Near-IR variability of the bulge stellar population

Dante Minniti

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Universidad Andrés Bello

Centro de Astrofísica y Tecnologías Afines

Millennium Institute of Astrophysics

Specola Vaticana

IR Surveys

Spectroscopic IR Surveys

GALACTIC:
Apogee (Majewski +)
Moons (Gonzalez +)

EXTRAGALACTIC:
Moons (Girasuolo +)

Photometric IR Surveys

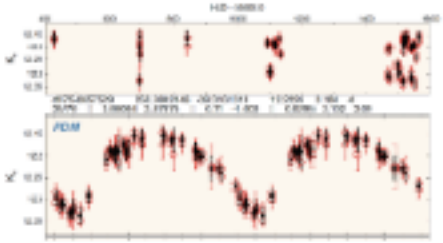
GALACTIC:
2MASS (Skrutskie, Cutri, +)
UKIDSS GPS (Lucas, +)
VVV (Minniti, Lucas, +)

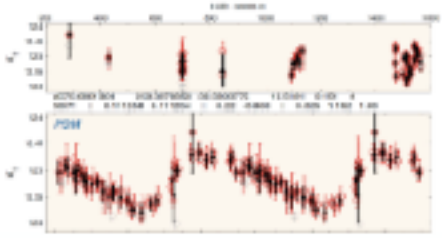
EXTRAGALACTIC:
VMC (Cioni +)
VHS (McMahon +)

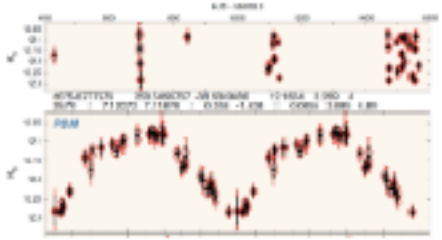
Near-IR variability of the bulge stellar population

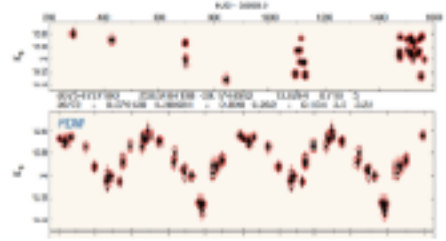
Outline

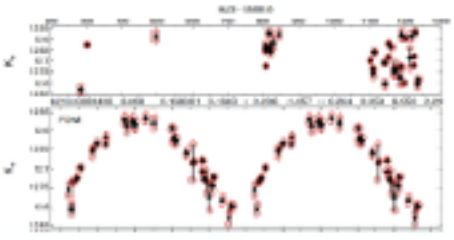
- Introduction
- RR Lyrae
- Classical Cepheids
- Type 2 Cepheids
- Miras and LPVs
- Eclipsing Binaries
- Microlensing
- Novae
- WITs
- Wish List

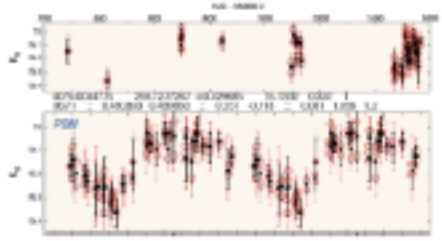

Type II Cepheid

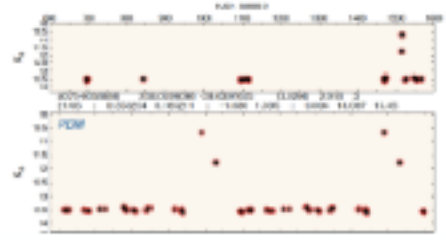

Delta Scuti

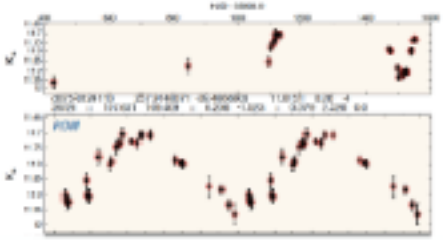

Classical Cepheid

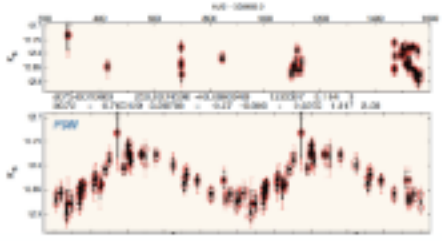

Eclipsing binary

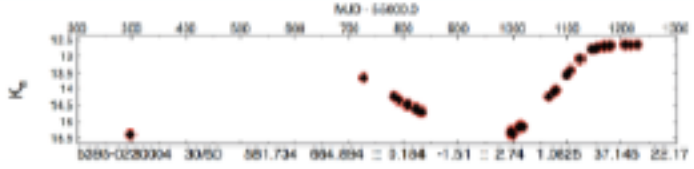

Contact binary

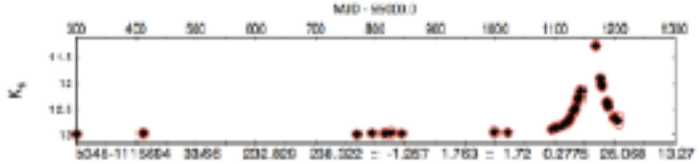

Distant RRab

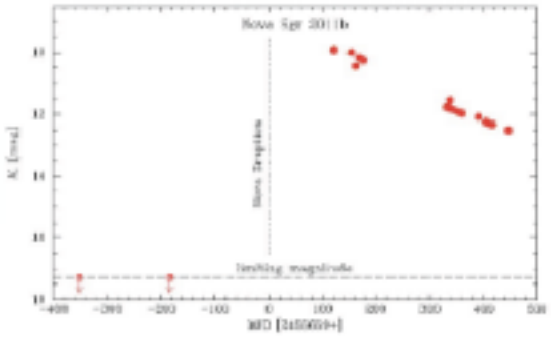

Erupting variable


Long period Cepheid


Nearby RRab

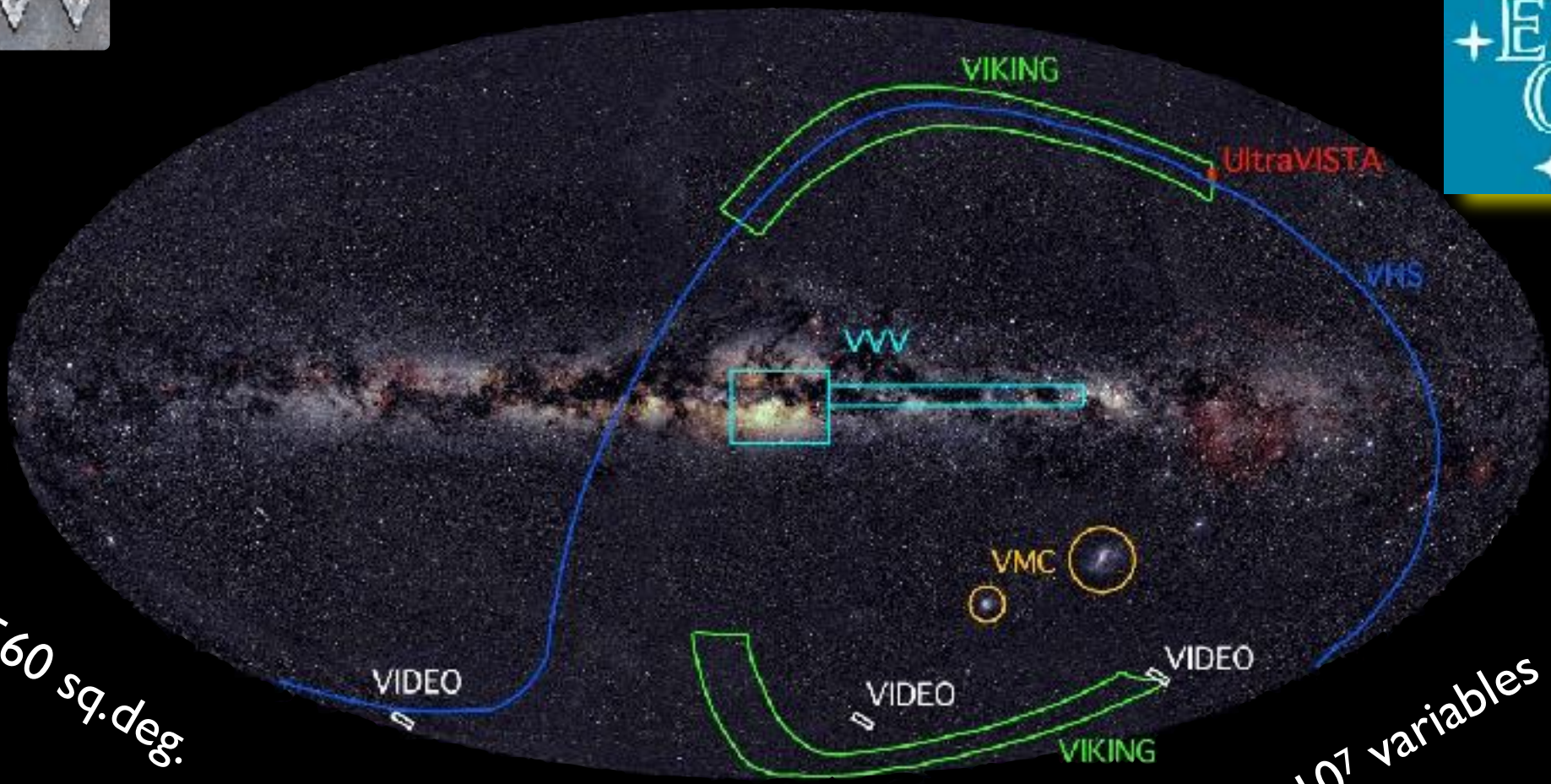

Long period variable


Microlensing event


Light curve for Nova Sgr 2011b

Discovery of novae in the Galactic disk
(R. Saito et al. 2014)

Introduction: The VVV Survey



560 sq.deg.

~10^9 stars

~100 epochs

~10^7 variables

VISTA PUBLIC SURVEYS

VISTA VARIABLES IN THE VIA LACTEA (VVV)

VISTA Telescope

- 4m diameter
- IR optimized
- large field

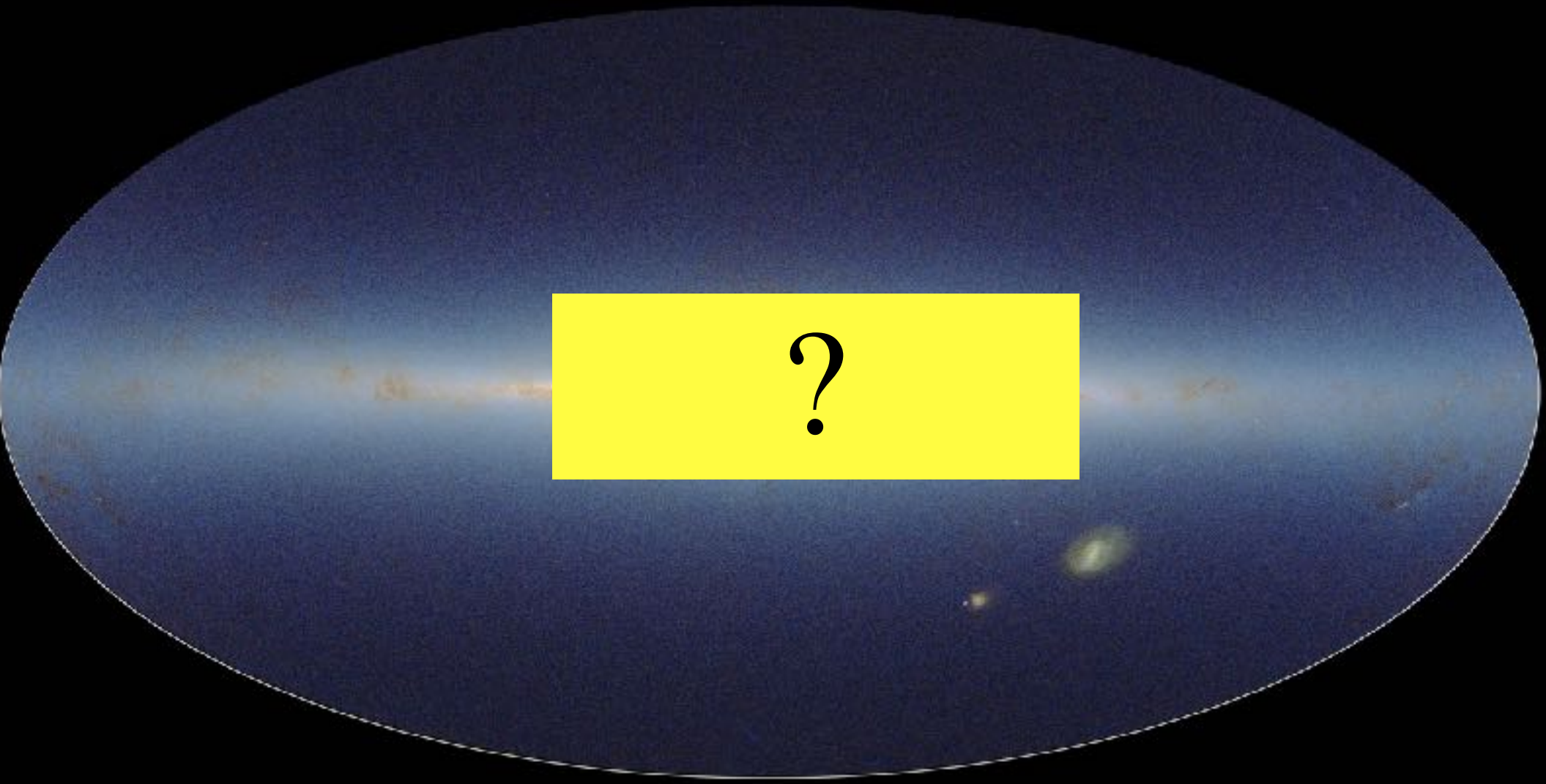
vvvsurvey.org

R. K. Saito[1], M. Hempel[1], D. Minniti[1,2,3], P. W. Lucas[4], M. Rejkuba[5], I. Toledo[6], O. A. Gonzalez[5], J. Alonso-García[1], M. J. Irwin[7], E. Gonzalez-Solares[7], S. T. Hodgkin[7], J. R. Lewis[7], N. Cross[8], V. D. Ivanov[9], E. Kerins[10], J. P. Emerson[11], M. Soto[12], E. B. Amôres[13,14], S. Gurovich[15], I. Dékány[1], R. Angeloni[1], J. C. Beamin[1], M. Catelan[1], N. Padilla[1,16], M. Zoccali[1,17], P. Pietrukowicz[18], C. Moni Bidin[19], F. Mauro[19], D. Geisler[19], S. L. Folkes[20], S. E. Sale[1,20], J. Borissova[20], R. Kurtev[20], A. V. Ahumada[9,15,21], M. V. Alonso[15], A. Adamson[22], J. I. Arias[12], R. M. Bandyopadhyay[23], R. H. Barbá[12,24], B. Barbuy[25], G. L. Baume[26], L. R. Bedin[27], R. Benjamin[28], E. Bica[29], C. Bonatto[29], L. Bronfman[30], G. Carraro[9], A. N. Chenè[19,20], J. J. Clariá[15], J. R. A. Clarke[20], C. Contreras[4], A. Corvillón[1], R. de Grijs[31,32], B. Dias[25], J. E. Drew[4], C. Fariña[26], C. Feinstein[26], E. Fernández-Lajús[26], R. C. Gamen[26], W. Gieren[19], B. Goldman[33], C. González-Fernández[34], R. J. J. Grand[35], G. Gunthardt[15], N. C. Hambly[8], M. M. Hanson[36], K. Helminiak[1], M. G. Hoare[37], L. Huckvale[10], A. Jordán[1], K. Kinemuchi[38], A. Longmore[39], M. López-Corredoira[34,40], T. Maccarone[41], D. Majaess[42], E. Martín[34], N. Masetti[43], R. E. Mennickent[19], I. F. Mirabel[44,45], L. Monaco[9], L. Morelli[46], V. Motta[20], T. Palma[15], M. C. Parisi[15], Q. Parker[47,48], F. Peñaloza[20], G. Pietrzyński[18,19], G. Pignata[49], B. Popescu[36], M. A. Read[8], A. Rojas[1], A. Roman-Lopes[12], M. T. Ruiz[30], I. Saviane[9], M. R. Schreiber[20], A. C. Schröder[50,51], S. Sharma[20,52], M. D. Smith[53], L. Sodré Jr.[25], J. Stead[37], A. W. Stephens[54], M. Tamura[55], C. Tappert[20], M. A. Thompson[4], E. Valenti[5], L. Vanzi[16,56], N. A. Walton[7], W. Weidmann[15], and A. Zijlstra[10]

The VVV Science Team

The photo album of the MW is not complete yet!!!

