UNIVERSITY OF Southampton

Unveiling the behaviour of matter around black holes

Dimitrios Emmanoulopoulos

The 12th Hellenic Astronomical Conference

Thessaloniki, 28 June–2 July 2015

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο

ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ

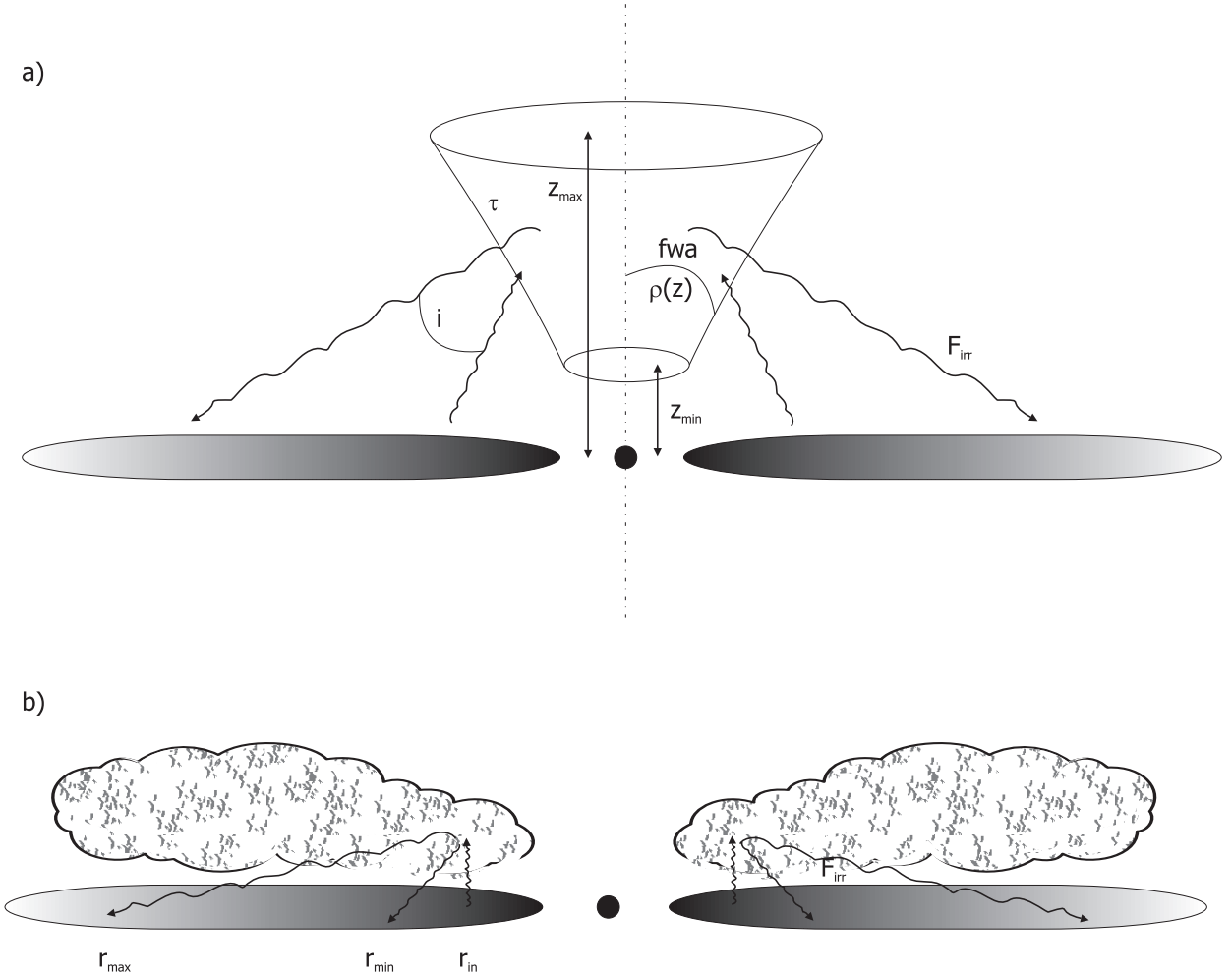
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Central Aim

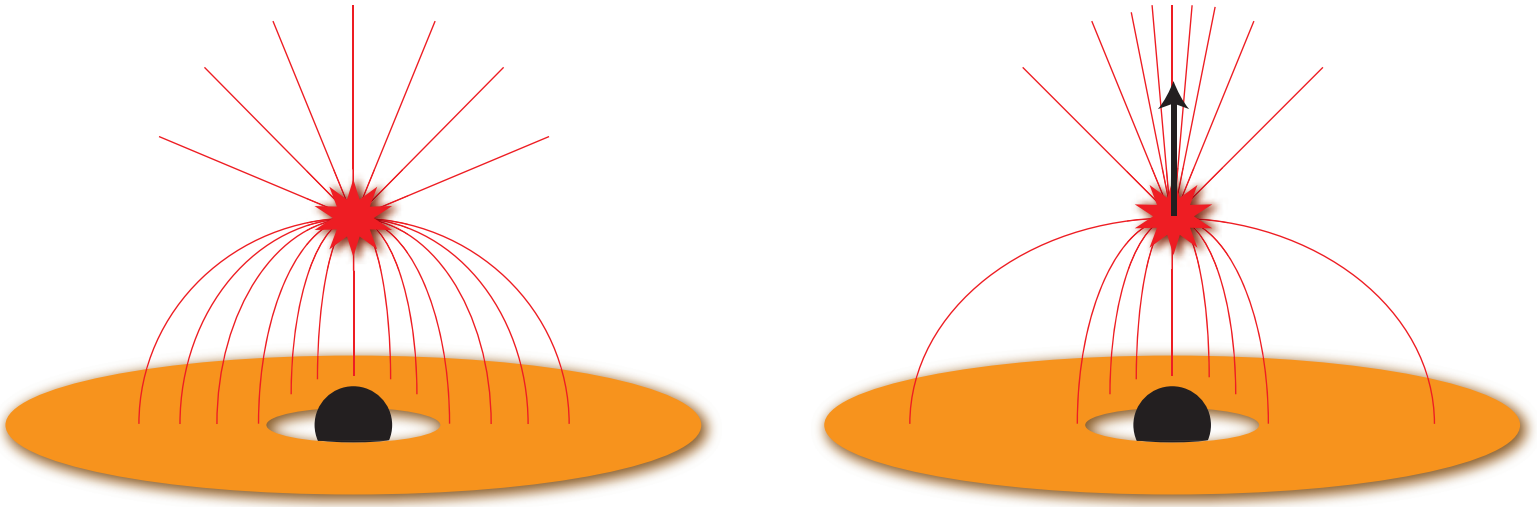
To constrain the geometry around the black holes

Motivation



Czerny & Janiuk 2007, A&A, **464**, 167

Motivation



Wilkins & Fabian 2012, MNRAS, **424**, 1284

Aims

- X-ray source position/size/shape.
- Accretion disc geometry in strong gravity.

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  - Mass
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- Accretion disc geometry in strong gravity.
- Host BH parameters:
  - Mass
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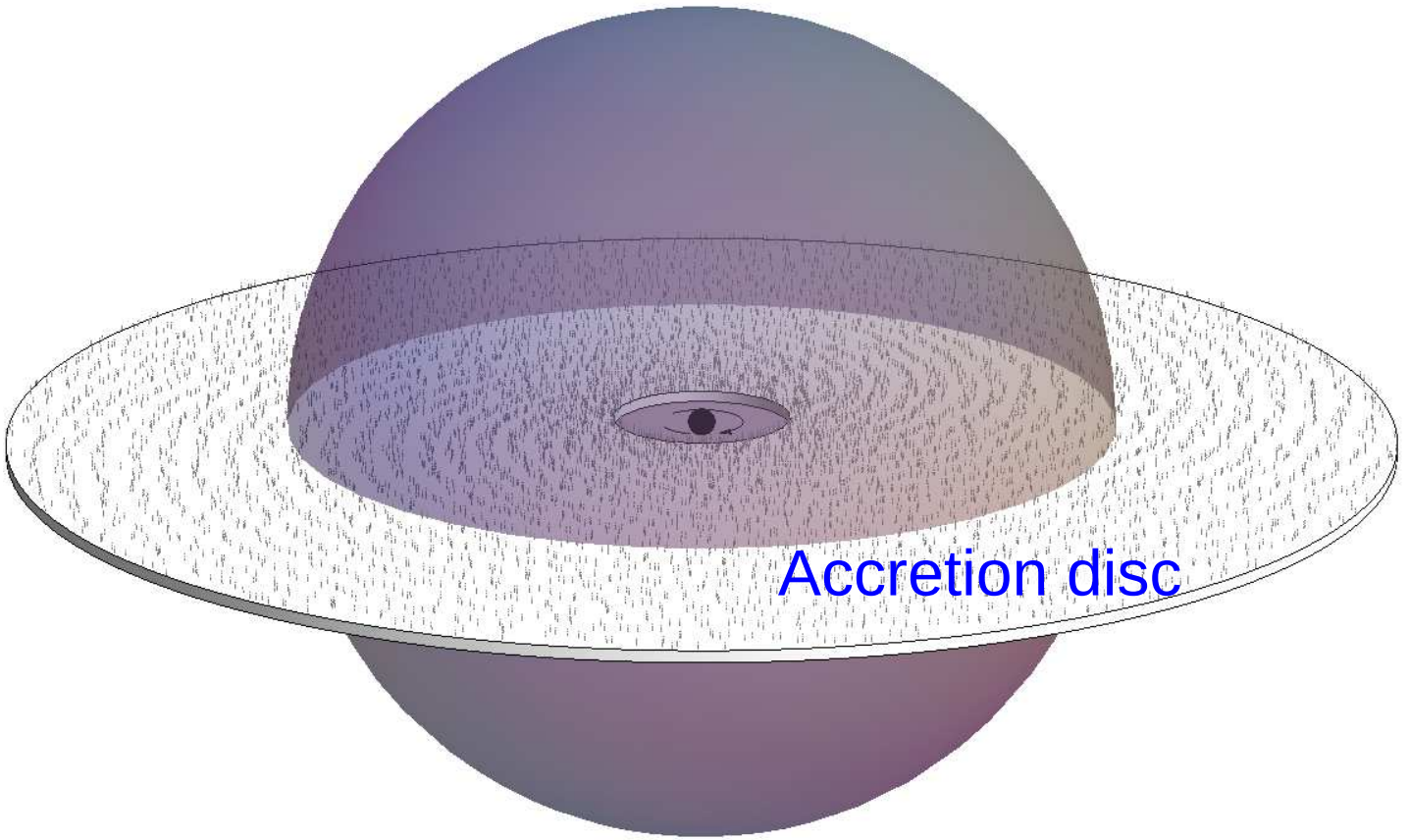
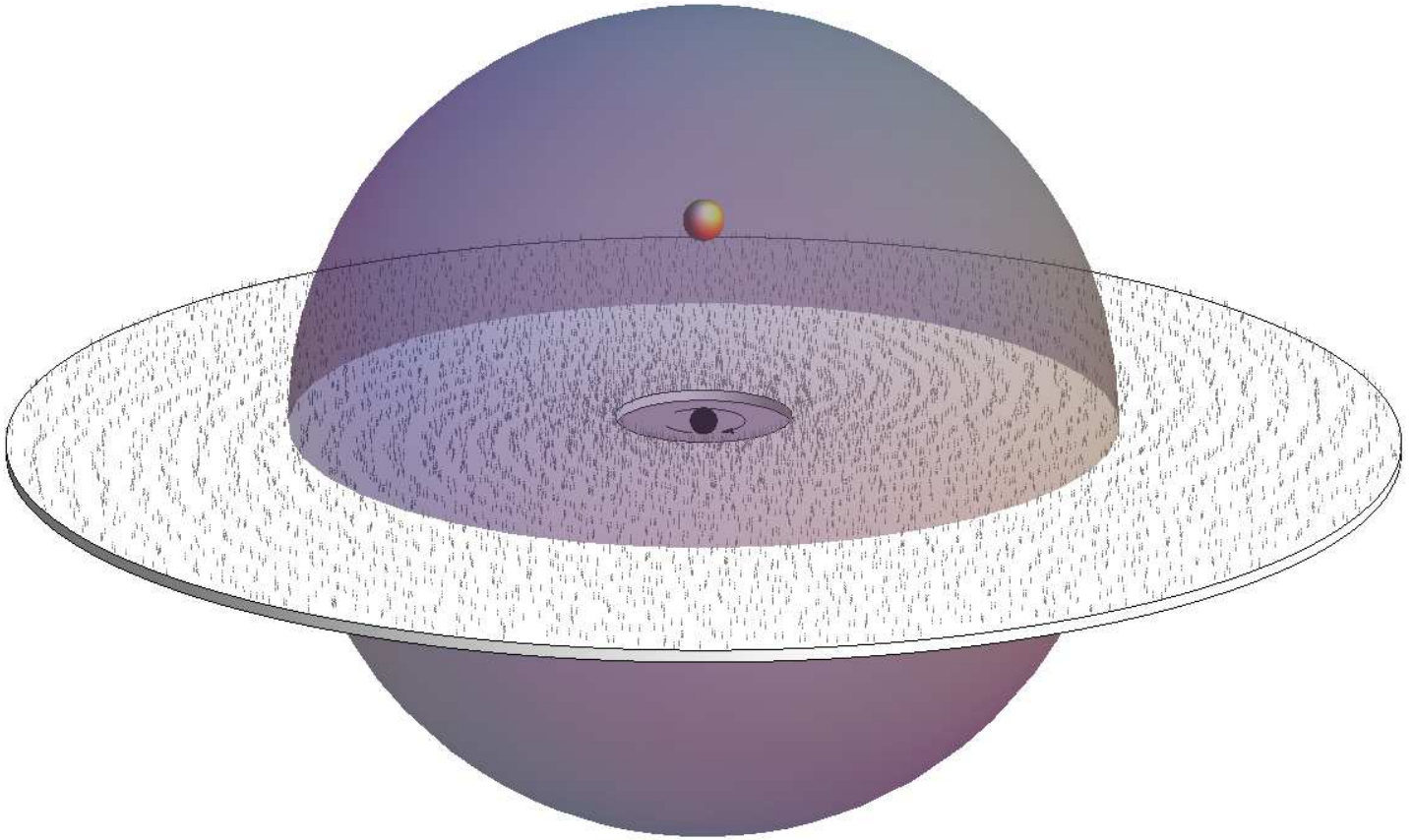
- Scaling relations between AGN and XRBs.

Current paradigm

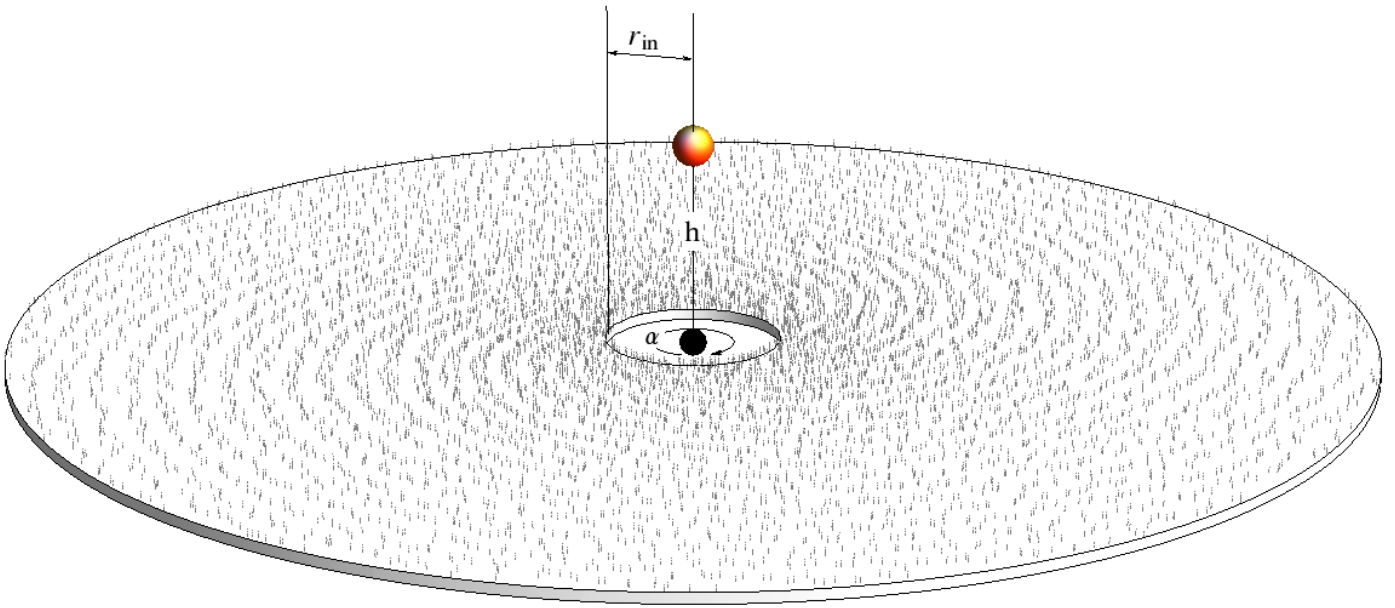


Current paradigm

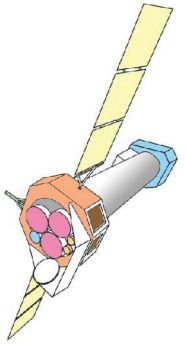
Approximation of spherical corona by point source

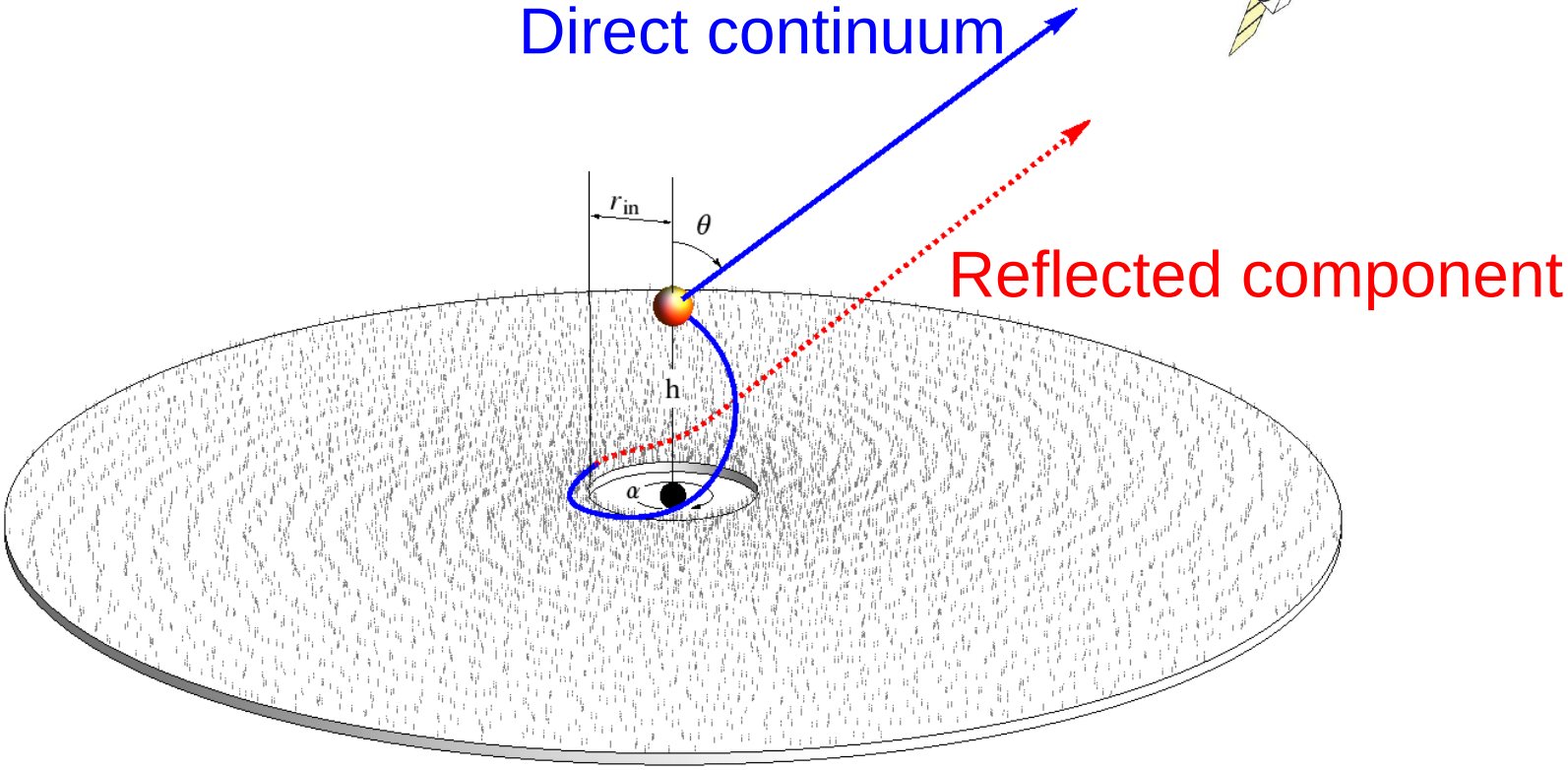


Current paradigm



Current paradigm





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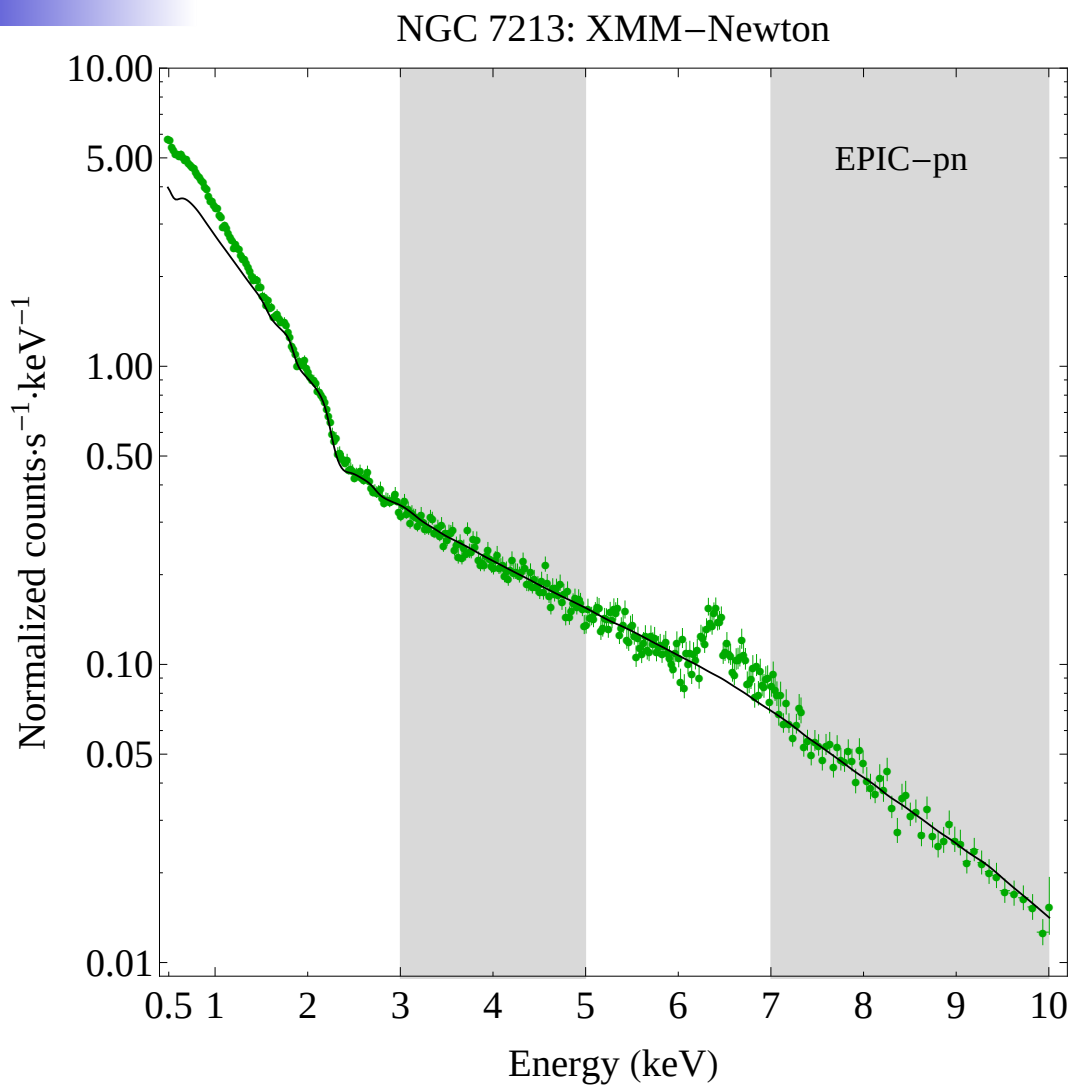
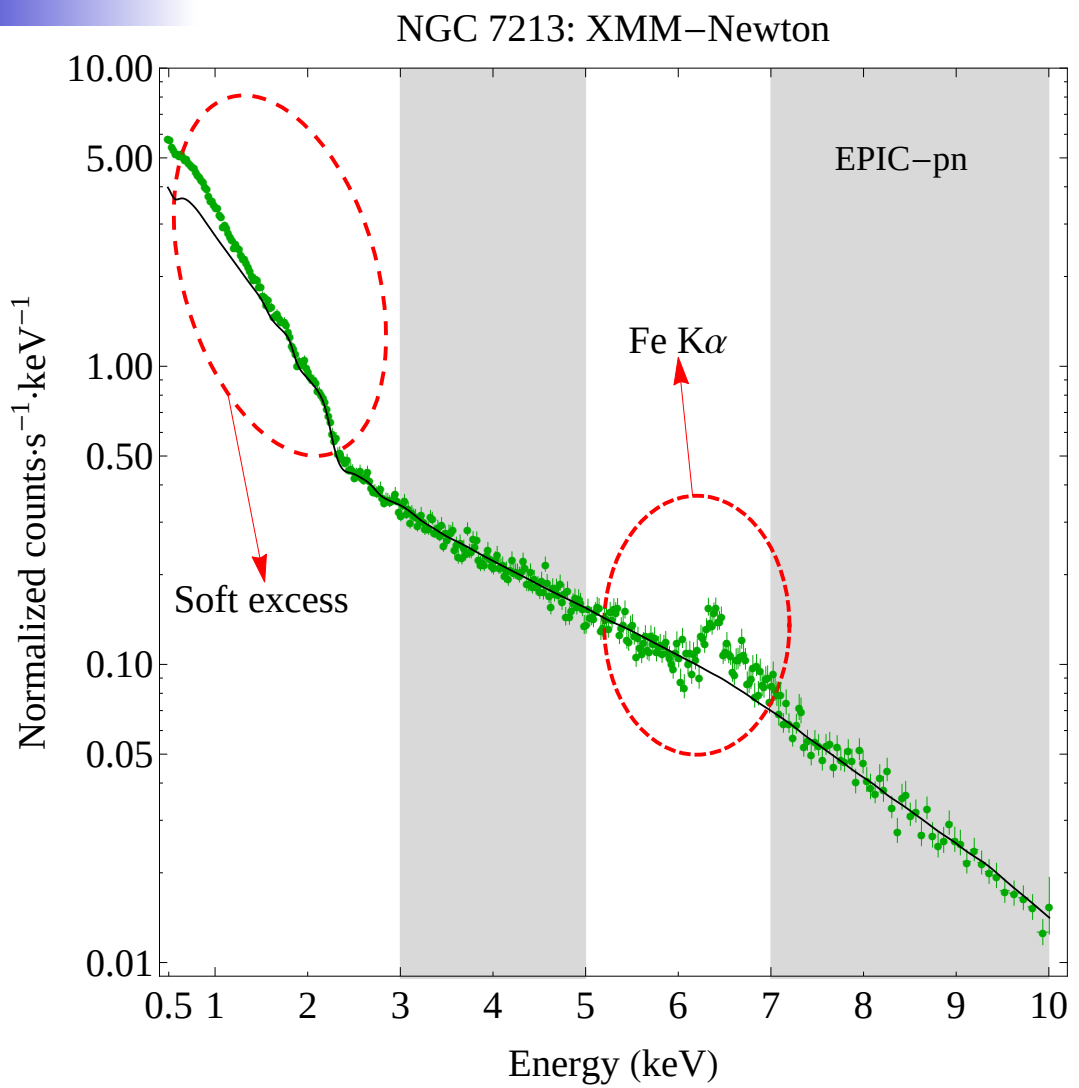


