A First View on RR Lyrae Stars in VVV

István Dékány

Millennium Postdoctoral Fellow

P. Universidad Católica de Chile

Credit: ESO

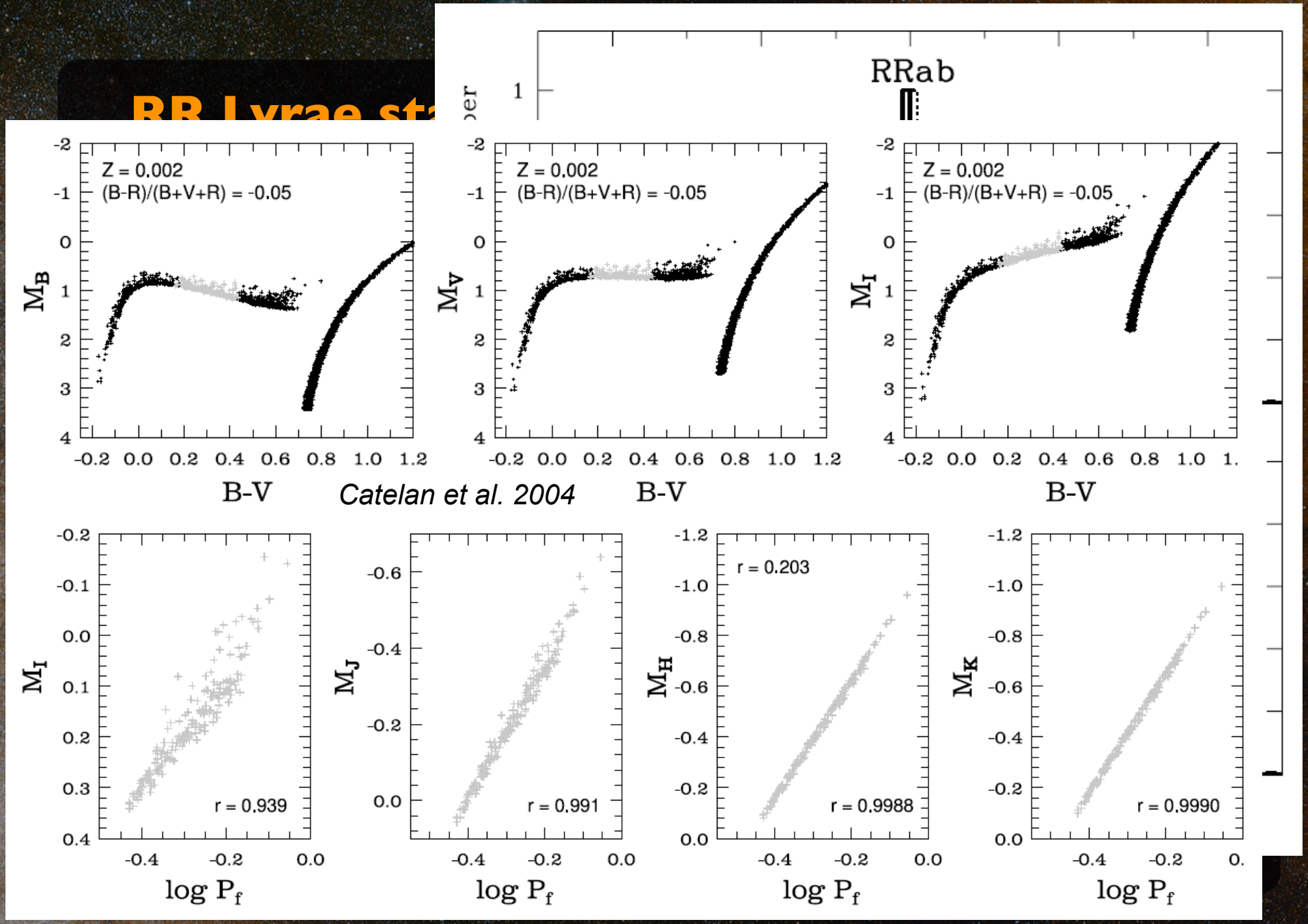
WHY RR LYRAE STARS?

OUR GAME: THE GALAXY-PUZZLE

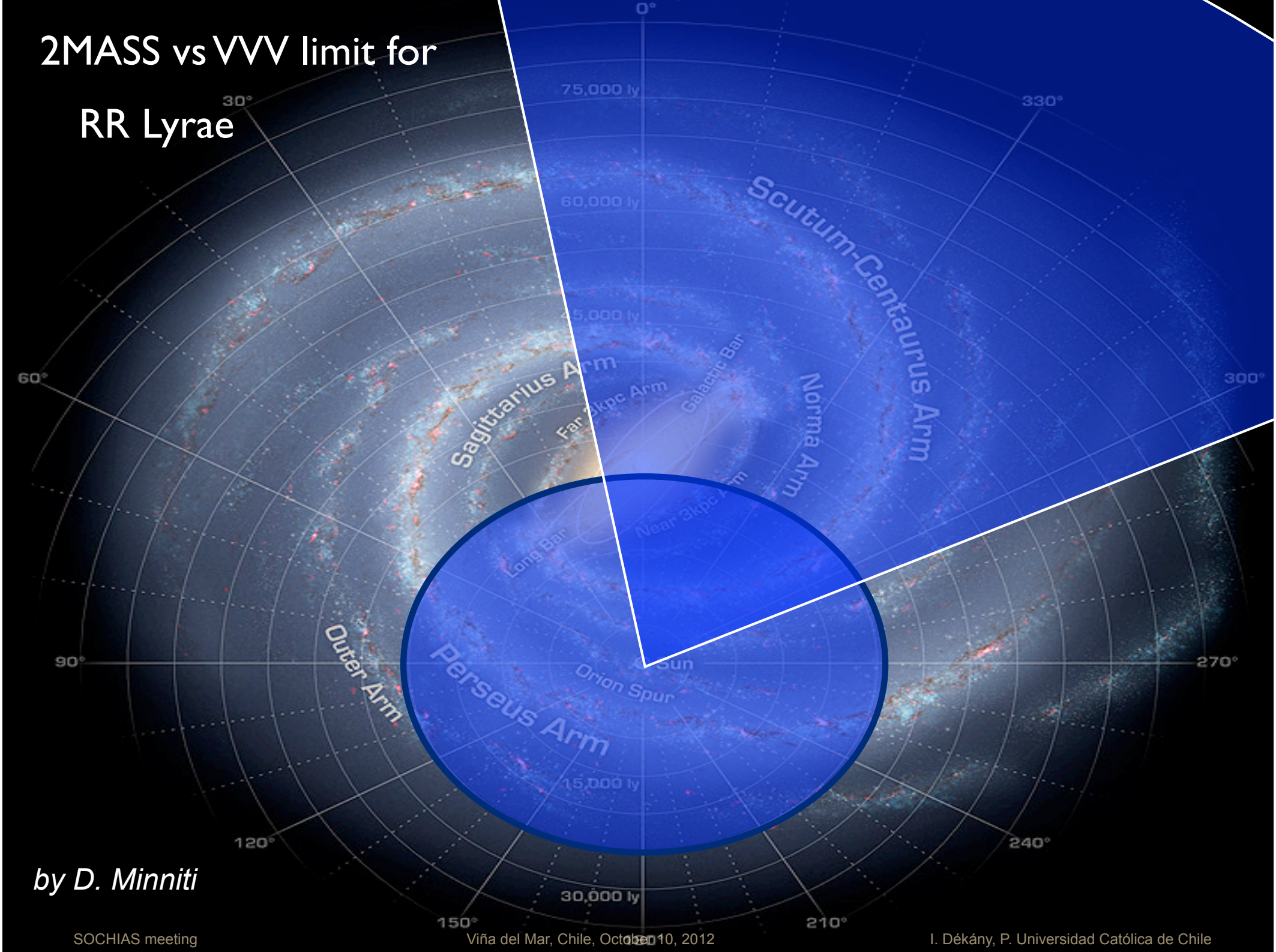
- *What is the 3-D structure of the bulge?*
- *Are there various subcomponents of the bulge?*
- *How old are these components?*
- *What are their chemical properties?*
- *Is there a spheroidal subcomponent?*
- *What is the structure of the disk behind the bulge?*

WHAT IS THE FORMATION HISTORY OF OUR GALAXY?

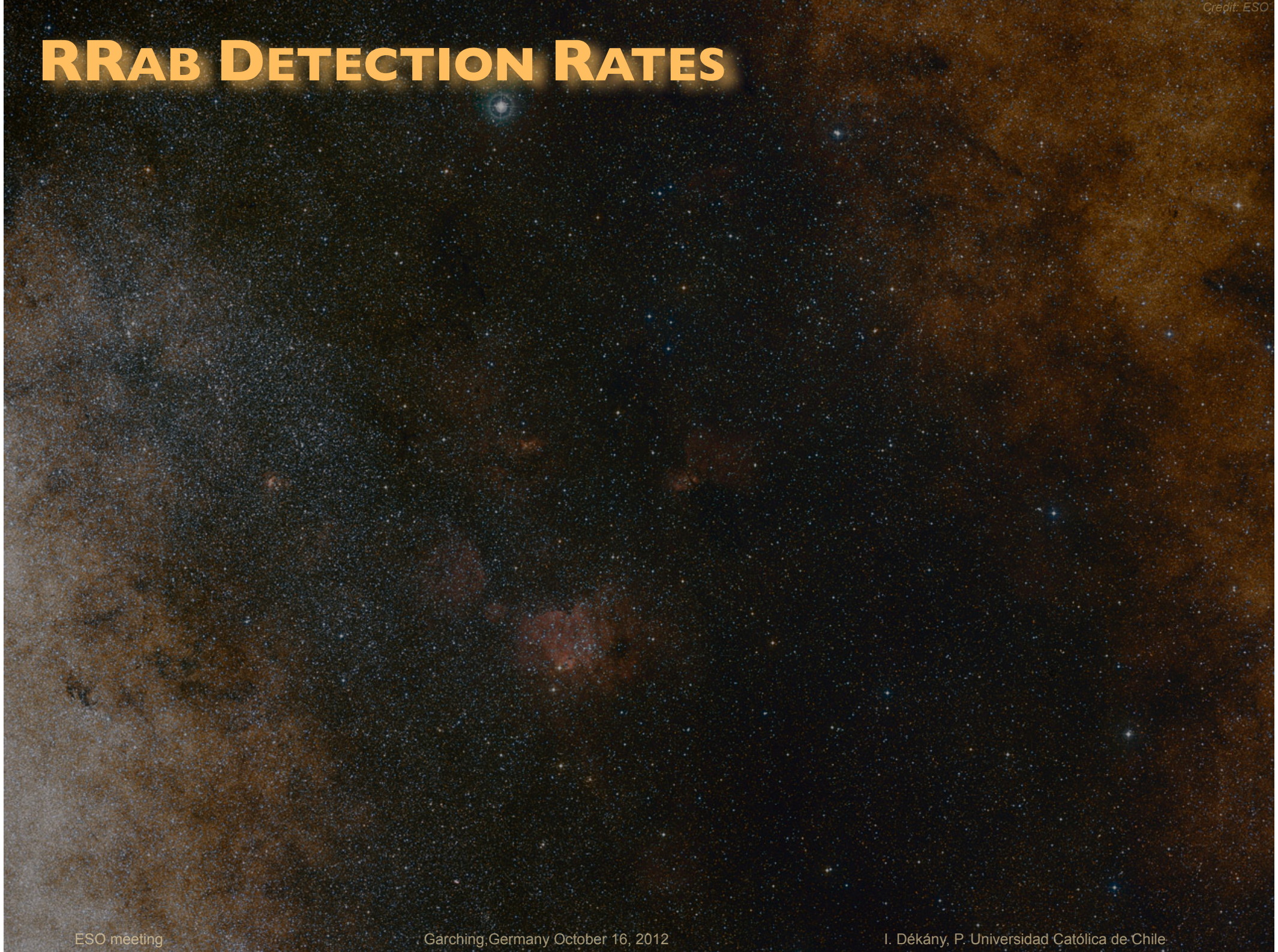
WHY RR LYRAE STARS?



2MASS vs VVV limit for RR Lyrae



by D. Minniti



RRab Detection Rates

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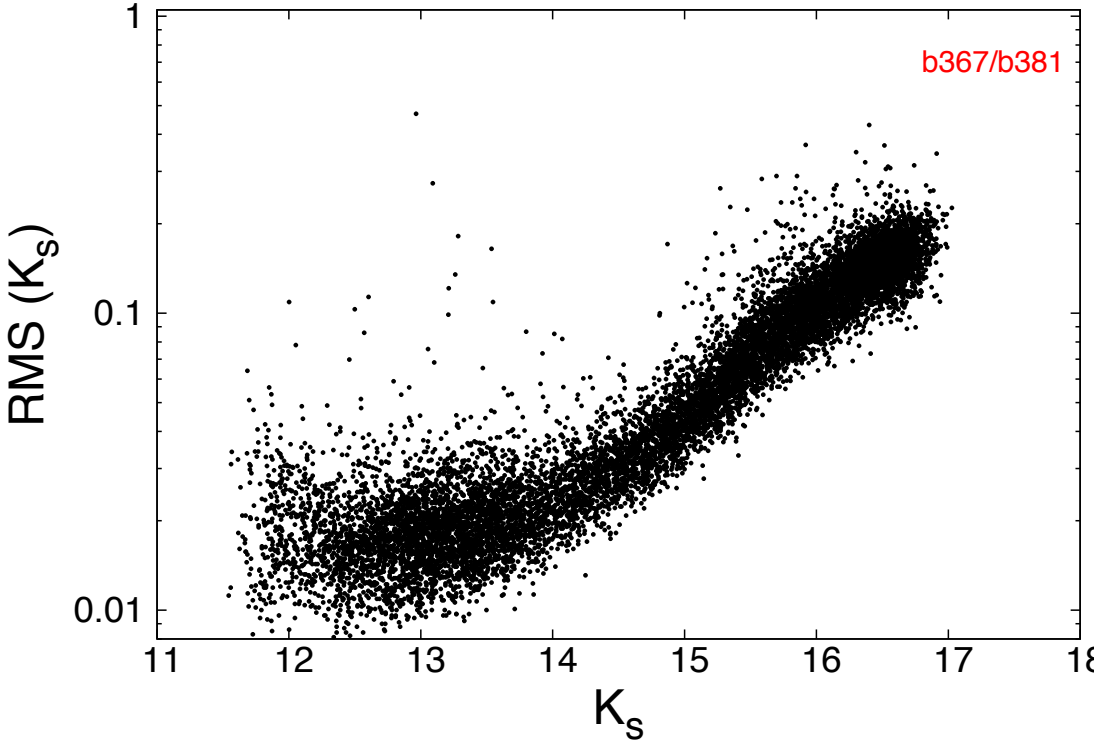

(1) MC-based LC's

- $\sigma(K)$ from VVV LC's
- Gaussian noise
- random cadence with visibility dependence (50% for 2nd point on a night)

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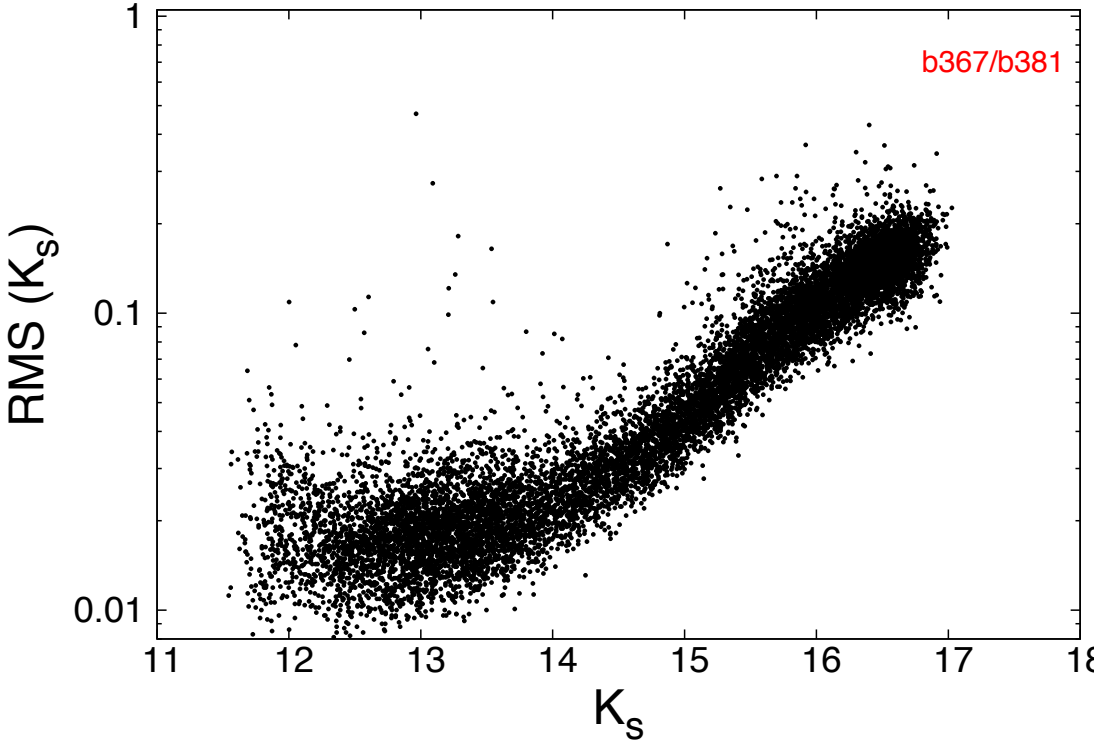

