Instruments, Chemistry, Minerals, and the Periodic Table

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Space Objects and their Composition

A crater on asteroid Lutetia: showing a landslide

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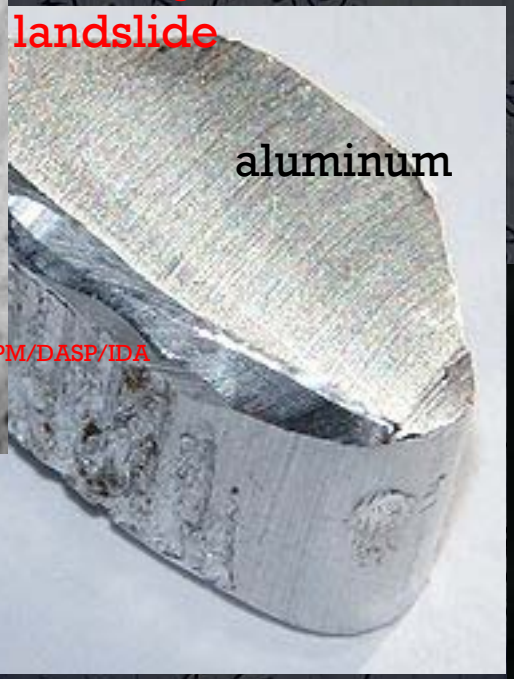
sulfur

Images courtesy: Windows to the Universe.



