

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

Yuuki Moritani (Kyoto Univ.)

Collaborators:

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S. Honda⁽¹⁾ and O. Hashimoto⁽⁴⁾

(1): Kyoto Univ., (2): Hokkai-gakuen Univ.,
(3): OAO/NAOJ, (4): GAO

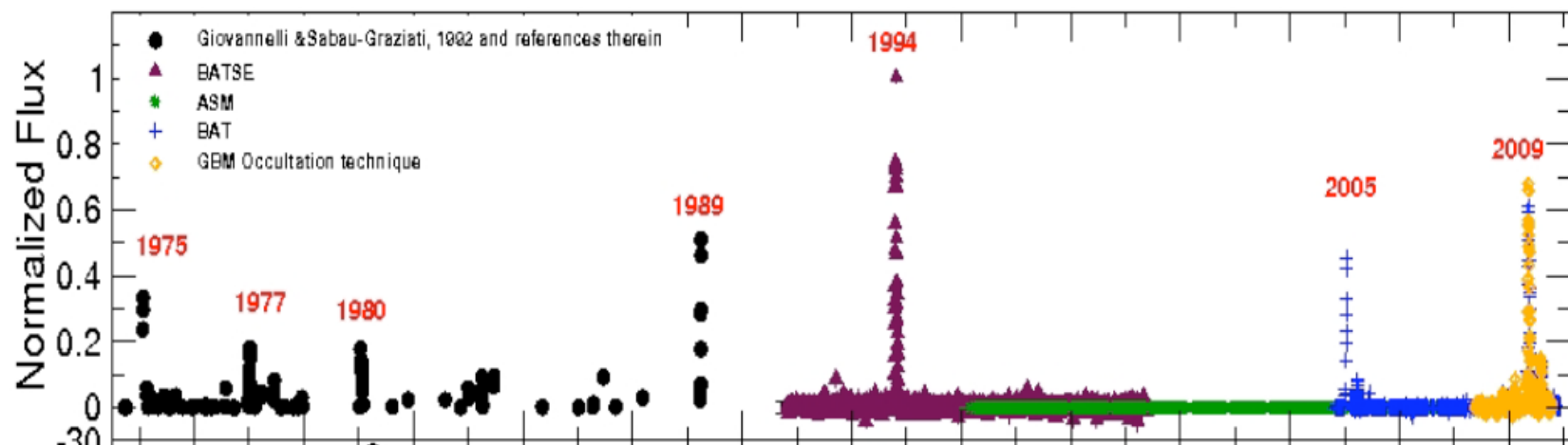
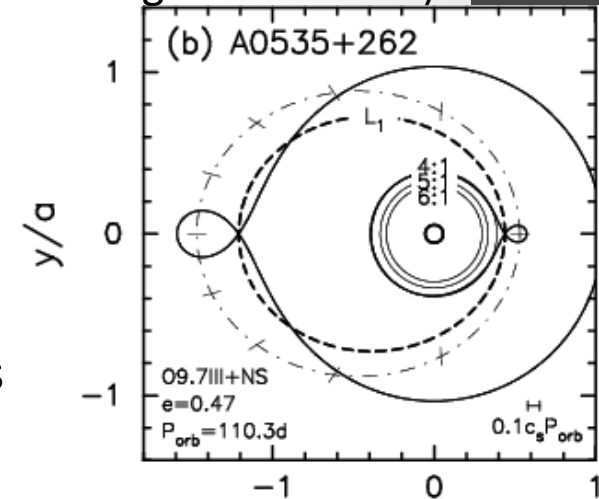


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A0535+262/V725 Tau

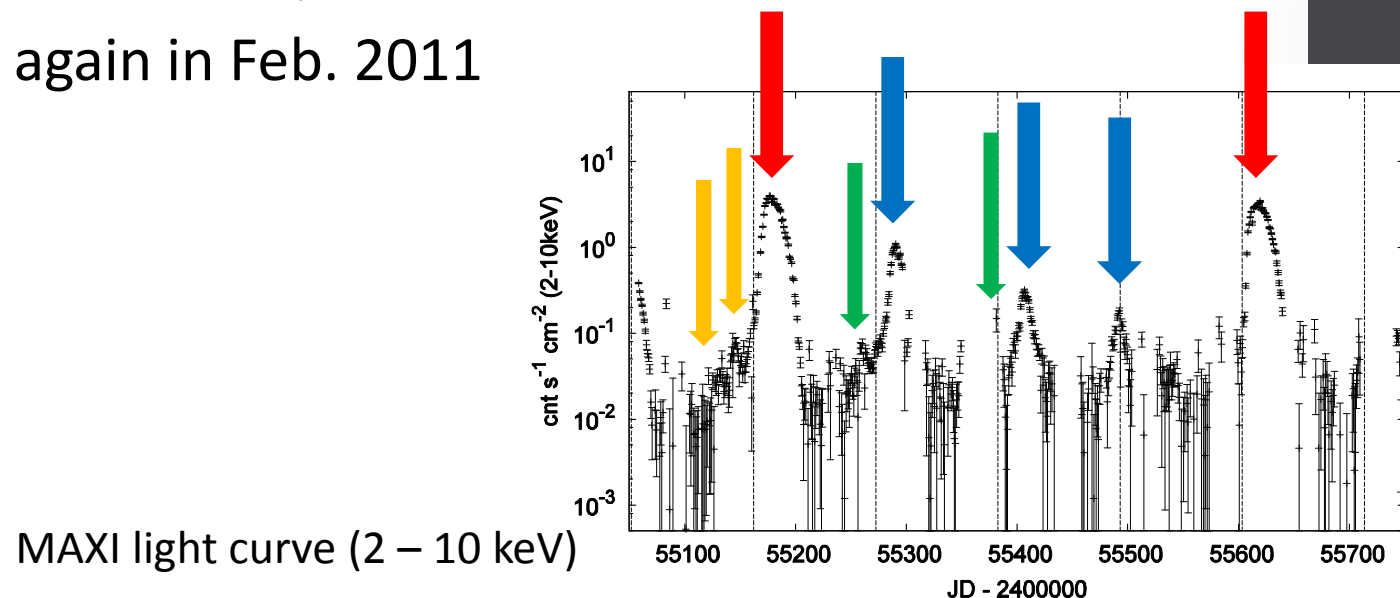
- One of the most famous Be/X-ray binaries
- Parameters
 - O9.7IIIe + NS, V = 8.9 mag
 - orbital eccentricity: ~ 0.47 , orbital period: 110.2 days
 - NS: 103-sec pulsar
- Up to now, 8 giant outbursts have been observed
 - in 1975, 1977, 1980, 1989, 1994, 2005, 2009, 2011
- Bright enough to perform high-dispersion spectroscopy in optical



X-ray history of A0535+262 (Camero-Arranz et al. 2011)

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



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

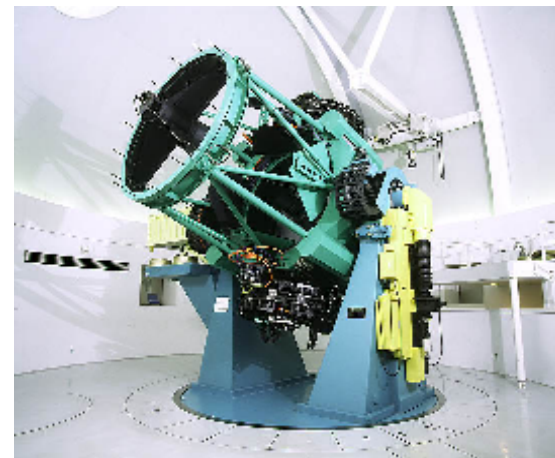
Motivation:

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



188cm tel. @OAO



1.5m tel. @GAO

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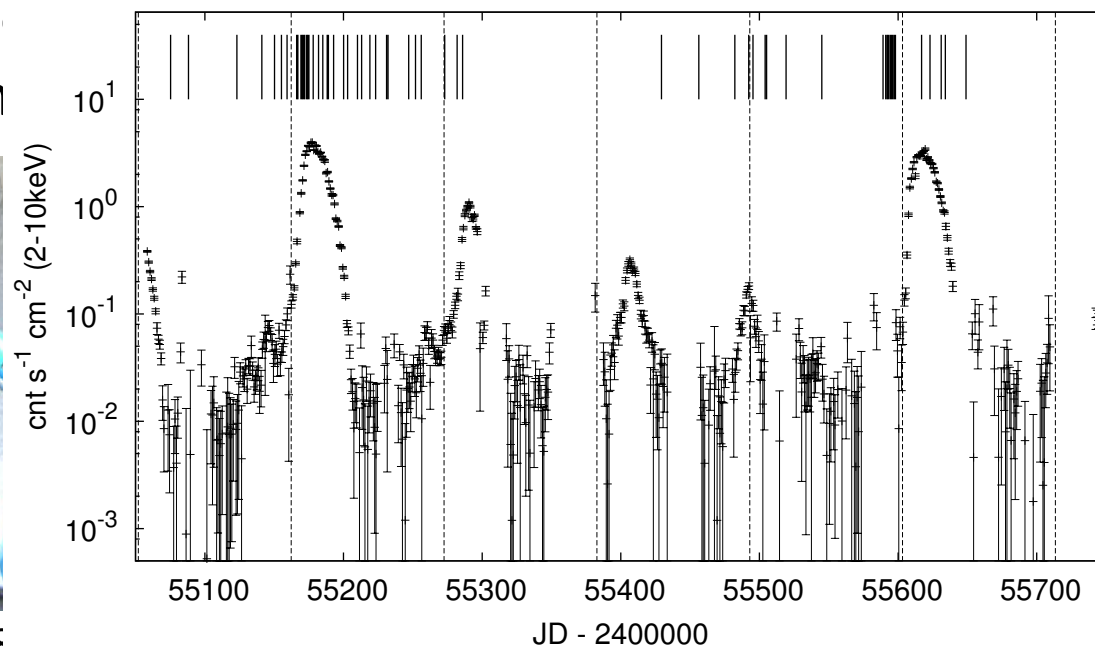
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188cm tel. @ OAO