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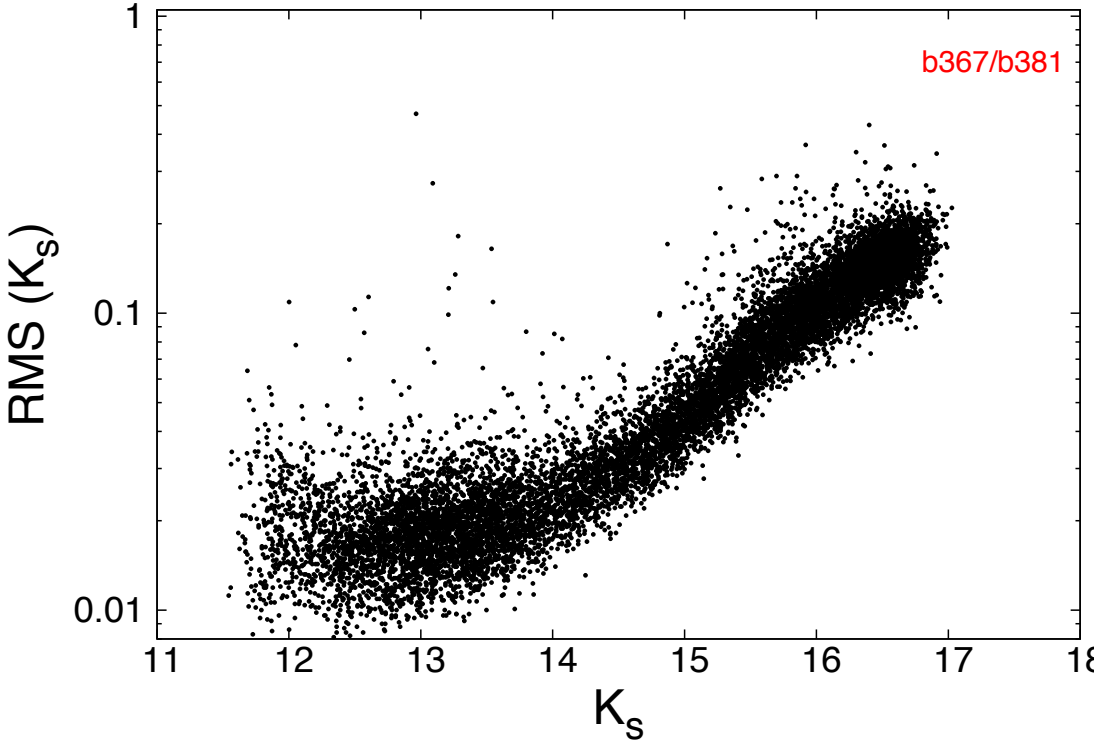

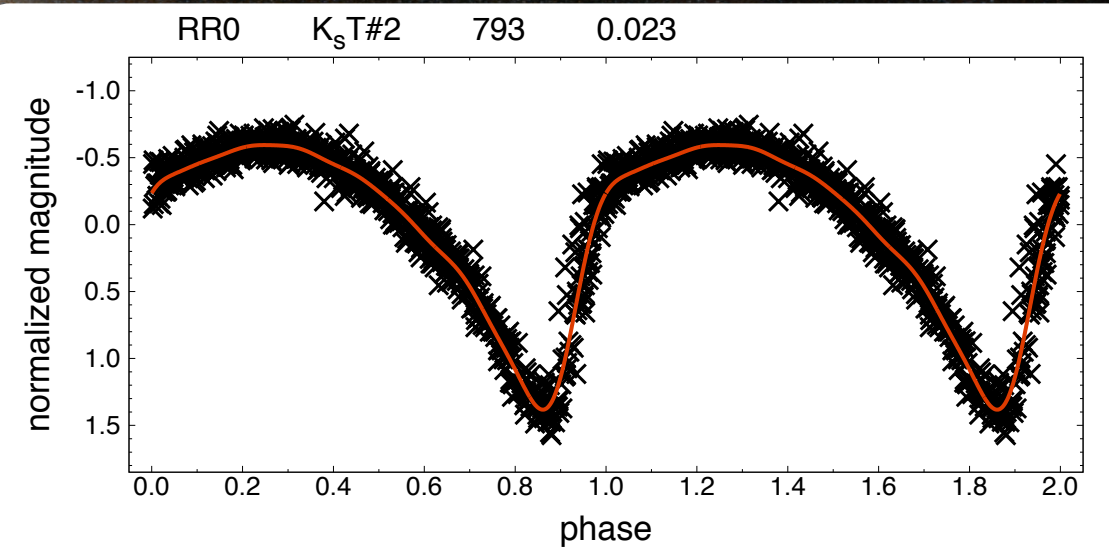

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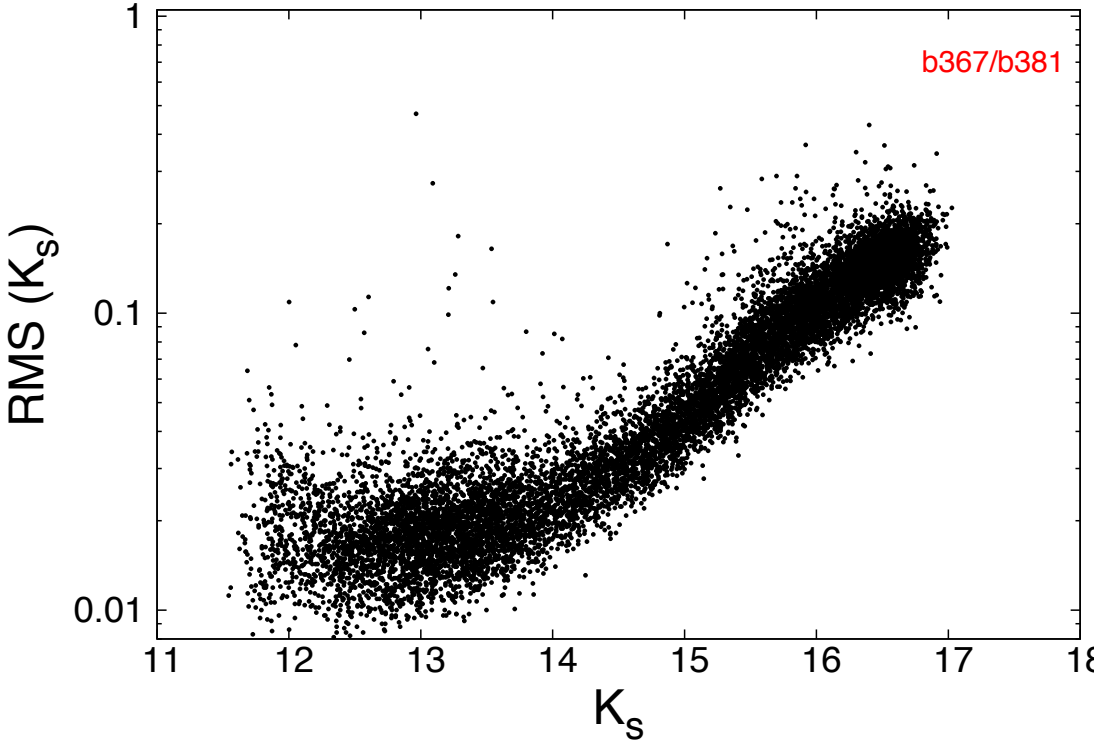

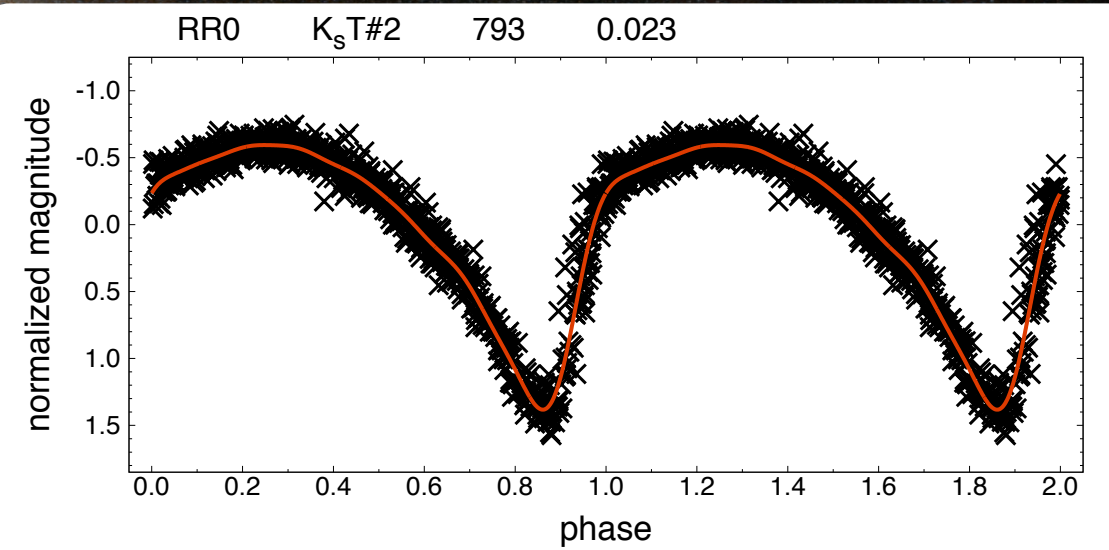

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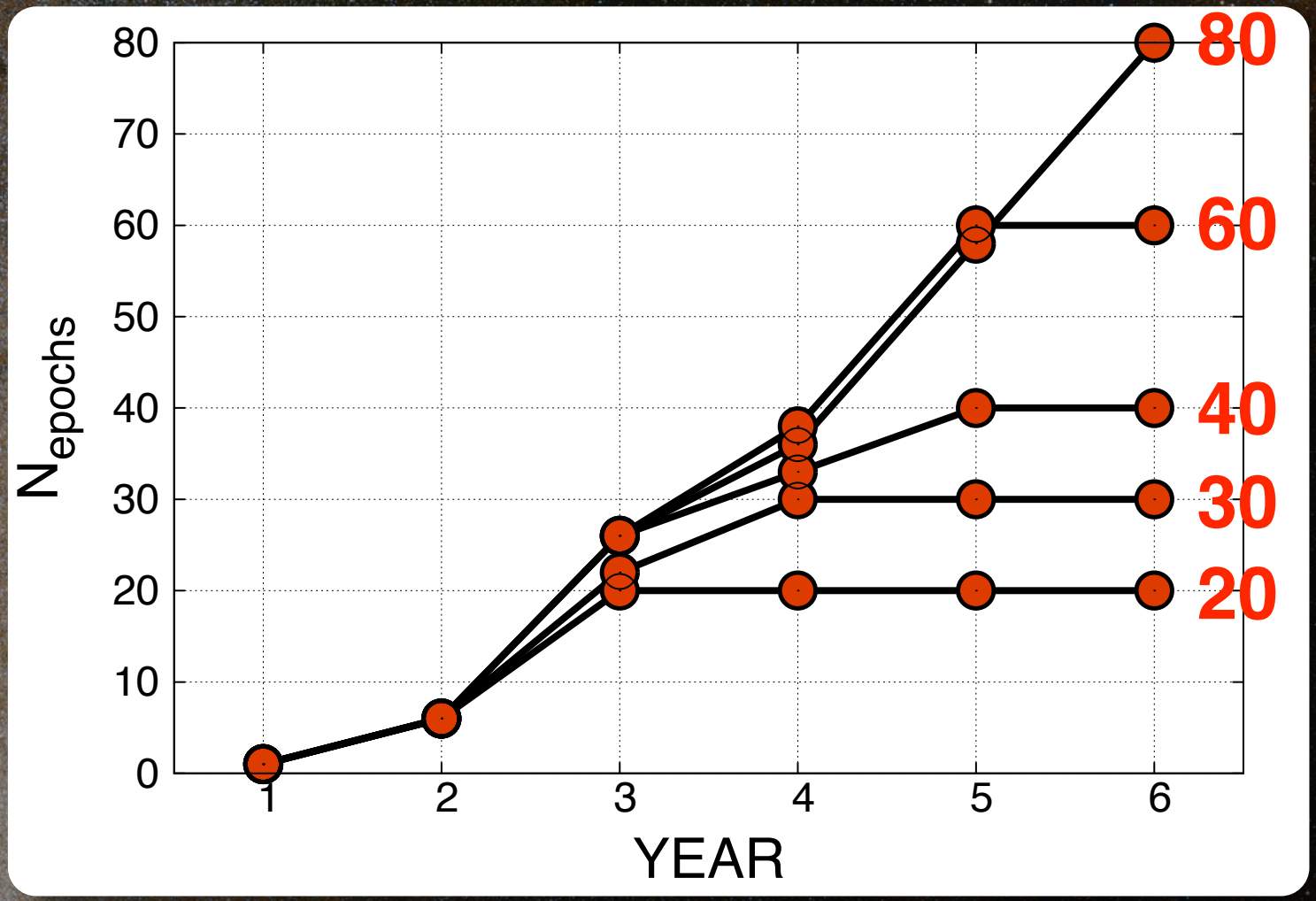
Detection in normalized Lomb periodogram

RRab Detection Rates

5 scenarios



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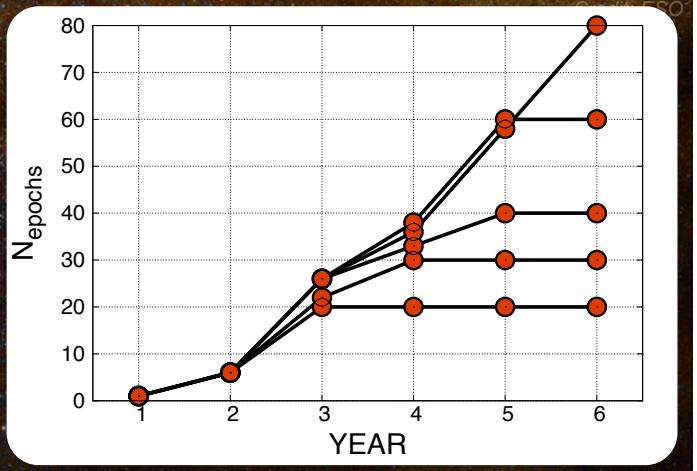

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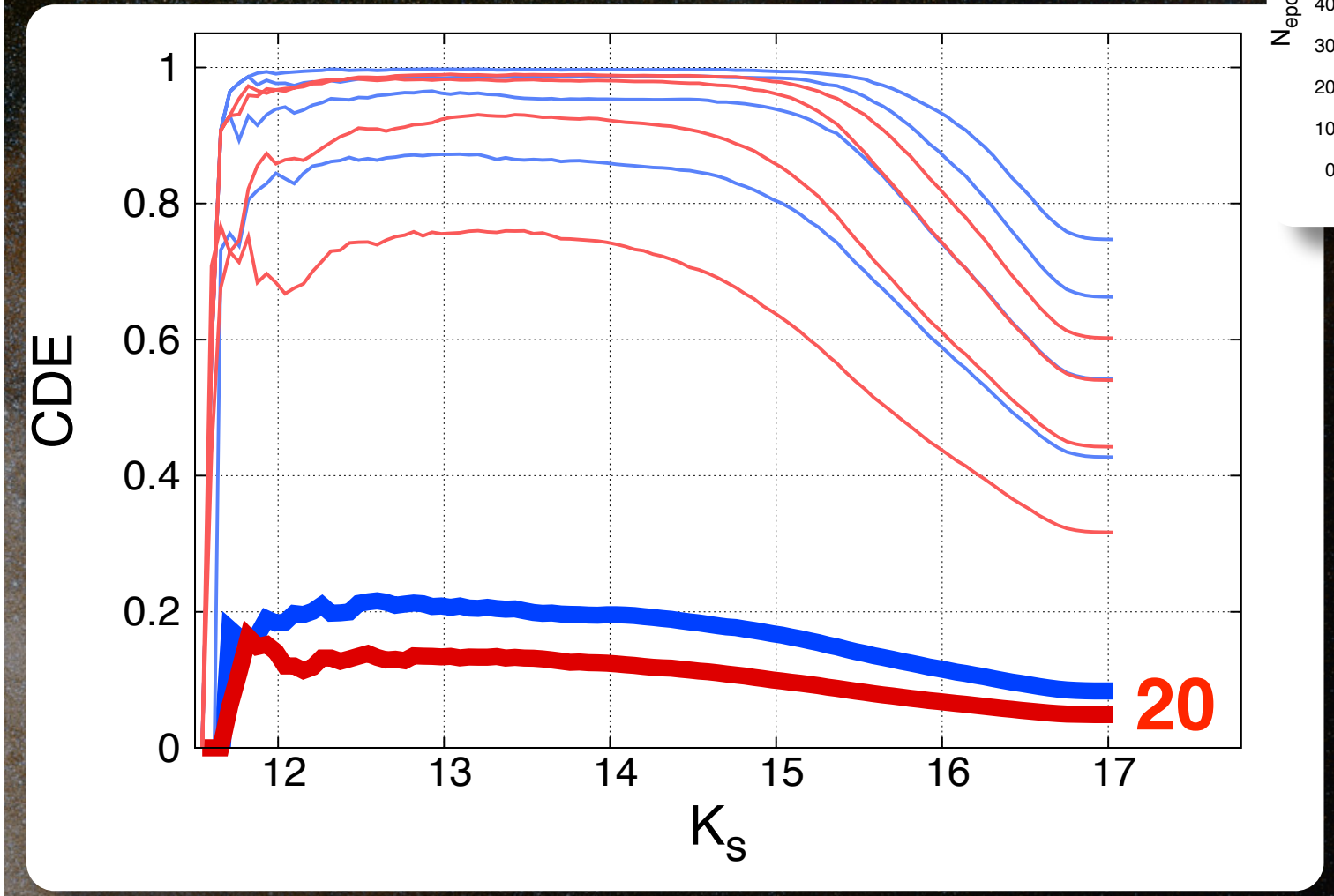
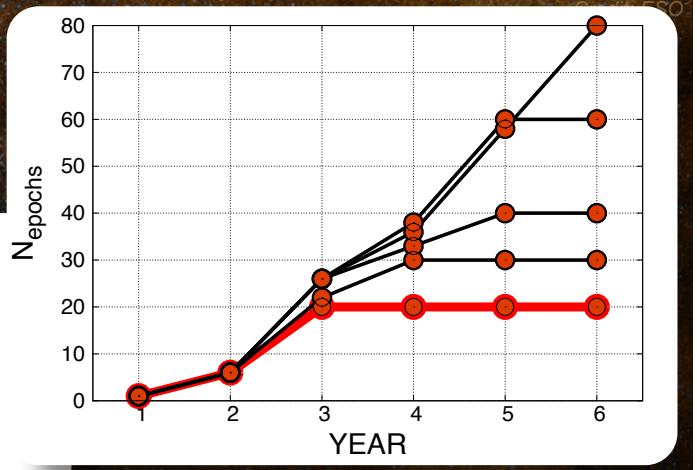
cumulative detection efficiency

