

Hidden properties of AGNs and ring galaxies

Elena Bannikova,

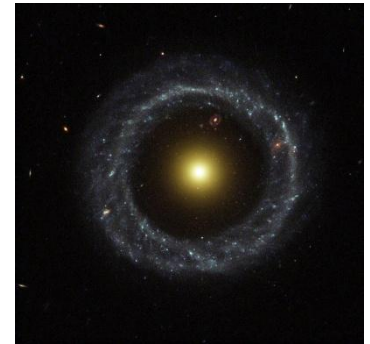
Alexey Sergeev, Nina Akerman

Institute of Radio Astronomy of National Academy of Science

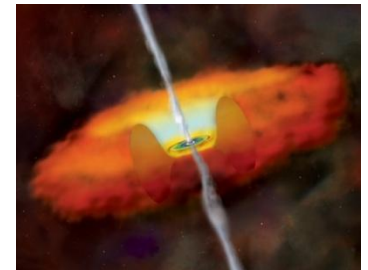
V.N.Kharazin Kharkov National University

Hidden properties of AGNs and ring galaxies

- Ring galaxies: observational proprieties
- Lagrangian circle
- The last stable circular orbit
- OSCO vs ISCO
- Region of unstable orbit
- _____



- AGNs 1,2: unified scheme
- What is it hidden in the center of AGNs ?
- IR band: what do we know from it ?
- ALMA observation
- N-body simulation of obscuring torus in AGNs



The structure and stability of orbits in Hoag-like ring systems

Elena Yu. Bannikova^{1,2}★

¹*Institute of Radio Astronomy of National Academy of Sciences of Ukraine, Mystetstv 4, UA-61022 Kharkiv, Ukraine*

²*V. N. Karazin Kharkiv National University, Svobody Sq. 4, UA-61022 Kharkiv, Ukraine*

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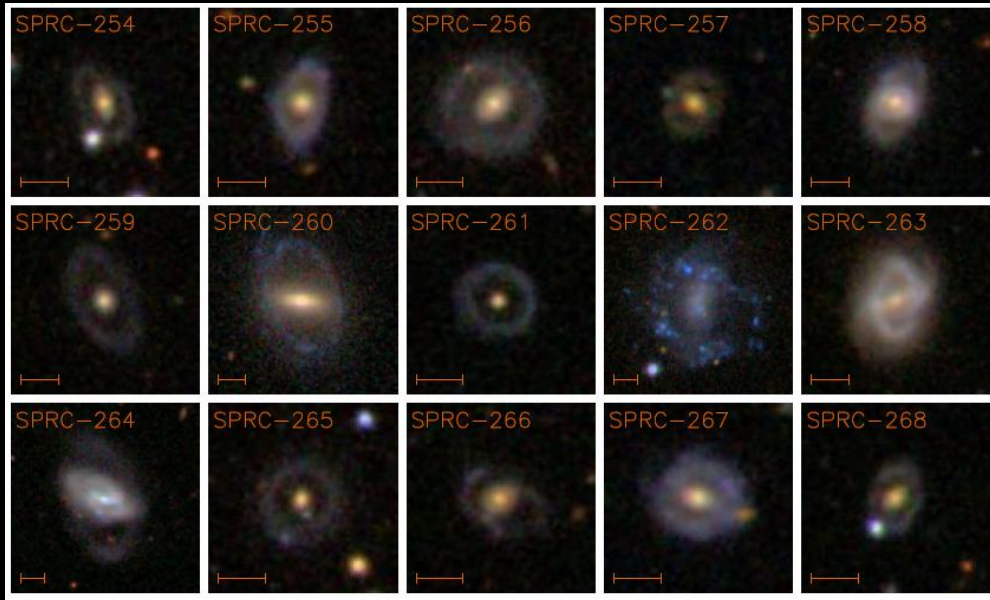
ABSTRACT

Ring galaxies are amazing objects exemplified by the famous case of Hoag’s Object. Here the mass of the central galaxy may be comparable to the mass of the ring, making it a difficult case to model mechanically. In a previous paper, it was shown that the outer potential of a torus (ring) can be represented with good accuracy by the potential of a massive circle with the same mass. This approach allows us to simplify the problem of the particle motion in the gravitational field of a torus associated with a central mass by replacing the torus with a massive circle. In such a system, there is a circle of unstable equilibrium that we call ‘Lagrangian circle’ (LC). Stable circular orbits exist only in some region limited by the last possible circular orbit related to the disappearance of the extrema of the effective potential. We call this orbit ‘the outermost stable circular orbit’ (OSCO) by analogy with the innermost stable circular orbit (ISCO) in the relativistic case of a black hole. Under these conditions, there is a region between OSCO and LC where the circular motion is not possible due to the competition between the gravitational forces by the central mass and the ring. As a result, a gap in the matter distribution can form in Hoag-like system with massive rings.

Key words: gravitation – galaxies: kinematics and dynamics.

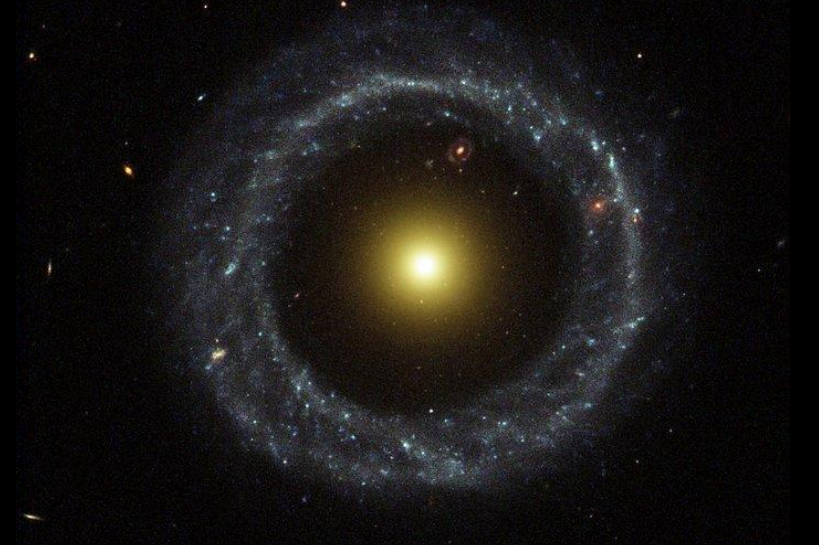
Hoag-like galaxies: observations

Moiseev et al., 2011

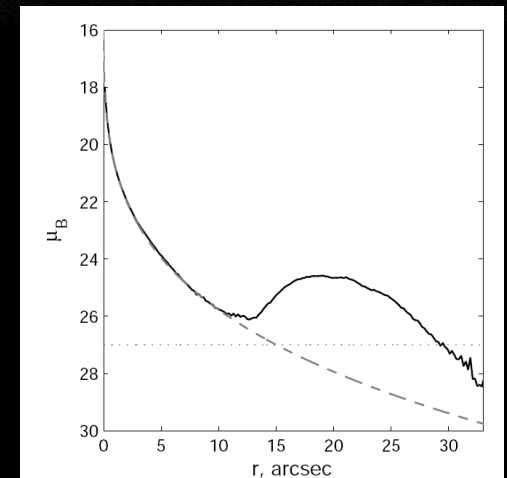


- Mass of the central galaxy is comparable with a mass of the ring

HST



Surface brightness profile



Finkelman, Moiseev, Brosch, Katkov, 2011

Gravitational potential of a torus/ring

- The outer potential of the homogeneous circular torus can be represented with a good accuracy by the potential of a massive circle (MC) (*Bannikova et al., MNRAS, 2011, 2012*).
- This is analogy with Newton result for a solid sphere.
- It means that we can replace the outer potential of the torus by the MC potential

