AST 1420

Galactic Structure and Dynamics

Q&A

Presentations

Presentations

- Week 10: Nov 23 to 27, date/time TBD
- Each student presents on a topic for ~10 min.
- Encouraged to find your own topic in Galactic structure and dynamics!
- Could be a survey and some results on a topic addressed by the survey: e.g., *Gaia* and co-moving stars, ATLAS 3D integral-field-spectroscopy and the IMF, APOGEE and chemical evolution, …
- Or a topic: e.g., rotation curves of low-surface brightness galaxies, rotation curves at redshift ~ 2, the dynamics of the inner Milky Way, Schwarzschild modeling of galactic nuclei to constrain black holes, …
- **Please email me with your proposed topic by Oct. 22**

Agenda for today

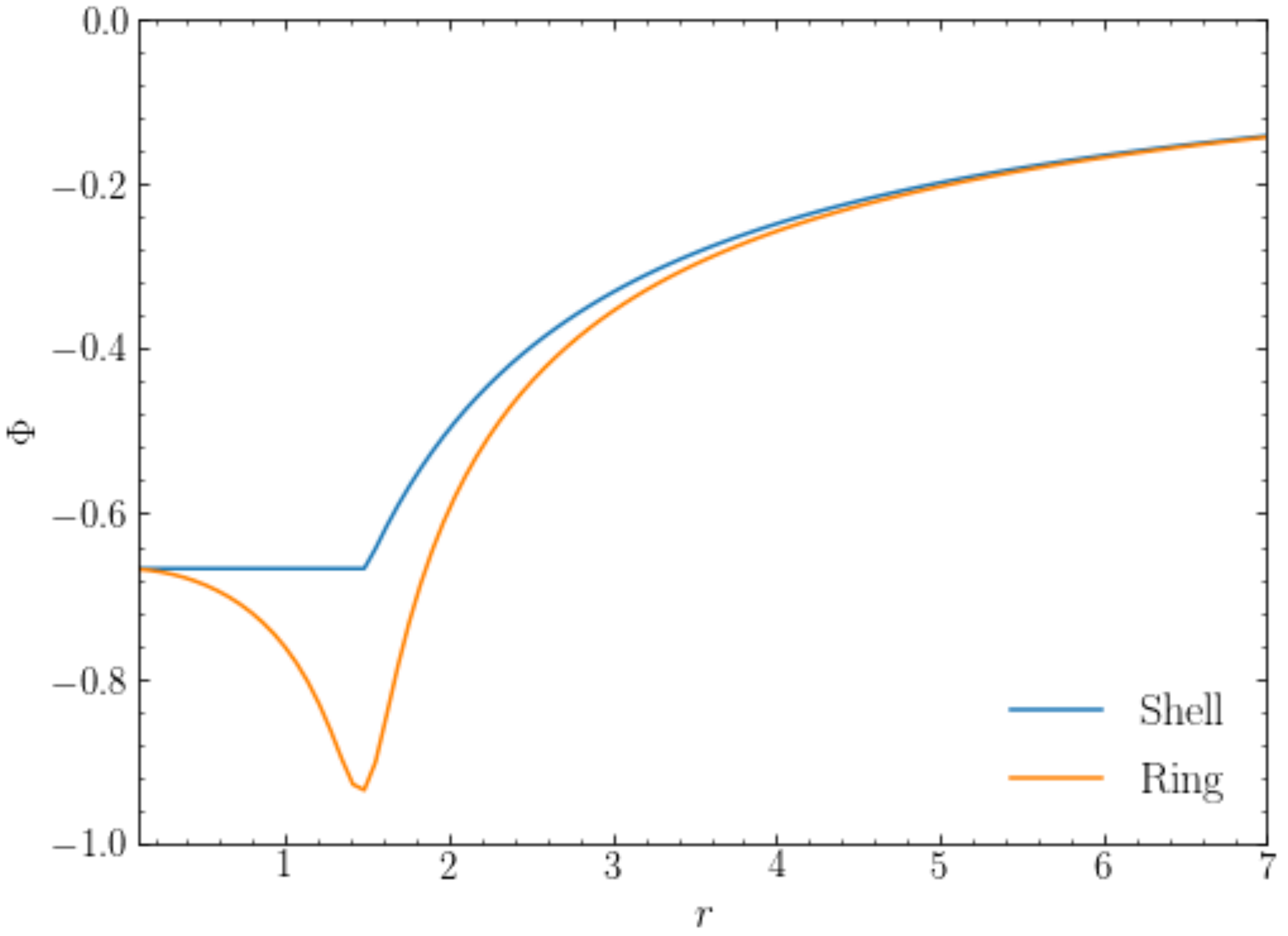
Questions on gravitation in disks and orbits

