Lifetimes and aspect ratios

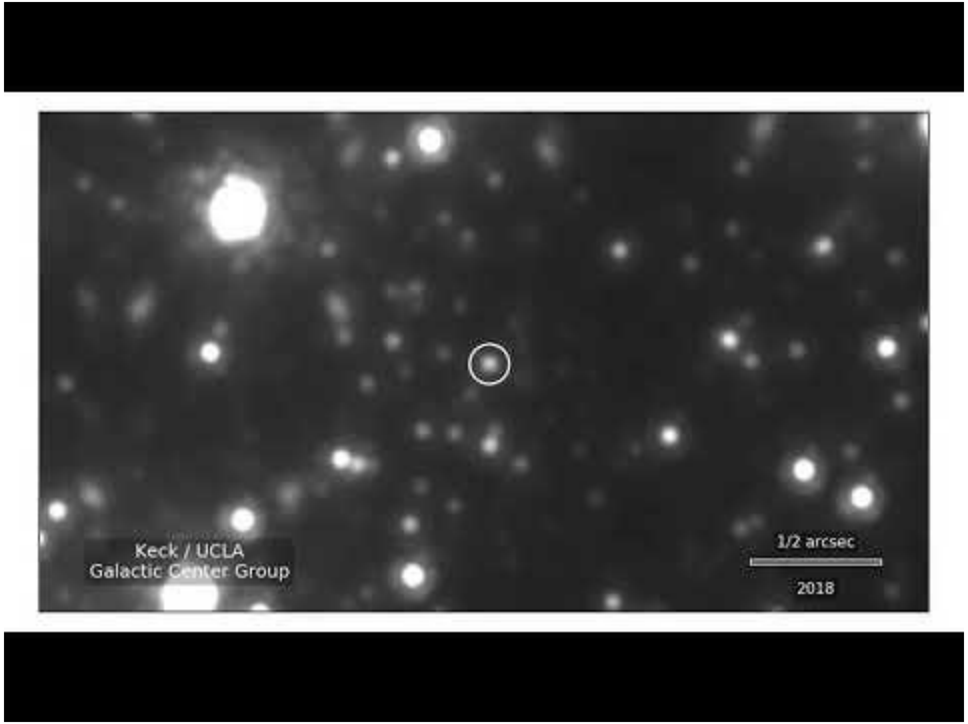
Our nearest galactic nucleus

Pericenter ~few $1000r_g$

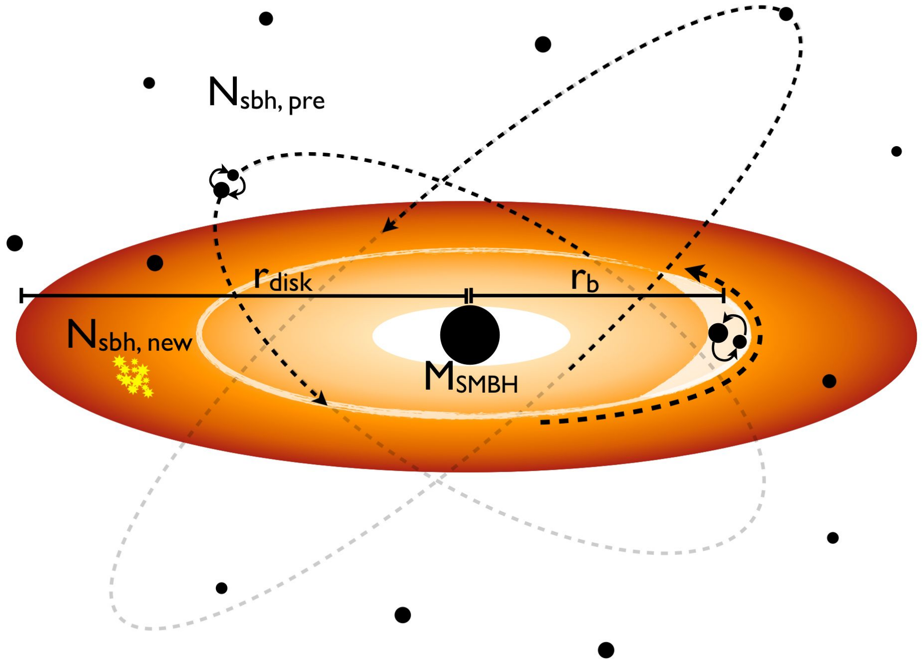
Genzel++ 2018

N_{sBH} ~$2x10^4$

Hailey++ 2018



A cartoon AGN



McKernan, Ford++ 2012
McKernan, Ford++ 2014
Bellovary++ 2016
Bartos++ 2017
Stone++ 2017
McKernan, Ford++ 2018

Image credit: O'Dowd

LIGO-Virgo's GW190706 came from an AGN

Distance means (low mass) IMBH

Progenitors both >50M_{sun}

Formed from prior mergers

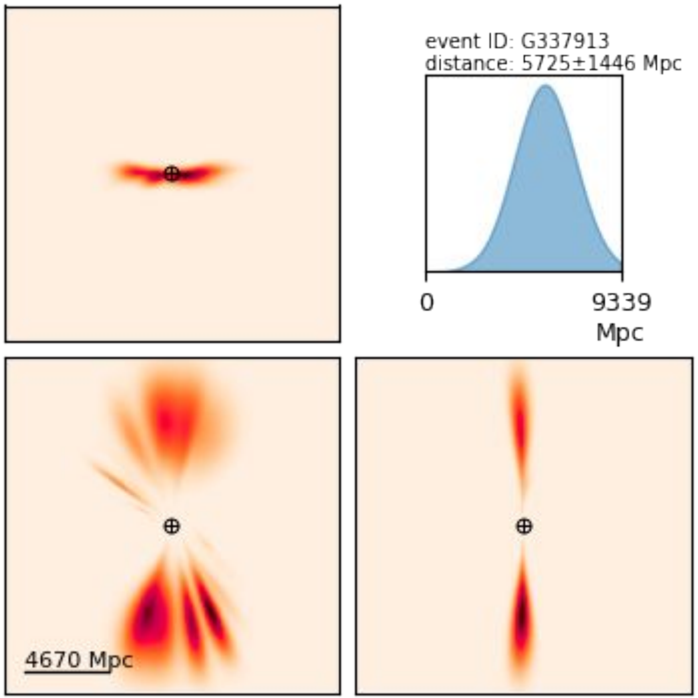
Where v_{esc}>50km/s (Gerosa & Berti 2019)

So a galactic nucleus, but why ***A***GN?

