The TDE/EMRI/stellar distribution by considering the interaction of stellar objects with AGN disk

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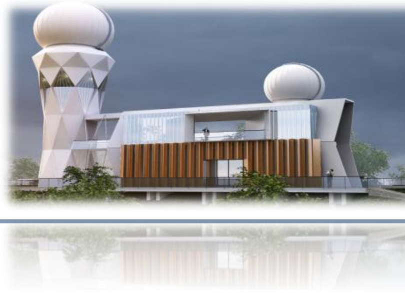


Accretion Modified Star (AMS) in AGN case

QPEs: Wang… Wu 2022 ApJ

AGN disk stars and metal enrichment: Fan, Wu 2023 ApJ

EMRI GW background: Wang… Wu 2023 MNRAS

TDE rates : Wang, Ma, Wu et al. 2024 ApJ

Stellar distribution: Fan, Wu et al. 2024 ApJ

TDE emission line: Zhang, Wu et al. 2024 ApJ

Radio TDE simulation: Lei, Wu et al. 2024 submitted to ApJ

EM flares: Ma, Wang,Wu et al. 2024, submitted to PRD

Changing-look AGNs

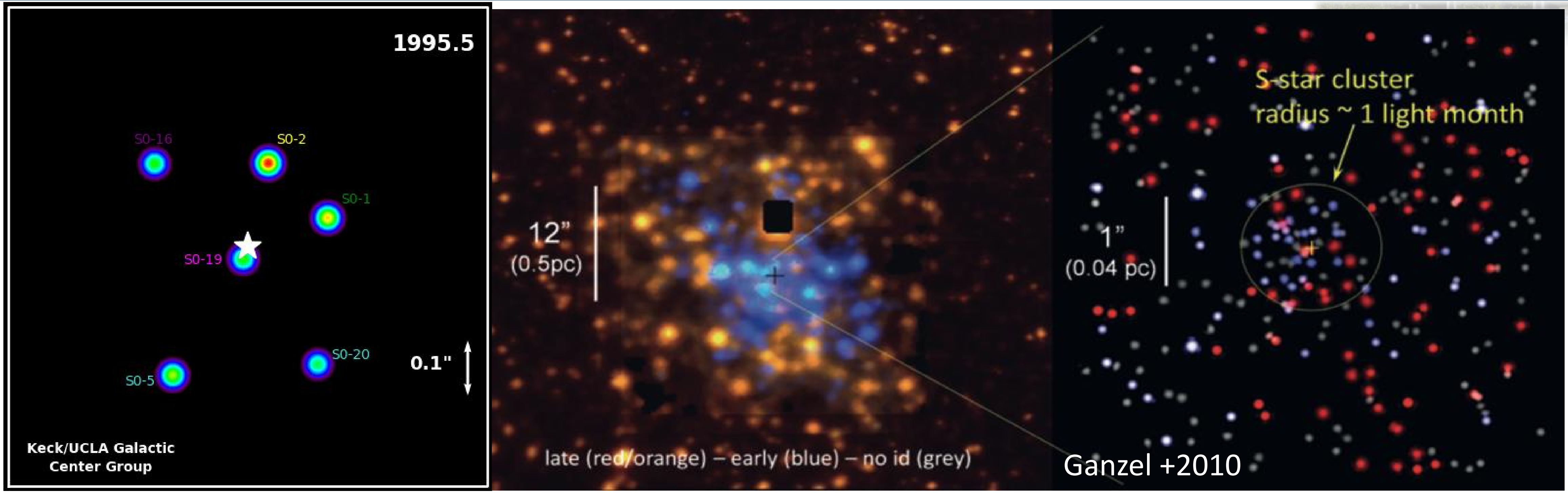
CL blazar: Kang, Lyu, Wu et al. 2024 ApJ; CL blazar: Kang, Wu et al. 2023 MNRAS

Balmer Decrement: Wu, Wu et al. 2023 ApJ; X-ray CLAGN: Liu, Wu et al. 2022 ApJ

WISE CLAGN:Lyu, Wu et al. 2022 ApJ; CL Mrk 1018: Lyu,.. Wu 2021 ApJ

Radio CLAGN: Yang, …Wu et al. 2021a,2021b,MNRAS

Background

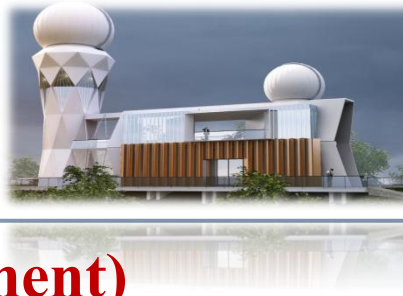


Nuclear Star Cluster in GC ~1-10 pc scale, star density~$10^{6\text{-}7}/pc^3$, which may be serve as a bridge between galaxy and central supermassive black hole.

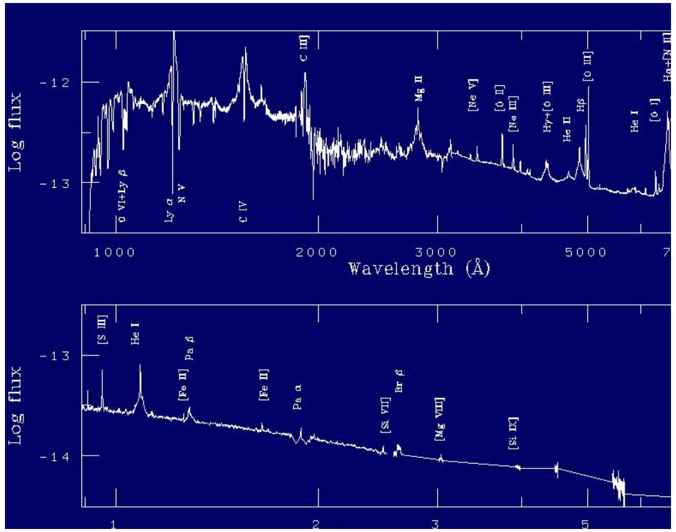
~100 OB and Wolf-Rayet within 0.05-0.5 pc of Sgr A* with the age of ~4-6 Myr.

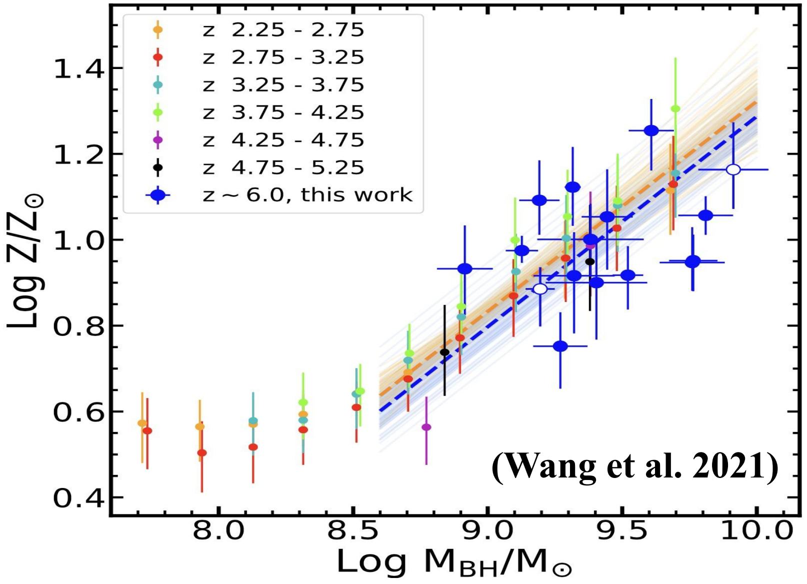
Locally formed or captured?

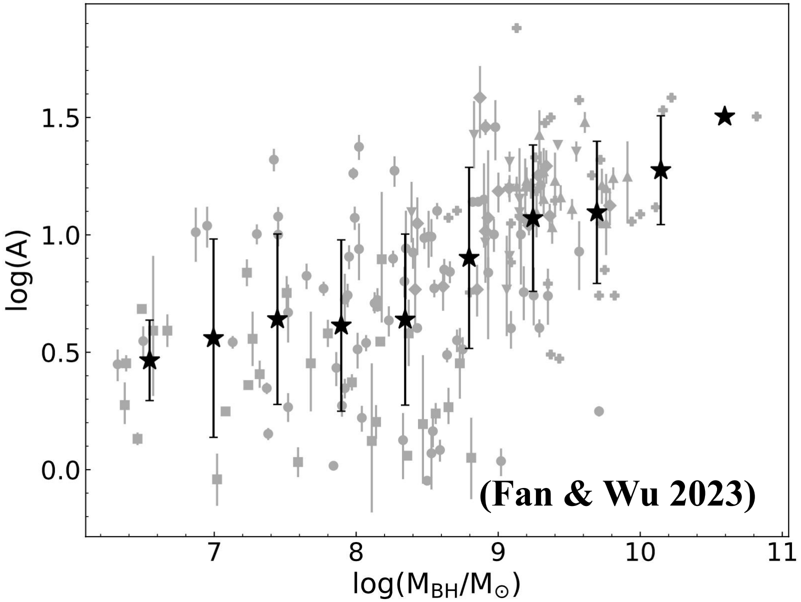
Background

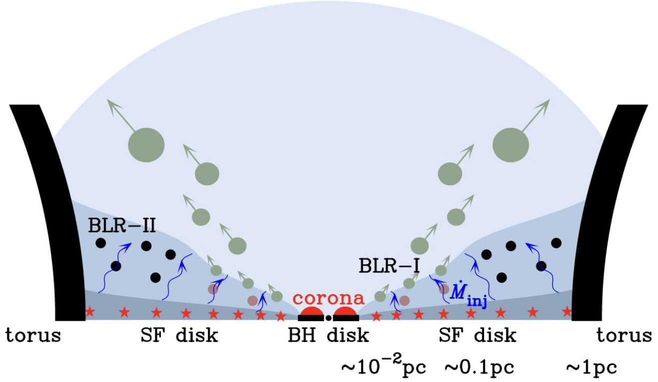


Evidence for Nuclear Star Clusters in AGNs (Fast Metallicity Enrichment)



