HI 21 cm line

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HI line in External galaxies.

The HI 21 cm line is an extremely powerful tool in studying the ISM of external galaxies. It can be used to calculate the:

1. Distance to the galaxies
   - The observed HI frequency can be used to measure the radial velocity of the galaxy.

$$v_r \approx c\left(\frac{\nu_{emi} - \nu_{obs}}{\nu_{emi}}\right) \tag{1}$$

   - The distance to the galaxy is then given by:

$$D \approx \frac{v_r}{H_o} \tag{2}$$

   where H_o [1] is the Hubble constant.

[1] $H_o = 67.8 \pm kms^{-1}Mpc^{-1}$

Example: Find the distance to the galaxy UGC 11707. Observed line frequency is $\nu_{obs} = 1416.2 MHz$. We know that the emitted frequency is $\nu_{emi} = 1420.4 MHz$.

2 Mass of the galaxy

- HI mass of the galaxy is given by:

$$\frac{M_H}{M_o} \approx 2.36 \times 10^5 \left(\frac{D}{Mpc}\right)^2 \int \frac{S(v)}{Jy} \frac{dv}{kms^{-1}} \tag{3}$$

The integral $S(v)dv$ over the line is called the line flux.

- The total mass of the galaxy enclosed in a radius r, M(r) assuming the gas orbits in a circular orbit.

$$\frac{GM(r)}{r^2} = \frac{v_{rot}^2}{r} \tag{4}$$

$$v_r = v_{rot} sin\imath \tag{5}$$

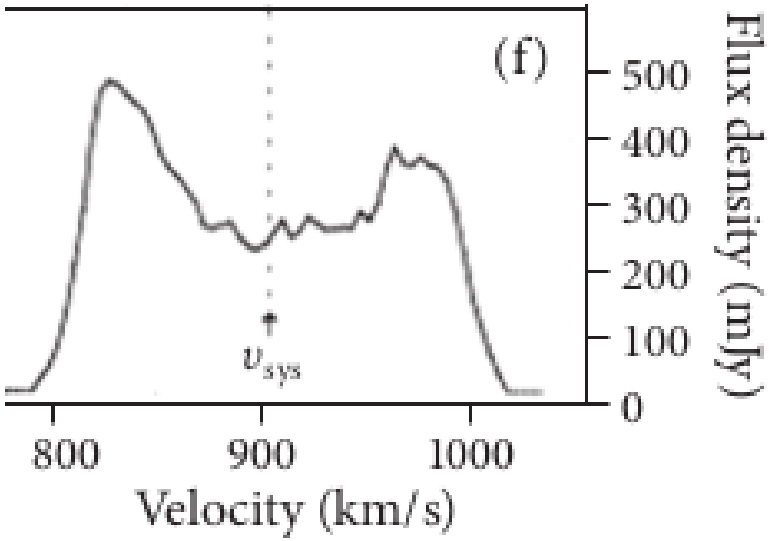
Here $\imath$ is the angle between orientation of galaxy and line of sight.

$$M(r) = \frac{rv_r^2}{G\, sin^2\imath} \tag{6}$$

$$\frac{M}{M_o} \approx 2.3 \times 10^5 \left(\frac{v_r}{km/s}\right)^2 \left(\frac{r}{kpc}\right) \left(\frac{1}{sin\imath}\right)^2 \tag{7}$$