JD - 2400000

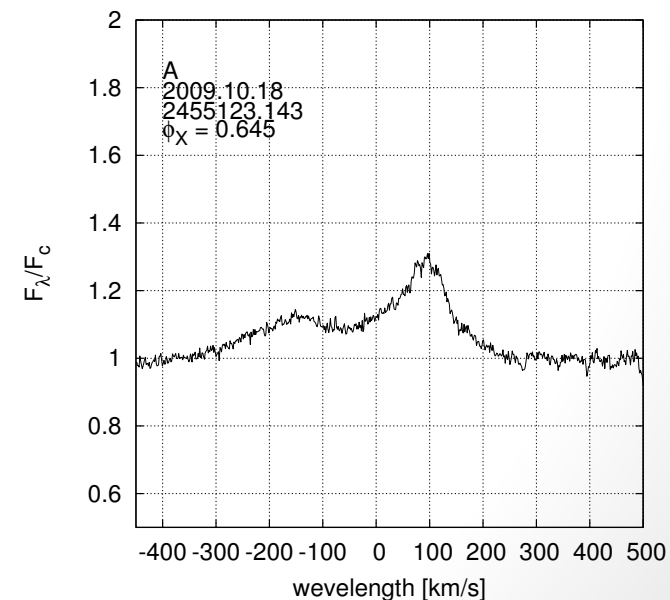
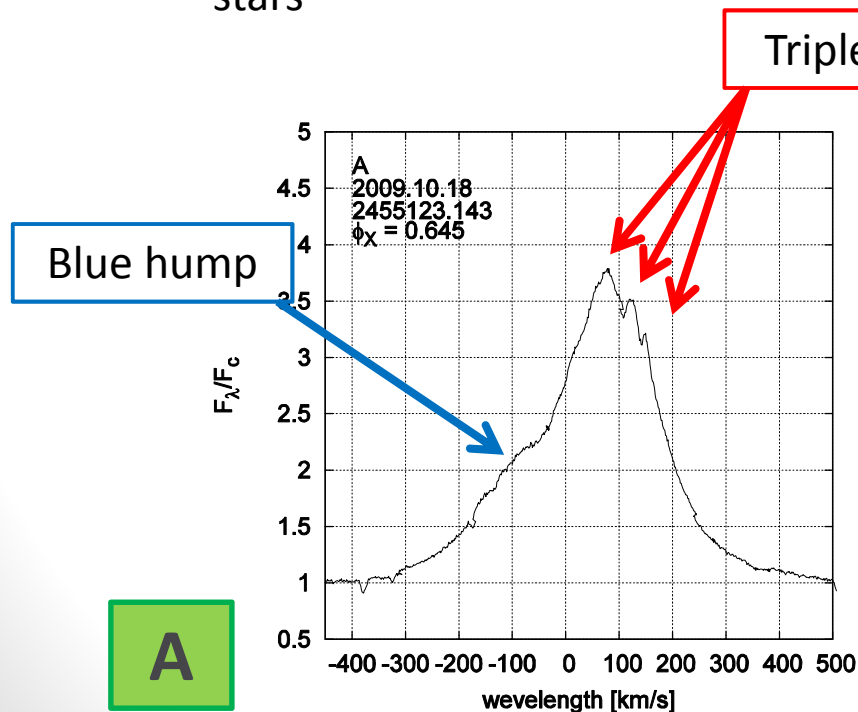
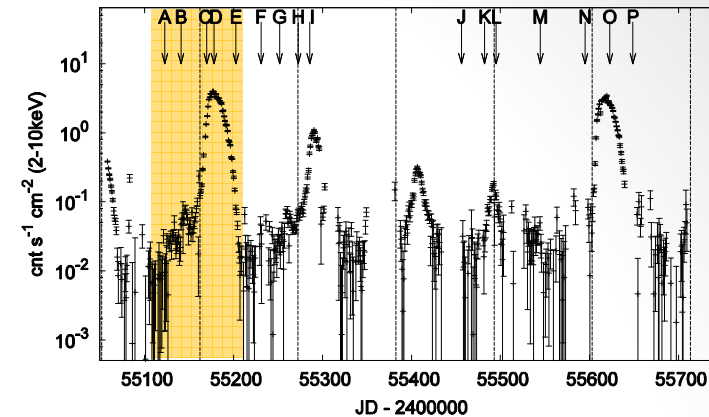
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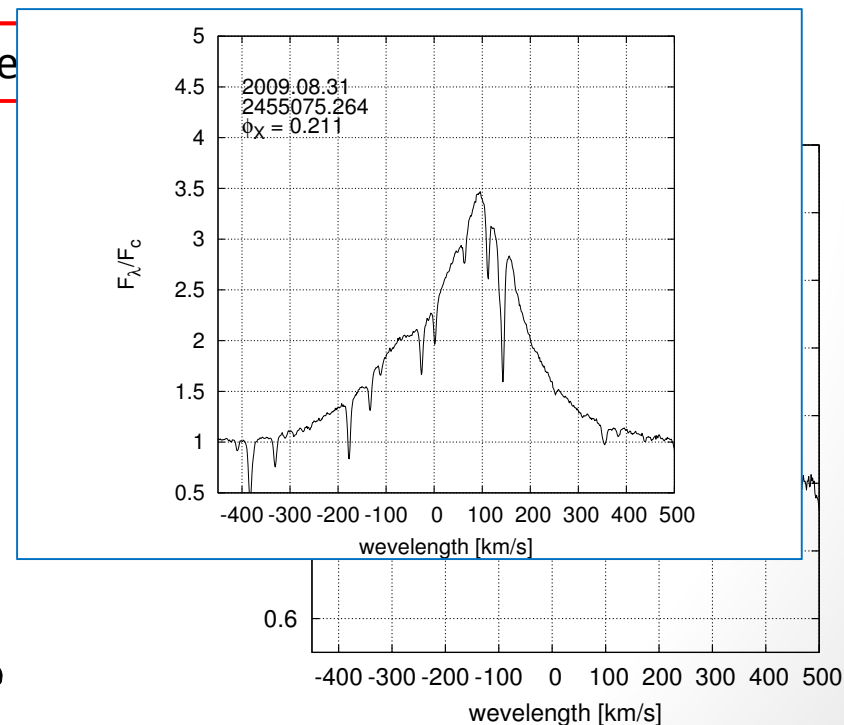
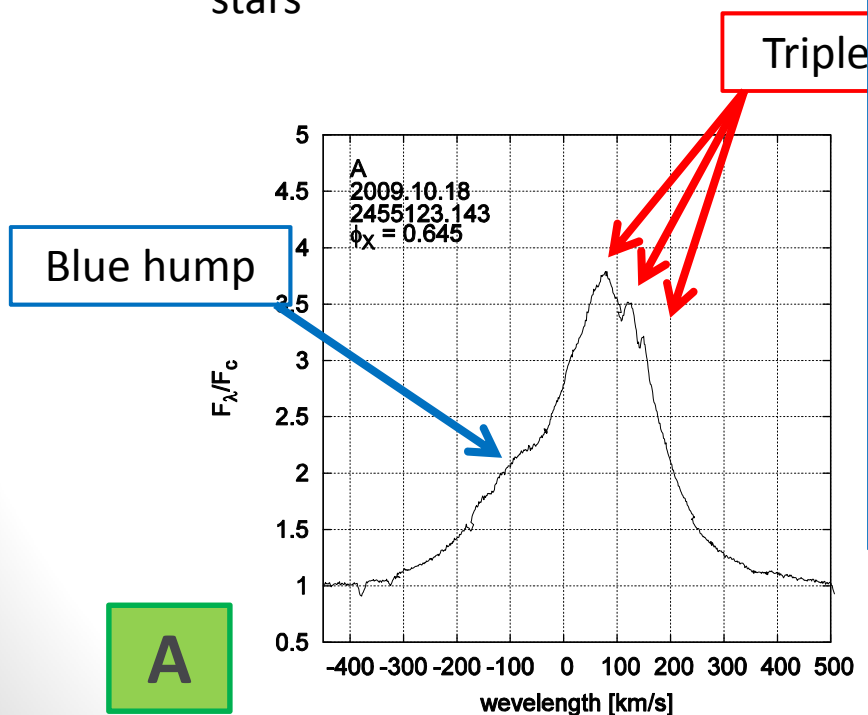
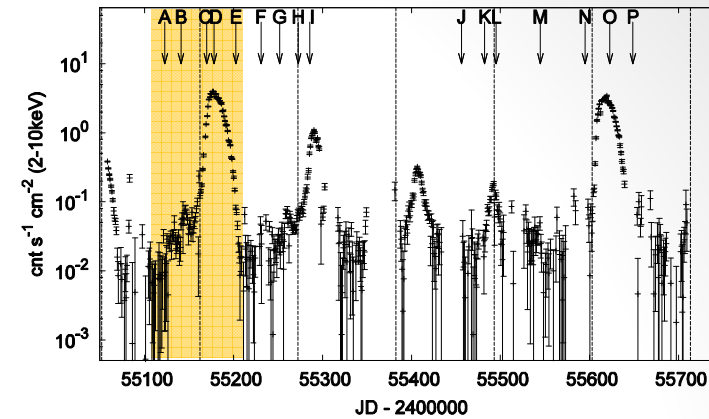
Results (1)