vvvsurvey.org

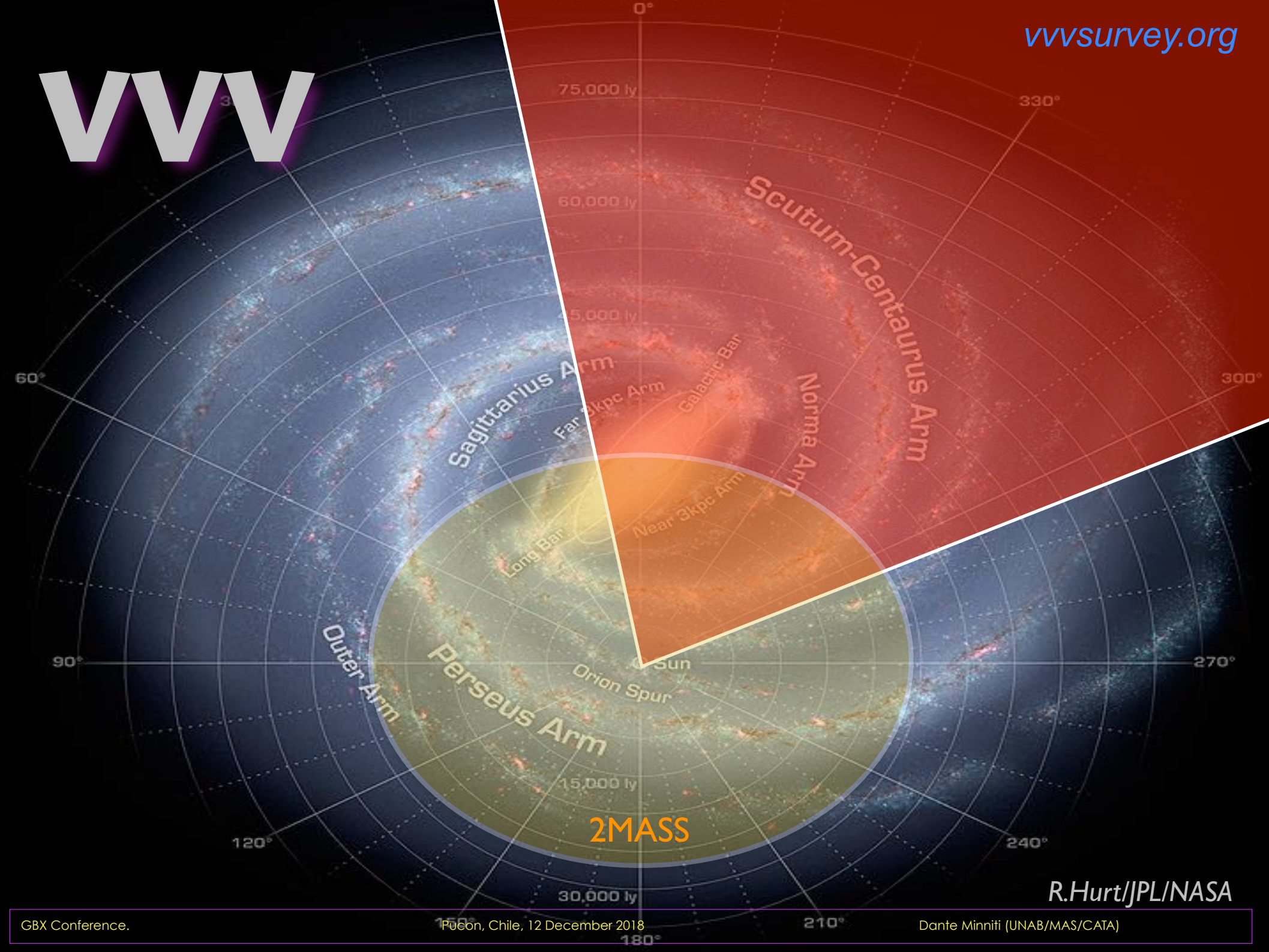


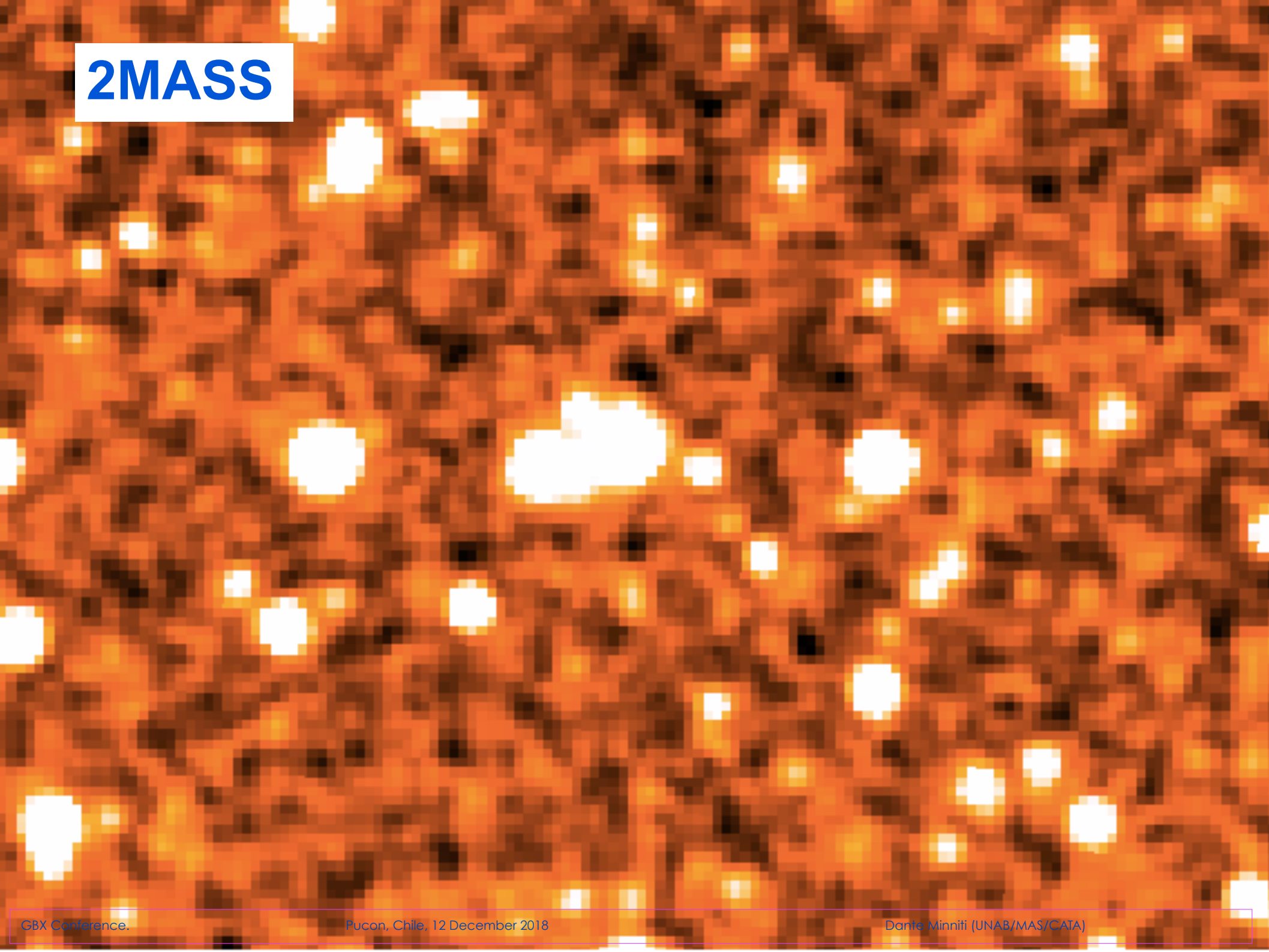
2MASS IMAGE OF THE MILKY WAY

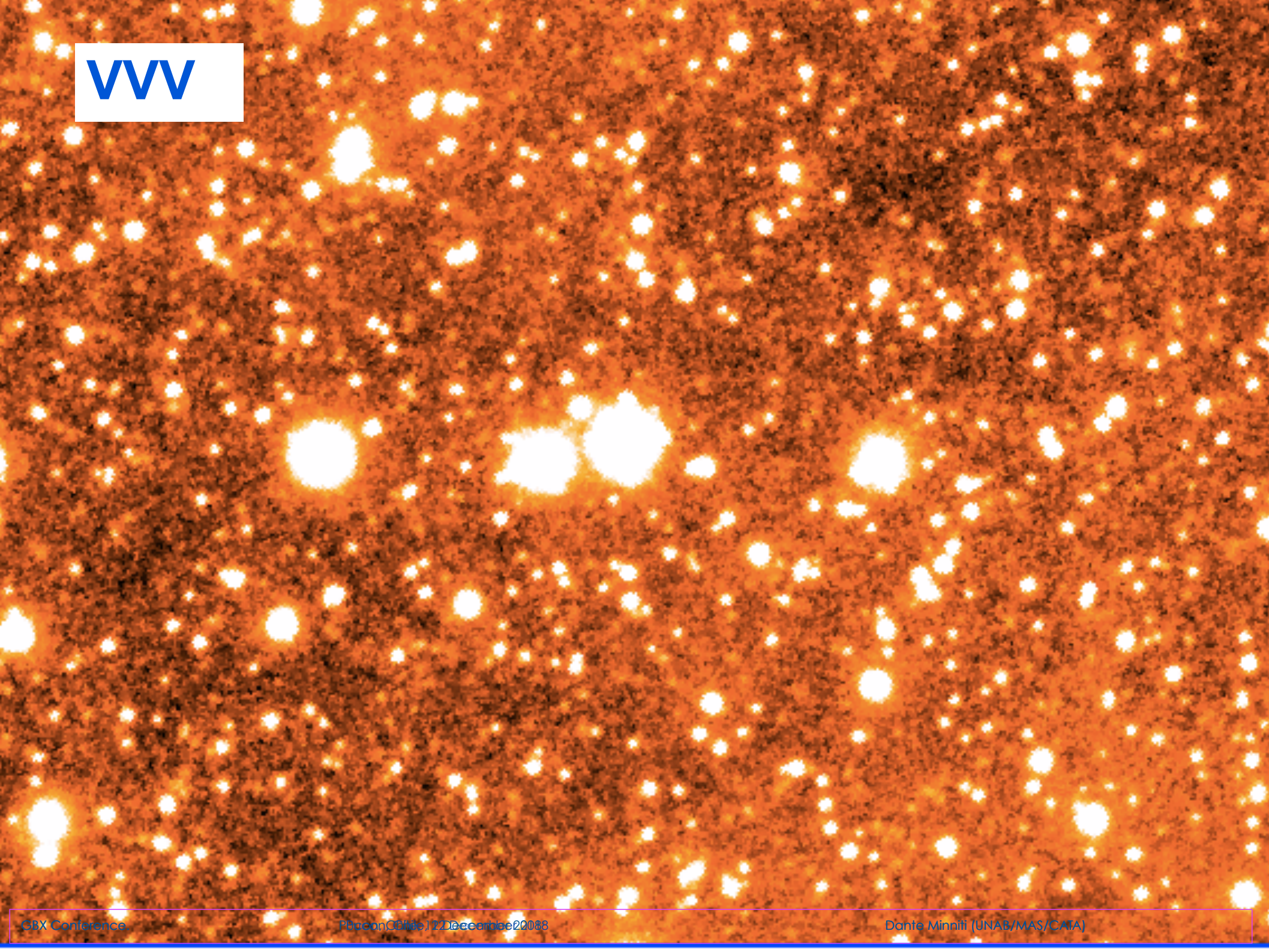
Goal

What is the 3-D structure of the Milky Way

We use RRLyrae, Cepheids and clump giants to investigate this.

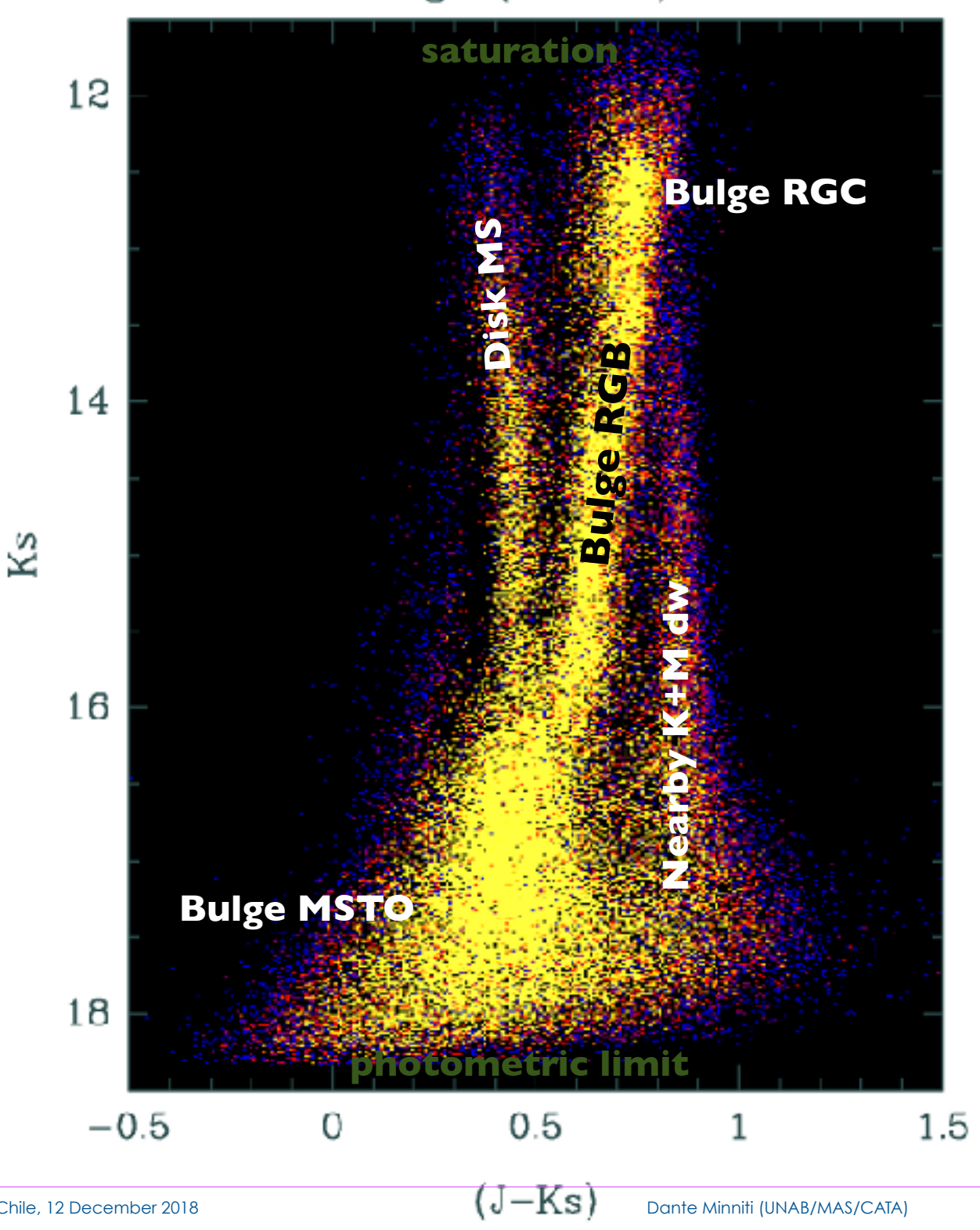

VVV
vvvsurvey.org
0°
75,000 ly
330°
60,000 ly
60°
300°
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
90°
270°
Outer Arm
Perseus Arm
Sun
Orion Spur
15,000 ly
2MASS
120°
240°
30,000 ly
210°
180°
R.Hurt/JPL/NASA


2MASS


VVV

VVV STARS CMD

outer bulge fields b209-b211

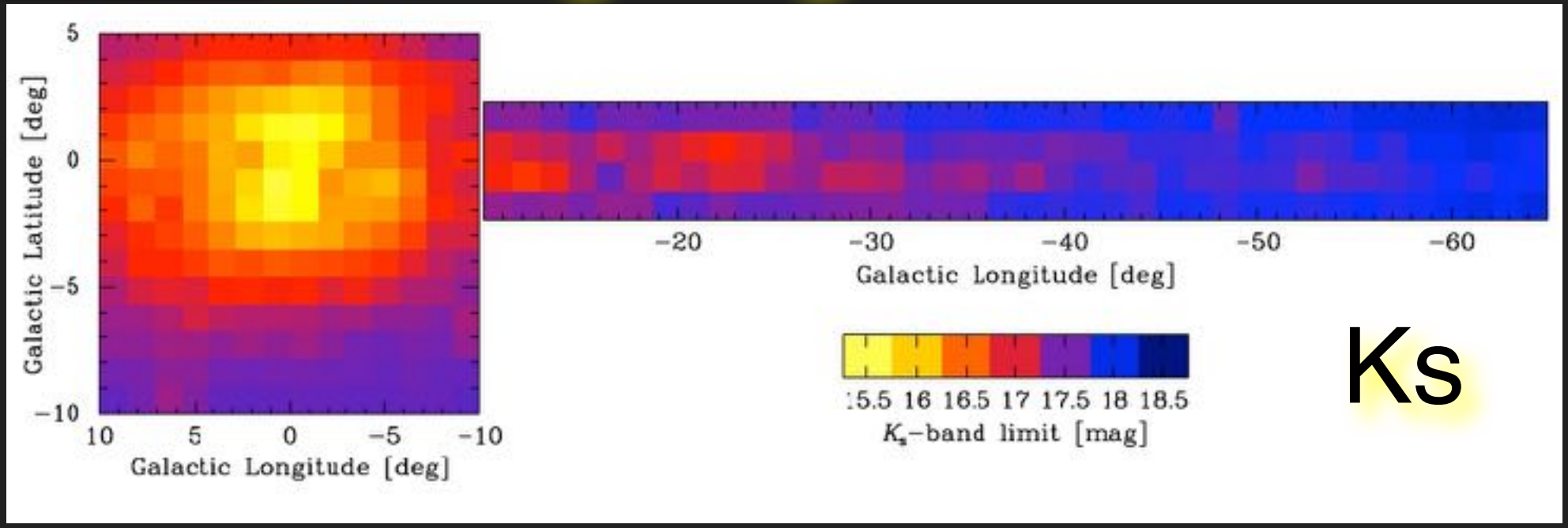


140 Gb single 25.000 Megapix image of ~300 sqdeg,
made of ~400.000 images of 512x512pix each,
scale 1pix = 0.4", JHKs filters, by Ignacio Toledo

