Lynx observations of LISA triggers

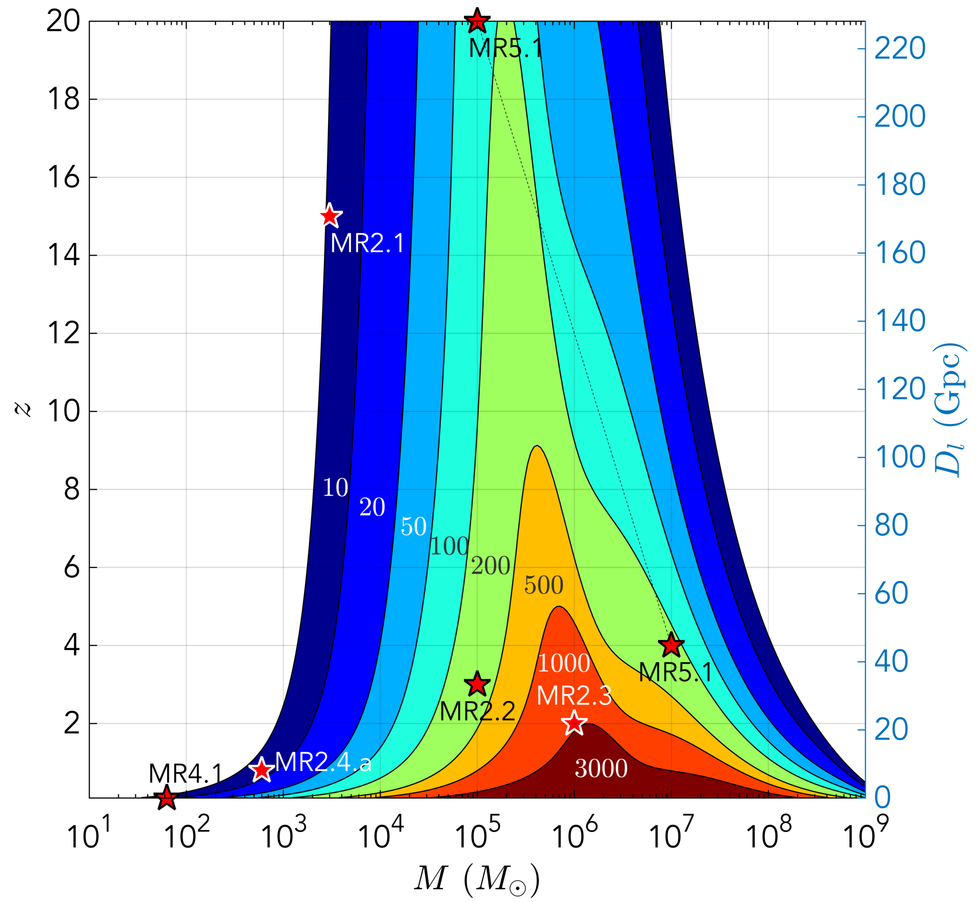
Zoltán Haiman

Columbia University

Lynx meeting, 13 Dec. 2017

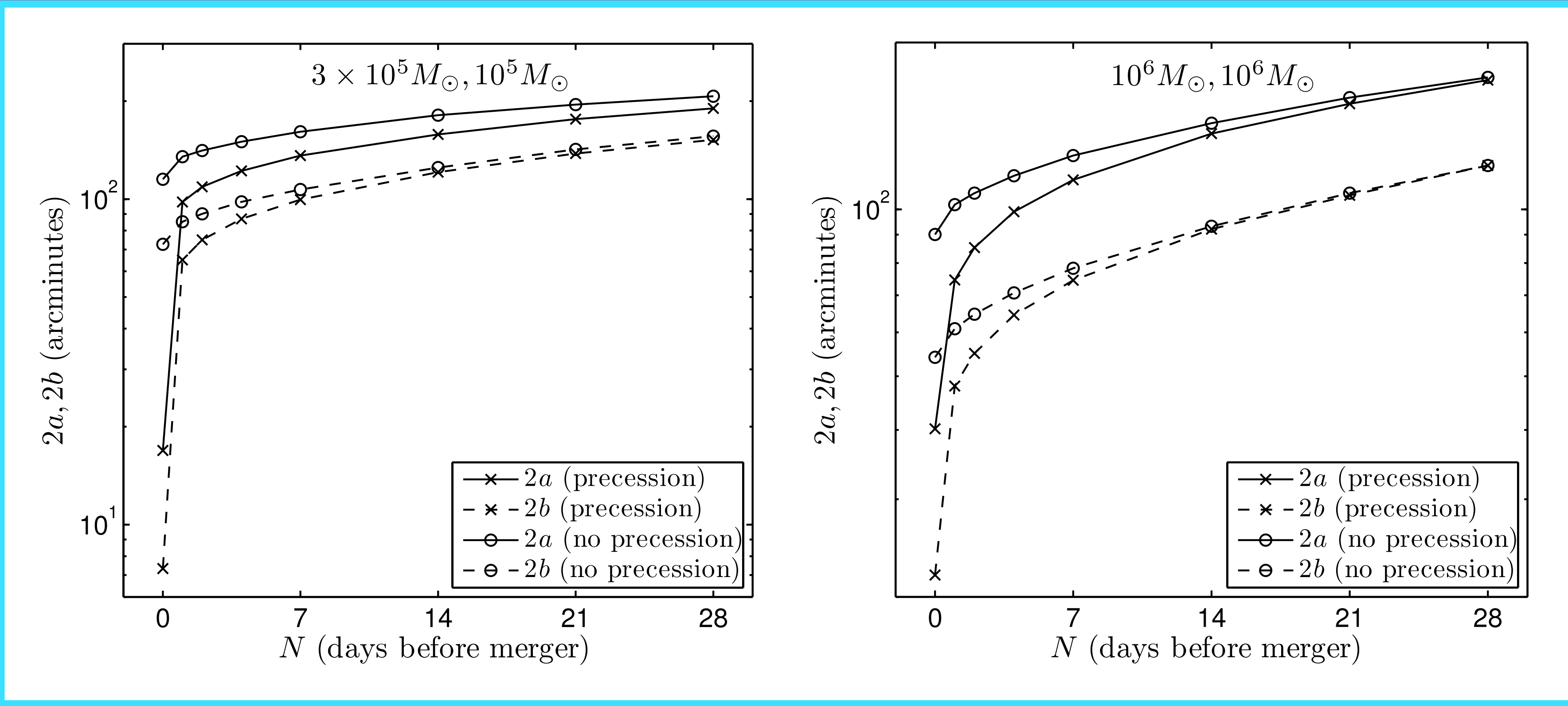
LISA reach