- Representative spectra of $H\alpha$, He I λ 5876
 - Before the giant outburst 2009
 - $H\alpha$ 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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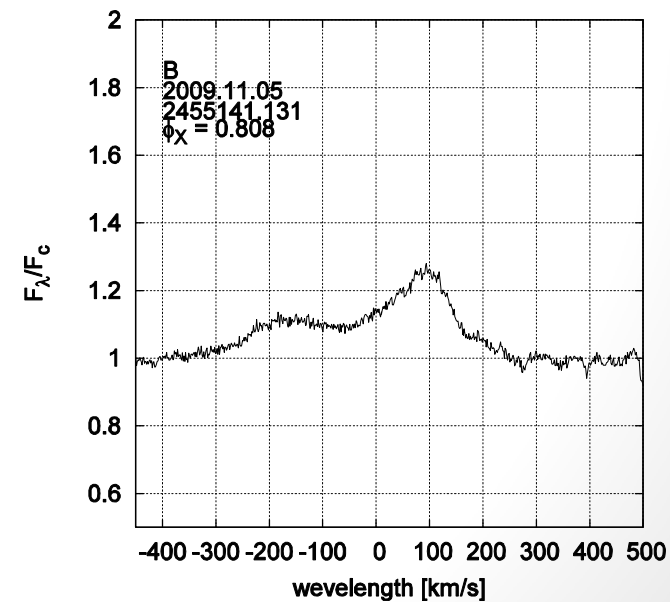
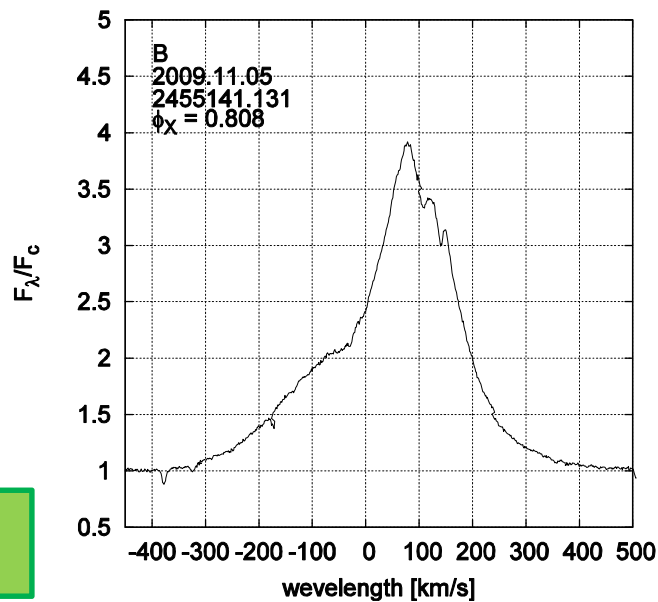
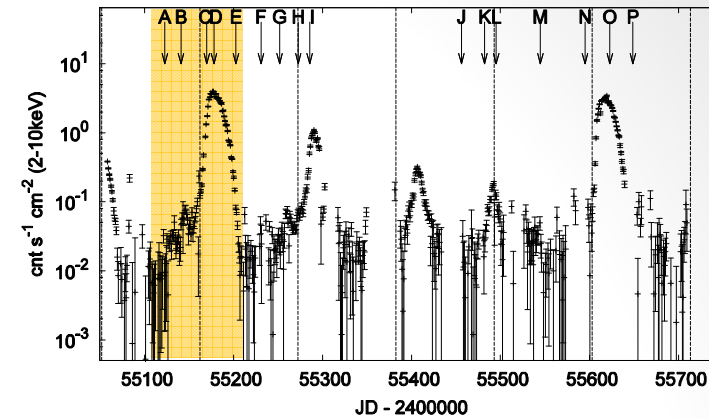
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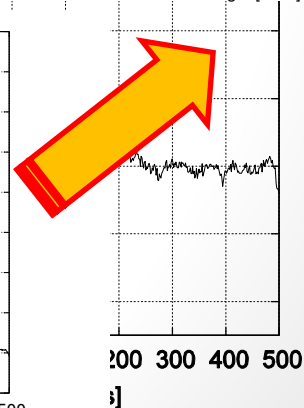
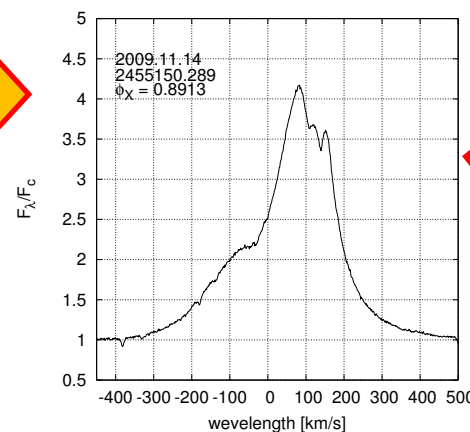
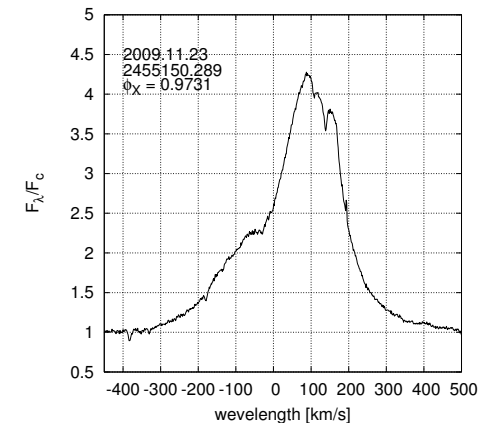
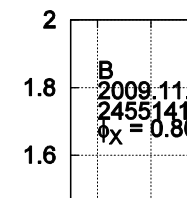
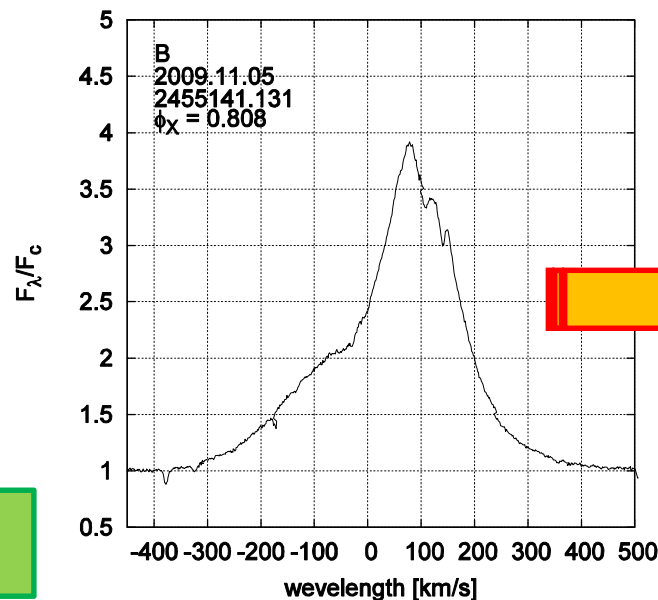
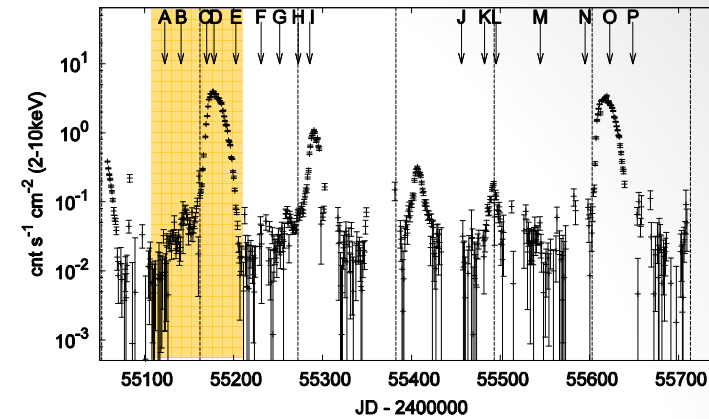
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 - Precursor of the giant outburst 2009
 - The intensity of normalized flux, E/C , of both lines significantly increased
 - The blue hump became more outstanding



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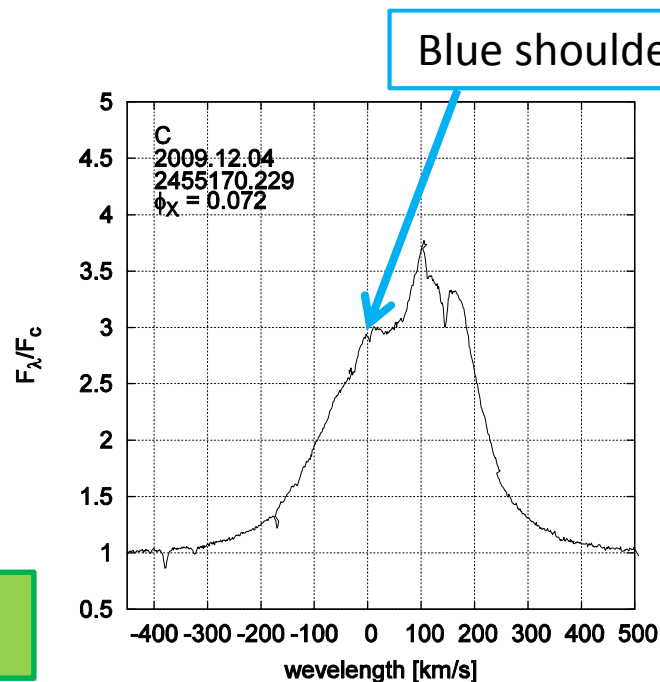
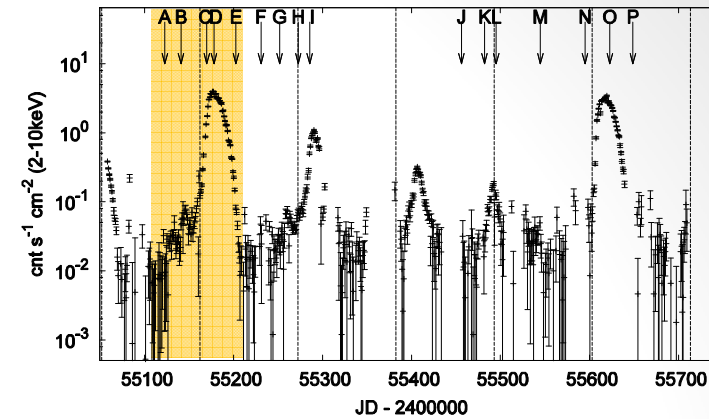
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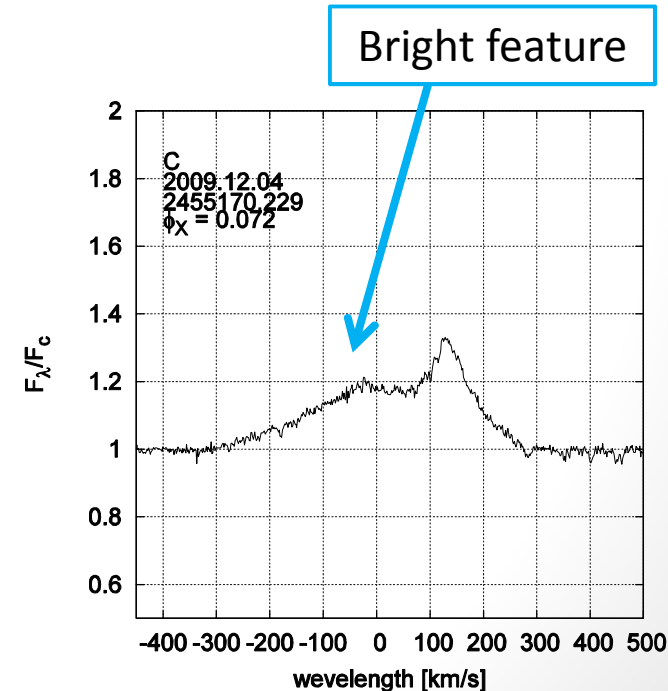


Results (1)

- Representative spectra of $H\alpha$, He I $\lambda 5876$
 - during the giant outburst 2009
 - In $H\alpha$ line profile, a bright “shoulder” appeared $\sim 0 \text{ km s}^{-1}$ in the blue wing
 - A similar, bright feature was seen in the central part of the He I $\lambda 5876$ line profile (between -50 km s^{-1} and $+50 \text{ km s}^{-1}$).



