SMBH spin measurement in AGN: achievements, controversies and prospects

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ESAC, 12 June 2018

Evidence for supermassive black holes

THE ASTRONOMICAL JOURNAL, 115:2285–2305, 1998 June

THE DEMOGRAPHY OF MASSIVE DARK OBJECTS IN GALAXY CENTERS

JOHN MAGORRIAN,[1] SCOTT TREMAINE,[1,2] DOUGLAS RICHSTONE,[3] RALF BENDER,[4] GARY BOWER,[5] ALAN DRESSLER,[6] S. M. FABER,[7] KARL GEBHARDT,[3] RICHARD GREEN,[5] CARL GRILLMAIR,[8] JOHN KORMENDY,[9] AND TOD LAUER[5]

NATURE, VOL. 223, AUGUST 16, 1969

Galactic Nuclei as Collapsed Old Quasars

by

D. LYNDEN-BELL

Royal Greenwich Observatory, Herstmonceux Castle, Sussex

Such a huge luminosity can be confined in a very compact region only in the form of a SMBH accretion disc

Radiation $$L = \eta \dot{m} c^2$$ Gravity

efficiency = 0.1

It takes just a solar mass per year to power an active galactic nucleus

The *simplest* astrophysical objects

No-hair theorem:

mass spin charge

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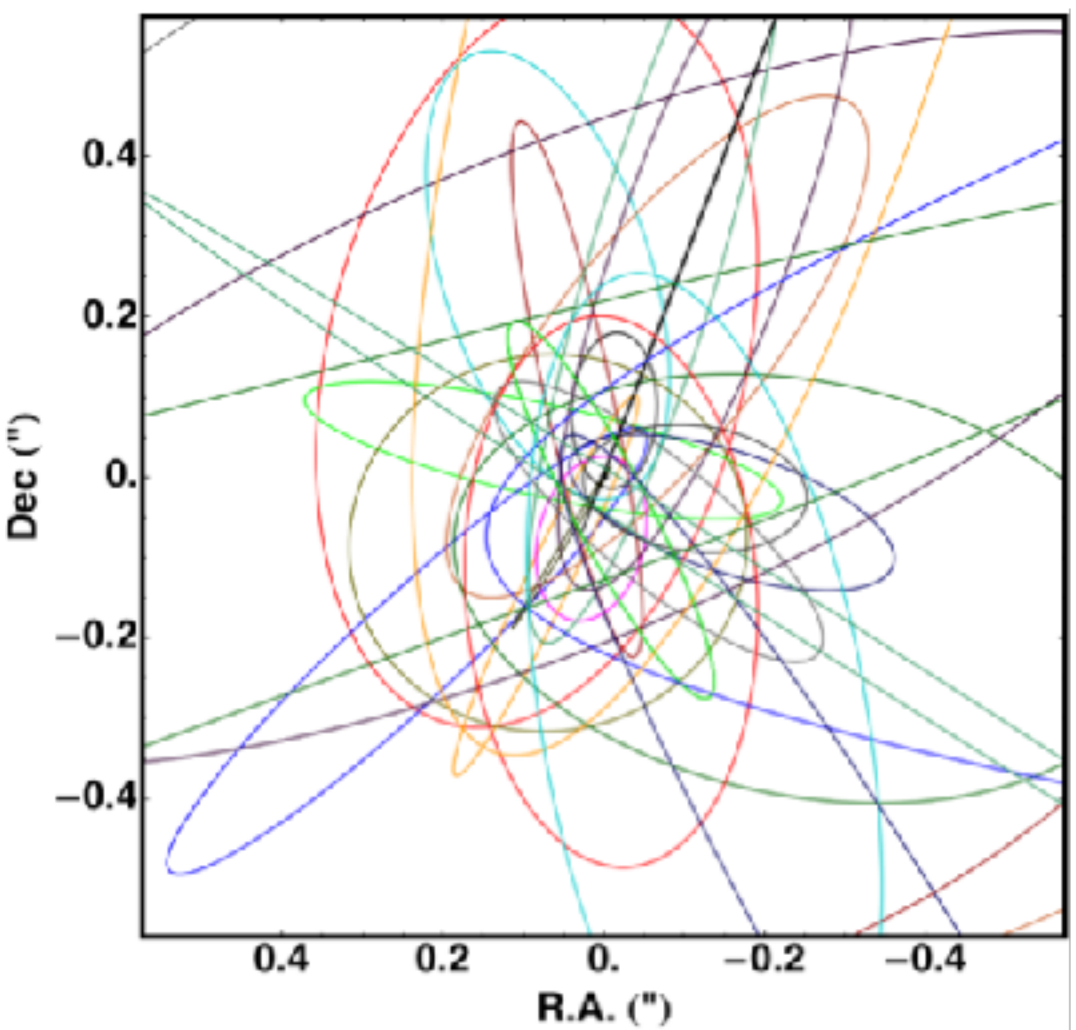
No-hair theorem:

mass spin charge

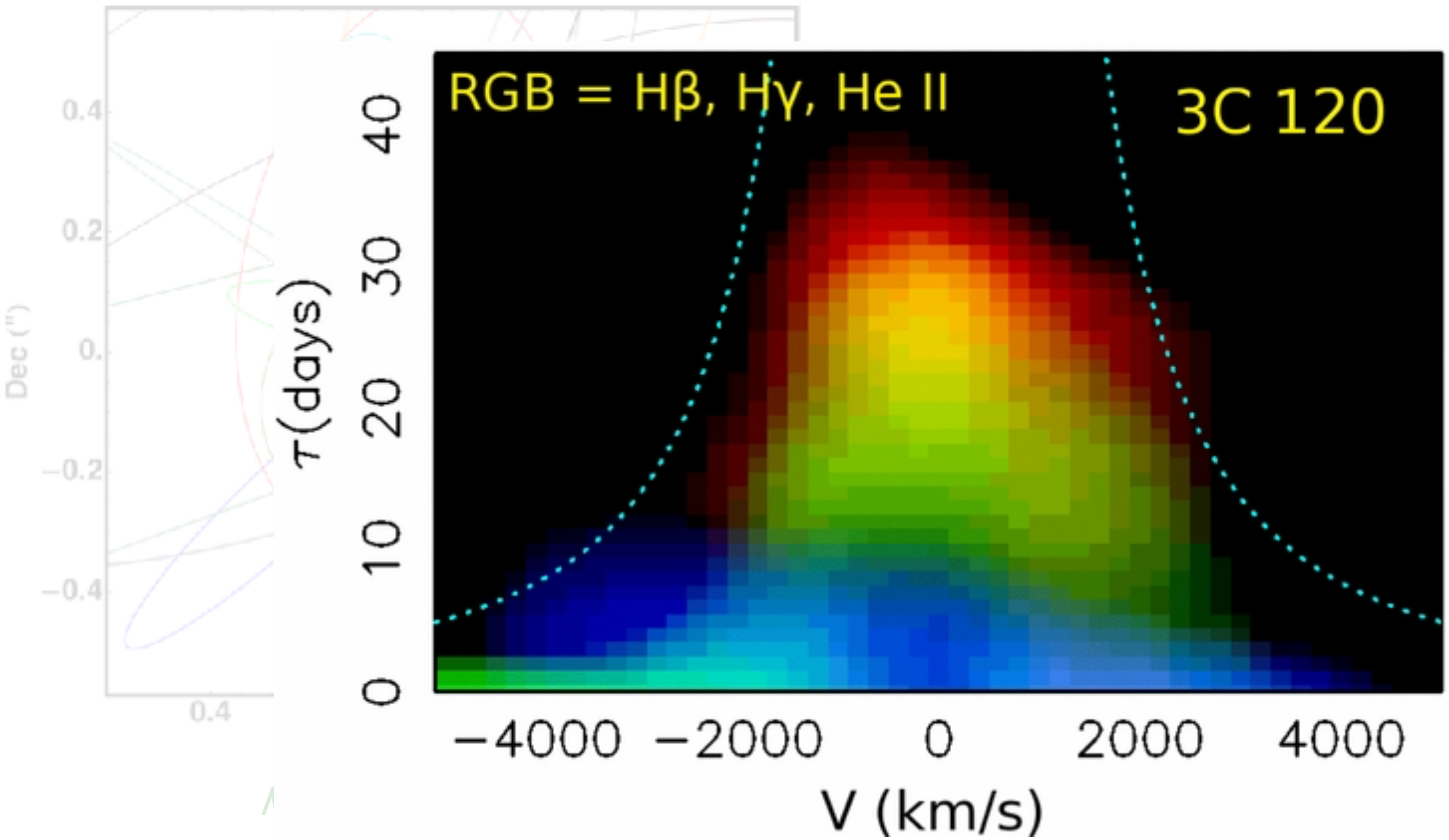


MPE/Galactic Centre

The *simplest* astrophysical objects

No-hair theorem:

mass spin charge



Grier+13

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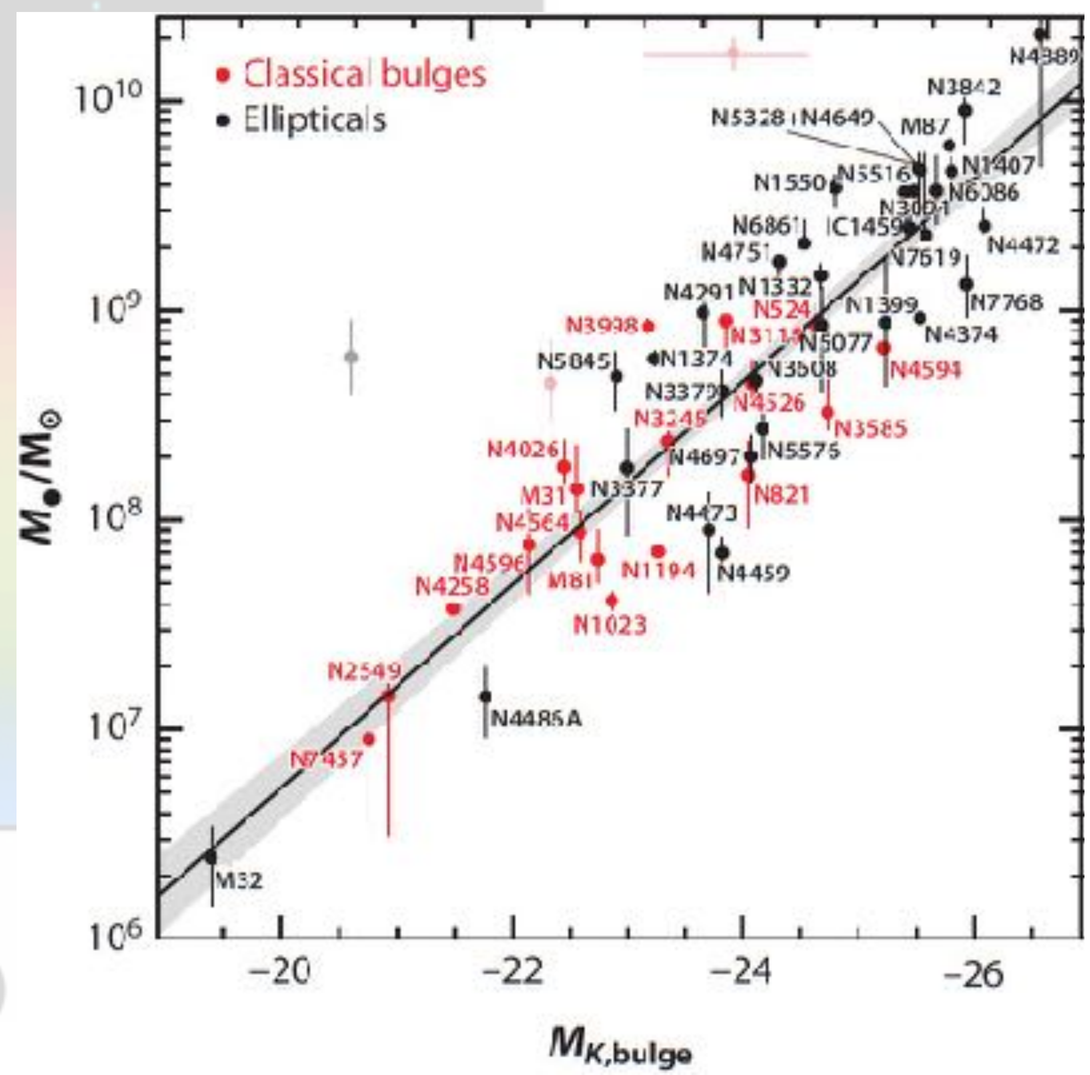


