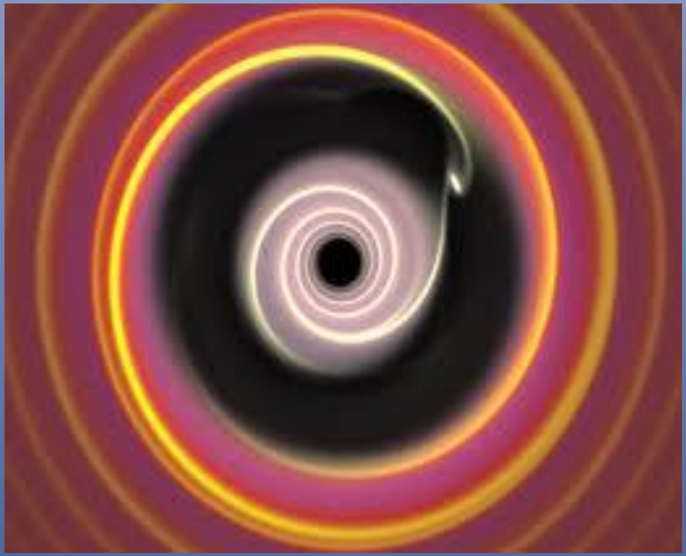
IMBH in AGN: Observables



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Overview

- Gaps & cavities – IMBH & SMBH
  - Formation
  - Signatures
- Imaging
- Embedded objects & intermittent events
- Gravitational Waves

Mind the Gap – IMBH & SMBH

- Minimum condition to open gap
  - $M_2/M_1=q>q_{crit}\approx(27\pi/8)^{1/2}\ (H/r)^{5/2}\ \alpha^{1/2}$
- Note
  - q_{crit} implies IMBH is minimum mass
  - Gap formation prevented by
    - High disk viscosity
    - Geometrically thick disk
- Gap mostly, but not totally empty
- Back wall irradiated → further structural changes

