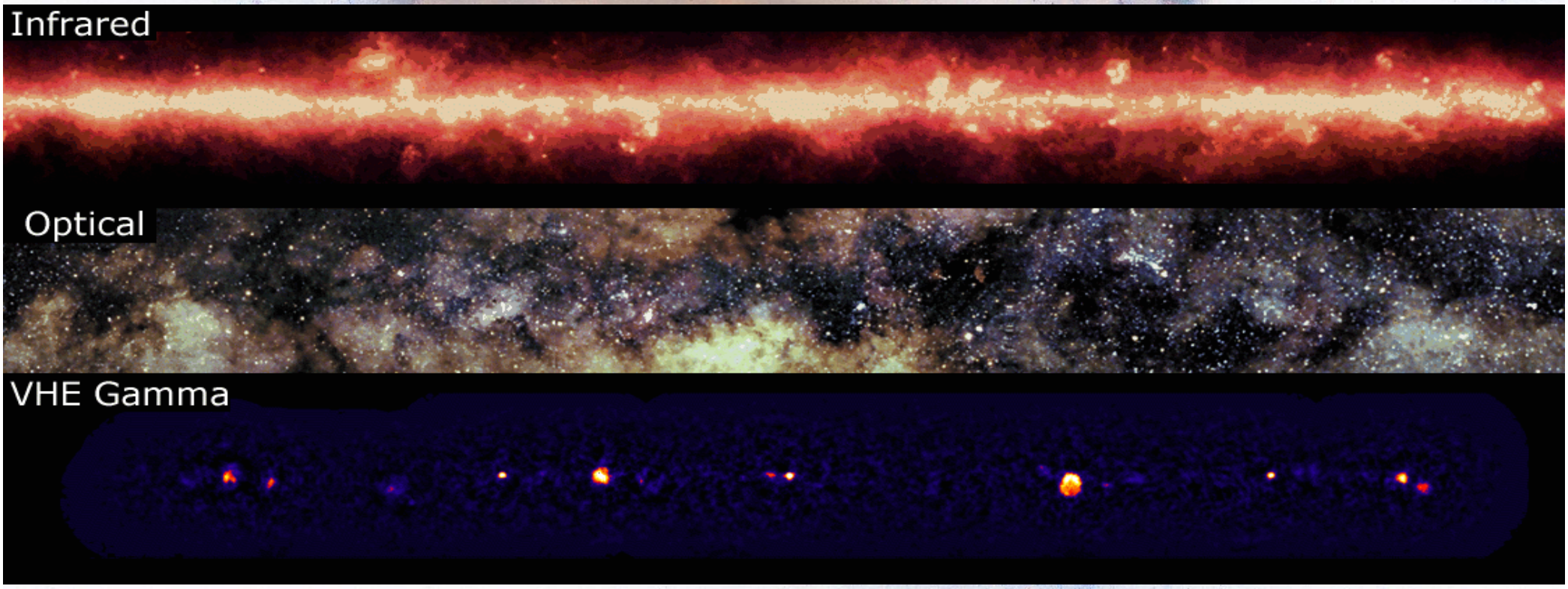
gamma-ray



Microwave

Milky Way

Milky way images in different wavelength: Infared, Optical, Gamma-ray



Mass-Energy Equivalence

Mass of the body is the measure of its energy content

Energy Content

Energy in wooden stick: **1kg**

$\mathbf{E_0 = mc^2 = 1\ (300\ 000\ 000)^2 = 9\ 10^{16}\ J}$

c – speed of light

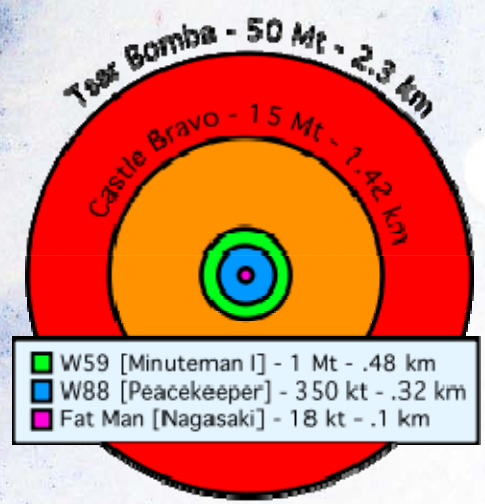
TNT eqvivalent: 1 Ton = $4\ 10^9$ J

E_0(1kg) = 22.5 megaton TNT

Energy content of the 1kg of wood is the half of the energy released during biggest H-bomb explosion on the Earth

(x1000 Nagasaki explosions)

How to release this energy?