Kormendy & Ho 13

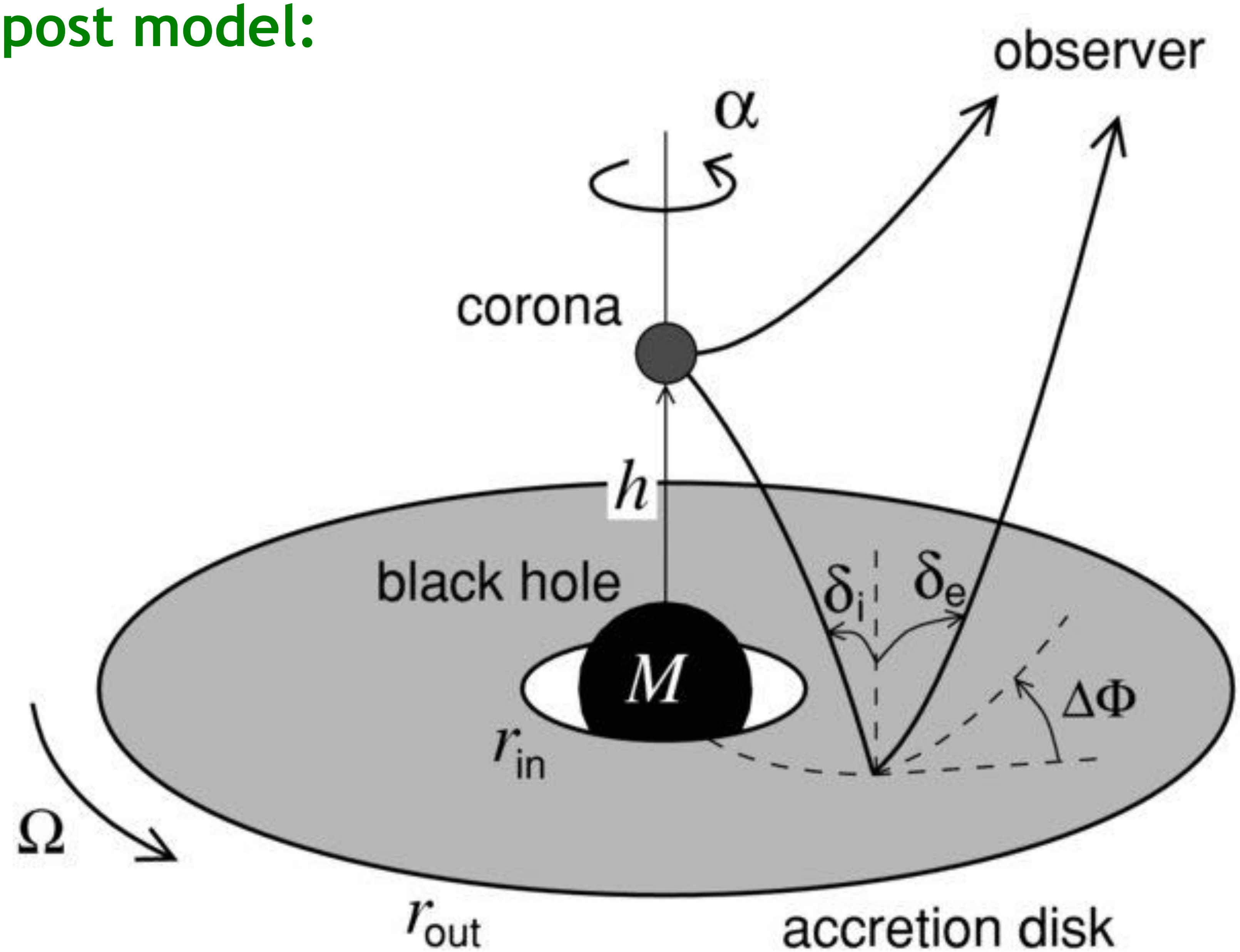
Spin measurements methods

- Binary SMBH systems *(Abbott+16, Valtonen+08)*
  - gravitational waves, orbital precession
- Spectral energy distribution *(Davis & Laor 11, Done+13)*
  - comparison with accretion disc models
- X-ray polarimetry *(Schnittman & Krolik 10)*
  - polarization degree and angle
- X-ray variability *(Mohan & Mangalam 14, Kara+16)*
  - PSD break, quasi-periodic oscillations
  - negative time lags, Fe K reverberation
- X-ray microlensing *(Chartas+17)*
  - Fe K line magnification, *g*-factor distribution
- X-ray reflection spectroscopy *(Fabian+09)*
  - General relativistic distortion effects

Most methods are not applicable to the SMBH range and/or ambiguous

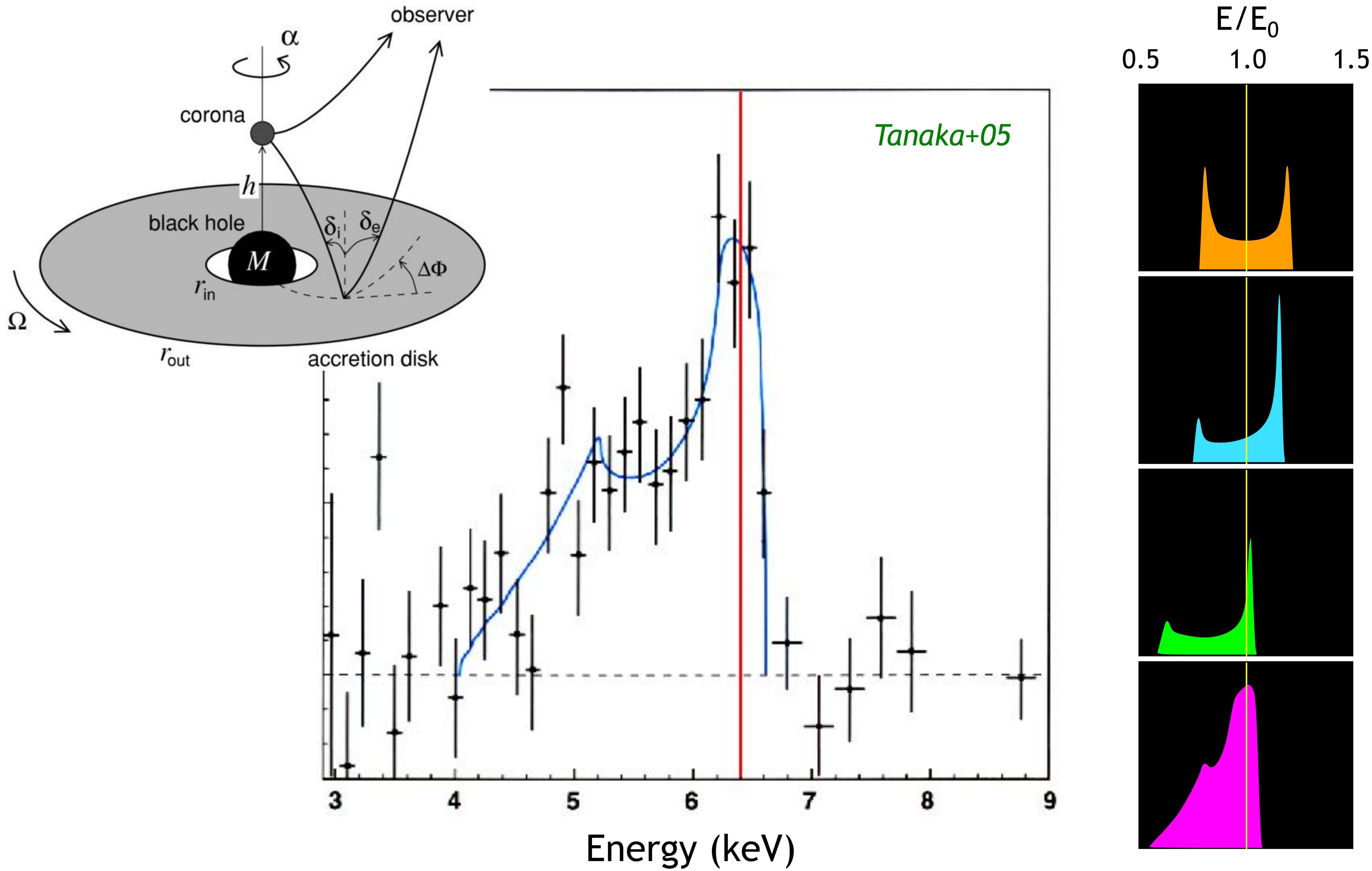
X-ray reflection

The lamp-post model:

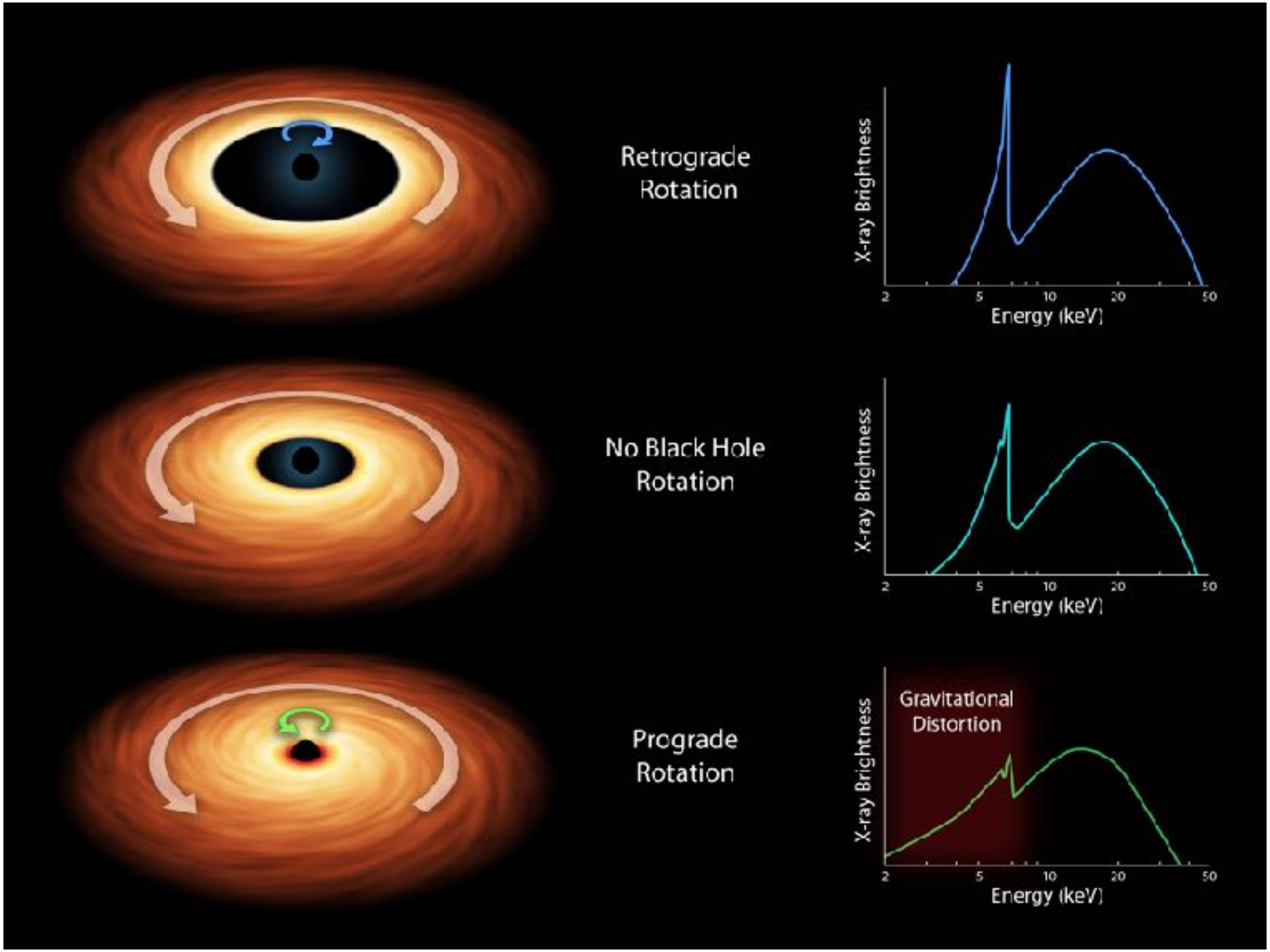


e.g. *Dovčiak+11*

X-ray reflection: Fe K line



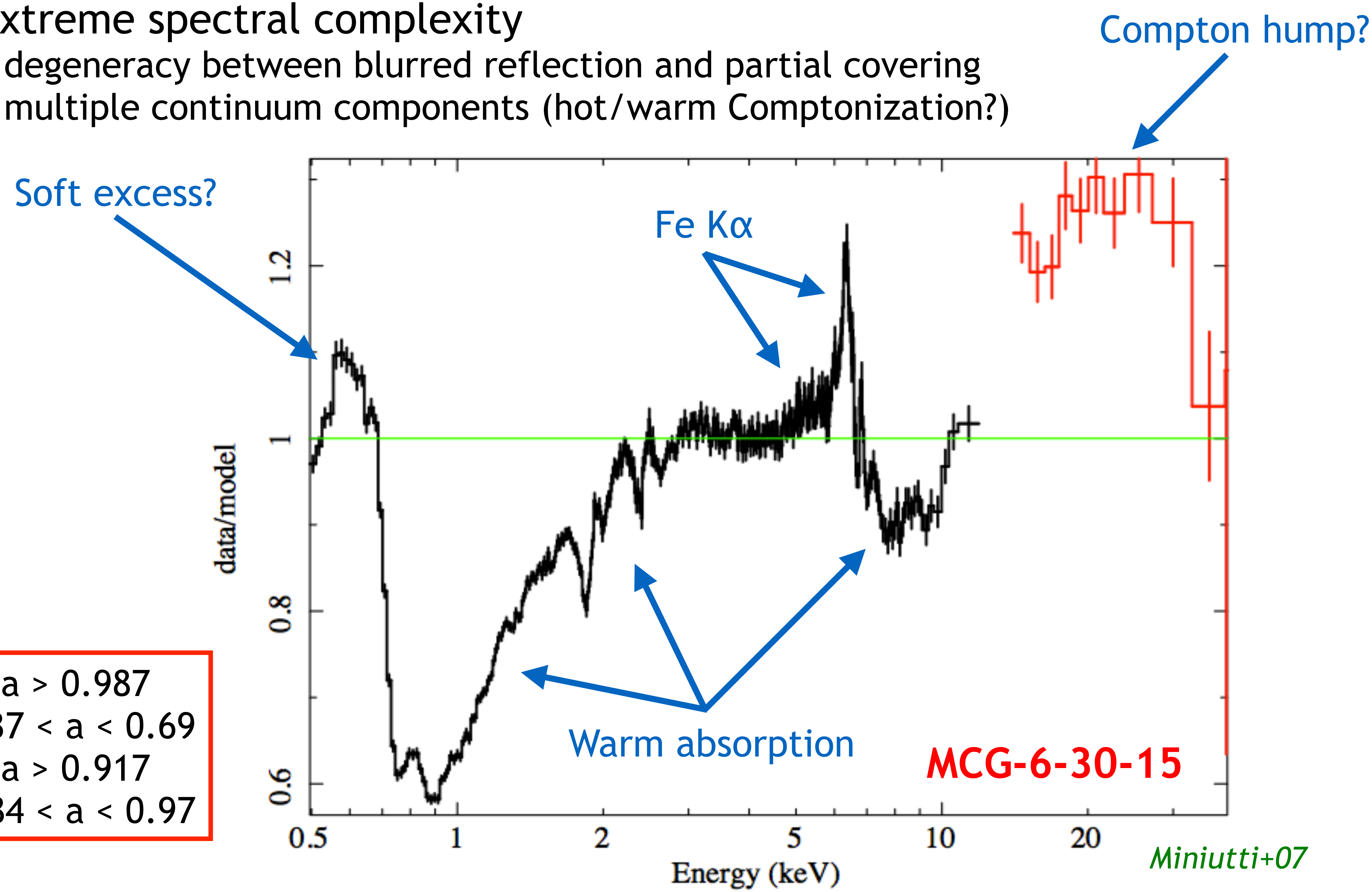
X-ray reflection: broadband spectrum



NASA/JPL-Caltech

Reflection or absorption?

