Symbiotic stars, weird novae, and related embarrassing binaries
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Hide-and-seek with symbiotic stars

Dr. Stavros Akras
Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing
National Observatory of Athens

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Playing Hide-and-seek *with* Symbiotic stars from **1900 to 2000**

The first report of SySt has been made in 1898 (RS Oph) as a variable sources with HI and He II λ4686 lines in its spectrum.

The second one may be Z And (1901) again as a variable star.

For years, scientists had been searching for stars with similar characteristics

- Bidelman (1954)	23 SySts
- Merrill (1958)	Introduced the term Symbiotic Stars"
- Boyarchuk (1969)	21 SySts and 16 candidates
- Allen (1984)	129 SySts and 15 candidates
- Kenyon (1986)	133 SySts and 20 candidates
- Belczyński et al. (2000)	188 SySts and 30 candidates

In parallel

Several studies were also carried out to get an estimation of the expected population of SySts in the Milky Way → **1000 up to 100000** (Kenyon 1986, 1993; Munari & Renzini 1992)

These numbers were 1 to 3 order of magnitudes lower

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Symbiotic stars are better players in hide-and-seek

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Playing Hide-and-seek *with* Symbiotic stars from **2000 to 2019**

In 2019, two new **independent** catalogs of SySts were published (Akras et al. and Merc et al.)

- The number of known Galactic SySts is 257 + 66 extragalactic
  - In 20 years, the number of known SySts is almost double (~70%)
    - This new number is still order of magnitudes lower than the most recent estimations for their Galactic population 1200-15000 (Lu et al. 2006) or >1690 and expected=32300 (Laversveiler & Gonçalves 2023)

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The key question is “Why?”

Playing Hide-and-seek *with* Symbiotic stars from **2000 to 2019**

Known	Candidate	Environment	References	
–	2[a]	Galactic	Corradi (1995), Weidmann & Gamen (2011)	
188	30[b]	Catalog	Bel2000 and references therein	
–	2[c]	Galactic	Schmeja & Kimeswenger (2001), Corradi et al. (2011b)	
–	1	Galactic	Feibelman (2001), Groves et al. (2002)	
2[d]	2[d]	Galactic	Van Eck & Jorissen (2002)	
4	–	Galactic	Munari & Zwitter (2002), Downes & Keyes (1988)	
1	–	Galactic	Pereira et al. (2002)	
1[e]	–	Galactic	Wheatley et al.(2003)	
–	1	Galactic	Pereira & Miranda (2005), Miranda et al. (2010), Weidmann & Gamen (2011)	
1[f]	–	Galactic	Mattana et al. (2006), Masetti et al. (2006a)	
1[f]	–	Galactic	Masetti et al. (2006b)	
1[f]	–	Galactic	Kaplan et al. (2007)	
1[f]	–	Galactic	Masetti et al. (2007)	
3	1183[g]	Galactic	Corradi et al (2008)	IPHAS survey
–	1	Galactic	Phillips & Ramos-Larios (2008)	
1	–	IC 10	Gonçalves et al. (2008)	
1	–	Galactic	Mennickent et al. (2008)	
4	8[h]	Galactic	Miszalski et al. (2009)	SuperCOSMOS Sky Survey
–	1[i]	Galactic	Viironen et al. (2009)	
1	–	NGC 6822	Kniazev et al. (2009)	
1	–	Galactic	Corradi & Giammanco (2010)	IPHAS survey
1	–	Galactic	Corradi et al. (2010a)	IPHAS survey
8	–	Galactic	Corradi et al. (2010b)	IPHAS survey
1[f]	1[f]	Galactic	Nespoli et al. (2010)	
–	1	Galactic	Weidmann & Gamen (2011)	
1	–	Galactic	Corradi et al. (2011a)	IPHAS survey
–	5	LMC	Miszalski et al. (2011)	
1[f]	–	Galactic	Masetti et al. (2011)	
1	–	SMC	Torres et al. (2012)	

Playing Hide-and-seek *with* Symbiotic stars from **2000 to 2019**

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1	–	Galactic	Bond & Kasliwal (2012)
1	–	NGC 185	Gonçalves et al. (2012)
–	1	Galactic	Tang et al. (2012)
1	–	SMC	Oliveira et al. (2013)
1	–	Galactic	Baella et al. (2013)
16	13[h]	Galactic[j]	Miszalski et al. (2013)
1[f]	–	Galactic	Luna et al. (2013)
–	1	Galactic	Munari et al. (2013b)
–	1	SMC	Hajduk et al. (2014)
12	3	Galactic	Miszalski & Mikolajewska (2014)
1	–	SMC	Miszalski et al. (2014)
5	–	Galactic	Rodríguez–Flores et al. (2014)
31	4	M31	Mikolajewska et al. (2014)
1[f]	–	Galactic	Bahramian et al. (2014)
–	7[k]	LMC	Reid (2014)
–	5	SMC	Kamath et al. (2014)
1	–	Galactic	Mroz et al. (2014)
–	1	Galactic	Hynes et al. (2014)
1	–	Galactic	Joshi et al. (2015)
1	–	Galactic	Srivastana et al. (2015)
–	1	Galactic	Hambsch et al. (2015)
–	2	LMC	Kamath et al. (2015)
1	2	NGC 205	Gonçalves et al. (2015)
2	–	Galactic	Li et al. (2015)
–	1[l]	Galactic	Clyne et al. (2015)
1	–	Galactic	Margon et al. (2016)
1	–	Galactic	Baella et al. (2016)
1	–	Galactic	Mukai et al. (2016)
12	–	M33	Mikolajewska et al. (2017)
1	–	Galactic	Bozzo et al. (2018)
1	–	LMC	ilkiewicz et al. (2018)