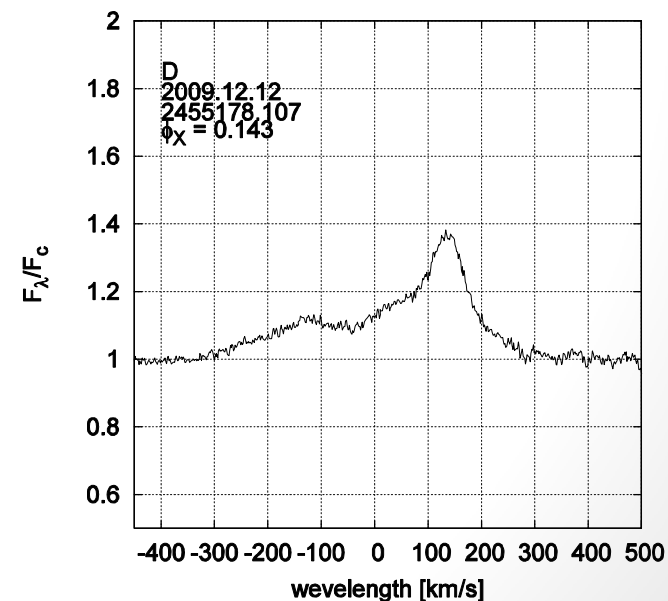
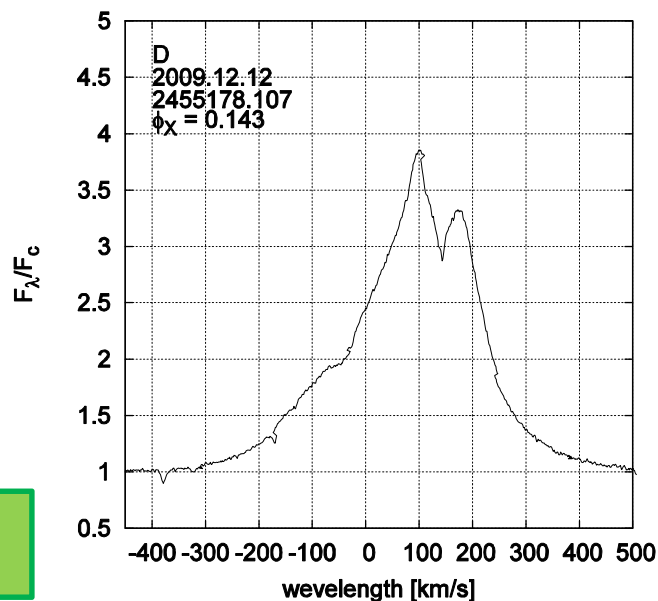
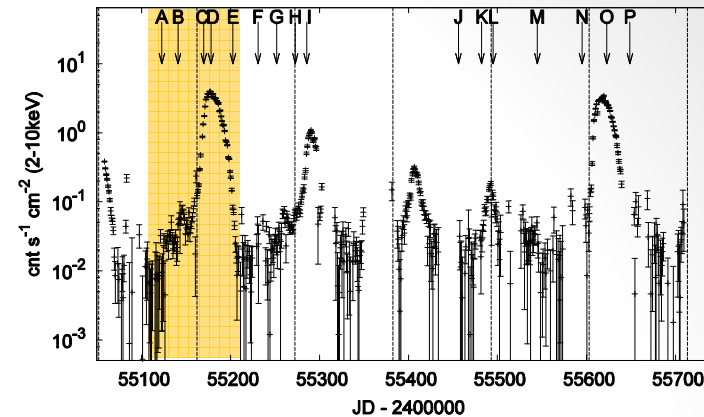
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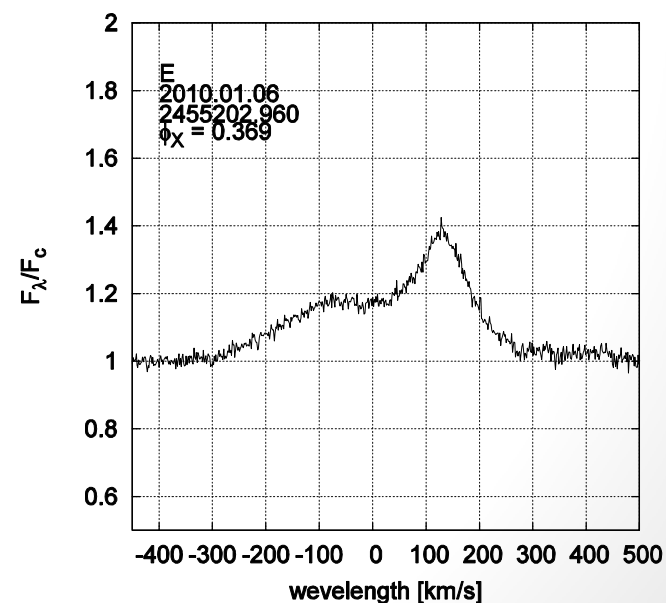
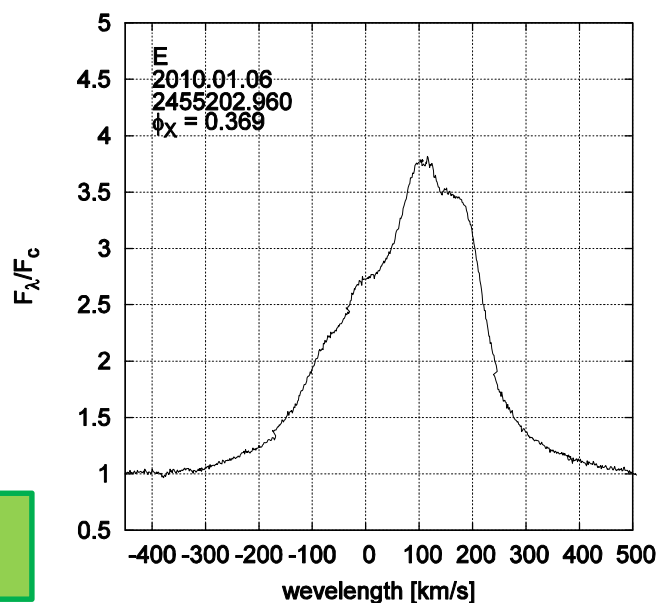
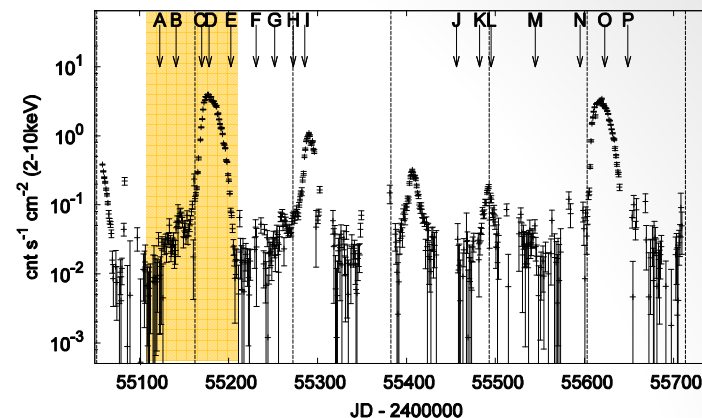
- Representative spectra of $H\alpha$, He I λ 5876
 - during the giant outburst 2009
 - The blue bright “shoulder” in $H\alpha$ line and bright feature in He I λ 5876 has gone



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Results (1)

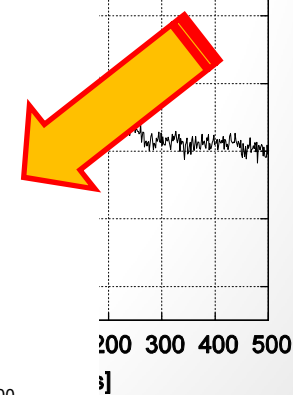
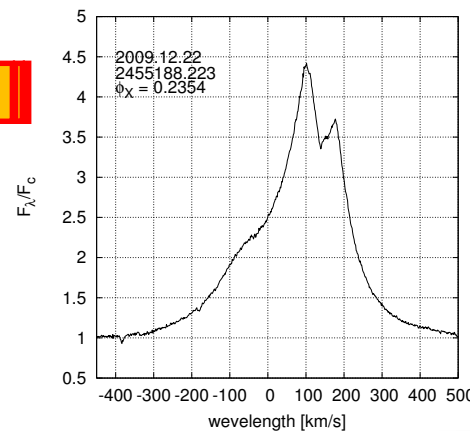
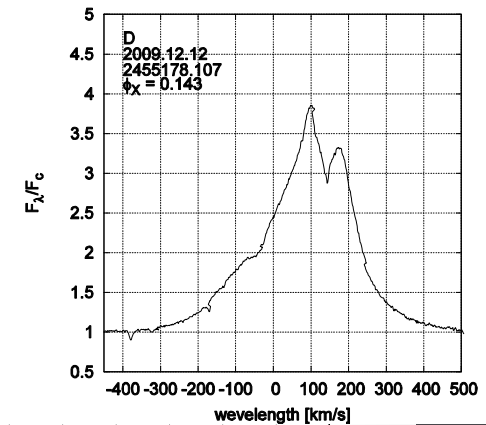
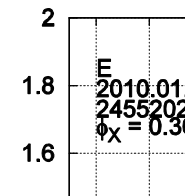
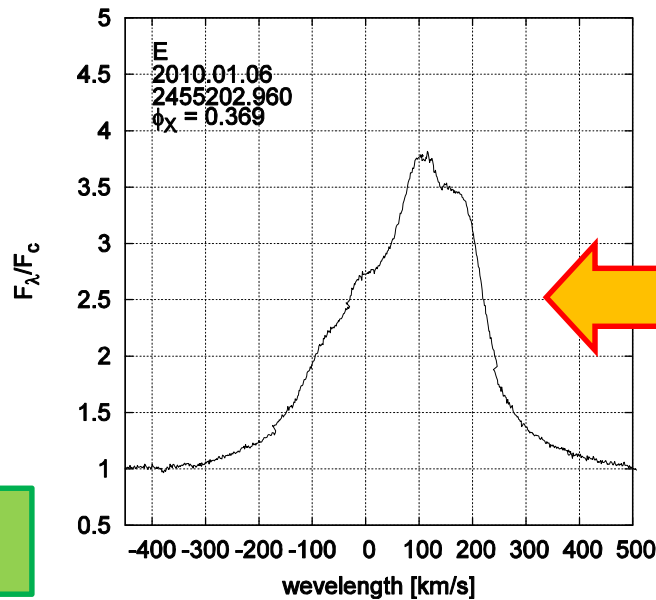
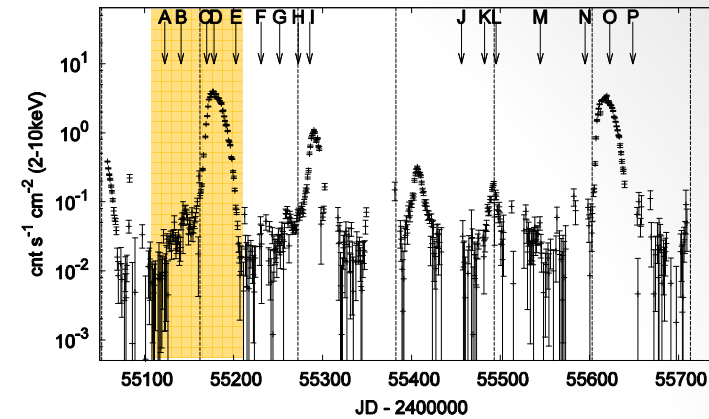
- Representative spectra of $H\alpha$, He I λ 5876
 - during the giant outburst 2009
 - The E/C ratio gradually increased until 22 December 2009 and then decreased in fading phase



