Credit: ESO

A First Glance on Stellar Variability in VVV

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The VVV Survey: Timeline

We are here

year

1
- 6 epochs in K for bulge and disk; K_{lim}=18/20 mag (single/combined epochs)
- Z,Y,J,H, K single (quasi-simultaneously) epoch observations (bulge & disk)

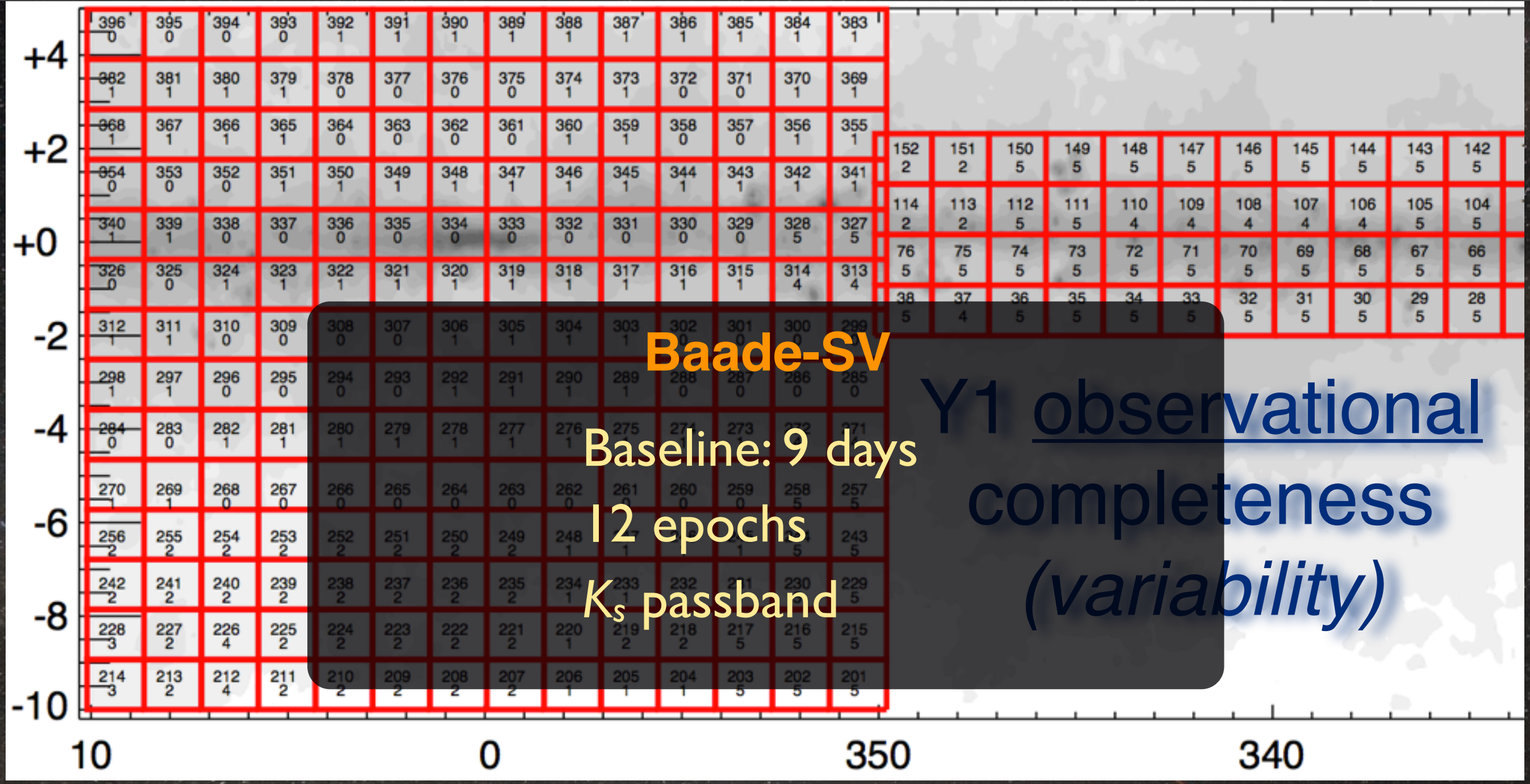
2
- 4 epochs in K_s for bulge and disk

3
- main part of bulge variability campaign (80 epochs, 652 h)
- map bulge and disk once per night

4
- main disk variability campaign (similar to bulge, but 70 epochs, 525 h)

5
- bulge and disk observations in K band
- 20/9 epochs spread over the whole year
- subset will be observed more frequently (10-40 times per night)

Signal search via time-frequency transformations and image subtraction,
automated variable star classification,
10^6+ new variables, ...



Baade-SV

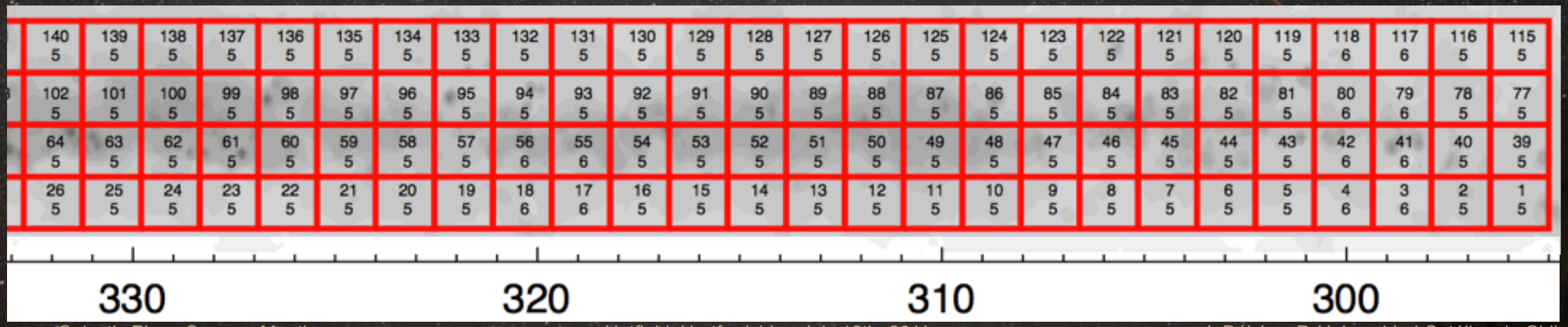
Baseline: 9 days

12 epochs

K_s passband

Y1 observational completeness *(variability)*

by Maren Hempel



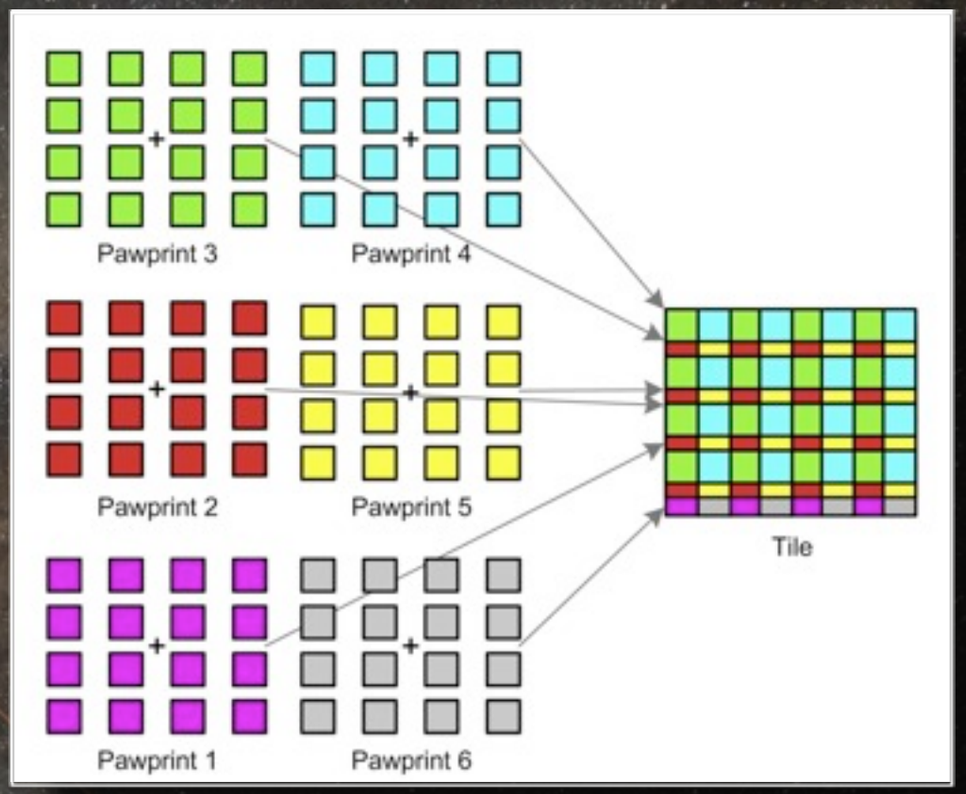
Credit: ESO

Seek for Variability

Pawprint photometry:

subsequent observations within 5 min 8 seconds (or so)

Information about the internal noise



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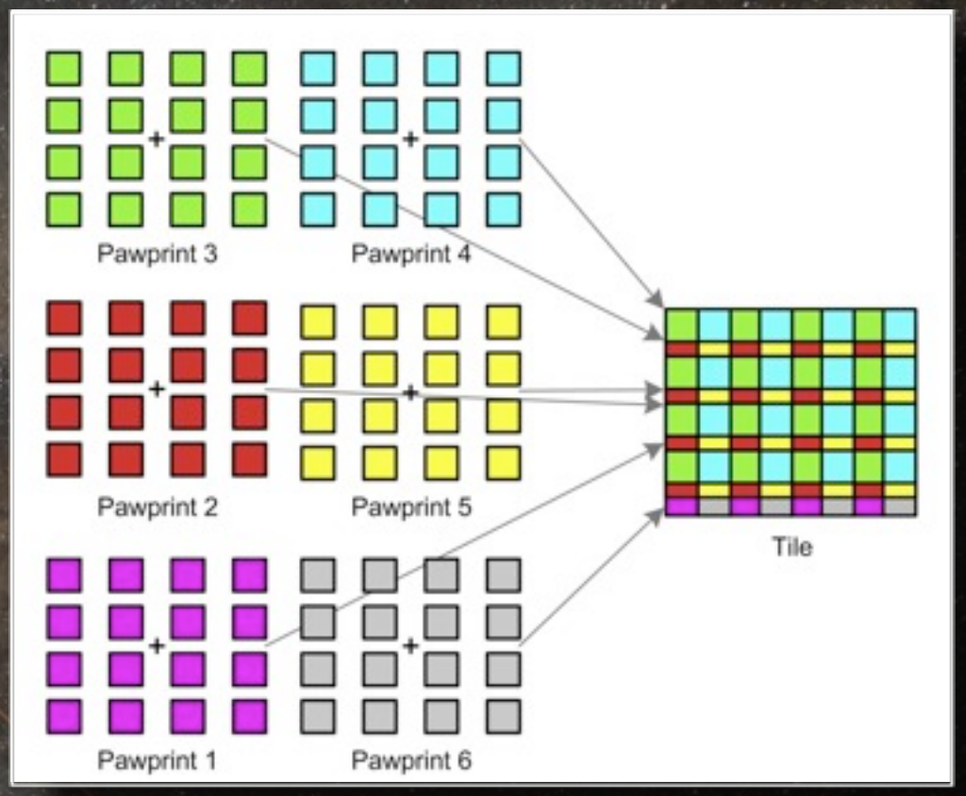

$$\sigma_i = \frac{\sum_{j=1}^{N} (m_j - m_{j+1})^2}{2\mathrm{M}} \quad \text{where:} \quad t_{(j+1)} - t_j \leq \mathrm{T}_{\mathrm{tile}}$$

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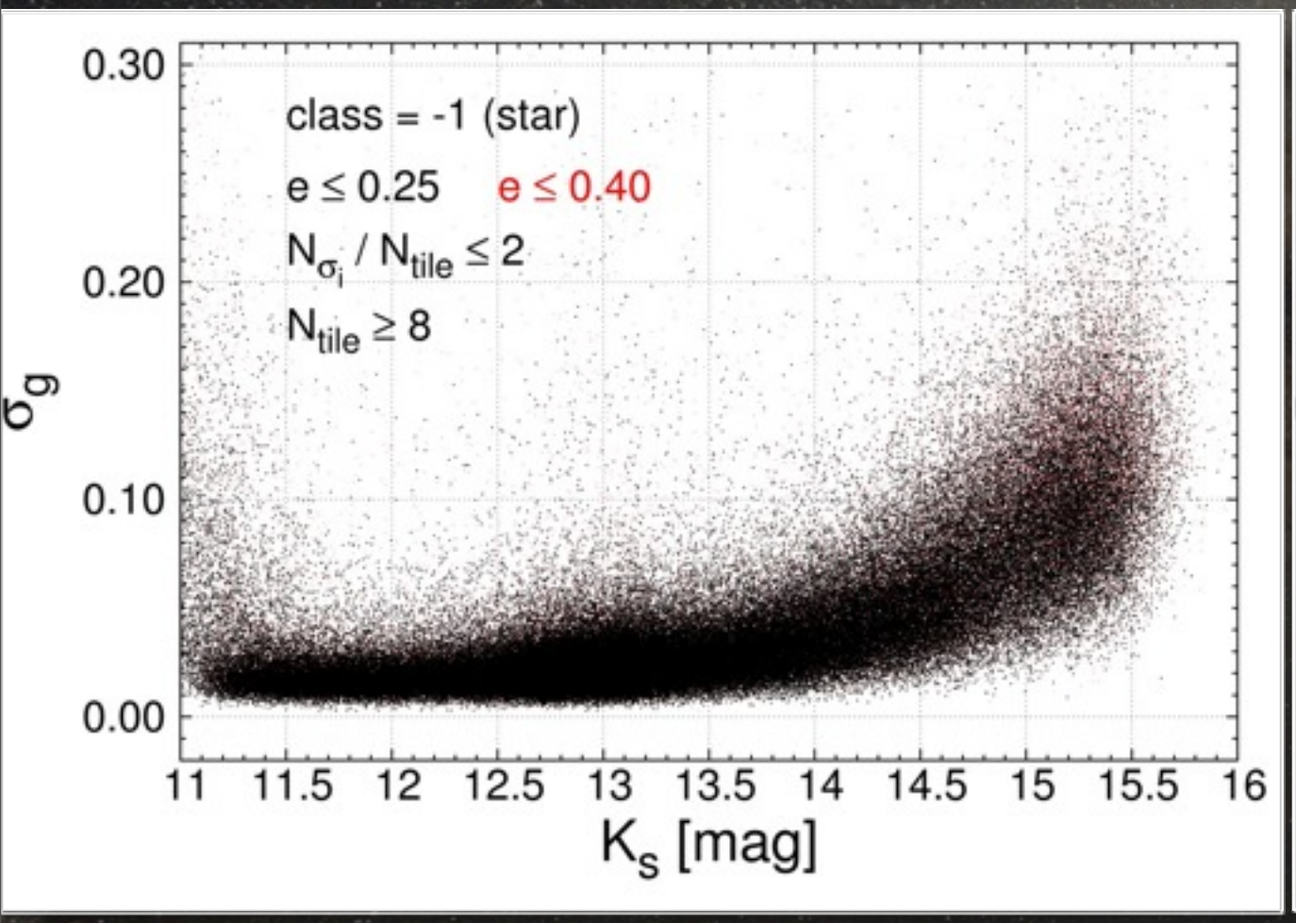
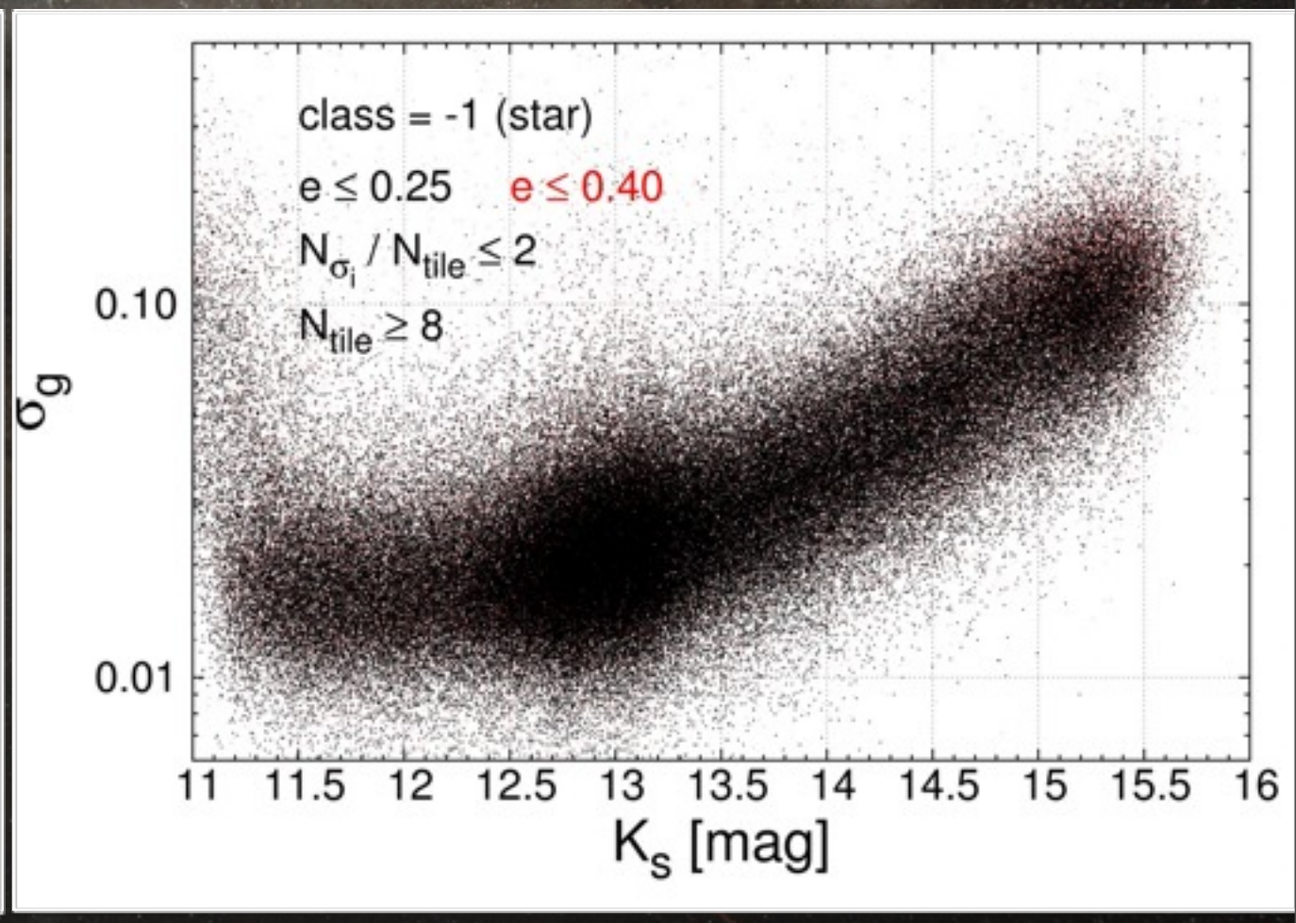
Seek for Variability

Baade-SV





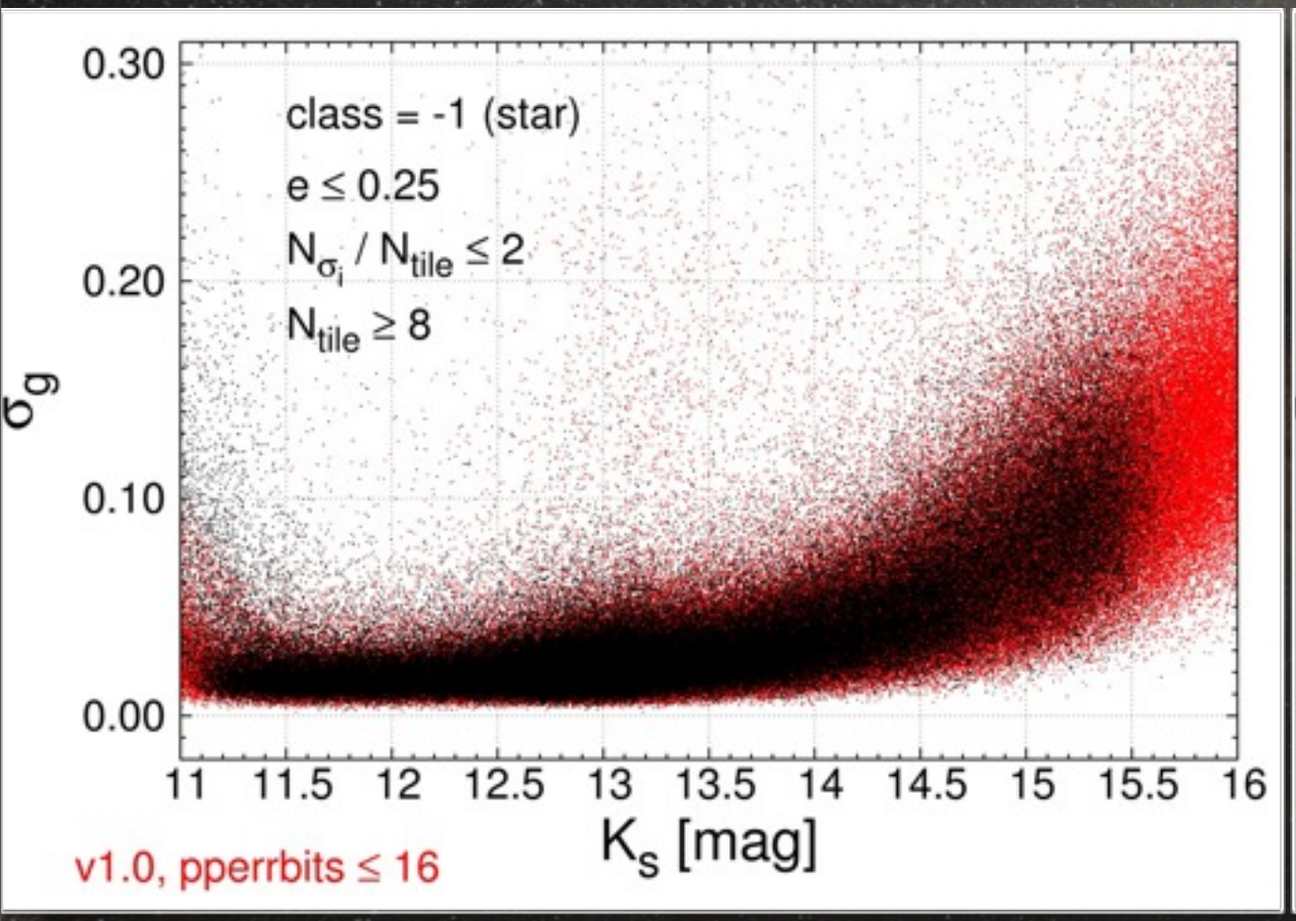
Sample:

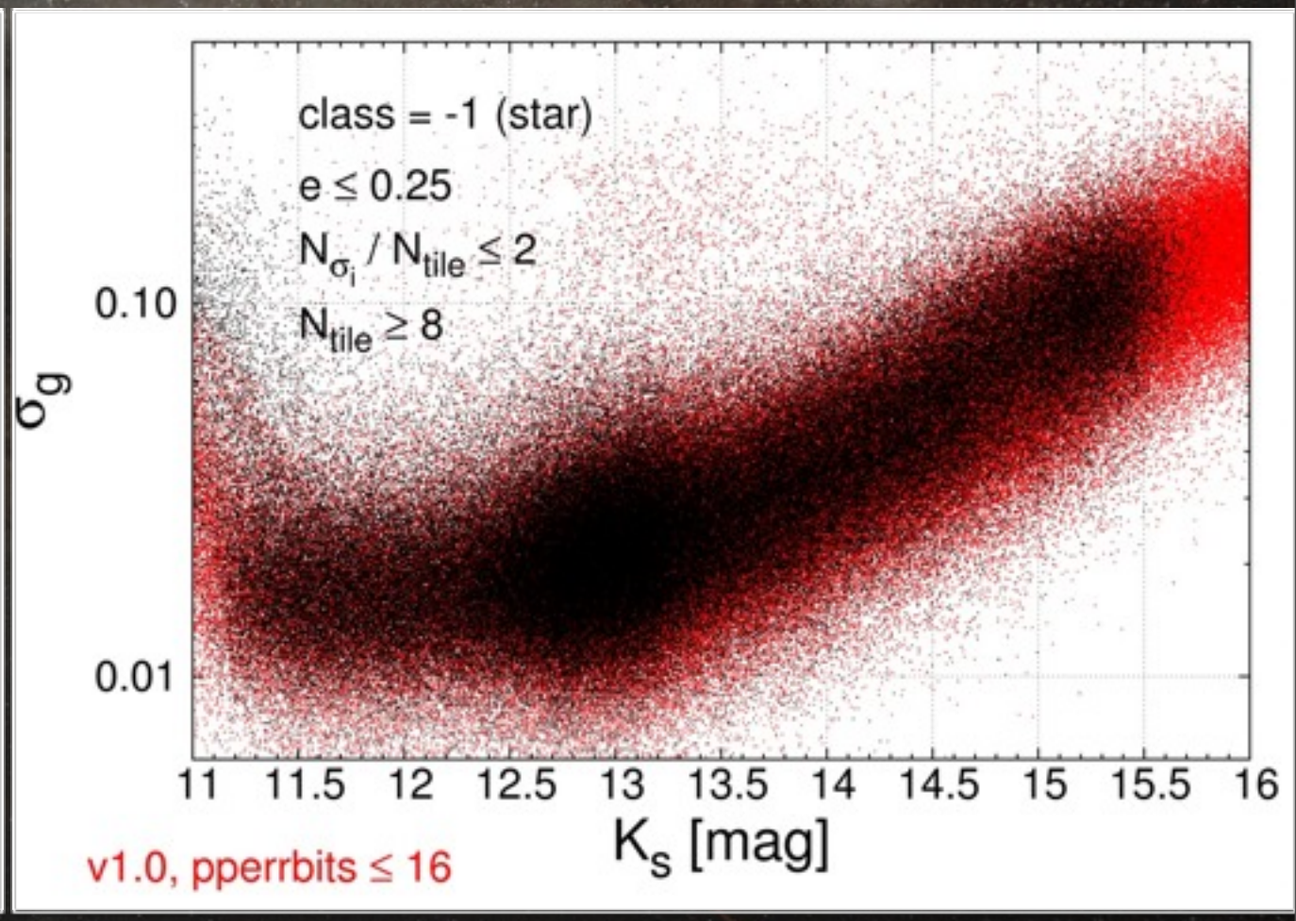
pawprint photometry for sources with stellar (-1) detections on all tiles

Credit: ESO

Seek for Variability

Baade-SV





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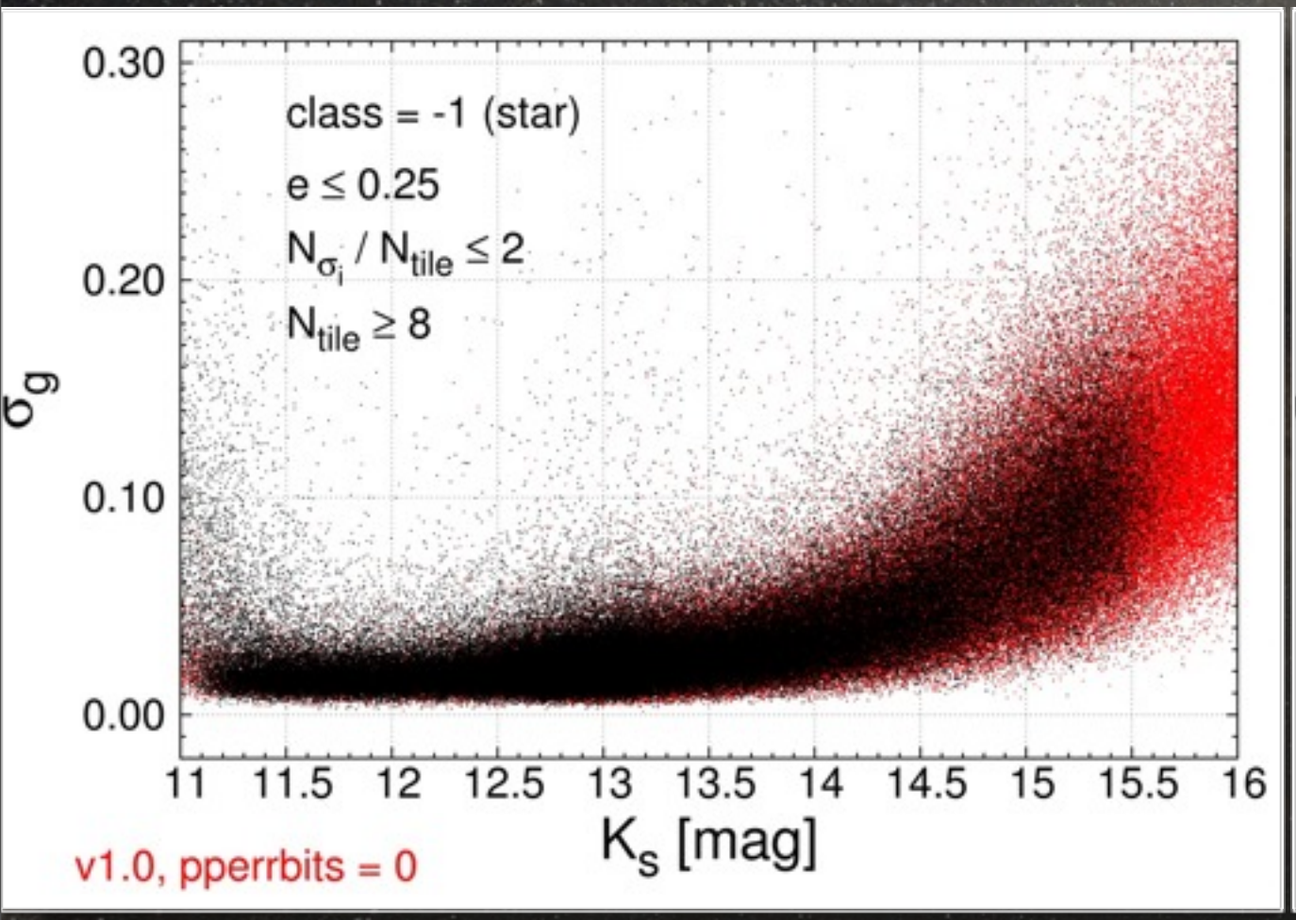