BIG DATA

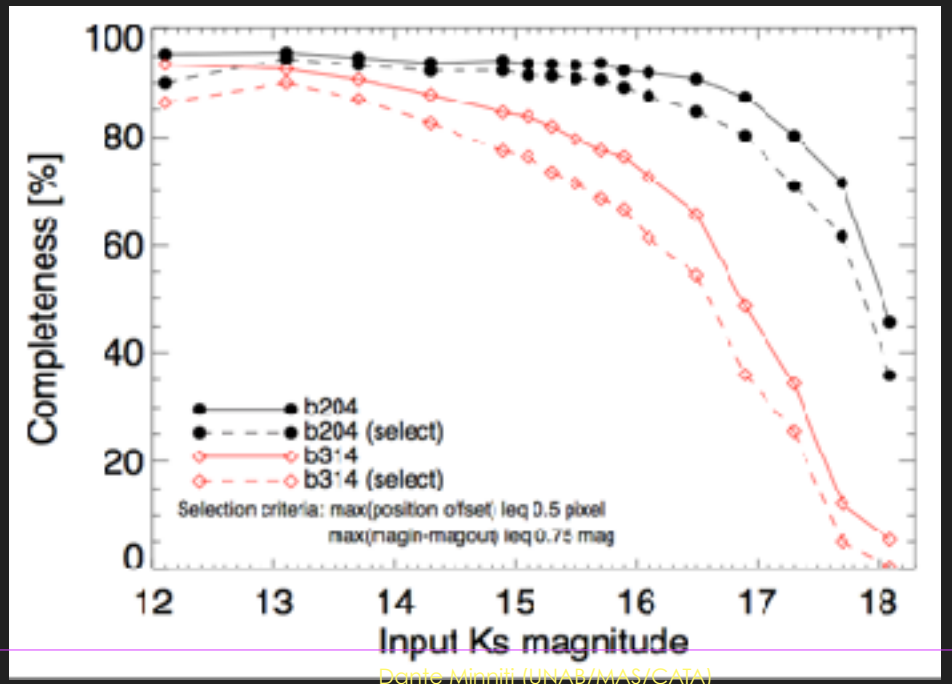
limiting magnitudes

vvvsurvey.org



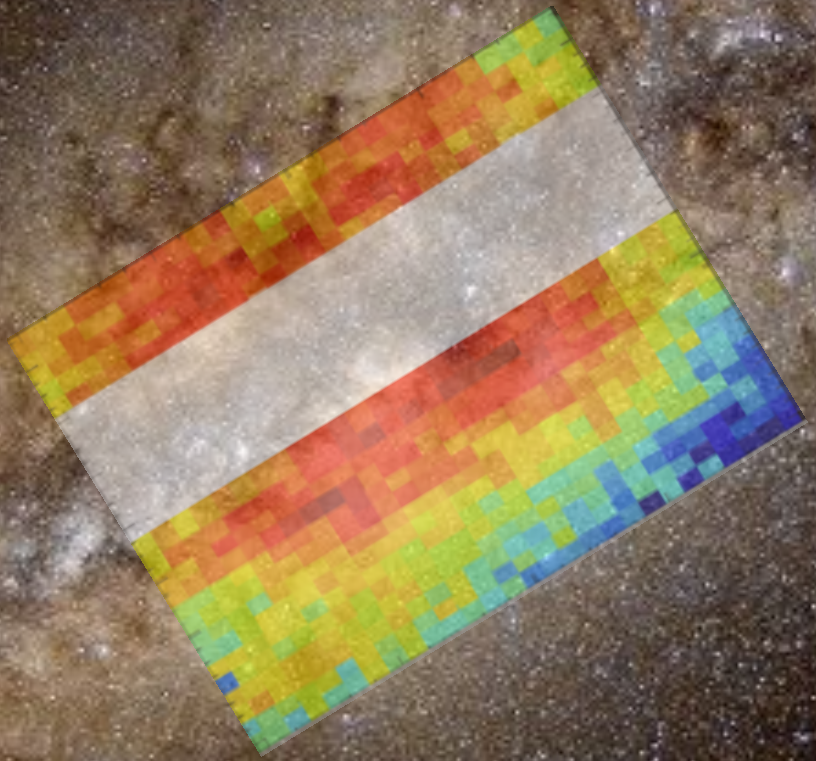
R. Saito

Completeness tests



M. Hempel, E. Valenti

Structure of the Milky Way Bulge



GIBS Survey: Manuela Zoccali et al.

Why the Near-IR?

Why the Near-IR?

The PL relations are tighter in the near-IR

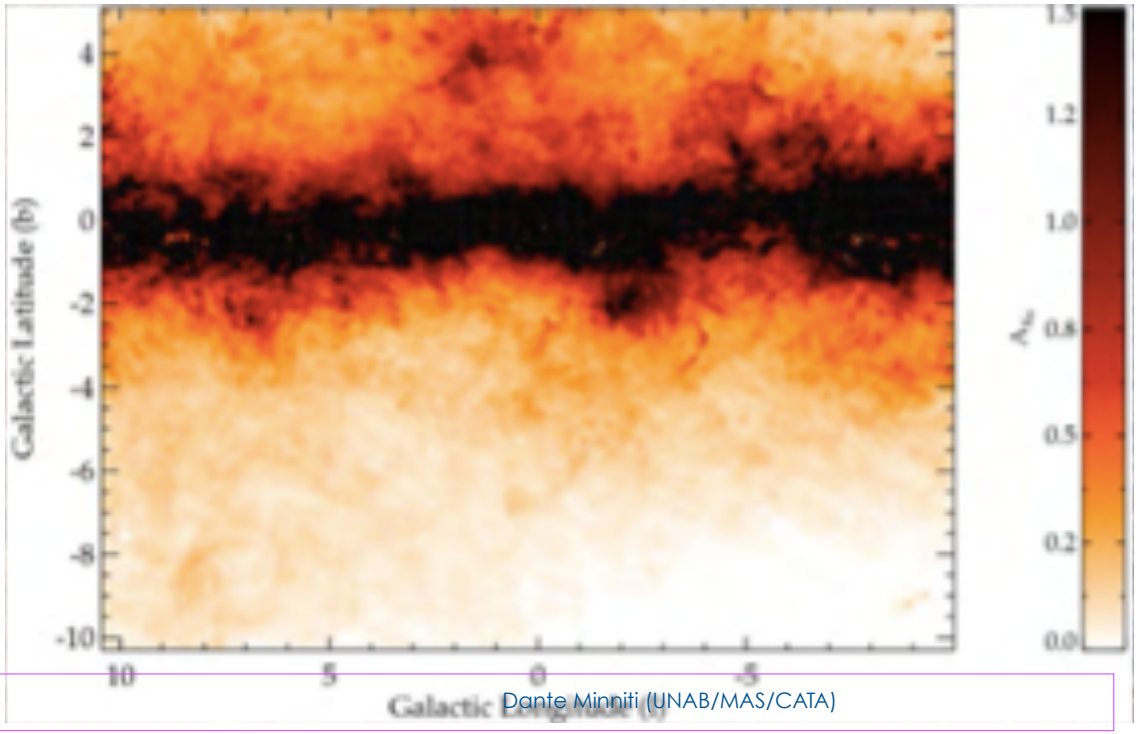
The red giants peak in the near-IR

The Galactic extinction is reduced: Ak~0.1Av

Some problems:
— the near-IR background is higher
— the near-IR data rate is larger
— amplitudes are smaller in the near-IR
— variations in the Galactic reddening law:
Ak=0.40Ej-k for Alonso-García
Ak=0.528Ej-k for Nishiyama
Ak=0.72Ej-k for Cardelli

Dust Distribution and the Reddening Laws

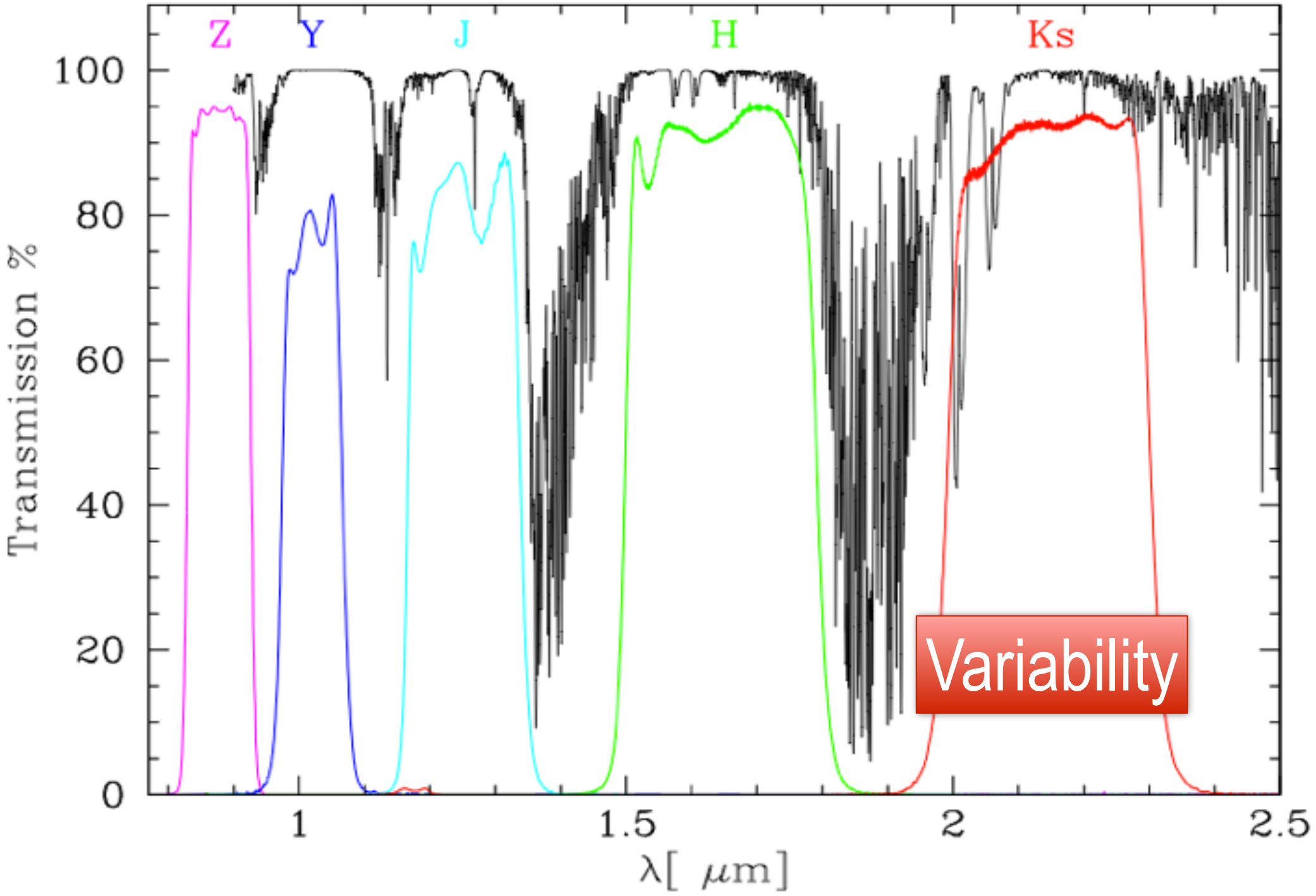
Gonzalez et al. 2012, A&A, 543, 13 (arXiv:1204.4004)
Gonzalez et al. 2013, A&A, 552A, 110G (arXiv:1302.0243)
Gonzalez et al. 2018, MNRAS in press
The global photometric reddening and metallicity maps of the Galactic bulge
Chen et al. 2013, A&A, 550, 42 (arXiv:1211.3092)
Schultheis et al. 2014, A&A 566, 120 (arXiv:1405.0503)
Mapping the Milky Way Bulge at high resolution: the 3D dust extinction, CO and X factor map
Minniti et al. 2015, A&A, 571, A91 (arXiv:1409.5836)
The Great Dark Lane toward the Galactic Bulge
Nataf et al. 2015 ApJ (arXiv:1510.01321)
Interstellar Extinction Curve Variations Toward the Inner Milky Way
Alonso-García et al. (2017 ApJL)
Extinction in the Galactic Centre Region
Saito et al. (2018 A&A in press)
Extinction in the Galactic Centre Region
Surot et al. (2018 A&A submitted)
Extinction in the Galactic Centre Region



Javier Alonso, Rodrigo Contreras, Istvan Dekany, Tali Palma, Roberto Saito, Marcio Catelan, Gergely Hagdu, Joyce Pullen, Rodolfo Angeloni, Wolfgang Gieren, Daniel Majaess, Manuela Zoccali, Marina Rejkuba, Elena Valenti, Valentin Ivanov, Carlos Ferreira, Nick Cross, Phil Lucas, et al.

VVV Variables

N~36 Million (C. Ferreira, N. Cross et al. 2018 in prep.)



VISTA filter transmissions

year

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

multicolor maps — 2010

2 - 4 epochs in K_s for bulge and disk

variability — 2011

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

variability — 2012

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

variability — 2013

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)

variability — 2014

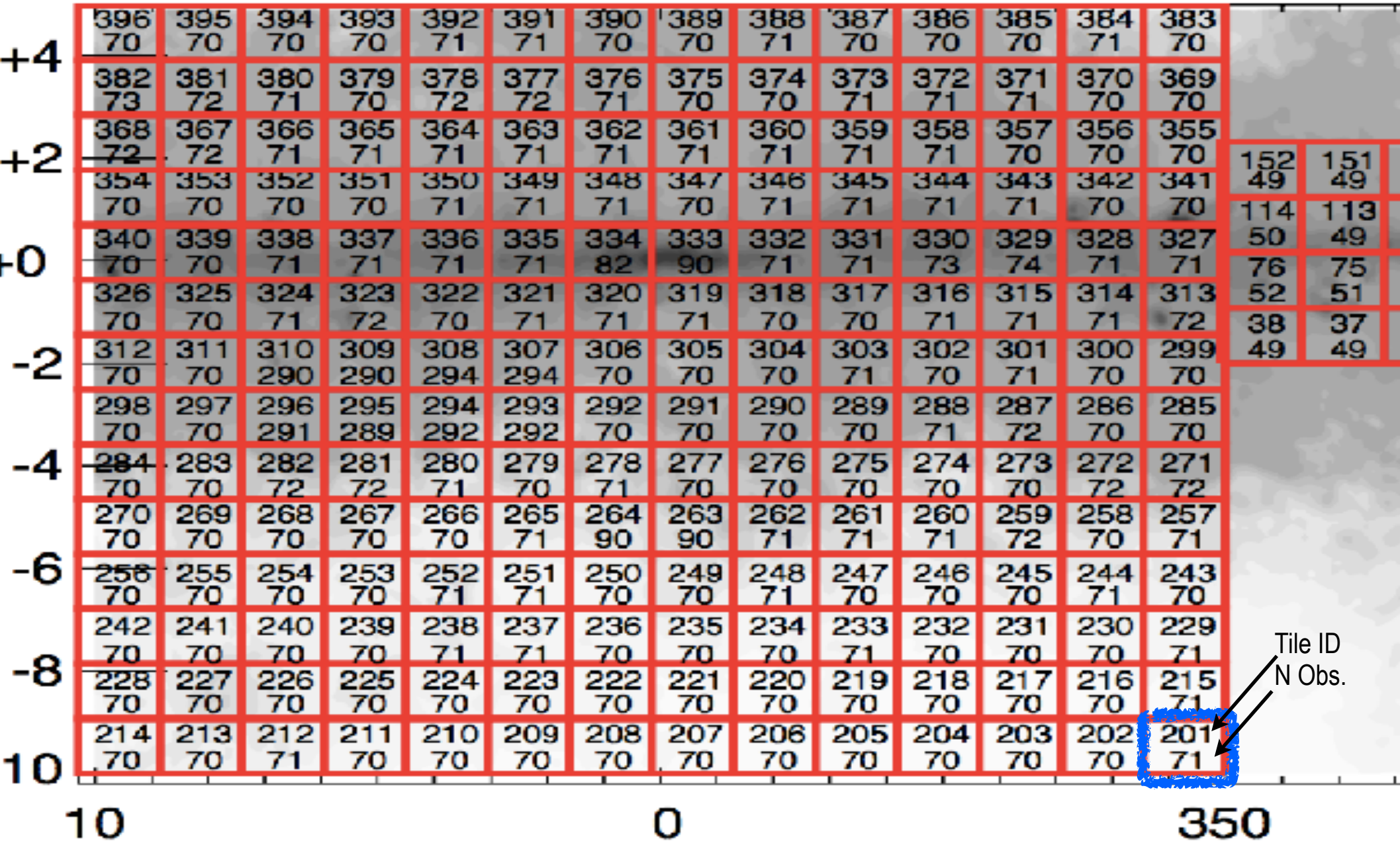
proper motions — 2015

...