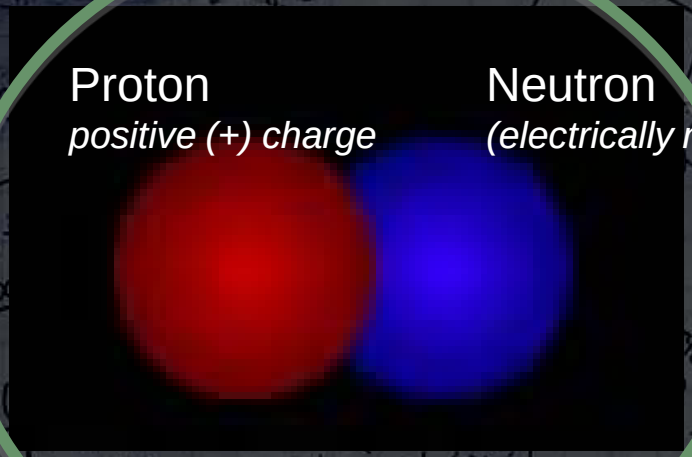
aluminum

Water – in 3 forms

Picture from: Ute Kaden/PolarTREC

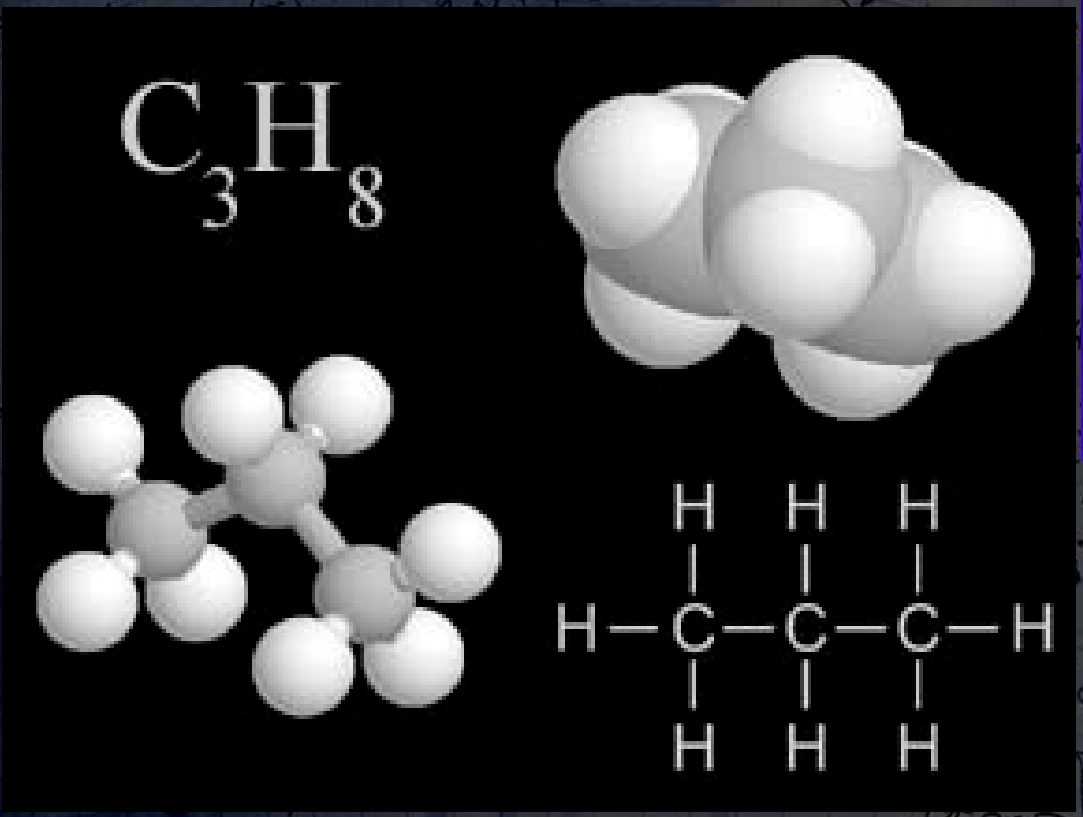
Quartz – source of Si

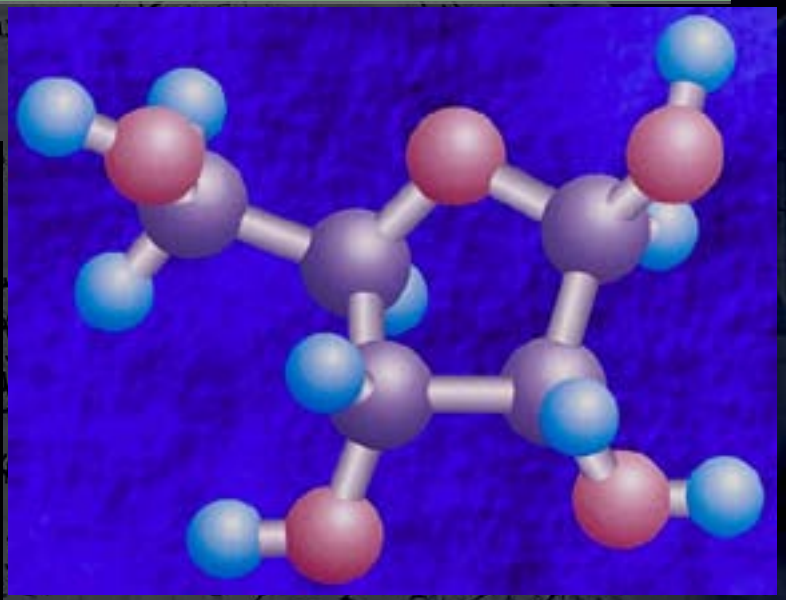
Atom



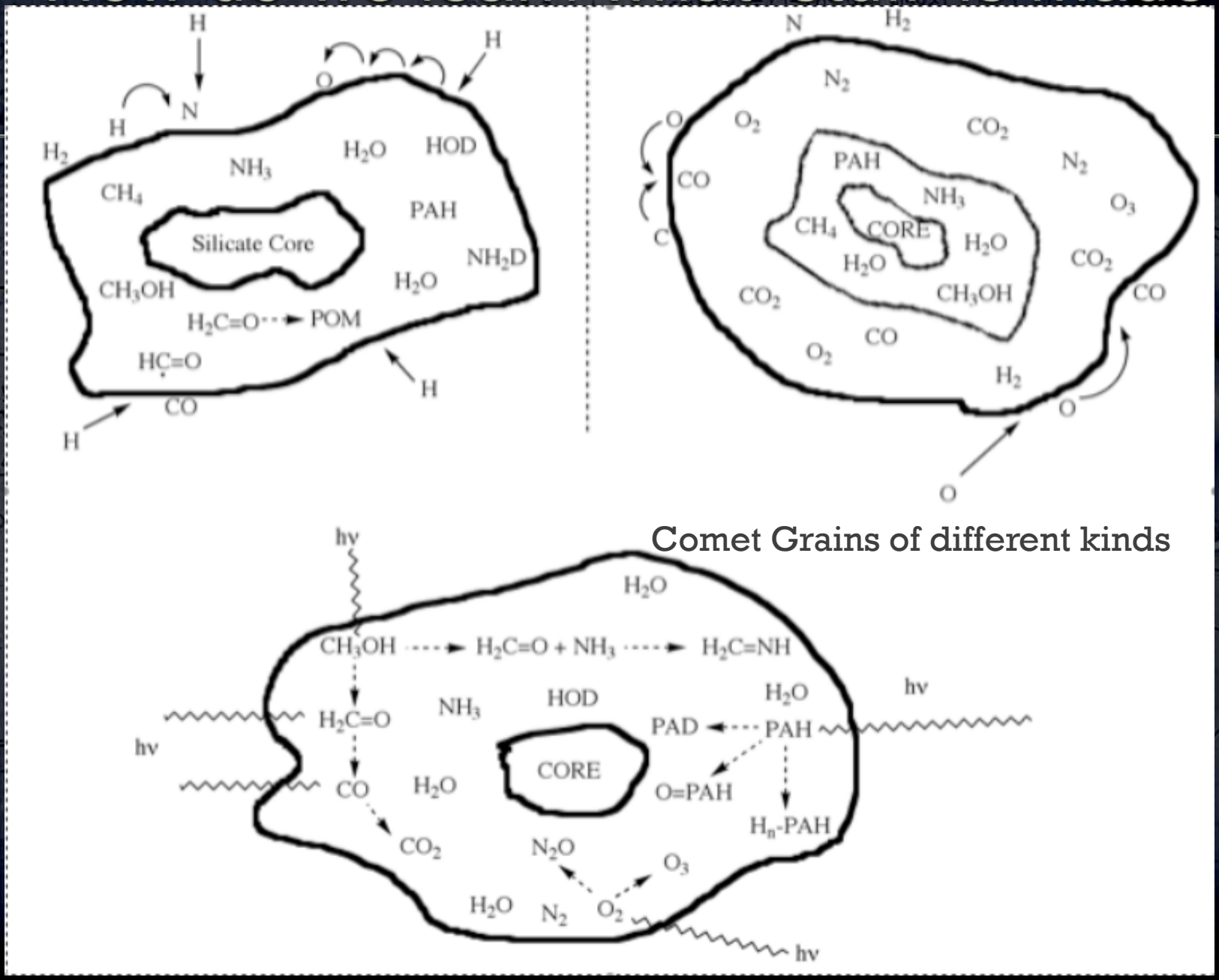
Electron
negative (-) charge

Molecules

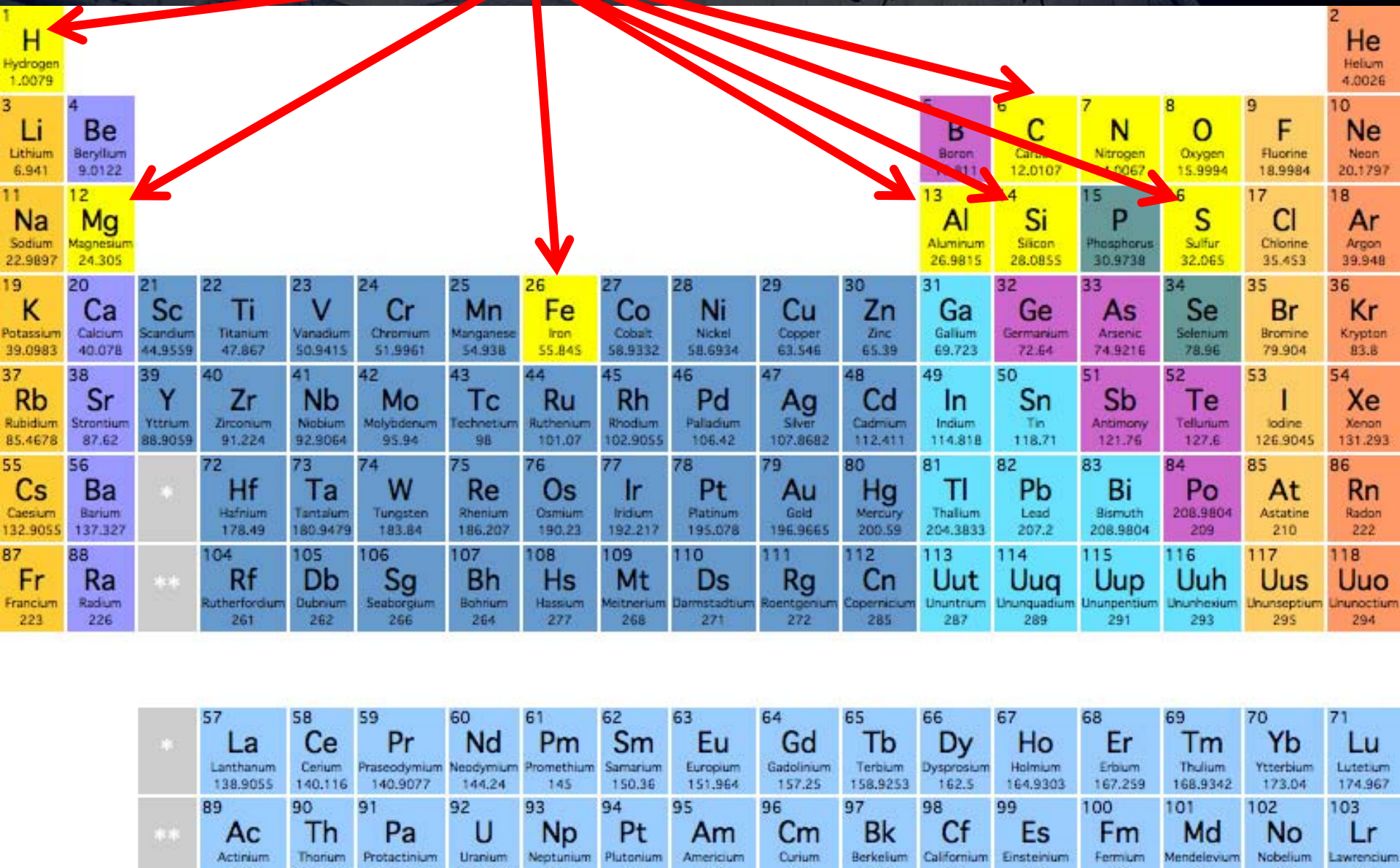




How do we learn what 'stuff' is made of?



In planetary science, 9 elements constitute the building blocks (in yellow)