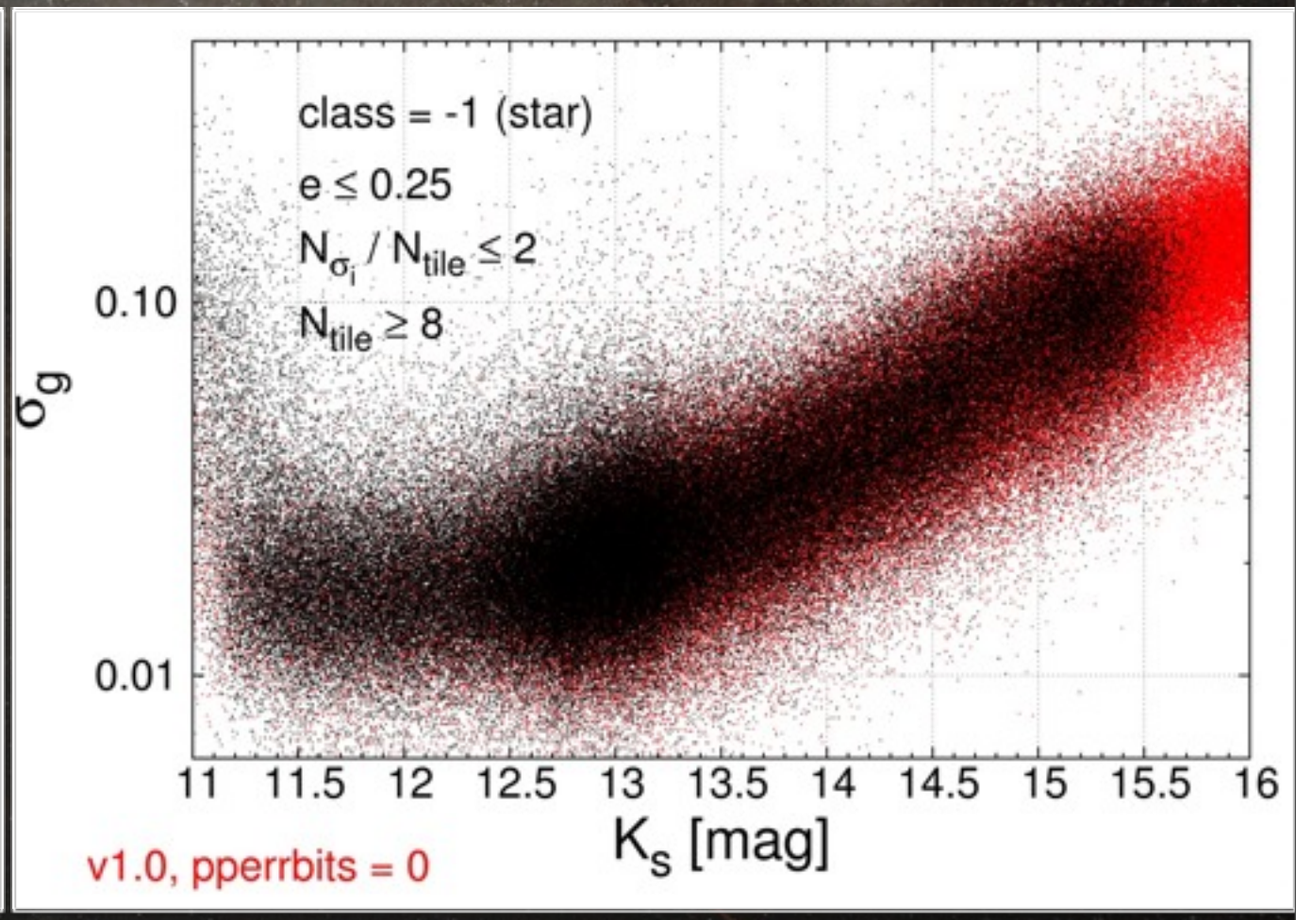

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Seek for Variability

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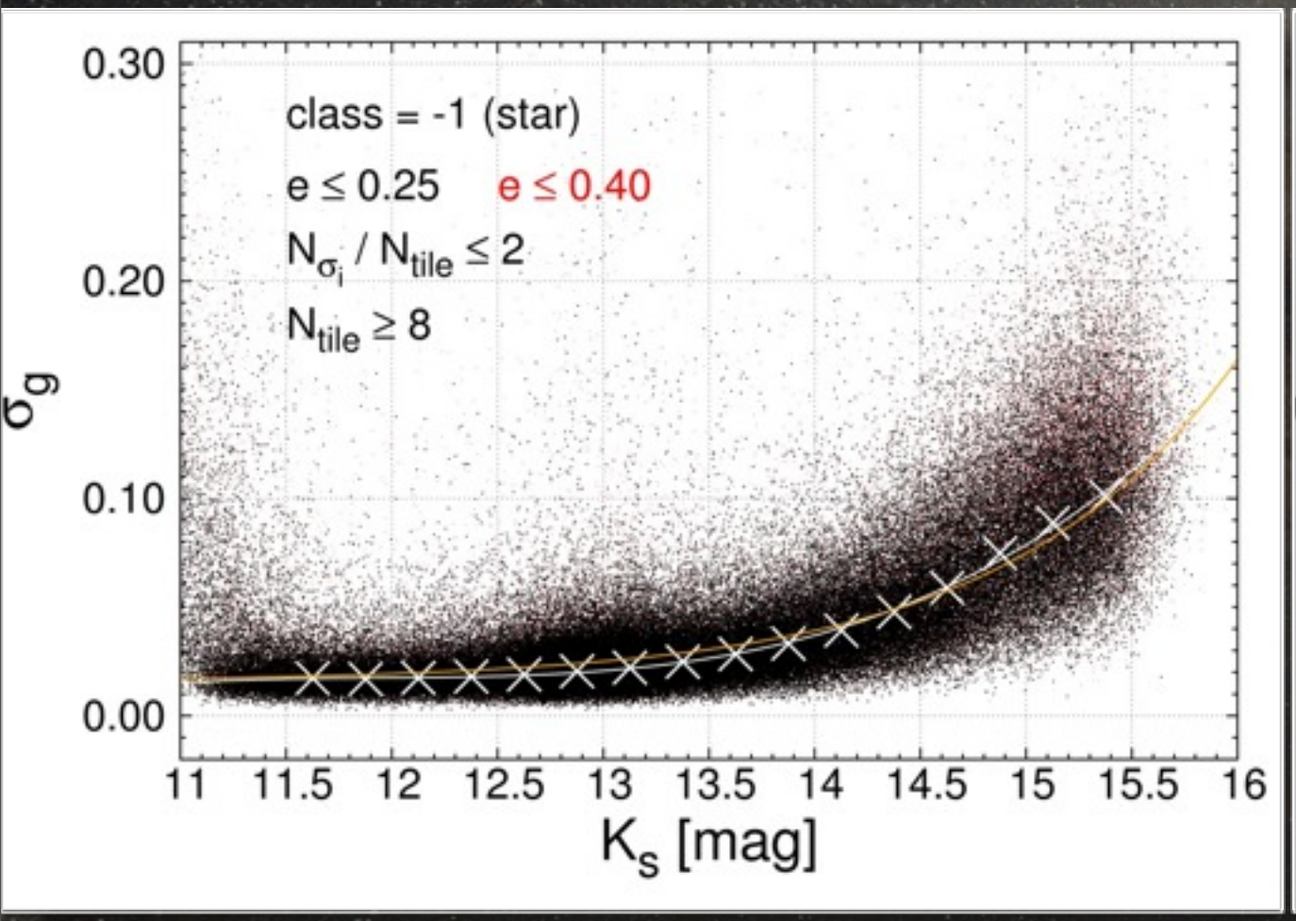

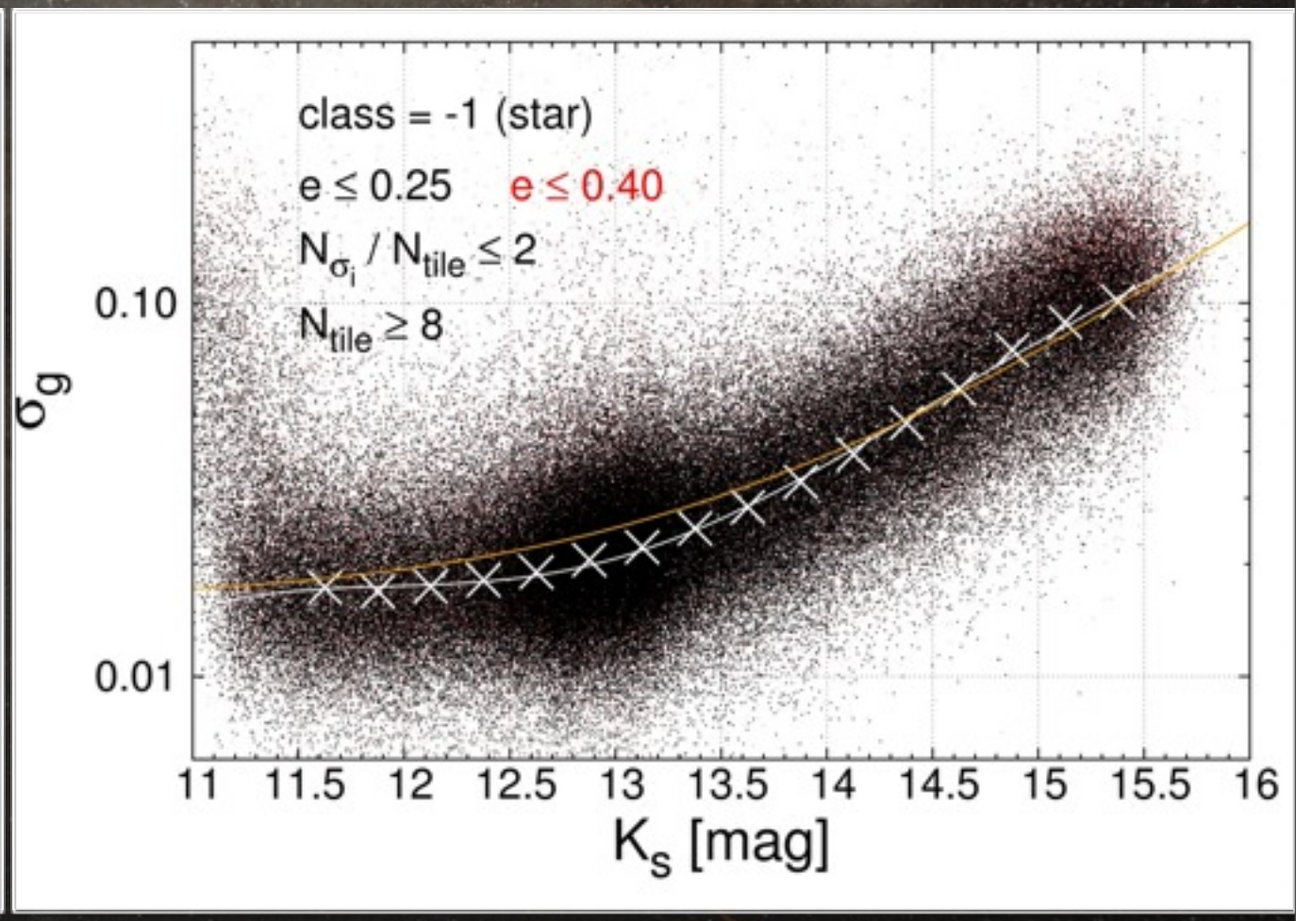

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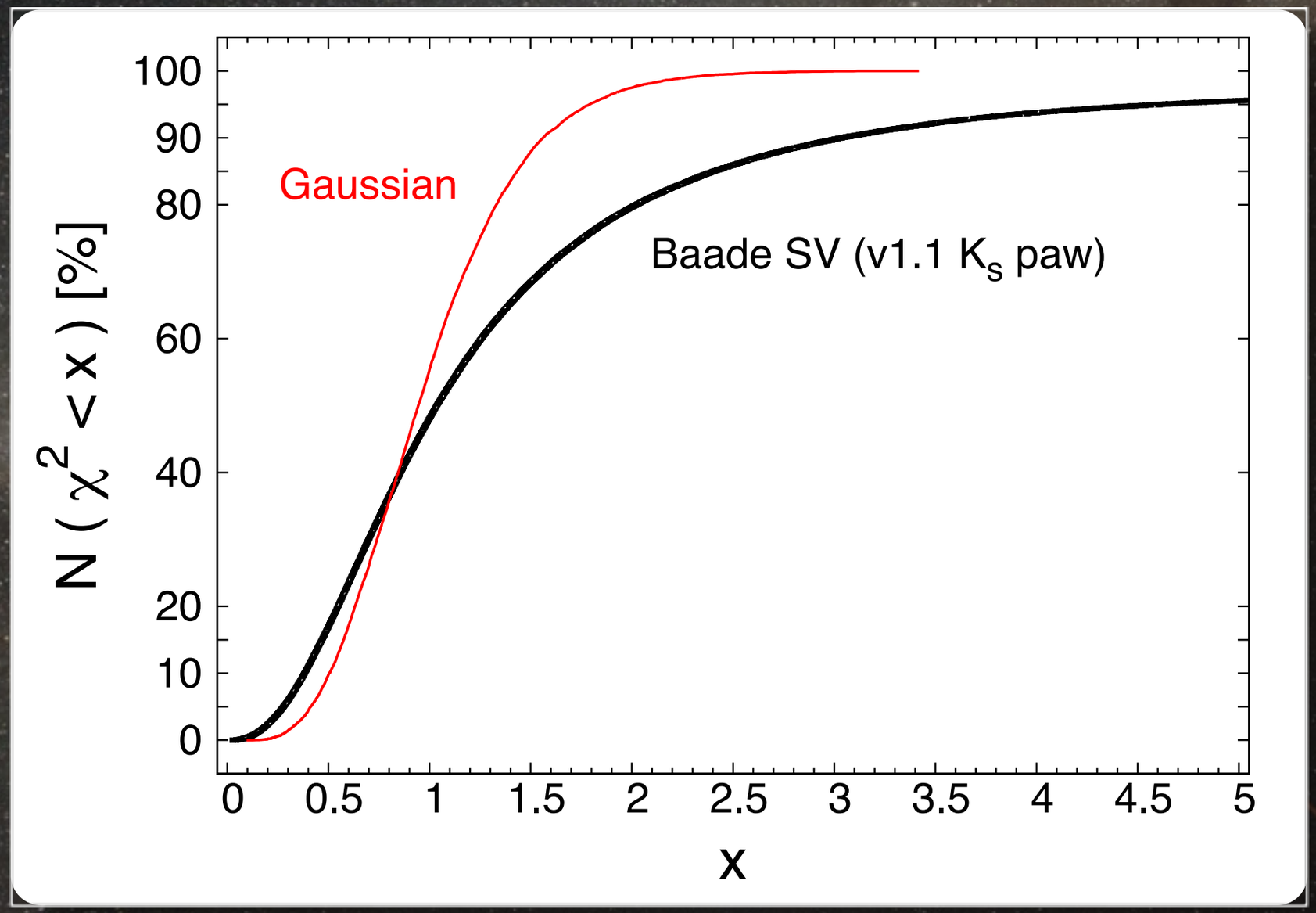
Seek for Variability

cumulative distribution of chi-squared per degree of freedom



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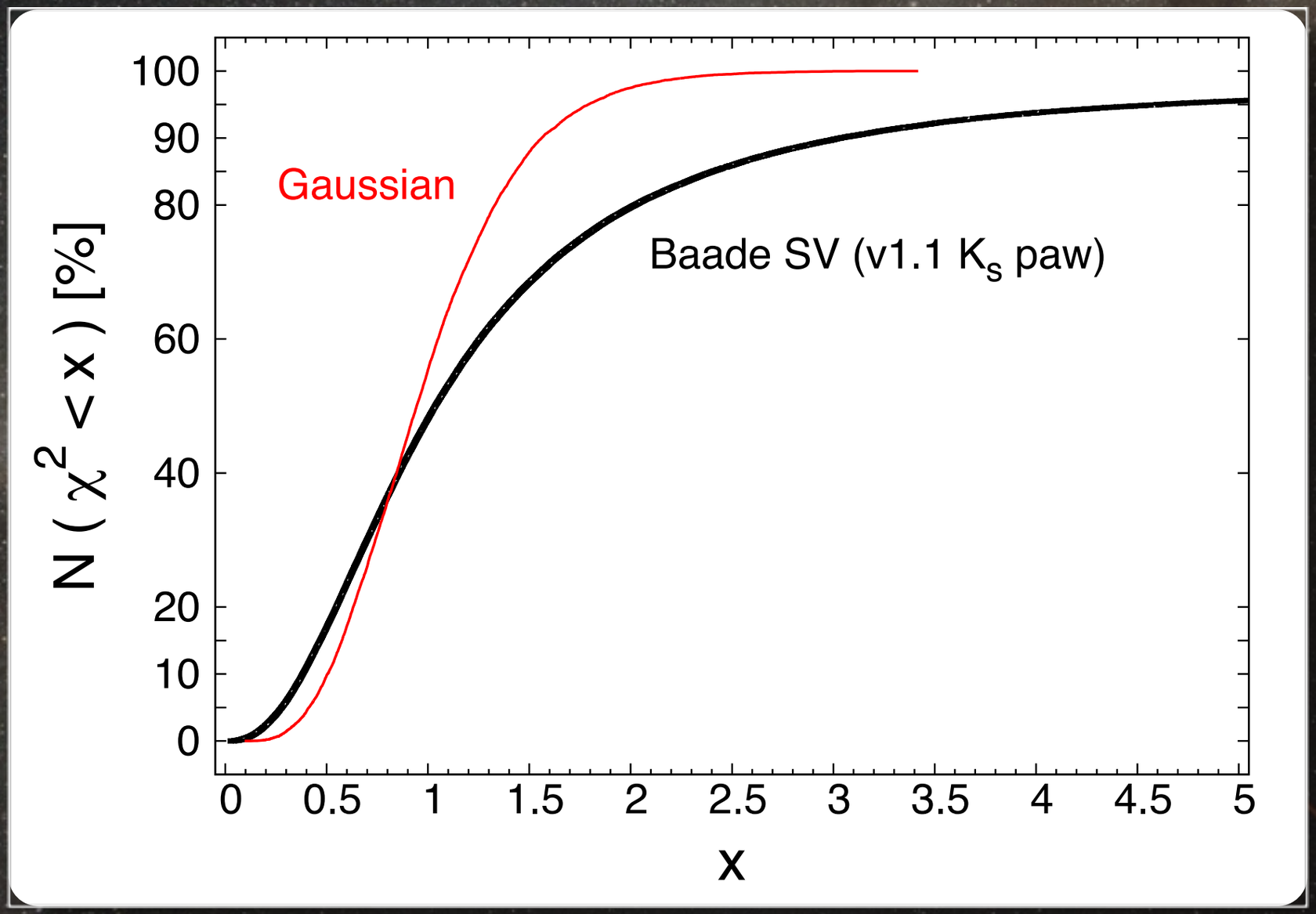


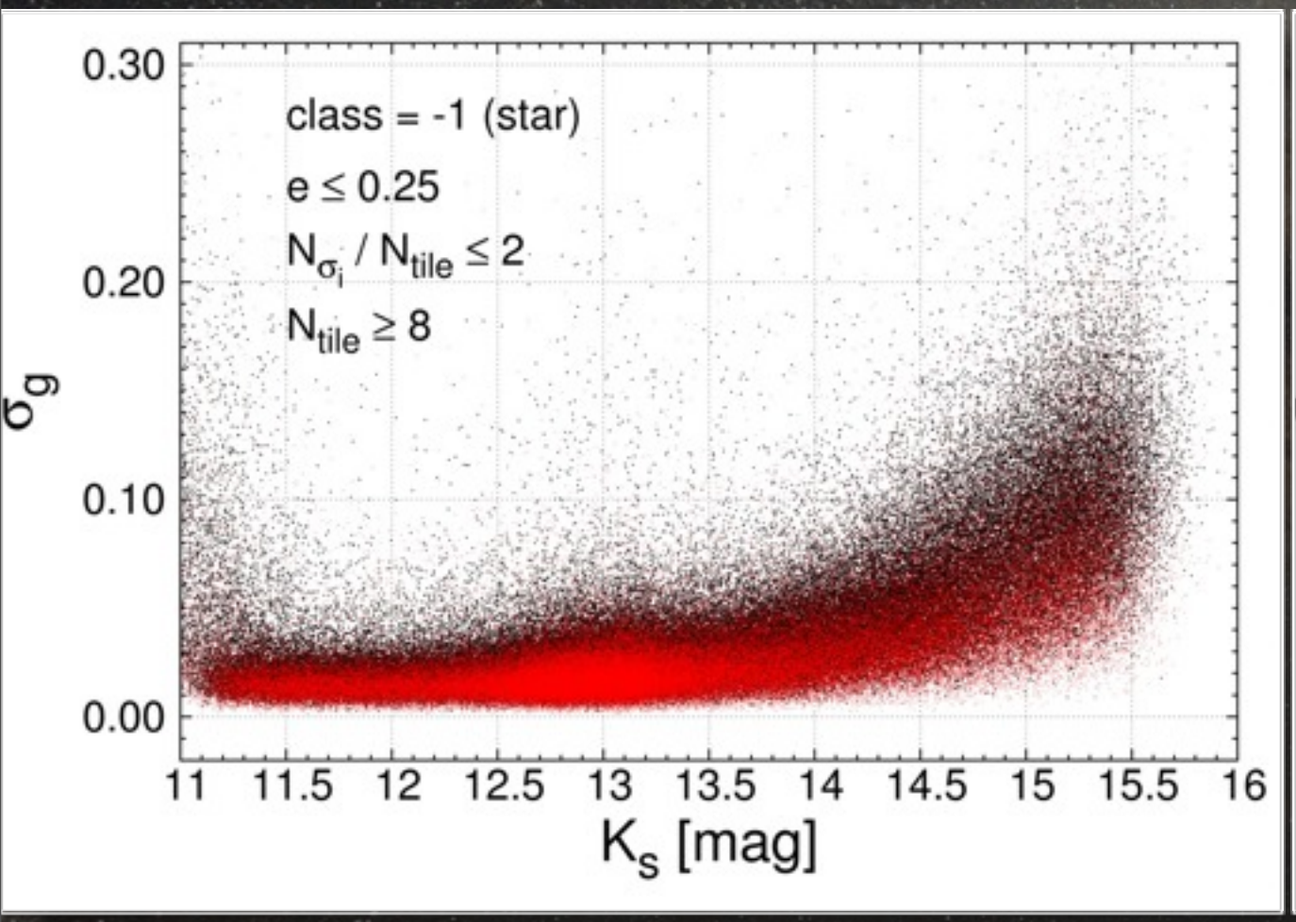
non-normality

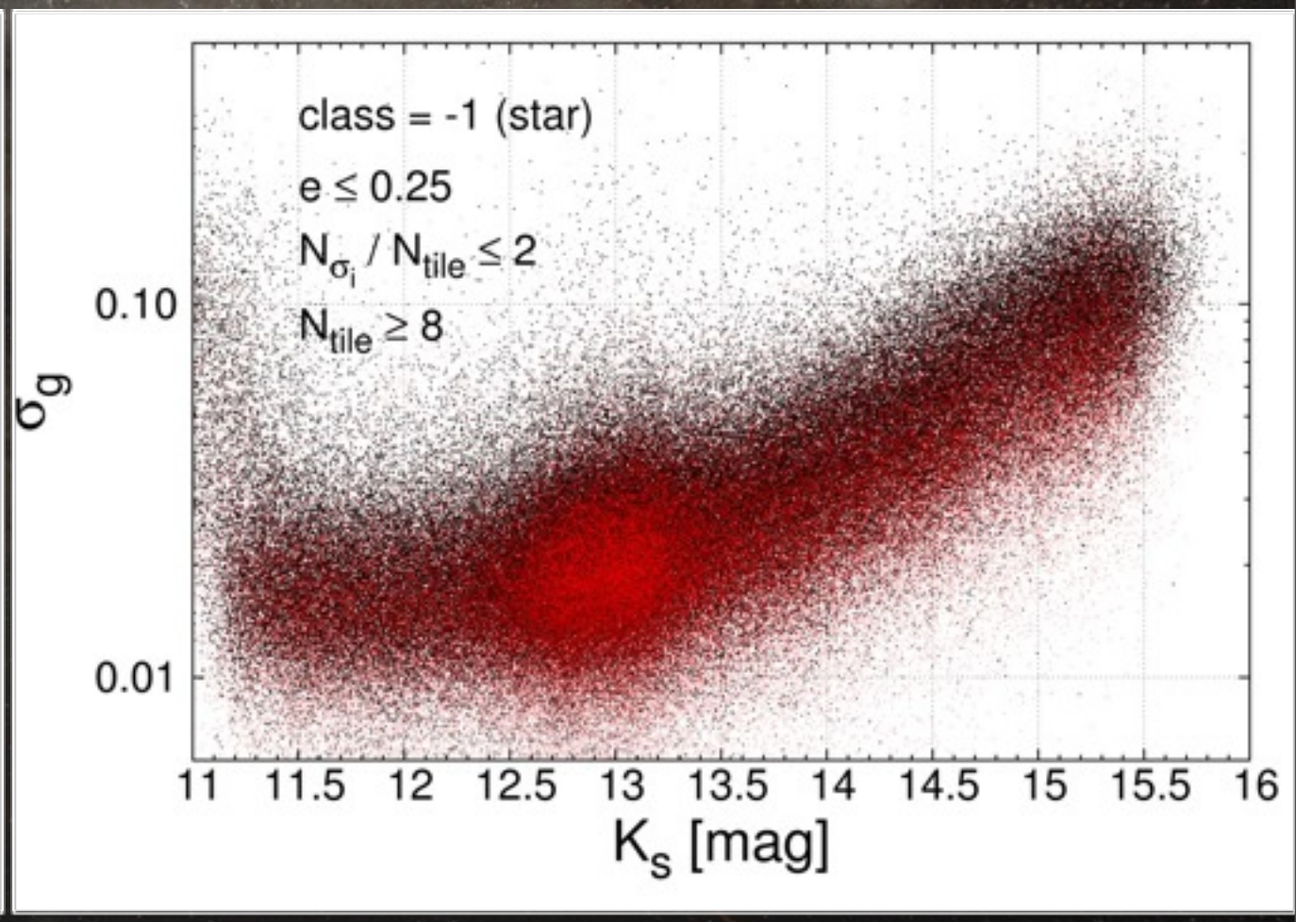
Main reason:
aperture photometry + crowdedness

Credit: ESO

Seek for Variability

rms scatter of time-series

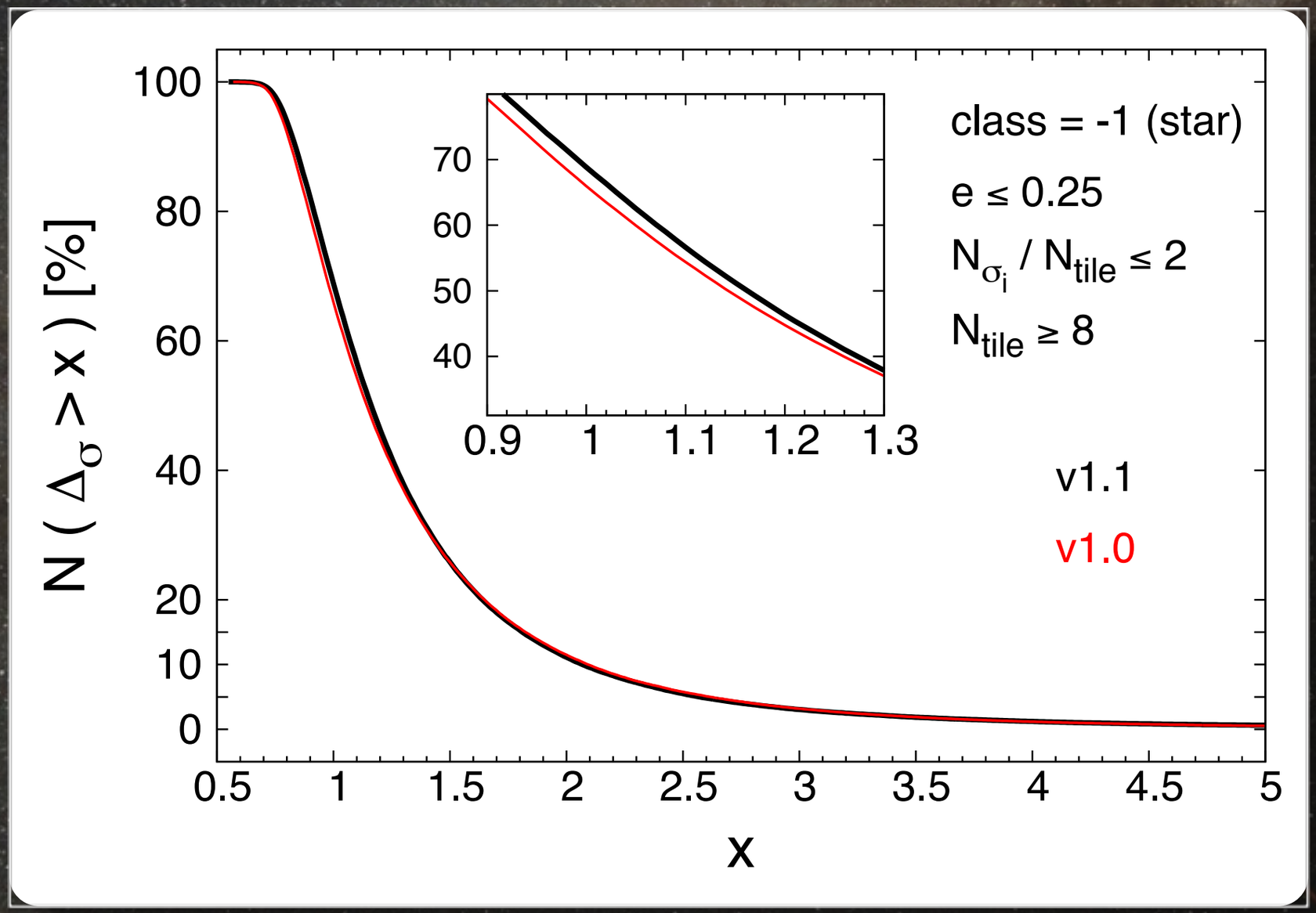




RED points: internal scatter

Seek for Variability

Baade-SV



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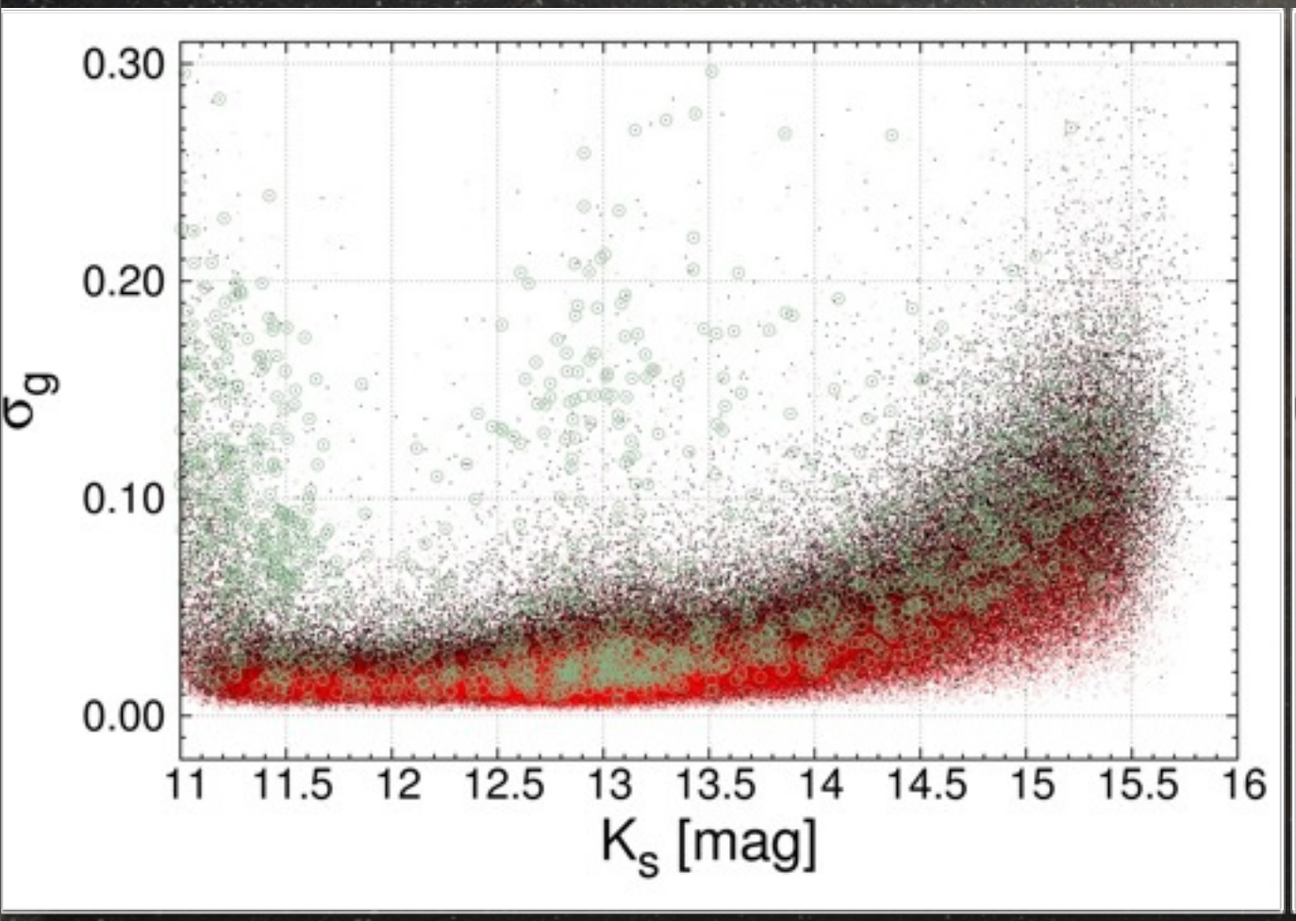

