Cygnus X-1:
The Prototype
Under The Magnifying Glas

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& collaborators/advisors, acknowledged in the following by project

Cygnus X-1

persistent HMXB: 10 $\mathrm{M}_\odot$ black hole + 16 $\mathrm{M}_\odot$ primary (O9.7 Iab supergiant),

accretion via “focussed stellar wind” (absorption dips),

$\sim$2 kpc distance, 5.6 d orbit, $\sim$150 d precession period (X-ray/radio)

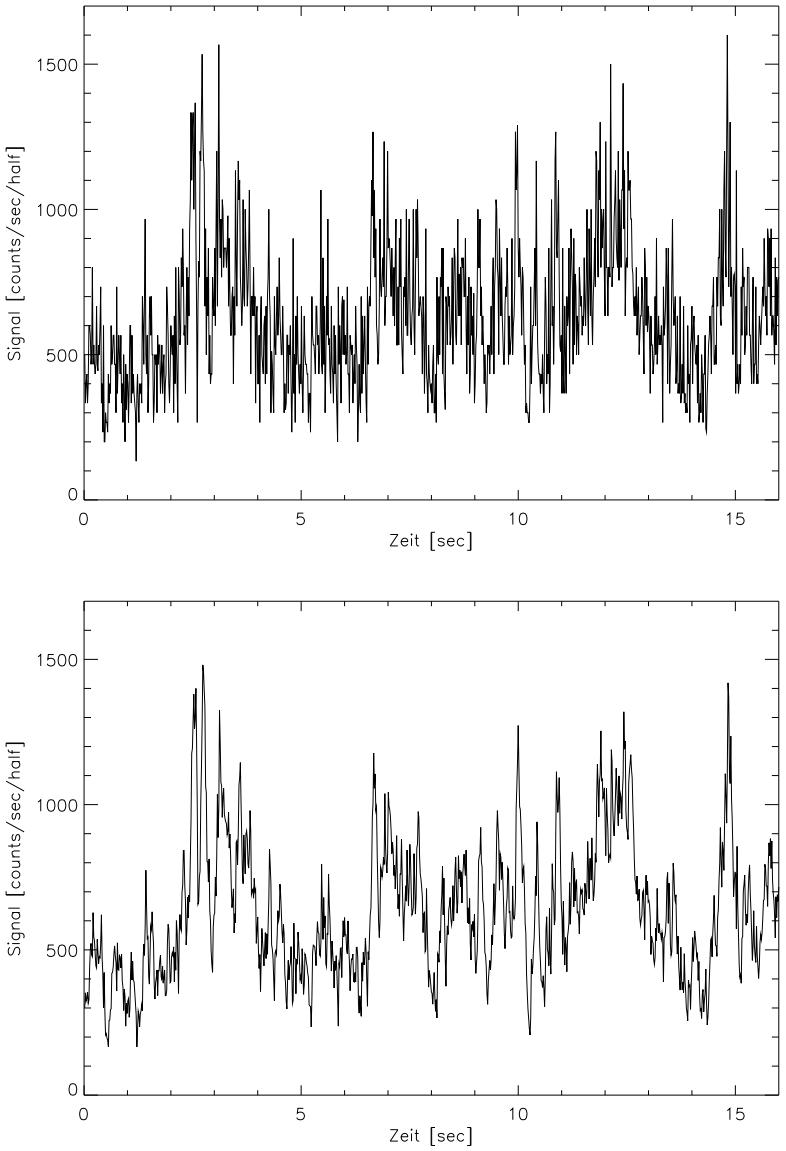
The big picture in 1996

- only persistently bright black hole binary in the low state $\rightarrow$ prototype
- focus on spectral modeling (Comptonization), low state

  (the expression “hard state” not yet widely used, state picture not too clear)
- strong aperiodic short term variability ($<$ 1 s)
- shot noise models, *many* parameters (Lochner et al., 1991, ApJ, 376, 295)
- success describing aperiodic variability of AGN (*EXOSAT*, 91 h orbit) using a new stochastic approach (König, Staubert, & Wilms, 1997, A&A, 326, 25)

$\Rightarrow$ **apply the new variability model to “the” prototype for “noise”: Cyg X-1**

The Linear State Space Model (LSSM)



Modeling 900 Cyg X-1 *EXOSAT* lightcurves (of 1983-86) in the time domain:

- good description with LSSM(AR[1])
- system equation:

  $x(t) = a_\tau \times x(t-1) + \epsilon(t), \epsilon(t) \propto N(0, \sigma_\epsilon^2)$

  observation equation:

