Virialization and bulgeless galaxies

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Outline

- Virial theorem
- Virialization of BLGs

Virial theorem-general

-"virial" - the word from Latin *vis=force* or *energy.*

-*Virial theorem,* Rudolf Clausius, 1870, the average total kinetic energy can be calculated even for very complicated systems $\langle T \rangle = -\sum_{k=1}^{N} \langle \mathbf{F}_k \cdot \mathbf{r}_k \rangle$

-T is kinetic energy, **F** is the force on a particle at the position **r,** *k* indexes the *k*-th particle. Angle brackets <> are for the time average of the quantities.

-If the force between any two particles of the system results from a potential energy that is proportional to some power n of the inter-particle distance r, V(r)=const r^n, the virial theorem becomes $2\langle T \rangle = n \langle V_{\mathrm{TOT}} \rangle.$

-V_тот is the sum of the potential energy V(r) over all pairs of particles in the system. For gravity, n = −1, and for average over a time τ: $\langle T \rangle_\tau = -\frac{1}{2} \langle V_{\mathrm{TOT}} \rangle_\tau$

-For a galaxy=system of stars, one can assume a gravitational balance, Doppler measurements give lower bounds for their relative velocities, and the virial theorem gives a lower bound for the total mass of the star (or a cluster of stars or galaxies), including any dark matter.

-generalizations to special relativistic case and inclusion of electromagnetism exist

Galaxies and virial theorem

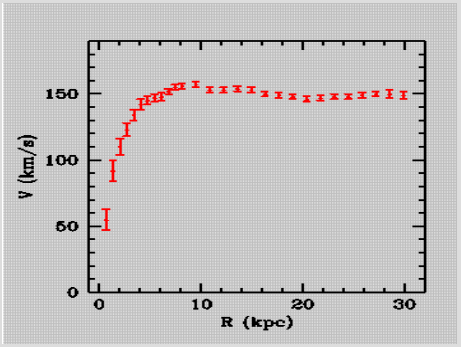
-the mass and size of a galaxy (or any region denser than surrounding) is defined in terms of the "virial radius" and "virial mass".

-the mass of a galaxy is often measured by the rotation velocity of its gas and stars, assuming circular Keplerian orbits. Using the virial theorem, the dispersion velocity σ is defined by $\frac{GM}{R} \approx \sigma^2.$ Usually, a **maximum** is taken: $\frac{GM_{\rm vir}}{R_{\rm vir}} \approx \sigma^2_{\rm max}.$

- a typical galaxy shows flat rotation curve profile, which implies that the mass continues to increase linearly with radius=there must be some matter which we do not see=dark matter, inside.

Sofue & Rubin, 2001

-for NGC3198, Begeman 1989, and for more spirals:



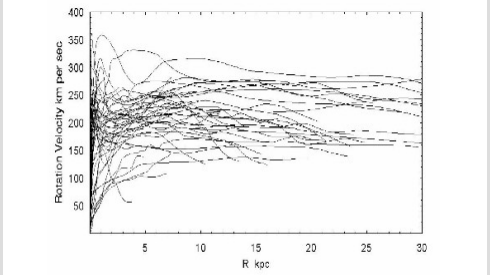


Fig. 4. Rotation curves of spiral galaxies obtained by combining CO data for the central regions, optical for disks, and HI for outer disk and halo (Sofue et al. 1999).

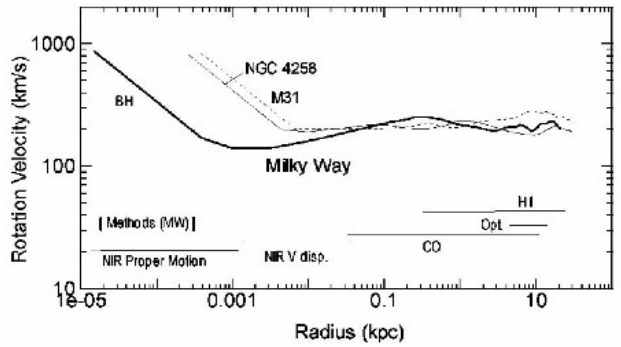


Fig. 3. Logarithmic rotation curves of the Milky Way (thick line), NGC 4258 (thin line) and M31 (dashed line). Innermost rotation velocities are Keplerian velocities calculated for massive black holes. Observational methods for the Milky Way are shown by horizontal lines.

Virialization of bulgeless galaxies

-that the galaxies are “virialized” means that they are gravitationally bound with velocities corresponding to predicted orbital velocities of general relativity.

-galaxies are in general virialized up to ten times their visible radii. This suggests that a dark matter is 95% of the total amount of gravitating matter.

-my question: does the virialization of bulgeless galaxies proceeds the same way as it goes for other galaxies? If not, where is the difference? Can we learn something from it?

-if not already done (I believe a lot of work IS done, more literature search needed), I would investigate virialization scenarios of galaxies in general, and then of BLGs, using simple N-body simulations, and then eventually something more involved. If not completely outdated, both are neat problems for Summer School student(s).

-comparison of scenarios with observations, eventually synthetic observation maps.

-if completely outdated question, no problem, just look into the refined versions of the virial theorem, with inclusion of more effects (General relativity on the menu for gourmets) and see what can be done with that.

Summary: questions

- BLGs are, as all galaxies ... virialized?
- What can we learn from their virialization history?