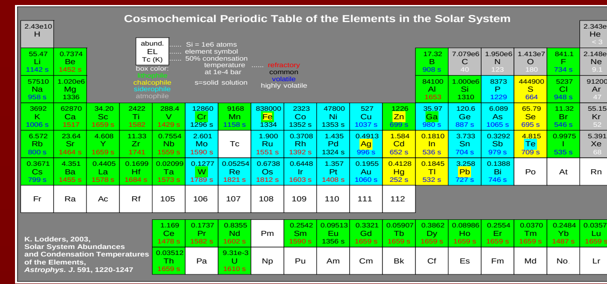
Solar System Abundances of the Chemical Elements

Katharina Lodders

Planetary Chemistry Laboratory, Dept. of Earth & Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO



Solar abundances: present-day observable composition of Sun, mainly photosphere; also sunspots, solar flares, solar wind

Solar system abundances: elemental composition of the local interstellar medium and molecular cloud ~4.56 billion years ago that became the solar system ("proto-solar abundances")

Cosmic abundances: there is no "generic" cosmic composition many nearby dwarfs stars are similar in composition as the Sun, but the amount of elements heavier than He (the "metallicity") changes with time and varies across the Milky Way Galaxy and other galaxies

Solar system abundances

- How the sun works
- Clues about the basic make-up & origins of matter
- Composition & formation of the solar system; planetary compositions
- Constitution of (baryonic) matter, numbers & amounts of stable elements/isotopes
- Test for models of element nucleosynthesis & galactic chemical evolution
- Composition & formation of other solar systems; exoplanets
- *It's the stuff we are made of*

Solar system abundances are periodically reviewed and updated as new measurements become available. New developments for solar atmospheric models lead to substantial revisions in the solar photospheric C, N, and O abundances in the early 2000s. New analytical instrumentation (ICP-MS) lead to many updates for meteoritic elemental and isotopic abundances. The data from Lodders 2003 are summarized in the periodic table above, which also gives other cosmochemical properties of the elements.
A new abundance evaluation was just completed (Lodders, Palme, & Gail 2009).

Spectroscopic analyses of the Sun's photosphere - Happy 80th Birthday

The Sun has >99.8% of the solar system's mass and should provide a good approximation for the composition of the entire solar system.
First quantitative solar spectrum analysis done by Henry N. Russell in 1929

~66 elements out of 83 naturally occurring elements are identified in the solar photosphere
all stable elements up to atomic number 83 (Bi) plus long-lived radioactive Th & U
~30 – 35 elements are well determined in the photosphere

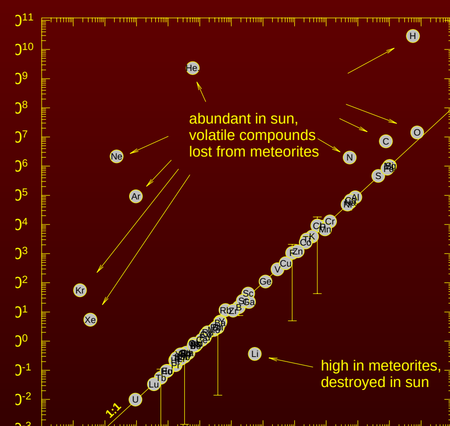
Some elements are difficult to determine because there are no suitable lines in the solar spectrum, line blends, and/or low abundance.
Sun-spot spectra are used for F, Cl, and In abundances

Helium was discovered in solar chromospheric spectrum; He, Ne, Ar, Kr, Xe are found in solar wind but not in the photosphere. Their "solar" abundances rely on values from other astronomical objects (e.g., B stars, HII regions, PNe) and nucleosynthetic modeling.

Solar System elemental abundances for non-volatile elements can be obtained from meteorite analyses.
The first more comprehensive attempts to derive solar system or "cosmic" abundances were done by Farrington 1915, Harkins 1917, and especially Goldschmidt 1922 using meteorite and terrestrial rock data. This was *before* the first spectroscopic analysis of the Sun from Russell 1929 became available.