  $y(t) = x(t) + \eta(t), \eta(t) \propto N(0, \sigma_\eta^2)$
- $\tau = 0.19 \pm 0.04$ **s, one relaxation time scale is sufficient!**

Pottschmidt, König, Wilms, & Staubert, 1998, A&A, 334, 201

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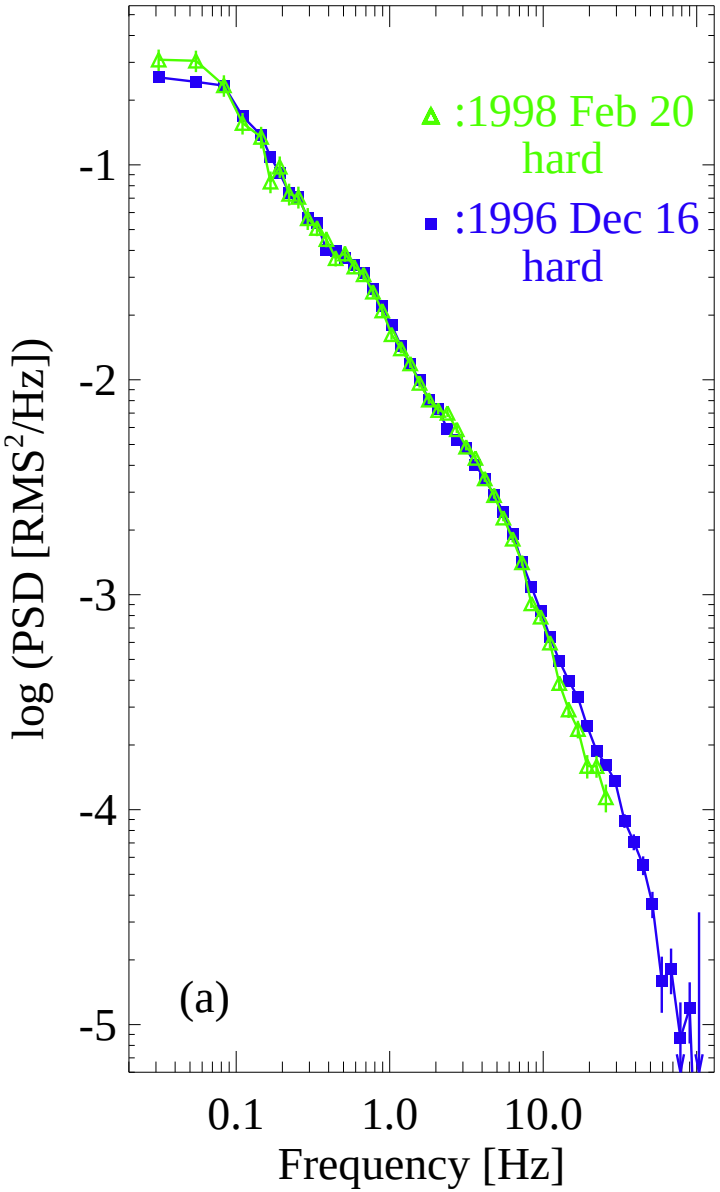
The Power Spectrum: Zooming In



$P(\nu) = \nu \times (A\langle|FT(x(t))|^2\rangle - \mathrm{Noise})$:
variance at a given frequency

The big picture in 1998

- break frequencies in the PSD
  (Nowak et al., 1999, ApJ, 510, 874)
- importance of:
  – spectro-temporal modeling
  – evolution of states (disk↔corona)
  – jets

⇒ **14-daily *RXTE/Ryle* monitoring of the prototype Cyg X-1, 1998 – today**

Pottschmidt, Wilms, Nowak, Gleissner, Pooley, Heindl, Smith, Staubert, . . .

