

# Gravitational Waves from Compact Objects Accreting onto AGN

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# Acknowledgements

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Latex-beamer template: John Fregeau (Northwestern)



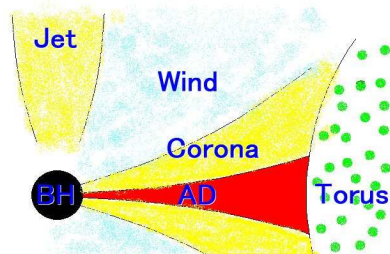
# Outline

- Astrophysical background and motivation
- Results
  - Description of model
  - Types of GW sources
  - Dependence on model parameters
  - Resolvability and Subtractability
- Applications/Implications for LISA



# AGN emit EM radiation at all wavelengths

- For SMBH masses of  $M \sim 10^6 - 10^9 M_{\odot}$ , typical accretion disks can extend many parsecs and have masses comparable to  $M$
- EM spectra should be dominated by IR-UV wavelengths, with non-thermal radio and X-ray emission from the jet and corona
- The outermost region of the disk is thought to be a torus of molecular gas



credit: J. Fukue

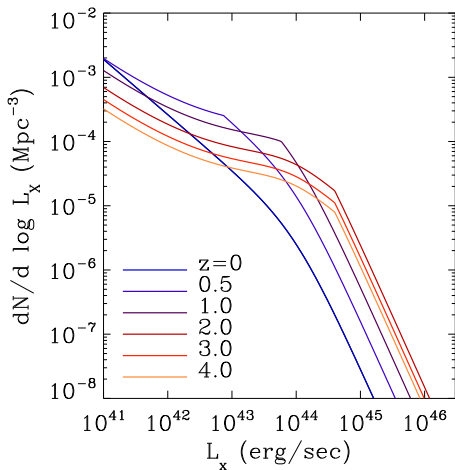


# Star formation in the outer disk

- The outer regions of the disk/torus will be dominated by gas pressure and should be self-gravitating [Shlosman & Begelman 1987](#)
- Above the Toomre limit ( $\Sigma \gtrsim \frac{c_s \Omega}{\pi G}$ ; [Toomre 1964](#)) the disk will be gravitationally unstable to collapse
- This may result in a complete fragmentation of the disk into massive stars [Levin 2003, 2006](#)
- Or isolated super-massive stars may form and subsequently clear gaps in the disk via gas accretion [Goodman & Tan 2004](#)
- The disk-embedded stars will then evolve to compact objects (COs) on the accretion time-scale as they migrate through the disk and eventually merge with the SMBH via gravitational radiation



# AGN activity can act as a tracer for inspiral events



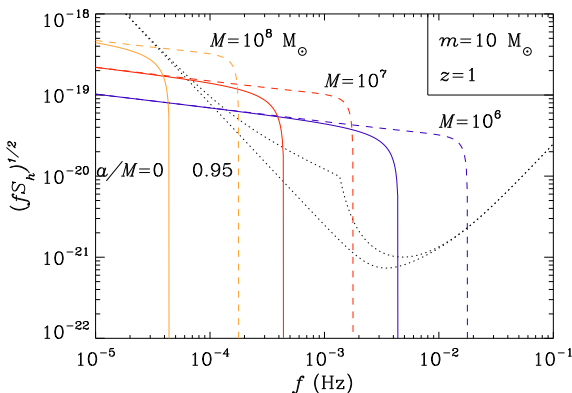
Ueda et al. 2003

- $L_X = f_X f_{\text{Edd}} L_{\text{Edd}}(M)$
- The hard X-ray luminosity function is relatively well-determined out to  $z \sim 3 - 4$
- X-rays suffer less extinction than IR/visible emission
- Provide good estimate of *intrinsic* luminosity



# Each inspiral event is adiabatic and circular

The GW spectrum is characterized by a cut-off frequency determined by the mass and spin of the SMBH.



cf. Finn & Thorne 2000



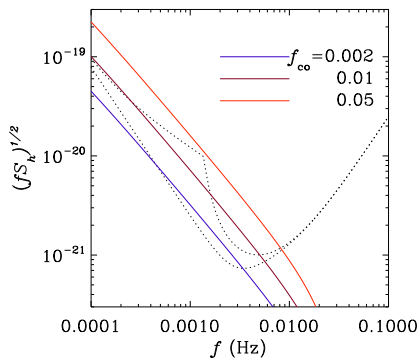
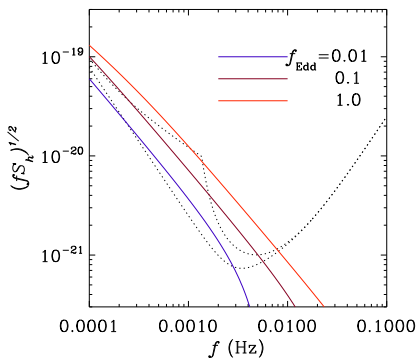
# Model Parameters