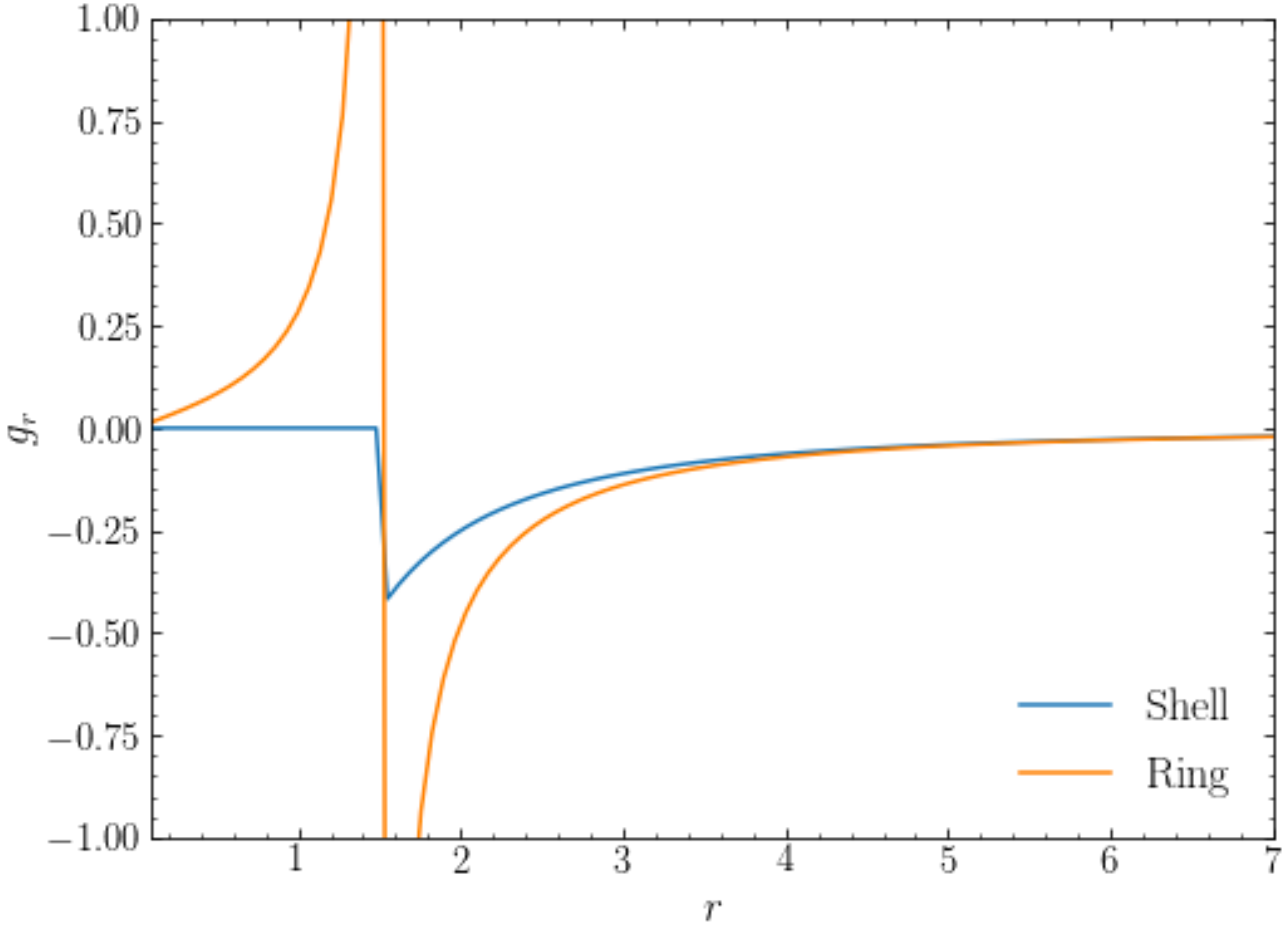
Group activity

Questions on galactic rotation and dark matter

Gravitation disks

Gravity from a disk vs. a sphere

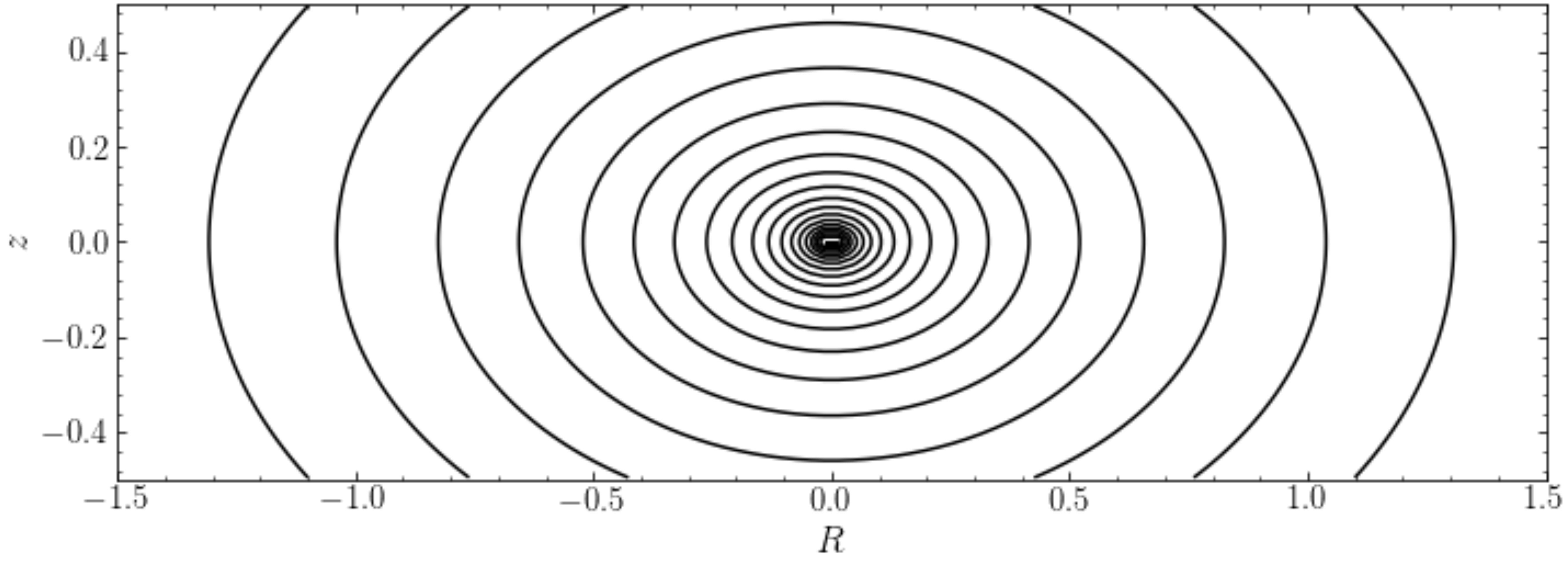


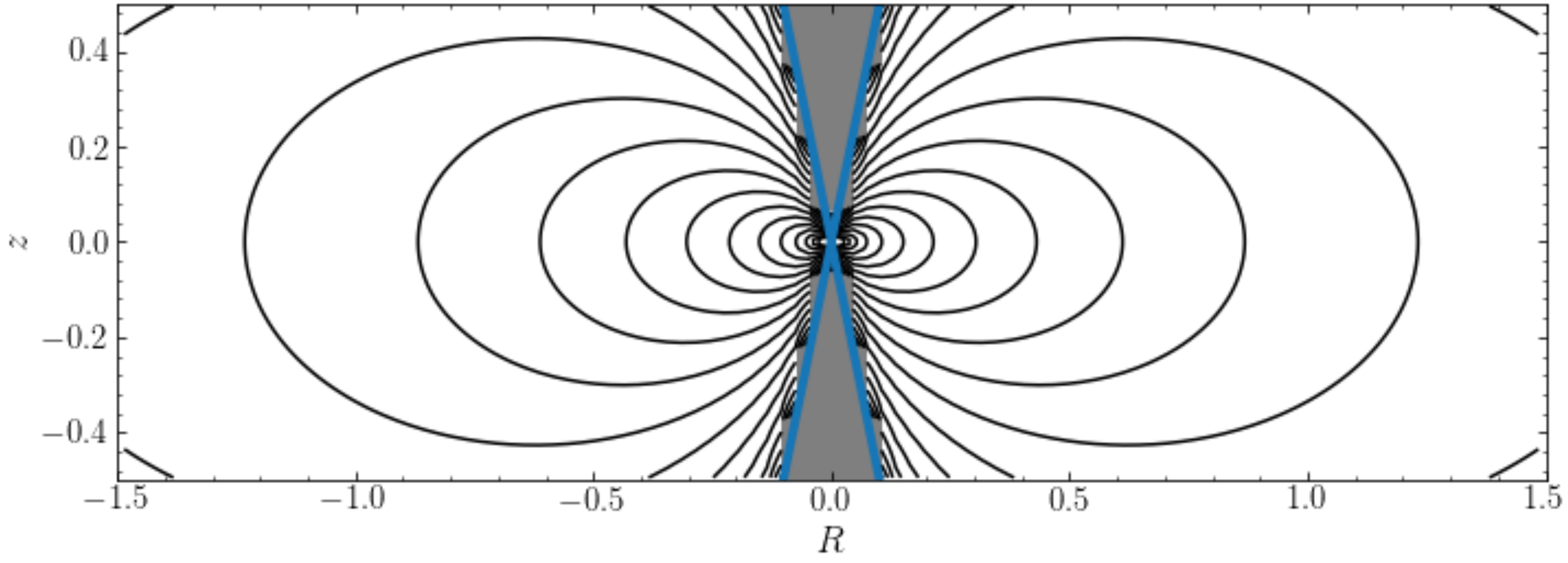


- Why the discontinuity?

The flattened logarithmic potential

- Negative density? What does that mean?





Poisson equation for *axisymmetric razor-thin* disks

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\,\frac{\partial\Phi(R,z)}{\partial R}\right)+\frac{\partial^2\Phi(R,z)}{\partial z^2} = 4\pi\,G\,\Sigma(R)\,\delta(z)$$

- Solution:

$$\tilde{\Phi}(R;k) = -2\pi\,G\,e^{-k|z|}\,J_0(kR)$$

- With Σ

$$\tilde{\Sigma}(R;k) = k\,J_0(kR)\,.$$

- Potential-density pair —> complete?

Poisson equation for *axisymmetric razor-thin* disks

- If we can decompose

$$\Sigma(R) = \int_0^\infty \mathrm{d}k\, J_0(kR)\, k\, S_0(k)\,,$$

- Then the potential is

$$\begin{aligned}\Phi(R,z) &= -2\pi\, G \int_0^\infty \mathrm{d}k\, e^{-k|z|}\, J_0(kR)\, S_0(k)\\ &= -2\pi\, G \int_0^\infty \mathrm{d}k\, e^{-k|z|}\, J_0(kR) \int_0^\infty \mathrm{d}R'\, J_0(kR')\, R'\, \Sigma(R')\,.\end{aligned}$$

- Decomposition from the Fourier-Bessel theorem

$$S_0(k) = \int_0^\infty \mathrm{d}R'\, J_0(kR')\, R'\, \Sigma(R')$$

Bessel functions!

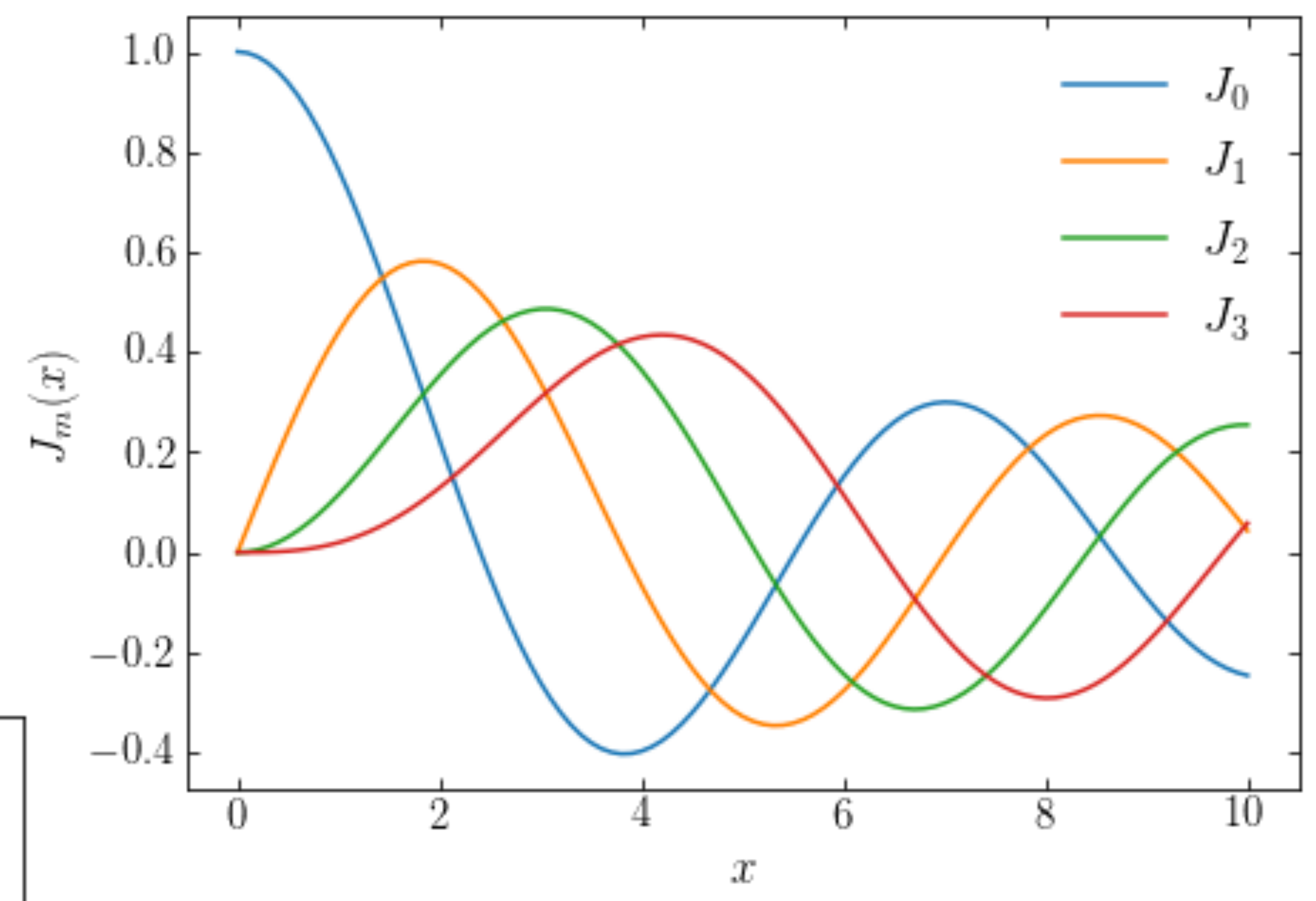
- Defined by

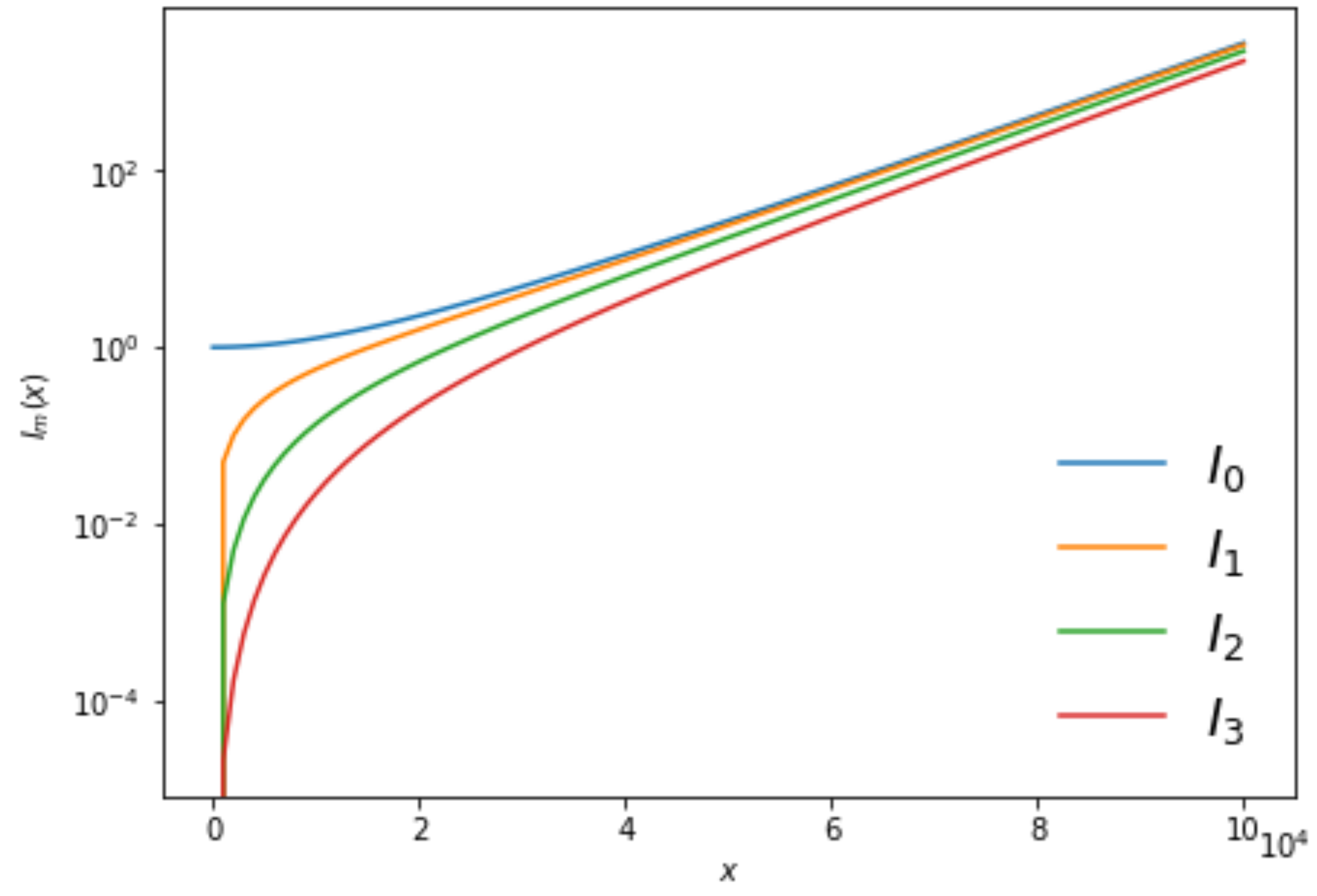
$$x^2 \frac{d^2 y}{dx^2} + x \frac{dy}{dx} + \left(x^2 - \alpha^2\right) y = 0 \,.$$