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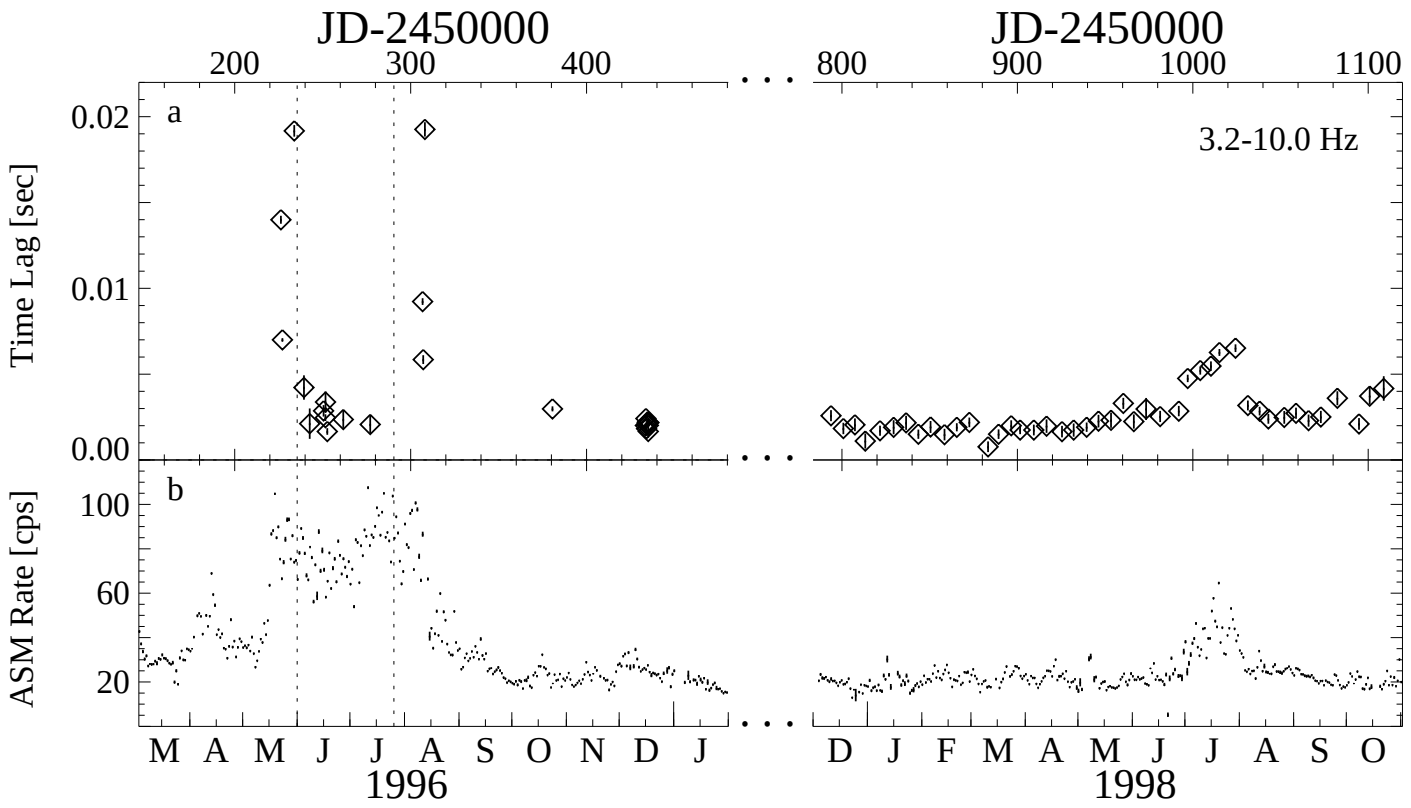
Time Lags



variability structures at higher energies are delayed

(2–4) vs (8–13) keV

Pottschmidt et al., 2000, A&A, 357, L17

- **enhanced time lags during state transitions + "failed transitions"**
- idea: vertically extended corona, in connection with (radio) outflow
- meanwhile also seen in other BHCs, e.g., GX 339−4 (Nowak et al., 2003), XTE J1650−500 (Kalemci et al., 2002)