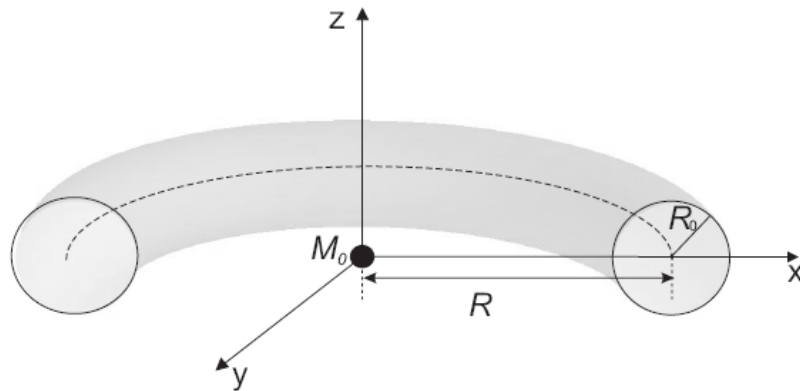
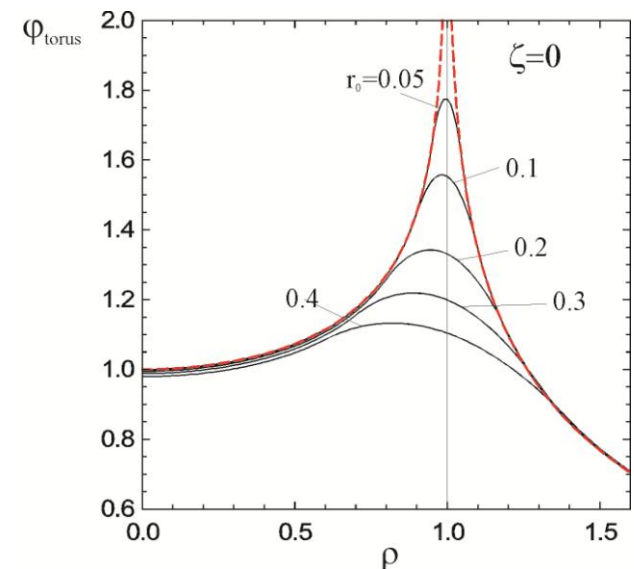


Figure 1. Scheme of a torus with a central mass. The massive circle (MC) is indicated by the dashed curve.

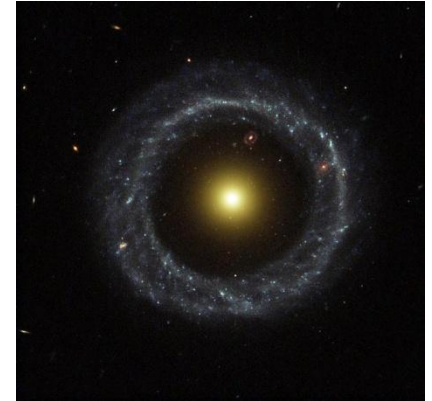


Lagrangian circle

Lagrangian circle (LC) is the geometrical locus where the balance of these forces is realized (by analogy with L1 in 3-body problem). LC is obviously a place of unstable equilibrium. Small perturbations determine the destiny of a particle, which will be captured either by the central mass or by the ring.

Equation for exact solution
of LC radius

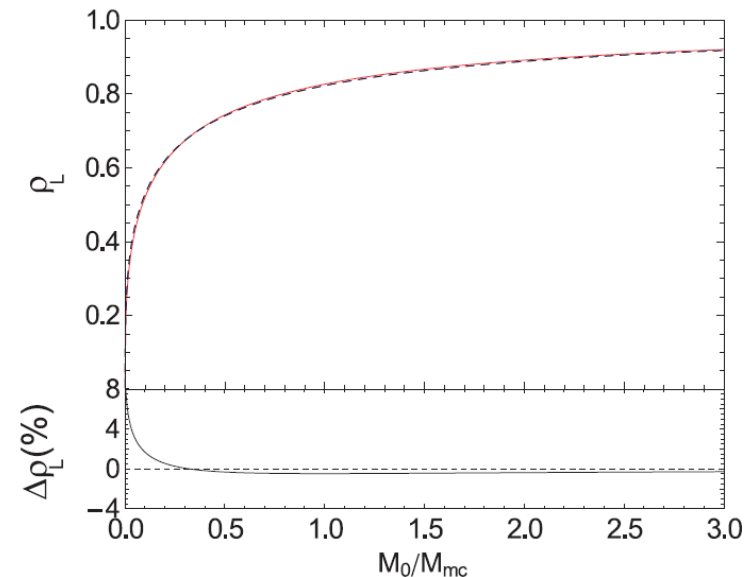
$$\frac{\rho_L}{1 - \rho_L^2} E(\rho_L) - \rho_L K(\rho_L) = q \frac{\pi}{2}$$



$K(\cdot)$, $E(\cdot)$ are the complete elliptical integrals

Equation for approximate solution
of LC radius

$$\rho_L^3 - q\pi(1 - \rho_L) = 0.$$



The last stable circular orbit

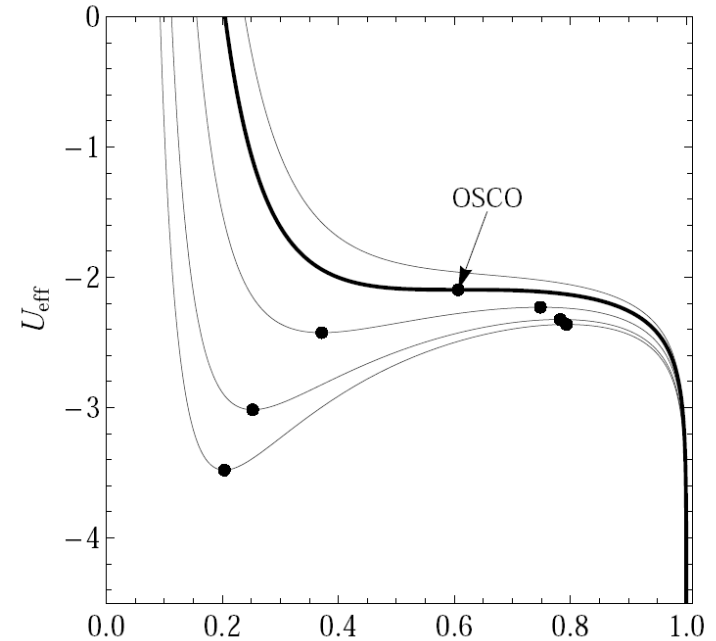
Effective potential

$$U_{eff} = U_0 + U_{mc} + \frac{I^2}{2R^2 \rho^2},$$

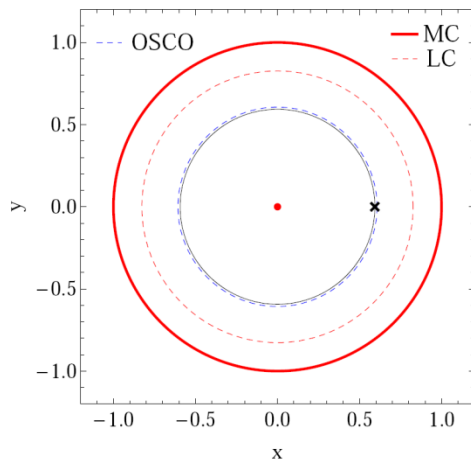
Equation for the last stable circular orbit (OSCO)

