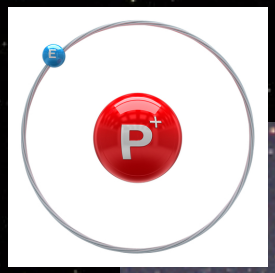
Astronomers' Periodic Table



H

He

C N O

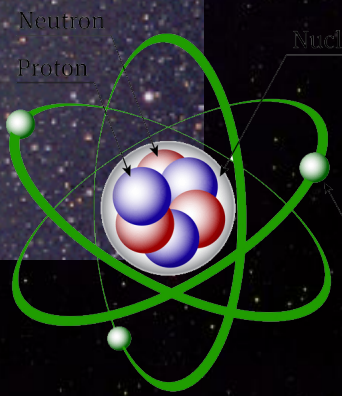
Ne

Si S

Ar

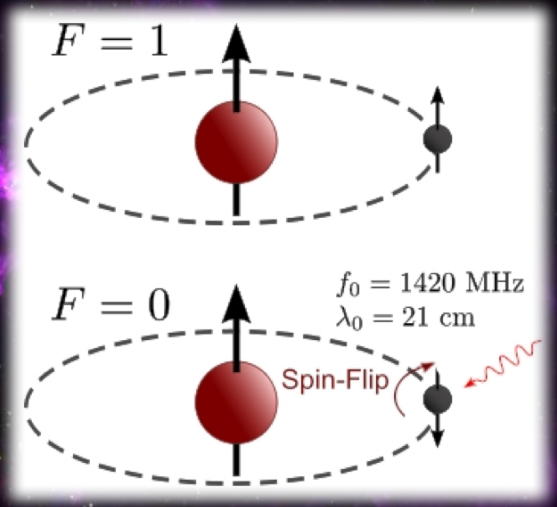
Mg

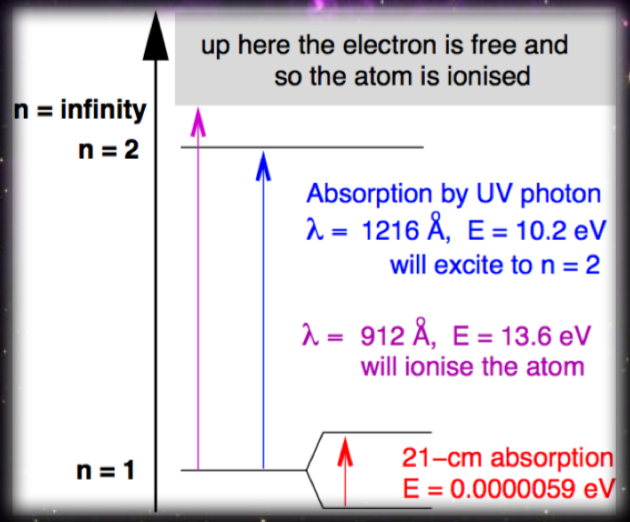
Fe



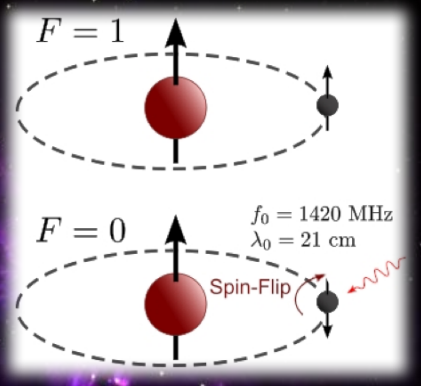
Hydrogen (HI) the most common element in the Universe (75%):

- In 1940 *Oort* suggested emission lines in radio part of spectrum, in 1944 *van de Hulst* predicted hydrogen should produce radiation of frequency $\nu = 1420$ MHz ($\lambda = 21.1$cm) from spin-flip of the electron.
- Detected in 1951 *by Ewen & Purcell*, despite being "forbidden" ($A = 2.9 \times 10^{-15}$ s^{-1} =>lifetime of 10^7 years, cf. 10^{-8} secs in the n = 2 level)
- However, a giant molecular cloud can contain 10^6 solar masses of hydrogen ($1M_\odot = 2 \times 10^{30}$ kg => ~10^{42} atoms), so extra-solar 21-cm readily detectable ➔ birth of spectral line radio astronomy in 1951.

