# Astrophysics Lecture Plan

Dr Andrew Taylor

Lecture 1: Stars- How they Work
Lecture 2: Stars- Their Evolution
Lecture 3: Planets
Lecture 4: Supernova Remnants
Lecture 5: Black Holes
Lecture 6: Dark Matter

**Course Books:**

"High Energy Astrophysics" Vol. 1+ 2
by Malcolm Longair

# Some Important Numbers

## Energetics:

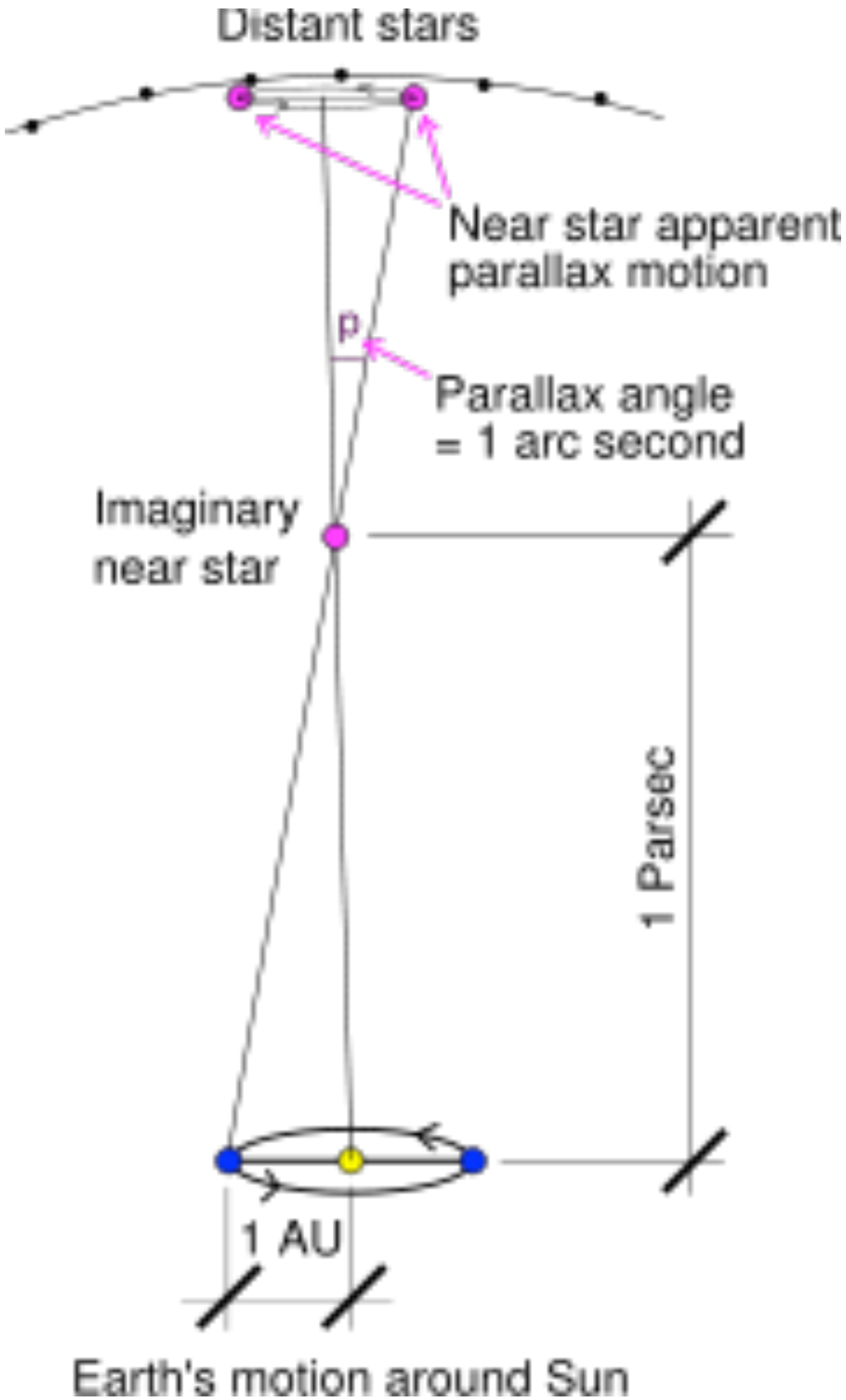
$L_{Sun}$~$10^{26}$ W (Power)
0 K ~ -273 C
eV ~ $10^{-19}$ J~$10^{4}$ K

## Distances:

1 AU (Astronomical Unit)- Earth-Sun distance ~$10^{11}$ m

1 ly (Light Year)- distance light travels in 1 year ~$10^{16}$ m

1 Parsec ~3x$10^{16}$ m




Parallax in astronomical terms is the apparent shift of an astronomical object due to the motion of the earth it is measured in arcseconds

A parsec is the distance at which the semi-major axis of the Earths orbit would sub-tend an angle of 1 arcsecond

# The Nature of the Sun

# The Nature of the Sun


1000 K

3000 K

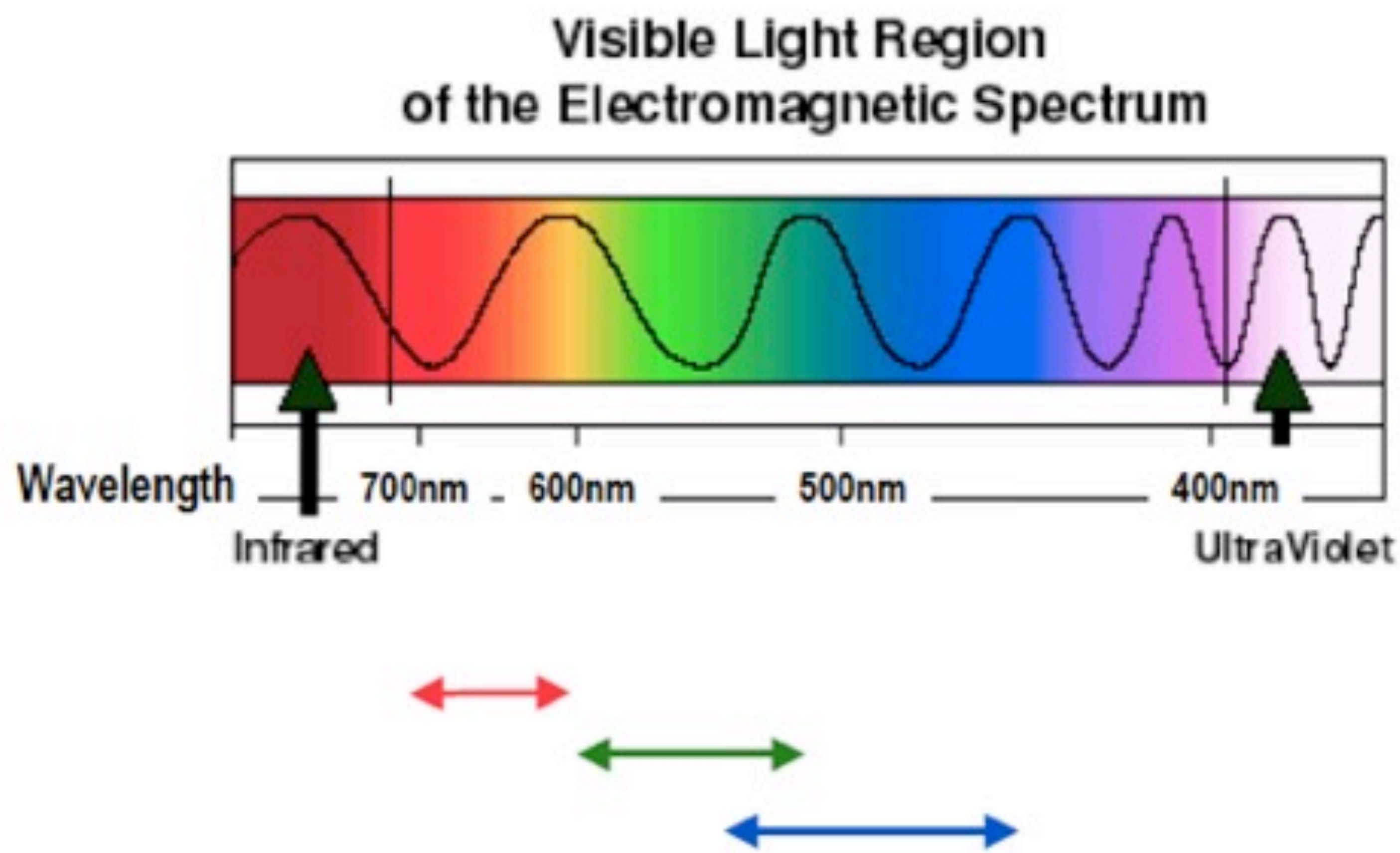
5000 K

7000 K

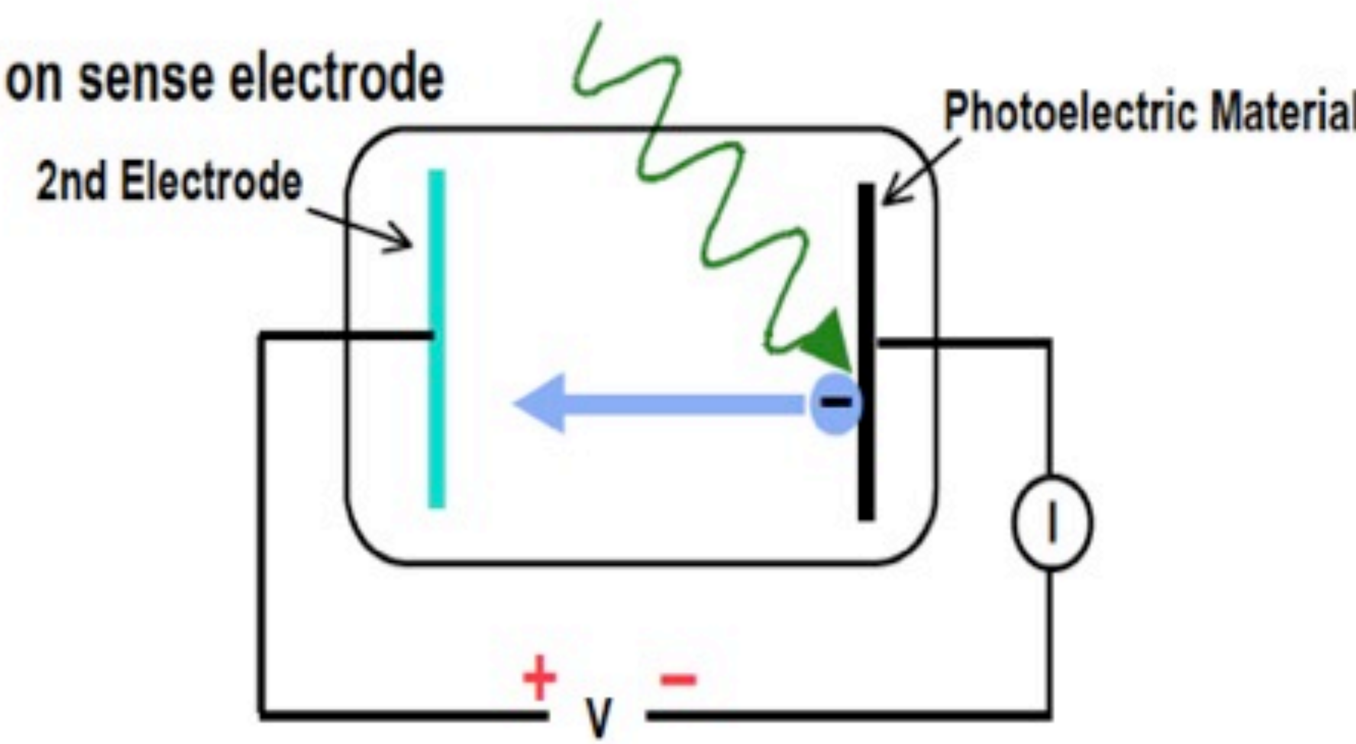
9000 K

# Measuring the Sun's Spectrum

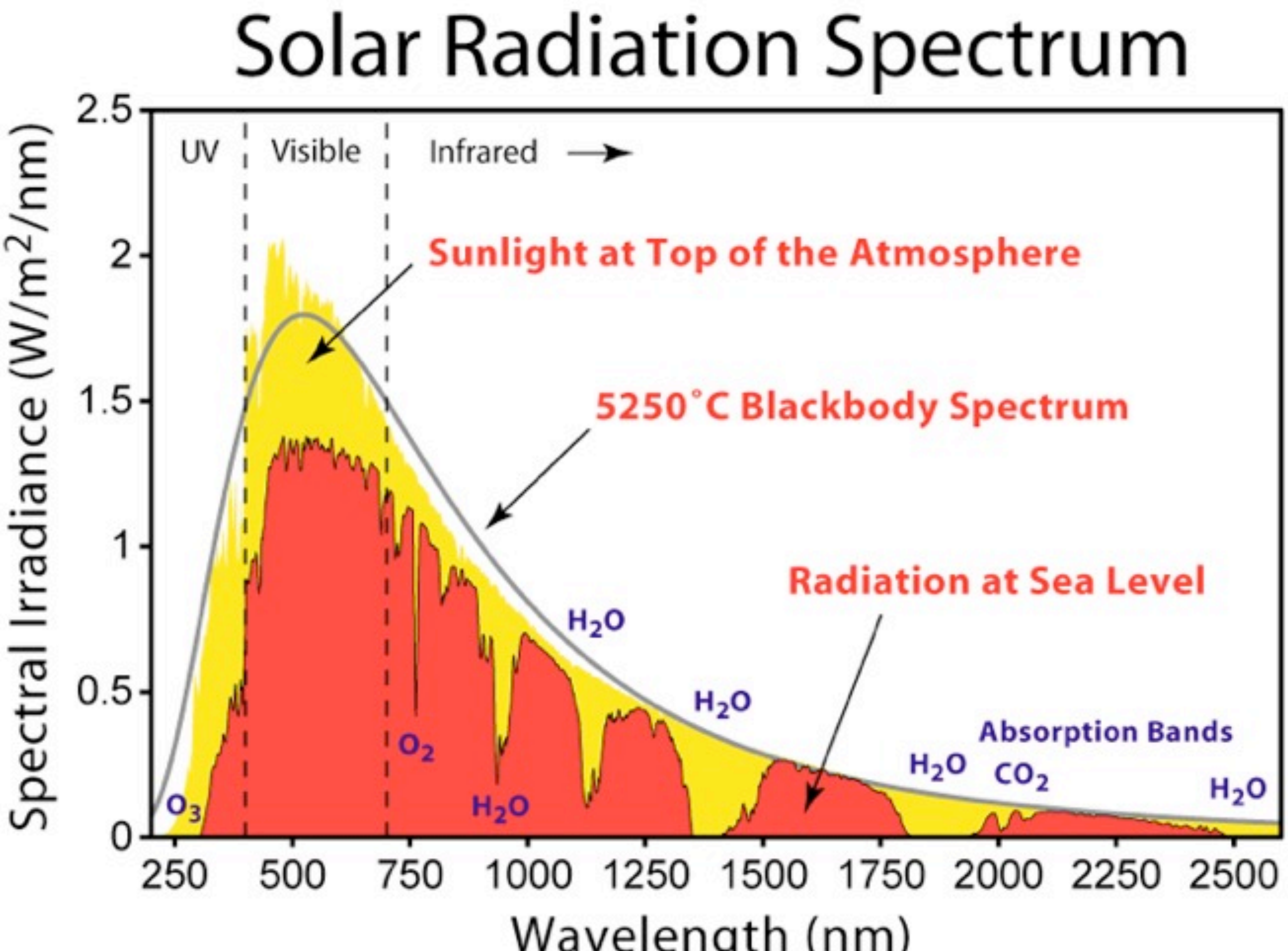
- Filters - approximate band-pass
  - Red 600-700 nm
  - Green 520-600 nm
  - Blue 450-550 nm



