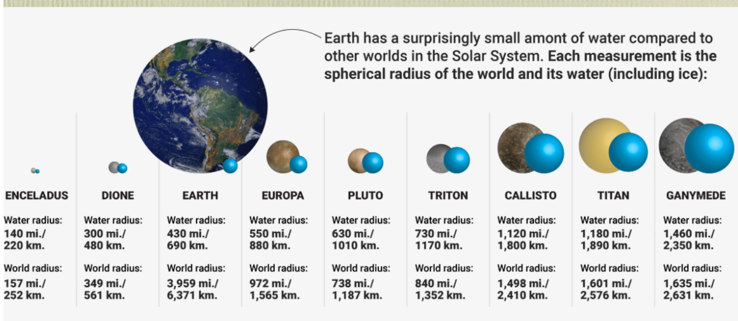
Business arising

- Thanks Brian Carroll



And one of the most extraordinary animations

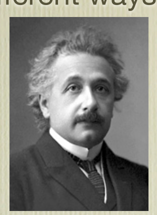
- https://earth.nullschool.net/

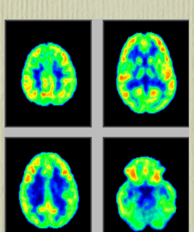
If we look at it with "white" light, it's a bit dull!

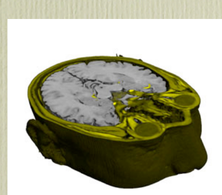
- But we can still see a few sunspots
- And Mercury!
- Note it's darker at the edges
- And about 5800°C

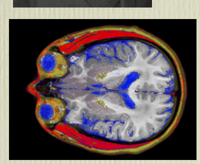
But if we want to find out how the sun works, we need to look at it in different ways

- Just like a human!



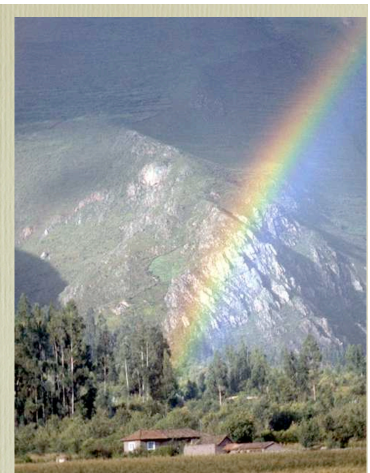




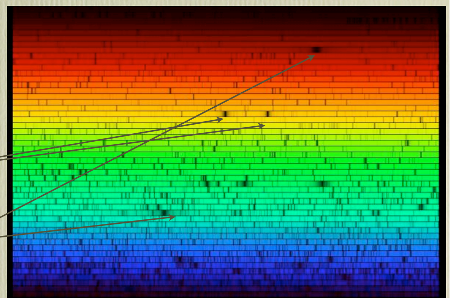


So we need to look at the sun in different ways

- Start by splitting up the light

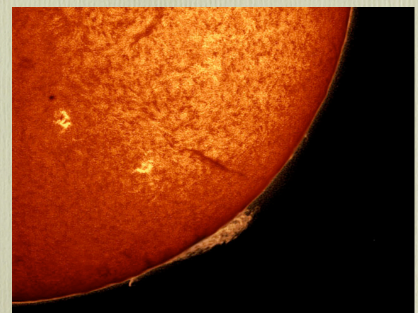


- We can look at the light from the sun
- Each line is corresponds to a particular element
  - e.g sodium
  - and hydrogen

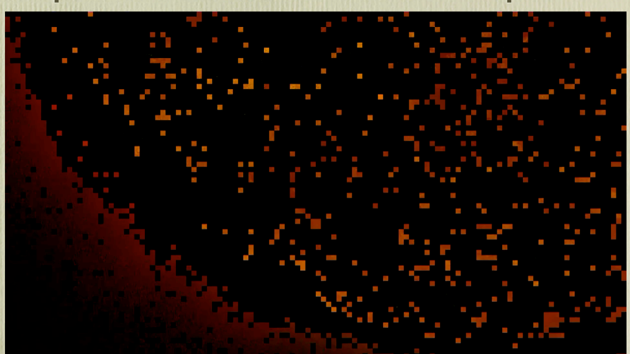


- So we can look at the hydrogen in the sun

- This is looking at the hydrogen (H) in the sun
- which picks up the "prominences" very clearly

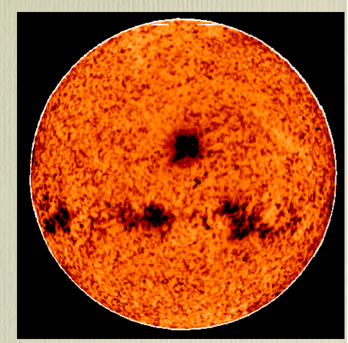


And we can watch a prominence in time-lapse



But we can look at the sun in different ways, so we can see how structure varies.

- This is Helium:
- Note the sunspots, where the sun is cooler (~4500°)
- a "rösti" picture



Since you asked: Rösti

A traditional Swiss potato dish that can be served as a crispy side dish or even as a snack. This recipe can also be enhanced with cheese, meat and vegetables if desired to make it into a tasty potato pizza.

Directions

Peel potatoes and shred using a food processor or a box grater. Hand or machine grate potatoes into strips similar to hash browns. If hand grating, grate the potato lengthwise for best results.

Place strips of potatoes into water to wash off excess starch. When finished washing, place shredded potatoes into a dish towel or cloth. Wrap tightly and wring or squeeze out excess water, making sure to remove as much as possible so cooking results are not affected by the excess moisture.

Crack egg into mixing bowl and whisk until smooth.

Add potatoes, ground pepper and salt, mixing all ingredients together well.

On stovetop, add 2 tablespoons of oil to a 10 inch non-stick skillet to be warmed on medium heat setting.

Add potato mixture to the 10 inch non-stick skillet, using a spatula to level the potatoes evenly across the pan. Since the potato mixture does not firm up after cooking only one side, the non-stick skillet will assist with the ease of turning the Rösti over when the first side if finished cooking. Cover pan and cook over medium heat for 6 to 8 minutes or until golden brown on bottom surface of potatoes. Remove cover and cook an additional 5 minutes.

