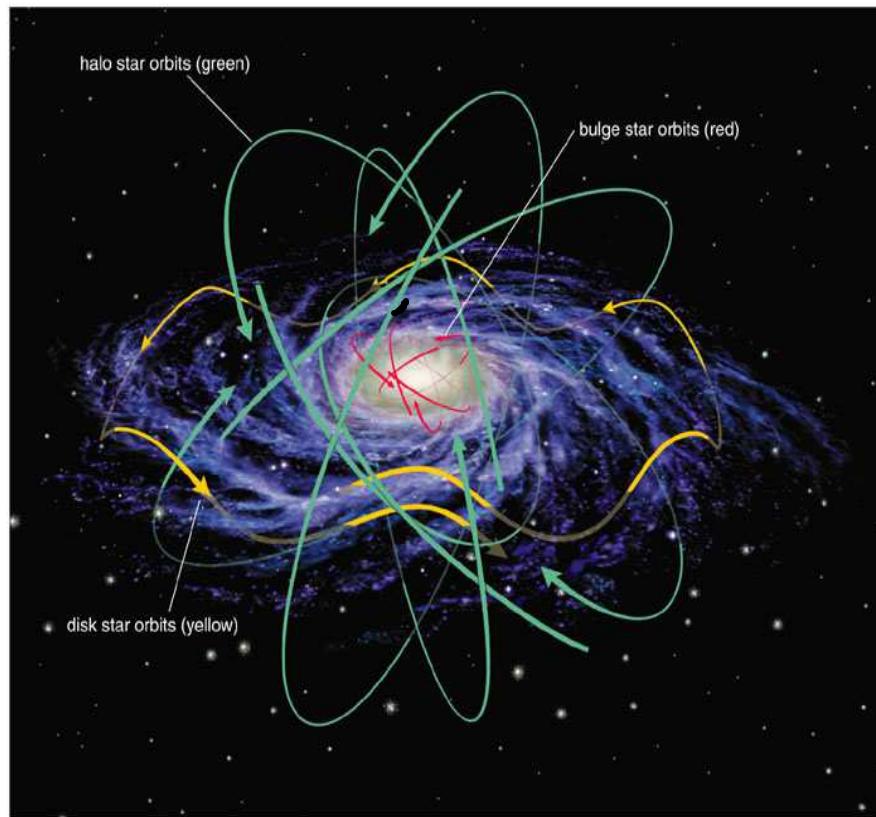


MOTIONS OF STARS IN THE MILKY WAY



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DISK: STARS MOVE IN CIRCULAR, SLIGHTLY UNDAULATED, ORBITS IN THE SAME DIRECTION. THE SUN MOVES AT A SPEED OF ABOUT 220 km/s AROUND THE GALACTIC CENTER AND IT TAKES ABOUT 230 MILLION (2.3×10^8) YEARS TO COMPLETE ONE REVOLUTION AT A DISTANCE OF ABOUT 30,000 ly.

IN 4.6 BILLION (4.6×10^9) YEARS SINCE IT WAS FORMED, THE SUN COMPLETED

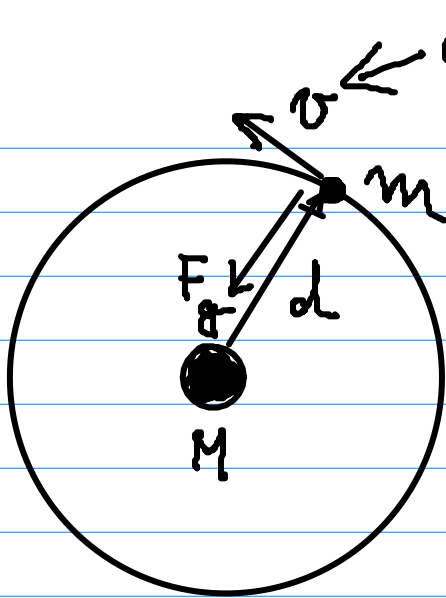
$$\frac{4.6 \times 10^9 \text{ Y}}{2.3 \times 10^8 \text{ Y}} = 20 \text{ REVOLUTIONS.}$$

REVOLUTION

HALO: STARS MOVE ALONG HIGHLY ELLIPTICAL ORBITS RANDOMLY ORIENTED AND WITH NO OVERALL DIRECTION OF MOTION (LIKE THE BEES IN A BEEHIVE).

