Dark Matter

ASTR 333/433
Fall 2013
M T 4:00-5:15pm
Sears 552

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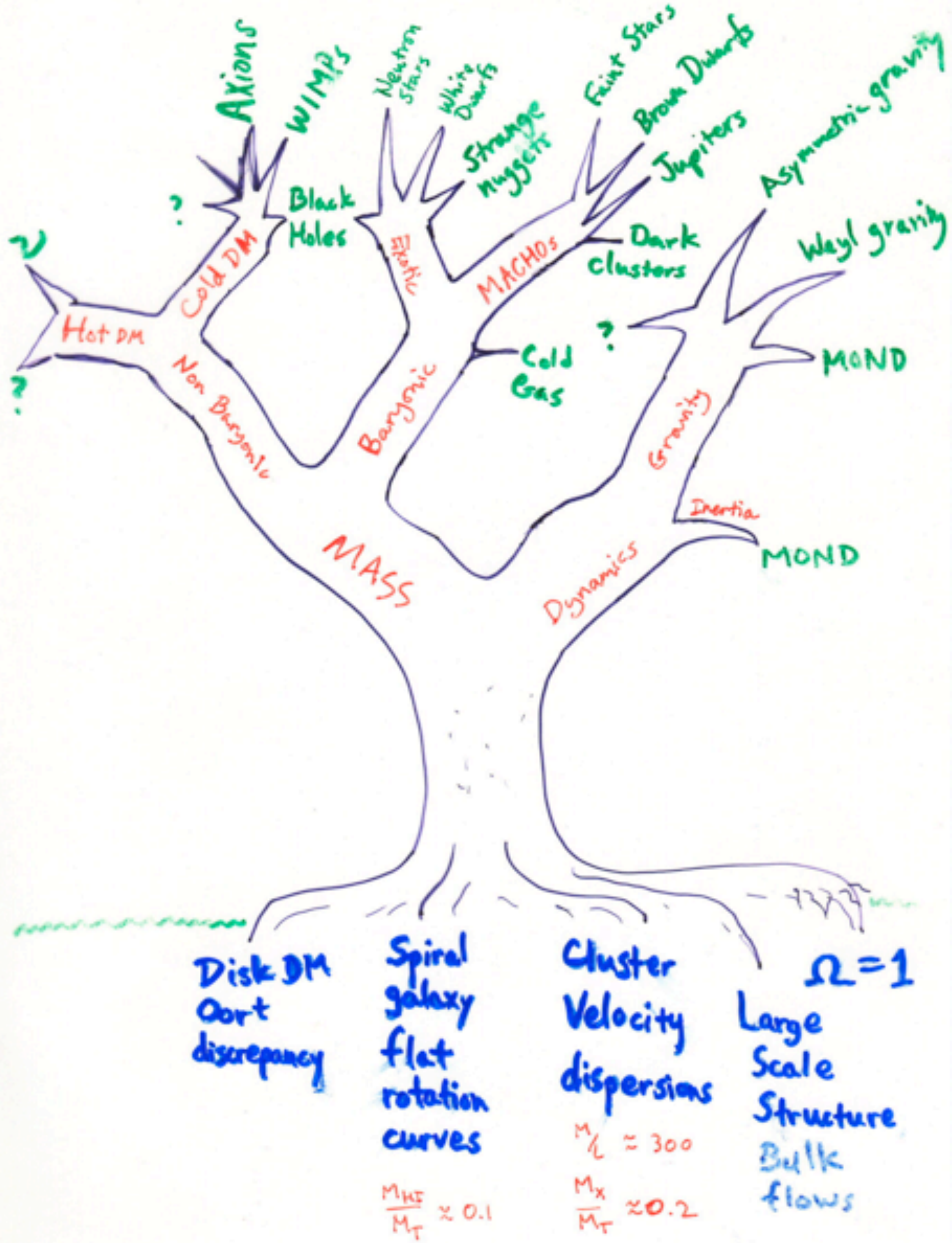
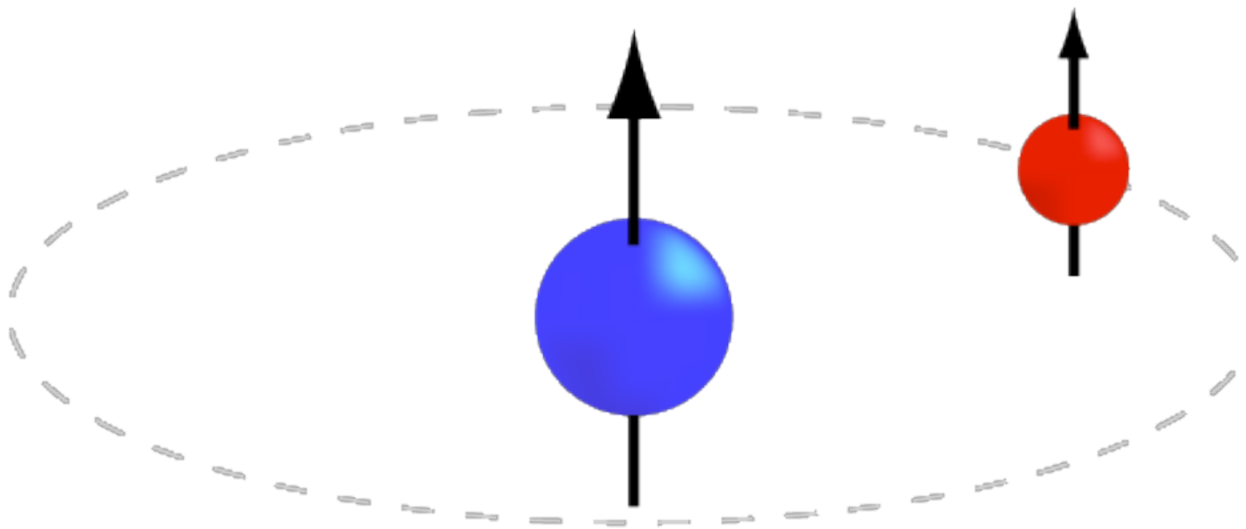


