MULTI-WAVELENGTH OBSERVATIONS OF CYGNUS X-3

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CYGNUS X-3

- High mass X-ray binary (HMXBs), made of a Wolf-Rayet companion star and of a compact object:
- Distance ~9 kpc, orbital period 4.8h (more typical of a LMXB).
- Due to tight orbit (d~10^{11} cm), the compact object is enshrouded in stellar winds (v~1000 km/s).
- Still uncertainty on nature and mass of compact object.
- Microquasar scenario (black hole + relativistic jets) scenario is favored.

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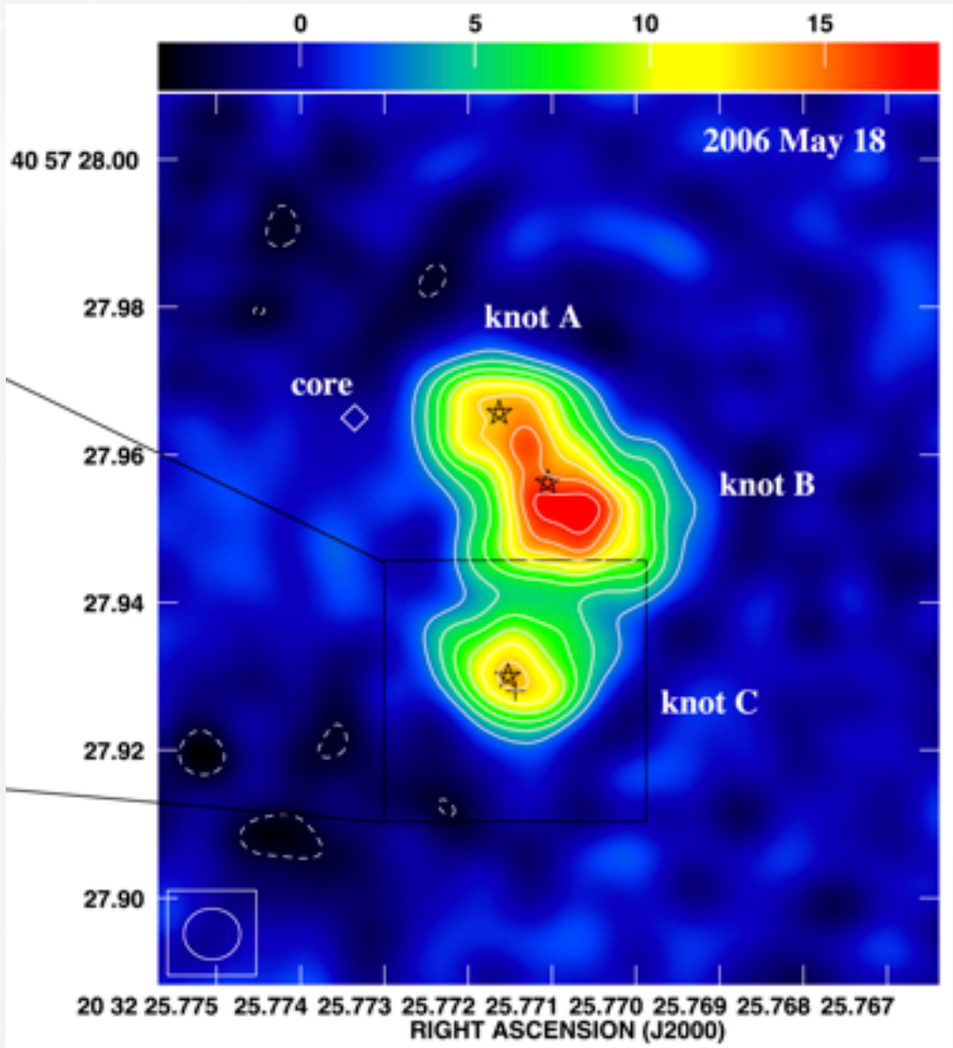
CYGNUS X-3 RADIO SOURCE

- Cygnus X-3 is a reasonably strong persistent galactic radio source:
  - Strong persistent radio emission at ~60-100 mJy, in quiescent state.
  - VLBI observations show milli-arcsec relativistic jets (v~0.81c), with angle to the line of sight of <14º.
  - Sufficiently long (>3 days) quenched radio states (~1-15 mJy) are followed by giant radio outburst (~1-20 Jy).



Tudose et al. 2007

CYGNUS X-3 RADIO STATES

- Major flaring: ~1-20 Jy
- Minor flaring: <1 Jy
- Quiescent states: ~60-100 mJy
- Quenched states: ~1-15 mJy

