X-ray spectral signatures of LISA binary black holes

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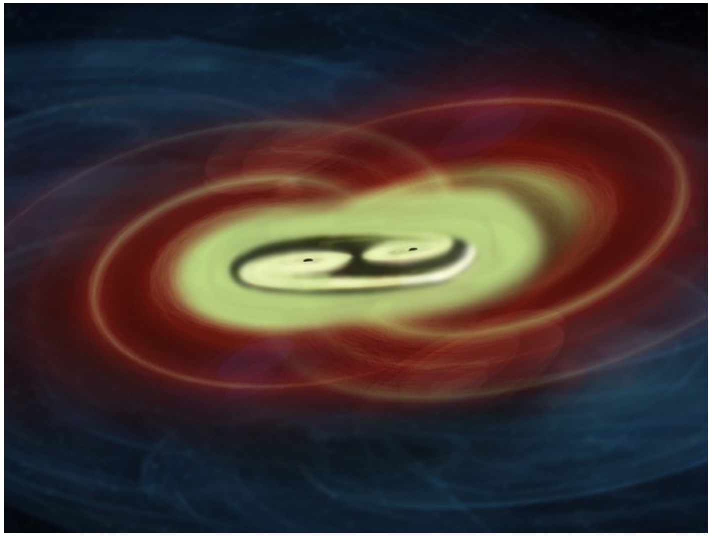
Exploring the Origin and Evolution of Massive Black Holes

Co-evolution with host galaxy

Growth through mergers and accretion



Credit: ESA

Enigmatic birth

Cosmology and Fundamental Physics

Massive Binary Black Holes (MBBHs) approaching merger, target of LISA

Detectability and observational signatures of their complex surrounding in X-ray band with forthcoming NewAthena

Challenging identification

- Gas-rich but complex environment
- No observations to draw on
- Similarities to single AGNs

Credit: IRAP, CNES, ESA & ACO

X-ray Astronomy of paramount importance

Fewer transient sources / Specific of inner regions of MBH accretion discs

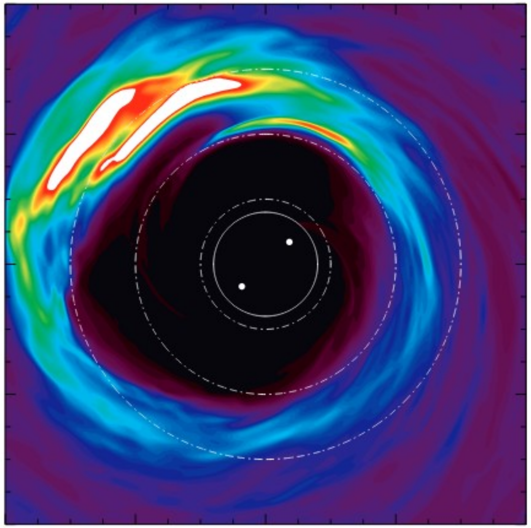
Athena, a unique opportunity ?

Advanced **T**elescope for **H**igh-**EN**ergy **A**strophysics

12m length focal, 2 instruments :

- **WFI Wide Field Imager : large Field of View 0.4 deg2**
- X-IFU X-ray Integral Field Unit : high spectral resolution 2.5 eV

High X-ray sensitivity : max 2 10^{-17} $erg.cm^{-2}.s^{-1}$ (400 ks exposure time)