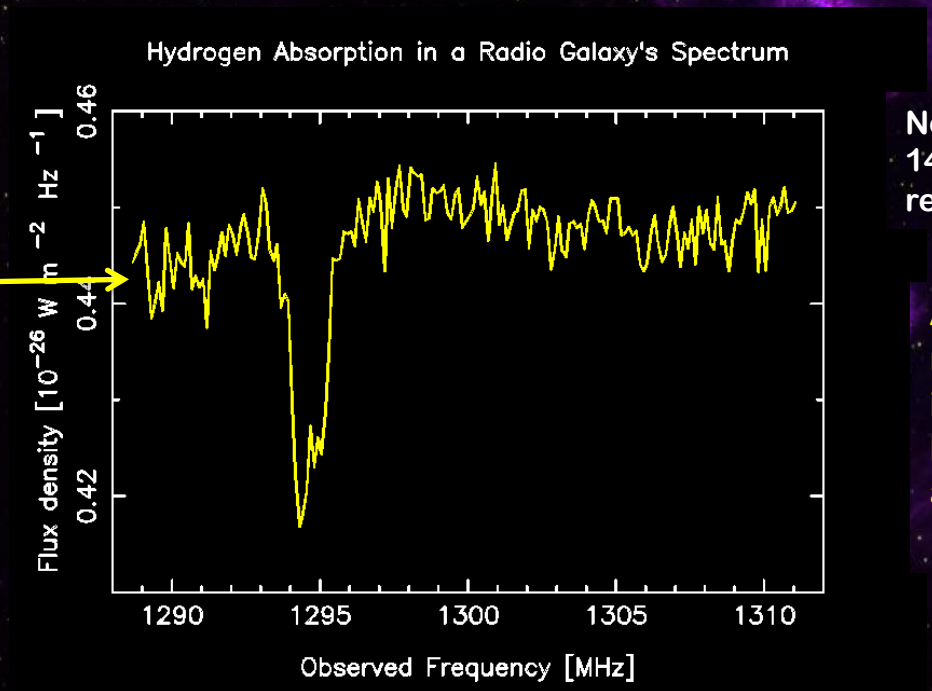




Can be detected in *emission* or *absorption* …



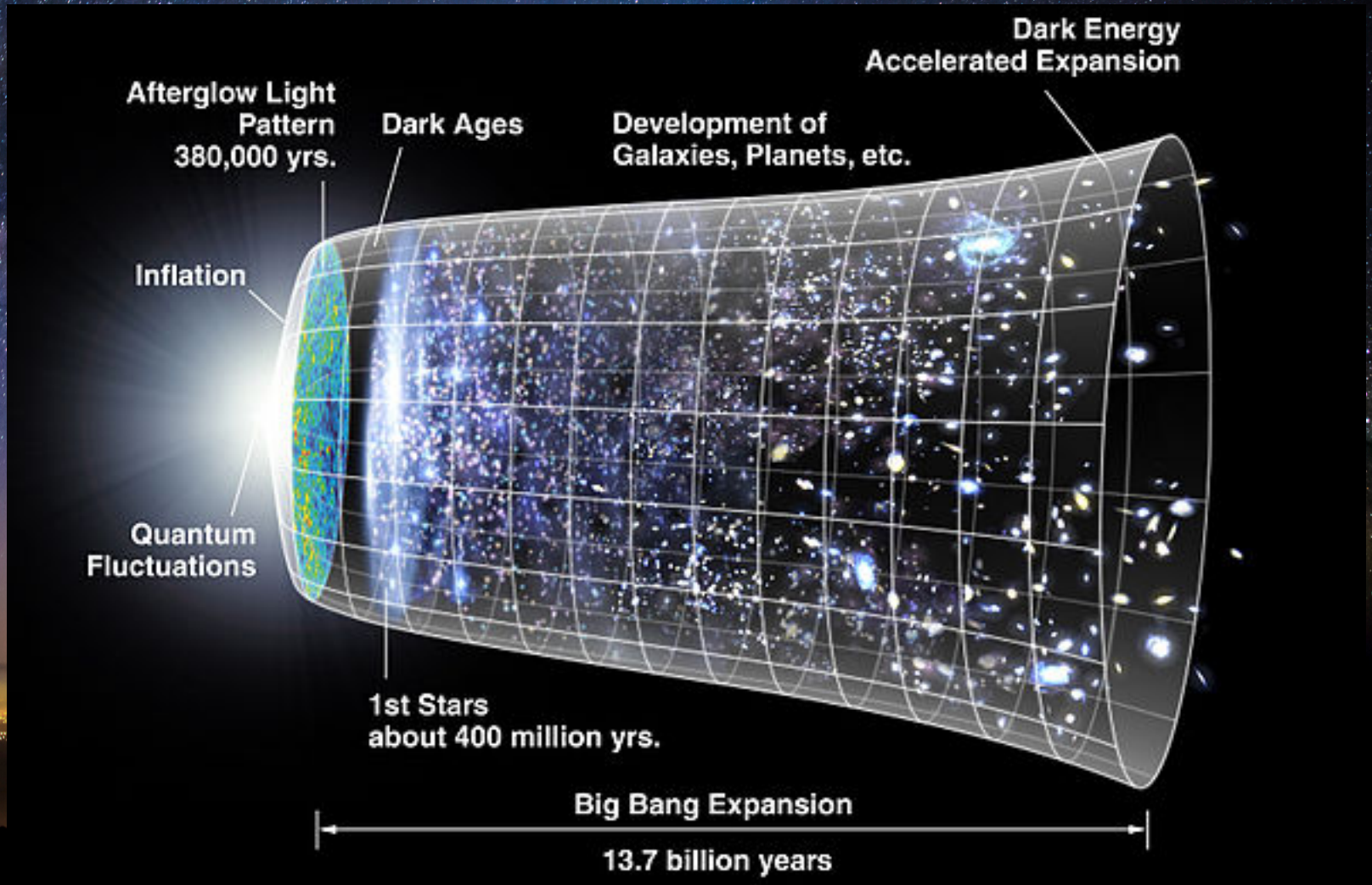
Radio continuum emission from background source – UV from matter accreted onto supermassive black hole. Radio from electrons accelerated along jets

