

New UX Ori type candidates detected using Gaia DR2 and Machine Learning

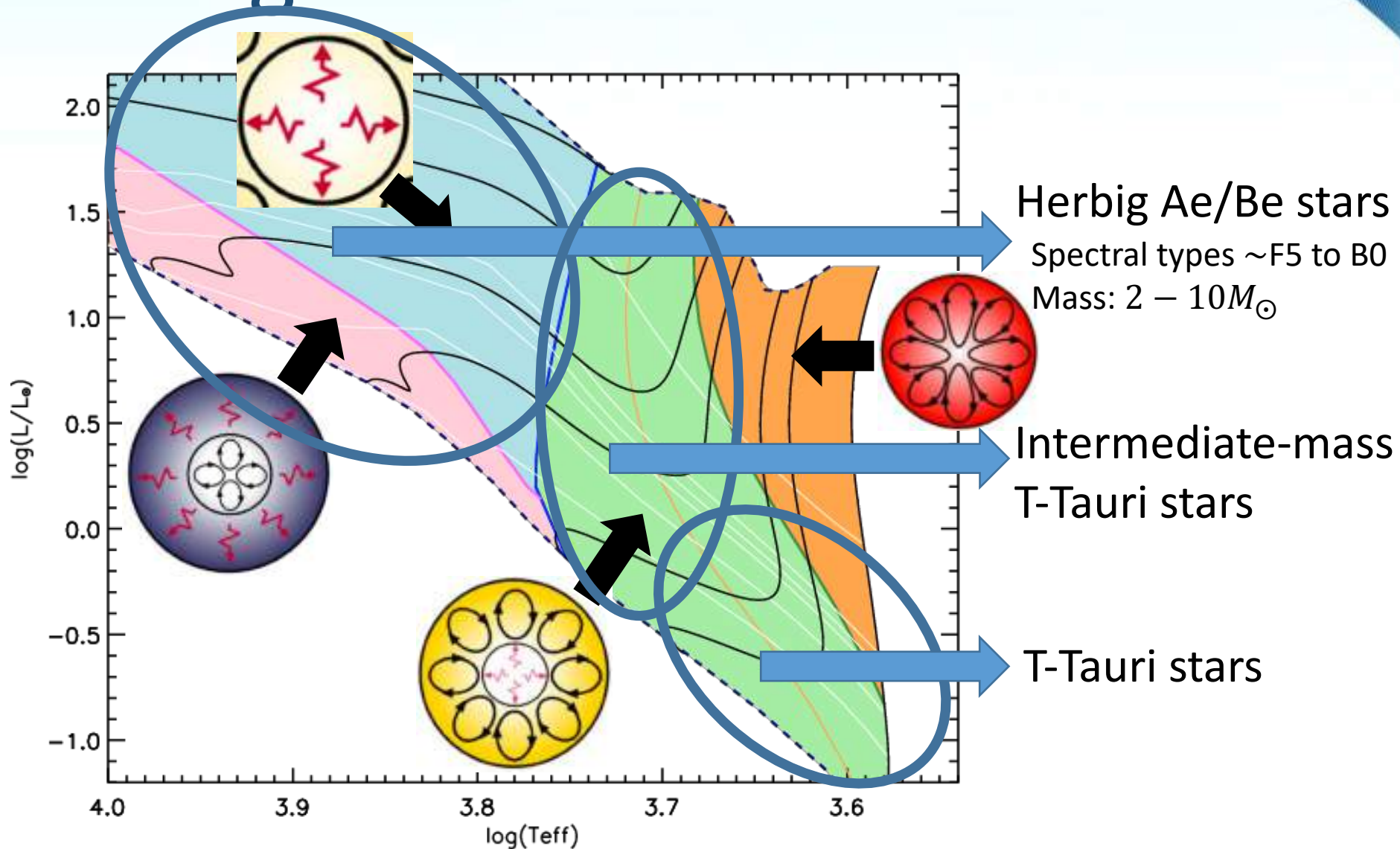


Miguel Vioque
University of Leeds

R. D. Oudmaijer (University of Leeds, UK), M. Schreiner (Desupervised, Denmark), D. Baines (ESAC, Spain), and R. Pérez-Martínez (Isdefe, Spain)

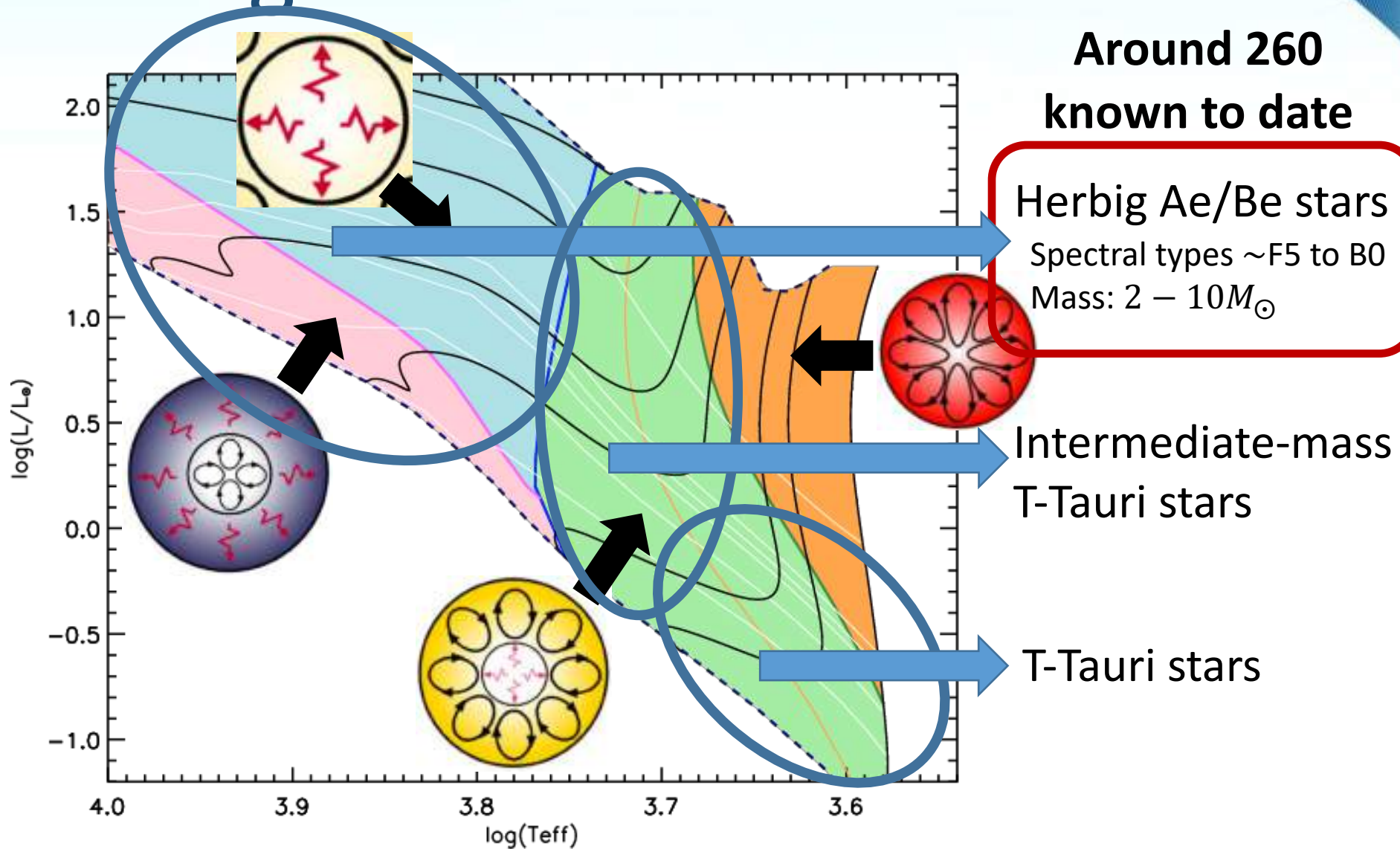


High-Mass Star Formation



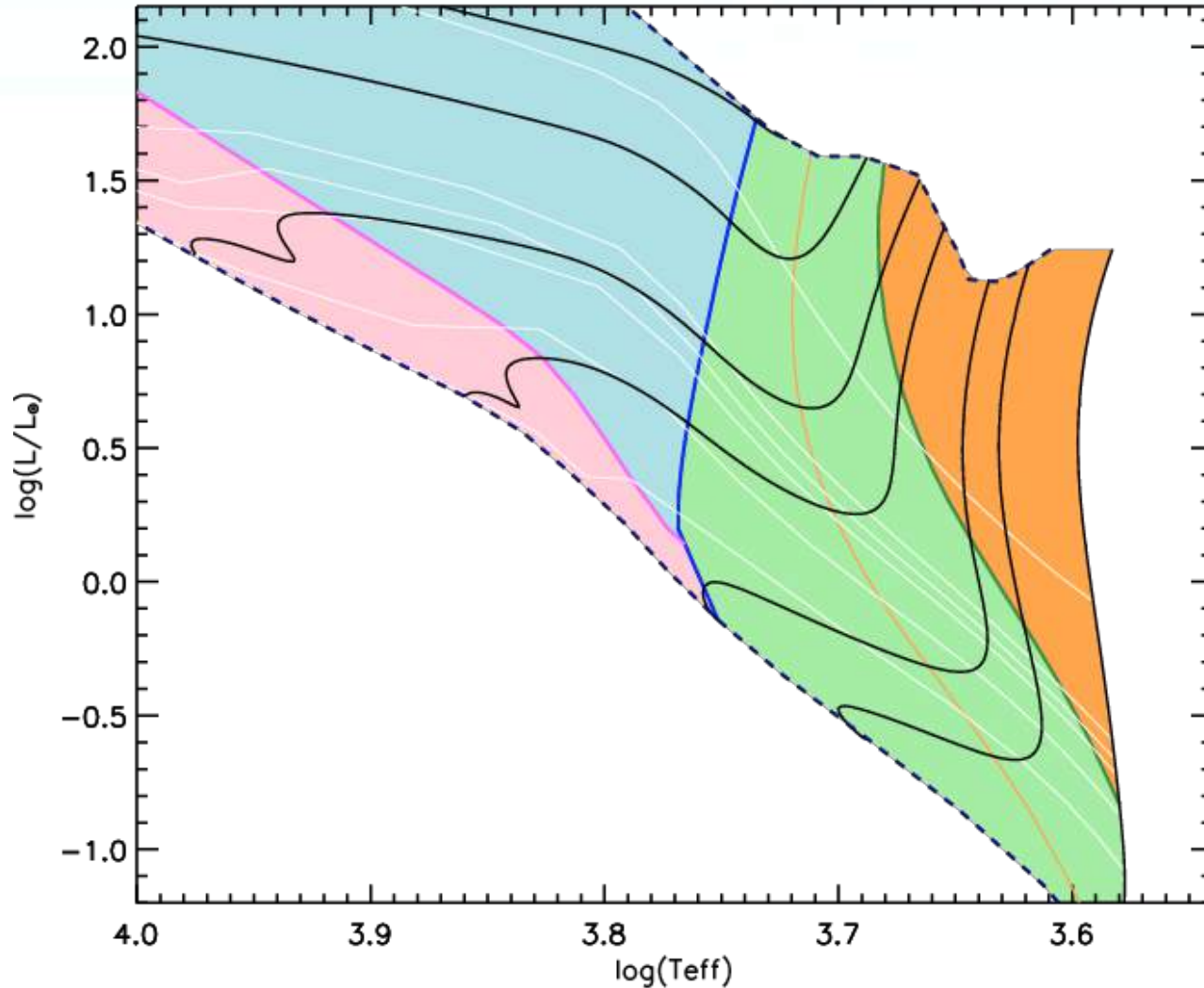
Alecian, *et al.* (2013), Villebrun, *et al.* (2019)

High-Mass Star Formation



Alecian, *et al.* (2013), Villebrun, *et al.* (2019)