$$\frac{d\rho_{\text{gw}}(f)}{d \ln f} = \frac{\eta_{\text{gw}} f_{\text{CO}}}{\eta_{\text{em}} f_X} \int \left| \frac{dt}{dz} \right| \frac{dz}{1+z} \int_{L_{\text{min}}}^{L_{\text{max}}} dL_X \frac{dN(L_X)}{d \ln L_X} \frac{1}{E_{\text{gw}}} \frac{dE_{\text{gw}}}{d \ln f} [f_z(M)]$$

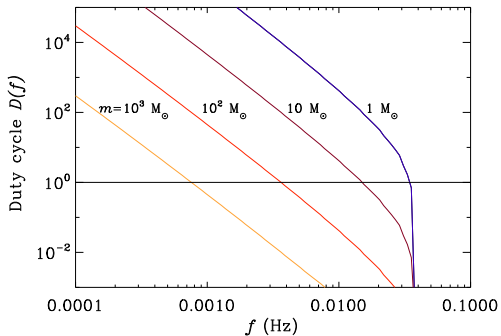
parameter	min	max	preferred	description
$f_{\text{CO}}$	0	1	0.01	fraction of accreted mass in COs
$f_X$	0	1	0.03	fraction of EM radiation in X-rays
$f_{\text{Edd}}$	0	$\gtrsim 1$	0.1	fraction of Eddington luminosity/accretion rate
$\eta_{\text{em}}$	0	0.4	0.2	efficiency of converting gas to EM radiation
$\eta_{\text{gw}}$	0	0.4	0.2	efficiency of converting COs to GW radiation



# The time-averaged GW signal is comparable to the LISA noise curve



# Stochastic vs. chirp signals

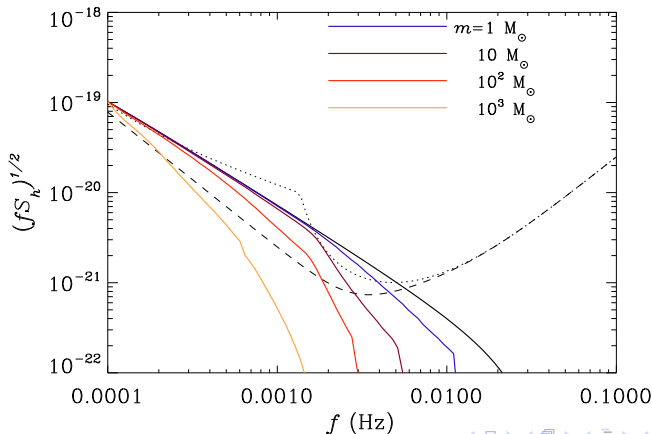


- The duty cycle is an estimate of the number of sources around each frequency at any time
- When  $D(f) \gtrsim 1$ , the sources may be treated as stochastic
- Above a certain frequency, the GW signal will be more like an isolated chirp



# We can subtract the chirp signals with large SNR

For a given  $M$ ,  $m$ , distance, and SNR threshold, we calculate a cut-off frequency above which the inspiral signal can be subtracted, leaving behind an unresolvable stochastic background



# Astrophysical considerations/caveats

- We have relatively little data on the low-luminosity and low-mass end of the distribution function
- Accretion and stellar evolution time scales may compete: main sequence stars would likely be tidally disrupted before merger
- Still very large uncertainty in  $f_{\text{CO}}$  and  $m$
- Greater understanding will require detailed simulations of outer disk
- $f_X$  and  $f_{\text{Edd}}$  most likely are functions of  $M$  and also evolve in time: “anti-hierarchical” evolution [Marconi et al. 2004](#); [Merloni 2004](#)



# Applications/Implications

- Event rates should be comparable to other stochastic EMRI signals, e.g. WD, NS captures [Barack & Cutler 2004](#)

## Stochastic regime ( $f \lesssim 1$ mHz):

- LISA should be able to put interesting limits on a number of model parameters, in particular  $f_{\text{co}}/f_X$
- If the stochastic background is high enough, it still may be subtractable; not like WD background

## Chirp regime ( $f \gtrsim 1$ mHz):

- Individual events should be resolvable as EMRIs: can be used to measure SMBH spin and possibly test GR
- Could be new source of IMBH-SMBH binaries, with *clear EM counterpart* cf. [Milosavljevic & Phinney 2005](#)
- Should have high SNR even at large redshifts; individual events can be detected and subtracted