SuperCOSMOS Sky Survey

SuperCOSMOS Hα Survey

IPHAS survey

- 51 new SySts from surveys

- 28 new SySts from individual studies

Playing Hide-and-seek *with* Symbiotic stars from **2000 to 2019**

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–	7[k]		
			(2015)
			Gonçalves et al. (2015)
			Li et al. (2015)
		Galactic	Clyne et al. (2015)
	–	Galactic	Margon et al. (2016)
1	–	Galactic	Baella et al. (2016)
1	–	Galactic	Mukai et al. (2016)
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SuperCOSMOS ... Survey

...urvey

Seeking SySts in photometric surveys is more efficient

- 51 new SySts from surveys
- 28 new SySts from individual studies

SySts Selection criteria & Diagnostic diagrams

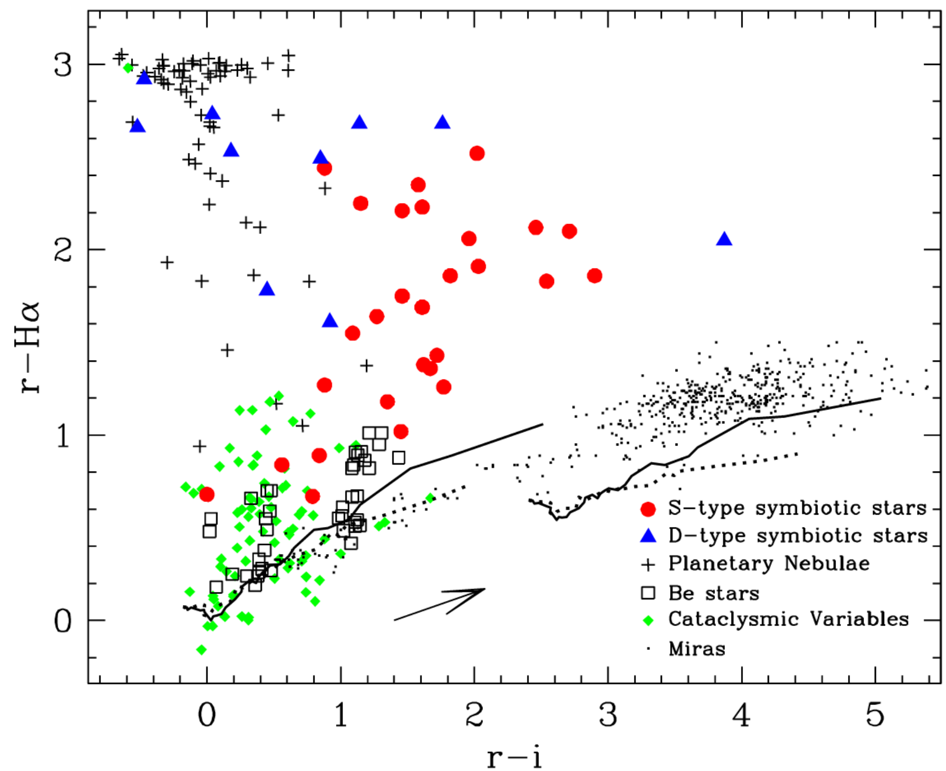
- Besides the optical spectroscopic criteria
  - (I) strong He II and Hα lines
  - (II) highly ionized Fe lines
  - (III) absorption TiO, VO features
  - (IV) the presence of Raman OVI 6830 line

- **In the era of photometric surveys**

SySts in the IPHAS survey

- **r-Hα >= 0.25*(r-i) +0.65** (e.g. Corradi et al. 2008)

Discovery of 18 new SySts



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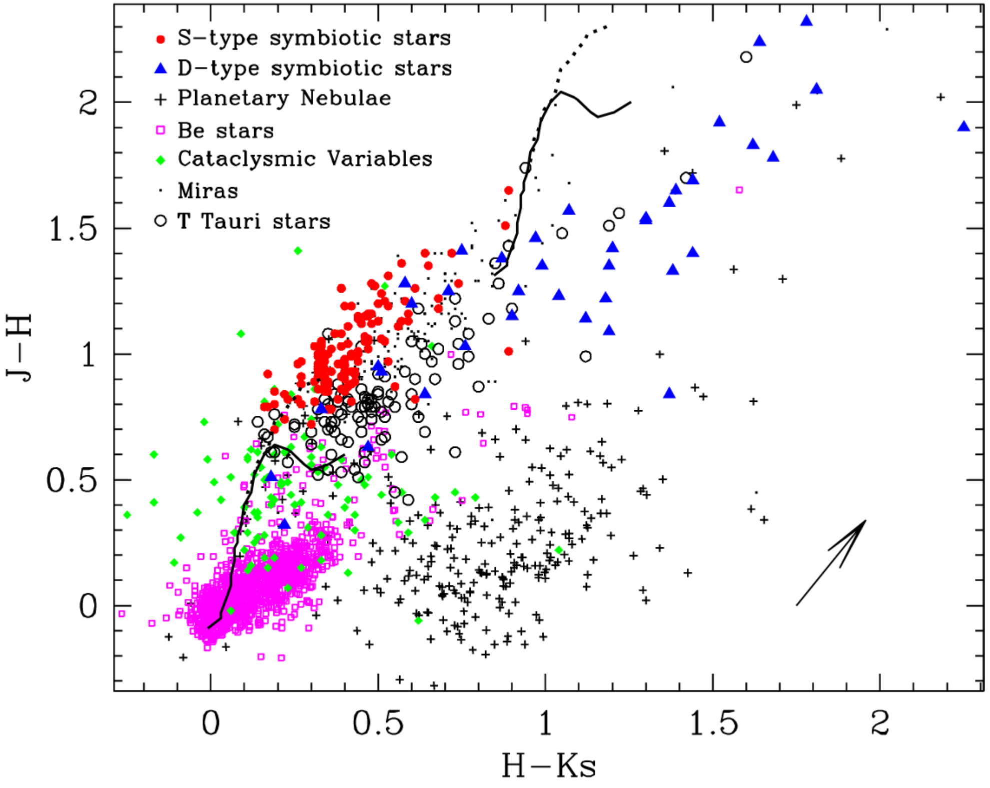
- **In the era of photometric surveys**