Energy Release

Energy production methods:

Method 1. Chemical Reactions

(e.g. burning wood)

$\mathbf{E_{chem} = \lambda\ m = 20\ MJ/kg\ 1\ kg = 2\ 10^7\ J}$

λ – *Heat of combustion*

($E_0 = 9\ 10^{16}$ J)

$$\mathbf{E_{chem}/\ E_0 = 2.22\ 10^{-10} \approx 0}$$

Energy release of the wood after oxygen-burning is negligable (0.00000002% mc^2)

Nuclear Energy

Masses before and after reaction do not match:

$$m_1 \neq m_2 \quad (\Delta m = m_2 - m_1)$$

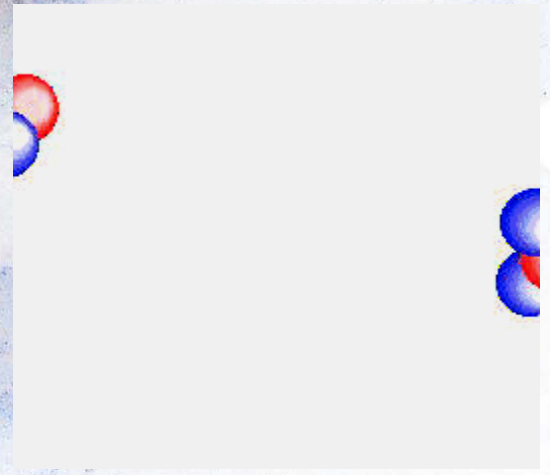
Energy Production: $E = \Delta m\, c^2$

Method 2. Nuclear Fission

E ~ 0.1% ($0.001\ mc^2$)

- Atomic bomb (U^{235})
- Nuclear Reactors ☺

Method 3. Nuclear Fusion



E ~ 0.7% ($0.007\ mc^2$)

