Pattern Speed determination of the NGC 2903 galaxy through molecular and HI data

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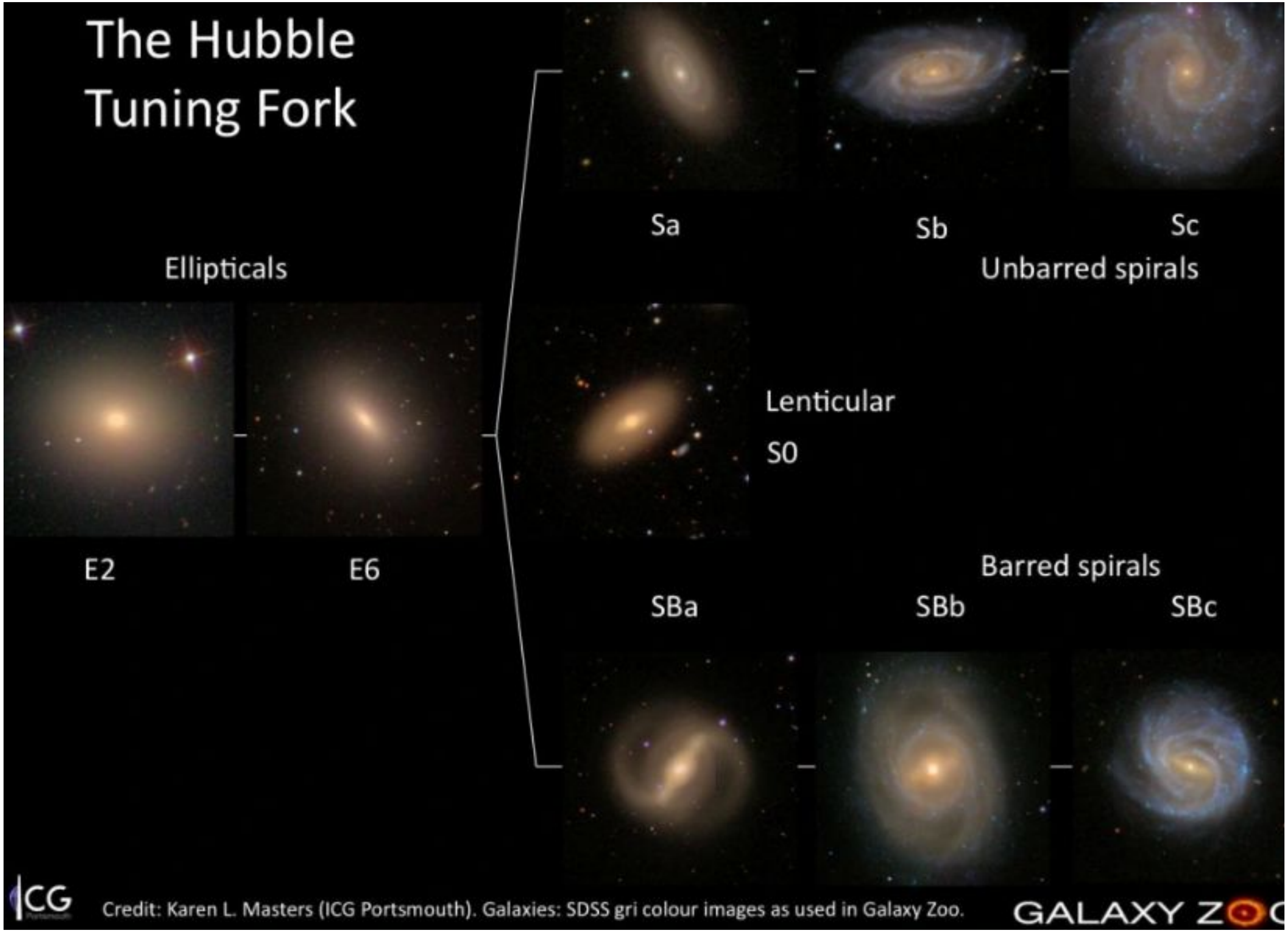

The Hubble
Tuning Fork
Ellipticals
E2
E6
Sa
Sb
Sc
Unbarred spirals
Lenticular
S0
Barred spirals
SBa
SBb
SBc
ICG
Credit: Karen L. Masters (ICG Portsmouth). Galaxies: SDSS gri colour images as used in Galaxy Zoo.
GALAXY ZO