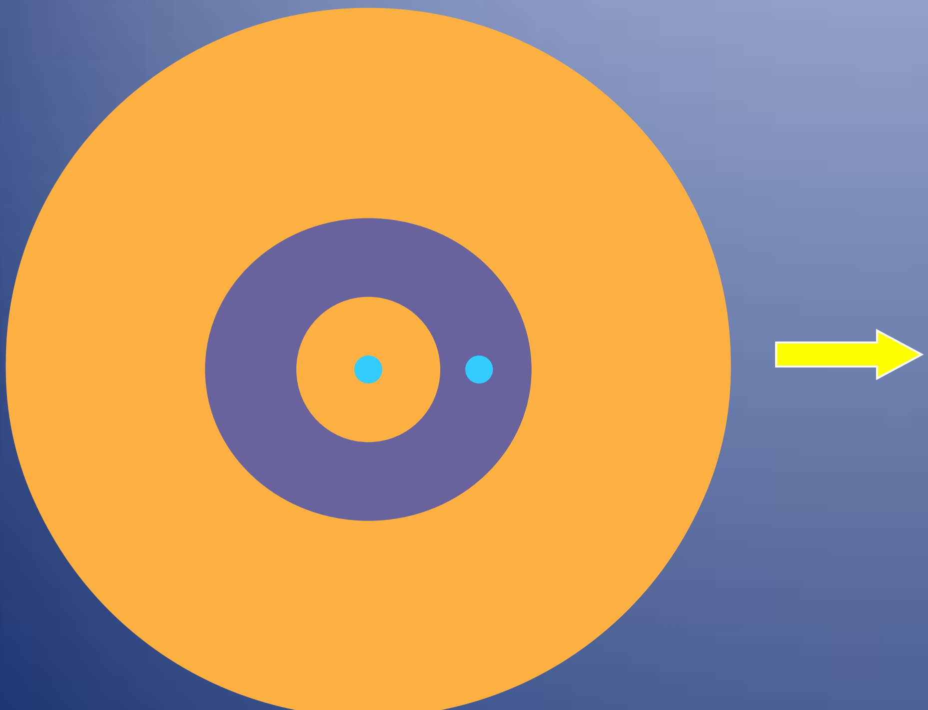
Signatures of gaps

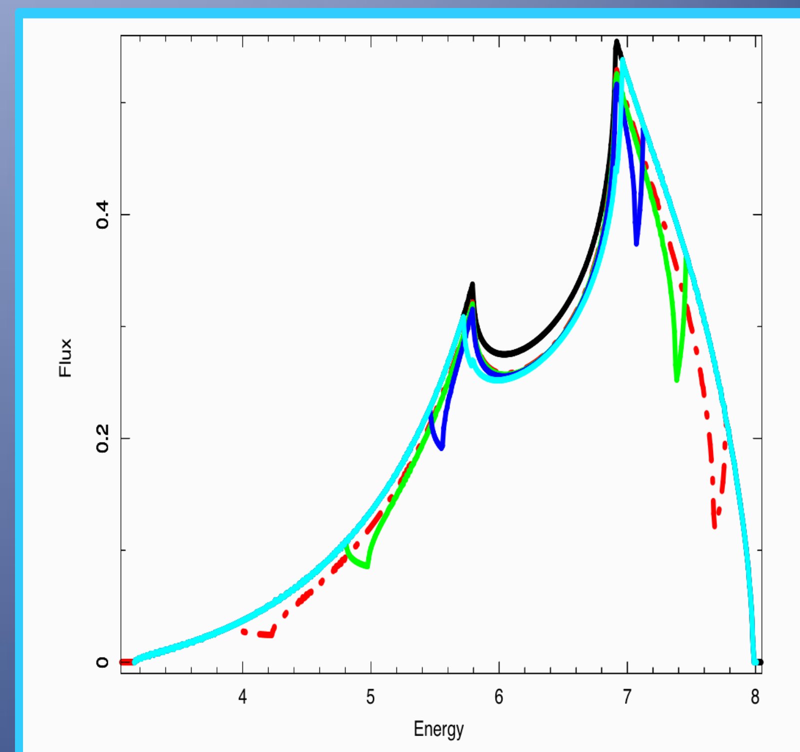
- SED (see Gültekin & Miller 2012)
  - Annular gap produces break in SED
    - Width ~ $2a(q/3)^{1/3}$
  - Irradiated back wall should produce adjacent SED peak
- Lines
  - FeKα line (McKernan, Ford, Kocsis & Haiman 2013)

Relativistic FeKα line

Effect of annular gap: 'pair of notches'

(McKernan, Ford, Kocsis & Haiman 2013)





R_{in}=6 R_g R_{out}=100 R_g

$\Theta = 60^{\circ}$

$\varepsilon(r) \sim r^{-2.5}$

R_{gap}= 90±9 R_g 50±5 R_g

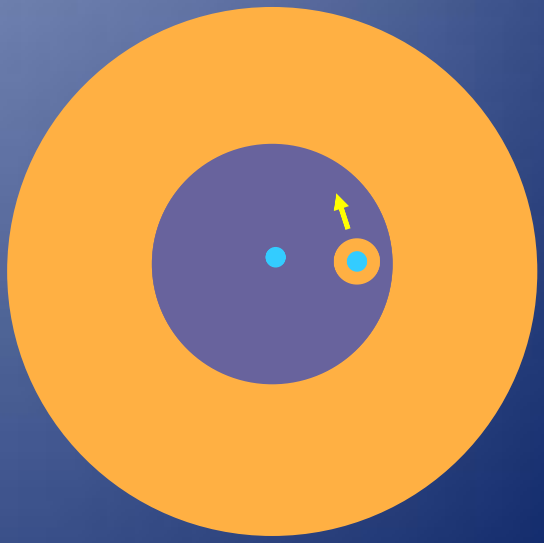
20±2 R_g 10±1

Gaps can become cavities

- Gap-openers raise spiral density waves, unequal torques
- Begin Type II migration
  - $\tau_{II}=\alpha^{-1} (H/r)^{-2} \omega^{-1}$
  - Tiny fraction of Type I time
- Stalls when $m_{gas}(r<r_{orb}) \approx m_{IMBH}$
- Inner disk drains on dynamical time
  - Cavity replaces gap
  - Pileup behind cavity

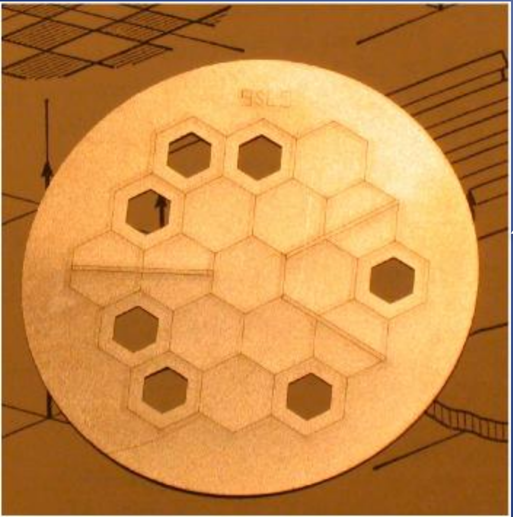
Signatures of cavities

- Inner disk material removed
  - Missing part of Big Blue Bump
  - Short timescale variability material gone→PDS break
  - Possible explanation for some LINERs
- FeKα much harder to distinguish except ‘see-saw wings’ (XMM?)



