Accretion Outbursts from Supermassive Black Hole Binaries

Takamitsu Tanaka
(Max Planck Institute for Astrophysics)

Pau Amaro-Seoane, Jorge Cuadra, Nicolas Gonzalez-Jimenez,
Zoltan Haiman, Kimitake Hayasaki, Kristen Menou, Rashid Sunyaev

Tidal Disruption Events and AGN Outbursts Workshop — June 27, 2012

Overview

- Compact and merging SMBH binaries can trigger rapidly time-varying accretion episodes

- Optimal scenario:
  Concomitant, multi-messenger astronomy;
  Observe these systems with gravitational waves, electromagnetic emission.

- May be observed serendipitously by wide-field, high-cadence surveys, whether you want them or not.

Overview

- Compact and merging SMBH binaries can trigger rapidly time-varying accretion episodes

- Optimal scenario:
  Concomitant, multi-messenger astronomy;
  Observe these systems with gravitational waves,
  electromagnetic emission.

  Luminosity distance,
  SMBH properties

- May be observed serendipitously by wide-field, high-cadence surveys, whether you want them or not.

Overview

- Compact and merging SMBH binaries can trigger rapidly time-varying accretion episodes

- Optimal scenario:
  Concomitant, multi-messenger astronomy;
  Observe these systems with gravitational waves, electromagnetic emission.

  Source redshift, accretion physics

  Luminosity distance, SMBH properties

- May be observed serendipitously by wide-field, high-cadence surveys, whether you want them or not.

Overview

- Compact and merging SMBH binaries can trigger rapidly time-varying accretion episodes

  ... i.e., "weird [crap]"

- Optimal scenario:
  Concomitant, multi-messenger astronomy;
  Observe these systems with gravitational waves, electromagnetic emission.

- May be observed serendipitously by wide-field, high-cadence surveys, whether you want them or not.

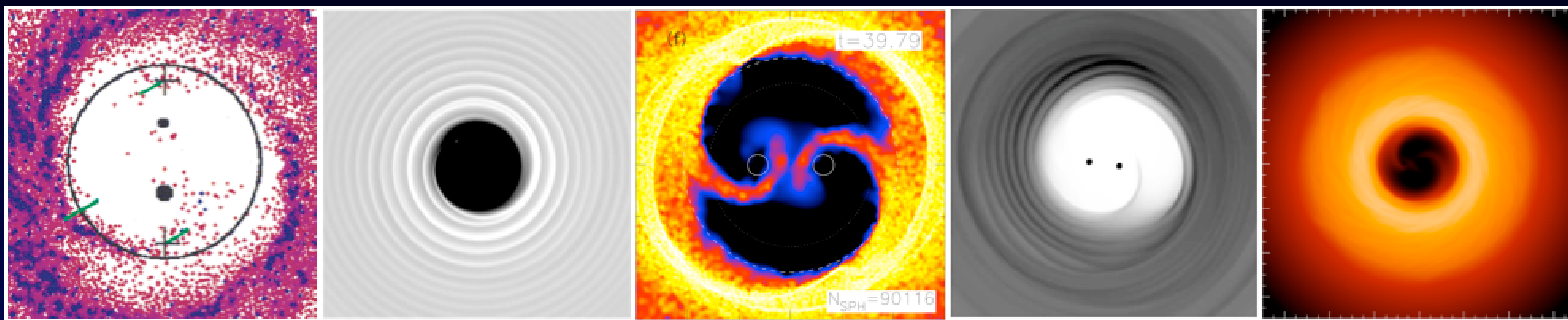
Why should we expect them?

- SMBH binaries should exist (but be difficult to detect)
  - Galaxy mergers *should* form SMBH pairs, *may* trigger AGNs
  - Many candidates of AGN pairs/triplets at ~kpc separations
    Komossa et al. (2003), Bianchi et al. (2008), Comerford et al. (2009), Green et al. (2010), Liu et al. (2010); Djorgovski et al. (2007), Barth et al. (2008), Liu et al. (2011)
  - One at ~6 pc (Rodriguez et al. 2006)
- Extreme gravitational potentials that vary & evolve coherently
  - Orbital period
  - GW-driven orbital decay timescale
  - At merger: spin reorientation, recoil (~100 km/s?)