$$3\rho_{osco}^4 - 4\rho_{osco}^3 + \pi q(1 - \rho_{osco})^2 = 0$$

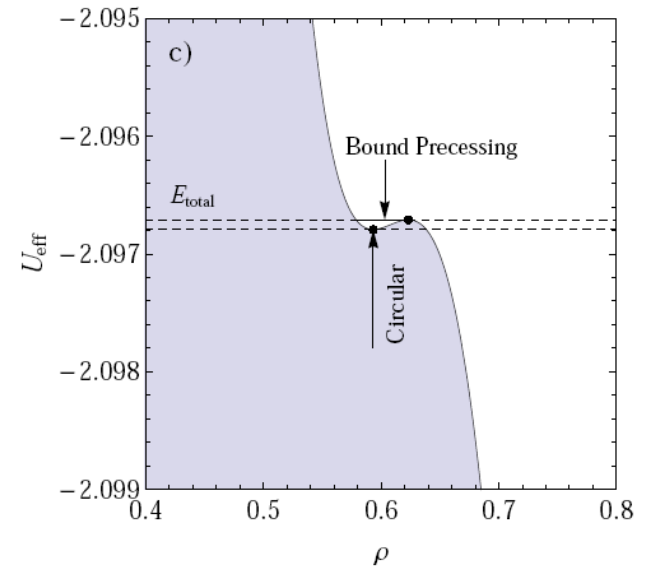
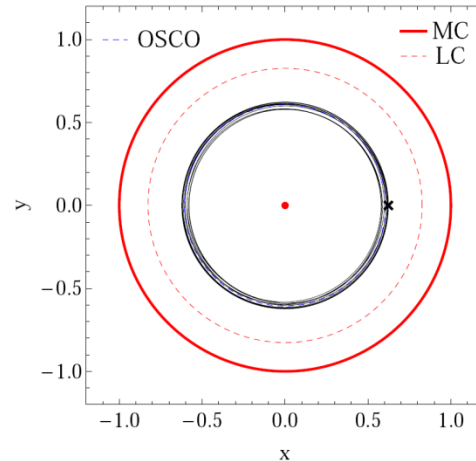
The example of the orbits next to the radius of OSCO



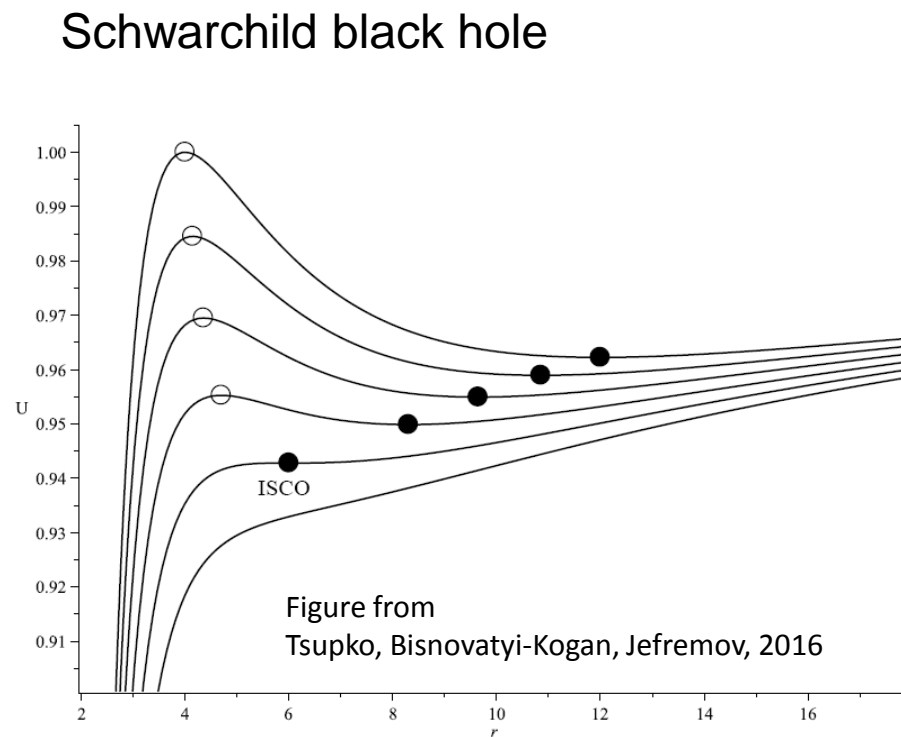
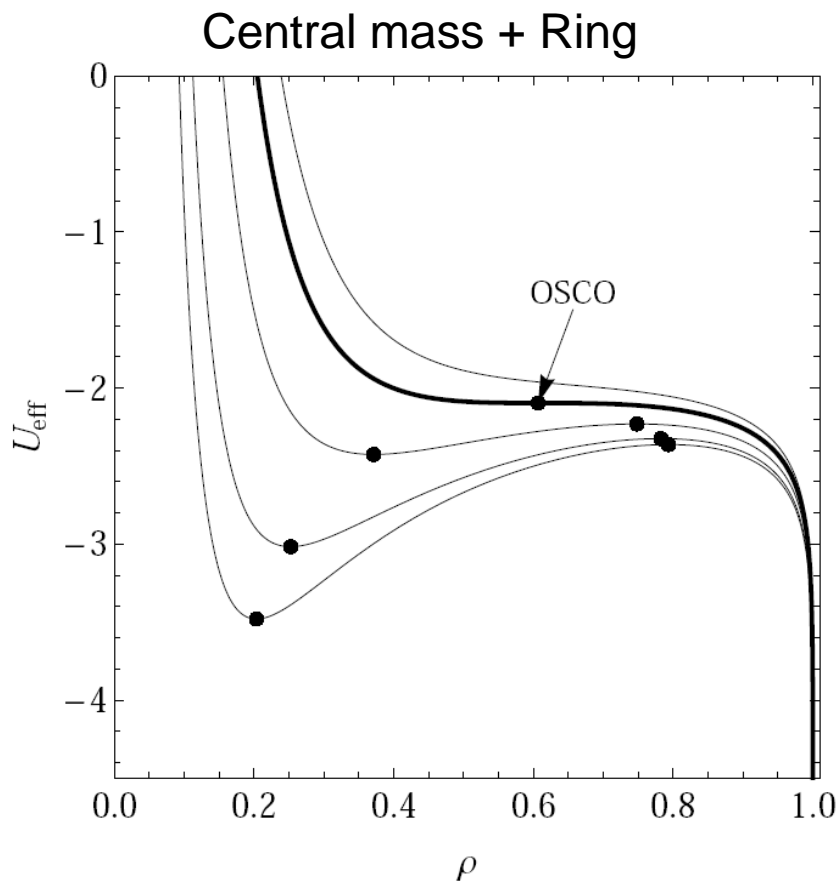
Close orbit



Open orbit



The last stable circular orbit OSCO vs ISCO



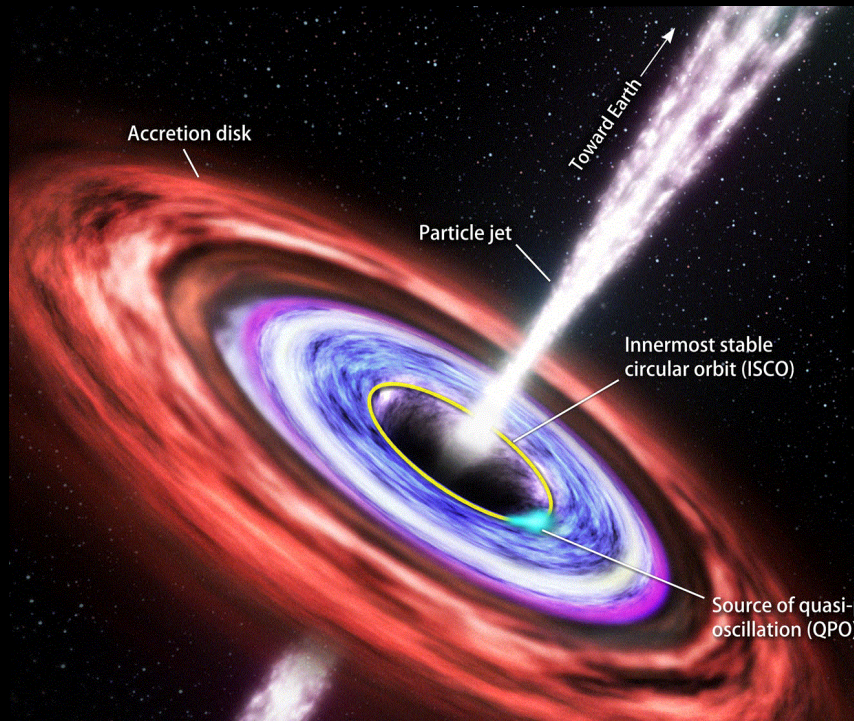
In the considered potential here the situation is opposite to the relativistic case: the stable circular orbits are located inside of the last stable circular orbit. By analogy with relativistic case, we will call this orbit "the outermost stable circular orbit" (OSCO).