Hierarchical mergers

McKernan, Ford++ 2018; 1702.07818

Yang++ 1906.09281



From GraceDB

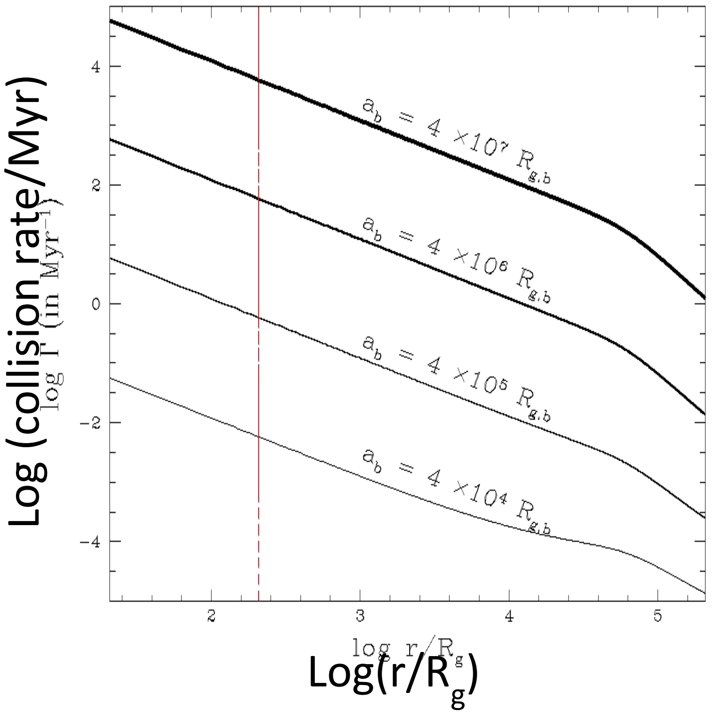
Assume GR

- Isolated, circularized binary

$$\tau_{GW} = \left(\frac{5}{64}\right)\left(\frac{c^5}{G^3}\right)\frac{a_{bin}^4}{M_{bin}^2\mu_{bin}}.$$

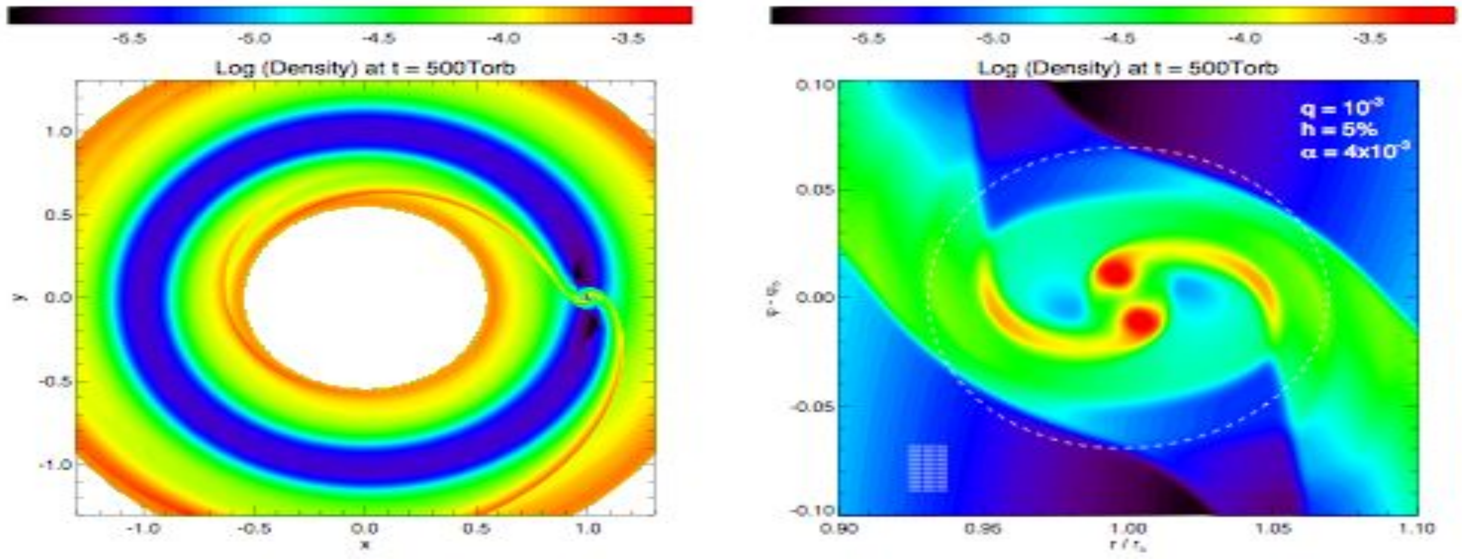
- M_1=15M_{sun}, M_2=10M_{sun}, a_b=4AU
- $t_{GW}=10^5\, t_{Hubble}$