Coat flat baking sheet with oil or cooking spray.

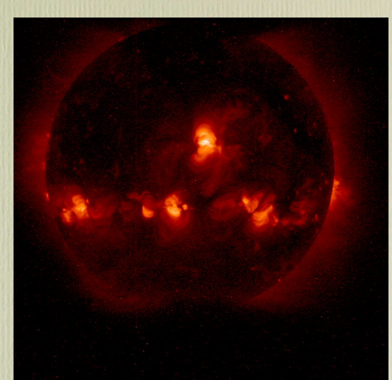
Remove skillet from stovetop. Using protective mitts or hotpads, place a flat baking sheet over the skillet. Hold baking sheet against skillet and turn skillet over so Rösti drops out of skillet onto baking sheet.

Remove bits of potato from skillet and place it back onto burner, adding remaining 1 tablespoon of oil.

Slide Rösti potato cake off baking sheet and into skillet, allowing uncooked surface to begin cooking.

Cook second side in uncovered skillet for 6 to 8 minutes, until golden brown. When finished cooking, tilt skillet and allow potato cake to slide out of skillet onto serving plate. Cut into 4 pie-shaped pieces and serve warm.

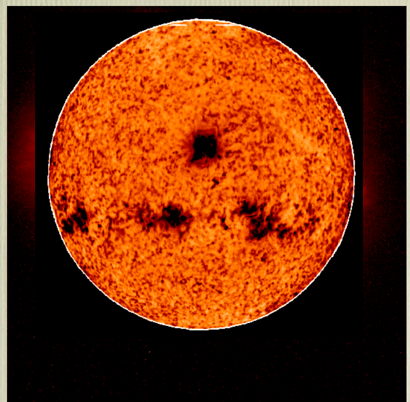
- X-rays come from hot gas
- Note the hot X-rays come from the cool sunspots



And this shows the magnetic field

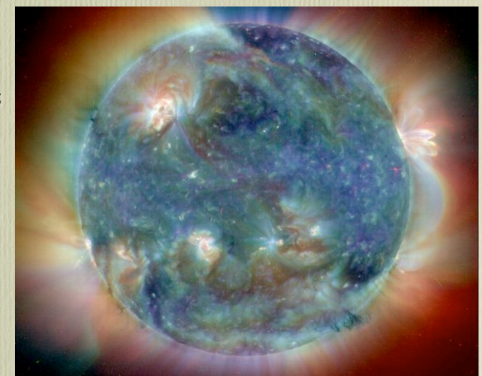
- Note how they all line up

•So the hot X-rays come from the cold sunspots
•And they are tied to the magnetic fields



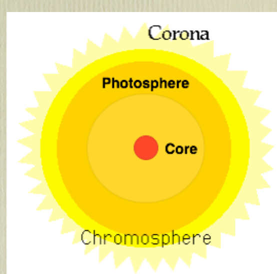
And this looks at the sun at 3 different temperatures

- Red at 2000000 °C
- green at 1500000 °C
- blue at 1000000 °C
- The outer part of the sun is the hottest!

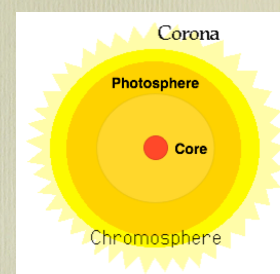


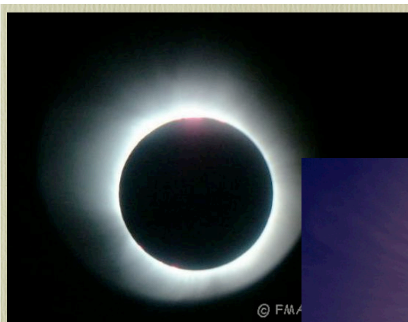
So lets look in a bit more detail

- **Core**: all nuclear reactions go on in core of sun
- **Photosphere** is at a fairly uniform 6000°.
- Not a surface in any normal sense.
- Light coming out of interior of sun will take ~ 100,000 years to get to the "surface"
- then it takes 7 minutes to reach earth.

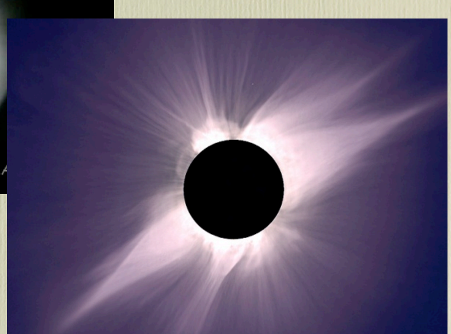


- Chromosphere: ~ solar atmosphere.
- Thickness ~ 10,000 km,
- Hotter than the photosphere.
- Corona: very diffuse, very hot (1,000,000 °C)



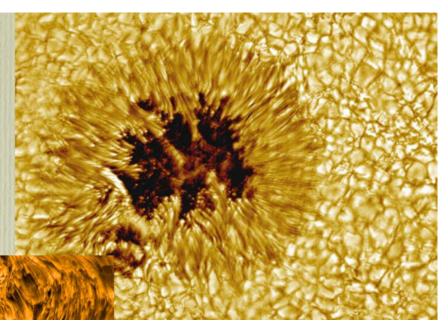


- Corona is faint, so can only be seen directly during a solar eclipse.