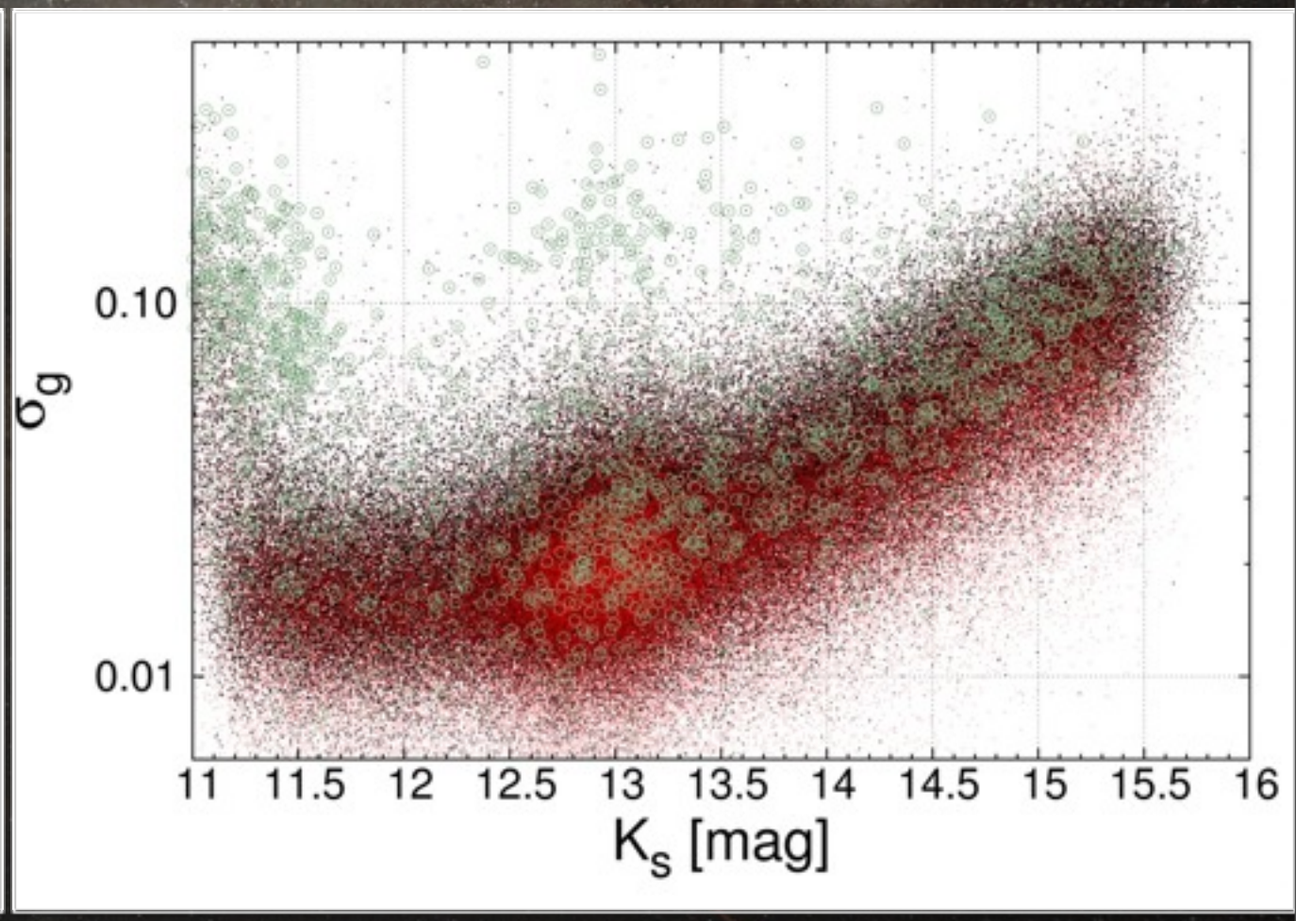

RED points: internal scatter

$$\Delta_\sigma \geq 4$$

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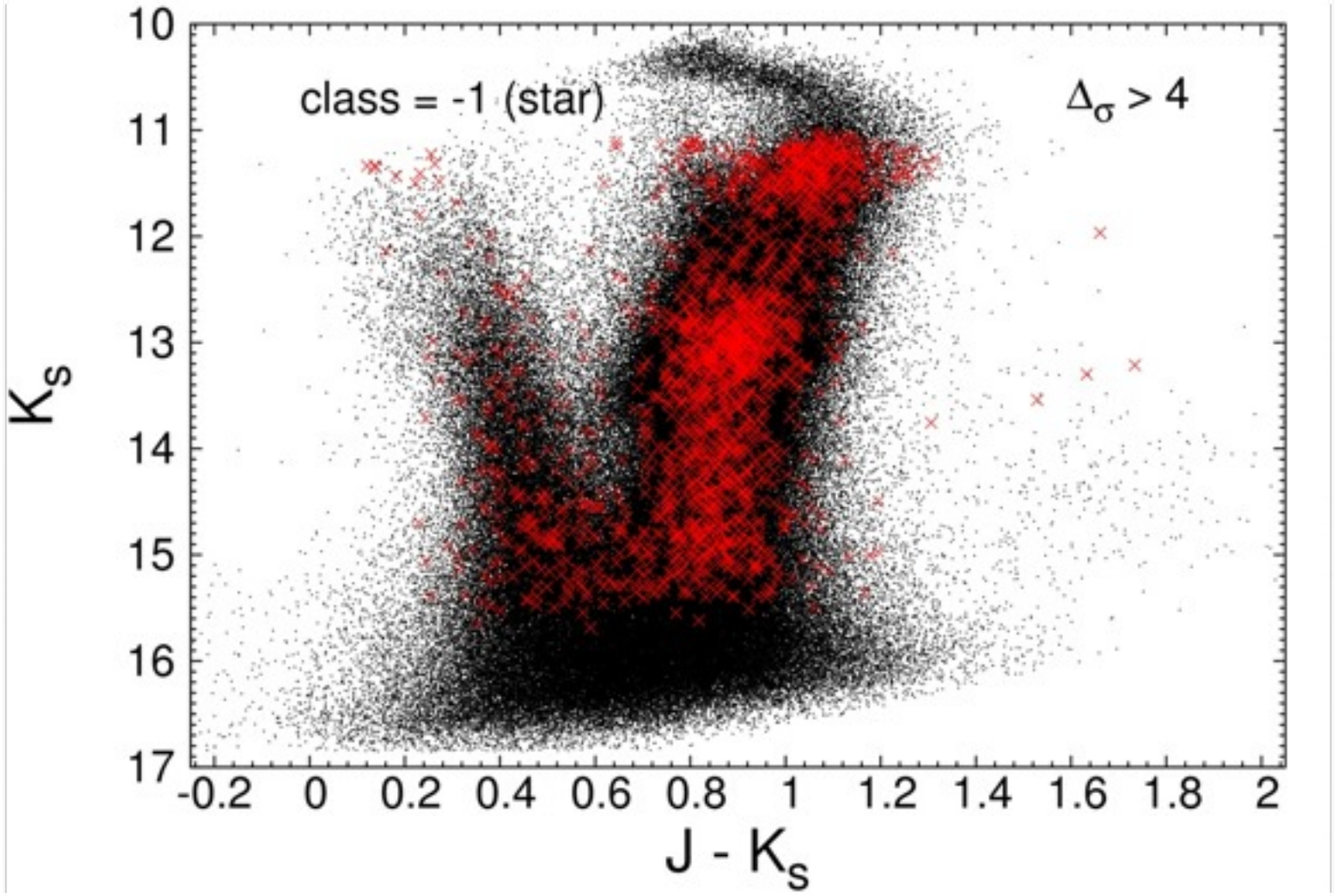

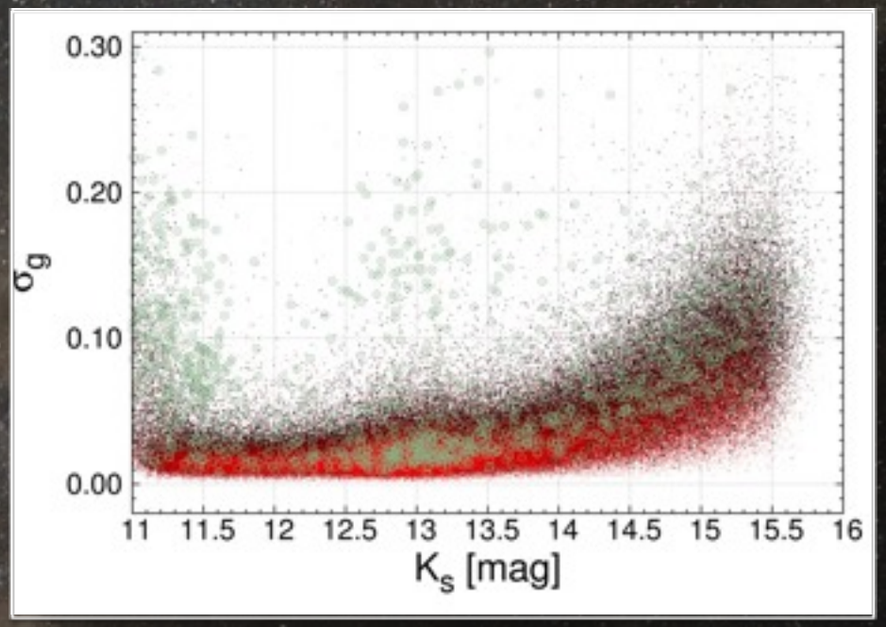

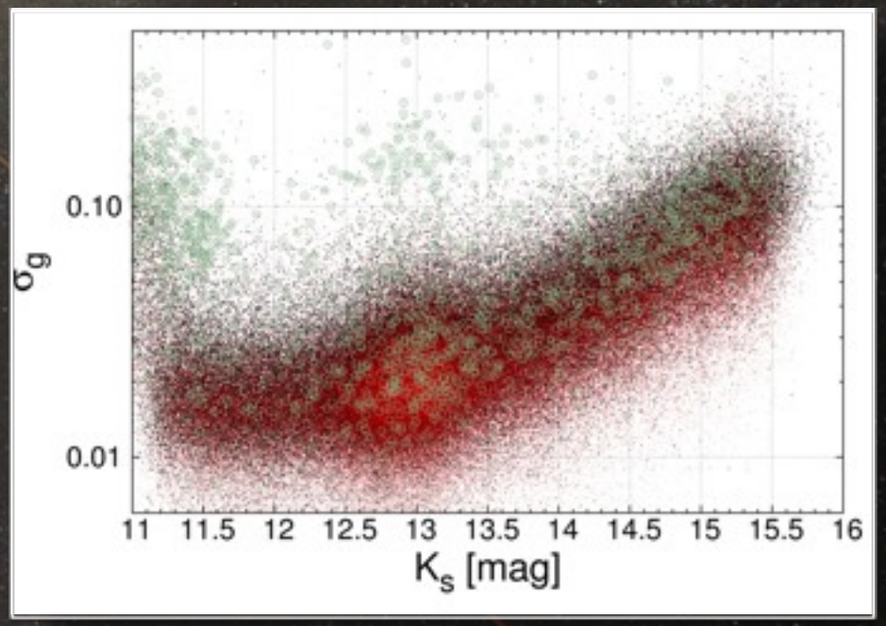

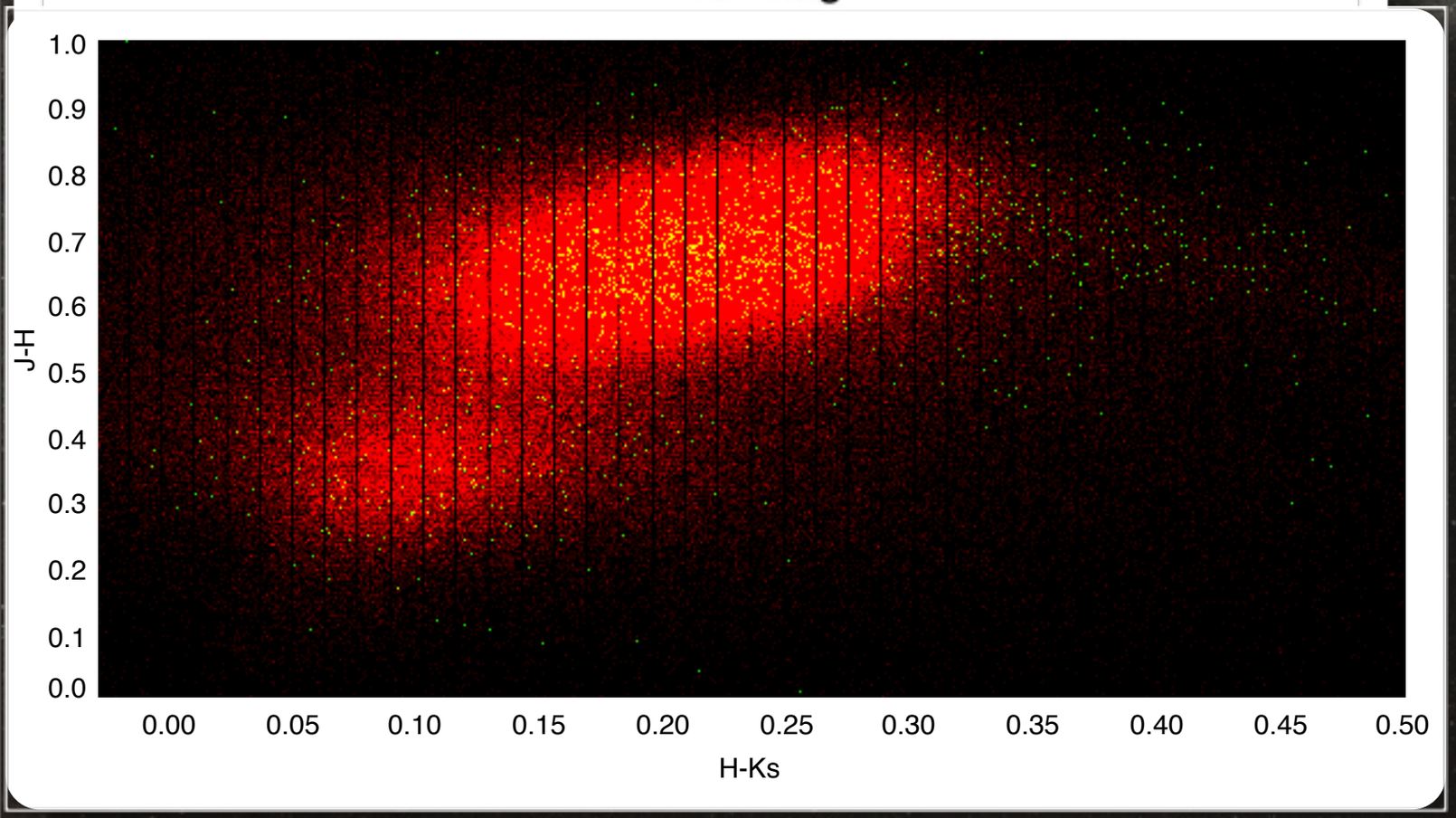

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Seek for Variability

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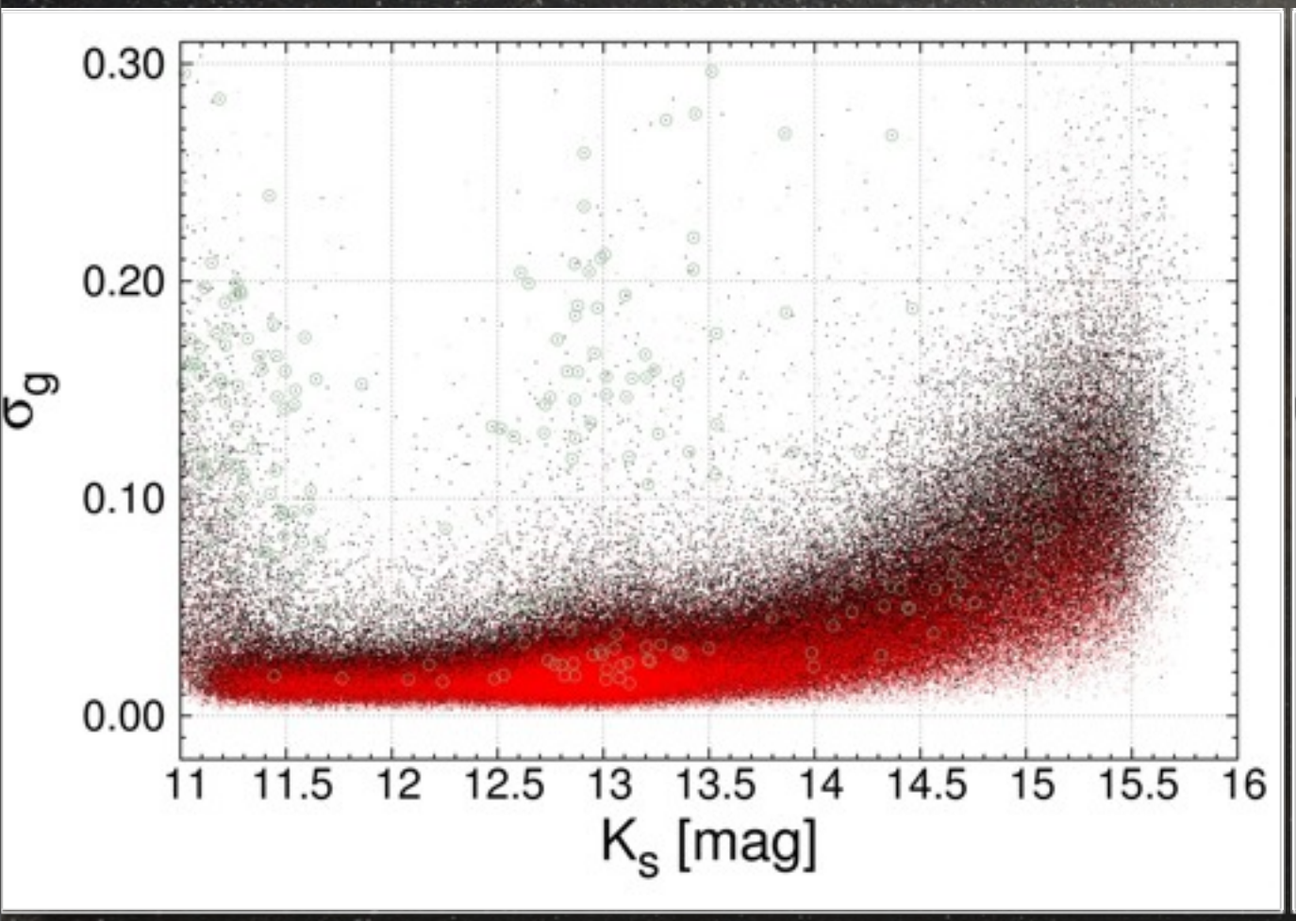

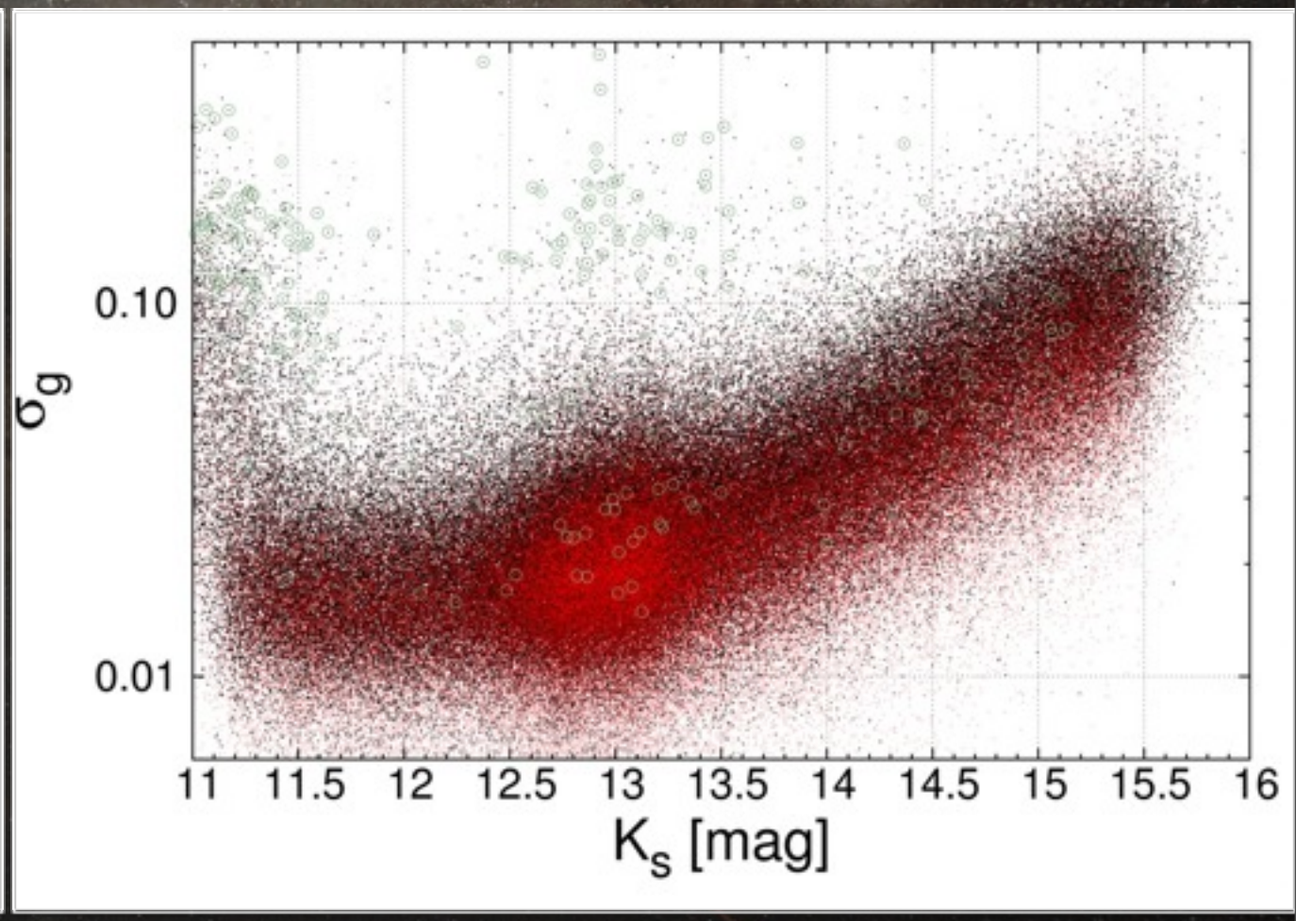

RED points: internal scatter

$$\Delta_\sigma \geq 8$$

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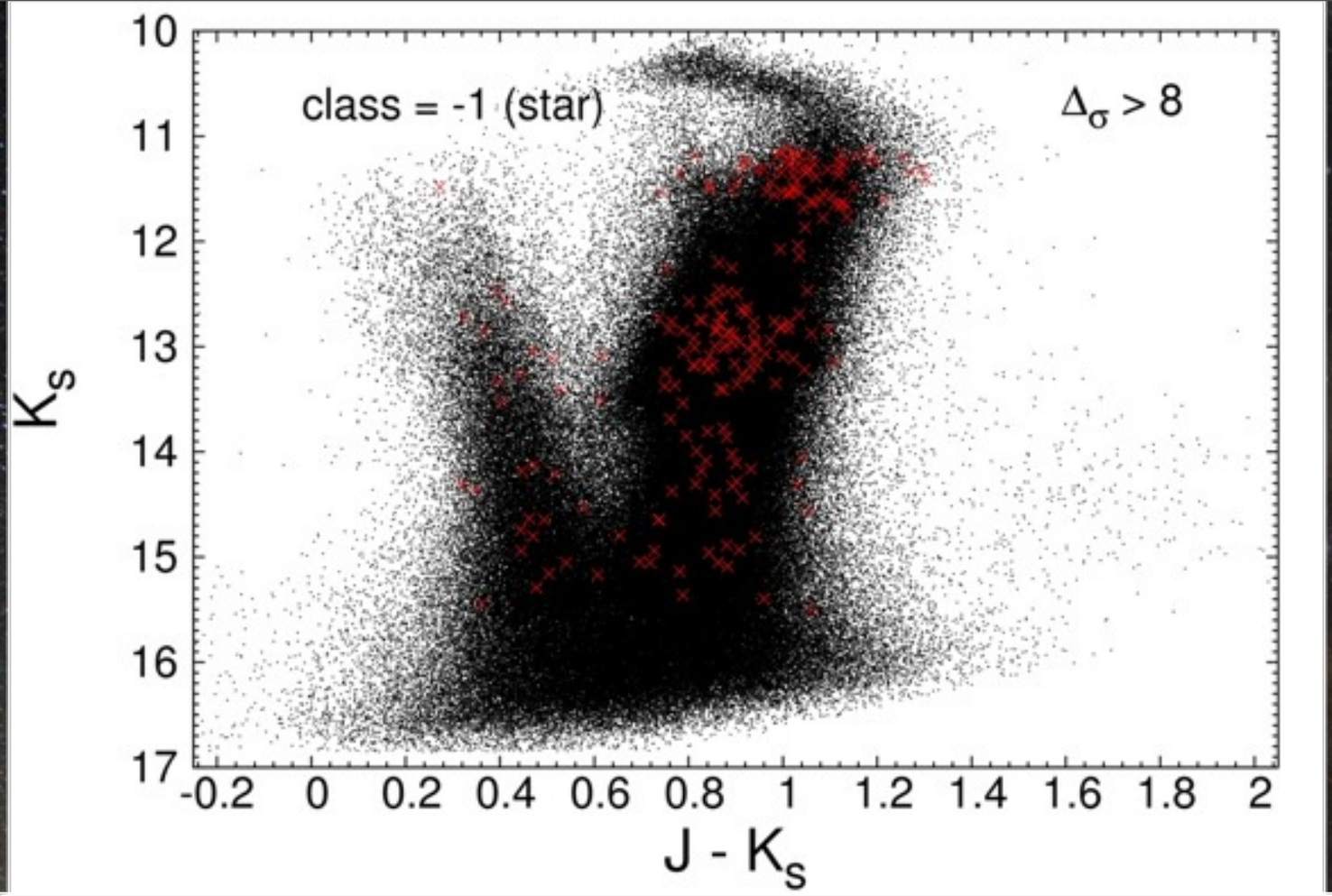
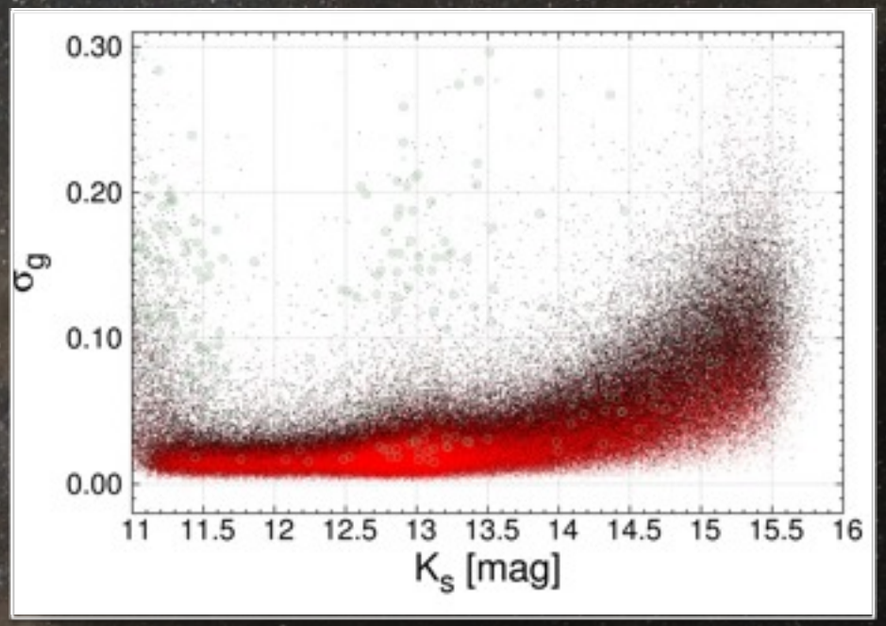
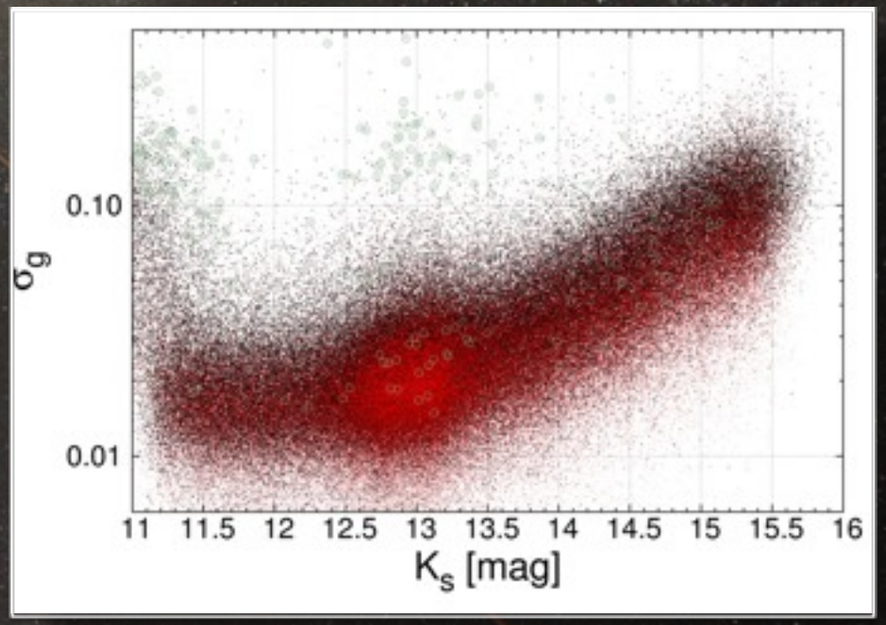
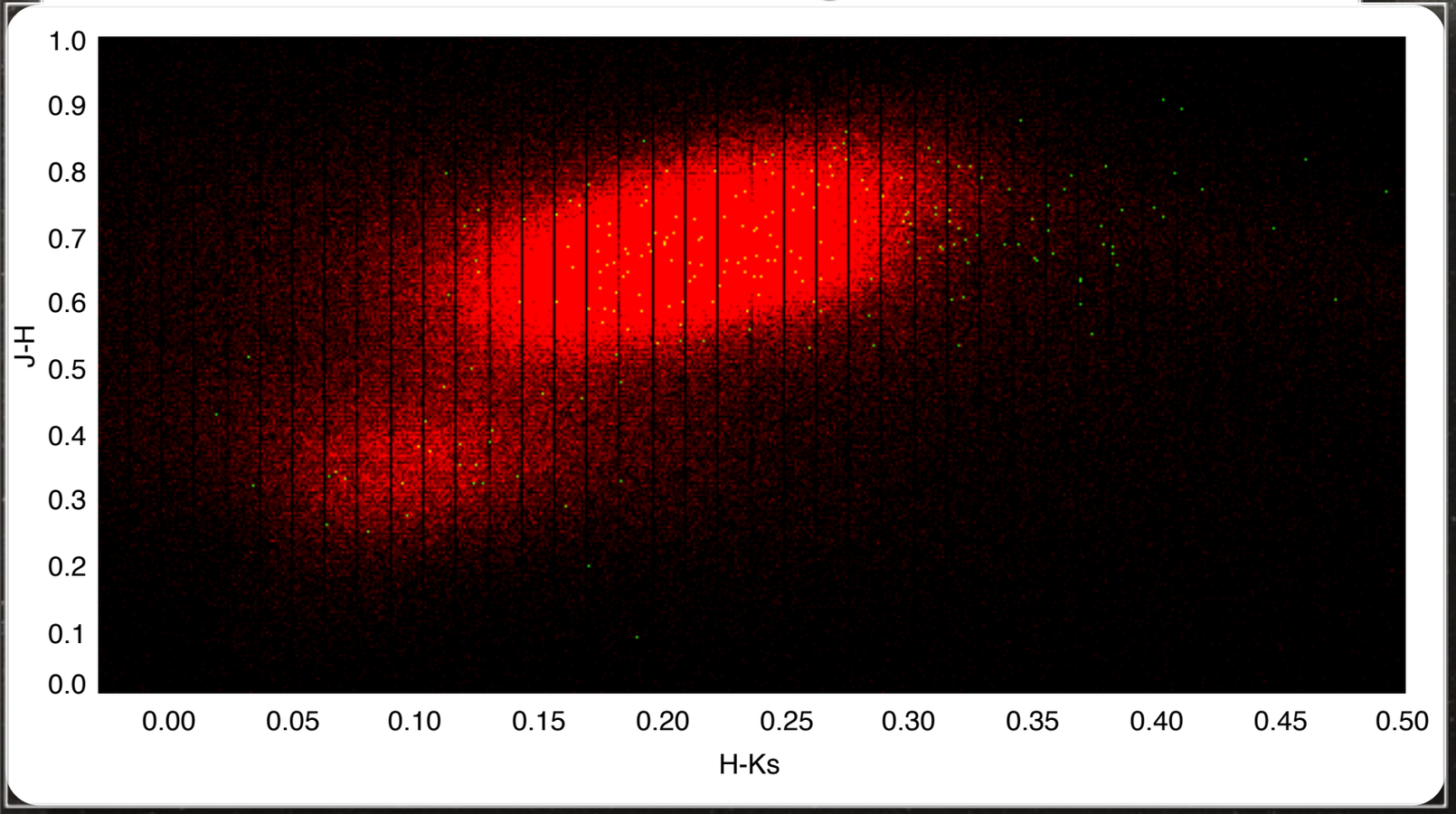








