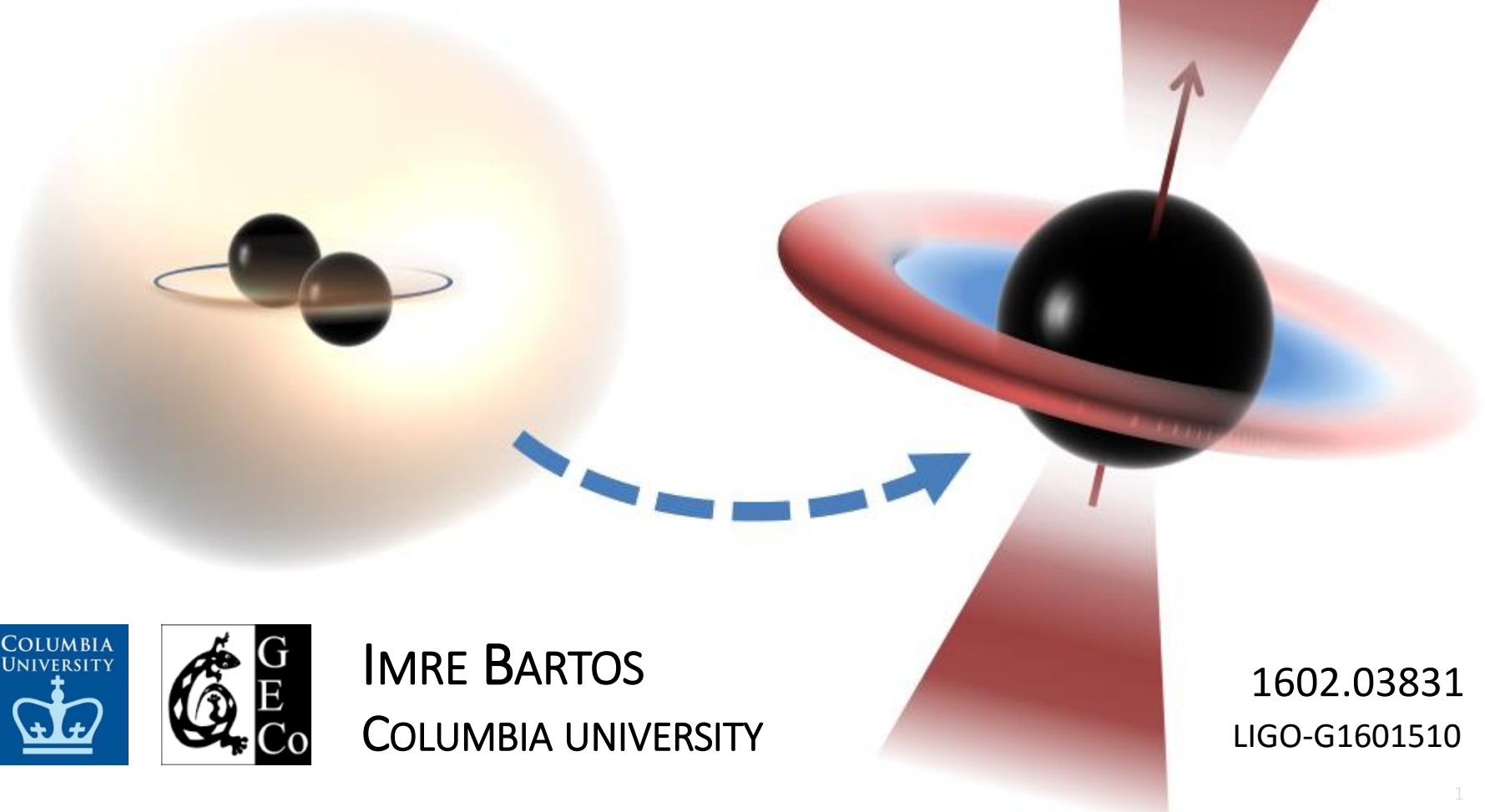


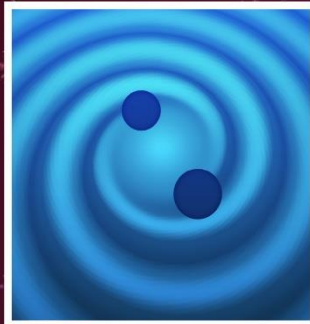
# RAPID AND BRIGHT STELLAR-MASS BLACK HOLE BINARY MERGERS IN ACTIVE GALACTIC NUCLEI



