Gap Year Planning

January 29: 5:00 – 6:30 pm

Zoom only: https://arizona.zoom.us/j/82615759625

Do you find yourself thinking…
“I want to go to grad school, but don’t have enough research experience to be competitive.”
“What do I do if I don’t get into grad school?”
“I’m not clear on what I want to do after graduation.”

This panel discussion focuses on post-graduation options, featuring UA Astronomy & Physics Alumni who took a gap year between their undergraduate studies and their next careers in industry or academia. Learn why and how they took advantage of a gap year to find clarity and move further toward their goals.

Panelist bios and Zoom link here ⇨

Jiyun Di
Astronomy & Math, 2022

Olivia Pitcl
Physics, 2023

Sai Krishanth PM
Physics & Astronomy, 2022

Charlie Goldberg
Physics & Astronomy, 2023

ASTR400B Lecture 4

Rotation Curve

- the velocity a test particle would have if it was on a circular orbit in an axially-symmetrized version of a galaxy's mass distribution. (Jo Bovy)

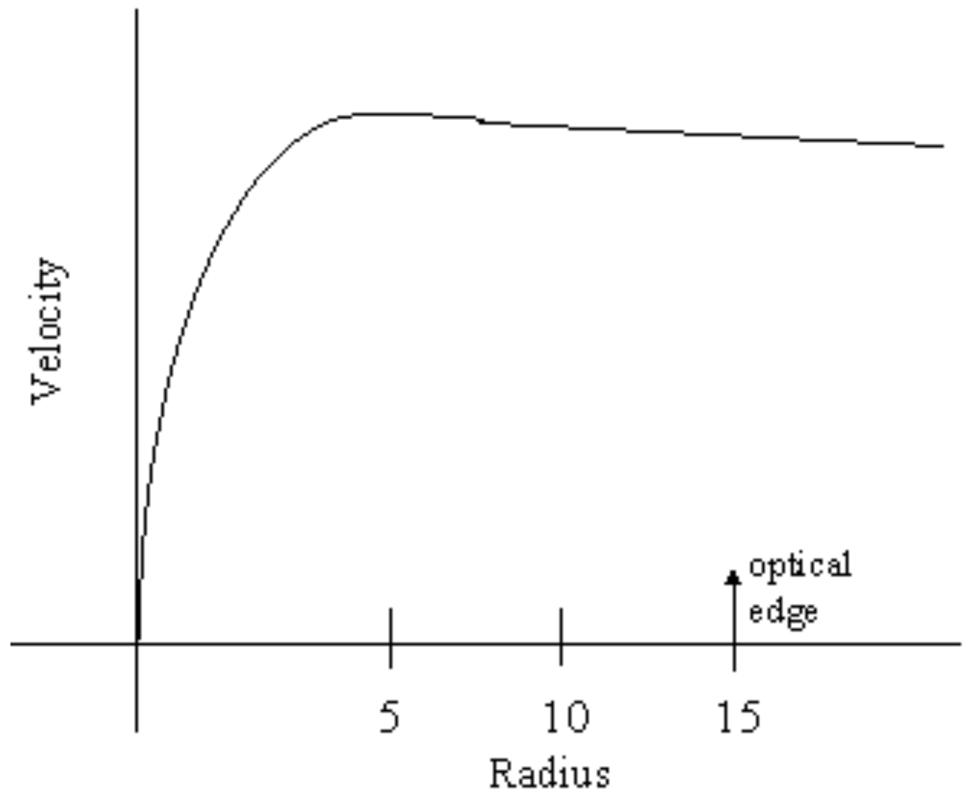
$$GMm/R^2 = mV^2/R$$

$$M(< R) \propto V^2 R$$

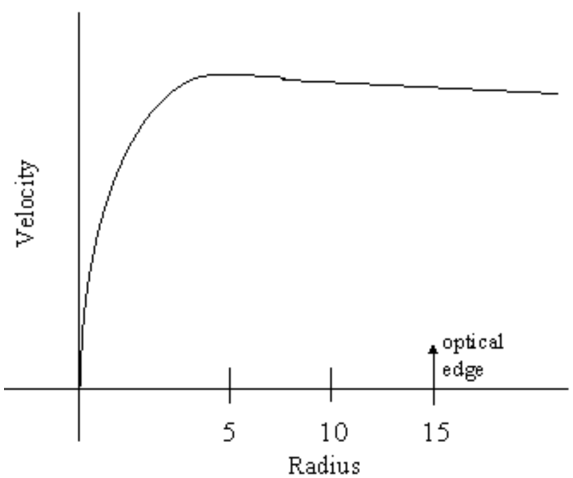
$$v_c(R) = \sqrt{GM(< R)/R}$$

$$v_c(R) = Rw$$

Rotation curve of typical galaxy

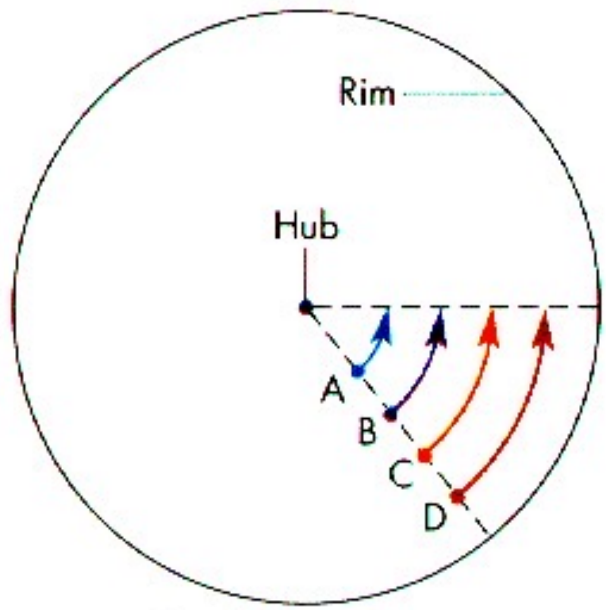


Solid Body Rotation. *w* = constant

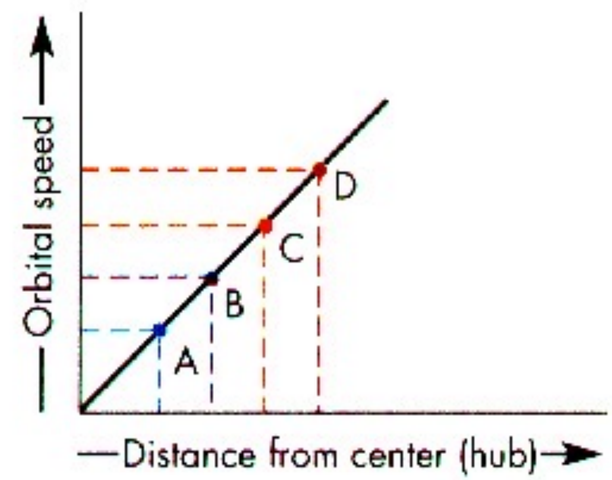


$V \propto R$

Density is constant



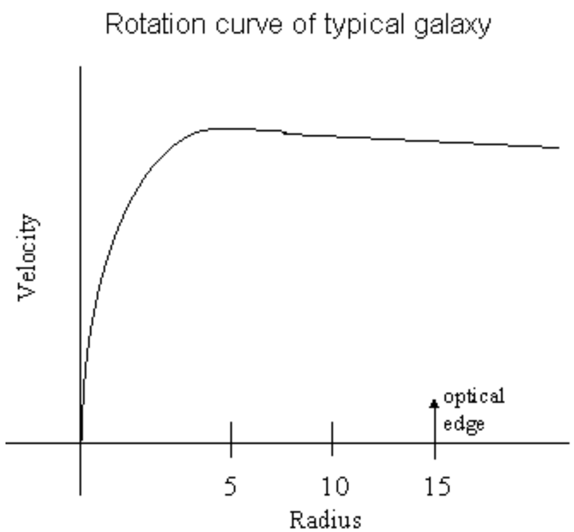
Wheel-like rotation

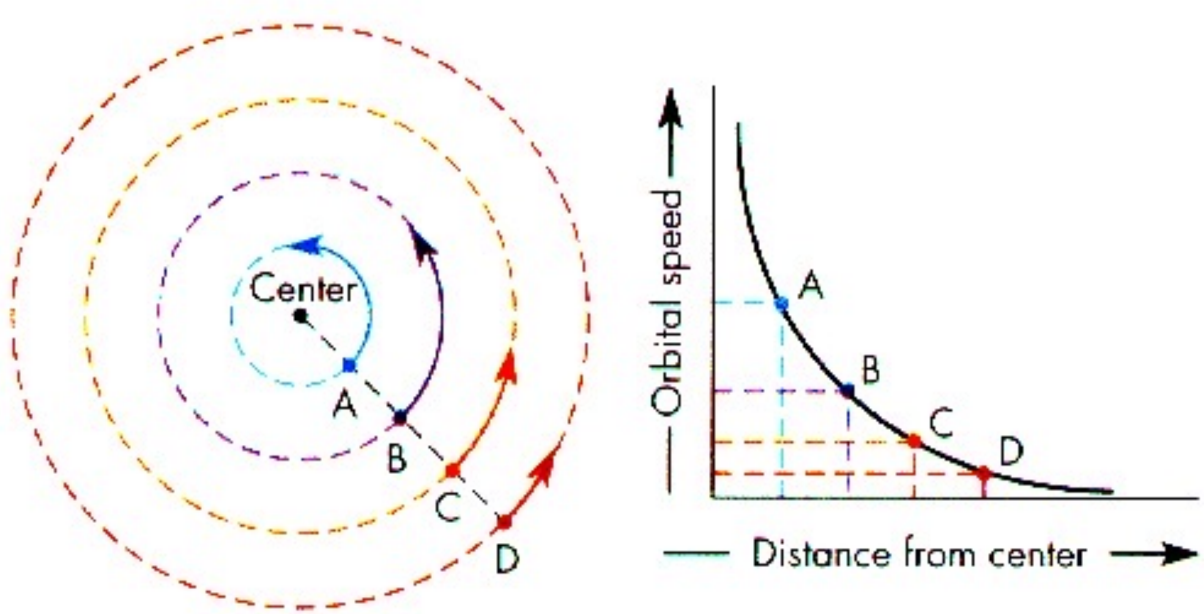


Rotation curve for wheel-like rotation

Keplerian Rotation (mass is constant and at center)

