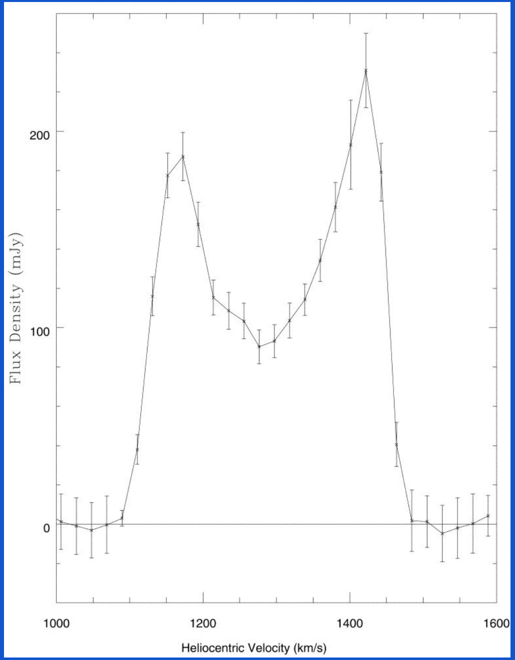
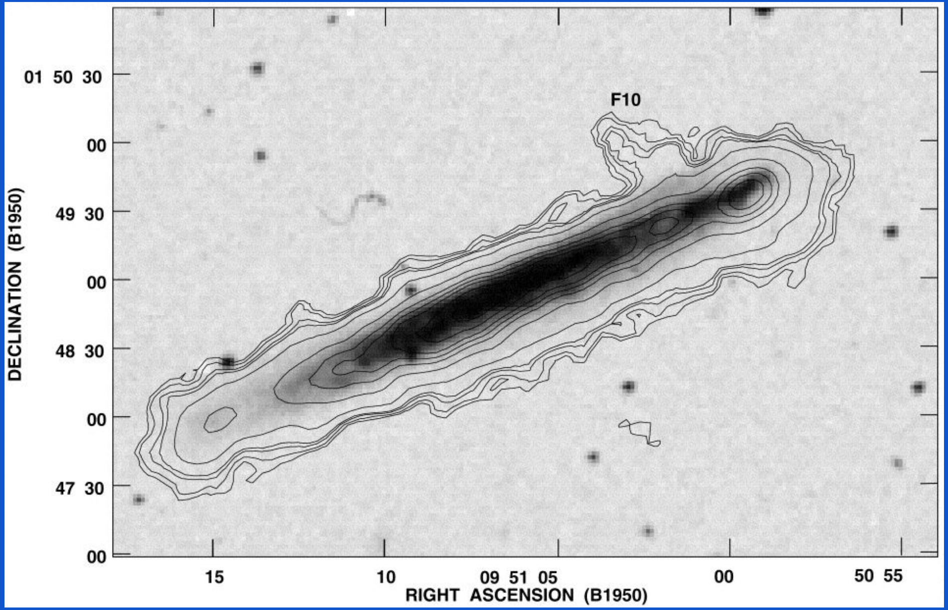
The HI Emission Line





Images: Lee & Irwin, 1997

Catie Ball

Green Bank UAT Workshop

June 19, 2019

The 21 cm Line

- Transitions between states → spectral lines!
- Particular transition related to HI 21 cm line
  - Neutral hydrogen -- proton + electron
  - Spin-spin interaction of magnetic dipole moments
- Energy difference of states: 5.8 μeV
- 1420.405 MHz, 21 cm