RRab Detection Rates





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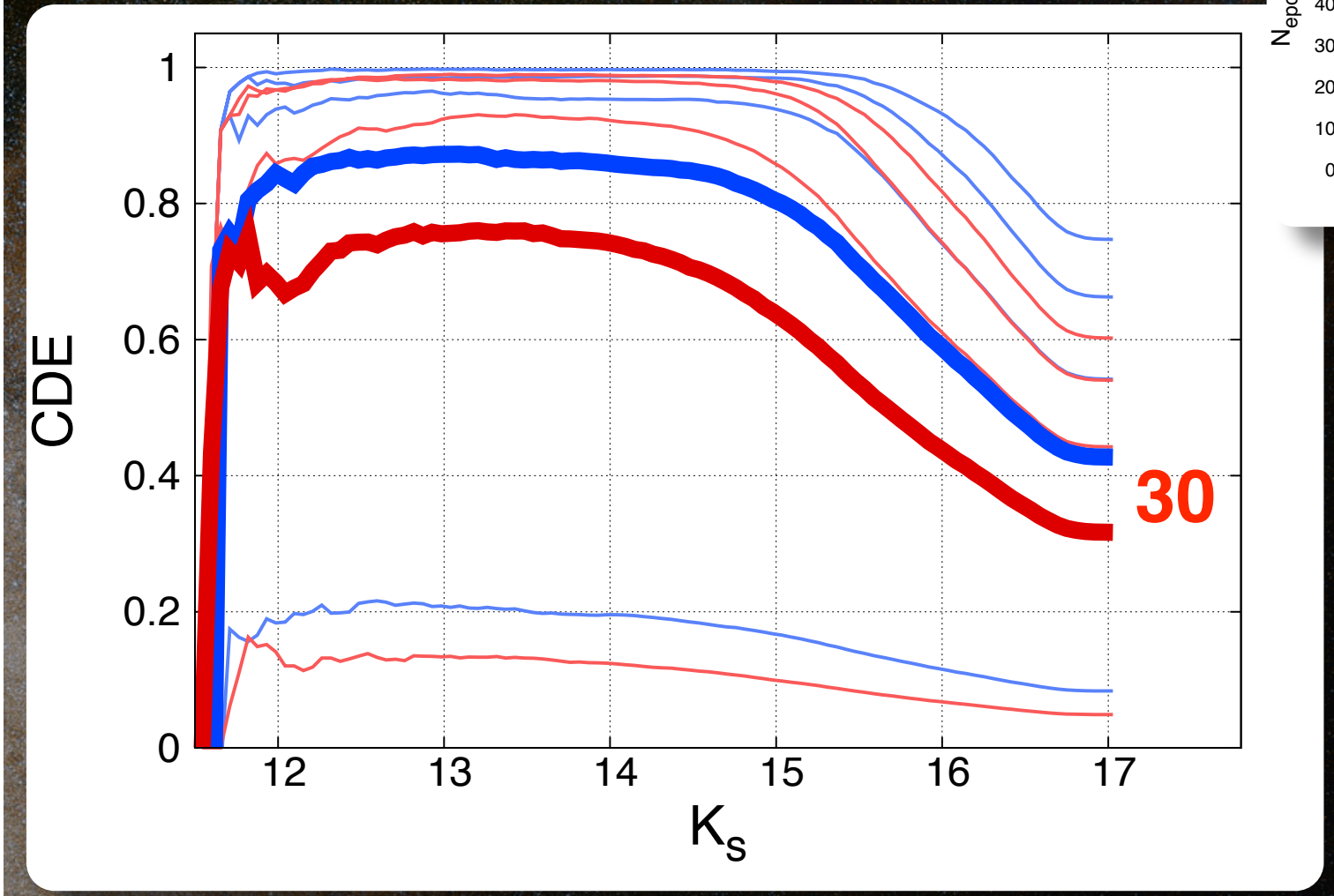

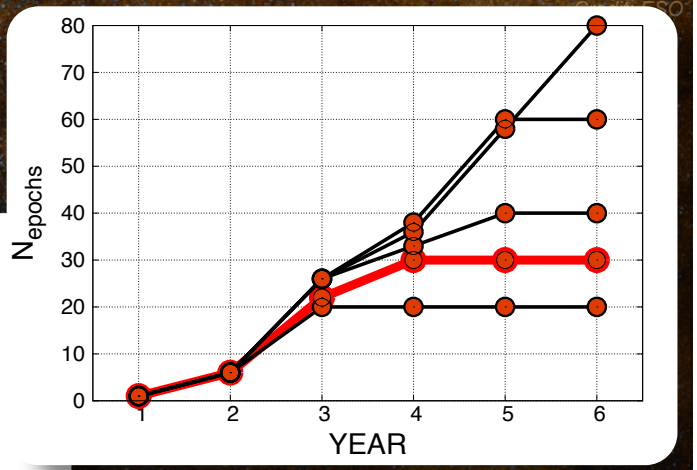

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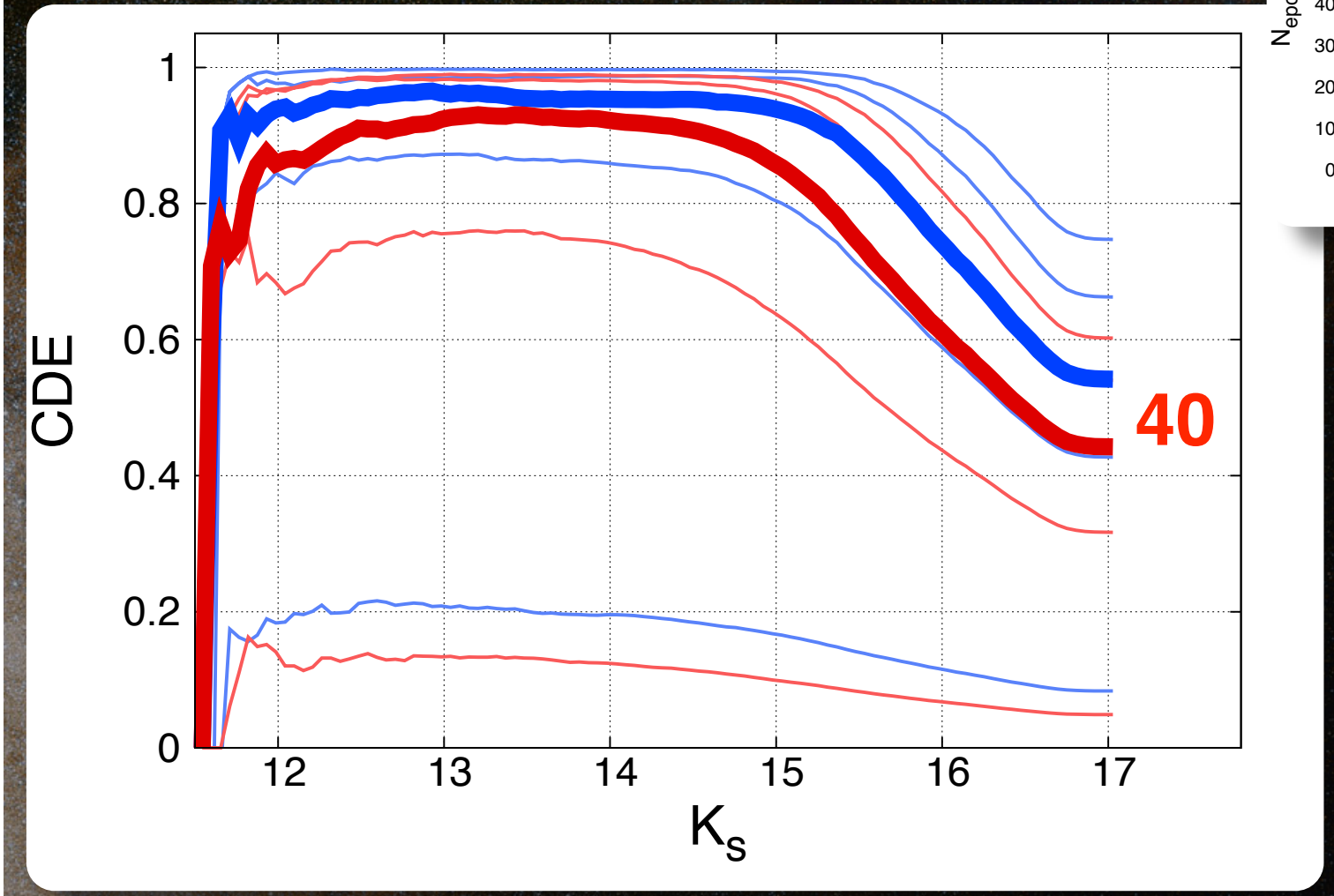

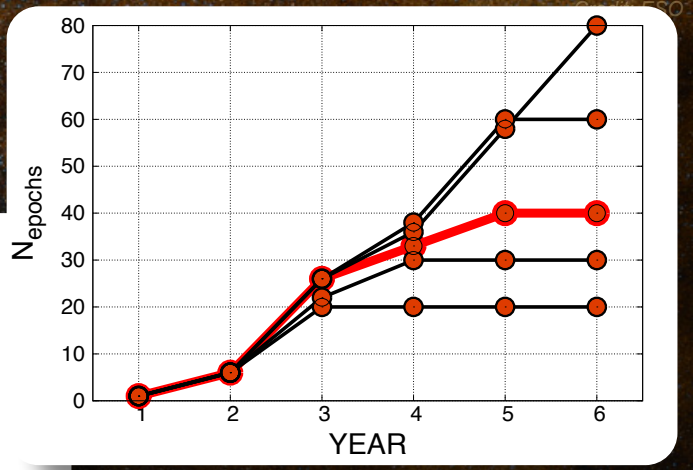

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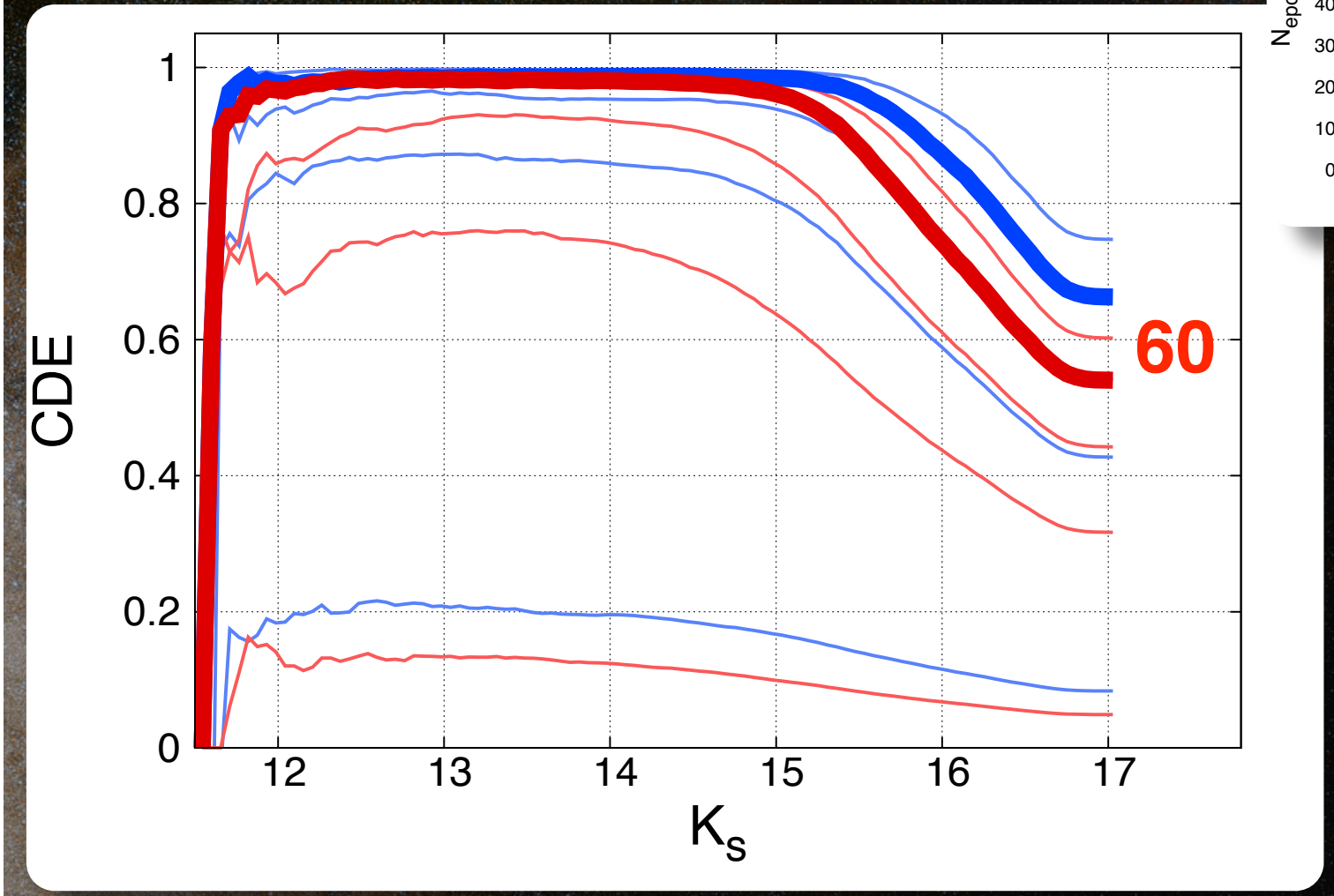

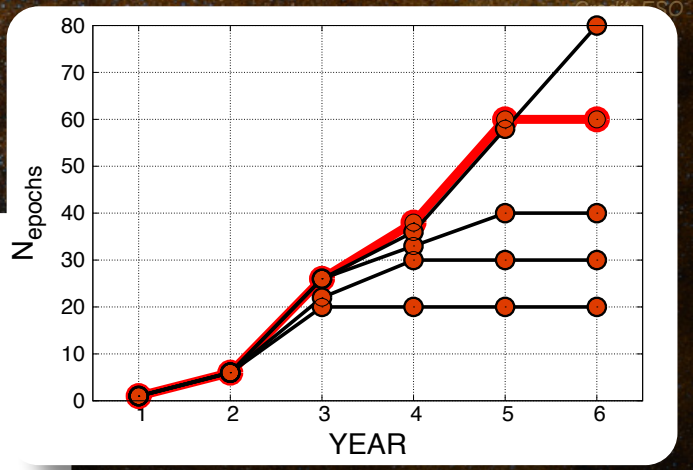

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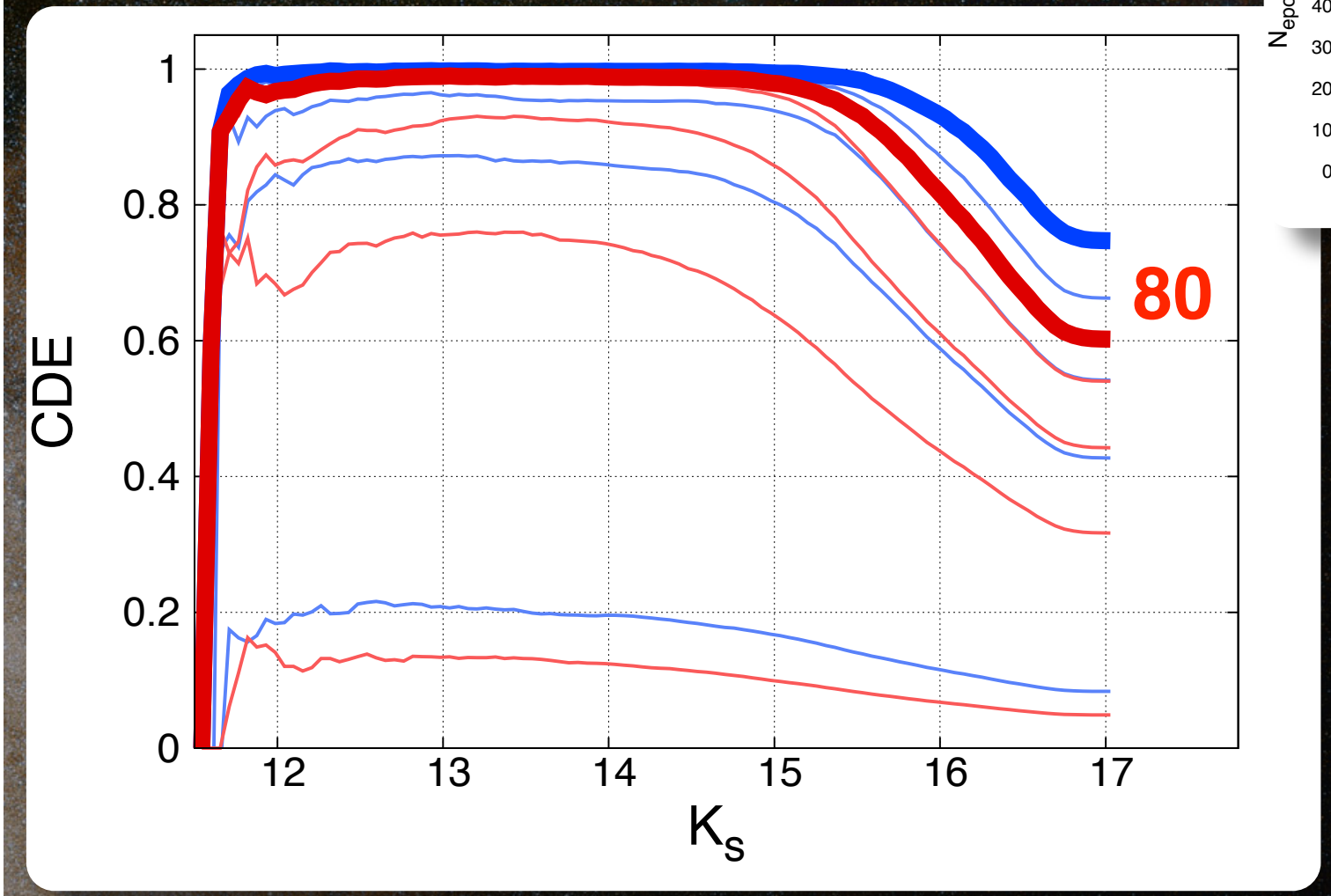

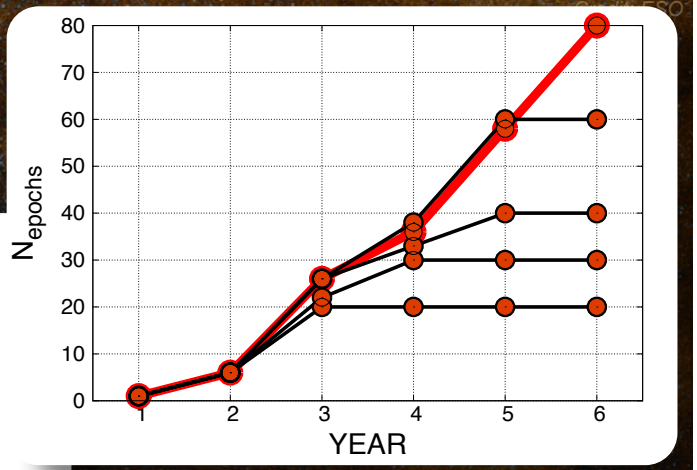

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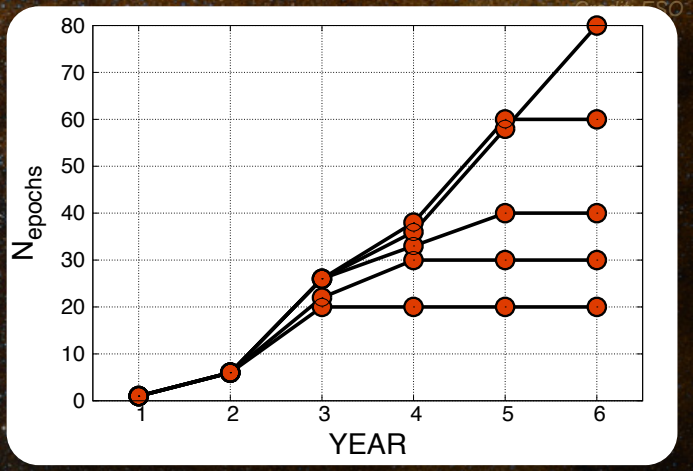