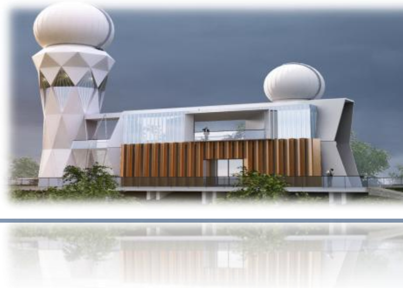


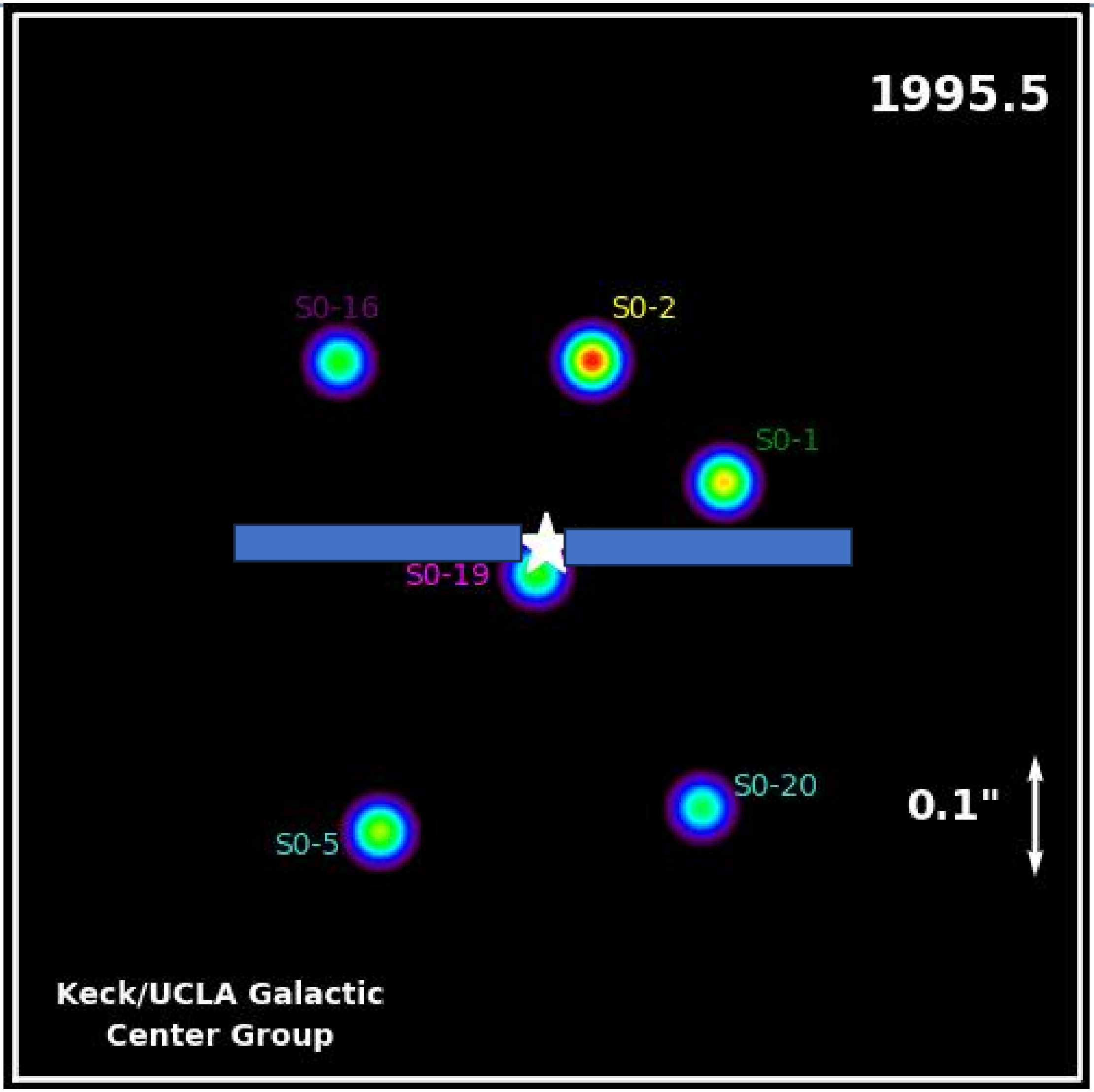




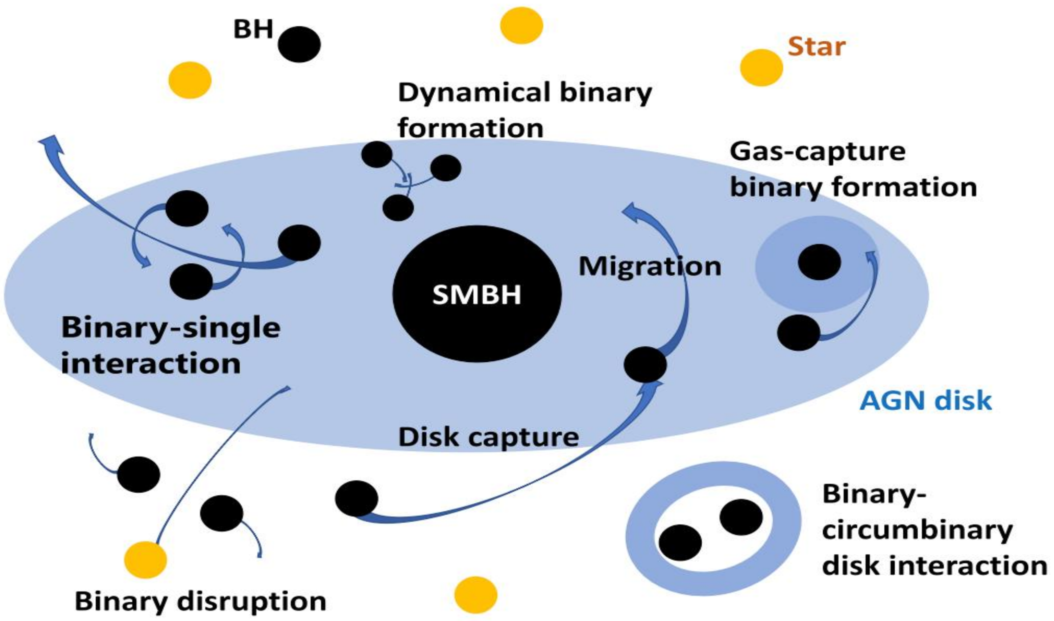
Broad Line ratio → super solar metallicity: strong and fast stellar evolution in AGN center

Background





The star formation, stellar evolution/dynamics should be much different in AGN phase.

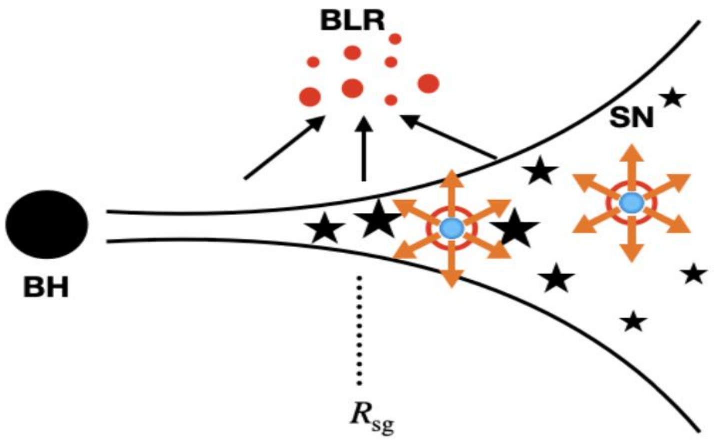


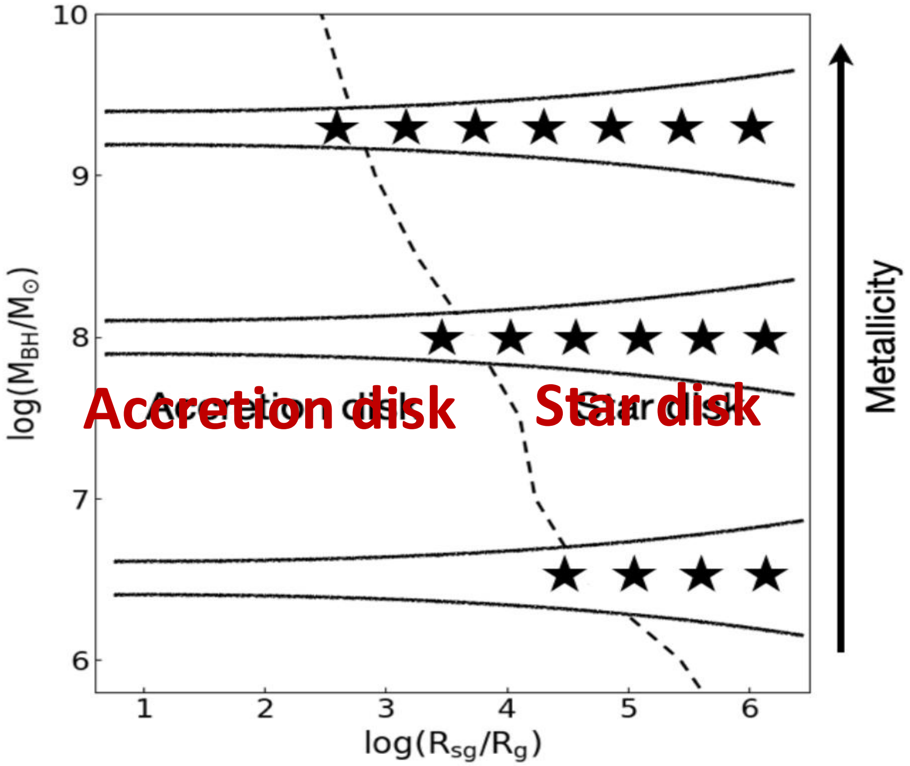
1) AGN disk stars and metal enrichment

2) Star-disk interaction and stellar distribution in GC

3) EMRI mHz GW background and TDE rates in AGN case

1）AGN-disk stars and metal enrichment





$$Q = \frac{c_s \Omega}{\pi G \Sigma}$$

AGN disk instability:

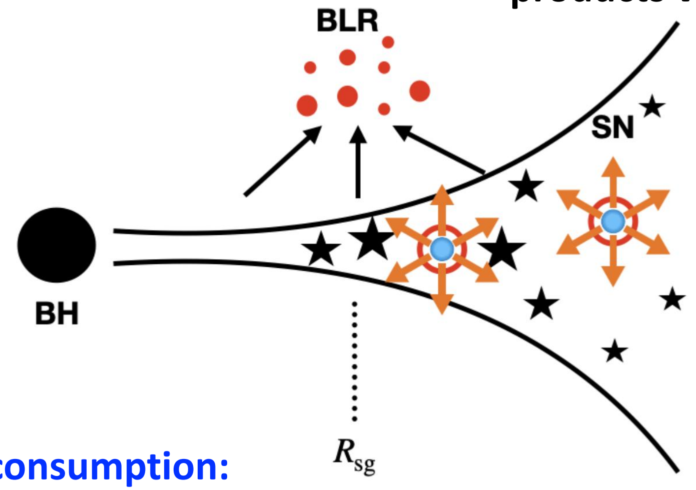
Heavier SMBH-> Smaller Rsg/Rg

(larger star disk and smaller accretion disk)

1）AGN-disk stars and metal enrichment

Metal contribution/consumption in disk

contribution:
nucleosynthesis
products via SN



$$\dot{\Sigma}_* = \mathrm{C}\left(\frac{\Sigma_{\rm gas}}{\mathrm{M_\odot pc^{-2}}}\right)^{\gamma} \mathrm{M_\odot yr^{-1} kpc^{-2}}$$

$$\phi(M_*) \propto M_*^{-\Gamma}$$

consumption:
accretion into BH

consumption:
condense into stars
and their remnants

Metallicity evolution

$$Z(t)M_{\rm gas} = \int_0^t (Z_0\dot{M}_{\rm out} + \bar{Z}_{\rm star}\dot{R}_* - Z(\tau)\dot{M}_{\rm BH} - Z(\tau)\bar{f}_{\rm rem}\dot{R}_*)d\tau,$$

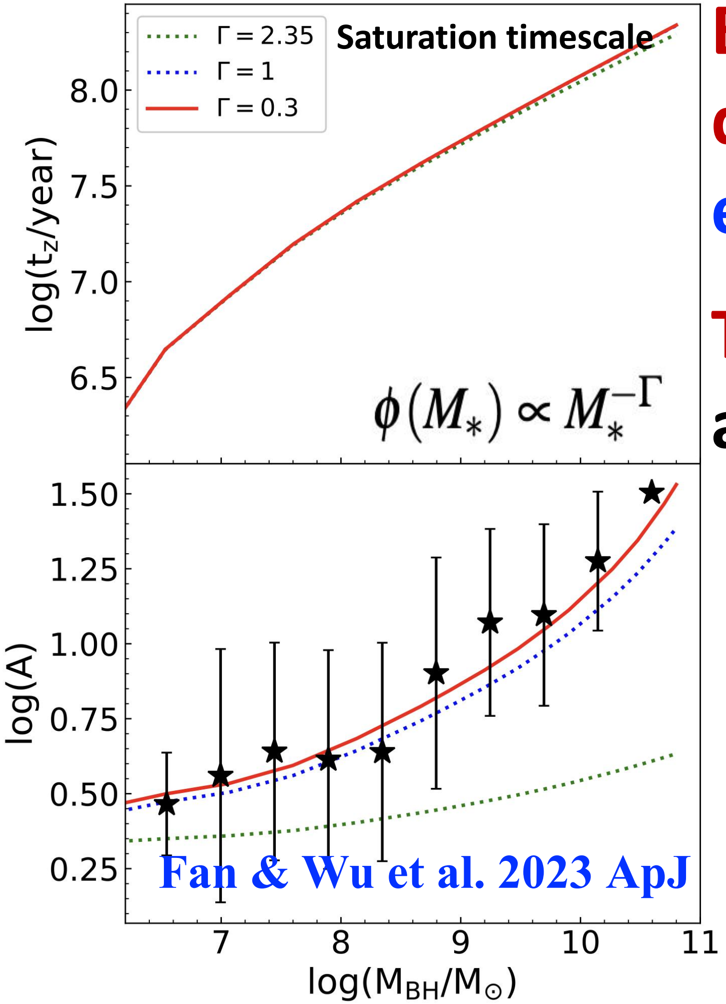
Solution:

$$Z(t) = Z_{\rm max} + (Z_0 - Z_{\rm max})\exp(-t/t_{\rm z}),$$

$$Z_{\rm max} = \frac{Z_0\dot{M}_{\rm out} + \bar{Z}_{\rm star}\dot{R}_*}{\dot{M}_{\rm BH} + \bar{f}_{\rm rem}\dot{R}_*}.$$

