AY 20 Fall 2010

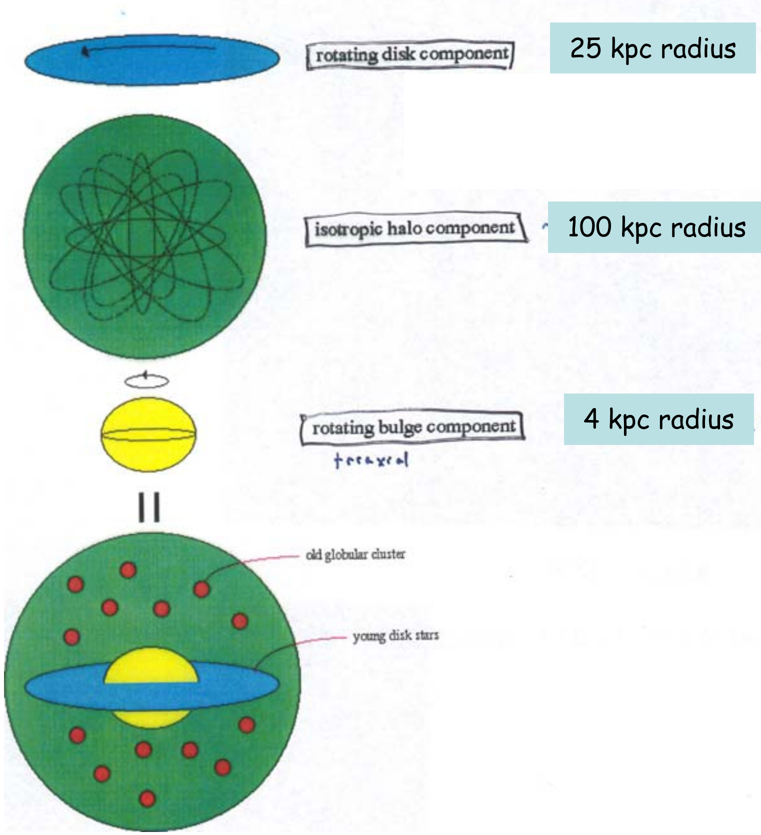
Structure & Morphology of the Milky Way

Reading: Carroll & Ostlie, Chapter 24.2, 24.3

Galactic Structure cont'd: distribution of each population related to orbital characteristics

thin disk <10^2 Myrs, thick disk 2-10 Gyrs

scale heights ` 100-350 pc, 1 kpc resp.



neutral gas also a disk component;
radius ~25 kpc, age < 10 Gyrs
scale height < 100 pc*,

Sun in thin disk ~ 30 pc above plane

number density of stars in thick disk
<10% that in thin disk

stars in thick disk older

star formation continuing in thin disk

From star counts & kinematics:

thin disk: mass ~ 6.5×10^{10} $M_\odot$

$L_B = 1.8\times 10^{10} L_\odot$

thick disk: $L_B = 2\times10^8 L_\odot$ (much fainter)

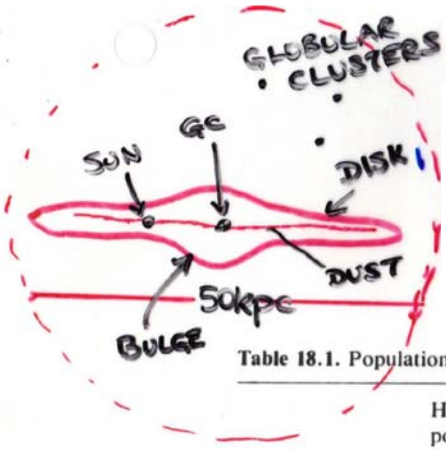
mass ~ $2\text{-}4 \times 10^9$ $M_\odot$