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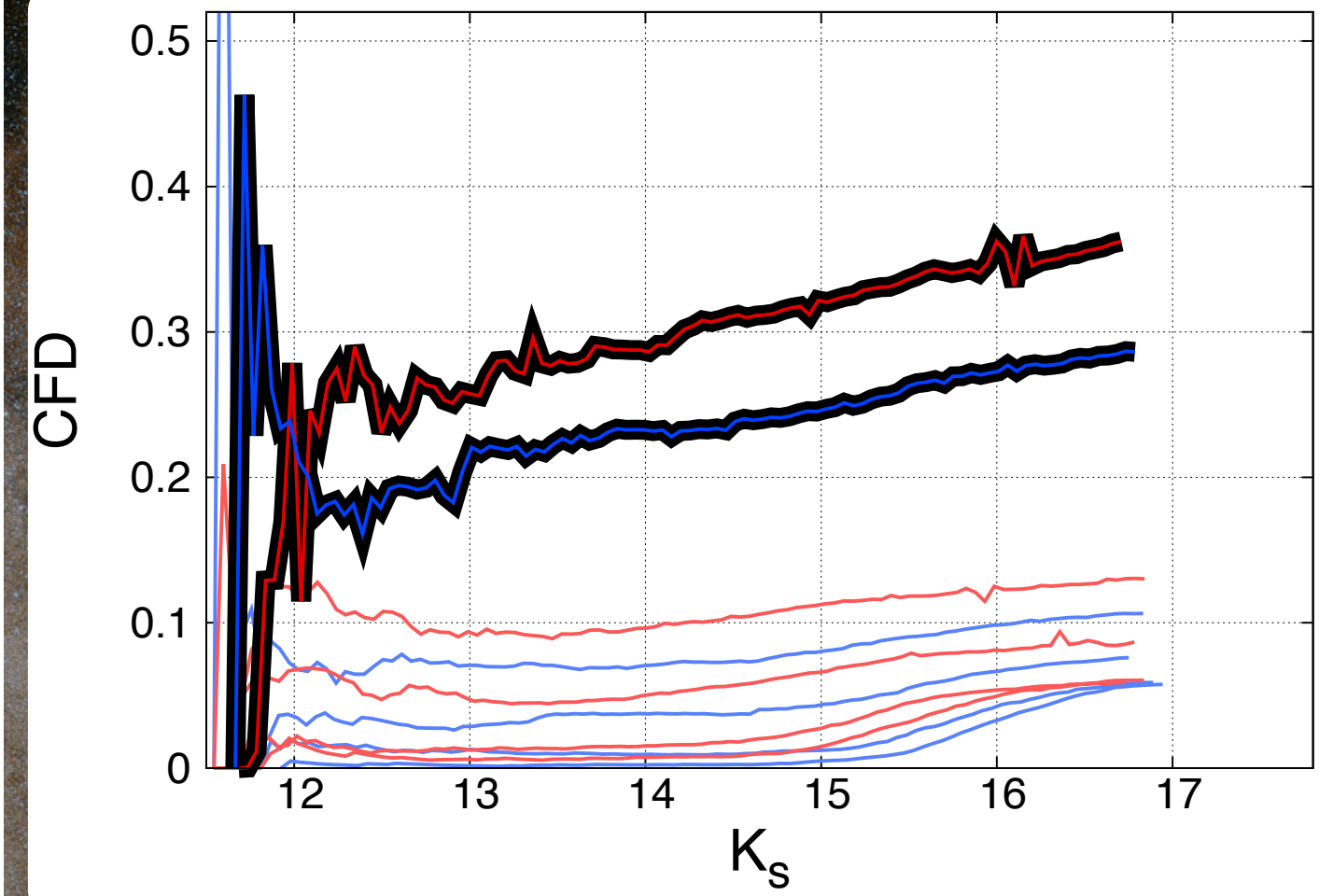

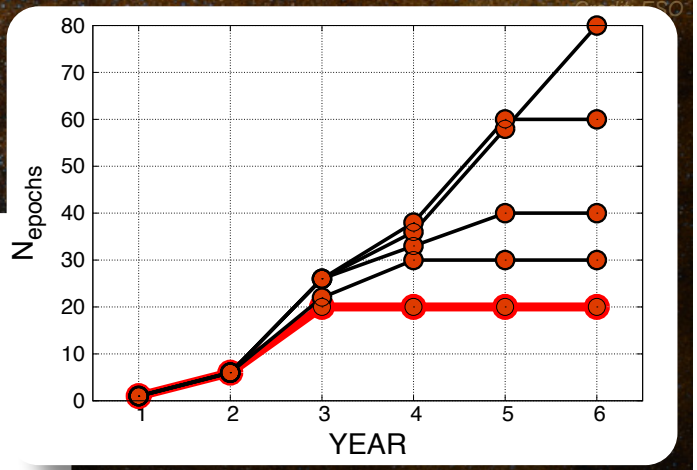

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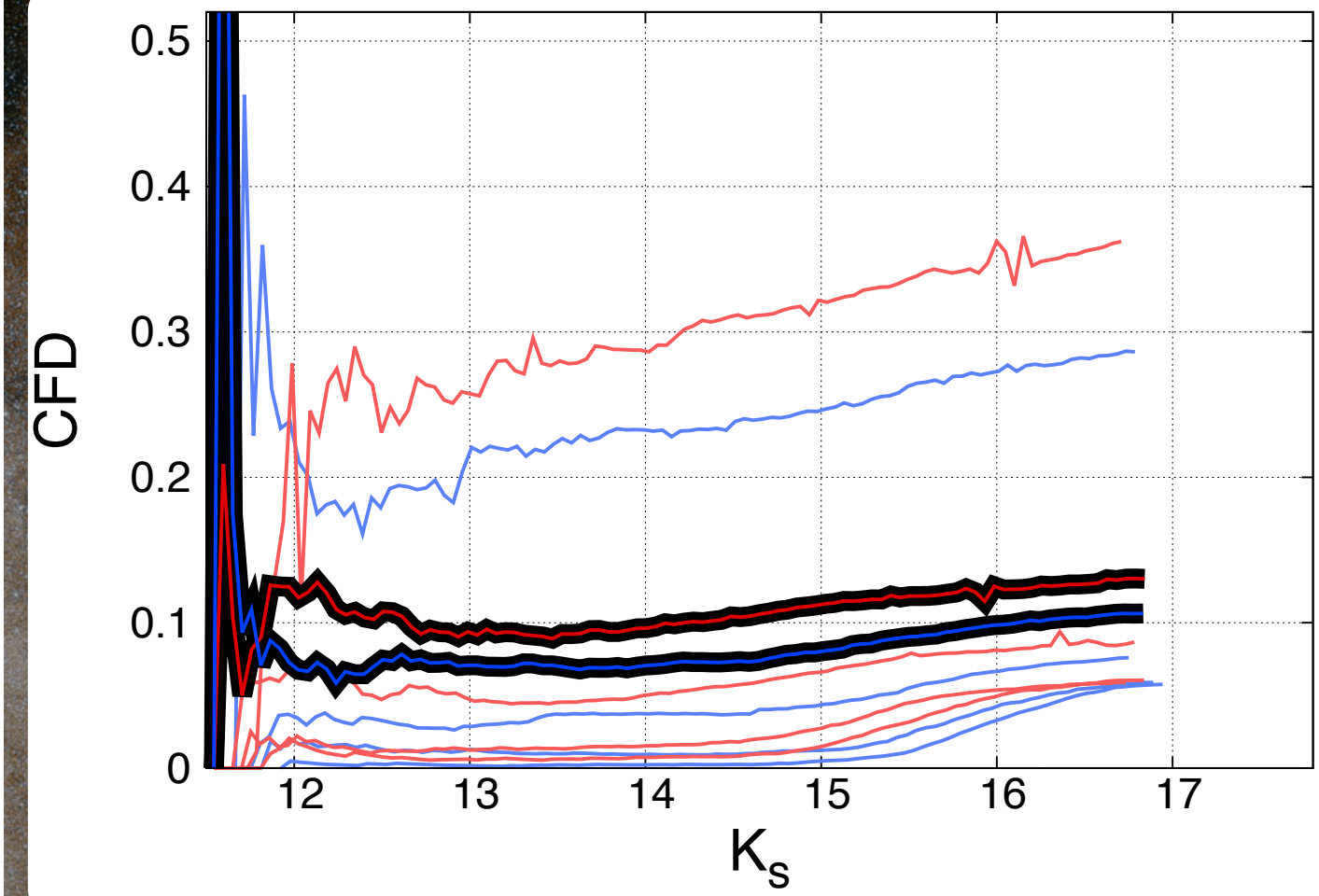

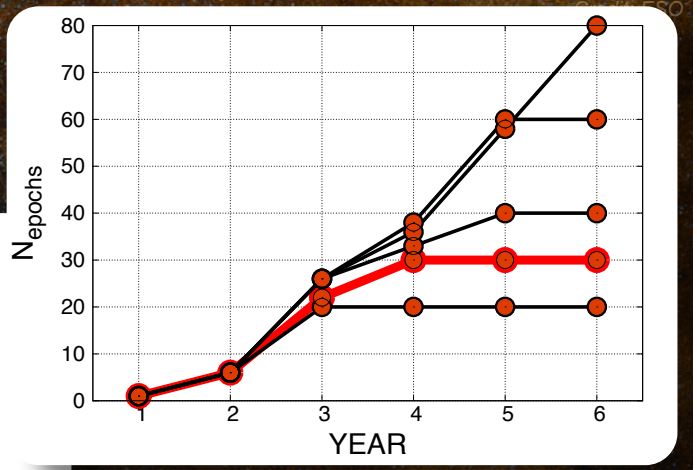

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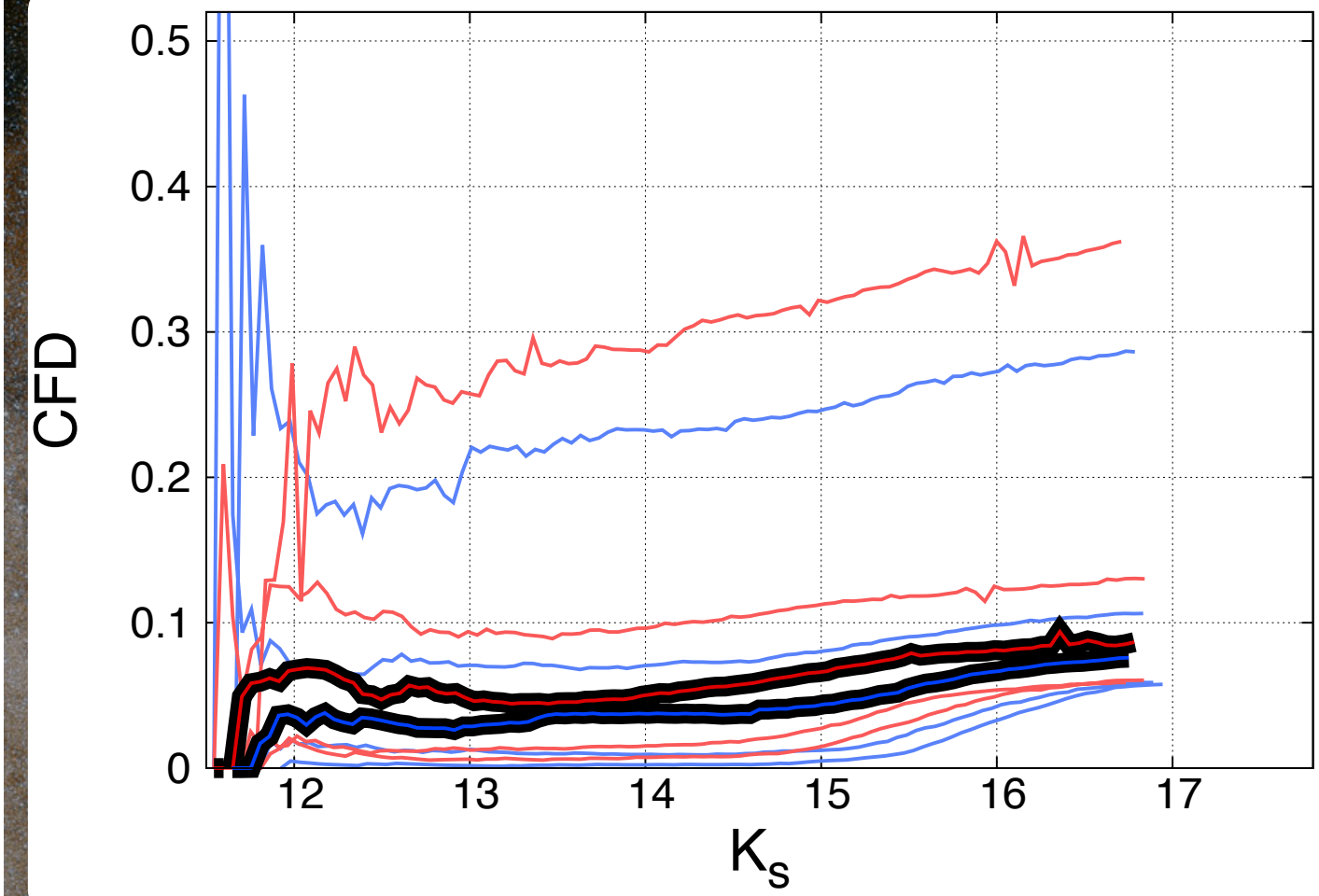

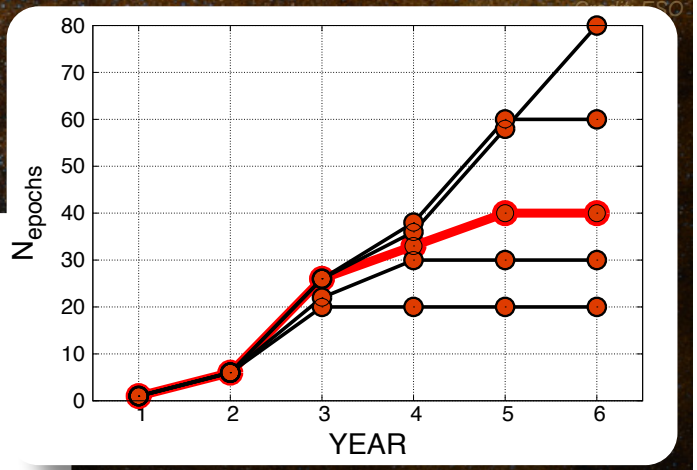

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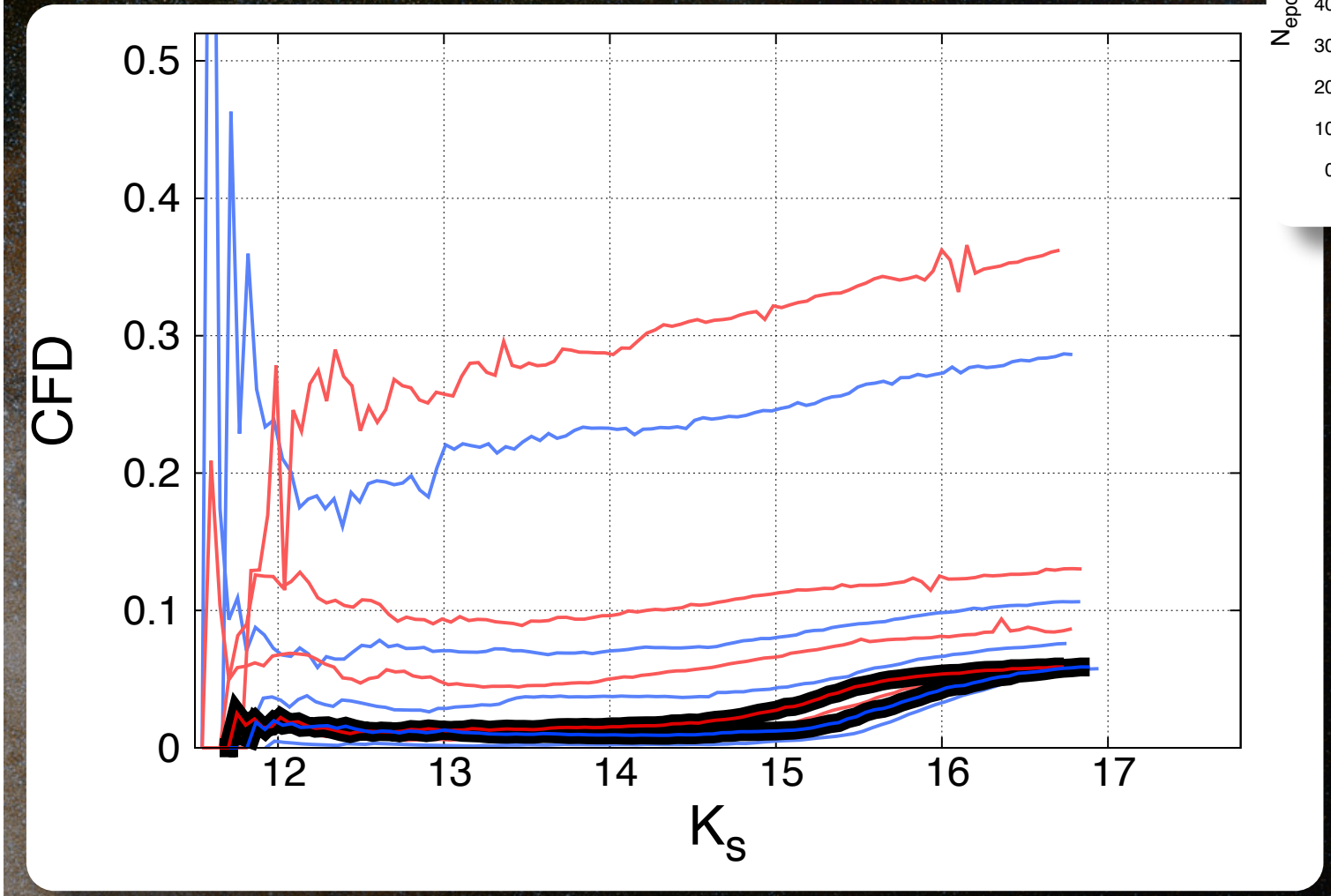