SySts in infrared surveys

2MASS: J-H vs H-K
(Allen & Glass 1974, Phillips 2007)

Near-IR: I-J vs J-Ks
(Schmeja & Kimeswenger 2001)

Mid-IR: K-[12] vs [12]-[25]
(Luud & Tuvikene 1987, Leedjarv 1992)

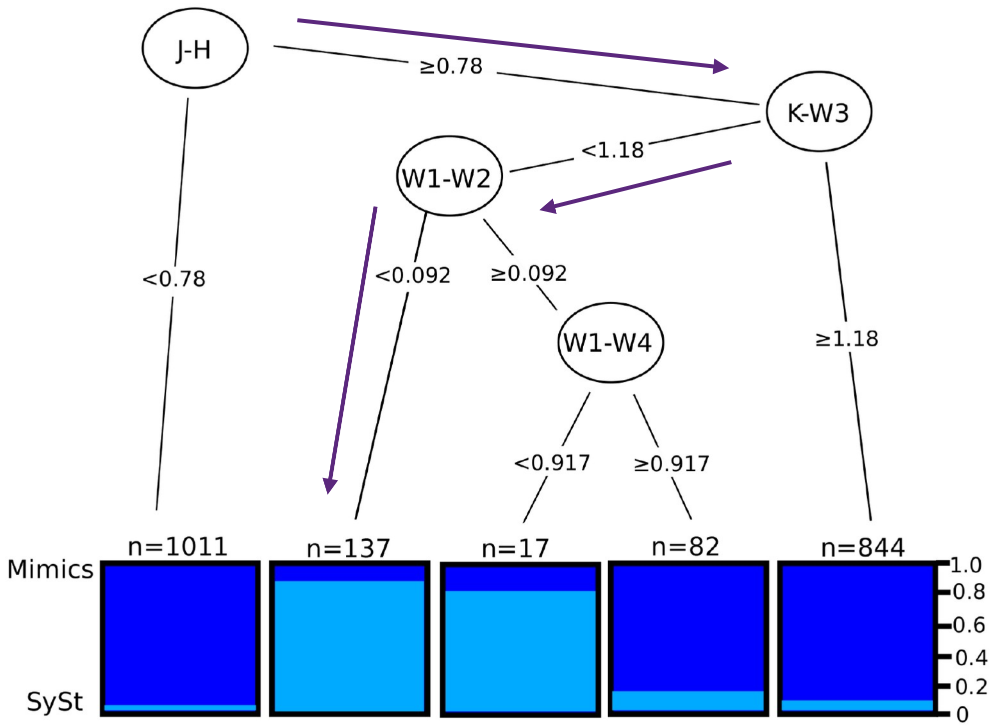


Playing Hide-and-seek *with* Symbiotic stars from **2019 to 2024**

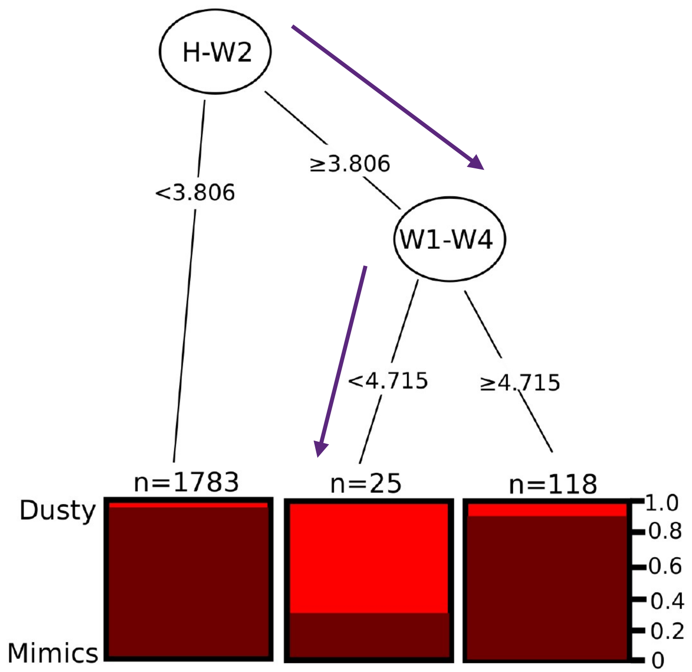
<u>The era of all-sky surveys, big data and machine learning algorithms</u>

Using 2MASS & WISE colour indices, we trained the Decision tree algorithm and extract new selection criteria for SySts in the infrared regime (Akras et al. 2019b)