H_2, cool dust: 3-8 kpc from GC

HI: 3 – 25 kpc

$mass_{HI}$ ~ 4×10^9 $M_\odot$ $mass_{H2}$ ~ 10^9 $M_\odot$

* scale height HI increases beyond 12 kpc radius to 900 pc



Shape of each population depends on orbital characteristics. Note also a range of <u>metallicities</u>

Table 18.1. Populations of the Milky Way

	Halo population II	Intermediate population II	Disc population	Old population I	Young population I
Typical objects	Subdwarfs, globular clusters, RR Lyr ($P>0.4$d)	Long period variables	Planetary nebulae, novae, bright red giants	A stars, Me dwarfs, classical cepheids	Gas, dust, supergiants, T Tau stars
Average age [10^9 y]	17 – 12	15 – 10	12 – 2	2 – 0.1	0.1
Distance from galactic plane [pc]	2000	700	400	160	120
Vertical velocity [km/s]	75	25	18	10	8
Metal abundance	0.001	0.005	0.01 – 0.02	0.02	0.03 – 0.04

age-metallicity relation not a simple correlation!

Abundance of iron (Fe) - product of type 1a SN – correlates w. star age

$$\left[{}^{Fe}\!/\!{}_{H}\right] \equiv \log\left[\frac{\left({}^{N_{Fe}}\!/\!{}_{N_H}\right)_{star}}{\left({}^{N_{Fe}}\!/\!{}_{N_H}\right)_{\odot}}\right]$$

indicates "metallicity" Adopt [Fe/H] = 0 for Sun

For more metal rich stars [Fe/H] +ve; metal poorer [Fe/H] -ve

Not entirely 1 to 1 correlation – iron production small and may be local

[O/H] from core collapse SNs may be more accurate (occur sooner than type Ia)

N.B. errors of 0.1 in distance modules from m-s turn-off → errors of 10% in age

additional characteristics

COBE 1.2 μm, 2.2 μm, 3.4 μm

<u>Galactic bulge</u>:

COBE + K & M giants + RR Lyraes → number density of stars
→ scale height 100- 500pc

from IRAS, effective radius (radius inside which 50% light emittted) ~ 700 pc
diameter ~ 3 kpc

3 age groups of stars: < 200 Myr, 200 Myr to 7 Gyr, 7-10 Gyr; metallicities not correlated with age in usual way

Older stars in spherical orbits typical of relaxed spheroidal systems

<u>Baade's window</u>: 3.9°below plane in direction of NGC 6522, RR Lyrae stars visible beyond galactic center. Usually 30^m extinction to GC

Halo

old stars > 10 Gyrs, high velocity strsglobular clusters, low metallicity

stellar density very low

diameter ~ 100 kpc, scale height ~ 2 kpc

high velocity atomic gas clouds present, most appear to be moving towards disk

Galactic fountain? Accreting cloud model of galaxy formation?

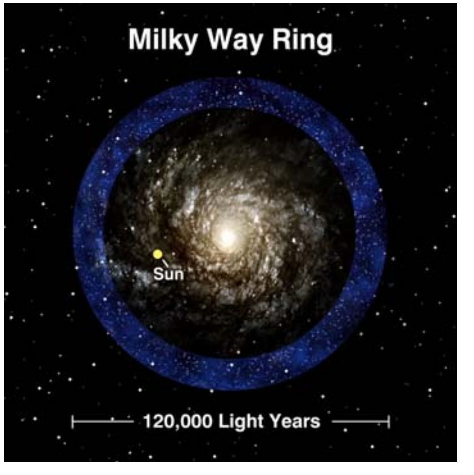
(H clouds could introduce unprocessed material, counteract increasing metallicity with age – still controversial)

Galaxy formation models – collapse or accretion or galaxy-galaxy collisions and capture – challenged

Sloan Digital Sky Survey (Apache Point)