$\imath = 0$ for face on and 90^o for edge on

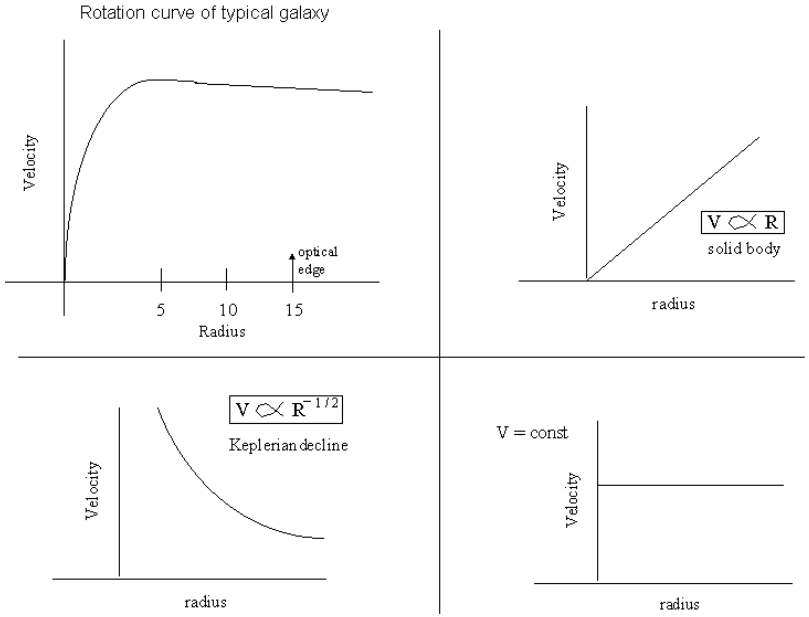
Example: Let's go back to UGC 11707.



$v_r = \Delta v = 200 km/s$
$sin i \approx 0.93 \approx 1$
$r = 12.4 kpc$

Find the mass of the galaxy enclosed in this region.

3 Evidence of Dark Matter



- Most of the galactic mass is concentrated at its centre. In that region, it should behave as a solid body. And when you go out of that region, it should show a Keplerian decline, like we see in our solar system. But most of the galaxies shows a flat rotation curve which implies that mass continues to increase linearly with radius. Mass that is not observed!!

  DARK MATTER!!

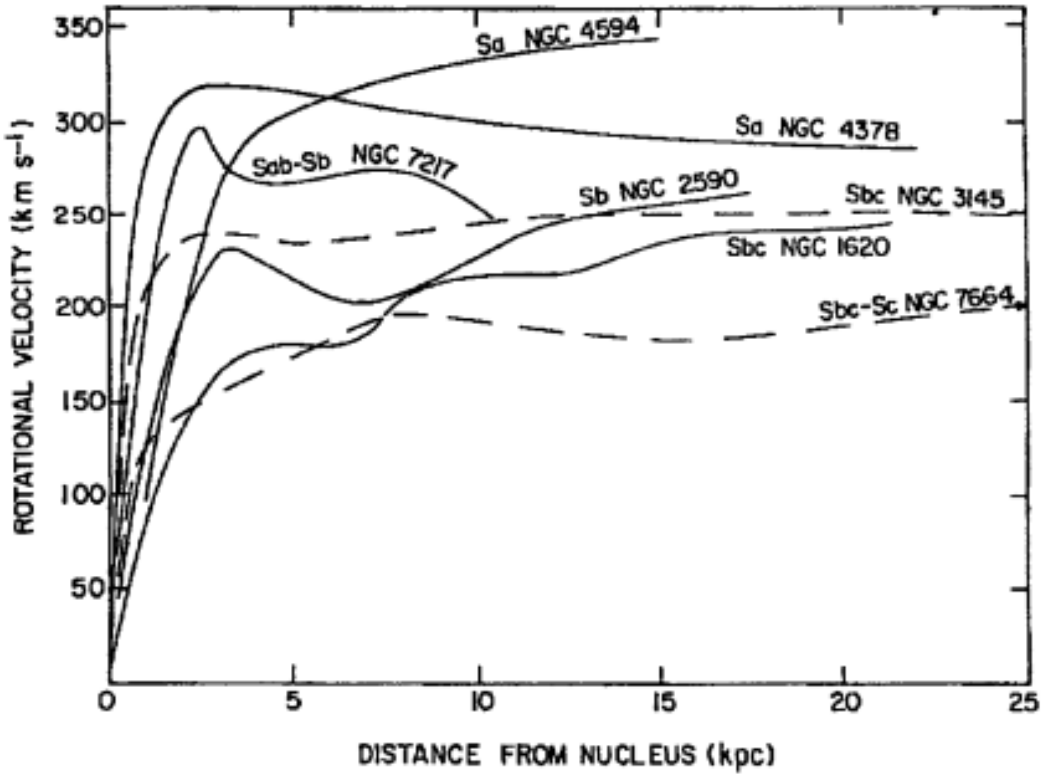


Figure: Rotation curves of different galaxies

- An alternative to the hypothesis of dark matter is the Modified Newtonian Dynamics(MOND). Here, the gravitational force varies inversly with distance and accounts for flat rotation curves of the galaxies.

