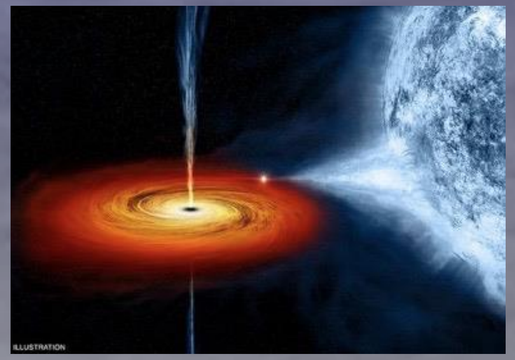
Never throw away old data: Cygnus X-1's fast X-ray variability behaviour in the 70's revisited…

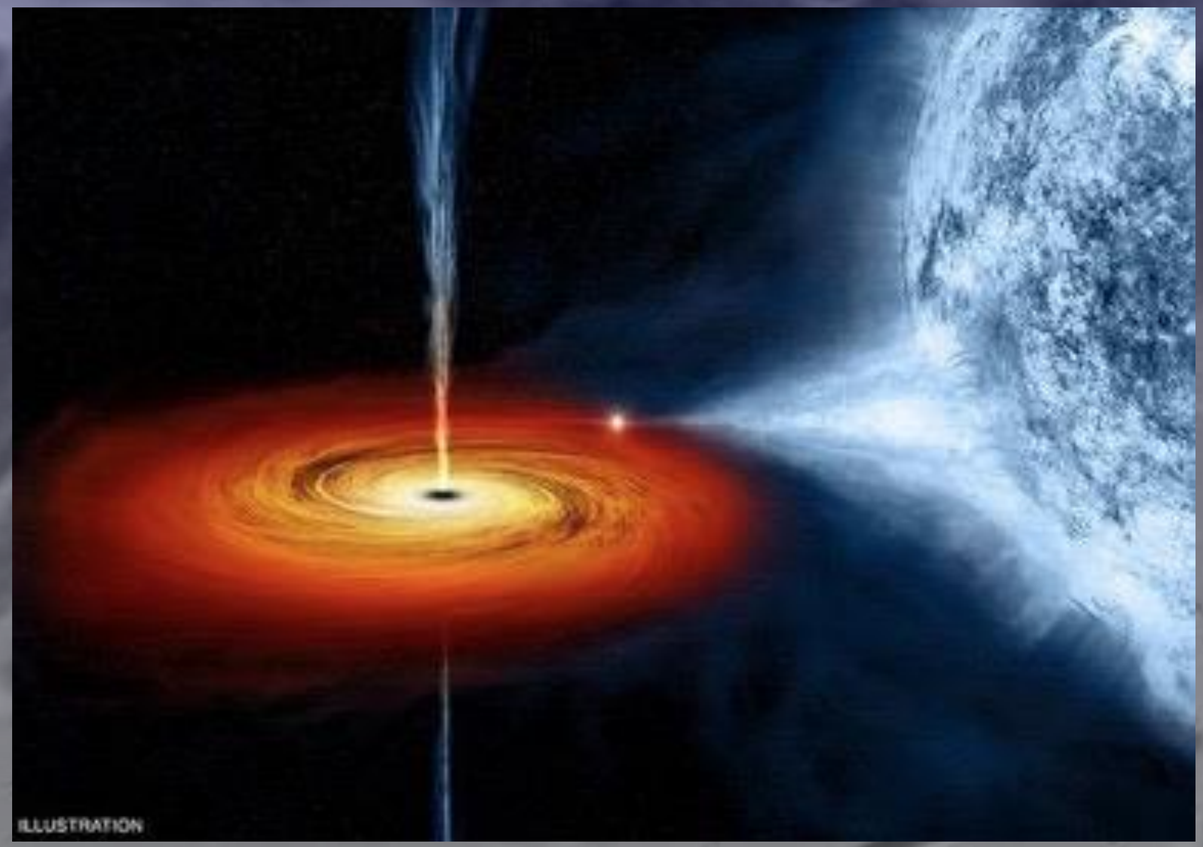


Erik Kuulkers
European Space Agency

Adam Ingram *Newcastle University*
Victoria Grinberg *ESA/ESTEC*
Jörn Wilms *University of Erlangen-Nuremberg*
Katja Pottschmidt *CRESST, UMBC & NASA/GSFC*
Rick Rothschild *University of California at San Diego*
Yoan Mollard *Bordeaux INP*

Cygnus X-1

- Discovered early 60’s
- X-ray binary
- O-star: 41 $M_{\odot}$
- Black Hole: 21 $M_{\odot}$
- Orbital period: 5.6 days
- Distance: 2.2 kpc

