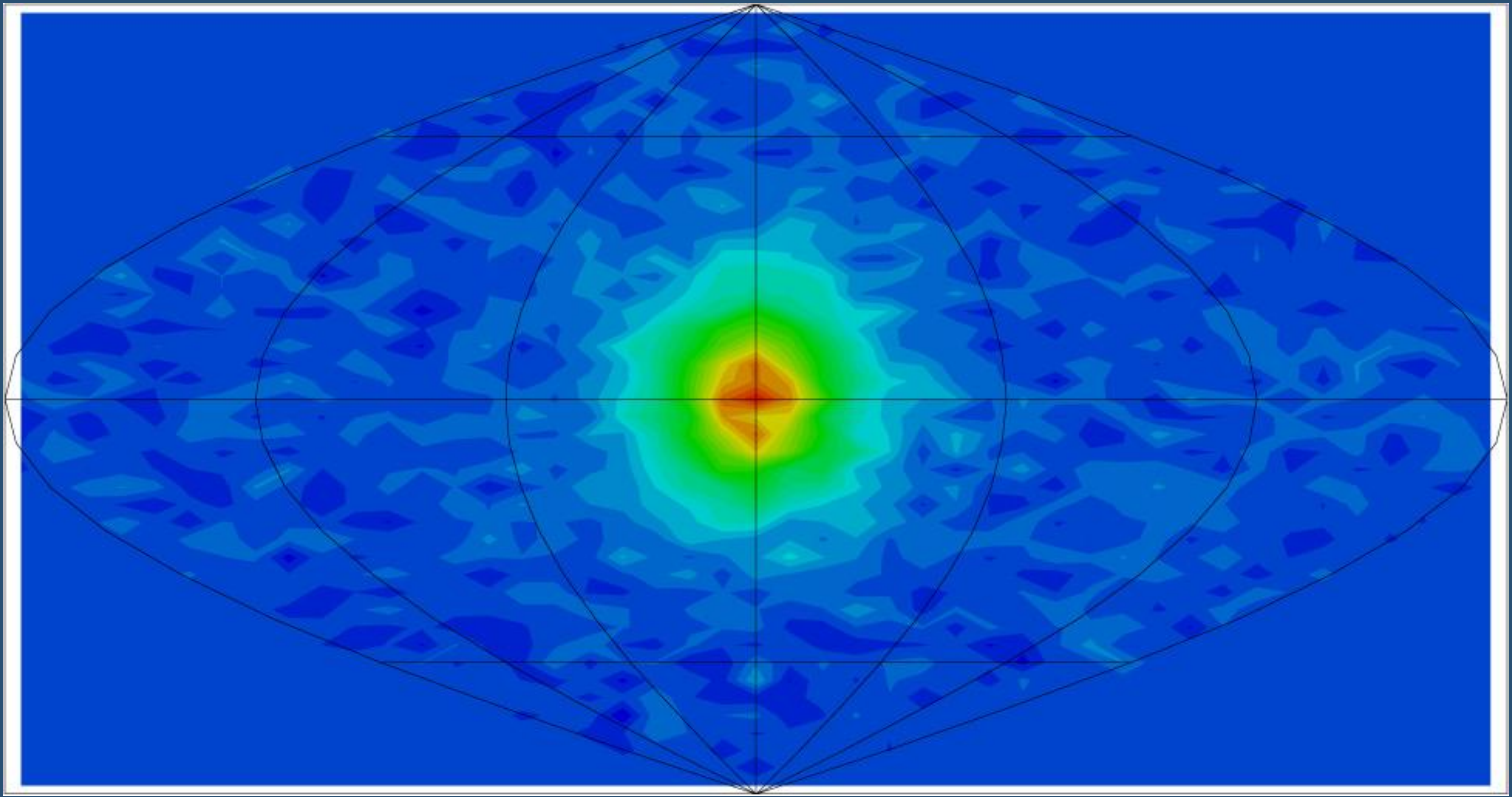
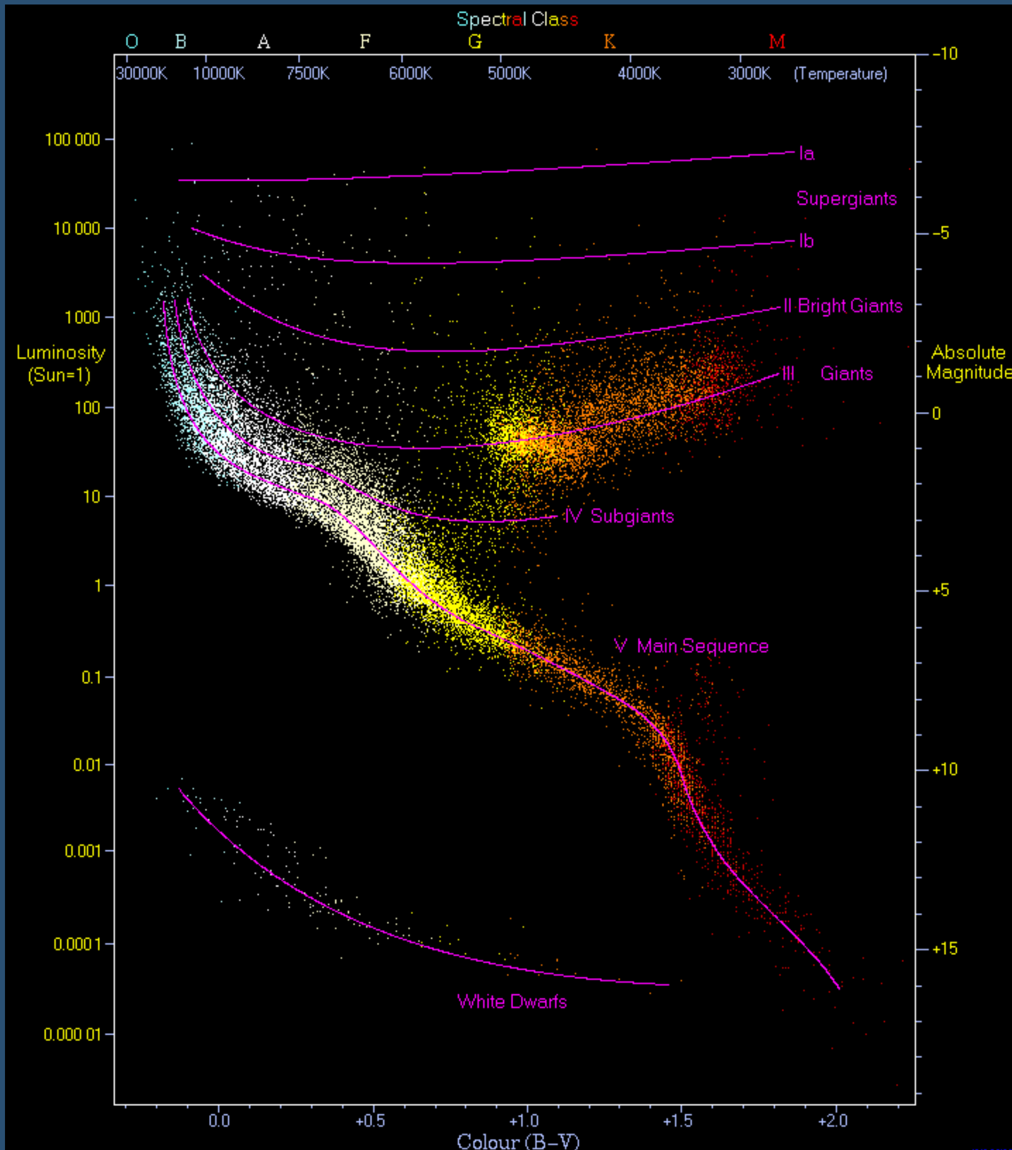
Seeing Inside The Sun

Christopher Berry



The Sun: Our Nearest Star

The Sun: Our Reference Star

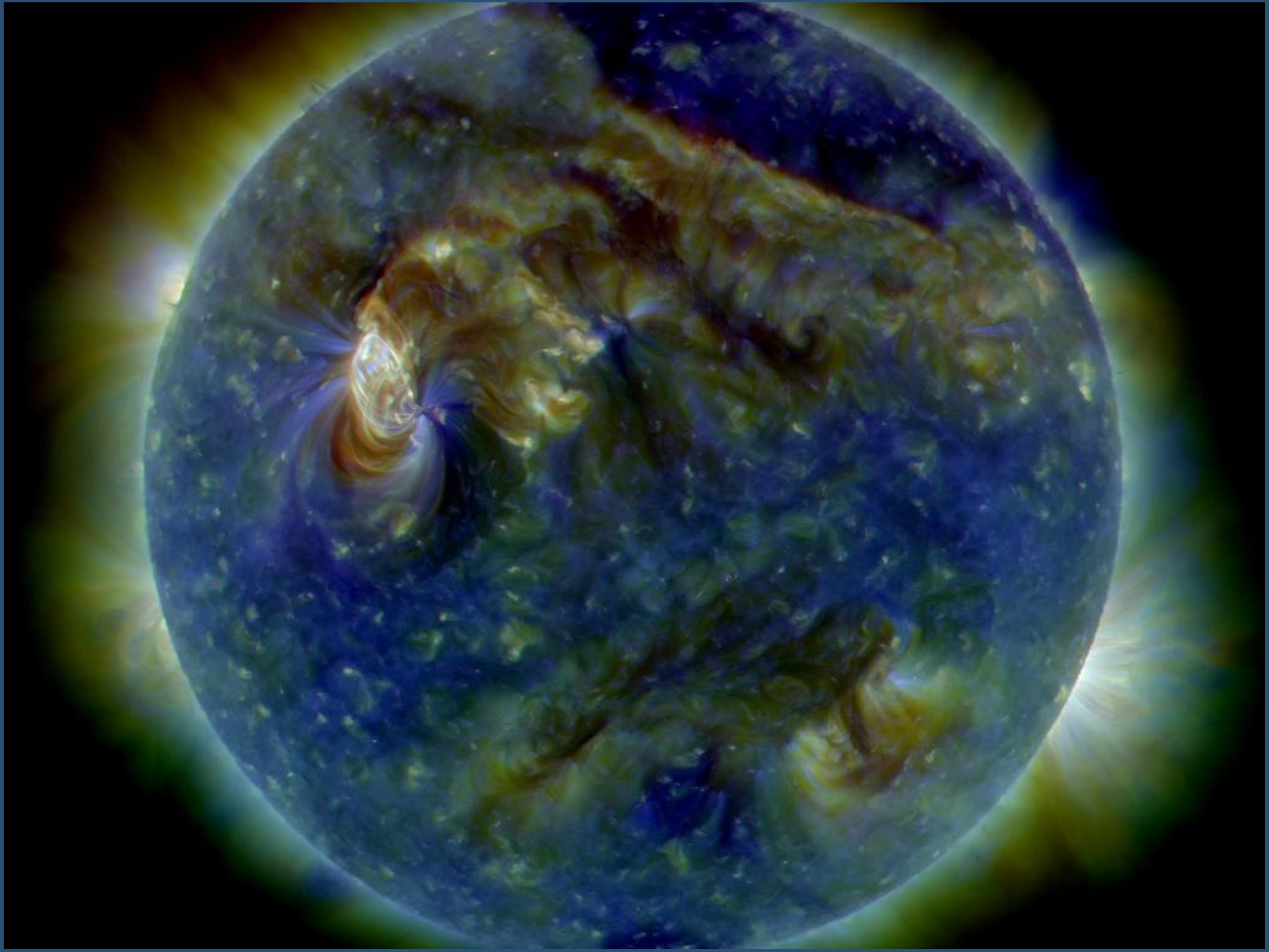


The Sun is a main sequence star.