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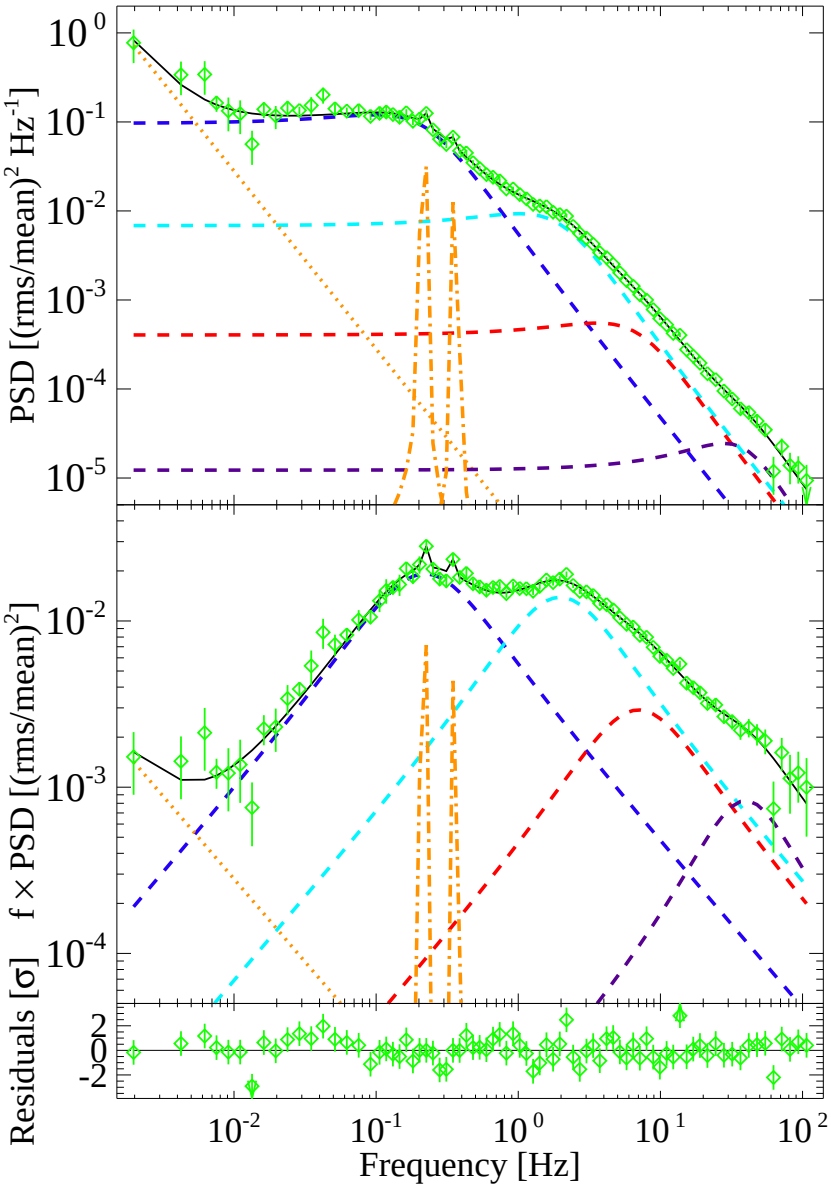
Broad Lorentzians



- **the hard state power spectrum can be well described by 4 broad Lorentzians**
  (Pottschmidt, Wilms, Nowak, Pooley, Gleissner, Heindl, Smith, Remillard, Staubert, 2003, 407, 1039)
- meanwhile this is well known, confirmed for many XRBs (same frequency correlations as for the narrow QPOs of NS and WD)
- work is on-going to understand this, most promising at the moment: characteristic GR frequencies imposed on the accreting material

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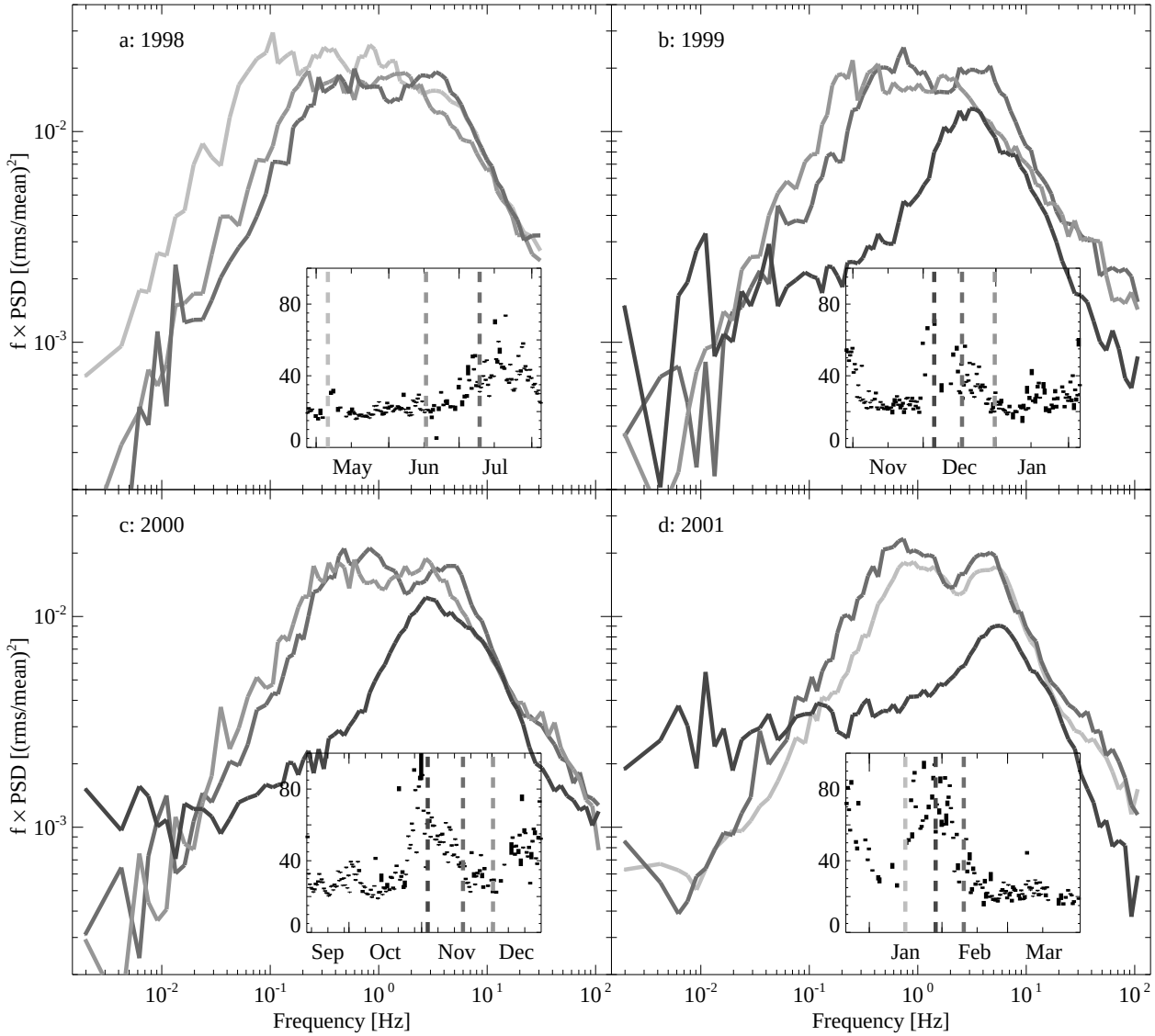
Lorentzians & Failed State Transitions