IMRE BARTOS  
COLUMBIA UNIVERSITY

1602.03831  
LIGO-G1601510

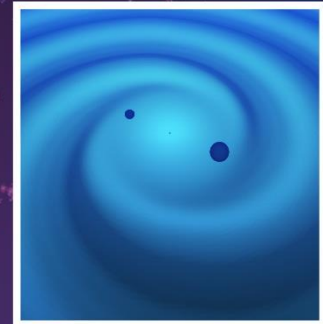
September 14, 2015  
CONFIRMED



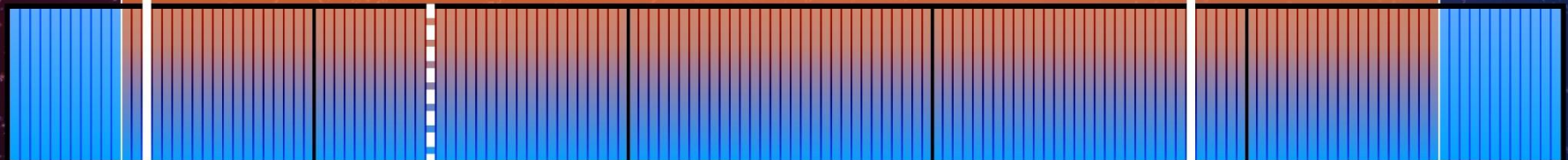
October 12, 2015  
CANDIDATE



December 26, 2015  
CONFIRMED



LIGO's first observing run  
September 12, 2015 - January 19, 2016



September 2015

October 2015

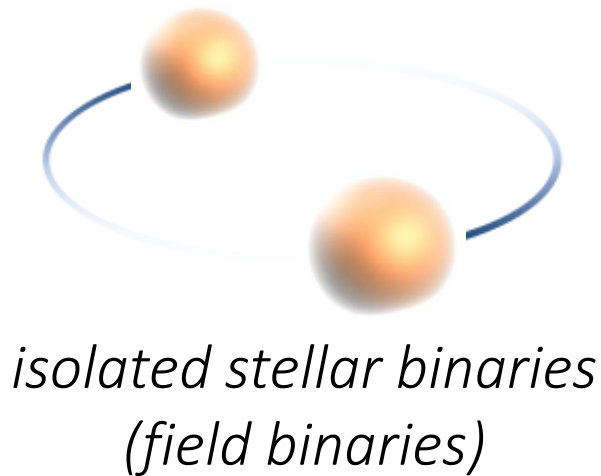
November 2015

December 2015

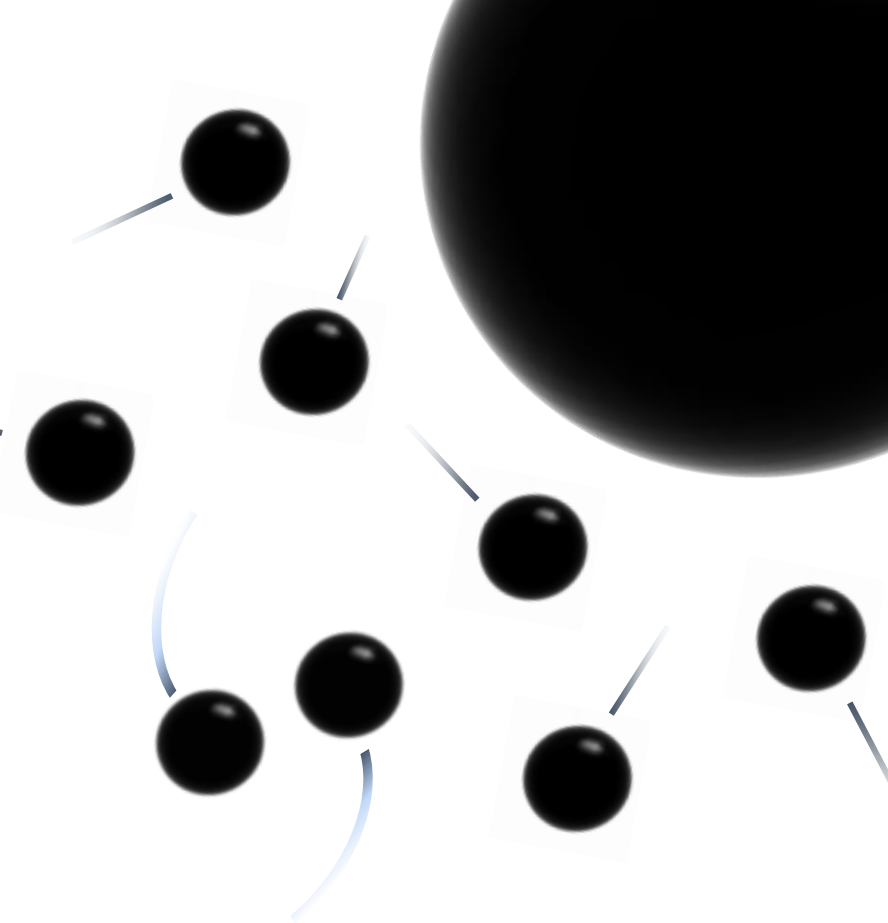
January 2016

Image credit: LIGO

# Origin



probe: mass, spin?



*dense stellar systems  
(dynamical encounter)*

probe: eccentricity?

# Information content

chirp mass

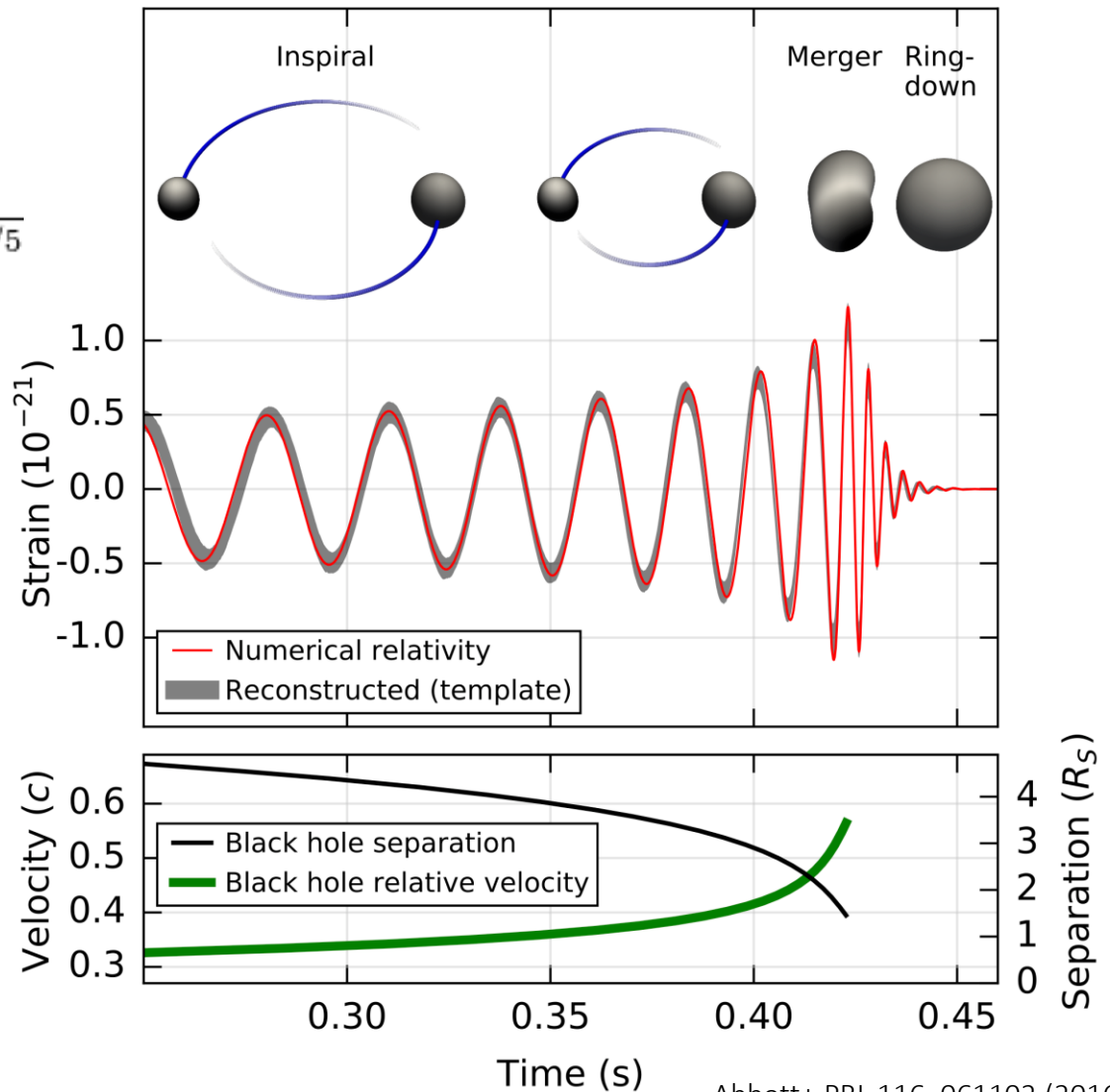
$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

