Electromagnetic Signatures of Supermassive Binary Black Holes

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Desirable Targets

Direct indicator of major galaxy mergers

Illustrate process of supermassive black hole growth

Run-up to black hole merger, maybe early warning

But Frustratingly Hard to Find

LISA (or eLISA, iLISA, LISA-light, ….) not any time soon

Lots of *photon* telescopes available now, but….

What Distinguishes SMBBH from AGN?

Continuum modulation on orbital period? But most light from near-ISCO region of "mini-disks", and $t_{inflow} >> P_{orb}$ until separation quite small (*but see counter-example later)*

Split broad-line profiles? But BLR shared by BHs when $v_{orb} >> v_{BLR}$, while BLR profiles merge when $v_{orb} << v_{BLR}$

Two Potentially Better Possibilities:

- **Spectral contrasts**
- Pulsar timing

Accretion through Prograde Circumbinary Disks

A brief history of $\dot{M}(r_{\rm in})/\dot{M}(r_{\rm out})$

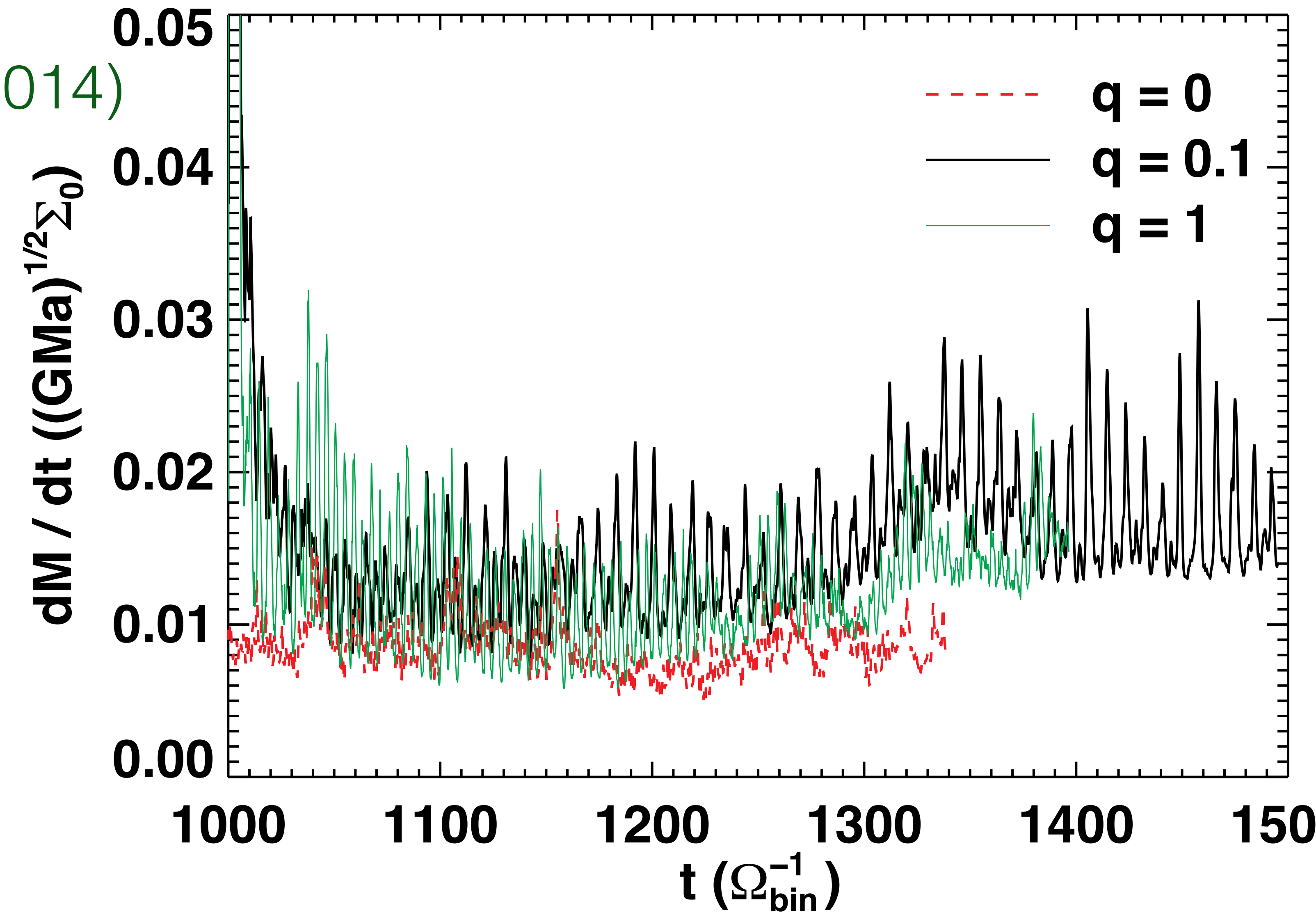
~0 analytic (Pringle 1991)

