Observing the Hypersoft State of Cygnus X-3 with XRISM and Chandra

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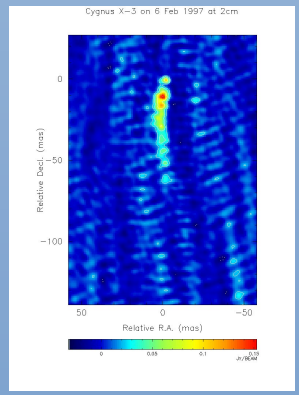
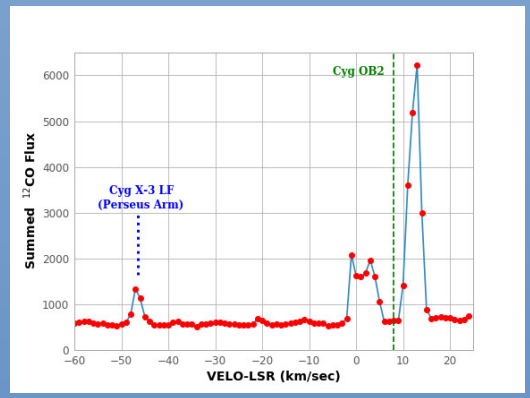
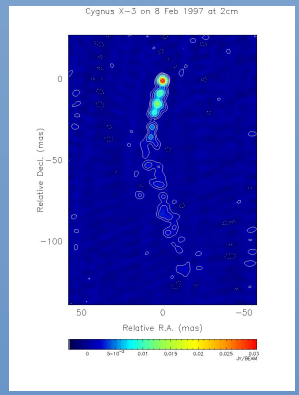
Cygnus X-3

- HMXRB with a Wolf-Rayet (WN 4-6) with a likely Black Hole. companion (~5-7 $M_{\odot}$).
- Has a 4.8 hour orbital period.
- Distance: 9.7 kpc
- Lies behind three bands of molecular clouds.
- Relativistic jets (VLBI) aligned close at our line-of-sight (~10o).
- Gamma-ray source during major flaring activity.

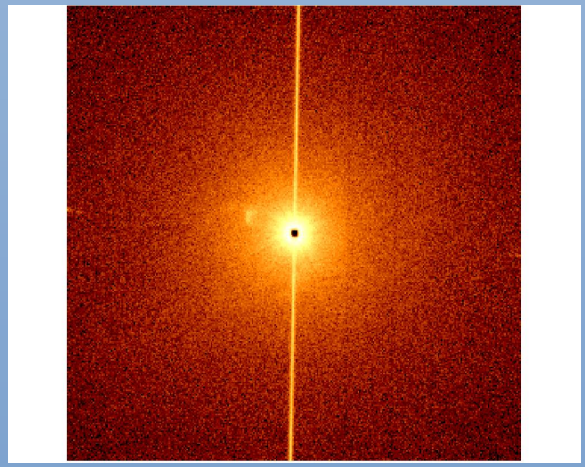


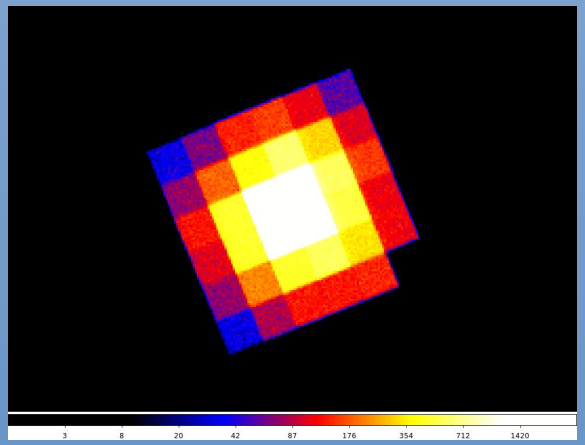




Cyg X-3 Spatial Resolution (Chandra vs. XRISM)

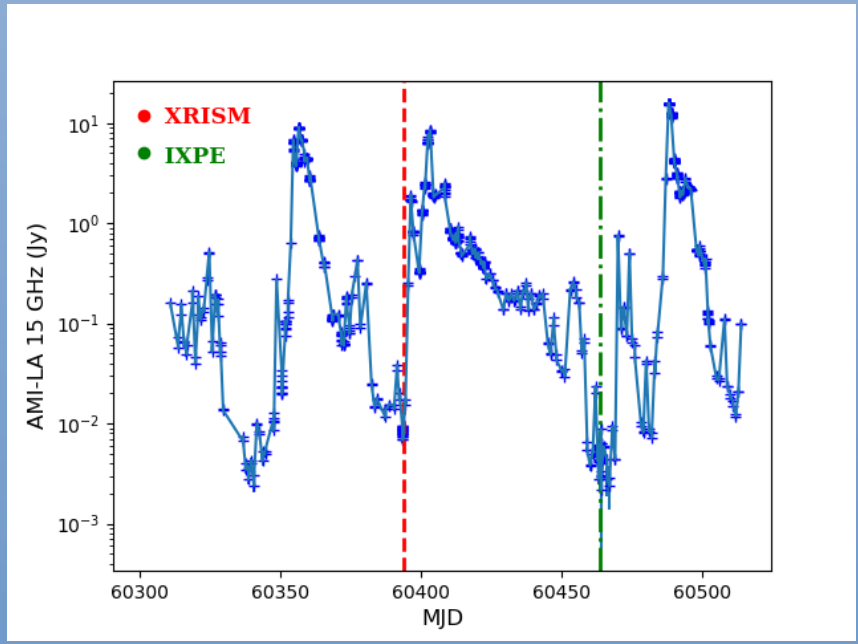
- Chandra:
  - On axis resolution is sub-arcsecond.
  - ACIS chip is 8x8 arcminutes
  - Cyg X-3's Little friend is 16 arcseconds away from Cyg X-3 and is 3X5 arcseconds in size
- XRISM:
  - Field of view of 3.1x3.1 $arcmin^2$.
  - 36 pixels each is an individual detector.
  - Angular resolution of 1.3 arcminutes.