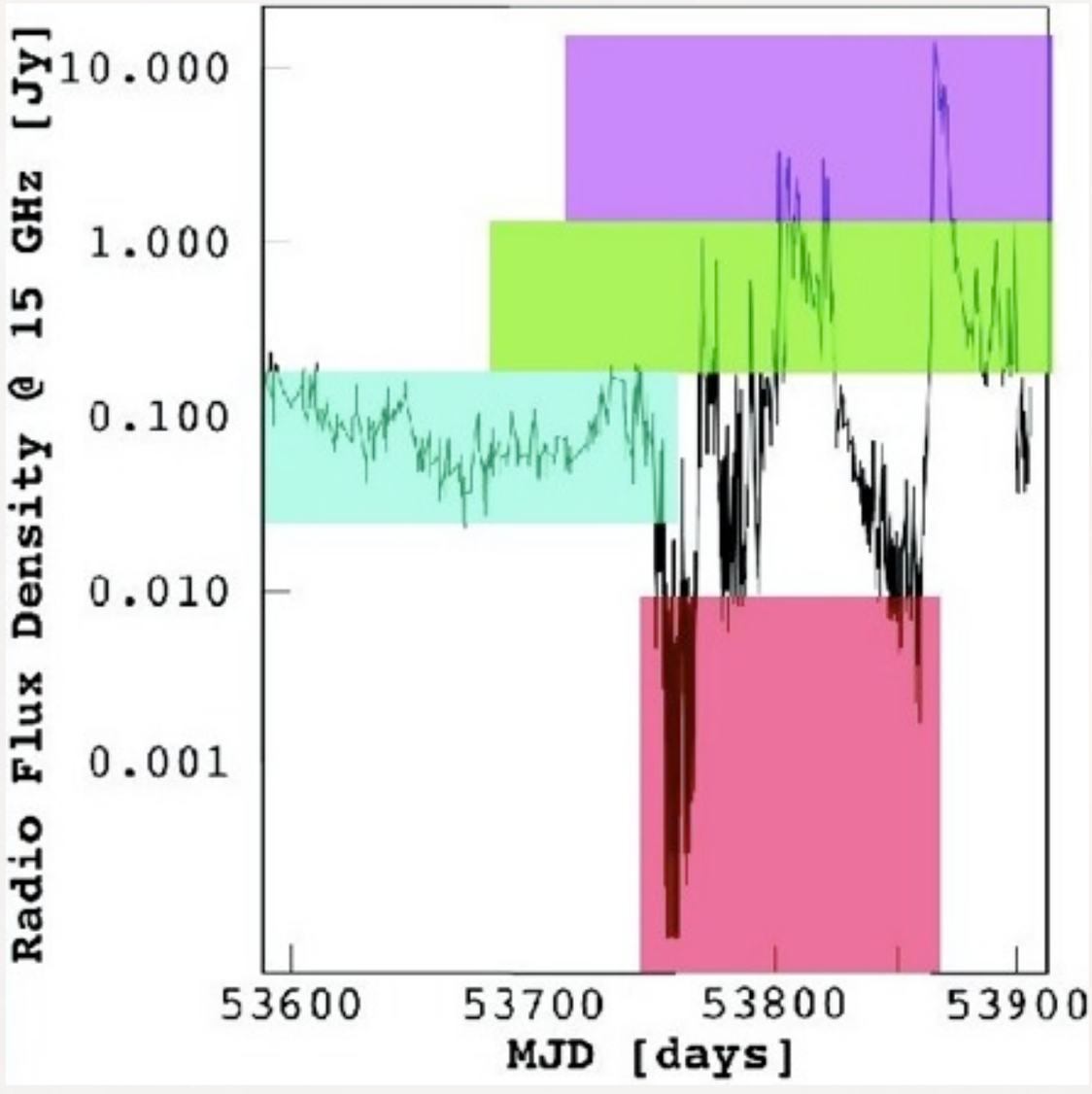


Image courtesy of Karri Koljonen

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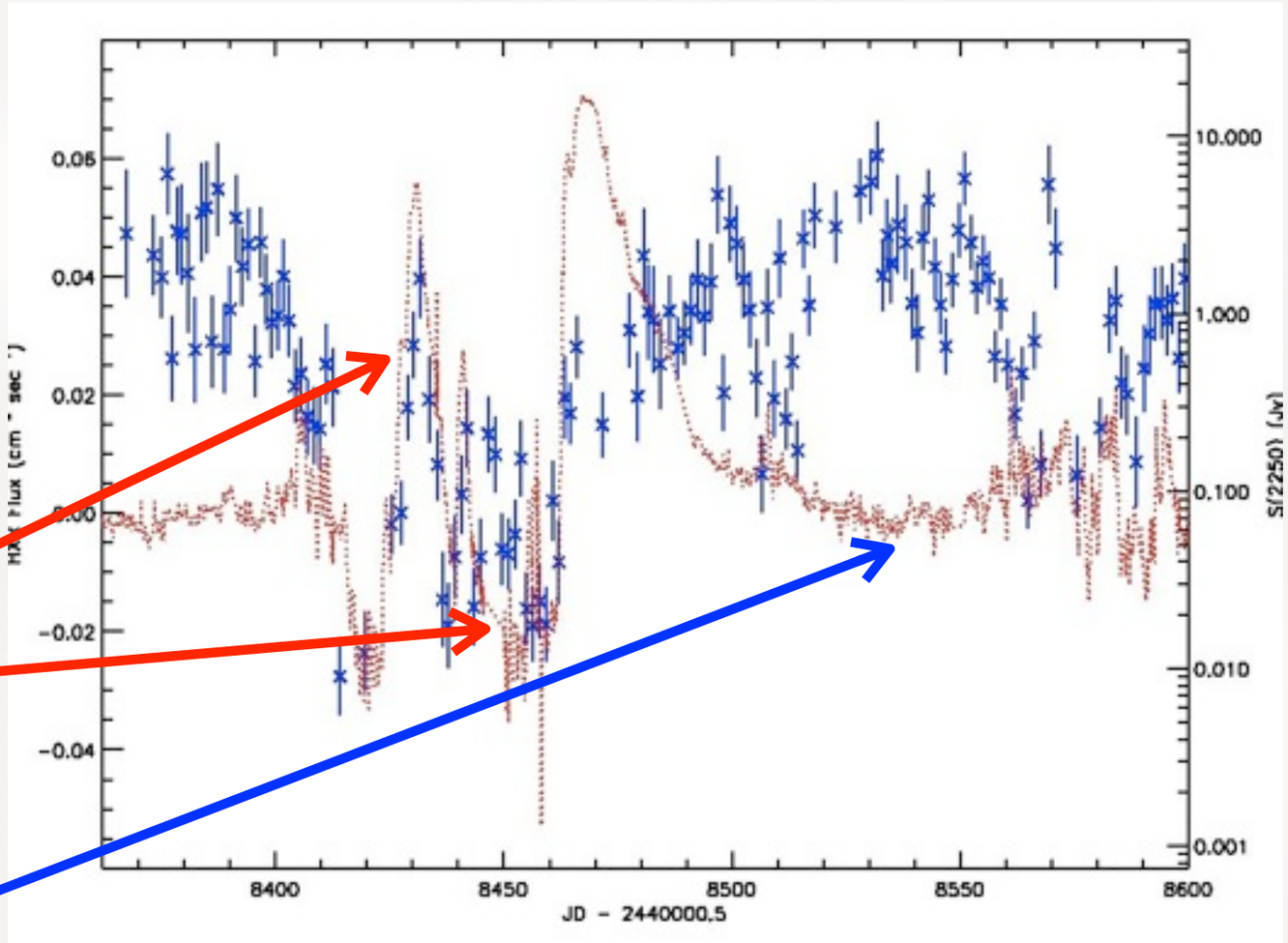
CYGNUS X-3 RADIO/HARD X-RAY

- Correlation & anti-correlation between hard x-ray and radio.
  - Correlation radio/ hard x-ray during major flares and quenched state.
  - Anti-correlation radio/hard x-ray during quiescence.