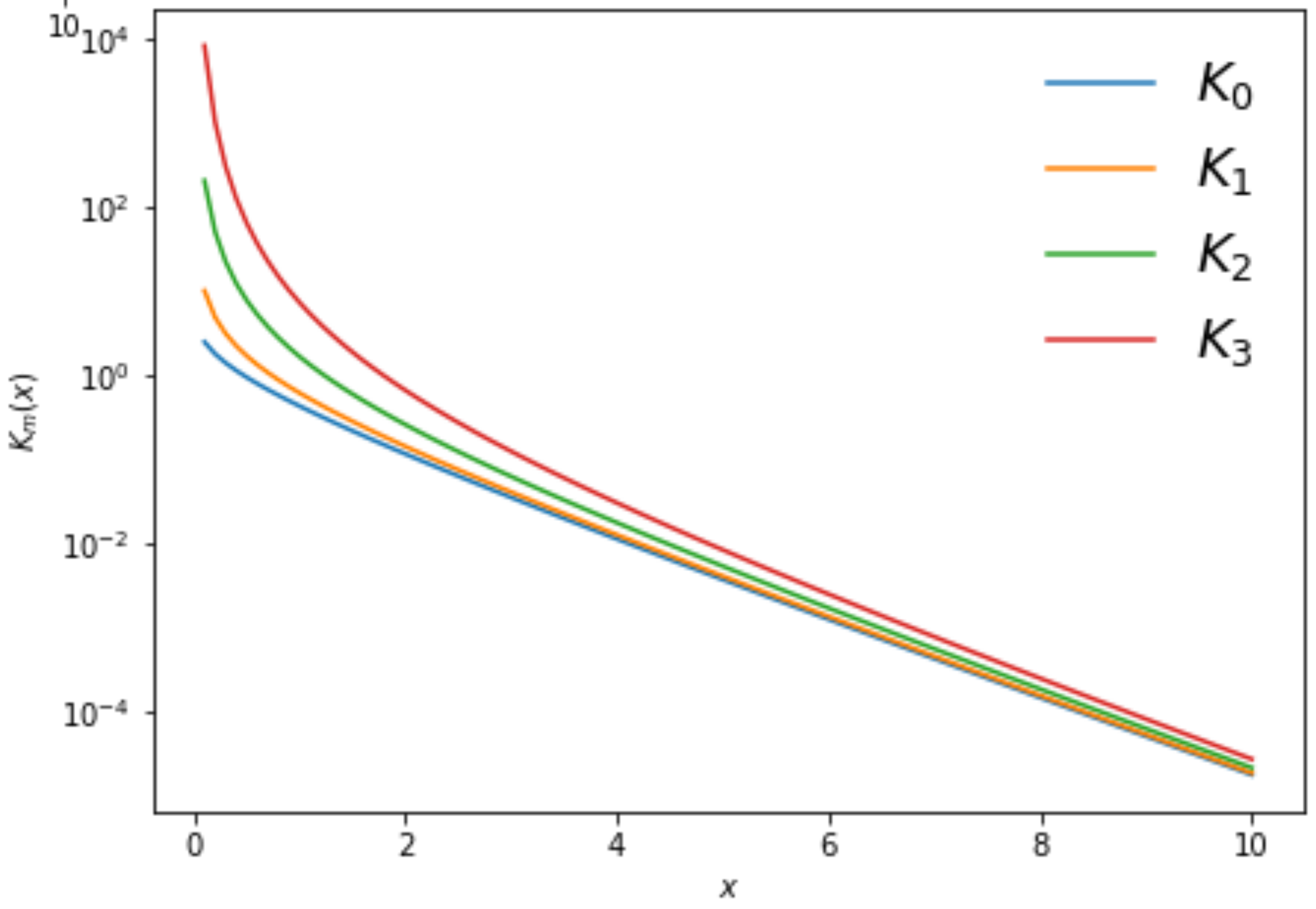
- Should have two linearly-independent solutions as a second-order diff. equation —> $Y_m(x)$ is second for m=integer

- Modified Bessel functions defined by

$$I_\alpha(x) = i^{-\alpha} J_\alpha(ix) \,,$$
$$K_\alpha(x) = \frac{\pi}{2} \frac{I_{-\alpha}(x) - I_\alpha(x)}{\sin(\alpha\pi)} \,.$$

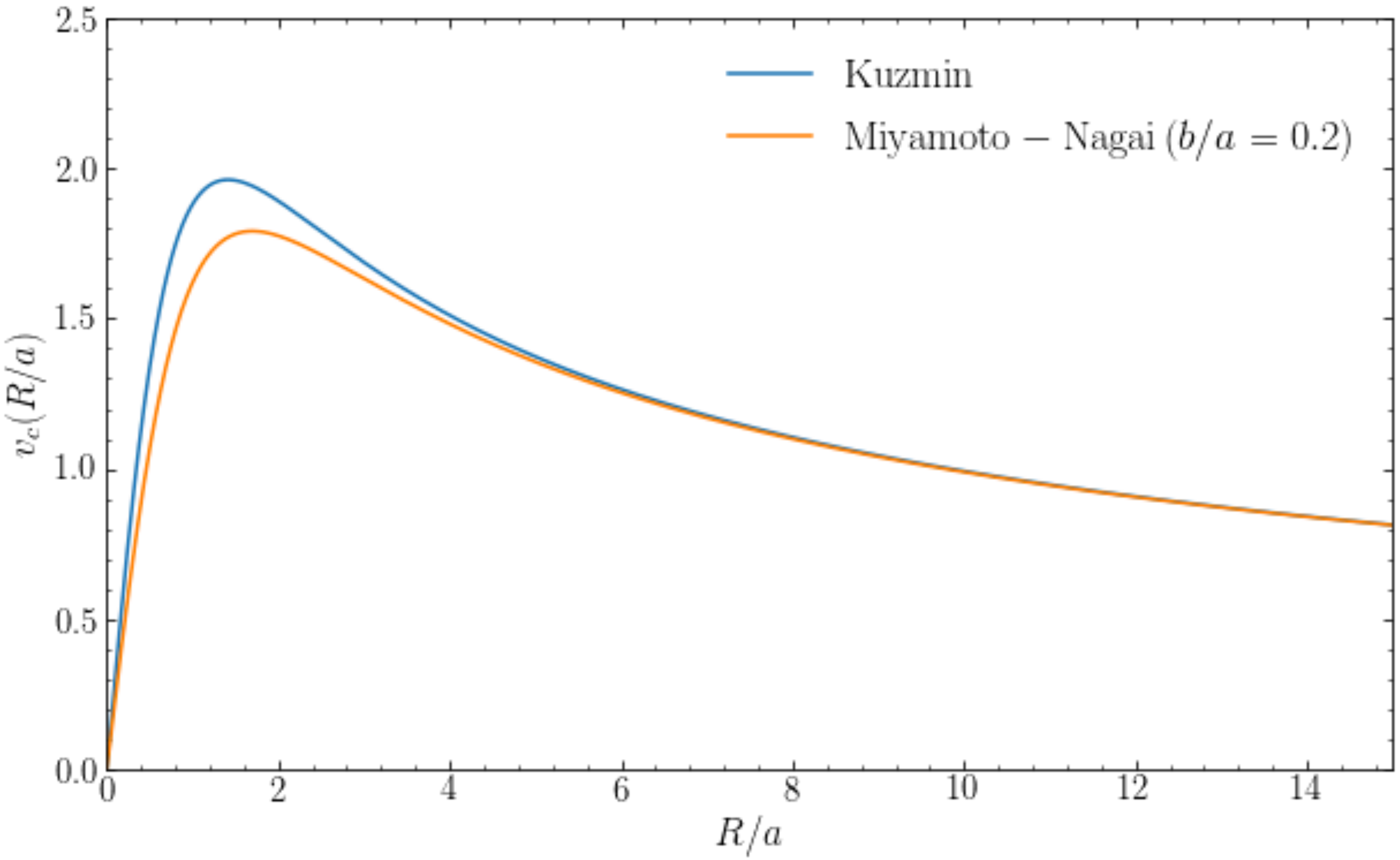






Kuzmin, Miyamoto-Nagai disks

- How do these account for the radius of the galaxy?
- Which peaks higher?