High-Mass Star Formation

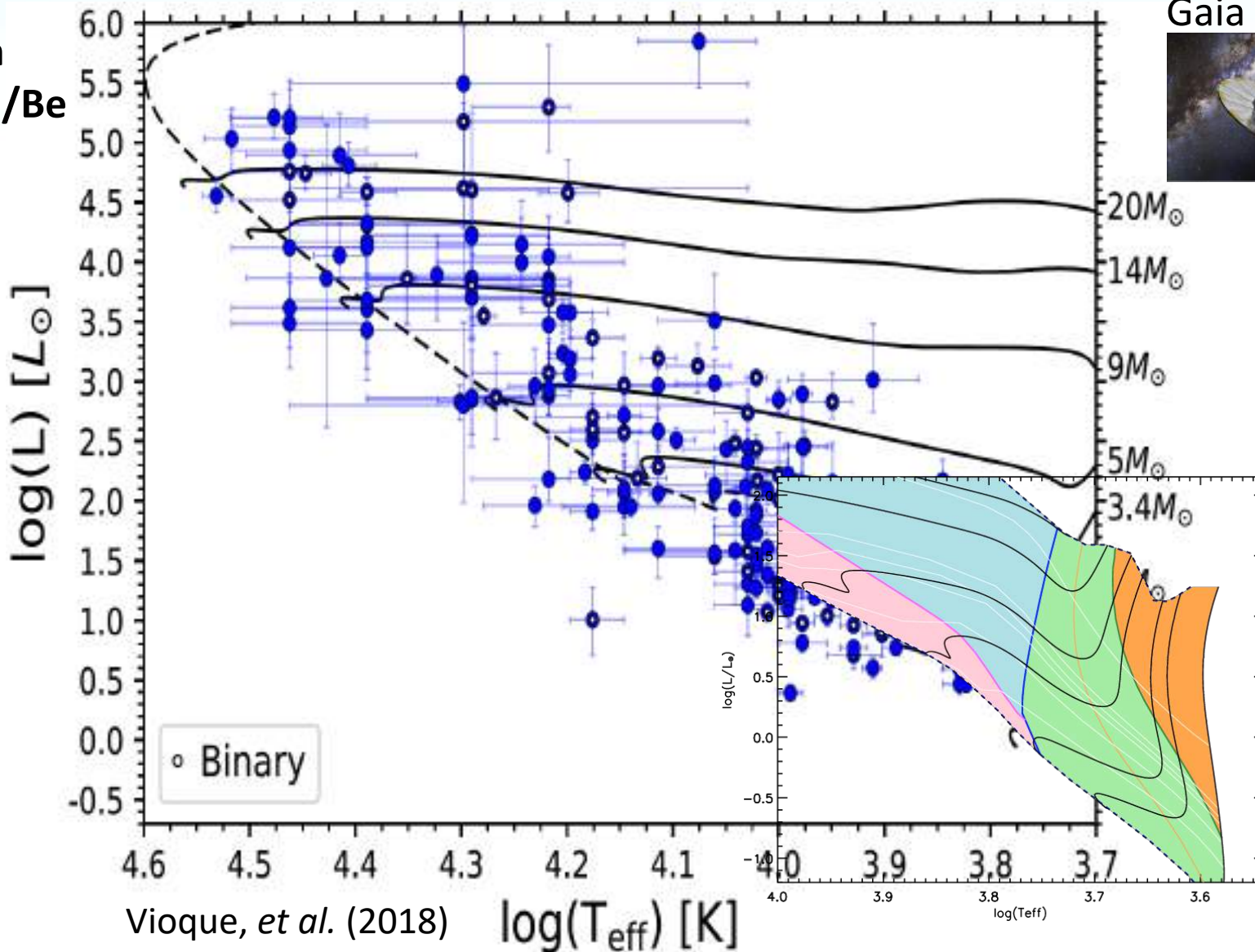


High-Mass Star Formation

Gaia DR2



All known
Herbig Ae/Be
stars

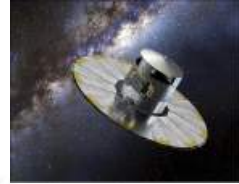


Vioque, *et al.* (2018)

