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Review

Going Forward to Unveil the Nature of γ Cas Analogs

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Abstract: The star γ Cas and its analogs are a subset of Be stars that display particularly hard and bright thermal X-ray emission, which has no equivalent among other massive stars. Here, I will review their characteristics and present the latest results of our optical and X-ray monitoring campaigns, including an assessment of the links between the circumstellar environment and the high-energy properties. Possible scenarios to explain this phenomenon will be presented in light of these observational results.

Keywords: early-type stars; emission-line stars; Be stars; massive stars; X-rays; stars

1. Introduction

Since the 1970s, it has been known that massive stars can be sources of X-rays. Knowledge of their high-energy properties has greatly improved over the last 25 years, thanks to observations with XMM-Newton and Chandra, two sensitive X-ray observatories. Generally, the high-energy emission of these stars is linked to their fast and dense winds. The line-driving process giving rise to such winds is unstable, creating shocks throughout the winds. These, in turn, generate hot plasma, which emits X-rays [1]. This intrinsic emission displays several specific properties, the understanding of which has been refined over time [2–11]. The X-ray spectrum corresponds to that of an optically thin thermal plasma in collisional equilibrium, with a weak bremsstrahlung continuum and strong metallic lines (often from He-like or H-like ions). These lines are broad since they arise in a wind expanding with velocities of several thousand km s^{-1}. The associated temperatures remain low, typically ∼0.6 keV but with fainter plasma components up to 1–2 keV. In some cases, a small circumstellar absorption is needed, in addition to the interstellar one, to fit the spectra; it is attributed to the cool wind. The intrinsic X-ray flux remains remarkably constant, indicating a large number of clumps/shocks, hence a highly fragmented wind. However, some modulations of limited amplitude (<20%) may exist if large-scale structures are present in the winds (e.g., [12,13] and the references therein). Finally, the overall X-ray luminosity appears directly proportional to the bolometric luminosity ($L_X \sim 10^{-7} L_{BOL}$), as could be expected in view of the embedded wind shock origin (UV → wind → X-rays).

In addition to this intrinsic emission, two other phenomena can generate X-rays from the winds of massive stars: magnetic confinement and colliding winds. In about 10% of massive stars, a strong (kG) dipolar magnetic field has been detected. Such a field is able to channel the wind flows toward the equator, where they collide, generating additional X-rays (for a review, see ud-Doula and Nazé [14]). Compared to embedded wind shocks, this high-energy emission may correspond to hotter plasma (especially in O-stars). Rotational modulation has also been detected in some cases due to the misalignment of the magnetic and rotational axes (the so-called "magnetic oblique rotator"). In contrast, colliding winds arise in binaries composed of two massive stars, which are common, but these collisions

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rarely appear X-ray bright (for a review, see Rauw and Nazé [15]). When they do, the X-ray luminosity may jump by one dex, and harder thermal (∼2 keV) components are often detected. The typical signature of colliding winds consists of orbital modulation due to a varying collision strength in eccentric systems or to different wind absorptions in the line of sight (an effect particularly remarkable in systems with unequal wind strengths such as WR+O cases).

However, one object has long challenged this overall picture: γ Cas. It was subsequently found not to be alone, leading to the definition of a "γ Cas-analogs" subgroup. The following sections examine these peculiar properties in detail.