Spiral and barred galaxies

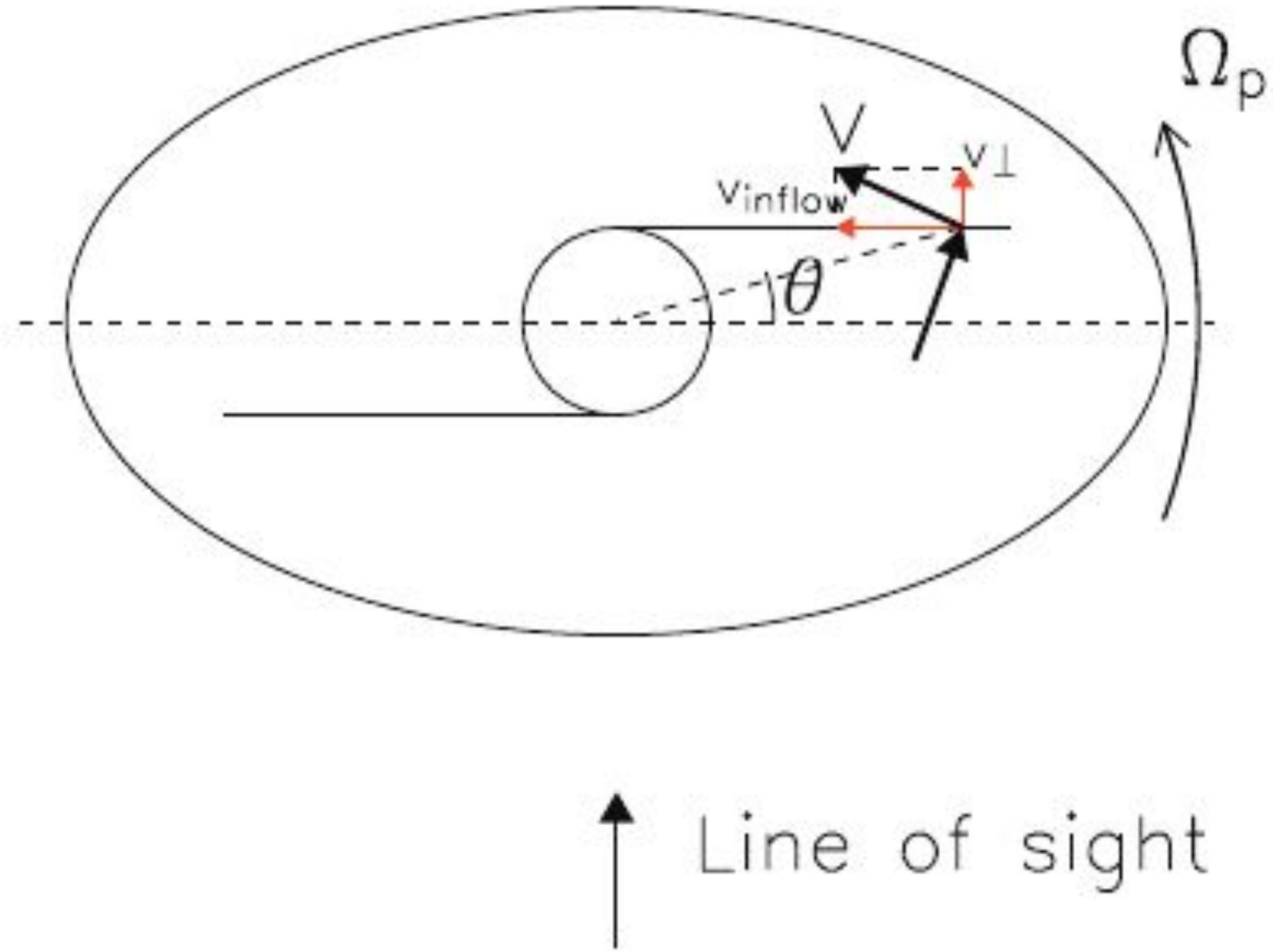
NGC 1300, credit: Hubble Space Telescope.

The bar

Schematic diagram of gas motion in the bar region.

The dashed line represents the major axis of the bar, and the two solid lines parallel to the major axis represent the offset ridges. For simplicity, the offset ridges are assumed to be parallel to the major axis of the bar. The thick solid arrow indicates the motion of the gas cloud.

The figure was gathered from Hirota et al. (2019)



Why is it important to characterize the bar?

Bars are connected to different physical processes such as :

- The outward transfer of angular momentum (Binney & Tremaine 1987),
- the growth of a pseudobulge linked to secular evolution (e.g., Combes & Elmegreen 1993; Kormendy & Kennicutt 2004; Sellwood 2014; Salak et al. 2017),
- the inflow of gas resulting in an enhanced nuclear star formation (Aguerri et al. 1999),
- the central fueling of an AGN (Shlosman et al. 1989; Friedli & Martinet 1993),
- Dynamical friction between the bar and the dark matter halo (Debattista & Sellwood 1998).