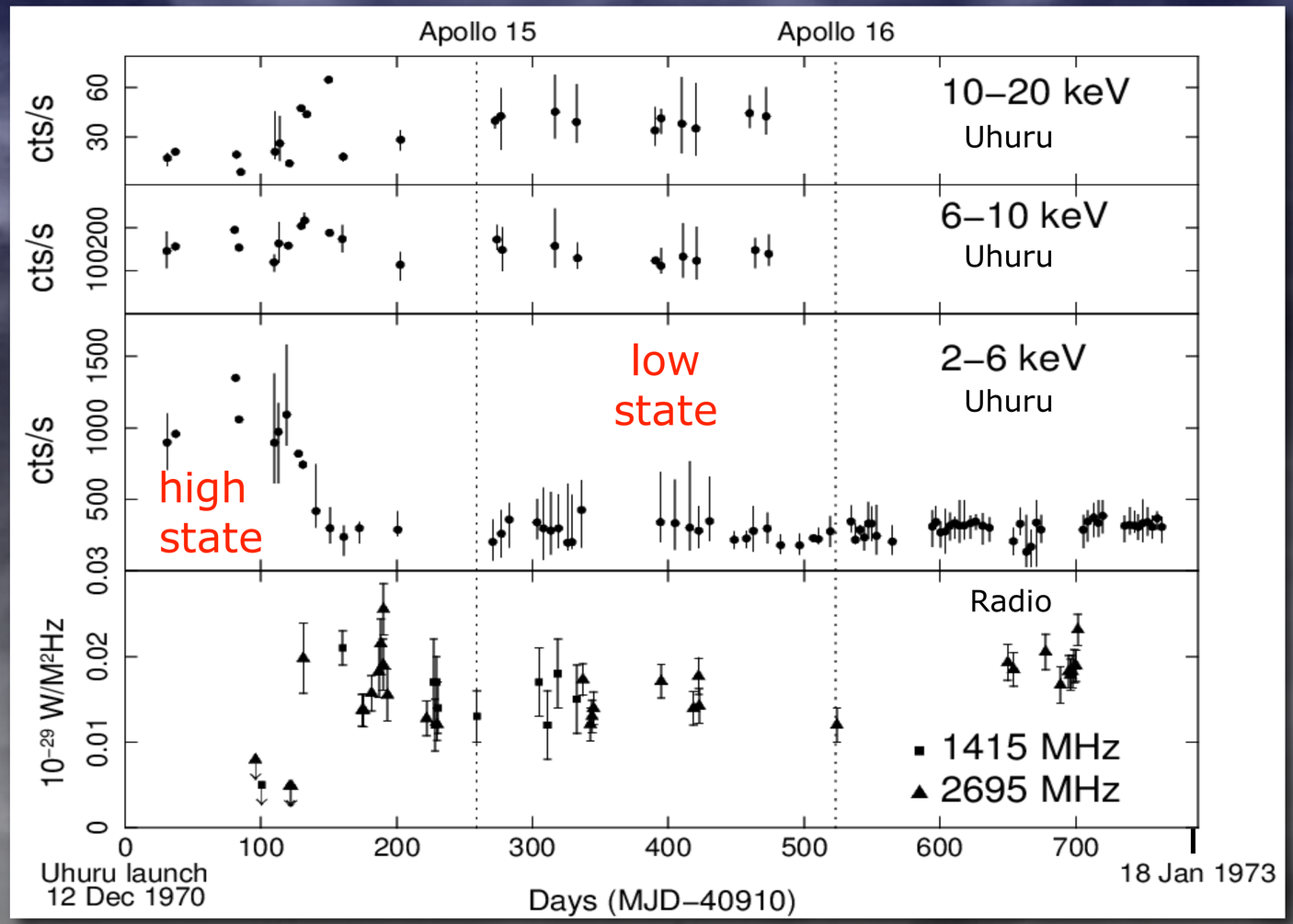


Cygnus X-1 1st long-time X-ray lightcurve

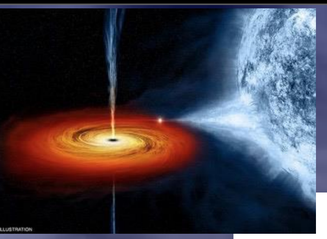
"Hard" X-rays

"Soft" X-rays

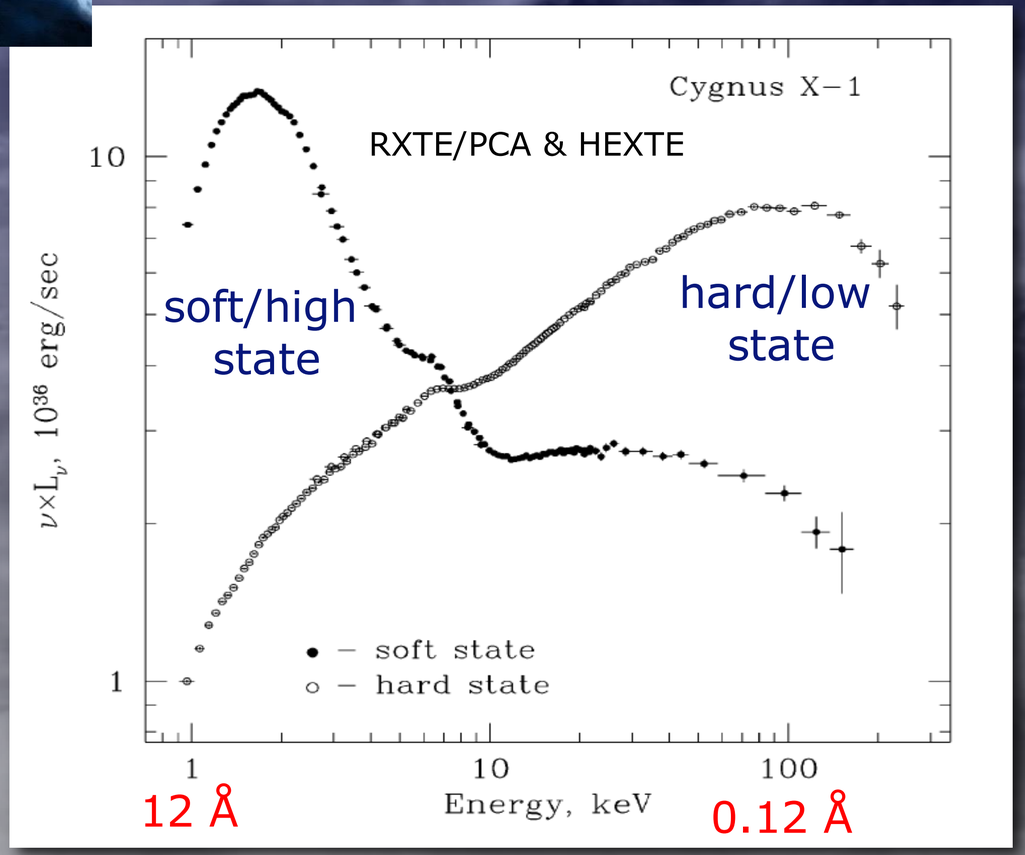
radio

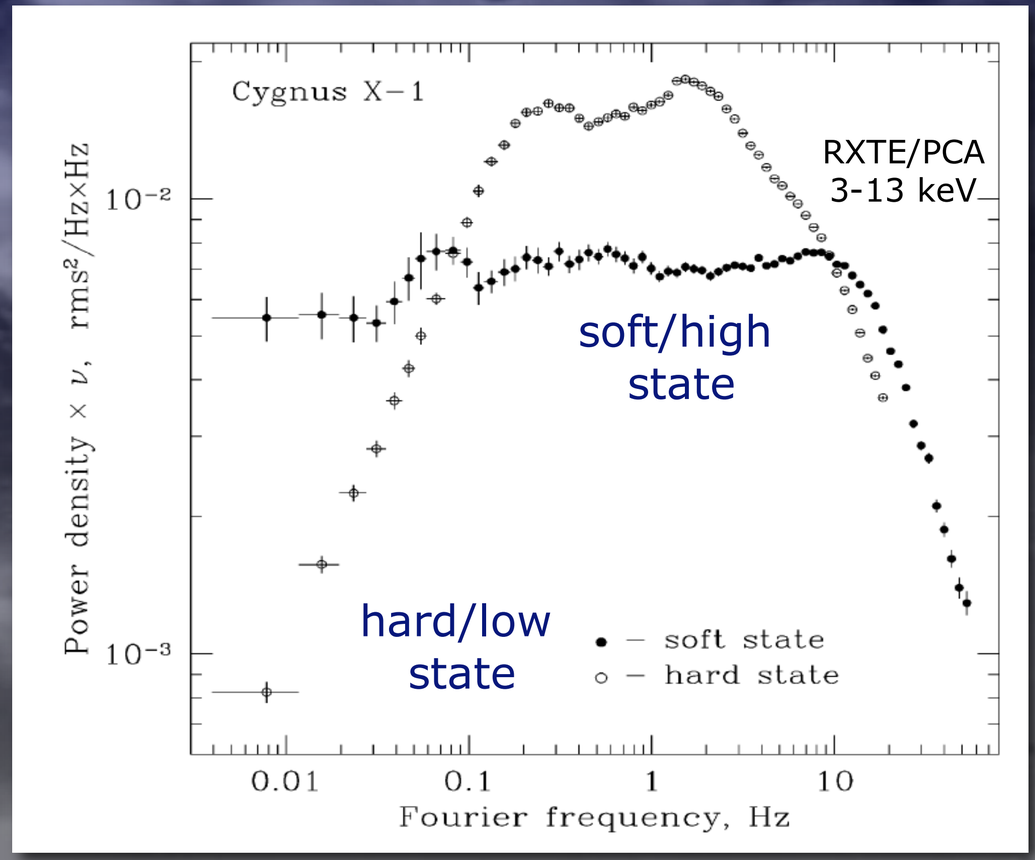


Tananbaum *et al.* 1972 & Giacconi 1974



Cygnus X-1 X-ray states





Gilfanov *et al.* 2000

X-ray states in X-ray binaries are mainly defined by their spectra and timing behaviour
These states correspond to different accretion regimes of the compact object:
Accretion rate **increases** from low to high state

Cygnus X-1 low state observations

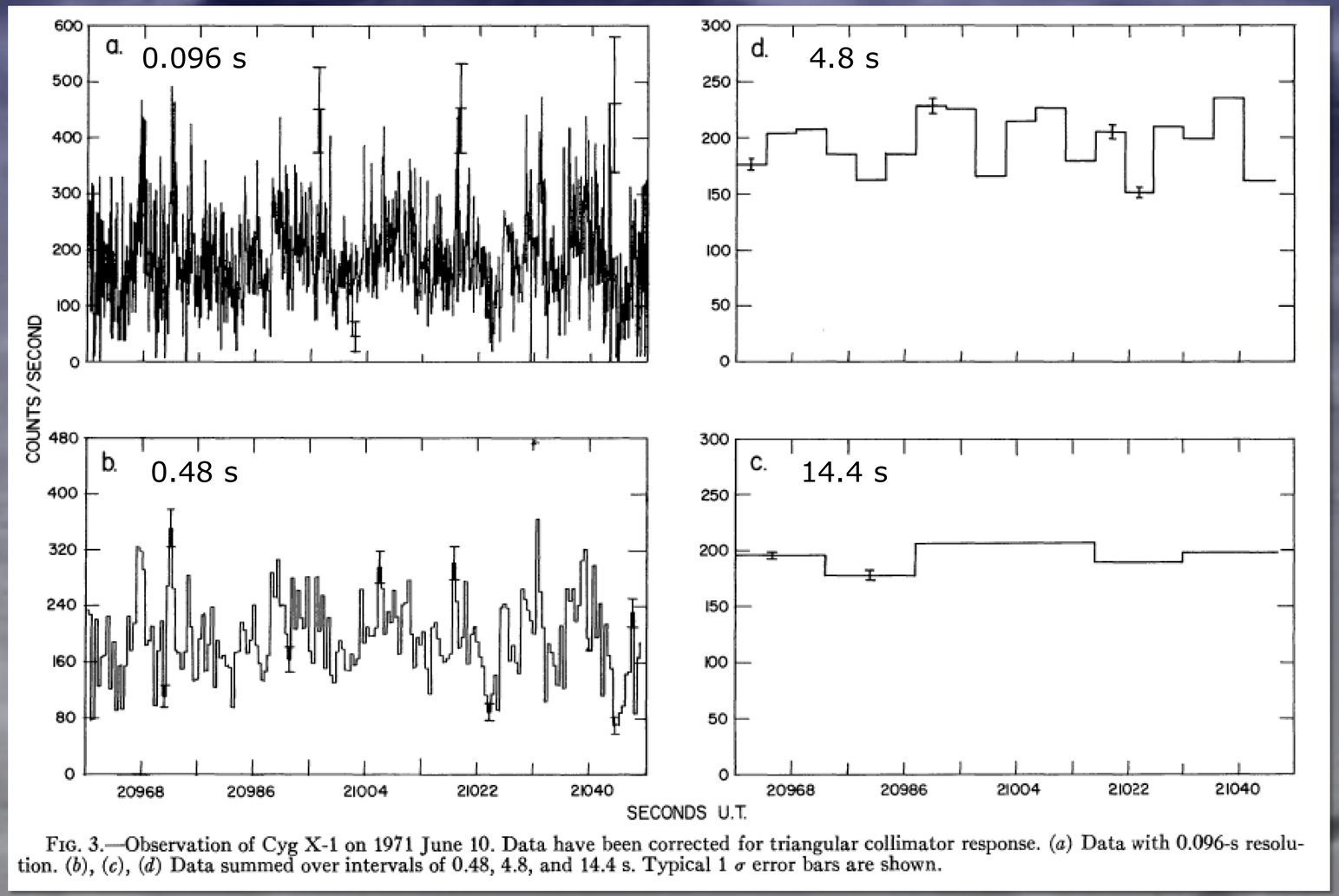


FIG. 3.—Observation of Cyg X-1 on 1971 June 10. Data have been corrected for triangular collimator response. (*a*) Data with 0.096-s resolution. (*b*), (*c*), (*d*) Data summed over intervals of 0.48, 4.8, and 14.4 s. Typical 1 σ error bars are shown.

Schreier *et al.* 1971 - Uhuru; 10 June 1971

Cygnus X-1 Apollo 15 X-ray observations

Apollo 15 X-ray data: binary tape dump at NASA Space Science Data Coordinated Archive (NSSDC)