Collisions in NSCs



Leigh, Geller, McKernan, Ford + 2018

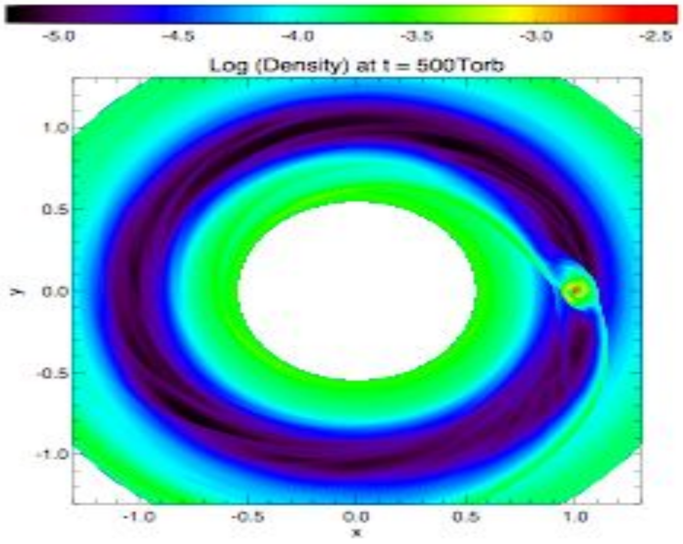
Wakes within Hill sphere harden binary

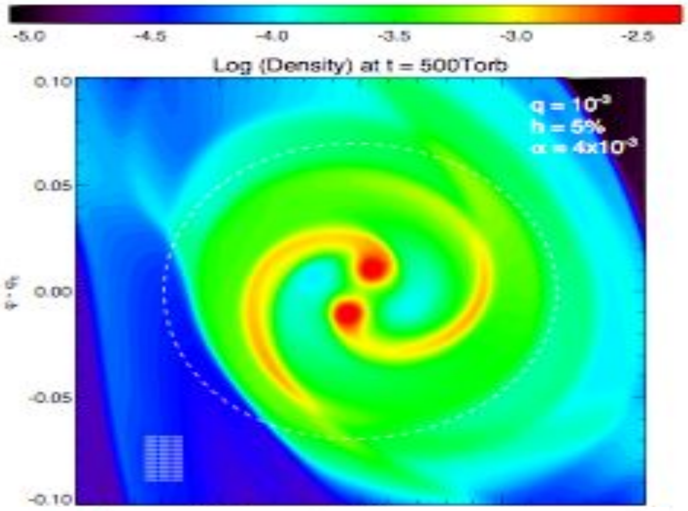


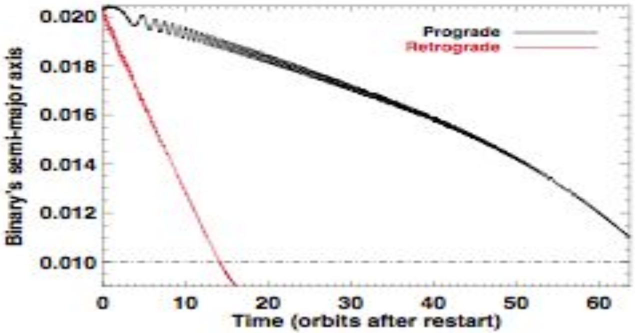
Baruteau+11

- $a_b \rightarrow a_b/2$ in only $\sim 10^3\ T_{orb,bin}$

Retrograde binaries harden faster







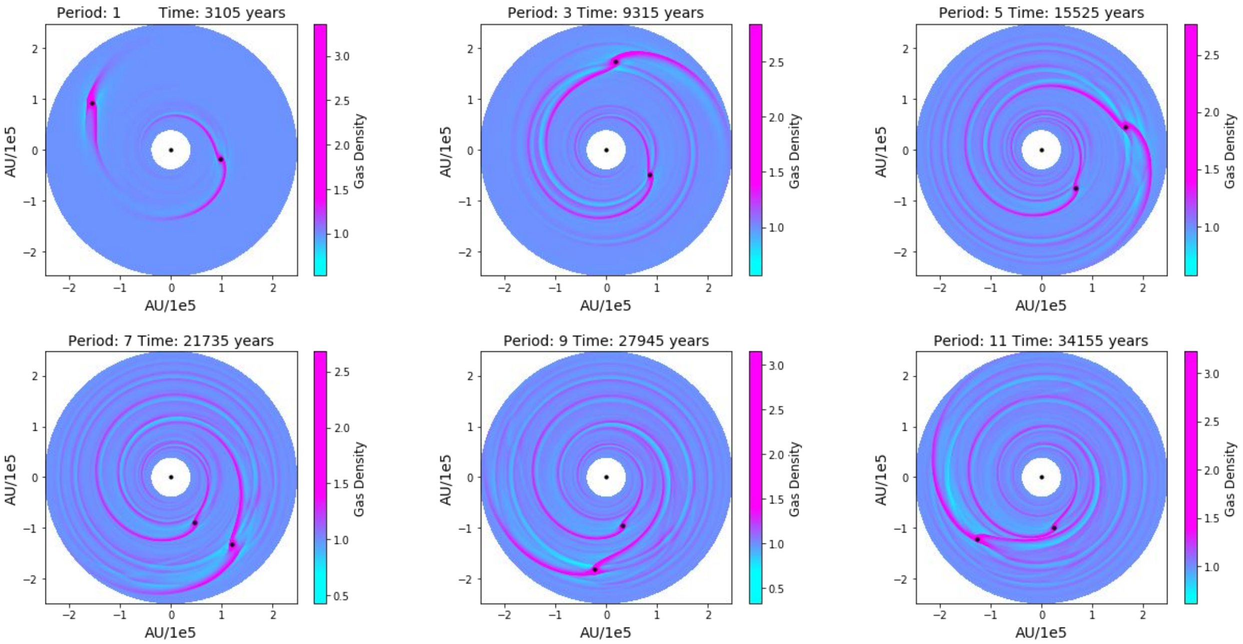
Baruteau+11

- $a_b \rightarrow a_b/2$ in only ~200 $T_{orb,bin}$

Look for Hernandez, Lyra++ 2020

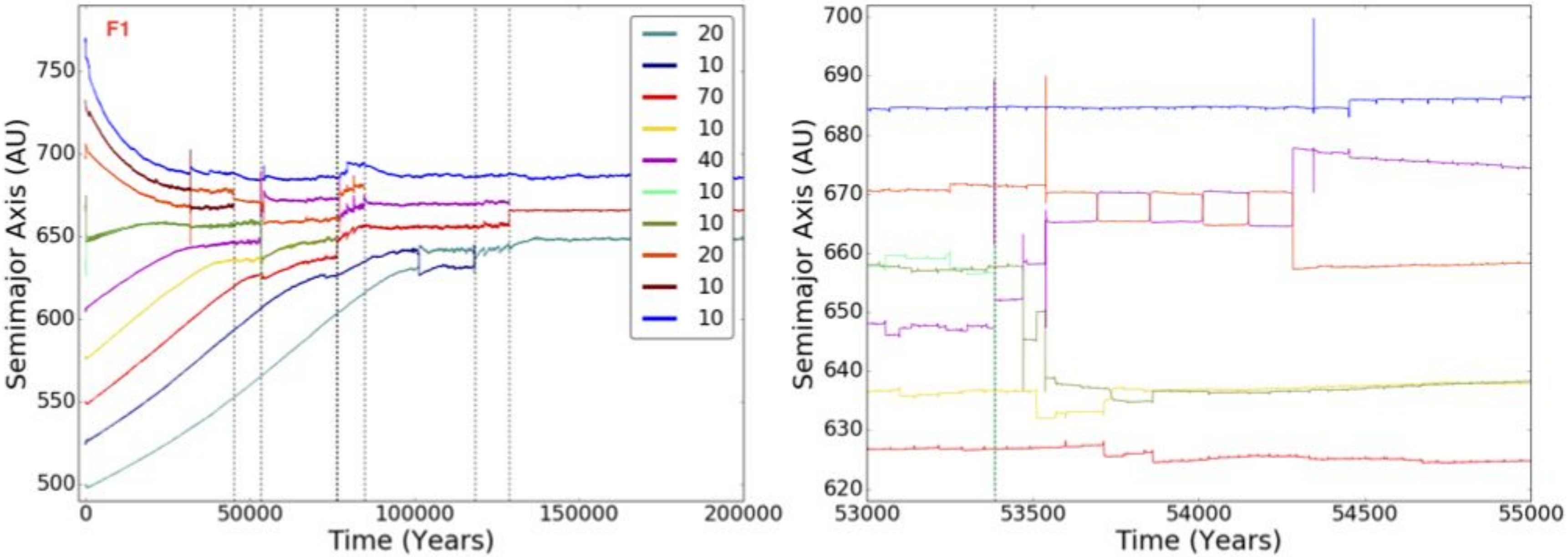
2 bodies in a disk

How do torques change?



