Characteristic geometries of accretion in Cyg X-1 found with INTEGRAL

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Project

"Distinct accretion modes of Cygnus X-1 revealed from hard X-rays",
A. Filothodoros et al.

- primary aim: independent hard X-ray state classification
- phenomenological characterization of the plasma region
- diagnosis of the system geometry
- plasma-jet connection

Data

INTEGRAL data from Revs 0022–1882

- 15 years
- 7821 science windows selected
- 18.53 Ms exposure time
- 2.1 billion photons

Other observatories

- RXTE/ASM, MAXI/GSC, JEM-X
- SPI, Swift/BAT, CGRO/BATSE, PICsIT
- RT/AMI 15 GHz

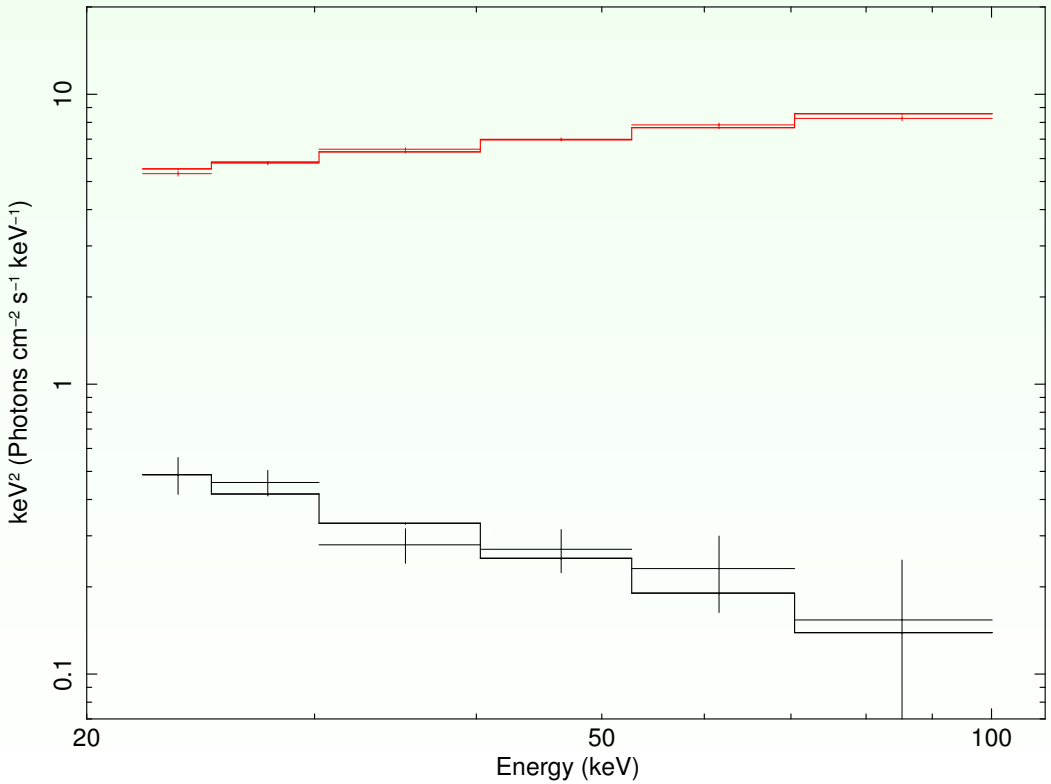
Analysis of the ISGRI spectra

Spectral model parameters instead of the count rate/hardness to reduce the ISGRI calibration issues

- power-law model fitted in the 22–100 keV band
- set of 6 own ARFs after Rev. 1626
- hard X-ray flux F_{H}
- hard X-ray photon index Γ_{H}