- characteristic evolution of the contribution of each noise component during failed state transitions
- during the peak of the flare, the power spectrum is enhanced in the same frequency range as the time lags

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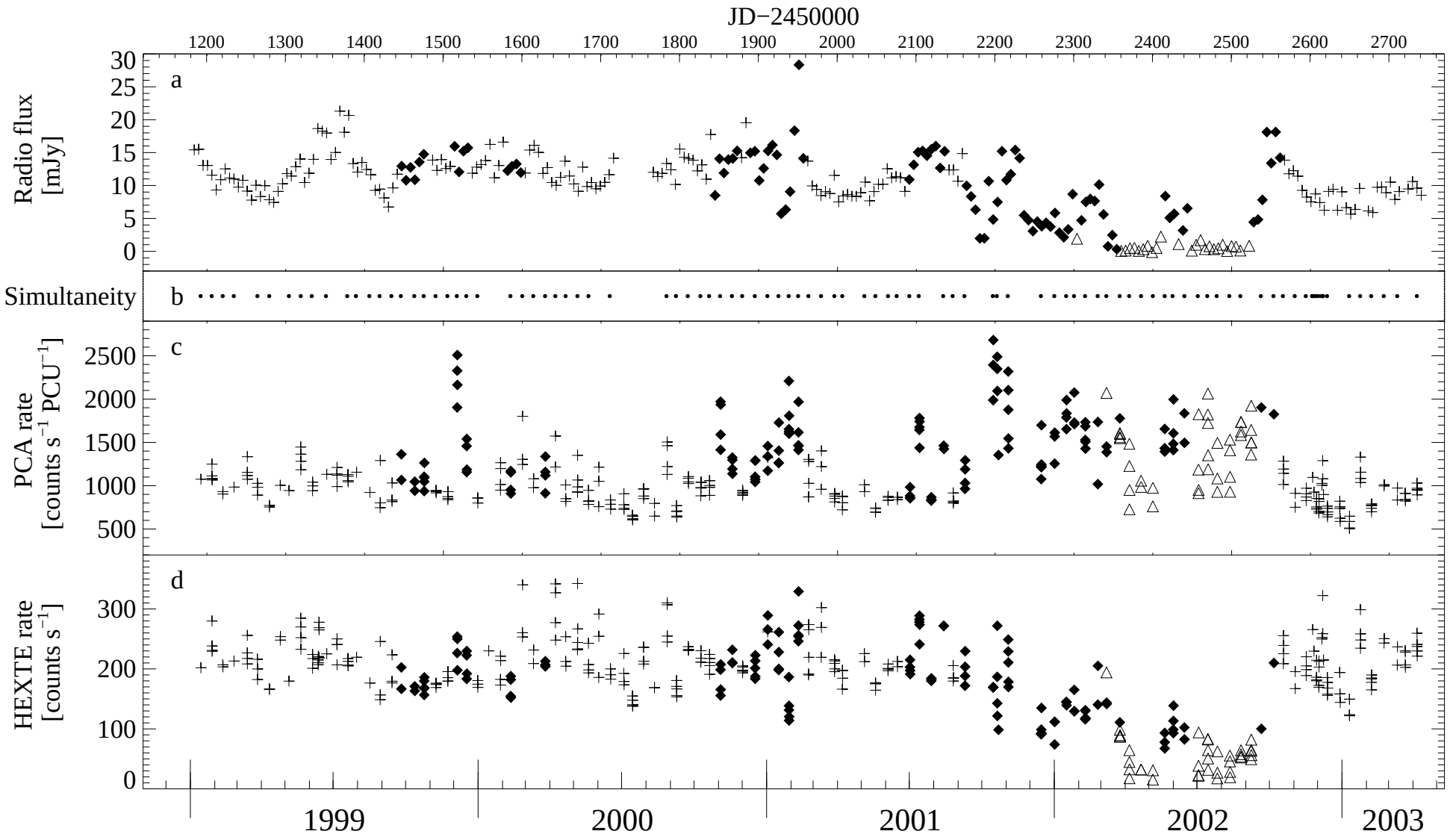
On-going monitoring