$$V \propto R^{-1/2}$$

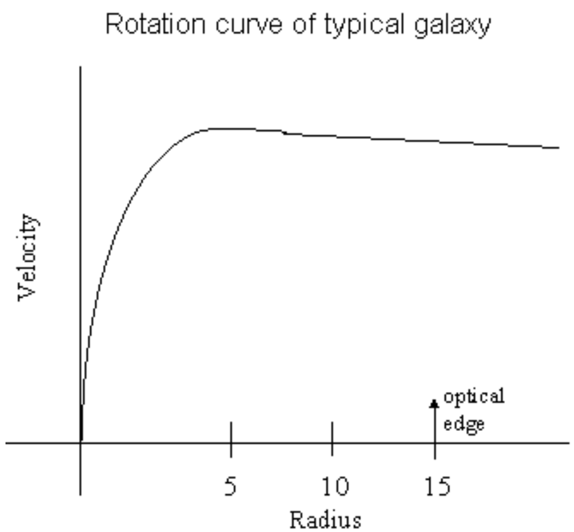




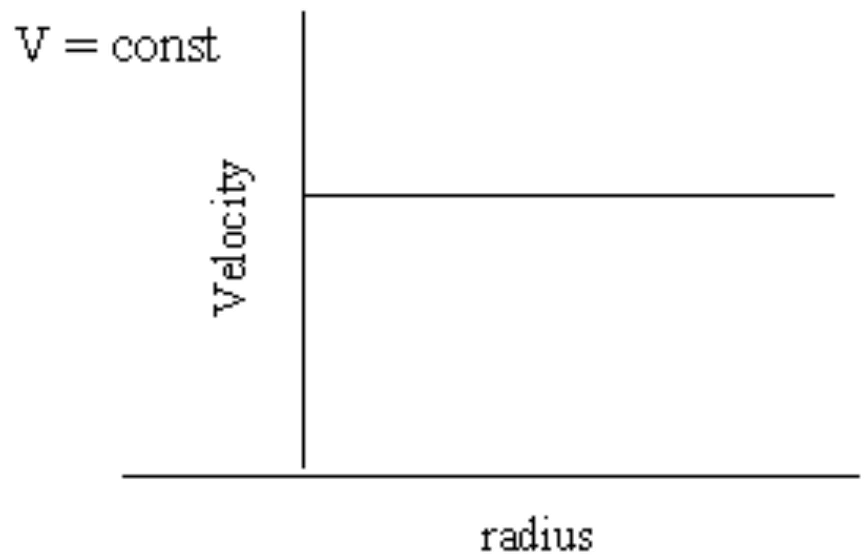
Planet-like rotation

Rotation curve for planet-like rotation

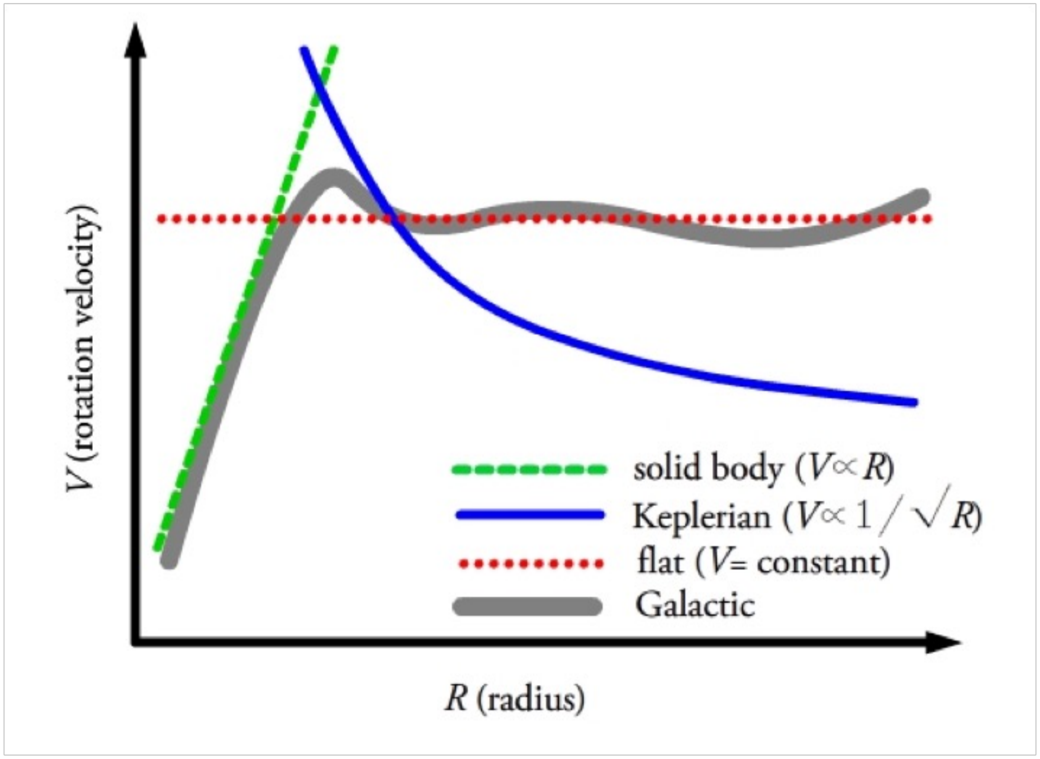
Flat Rotation Curve, V is constant



$M \propto R$



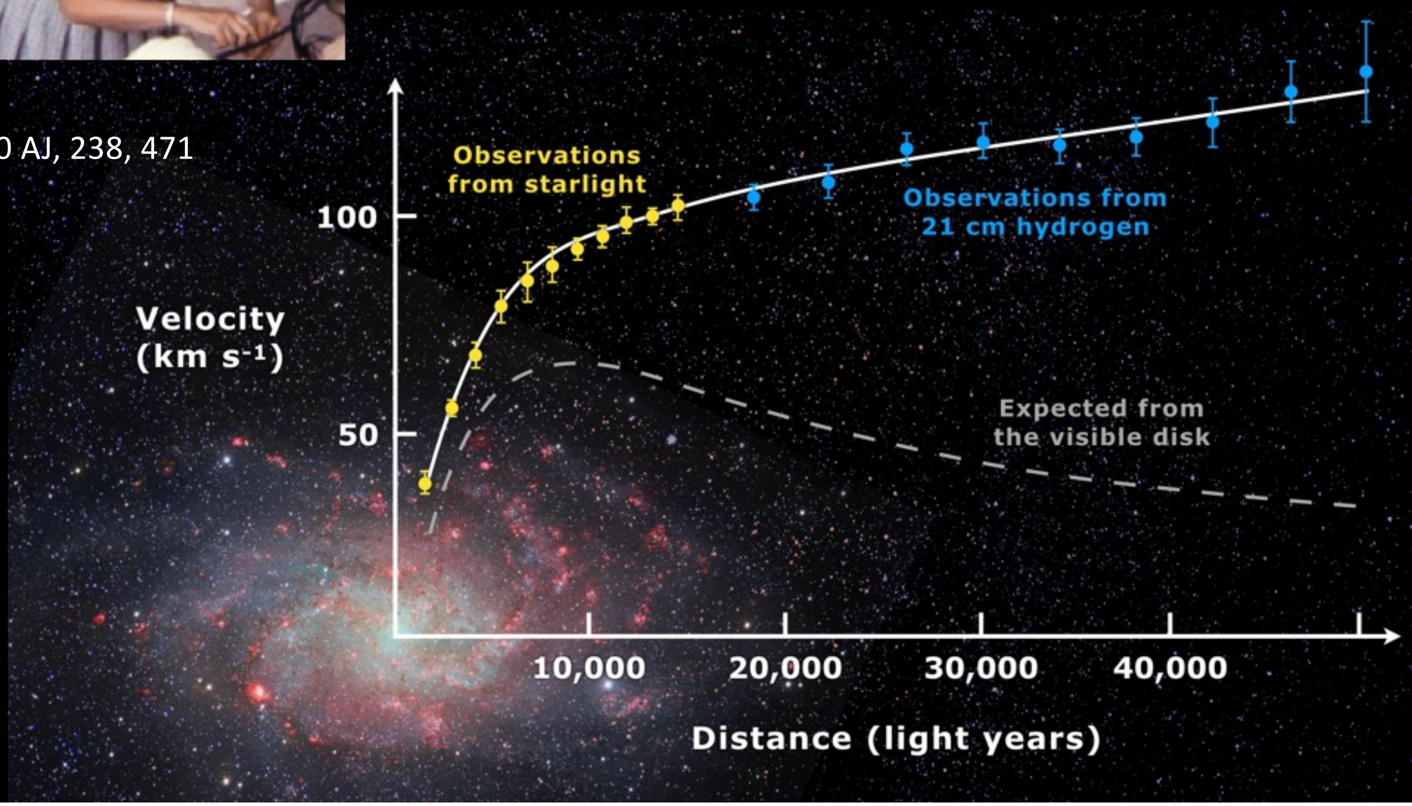
Rotation curve and the dark matter



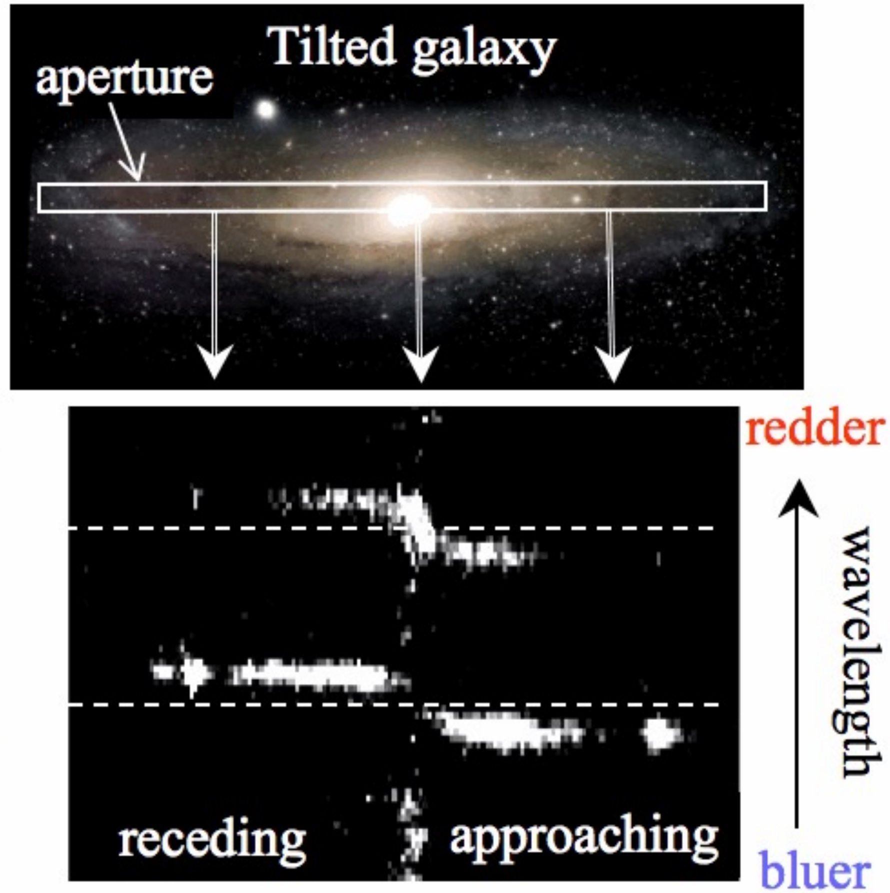
https://en.wikipedia.org/wiki/Oort_constants

Vera Rubin measured that stars in galaxies are moving faster than they should be, inferring the existence of an unseen mass we call “dark matter”

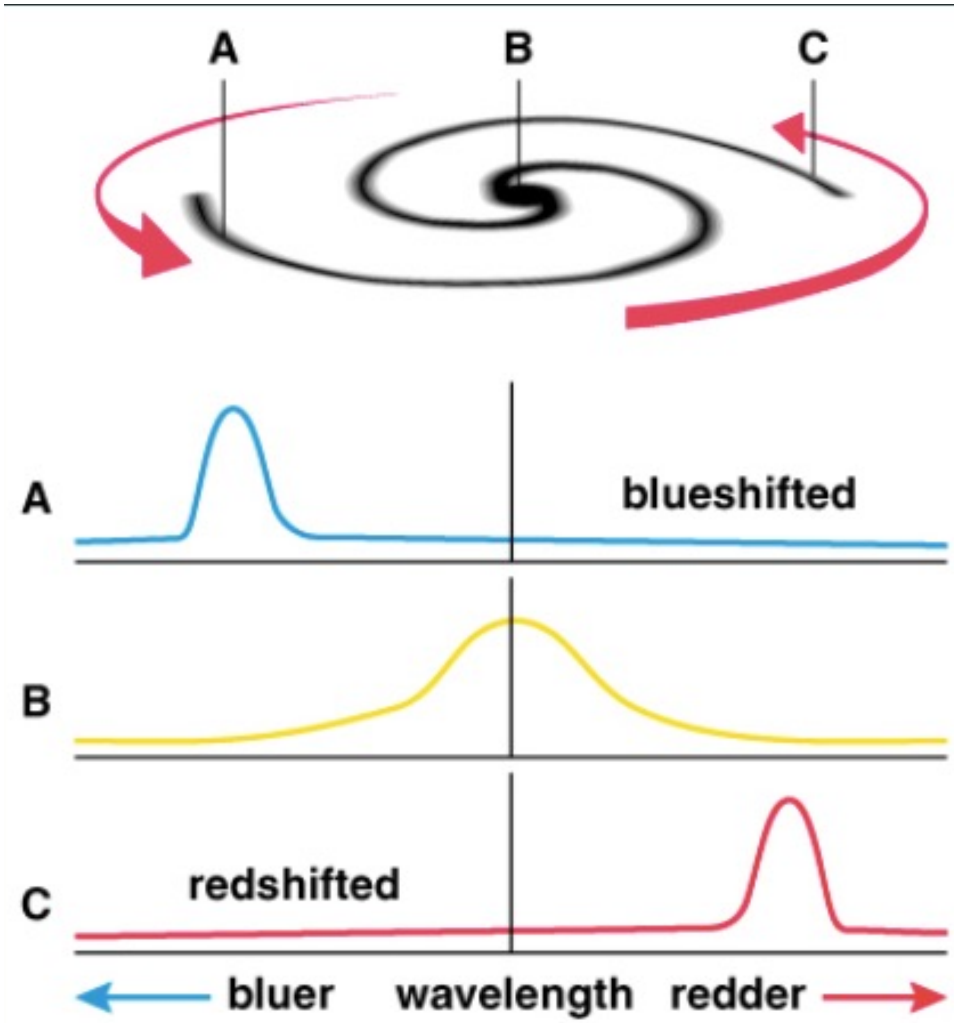
Rubin+1980 AJ, 238, 471



Vera Rubin measuring galaxy rotation curves (~1970)



