The *new* Siderius Nuncius: Astronomy without light

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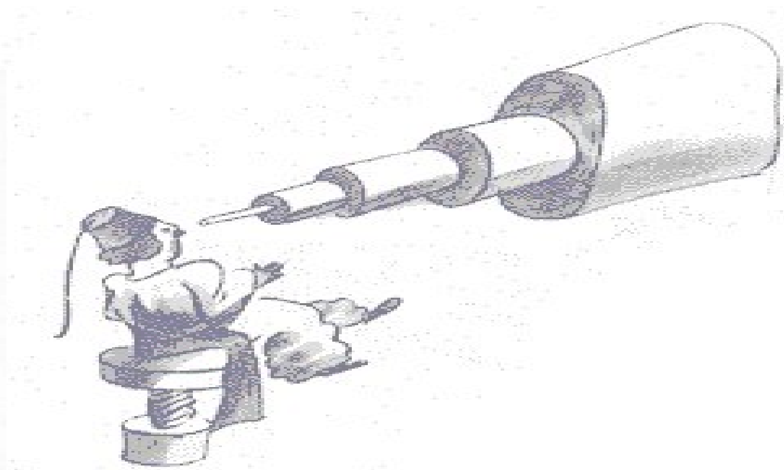
SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt observata in LVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.



1609-2009 – four centuries of telescopes

Conclusions

- Optical astronomy has made dramatic progress in 400 years since Galileo's Siderius Nuncius; non-optical wavelengths are more recent and give complementary information

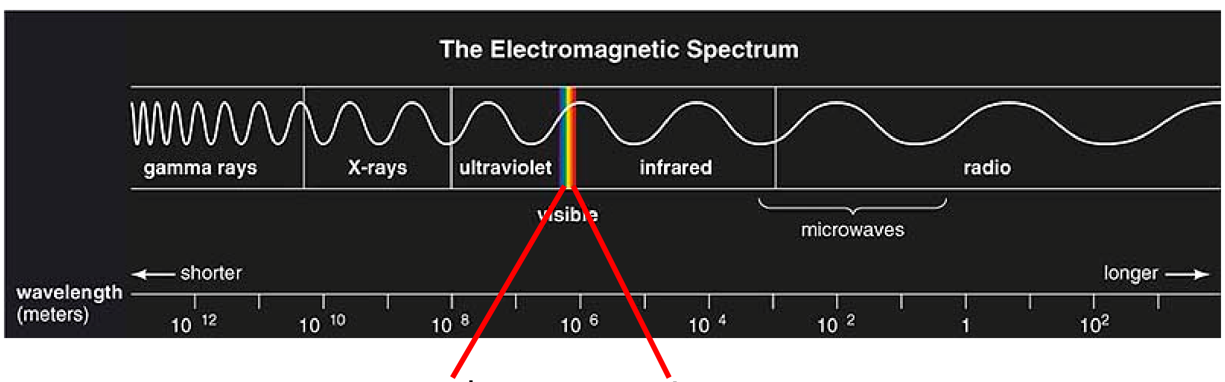
- Other messengers can be studied – their information too is complementary

- "Telescopes" for these other messengers lead to "astronomy" on isolated prairies, in Antarctic ice, in the deep sea, deep underground… and at particle accelerators!

How do we know about the Universe?

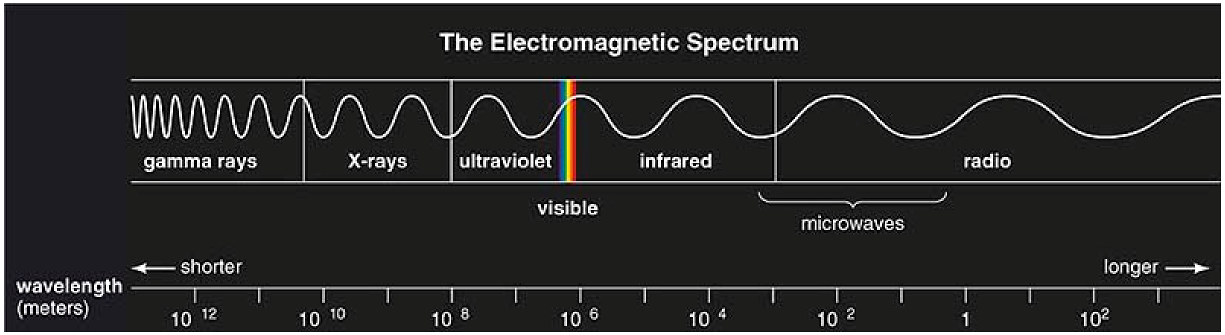
Historically, until recently all observational information about the cosmos comes to us carried by light - electromagnetic radiation.

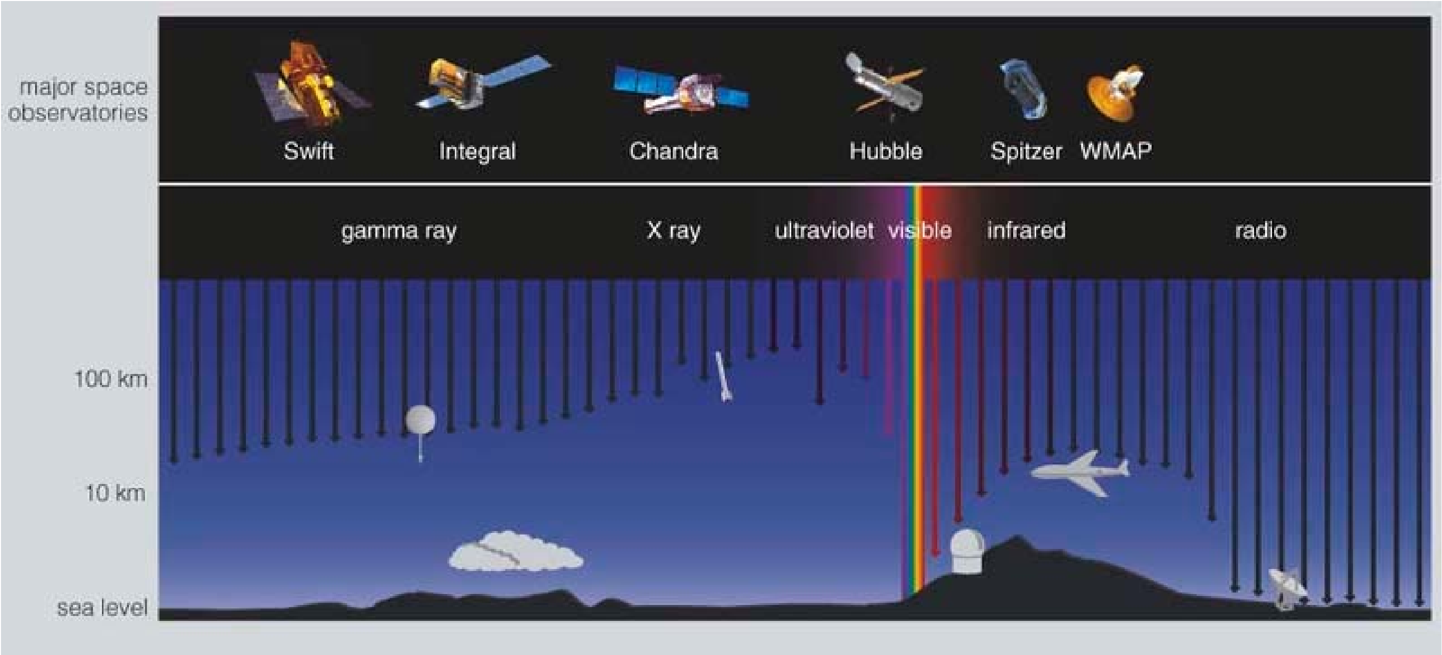
The EM spectrum is broad – from radio waves (very long wavelengths) to gamma-rays (very short wavelengths).



where we see!

The atmosphere doesn’t make it easy!