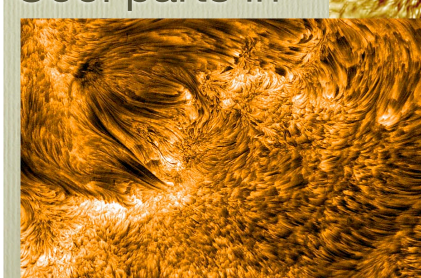


But its appearance changes dramatically according during the solar cycle

So what are these sunspots? Cool parts in

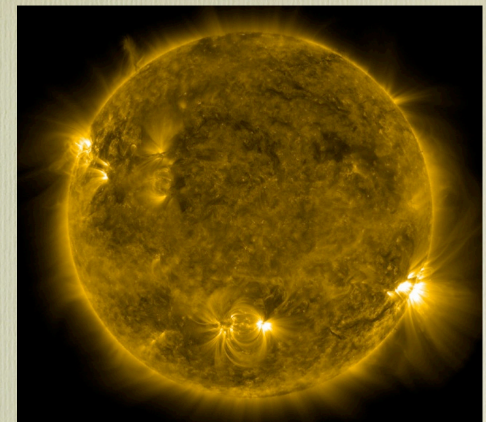


Credit: Vacuum Tower Telescope, NSO, NOAO)



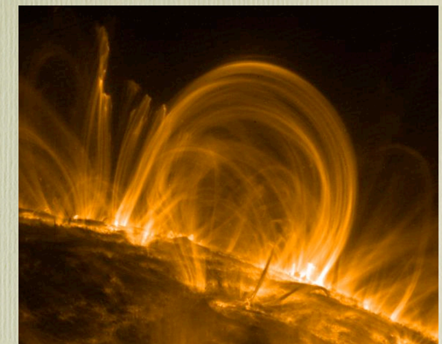
And round the we can see spicules: “flames” of hydrogen gas

From the side we can see clearly what the sunspots are



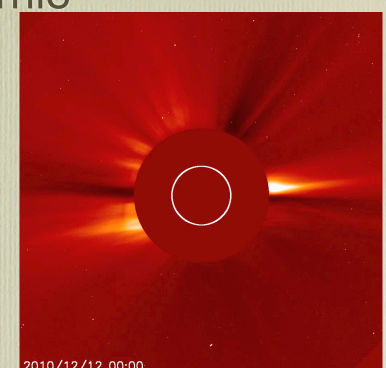
Close up view:

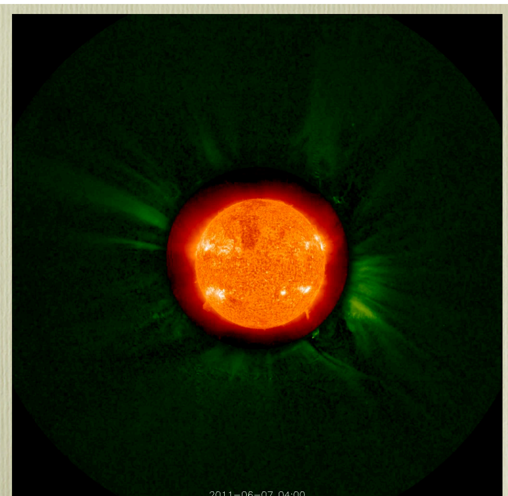
- magnetic field is traced out by hot plasma
- Loop of hot gas extends into the corona:
- About 50000 km



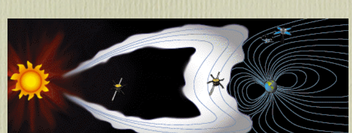
But magnetic fields are dynamic

- They can expand and squirt out gases
- or collapse and spray out high energy particles
- Solar & Heliospheric Observatory (SOHO)



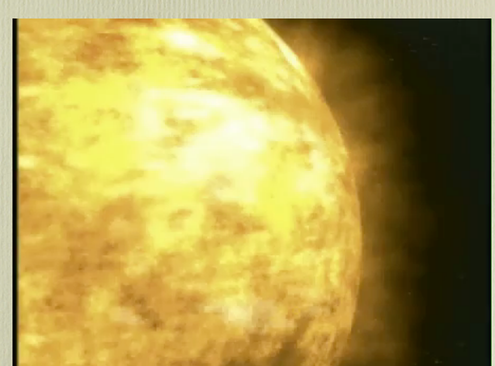


Which travel towards the earth



- So particles get filtered down to the poles

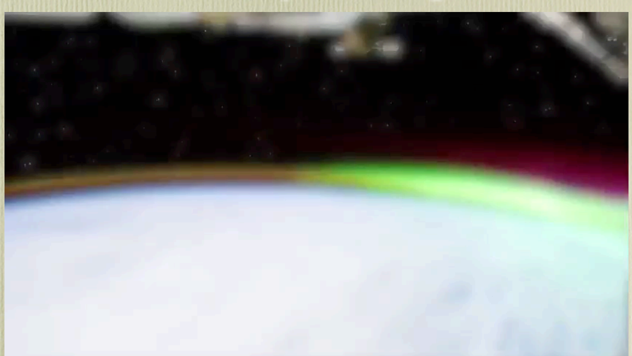
Like this



And become auroras

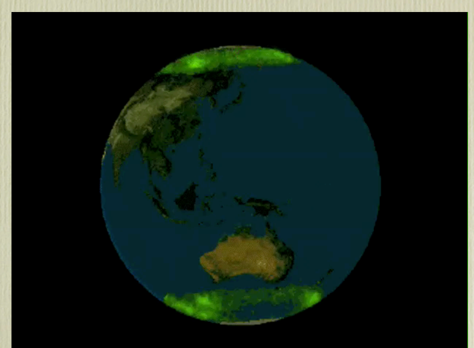
Which we can even see from space!

And fly through it

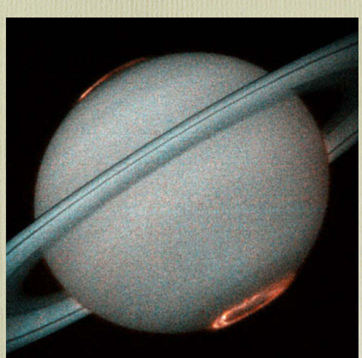


International Space Station movie

- Note we always get simultaneous aurora at N & S poles

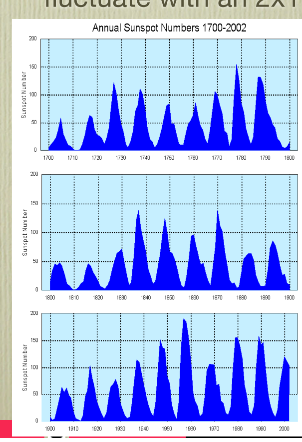


- And we can even see them on other planets



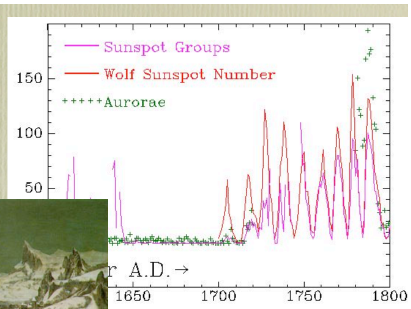
What we don’t understand

- Is why the number of sunspots/flares/aurora fluctuate with an 2x11 year cycle



Cycle is irregular, sometimes very few spots.