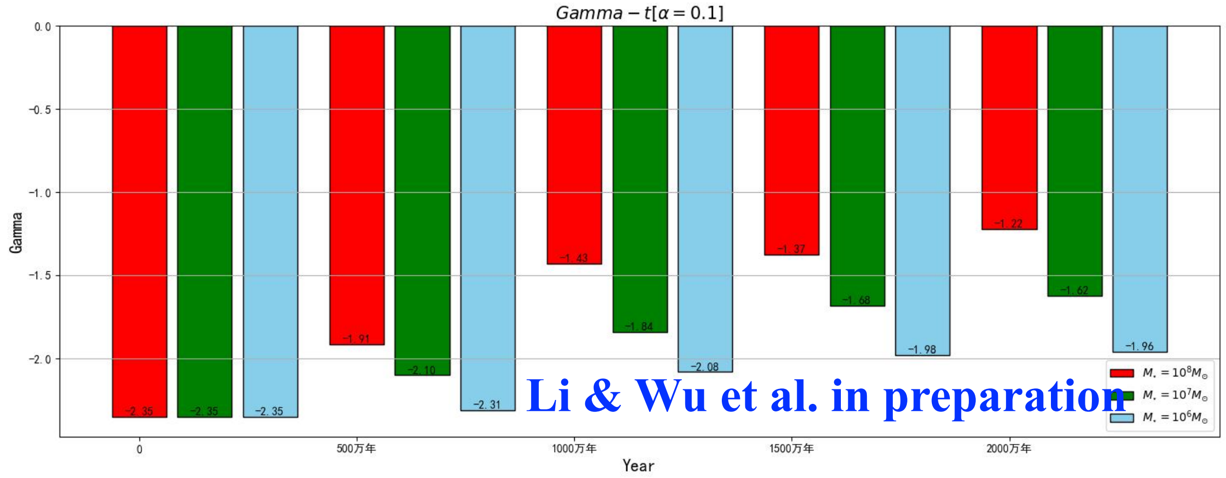
$$t_{\rm z} = \frac{M_{\rm gas}}{\dot{M}_{\rm BH} + \bar{f}_{\rm rem}\dot{R}_*}$$

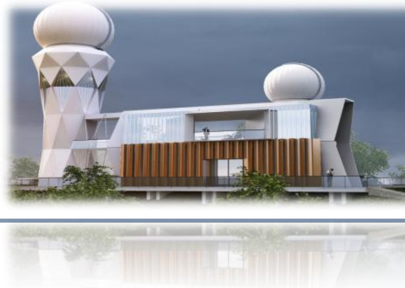
1）AGN-disk stars and metal enrichment



Enrichment timescale is only 0.1-1 Gyr ~ AGN duty cycle, which is consistent with **no redshift evolution in AGN metallicity at z=0-7**!

Top-heavy stellar distribution suggests fast accretion of stars in dense region of AGN disk.



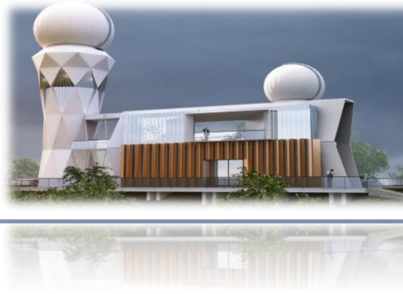


1) AGN disk stars and metal enrichment

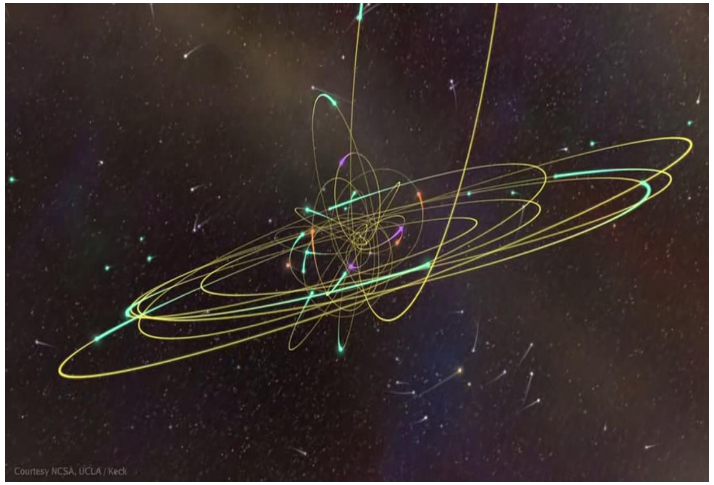
2) Star-disk interaction and stellar distribution in GC

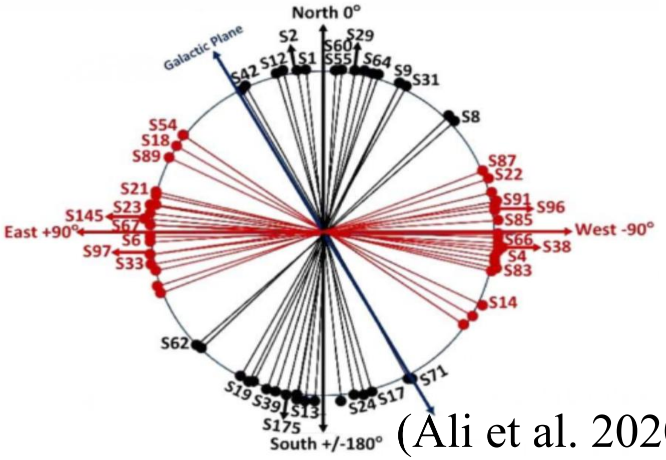
3) EMRI mHz GW background and TDE rates in AGN case

2）Star-disk interaction and Galactic NSC

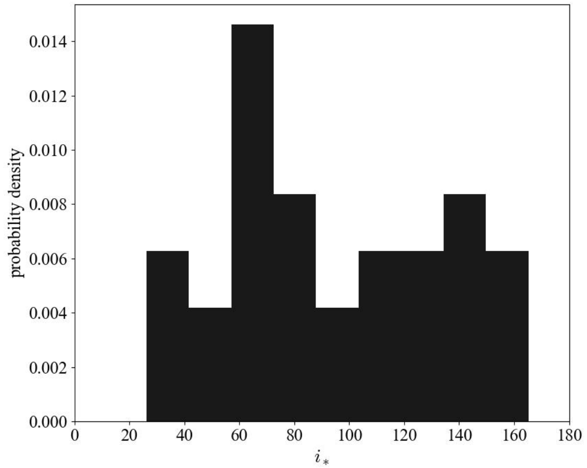


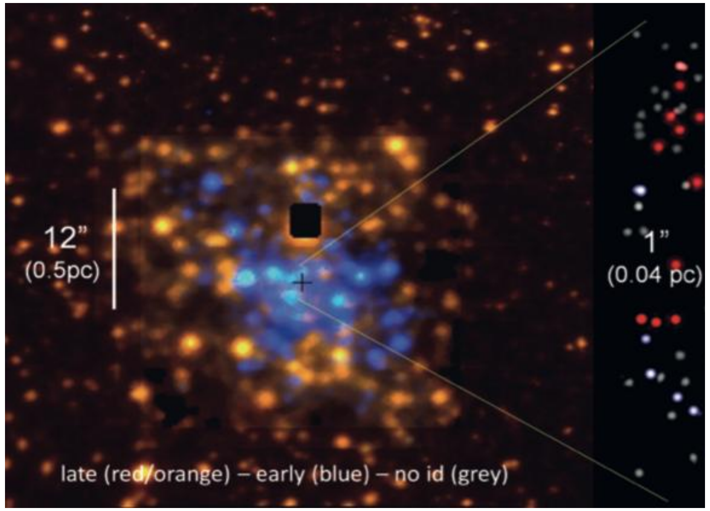
Stellar kinematics in Galactic Center

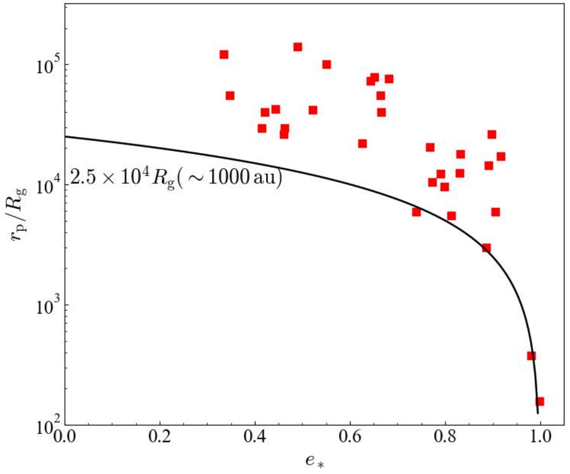




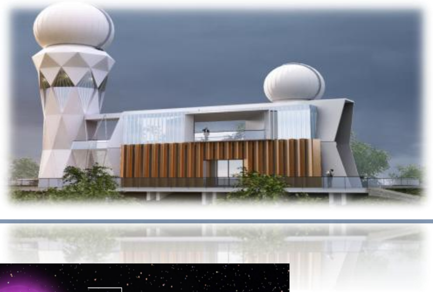
(Ali et al. 2020)







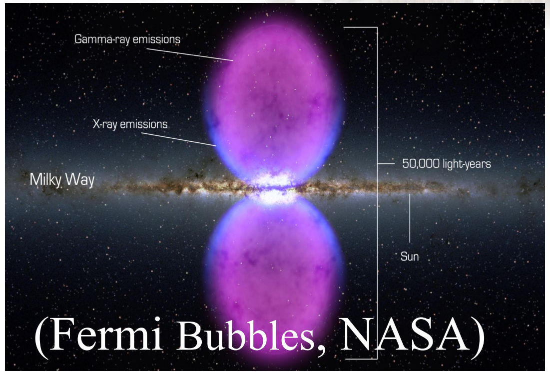
Young, high eccentricity and bimodal distribution of inclination



2）Star-disk interaction and Galactic NSC

Past AGN phase for Sgr A* in million yeas ago?

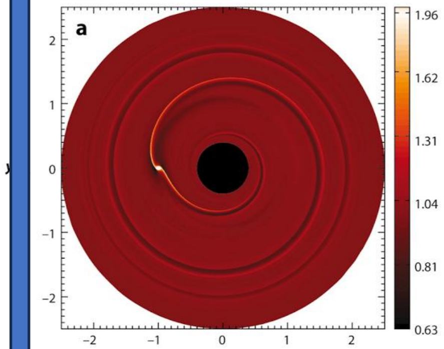
Sgr A* accretion disk will trigger star formation and reshape the stellar distribution.