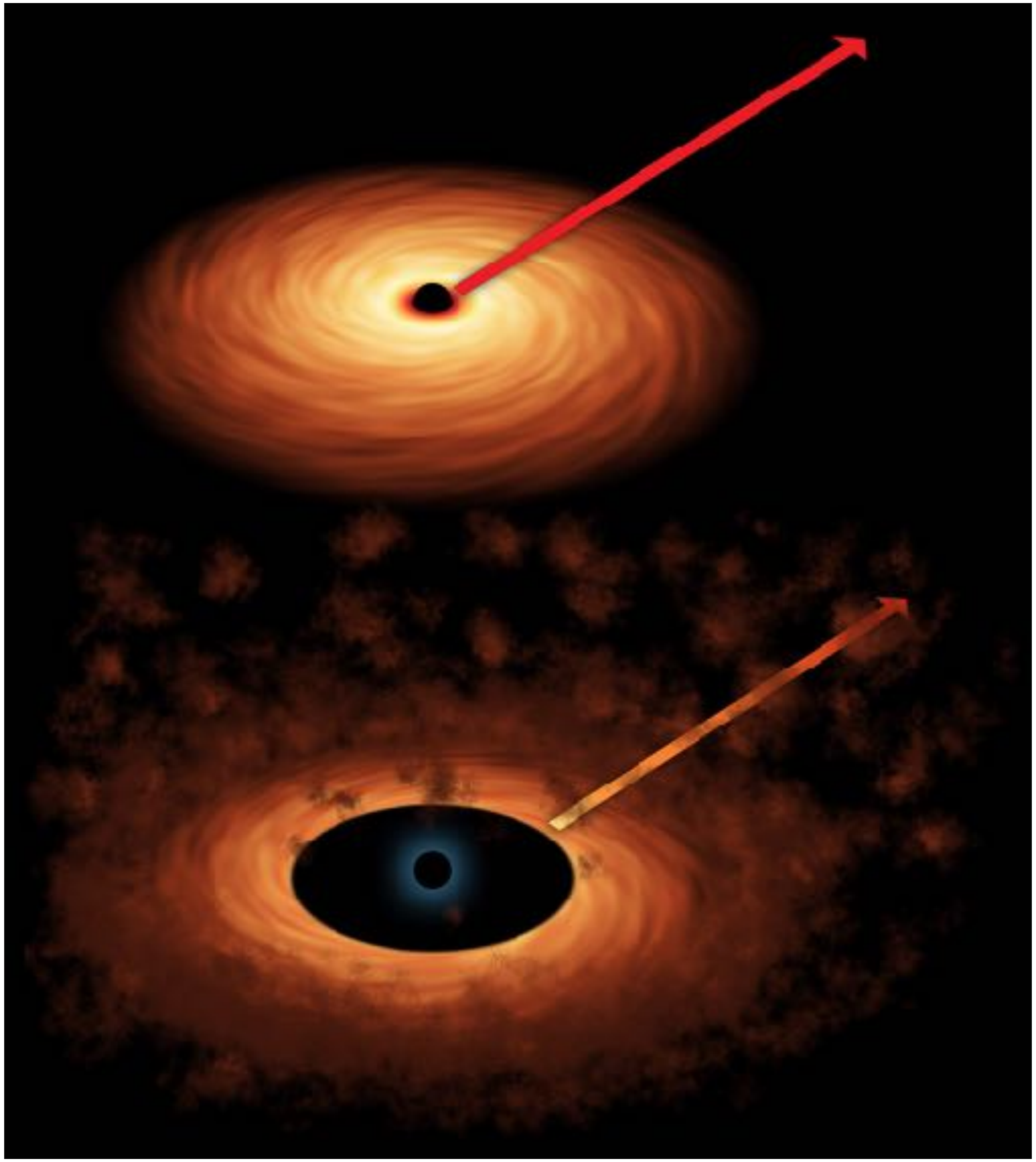
- Extreme spectral complexity
  - degeneracy between blurred reflection and partial covering
  - multiple continuum components (hot/warm Comptonization?)

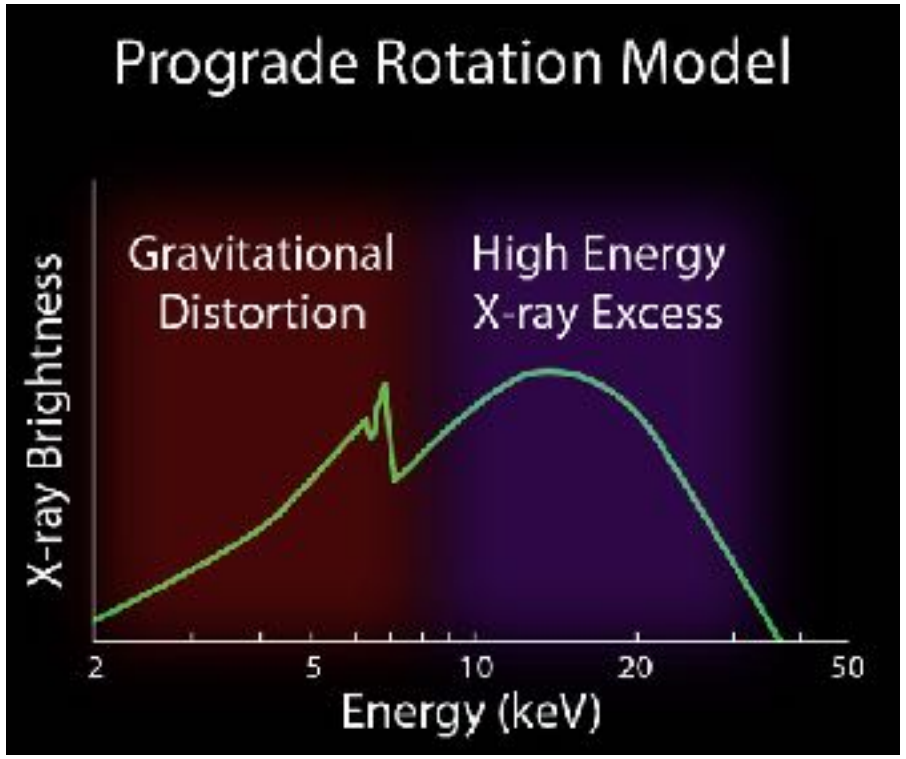


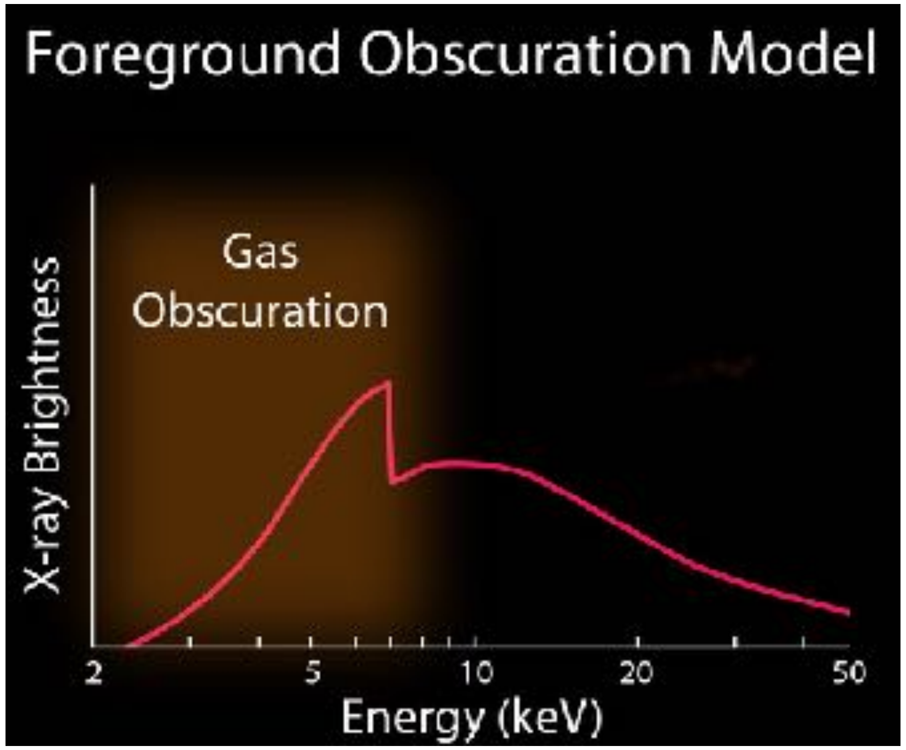
$a > 0.987$
$0.37 < a < 0.69$
$a > 0.917$
$0.84 < a < 0.97$

Miniutti+07

Reflection or absorption?