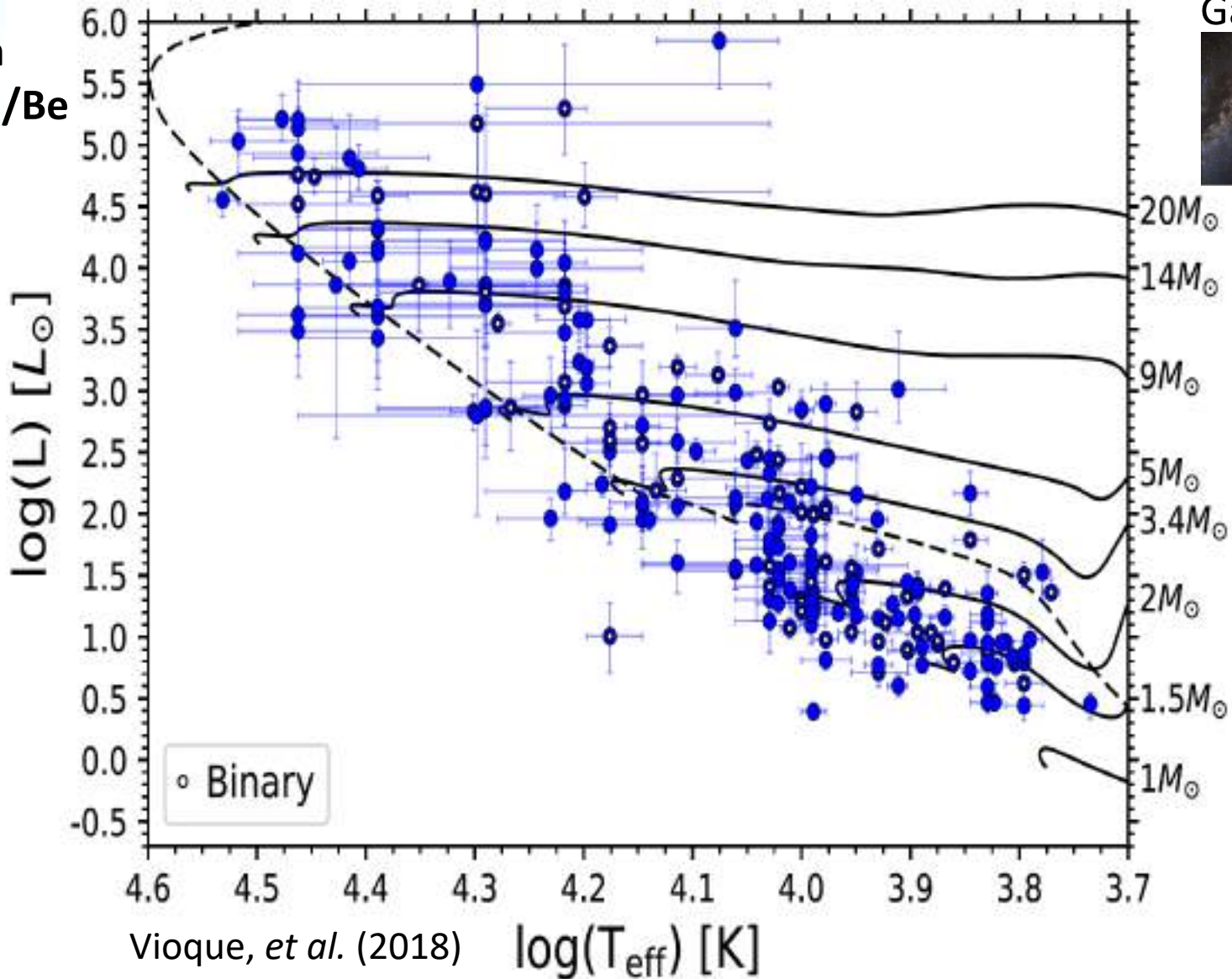
$\log(T_{\text{eff}}) [K]$

High-Mass Star Formation

Gaia DR2



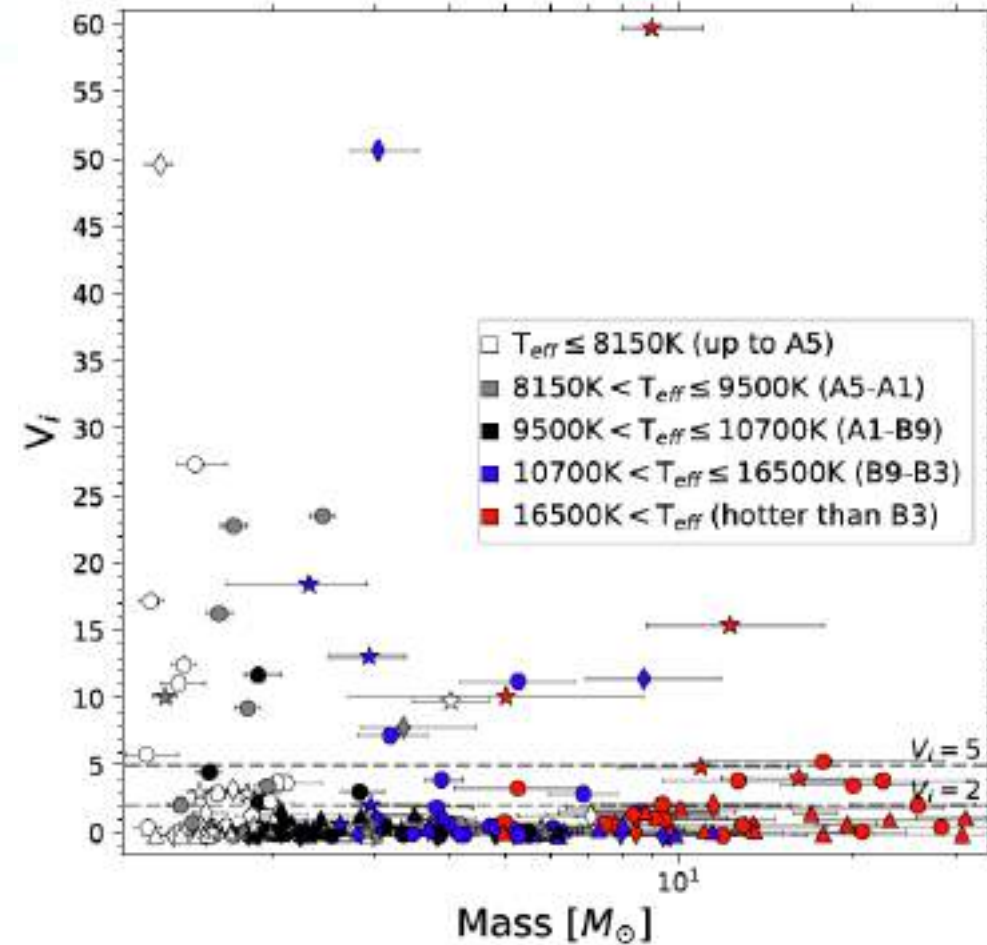
All known
Herbig Ae/Be
stars



Gaia variability

$$V_i \sim \frac{\sigma(F_G) \sqrt{N_{obs}}}{F_G}$$

Deason et al. 2017

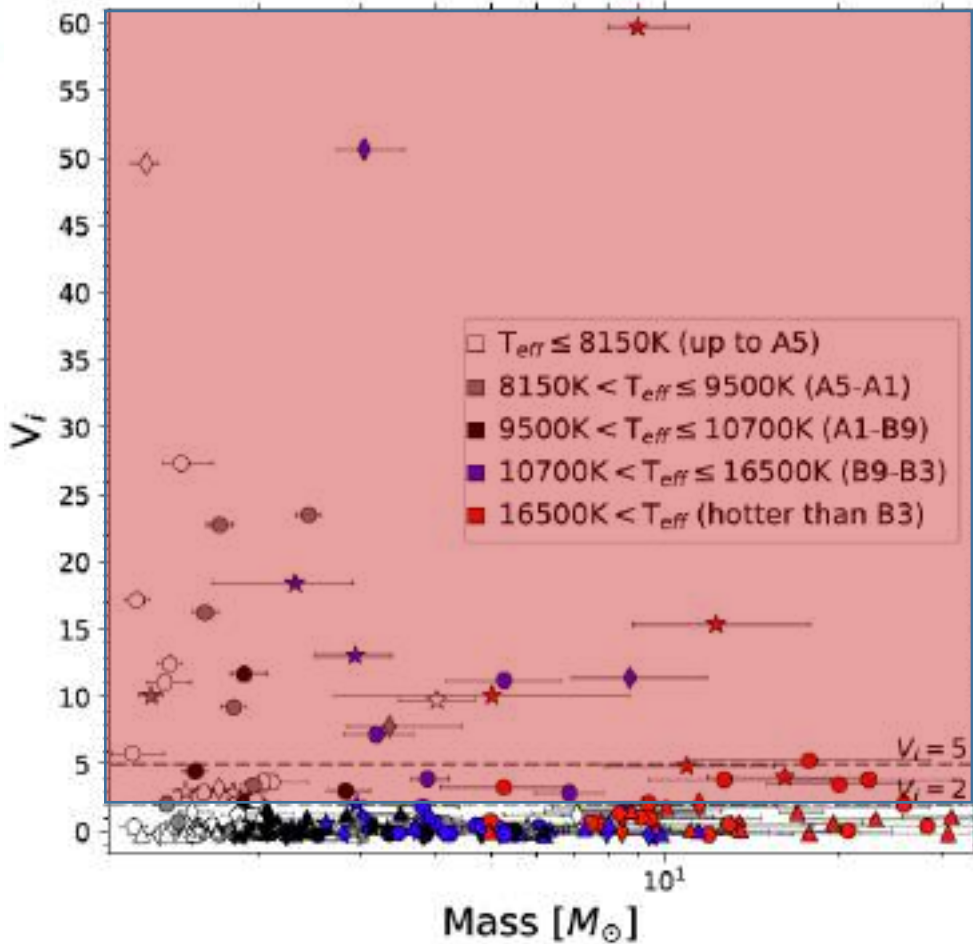


Vioque et al. 2018

Gaia variability

$$V_i \sim \frac{\sigma(F_G) \sqrt{N_{obs}}}{F_G}$$

Deason et al. 2017



Vioque et al. 2018

$V_i > 2$

**All known
UXORs in the
sample (17)**

With variabilities larger than 0.5mag ...

Gaia variability

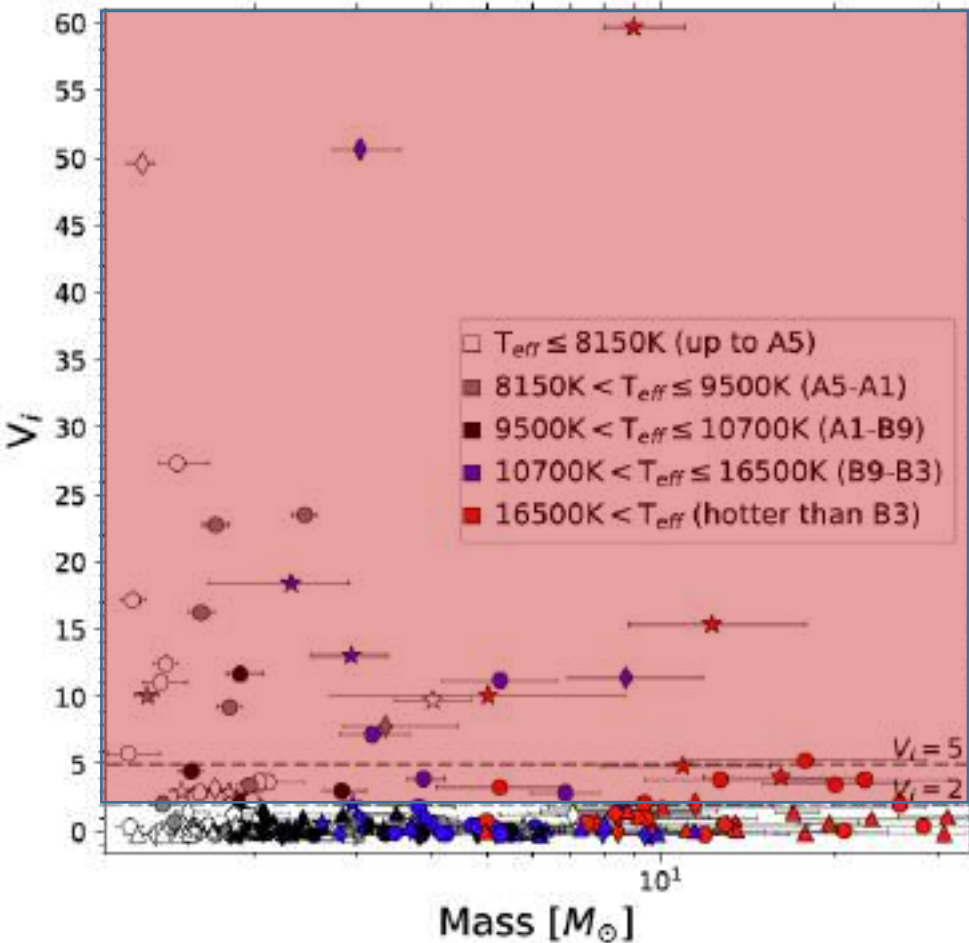
$$V_i \sim \frac{\sigma(F_G) \sqrt{N_{obs}}}{F_G}$$

Deason et al. 2017

Proposed 31
new UX Ori
candidates

All known
UXORs in the
sample (17)

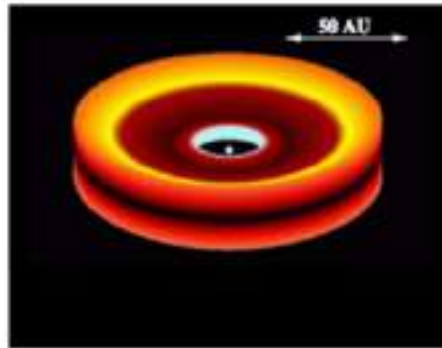
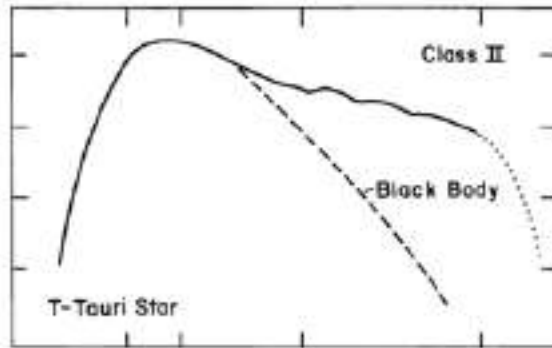
$$V_i > 2$$



Vioque et al. 2018

With variabilities larger than 0.5mag ...

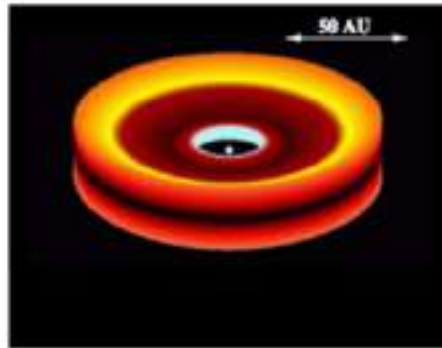
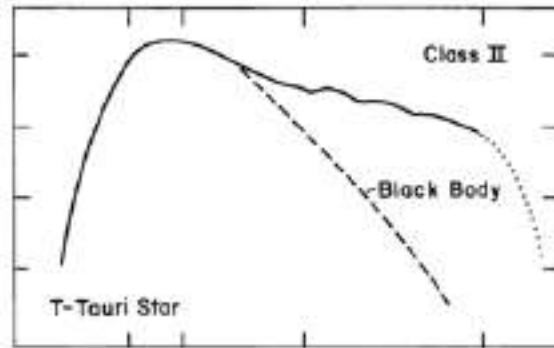
Looking for new **Pre-Main Sequence (PMS)** objects in Gaia!



Main characteristics of PMS objects:

- Infrared excesses
- $H\alpha$ emission
- Photometric variability

Looking for new **Pre-Main Sequence (PMS) objects** in Gaia!

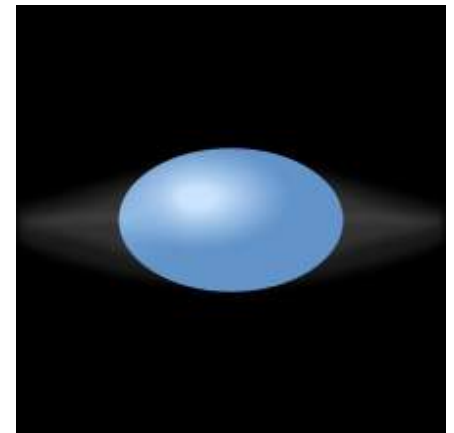


Main characteristics of PMS objects:

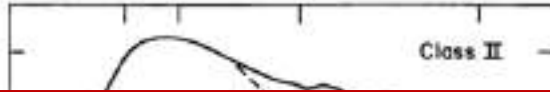
- Infrared excesses
- $H\alpha$ emission
- Photometric variability

High mass PMS objects (Herbig Be stars) are very similar to **Classical Be stars**

... and supergiants, B[e] stars, ...



Looking for new **Pre-Main Sequence (PMS)** objects in Gaia!



**Perform an homogeneous
selection, distance and
position independent!**

High mass PMS objects (Herbig Be stars) are
very similar to **Classical Be stars**

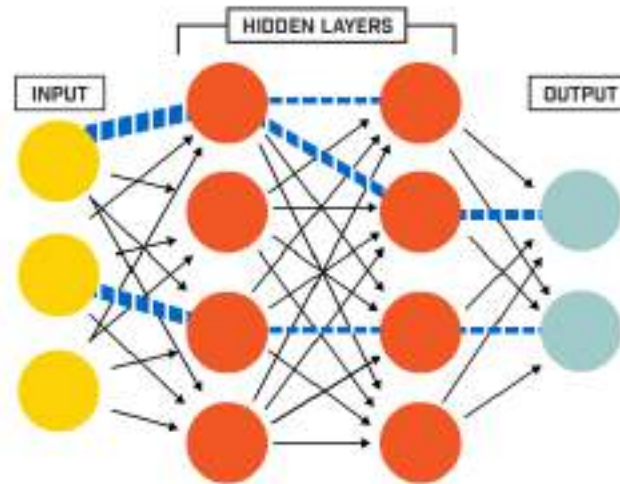
... and supergiants, B[e] stars, ...

Neural Network

Algorithm is trained with known labeled data

Before training:

- Training Set
- Set of characteristics
- Set of categories



After generalizing:

- Each category gets a probability
- Efficiency of the algorithm

The best architecture is selected

Neural Network

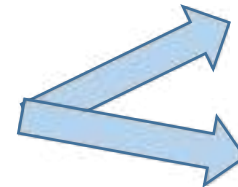
Selection of the **characteristics**:

AllWISE (WISE+2MASS)



$W1, W2, W3, W4$

J, H, K_s



IPHAS



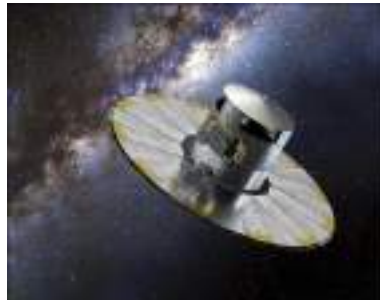
VPHAS+



$r - H_\alpha$

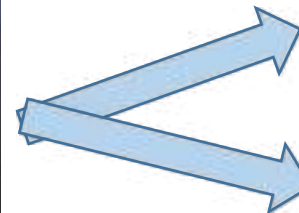


Gaia



2 variability indicators

B_p, G, R_p



- Infrared excesses

- $H\alpha$ emission

- Photometric variability

Create all possible colours

Distance independent!