Orbits in disks

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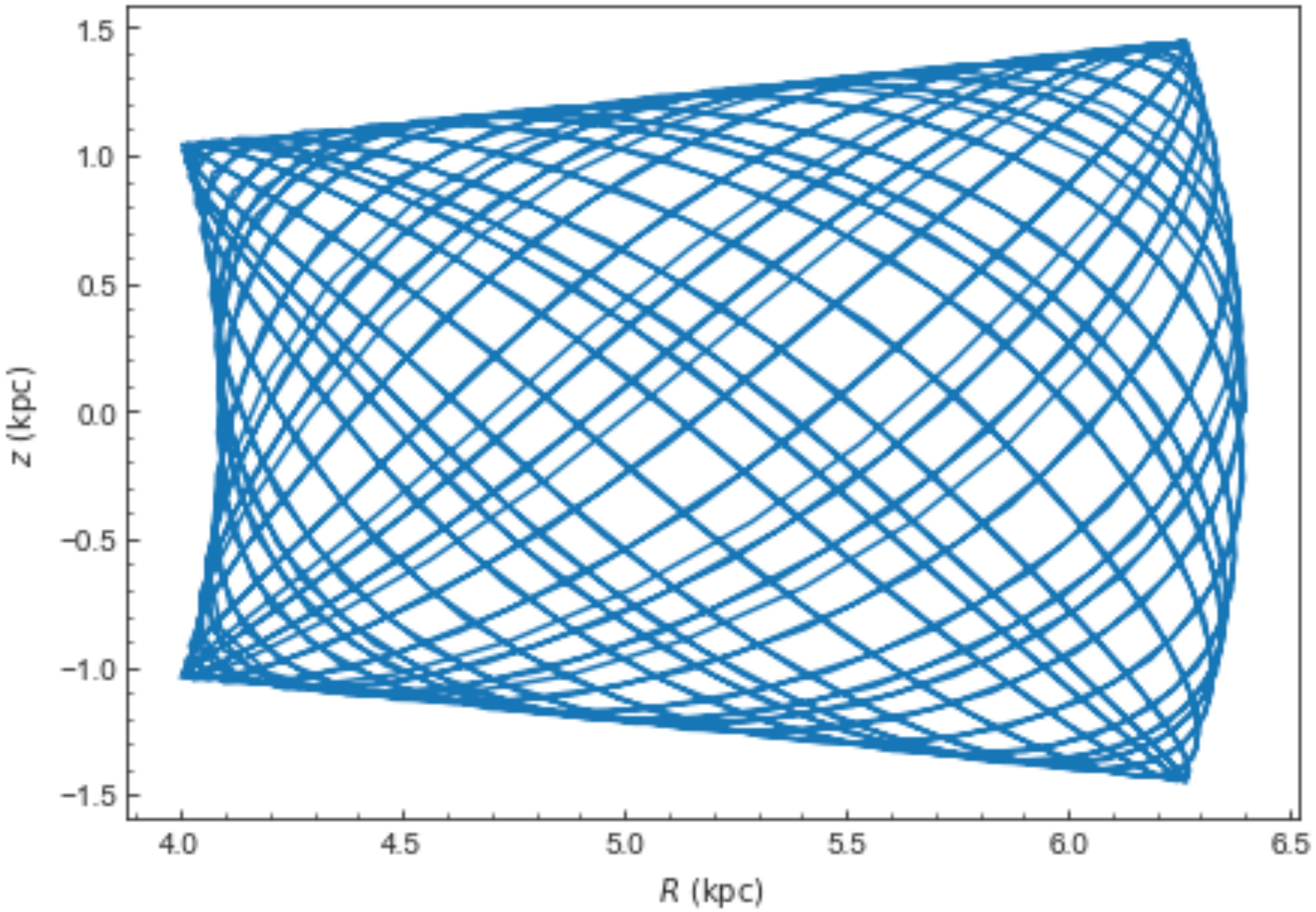
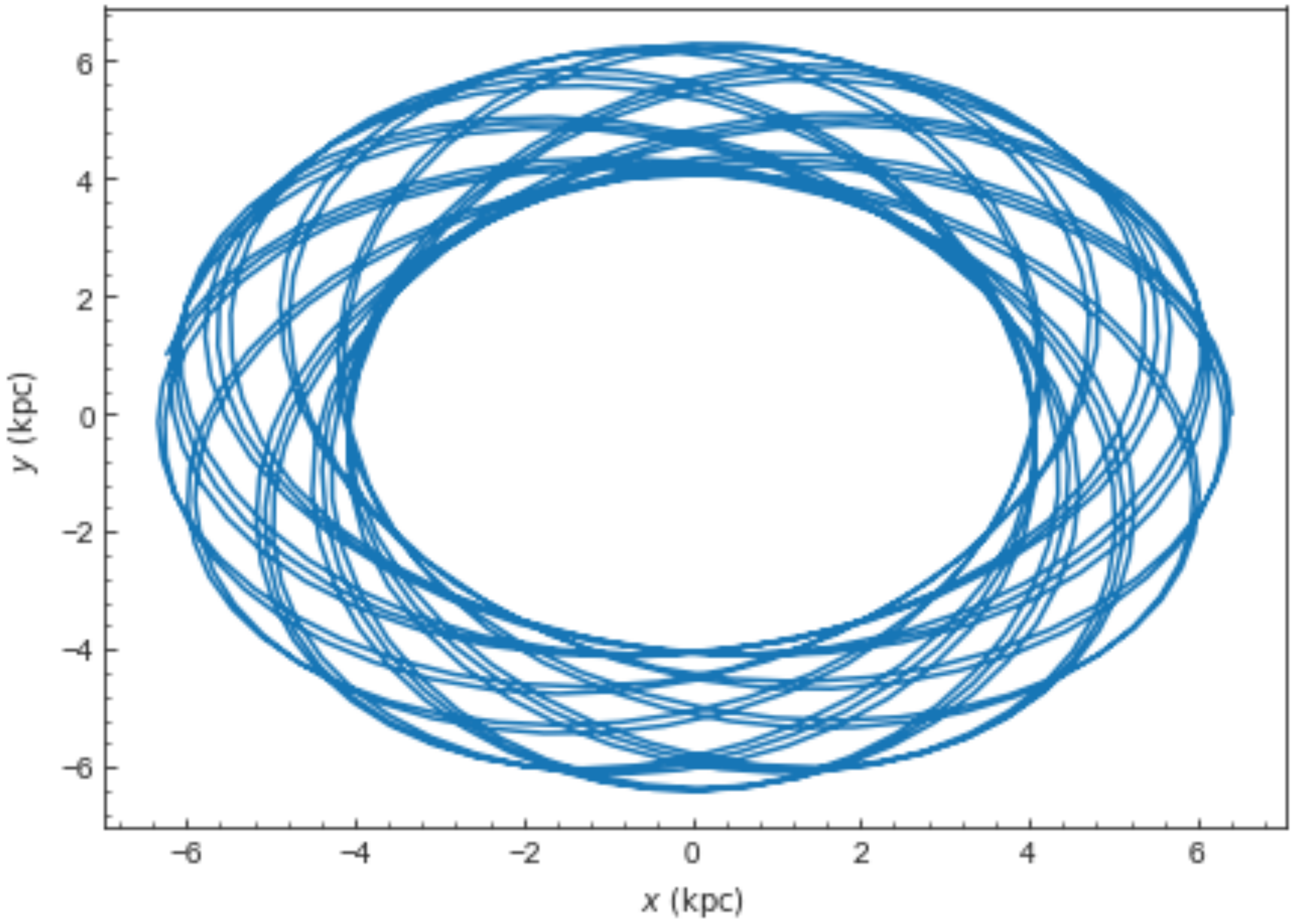




How many orbits are there?

- What is the relation between initial condition and orbit?
  - In some sense every initial condition is its own orbit, especially for galaxies which are only O(10-100) dynamical times old —> 6D space of orbits
  - But on long timescales, most potentials are regular, meaning that they have three integrals of the motion, called the *actions*, that define the orbit
    - Three remaining phase-space dimensions are the angles or phases
    - Orbits are then *tori* in 6D space
    - Angles say where you are along the torus, but tori with the same actions are essentially the same —> 3D orbit space
  - Chaotic orbits have *fewer* integrals of the motion (two, one, or zero) —> less restrained in phase space —> lower dimensional space of separate orbits. In a very chaotic potential, a single initial condition could pass near every point in phase space

Integrals of the motion

- Are there integrals of the motion that aren't isolating?
  - Yes, but typically contrived. See example in B&T08 3.1.1
- Does E_z (the vertical energy) constrain the dimensionality of the orbit?
  - No! Not an exact integral for all non-circular orbits, so eventually leads to mixing outside of the surface $E_z = E_{z,\mathrm{initial}}$

$$\Phi(r) = -GM\left(\frac{1}{r} + \frac{a}{r^2}\right). \tag{3.57}$$

For this potential, equation (3.11b) becomes

$$\frac{\mathrm{d}^2 u}{\mathrm{d}\psi^2} + \left(1 - \frac{2GMa}{L^2}\right)u = \frac{GM}{L^2}, \tag{3.58}$$

the general solution of which is

$$u = C\cos\left(\frac{\psi - \psi_0}{K}\right) + \frac{GMK^2}{L^2}, \tag{3.59a}$$

where

$$K \equiv \left(1 - \frac{2GMa}{L^2}\right)^{-1/2}. \tag{3.59b}$$

Hence

$$\psi_0 = \psi - K\,\mathrm{Arccos}\left[\frac{1}{C}\left(\frac{1}{r} - \frac{GMK^2}{L^2}\right)\right], \tag{3.60}$$

Group work

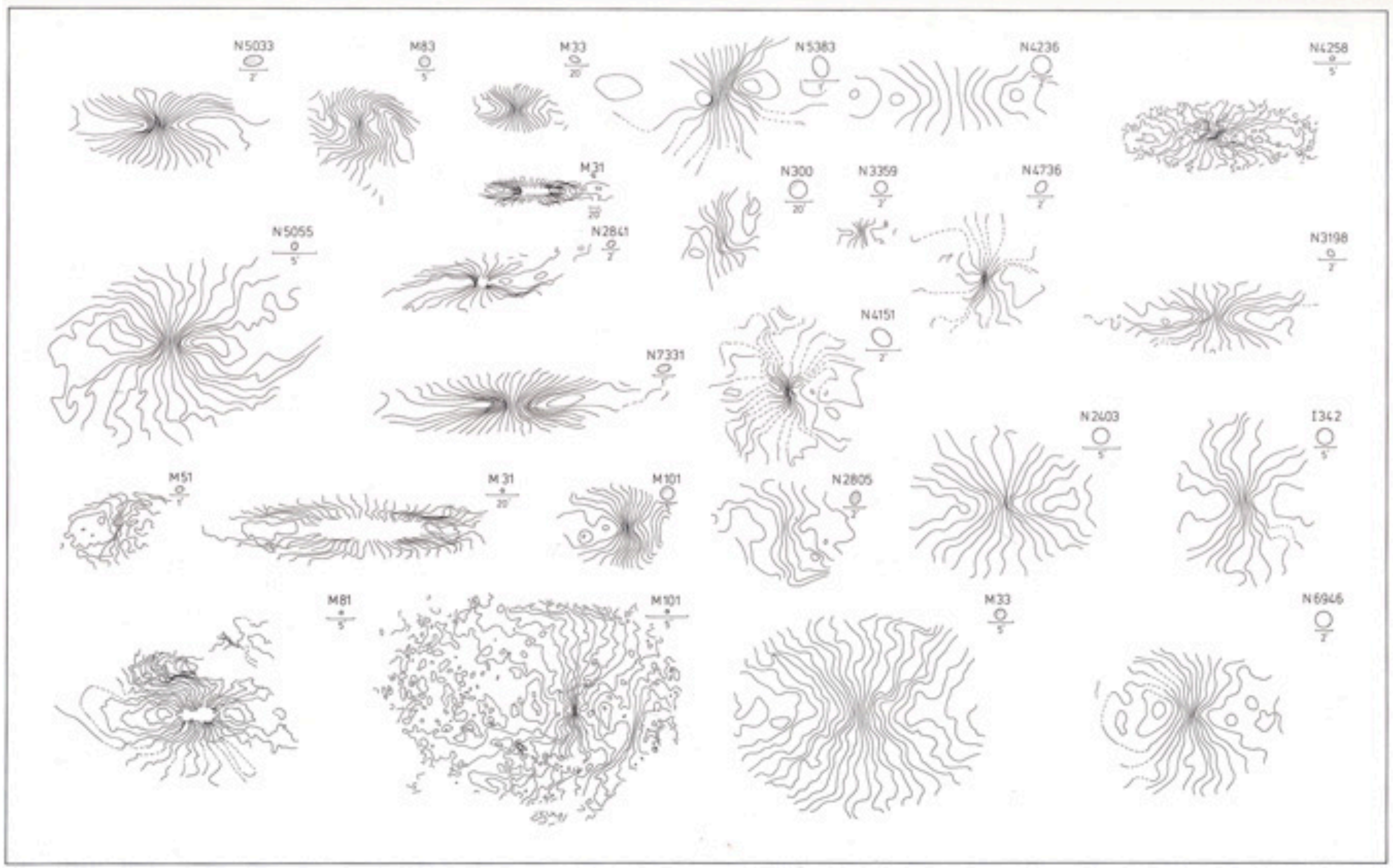
https://github.com/jobovy/sparc-rotation-curves