mass ratio

$$q = m_2/m_1$$

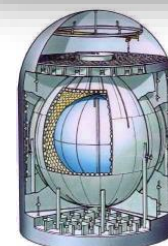
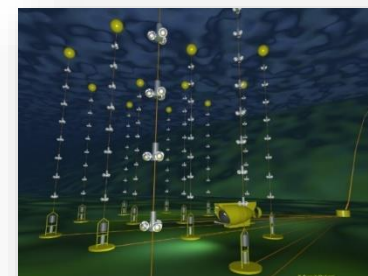
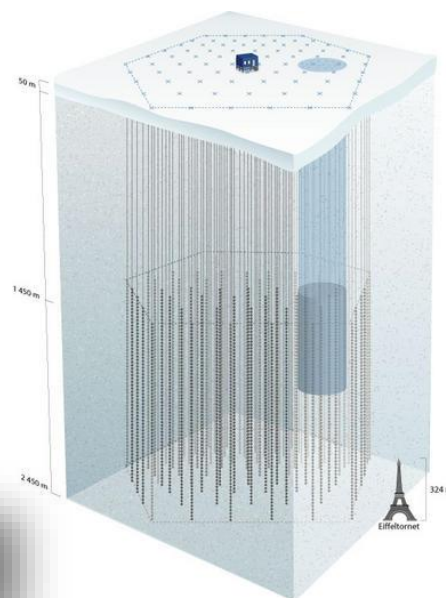
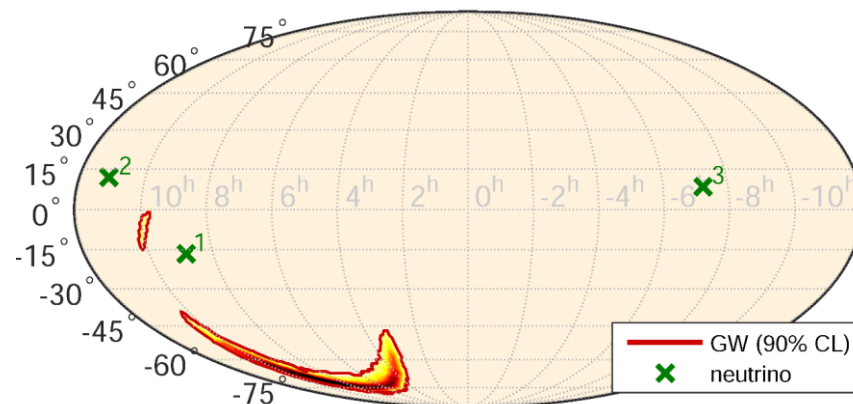
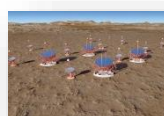
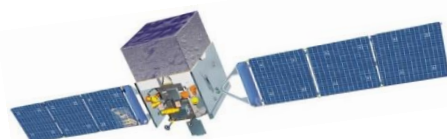
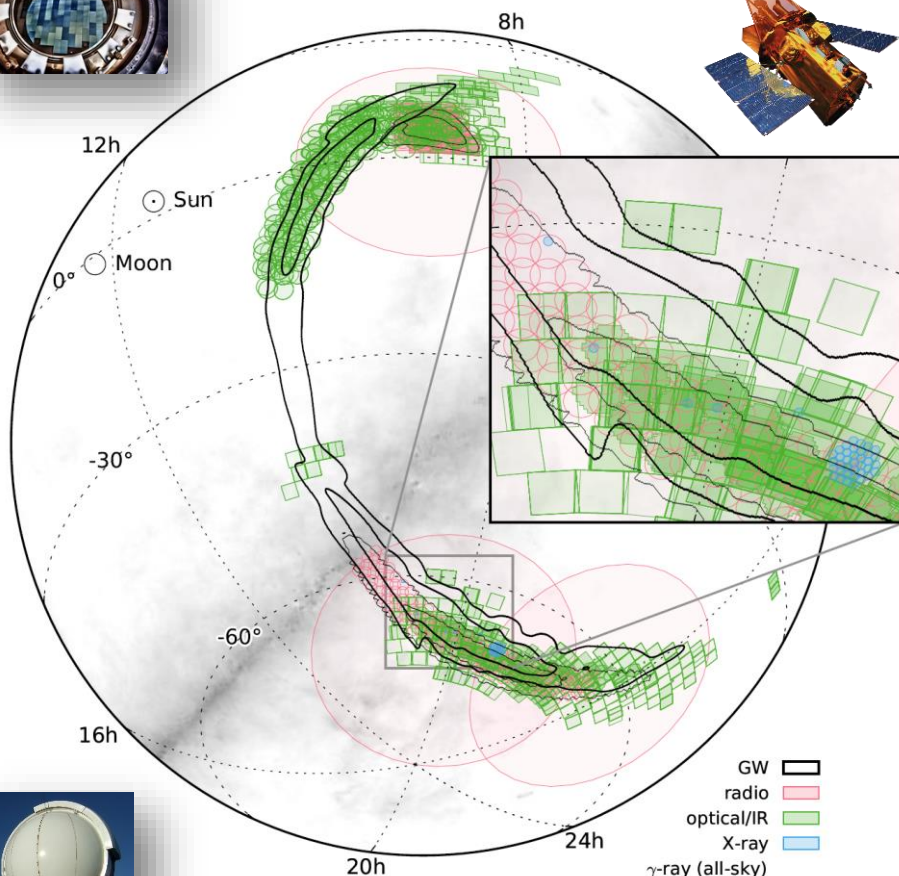
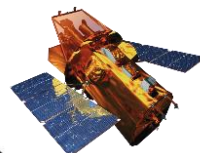
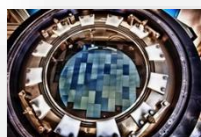
spin parallel to the orbital  
angular momentum

spin perpendicular to the orbital  
angular momentum



Abbott+ PRL 116, 061102 (2016)

# ELECTROMAGNETIC AND NEUTRINO COUNTERPART



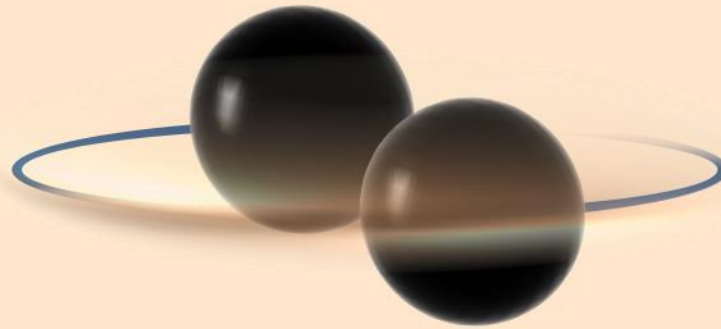
KamLAND 2016  
(1606.07155)

Abbott+ 2016 (1602.08492)