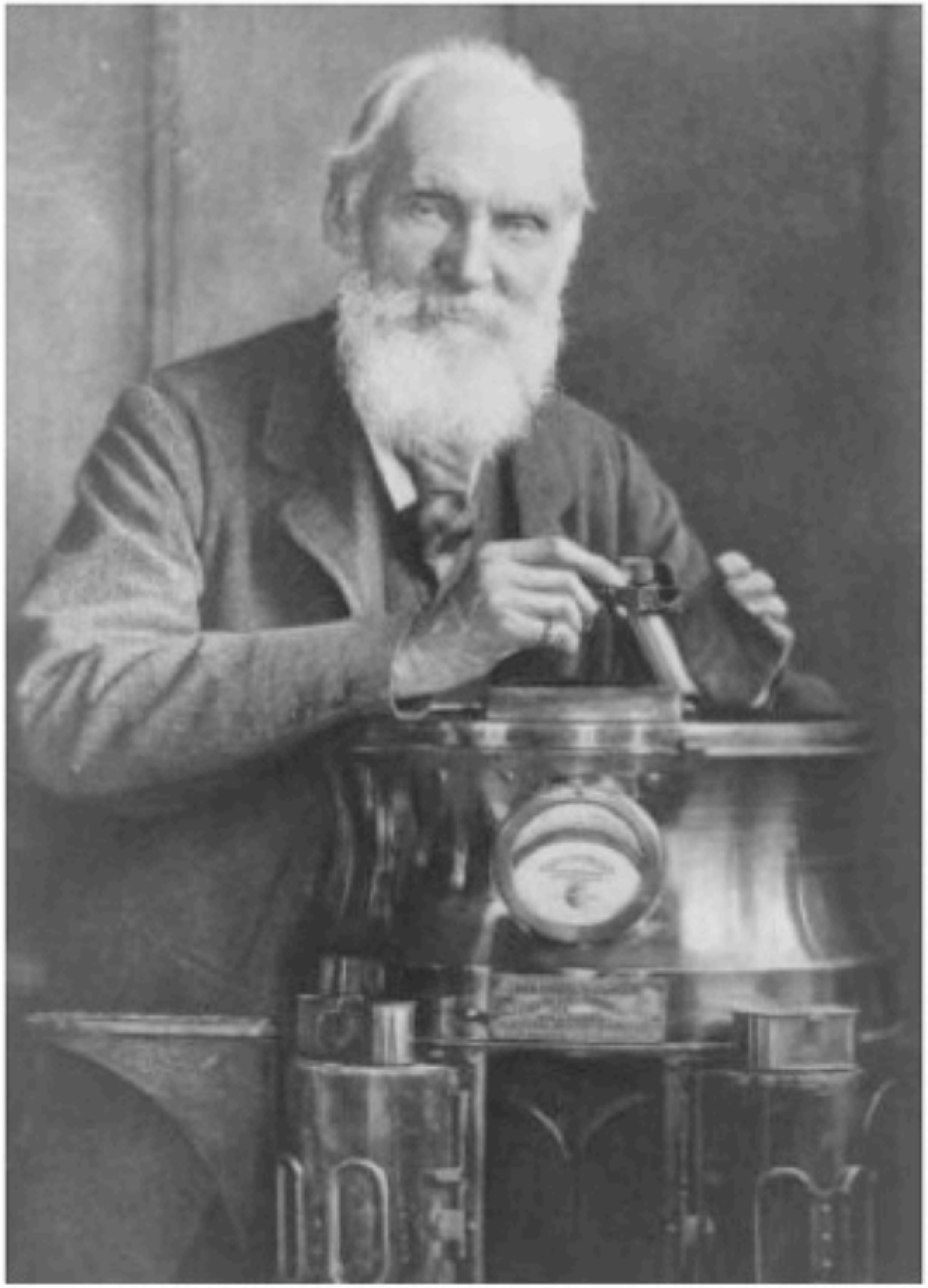

- +ve bias on sense electrode



# What's the Origin of its Colour?



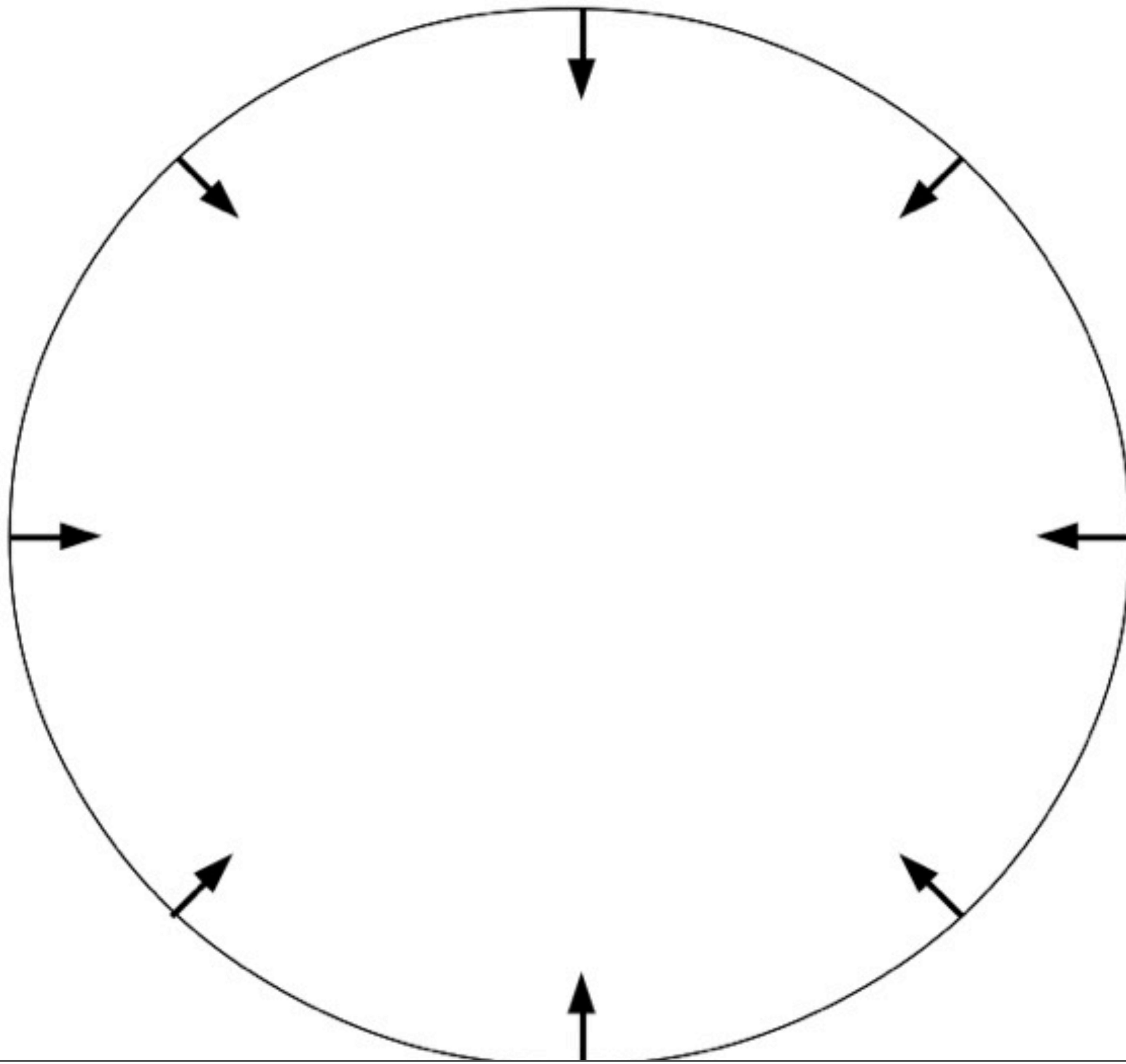
# Why's It Hot?



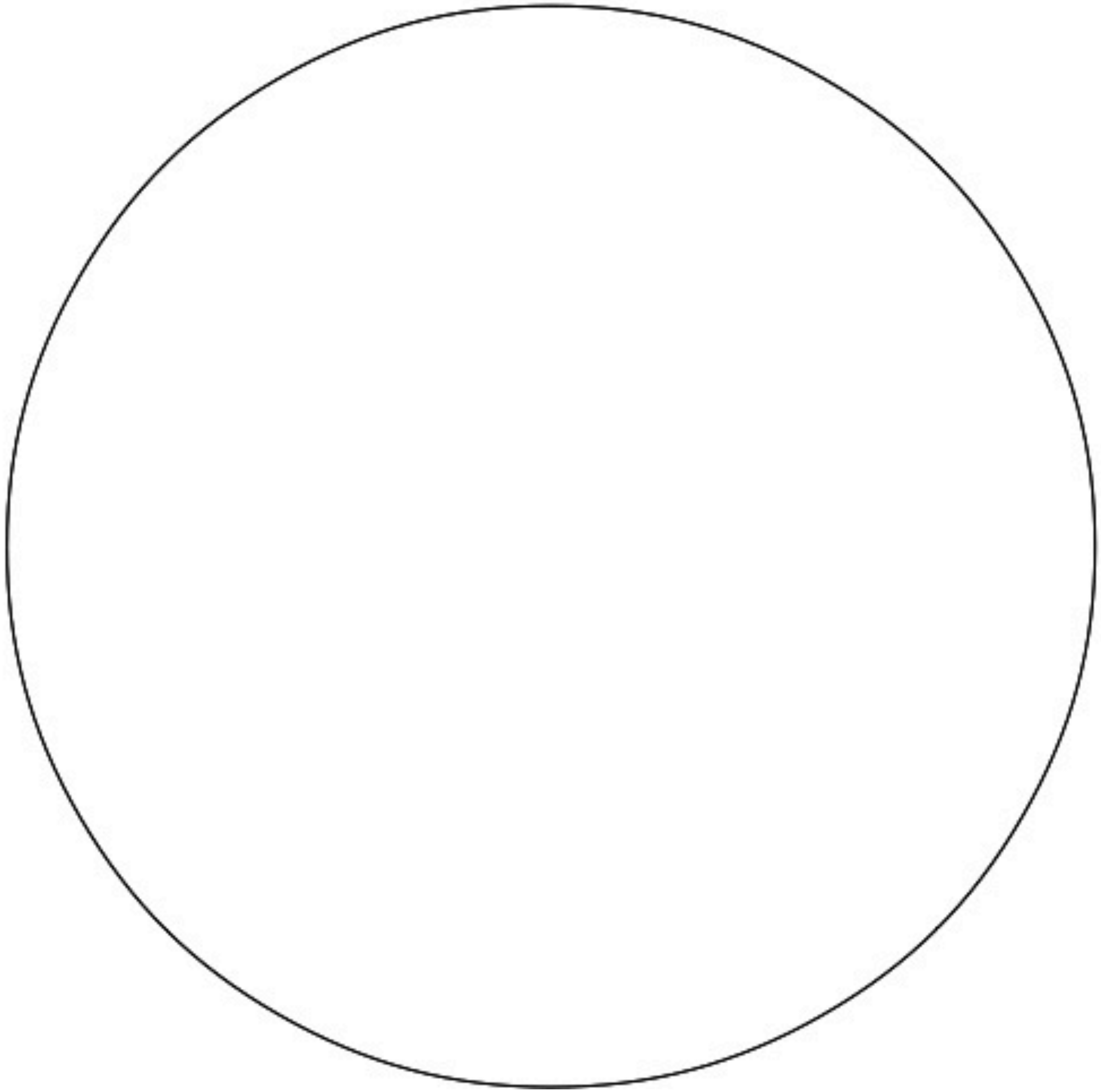
Kelvin

Helmholtz

# Why's It Hot (~eV in temperature)?



# Why's It Hot (~eV in temperature)?



# Kelvin-Helmholtz Suggested Timescale

$$t \sim \frac{GM_\odot^2}{L_\odot R_\odot}$$

$$\sim \frac{U_\odot}{L_\odot}$$

$$U_\odot \sim 10^{49}\ \mathrm{erg}$$

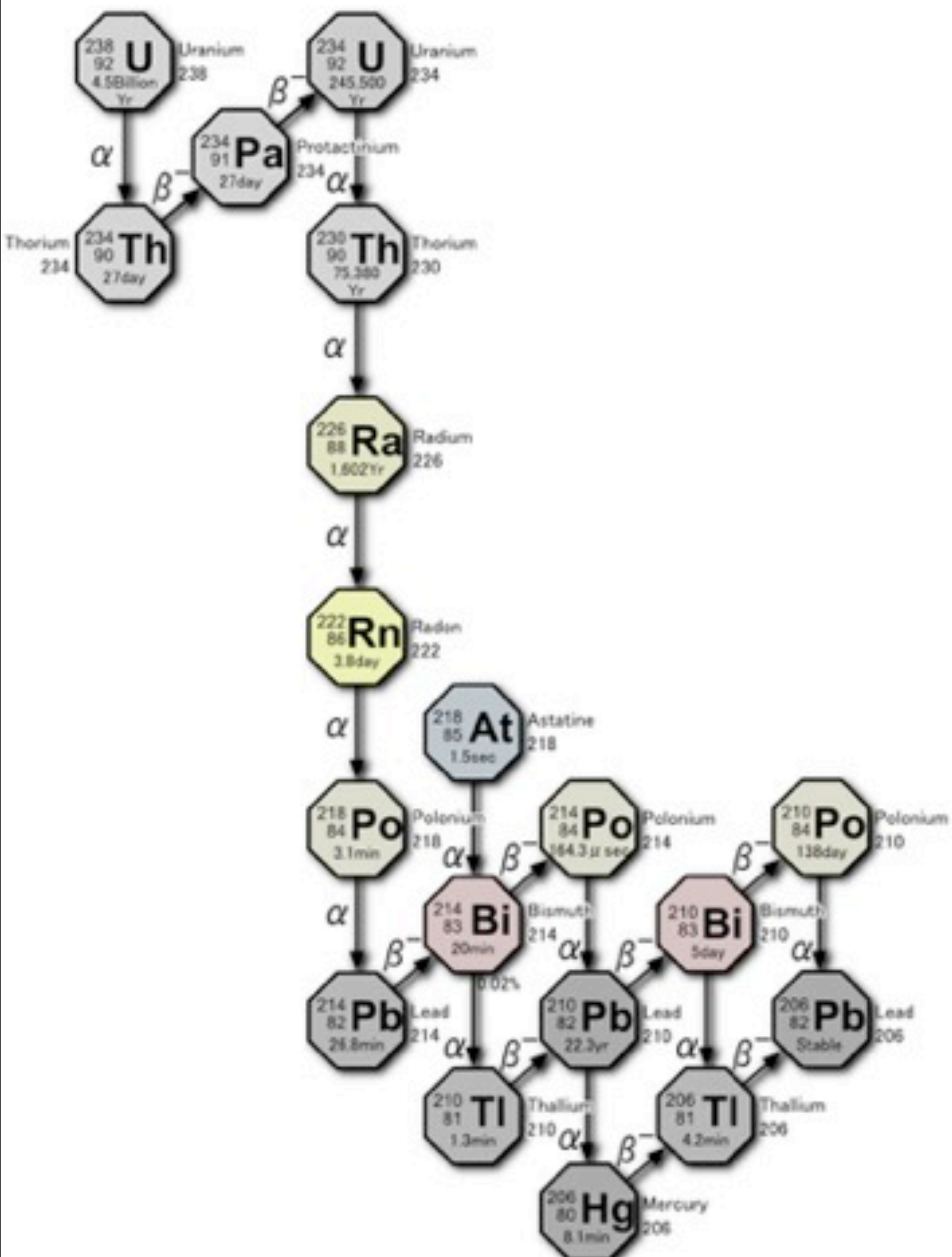
$$L_\odot \sim 10^{33}\ \mathrm{erg\ s^{-1}}$$