Its spectral classification is G2V.

Credit: Richard Powell

Studying The Sun

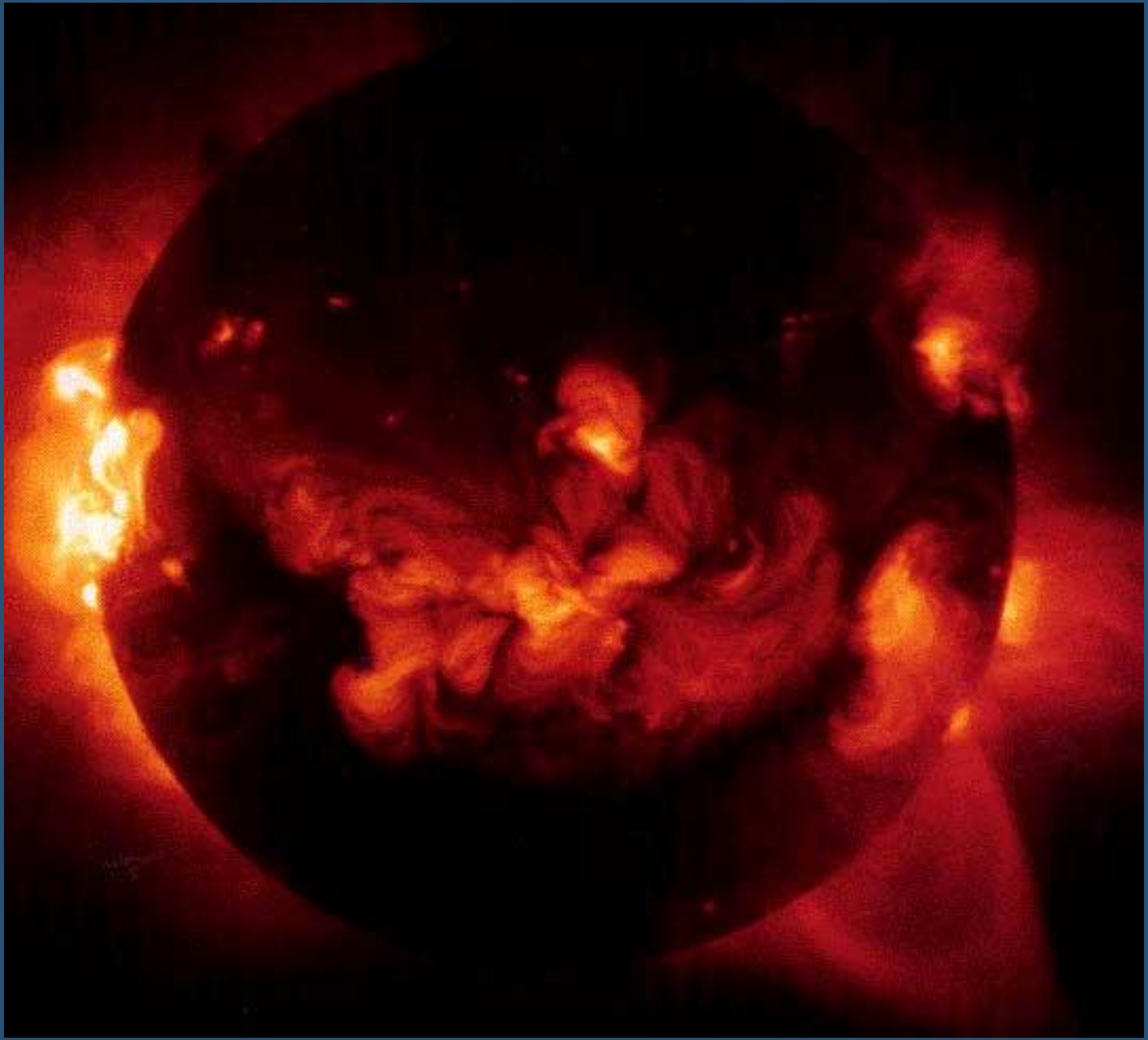


UV

Credit:
NASA, SDO

Studying The Sun

X-ray

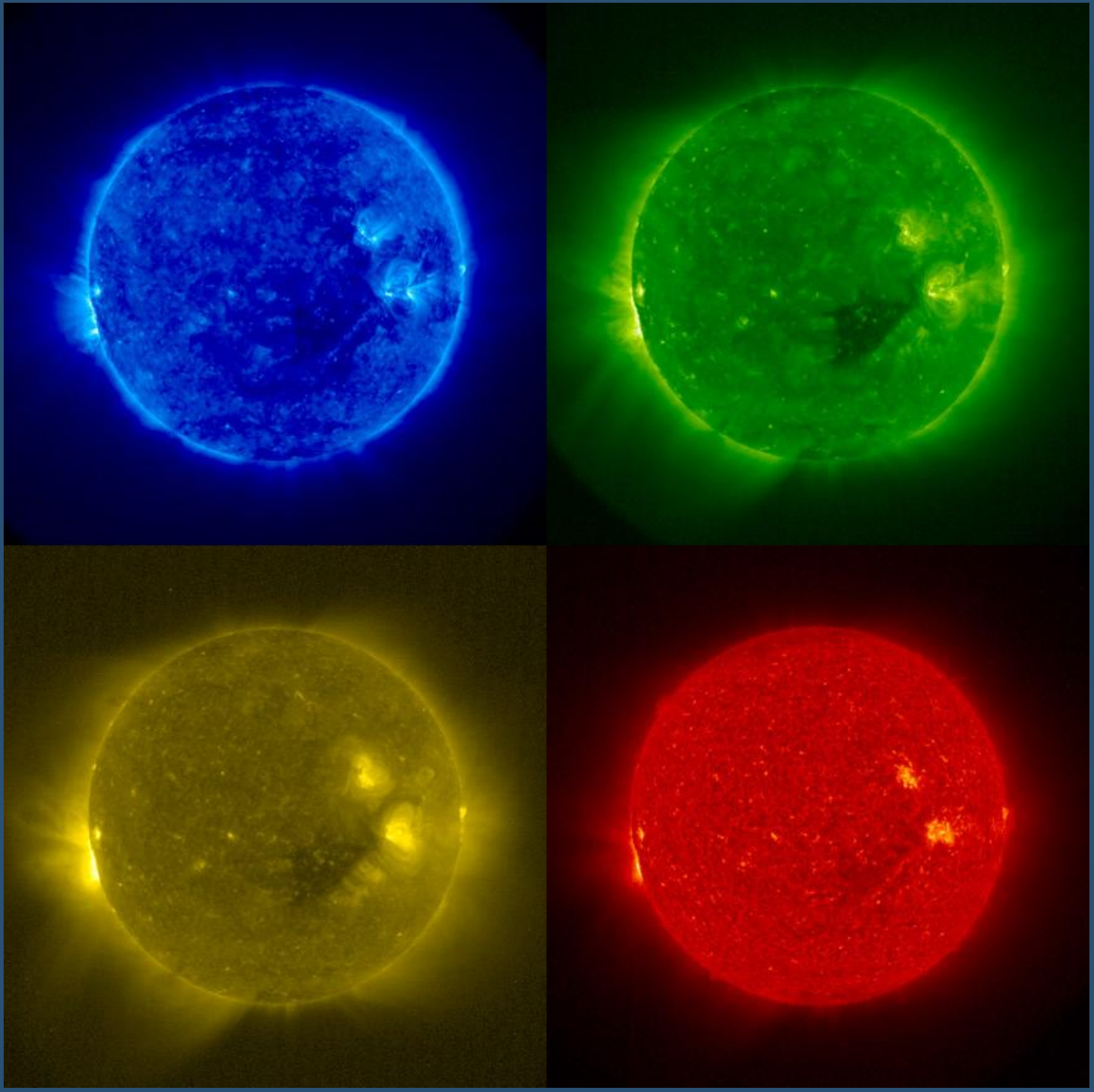


Credit: JAXA, Yohkoh

Studying The Sun

Fe IX

Fe XII

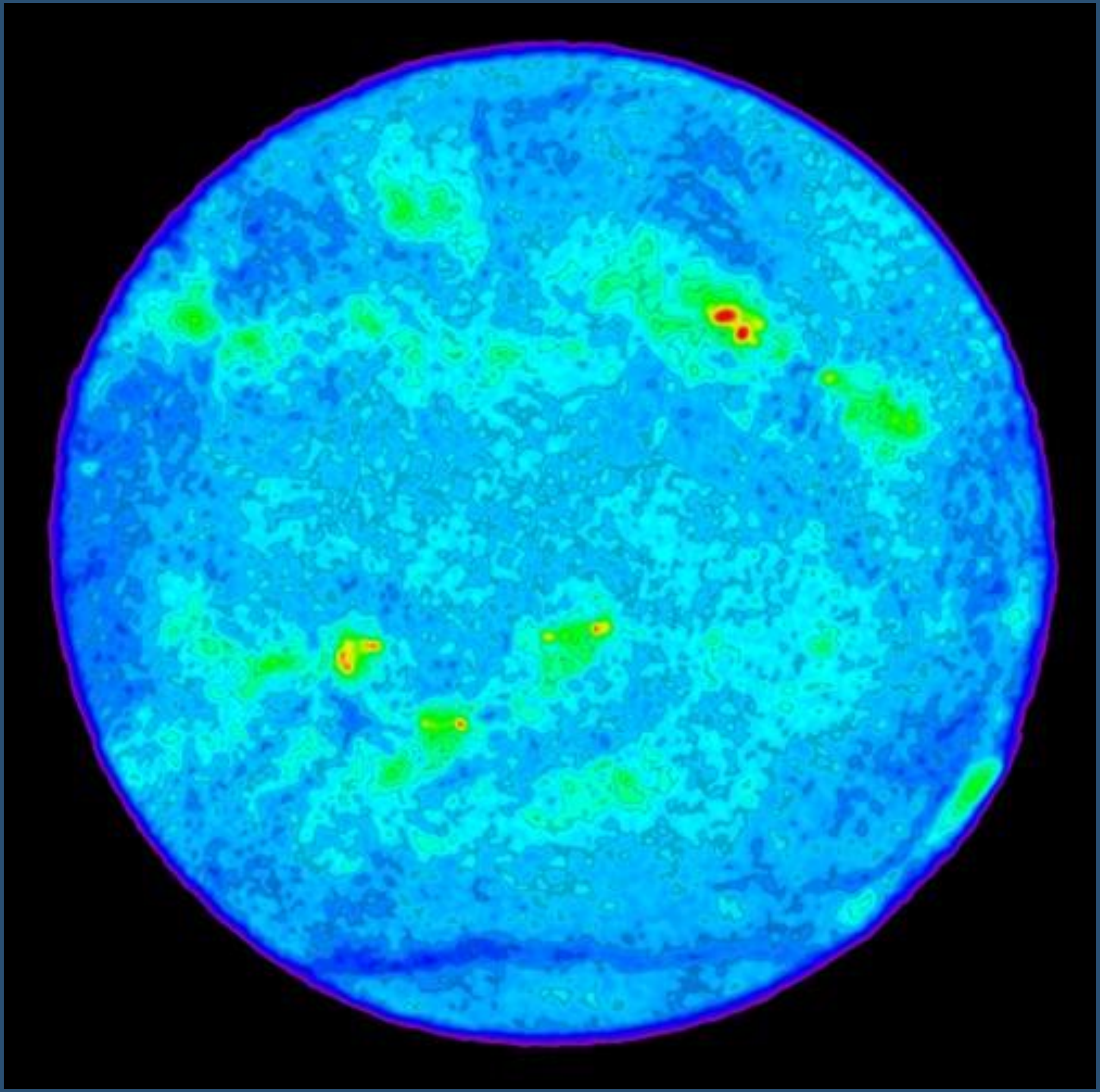


Fe XV

He II

Credit: NASA, STEREO

Studying The Sun

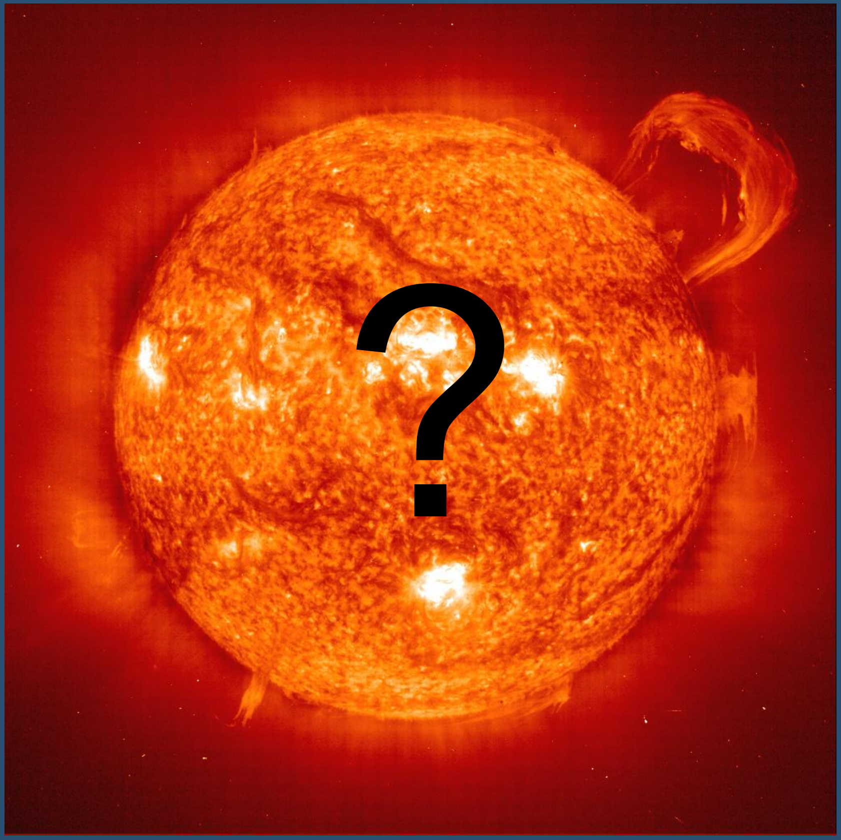


Radio