Timeline

Maren Hempel

VVV Survey Area



Number of Epochs: MW Bulge

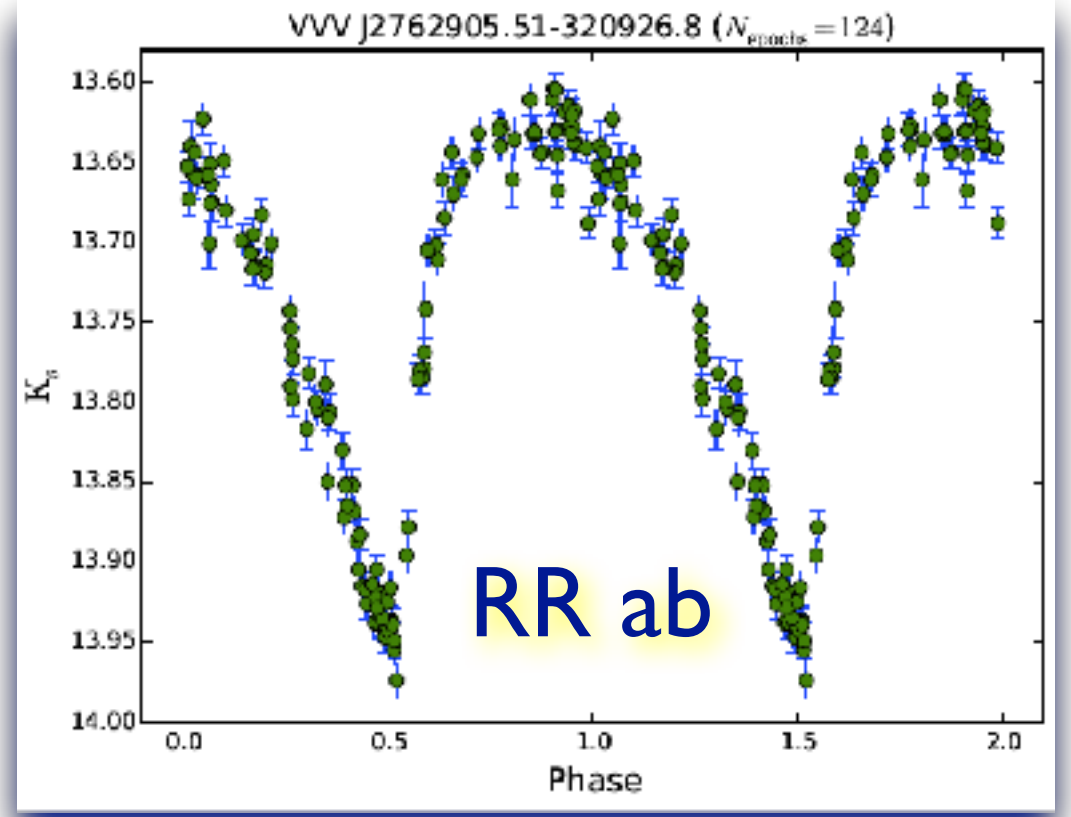
Template IR Light Curves Database

Angeloni, Catelan, et al. 2014, A&A 567, 100 (arXiv:1405.4517)

The VVV Templates Project Towards an Automated Classification of VVV Light-Curves: Building a database of stellar variability in the near-infrared. Our database contains near-IR light-curves for:

RR Lyrae
Cepheids
Eclipsing Binaries
Delta Scutis
Cataclysmic Variables
Miras and LPVs
etc.

vvvsurvey.org



see talks by G. Hagdu, A. Bhardwaj

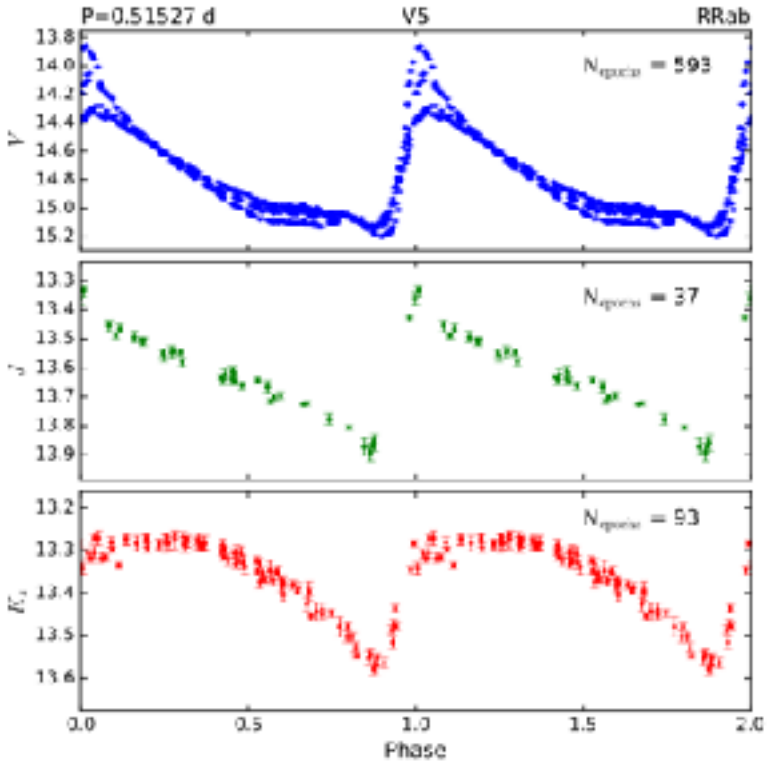
VVV

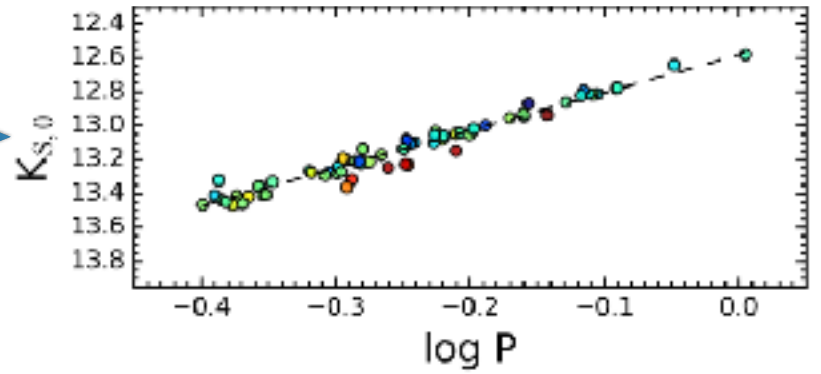
RRLyrae

Galactic structure,
stellar evolution,
star clusters,
interstellar medium,
…

RRLyrae

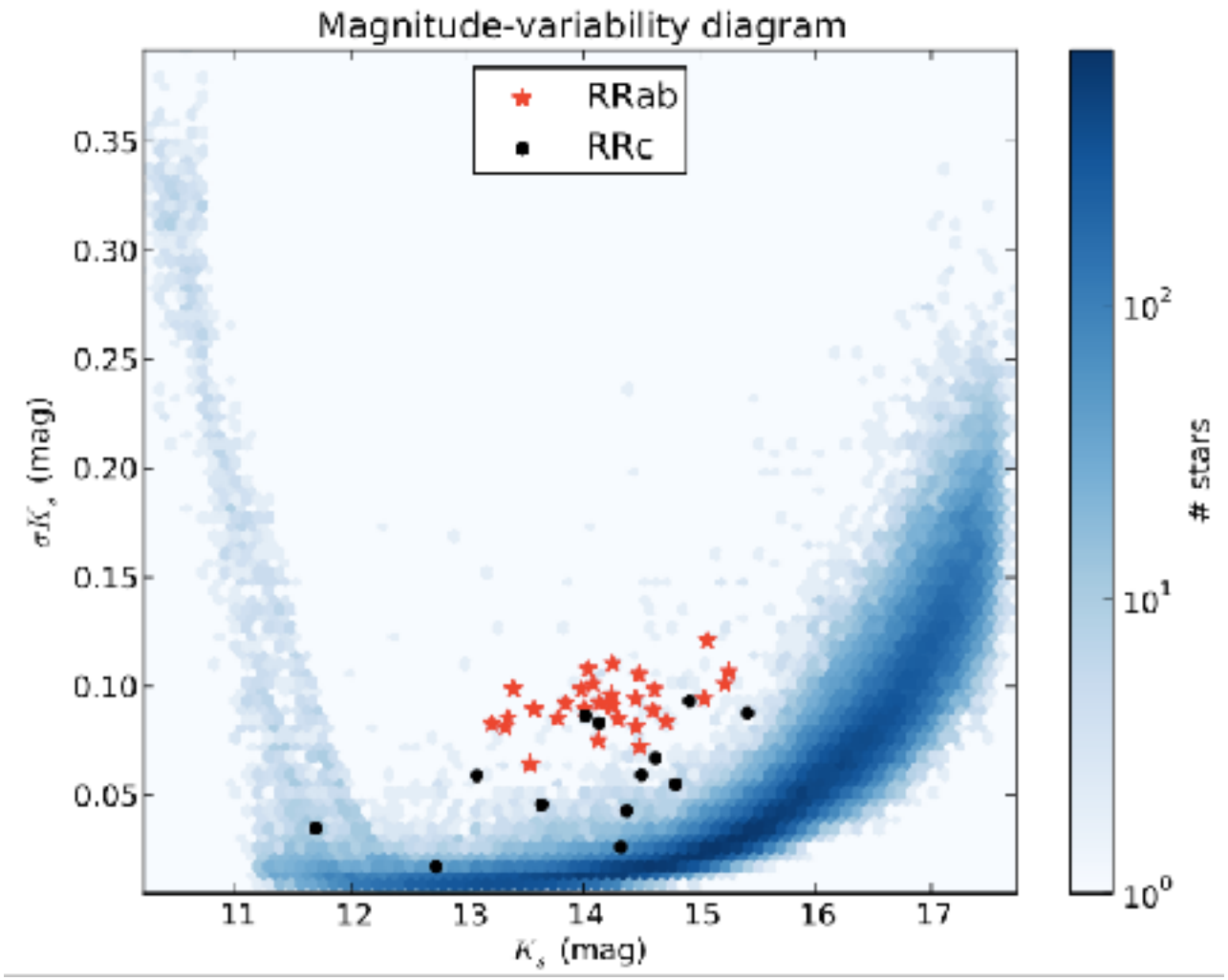
- RR Lyrae are pulsating variable stars.
- They have 0.2<P<1.1 days
- Their characteristic periods and light curves make them simple to identify.
- They represent an old and metal-poor population.
- They are present in globular clusters.
- They follow a Period-Luminosity relation
- RR Lyrae are primary distance indicators



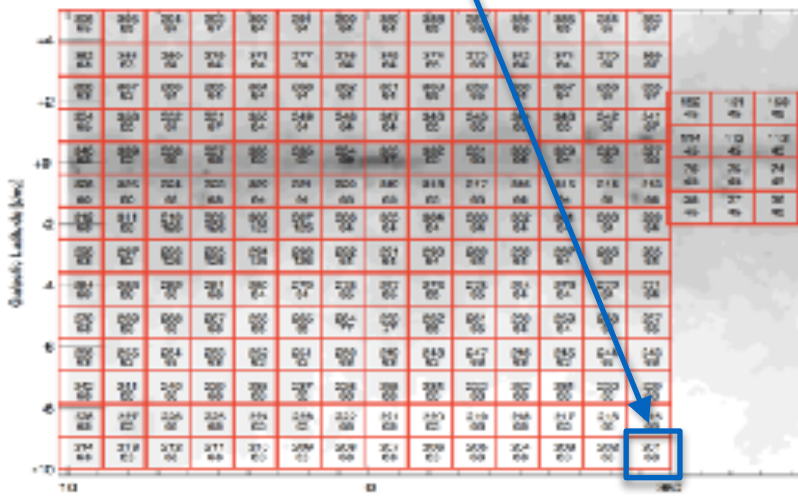


Navarrete et al. 2017
(arXiv:1706.03899)

Clump giants represent about 10% of the stars we measure in the bulge, while RR Lyrae represent 0.01% of the stars measured.

