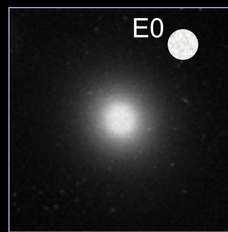
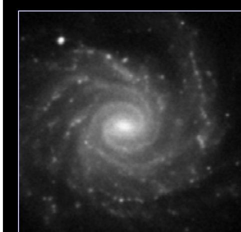
Winning Entries in this week's Galaxy Classification Lottery



E1

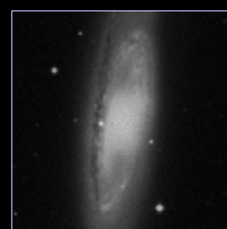
E6

S0
(but formerly known as E7)

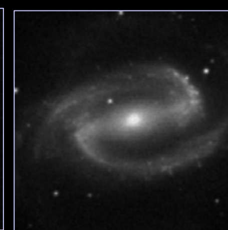


Sc

Sb



Sa



SBb

Note– I am skipping the last two slides in the lecture notes posted for Sept 15.

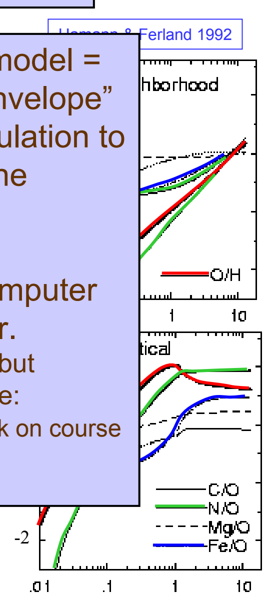
Tools of the Trade

Modeling Chemical Enrichme…

- One zone, accreting box model.
  - Start with pure H, He mix.
  - Further H, He falls in at specified ra…
- Follow evolution of individual eleme… N, O, Ne, Mg, Si, S, Ar, Ca and Fe.
- Subdivide stellar population into thr… stars:
  - < 1M$_\odot$ nothing recycled
  - 1.0 – 8.0 M$_\odot$ fraction give white dwarf…
  - > 8M$_\odot$ Core collapse supernova…
- Assume that each class of stars spe… % of its mass of each element back… end of a specified lifetime.
- Must provide IMF to specify mix of…
- Two extreme models:
  - "Solar neighborhood": conventional IMF, slow stellar birthrate, slow infall (15% gas at 10 Gyr) .
  - "Giant Elliptical": flatter IMF, 100x higher birthrate, fast infall (15% gas at 0.5 Gyr).

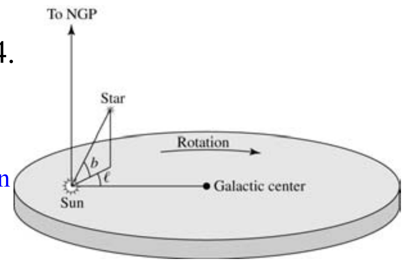
"Closed box" model = "back of the envelope" analytical calculation to get a feel for the problem.

Then… the computer sledgehammer.
Need a powerful but versatile language:
Python? (free book on course website)
C++? Fortran?

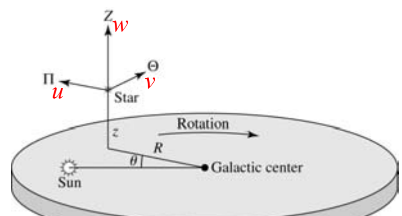


Kinematics of the Milky Way

- From [CO] 24.3, especially pp 901-14.
- Coordinate systems
  - Galactic latitude (l_{II}) , longitude (b_{II})
    - Spherical coordinates centered on Sun



  - *R, θ, z*
    - Cylindrical coordinate system centered on Galactic Center
  - Π, Θ, Z
    - Velocity components in *R, θ, z* system.



  - Peculiar velocities *u, v, w*
    - Π, Θ, Z velocities but relative to *Local Standard of Rest*
    - LSR is point instantaneously centered on Sun, but moving in a perfectly circular orbit.
    - *Solar motion* = motion of sun relative to LSR

- Star density is higher towards GC.
  - Those stars are on orbits that Sun overtakes.
- Velocity ellipsoids and asymmetrical drift.

