Circumbinary accretion disks

Simulation results and Applications

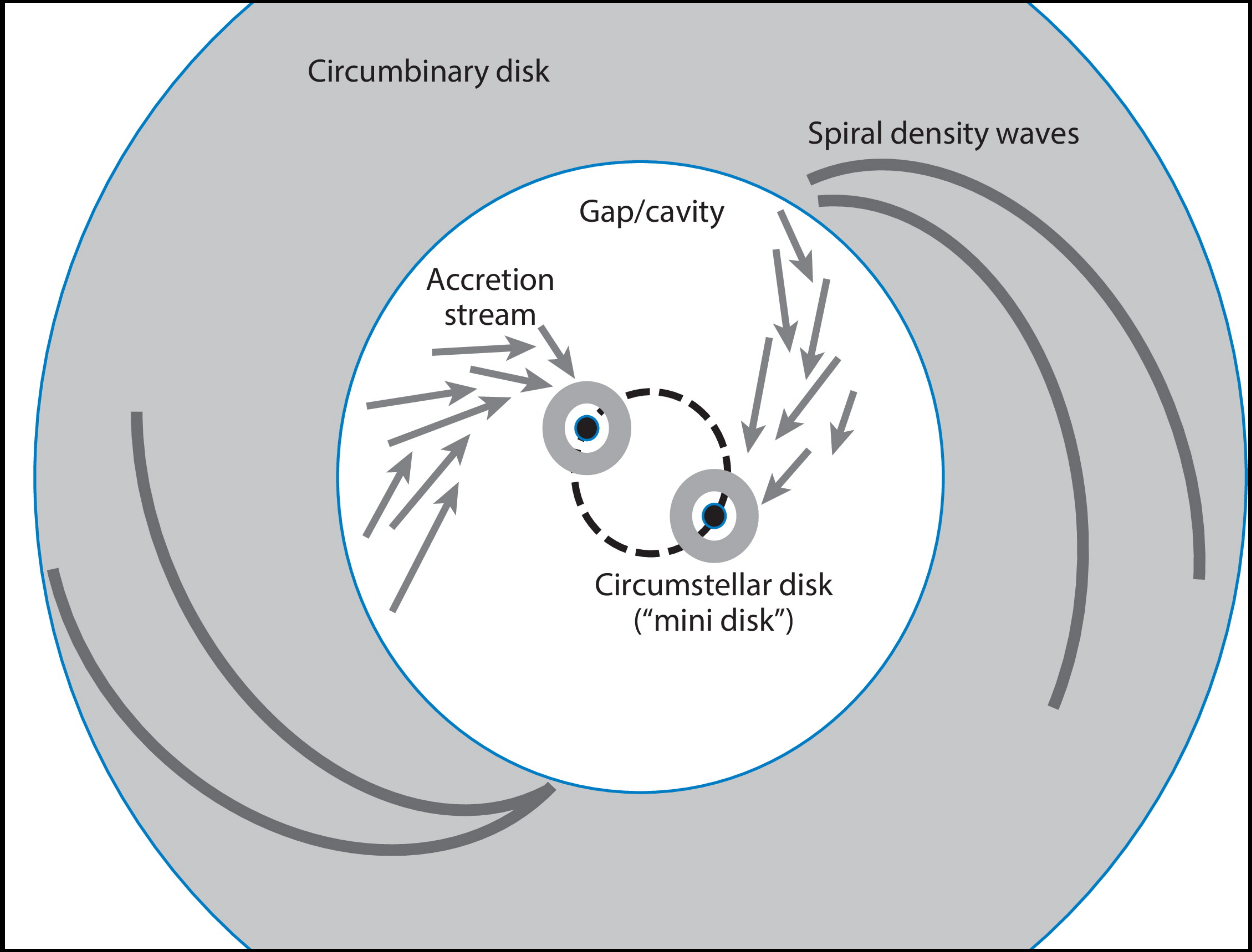
Ruiqi Yang
2023.11

Content

- 1. Introduction
- 2. Basic concepts and overview
- 3. Key results of simulations
    - Short-term variabilities
    - Long-term variabilities
    - Final Parsec problem
    - Angular momentum transfer
- 4. Applications
- 5. Misaligned disks
- 6. Binary embedded in “big” disks
- 7. Summary
- 8. Prospects

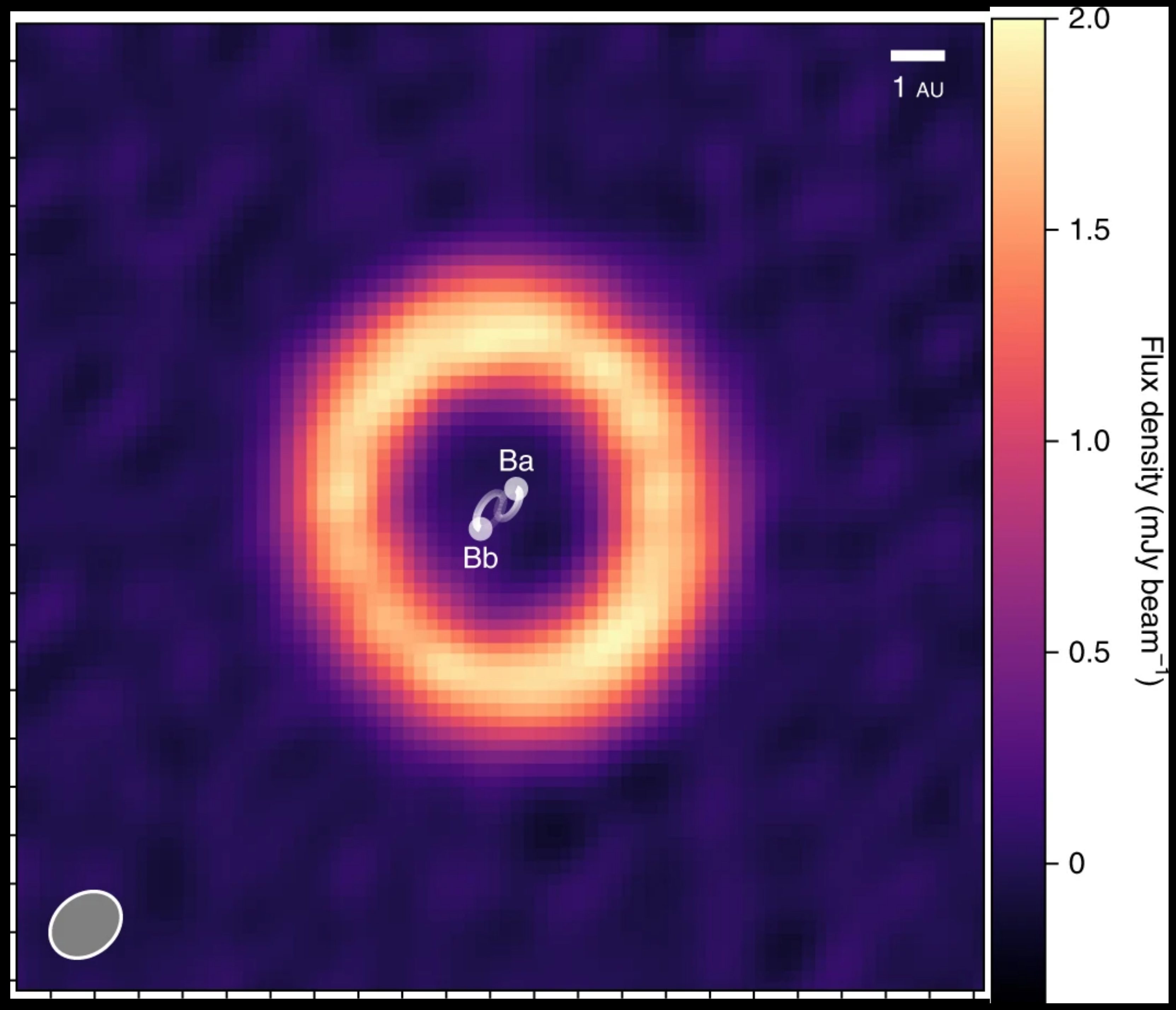
Introduction

- **Basic scheme**
  - **Circumbinary disk**
  - **Spiral density waves**
  - **Low dens Gap/ cavity**
  - **Accretion stream**
  - **Circumstellar disk (mini disk)**