$$t \sim 10^{14}\ \mathrm{s}$$

# A problem with Gravitational Collapse Powered Heating

Rutherford

# A Spanner in the Works



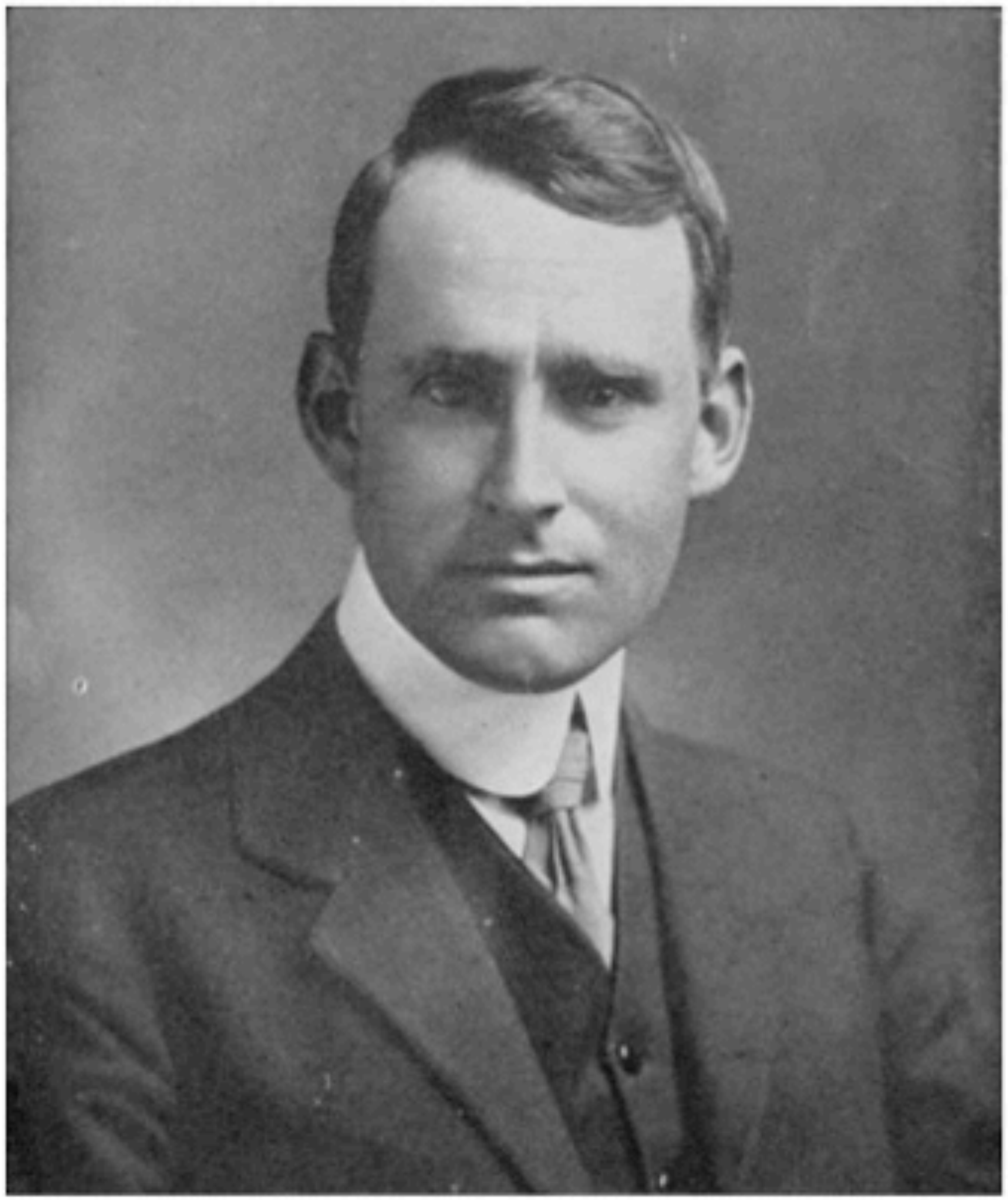

Uranium decay series

$$\tau_{1/2}(^{238}U) = 4 \times 10^9 \text{ yrs}$$

$$\tau_{1/2}(^{236}Ra) = 1000 \text{ yrs}$$

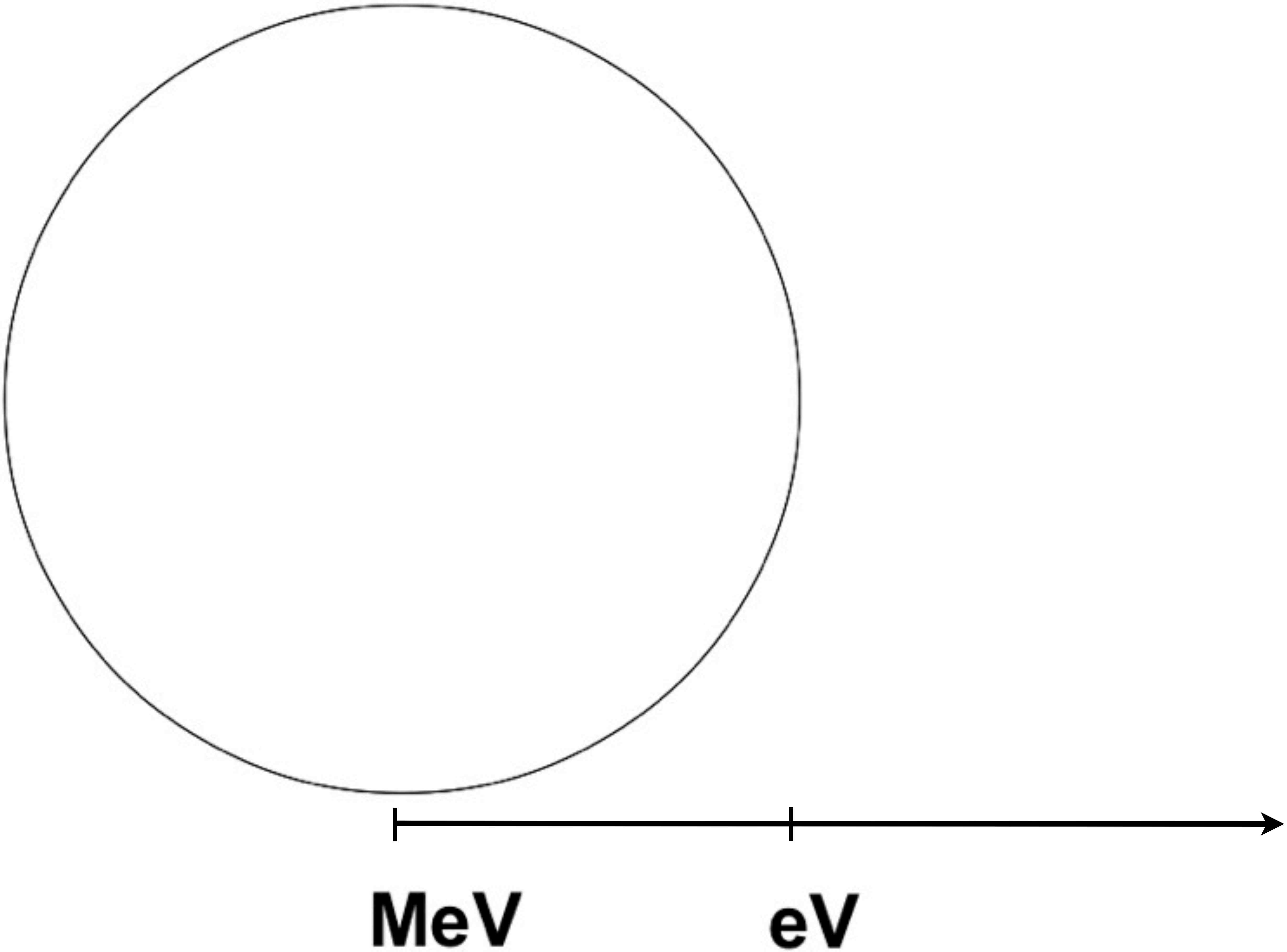
Could radioactive decay be powering the sun?

# A New Hypothesis

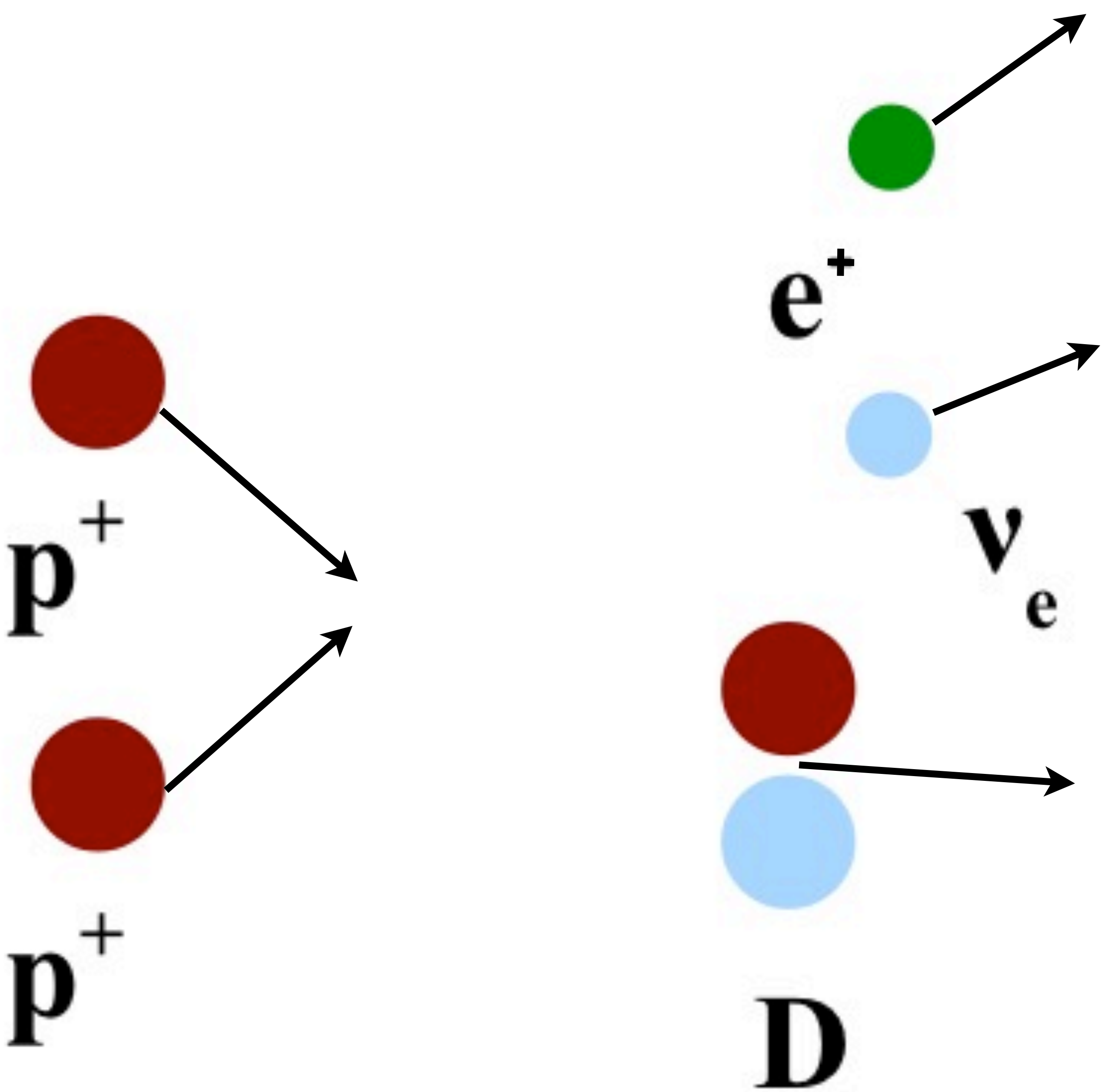


Eddington

# Nuclear Heating



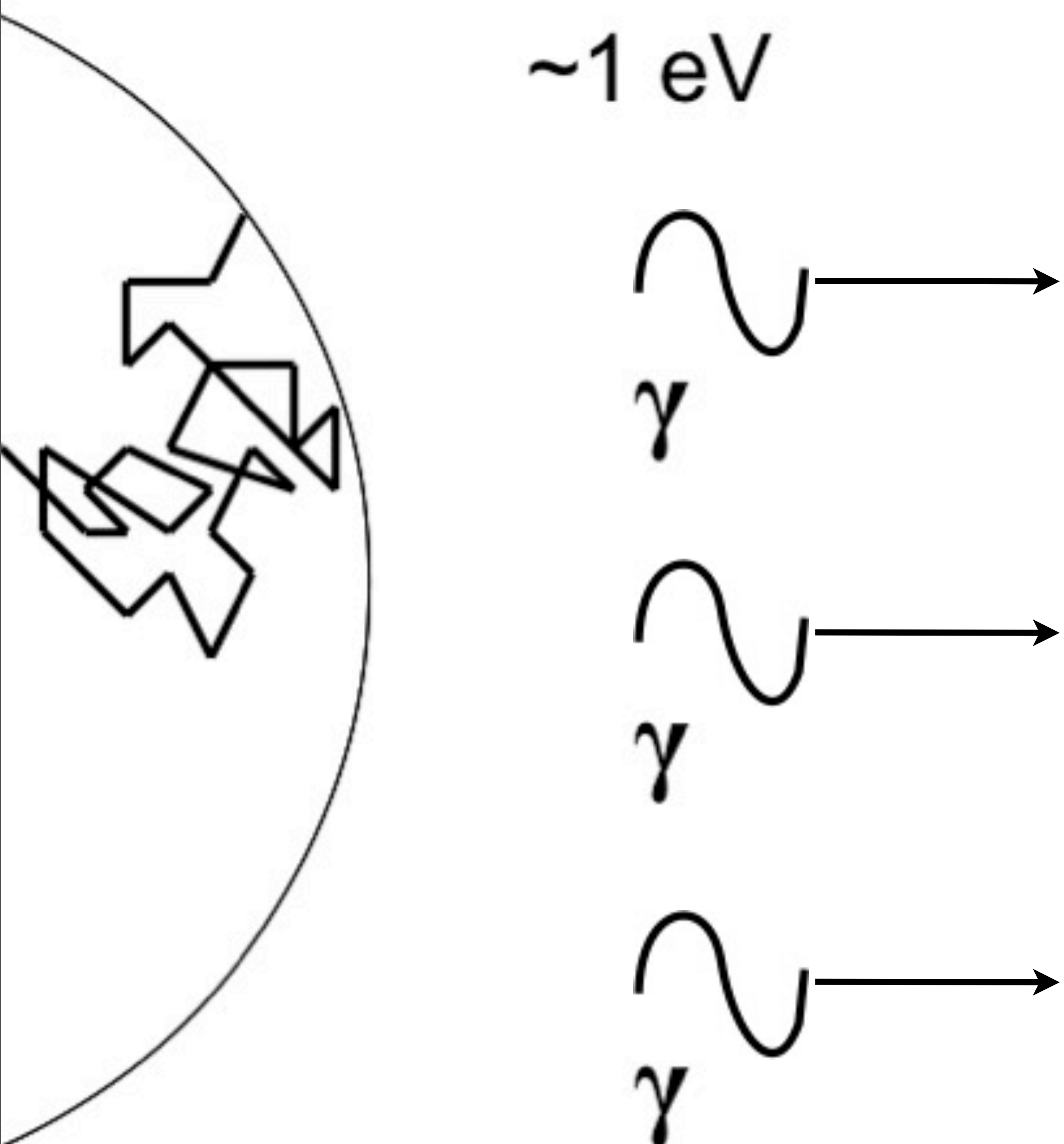
# Where does the MeV Scale Come From?




2(938.27 MeV) + 0.511 MeV = 1877.05 MeV

1875.6 MeV

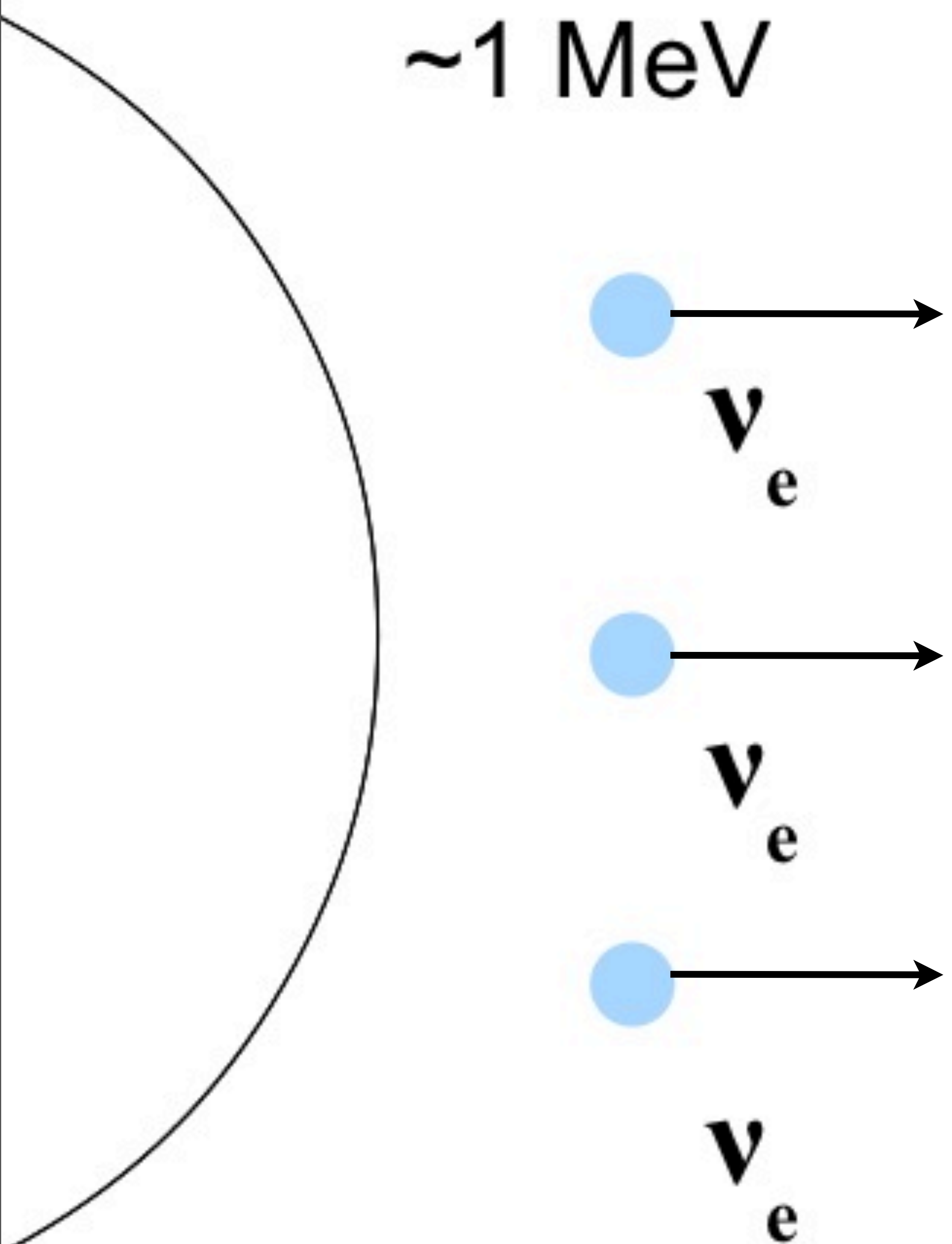
# We See The Visible Radiation (which starts off as γ-rays)




$$l_{\mathrm{int}} \sim \frac{1}{n_e \sigma_{\mathrm{T}}} \sim 1 \text{ cm}$$

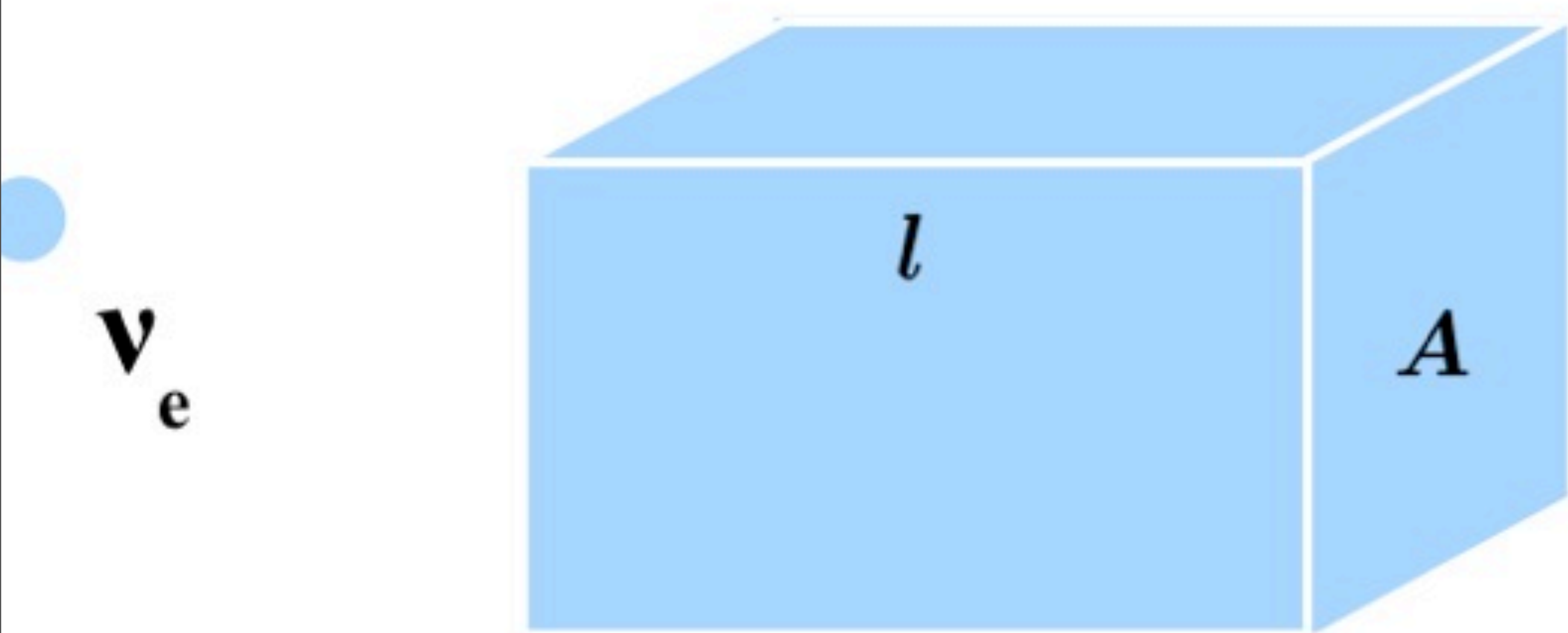
$$t_{\mathrm{esc.}} \sim \frac{R_{\odot}^2}{c\, l_{\mathrm{int}}} \sim 5000 \text{ yrs}$$