~0.1 2-d α hydro (Milosavljevic & MacFadyen 2008)

~0.3 3-d MHD (Shi et al. 2012)

~1 2-d α hydro (Farris et al. 2014)

~1 3-d MHD (Shi & K. 2015)

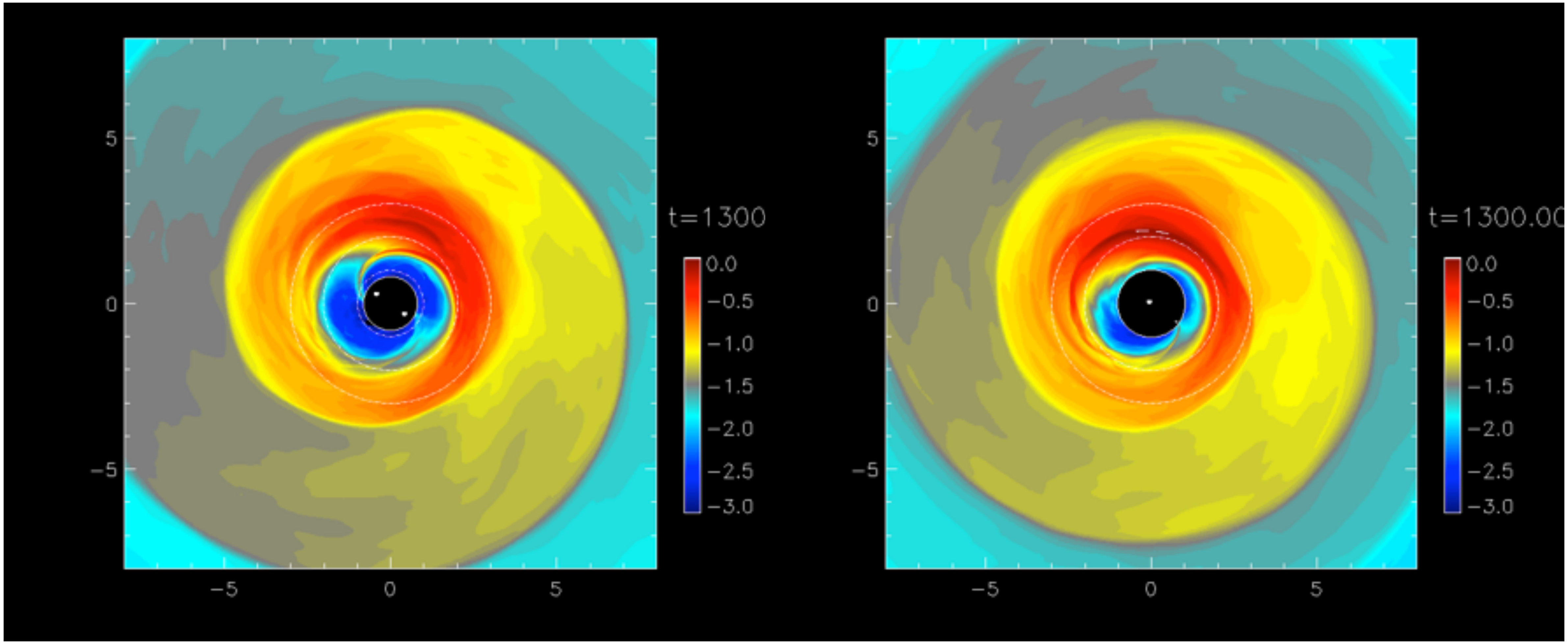


Accretion Streams across the Gap

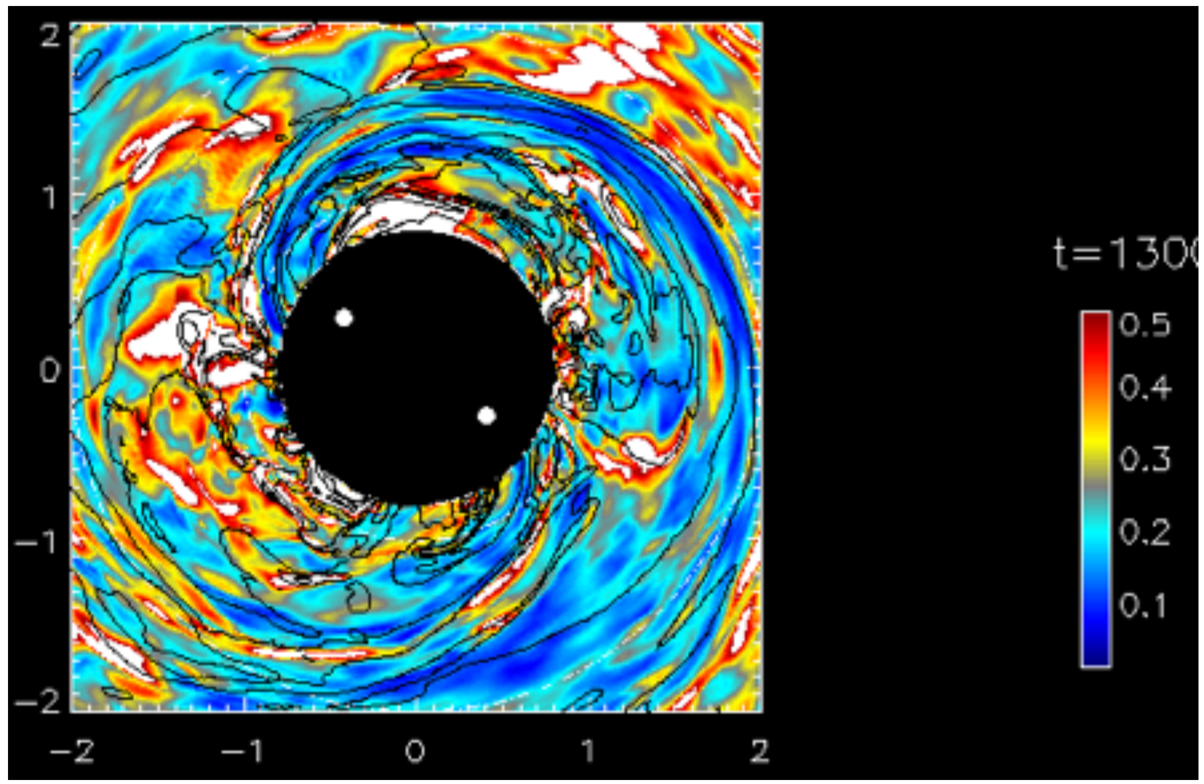
Prograde q ~ O(1) circumbinary disks have gaps crossed by accretion streams

q=1

q=0.1



Stream orbits are almost constant-energy, laminar, ballistic; i.e., little orbital energy dissipated into heat.   Inflow speed >> turbulent speed —> stretched field lines, little heat production.