(Accepted LISA proposal, science justification)



LISA sky localization

(Kocsis et al. 2008; Lang & Hughes 2008)

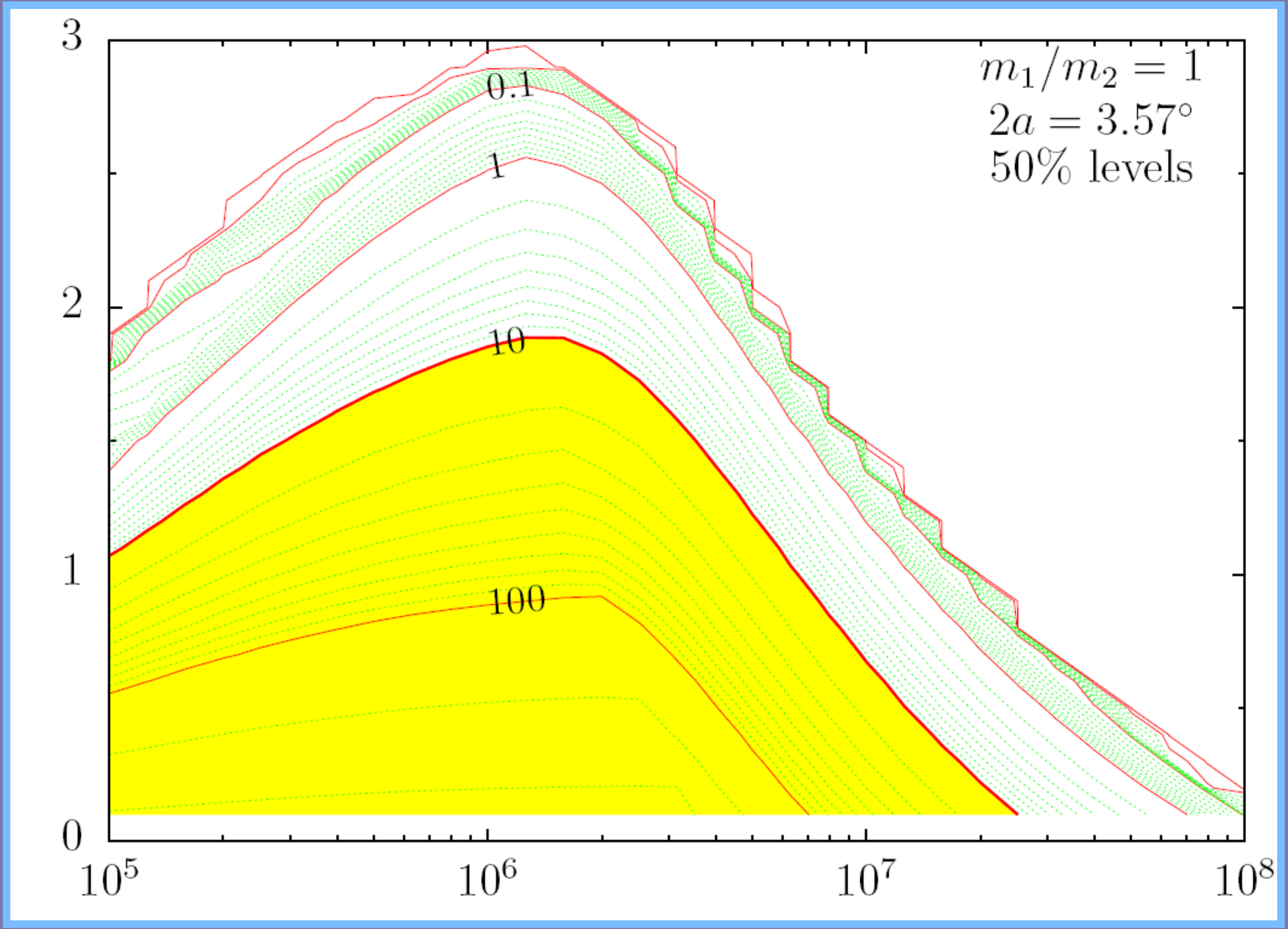


How much advance notice?

