RAMSES II

RAMan Search for Extragalactic Symbiotic Stars

Jeong-Eun Heo
Sejong University, Korea

On behalf of the RAMSES II Team
D.R. Gonçalves¹, H.-W. Lee², R. Angeloni³, R. Diaz⁴, G. Gimeno⁴, J. Scharwächter⁵, S. Akras⁶, G.J. Luna⁷, N.E. Nuñez⁸, J.L. Sokoloski⁹, L. Adrian⁹ et al.

¹Observatório do Valongo, UFRJ, Brazil, ²Sejong University, Korea, ³Universidad de La Serena, Chile, ⁴Gemini-South Observatory, Chile, ⁵Gemini-North Observatory, USA, ⁶Observatório do Valongo, UFRJ, Brazil, ⁷IAFE-CONICET, Argentina, ⁸ICATE-CONICET, Argentina, ⁹Columbia University, USA
Symbiotic Stars

- Long-period interacting binaries composed of a hot compact star (usually a white dwarf) and an evolved giant star.

- Mutual interaction via accretion processes is at the origin of the extended emission recorded from radio to X-rays.
Symbiotic Stars

• nova-like thermonuclear outbursts (e.g. Munari et al. 1997; Shore et al. 2011)

• formation and collimation of jets (e.g. Angeloni et al. 2011; Camps et al. 2018)

• formation of bipolar PNe (e.g. Corradi 2003; Phillips & Ramos-Larios 2008)

• effect of binary evolution on AGB component (e.g. Marigo & Girardi 2007)

• dust formation/destruction processes (e.g. Angeloni et al. 2007a, 2010)

• colliding-wind processes (e.g. Mürset et al. 1995; Kenny & Taylor 2005, 2007)

• candidate progenitors of Supernovae Ia (e.g. Munari & Renzini 1992, Hachisu et al. 1999, Lü et al. 2009, Mikolajewska & Shara 2017)
Symbiotic Stars

- **Galactic Symbiotic Stars**
  - Predicted population: $10^3$-$10^5$ (Allen 1984; Magrini et al. 2003; Lu et al., 2012)

- **Population of Symbiotic Stars in Local Group Galaxies**

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>Distance (kpc)</th>
<th>$M$ ($M_\odot$)</th>
<th>Size (arcmin$^2$)</th>
<th>Expected # of SySt</th>
<th>Observed # of SySt</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC10</td>
<td>862±30</td>
<td>$6.0 \times 10^8$</td>
<td>6.8X5.9</td>
<td>150</td>
<td>1</td>
</tr>
<tr>
<td>NGC 147</td>
<td>730±101</td>
<td>$5.5 \times 10^7$</td>
<td>13.2x7.8</td>
<td>2 800</td>
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</tr>
<tr>
<td>NGC 185</td>
<td>616±26</td>
<td>$6.6 \times 10^7$</td>
<td>11.7x10.0</td>
<td>4 200</td>
<td>1</td>
</tr>
<tr>
<td>NGC 205</td>
<td>824±27</td>
<td>$7.5 \times 10^8$</td>
<td>21.9x11.0</td>
<td>17 000</td>
<td>1</td>
</tr>
<tr>
<td>M 32</td>
<td>771±63</td>
<td>$1.1 \times 10^9$</td>
<td>8.7x6.5</td>
<td>19 000</td>
<td></td>
</tr>
<tr>
<td>M 31</td>
<td>792±440</td>
<td>$2.4 \times 10^{11}$</td>
<td>190x60</td>
<td>660 000</td>
<td>31</td>
</tr>
<tr>
<td>M 33</td>
<td>883±246</td>
<td>$0.8-1.4 \times 10^{10}$</td>
<td>70.8x41.7</td>
<td>45 000</td>
<td>12</td>
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<tr>
<td>Fornax</td>
<td>138±5</td>
<td>$6.8 \times 10^7$</td>
<td>17.0x12.0</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Leo I</td>
<td>254±17</td>
<td>$&gt; 2.0 \times 10^7$</td>
<td>9.8x7.4</td>
<td>200</td>
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<tr>
<td>Leo II</td>
<td>233±15</td>
<td>$1.1 \times 10^7$</td>
<td>12.0x11.0</td>
<td>50</td>
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<tr>
<td>Draco</td>
<td>76±6</td>
<td>$1.7 \times 10^7$</td>
<td>35.5x24.5</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>
Symbiotic Stars

Because many other stellar sources appear to mimic SySt colors (PNe, Be and T Tauri stars, CVs, Mira LPVs, etc.), no photometric diagnostic tool has so far demonstrated the power to unambiguously identify a SySt, thus making the recourse to costly spectroscopic follow-up still inescapable.
6830 Å band

- Broad feature at 6830 Å has been detected only in *bona fide* symbiotic stars, and served as one of the criteria for classifying a star as symbiotic. (Belczyński et al. 2000).

