Modelling the X-ray spectra of black hole binaries: The black hole spin controversy

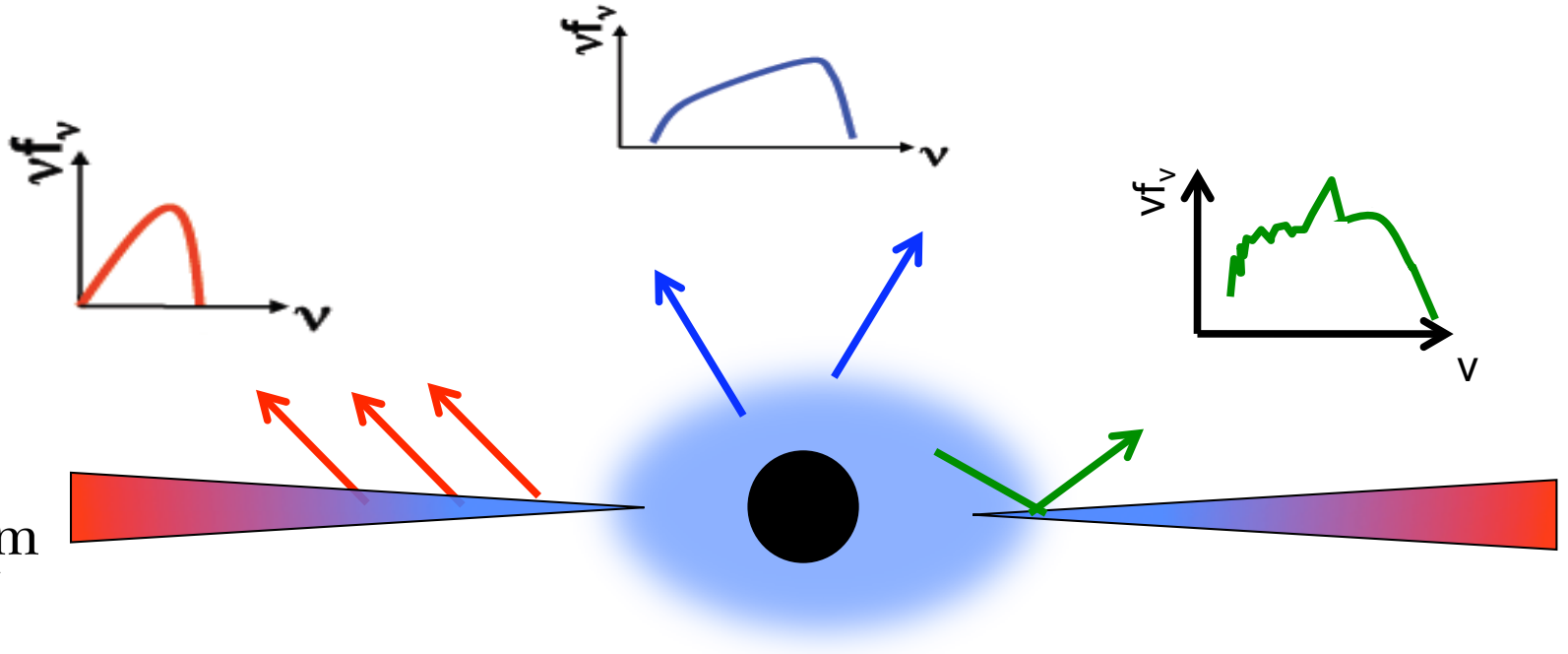
Mari Kolehmainen & Chris Done,
Durham University
Maria Diaz Trigo, ESO

Durham University

Astronomers' Days
Porvoo, Finland
4 – 6 June, 2012

Time-averaged energy spectrum

- Thermal emission at low energies ➔ Accretion disc
- Comptonised emission at high energies ➔ Corona
- Secondary processes ➔ Reflection

