Drastic Spectroscopic Variability of the Be/X-ray Binary A0535+262/V725 Tau during and after the 2009 Giant Outburst

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A0535+262/V725 Tau

- One of the most famous Be/X-ray binaries
- Parameters
  - O9.7IIIe + NS, $V = 8.9$ mag
  - orbital eccentricity: $\sim 0.47$, orbital period: 110.2 days
  - NS: 103-sec pulsar
- Up to now, 8 giant outbursts have been observed
- Bright enough to perform high-dispersion spectroscopy in optical
Outbursts in 2009 - 2011

• Giant outburst in Nov./Dec. 2009
  • Precursors in Oct. (Sugizaki+ 2009, Atel. #2277)
  • Rapid brightening at 30 Nov. (JD 2455166)
  • 3.1 Crab at the peak in 15-50 keV (Krimm+ 2009, Atel. #2336)

• Normal outbursts after the giant outburst
  • Precursor... outbursts in Mar. and July 2010
  • No precursor? ... outburst in Oct. 2010
  • X-ray peak shift: Mar. and July 2010

• Giant outburst again in Feb. 2011

MAXI light curve (2 – 10 keV)
Observations (1)

- Okayama Astrophysical Observatory
  - 188cm telescope/ HIDES, 350 – 680 nm
- Gunma Astronomical Observatory
  - 1.5m telescope/ GAOES, 480 – 670 nm
- $R \sim 50,000$, $S/N \sim 100$ @ H$\alpha$
- We were very lucky to perform monitoring during the giant outburst in 2009

Motivation:
To understand the mechanism of Be phenomena in both short (< 1 orbit) and long (> 1 orbit) time scale

Detailed analysis of variations can be dealt with
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Results (1)

- Representative spectra of Hα, He I λ 5876
  - Before the giant outburst 2009
    - Hα line profile: characterized by a strongly redshifted triple peak and a broad hump in the blue wing
    - He I λ 5876 line profile: more or less a typical double peaked seen in many Be stars
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  - Precursor of the giant outburst 2009
    - The intensity of normalized flux, E/C, of both lines significantly increased
    - The blue hump became more outstanding
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• Representative spectra of Hα, He I λ 5876
  • during the giant outburst 2009
    • In Hα line profile, a bright “shoulder” appeared $\sim$ 0 km s$^{-1}$ in the blue wing
    • A similar, bright feature was seen in the central part of the He I λ5876 line profile (between -50 km s$^{-1}$ and +50 km s$^{-1}$).
Results (1)

- Representative spectra of Hα, He I λ 5876
  - during the giant outburst 2009
    - The blue bright “shoulder” in Hα line and bright feature in He I λ 5876 has gone
Results (1)

• Representative spectra of Hα, He I λ 5876
  • during the giant outburst 2009
    • The E/C ratio gradually increased until 22 December 2009 and then decreased in fading phase
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- Representative spectra of Hα, He I λ 5876
  - after the giant outburst 2009 to the normal outburst in March 2010
    - the double peak of the Hα line continued to grow
Results (1)

- Representative spectra of Hα, He I λ 5876
  - after the giant outburst 2009 to the normal outburst in March 2010
    - the double peak of the Hα line reached the highest intensity
Results (1)

- Representative spectra of Hα, He I λ 5876
  - during the normal outburst in March 2010
    - The blue “shoulder” seems to reappear
Results (1)

- Representative spectra of Hα, He I λ 5876
  - during the normal outburst in March 2010
    - In the Hα line, the strongly redshifted double peak weakened and a huge, broad shoulder appeared in the blue wing and Hα line profile became like a top-hat profile
    - In the He I λ5876 line, a bright component appeared
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Results (2)

- Equivalent width of H\(\alpha\), He I \(\lambda\) 5876
  - Highest in the last five years
  - H\(\alpha\) and He I \(\lambda\) 5876 lines show similar trend
  - For H\(\alpha\), temporarily decreased in precursor phase (October 2009, JD 2455140)
  - Increased for a while until two days before the peak of the outburst
  - At first decreased and increased in fading phase
  - Gradually decreased after the giant outburst 2009
  - Increased before normal / giant outbursts
Results (3)

- E/C (intensity of normalized flux) of Hα, He I λ5876
  - Similar trend to Equivalent width
  - Hα: Highest during giant outburst (> 3.5)
    - due to highly redshifted triple peak component ... also responsible for equivalent width
Discussion

- High E/C ratio, asymmetric line profile
  - not only the Be disc has grown denser, but also a non-axisymmetric bright region has appeared in the disc
- Enhanced Hα profile has a blue hump and a triple peak
- Blue shoulder
  - can be seen only at periastron passage
  - Blue hump: $\sim -100 - 0$ km s$^{-1}$; similar to the velocity of the violet peak of double-peaked profiles that showed the V/R variability (YM+ 2010)

$\phi_X = 0.808$

Giant outburst rise

$\phi_X = 0.039$

$\phi_X = 0.072$

Giant outburst peak

$\phi_X = 0.089$

$\phi_X = 0.143$
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- **Blue hump arise from...**
  - The outermost region of the Be disc
  - The density is higher than usual, possibly due to a one-armed density wave
  - The neutron star passes the periastron, an enhanced mass transfer should take place from the dense part of the Be disk to the neutron star (blue shoulder)
Discussion

• **Triple peak**
  - Negueruela et al. (2001) : 4U 0115+63
    - The profile often shows a succession of single-peaked and shell profiles around a giant outburst
  - Warped Be disc:
    - driven by radiation from the central star (Porter 1998)
    - Tidal warping and precession (Martin et al. 2011)
  - Such a strong disturbance in the Be disc can shift the phase of maximum mass transfer toward the neutron star
More observe, more complex ...?

- Spectra during giant outburst in 2011
  - Before the outburst, Hα line was rather normal double-peaked profile
  - Equivalent width (|EW(Hα)| ≤ 9 Å), E/C(Hα) ≈ 2.5 is rather small to involve in type II outburst?
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Conclusions

• We observed the giant outburst of the Be/X-ray binary A0535+262/V725 Tau in Nov./Dec. 2009.

• Observed emission line profiles during the giant outburst imply active components in the Be disk, which cause significant variability in the observation period.

• The bright blue shoulder indicates the enhanced gas stream from the outermost part of the Be disk to the neutron star at periastron.

• Highly redshifted, enhanced triple-peaked feature in the Hα line profiles is possibly from a warping component.