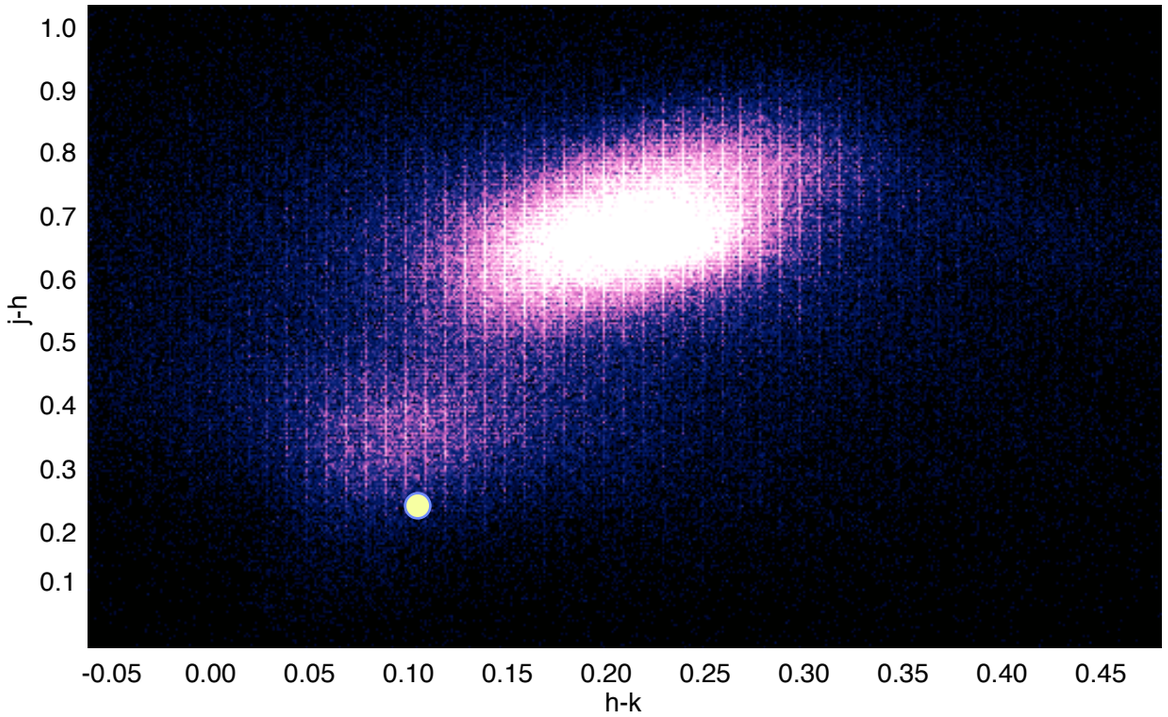
$$\Delta_\sigma \geq 8$$

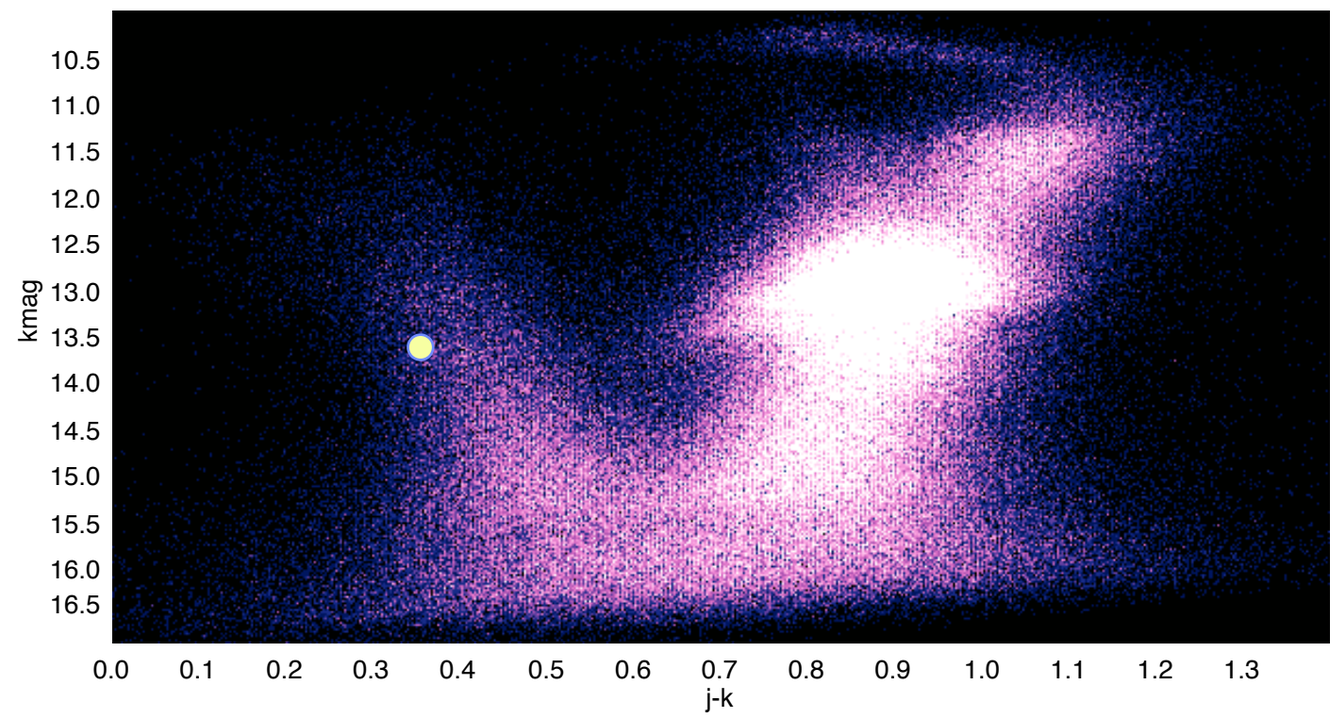
Baade-SV

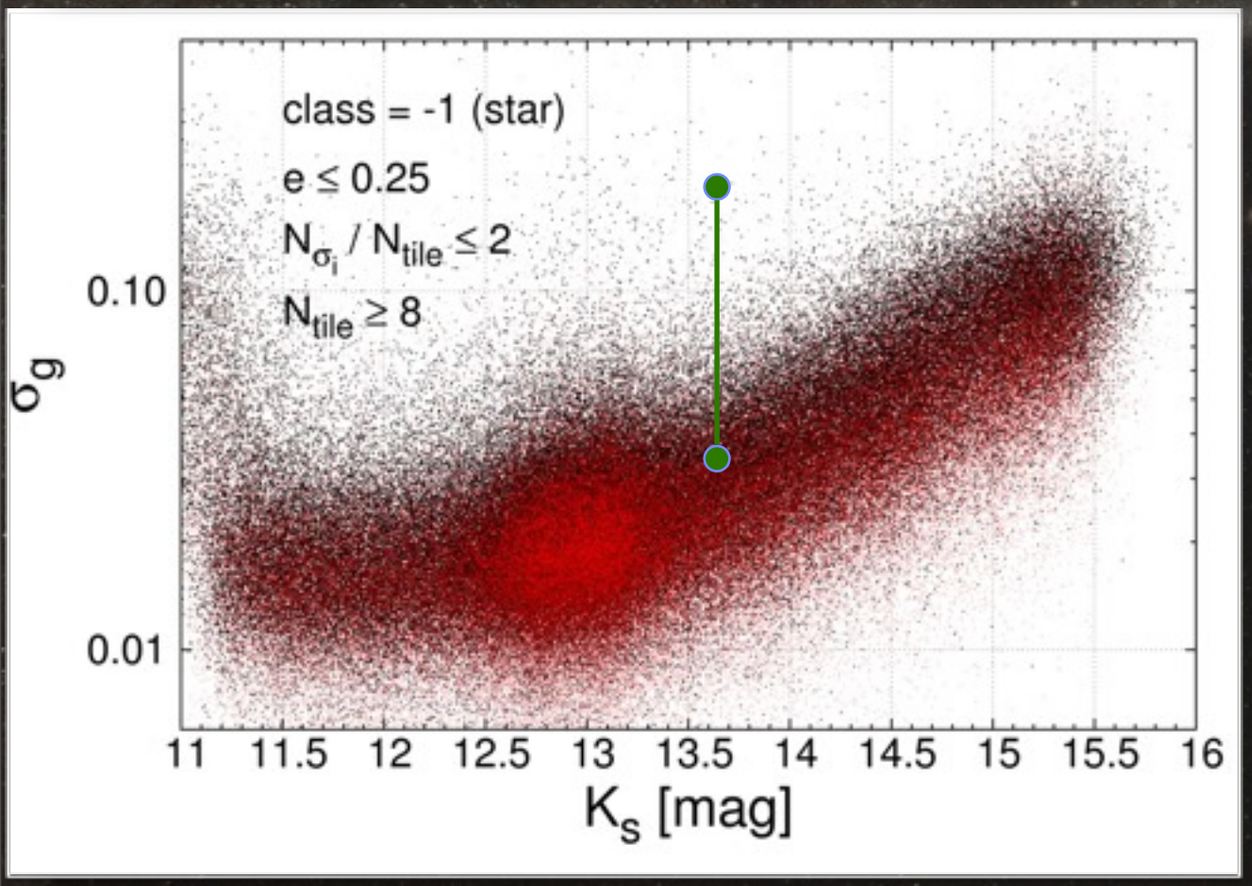
Baade-SV

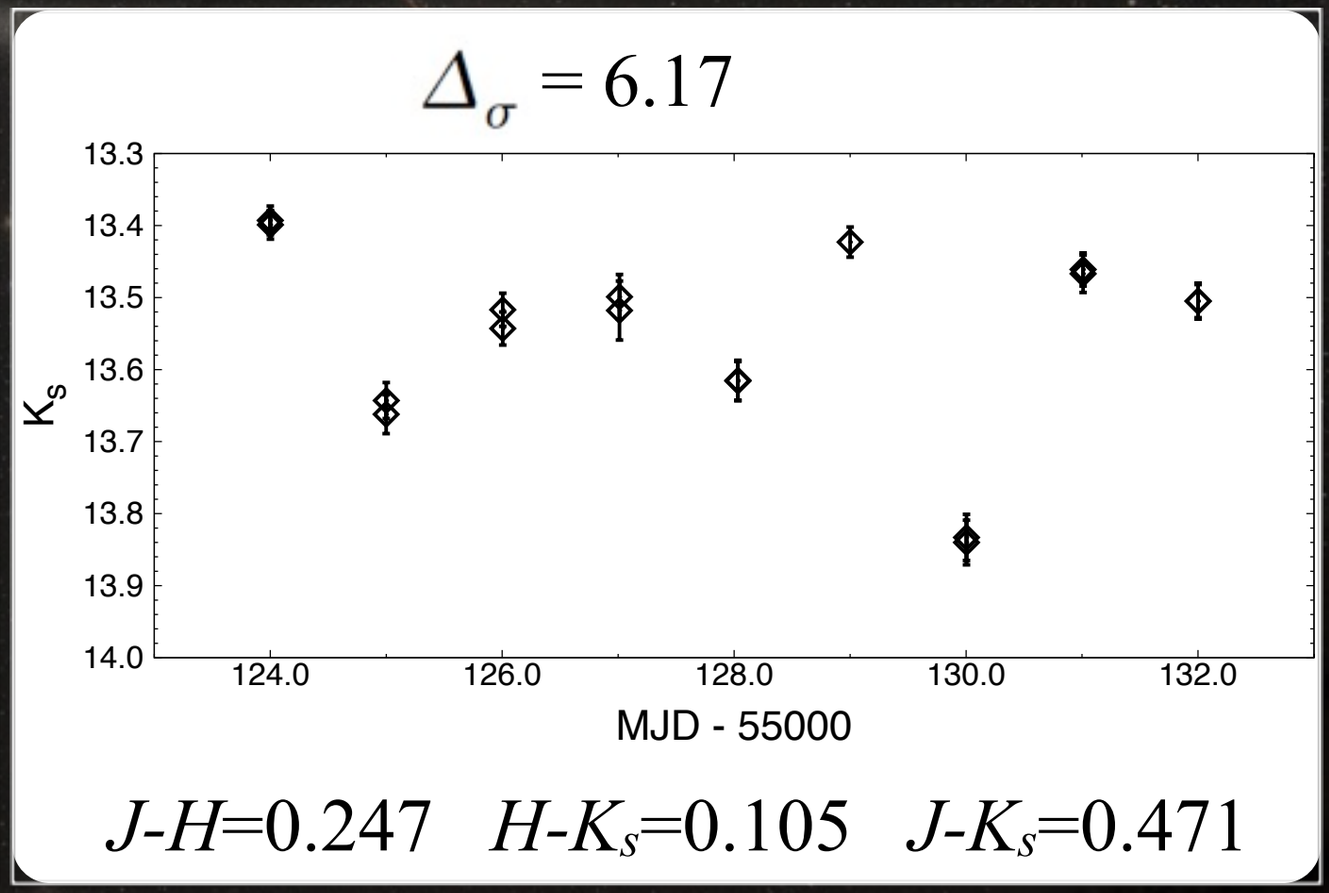
a few examples...

Credit: ESO









Baade-SV

a few examples...

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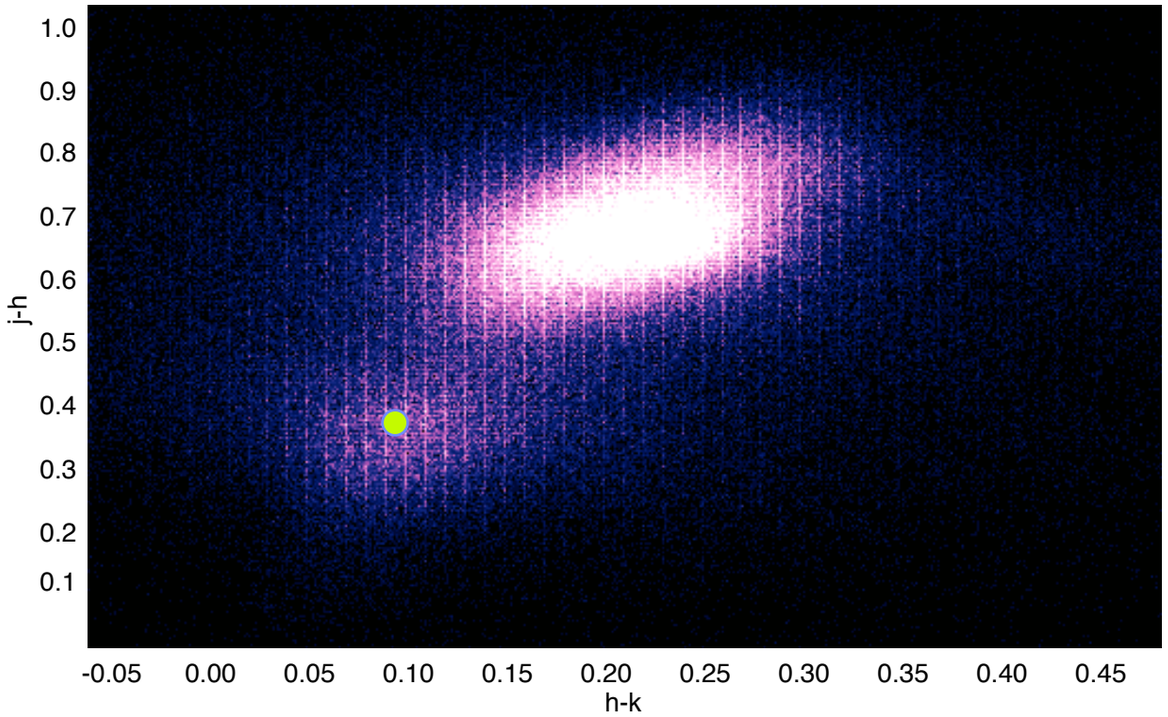

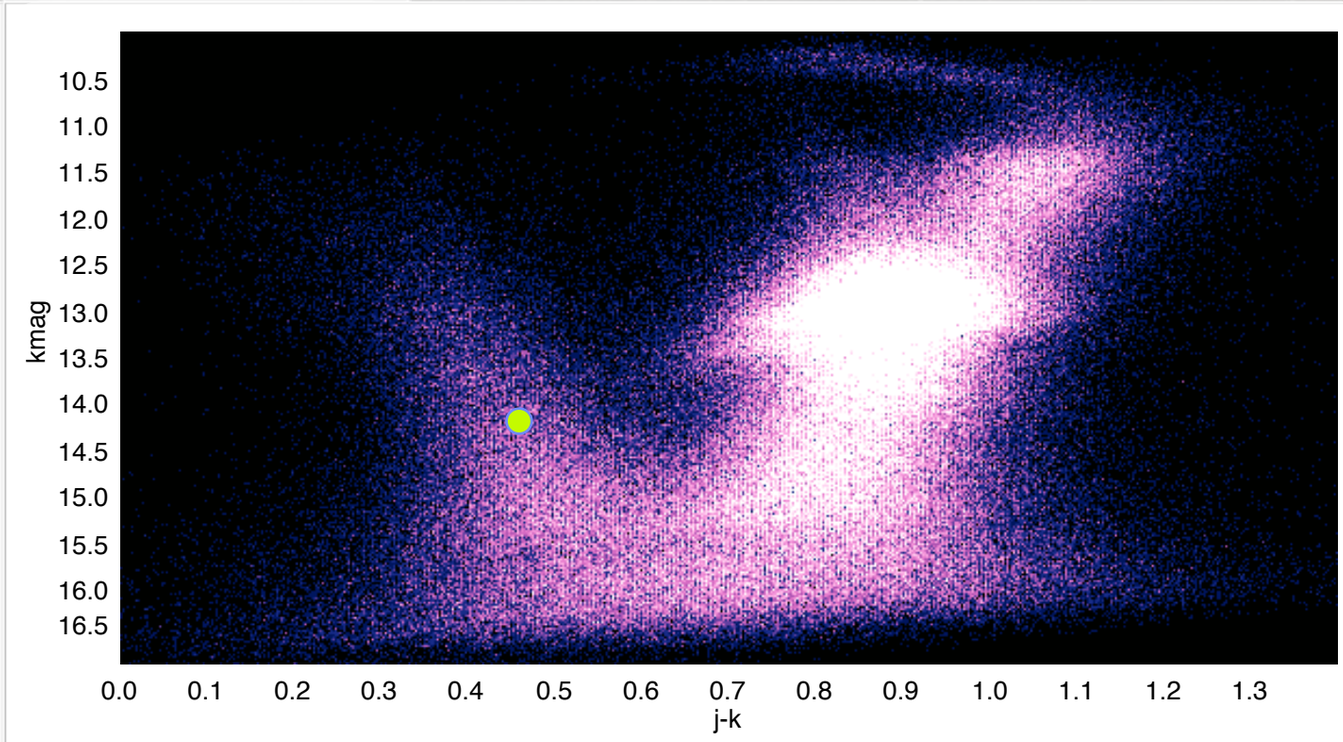

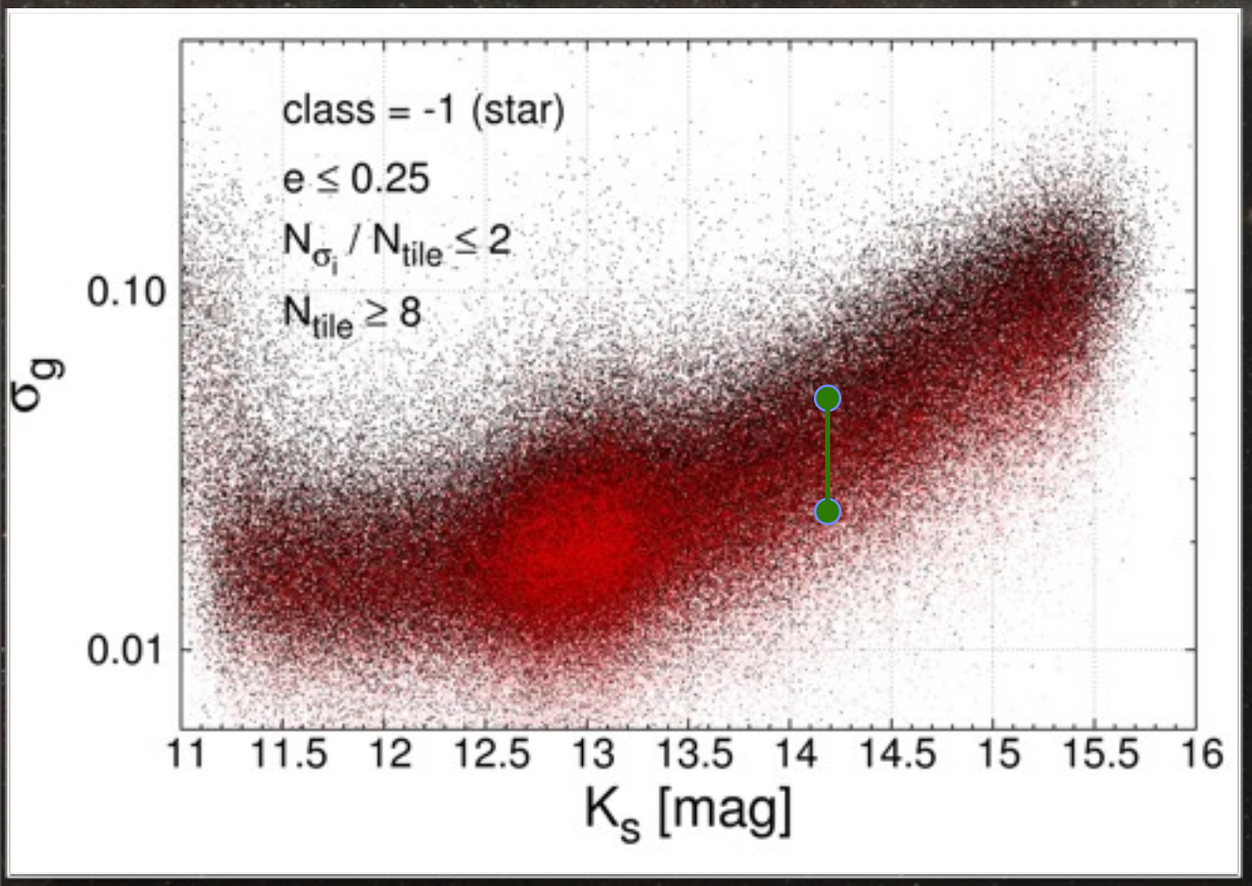

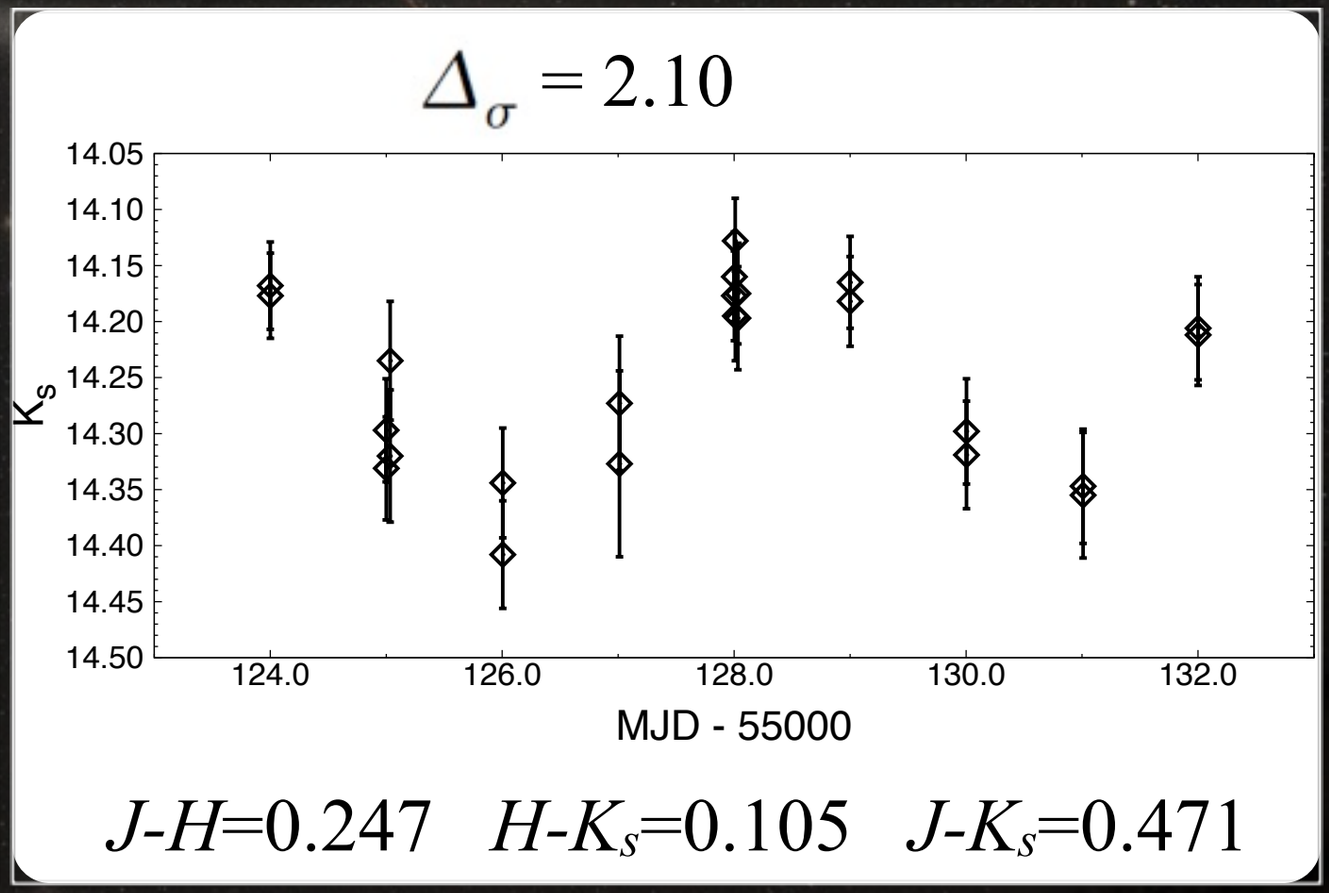

Baade-SV

a few examples...

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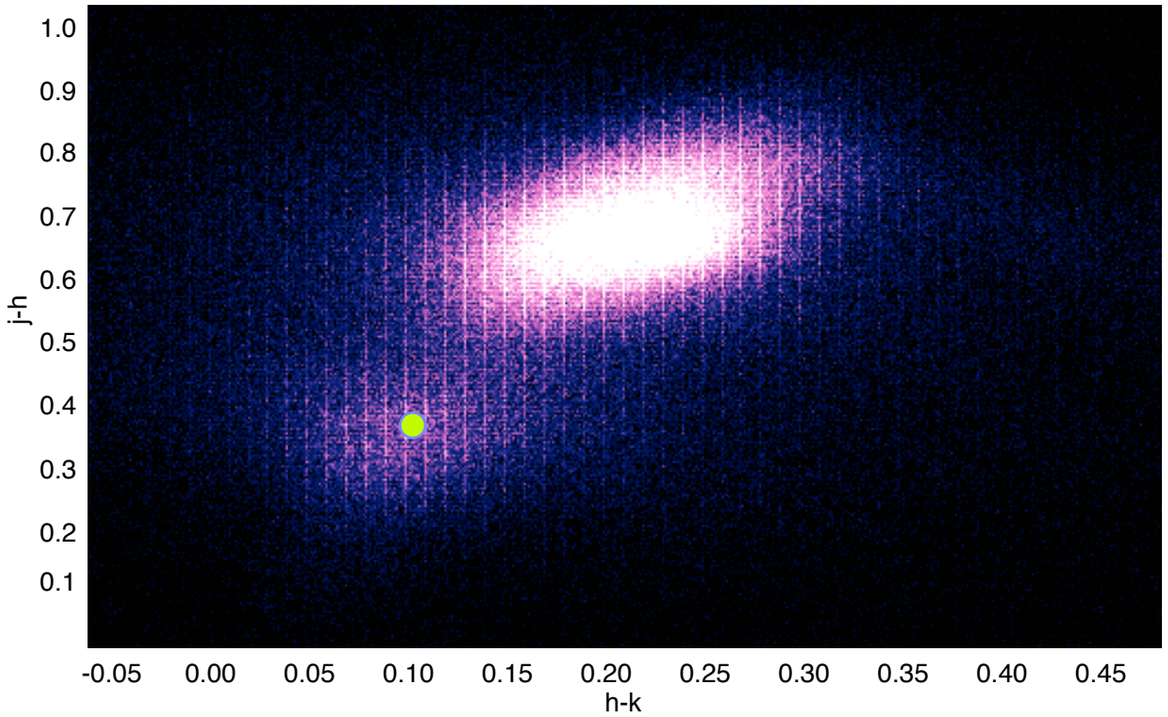
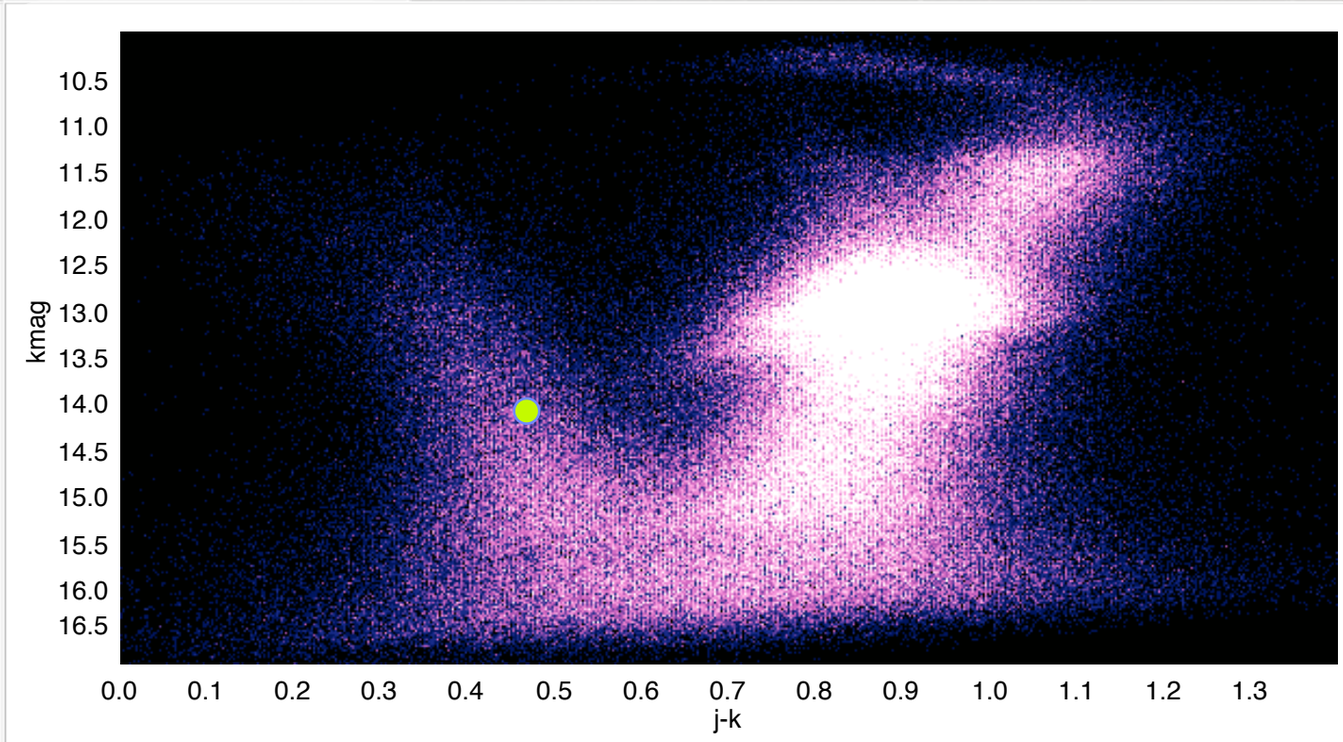
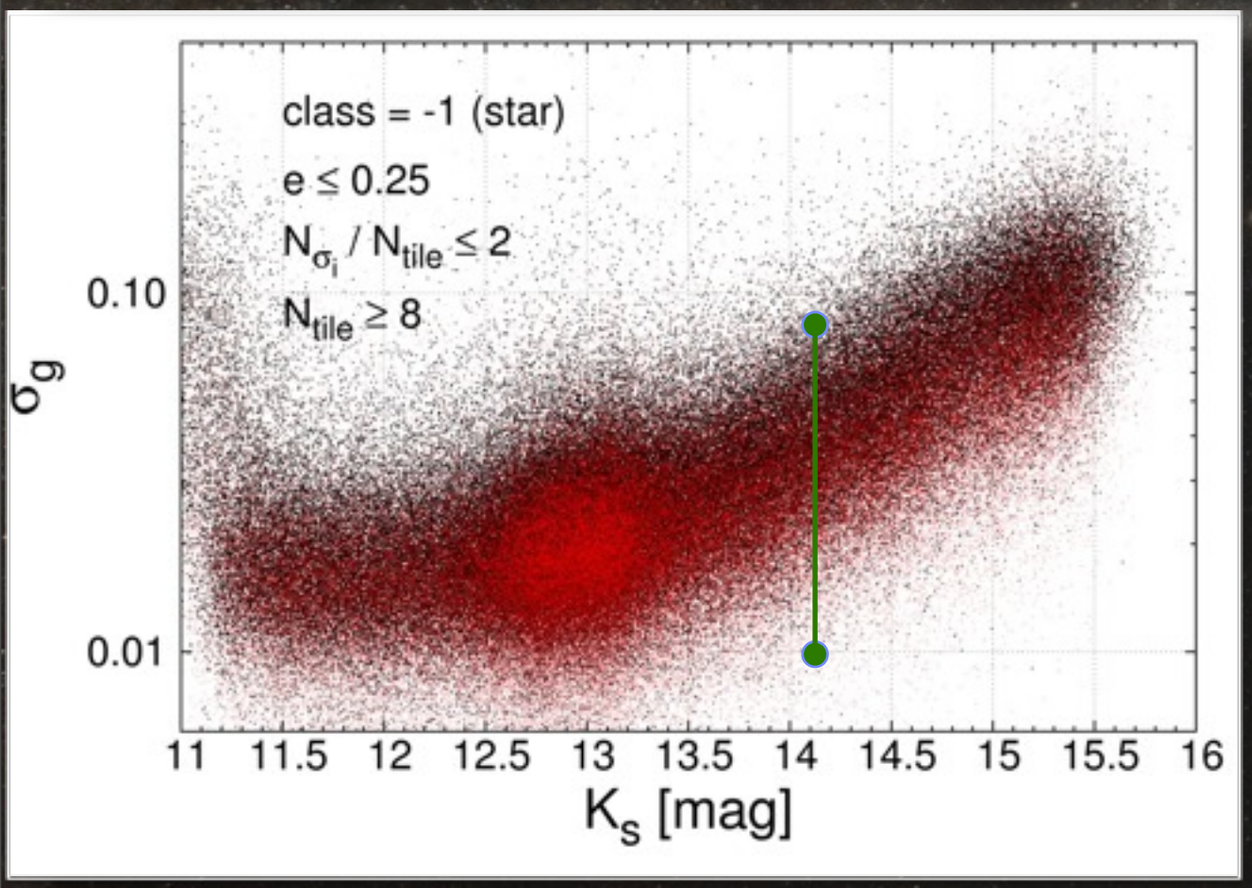
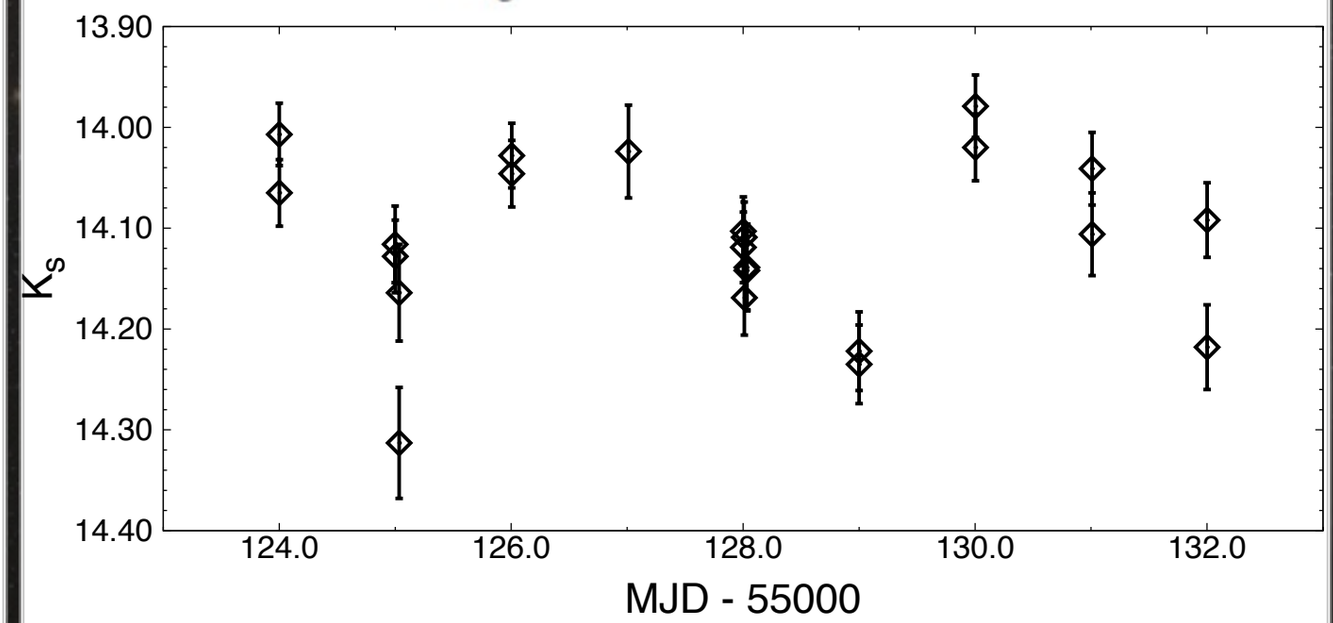