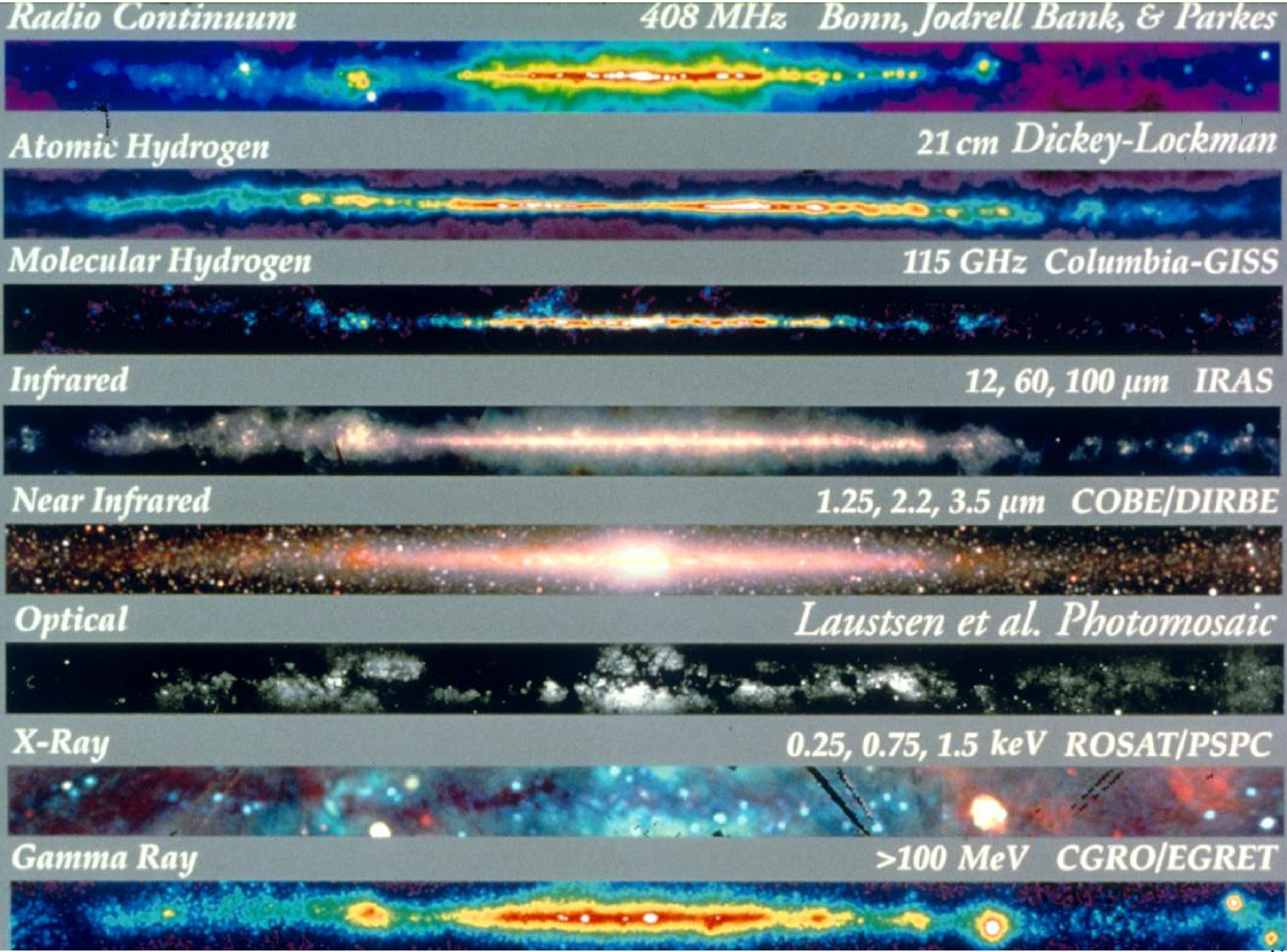
→ ring of stars around Milky Way

0.5×10^9 stars, 3kpc thick



artist's impression

Galactic Center $10^6\ M_\odot$ Black Hole


Radio Continuum
408 MHz Bonn, Jodrell Bank, & Parkes
Atomic Hydrogen
21 cm Dickey-Lockman
Molecular Hydrogen
115 GHz Columbia-GISS
Infrared
12, 60, 100 μm IRAS
Near Infrared
1.25, 2.2, 3.5 μm COBE/DIRBE
Optical
Laustsen et al. Photomosaic
X-Ray
0.25, 0.75, 1.5 keV ROSAT/PSPC
Gamma Ray
>100 MeV CGRO/EGRET

The Rotation of the Milky Way

- Flatness of MW suggests rotation about axis perpendicular to plane
- Observations of stars, gas confirm differential rotation
- i.e. Milky Way does not rotate like a rigid body
- angular velocity depends on distance from GC