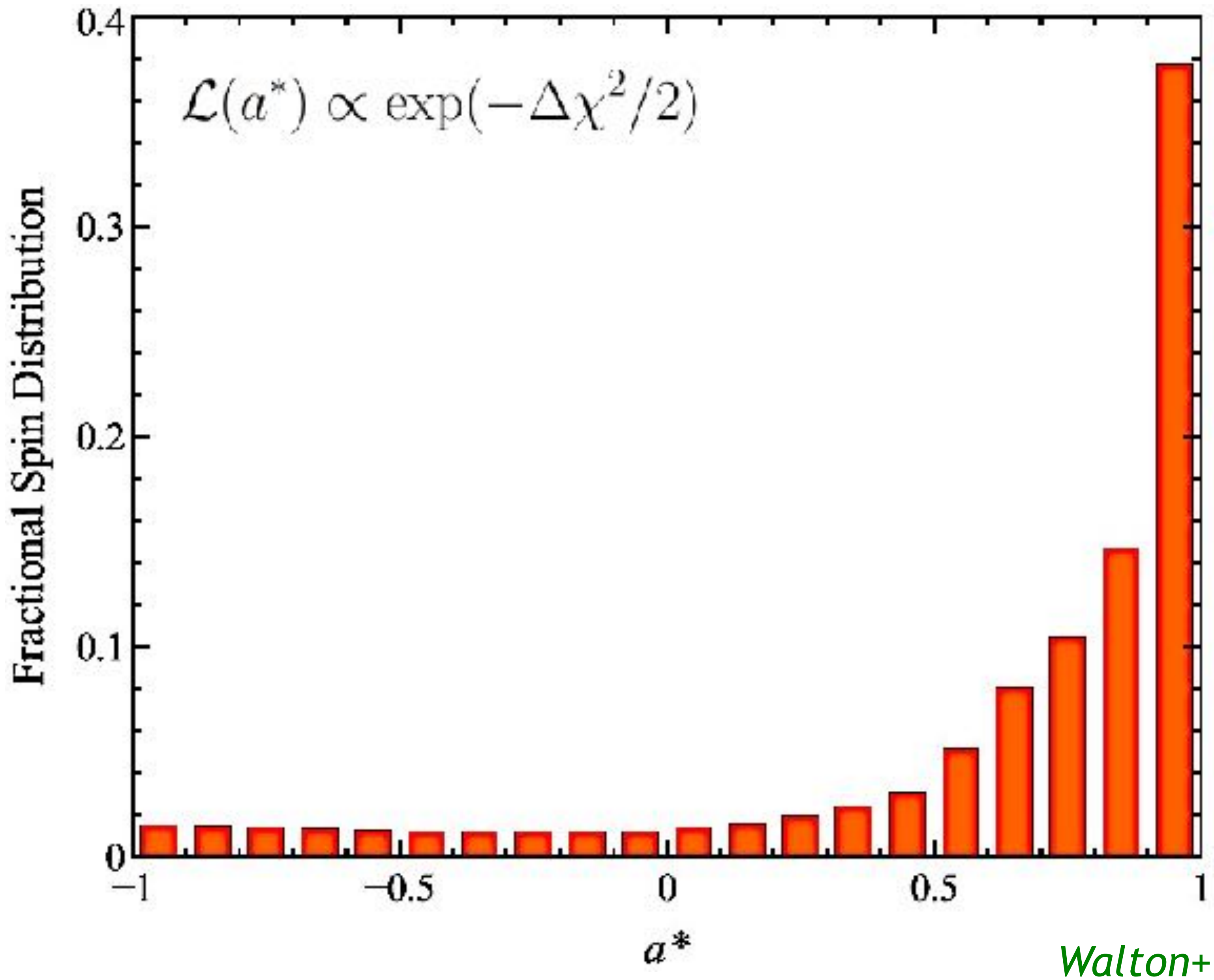




NASA/JPL-Caltech

Bare AGN and spin distribution

- Broadband analysis of a sample of 25 bare AGN observed with *Suzaku*



Walton+13

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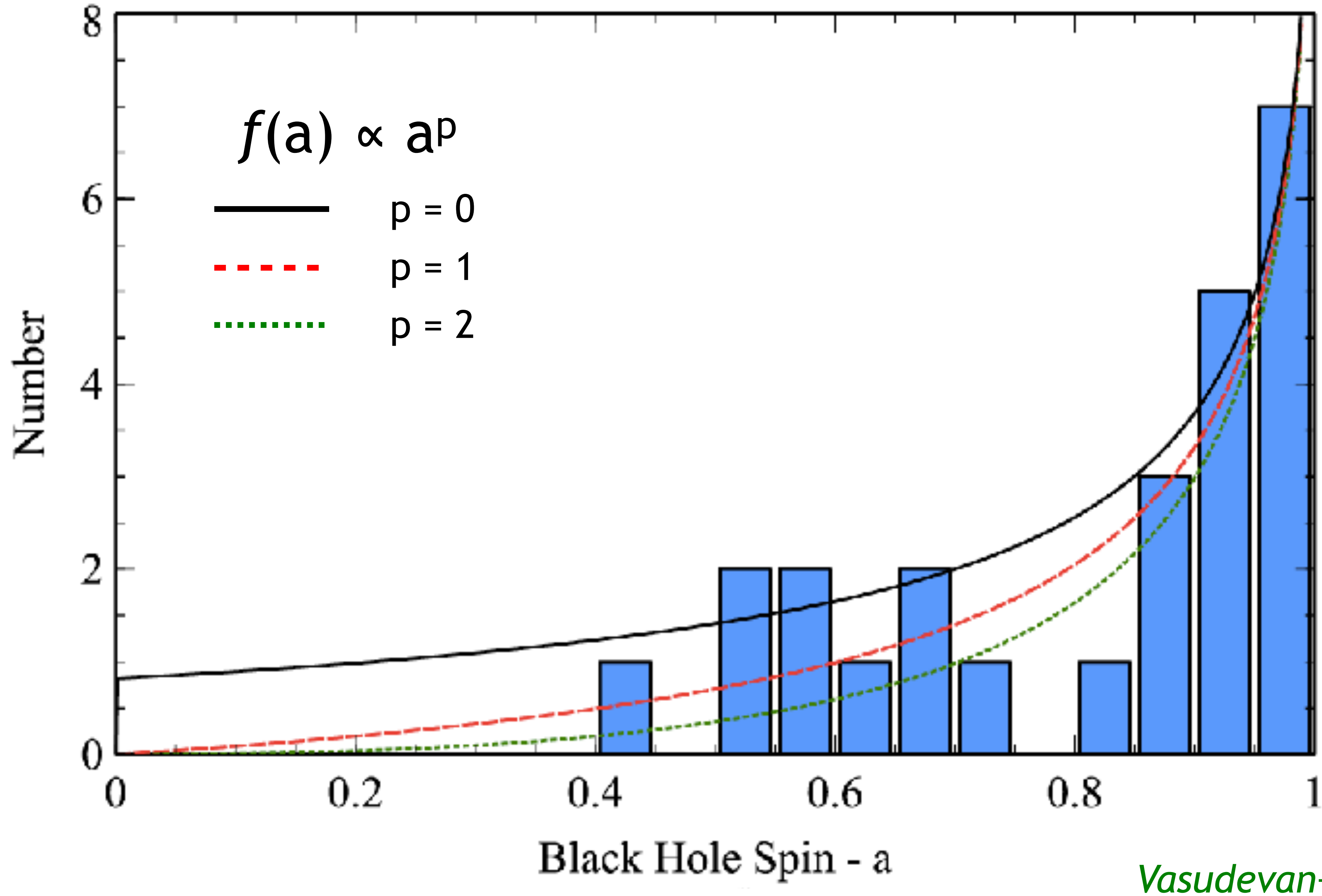
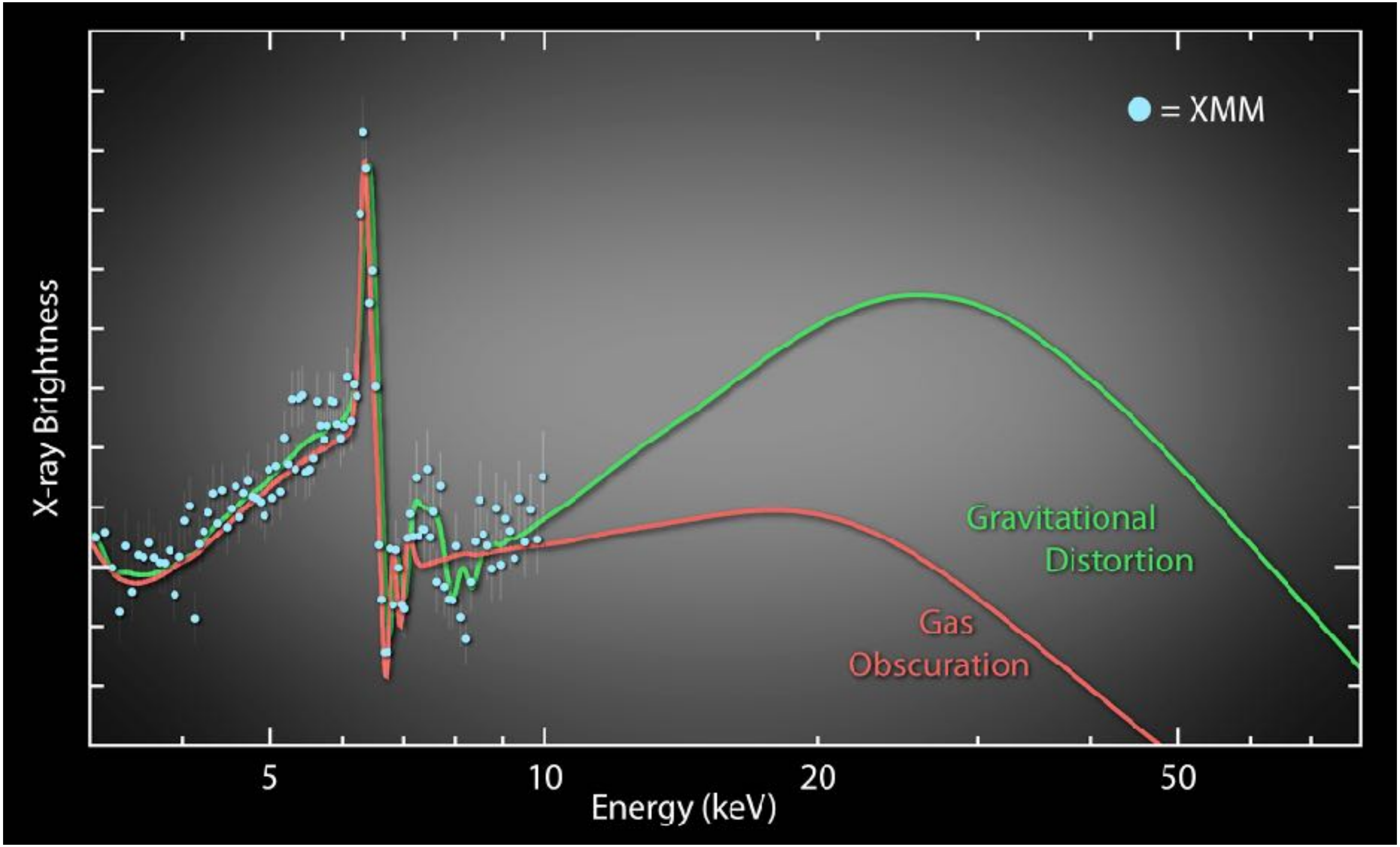


Vasudevan+16

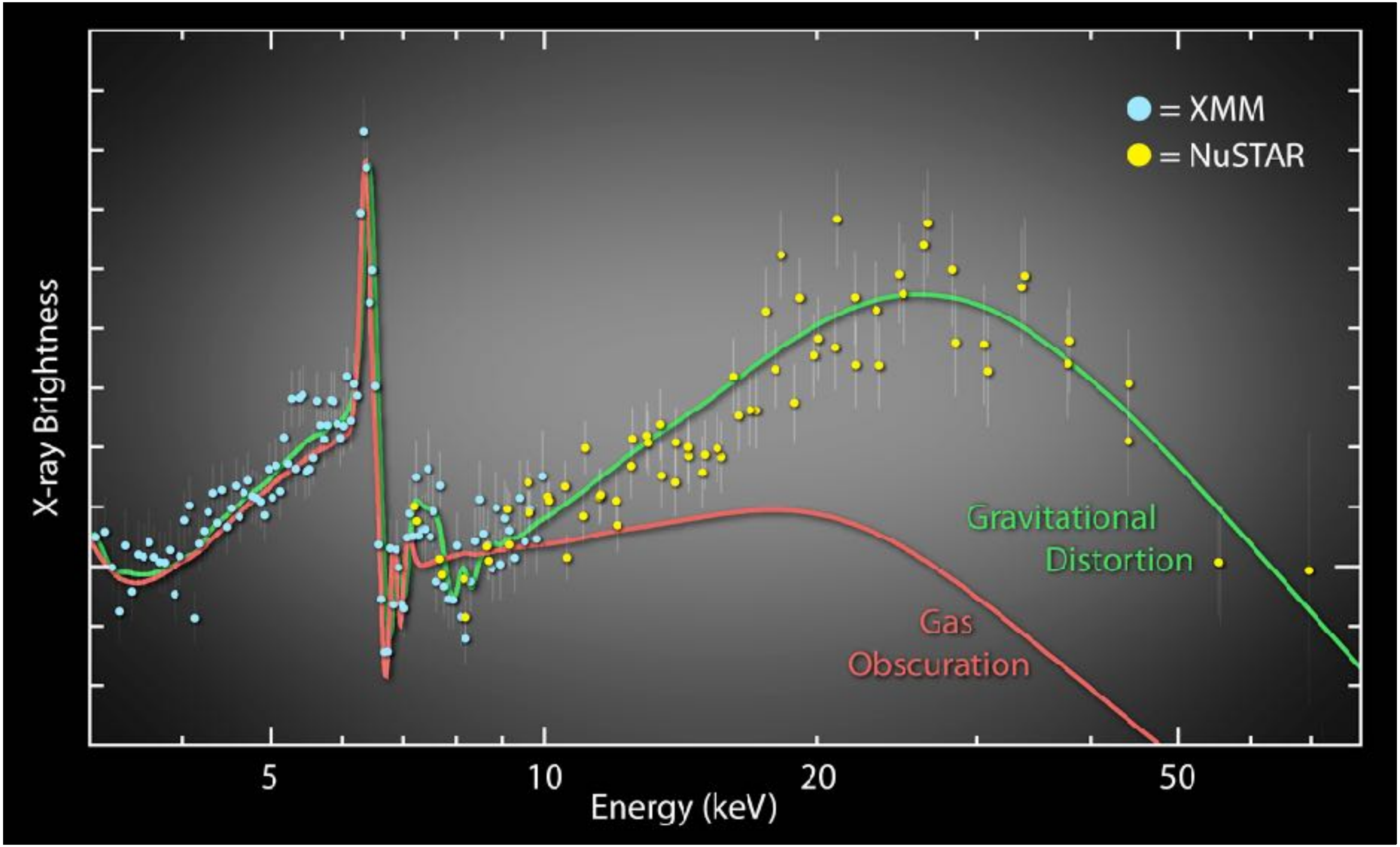
- Problem: actual nature of the soft excess *(Boissay+16)*
  Ark 120: *Nardini+11* vs. *Porquet+18* / Ton S180: *Nardini+12* vs. *Parker+18*

The remarkable case of NGC 1365



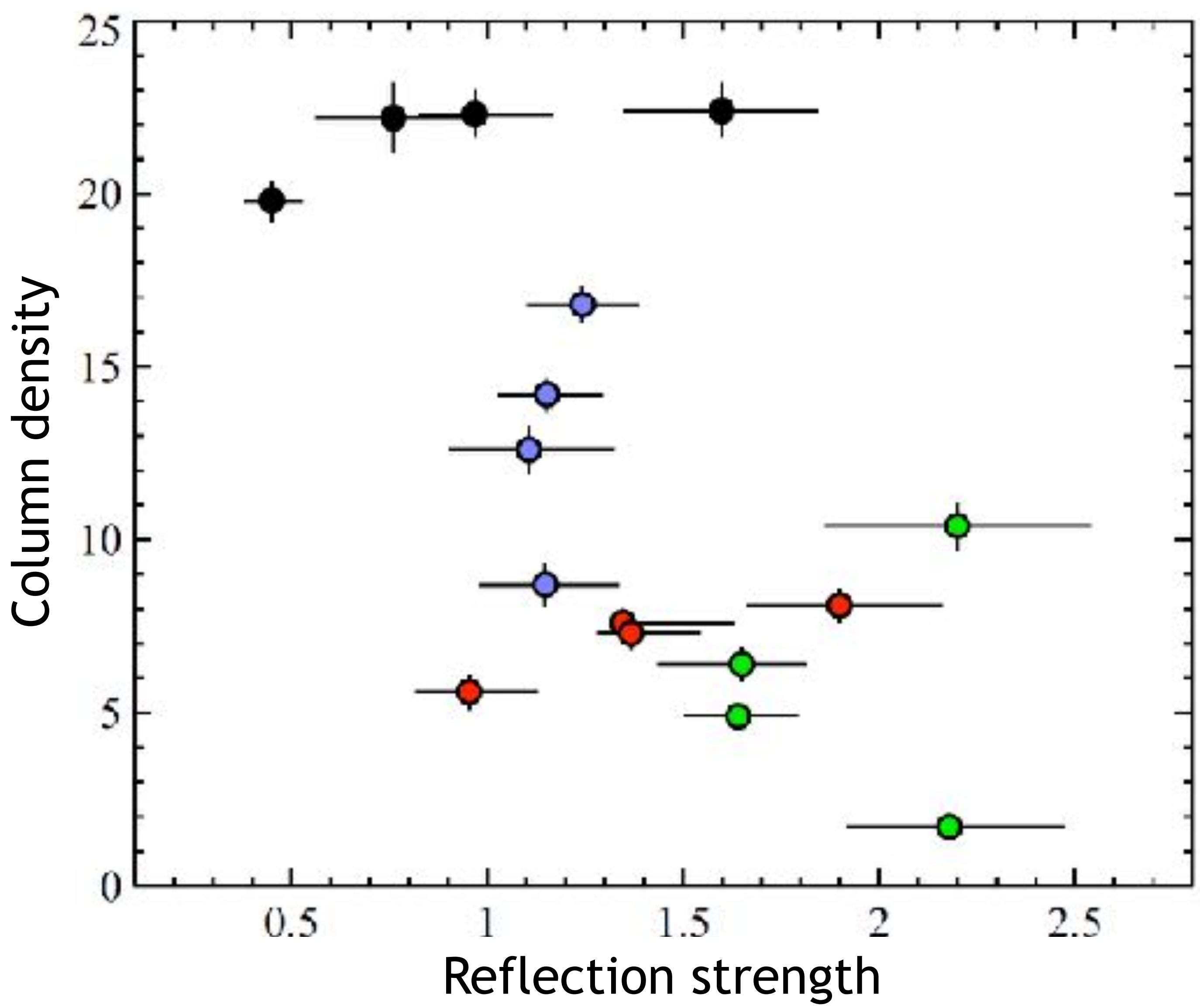
NASA/JPL-Caltech *Risaliti+13*

The remarkable case of NGC 1365



NASA/JPL-Caltech *Risaliti+13*

A rapidly spinning SMBH?