Credit: Shi et al, 2012

MBBH specific features

- Circumbinary disc (CBD) truncated at 2a

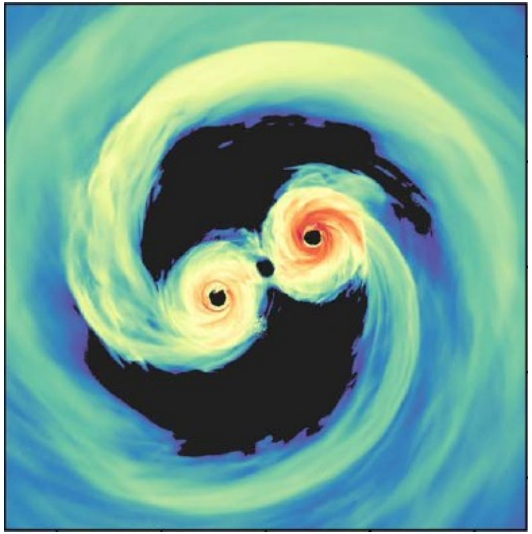
Artymowicz & Lubow 94

- Low-density cavity
- Mini-discs (MDs) around each BH

Farris+14

- Streams from CBD to MDs
- Over-density (lump) at inner edge of CBD

Shi+12, Mignon Risse+23



Credit: d'Ascoli et al, 2018

Importance of a multi-feature characterisation for unambiguous identification

MDs Doppler shift (see PA Duverne presentation) D'Orazio+15, Dal Canton+19

Lump modulation Tang+18, MR+subm

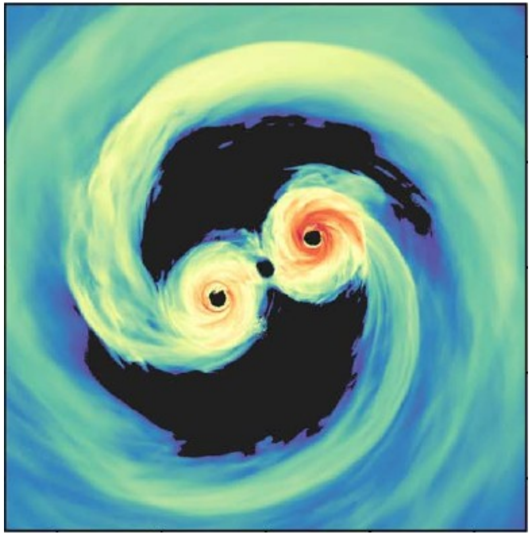
Hard X-ray emission from stream shocks Roedig+14

Notch in thermal continuum Roedig+14

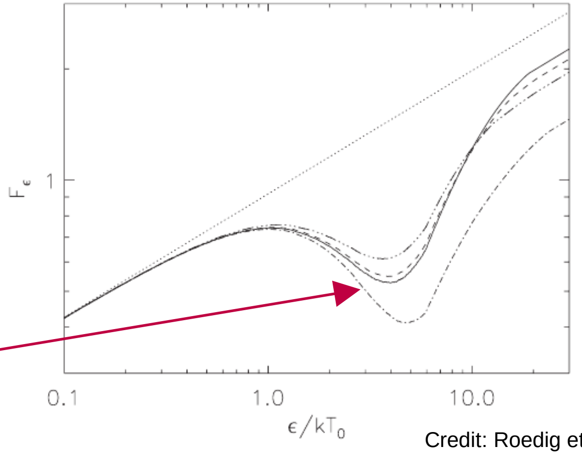
Models for MBBH spectral signatures

Simulation-lightened analytical models to explore parameter space

- Geometrically thin and optically thick accretion disc radiating as a multi-colour blackbody
  Shakura and Sunyaev 1973
- Flux deficit (notch) due to the low-density cavity between circumbinary disc and mini-discs
  Roedig et al. 2014
- The initial step of this work was to extend the model to the ISCO radius of the mini-discs and to explore the impact on the spectrum shape



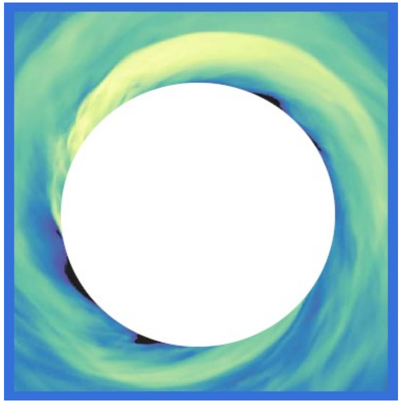
Credit: d'Ascoli et al, 2018

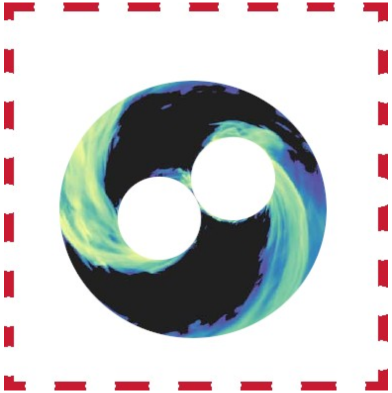


Notch (flux deficit)