IBM 360/370 data structure

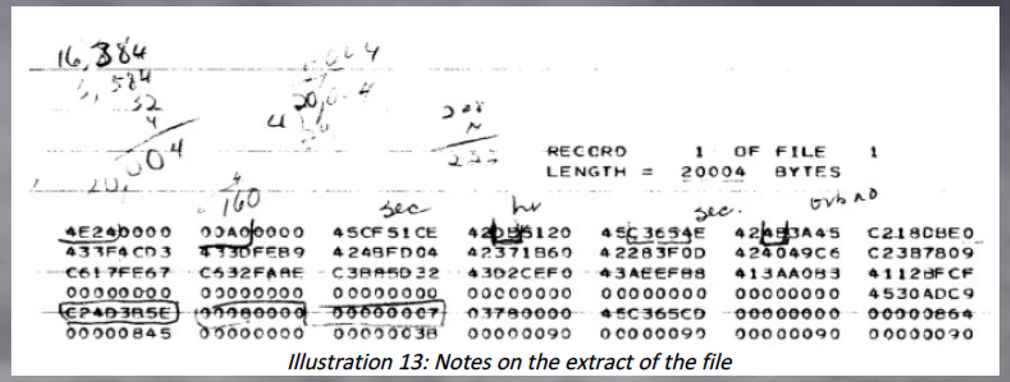
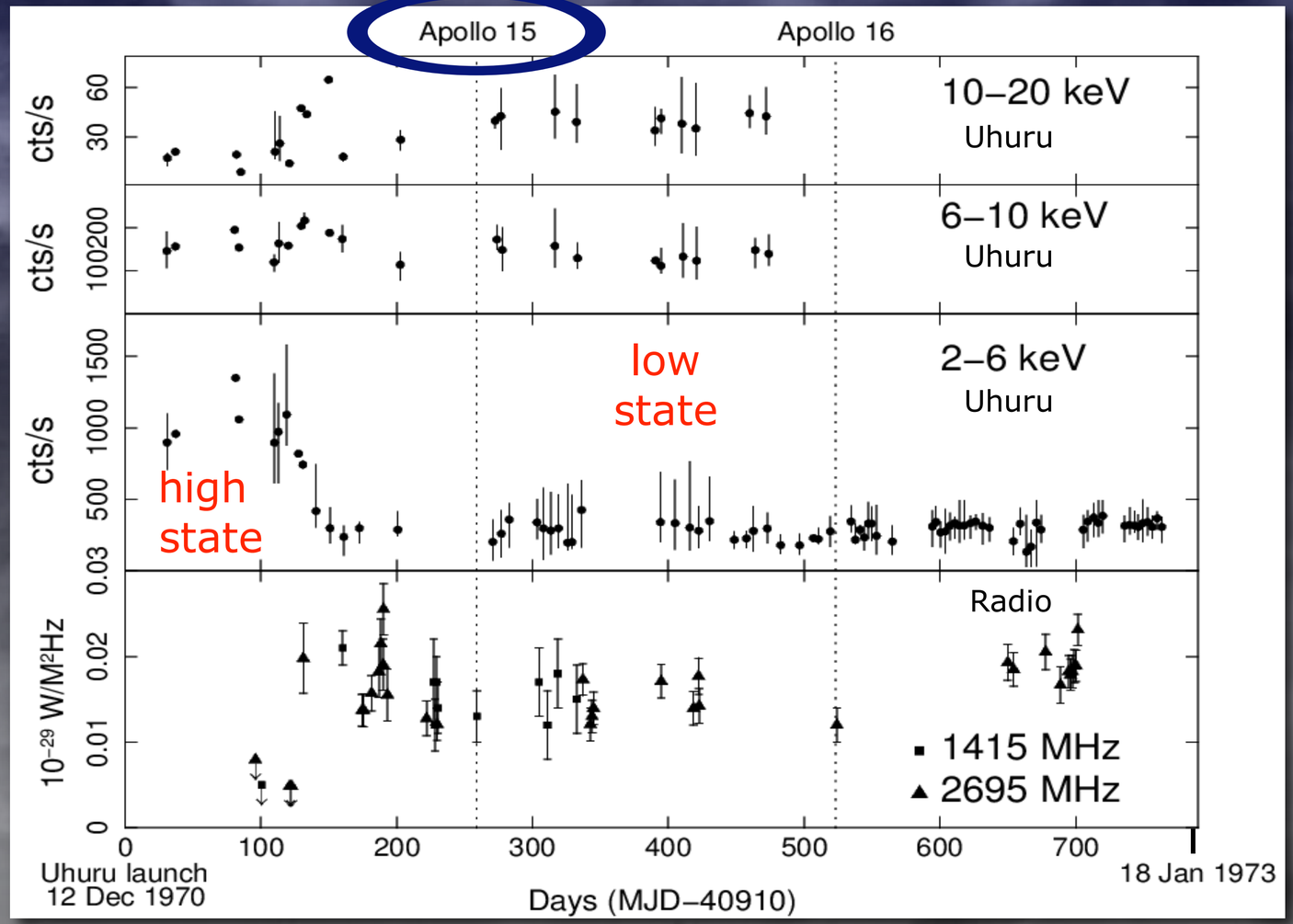


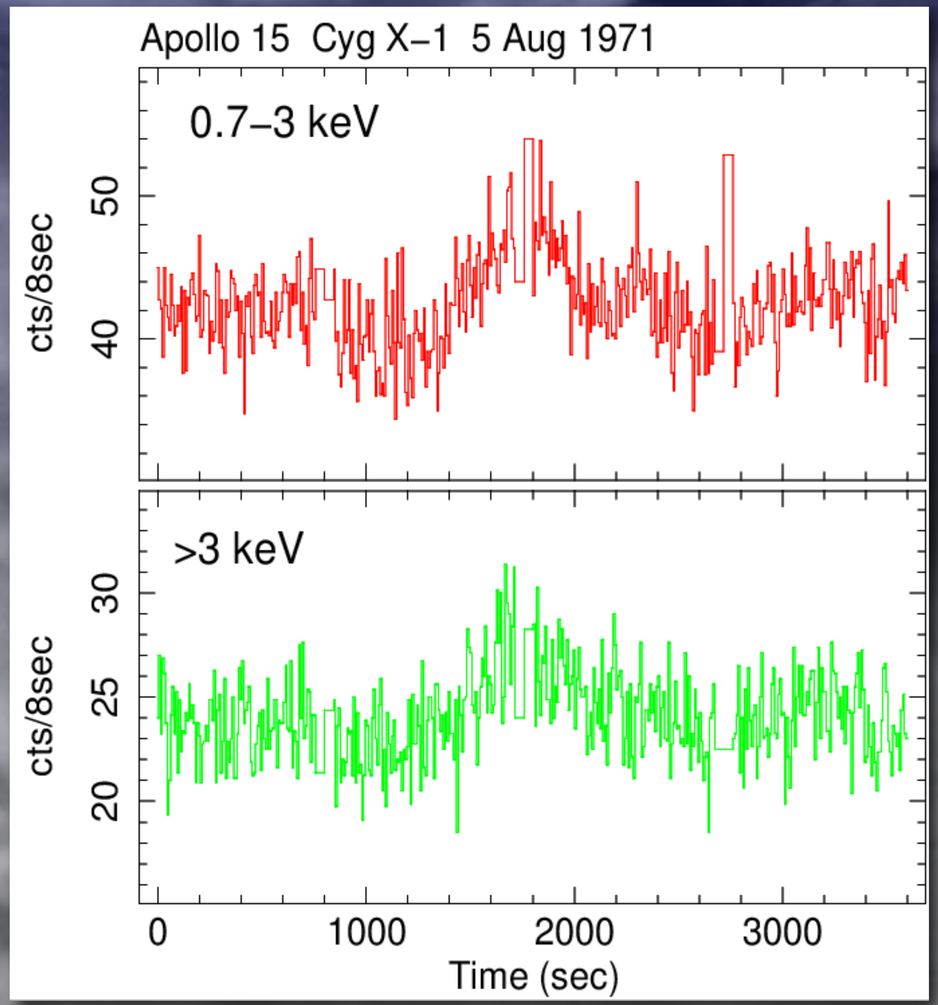
Illustration 13: Notes on the extract of the file

Yoan Mollard 2011-212, 3-month intern @ ESAC

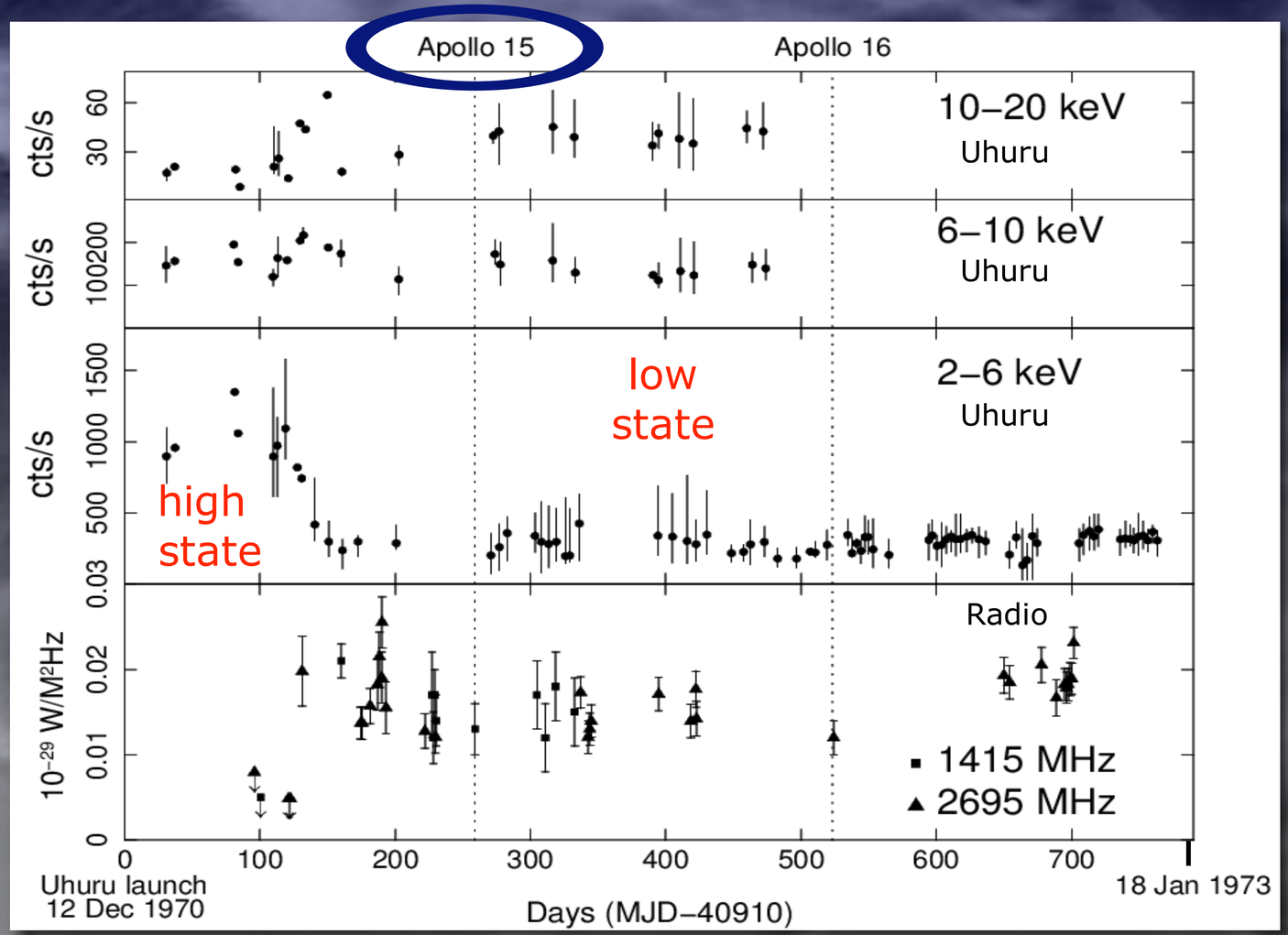


Tananbaum *et al.* 1972 & Giacconi 1974

Cygnus X-1 Apollo 15 X-ray observations



First long (30-60 min) pointed X-ray observations!