Credit:
NRAO/AUI,
Stephen White

How do we see inside the Sun?

What is happening beneath the surface?



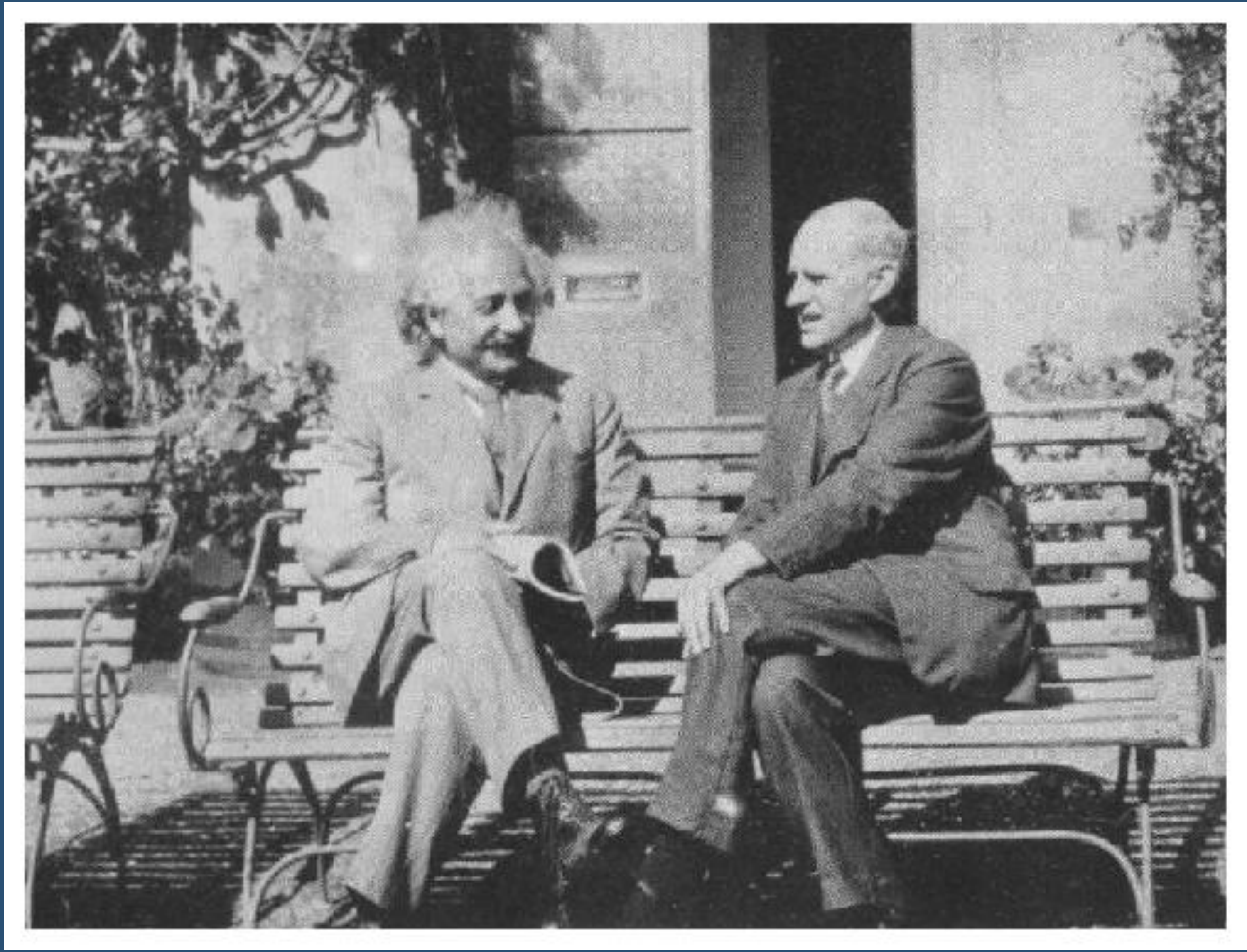
Credit: NASA, SOHO

The Sun's Inner Workings

The Solar System is billions of years old.

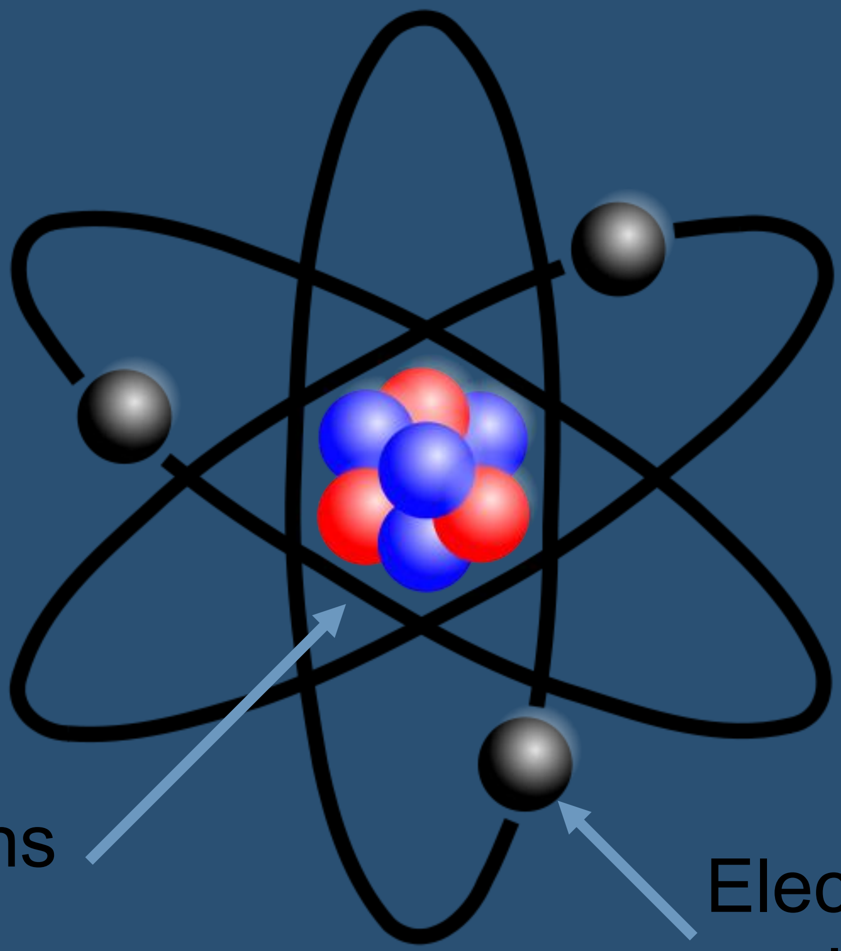
What could keep the Sun shining for so long?

The Sun's Power



Subatomic Particles

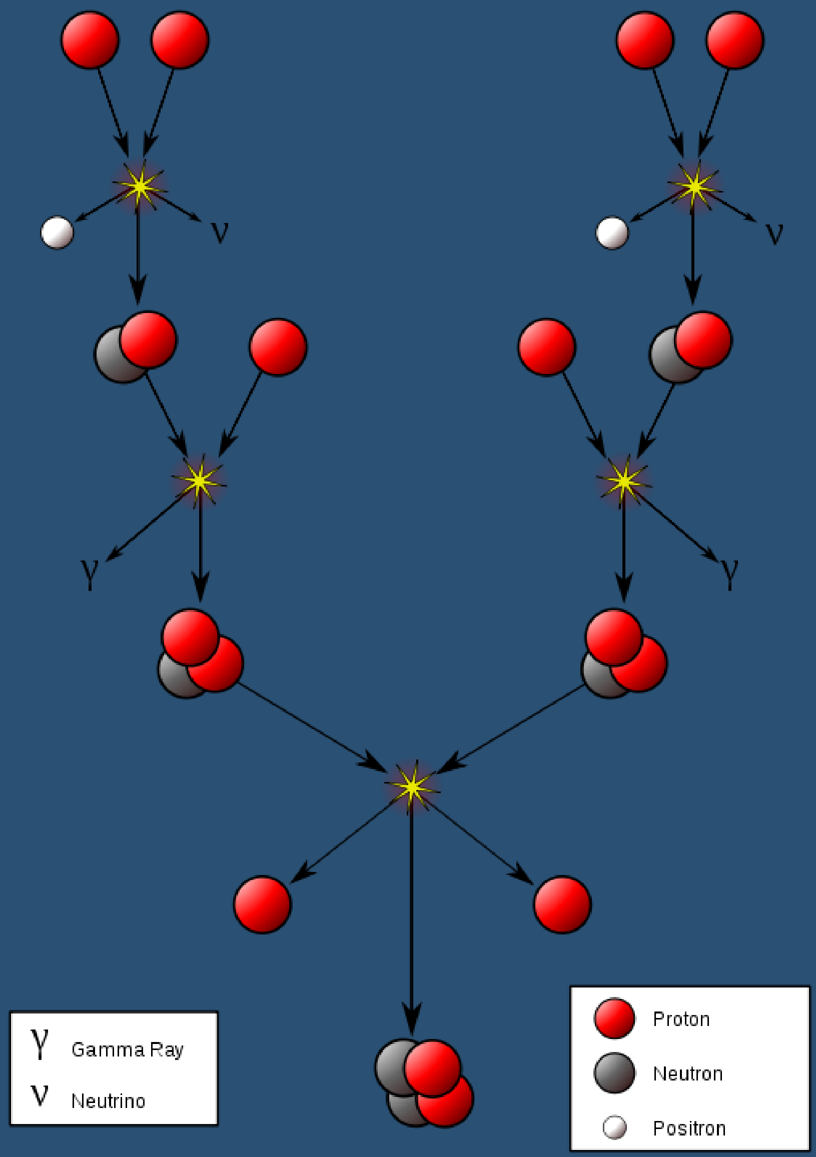
An atom:



Nucleus contains protons and neutrons

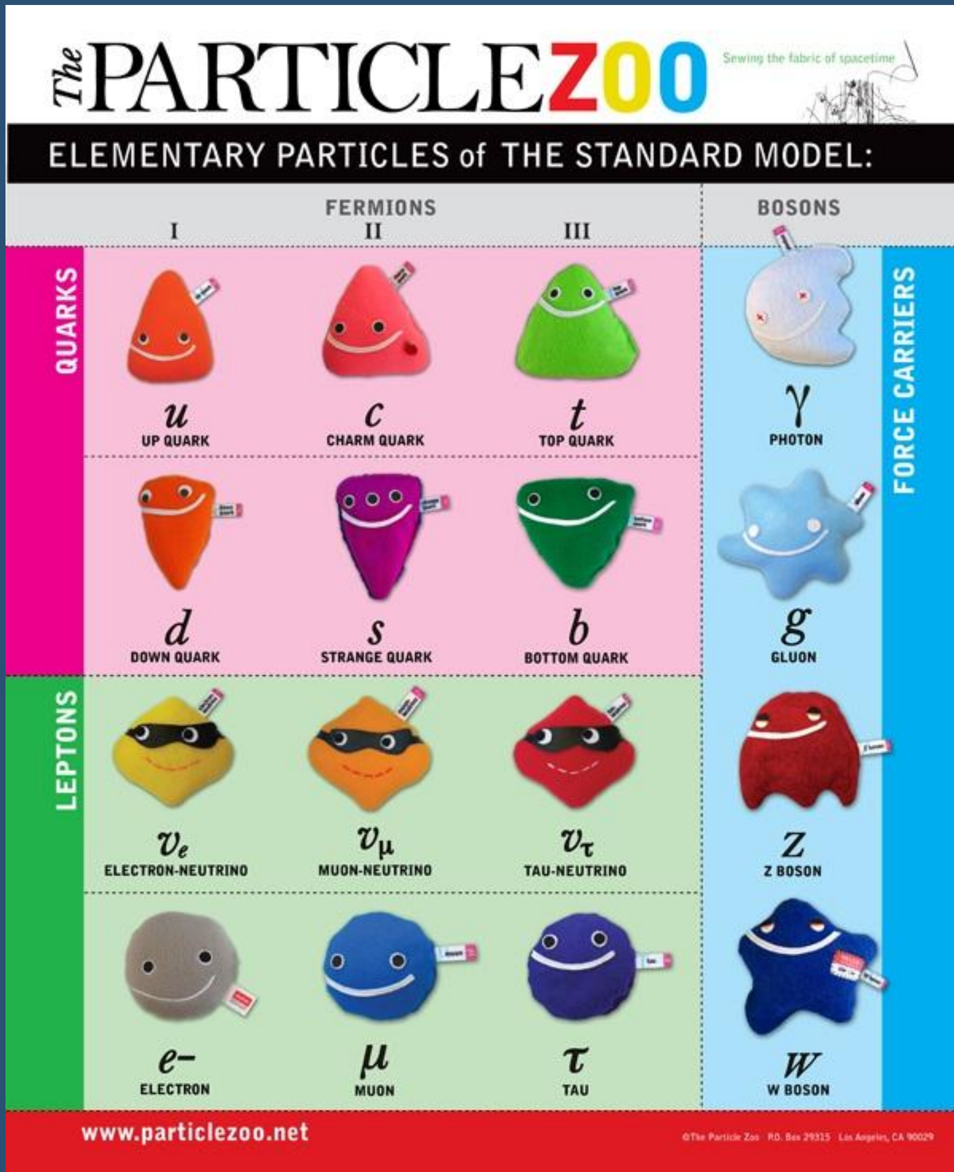
Electrons orbit nucleus

Nuclear Fusion



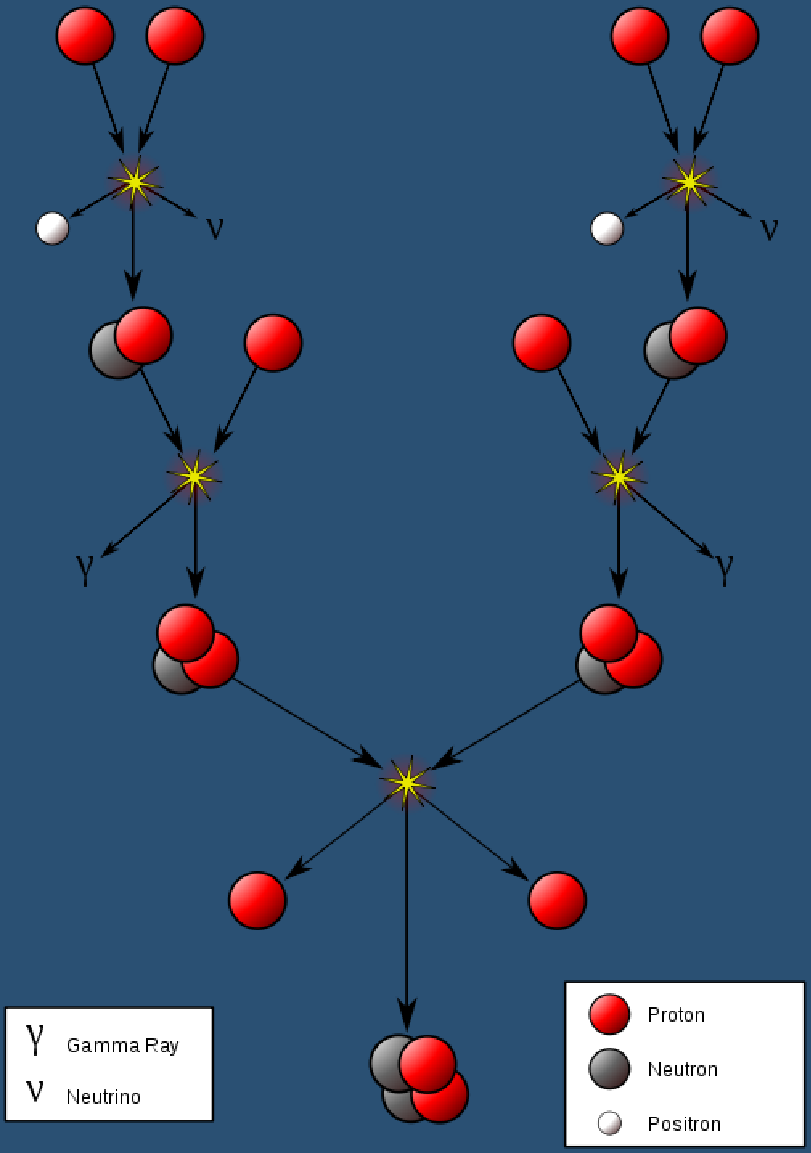
Most of the Sun's energy is generated from the proton-proton (*pp*) chain of reactions.

The Particle Zoo



There are many subatomic particles currently known.

Neutrino Creation



Neutrinos are produced as a by-product of fusion.

Neutrinos

Credit: Particle Zoo

Neutrinos are:

- Light
- Uncharged
- Weakly interacting
- Hard to detect
- Numerous

Seeing With Neutrinos

If we detect neutrinos coming from the Sun we know it must be powered by fusion.

By measuring the number and energy of the neutrinos we can see in to the core of the Sun.

How To Catch Neutrinos I

A neutrino is absorbed by a nucleus, which undergoes radioactive decay.

The first experiment was the Homestake experiment.

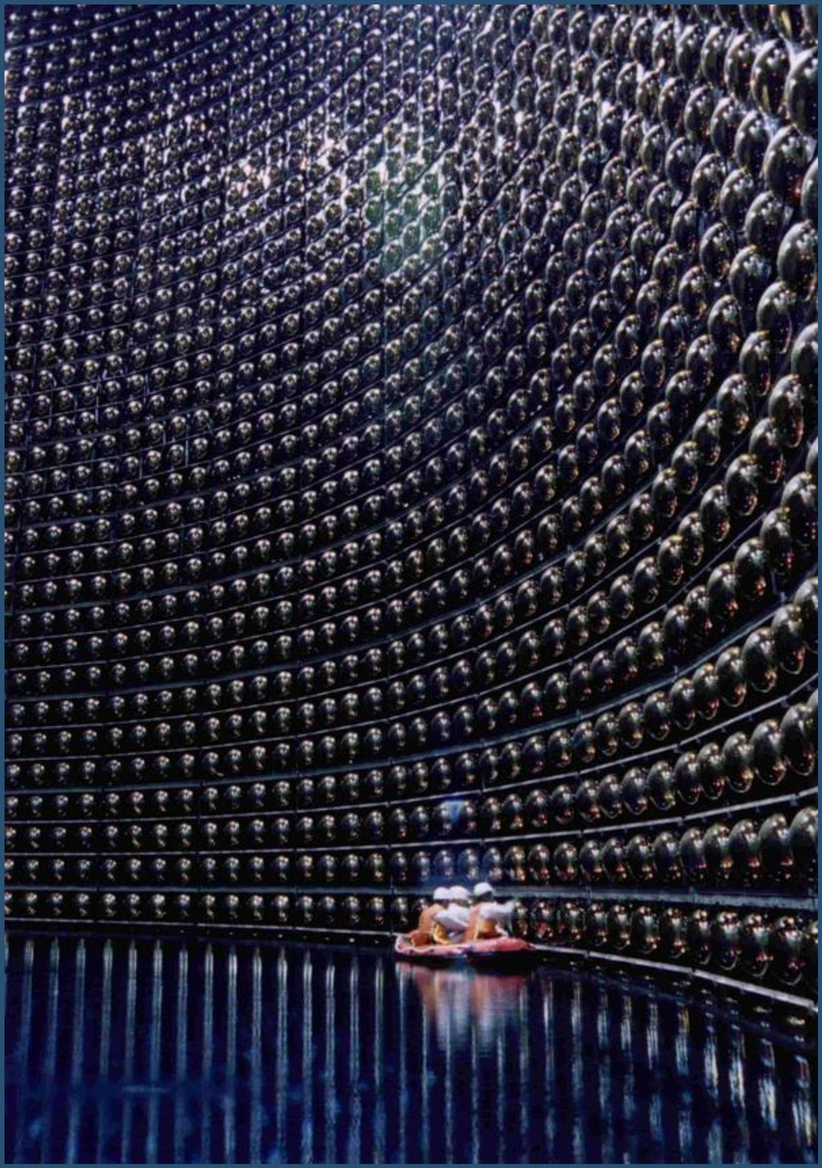
Later experiments used gallium.

Credit: Homestake

How To Catch Neutrinos II

Neutrino scatters off an electron, the fast-moving electron emits a burst of light.