Resulting spectrum of light within aperture


A
B
C
A
blueshifted
B
C
redshifted
bluer
wavelength
redder

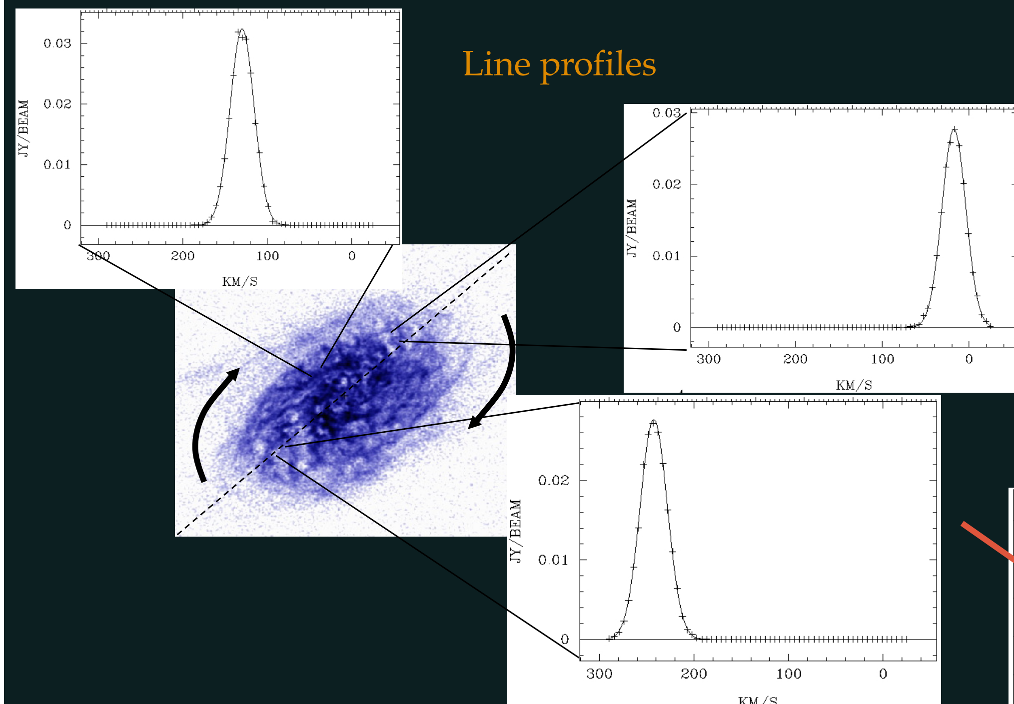
2D

Rotation of a galactic disc

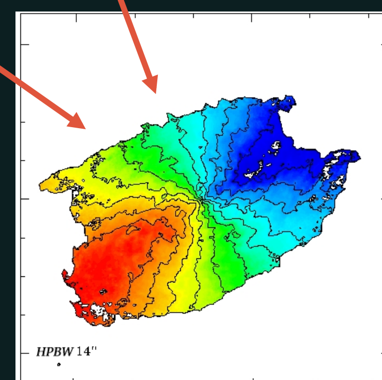
Line profiles

Doppler effect

$$v_r \equiv \frac{\Delta\lambda}{\lambda_{HI}} c$$



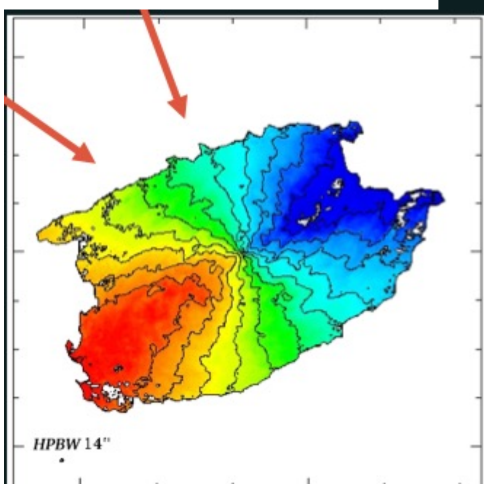
Velocity field

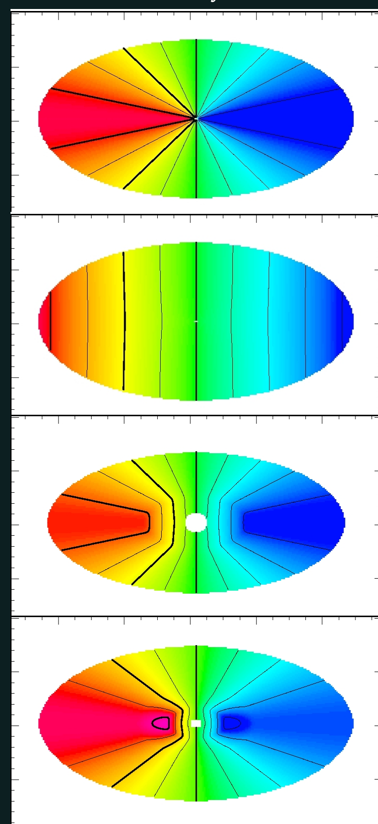


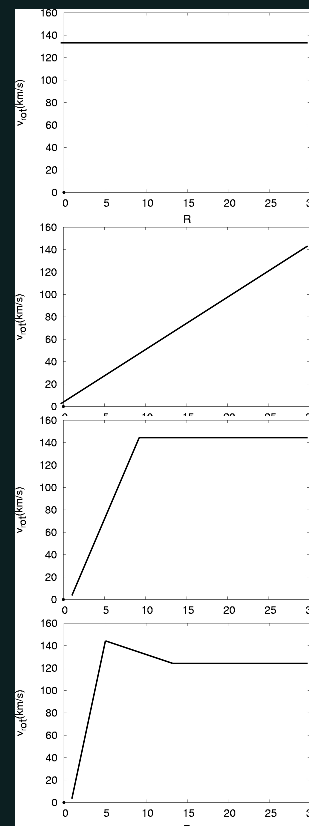
Spider Diagram

Velocity fields versus rotation curves

$$V_{\mathrm{LOS}} = v_{\mathrm{sys}} + v_{\mathrm{R}}\sin(\varphi)\sin(i) + v_{\varphi}\cos(\varphi)\sin(i) + v_{z}\cos(i)$$





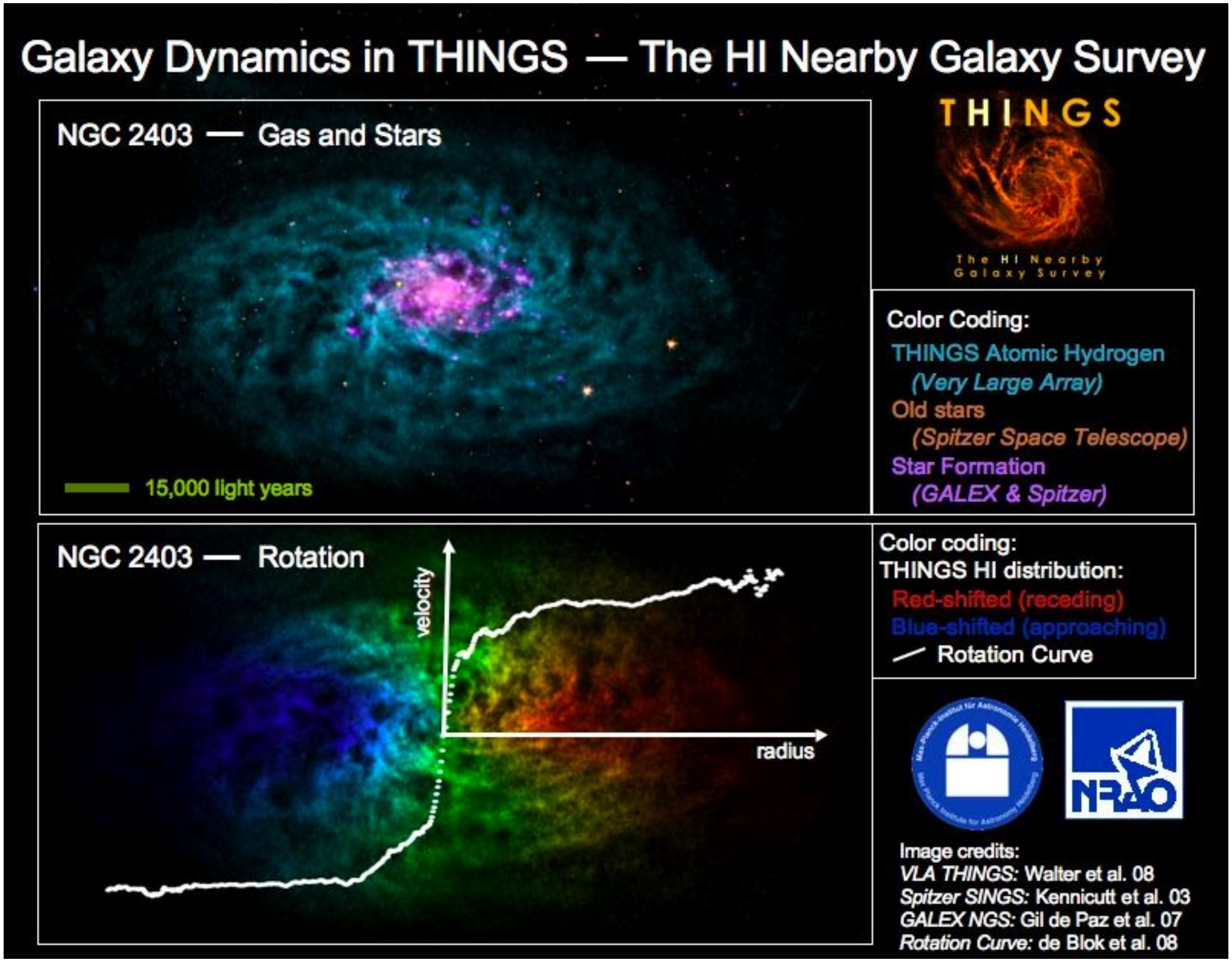


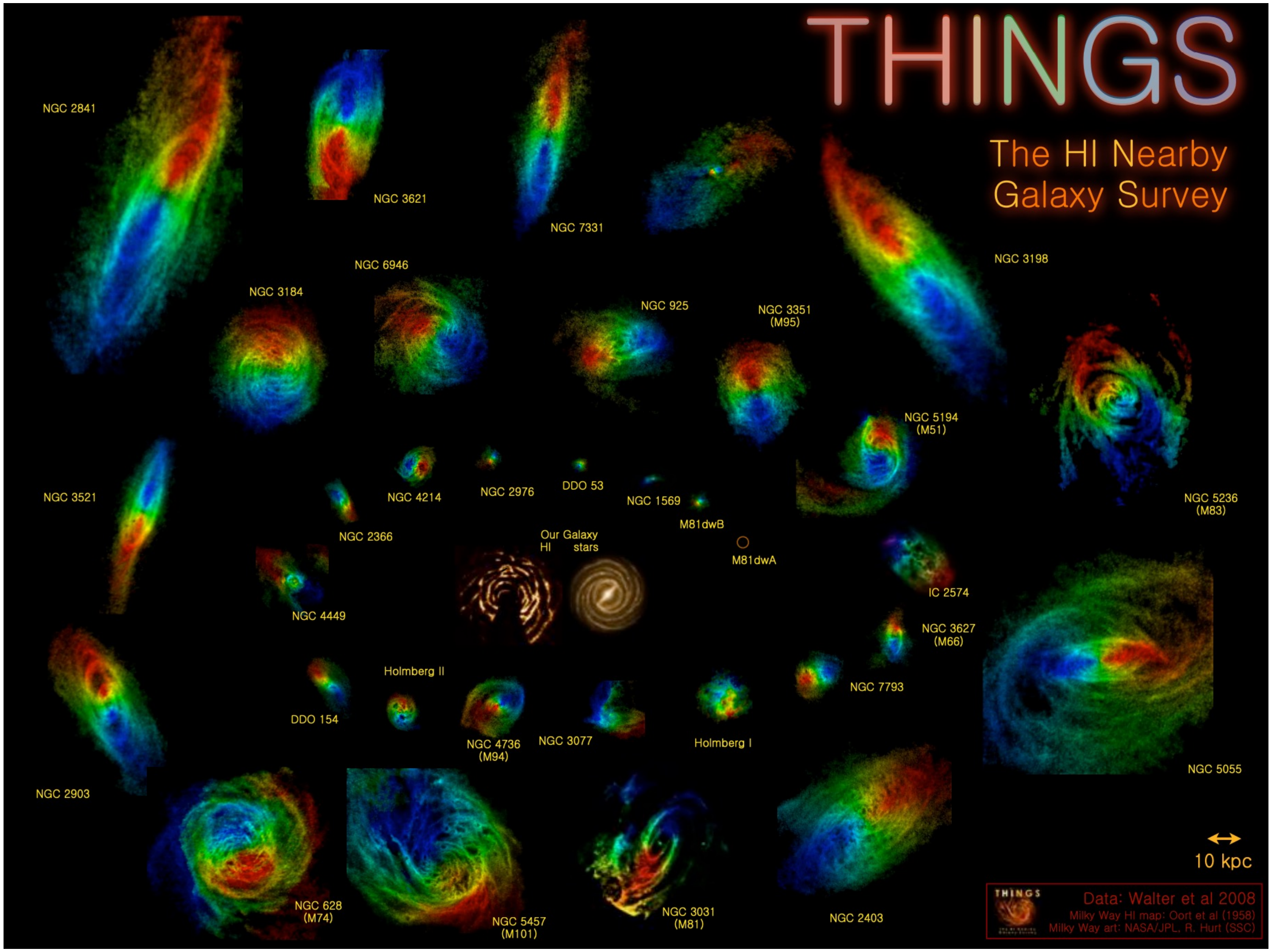
Flat M ~ R

Solid body

Rising + flat

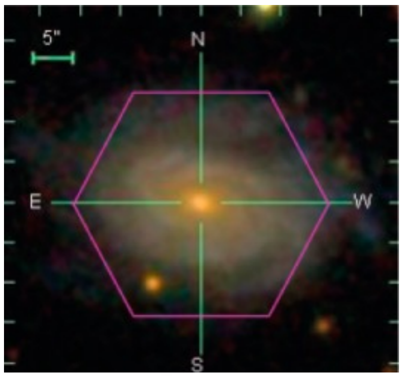
Rise+decline+flat

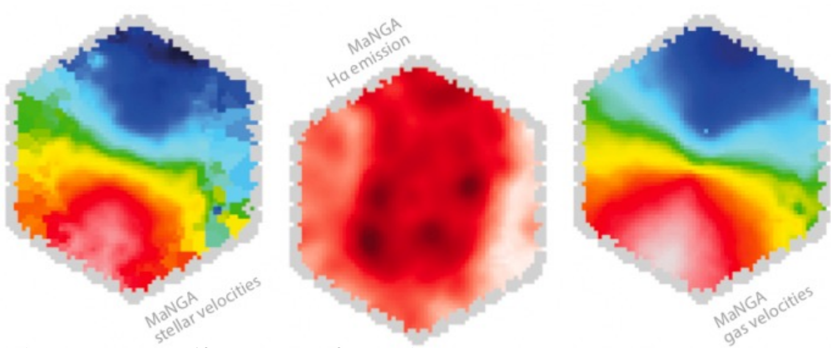

Galaxy Dynamics in THINGS — The HI Nearby Galaxy Survey
NGC 2403 — Gas and Stars
15,000 light years
THINGS
The HI Nearby Galaxy Survey
Color Coding:
THINGS Atomic Hydrogen
(Very Large Array)
Old stars
(Spitzer Space Telescope)
Star Formation
(GALEX & Spitzer)
NGC 2403 — Rotation
velocity
radius
Color coding:
THINGS HI distribution:
Red-shifted (receding)
Blue-shifted (approaching)
Rotation Curve
NRAO
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


