Stellar kinematics

What would we expect for:

Disk?

Bar?

Thick disk?

Halo?

What can we observe?

Reference frames

Any observation of kinematics taken from the Earth has to be corrected for its heliocentric motion

U, V and W are the components of a Sun-centered Cartesian reference frame

U (radial) is positive toward the galactic center

V (azimuthal) is positive toward the direction of galactic rotation

W (out of plane) is positive toward the NGP

Disk kinematics

M & B ch 7

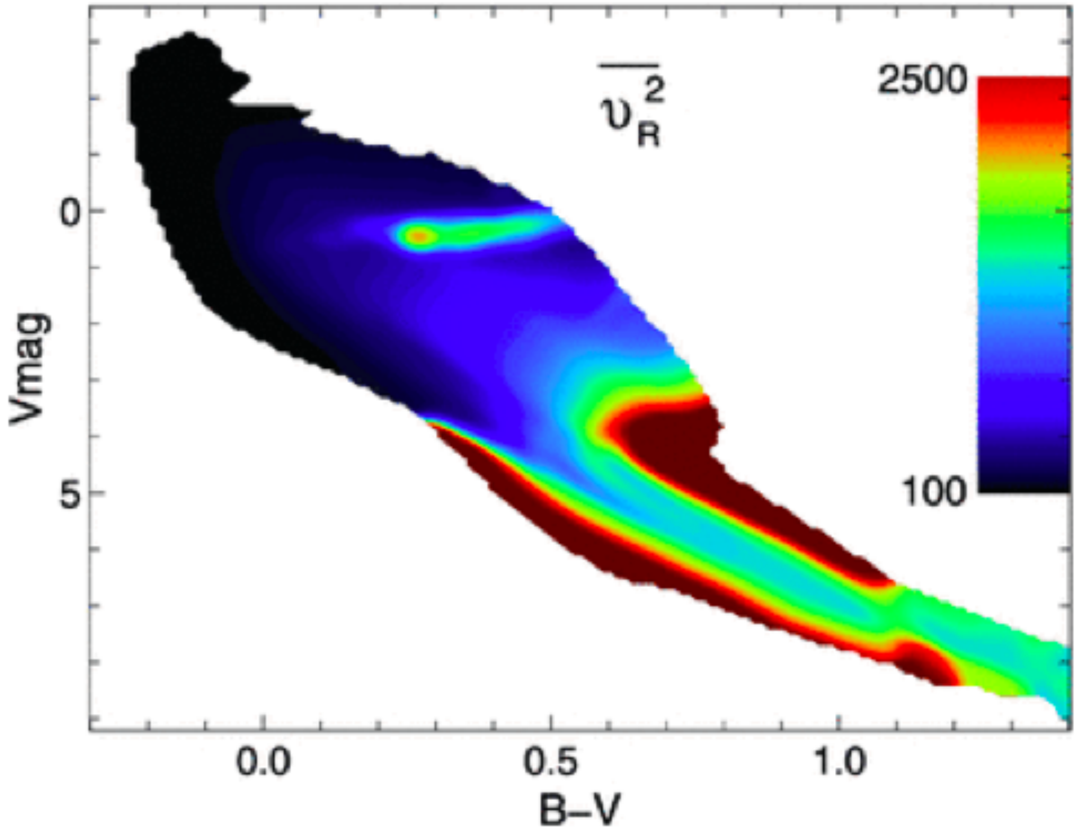
- circular orbits w/ small deviations

$$\left.\begin{array}{l}\sigma_u \\ \sigma_v \\ \sigma_w\end{array}\right\}$$ dispersion around motion of LSR

"the velocity ellipsoid"

Disk kinematics

- velocity dispersion ↗ w/ mean age
- $\sigma_u > \sigma_v > \sigma_w$
- $\sigma_u \sim 2\sigma_w$
- young stars not in equilibrium
  "vertex deviation"



From Schoenrich et al 2010: model prediction of variation of radial component of velocity dispersion with stellar absolute magnitude and color

Q: why do we see such a complex behavior?

