Zifan Tang
Email: zifan@ucsb.edu
PHYS137 - Planets and Exoplanets
Instructor: Prof. Ben Mazin

Astrobite paper
ID: X312826
Term: Winter 2024
March 21, 2024

A new class of objects – blanet

Title: Formation of "Blanets" from Dust Grains around the Supermassive Black Holes in Galaxies
Authors: Keiichi Wada, Yusuke Tsukamoto, and Eiichiro Kokubo
First Author's institution: Kagoshima University, Kagoshima, Japan
Status: Published on 2021 March 9 on ApJ

What is a blanet?

It is a kind of possible planet that is formed around the black hole. A **bla**ck-hole-hosting pl**anet** is named *blanet* by the authors. They propose the model of the formation of the blanet in this article. Evidence shows that there are Supermassive Black Holes(SMBHs) in the center of Active Galactic Nucleus(AGNs). Gas disks around SMBHs are very similar to the protoplanet disk. The latter one is believed to conceive planets. The reason why we haven't found a blanet may be because the black hole is silent in most of the bands. Therefore, it is hard to use traditional methods like transit or radial velocity.

Background

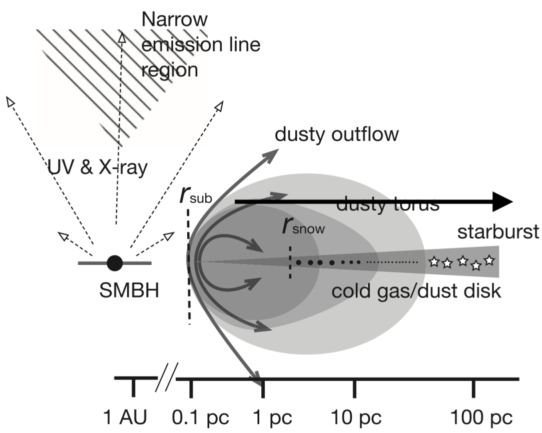

Figure 1: Schematic picture of the active galactic nucleus (AGN) and the circumnuclear disk. A supermassive black hole is surrounded by an accretion disk. In the midplane of the torus, cold, dense gas forms a thin disk, where icy dust particles can present beyond the snow line. The dust aggregates evolve by collisions to form planetesimals, and eventually "circum-black-hole planets" by the gravitational instability of the aggregate disk.

The schematic picture of AGN and its circumnuclear disk is shown in Figure 1. (See in Izumi *et al.* 2018. A SMBH ($M_{\rm BH} = 10^6 - 10^9 M_\odot$) is surrounded by an accretion disk, which radiates enormous energy. In the midplane of the torus, cold, dense gas forms a thin disk, where icy dust particles can present beyond the snowline. The dust aggregates evolve by collisions to form planetesimals and eventually form "circum-black-hole planets" by the gravitational instability of the aggregate disk.

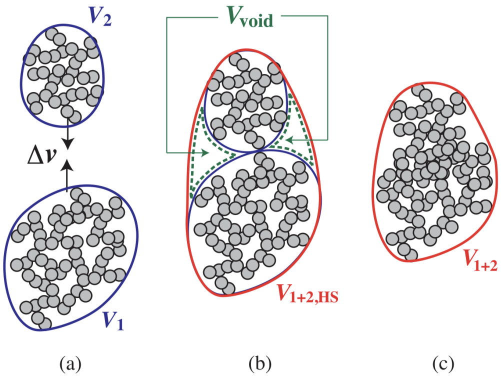

Figure 2: Schematic illustration of our porosity change model. Porous aggregates with two masses (a) before contact, and (b)(c) just after contact. (b) If the collision energy is much smaller than the rolling energy, the final density of the new aggregate is smaller. (c) If not, collisional compression occurs.

The formation process of Blanets

The model for the growth of dust particles here is based on the elementary processes found around stars. The dust grain in the disk of SMBH will go through three stages. I will leave most of the mathematical formulae out and concentrate on the physical picture.

Hit-and-stick Stage The author assumes that the dust aggregates grow through ballistic cluster-cluster aggregation (BCCA). This is a widely accepted collision theory. The process is shown in Figure 2(b) from Satoshi *et al.*, 2012. If two aggregates have a collision energy E_{imp} (proportional to the multipication of the mass and the relative velocity), is much smaller than the rolling energy E_{roll} (the energy needed for one monomer to roll over 90° on the surface of another monomer in contact), then the two clusters simply stick together and become a fluffy, bigger aggregate. This makes the aggregates slow down. Their density also decreases because this type of "stick" is not so secure. But the mass and the size increase.