Why should we expect them?

- SMBH binaries should exist (but be difficult to detect)
  - Galaxy mergers *should* form SMBH pairs, *may* trigger AGNs
  - Many candidates of AGN pairs/triplets at ~kpc separations
    Komossa et al. (2003), Bianchi et al. (2008), Comerford et al. (2009), Green et al. (2010), Liu et al. (2010); Djorgovski et al. (2007), Barth et al. (2008), Liu et al. (2011)
  - One at ~6 pc (Rodriguez et al. 2006)
- Extreme gravitational potentials that vary & evolve coherently
  - Orbital period
  - GW-driven orbital decay timescale
  - At merger: spin reorientation, recoil (~100 km/s?)

Geometry of circumbinary disks



- Theory: Binary torques open central cavity in a thin accretion disk (weak viscosity dependence!).
- Leakage into cavity is ~0.01-0.1 x dM/dt (disk), and occurs quasiperiodically at ~binary orbital period.
- Does this geometry have observable features?
  (... that are distinguishable from disks around solitary BHs?)

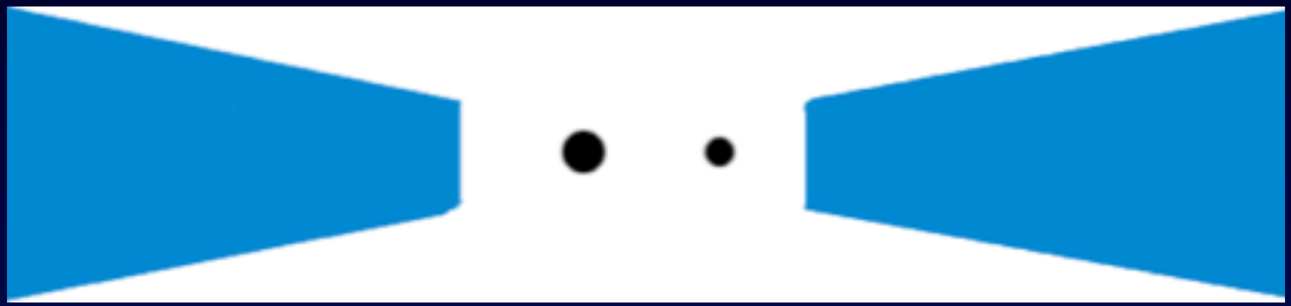
Images taken from (left to right):
Artymowicz & Lubow (1996); Armitage & Natarajan (2002); Hayasaki et al. (2007); MacFadyen & Milosavljevic (2008), Cuadra et al. (2009)

GW-driven orbital decay: X-ray afterglow of SMBH merger

Milosavljevic & Phinney (2005), Tanaka & Menou (2010)

1. Quasi-static geometry

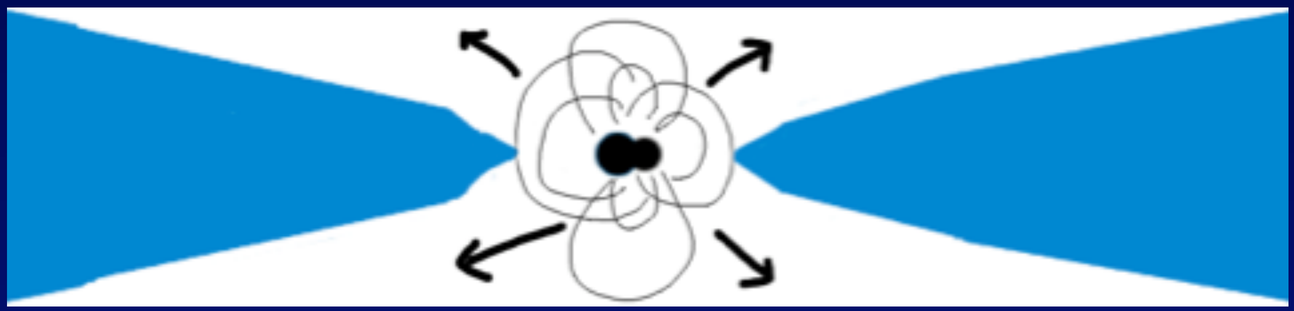
Binary & disk are coupled:
cavity radius ~ 2a
a > ~100 GM/c^2
(e.g. Ivanov et al. 1999, Liu & Shapiro 2010)



