High energy spectral variability of V404 Cygni during the June 2015 outburst

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V404 brief history

- First time detection with Ginga in 1989 (Makino+89; Kitamoto+89)
- 2-300 keV spectra obtained with Roentgen on Mir-Kvant (Sunyaev+91)
- Optical follow-up and identification (Wagner+1989; Casares+93)
- Two previous outbursts in 1938 and 1956, identified in archival optical data
- Observed multiple times during quiescence:
  - X-ray (Bradley+07, Rana+15)
    - multiwavelength (Hynes+09)
- Swift and MAXI detection on 2015, June 15
- Multiwavelength follow-up reported in many ATELs and in a few recent papers appeared on astro-ph
V404 Id

Black Hole mass: ~9 to 12 $M_\odot$
Orbital period: 6.5 days
Companion star: K0IV (1 $M_\odot$)
Distance: 2.39±0.14
Inclination: ~56 to 67°
X-ray quiescent luminosity: ~$10^{32}$ cgs

- One of the highest quiescent luminosities found in Black Holes
- Strong variability observed at all frequencies. Radio flux variations are on time scales of minutes
- The high energy spectrum, reported for the 1989 outburst is hard even at high luminosities (> ~0.1$L_{\text{Edd}}$)
Spectral variability during the 1989 outburst

Sunyaev+91
Kvant/TTM observation
9-10 June 1989, variability in absorption

Hard spectra detected with TTM, HEXE and Pulsar X-1
Radio/X-ray correlation for V404 Cygni

- Strong radio flux detections show evidence for jet-like emission

Radio/X-ray flux correlation
Corbel+08, Rana+15

Radio LC of the 1989 outburst
Han & Hjellming 1990
High energy observations of quiescent emission

- Previous observations by ROSAT, Asca, BeppoSAX, Chandra, XMM.
- Quiescent luminosity reported as $\sim 10^{33}$ erg/s (varying across the observations)
- Power-law spectrum ($\Gamma \sim 2$)
- XMM observation (Bradley+04) places upper limit on Fe line EW
- No strong ionized lines in the XMM or Chandra data (Hynes+09)

- The recent NuSTAR+VLA simultaneous observations report no evidence of correlated variability with radio flux during observation (Rana+15)
- Similar variability timescale in soft and hard X-rays (XMM-Newton+NuSTAR)
The 2015 outburst – the INTEGRAL monitoring

- INTEGRAL started to monitor the source on June 17
- Strong X-ray/soft gamma-ray flares reaching ~50 Crab in intensity
- Optical flaring correlated with X-ray flares in a complex way

IBIS/ISGRI Light curve (17-22 June)  Credit: ESA

INTEGRAL Light curves (20-25 June)  Rodriguez+15

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Multi-wavelength follow-up

✓ Fantastic opportunity to follow-up; instrumentation much more performant than was available in 1989

Credit: http://deneb.astro_warwick.ac.uk/phsaap/v404cyg/data/all.png
Radio & optical data

✓ Radio spectra point to optically thick synchrotron radiation probably from a compact jet

Spectra obtained with the RATAN-600 radio telescope

Optical LC from WCO
Spectral variability with IBIS and SPI

- Analysis of orbit 1554, period: June 17-20. Using OSA v10.1
- High count rates in ISGRI produce frequent gaps in the TLM data stream at the highest fluxes. The gaps duration is of the order of a few (~2-4) seconds.
- Our spectral analysis attempts to use both IBIS and SPI data in the 20-300 keV band. The two instruments are cross-calibrated, using Crab model spectrum on March 2015 data.
IBIS/ISGRI Light curves, orbit 1554

Start Time MJD 57190 21:30:45

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Hardness variations: the HorseHead

- At low fluxes (<0.1 Crab) the hardness variations are much wider
- More stable at intermediate fluxes. Positively correlated with flux up to ~2 Crab
- But within a single flare, harder spectra occur at higher fluxes

The spectral state seems rather independent of flux for a wide range of source luminosities (above ~10^{36} erg/s)