Lai, Muñoz . 2023

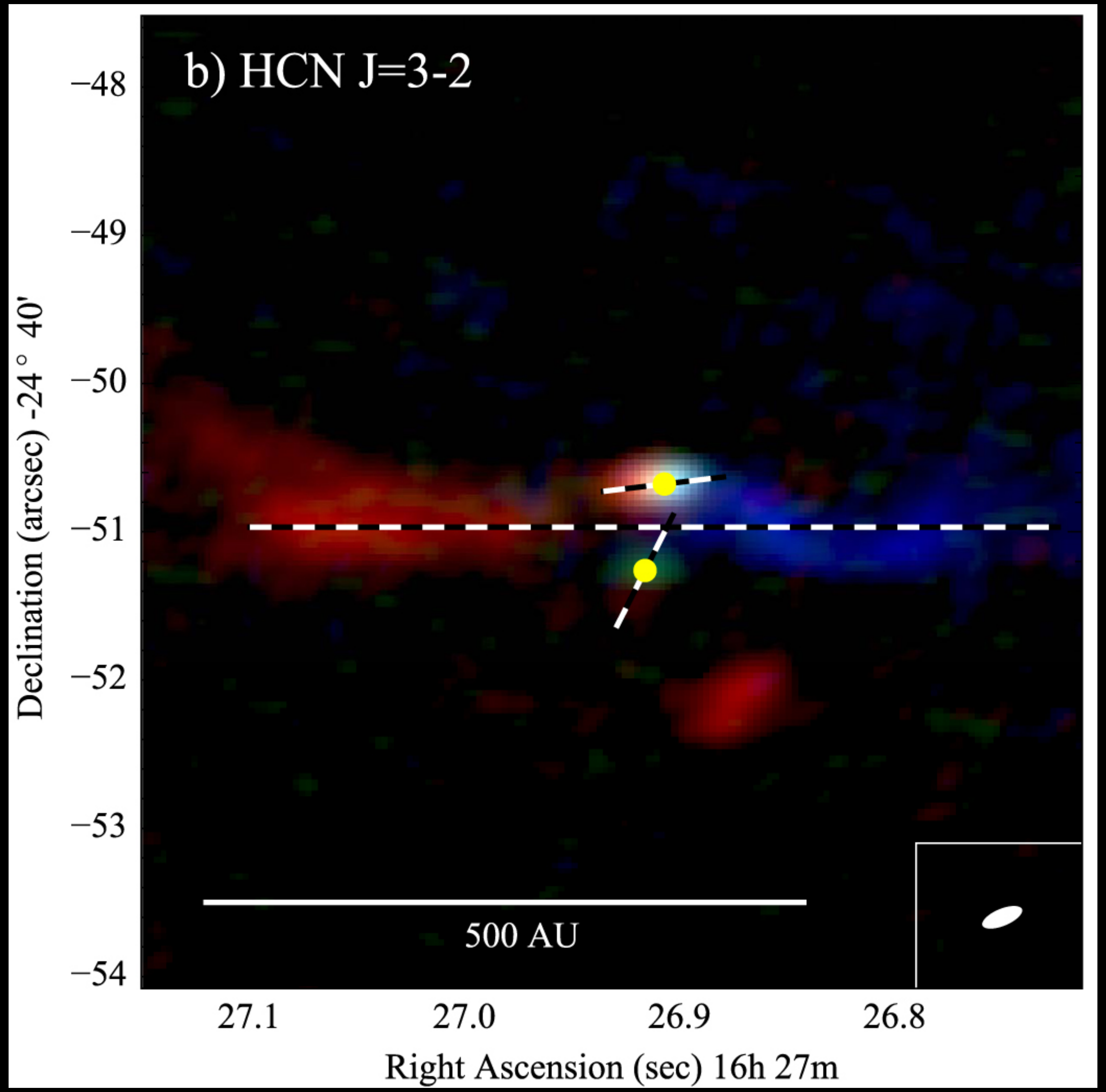
Introduction



Protoplanetary disks

HD 98800

Kennedy et al. 2019/ALMA



Protostellar disks

IRS 43

Brinch et al. 2016/ALMA

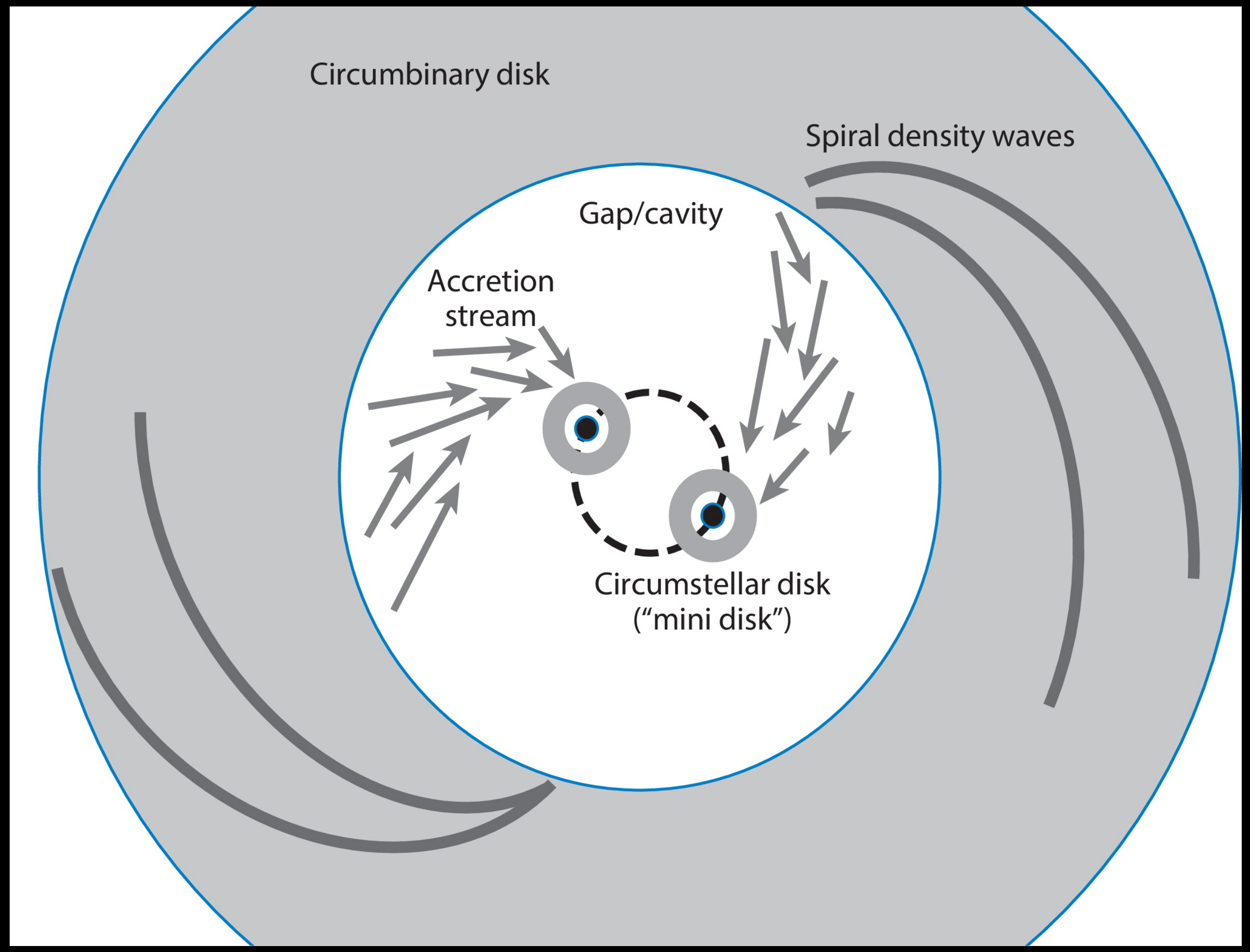
Galaxy merge Massive black holes

NGC 4676

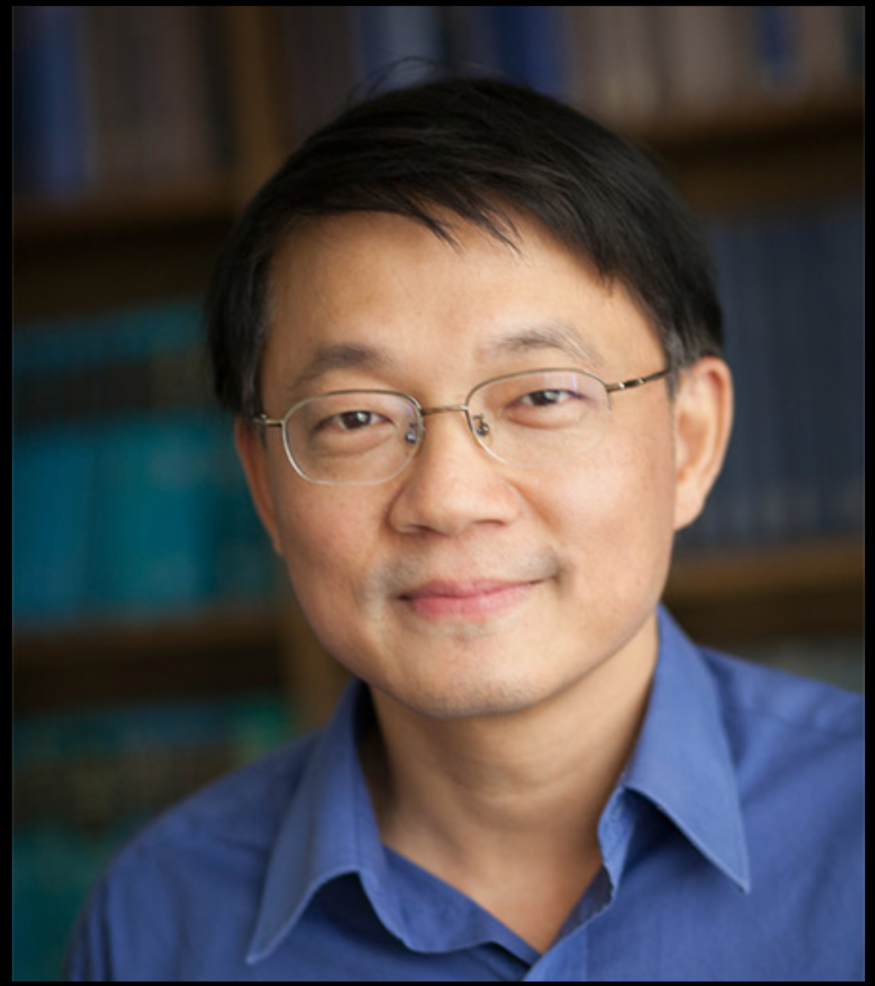
HST

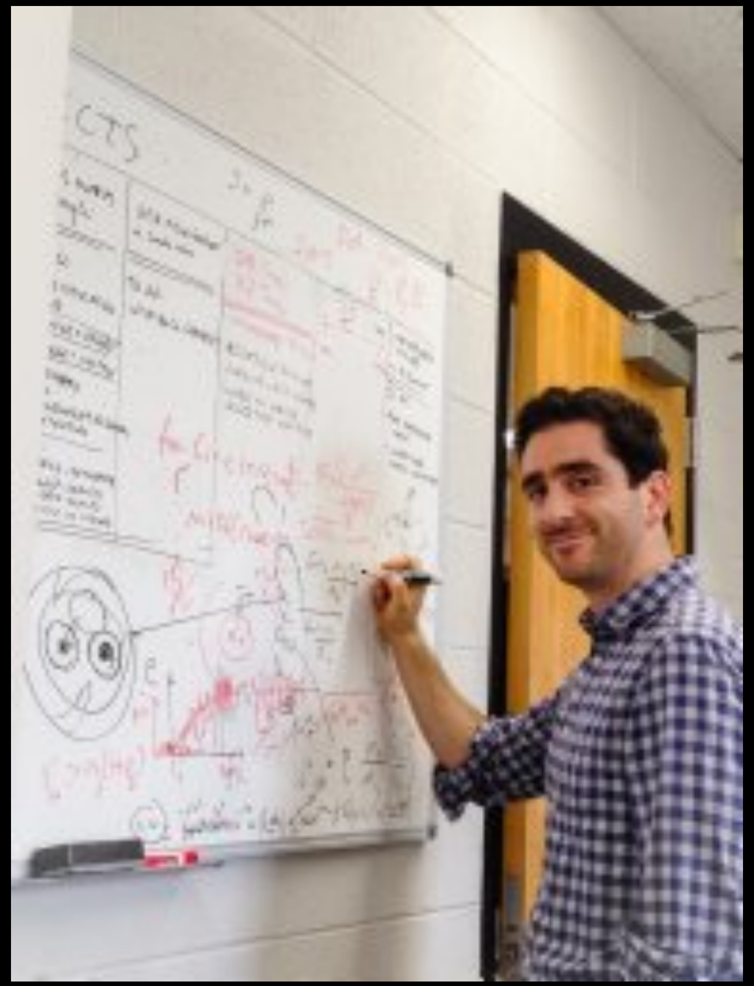
Key results of simulations

- Algorithm： AREPO （Lagrangian）
- Challenge： Large sacle, Long period, change swiftly



- Mass ratio $q_b \sim 1$, Viscosity $\alpha = 0.05 - 0.1$
- Aspect ratio $h = \dfrac{H}{r} \sim 0.1$, Co-planar configuration