S-type

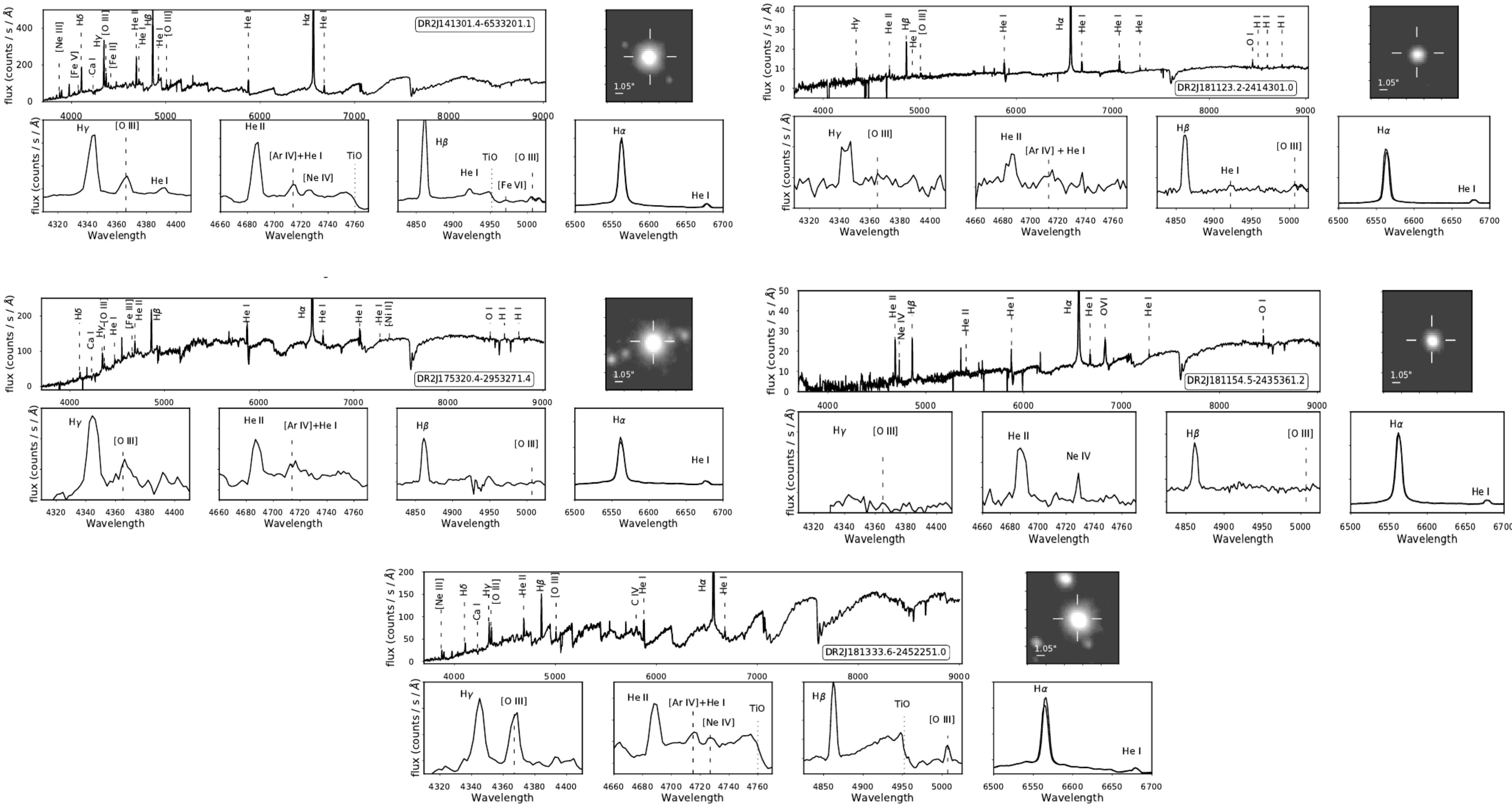


D-type



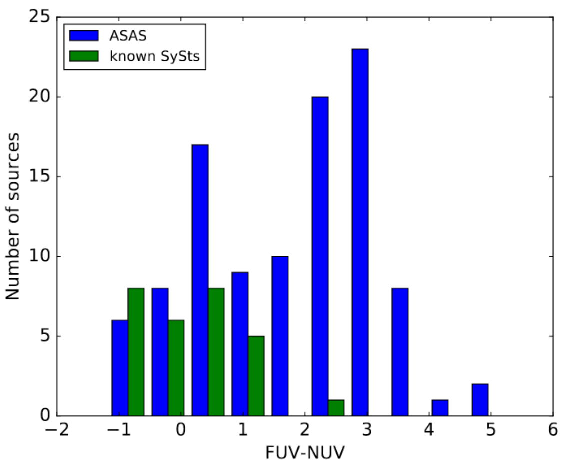
Playing Hide-and-seek *with* Symbiotic stars from **2019 to 2024**

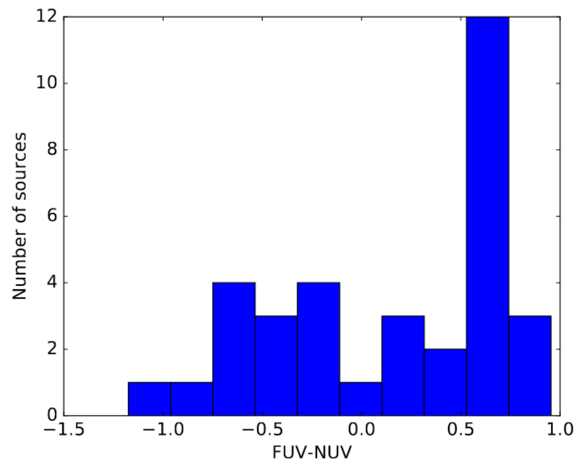
I) 5 new genuine SySts after observing only 7 candidates (Akras et al. 2021)



Playing Hide-and-seek *with* Symbiotic stars from **2019 to 2024**

II) 2 new genuine SySts were found combining photometric data from 2MASS/WISE & GALEX