Thick Disk

$\sigma_U \sim 60$ km/s
$\sigma_V \sim 40$ km/s
$\sigma_W \sim 40$ km/s

asymmetric drift ~ 30 km/s

Local Standard of Rest

The LSR is a point at R_sun moving in a circular orbit about the galactic center

Q: how would you go about estimating the Sun's velocity with respect to the LSR?

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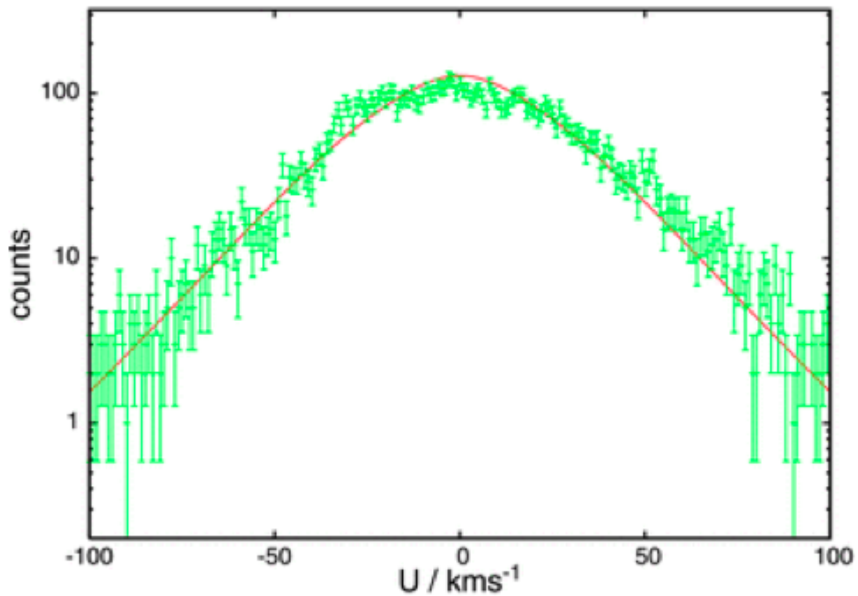
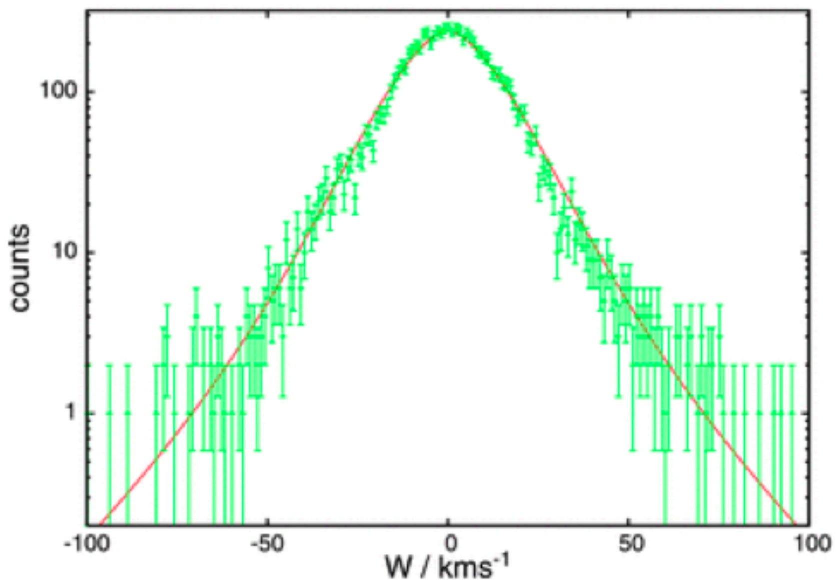
A: two components (U and W) are simple: average the velocities of nearby stars with respect to the Sun; U_sun and W_sun will be the reflex velocities