ANTARES+IceCube+LIGO+Virgo PRD 2016



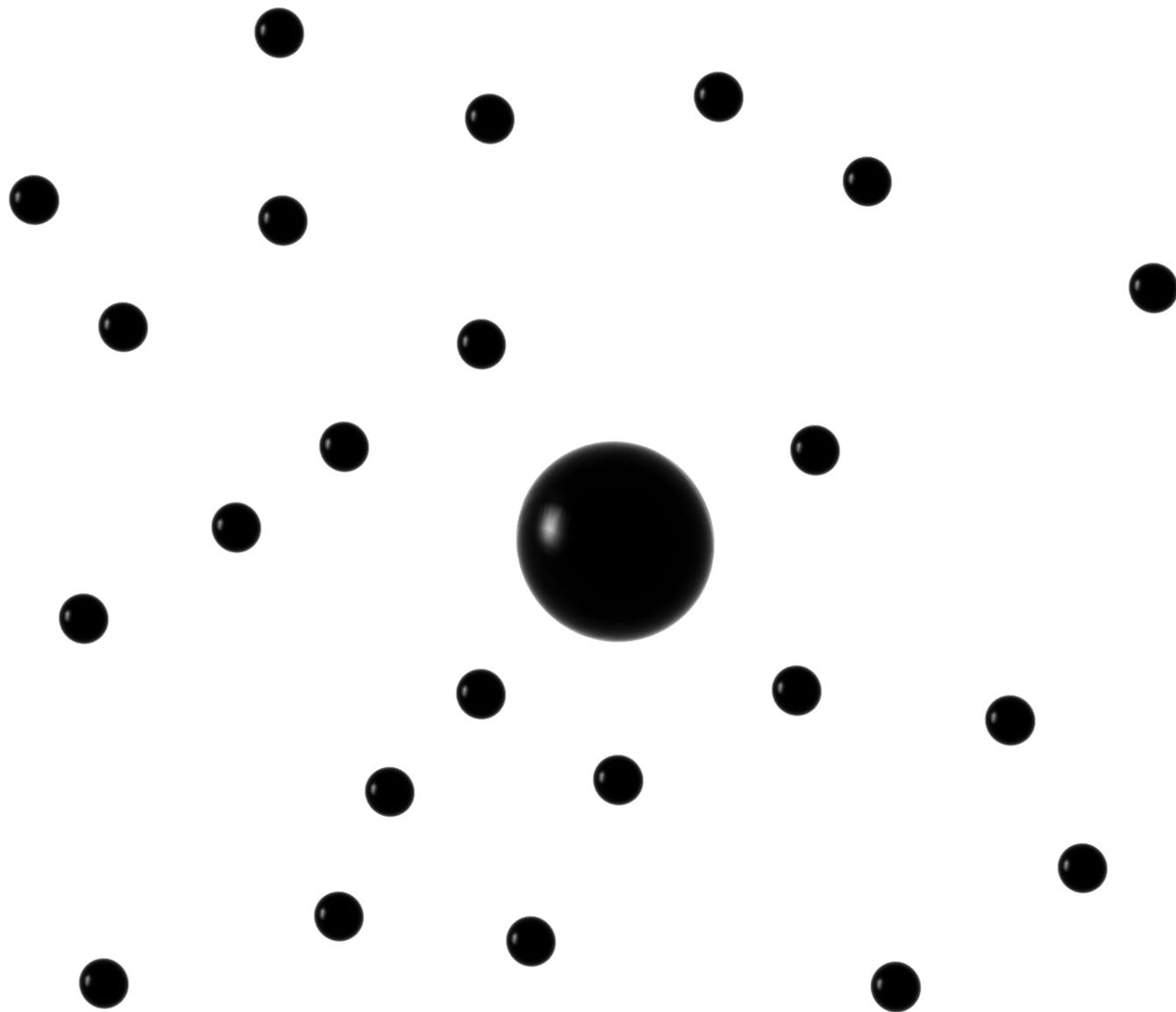
# Electromagnetic counterpart?



*gas accretion*

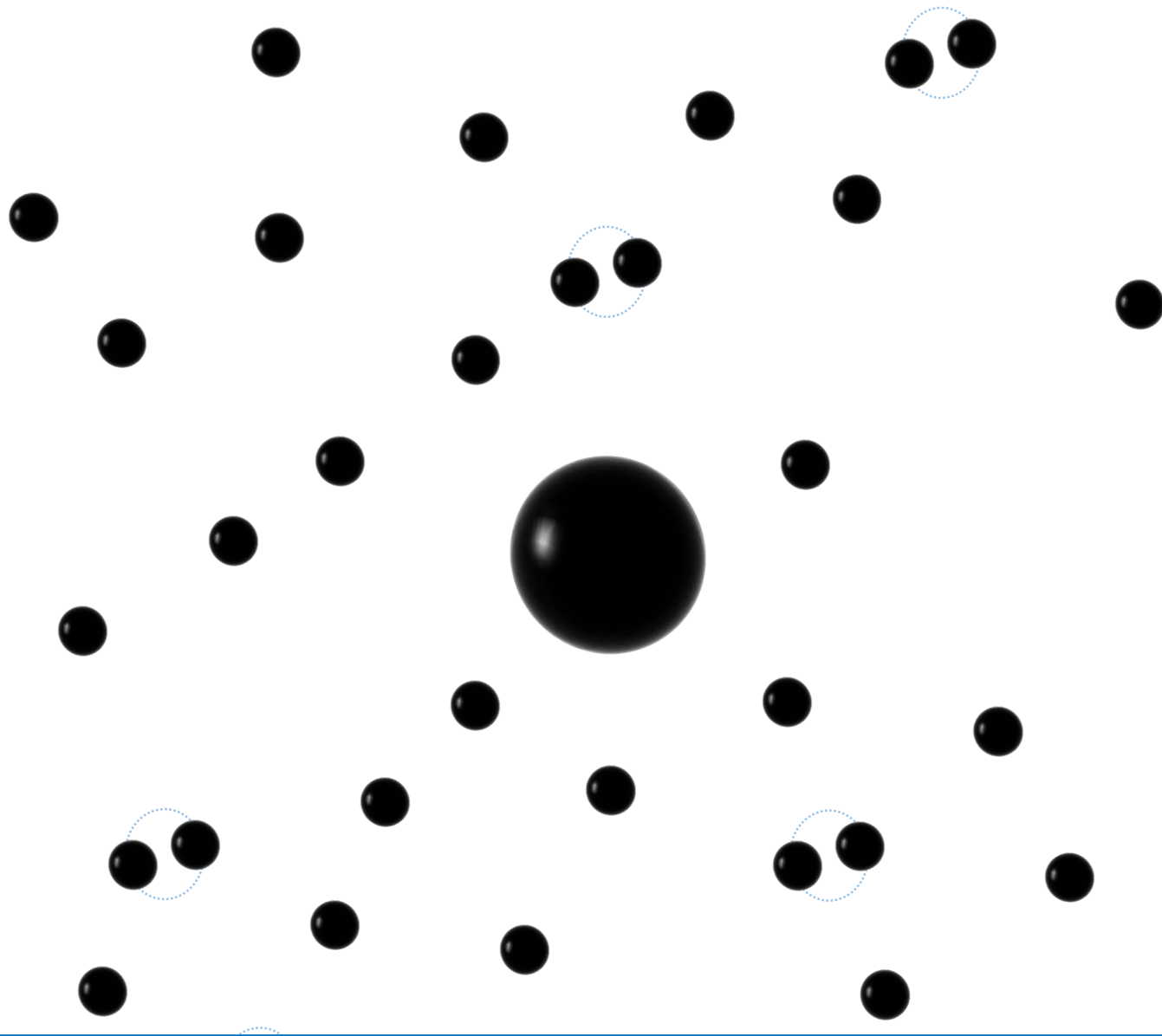
*no significant gas around field binaries*