$\langle |B_z| / |B_\phi| \rangle$

And initial heat radiated quickly:

$$t_{\rm cool}/t_{\rm cross} \sim 2\pi h_{\rm stream} h_{\rm disk}/r^2_{\rm stream}$$

—> Little radiation from the streams

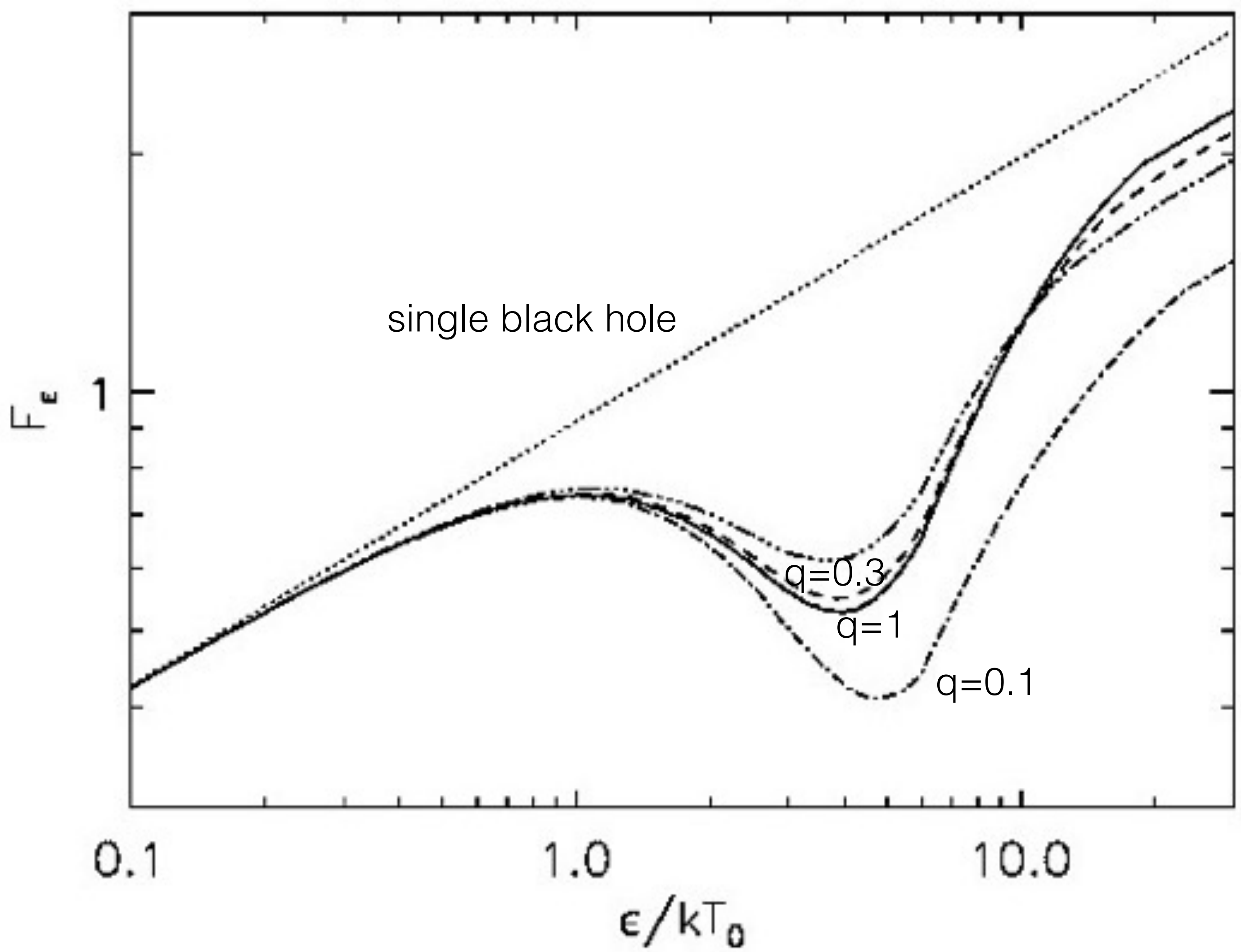
"Notches"