4 Tully-Fisher Relation

- Brent Tully and Richard Fisher showed that the rotation speed of a galaxy increases with its luminosity roughly as

$$L \propto v_{max}^4 \tag{8}$$

- **Derivation**: Virial theorem $\rightarrow W = 2K$

$$v_{max}^2 = \alpha \frac{GM(R)}{R} \tag{9}$$

The radial surface brightness for a spiral galaxy is given by:

$$I(r) = I_o e^{-r/R} \tag{10}$$

Integrating it over a disk, we will get the luminosity given by:

$$L = 2\pi \int_0^\infty I(r) r dr \tag{11}$$

$$L = 2\pi R^2 I_o \tag{12}$$

Combining eq (9) and (12)

$$L = \frac{2\pi I_o \alpha^2 G^2 M^2}{v_{max}^4} \tag{13}$$

Rearraging

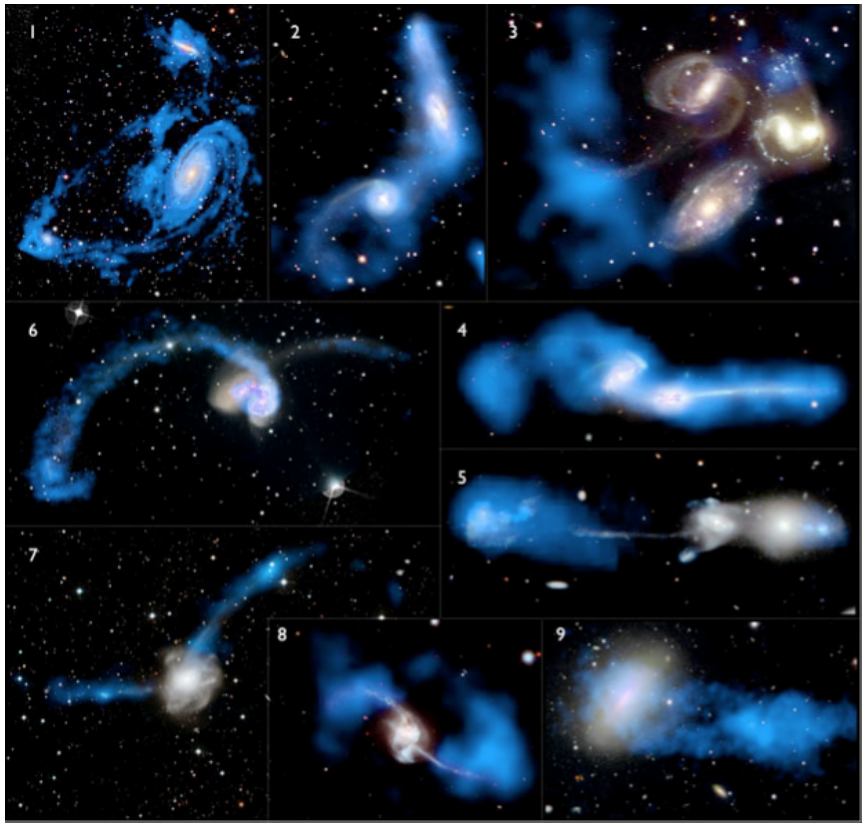
$$v_{max}^4 = 2\pi I_o \alpha^2 G^2 (\frac{M}{L})^2 L \tag{14}$$

- Tully-Fisher relation is only valid for spiral galaxies where $\frac{M}{L}$ is a approximated to be a constant
- Elliptical galaxies obey Faber Jackson relation.