Schoenrich et al 2010, shifted by U_sun and W_sun

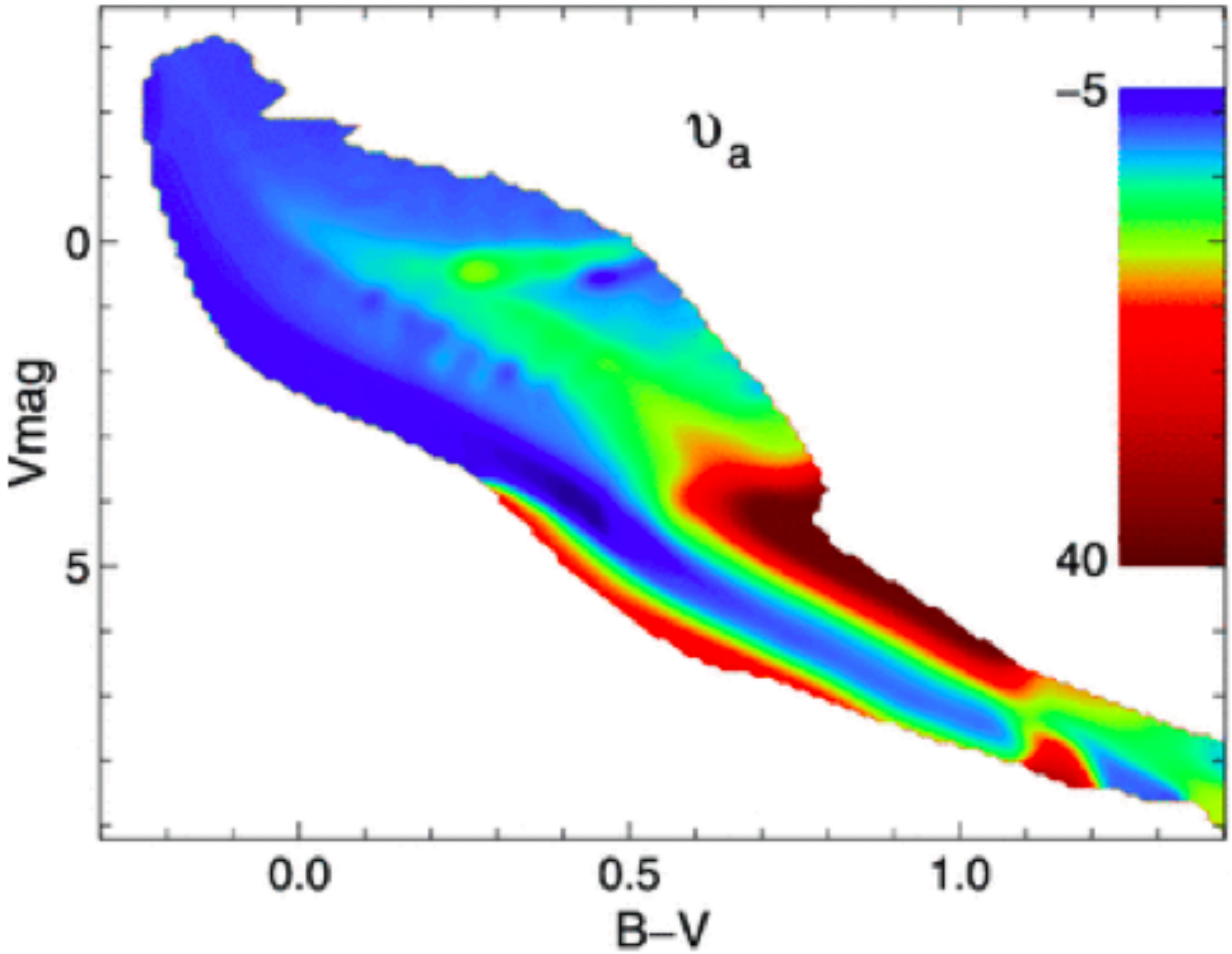
BUT:

Asymmetric Drift

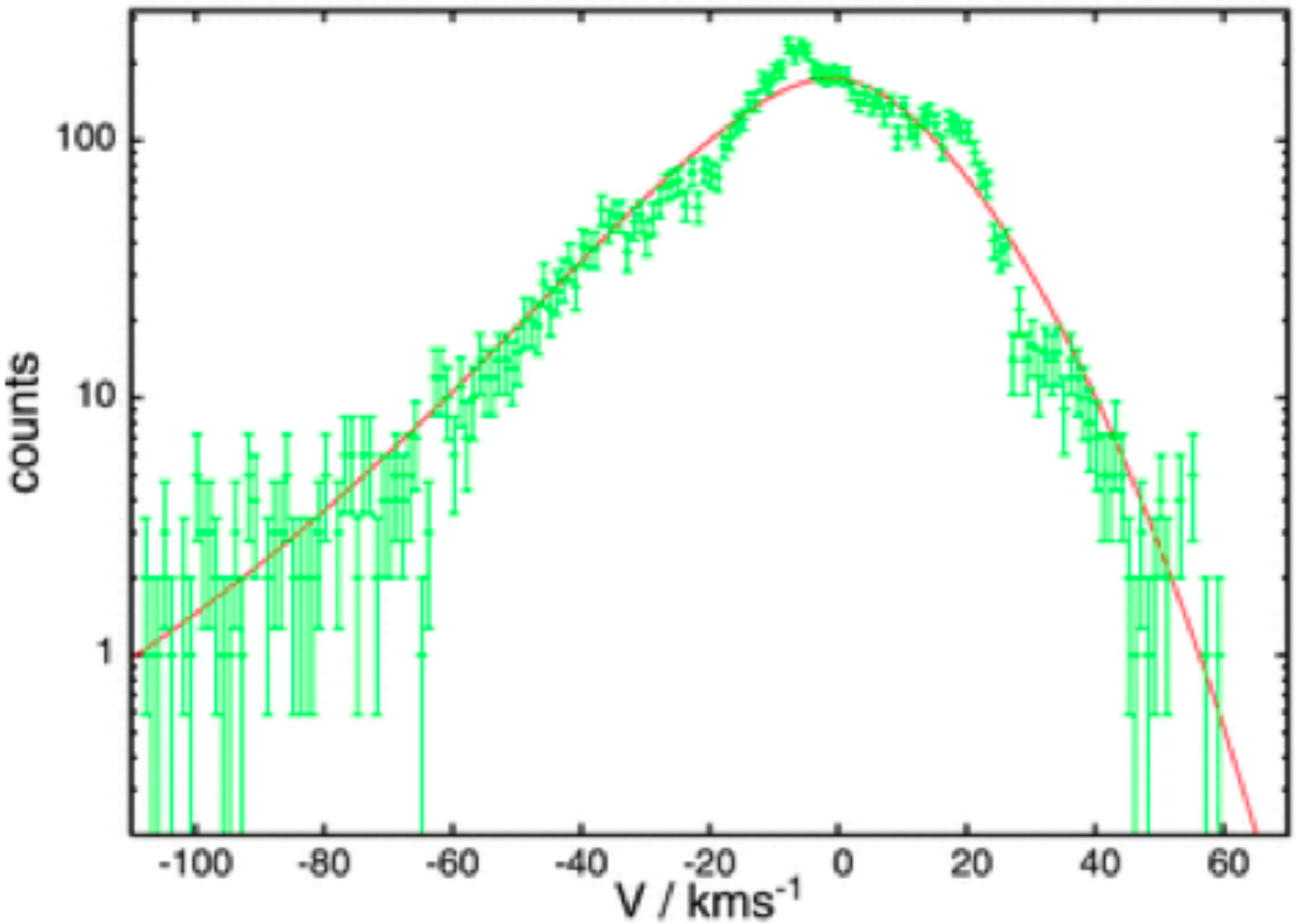
- stars tend to lag the LSR
- lag ↗ w/ ↗σ/age
- drift velocity for old disk ~ 15 km/s

why?