Mejia ++ in prep

N-body with migration



Secunda ++2018;
Secunda, Adorno ++ in prep

A Parameterized Rate Equation

$$\mathcal{R}_A = \frac{N_{GN} N_{sBH} f_{AGN} f_d f_b \epsilon}{\tau_{AGN}}$$

McKernan, Ford ++ 2018

arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

AGN fraction

Frac sBH in disk

Binary sBH frac

Ratio Nsbh at t0, i to i+1

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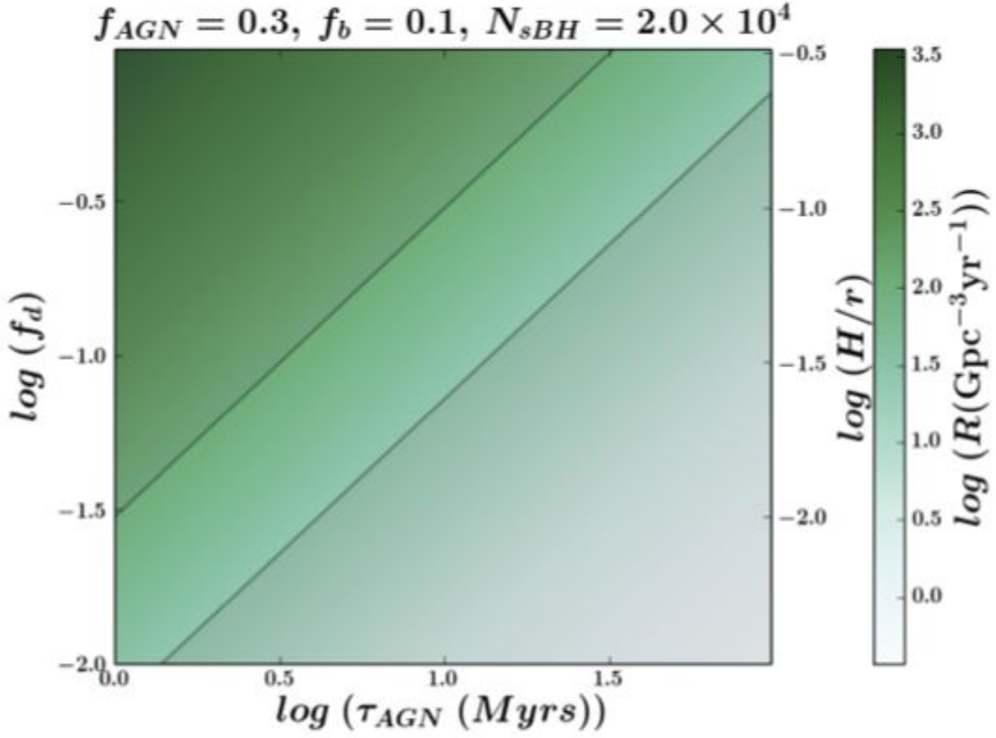
AGN lifetime

McKernan, Ford ++ 2018

arXiv:1702.07818

LINERs: not optically thick RIAFs



Ford & McKernan 2019

What else can we learn?

Statistical inference: current localization + galaxy catalogs

Bartos++ 2017; Ford++ 2019

EM counterparts: multimessenger sources

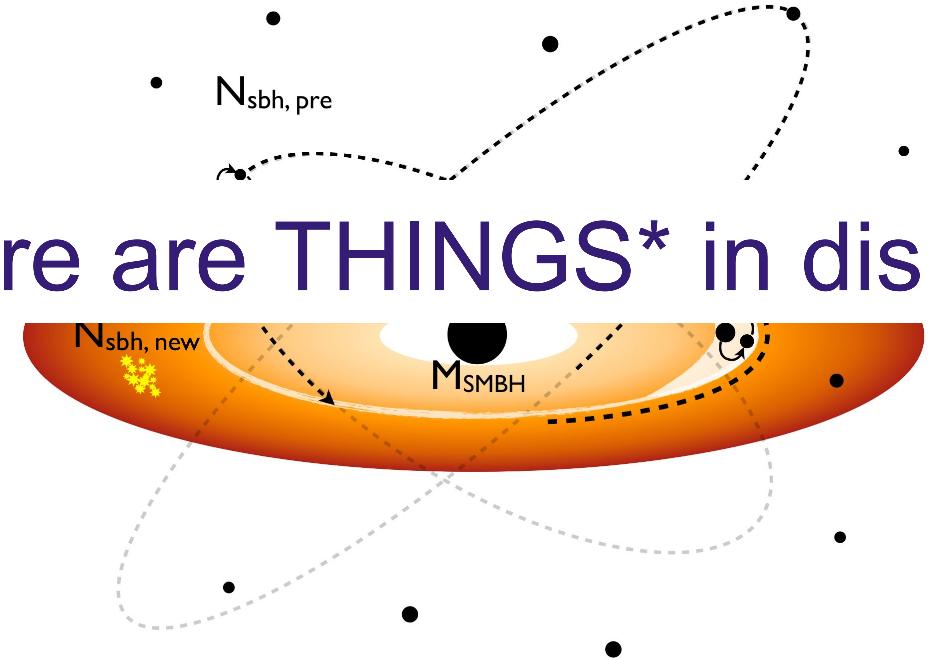
McKernan, Ford++ 2013, 2014, 2015

McKernan, Ford++ 2019: 1907.03746

Make lots of LISA sources

IMBH-SMBH binaries; evolution of multiband BBH

Summary



There are THINGS* in disks!

*THINGS may cause: SNe, TDEs, turbulence, heating… and death. Astrophysicists are not liable for any adverse effects. Ask your astrophysicist about THINGS today.