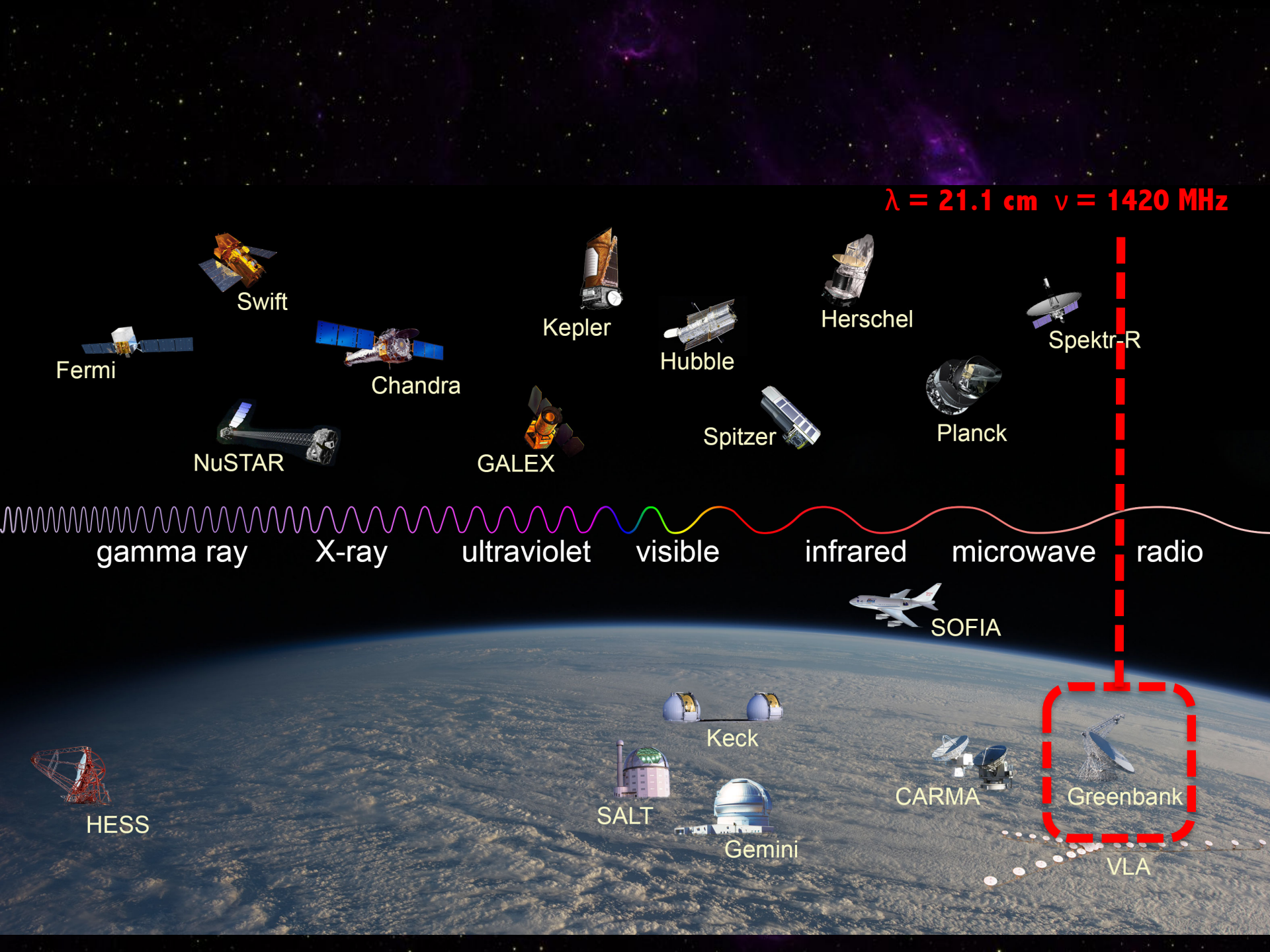


Note transition shifted from 1420 to 1295 MHz, giving redshift of z = 0.097

Absorption due to neutral hydrogen in intervening galaxy – line broadened thermally and also by rotation

Water vapour, sunlight and dust (atmospheric & interstellar) are transparent to radio waves, meaning that 21-cm can be observed from the ground 24/7 (dark patches in Milky due to to dust obscuration of visible light). This gives us an unobscured view of the Universe back to near the beginning (>13 billion years).