*typically not expected in galactic centers / globular clusters*



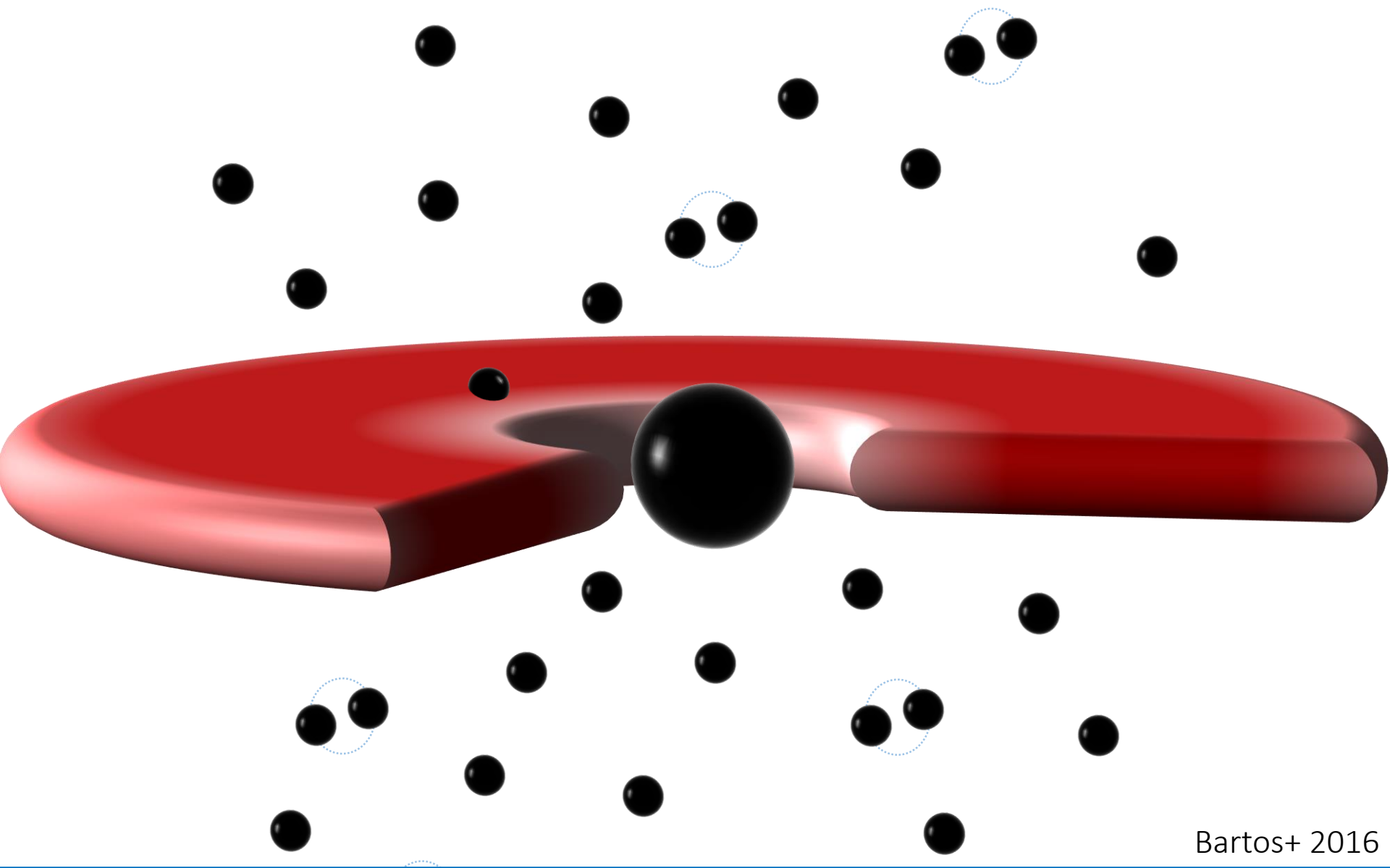
Bartos+ 2016

Galactic centers may harbor thousands of stellar mass black holes within the inner parsec (Morris 1993, O’Leary+ 2009).



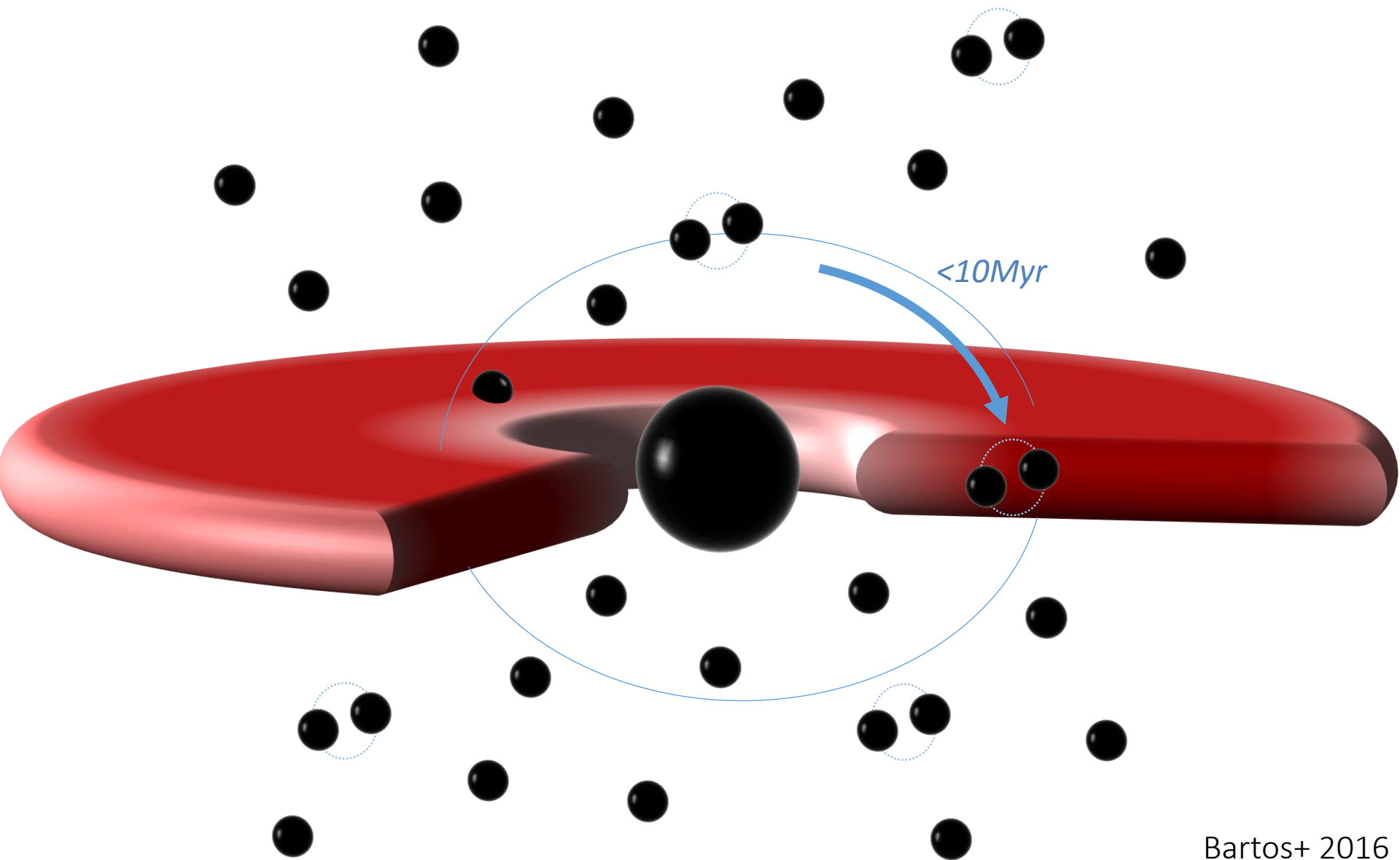
Bartos+ 2016

A fraction of black holes may be in binaries (30%; Pfuhl 2014).



