Raman O VI Profile Analysis of Accretion and Bipolar Outflow in Sanduleak's Star

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A Profile Analysis of Raman-scattered O VI Bands at 6825 Å and 7082 Å in Sanduleak's Star[1]

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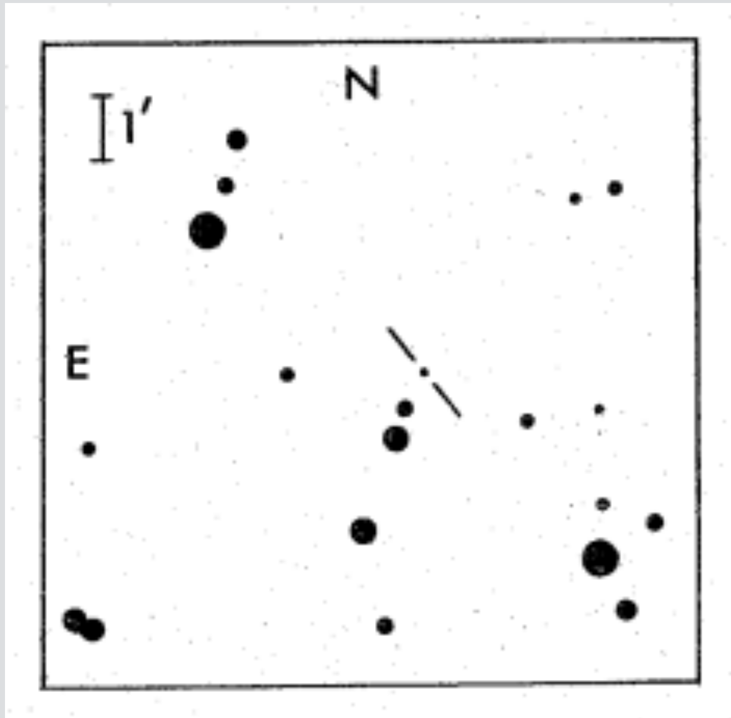
ABSTRACT

We present a detailed modeling of the two broad bands observed at 6825 Å and 7082 Å in Sanduleak's star, a controversial object in the Large Magellanic Cloud. These bands are known to originate from Raman-scattering of O VI $\lambda\lambda$ 1032 and 1038 photons with atomic hydrogen and are only observed in *bona fide* symbiotic stars. Our high-resolution spectrum obtained with the *Magellan Inamori Kyocera Echelle* (MIKE) spectrograph at the Magellan-Clay Telescope reveals, quite surprisingly, that the profiles of the two bands look very different: while the Raman 6825 Å band shows a single broad profile with a redward extended bump, the Raman 7082 Å band exhibits a distinct triple-peak profile. Our model suggests that the O VI emission nebula can be decomposed into a red, blue and central emission regions from an accretion disk, a bipolar outflow and a further compact, optically thick region. We also perform Monte Carlo simulations with the aim of fitting the observed flux ratio $F(6825)/F(7082) \sim 4.5$, which indicate that the neutral region in Sanduleak's star is characterized by the column density $N_{HI} \sim 1 \times 10^{23}$ cm^{-2}.

Subject headings: scattering – profile – radiative transfer – binary — Sanduleak's Star

I. Sanduleak's Star

Sanduleak (1977)



- Strong variation of Hα emission
- Strong emission in Balmer series and [O III] 5007 and 4959
- Variable emission at He II 4686 and [O III] 4363

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INFORMATION BULLETIN ON VARIABLE STARS
Number 1304

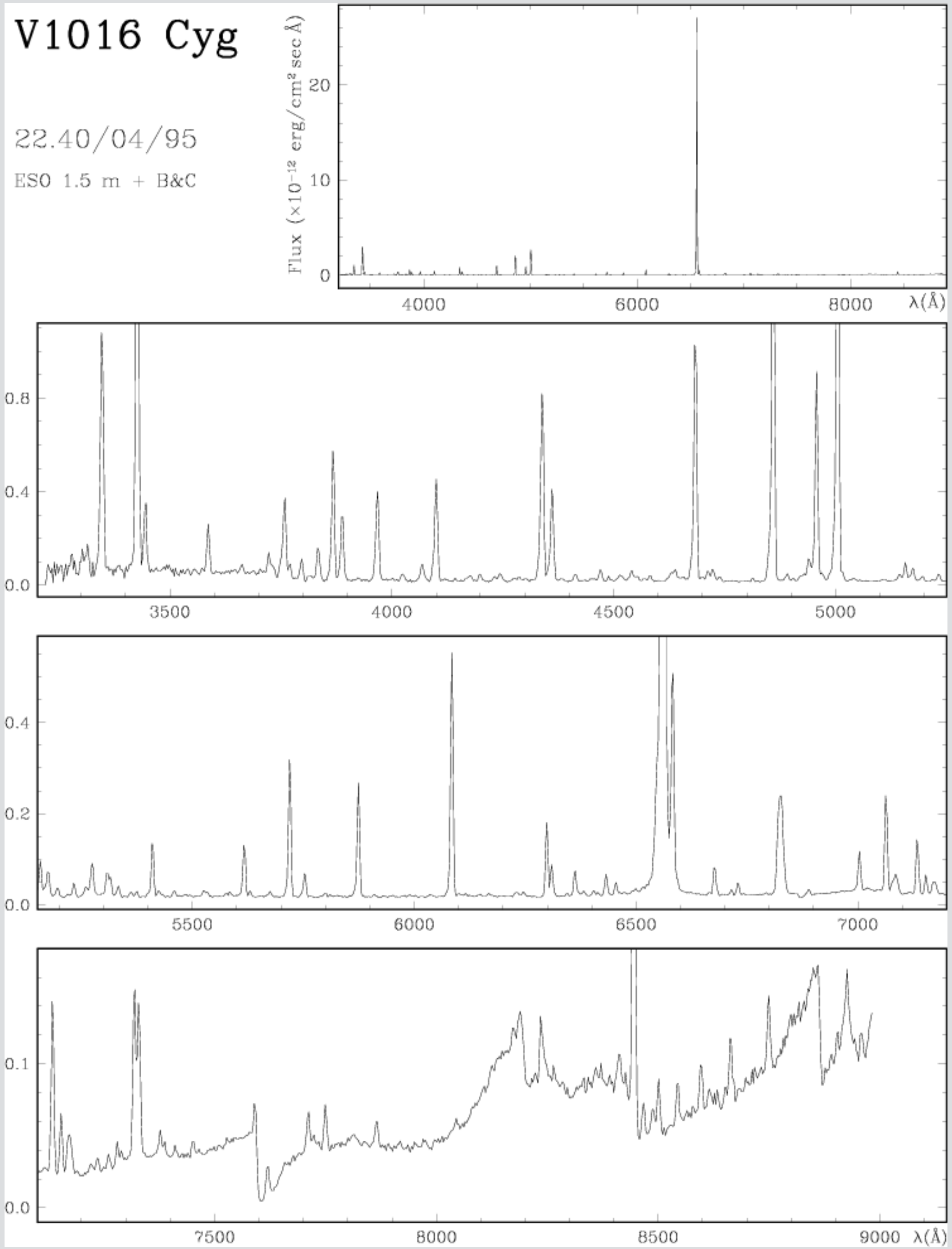
Konkoly Observatory
Budapest
1977 July 18

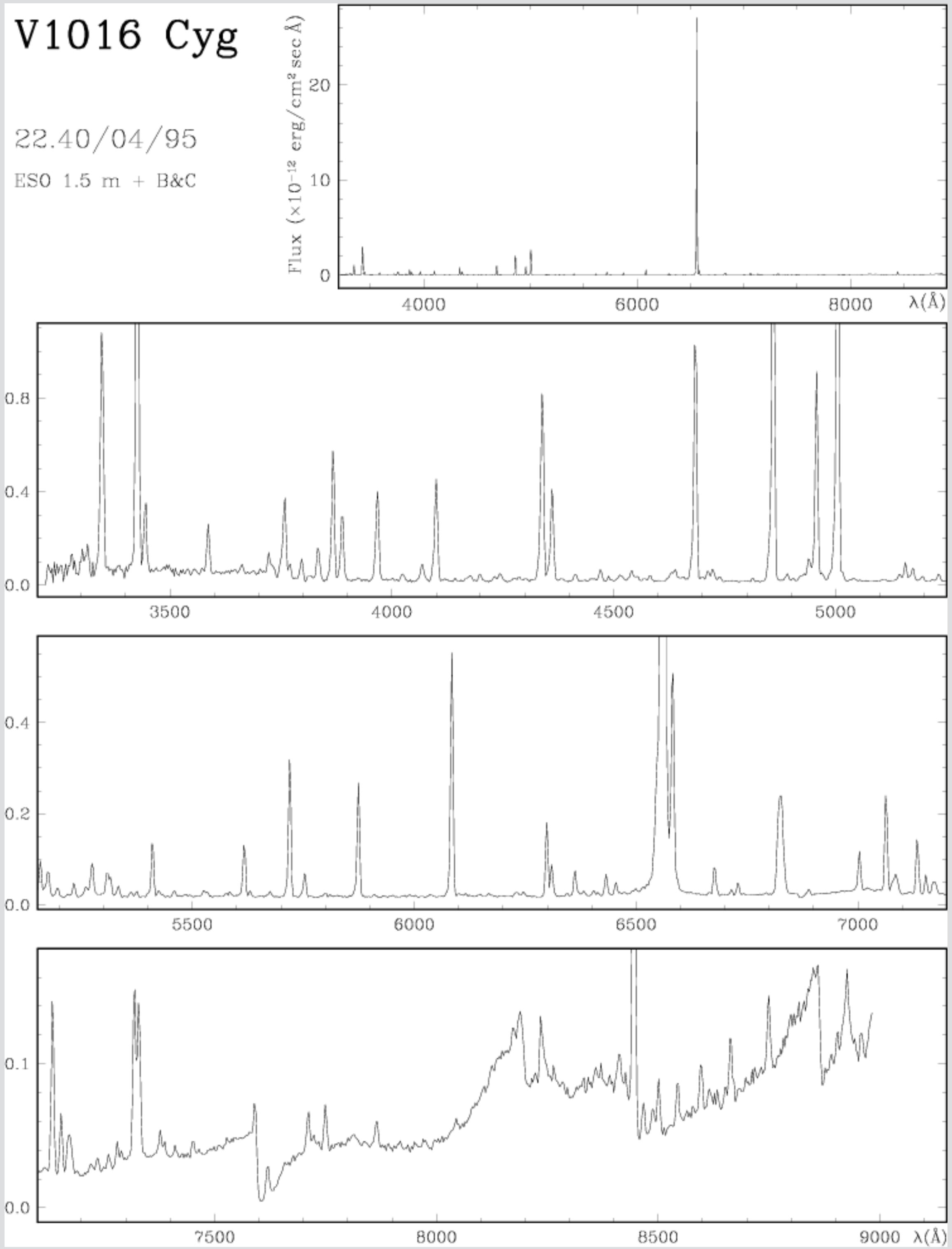
A SUSPECTED VARIABLE EMISSION-LINE OBJECT
IN THE DIRECTION OF THE LARGE MAGELLANIC CLOUD

A new emission-line object ($\alpha = 5^h45^m\!.7$, $\delta = -71^\circ 17'$, 1975), possibly associated with the Large Magellanic Cloud, appears to have shown strongly variable Hα emission. This object, for which we provide an identification chart, is not listed in the surveys of either Henize (Ap.J. Suppl. 2, 315, 1956) or Lindsay and Mullan (Irish A.J. 6, 51, 1963). However, on red-sensitive objective-prism plates, taken with the Curtis Schmidt telescope at the Cerro Tololo Inter-American Observatory on March 24, 1968 and Nov. 15, 1974, it shows a rather strong and sharp Hα emission line. No continuum is visible (i.e. V > 15 mag), giving the appearance of a planetary nebula. At our request, Dr. Henize kindly examined his original LMC survey plates, which have a limiting magnitude comparable to our own plates, and confirmed that emission at Hα was not evident at that epoch.