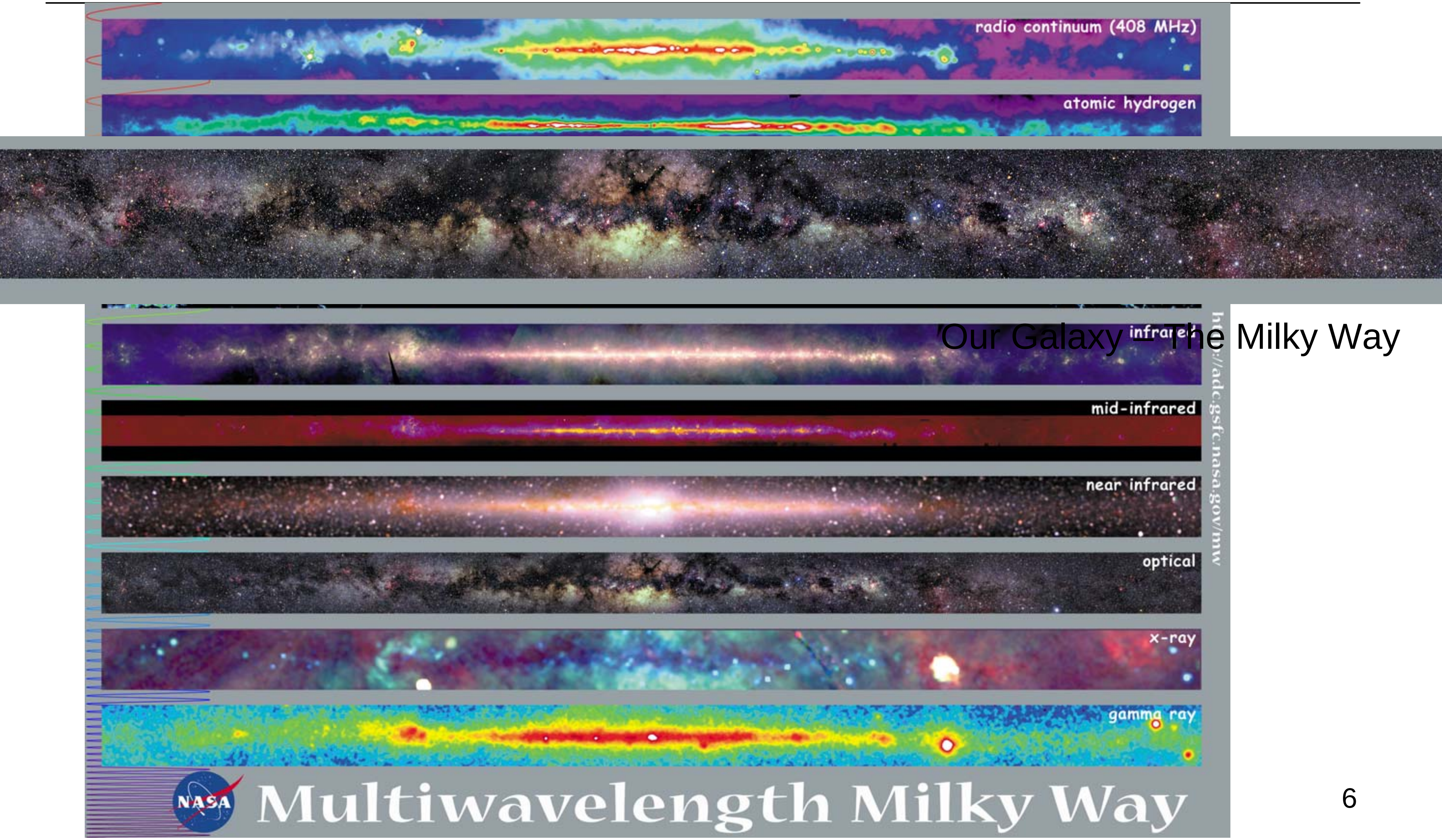


Our local neighborhood:

we are here!

Our Galaxy – The Milky Way

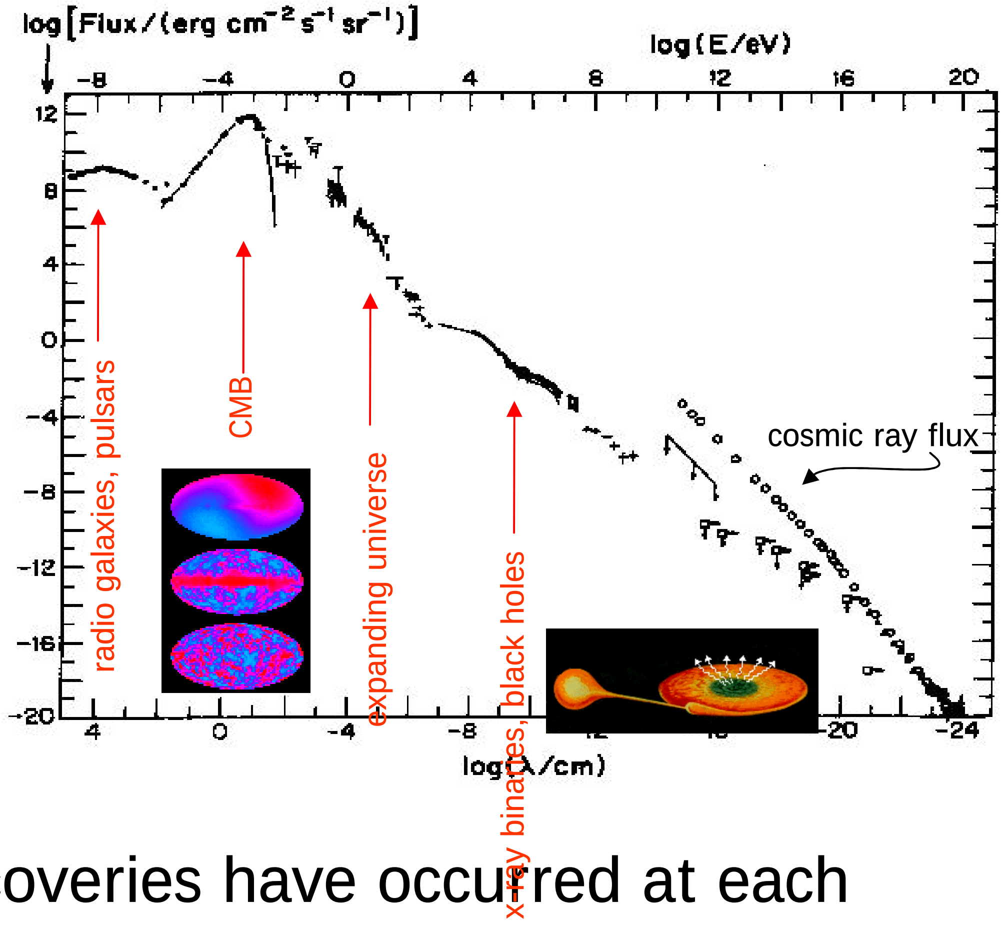
The view is different at different wavelengths!



Our Galaxy – The Milky Way

Different wavelengths give different information:

Diffuse photon flux



Revolutionary discoveries have occurred at each new wavelength !

If different wavelengths give different views, what about other messengers?

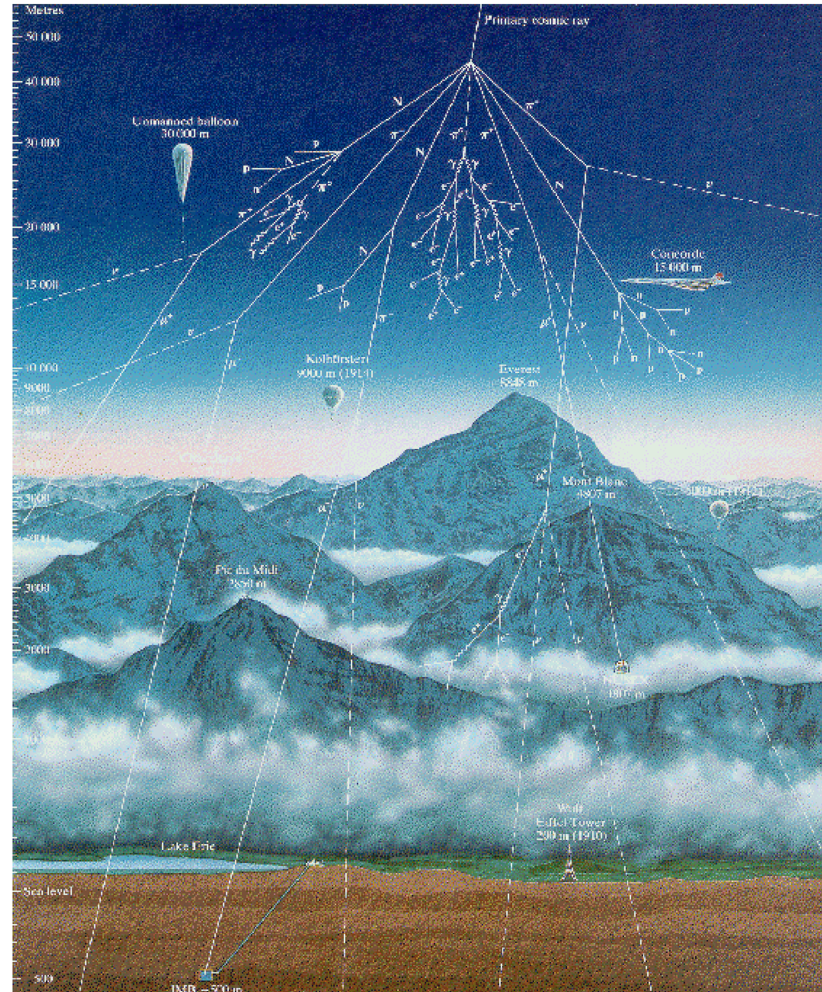
- charged cosmic rays
- neutrinos
- gravity waves
- dark matter particles

All of these are (potentially) detectable, and give us complementary information about the cosmos: new ‘starry messengers’.

