Galactic Rotation

- From observations of the velocity of stars or gas around the Galactic center, the rotational velocity V can be determined as a function of the distance R from the Galactic center.
- We consider an object at distance R from the Galactic center which moves along a circular orbit in the Galactic plane, has a distance D from the Sun, and is located at a Galactic longitude l.
- We disregard the difference of velocities of the Sun and the LSR to get $v_o = v_{LSR} = (v_o, 0)$ in this coordinate system.

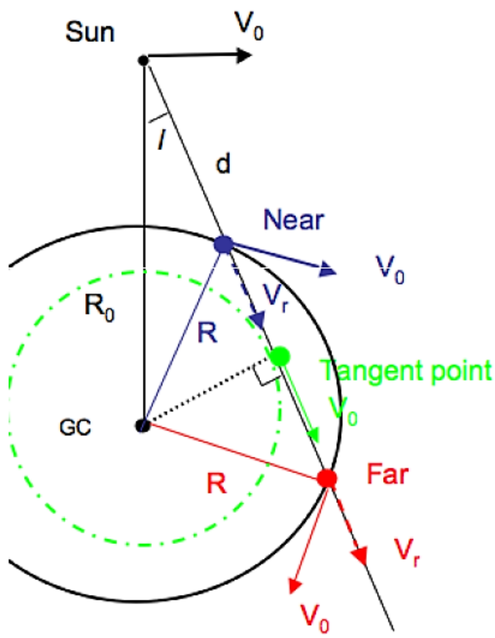


Figure 1: Tangent Point Method to Estimate Galactic Rotational Velocity

- **Computation for the whole galactic rotation is done in two different ways :**

1. **The Inner part(Tangent Point Method)** $(R < R_o)$

   Where : $R_o = 8kpc$

   * For this I and IV galactic quadrants are being considered.

   * The radial velocity v_r along this line-of-sight for objects moving on circular orbits is a function of the distance d.

$$\begin{aligned} v_r &= vcos(90-\theta) - v_ocos(90-l) \\ v_r &= vsin(\theta) - v_osin(l) \end{aligned} \quad (1)$$

* Sine law(figure 2):

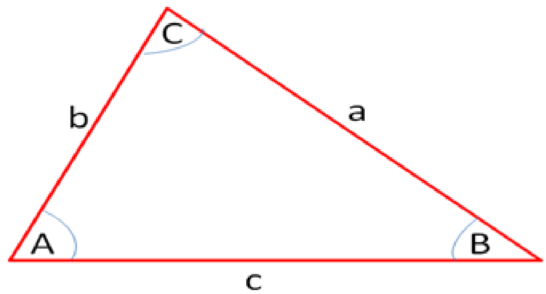


Figure 2: Sine rule triangle

$$\frac{sin(A)}{a} = \frac{sin(B)}{b} = \frac{sin(C)}{c} \tag{2}$$

* Applying the sine law to find θ in terms of R

$$\begin{aligned} \frac{sin(180-\theta)}{R_o} &= \frac{sin(l)}{R} \\ sin(\theta) &= sin(\frac{R_o}{R}sin(l)) \end{aligned} \tag{3}$$

* Putting the value of $sin(\theta)$ in (1) :

$$\begin{aligned} v_r &= vsin(l)\frac{R_o}{R} - v_o sin(l) \\ &= sin(l)[v\frac{R_o}{R} - v_o] \\ v(R) &= [v_o + \frac{v_r}{sin(l)}](\frac{R}{R_o}) \end{aligned} \tag{4}$$

* The velocity v_r attains a maximum where the line-of-sight is tangent to the local orbit, thus its distance R from the Galactic center attains the minimum value R_{min}.

$$\begin{aligned} v(R) &= [v_o + \frac{v_{r,max}}{sin(l)}](\frac{R_{min}}{R_o}) \\ Whrer: R_{min} &= R_o sin(l) \end{aligned} \tag{5}$$

* Above equation(5) gives the velocity of an object wrt. the inner distance R in galactic disc.
* Figure(3) shows the velocity curve for different points.