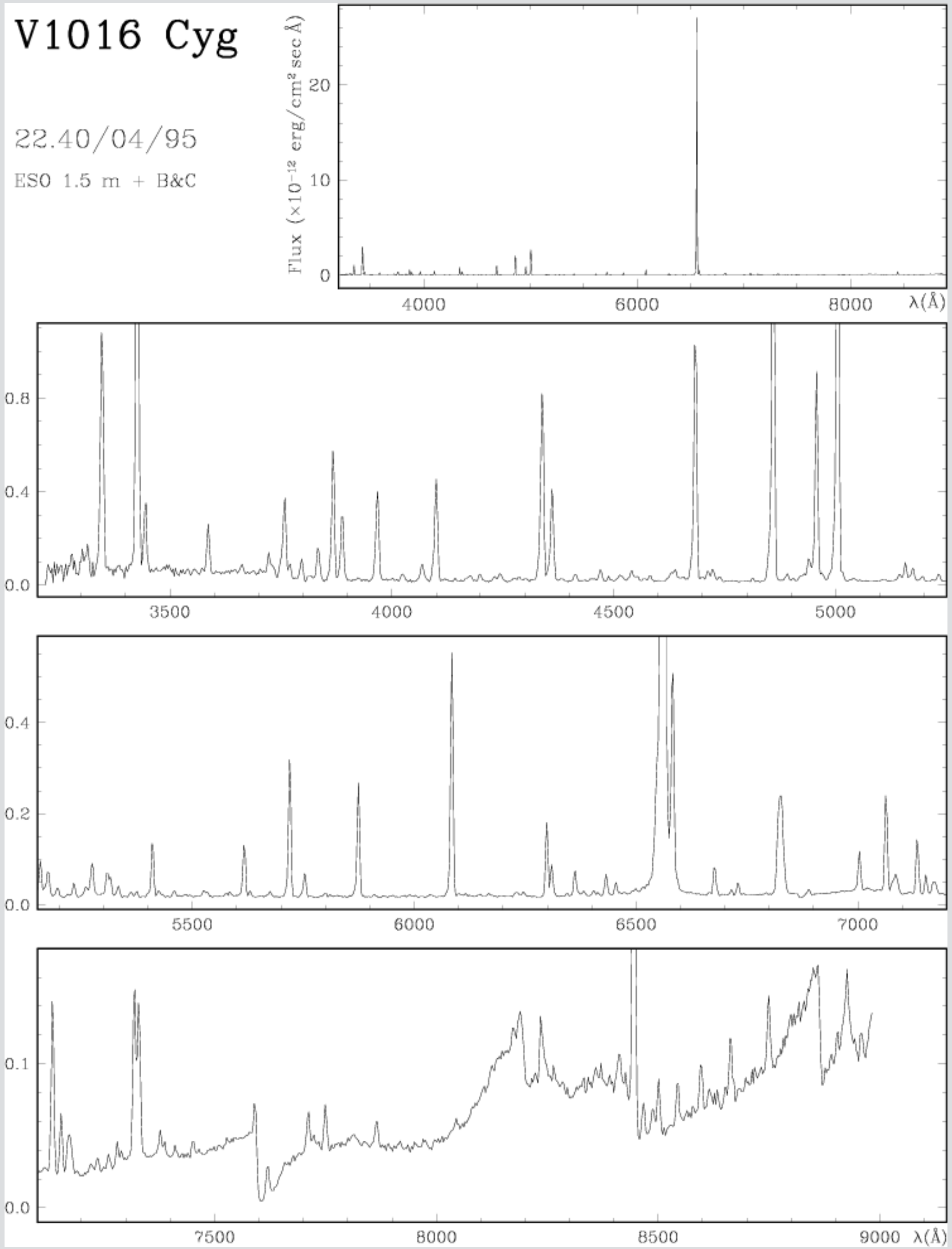
Images of this object appear on the charts in the Hodge-Wright atlas of the LMC and from these one can estimate B∿16.0 and V∿16.0. It is not listed among the Harvard variable stars. On deep blue-sensitive objective-prism plates, also taken with the Curtis telescope on March 20, 1968 and Jan. 7, 1975, the spectrum contains strong emission in the Balmer series and [OIII] λ5007 and λ4959. We also suspect variable emission at He II λ4686 and [OIII] λ4363. The suspected spectral variability would suggest that this is some type of eruptive variable star rather than a planetary nebula. However, the available data indicate a rather small range in light variability.

N. SANDULEAK
Warner and Swasey Observatory
E. Cleveland, Ohio, U.S.A.


V1016 Cyg
22.40/04/95
ESO 1.5 m + B&C
Flux (×10⁻¹² erg/cm² sec Å)
λ(Å)



- ✓ Strong nebular emission lines of Balmer HI, HeII and forbidden lines of [OIII], [NeIII], [NeV] and [FeVII]
- ✓ Absorption features and continuum of the late type giant
- ✓ Raman-scattered O VI features at 6825 Å and 7082 Å


V1016 Cyg
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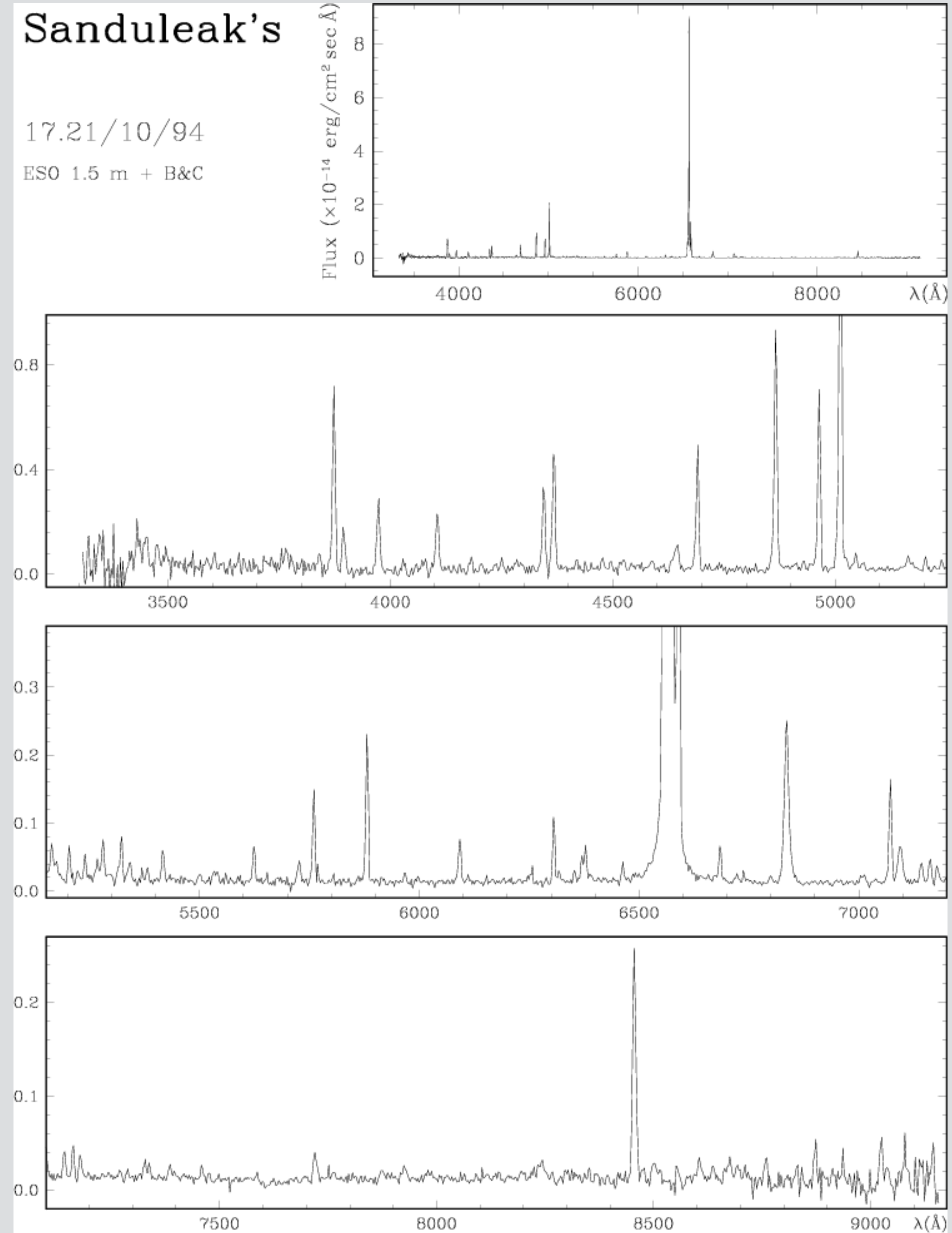
Sanduleak's
17.21/10/94
ESO 1.5 m + B&C
Flux (×10⁻¹⁴ erg/cm² sec Å)
λ(Å)