2. γ Cas: A Different Source of X-Rays

2.1. Characteristics

γ Cas was the first star identified to display Balmer emission lines. It then served as a prototype for the definition of the "Be" category; however, over time, some doubts about this status arose. Indeed, its X-ray emission, first detected in 1976, was puzzling (for a review, see Smith et al. [16]). In fact, the X-ray luminosity is clearly too low for typical X-ray binaries and too high for "normal" OB stars. While low-resolution spectra limited to low energies can be fitted by various models (e.g., a warm plasma component combined with a power law may seem to fit as well as a combination of warm and hot thermal components), the high-resolution, high-energy, and high-quality observations leave little doubt about the nature of the emission [17–19]. First, with its continuum coupled to emission lines, it is thermal in nature [17]. Second, the presence of the iron lines near 6.7 and 7.0 keV *requires* the presence of an extremely hot plasma ($kT = 5 - 20$ keV), as lower-temperature components (associated with warm, $kT < 2$ keV, plasma) or non-thermal power laws cannot reproduce them. Finally, hard X-ray observations show that the spectrum drops at $E > 10$ keV, as expected for the thermal component fitting the lower-energy spectrum [18,19]; any non-thermal contribution must be very weak at best as it is currently undetectable.

High-resolution spectra [17] have also revealed a weak forbidden line in the fir (forbidden–intercombination–resonance line) triplets associated with He-like ions. This indicates that the plasma either has a high density or is close to a source of UV photons. In addition, the iron complex contains fluorescence lines at 6.4 keV, indicating the reprocessing of the X-ray emission by dense, cool material located nearby.

Finally, γ Cas has proven to be variable on various timescales in a manner unlike that seen in "normal" OB stars or X-ray binaries [20–24]. Short-term, flare-like activity (also called "X-ray shots" or "flickering") is prominently detected. The amplitude of the frequency spectrum of such light curves follows a power law $\propto f^{-1/2}$. From time to time, soft "dips" are also recorded. Long-term, quasi-periodic ∼70 d cycles have been observed, as well as (stochastic) flux changes. Up until now, no stable periodicity has been recorded; in particular, no trace of rotational or orbital modulation has been found. Only transient peaks (signals often at a few ks) have been found, sometimes detected only by one instrument, while several instruments observing simultaneously (as with XMM) have detected nothing, highlighting their uncertain nature.

In recent decades, it has been realized that γ Cas is not an oddball: at least two dozen Oe/Be stars displaying the same high-energy behavior have been identified [25–28]. The incidence rate of the γ Cas phenomenon has been pinpointed as being around 12% among early-type Oe/Be stars. The main challenge in detecting such analogs is the need for X-ray observations. Up until now, no specific signature of the γ Cas phenomenon has been found at other wavelengths. For example, the short-term photometric behavior appears similar in γ Cas and non-γ Cas Be stars (Nazé et al. [29]).

2.2. Origin

With so many peculiarities, the X-ray emission of γ Cas analogs defies usual explanations. Two categories of scenarios have been proposed to explain the origin of the high-energy emission. The first involves star–disk interactions through localized, small-scale magnetic fields [16,20]. The second considers the X-ray emitter to be the companion of the Be star, not the Be star itself. Growing evidence underlines the importance of past interactions in a close binary to form Be stars. In this context, the Be star was initially the least massive star in the system, but it accreted matter and angular momentum during the interaction. In parallel, the mass donor, initially more massive, has now become a low-mass object, either a stripped star (sdOB) or a compact object (black hole—BH; neutron star—NS; white dwarf—WD). Such companions were not only predicted but were also observed. For example, many high-mass X-ray binaries composed of a Be star and an NS (or BH?) have been detected (for a review, see Reig [30]). X-ray observations have also revealed a few very bright and soft sources, typical of novae emission, in the Magellanic Clouds. Their optical counterpart was identified as a Be star, demonstrating that the systems are Be+WD pairs (e.g., Kennea et al. [31]). UV observations, complemented by optical and interferometric data, have also revealed the presence of hot subdwarfs next to Be stars [32]. In this context, it should be noted that a few γ Cas analogs have long been known to be binaries (e.g., γ Cas, π Aqr, ζ Tau), and additional monitoring has detected new cases [33]. The companions have low masses and long orbital periods, similar to other Be stars. Their nature has not yet been ascertained, but WDs have been advocated by some authors [34]. It is true that the other companions cannot explain the X-ray emission.