- The 6830 Å band appears as a rather strong feature: it is *among the 10 most intense lines in the optical*, able to reach up to 5% of the intensity of Hα. (Allen 1980; Schmid 1989; Akras et al. 2019a)

- Two bands have abnormally **broad width of 20-30 Å** and composite profiles.

Symbiotic Star RR Tel (Munari & Zwitter 2001)

![Spectra of Symbiotic Stars](image)

Harries & Howarth 1996
Raman-scattering of O VI 1032Å

Atomic Hydrogen

O VI

2P

2S

O VI 1032 Å

P(3/2)

P(1/2)

Raman O VI 6830 Å

3S

2S

1S - e

O VI 1032 Å

Raman-scattering of O VI 1032Å
Raman-scattering of O VI 1032Å
Raman-scattering of O VI 1032Å

O VI

Atomic Hydrogen

O VI 1032 Å

Raman O VI 6830 Å

1S  2S  3S

2P

P_{3/2}

P_{1/2}

-e

-e
Raman O VI in Symbiotic Stars

• Given the high ionization potential of O5+ (114 eV), Raman-scattered OVI lines indicate the presence of a strong ionizing source, i.e., of a very hot WD.

• High temperatures can be achieved if the accreted material is burned as it is accreted onto the WD surface.

The environment of shell-burning symbiotic stars is ideal for the operation of Raman scattering.
Raman O VI Detections (Akras et al. 2019)

Table 2. Number of positive and negative O VI Raman-line Detections in the Milky Way, SMC, LMC, M31, and M33

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>Total number</th>
<th>Positive detections</th>
<th>Negative detections</th>
<th>O VI Raman (%)</th>
<th>[Fe/H]</th>
<th>References</th>
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<tr>
<td>Milky Way</td>
<td>257</td>
<td>131</td>
<td>108</td>
<td>55</td>
<td>-0.11</td>
<td>1</td>
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<tr>
<td>SMC</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>100</td>
<td>-0.99</td>
<td>2</td>
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<td>LMC</td>
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<td>4</td>
<td>3</td>
<td>57</td>
<td>-0.60</td>
<td>3,4</td>
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<tr>
<td>M31</td>
<td>31</td>
<td>16</td>
<td>15</td>
<td>52</td>
<td>-0.45</td>
<td>5</td>
</tr>
<tr>
<td>M33</td>
<td>12</td>
<td>5</td>
<td>7</td>
<td>42</td>
<td>-0.11</td>
<td>6</td>
</tr>
</tbody>
</table>

aTotal number of optical spectra examined in this work.

RAMSES II Project

**RAMMan Search for Extragalactic Symbiotic Stars**

Using Raman O VI emission as a new photometric diagnostic tool to systematically discover new symbiotic stars

- D.R. Gonçalves (PI, Observatório do Valongo, UFRJ, Brazil)
- H.-W. Lee, J.-E. Heo (Sejong University, Korea)
- R. Angeloni (Universidad de La Serena, Chile)
- R. Diaz, G. Gimeno (Gemini-South Observatory, Chile)
- J. Scharwächter (Gemini-North Observatory, USA)
- S. Akras (Observatório do Valongo, UFRJ, Brazil)
- G.J. Luna (IAFE-CONICET, Argentina)
- N.E. Nuñez (ICATE-CONICET, Argentina)
- J.L. Sokoloski, L. Adrian (Columbia University, USA)