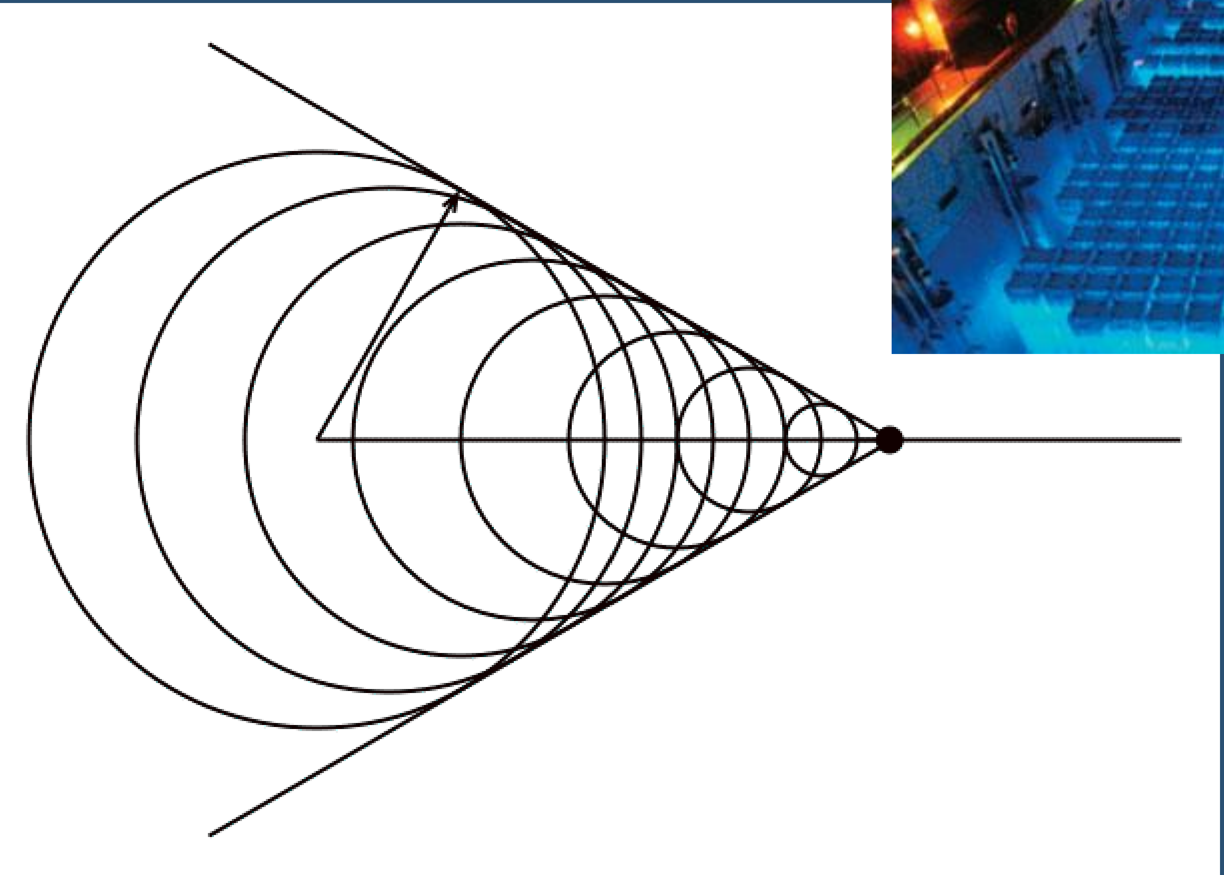
This allows you to see where the neutrino came from.

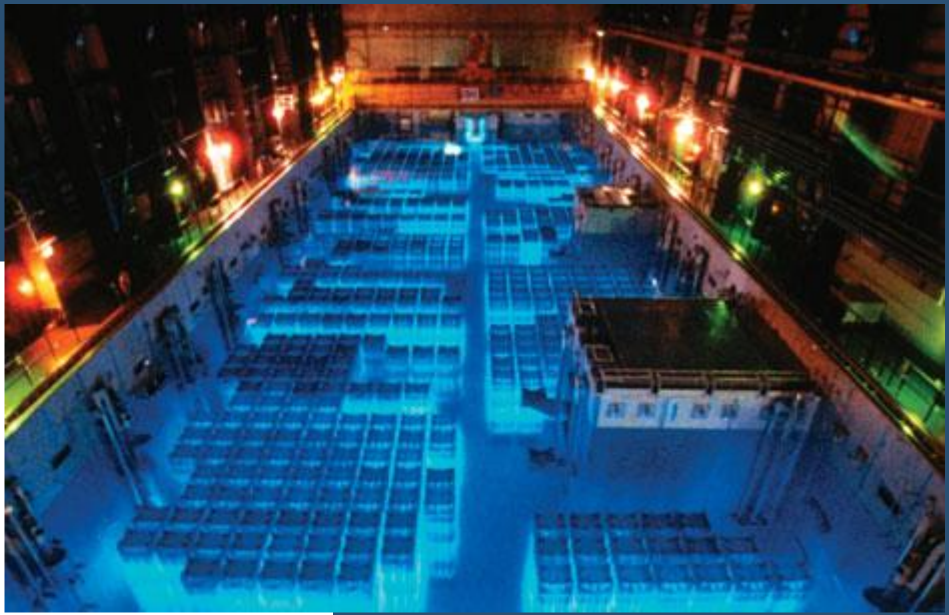


Credit: Kamiokande

Cherenkov Radiation

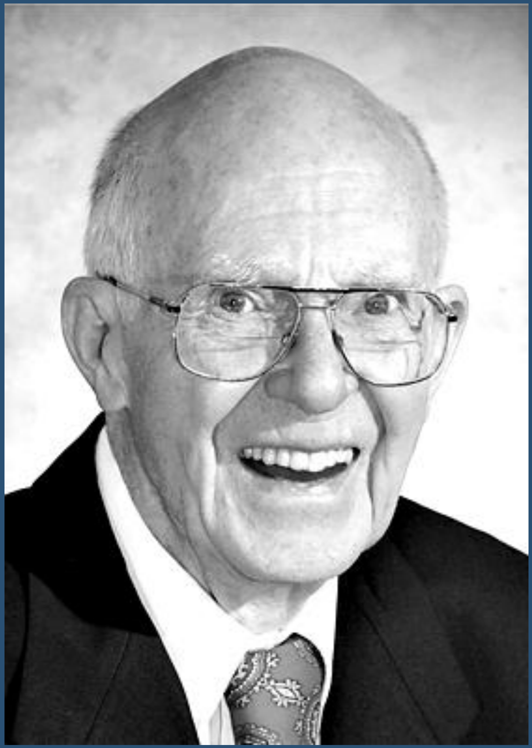
Like a sonic boom for light





Credit: IEEE Spectrum

The 2002 Nobel Prize In Physics



Raymond Davis Jr.

Masatoshi Koshiba

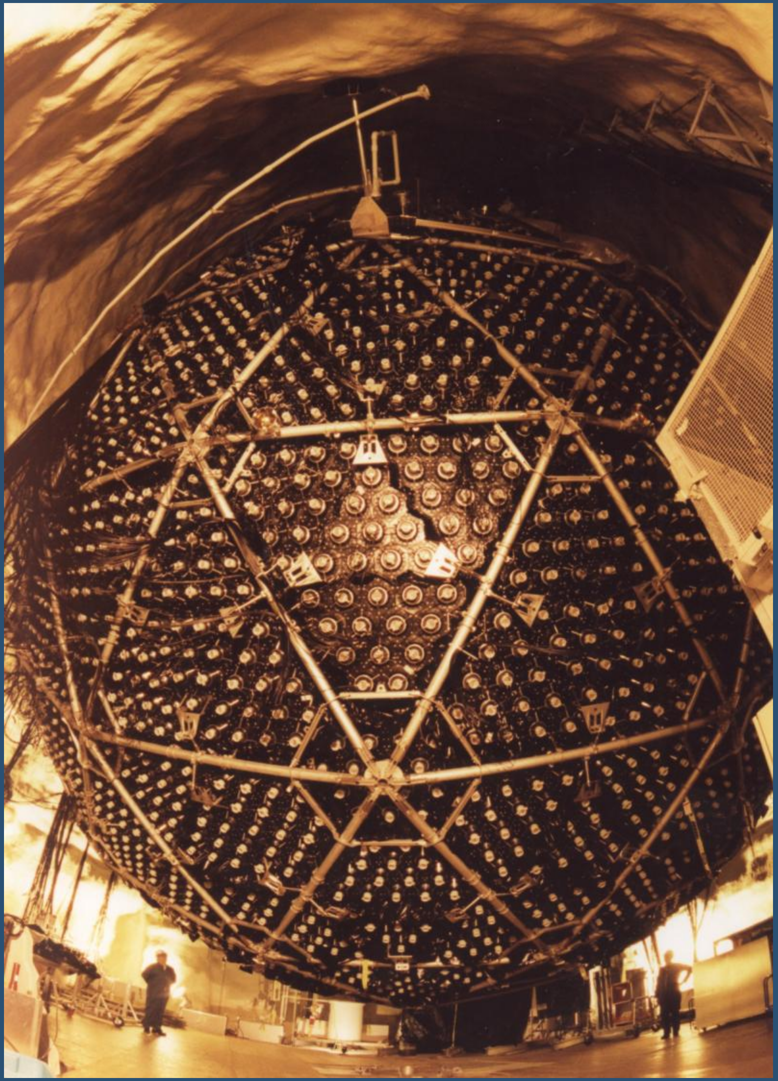
One half jointly to Raymond Davis Jr. and Masatoshi Koshiba "for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos“.

The other half to Riccardo Giacconi "for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources".

Sudbury Neutrino Observatory

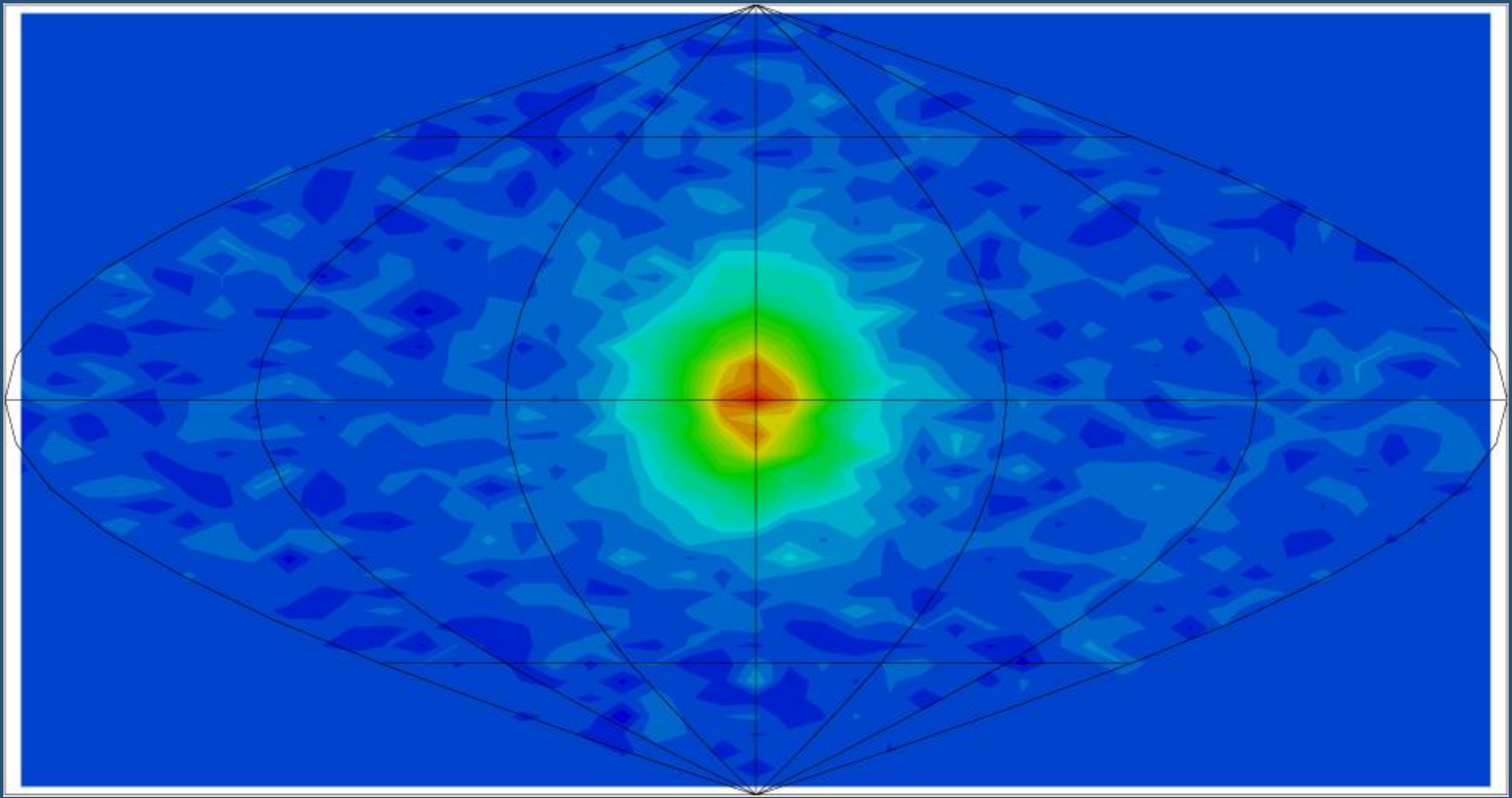
Three different ways of detecting neutrinos.