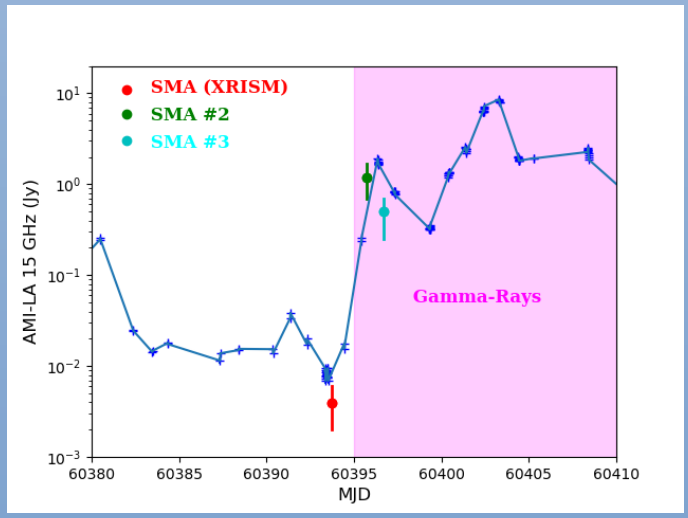
Cygnus X-3 2024

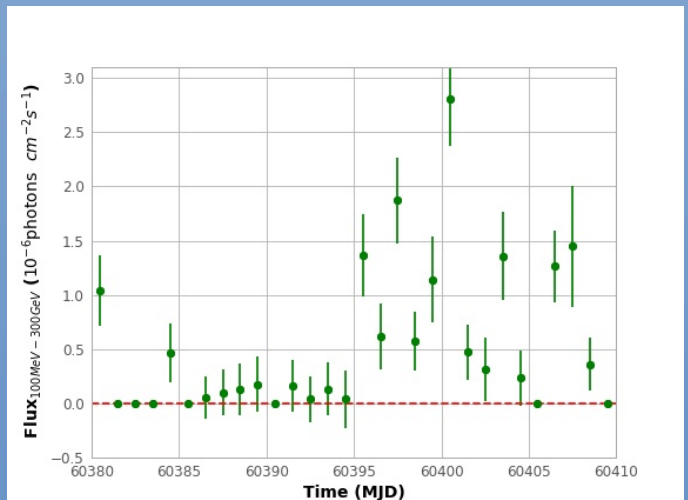
- AMI-LA (15 GHz): Radio monitoring observations during flaring activity in 2024(blue).
- XRISM: The time of the 60ksec XRISM (red dashed line) taken during the hypersoft/ultrasoft state.
- IXPE: The green dashed-dotted line is the time of an IXPE observation. Also done during a hypersoft/ultrasoft state.



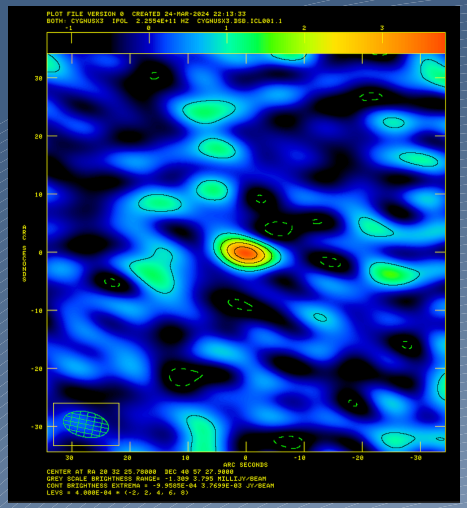
Cygnus X-3 XRISM & SMA

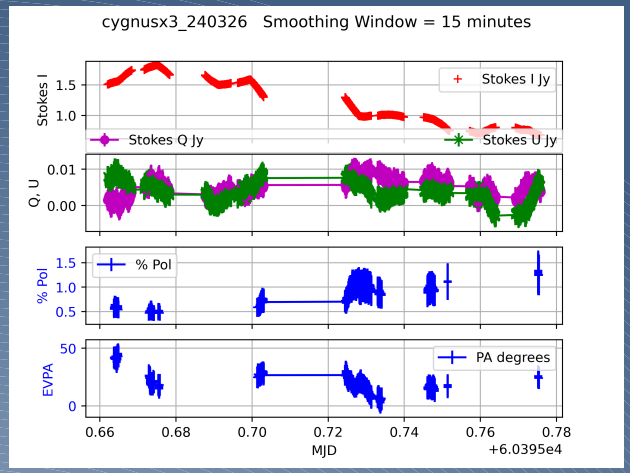
- XRISM: The red point is the time of the SMA observation which was made during the XRISM observation (3.7 mJy at238 GHz).
- SMA: In addition there was an observation two and three days later. The lines shown on the data points are NOT error bars. The are the variation of flux during the observation.
- Fermi: The lower plot shows Fermi LAT observations and in the top plot it the magenta shaded area.

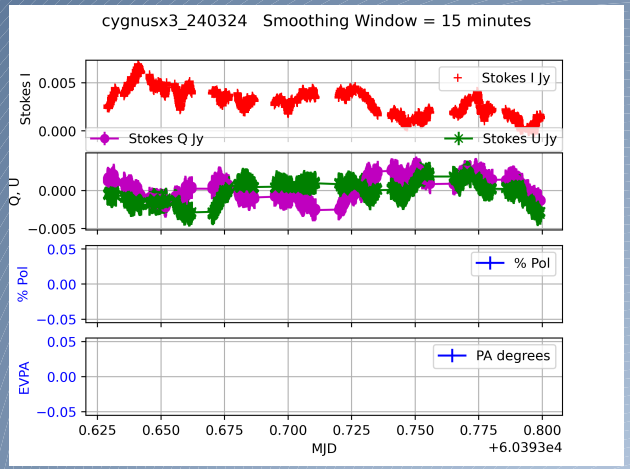


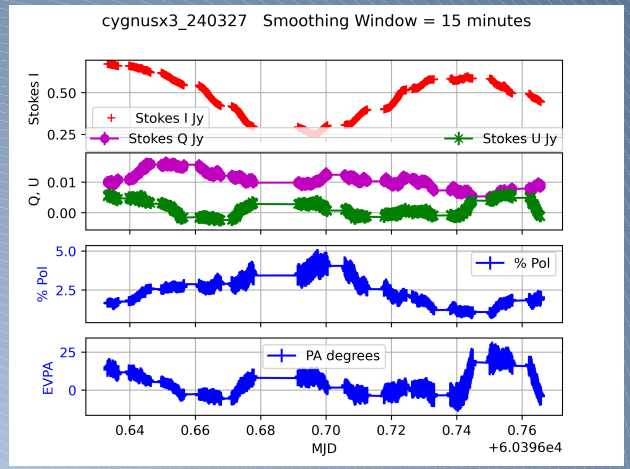


Cygnus X-3 SMA (XRISM)