THINGS
The HI Nearby Galaxy Survey
NGC 2841
NGC 3621
NGC 7331
NGC 3198
NGC 6946
NGC 3184
NGC 925
NGC 3351 (M95)
NGC 5194 (M51)
NGC 5236 (M83)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 1569
M81dwB
M81dwA
NGC 2366
Our Galaxy
HI stars
IC 2574
NGC 4449
NGC 3627 (M66)
NGC 7793
Holmberg II
DDO 154
NGC 4736 (M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628 (M74)
NGC 5457 (M101)
NGC 3031 (M81)
NGC 2403
THINGS
Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)

IFUs : SDSS V, IV

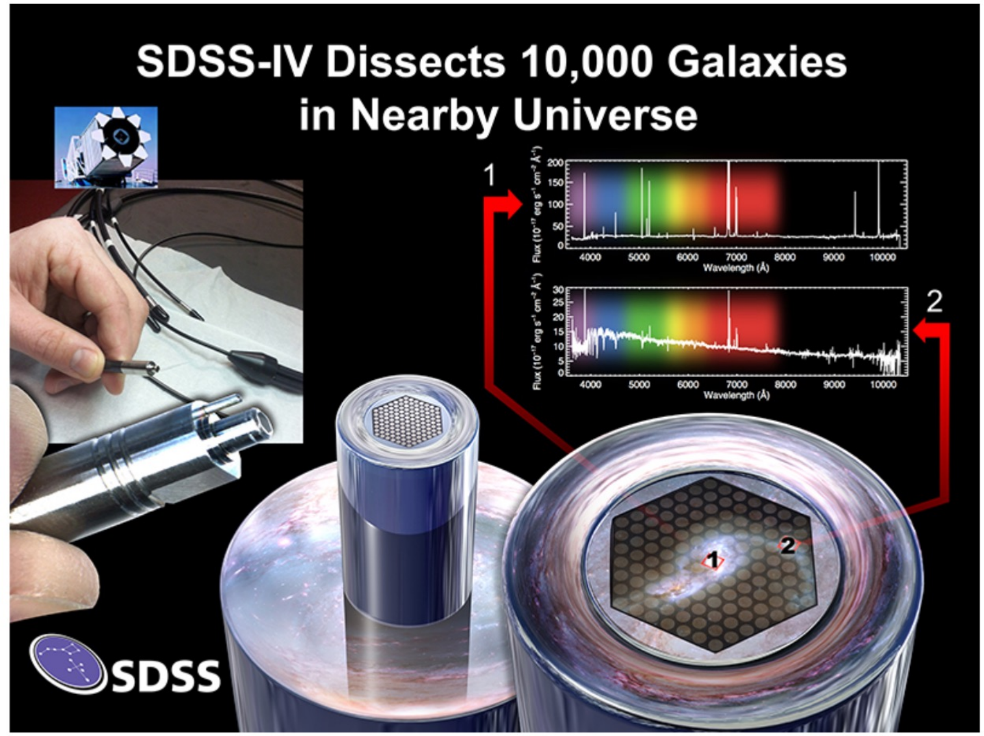
(Integral Field Units)





Credit: Francesco Belfiore, Univ. of St Andrews Print & Design.

Bundy + 2015

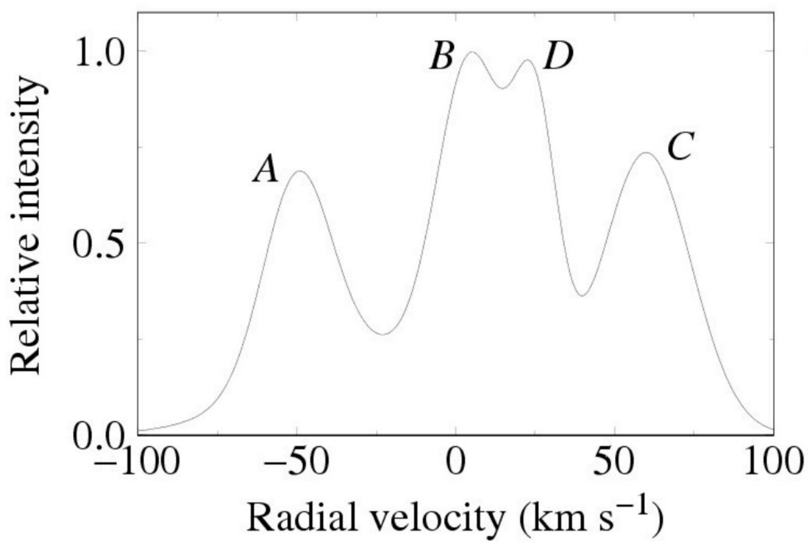


MaNGA obtains spectra across the entire face of target galaxies using custom designed fiber bundles. The bottom right illustrates how the array of fibers spatially samples a particular galaxy. The top right compares spectra observed by two fibers at different locations in the galaxy, showing how the spectrum of the central regions differs dramatically from outer regions. Image Credit: Dana Berry / SkyWorks Digital Inc., David Law, and the SDSS collaboration.

Galactic rotation: a gas cloud at marked points. Gas cloud at C with longitude l and Galactocentric radius R, at distance d from the Sun, orbits with speed V(R). The line of sight is closest to the Galactic center at the tangent point, C.

$$d = R_o cos(l) \qquad v_{los} = V_c + V_o sin(l)$$

$$R = R_o\, sin(l)$$



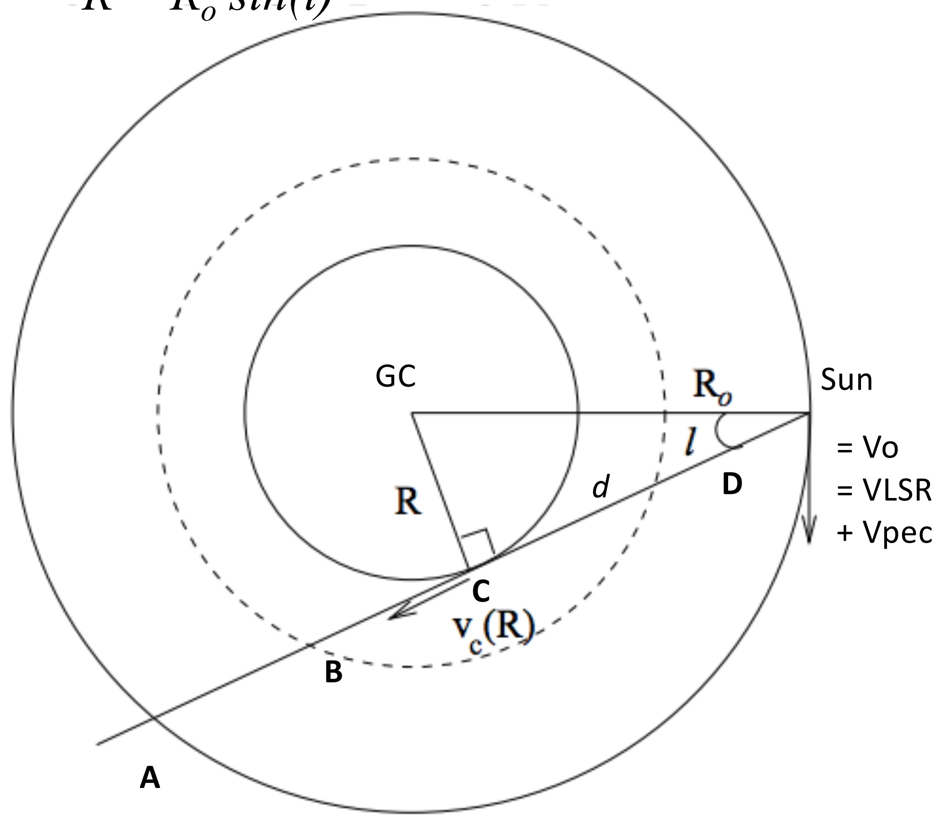


Figure 1: The tangent point method

NOTE: This only works within Rsun

To compute the MW's rotation Curve we need to measure:

- **VLSR** Velocity of the Local Standard of Rest
  - Equivalent to the velocity a test particle would have if it was on a circular orbit at the location of the Sun
  - (this is not the Sun's motion).
- **Ro** : Distance of the Sun from the Galactic Center
- **Vpec** : Peculiar motion of the Sun with respect to the VLSR