Gleissner et al., 2004, A&A, submitted; state definitions: Benlloch, Pottschmidt, et al., 2004, Proc. XRT 2003

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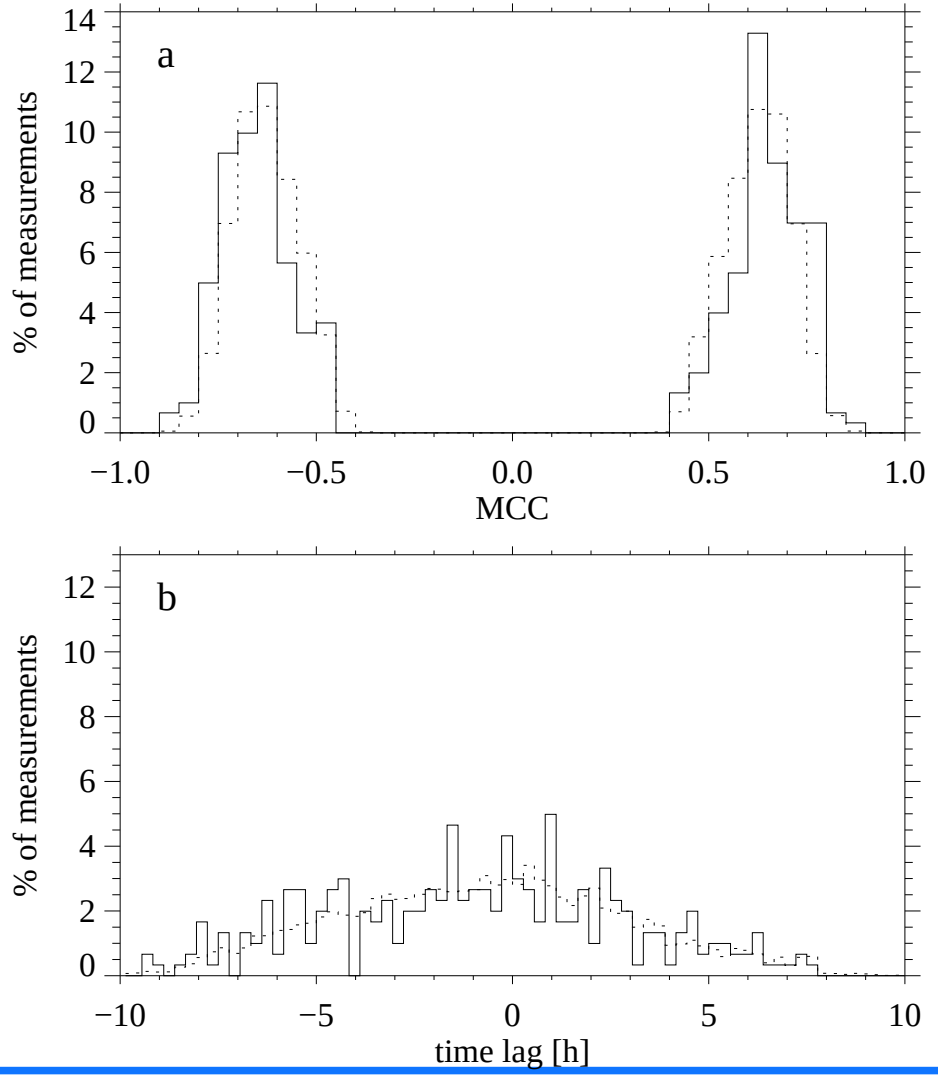
X-ray / Radio Correlations & More

