# Introduction to Astrophysics and Cosmology

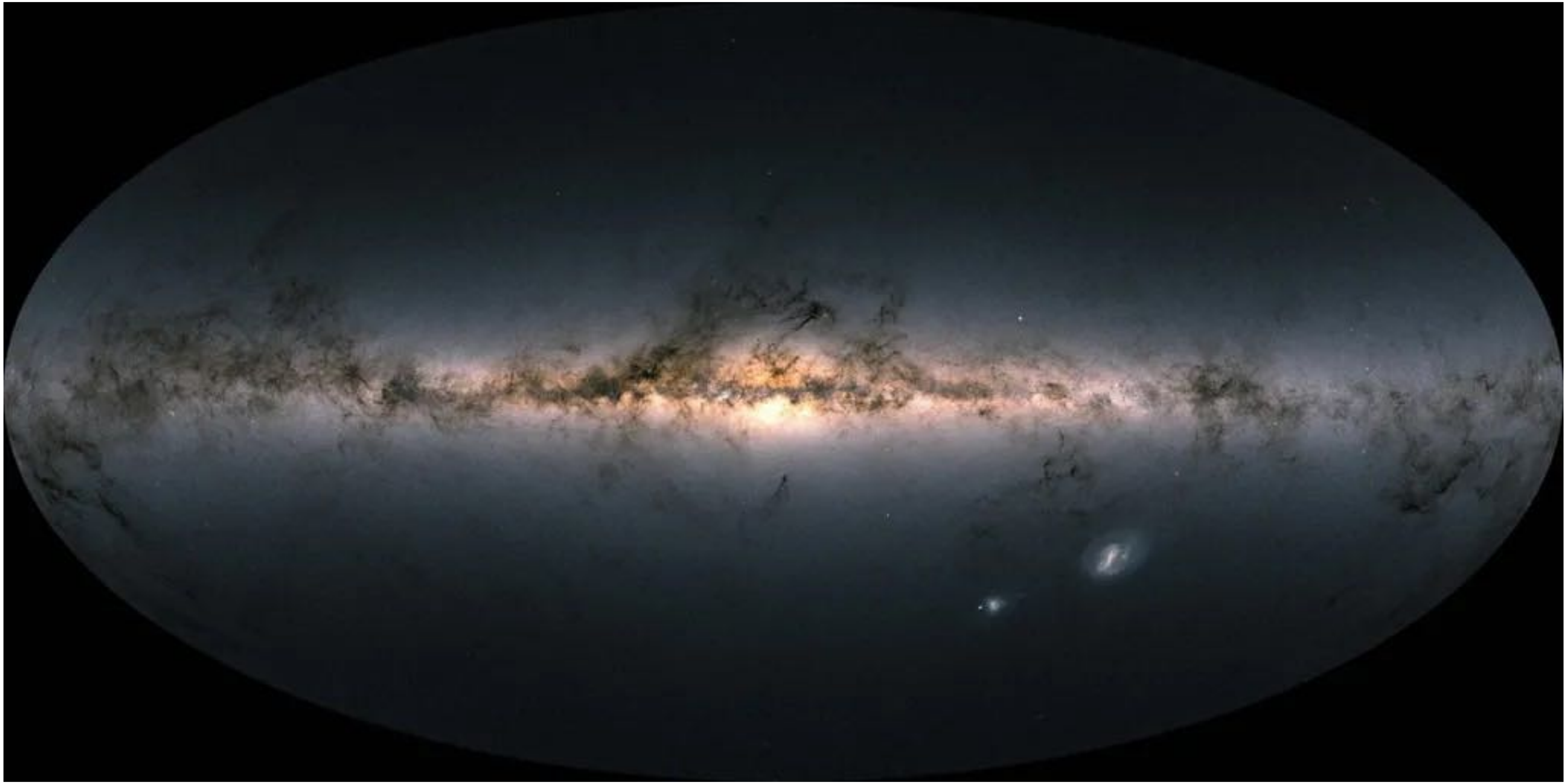
## Extragalactic astrophysics

**Helga Dénes 2025 S1 Yachay Tech**

hdenes@yachaytech.edu.ec

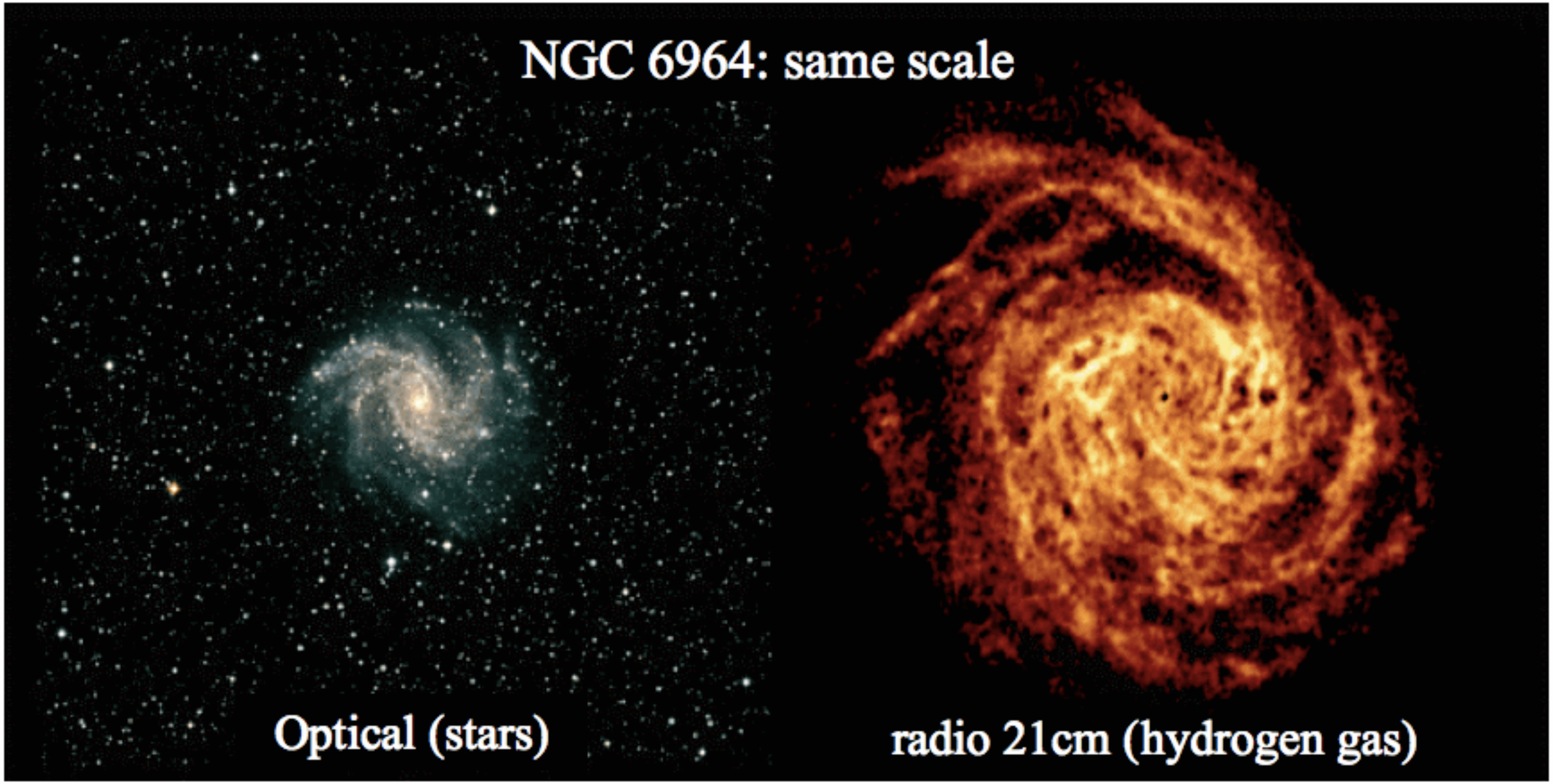
# The Milky Way

Stars and dust in the Milky Way