(Roedig, K & Miller 2014)

See partial accounts in Roedig et al. 2012, Tanaka et al. 2012, Gultekin & Miller 2012, Kocsis et al. 2012, Tanaka & Haiman 2013, Tanaka 2013; also Farris et al. 2015

Absence of thermally-radiating material removes spectrum for a factor ~3 on either side of

$$h\nu_0/4k_B \simeq 3.3 \times 10^4 \left[\dot{m}(\eta/0.1)^{-1} M_8^{-1} (a/100r_g)^{-3}\right]^{1/4} \text{ K}$$



Notch falls in middle of visible band for $\dot{m}(\eta/0.1)^{-1} M_8^{-1} (a/100r_g)^{-3} \simeq 2 \times 10^{-3} (1+z)^4$

(Roedig, K & Miller 2014)

Hard X-ray Bumps

Accretion streams join “mini-disks” around each black hole, with majority of accretion going to the secondary

Streams shock at edges of “mini-disks” with high temperature

$$T_{s1,2} \simeq 6 \times 10^{10} (a/100r_g)^{-1} (1+q)^{-1} (q^{0.3}, q^{0.7}) \text{ K}$$

assuming circular orbits, as GW likely enforces

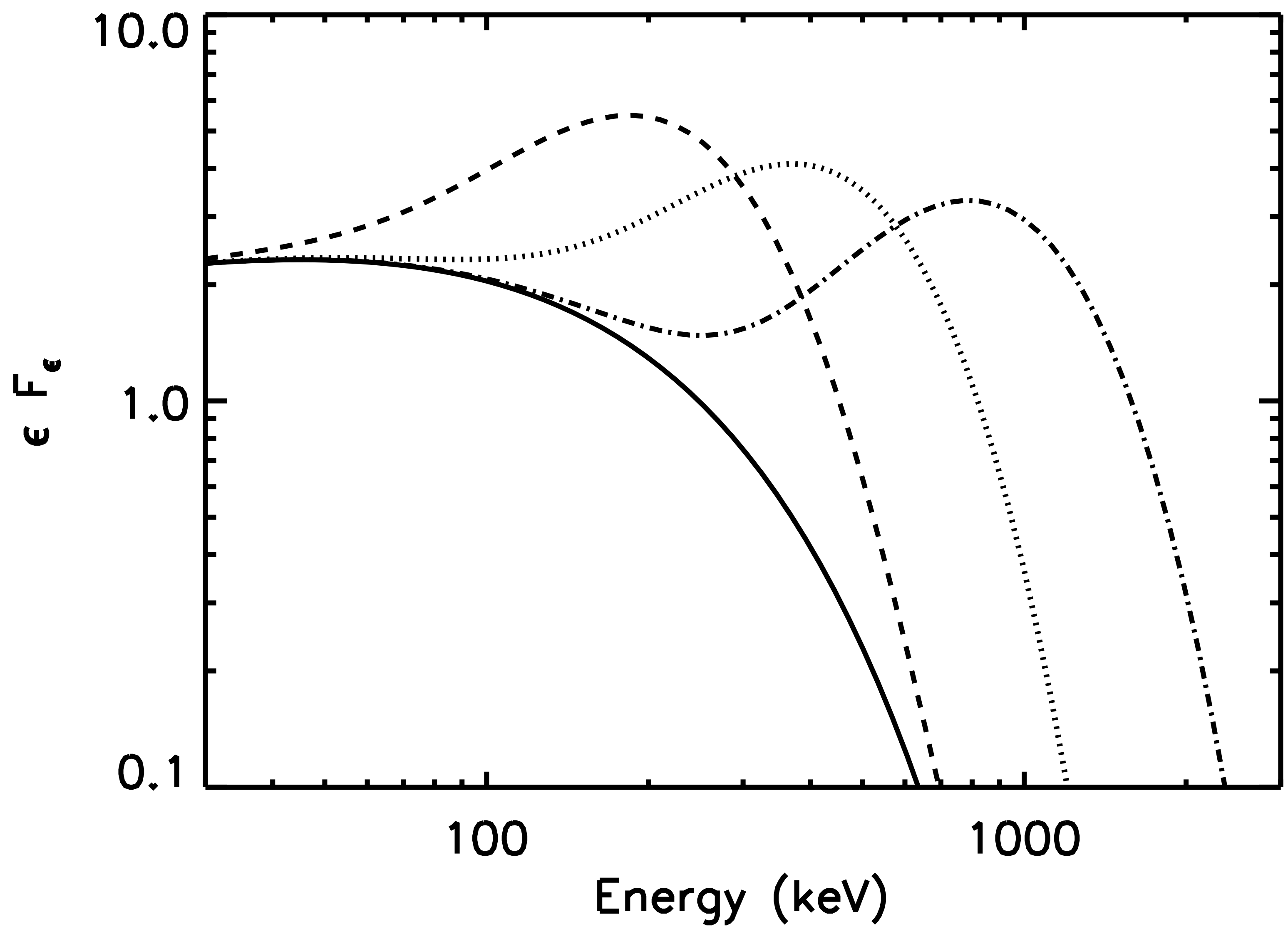
But cool quickly

$$t_{\rm cool}\Omega_{\rm mini} \simeq 0.01 \dot{m}^{-1} (a/100r_g)^{-1/2} (1+q)^{-3/2} (q^{0.15}, q^{1.35})$$

and brightly

$$L_{\rm hot}/L_X \simeq 0.35 (a/100r_g)^{-1} (1+q)^{-1} (f_1 q^{0.3} + f_2 q^{0.7})$$

Very Hard X-ray Components



q=1, fiducial parameters

Expect modulation on the binary orbital period to the extent that accretion is modulated

Two Better Possibilities:

- Spectral contrasts
- **Pulsar timing**

Pulsar Timing Arrays and Black Hole Binaries

Expect a diffuse gravitational wave background from the Universe's supermassive black hole binaries.

Gravitational redshift at pulsar reflects local GW wave background; likewise at Earth: $g_{tt} \simeq 1 + 2\Phi + h_{tt}$

Observe pulsars in many directions over many years and constrain the fluctuation power on year/multi-year timescales

Low-eccentricity orbital evolution produces gravity wave spectrum $dE/df \sim f^{-1/3}$

Retrograde Binaries Break the Rules

Accretion of negative angular momentum rapidly increases binary eccentricity, decreases pericenter