Look-back time when sky position error shrinks down to ~10 deg²

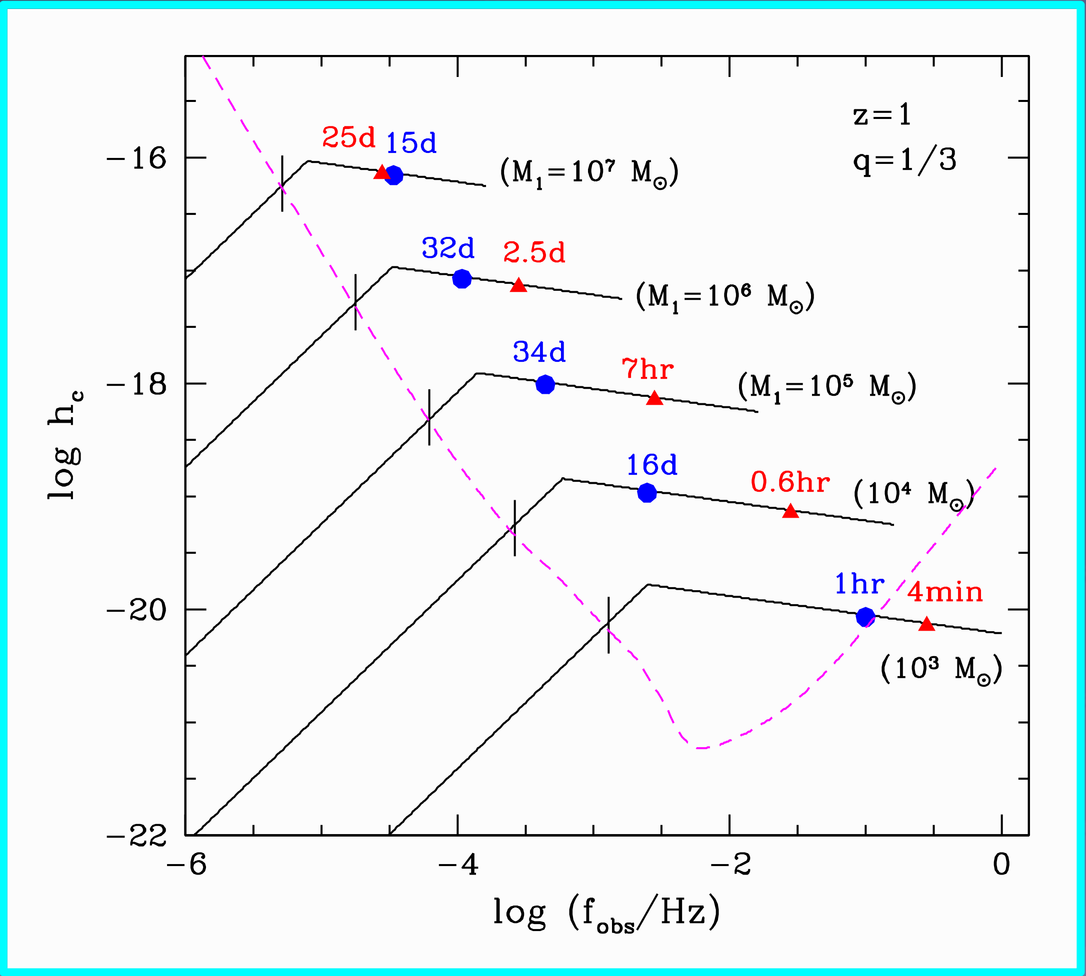
(Kocsis et al. 2007; 2008; Lang & Hughes 2008)

redshift



mass (solar mass)

Track of binary in the LISA band



(Haiman 2017)

Example:

$M_{tot}=10^6 M_\odot$, q=1/3, z=1

Enter LISA band: 125 R_g

Localized (10 deg^2): 38 R_g

Tidal radius < 10 R_g: 387 cycles

V(orb) ~ O(0.1c)
T(orb) ~ O(hr)