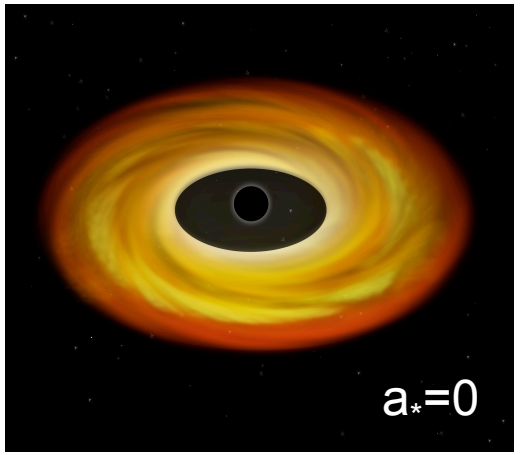


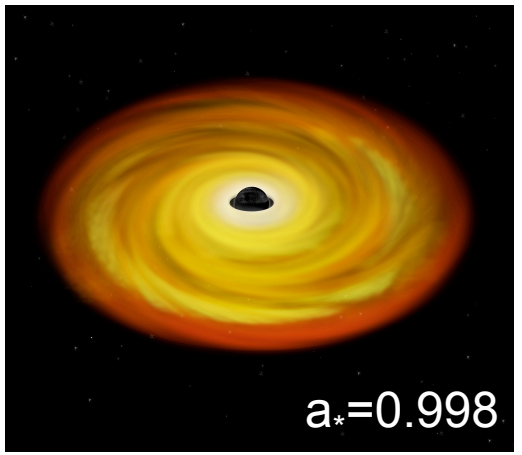
Black hole spin

- Specific angular momentum
  - a_* : 0 - 0.998

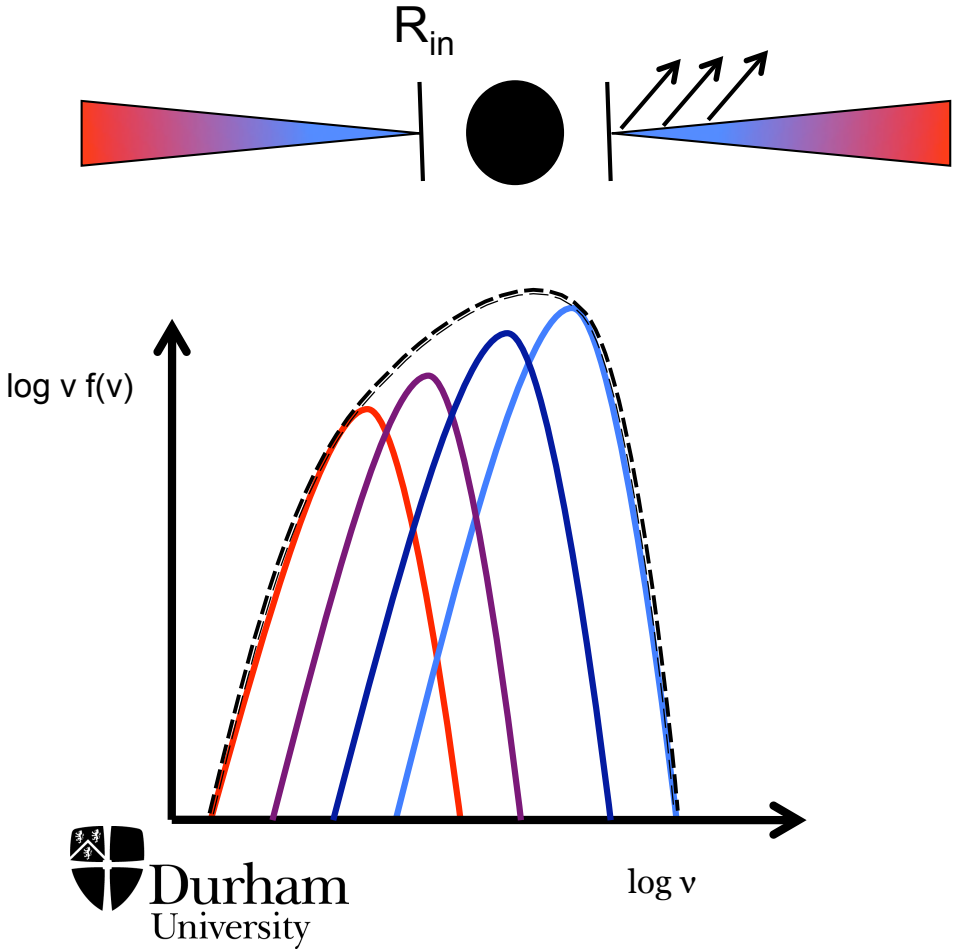
    R_{in} : 6 - 1.24 R_g

- Currently 2 ways to determine
  - Disc continuum fitting
  - Fe line profile

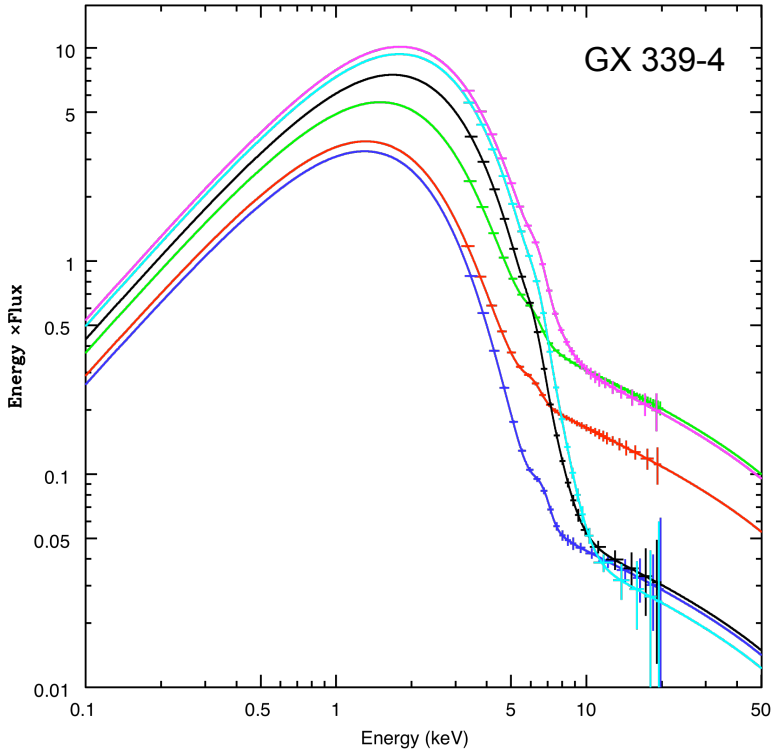




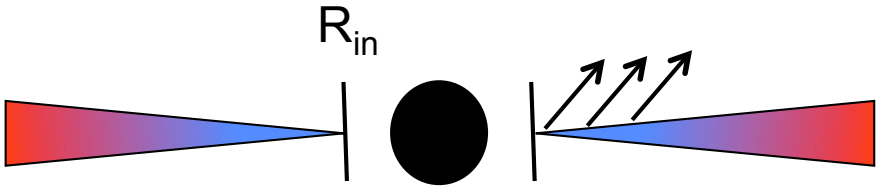
Black hole spin: disc fitting

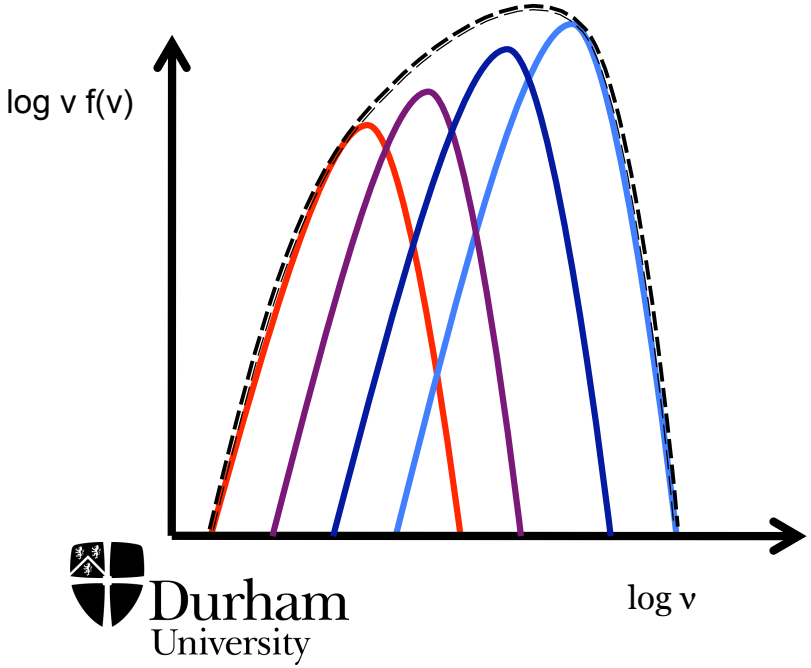


Durham University

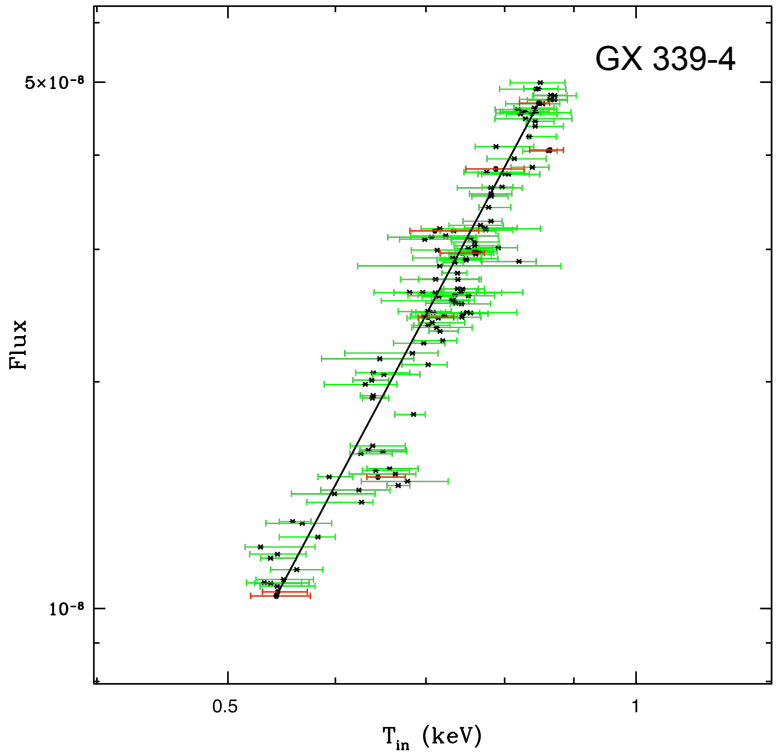


Black hole spin: disc fitting



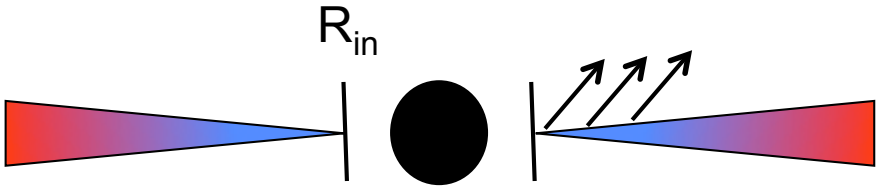


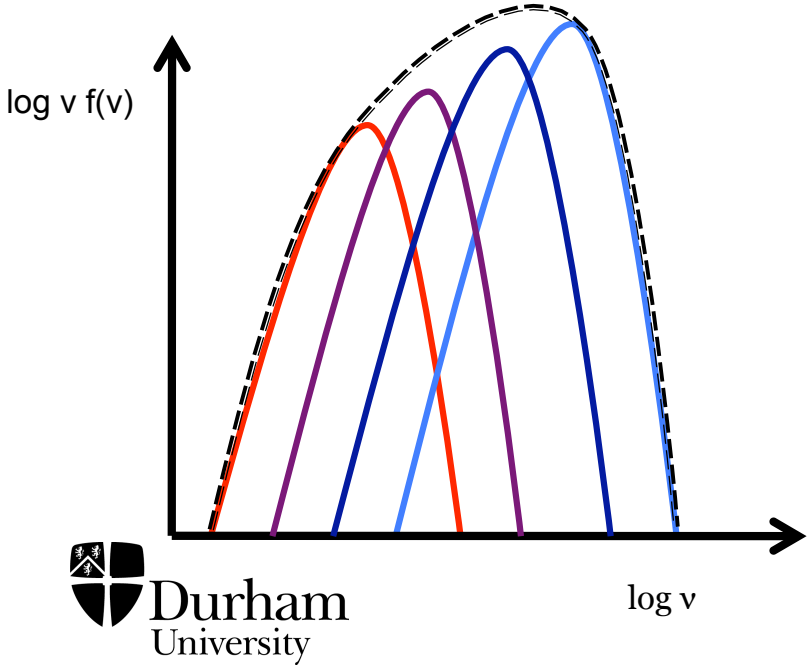
$$L \propto 2\pi D^2 F/\cos i \propto A T_{\rm disc}^4$$