The NGC 2903 galaxy

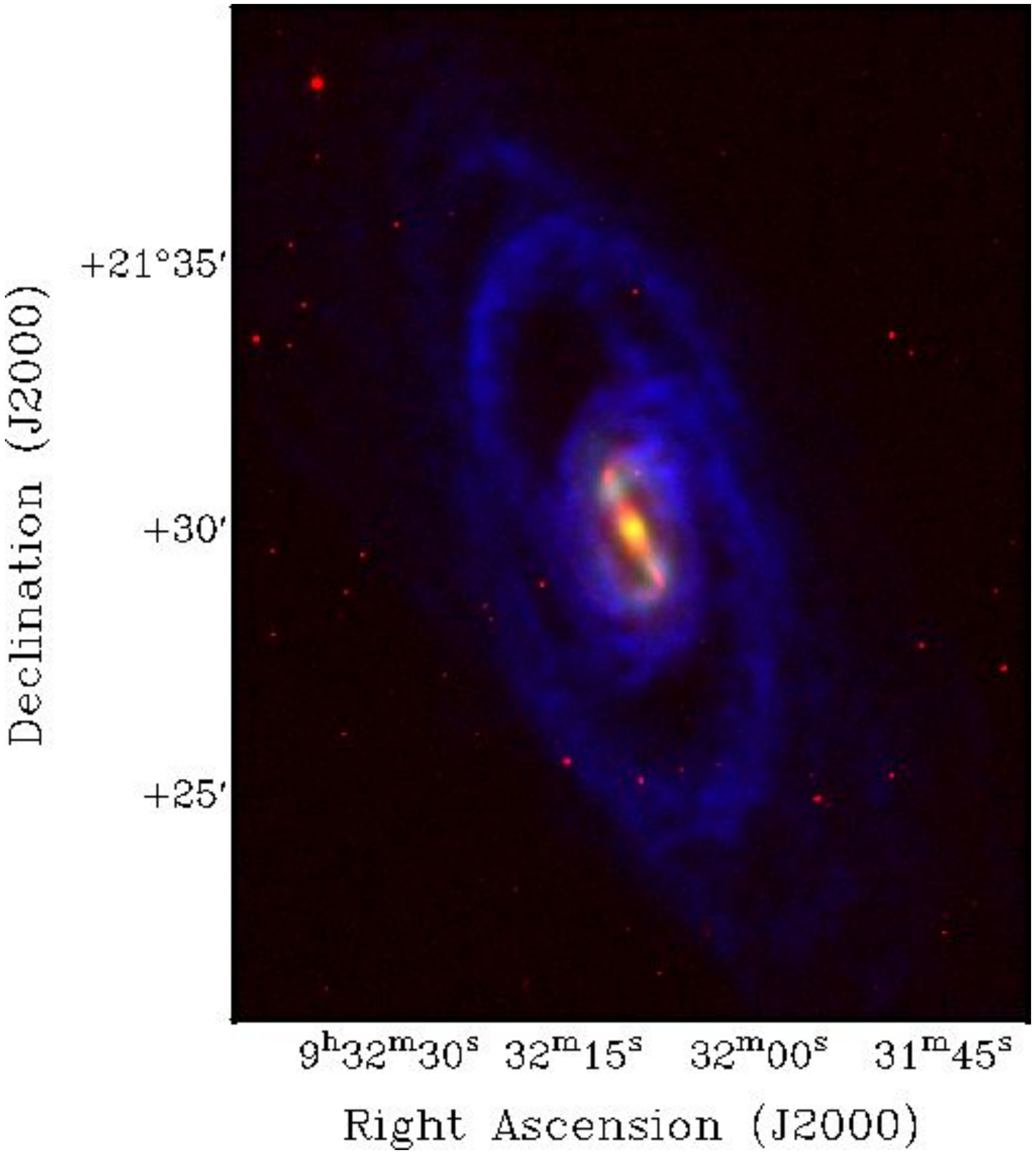
Parameters	Values	Ref.
Morphology type	SAB(rs)bc	(1)
RA (J2000) [h m s]	09:32:10.11	(1)
DEC (J2000) [° ′ ″]	+21:30:03.0	(1)
D [Mpc]	10	(2)
m_{B} [mag]	9.59	(1)
r_{25} [arcmin]	5.9	(1)
i [deg]	66.8	(1)
PA [deg]	203.7	(1)
v_{sys} [km s^{-1}]	556.6	(1)

References: (1) Walter et al. (2008); (2) Tully et al. (2009)

Data available

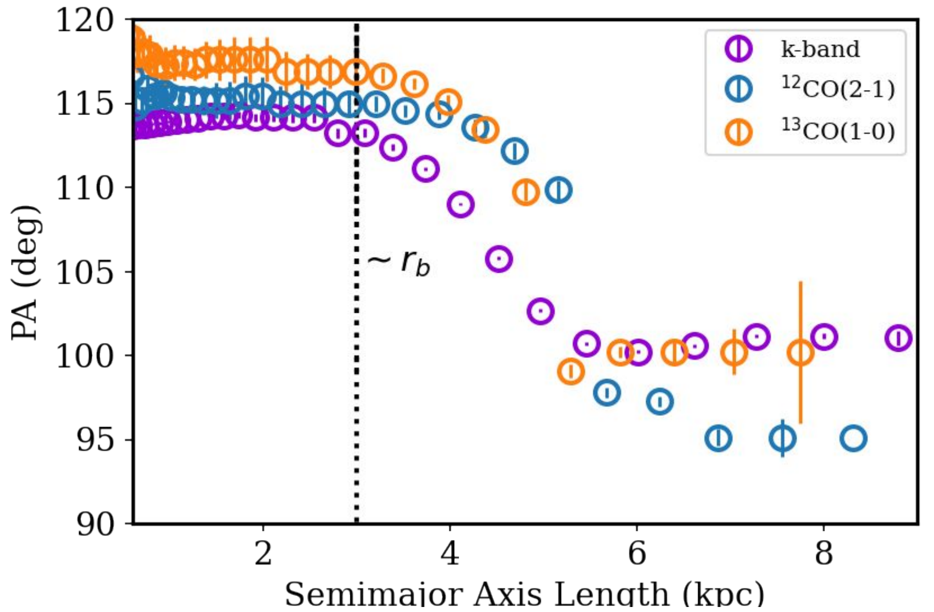
Species	ν_{rest} [GHz]	η_{crit} [cm^{-3}]	beam size ["]	rms [mK]
$^{12}CO(2-1)$	230.5	4×10^2	21.8	2.3
$^{13}CO(1-0)$	110.20	4×10^2	26.1	0.3
HCN(1 − 0)	88.63	2×10^5	33.3	0.1
				$[\frac{mJy}{beam}]$
H I	1.4		10×8.6	0.36