LISA binaries produced in “wet” mergers

Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2

PRC97-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

LISA binaries will be surrounded by gas

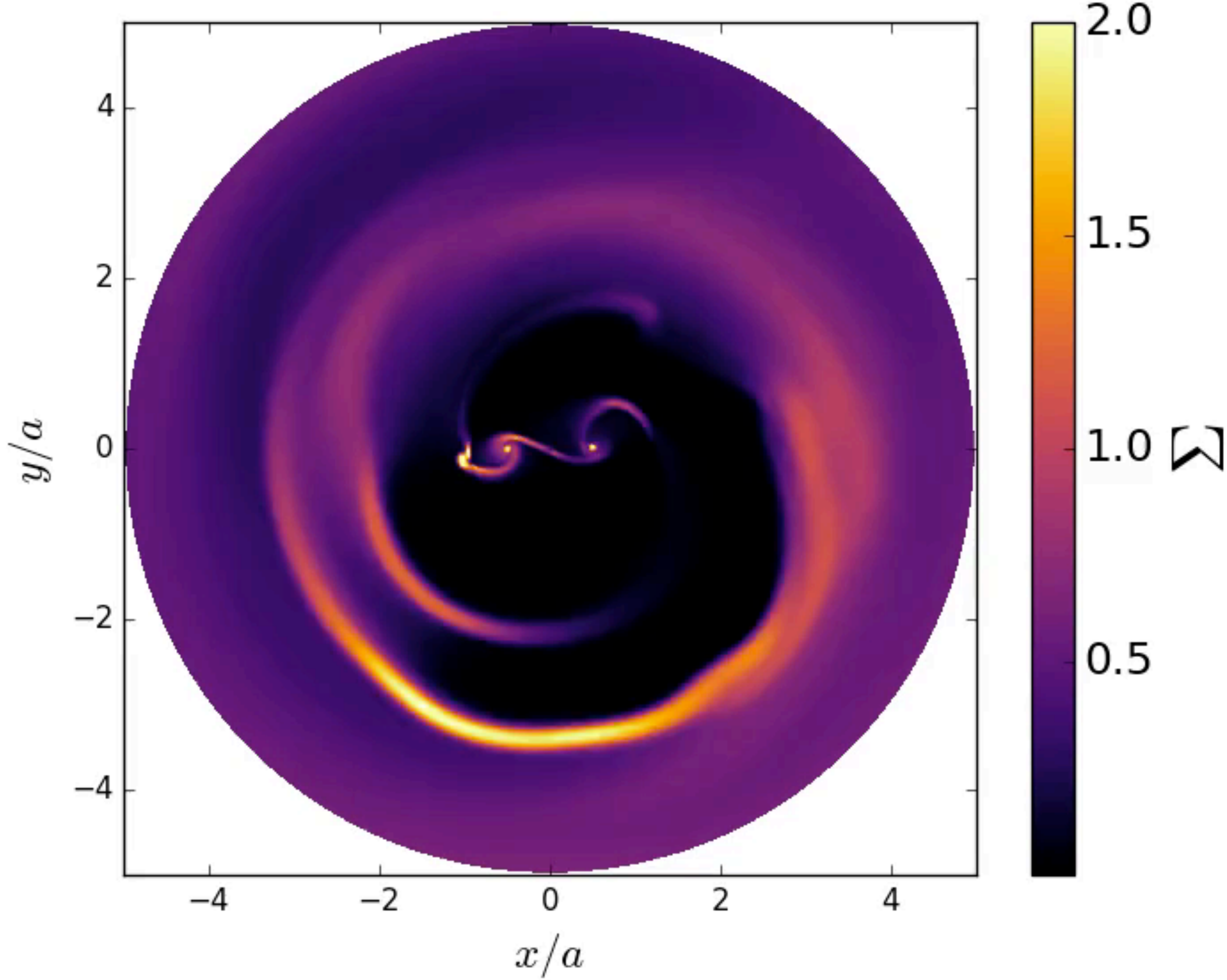
1. **Most galaxies contain SMBHs**
   - SMBH mass correlates with galaxy size

2. **Galaxies experience several mergers**
   - typically a few major mergers per Hubble time

3. **Most galaxies contain gas**
   - $M < 10^7 M_\odot$ SMBHs are in gas-rich disk galaxies
   - $M > 10^7 M_\odot$ SMBHs are in “dry” ellipticals, but still with gas

4. **Both SMBHs and gas are driven to new nucleus (~kpc)**
   - SMBHs sink by dynamical friction on stars and on DM
   - gas torqued by merger and flows to nucleus