The dust is part of the interstellar medium

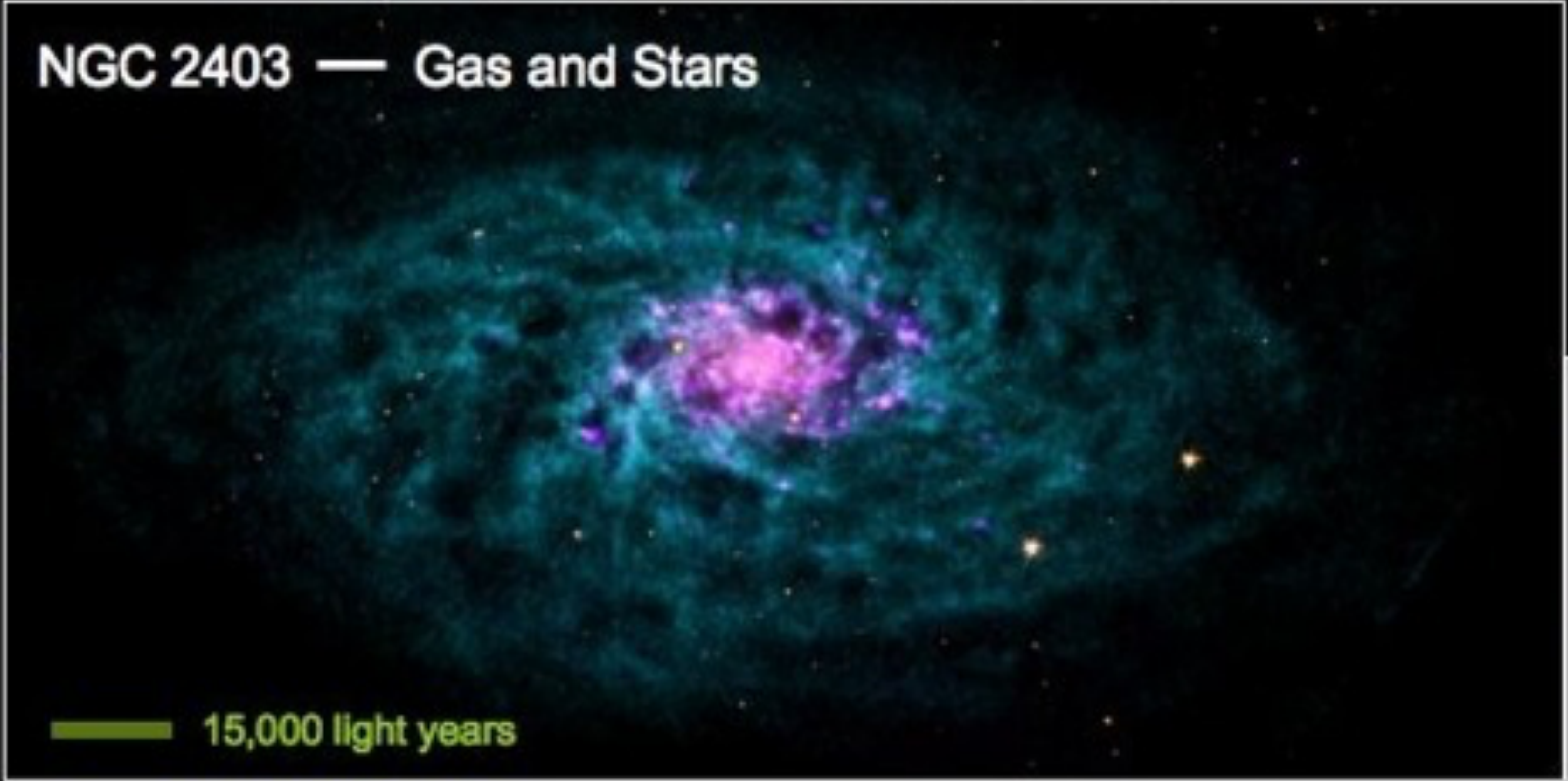


# A typical spiral galaxy

Face-on view of a spiral galaxy

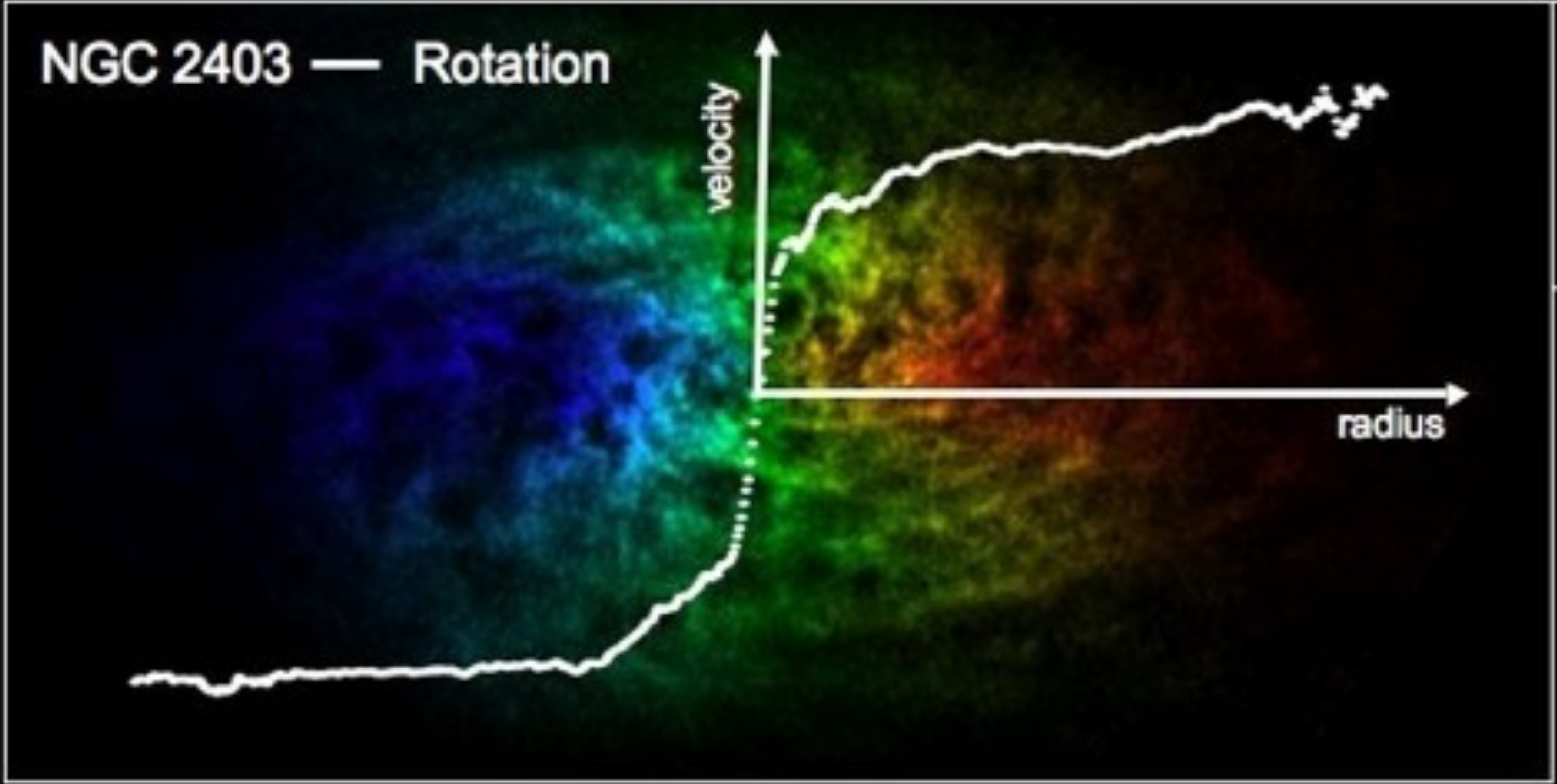


# Galaxy Dynamics in THINGS — The HI Nearby Galaxy Survey




THINGS
The HI Nearby Galaxy Survey