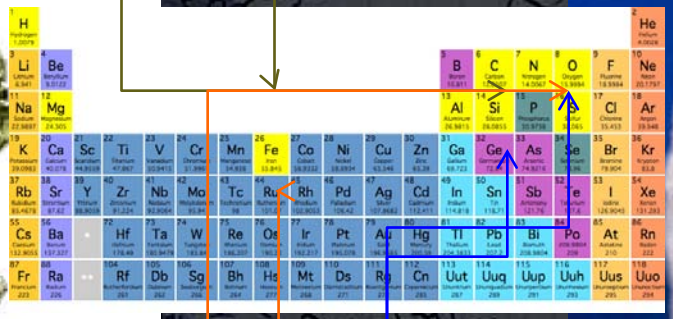


Rocks are made of minerals are made of molecules and elements

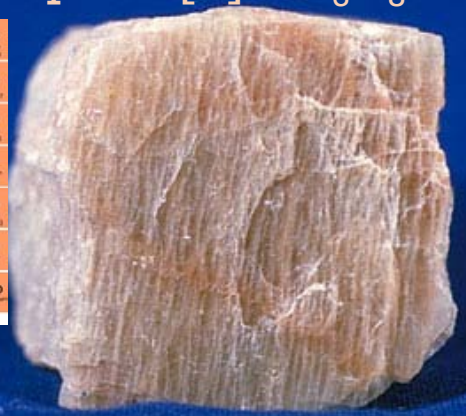
Fools gold

Pyrite = FeS_2

Iron sulfide



Feldspar = $[X]AlSi_3O_8$



Earth's crust: most abundant

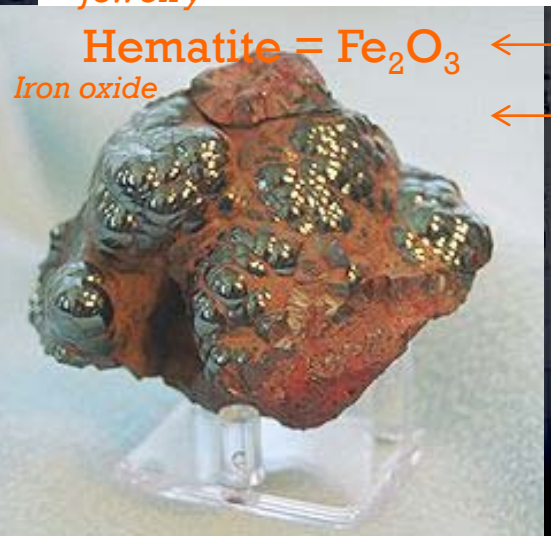
Quartz = SiO_2

Earth's crust: 2nd most abundant

jewelry

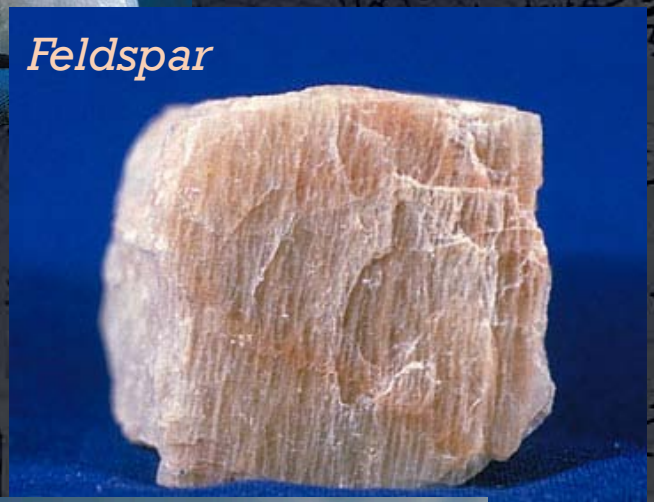
Hematite = Fe_2O_3

Iron oxide



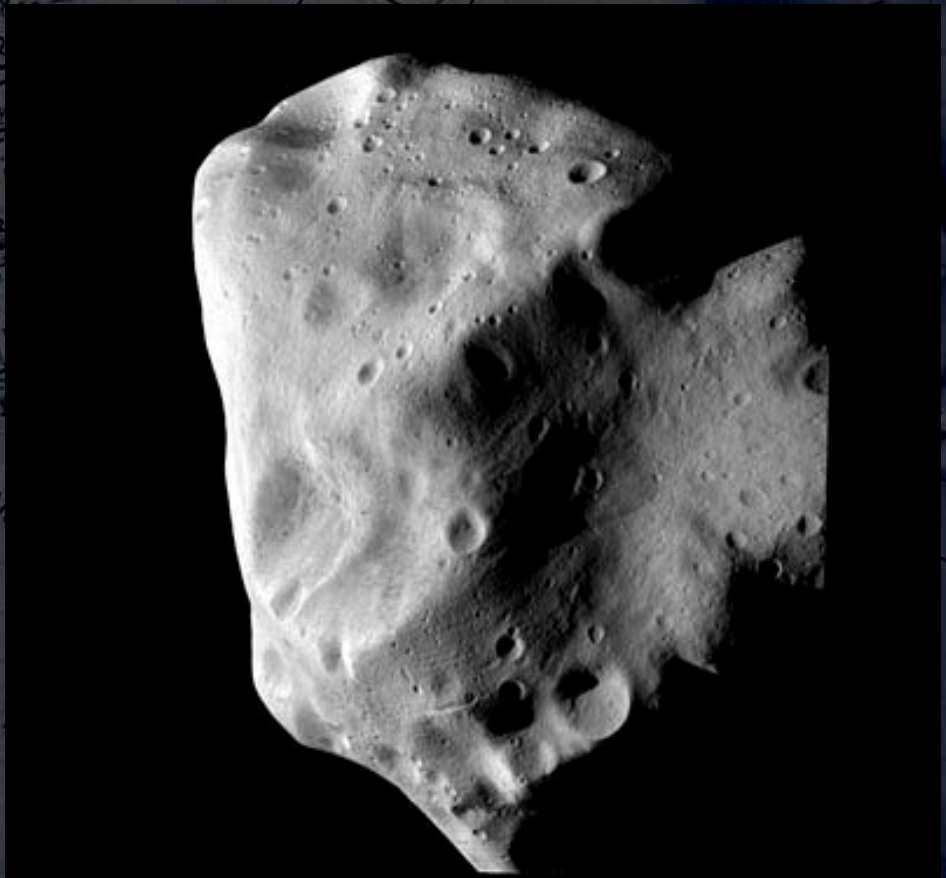
Granite!

Is made of quartz, feldspar, mica + more



Asteroid Lutetia: what's it made of?

- We can't go there in person, so we have to devise experiments, and instruments, to do the tests for us.



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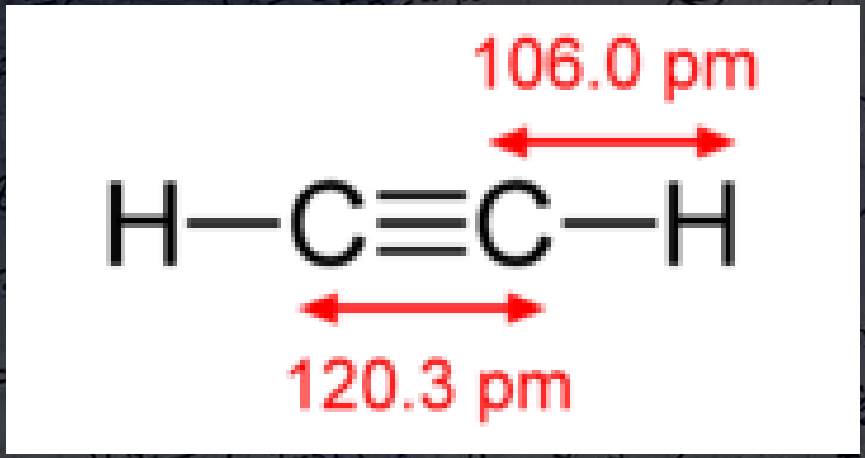
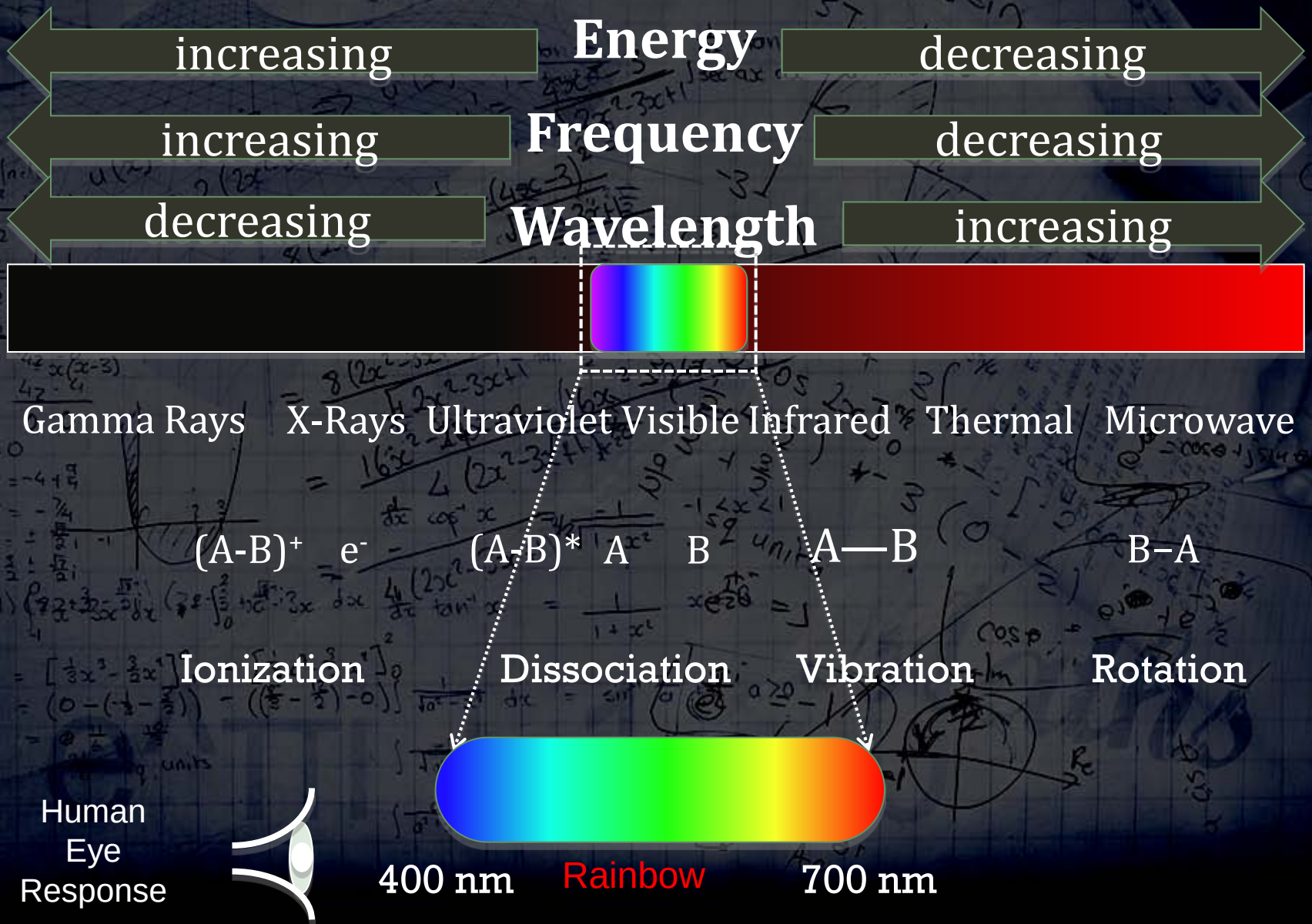
Turns out, 'stuff' gives off a signal