Dynamics in Hoag-like ring galaxies

Black Hole

ISCO

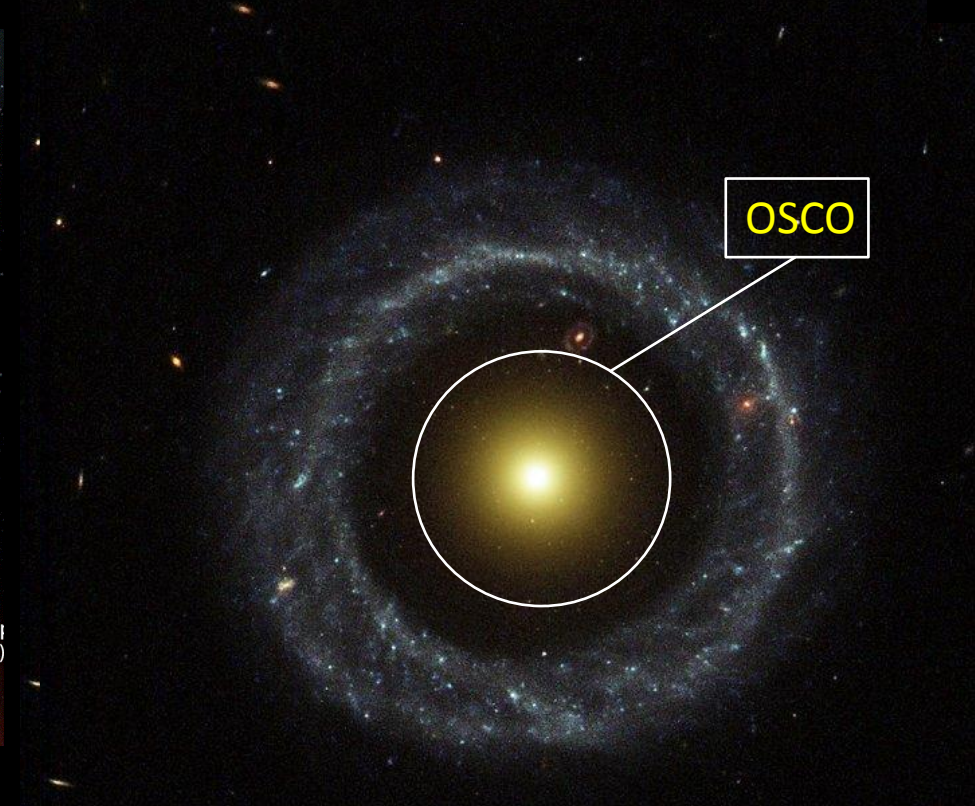
the INNERMOST stable circular orbit



Hoag's Object

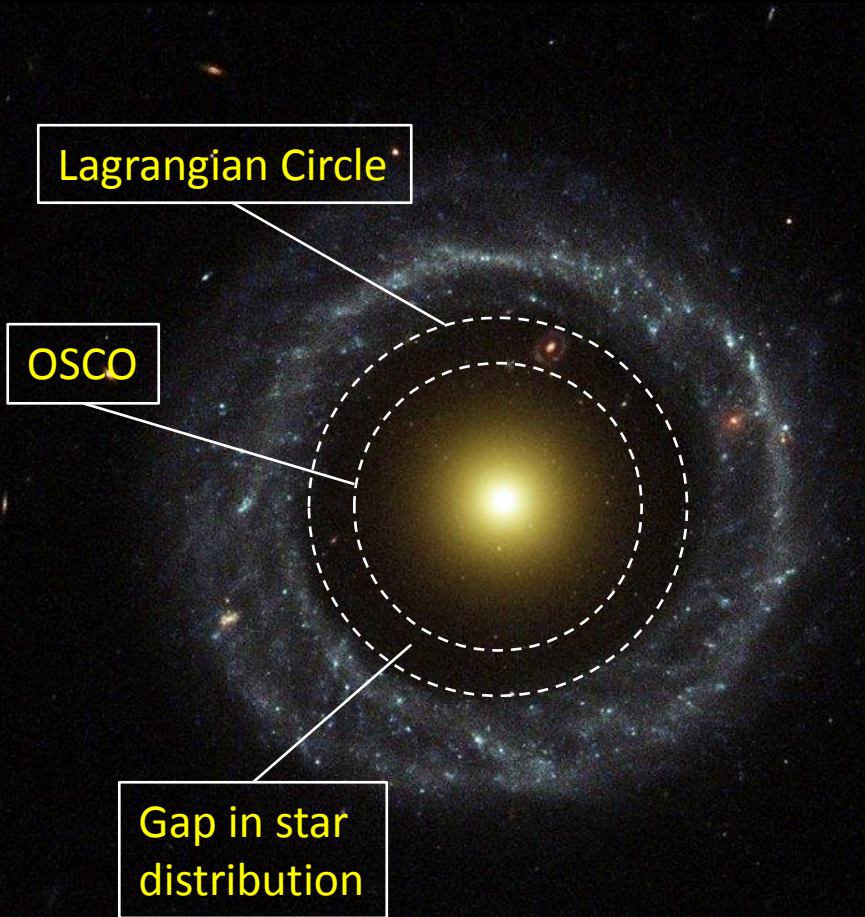
OSCO

the OUTERMOST stable circular orbit



The OSCO can be a useful tool for investigating Hoag-like galaxies as well as ISCO is used in order to model black holes via the surrounding accretion disc.

Dynamics in Hoag-like ring galaxies

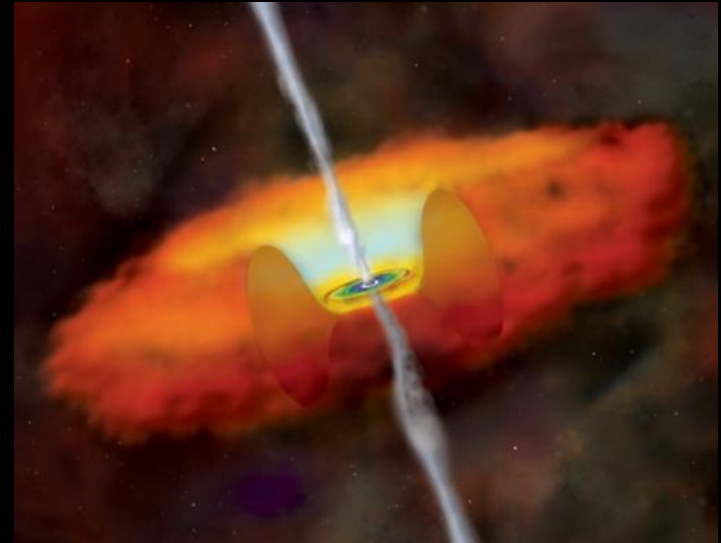


- *Lagrangian Circle (LC)* is a circle where the forces by the massive ring and the central core balance each other.
- The stable circular motion is possible only inside this last stable circular orbit, which we call "*the outermost stable circular orbit*" (*OSCO*) in analogy with a relativistic case.
- Region of unstable orbits can lead to the formation of *a stellar matter gap* in Hoag-like ring systems.
- The width of the region of unstable orbits is about 3kpc for Hoag Object.