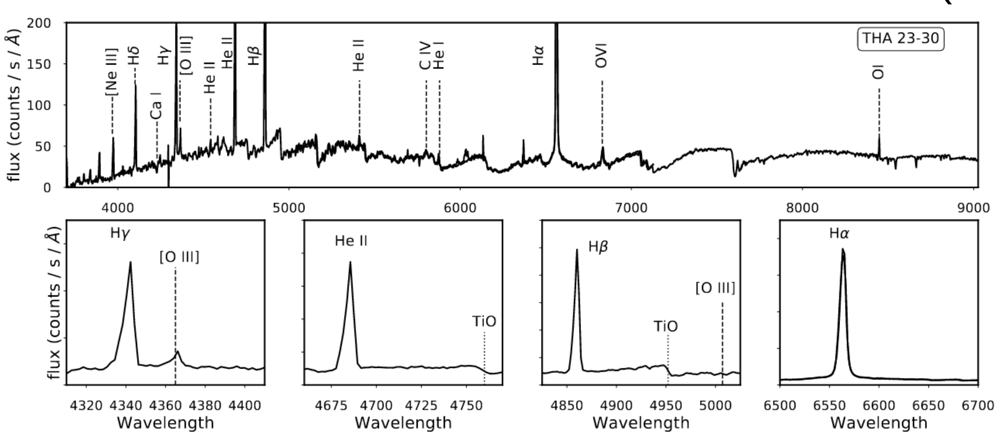


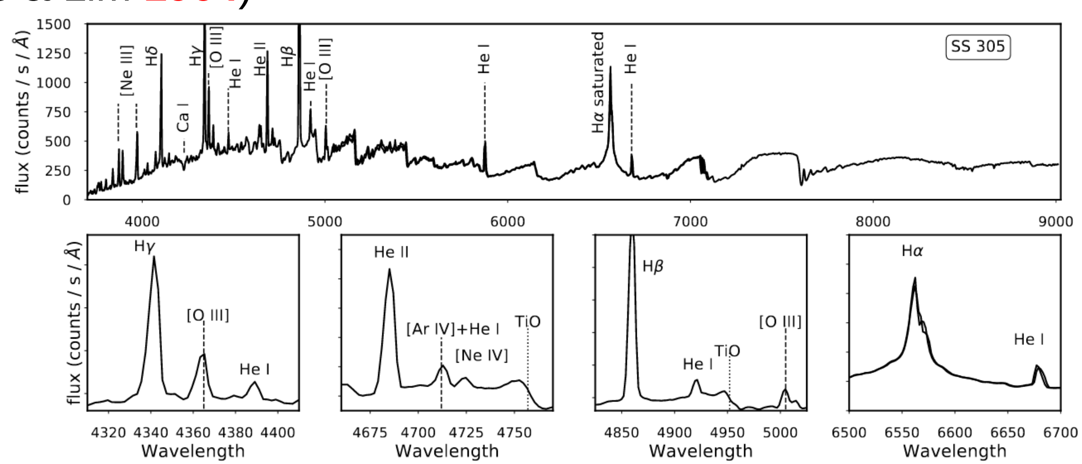
- FUV-NUV<1 selection criteria

- **without any Hα information**
(Akras et al. 2023)

SS 305 was classified as an Hα emitter
(Stephenson & Sanduleak **1977**)

THA 23-30 was classified as an Hα emitter (The & Lim **1964**)





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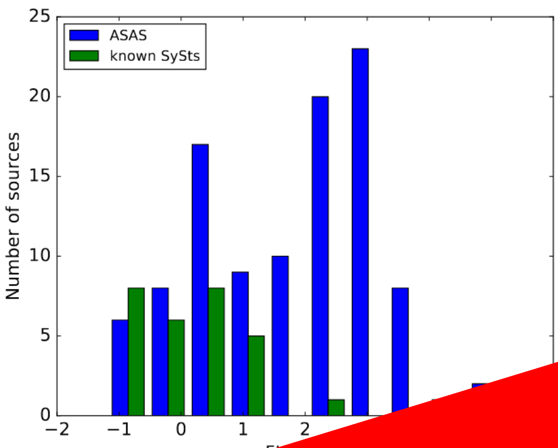
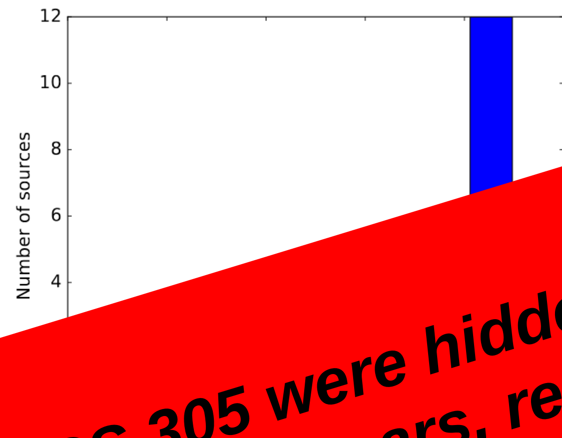