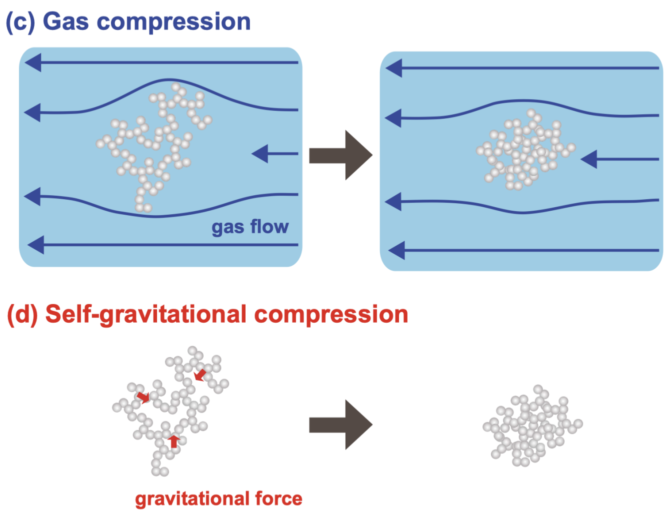

Figure 3: Schematic drawing to illustrate dust growth via fluffy aggregates. c) Dust aggregates have a velocity difference against gas, and they feel the ram pressure by the gas. The ram pressure statically compresses the dust aggregates. d) When the dust aggregates become so massive that they do not support their structure, they are compressed by their own self-gravity.

Compression Stage When the stick continues and E_{imp} increases gradually, it is comparable to the E_{roll}. Compressions and reconstructions happen to the clusters. (See in Figure 2(c)). At this stage, the density bounces back, and the mass and radii are still growing. Moreover, the fluffy dust aggregates can

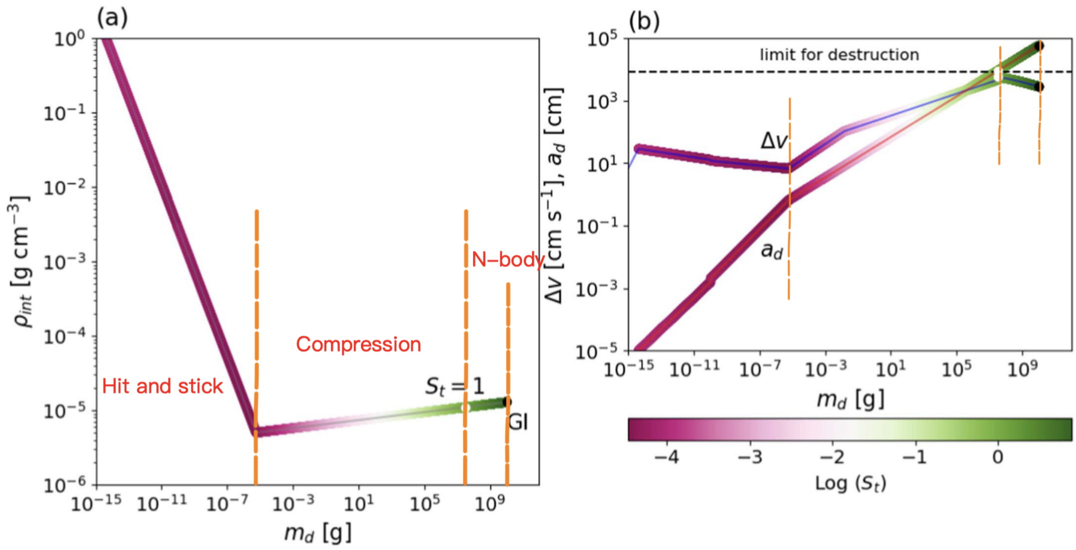

Figure 4: (a) Evolution of the internal density of a dust aggregate at the snowline as a function of the aggregate mass. (b) Same as (a), but for collision velocity of the aggregates and size of the aggregate.

be compressed owing to the ram pressure of the ambient gas. This mechanism is shown in Figure 3(c).

N-body Stage As the aggregates become more massive, the aggregates have a large *Stokes number*. Roughly speaking, a particle with a large Stokes number is dominated by its inertia, not the flow of the gas. In this research, when $S_t \gtrsim 1$, kinematics of the aggregates is affected by mutual interaction between the aggregates as an *N-body system*. Then the collision velocity between the aggregates is determined by a balance between various heating and cooling processes as the N-body particles (See in Michikoshi & Kokubo (2016).

The increase of the mass also brings the compression owing to their self-gravity(See Figure 3(d)). This is a very similar process to the normal planet formation. The author uses Toomre's Q parameter to investigate the gravitational instability (GI) of the disk consisting of dust aggregates, Q_d. For the non-axisymmetric mode, the aggregates can develop for $Q_d < 2$. This leads to the formation of massive objects, i.e., blanets.