Longitude Velocity Diagram for the MW

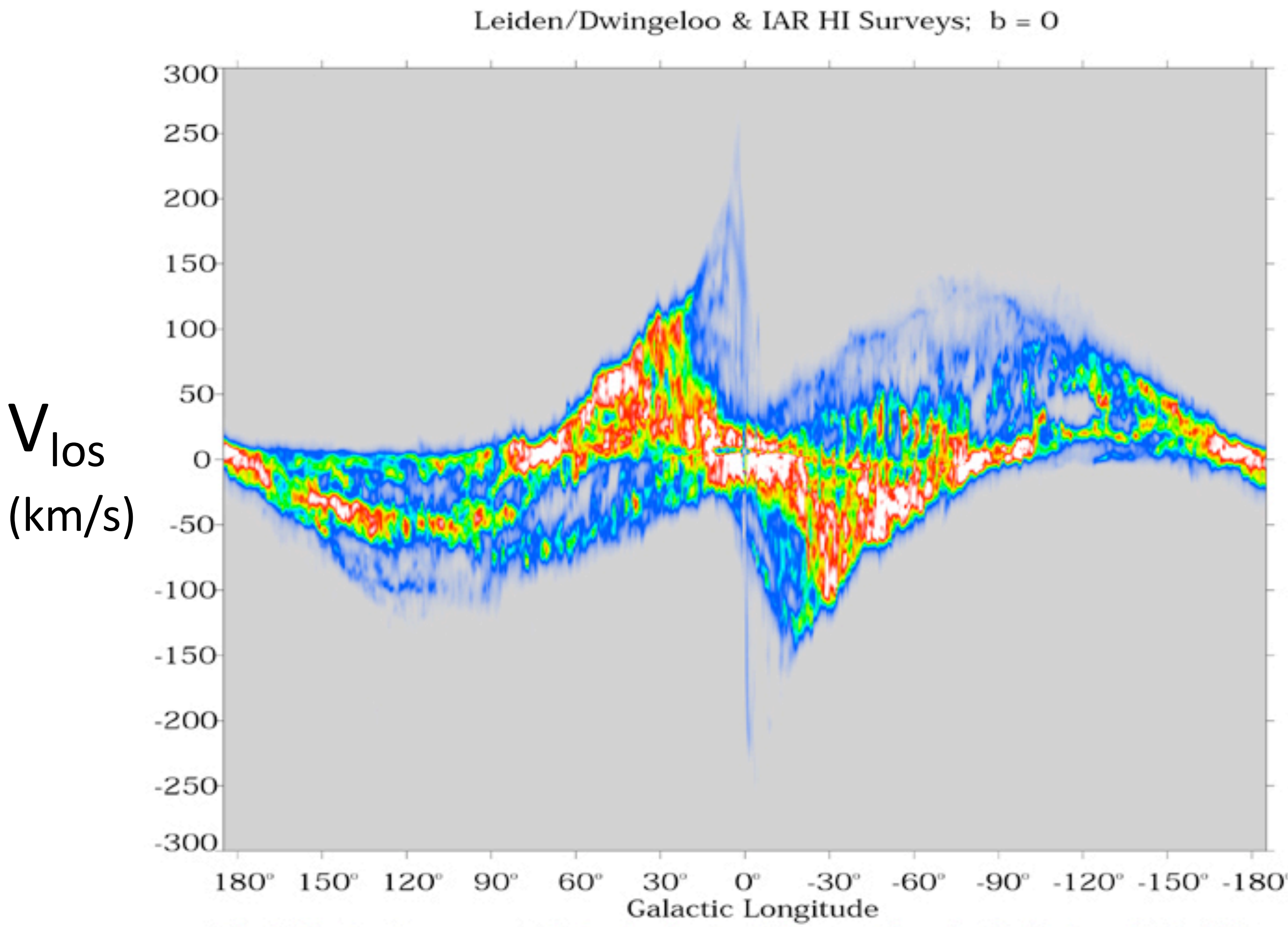


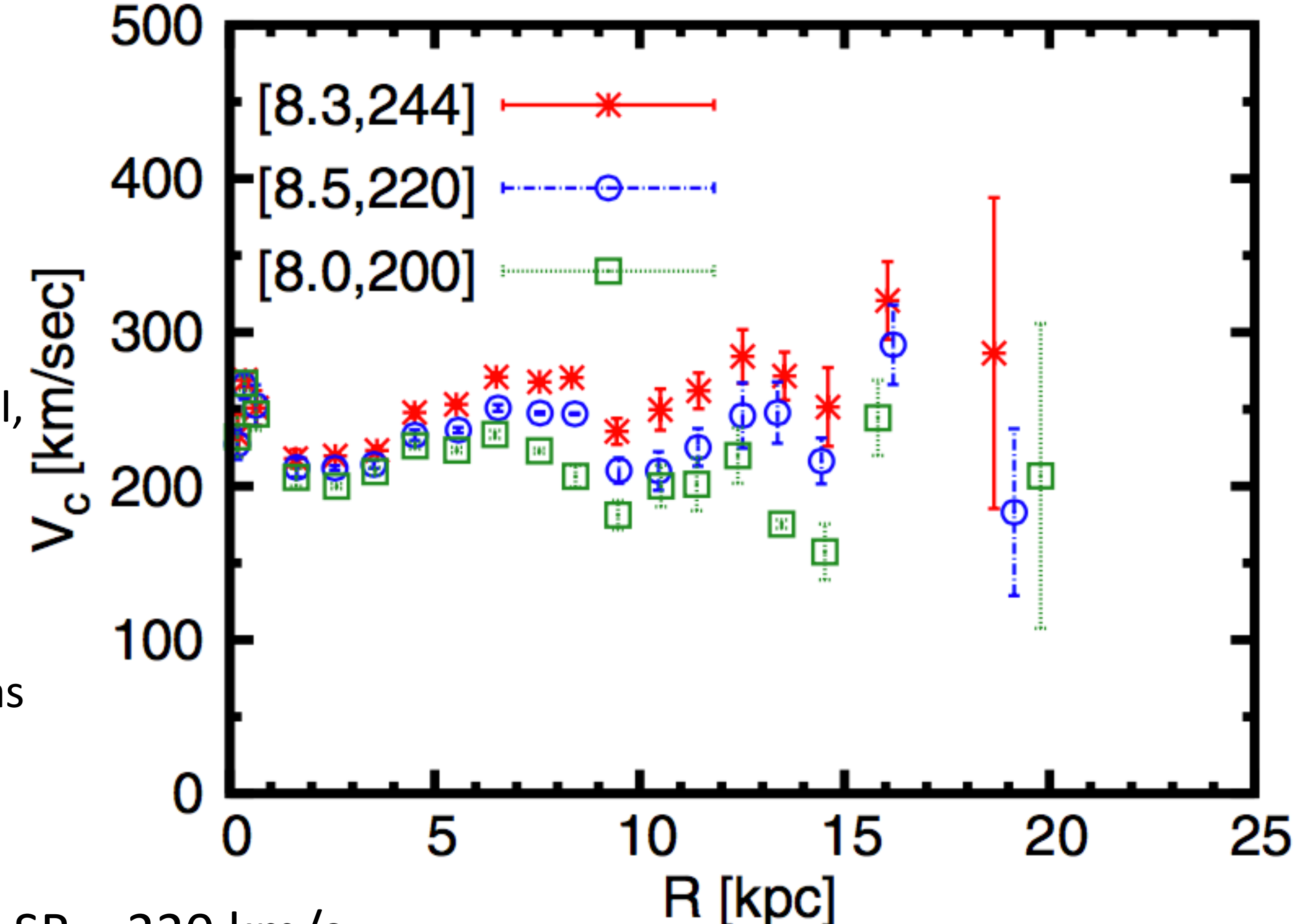
Fig 2.20 (D. Hartmann) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

In the plane of the disk, the intensity of 21 cm emission from neutral hydrogen moving toward or away from us with velocity V_{LSR} measured relative to the local standard of rest.

Yields terminal velocity at each Galactic l

Bhattacharjee + 2014 ApJ 785 Fig. 2

Average rotation curves obtained by weighted averaging over the combined Vc data from all the disk tracer samples (HI, Cepheids, HII regions, Carbon stars, CO) , for three different sets of values of [(Ro/kpc),(VLSR/km s^{-1})] as indicated



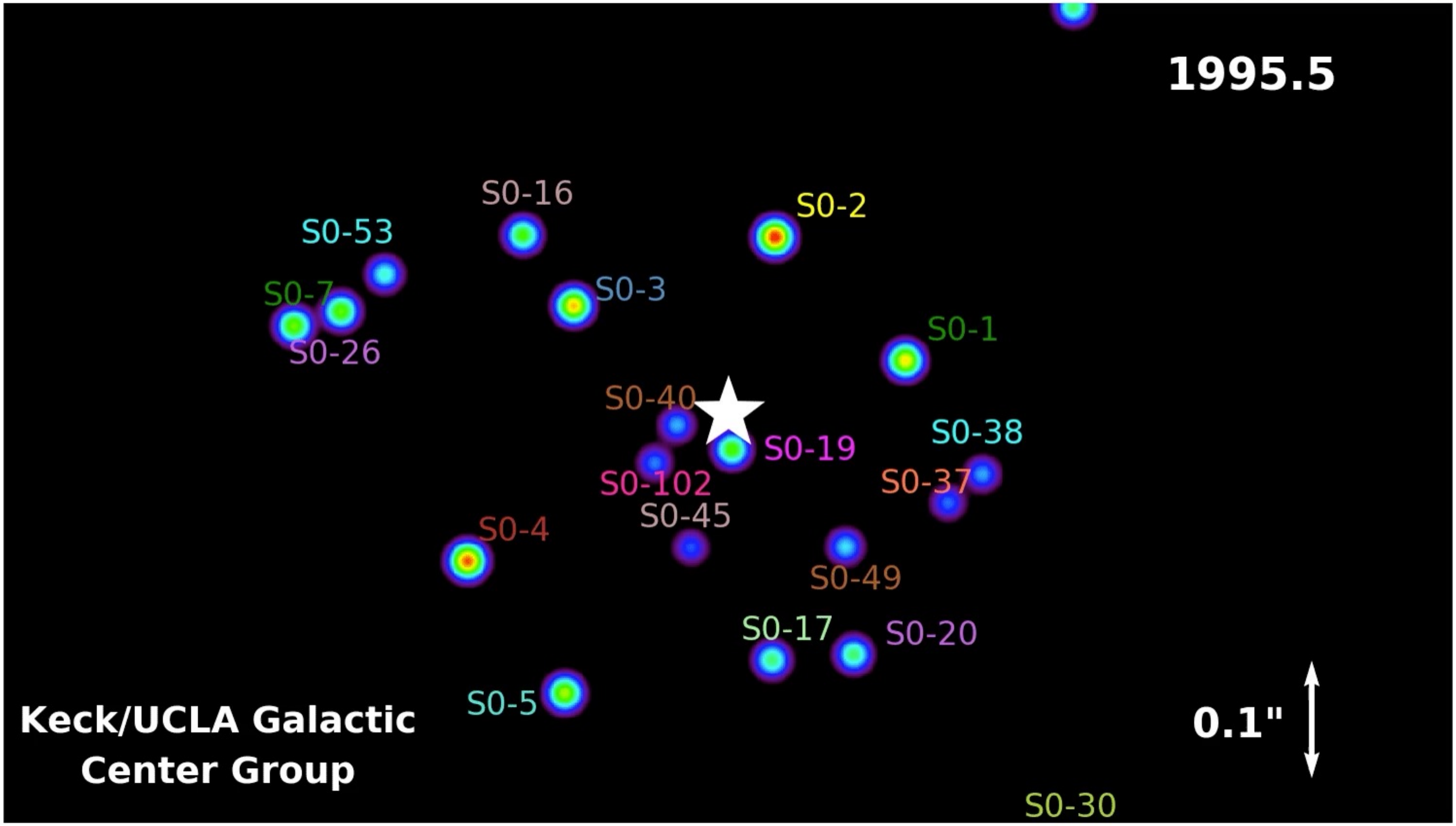
IAU STANDARD => VLSR = 220 km/s

Proper Motion of Sgr A*

$$\mu_{SGRA*} = -6.379 \pm 0.026 \text{ mas/yr}$$

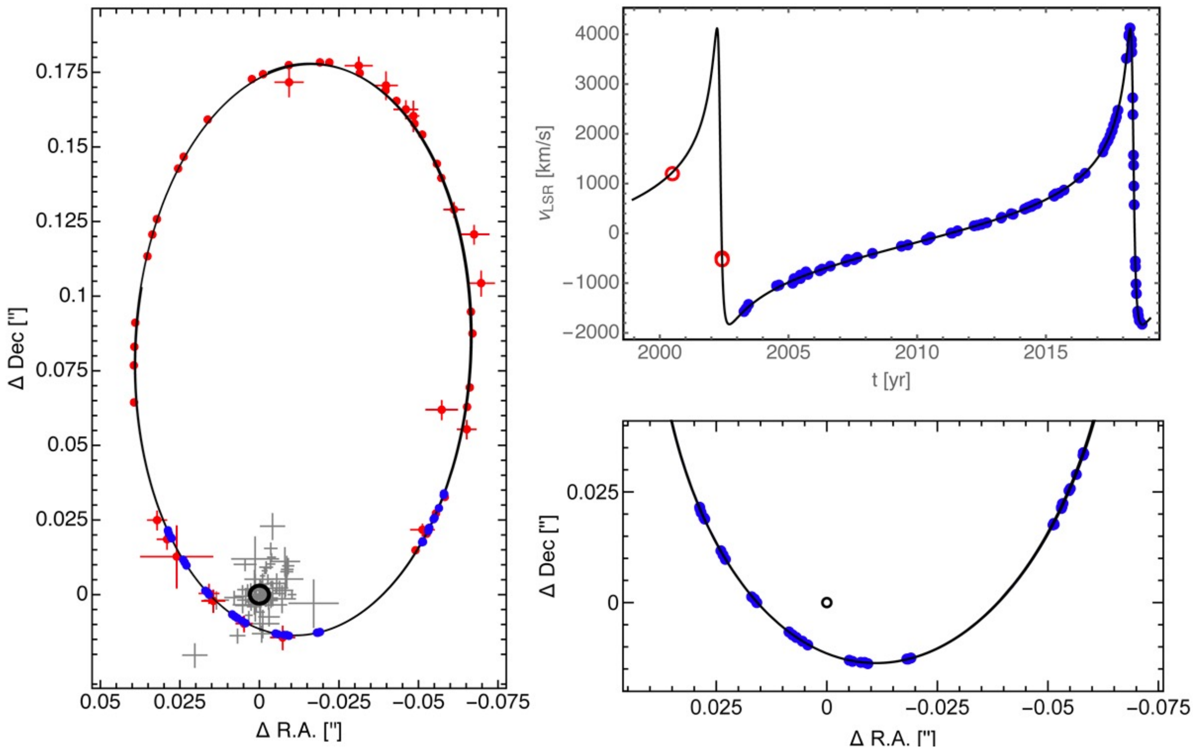
Reid & Brunthaler 2004, VLBI measurements of SgrB2

$$v_{tan} = 4.74 \frac{\mu}{\text{mas/yr}} \frac{R_o}{\text{kpc}} = V_{LSR} + v_{\odot}$$



1995.5
S0-16
S0-2
S0-53
S0-7
S0-3
S0-26
S0-1
S0-40
S0-19
S0-38
S0-102
S0-37
S0-45
S0-4
S0-49
S0-17
S0-20
S0-5
Keck/UCLA Galactic
Center Group
0.1"
S0-30

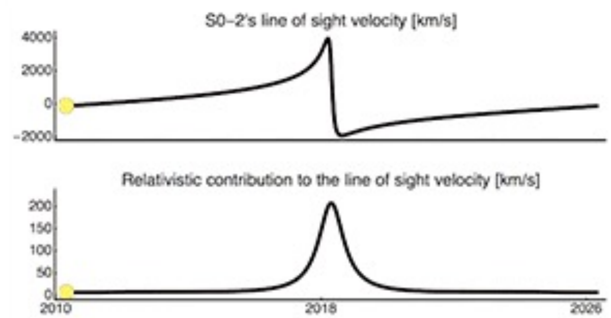
Galactic Center Distance: Fitting the orbit of S2

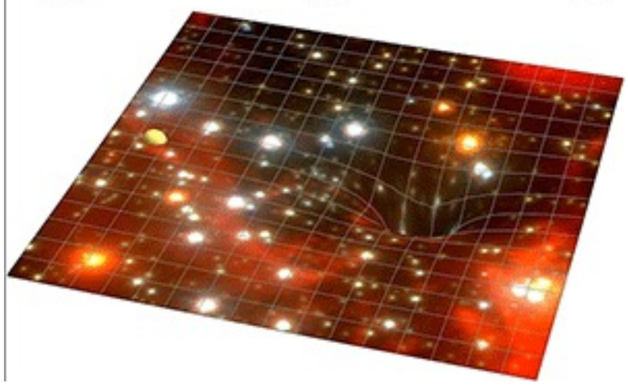


Orbit of S2. *Left*: on-sky view of the astrometric data (red: AO data, blue: GRAVITY data) in the down-sampled version with the best-fit orbit (black ellipse). The black circle marks the position of Sgr A*. The locations of previous AO-based flares agree with that position (gray crosses). *Right top*: radial velocity data of S2 together with the best-fit orbit. The blue data are from the VLT, the red are earlier epochs from the Keck data set ([Ghez et al. 2008](#)). *Right bottom*: zoom into the on-sky orbit in 2017 and 2018, showing the GRAVITY data that have error bars smaller than the symbol size.