- Observable effects of galactic rotation derived by Jan Oort
- Sun shares in differential rotation – has to be taken into account

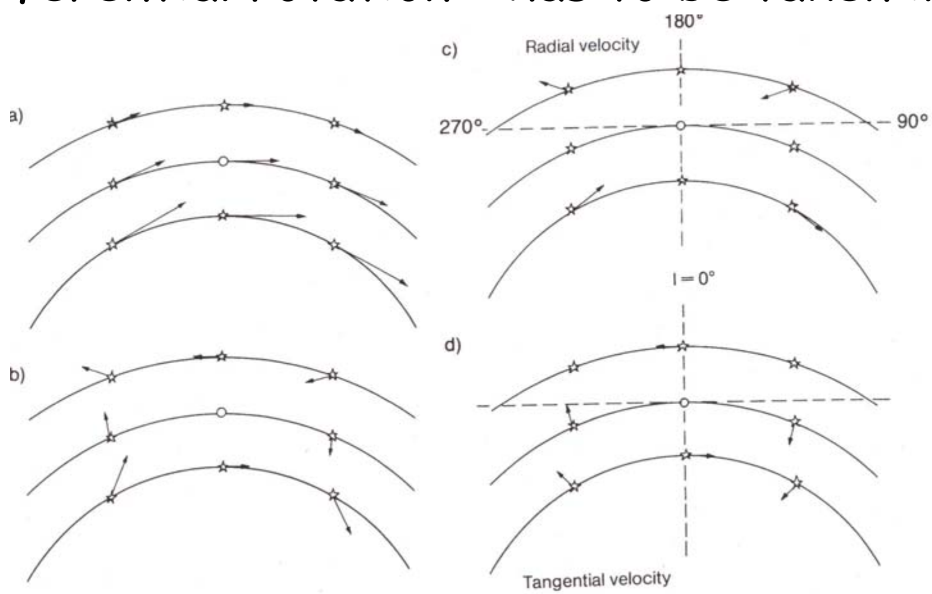


Fig. 18.13a – d. The effect of differential rotation on the radial velocities and proper motions of stars. **(a)** Near the Sun the orbital velocities of stars decrease outwards in the Galaxy. **(b)** The relative velocity with respect to the Sun is obtained by subtracting the solar velocity from the velocity vectors in **(a)**. **(c)** The radial components of the velocities with respect to the Sun. This component vanishes for stars on the same orbit as the Sun. **(d)** The tangential components of the velocities