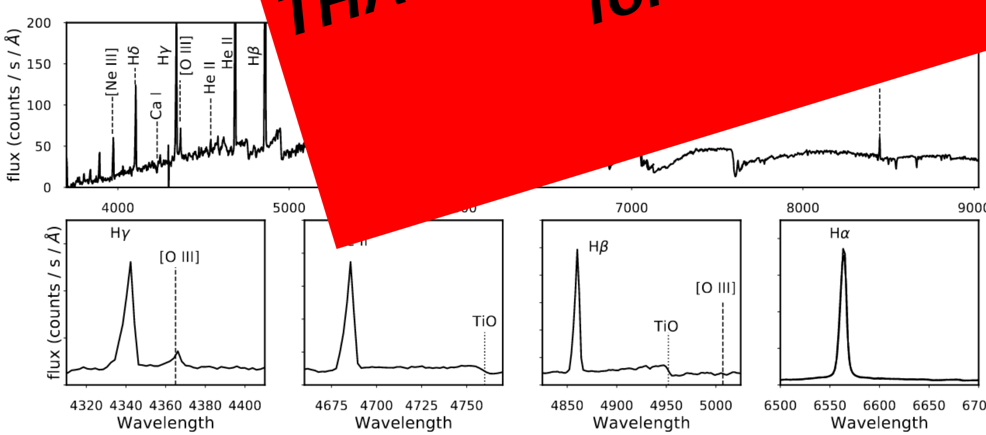
- FUV … on criteria

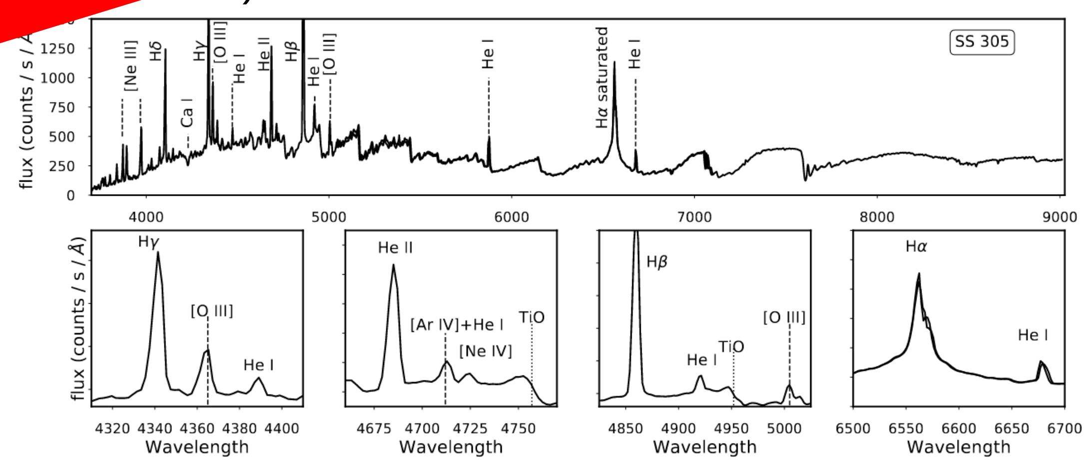
… **rmation** … 2023)

… as classified as an Hα emitter (Stephenson & Sanduleak **1977**)

THA 23-30 and SS 305 were hidden under our noses for 60 and 47 years, respectively

THA 23-30 … **1964**)





Playing Hide-and-seek *with* Symbiotic stars from **2019 to 2024**

Since the publication of the near-infrared selection criteria,
6 new genuine SySts have also been discovered and **all of them** satisfy the criteria.

1) Hen 3-860 (Merc et al. 2021)

2) V2204 Oph (Merc et al. 2021)

3) THA 15-31 (Munari et al. 2022) was classified as an Hα emitter (The & Lim 1964)

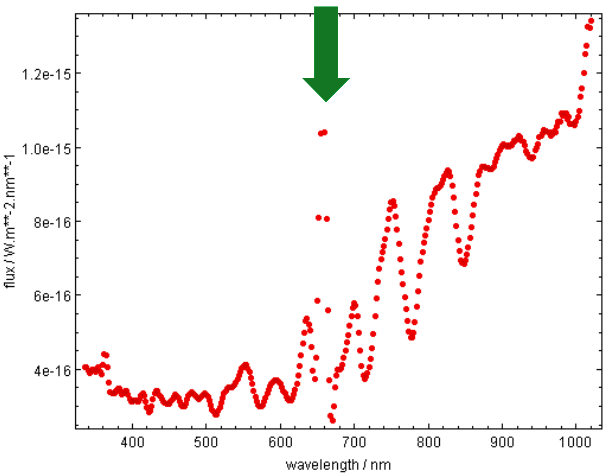
4) Sct 1 (De et al. 2022). D-type SySt with X-ray emission

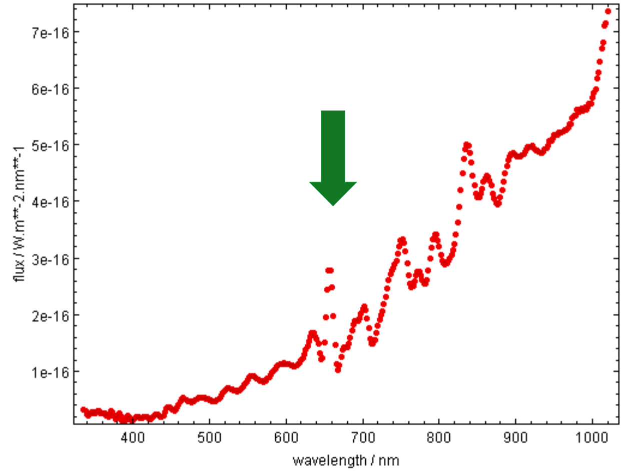
5) V618 Sgr (Merc et al. 2023)

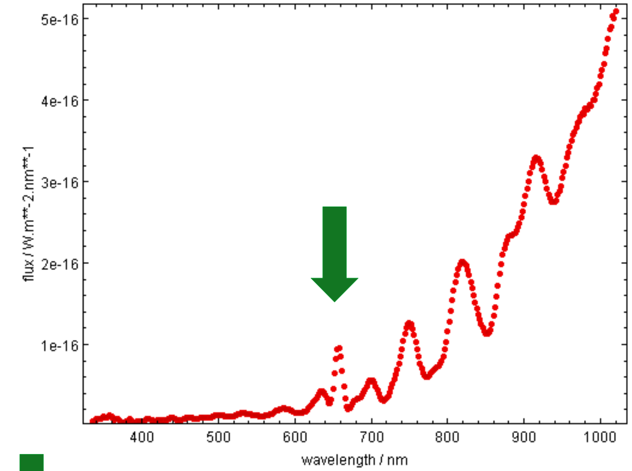
6) DeGaPe 35 (Petit et al. 2023) - Thomas Petit's talk