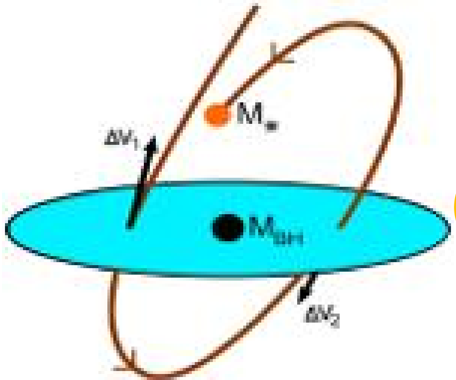


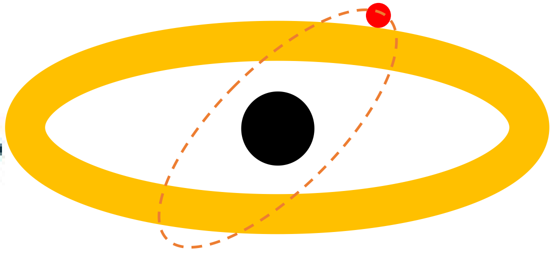
(Fermi Bubbles, NASA)

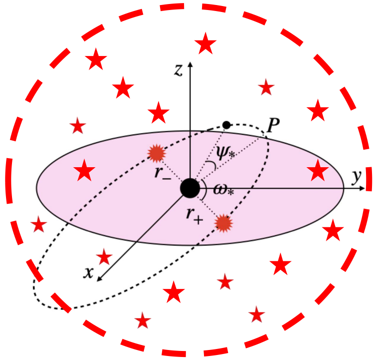
Disk star | **Off-Disk star**

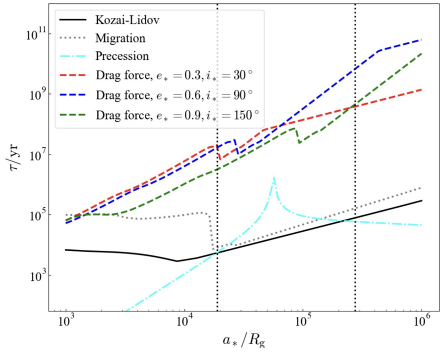
Migration | **Drag force** | **KL mechanism** | **Precession(GR/NSC)** | **Timescale**





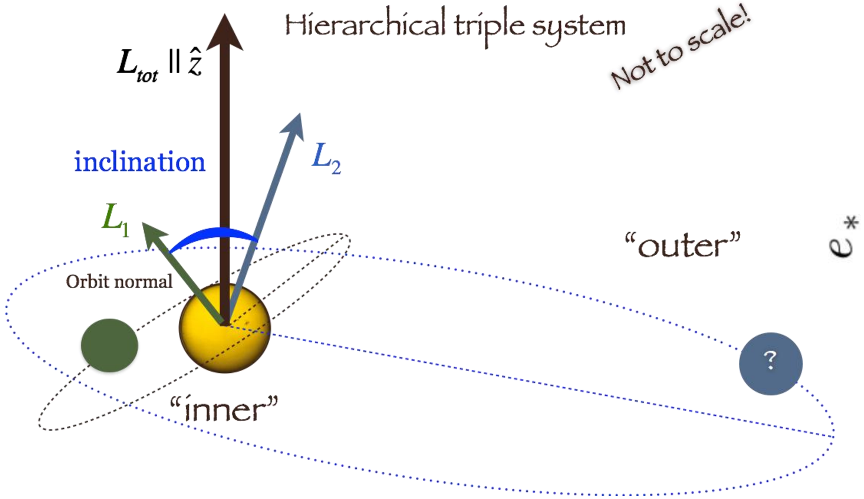


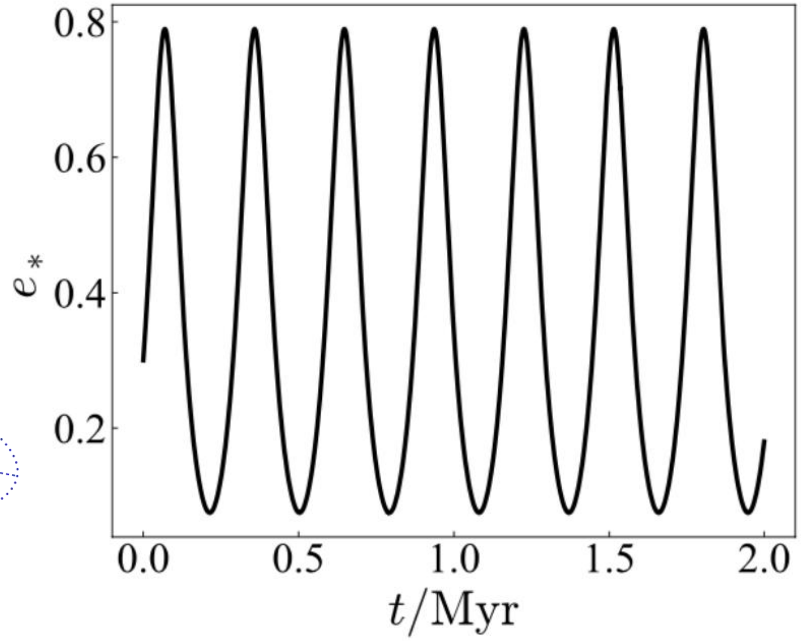


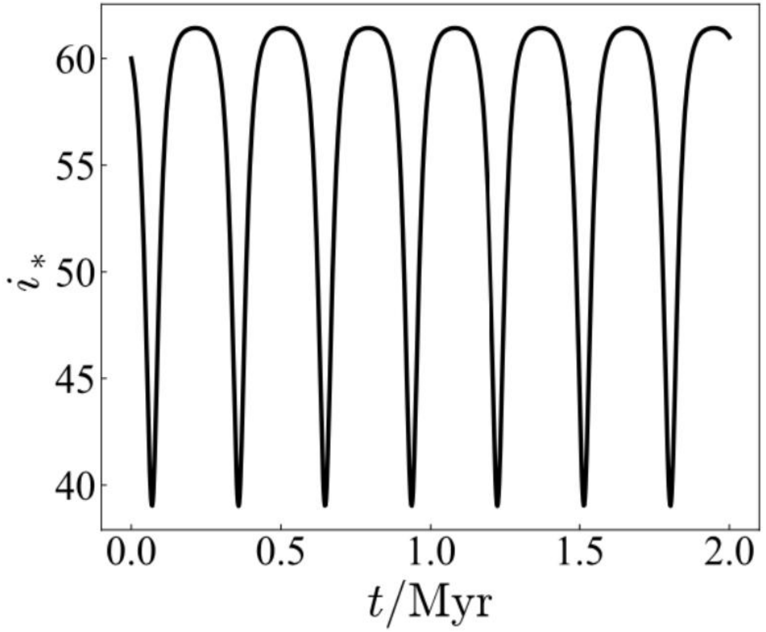


2）Star-disk interaction and Galactic NSC

Kozai-Lidov ossillation







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2）Star-disk interaction and Galactic NSC

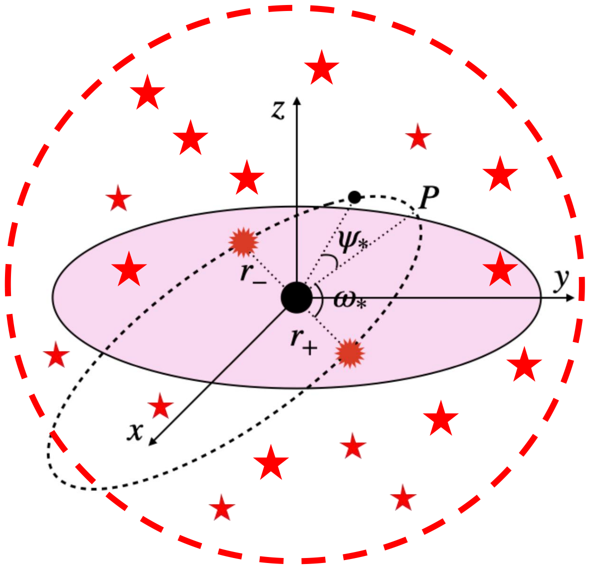
Precession

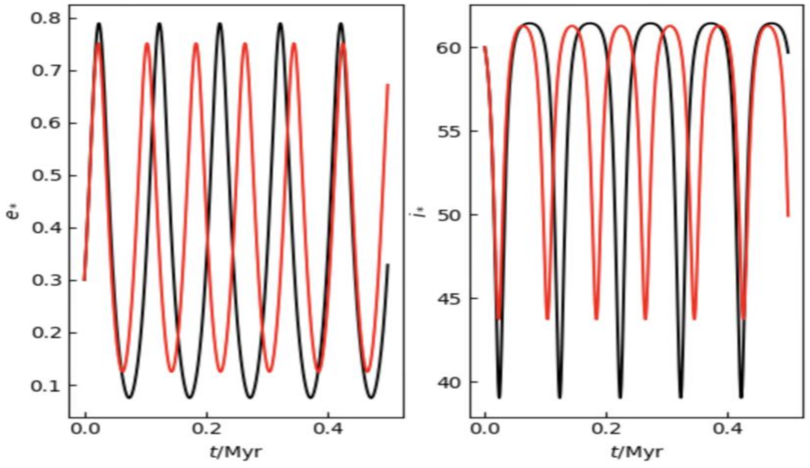
$$\dot{\omega}_{*,\mathrm{prec}} = \boxed{\frac{3(GM_{\mathrm{BH}})^{3/2}}{a_*^{5/2}c^2(1-e_*^2)}} - \boxed{\xi\frac{M_{\mathrm{bulge}}}{M_{\mathrm{BH}}}\sqrt{\frac{GM_{\mathrm{BH}}}{a_*^3}}},$$

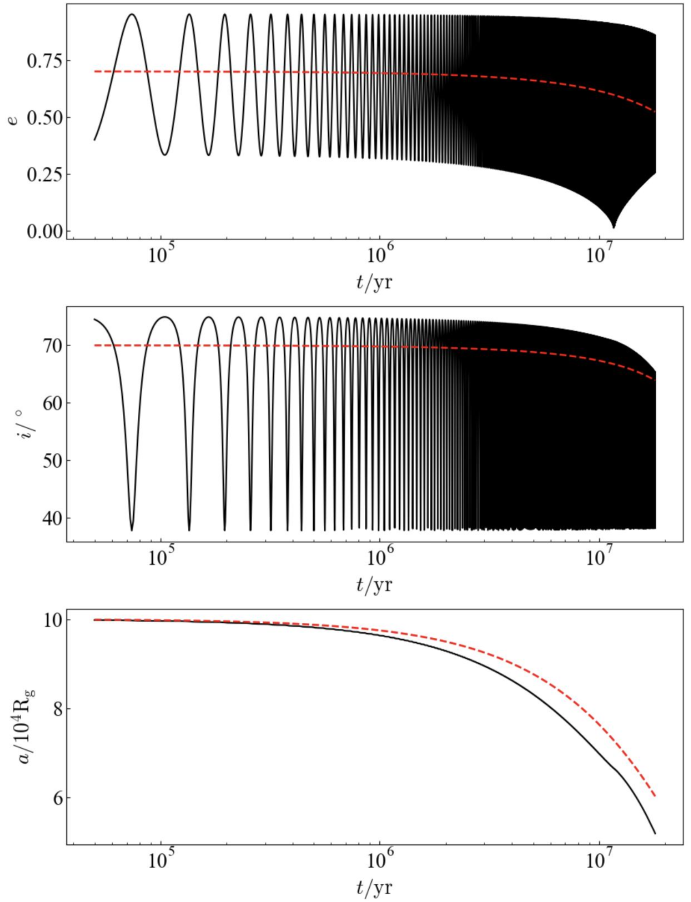
GR

Nuclear star cluster

KL oscillations modulated by periapsis precession







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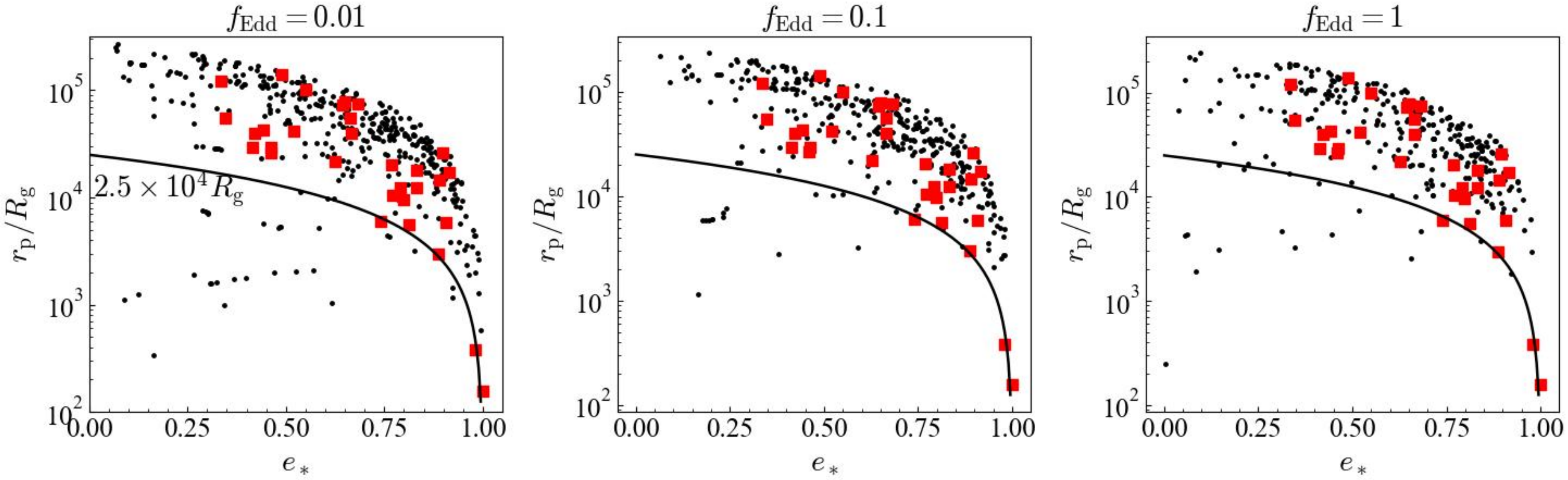
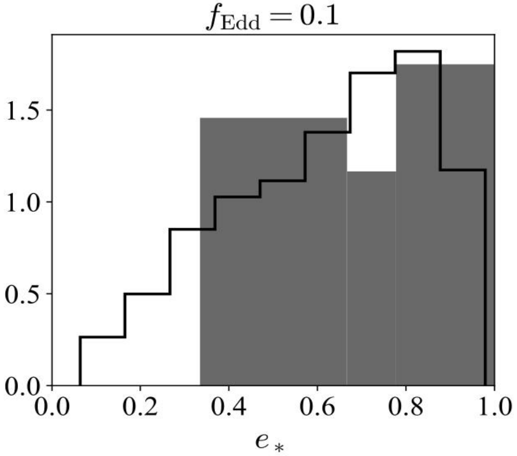
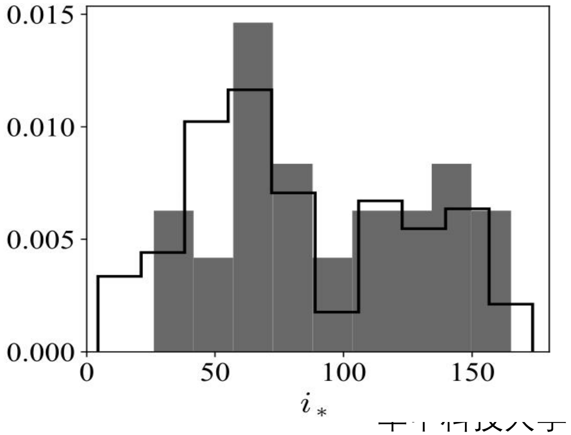
2）Star-disk interaction and Galactic NSC