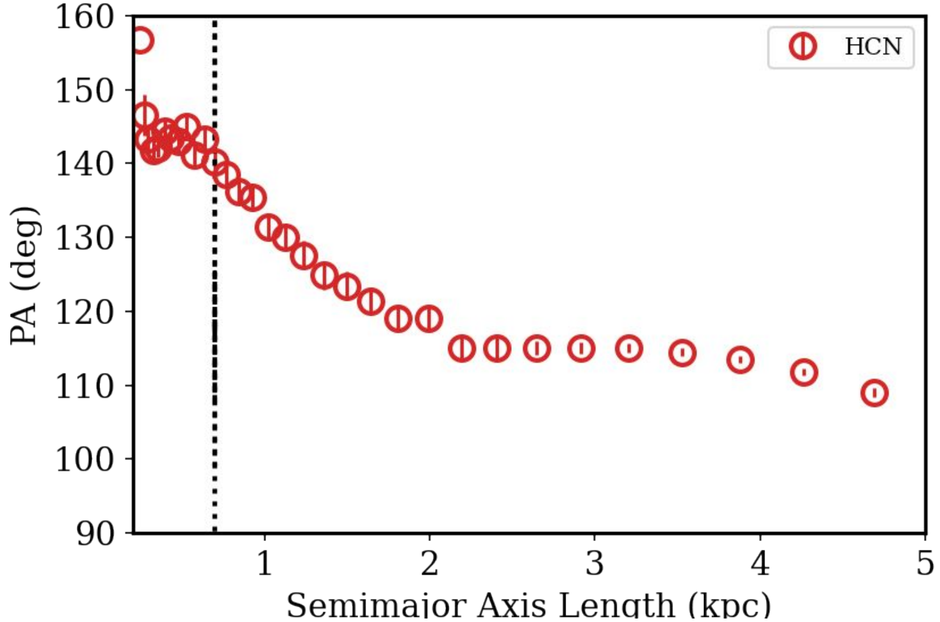
References: Jiménez-Donaire et al. (2019); Walter et al. (2008)



Multi-wavelength colour-composite image of the galaxy NGC 2903 obtained using the 2 MASS image ks-band (red), 12CO(2 − 1) (green), and HI (blue).

Preliminary results





<u>Bar length</u>

- The length of the gaseous bar is one of the critical physical parameters. However, unlike stellar bars, the gas bars generally do not exhibit strongly ordered structures and are highly susceptible to external perturbations leading to disturbed morphology.

- Here we show the results obtained using the PA variation method. The result agrees with previous works present in the literature.

The Tremaine & Weinberg method

The method is applied directly to astronomical observables, the surface brightness distribution of a tracer, and its radial velocity field.

The method relies on three main assumptions:

1) the disk of the galaxy is flat,

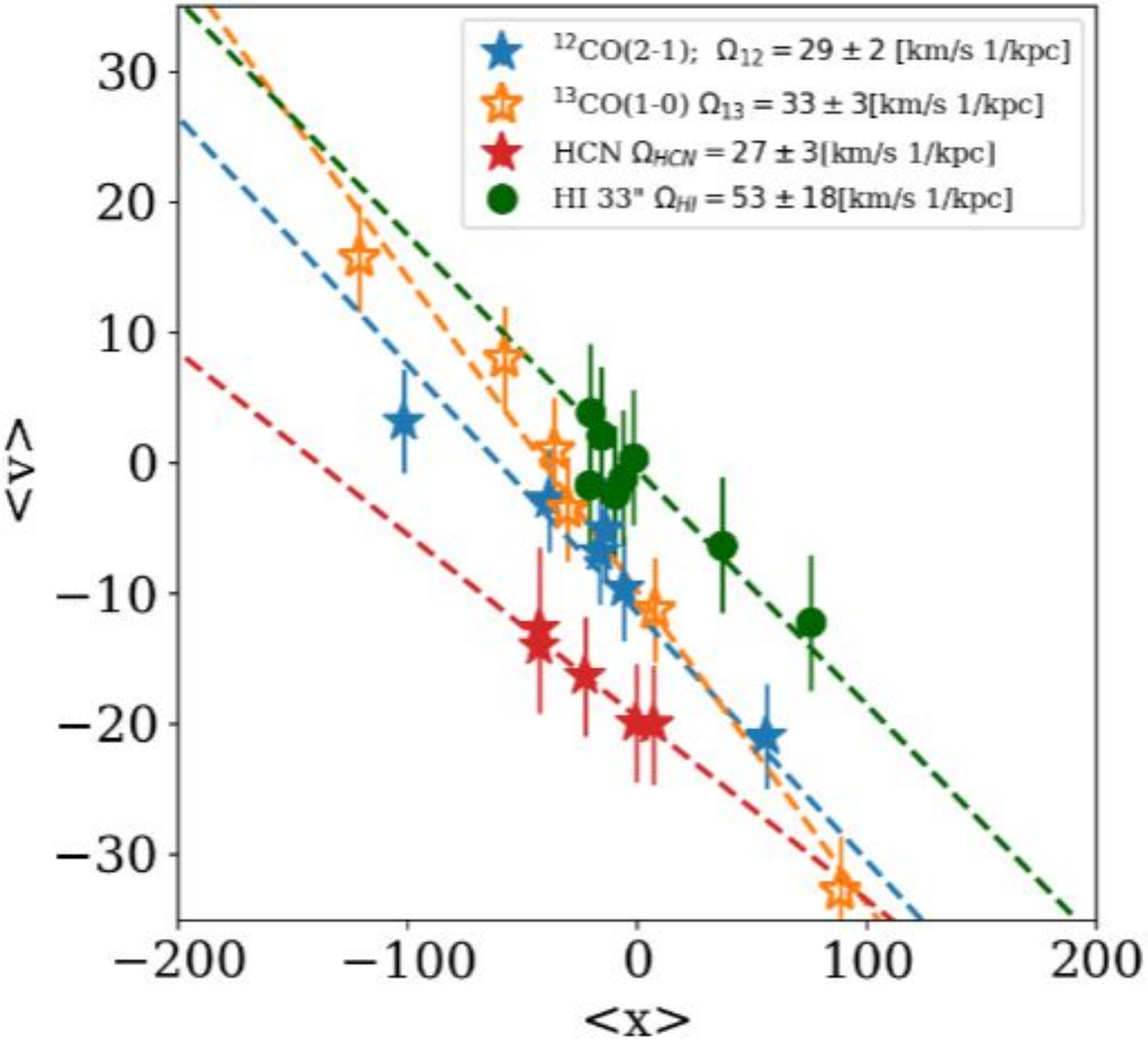
2) there is a well-defined rigid pattern speed,