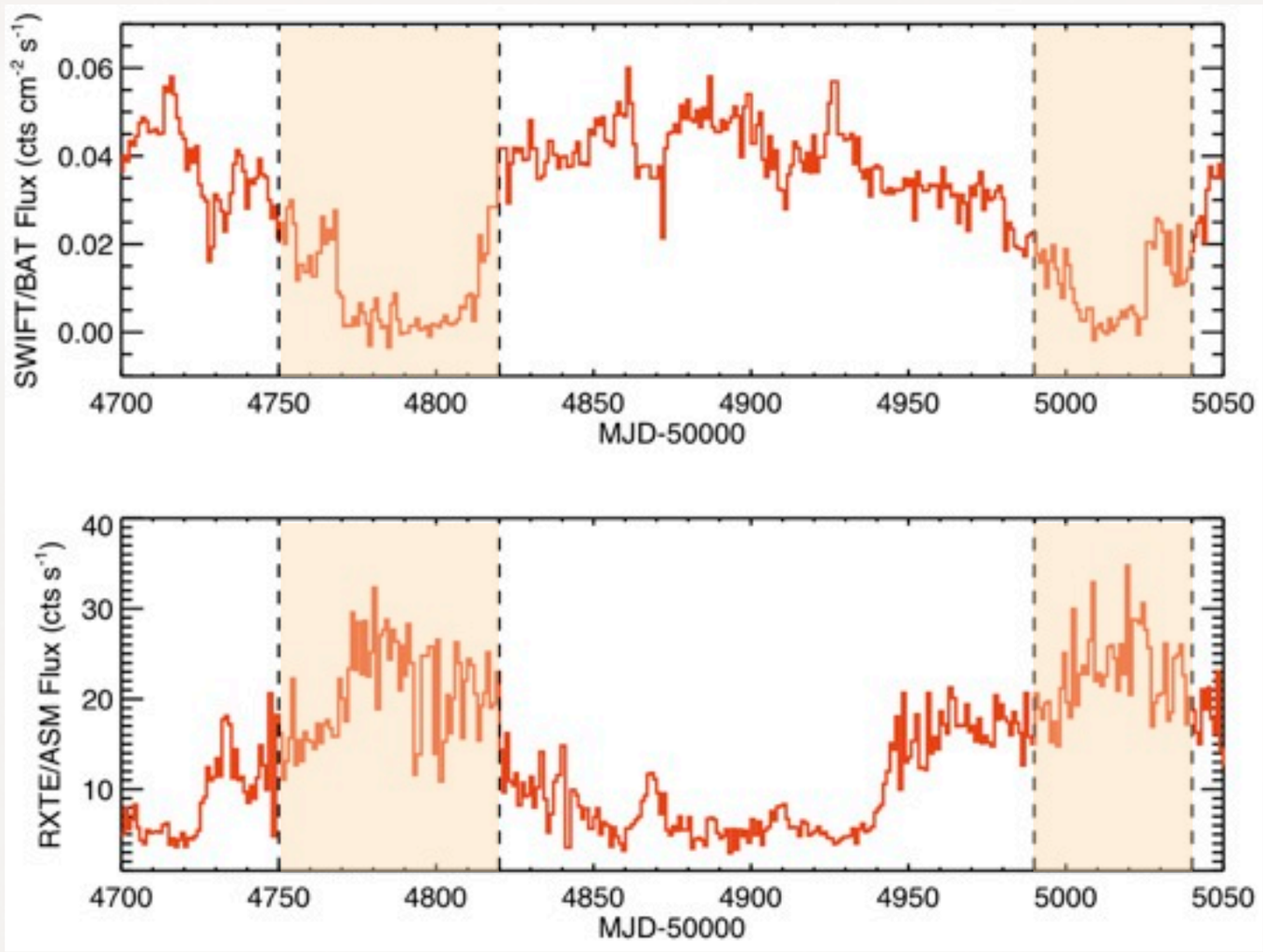


McCollough et al. 1999

CYGNUS X-3 SOFT/HARD X-RAY CORRELATION

- Anti-correlation between Swift/BAT (15-50 keV, top) hard x-rays and RXTE/ASM (1.3-12 keV, bottom) soft x-rays.

- The hard x-rays are anti-correlated with the soft x-rays during the periods of the Fermi/LAT active state, shown by the orange-shaded areas.