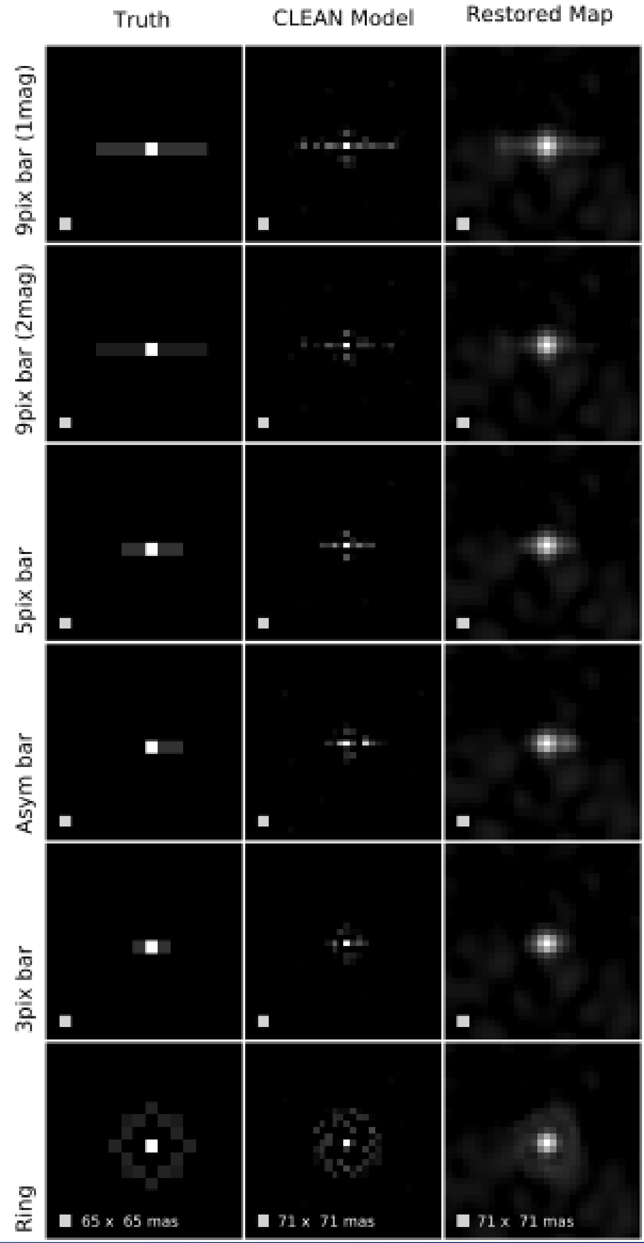
Friends with ~~benefits~~ planets

- Imaging AGN disks and proto-planetary disks similar
  - Contrast problem
  - pc scale disk at 10-100Mpc (20-2mas) ~ AU scale disk at 10-100pc (100-10mas)



JWST NIRISS-AMI
Sivaramakrishnan et al SPIE 2012

θ=0.5λ/D=71mas
extended structure
contrast ≥ 10^3



Ford et al. 2013 ApJ submitted

Ford: Observing IMBH in (A)GN

Embedded objects & intermittent events

- Non-gap openers accrete too
  - IMBH will peak in soft X-ray
- Retrograde orbits
  - Can persist for long time
  - Bow shock generates soft X-rays
- Tidal disruption events
  - Under-luminous Type Ia SNe
- IMBH after an AGN-scatterers of low mass stars

Gravitational Wave Signatures

- Frequency from ISCO
  - LISA freq 10^{-4}-1Hz: $M_{tot}=10^3-10^7 M_{sun}$
  - LIGO freq 10-3000Hz: $M_{tot}=1-10^3 M_{sun}$
- LISA detects SMBH-IMBH inspiral to ~1Gpc
  - S/N~10
  - $D_{LISA} \sim 1\text{Gpc} \, (M_{tot}/10^6 M_{sun})^{-2} \, \mu/10^3 M_{sun} \, (r/30 r_g)^{-4} \, (T_{obs}/1\text{yr})^{1/2}$