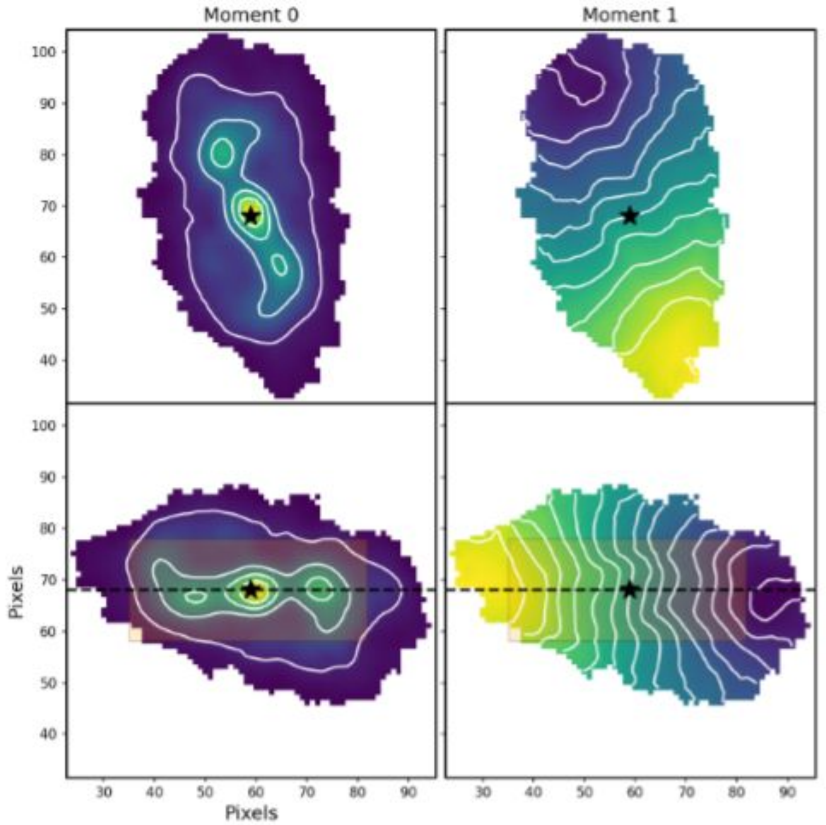
3) the method required that the luminosity of the tracer obeys the continuity equation (the tracer is neither created nor destroyed at a significant rate compared to the galactic orbital period).