For example, Langer et al. [35] proposed that the X-rays of γ Cas analogs arise from the collision between the wind of a companion subdwarf and the disk of a Be star. To test this idea, a sample of Be+sdO systems (secure cases or candidates) was investigated at X-ray wavelengths [36]. The data mostly resulted in non-detections or detections of soft and faint emissions; only two cases of γ Cas-like X-rays were detected, in line with the general incidence of such objects among Be stars. Additionally, no link could be established between the X-ray luminosity and the binary properties (orbital period, effective temperature of companion, companion's mass, etc.), falsifying model predictions. Finally, the scenario itself was found to be at odds with the observed properties of subdwarfs, as well as with the observed properties of wind collisions (particularly for the plasma temperature and orbital modulation).

There are also problems if the X-rays are supposed to be produced by an NS companion. In fact, the absence of outbursts and periodic signals (linked to NS rotation) discards the usual accreting NS scenarios. The only remaining possibility is to consider an NS in the propeller phase, for which a shell of material accumulates around the NS [37]. However, the short-lived duration of such a phase contradicts the observed incidence of γ Cas stars in the Be population. Moreover, it provides no explanation for the correlated UV-X variability [20,38] or the absence of the Baldwin effect [24]. Finally, in that model, the observed low value for the circumstellar absorption could not be reconciled with the observed strength of the fluorescence line [39].

2.3. Influence of the Disk on X-Rays

Whatever the physical process at the origin of the X-ray emission, the material involved most probably comes from the largest reservoir in these systems: the Be disks. Multiwavelength monitoring has thus been performed in order to assess the link between X-ray properties and disk diagnostics.

Because of its brightness, γ Cas has been the target of detailed monitoring in recent decades. A Copernicus UV dataset coupled with simultaneous Hα observations revealed a brief increase in Hα associated with small changes in some UV lines [40] and an increase in X-ray emission [41]. A similar event may also have been observed with X-rays and He I λ6678Å increasing at the same time [42–44]. In addition, a simultaneous HST/GHRS-RXTE campaign revealed an anticorrelation between the X-ray fluxes and the UV continuum fluxes, with simultaneous changes in UV lines also observed and attributed to changes in ionization due to varying X-ray illumination [20,45]. Cycles of about 70 d were also observed at both optical and X-ray wavelengths [22], and correlations were found between X-ray absorption and $B - V$ color [16], as well as between X-ray fluxes and V magnitudes [24,46]. In contrast, no correlation was found with the orbital phase or strength of the Hα line [24].

The hottest γ Cas analog is the Oe star HD 45314. Long-term changes were detected for this star, with both disk building and disk dissipation events. X-ray data taken during a dissipation event (detected through both Hα and broad-band magnitudes) revealed a significant decrease in both X-ray brightness and hardness. The star could no longer be classified as γ Cas [47]. This "downstate" continued afterward, with the X-rays being softer and fainter in the more recent e-ROSITA data [28].

ζ Tau displays the highest absorbing column among all γ Cas analogs. This is most likely an inclination effect, as this Be star is seen edge-on. Combining Chandra, XMM, and e-ROSITA data with Hα observations again revealed an absence of correlation between the X-ray properties and orbital phase or Hα line characteristics, despite the presence of significant changes in the absorbing column [48]. It should be noted that, at the same epoch, the broad-band optical fluxes remained relatively stable (ignoring pulsations typical of Be stars).

HD 119682 and V767 Cen were both monitored, as their Hα emissions had decreased for some time and remained low or underwent only small surges [49] (see also Labadie–Bartz, in prep.). Despite the weak Hα emissions, the γ Cas character of these two stars was clear, with constant hardness and few flux changes. It should be noted that, at the same epoch, the broad-band optical fluxes of V767 Cen were relatively stable (ignoring pulsations and small flickers typical of Be stars).