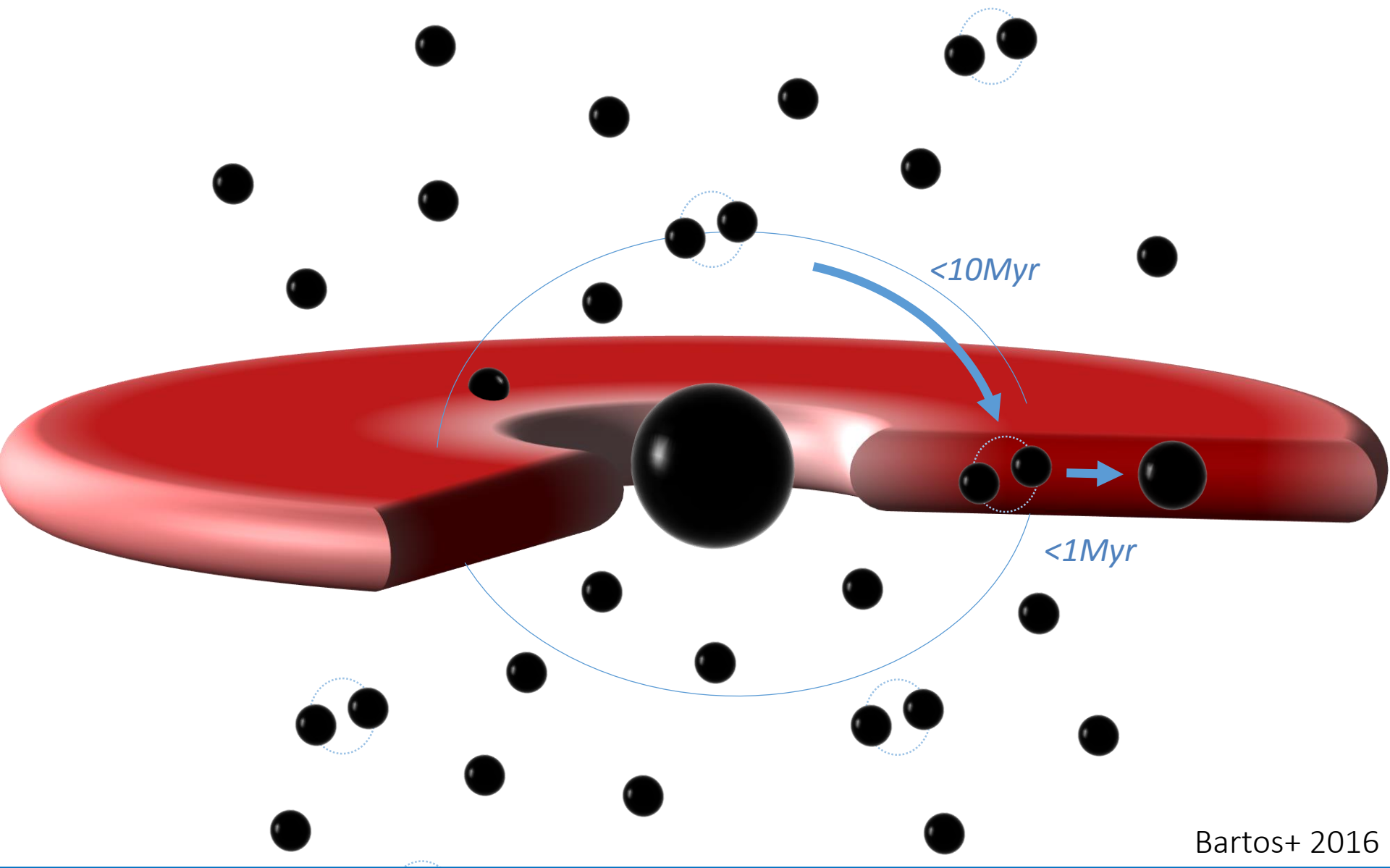
Bartos+ 2016

Some galactic centers accrete large amounts of gas (active galactic nuclei).



Bartos+ 2016

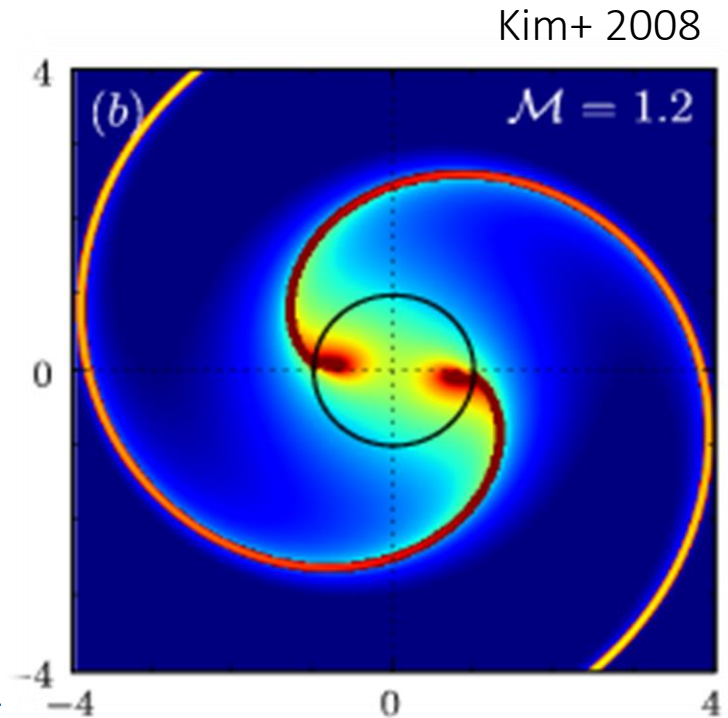
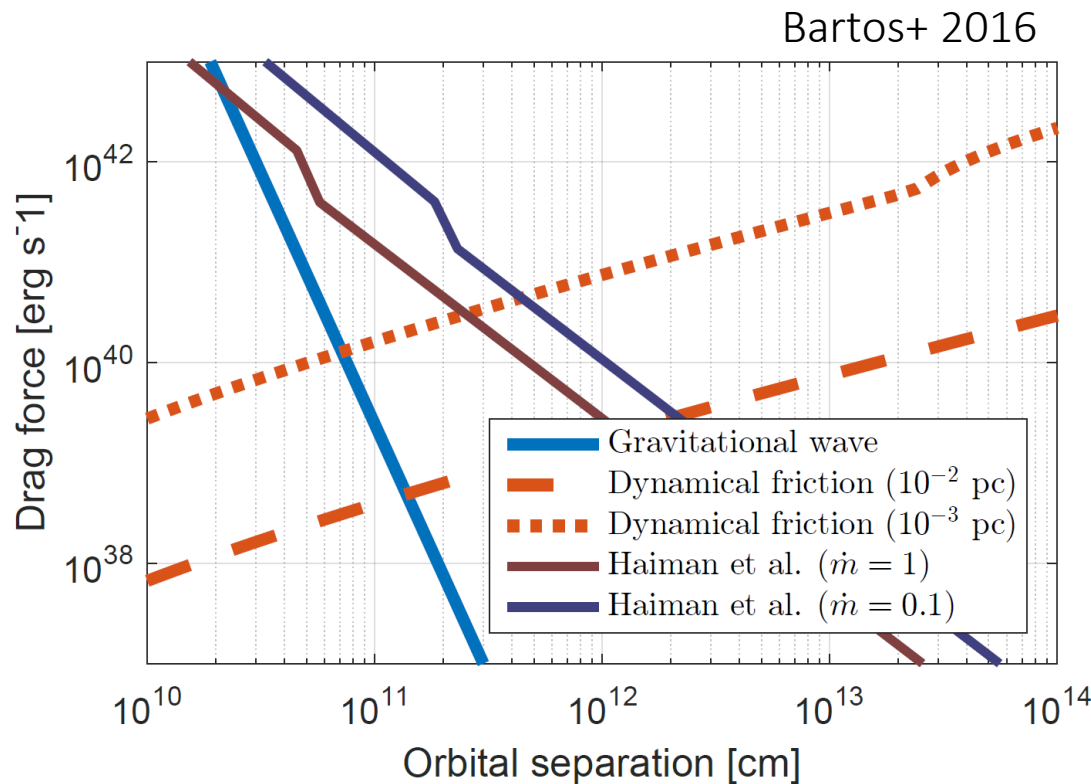
Binaries migrate into the disk...