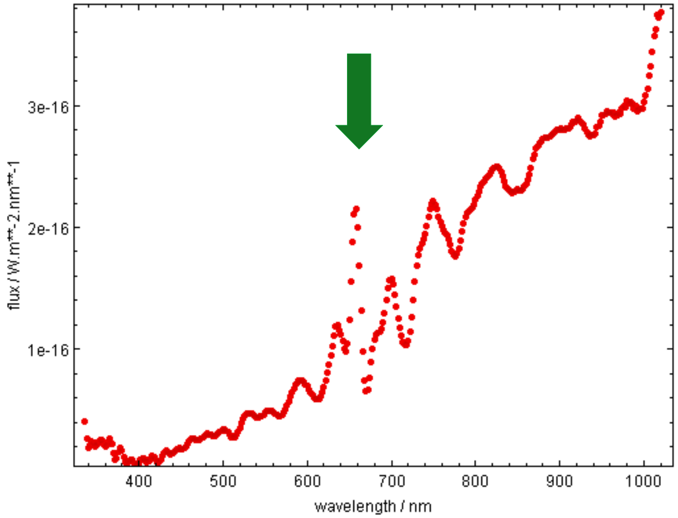
Playing Hide-and-seek *with* Symbiotic stars from **2019 to 2024**

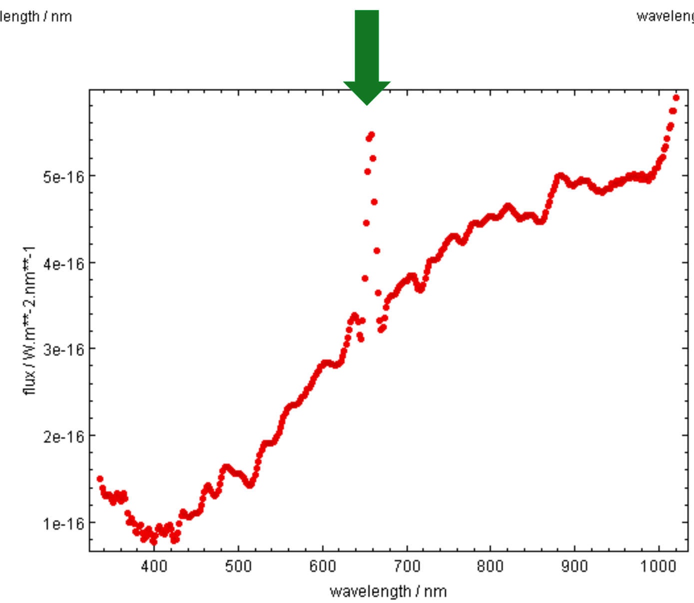
Seeking SySts in GAIA, we have ended up with **5 bonafide genuine SySts (+42 candidates)**. All of them pass the new IR selection criteria





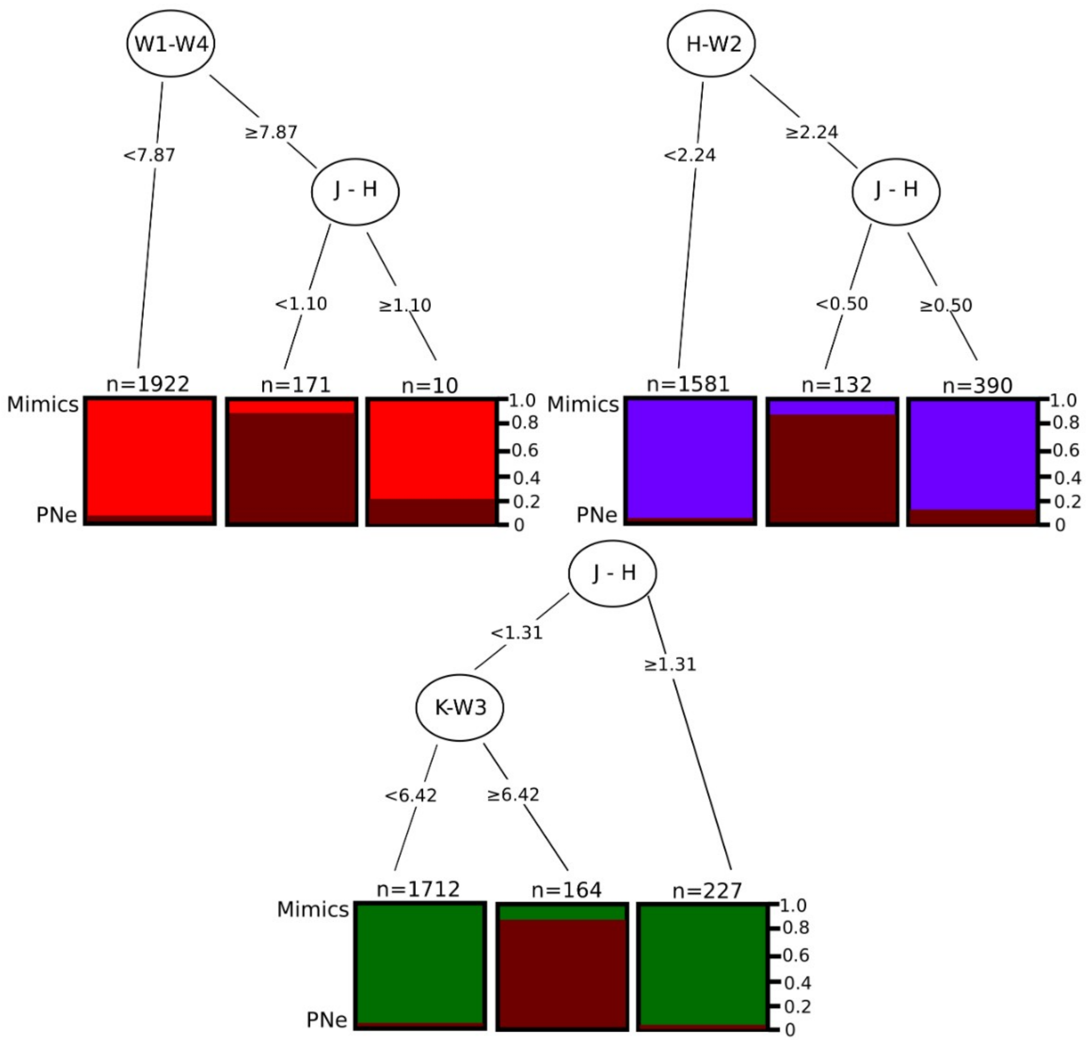






Playing Hide-and-seek *with* **Hα emitters**

ML has also used to seek PNe in publicly available catalogs (Akras et al. 2019c)