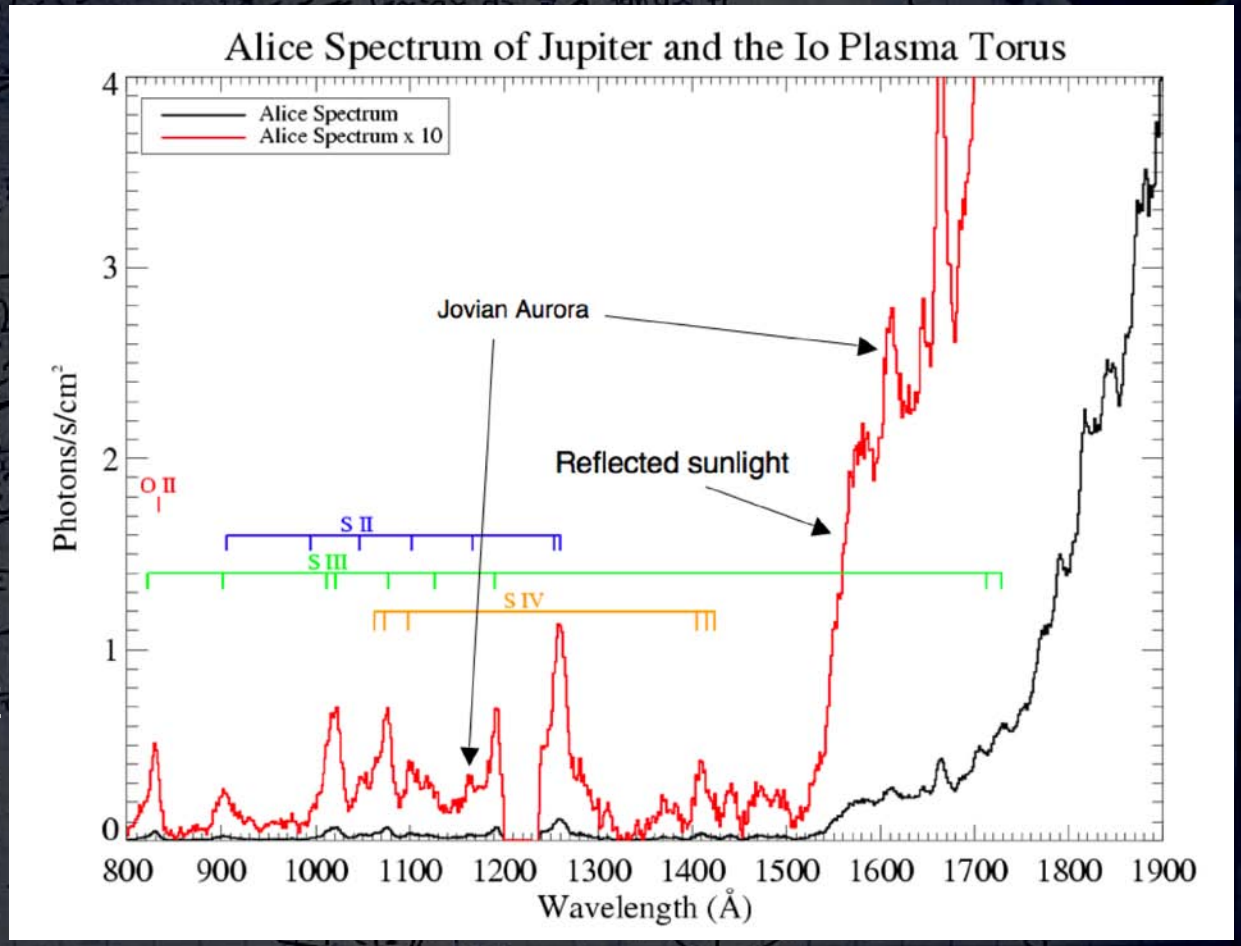
This molecule (acetylene) will vibrate differently along the different bonds

Electromagnetic Spectrum (Light)



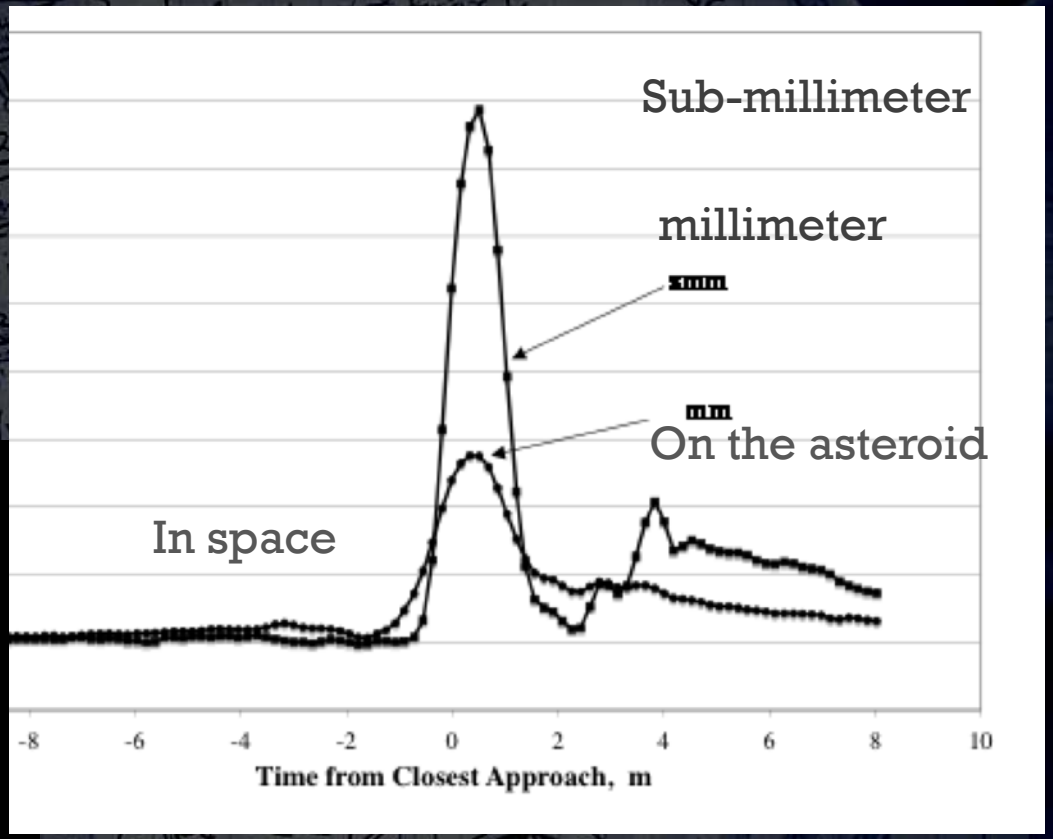
(A) Spectrometers (ultraviolet shown here)

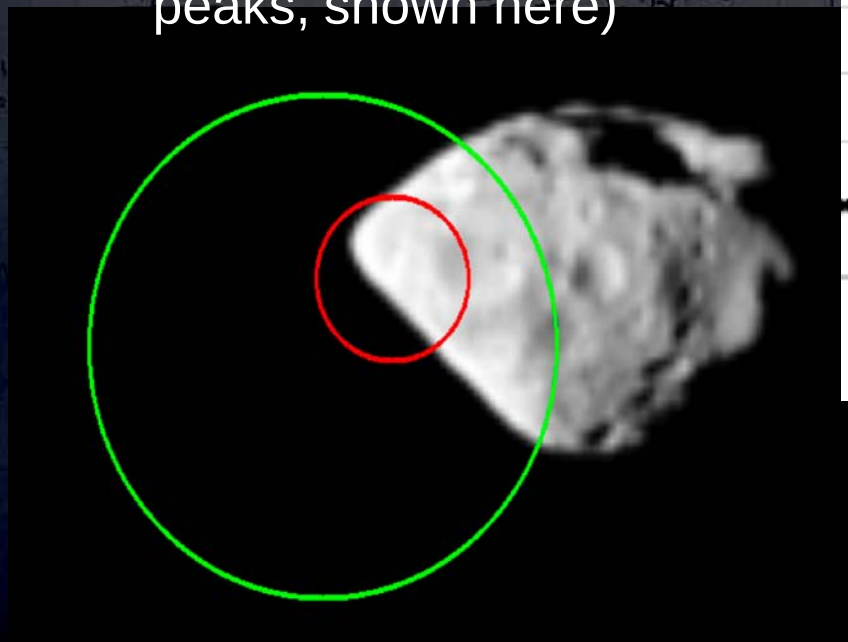
- When atoms and molecules emit (characteristic electro-magnetic) radiation in the ultra-violet, those emissions are detected by a UV spectrometer.
- The figure at the right shows detected molecule "transitions"



Spectrometers in Microwave Wavelengths

- What are these wiggly lines?
  - Atoms and molecules emit radiation at very specific microwave frequencies, which appear as characteristic "lines" (or peaks, shown here)