- ✓ Strong nebular emission lines of Balmer HI, HeII and forbidden lines of [OIII], [NeIII], [NeV] and [FeVII]
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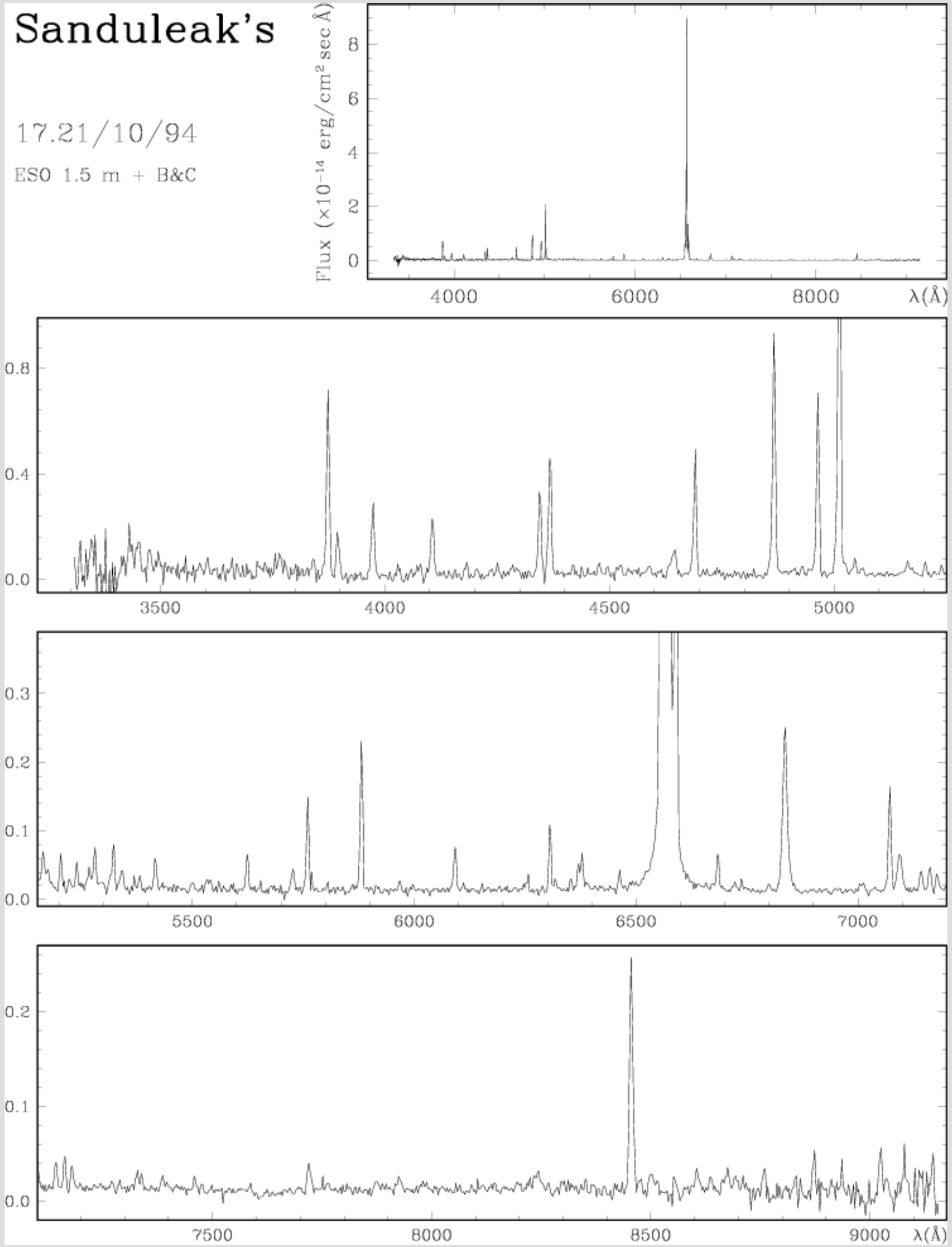


Sanduleak's Star

Allen

"Symbiotic star candidates in LMC"
Numerous high-excitation emission lines
Presence of λ6830 bands
No clear signature of any late-type giant

1980

Kafatos et al.

"CNO processed material"
Large overabundance of N

1983

Michalitsianos et al.

"Similarity with η Car and SN1987A"
IUE observations

1989

Belczynski et al.

"A catalogue of symbiotic stars"

2000

Munari & Zwitter

"Atlas of symbiotic stars"

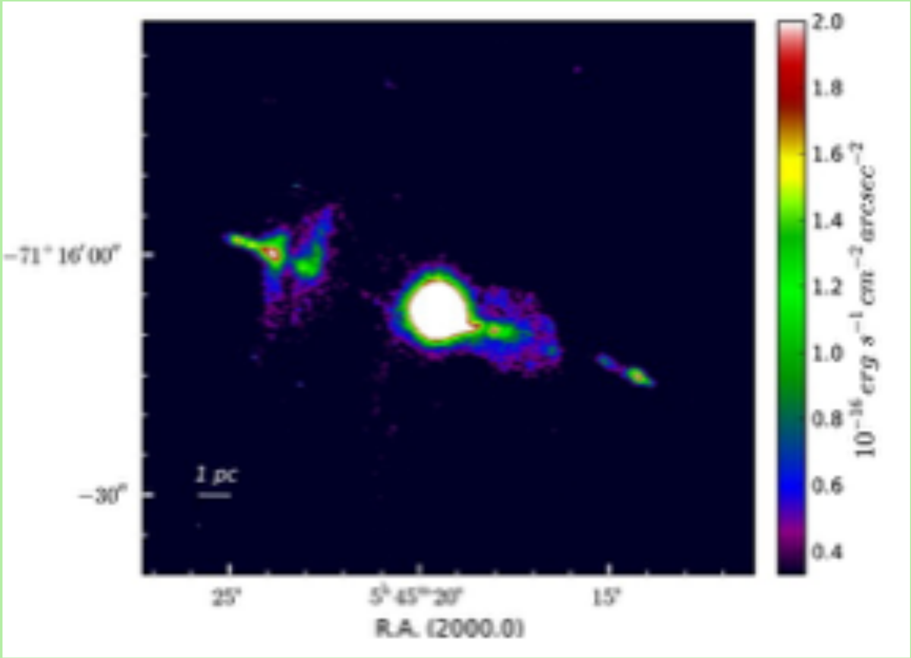
2002

Sanduleak's Star

Angeloni et al.

"A giant, highly-collimated bipolar jet"
The first resolved stellar jet outside of the MW with the size of 14pc

2011

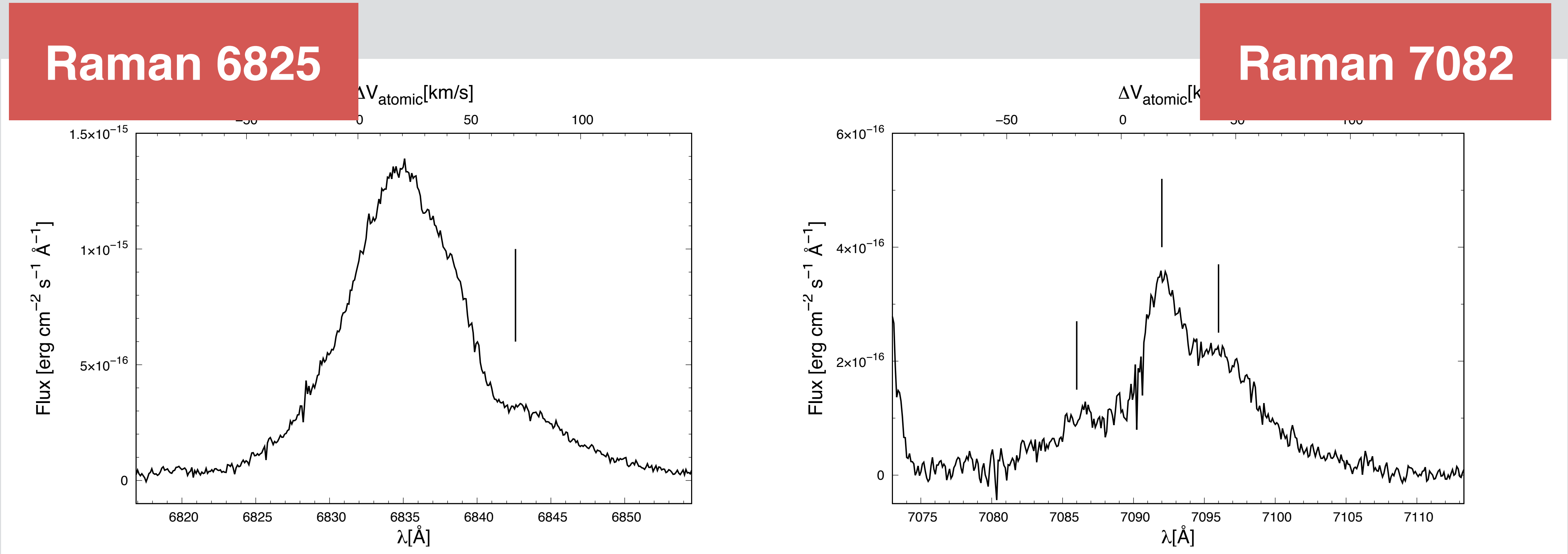


2011

MIKE Observation

- The Magellan Inamor Kyocera Echellle (MIKE)
- 6.5m Magellan-Clay Telescope, Las Campanas Obs., Chile
- Observing Date: 21, Nov. 2010
- Spectral Coverage: (Red) 4,900~9,500 Å
- Resolving Power ~ 22,000
- Exposure Time: 3 * 900 sec