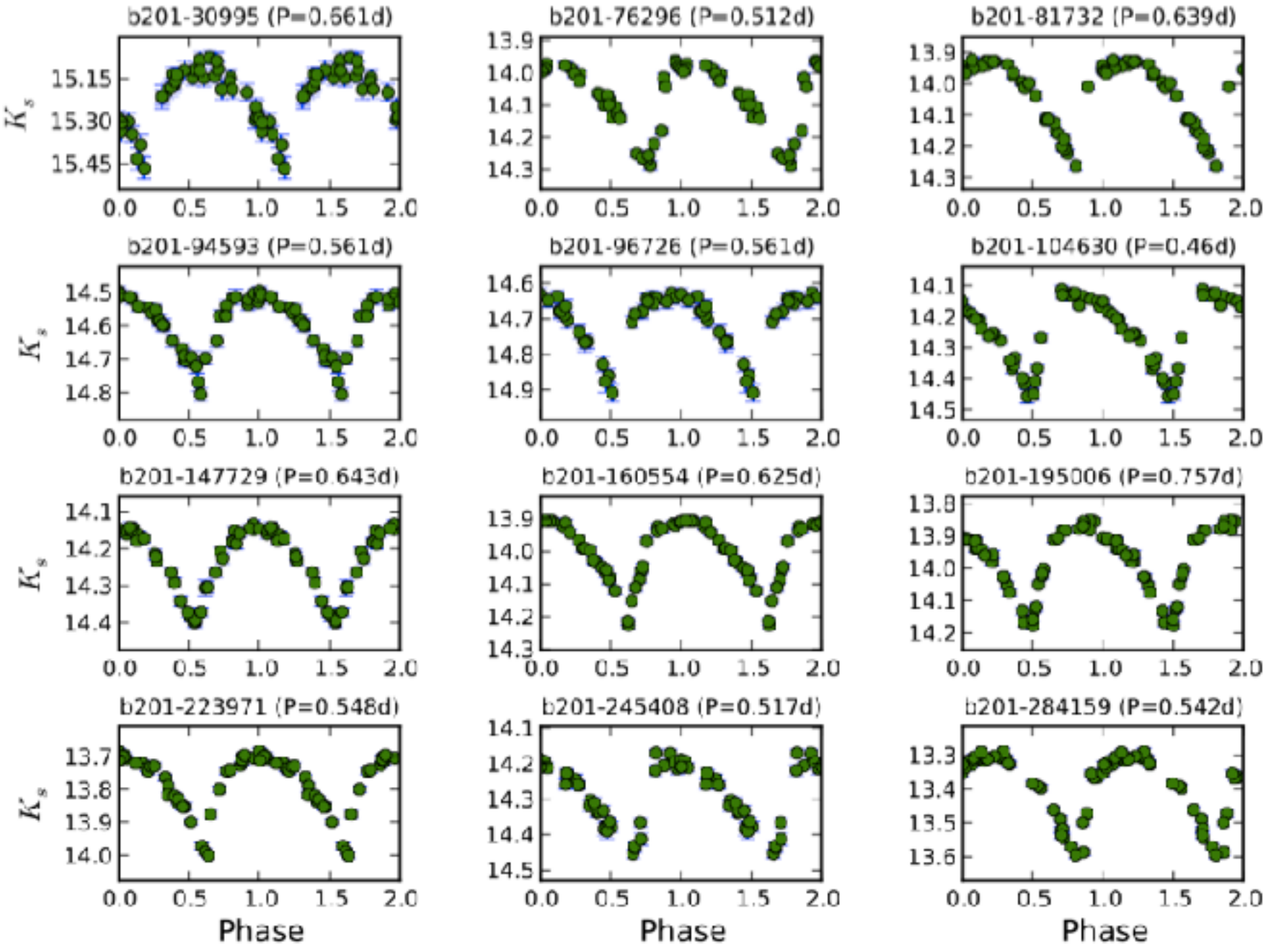


Tile d201



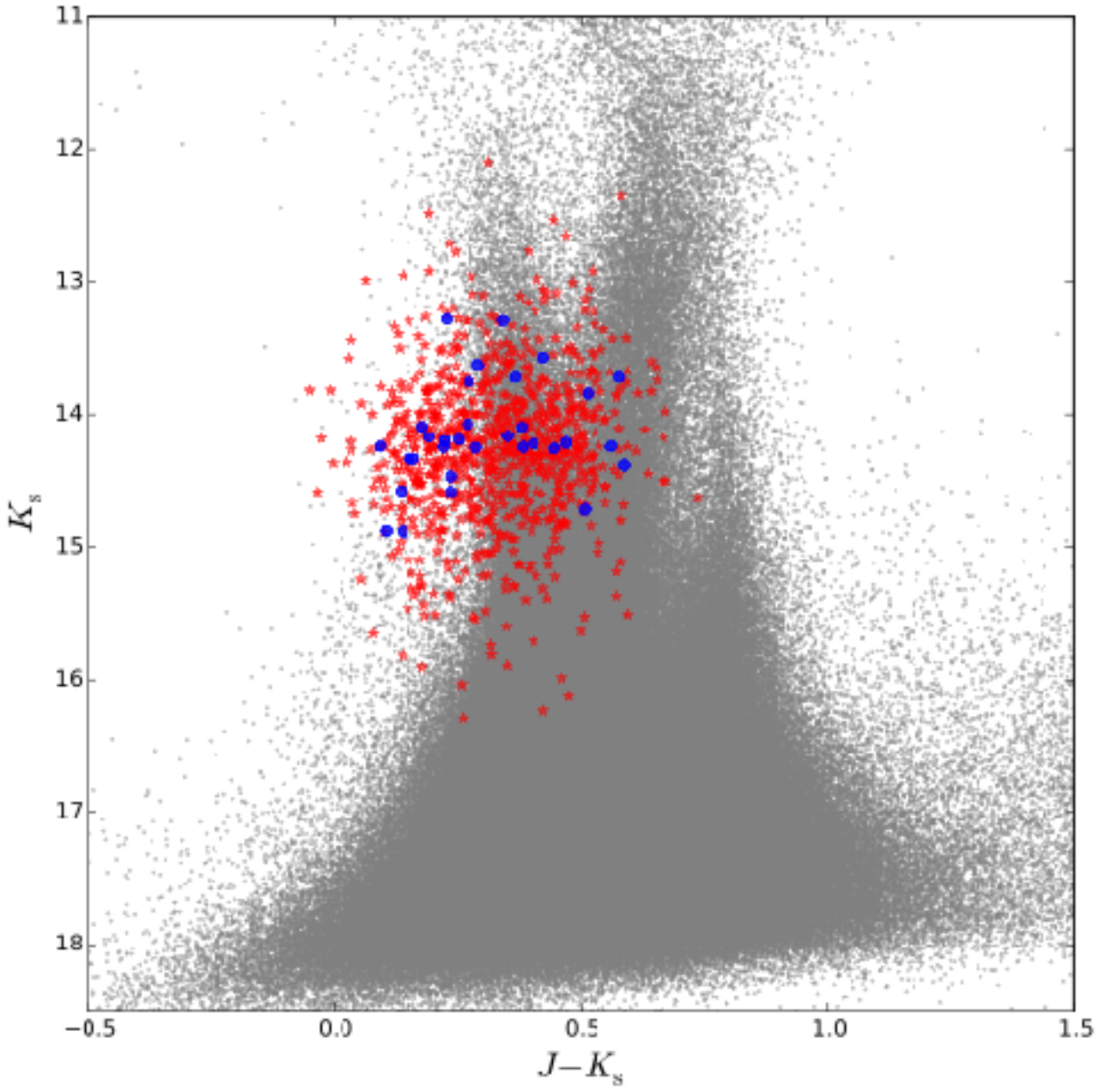
Outer Bulge RR Lyrae

F. Gran, et al. 2014, A&A

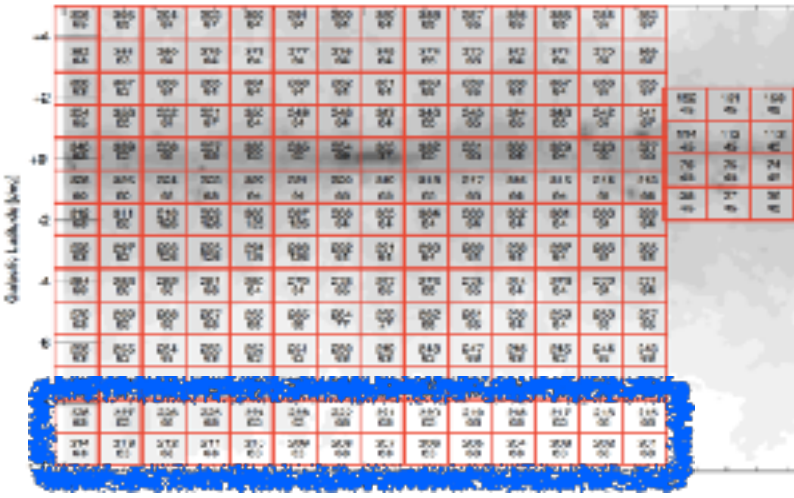


Outer Bulge RR Lyrae

F. Gran, et al. 2014, A&A

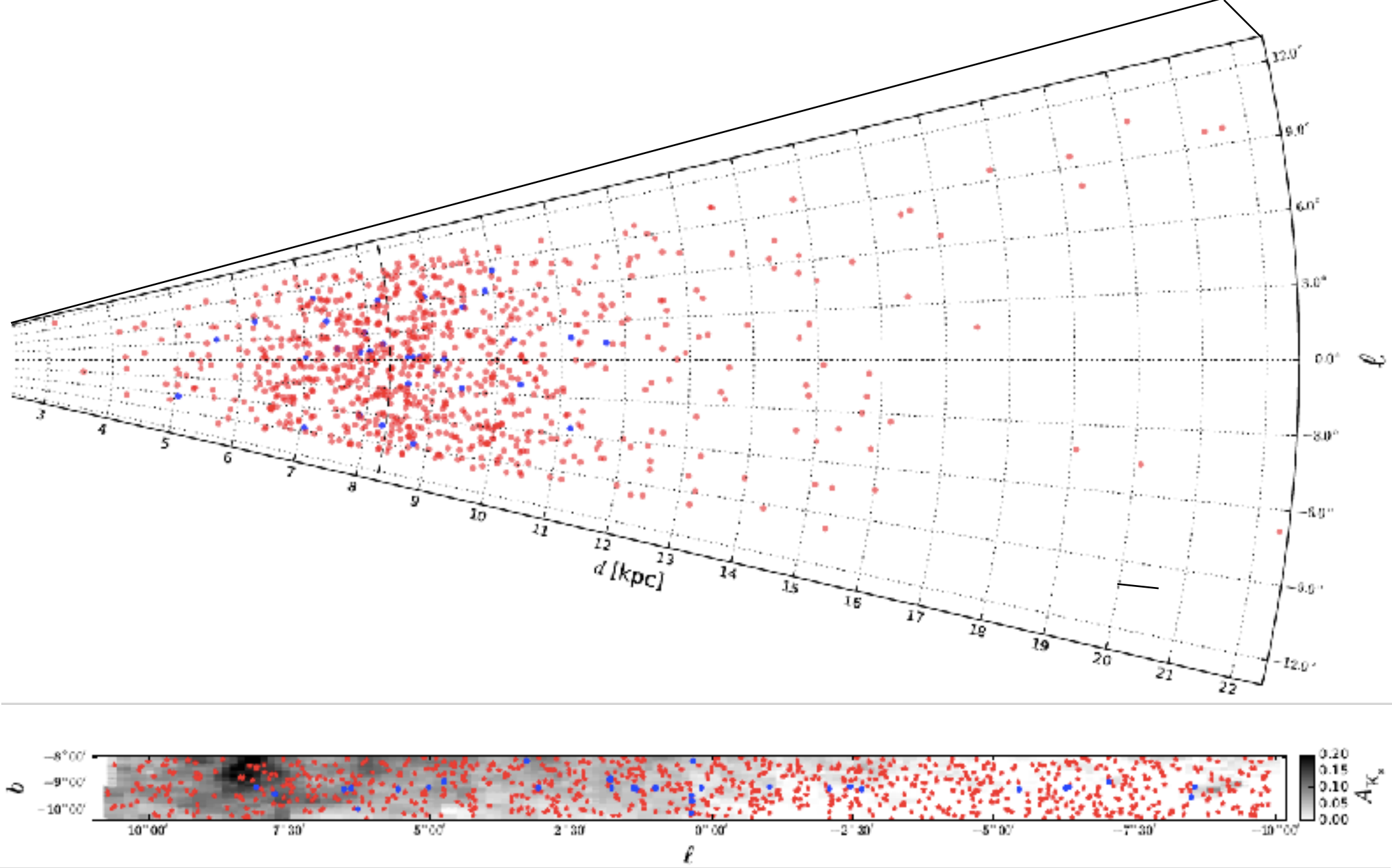


- The RR Lyrae stars represent old and metal-poor stellar populations.
- RR Lyrae are excellent distance indicators.
- They are also excellent reddening indicators.



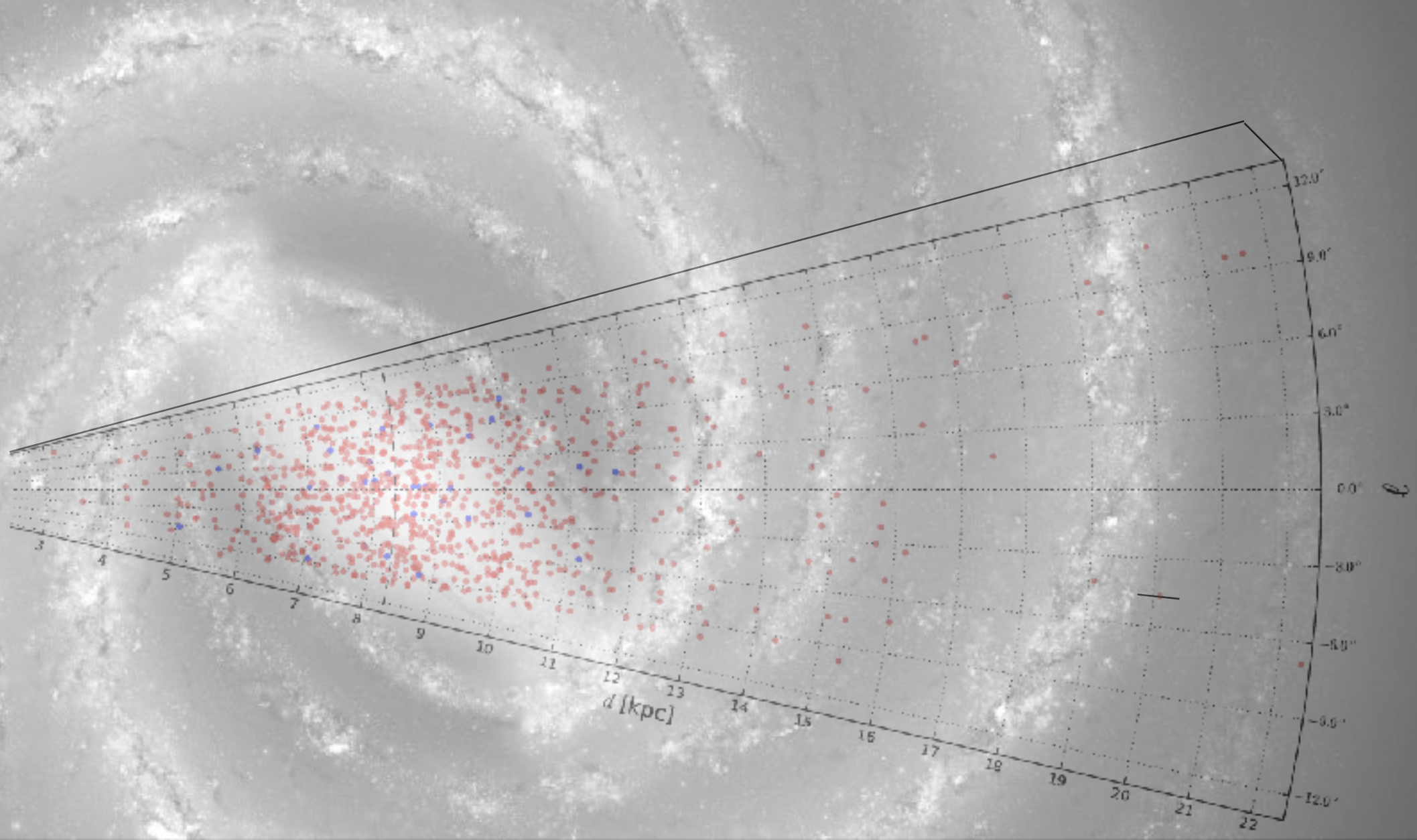
Outer Bulge RR Lyrae

F. Gran, et al. 2016, A&A



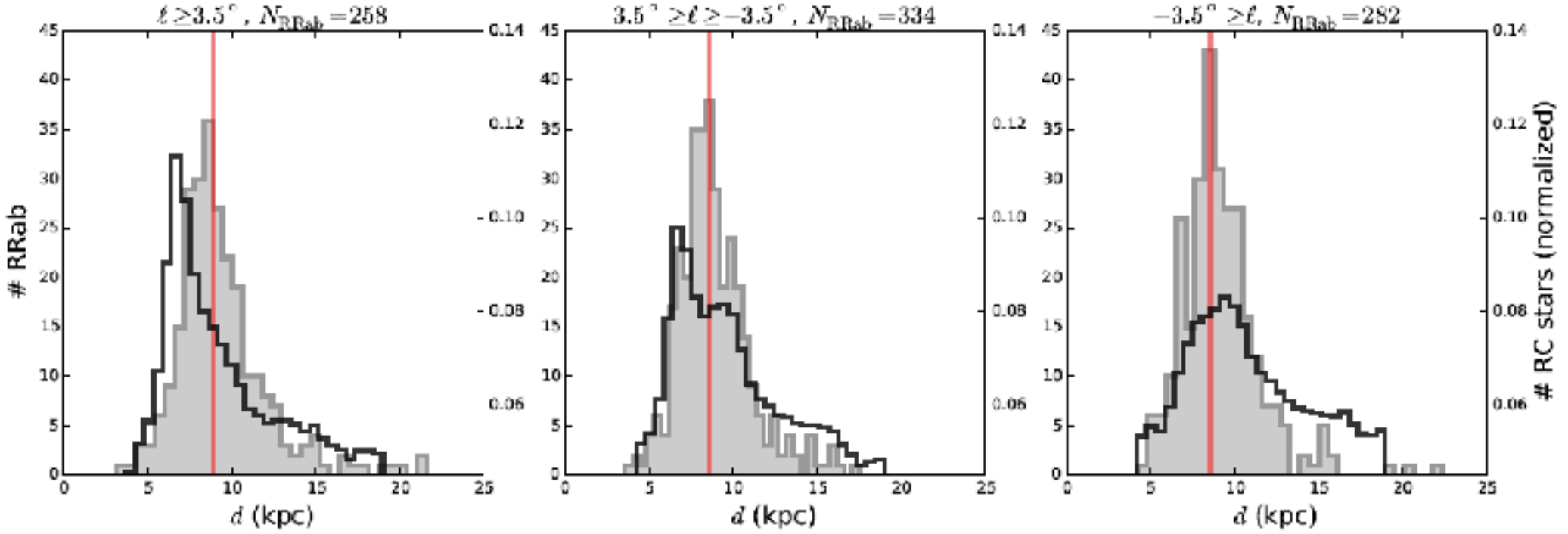
Outer Bulge RR Lyrae

F. Gran, et al. 2016, A&A



Outer Bulge RR Lyrae

F. Gran, et al. 2014, A&A



ig. 8. Histogram of distances of RR Lyrae (gray filled) and RC stars (black steps) as function of galactic latitude (ℓ). Since the total number of R
ars in the same areas overwhelms the number of RR Lyrae, the histogram showing their distribution in distance was normalized for visualizatio
rposes. The vertical line represents the RR Lyrae median distance of each region.

The VVV distance distribution of known bulge RR Lyrae is different from the clump giants (Gran et al. 2016).
This contrasts with the inner bulge RR Lyrae from OGLE that appear to be barred (Pietrukowicz et al. 2016).
Kinematics confirm spheroidal population (Kunder et al. 2016).

Outer Bulge RR Lyrae

F. Gran, et al. 2016, A&A

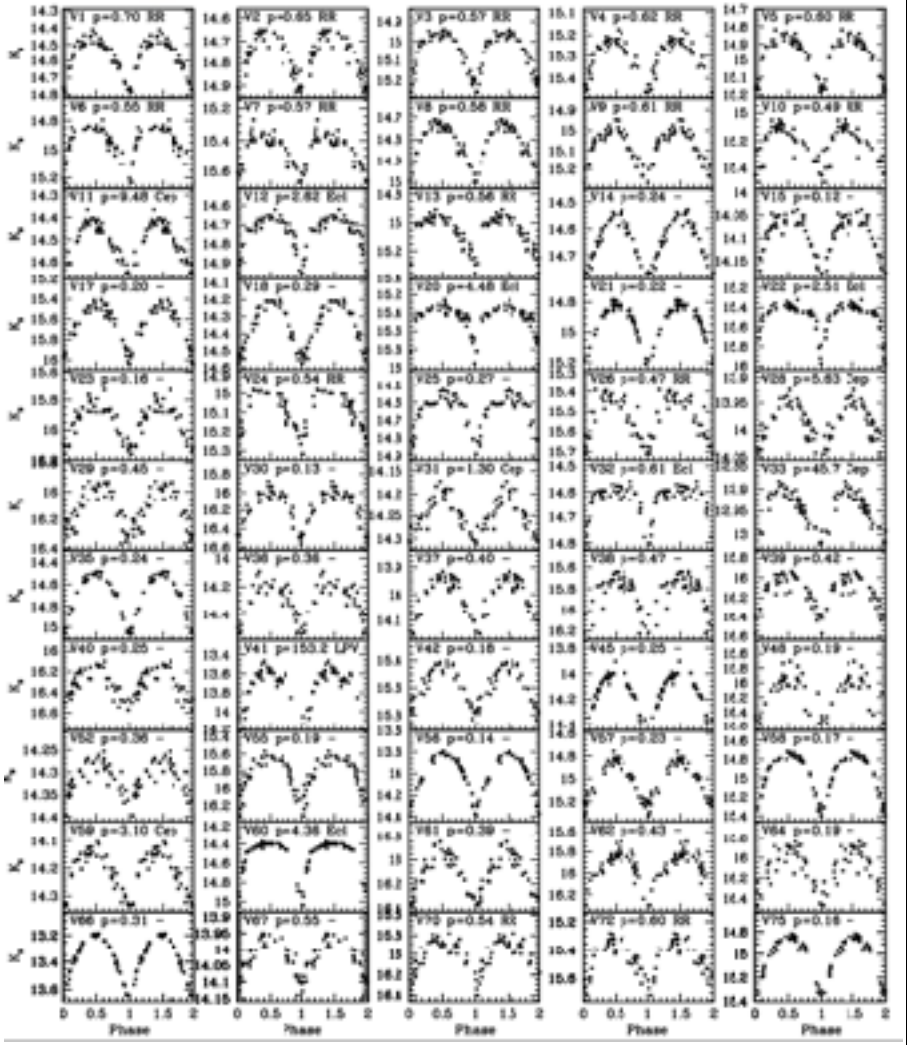
Javier Alonso-García et al. (2016, ApJ)