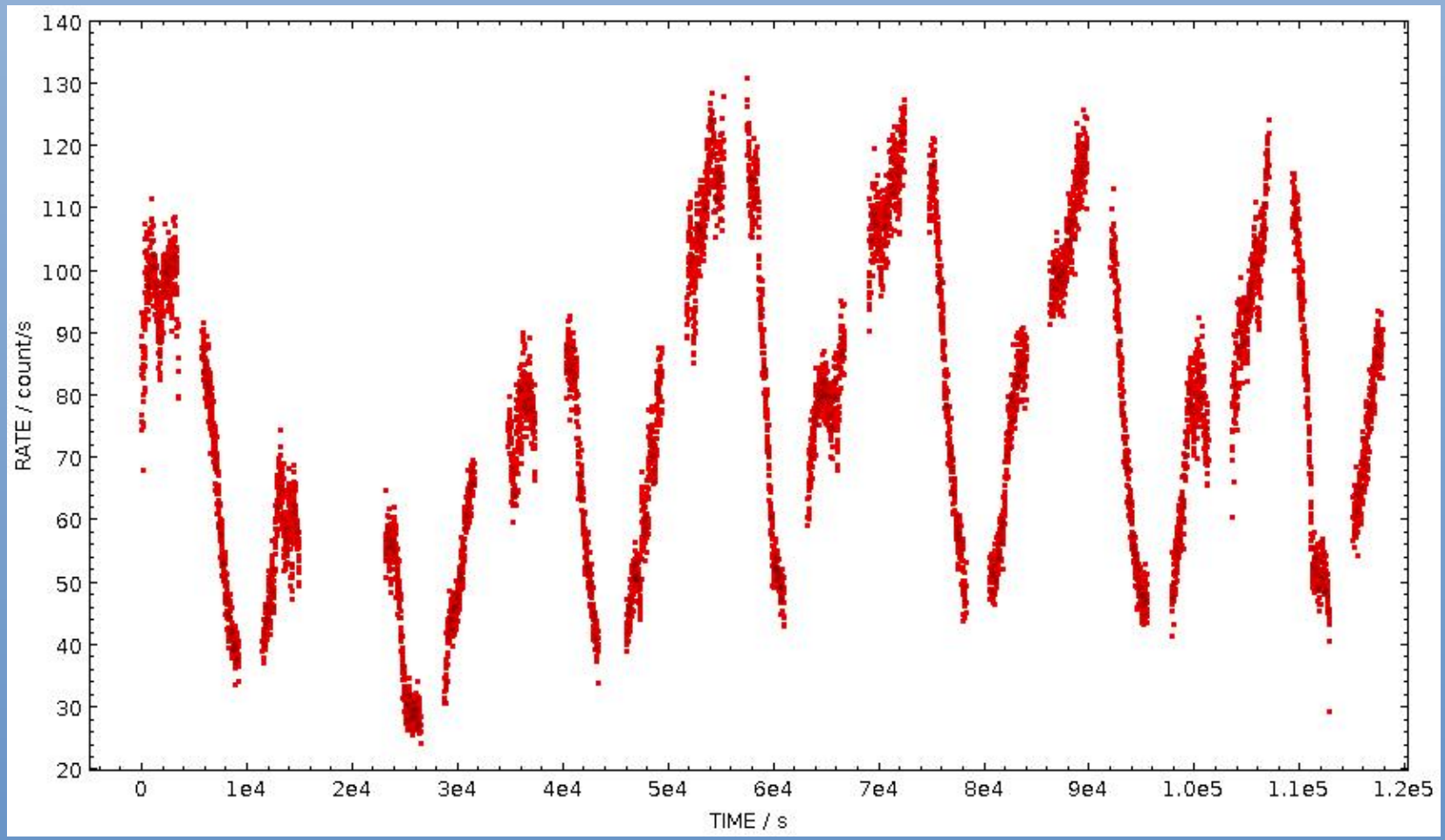




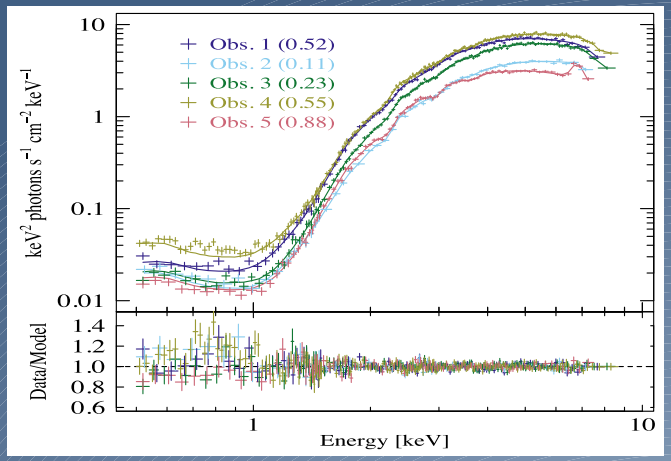


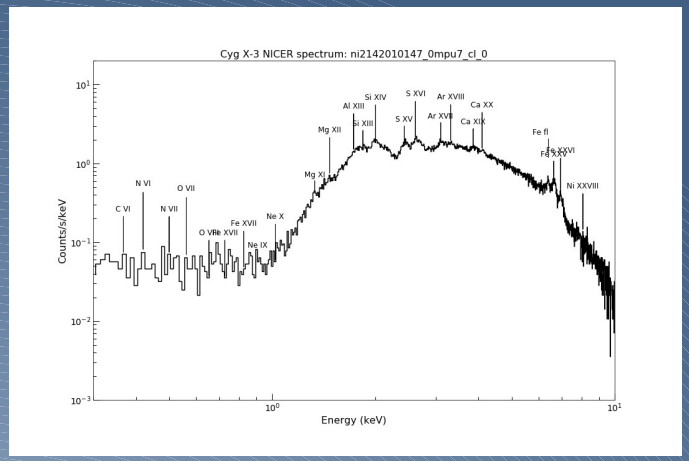


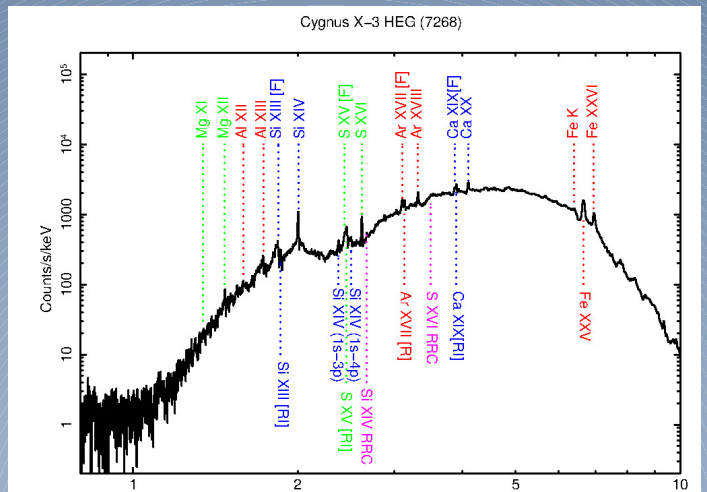