Typical hard and weak soft state spectra

- 046000110010
- 122900380010

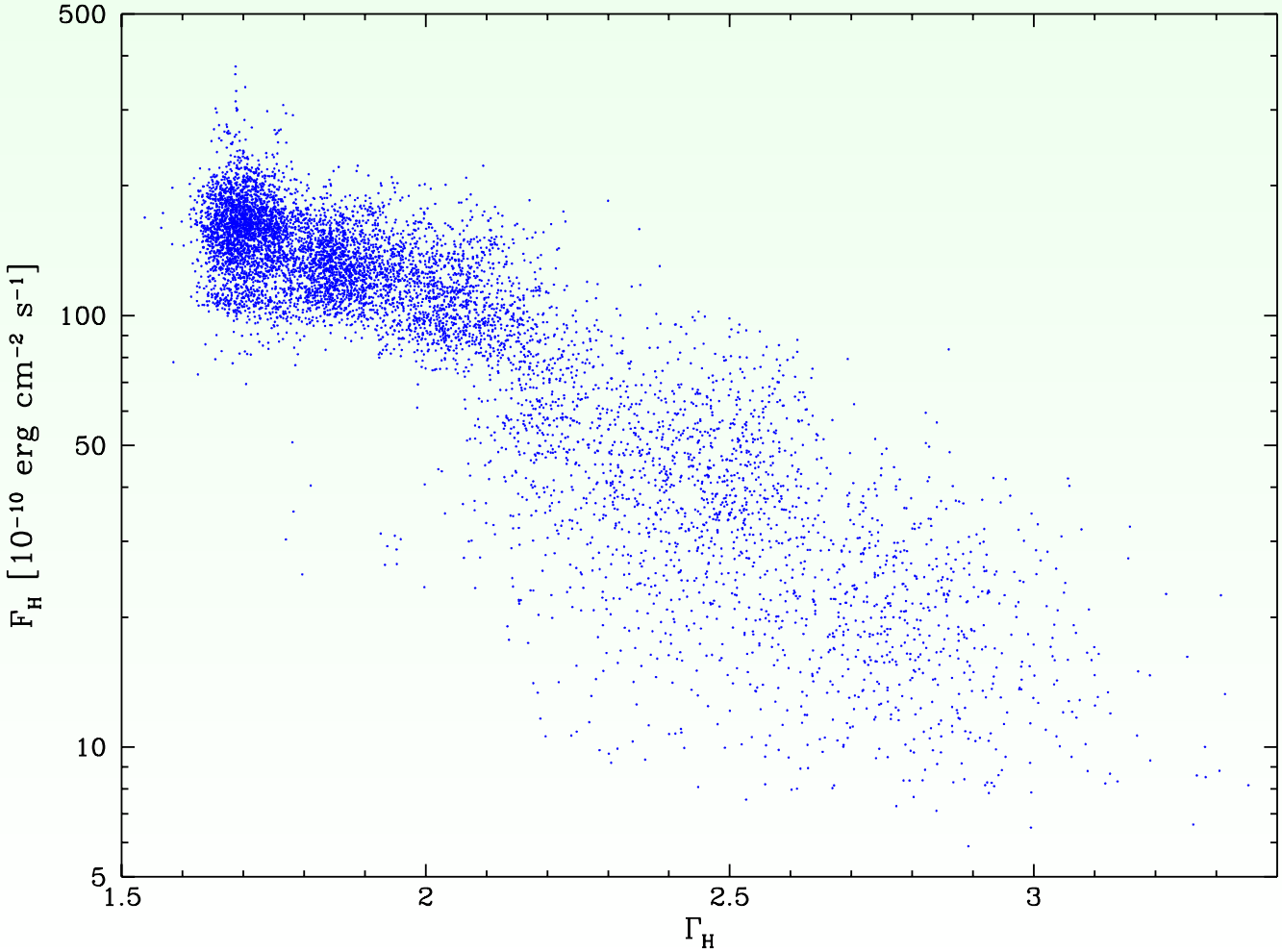


Photon index - Flux diagram

Analogue of the hardness–intensity diagram in the soft X-rays

Flux and photon index in the 22–100 keV band

- hard, intermediate and soft state regions
- hard/intermediate states: three substates regions
- soft state: extended region