Finally, π Aqr was the target of several X-ray campaigns [49,50] (see also Carciofi et al., in prep.). The Swift X-ray telescope monitored three orbits of the system without finding any evidence of orbital modulation at X-ray wavelengths. These Swift data were taken in 2018 when the Hα emission was strong and still growing. These could be compared to the XMM-Newton observations taken in 2013 when the disk had nearly fully disappeared and in 2023 at the start of a new dissipation event. It should be noted that these disk changes were accompanied by changes in broad-band magnitudes. At all times, π Aqr displayed a γ Cas character, but the emission was much softer and fainter in 2013 when the disk was minimal. In 2018, the X-ray emission had increased on average by 50%, and the X-ray-absorbing column had doubled, leading to a clear hardening. In 2023, a new disk dissipation started; this time, the polarization degree decreased smoothly and the V/R variations in the Hα line re-appeared. While the disk cleared inside first and outside later, the 2023 X-ray data indicated a luminosity that remained high, but absorption that already decreased by 15%. Clearly, continued monitoring of π Aqr is required to follow the current exceptional event and assess its impact.

3. Conclusions

About 10% of early-type Be stars display unusually bright, hard, and varying X-rays. The prototype for this class of objects is γ Cas. Up until now, peculiarities have been detected for these stars only in X-ray wavelengths, but more investigations may help find additional signatures in the near future (e.g., in the UV, infrared, or radio ranges). The origin of the X-ray emissions was linked to a subdwarf or NS companion to the Be stars, but these scenarios can now be discarded, thanks to detailed observations and in-depth modeling. Multiwavelength monitoring has been performed on several γ Cas objects. Long-term variations have been detected but without any orbital modulation or clear correlations with Hα properties. However, links have been found with UV features and/or broad-band V magnitudes, which probe parts of the disk that are closer to the star than Hα. It should be noted that, in this context, the γ Cas character may remain even with little Hα emission. While work over the last two decades has advanced knowledge significantly, much remains to be done to reach a full understanding. New observations are, of course, planned, and it is hoped that the γ Cas mystery will be solved in the coming years.