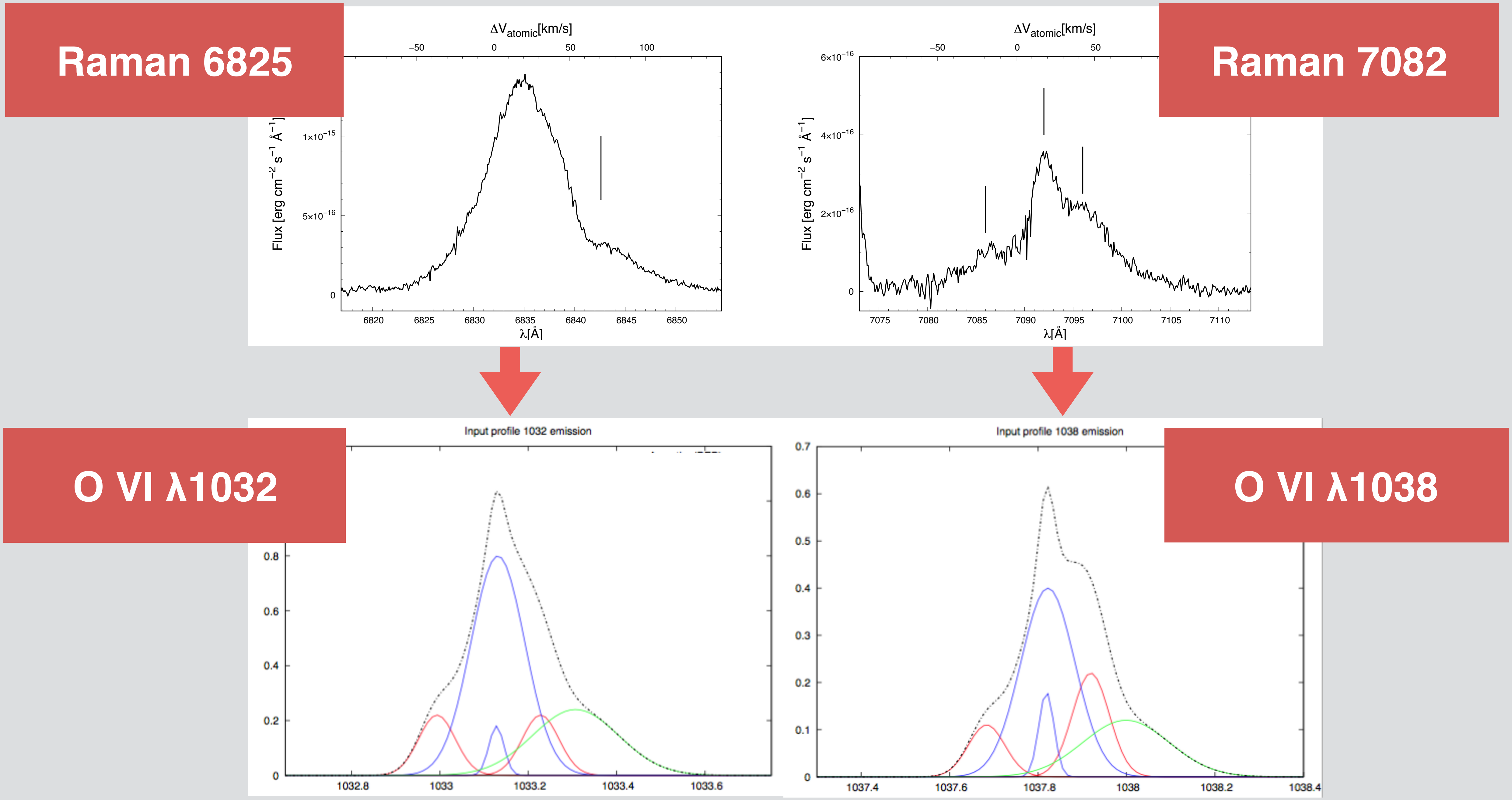
Raman O VI in Sanduleak's star



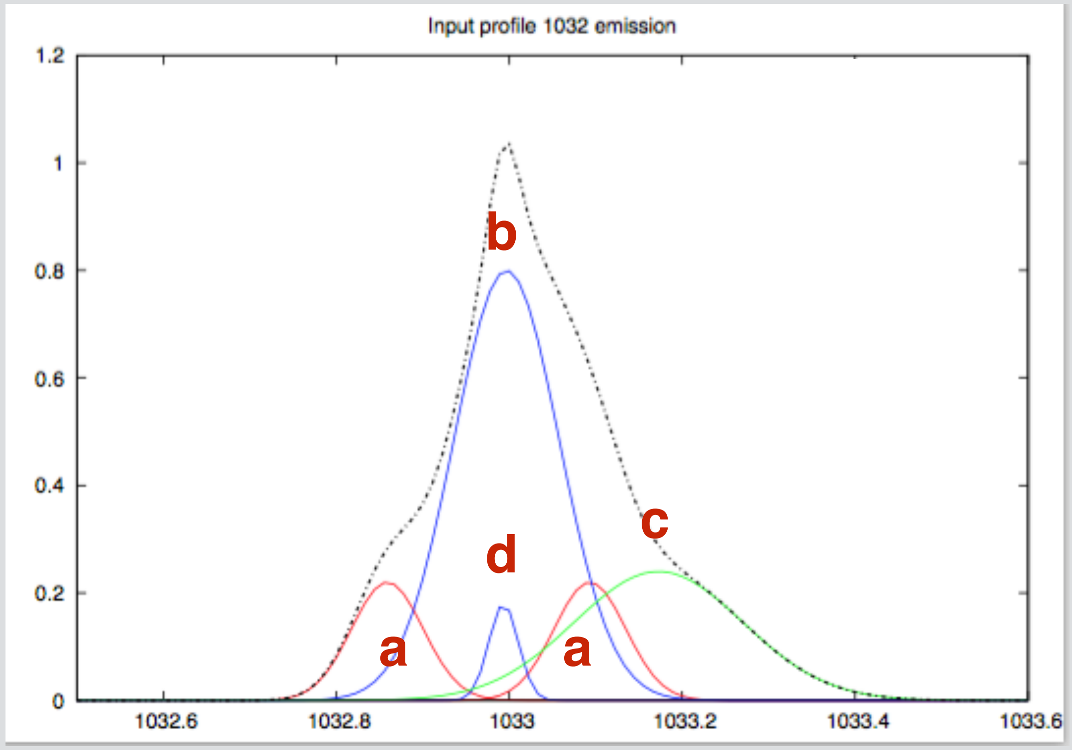
- The two Raman profiles are quite different: while the 6825 feature shows a single broad profile, the 7082 one exhibits a distinct triple-peak profile.

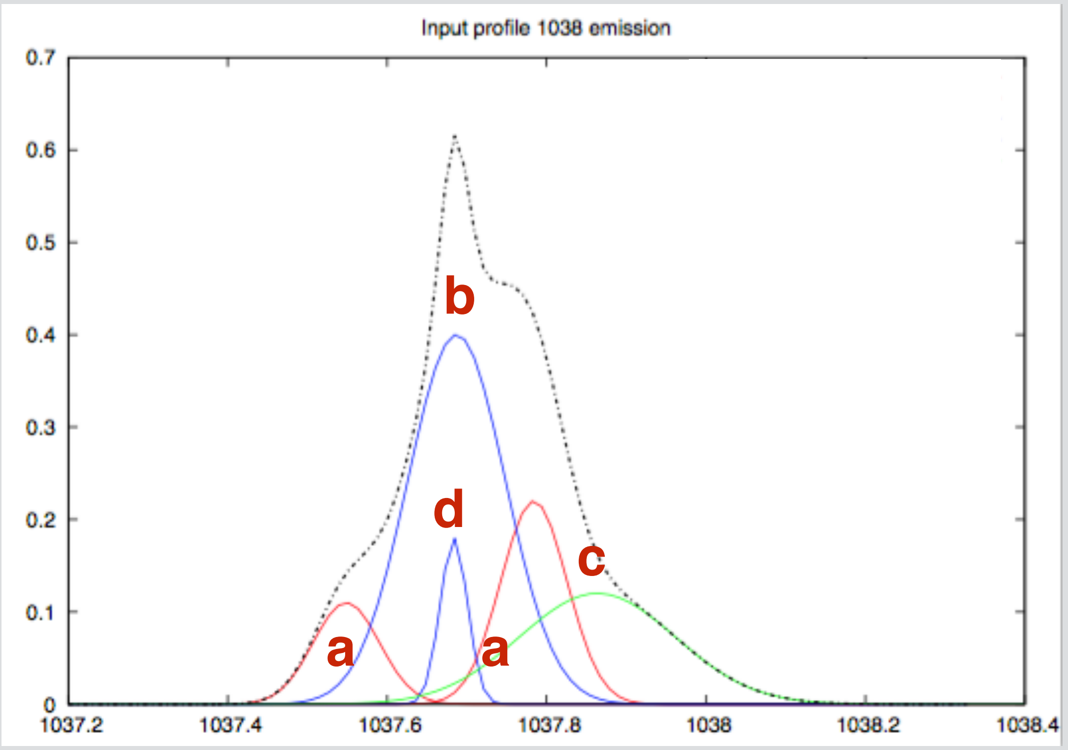
II. Profile Decomposition

Decomposition of O VI Emissions



Decomposition of O VI Emissions





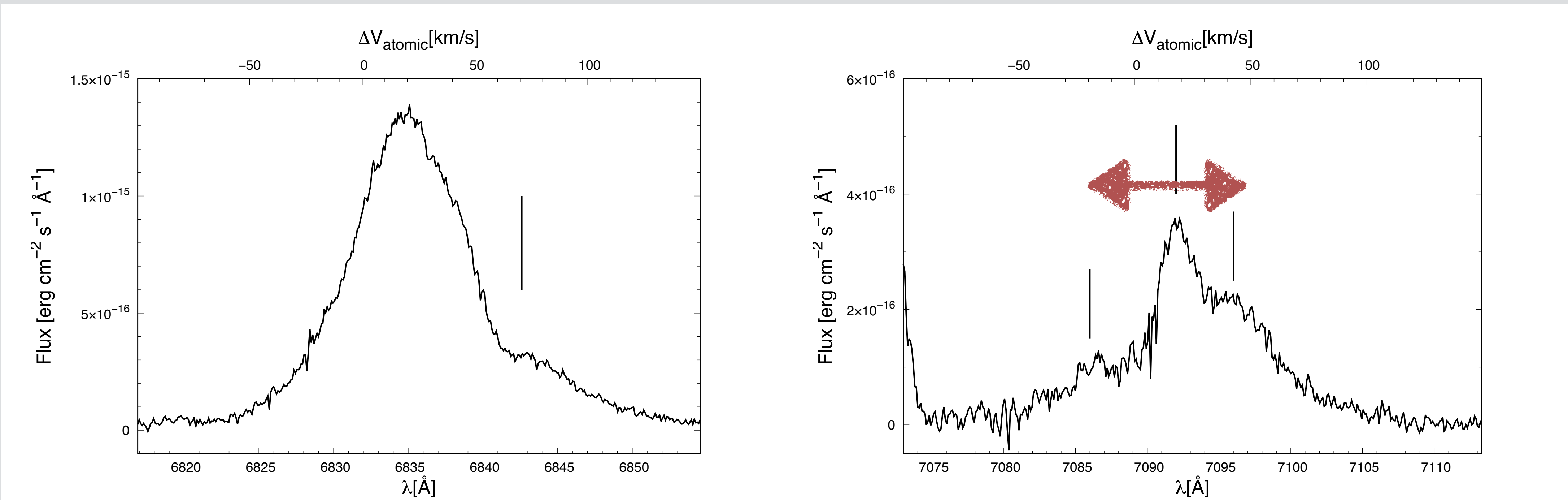
a) Blue Emission Part and Red Emission Part of Accretion Disk