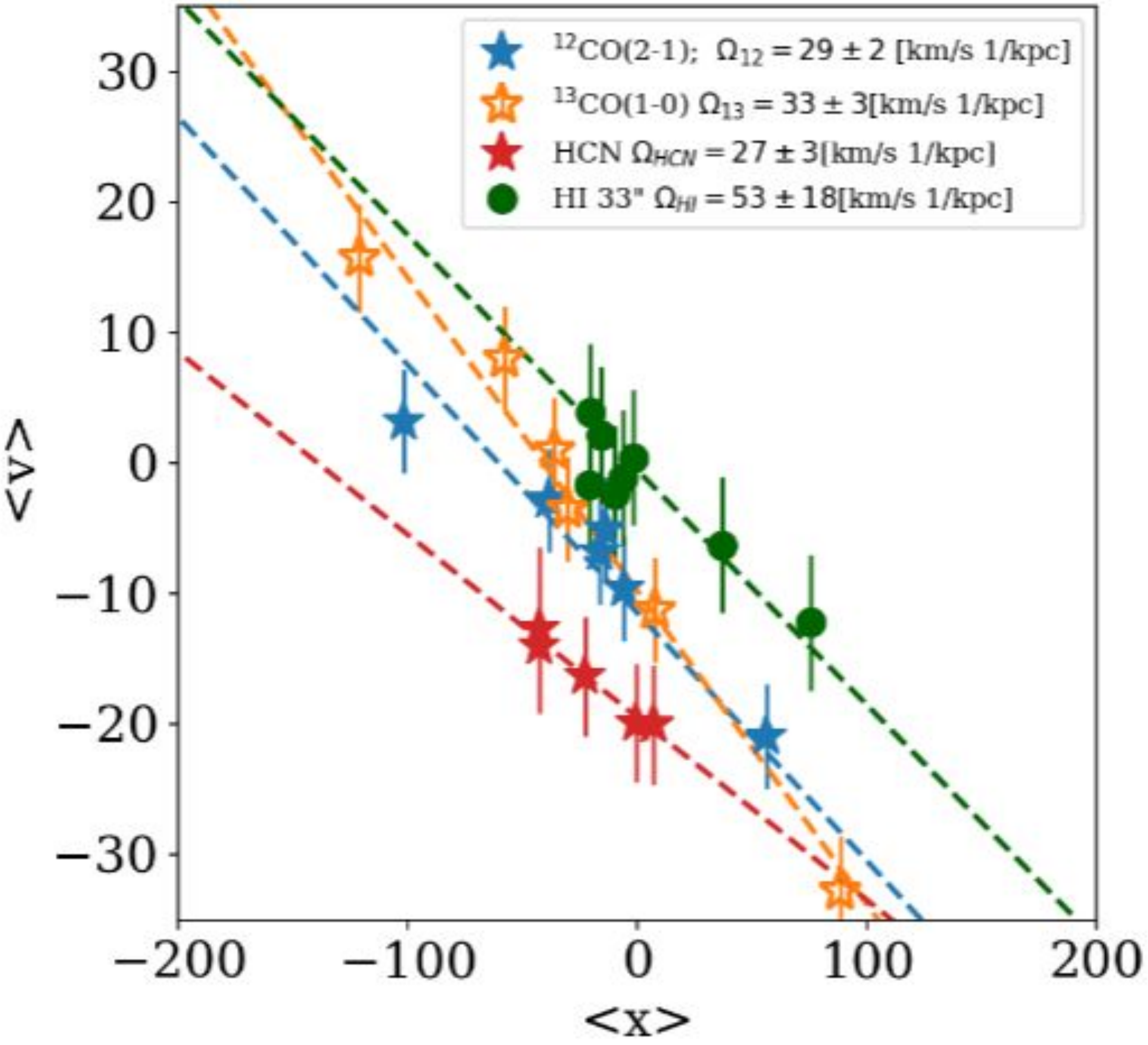
Under these assumptions, a well-defined pattern speed, $\boldsymbol{\Omega_p}$ can be given as

$$\Omega_p sin(i) = \frac{\int_{-\infty}^{\infty} h(y) \int_{-\infty}^{\infty} \Sigma(x,y) v_r(x,y) dx dy}{\int_{-\infty}^{\infty} h(y) \int_{-\infty}^{\infty} \Sigma(x,y) dx dy} = \frac{< v >}{< x >}$$