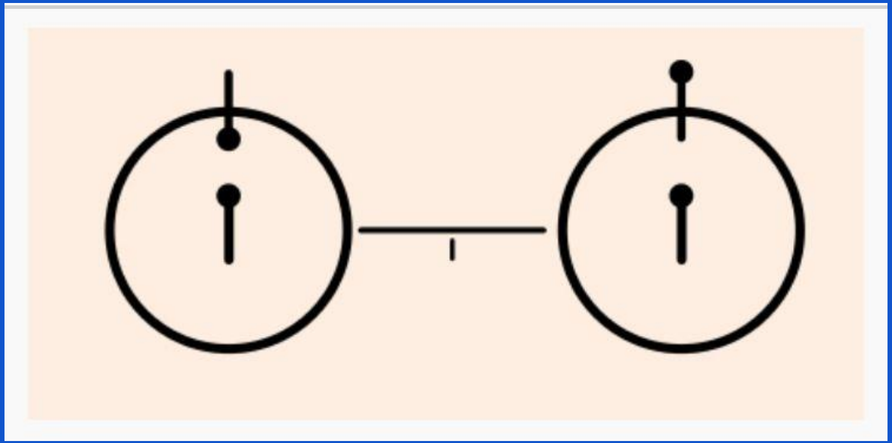


Illustration of 21 cm line transition from Voyager plaque!

Properties of 21 cm Line

- Transition lifetime ~10^7 years!
  - Emission is weak!
  - HI gas can have atoms in excited state at low densities
- Generally optically thin
- Low energy
  - Less dust extinction than optical light
- Originates from neutral, atomic Hydrogen
  - Which is a non-negligible part of the universe’s baryons

Atomic Gas in the ISM

- Multi-phase interstellar medium
  - Temperature, density of gas determine properties
- Molecular gas
  - Cold and dense
  - Gas most likely to collapse and form stars
- Ionized gas
  - Gas pumped with significant energy
  - Need something to put energy in!
- Atomic gas
  - Less dense than molecular clouds, cooler than ionized gas
  - Extended reservoirs of future star-formation fuel

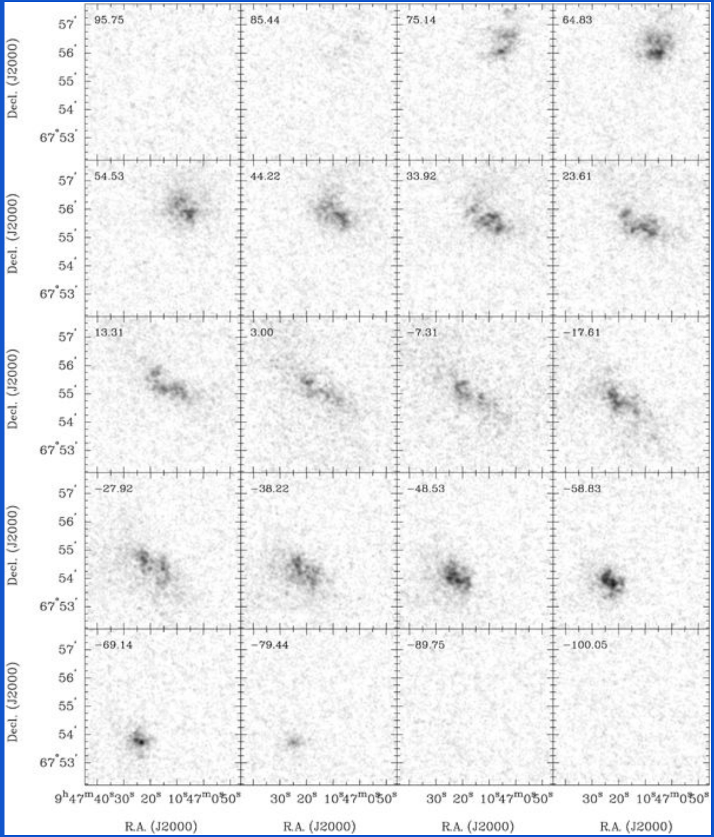
Three-dimensional HI Information - R.A., Dec, v

- Gas that appears at different wavelengths - moving at different velocities relative to observer
- For small velocities,

$$\frac{\Delta\nu + \nu}{\nu} = 1 + \frac{v}{c}$$

- HI spectral "cube" tells where gas is and how it is moving

Walter et al. 2008



Moment Maps

- Condense information in 3d data cube to 2d by summing along frequency/velocity axis
- Moment 0:

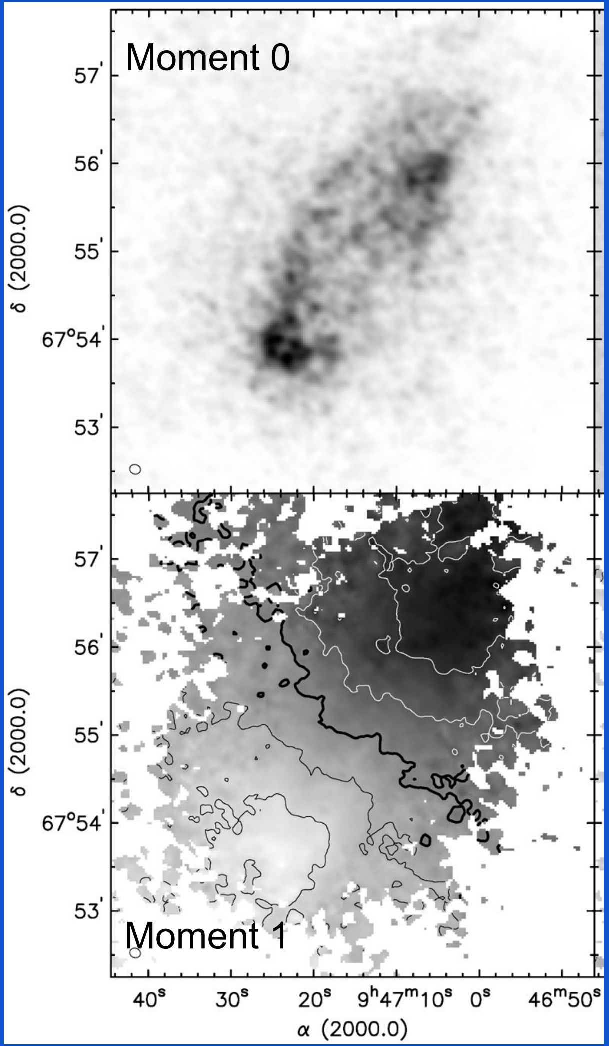
$$\int S(v)dv$$

- Moment 1:

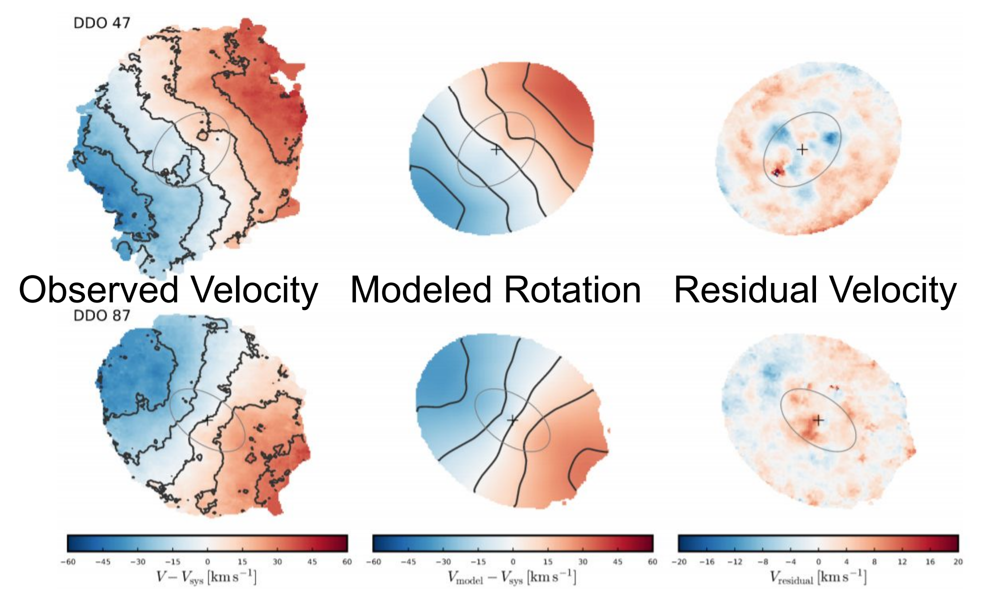
$$\int vS(v)dv$$

Black: receding emission
White: approaching emission

Walter et al. 2008



Gas Kinematics



Oman et al 2019

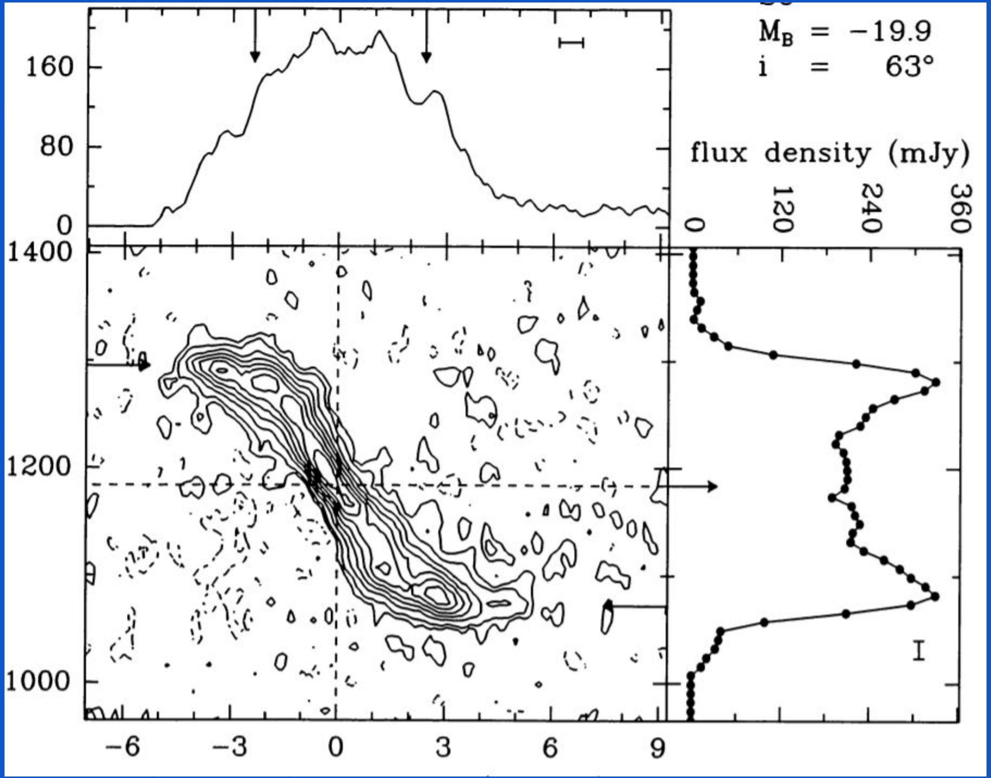
- Rotation
  - In most galaxies, dictates extreme observable line-of-sight velocities
  - Spiral disks primarily supported by bulk gas rotation
- Dispersion
  - Variance of gas velocity
  - Plenty of possible sources:
    - Gas turbulence
    - Non-circular motion
    - “Pressure support” in lowest mass galaxies
  - Can broaden line profiles

Distribution & Kinematics

- Can be separated, in theory:
  - Surface density profiles and velocity curves
- Position/Velocity slices, 3d tilted ring fitting
- Potential for degeneracy in solutions

Distribution:
Gas surface density

Kinematics:
Velocity (km/s)