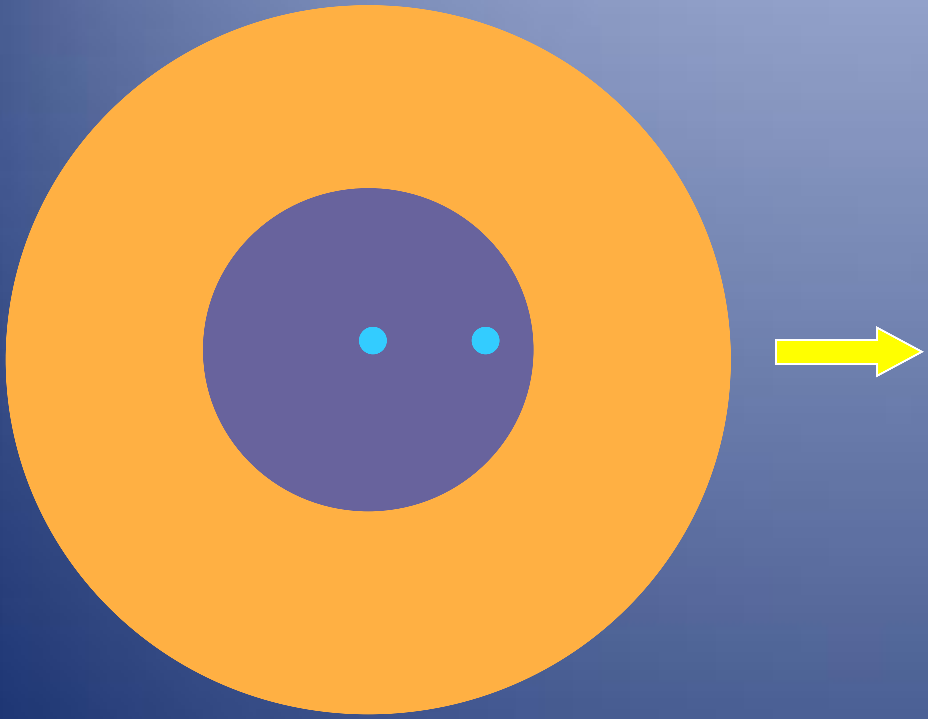
Take Home Points

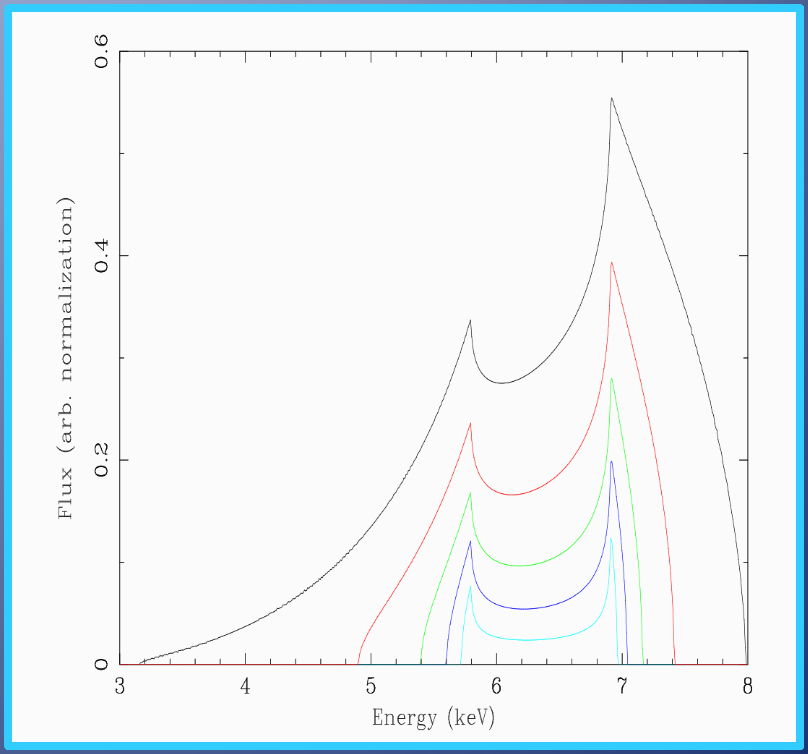
- Many signatures of IMBH
  - Especially gaps & cavities
    - Detection provides constraints on H/r, α
  - Analogous to protoplanetary disk signatures
  - Pay close attention to their instruments
- Some signatures extend to SMBH regime
- FeKα: EM pre-cursor to GW merger events