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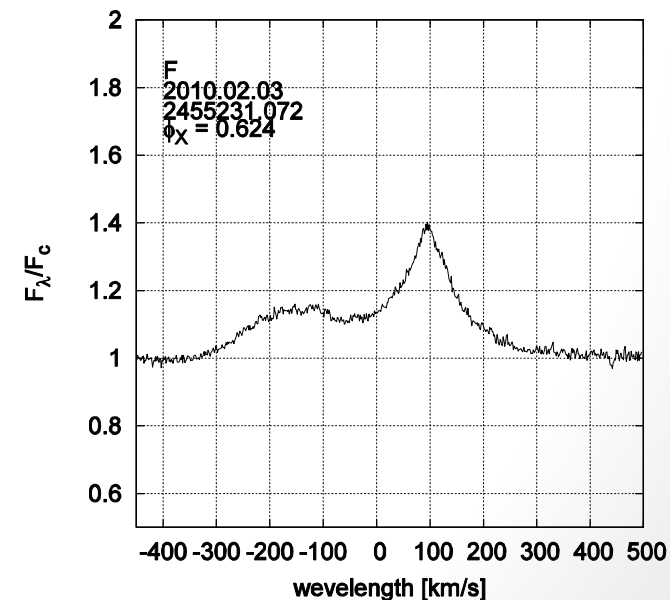
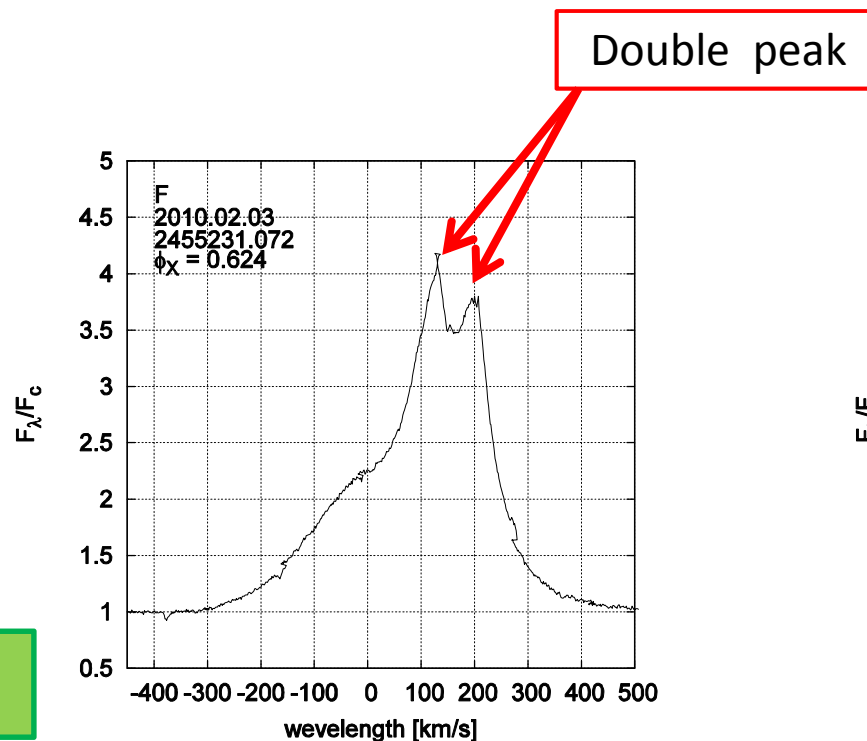
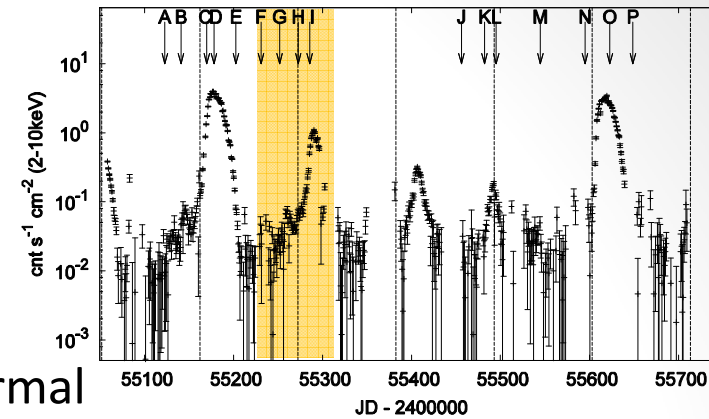
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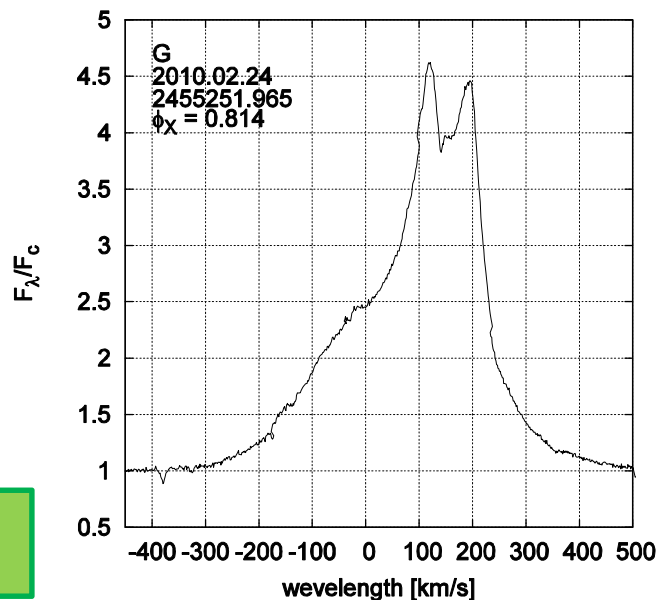
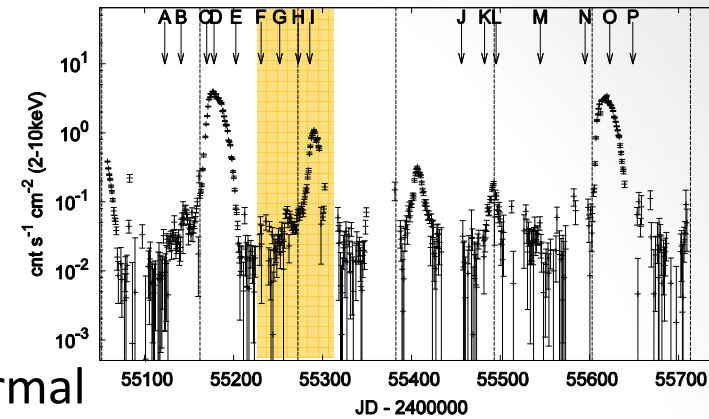
- Representative spectra of $H\alpha$, He I λ 5876
 - after the giant outburst 2009 to the normal outburst in March 2010
 - the double peak of the $H\alpha$ line continued to grow



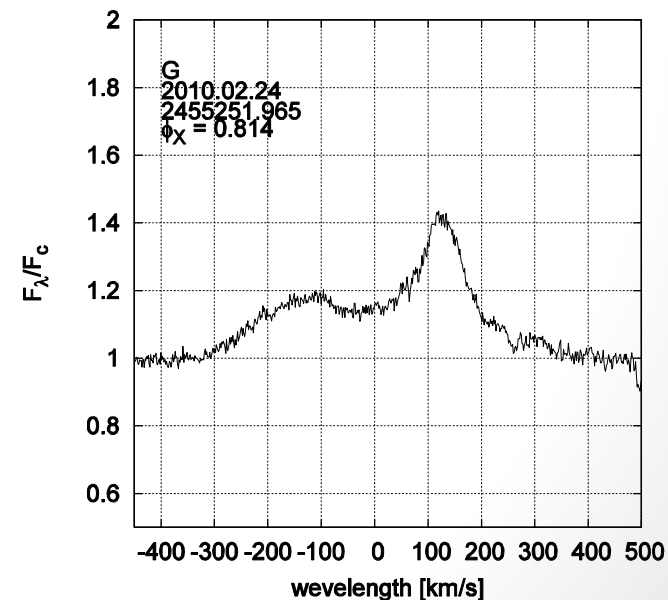
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Results (1)

- Representative spectra of $H\alpha$, He I λ 5876
 - after the giant outburst 2009 to the normal outburst in March 2010
 - the double peak of the $H\alpha$ line reached the highest intensity



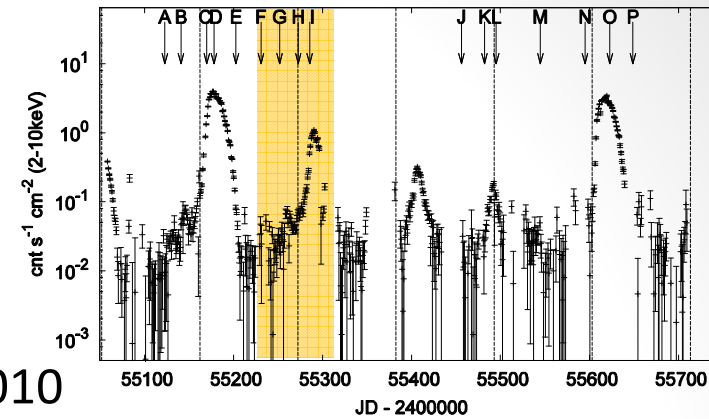
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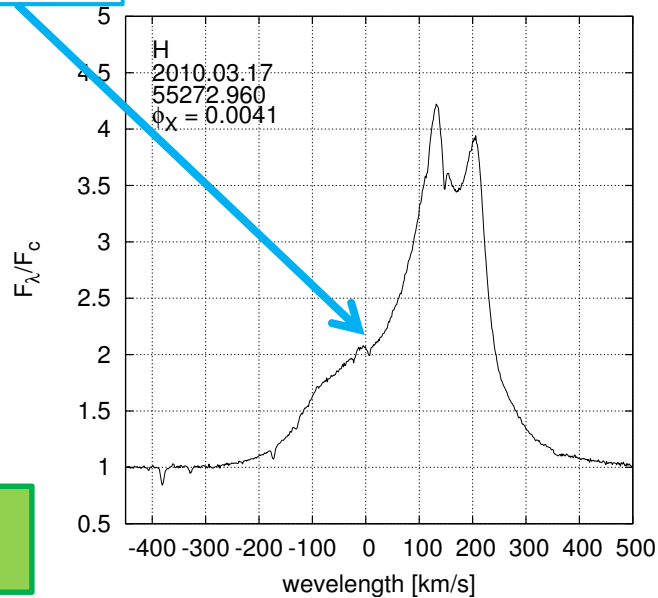
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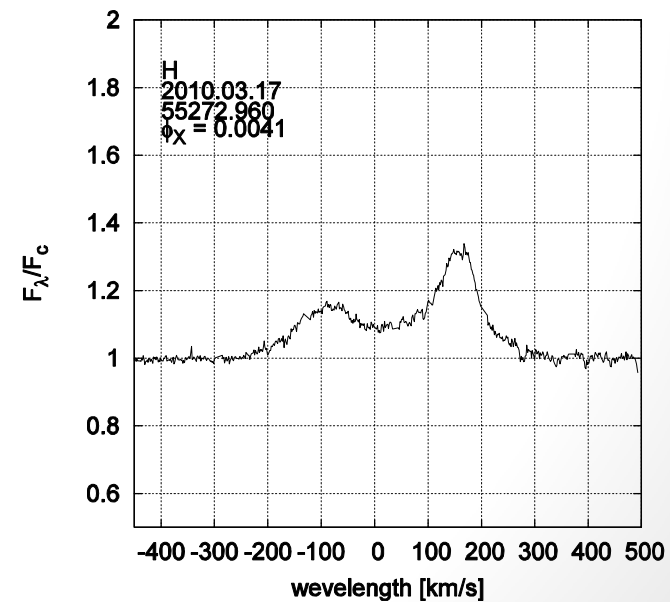
- Representative spectra of $H\alpha$, He I λ 5876
 - during the normal outburst in March 2010
 - The blue “shoulder” seems to reappear