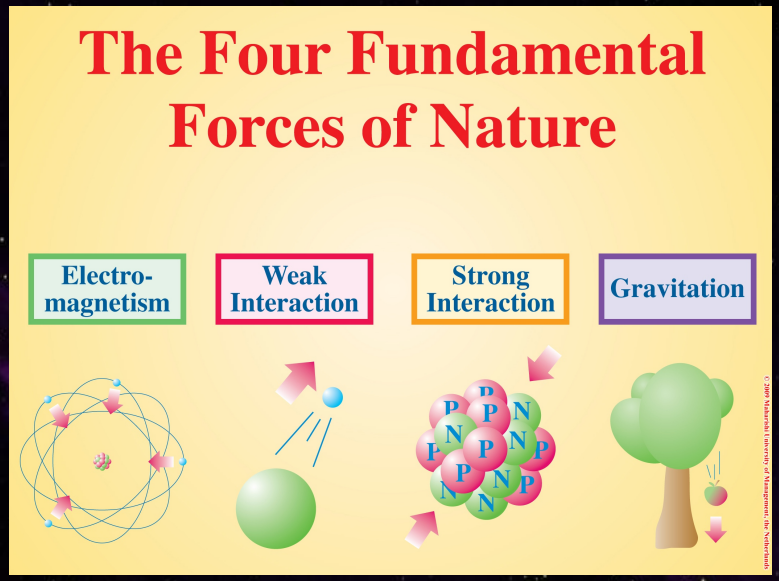


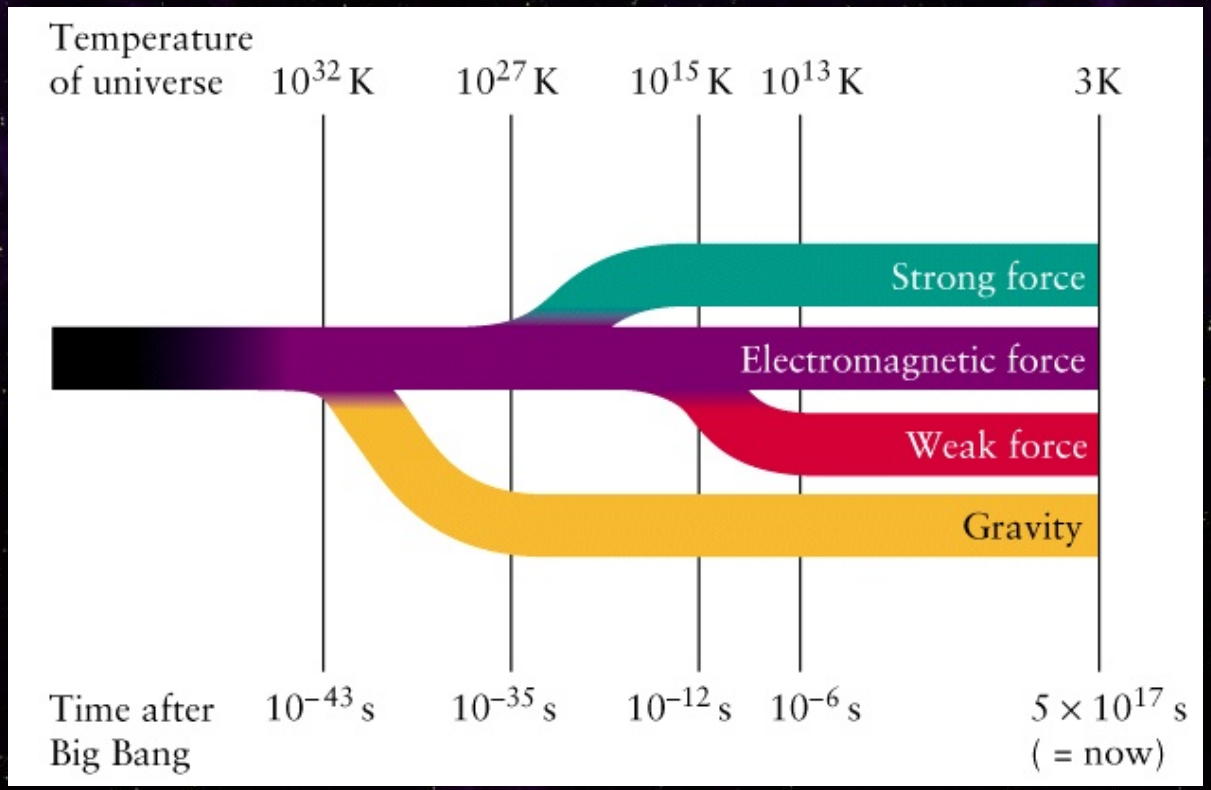

λ = 21.1 cm ν = 1420 MHz
Swift
Kepler
Herschel
Spektr-R
Fermi
Chandra
Hubble
Planck
Spitzer
NuSTAR
GALEX
gamma ray
X-ray
ultraviolet
visible
infrared
microwave
radio
SOFIA
Keck
HESS
SALT
Gemini
CARMA
Greenbank
VLA

Current *Grand Unified Theories of Physics* (Theories of Everything), which aim to unify the fundamental forces, predict an evolution in the "constants" of Nature

All atomic, molecular and ionic transitions occur at specific quantised frequencies with difference dependencies on various combinations of fundamental constants.