Emmanoulopoulos et al. 2013, MNRAS, **429**, 3439

Motivation



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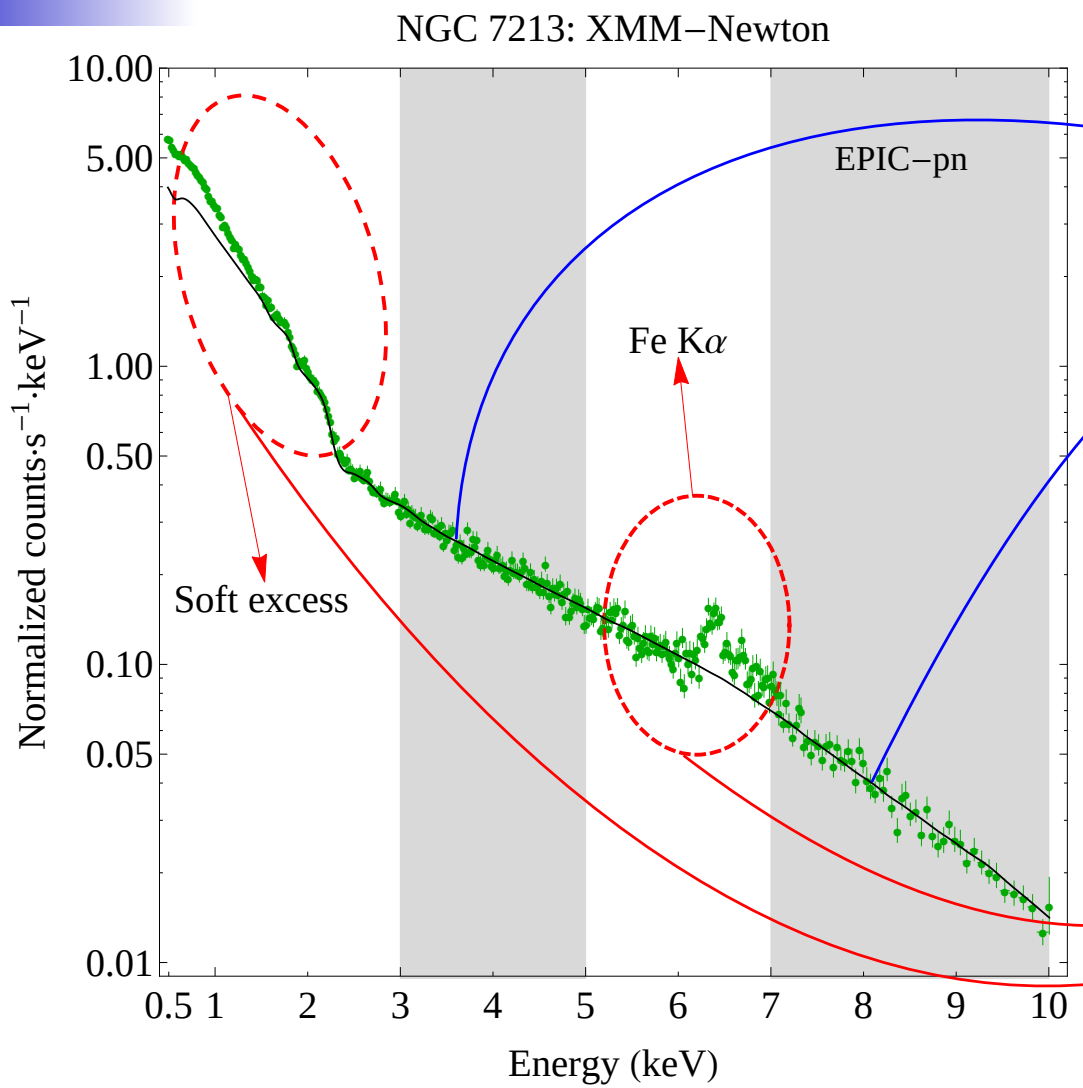
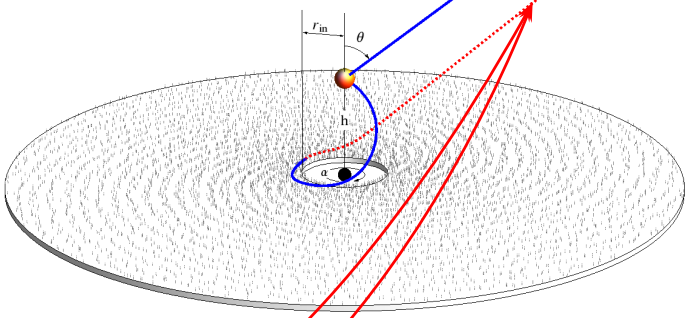


Direct continuum



Reflected component

X-ray reverberation: Observations

-Soft band variations lag behind hard band variations-

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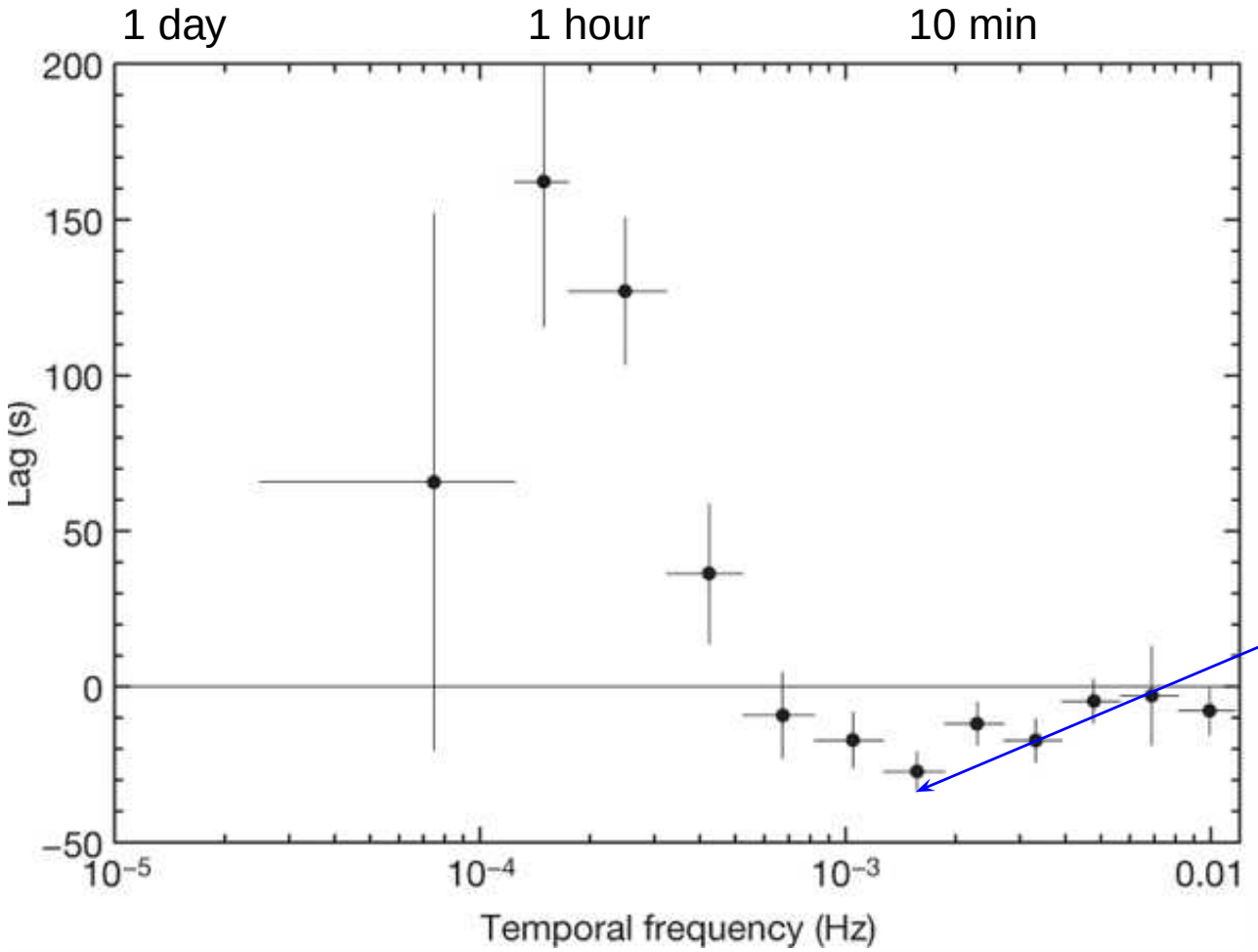


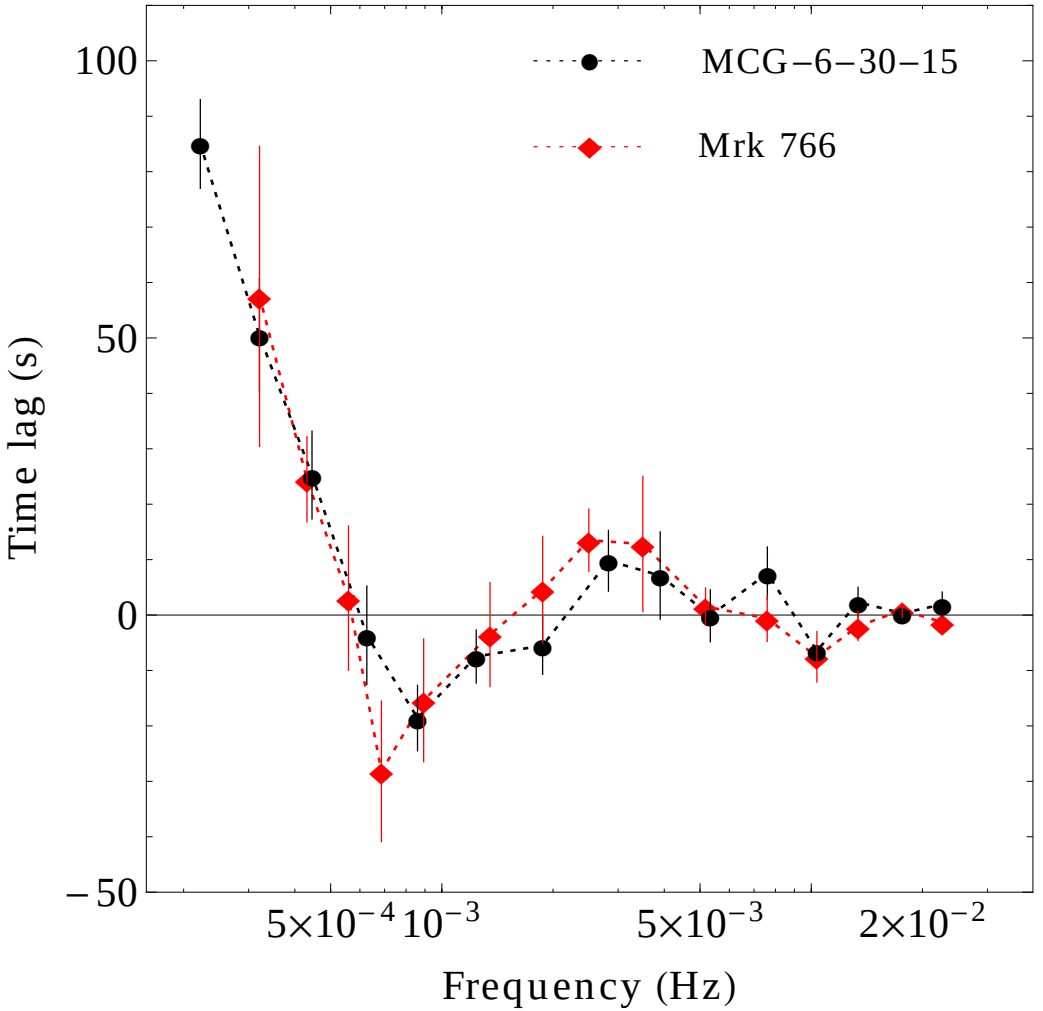
1H 0707-495

0.3–1 keV vs 1–4 keV

Most negative delay 30 s

Fabian et al. 2009, Nat, **459**, 540

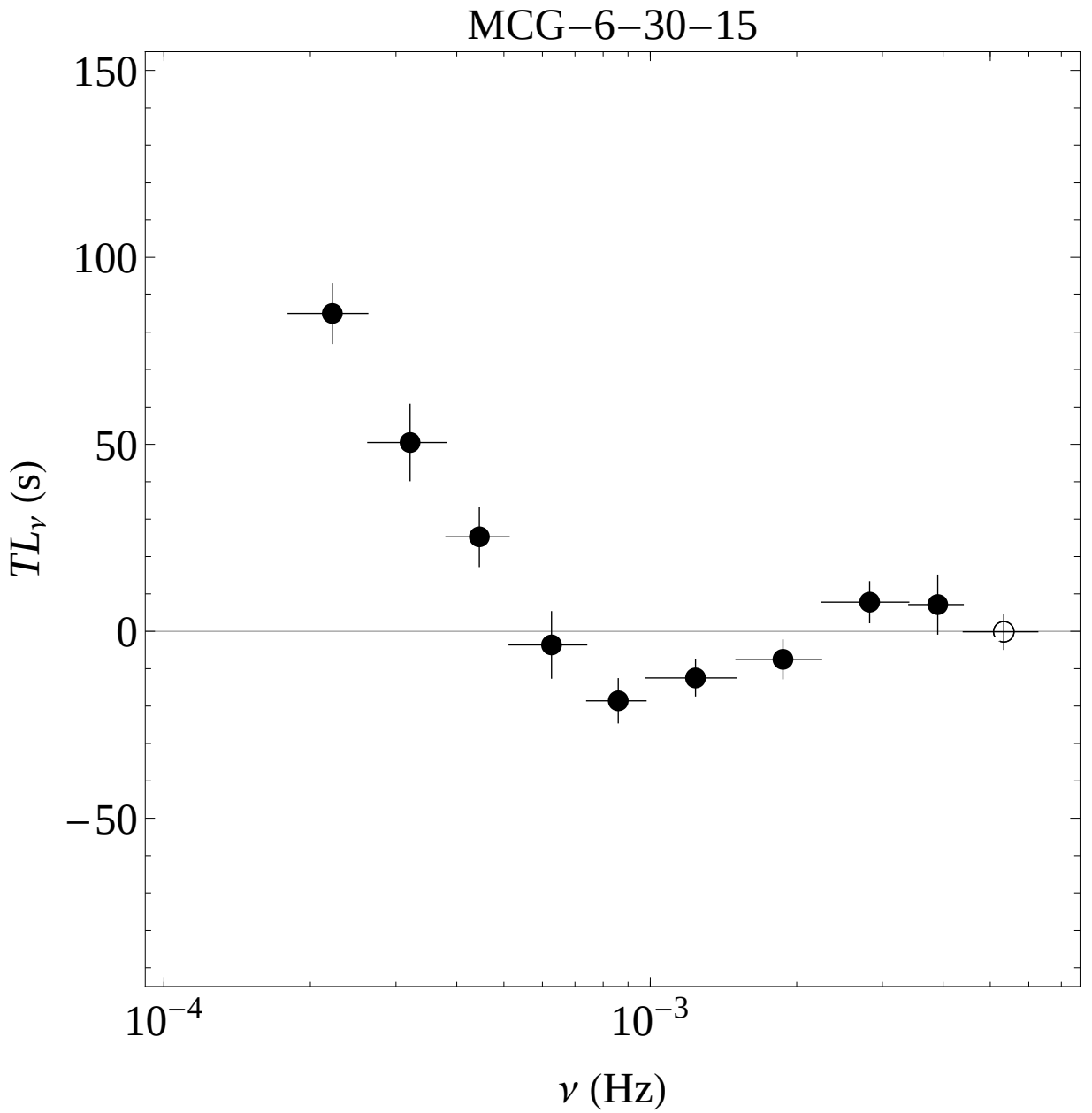
X-ray reverberation: Observations



0.5–1.5 keV vs 2–4 keV

Emmanoulopoulos et al. 2011, MNRAS, **416**, L94

X-ray reverberation: Observations



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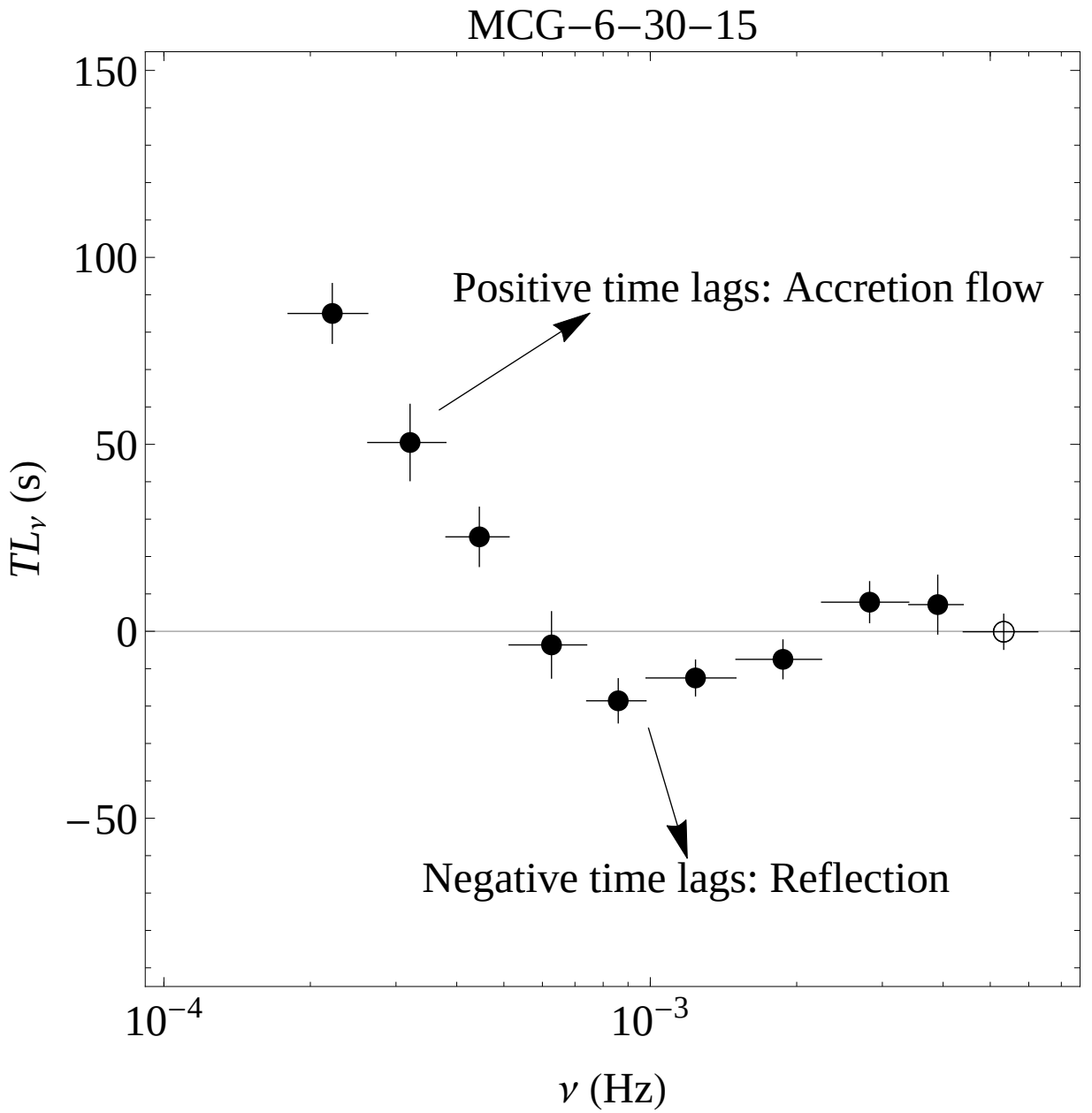
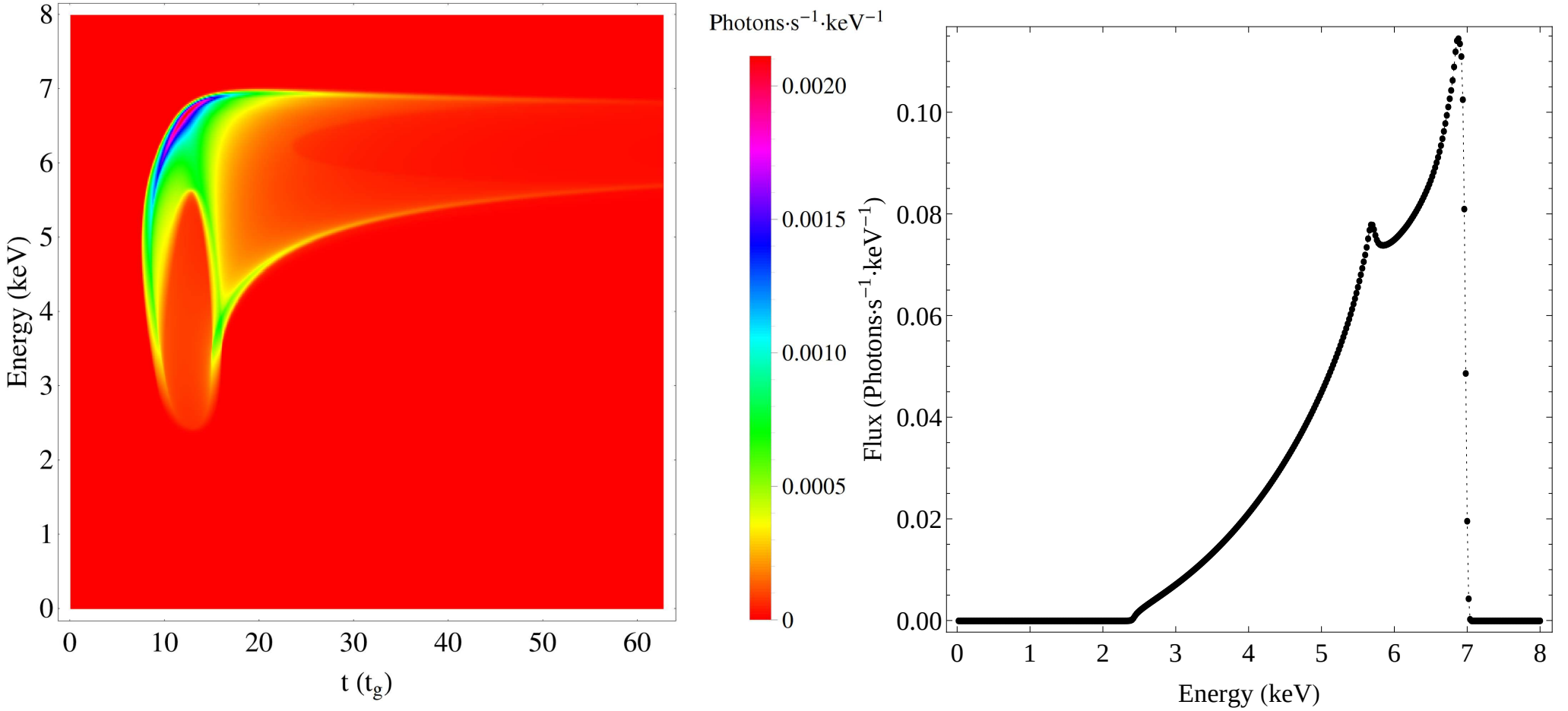