Durham University

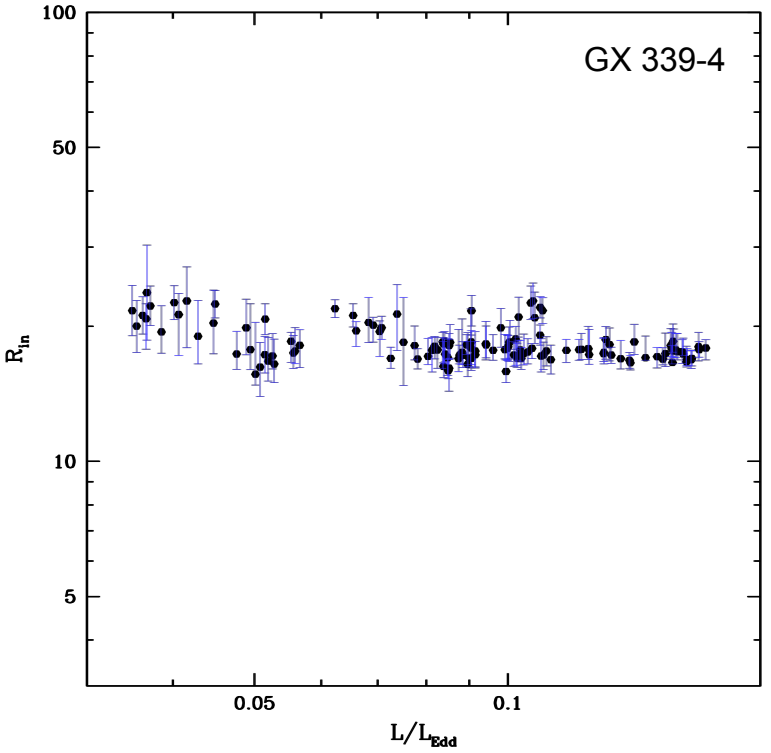
Black hole spin: disc fitting



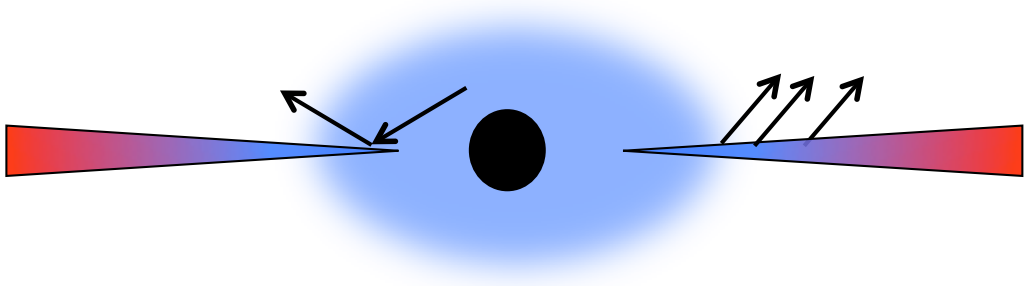


Durham University

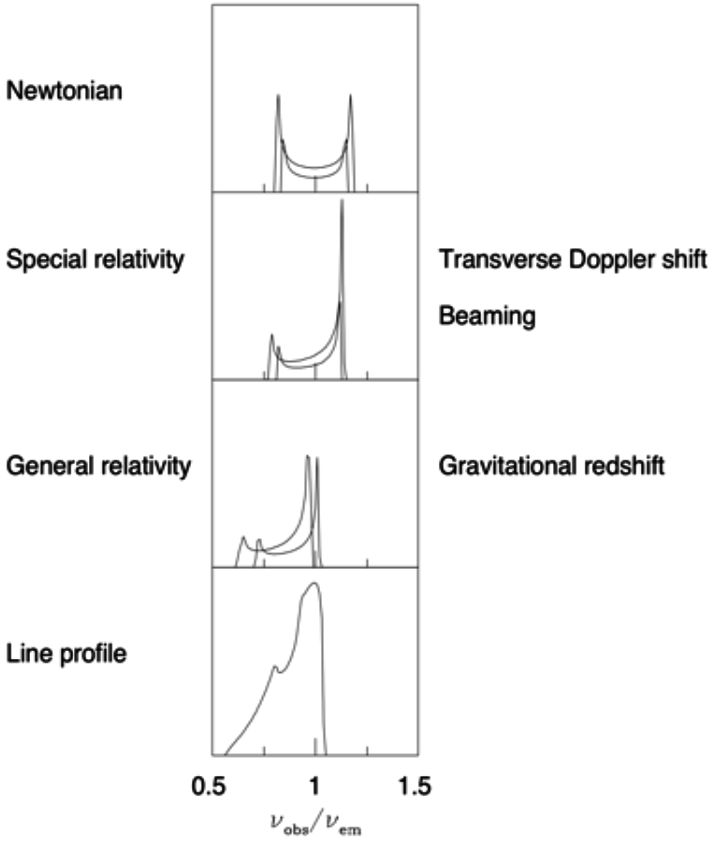
$$r_{in}^2 \propto D^2/(M^2 \cos i)$$



Black hole spin: Fe-line profile



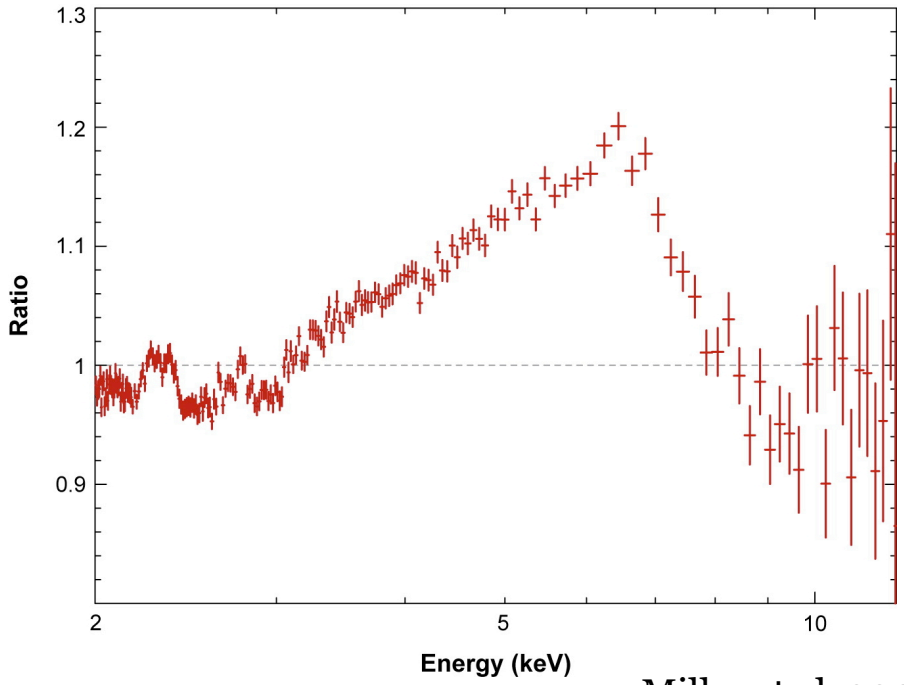
- Iron emission line at 6.4 keV from reflected emission



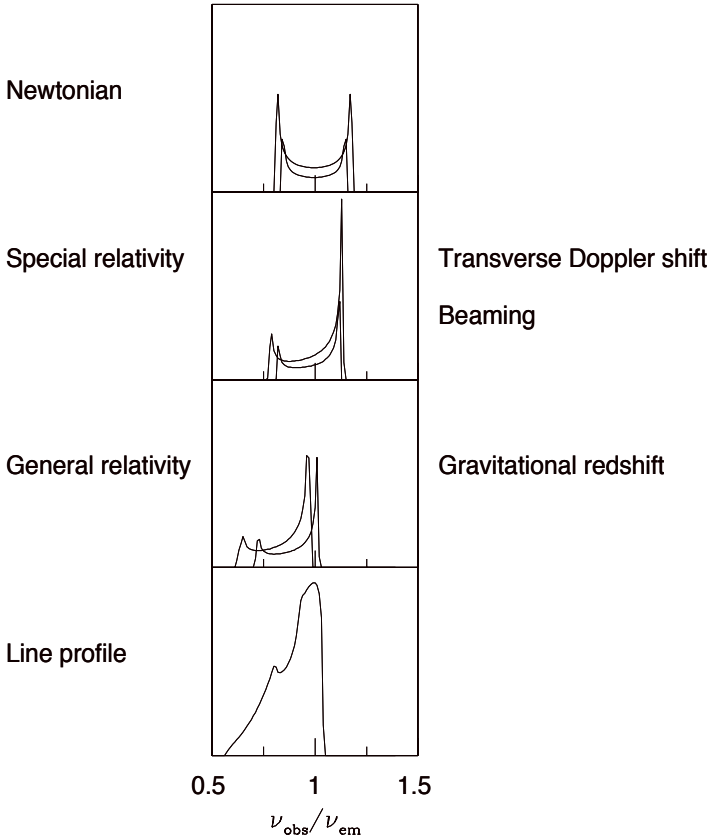
Fabian et al. 2000

Durham University

Black hole spin: Fe-line profile



Miller et al. 2004

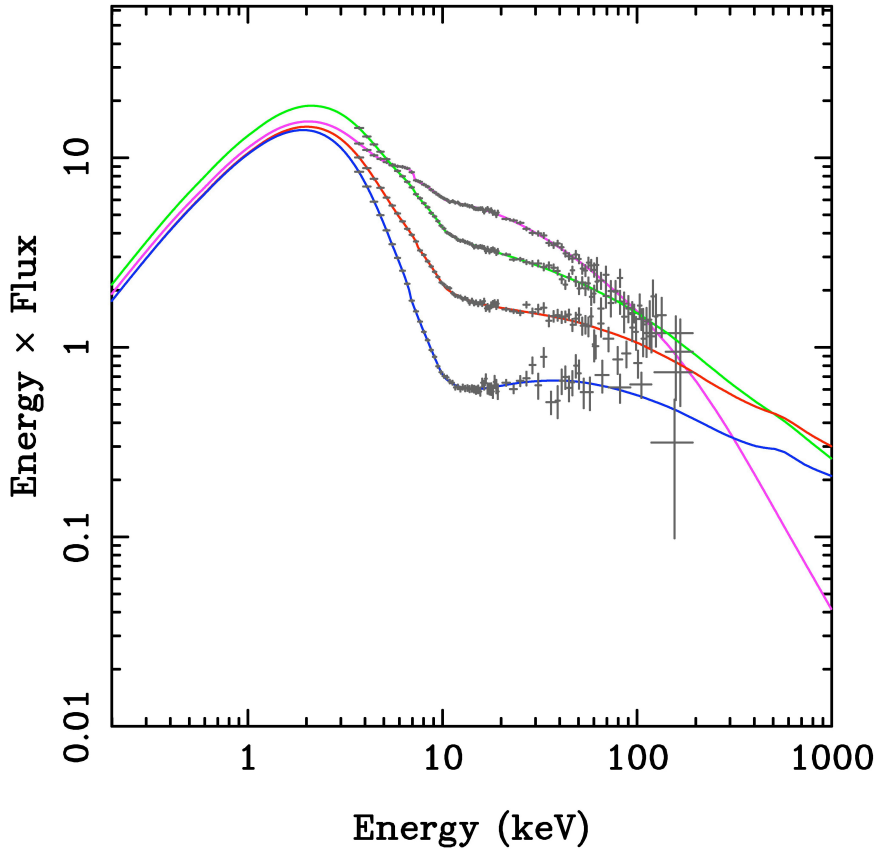


Fabian et al. 2000

Durham University

Comparing spin measurements: High mass accretion rate spectra

- Disc continuum fitting
  - disc dominated spectra
  - classical high/soft state
- Fe line profile
  - strong hard X-ray tail
  - very high/soft intermediate states



Durham University

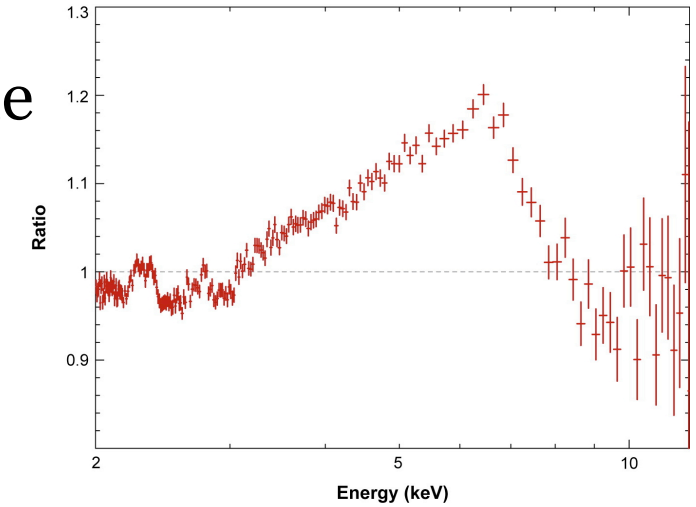
Comparing spin measurements: GX 339-4

Previously derived an upper limit for the spin using continuum fitting of disc dominated RXTE spectra
(Kolehmainen & Done, 2010)

- $a_* < 0.9$ for any reasonable mass ($<15M_\odot$), distance (>6 kpc) and inclination ($i > 45°$)

Also widely studied in terms of Fe-line

- XMM-Newton burst mode spectrum gave $a_* \approx 0.94$
  (e.g. Miller et al. 2004; Reis et al. 2008)