Galactic rotation and dark matter

The observations

- Rotation curves obtained from long-slit optical spectra, optical IFU observations, or radio 21cm
  - Now also done with ALMA in the millimeter!
- How do we get the inclination?
  - In general we cannot know the inclination
  - Assuming models, we can determine the inclination
    - Simple model: galaxy disk is circular, so observed shape is due to inclination

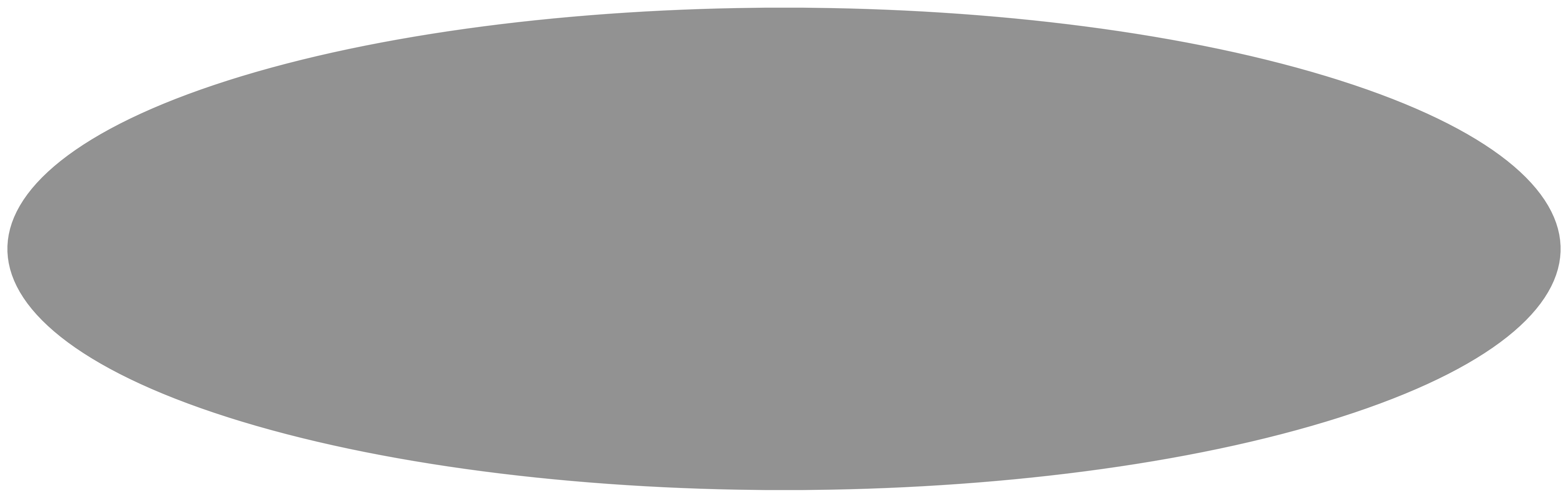
The Bosma rotation fields

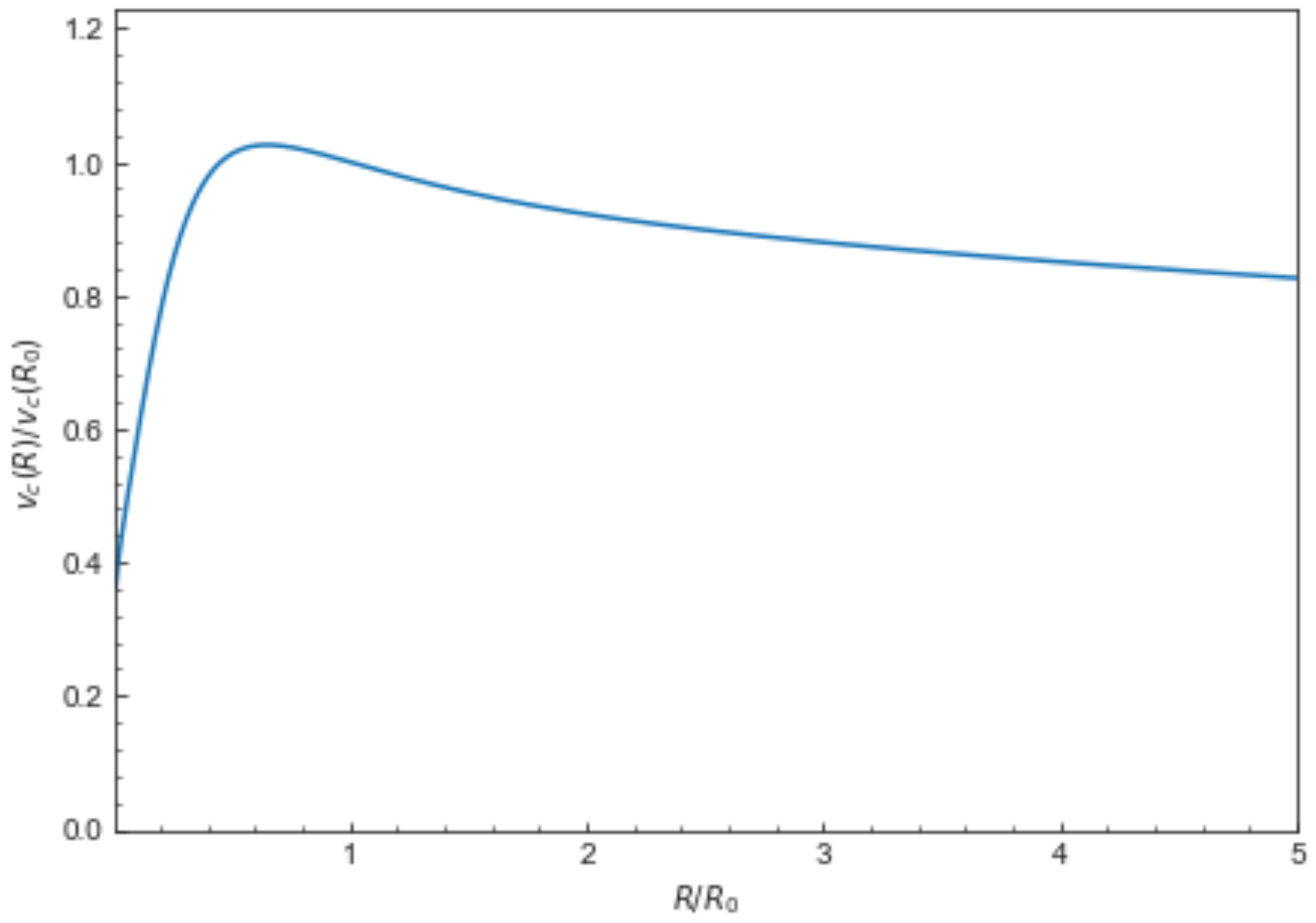


Bosma (1978)

Model 2D velocity fields

- Why are there closed contours when there is a peak in the rotation curve?





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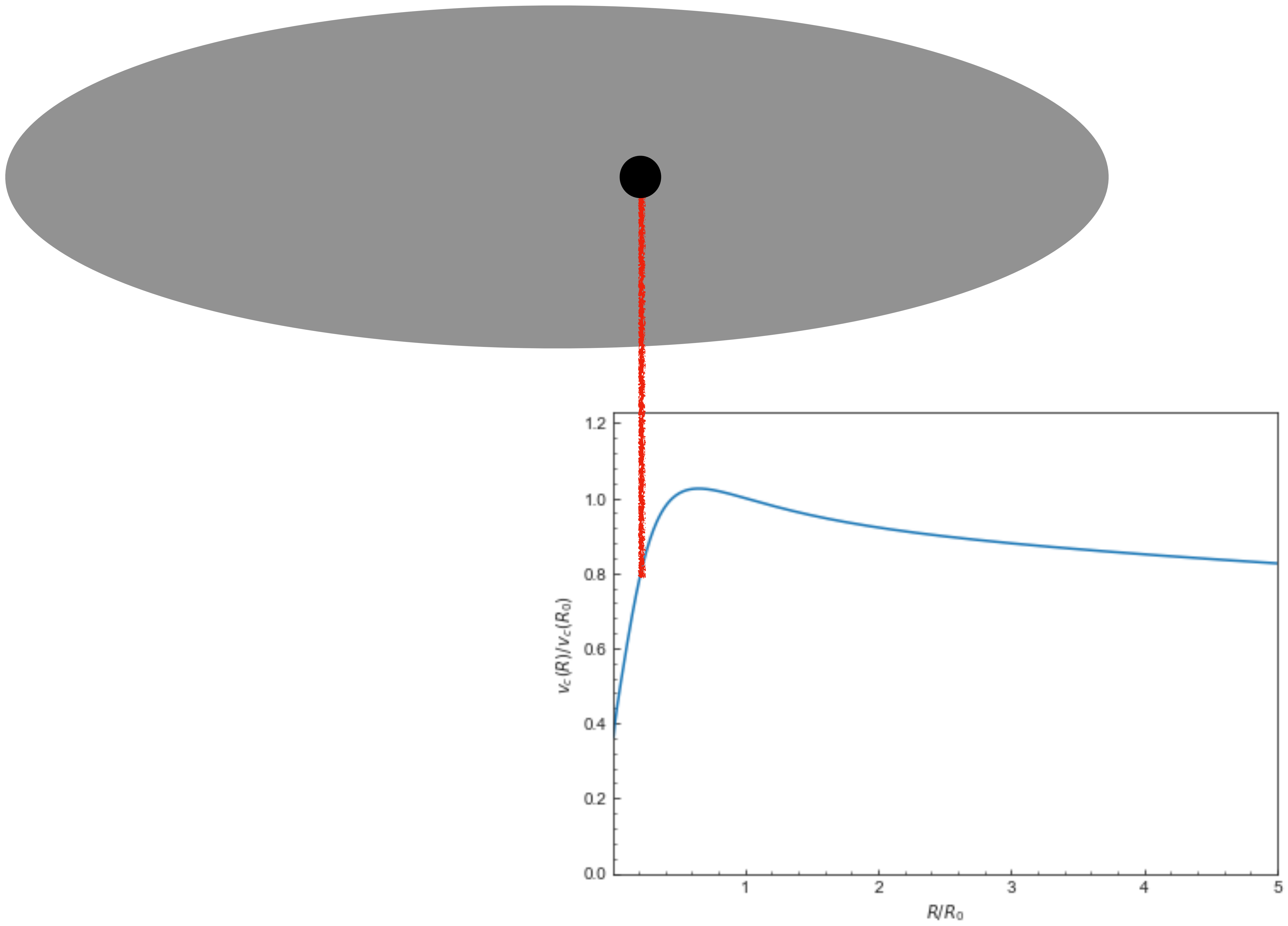