X-ray reverberation: Modelling

Response profiles: Dovčiak et al. 2011, ApJ, **731**, 75

Spin$= 0.676$, Height$= 3.6\ r_{\rm g}$ and Angle=$40°$



Flux of the Fe Kα line at 6.4 keV

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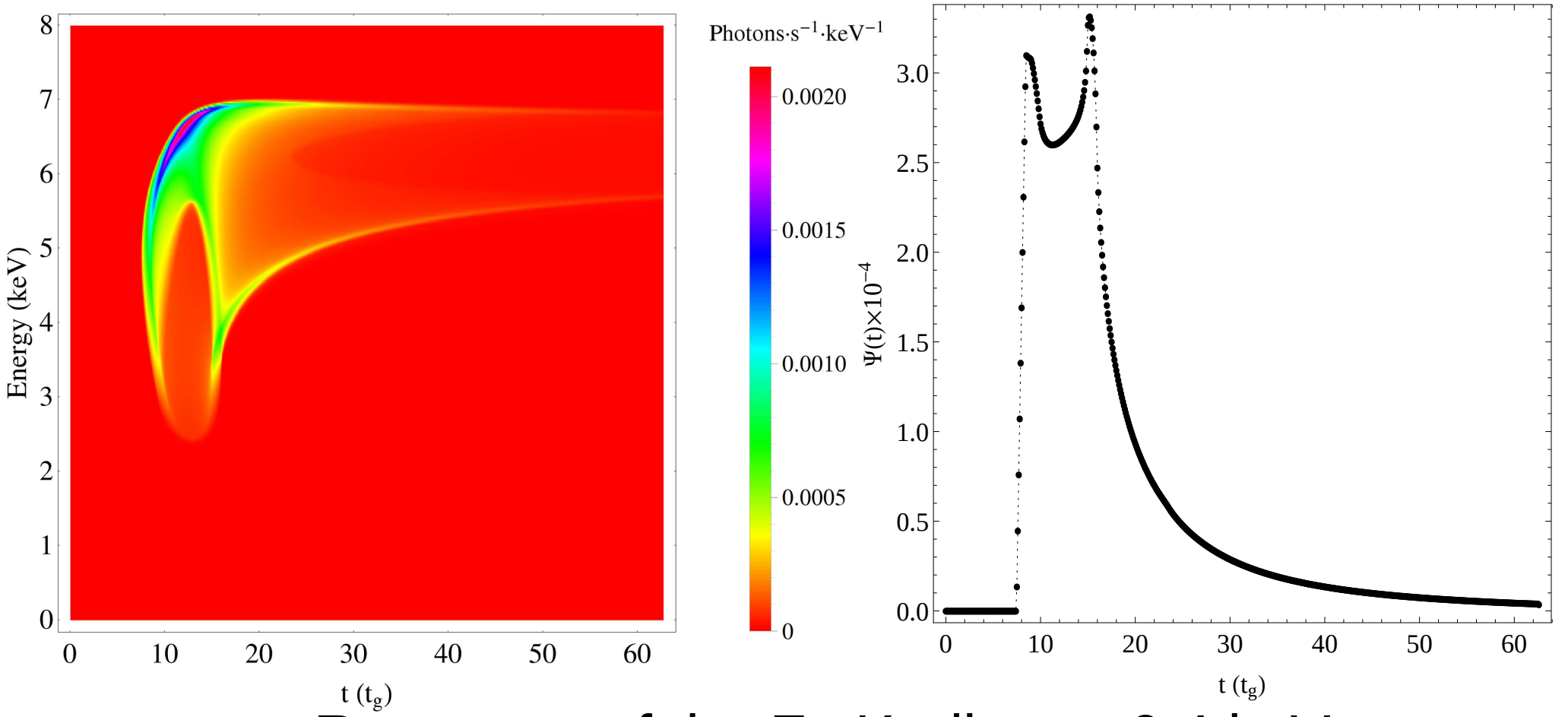
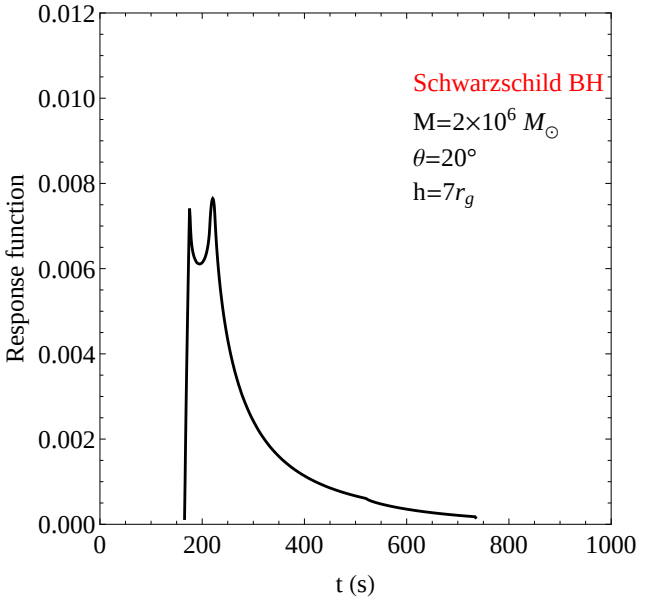
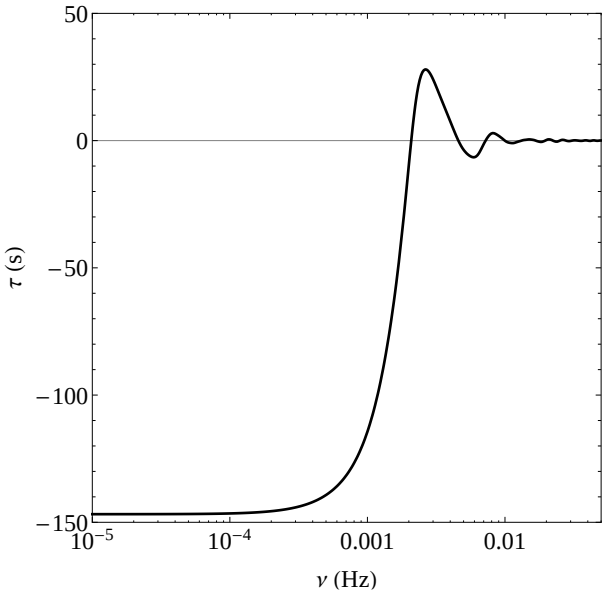


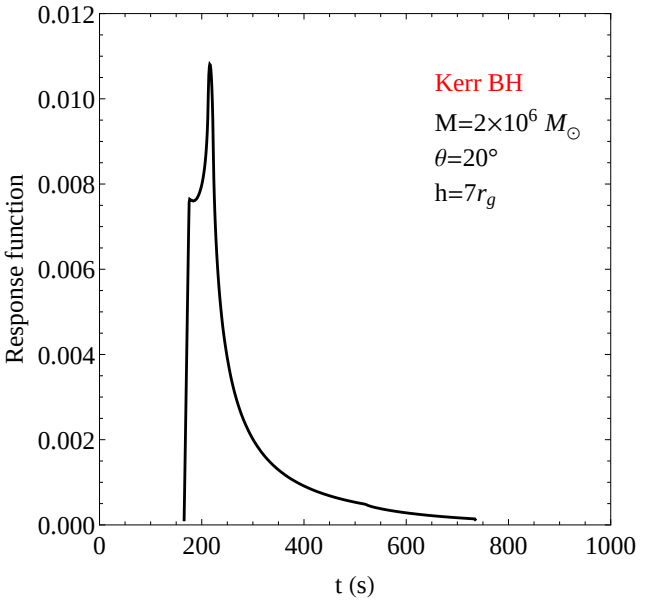
Response of the Fe Kα line at 6.4 keV

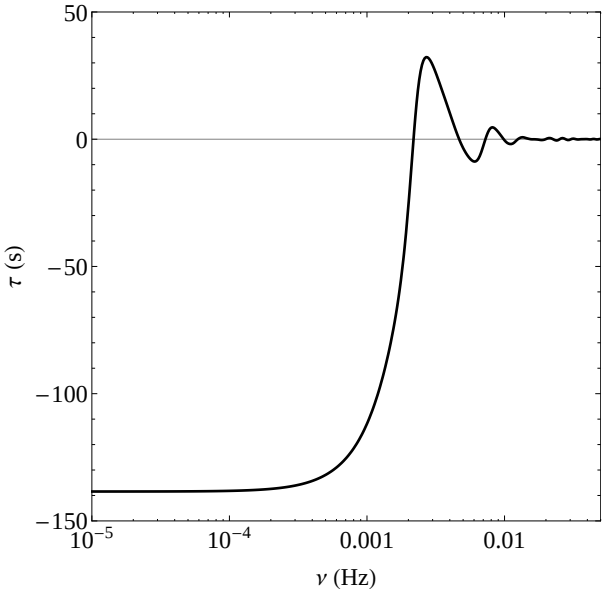
X-ray reverberation: Modelling

GR reflection component: BH Spin









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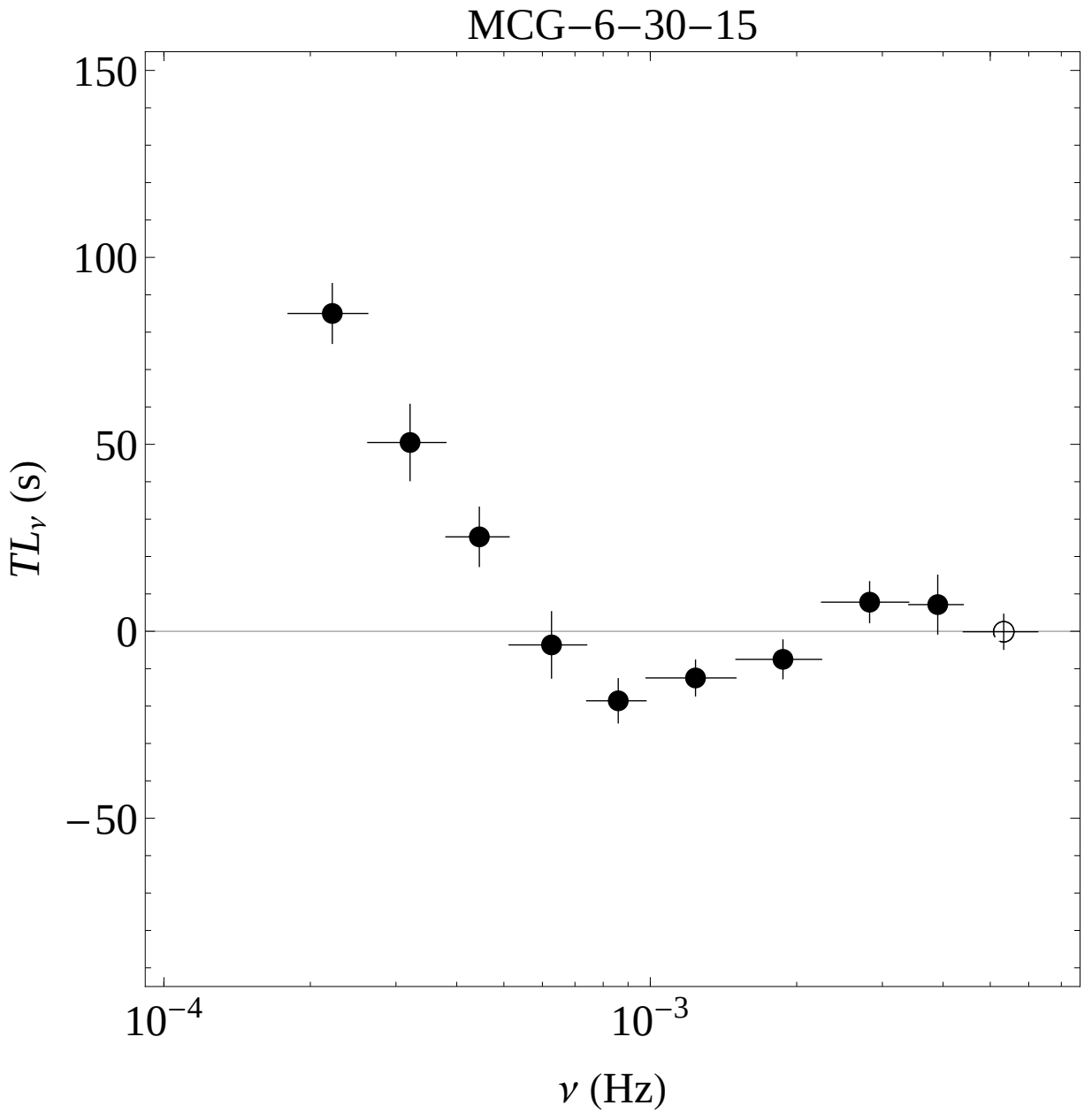

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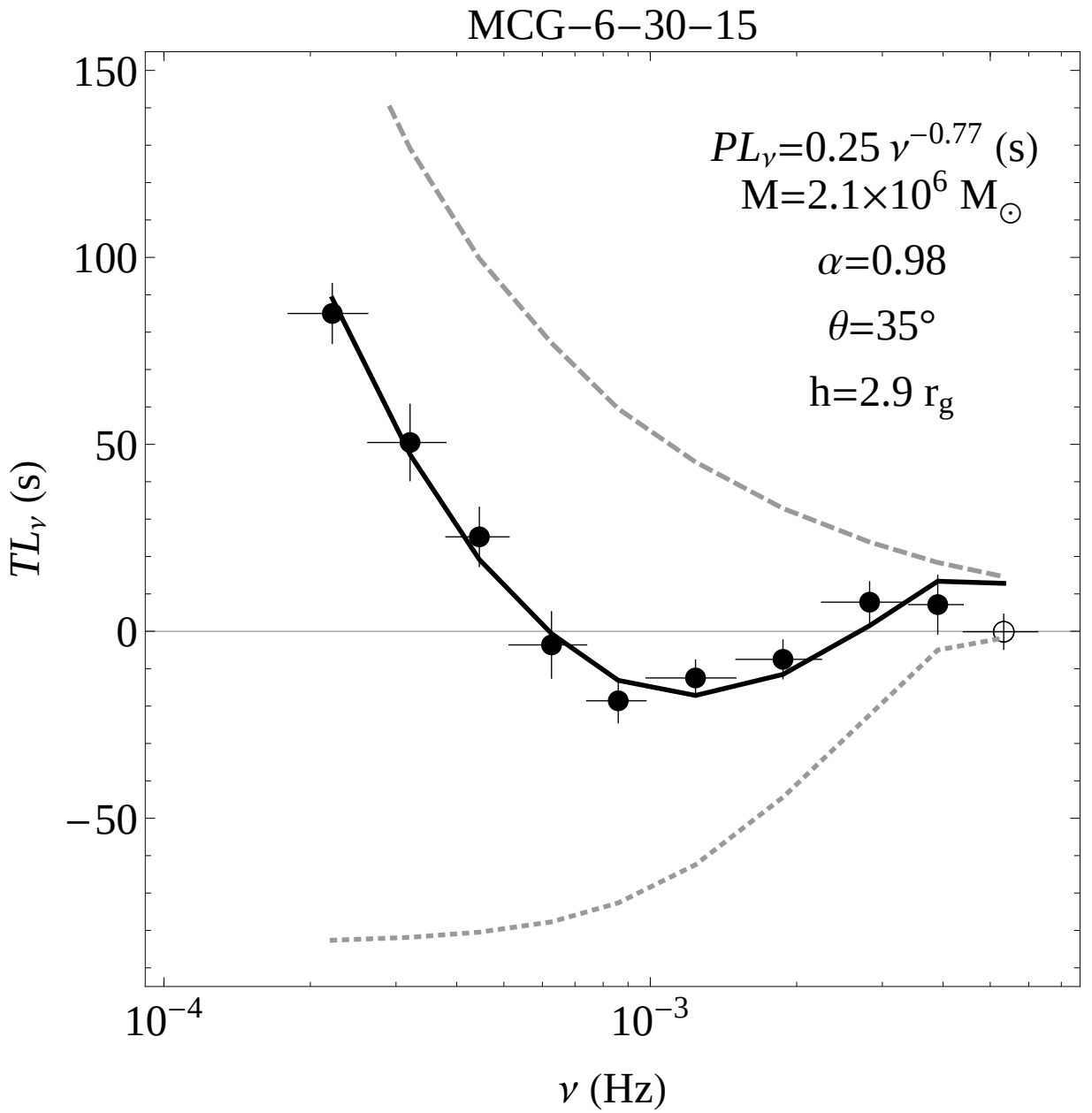

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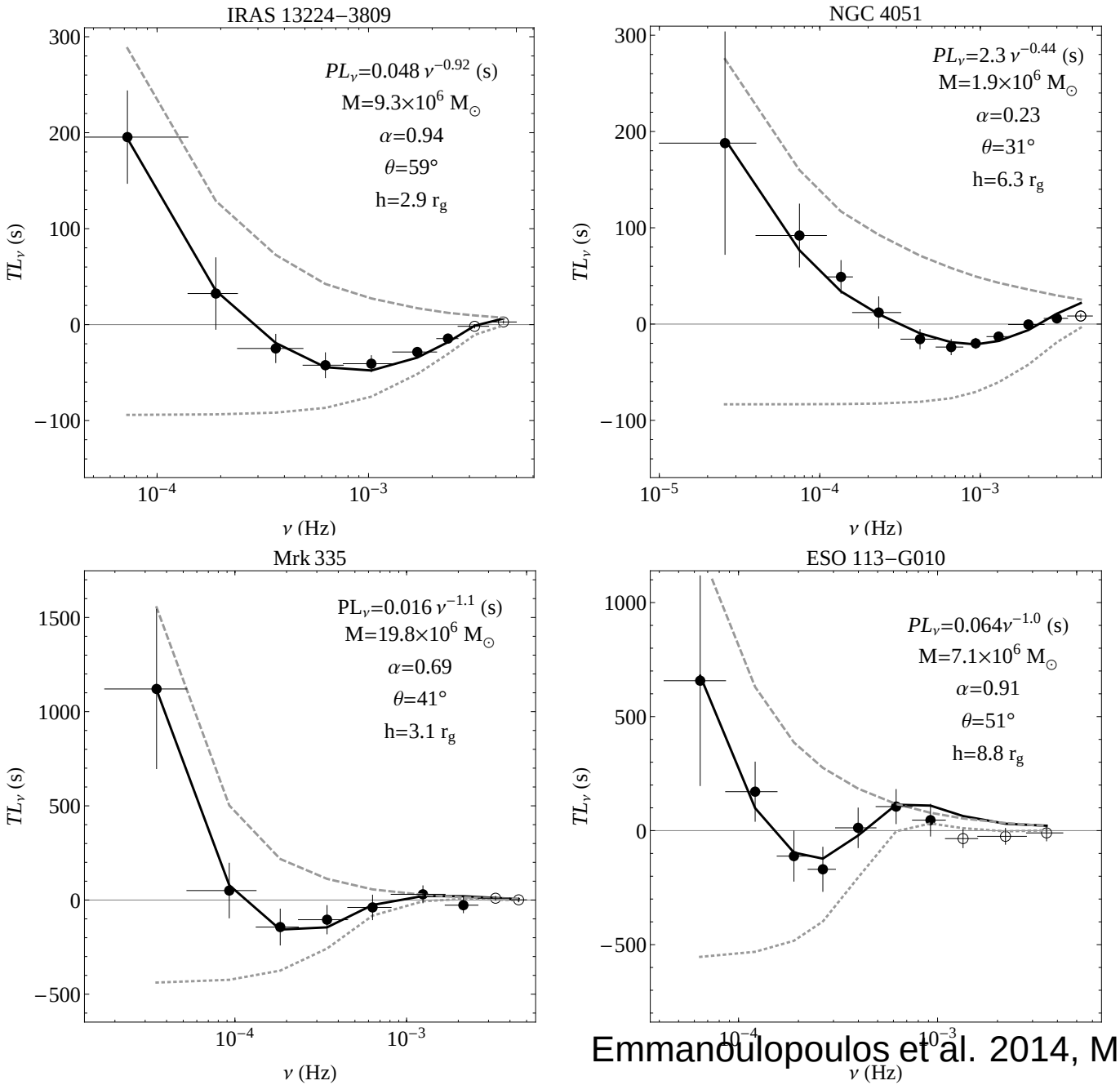

Emmanoulopoulos et al. 2014, MNRAS, **439**, 3931

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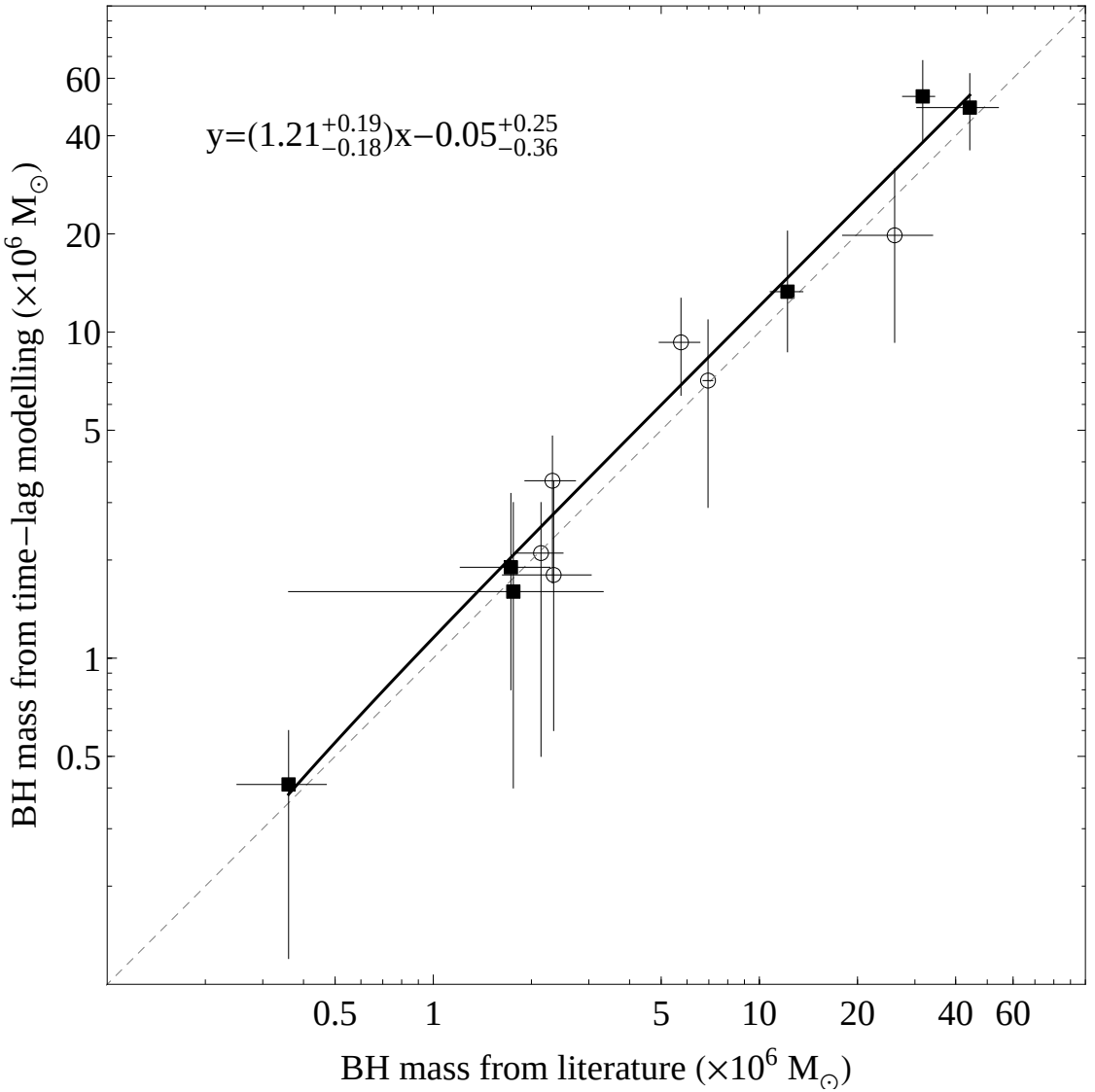