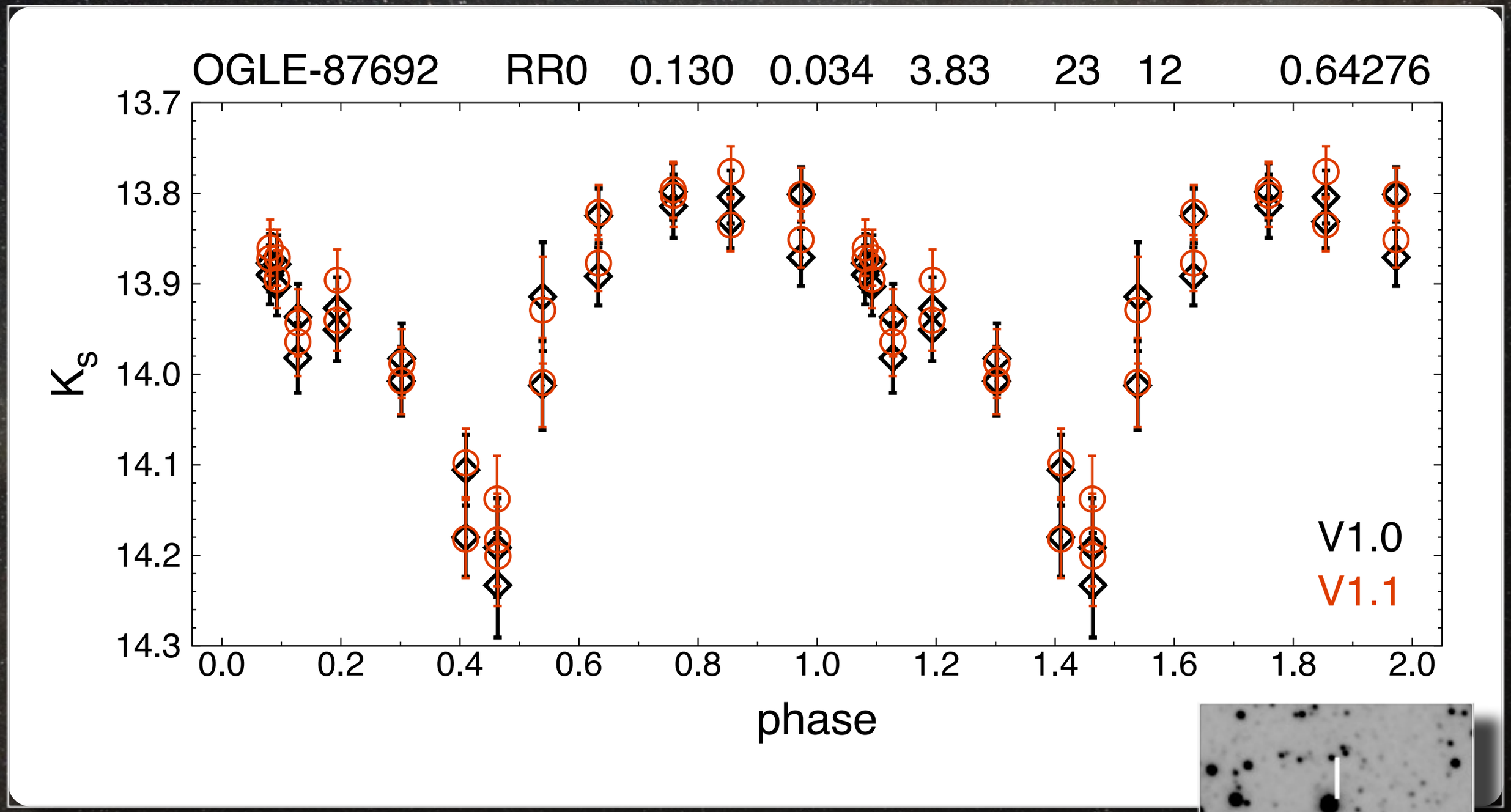


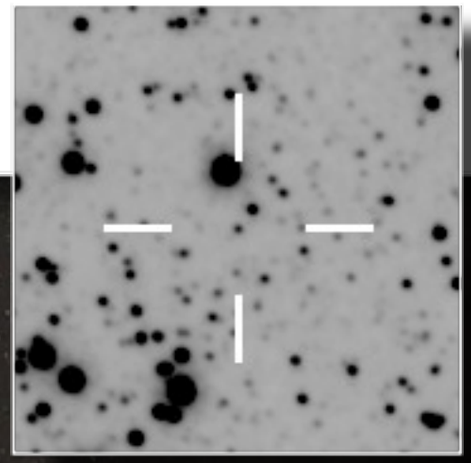
$\Delta_\sigma = 8.72$



J-H=0.366 H-K_s=0.105 J-K_s=0.471

RR Lyrae Light Curves





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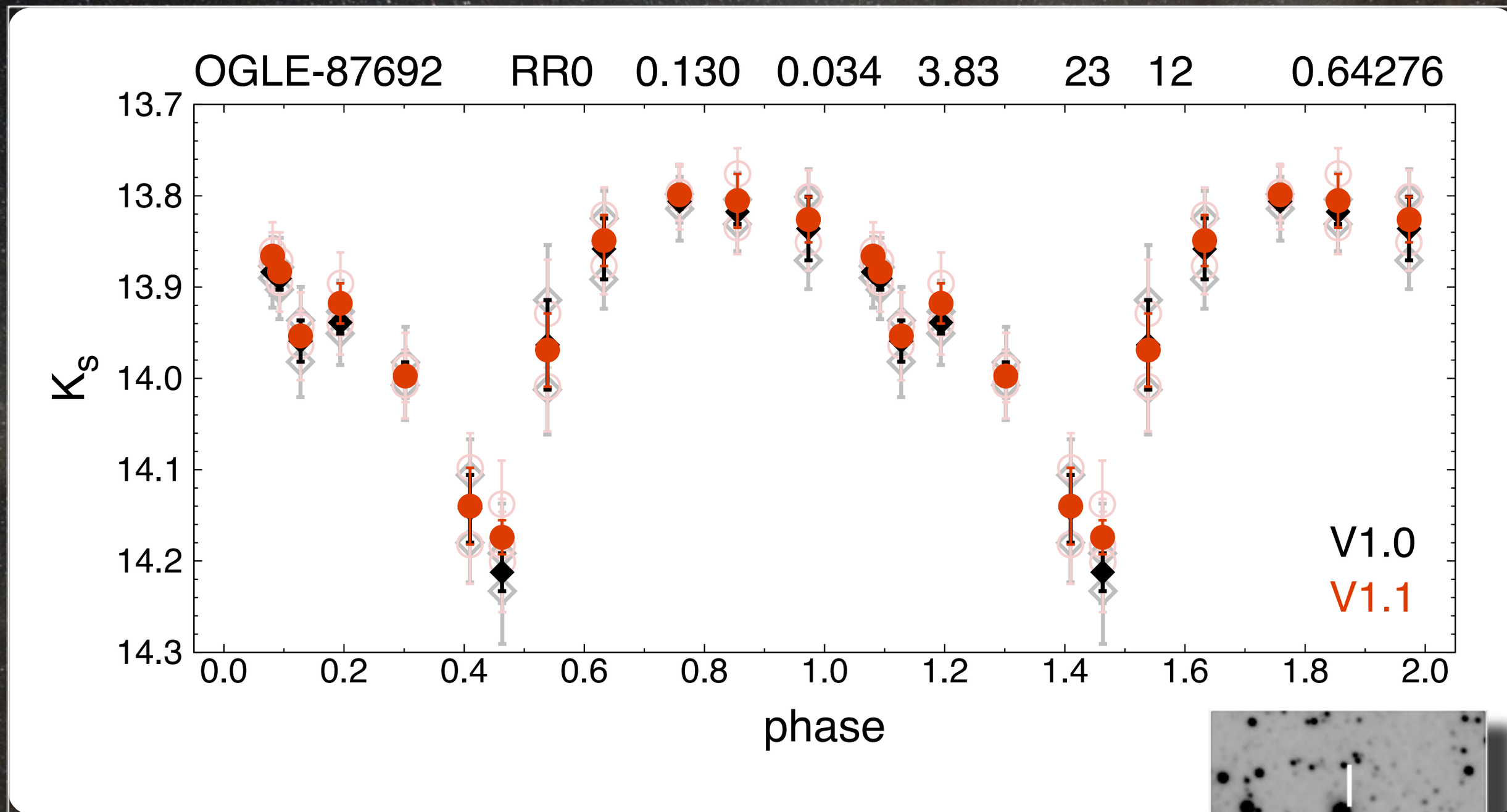

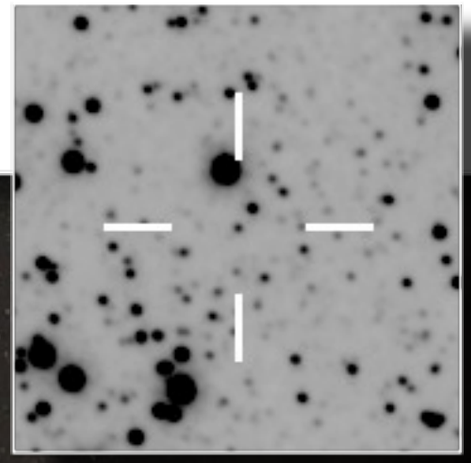

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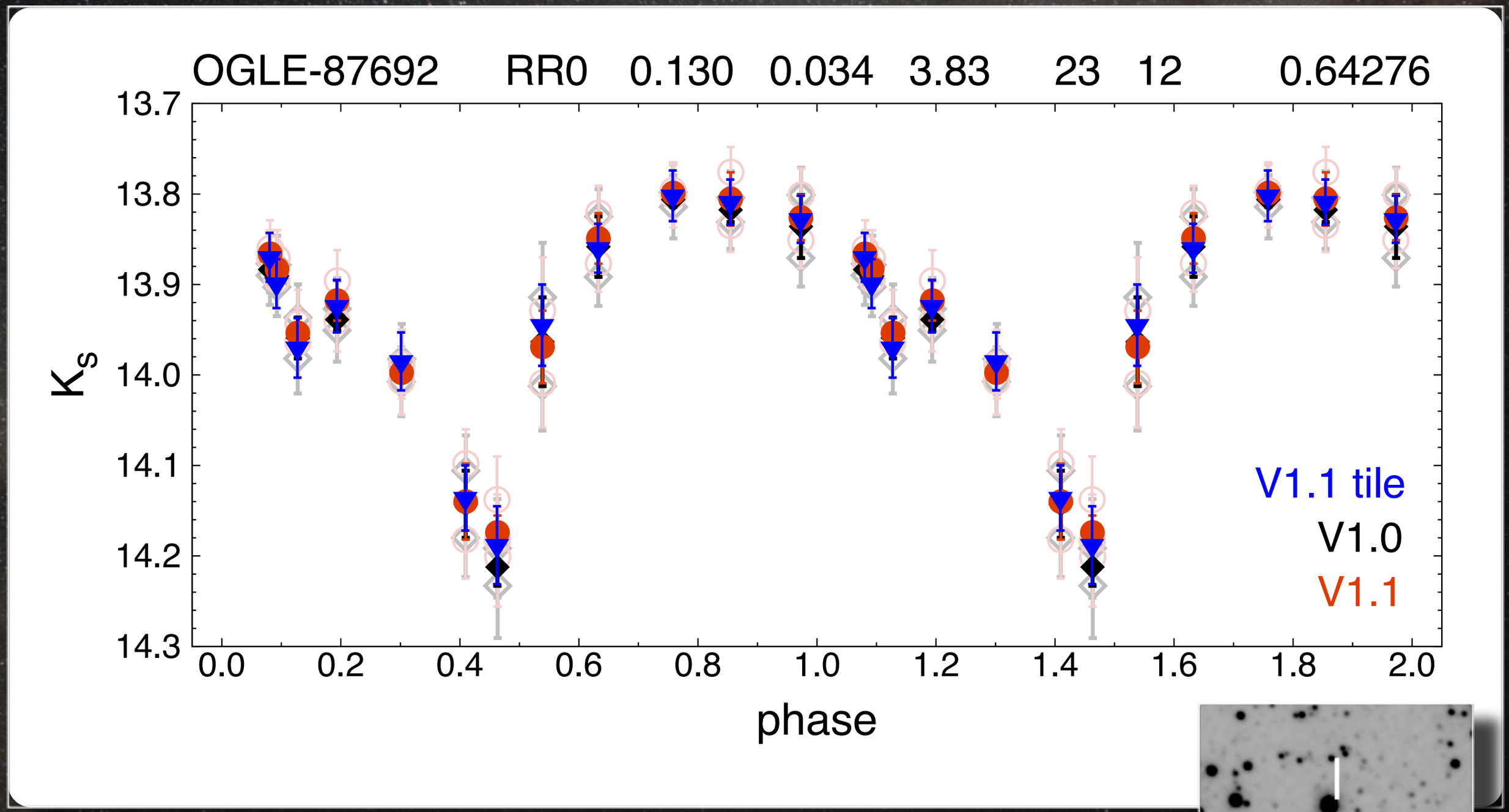

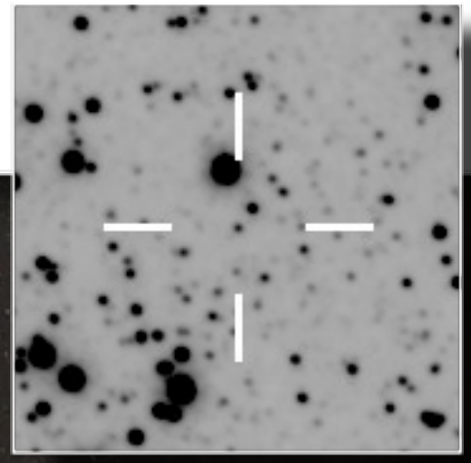

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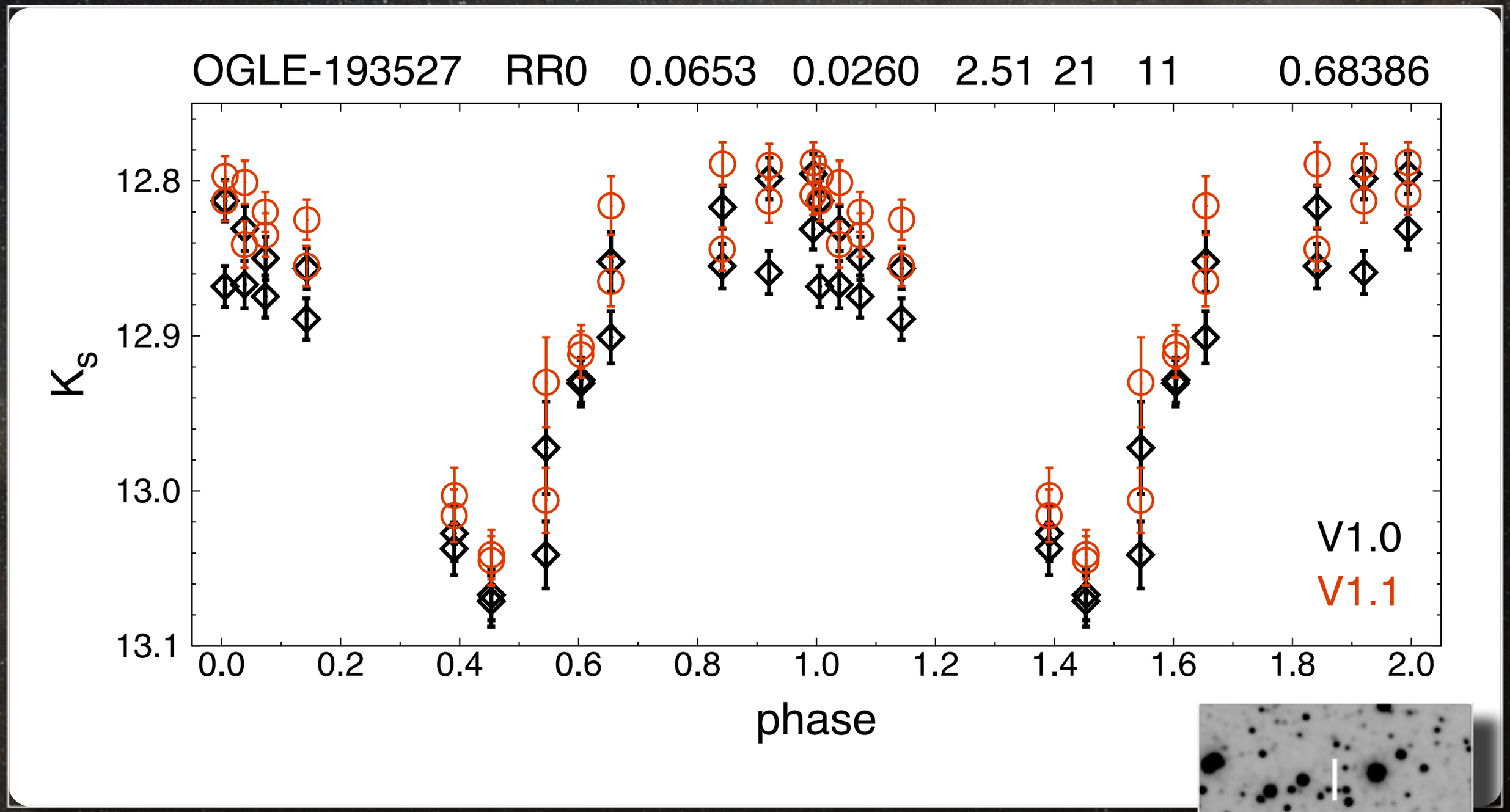

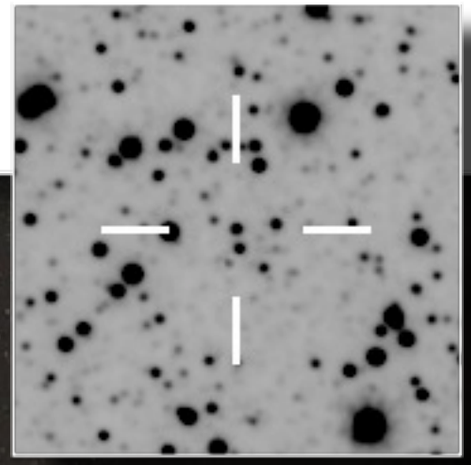

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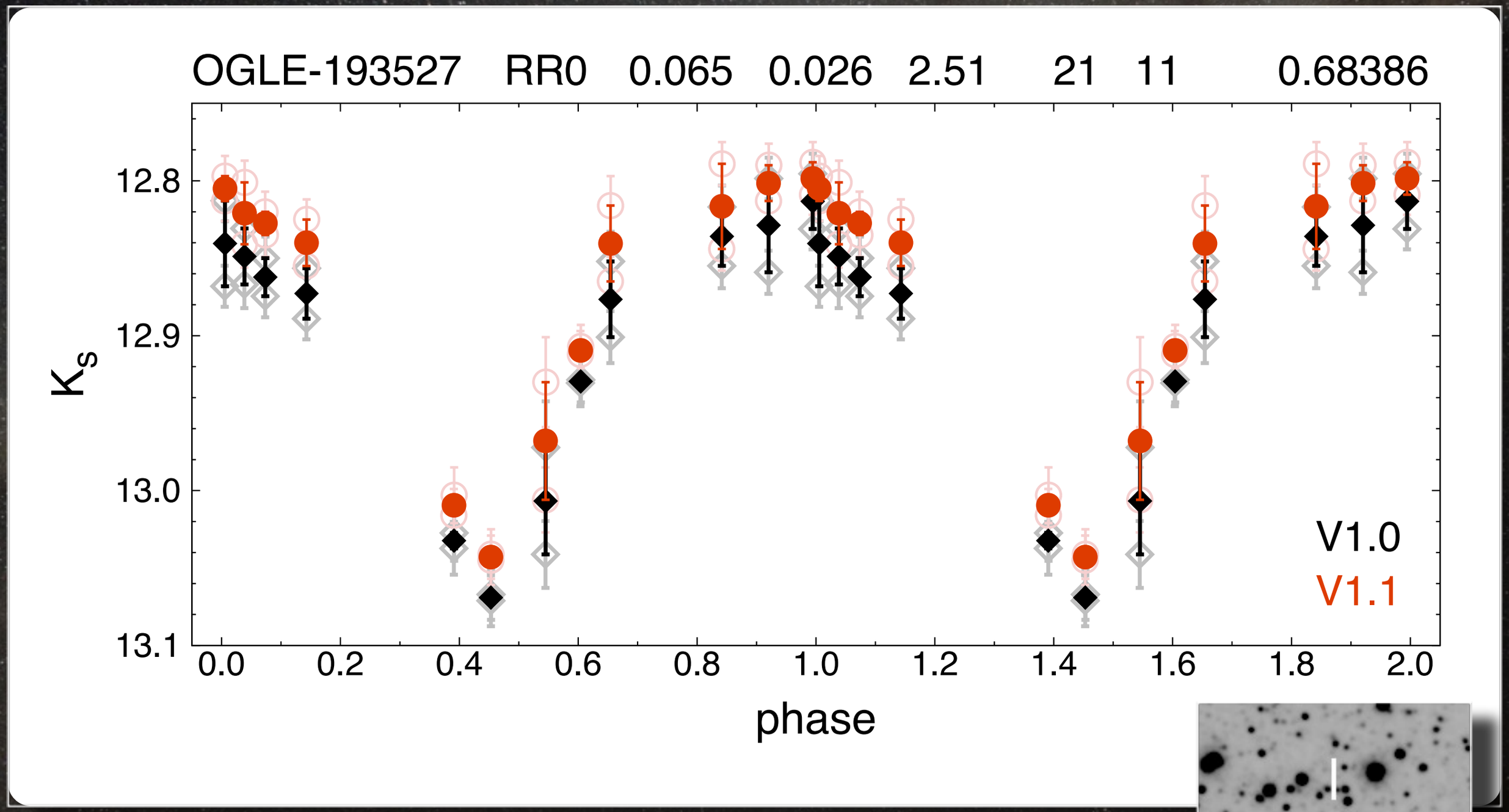
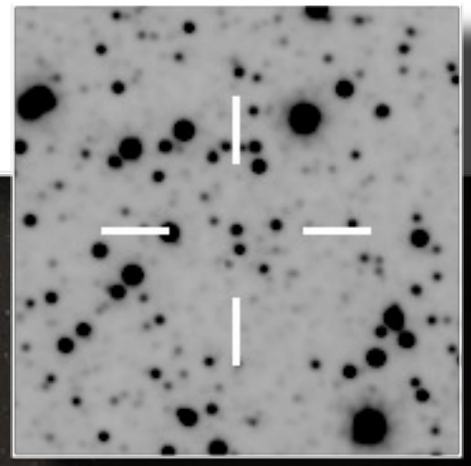
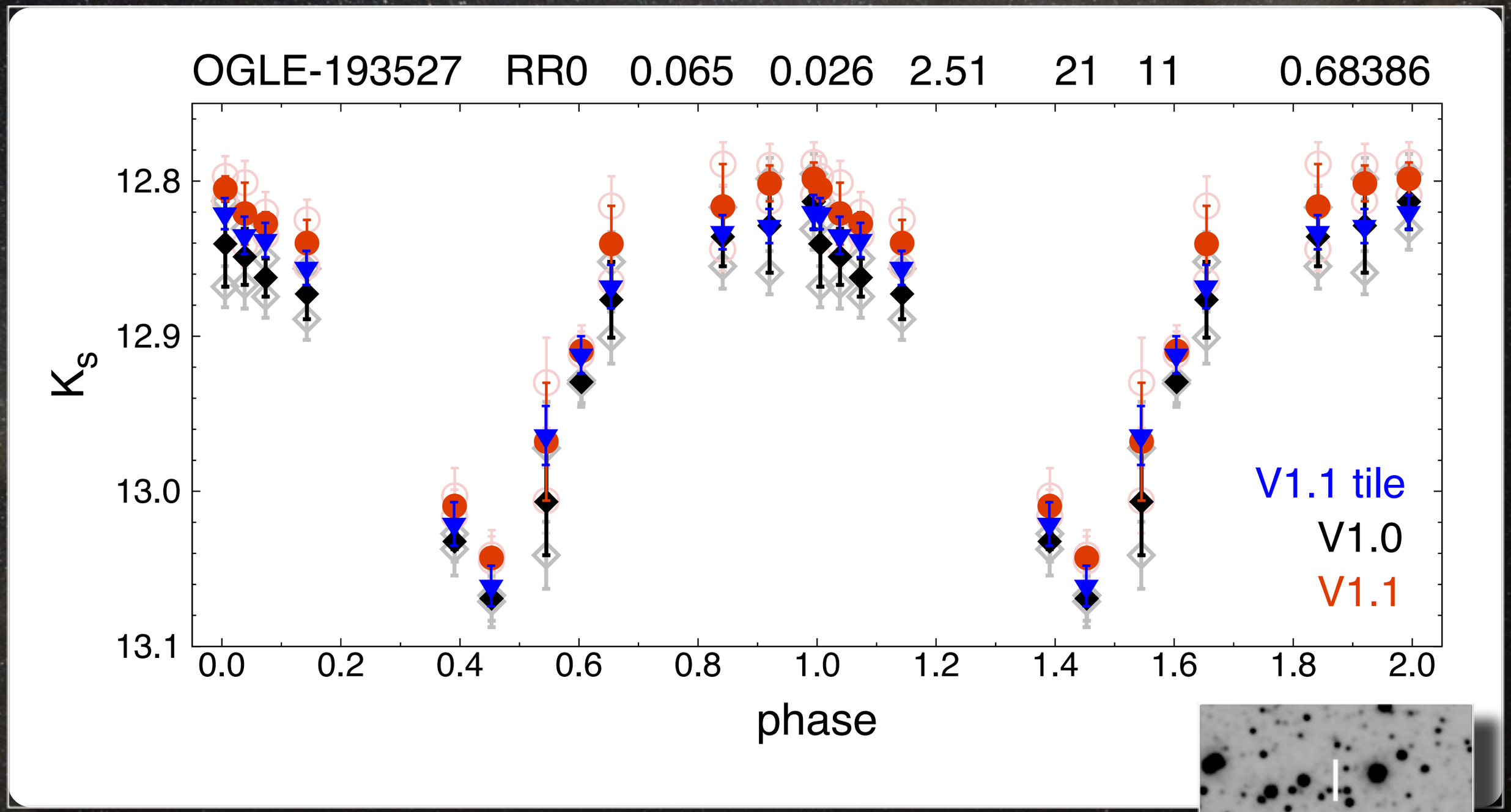
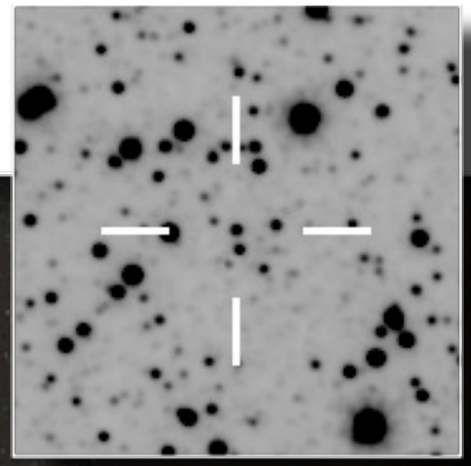