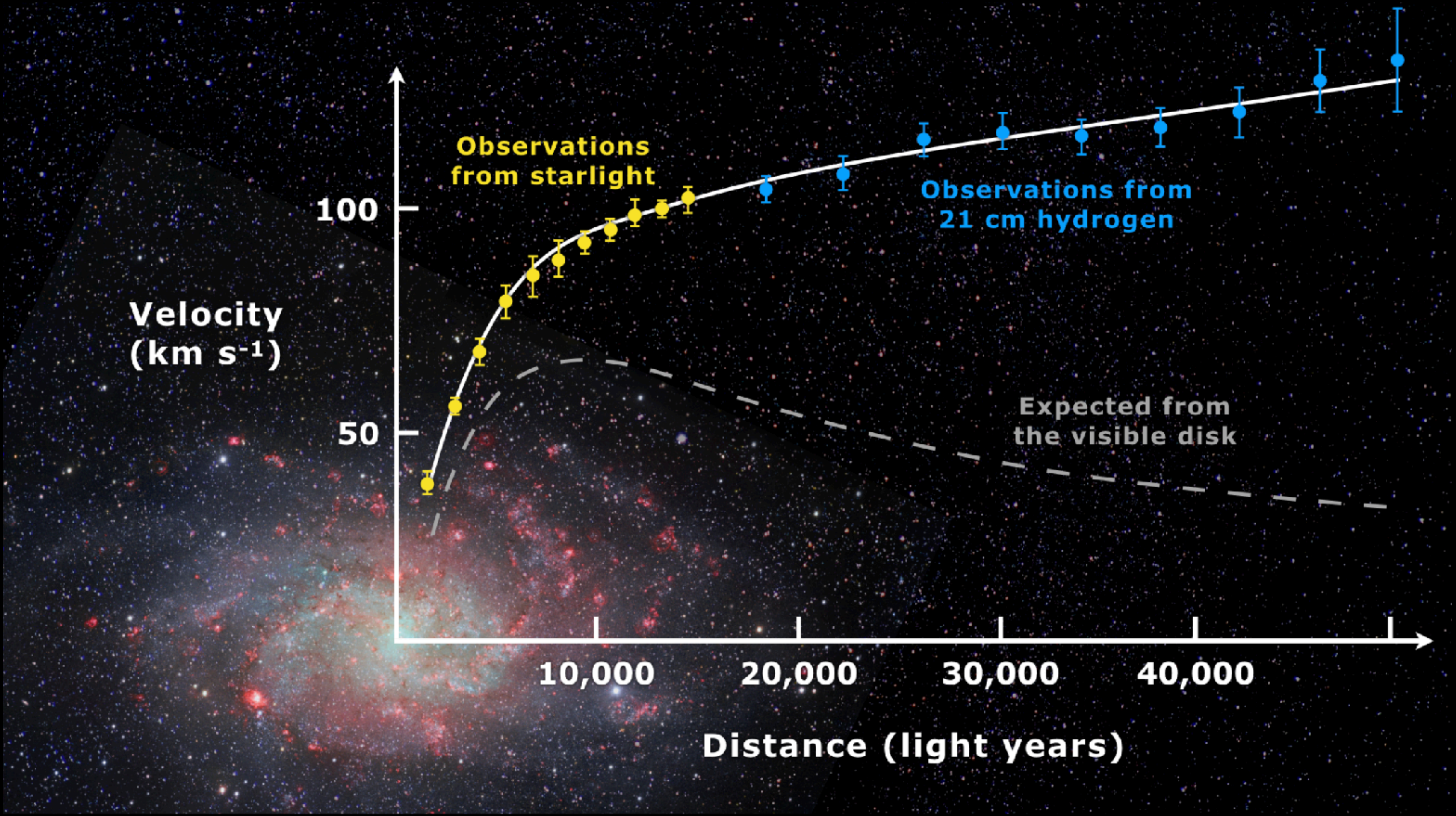
Color Coding:
THINGS Atomic Hydrogen
*(Very Large Array)*
Old stars
*(Spitzer Space Telescope)*
Star Formation
*(GALEX & Spitzer)*




Color coding:
THINGS HI distribution:
Red-shifted (receding)
Blue-shifted (approaching)
Rotation Curve