- H-Bomb (H^1, H^2, H^3)
- Controlled Nuclear Fusion ☹

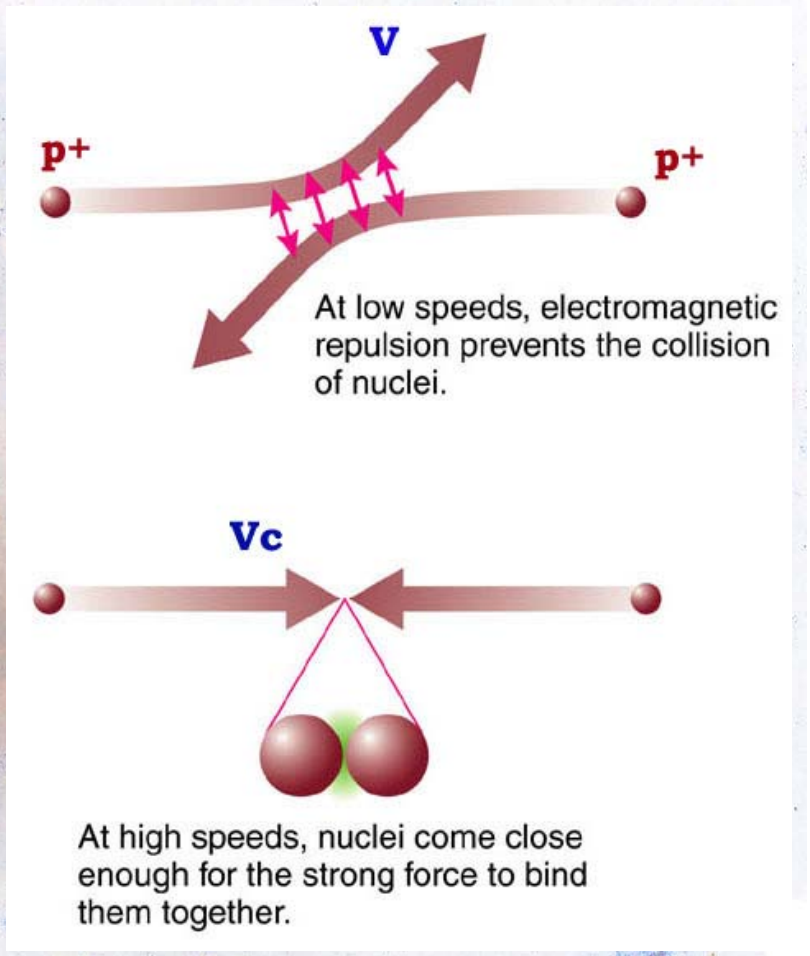
Nuclear Fusion

Protons are positively charged Particles that are repelled due to Coulomb force

At high enough speeds particles Come close enough to FUSE

Nuclear fusion reaction:

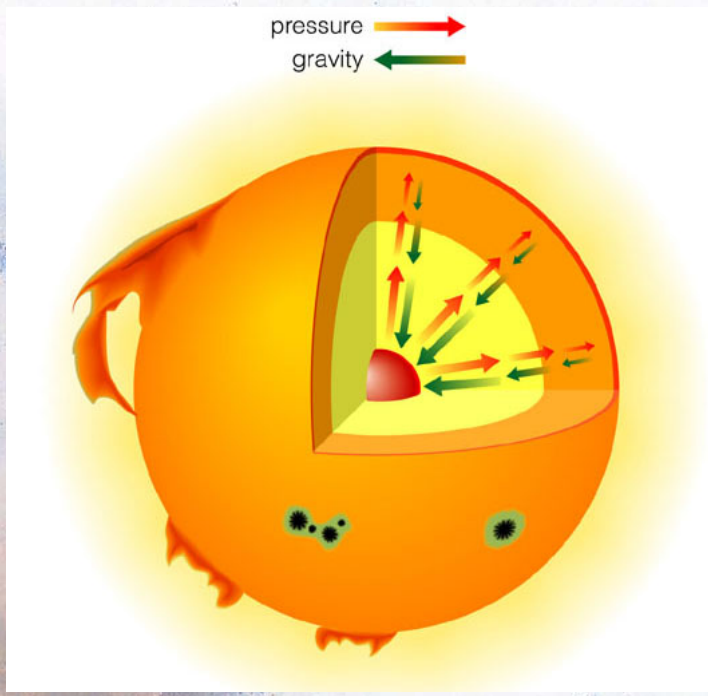
H + H = He + ***energy***



High speed of particles = High temperature of gas

The Sun

The Sun is the main sequence star, one of typical stars in our Universe.



Gravity tends to compress

Compression leads to heating

Core Temperature: 15×10^6 K

Hydrogen ignites into nuclear fusion:

Energy release in the core

Fusion creates pressure to compensate gravity

"The theory of stellar nucleosynthesis"