Bartos+ 2016

...and then rapidly inspiral via dynamical friction.

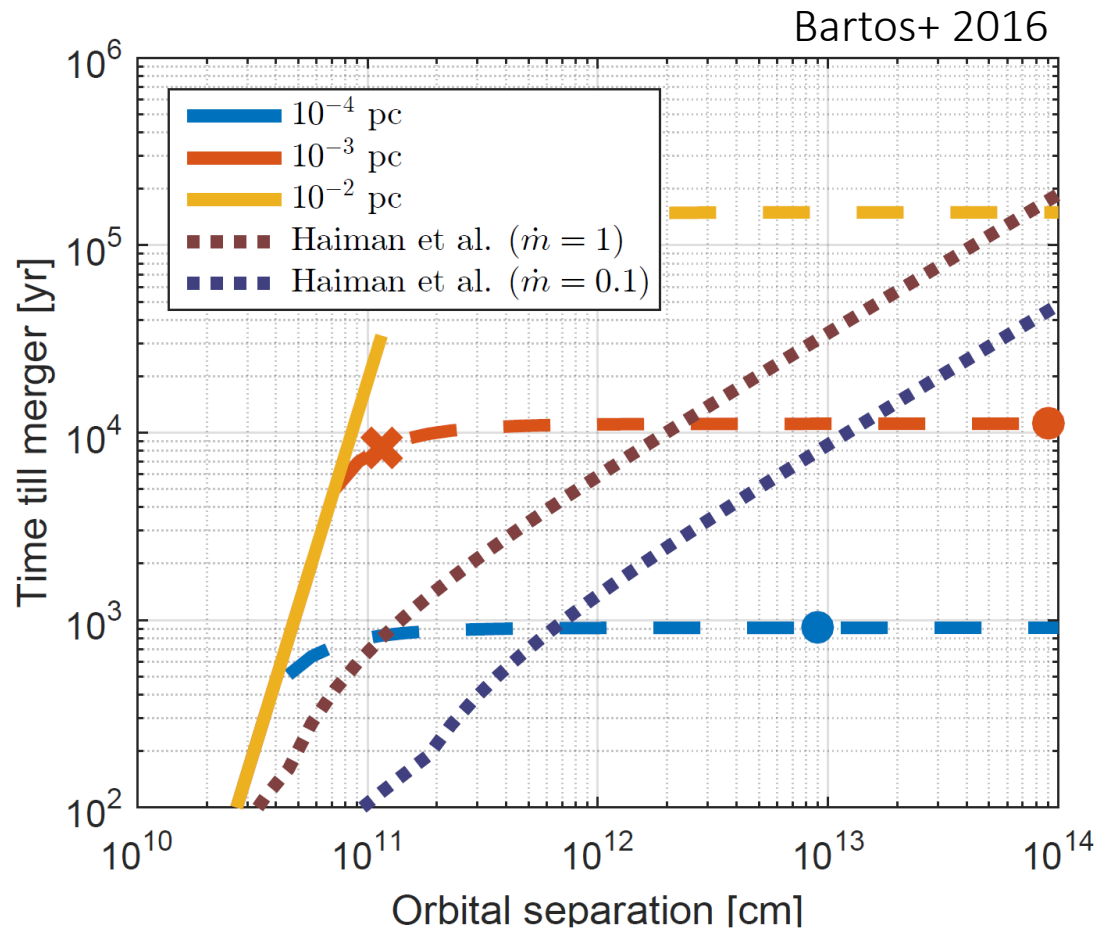
# Drag force



Binary creates density wakes within gaseous medium → drag force

- Kim+ 2007, 2008 (semi-analytic model): binary perturber in uniform gas.
- Haiman+ (mini accretion disk): gas has net angular momentum around BBH.
- Small separations: GW emission dominates.

# Merger time scale



Inspiral is significantly accelerated in region where GW is weak.

# Detection rate

Merger rate in single AGN

$$\Gamma(M_{\bullet}) = \frac{f_{\text{capt}} N_{\text{cross}}}{\tau_{\text{align}} + \tau_{\text{merger}}}$$

$N_{\text{cross}}$  disk-crossing BBHs  
 $f_{\text{capt}}$  fraction align with disk

Log-normal AGN mass function  $\frac{dn_{\text{AGN}}}{dM_{\bullet}}$  (Greene+ 2007, 2009)

Total merger rate

$$\mathcal{R} = \int \frac{dn_{\text{AGN}}}{dM_{\bullet}} \Gamma(M_{\bullet}) dM_{\bullet} = 1.1 \text{ Gpc}^3 \text{ yr}^{-1}$$

Regular detection by Advanced LIGO-Virgo.