Cygnus X-3 XRISM 2-10 keV Light Curve (10 sec resolution)



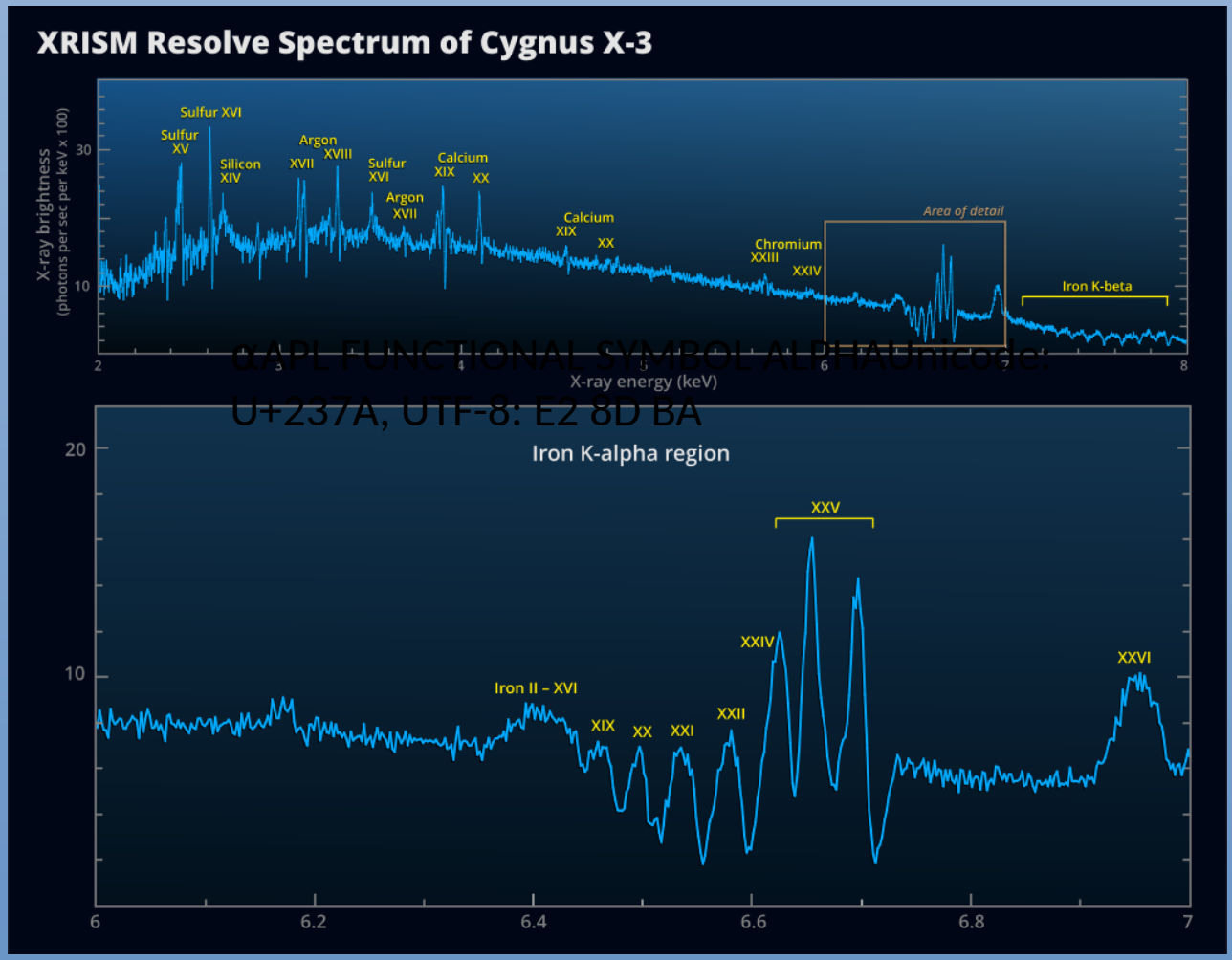
Cygnus X-3 Spectra
(Swift – Nicer – Chandra HETG)