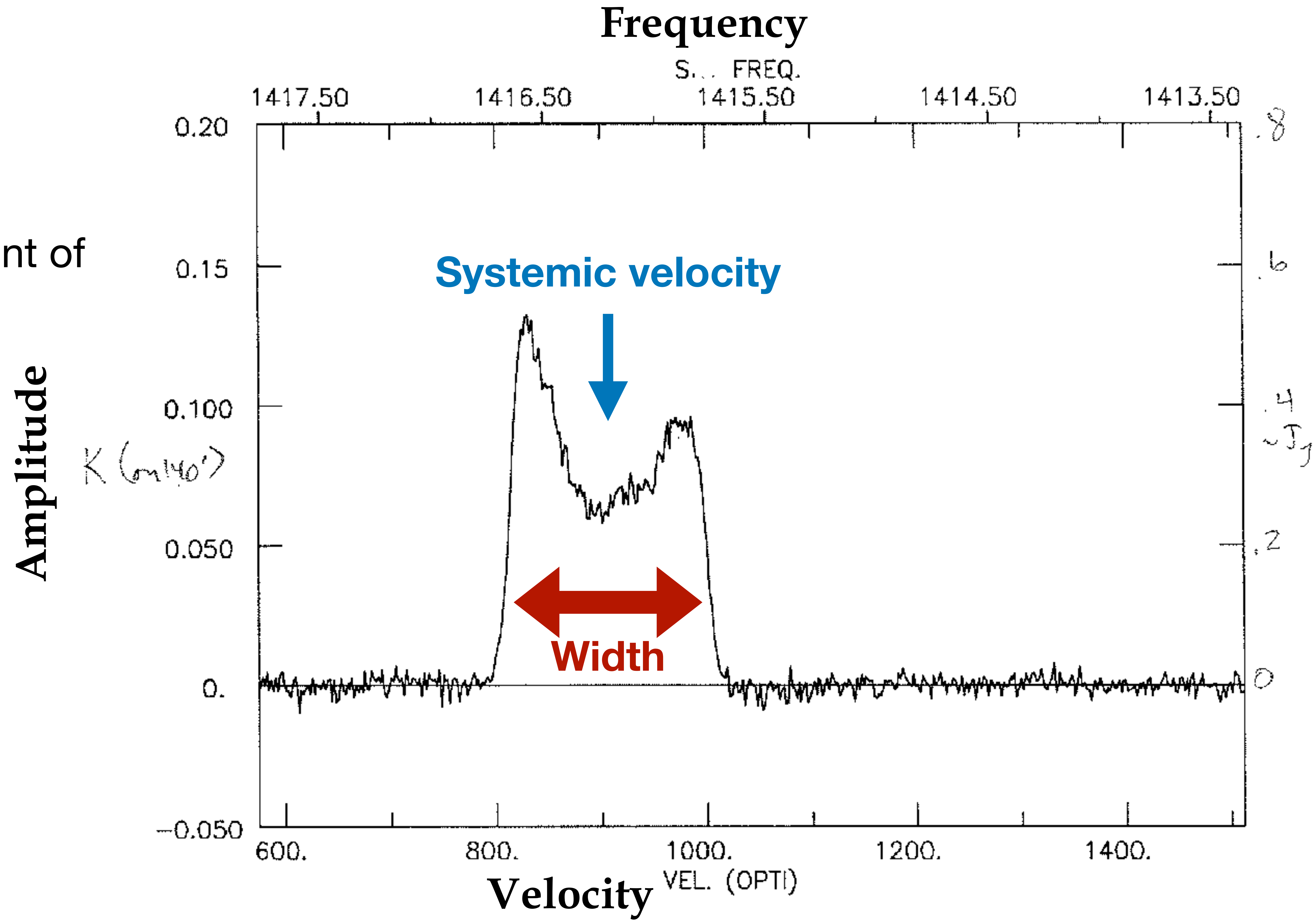
Image credits:
*VLA THINGS:* Walter et al. 08
*Spitzer SINGS:* Kennicutt et al. 03
*GALEX NGS:* Gil de Paz et al. 07
*Rotation Curve:* de Blok et al. 08

# Rotation curve



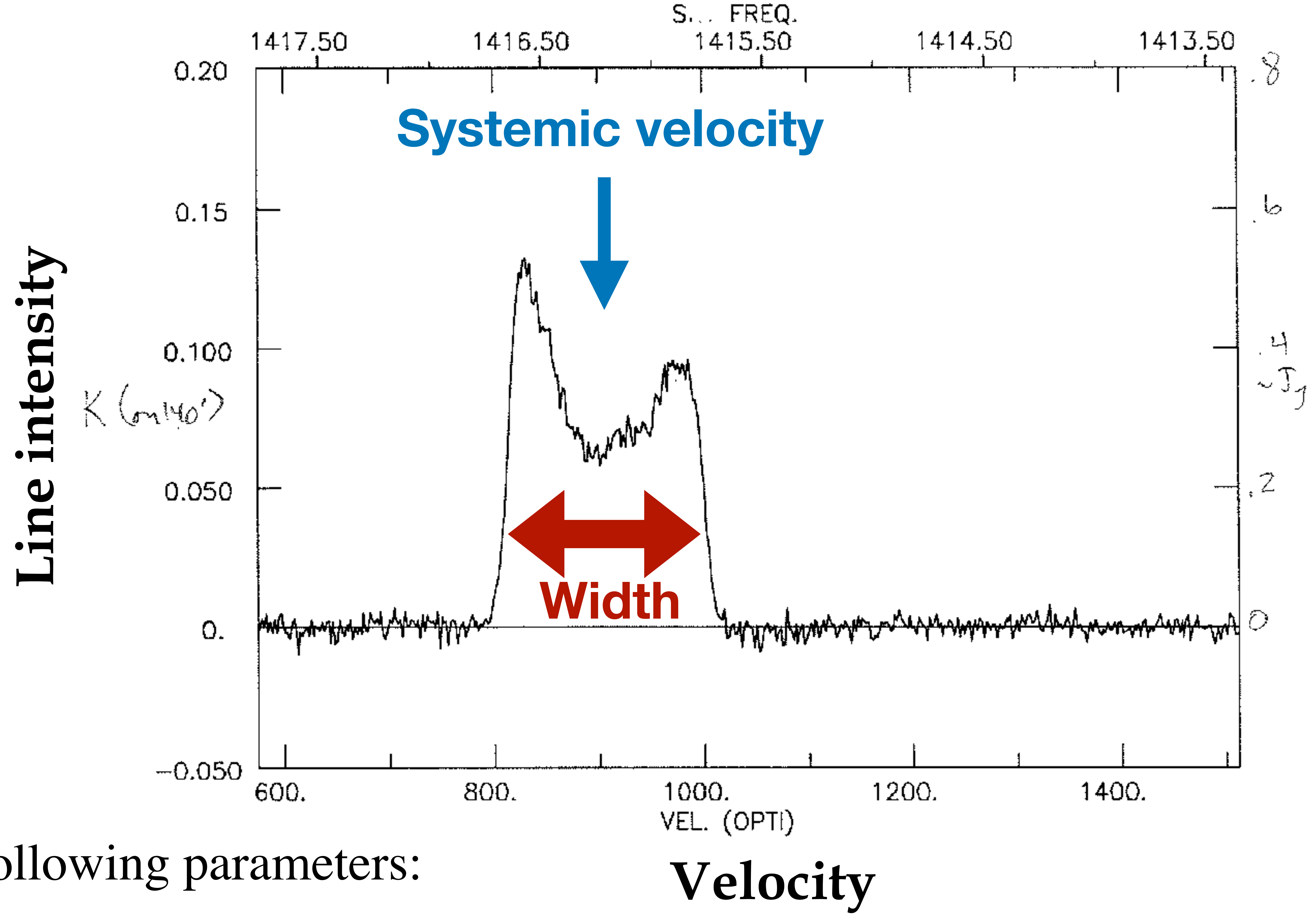
# HI in spiral galaxies

UGC 11707 is a very blue spiral galaxy, indicative of a large amount of HI in the galaxy




HI profile of UGC 11707
https://www.cv.nrao.edu/~sransom/web/Ch7.html

# HI in spiral galaxies




We use the HI profiles of galaxies to calculate the following parameters:

1. The midpoint of the emission profile in km/s, yields the **systemic velocity** of the galaxy → **distance** using Hubble's law.
2. The **total HI line flux** → total **HI mass**.
3. The observed width of the HI line profile, in km/s, gives the **observed Doppler broadening** due to the galaxy's **rotation** → **dynamical mass**.