PP chain

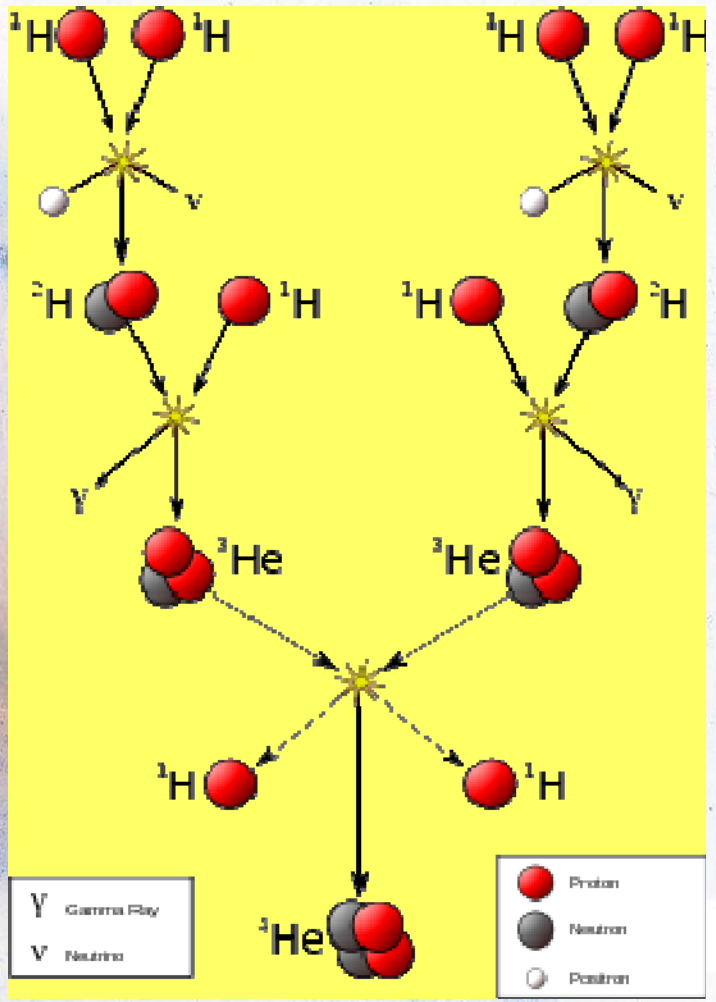
proton-proton chain reactions

T = 5 - 15 x 10^6 K

$$H^1 + H^1 \rightarrow D^2 + e^+ + \nu_e + 0.42\ \text{MeV}$$

$$e^+ + e^- \rightarrow 2\,\gamma + 1.02\ \text{MeV}$$

$$D^2 + H^1 \rightarrow He^3 + \gamma + 5.49\ \text{MeV}$$



$\Delta E = 0.007\ mc^2$

Energy release: ~ 0.7%

CNO cycle

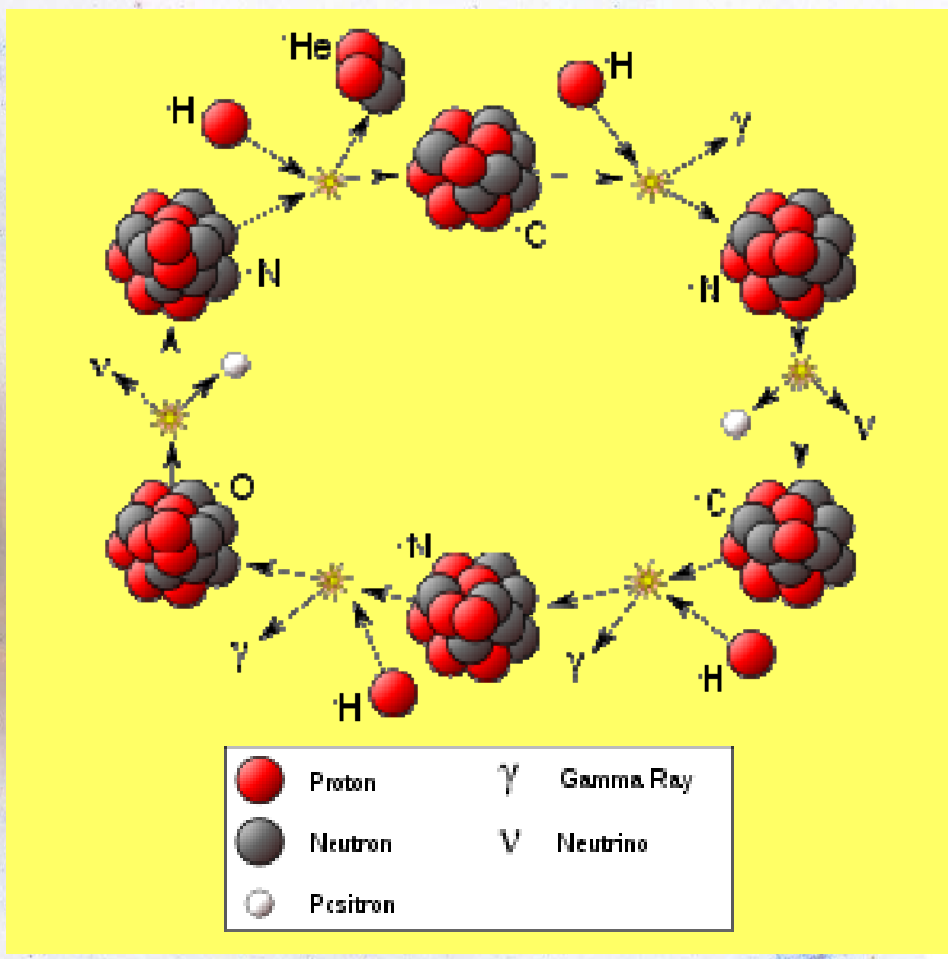
(Bethe-Weizsäcker-cycle)