ISM

The stuff between the stars

Atomic gas
Molecular gas
Ionized gas
Dust

HI: atomic hydrogen in the interstellar medium



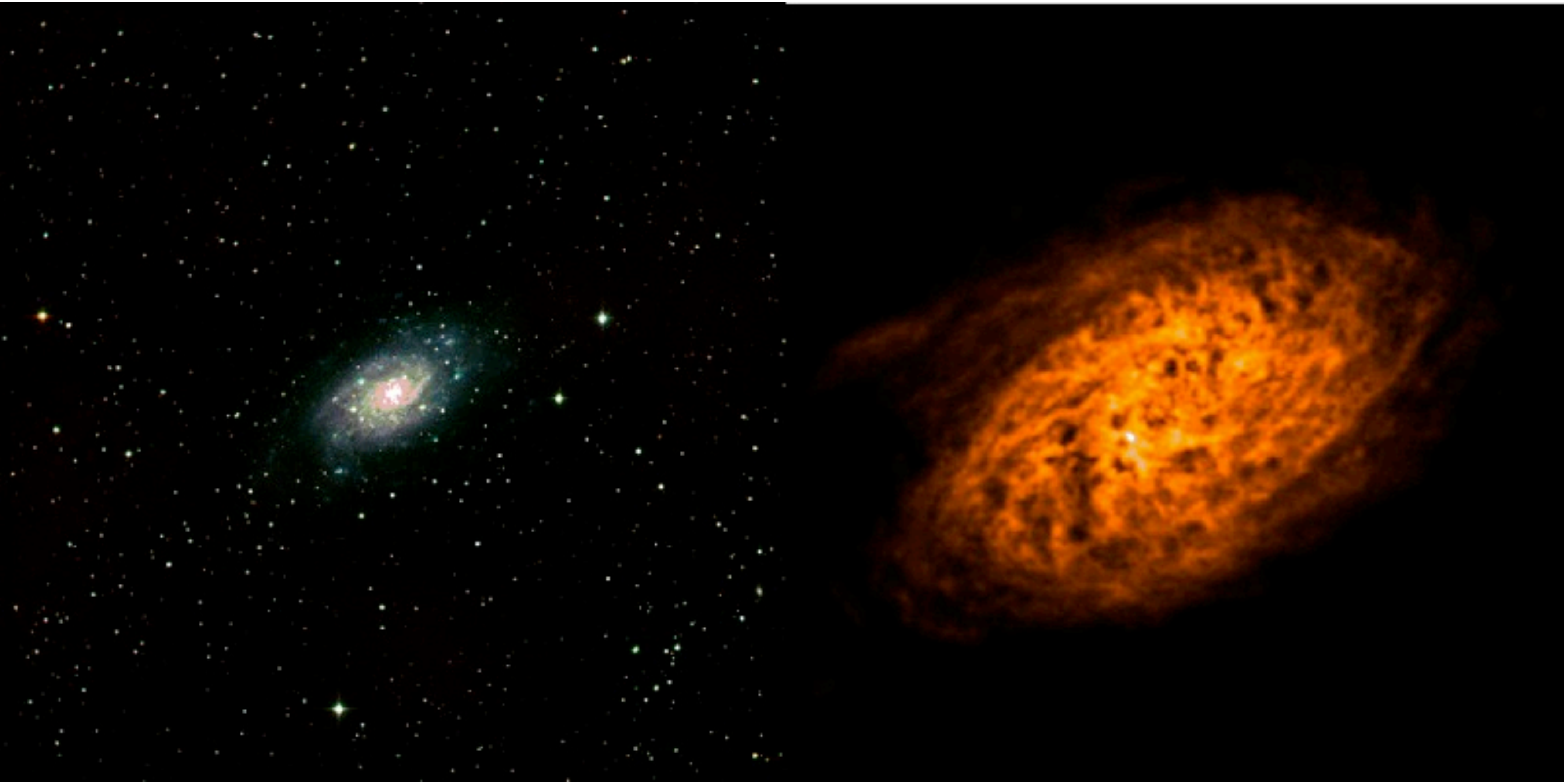
21 cm emission from hyperfine transition: parallel to anti-parallel spins

$$\nu = \frac{8}{3} g_I \frac{m_e}{m_p} \alpha^2 R_m c = 1420.405751 \text{ MHz}$$

Radio line!