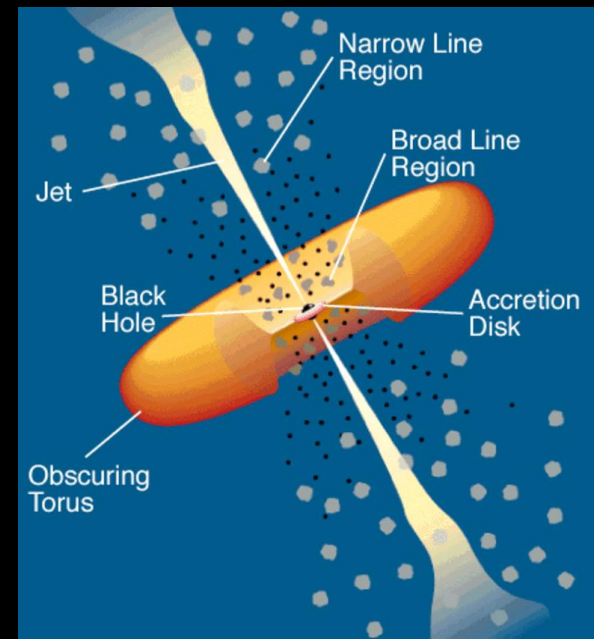
Dusty torus in AGNs: unified scheme

- The observational properties of AGNs are explained by the different orientation of the torus relative to an observer

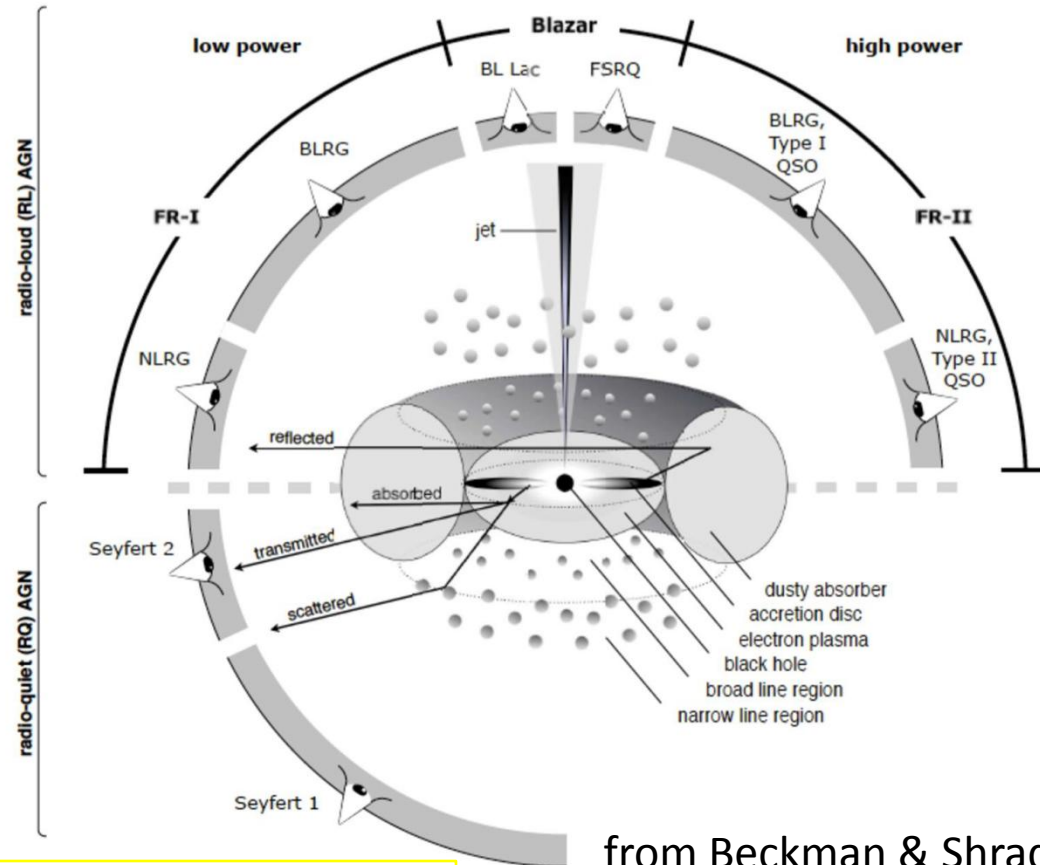
Antonucci & Miller 1985,
Antonucci 1993



- AGNs II – torus is seen from edge-on, accretion disk and BLR is obscured by dust
- AGNs I – the accretion disk and BLR are seen



Unified Scheme for low / high power AGNs



from Beckman & Shrader et al. (2012)

Main properties of a torus

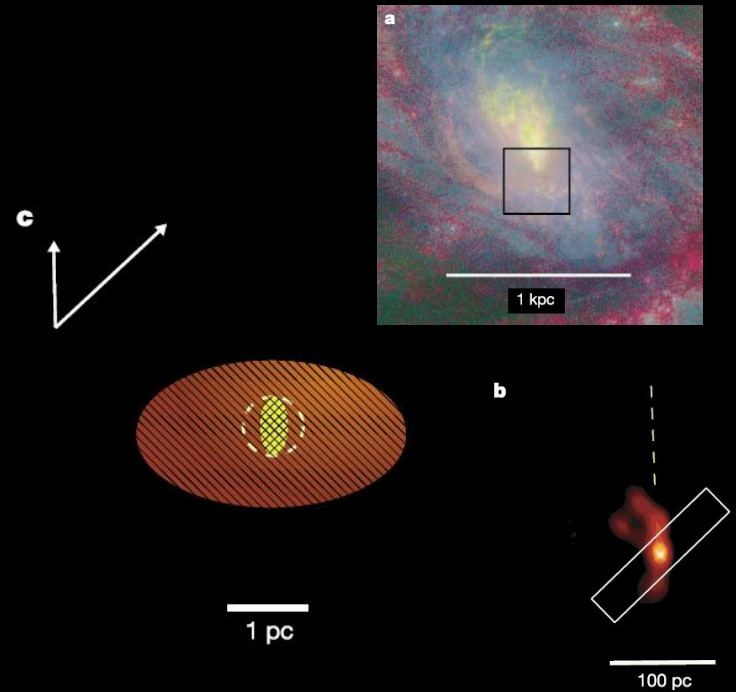
- Geometrically thick → Doughnuts shape
- Homogeneous or clumpy ?
- Scale of the torus ?

IR observation of a dusty torus in NGC1068 (Sy2)

- The first direct resolution of torus
Jaffe et al. 2004
- VLT/MIDI: 10 mas ($\lambda \approx 10 \mu\text{m}$)
- Thermal emission of dust
- Hot component $T=800\text{K}$
- Warm component $T=300\text{K}$

Main properties of a torus

- Geometrically thick
- Clumpy structure
- pc-scale



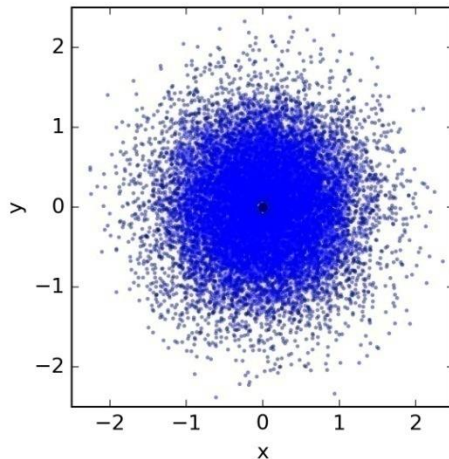
Dynamical model of active galactic nucleus (AGN)

- N-body simulation of clouds moving in grav field of the SMBH

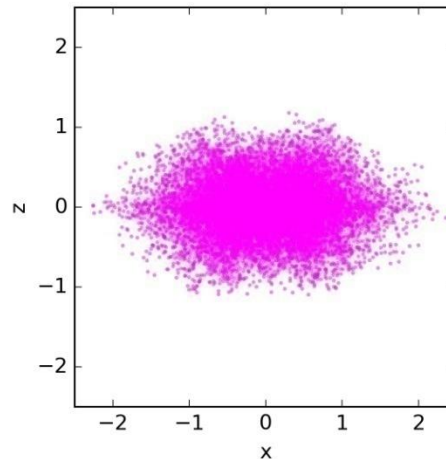
Initial state

Random distribution of clouds by orbital elements with two cones without clouds which simulate the winds/outflows in AGNs