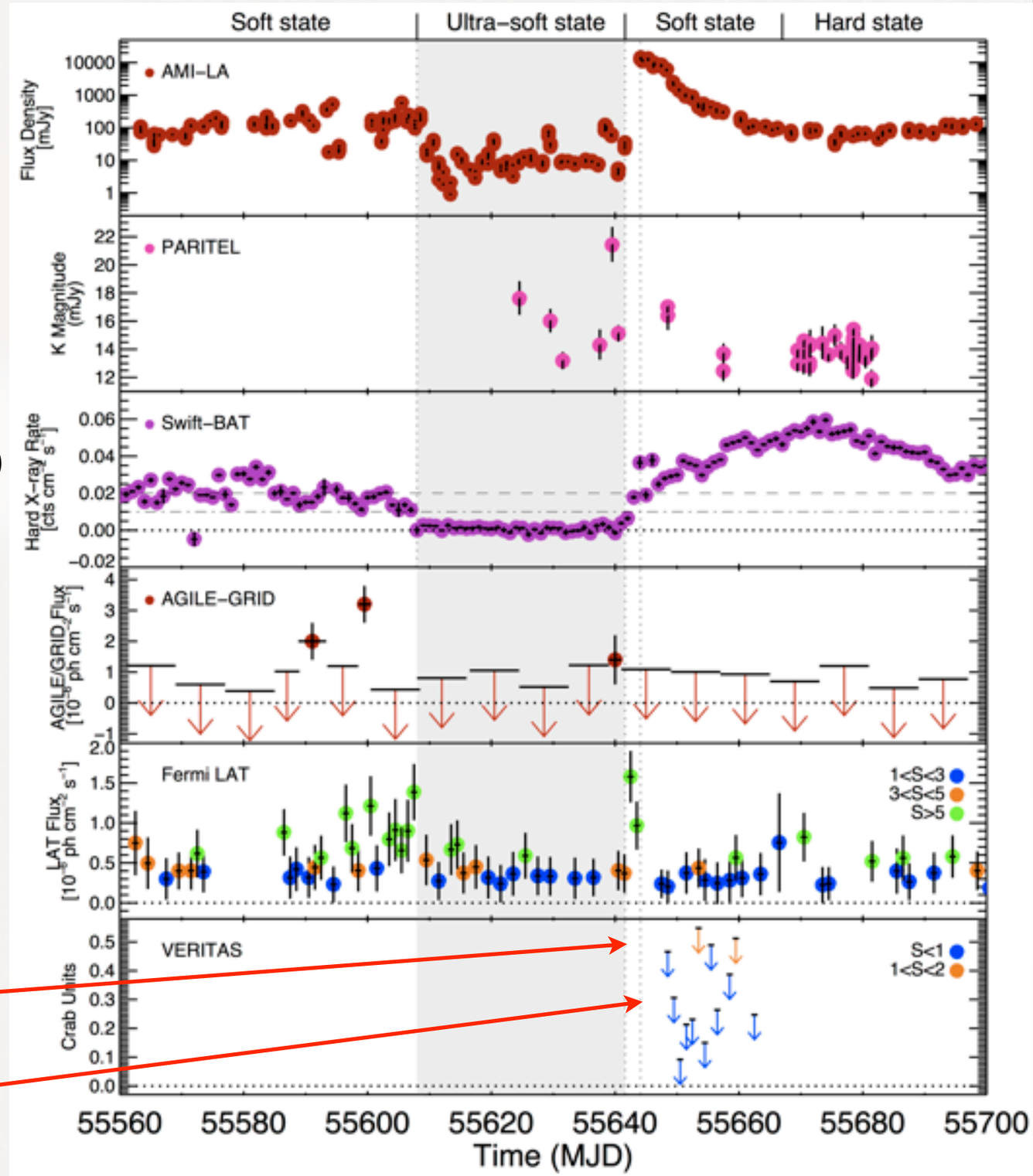


Szostek et al. 2008

Multi-wavelength plot of Cygnus X-3:

- AMI-LA, (radio, 15 GHz)
- PAIRITEL, (IR, K_s mag., 2.2 μm)
- Swift BAT (hard x-ray, 15-50 keV)
- AGILE (γ-rays, 0.1-3 GeV)
- Fermi LAT (γ-rays, 0.1-100 GeV)
- VERITAS (γ-rays, 0.1-30 TeV)

- Grey area: radio-quenched state.
- 1st dotted line: major radio flare onset.
- 2nd dotted line: major radio flare peak.



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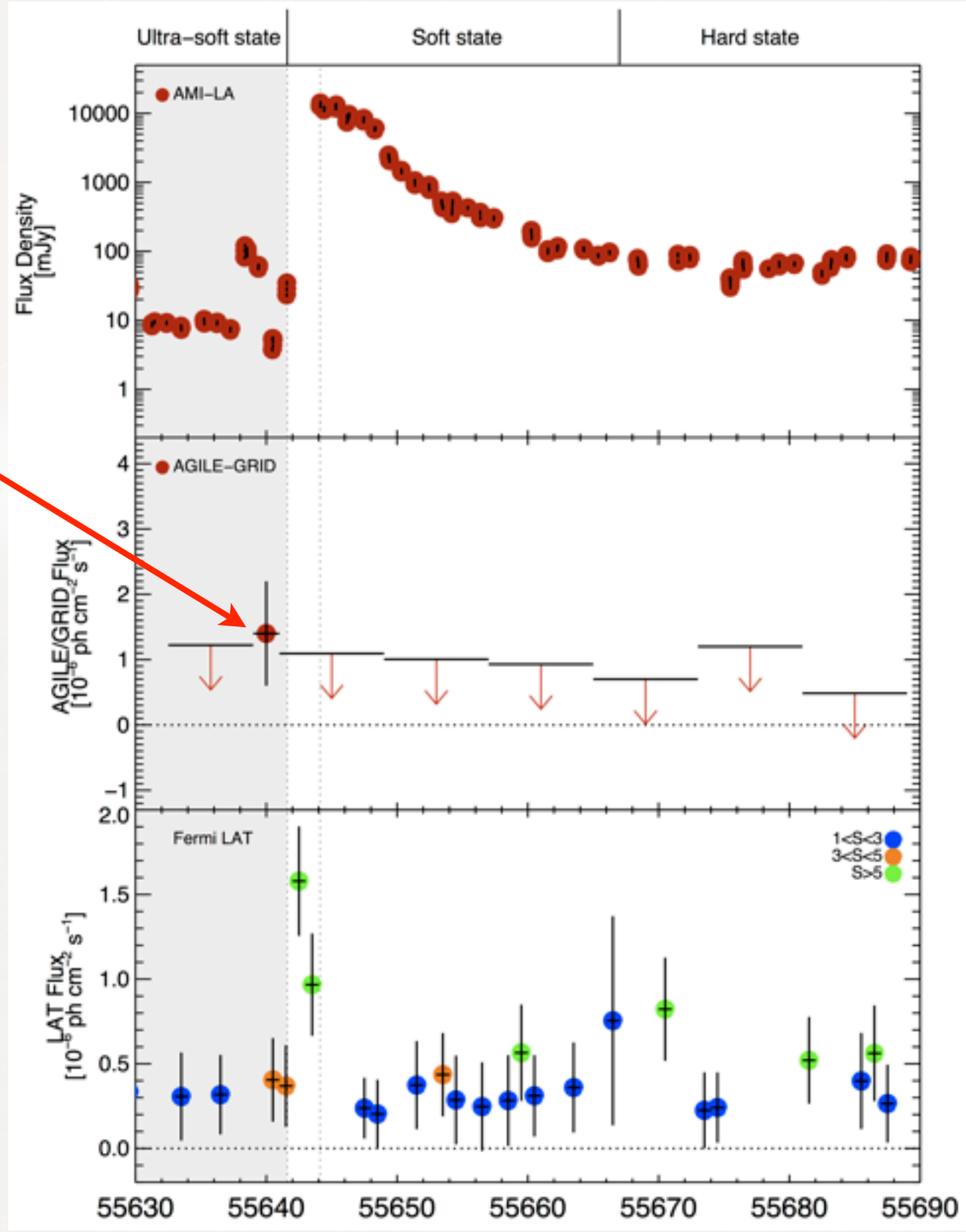
- **Multi-wavelength plot of Cygnus X-3:**

- AGILE detection of γ-ray emission (0.1-3 GeV **before** onset of major radio flare and before Fermi LAT.

- AGILE has a high live time (~40%), more suited for brief impulse events (<1 day).

- γ-ray emission before radio may give support for **leptonic model**: *γ-rays* from IC upscatter of jet electrons, with subsequent *radio emission* (cooling electrons become transparent to own synchrotron emission).