Selectio

AllWISE (WISE+2MASS)



$W1, W2, W3, W4$

J, H, K_s

- Infrared excesses

IPHAS

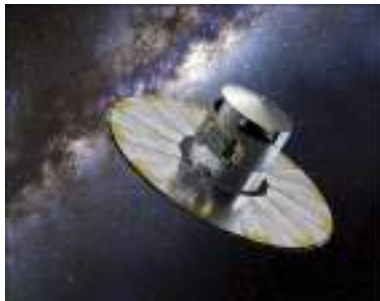
VPHAS+



$r - H_\alpha$

- $H\alpha$ emission

Gaia



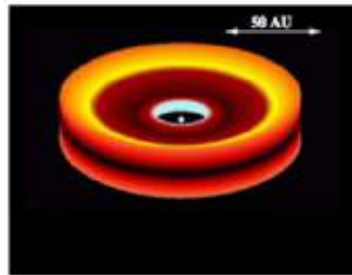
2 variability indicators

B_p, G, R_p

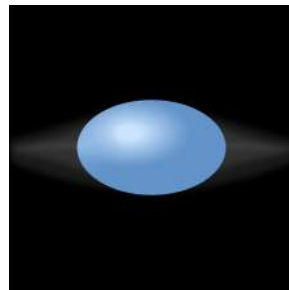
- Photometric variability

Selection of the **categories**:

PMS category



Classical Be
category



Other sources



Selection of the **Training Set**:

AllWISE



+

IPHAS

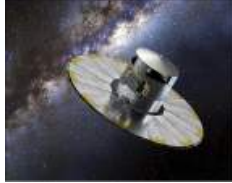


VPHAS+



+

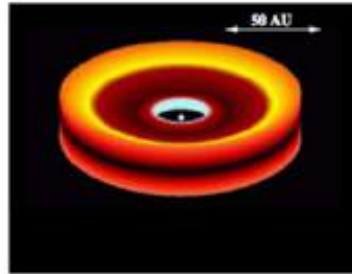
Gaia



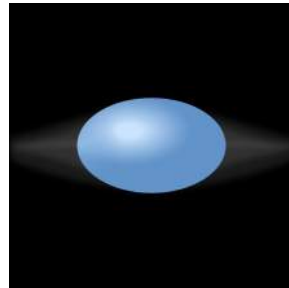
=

4,151,538
sources

PMS category



Classical Be
category




Other sources

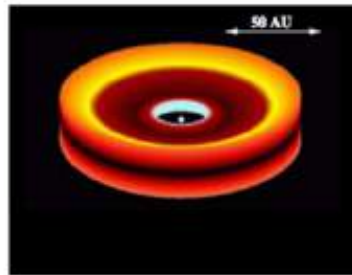


Selection of the **Training Set**:

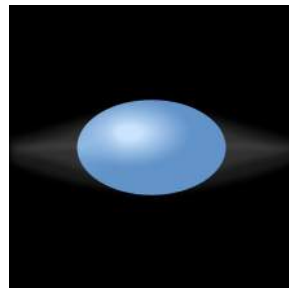
AllWISE + IPHAS + VPHAS+ + Gaia = **4,151,538 sources**



PMS category



Classical Be category



Other sources



- **848** Pre-Main Sequence objects (**163** Herbig Ae/Be)
- **775** Classical Be stars
- **471,111** random sources