→ common outcome: pair of SMBHs in gas disk

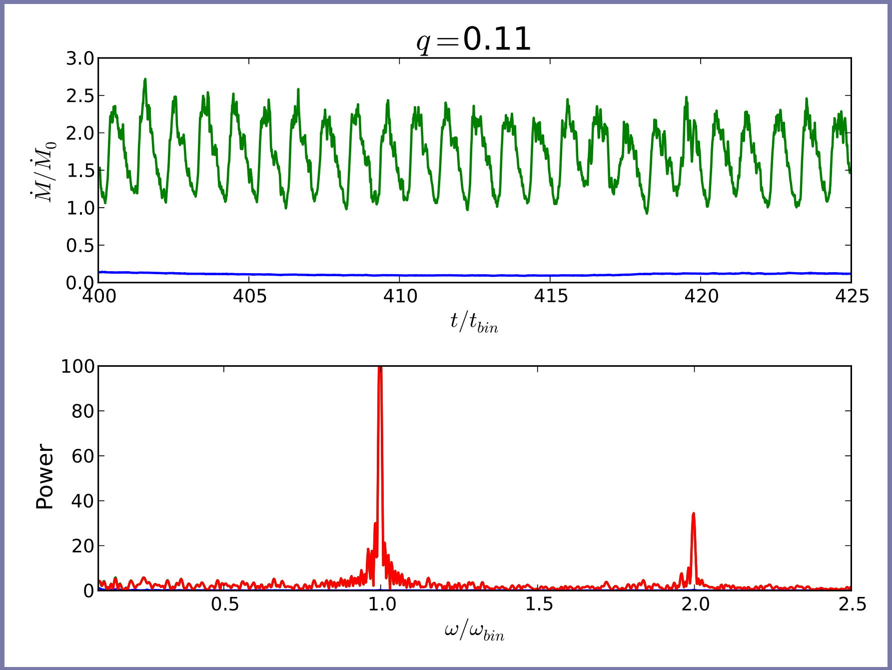


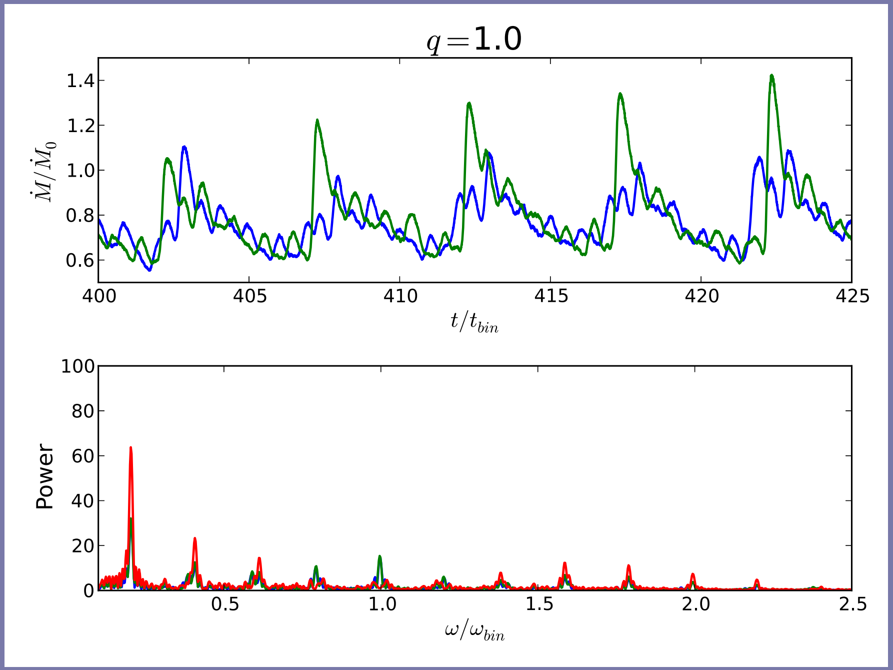
2.0
1.5
1.0
0.5
Σ
4
2
0
−2
−4
y/a
−4
−2
0
2
4
x/a

Accretion onto BHs

0.05 < q < 0.3

0.3 < q < 1





Factor of ~two variability on **orbital timescale**

Factor of ~two variability on **orbital time at cavity wall**

Total accretion is **not suppressed** by binary

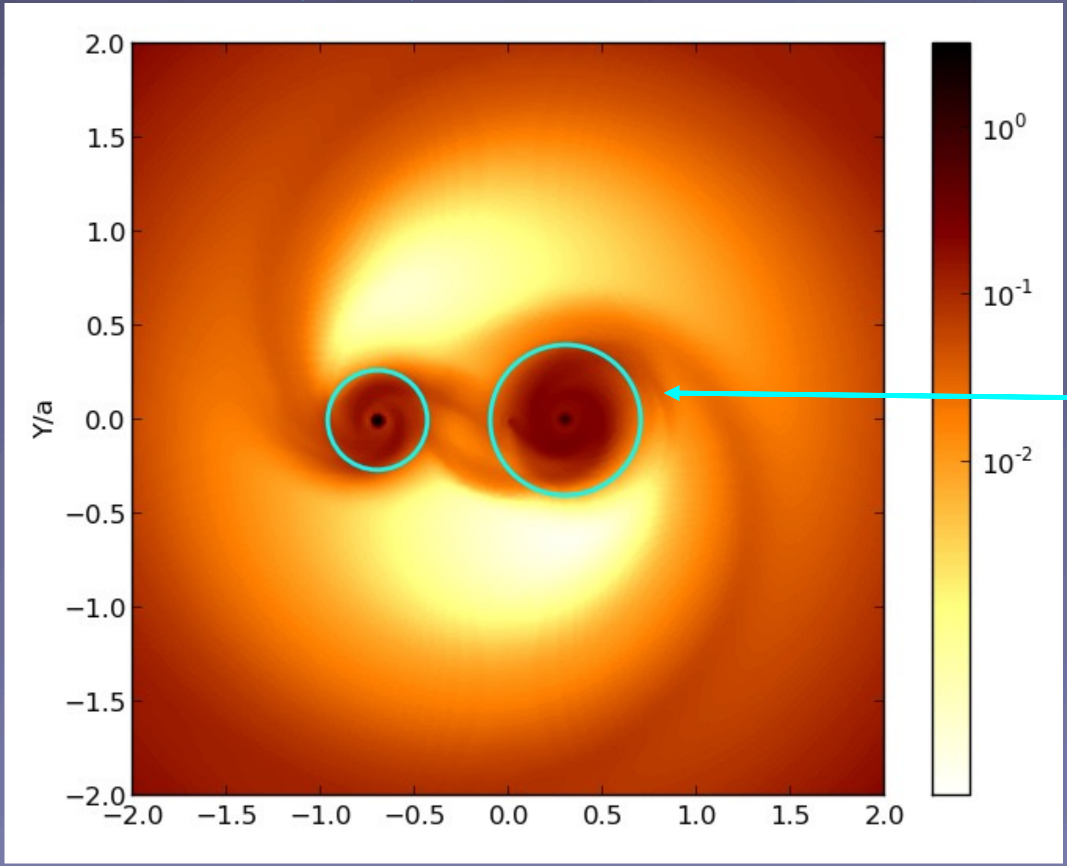
X-ray chirp inevitable

- Optical – X-ray emission from quasars from 10-1000 R_g
- Smaller than tidal truncation radius for wide binary
- Minidisk ~ quasar disk
- Doppler effect modulates brightness at O(v/c)