$M > 1.5\ M_{Sun}$

$T > 20\ 10^6\ K$

$C + N + O = F + He + energy$

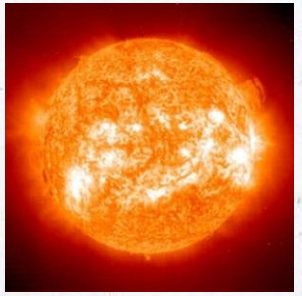
Energy release: ~ 0.71%



Energy production in massive stars is slightly more effective

Stars in the Sky

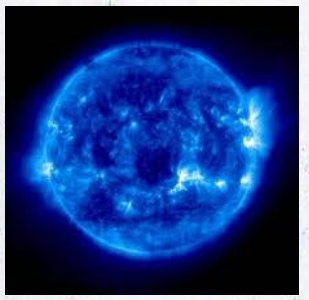
Moon, Planets: Reflect Solar Radiation



Sun and smaller stars: **pp chain**

Stars bigger then Sun: **CNO cycle**

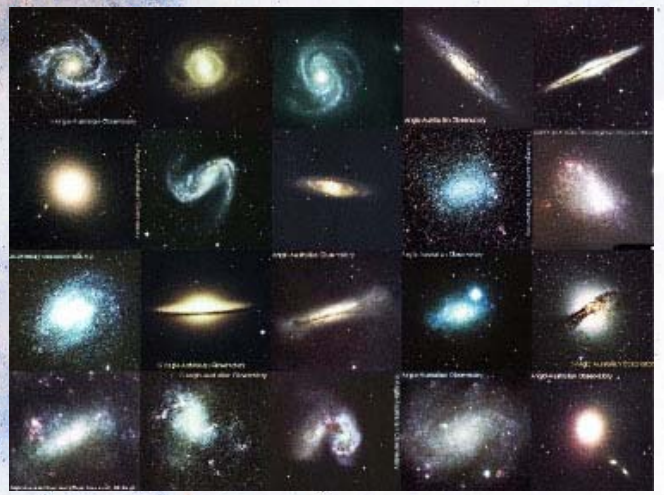
($>1.5M_{sun}$)



Galaxies:

Billions of stars often rotating around a common center;