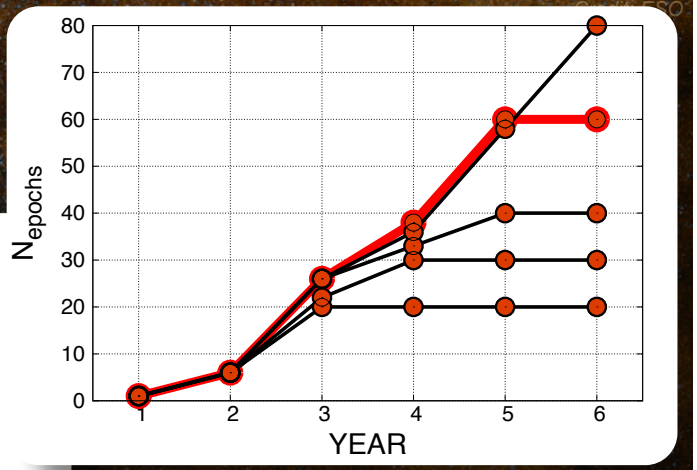

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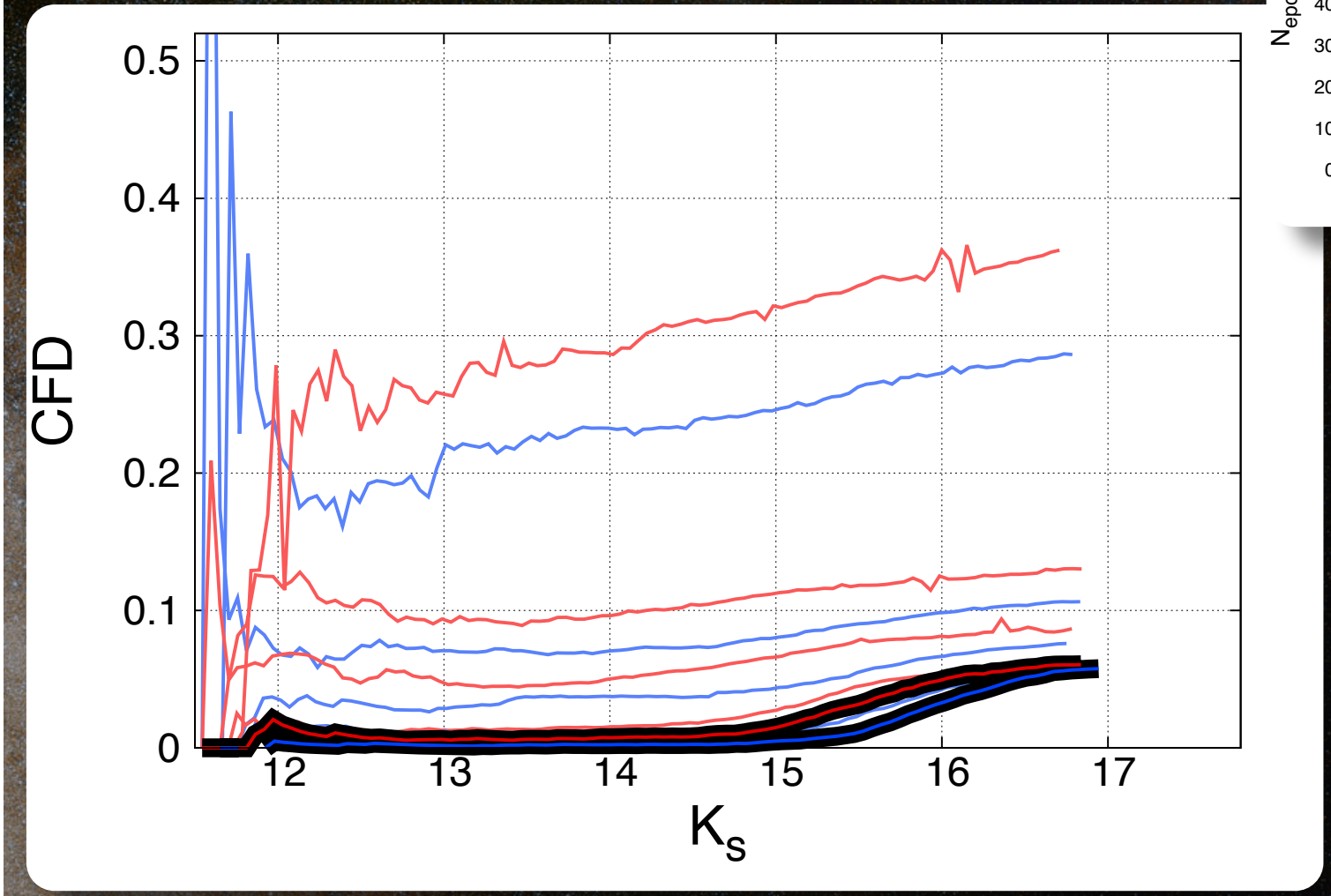

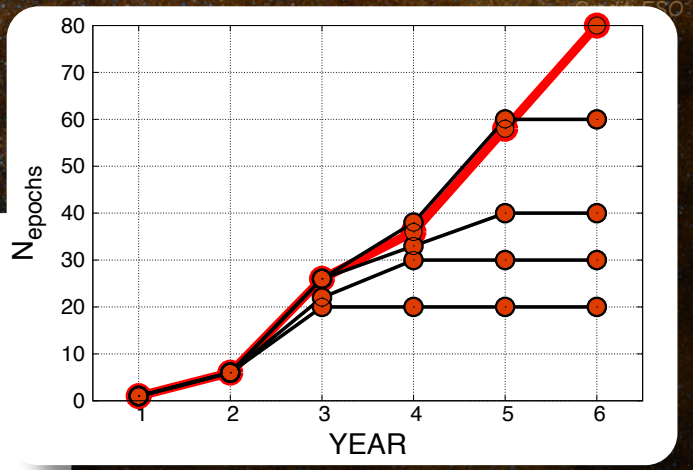

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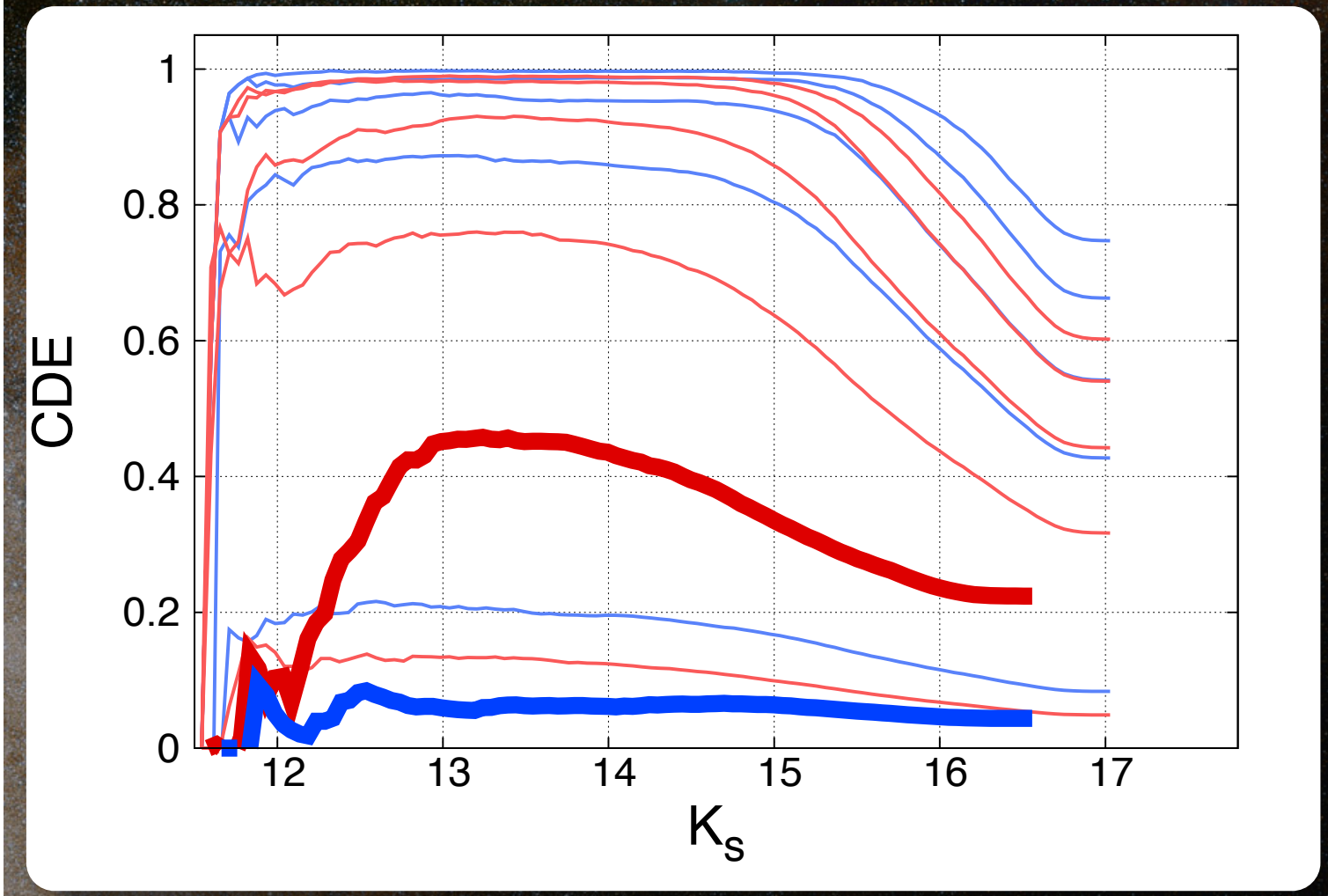
RRab Detection Rates

injected signal



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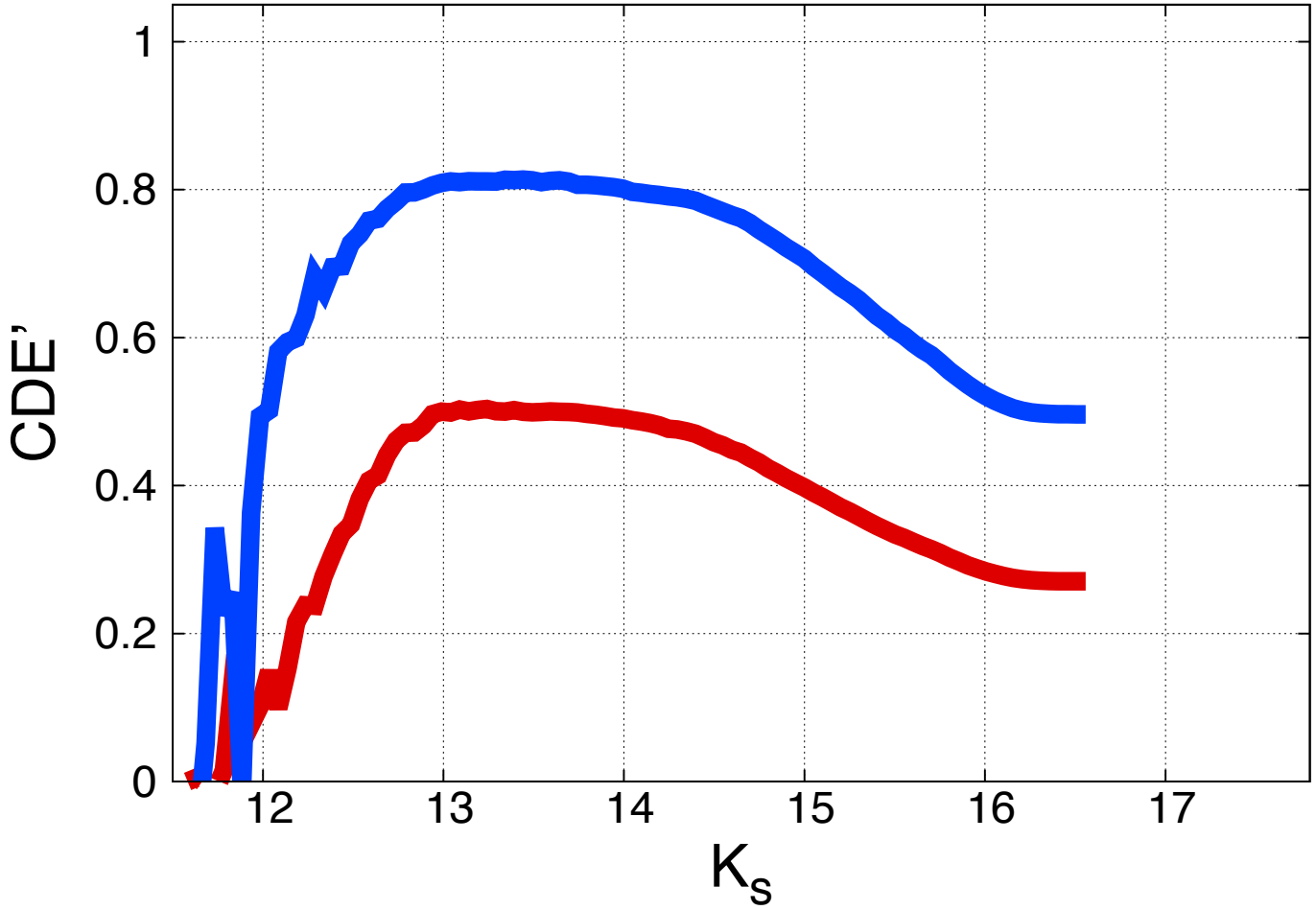

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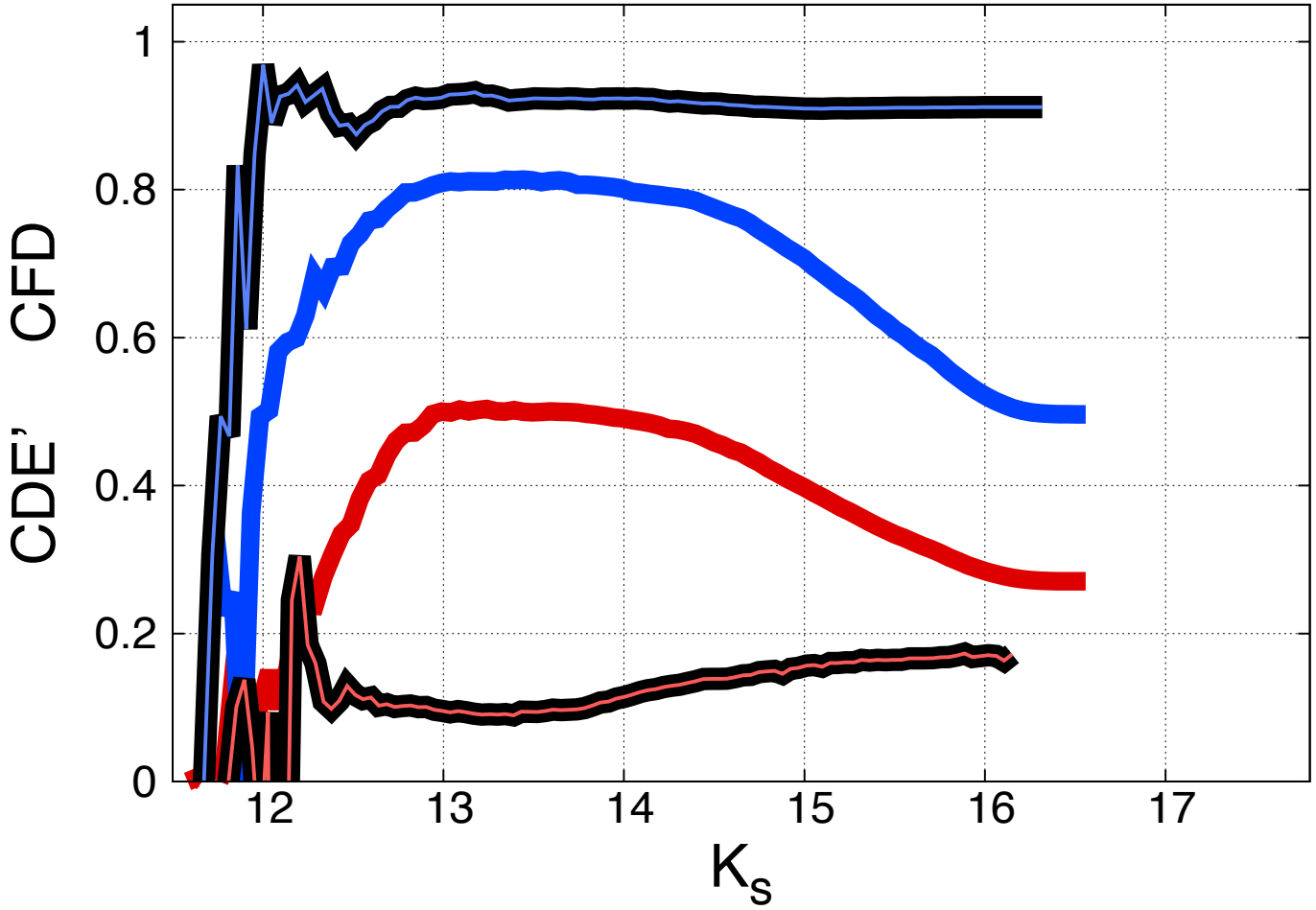

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RRab Detection Rates

SOME CONCLUSIONS (only for RRab stars)

- We can already detect RRab stars and do science with them.
- CDE is ~20% at the end of the 3rd year for the bulge
- 10 -15 more epochs will have a huge impact
- >60 epochs are needed for:
  - total completeness in the bulge
  - secure classification
  - few % false detection rate
- clumped cadence is harmful
  - (randomize the operator)

SYSTEMATIC VARIABILITY SEARCH

STANDARD PROCEDURE

PURPOSE: fast extraction of RR Lyrae and Cepheids
using PUC-DAA's equipment *(VVV + Geryon)*