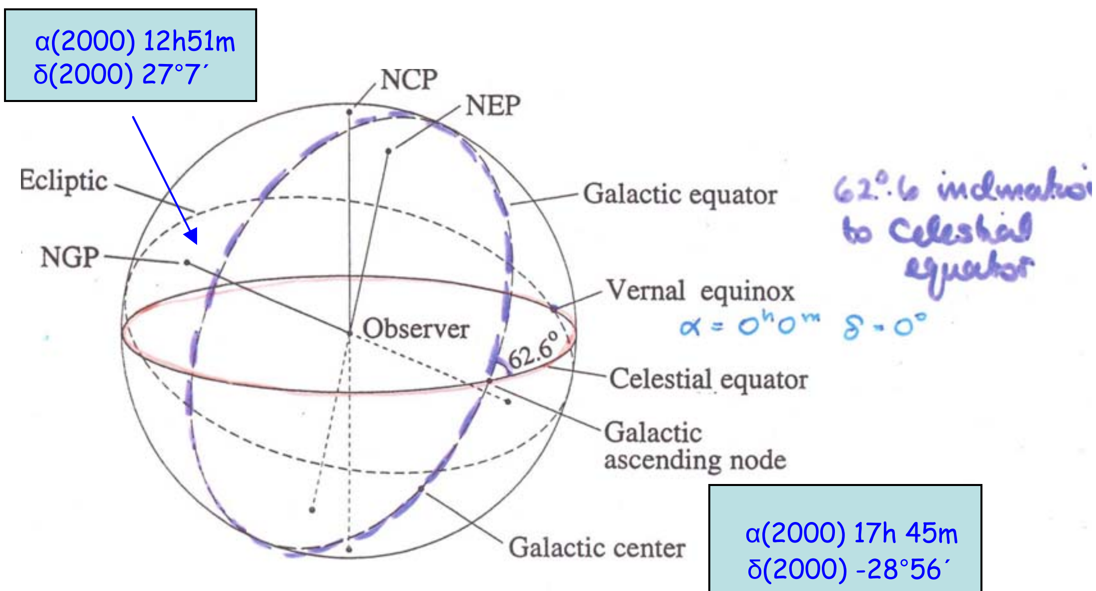
First – need a new coordinate system

Use fact that Galactic disk has well-defined plane (tilted at 62.6° to celestial equator –recall inclination of observed Milky Way

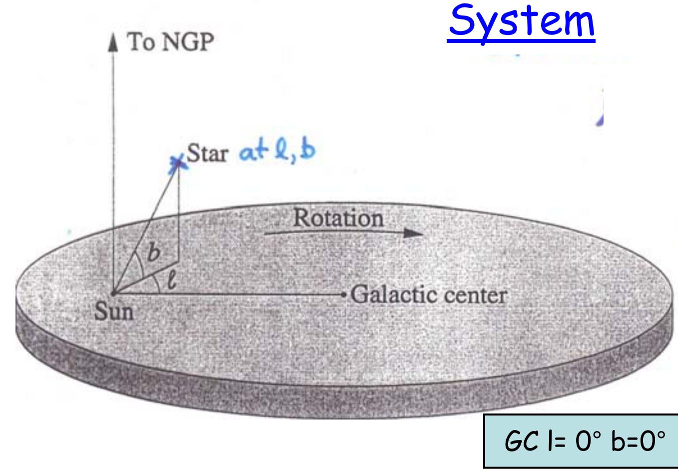
Galactic equator defined by intersection of mid-plane with celestial sphere, (assuming Sun in Galactic midplane)

→ Galactic longitude, l, latitude, b (Galaxy rotates clockwise as seen from b= 0)

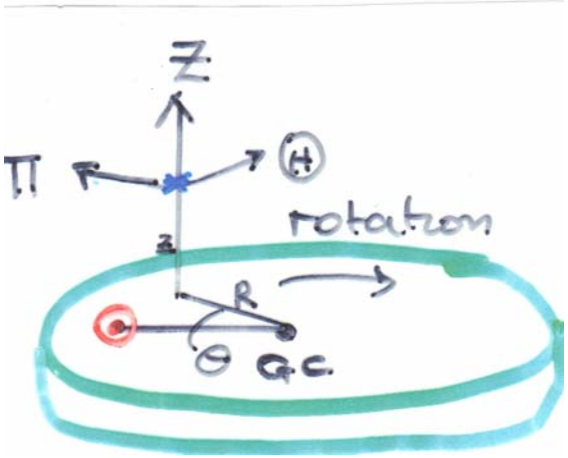
Transform from Galactic to equatorial coords from charts or spherical trig equations (C & O pp 901,902)



