Spectral Lines

- This is only a very brief summary!
- There are many spectral lines in the higher end of the radio band (>>20GHz)
  - but some of these are rare in the interstellar medium (e.g. found in special areas like Orion or the galactic centre)
  - some lines are extremely weak!
  - there are lists (http://www.splatalogue.net)

Types (1) -atoms

- recombination lines

  - associated with HII regions, PNs

- hyperfine atomic (magnetic interactions)

  - HI (atomic hydrogen), $^{3}He^{+}$
  - HI is weak but abundant

Types (2) molecules

- molecular (water, OH radical, CO, methanol, formaldehyde ...) in cooler regions. These include many molecules not easily made on earth; usually H,C,N and O dominate (roughly in that order)
  - Some are big (glyceraldehyde, HC_7N, acetamide...)
  - Some of these maybe relevant for life starting (prebiotic)
  - Some give rise to masers (OH, water, methanol, ammonia, SiO) when pumping conditions are right (Shock or IR)
    - water and OH megamasers (and gigamasers) are seen in some starburst galaxies

more about moleculess

- Want a big electric dipole moment to radiate much (CO, HCN)
- form ladders of many transitions
  - Can make good thermometers
- strength (spontaneous emission) goes as ν^3 so they matter more in millimetre and submillimetre
  - not true of stimulated emission

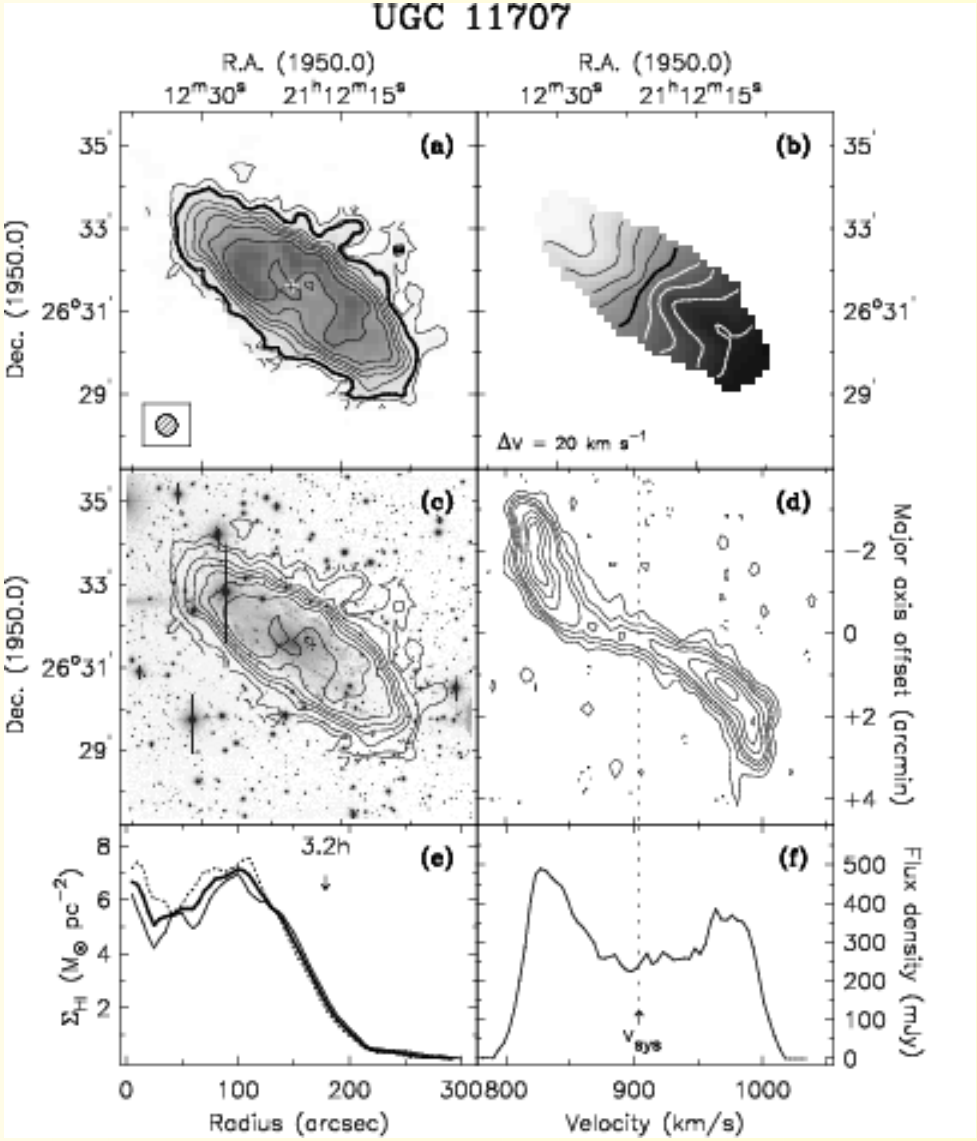
HI

- The line is moderately weak, but there is LOTS of it.
  - in galaxies
  - left in streams after galaxy interactions
  - in 'high velocity clouds'
  - seen (in absorption) against distant radio sources
- A good tracer of galaxy dynamics