Simulation on the orbital evolution for stra-dsik interaction(stars in Galactic center)



The stars within 1000 AU will sink into disk and migrate into SMBHs within 5Myr.





KL oscillations of stars are responsible for the bimodal distribution of S-star inclinations.

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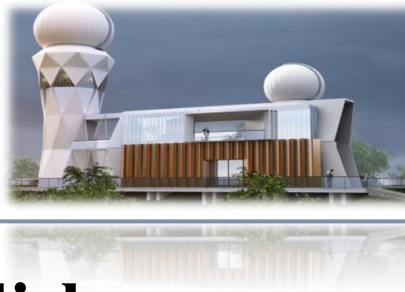
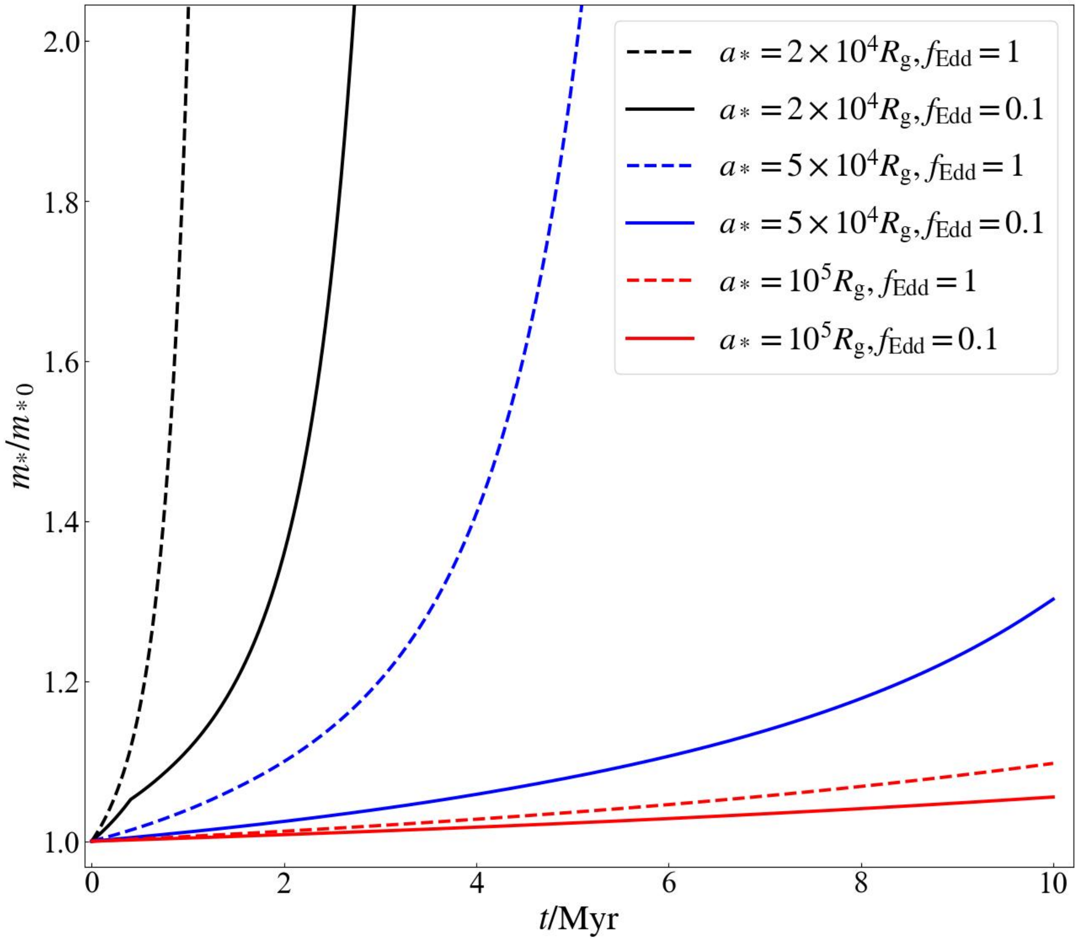
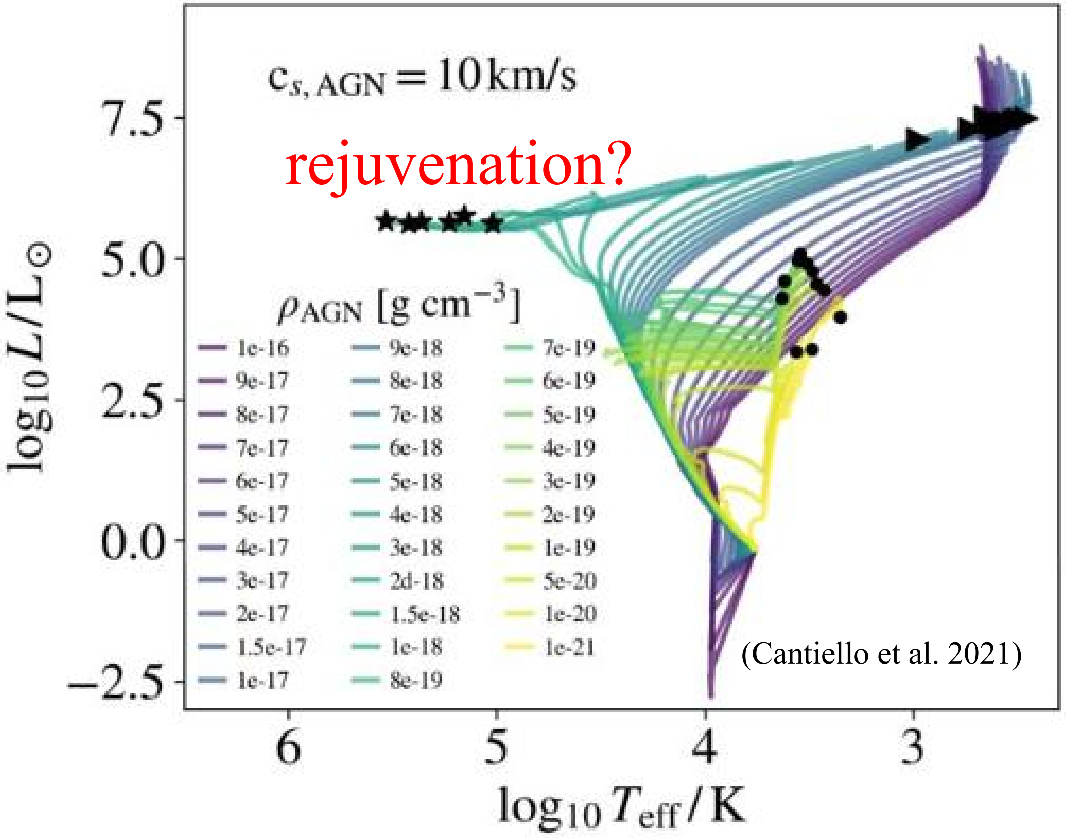


2）Star-disk interaction and Galactic NSC

Star accretion keep them in young during crossing the AGN disk





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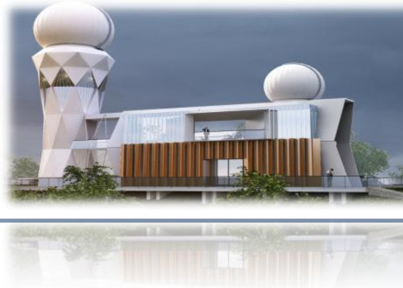

1) **AGN disk stars and metal enrichment**

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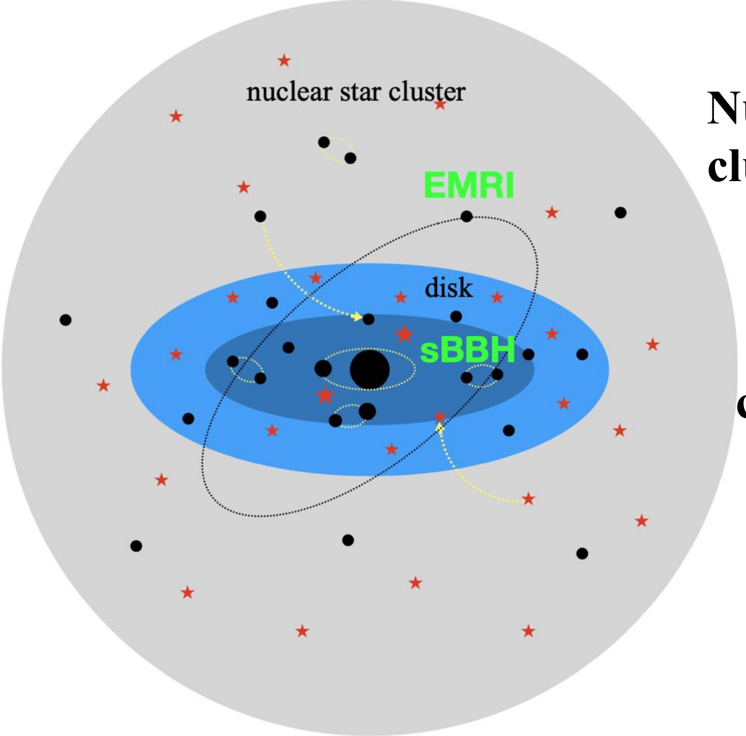
3）EMRI/TDE in AGN phase



Nuclear star cluster component

Disk star component

Extended Fokker-Planck equation

$$\mathscr{C}\frac{\partial f}{\partial t} = -\frac{\partial}{\partial E}F_E - \frac{\partial}{\partial \mathcal{R}}F_{\mathcal{R}} - \boxed{\mathscr{C}\frac{\partial}{\partial m}(f\dot{m})}$$

Accretion effect

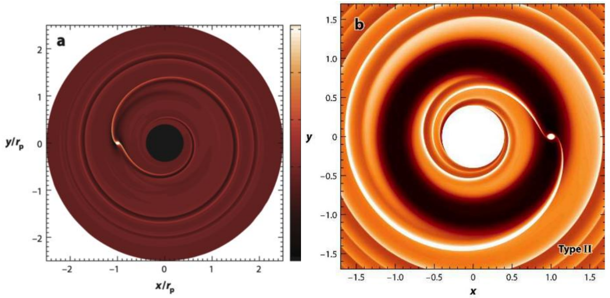
Flux terms:

$$F_E = -\left(D_{EE}\frac{\partial f}{\partial E} + D_{E\mathcal{R}}\frac{\partial f}{\partial \mathcal{R}} + D_E f\right),$$

$$F_{\mathcal{R}} = -\left(D_{\mathcal{R}\mathcal{R}}\frac{\partial f}{\partial \mathcal{R}} + D_{E\mathcal{R}}\frac{\partial f}{\partial E} + D_{\mathcal{R}} f\right).$$