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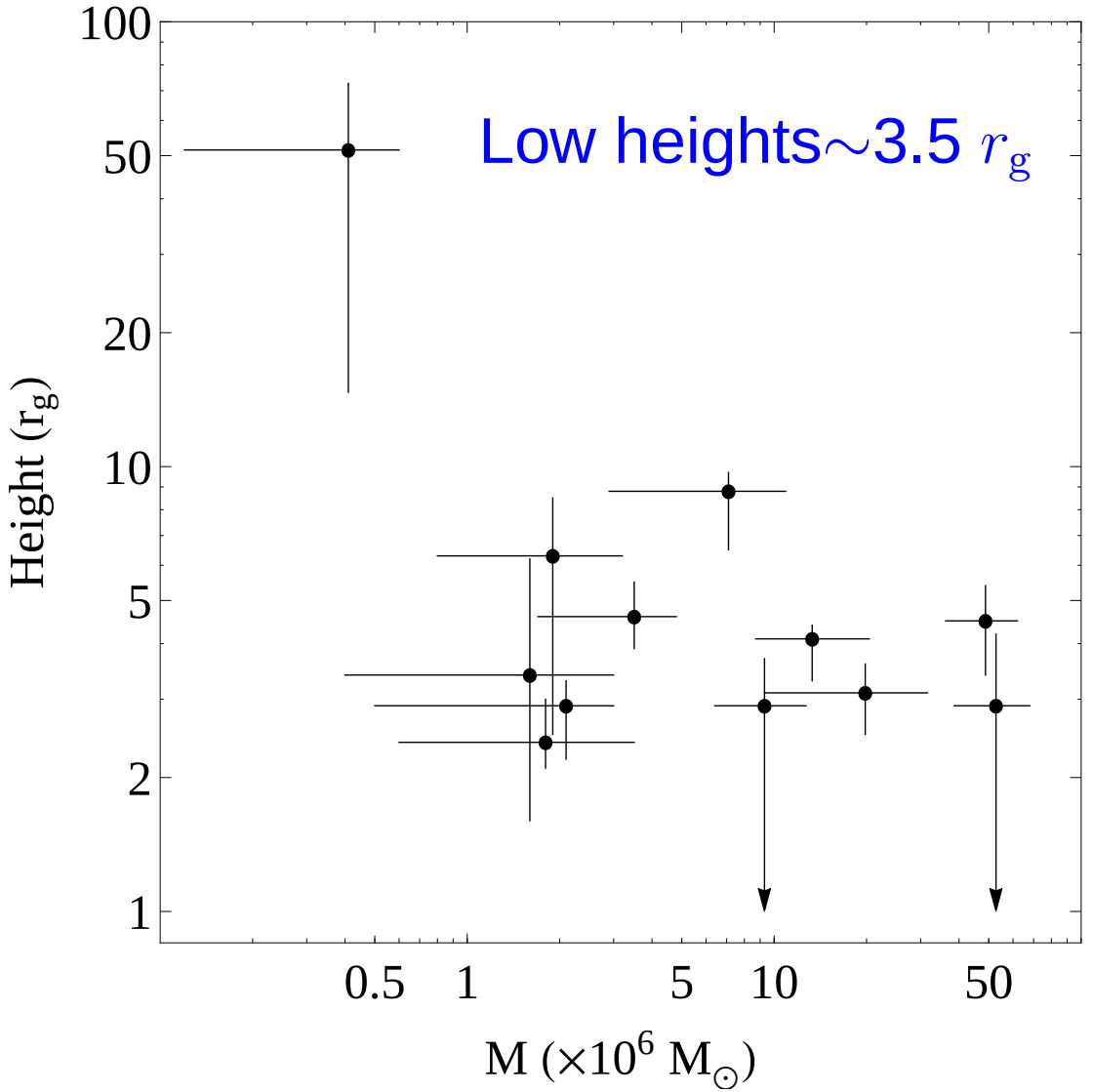

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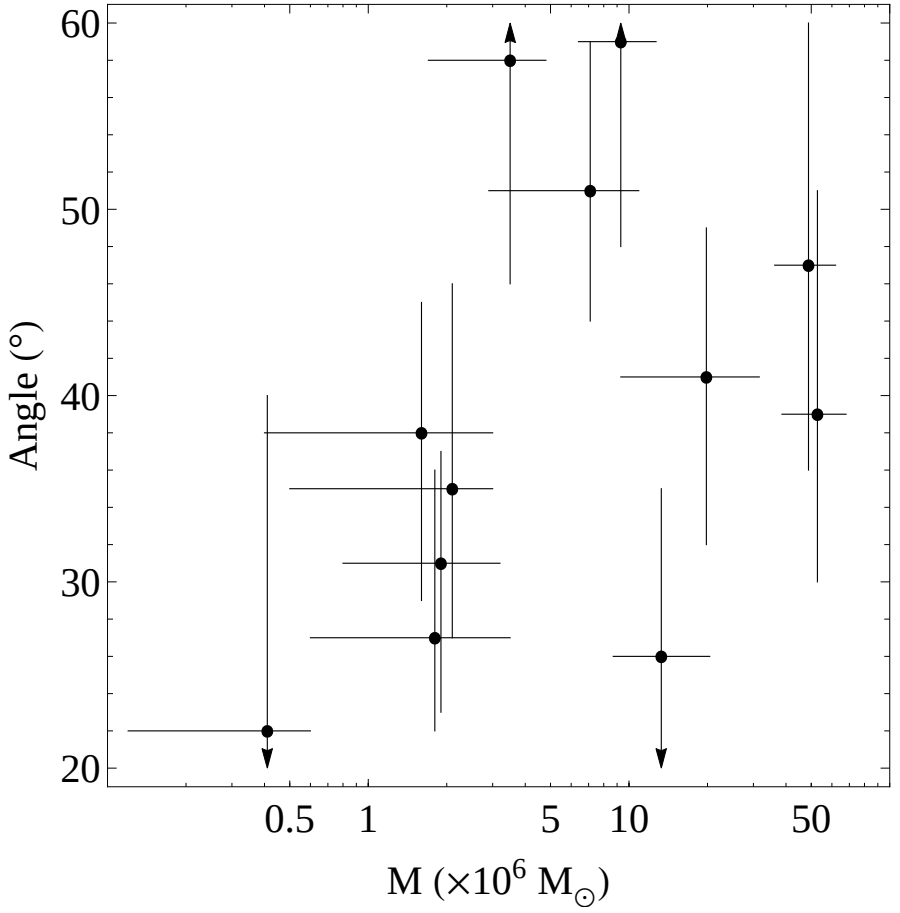
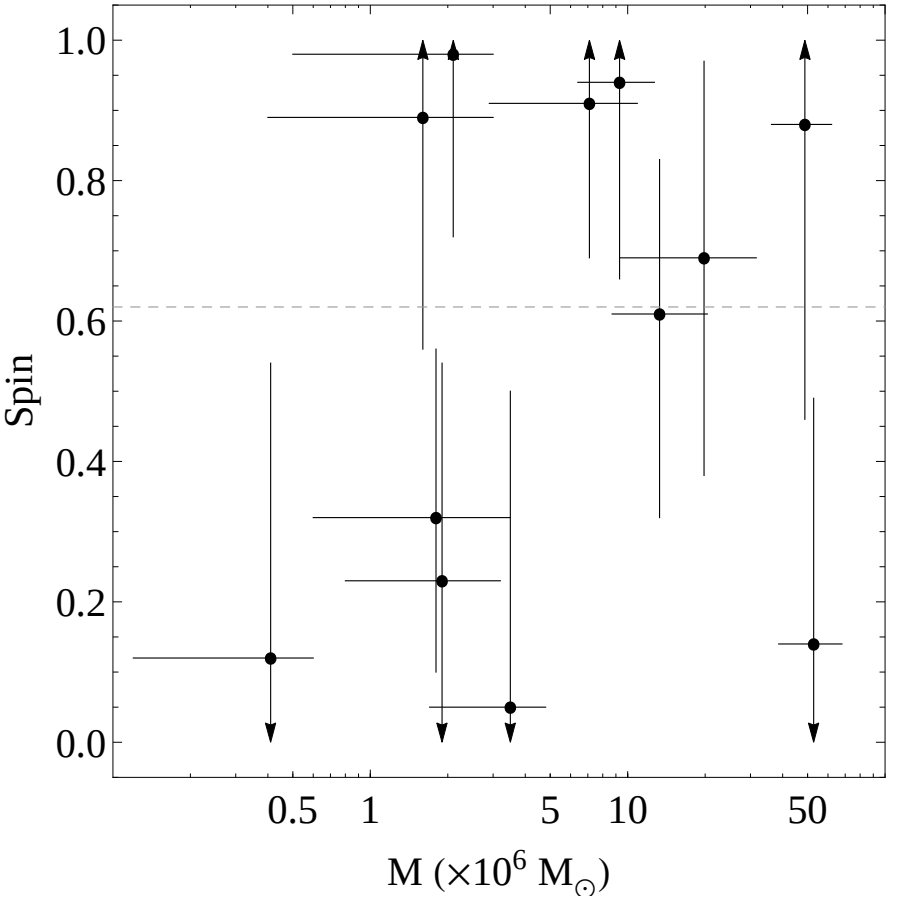




Real range of angles

Spin bimodality

Emmanoulopoulos et al. 2014, MNRAS, **439**, 3931

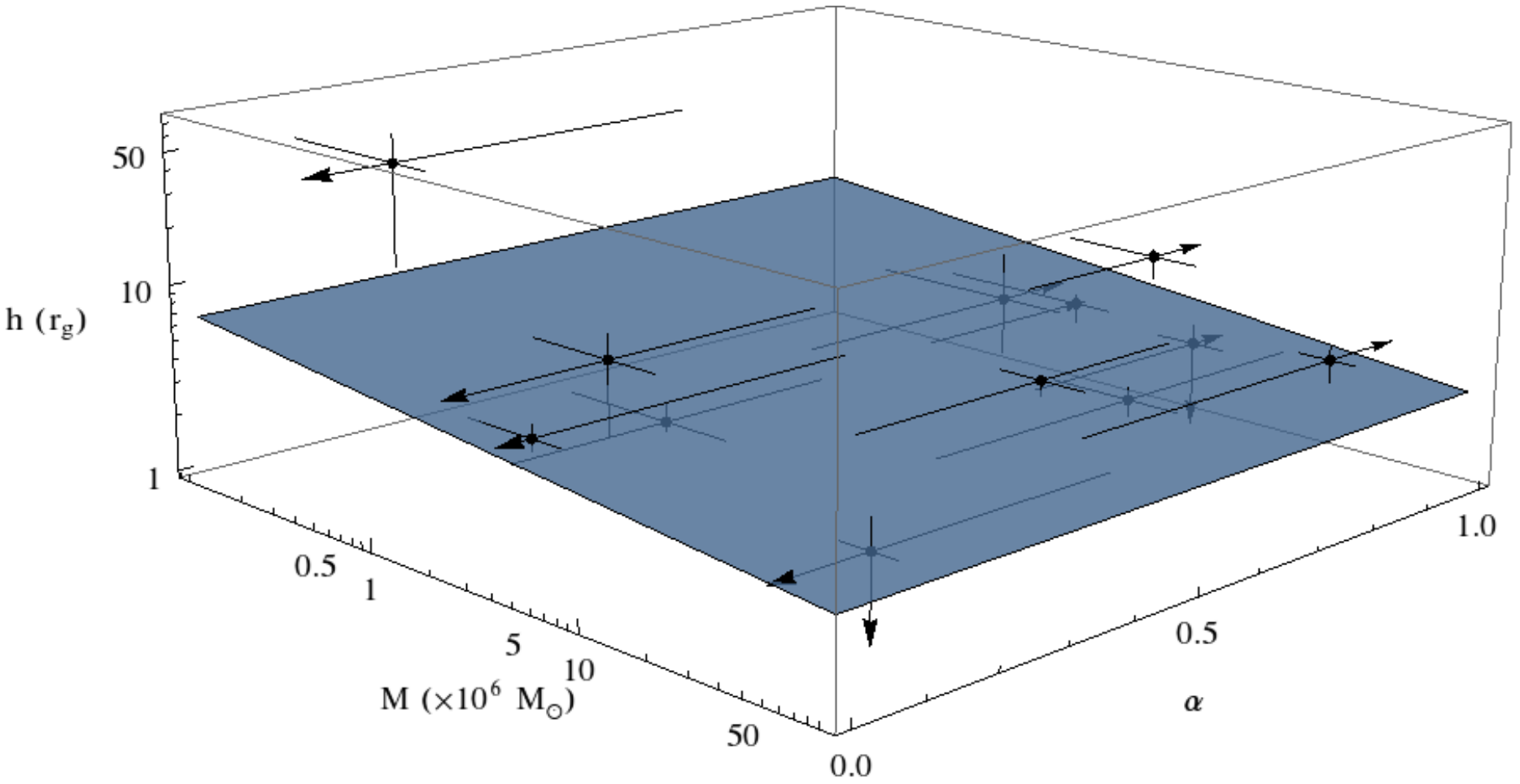
Conclusions

- Small heights, $\approx 3.5\, r_{\rm g}$, above the accretion disc.

Conclusions

- Small heights, $\approx 3.5\, r_{\rm g}$, above the accretion disc.
- New method, INDEPENDENT from X-ray spectral fitting:
  - BH mass
  - BH spin
  - Viewing angles

Complimentary: TL studies



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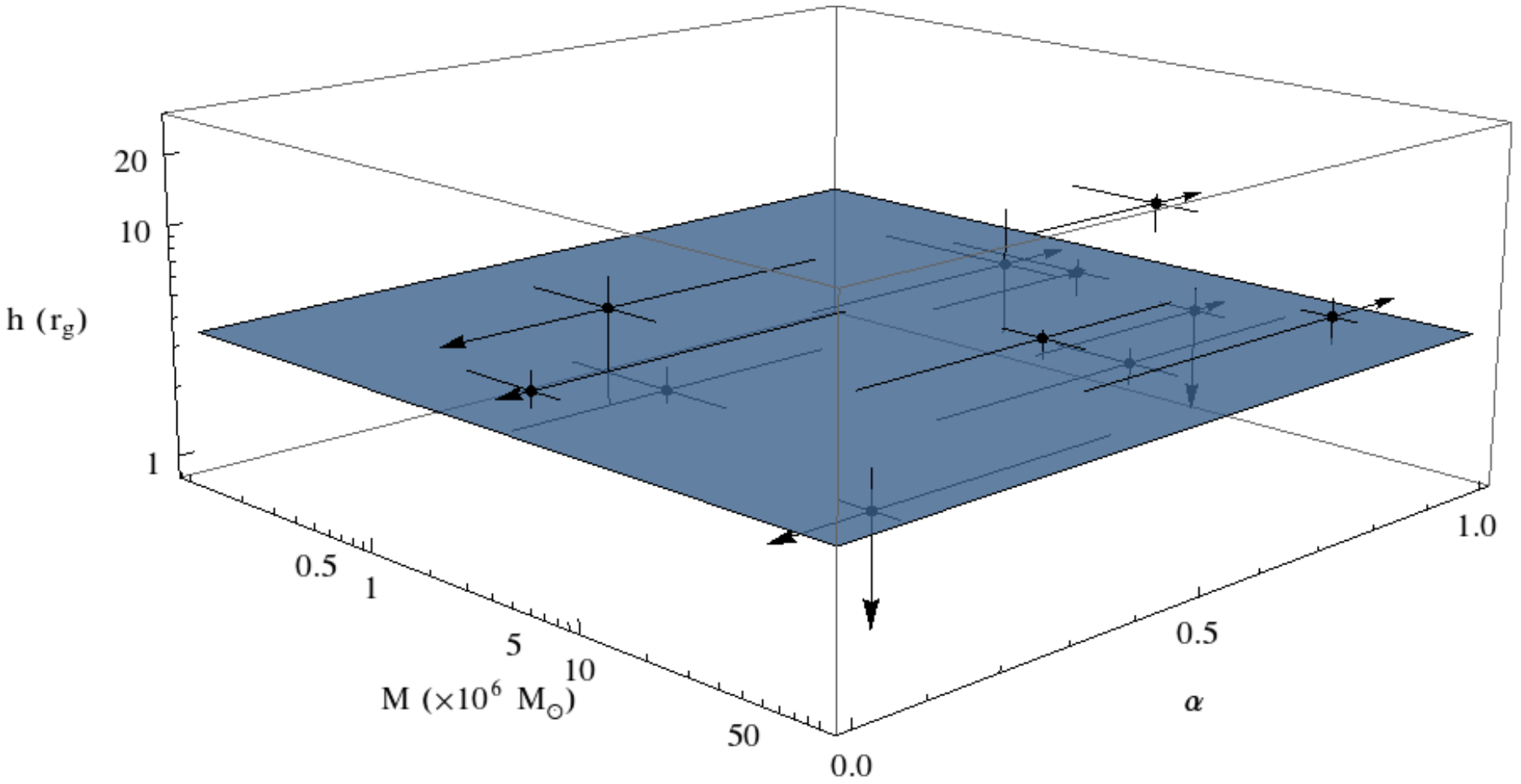


Complimentary: TL studies

Light-curve decomposition$\Longleftrightarrow$Power spectral density

For a set of observations x_i measured at t_i ($i = 1, \ldots, N$)

$$|DFT(f_j)| = \left| \sum_{i=1}^{N} x_i e^{2\pi i f_j t_i} \right|^2$$

where $j = \frac{j}{N\Delta t}$ and $j = 1, \ldots, N/2$

Complimentary: TL studies

- Reprocessing: Neutral Fe Kα

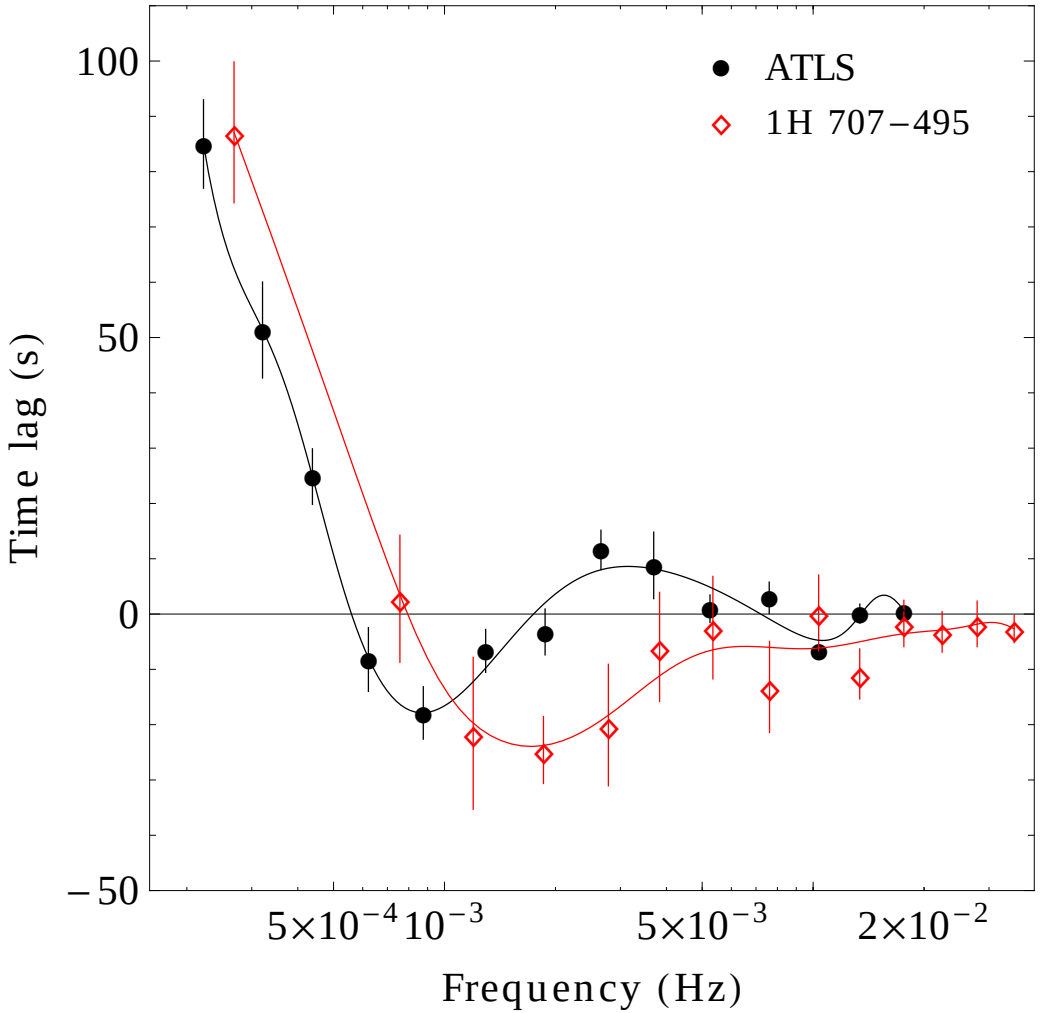
  (NOAR MC scattering code, Dumont et al. 2000, A&A, **357**, 823)

- GR effects

  (Dovčiak et al. 2011, ApJ, **731**, 75, Dovčiak et al, 2004, MNRAS, **355**, 1005)

  - light bending
  - gravitational lensing
  - energy shift (Doppler and gravitational)
  - relativistic time delays