+ several present (and future) students...
Gemini Instrument Upgrade Project

Gemini Instrument Upgrade Projects: Awarded Proposals

2015-2017 IUP Project

During the 2015 program cycle, Gemini awarded Professor Casey Papovich from Texas A&M University (USA) for the proposal "Two K-filters for F-2 (K2F)." Professor Papovich and his team proposed a small upgrade to F-2 by providing two medium band filters, which split the spectral range, 1.9-2.5 microns. The team also includes astronomers from the University of Toronto (Canada), Swinburne University of Technology and Macquarie University (Australia), and Leiden University (Netherlands). The main science case supporting the upgrade use imaging K-band color deep surveys to perform high redshift demography and exploit synergies with current and forthcoming synoptic surveys. The project envisages other applications as censuses of low mass stars in high extinction environments. In addition to funding the design, the procurement, and testing of the filters, Gemini has awarded the team with 10 hours of telescope time to demonstrate the scientific benefits of the new capability. The filters have been commissioned, the team is preparing their first publication and the new capability of Flamingos-2 is already offered to users. It is noted to state that several queue and fast turn around proposals have requested to use the filters.

2016-2018 IUP Projects

During the 2016 program cycle, Gemini awarded two proposals.

Professor Denise Gonçalves from the Federal University of Rio de Janeiro (Brazil) for the proposal "Raman OVI narrow-band imaging with Gemini/GMOS." The team also includes Professor Rodolfo Angeli from the University of La Serena (Chile) as co-PI, and researchers from Sejong University (Korea), National Observatory of Brazil, Institute of Earth and Space Sciences (Argentina), and Columbia University (USA). The project envisages a promising new technique to discover symbiotic stars in the Local Group of Galaxies by providing a special set of narrow band filters for both GMOS-S and GMOS-N instruments. The symbiotic stars are binary systems in which a dwarf star accretes mass from a red giant companion, possibly the progenitors of one type of supernovae. In addition to funding the procurement and testing of the filters, Gemini has awarded the team with 10 hours of telescope time to demonstrate the scientific benefits of the new capability. The filters acceptance tests have been completed, commissioning is underway, and the new capability will be offered to users after November 2018.

GMOS Raman OVI Filters Upgrade Acceptance Test Plan

Denise F. Gonçalves, Rodolfo Angeli, Seonghun Ahn, and Youn Sol Park on behalf of the Raman OVI Search for Extragalactic Supernova (RAMOSS) Team

Robert Han, Cameron Bennek, and Julie Schmechtig on behalf of Gemini Instrumentation Program
Filter Design

- Raman O VI **on-band**: $\lambda_{\text{OVI}}=6835\text{Å}$, FWHM=50Å
Filter Design

- Raman O VI **on-band**: $\lambda_{OVI}=6835\text{Å}$, FWHM=50Å
- Raman O VIC **off-band**: $\lambda_{OVIC}=6780\text{Å}$, FWHM=50Å
IUP - Filter Characterization

- **OVIC (6780 Å)**
  - GMOS-N

- **OVI (6835 Å)**
  - GMOS-S

### GMOS Filters

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Hβ</td>
<td>G0320</td>
<td>466</td>
<td>454-472</td>
<td>GMOS-h data / GMOS-S data/plot</td>
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<tr>
<td>HβIC</td>
<td>G0321</td>
<td>478</td>
<td>474-482</td>
<td>GMOS-h data</td>
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<tr>
<td>OIII</td>
<td>G0341</td>
<td>466</td>
<td>490.5-501.5</td>
<td>GMOS-h data / GMOS-S data/plot</td>
</tr>
<tr>
<td>OVIC</td>
<td>G0322</td>
<td>514</td>
<td>309.2-519.0</td>
<td>GMOS-h data / GMOS-S data/plot</td>
</tr>
<tr>
<td>Hα</td>
<td>G0310</td>
<td>656</td>
<td>554-561</td>
<td>GMOS-h data</td>
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<td>HαIC</td>
<td>G0325</td>
<td>662</td>
<td>553-565</td>
<td>GMOS-h data / GMOS-S data/plot</td>
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<tr>
<td>SII</td>
<td>G0317</td>
<td>672</td>
<td>650.4-673.7</td>
<td>GMOS-h data</td>
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<tr>
<td>OVIC</td>
<td>G0346</td>
<td>676</td>
<td>673.1-680.9</td>
<td>GMOS-h data / GMOS-S data/plot</td>
</tr>
<tr>
<td>OVI</td>
<td>G0345</td>
<td>674</td>
<td>673.5-686.5</td>
<td>GMOS-h data / GMOS-S data/plot</td>
</tr>
<tr>
<td>(28820)</td>
<td>G0347</td>
<td>674</td>
<td>673.5-686.5</td>
<td>GMOS-h data / GMOS-S data/plot</td>
</tr>
</tbody>
</table>