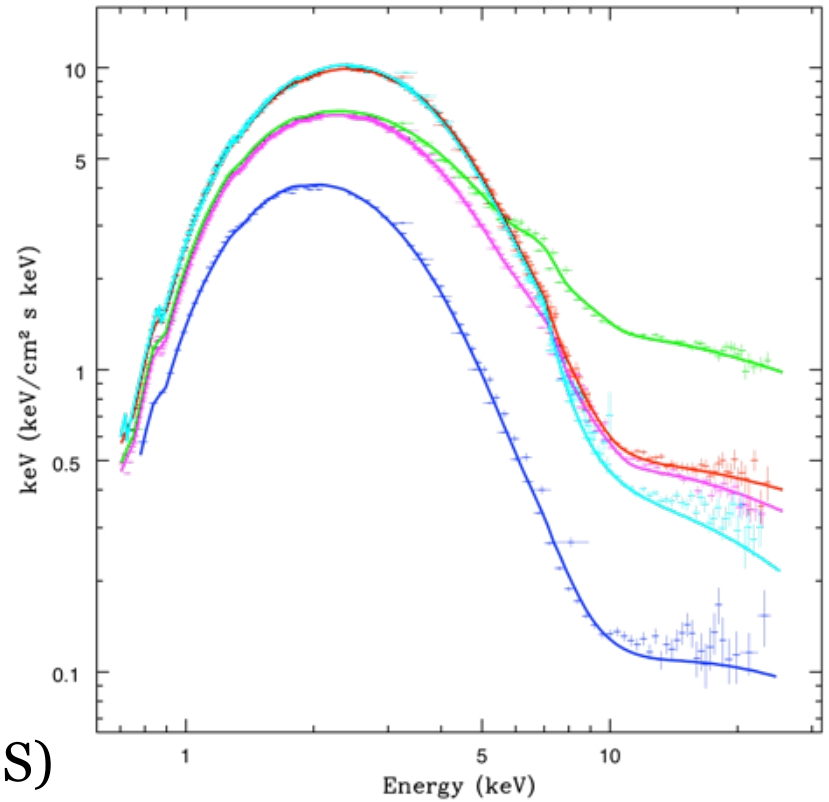


Miller et al. 2004

Durham University

High mass accretion rate spectra of GX 339-4

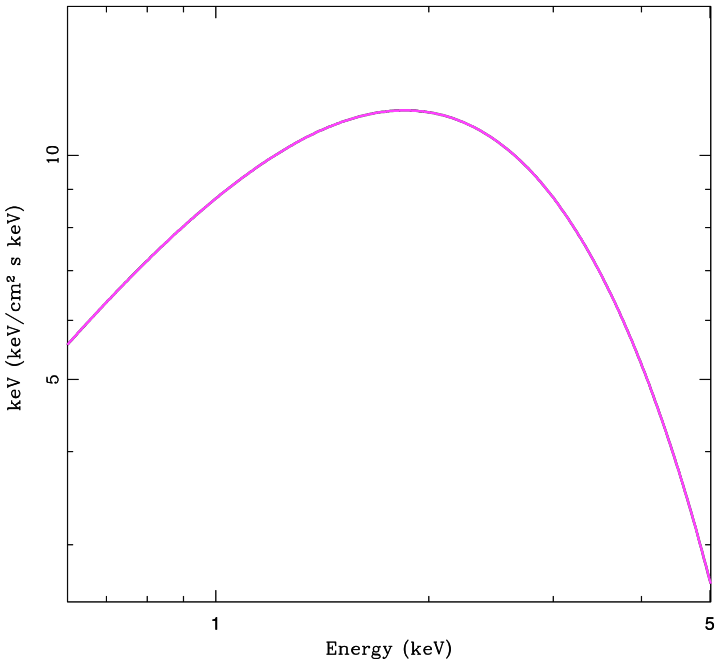
- Joint EPIC-pn/RXTE observations (0.7-25 keV)
- Fast timing mode data, not piled up!
- 3 disc dominated states
- 2 soft intermediate states (SIMS)



Durham University

Modelling the high mass accretion rate spectra: Disc dominated state

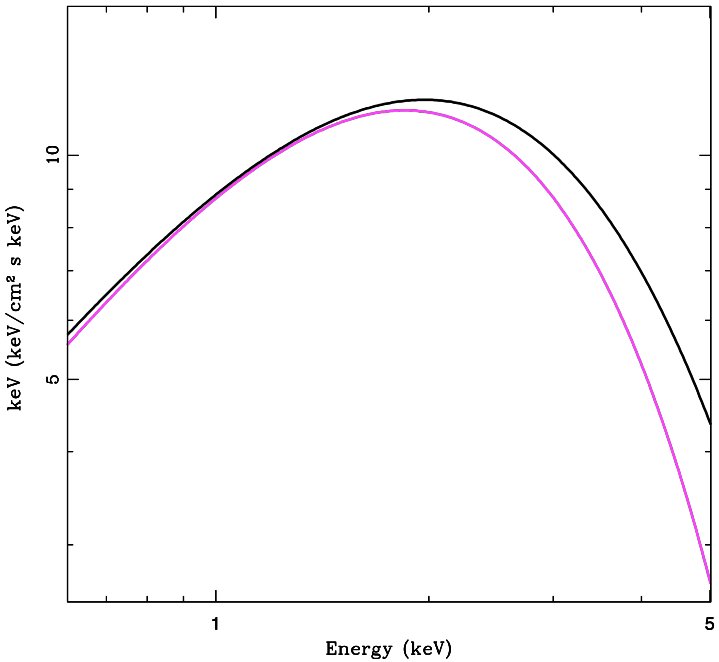
- DISKBB
  - simplest multi-colour disc blackbody
- KERRBB
  - stress-free inner boundary condition, colour- temperature correction and relativistic smearing
- BHSPEC
  - calculates radiative transfer through each disc annuli
  - includes all relativistic corrections
  - assumes $R_{in}=R_{ISCO}$



Durham University

Modelling the high mass accretion rate spectra: Disc dominated state

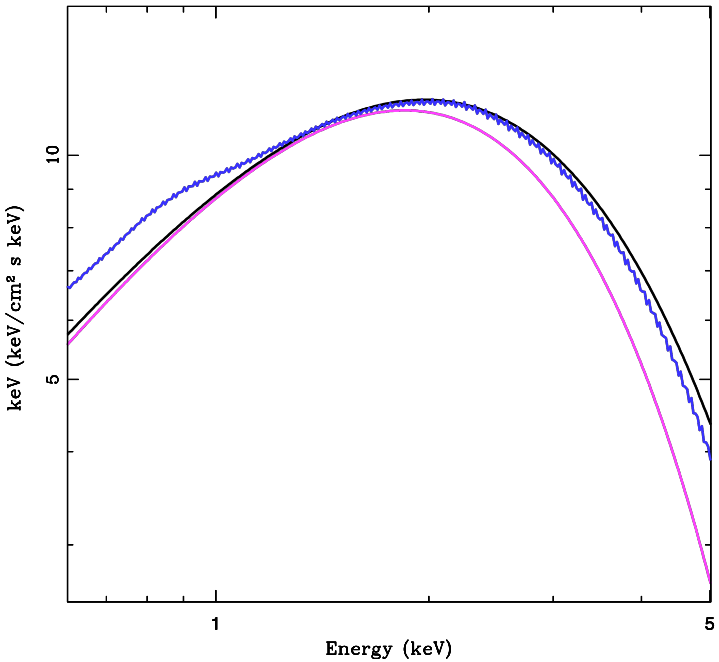
- DISKBB
  - simplest multi-colour disc blackbody
- KERRBB
  - stress-free inner boundary condition, colour- temperature correction and relativistic smearing
- BHSPEC
  - calculates radiative transfer through each disc annuli
  - includes all relativistic corrections
  - assumes $R_{in}=R_{ISCO}$



Durham University

Modelling the high mass accretion rate spectra: Disc dominated state

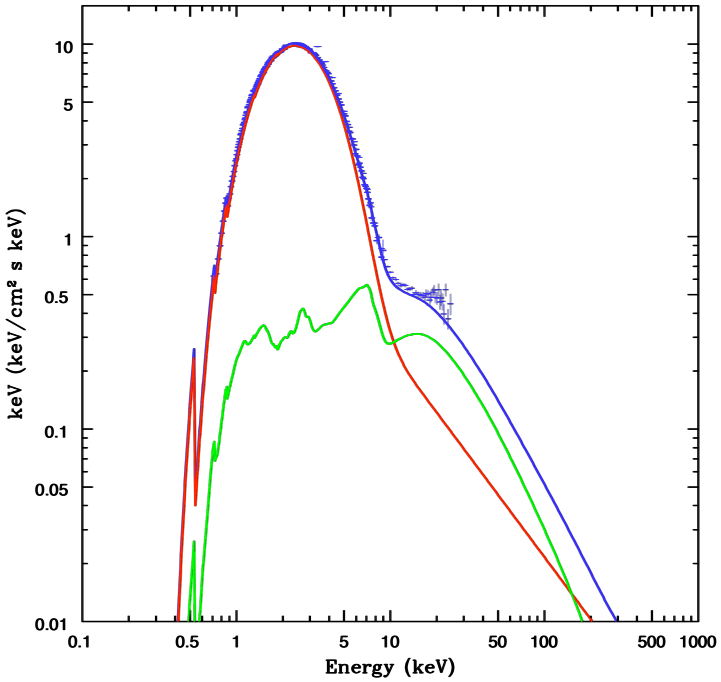
- DISKBB
  - simplest multi-colour disc blackbody
- KERRBB
  - stress-free inner boundary condition, colour- temperature correction and relativistic smearing
- BHSPEC
  - calculates radiative transfer through each disc annuli
  - includes all relativistic corrections
  - assumes $R_{in}=R_{ISCO}$