Primitive meteorites of the "CI chondrite" group

Meteorites are among the oldest known solids that assembled when the Sun and planets formed about 4.56 billion years ago. Since then, "primitive" meteorites did not experience any severe heating and elemental fractionations and they preserved a chemical memory of the original element mixture in the solar system. Of the several different groups of meteorites, the group of "CI-chondrites" match best to photospheric abundances for many elements:



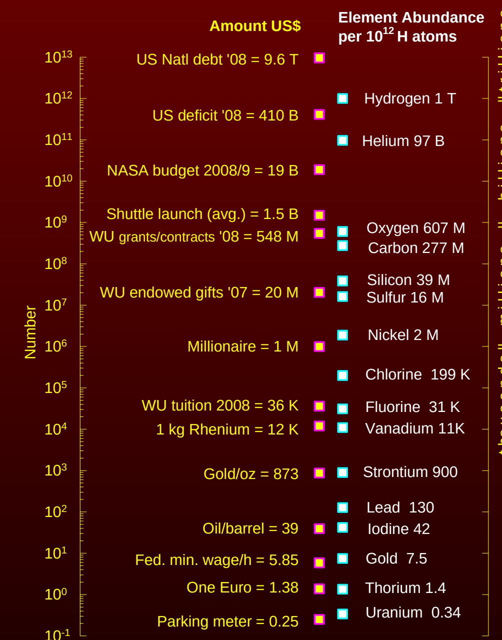
Orgueil meteorite, sample about 1 inch in size

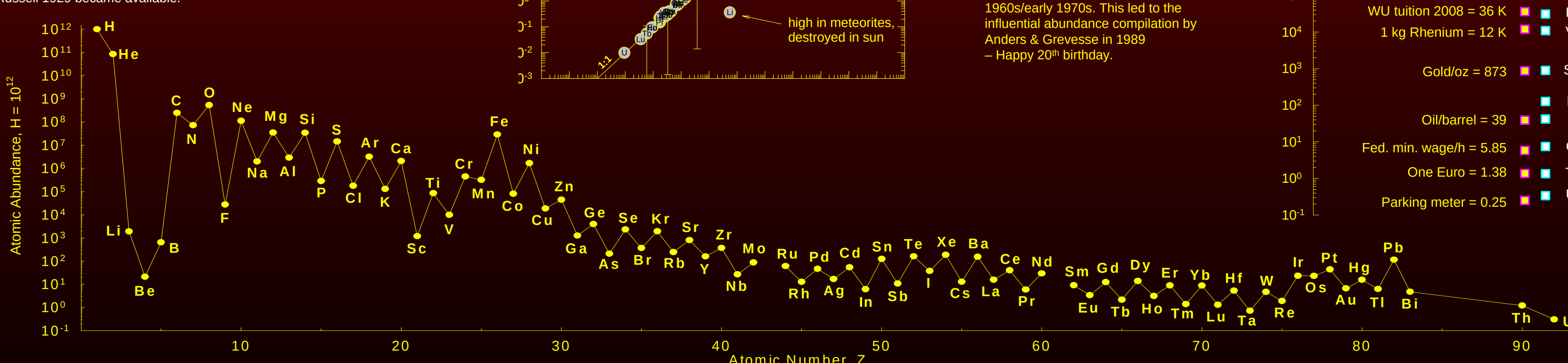
Out of ~40,000 collected meteorites, ~1,000 were observed to fall. Among these falls are 5 CI chondrites, and only a total mass of ~20 kg is preserved for 3 of them.

The significance of CI chondrites as "standard rocks" for solar system abundances was realized in the late 1960s/early 1970s. This led to the influential abundance compilation by Anders & Grevesse in 1989 – Happy 20th birthday.

The relative abundances of the elements in the overall solar system vary over 13 orders of magnitude: per 1 trillion H atoms there are only 0.3 U atoms

More recently, the financial sector provides a similarly large range of numbers for comparison





Lodders, Palme, & Gail 2009, Solar System Abundances of the Elements, Landolt Börnstein, New Series (submitted Dec. 2008)
Lodders 2009, Solar system abundances of the Elements, Proc. Kodai School on Nucleosynthesis (submitted Dec. 2008)