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References

1. Feldmeier, A.; Puls, J.; Pauldrach, A.W.A. A possible origin for X-rays from O stars. *Astron. Astrophys.* **1997**, *322*, 878–895.
2. Berghoefer, T.W.; Schmitt, J.H.M.M.; Danner, R.; Cassinelli, J.P. X-ray properties of bright OB-type stars detected in the ROSAT all-sky survey. *Astron. Astrophys.* **1997**, *322*, 167–174.
3. Oskinova, L.M. Evolution of X-ray emission from young massive star clusters. *Mon. Not. R. Astron. Soc.* **2005**, *361*, 679–694. [CrossRef]
4. Waldron, W.L.; Cassinelli, J.P. An Extensive Collection of Stellar Wind X-Ray Source Region Emission Line Parameters, Temperatures, Velocities, and Their Radial Distributions as Obtained from Chandra Observations of 17 OB Stars. *Astrophys. J.* **2007**, *668*, 456–480. [CrossRef]
5. Zhekov, S.A.; Palla, F. X-rays from massive OB stars: Thermal emission from radiative shocks. *Mon. Not. R. Astron. Soc.* **2007**, *382*, 1124–1132. [CrossRef]
6. Nazé, Y. Hot stars observed by XMM-Newton. I. The catalog and the properties of OB stars. *Astron. Astrophys.* **2009**, *506*, 1055–1064. [CrossRef]
7. Nazé, Y.; Broos, P.S.; Oskinova, L.; Townsley, L.K.; Cohen, D.; Corcoran, M.F.; Evans, N.R.; Gagné, M.; Moffat, A.F.J.; Pittard, J.M.; et al. Global X-ray Properties of the O and B Stars in Carina. *Astrophys. J. Suppl.* **2011**, *194*, 7. [CrossRef]
8. Nazé, Y.; Oskinova, L.M.; Gosset, E. A Detailed X-Ray Investigation of ζ Puppis. II. The Variability on Short and Long Timescales. *Astrophys. J.* **2013**, *763*, 143. [CrossRef]
9. Huenemoerder, D.P.; Ignace, R.; Miller, N.A.; Gayley, K.G.; Hamann, W.R.; Lauer, J.; Moffat, A.F.J.; Nazé, Y.; Nichols, J.S.; Oskinova, L.; et al. A Deep Exposure in High Resolution X-Rays Reveals the Hottest Plasma in the ζ Puppis Wind. *Astrophys. J.* **2020**, *893*, 52. [CrossRef]
10. Cohen, D.H.; Parts, W.; Doskoch, G.M.; Wang, J.; Petit, V.; Leutenegger, M.A.; Gagné, M. Chandra grating spectroscopy of embedded wind shock X-ray emission from O stars shows low plasma temperatures and significant wind absorption. *Mon. Not. R. Astron. Soc.* **2021**, *503*, 715–725. [CrossRef]
11. Gunderson, S.J.; Gayley, K.G.; Huenemoerder, D.P. Support for the standard picture of thermal X-rays in the wind of ζ Puppis from dielectronic recombination of He-like ions. *Mon. Not. R. Astron. Soc.* **2023**, *522*, 2739–2746. [CrossRef]
12. Oskinova, L.M.; Nazé, Y.; Todt, H.; Huenemoerder, D.P.; Ignace, R.; Hubrig, S.; Hamann, W.R. Discovery of X-ray pulsations from a massive star. *Nat. Commun.* **2014**, *5*, 4024. [CrossRef]
13. Nichols, J.S.; Nazé, Y.; Huenemoerder, D.P.; Moffat, A.F.J.; Miller, N.A.; Lauer, J.; Ignace, R.; Gayley, K.; Ramiaramanantsoa, T.; Oskinova, L.; et al. Correlated X-Ray and Optical Variability in the O-Type Supergiant ζ Puppis. *Astrophys. J.* **2021**, *906*, 89. [CrossRef]
14. ud-Doula, A.; Nazé, Y. Magnetically confined wind shocks in X-rays—A review. *Adv. Space Res.* **2016**, *58*, 680–693. [CrossRef]
15. Rauw, G.; Nazé, Y. X-ray and optical spectroscopy of the massive young open cluster IC 1805. *Astron. Astrophys.* **2016**, *594*, A82. [CrossRef]