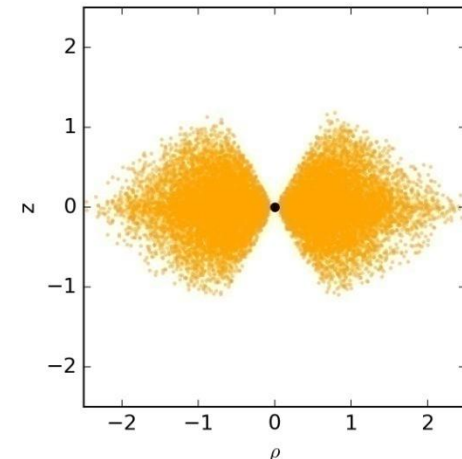
Equatorial plane



Edge-on



All clouds are gathered in one plane



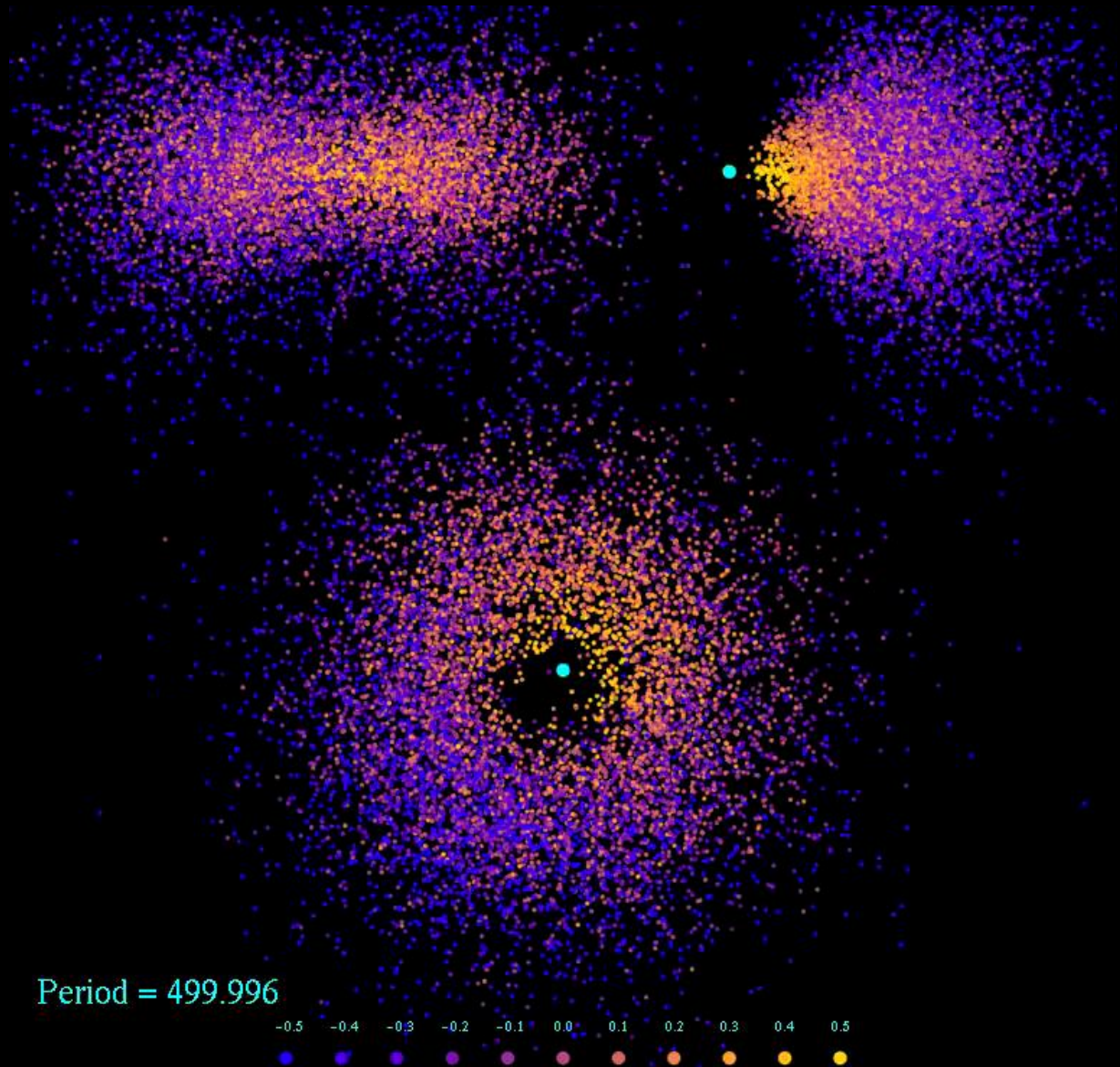
Dynamical model of active galactic nucleus (AGN)

For example:

$$N_{\text{clouds}} = 10^4$$

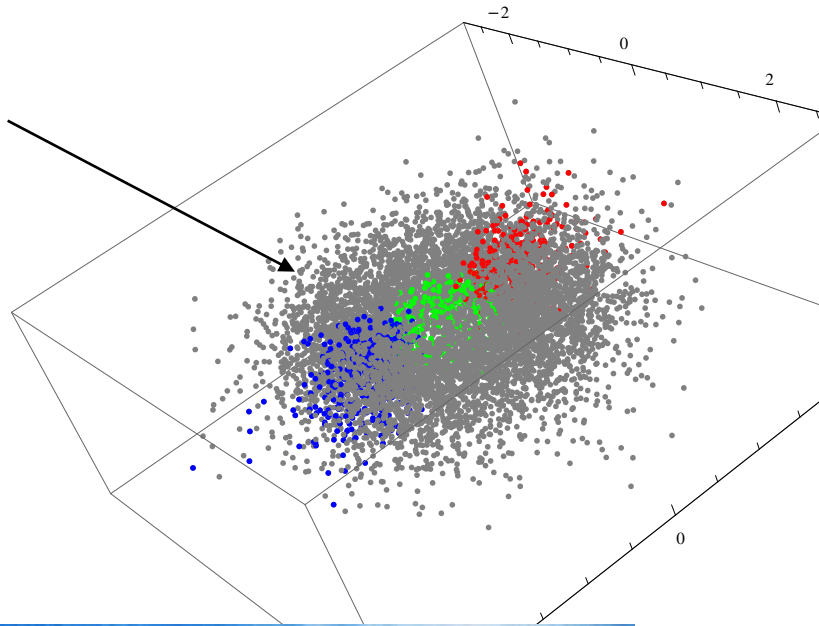
$$M_{\text{torus}} = 0.01 M_{\text{SMBH}}$$

- Such distribution of clouds provides the obscuration conditions in AGNs
- Explanation of non-Keplerian rotation and observational velocity dispersion in the obscuring tori of Sy 2 galaxies