b) Central Emission Part of Accretion disk

c) Bipolar Outflow

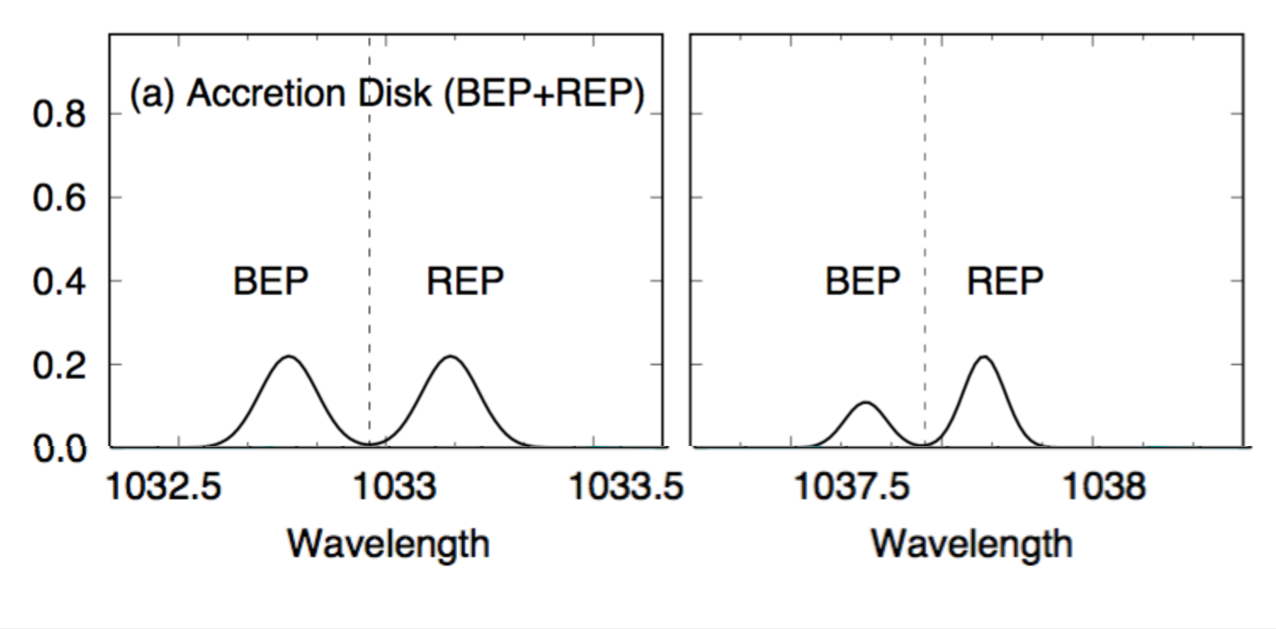
d) Optically Thick Compact Component

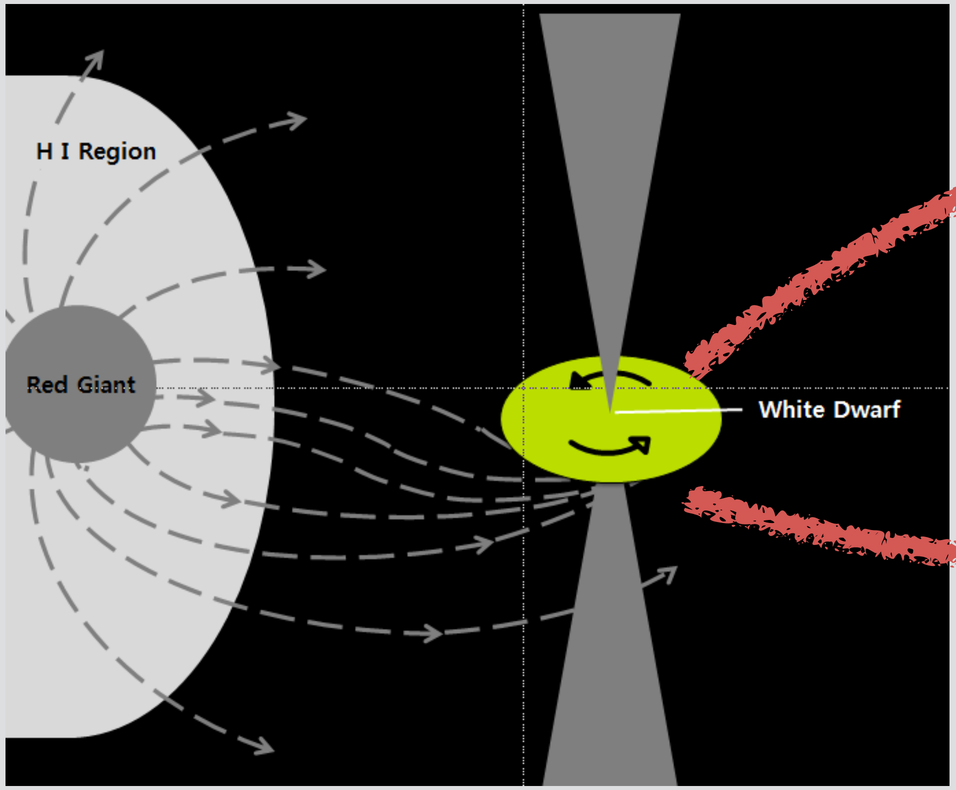
a) BEP and REP in the Accretion Disk



- **Peak separation of the first peak and the third peak is ~ 70km/s.**
  - It is consistent with a Keplerian motion with a velocity of ~ 35km/s

a) BEP and REP in the Accretion Disk





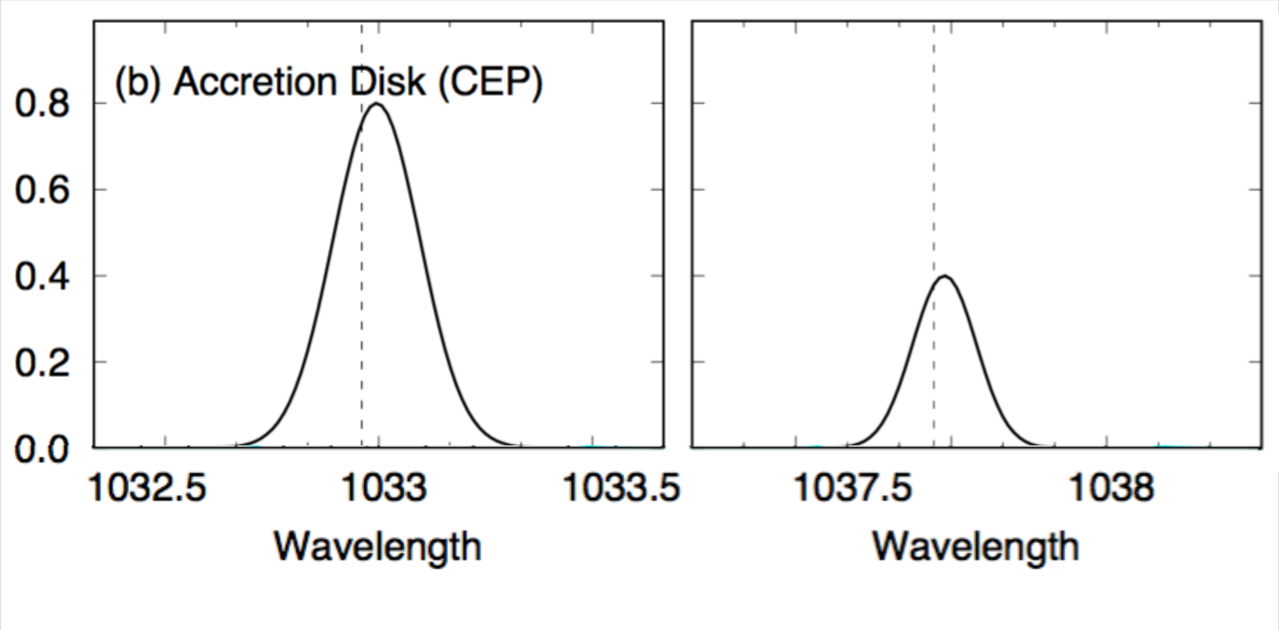
① Blue Emission Part (BEP)

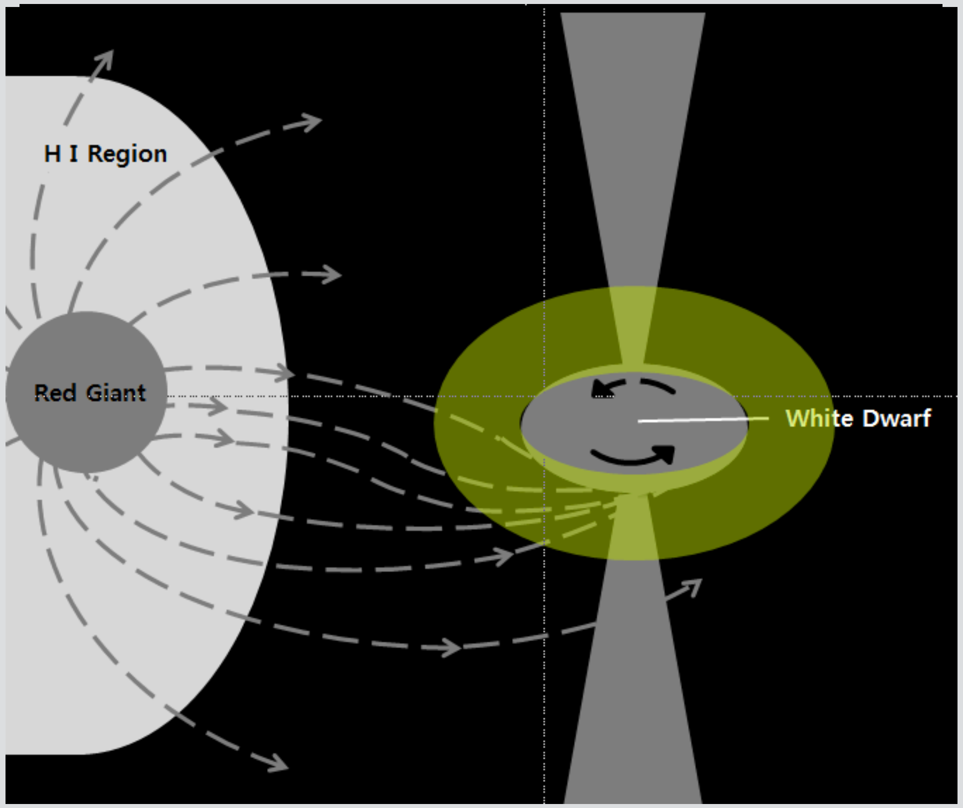
- Approaching the giant v~-35km/s
- Optically thin
- F(1032):F(1038)=2:1

② Red Emission Part (REP)

- Receding from the giant v~+35km/s
- Optically thick
- F(1032):F(1038)=1:1

b) CEP in the Accretion Disk





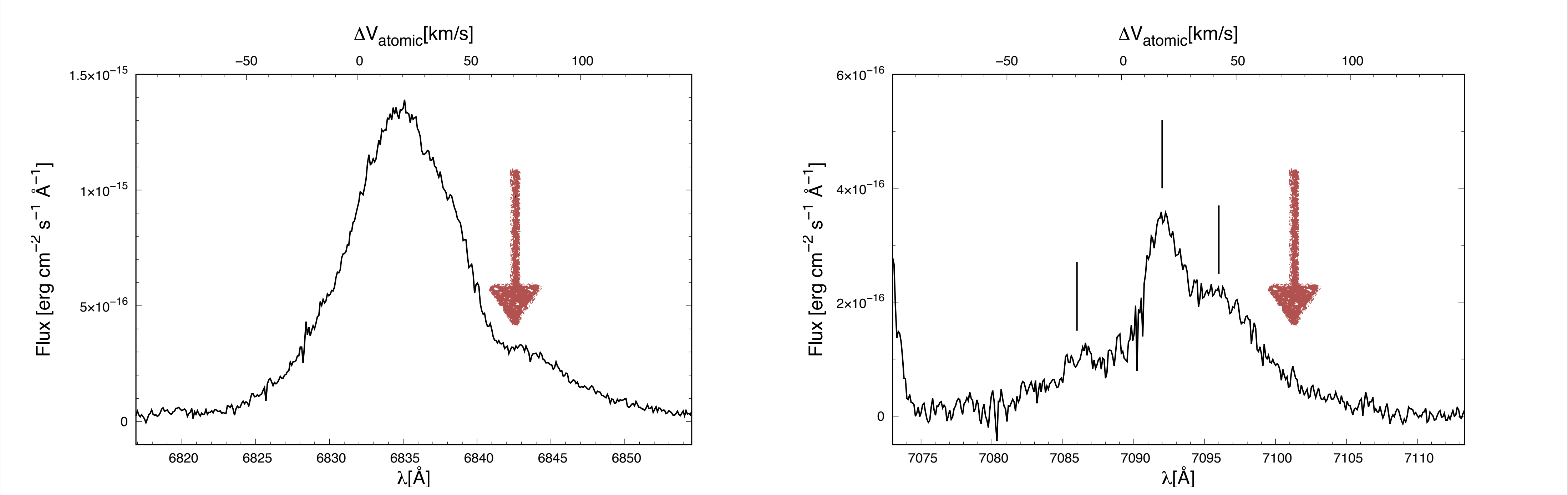
b) Central Emission Part (CEP)