Blue shoulder

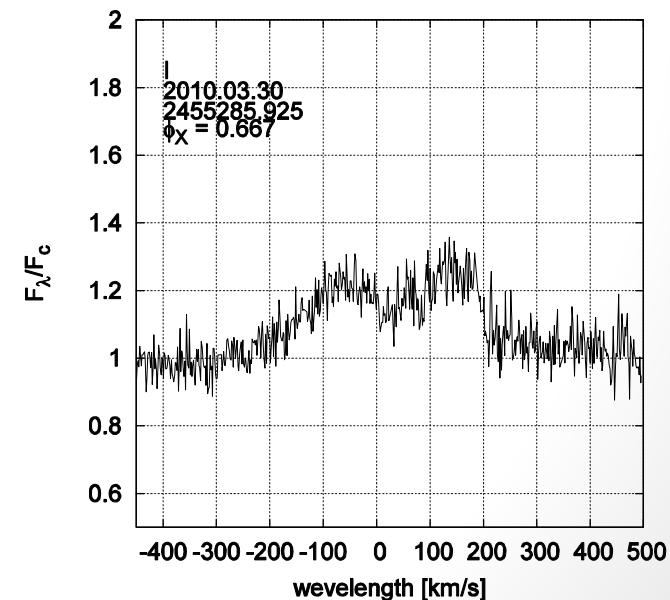
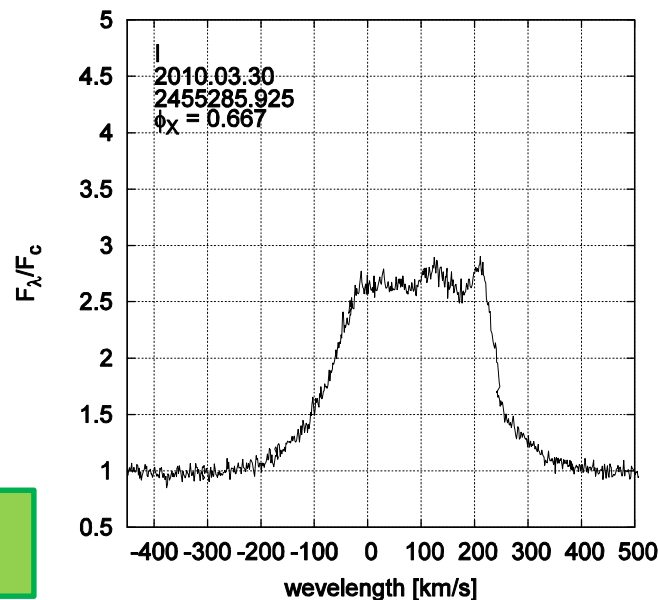
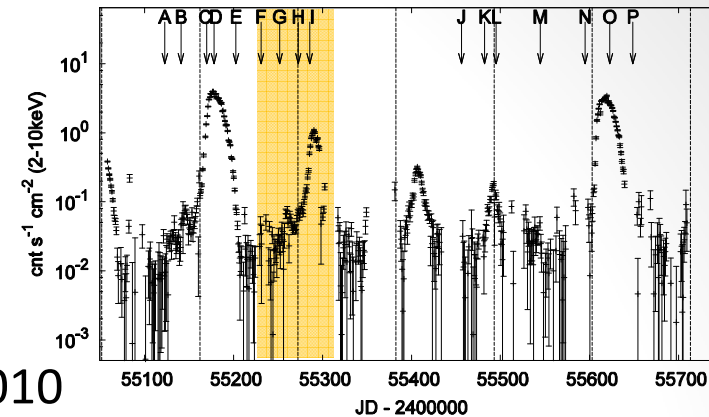


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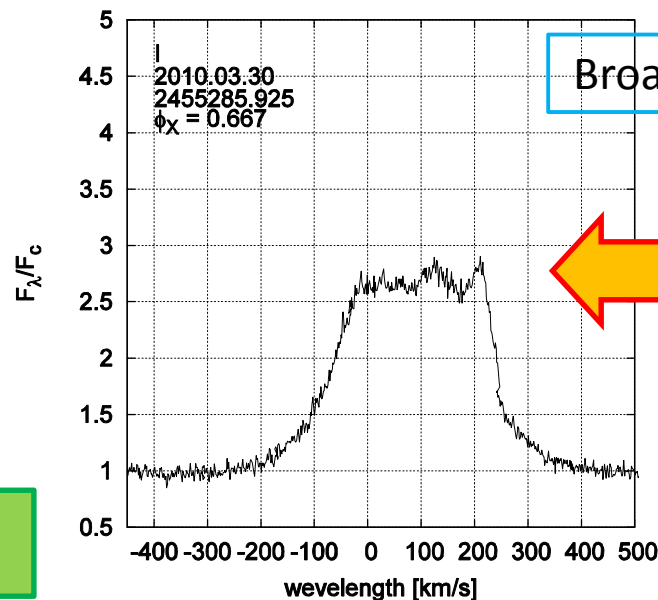
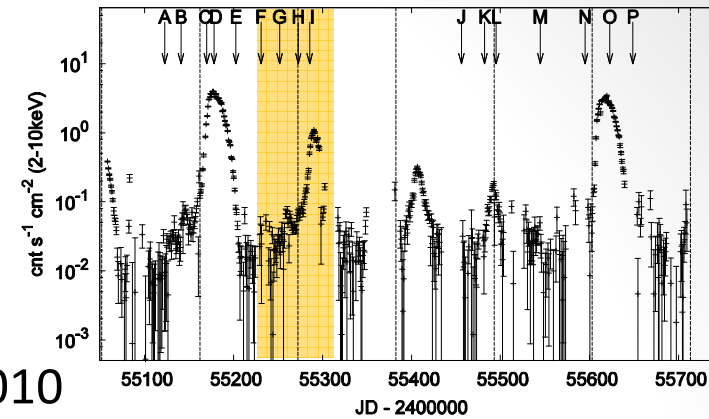
Results (1)

- Representative spectra of $H\alpha$, He I λ 5876
 - during the normal outburst in March 2010
 - In the $H\alpha$ line, the strongly redshifted double peak weakened and a huge, broad shoulder appeared in the blue wing and $H\alpha$ line profile became like a top-hat profile
 - In the He I λ 5876 line, a bright component appeared

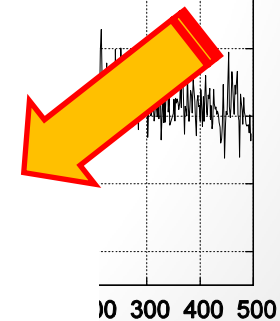
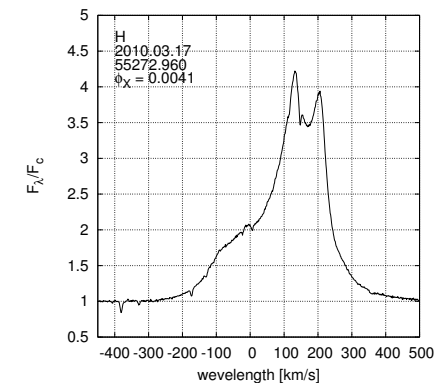
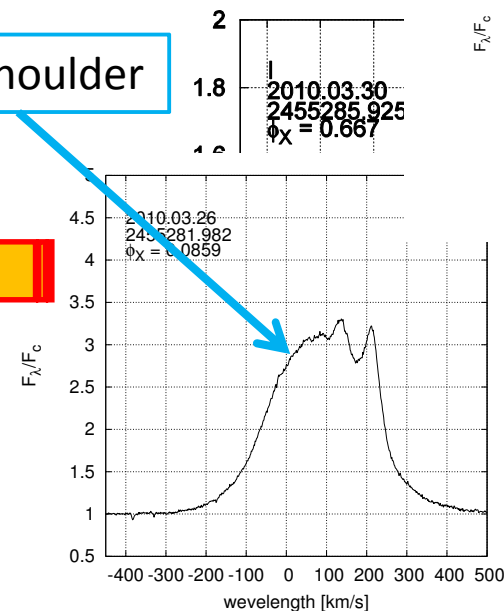


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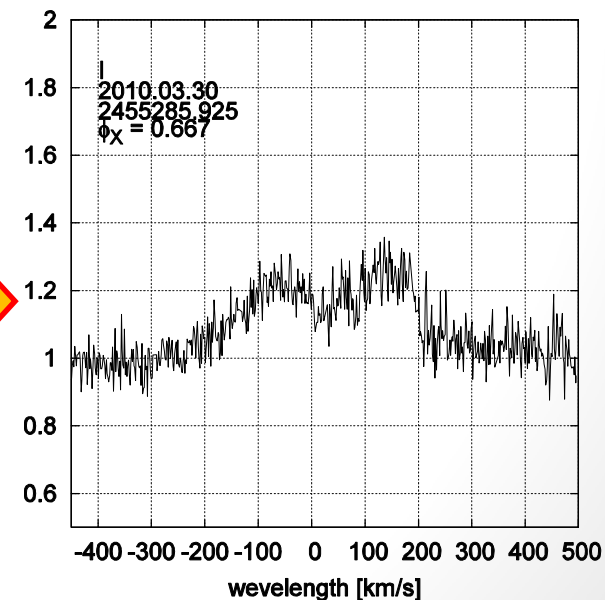
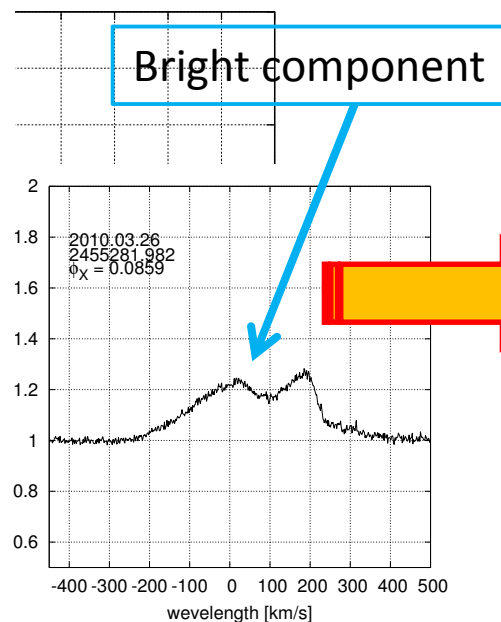
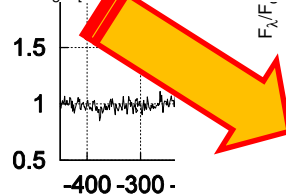
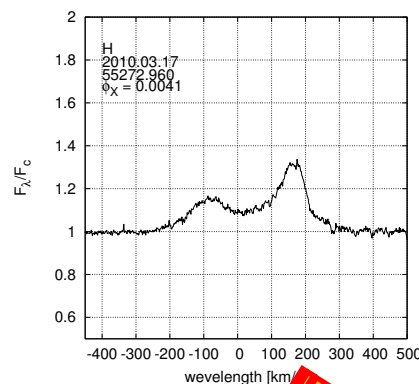
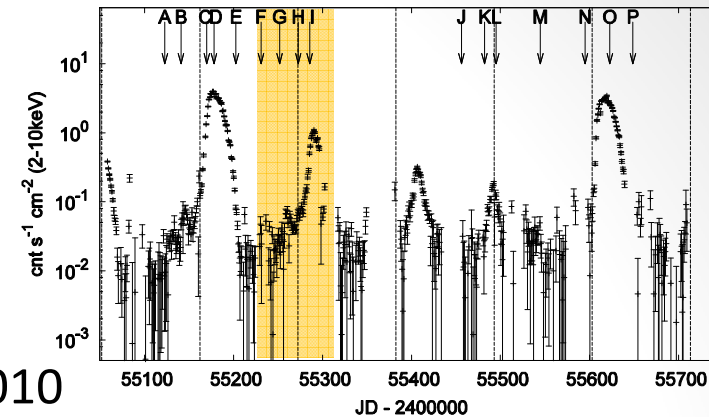