# Can We Ever See This Invisible Radiation?



# Can We Ever See This Invisible Radiation?

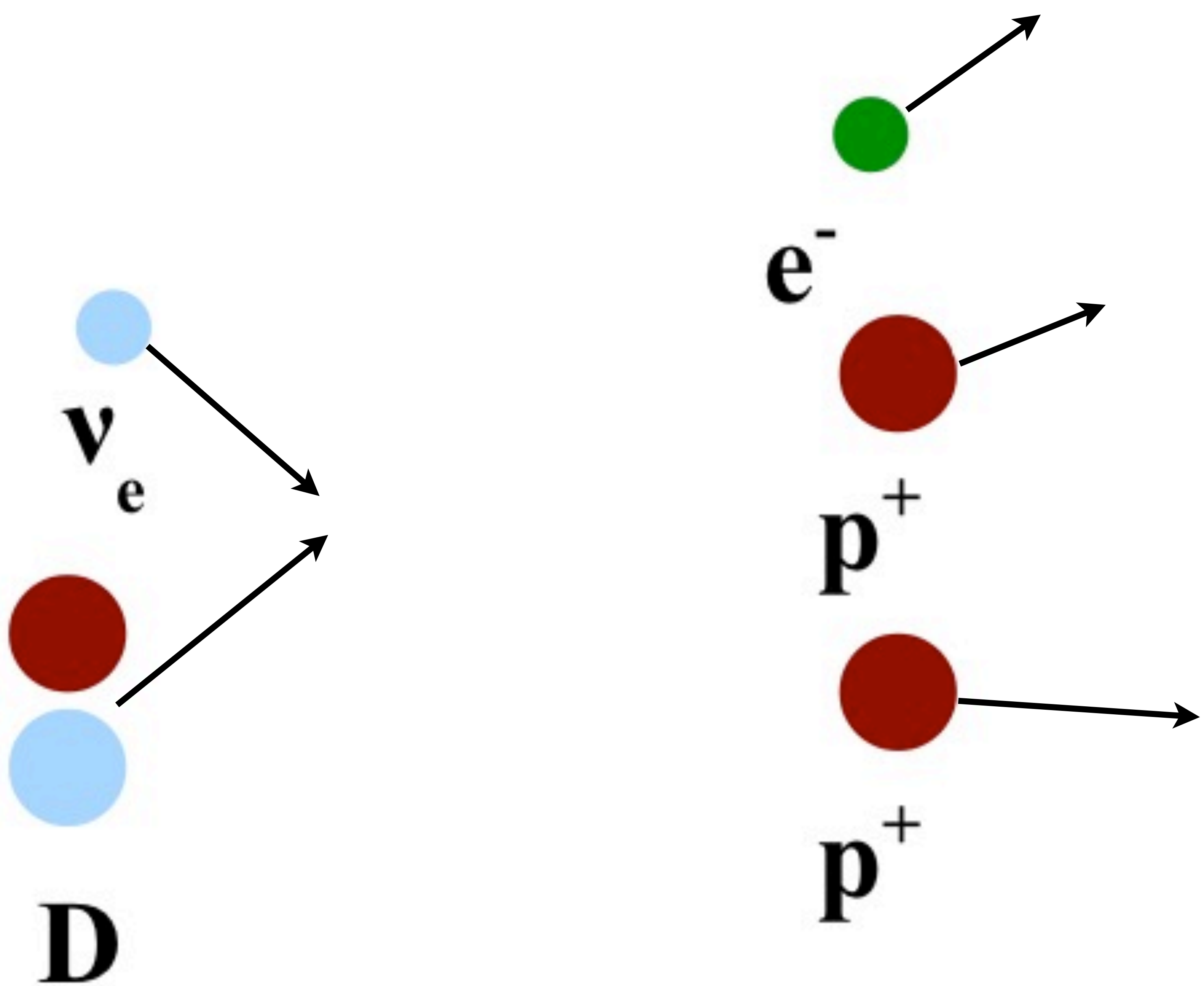
(Heavy) Water Tank



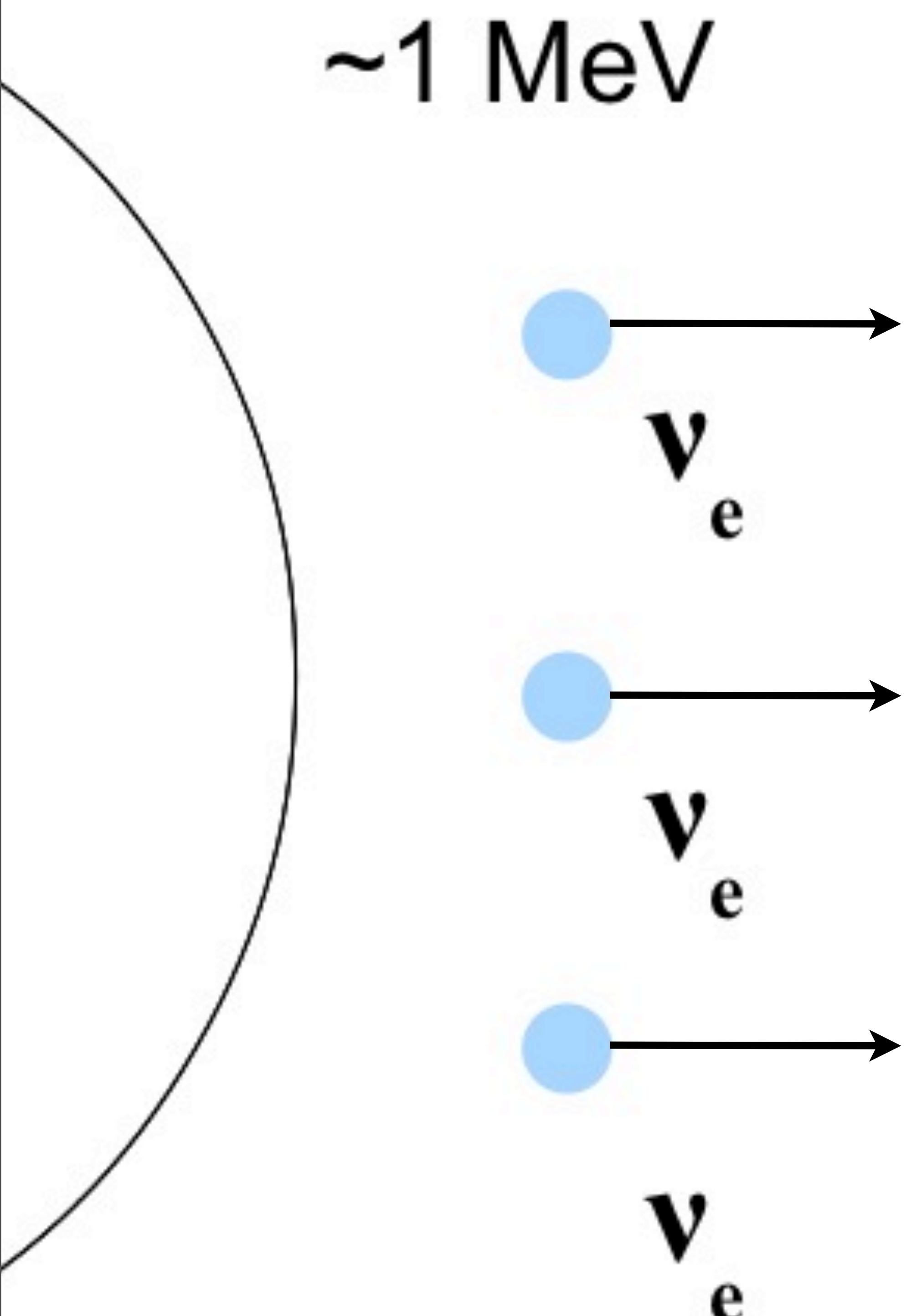

$$l_{\text{int}} \sim \frac{1}{n_e \sigma} \sim 10^{15}\ \text{m}$$

$$N(1\ \text{yr}) = \frac{dN}{dA\,dt} \times t_{\text{yr}} \times A \times \frac{l}{l_{\text{int}}}$$

# Can We Ever See This Invisible Radiation?



# Can We Ever See This Invisible Radiation?

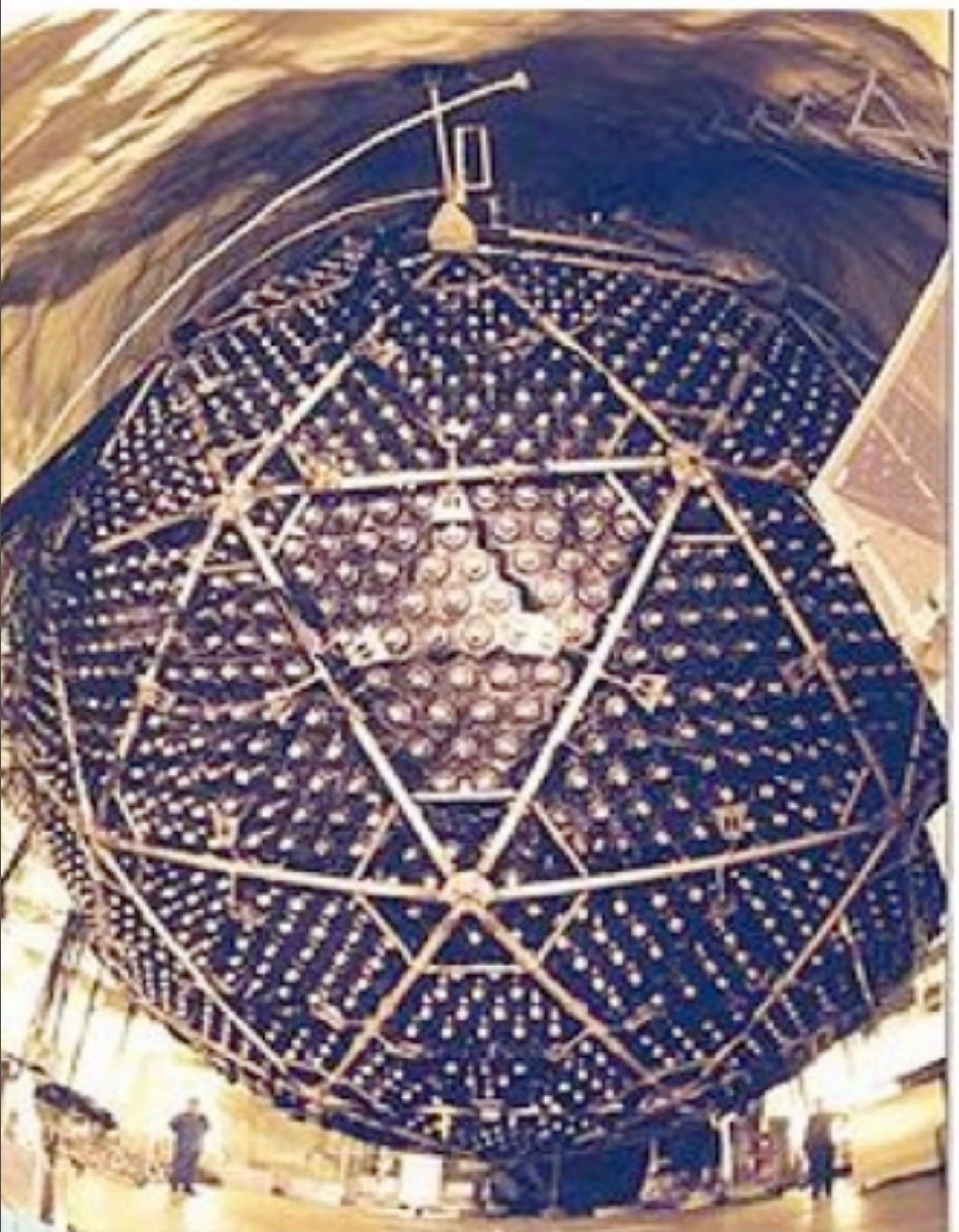



Ray Davies

Yes....but only ~1/3 of the expected number of electron neutrinos are observed!

# SNO- Sudbury Neutrino Observatory

m

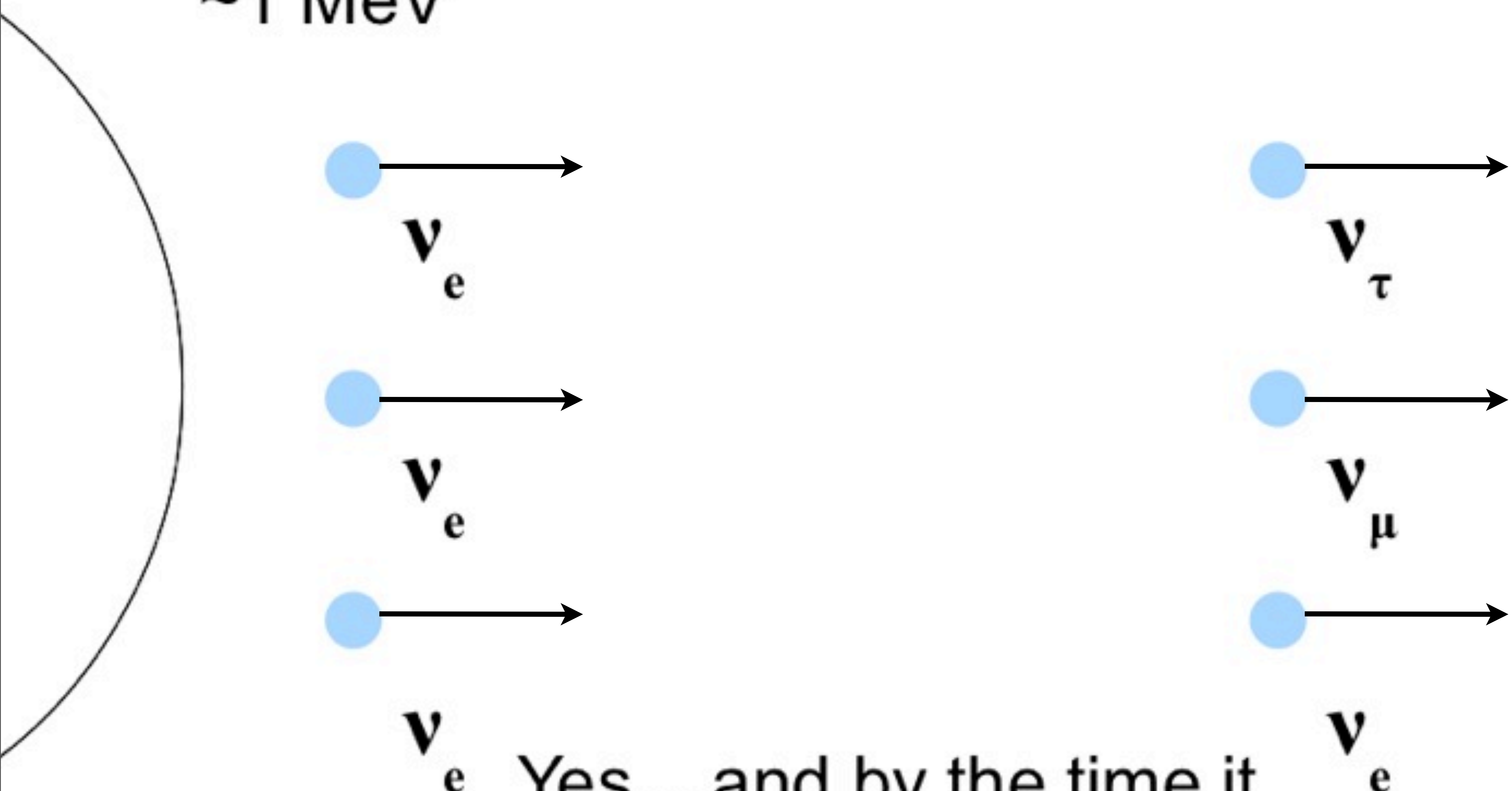


16 m

Steve Biller

# Can We Ever See This Invisible Radiation?

~1 MeV




Yes....and by the time it arrives to the Earth it consists of all 3 flavours!