NGC 2403

Stars　　　　　　Hɪ gas

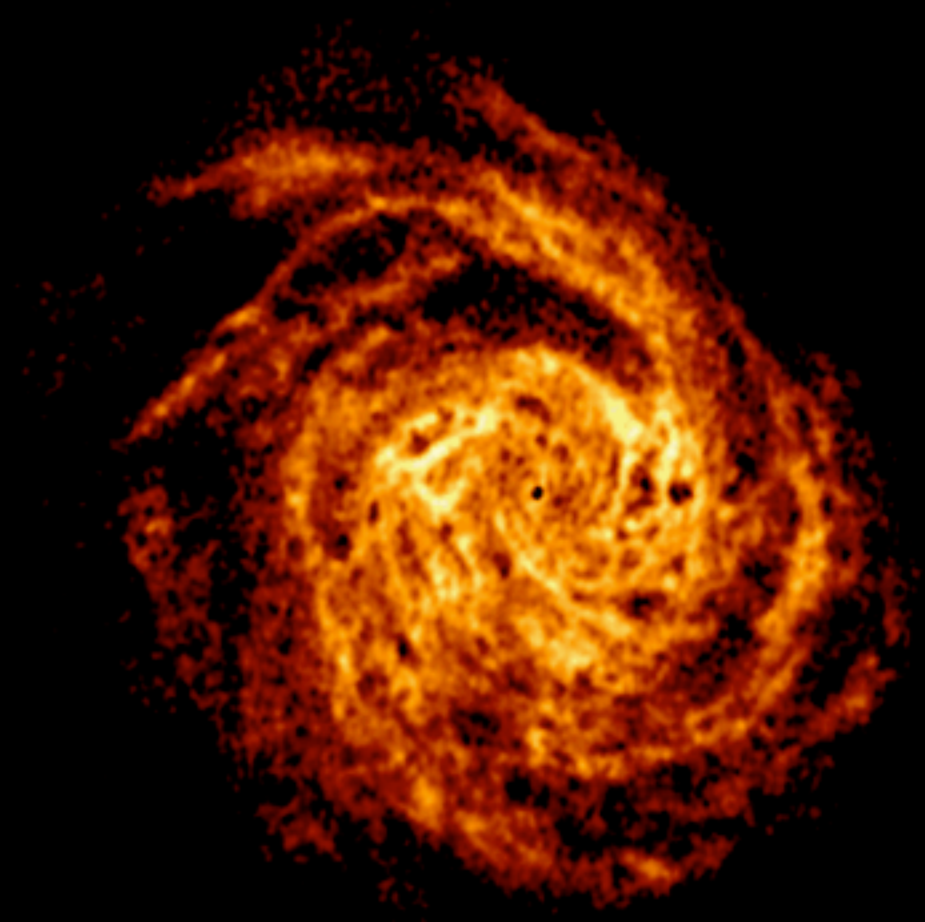


Fraternali, Oosterloo, Sancisi, & van Moorsel 2001, ApJ, 562, L47

NGC 6946

Stars

HI gas



Boomsma 2005

emission coefficient

$$A_{UL} = \frac{64\pi^4}{3hc^3}\nu^3|\mu^*|^2$$

Bohr magneton

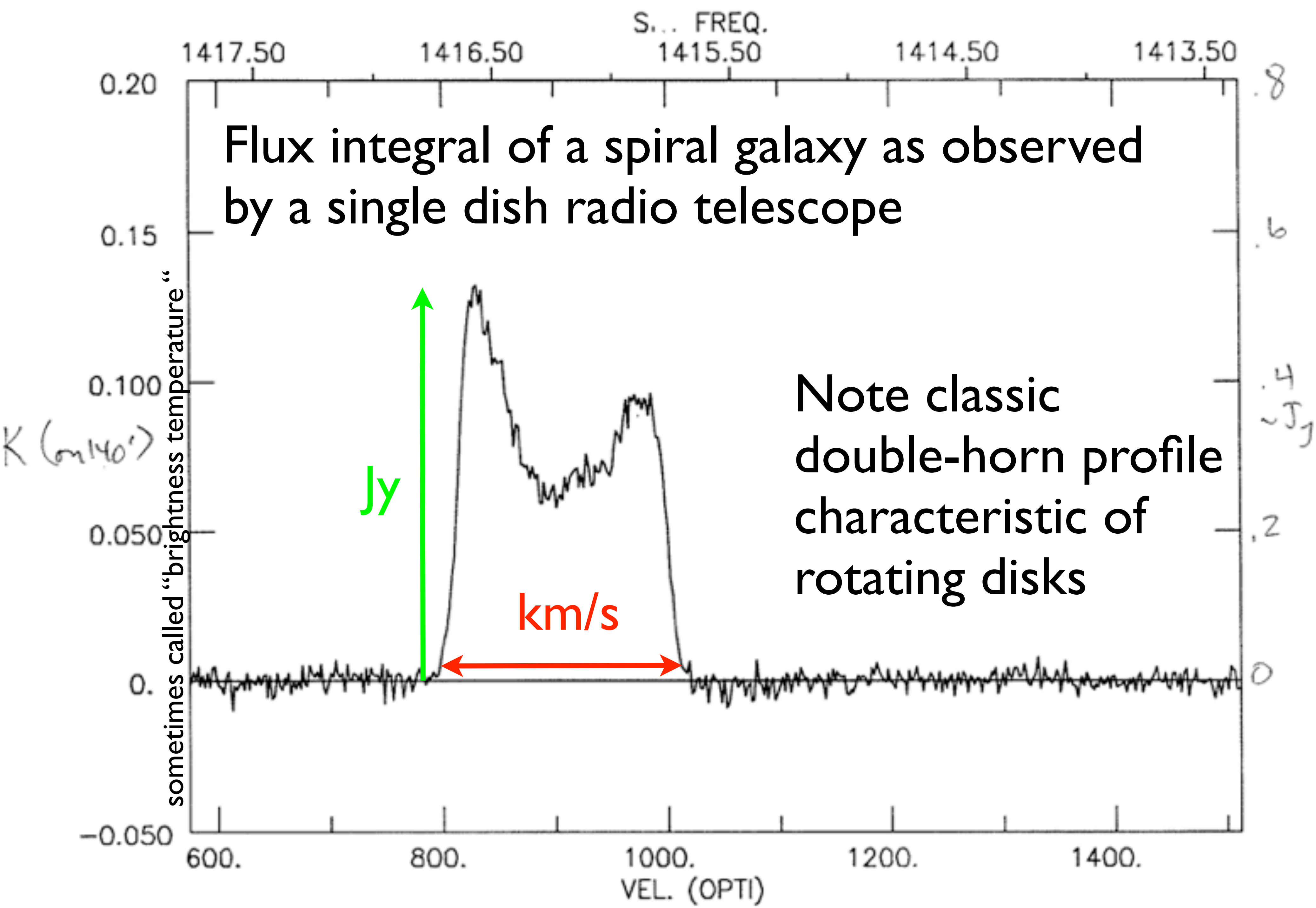
The radiative half-life of this transition is 11 Myr. This is readily maintained in equilibrium even in a cool (~100 K), diffuse ISM (< 1 atom/cc)

Counting 21 cm photons is equivalent to counting hydrogen atoms - a direct relation to mass!

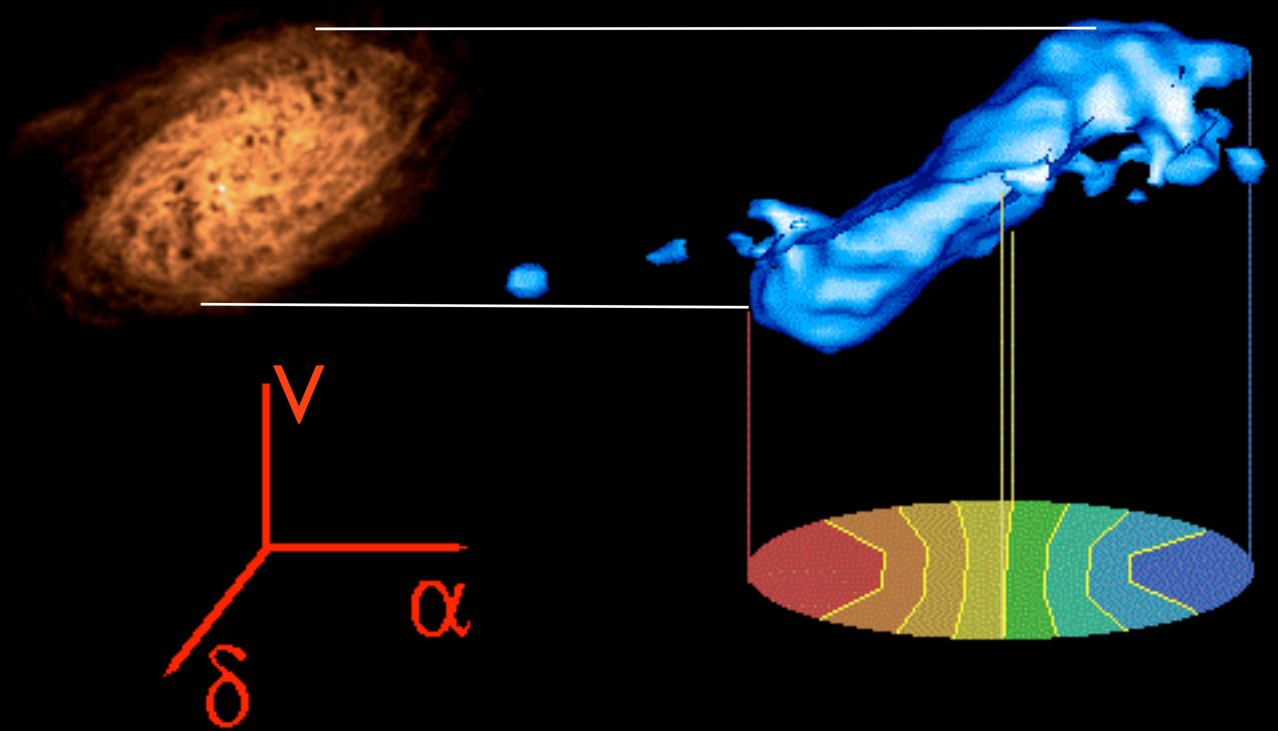
$$M_{HI} = 2.36 \times 10^5 D^2 F_{HI}$$

Give mass in solar masses for D in Mpc and measured F_{HI}, the flux integral in Jy-km/s

$1\ \mathrm{Jy} = 10^{-26}\ \mathrm{W\,m^{-2}\,Hz^{-1}}$


S... FREQ.
1417.50
1416.50
1415.50
1414.50
1413.50
0.20
0.15
0.100
0.050
0.
−0.050
600.
800.
1000.
1200.
1400.
VEL. (OPTI)
Flux integral of a spiral galaxy as observed by a single dish radio telescope
Note classic double-horn profile characteristic of rotating disks
Jy
km/s
sometimes called "brightness temperature"
.8
.6
.4
.2
0