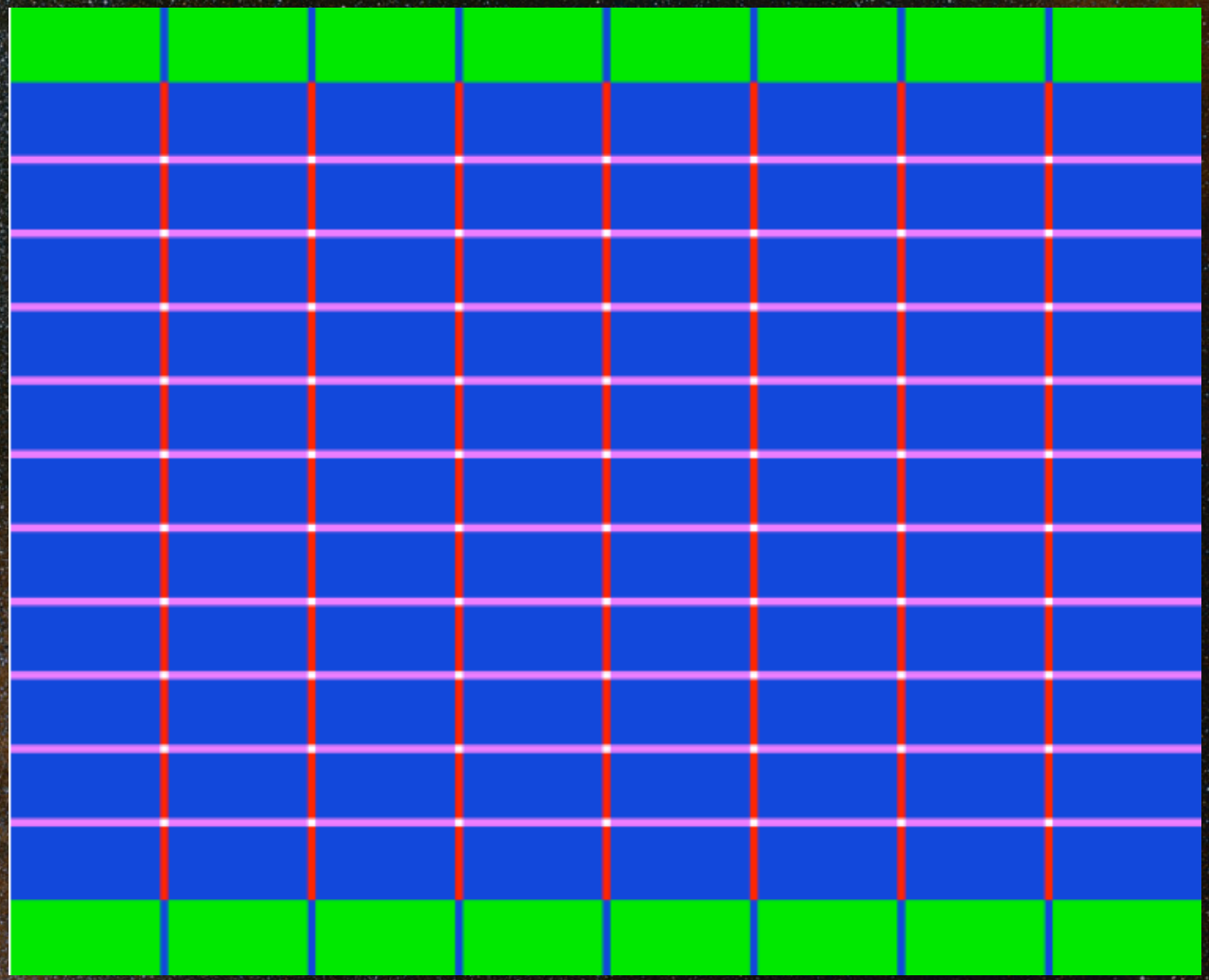
(1) list-driven cross-match of *pawprint* catalogs
(2) light curve extraction
(3) various outlier rejections and concatenation
(4) general variability search via variability index
(5) computation of various statistics
(6) frequency analysis of variable candidates (Lomb-method)
(7) OUTPUT:

- variability statistics tables
- frequency analysis tables
- light curves
- phase curves

Systematic Variability Search

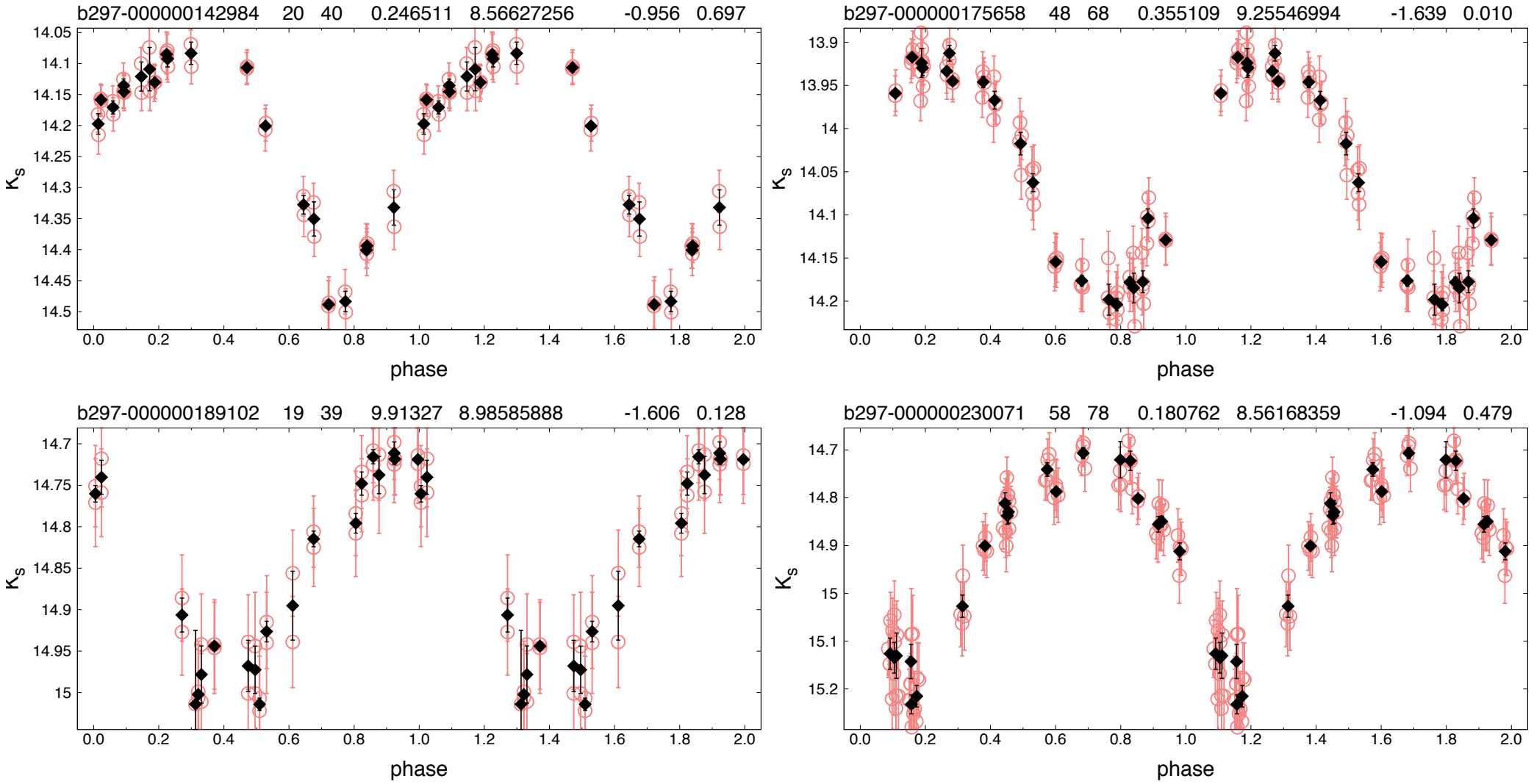
Variability index

Modified weighted mean of squared successive differences



Cross et al. 2012

Systematic Variability Search



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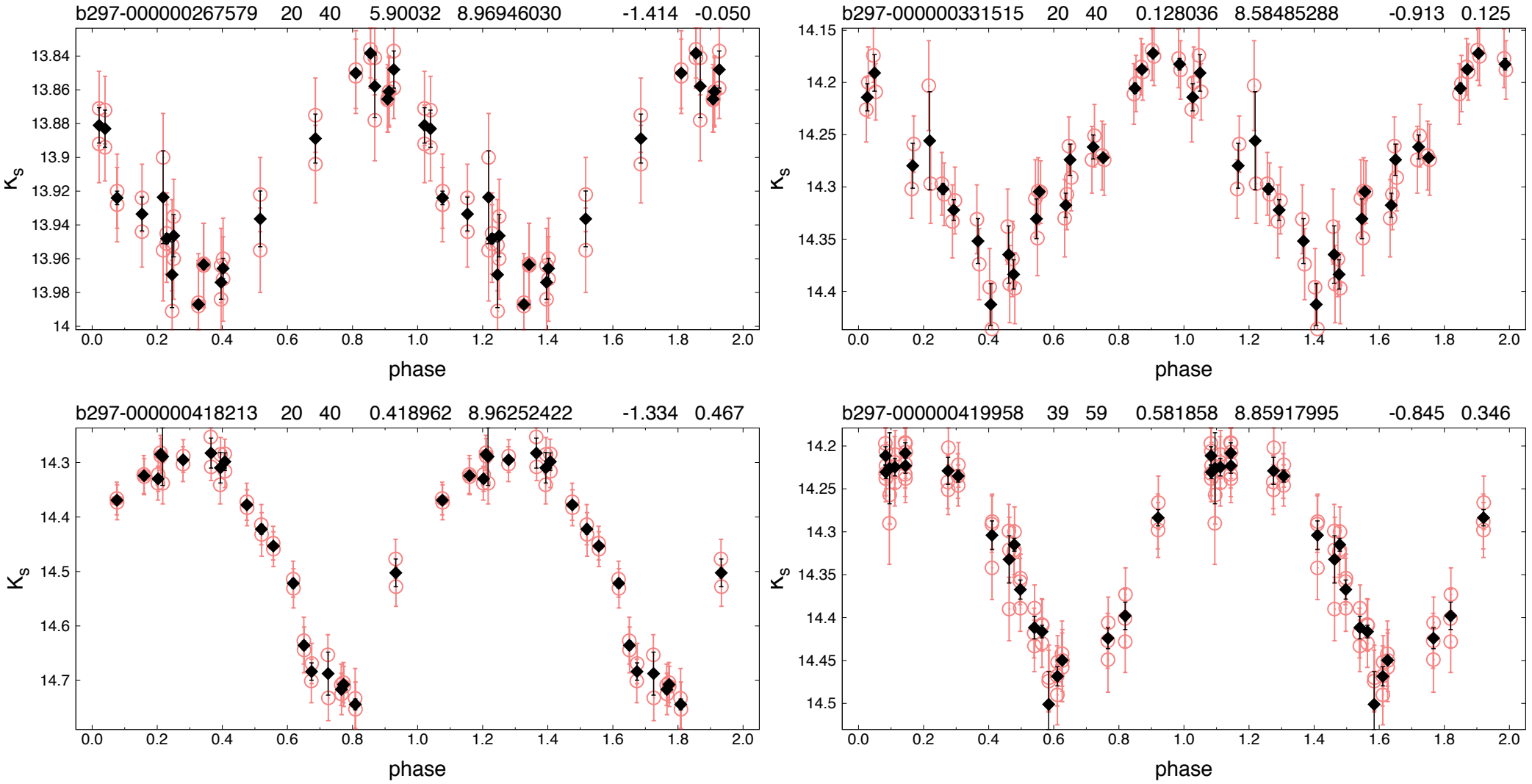
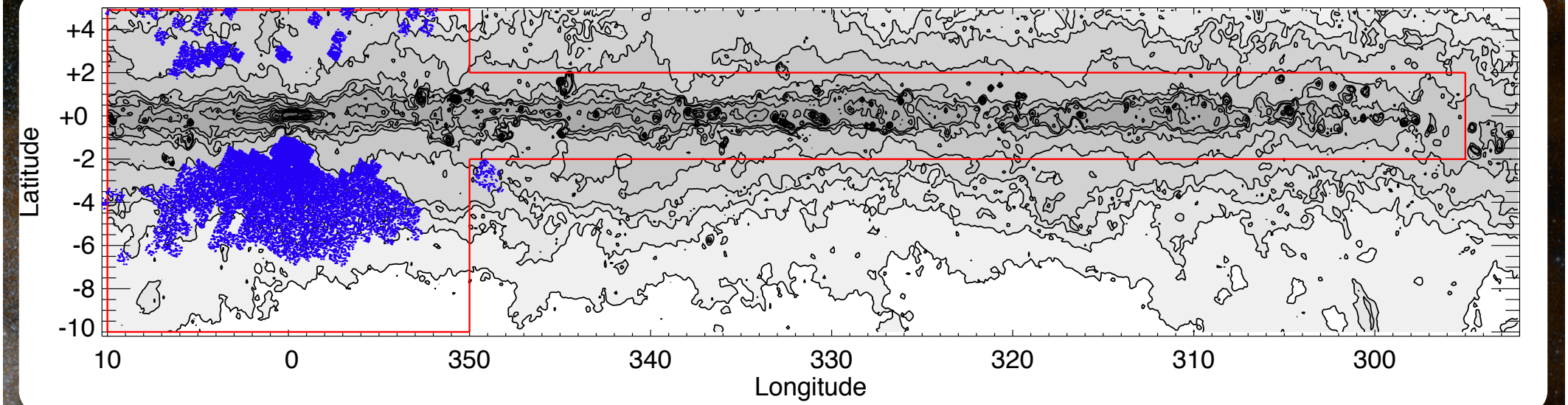


Analysis of the OGLE3 RRab Stars

courtesy of M. Hempel



OGLE3 catalog

(Soszynski et al. 2011)

- 11756 RRab , 4989 RRc , 91 RRd
- Analysis of Pietrukowicz et al. (2012) with *V, I*
- VVV data are less affected by reddening
- K_s P-L relation less dependent on metallicity
- Cross-match with VVV ZYJHK *pawprint* photometry

Analysis of the OGLE3 RRab Stars

Absolute magnitude from P-L relations:

$$M_I = 0.471 - 1.132 \log P + 0.205 \log Z,$$

$$M_J = -0.141 - 1.773 \log P + 0.190 \log Z,$$

$$M_H = -0.551 - 2.313 \log P + 0.178 \log Z,$$

$$M_K = -0.597 - 2.353 \log P + 0.175 \log Z,$$

Catelan et al. (2004)

Where:

periods and metallicities from OGLE3 *I* light-curves

$$\begin{array}{lllll} [\mathrm{Fe/H}] = & -3.142 & -4.902P & +0.824\phi_{31} & \\ & \pm 0.646 & \pm 0.375 & \pm 0.104 & \sigma = 0.18 \end{array}$$

Smolec (2005)

Reddening from intrinsic color index:

$$(I-K_s)_0 = M_I - M_{K_s}$$

$$A_{K_s} = 0.163\,\mathrm{E}(I-K_s)$$

Dean (1978) + Cardelli (1989) + Indebetouw (2005)

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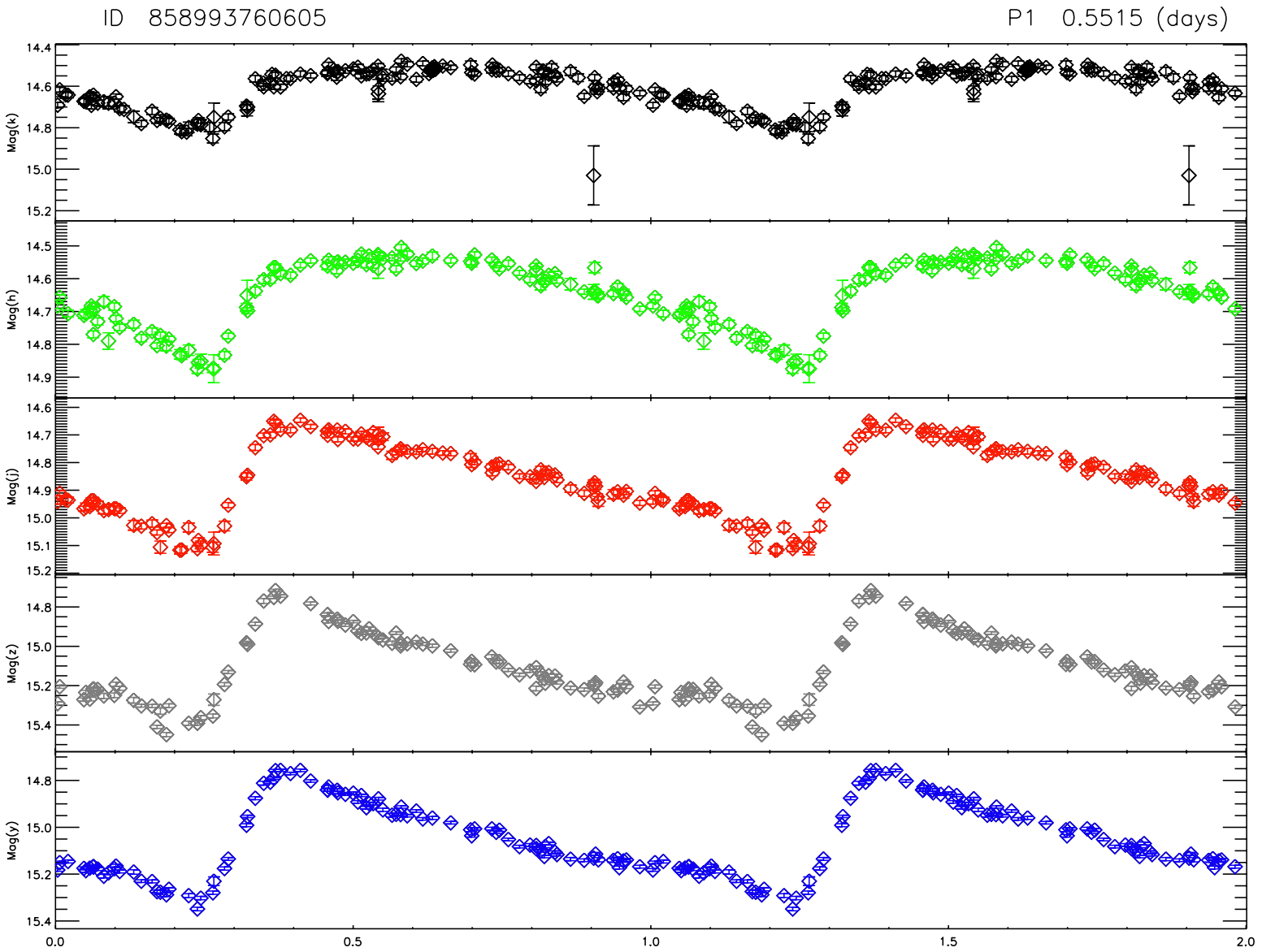
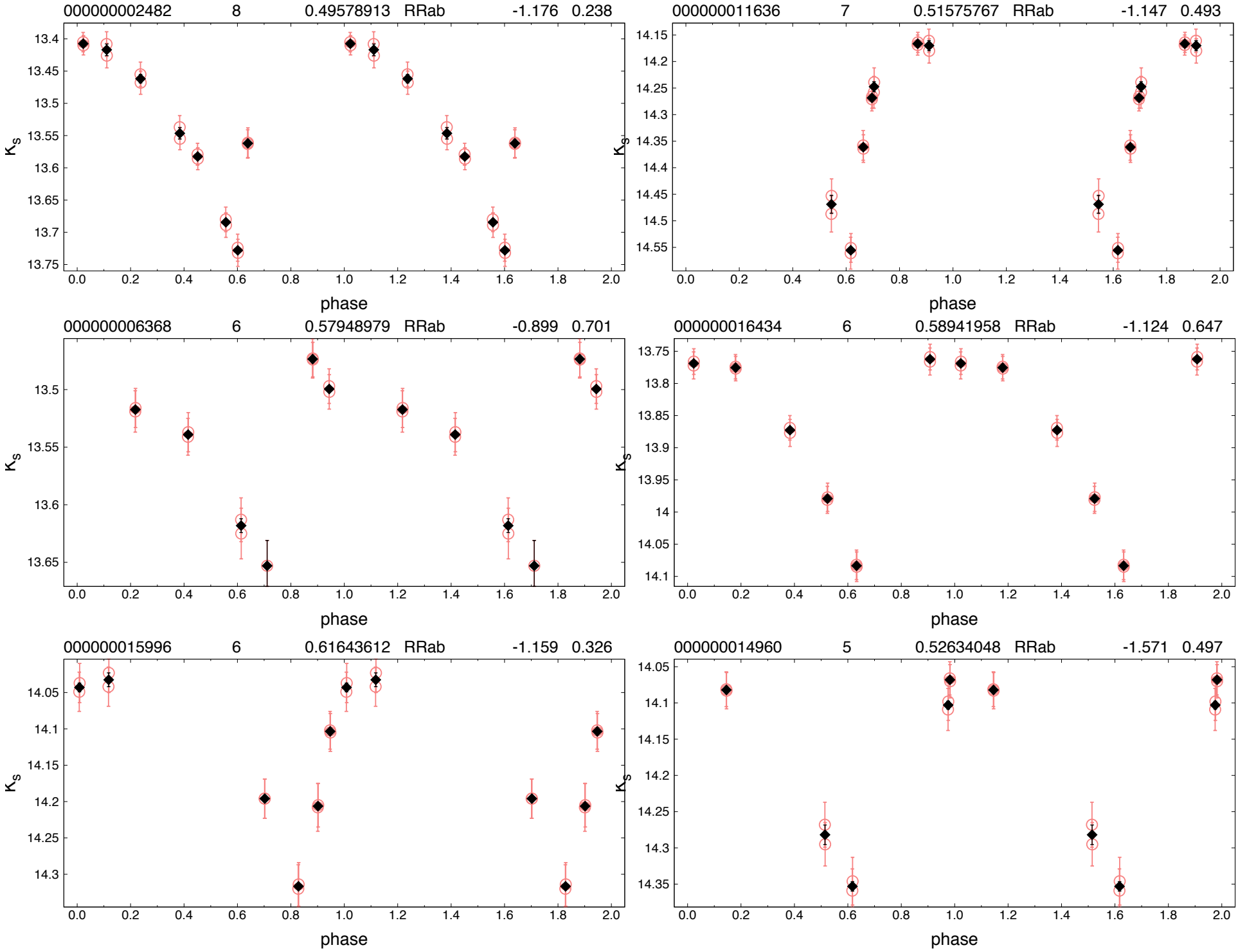