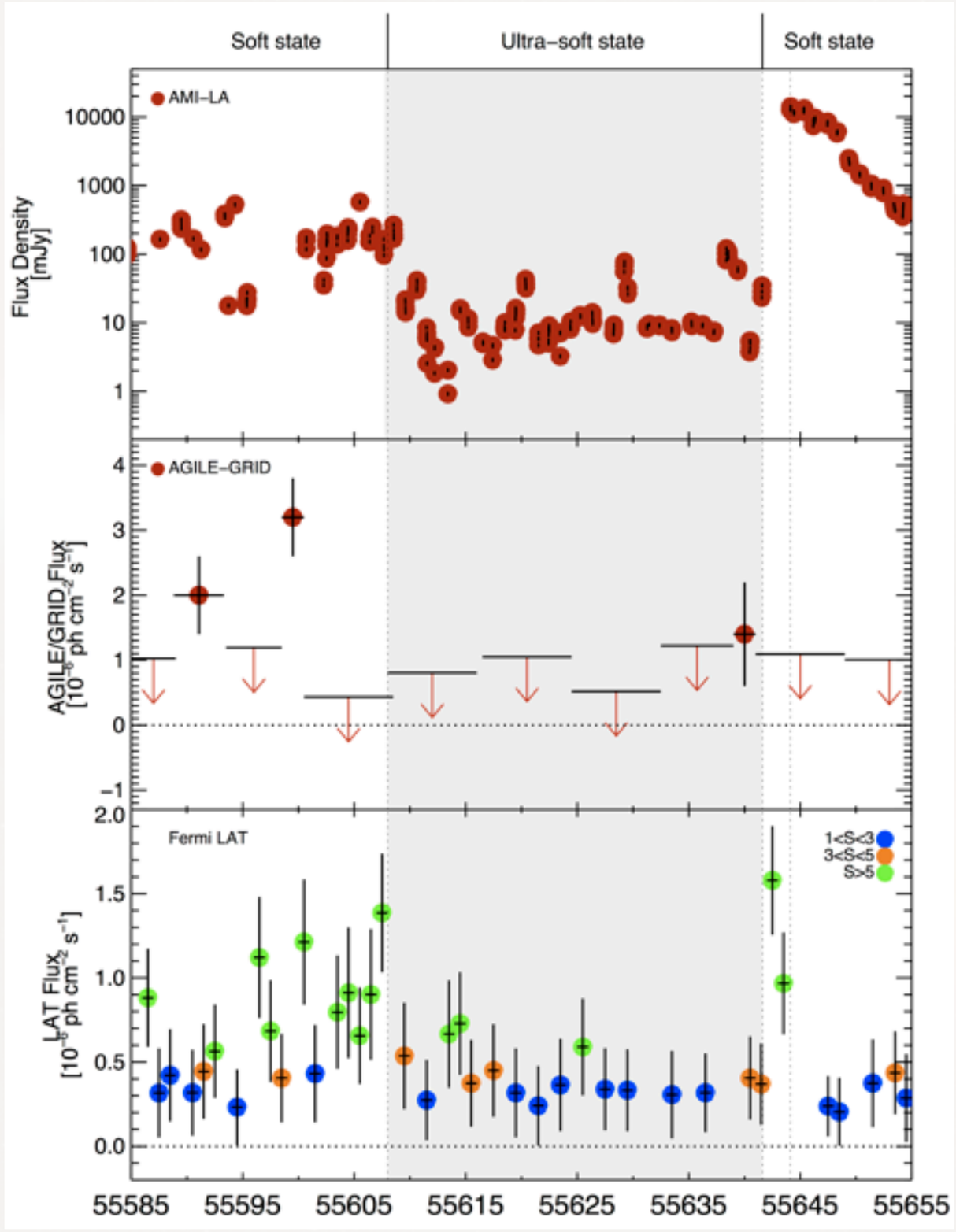


- **Multi-wavelength plot of Cygnus X-3:**

- AGILE detection of γ-ray emission is observed **before** the descent into radio-quenched state.

- Detection by AGILE (0.1-3 GeV) at a harder spectral index Γ~1.8 than Fermi LAT (0.1-100 GeV) (Γ~2.7), for γ-ray active states.

- AGILE live time ~40% versus ~15% of Fermi LAT.