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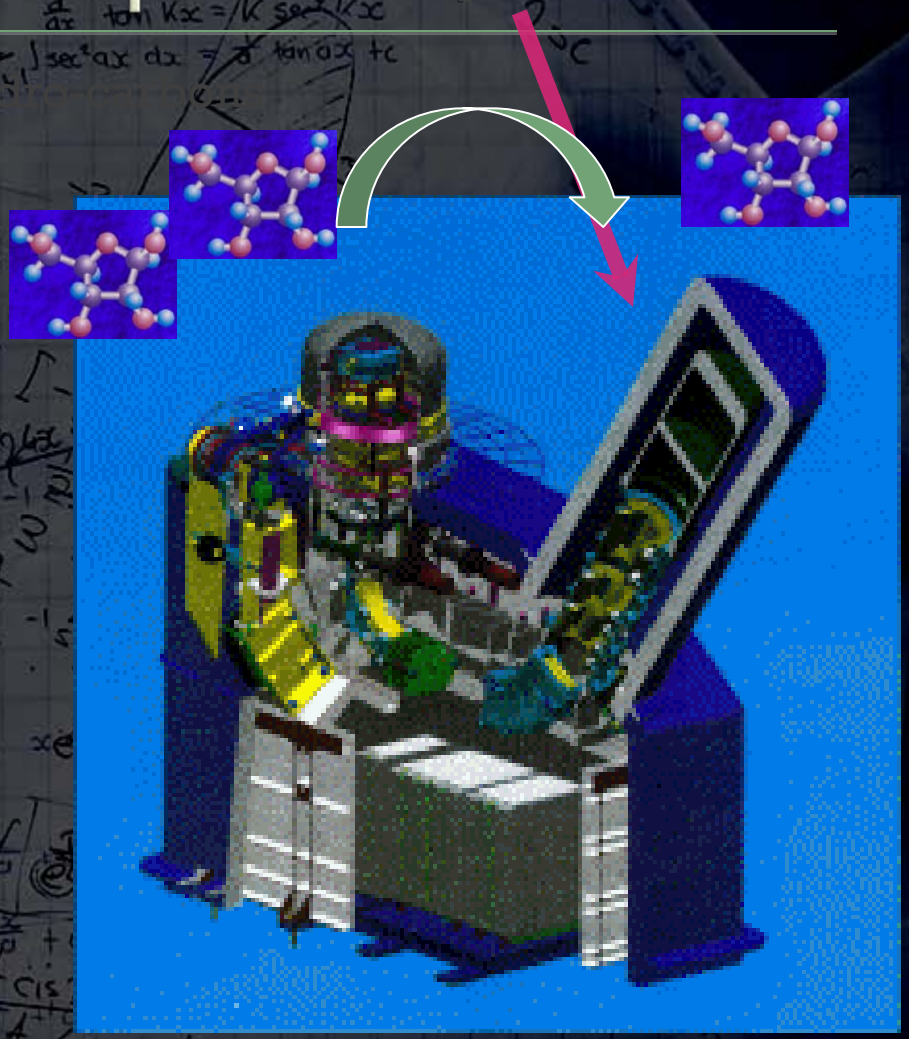
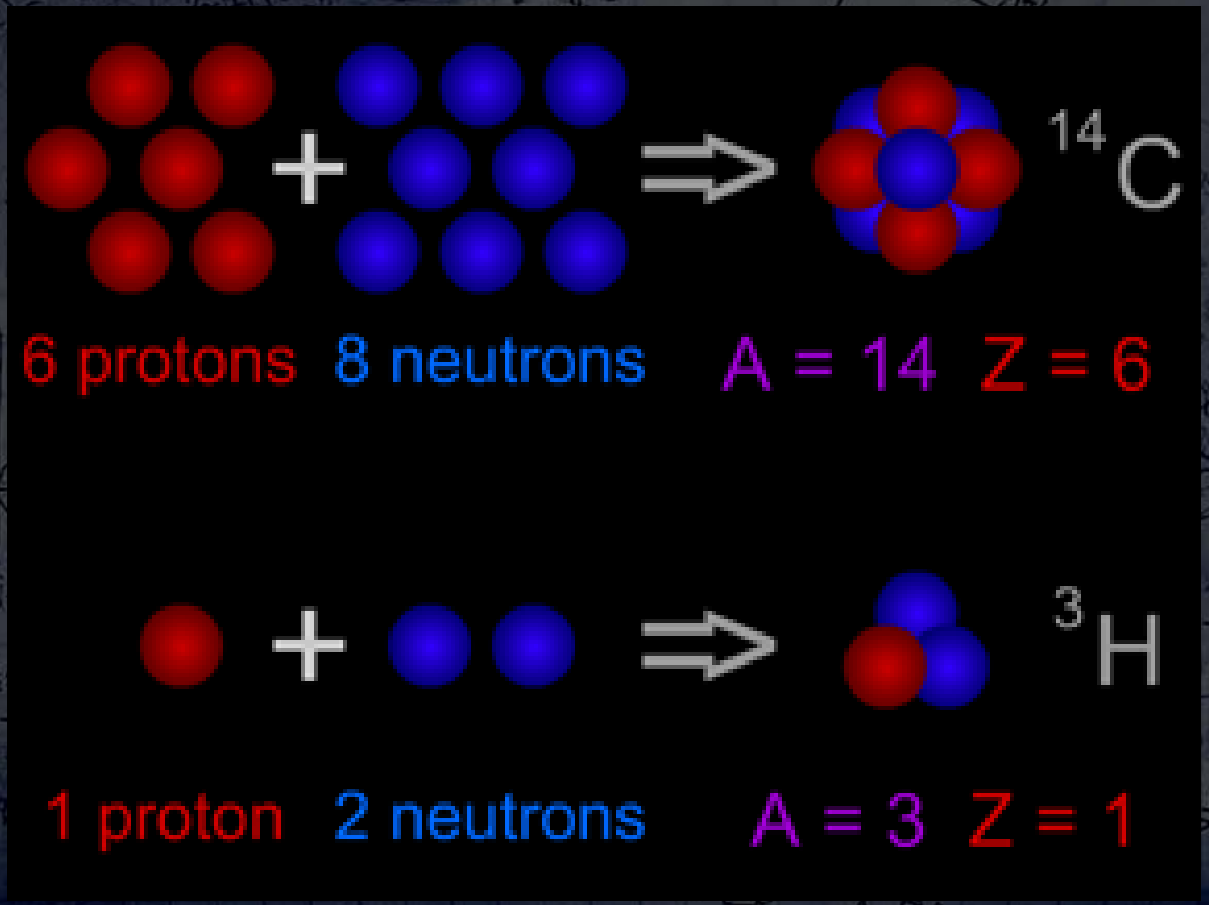
(B) Mass Spectrometers

- What do we learn with Mass Spectrometers?
  - Particles ‘go in’ and hit the target.
  - Kind of like putting different flavors of candy in your mouth – you can tell what you’ve got!
    - Gum ball vs m&m
  - atoms, isotopes, molecules, and heavy hydrocarbons (the size of small grains) up to 300 atomic mass units!
  - Example: ROSINA will measure isotopes such as C^{13}/C^{12} and N^{14}/N^{15} and Si^{28}/Si^{29} that tell us so much about the conditions under which comets (and our solar system) formed.



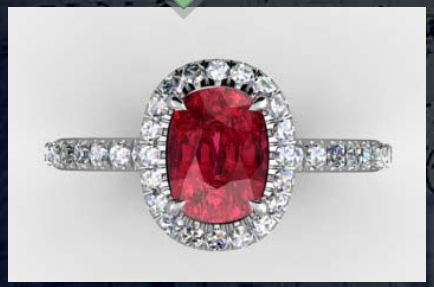
Isotopes



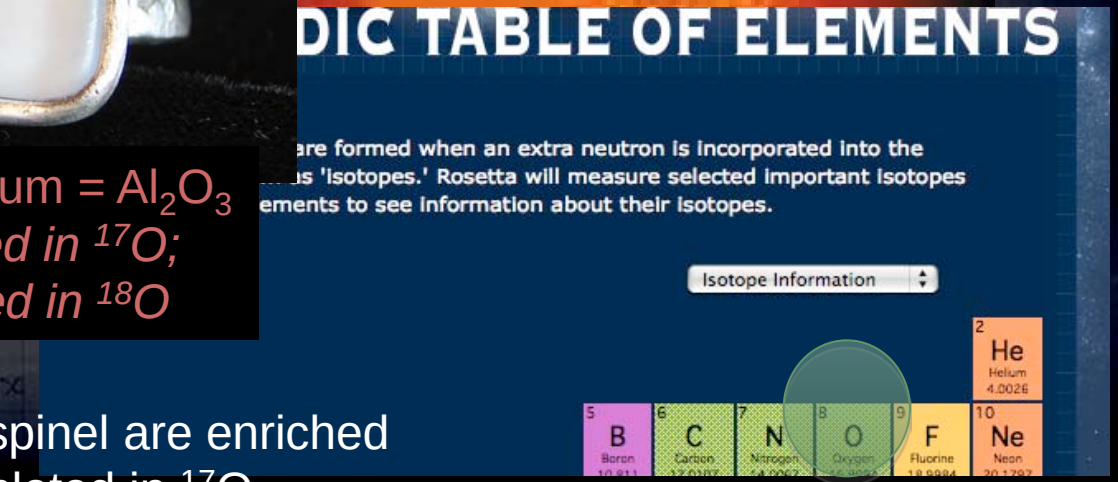
Oxygen Isotopes: ^{17}O, ^{18}O

Grains of Conundrum that formed near a red giant star are expected to be enriched in ^{17}O and depleted in ^{18}O