Training the Neural Network



Trained Neural Network



AllWISE



+

IPHAS



VPHAS+



+

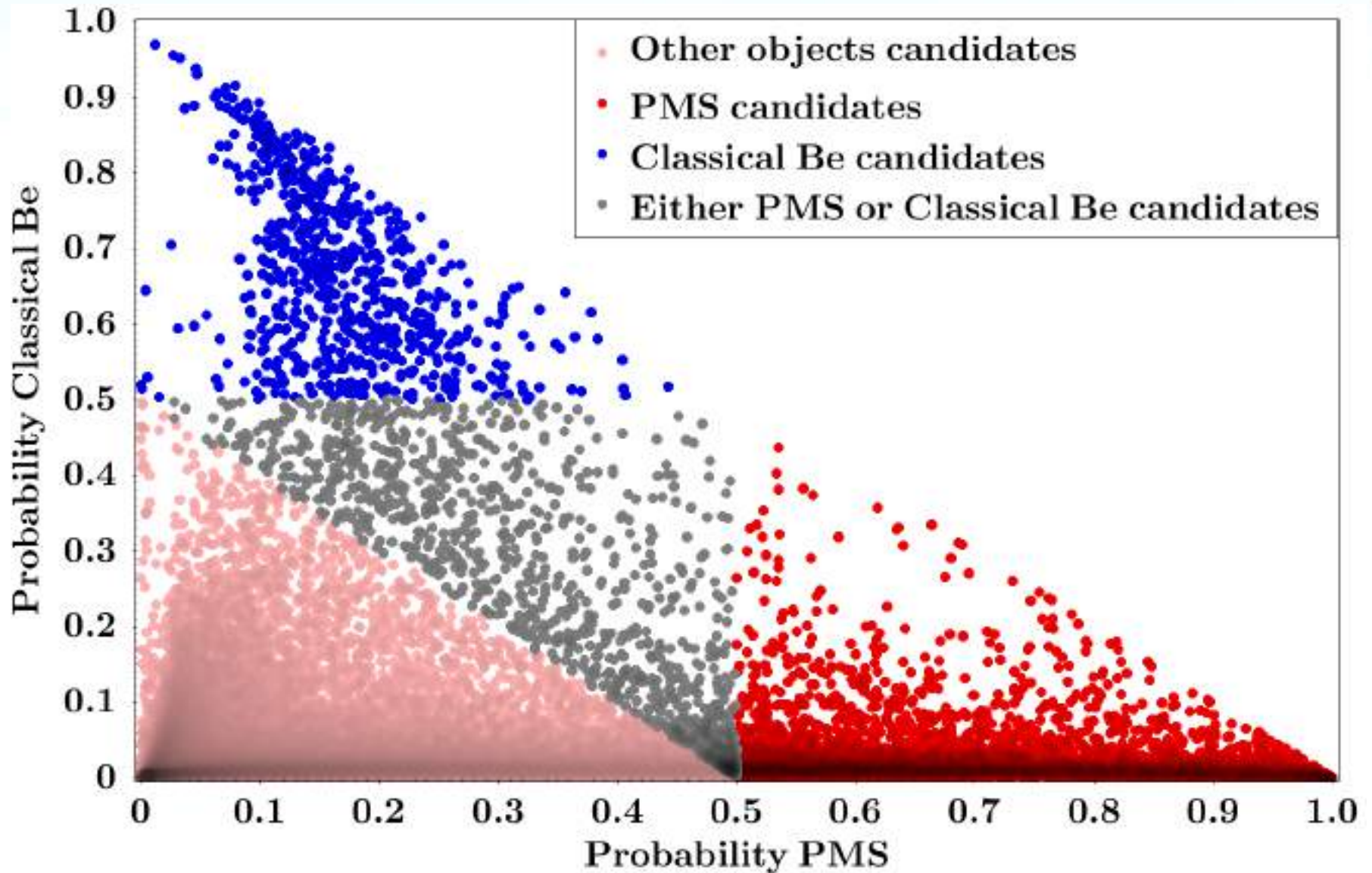
Gaia



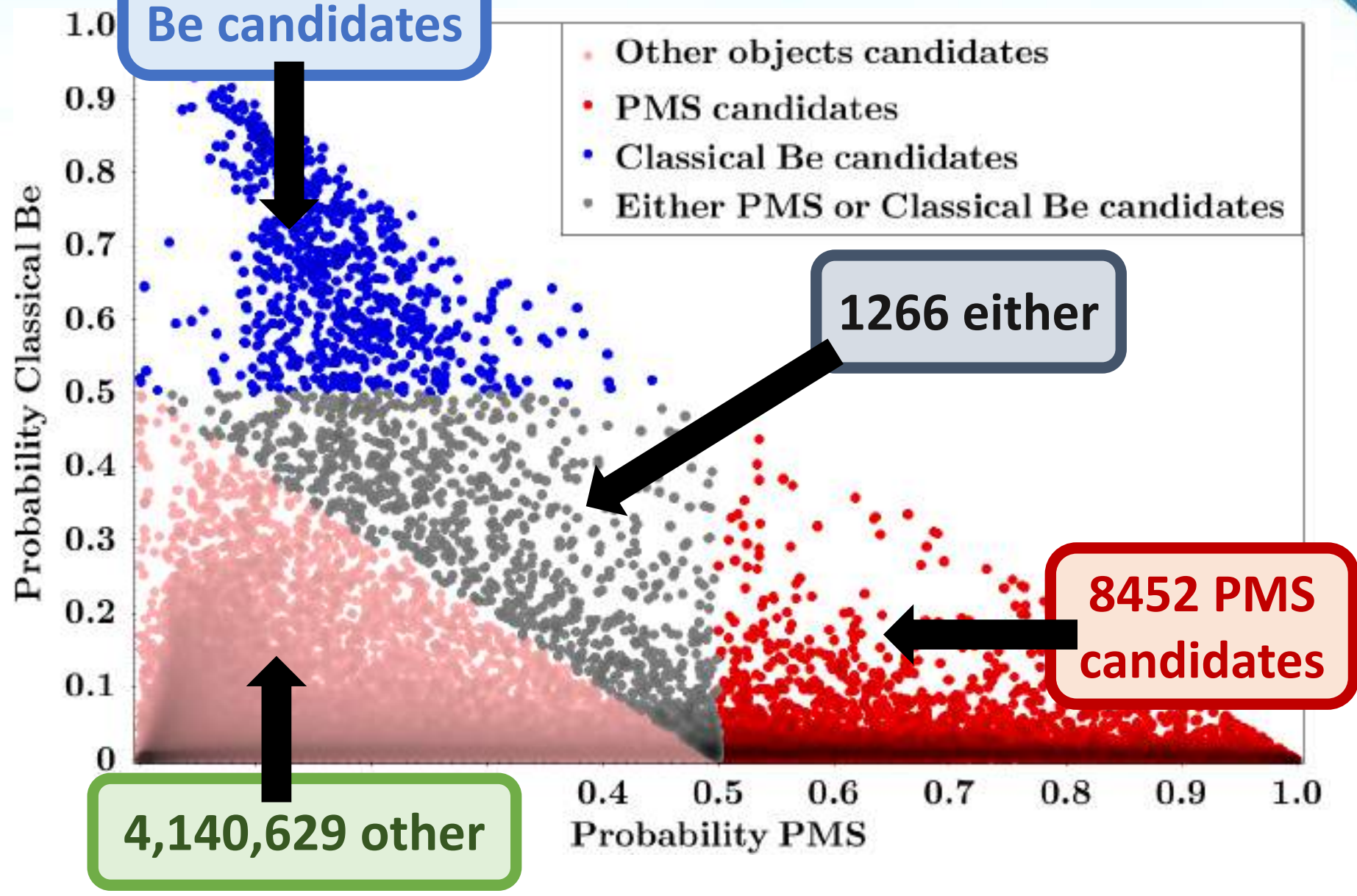
=

4,151,538
sources

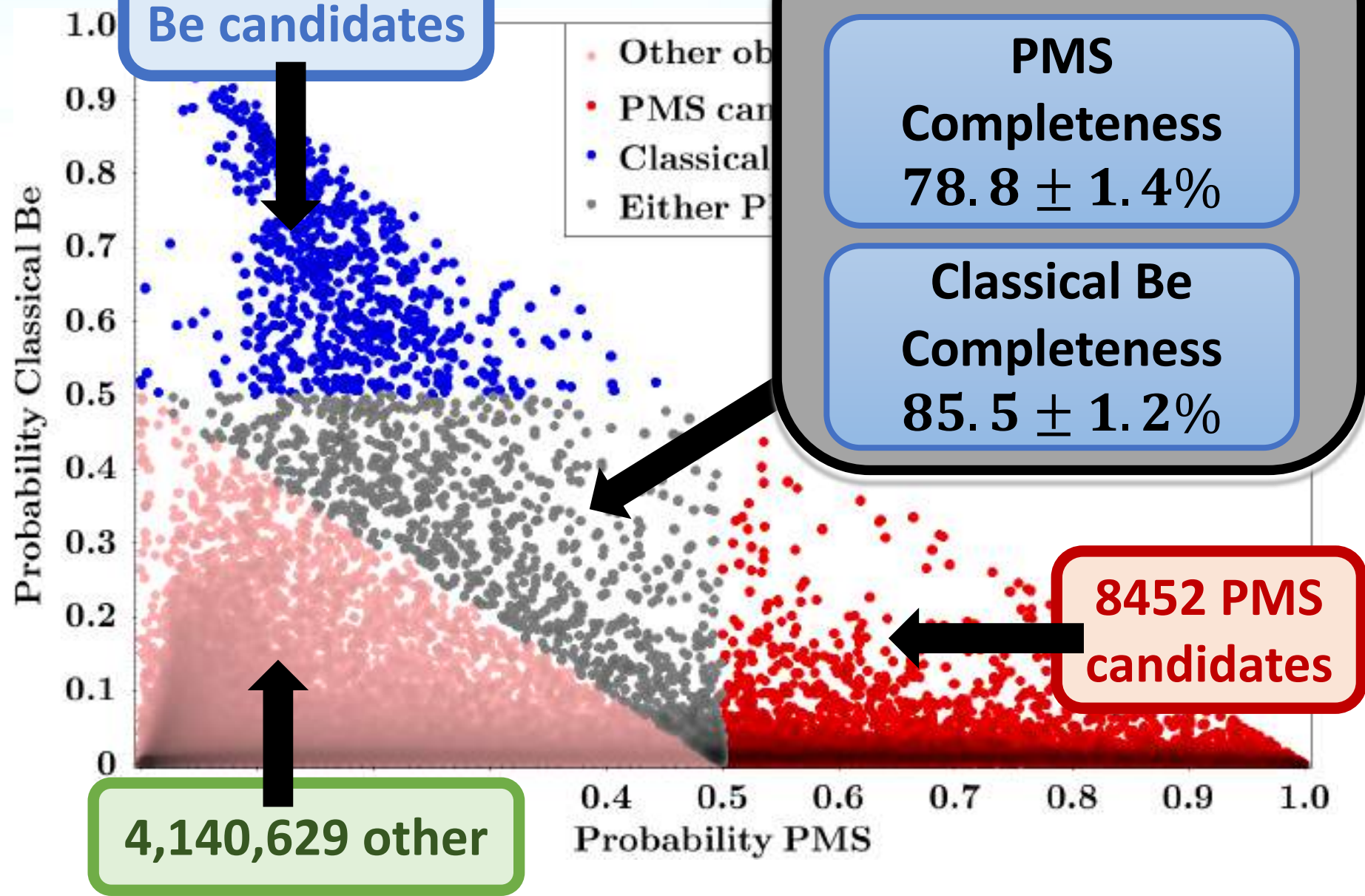
Probability Map



Probability Map



Probability



636 Classical Be candidates

Evaluation on Test Set

PMS

Completeness
 $78.8 \pm 1.4\%$

Classical Be

Completeness
 $85.5 \pm 1.2\%$

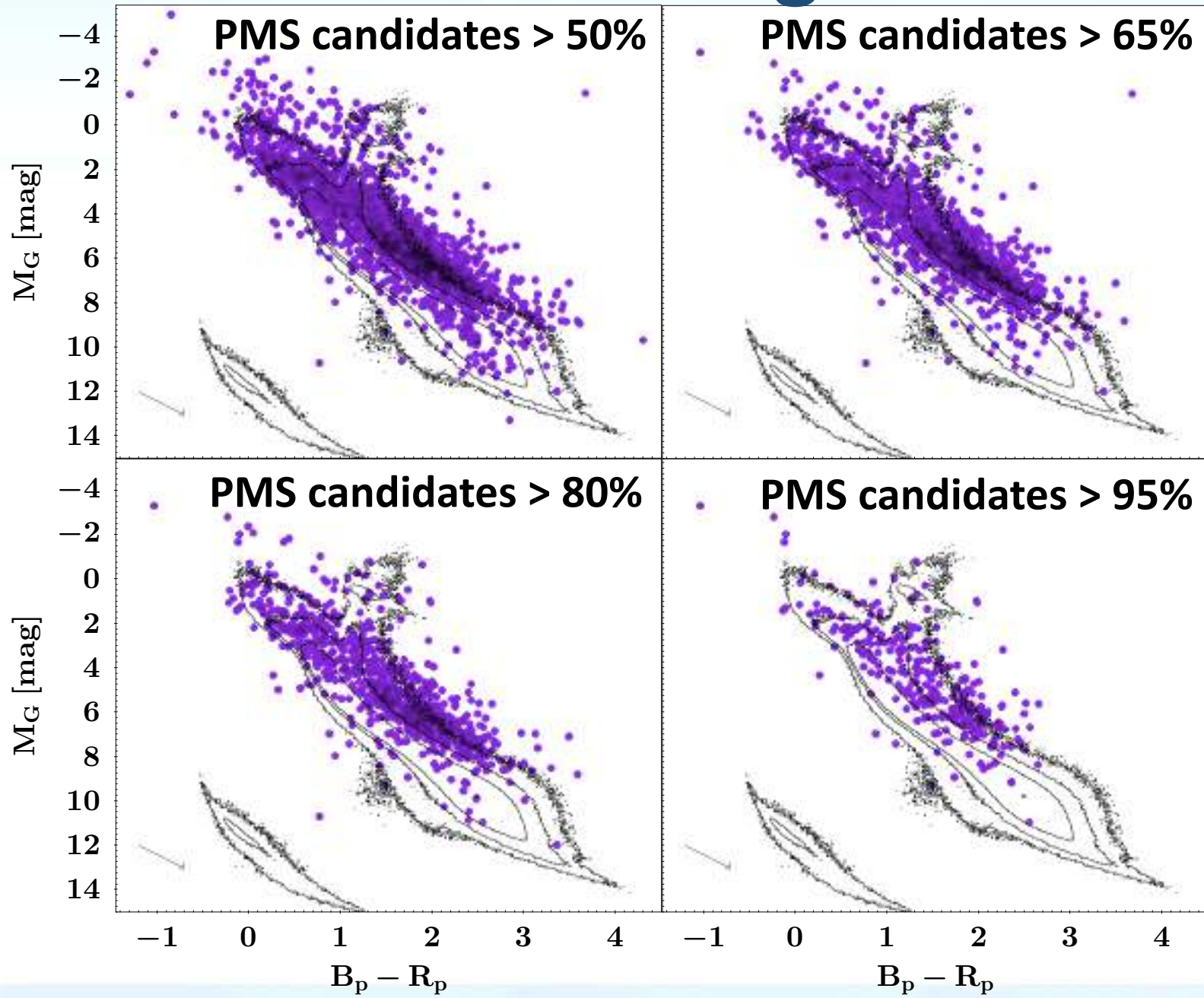
8452 PMS candidates

4,140,629 other

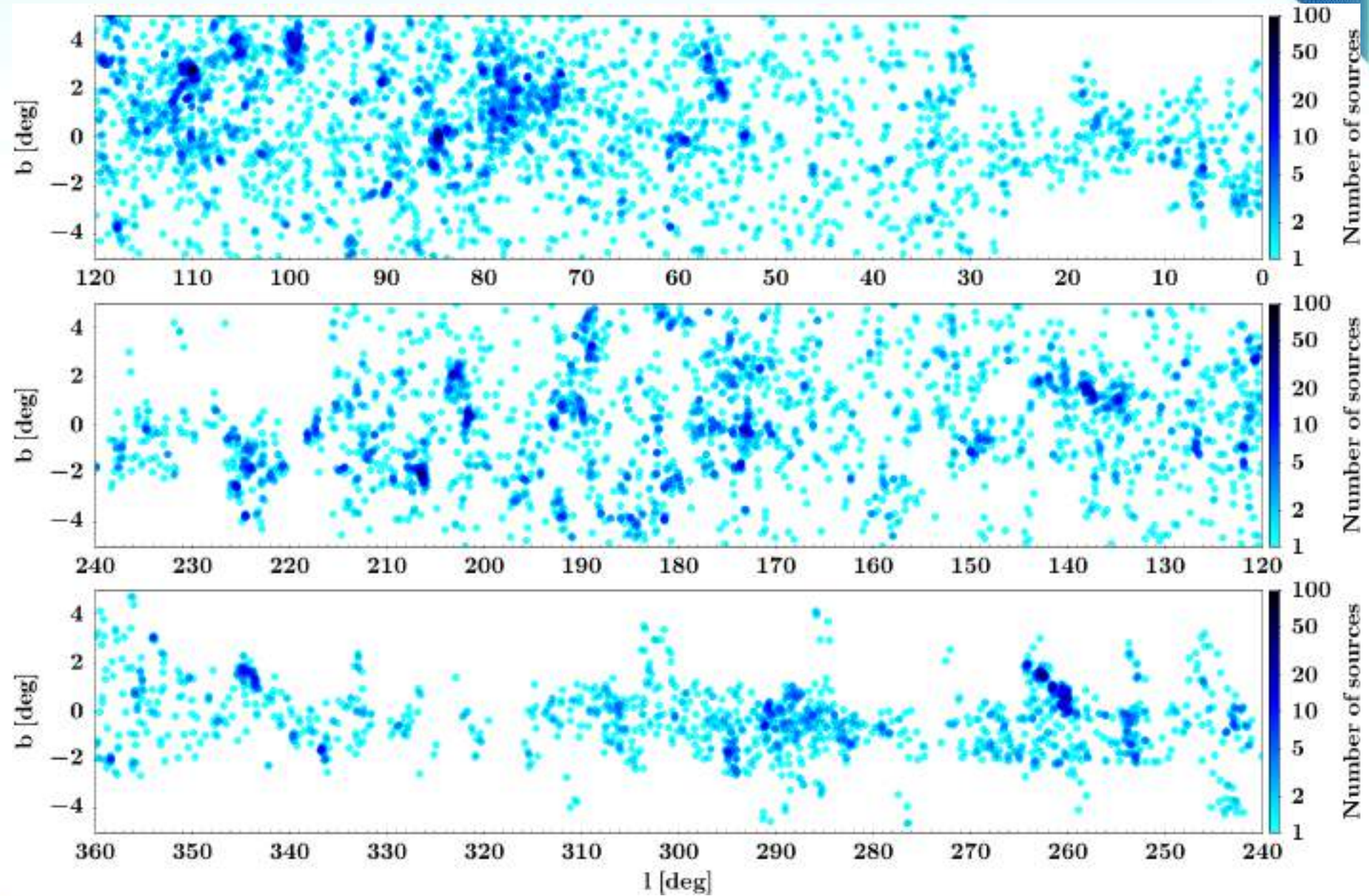
- Other ob...
- PMS can...
- Classical
- Either P...