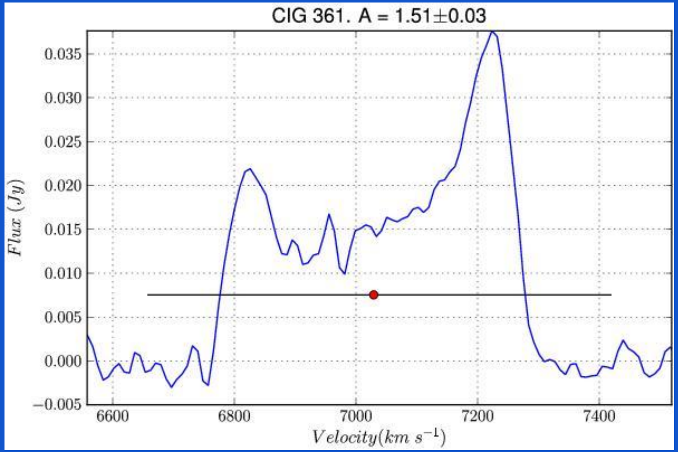


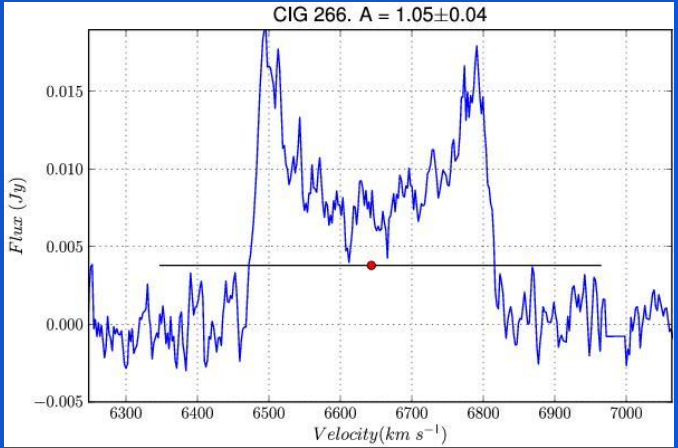
Distance from center (arcmin)

Broeils & van Woerden 1997

Global HI Line Profile

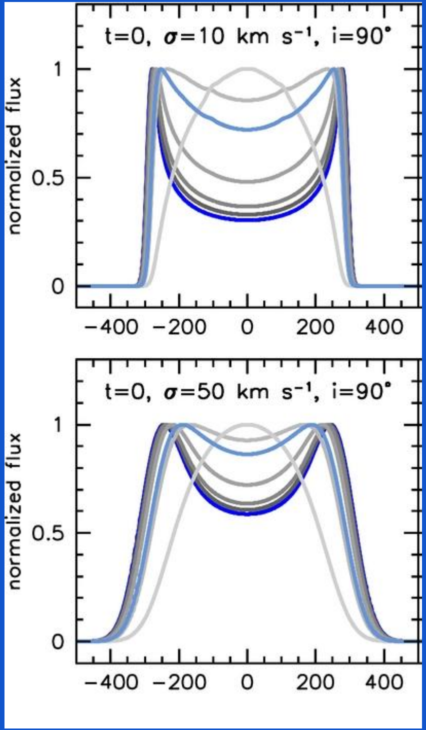
- Unresolved profiles also informed by gas distribution & kinematics
- Long wavelength light -- need larger telescope for resolving
- Single dish observations more efficient
- Some available information:
    - Δv, v
    - $$M_{HI} \propto d^2 \int S(\nu) \frac{dv}{km/s}$$