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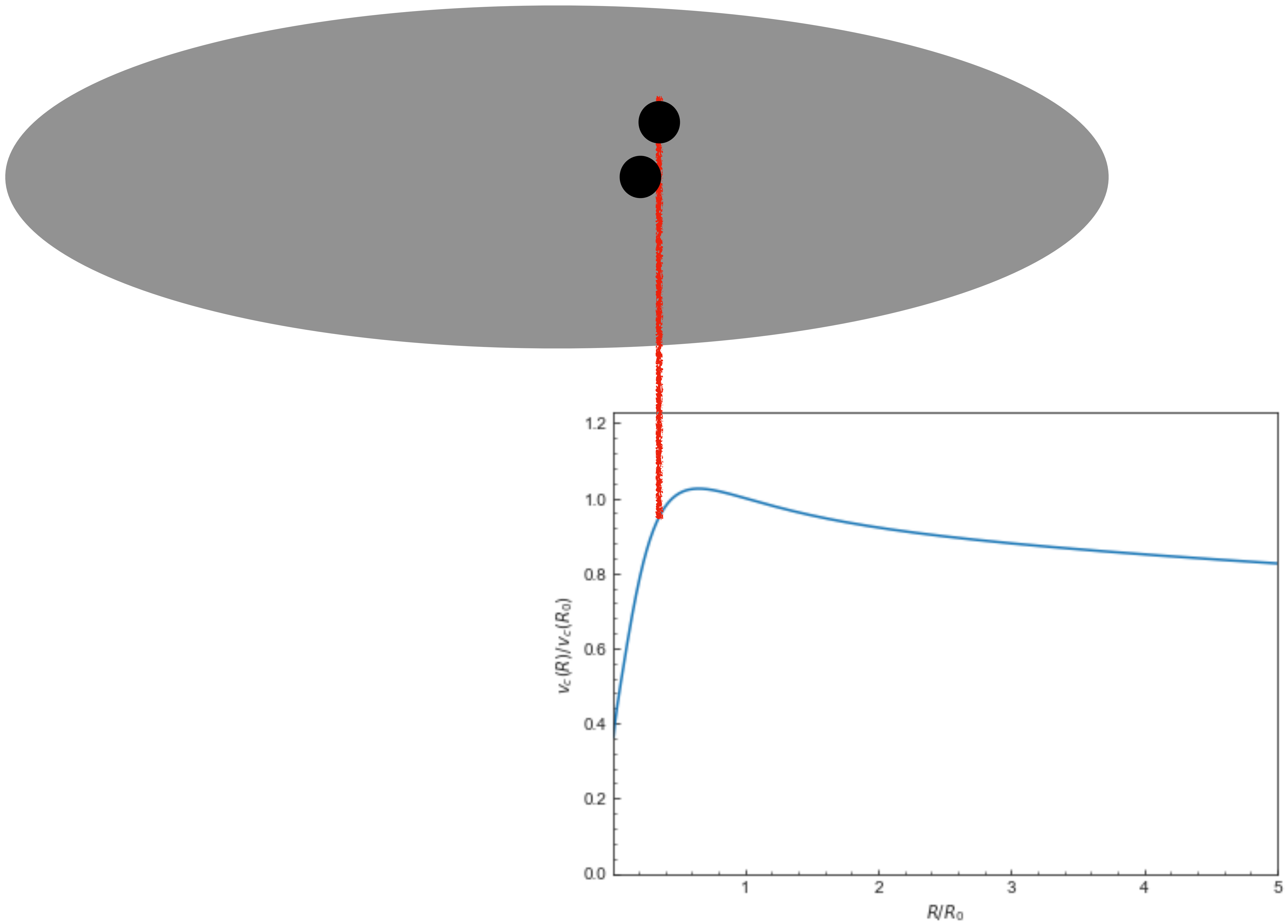

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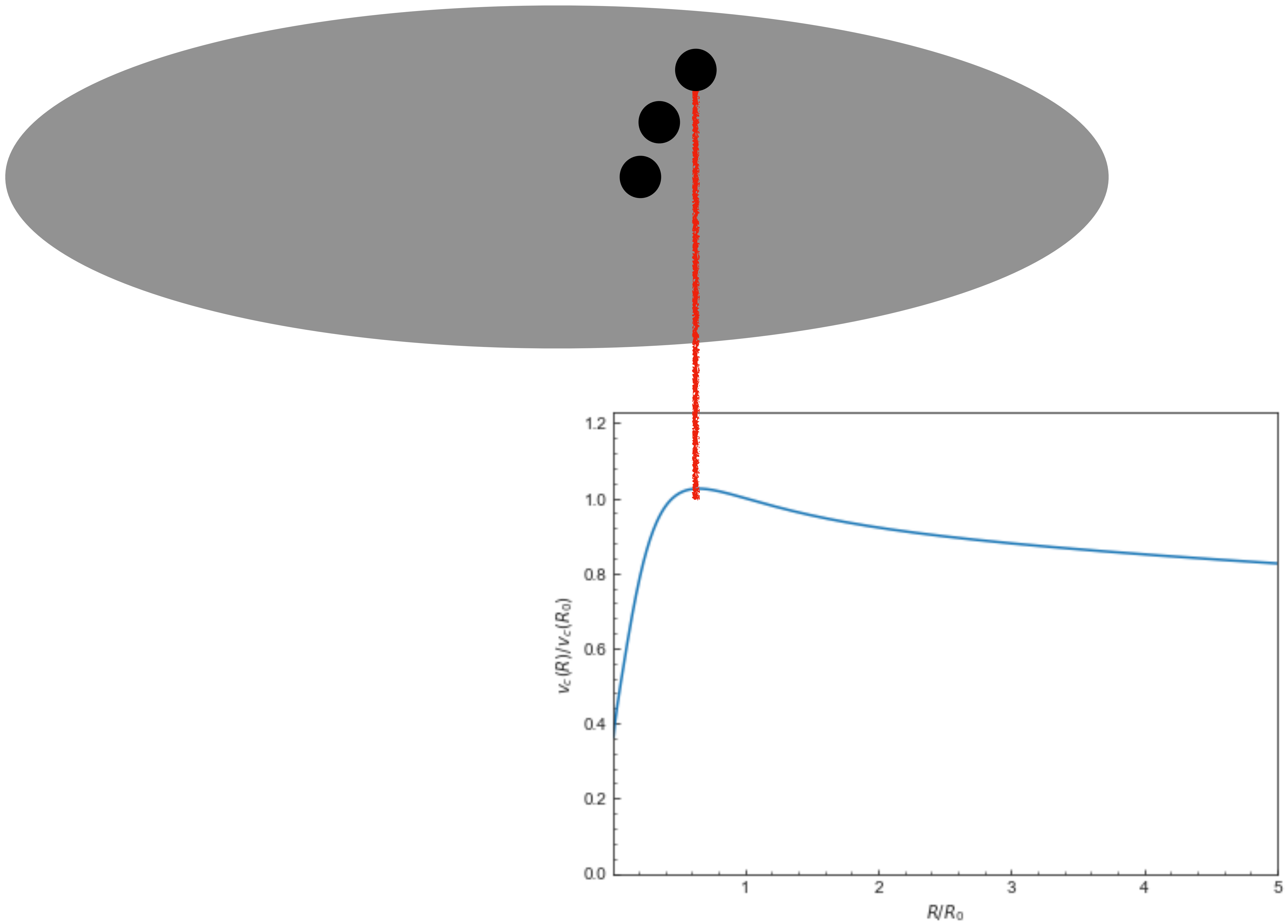

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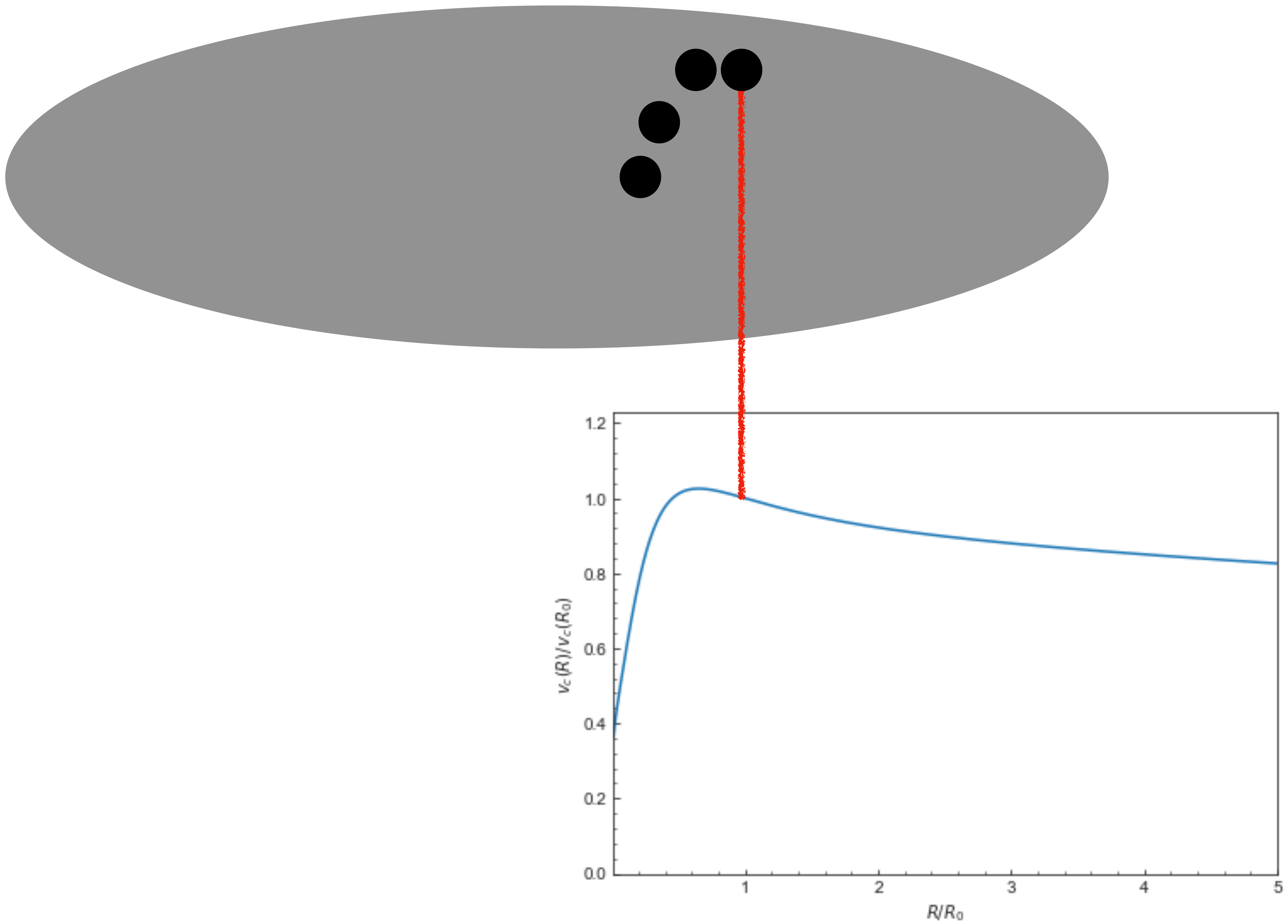