Natalucci+15

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Zooming on a bright flare

Fits with thermal Comptonization

- All spectra are well fit by \texttt{comptt} model (thermal plasma with disk seed photons)
- Spectrum C is better fitted by a direct continuum plus reflection (\textit{xillver})
- Seed photon temperature is very high for all spectra. Similar results using \textit{eqpair} (Coppi 1999)

### Results of Spectra Fitting Using the \texttt{comptt} Model.

<table>
<thead>
<tr>
<th>Spec.Id$^a$</th>
<th>$kT_0$ (keV)</th>
<th>$kT_e$ (keV)</th>
<th>$\tau$</th>
<th>Flux$^b$</th>
<th>$\chi^2$/dof</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>7.05 ± 0.2</td>
<td>$42^{+7}_{-4}$</td>
<td>0.7$^{+0.1}_{-0.2}$</td>
<td>5.5</td>
<td>25.8/38</td>
</tr>
<tr>
<td>C</td>
<td>7.4 ± 0.2</td>
<td>$40^{+5}_{-3}$</td>
<td>1.0 ± 0.16</td>
<td>5.0</td>
<td>54.9/39</td>
</tr>
<tr>
<td>C$^R$</td>
<td>8.6$^{+1.0}_{-1.4}$</td>
<td>$42^{+8}_{-18}$</td>
<td>0.9 ± 0.3</td>
<td>5.0</td>
<td>40.3/36</td>
</tr>
<tr>
<td>D</td>
<td>7.2 ± 0.3</td>
<td>$34^{+3}_{-2}$</td>
<td>1.2 ± 0.2</td>
<td>6.6</td>
<td>42.0/37</td>
</tr>
<tr>
<td>E</td>
<td>7.4 ± 0.3</td>
<td>$41^{+5}_{-11}$</td>
<td>$0.9^{+0.2}_{-0.3}$</td>
<td>3.5</td>
<td>37.9/38</td>
</tr>
<tr>
<td>F(*)</td>
<td>6.4 ± 0.2</td>
<td>$182^{+8}_{-93}$</td>
<td>$&lt;0.09$</td>
<td>1.73$^d$</td>
<td>91.5/73</td>
</tr>
<tr>
<td>G(*)</td>
<td>6.0 ± 0.3</td>
<td>$63^{+88}_{-33}$</td>
<td>$&lt;0.7$</td>
<td>1.17$^d$</td>
<td>101.3/66</td>
</tr>
</tbody>
</table>

**Note.** — $^a$ Fits with IBIS and SPI spectra are marked by (*). In all other cases, only IBIS data have been used. $^b$ Flux values in units of $10^{-7}$ erg s$^{-1}$ cm$^{-2}$, in the 20-200 keV range. $^c$ Fit with added reflection component (see text for more details). $^d$ Flux measured by IBIS. $^e$ Flux measured by SPI.
Low state vs. flaring spectra
The high energy variability

✓ At hard X-rays, the variability is characterized by strong variations of the hardness ratio down to timescales of ~10s or less, as detected by \textit{INTEGRAL}

✓ The hard X-ray variability must be correlated to the central accreting source. Possible contribution by jet?

✓ The source is also much variable in the soft X-rays, but the origin could be different. Two recent \textit{Chandra} observations show that this can be mostly explained by variable absorption in the outer disk

Slope vs flux variability in the Chandra observations (22-23 June)

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Conclusions

✓ We reported on the analysis of the initial phase of the V404 Cygni outburst, using the IBIS and SPI instruments

✓ V404 Cygni exhibits a strong variability up to the hardest X-ray energies. The origin of the variability is still unclear, but most probably related to the central accreting source.

✓ The variability picture and spectral behaviour at high energies is consistent with the results for the previous outburst (Sunyaev+1991)

✓ The spectra at the highest fluxes seem well described by a thermal corona with ~40 keV temperature.

✓ Using a single component model for the direct emission, the seed photon temperature is constrained to be ~7 keV (too high to originate within the accretion disk).

✓ A more complete analysis is ongoing