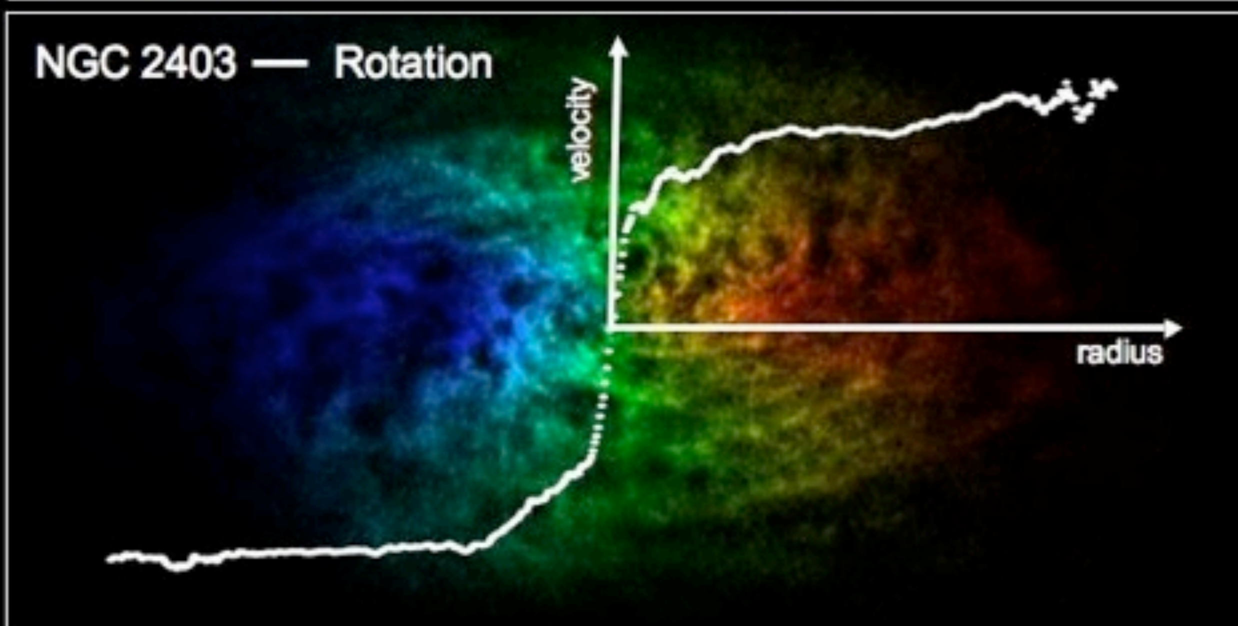
Multi-dish radio synthesis telescope arrays give brightness temperature (HI surface density) & velocity



from 3D data cube of 21 cm position and redshift

Galaxy Dynamics in THINGS — The HI Nearby Galaxy Survey

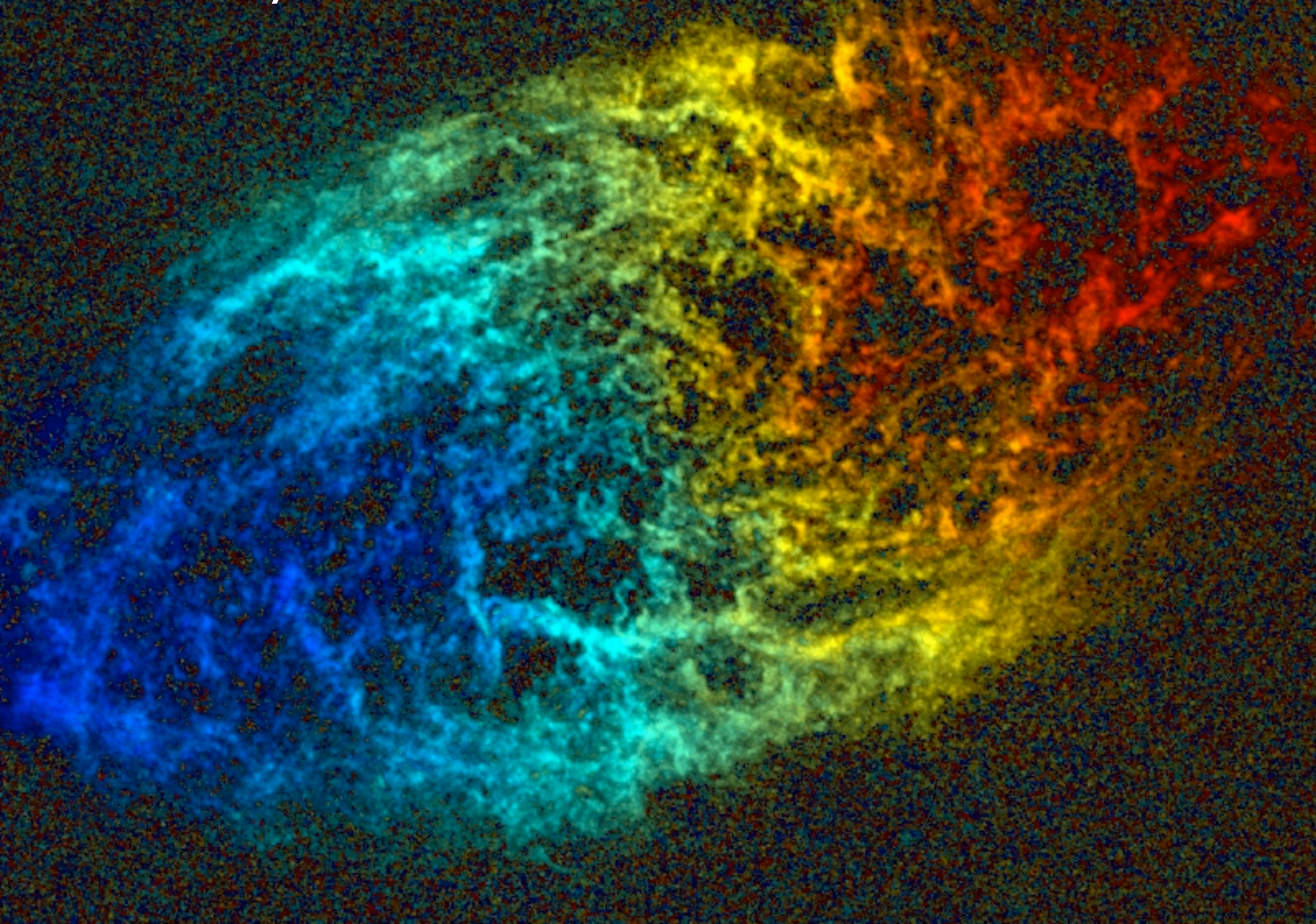
Color Coding:
- THINGS Atomic Hydrogen
  (Very Large Array)
- Old stars
  (Spitzer Space Telescope)
- Star Formation
  (GALEX & Spitzer)