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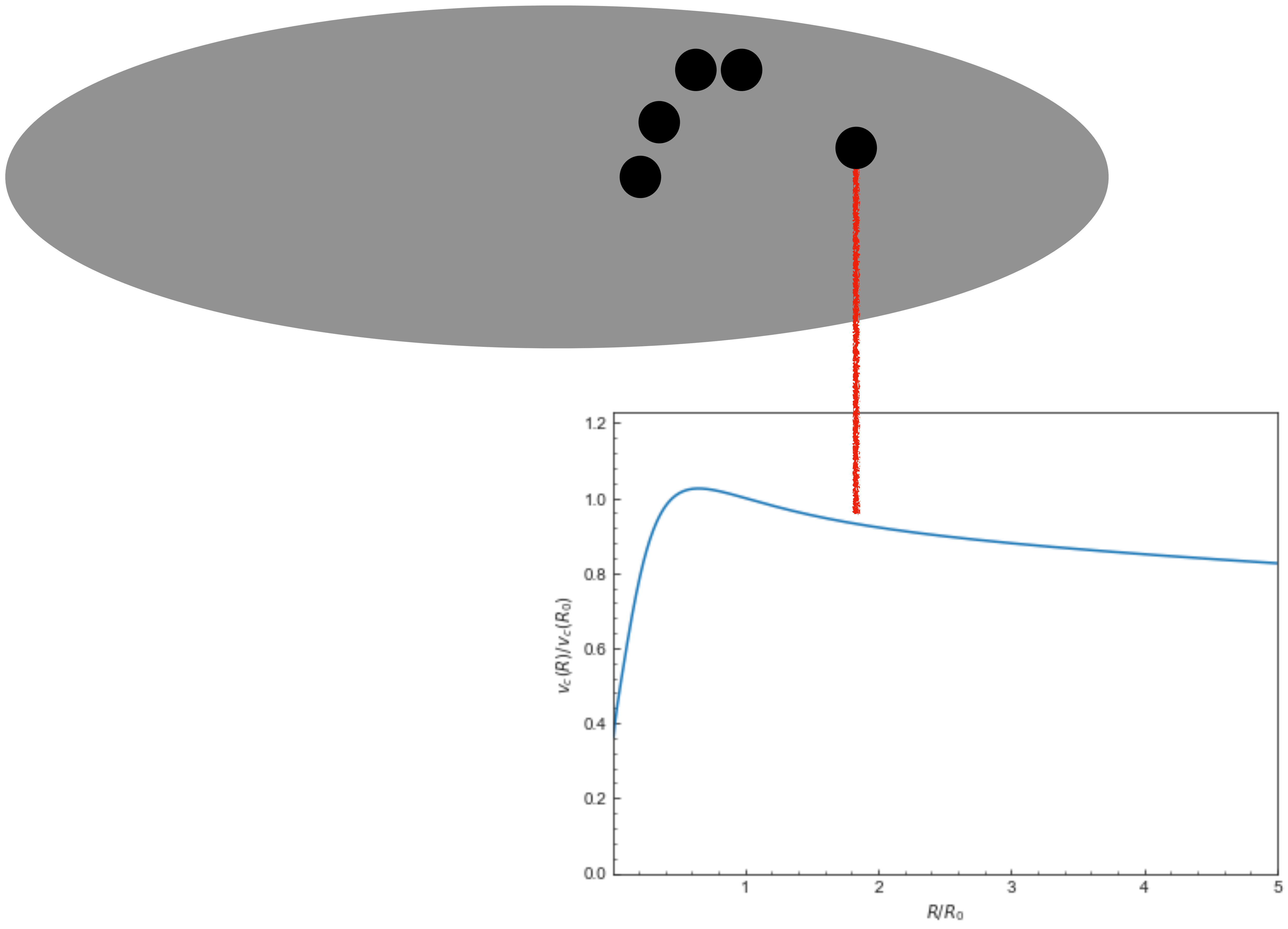

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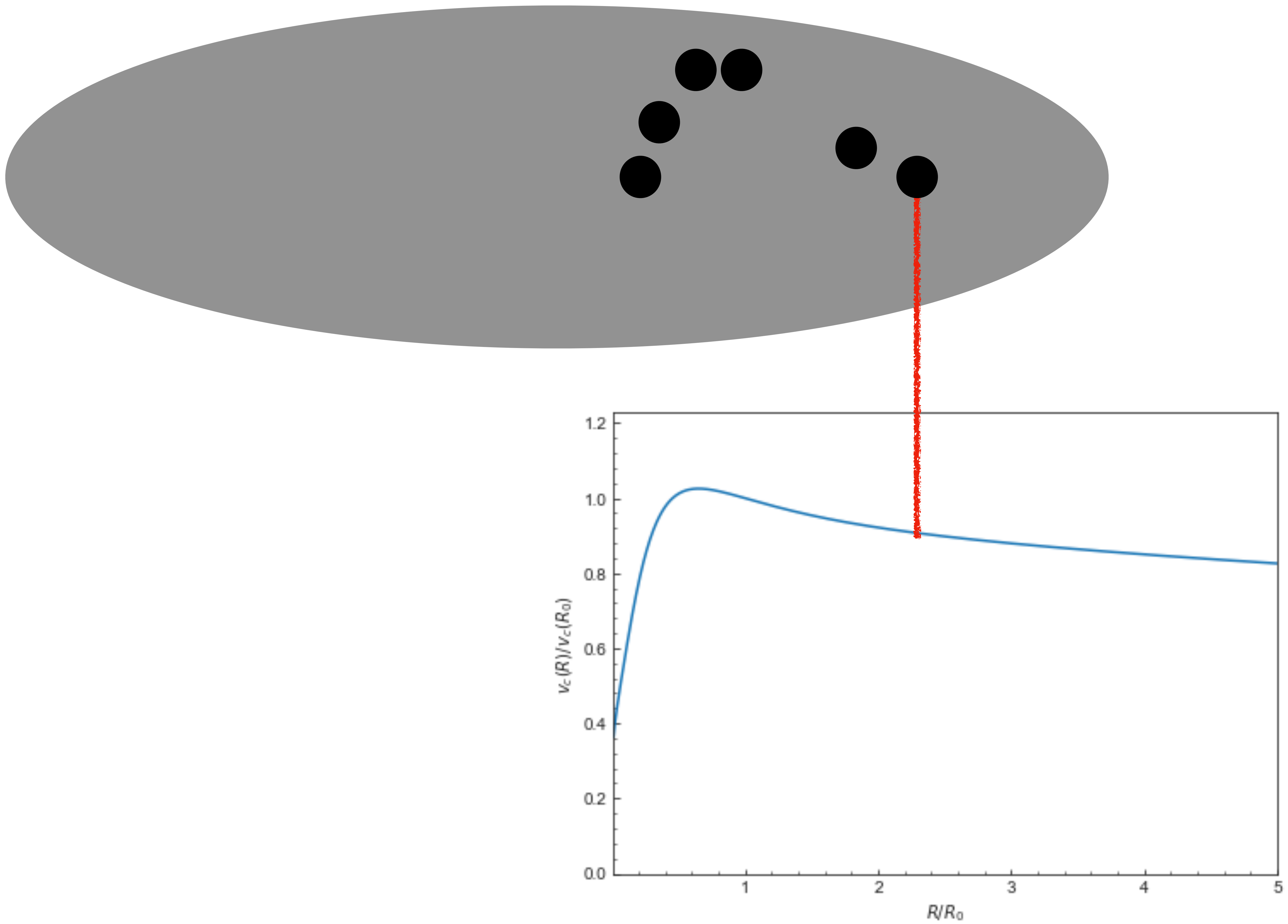

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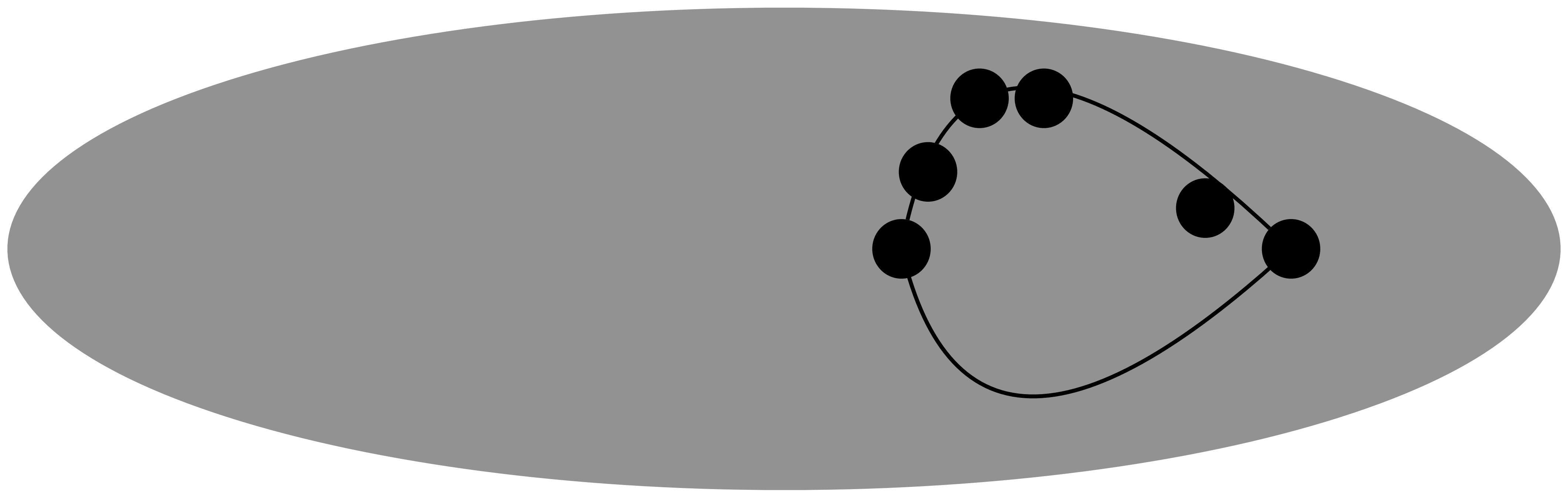