Charged cosmic rays

- discovered in 1911 by Viktor Hess (from balloon)
- initially studied at mountain observatories and from balloons

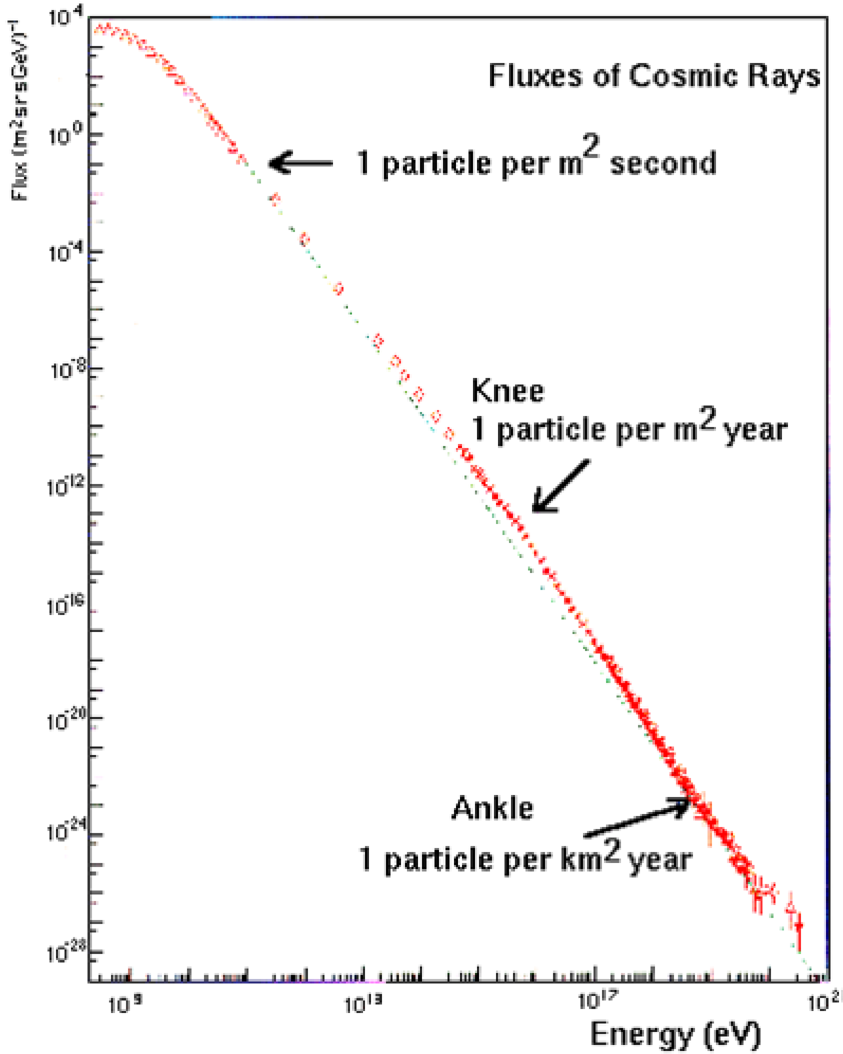
- now known to be charged particles (protons, He nuclei, electrons)
- collectively contain as much energy as starlight



Cosmic ray spectrum

- distribution of fluxes and energies (spectrum) extends over 30 orders of magnitude (powers of 10) !

- energies of individual particles extend to 10^{20} eV – ten billion times the energy of a starlight photon, or about the energy of a hard pitched baseball!



Cosmic ray origins

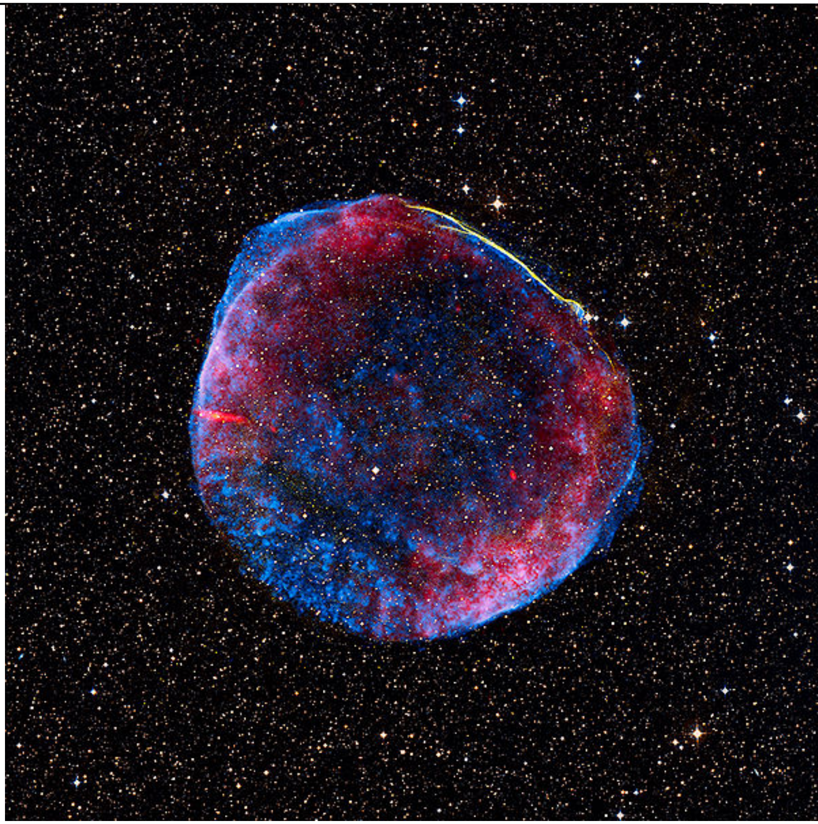
• Up to ~ 10^{16} eV, believed to come from supernova remnants – galactic leftovers of exploding (high-mass) stars

• most intriguing are rare high-energy events: ~ 10^{19} - 10^{20} eV

• at high energies, CR directions should point back towards sources

• interaction with low-energy CMB photons makes universe opaque at *cosmological* distances

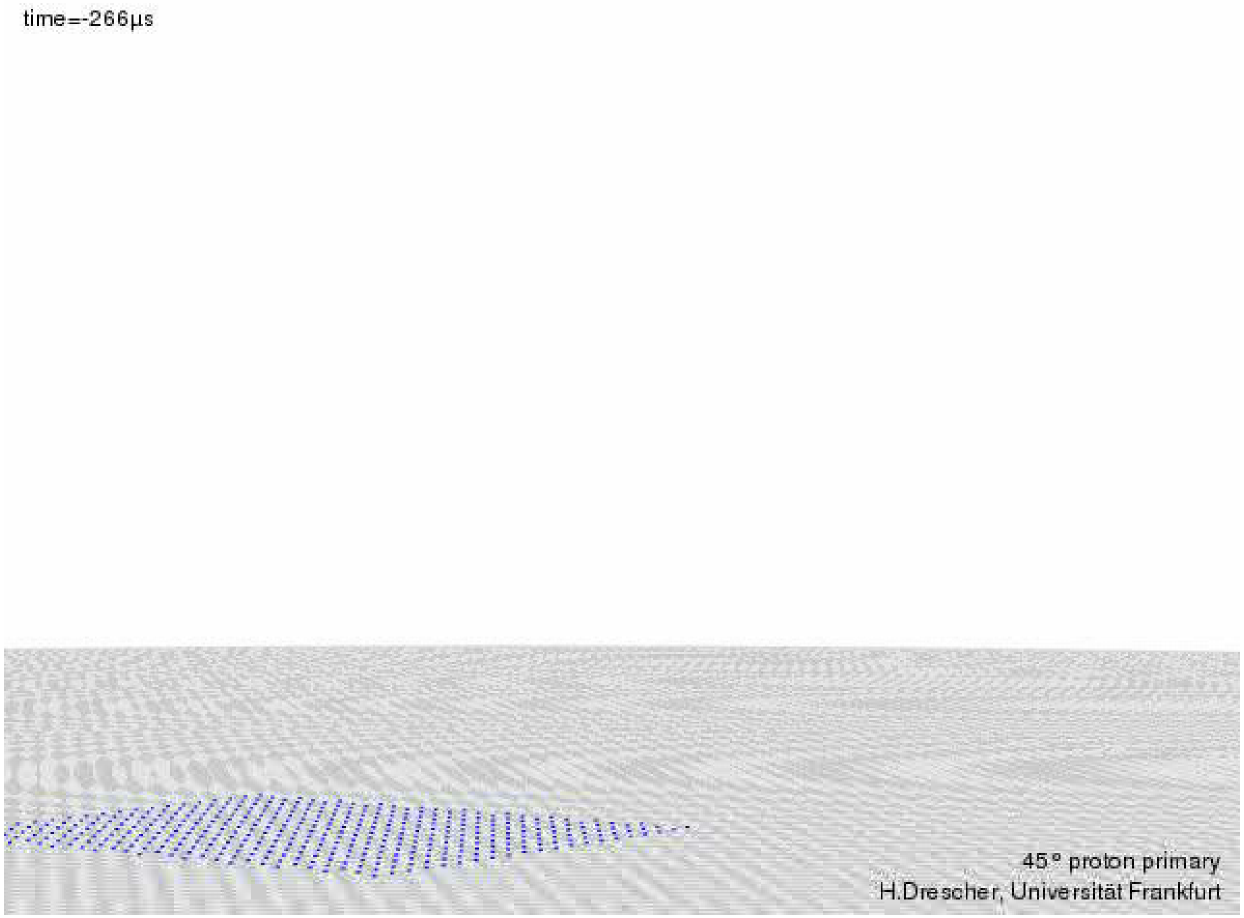
➔ *If* you see very high energy CR, *then* sources must be local – in our galaxy (but such sources are unknown)!