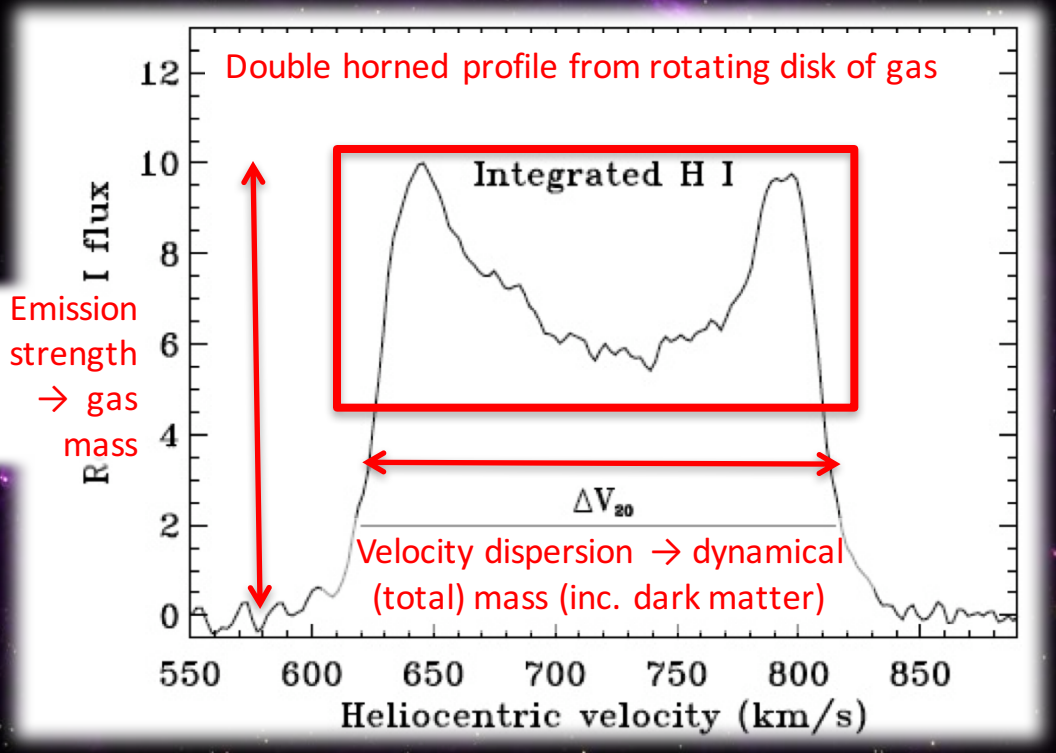
The finite speed of light means that distance ≡ look-back time. E.g. observations at $z > 3$ correspond to > 12 billion years, cf. atomic clocks (a few years), Oklo reactor (2 billion), radioactive decay of meteorites (4.6 billion)