ZYJH templates from *Ferreira-Lopes et al. (2012)*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000000011636 7 0.51575767 RRab -1.147 0.493
000000006368 6 0.57948979 RRab -0.899 0.701
000000016434 6 0.58941958 RRab -1.124 0.647
000000015996 6 0.61643612 RRab -1.159 0.326
000000014960 5 0.52634048 RRab -1.571 0.497
Ks
phase

Analysis of the OGLE3 RRab Stars

TFF

Template Fourier fitting

Kovács & Kupi (2007)

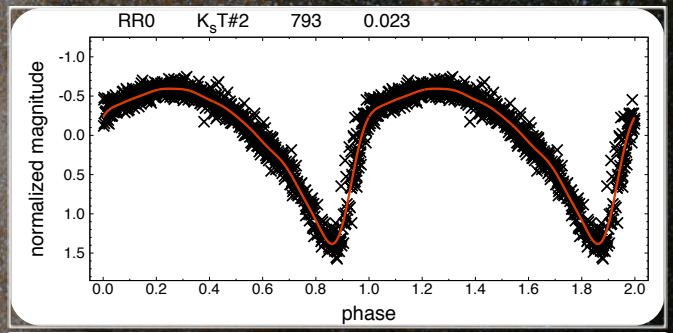
How to derive accurate mean magnitudes from incomplete and noisy time-series?

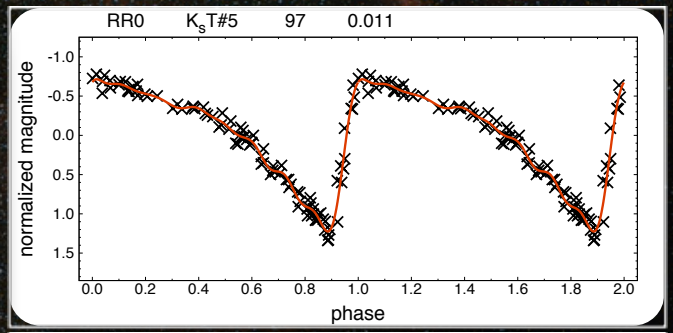
Use template light curves with all the flavors of variability...

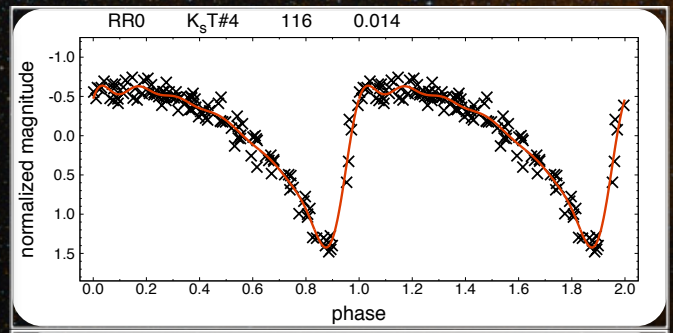
$$\{x_{i,j}(\varphi)\}$$

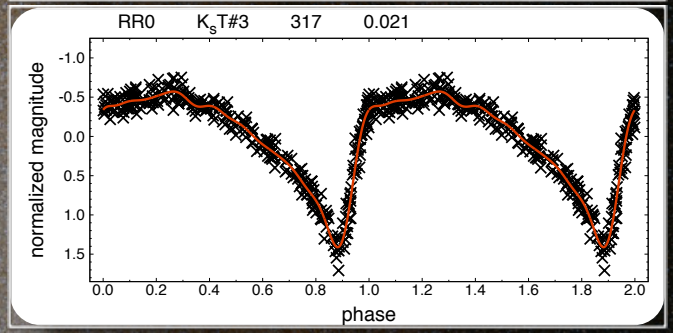
...to fit the light curve:

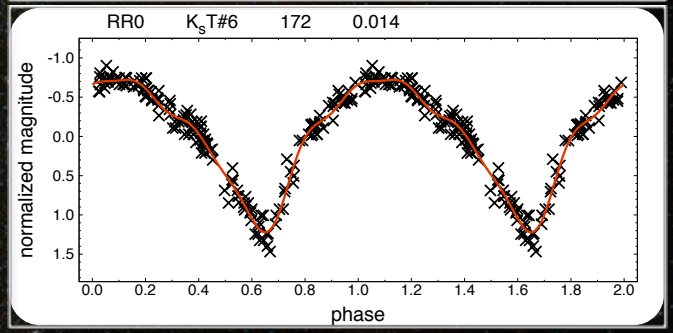
$$\{Y_i\}$$

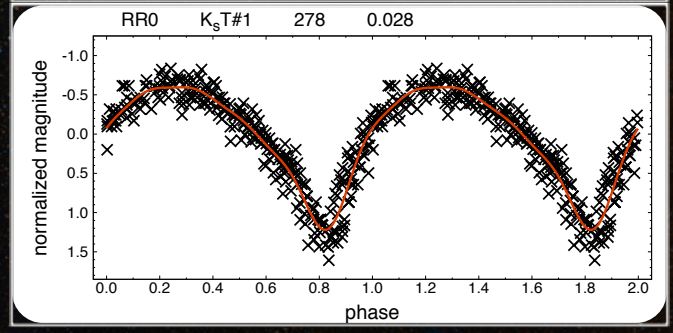












Credit: ESO

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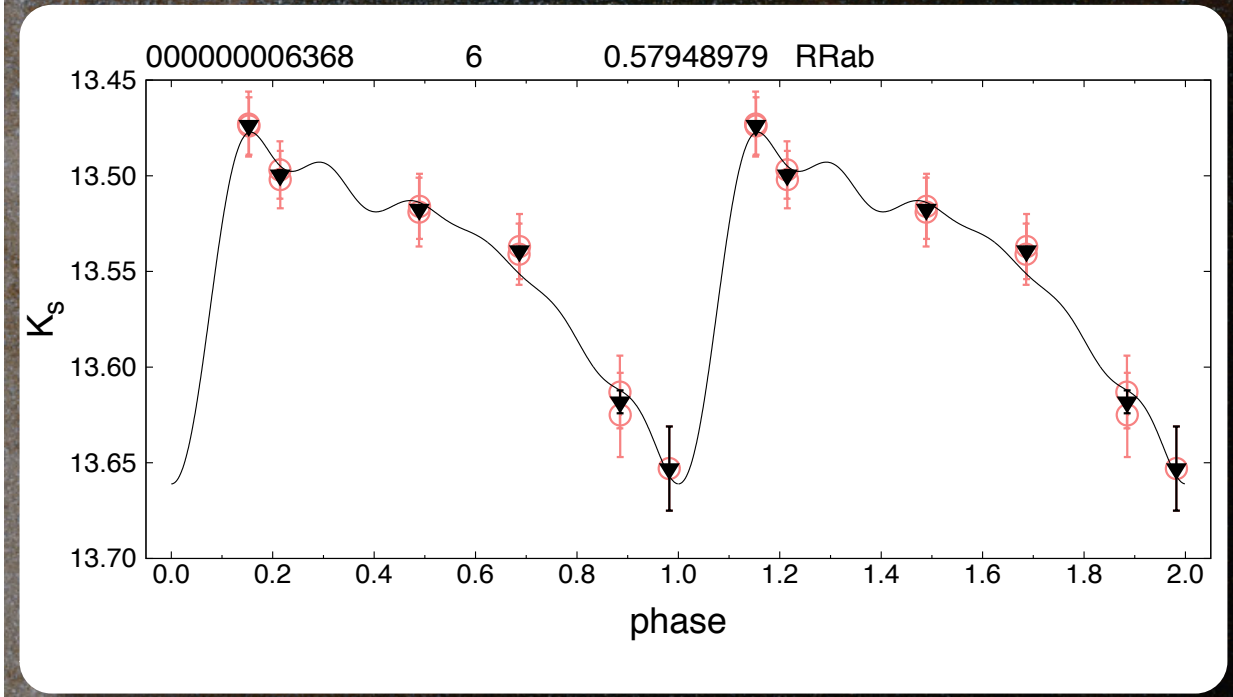


$$D_j(\varphi)=\frac{1}{N}\sum_{i=1}^{N}[Y_i-X_i(\varphi)]^2$$

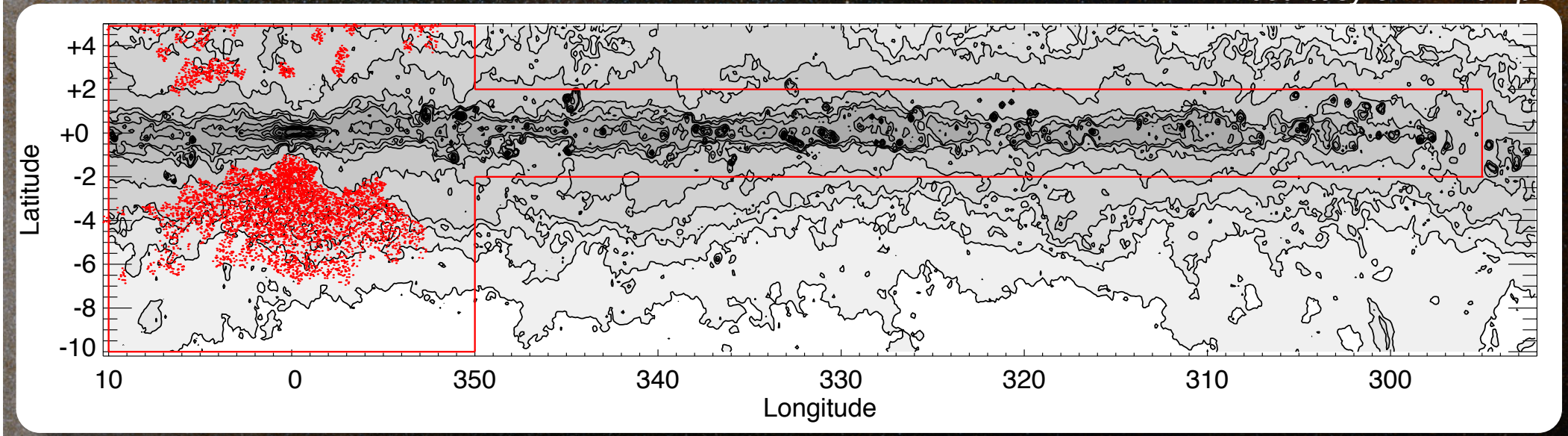
$$X_i(\varphi)=c_0+c_1 x_i$$

Analysis of the OGLE3 RRab Stars

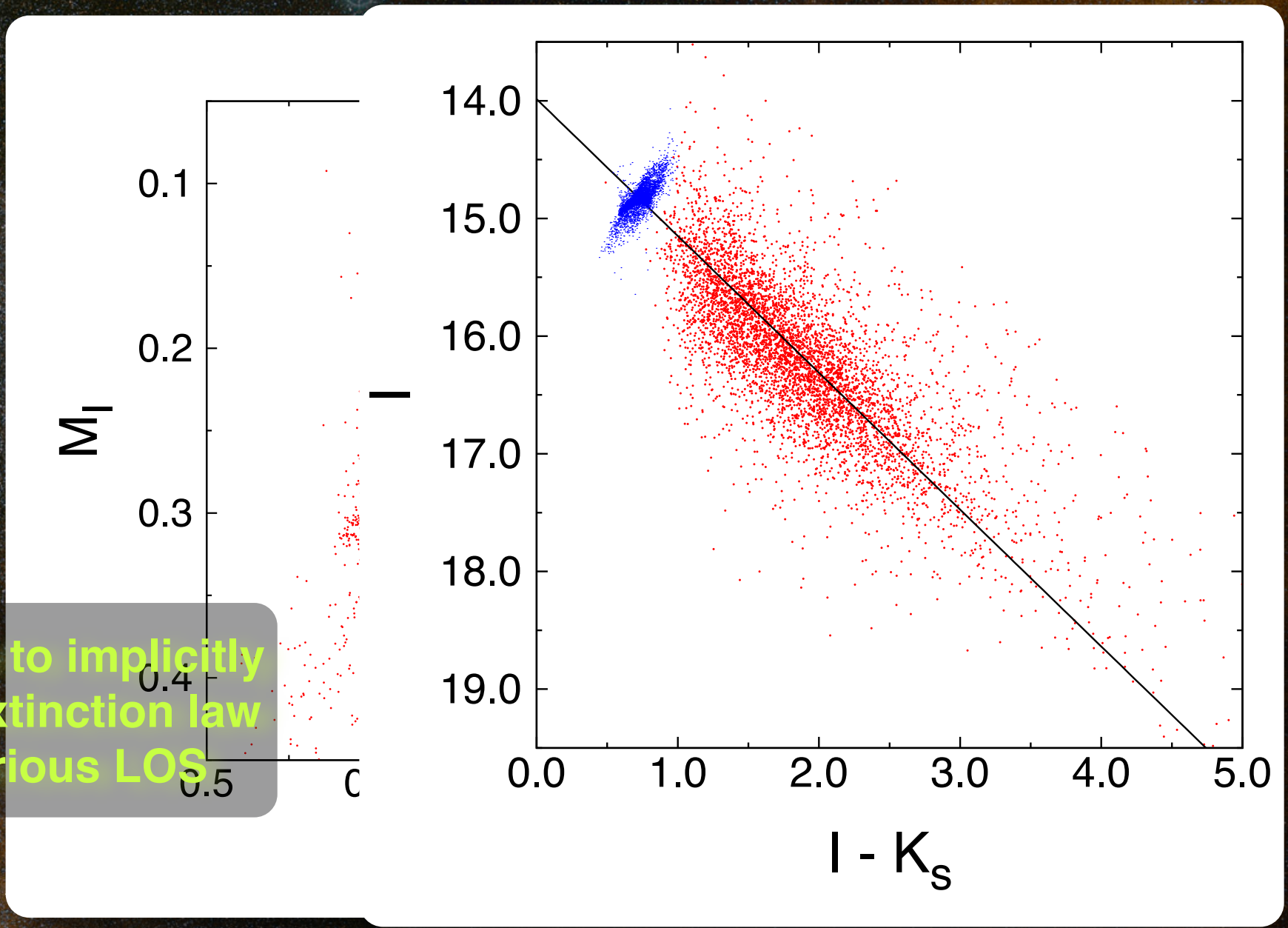
CUTS

- Phase coverage (1 - max. phase lag) > 0.5
- Remove blends based on A(K)
- Remove runaways based on A(K)
- $\text{sigma}_{TFF} < 0.05$
- min. points: 5