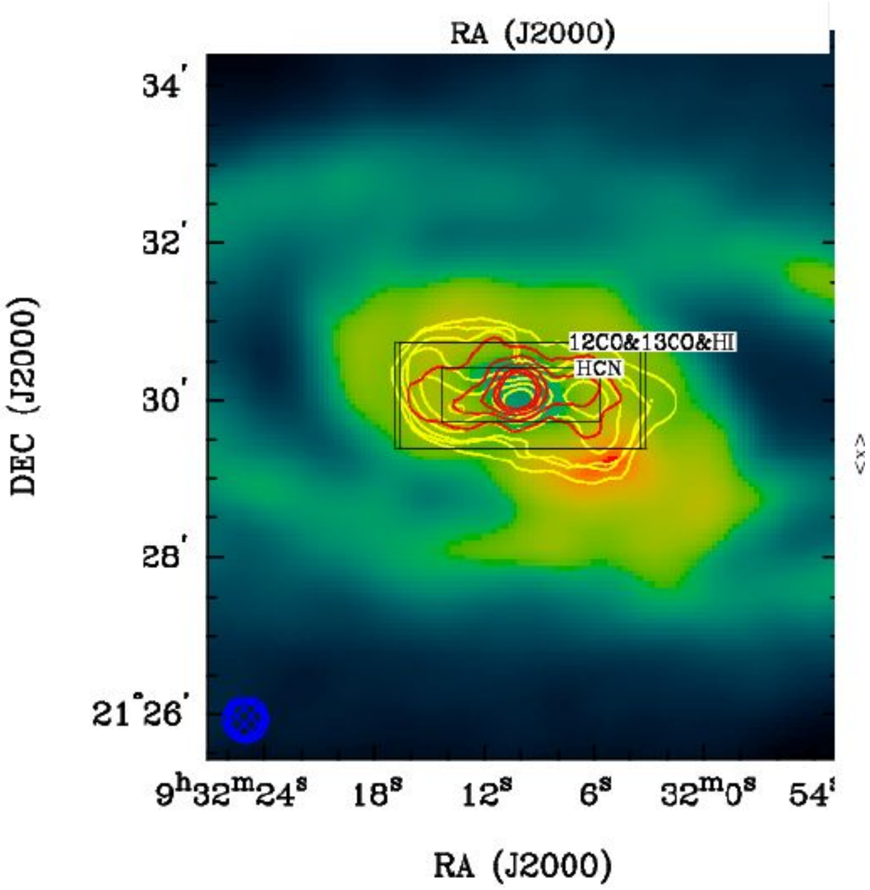
Pattern speed





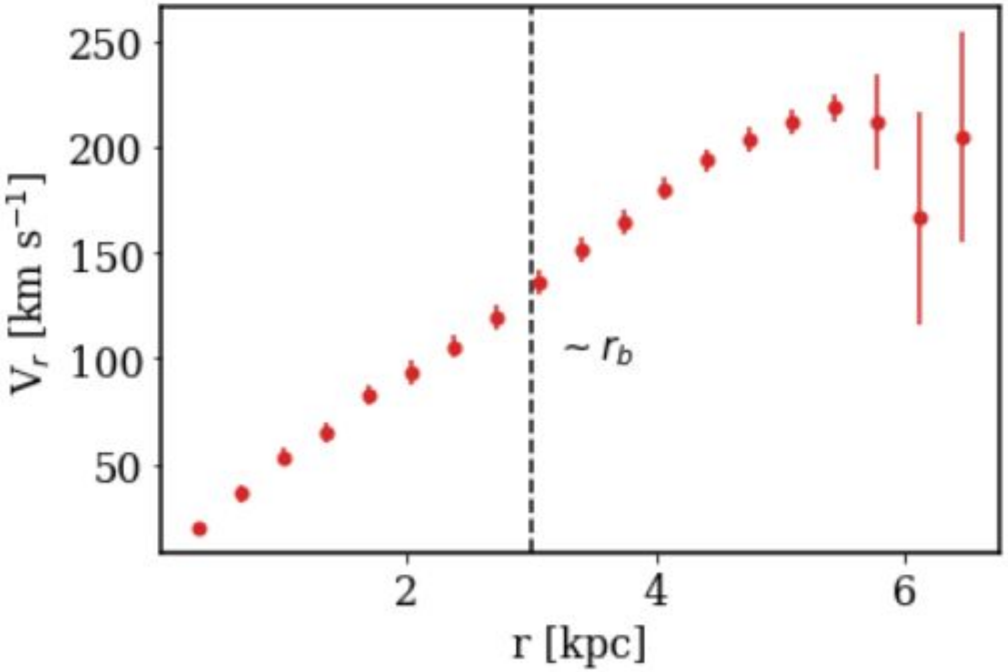


Pattern speed



The rotation curve and the corotation radius

(using $^{12}CO=(2-1)$)



The observed radial velocity V_{obs} is given by

$$V_{obs} = V_{sys} + V_r\,(\mathrm{r})\cos(\beta)\sin(i)$$

Where, β is the azimuthal coordinate in the plane of the galaxy measured from the major axis;

V_{sys}, the systemic velocity (mean radial velocity);

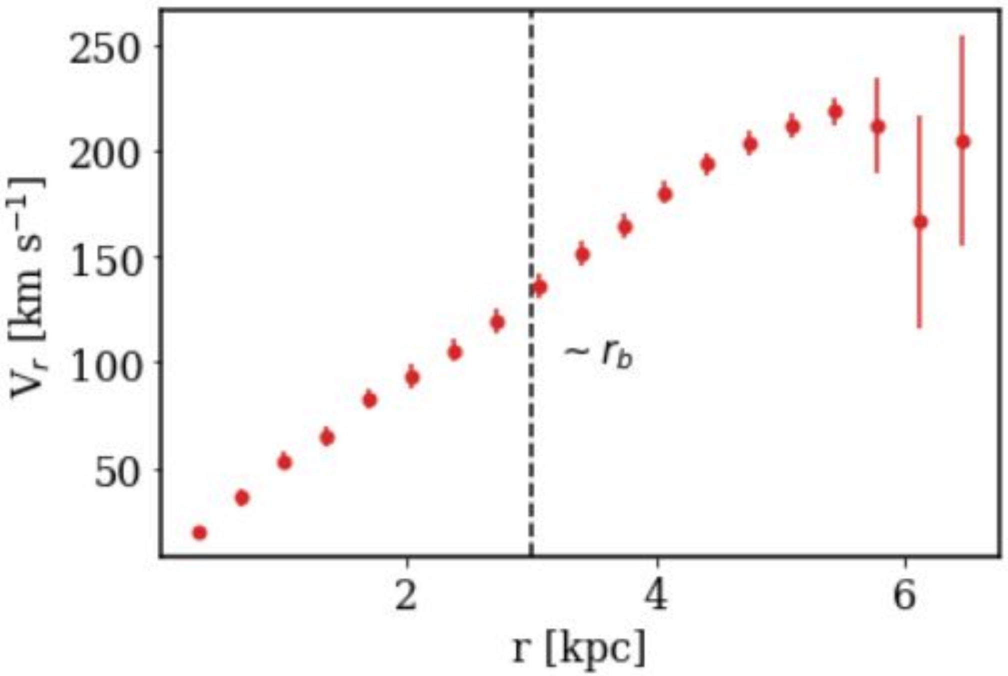
i, the inclination of the normal of the plane of the line of sight and,

$V_r(r)$ the rotation curve at the radial distance, r.