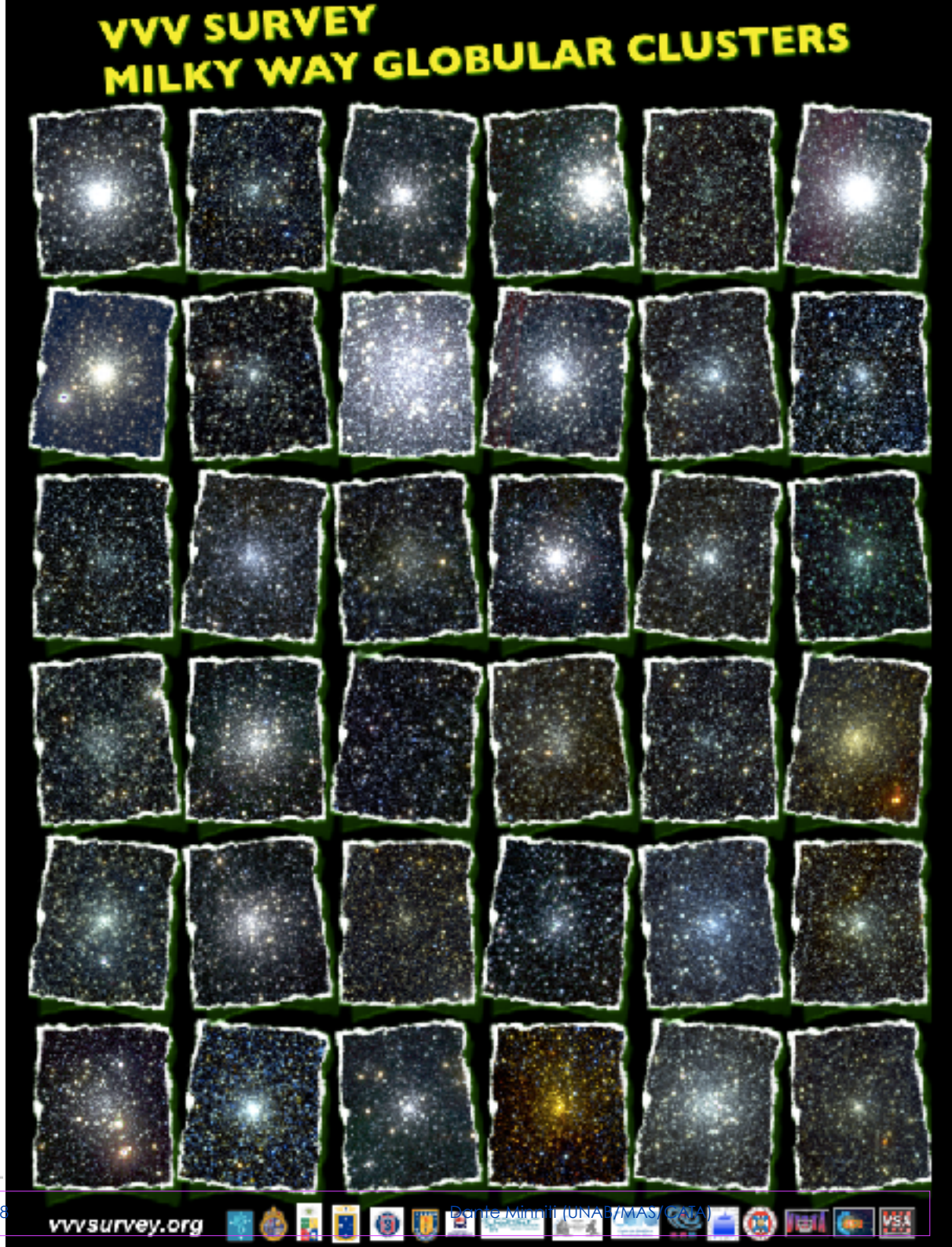
RRLyrae in GCs

Variable stars in the VVV GCs: 2MASS-GC02 and Terzan 10

J. Alonso-Garcia et al. (AJ 2014)

RR Lyrae in GCs





Variable stars in the VVV globular clusters. 2MASS-GC02

J. Alonso-Garcia et al. (AJ 2014)

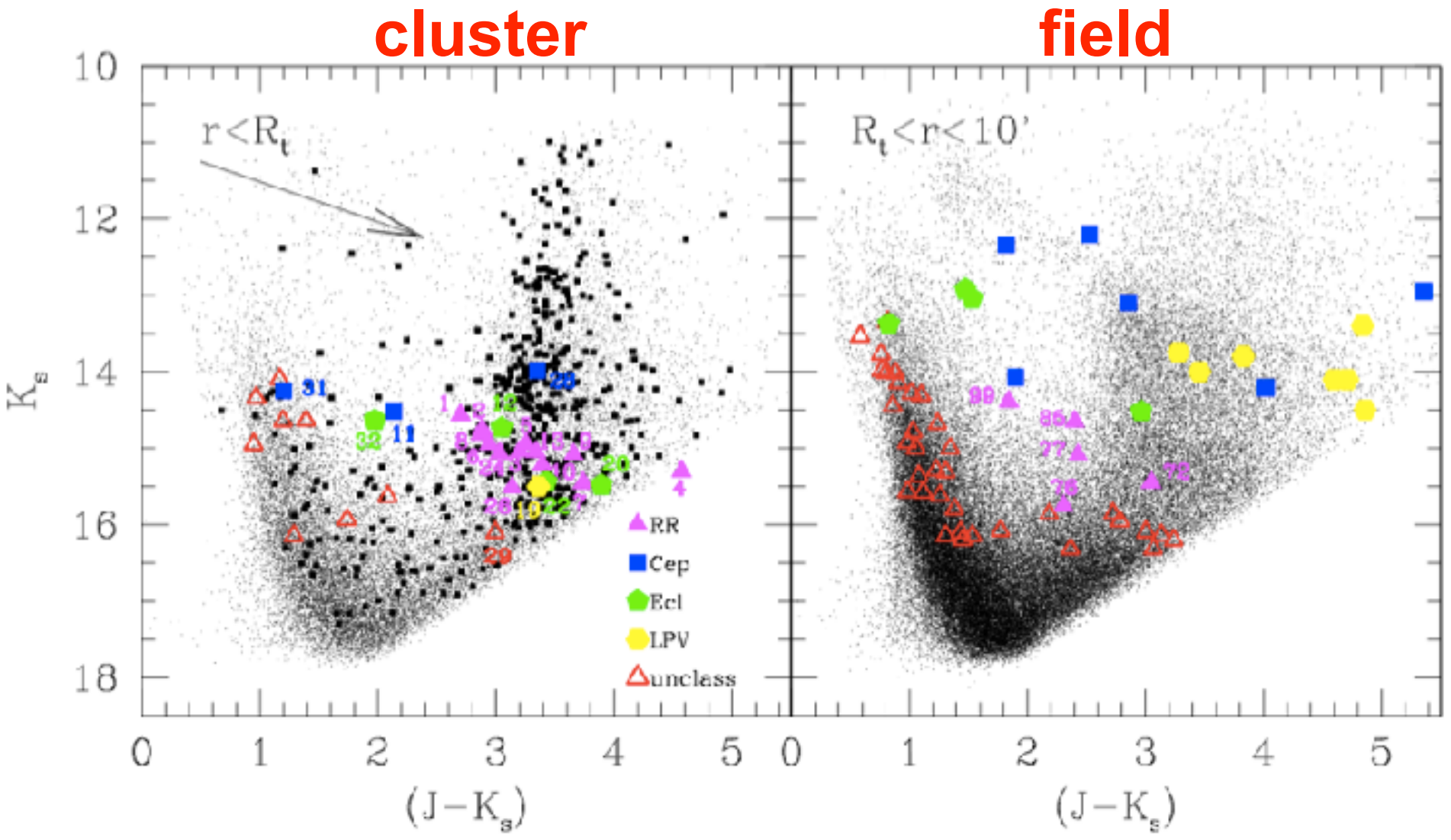


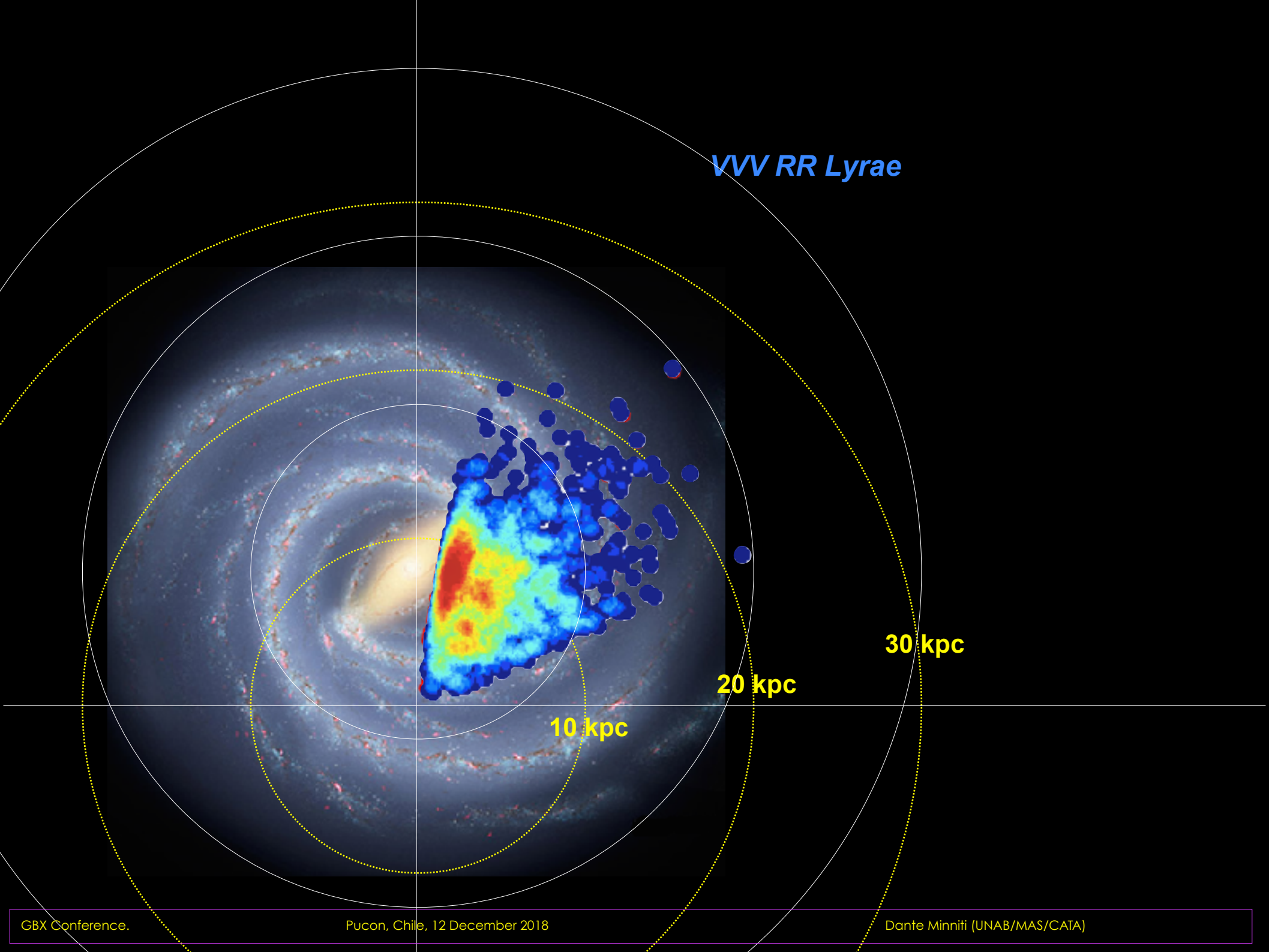
Fig. 1.— $J-K_s$ vs. K_s CMDs of 2MASS-GC02, out to its tidal radius $r_t = 4.9'$ (left), and of its surrounding region (right). The arrow shows the reddening vector according to Nishiyama

Extremely Reddened Globular Clusters

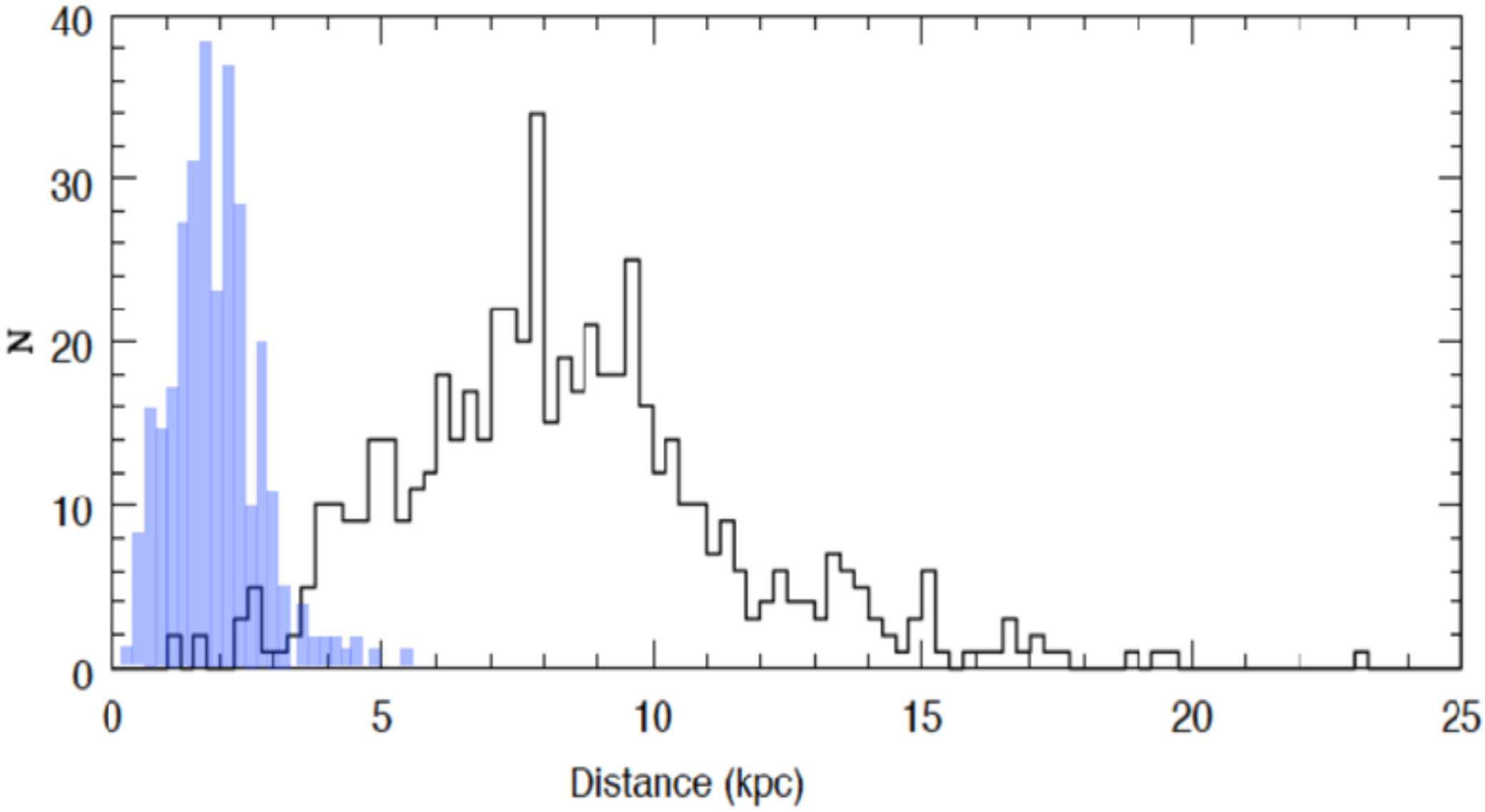
2MASS-GC02 Distance 4.9 kpc → 7.1 kpc

see talk by Felipe Gran

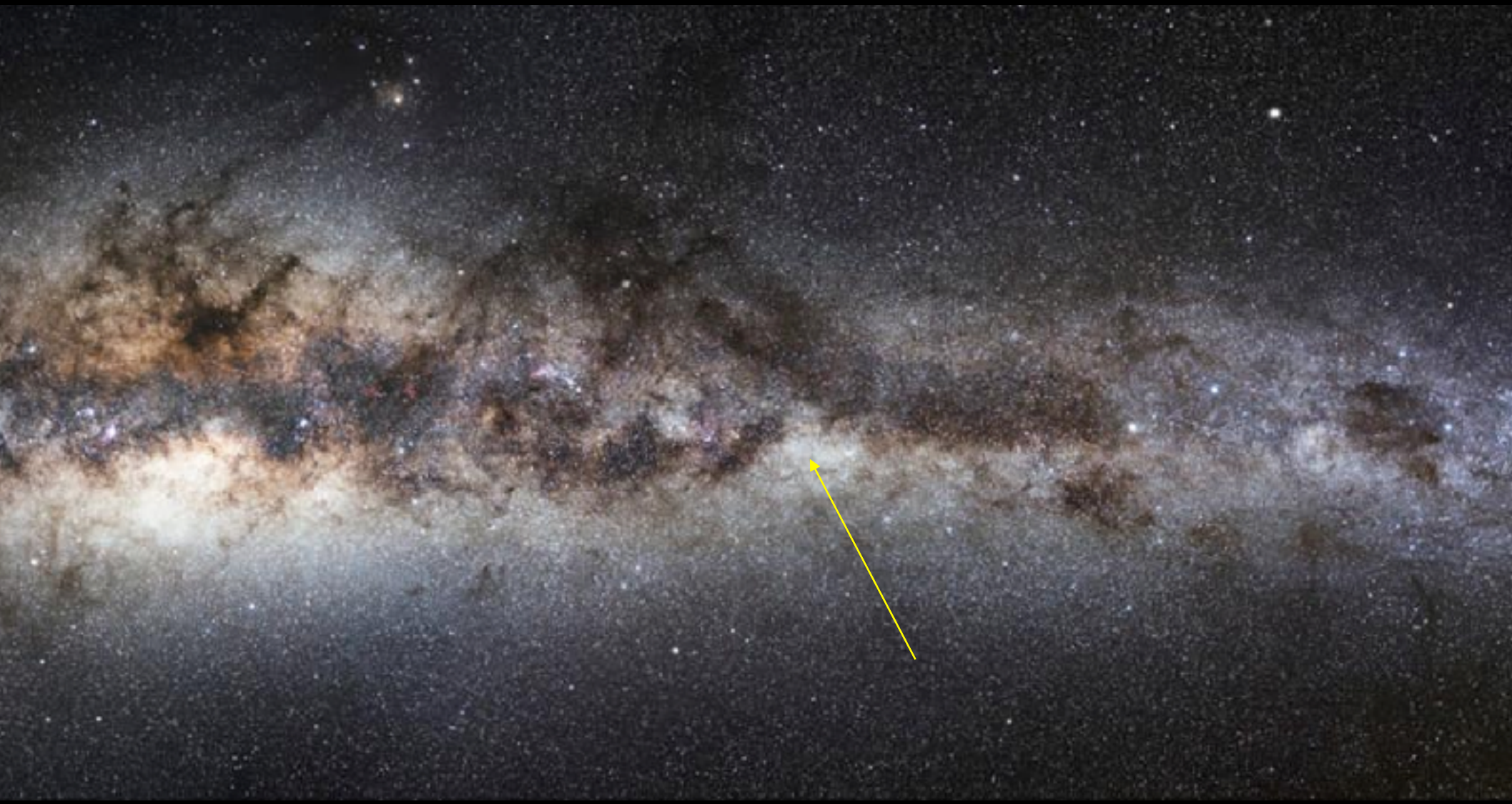
VVV Star Clusters


VVV RR Lyrae
30 kpc
20 kpc
10 kpc

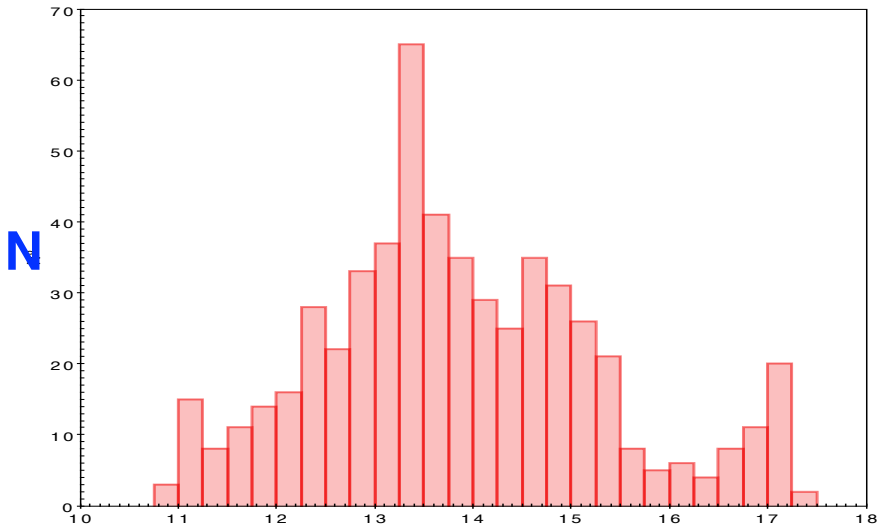
A. Layden (1994) *D. Minniti, T. Palma et al. (2017)*