Broad shoulder



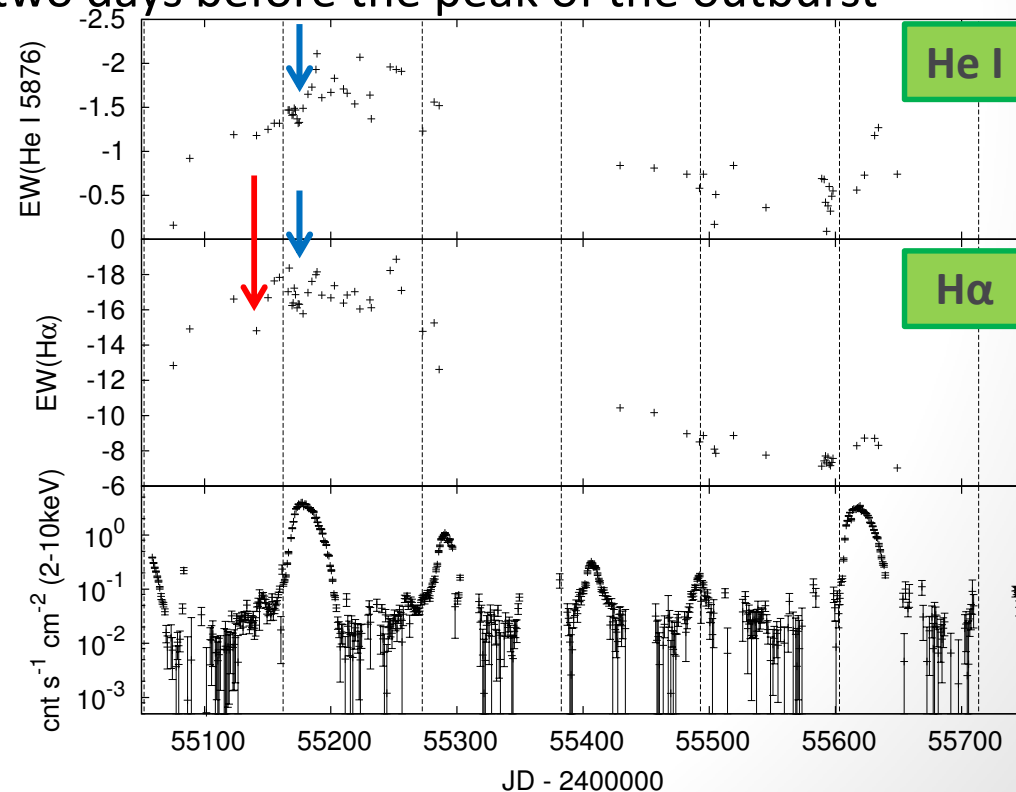
Results (1)

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



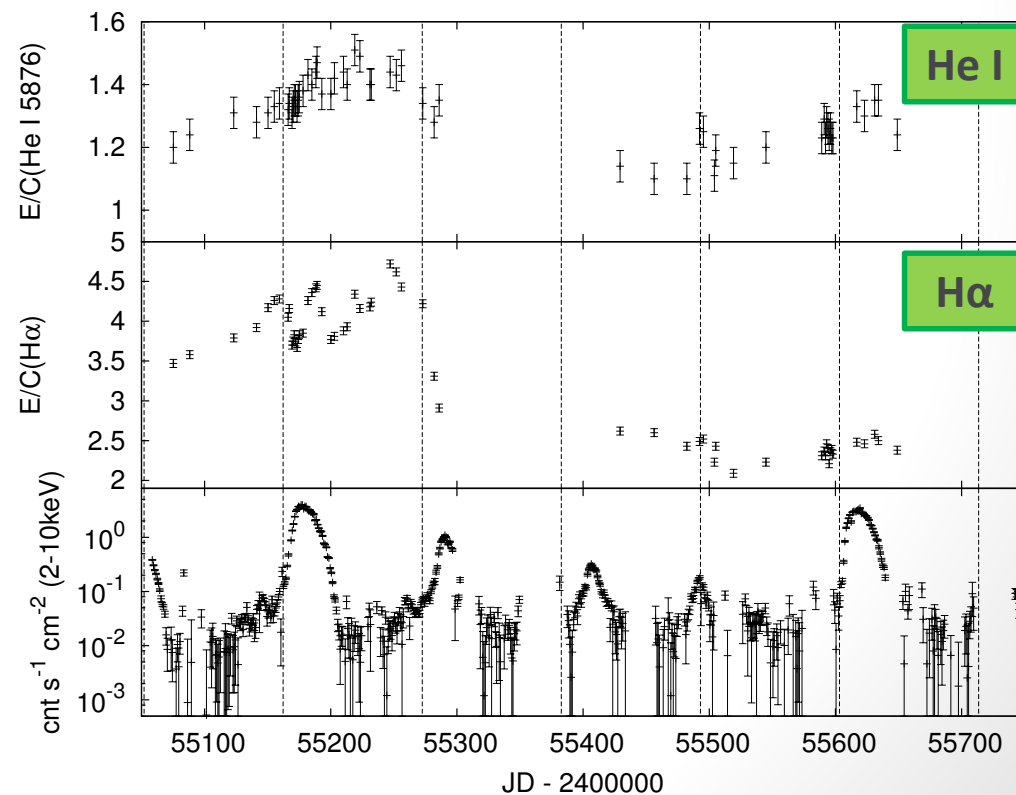
Results (2)

- Equivalent width of H α , He I λ 5876
 - Highest in the last five years
 - H α and He I λ 5876 lines show similar trend
 - For H α , 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



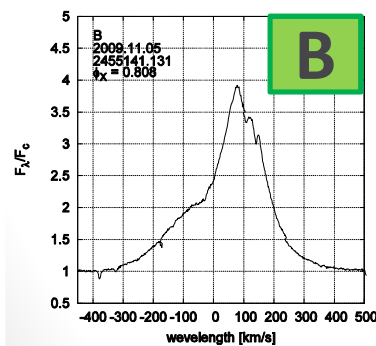
Results (3)

- E/C (intensity of normalized flux) of $H\alpha$, He I $\lambda 5876$
 - Similar trend to Equivalent width
 - $H\alpha$: Highest during giant outburst (> 3.5)
 - due to highly redshifted triple peak component ... also responsible for equivalent width

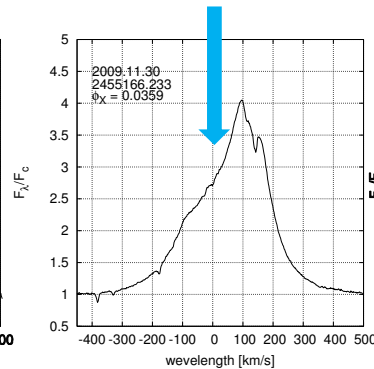


Discussion

- 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 H α profile has a blue hump and a triple peak
- Blue shoulder
 - can be seen only at periastron passage
 - Blue hump: $\sim -100 - 0 \text{ km s}^{-1}$; similar to the velocity of the violet peak of double-peaked profiles that showed the V/R variability (YM+ 2010)

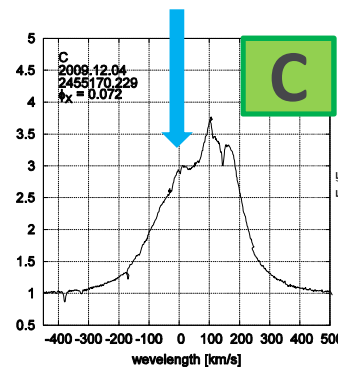


$$\phi_{\chi} = 0.808$$

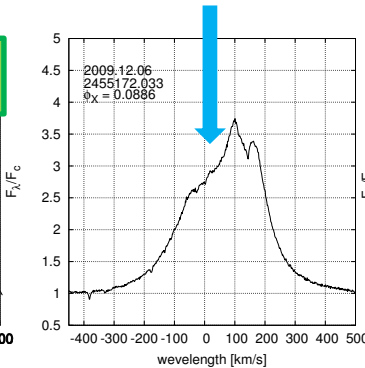


$$\phi_{\chi} = 0.039$$

Giant outburst rise

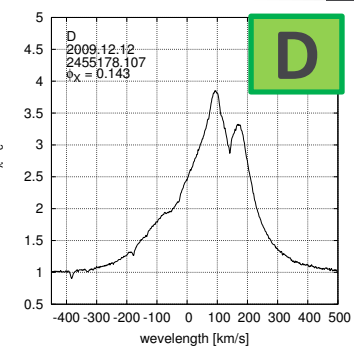


$$\phi_{\chi} = 0.072$$



$$\phi_{\chi} = 0.089$$

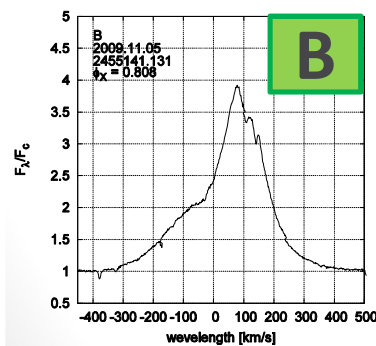
Giant outburst peak



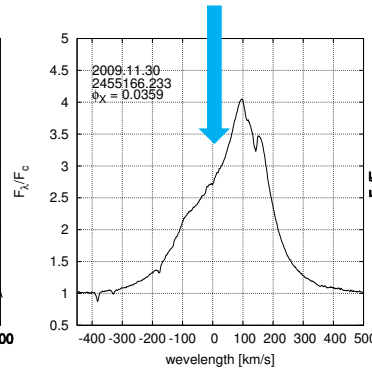
$$\phi_{\chi} = 0.143$$

Discussion

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- Enhanced H α profile has a blue hump and a triple peak
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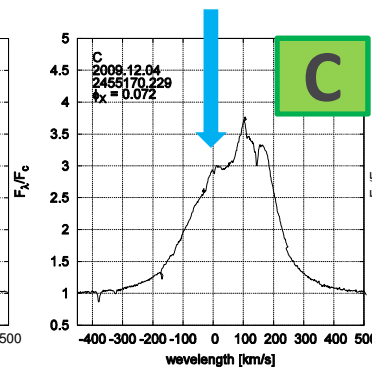


$\phi_X = 0.808$



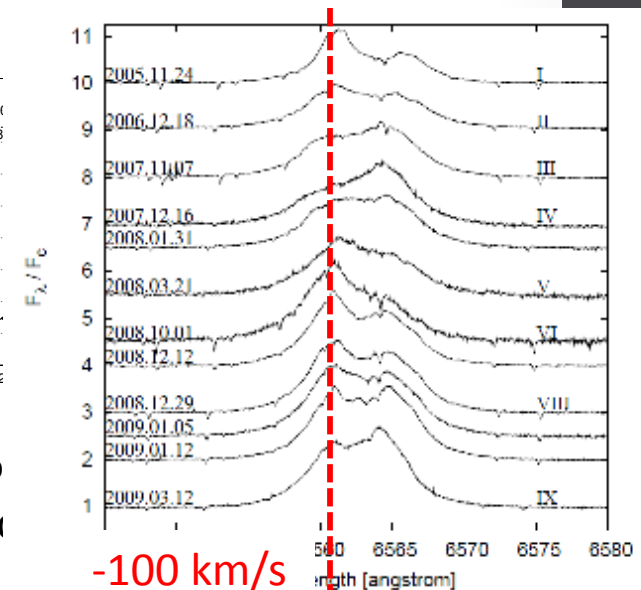
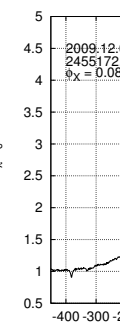
$\phi_X = 0.039$

Giant outburst rise



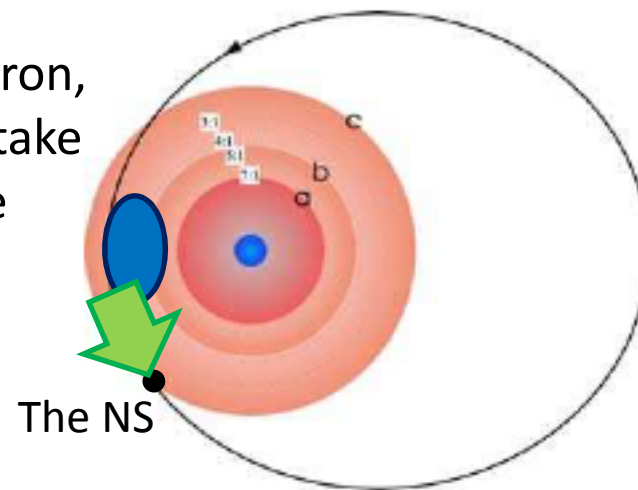
$\phi_X = 0.072$

Giant (



Discussion

- Blue shoulder
 - can be seen only at periastron passage
 - Blue hump: $\sim -100 - 0 \text{ km s}^{-1}$; similar to the velocity of the violet peak of double-peaked profiles that showed the V/R variability (YM+ 2010)
- 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)