HI

- Important parameters
  - rest frequency 1420.405751 MHz (about 21cm)
  - radiative lifetime about 11million years (without collisions) - but reduces to few hundred with typical densities
  - usually fairly cold (100-150K- set by cooling in infrared by CII) or warm (5000-10000K)
  - usually low optical depth, (but there are a few places where it is about 1)
    - can see a background galaxy through a foreground
    - good tracer of galaxy dynamics

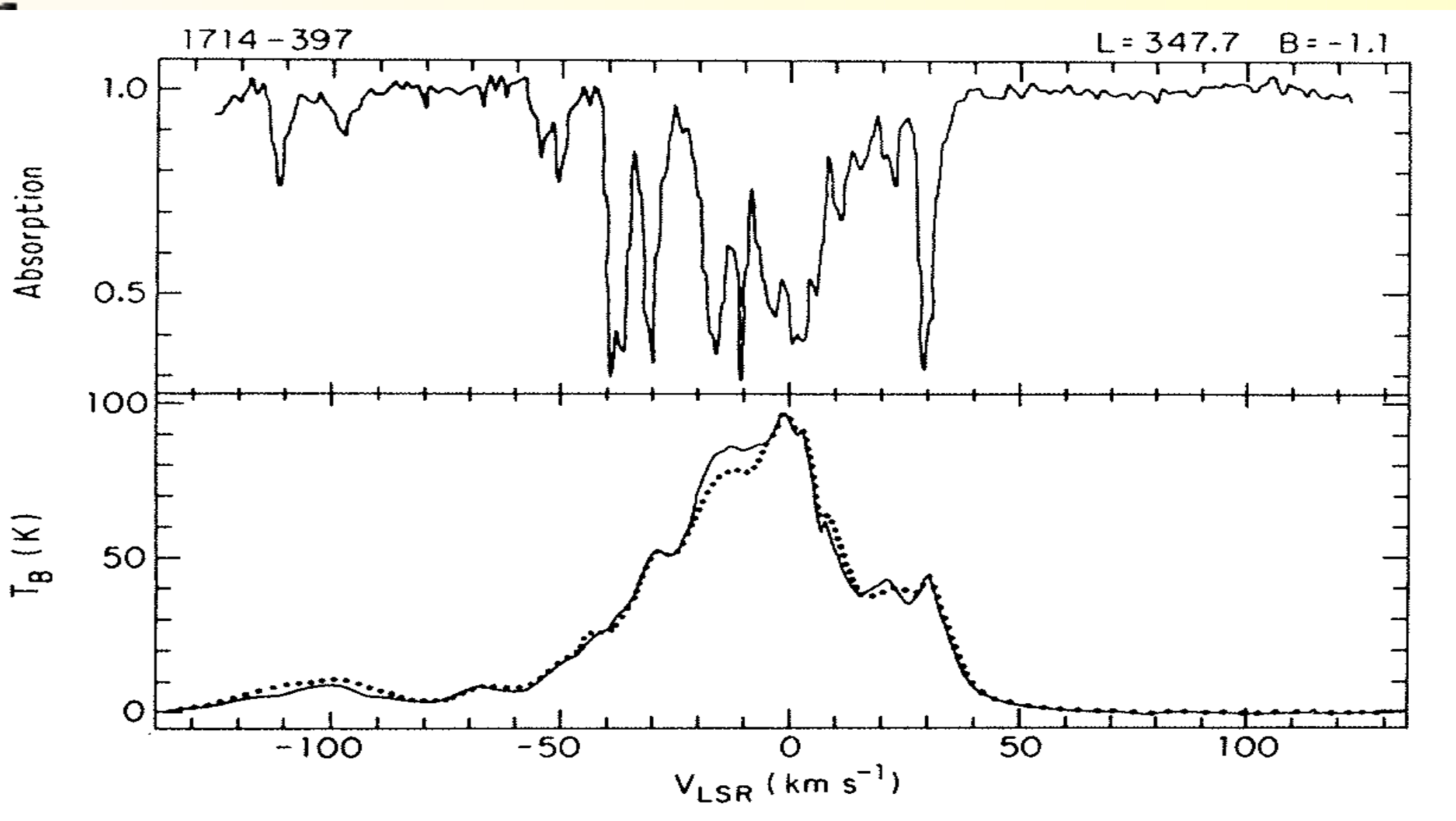
What do we see



So

- We can get systemic velocity- Doppler shift (and so via cosmology - distances)
- Can get velocity at given distances (and assuming Keplers law and an inclination angle - enclosed mass at that distance)
    - which we see to a large distance
- If there have been interactions we can see the trails

and with absorption



HI

- Emission Column density (integral over line of sight) $$(\frac{n_H}{cm^{-2}}) = 1.82 \times 10^{18} \int \frac{T_b}{K} d\frac{v}{km\,s^{-1}}$$
- T_b is observed brightness profile (if optically thin this about τT_{spin}) so it is weighted to warm gas
- absorption is weighted towards cold gas

integrated mass

- can integrate to find mass in neutral hydrogen in a galaxy if the optical depth is thin and we assume circular motions

$$\left(\frac{M_H}{M_{sun}}\right) = 2.36\times10^5 \left(\frac{D}{Mpc}\right)^2 \int \frac{S(v)}{Jy}\left(\frac{dv}{km\ s^{-1}}\right)$$

- typically 1% of stellar mass in a spiral (very much less in an elliptical galaxy)