➔ Sun's orbital velocity

$V \sim 220$ km s^{-1}

- Sun's orbital period

$$P = \frac{R_0}{V} \sim 230 \text{ million yrs.}$$

- Approx. mass interior to Sun's orbit:

$$F_{centrifugal} = F_{grav}$$

$$\frac{mV^2}{R_0} = \frac{GmM}{R_0^{\ 2}}$$

$$M = \frac{V^2 R_0}{G} \sim 9\text{x}10^{10}\ M_\odot$$

Fig 24.20

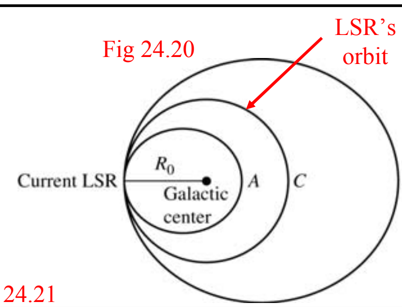
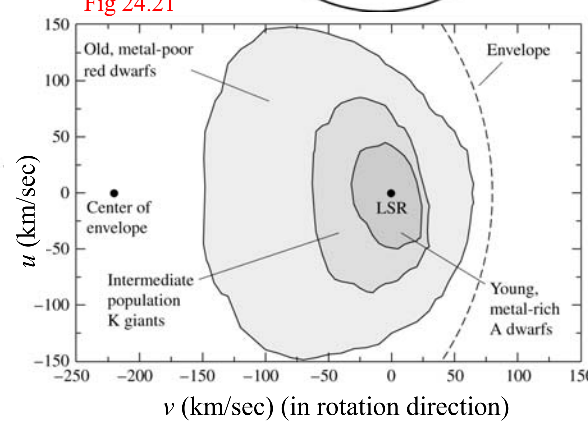


Fig 24.21



Differential Rotation (see [CO pp. 909-911)

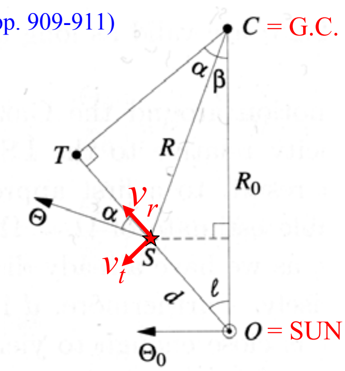
- From the figure:

$$v_r = \Theta\cos\alpha - \Theta_0\sin\ell,$$
$$v_t = \Theta\sin\alpha - \Theta_0\cos\ell,$$

- Angular rotation velocity: $\Omega(R) \equiv \dfrac{\Theta(R)}{R}$

- + some geometry ➔

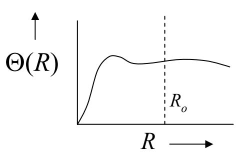
$$v_r = (\Omega - \Omega_0)\,R_0\sin\ell,$$
$$v_t = (\Omega - \Omega_0)\,R_0\cos\ell - \Omega d.$$



[Fig 24.22]

- Taylor expansion:

$$\Omega(R) = \Omega_0(R_0) + \left.\frac{d\Omega}{dR}\right|_{R_0}(R - R_0) + \cdots$$



$$v_r \simeq Ad\sin 2\ell,$$
$$v_t \simeq Ad\cos 2\ell + Bd$$

Oort's Constants:

$$A \equiv -\frac{1}{2}\left[\left.\frac{d\Theta}{dR}\right|_{R_0} - \frac{\Theta_0}{R_0}\right]$$
$$B \equiv -\frac{1}{2}\left[\left.\frac{d\Theta}{dR}\right|_{R_0} + \frac{\Theta_0}{R_0}\right]$$