Tananbaum *et al.* 1972 & Giacconi 1974

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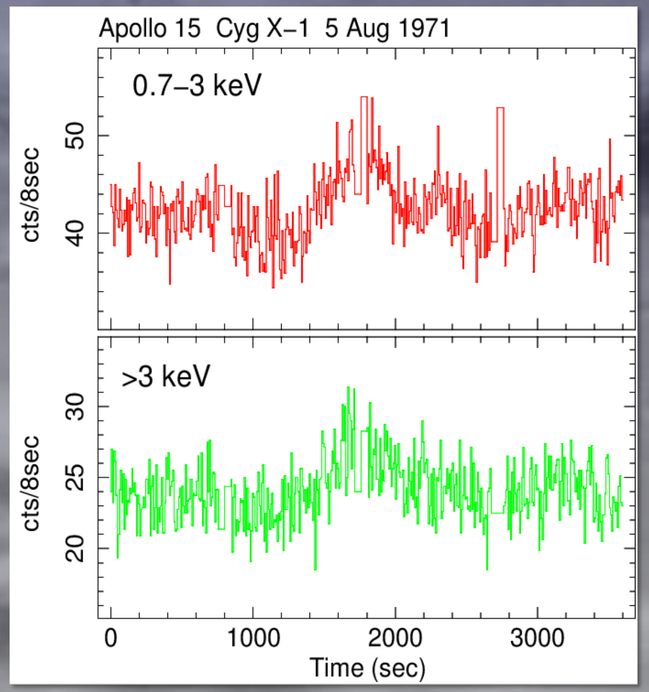
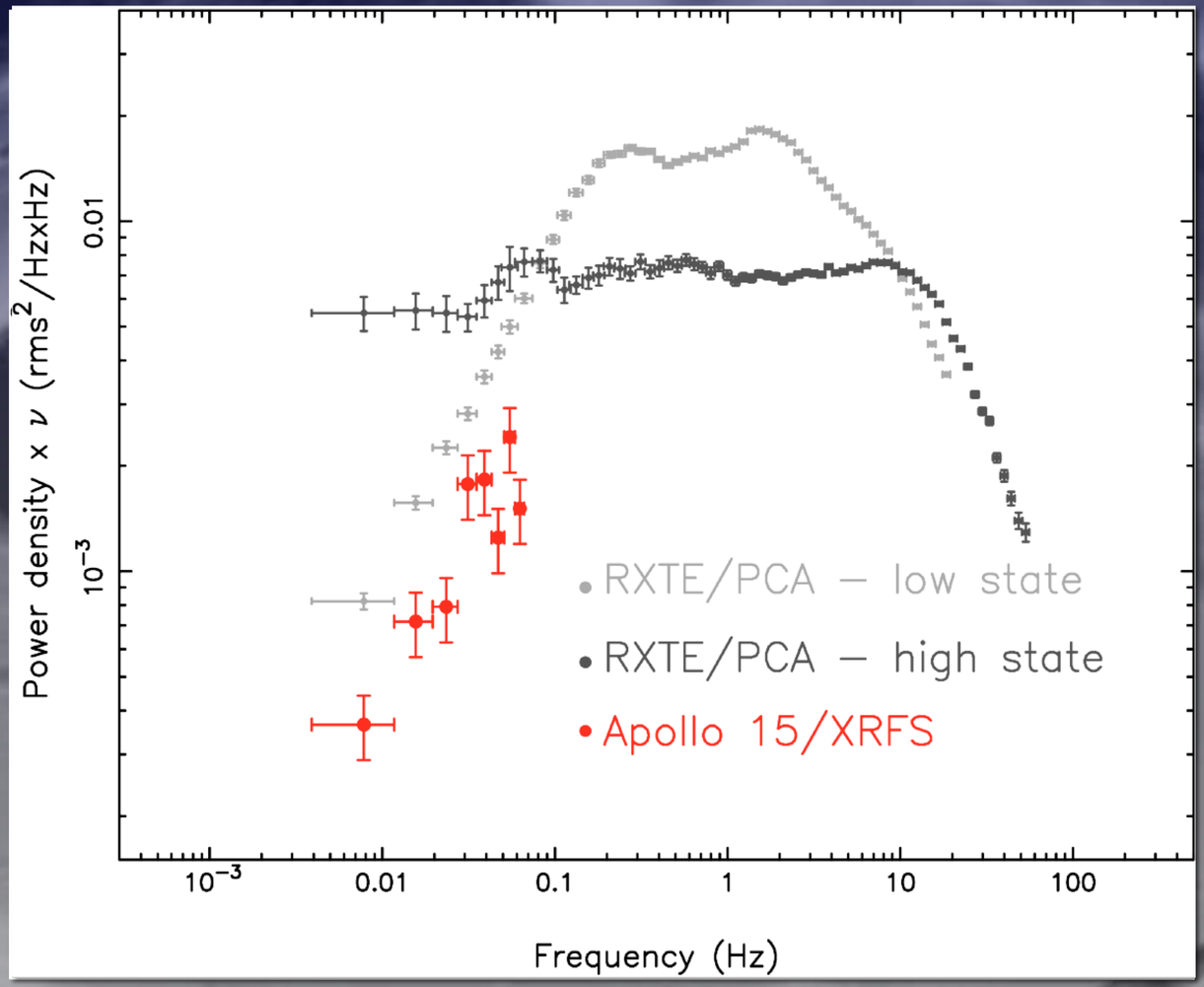
Cygnus X-1 Apollo 15 X-ray observations





Apollo 15: 0.7->3 keV

RXTE/PCA: 3-13 keV

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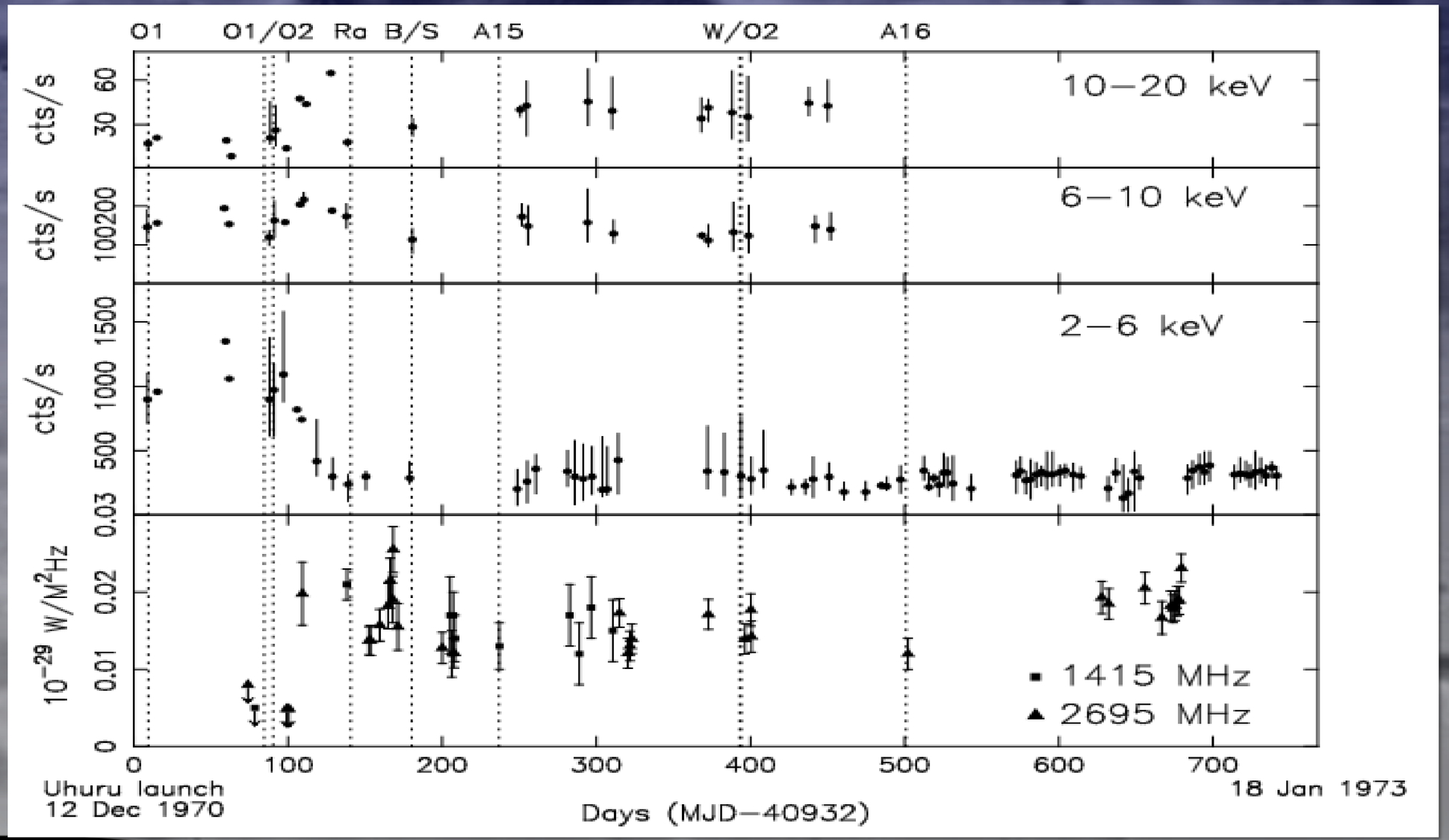
Cygnus X-1 70's X-ray observations



Cygnus X-1 70’s X-ray observations

Use literature to digitize (*by hand*, *during pandemic*) data from:

- Uhuru
- SAS-3
- HEAO-1
- + various rocket flights

- Energy ranges between 0.25-60 keV, one to several bands
- Time resolution from 7.8 μs (HEAO-1/A-1) to 8 s (Apollo 15/XRFS)