# Lecture Problems

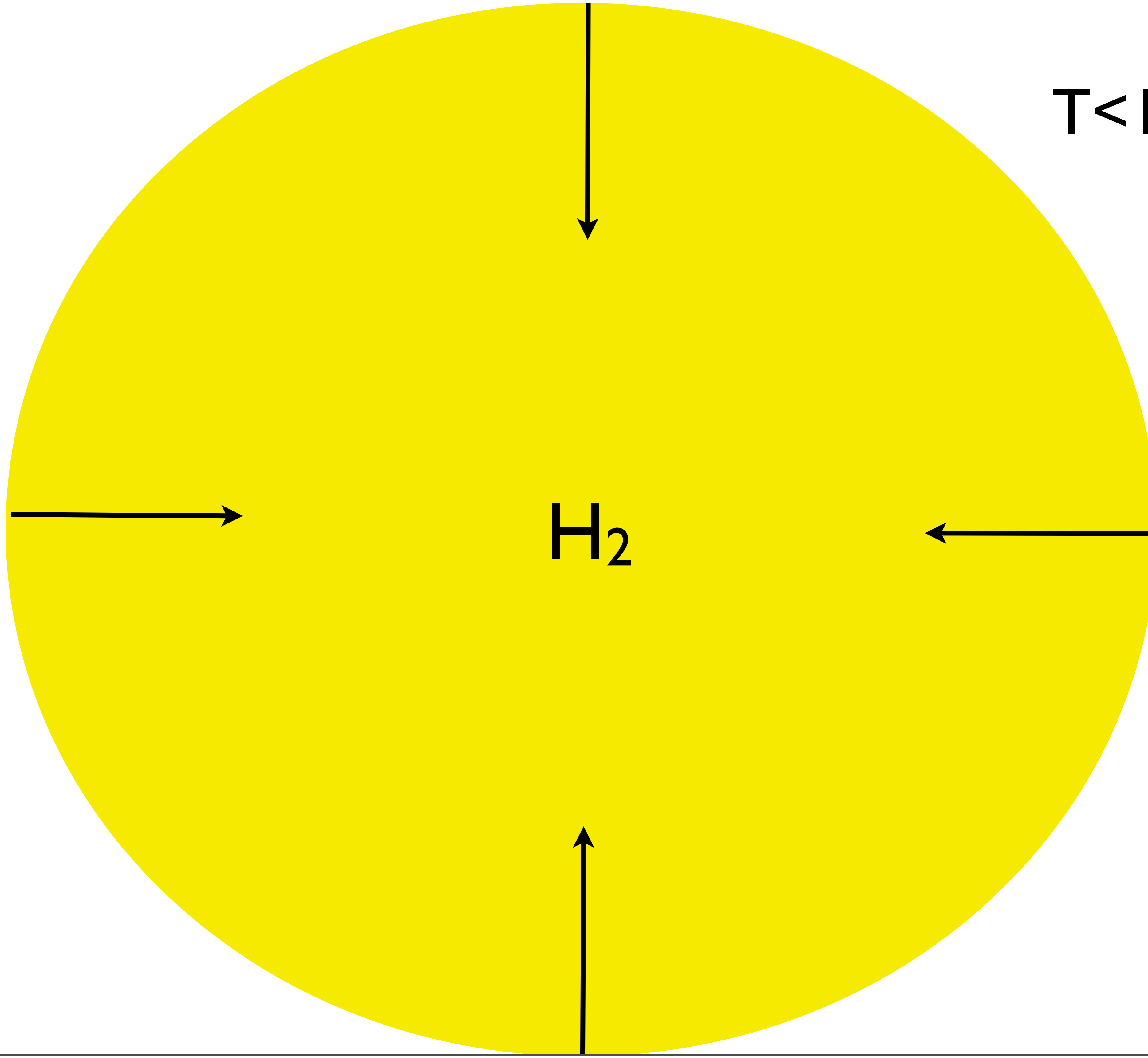
Sitting on the beach at the equator on March 21st/Sep 21st (spring + autumn equinoxes), the Sun is overhead at midday. What power from it in photons do I receive at this time?
(see slide 2)

Sitting on the beach at the equator on March 21st/Sep 21st (spring + autumn equinoxes), the Sun is overhead at midday. What power does my 15m x 15m x 15m water tank receive in neutrinos at this time (I brought it on the beach with me!)?

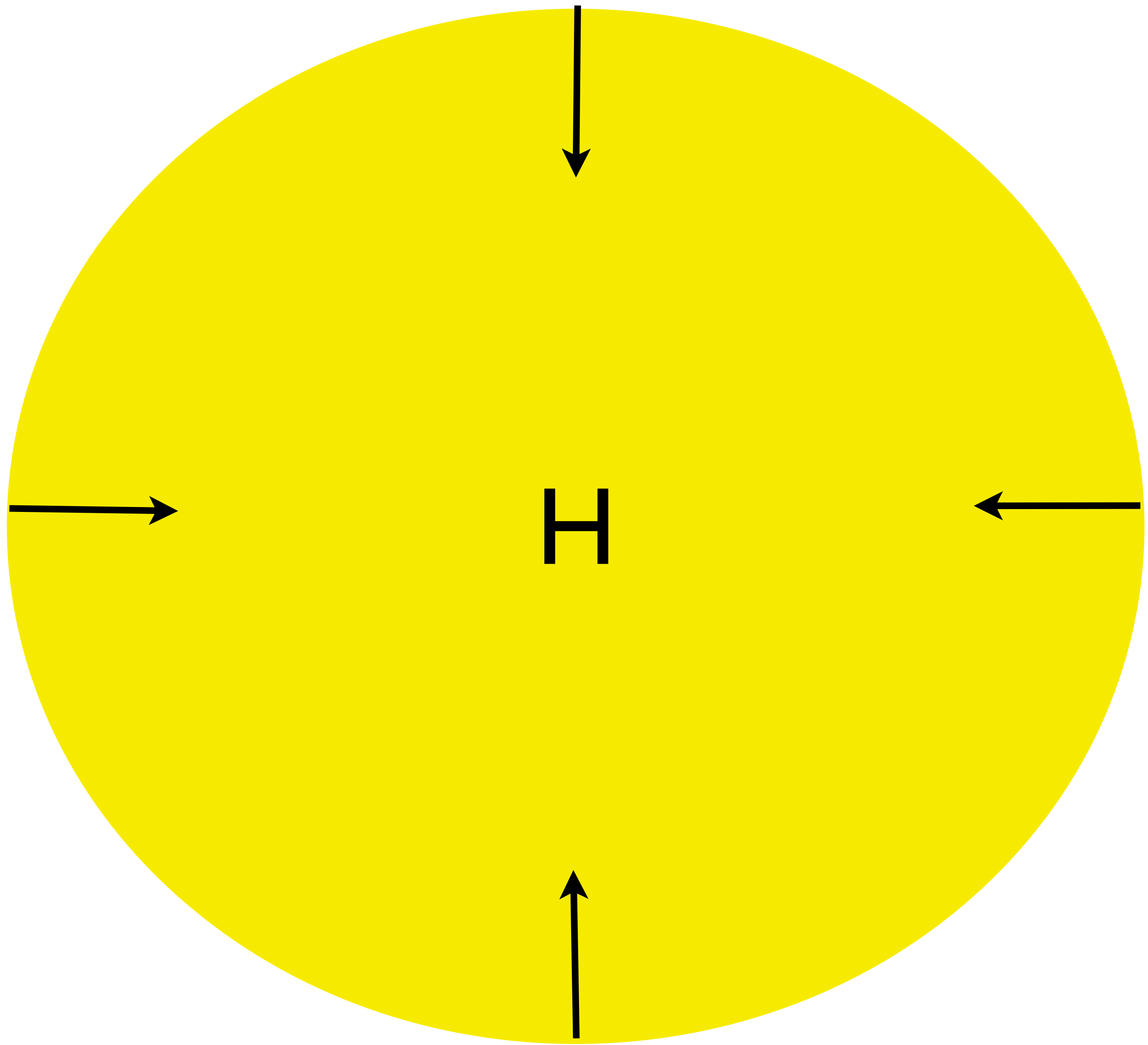
# Types of Stars

| Type | Prominent spectral lines | colour | average temp | Examples |
|---|---|---|---|---|
| O | He, H,O,N,C,Si | Blue | 45,000 K | Regor |
| B | He, H,O,N,Fe,Mg | bluish white | 30,000 K | Rigel |
| A | H, ionised metals | white | 12,000 K | Sirius |
| F | H, Ca, Ti, Fe | yellowish white | 8,000 K | Procyon |
| G | Ca, Fe, Ti, Mg, H some molecular bands | yellowish | 6,500 K | The Sun |
| K | Ca,H,molecular bands | orange | 5,000 K | Aldebaran |
| M | TiO,Ca, molecular bands | red | 3,500 K | Betelgeuse |