No center = X-ray-deficient

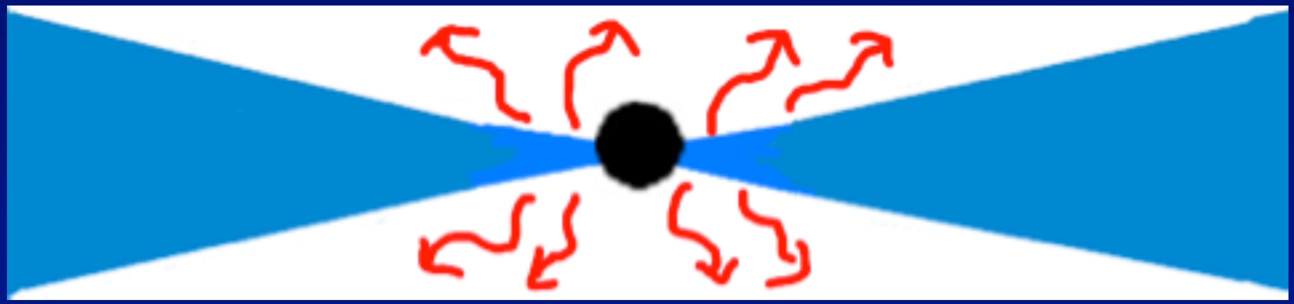
2. Decoupling and merger

GWs cause binary to inspiral
faster than gas can viscously respond
a < ~100 GM/c^2