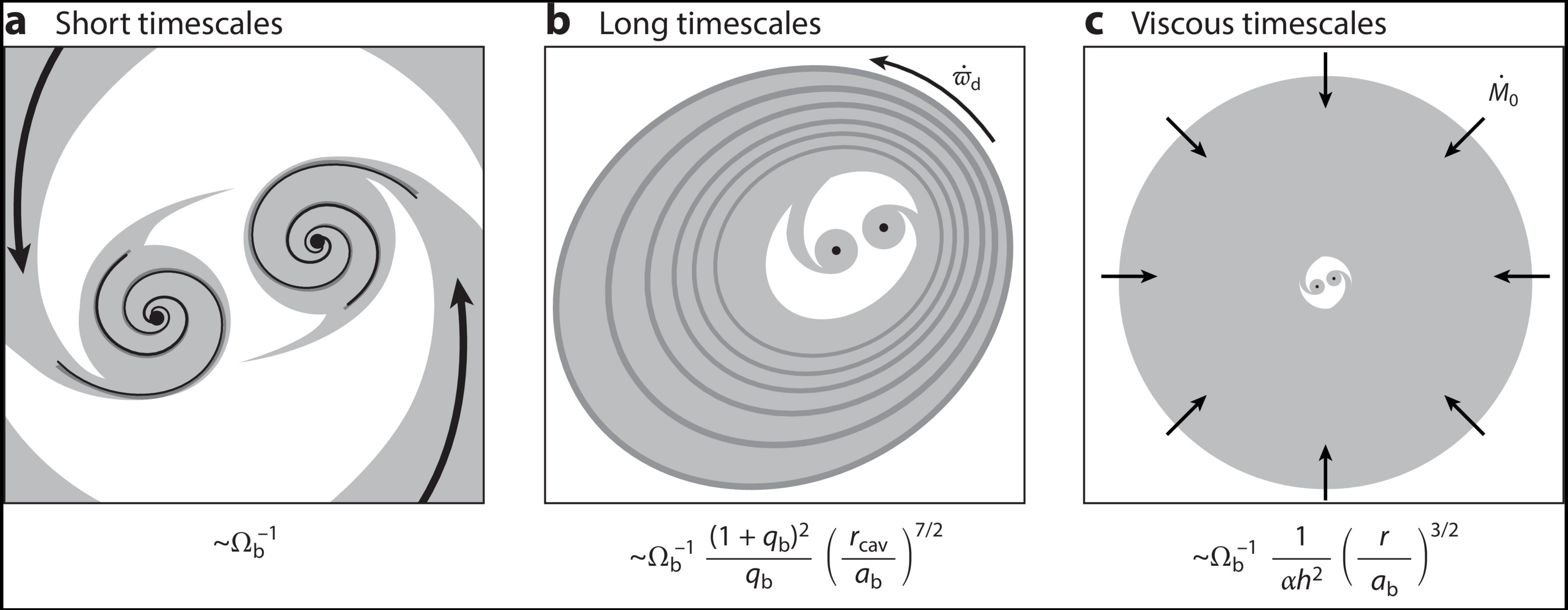


Lai, Muñoz . 2023

Circumbinary Accretion: From Binary Stars to Massive Binary Black Holes

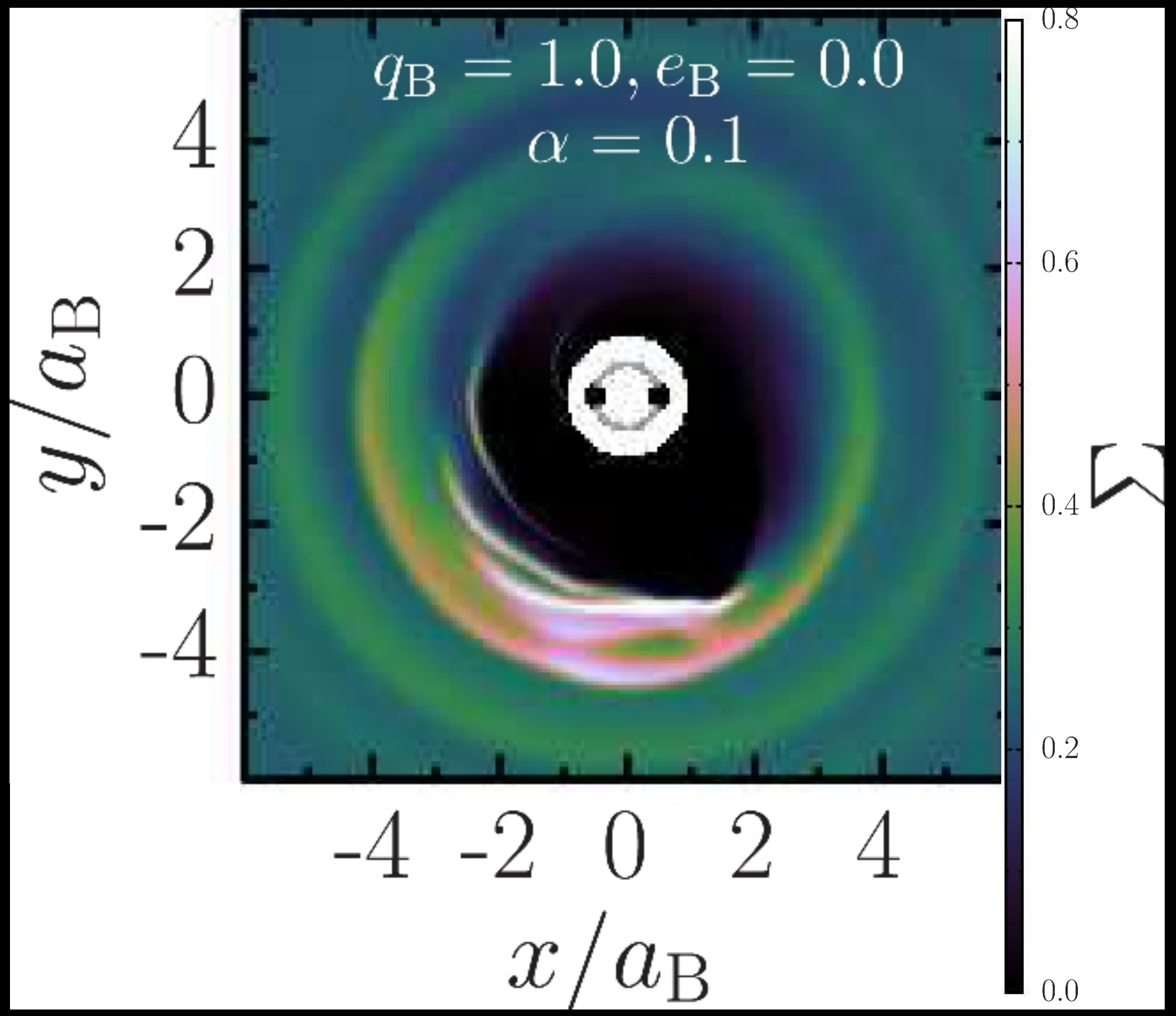
ANNUAL REVIEWS

Different time scale

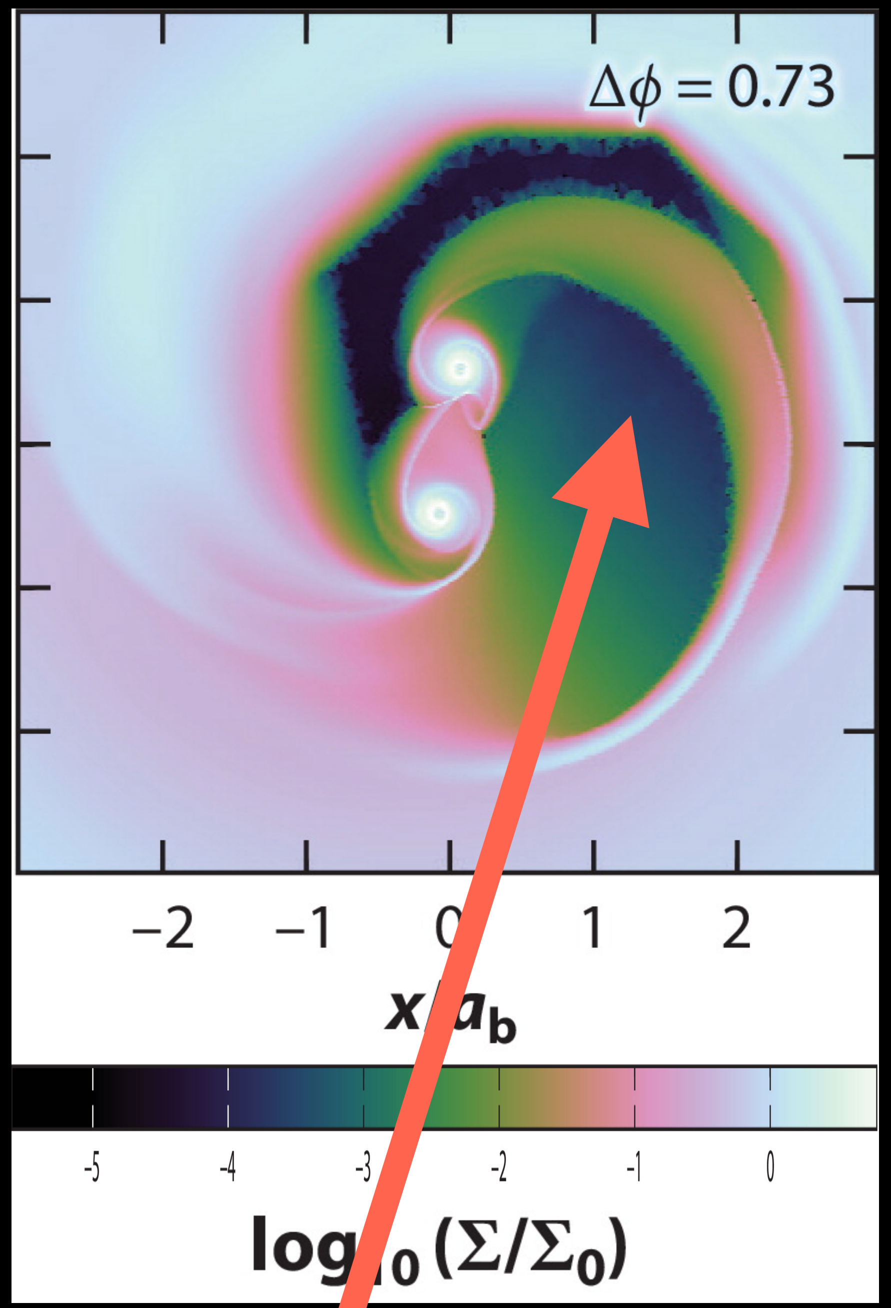