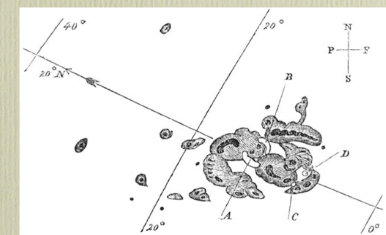
•Maunder minimum (long period of very few spots)



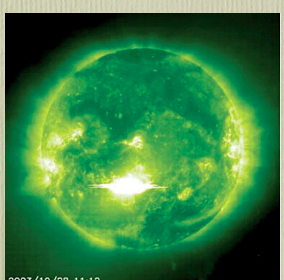
•coincided with "little ice age" in Europe (1550-1700)

Carrington Event

- Biggest solar storm in (recorded) history
- 28th August-2nd Sept 1859
- Blew out telegraph linkages all over Europe & US



- Aurora seen in Caribbean
- From Sciam



- March 1989
- Quebec blackout: 9 hours,
- communications down everywhere
- aurora in Texas (thought to be first-strike in nuclear war.
- Probably 1/10th of strength of Carrington event
- Hydro Quebec spend B$4.3 to improve protection

If it happened today .....

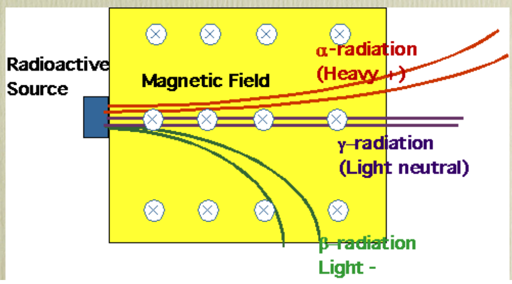
- Nightmare scenario:
- surge protectors don't trip fast enough, all power transformers in North America melt.
- Lead time for construction is 3 years...
- Hopefully:
- 12 hours warning of storm would allow power lines to be isolated
- surge protectors would burn out but could be replaced ...

Something Nu Under the Sun

Art McDonald,
Queens U
Nobel Prize for Physics
2015

Radioactivity and Decays Becquerel (1896)

- (alpha) α-rays ~heavy, positively charged
- (beta) β-rays ~ light, negatively charged
- (gamma) ɣ-rays ~ neutral, light



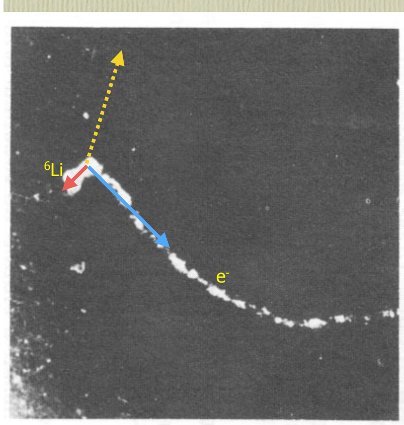
PW

Radioactive β-decays

- β particle is just an electron
- e.g. an isolated neutron will decay.
- n ➠ p + e^-

PW

β-Decay and Momentum Conservation

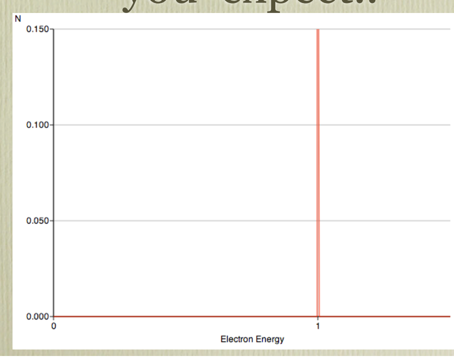


$^6He \rightarrow {}^6Li + e^-$

Appears to violate Momentum Conservation

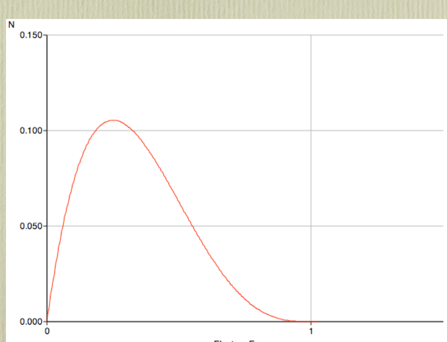
e.g. a neutron can decay: n ➠ p + e^-

Energy of Electron: What you expect..



PW

Energy of Electron: What you get..



PW

Wolfgang Pauli ... Neu...

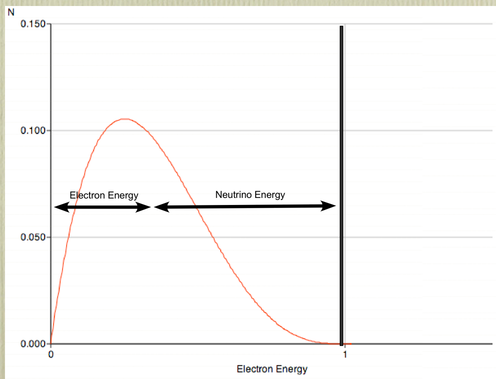
- 1930 – Neutral part... carry off missing ... momentum
- Shortly af... discov... (mu...

I have done a terrible thing, I have postulated a particle that cannot be detected.