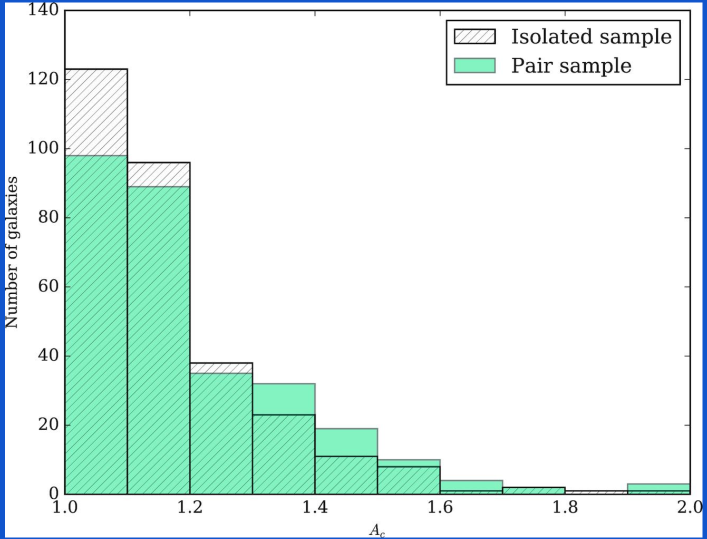
Espada et al. 2011

Global HI Line Profile - Other Interesting Qualities



Different colors -- different radial gas distributions

Asymmetry vs. number



Left: de Blok & Walter 2011
Right: Bok et al 2019

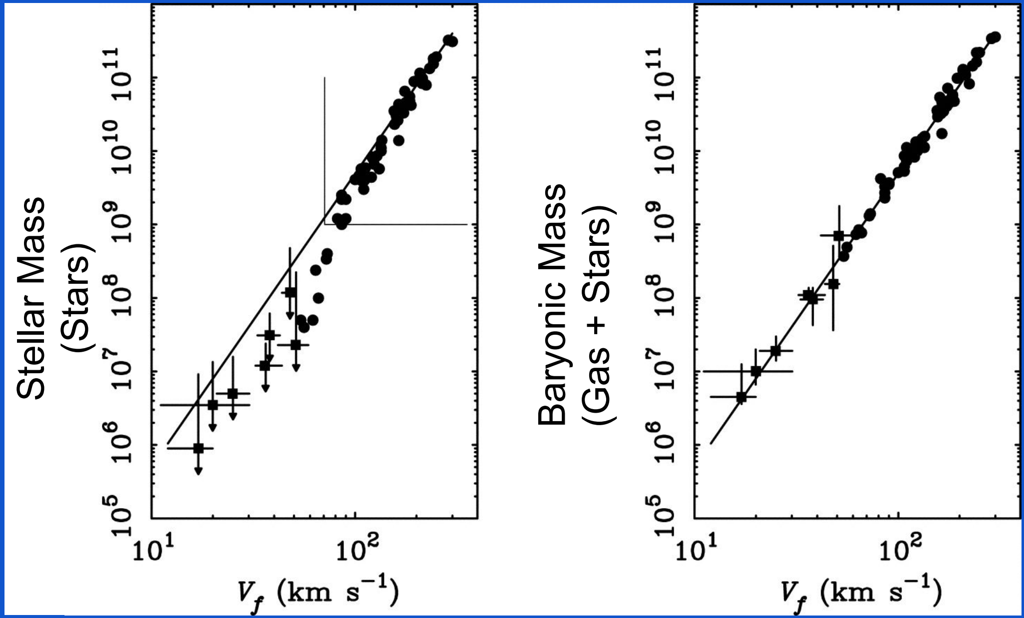
- Shape of profile hosts information as well!
- Common (observationally justified) assumptions make these profiles easier to digest but may be worth testing!
- Asymmetry: gas distribution? Environmental effects?
- Single vs. double horned - gas distribution? Rotation vs. dispersion?

Baryonic Tully-Fisher Relation

- Tully-Fisher Relation improved with inclusion of gas mass at low mass (more gas-dominated)
- Hubble-independent distance measurement
  - But… still get redshift information from spectral lines! Get distance + peculiar velocity!
- Initially empirical, but underlying correlation informed by relationship between halo mass, angular momentum, how baryons populate halos

Tully Fisher Relation

Baryonic Tully Fisher Relation



Rotational velocity (km/s)

McGaugh, 2005.

References and Acknowledgements

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