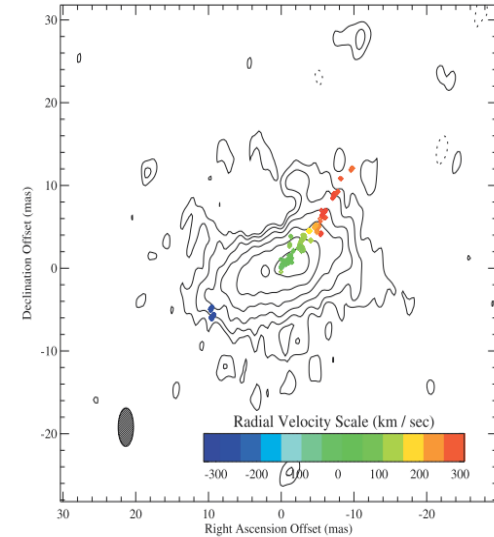


Maser emission in NGC1068

IR



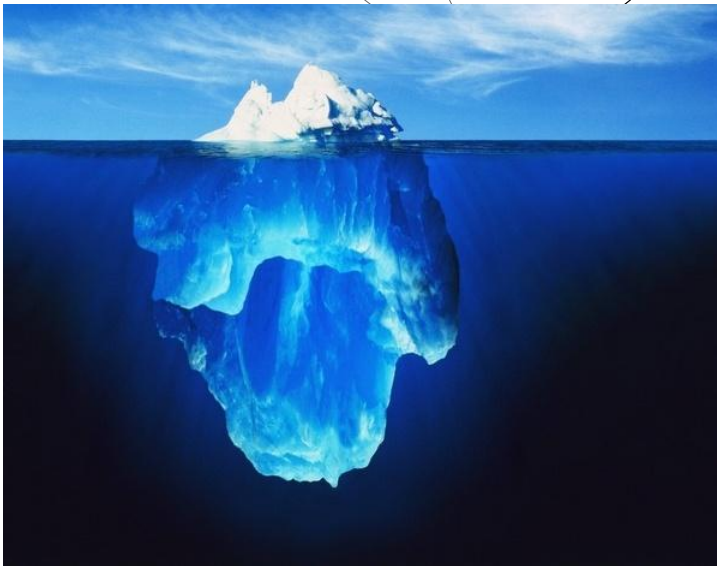
MERLIN 5GHz,
Gallimore, 2004



1. Torus is inclined by some angle relative to line of sight => IR emission from the hot region of the torus

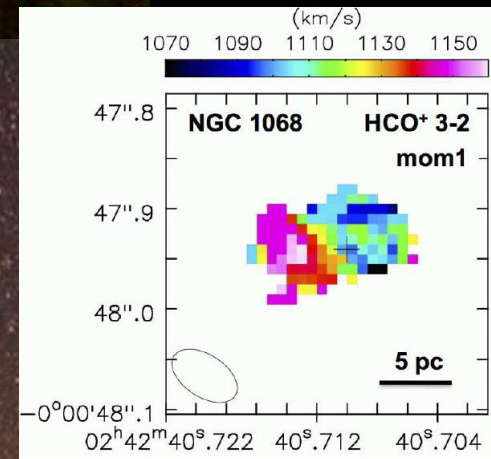
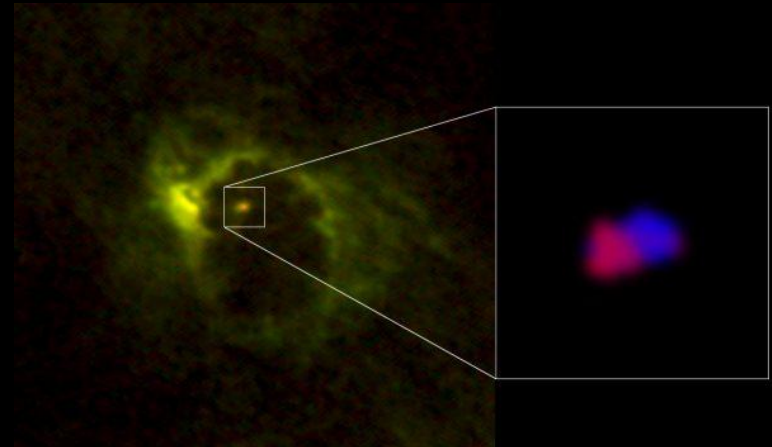
2. Masers trace some narrow region where V is parallel to the line of sight and the pumping conditions exist (interaction with wind) =>

The maser spots distribute in one line and looks like disk.