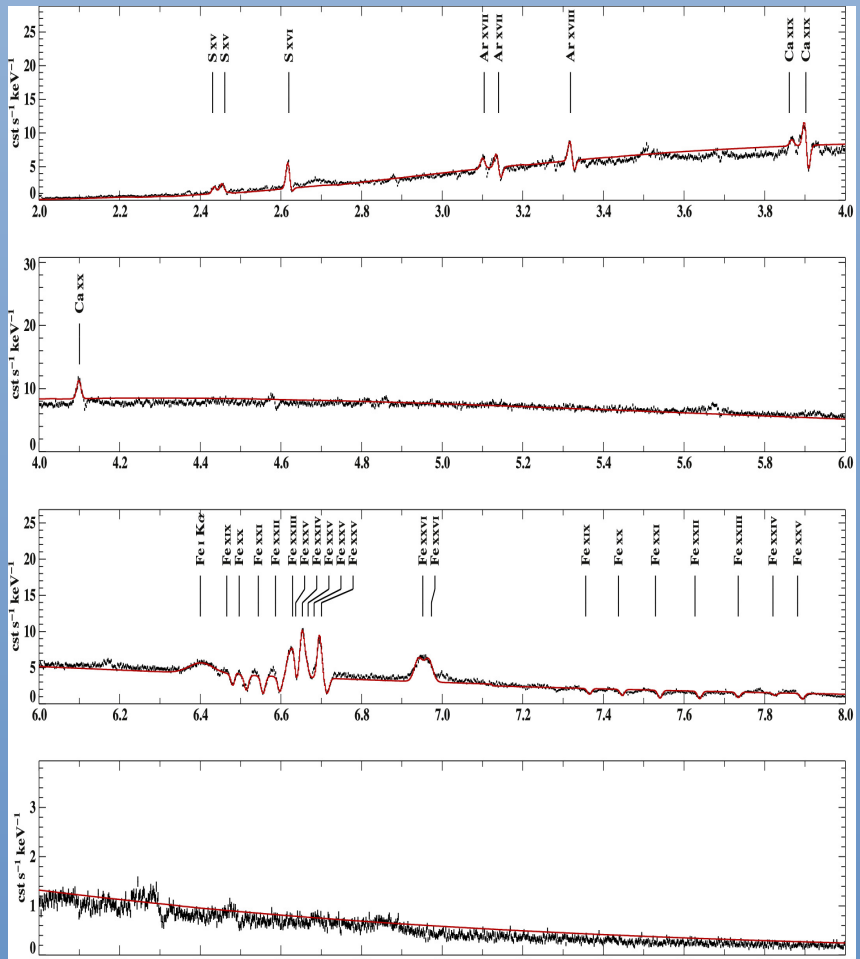
Cygnus X-3 Spectra XRISM



&APL FUNCTIONAL SYMBOL ALPHA Unicode: U+237A, UTF-8: E2 8D BA

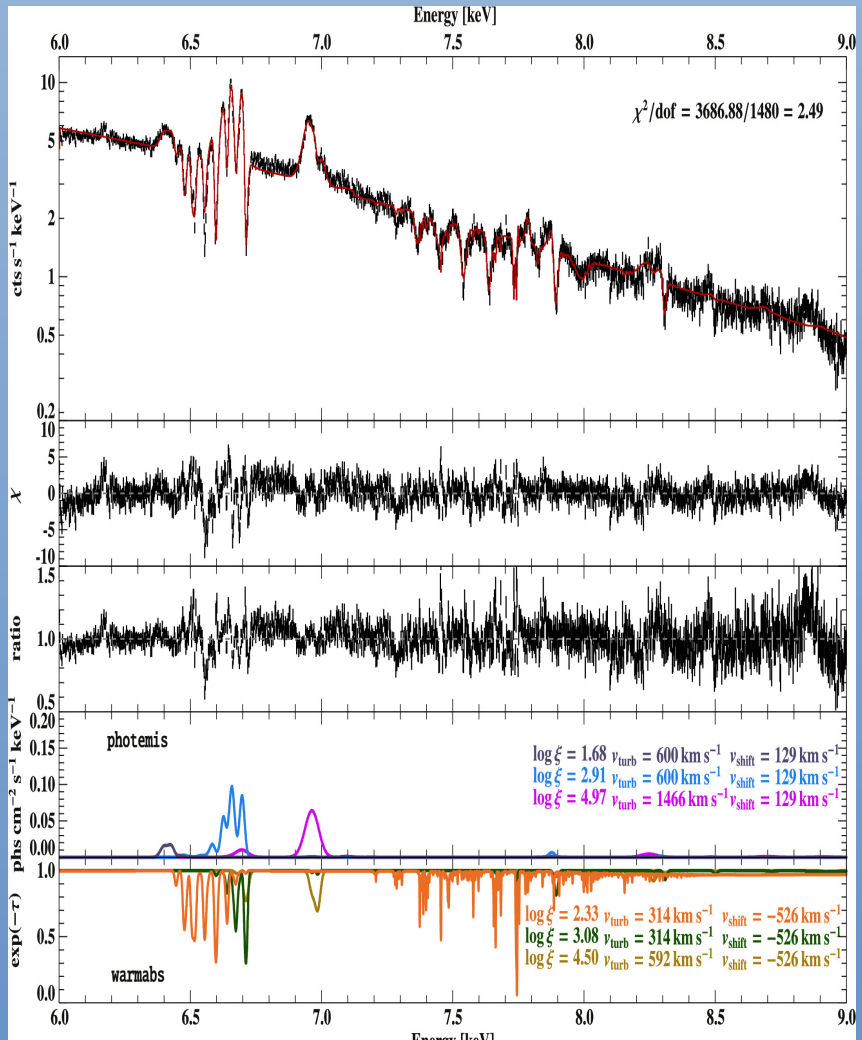
Cygnus X-3 Line IDs

- XRISM spectrum:
  - Rich in H-like He-like lines and RRC. All at 5 eV resolution.
  - Fe Kα H-like Fe show broaden lines.
  - The absorption dip is now resolved into a number of absorption lines
  - These lines appear to be F to C like Fe lines
  - He-like Fe is broken into its R, F, and I components (x,y, w).
  - Past 7 keV a number of Fe Kβ lines.