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

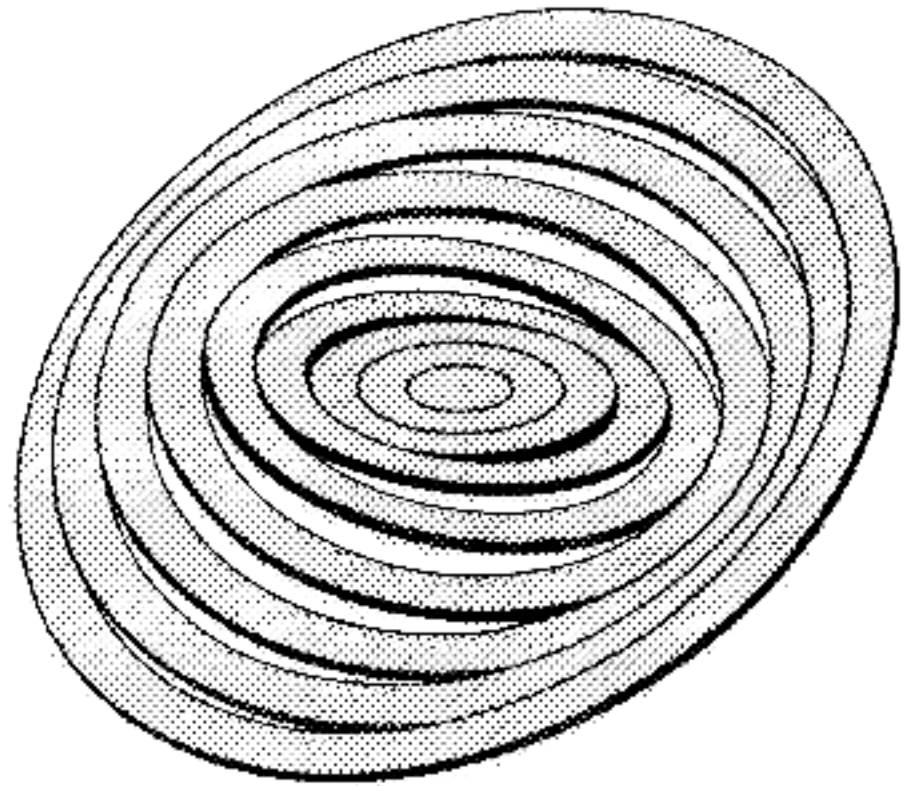
M33 velocity field

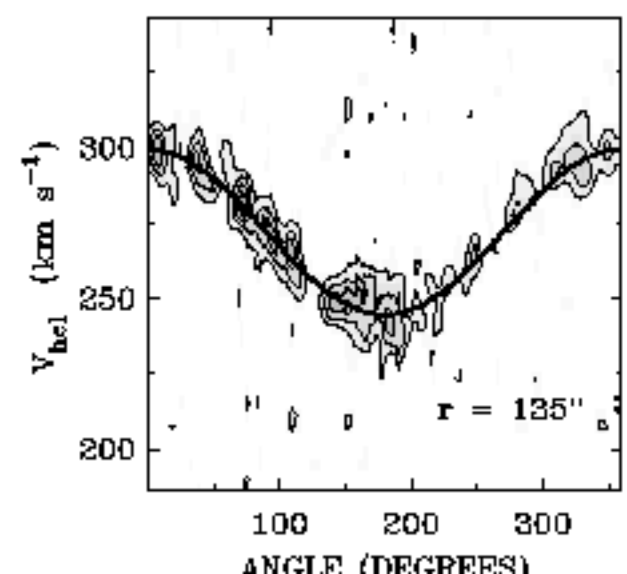


Rotation curves extracted using "tilted ring" fits

Fit ellipses that most closely match the circular velocity at a given radius. In principle, get ellipse center, position angle, axis ratio, inclination, and rotation velocity. In practice, usually have to fix some of these parameters.