Walton+14

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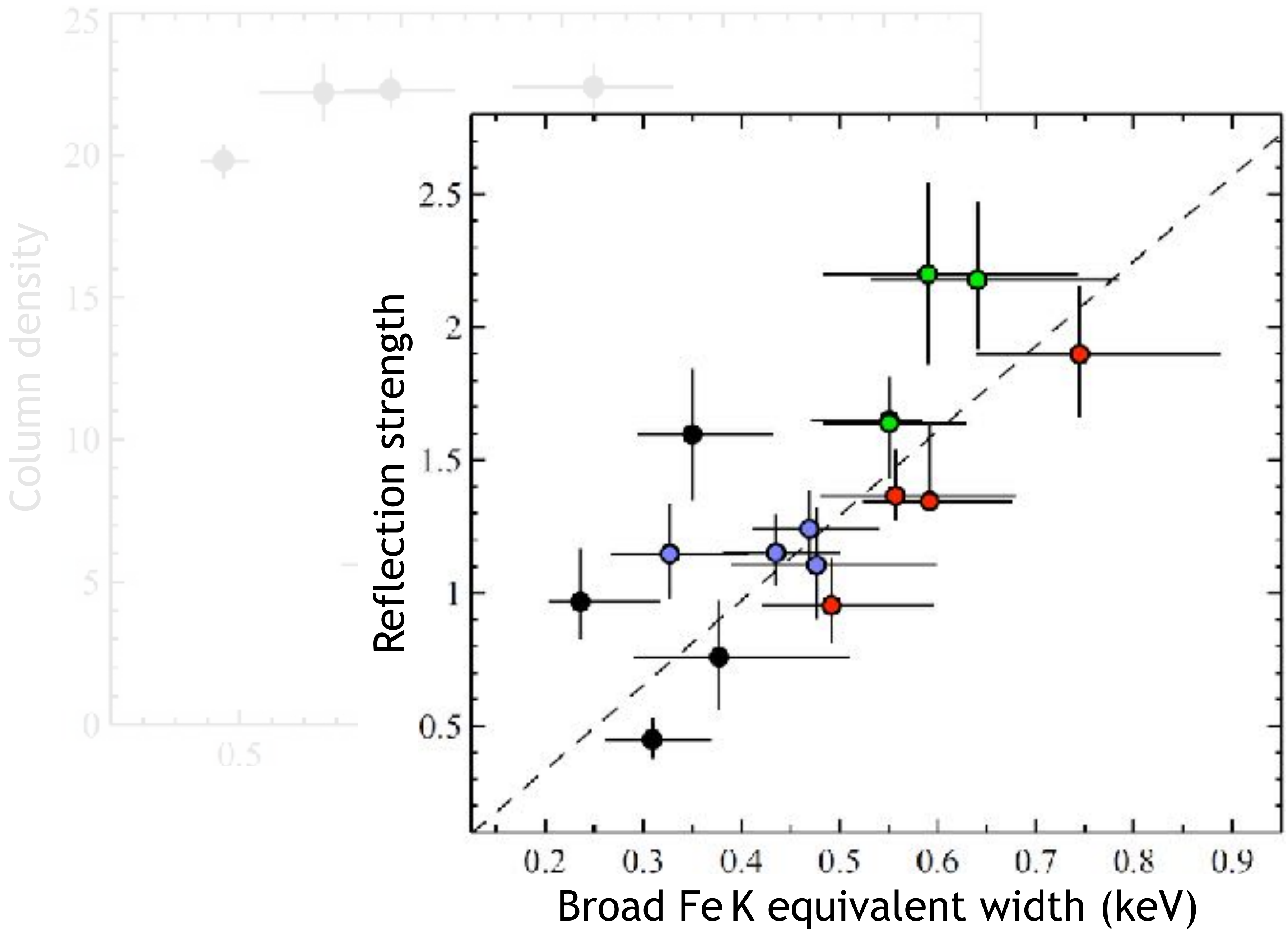

Walton+14

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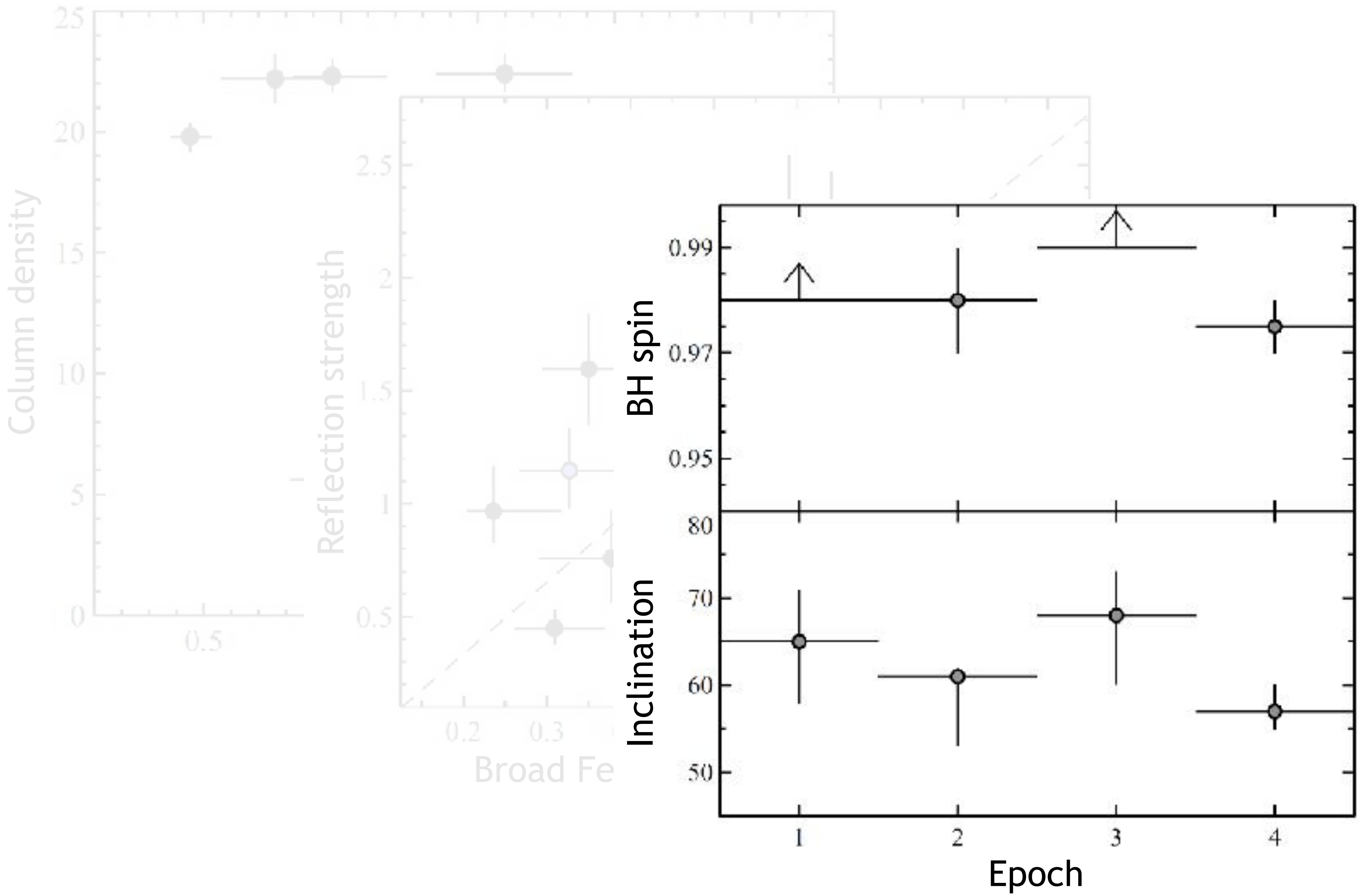

Walton+14

A rapidly spinning SMBH?

THE HARD X-RAY SPECTRUM OF NGC 1365: SCATTERED LIGHT, NOT BLACK HOLE SPIN

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[2] Department of Physics, University of Maryland Baltimore County, Baltimore, MD 21250, USA
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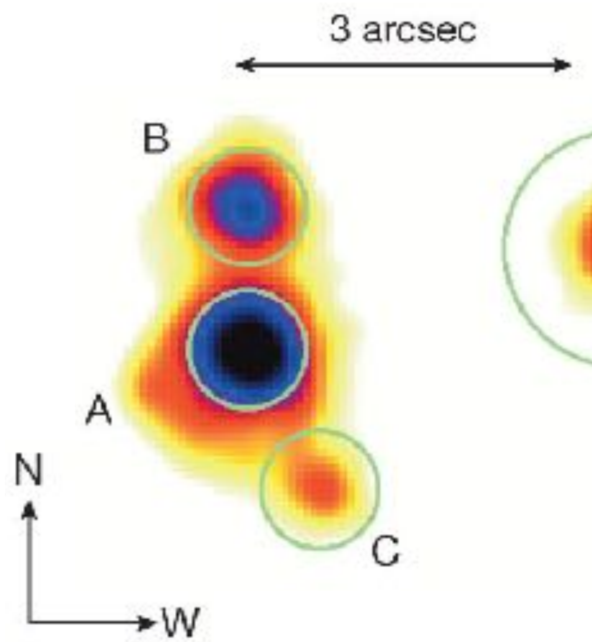
ABSTRACT

Active galactic nuclei (AGNs) show excess X-ray emission above 10 keV compared with extrapolation of spectra from lower energies. Risaliti et al. have recently attempted to model the hard X-ray excess in the type 1.8 AGN NGC 1365, concluding that the hard excess most likely arises from Compton-scattered reflection of X-rays from an inner accretion disk close to the black hole. Their analysis disfavored a model in which the hard excess arises from a high column density of circumnuclear gas partially covering a primary X-ray source, despite such components being required in the NGC 1365 data below 10 keV. Using a Monte Carlo radiative transfer approach, we demonstrate that this conclusion is invalidated by (1) use of slab absorption models, which have unrealistic transmission spectra for partial covering gas, (2) neglect of the effect of Compton scattering on transmitted spectra, and (3) inadequate modeling of the spectrum of scattered X-rays. The scattered spectrum is geometry-dependent and, for high global covering factors, may dominate above 10 keV. We further show that, in models of circumnuclear gas, the suppression of the observed hard X-ray flux by reprocessing may be no larger than required by the "light bending" model invoked for inner disk reflection, and the expected emission line strengths lie within the observed range. We conclude that the time-invariant "red wing" in AGN X-ray spectra is probably caused by continuum transmitted through and scattered from circumnuclear gas, not by highly redshifted line emission, and that measurement of black hole spin is not possible.

Key words: galaxies: active – radiative transfer – X-rays: galaxies – X-rays: individual (NGC 1365)

"We conclude that … measurement of black hole spin is not possible."

Reflection-based spins at high redshift

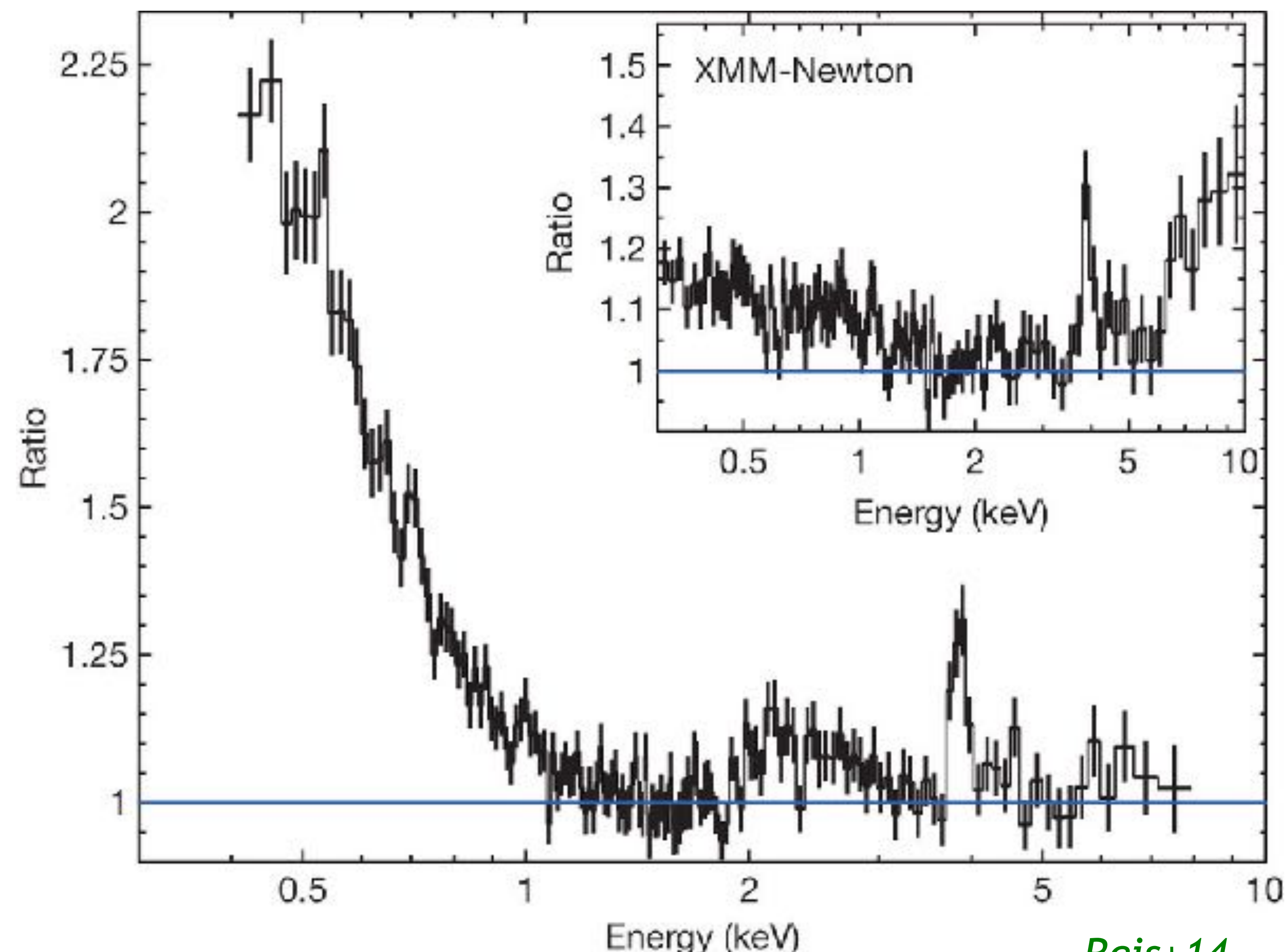


RX J1131–1231 (z = 0.658)

Single *XMM* observation +
stacked *Chandra* images

spin: 0.87 (0.72–0.95)

inclination: 15 (<24)



Reis+14

Problem: 78 microlensed Fe K features detected in the 38 x 4 *Chandra* spectra

- Spin still compatible with zero (r_{in} < 8.5 r_g), inclination >76 *(Chartas+17)*
- New simultaneous *XMM*+*NuSTAR* observation performed last week