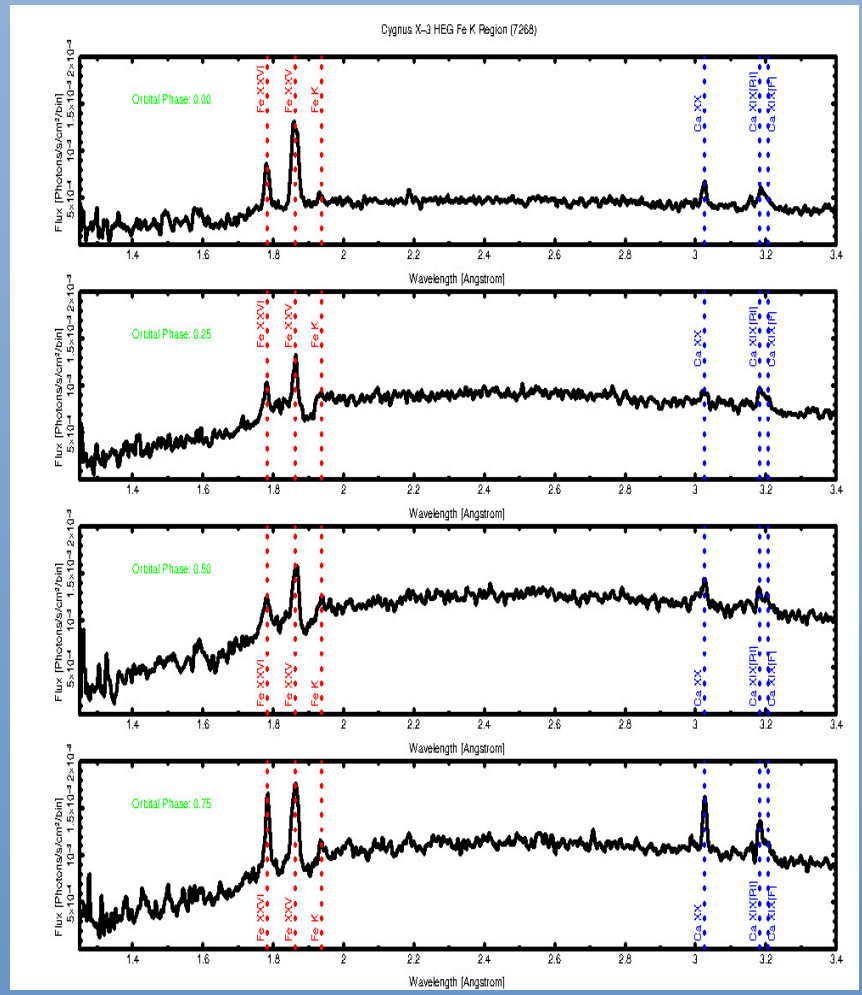
Cygnus X-3 Spectra Fit (Fe region)

- Spectra fits (Fe Line Region):
  - The continuum was fit with 1.3 keV diskbb.
  - Ion populations were calculated using XSTAR.
  - The ion populations were used in analytic models to fit the Fe region spectrum.
  - The XSPEC model photemis was to fit the emission lines.
  - The XSPEC warmabs model was used to fit the absorption line.
  - Multiple ionization regions were necessary to fit the data.



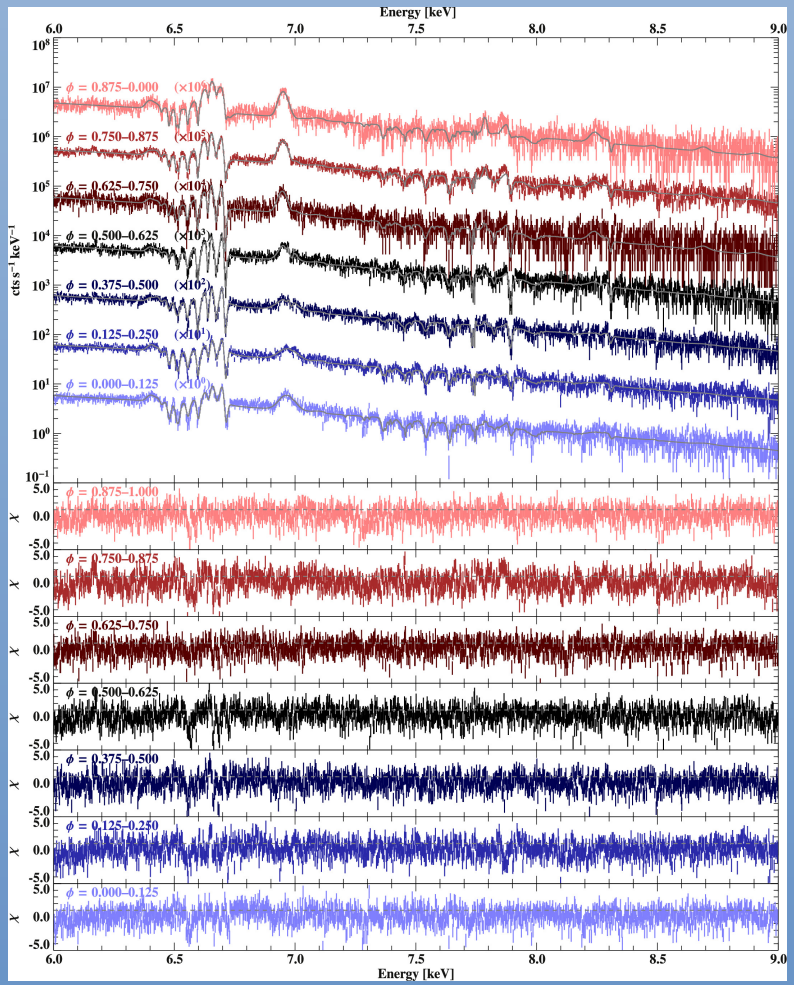
Chandra HETG Phase Resolved

- Chandra HETG phase resolved spectra of Fe line region for the hypersoft state.
- .Note the orbital variation of the Fe and Ca lines.
- The absorption dip (which we know now are a group of Fe absorption lines) also show orbital changes.