- think orbits
- why asymmetric?



From Schoenrich et al 2010. Since ages of stars are difficult to measure directly we need to model their behavior to work out how the asymmetric drift will affect measurements of V_sun



Final values: Usun=11 km/s (toward GC)

Vsun=12 km/s (leads rotation)

Wsun= 7 km/s (toward NGP)

Measuring LSR velocity

Q: how would you go about measuring the velocity of the LSR, given that almost all of the nearby stars are moving with the LSR?

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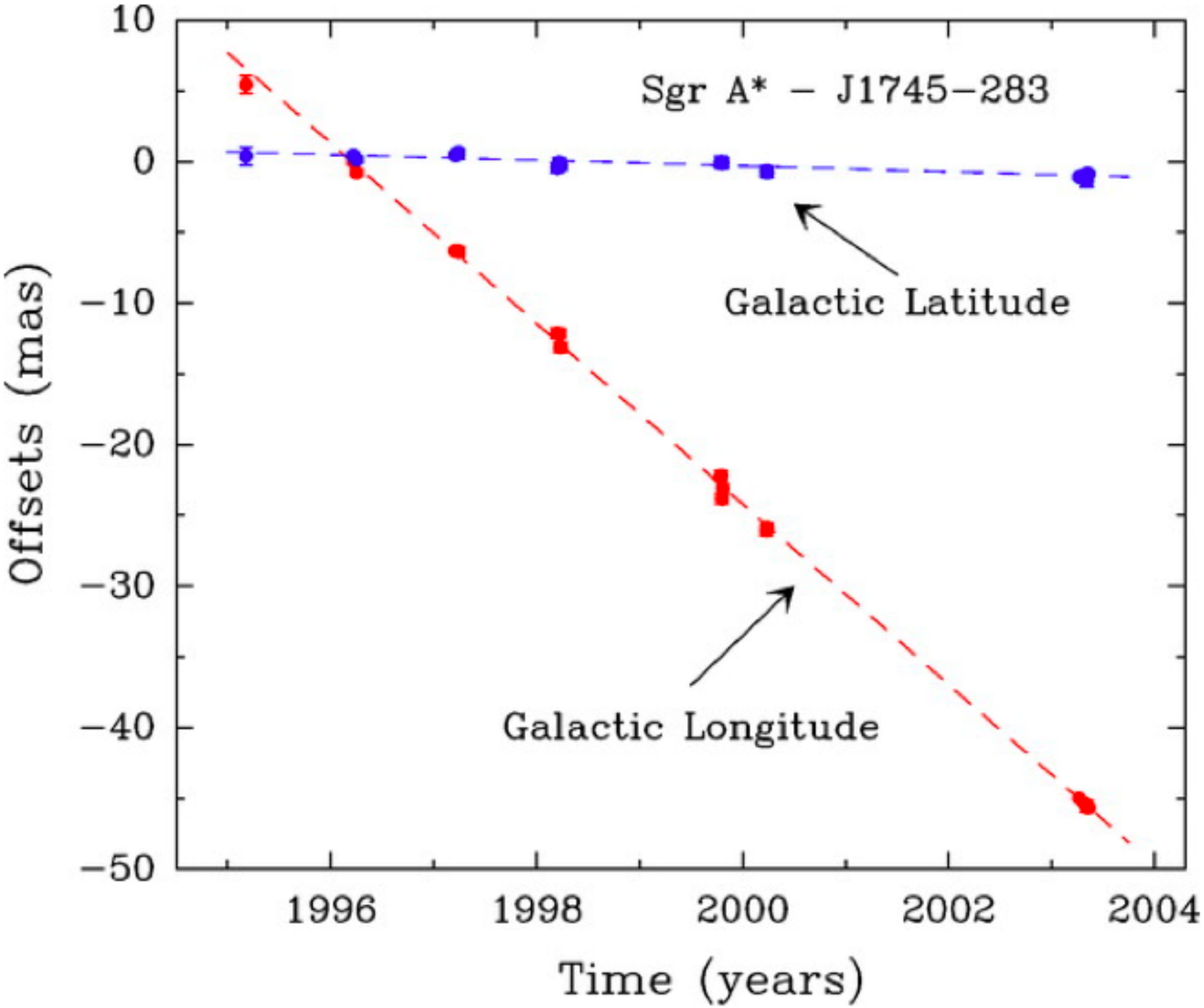
A: you will need an extragalactic reference frame, like that provided by radio galaxies or QSOs