2. **The Outer part(Rotation Curve)** ($R > R_o$)

Where : $R_o = 8kpc$

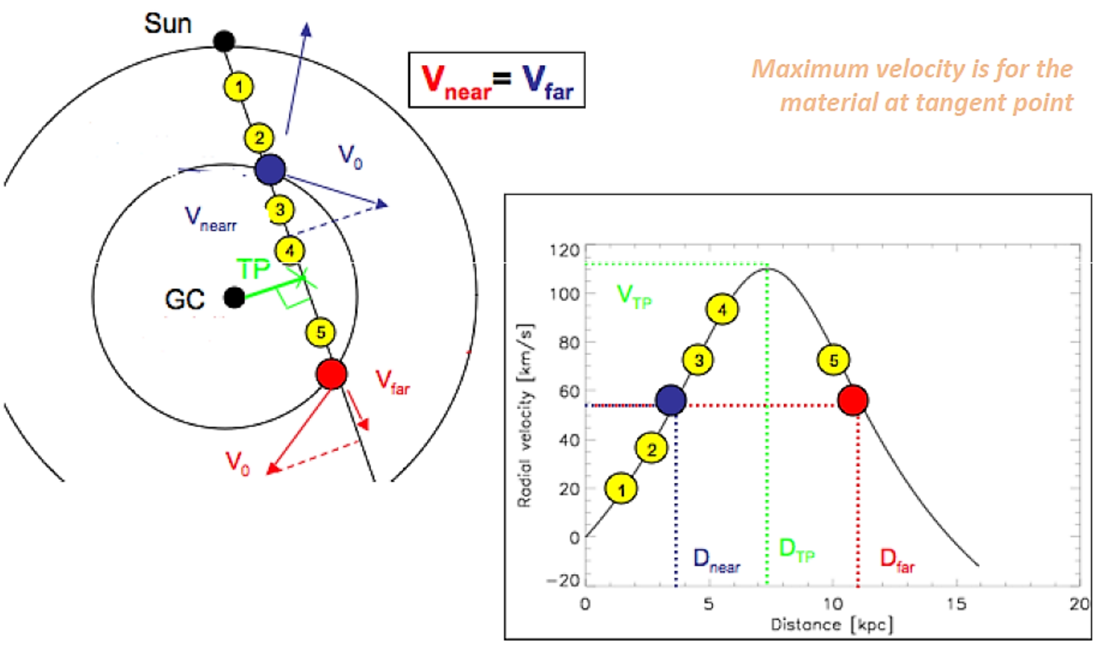


Figure 3: Tangent Point Method to Estimate Galactic Rotational Velocity

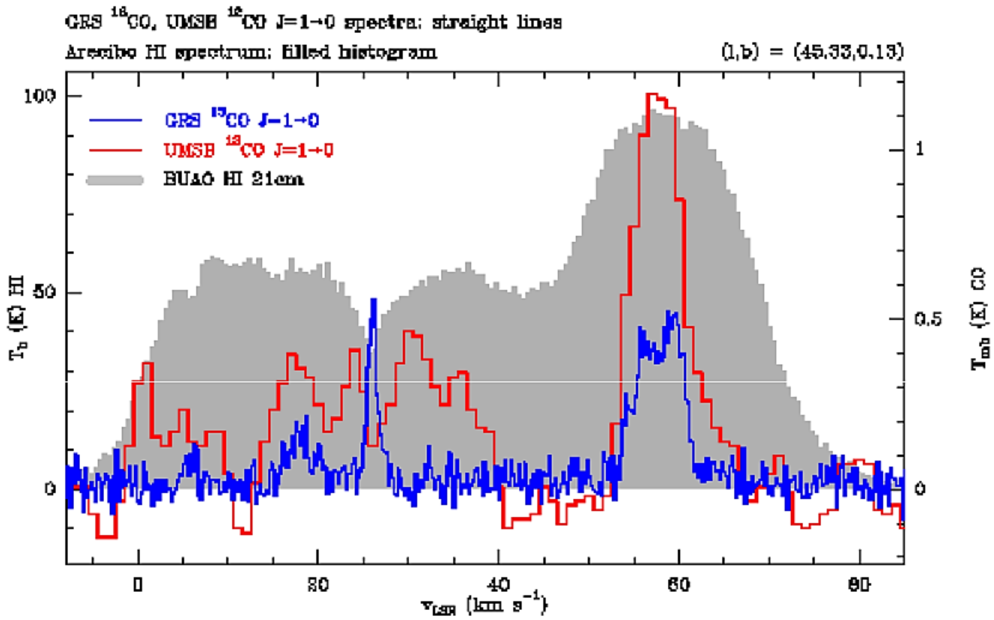
* For this II and III galactic quadrants are being considered.
* The tangent point method cannot be applied for R ¿ R_0 because for linesof-sight, the radial velocity v_r attains no maximum.
* Measuring V(R) for $R > R_0$ requires measuring v_r for objects whose distance can be determined directly e.g. Cepheids.
* Refer figure(5) for different calculation parameters.

$$
\begin{aligned}
v_r = v_o cos(l - 90) - v cos(90 - \theta) \\
v_r = v_o sin(l) - v sin(\theta)
\end{aligned} \tag{6}
$$

* Using sine rule we find the value of $sin(\theta)$ in terms of R and R_o

$$
\begin{aligned}
\frac{sin(\theta)}{R_o} = \frac{sin(l)}{R} \\
sin(\theta) = sin(\frac{R_o}{R} sin(l))
\end{aligned} \tag{7}
$$

* Putting the value of $sin(\theta)$ in equation(6), we get



The BU-FCRAO Milky Way Galactic Ring Survey; Simon et al.