$\Delta F_\nu / F_\nu = (3-\alpha)(v_{||}/c)$

$\alpha = d\ln F_\nu / d\ln\nu$

Farris et al. (2015)



Tidal force from companion truncates minidisk

Gravitational lensing size scales of quasars

X-rays: **Chartas, Rhea, Kochanek et al. (2015)**

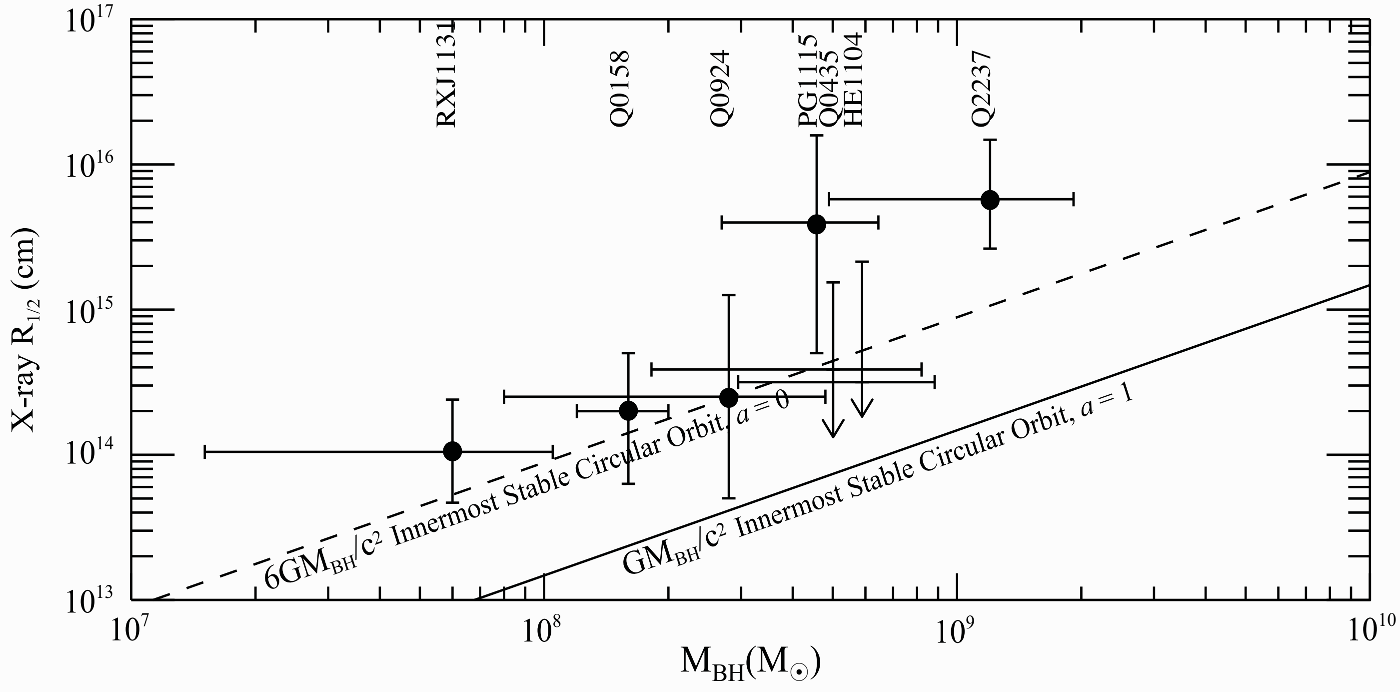


Fig. 1 X-ray half-light radii of quasars as determined from our microlensing analysis versus their black hole masses.

Gravitational lensing size scales of quasars

UV: **Morgan et al. (2007)**

e.g. $R=10^{14}$ cm → $R=600\ R_g$ for $M=10^6\ M_\odot$:

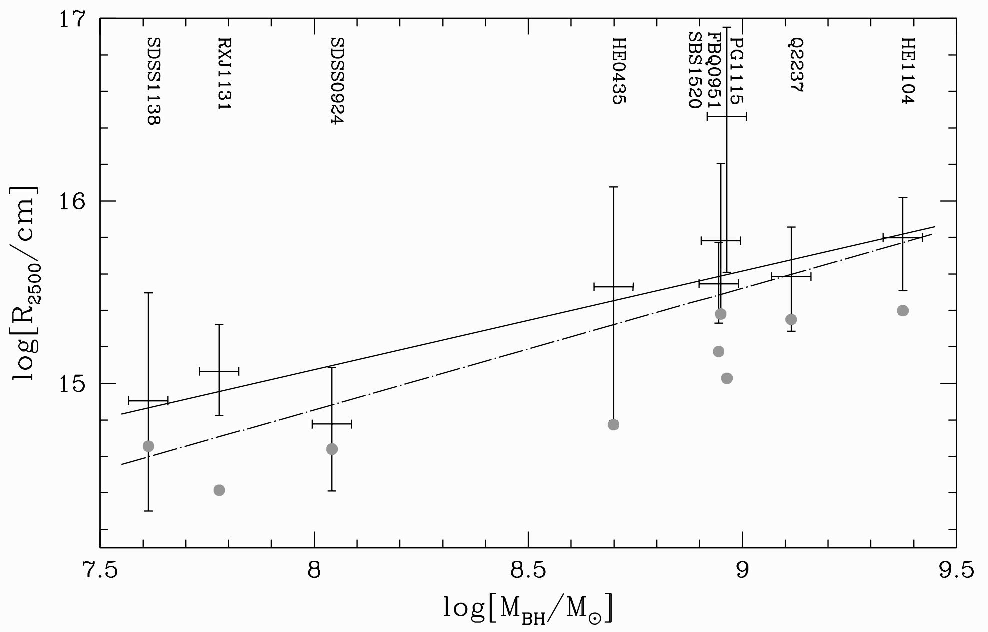
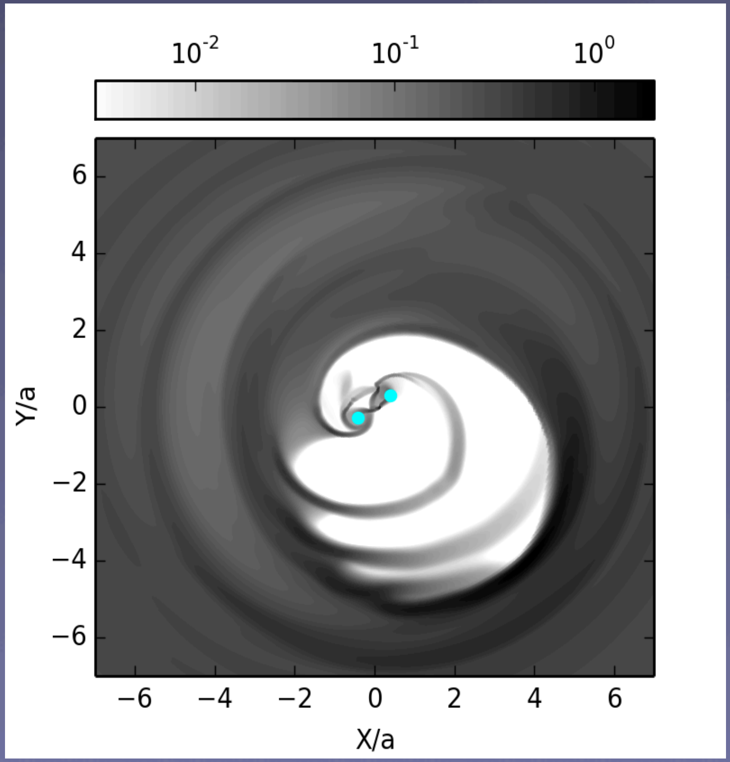


FIG. 1.— Inclination-corrected accretion disk size R_{2500} versus black hole mass M_{BH}. The solid line shows our best power-law fit to the data and the dot-dashed line shows the prediction from thin disk theory ($L/L_E = 1$ and $\eta = 0.1$). Disk sizes are corrected to a rest wavelength of $\lambda_{rest} = 2500$Å and the black hole masses were estimated using emission line widths. The filled points without error bars are R_{2500} estimates based on the observed, magnification-corrected I-band fluxes. They have typical uncertainties of 0.1-0.2 dex.

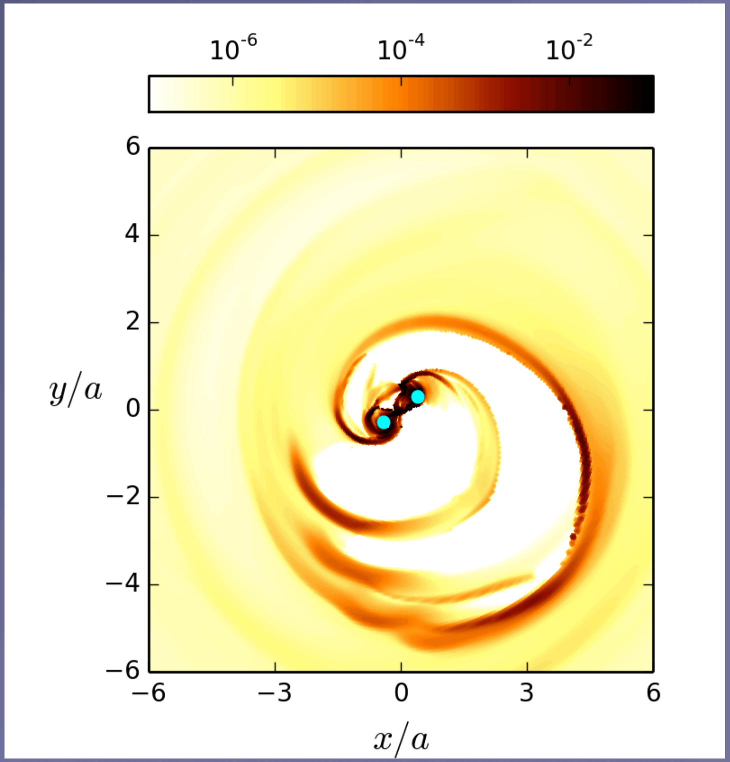
Thermal Emission from Binary

Farris et al. (2015a)