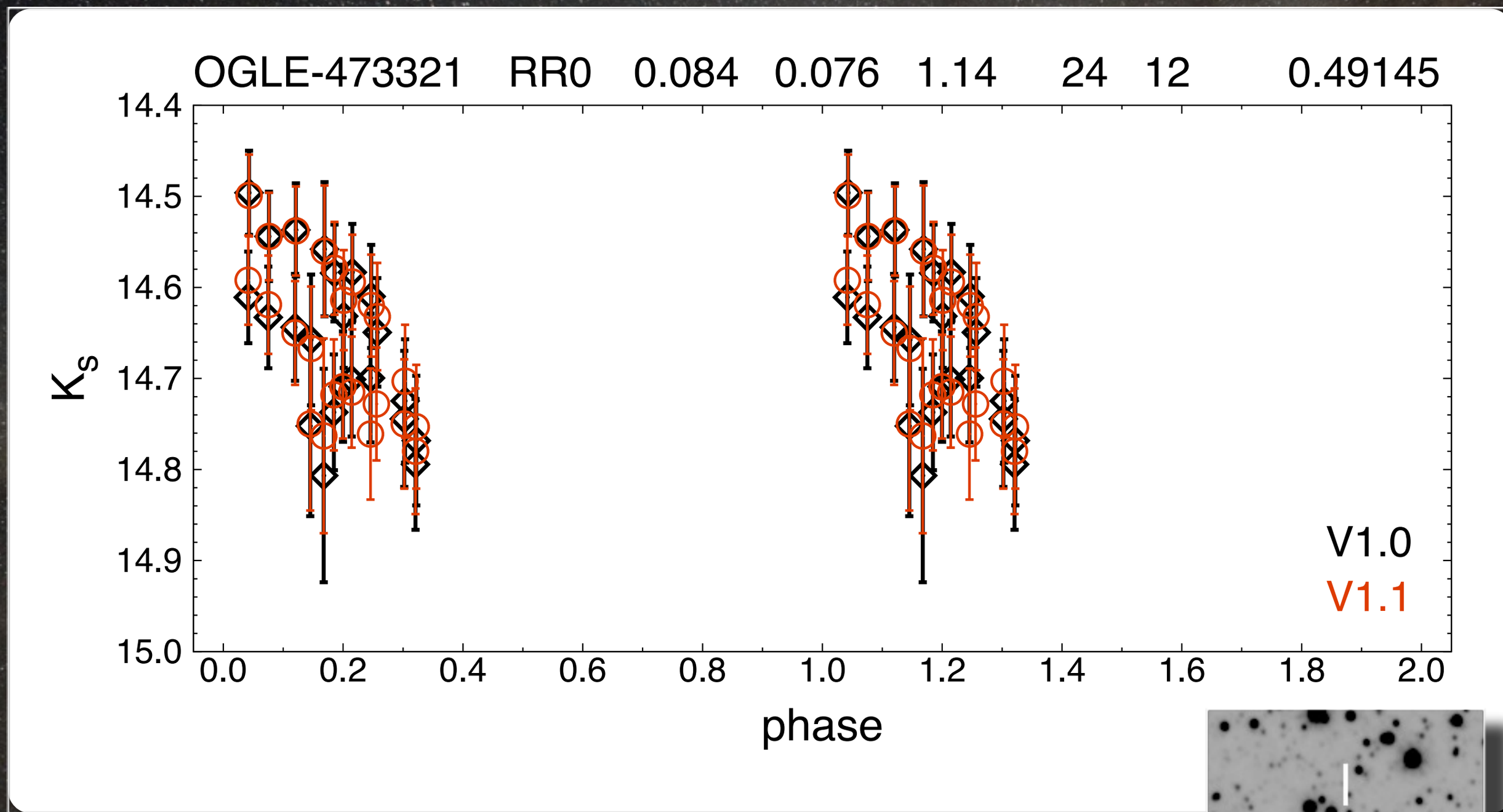
Credit: ESO

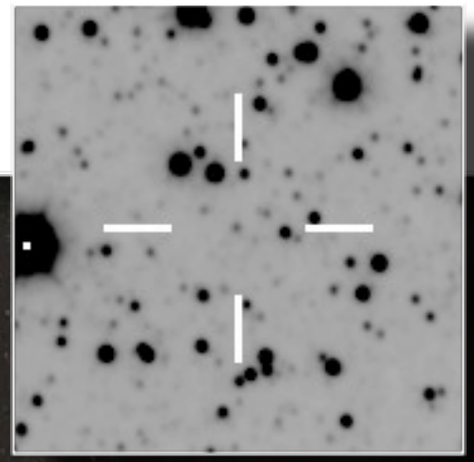
RR Lyrae Light Curves



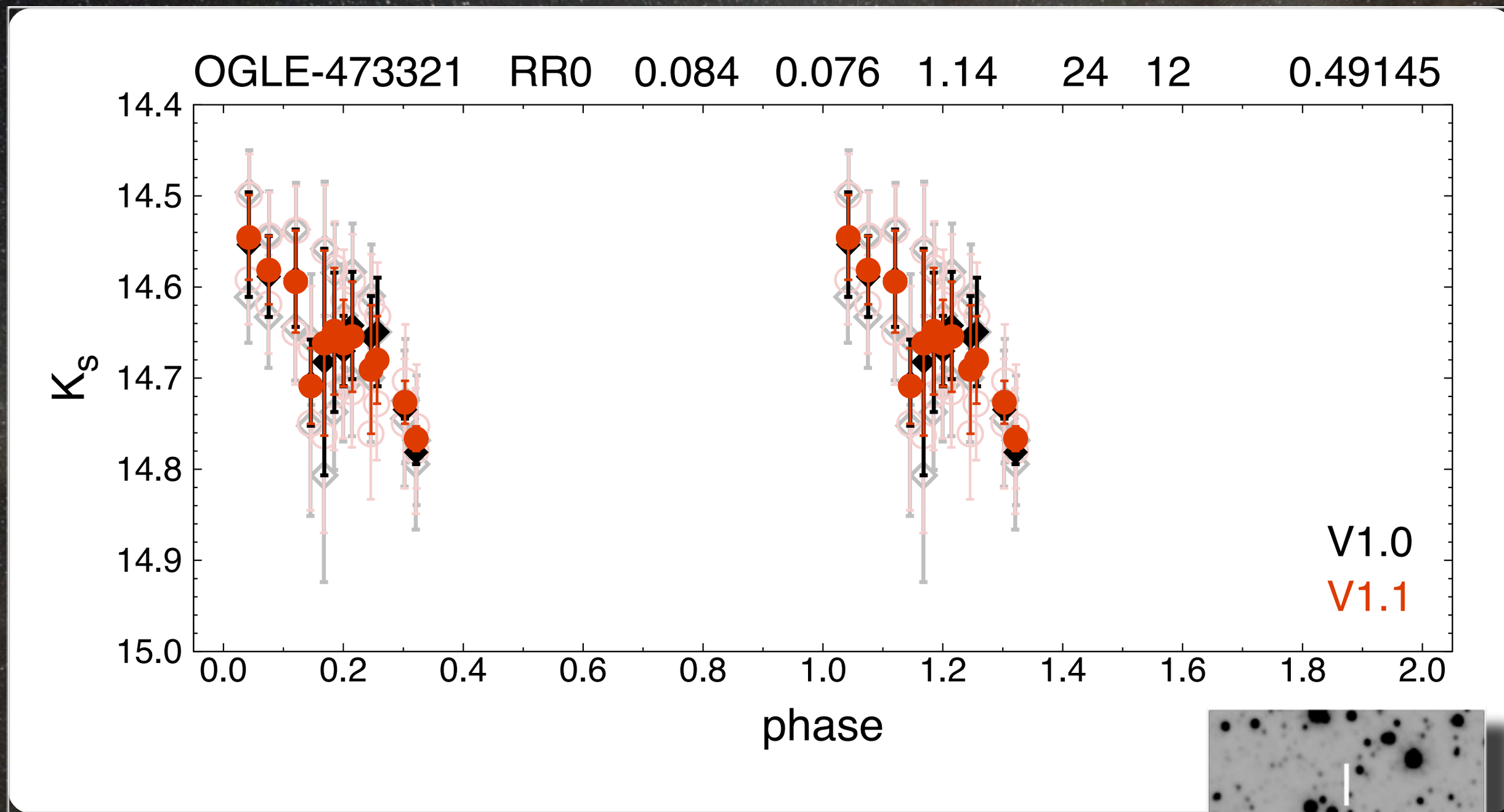


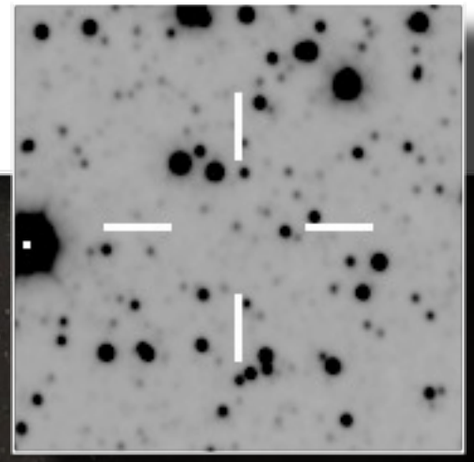
RR Lyrae Light Curves



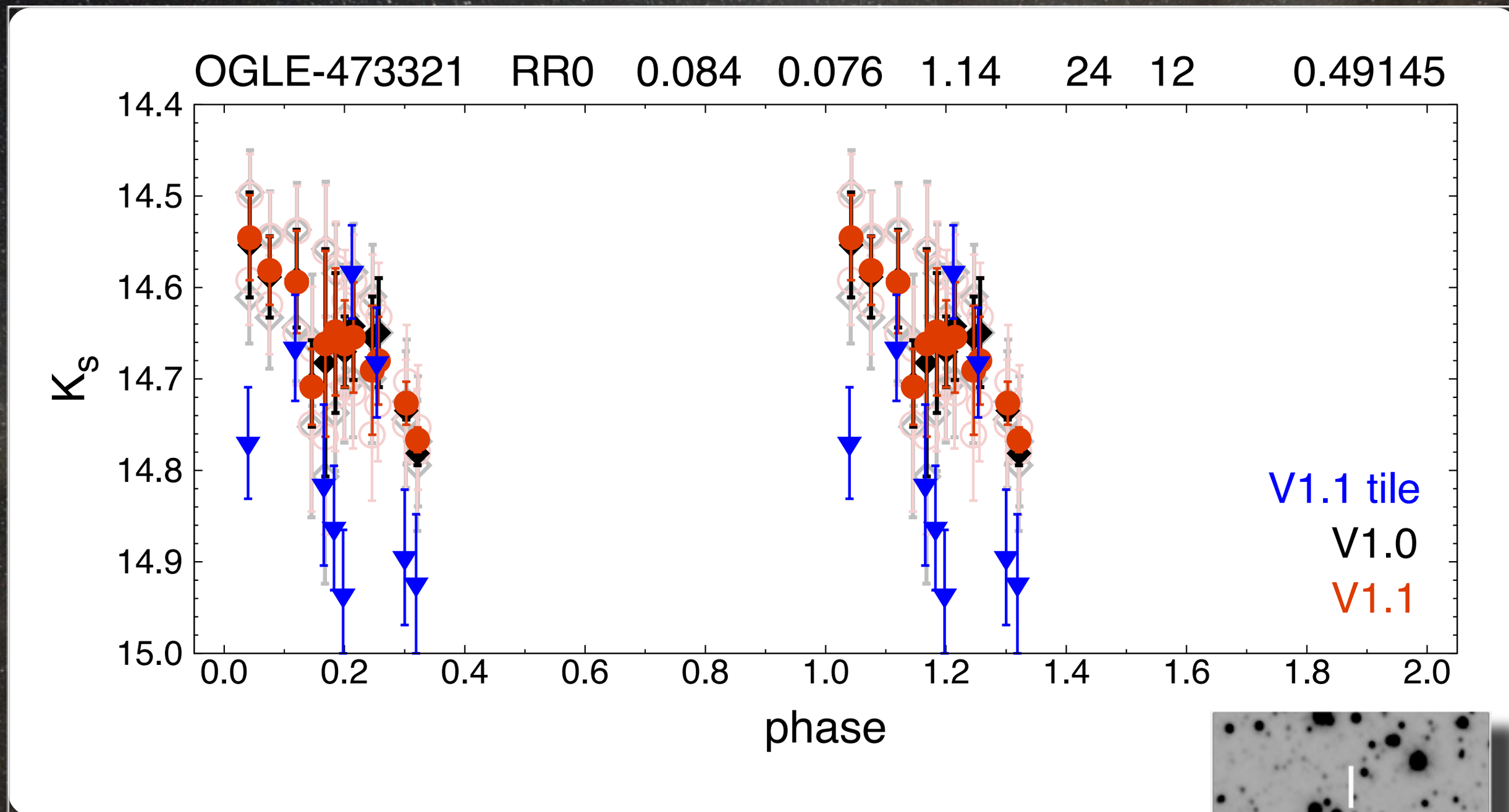


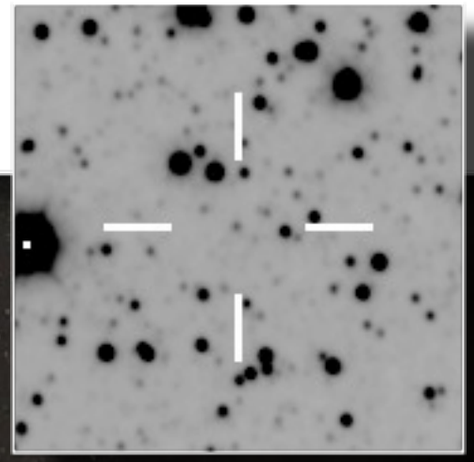
RR Lyrae Light Curves



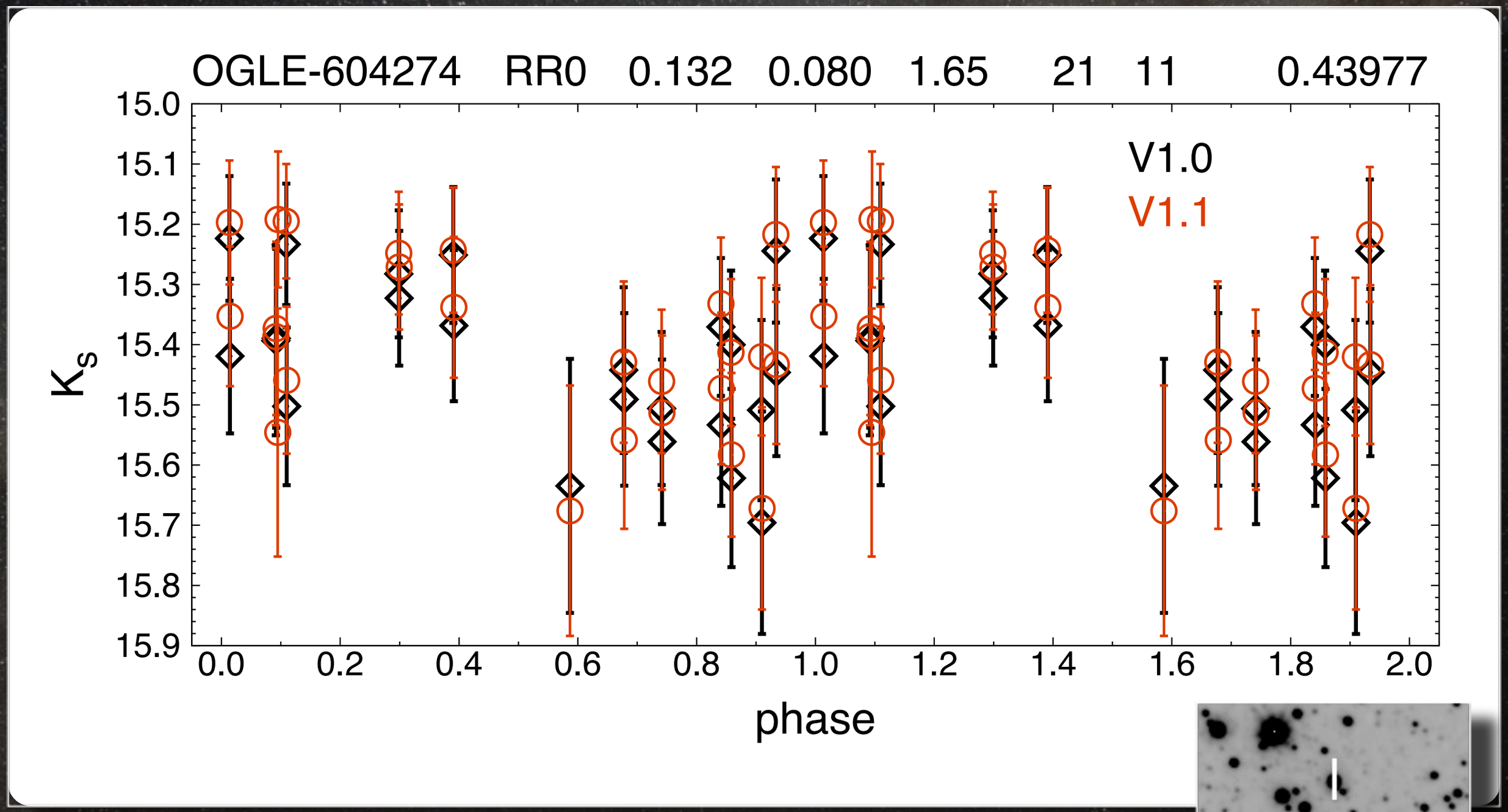


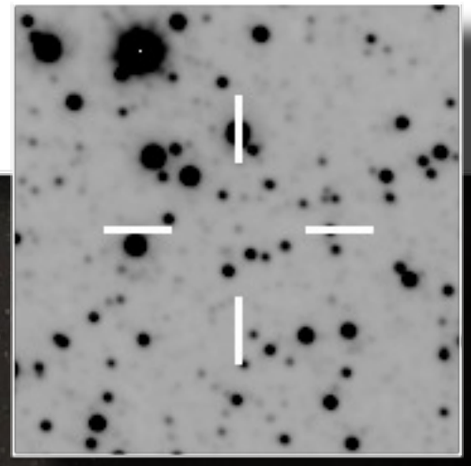
RR Lyrae Light Curves



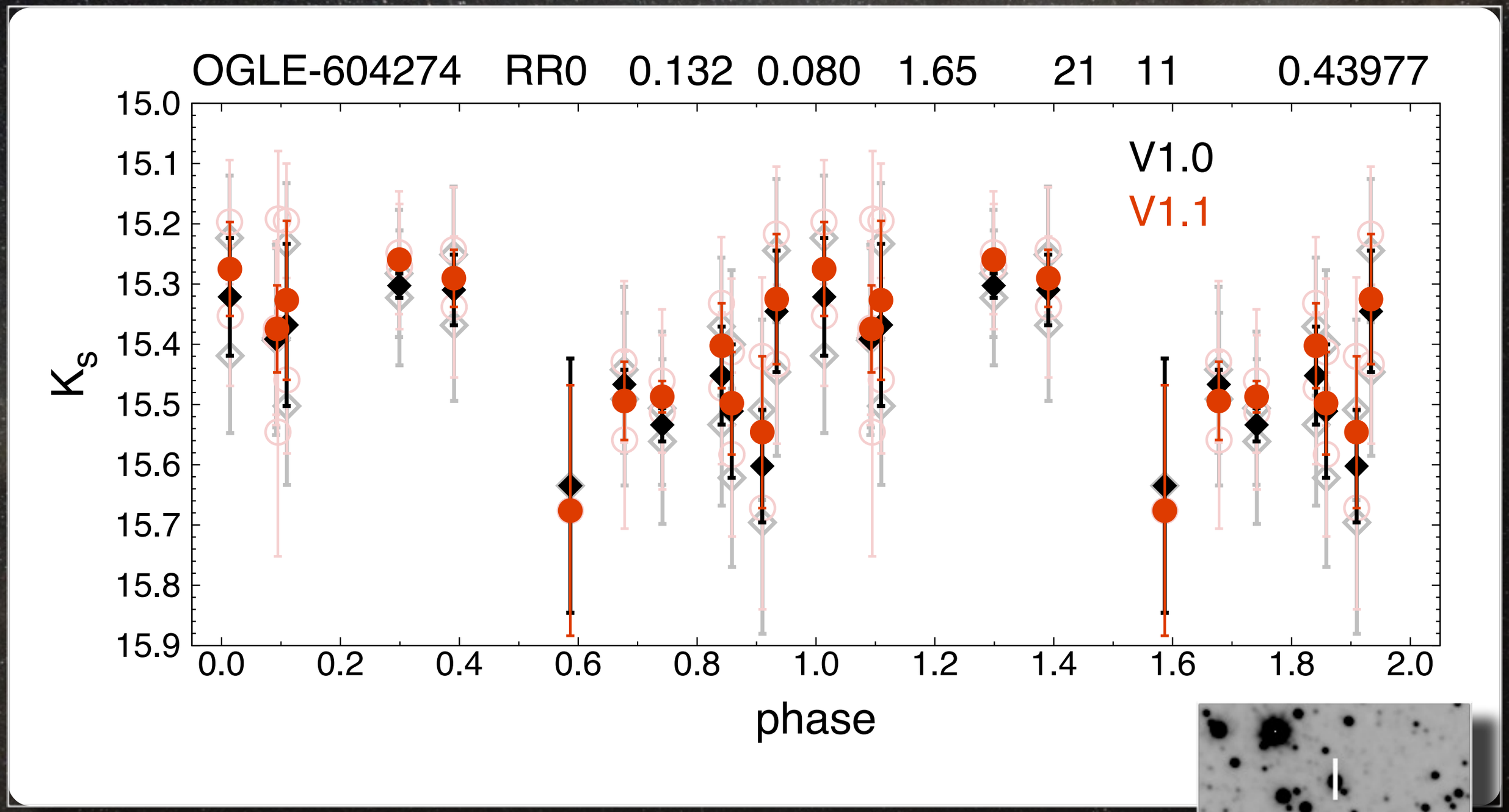


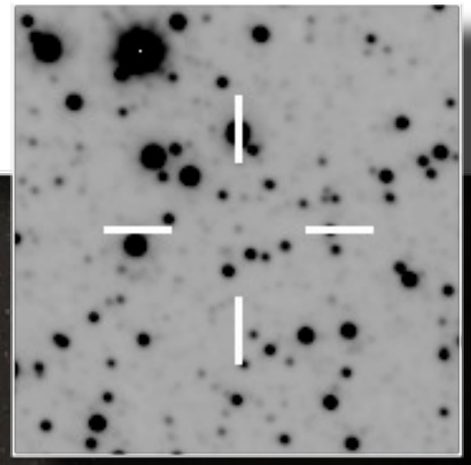
RR Lyrae Light Curves



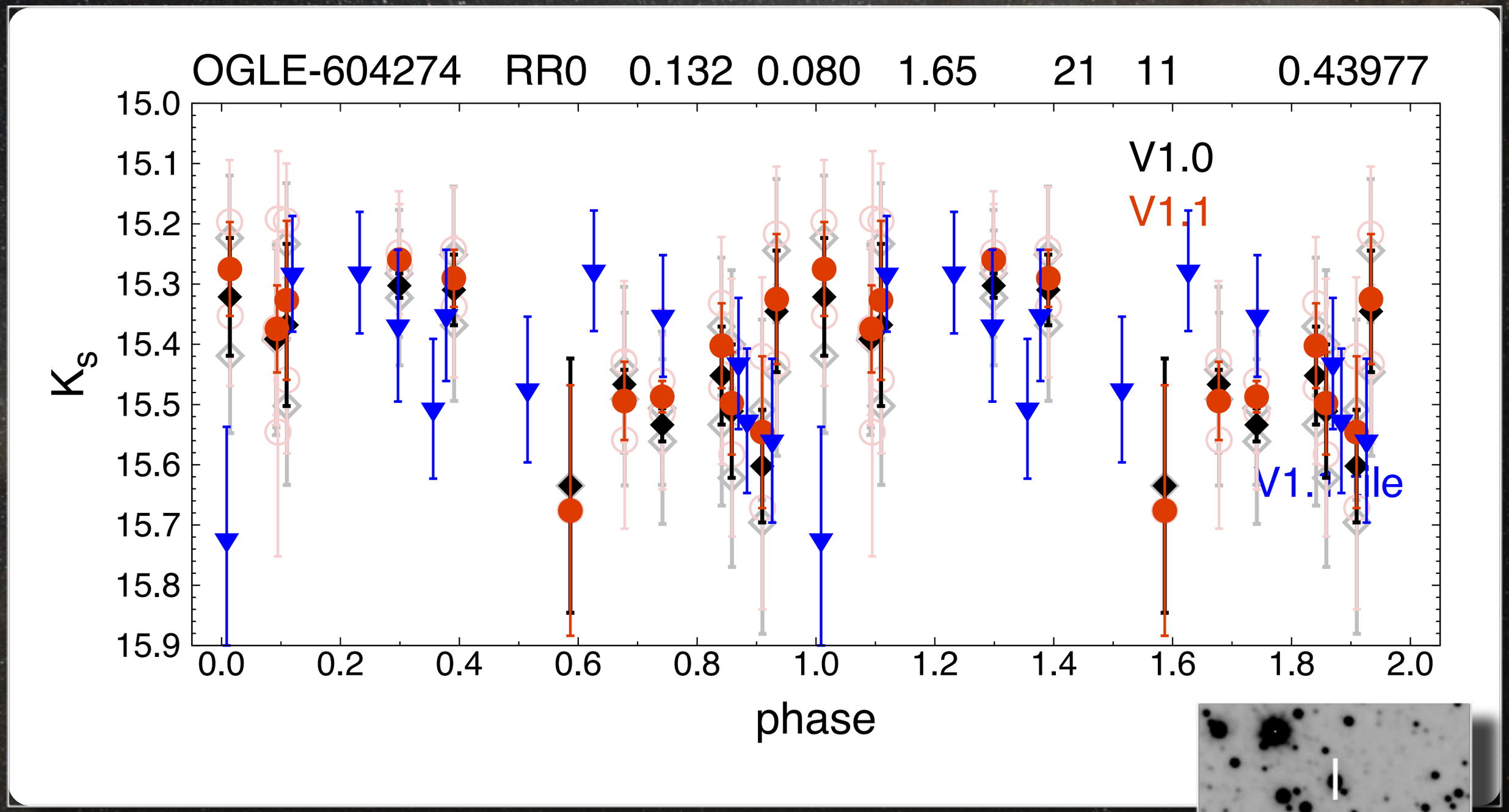


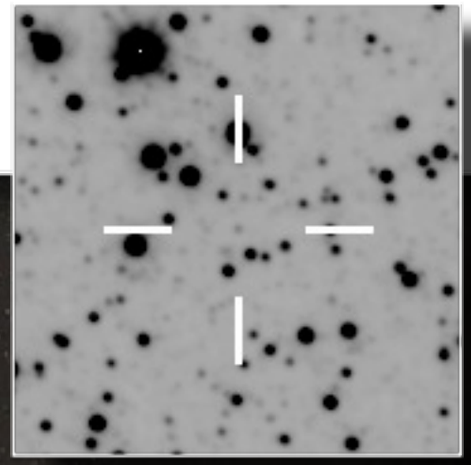
RR Lyrae Light Curves



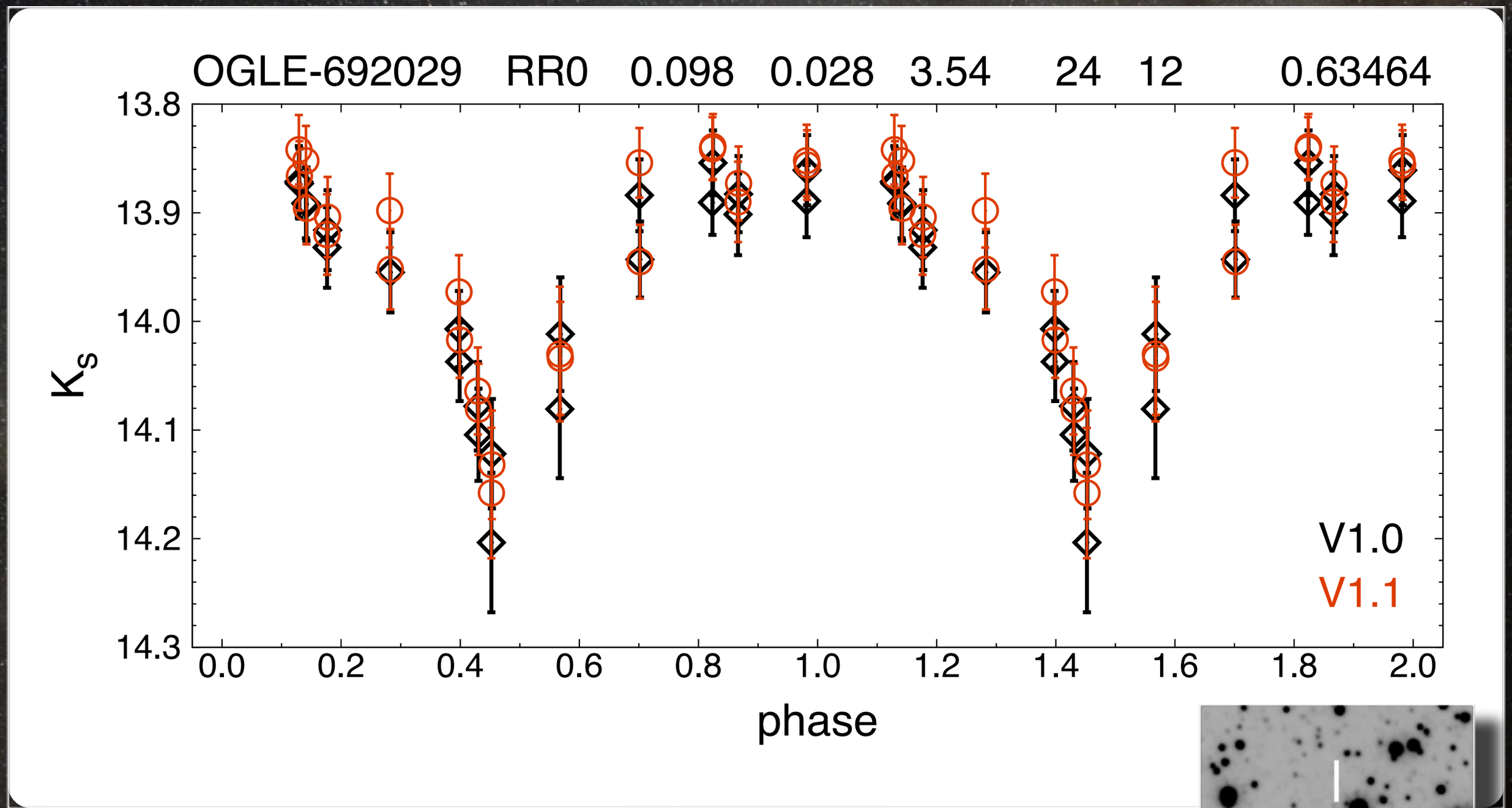


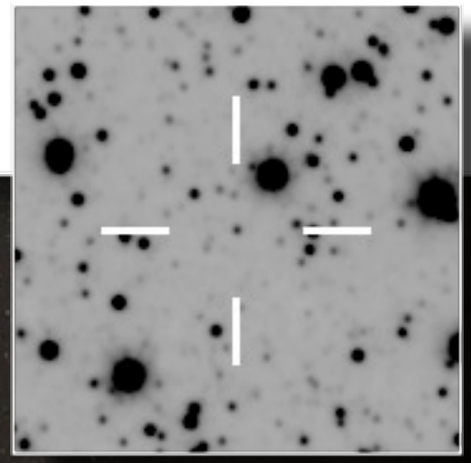
RR Lyrae Light Curves



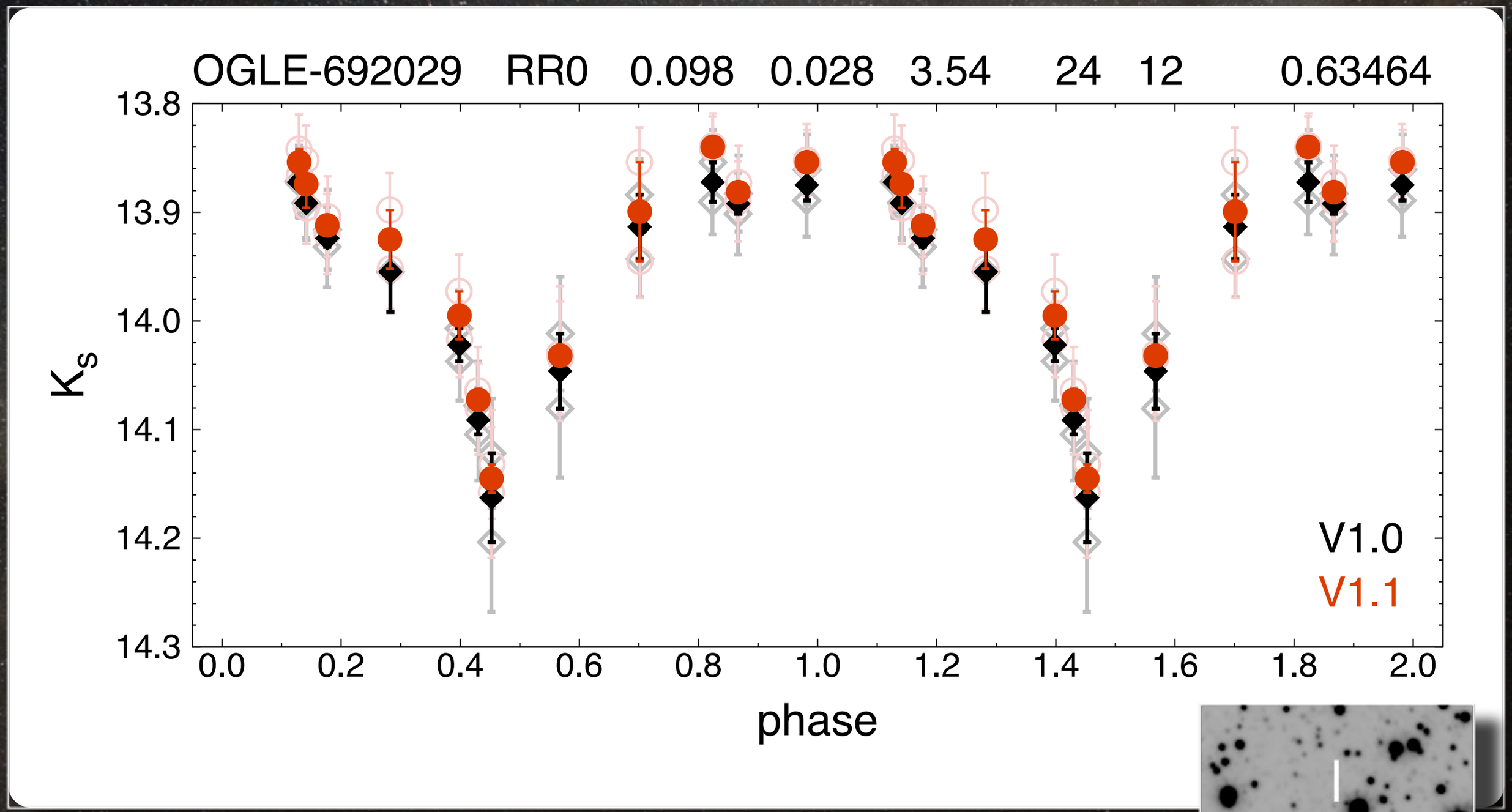


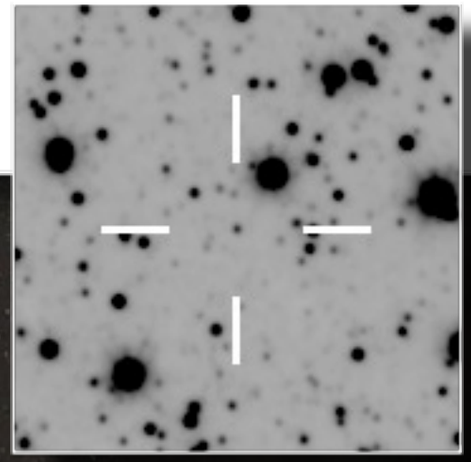
RR Lyrae Light Curves



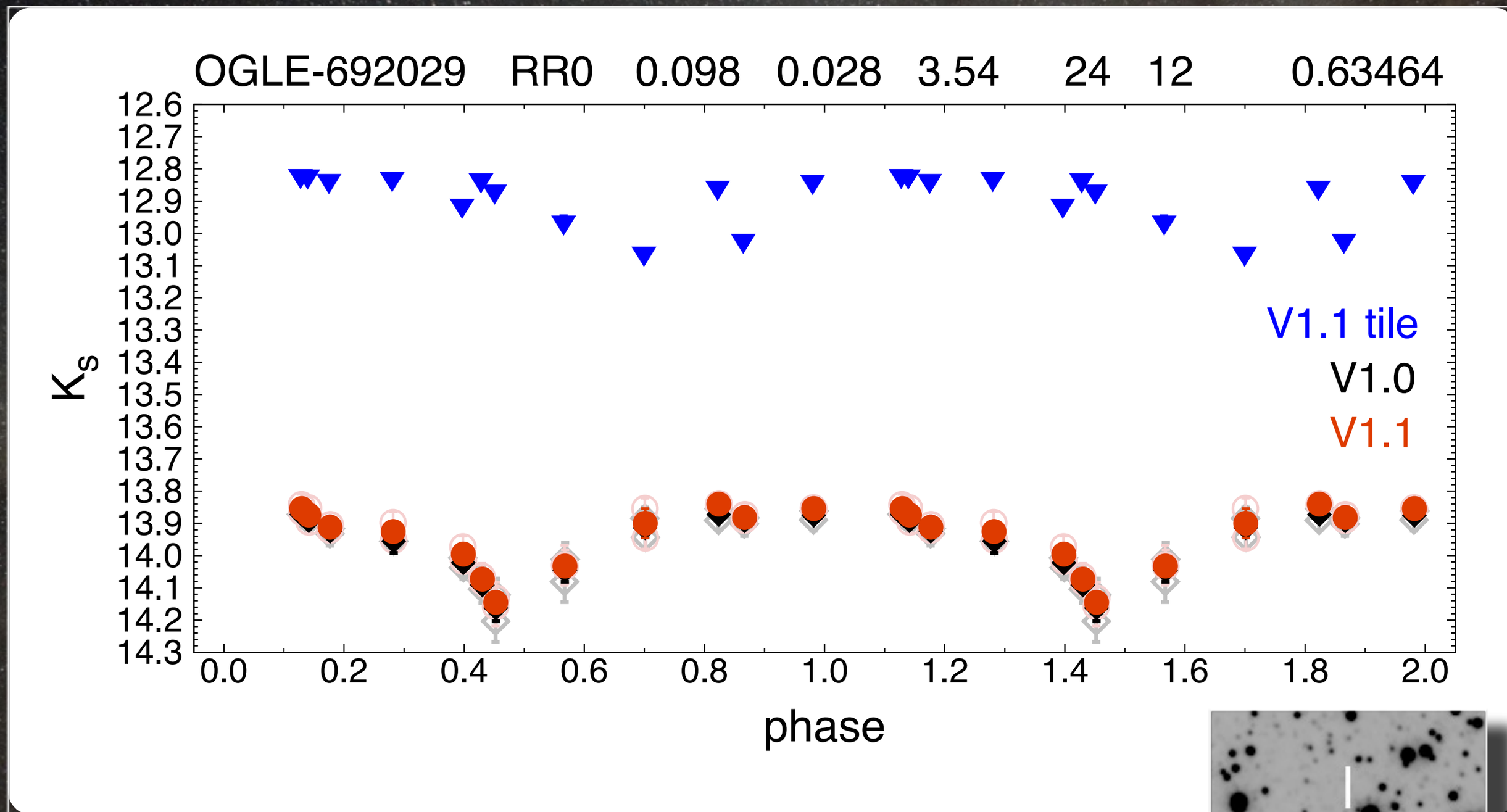


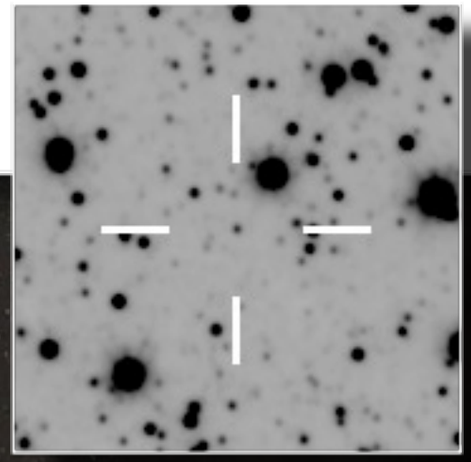
RR Lyrae Light Curves





RR Lyrae Light Curves





Credit: ESO

Credit: ESO

Projects with RR Lyrae stars

What is the 3-D structure of our Galaxy?