Figure 4: The figure shows $HI21$ cm, and CO^{12} and CO^{13} emission along a particular sightline through the Galactic plane. The emission with the largest v_{LSR} is likely to be close to the tangent point.

$$
\begin{aligned}
v_r &= v_o sin(l) - v sin(l)\frac{R_o}{R} \\
&= sin(l)[v_o - v\frac{R_o}{R}] \\
v(R) &= [v_o - \frac{v_r}{sin(l)}](\frac{R}{R_o})
\end{aligned} \tag{8}
$$

* Above equation(8) gives the velocity of an object wrt. the outer distance R in galactic disc.
* Figure(6) shows the Rotation curve for different orbital objects taken together after various surveys.

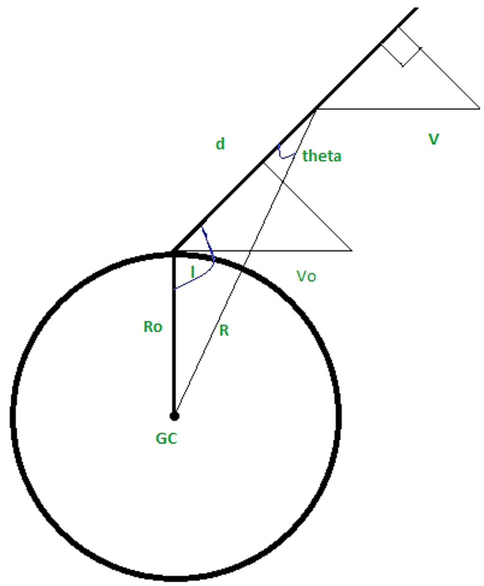


Figure 5: Rotation curve method

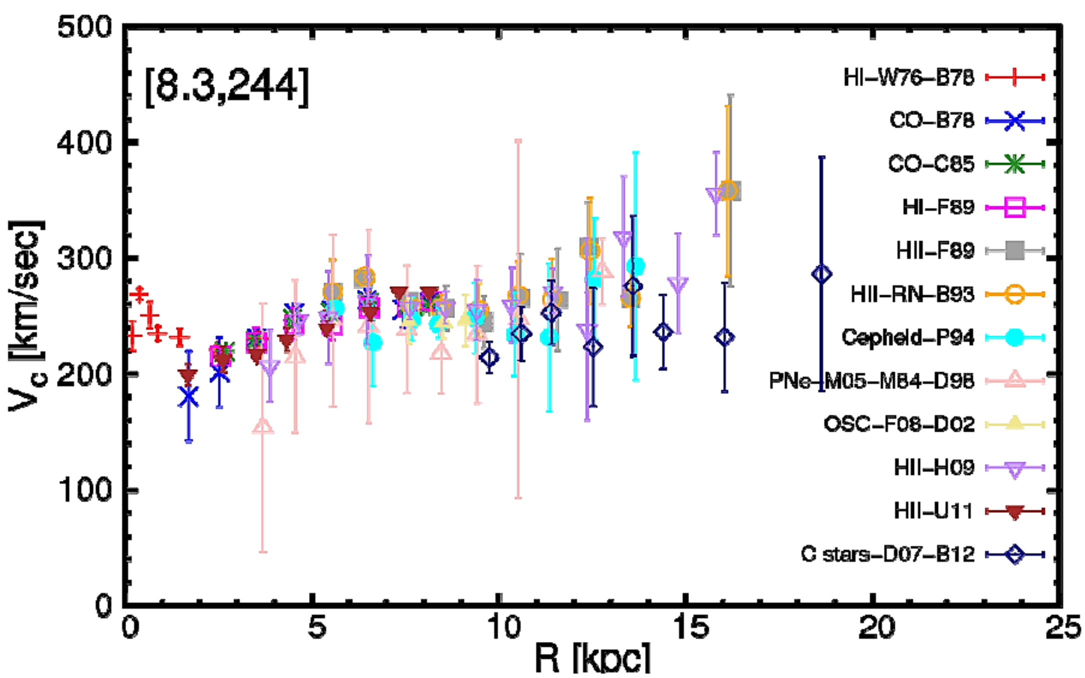


Figure 6: Milky Way Rotation Curve Bhattacharjee et al. (2014, *ApJ*)