SN 1006, composite image

Cosmic ray interactions

• Cosmic ray interactions in atmosphere create extensive *air showers*

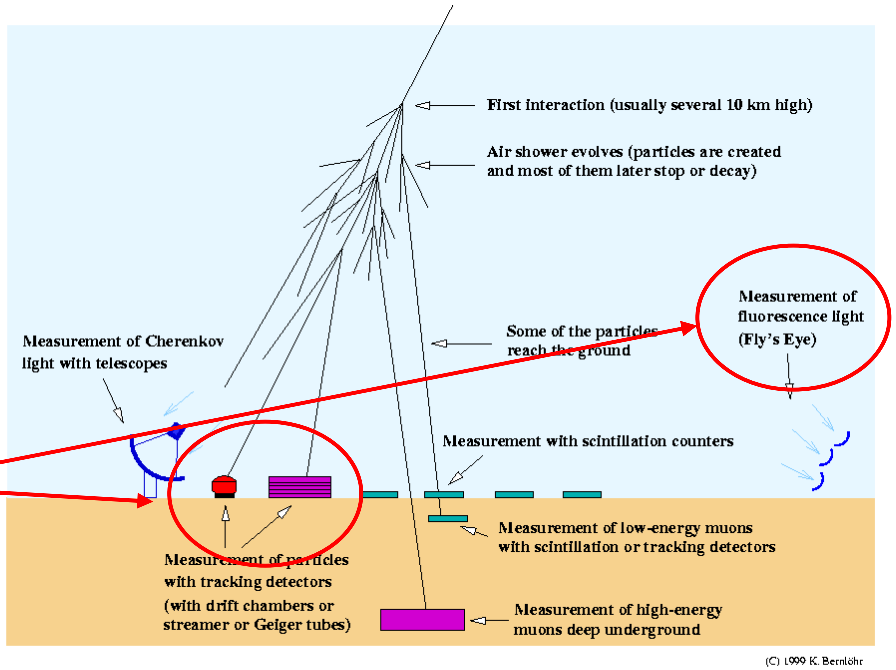


Highest energy cosmic rays

- To study fluxes of 1 particle/km^2/yr requires:
    - many years or
    - many km^2 !

- Largest experiments cover an area approximately as large as island of Montreal !

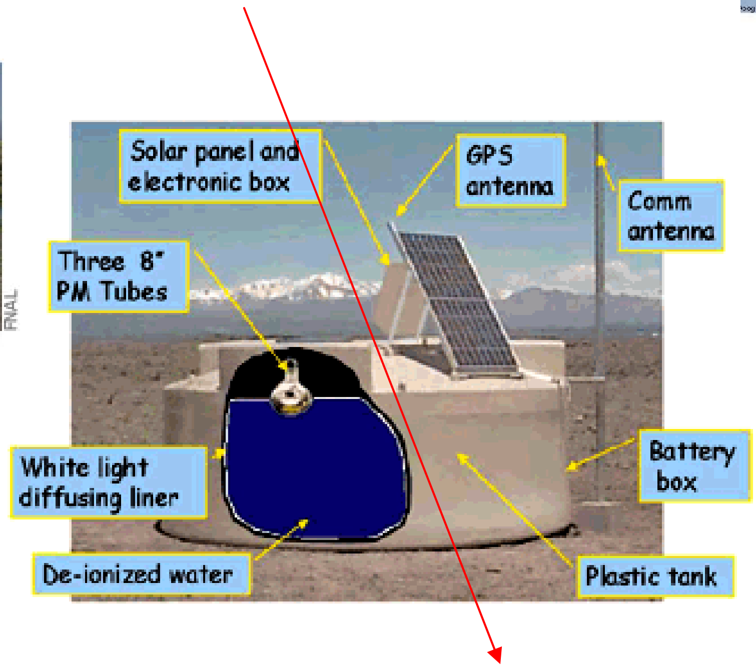
measure particles or fluorescence light that gets to ground level

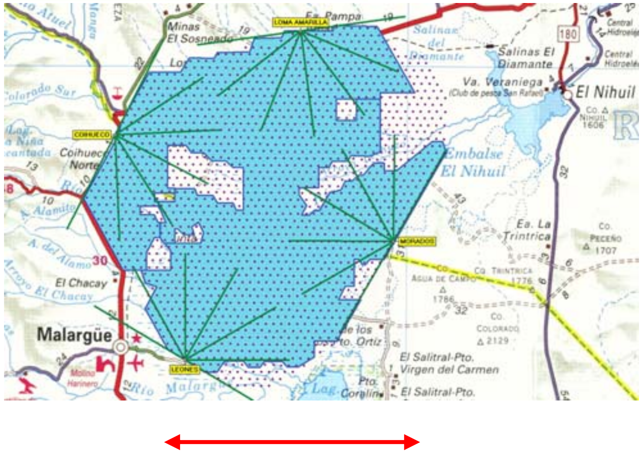


Pierre Auger Observatory – the largest cosmic ray detector

• uses charged particle interactions in water tanks to study high energy cosmic ray showers
• second part of detector images fluorescence light from upper atmosphere (like a 4W blue light bulb moving at the speed of light!)