# HI in spiral galaxies

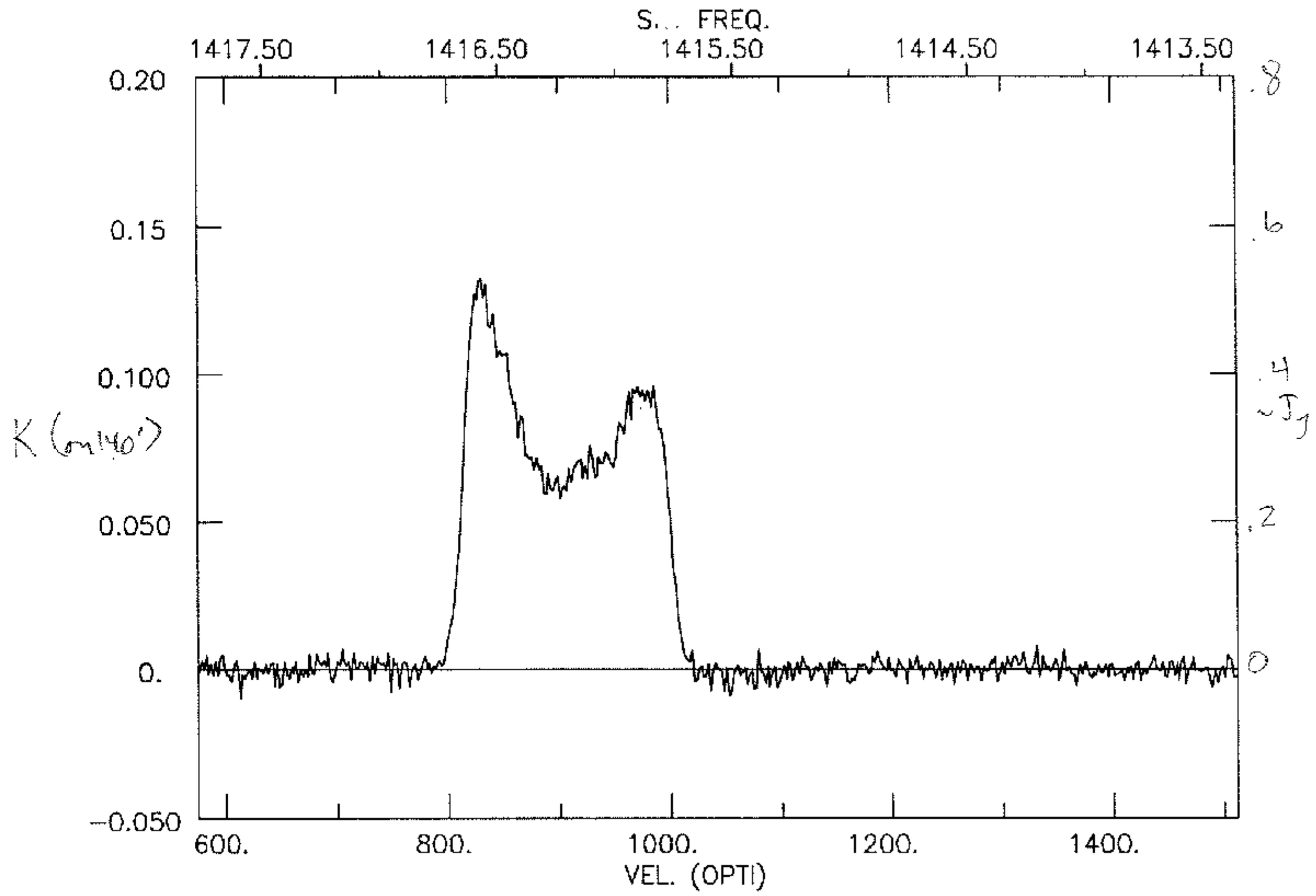
**Line intensity is proportional to HI mass, if the gas is optically thin $\tau << 1$**

$$\left(\frac{M_{\mathrm{H}}}{M_{\odot}}\right) \approx 2.36 \times 10^{5} \left(\frac{D}{\mathrm{Mpc}}\right)^{2} \int \left[\frac{S(v)}{\mathrm{Jy}}\right] \left(\frac{dv}{\mathrm{km\ s^{-1}}}\right)$$

HI mass of a galaxy — Distance — Integrated intensity

**Hubble flow distance** to the galaxy, based on the redshift of the line: $D = v/H_0$

Where $v$ is the velocity of the line centre (recession velocity) and $H_0$ is the Hubble constant.