Wikipedia

e⁻ and ν (nu)split the energy

e.g. a neutron can decay: n ➠ p + e⁻+ν



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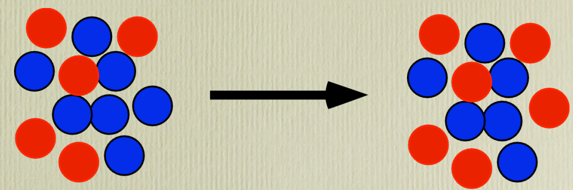
- This can also happen in a nucleus if the energies are favorable: e.g. could have



$^{12}B \rightarrow {}^{12}C + e^- + \nu$

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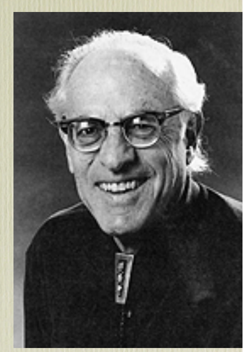
Nuclear Reactors are also (anti-) neutrino sources

- In a reactor uranium fissions to form lighter fragments
- Fragments are very neutron rich
- Neutrons decay to protons to form more stable nuclei giving neutrinos

PW

Neutrinos Finally Found

- Reines and Cowan (1957)
- Detected neutrinos from a reactor
- Efforts at Chalk River by John Robson ended due to reactor problem

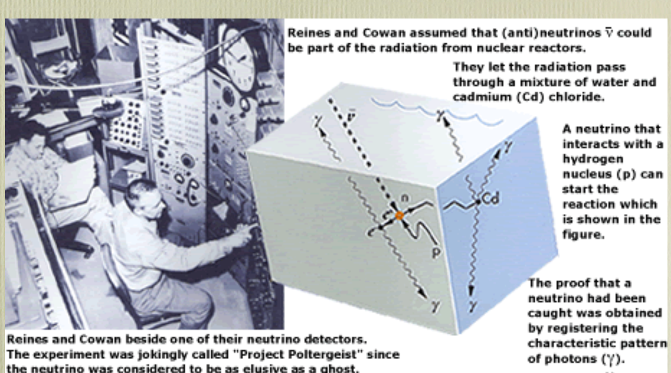


if a neutron can decay: n ➠ p + e⁻+ν

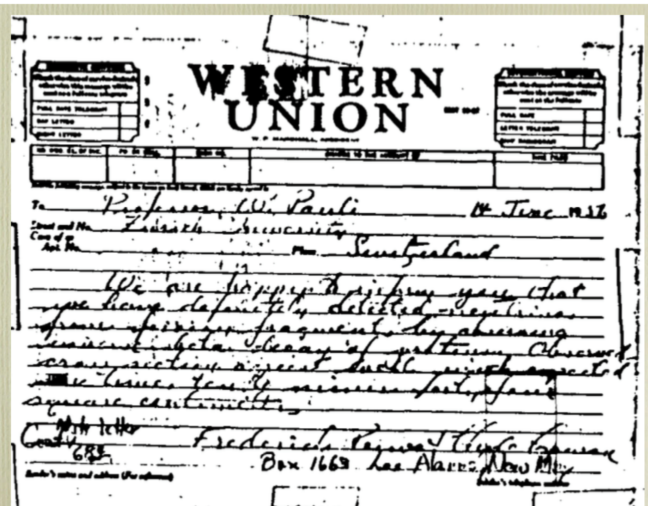
then we can reverse it ν + p ➠ n + e⁺

Fred Reines

Neutrinos meet Experiment



Savannah River



WESTERN UNION

To Professor W. Pauli 14 June 1956

Zurich University

Switzerland

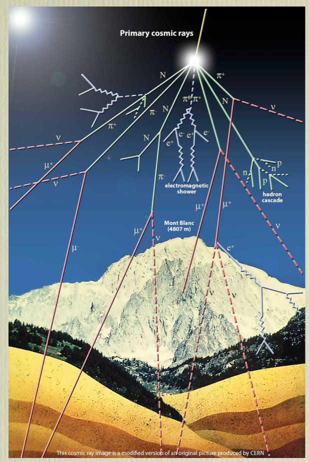
We are happy to inform you that we have definitely detected neutrinos from fission fragments by observing inverse beta decay of protons. Observed cross section agrees well with expected six times ten to minus forty-four square centimeters.

Frederick Reines Clyde Cowan

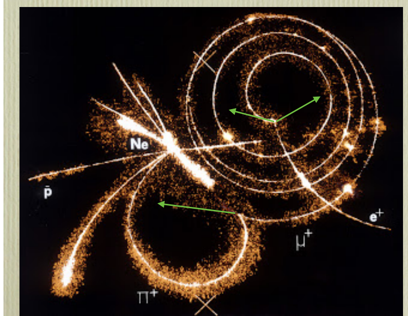
Box 1663 Los Alamos New Mex

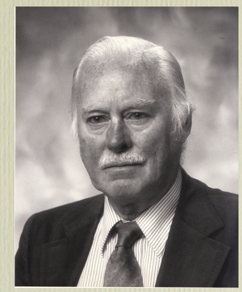
Muons

- Muons (μ) are particles like heavy electrons produced by cosmic rays
- One goes through you each minute on average)!
- Lifetime ~ 2 μs



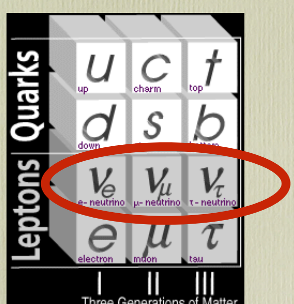
Pontecorvo/Hincks (Chalk-River/ NRC/Carleton) study muons





Muon decays to electron and 2 different neutrinos

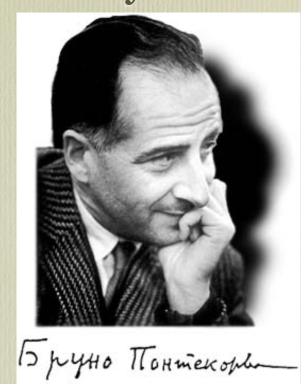
What we know so far (2016): The building blocks of the universe



PW

Pontecorvo Questions Neutrino Stability

- Perhaps neutrinos 'oscillate': a neutrino created as electron type *might* change to muon type and back again



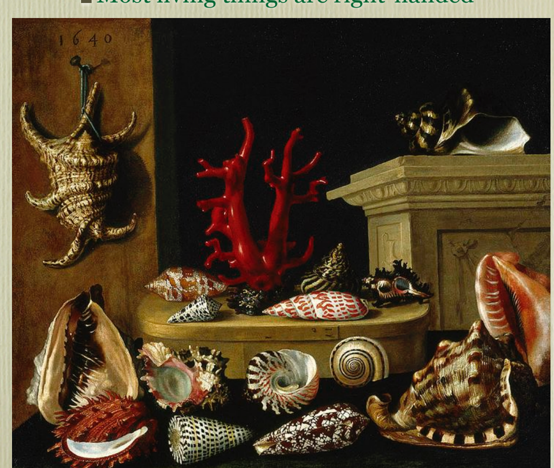
Bruno Pontecorvo

What Are Neutrinos?