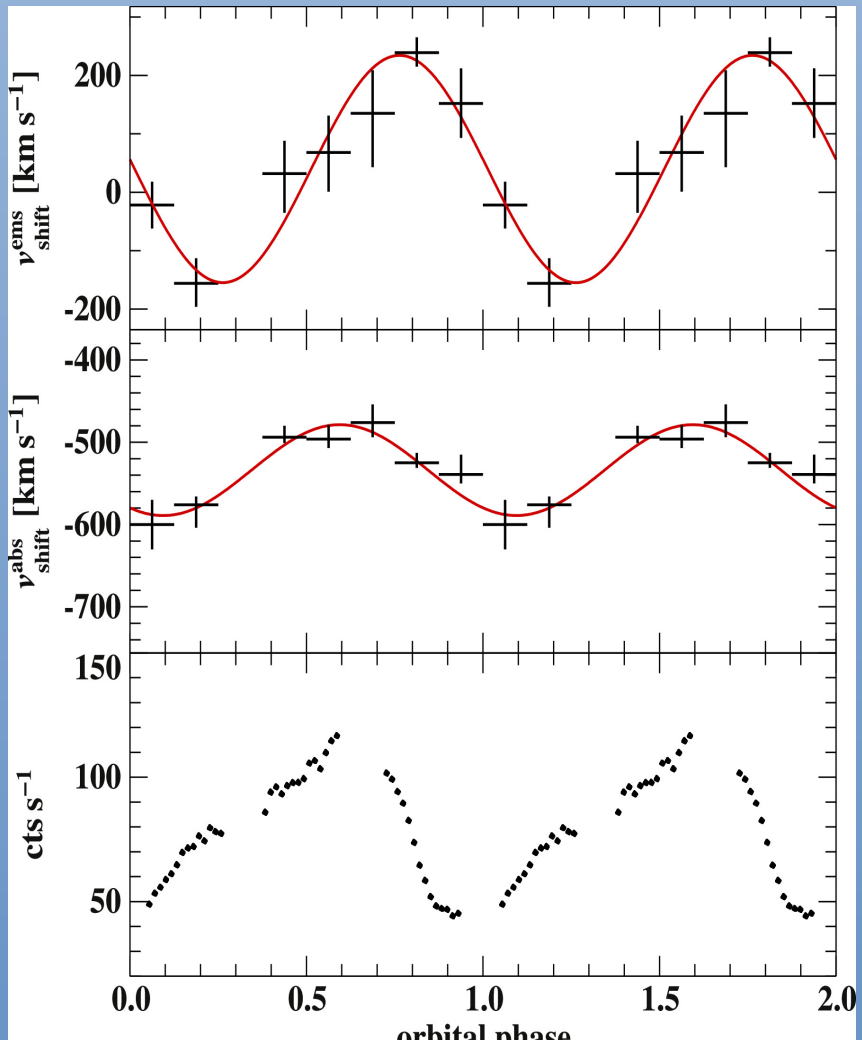
Cygnus X-3 Spectra Phase Resolved (Fe region)

- Phase resolved spectra
  - The data were folded on Cyg X-3's orbital into 8 phase bins.
  - Because of Cyg X-3 orbital period beating with the spacecraft orbital period the phase bin 0.250-0.375 does not have enough counts to fit.
  - The intensity of these emission components vary by ≃ 2. with the maximum near phase 0.75.
  - The ionizational parameters of the emission components do not vary significantly around the orbit.



Cygnus X-3 Line Orbital Modulation

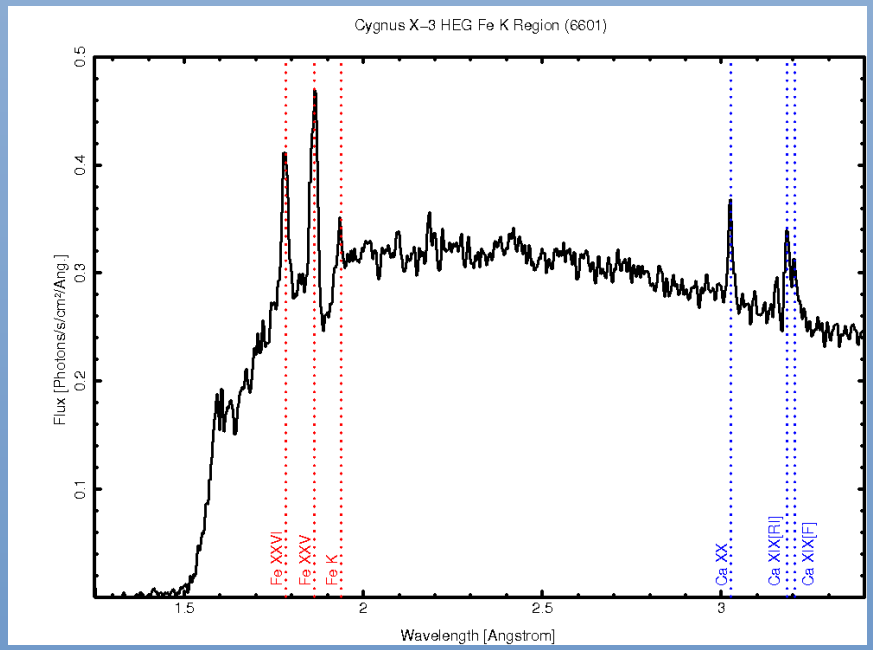
- Continuum (bottom):
  - 2-10 keV folded light curve is not sinusoidal.
  - Maximum occurs near phases 0.6-0.7.
- Emission Lines (top):
  - The emission components have a velocity variations of K = 194 +/- 20 km/s.
  - Vsys = 40 +/- 20 km/s
  - The extreme values occur near phase 0.25 and 0.75.
  - Some phases show a redshift and others show a blueshift.
- Absorption Lines (middle):
  - The absorption velocities vary with an amplitude of K=55+/- 7 km/s.
  - Vsys =-534 +/- 6 km/s.
  - Absorption lines are always blueshifted by at least -400 km/s.