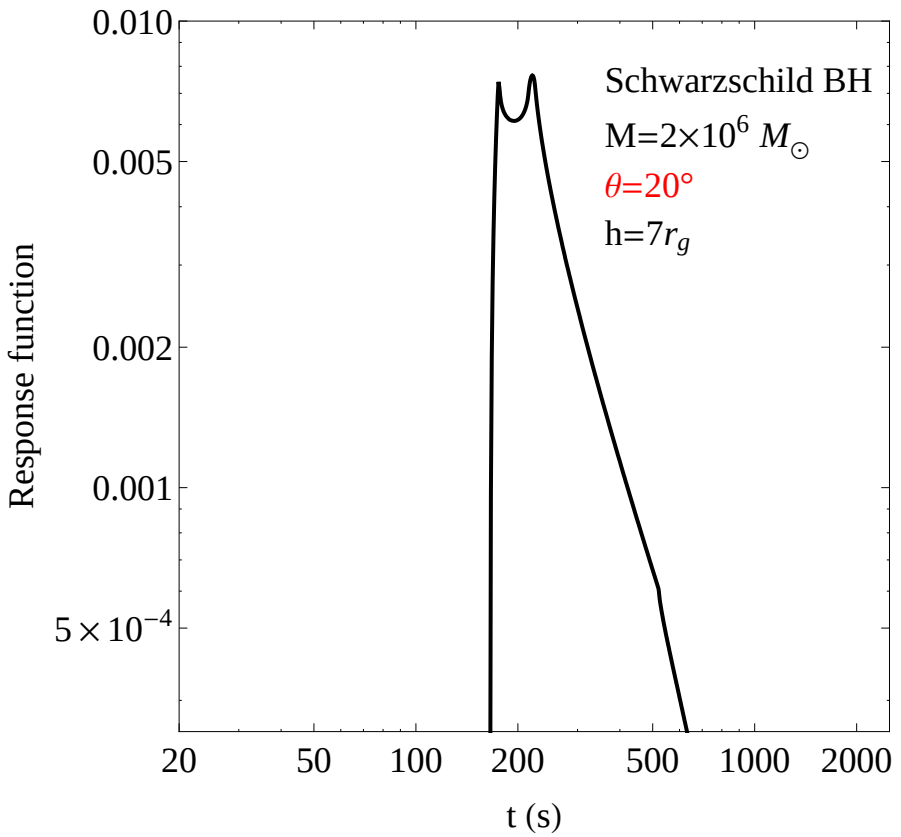
Complimentary: TL studies

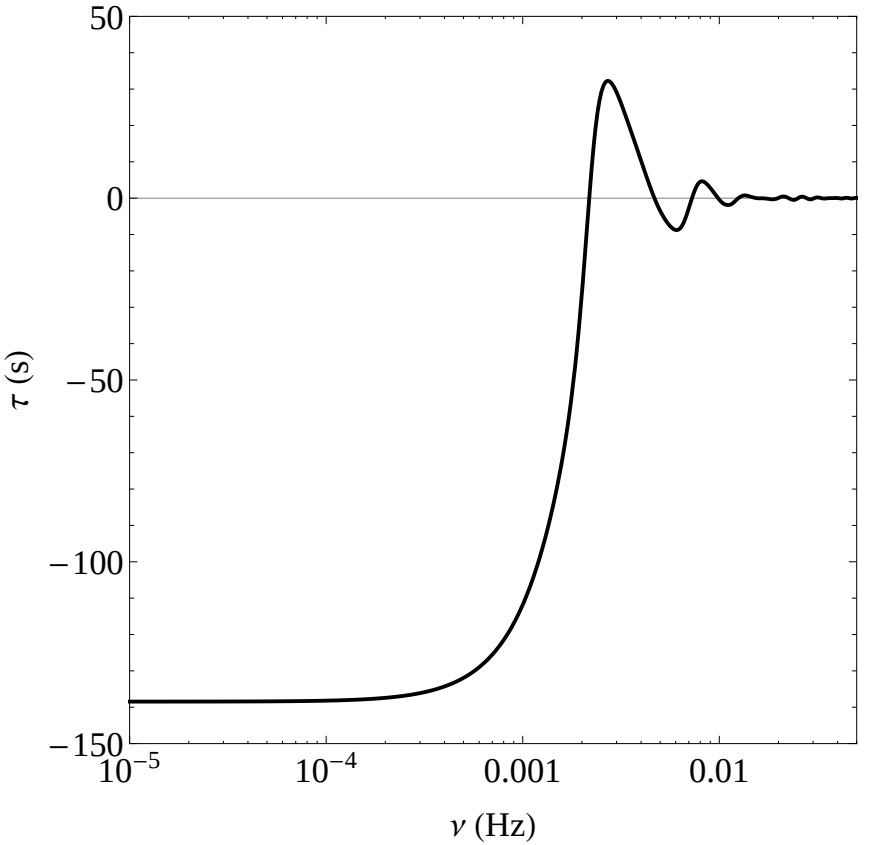


Emmanoulopoulos et al. 2011, MNRAS, **416**, L94

Complimentary: TL studies

GR reflection component: Angle, θ





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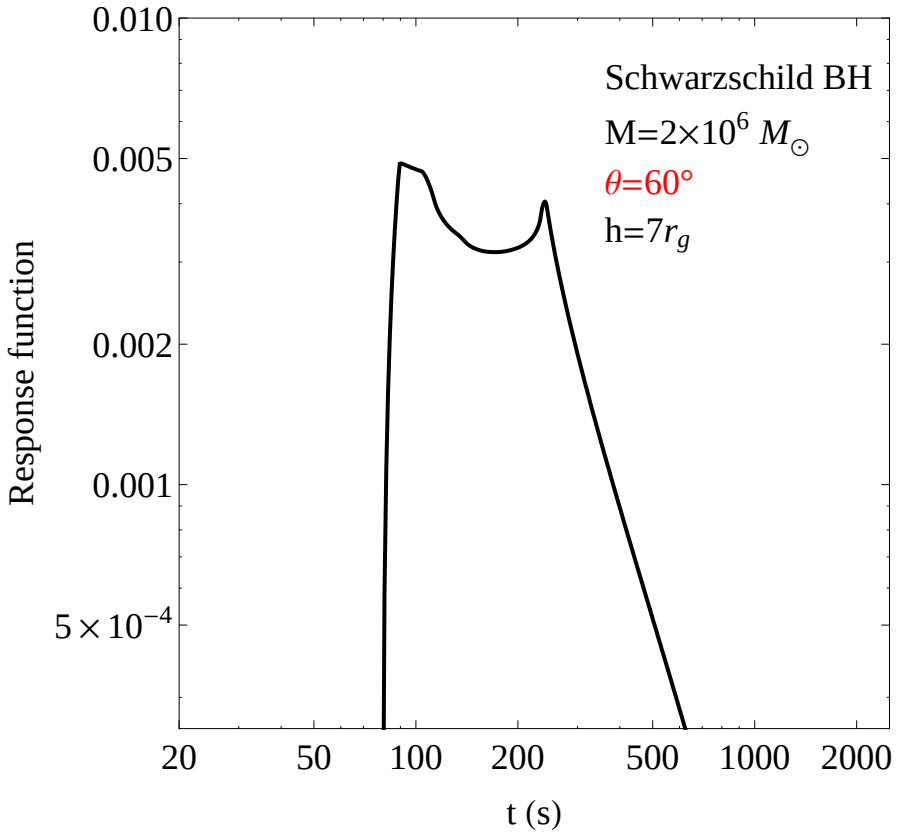
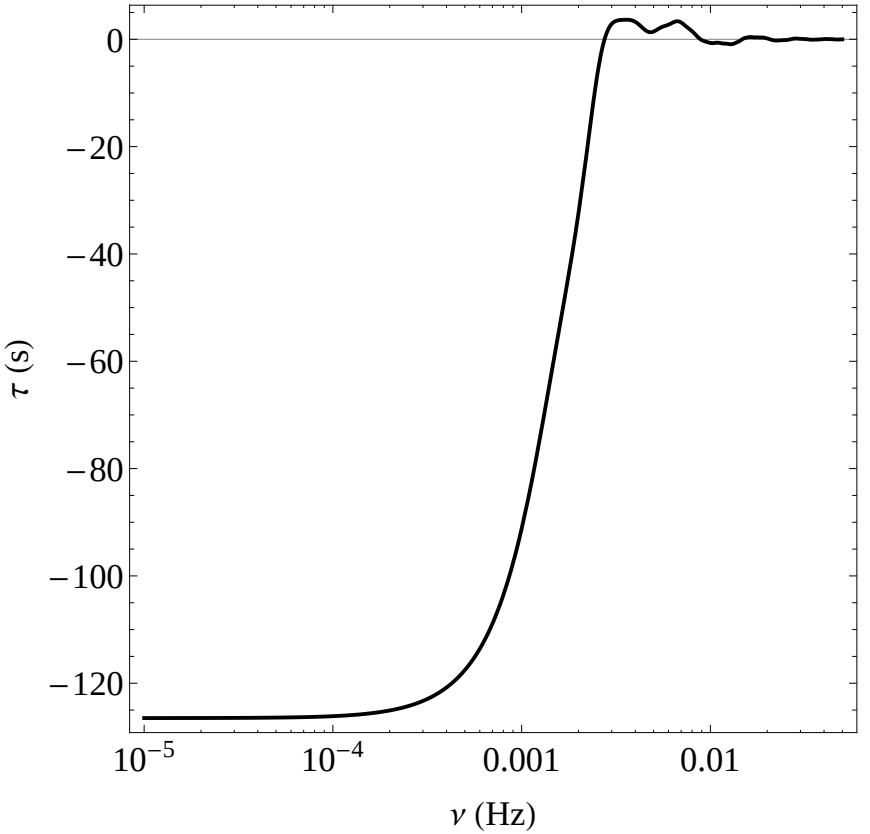
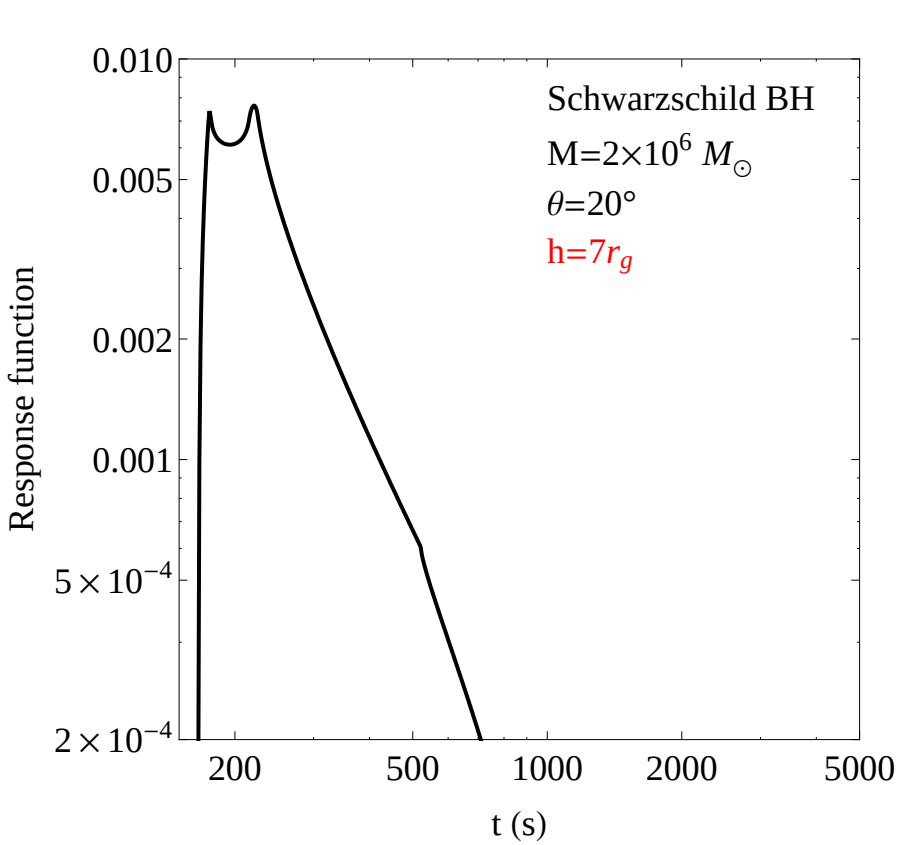
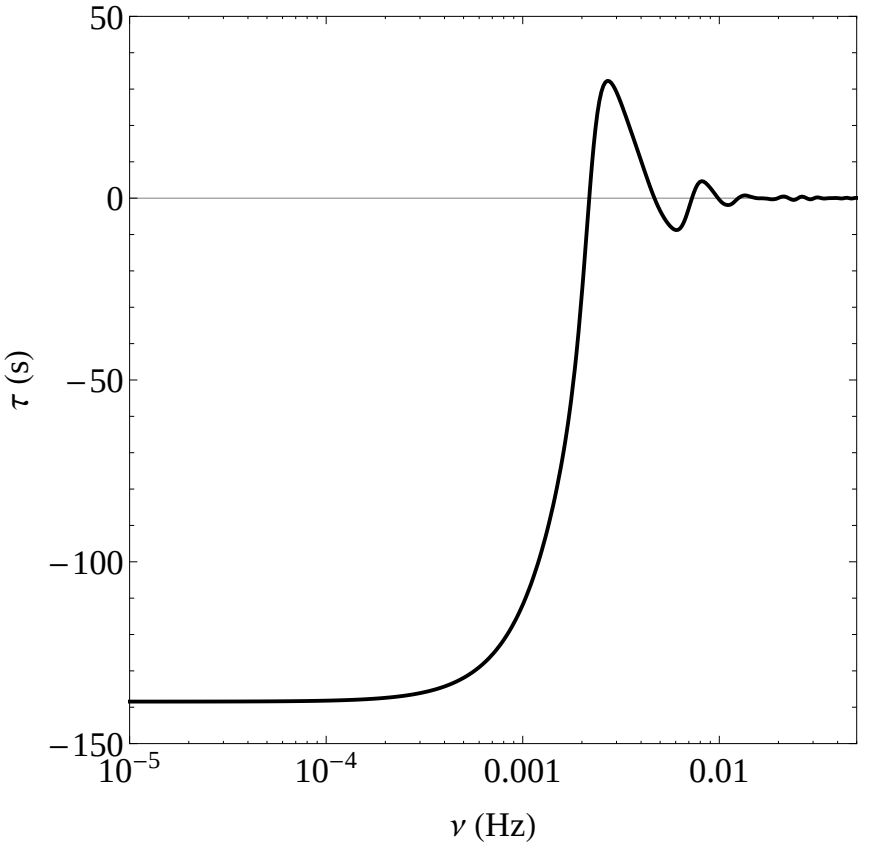




Complimentary: TL studies

GR reflection component: Height, $r_{\rm h}$





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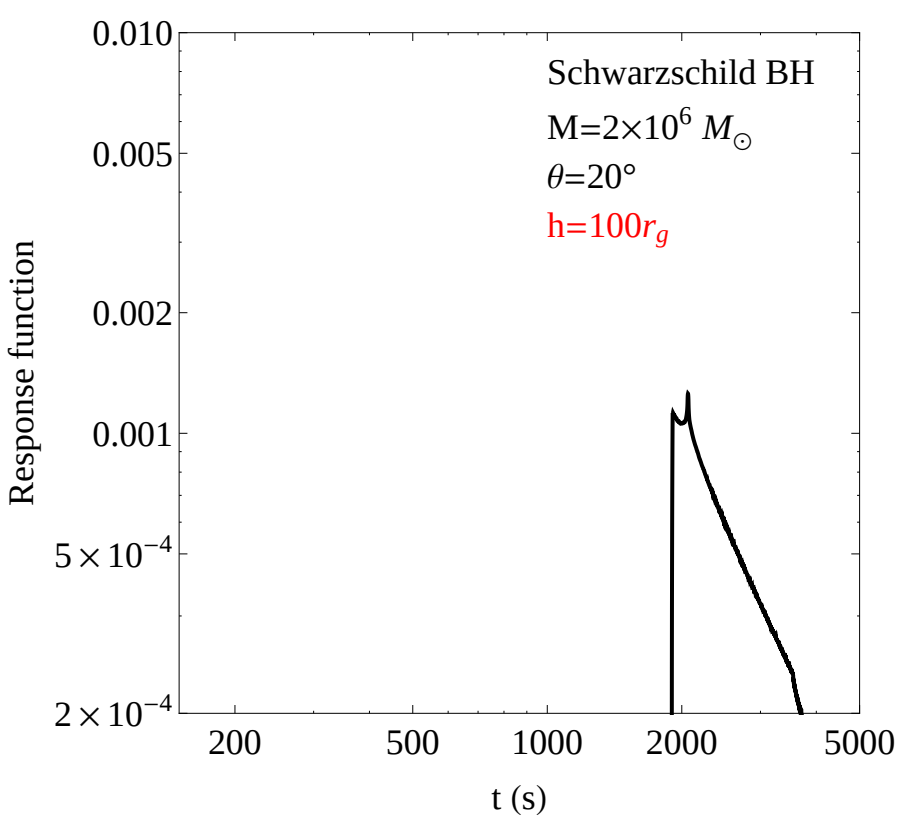

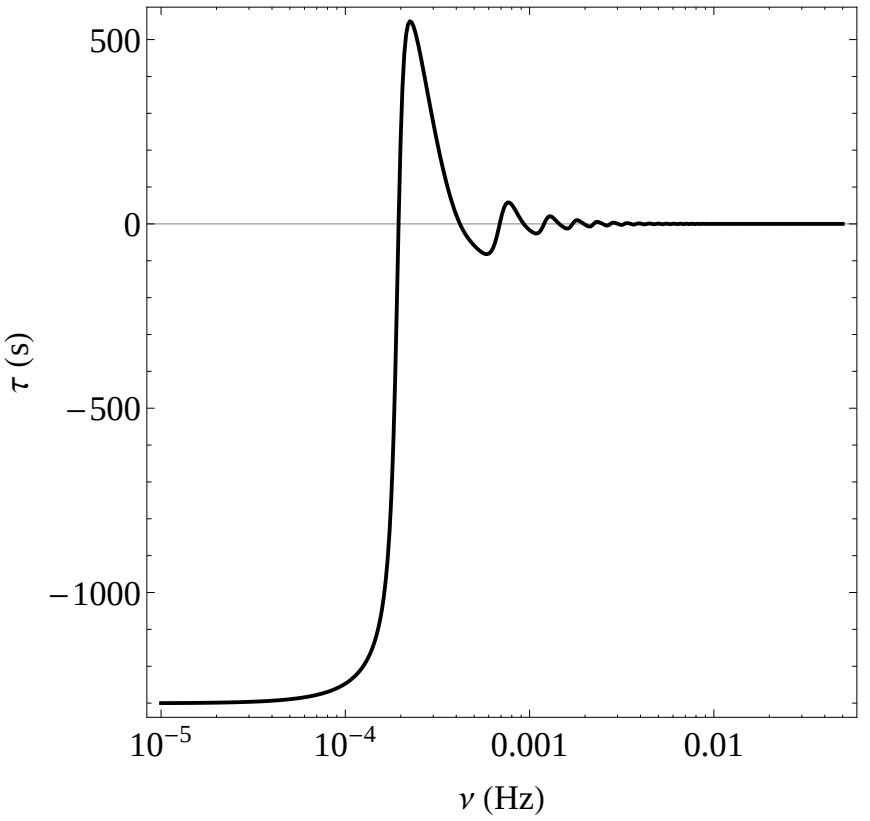

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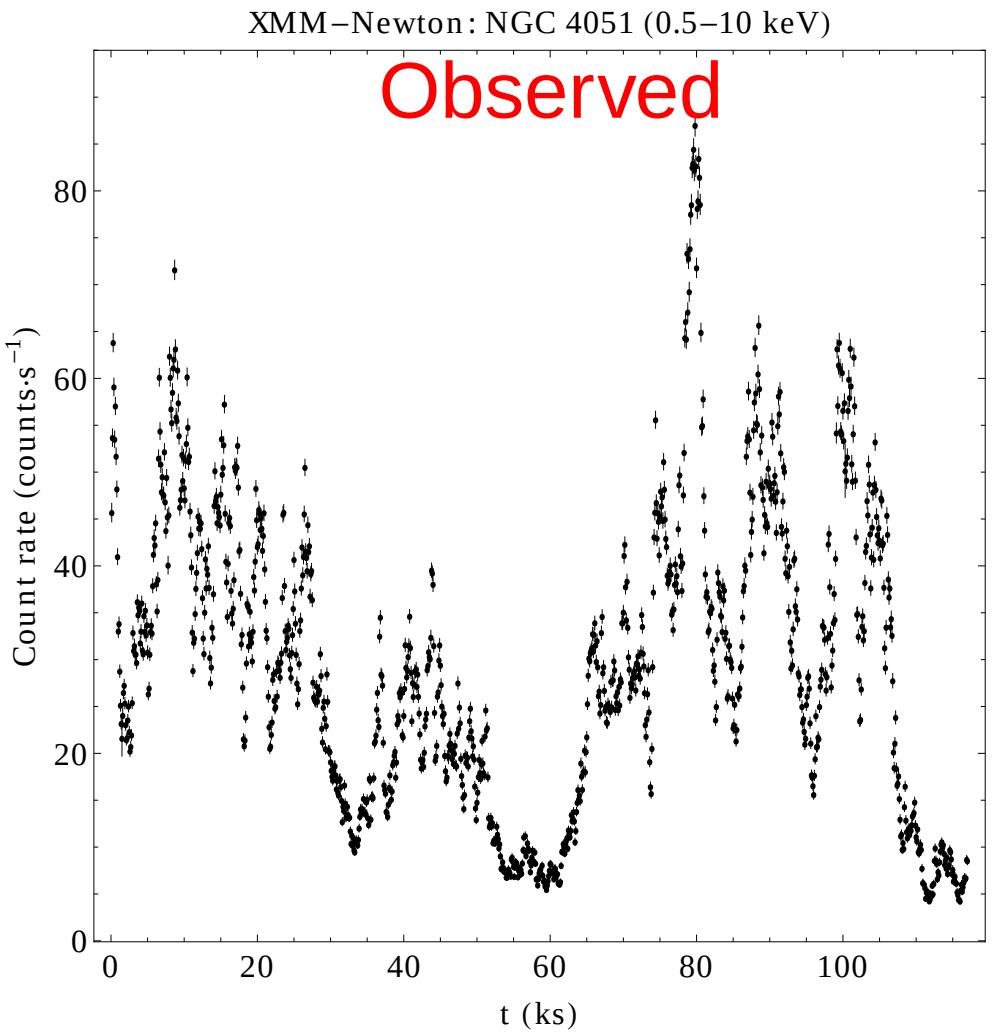
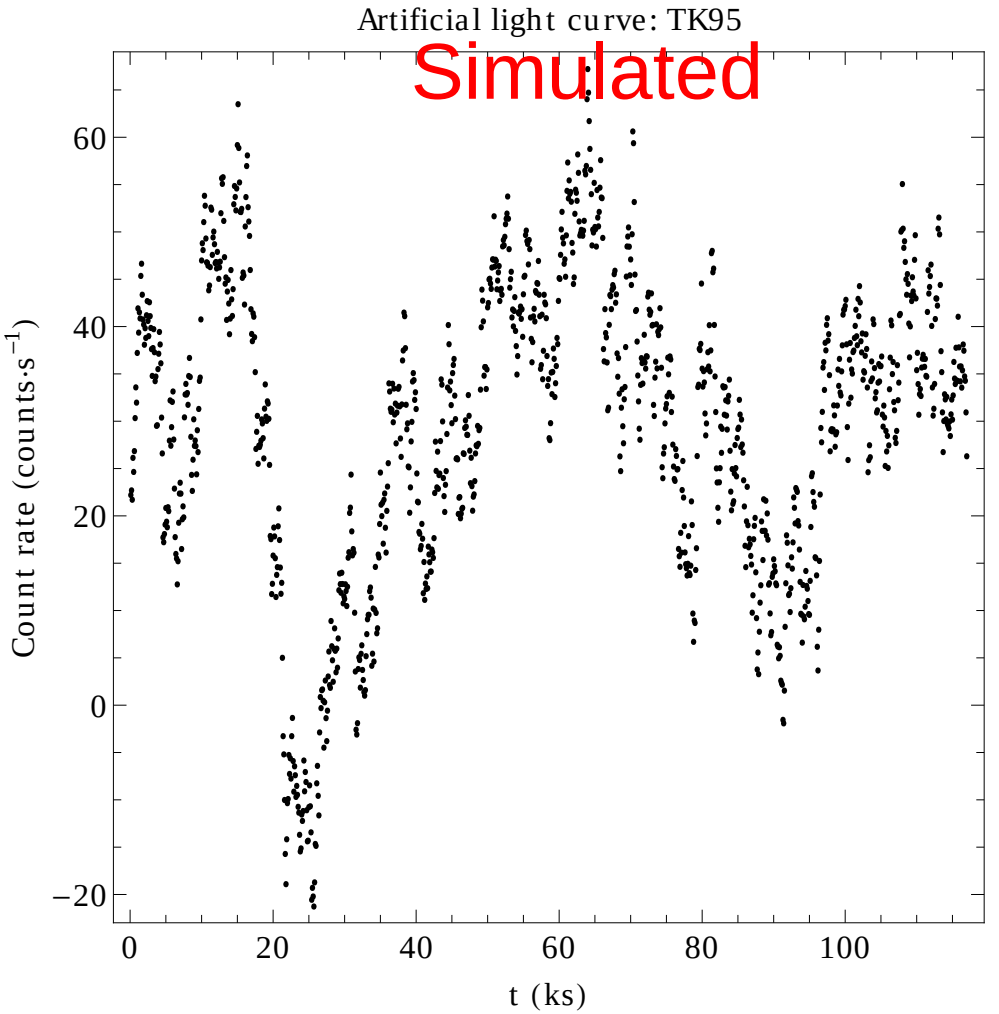
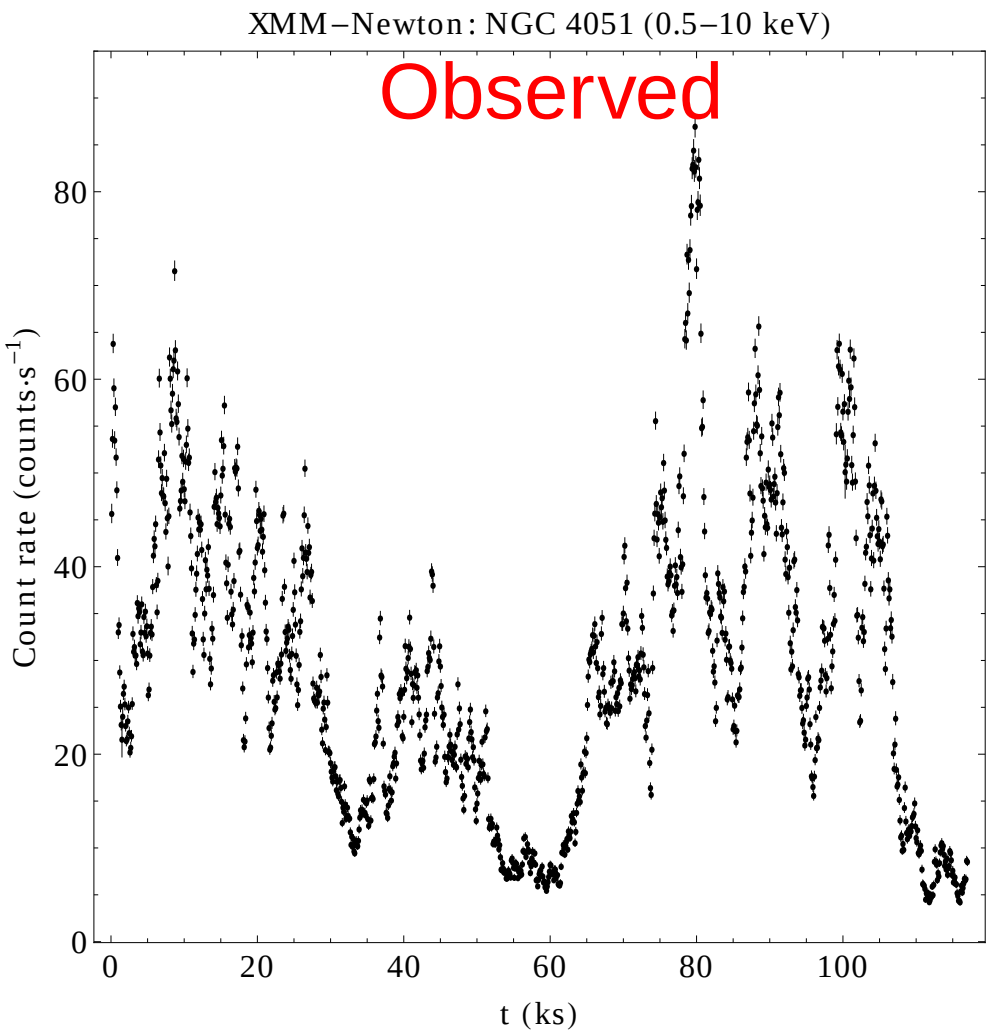
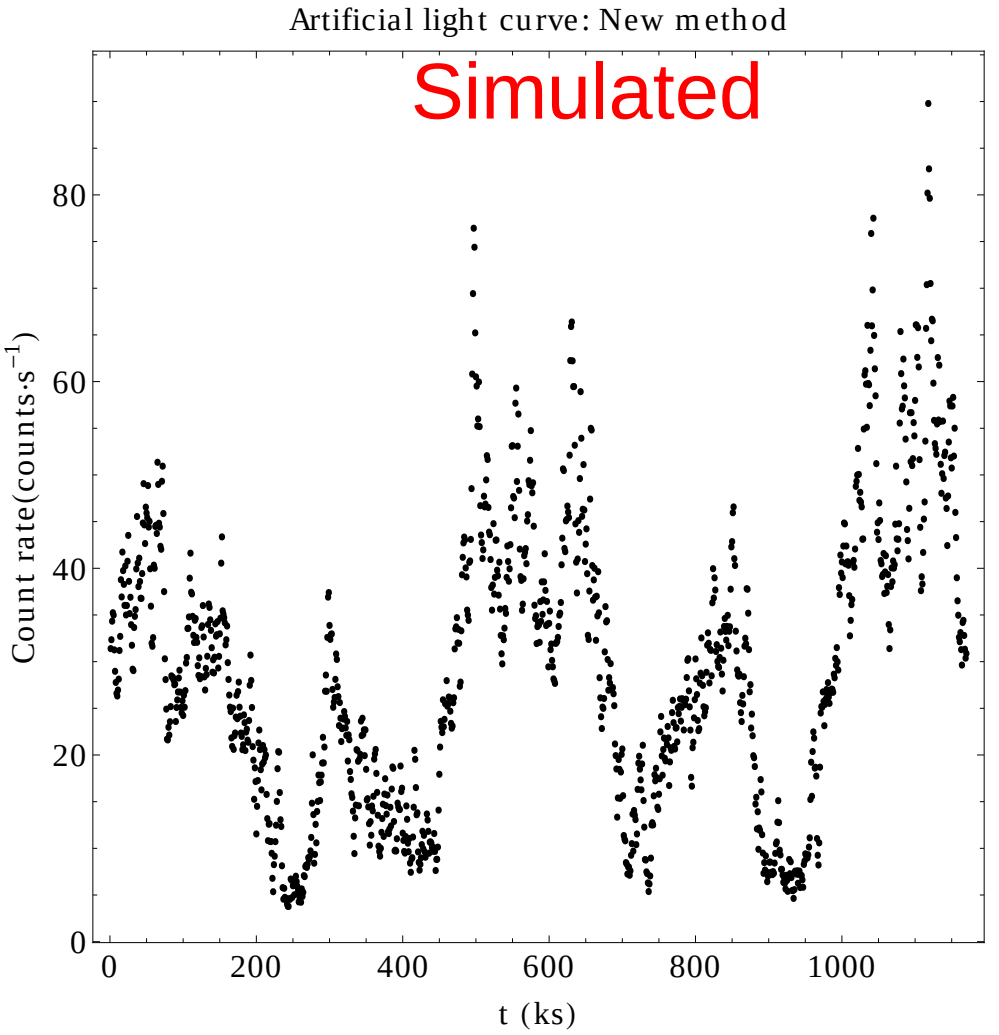