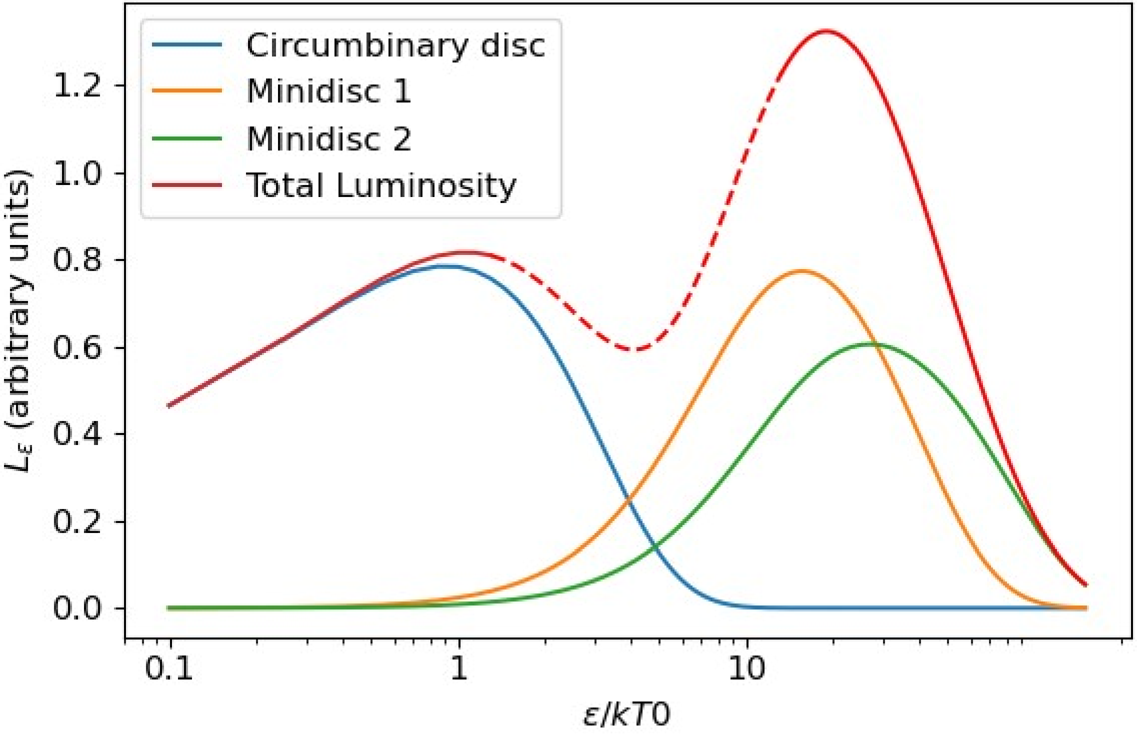
Credit: Roedig et al, 2014

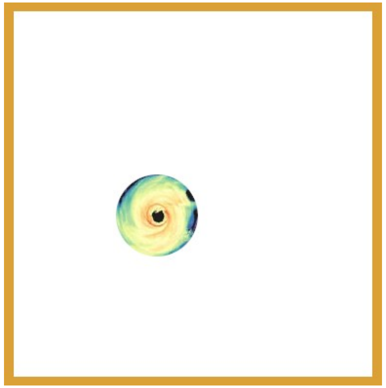
Circumbinary and Mini-discs contributions