A different approach

Simulation of high-quality broadband X-ray spectra plus blind spectral analysis

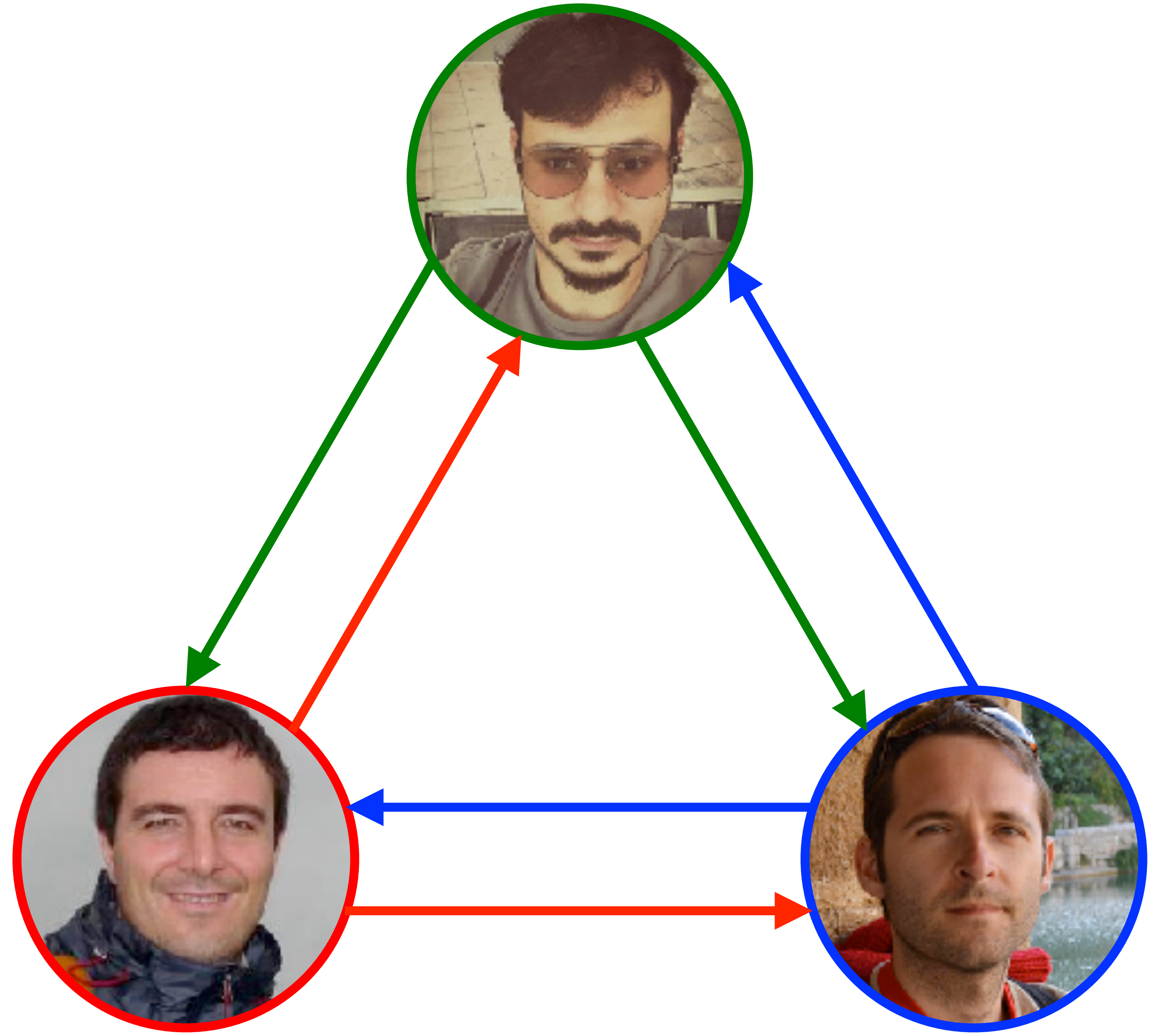
- Single-epoch *XMM+NuSTAR* observation of bright AGN
  - general parent model
  - typical parameter space
- 30 simulated spectra
  - 15 unrestricted
  - 9 Kerr SMBHs
  - 6 'bare' AGN
- 2 blind fits per spectrum
  - 60 realizations
  - output vs. input

Testing the accuracy of reflection-based SMBH spin measurements

Kammoun, Nardini & Risaliti

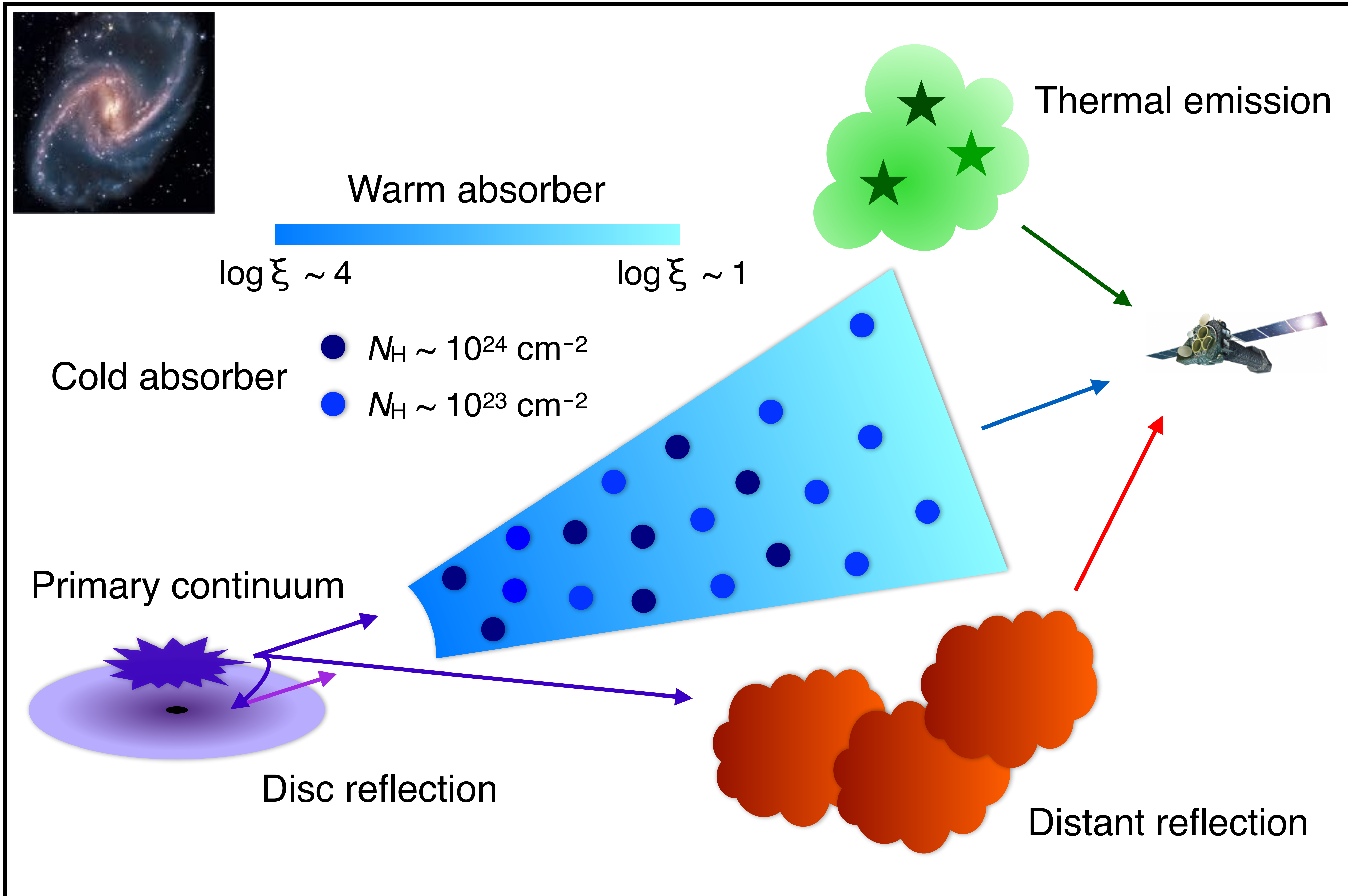
(A&A in press)

Elias Kammoun (SISSA)



Guido Risaliti (UniFI)

Emanuele Nardini (OAA)


Thermal emission
Warm absorber
log ξ ~ 4
log ξ ~ 1
Cold absorber
$N_H \sim 10^{24}$ cm^{-2}
$N_H \sim 10^{23}$ cm^{-2}
Primary continuum
Disc reflection
Distant reflection

Results - part I

Ockham's razor approach:

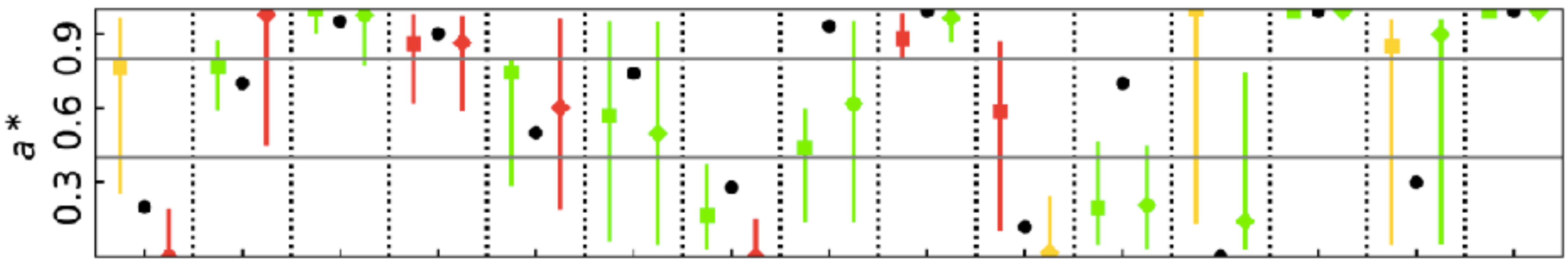
good statistics, stable minimum, negligible residuals

(**Note:** this does not ensure that a fit is also physically accurate!)

Irrespective of the fit accuracy, most parameters are retrieved with success

… apart from the spin

General case



Kammoun+18

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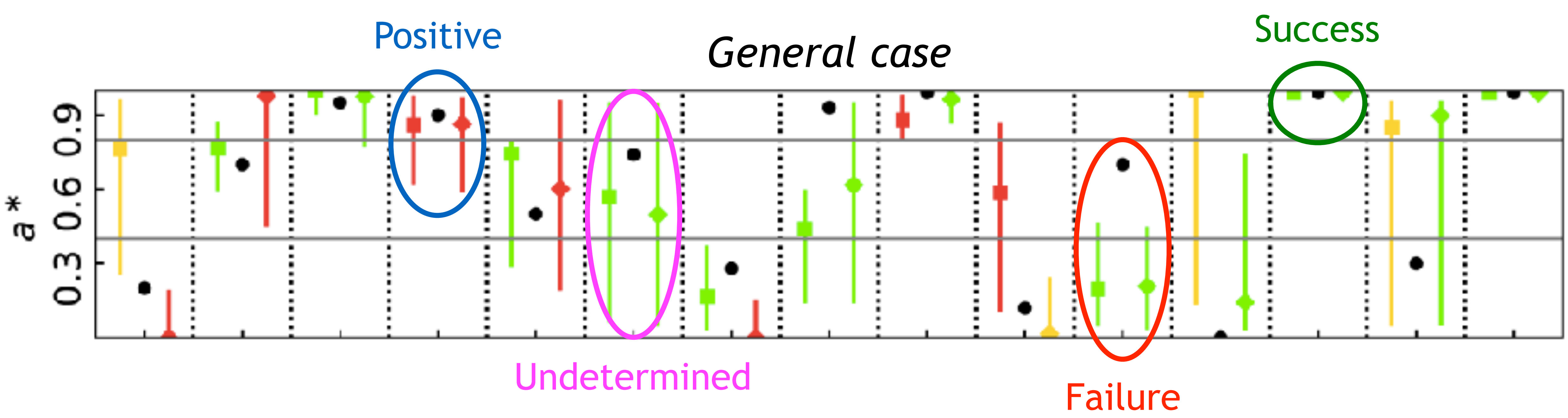