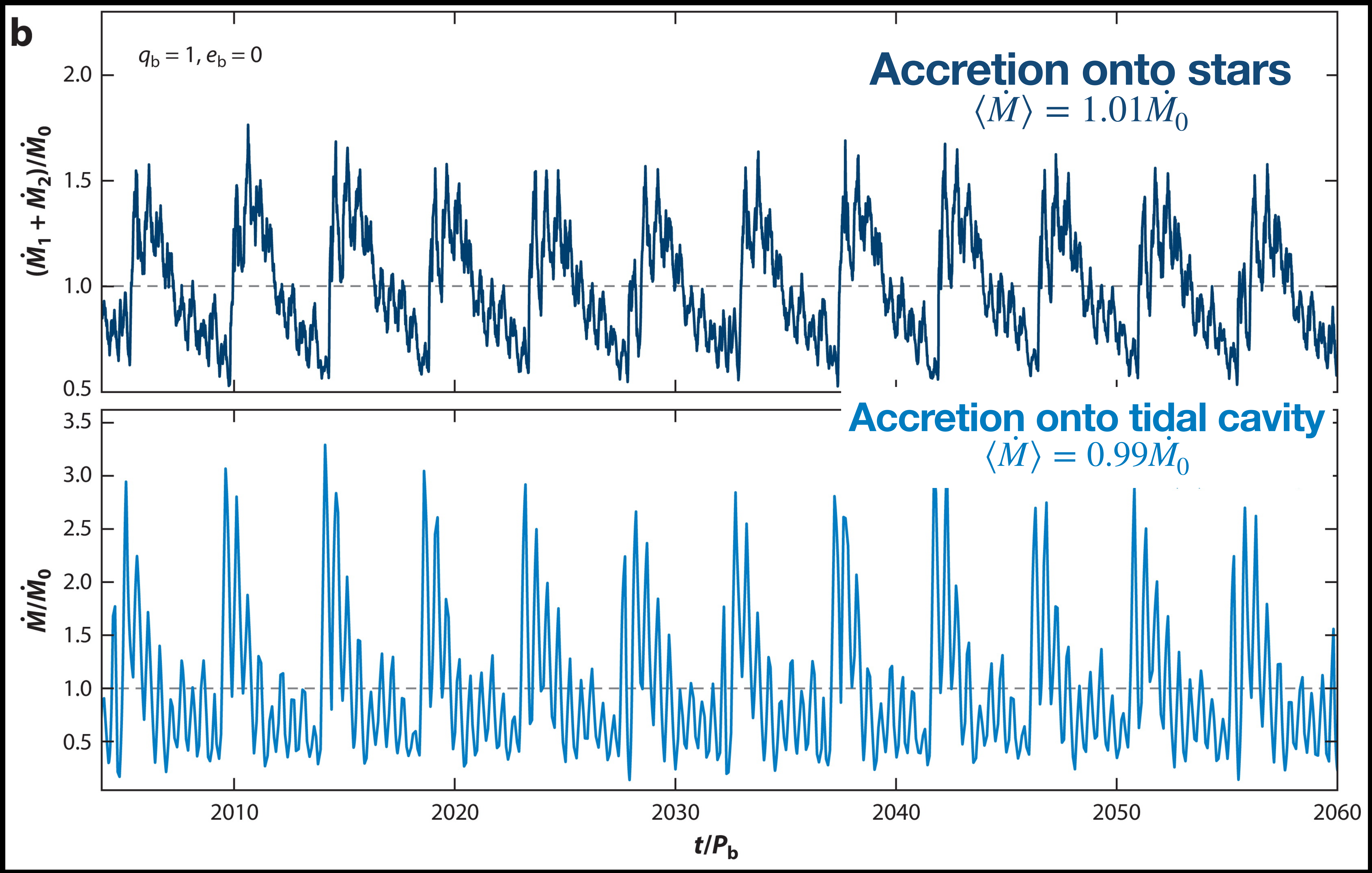
Lai, Muñoz . 2023

Short-term variability



Miranda et al . 2017





$e_b = 0$

$\sim 5P_b$

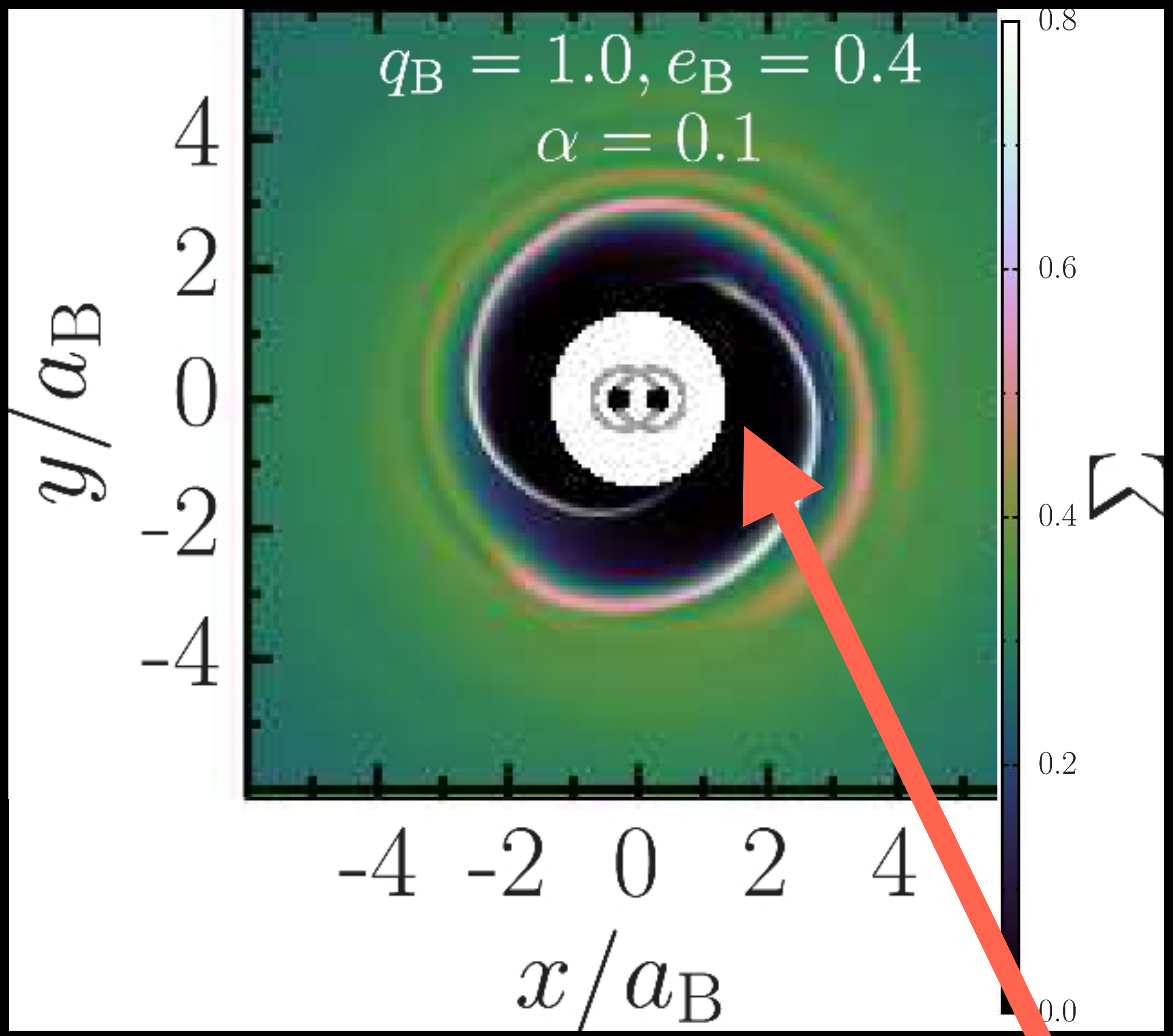
Clump for

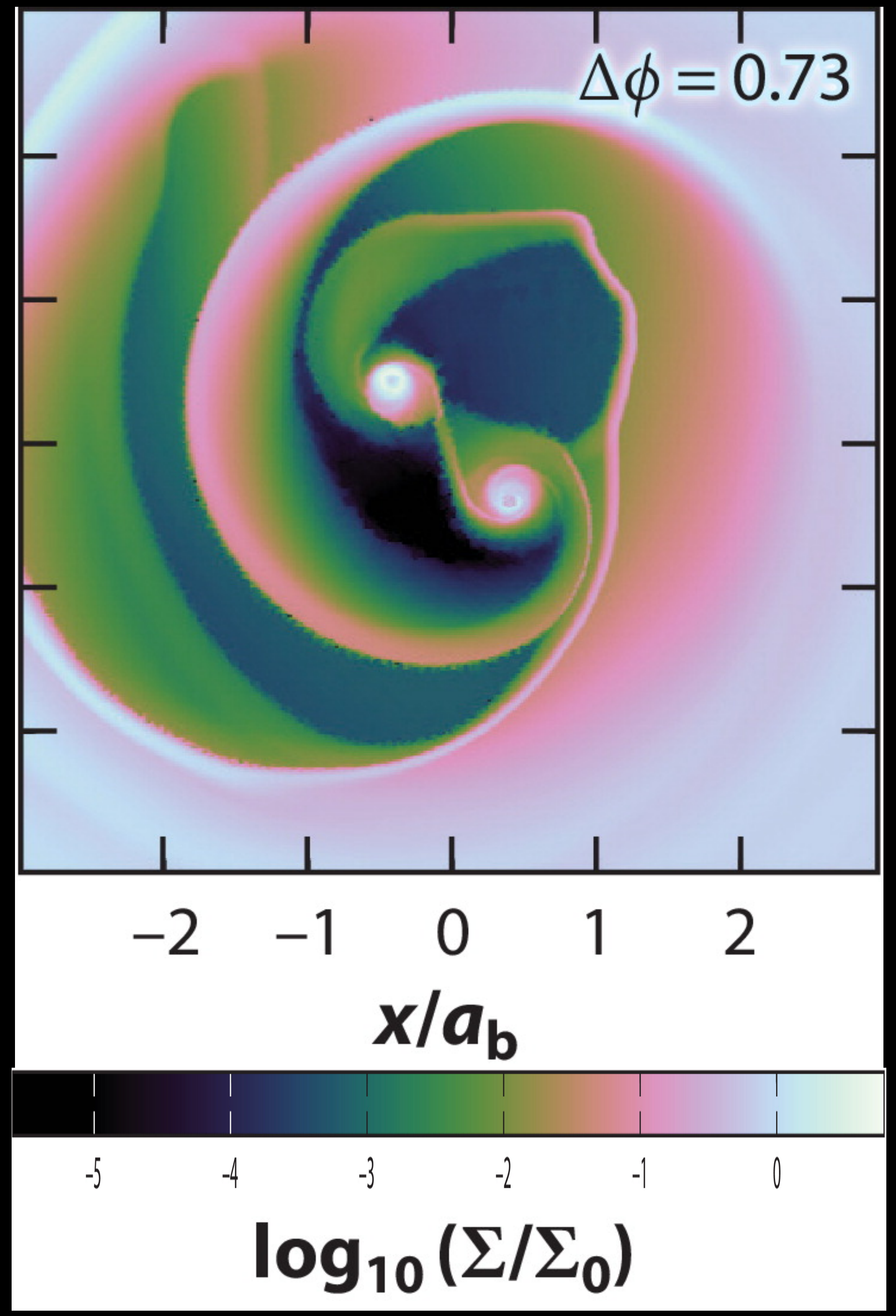
$e_B < 0.1$

$r_{cav} \approx (2 \sim 3)a_b$

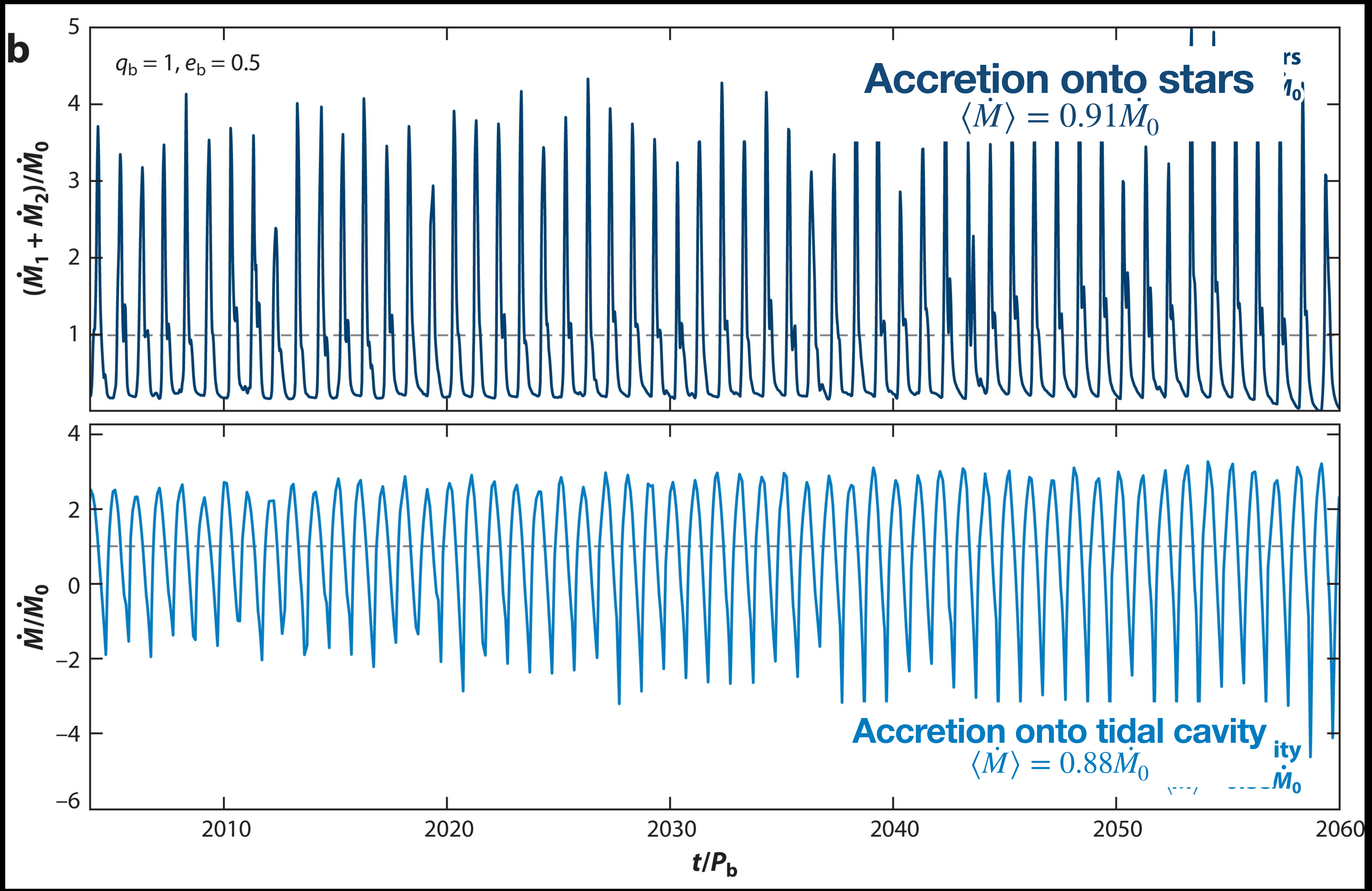