- Huge combined luminosity

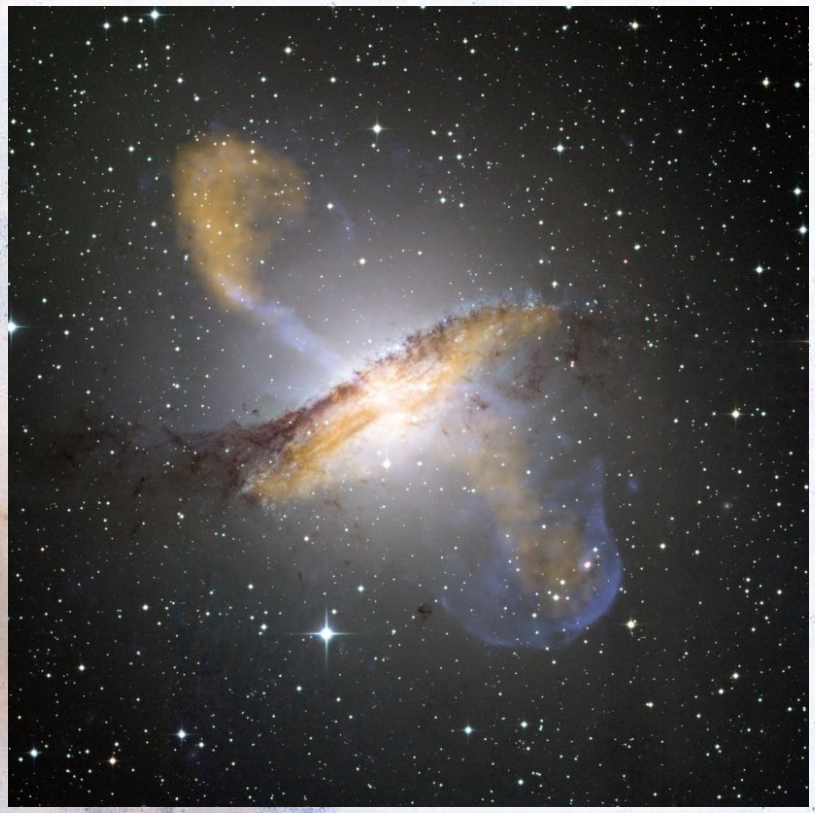


Active Galactic Nuclei

Central parts of some galaxies are extremely luminous

We can estimate the mass of central part by its Gravitational attraction

Non-stellar Luminosity



Can not be explained by simple combination of billions of stars

Energy production rate is much higher then 0.7% limit set by nuclear fusion.

Gravitational Energy

$E_g = m\ g\ h$

Energy of waterfall:

Gravitational energy

↓

Kinetic Energy

↓

Thermal Energy

Waterfall height: **100m**

Water temperature increase: **+0.24 °C**

Accretion

Gravitational energy in the Universe

Gravity force: $\mathbf{F_g = GMm/r^2}$

Gravity potential: $\mathbf{U = GMm/r}$

Energy release: $\mathbf{\Delta E = \Delta U}$

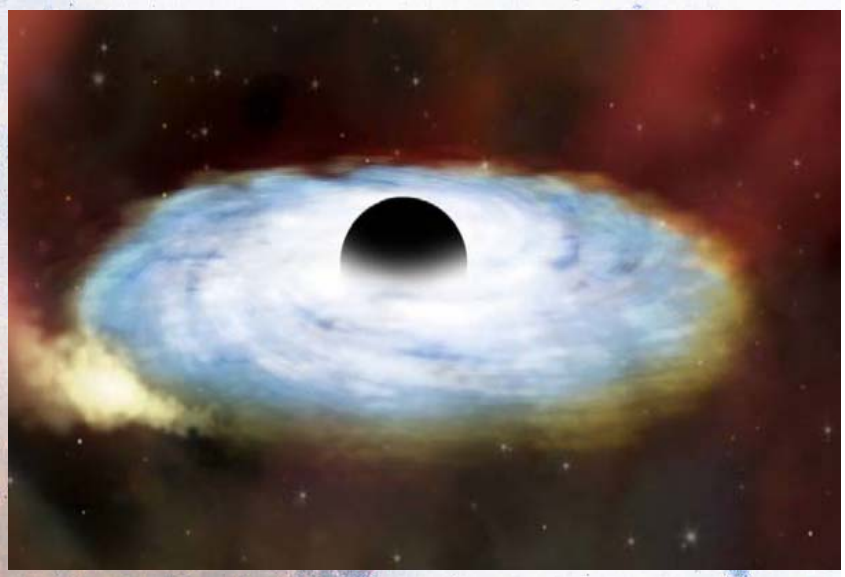
How to increase the energy output from mass **m**?