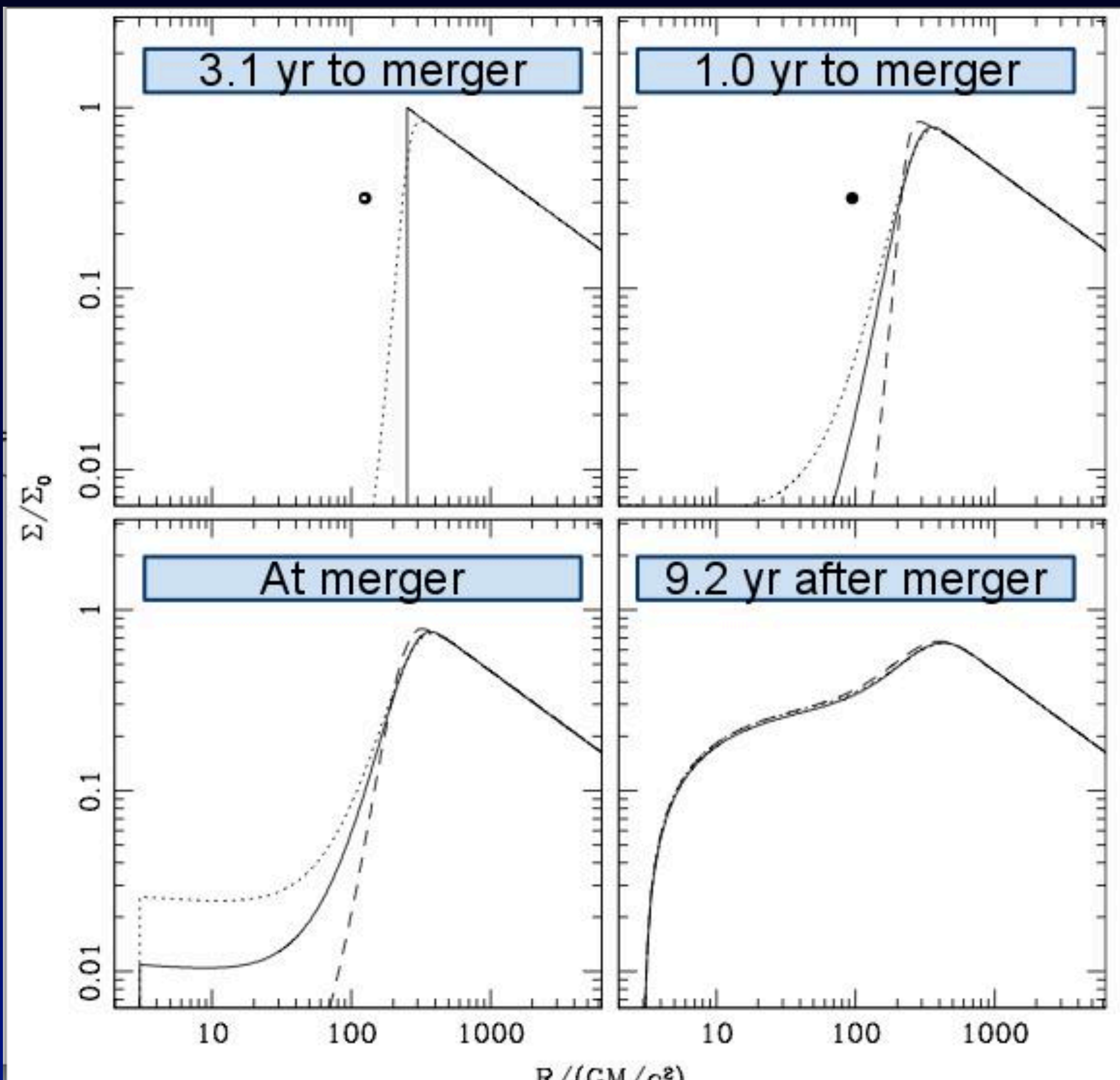


3. Afterglow

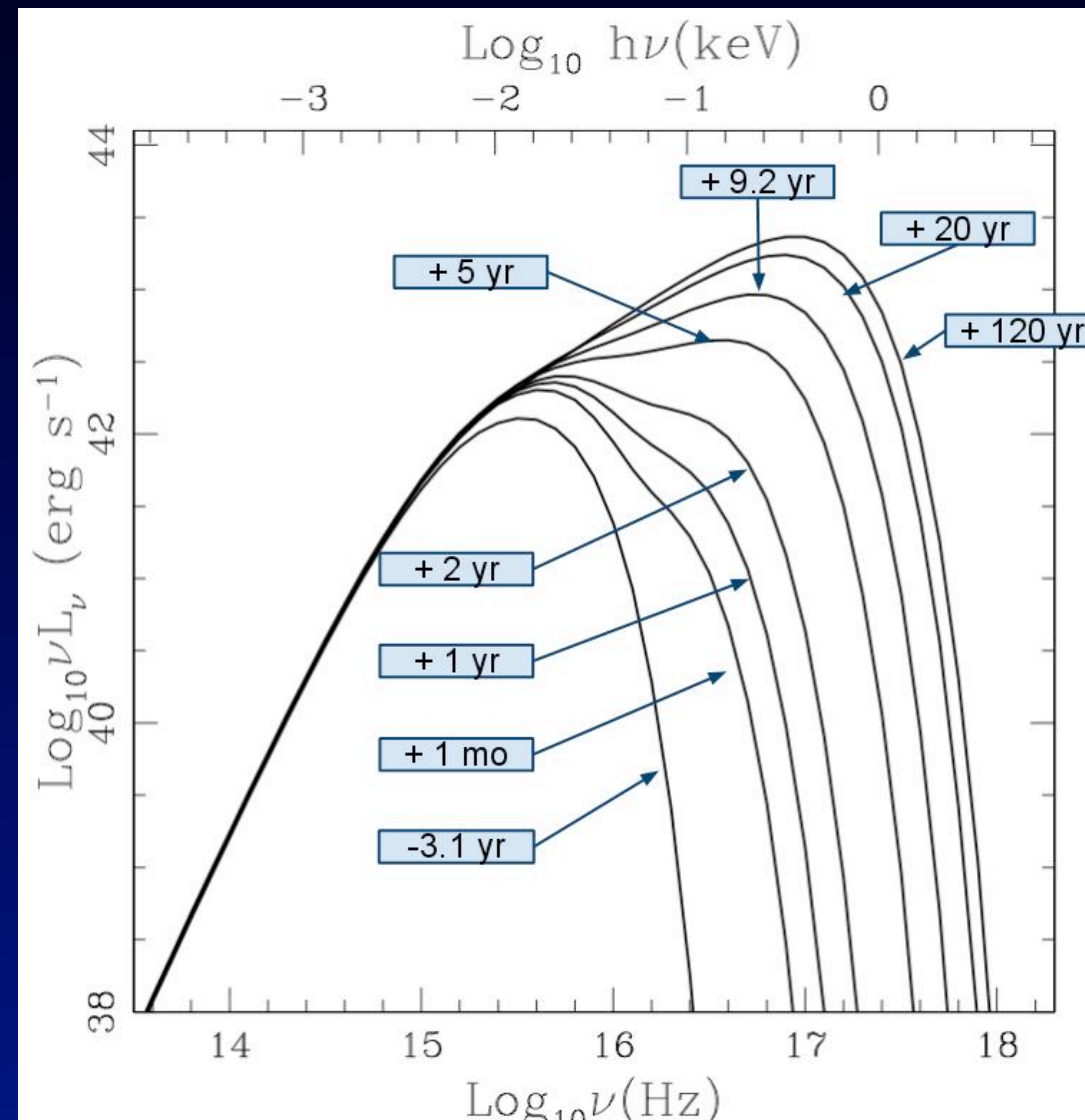
cavity fills ~ 1-10 years after merger
X-rays from filled, central region