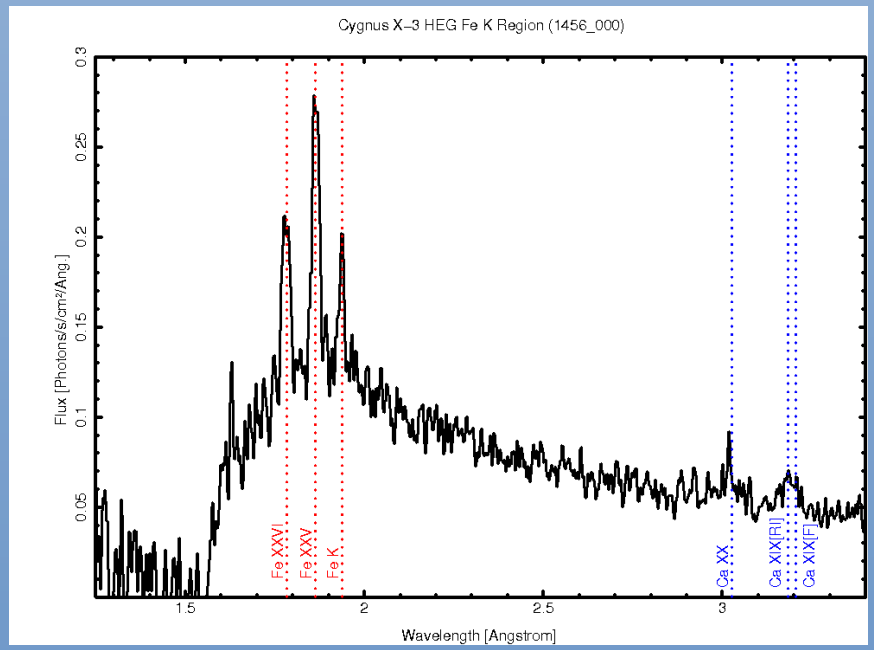


Conclusions

- XRISM show a spectrum with exceptional strong emission and absorption lines.
- The radio, SMA, and Gamma-ray show that the jet had “shut off” in
- Cyg X-3 during the XRISM observations.
- This spectrum will serve as a template to compare against spectrum taken when jet activity is present.
- Single-zone photoionization models can not explain the Fe line region, much less the entire spectrum.
- The Fe emission lines are consistent with emission arising from a region near the compact object.
- The absorption lines can be explained from the wind (WR)or associated structures on a size scale of the binary orbit.
- Other non-Fe lines still being worked on.
- XRISM Collaboration, et al. 2024, ApJL, 977, L34
- Work on the Orbital modulation of the Fe Lyα (Miura, et al. 2025) has been submitted to PASJ.

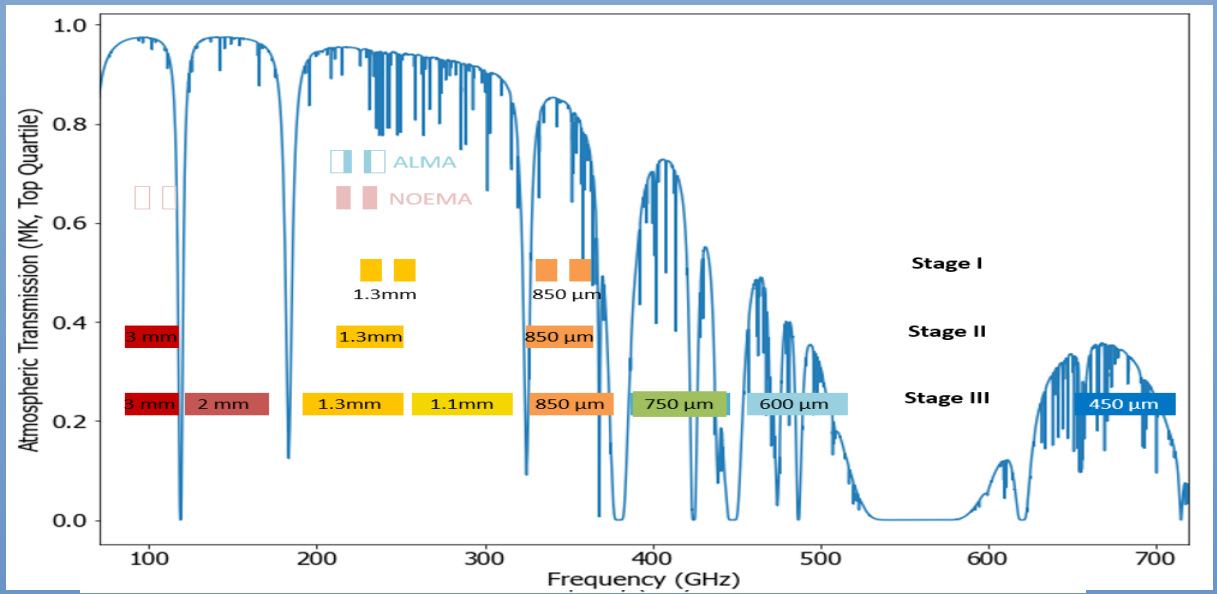
Hypersoft/Ultrasoft vs. Quiescent (hard state)





wSMA (in progress)

- Instantaneous spectral coverage for example tunings of the various stages of wSMA, along with some existing facilities. Compared with ALMA (currently 8 GHz instantaneous bandwidth, 32 GHz proposed for ALMA2030) and NOEMA (16 GHz instantaneous bandwidth, dual band observing proposed), Stage II and III would offer approximately instantaneous spectral coverage for example tunings of the various stages of the wSMA, along with some existing one and two orders of magnitude greater instantaneous spectral coverage, respectively. Stage of the wSMA I upgrade has the same instantaneous bandwidth as the current SMA receivers.



VLBA Campaign (coming soon)

- VLBA Campaign:
  - Approved VLBA observation of a Cyg X-3 major radio flare.
  - 30 hrs VLBA time over 5 daily observations.
  - Two frequencies (15 and 22 GHz) with polarization
  - 15 ksec of approved pointed Swift time
  - 5 approved daily SMA observations with polarization.
  - Fermi proposal pending with the possibility of VERTIAS observations.
  - IXPE proposal submitted for this campaign.
  - Additional observation are welcomed.