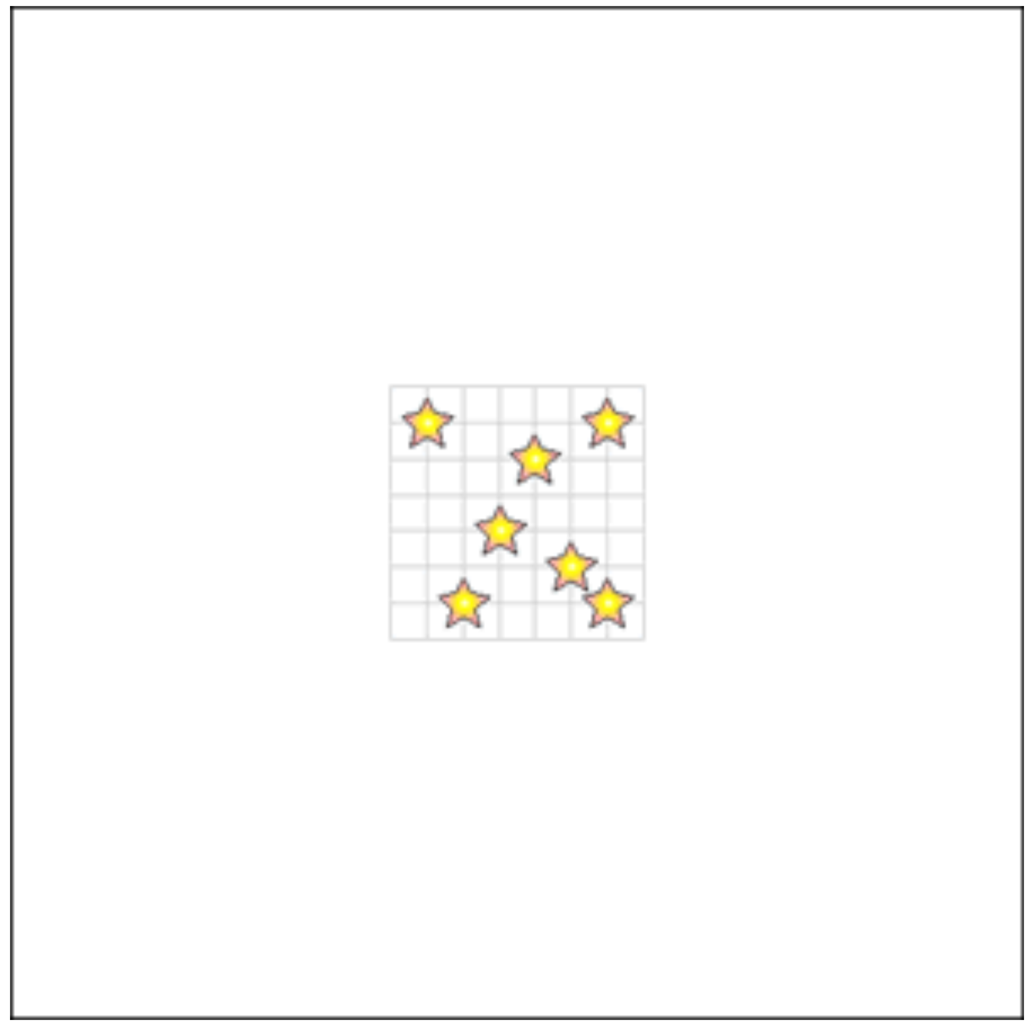


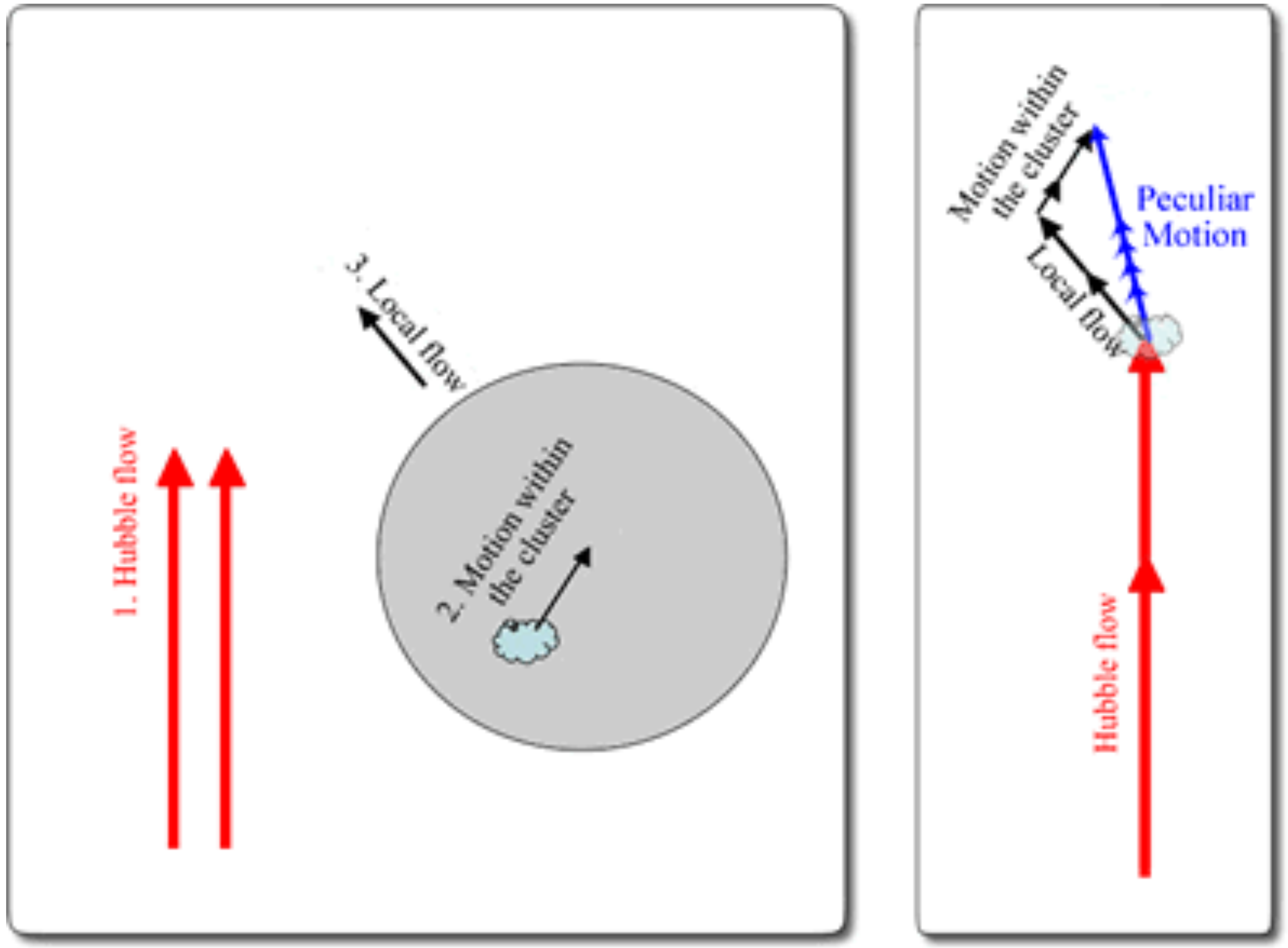

HI profile of UGC 11707
https://www.cv.nrao.edu/~sransom/web/Ch7.html

# Hubble flow

The **‘Hubble flow’ describes the motion of galaxies due solely to the expansion of the Universe.** The idea of the expanding Universe was first put forward by Edwin Hubble in 1929, after observing a **correlation between the redshifts of galaxies and their distances measured** using the period-luminosity relationship for Cepheid variable stars. Hubble found that all galaxies were moving away from us, and that the velocity of their recession was proportional to their distance from us, this is called the **Hubble Law:**
$v = H_0 \times D$

The motions of galaxies are influenced by more than just the Hubble flow. The net motions of galaxies are comprised of the Hubble flow, the local flow, and the motion of the galaxy within its cluster and/or group environment. These deviations from the pure Hubble flow are referred to as **peculiar motions**.