- Neutral particles
- Very weakly interacting with matter
- If 100,000,000,000 neutrinos strike the earth, all but 1 will pass right through
- Must have very little mass, if any
- Seem to come in 3 distinct types – electron, muon, tau

PW

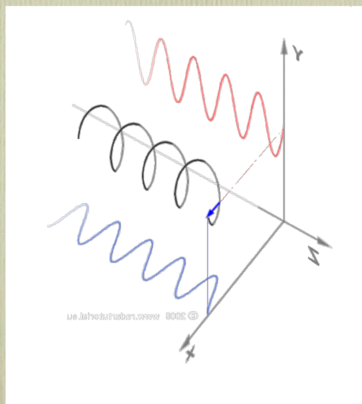
- Most living things are right-handed



Jacques Linard, early 17th, c

What Are Neutrinos?

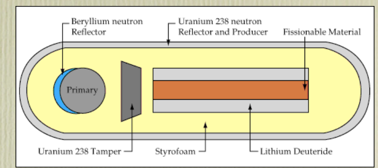
And they are left-handed....meaning



Wikipedia

So how does the sun work?

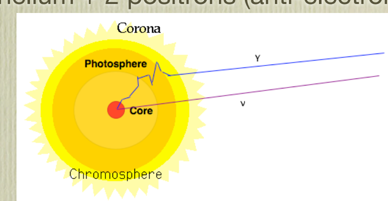
- Sun is ~ 90% hydrogen,
- ~9% Helium
- ~1% everything else
- It "burns" Hydrogen to Helium (almost the same reaction as a hydrogen bomb!)



Every second the sun converts 4 million tons of matter into energy!

PW

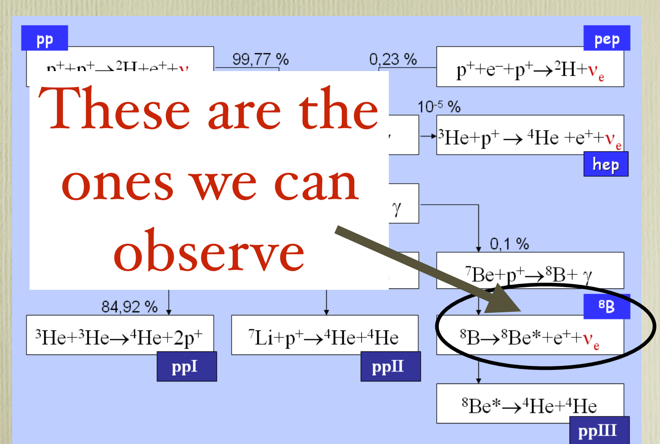
- And this is what keeps us warm!
- How do we know it's true?
- What really goes on in the core is a bit more complicated
- 4 protons become helium + 2 positrons (anti-electrons) + 2 neutrinos



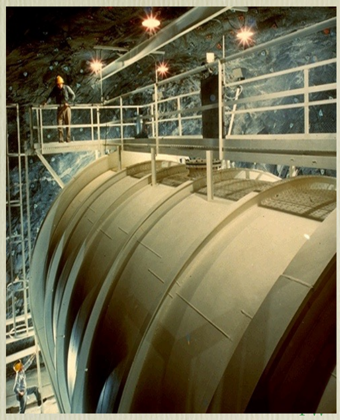
The neutrinos produced at the centre make it to earth in 8 minutes

- One Trillion (roughly) go through your thumbnail each second
- you hadn't noticed?
- tsk tsk!
- If we could see the neutrinos, we can see the centre of the sun, but they have almost no interactions!

It's a bit more complicated....Proton-Proton Chain



37-Chlorine Experiment
Ray Davis (Nobel 2002)



- 100,000-gallon tank of perchloroethylene
- 4800 feet underground in the Homestake Gold Mine

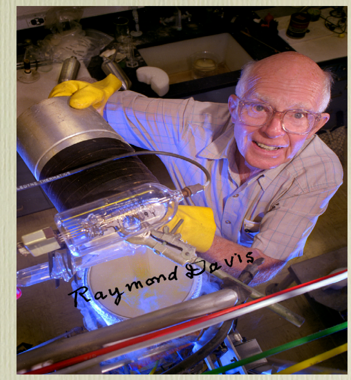
37-Chlorine Experiment

- A solar neutrino interacts with ^{37}Cl to produce Argon and an electron

$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$

- Argon decays after 35 days: detect the electrons

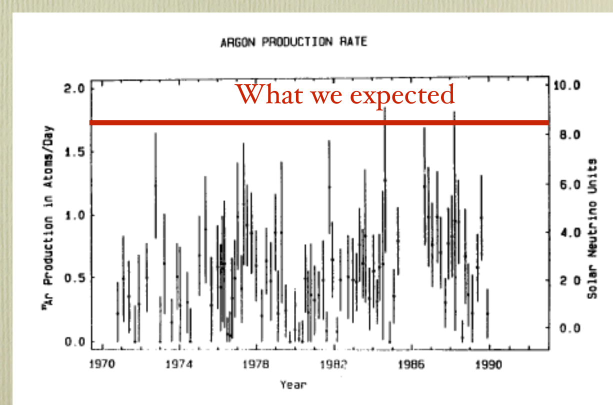
$^{37}Ar \rightarrow Cl + e^-$



PW

Ray Davis tells me that the experiment is simple ('only plumbing') and the chemistry is 'standard.' I suppose I must believe him, but as a non-chemist I am awed by the magnitude of his task and the accuracy with which he can accomplish it. –John Bahcall 1969

PW



PW

Results of th... Chl...rine Exp...me...