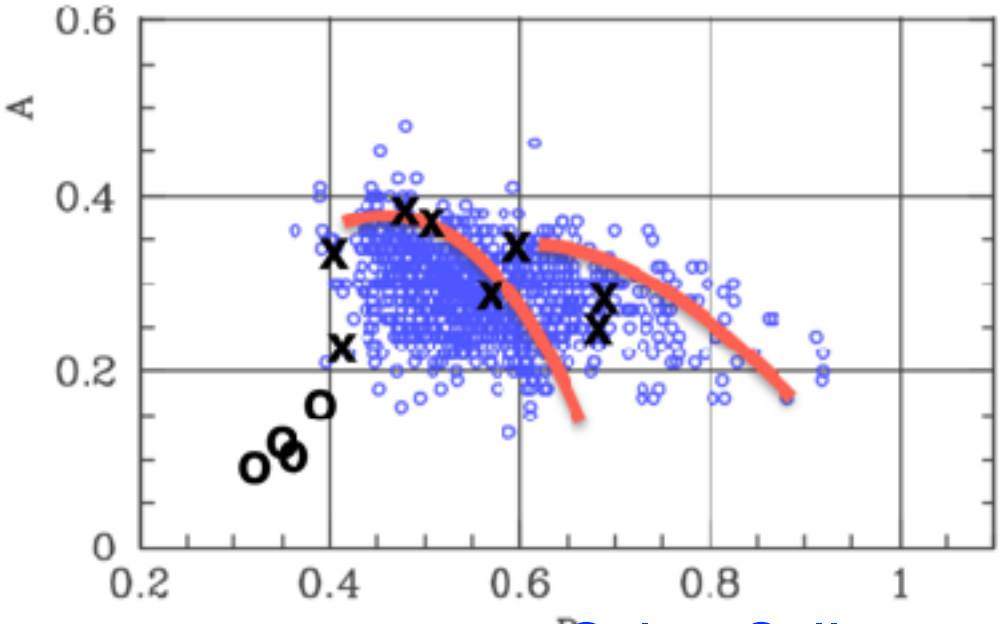


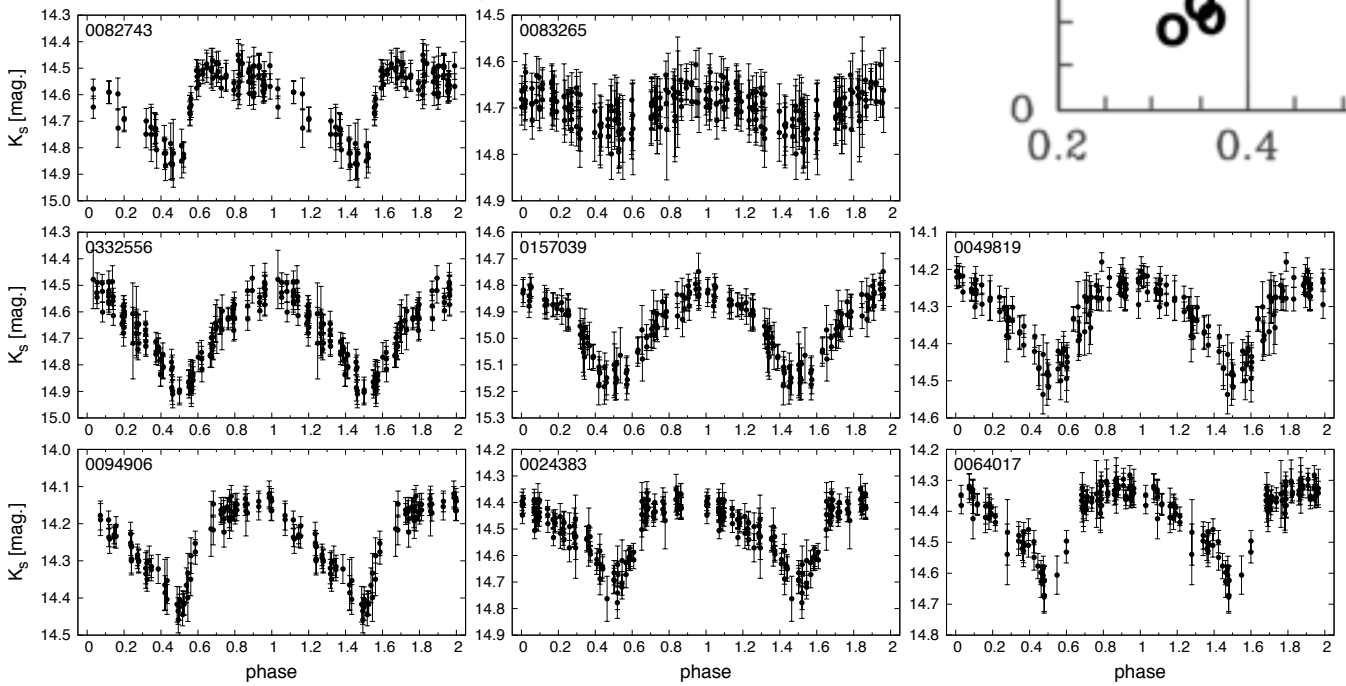
Disk RR Lyrae Distances



VVV-GC05







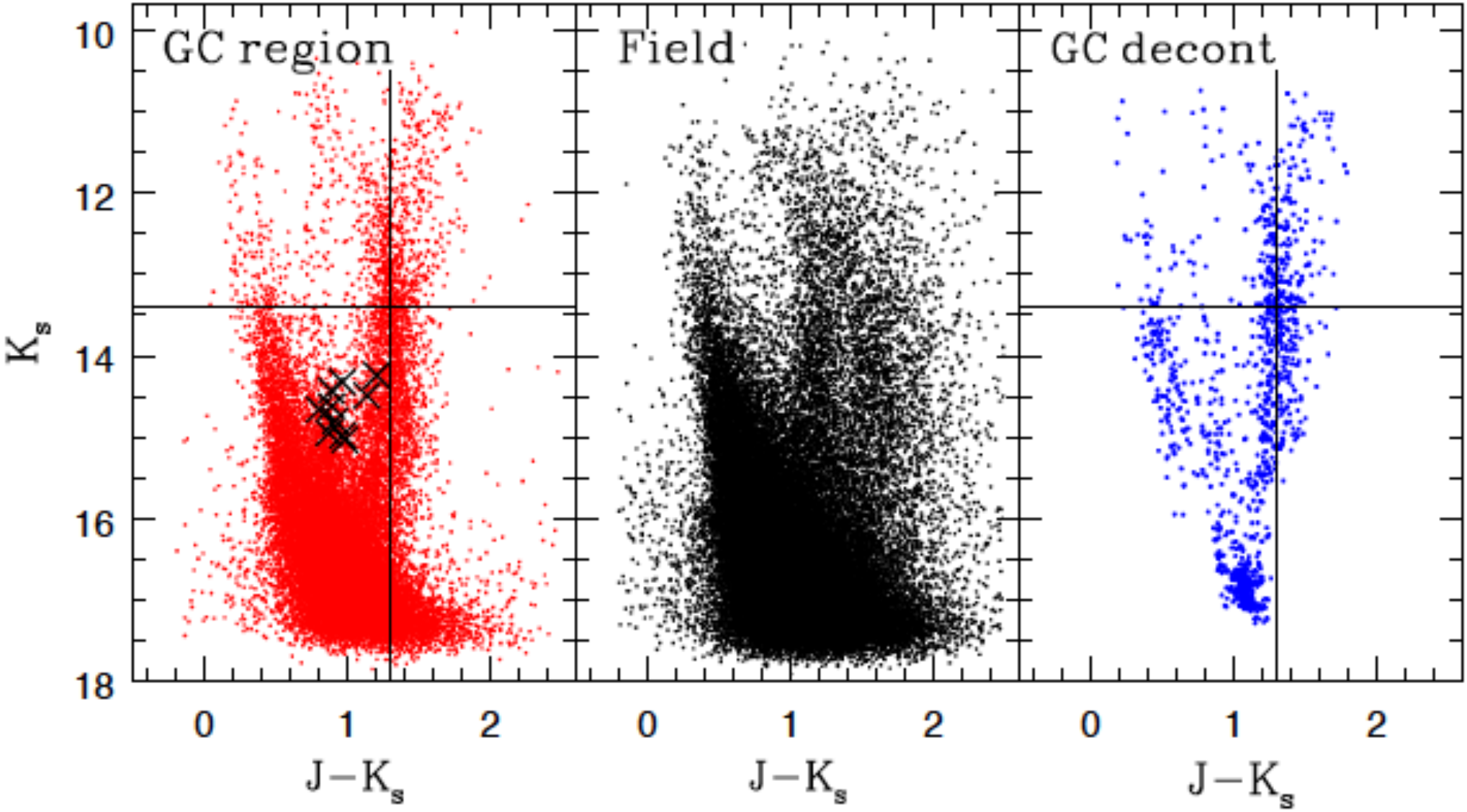
RR Lyrae

VVV-GC05

VVV-GC05

E_{J-Ks} = 0.72 +/- 0.02
A_{Ks} = 0.38 +/- 0.02
D= 8.0 +/- 0.4 kpc

Red Clump
Ks = 13.35 +/- 0.04
J-Ks = 1.30 +/- 0.05

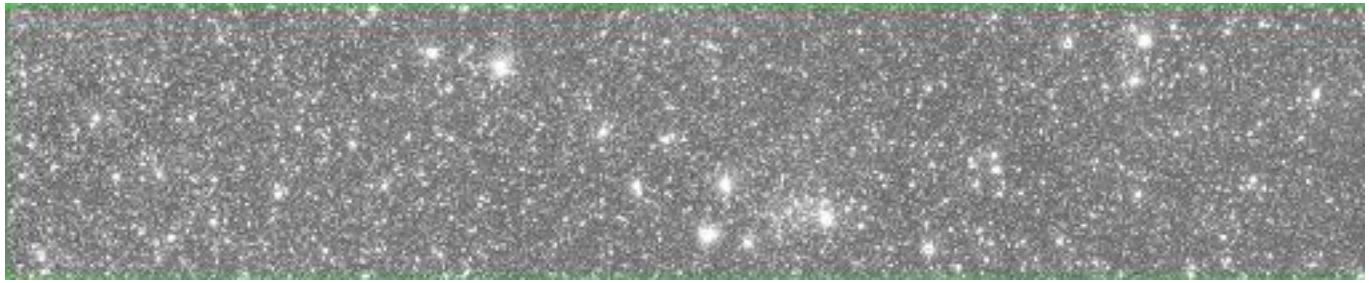


VVV-GC05

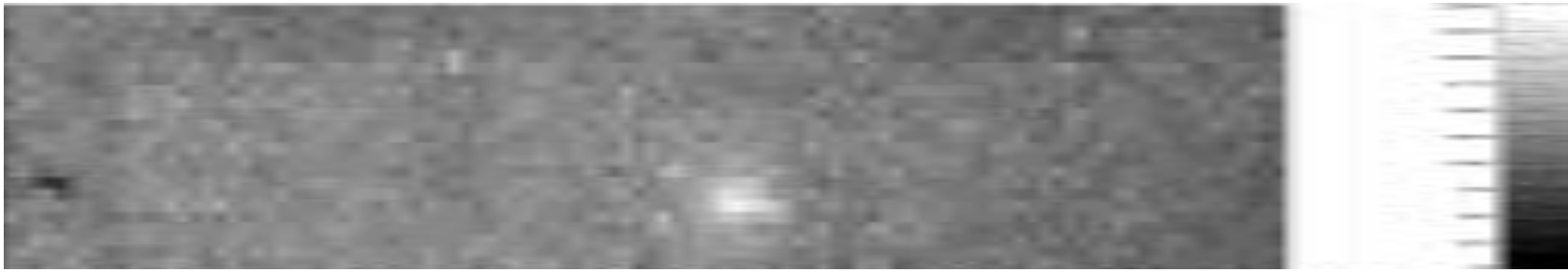
The significance of the discovery is measured using a Koposov (2008) test.

This is a >100 sigma detection with respect to the background.

Ks-band image



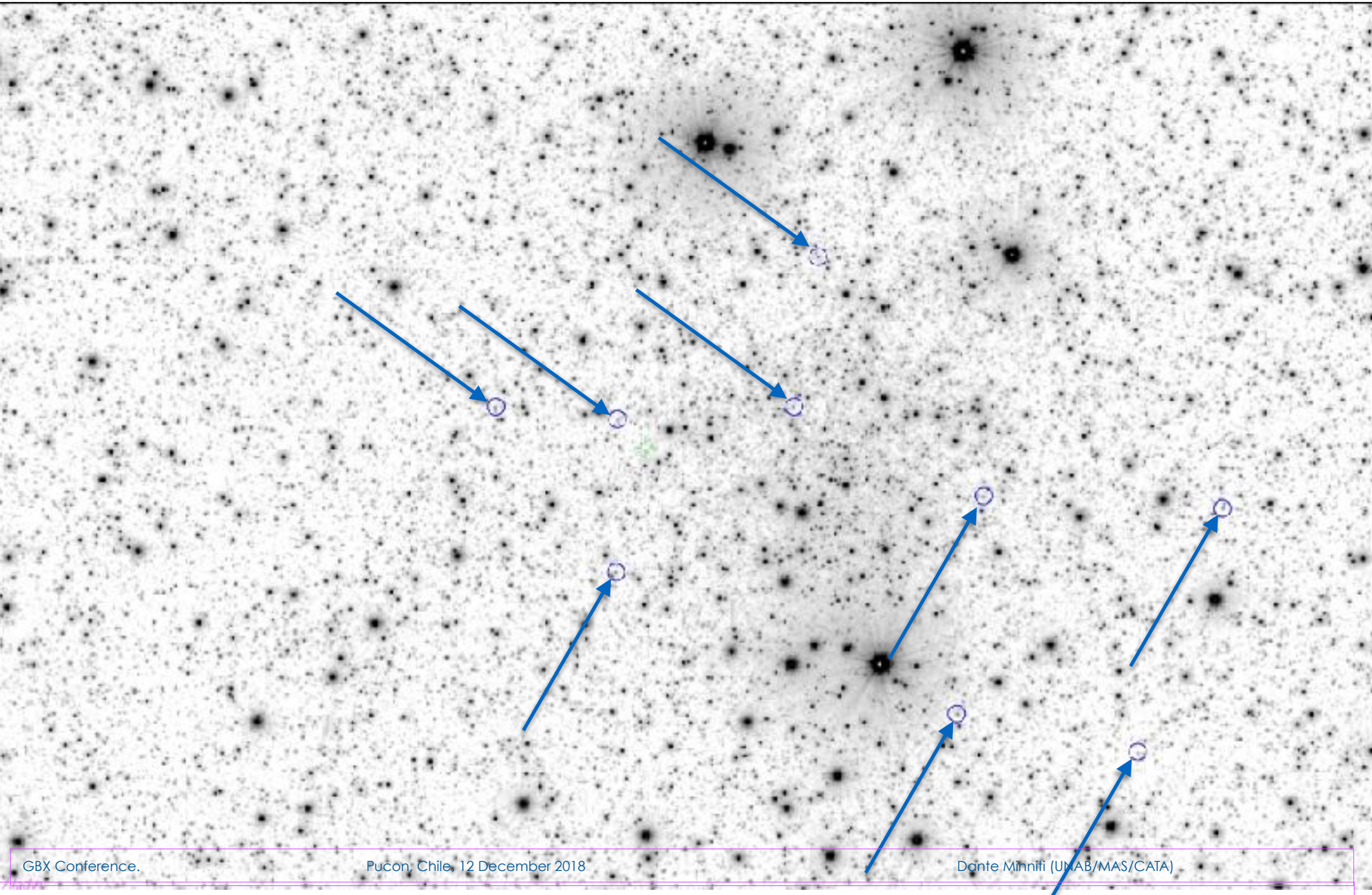
Source density



VVV-GC05

VVV-GC05

Spectroscopy needed!



VVV-GC05

Orbital parameters

Radial velocities are used to confirm the membership of 11 RR Lyrae.

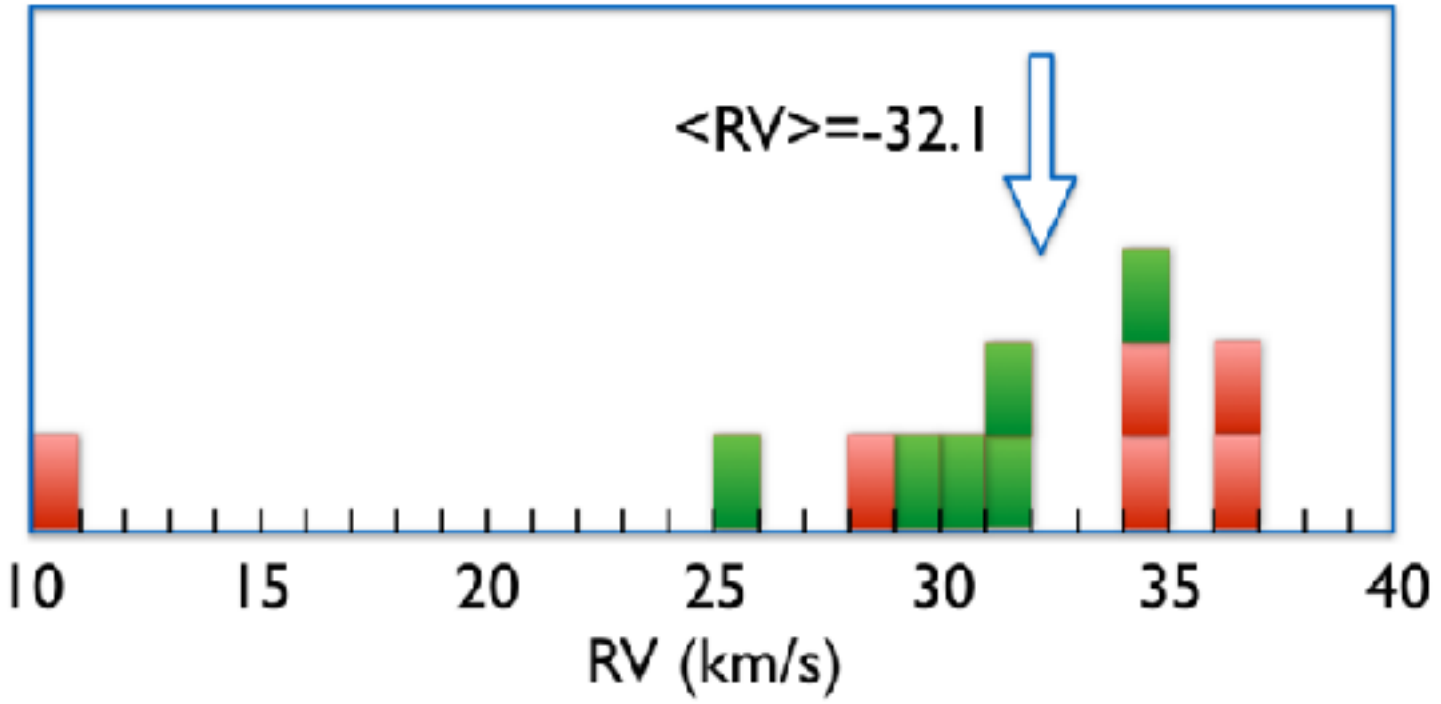


Figure 5. Radial velocities for red giants in the field of the globular cluster VVV-GC05, showing the velocities measured by Koch et al. (2017) in green, and those measured in this work in red.