Cygnus X-1 70's X-ray observations

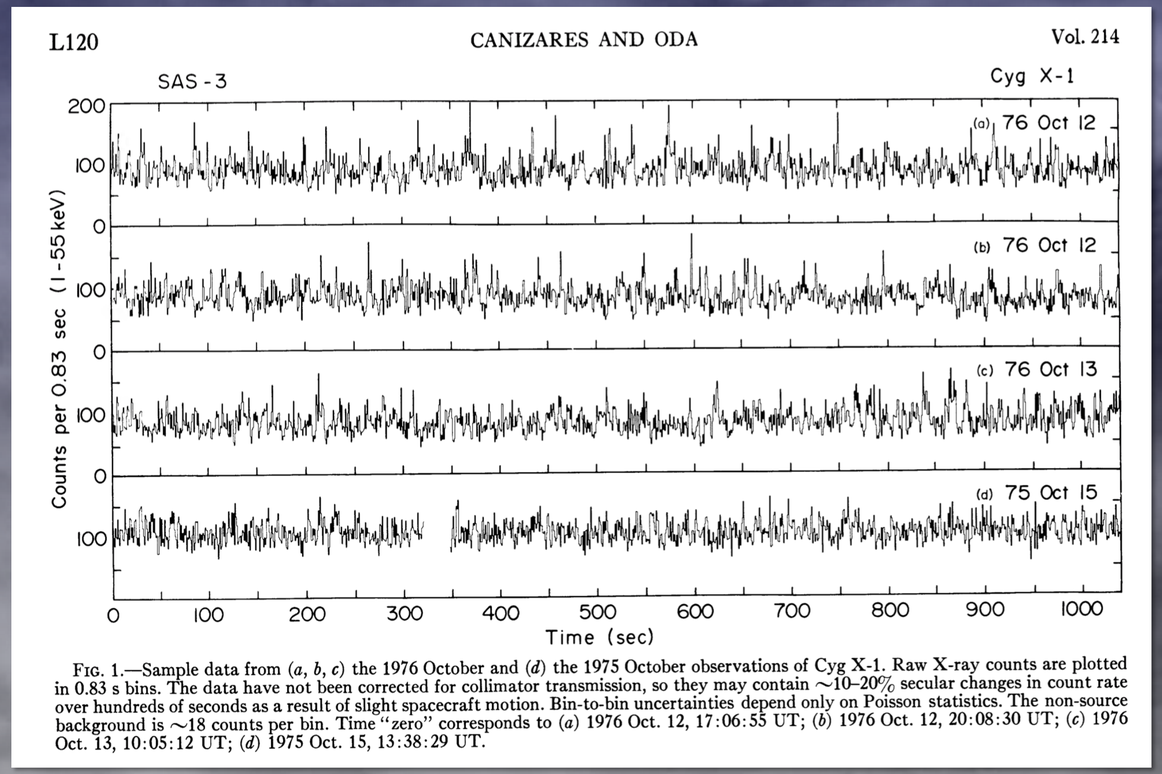
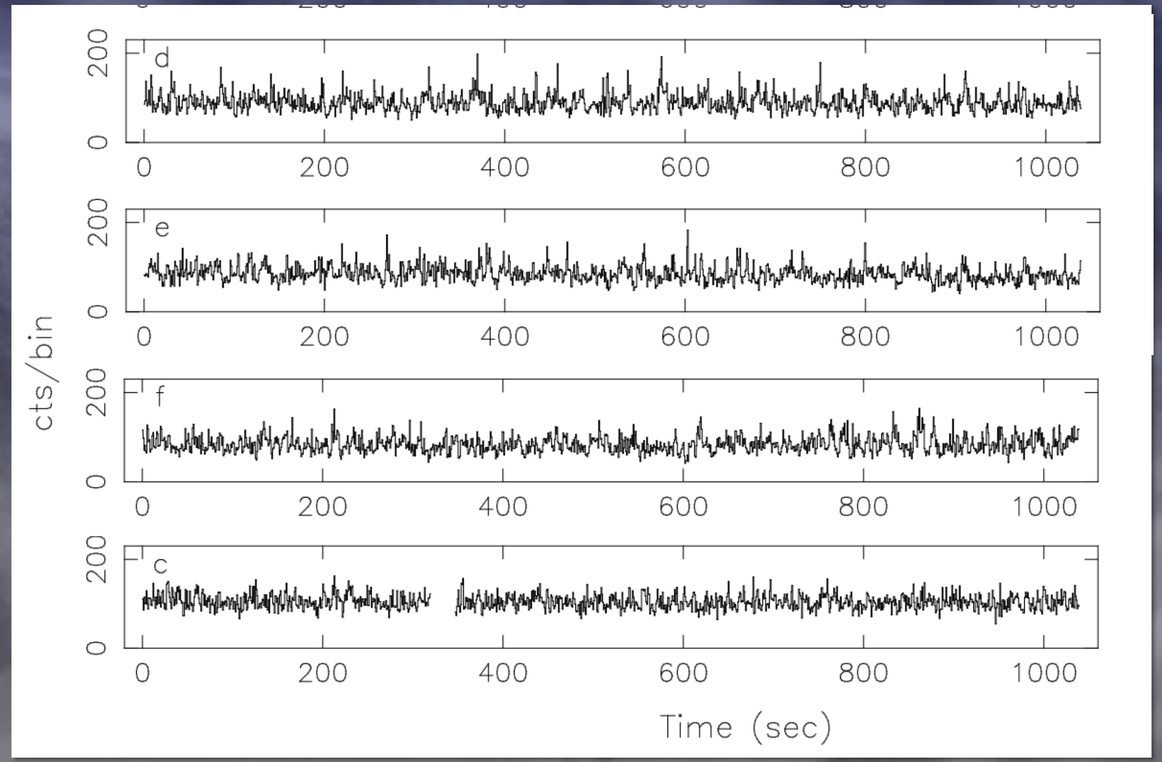
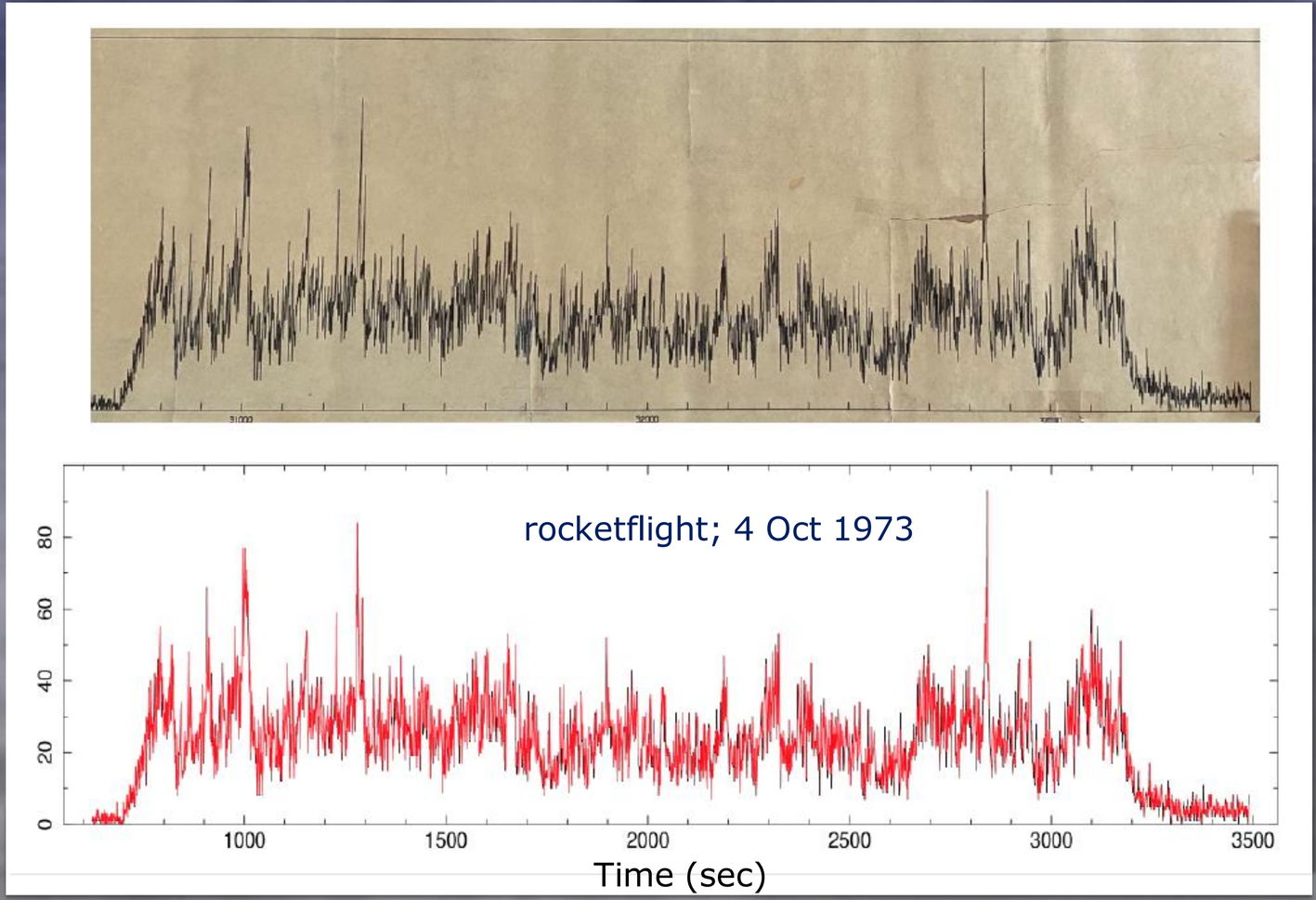


FIG. 1.—Sample data from (*a*, *b*, *c*) the 1976 October and (*d*) the 1975 October observations of Cyg X-1. Raw X-ray counts are plotted in 0.83 s bins. The data have not been corrected for collimator transmission, so they may contain ~10–20% secular changes in count rate over hundreds of seconds as a result of slight spacecraft motion. Bin-to-bin uncertainties depend only on Poisson statistics. The non-source background is ~18 counts per bin. Time "zero" corresponds to (*a*) 1976 Oct. 12, 17:06:55 UT; (*b*) 1976 Oct. 12, 20:08:30 UT; (*c*) 1976 Oct. 13, 10:05:12 UT; (*d*) 1975 Oct. 15, 13:38:29 UT.

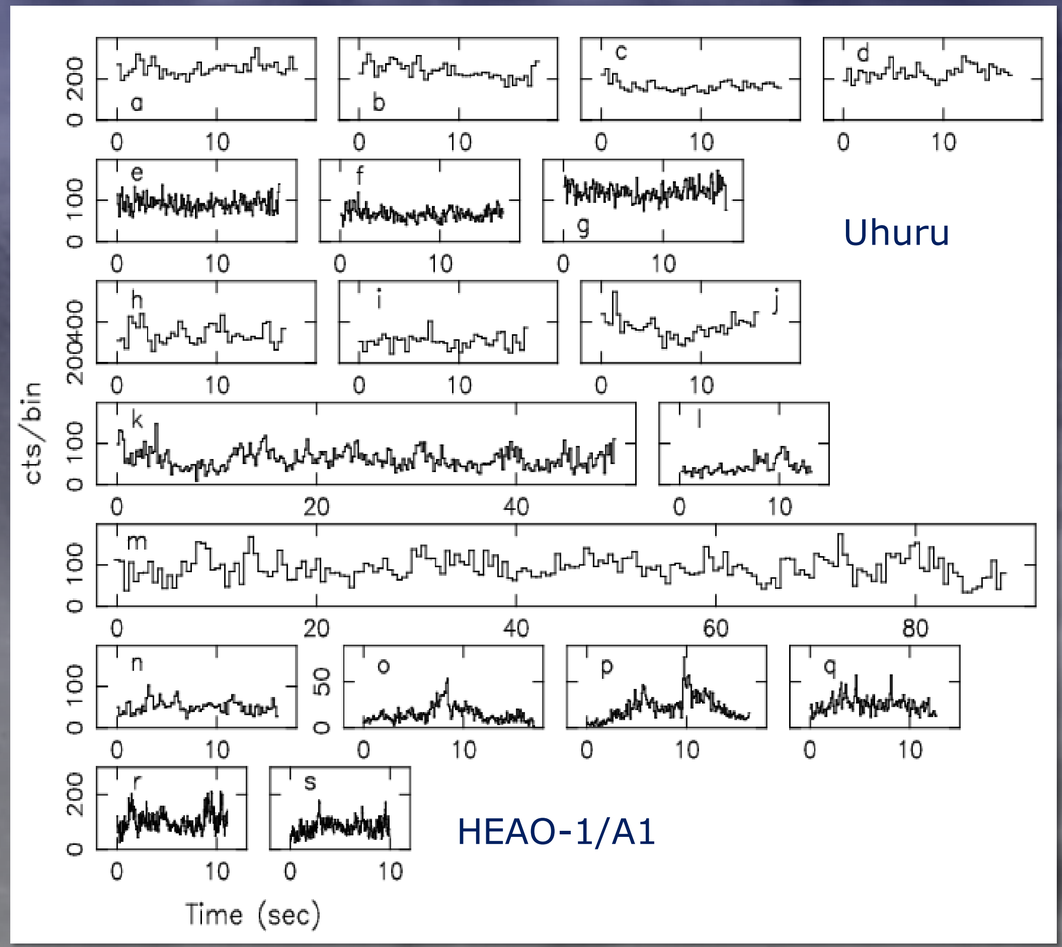


Canizares & Oda 1977 (SAS-3; 0.83 s; 1-55 keV)