# Stars: Evolution Theory

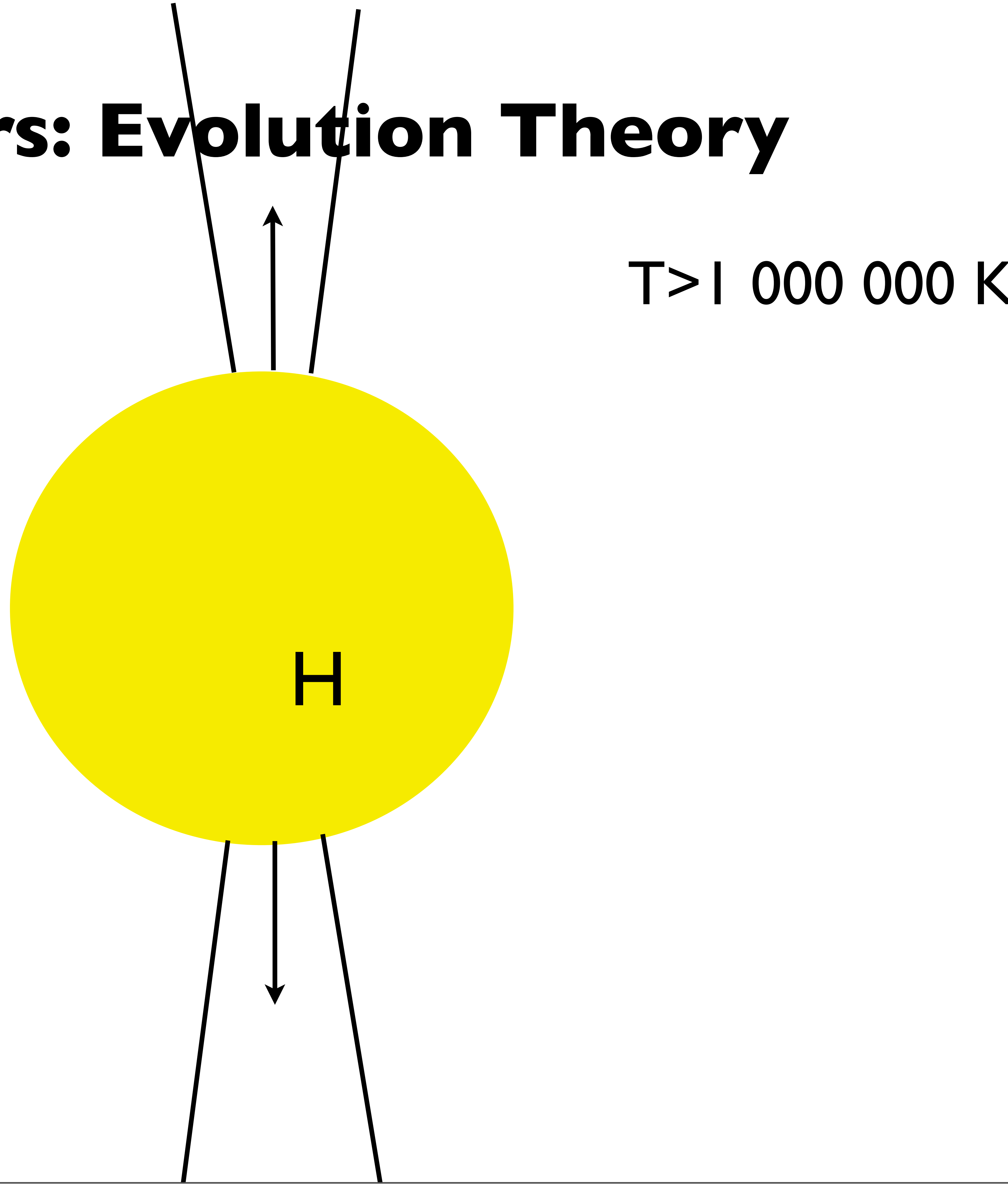


# Stars: Evolution Theory



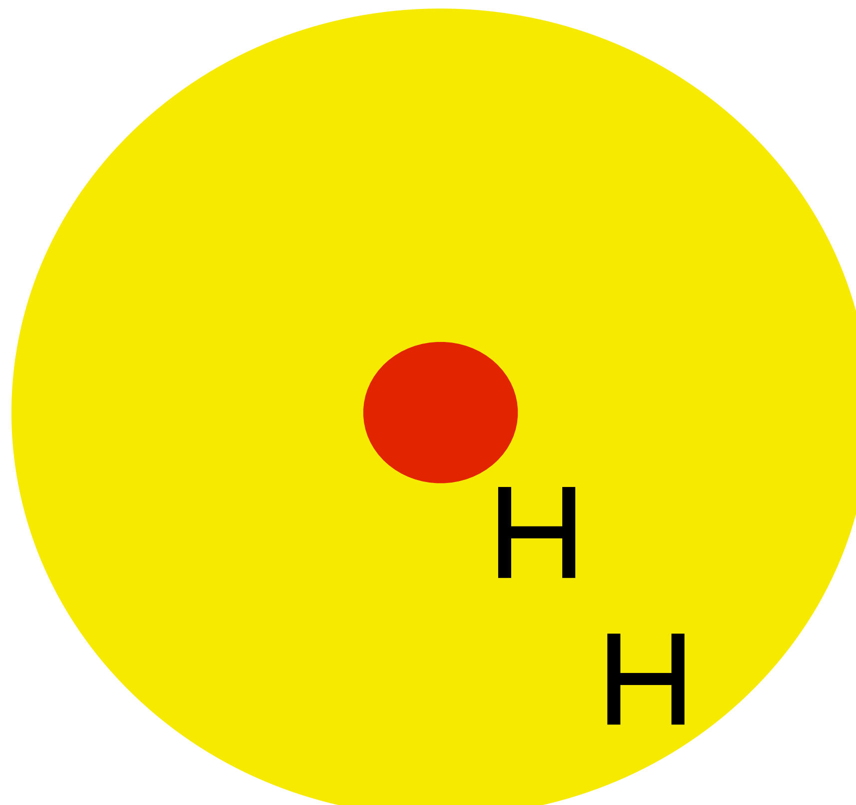

T>10 000 K

# Stars: Evolution Theory



# Stars: Evolution Theory

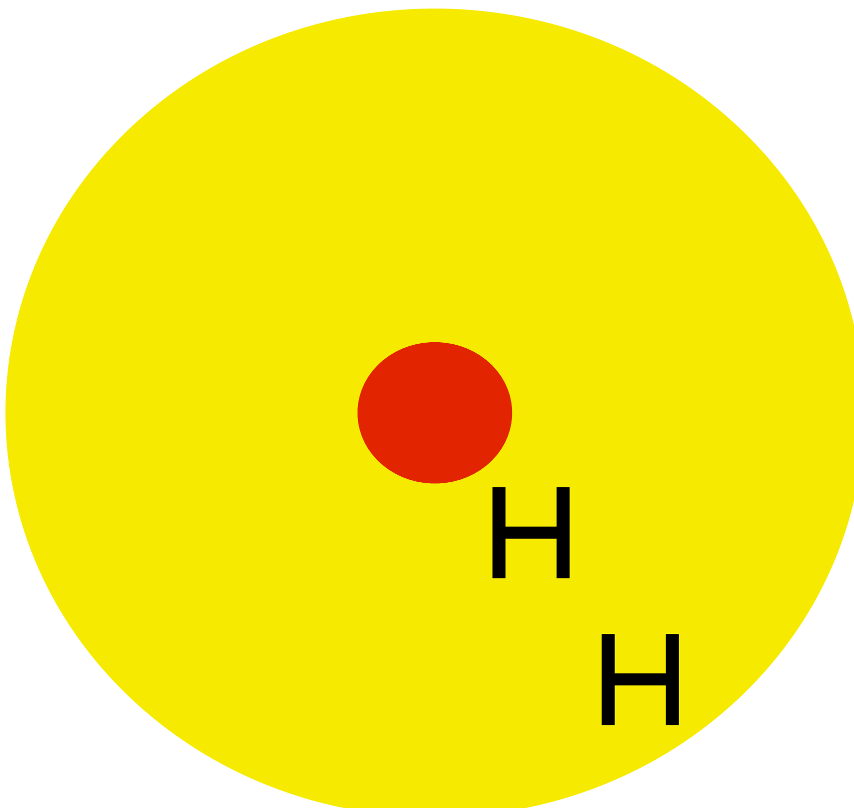
T>10 000 000 K




Takes ~50 Myr to form from the
Molecular Cloud

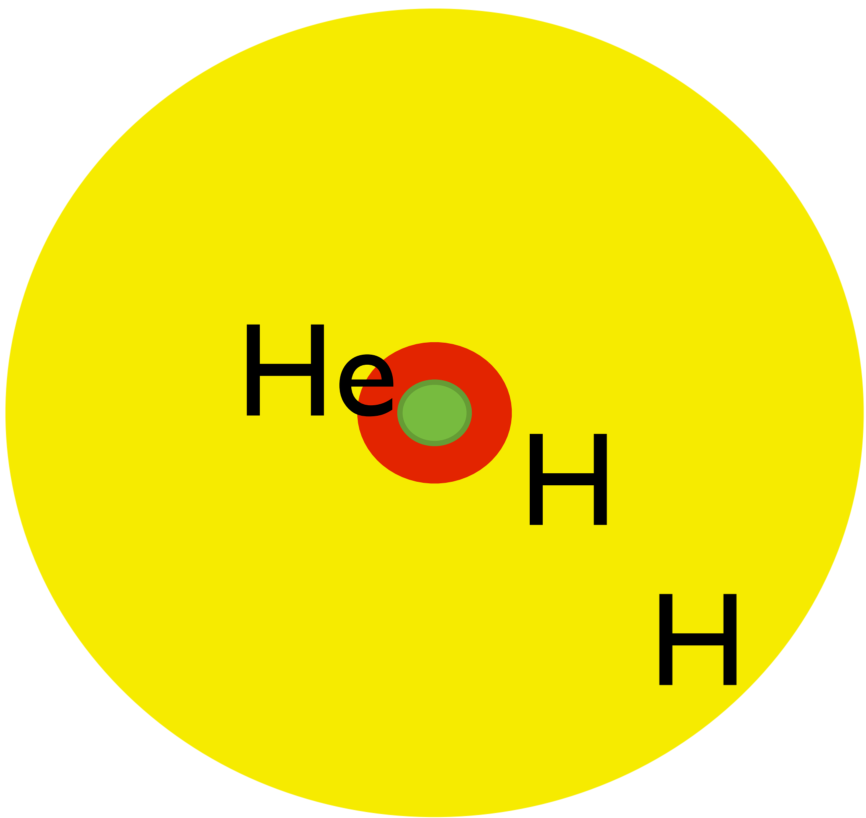
# Stars: Evolution Theory

T>10 000 000 K

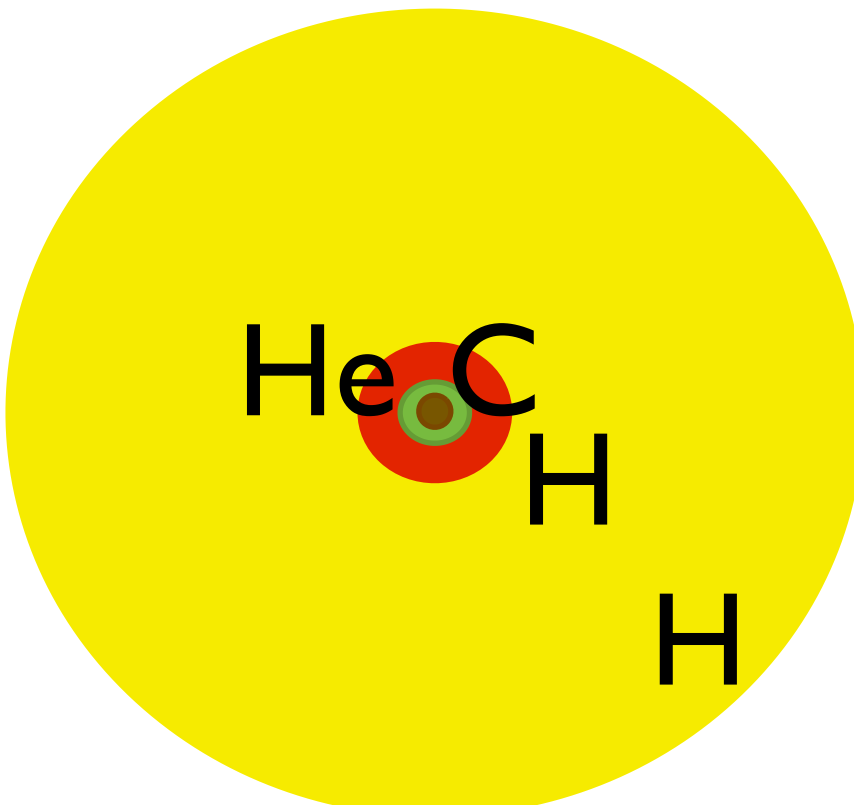



Burns for the next ~10 Gyr during this “stable stage” of its life

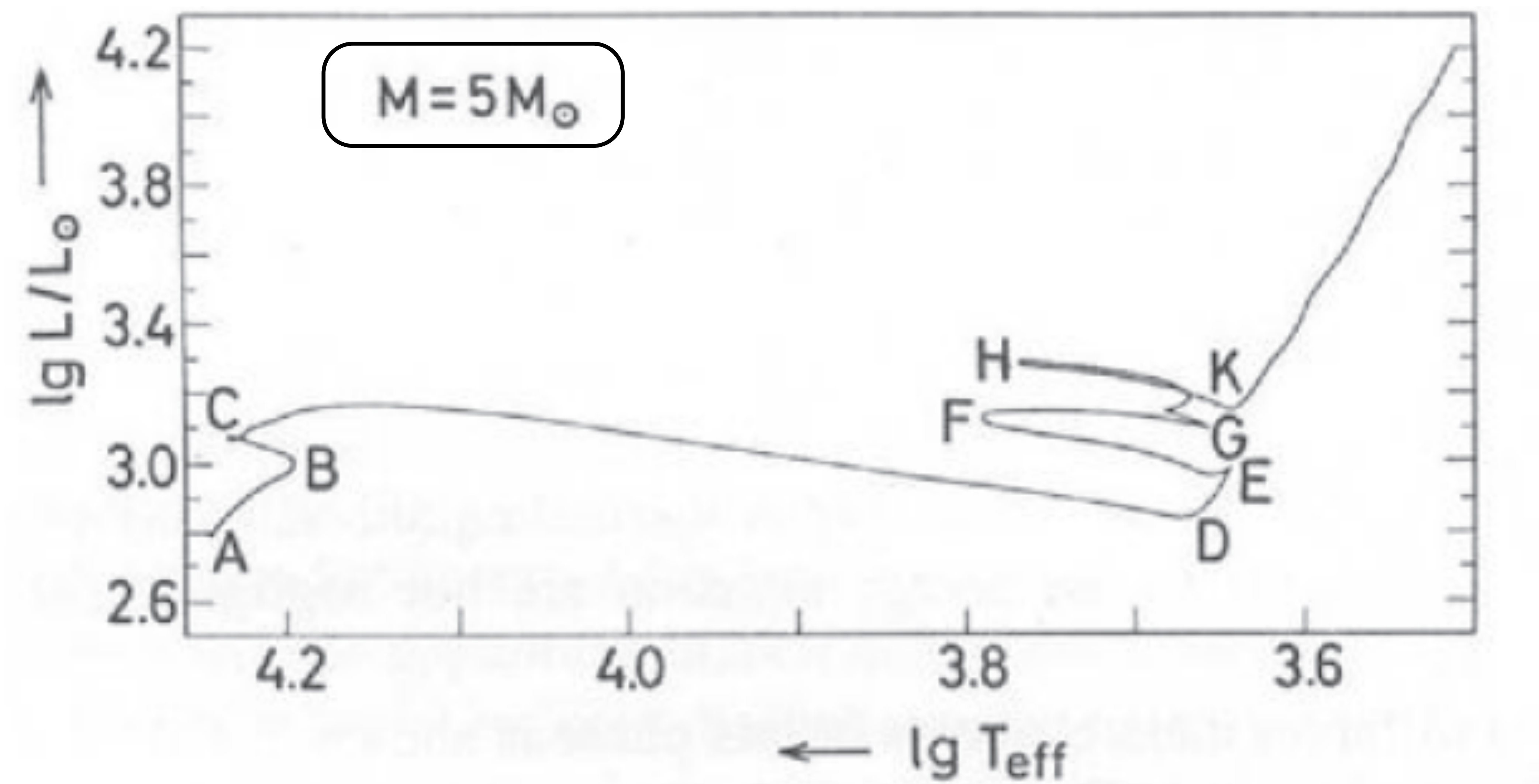
# Stars: Evolution Theory



# Stars: Evolution Theory

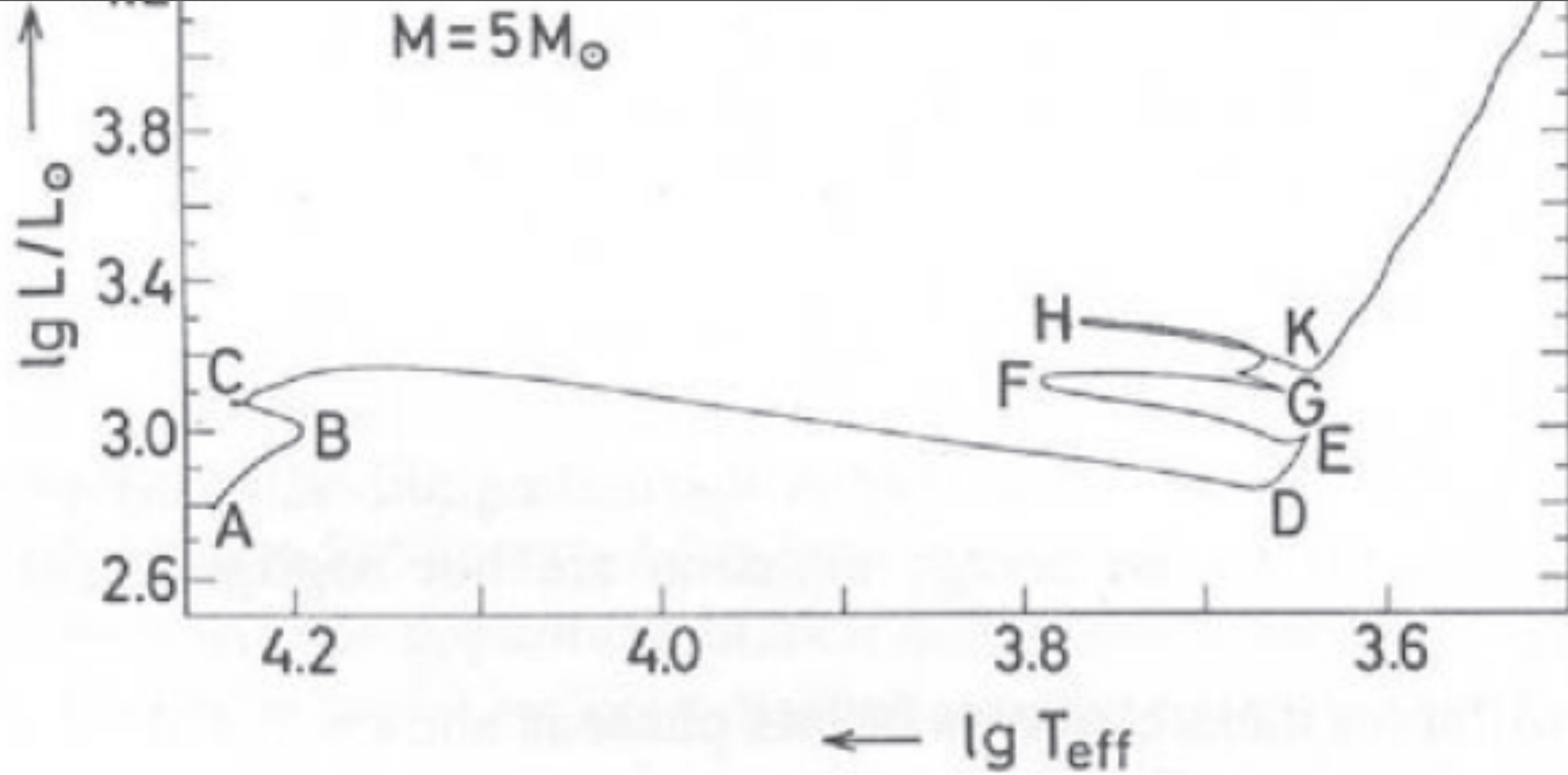


# Stars: Evolution Theory




- At the point A, the star begins its lifetime on the main sequence. The convective core contains 21% of the mass of the star and nuclear burning takes place within the inner 7% by mass. During the first $5.6 \times 10^7$ years, the star remains at roughly the same location on the H-R diagram, evolving to the point B.
- By the point C, the central hydrogen fuel is exhausted and during the transition from C to D, an isothermal helium core is formed which begins to collapse, accompanied by the rapid expansion of the envelope to form a giant star. During the evolution from C

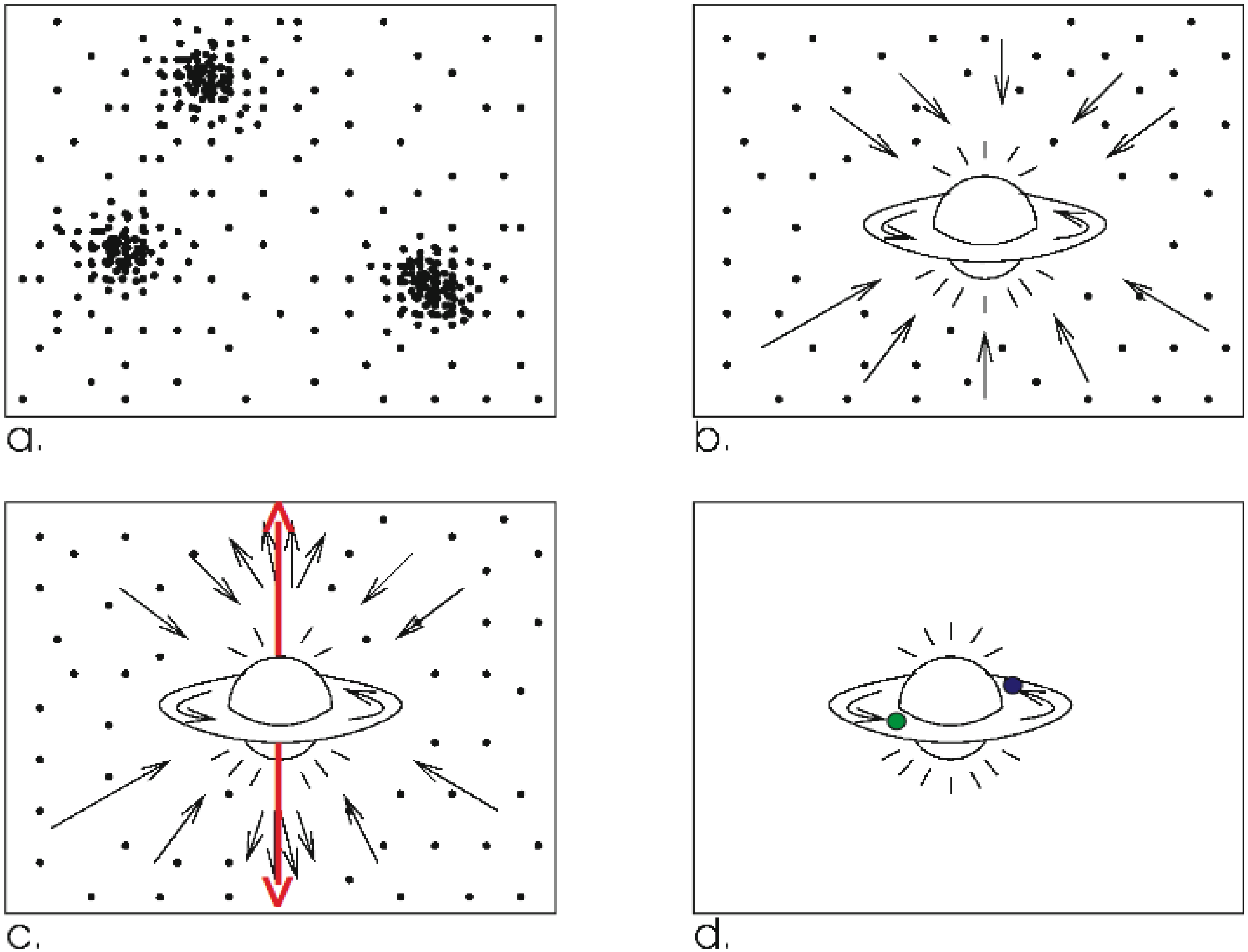
Hertzprung-Russell Diagram




to D, hydrogen burning continues in a shell about the helium core. At the point D, the star arrives at the Hayashi track and then an outer convection zone is formed in the giant envelope.

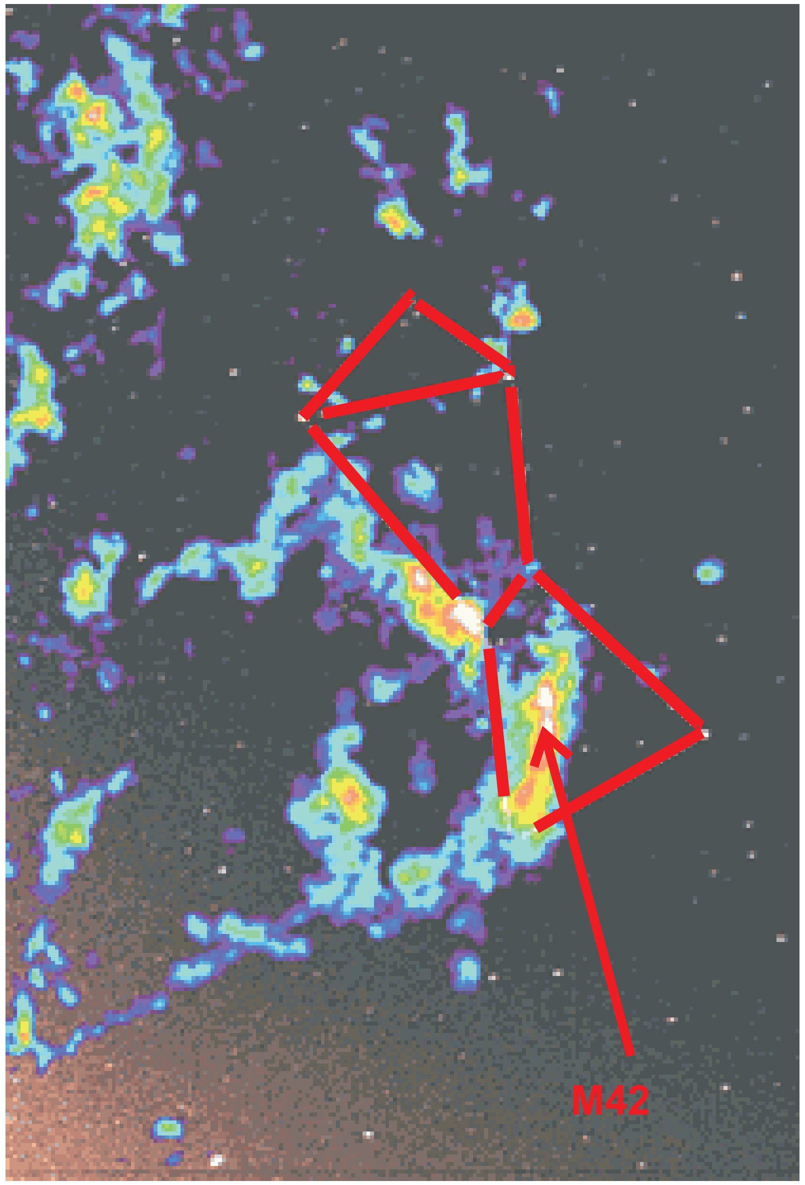
- The continuing contraction of the central regions heats up the core until helium burning takes place at E. In the helium burning process, helium is converted into carbon $3\,^{4}He \rightarrow {}^{12}C$ through the rare triple-$\alpha$ process. This is accompanied by an excursion to higher temperatures across the H-R diagram to F.
- Helium burning continues until the central helium abundance is reduced to zero and an isothermal $^{12}C$ core forms at G. Helium burning continues in a shell about the isothermal C,O core.
- Throughout the stages D to H, hydrogen shell burning continues to larger and larger radii, but at H hydrogen shell burning ends because the temperature in the envelope is too low.
- At K, the star develops a deep outer convection zone and subsequently moves almost vertically up the Hayashi track.