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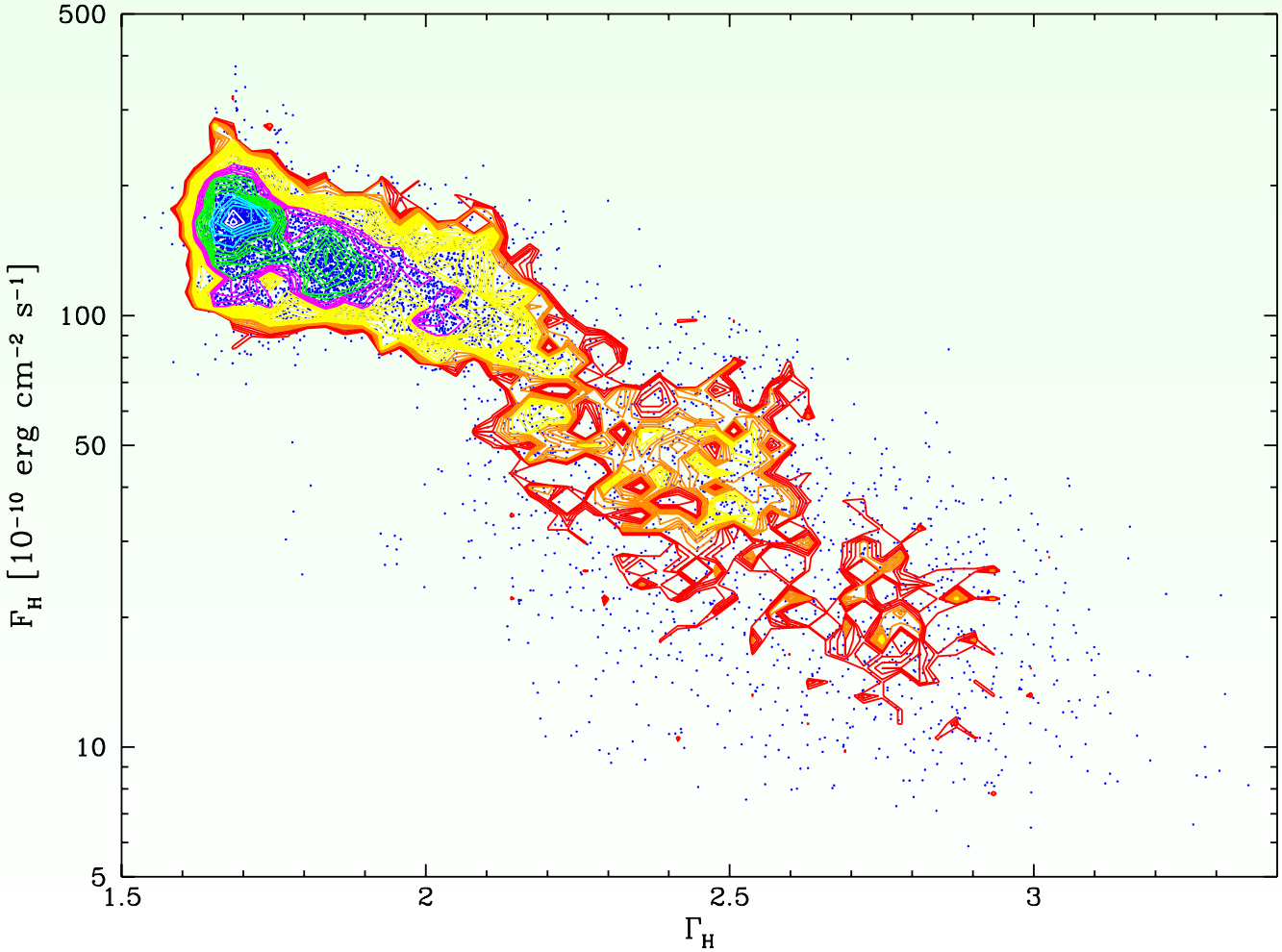
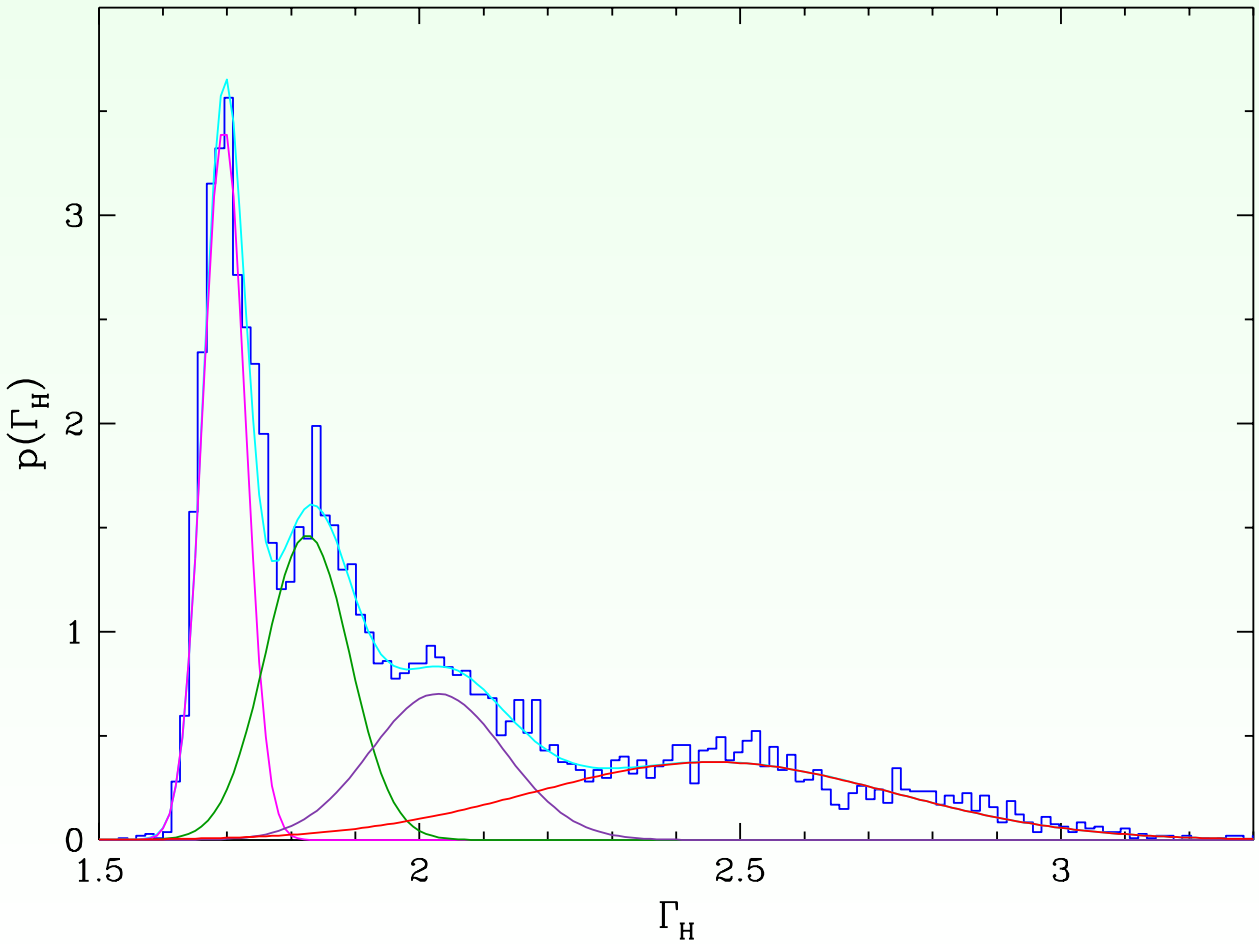