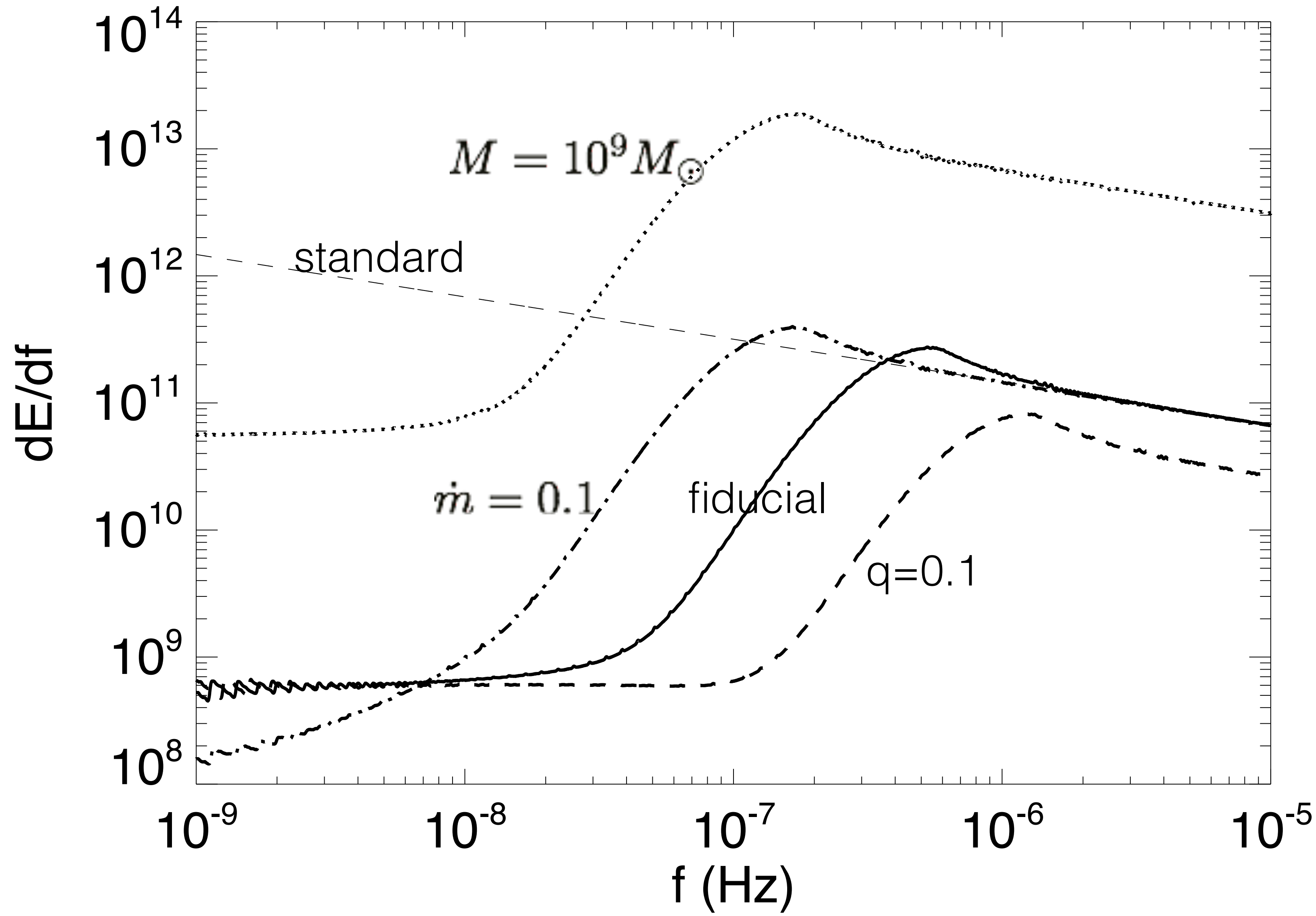
—> Pulsed gravitational wave emission when *a* is still so large little would be expected from a circular orbit

$$\dot{\phi}(r_p) \gg \Omega \rightarrow f_{\rm GW} \gg f_{\rm orb}$$

Ultimately GW emission circularizes the orbit

Resulting Spectrum: Suppressed at P ~ few yr, enhanced at P ~ few months

(Schnittman & K 2015)



fiducial: $q = 1,\ M = 10^8 M_\odot,\ \dot{m} = 1,\ a_0 = 10^5 r_g$

Retrograde May Be Generic

Accreting only ~ 1/5 M_2 suffices to drive system to merger; orbital evolution due to prograde evolution several times slower

Oblique retrograde alignment leads quickly to orbit flip to prograde, may not overcome that factor of 5

Conclusions

- Prograde circumbinary disks should exhibit a “notch” in their thermal continua
- They should also have a “bump” at ~ 100 keV that exceeds the intrinsic coronal emission when $a < \sim 100\ r_g$; this bump should be modulated on the orbital period
- Retrograde accretion pushes GW power from $f < \sim 1\ yr^{-1}$ to $f > \sim 1\ yr^{-1}$