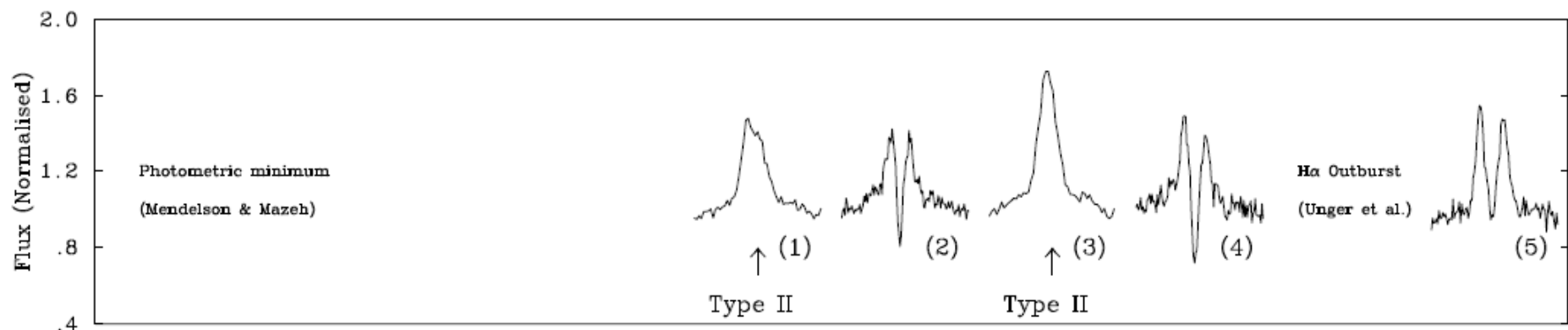


Observer sight

Coe + (2006)

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



4U0115+63 Negueruela et al. (2001)

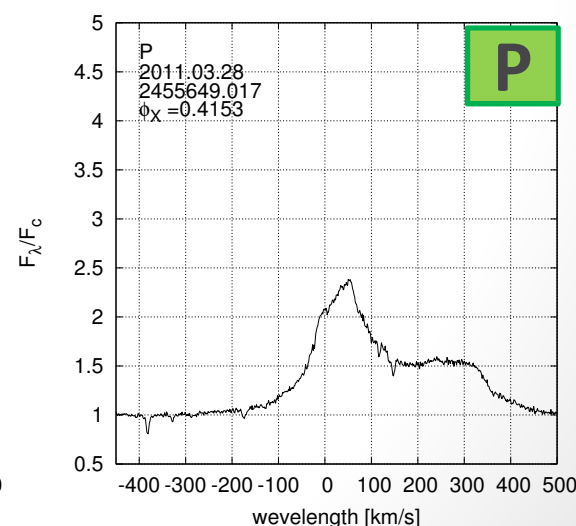
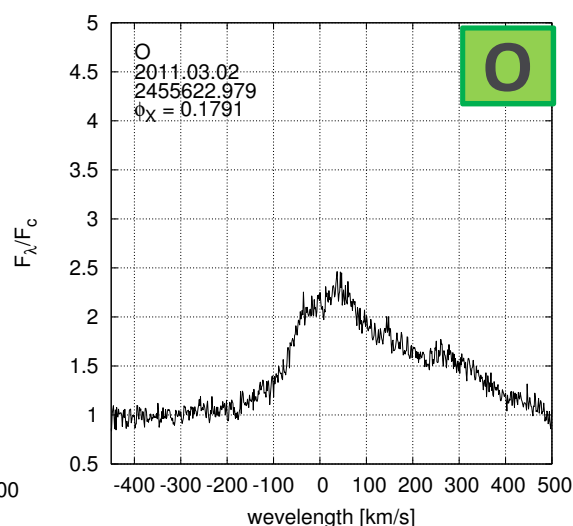
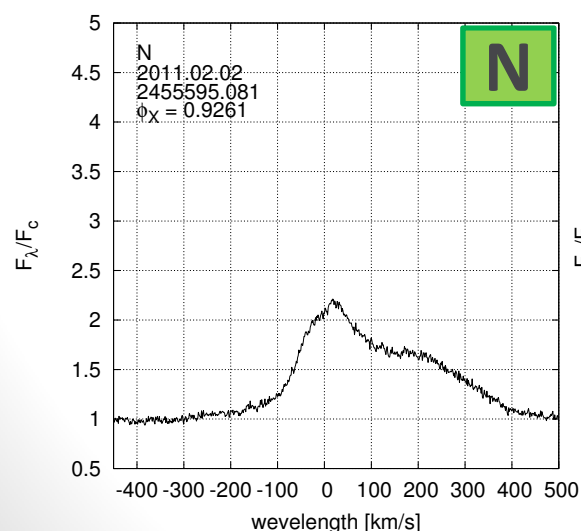
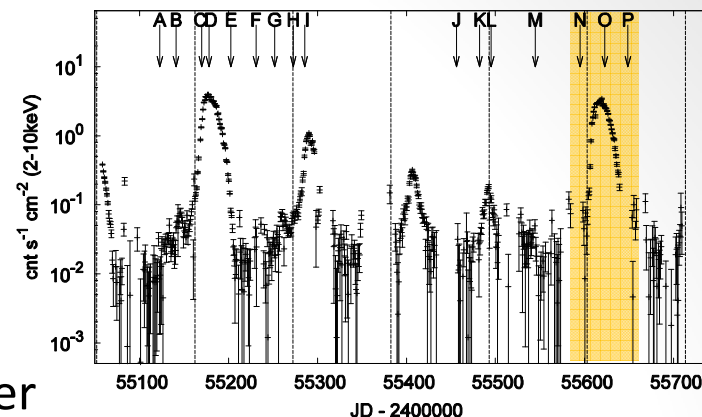
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More observe,

more complex ...?

- Spectra during giant outburst in 2011

- Before the outburst, H α line was rather normal double-peaked profile
- Equivalent width ($|EW(H\alpha)| \lesssim 9 \text{ \AA}$), $E/C(H\alpha) \sim 2.5$ is rather small to involve in type II outburst?

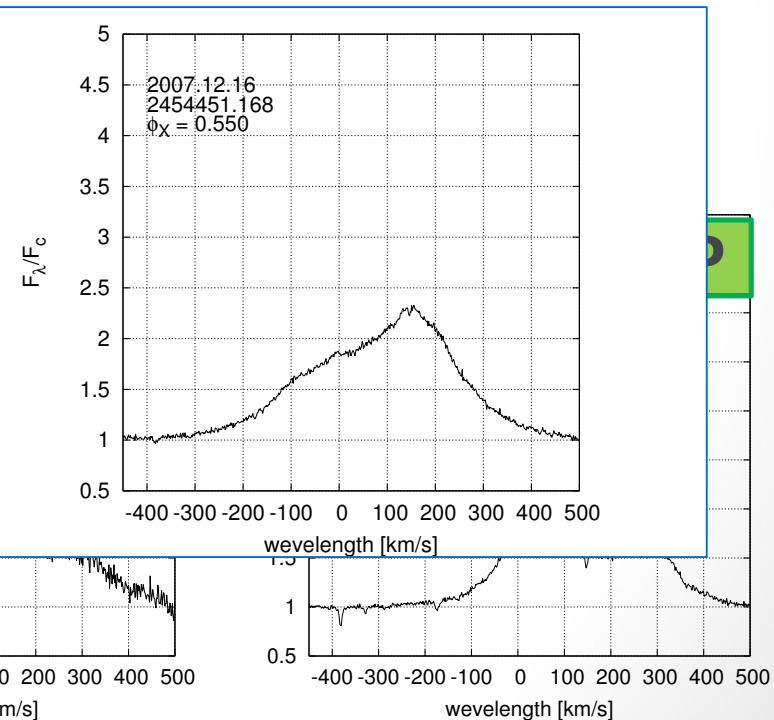
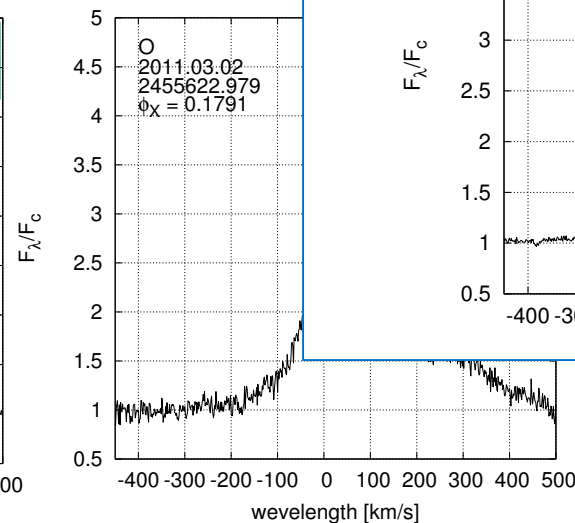
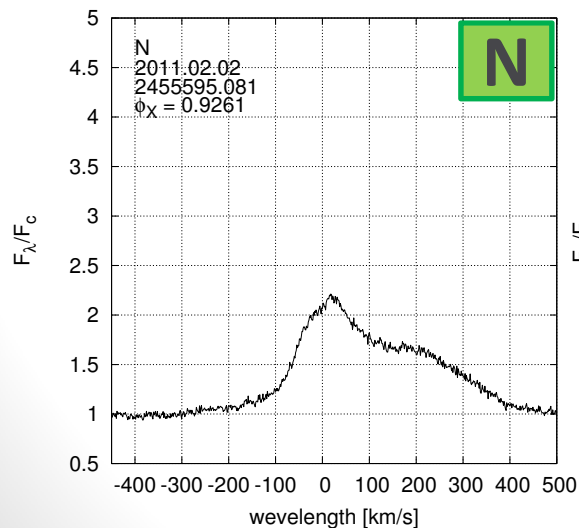
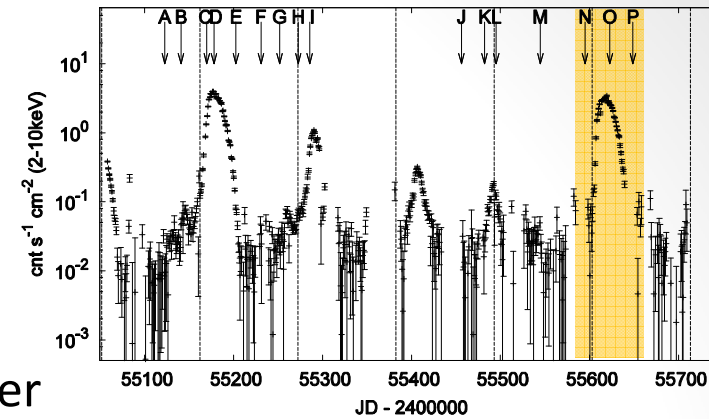


19/20

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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 $H\alpha$ line profiles is possibly from a warping component.