Photon index distribution

Deconvolution into four Gaussians

- pure hard state: $\overline{\Gamma}_{\mathrm{H}}$ = 1.70, 29%
- transitional hard state: $\overline{\Gamma}_{\mathrm{H}}$ = 1.83, 25%
- intermediate state: $\overline{\Gamma}_{\mathrm{H}}$ = 2.03, 19%
- soft state: $\overline{\Gamma}_{\mathrm{H}}$ = 2.46, 27%



Additional parameters

Short-term hard X-ray variability

Fractional variability amplitude S_V computed for each science window

- 22–100 keV band
- time bin of 1 minute
- $\geqslant$ 20 minutes science windows

$$S_{\mathrm{V}} = \left(\sigma_{\mathrm{V}} / \overline{F}_{\mathrm{H}}\right) \times 100\% \quad (1)$$

with σ_{V} being the excess over the statistical variations.

Daily-scale hard X-ray variability

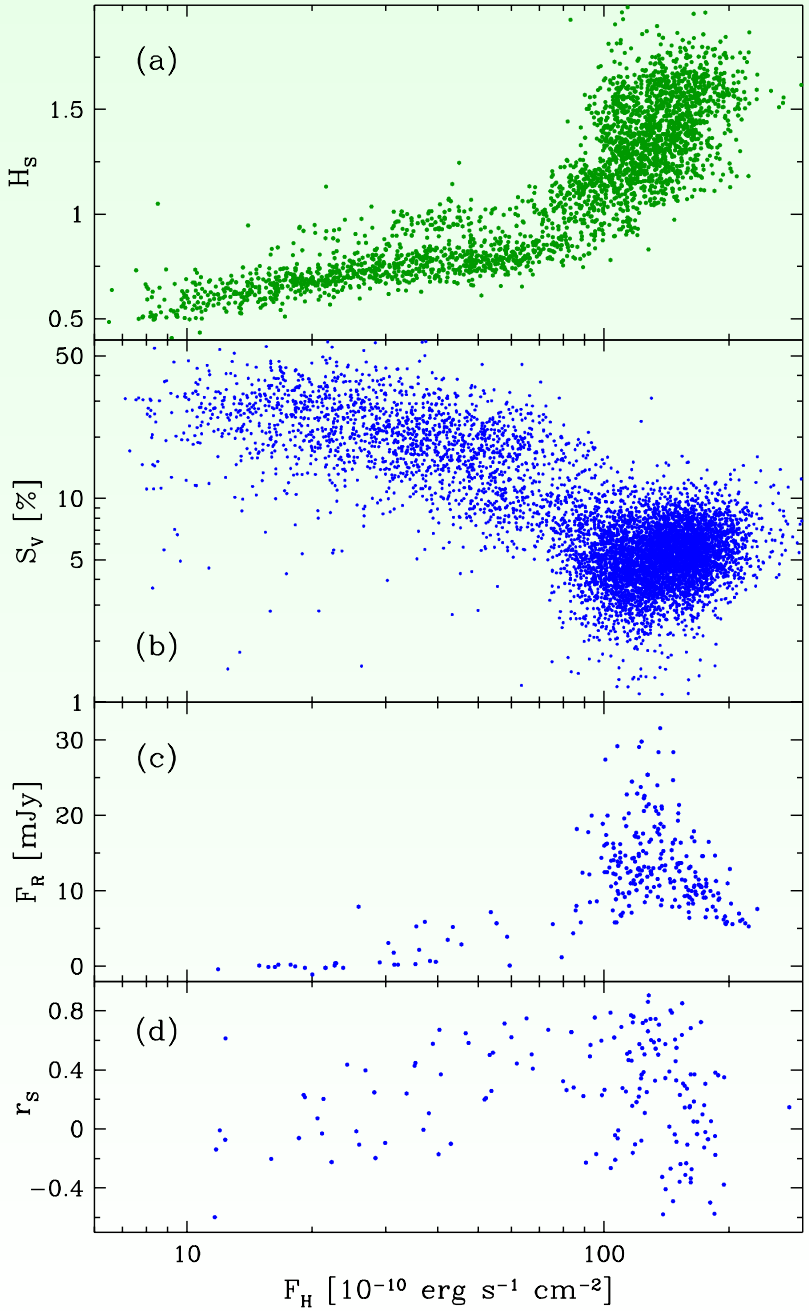
Γ_{H}-F_{H} correlation for each orbit, Spearman rank-order test