Lai, Muñoz . 2023

Short-term variability





Miranda et al . 2017

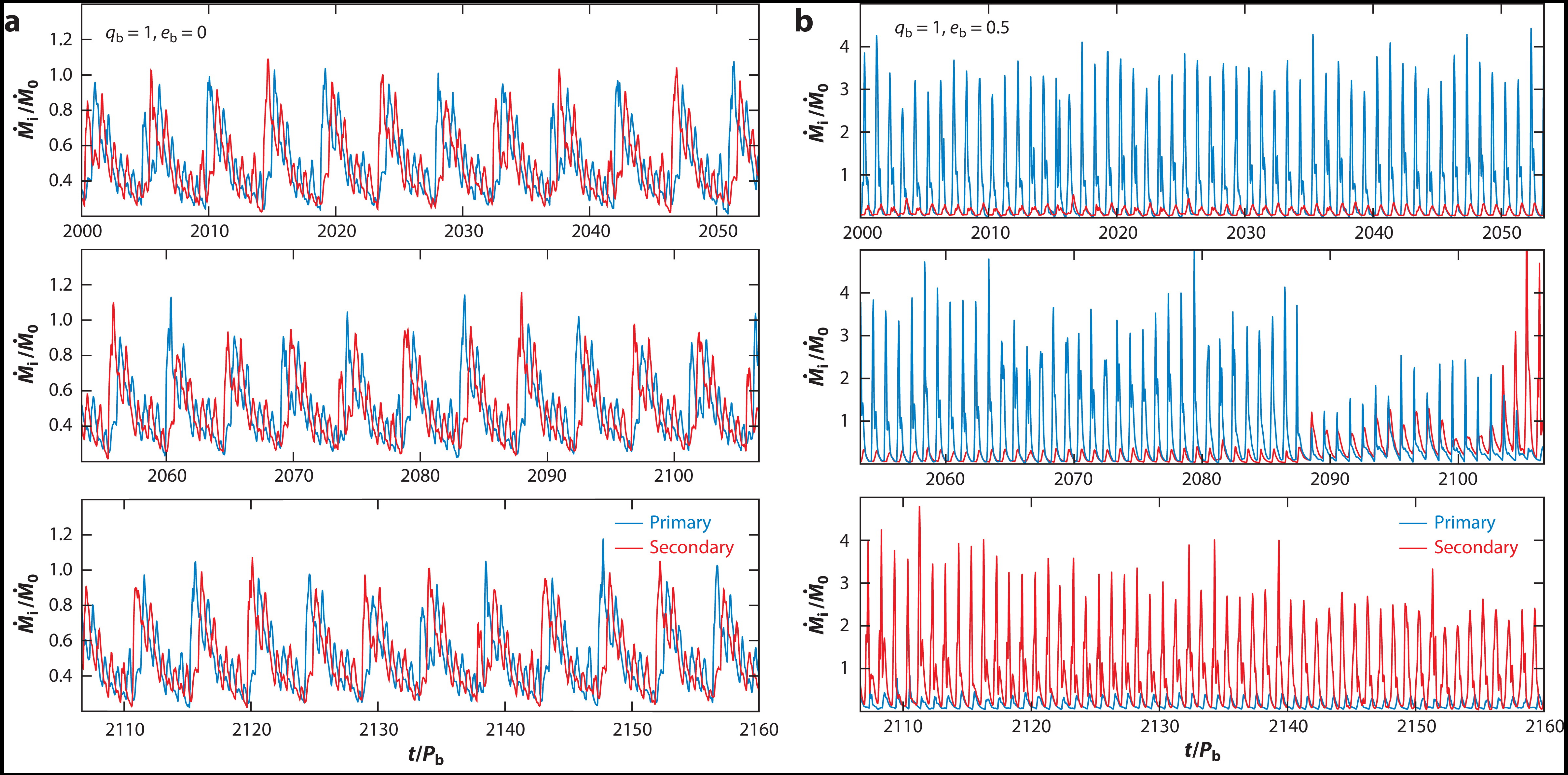


$$e_b = 0.5$$
$$\sim P_b$$

轨道远点吸积

Lai, Muñoz . 2023

Long-term variability $\sim 100P_b$ $\dot{M}_1 \geq 20\dot{M}_2$ $e_b = 0.5$ Observation