The big picture in 2001 ++

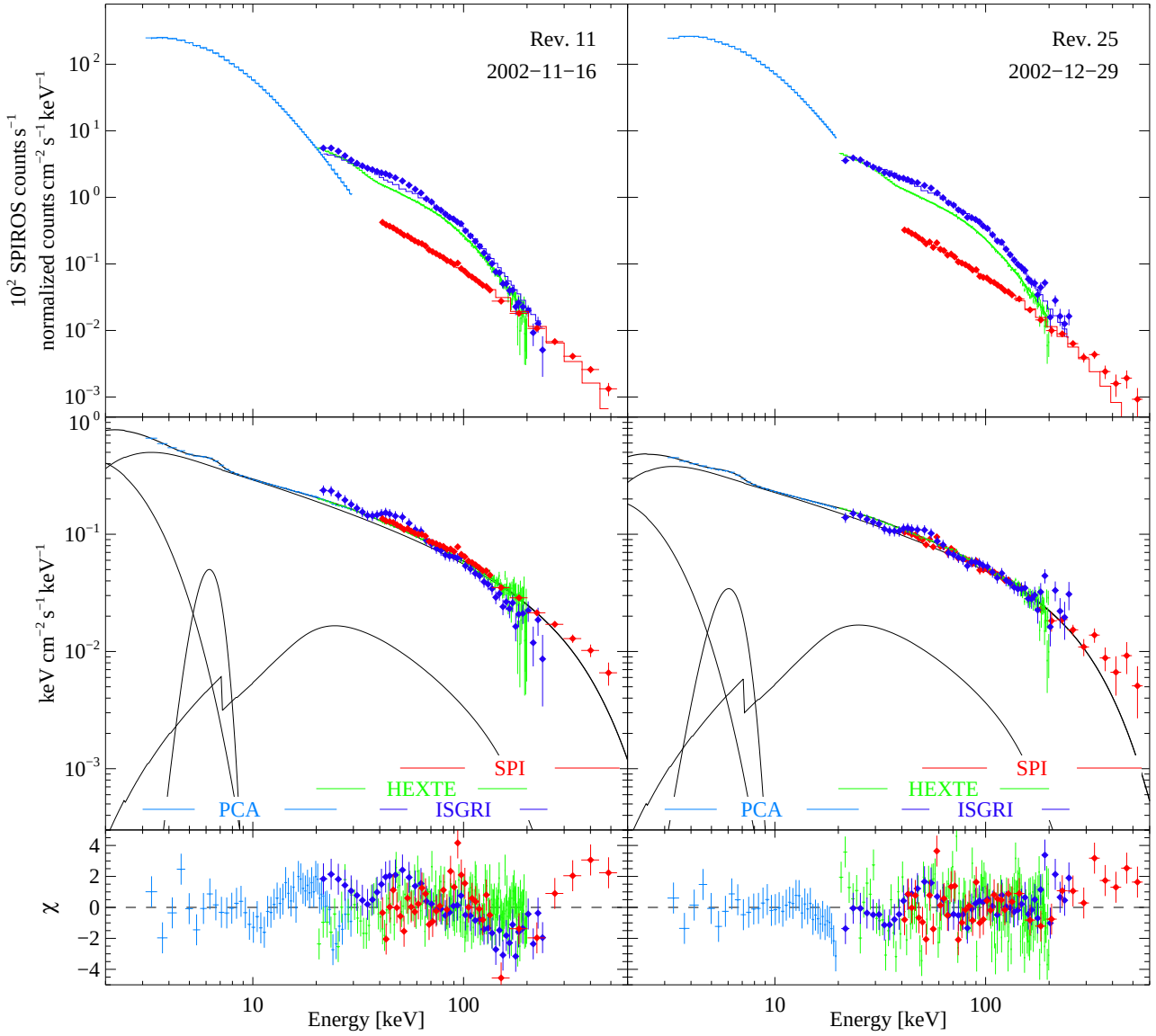
continuation of *RXTE/Ryle* monitoring: PhD work of Thomas Gleissner (IAAT)