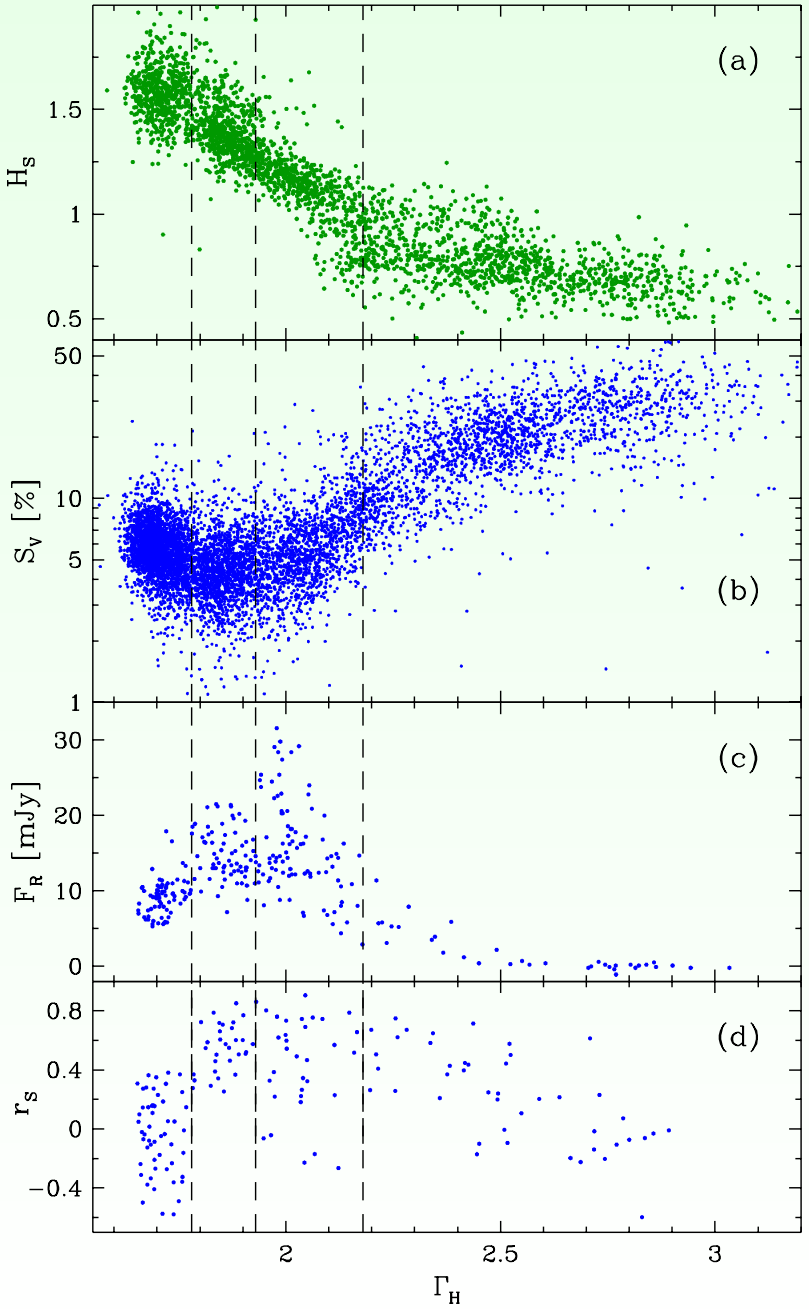
- correlation coefficient r_{S}
- no-correlation (null hypothesis) probability P_{S}
- $\geqslant$ 10 science windows per orbit

Soft X-ray hardness F_{S}

JEM-X 1 count rates, ratio 5–12 keV/3–5 keV

Correlations over four states





Physical interpretation

Pure hard state

Can be explained with the synchrotron boiler model with Comptonization of only plasma soft photons and either thermal or nonthermal electron population

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The synchrotron boiler and the spectral states of black hole binaries

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3.1 Synchrotron self-Compton models with pure non-thermal injection