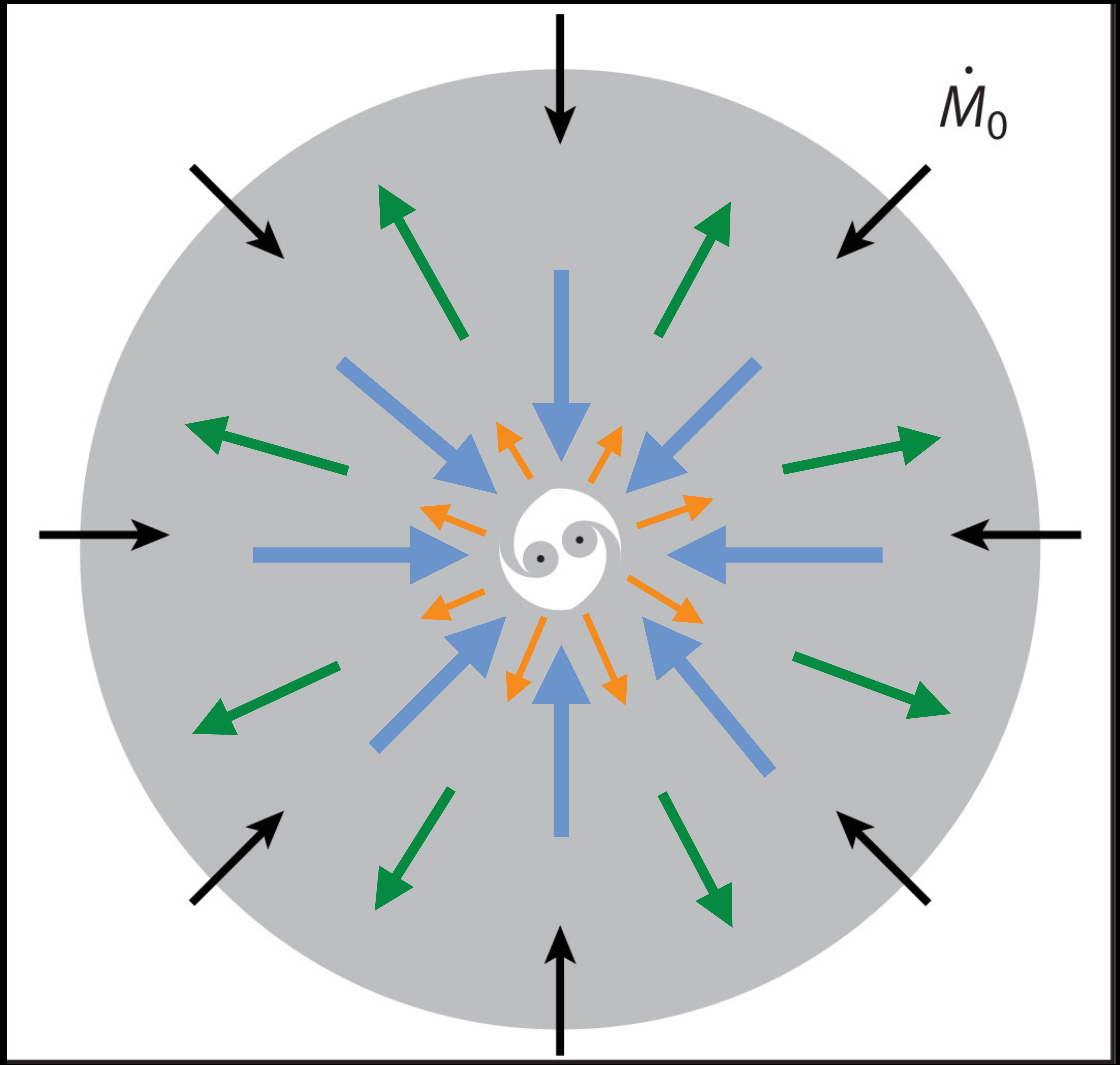


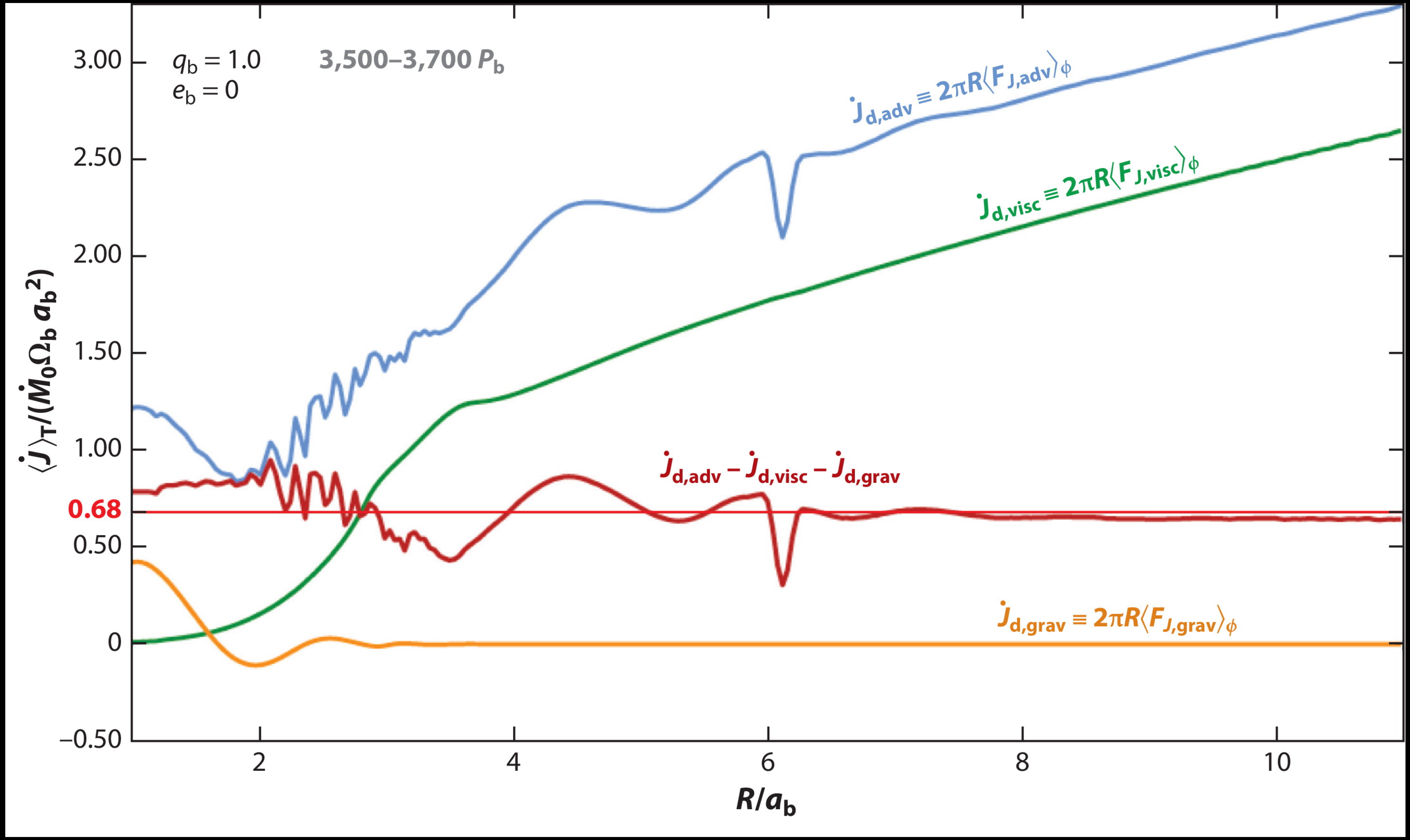
Lai, Muñoz . 2023

Angular momentum transfer

Time-averaged

Gain momentum and expand orbit!





Outward, viscous $\dot{J}_{d,visc}$

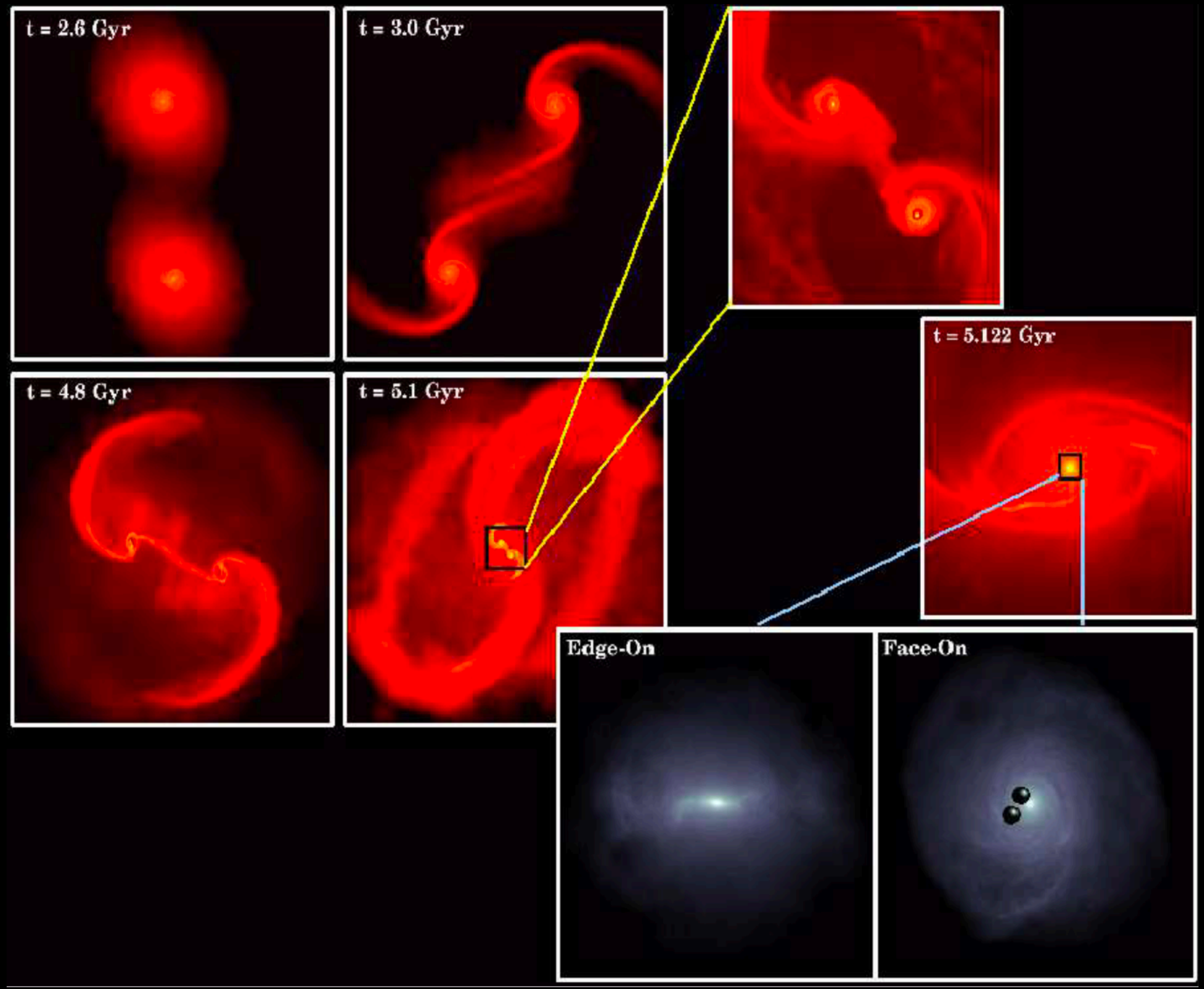
Inward, advection $\dot{J}_{d,adv}$

Outward, binary $\dot{J}_{d,grav}$

$$l_0 \equiv \frac{\langle \dot{J}_b \rangle}{\langle \dot{M}_b \rangle} = 0.68 a_b^2 \Omega_b$$

Lai, Muñoz . 2023

Final-parsec problem



Mayer et al . 2007

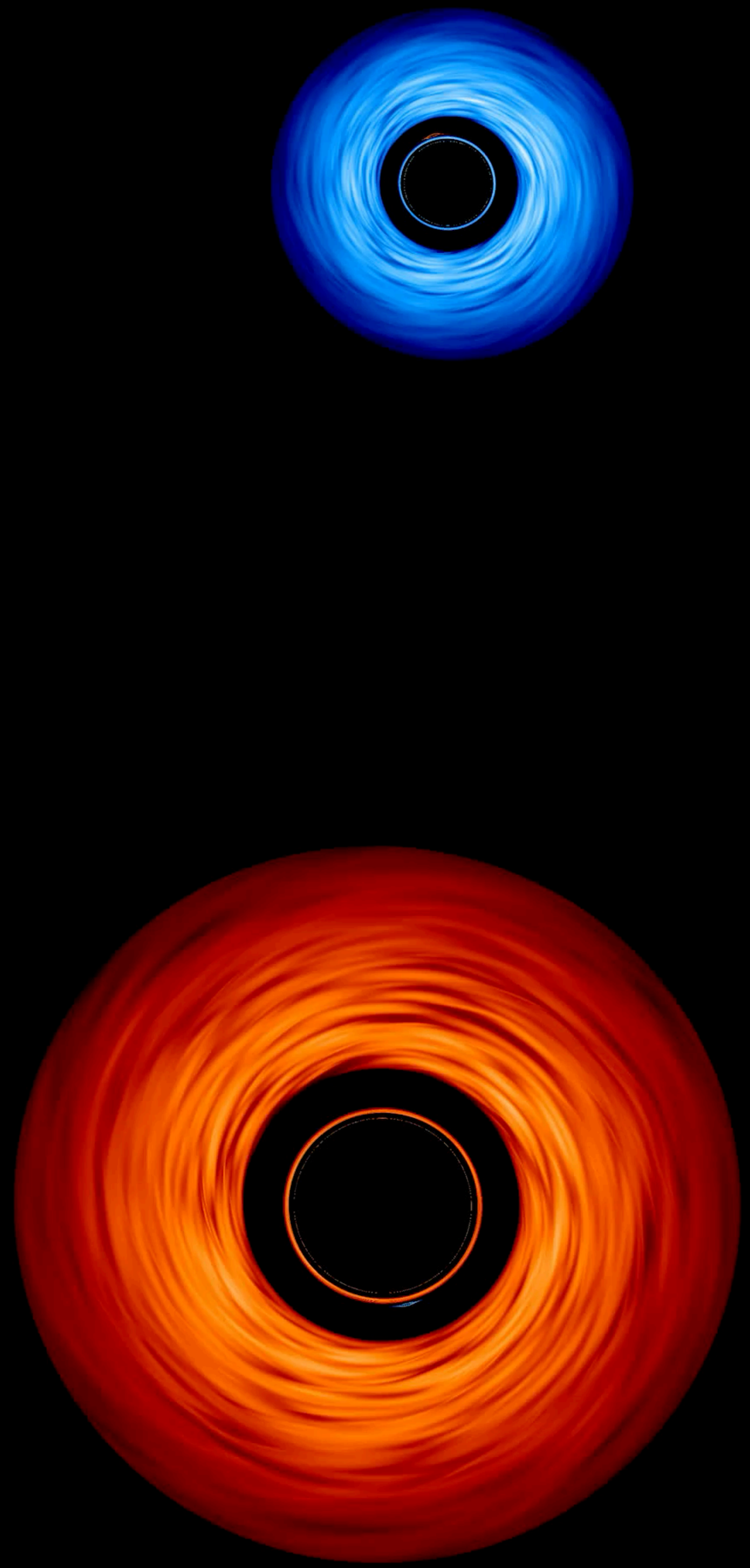
Orbit decay and merge?