Cygnus X-1 70's X-ray observations



After Rothschild et al. 1974 (20.48 ms; 1.5-35 keV)



Oda et al. 1971, 1975, 1976; Brinkman et al. 1974; Jones Forman 1974; Schreier et al. 1971, Weisskopf et al. 1971; Meekins et al. 1979

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Cygnus X-1 X-ray state evolution

- Transitions between states are continuous
(e.g., Oda 1977; Belloni et al. 1996: “intermediate state”);

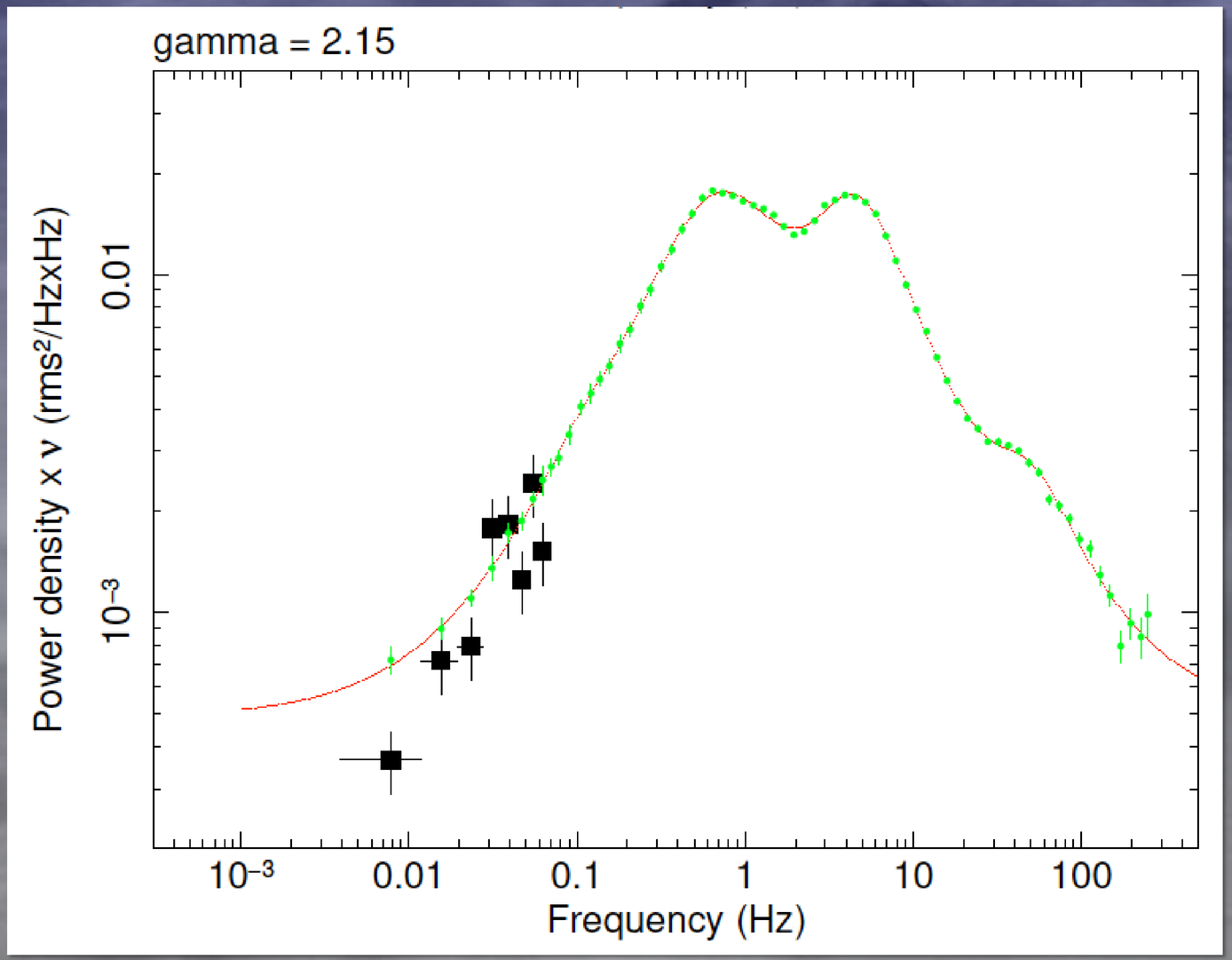
Power spectral shape correlates with energy spectral shape (power-law index) – see Grinberg et al. 2013, 2014

- Compute average power spectra for ~20 spectral shapes from RXTE/PCA data (data from Grinberg et al. 2013, 2014)