Corundum = Al_2O_3
Enriched in ^{17}O;
Depleted in ^{18}O



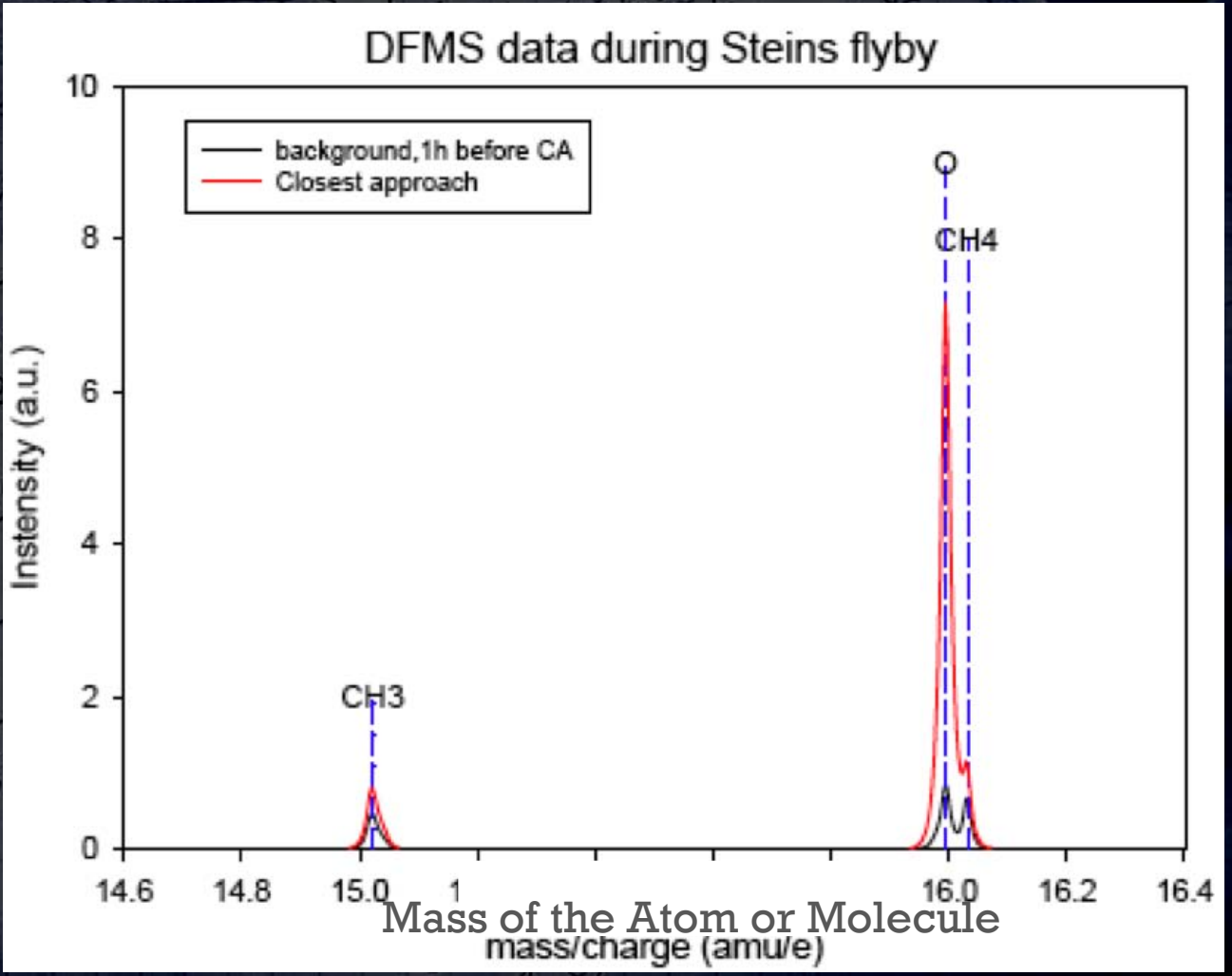
Spinel = $MgAl_2O_4$
Enriched in ^{18}O



But grains of spinel are enriched in ^{18}O and depleted in ^{17}O

Mass Spectrometer (Ion and Neutral Analysis)

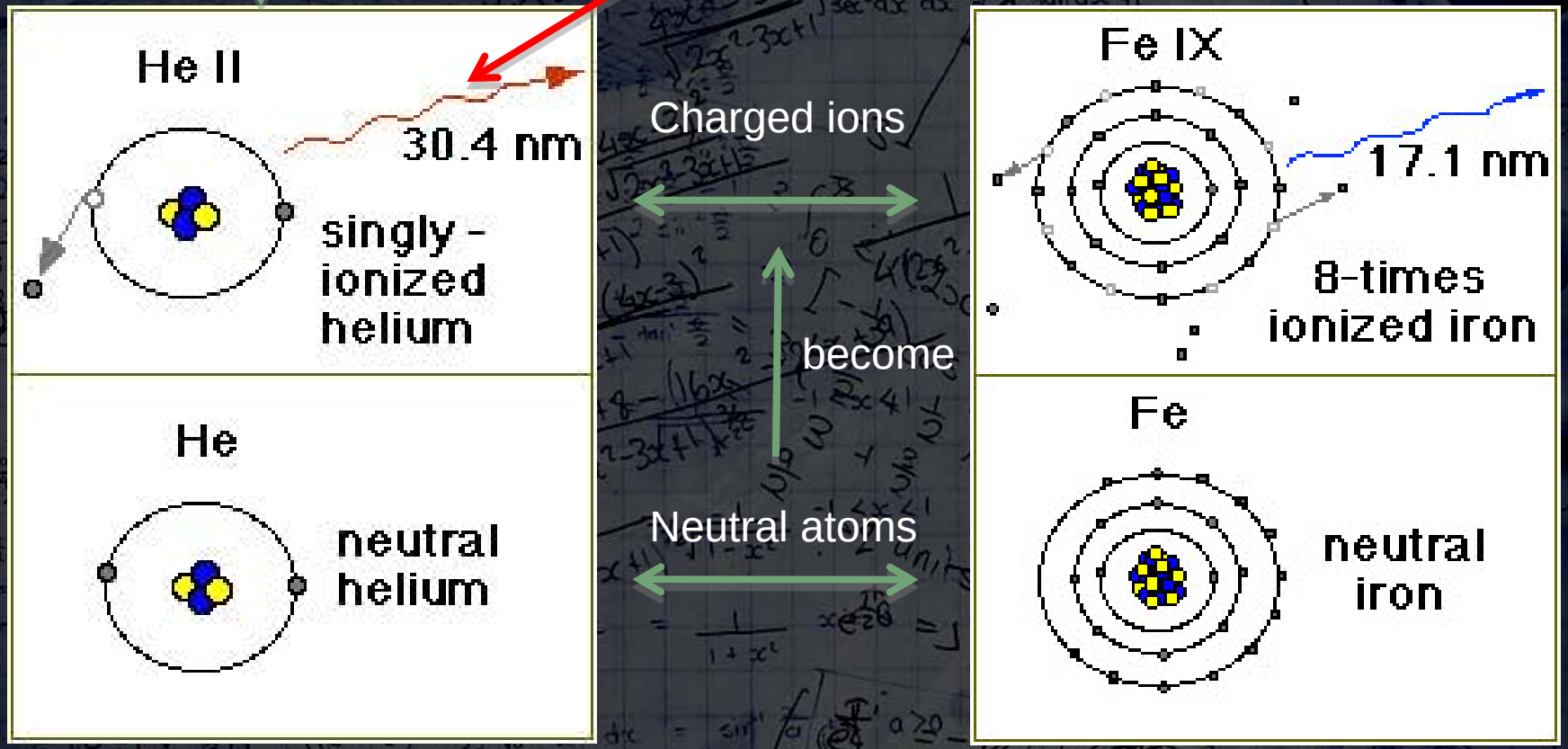
- What are these spikes?
  - When an ion or atom enters the aperture of the instrument it registers a 'hit' – examples shown here
  - Detections shown here are: methane, some carbon products and oxygen
  - O = 16
  - CH_3=12+3=15
  - CH_4=12+4=16