Probability PMS

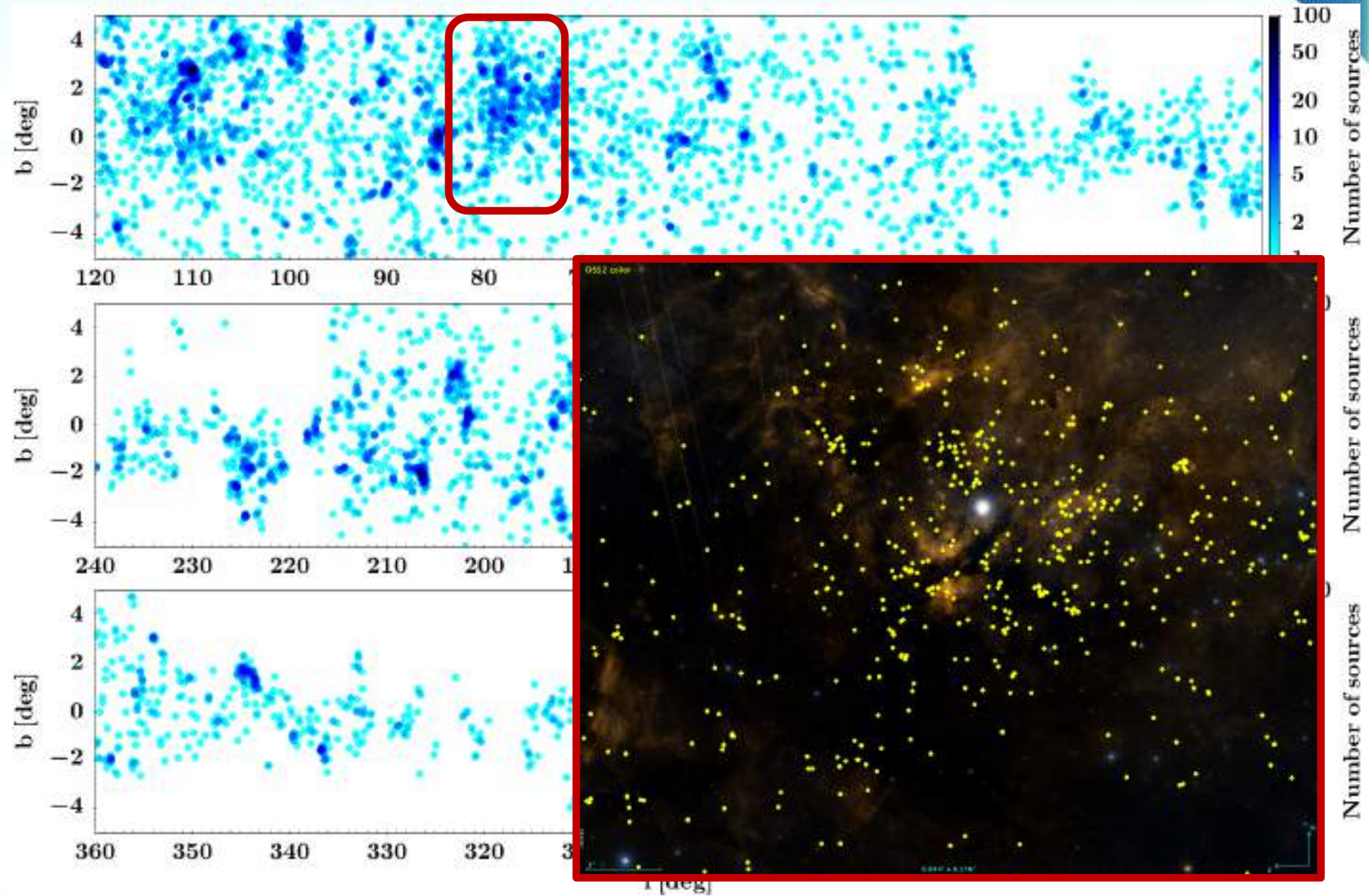
Gaia HR diagram



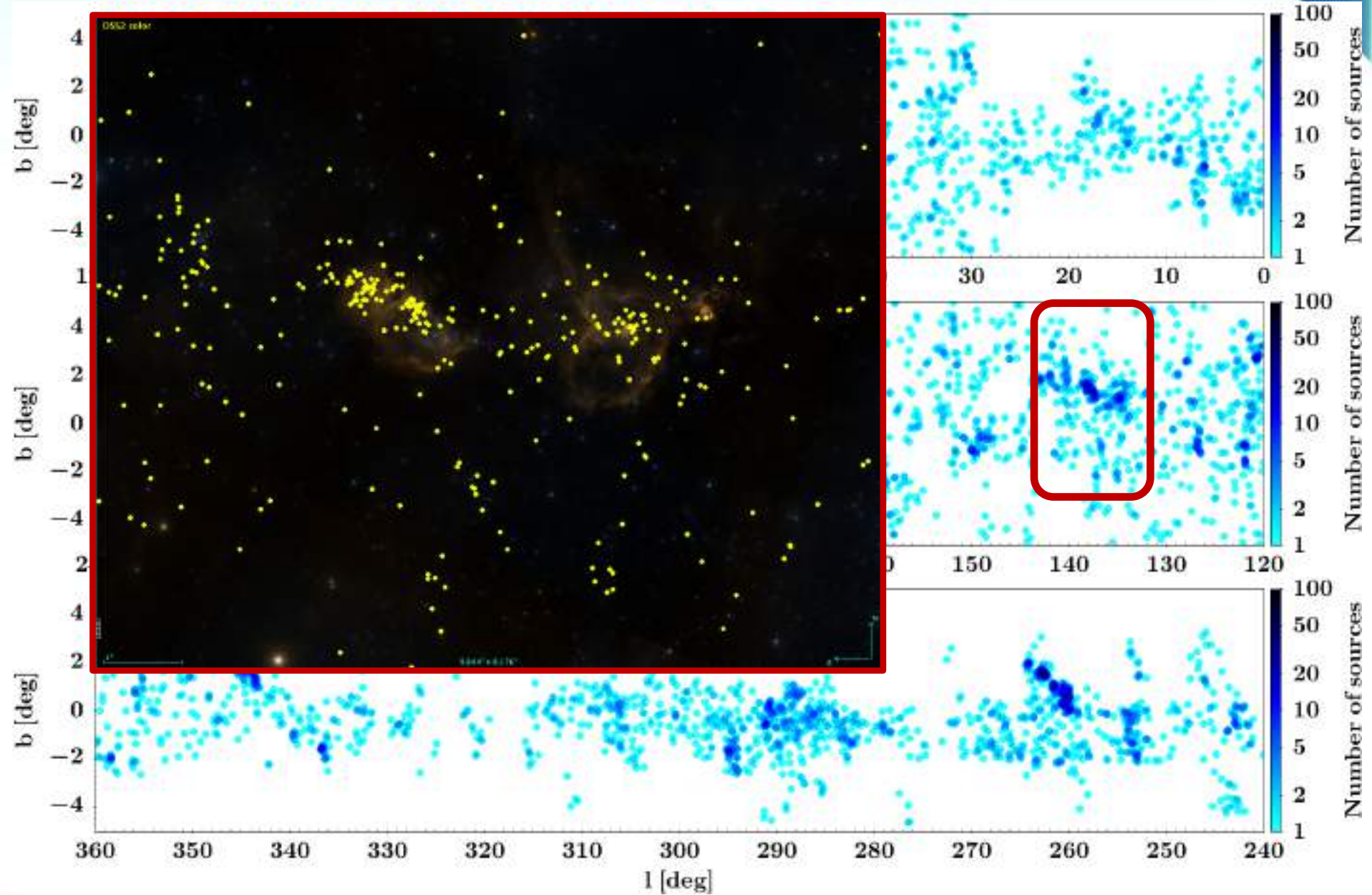
Coordinates



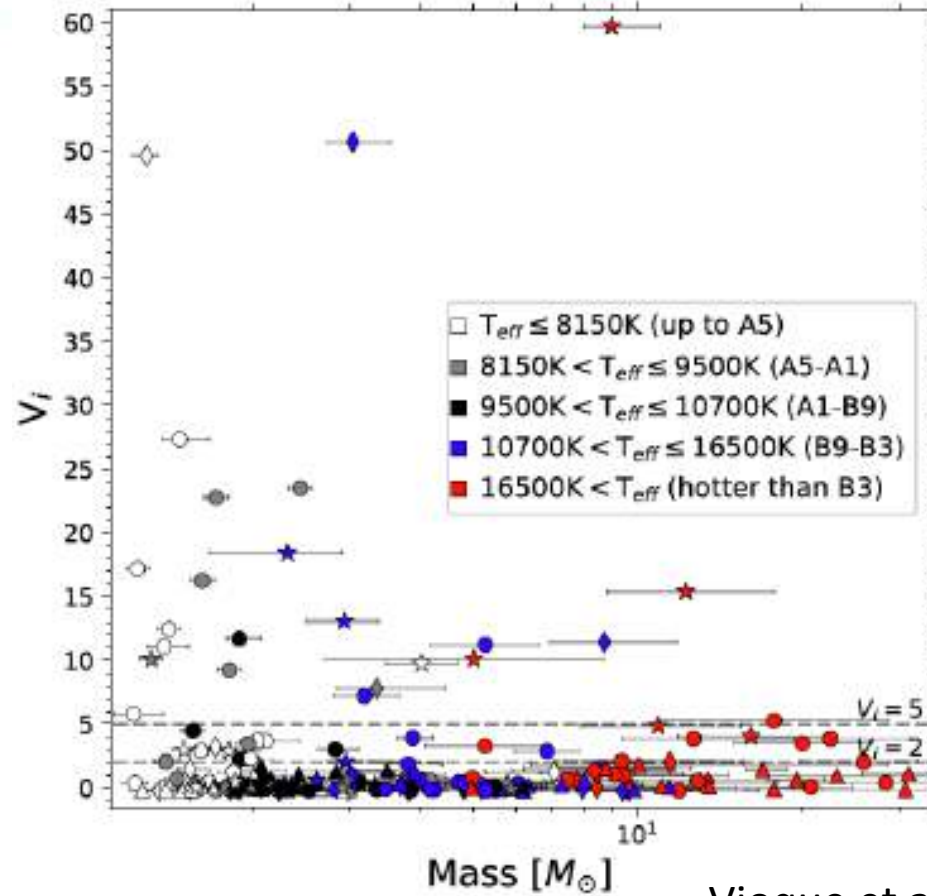
Coordinates



Coordinates

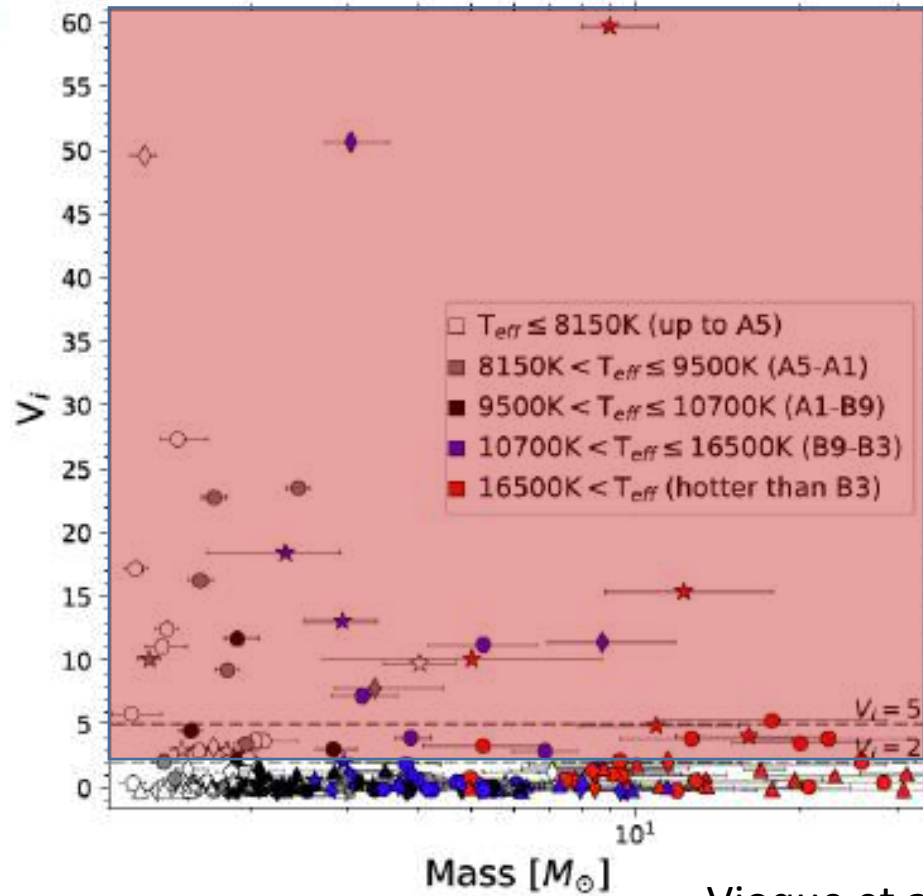


UX Ori candidates



Vioque et al. 2018