*Note: Filter numbers in GMOS-N and GMOS-S are used to identify filters. The data and plots for these filters can be found in GMOS-h data and GMOS-S data/plot.*
IUP - Filter Characterization

- The sky field around the photometric standard star TYC 9054-1091-1
- March 14, 2018
- $t_{\text{exp}} = 5$ sec
### IUP - Science Verification Phase

<table>
<thead>
<tr>
<th>Name</th>
<th>$\alpha_{J2000}$</th>
<th>$\delta_{J2000}$</th>
<th>Obs. date</th>
<th>$t_{exp}$</th>
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<tr>
<td>LHA120 S154</td>
<td>04 51 50.469</td>
<td>-75 03 35.36</td>
<td>03/15</td>
<td>3×120</td>
</tr>
<tr>
<td>LHA120 S147</td>
<td>04 54 03.473</td>
<td>-70 59 32.18</td>
<td>04/02</td>
<td>4×90</td>
</tr>
<tr>
<td>LMC 1</td>
<td>05 25 01.106</td>
<td>-62 28 48.78</td>
<td>03/14</td>
<td>3×60</td>
</tr>
<tr>
<td>LHA120 N67</td>
<td>05 36 07.576</td>
<td>-64 43 21.34</td>
<td>03/14</td>
<td>3×30</td>
</tr>
<tr>
<td>SMP LMC 88</td>
<td>05 42 33.193</td>
<td>-70 29 24.08</td>
<td>03/14</td>
<td>2×120</td>
</tr>
<tr>
<td>Sanduleak’s star</td>
<td>05 45 19.569</td>
<td>-71 16 06.72</td>
<td>03/15</td>
<td>3×60</td>
</tr>
<tr>
<td>V366 Car</td>
<td>09 54 43.284</td>
<td>-57 18 52.40</td>
<td>03/14</td>
<td>3×30</td>
</tr>
<tr>
<td>GSC 09276-00130</td>
<td>17 18 09.290</td>
<td>-67 57 26.00</td>
<td>05/14</td>
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<td>M 1-21</td>
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<td>Hen 3-1768</td>
<td>19 59 48.418</td>
<td>-82 52 37.49</td>
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<tr>
<td>V1016 Cyg</td>
<td>19 57 05.019</td>
<td>+39 49 36.09</td>
<td>06/23</td>
<td>3×5</td>
</tr>
</tbody>
</table>

**Raman O VI**

- ✔️
- ✔️
- ✔️
- ✔️
- ✔️
- ✗
- ✔️
- ✔️
- ✔️
- ✔️
- ✔️

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14/02/2019 K-GMT Science Program Users Meeting 2019 @KASI

J.-E. Heo
IUP - SV Phase (V1016 Cyg)

BOES spectrum of V1016 Cyg (Heo & Lee 2015)
IUP - SV Phase (V1016 Cyg)

- $t_{\text{exp}} = 3 \times 5$ sec
- June 23, 2018
IUP - SV Phase  (Known Raman O VI Emitters)

Sanduleak’s Star

- OVI (6835Å)
- OVI - OVIC

M1-21

- OVI (6835Å)
- OVI - OVIC

LHa120 N67

- OVI (6835Å)
- OVI - OVIC

LHa120 S147

- OVI (6835Å)
- OVI - OVIC
IUP - SV Phase (V366 Car)

- $t_{\text{exp}} = 3\times30$ sec
- March 14, 2018
IUP - SV Phase (GDS J0954243-571655)

- $t_{\text{exp}} = 3 \times 30\ \text{sec}$
- March 14, 2018

✓ GDS J0954243-571655 ($\alpha_{\text{J2000}}=09:54:24.38, \delta_{\text{J2000}}=-57:16:55.5$)

✓ A semi-regular variable with an amplitude $\Delta V \sim 0.6\ \text{mag}$ and a period $P \sim 270\ \text{days}$
  (Shappee et al. 2014; Kochanek et al. 2017)
IUP - SV Phase (GDS J0954243-571655)

