X-ray observations of gCas stars

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UMBC
X-RAYS DEFINING (again) A NEW CLASS: gCas-like systems

- multiple X-ray plasma (not a cooling flow)
- a dominant hard, thermal X-rays ($kT > 7$ keV) associated with a Be star (>80% of the total flux)
  - iron lines (Fe K complex; fluorescence)
  - variability (in all timescales)
  - moderated luminosity ($10^{32-33}$ erg/s)

From infrared, optical, UV:
Prototype of Be stars
standard Be star

From X-rays:
Prototype of a new class
non-standard Be star

Why?
From infrared, optical, UV:

Prototype of Be stars

standard Be star

From X-rays:

Prototype of a new class

non-standard Be star

Why?

Suggested models:

- accreting neutron star
- accreting white dwarf
- magnetic activities

the circumstellar disk
From infrared, optical, UV:

Prototype of Be stars

standard Be star

From X-rays:

Prototype of a new class

non-standard Be star

Why?

X-rays constitute an important piece but:

optical, UV and X-ray correlations need to be explained

My personal feeling: the next more significant contribution will be with a comprehensive multiwavelength campaign during dissipation/formation of the circumstellar disk.
X-ray surveys (hard X-ray sources) → gCas candidates → Optical catalogues (stars; massive star candidates) → gCas analogs

Lopes de Oliveira, Motch e al. 2006, Lopes de Oliveira 2007 (thesis)

POPULATING THE CLASS
### THE gCas (X-ray) CLASS

<table>
<thead>
<tr>
<th>Star Name</th>
<th>Sp. Type</th>
<th>(Lobe) vsini i km s(^{-1})</th>
<th>EW(_{H\alpha}) Å</th>
<th>SB1? (Blue Str.)</th>
<th>V mag</th>
<th>(kT_{\text{hot}}) (keV)</th>
<th>(L_X \times 10^{-32}) erg s(^{-1})</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ Cas</td>
<td>B0.5 IV-Ve</td>
<td>(d) 385</td>
<td>-34</td>
<td>SB1</td>
<td>2.39</td>
<td>12–15.7</td>
<td>7–11</td>
<td>(1)</td>
</tr>
<tr>
<td>HD 110432</td>
<td>B0.5 IIIe</td>
<td>(d) 350</td>
<td>-52</td>
<td>BS</td>
<td>5.31</td>
<td>16–37</td>
<td>4.2–5.2</td>
<td>(2)</td>
</tr>
<tr>
<td>HD 161103</td>
<td>B0.5 III-Ve</td>
<td>(s) 224</td>
<td>-31</td>
<td>–</td>
<td>8.69</td>
<td>7.4–10</td>
<td>4–6:</td>
<td>(3)</td>
</tr>
<tr>
<td>SAO 49725</td>
<td>B0.5 III-Ve</td>
<td>(s) 234</td>
<td>-30</td>
<td>–</td>
<td>9.27</td>
<td>12.3</td>
<td>4–12:</td>
<td>(3)</td>
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<td>HD 119682</td>
<td>B0.5</td>
<td>220</td>
<td>-30</td>
<td>BS</td>
<td>7.91</td>
<td>10.4</td>
<td>6.2</td>
<td>(4)</td>
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<tr>
<td>SS 397</td>
<td>B1 Ve</td>
<td>–</td>
<td>-34</td>
<td>–</td>
<td>11.76</td>
<td>6.3–13</td>
<td>3.4</td>
<td>(5)</td>
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<tr>
<td>NGC 6649 WL9</td>
<td>B1-1.5 IIIe</td>
<td>–</td>
<td>-36</td>
<td>BS</td>
<td>11.9</td>
<td>10</td>
<td>5</td>
<td>(5)</td>
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<tr>
<td>*XGPS-36</td>
<td>B1 Ve</td>
<td>–</td>
<td>-27</td>
<td>–</td>
<td>14.3:</td>
<td>10</td>
<td>3.4</td>
<td>(6)</td>
</tr>
<tr>
<td>HD 157832</td>
<td>B1.5 Ve</td>
<td>(d) 217–266</td>
<td>-25</td>
<td>–</td>
<td>6.6</td>
<td>10–11.3</td>
<td>1.3–3.4</td>
<td>(7)</td>
</tr>
<tr>
<td>HD 45314</td>
<td>B0 IVe</td>
<td>285</td>
<td>-30</td>
<td>SB1?</td>
<td>6.6</td>
<td>21</td>
<td>(L_X/L_\ast) = -6.1</td>
<td>(8)</td>
</tr>
<tr>
<td>*TYC3681-695-1</td>
<td>B1-2 III/Ve</td>
<td>–</td>
<td>-31</td>
<td>–</td>
<td>11.36</td>
<td>–</td>
<td>1.4–5.8</td>
<td>(9)</td>
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<tr>
<td>*2XMMJ ...</td>
<td>B0 Ve</td>
<td>–</td>
<td>-50</td>
<td>SB?, BS?</td>
<td>22:</td>
<td>–</td>
<td>2.4–3.3</td>
<td>(9)</td>
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<tr>
<td>180816.6-191939</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>*3XMMJ ...</td>
<td>O9e-B3e</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4–3.0</td>
<td>(10)</td>
</tr>
</tbody>
</table>


*These are “candidate” objects (see text).
1866 (AN, 68, 63): Secchi (optical)
“[…] une particularité curieuse de l’étoile g Cassiopée, unique jusqu’à présent. Une ligne lumineuse très-belle et bien plus brillante que tout le reste du spectre.” (Hbeta; lambda λλ4861Å)


2000 (A&A, 364, 85) Harmanec et al. (optical): gCas in a binary system (~203d; 1M⊙)

2018: …………………………………………………………………………
A high-energy excess in the spectrum of X Per, spectral variations across the X Per pulse, and the lack of any iron emission at 6.7 keV from both gCas and X Per suggest that the emission is not truly thermal [...]”