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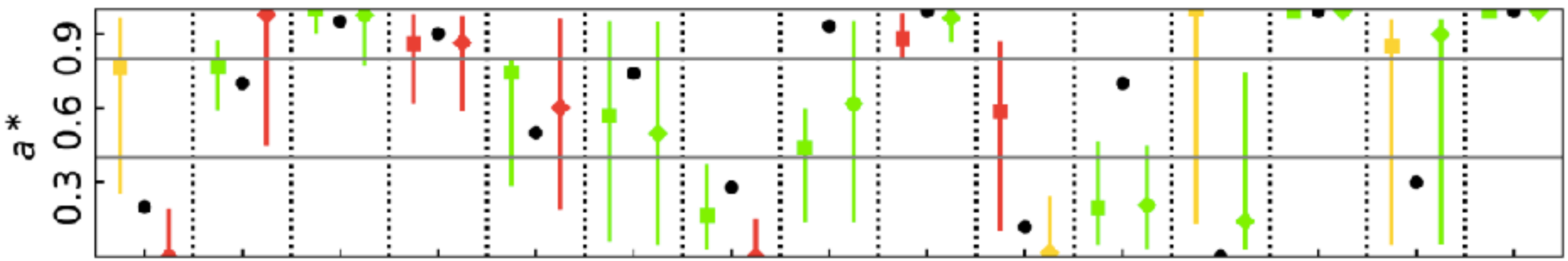
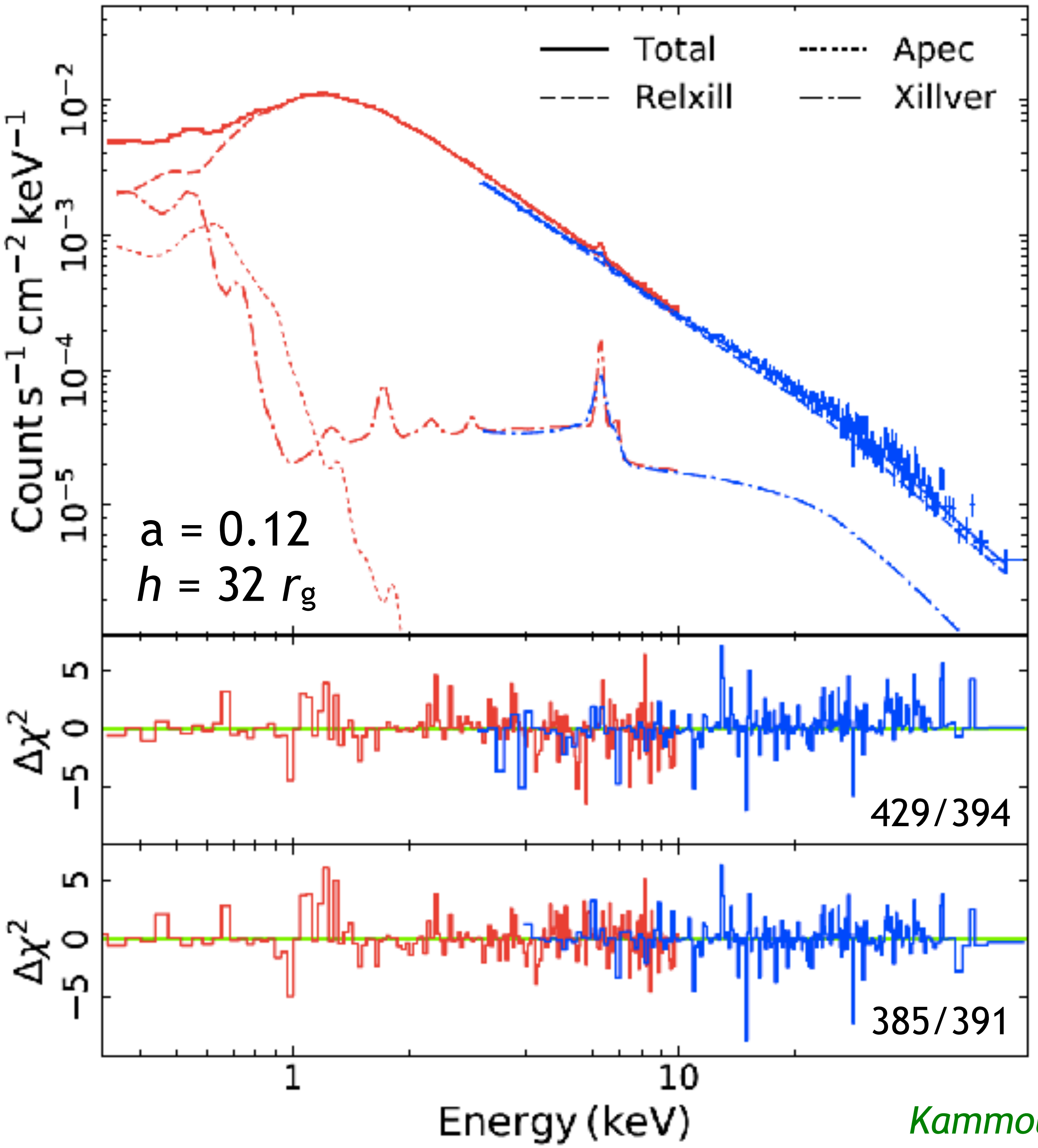
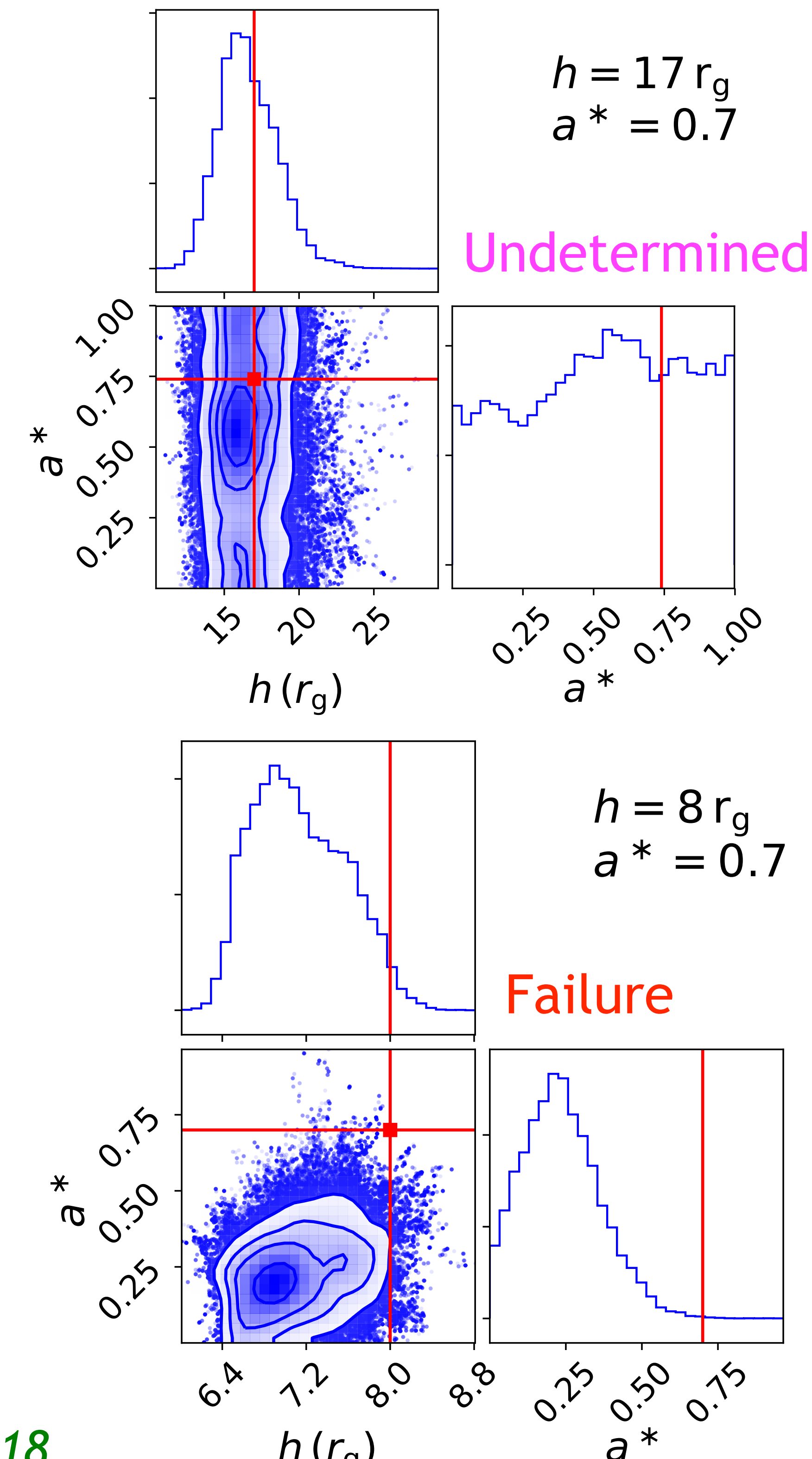


Preliminary conclusion:
High spins (10/12) are more likely recovered
than low/intermediate spins (7/18)

Kammoun+18

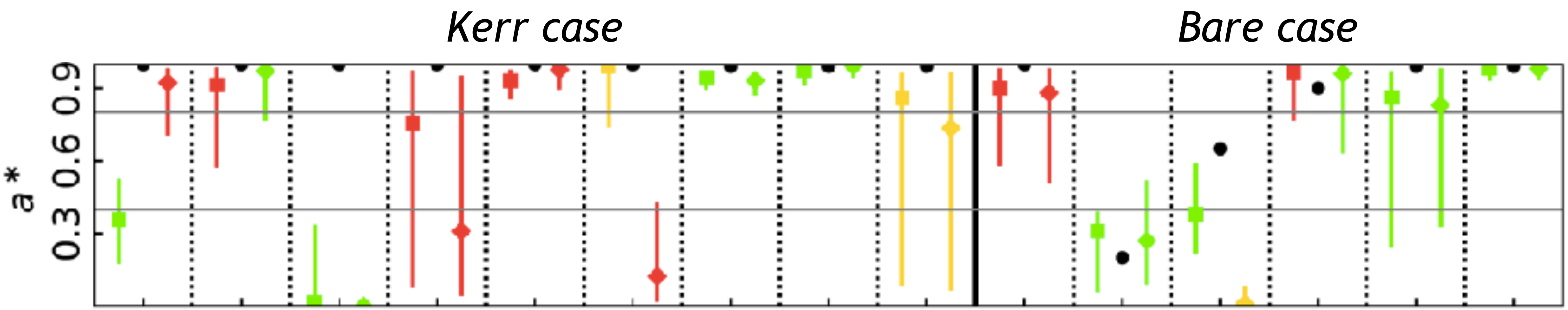
Examples





Kammoun+18

Results - part II



a < 0.8: 11 models

$h \leq 5\ r_g$: 6 (5) fits

– Success	4/6 (3/5)
– Undetermined	0/6 (0/5)
– Failure	2/6 (2/5)

$h > 5\ r_g$: 16 (12) fits

– Success	5/16 (3/12)
– Undetermined	6/16 (4/12)
– Failure	5/16 (5/12)

a ≥ 0.8: 19 models

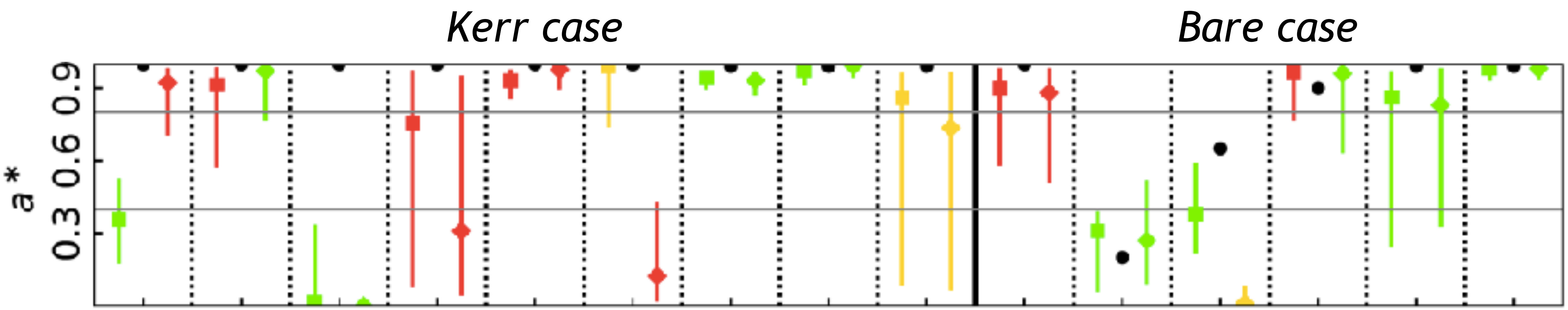
$h \leq 5\ r_g$: 24 (16) fits

– Success	22/24 (16/16)
– Undetermined	0/24 (1/16)
– Failure	2/24 (0/16)

$h > 5\ r_g$: 14 (9) fits

– Success	0/14 (0/9)
– Undetermined	1/14 (1/9)
– Failure	13/14 (8/9)

Results - part II



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h > 5 r_g: 14 (9) fits

– Success	0/14 (0/9)
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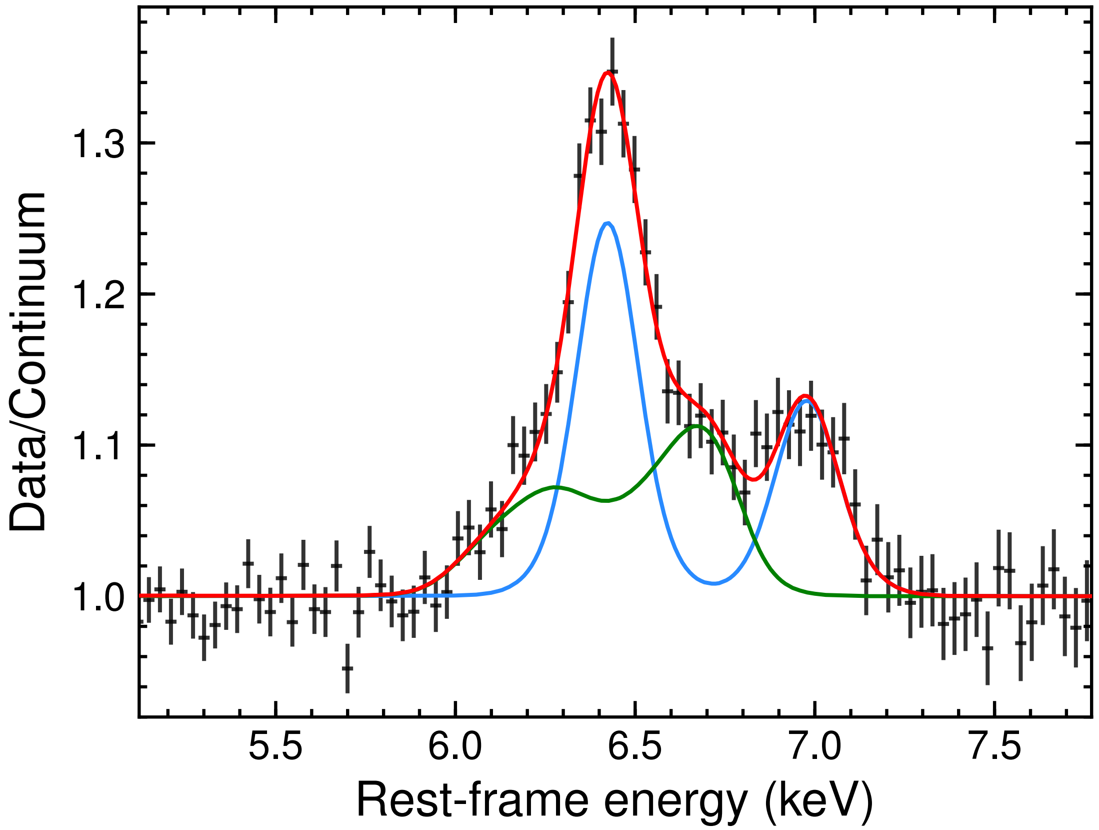
– Failure	13/14 (8/9)

- Source height (hence inner disc emissivity) is critical for SMBH spin measure

Ancillary considerations

- Physically accurate fits (42/60) are evenly distributed in the parameter space
- Wrong and undetermined spin values (29/60) have a nearly flat distribution
- Possible dependence on other reflection parameters *(A_{Fe}, ξ, θ, Γ)*
  - increased statistics needed to investigate hidden degeneracies
- One or more spectral components are missed in 7/60 fits
  - spin estimate: 1/7 success, 1/7 undetermined, 5/7 failure
- One or more spectral components are added in 11/60 fits
  - spin estimate: 6/11 success, 1/11 undetermined, 4/11 failure
- Partial covering and relativistic reflection can be generally disentangled
  - only 1/30 model could be fitted with 3 absorption layers and no reflection
  - in other 3/30 models reflection could be missed at lower X-ray brightness
  - none of the above cases represent *bare* configurations
  - extreme blurring can become a serious issue even at high spectral quality
  - multi-epoch observations are a viable means to remove ambiguities