GW-driven orbital decay: X-ray afterglow of SMBH merger



Surface density evolution for thin disk around merging binary
$M = 10^6 M_{\odot}$, $M_2/M_1 = 1$



Spectral evolution for same

Tanaka & Menou (2010)

GW-driven orbital decay: X-ray afterglow of SMBH merger

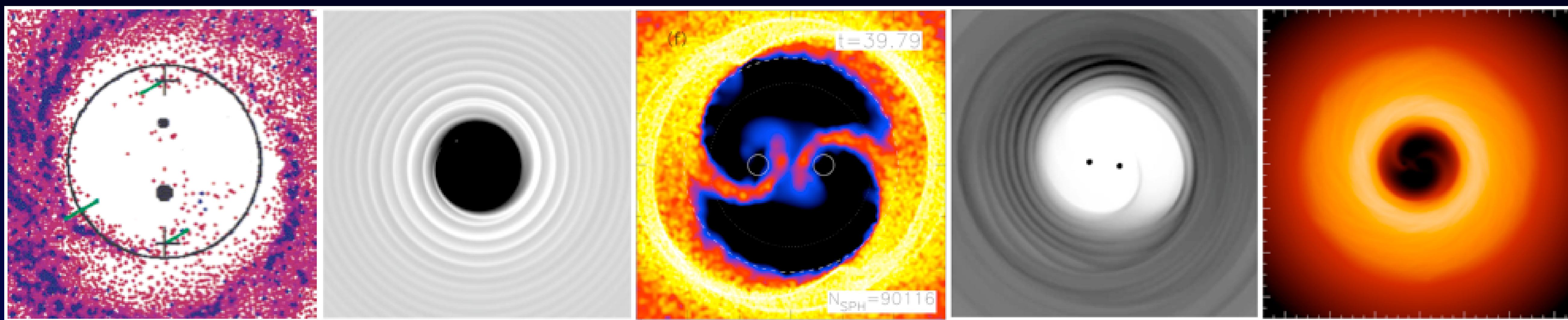
- Steady increase in UV and soft X-ray flux;
  Transition from optically luminous, UV- and X-ray-dim AGN (e.g. Shemmer et al. 2009) to more "normal" AGN in ~1-100 yr.