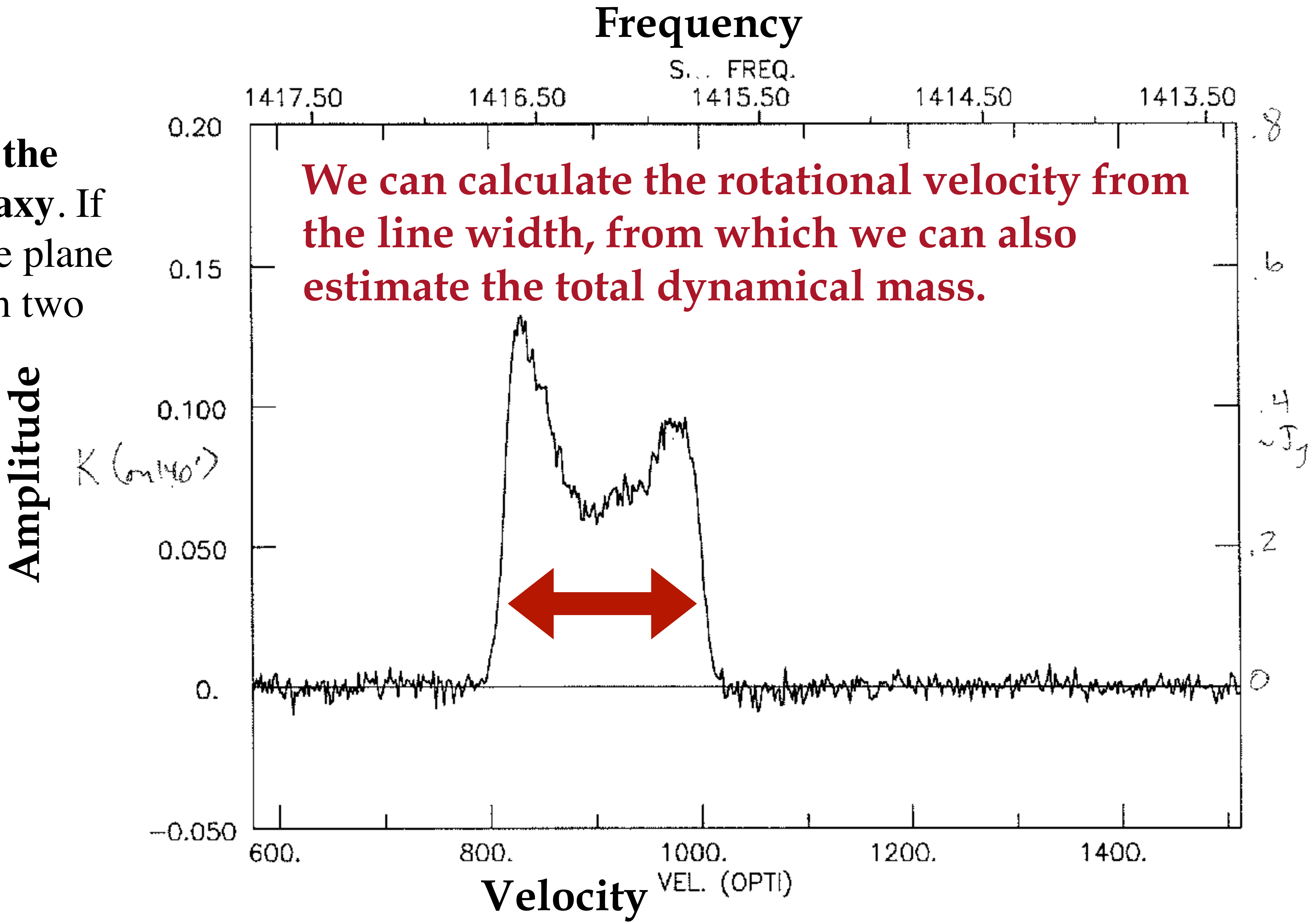





https://astronomy.swin.edu.au/cosmos/h/hubble+flow

# HI in spiral galaxies

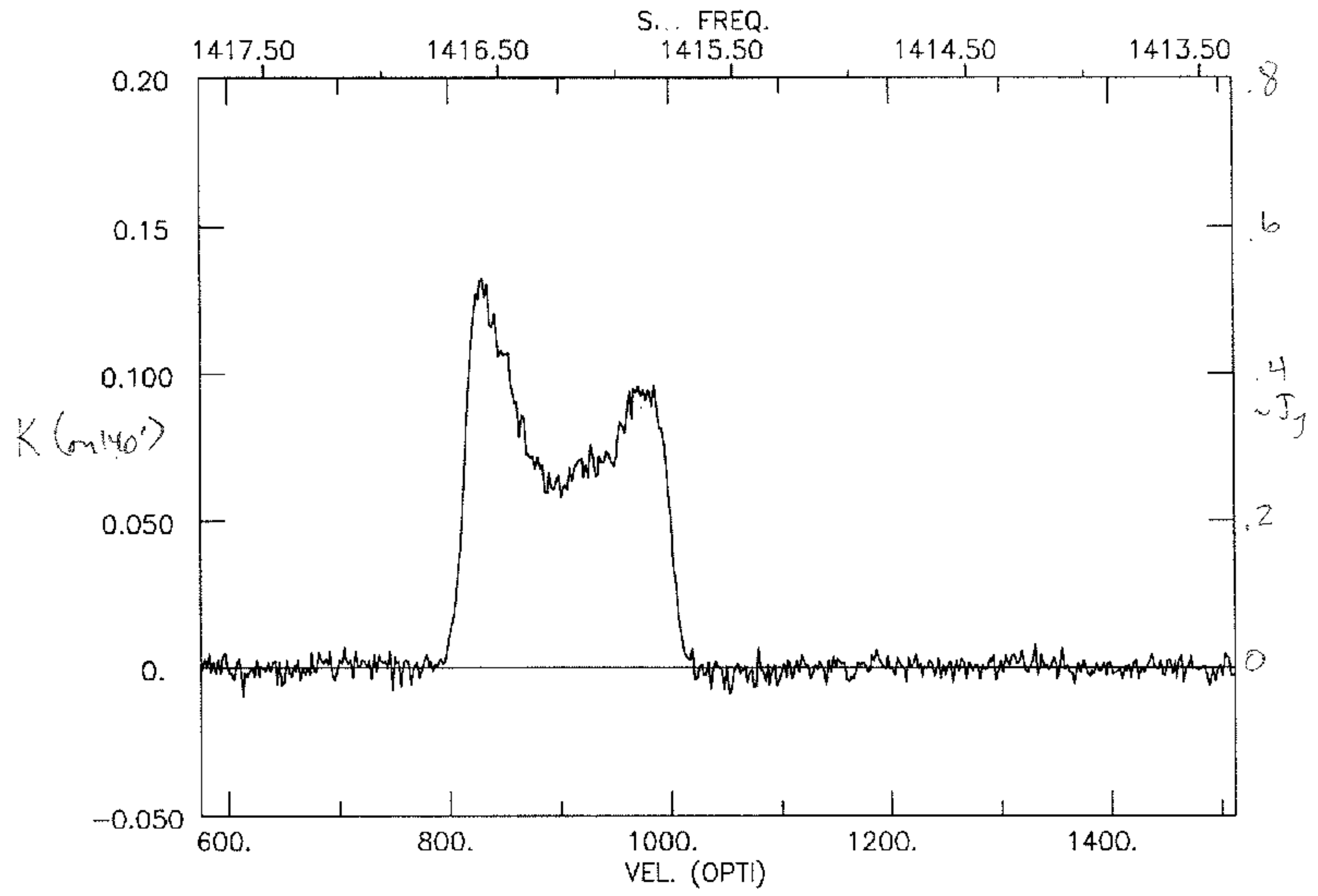
The **shape of the HI line is due to the gas rotating in the disk of the galaxy**. If a galaxy is inclined compared to the plane of the sky, we see a line profile with two peaks.




**We can calculate the rotational velocity from the line width, from which we can also estimate the total dynamical mass.**

HI profile of UGC 11707
https://www.cv.nrao.edu/~sransom/web/Ch7.html

# HI in spiral galaxies




$$v(r) = \frac{v_r(r)}{\sin i}$$

- Where $v(r)$ is the rotational velocity at radius r,
- $v_r(r)$ is the tangential component of the rotational velocity, contributing to the width of the line profile,
- And $i$ is the inclination of the galaxy compared to the plane of the sky. The inclination is proportional to the axis ratio of the galaxy.