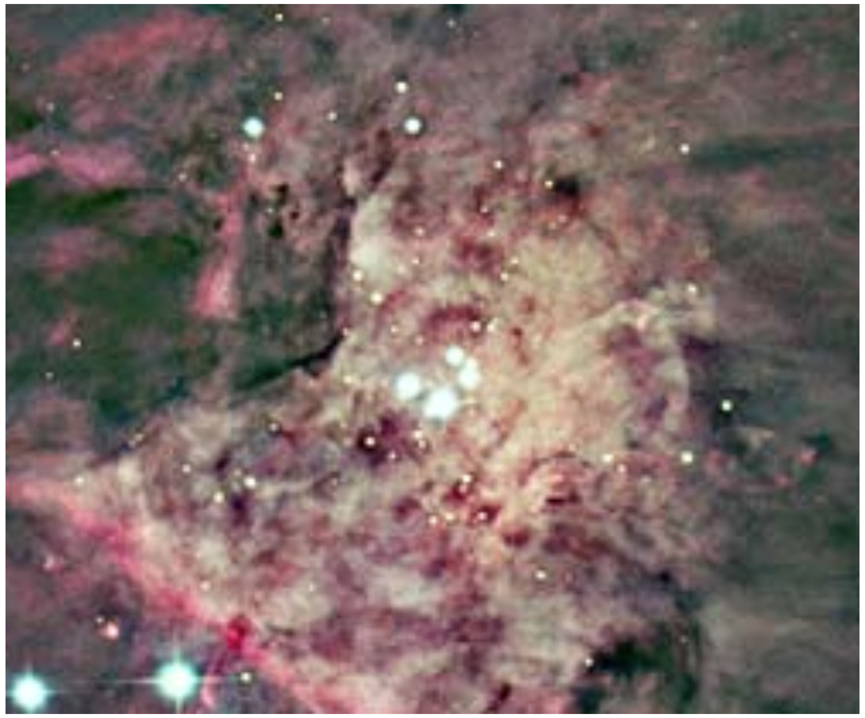
# Star Formation



# **Star Formation:** Observational Evidence

# Star Factories: M42 GMC in Orion



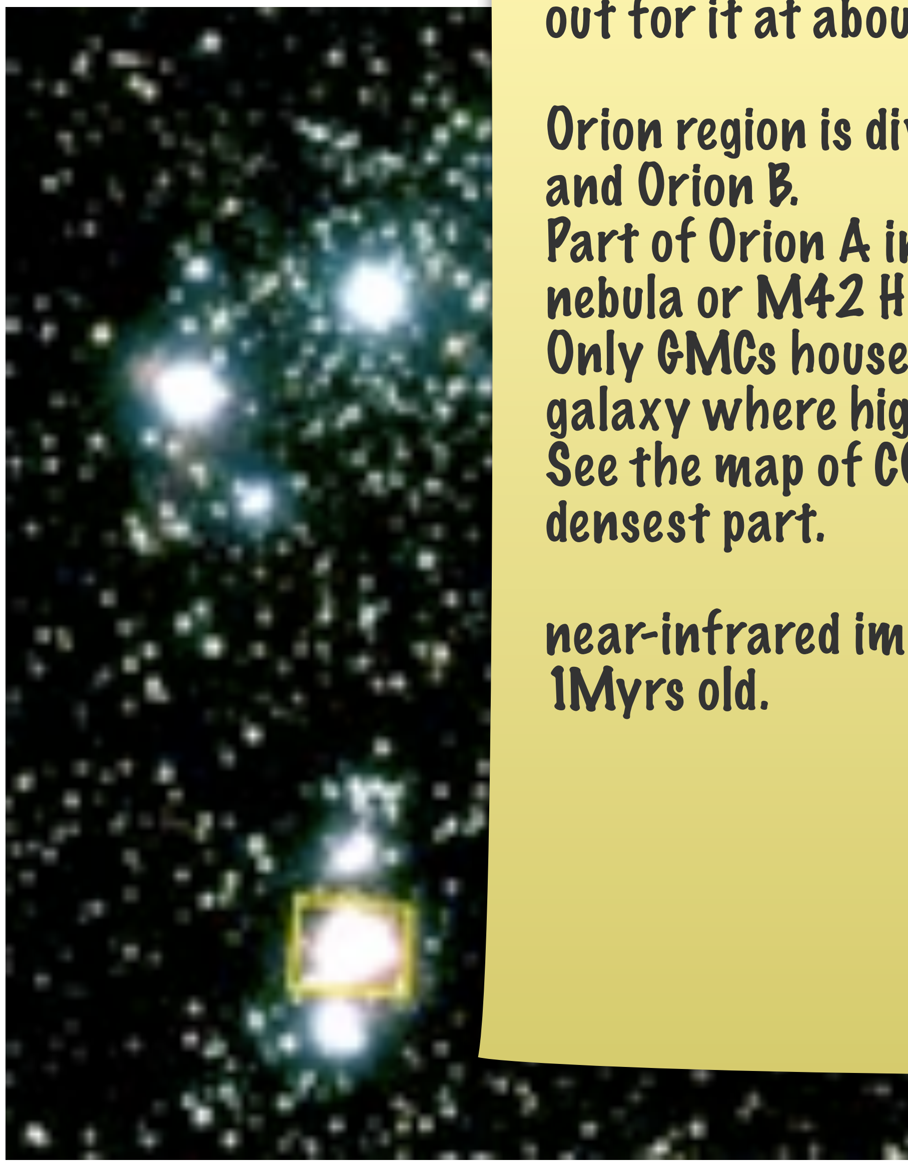
The Orion nebula is an intense region of Star Formation. Most of first protostars were discovered here aswell as many interstellar molecules

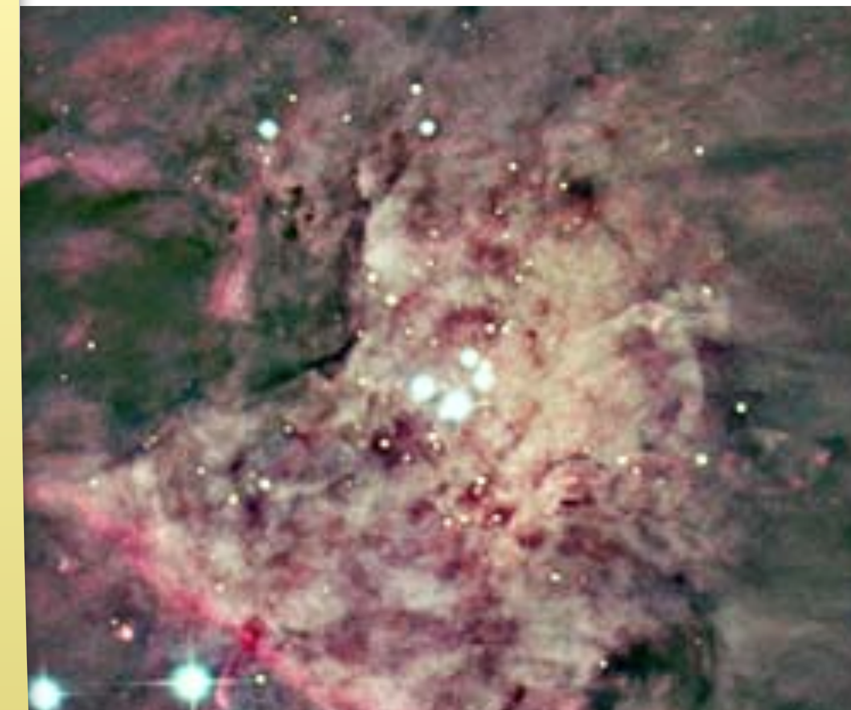
# Star Factories: M42 GMC in Orion

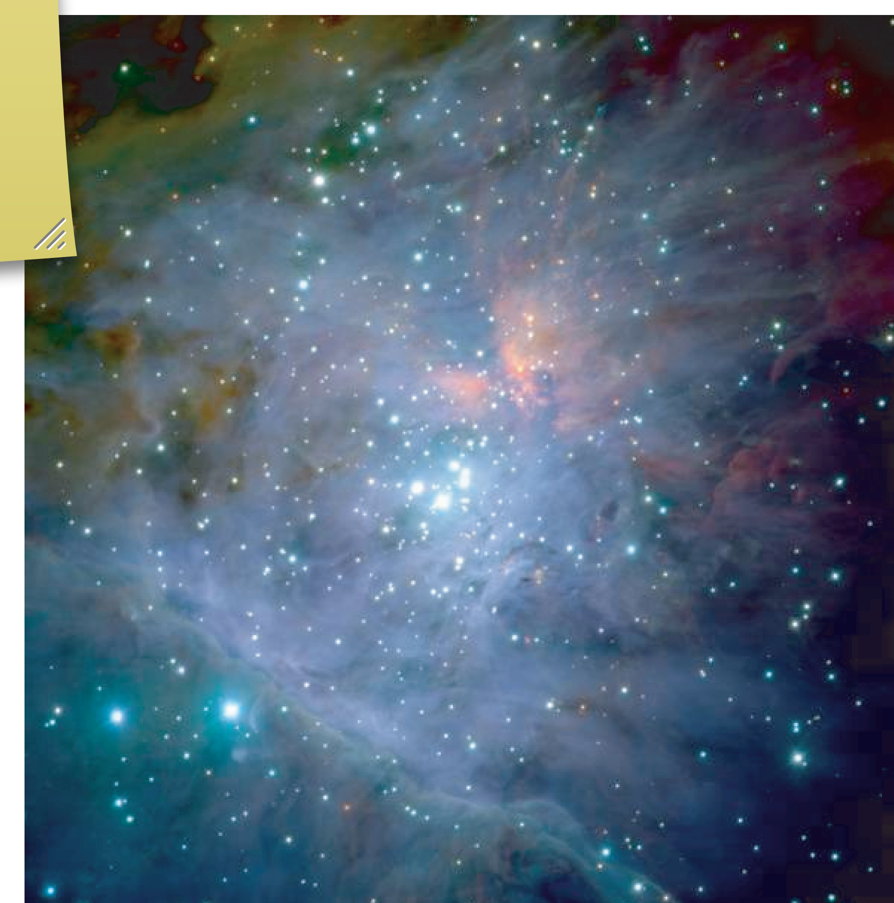
Orion is a well known constellation to all of us. Watch out for it at about ? 2nte.

Orion region is divided into two MC complexes Orion A and Orion B.
Part of Orion A in Orions sword is the famous Orion nebula or M42 Home to the massive trapezium stars. Only GMCs house massive stars. Nearest place in our galaxy where high mass stars are being formed.
See the map of CO in the complex M42 is located in the densest part.

near-infrared image bottom right. 1,000 young stars ~ 1Myrs old.





**The Orion nebula is an intense region of Star Formation. Most of first protostars were discovered here aswell as many interstellar molecules**

# Molecular Clouds: Star Making Factories

# Molecular Clouds: Star Making Factories

**The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe**

# Molecular Clouds: Star Making Factories

**The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe**

**Molecular Clouds are massive ($10^7$ times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects**

# Molecular Clouds: Star Making Factories

The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe

Molecular Clouds are massive ($10^7$ times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects

1 pc ~ 3 lightyears

# Molecular Clouds: Star Making Factories

**The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe**

**Molecular Clouds are massive ($10^7$ times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects**

1 pc ~ 3 lightyears

0 K ~ -273 Celsius

# Molecular Clouds: Star Making Factories

The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe

Molecular Clouds are massive ($10^7$ times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects

Molecular Clouds are composed of a cocktail of molecules ($H_2$, CO, $NH_3$, ethanol) and DUST a vital component

1 pc ~ 3 lightyears

0 K ~ -273 Celsius

# Molecular Clouds: Star Making Factories

The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe

Molecular Clouds are massive ($10^7$ times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects

Molecular Clouds are composed of a cocktail of molecules ($H_2$, CO, $NH_3$, ethanol) and DUST a vital component

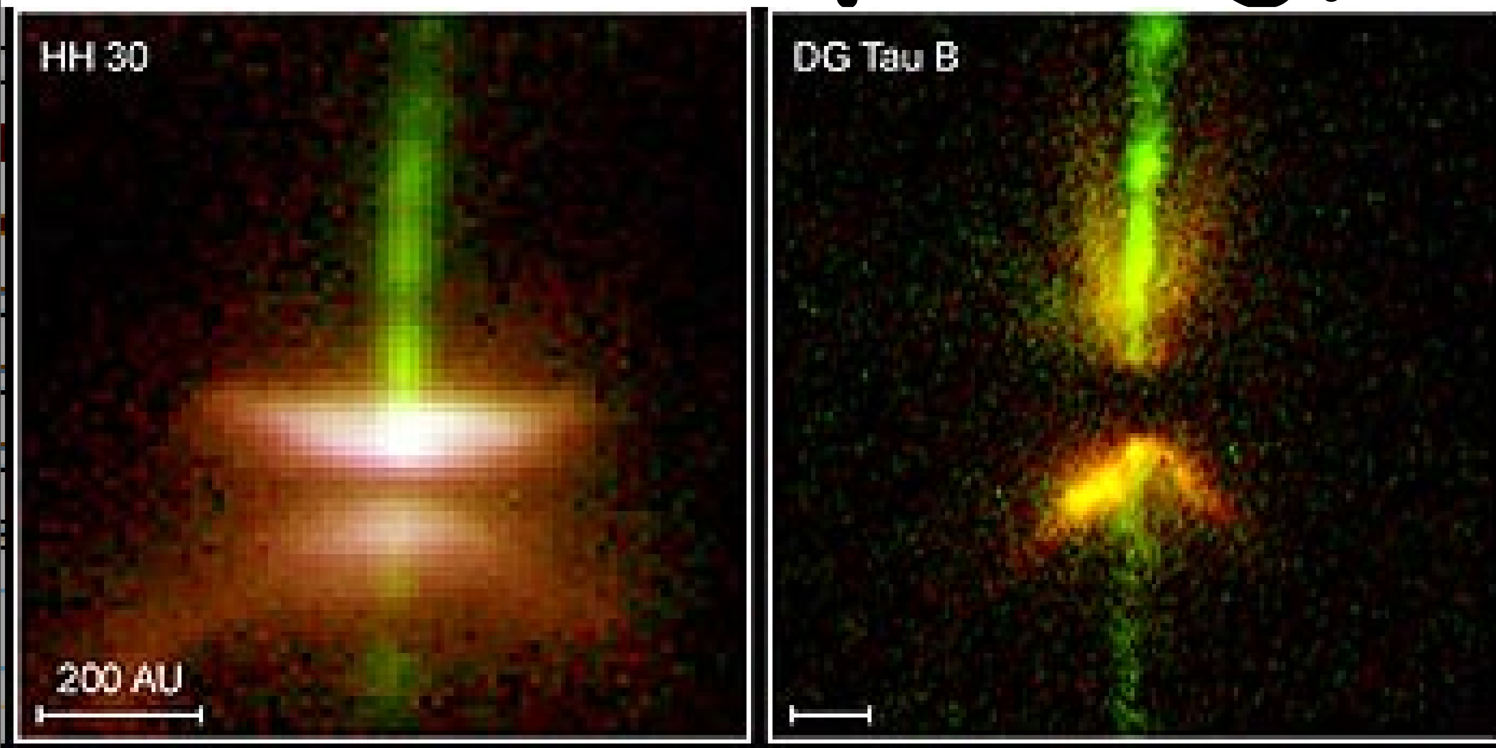
Molecular Clouds are divided into 2 types. Small molecular clouds (SMCs) are colder and are distributed throughout the galaxy. There are some 4,000 giant molecular clouds (GMCs) in the Milky Way. They are confined to the spiral arms have average temperatures closer to 100 K.