# Detection rate

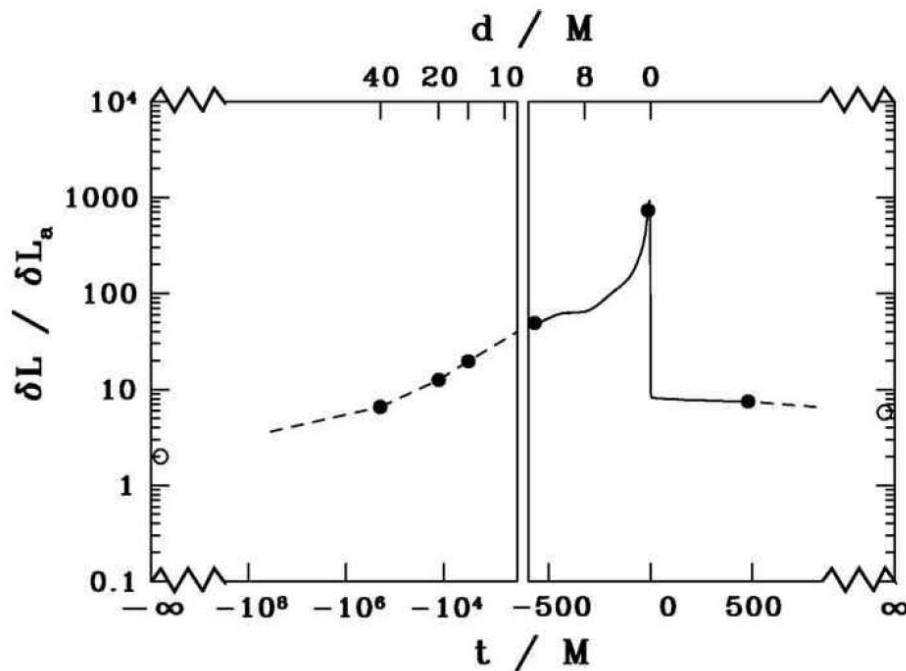
Disk accretion: super Eddington accretion and luminosity is possible (e.g., Jiang+ 2014)

$$L_{\text{bol}} = \eta_{\text{bol}} L_{\text{Edd}}$$

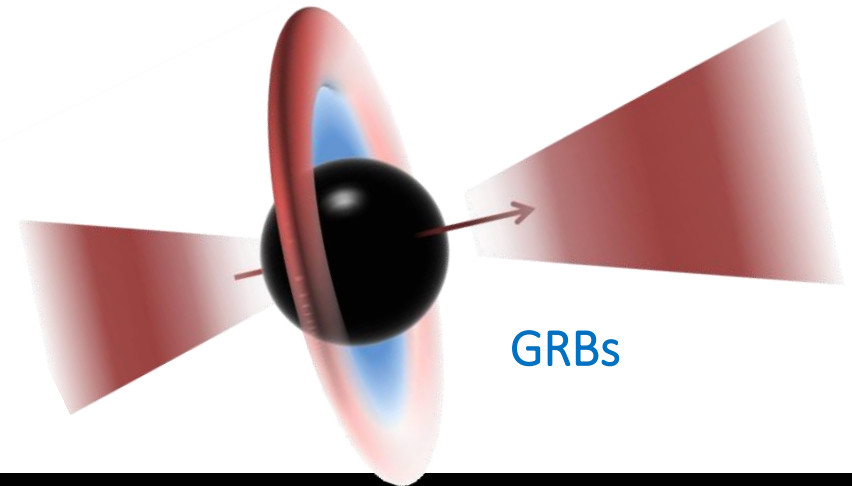
Flux at Earth:

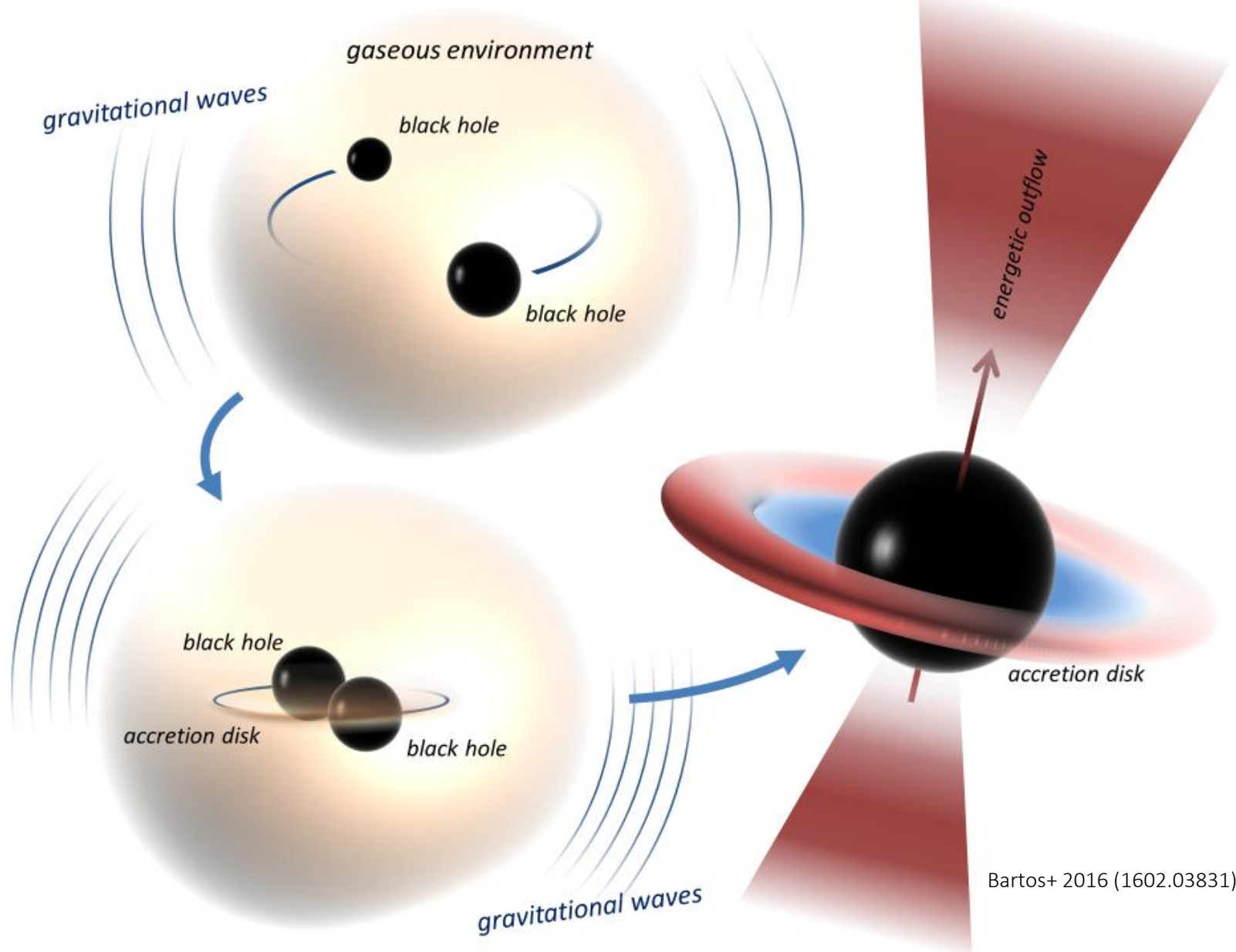
$$\Phi_{\gamma} = 10^{-14} \eta_{\text{bol}} F \left[ \frac{M_{\text{bh}}}{100 M_{\odot}} \right] \left[ \frac{d_L}{100 \text{ Mpc}} \right]^{-2} \frac{\text{erg}}{\text{cm}^2 \text{s}}$$

Hyper-Eddington accretion is necessary.



Luminosity enhancement over single BH  
Uniform gas simulation (Farris+ 2009)





- Detectable EM emission is viable for some binary black hole mergers
- Look for observational signatures in both EM and GW parameters