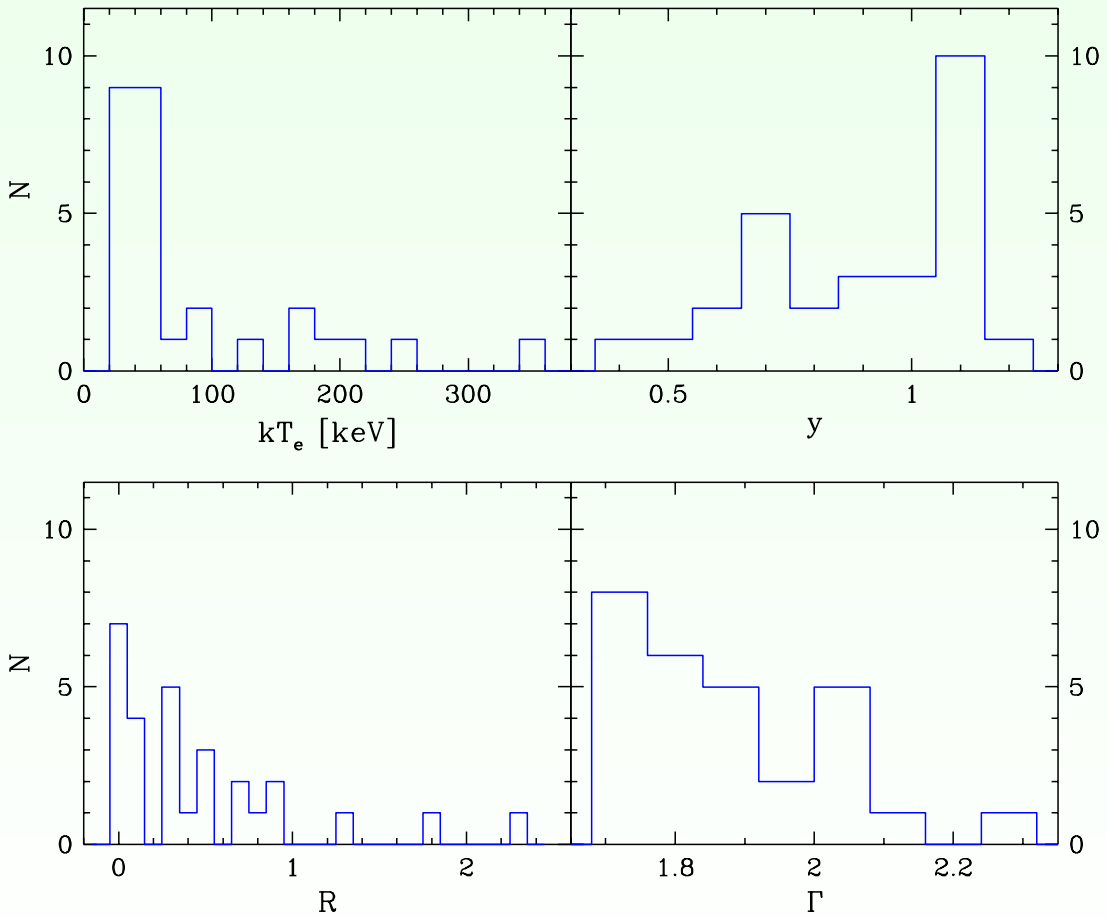
In this section we assume that the protons are cold ($l_c = 0$) and the external photons are neglected ($l_s = 0$). Fig. 1 shows the dependence of the photon spectrum on l_{nth} for $l_B = l_{nth}/3$, which corresponds to approximate equipartition of magnetic field with radiation. The other fixed parameters are $\Gamma_{inj} = 3$, $R = 5 \times 10^7$ cm, and $\tau_i = 2$. For a wide range of compactness the spectrum peaks around 65 keV and the X-ray photon index is $\Gamma \simeq 1.7$ (see also Table 1). The right-hand panel of Fig. 1 shows the steady state

Comparison with AGN

Cyg X-1 versus radio-quiet and radio-loud Seyferts

similar ranges of the plasma temperatures, Compton parameter y and Γ

- pure hard state/radio-quiet Sy: $y \approx 1.1$, $\Gamma \approx 1.7$
- transitional and intermediate state/radio-loud Sy: $y \approx 0.7$, $\Gamma \approx 2$



Γ extracted indirectly, from the Comptonization model, Lubinski et al. 2016, MNRAS 458, 2454

Summary

Results

- clustering of the hard X-ray photon index, four states
- hard state separated into two substates: pure and transitional
- state classification based on hard X-rays (hot plasma emission) consistent with the soft X-ray selection
- hard X-ray variability anti-correlated with the photon index
- different ranges of radio emission observed for each of four states
- no flux-photon index correlation for pure hard state (no plasma - disk interaction)

Interpretation

- pure hard state: synchrotron self-Compton with pure non-thermal injection
- similar clustering of photon index around (minimal) value of 1.7 observed for radio-quiet Seyfert galaxies
- specific geometries of the states related rather to the jet physics (stratified radio emission) than to the variable accretion rate

Findings exclusively specific to INTEGRAL

- high quality spectra
- huge amount of data