- Tully-Fisher relation can be used to find the distance to the galaxy.
- From the HI profile of the galaxy:
  maximum rotation speed $\rightarrow$ intrinsic luminosity

  Comparing this with the apparent luminosity will give the distance to the galaxy.

5 Tracing Tidal Interactions



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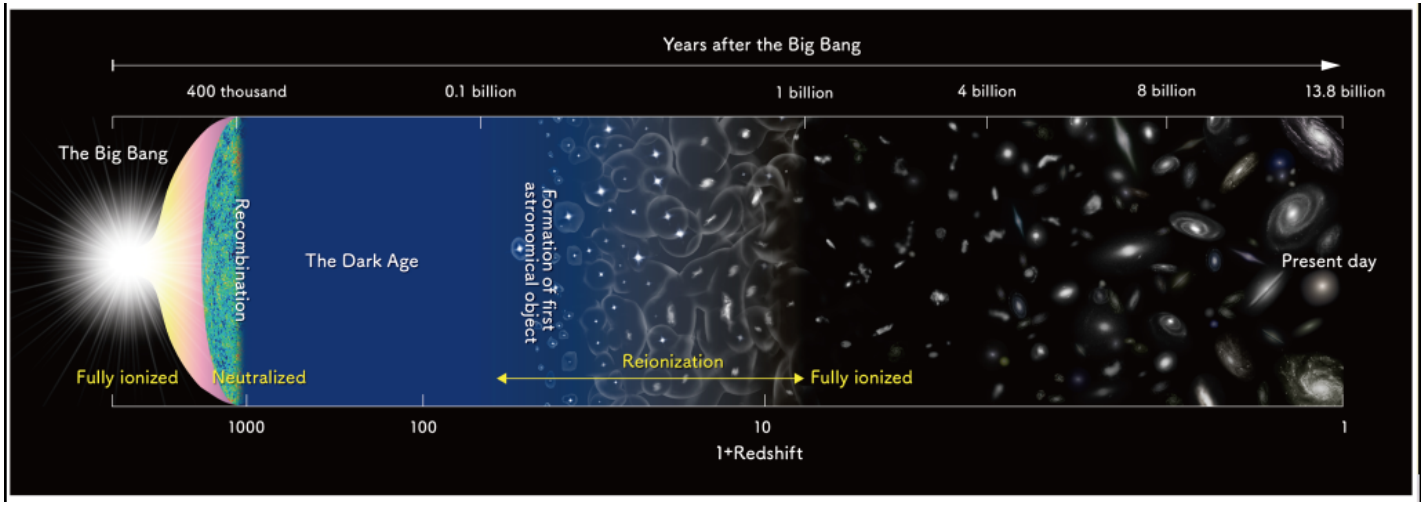
- 70% of the total amount of hydrogen in the galaxy pair is distributed along the tidal tails.
- The HI gas appears as the most massive and principle ingrediant of tidal tail and is an important tracer of tidal interactions of galaxies.