In AGN disk, sBH quickly growth, fast migration, or merger

LIGO: sBH-sBH **Space GW: EMRI**



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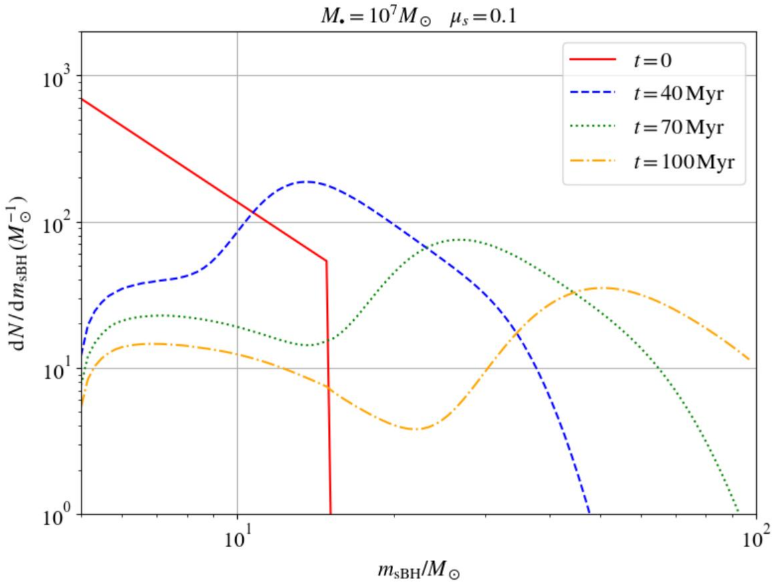
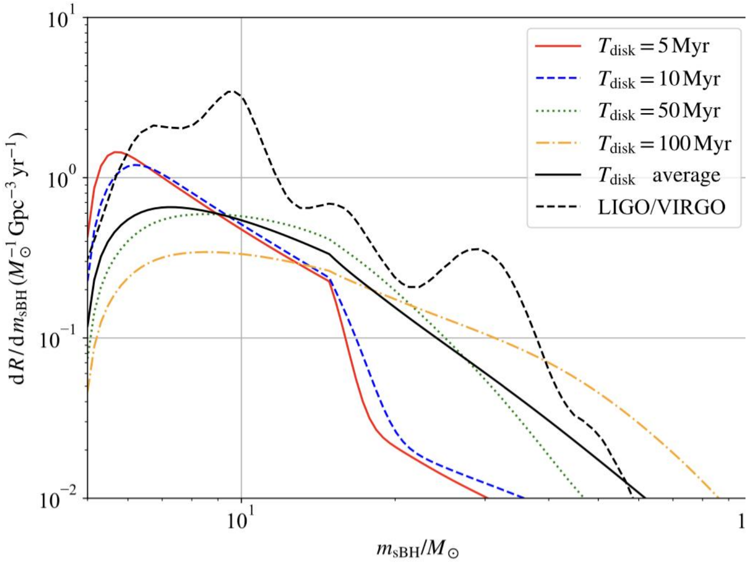
3）EMRI/TDE in AGN phase

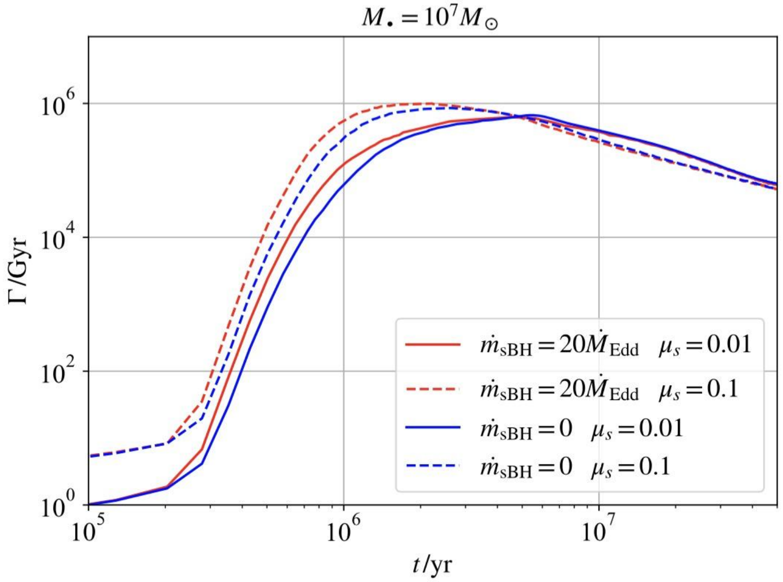
sBH mass distribution



BBH distribution



Simulated EMRI rate



Possible contribution to LIGO detection:~10%-30%

sBH can growth upto ~100Msun within 10 Myrs in AGN disk.

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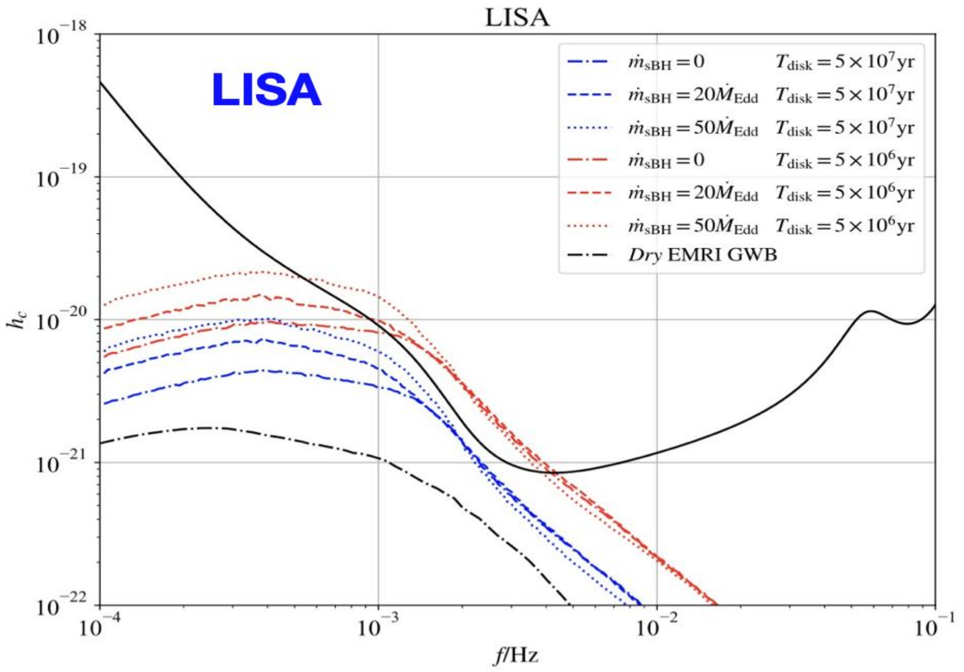
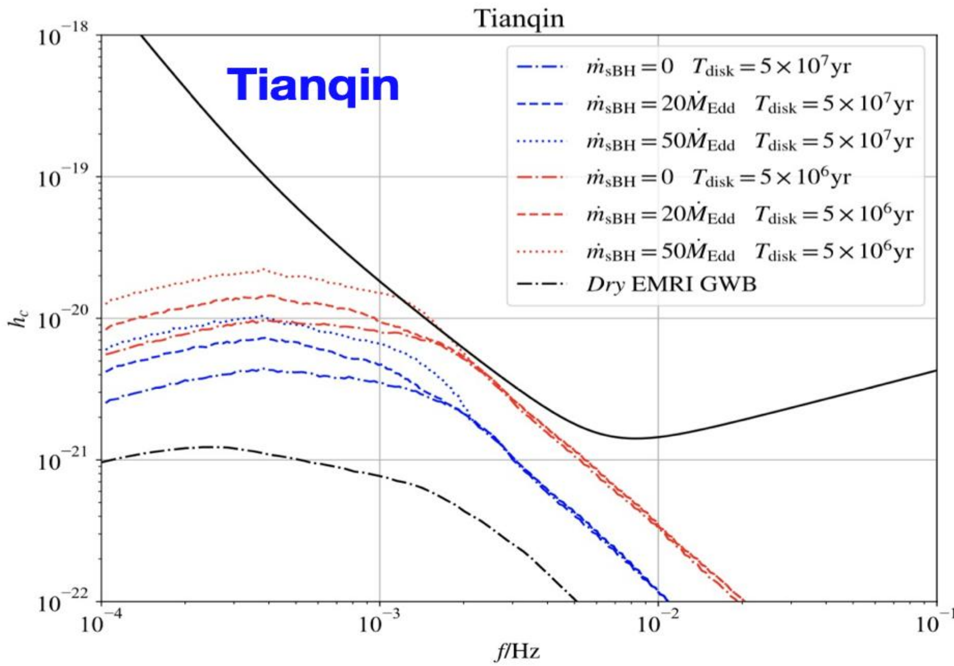
3）EMRI/TDE in AGN phase

Stochastic gravitational wave background for space-borne GW detectors





As foreground, will deteriorate sensitivity by ~3-4 **GW background ~ 10 times stronger than dry one.**

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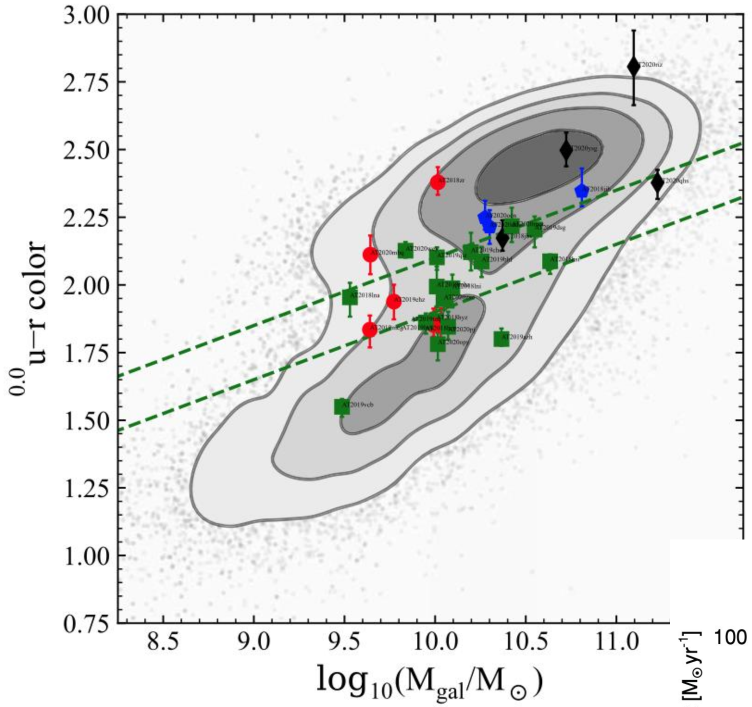
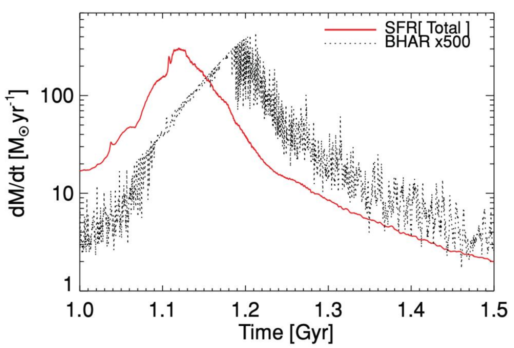
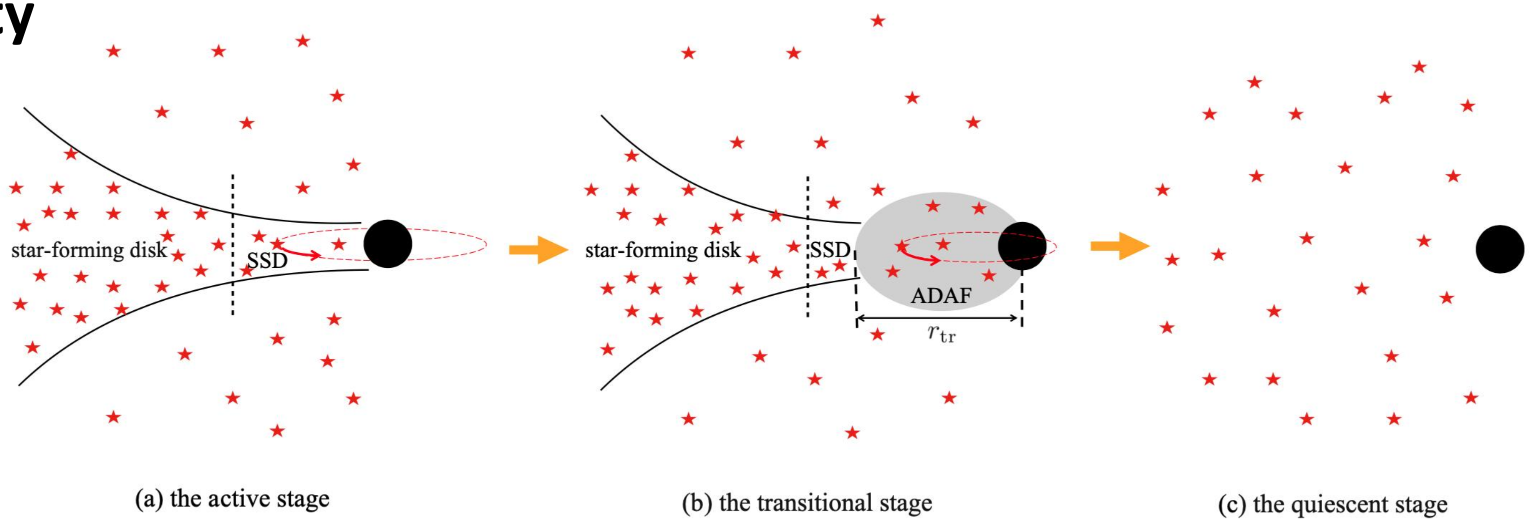
3）EMRI/TDE in AGN phase