- GMOS-S spectroscopic follow-up of GDS J0954243-571655
- April 02, 2018
IUP - SV Phase  (SMP LMC 88)

SMP LMC 88

RAMSES II images of SMP LMC 88
(March 14, 2018)
IUP - SV Phase (SMP LMC 88)

SMP LMC 88

[Images of OVI (6835Å) and OVI - OVIC]

RAMSES II images of SMP LMC 88 (March 14, 2018)

[Image of GMOS-S spectrum of SMP LMC 88]

GMOS-S spectrum of SMP LMC 88 (April 02, 2018)

F(Raman OVI) < 6.8×10^{-16} \text{ erg cm}^{-2} \text{ s}^{-1}

IUP - SV Phase (LMC 1)

October 15, 1994
(Munari & Zwitter 2001)
IUP - SV Phase (LMC 1)

October 15, 1994 (Munari & Zwitter 2001)

March 14, 2018 (RAMSES II)

OVI (6835Å)

OVI - OVIC
• GMOS-S spectroscopic follow-up of GDS J0954243-571655
• March 15, 2018 (+1 night following the RAMSES II images)
# IUP - SV Phase

<table>
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<tr>
<th>Name</th>
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<td>19 57 05.019</td>
<td>+39 49 36.09</td>
<td>06/23</td>
<td>3 x 5</td>
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</tbody>
</table>

Raman O VI

- **X, ✔**
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
- ✔,
The Future is Now!

RAMSES II – RAMan Search for Extragalactic Symbiotic Stars
Project concept, commissioning, and early results from the science verification phase

Rodolfo Angeloni,1,2 Denise R. Gonçalves,3 Stavros Akras,3 German Gimeno,4 Ruben Díaz,4
Julia Scharwächter,5 Natalia E. Nuñez,6 Gerardo Juan M. Luna,7,8,9 Hee-Won Lee,10 Jeong-Fun Heo,10
Adrian B. Lucy,11,* Marcelo Jaque Aranchibia,2 Cristian Moreno,4 Emmanuel Chirre,4 Stephen J. Goodsell,5,12
Piera Soto King,3 J. L. Sokoloski,11,13 Bo-Eun Choi,10 and Mateus Dias Ribeiro3

1 Instituto de Investigación Multidisciplinar en Ciencia y Tecnología, Universidad de La Serena, Av. R. Eitrún 1305, La Serena, Chile
2 Departamento de Física y Astronomía, Universidad de La Serena, Av. J. Cisternas 1200, La Serena, Chile
3 Observatório do Valongo, Universidade Federal do Rio de Janeiro, Ladeira Pedro Antonio 43, 20089-090, Rio de Janeiro, Brazil
4 Gemini Observatory, Southern Operations Center, Casilla 603, La Serena, Chile
5 Gemini Observatory, Northern Operations Center, 670 N. A`u`oku Place, Hilo, HI 96720, USA
6 Instituto de Ciencias Astronómicas, de la Tierra y del Espacio (ICATE-CONICET), Av. España Sur 1512, J5402DSP, San Juan, Argentina
7 CONICET-Universidad de Buenos Aires, Instituto de Astronomía y Física del Espacio (IAFE), Av. Inte. Güiraldes 2620, C1428ZAA, Buenos Aires, Argentina
8 Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Buenos Aires, Argentina
9 Universidad Nacional Arturo Jauretche, Av. Callejón 6200, F. Varela, Buenos Aires, Argentina
10 Department of Physics and Astronomy, Sejong University, Seoul 05006, Republic of Korea
11 Columbia University, Dept. of Astronomy, 550 West 120th Street, New York, NY 10027, USA
12 Department of Physics, Durham University, South Road, Durham, DH1 3LE, UK
13 Large Synoptic Survey Telescope Corporation, 935 North Cherry Ave, Tucson, AZ 85719, USA
## The Future is Now!

<table>
<thead>
<tr>
<th></th>
<th>Hα</th>
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<th>O VI</th>
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<td><strong>NGC 55</strong></td>
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<td>GS-2018B-Q-219</td>
<td>(Korean Time)</td>
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*2018B regular CfP  2019A 10hr DDT*
RAMSES II

RAMan Search for Extragalactic Symbiotic Stars

Stay tuned!