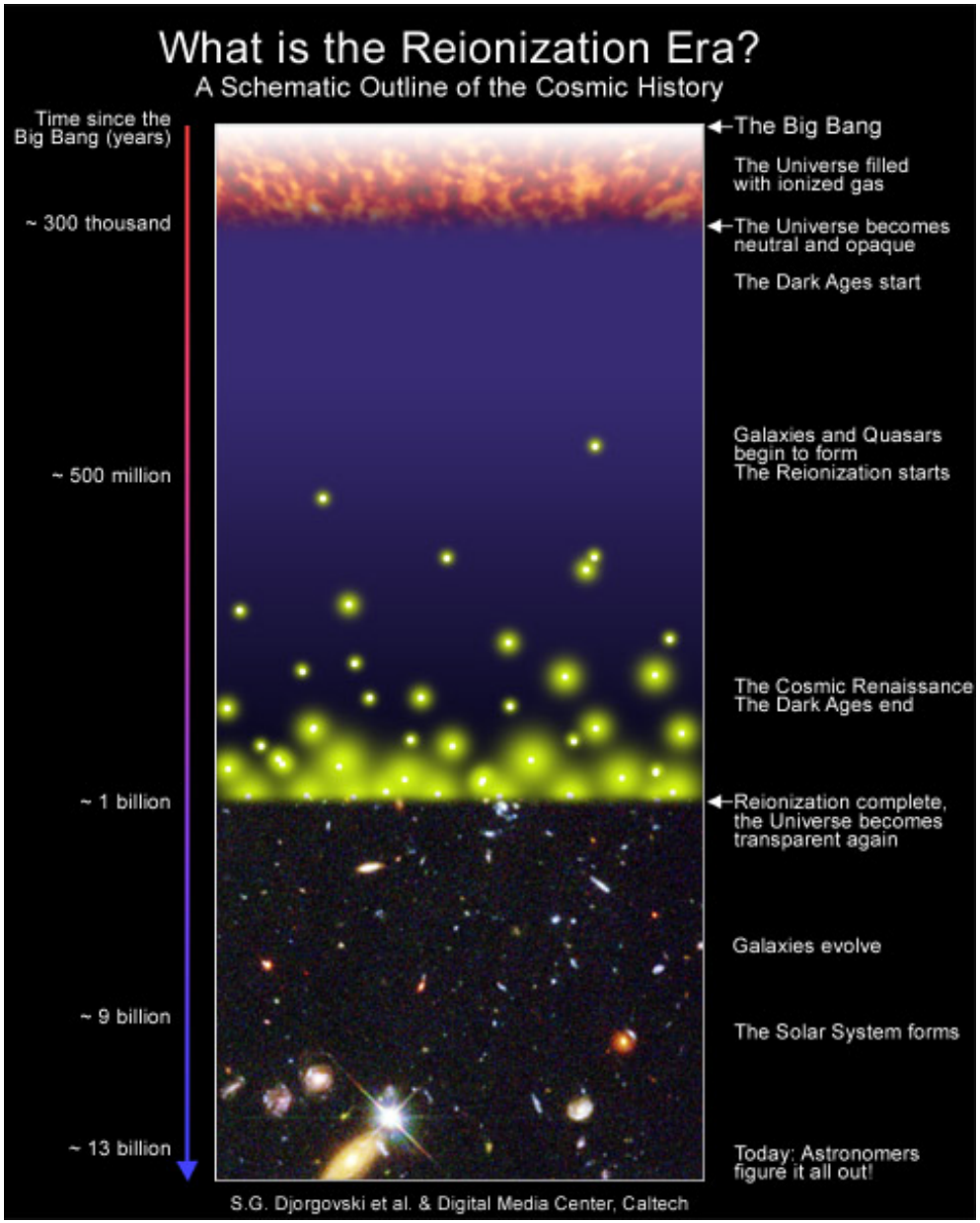
[2] Image credits: P. Duc and F.Renaud

Dark ages and Epoch of Reionization.



- When the universe started cooling after the big bang, the protons and electrons combined to formed hydrogen and some helium. The photons released during that time ($z \approx 1100$) make up the CMB.
- The following period ($1000 > z > 80$) is known as the **Dark Ages**, so called because there were no stars and the universe as essentially Dark!!
- Stars and galaxies form and UV light from these stars reionized the hyrogen atoms around them. The point when most of the neutral hydrogen was reionized is called the **Epoch of Reionization**.
- $z \approx 6$ - 30

- HI 21 cm line is a probe into this epoch of reionization.
- This line is redshifted to $\approx$ 200 MHz.
- Very weak signal!


What is the Reionization Era?
A Schematic Outline of the Cosmic History
Time since the Big Bang (years)
~ 300 thousand
~ 500 million
~ 1 billion
~ 9 billion
~ 13 billion
The Big Bang
The Universe filled with ionized gas
The Universe becomes neutral and opaque
The Dark Ages start
Galaxies and Quasars begin to form
The Reionization starts
The Cosmic Renaissance
The Dark Ages end
Reionization complete, the Universe becomes transparent again
Galaxies evolve
The Solar System forms
Today: Astronomers figure it all out!
S.G. Djorgovski et al. & Digital Media Center, Caltech


Aliens??