Durham University

Modelling the high mass accretion rate spectra

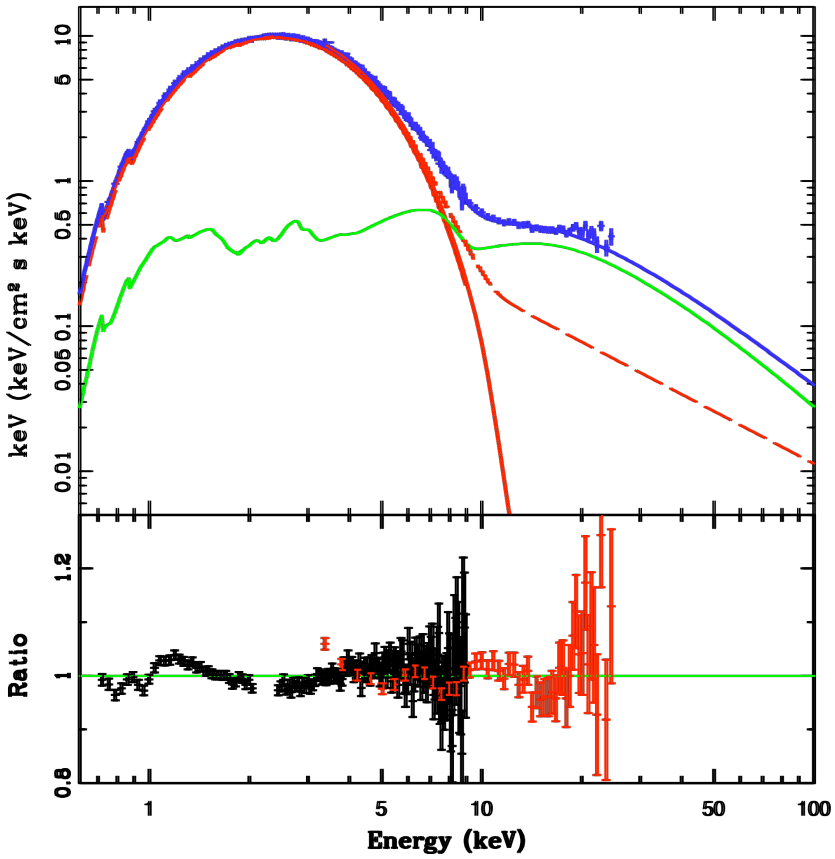
- Disc model
  - use this as seed photons for Comptonisation to make X-ray tail (convolved with Simpl (Steiner et al. 2009))
- Reflection of Comptonised continuum using ionised reflection models of Ross & Fabian
- Relativistic smearing (kdblur)



Durham University

Fitting the continuum: Disc dominated state

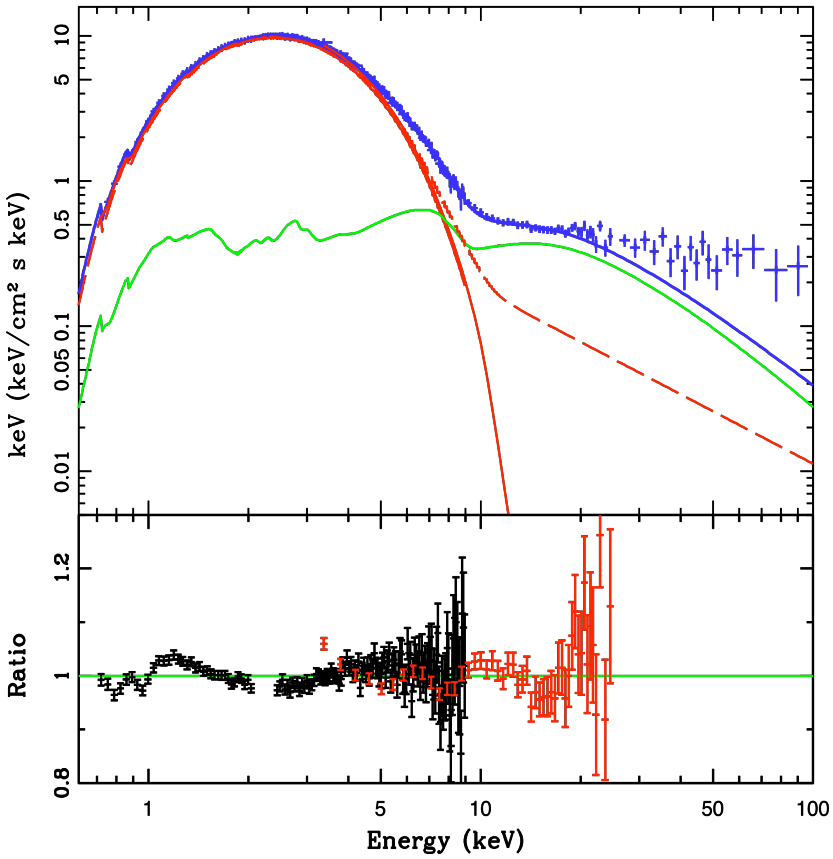
- BHSPEC+reflected continuum
  - very steep continuum to make disc broader
  - high reflection fraction
  - misses high energies
  - residuals around 1 keV



Durham University

Fitting the continuum: Disc dominated state

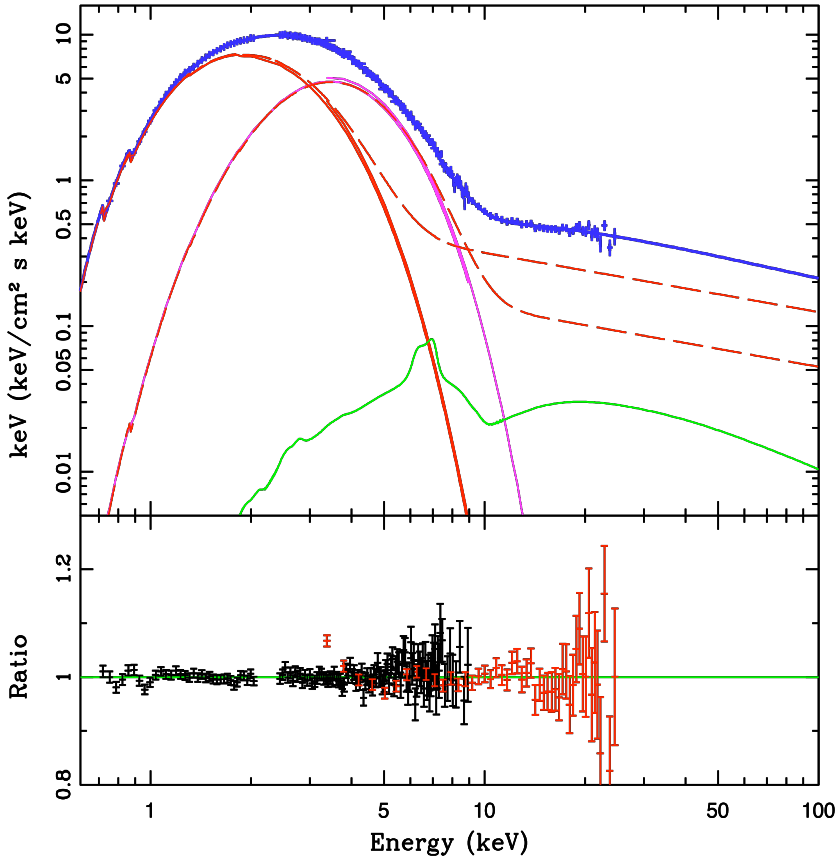
- BHSPEC+reflected continuum
  - very steep continuum to make disc broader
  - high reflection fraction
  - misses high energies
  - residuals around 1 keV



Durham University

Fitting the continuum: Disc dominated state

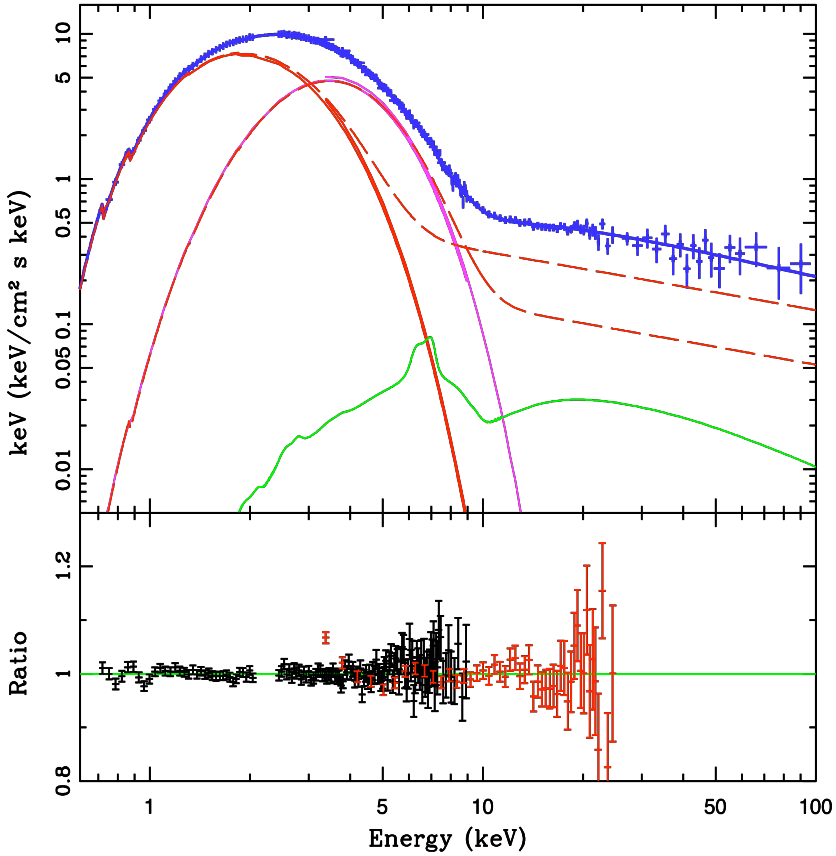
- (diskbb+compTT) +reflected continuum
  - reasonable reflection fraction+continuum
  - extrapolates to high energies
  - fit for different mass accretion rates



Durham University

Fitting the continuum: Disc dominated state

- (diskbb+compTT) +reflected continuum
  - reasonable reflection fraction+continuum
  - extrapolates to high energies
  - fit for different mass accretion rates