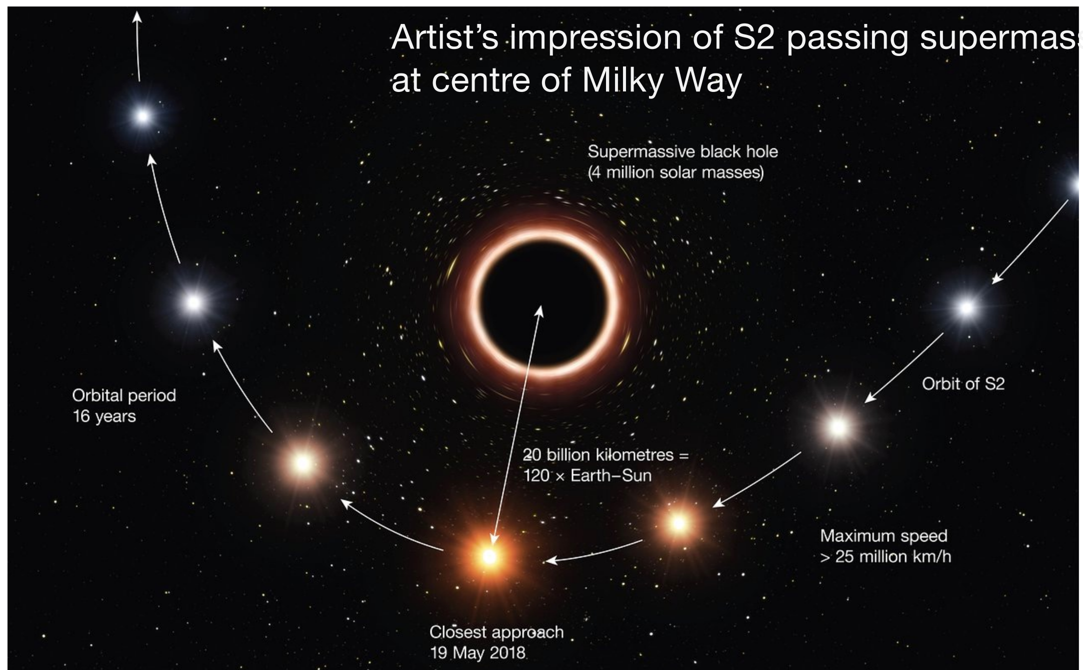
Abuter + 2019 GRAVITY Collaboration

Ro = 8.178 +/- 0.013_{stat} +/- 0.022 sys





As the star S0-2 nears our galaxy's supermassive black hole (orbit exaggerated), the light it emits has to climb out of the gravitational potential well, losing energy. This process reddens the light. The star's motion along our ling of sight also shifts the light's wavelengths, and so astronomers measure both shifts in km/s.
Credit: Aurelien Hees / Keck UCLA Galactic Center Group

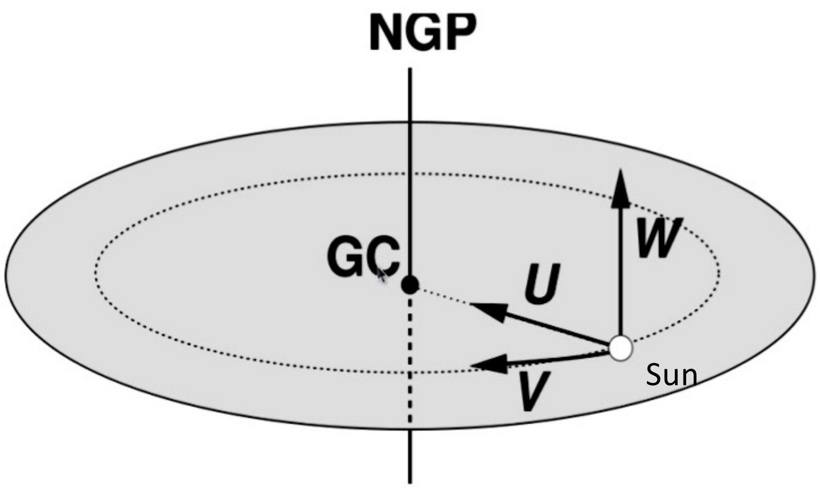


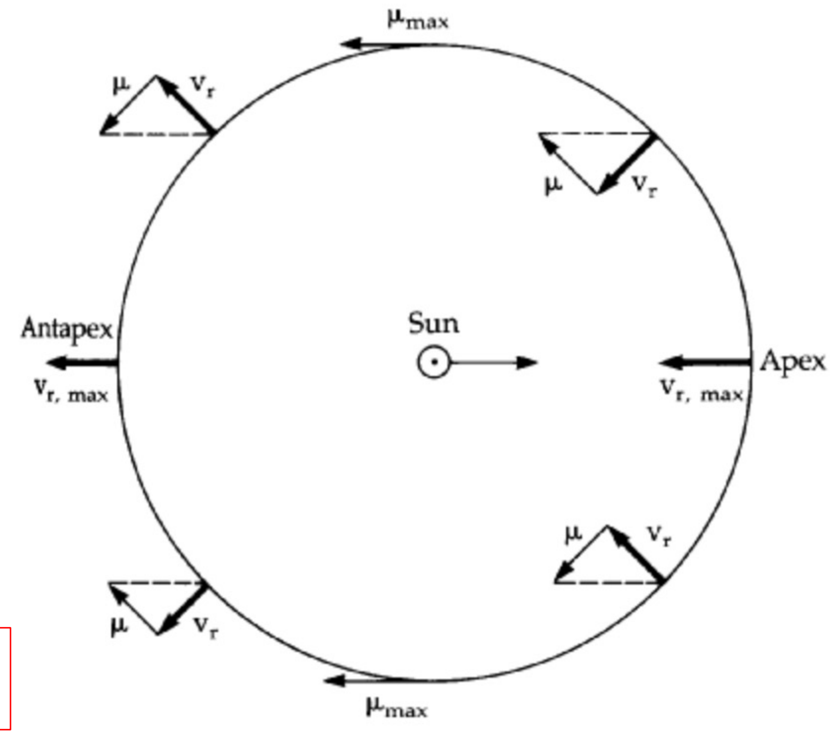
UCLA Team:
Do + 2019

GRAVITY Collab
Abuter+2018

Peculiar motion of the Sun wrt LSR

See Carroll & Ostlie Chap 24





Solar Peculiar Motion: Schonrich+ 2010

$$\boxed{(u, v, w)_\odot = 11.1 \pm 1.23, 12.24 \pm 2.05, 7.25 \pm 0.62}$$

Units of km/s

Vpeculiar we care about is in the v direction

So going back to the proper motion of Sgr A*

$$v_{tan} = 4.74 \frac{\mu}{\mathrm{mas/yr}} \frac{R_o}{\mathrm{kpc}} = V_{LSR} + v_{\odot}$$

V_{LSR} = → LAB 1 !

Local Standard of Rest = The average velocity of stars near the sun.

Rsun = 8.09 kpc
So :V_{LSR} = ~ 233 km/s

Most studies adopt:

Rsun = 8.29 ± 0.16 kpc
V_{LSR} = 239 ± 5 km/s
McMillan+2011

Milky Way Rotation Curve

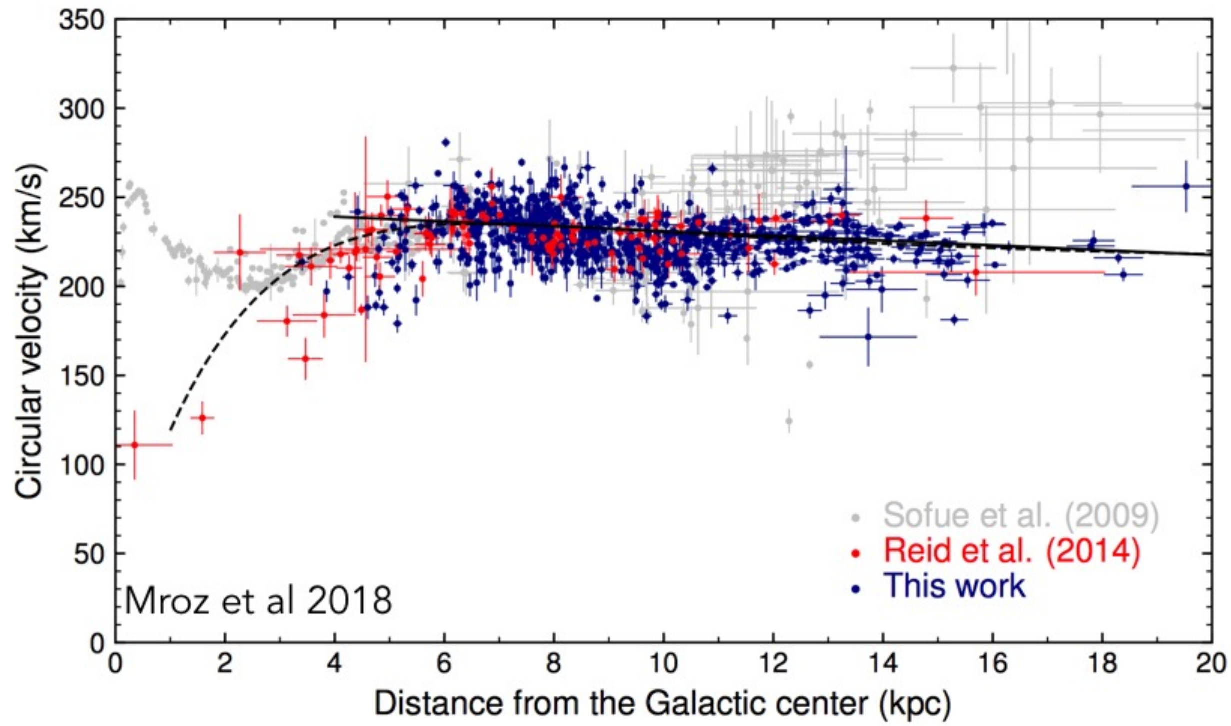
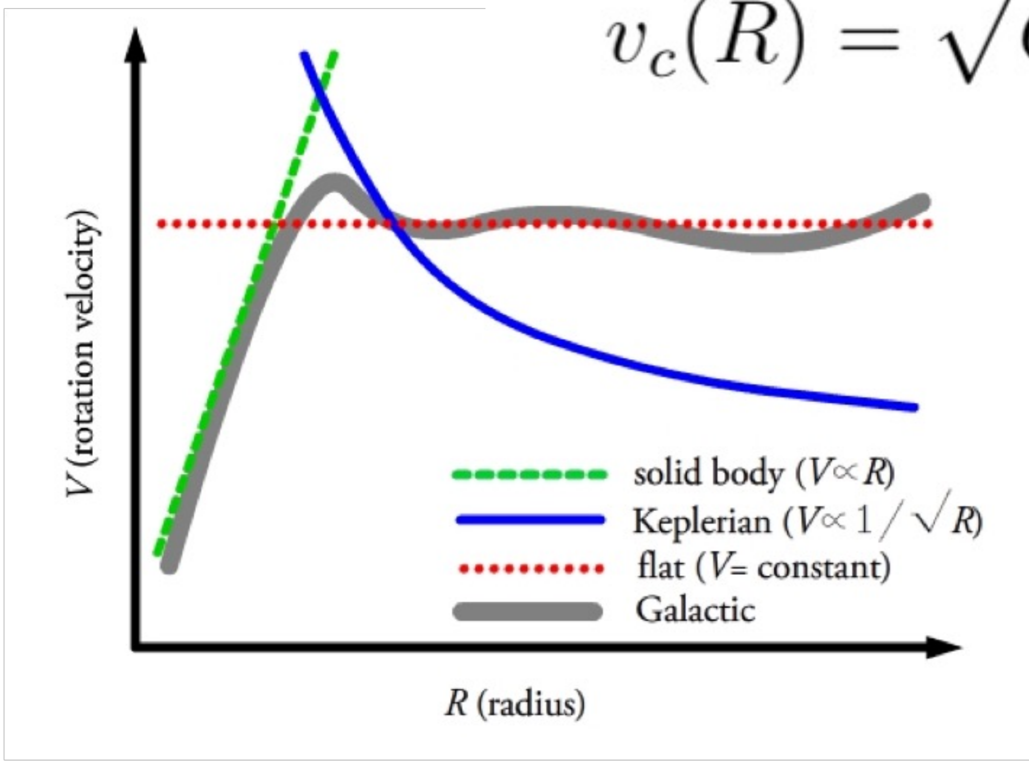


FIG. 2.— Rotation curve of the Milky Way for Cepheids assuming $R_0 = 8.09$ kpc and $\Theta_0 = 233.6\,\mathrm{km\,s^{-1}}$ (model 2). Red data points represent high mass star forming regions (Reid et al. 2014). Grey data points are taken from Sofue et al. (2009) and were rescaled to new (R_0, Θ_0) using formula $V_{\rm new} = V_{\rm old} + \frac{R}{8.0}(\Theta_0 - 200)$. Solid and dashed lines show the best-fitting models (linear and universal, respectively).