Timmer & Koenig, 1995, A&A, **300**, 707

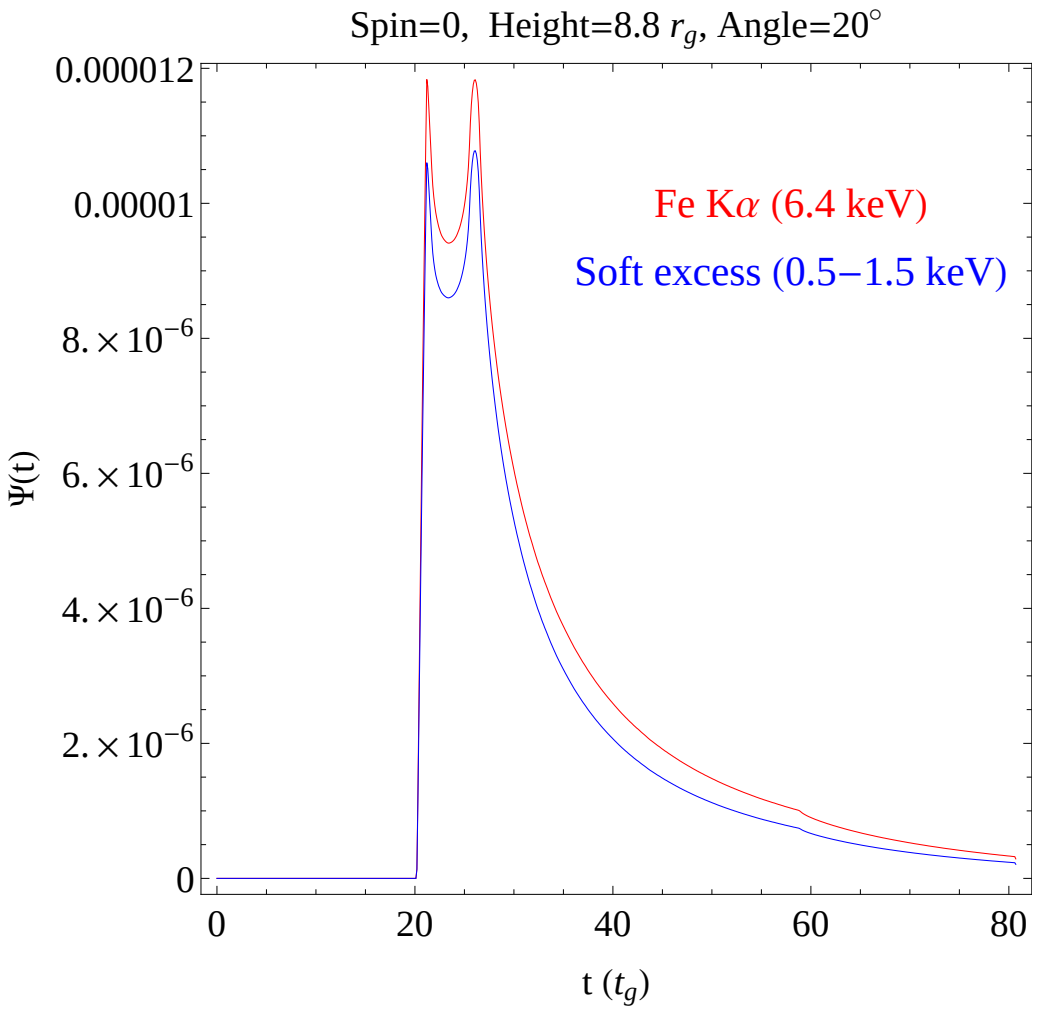
Complimentary: TL studies





Emmanoulopoulos et al. 2013, MNRAS, **433**, 907

Complimentary: TL studies



Complimentary: TL studies

THE ASTROPHYSICAL JOURNAL, 563:569–581, 2001 December 20

VARIABILITY TIMESCALES OF TeV BLAZARS OBSERVED IN THE *ASCA* CONTINUOUS LONG-LOOK X-RAY MONITORING

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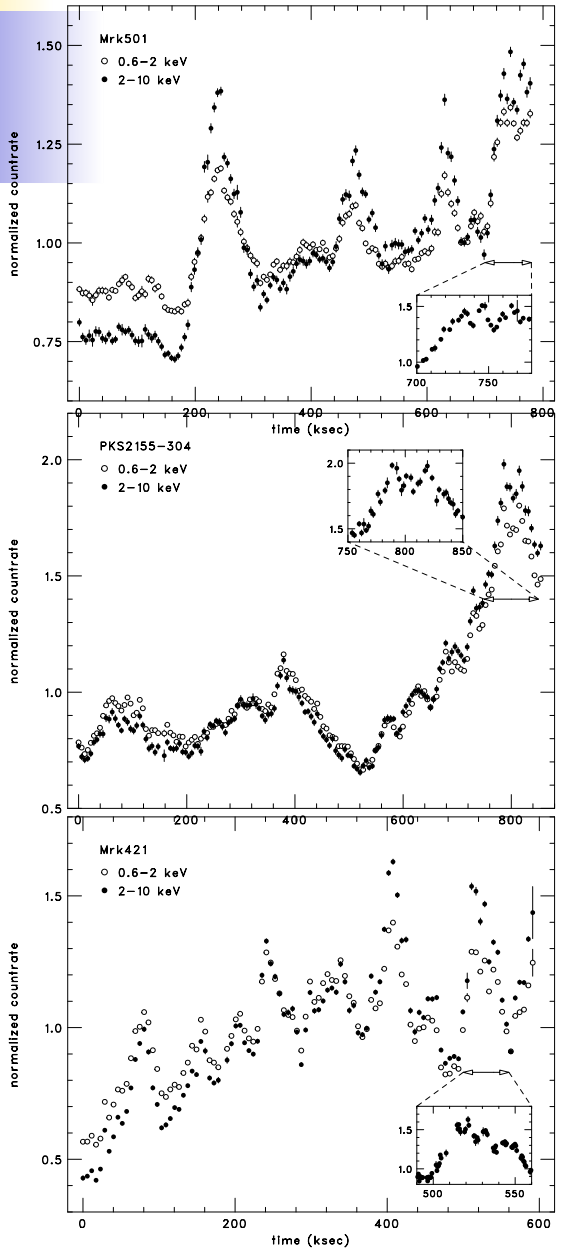
Received 2001 June 10; accepted 2001 August 17

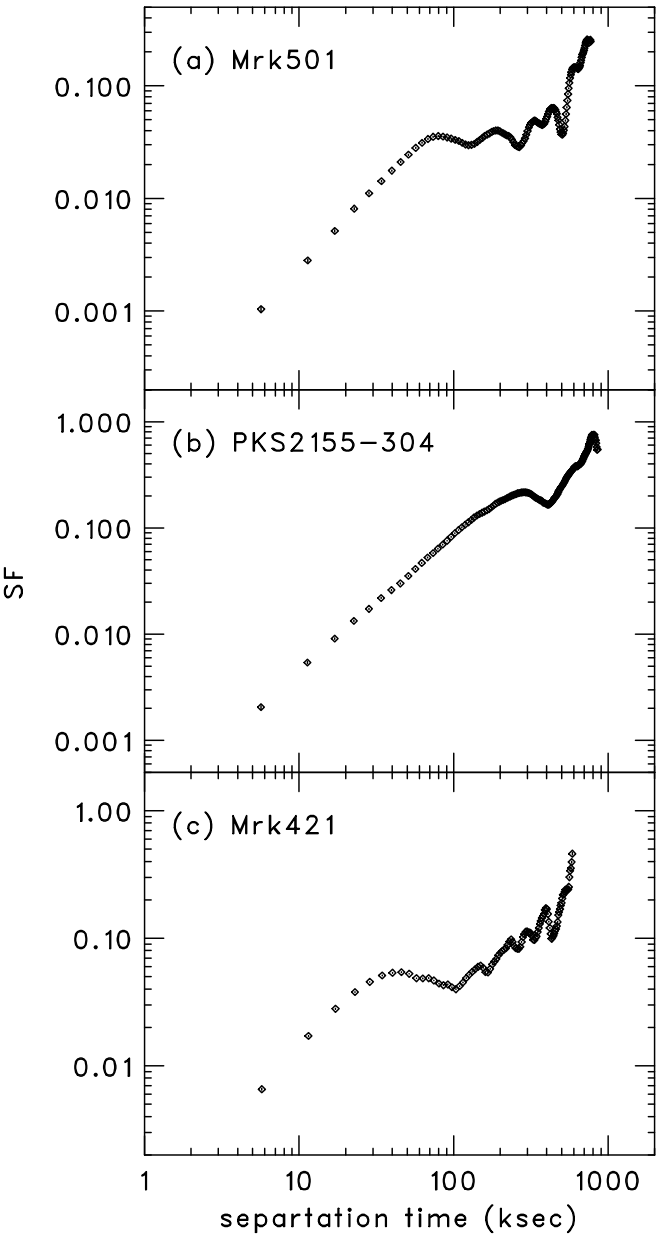
ABSTRACT

Three uninterrupted, long (lasting respectively 7, 10, and 10 days) *ASCA* observations of the well-studied TeV-bright blazars Mrk 421, Mrk 501, and PKS 2155−304 all show continuous strong X-ray flaring. Despite the relatively faint intensity states in two of the three sources, there was no identifiable quiescent period in any of the observations. Structure function analysis shows that all blazars have a characteristic timescale of ~1 day, comparable to the recurrence time and to the timescale of the strong-

Is this really the case?

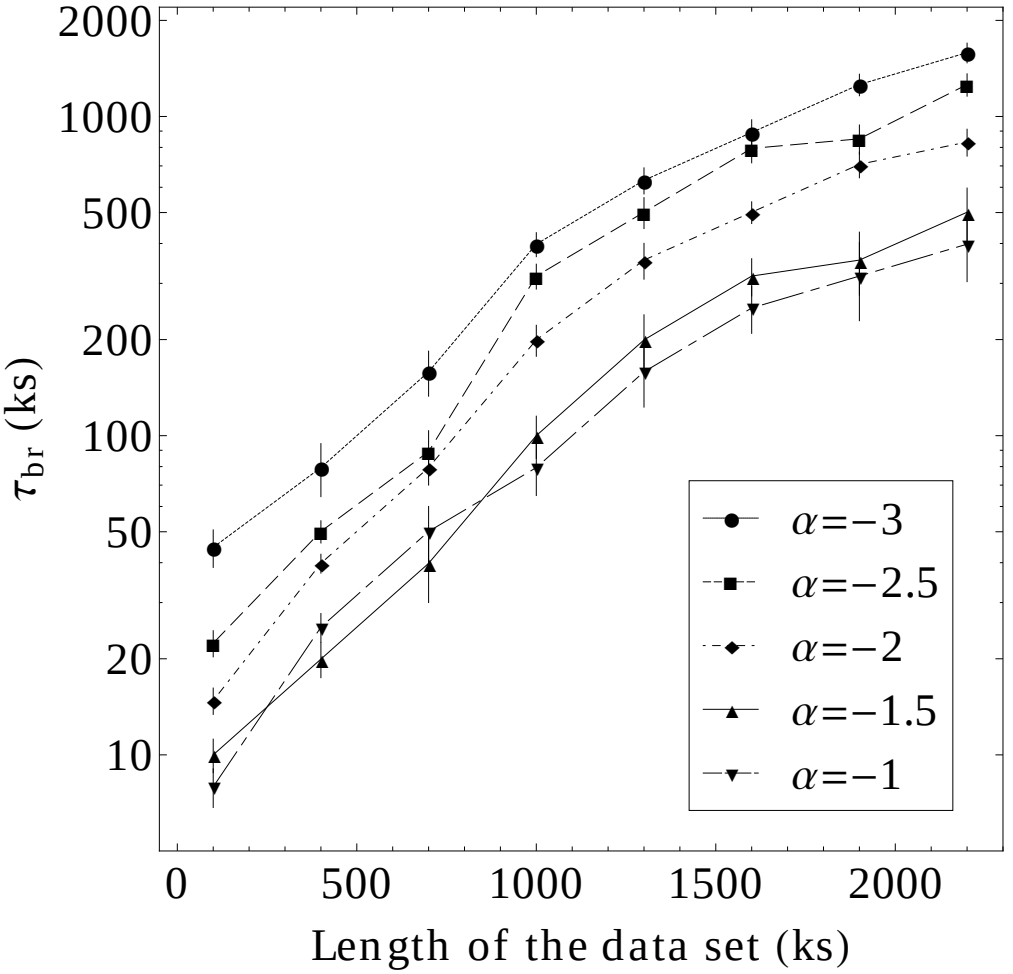
Complimentary: TL studies



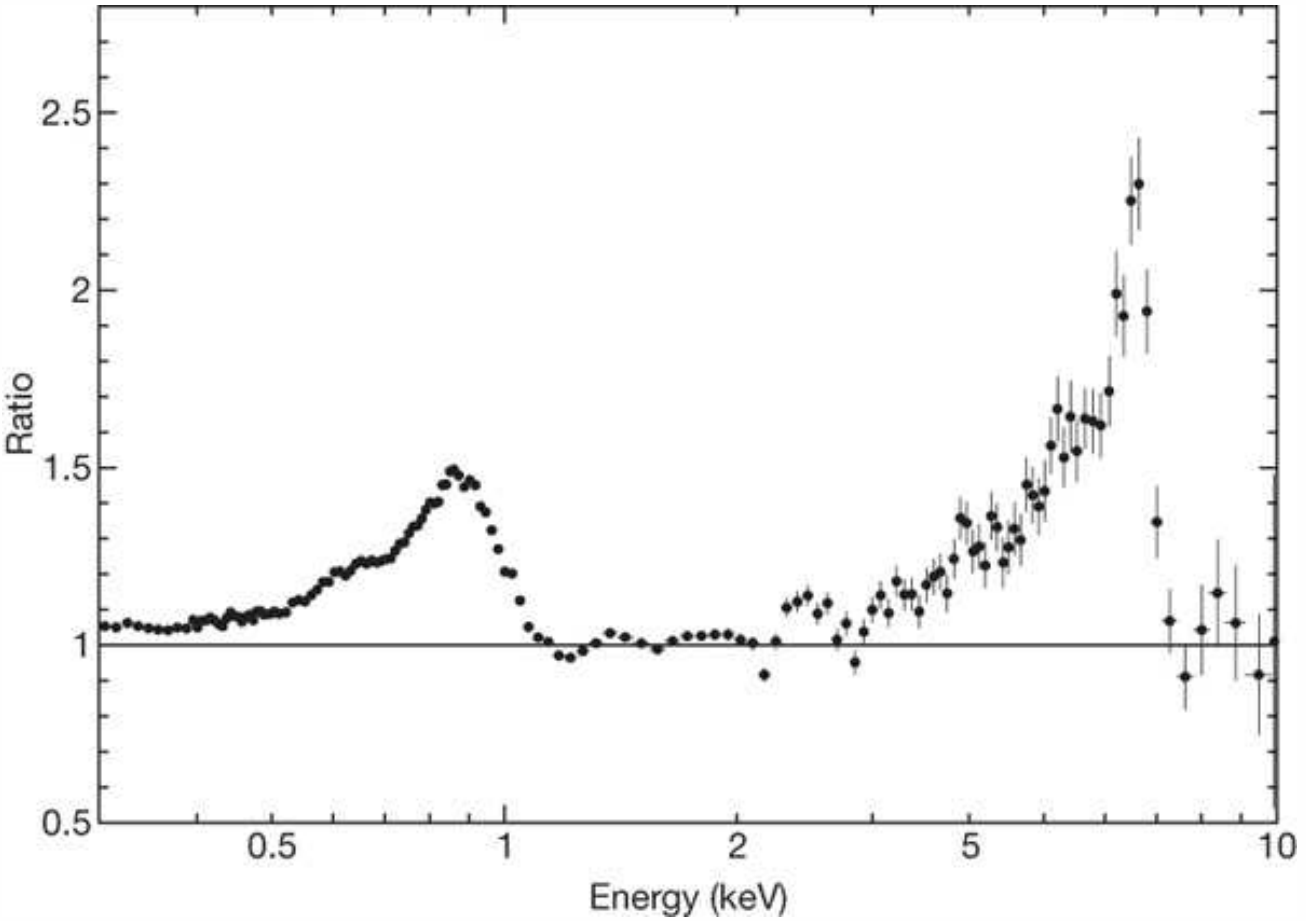


Tanihata et al. 2001, Apj, **563**, 569

Complimentary: TL studies

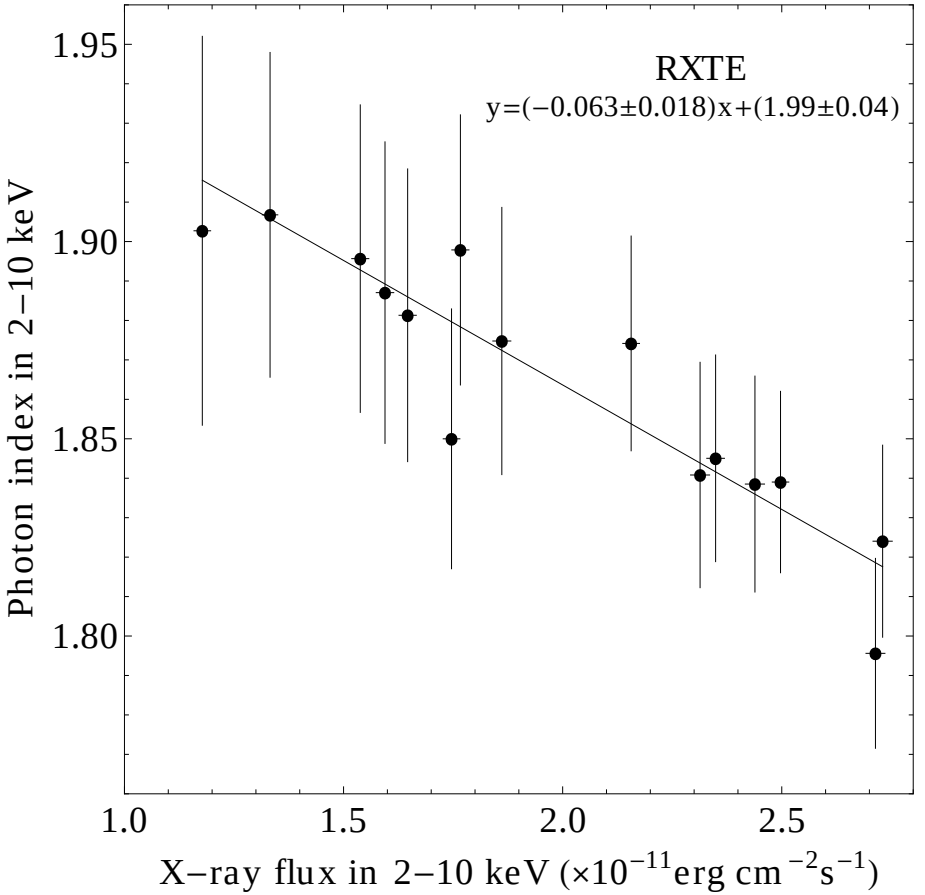


Emmanoulopoulos et al. 2010, MNRAS, **404**, 931


2.5
2
1.5
1
0.5
Ratio
0.5
1
2
5
10
Energy (keV)

Complimentary: X-ray spectral studies

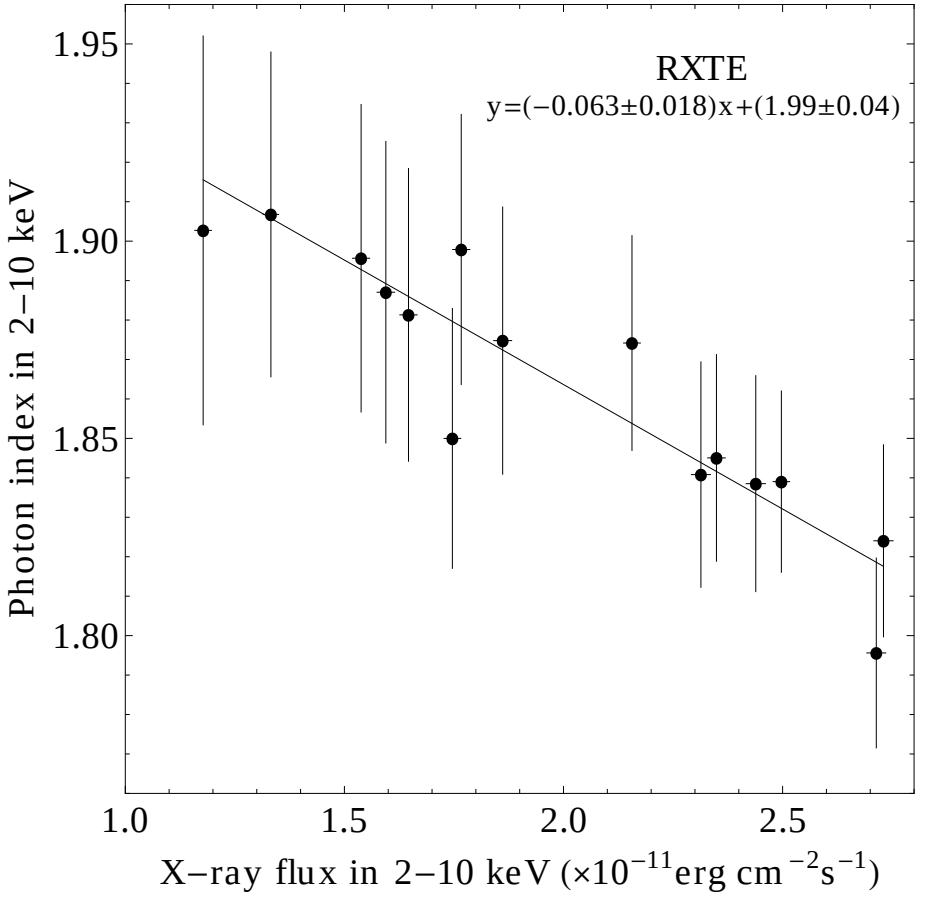
’Harder when brighter behaviour’