1. **Increase M**
2. **Decrease r**

m mass falling on gravitationally compact object

Accretion

Mass accretion on a black hole



Gas rotating and spiraling down to the center heats up closer to black hole

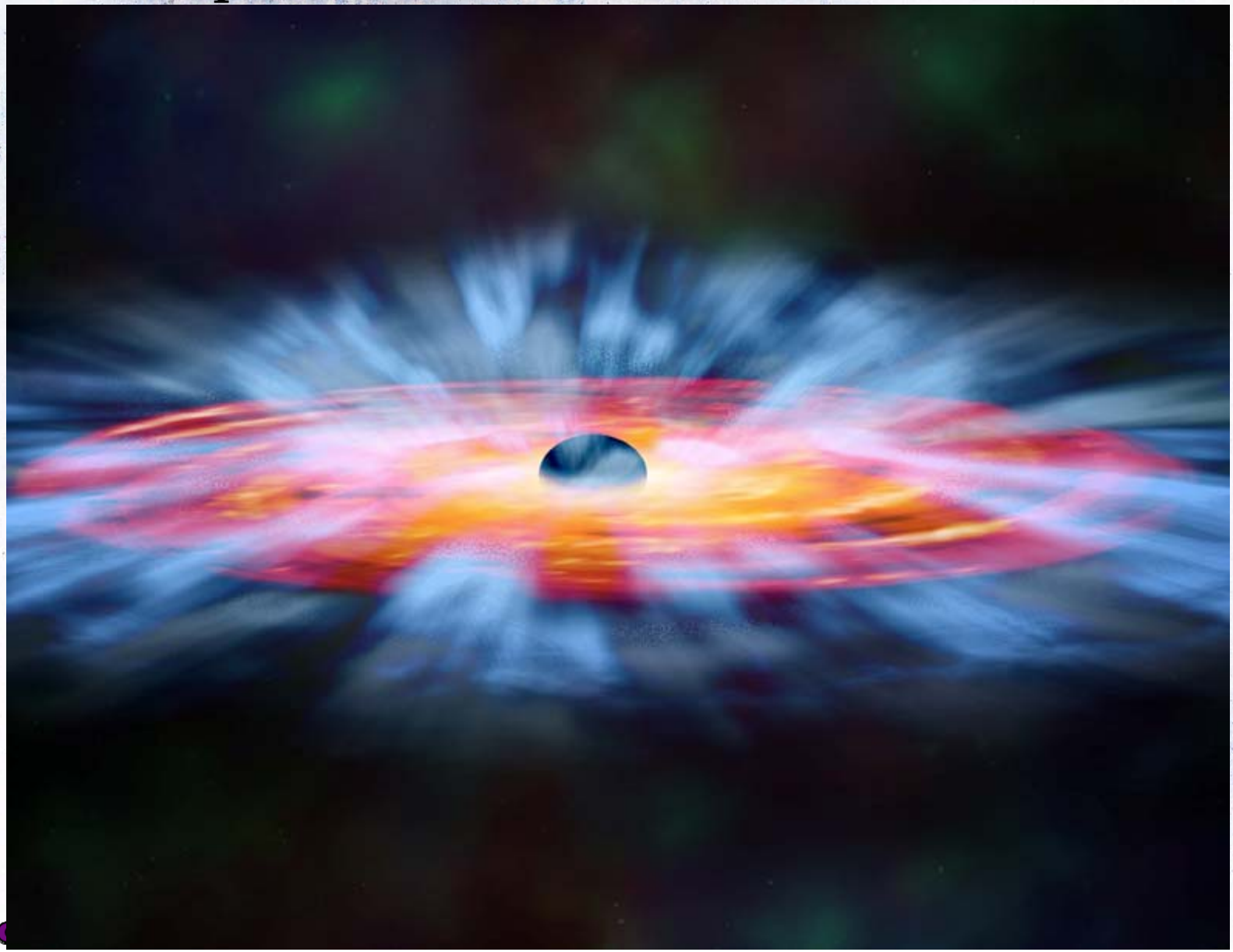
Thermal emission provides huge luminosity (radiation area outside the event horizon)