- Look for Cl ... -> A...
- First d... 196...
- P...ctio... rgon ... rate

Experiment may be wrong

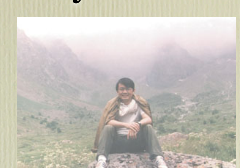
Model of Sun may be wrong

Model of neutrino may be wrong

PW

Neutrino Detection in Heavy Water

Suggested by Herb Chen d. 1987



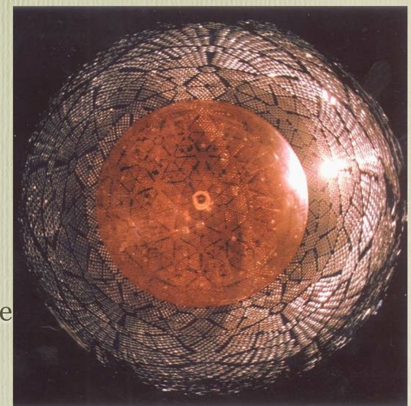
- Heavy water is D_2O – D is Deuterium
- Deuterium nucleus is weakly bound proton and neutron
- **allows us to detect ν_e's (electron nu's) and ν_x's (all nu's) simultaneously**

Sudbury Neutrino Observatory (SNO)

- Patience: idea formulated in 1985, construction started in 1990, First results in Fall 2000
- Money: (depending on what you include) M$40 - M$150
- Skill: meant constructing a device that has never existed before

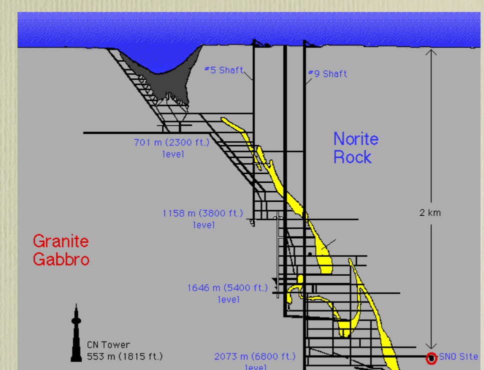
- Luck: Could only be built in Canada because of a political boondoggle, but more seriously:

- **if** we are lucky (we were!), we could
  1. Understand how the sun works
  2. Understand how neutrinos work
- **If** we had been unlucky, would just have found the previous experiments were wrong!

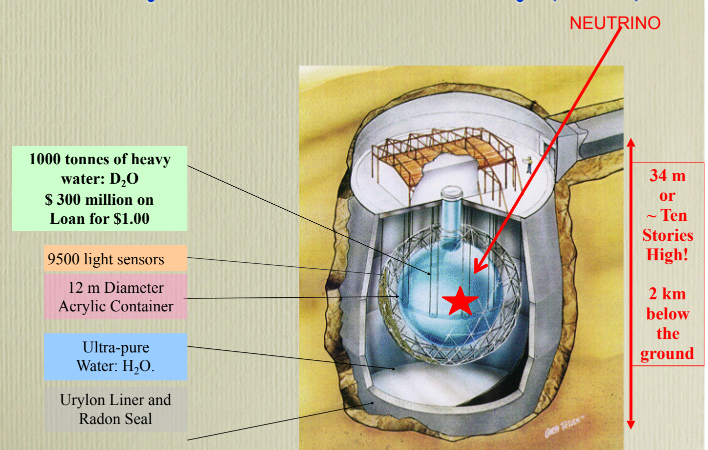


Sudbury Neutrino Observatory

- Let's look at the sun through 2 kilometres of rock!!
- And use 1000 tons of heavy water as our detector



Sudbury Neutrino Observatory (SNO)



Bursts of light from radioactivity were reduced to ~10 times less frequent than neutrinos

Excavating the Cavity

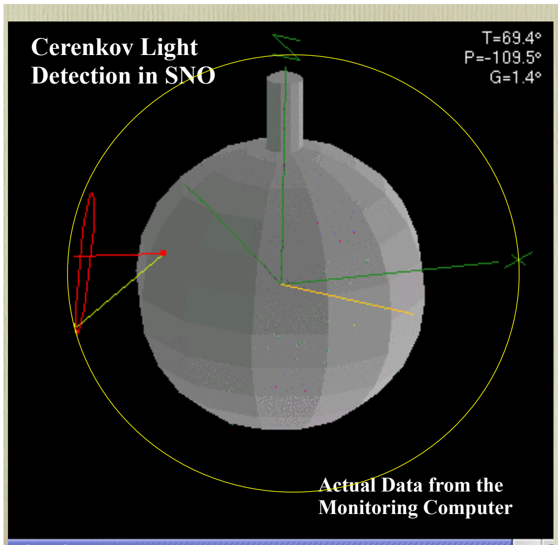
as large as a 10 story building

Largest cavity excavated at this depth

A part of the Heavy Water Purification System (Basement of Herzberg)

Detector partially filled

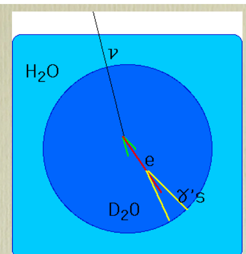
SNO



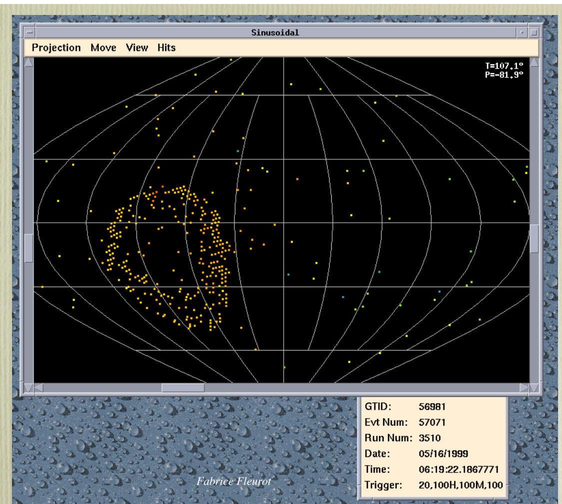
Cone of light emitted when neutrinos hit atoms in water