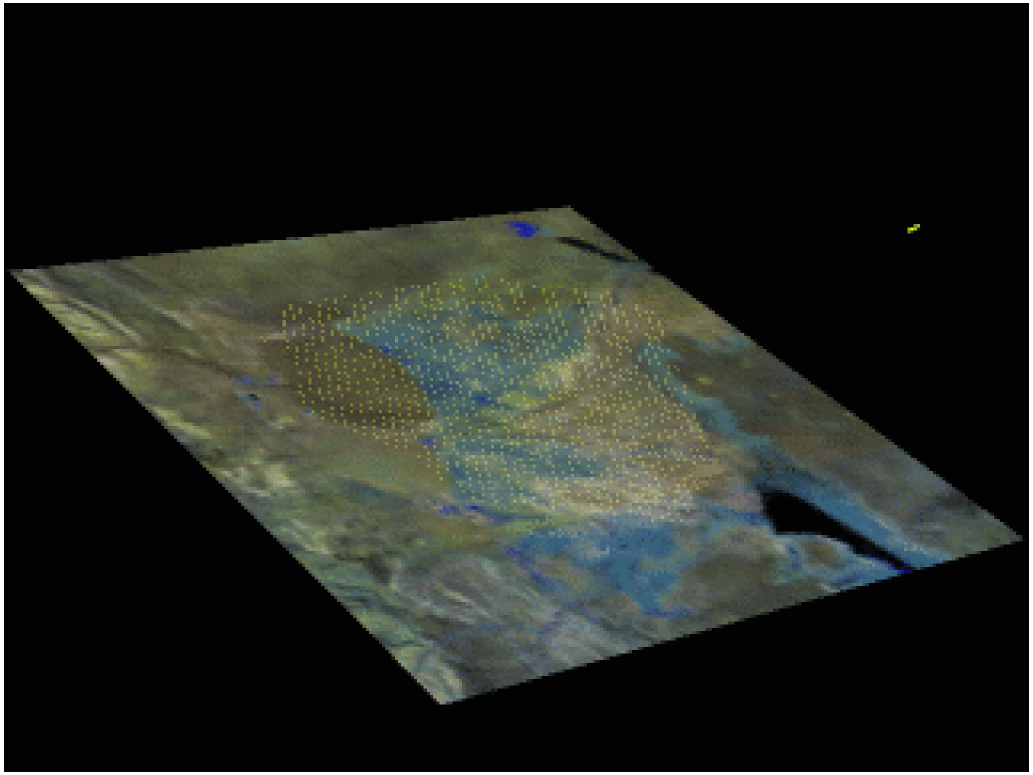
One of 1600 Auger water tanks





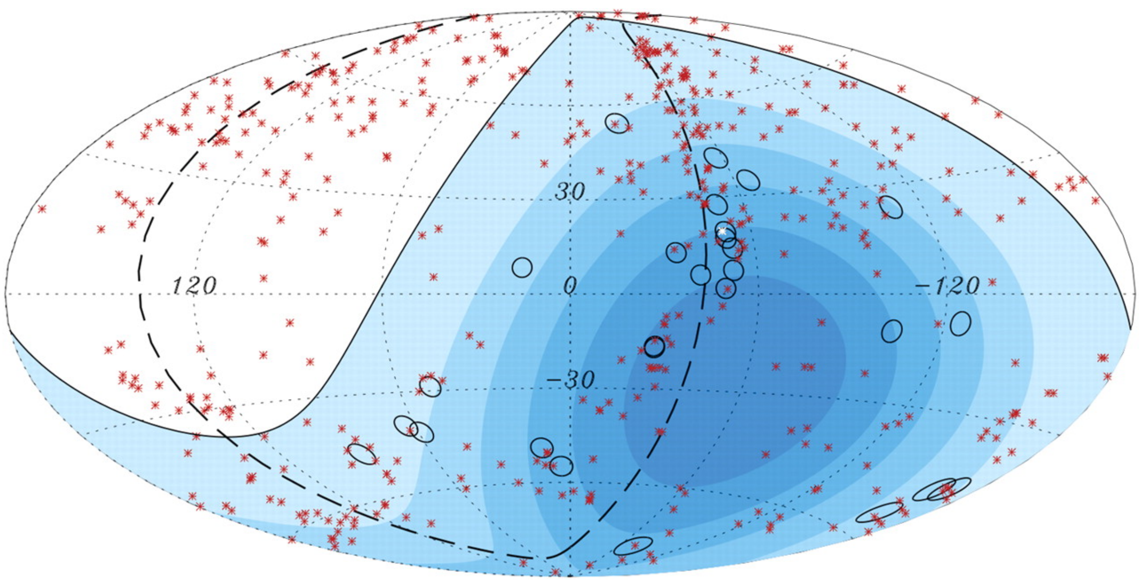
~50 km

Auger events



Auger highest energy events

- cutoff in spectrum (ie, missing very very high energy events) seems to be confirmed
- tantalizing evidence that highest energy events might be coming from a special class of course: <u>active galactic nuclei</u>



O – highest energy Auger events
X – AGN

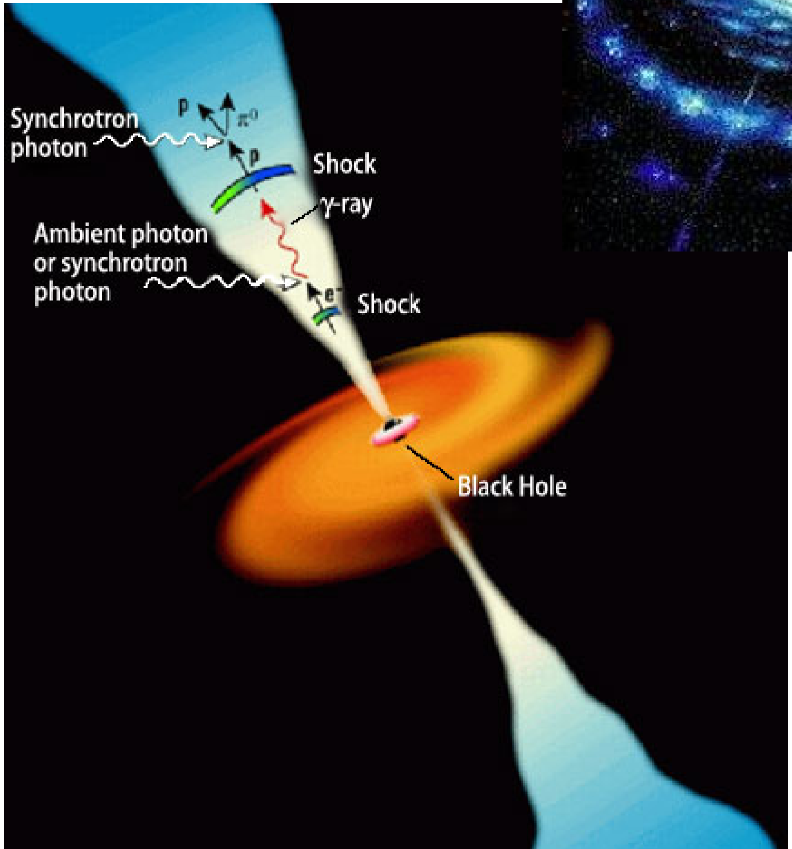
Active Galactic Nuclei

- Galaxies (ie, at cosmological distances) that are ‘driven’ by massive central black holes

- Believed to be accompanied by energetic outflows (“jets”)

- Nature and acceleration mechanism of jets uncertain

- If *protons* are being accelerated there, then we expect *neutrinos* too



Neutrinos

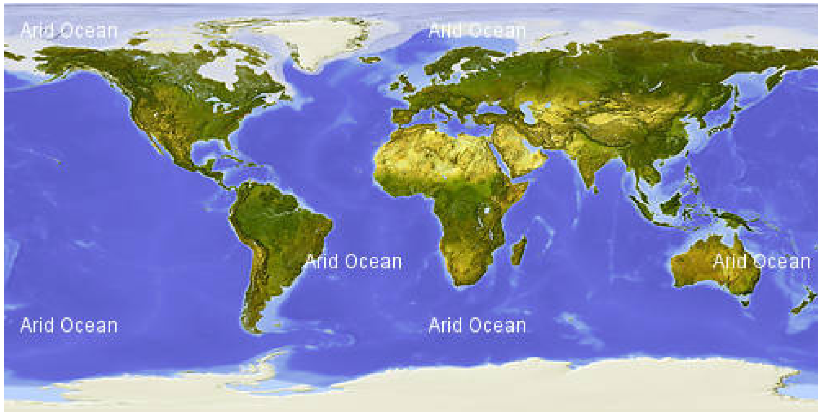
- Neutrinos (“little neutrons”) first proposed in 1930 by Pauli

- now known to be neutral, weakly interacting, with <u>very small mass</u> ← more later!

- like light and charged cosmic rays, their detection would give us more complementary information on the processes occurring in the cosmos

- small interaction probability means *large* (massive) detectors are necessary – megatons!

- Cheapest bulk materials: water and ice!



Neutrino detection

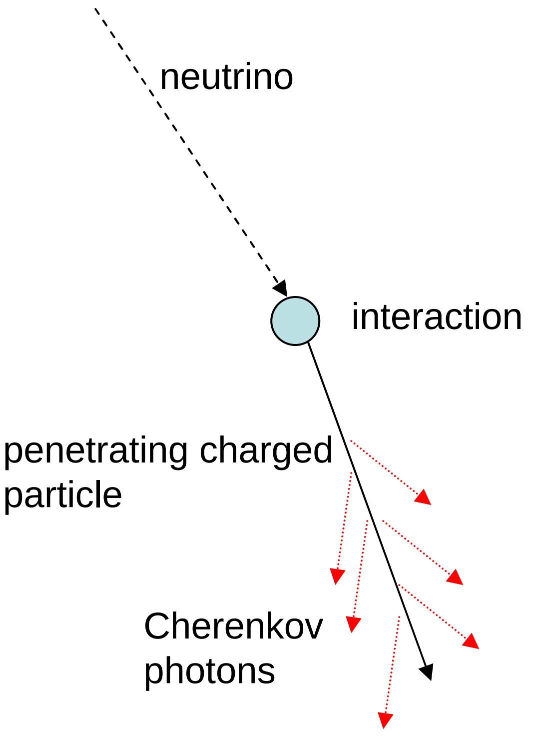
- Neutrino interactions with matter result in energetic charged particles – moving faster than the (local) speed of light!