- v ~ +5km/s
- Widely spread Δv ~ 42km/s
- Optically thin, F(1032):F(1038)=2:1

c) Bipolar Outflowing Region

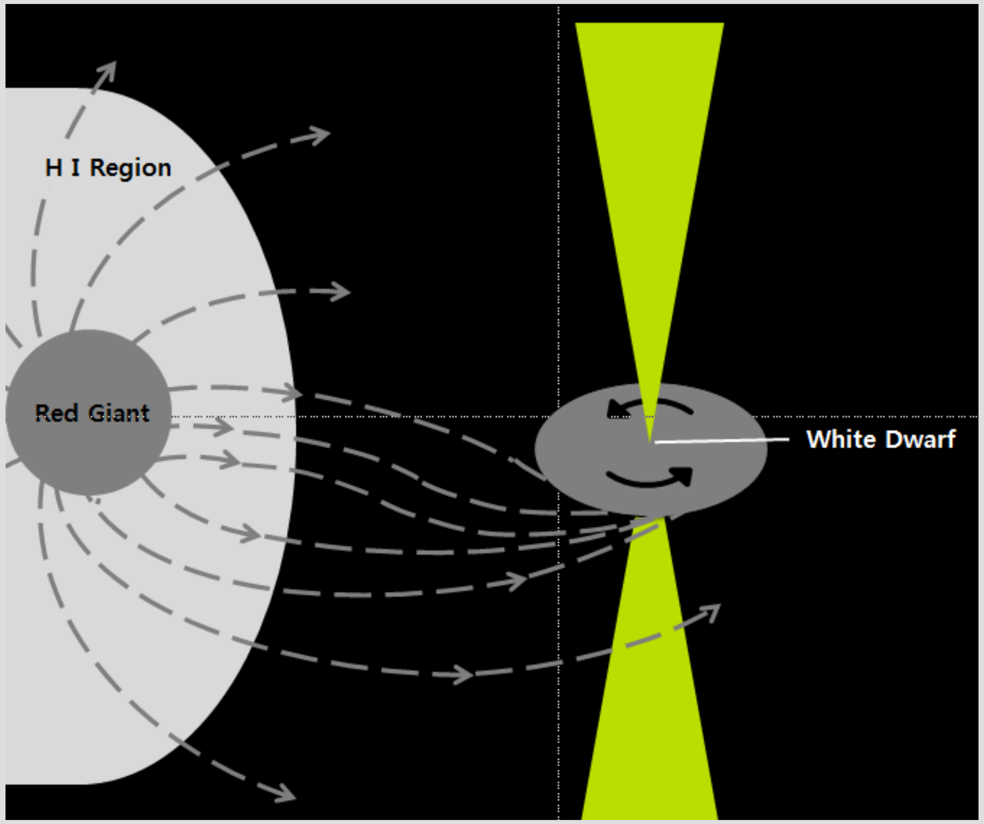
- Discovery of the Jet

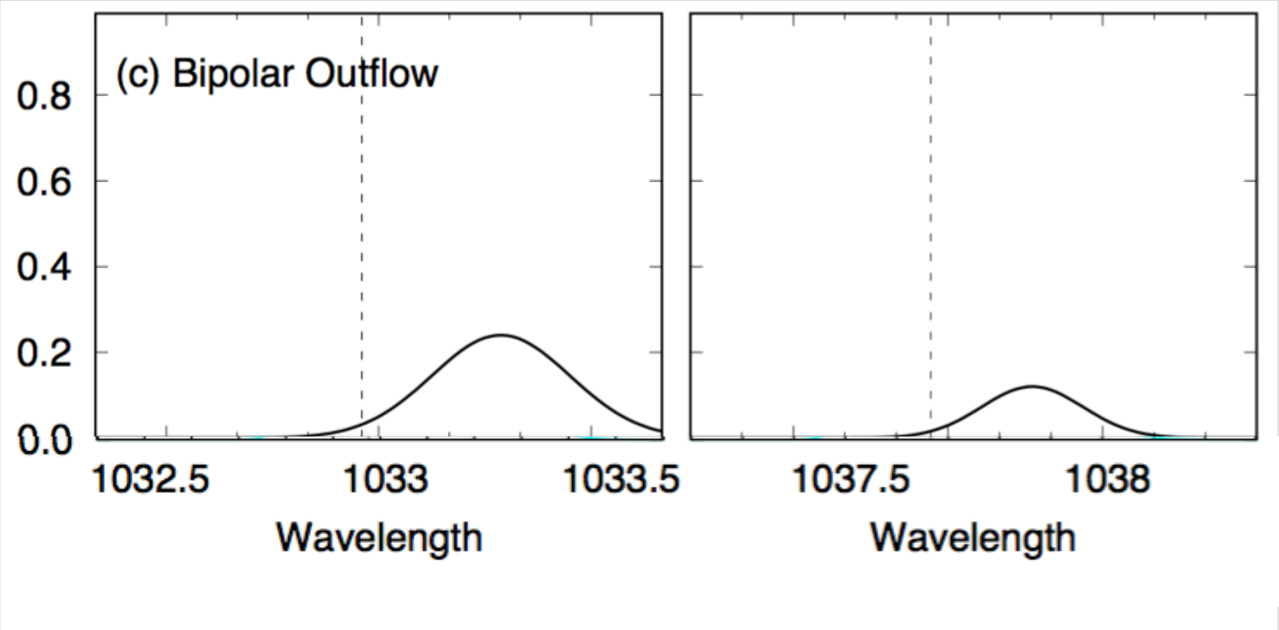
- **Red bump is apparent at v ~ + 60km/s in the 6825 feature.**
- The corresponding feature in the Raman O VI 7082 feature appears to be buried in the smooth red wing part.



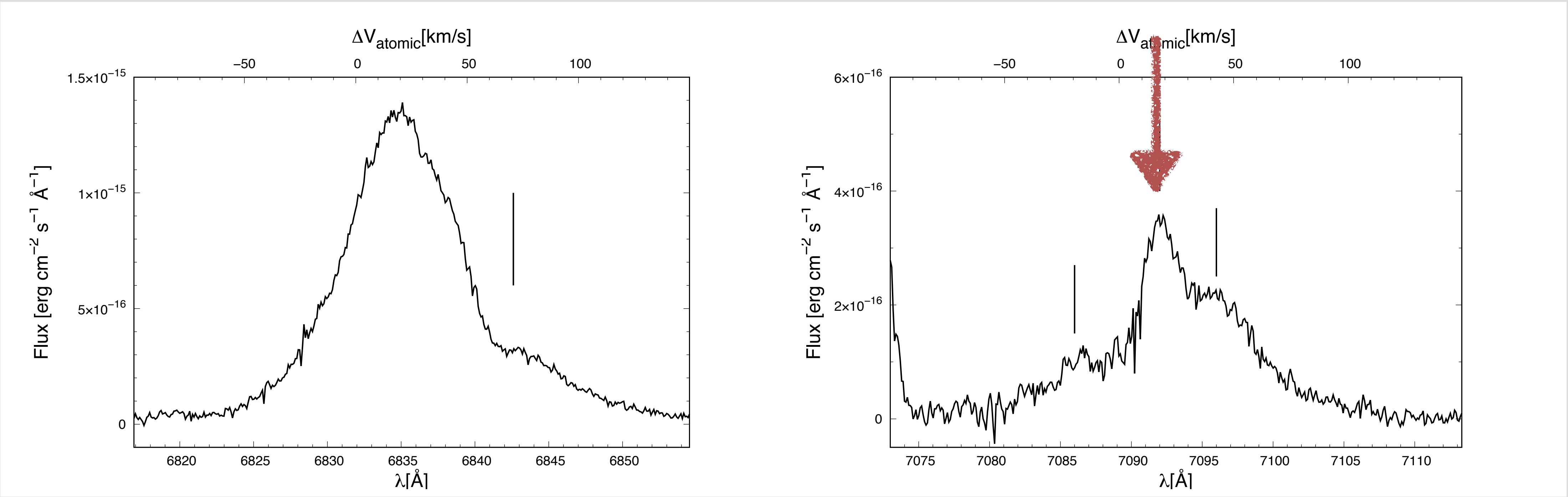
c) Bipolar Outflowing Region

- One gaussian component is formed from **c) the bipolar outflowing region**.
- Moves away with **v ~ 57km/s**
- Optically thin F(1032):F(1038)=2:1