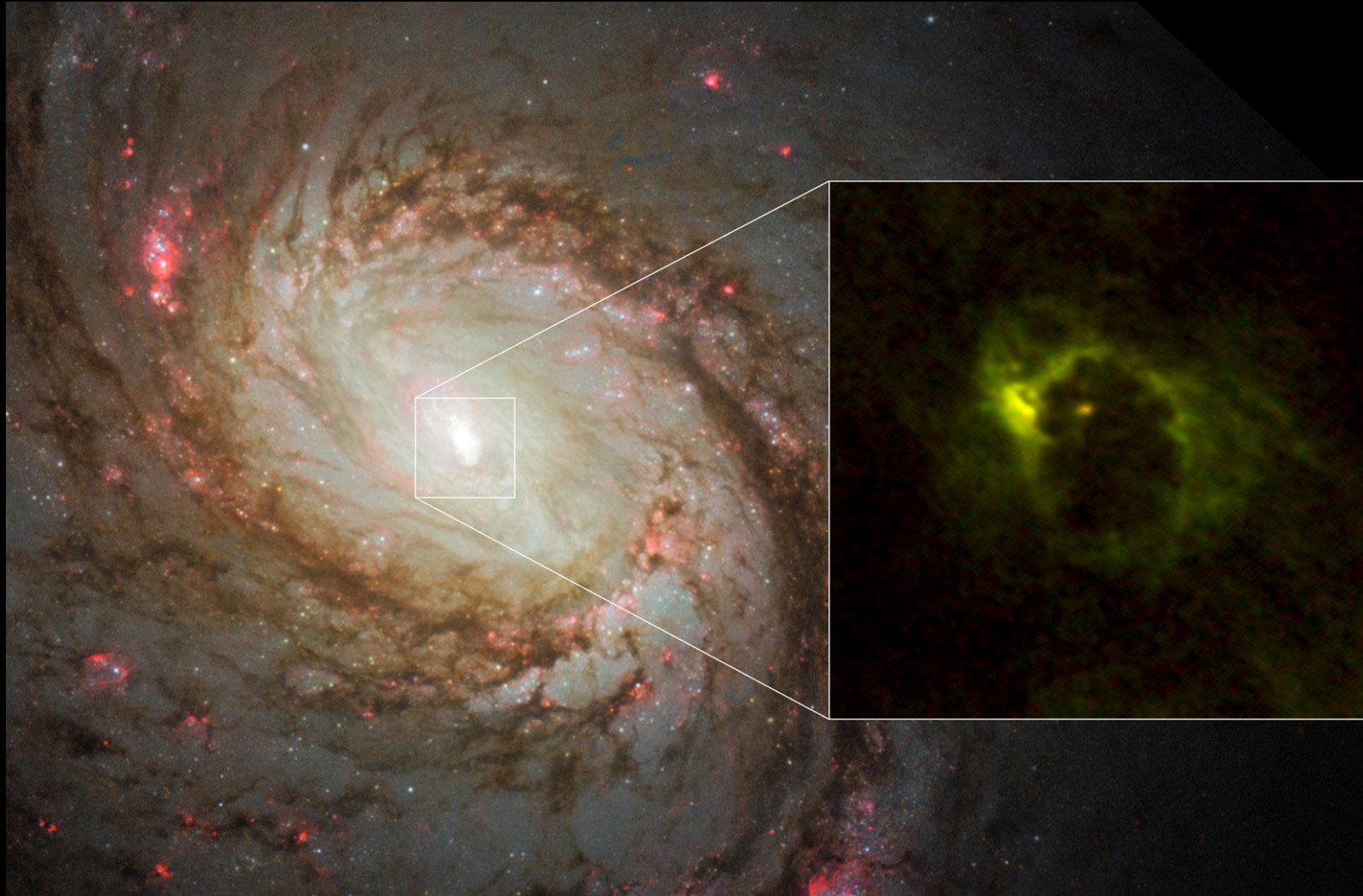


ALMA observations of a torus in NGC1068

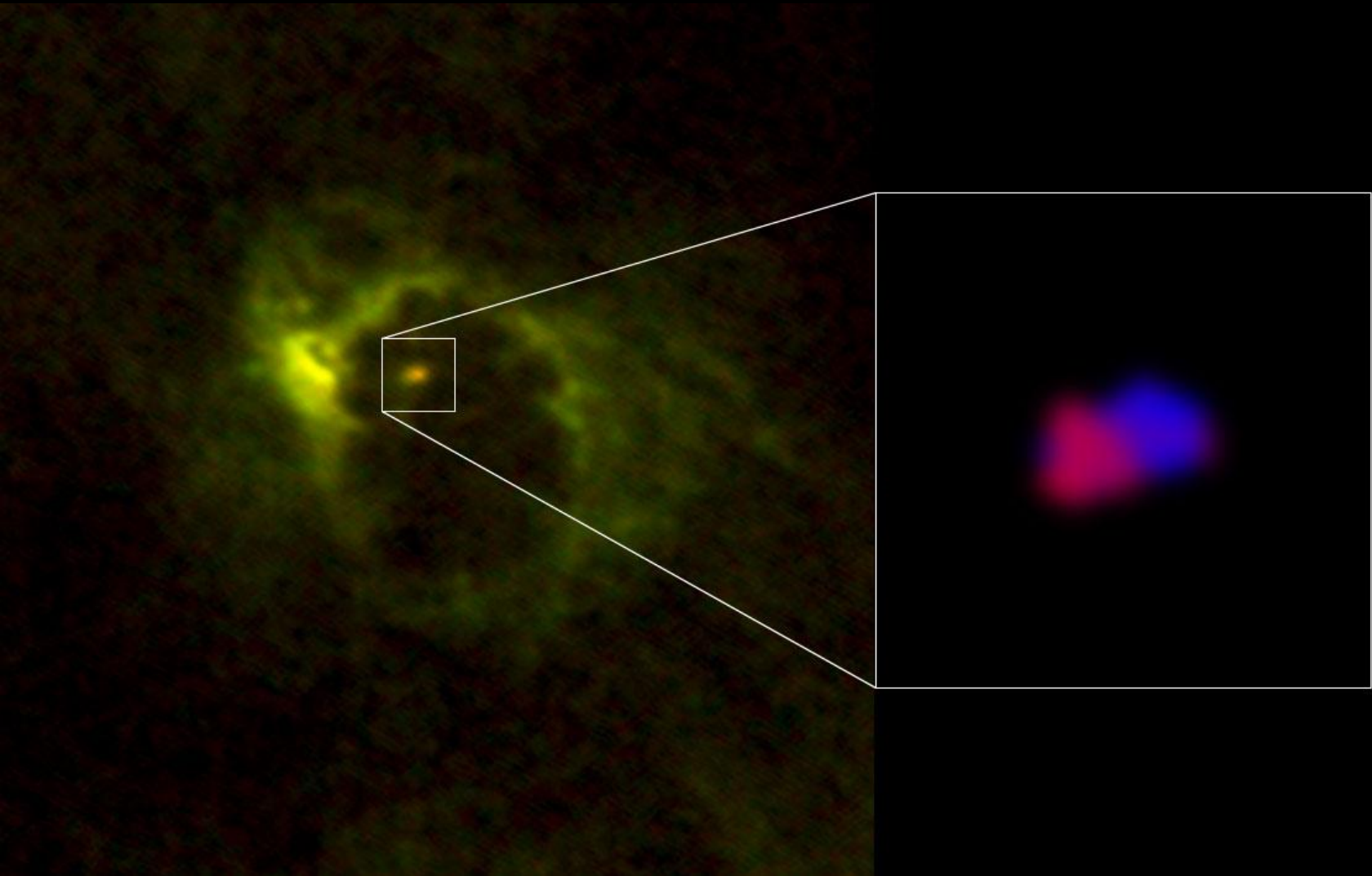
- January 2018
- Resolution is 40 mas
- ✓ The motion in the torus is far from Keplerian.
- ✓ The mass inside the rotating molecular disk is about $10^6 M_{\odot}$, which is much lower than the early estimated SMBH mass (by rotation curves).



ALMA observations: torus in NGC1068

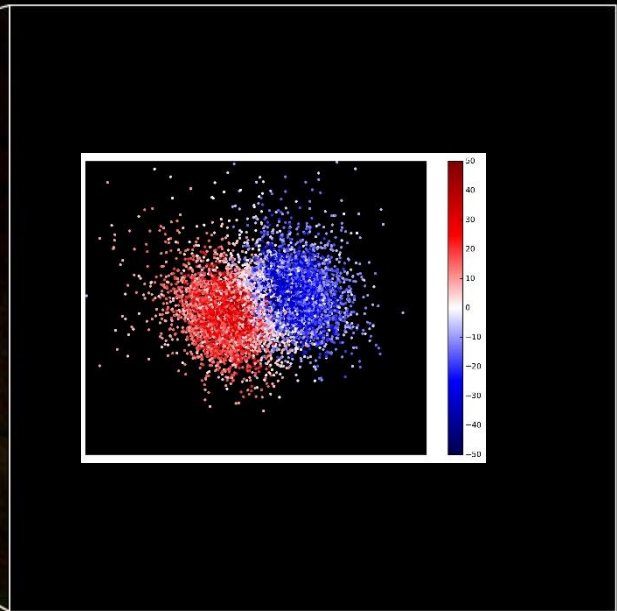
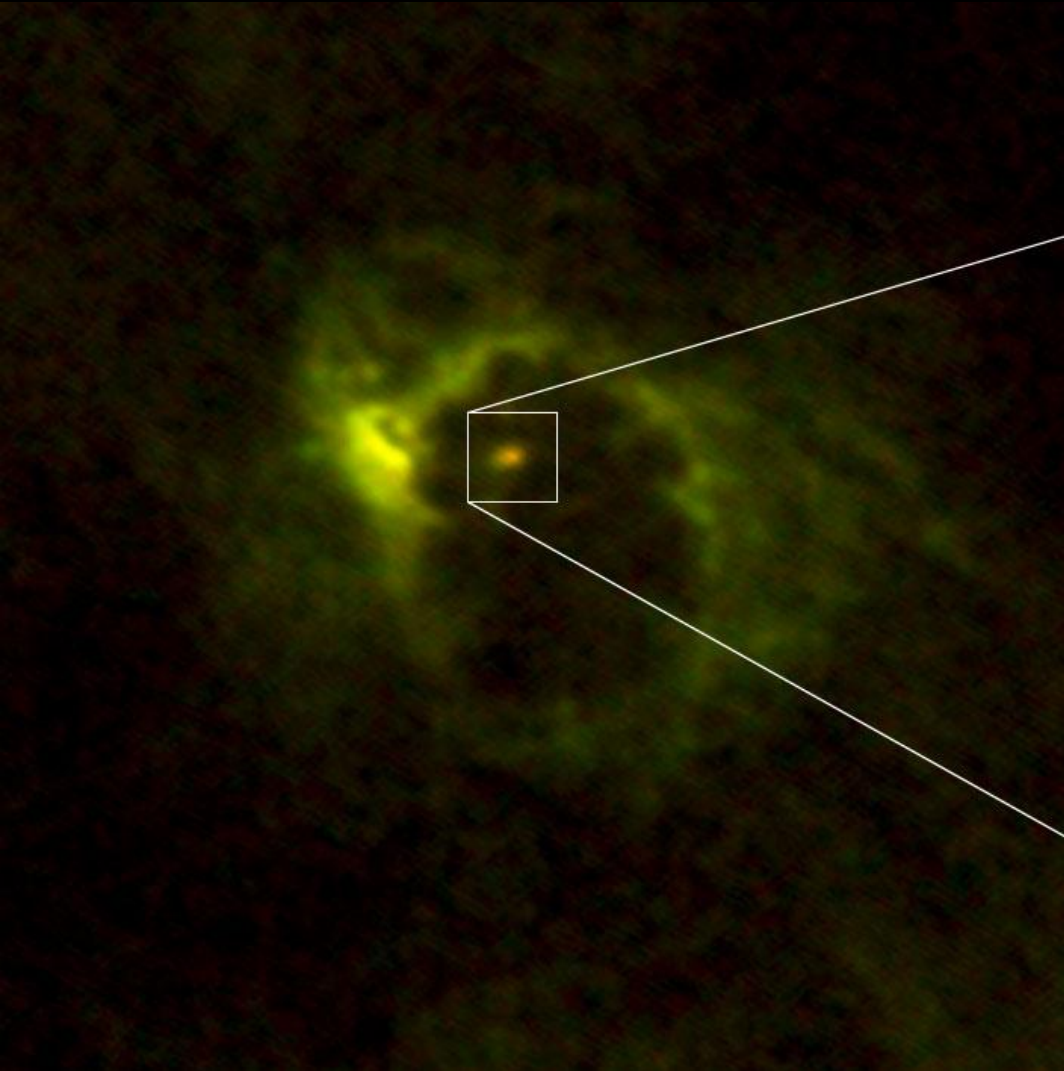


ALMA observations: torus in NGC1068



ALMA observations: torus in NGC1068

N-body simulation of clumpy torus



Grazie mille !