We used VELFIT, a MIRIAD TASK, which used a 2D model to estimate the rotation curve. The task requires the intensity distribution of data cube integrated over the velocity axis and a mean velocity image. Besides, it needs the V_{sys}, i, and the the position angle (PA) of the major axis.

The rotation curve and **the corotation radius**

(using ^{12}CO=(2 - 1))



The corotation radius R_{CR} is where the bar and the material at the disk have the same angular velocity;

Contopoulos (1980); Elmegreen (1996); Binney & Tremaine (2008).

Therefore, the corotation radius can be estimated from the bar pattern speed as $R_{CR} = Vr/\Omega_p$, where Vr is the disk circular velocity at bar ends.

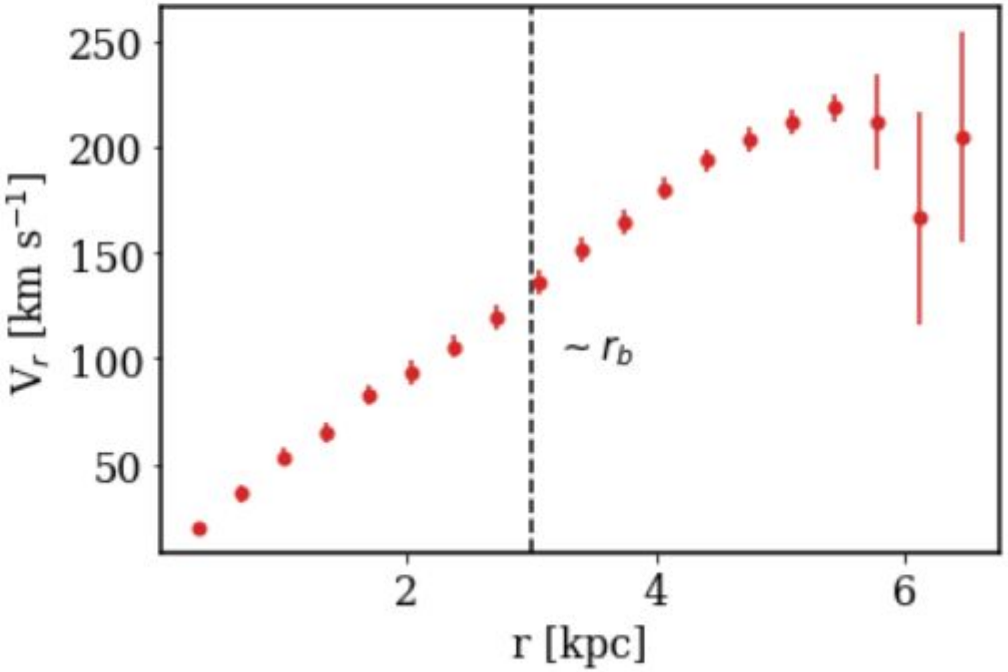
Athanassoula et al.1992 proposed from numerical simulations that the ratio of the corotations radius to the bar radius, defined as the parameter $R=R_{CR}/r_b$ is typically in the range between 1.0 and 1.4.

If 1.0 < R < 1.4 bars are considered fast

If R > 1.4 bars are considered slow

The rotation curve and **the corotation radius**

(using 12CO=(2 - 1))



$R_{CR} = Vr_{/}\Omega_p = 29$ [km/s 1/kpc] / 150 [km/s] = 5 [kpc]

$r_b = 3$ [kpc]

$\boldsymbol{R} = R_{CR}/r_b = 5$[kpc] /3[kpc] = 1.7

If $\boldsymbol{R} > 1.4$ they are considered slow.

Therefore, we found that is a slow bar.

Summary and prospects

- We were able to characterize the bar using different tracers:

^{12}CO=(2-1), ^{13}CO=(1-0) and HCN(1-0)

We can infer that all the molecules are mixed and seem to have the same original conditions. Therefore, the different components of the bar could be evolving in a similar way. As it stands, the bar is a complex system where different tracers are revealing similar patterns.

- The atomic gas: considering that the continuity is not guaranteed (at least at the central region of the galaxy where we see a hole in HI), and the high errors, the atomic gas might behave in a similar way as the molecules.

We need to keep looking at this result.

- We found that the bar is 'slow'

the CO bar have a dynamical friction with the dark matter halo.

- We plan to do simulations to figure out what would be the amount of dynamical friction for a bar and for a simple HI distribution to get deeper in this respect

As can be seen for the angular resolution we had to perform this work, an antenna like LLAMA is useful to continue this kind of studies!!!

Thanks!!

- Econtre esta pagina. Tal vez pueda servir para tomar de las simulaciones algunas galaxias.
- https://github.com/kyleaoman/martini
- Pedi de hacerme un usuario en eagle para poder sacar datos de ahi.

- Las preguntas que quiero responder es. A partir de galaxias ficticias controlar las cuentas. Ver que dependencia hay con las inclinaciones. Y si se puede hacer el trabajo sobre flucculent galxies. En un principio no se podria, pero que onda con que la rutina si parece detectar una barra.