BULGE: THE MOTIONS OF STARS ARE SIMILAR TO THOSE IN THE HALO.

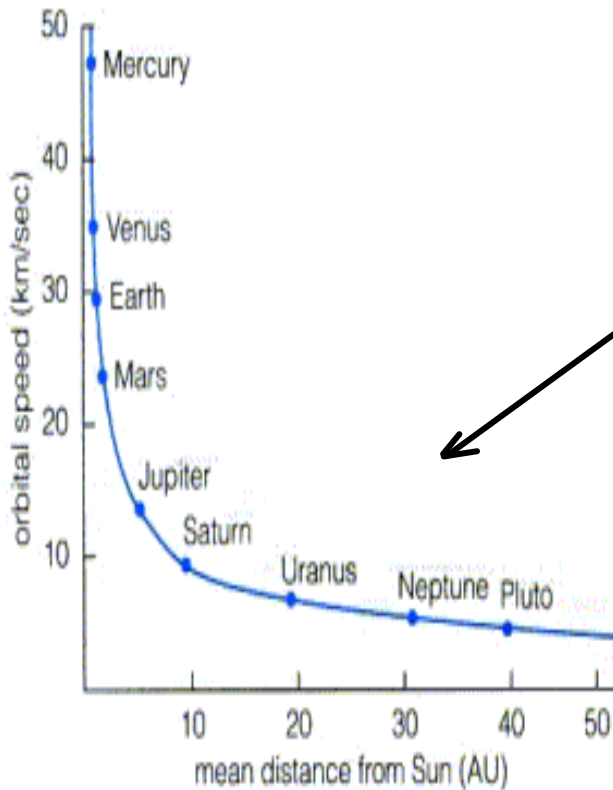
ONE CAN USE THE ORBITAL DATA OF STARS IN THE GALAXY (I.E. THEIR DISTANCE FROM THE GALACTIC CENTER AND THEIR ORBITAL SPEED/PERIOD) TO DETERMINE THE MASS OF THE GALAXY USING THE THIRD KEPLER'S LAW AS FORMULATED BY NEWTON:



$$m \frac{v^2}{d} = F = G \frac{mM}{d^2}$$

ACCELERATION
FOR UNIFORM
MOTION ALONG
CIRCULAR PATH

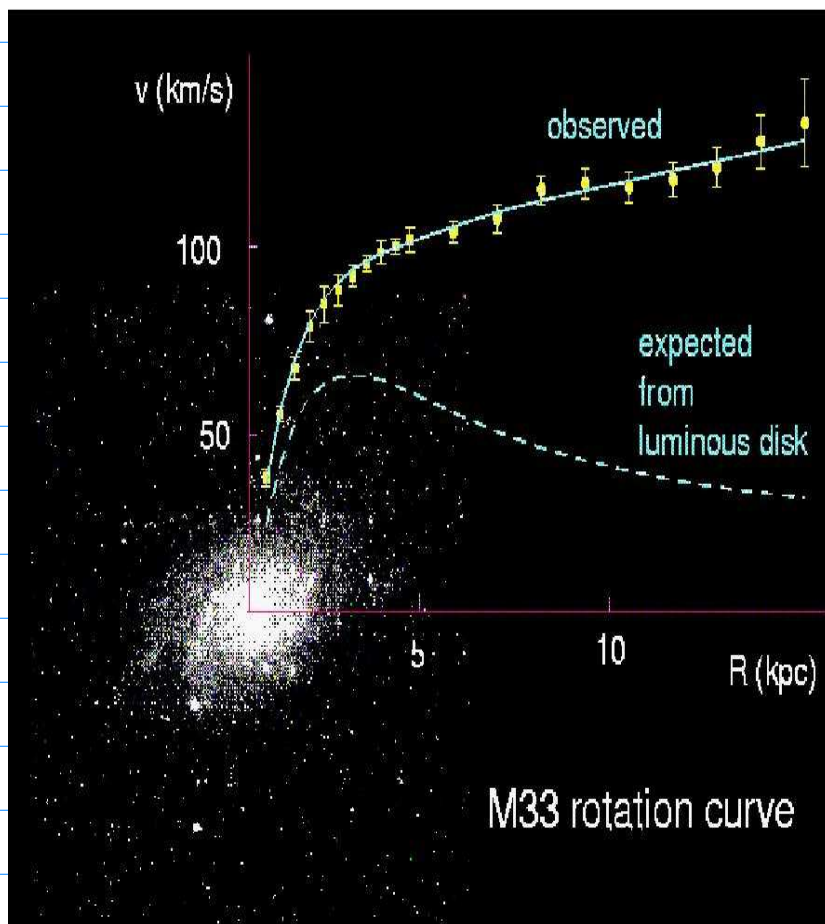
$$M = \frac{d v^2}{G} \quad \text{OR} \quad v = \frac{\sqrt{GM}}{\sqrt{d}}$$



