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

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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 λ 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
✓ 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
✓ 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
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Year</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Kafatos et al.</td>
<td>“CNO processed material”</td>
<td>1983</td>
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<td></td>
<td>Large overabundance of N</td>
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<td>Michalitsianos et al.</td>
<td>“Similarity with η Car and SN1987A”</td>
<td>1989</td>
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<td></td>
<td>IUE observations</td>
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<tr>
<td>Allen</td>
<td>“Symbiotic star candidates in LMC”</td>
<td>1980</td>
<td>✓</td>
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<tr>
<td></td>
<td>Numerous high-excitation emission lines</td>
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<td></td>
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<td></td>
<td>Presence of λ6830 bands</td>
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<td>No clear signature of any late-type giant</td>
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<tr>
<td>Belczynski et al.</td>
<td>“A catalogue of symbiotic stars”</td>
<td>2000</td>
<td>✓</td>
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<tr>
<td>Munari &amp; Zwitter</td>
<td>“Atlas of symbiotic stars”</td>
<td>2002</td>
<td>✓</td>
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</tbody>
</table>
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 ✔

05/12/2016 First Chile-Korea-Gemini Workshop
MIKE Observation

- The Magellan Inamor Kyocera Echelle (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

Raman 6825

O VI λ1032

Raman 7082

O VI λ1038
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

- \( v \sim +5 \text{km/s} \)
- Widely spread \( \Delta v \sim 42 \text{km/s} \)
- Optically thin, \( F(1032):F(1038)=2:1 \)
c) Bipolar Outflowing Region

- Discovery of the Jet

- **Red bump is apparent at** \( v \sim +60\text{km/s} \) **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 $v \sim 57\text{km/s}$
- Optically thin $F(1032):F(1038)=2:1$
d) Optically Thick Component

- $v \sim +6\text{km/s}$
- Narrow gaussian $\Delta v \sim 12\text{km/s}$
- 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 $N_{\text{HI}}$ 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 $N_{\text{H}}$ and static with respect to the emission region.
Monte-Carlo Simulations

- A good fit is obtained for $N_{\text{HI}} \sim 1 \times 10^{23}\text{cm}^{-2}$
- $F(6825)/F(7082) \sim 4.5$, which is an intermediate value between S- and D-type symbiotic stars.
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Please find Young-Min’s poster! (P4)
Thank you for your attention 😊