- Perhaps ~10-1000 AGNs at z~2 in this stage, if luminous AGNs associated w/ galaxy/SMBH mergers. Relevant for LISA sources, but also for PTA sources (Tanaka, Menou & Haiman 2011; Sesana et al. 2011)

- May be detected by MAXI, eROSITA, or LSST (if some of this energy is reprocessed) ... *without benefit of GW trigger* (Tanaka, Haiman & Menou 2010)

- Rapid onset of Eddington-scale accretion rates (birth of a quasar or X-ray AGN), relativistic jets plausible.

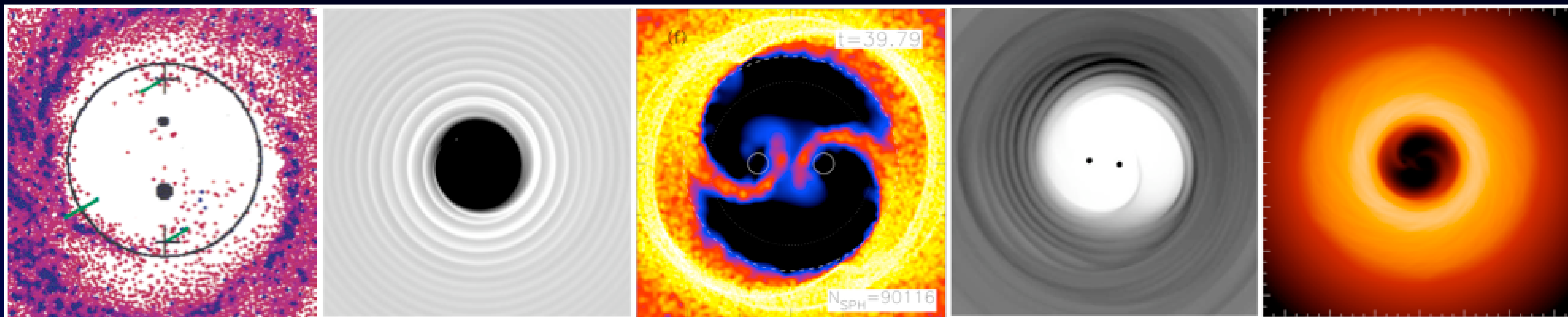
Geometry of circumbinary disks



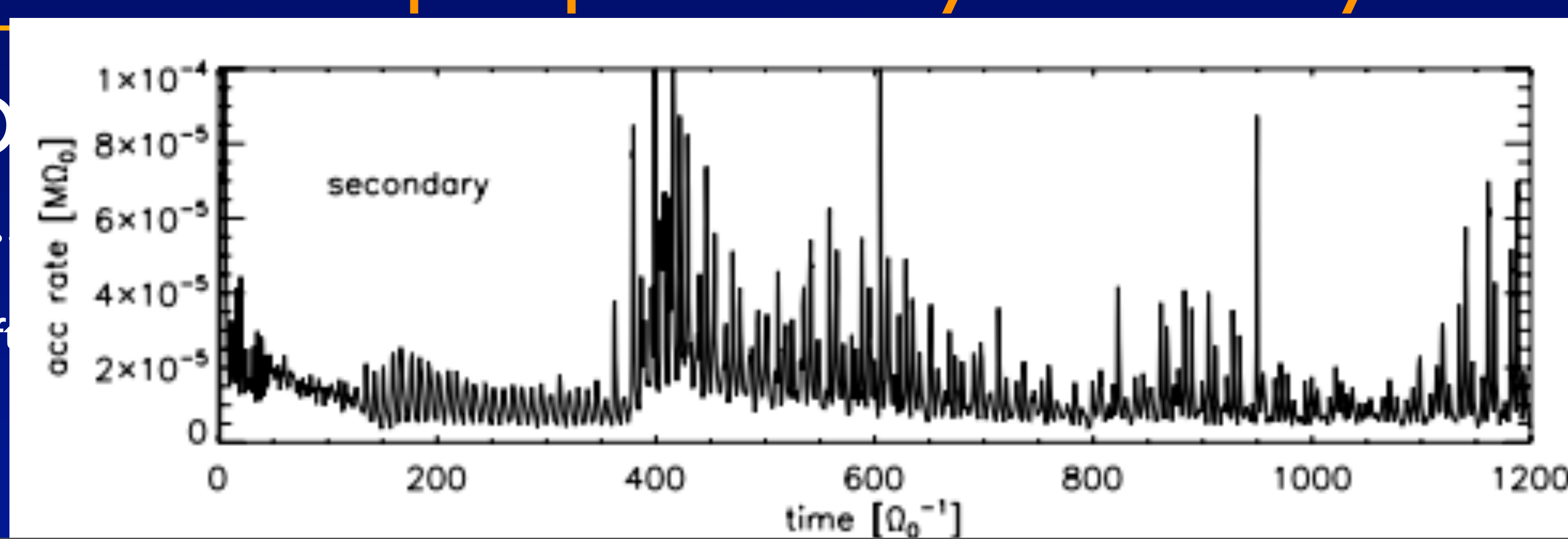
- Theory: Binary torques open central cavity in a thin accretion disk (weak viscosity dependence!).
- Leakage into cavity is ~0.01-0.1 x dM/dt (disk), and occurs quasiperiodically at ~binary orbital period.
- Does this geometry have observable features?
  (... that are distinguishable from disks around solitary BHs?)