Galactic Coordinate System



But kinematic studies need coord system NOT based on Sun (Sun orbiting GC and moving inward and away from mid-plane)



Use cylindrical coord system; origin at GC

R increases outwards, θ in dir^n of rotation
  z increases to north

Corresponding velocity components:

$\Pi \equiv dR/dt$, $\Theta \equiv d\theta/dt$ $Z \equiv dz/dt$

Assume all observations made from Sun:
  can easily remove Earth-based rotational, orbital motions

Define dynamical Local Standard of Rest to account for Sun's motion

LSR is a point instantaneously centered on Sun and moving in a circular orbit along the solar circle about the Galactic Center

Velocity components: $\Pi_{LSR} \equiv 0$, $\Theta_{LSR} \equiv \Theta_0 = \Theta(R_0)$, $Z_{LSR} \equiv 0$

R_0 is solar Galactocentric distance

In effect, LSR constantly changing (Sun drifts away) but not too noticeable (rotation period ~ 230 Myrs, solar peculiar velocities small)

A star's velocity relative to LSR = star's peculiar velocity

$\underline{\mathbf{V}}$ = (V_R, V_θ, V_z) ≡ (u,v,w), with:

u = Π –Π_{LSR}, v = Θ – $\Theta_{LSR,}$ = Θ – Θ_0 and w = Z – Z_{LSR} =Z

Sun's peculiar velocity w.r.t. LSR = solar motion

For an axisymmetric Galaxy, ‹u› = 0, ‹w› = 0 in solar neighborhood (1kpc) –excluding Sun

(equal numbers of stars moving inward/outward or toward NGP or SGP)

Thus $$\langle u \rangle = \frac{1}{N}\sum_{i=1}^{N} u_i \simeq 0 \text{ and } \langle w \rangle = \frac{1}{N}\sum_{i=1}^{N} w_i \simeq 0$$

Not the case for v component: orbits of stars in solar neighborhood coincide with LSR at either perigalacticon or apogalacticon. Only for stars on solar circle is semi-major axis of orbit identical to R_0.

For orbits with semi-major axes less than R_0, Θ_A < Θ_0; greater than R_0, Θ_B > Θ_0 (see Fig 24.20 C & O)

Thus for orbits inside solar circle, v_A < 0; outside solar circle, v_B > 0

Since more stars inside solar galactocentric radius, ‹v› < 0

[Kinematic LSR based on average motion of stars within 1 kpc of Sun is at lower velocity than ‹v› and so systematically lags behind dynamical LSR]

Velocity for any star relative to the Sun =
star's peculiar velocity – solar motion (with respect to LSR)

Thus: $\Delta u \equiv u - u_\odot$, $\Delta v \equiv v - v_\odot$, $\Delta w \equiv w - w_\odot$

Since $\langle v \rangle < 0$ and $\langle u \rangle = \frac{1}{N}\sum_{i=1}^{N} u_i \simeq 0$ and $\langle w \rangle = \frac{1}{N}\sum_{i=1}^{N} w_i \simeq 0$

$u_\odot = -\langle \Delta u \rangle$, $v_\odot = \langle v \rangle - \langle \Delta v \rangle$, $w_\odot = -\langle \Delta w \rangle$

Hence, $u_\odot = -10 \pm 0.4$ km/s

$v_\odot = 5.2 \pm 0.6$ km/s

$w_\odot = 7.2 \pm 0.4$ km/s

Relative to LSR, Sun moving towards GC, more rapidly in the direction of galactic rotation , north out of the plane

Stars with orbital components opposite to overall galactic rotation direction have $v < -\Theta_0 \rightarrow \Theta_0(R_0) = 220$ km/s