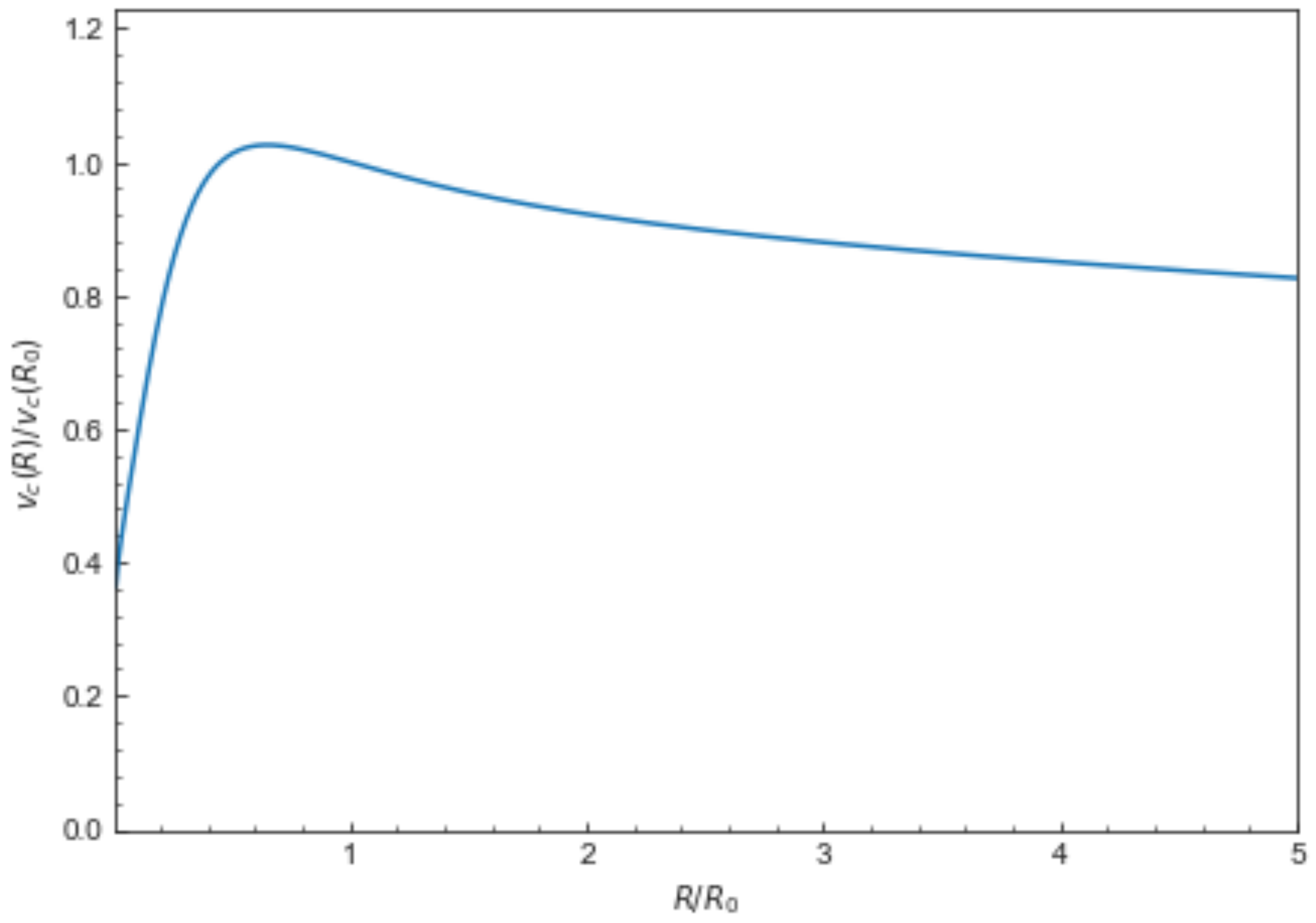

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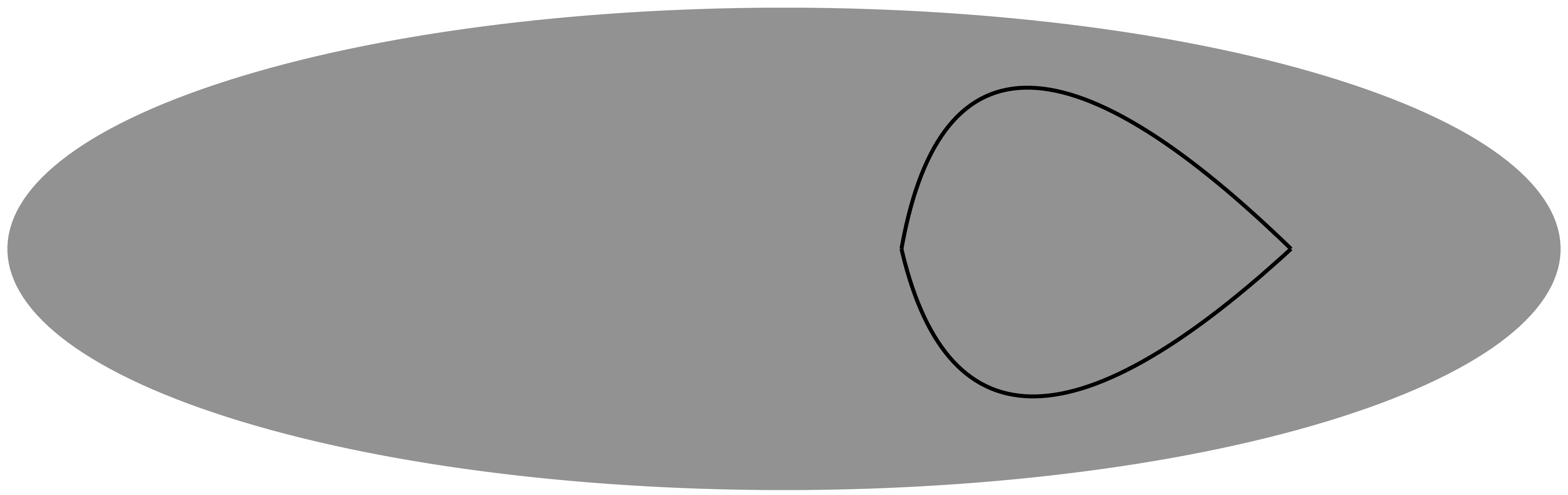

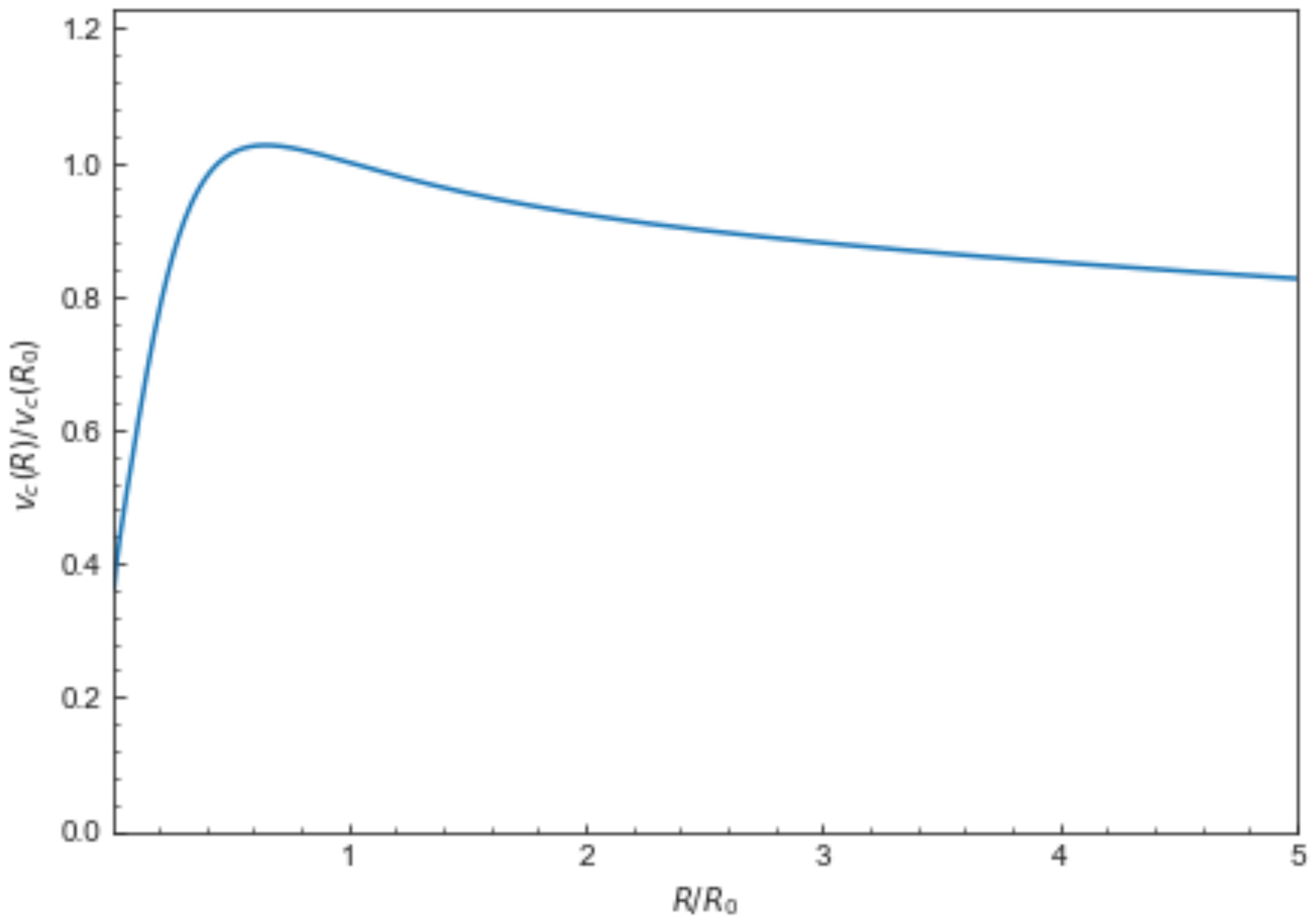

Disk-bulge decompositions

- Why can we treat the bulge and disk independently, do they not affect each other?
    - Yes, total circular velocity squared is sum of squared contributions from disk and bulge separately
    - But mass can be separated

Dark matter

- Why not low-luminosity object? Brown dwarfs etc.?
  - Could be! But expect those to be distributed similar to more luminous stars (that’s included in the M/L assumption) —> why would compact baryonic objects be floating in the halo?
  - Microlensing searches show that DM cannot be compact objects floating the halo
  - Big Bang nucleosynthesis depends strongly on total amount of baryons in the Universe —> 5%
  - CMB and structure formation would also be different (see later)
- Ways to constrain other DM interactions?
  - Gamma-ray searches of DM decay and annihilation
  - Dynamical effects of interactions in the dark sector
  - …