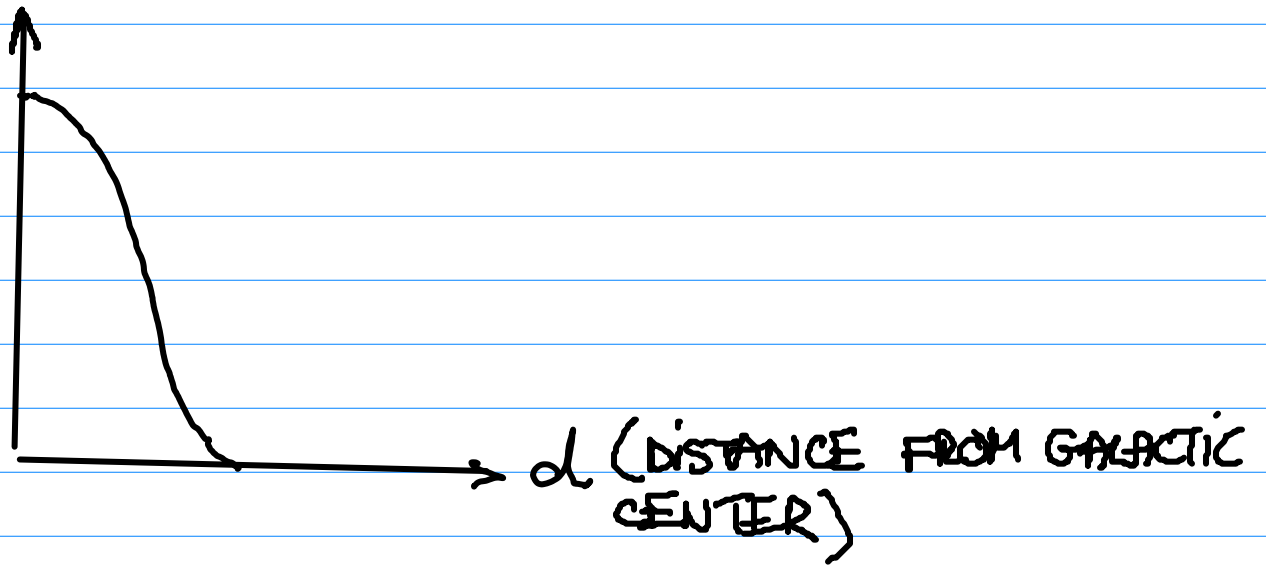
↑
KEPLERIAN ROTATION
CURVE

THE ROTATION CURVES OF STARS IN THE

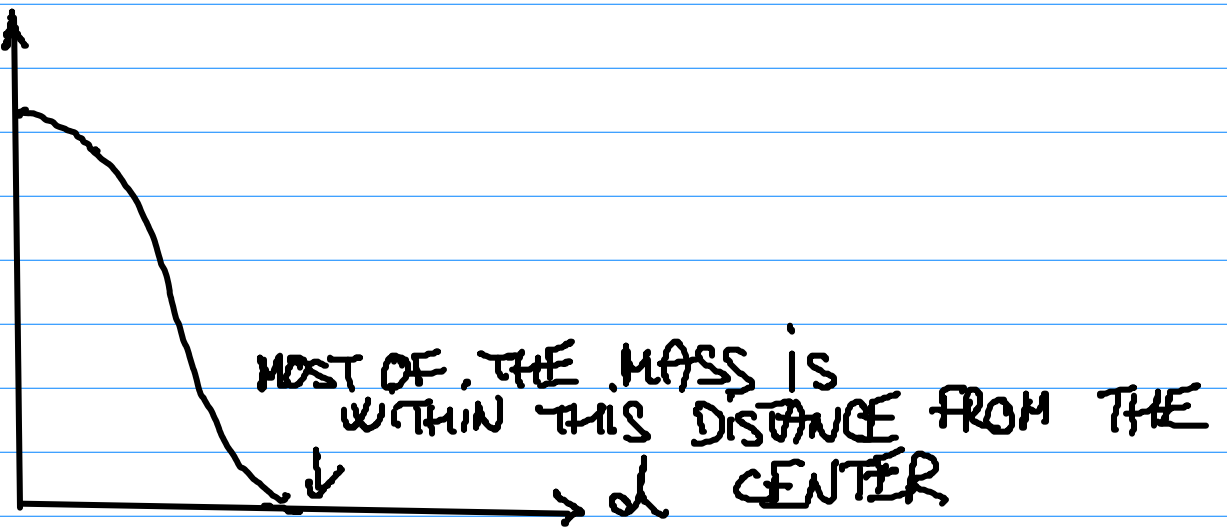
GALAXIES ARE VERY DIFFERENT. THEY WERE FIRST MEASURED BY VERA RUBIN IN 1970s:



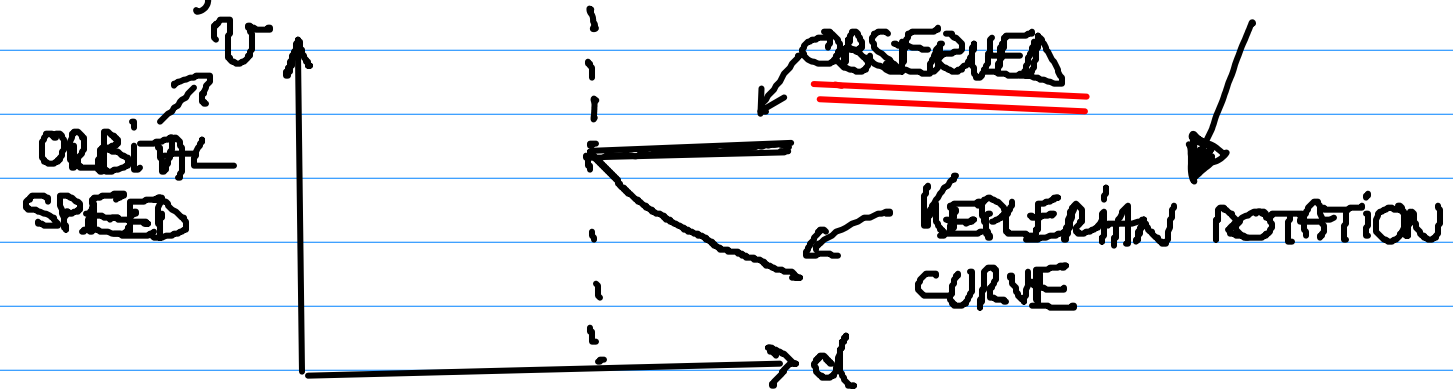
THE LIGHT INTENSITY OF A GALAXY:



THE DENSITY OF LUMINOUS MASS:



THEN, THE EXPECTED ROTATION CURVE IS



IF ONE ASSUMES THAT THE NEWTON'S LAWS ARE WORKING AT THESE LARGE DISTANCES THERE MUST BE ADDITIONAL MASS THAT WE CANNOT SEE -
- SO-CALLED DARK MATTER.