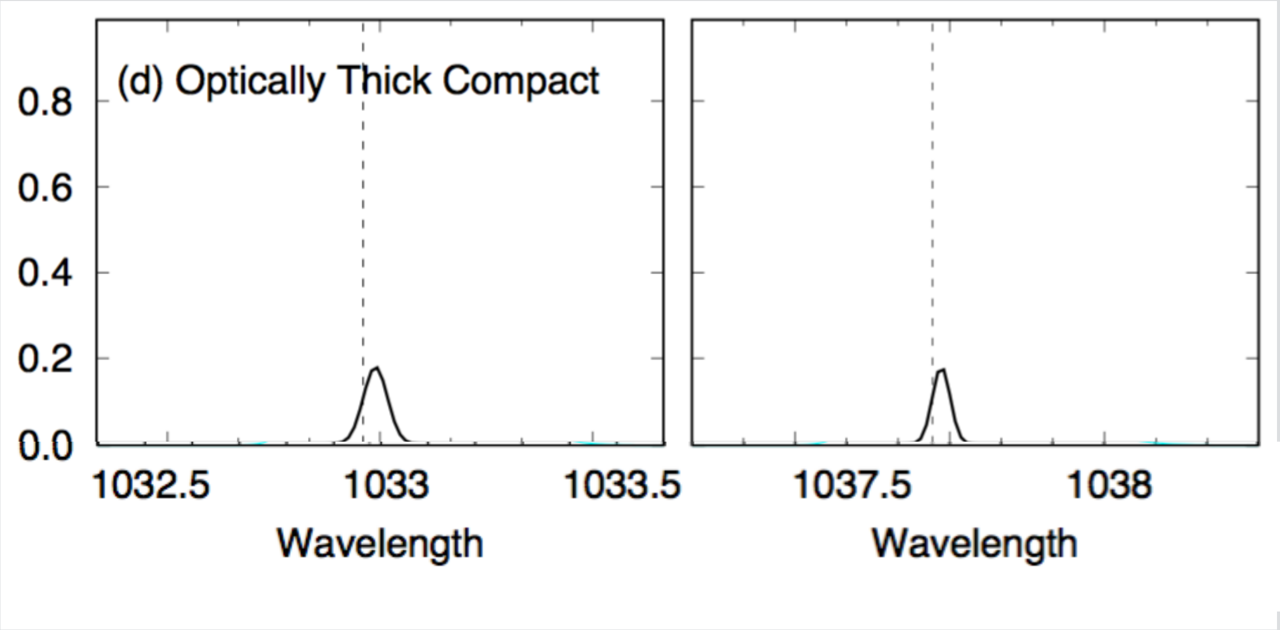


d) Optically Thick Component

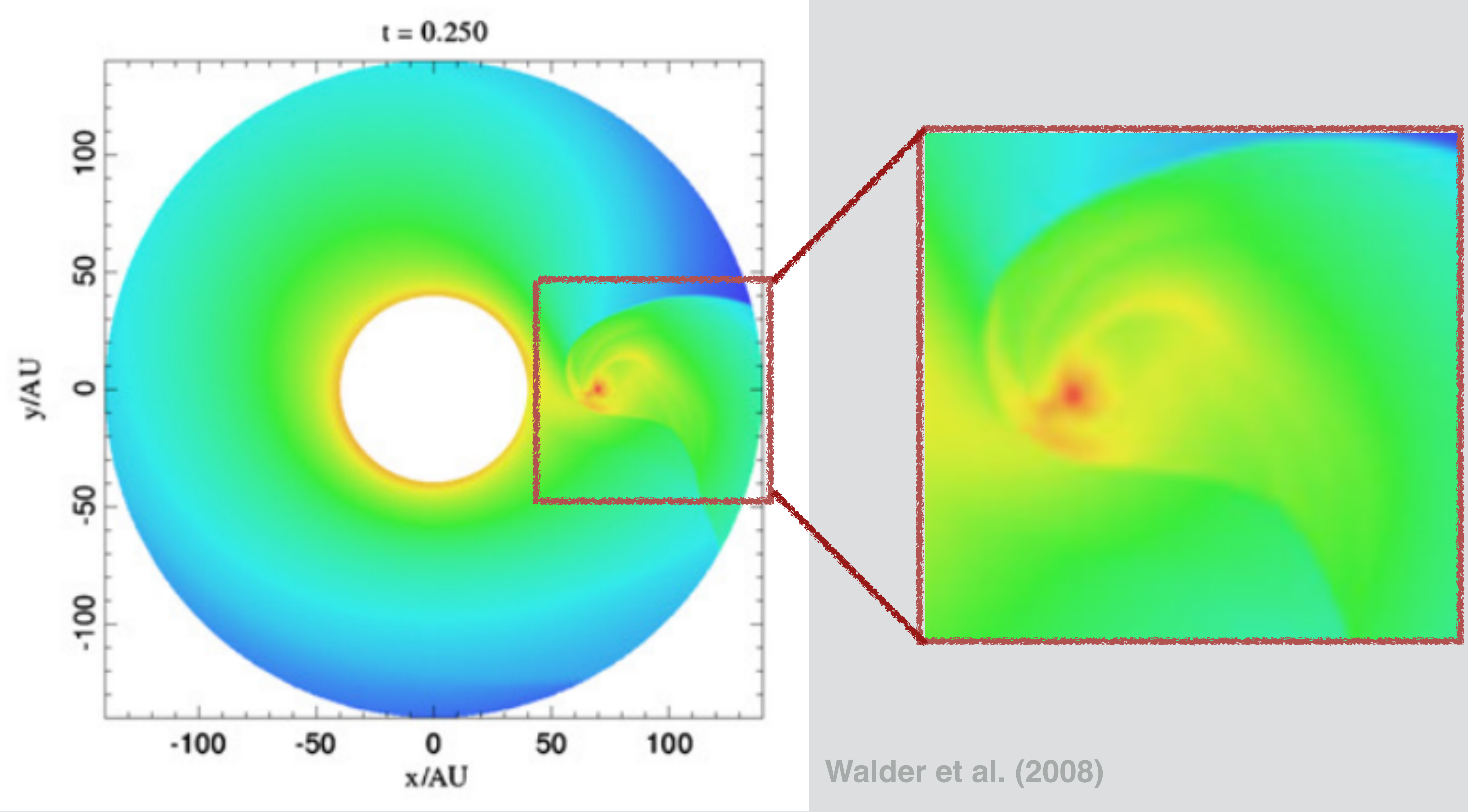


d) Optically Thick Component

- v ~ +6km/s
- Narrow gaussian Δv ~ 12km/s
- Optically thick, F(1032):F(1038)=1:1



d) Optically Thick Component

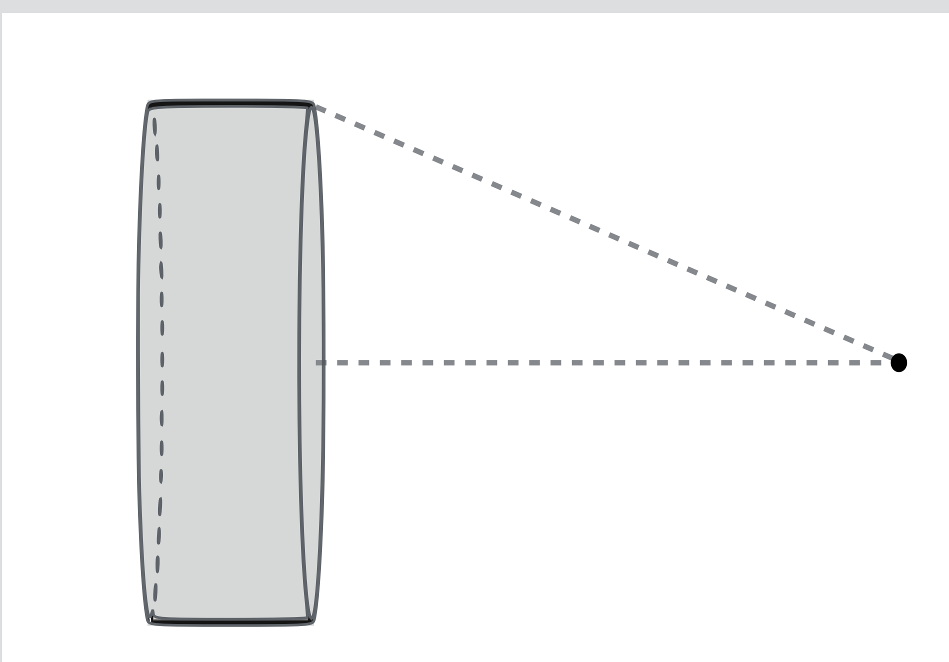


Walder et al. (2008)

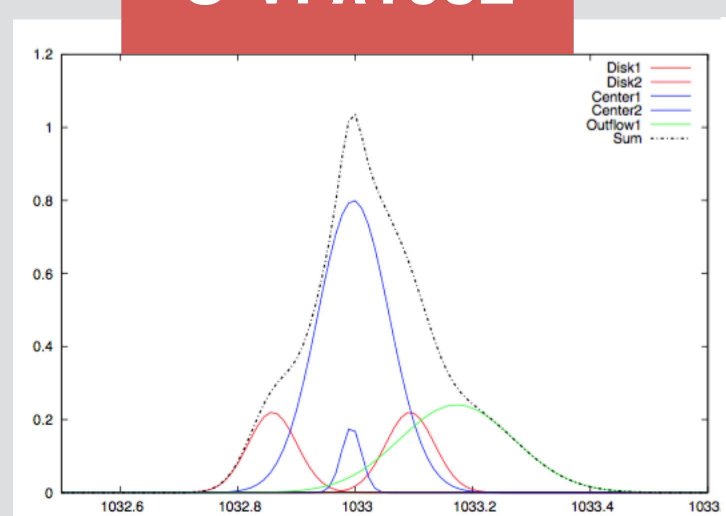
III. Results

Monte-Carlo Simulations

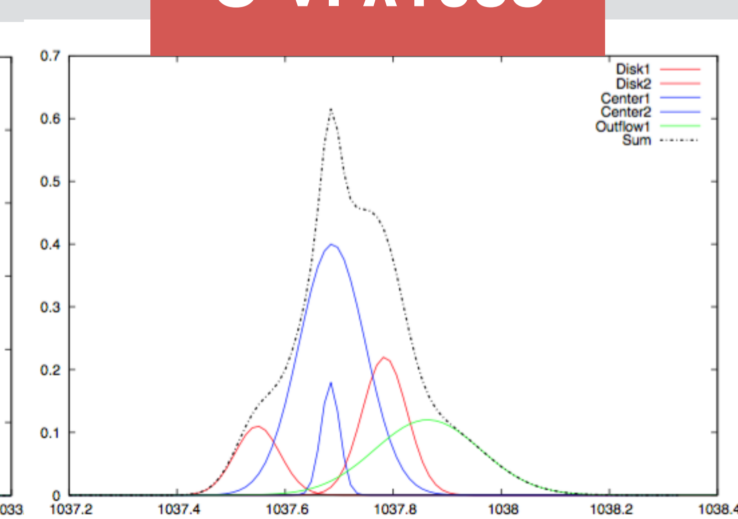
- We perform Monte Carlo simulations in order to estimate the representative value of N_{HI} in Sanduleak's star by reproducing the observed F(6825)/F(7082).
- A neutral scattering region is a circle slab characterized by a single column density NH and static with respect to the emission region.