16. Smith, M.A.; Lopes de Oliveira, R.; Motch, C. The X-ray emission of the γ Cassiopeiae stars. *Adv. Space Res.* **2016**, *58*, 782–808. [CrossRef]
17. Smith, M.A.; Cohen, D.H.; Gu, M.F.; Robinson, R.D.; Evans, N.R.; Schran, P.G. High-Resolution Chandra Spectroscopy of γ Cassiopeiae (B0.5e). *Astrophys. J.* **2004**, *600*, 972–985. [CrossRef]
18. Shrader, C.R.; Hamaguchi, K.; Sturner, S.J.; Oskinova, L.M.; Almeyda, T.; Petre, R. High-energy Properties of the Enigmatic Be Star γ Cassiopeiae. *Astrophys. J.* **2015**, *799*, 84. [CrossRef]
19. Tsujimoto, M.; Morihana, K.; Hayashi, T.; Kitaguchi, T. Suzaku and NuSTAR X-Ray Spectroscopy of γ Cassiopeiae and HD 110432. *Publ. Astron. Soc. Jpn.* **2018**, *70*, 109. [CrossRef]
20. Smith, M.A.; Robinson, R.D.; Corbet, R.H.D. A Multiwavelength Campaign on γ Cassiopeiae. I. The Case for Surface X-Ray Flaring. *Astrophys. J.* **1998**, *503*, 877–893. [CrossRef]
21. Robinson, R.D.; Smith, M.A. A Search for Rotational Modulation of X-Ray Centers on the Classical Be Star γ Cassiopeiae. *Astrophys. J.* **2000**, *540*, 474–488. [CrossRef]
22. Robinson, R.D.; Smith, M.A.; Henry, G.W. X-Ray and Optical Variations in the Classical Be Star γ Cassiopeia: The Discovery of a Possible Magnetic Dynamo. *Astrophys. J.* **2002**, *575*, 435–448. [CrossRef]
23. Hamaguchi, K.; Oskinova, L.; Russell, C.M.P.; Petre, R.; Enoto, T.; Morihana, K.; Ishida, M. Discovery of Rapidly Moving Partial X-ray Absorbers within Gamma Cassiopeiae. *Astrophys. J.* **2016**, *832*, 140. [CrossRef]
24. Rauw, G.; Nazé, Y.; Motch, C.; Smith, M.A.; Guarro Fló, J.; Lopes de Oliveira, R. The X-Ray Emission of γ Cassiopeiae During the 2020–2021 Disc Eruption. *Astron. Astrophys.* **2022**, *664*, A184. [CrossRef]
25. Nebot Gómez-Morán, A.; Motch, C.; Barcons, X.; Carrera, F.J.; Ceballos, M.T.; Cropper, M.; Grosso, N.; Guillout, P.; Hérent, O.; Mateos, S.; et al. The XMM-Newton SSC survey of the Galactic plane. *Astron. Astrophys.* **2013**, *553*, A12. [CrossRef]
26. Nazé, Y.; Motch, C. Hot stars observed by XMM-Newton. II. A survey of Oe and Be stars. *Astron. Astrophys.* **2018**, *619*, A148. [CrossRef]
27. Nazé, Y.; Motch, C.; Rauw, G.; Kumar, S.; Robrade, J.; Lopes de Oliveira, R.; Smith, M.A.; Torrejón, J.M. Three discoveries of γ Cas analogues from dedicated XMM-Newton observations of Be stars. *Mon. Not. R. Astron. Soc.* **2020**, *493*, 2511–2517. [CrossRef]
28. Nazé, Y.; Robrade, J. SRG/eROSITA survey of Be stars. *Mon. Not. R. Astron. Soc.* **2023**, *525*, 4186–4201. [CrossRef]
29. Nazé, Y.; Rauw, G.; Pigulski, A. TESS light curves of γ Cas stars. *Mon. Not. R. Astron. Soc.* **2020**, *498*, 3171–3183. [CrossRef]
30. Reig, P. Be/X-ray binaries. *Astrophys. Space Sci.* **2011**, *332*, 1–29. [CrossRef]
31. Kennea, J.A.; Coe, M.J.; Evans, P.A.; Townsend, L.J.; Campbell, Z.A.; Udalski, A. Swift J011511.0-725611: Discovery of a rare Be star/white dwarf binary system in the SMC. *Mon. Not. R. Astron. Soc.* **2021**, *508*, 781–788. [CrossRef]
32. Wang, L.; Gies, D.R.; Peters, G.J.; Götberg, Y.; Chojnowski, S.D.; Lester, K.V.; Howell, S.B. The Detection and Characterization of Be+sdO Binaries from HST/STIS FUV Spectroscopy. *Astron. J.* **2021**, *161*, 248. [CrossRef]
33. Nazé, Y.; Rauw, G.; Czesla, S.; Smith, M.A.; Robrade, J. Velocity monitoring of γ Cas stars reveals their binarity status. *Mon. Not. R. Astron. Soc.* **2022**, *510*, 2286–2304. [CrossRef]
34. Gies, D.R.; Wang, L.; Klement, R. Gamma Cas Stars as Be+White Dwarf Binary Systems. *Astrophys. J. Lett.* **2023**, *942*, L6. [CrossRef]
35. Langer, N.; Baade, D.; Bodensteiner, J.; Greiner, J.; Rivinius, T.; Martayan, C.; Borre, C.C. γ Cas stars: Normal Be stars with discs impacted by the wind of a helium-star companion? *Astron. Astrophys.* **2020**, *633*, A40. [CrossRef]
36. Nazé, Y.; Rauw, G.; Smith, M.A.; Motch, C. The X-ray emission of Be+stripped star binaries. *Mon. Not. R. Astron. Soc.* **2022**, *516*, 3366–3380. [CrossRef]
37. Postnov, K.; Oskinova, L.; Torrejón, J.M. A propelling neutron star in the enigmatic Be-star γ Cassiopeia. *Mon. Not. R. Astron. Soc.* **2017**, *465*, L119–L123, [CrossRef]
38. Smith, M.A.; Lopes de Oliveira, R.; Motch, C. Is there a propeller neutron star in γ Cas? *Mon. Not. R. Astron. Soc.* **2017**, *469*, 1502–1509. [CrossRef]
39. Rauw, G. Fluorescent Fe K line emission of γ Cas stars. I. Do γ Cas stars host propelling neutron stars? *Astron. Astrophys.* **2024**, *682*, A179. [CrossRef]
40. Slettebak, A.; Snow, T.P.J. Spectrophotometric variability in the Be star gamma Cassiopeiae: Simultaneous ultraviolet and Halpha observations. *Astrophys. J. Lett.* **1978**, *224*, L127–L131. [CrossRef]
41. Peters, G. The hard X-ray flux from GAM CAS during 1970–73. *Publ. Astron. Soc. Pac.* **1982**, *94*, 157–161. [CrossRef]
42. Murakami, T.; Koyama, K.; Inoue, H.; Agrawal, P.C. X-Ray Spectrum from Gamma Cassiopeiae. *Astrophys. J. Lett.* **1986**, *310*, L31. [CrossRef]
43. Smith, M.A. Dynamic Processes in Be Star Atmospheres. III. Rapid Multiwavelength Variability in gamma Cassiopeiae. *Astrophys. J.* **1995**, *442*, 812. [CrossRef]
44. Smith, M.A. Ultraviolet Activity as Indicators of Small-scale Magnetic Fields in γ Cassiopeiae. *Publ. Astron. Soc. Pac.* **2019**, *131*, 044201, [CrossRef]