- Compute power spectra from 70’s data

- Look for best match between 70’s PDS and RXTE/PCA PDS

Cygnus X-1 70's observations revisited

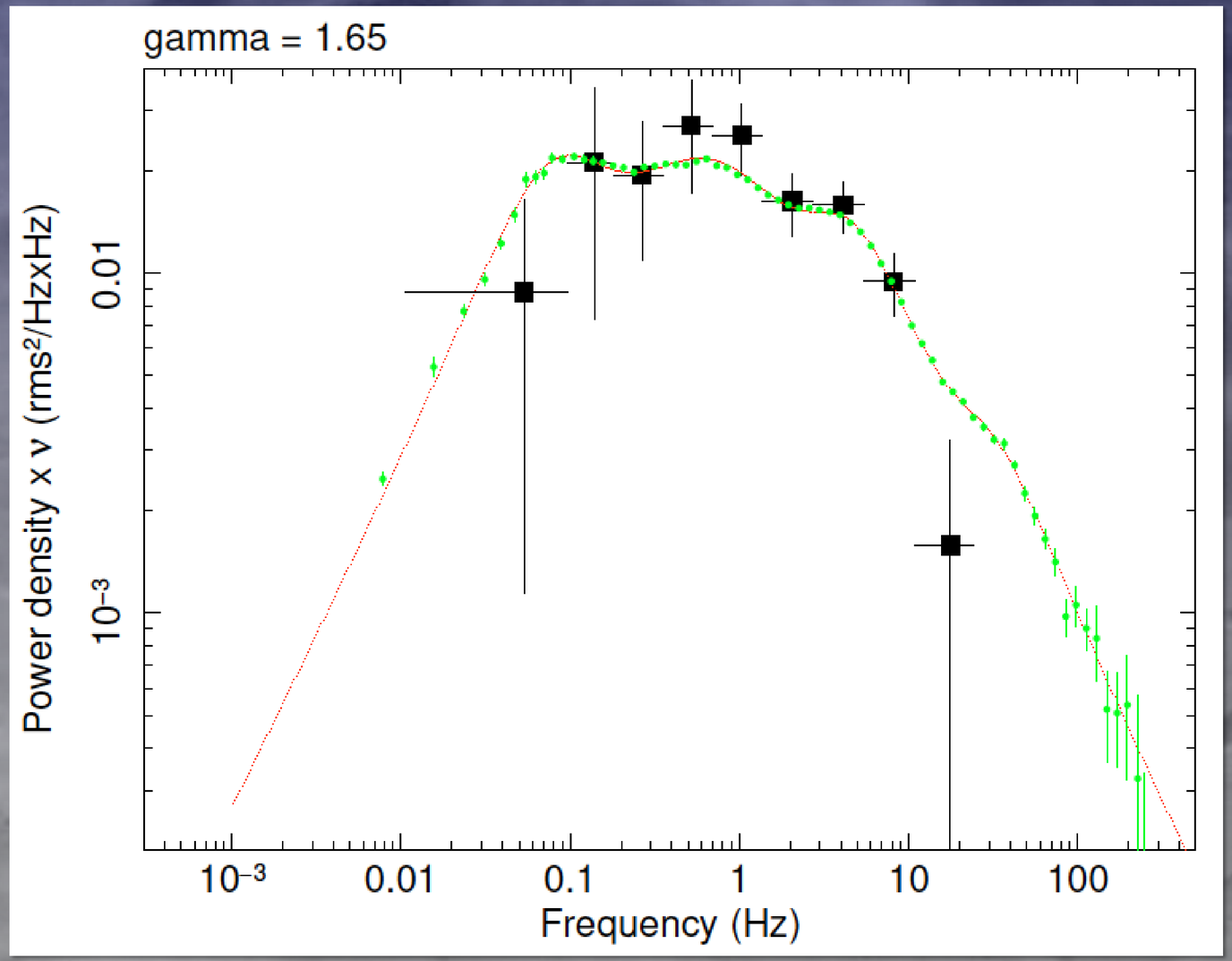


low
state

Apollo 15/XRFS

esa

Cygnus X-1 70's observations revisited

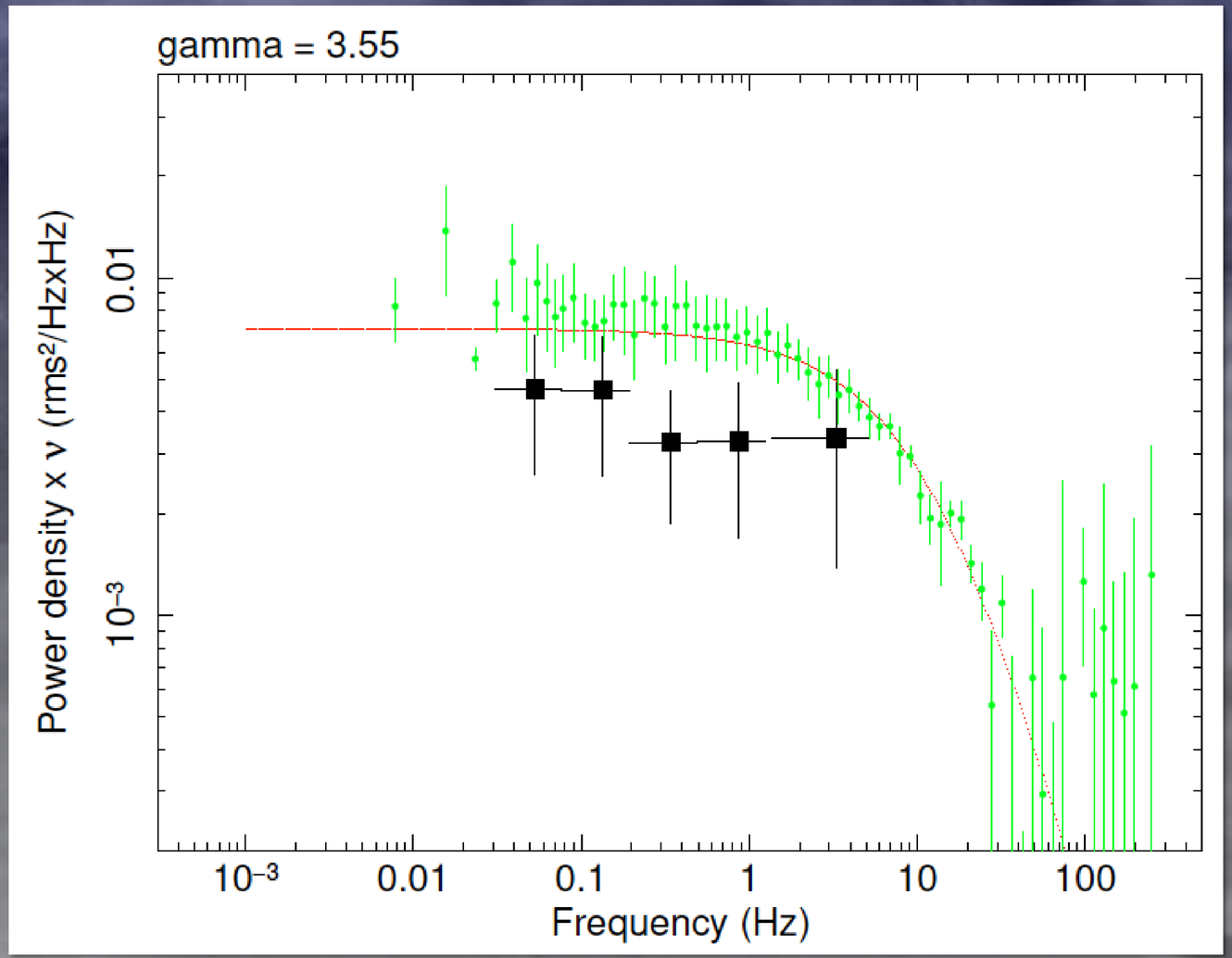


low state

Rocket data (Rothschild et al. 1974)

Cygnus X-1 70's observations revisited

high state



First high-state power spectrum

Uhuru – Dec 1970 & March 1971
(Oda 1971, 1976)

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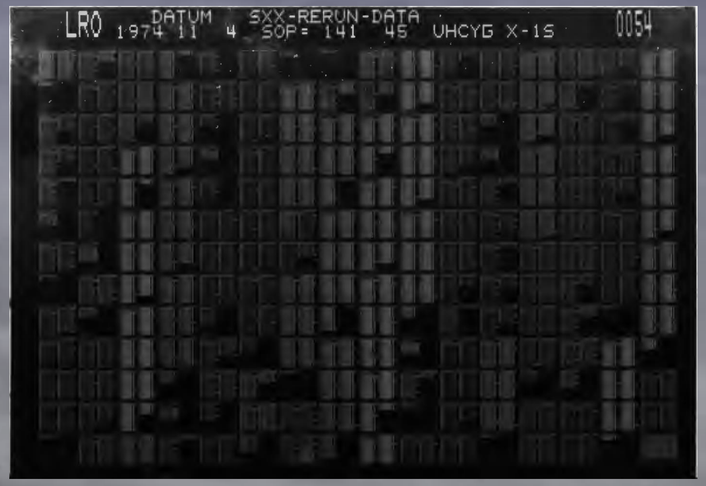
Cygnus X-1 70’s X-ray observations
Conclusions

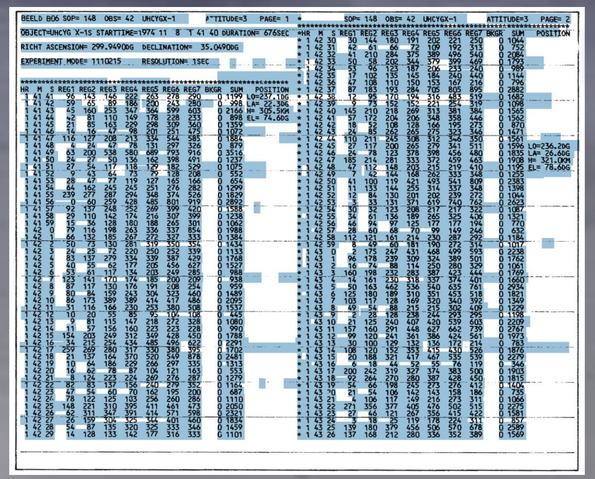
- 70’s data are (not only) of historical value
- 70’s data enable us to compare results with those of much later measurements and interpret them in light of what we know nowadays
- 70’s data extend long-term baseline for characterizing state change behaviour in Cygnus X-1
- **Never throw away old data**: (Legacy) Archives are important!

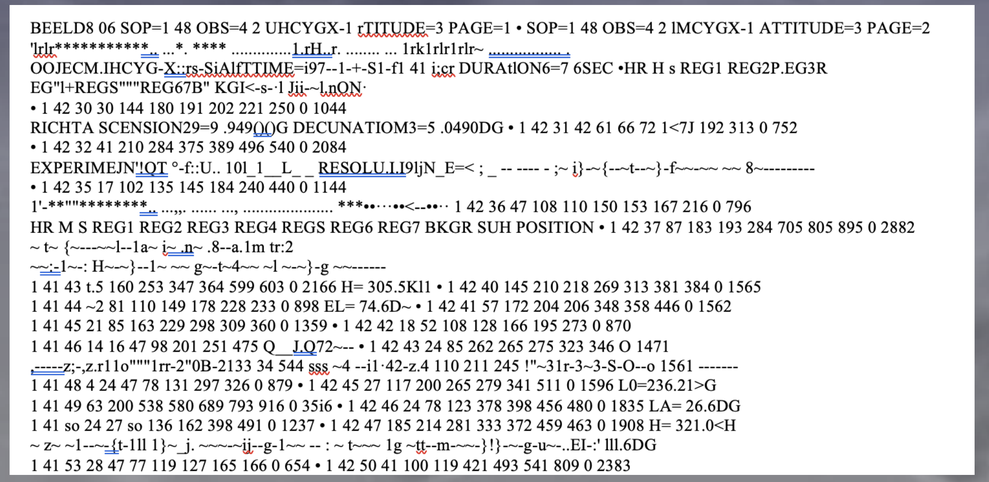
I’m not done yet…

Use scanned and OCR’ed data from:

- Soft X-ray eXperiment (SXX) onboard ANS - 1974/1975
- Energy range 1-7 keV
- Time resolution from 1/8 s (1 energy band) to 4 s (7 energy channels)







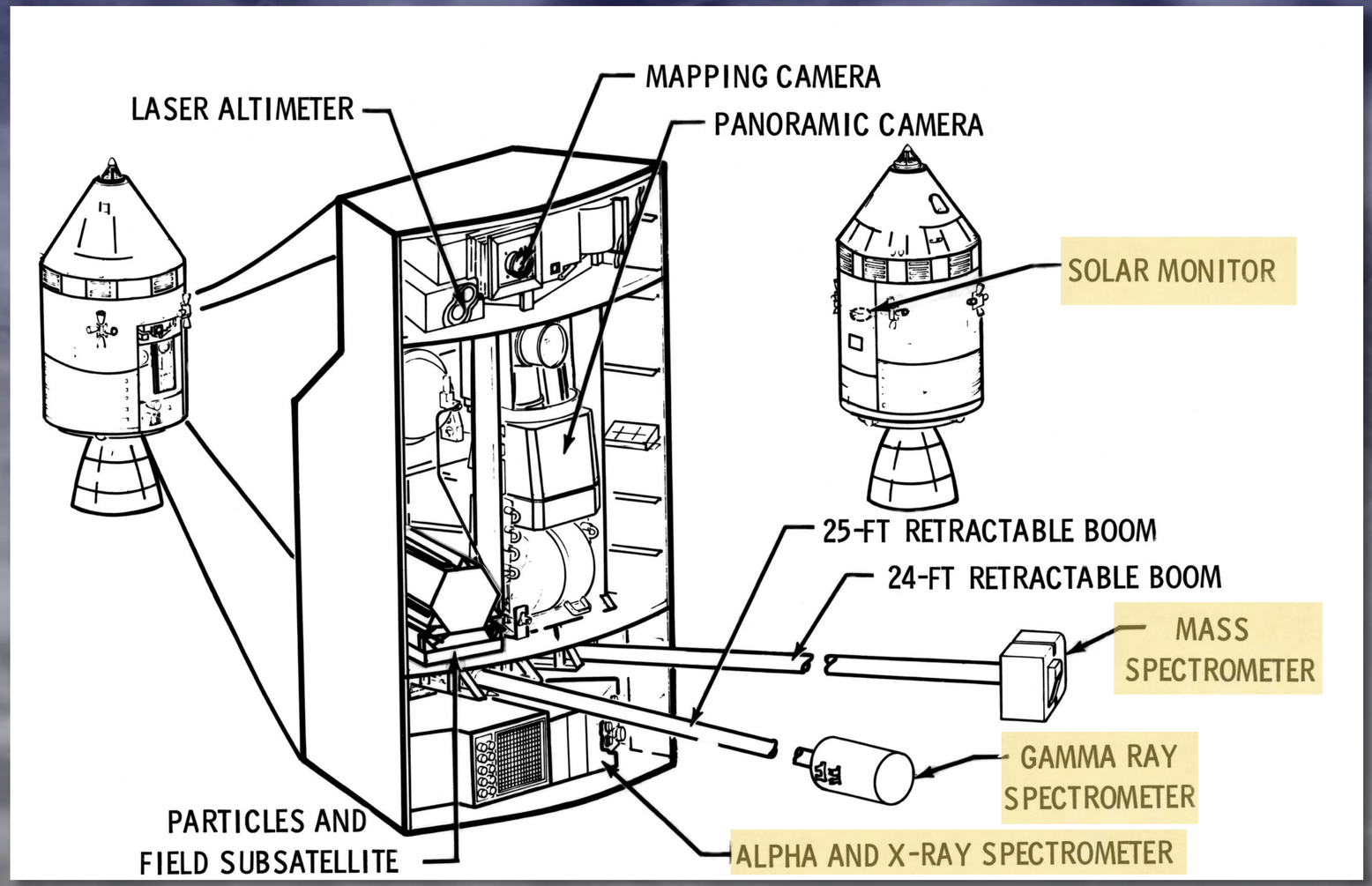
Total: 157 microfiche; each 208 pages of data