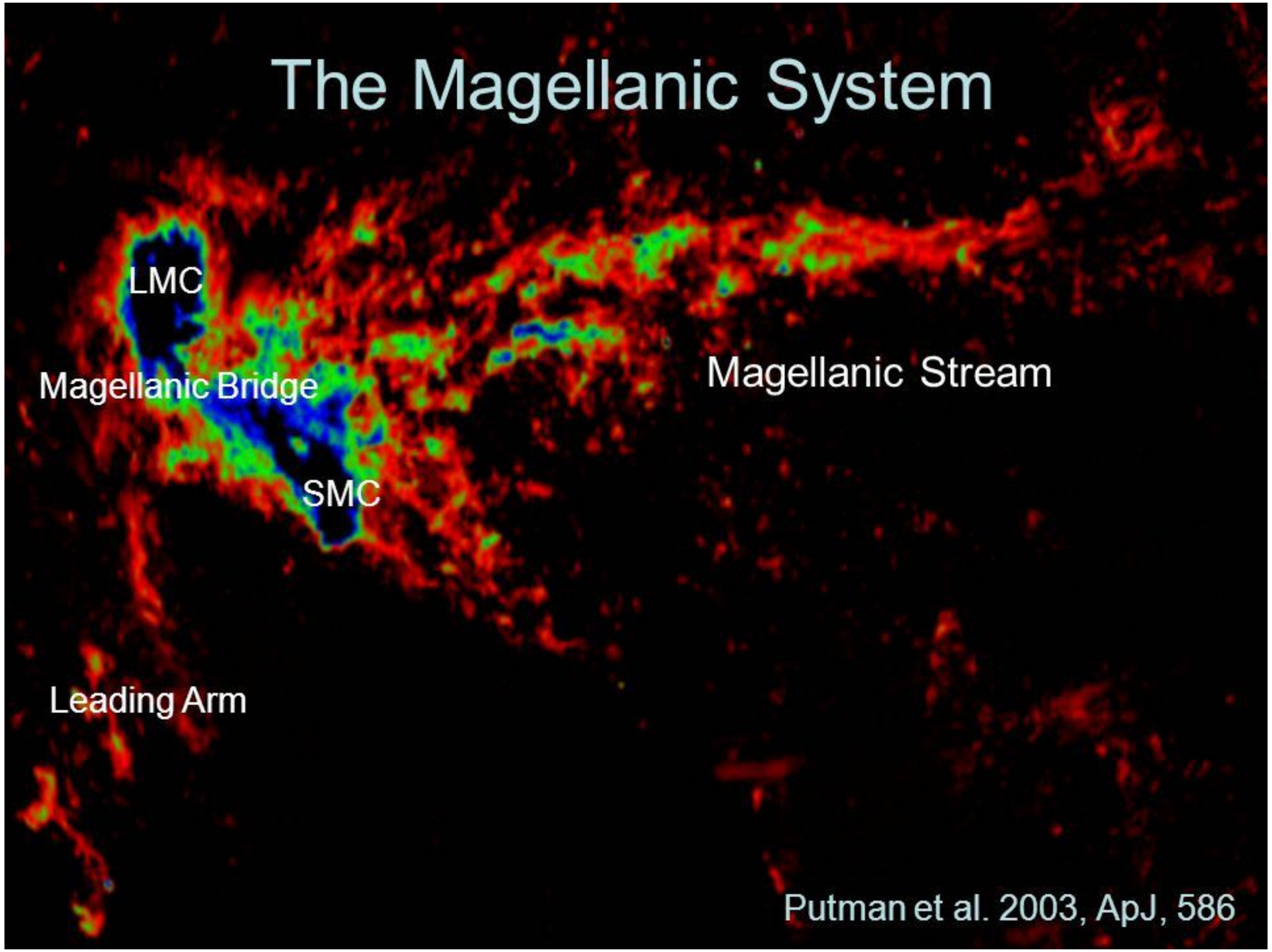
The galaxies **dynamical mass inside a radius r** is:

$$\left(\frac{M}{M_\odot}\right) \approx 2.3 \times 10^5 \left(\frac{v}{\mathrm{km\ s^{-1}}}\right)^2 \left(\frac{r}{\mathrm{kpc}}\right)$$

Here $v$ is the rotational velocity at radius r.

# Tidal interactions

HI image




Optical image

# Tidal interaction

Arp 87

The galaxy on the left is accreting material from the galaxy on the right.
The captured material is starting to form a polar ring.

# More extreme tidal interactions

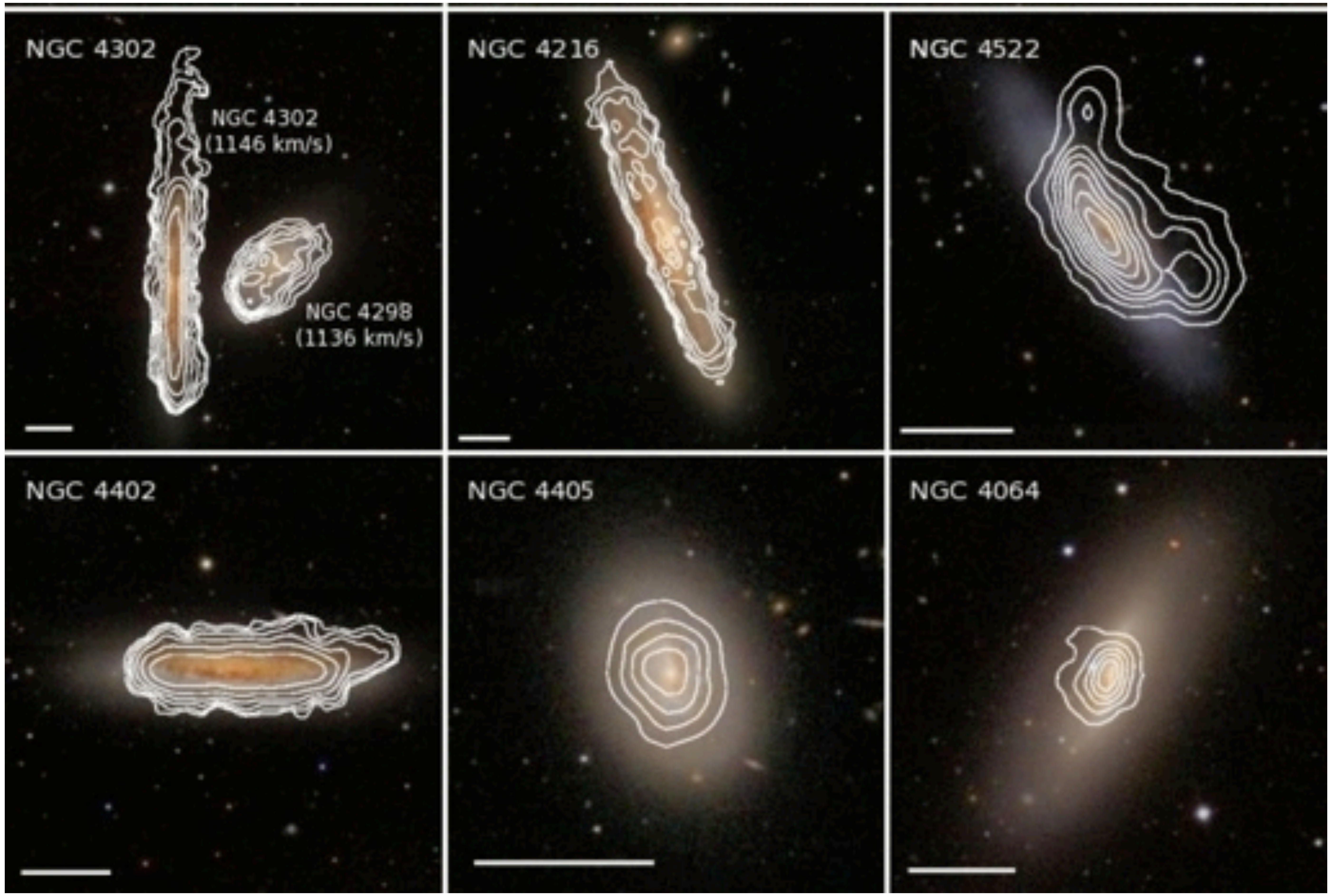
The antenna galaxy is two **merging spiral galaxies** with tails of stars created by the tidal interaction.

Optical image - gas and stars

Zoom in to the central region

# Gas removal in galaxy clusters

Galaxies in the Virgo cluster, optical image + HI contours.
They have significantly smaller HI disks compared to galaxies not in clusters.




Gas removal processes in galaxy clusters:

- Tidal interactions
- Ram pressure stripping
- Starvation

**Extreme gas removal can eventually transform a spiral galaxy into an elliptical galaxy.** -> reason for morphology - density relation in galaxy clusters.

# The Virgo galaxy cluster