- VVV ZYJHK$_s$ catalog of known RR Lyrae stars
- VVV K$_s$ light curve catalog of known RR Lyrae stars

  RR Lyrae stars in:

  bulge, field, globular clusters, Sagittarius dwarf galaxy
- Map extinction, compare with other extinction surveys
- Employ PL / PLC relations to derive distances
- Develop automatic ensemble photometry with CASU fluxes
- Explore and test data as much as possible
- ...more projects to be included

Credit: ESO

Projects with RR Lyrae stars

How to derive accurate mean magnitudes from incomplete and noisy time-series?

TFF

Template Fourier fitting

Kovács & Kupi (2007)

Use template light curves with all the flavors of variability...

$$\{x_{i,j}(\varphi)\}$$

...to fit the light curve:

$$\{Y_i\}$$

$$D_j(\varphi)=\frac{1}{N}\sum_{i=1}^{N}[Y_i-X_i(\varphi)]^2$$

$$X_i(\varphi)=\begin{cases} c_0+x_{i,j}(\varphi) & \text{if } M=0 \\ \sum_{k=0}^{M} c_k x_{i,j}^k(\varphi) & \text{if } M\geq 1 \end{cases}$$

Projects with RR Lyrae stars

TFF

Credit: ESO

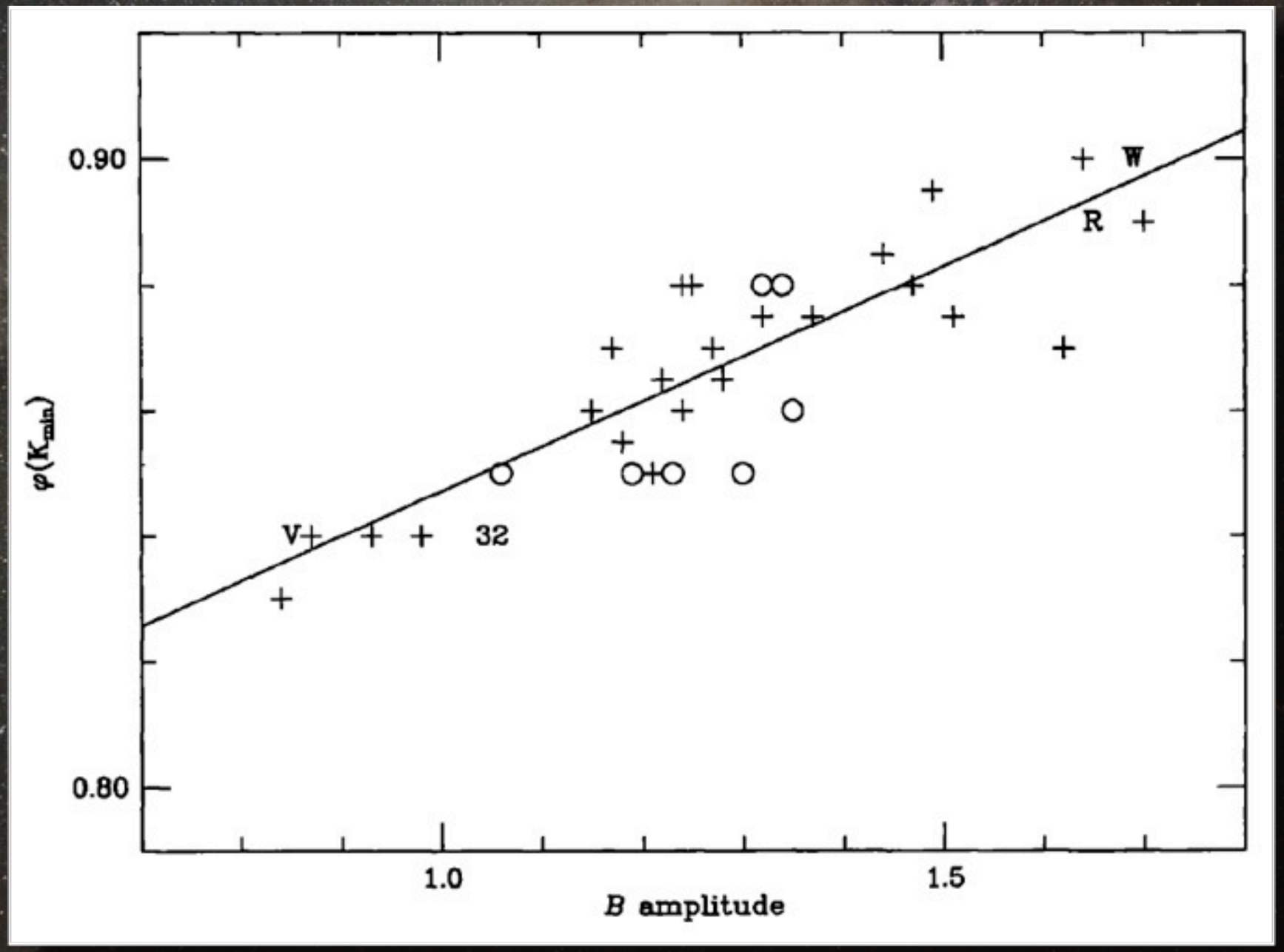
But we are in the NIR...

..so what do we have?

Projects with RR Lyrae stars

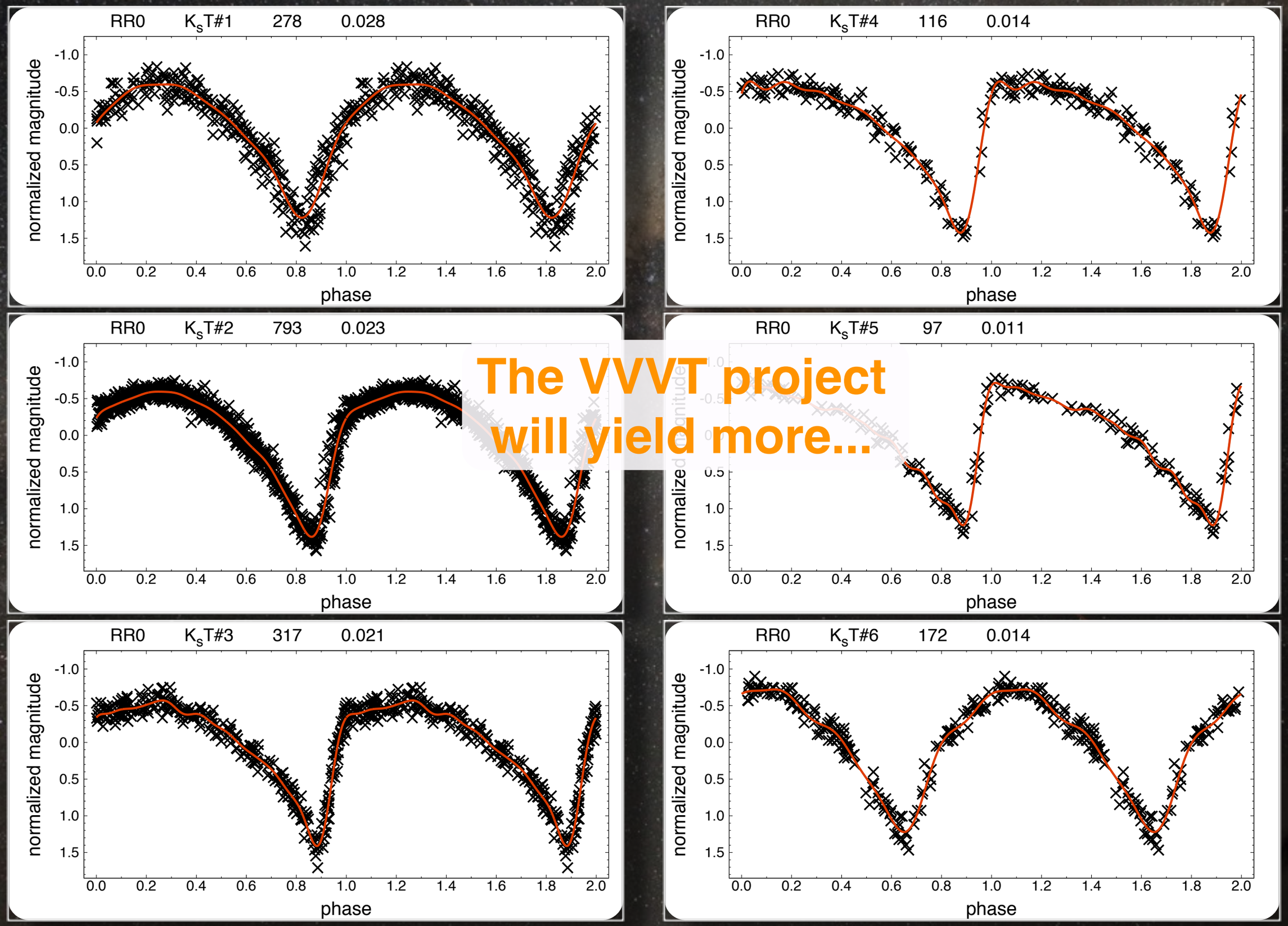
TFF

Jones' templates



Projects with RR Lyrae stars

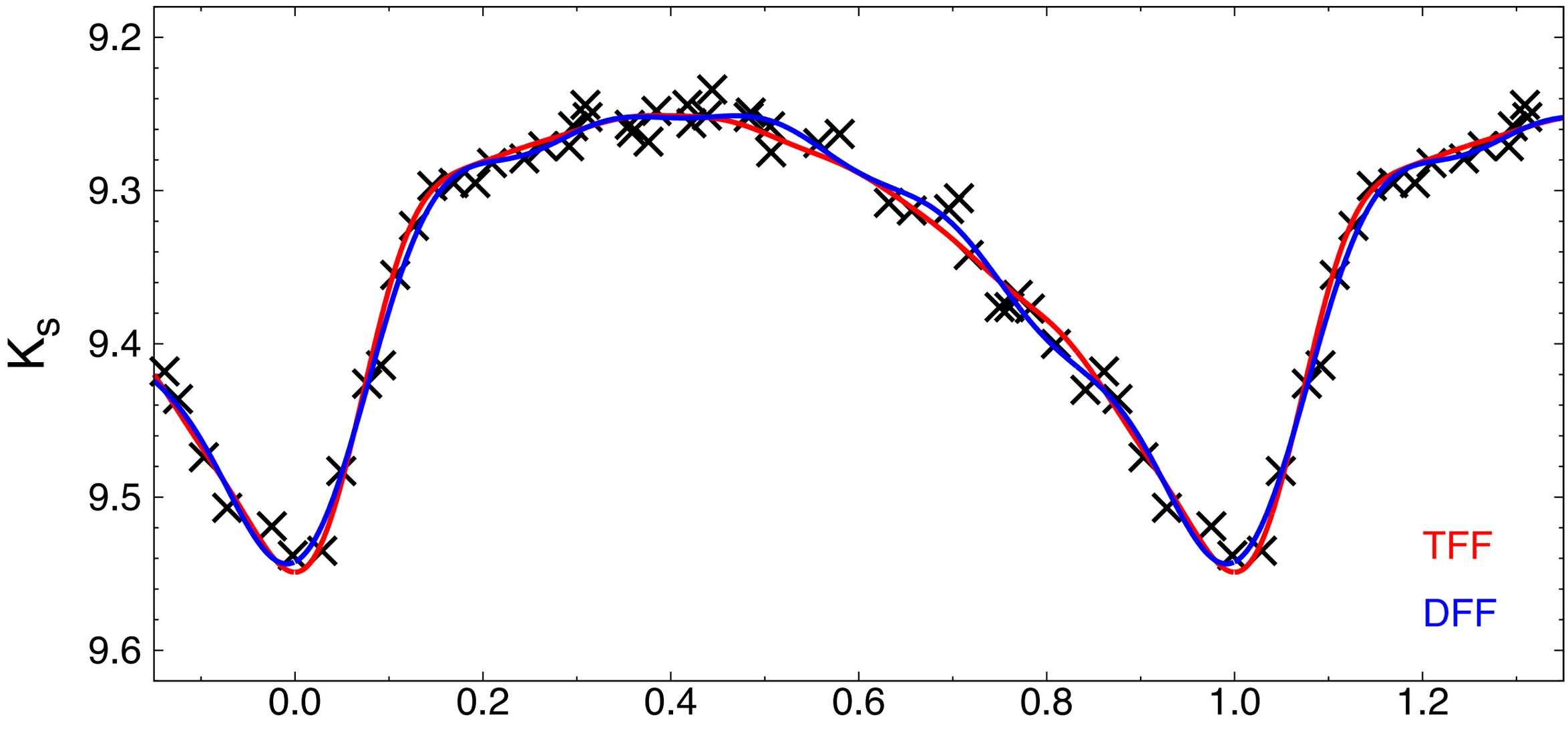
TFF



The VVVT project will yield more...