Images taken from (left to right):
Artymowicz & Lubow (1996); Armitage & Natarajan (2002); Hayasaki et al. (2007); MacFadyen & Milosavljevic (2008), Cuadra et al. (2009)

Geometry of circumbinary disks



- Theory: Binary torques open central cavity in a thin accretion disk (weak viscosity dependence!).
- Leakage into cavity is ~0.01-0.1 x dM/dt (disk), and occurs quasiperiodically at ~binary orbital period.
- D… s?
  (… s?)



Cuadra et al. (2009)

Images taken from (left … Artymowicz & Lubow … (2008), Cuadra et al. (2009)

Quasi-periodic outbursts?

- When cavity is empty, system is quiescent in UV & X-rays; can be dim in optical & IR if cavity (binary separation) is large.
- Expect that for most such systems, orbital period >> accretion timescale of streams by SMBH(s).
- e.g., for a system with total mass of $5 \times 10^6\ M_\odot$, mass ratio 1:4, $dM/dt_{(disk)}$ ~ 0.1-0.3 x Eddington (typical AGN disk; e.g. Kollmeier et al. 2006) P_{binary} ~ 300-1000 yr: M_{stream} ~ 1 $M_\odot$, dense gas deposited onto secondary SMBH on nearly radial orbits every ~300-1000 yr.

Evolution of a binary-modulated burst

- Dense stream of gas deposited almost radially onto secondary.
- Circularizes at some distance from secondary.
- Gas viscously spreads and evolves toward steady-state surface density profile $\Sigma \propto [1-\sqrt{(R_{ISCO}/R)}]\, R^{-n}$.
  Shape depends weakly on circularization radius.
  (Textbook problem; Lynden-Bell & Pringle 1974, Tanaka 2011)
- UV and Soft X-ray "flare" when gas reaches secondary.
- Disk becomes diffuse as gas is accreted in and spread out.
- Innermost surface density,
  which determines highest-frequency thermal emission and Mdot near SMBH, *decays as a power-law with index $n \gtrsim 1$.*

Summary

- Binary SMBHs have coherently evolving gravitational potentials that can produce corresponding time-dependent accretion signatures.
- Decay and coalescence of a merging SMBH binary may trigger dramatic increase in AGN UV and X-ray luminosity on ~yr timescales.
- Large-separation binaries can dump $\sim M_\odot$ of gas onto secondary every ~orbit ($P >> 1$ yr).
  Such an event (sharp rise in UV/X flux, power-law decay) may masquerade as a stellar TD flare.
- These events could/should be observed by wide-field, high-cadence surveys, without the aid of GW signals.