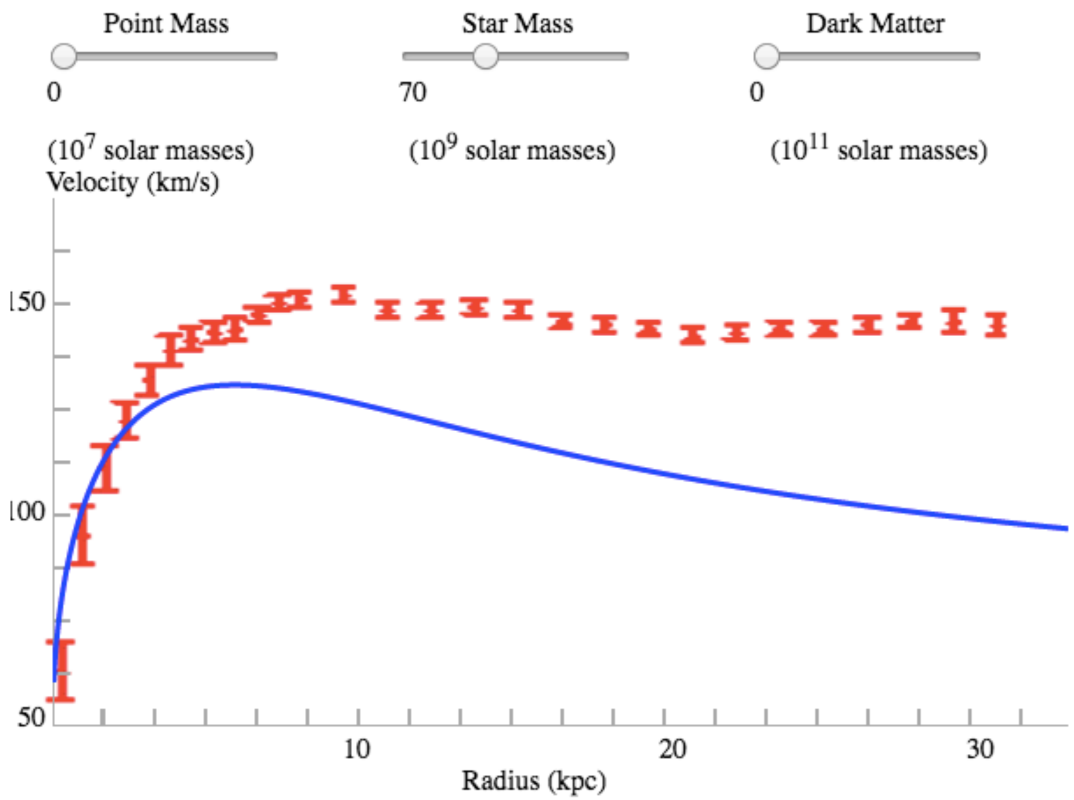
Recall …

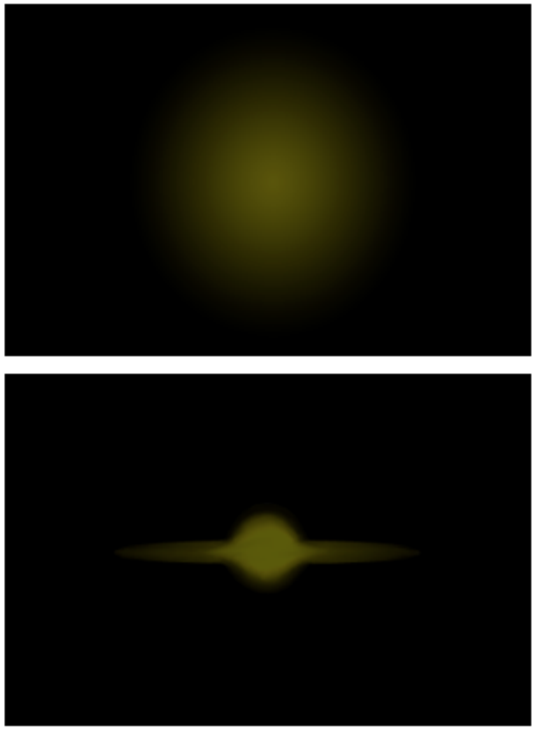
Rotation curve and the dark matter

$$v_c(R) = \sqrt{GM(< R)/R}$$



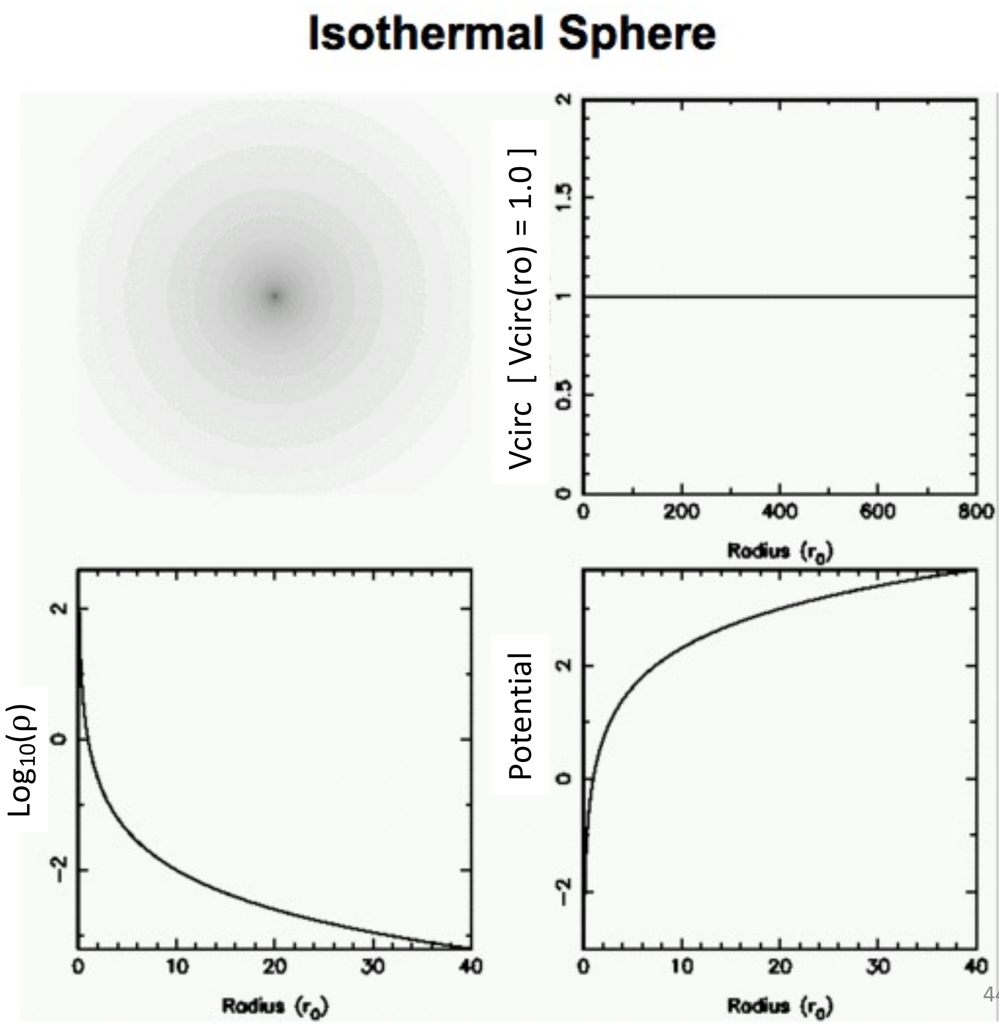
Try for yourself:
http://wittman.physics.ucdavis.edu/Animations/RotationCurve/GalacticRotation.html. (google wittman galactic rotation)





$$\rho(r) = \frac{V_o^2}{4\pi G r^2}$$

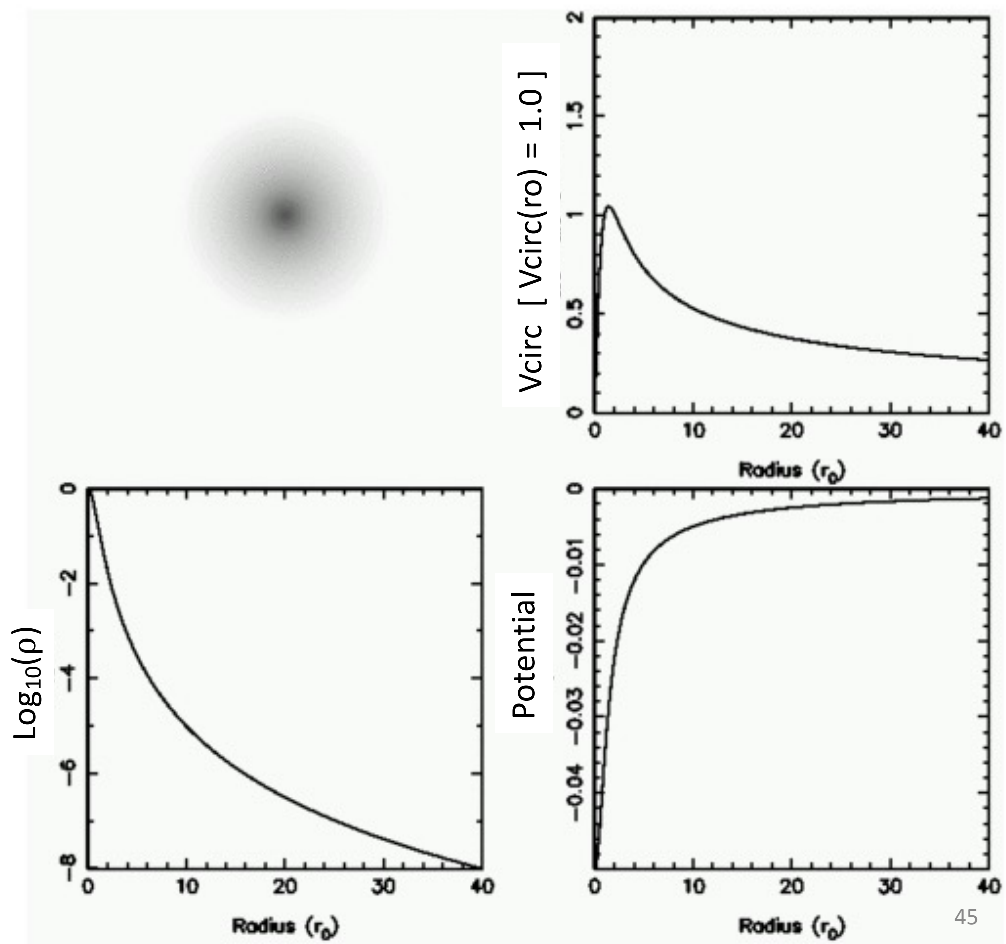
$$\Phi(r) = 4\pi G \rho_o ln(r) = V_o^2 ln(r)$$