Various groups have measured the proper motion of the black hole in the galactic center, Sgr A* .... After correcting for the Sun's V velocity, this will give us V_LSR=238 km/s (Schoenrich 2012)



Reid and Brunthaler 2004

$\boxed{\text{Epicycles}}$ .... a small review

Describes motion of disk stars in the plane to a good approximation

$\boxed{Q}$ Derivation of epicyclic motion assumes that orbital angular momentum $L_z = R . v_\phi$ is conserved. Will this be strictly true in a real galaxy?

orbits & epicycles

Sparke & Gallagher 3.3

think of orbits as being a sum of two motions

- circular motion around galactic center
  "the guiding center"

- motion <u>around</u> that guiding center
  "the epicycle"

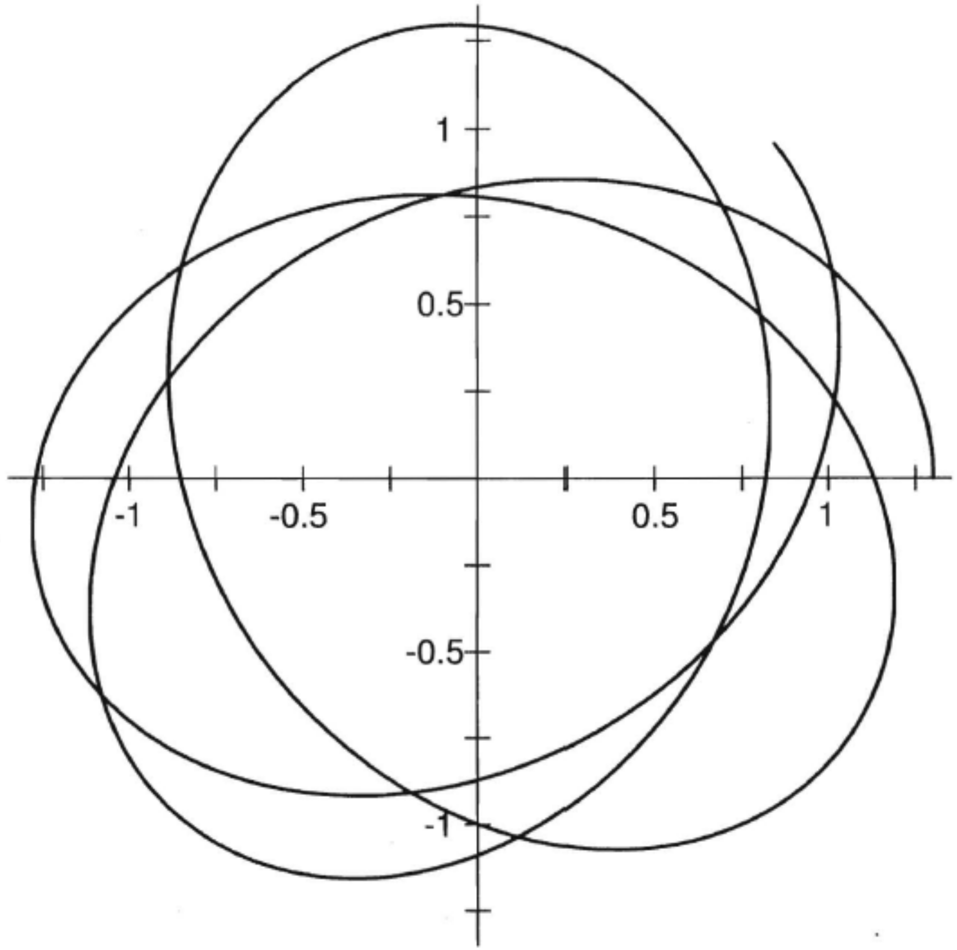


Figure 3.9 Path of the star of Figure 3.7, viewed from above the Galactic plane; the orbit started with ($R = 1.3,\ \phi = 0$) and ($\dot{R} = 0,\ R\dot{\phi} = 0.4574$).

Recall that only in a Keplerian potential (single point mass) are orbits closed

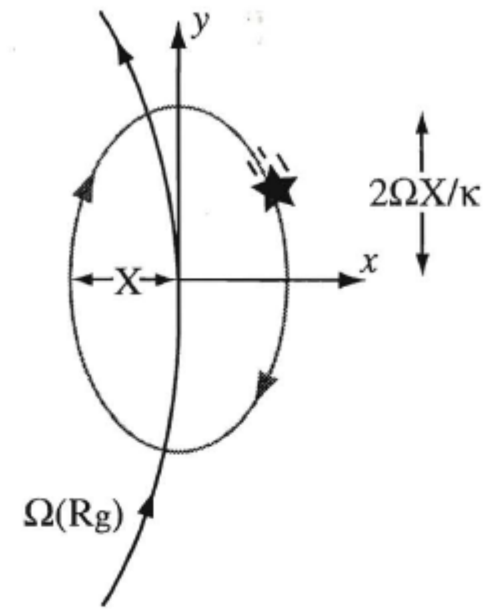


Figure 3.8 A star following an elliptical epicycle around its guiding center at ($x = 0$, $y = 0$), which is carried around the Galactic center with angular speed $\Omega(R_g)$.

Q: as the star moves around the epicycle, its orbital radius will change to higher and lower values. Would you expect the total motion of the star to increase or decrease if Lz (z comp of angular momentum) is conserved and R increases?