Mass ratio q = 0.3





Comparison MBBH / single AGN emissions

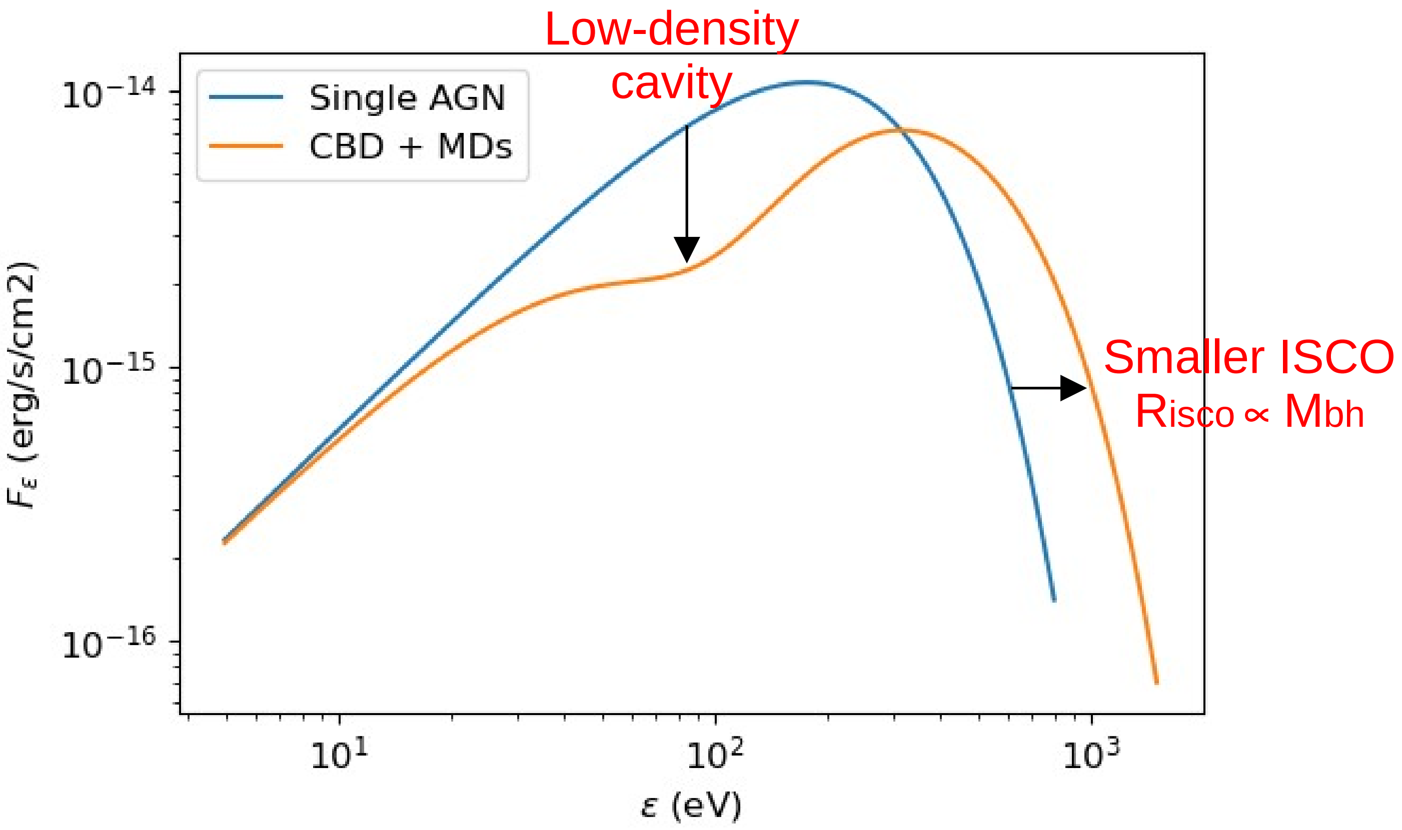
Black body emission

Same total mass :
1e6 M_{sun}

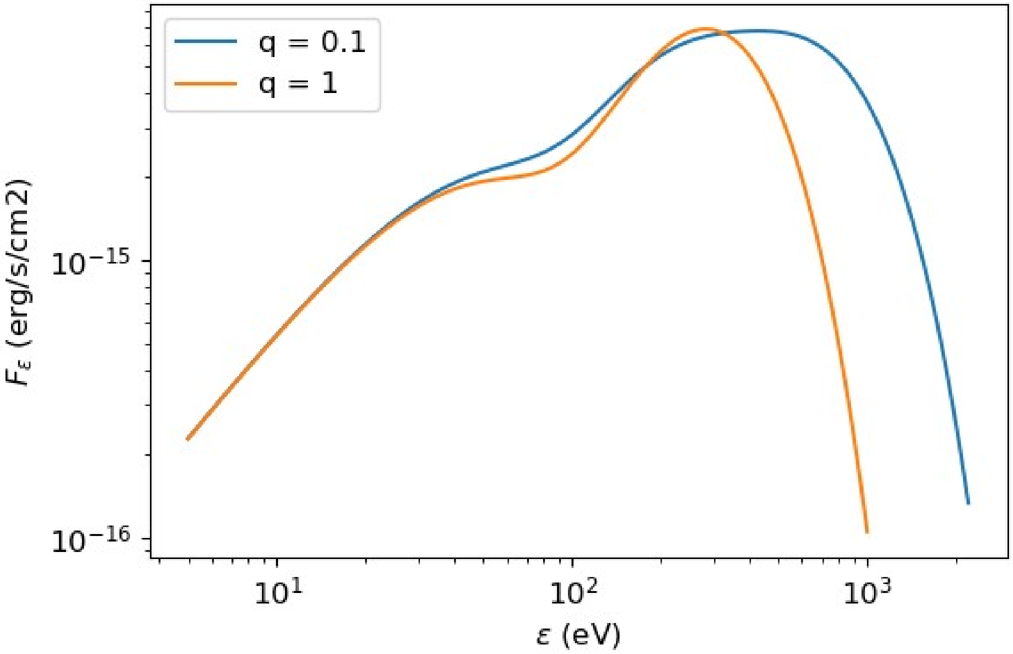
Mass ratio :
q = 0.3

Separation :
a = 20 Rg

Distance :
d = 13.6 Gpc



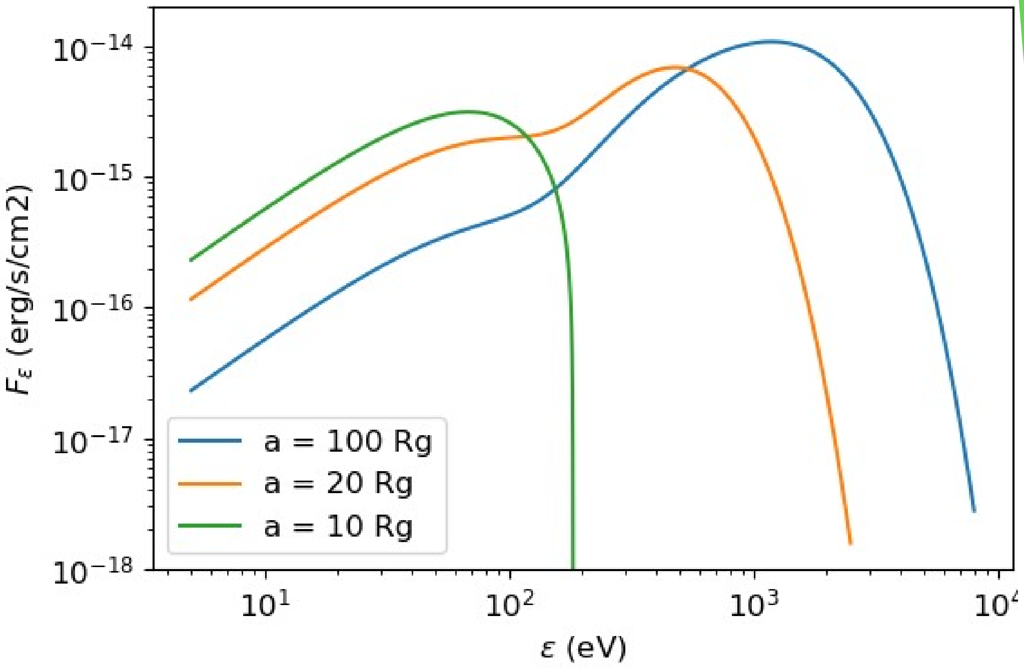
Mass ratio



Smaller mass ratio

- Radiation at higher energy from the shorter secondary inner edge
- Broadening of HE contribution

Separation



- High energy contribution melts with mini-discs reduction when the BHs get closer
- MDs vanished at 10 Rg

Conclusion

Preliminary work for modelling theoretical spectra

The medium-term aim is to produce simulated observations for Athena

=> Xspec (X-Ray Spectral Fitting Package, Arnaud 1996)

- Which binaries might be detectable with Athena depending on their BBH mass, mass ratio, spins, binary separation, inclination, distance ?
- With which exposure time, signal to noise ratio ?
- Is the notch (low-density cavity) in Athena energy range ?