Sensitive to electron neutrinos and all three flavours separately.



Credit: SNO

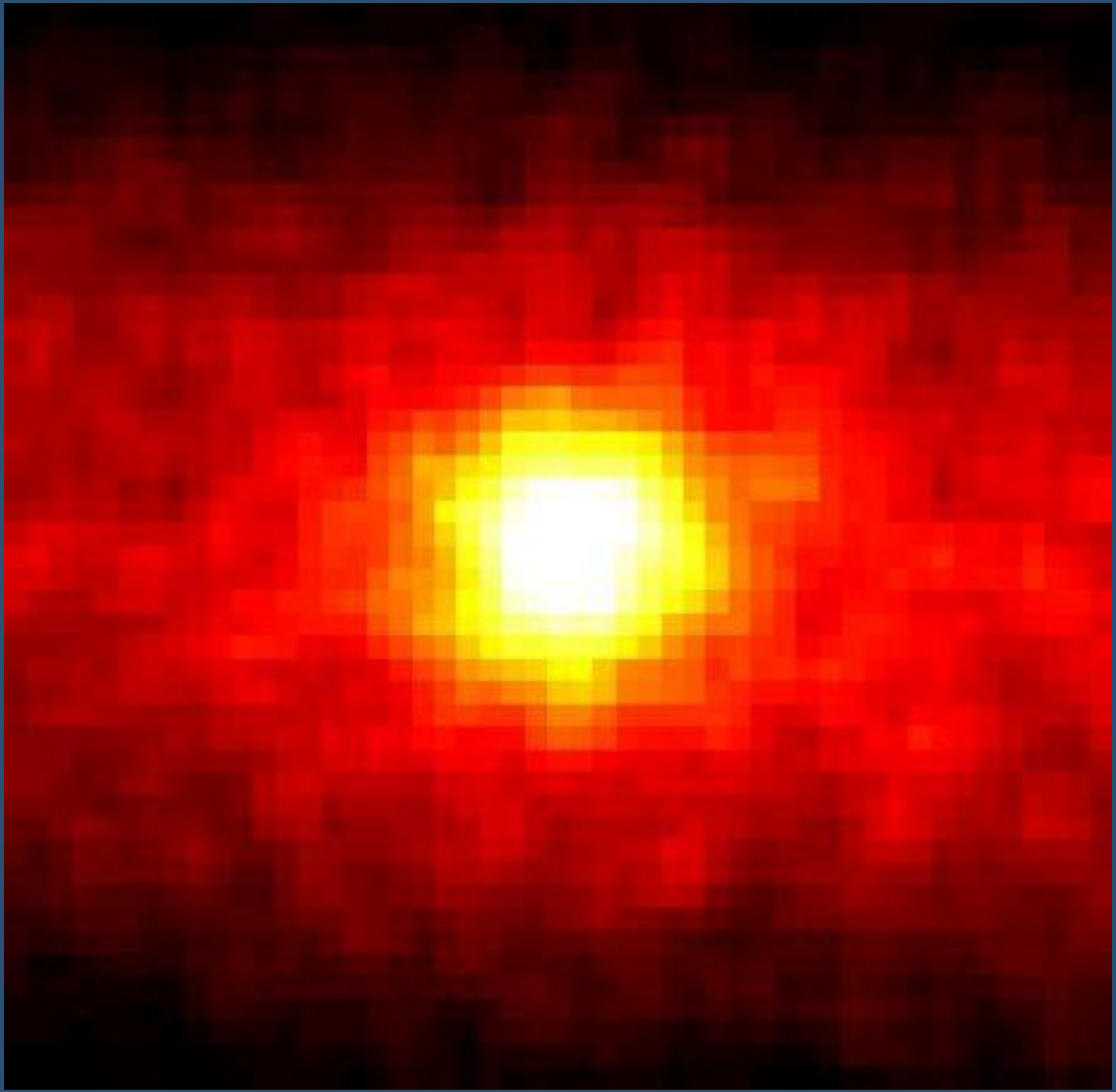
The Neutrino Sky



Credit: SuperKamiokande

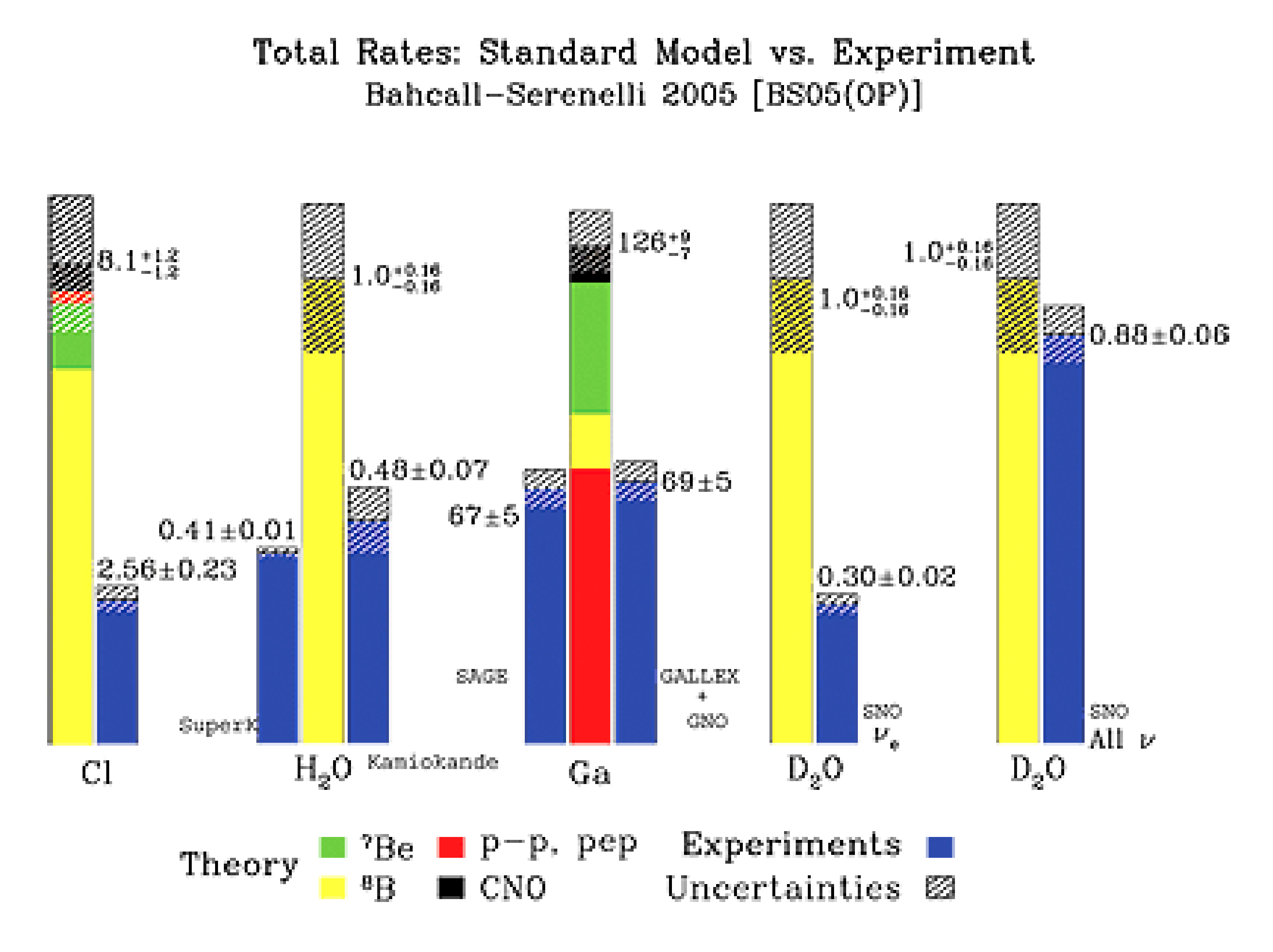
The Sun At Night

The Sun as seen through the Earth.