H/r is not that small

At least in CSQ:

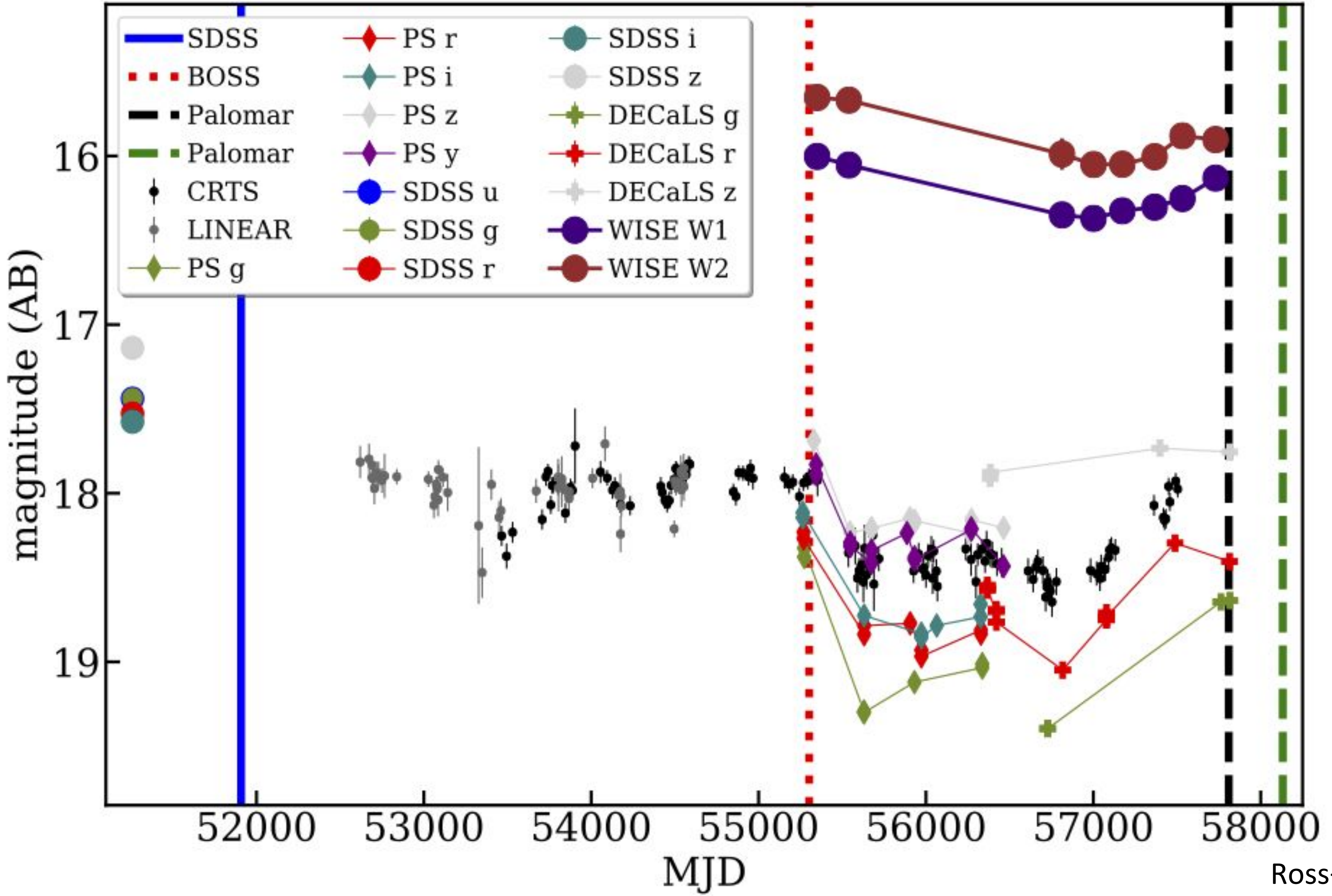
$$t_{\rm orb} \sim 10\,{\rm day} \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right) \left(\frac{R}{150 r_g}\right)^{3/2} \tag{5}$$

$$t_{\rm th} \sim 1\,{\rm yr} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right) \left(\frac{R}{150 r_g}\right)^{3/2} \tag{6}$$

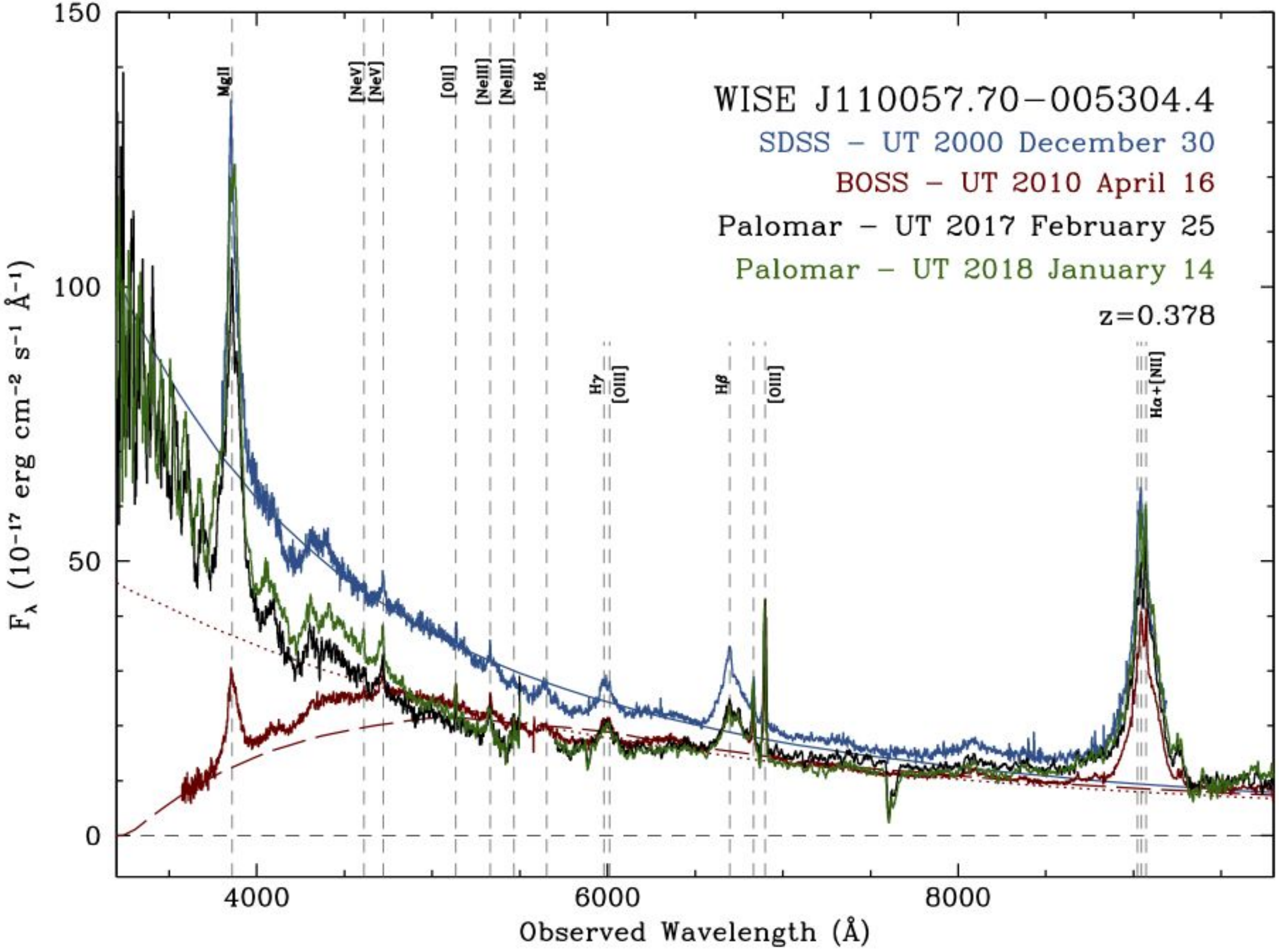
$$t_{\rm front} \sim 20\,{\rm yr} \left(\frac{h/R}{0.05}\right)^{-1} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right) \left(\frac{R}{150 r_g}\right)^{3/2} \tag{7}$$