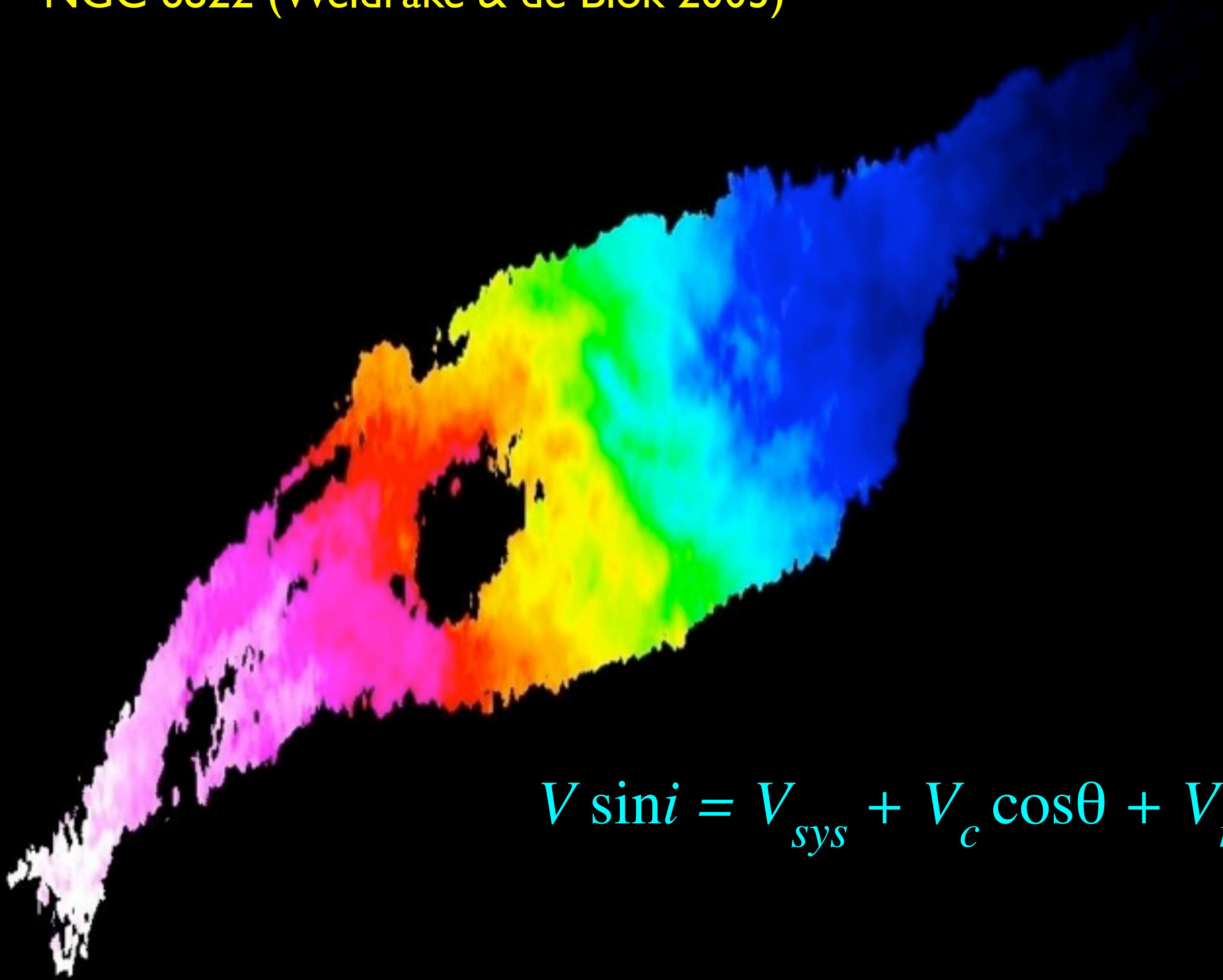
titled ring model





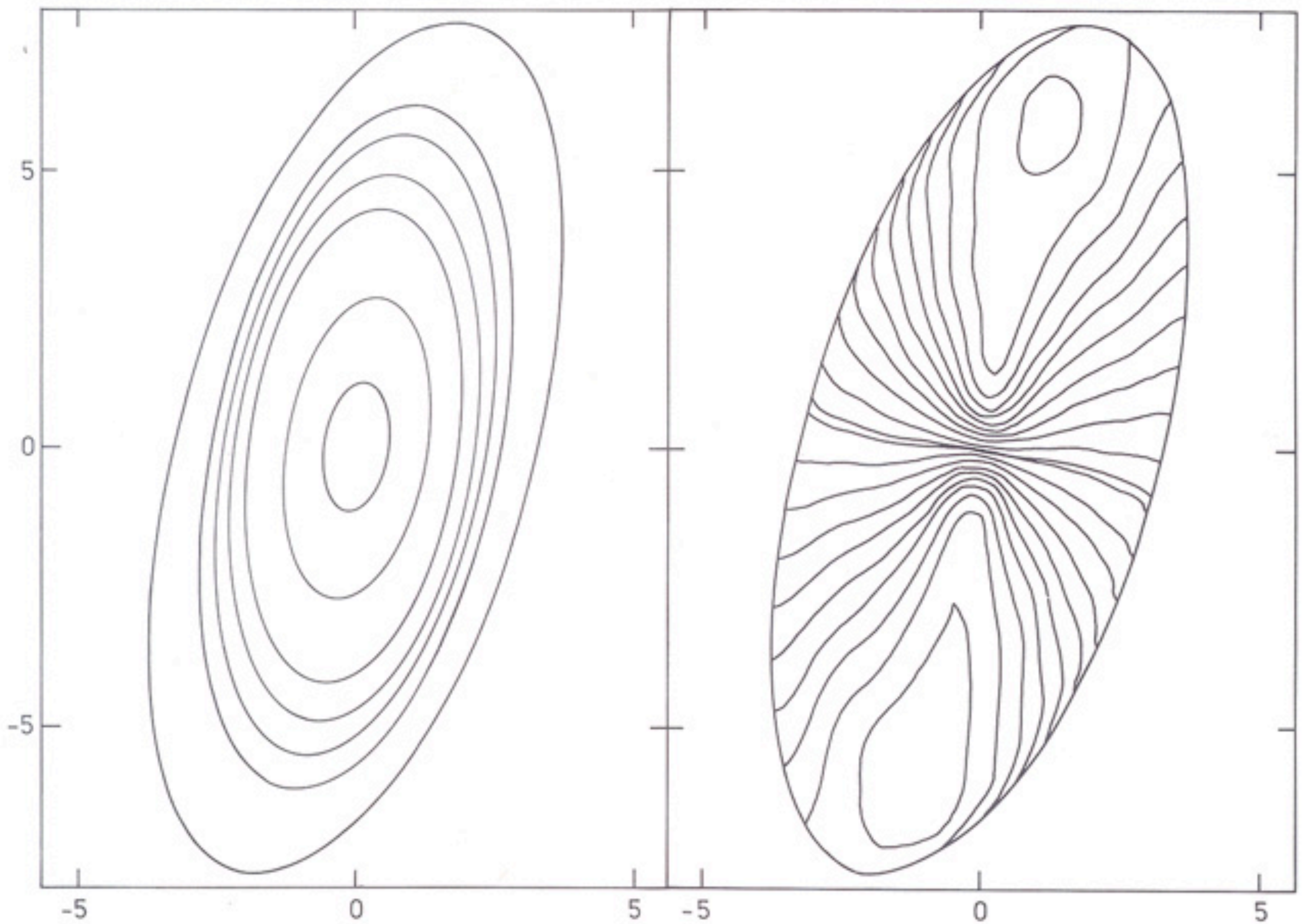
velocity variation along ring

NGC 6822 (Weldrake & de Blok 2003)



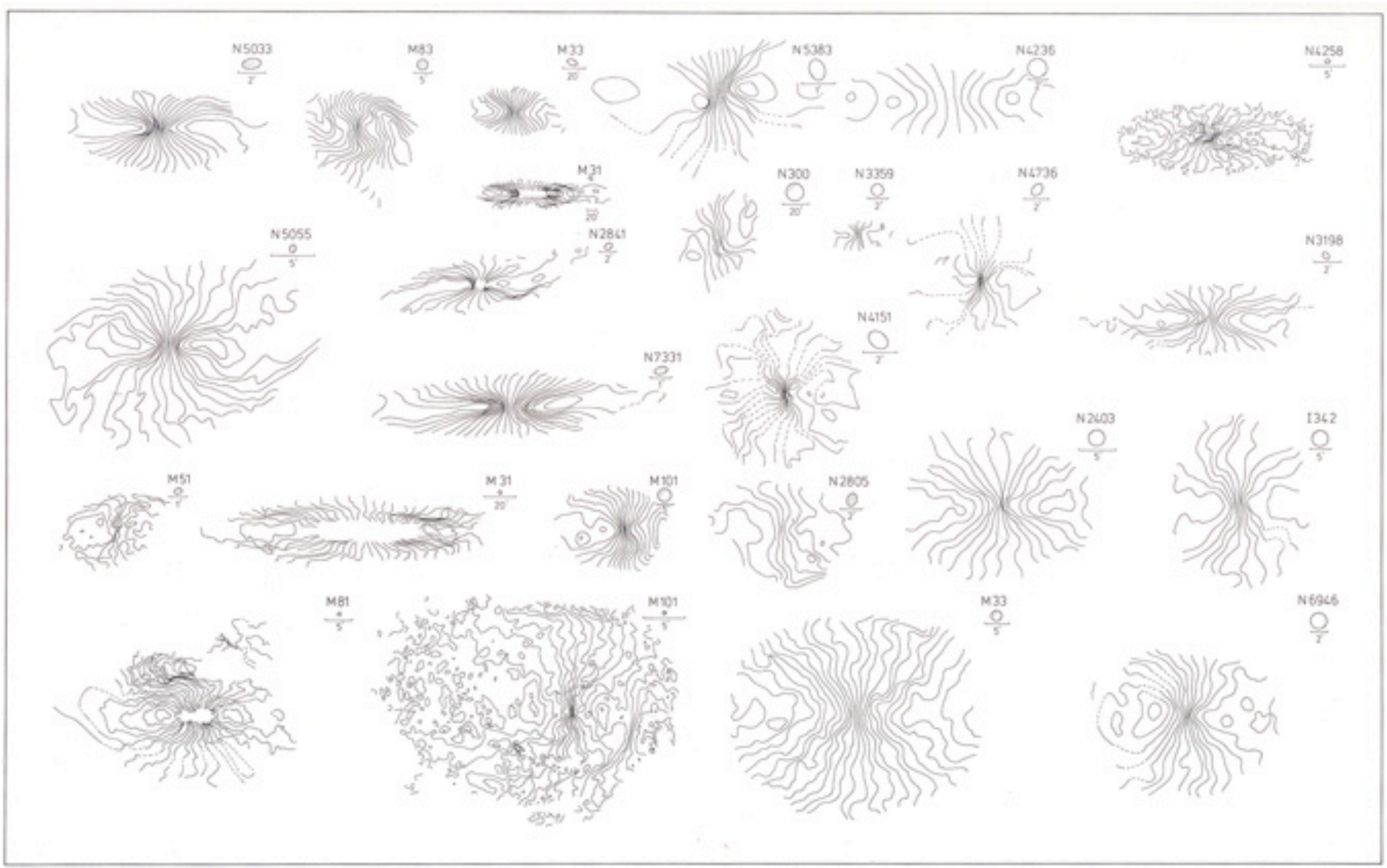
$$V \sin i = V_{sys} + V_c \cos\theta + V_r \sin\theta$$