Further complications



Nardini+16

Ark 120: nearest and brightest bare AGN

- Warm Comptonization as most likely origin of the soft excess *(Porquet+18)*
- Broad Fe K feature and Compton hump suggest reflection from outer disc
- Inner disc reflection over-smoothed by an extended corona? *(Wilkins & Gallo 15)*
- Spin constrained in the range 0.6–0.9 from SED modelling *(Porquet+, subm.)*

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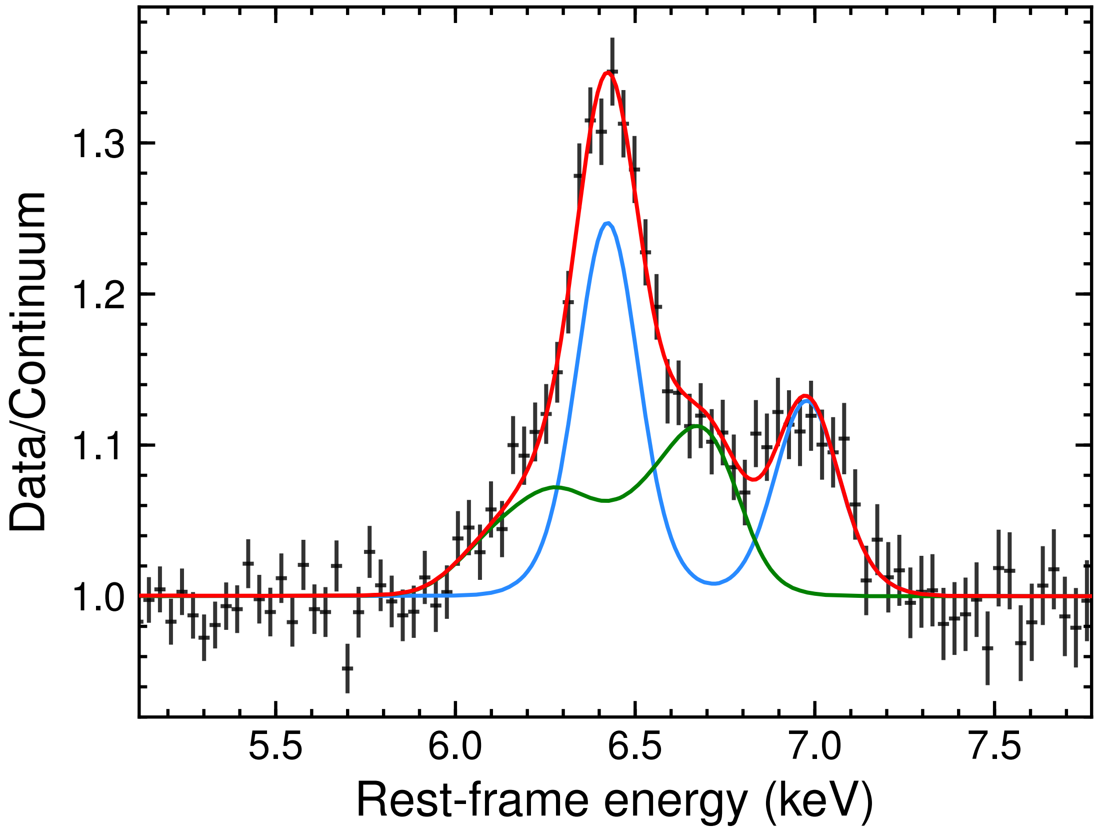

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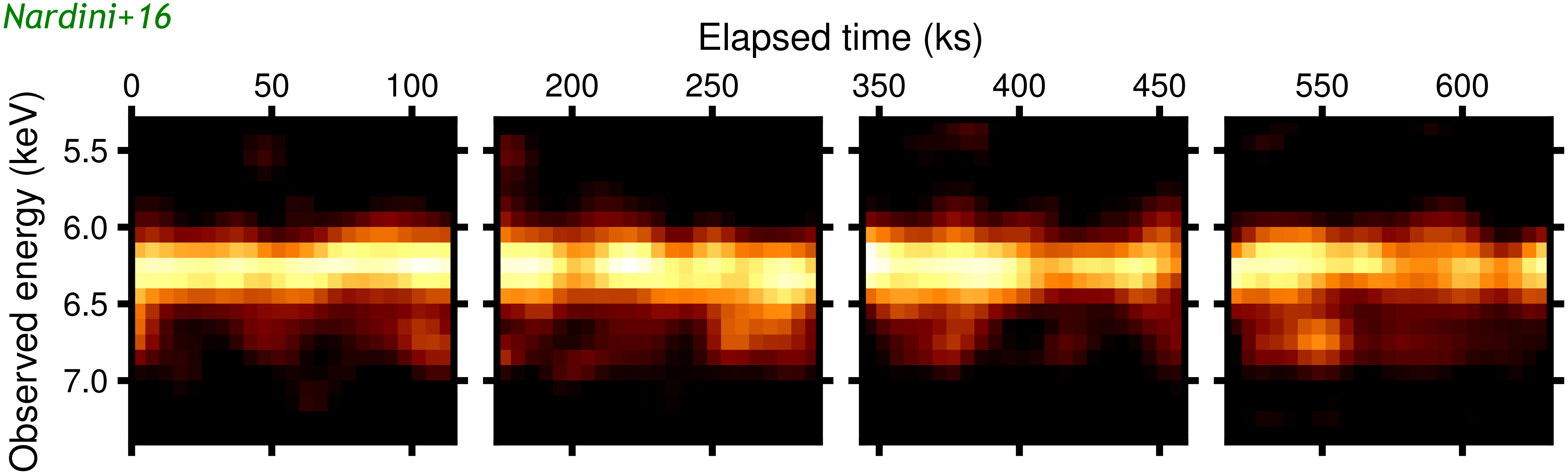
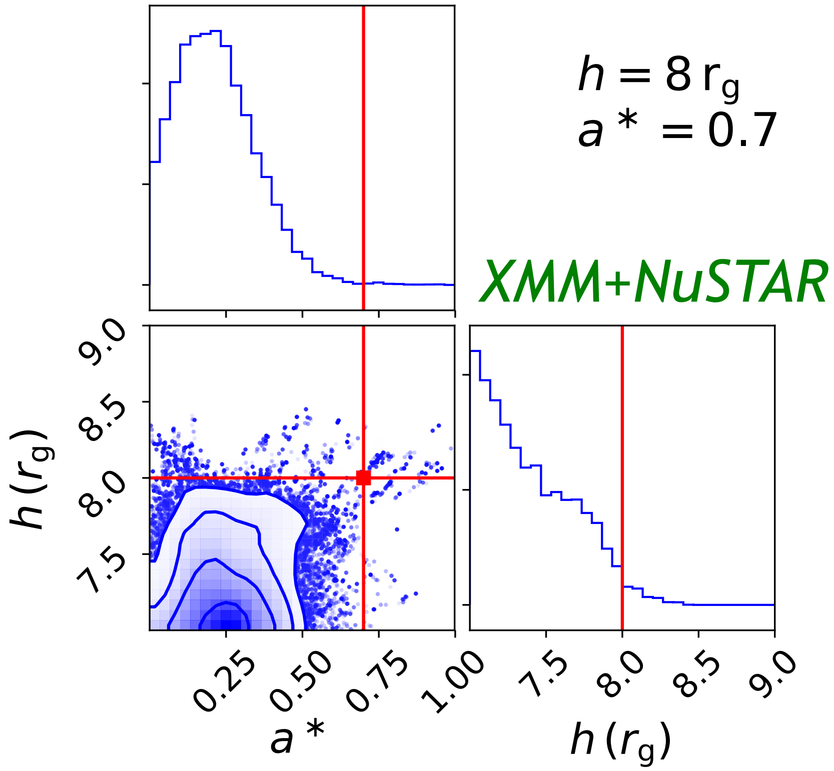
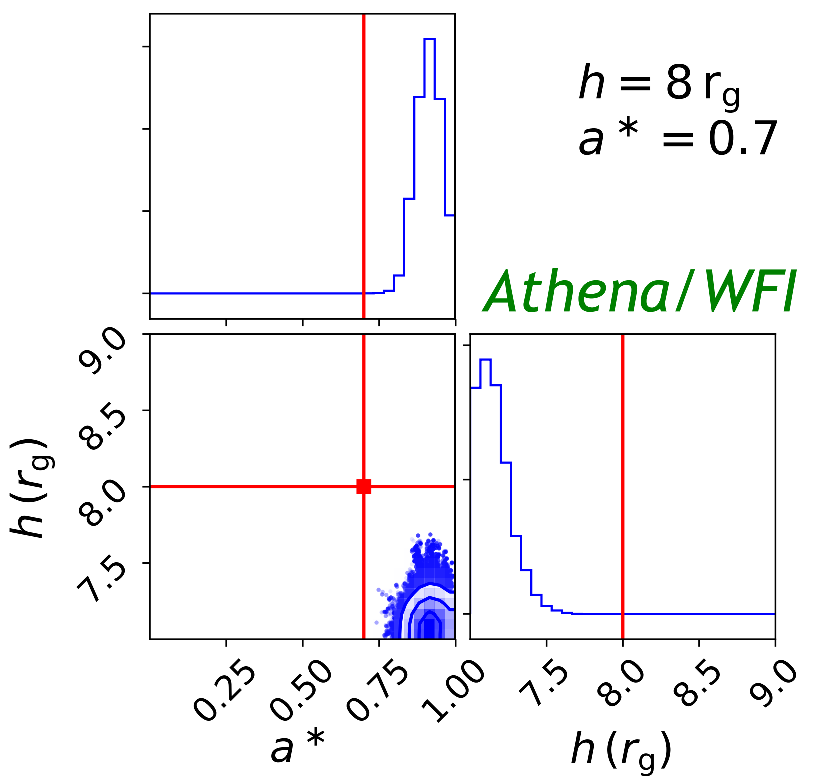
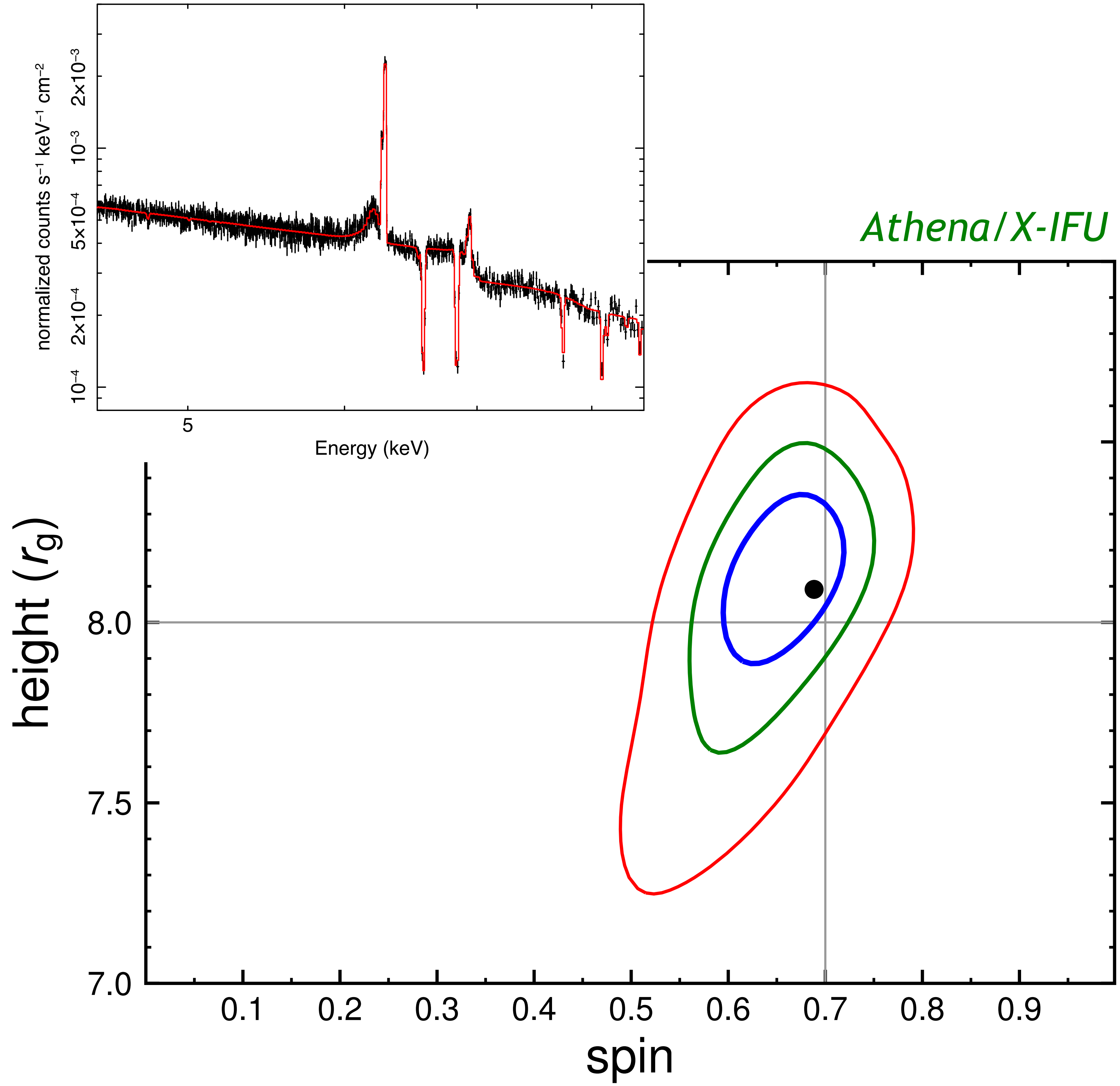


A bright future ahead







Conclusions

- Can we currently measure SMBH spins?
  - Yes. In a few cases and under very special conditions.
- Can spin-dependent X-ray signatures be identified?
  - Not always. Strong reflection from the inner disc and a physical characterization of the corona are mandatory.
- Will there be any improvements in the future?
  - Maybe. High resolution and large area are both needed to reveal any Fe K fine structure and track its time variability
- Is there anything we can do in the mean time?
  - Combine complementary diagnostics whenever possible.