Credit: R. Svoboda & K. Gordan, SuperKamiokande

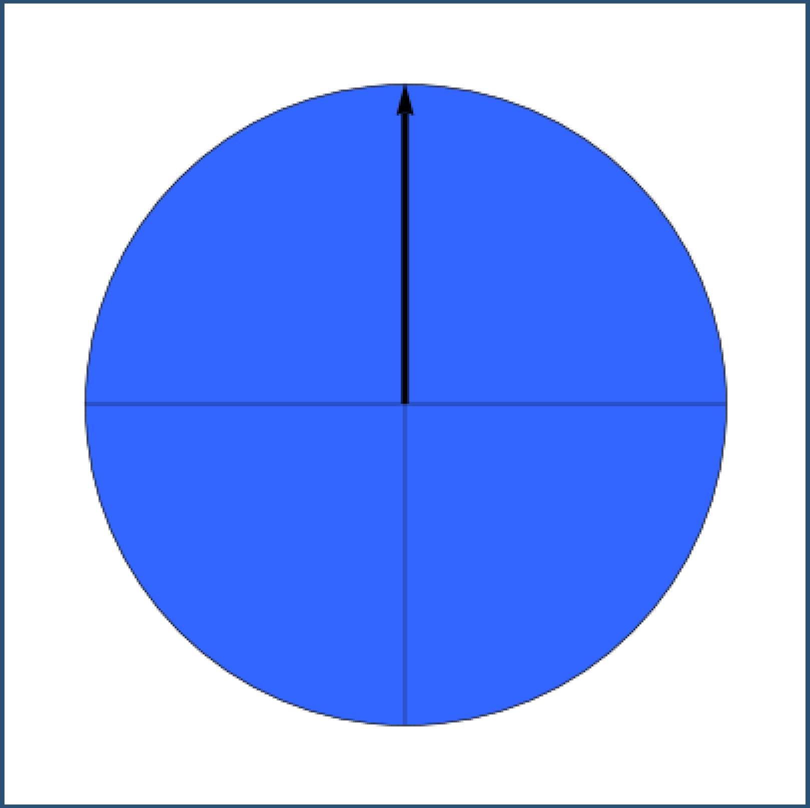
The Mystery Of The Missing Neutrinos



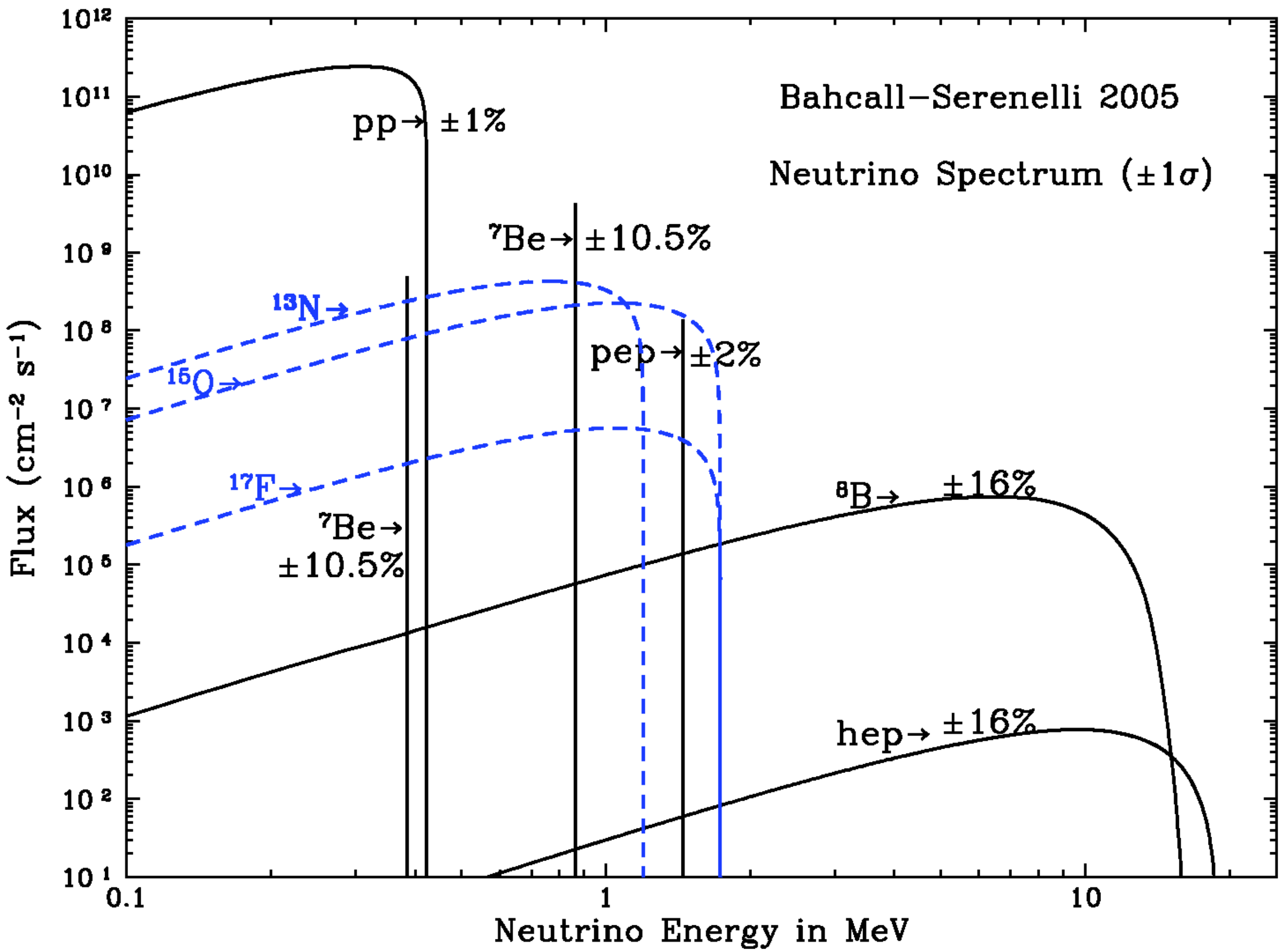
Credit: John Bahcall

Neutrino Oscillations

Neutrinos can change flavour!