so the epicycle is an oscillation around circular motion. notes:

- the epicycle is <u>retrograde</u>

- the frequency of this oscillation is known as the epicyclic frequency κ

- the epicyclic frequency & the angular speed of the guiding center $\Omega = V_c/R$ are both governed by the potential & are relatable:

see S&G 3.3

$$K^2 = \left[R \frac{d\Omega^2}{dR} + 4\Omega^2\right]_{R_g}$$

- epicycle has axis ratios $\frac{X}{Y} = \frac{K}{2\Omega}$

Cylindrical coords R, ϕ, z.

Two harmonic oscillations, independent

(i) $\ddot{z} = \dot{v}_z = -\boxed{\nu^2}(R_g)\, z$ vertical motion

$$z = \underset{\uparrow \atop \text{const}}{Z} \cos(\boxed{\nu}t + \underset{\nwarrow \atop \text{const}}{\theta})$$

(ii) $R = R_g + x$ radial motion

$\uparrow$ guiding center radius

$$\ddot{x} = -\boxed{\kappa^2}(R_g)\,x \quad \text{so} \quad x \simeq X \cos(\boxed{\kappa}t + \psi)$$

const

Then azimuthal coordinate ϕ given by

angular speed of guiding center

$$\phi(t) = \underbrace{\phi_0 + \Omega(R_g)t}_{\text{circular motion}} - \frac{1}{R_g}\frac{2\Omega}{\boxed{\kappa}} X \sin(\boxed{\kappa}t + \psi)$$

Near the Sun, $\kappa \simeq 1.4\,\Omega$

angular speed of guiding center

So its orbit around the galactic center is not closed.

$\boxed{\text{Special cases}}$

Point mass $\kappa = \Omega$ closed orbits,

ellipses with point mass at one focus

(Ptolemy only considered circular epicycles, not elliptical ones)