Result and discussion

Evolution phase diagram

After numerical solving some relevant equations, the author get the evolution phase diagram, which is shown in Figure 4. Starting from the leftmost, the aggregates evolve along the line. As we predicted above, the dust grains first pass through the Hit and Stick stage to get enough m_d , accompanied by losing Δv and $\rho_{\rm int}$. Secondly, the aggregates are compressed and accelerated until they reach $S \gtrsim 1$. Then they are treated as N-body problems. After $S_t = 1$ is attained, Δv drops and the disk of the *blanetesimal* becomes gravitationally unstable. Some of them may form the blanet or be destroyed by mutual collisions.

The dashed line shows $\Delta v = 80$m/s , which is the limit for the collisional destruction of the aggregates suggested by numerical experiments (Wada *et al.* 2009).

Dependence on α and $M_{\rm BH}$

The author analyses the evolution dependence on the viscosity parameter and the mass of the host black-hole. In Figure 5(a), they plot $\Delta v_{\rm max}$ and $t_{\rm GI}$ as a function of α for $M_{\rm BH} = 10^6 M_\odot$ and $10^7 M_\odot$. The final speed Δv in different $M_{\rm BH}$ is almost overlapped, which means Δv only depends on α and not

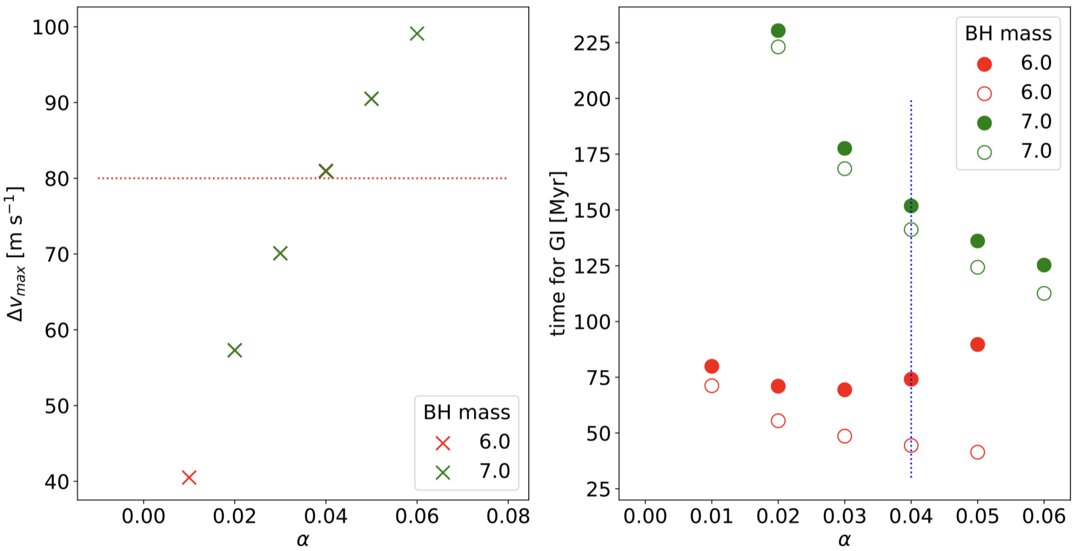

Figure 5: (a) velocity as a function of α. Red and green crosses are different $M_{\rm BH}$, The dotted line is the velocity limit for collisional destruction. (b) Time for the gravitational instability (GI) as a function of α. The filled circles are the time for GI and the open circles are the time for $S_t = 1.\alpha = 0.04$ is shown by the blue dotted line.

on $M_{\rm BH}$. The behavior of the dust growth (e.g., Figure 4) does not significantly depend on α and $M_{\rm BH}$, but the timescale to reach $S_t = 1$ is different as shown in Figure 5(b). The more the mass of the BH is, the quicker they grow up. This implies that **smaller BHs may preferentially host blanets within a lifetime AGNs**($\sim 10^8$yr).

Other distinguishable characters

1. Blanet is very close to each other ($\sim 10^{-3}$pc). Therefore, the system of blanets does not resemble any known exoplanet systems, in the sense that the "planets" are isolated, dominant objects in their orbits.
2. Observing planets around SMBHs should be challenging. Photometry by a hard X-ray interferometer in space might be a possible solution, but the occultation of the accretion disk by the blanets would be hard to distinguish from the intrinsic time variability of AGNs.
3. The blanet is just a new proposed celestial body that is untestified its exsitence. Up to now, there are only three publised papers related to the blanet. A successive research about the blanet is conducted by Giang *et al.*, 2022.