- **rms/flux correlation confirmed** for all Cyg X-1 observations
  (Gleissner, Wilms, Pottschmidt, Uttley, Nowak, Staubert, 2004, A&A, in press)
- **no correlation radio/X-ray flux on time scales of $\sim$32 s–5 h**
  (Gleissner, Wilms, Pooley, Nowak, Pottschmidt, Markoff, Heinz, Klein-Wolt, Fender, Staubert, 2004, A&A, submitted)

  $\rightarrow$ indication for moderate jet speeds
- further evaluation of jet models: $\Rightarrow$ ***INTEGRAL-RXTE* campaign**



INTEGRAL/RXTE Spectrum



- `c×phabs×(diskbb+gauss +compTT+reflect(compTT))`
- **results (e.g., Rev. 11):**
  $\tau = 0.71^{+0.05}_{-0.07}$, $kT = 82^{+16}_{-5}$ **keV,**
  $\Omega/2\pi = 0.11^{+0.01}_{-0.01}$, $\chi^2_{\rm red} = 1.58$
- also: thermal `eqpair`, `2compTT`
- work in progress, need better calibration (ISGRI 10% systematic error)

Pottschmidt, Wilms, Chernyakova, Nowak, Rodriguez, Zdziarski, Beckmann, Kretschmar, Gleissner, Pooley, Martínez-Núñez, Courvoisier, Schönfelder, Staubert, 2003, A&A, 411, L383

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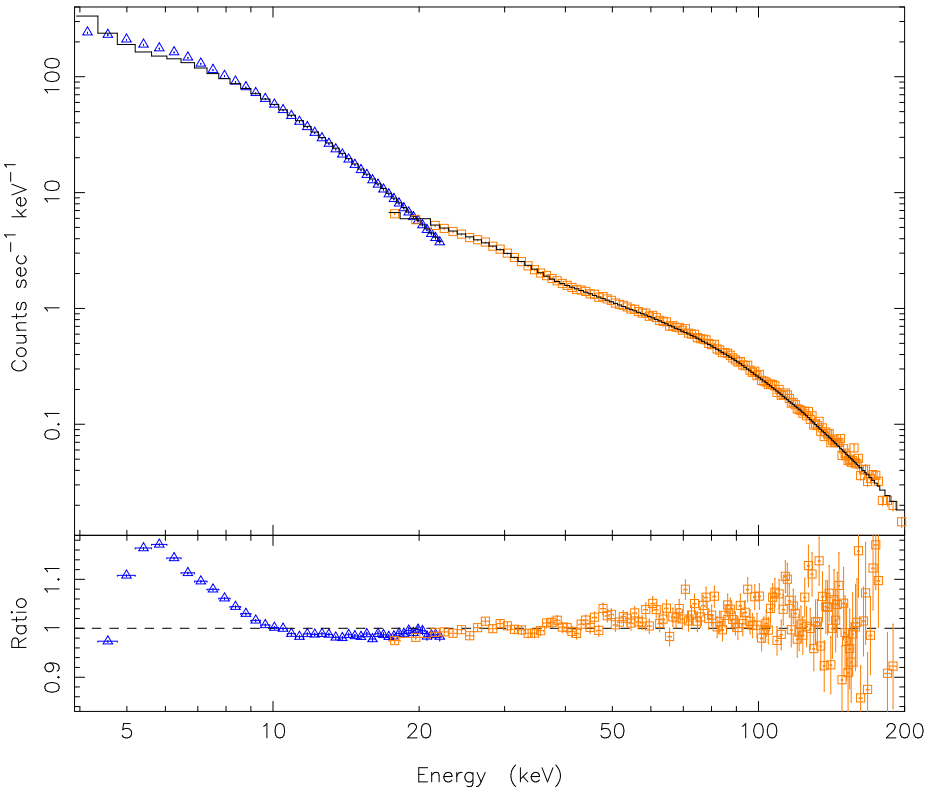
Cyg X-1 & The Future

- as calibration and intrinsic variability permit: extend spectral modeling to higher energies
- extend *INTEGRAL/RXTE* comparison to timing
- halo studies (see also talk by P. Predehl) using a recent *Chandra* observation of Cyg X-1 (Pottschmidt, Nowak, Wilms)
- even broader Cyg X-1 data set to be obtained in 2004 Nov:

  ***INTEGRAL–XMM–RXTE* (PI Wilms) / *Ryle* (Pooley) / *HST* (proposed, PI Dolan) / *Spitzer* (proposed, PI Heinz)**



courtesy Mike Nowak and Sera Markoff

- spectral fitting using the jet models of Markoff et al. (first example see above)