Ion

This atom is ionized 'one' time because one of its two electrons is taken away

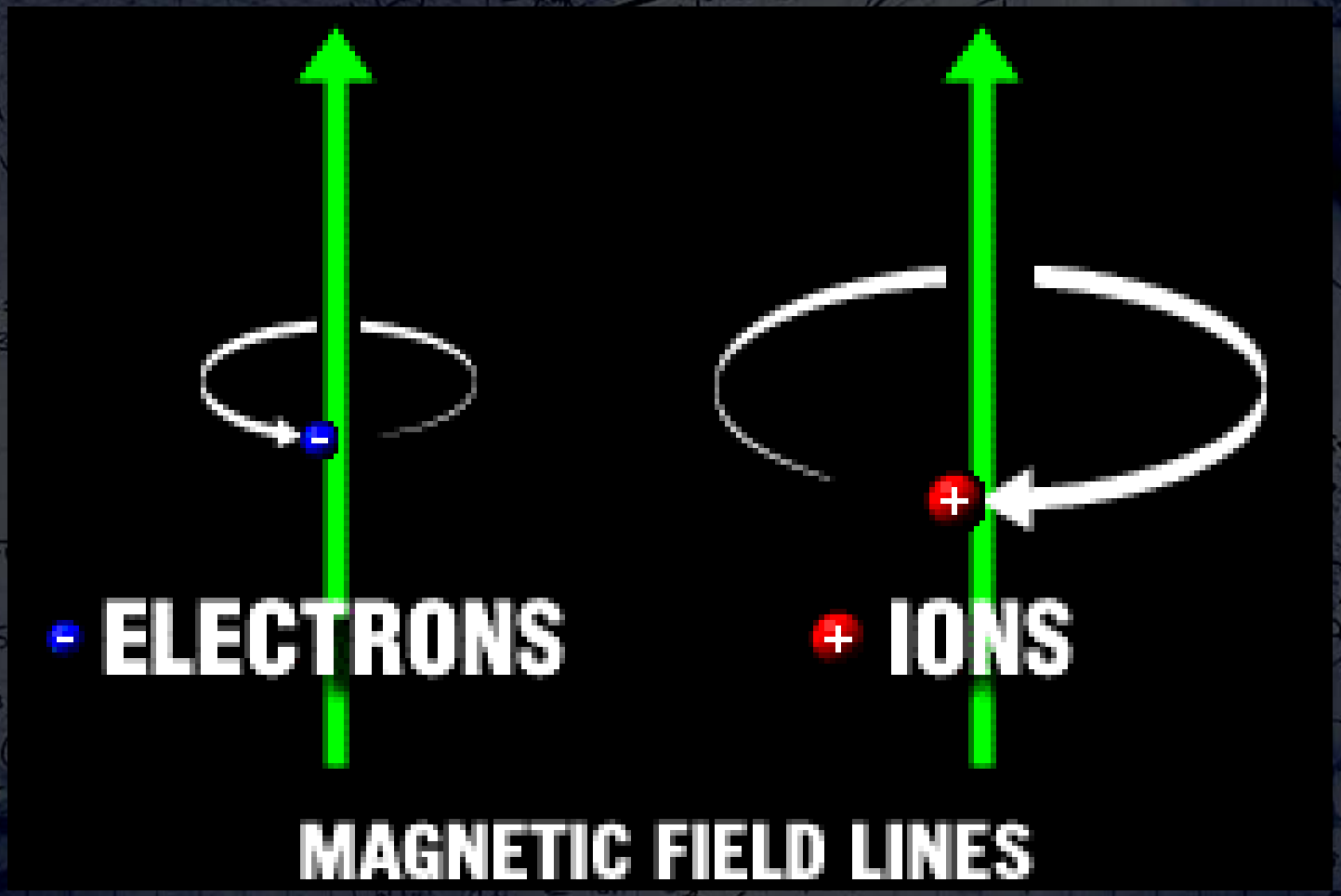
Often light is emitted during the ionization process



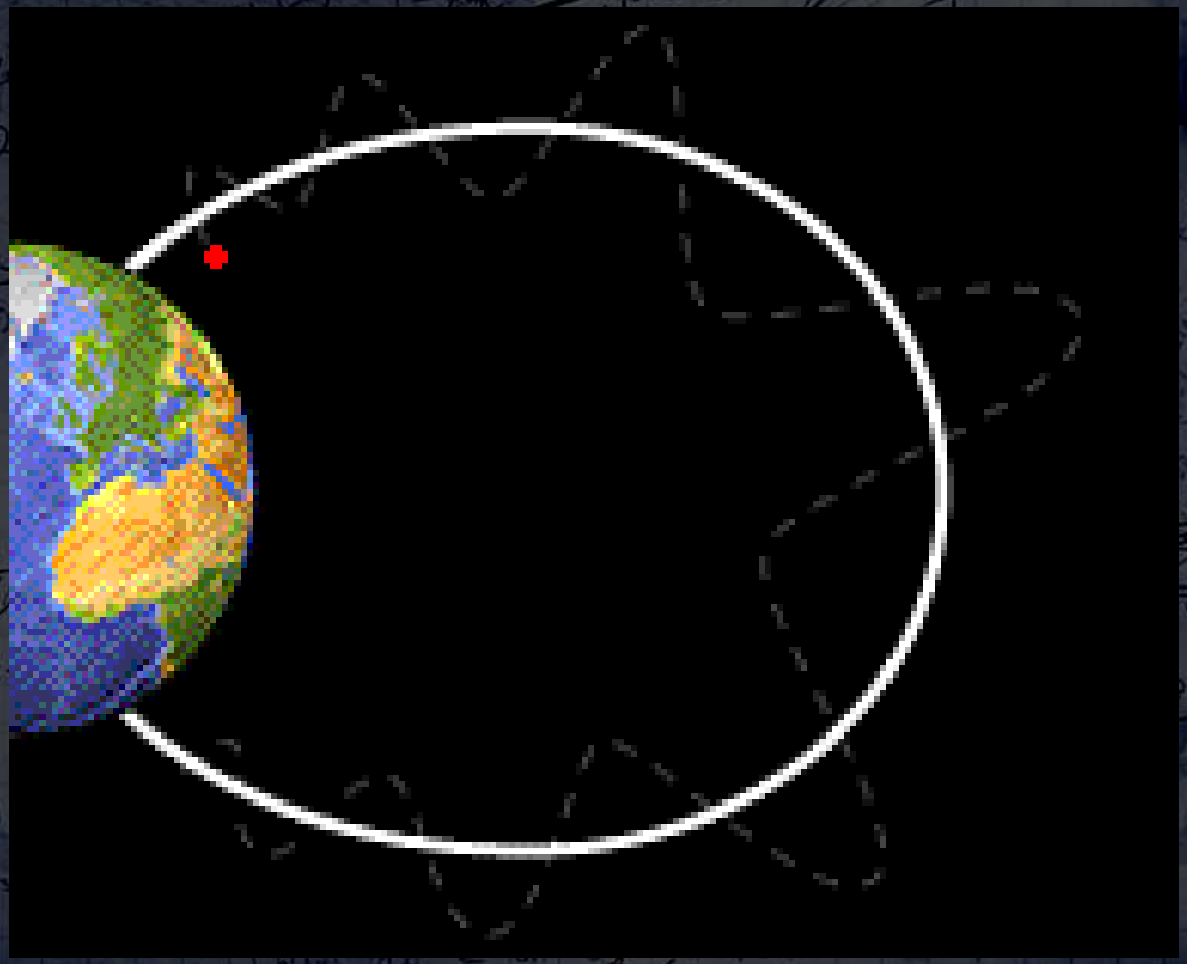
Ions and electrons constitute 'Plasma': the 4th state of matter

- Solid
- Liquid
- Gas
- Plasma (combined ion and electron 'fluid' that responds to electro-magnetic forces)
  - Examples of plasma include: galaxies, light bulbs, upper atmospheres of the planets; the Sun