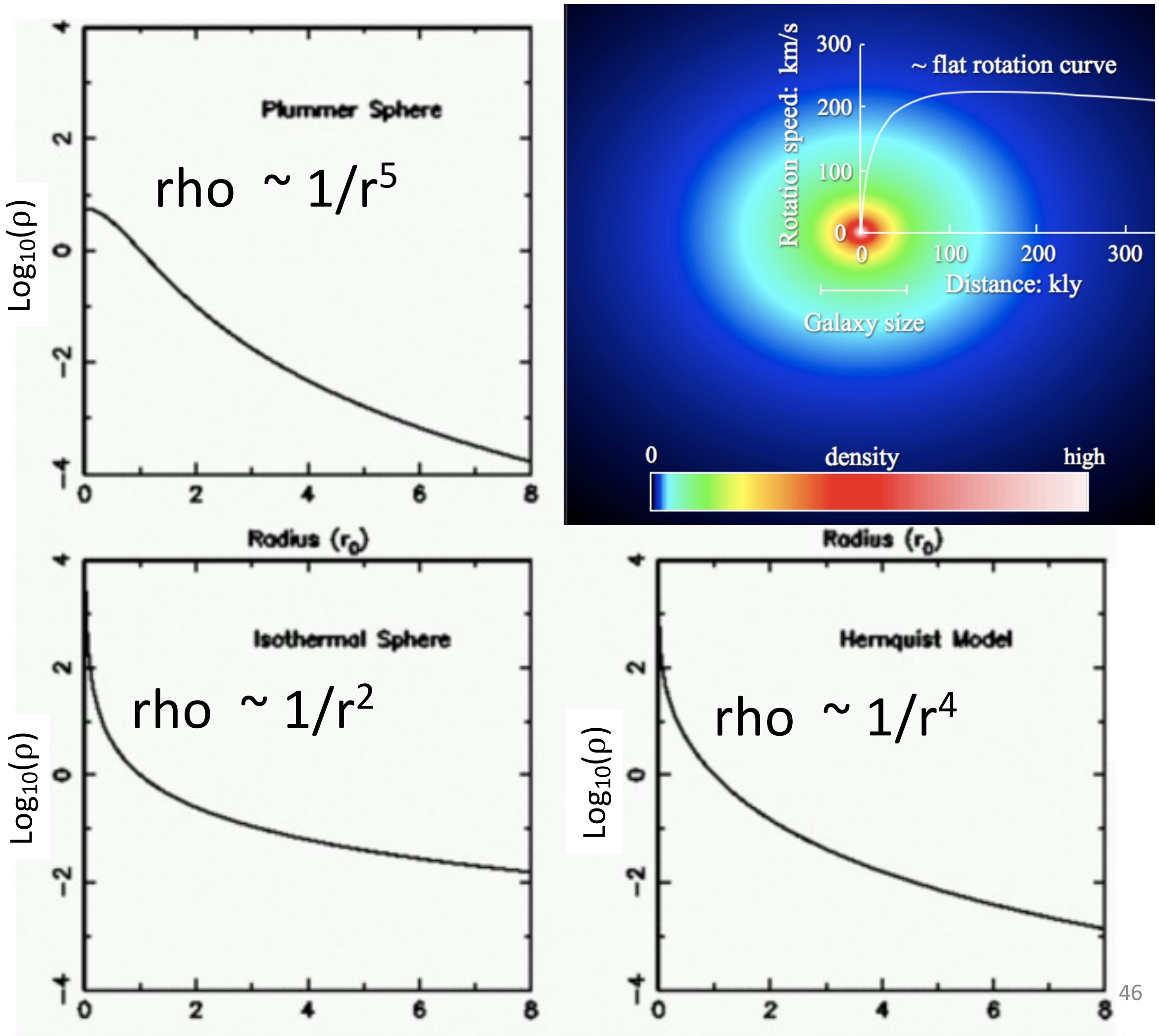


$$\rho(r) = \frac{M}{4/3\pi a^3}(1.0 + r^2/a^2)^{-5/2}$$

$$\Phi(r) = -GM/\sqrt{r^2 + a^2}$$

Plummer model





Hernquist 1990 Profile

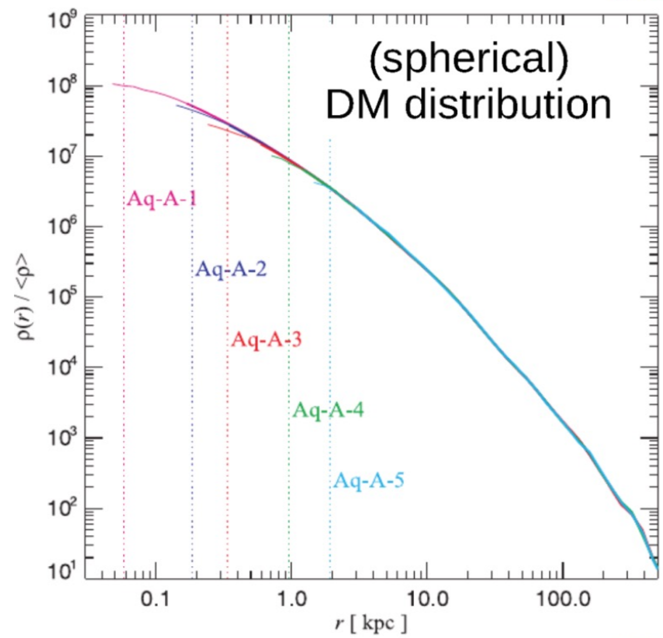
$$\rho(r) = (M/2\pi)\frac{a}{(r(r+a)^3)}$$

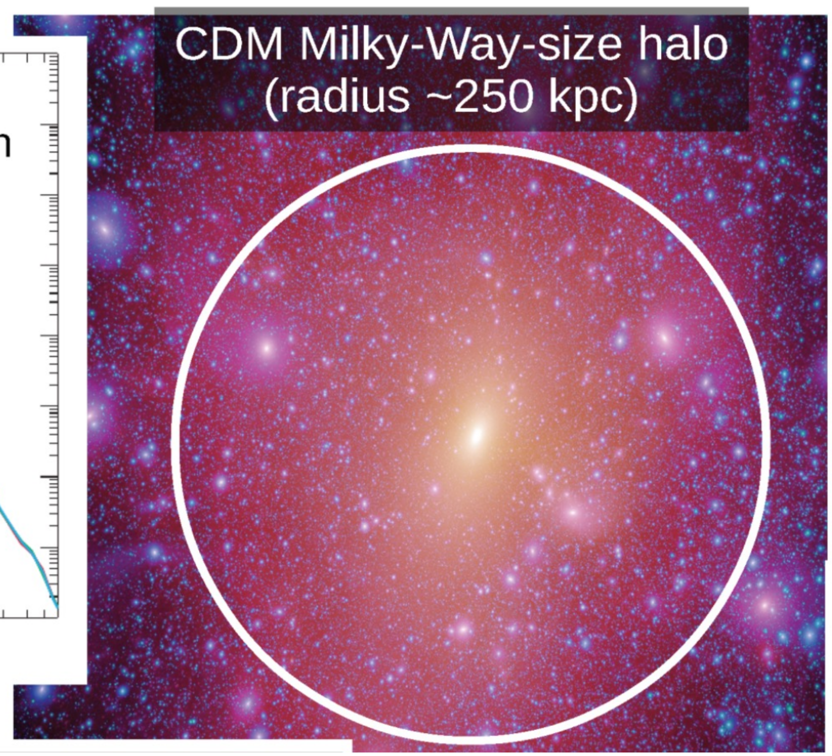
$$\Phi(r) = -GM/(r+a)$$

rho ~ $1/r^3$

NFW

$$\rho(r) = \frac{\rho_o}{r/r_s(1+r/r_s)^2} \qquad \Phi_{\rm NFW}(r) = -\sigma_N^2 \frac{\ln(1+{\rm r/r_s})}{r/r_s} \qquad \sigma_N = 4\pi G \rho_o r_s^2$$





Zavala & Frenk 2019 Review

Some complications at larger radii…

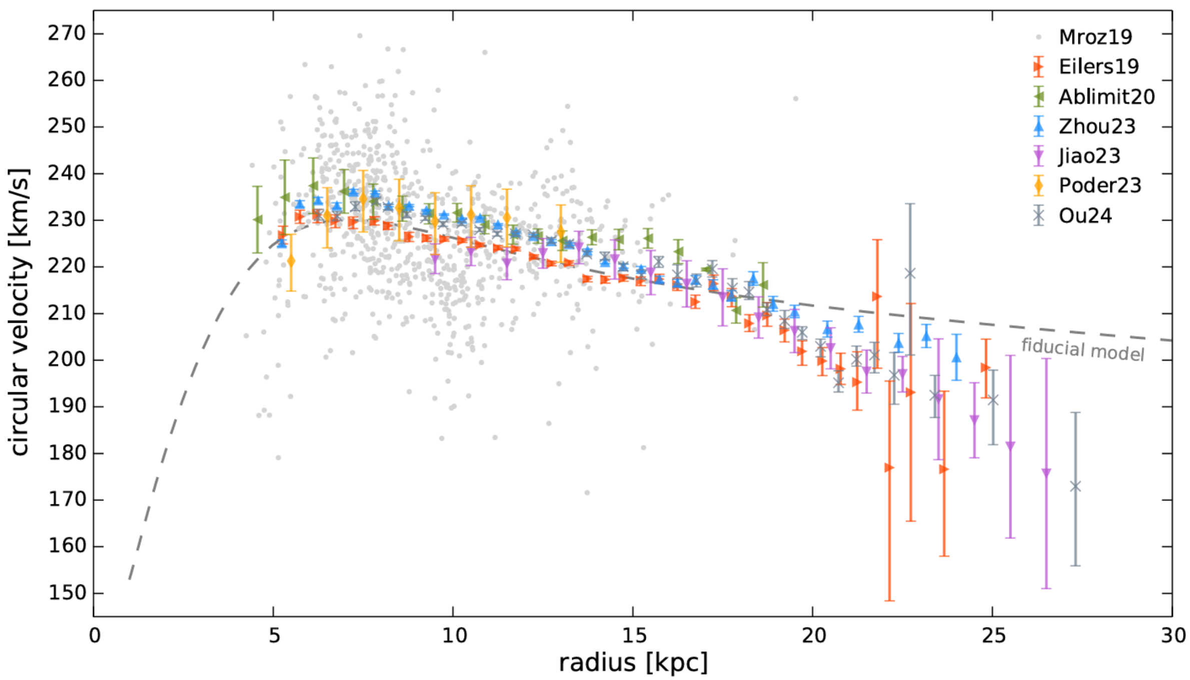
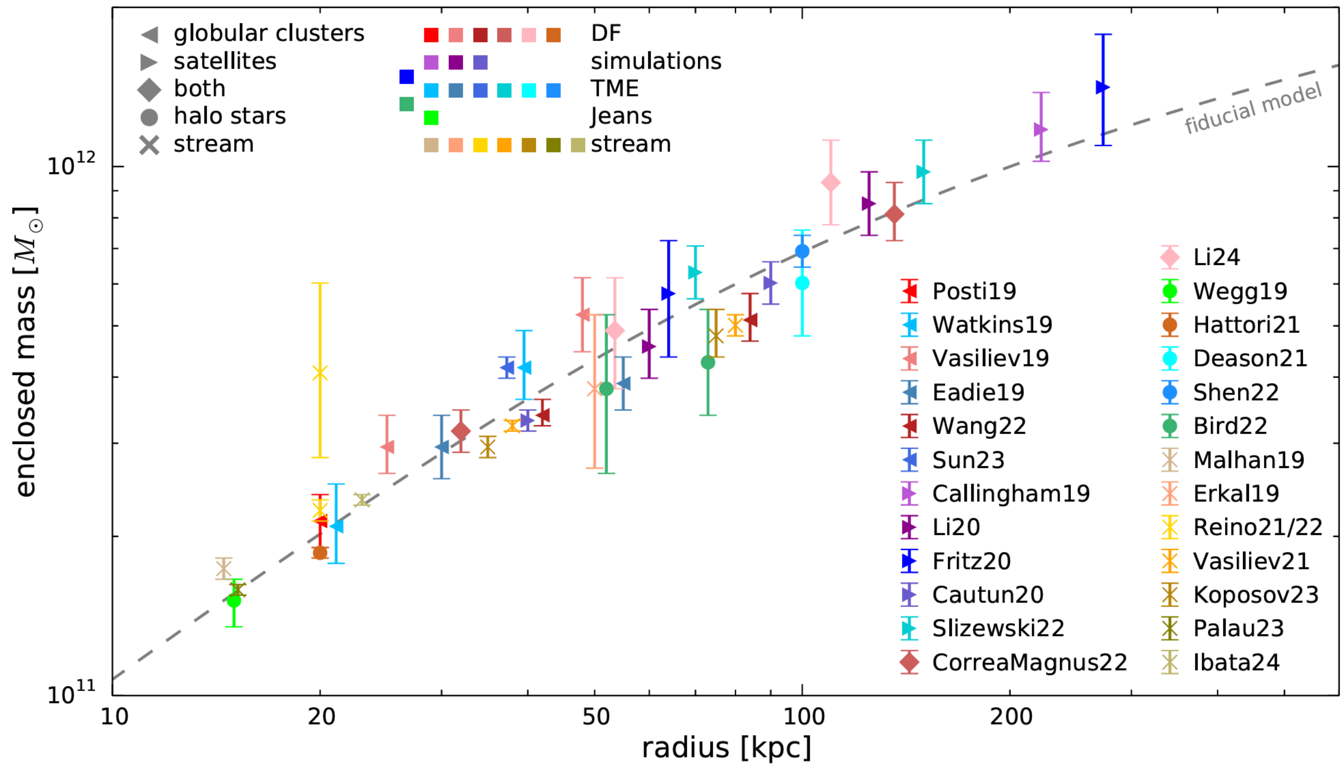


Figure 17: A compilation of measurements of the Milky Way circular-velocity curve in the radial range 5–30 kpc. The dashed line shows the same fiducial model as in the previous plot.

Hunt & Vasiliev 2025 Review ArXiv 2501.04075

Outer rotation curve is at odds with tracers at large radii



Hunt & Vasiliev 2025 Review ArXiv 2501.04075