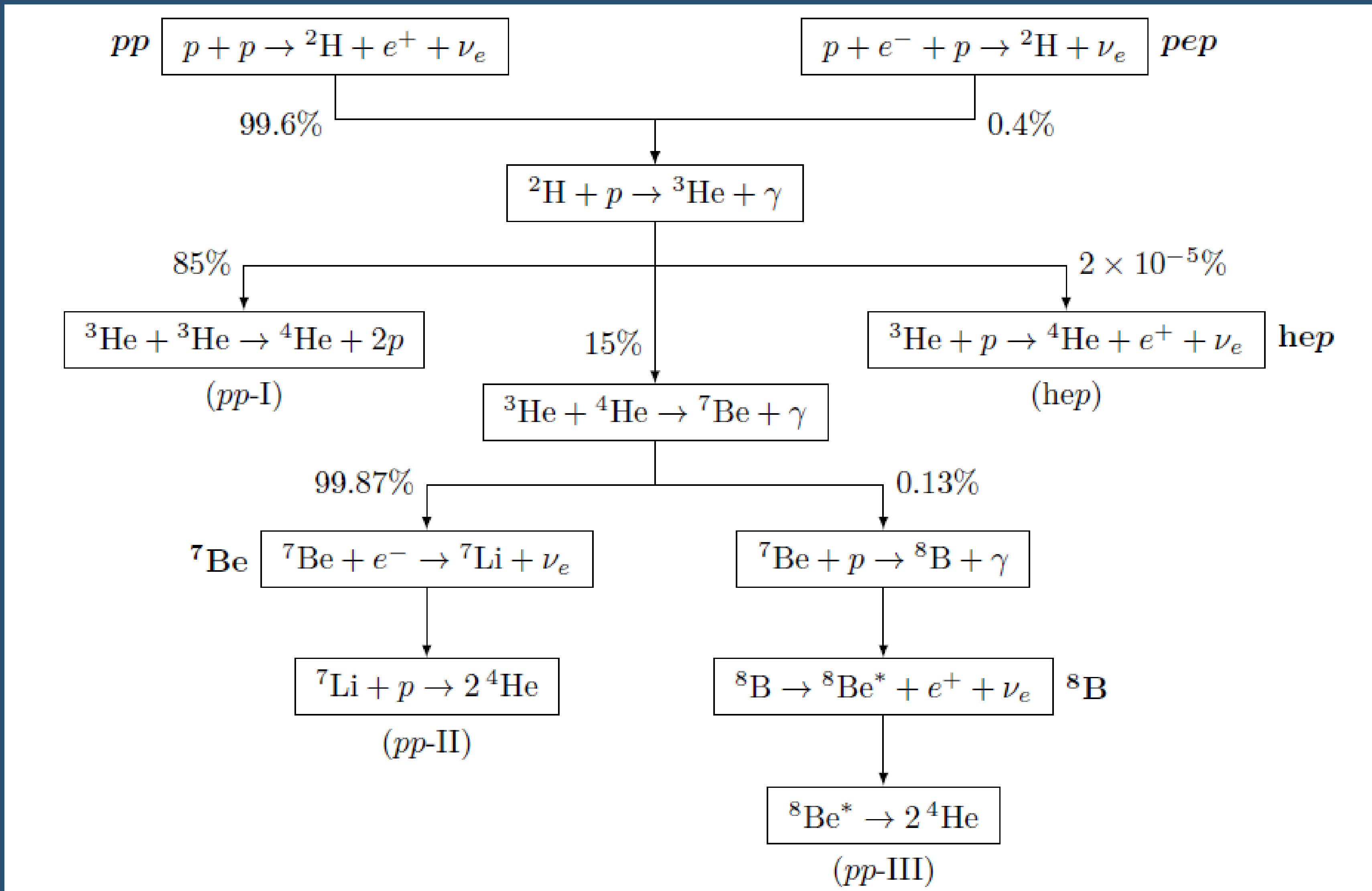


The Neutrino Spectrum

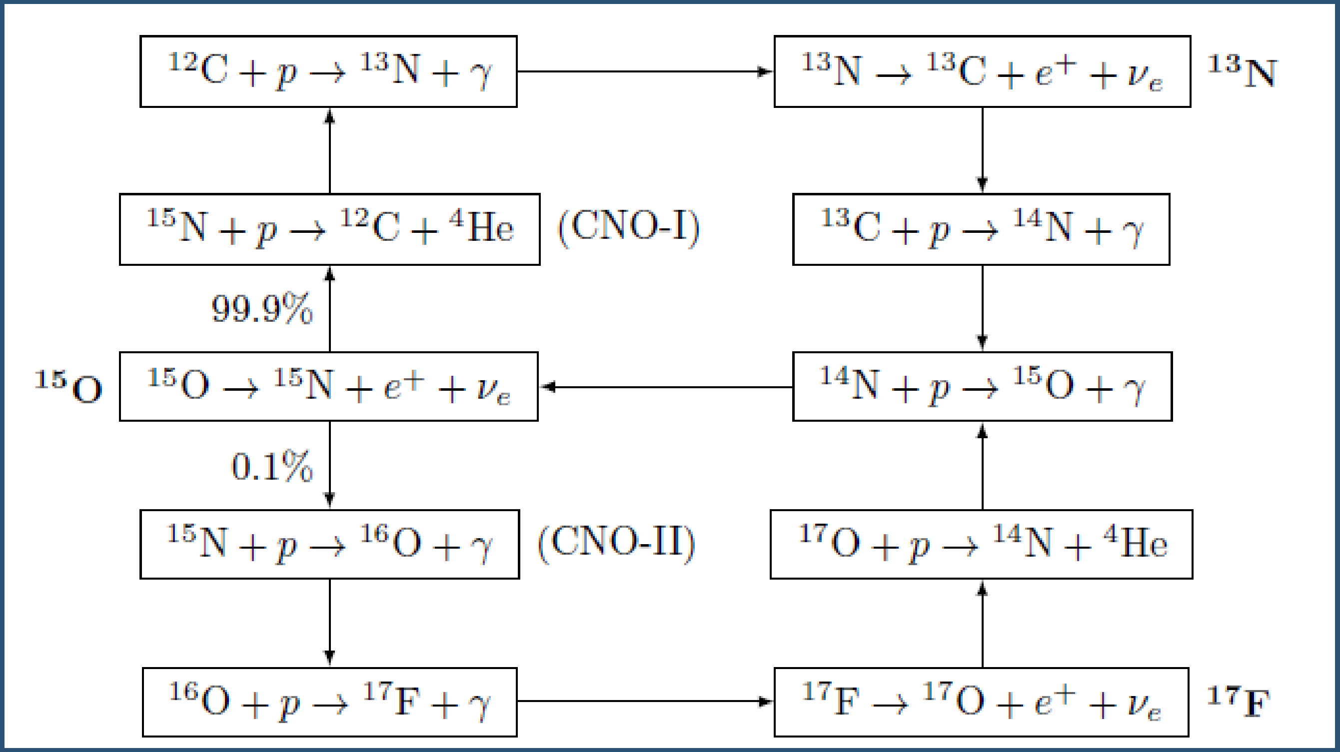


Credit: John Bahcall

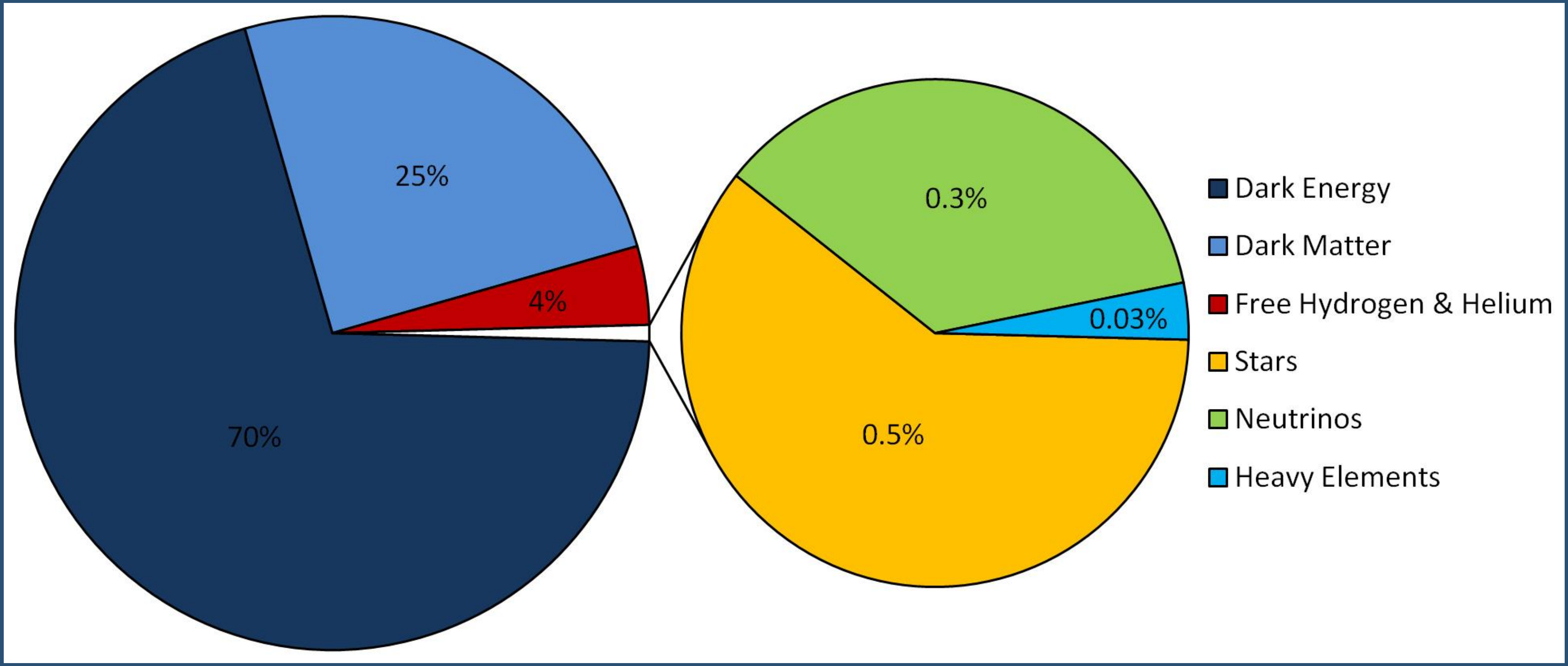
The *pp* chain


pp
$p + p \rightarrow {}^2H + e^+ + \nu_e$
$p + e^- + p \rightarrow {}^2H + \nu_e$
pep
99.6%
0.4%
${}^2H + p \rightarrow {}^3He + \gamma$
85%
$2 \times 10^{-5}\%$
${}^3He + {}^3He \rightarrow {}^4He + 2p$
(pp-I)
15%
${}^3He + p \rightarrow {}^4He + e^+ + \nu_e$
hep
(hep)
${}^3He + {}^4He \rightarrow {}^7Be + \gamma$
99.87%
0.13%
7Be
${}^7Be + e^- \rightarrow {}^7Li + \nu_e$
${}^7Be + p \rightarrow {}^8B + \gamma$
${}^7Li + p \rightarrow 2\,{}^4He$
(pp-II)
${}^8B \rightarrow {}^8Be^* + e^+ + \nu_e$
8B
${}^8Be^* \rightarrow 2\,{}^4He$
(pp-III)

The CNO cycle



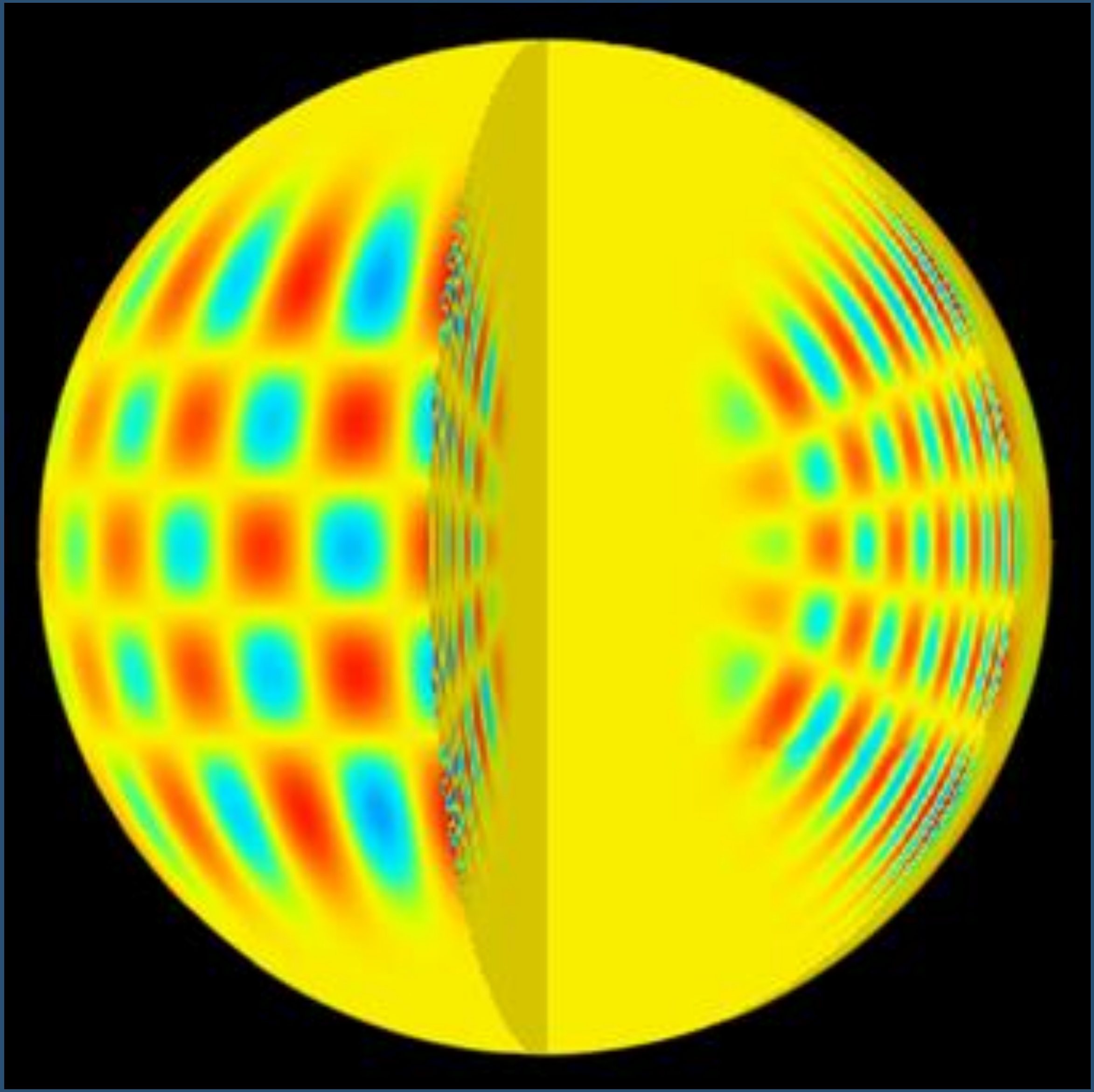
Cosmological Composition



Helioseismology

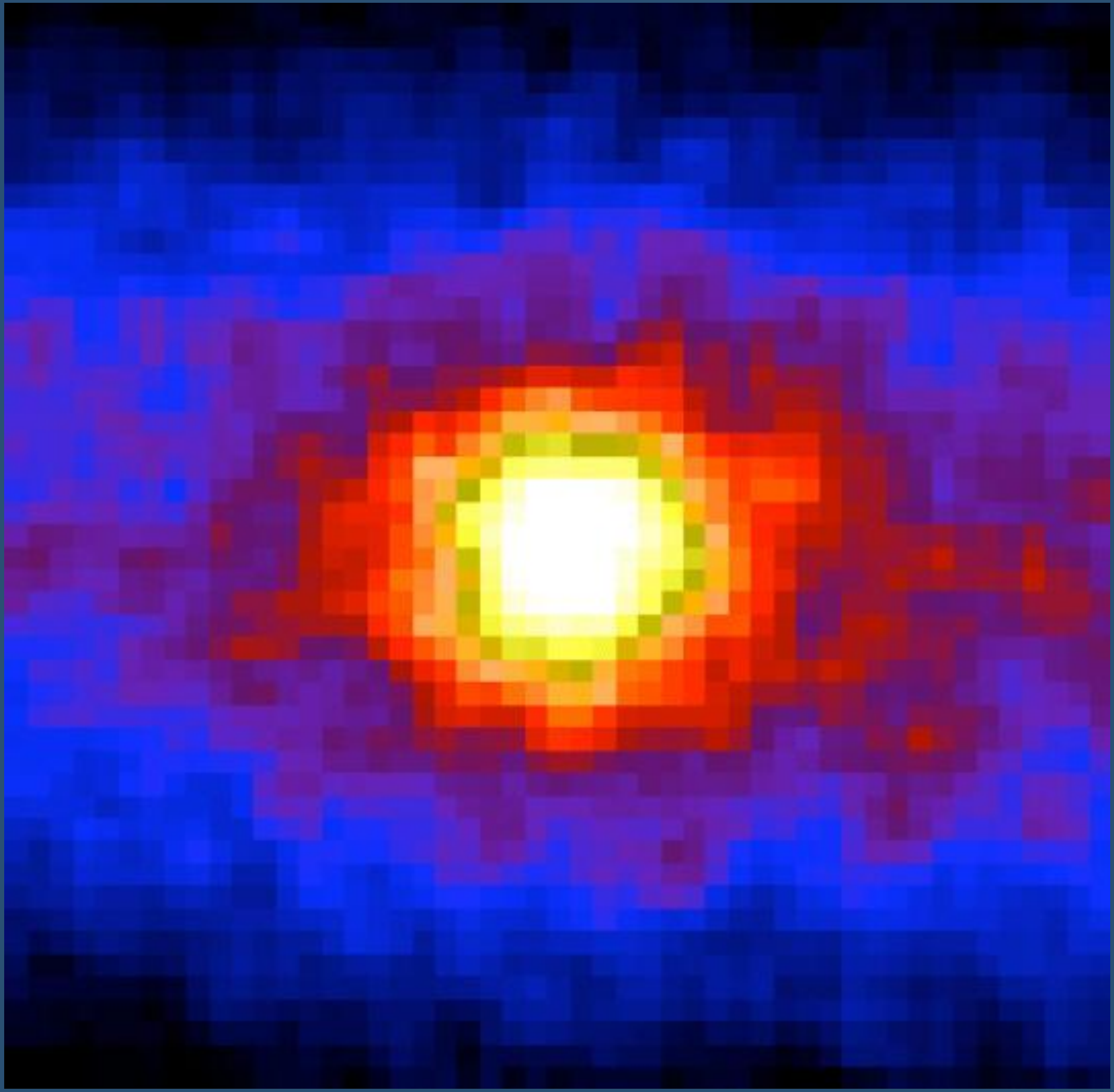
Map the vibrations of the Sun.

Like the ringing of a bell.



Credit: NASA

The Neutrino Sun



Credit: Marcus Chown, SuperKamiokande