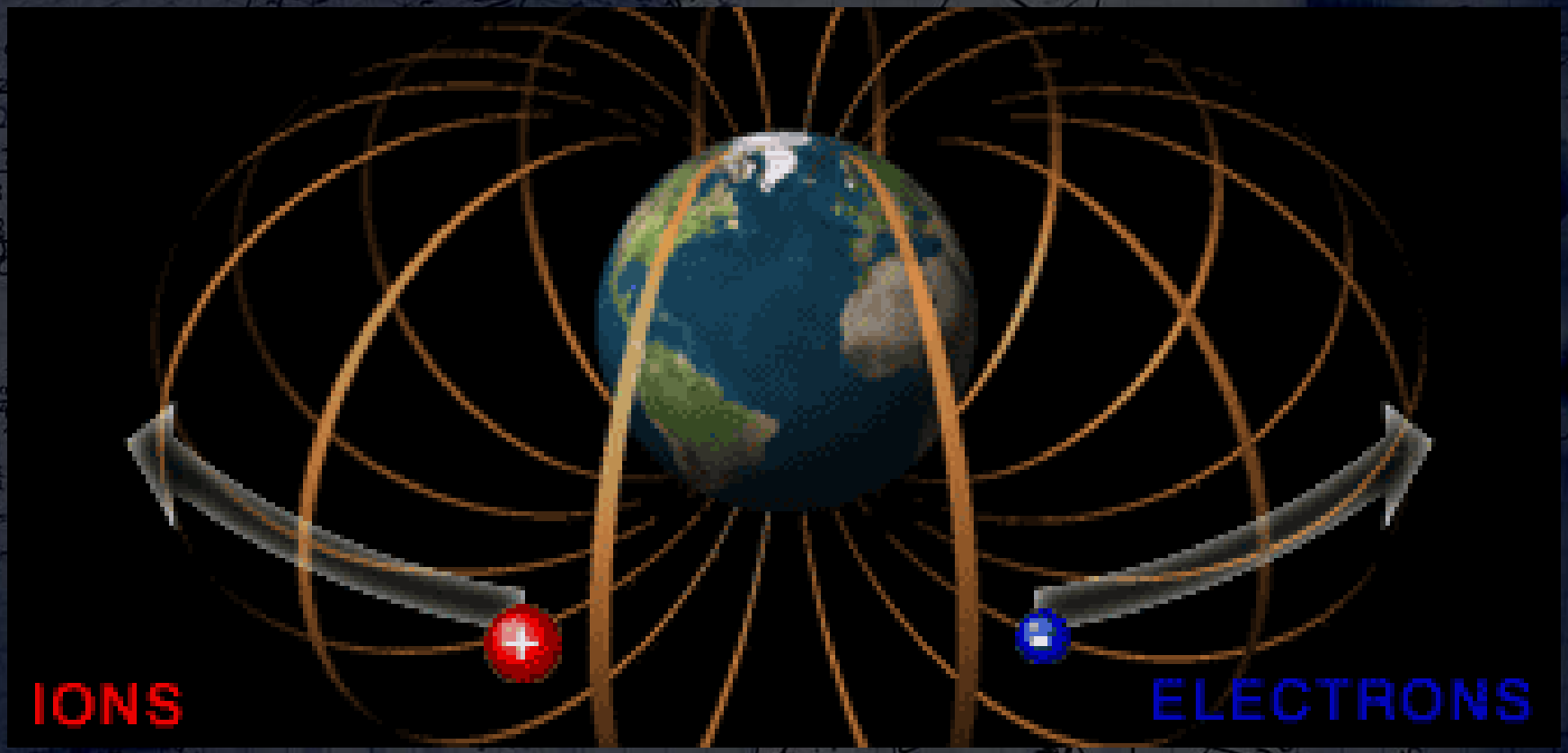
Ions and Electrons 'move' in space



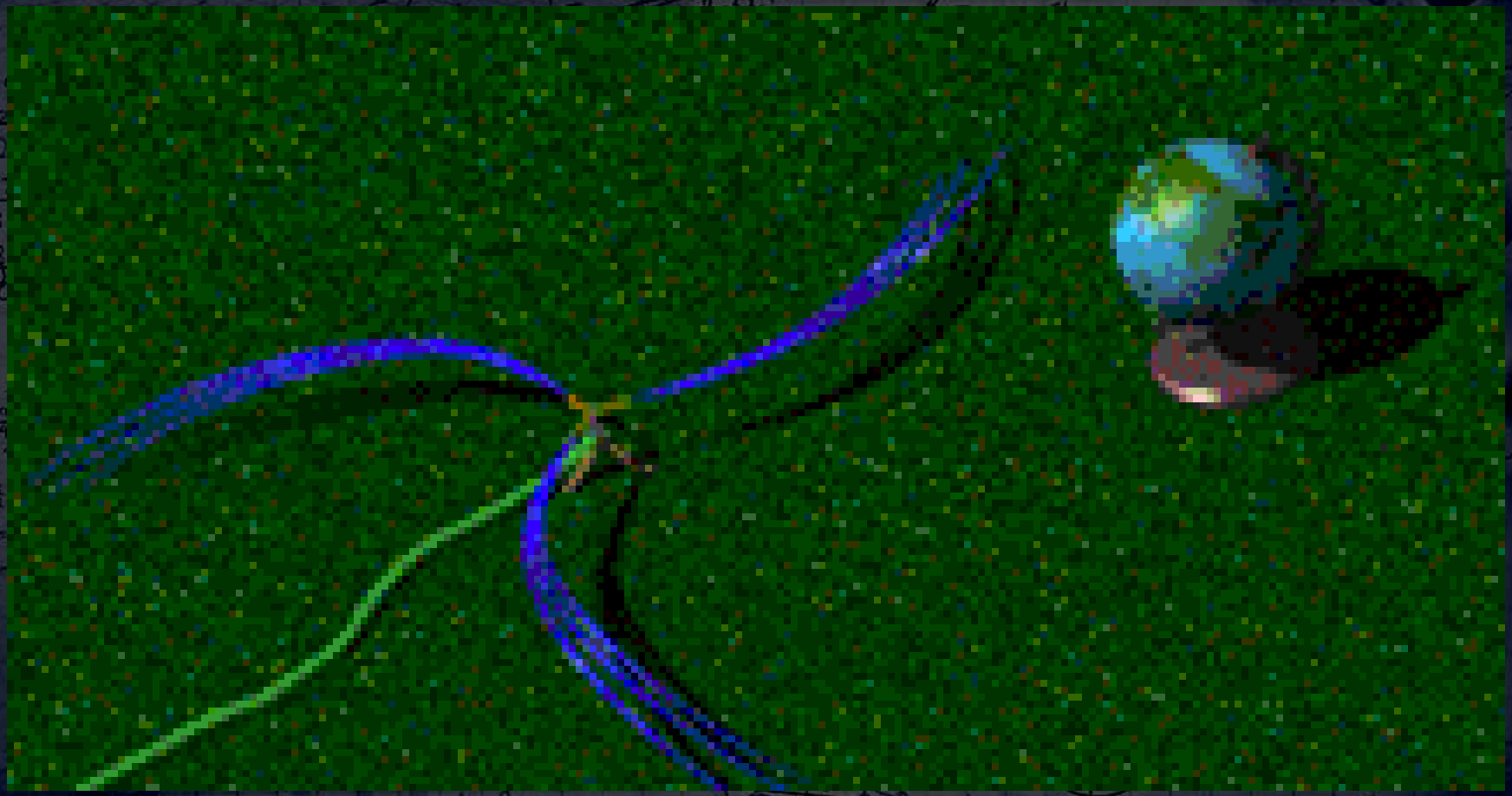
Electron and Ion motion, part 2



Electron and Ion motion in space, part 3

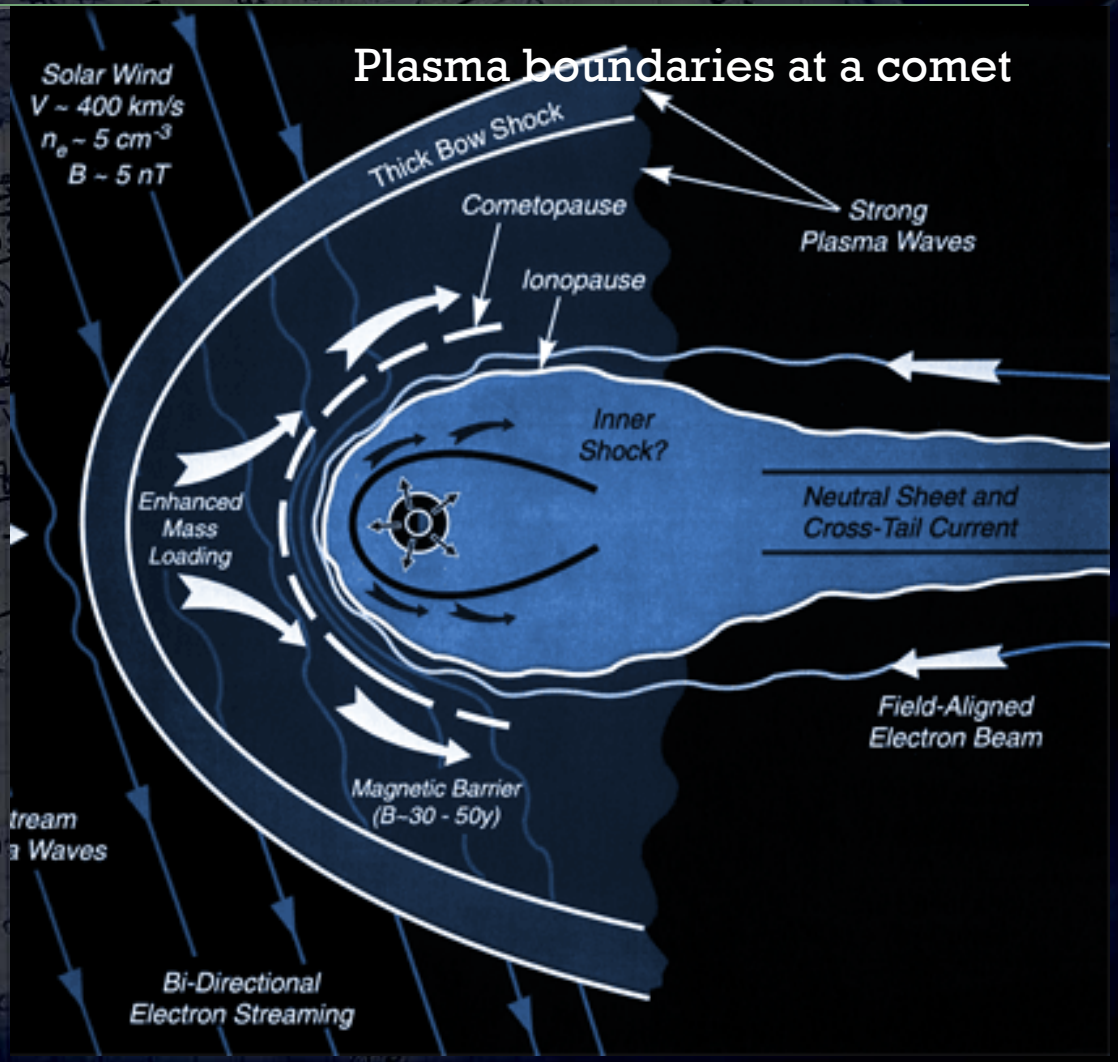


The Sun as a giant 'sprinkler' in space – delivering the solar wind



Plasma and Magnetic Field Instruments

- A plasma instrument can ‘see’ the energy as well as the presence of ions and electrons
- The detections allow investigators to discern the plasma boundaries surrounding the nucleus.
- Often, comet chemistry happens near those boundaries
- Important ions in the vicinity include (H+, O+ OH+).



Summary

- In space around a complex moving target, all the instruments at one's disposal are needed to answer the questions that we have – such as:
  - does this body have preserved inside the remnants of the history of the solar system?
  - Are the minerals and materials the same as we know them on earth (crystalline vs amorphous structure)
  - can we understand the geology of the surface, and how it formed from these detections
  - can we learn enough to understand the chemistry of ourselves from what we can detect on these surfaces?

Instrumentation will usually include:

- Visible spectrometer
  - (that is – a camera with 'bandpasses')
- Infrared spectrometer
- Radar
- Dust detector
- Plasma instruments
- magnetometer