Relativistic FeKα line

Effect of central cavity: ‘clipped wings’

(McKernan et al. 2013)





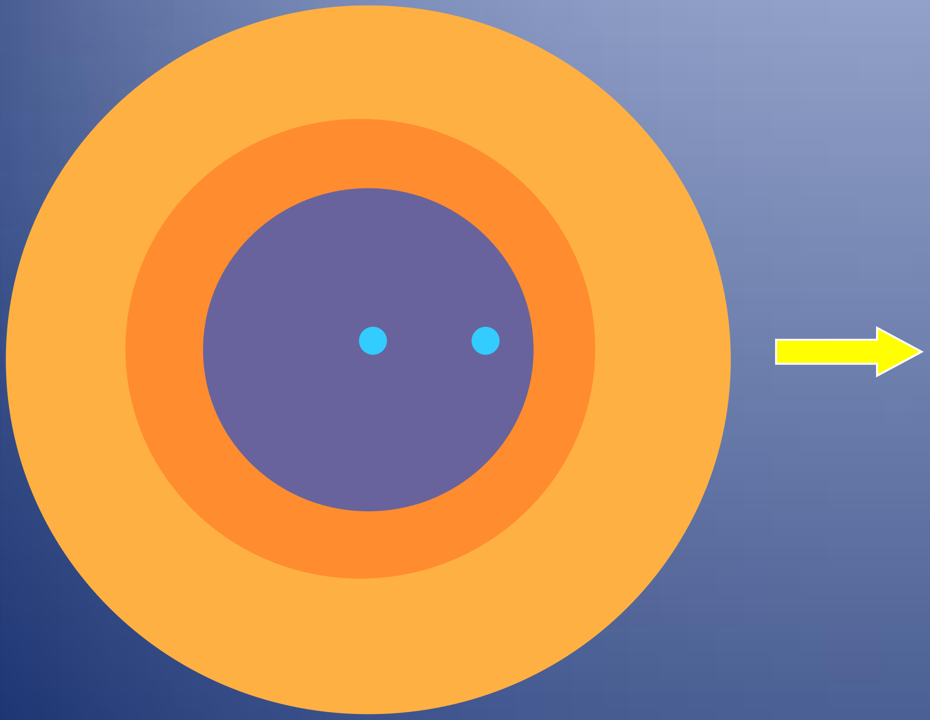
R_{out}=100 R_g
Θ = 60 °
$\varepsilon(r) \sim r^{-2.5}$

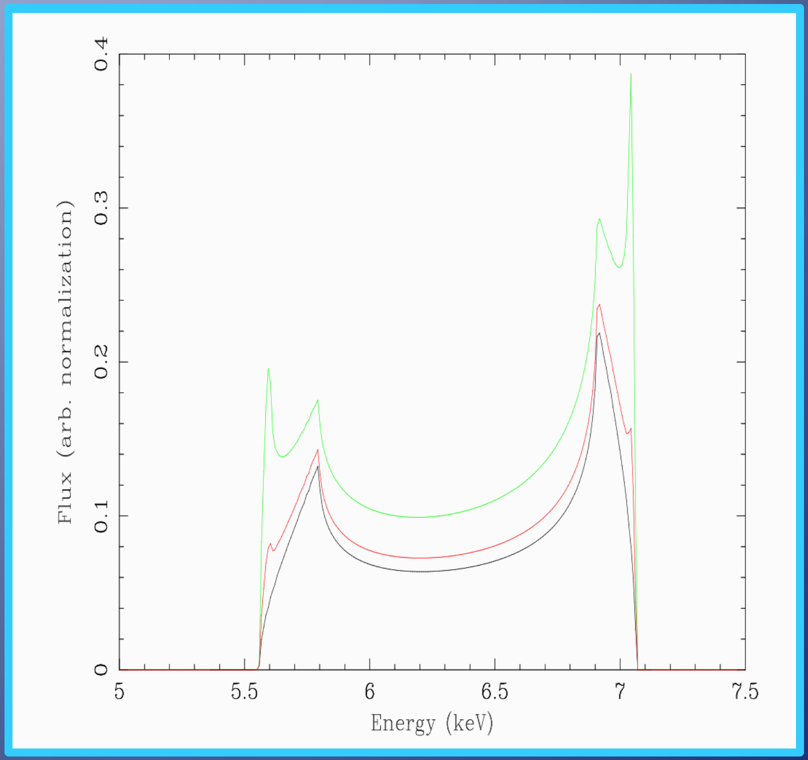
R_{in}=6, 20, 40, 60, 80 R_g

Relativistic FeKα line

Effect of central pile-up: 'double-twin horns'