$$t_{\nu} \sim 400\,{\rm yr} \left(\frac{h/R}{0.05}\right)^{-2} \left(\frac{\alpha}{0.03}\right)^{-1} \left(\frac{M_{\rm BH}}{10^8 M_\odot}\right) \left(\frac{R}{150 r_g}\right)^{3/2} \tag{8}$$

Stern++ 2018

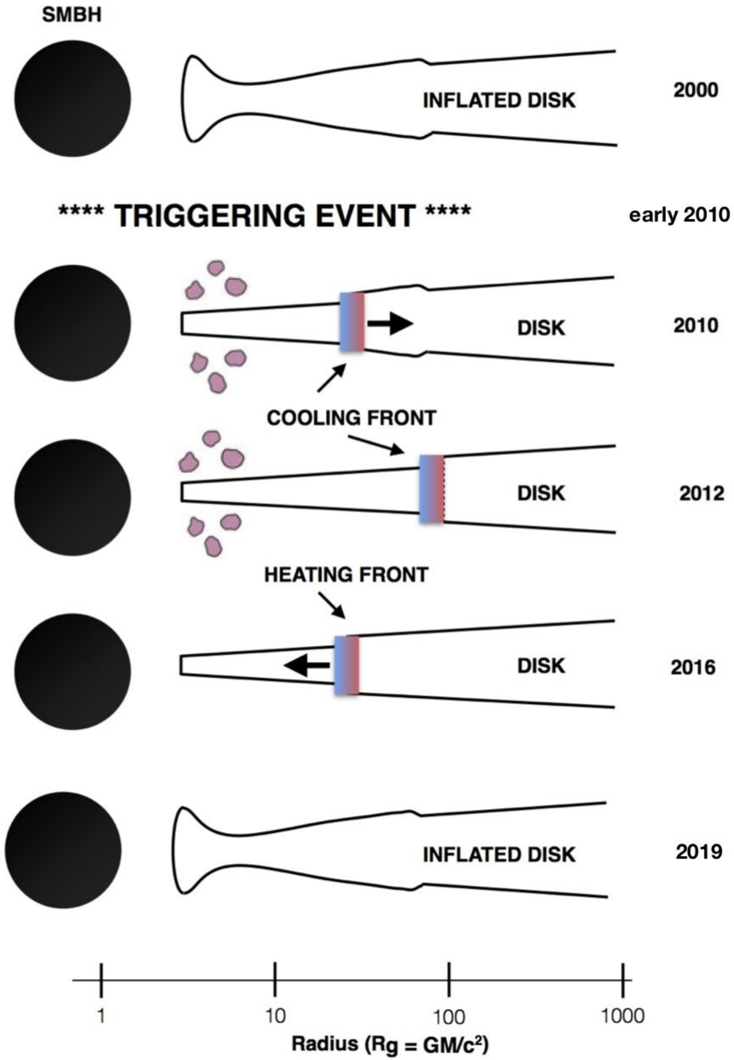

SDSS
BOSS
Palomar
Palomar
CRTS
LINEAR
PS g
PS r
PS i
PS z
PS y
SDSS u
SDSS g
SDSS r
SDSS i
SDSS z
DECaLS g
DECaLS r
DECaLS z
WISE W1
WISE W2
magnitude (AB)
16
17
18
19
52000
53000
54000
55000
56000
57000
58000
MJD

Ross++ 2018



WISE J110057.70−005304.4
SDSS – UT 2000 December 30
BOSS – UT 2010 April 16
Palomar – UT 2017 February 25
Palomar – UT 2018 January 14
z=0.378
MgII
[NeV]
[NeV]
[OII]
[NeIII]
[NeIII]
Hδ
Hγ
[OIII]
Hβ
[OIII]
Hα+[NII]
150
100
50
0
4000
6000
8000
Observed Wavelength (Å)
F$_\lambda$ (10^{-17} erg cm^{-2} s^{-1} Å^{-1})