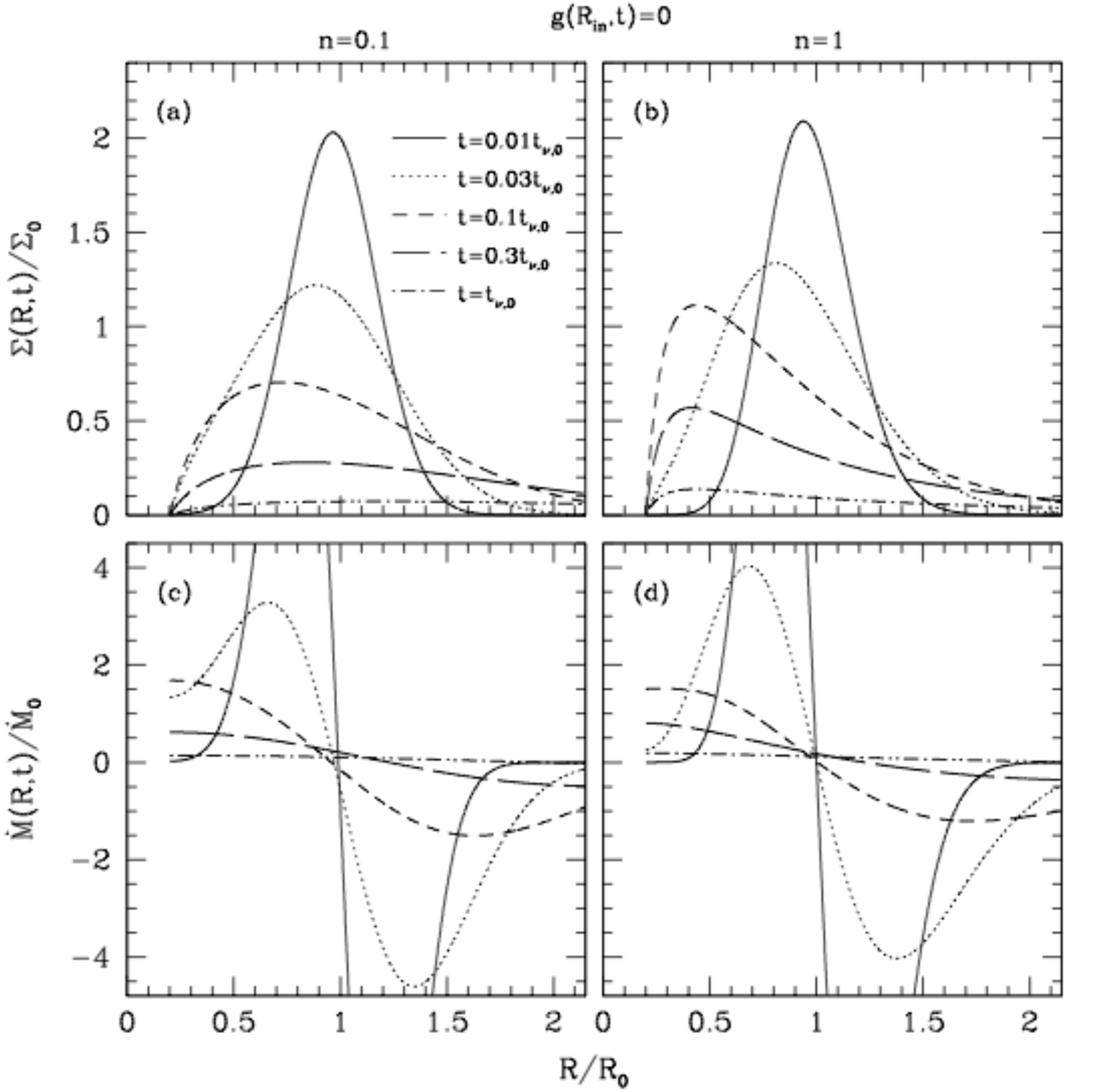


Figure 5.3 Same as as Figure 5.1, except that the zero-torque boundary condition is applied at a finite radius $R_{\rm in} = R_0/5$. As gas flows near the inner boundary, it exhibits the well-known behavior $\Sigma \propto R^{-n}(1 - \sqrt{R_{\rm in}/R})$ of LP74.

Tanaka (2011);
cf. Lynden-Bell & Pringle (1974)