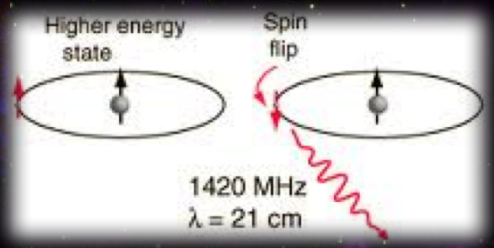


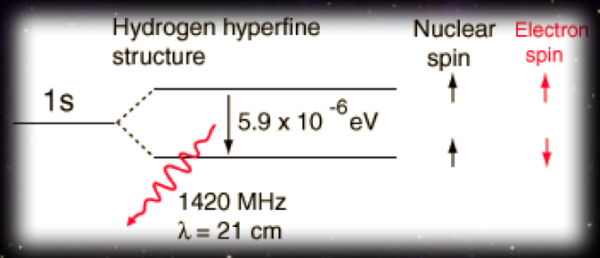


Mapping hydrogen in emission

Recessional velocity (direct from frequency), which gives redshift & distance

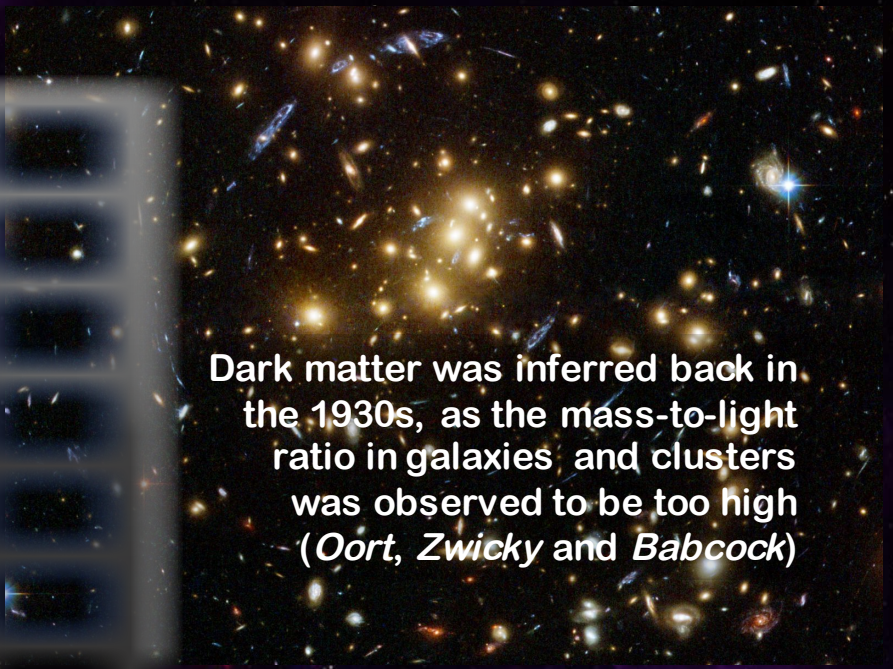






A picture may be worth a thousand words, but a spectrum is worth a thousand pictures

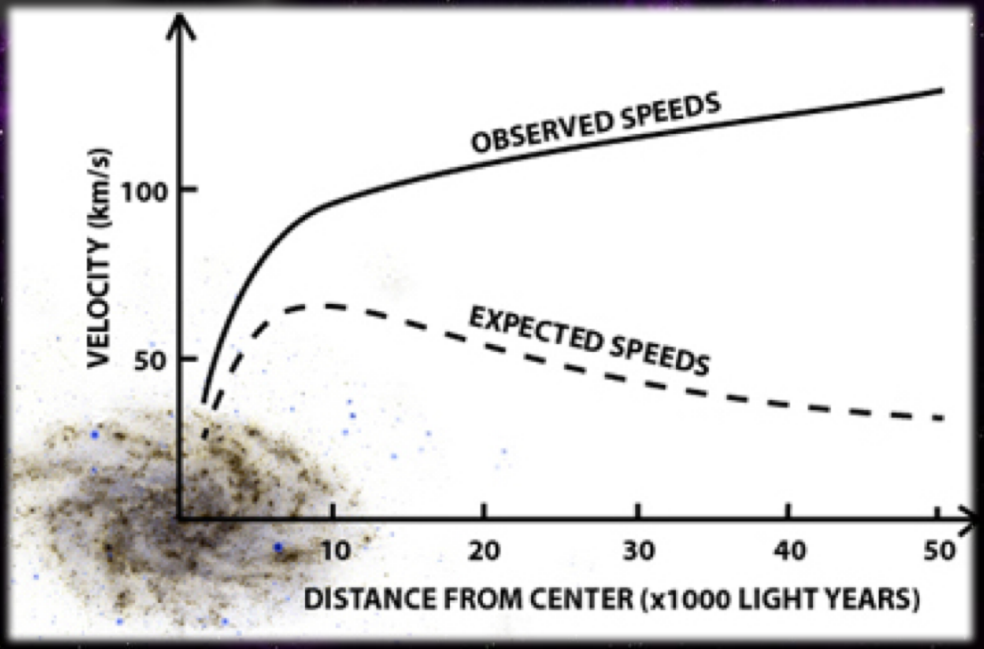
Galaxy rotation curves and dark matter



Dark matter was inferred back in the 1930s, as the mass-to-light ratio in galaxies and clusters was observed to be too high (*Oort*, *Zwicky* and *Babcock*)