45. Smith, M.A.; Robinson, R.D.; Hatzes, A.P. A Multiwavelength Campaign on γ Cassiopeiae. II. The Case for Corotating, Circumstellar Clouds. *Astrophys. J.* **1998**, *507*, 945–954. [CrossRef]
46. Motch, C.; Lopes de Oliveira, R.; Smith, M.A. The Origin of the Puzzling Hard-X-Ray Emission of γ Cassiopeiae. *Astrophys. J.* **2015**, *806*, 177. [CrossRef]
47. Rauw, G.; Nazé, Y.; Smith, M.A.; Miroshnichenko, A.S.; Guarro Fló, J.; Campos, F.; Prendergast, P.; Danford, S.; González-Pérez, J.N.; Hempelmann, A.; et al. Intriguing X-ray and optical variations of the γ Cassiopeiae analog HD 45314. *Astron. Astrophys.* **2018**, *615*, A44. [CrossRef]
48. Nazé, Y.; Motch, C.; Rauw, G.; Smith, M.A.; Robrade, J. X-raying the ζ Tau binary system. *Astron. Astrophys.* **2024**, *688*, A181. [CrossRef]
49. Nazé, Y.; Rauw, G.; Bohlsen, T.; Heathcote, B.; Mc Gee, P.; Cacella, P.; Motch, C. X-ray response to disc evolution in two γ Cas stars. *Mon. Not. R. Astron. Soc.* **2022**, *512*, 1648–1657. [CrossRef]
50. Nazé, Y.; Rauw, G.; Smith, M. Surprises in the simultaneous X-ray and optical monitoring of π Aquarii. *Astron. Astrophys.* **2019**, *632*, A23. [CrossRef]

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