- Charged particle emits Cherenkov light – the analog of a sonic boom

- In clear ice and water, Cherenkov photons propogate and can be detected

- Need to instrument large volumes, shielded from cosmic ray interactions: use ice caps and the deep ocean

- For added background rejection, use *upward-going* neutrinos



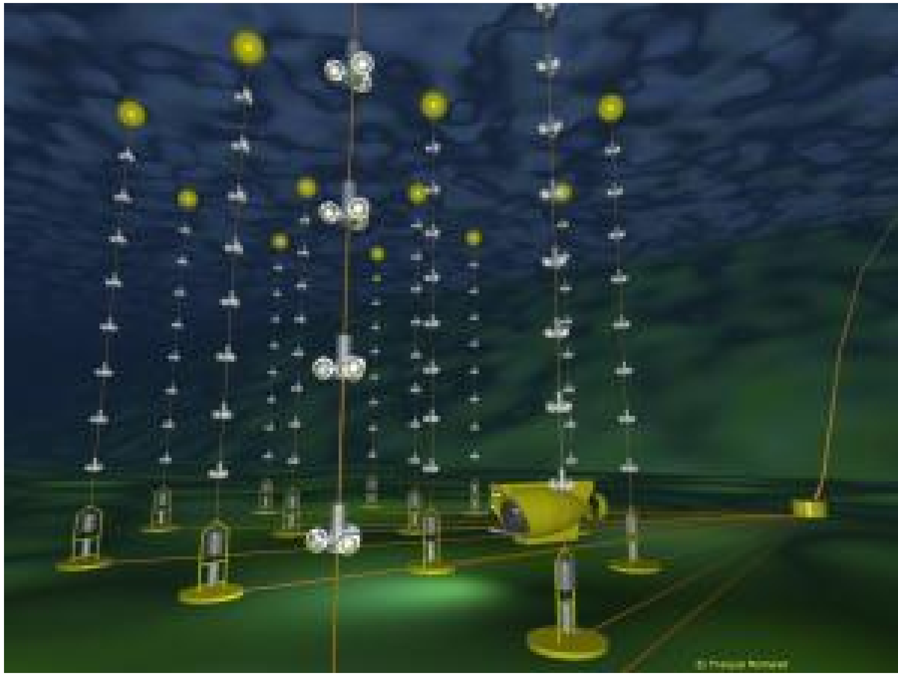
Neutrino detectors – ANTARES

• 2500 m deep off the French Mediterranean coast

• composed of “strings” of photomultiplier tubes (ultrasensitive light detectors)

• detection of Cherenkov light allows energy and arrival direction of neutrino to be reconstructed

• unusual experimental challenges include biolumineSence (remember ‘Finding Nemo’?)

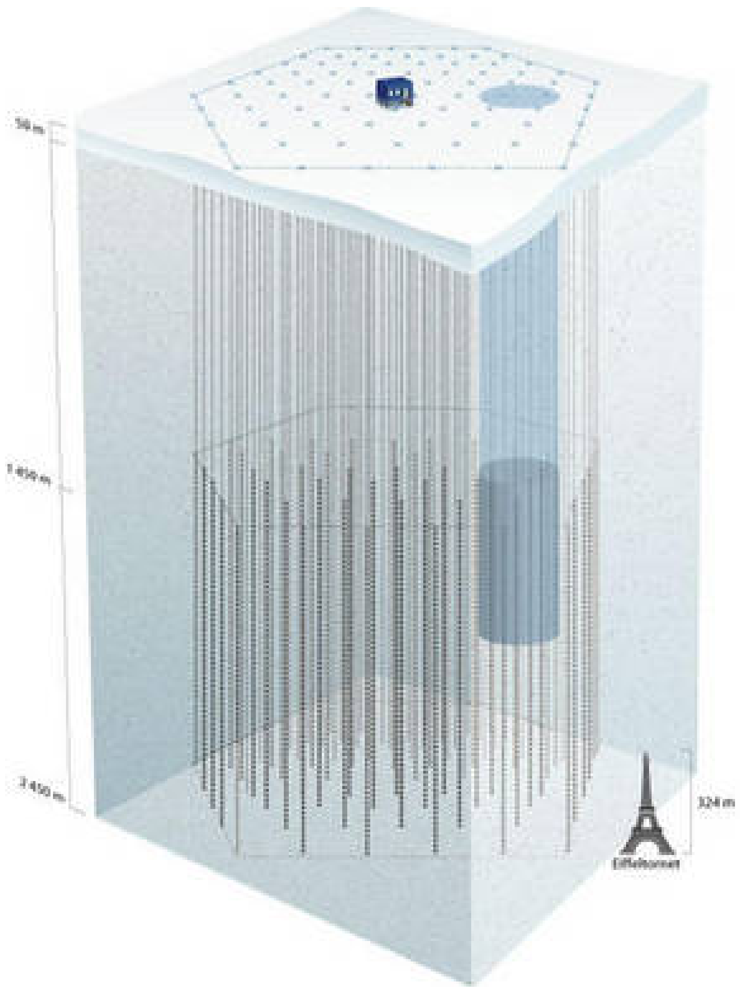


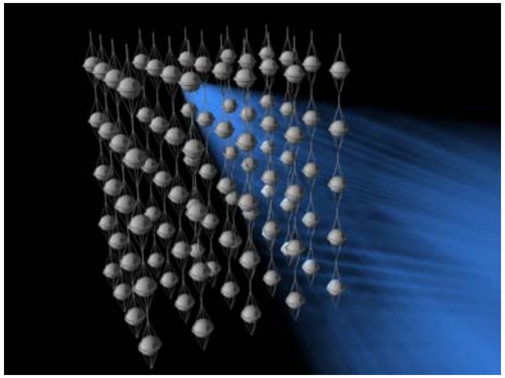
Ice works too! IceCube:

- 2500 m under the surface of the Antarctic icesheet, at the South Pole!

- Strings of phototubes drilled (and then frozen) into ice

- Detection method same as for undersea detectors

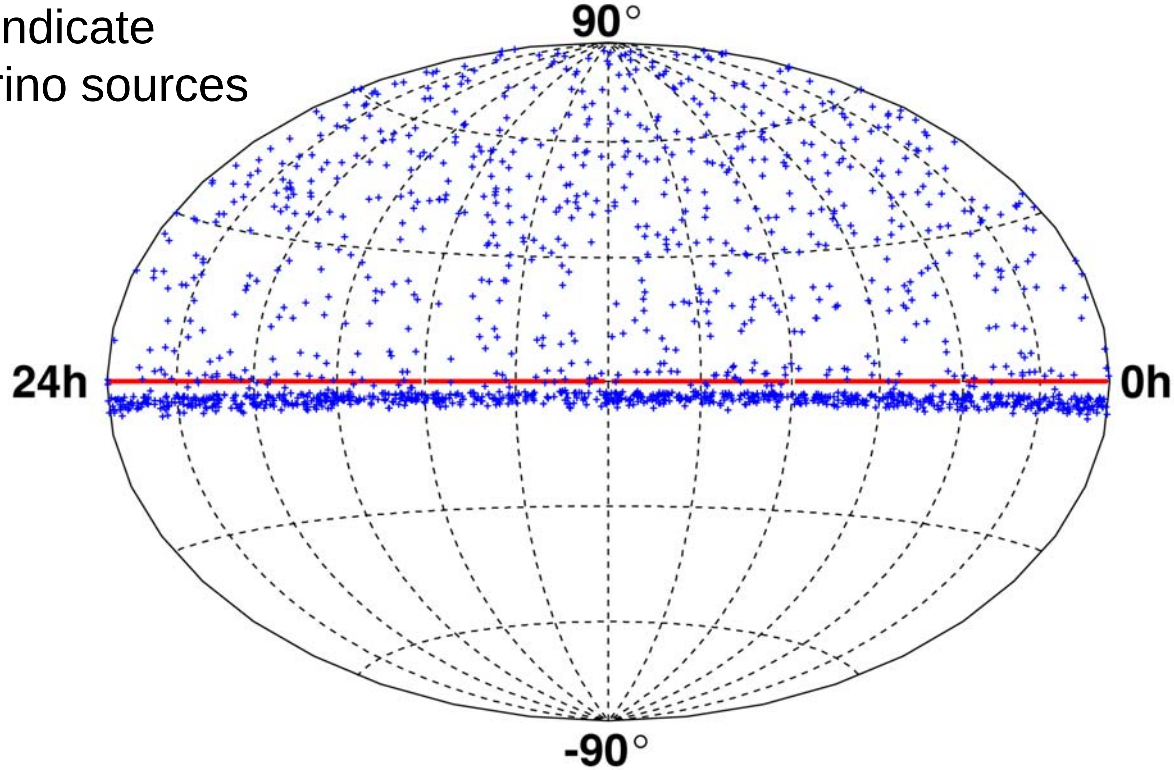




Neutrino ‘sky map’