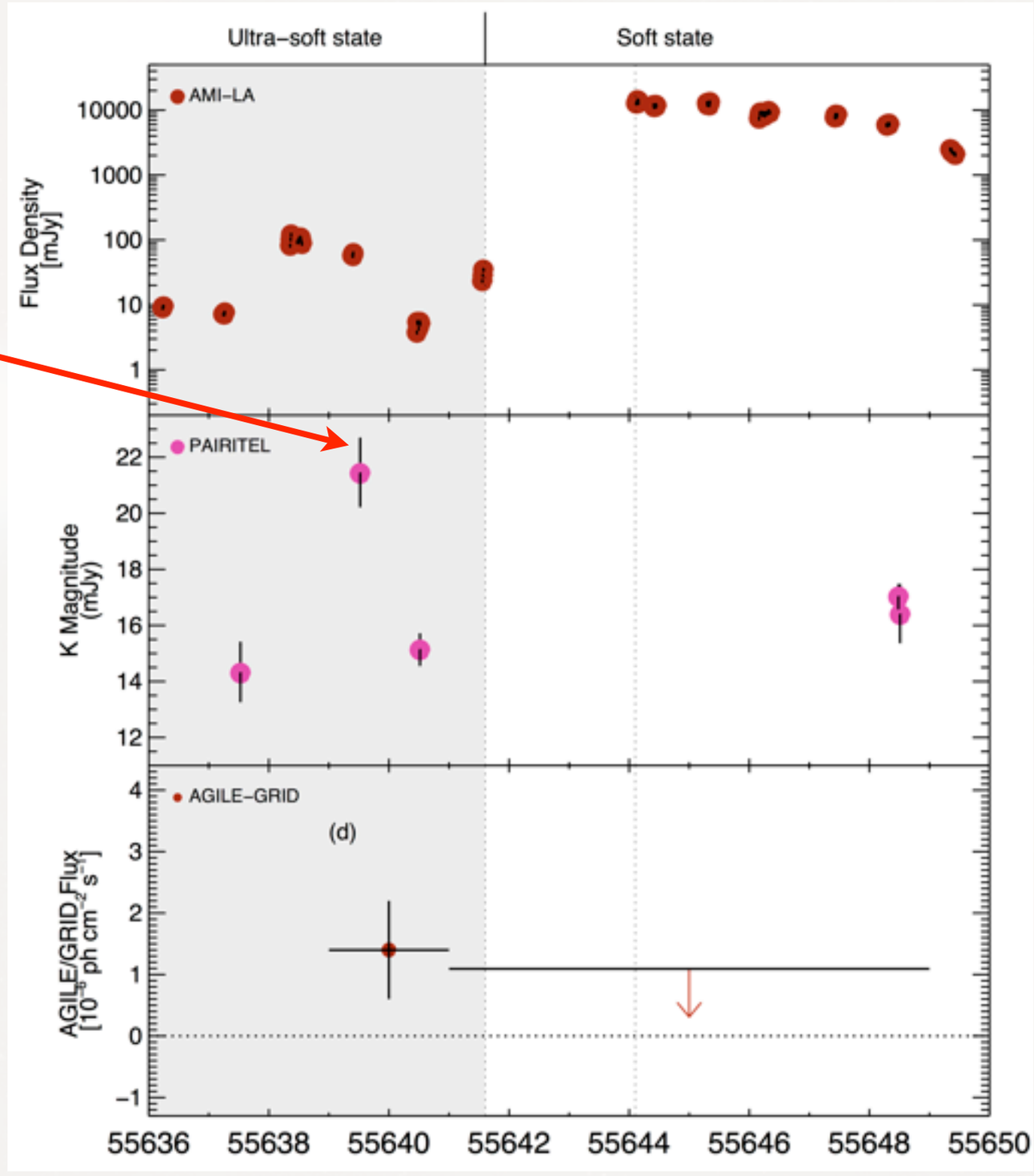


- **Multi-wavelength plot of Cygnus X-3:**

- Peak IR emission (K mag., 2.3 μm) before onset of major radio flare.

- IR emission before radio emission may be due to cooling electrons, but hard to point to IR emission origin (disk, jet, Wolf-Rayet star).

- AGILE and PAIRITEL peak emission observations for MJD 55640 **have overlap**. Overlap of IR/AGILE γ-ray event in 2010 as well.



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- **Cygnus X-3 Infrared Spectrum:**

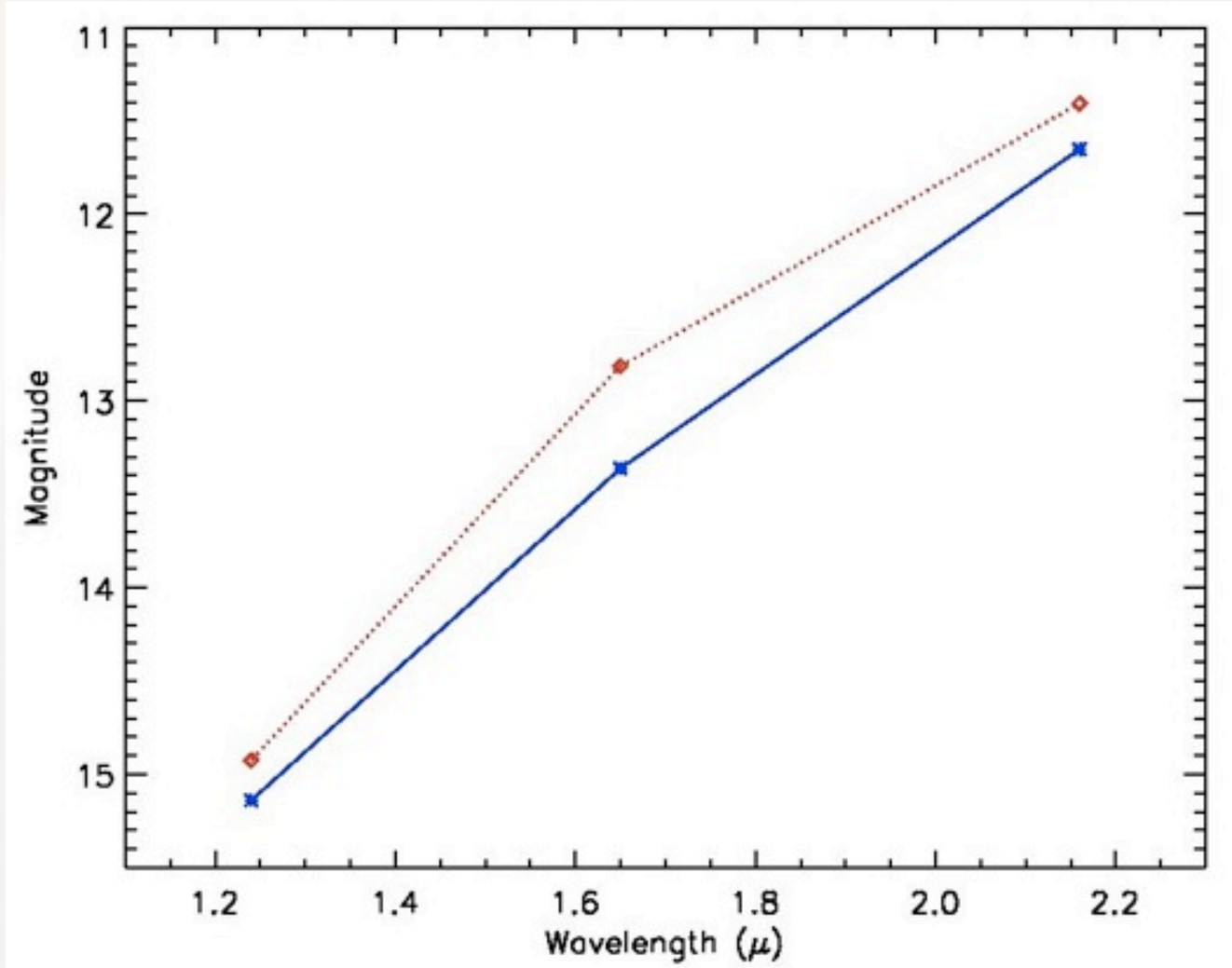
- Average waveband-centered IR data points for J (1.26 μm), H (1.60 μm) and K_s (2.22 μm) magnitudes.

  - Red curve: average spectrum for flaring radio state.

  - Blue curve: average spectrum for quiescent radio state.

- Spectral break may be due to exhaustion of electron energy in synchrotron process, but other IR contributions (i.e. dust) possible.

- Synchrotron contribution increases from IR to radio, while WR star contribution opposite.