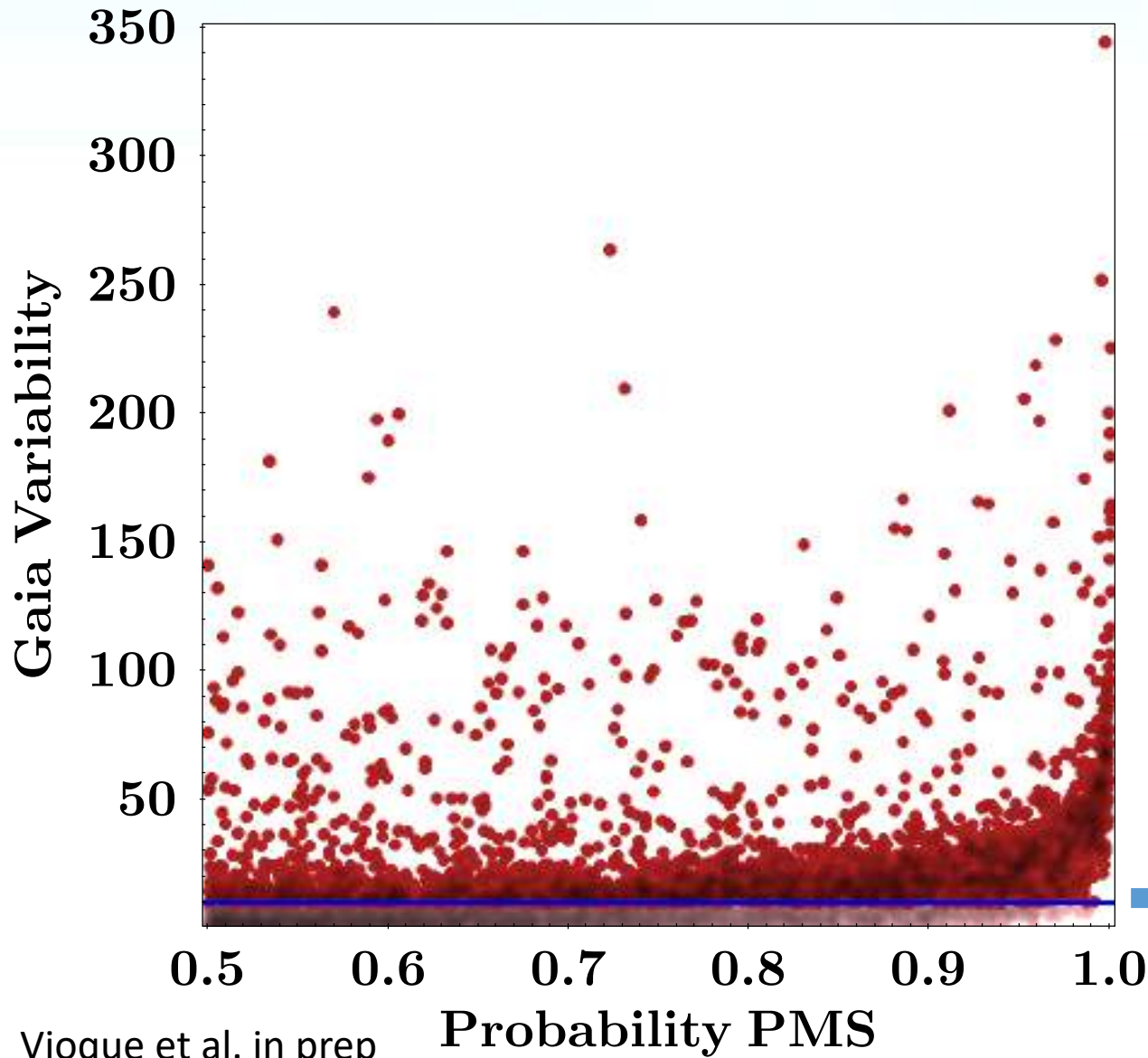
UX Ori candidates



Proposed 31
new UX Ori
candidates

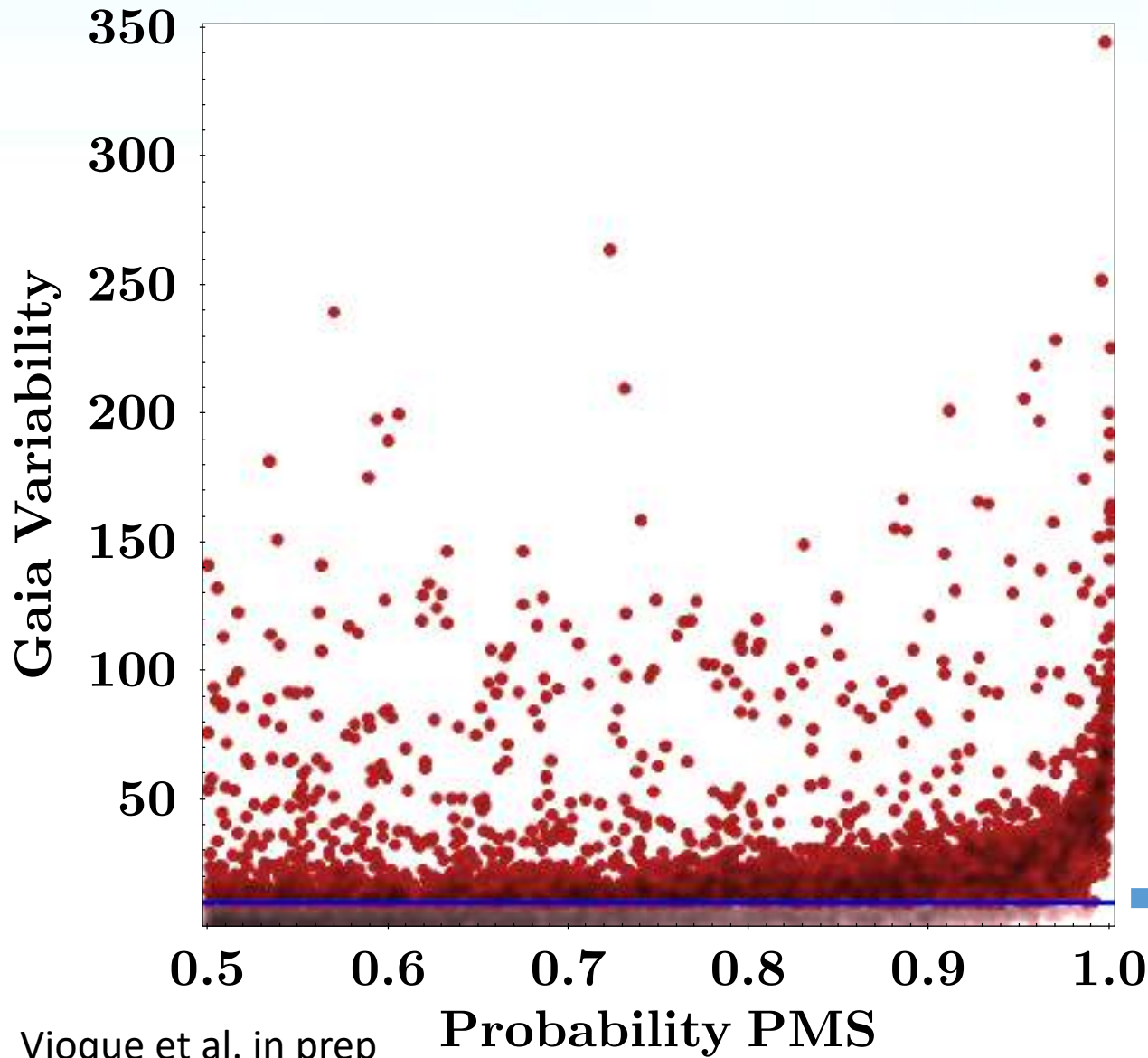
Vioque et al. 2018

UX Ori candidates



3436 UX Ori
candidates

UX Ori candidates

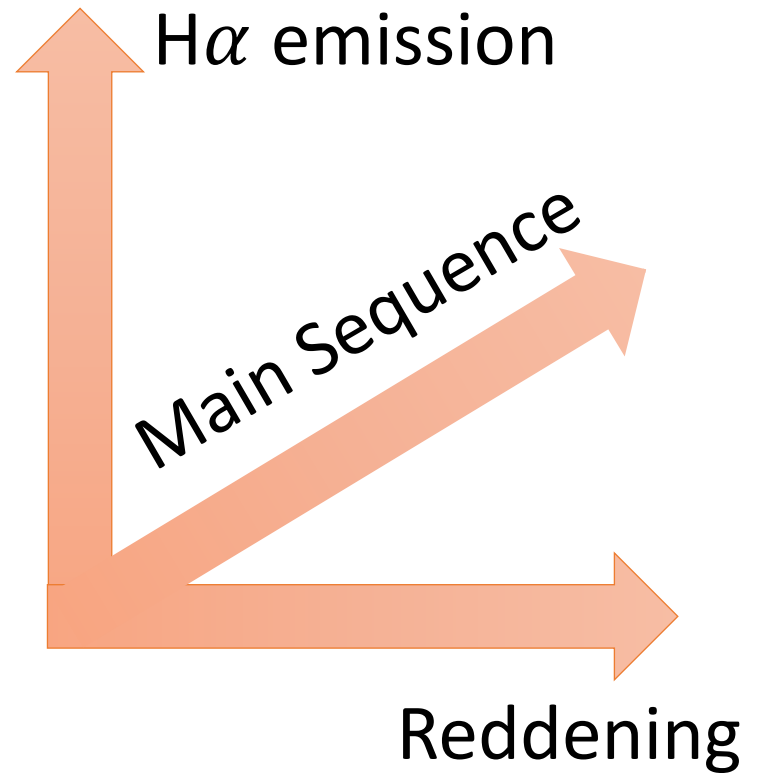
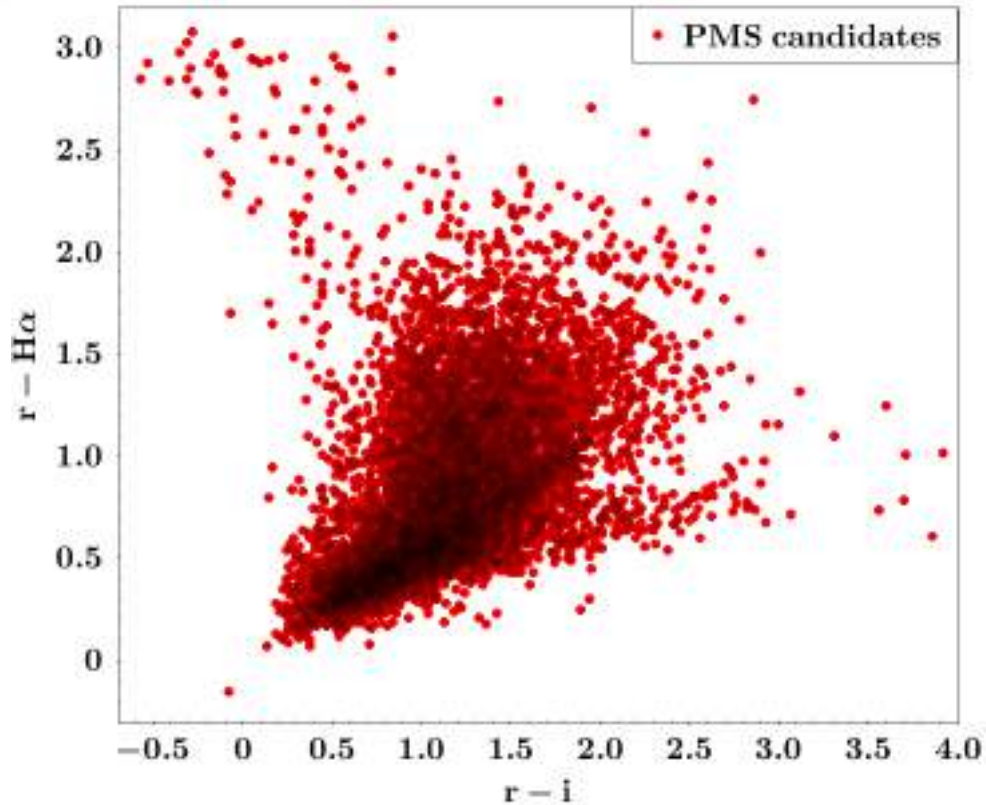