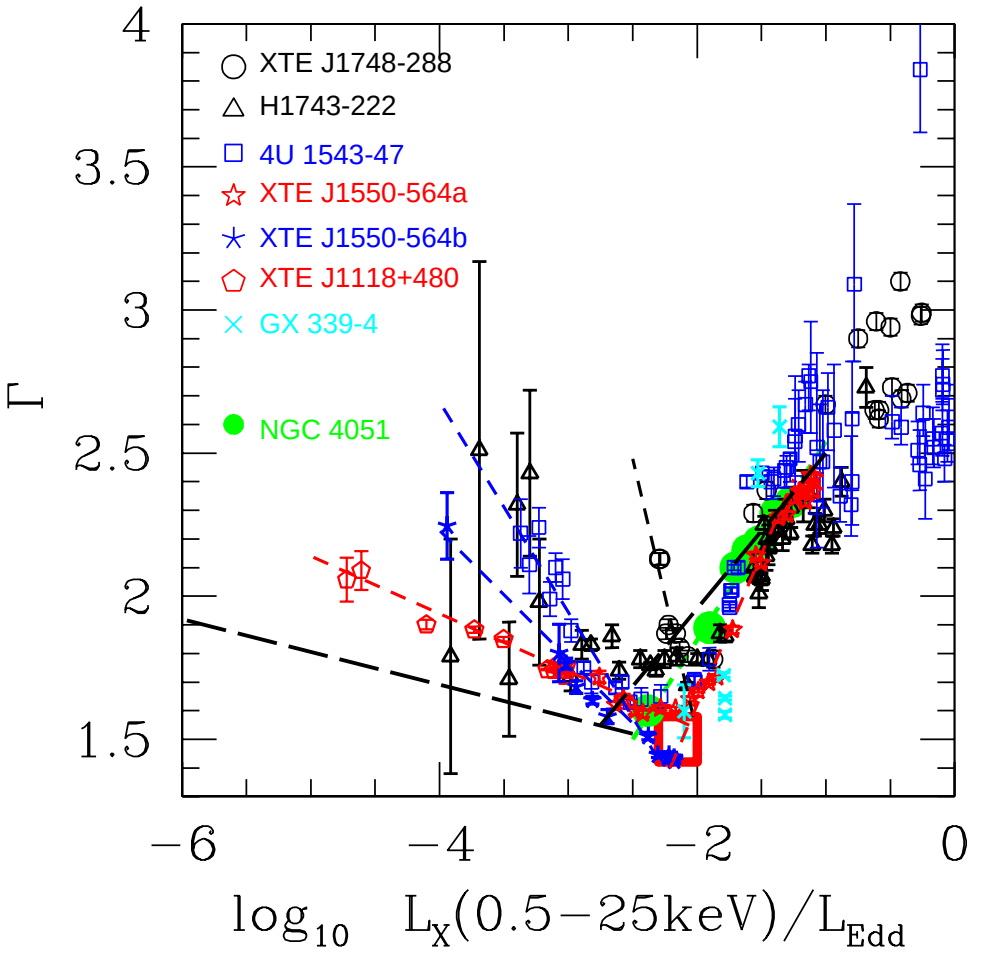


Emmanoulopoulos et al. 2012, MNRAS, **424**, 1327

Complimentary: X-ray spectral studies

NGC 7213: XRB in hard state

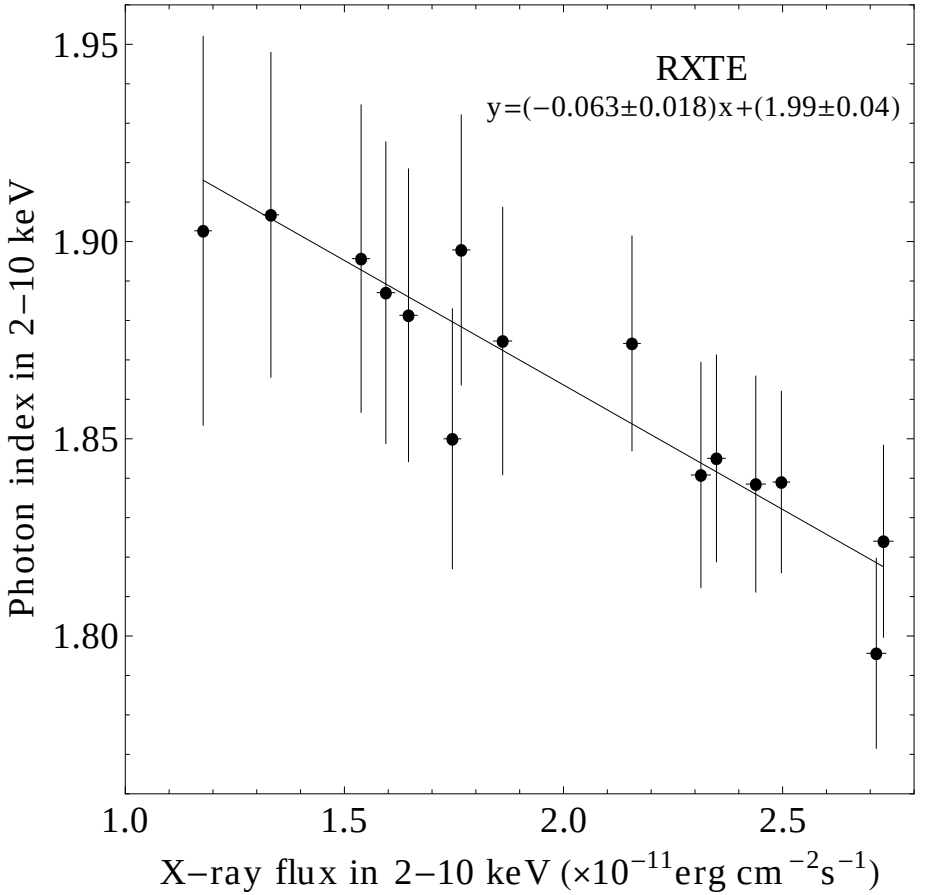


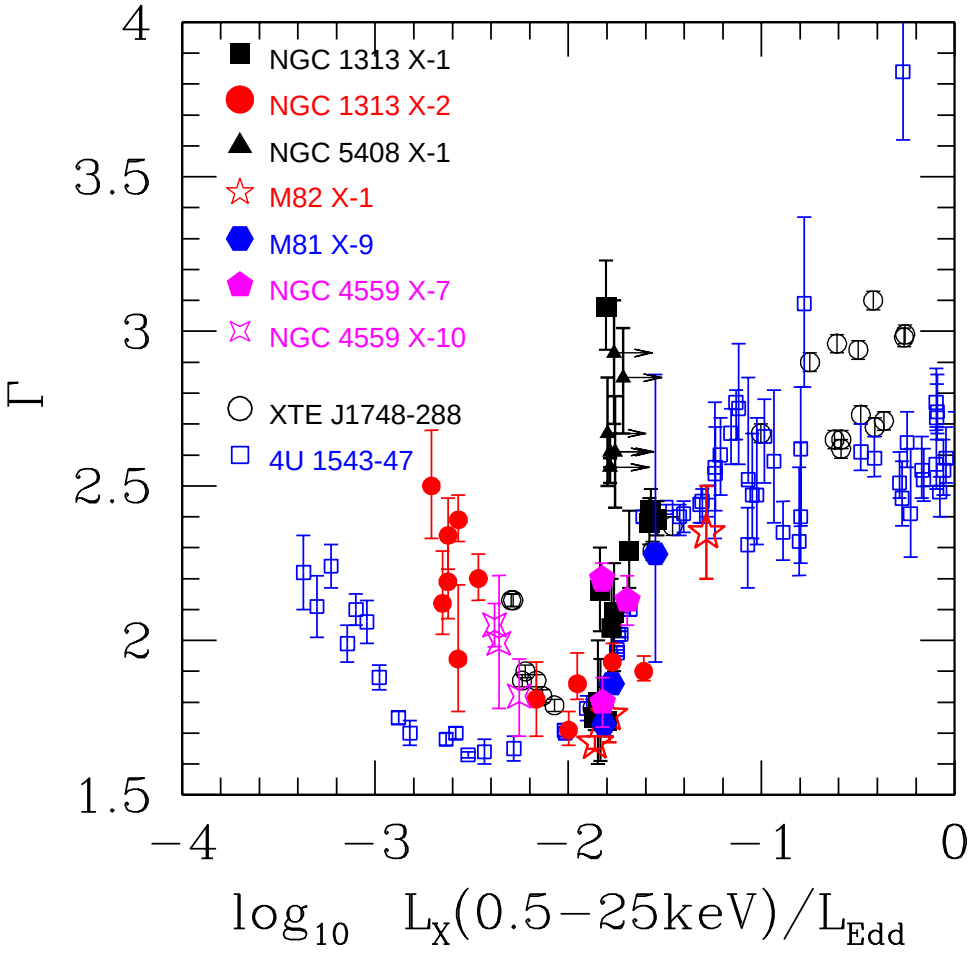


Wu, Q., & Gu, M. 2008, Apj, **682**, 212

Complimentary: X-ray spectral studies

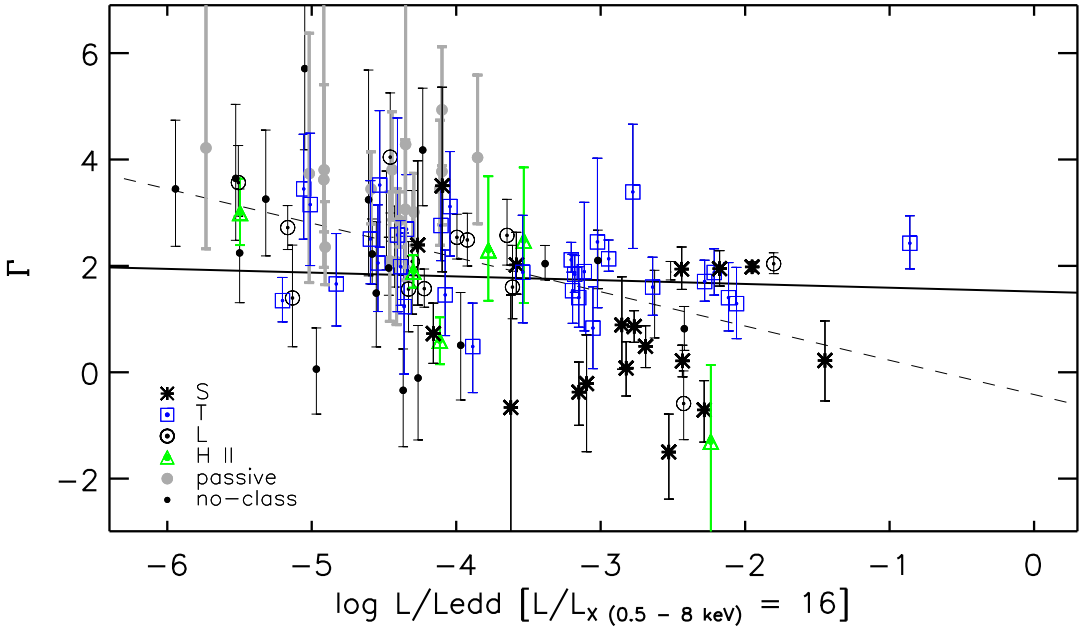
’Harder when brighter behaviour’



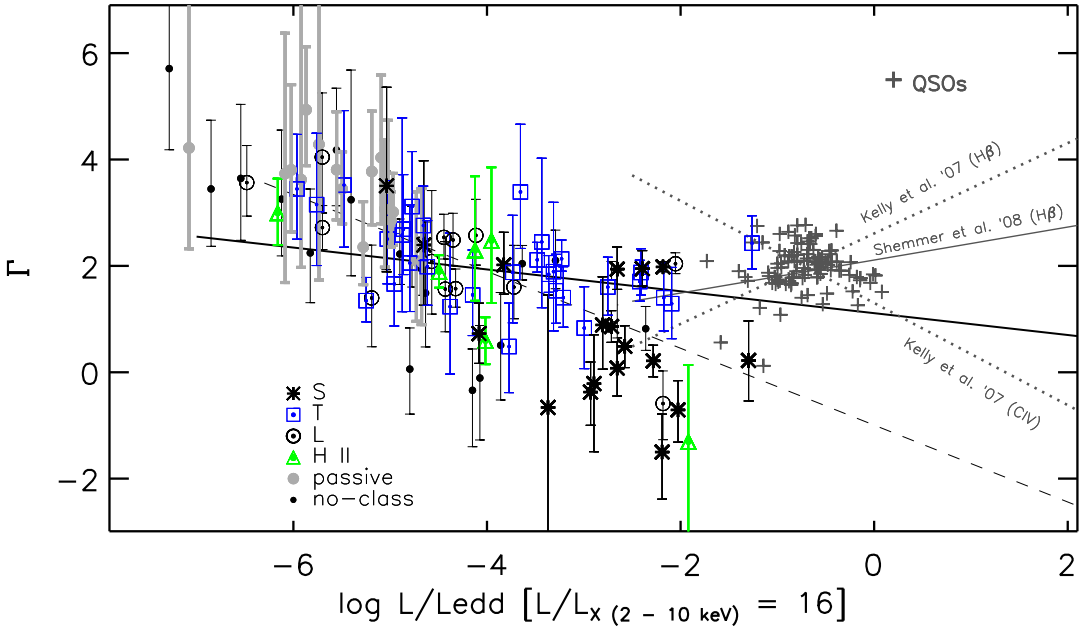


Wu, Q., & Gu, M. 2008, Apj, **682**, 212

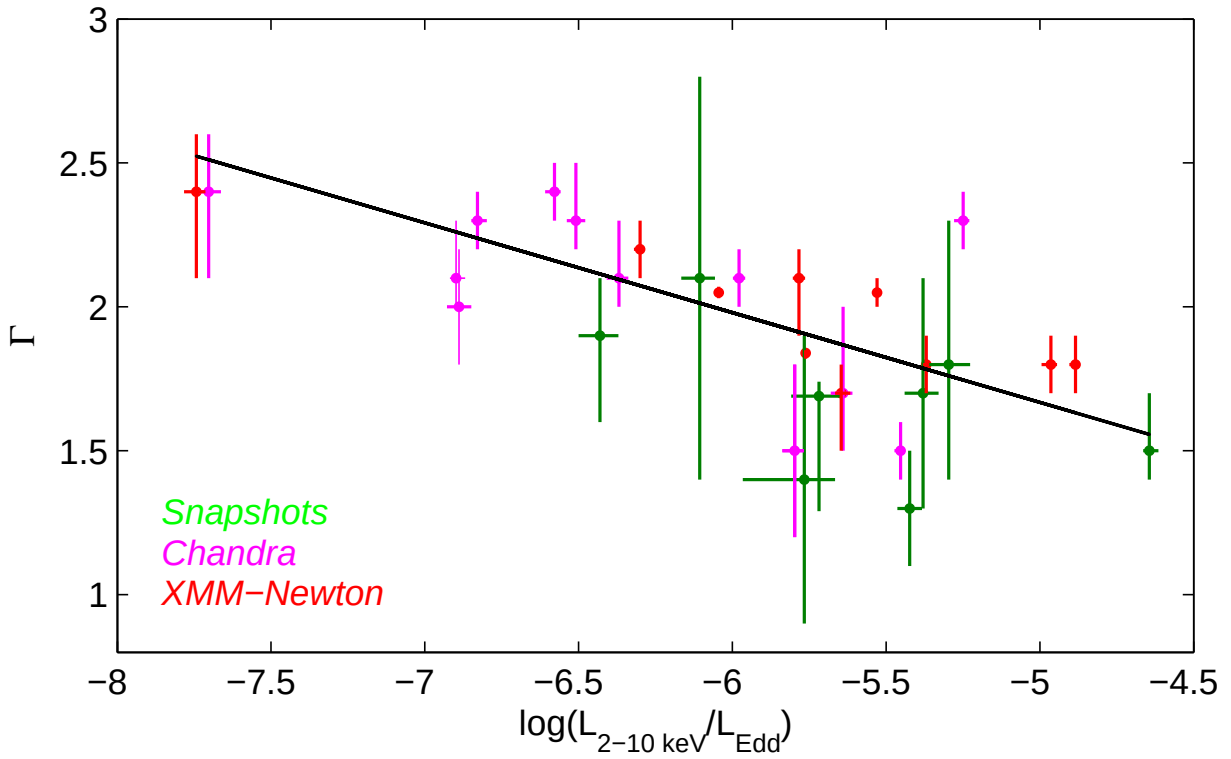
Complimentary: X-ray spectral studies



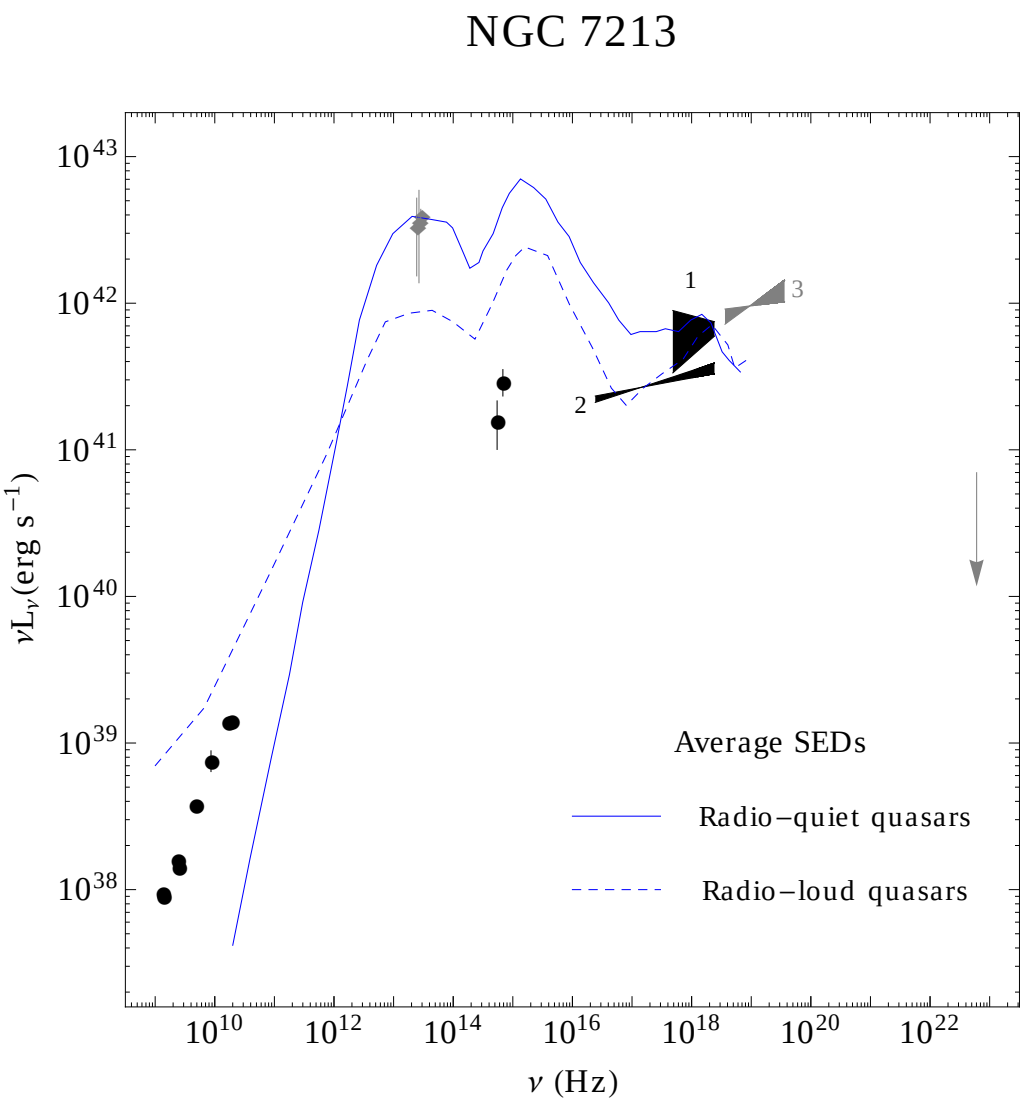
Complimentary: X-ray spectral studies



Complimentary: X-ray spectral studies

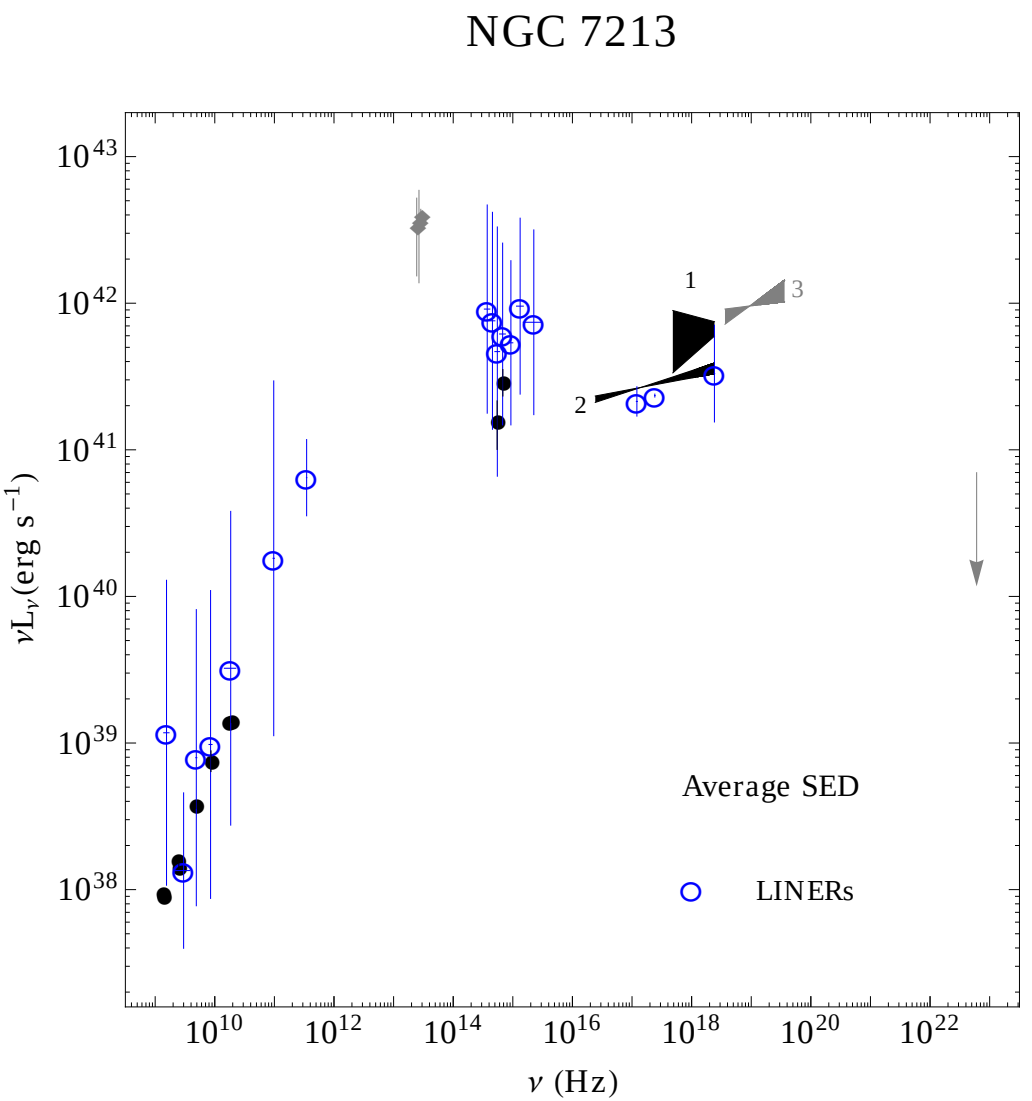


Complimentary: X-ray spectral studies



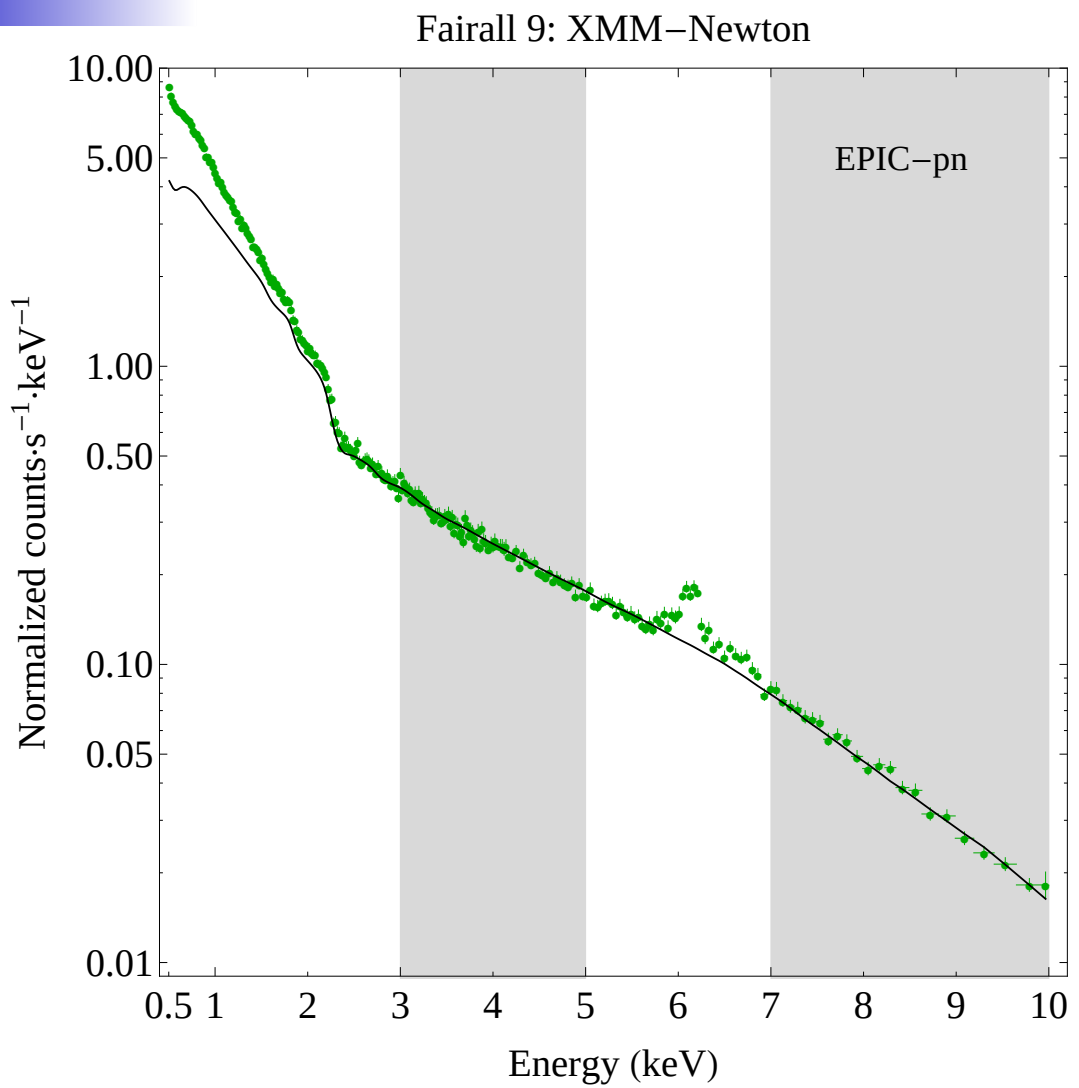
Emmanoulopoulos et al. 2012, MNRAS, **424**, 1327