(McKernan et al. 2013)





R_{out}=100 R_g

Θ = 60 °

$\varepsilon(r) \sim r^{-2.5}$

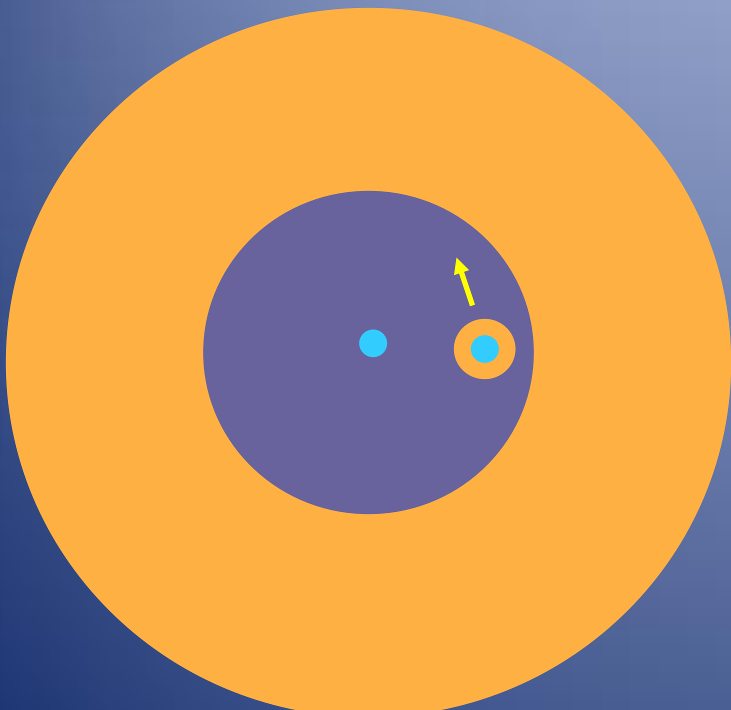
R_{in}=55 R_g

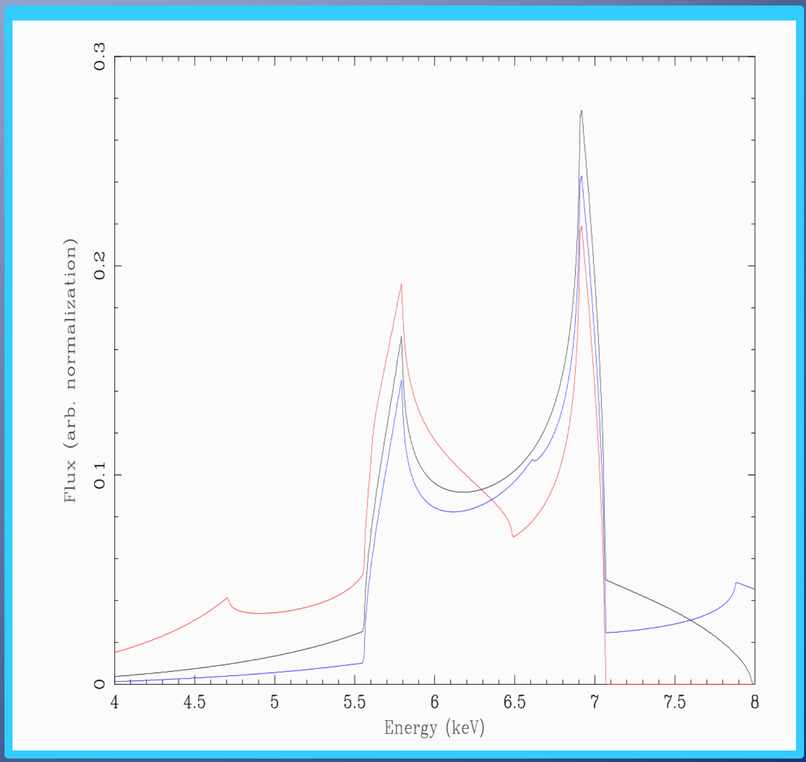
Pile-up by ×1, ×2, ×5

Relativistic FeKα line

Effect of circum-secondary minidisk: ‘see-saw wings’

(McKernan et al. 2013)





R_{out}=100 R_g

$\Theta = 60°$

$\varepsilon(r) \sim r^{-2.5}$

R_{in}= 55 R_g

R_2= 30 R_g