courtesy of M. Hempel



Analysis of the OGLE3 RRab Stars

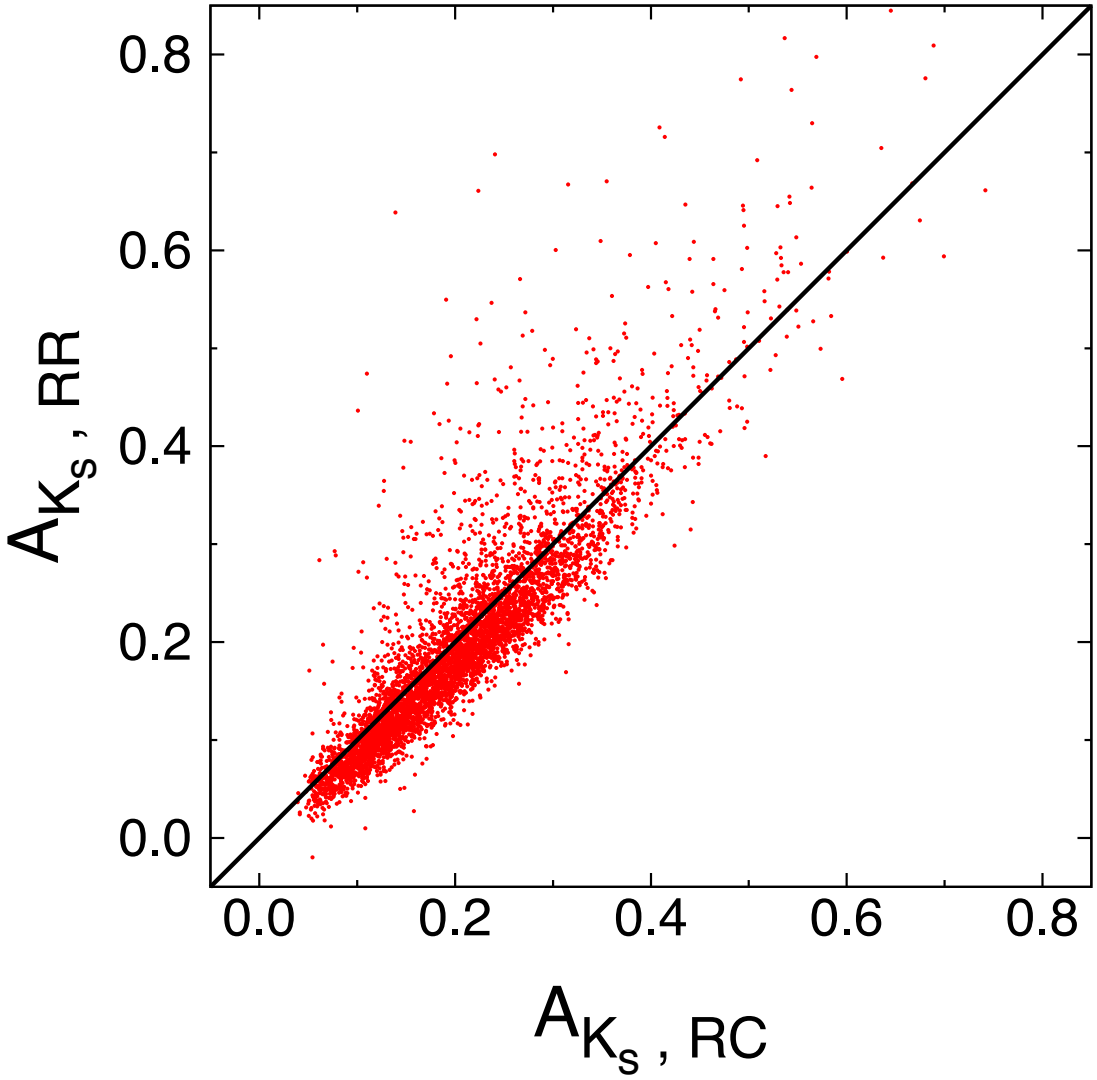


potential to implicitly derive extinction law for various LOS

Analysis of the OGLE3 RRab Stars

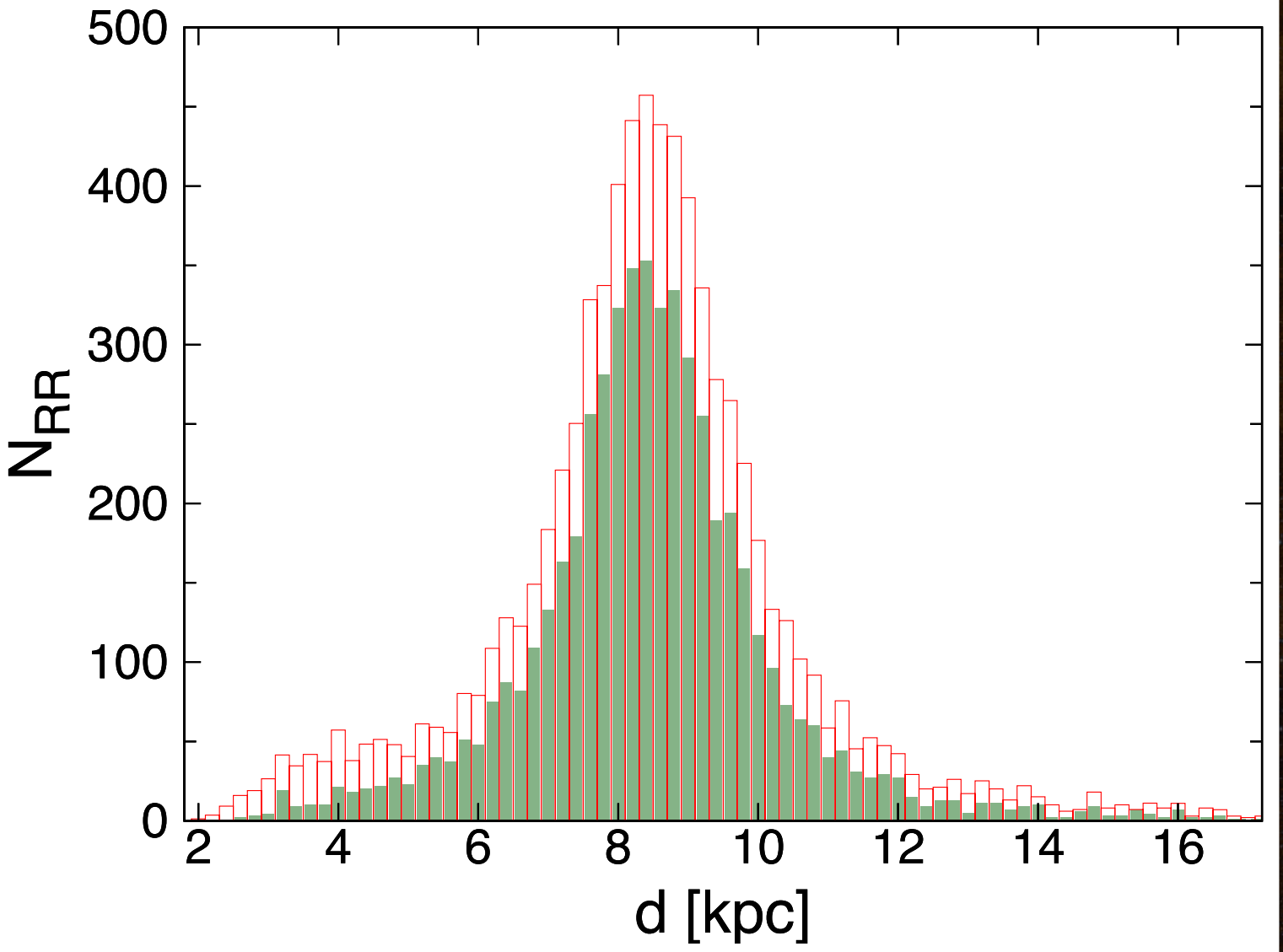
Comparison to BEAM values

Gonzalez et al. (2012)

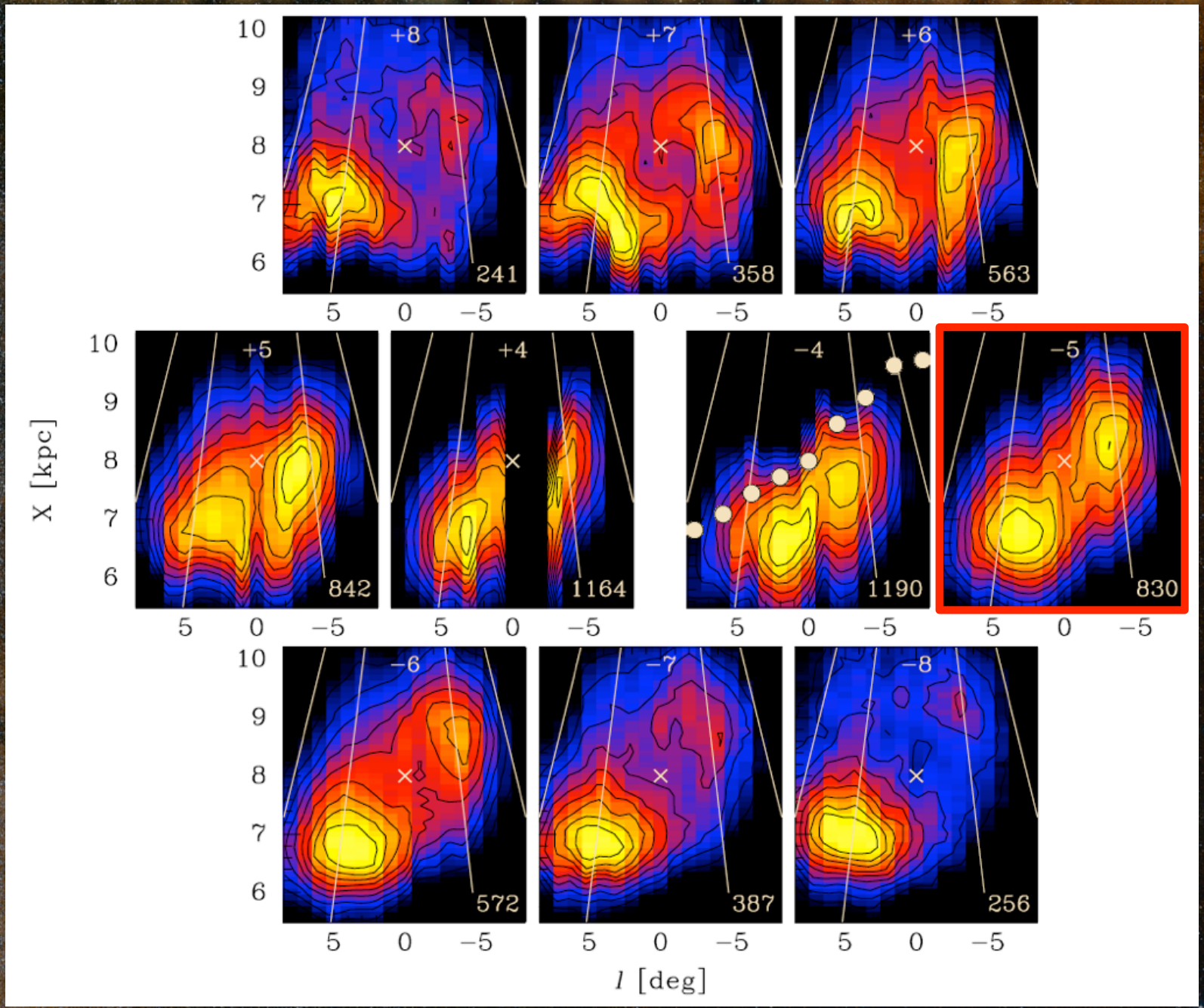


Analysis of the OGLE3 RRab Stars

Distance to the GC

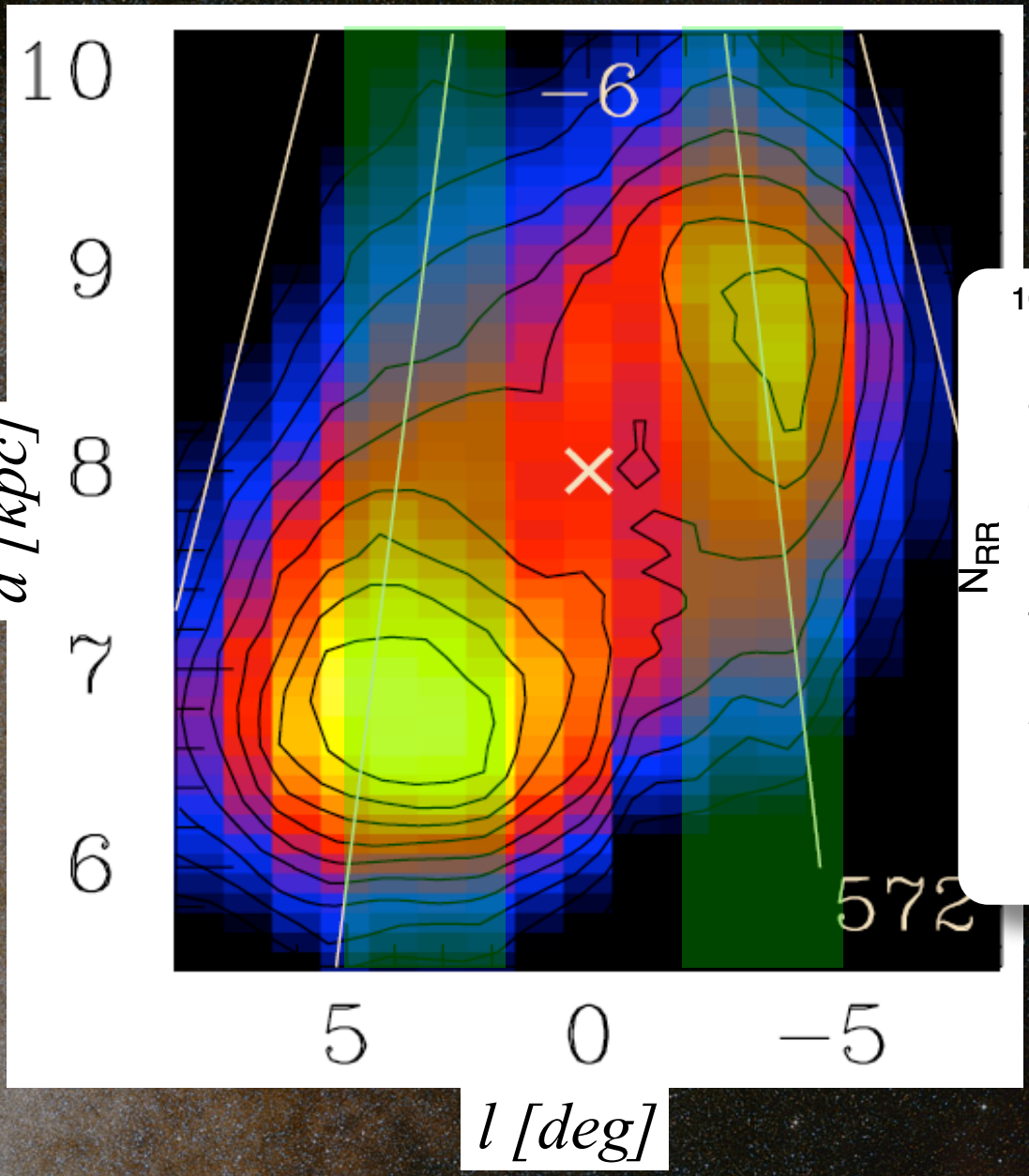


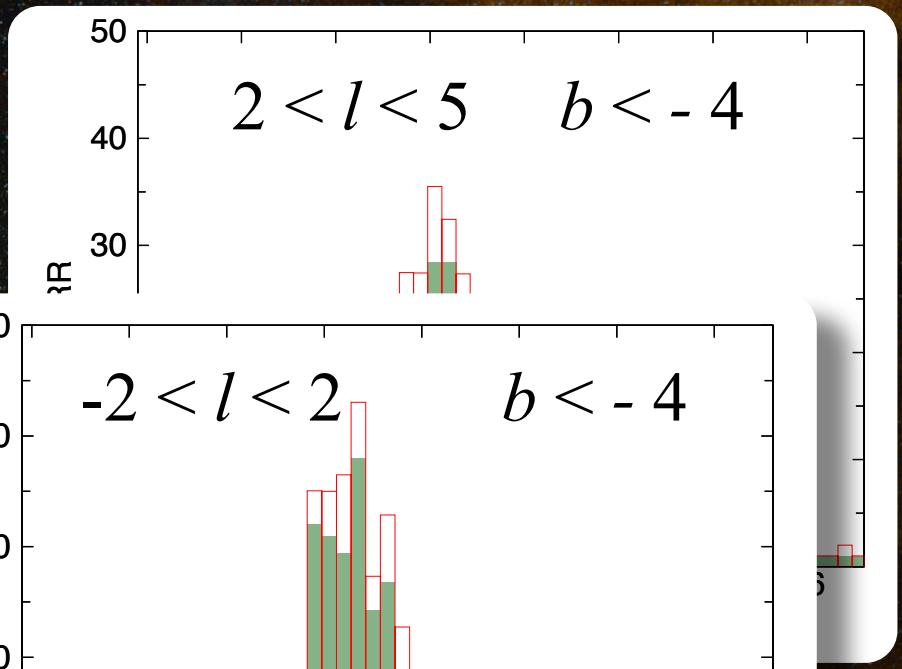
Analysis of the OGLE3 RRab Stars

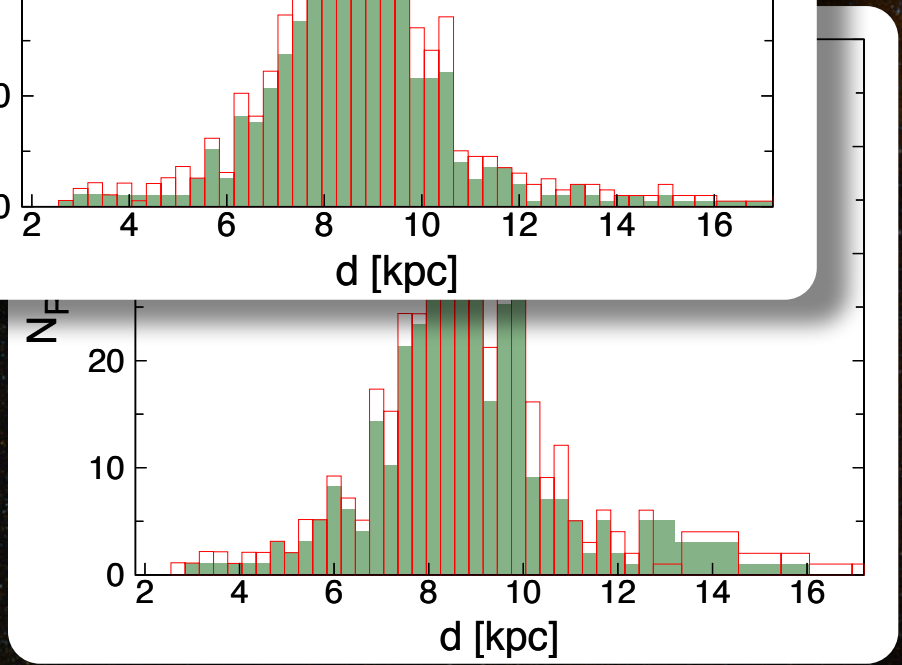


Saito et al. 2011

Analysis of the OGLE3 RRab Stars







ANALYSIS OF THE OGLE3 RRAB STARS

THE NEAR FUTURE:

- up to 25 epochs by the end of October
  complete VVV analysis of the OLGE3 sample
- full variability search by the end of this year
  extend the sample in *l*,*b*, and depth
  first RRab number density maps
- position-dependent reddening law from data
- more epochs will substantially increase:
  detecton rate (completeness) ➜ resolution
  classification accuracy
  accuracy in distances

Credit: ESO

More epochs are welcome...