Energy release: ~ 10 – 20 %

Accretion is the efficient in converting falling mass into the energy

Accretion

Artist's impression of the BH accretion luminosity



AGN Luminosity

Extremely bright galaxy nuclei: **$P \sim 10^{37}$ W**

Mechanism: Accretion

Super Massive Black Hole in the center of galaxy

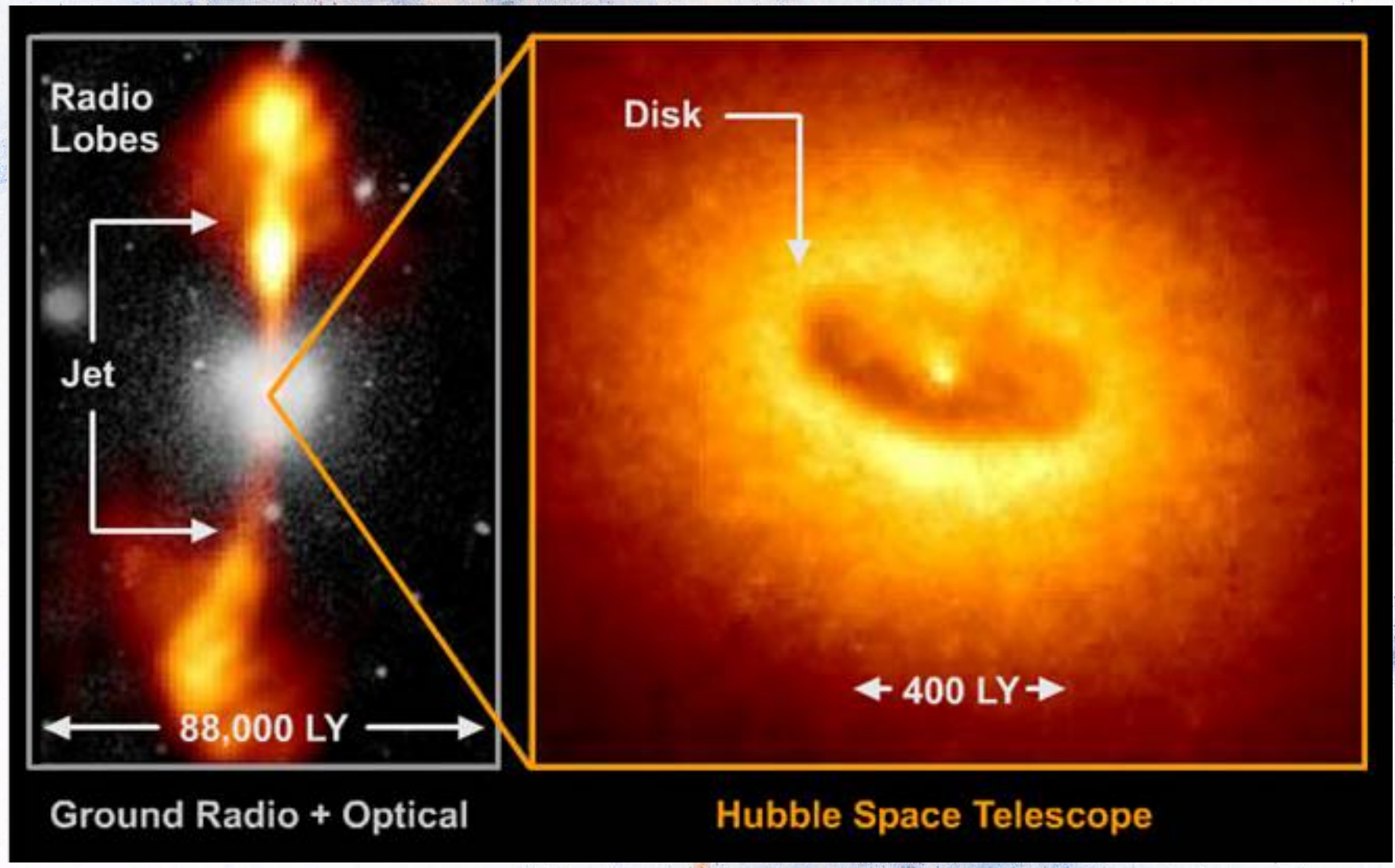
$$M_{BH} \sim 10^9 M_{Sun}$$

Mass accretion rate (m): **1 M_{Sun} in 1 year**

Most Luminous objects in the Universe

Accretion

AGN Observations (Galaxy NGC 4261)



1.) FILL QUIZ !

2.) QUESTIONS? (2:00 pm)