Ross++ 2018

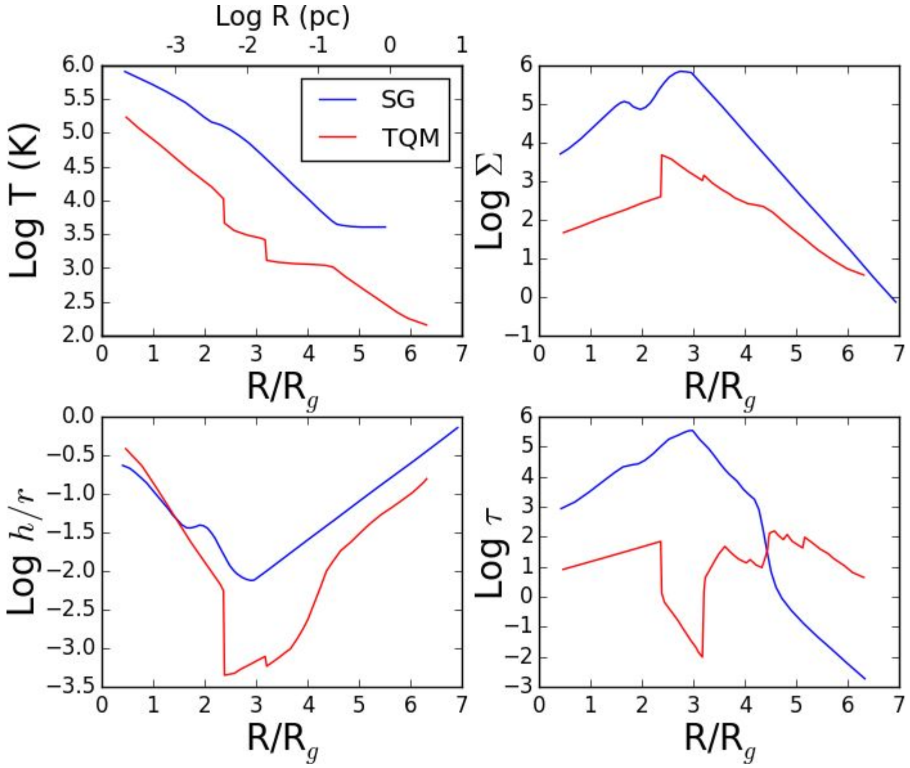

SMBH
INFLATED DISK
2000
**** TRIGGERING EVENT ****
early 2010
DISK
2010
COOLING FRONT
DISK
2012
HEATING FRONT
DISK
2016
INFLATED DISK
2019
1
10
100
1000
Radius (Rg = GM/c²)

Ross++ 2018

Spin

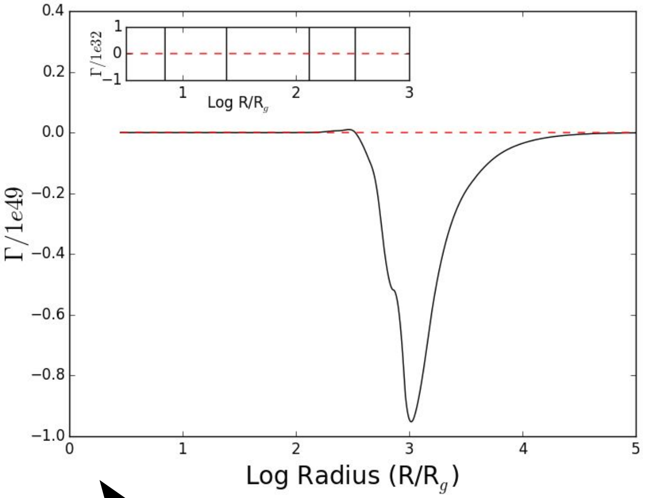
$$\vec{\chi}_{\mathrm{eff}} = \frac{M_1\vec{S}_1 + M_2\vec{S}_2}{M_1 + M_2} \bullet \vec{L}_b.$$