titled ring model

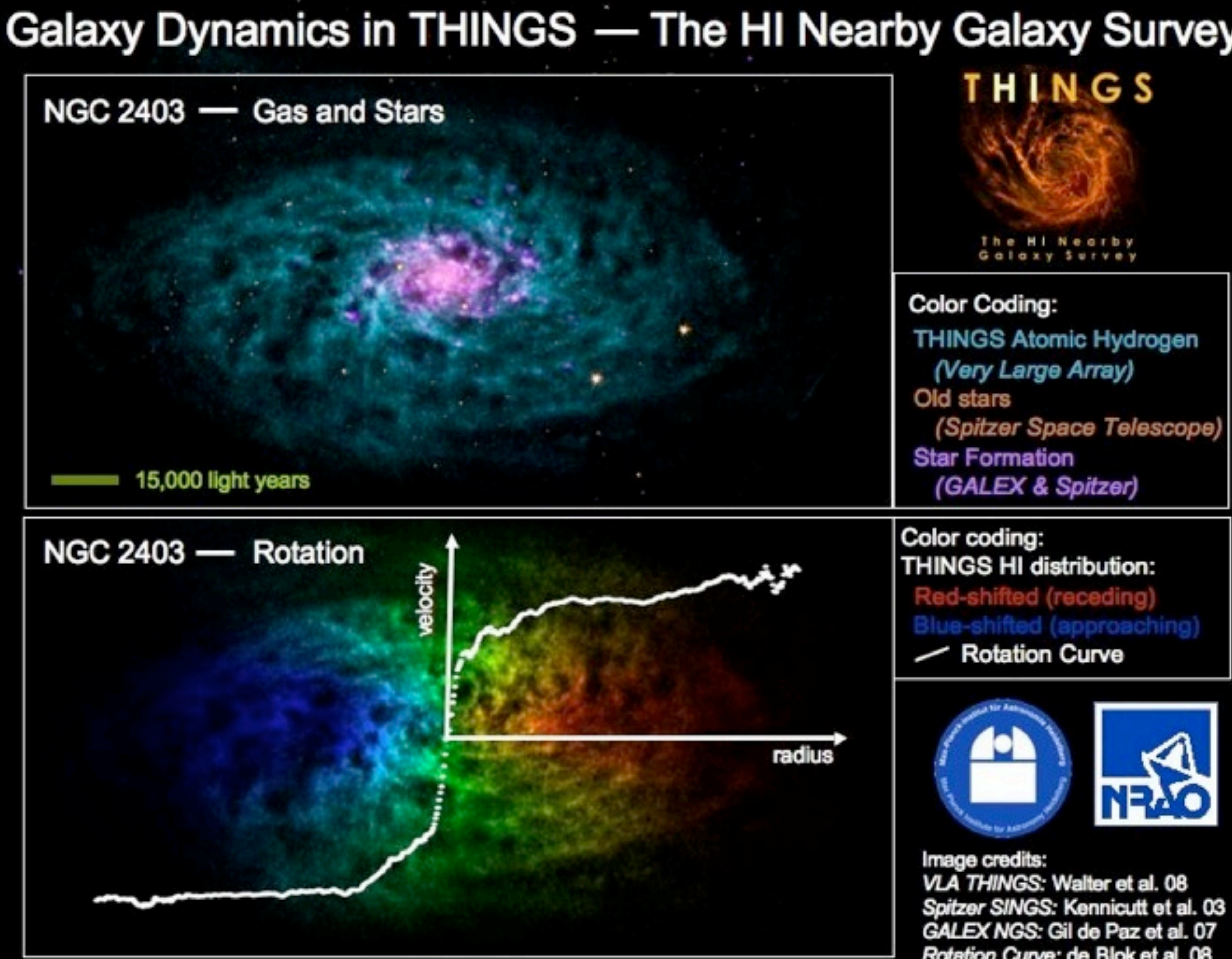


isovelocity contours

observed velocity fields



HI velocity fields demonstrated flat rotation curves to large radii



Molecular ISM

Cold (~ 30 K), "dense" (> 100 molecules/cc) phase of interstellar medium

Very clumpy, with low filling factor - much of the mass is in Giant Molecular Clouds ($\sim 10^6\ M_\odot$)
This is where stars form.

Diatomic molecules (H_2, N_2, O_2) boring - or at least hard to excite, as they have no dipole moment.

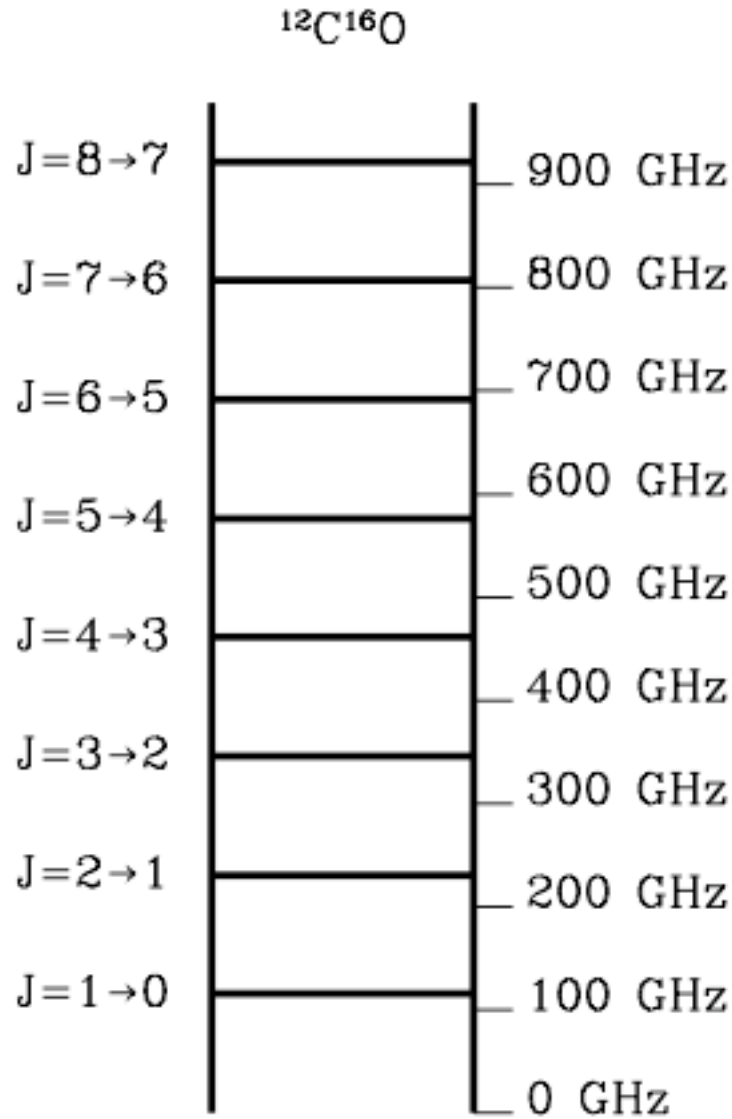
Polar molecules (esp. CO) have a permanent dipole moment thanks to asymmetry so have a rich rotational spectrum (typically in the mm or cm wavelengths).