Complimentary: X-ray spectral studies



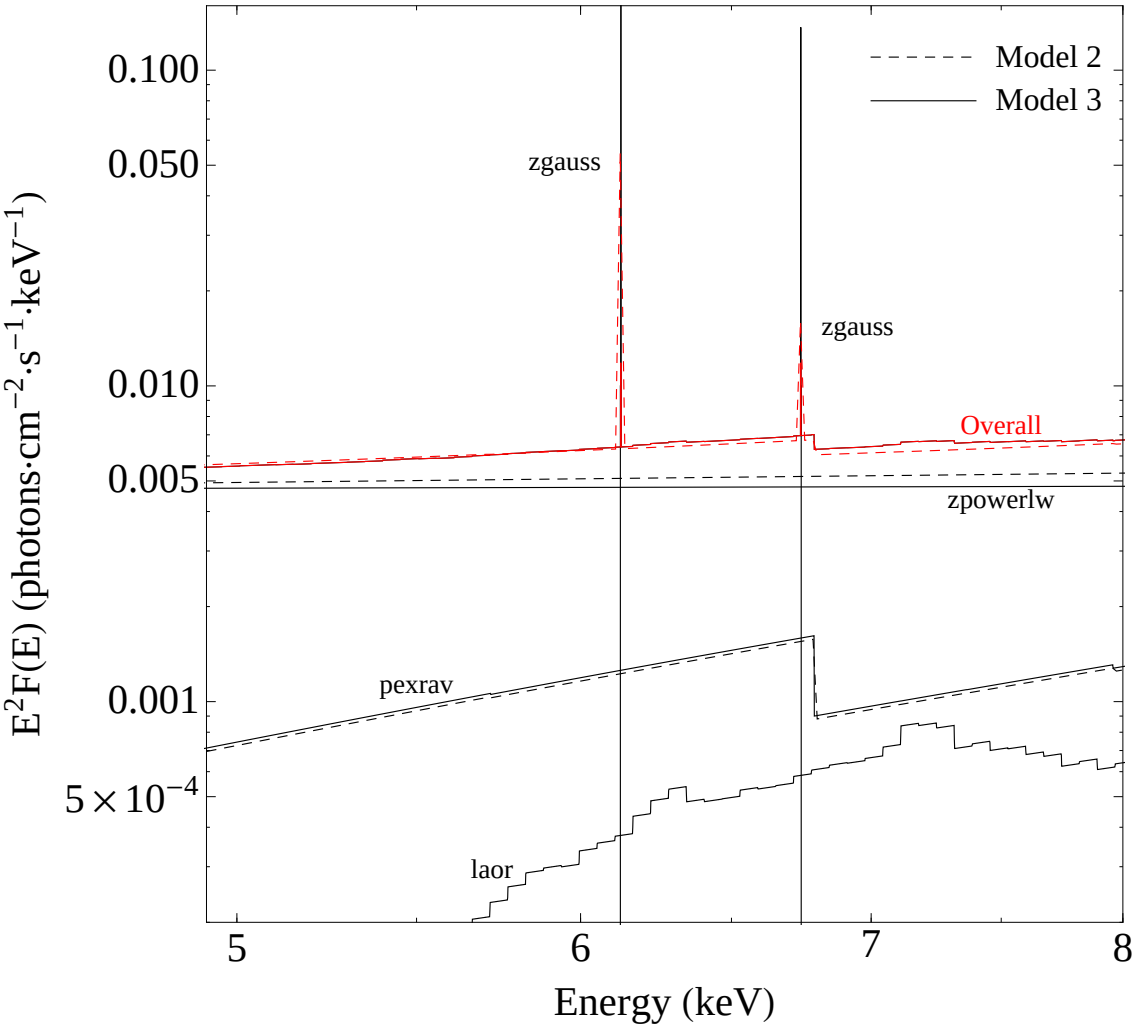
Emmanoulopoulos et al. 2012, MNRAS, **424**, 1327

Complimentary: X-ray spectral studies



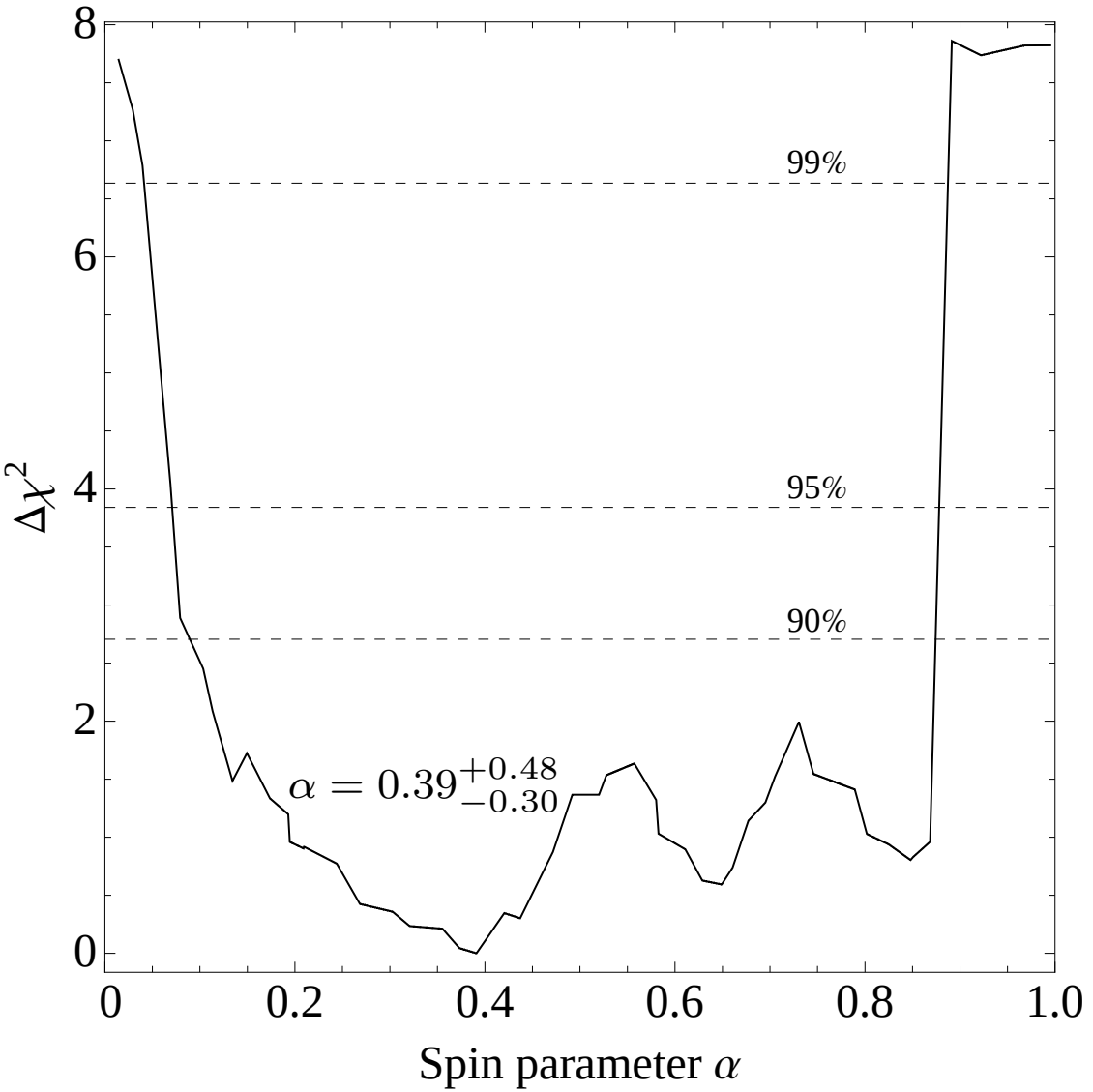
Emmanoulopoulos et al. 2011, MNRAS, **415**, 1895

Complimentary: X-ray spectral studies



Emmanoulopoulos et al. 2011, MNRAS, **415**, 1895

Complimentary: X-ray spectral studies



Inclination

$r_{\rm isco}$

ionisation

...

Emmanoulopoulos et al. 2011, MNRAS, **415**, 1895

Complimentary: X-ray spectral studies

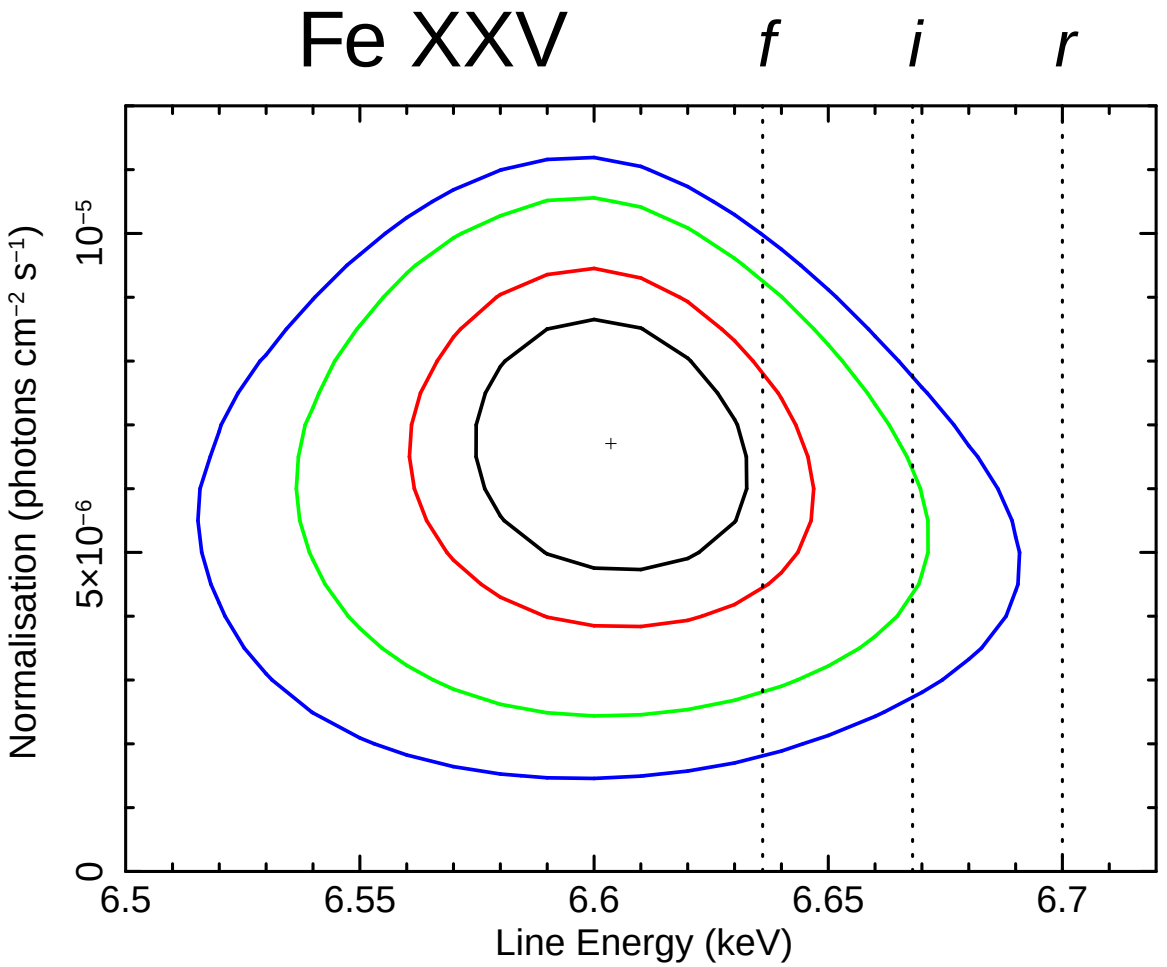
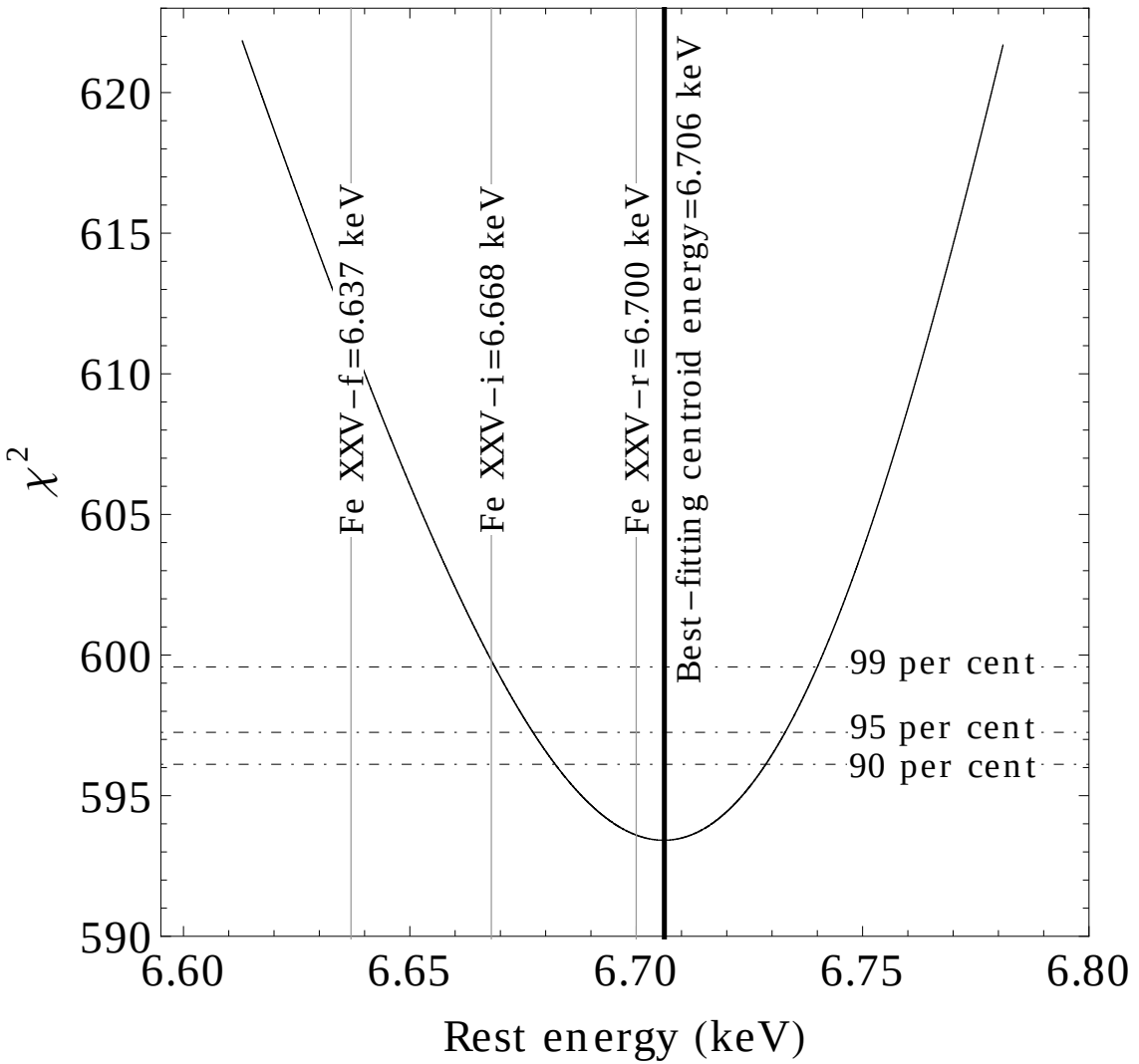


Photo-ionized plasma

Lobban et al. 2010, MNRAS, **408**, 551

Complimentary: X-ray spectral studies



Collisionally excited gas

Emmanoulopoulos et al. 2013, MNRAS, **429**, 3439

Complimentary: X-ray spectral studies

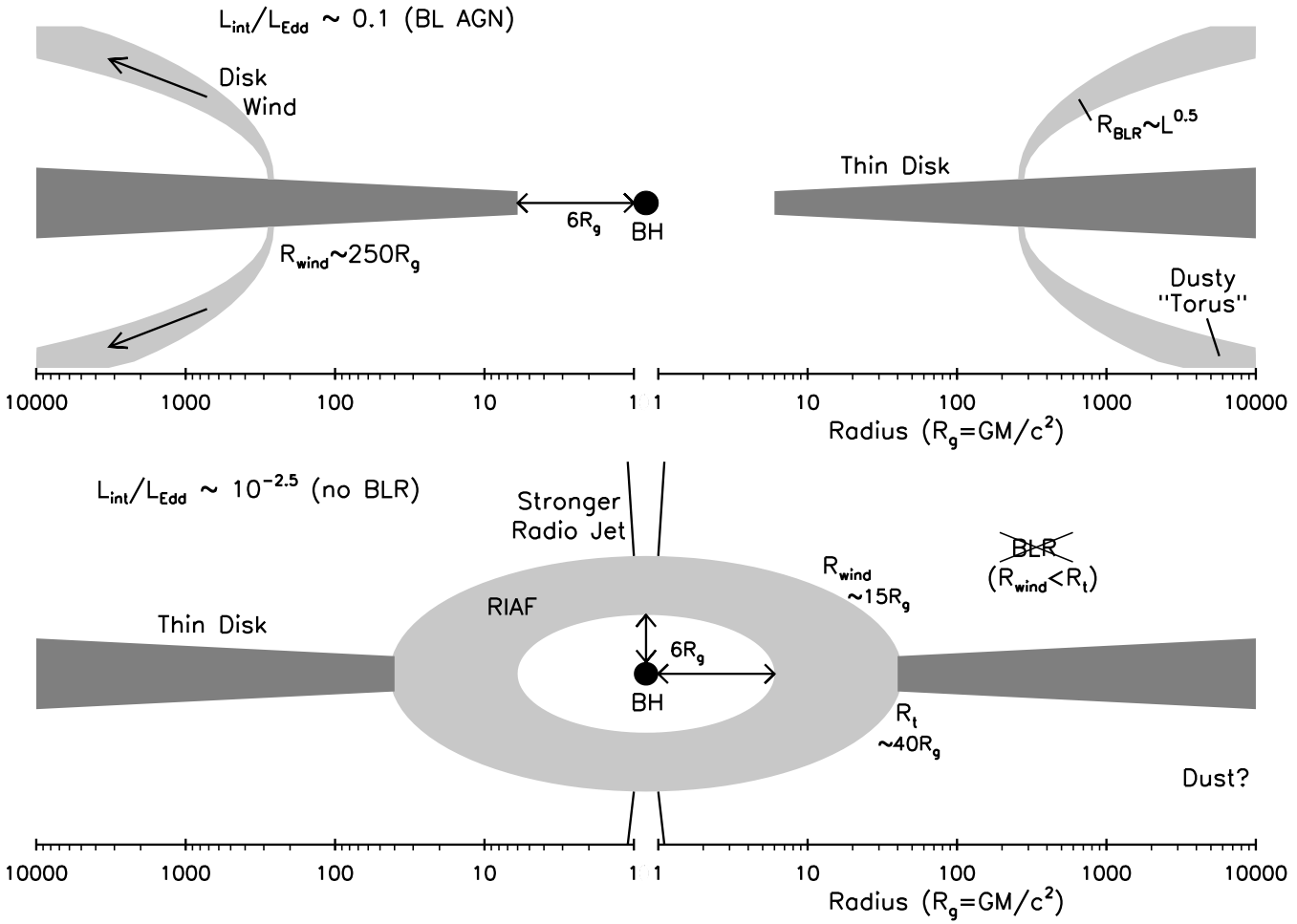


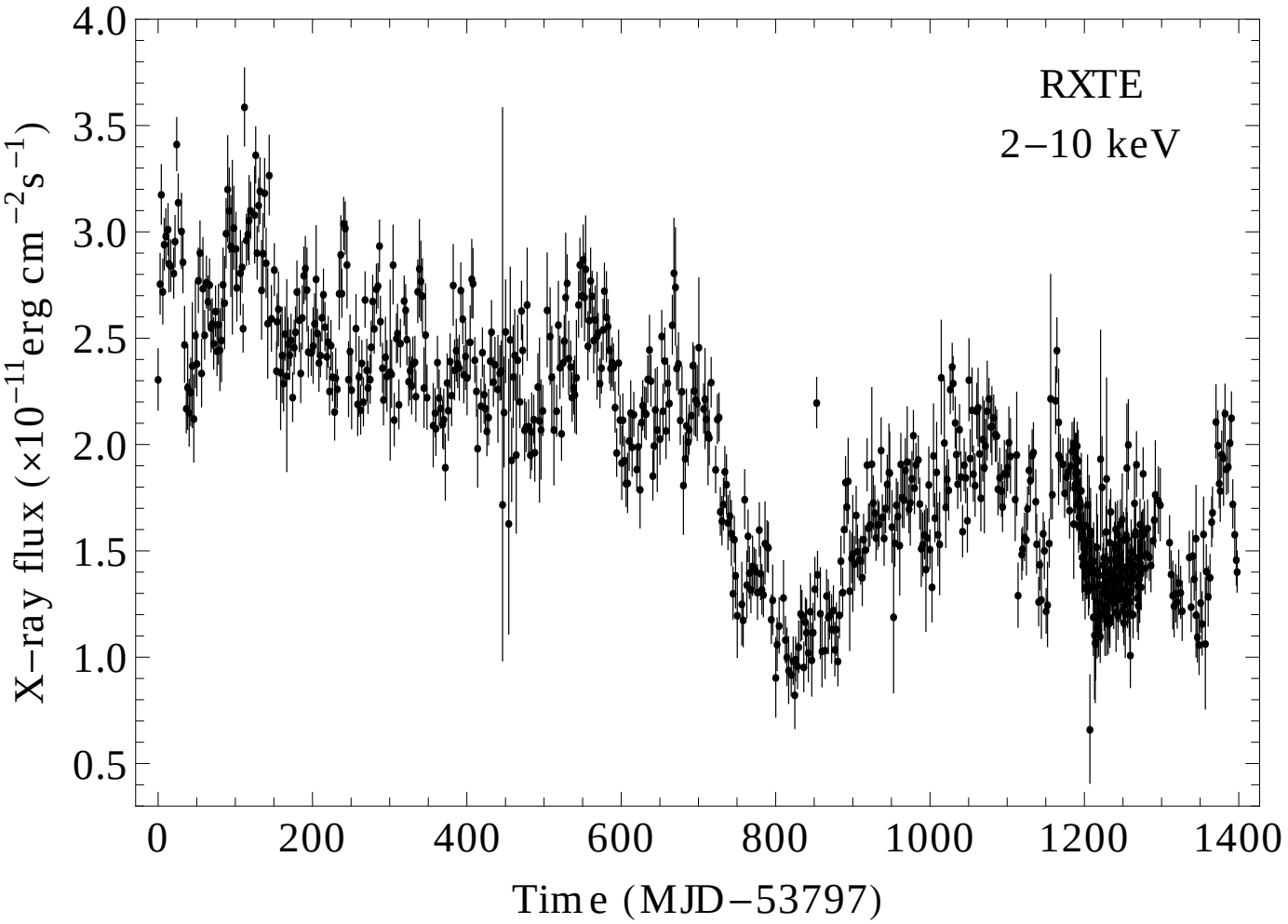
Photo-ionised plasma

Collisionally-ionised plasma

Trump et al. 2011, Apj, **733**, 60

Complimentary: X-ray spectral studies

NGC 7213



Emmanoulopoulos et al. 2012, MNRAS, **424**, 1327