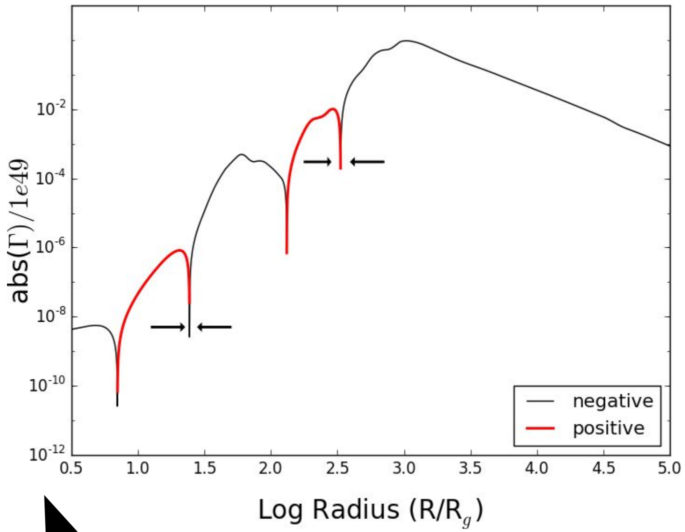
AGN disk models



Sirko & Goodman 2003 Thompson, Quataert & Murray 2005

Migration traps in S&G model





Bellovary, MacLow, McKernan & Ford 2016

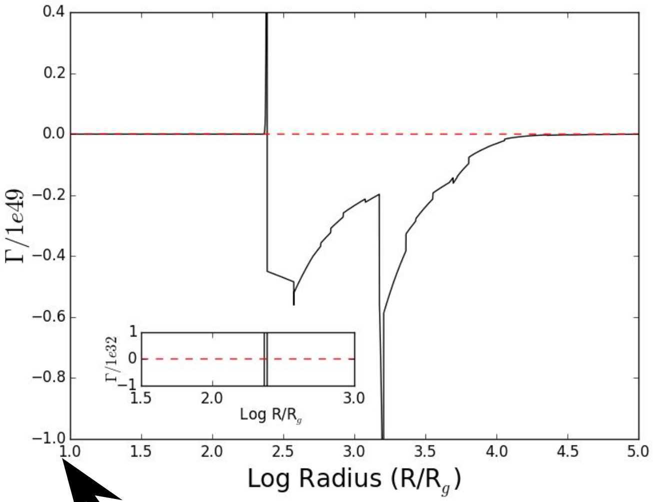
Linear scale

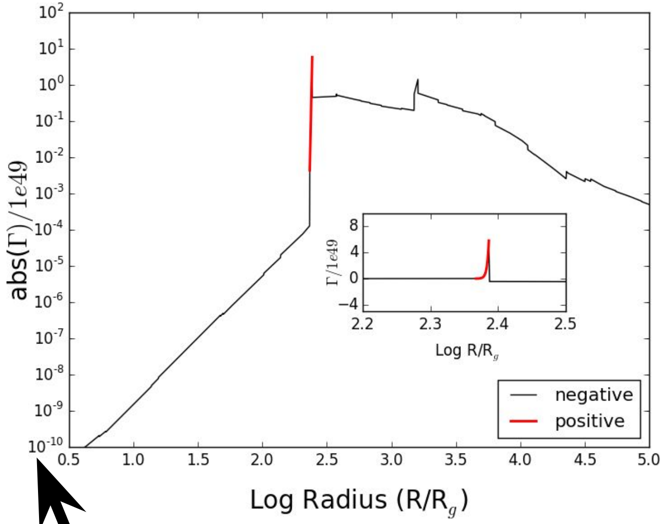
Log scale

24.5 and $331\ R_g$

Sirko & Goodman 2003 disk model: TWO TRAPS

Migration traps in TQM model





Bellovary, MacLow, McKernan & Ford 2016

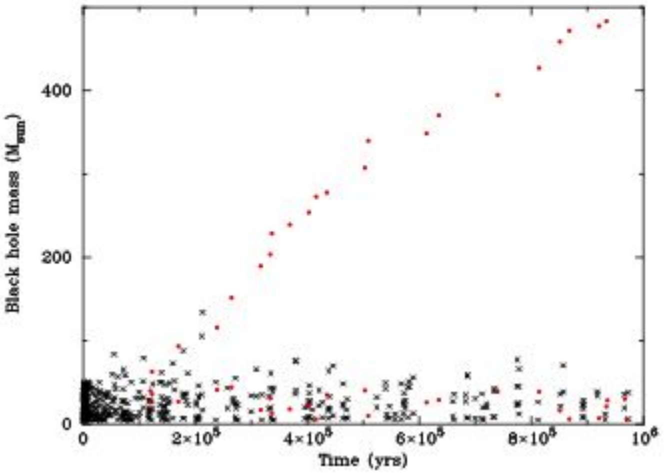
Log scale

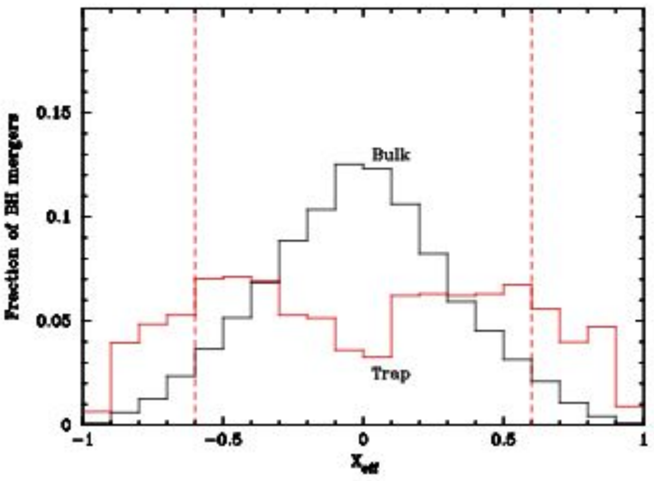
Linear scale

Thompson Quataert & Murray 2005 disk model: ONE TRAP

$\boxed{245\ R_g}$

BBH mergers in AGN disks





McKernan, Ford, O'Shaughnessy & Wysocki submitted
1907.04356

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McKernan, Ford ++ 2018

arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

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McKernan, Ford ++ 2018

arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

$$\mathcal{R}_A = \frac{N_{GN} N_{sBH} f_{AGN} f_d f_b \epsilon}{\tau_{AGN}}$$

McKernan, Ford ++ 2018
arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

AGN fraction

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arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

AGN fraction

Frac sBH in disk

$$\mathcal{R}_A = \frac{N_{GN} N_{sBH} f_{AGN} f_d f_b \epsilon}{\tau_{AGN}}$$

McKernan, Ford ++ 2018

arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

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Frac sBH in disk

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$$\mathcal{R}_A = \frac{N_{GN} N_{sBH} f_{AGN} f_d f_b \epsilon}{\tau_{AGN}}$$

AGN lifetime

McKernan, Ford ++ 2018

arXiv:1702.07818

A Parameterized Rate Equation

density of galactic nuclei

stellar mass BH

AGN fraction

Frac sBH in disk

Binary sBH frac

Ratio Nsbh at t0, i to i+1

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AGN lifetime

McKernan, Ford ++ 2018

arXiv:1702.07818

Naive timescale argument

- AGN rate dominates quiescent GN rate if

$$f_{AGN}\left(\frac{t_{b,Q}}{t_{b,A}}\right) > 1$$

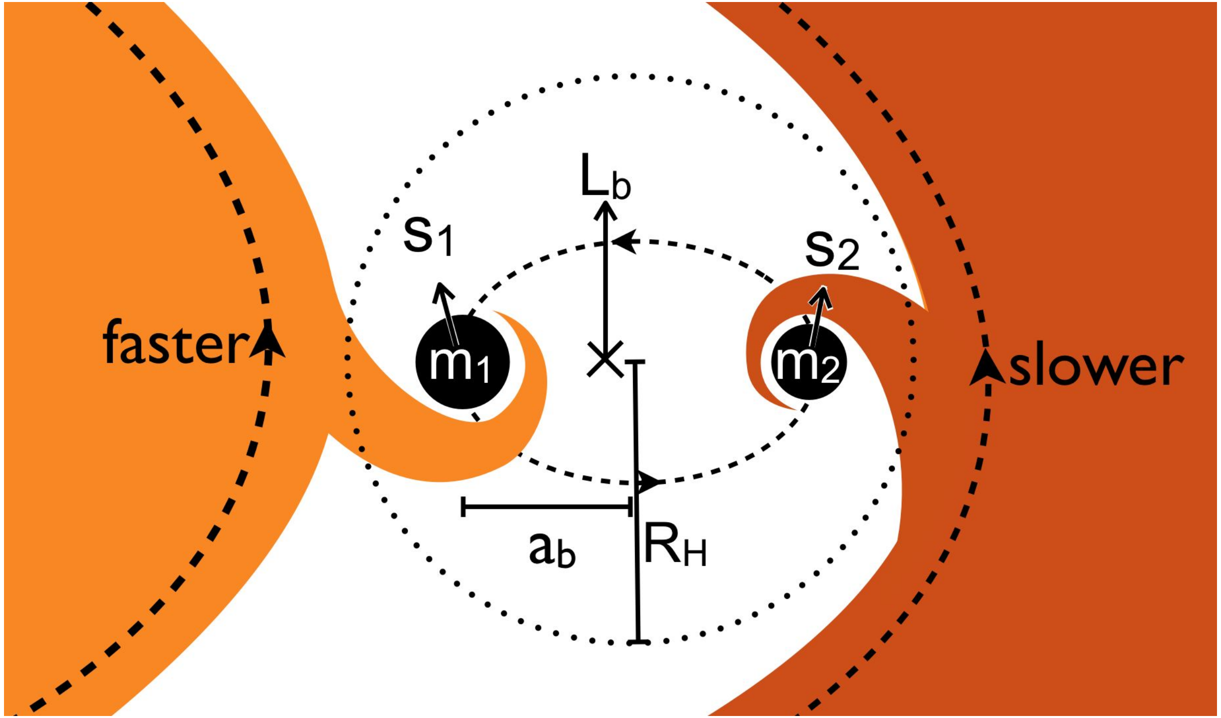
Naive timescale argument

- AGN rate dominates quiescent GN rate if

$$f_{AGN}\left(\frac{t_{b,Q}}{t_{b,A}}\right) > 1$$

- If $f_{AGN} \sim 0.01$, just need $t_{b,A} < 10^{-2}\, t_{b,Q}$

Binary merger timescales in disk?



$$R_H = r_b (q/3)^{1/3}$$