“[gCas is, like X Per] a widely separated binary system containing an accreting neutron star.”

“A strong iron line was observed at 6.8 keV [...] its strength [...] and the existence of a thin thermal plasma are in conflict with models that require a neutron star as the X-ray source [...] we suggest the possible existence of a degenerate dwarf [...] instead of a neutron star.”

“A 22,000 s observation [December 1984] with EXOSAT […] reveals oscillations in the X-ray flux with a period of about 6000 s.

[Wrong, but this is important: modulation comes and goes]

The source also exhibits chaotic variability with time scales down to a few tens of seconds.”


“A 30h duration EXOSAT observation made in 1985 December […] dominated by irregular energy-independent flaring on time-scales >~100 s. We find no evidence for the 6000 s oscillations reported by Frontera et al. (1987). We suggest that these arise from statistical fluctuations in the red noise power.”
“**temperature of 12 keV, or by a cut-off power-law model** with a narrow iron line at an energy of 6.67 keVt [...]”

The origin [...] remains open [...] consistent with both an accreting neutron star [burst source?] and a white dwarf while its high temperature argues against a coronal mechanism”.

![Graph showing data from EXOSAT observations.](image)
"There has been no clear way to distinguish which, if any, of these models is correct"

But

"The observed properties of rapid fluctuations on timescales down to 10 s and a spectrum with a temperature of 10.6 keV, together with iron line emission, are very similar to those of binary white-dwarf systems."
Kubo et al. 1998, PASJ, 50, 417

ASCA (three data sets)

“A rapid time variability on timescales down to 10 s.”

From the power-density spectrum:
“[…] there is no clear periodicity, a 1/f type fluctuation is clear.”
HD110432

0.3-12 keV

Brief pause: optical

“The first orbital RV curve of this star”: Porb: 203.59 days; eccentricity of 0.26
“The secondary has a mass of about 1 Msun.”


∼205 days, circular orbit.


Porb = 203.55 +/- 0.20 days; excentricity → 0
π Aquarii

“Aqr is a binary but, contrary to γCas, the nature of the companion to the Be star is known; it is a non-degenerate (stellar) object and its small separation from the Be star does not leave much room for a putative compact object close to the Be disk. This renders the accretion scenario difficult to apply in this system, and, hence, this discovery favors a disk-related origin for the γCas phenomenon.”

- \( P_{\text{orb}} \): 84 days
- \( 10-14M_{\odot} + 2-3M_{\odot} \)

Be A or F main sequence?

Bjorkman et al. (2002)

(non-degenerate)

OVII fir complex: (i+f)/r ~ 0.9 +/- 0.1 → collisional dominance (not conclusive: strong UV source)
Discrete plasma:

- strong lines of N VII ($Z_N \approx 2.3 \times Z_{N,sun}$) and Ne XI ($Z_{Ne} \approx 1.8 \times Z_{Ne,sun}$)

- a subsolar Fe abundance from K-shell lines but a solar abundance from L-shell ions.

Properties from high-resolution spectroscopy

“[…] is fitted extremely well with a thermal plasma emission model with a single absorption component.”

“We found no compelling need for an additional non-thermal high-energy component.”

“[…] the star–disk interaction model details remain to be worked out, although for now it seems to be the favored explanation for the long-standing γ Cas enigma.”
Other properties in X-rays
(correlated with optical and UV emission)
X-ray modulation (UV modulation)


RXTE + Hubble (1996)

Scaled UV Curve

~1400 Å

> 2 keV

Counts/sec

1996 March Decimal Date (U.T.)
Variable absorption column (variability in the disk)


absorption column

versus

disk brightness

(no clear relation between this column density and orbital phase)
In fact, absorption changes also in short timescales.

Softness dips (in X-rays)
Long term (year) variability of X-ray flux (variability in the disk)


gCas
Long term (year) variability of X-ray flux (variability in the disk)

Since the expected migration time from internal disk regions that emit most of the optical flux to the orbit of the companion star is several years, the simultaneity of the high energy and optical flux variations indicates that X-ray emission arises from close to the star.

"very well correlated on year timescales with no significant time delay"


ASM/RXTE (1.5-12 keV)

MAXI (2-20 keV)

V-band (from the disk)
“Whilst the star preserved its hard and bright X-ray emission during the shell phase, the X-ray spectrum during the phase of (partial) disk dissipation was significantly softer and weaker.

The observed behaviour of HD 45314 suggests a direct association between the level of X-ray emission and the amount of material simultaneously present in the Oe disk as expected in the magnetic star-disk interaction scenario.”
SUMMARY:

- A challenging subject
- Energy budget of the Galaxy
- A growing number of gCas stars
  - Hard, thermal X-rays
  - Multiple thermal components
  - Variability: short (seconds, minutes) and long timescales (hours, days, ...)
  - Moderated X-ray luminosity ($10^{32-33}$ erg/s)
  - Optical, UV, and X-ray correlations

"Any theory that attempts to explain the X-ray emission should have as its goal the ability to account for these characteristics."

- Myron A. Smith.
  (First in 1998, and again and again)