Mike McCollough, 8th INTEGRAL Workshop, 2010

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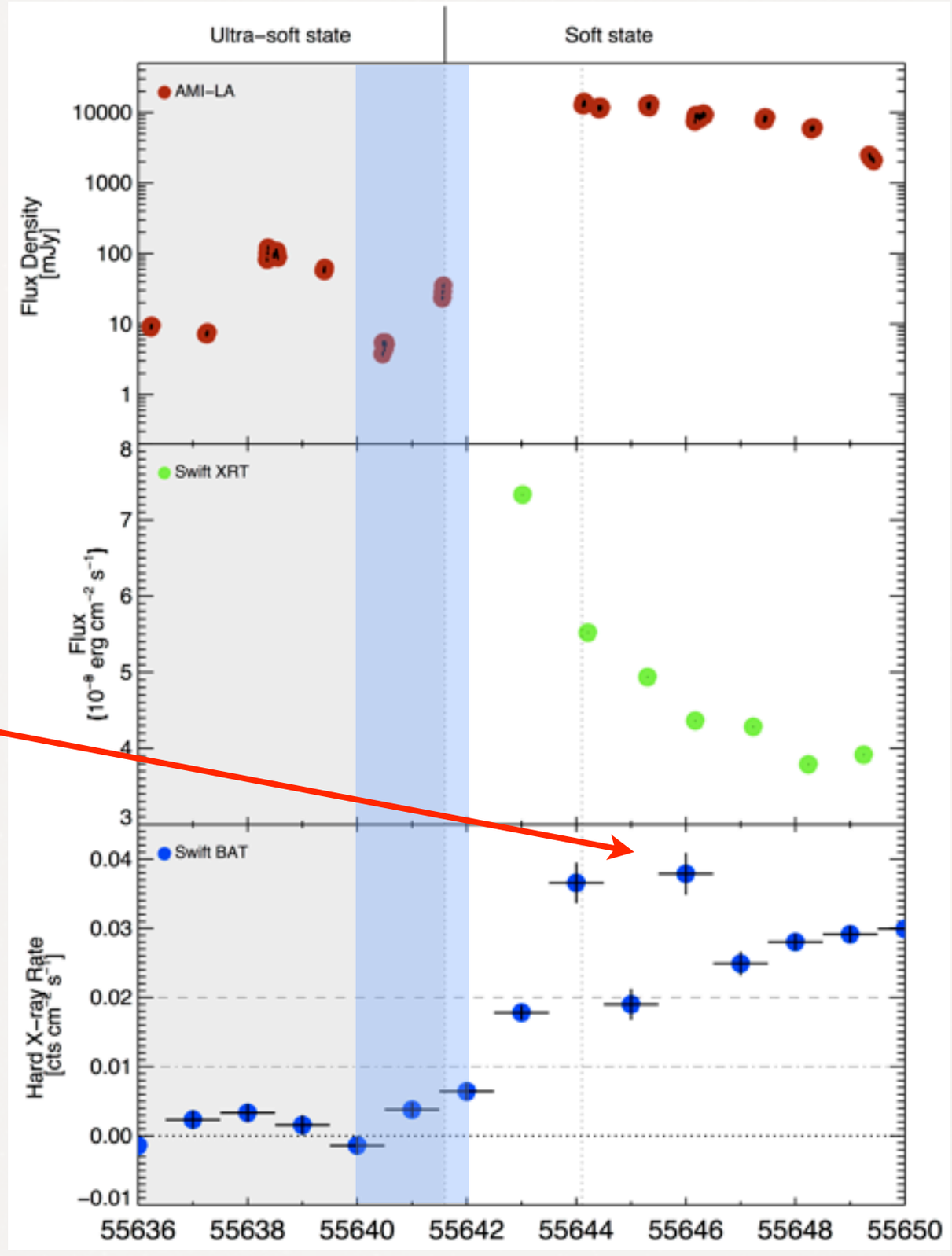
- **Multi-wavelength plot of Cygnus X-3:**

- Swift XRT (1-8 keV), decrease in soft x-ray emission, with decrease in disk accretion following major radio flare.

- <u>Two peaks</u> in the Swift BAT emission (15-50 keV), during soft x-ray descent ➜ <u>hard x-ray response to major radio flare.</u>

- Possible explanation of hard emission: **<u>internal shocks in jets</u>**.

- Fermi and AGILE emission region: shaded blue area.