Applying the selection criteria to IPHAS and VPHAS+ surveys

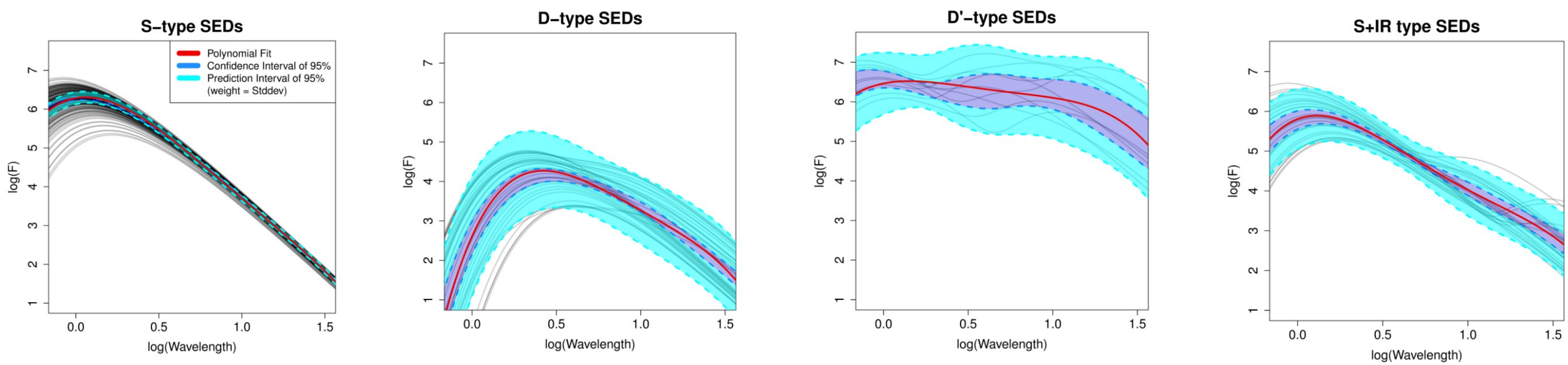
92 known were recovered

2 new PNe + 39 candidates

False positive identification is <15%

Statistical outcomes from my catalog (Akras et al. 2019)

-SEDs peak from 0.85 to 2.5 μm.



- 50-60% of SySts show the Raman OVI line in their spectra

- The majority of S-type are also X-ray emitters. Only α and β-type X-ray SySts (Muerset et al. 1997, Luna et al. 2013) display the Raman line in their spectra

Table 4. Characteristics of Different Types of SySts.

Type	All (#)	%	Known (#)	%	Peak (μm)	$T^{\dagger}_{eff}$ (μm)	T_{dust} (K)	O VI (%)	X-Ray (#)
S	263	64	238	74	0.83-1.7	3000-4000	–	61	33
S+IR	37	9	26	8	0.88-1.7	3000-3900	150-500	39	3
D	60	15	42	13	2.1-4.1	–	200-400/700-1350	55	8
D′	31	7.5	11	3.5	"flat"	3500-4400	150-350/550-1000	50	–
No type	19	4.5	6	1.5	–	–	–	–	2

Statistical outcomes from my catalog (Akras et al. 2019)

-He II λ4686/Hβ three time large in SySts with the Raman OVI line detected

Table 3. Emission-line ratios of SySts†

Galaxy	O VI λ6830/H α	He II λ4686/H β		He I λ5875/H β		He II λ4686/[O III] λ5007	
		O VI (✓)	O VI (✗)	O VI (✓)	O VI (✗)	O VI (✓)	O VI (✗)
All	0.06 (0.04)	0.66 (0.26)	0.22 (0.15)	0.43 (0.33)	0.38 (0.23)	1.45 (1.49)	1.21 (1.74)
Milky Way	0.06 (0.04)	0.65 (0.26)	0.21 (0.16)	0.46 (0.34)	0.40 (0.25)	1.15 (1.24)	1.42 (1.93)
M31	0.05 (0.03)	0.68 (0.27)	0.25 (0.10)	0.26 (0.22)	0.34 (0.15)	1.47 (1.40)	0.69 (0.83)
M33	0.04 (0.04)	0.81 (0.16)	0.24 (0.08)	0.35 (0.15)	0.27 (0.22)	3.78 (1.12)	0.73 (0.83)

† The number in parentheses corresponds to the standard deviations

Therefore, for the identification of the emission line center at 6830, as the Raman-scattered OVI line,

It is required the detection of the He II 4684A line too.

Take aways

- SySts were/are very good players in hide-and-seek but we are getting better and better because of the multi-wavelength studies and ML approaches
- 13 new genuine SySts have been discovered since 2020 (in 4 years).
- 2MASS and WISE data provide important information for identifying SySts
- GALEX also provides useful information for the hot companion (FUV-NUV)
- 50-60% of SySts show the Raman scattered-line OVI λ6830.
- He II λ4686/Hβ is three time large in SySts with the OVI line detected and the presence of strong He II λ4686 line supports the identification of the Raman line

Ευχαριστώ