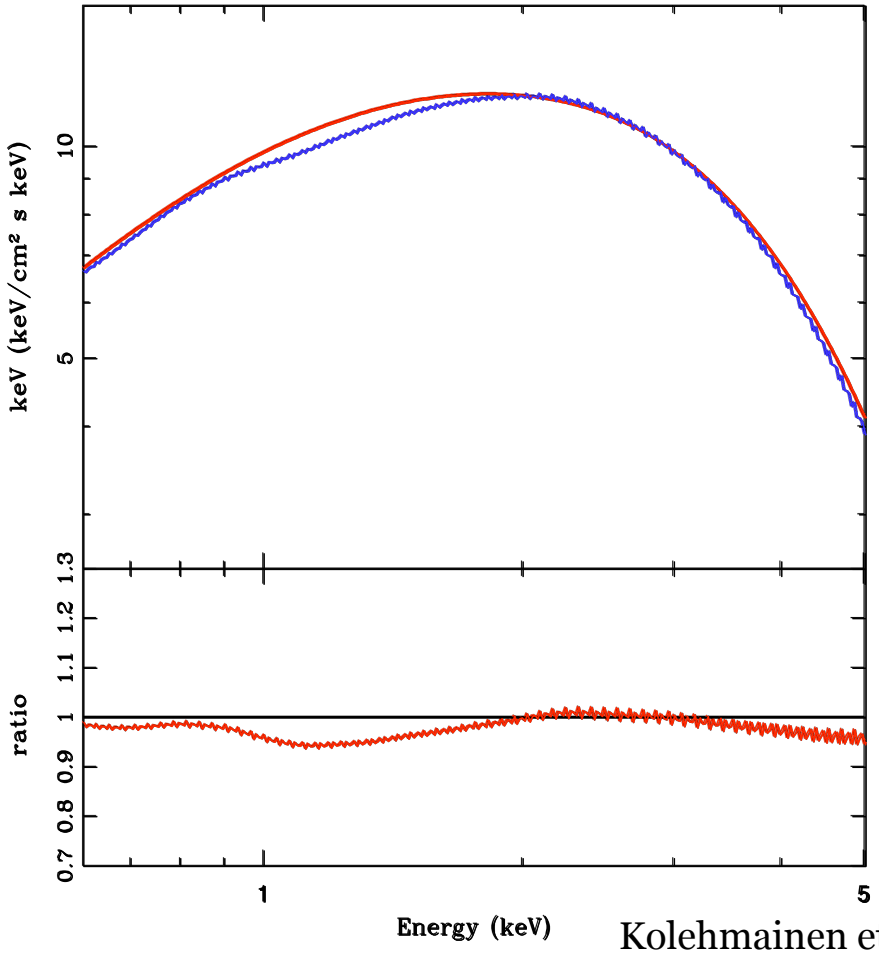
Durham University

Fitting the continuum: Disc dominated state

DATA

vs.

BHSPEC



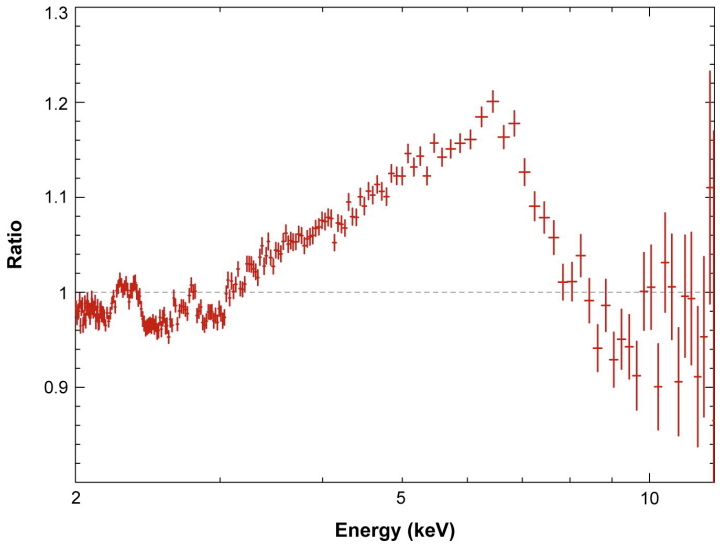
Kolehmainen et al. 2011

Durham University

Controversy: Spin values in disagreement

GX 339-4:

- $a_* < 0.9$ from disc fitting
  (Kolehmainen & Done 2010)
- $a_* = 0.935 \pm 0.01$ from iron line
  (Miller et al. 2004; Reis et al. 2008)