O VI λ1032



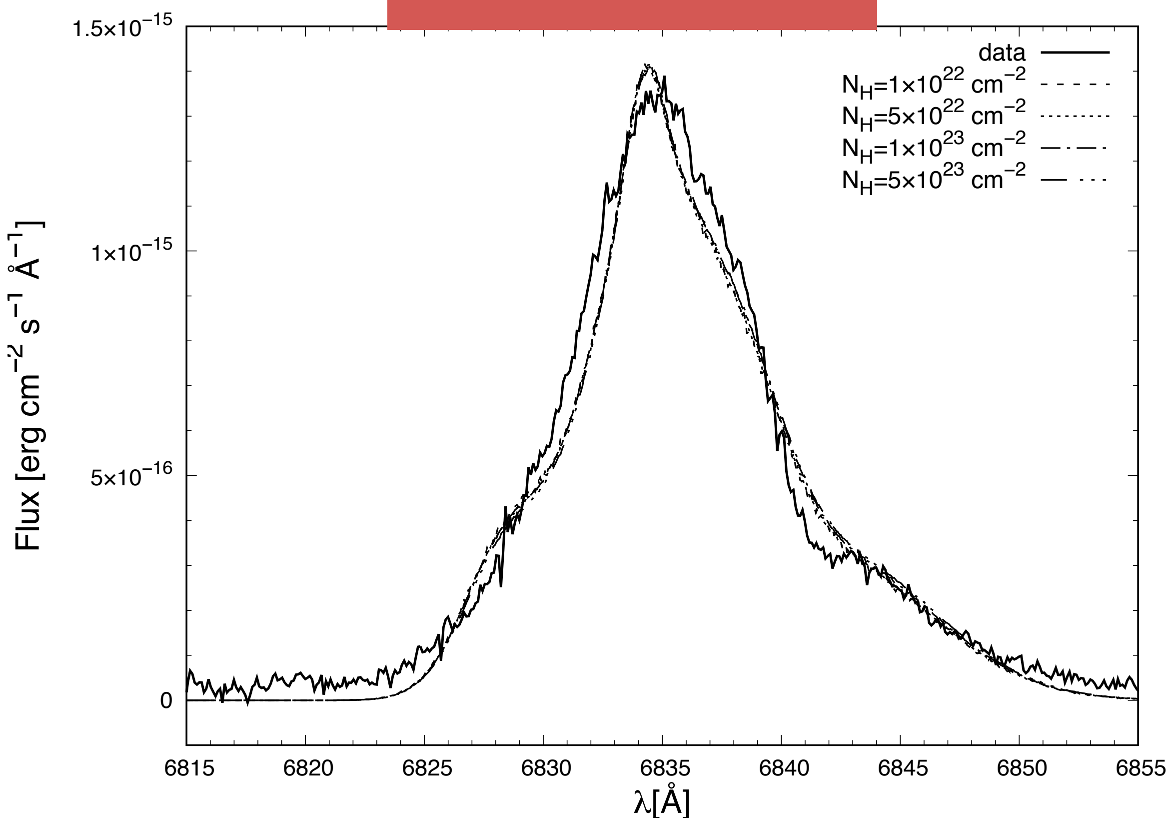
O VI λ1038



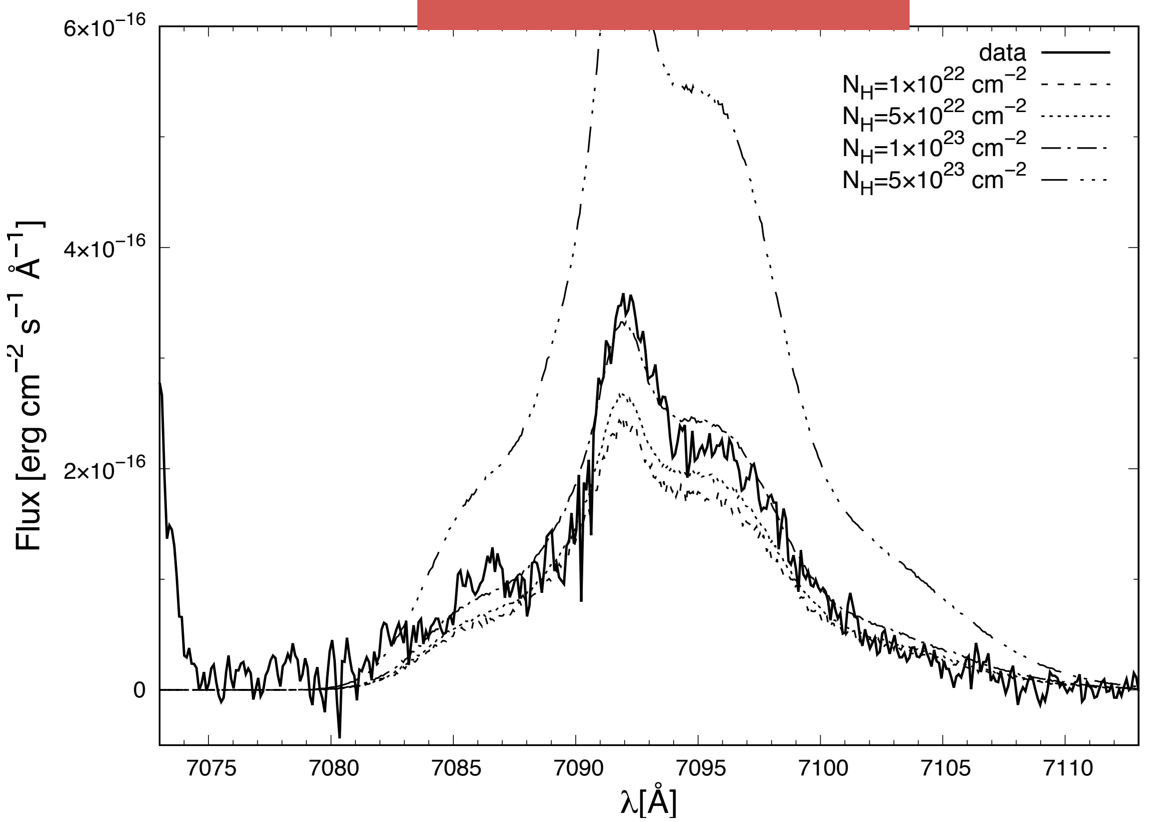
Monte-Carlo Simulations

- A good fit is obtained for $N_{HI} \sim 1\times10^{23}cm^{-2}$
- F(6825)/F(7082) ~4.5, which is an intermediate value between S- and D-type symbiotic stars.

Raman 6825



Raman 7082

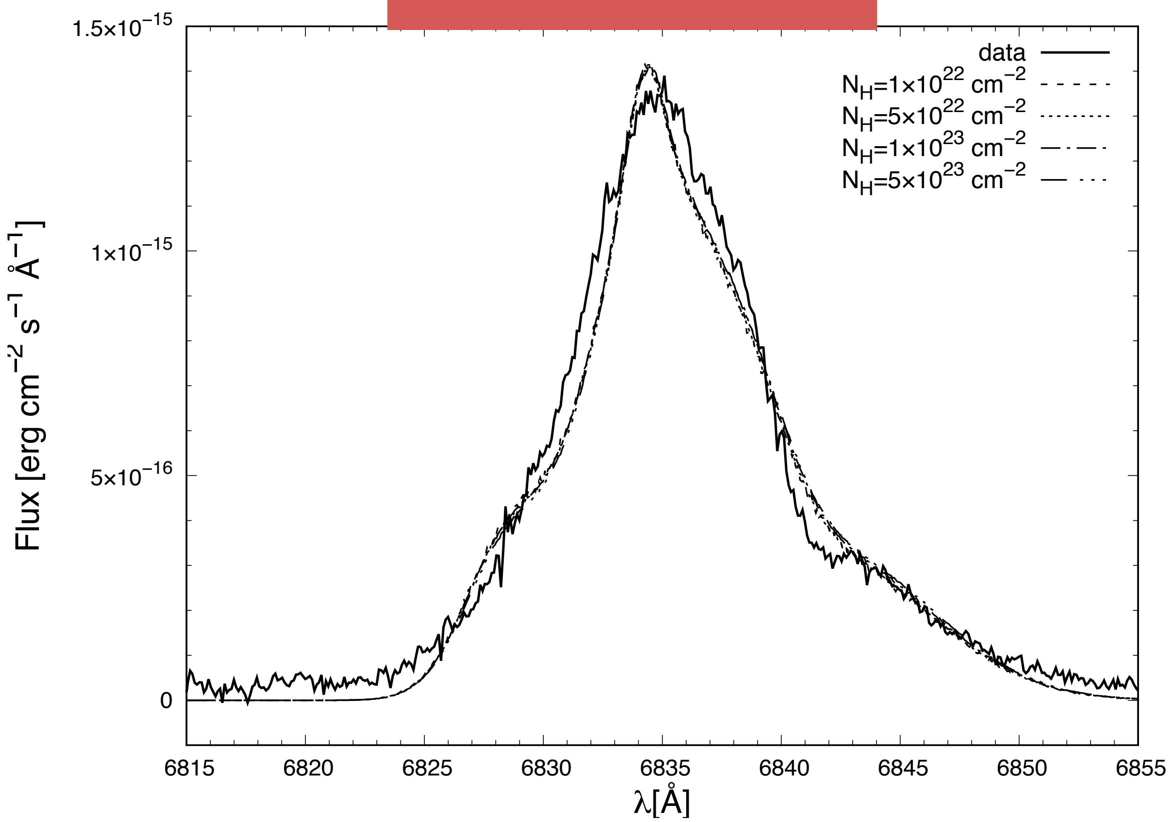


Monte-Carlo Simulations

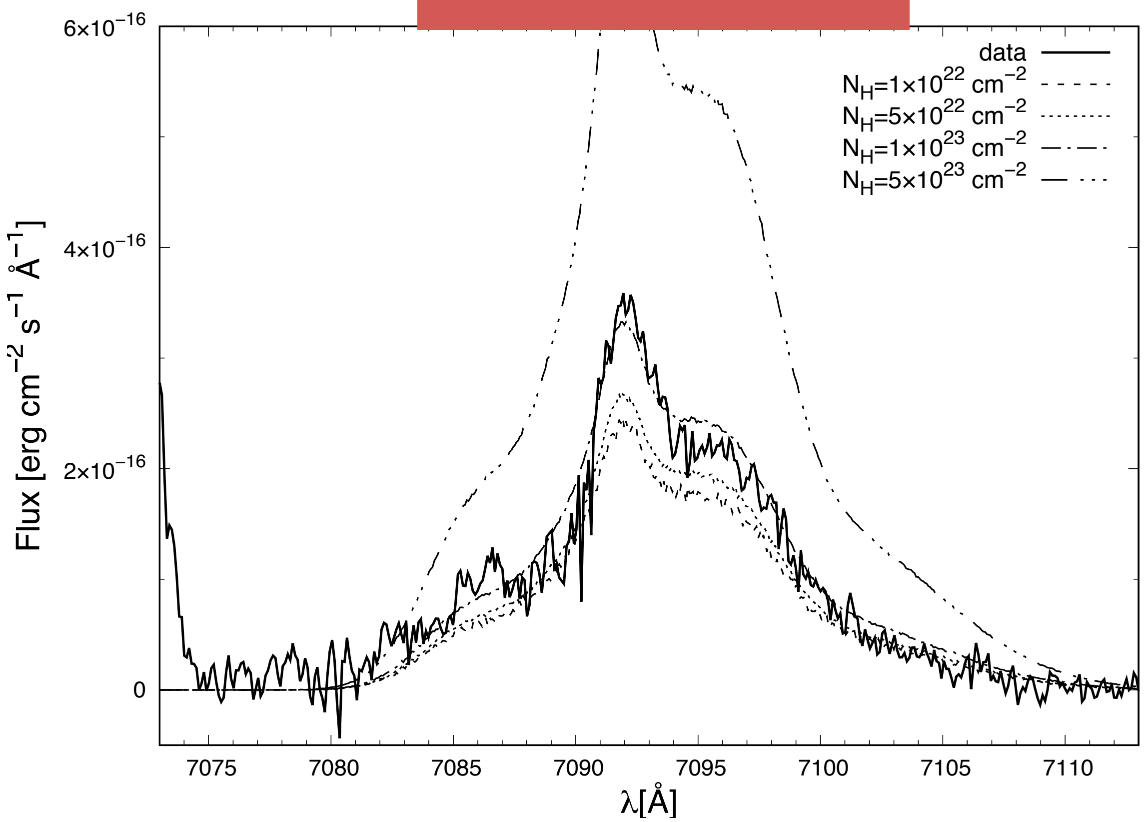
- A good fit is obtained for $N_{HI} \sim 1\times10^{23}cm^{-2}$
- F(6825)/F(7082) ~4.5, which is an intermediate value between S- and D-type symbiotic stars.

Please find Young-Min's poster! (P4)

Raman 6825



Raman 7082



Thank you for your attention ☺