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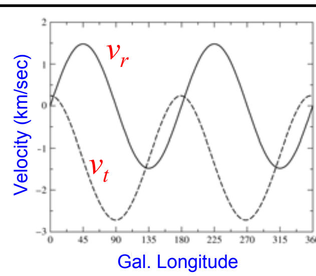
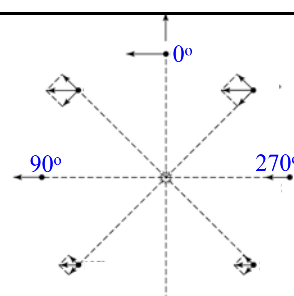




- Evaluated from observations:

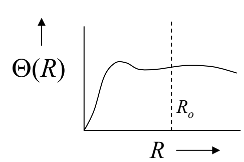
$$v_r \simeq Ad\sin 2\ell,$$
$$v_t \simeq Ad\cos 2\ell + Bd$$

- contain important information about Galactic rotation curve.
  - Angular velocity for circular motion at R_o:

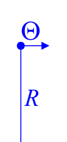
$$\Omega_o = A - B$$

  - Gradient of rotation curve at R_o:

$$\left.\frac{d\Theta}{dR}\right|_{R_0} = -(A + B)$$

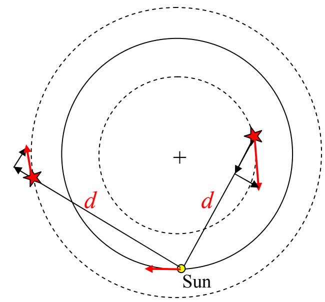


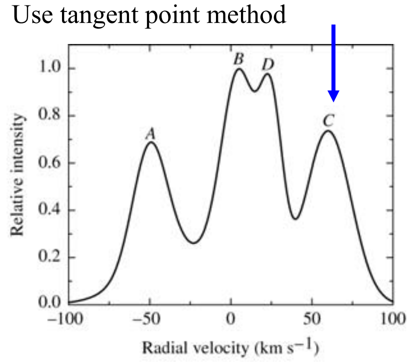
$$\Omega(R) = \frac{\Theta(R)}{R}$$

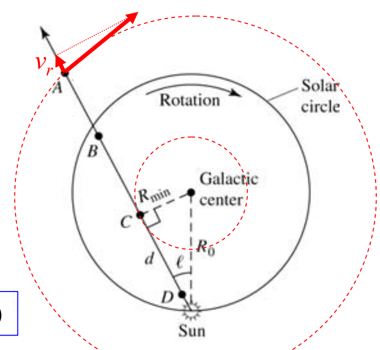


The Tangent Point Method

- In principle, for stars, clusters, etc:
  - measure distance d and v_r
  - assume circular orbit
- For H I 21cm, CO, etc. radio emission:
  - Only can measure v_r
  - Use tangent point method







For orbits almost at R_o: $v_{r,\max} \approx 2AR_o(1-\sin\ell)$

SO FAR:

- Galaxy types
- Ancient history
- Milky Way and spiral galaxy morphology
  - Nuclear bulge
  - Disk
  - Stellar halo
  - Dark matter halo
- Star-forming regions
- Chemical enrichment

Hwk 2 due Sept 23

Hwk 3 not yet assigned, but due Sept 30

NOW… Kinematics of spiral galaxies

- Rotation curves ➔ mass distribution

  (includes sidetrack about measuring distances)
- Spiral structure

- General properties of S, E, Irr galaxies
- Midterm 1 (Wed. Oct 2)

Homework Assignment 2 -- Due Wednesday Sept. 23

Oort(ure) Torture

- Do [CO] Problems 24.15, 24.16, 24.17
- Hints for Problem 24.16
  - Substitute into eqns. 24.37 and 24.38 the first order Taylor expansion for $\Omega - \Omega_o$
  - Look at figure 24.22
  - Don't forget to use those Old-Favorite trig identities:

    $\sin l \cos l = \frac{1}{2} \sin 2l$

    $\cos^2 l = \frac{1}{2} (1 + \cos 2l)$
- For problem 24.17, explain *both* the angular dependence and the offset in the zero-point of v_t

- Also do CO problems:
  - 24.21 (dark matter density).
  - 24.36 (lots of steps in this problem)

Note: There will be another homework assignment due on Wed. Sept. 30, followed by Midterm 1 on Friday Oct 2