TDE rate and BH/galaxy activity



Yao et al. 2023





Distribution function $f(E,R)$ of stars

Fokker-Planck equations

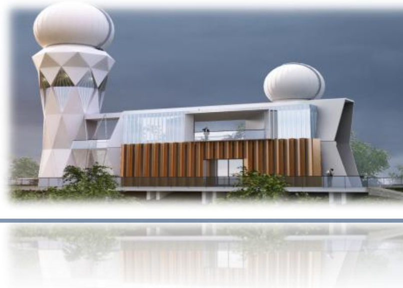
$$C\frac{\partial f}{\partial t} = -\frac{\partial}{\partial E}F_E^f - \frac{\partial}{\partial R}F_R^f - S_{\rm cap},$$

$$C\frac{\partial g}{\partial t} = -\frac{\partial}{\partial E}F_E^g - \frac{\partial}{\partial R}F_R^g + S_{\rm cap} + S_{\rm dSF}$$

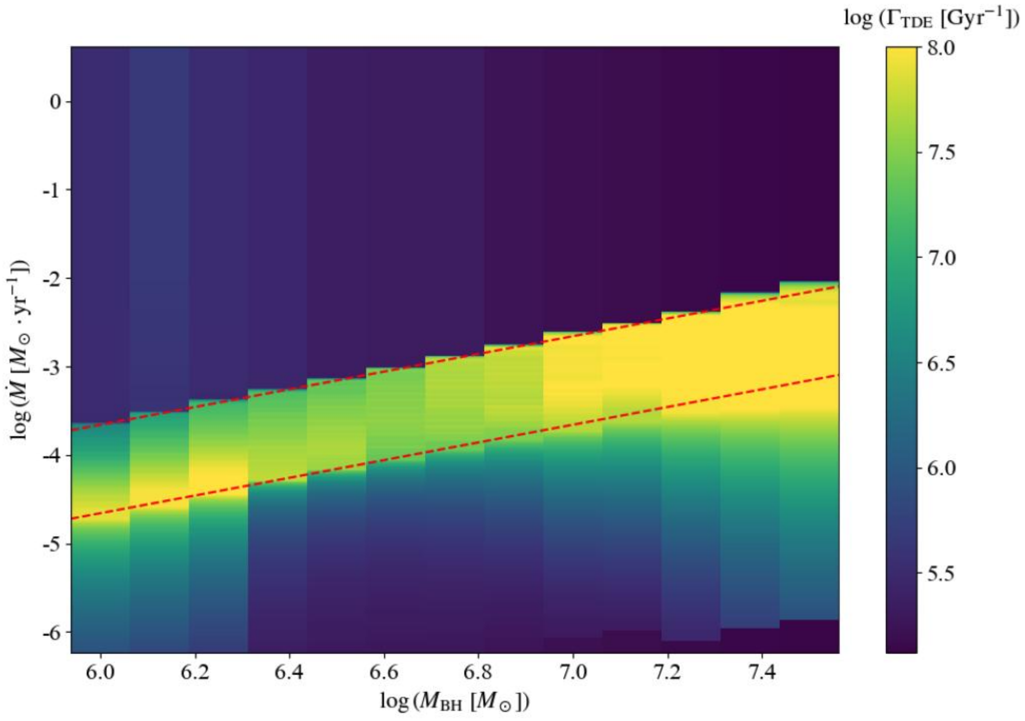
$$\Gamma_{\rm TDE}(M_{\rm BH},t) = \int -(F_R^g + F_R^f)\,dE.$$

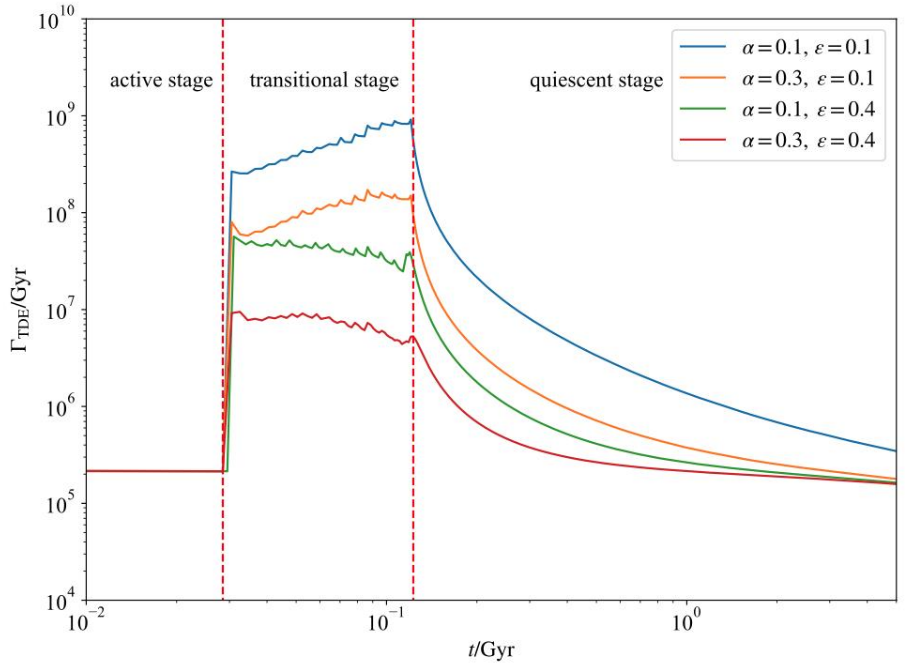
Wang & Wu et al. 2024 ApJ

3）EMRI/TDE in AGN phase



The TDEs are suppressed in AGN phase due to the circularization, and increase a lot after disappearance of AGN disk.





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Summary

The AGN disk will play an important role in reshaping the stellar evolution in nuclear region:

1) Fast growth of stars and metallicity enrichment

2) Special stellar orbit consider the star-AGN disk interaction

3) More EMRIs and stronger GW background due to fast migration

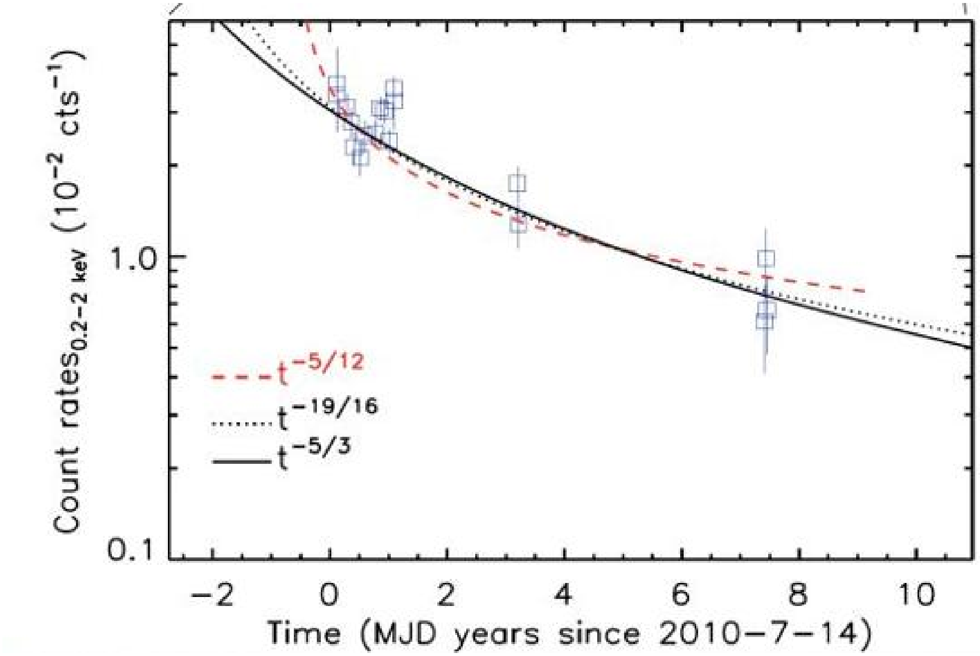
4) Less TDEs due to the circularization effect, and TDE rate will increase just after AGN phase.

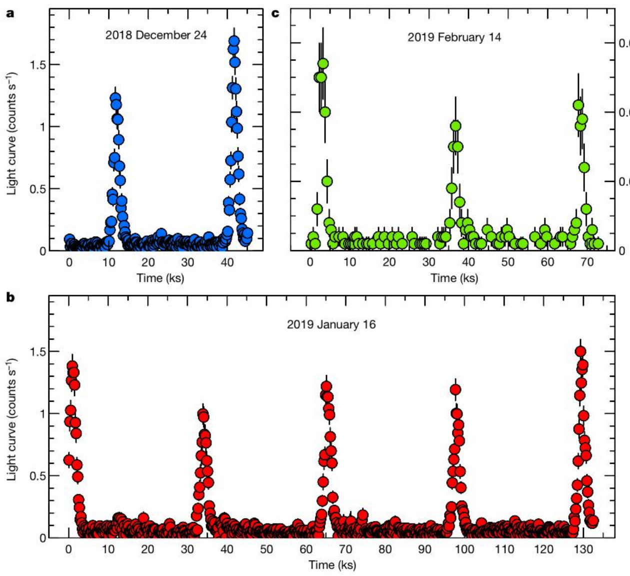

首届AGN吸积盘中AMS天体物理现象研讨会
2023年6月15-17日 南京


第二届AGN吸积盘中AMS天体物理现象研讨会
湖北武汉 2024年5月11日-12日

4 QPE and EMRI

GSN 069: A possible TDE in 2010 and QPE in 2018-2019





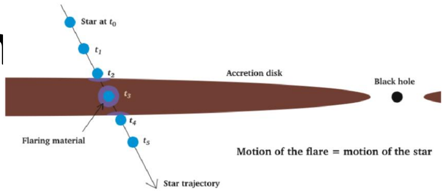
Miniutti et al. 2019 Nature

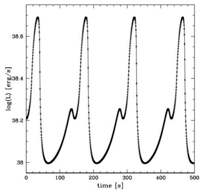
Physical mechanisms:

1) Star and accretion diskinteraction

2) Disk instability

……



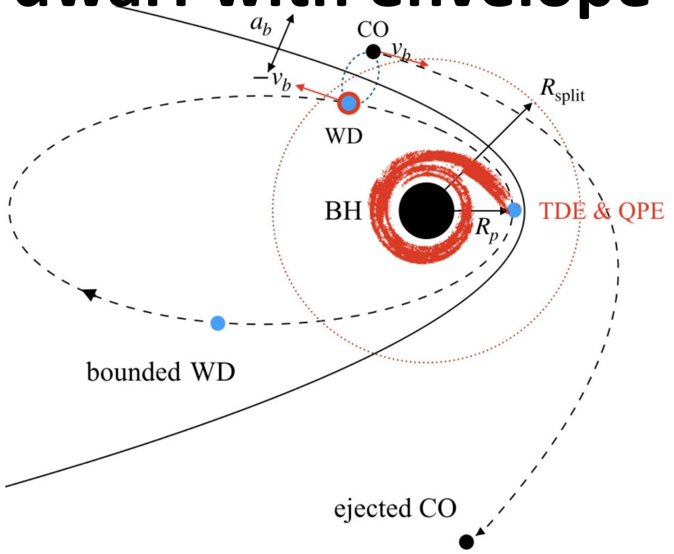


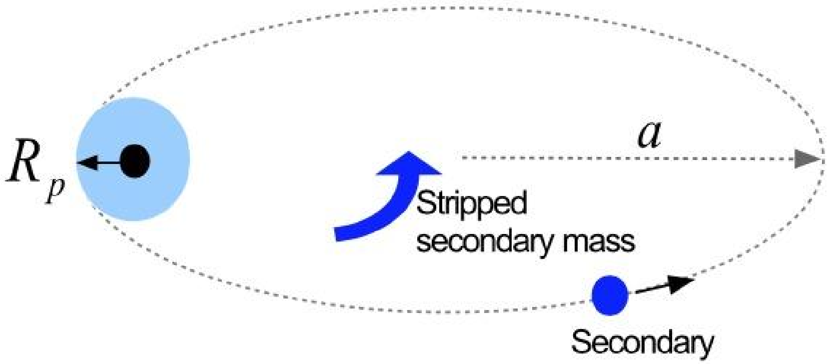
Our model: tidal disruption of white dwarf with envelope

White dwarfs

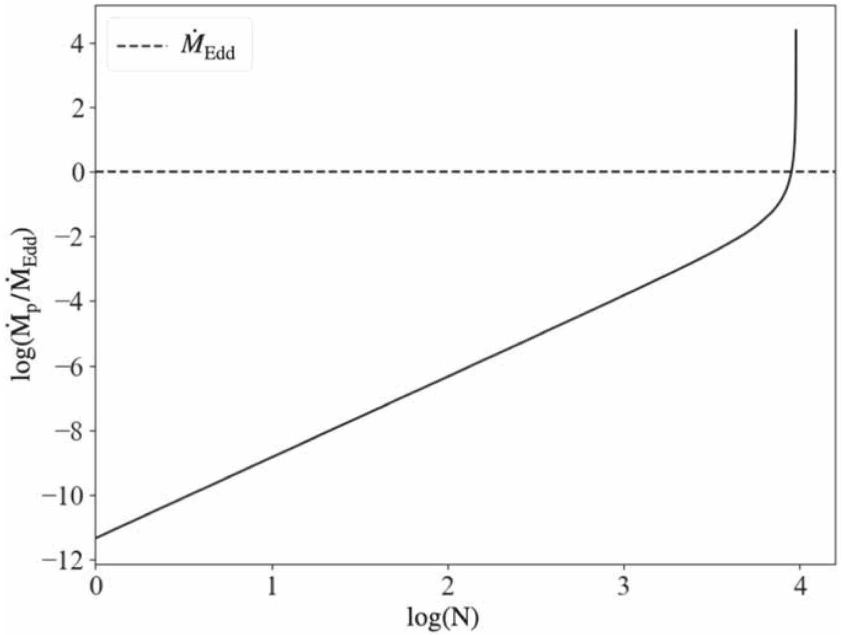
Envelope — Remaining core

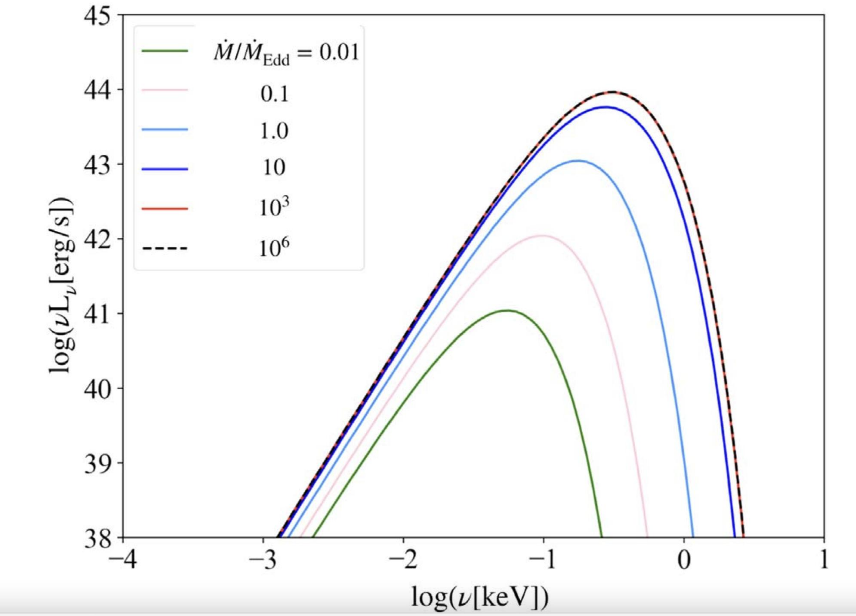
TDE-like flare — QPEs





4 QPE and EMRI

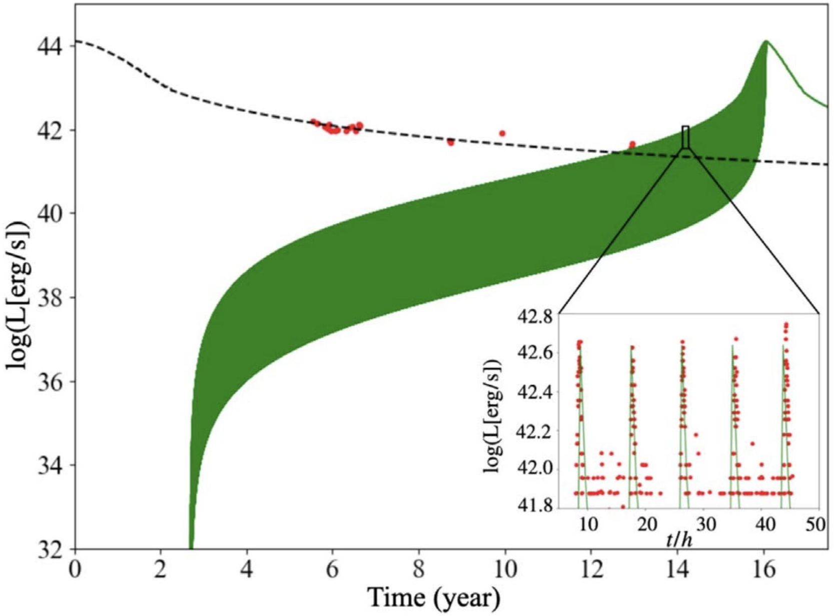


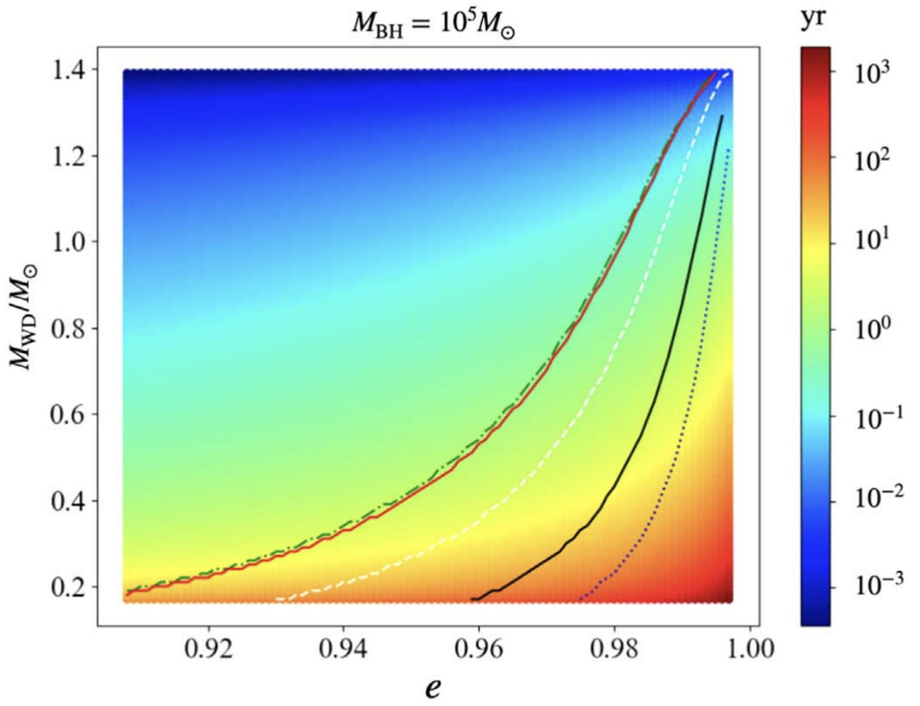


Extremely high accretion rate in last several tens orbits before the white dwarf is fully disrupted.

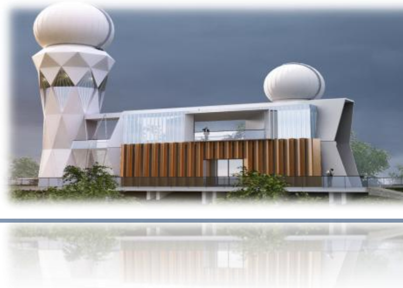
Accretion is super Eddington and radiates at soft X-ray band.

4 QPE and EMRI

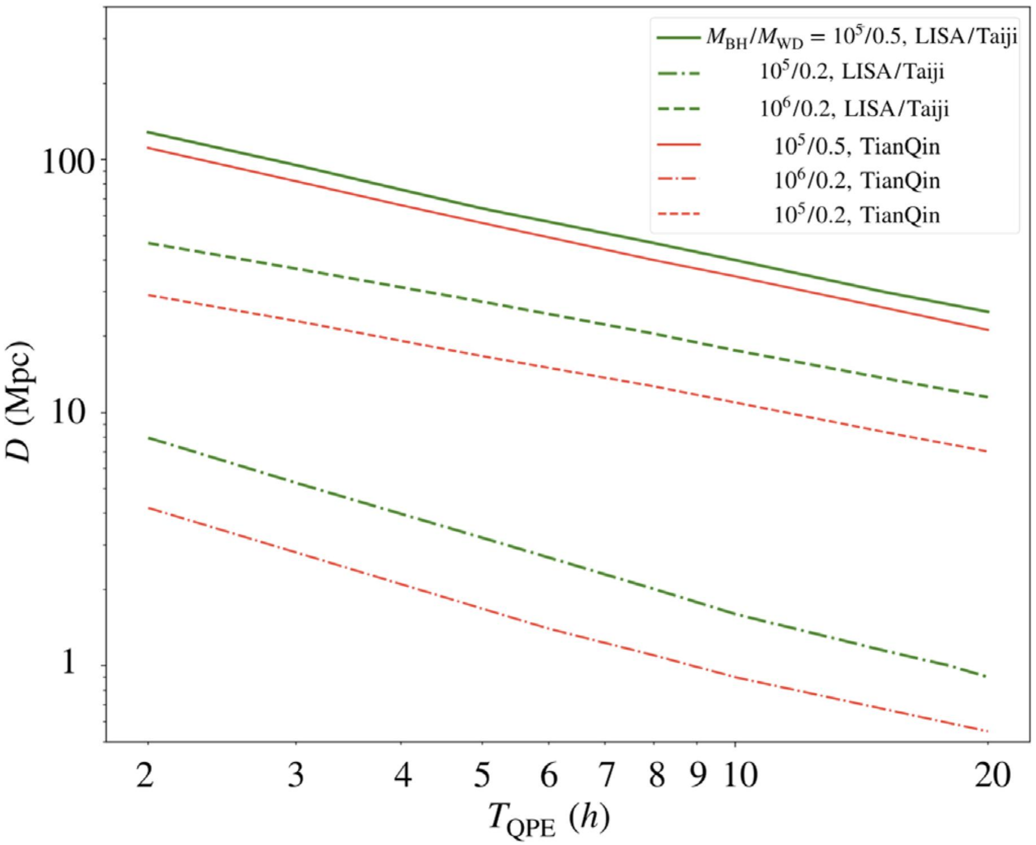




Our theoretical model can explain both the outburst 10 years before the QPE and QPE itself. We predict the the white dwarf will be fully disrupted within several years, and QPE do disappear in last year.



4 QPE and EMRI



Possibility of space-borne GW Detection