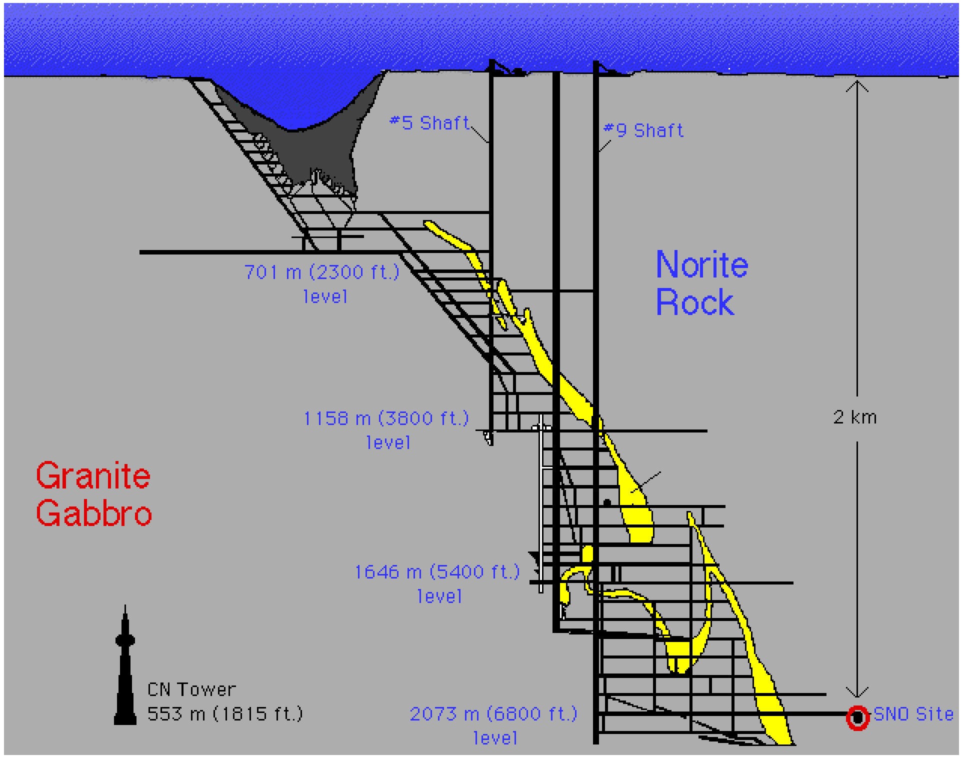
- Location at the South Pole gives a northern hemisphere map

- No obvious concentrations of events (yet!) that would indicate strong high-energy neutrino sources



Neutrinos closer to home

- *Solar* neutrinos (much lower energy) have been detected and studied for decades
- Requires low-background facility – in practice, deep underground
- Pre-eminent detector in 2000's was SNO – the Sudbury Neutrino Observatory
- 2000 m underground in Vale Inco's Creighton mine

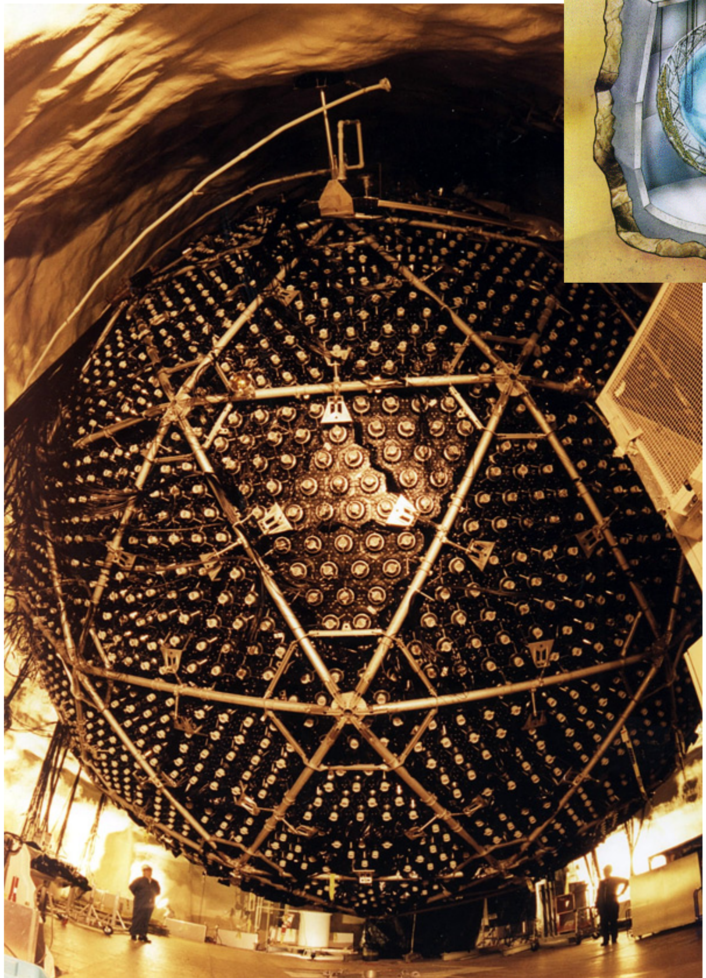


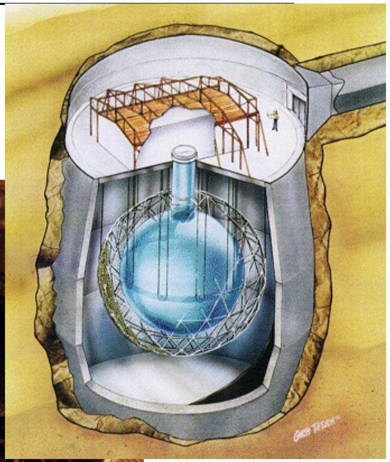
SNO

• Like Icecube and Antares, used the Cherenkov light from neutrino-water interactions

• Used heavy water (D_2O) from CANDU program to enhance neutrino interactions

• Definitively proved that neutrinos *oscillate* (change their type) on their way from the Sun to us – and thus, have mass!

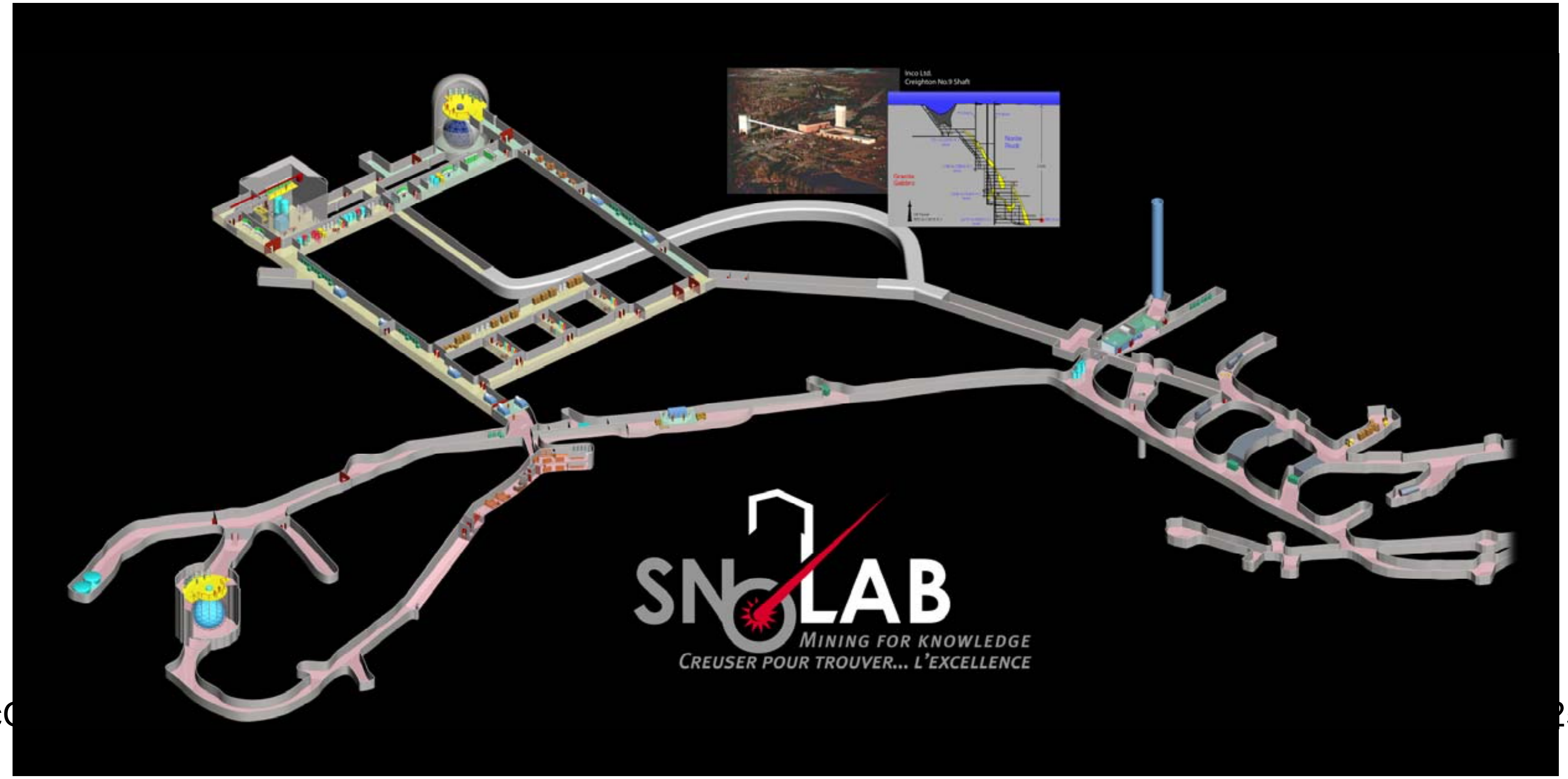




SNOLab

- SNO is now dismantled, but new (general purpose) lab has been constructed to take advantage of deep, clean conditions