Projects with RR Lyrae stars

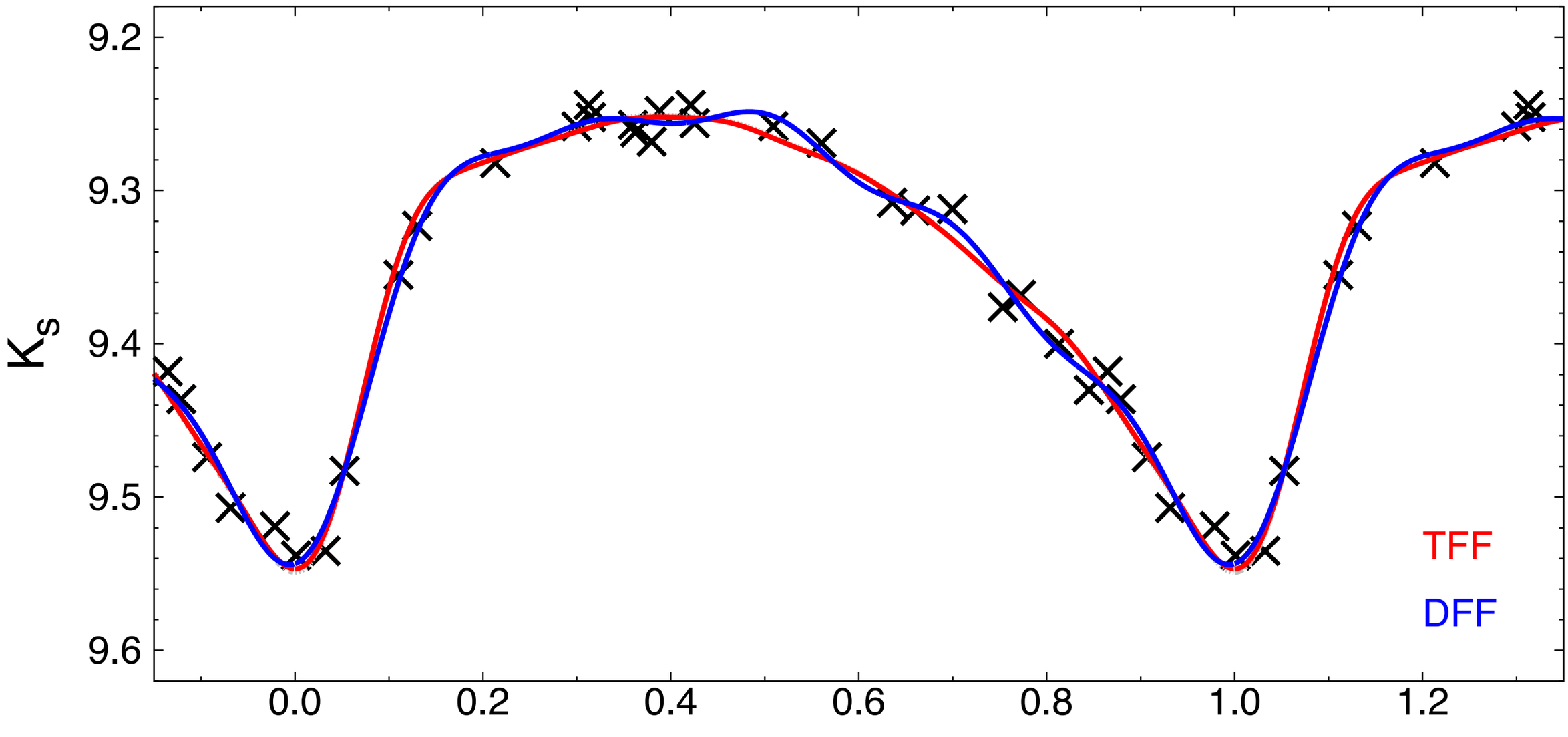
TFF



N = 47

Projects with RR Lyrae stars

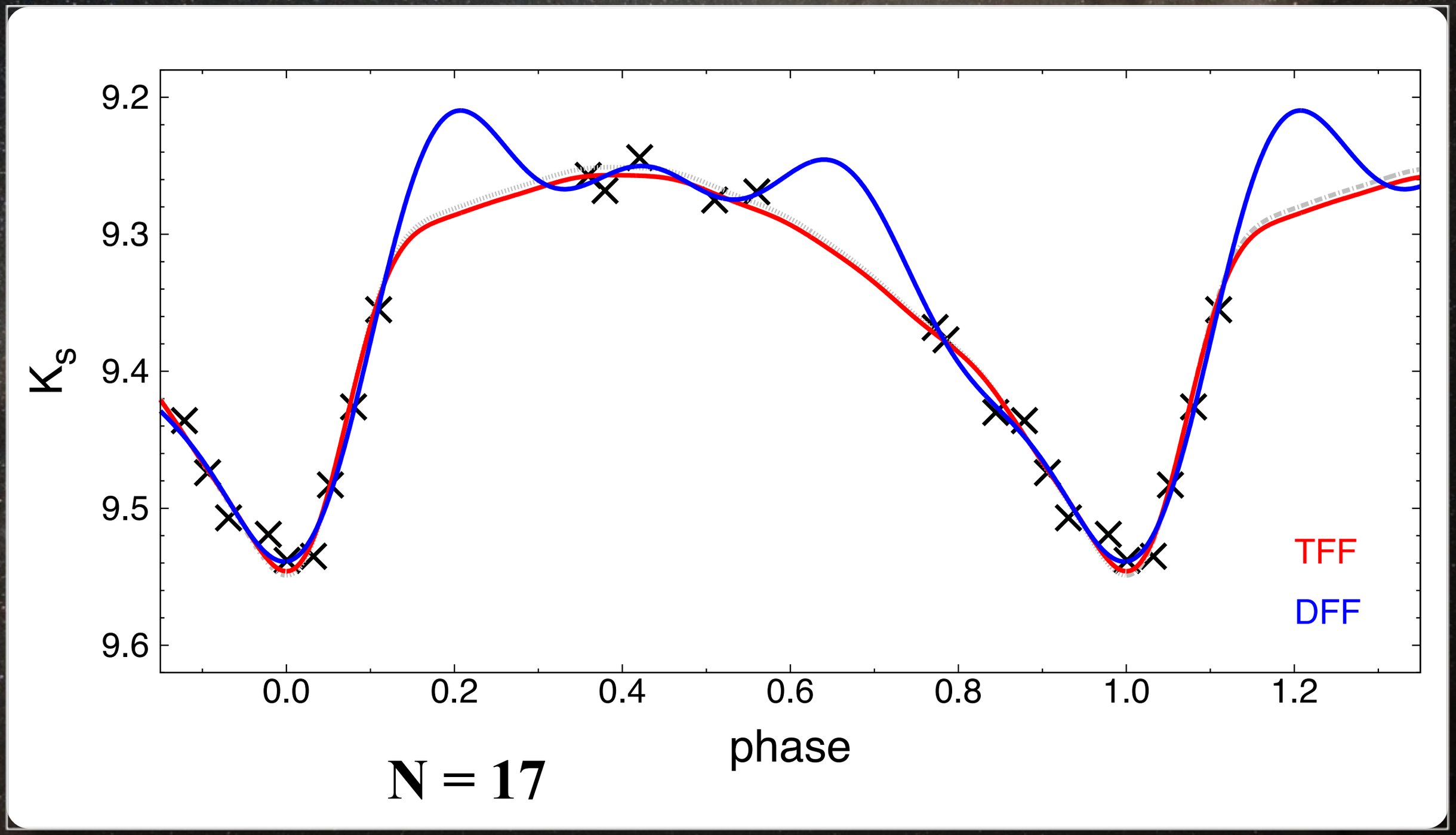
TFF



N = 29

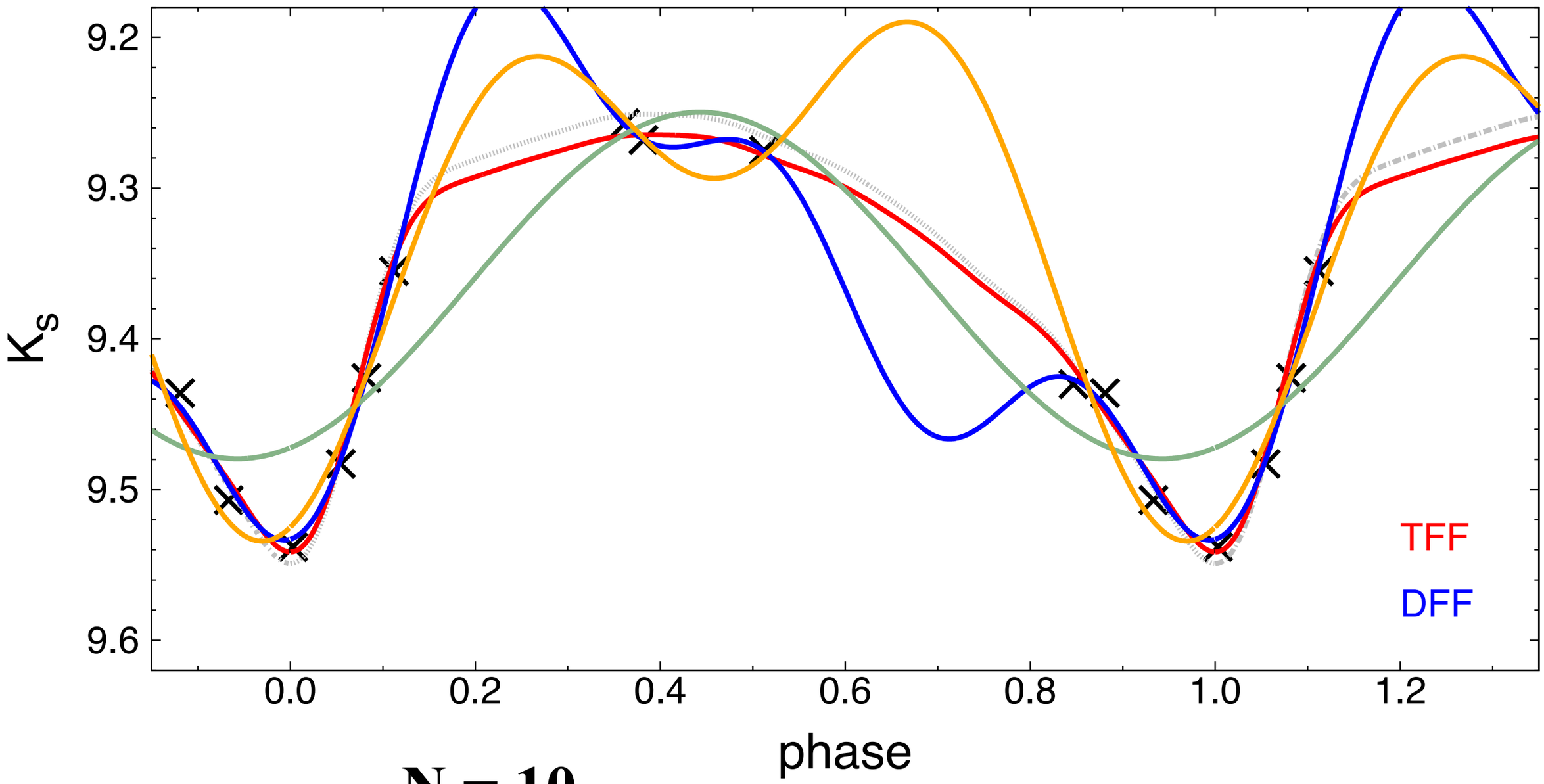
Projects with RR Lyrae stars

TFF



Projects with RR Lyrae stars

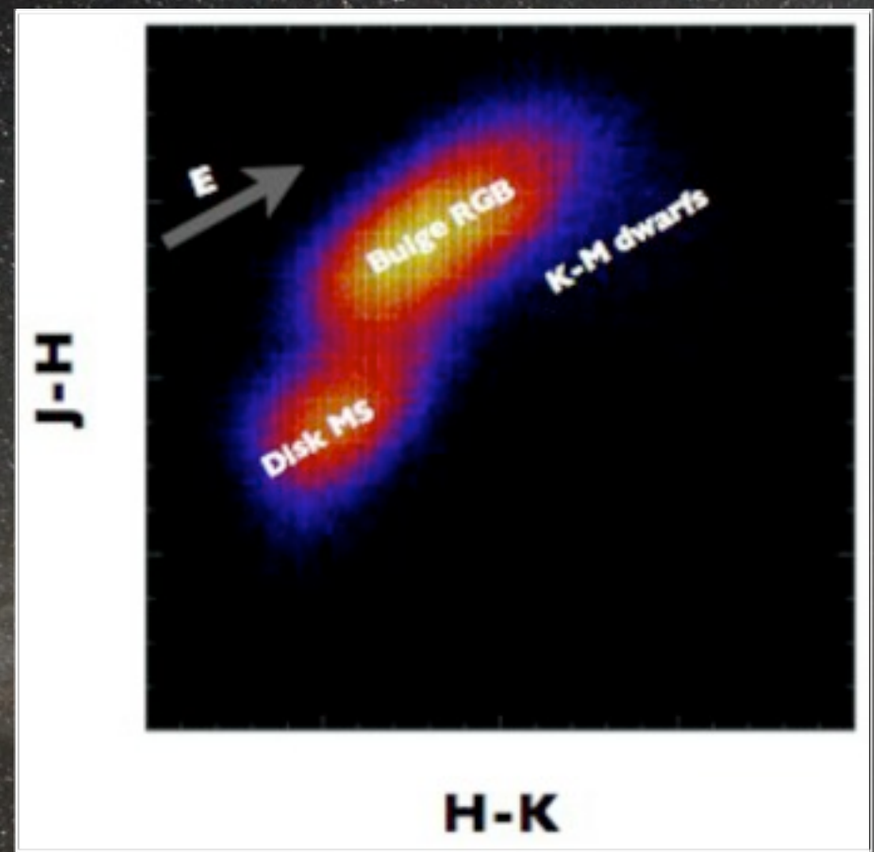
TFF

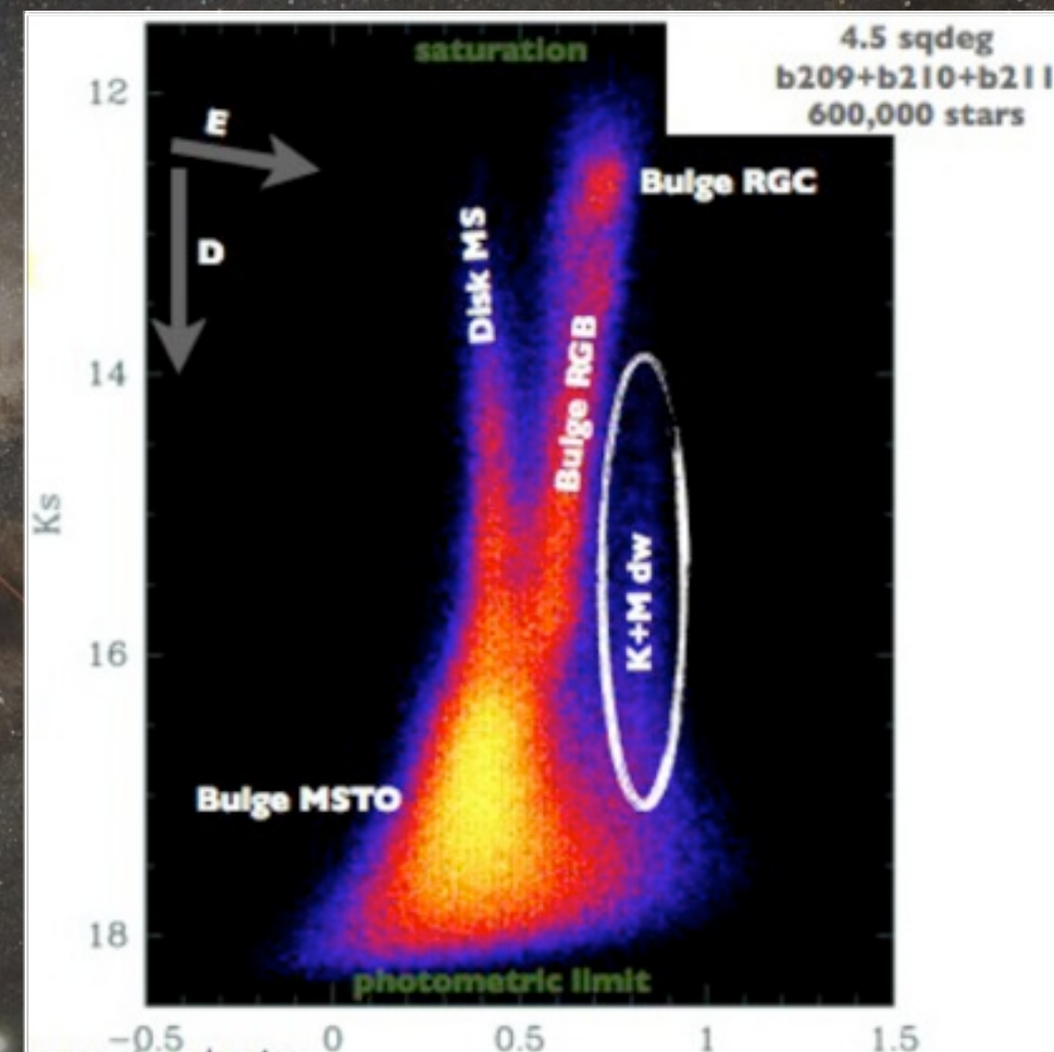


N = 10

Credit: ESO

Exoplanets in VVV



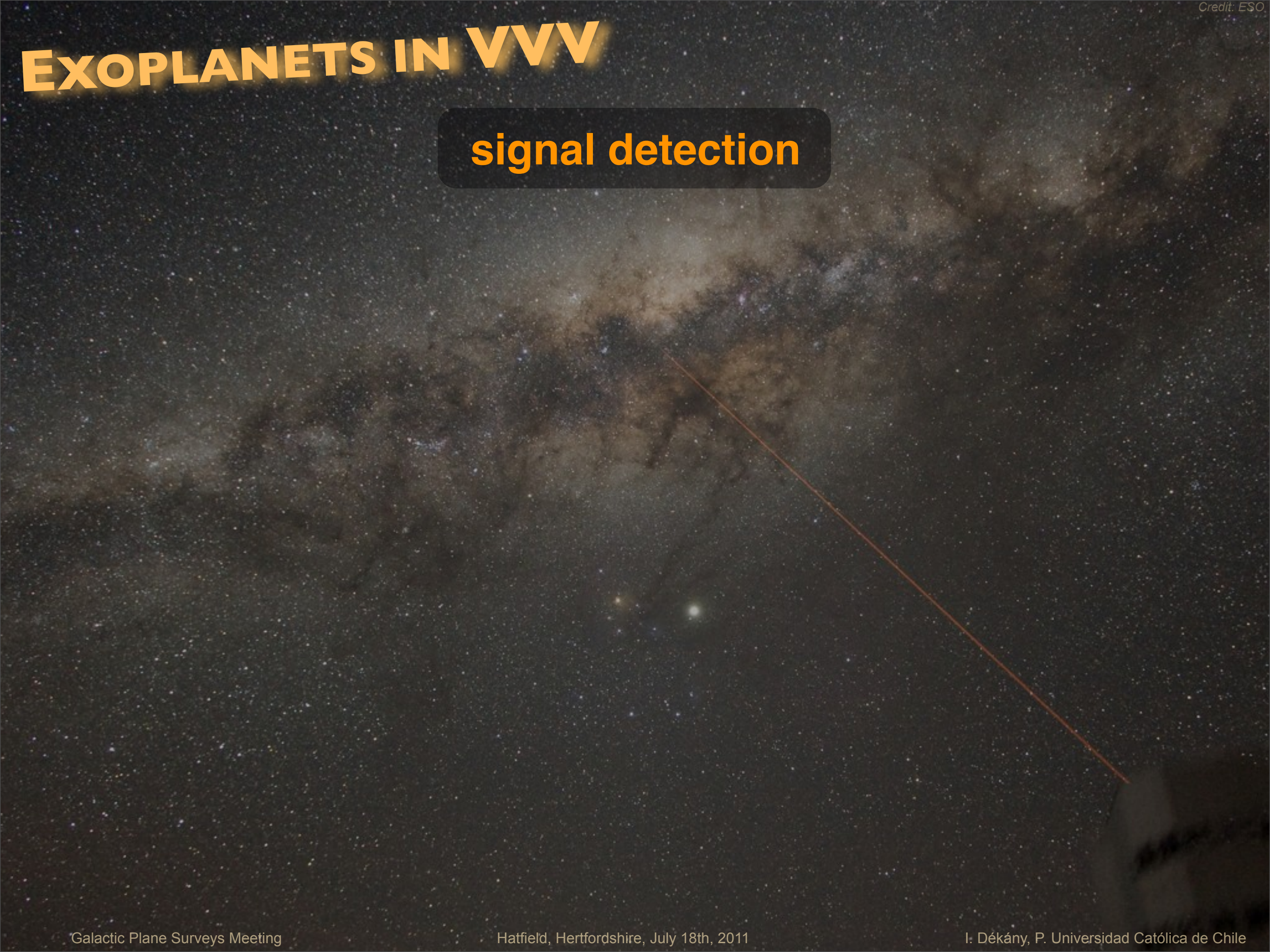


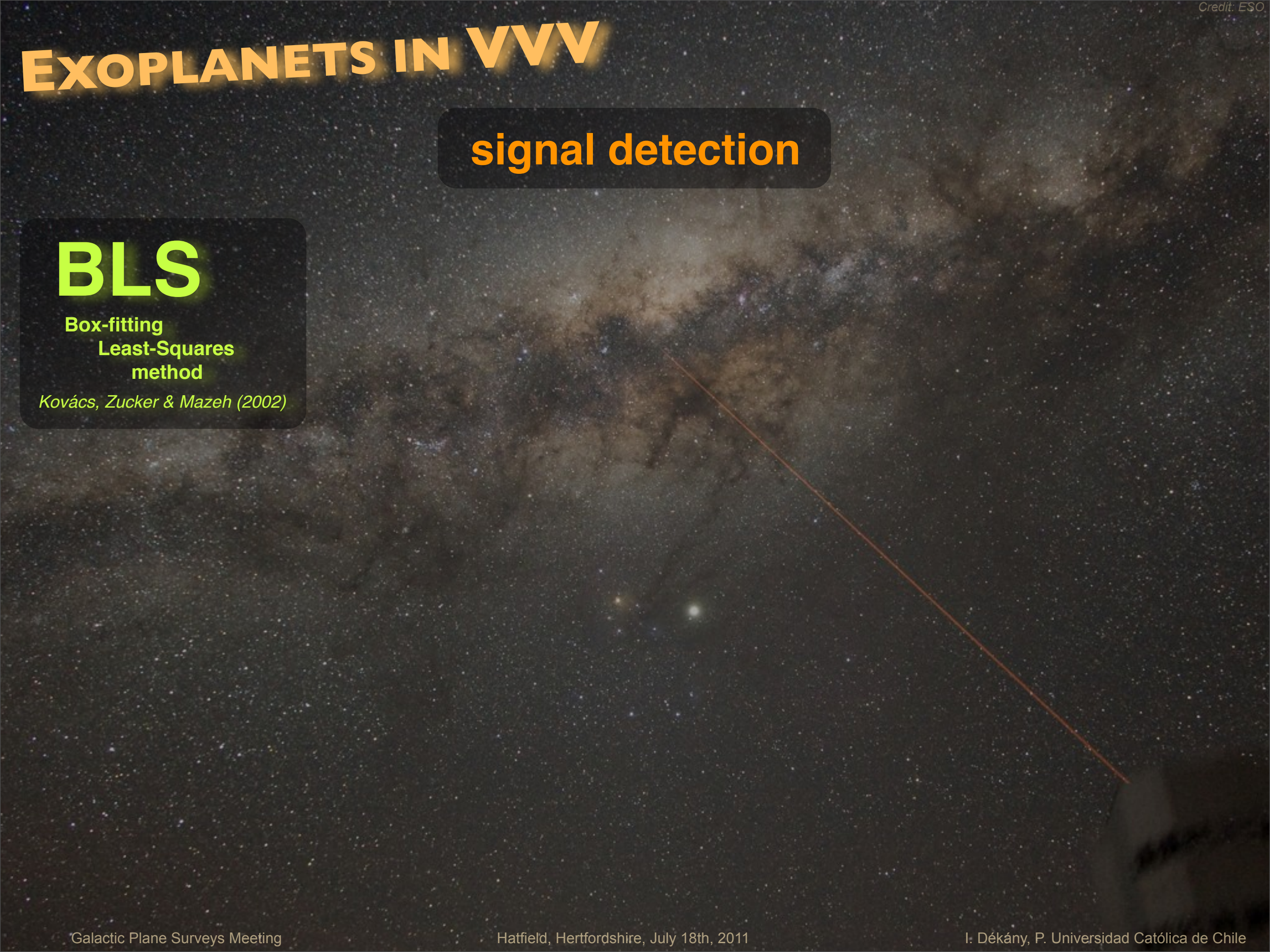
figures by R. Saito

K and M dwarfs:
Neptunes and Super-Earths around them
produce similar transits as
Hot Jupiters around Solar-like stars

Exoplanets in VVV

signal detection





Credit: ESO

Exoplanets in VVV

signal detection

BLS

Box-fitting Least-Squares method

Kovács, Zucker & Mazeh (2002)

Credit: ESO

Exoplanets in VVV

signal detection

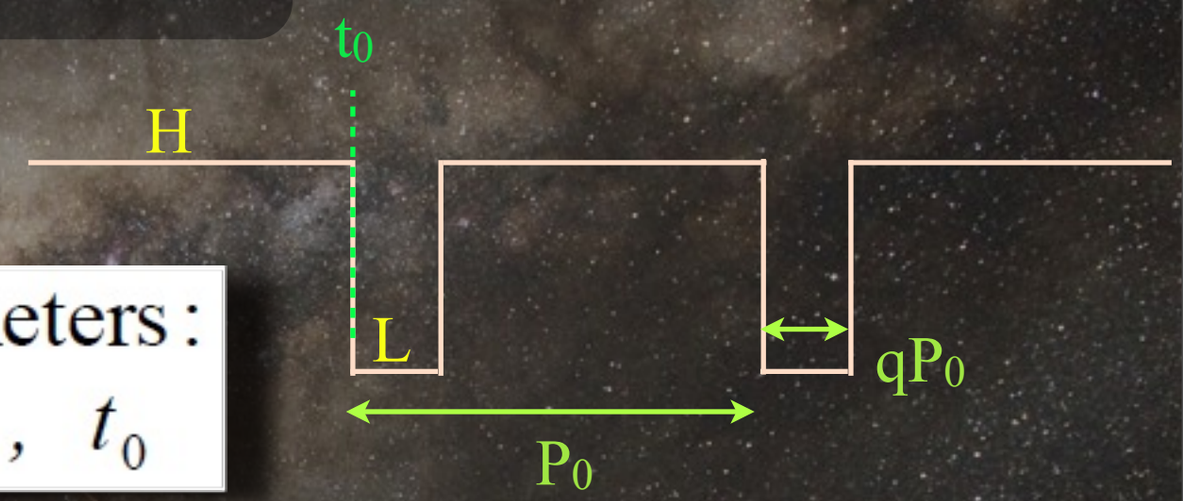
BLS

Box-fitting Least-Squares method

Kovács, Zucker & Mazeh (2002)

5 box transit parameters:

P_0, q, L, H, t_0



Credit: ESO

Exoplanets in VVV

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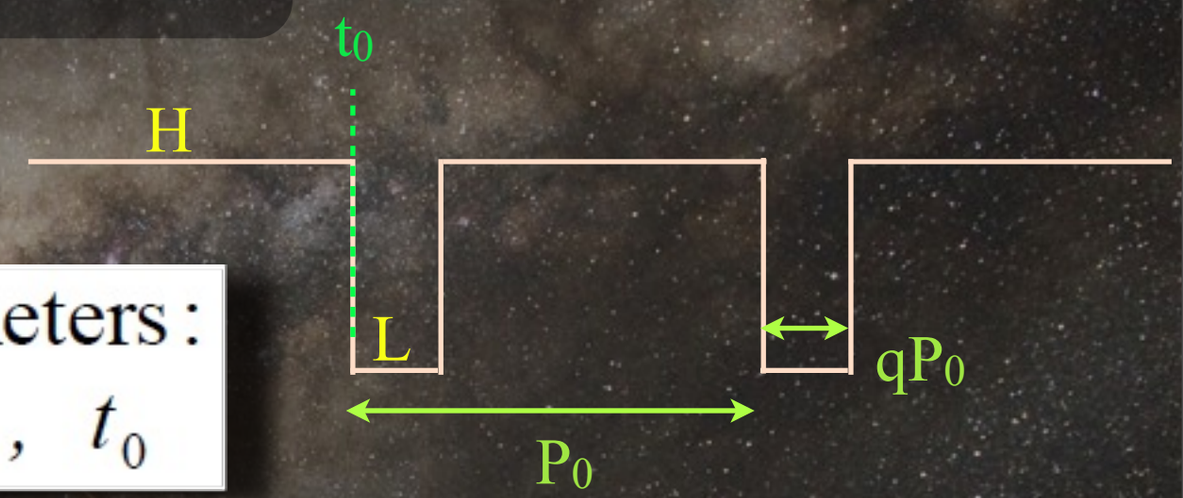


$$D=\sum_{i=1}^{i_1-1} w_i(x_i-H)^2+\sum_{i=i_2+1}^{n} w_i(x_i-H)^2+\sum_{i=i_1}^{i_2} w_i(x_i-L)^2$$

Credit: ESO

Exoplanets in VVV

signal detection

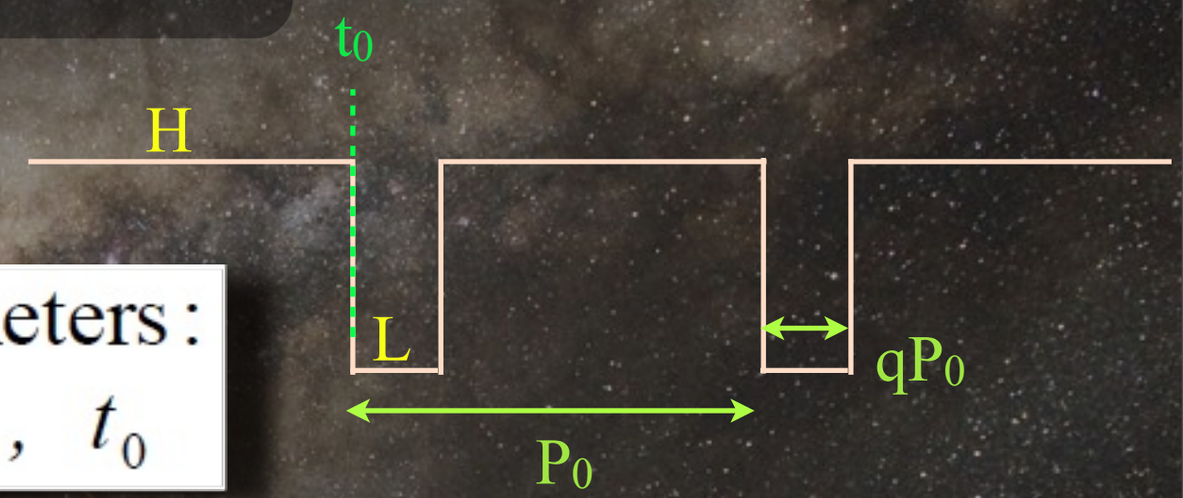
BLS

Box-fitting Least-Squares method

Kovács, Zucker & Mazeh (2002)

5 box transit parameters:

$$P_0\,,\quad q\,,\quad L\,,\quad H\,,\quad t_0$$



$$D=\sum_{i=1}^{i_1-1} w_i(x_i-H)^2+\sum_{i=i_2+1}^{n} w_i(x_i-H)^2+\sum_{i=i_1}^{i_2} w_i(x_i-L)^2$$

$$D=\sum_{i=1}^{n} w_i x_i^2-\frac{\left(\sum_{i=i_1}^{i_2} w_i x_i\right)^2}{r(1-r)}\quad,\quad \text{where}\quad r=\sum_{i=i_1}^{i_2} w_i$$

Credit: ESO

Exoplanets in VVV

signal detection

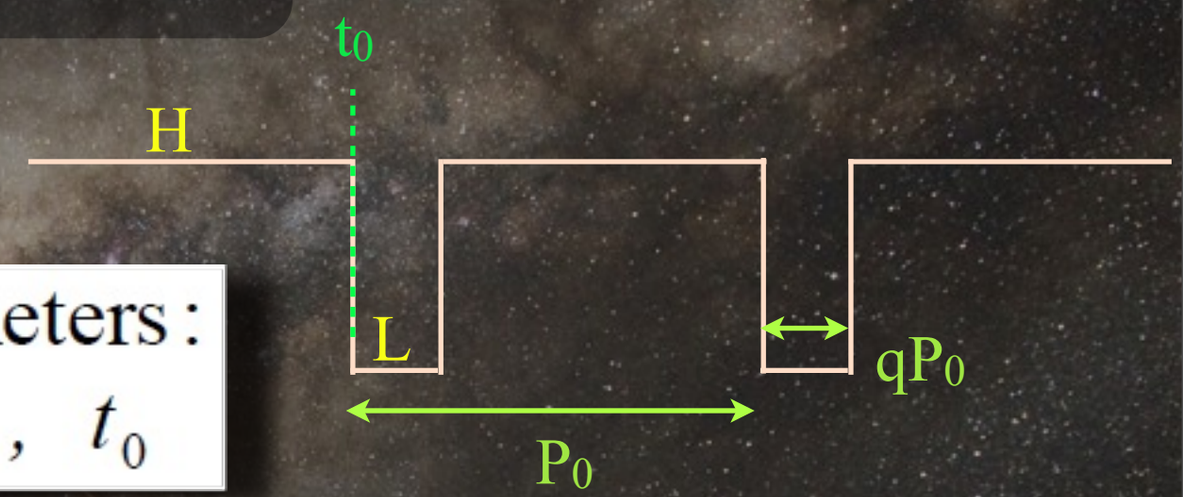
BLS

Box-fitting Least-Squares method

Kovács, Zucker & Mazeh (2002)

5 box transit parameters:

$$P_0\,,\quad q\,,\quad L\,,\quad H\,,\quad t_0$$



$$D=\sum_{i=1}^{i_1-1} w_i(x_i-H)^2+\sum_{i=i_2+1}^{n} w_i(x_i-H)^2+\sum_{i=i_1}^{i_2} w_i(x_i-L)^2$$

$$D=\sum_{i=1}^{n} w_i x_i^2-\frac{\left(\sum_{i=i_1}^{i_2} w_i x_i\right)^2}{r(1-r)},\quad \text{where}\quad r=\sum_{i=i_1}^{i_2} w_i$$

only this depends on the trial period

Credit: ESO

Exoplanets in VVV

signal detection

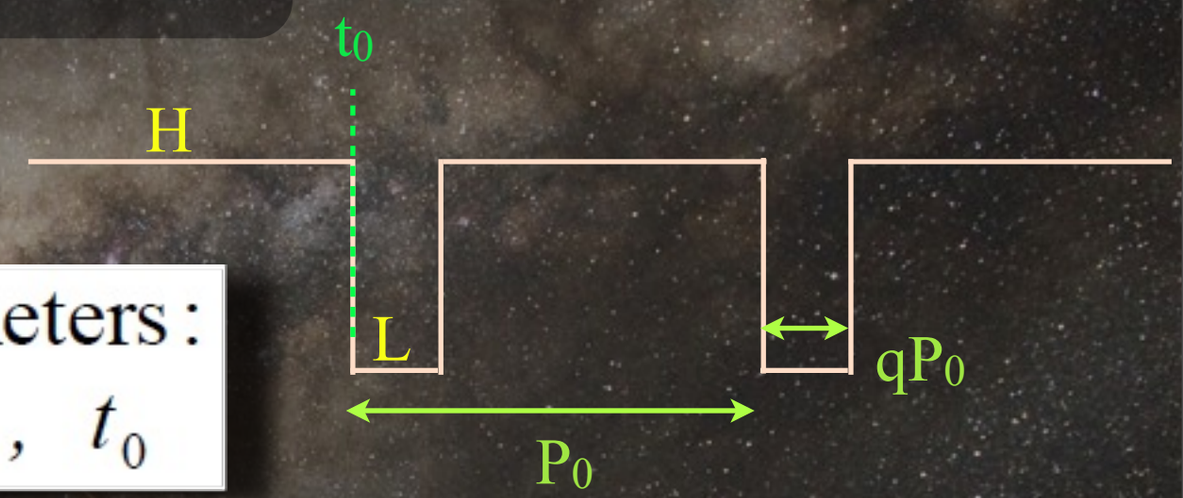
BLS

Box-fitting Least-Squares method

Kovács, Zucker & Mazeh (2002)

5 box transit parameters:

$$P_0\,,\quad q\,,\quad L\,,\quad H\,,\quad t_0$$



$$D=\sum_{i=1}^{i_1-1} w_i(x_i-H)^2+\sum_{i=i_2+1}^{n} w_i(x_i-H)^2+\sum_{i=i_1}^{i_2} w_i(x_i-L)^2$$

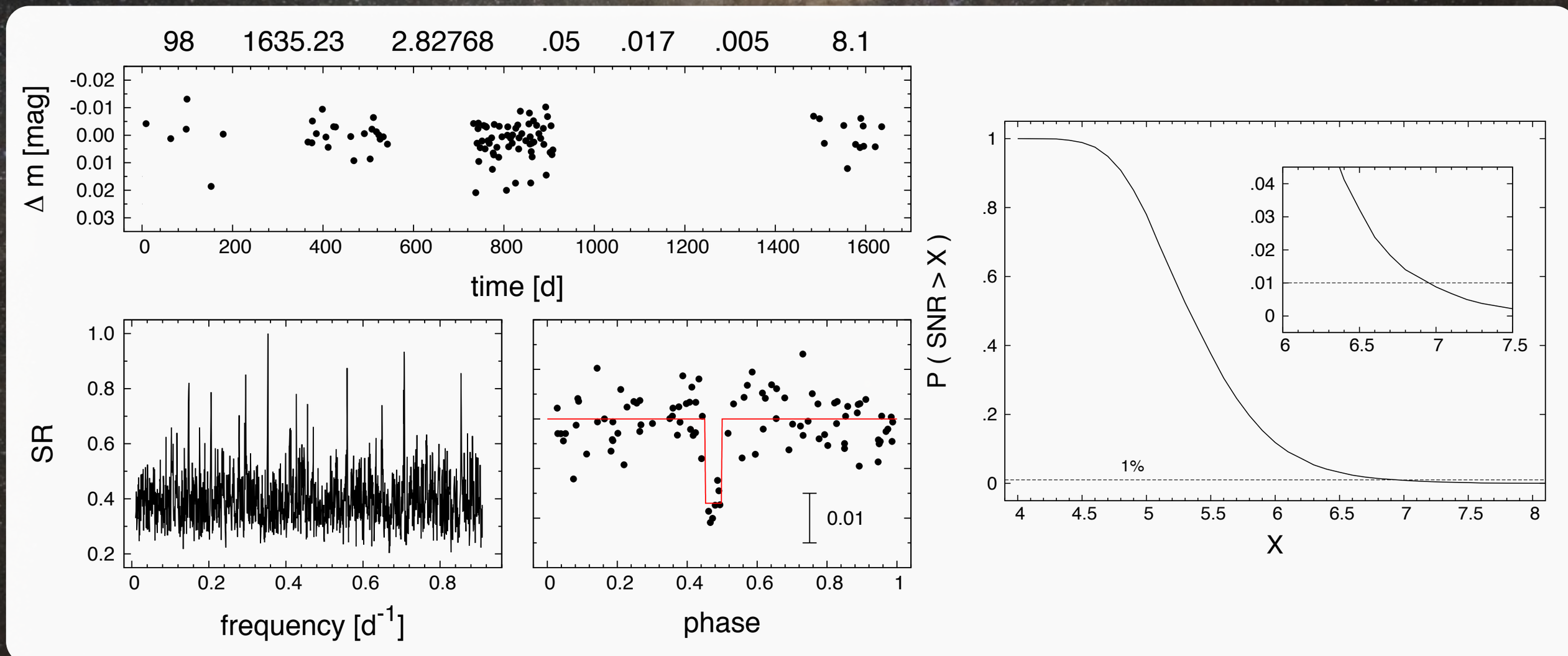
$$D=\sum_{i=1}^{n} w_i x_i^2-\frac{\left(\sum_{i=i_1}^{i_2} w_i x_i\right)^2}{r(1-r)}\,,\quad \text{where}\quad r=\sum_{i=i_1}^{i_2} w_i$$

$$SR=\delta\sqrt{r(r-1)}\,,\quad \text{where}\quad \delta\equiv H-L$$

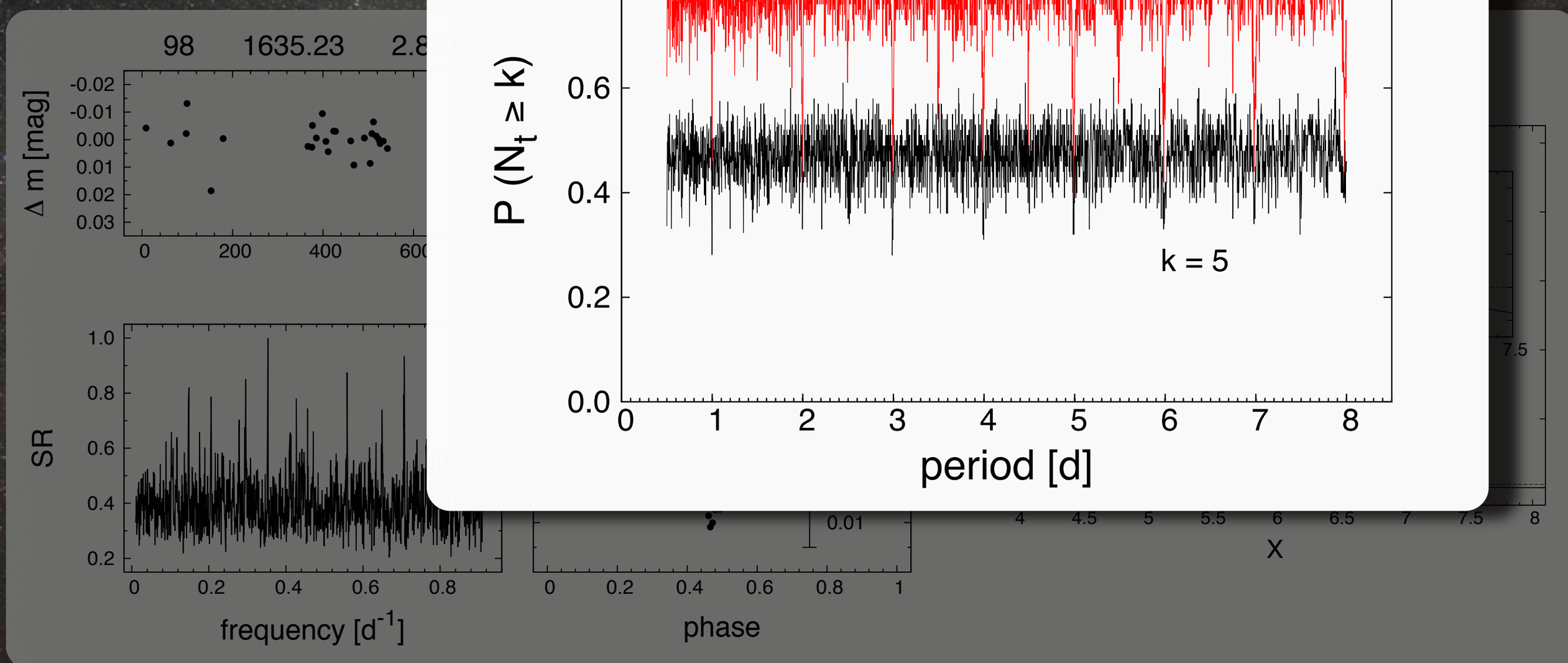
Credit: ESO

Exoplanets in VVV

'Semi-random' cadence:
visibility changes of b333
survey management plan & overheads
50% chance of second point on same night

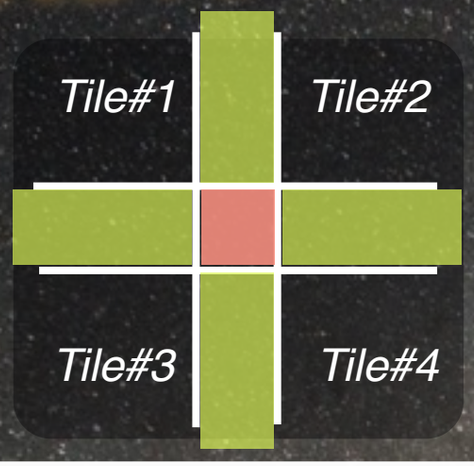


Exoplanets in VVV

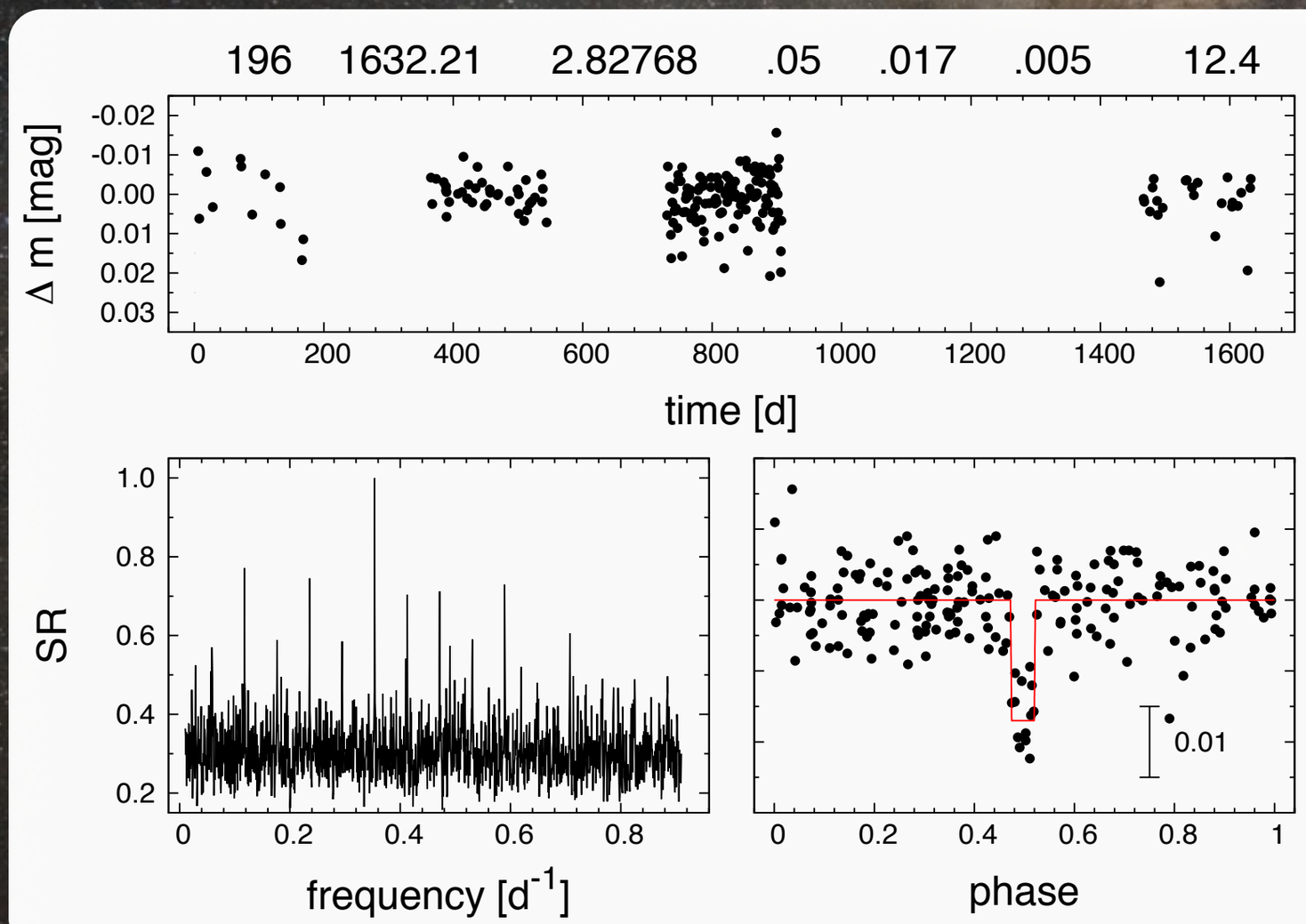


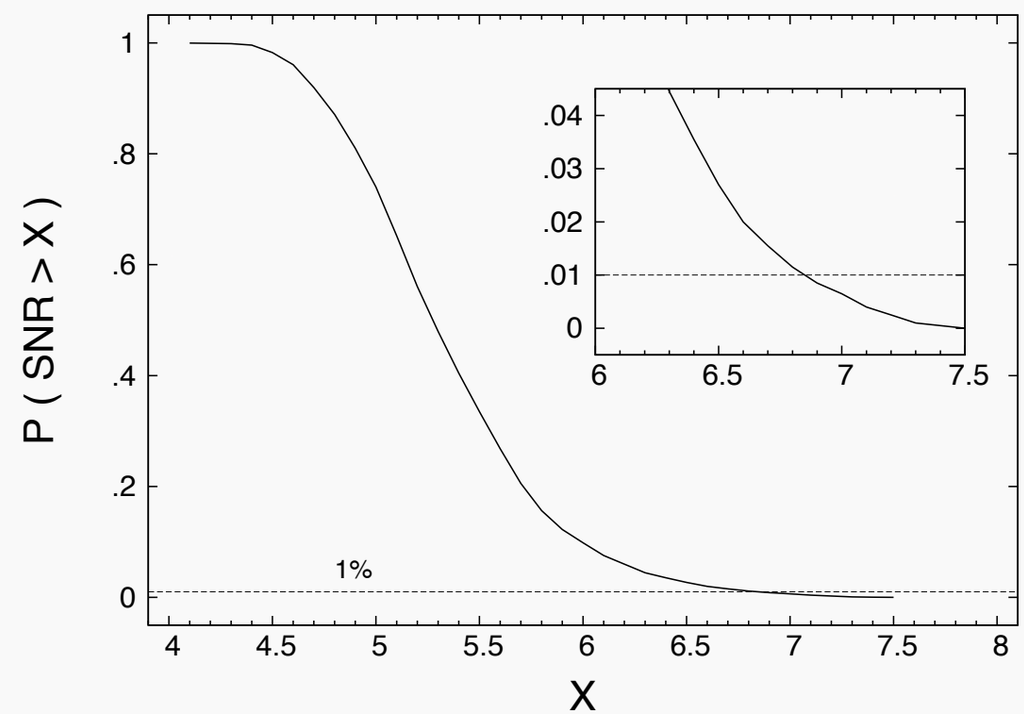
Credit: ESO

Exoplanets in VVV



Overlap between tiles:
~ 42 sq. deg. with double coverage
~ few more sq. deg. with quadruple coverage





More epochs are yet to come...