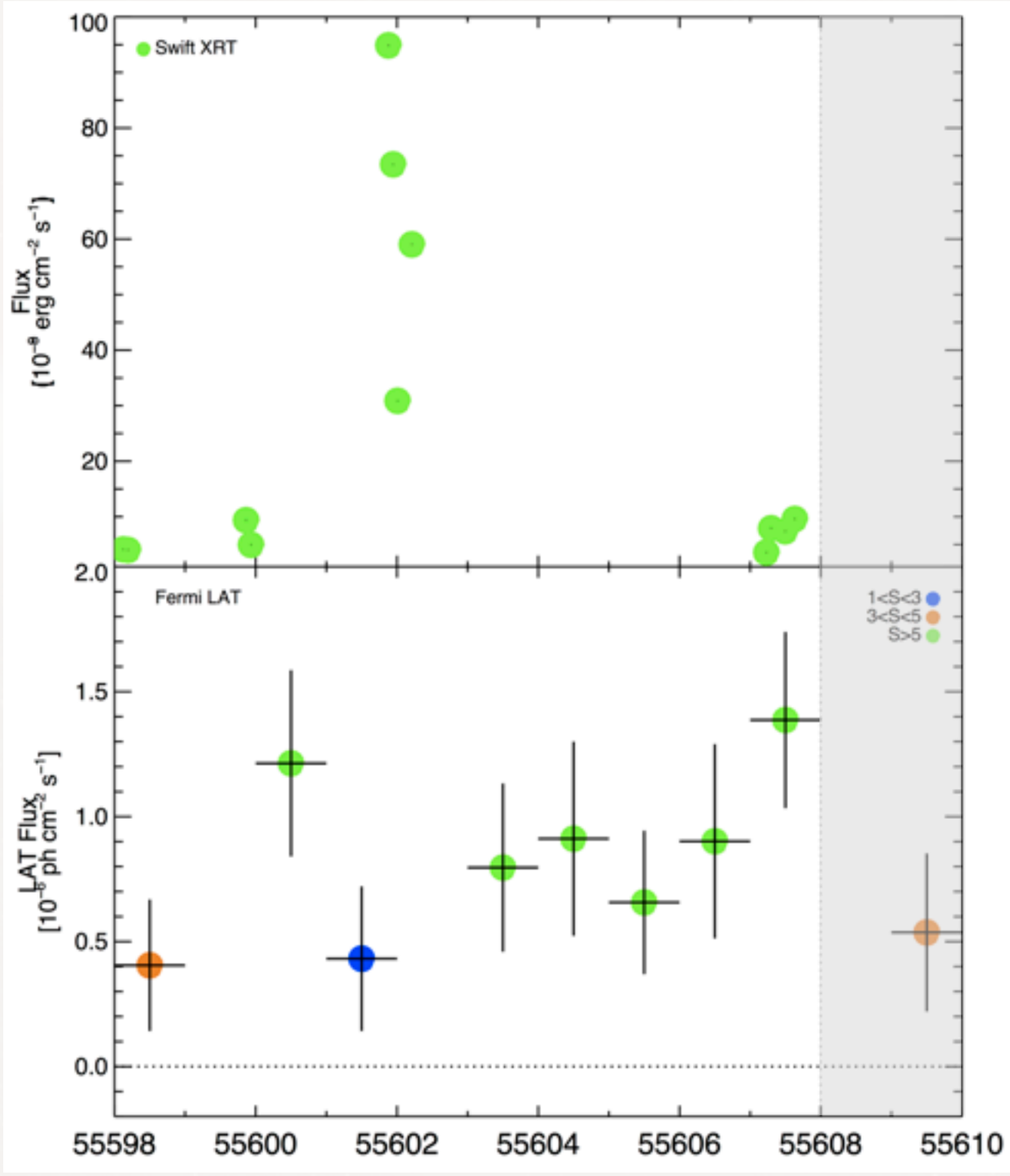


- **Multi-wavelength plot of Cygnus X-3:**

- Swift XRT (1-8 keV): increase in soft x-ray emission during Fermi LAT active state which precede descent into radio-quenched state.

- Possible explanation of soft x-ray emission: **half-day radio-quenched states**?

- Radio-quenched region: shaded grey area.



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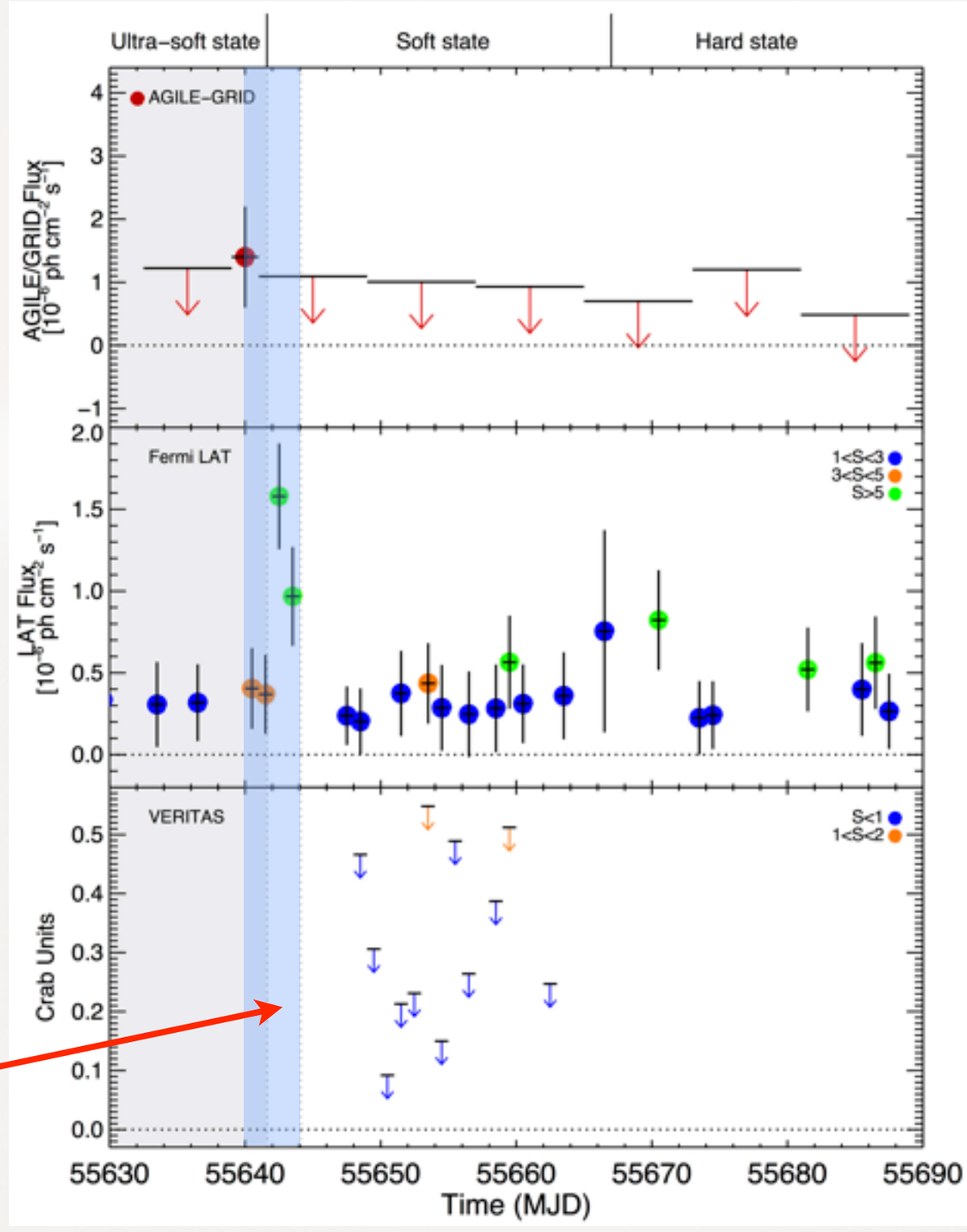
- **Multi-wavelength plot of Cygnus X-3:**

- VERITAS observations following radio flare (MJD 55648-55662).

- 99% c.l. upper limits on TeV observations, following major radio flare peak.

- TeV production most likely in descent/exit of quenched radio/hard x-ray state, more likely to occur closer to GeV emission area (blue shaded area).



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SUMMARY

- Two types of γ-ray emission: descent into and exit from quenched radio states, as confirmed by both AGILE and Fermi.
- Possible support for leptonic model, from AGILE data before onset of March 2011 radio flare.
- Possible internal shocks in jets, visible from comparison of soft x-ray (disk) and hard x-ray (jet) emission.
- Hard to pinpoint location of major infrared contribution (disk, jet, Wolf-Rayet star).
- Release of soft x-rays in between γ-ray emission ➜ half-day long radio-quenched states preceding final successful attempt into quenched state?
- TeV emission possibly occurs closer to GeV emission area, but hard to catch due to transient nature of event (~days).

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