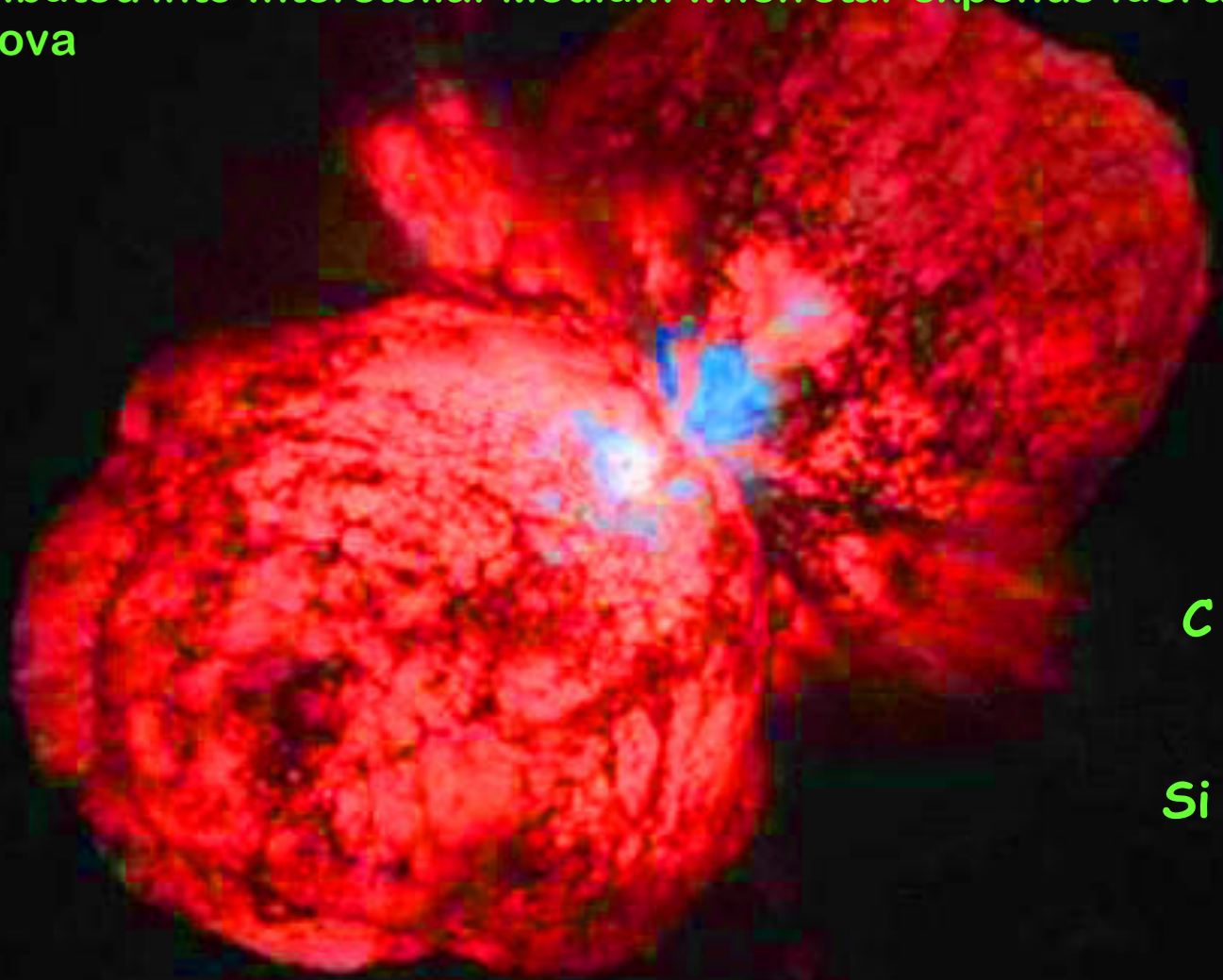
From the distribution of light, expect the gas (a diffuse fluid) to have Keplerian rotation around the centre of mass, cf. the orbits of the planets

Rubin 1970s – flat (solid body) rotation curves in galaxies → six times as much dark matter as visible



All the heavy elements form from stars which form from *cold* gas

Redistributed into Interstellar Medium when star expends fuel and goes supernova



H
He
C - life!
O
Ne
Si - rock
Fe

Nuclear fusion over star's lifetime produces increasingly heavier elements

What Spectral Line Radio Astronomy Tells Us of Our Universe:

- Provides an un-obscured view of Universe back to near the beginning.
- Can be used to measure the values of the fundamental "constants" of Nature, providing the only experimental test of *Grand Unified Theories* over large time scales.
- Predicts and traces the distribution of *dark matter* – invisible matter, which interacts only with normal (baryonic) via gravity and accounts for 80% of the mass in the Universe.