$q = M_2/M_1 = 1$



Surface density

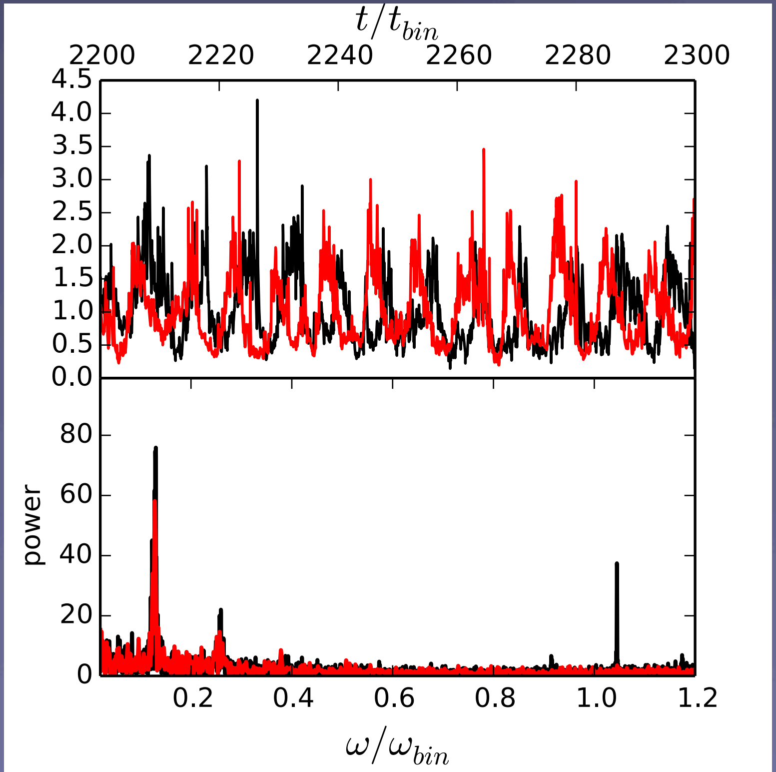


Surface luminosity:
shocks in streams and minidisks

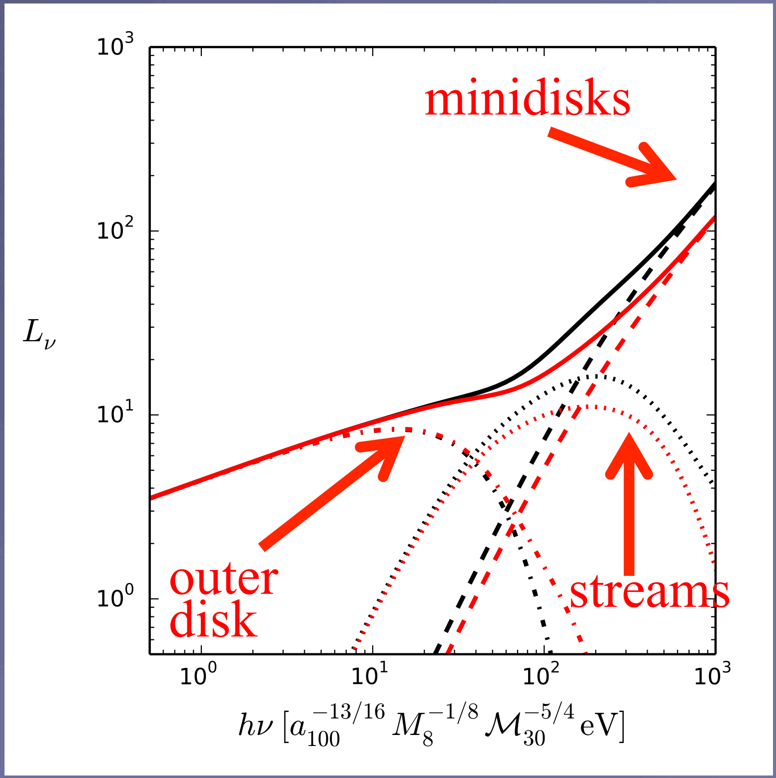
Composite Spectrum

Farris et al. (2015a)

- Spectrum **brighter, harder, variable** compared to single BH
- **opposite** of previous expectations based on empty cavity!



bolometric luminosity varies, tracks accretion



periodic spectral variability at high energies (~6 t_{orb})

EM vs. X-ray chirp

Test $A_{gw} \propto f^{2/3}e^{-i2\varphi}$ *vs* $A_\gamma \propto f^{1/3}e^{-i\varphi}$

$10^6\ M_\odot$ binary, q=1/3, z=1

→ $D/c = 3\times10^{18}$ s

→ $t_{orb} = (1+z)2\pi 10R_S/c \sim$ 4000 sec

(orbital time at merger)

=> $\Delta c/c \sim t_{orb} / [D/c] \sim 10^{-15}$

(10-100 × better from $S/N=10^{2\text{-}3}$) $\sim 10^{-17}$

Improve bounds from GW phasing alone ($\lambda_g \gtrsim 10^{16}$ km)

Berti+(2005), Will (2006)