Gravitational radiation

≤ 0.01 Parsec

LIGO LISA

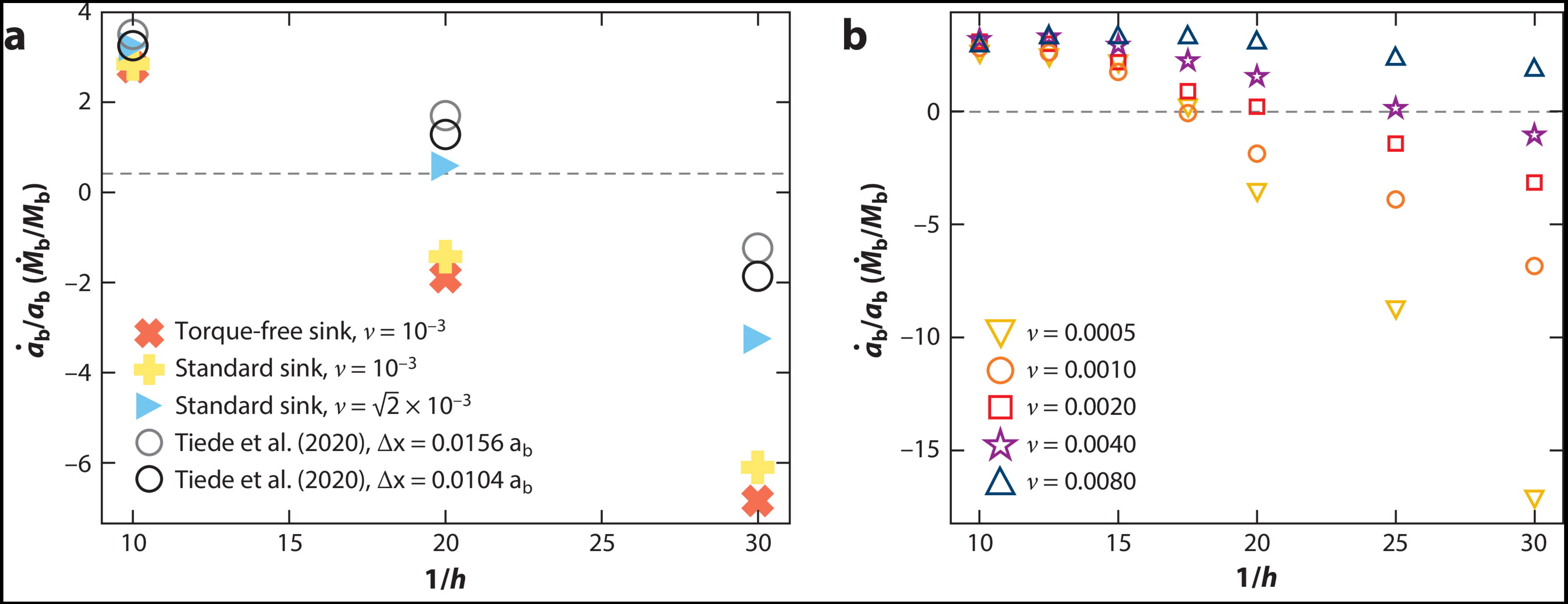
TianQin Taiji



Thickness and viscosity h & α

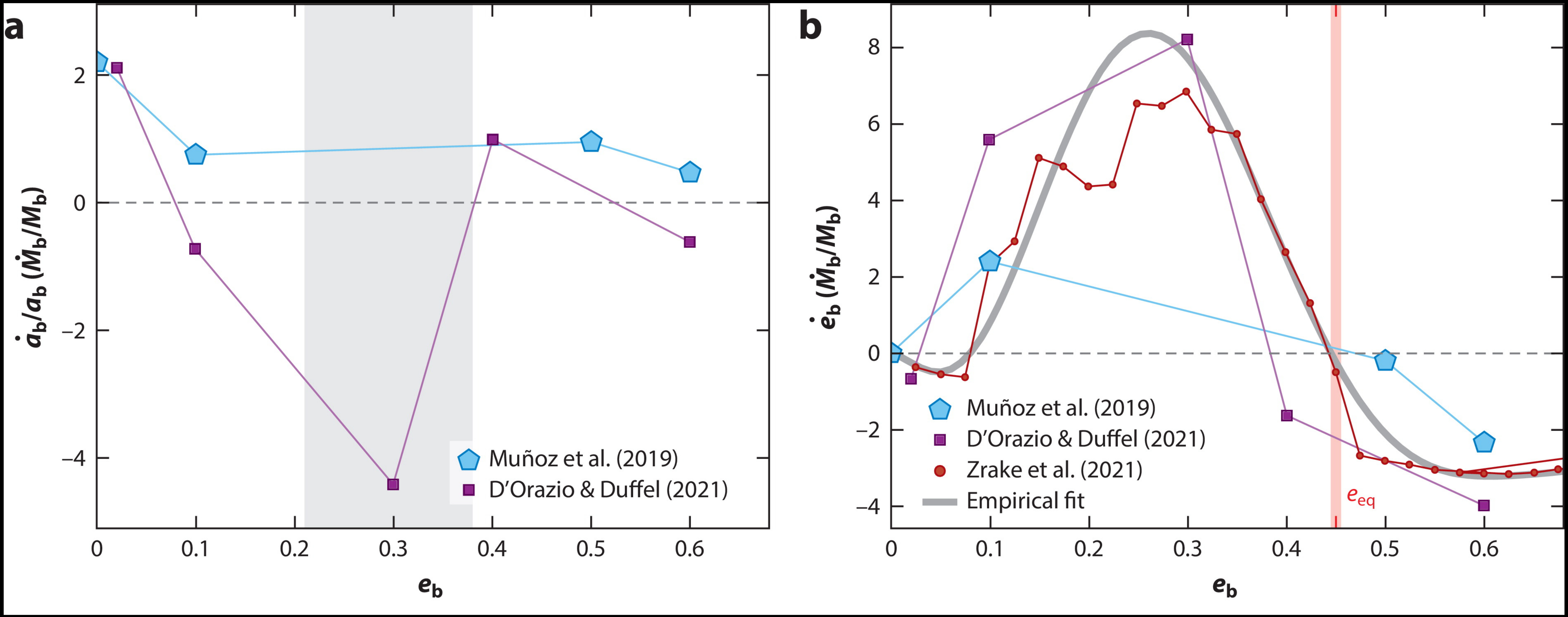
Protostellar disk $h \sim 1$

MBHBs $h \lesssim 0.01$



Tiede et al. 2020 Dittmann, Ryan. 2022 Lai, Muñoz. 2023

Long-term evolution: Eccentric orbit



Zrake et al . 2021 Dittmann, Ryan . 2022 Lai, Muñoz . 2023

Application

Observation
Binary formation

DQ Tau

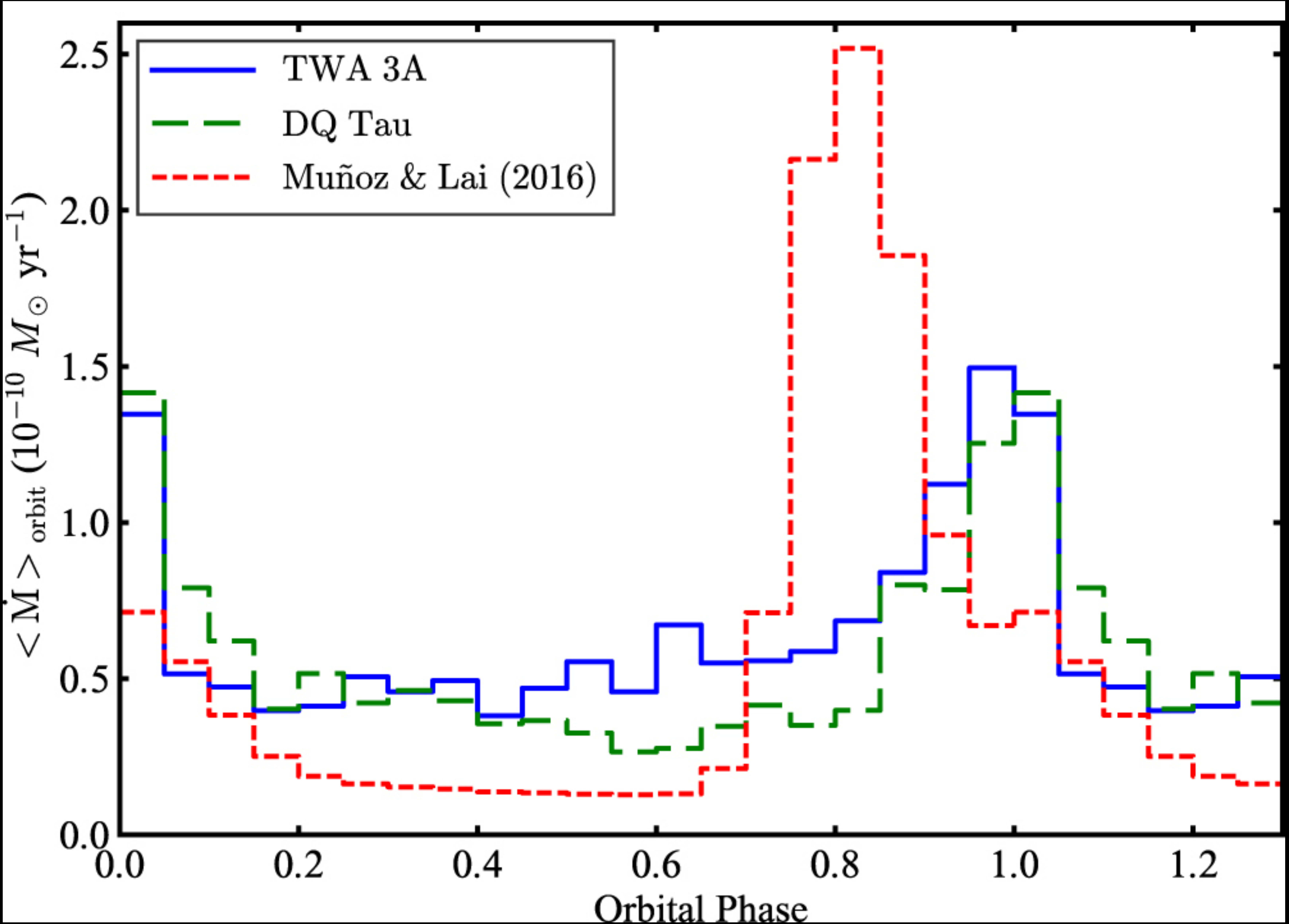
$e_b = 0.568$
$q_b = 0.936$

TWA 3A

$e_b = 0.6280$
$q_b = 0.841$

Tofflemire et al . 2017

Lai & Muñoz . 2016



Application

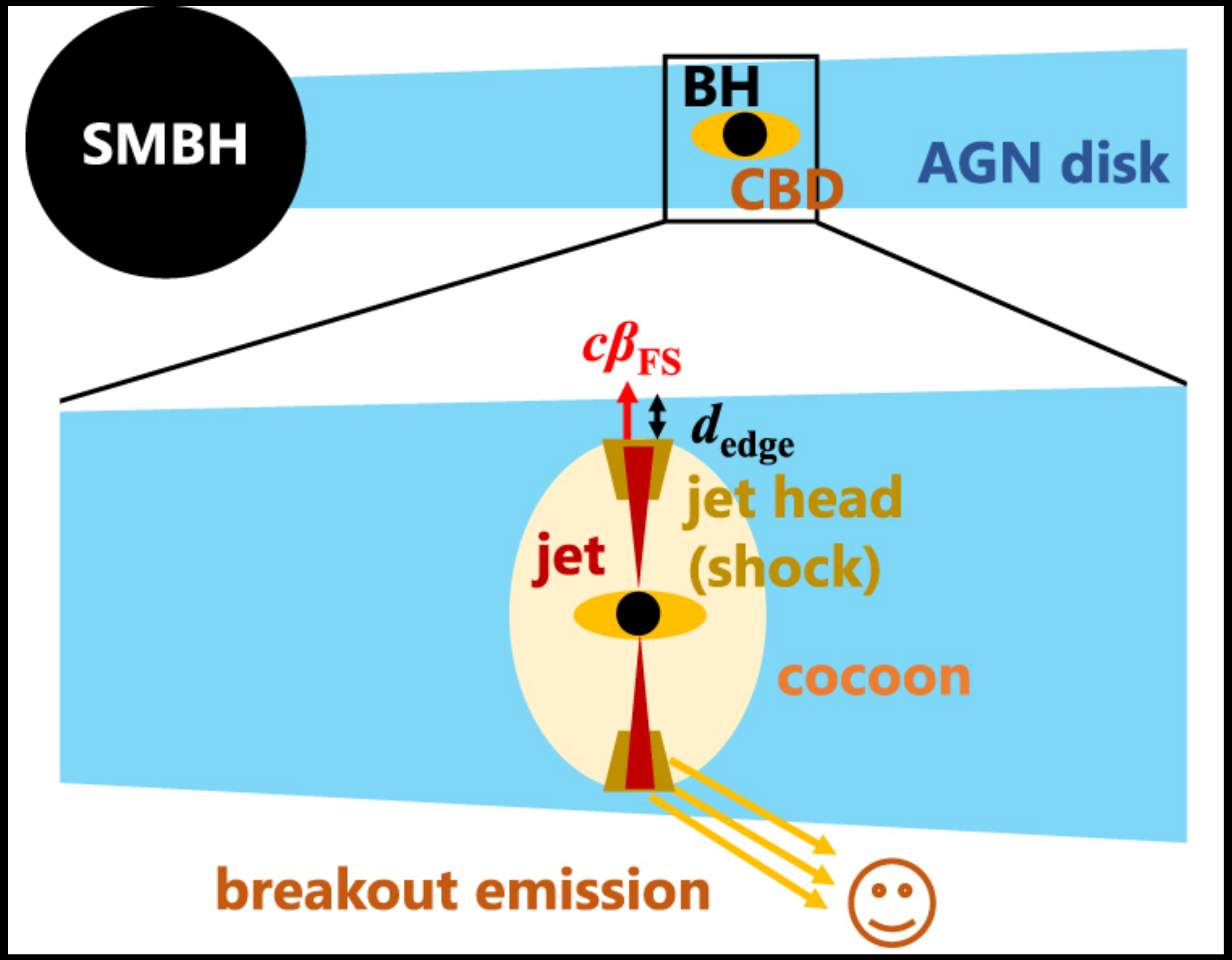
Circumbinary planets(CBPs)

- Observed properties
  - Planet size:
    - $0.3R_J \sim 1R_J$
  - Orbit:
    - Sub-AU、co-planar