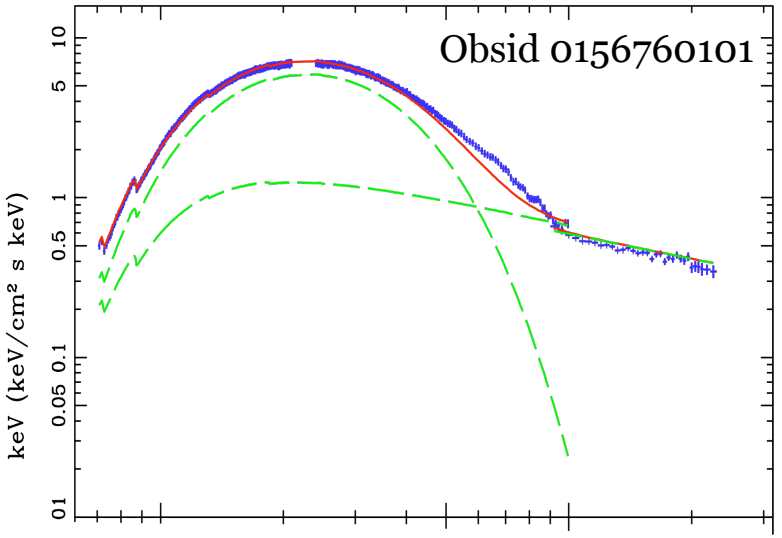


Miller et al. 2004

Soft intermediate state: the Fe line

diskbb+po

- disc, power law tail
- continuum modelled by ignoring 4–7 keV



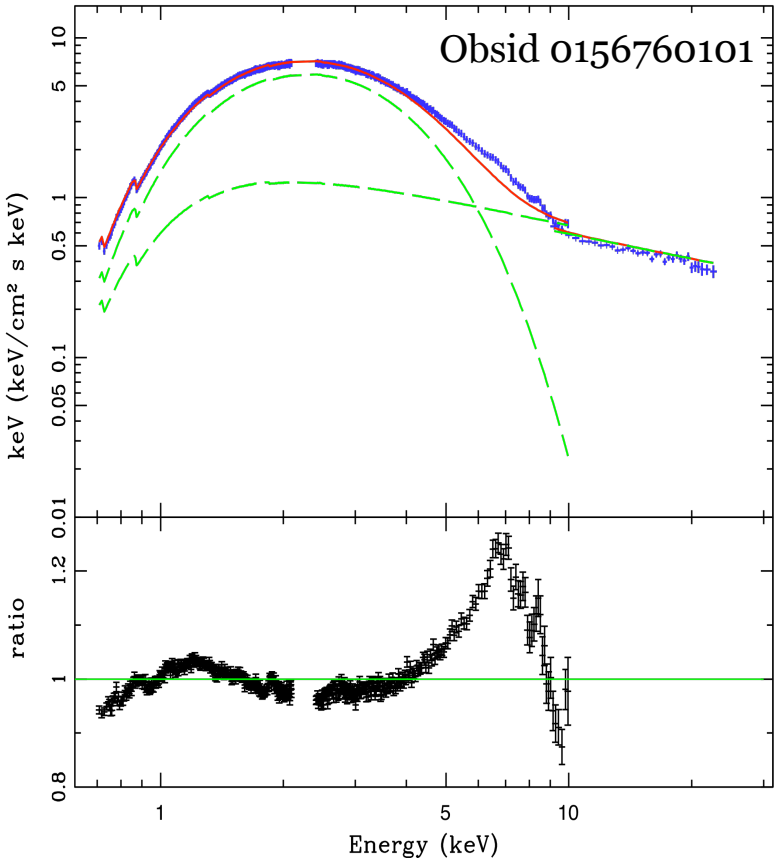
Durham University

Soft intermediate state: the Fe line

diskbb+po

- disc, power law tail
- continuum modelled by ignoring 4–7 keV

➔ Residuals show a broad iron line with $R_{in} \approx 1.6\ R_g$



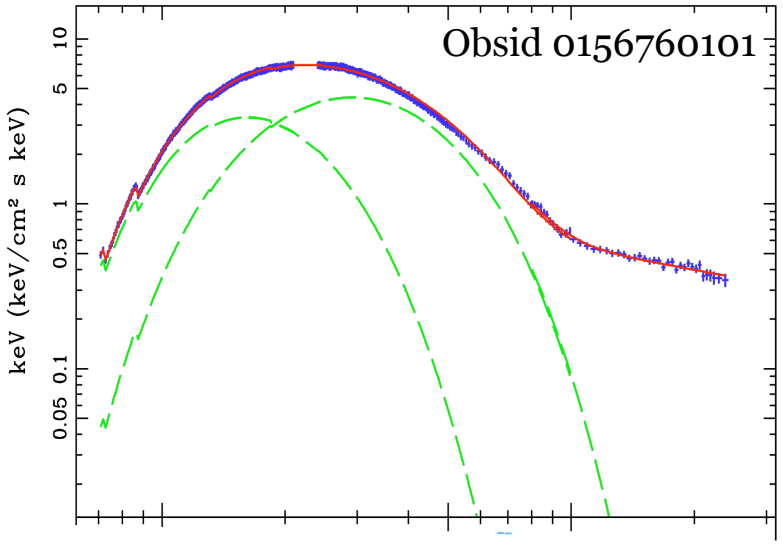
Kolehmainen et al. 2011

Durham University

Soft intermediate state: the Fe line

(diskbb+compTT)+reflected continuum

- convolved disc+thermal Comptonisation, ionised smeared reflection



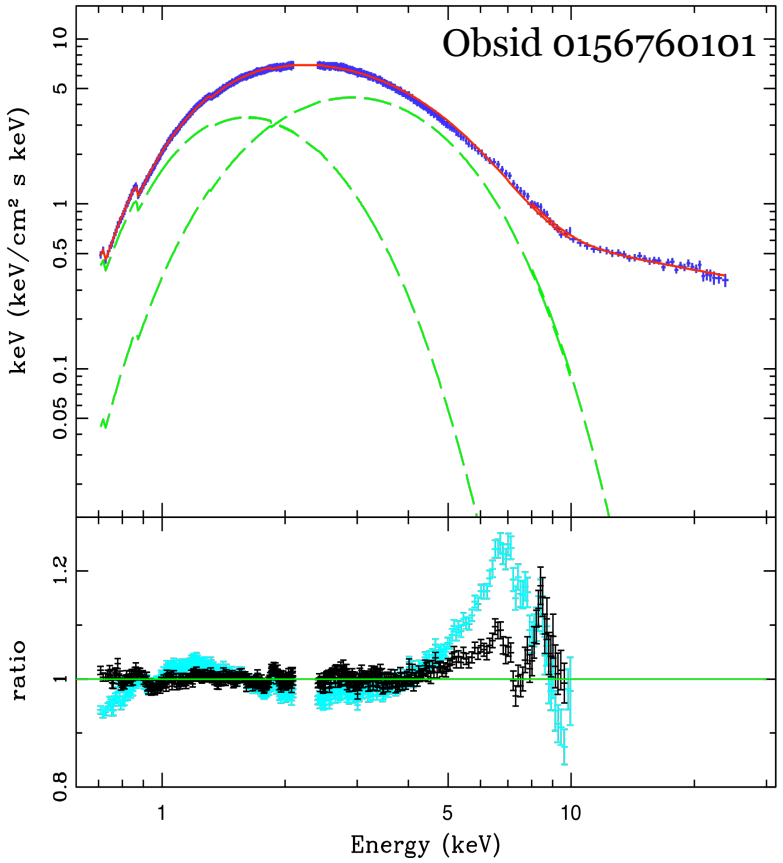
Durham University

Soft intermediate state: the Fe line

(diskbb+compTT)+reflected continuum

- convolved disc+thermal Comptonisation, ionised smeared reflection

➔ Narrow line does not constrain BH spin (R_{in}>30 R_g)



Kolehmainen et al. 2011

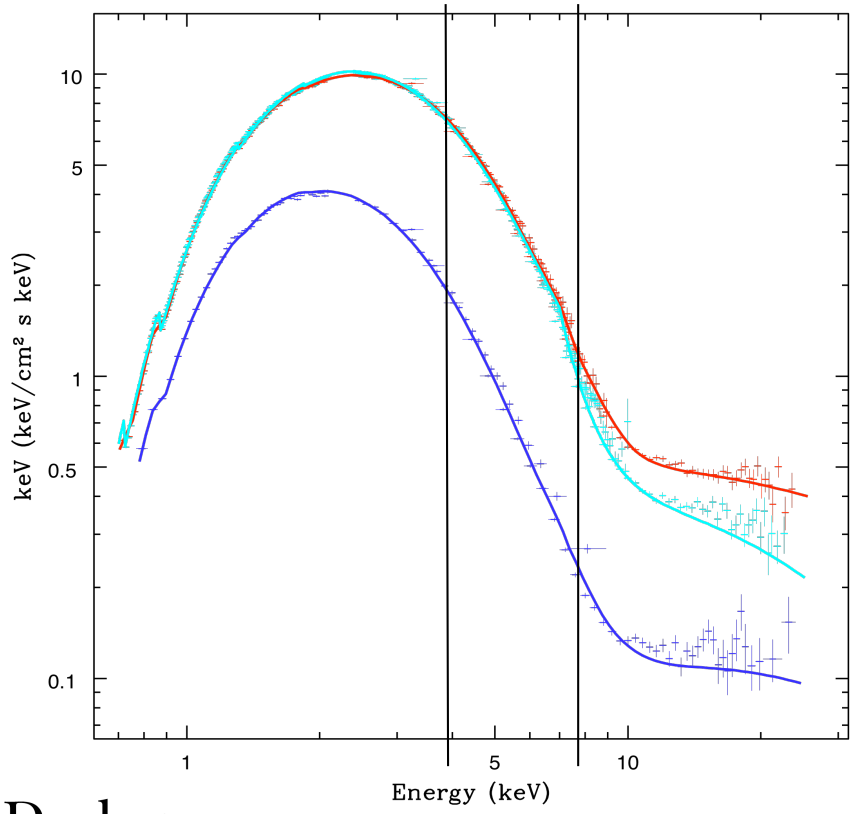
Durham University

Conclusions

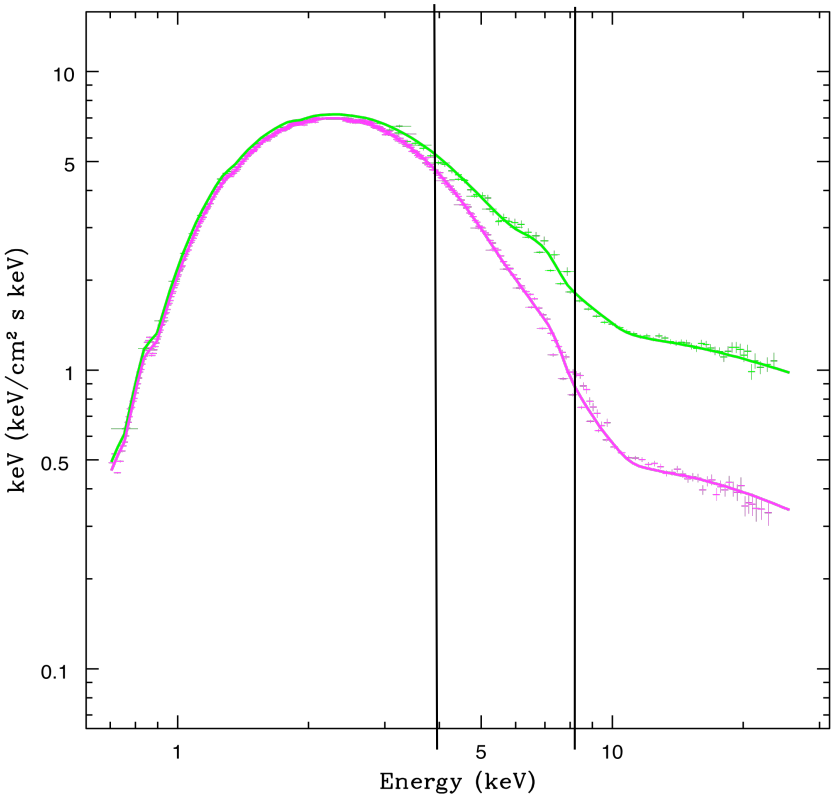
- Real disc spectra seem broader than diskbb or even BHSPEC
- Changing the continuum model changes the shape of the iron line (and the black hole spin)

Soft intermediate state: the Fe line

4-8 keV



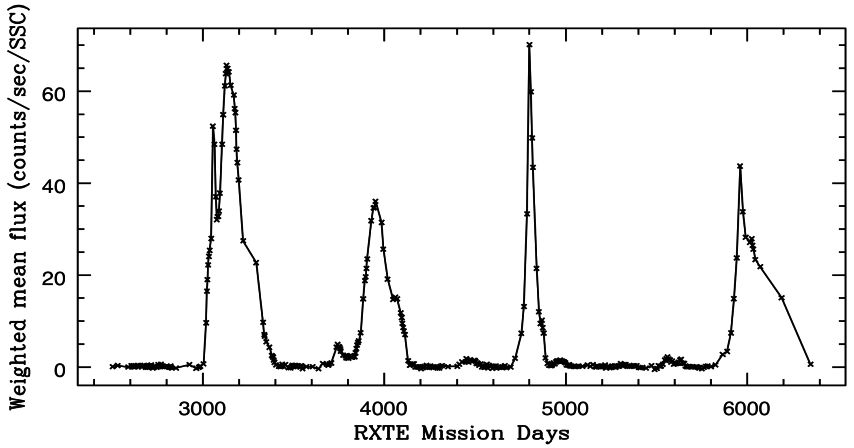
4-8 keV



Durham University

Comparing spin measurements: GX 339-4

- Disc fitting gives upper limit
  - $a_* < 0.9$ from RXTE spectra (Kolehmainen & Done 2010)
- Fe line values higher
  - $a_* \approx 0.94$ from XMM-Newton Burst mode soft intermediate state (Miller et al. 2004)
  - $a_* \approx 0.89$ from Suzaku intermediate state
  - (Miller et al. 2008 vs. Yamada et al. 2009)
  - $a_* \approx 0.94$ from XMM-Newton LHS (Reis et al. 2008 vs. Done & Diaz Trigo 2010)



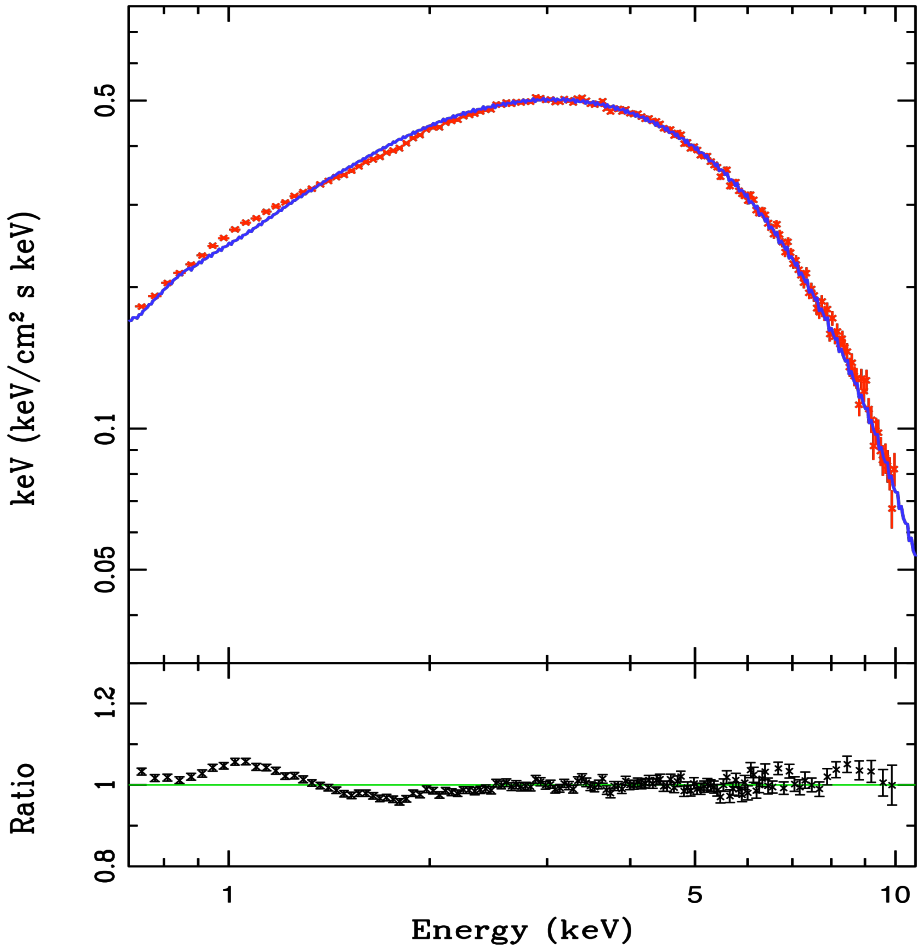
Durham University

Continuum fitting below 3 keV: LMC X-3

DATA

vs.