SNO

- Once every 3 hours a neutrino will hit an atom and produce light



- Which we can detect



SNO

The Basic SNO Result

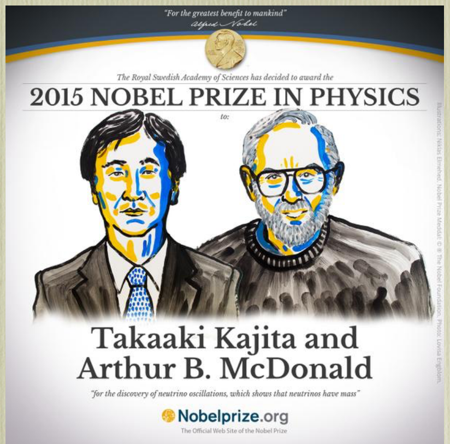
- Flux of Electron type Neutrinos ~ 1 million/sec
- Flux of All Neutrinos ~ 5 million/sec
- (note: these are just the high energy ones)

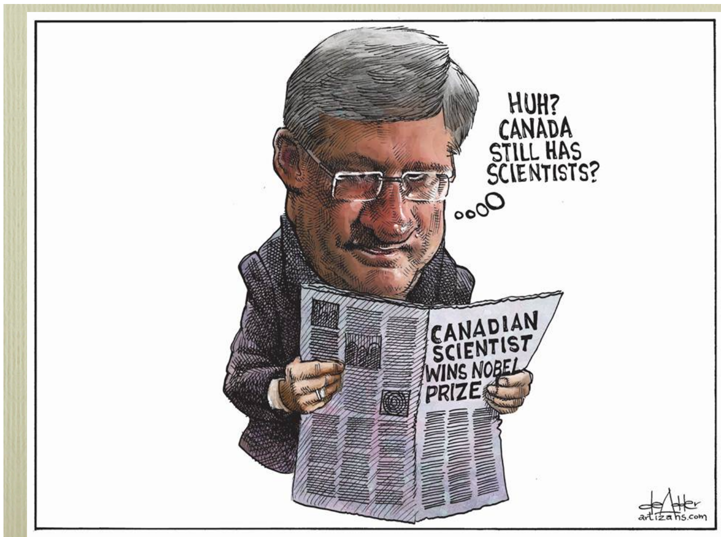
These numbers are different
Electron neutrinos must change into another kind

PW

So neutrinos really come from the core of the sun, but they change into another kind on the way over

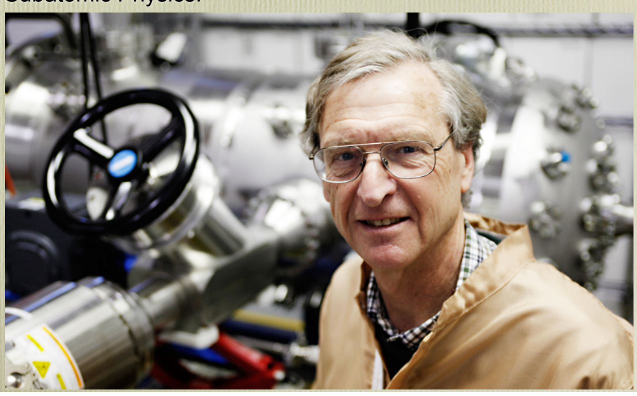
Why?



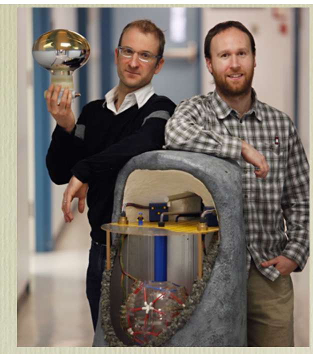


The Carleton Connection:

David Sinclair (Inaugural CAP-TRIUMF Vogt Medal) for Outstanding Experimental or Theoretical Contributions to Subatomic Physics.



- Alain Bellerive
- Etienne Rollin
- and about 20 others

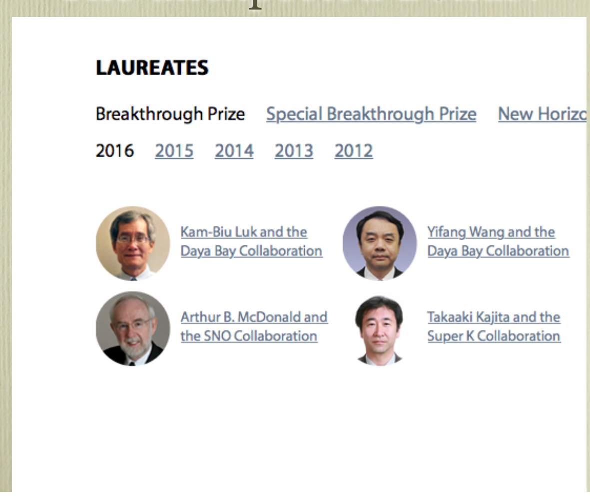


I will be with you in spirit (if I ever get off the phone today). Thanks to everyone from SNO for all they have done to create this success.
Way to go colleagues!!!
Art

The unexpected Bonus!

SAN FRANCISCO – November 3, 2015 – The Breakthrough Prize today announced that ten-time Grammy Award winner Pharrell Williams will perform at its third annual Breakthrough Prize ceremony, held to honor the world's top scientists and mathematicians, on Sunday, November 8 in Silicon Valley.
Williams will be joined at the exclusive ceremony by a star-studded lineup of presenters, including Academy Award winner Russell Crowe, Academy Award winner Hilary Swank, Lily Collins, and Thomas Middleditch and Martin Starr of HBO's Silicon Valley. As previously announced, Emmy-nominated Cosmos executive producer and Family Guy creator Seth MacFarlane will serve as the ceremony's host.
The Breakthrough Prize ceremony is hosted by co-founders Sergey Brin (Google) and Anne Wojcicki (23andMe), Jack Ma (Alibaba) and Cathy Zhang, Yuri Milner (DST Global) and Julia Milner, and Mark Zuckerberg (Facebook) and Priscilla Chan, along with Vanity Fair

The unexpected Bonus!


LAUREATES

Breakthrough Prize Special Breakthrough Prize New Horizo

2016 2015 2014 2013 2012

Kam-Biu Luk and the Daya Bay Collaboration
Yifang Wang and the Daya Bay Collaboration
Arthur B. McDonald and the SNO Collaboration
Takaaki Kajita and the Super K Collaboration

PW

And finally, written and performed by Maayan Blevis

rse.

- So we understand (more-or-less) how the sun works:
- It is 4.5 billion years old
- "Best before" date is 10 billion years when it runs out of hydrogen fuel