  - Many parameters are at the systems' unstable edge

- Factors:
  - Planet migration?
- Gravitational potential, Disk density non-uniform
- Gas resistance

Application

Binary embedded in a “big” disk(AGN)



Tagawa et al . 2023

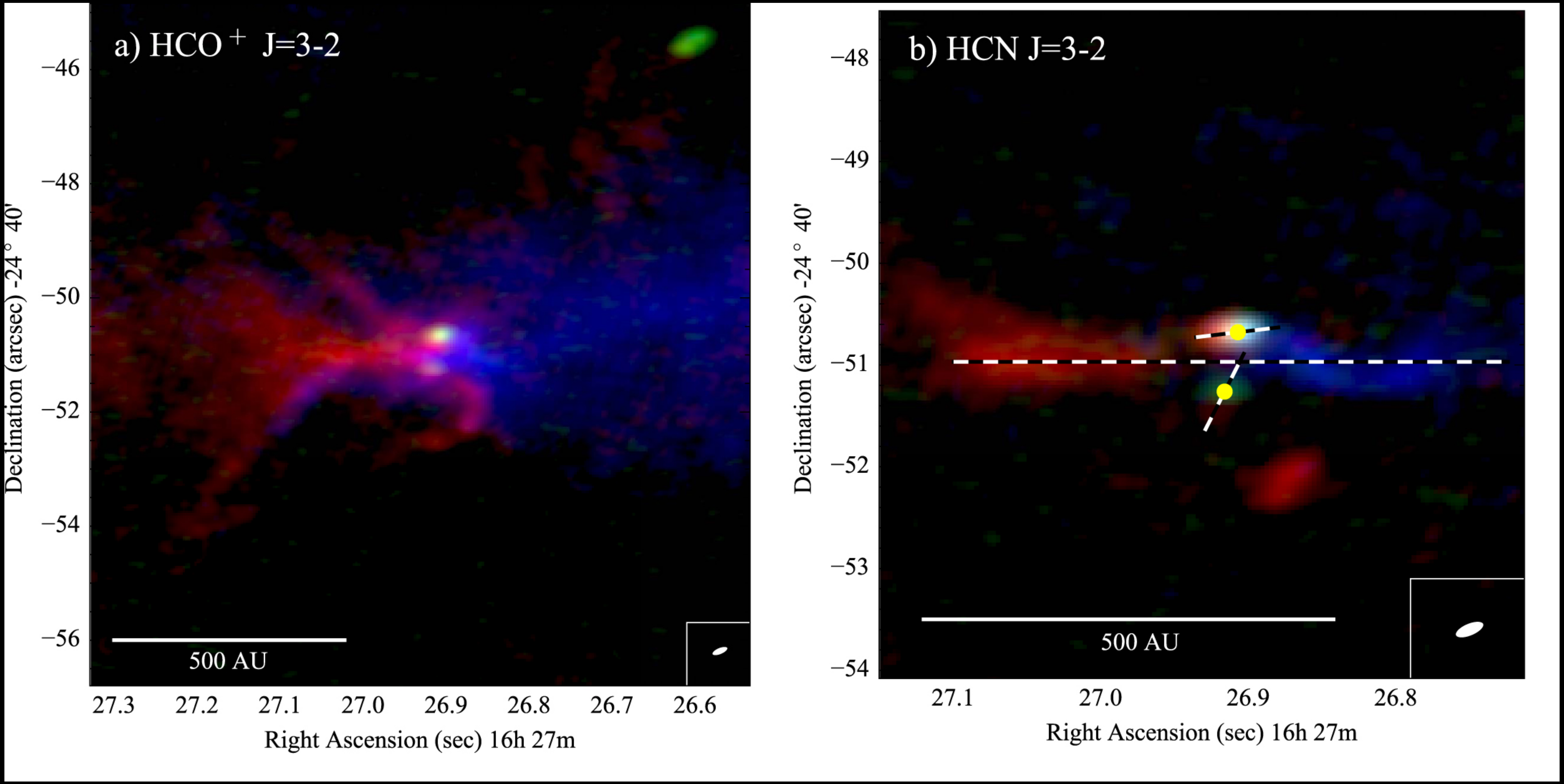
Complex hydrodynamics coupling process between BBH and larger scale

Probe Binary Low frequency GW

Confine MBH formation history

Circumbinary accretion

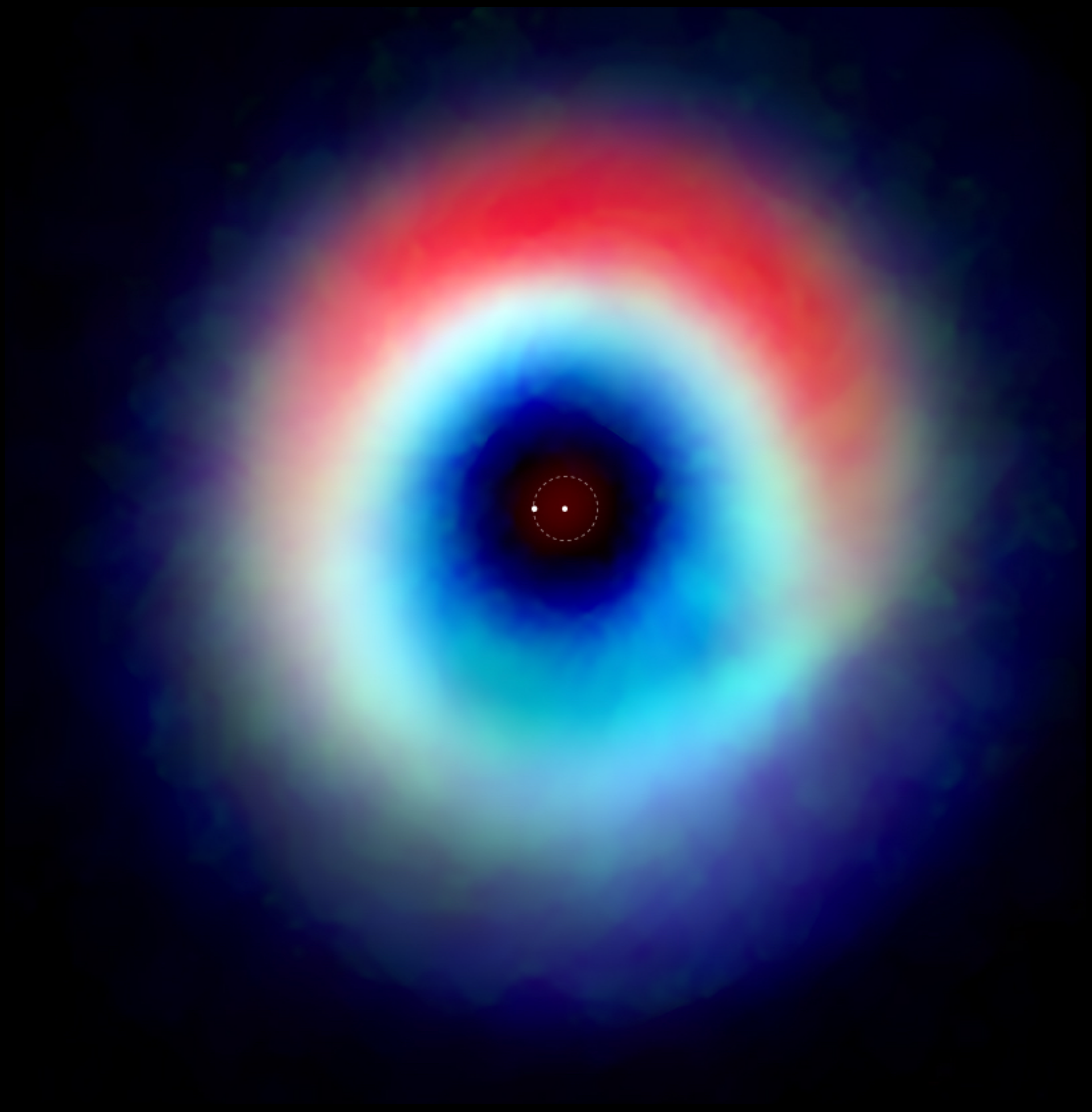
Misaligned disk



Brinch et al. 2016/ALMA **IRS 43**

Prospects

- Physical model choose
  - Self-gravity disk……
  - Radiation, Outflow, Turbulence……
  - Non coplanar、non equal-mass、non circular orbit……
- Ability of observation and computational simulations(3D, MHD, GRMHD)



HD 142527

A . Isella/ ALMA

Thanks!