X-ray data taken with (sub)second time resolution can uniquely help in defining Cygnus X-1's X-ray states

Thank you

erik.kuulkers@esa.int

CSM - Scientific Instrument Module – SIM-bay



Apollo 15:
26 July – 7 August 1971
Apollo 16:
16 – 27 April 1972

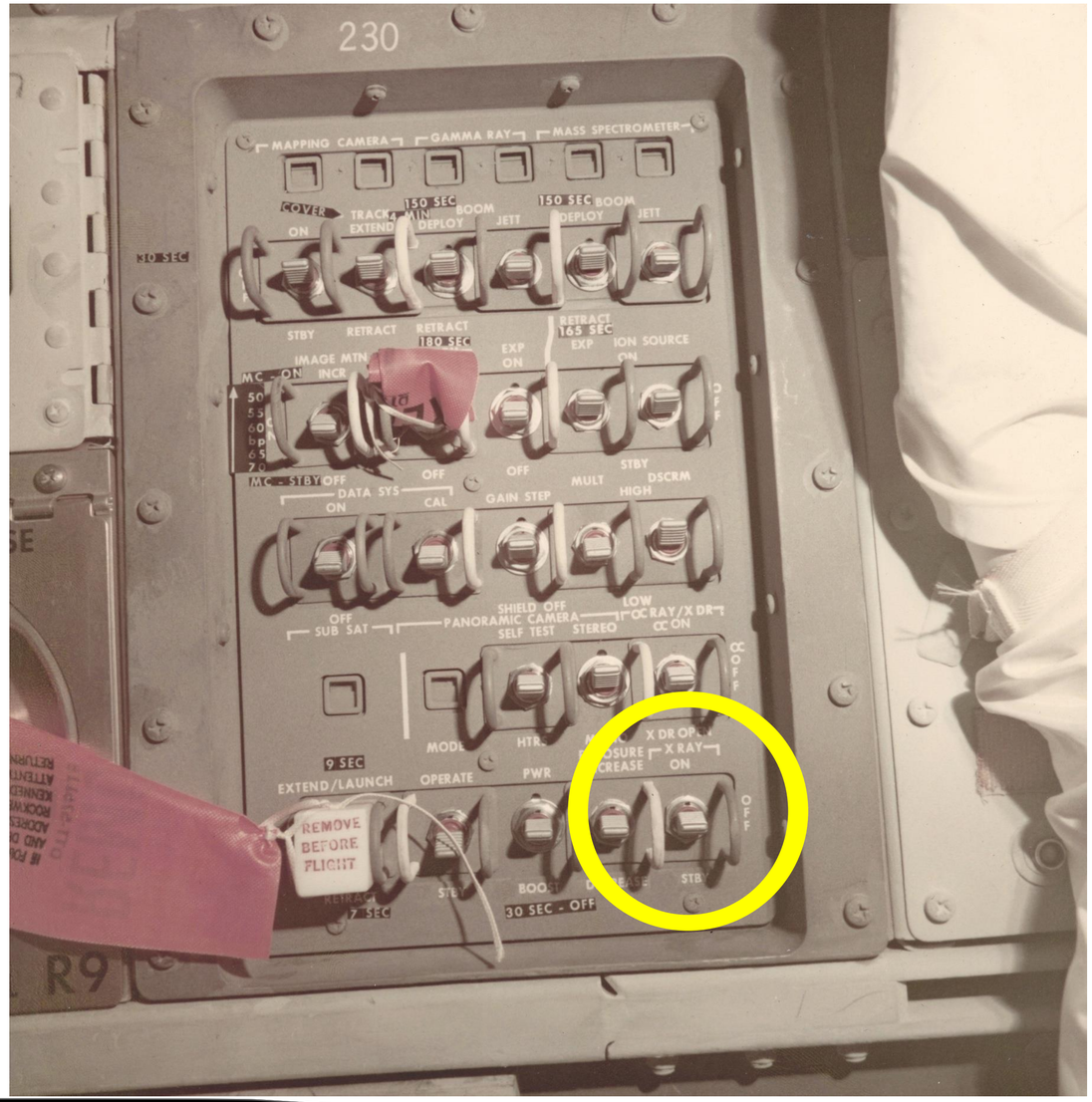
Geochemistry package:

- *Mass spectrometer*
- *Gamma-ray Spectrometer*
- *Alpha-particle Spectrometer*
- *X-ray Fluorescence Spectrometer (0.7 - >3 keV)*

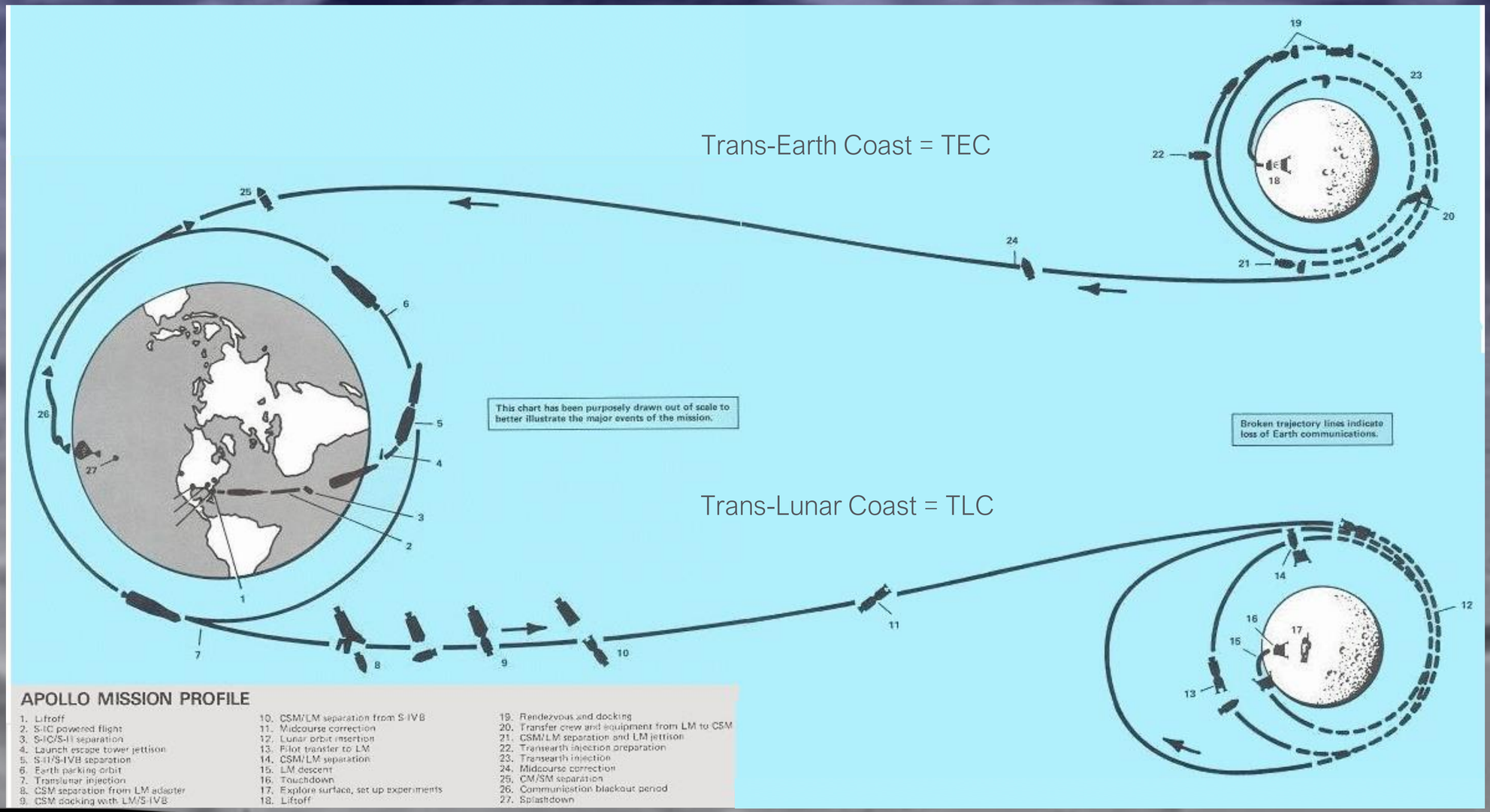
  + Solar X-ray Monitor

SIM-bay control panel 230

(lower instrument bay of CSM)



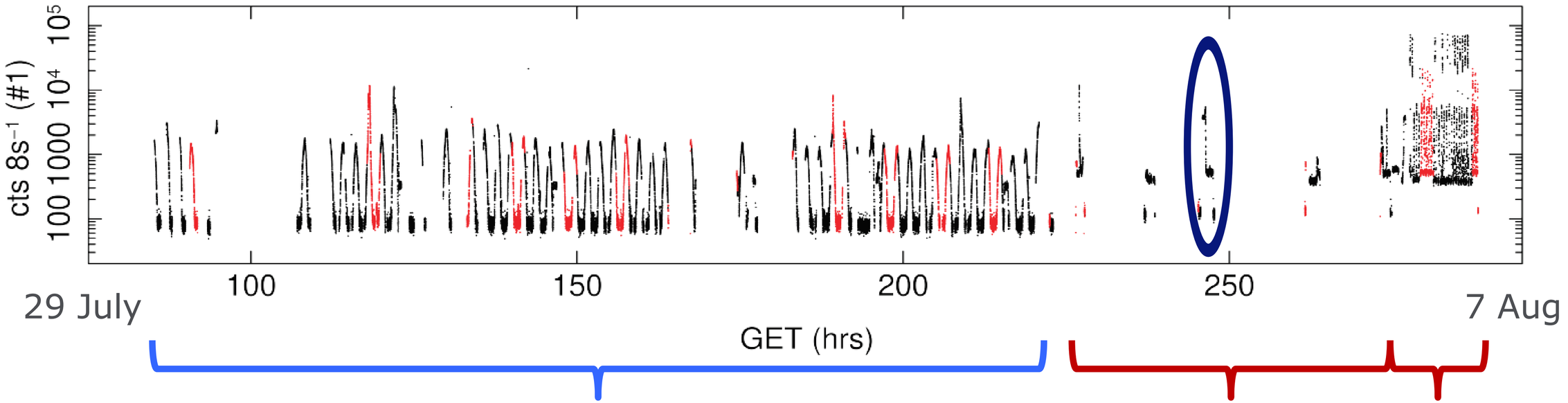
Apollo 15 Trajectory



X-ray Fluorescence Spectrometer data

Lunar orbit

Trans-Earth Coast



Black = 0.7-3 keV
Red = 1.4-6 keV

Lunar X-ray observations

X-ray astronomy

"BBQ" or PTC

GET = Ground Elapsed Time from launch
(26 July 1971; 13:34:00.6 UTC)

PTC = Passive Thermal Control