~40% of the PMS candidates

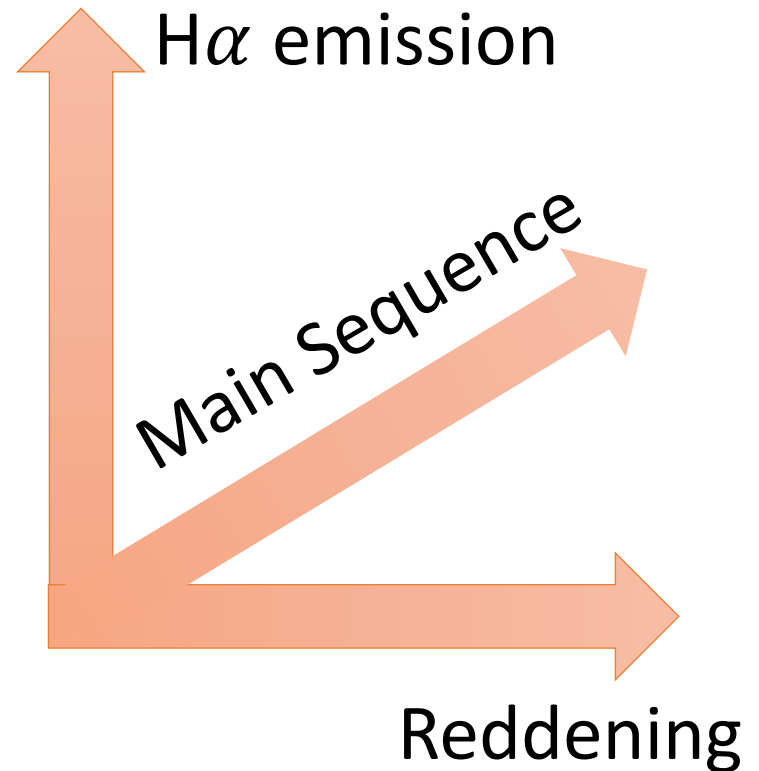
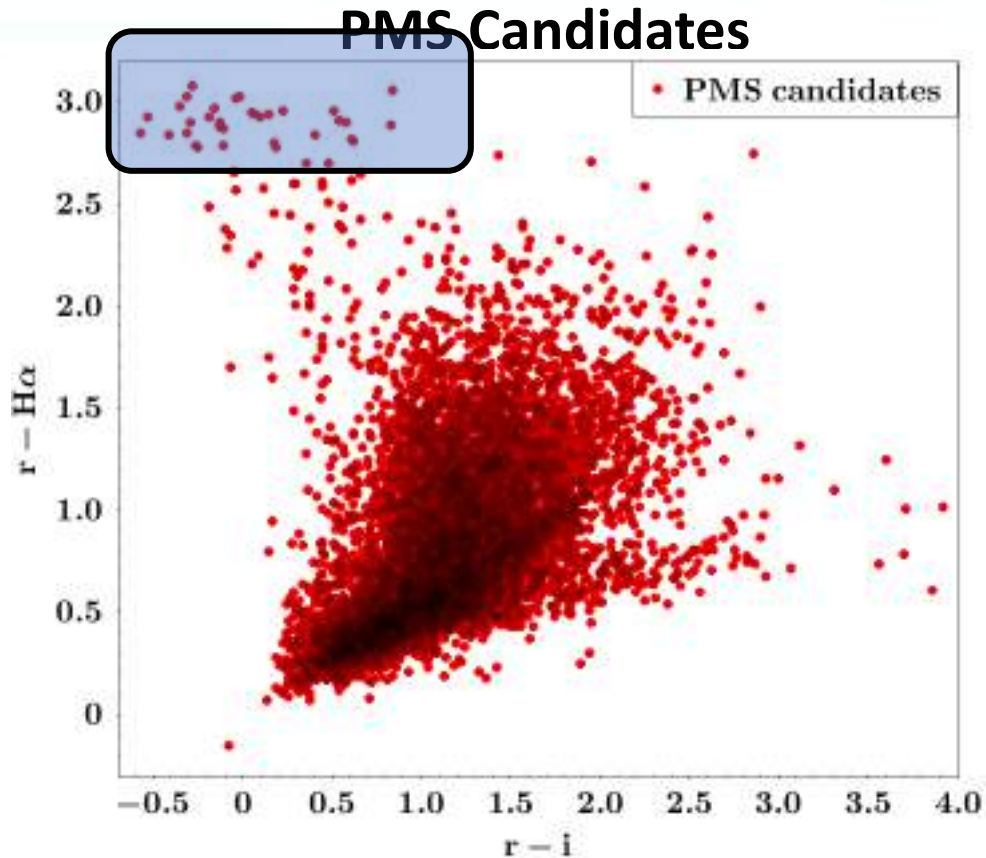
3436 UX Ori candidates

Caveats

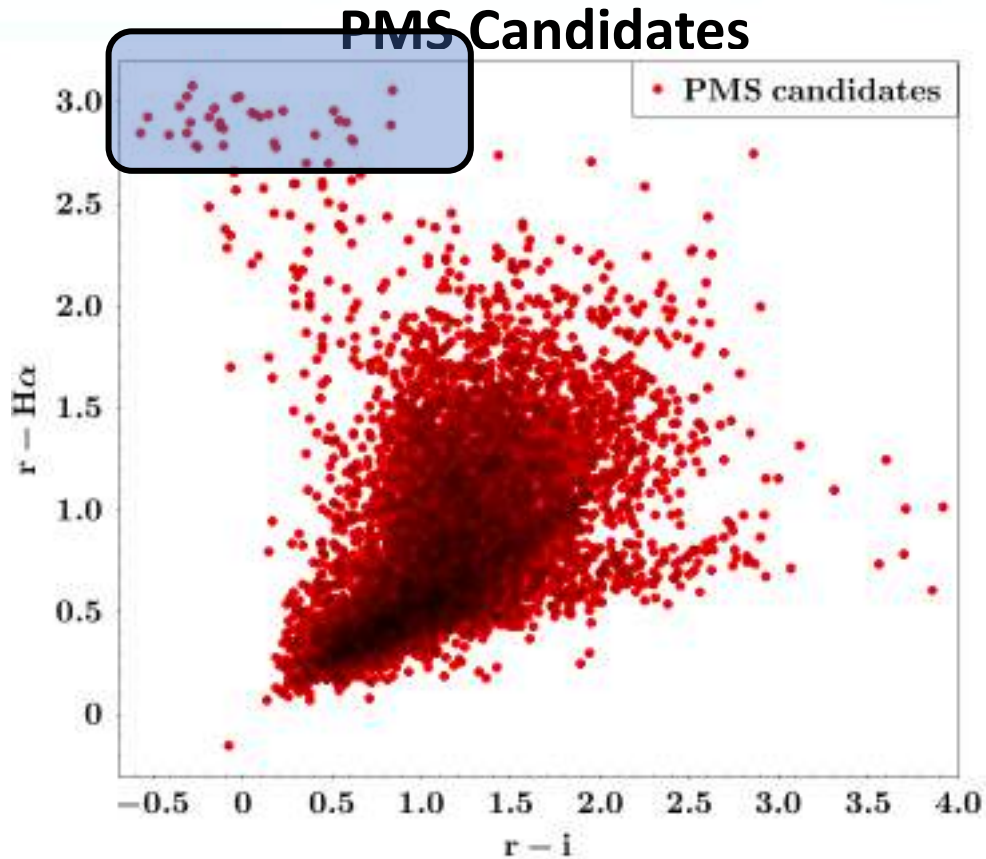
PMS Candidates



Caveats



Caveats



Planetary Nebulae!



Future work

Past and future observations



INT



2.2m Calar Alto



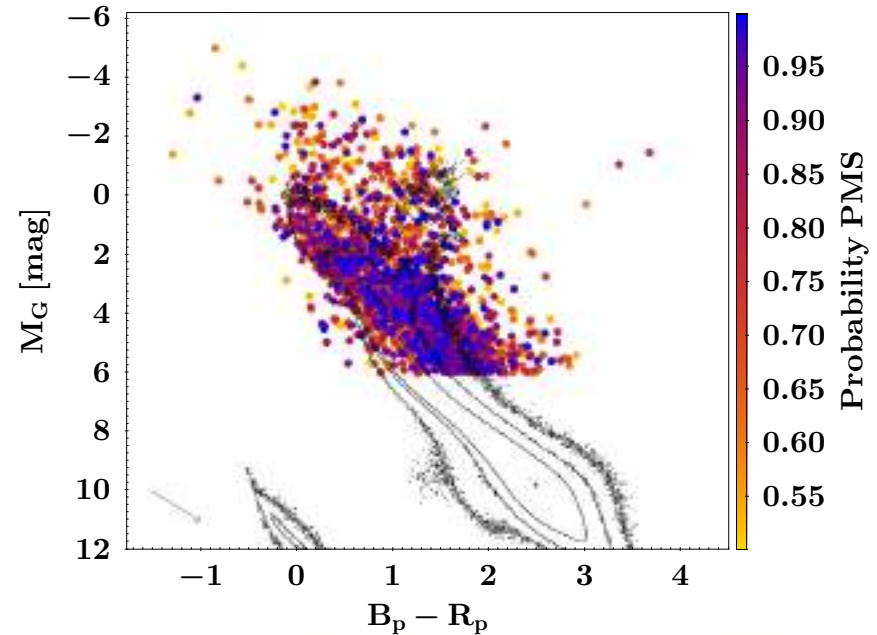
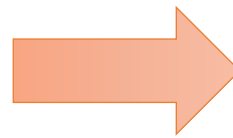
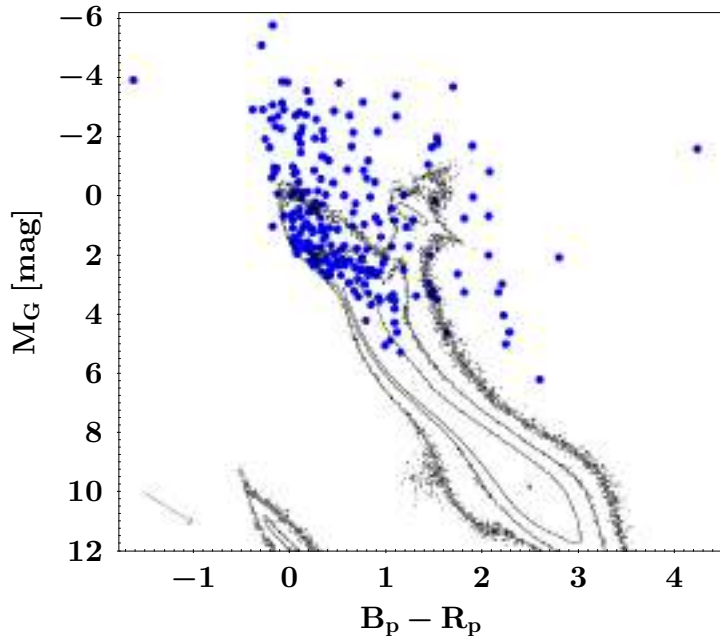
NTT



260 objects

Populate HR diagram

+ ~3000 objects

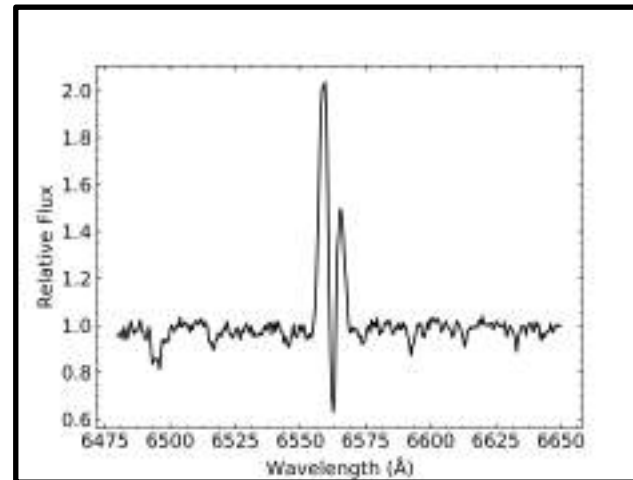


Results

- We retrieve **8452 new PMS candidates**. 3131 potential Herbig Ae/Be stars.

Completeness
 $78.8 \pm 1.4\%$

Gaia 2204517656901678848
 $G = 14.0\text{mag}$, $d = 940\text{pc}$



IDS/INT
 H_{α} line spectra

We retrieve **3436 new UX Ori type stars candidates**

- We retrieve **636 new Classical Be stars candidates**.

Completeness
 $85.5 \pm 1.2\%$