- Will be equipped with major new *dark matter* detectors



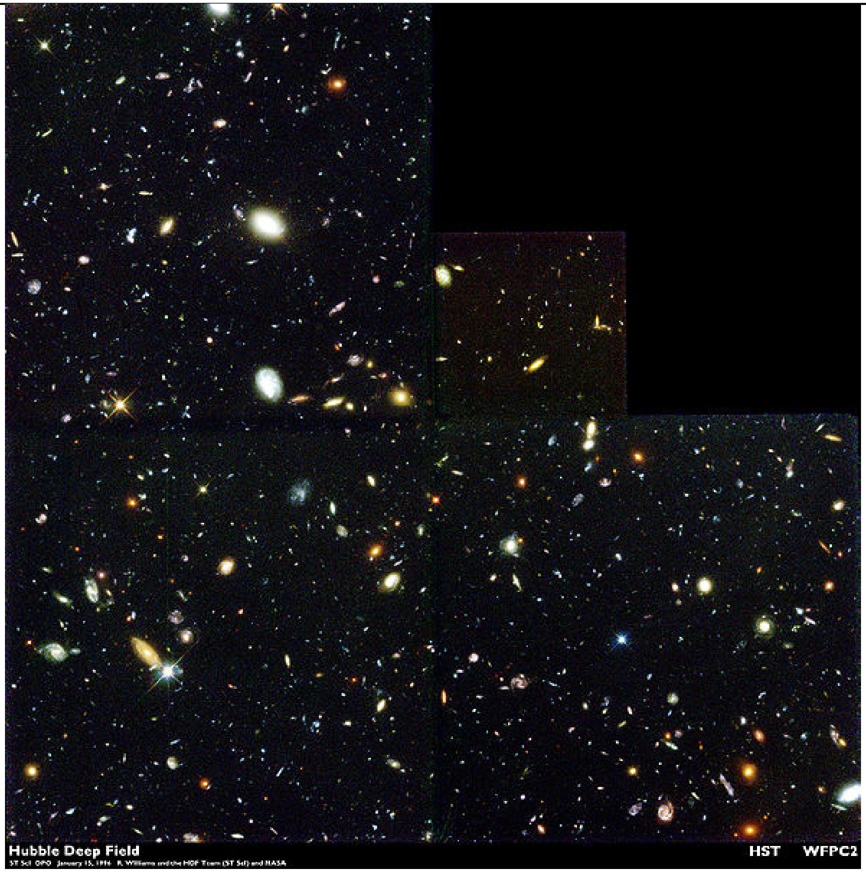
Why dark matter?

we are here!

• Come back to our galaxy, and study its motion to measure its mass

• We find that there is more mass than we'd expect from observed light – way more!

The big (ie, small) picture:

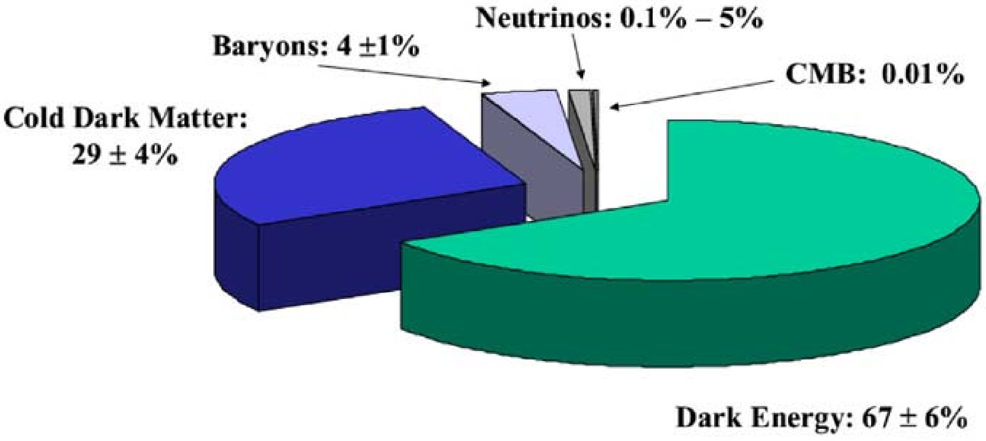


Hubble Deep Field: angular size: 2.5’’ (a dime at 10 km)

“billions and billions of galaxies…”

- Galaxies, galaxy cluster, superclusters: The bigger the scale, the worse the problem !

The even bigger picture:

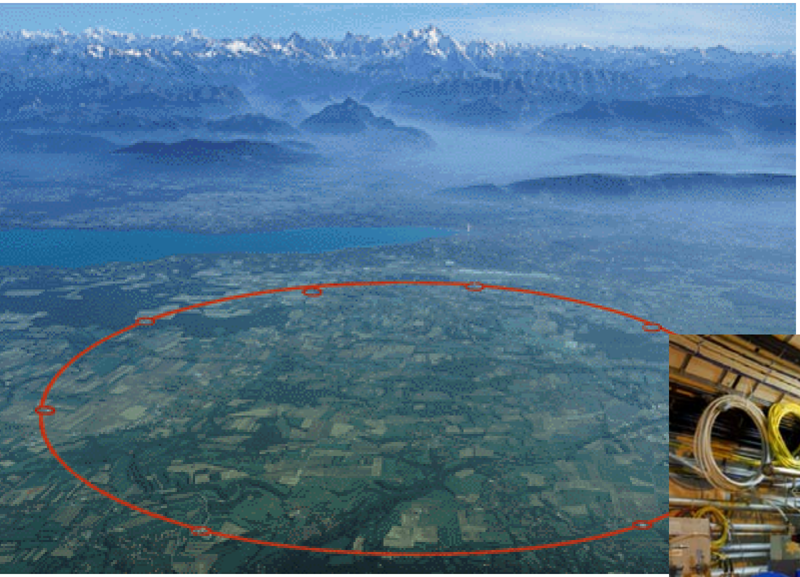


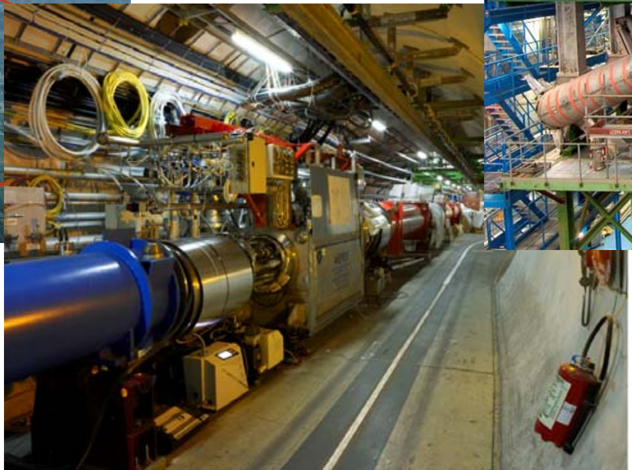
The stuff we see is only ~5% of the energy content of the Universe!
“Dark matter” is another 30%
“Dark energy” is nearly 70%

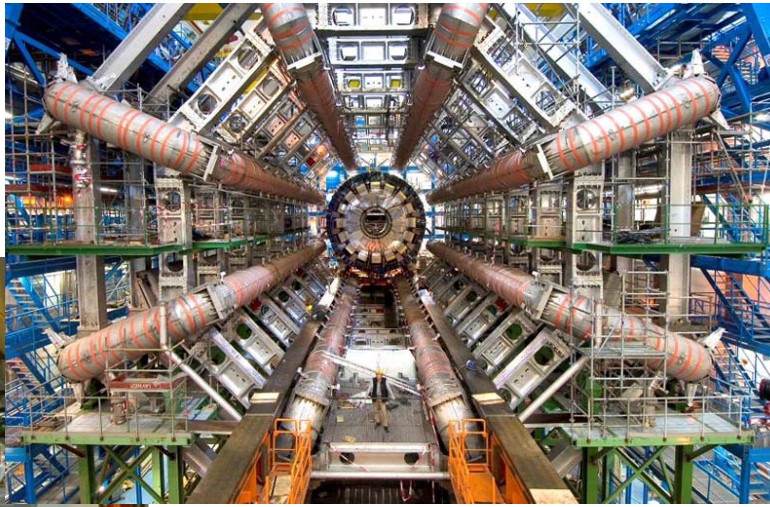
SNOLab and accelerators will do dark-matter *astronomy*

- SNOLab and other underground labs may detect dark matter particles in the next decade

- CERN's *Large Hadron Collider* could produce it in the lab on the same time scale







Conclusions

- Optical astronomy has made dramatic progress in 400 years since Galileo's Siderius Nuncius; non-optical wavelengths are more recent and give complementary information

- Other messengers can be studied – their information too is complementary

- "Telescopes" for these other messengers lead to "astronomy" on isolated prairies, in Antarctic ice, in the deep sea, deep underground… and at particle accelerators!