$$E_{rot} = \frac{J(J+1)\hbar^2}{2I}$$

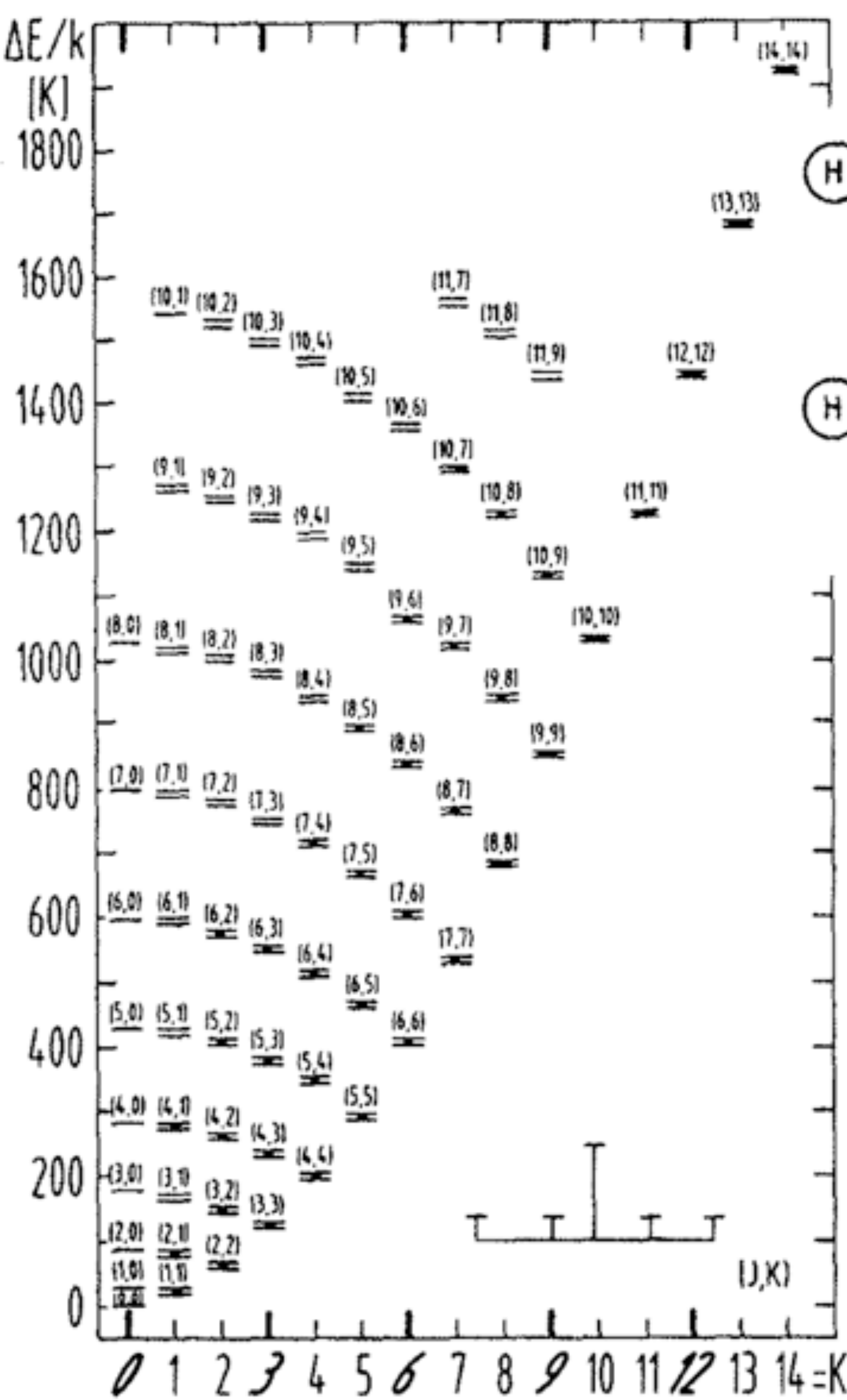
$$M_{H_2} = 1.1 \times 10^4 D^2 F_{CO}$$

$$X_{CO} = 2.8 \times 10^{20} \mathrm{cm}^{-2} (\mathrm{K\ km/s})^{-1}$$

CO



$^{12}C^{16}O$
J=8→7
J=7→6
J=6→5
J=5→4
J=4→3
J=3→2
J=2→1
J=1→0
900 GHz
800 GHz
700 GHz
600 GHz
500 GHz
400 GHz
300 GHz
200 GHz
100 GHz
0 GHz


ΔE/k
[K]
1800
1600
1400
1200
1000
800
600
400
200
0
(0,0)
(1,0)
(1,1)
(2,0)
(2,1)
(2,2)
(3,0)
(3,1)
(3,2)
(3,3)
(4,0)
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(4,4)
(5,0)
(5,1)
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(7,0)
(7,1)
(7,2)
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(8,0)
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(10,1)
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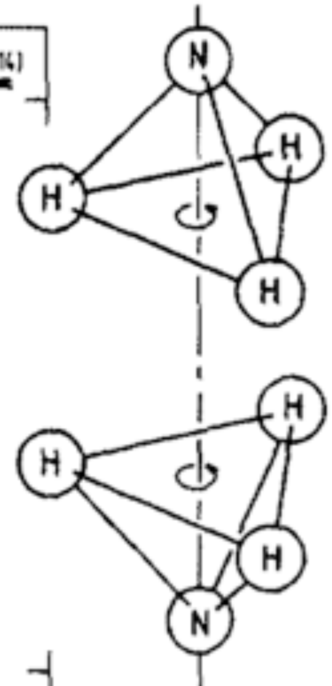
(10,10)
(11,7)
(11,8)
(11,9)
(11,11)
(12,12)
(13,13)
(14,14)
(J,K)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 =K


N
H
H
H
H
H
H
N

Ammonia