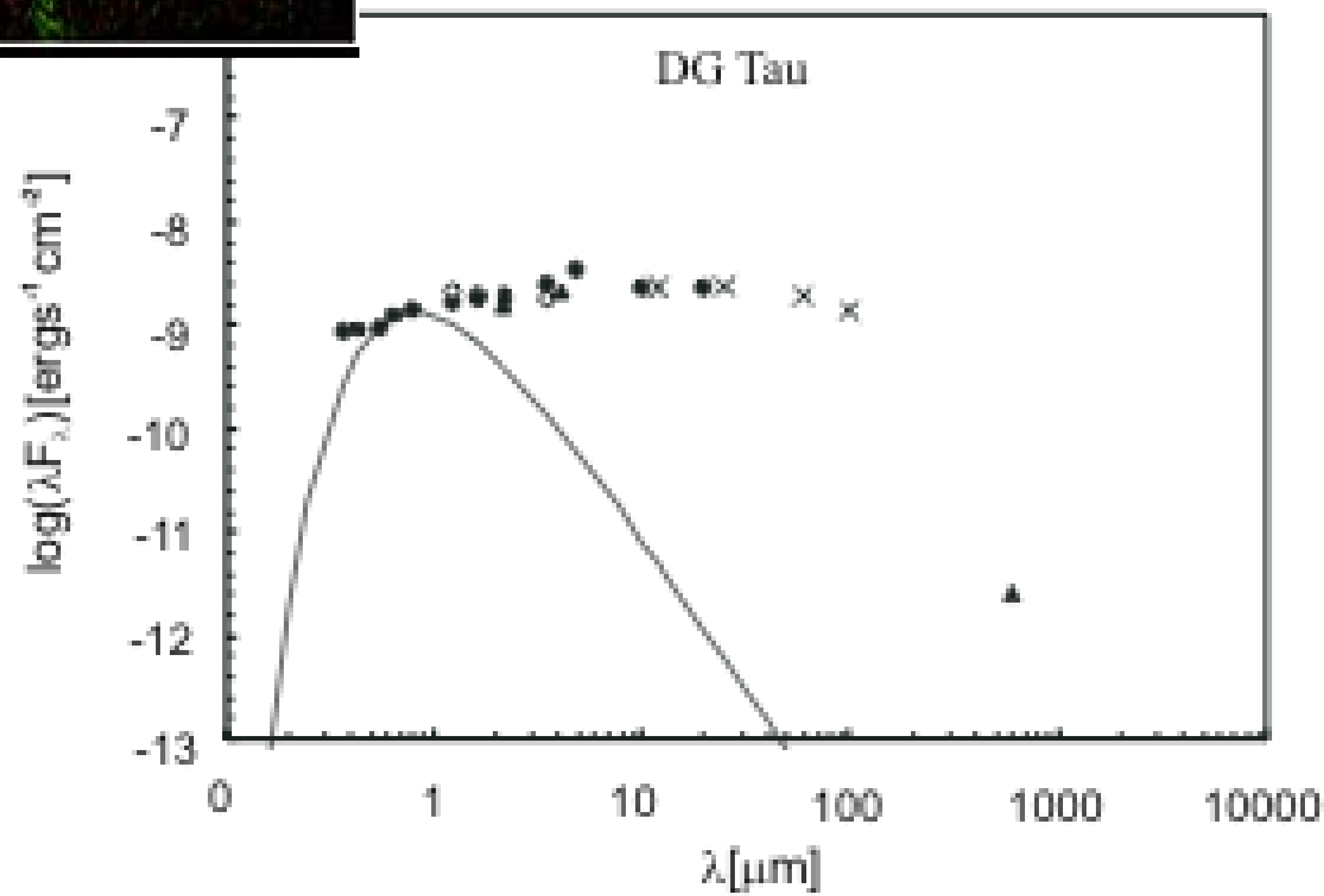
1 pc ~ 3 lightyears

0 K ~ -273 Celsius

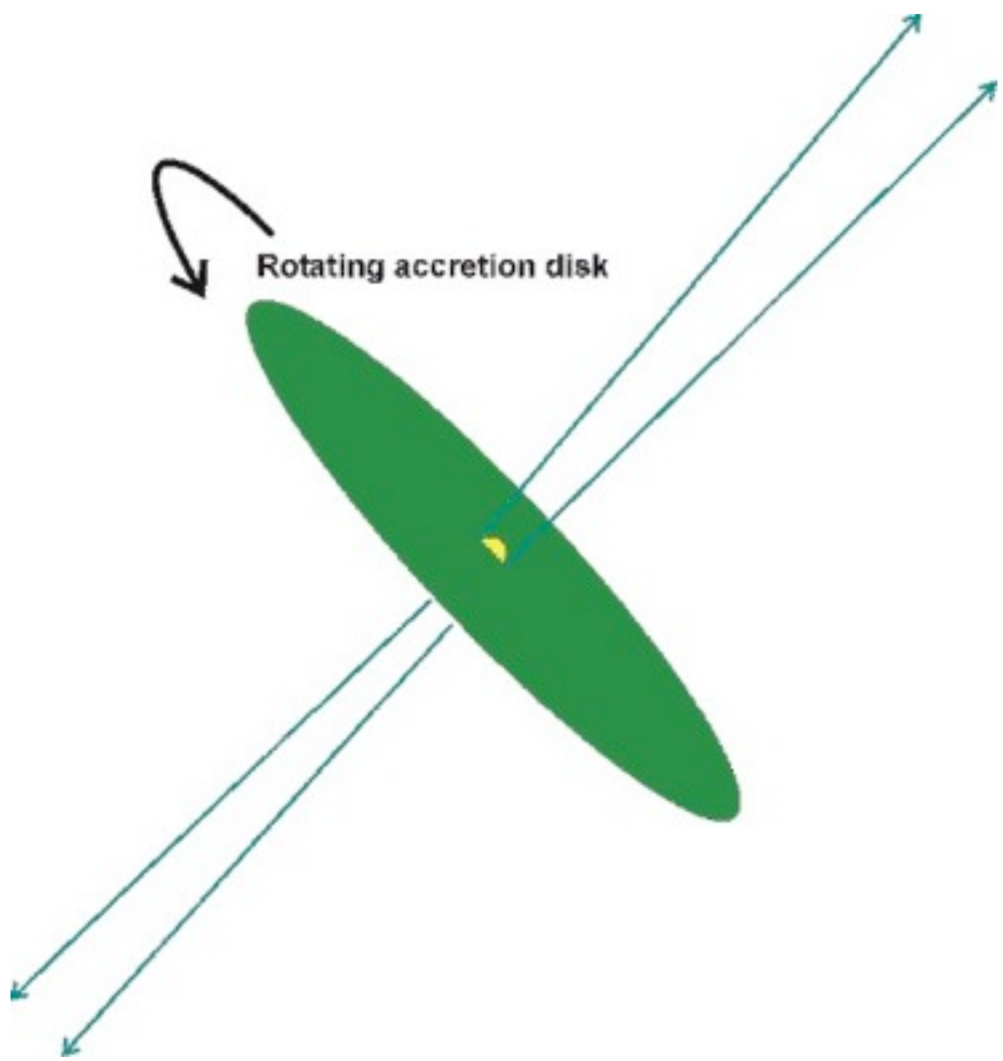
# Are Protostars Observed?

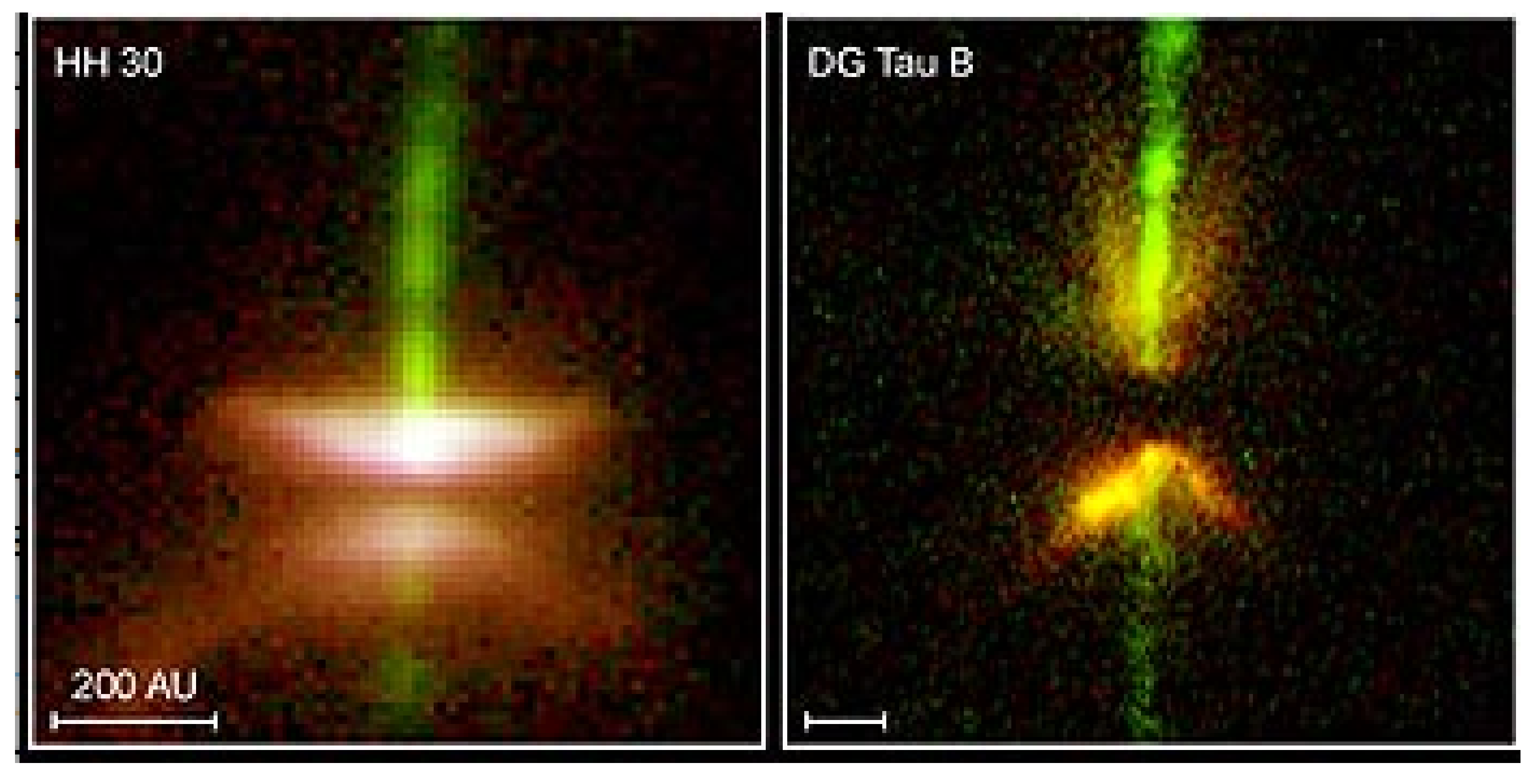
# Morphology + Spectra

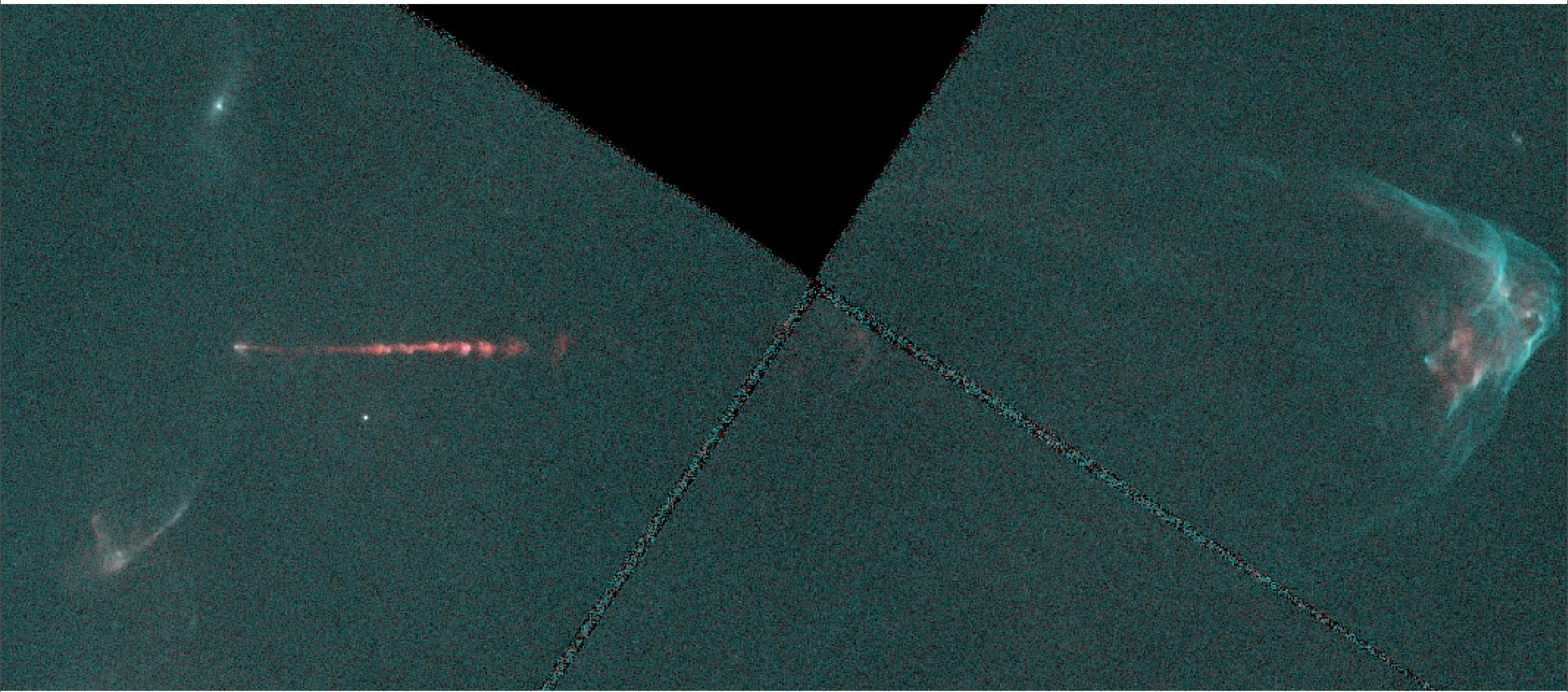


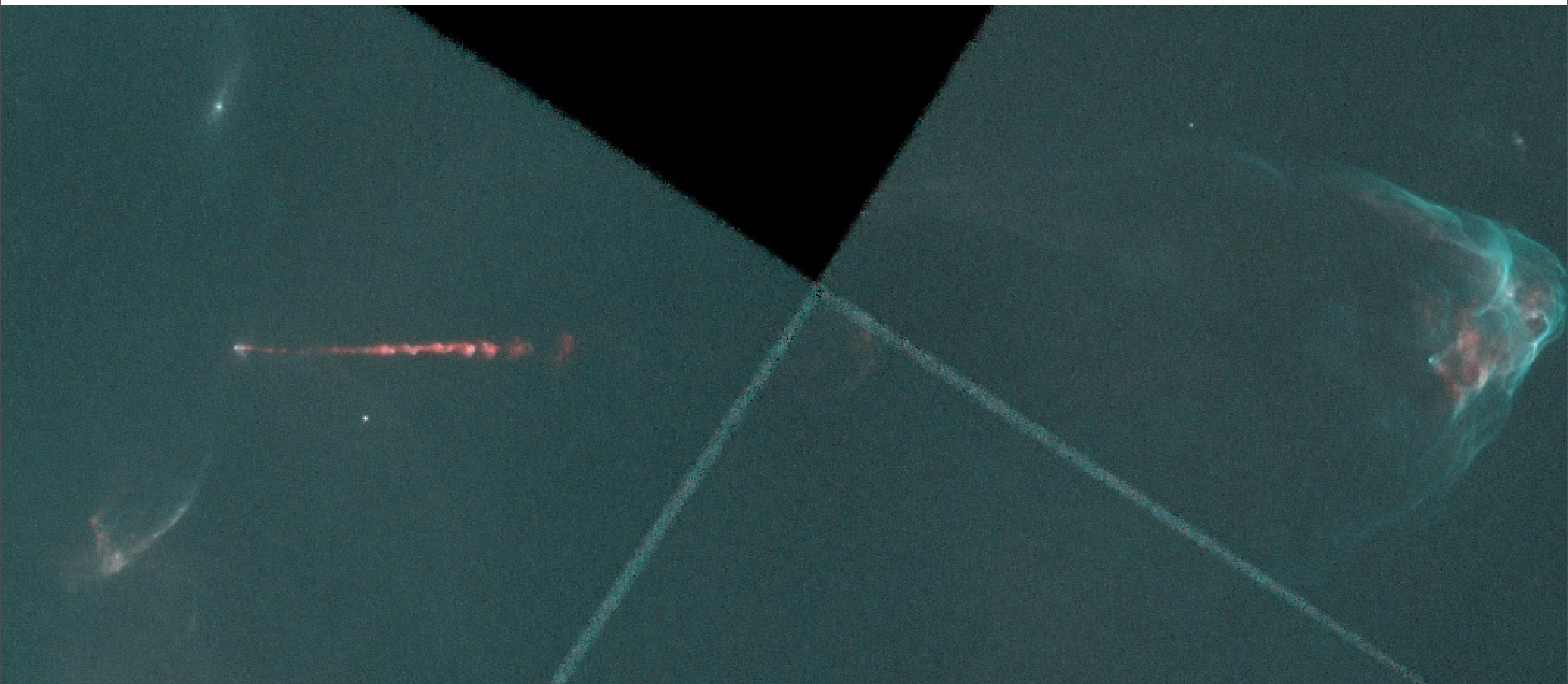



# Protostellar Jets the Most Spectactular Manifestation of the Star Formation Process







# Lecture Problems

The Sun's temperature at its surface is 5500 K, what is the corresponding mean energy per photon?

Nuclear fusion inside the Sun was able to commence once its core temperature had reached 10 000 000 K, what was the corresponding mean photon energy for this temperature and what is its significance in terms of particle physics?