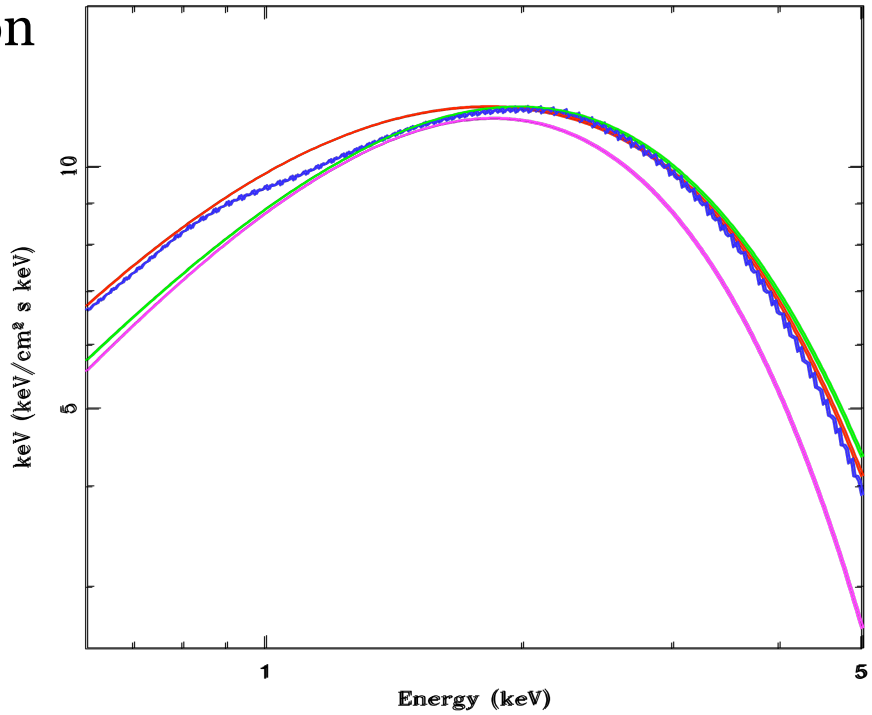
BHSPEC



Durham University

Continuum fitting below 3 keV: Disc dominated state

- DISKBB
  - simplest multi-colour disc blackbody
- KERRBB
  - stress-free inner boundary condition, relativistic smearing and the colour- temperature correction
- BHSPEC
  - calculates radiative transfer through each disc annuli
  - includes all the relativistic corrections
  - assumes $R_{in}=R_{ISCO}$



Durham University

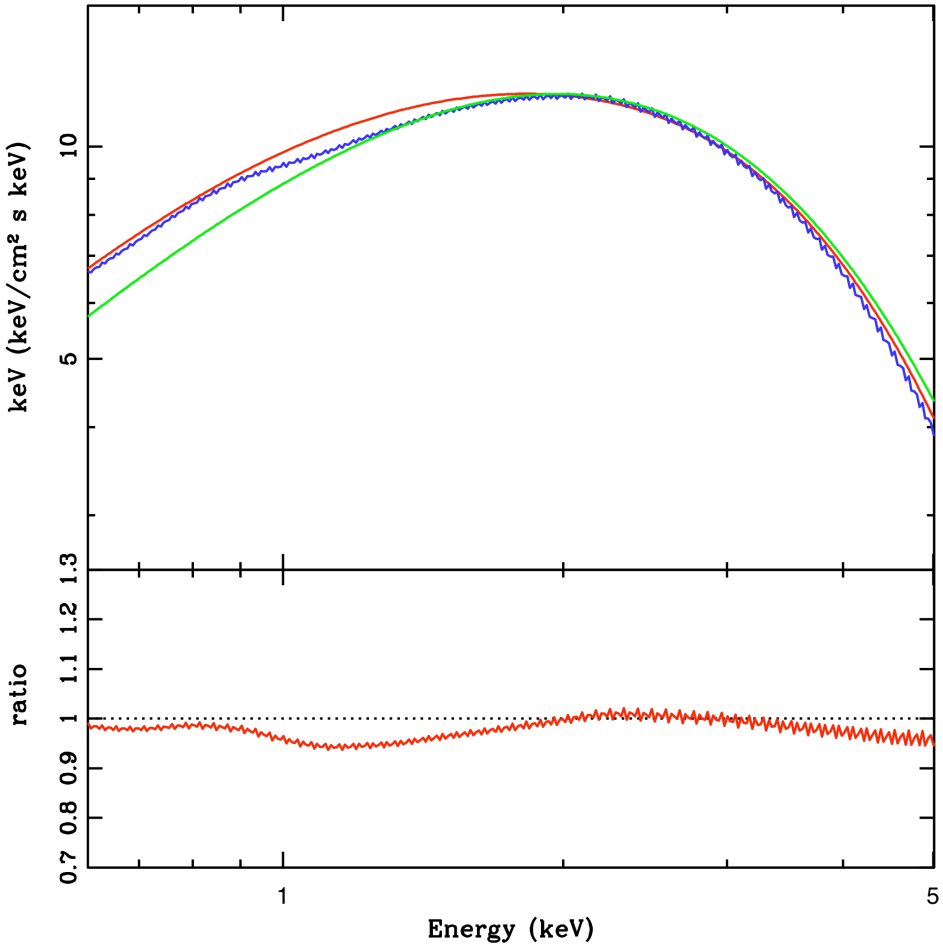
Continuum fitting below 3 keV: Disc dominated state

DATA

vs.

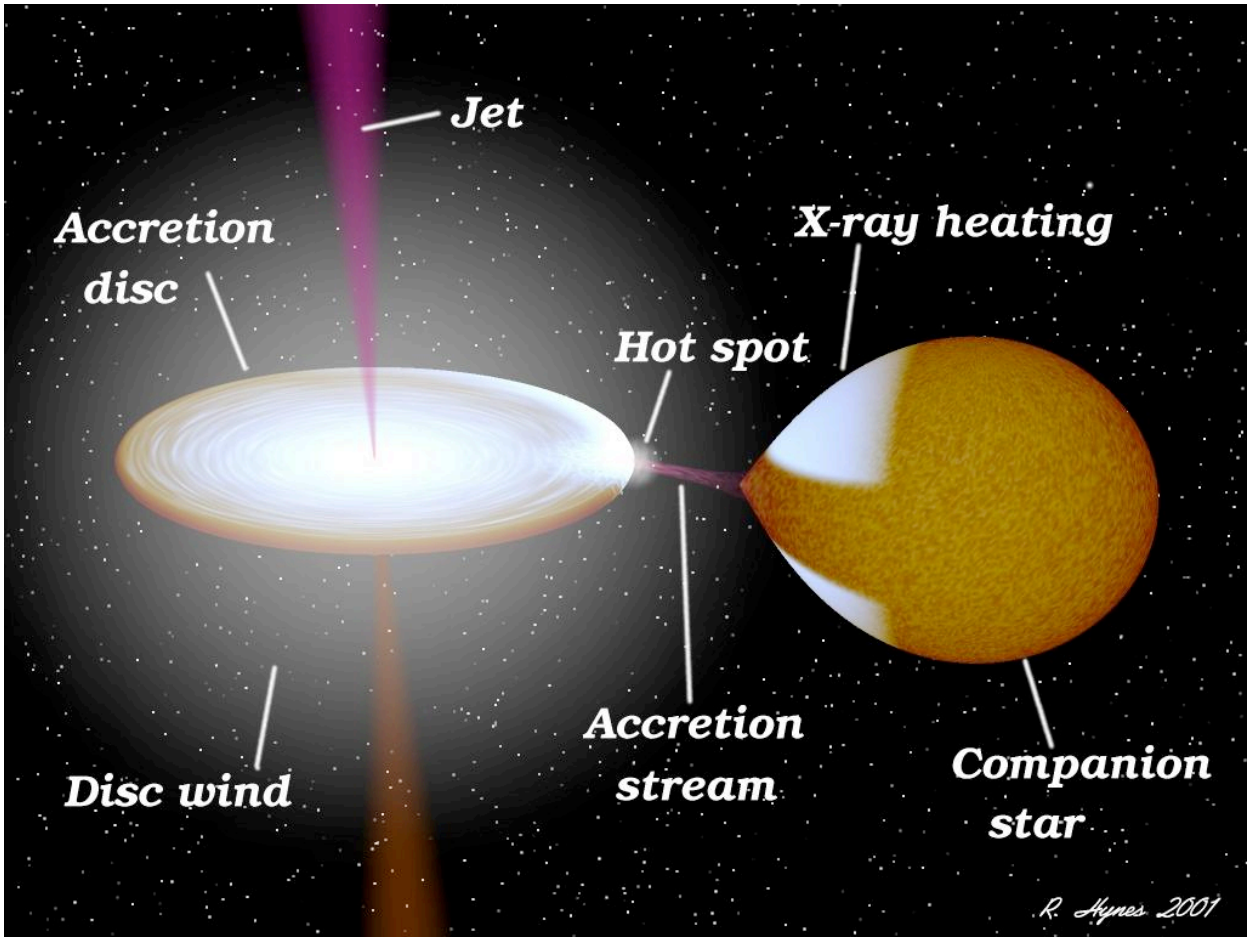
BHSPEC

Kerrbb



Durham University

Black hole binaries



Durham University