R. Contreras Ramos, J. Fernandez-Trincado, et al. (2018 ApJ)

VVV-GC05

Proper Motions

Proper motions can be used to discriminate cluster members from field stars.
We find that the cluster is quite flattened.

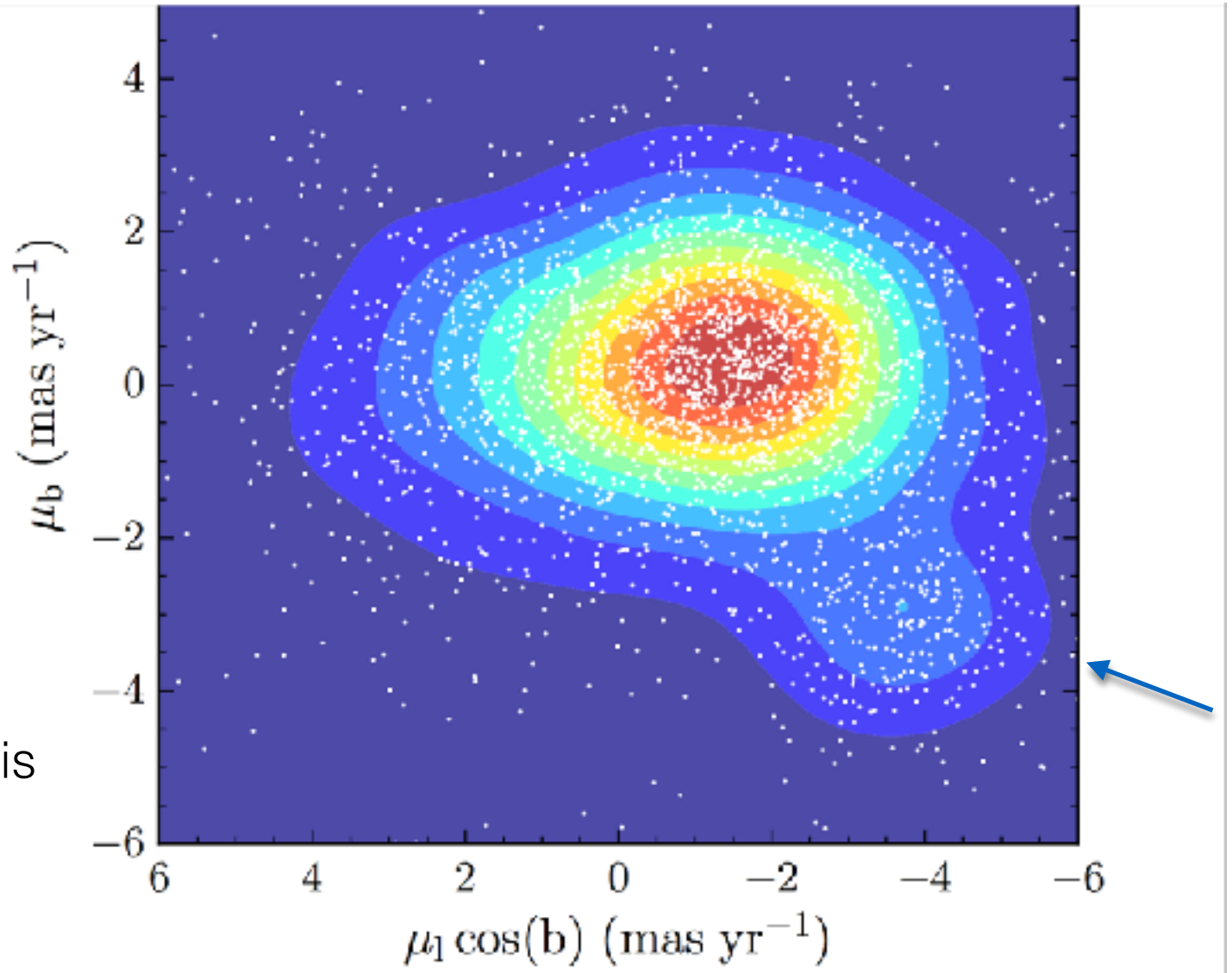


Figure 1. Smooth VPD for all the stars with $K_s < 15$ mag. Likely stars belonging to VVV-GC05 in the lower right corner clearly separate from the disk stars. The cloud of disk stars in the center appears elongated due to the disk rotation.

R. Contreras Ramos, J. Fernandez-Trincado, et al. (2018 ApJ)

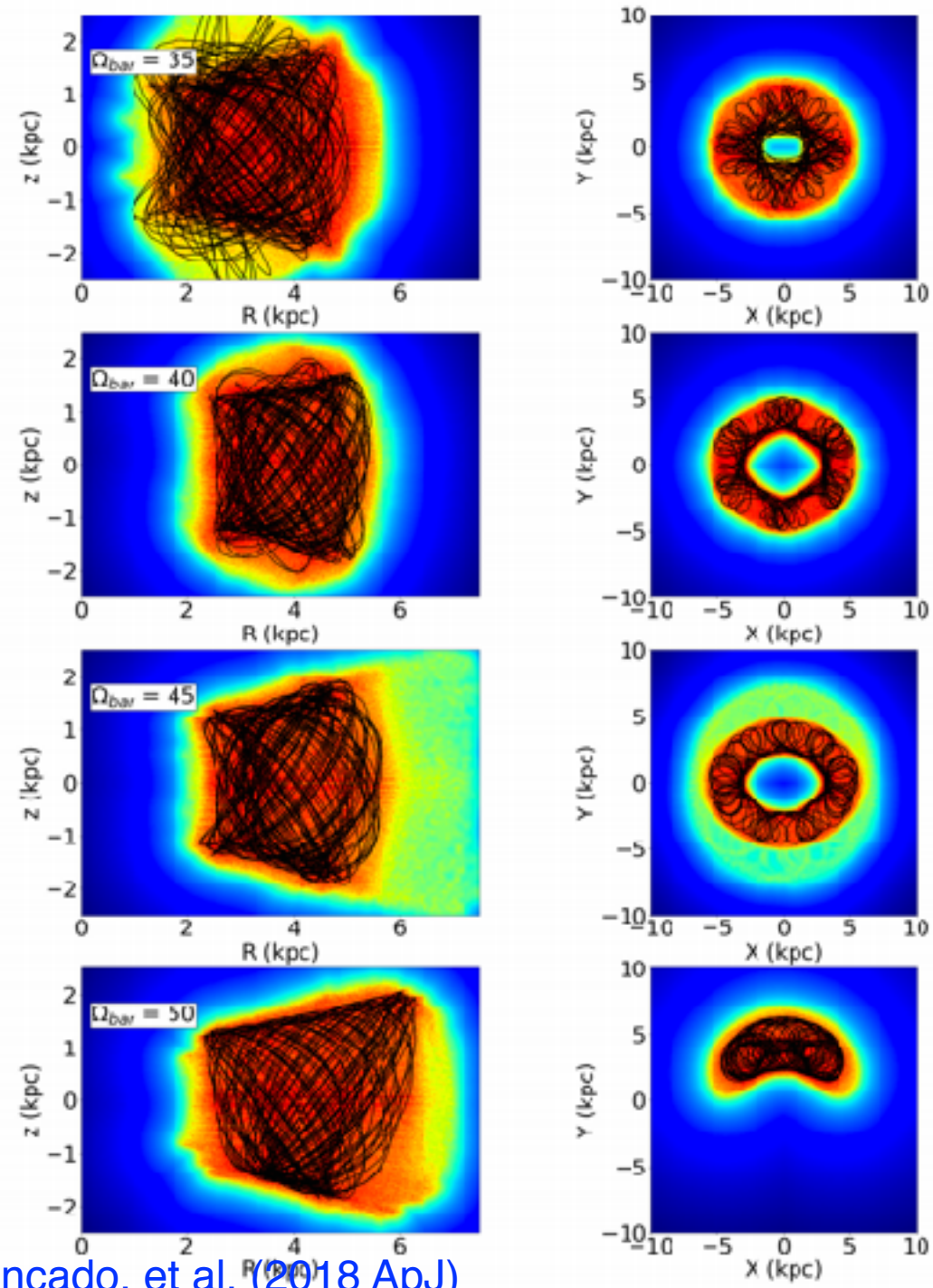
VVV-GC05

Orbital parameters

Having radial velocities and proper motions we can compute the orbit.

Regardless of the the choice of a Galactic potential, the cluster orbit is confined to the Galactic plane.

Thus, this cluster must suffer from disruption processes (dynamical friction, disk shocking).



R. Contreras Ramos, J. Fernandez-Trincado, et al. (2018 ApJ)

Globular clusters are astrophysically very important!

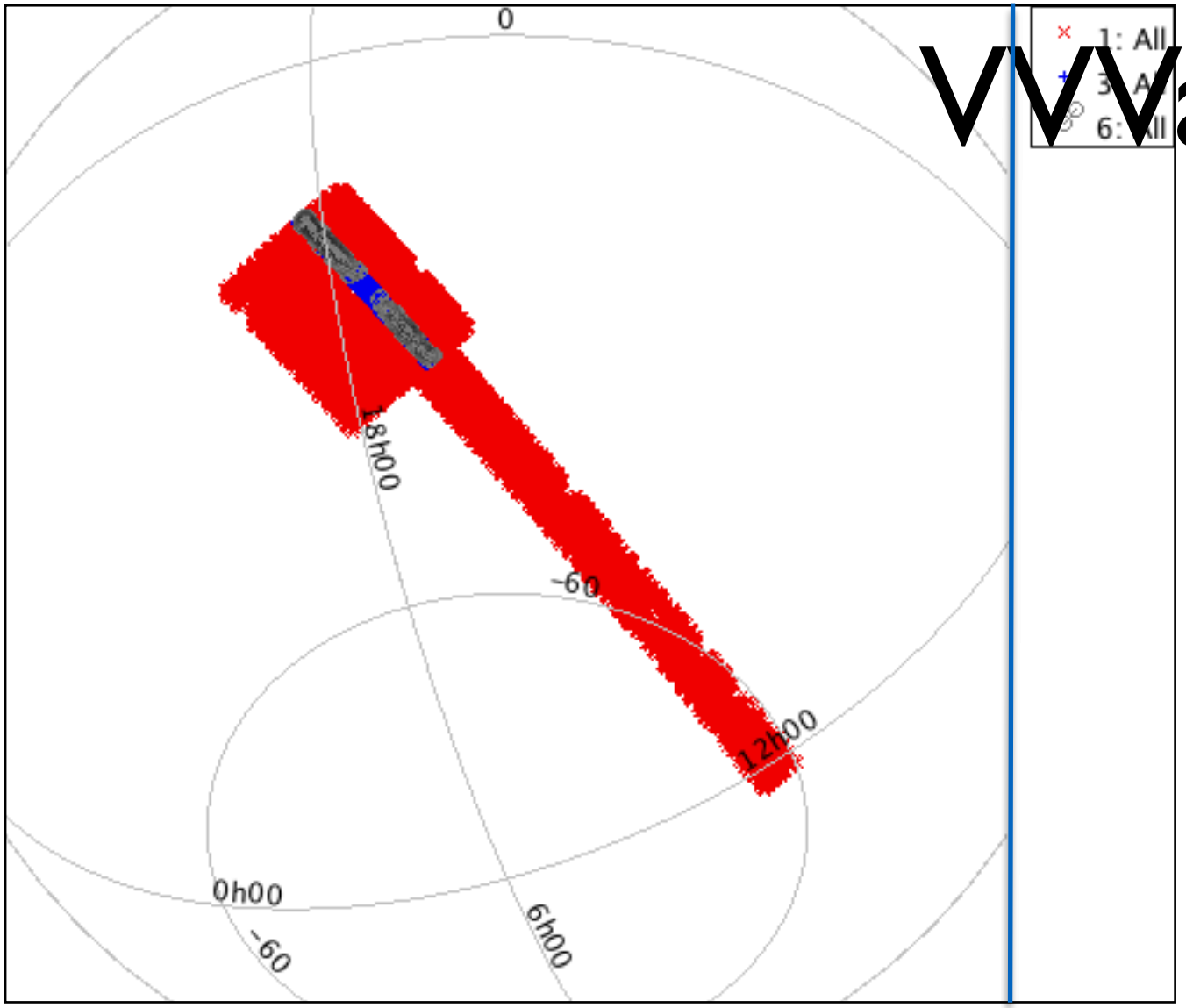
Age of the Universe,
Chemical evolution Universe,
Stellar evolution,
Galactic structure,
Formation of the Milky Way,
Distance scale,
Collissionless systems,
Interstellar medium,
…

Tali Palma, Jura Borissova, Rudy Kurtev, Rodolfo Barbá, Sebastián Ramírez, Javier Alonso-García, Christian Moni-Bidin, Roberto Saito, Roger Cohen, Rodrigo Contreras Ramos, Felipe Gran, Maren Hempel, Marcio Catelan, Doug Geisler, Francesco Mauro, Charles Bonatto, Eduardo Bica, Daniel Majaess, et al.

Daniel Majaess et al. (2018)

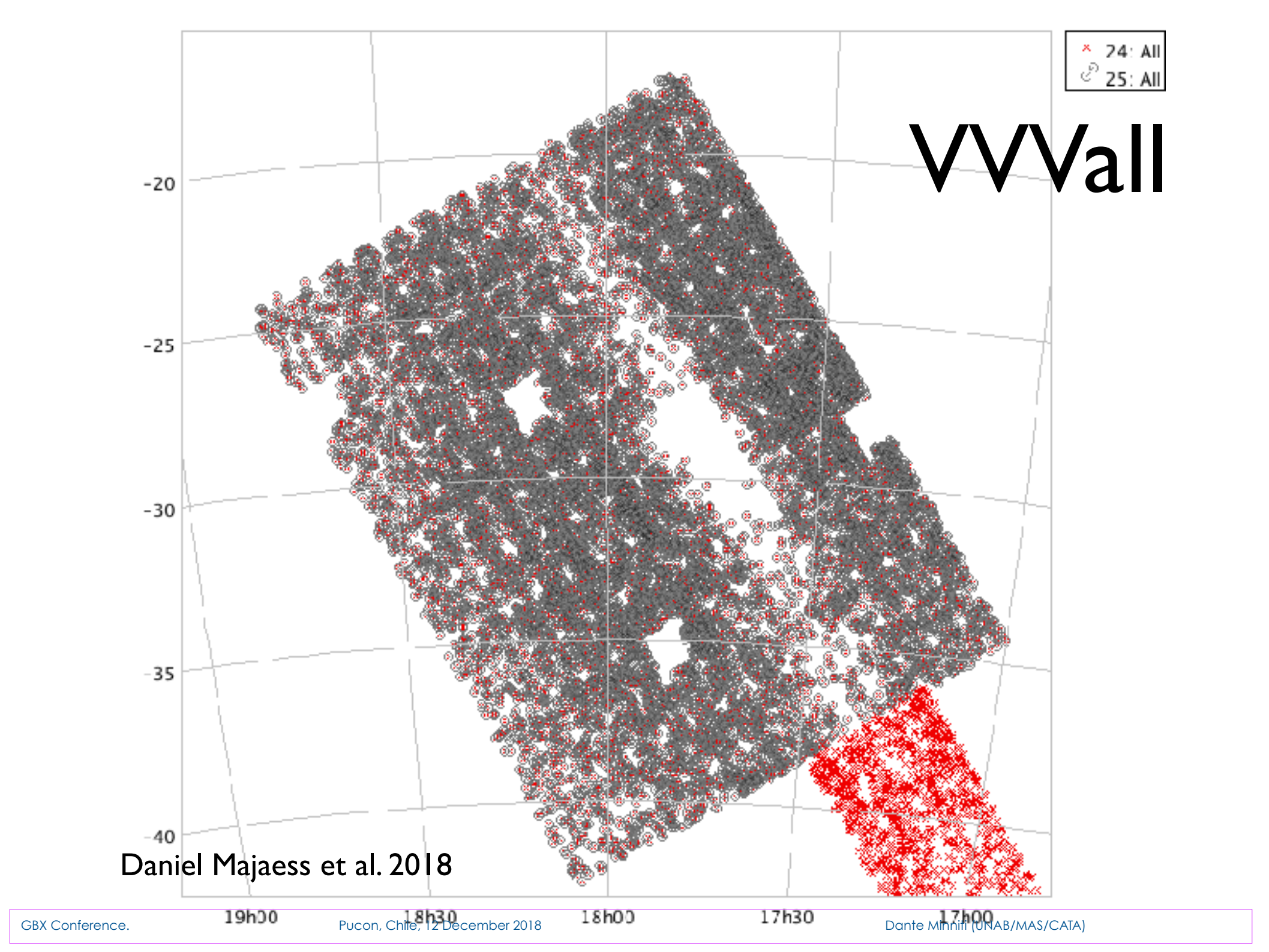
VVV

RRLyrae



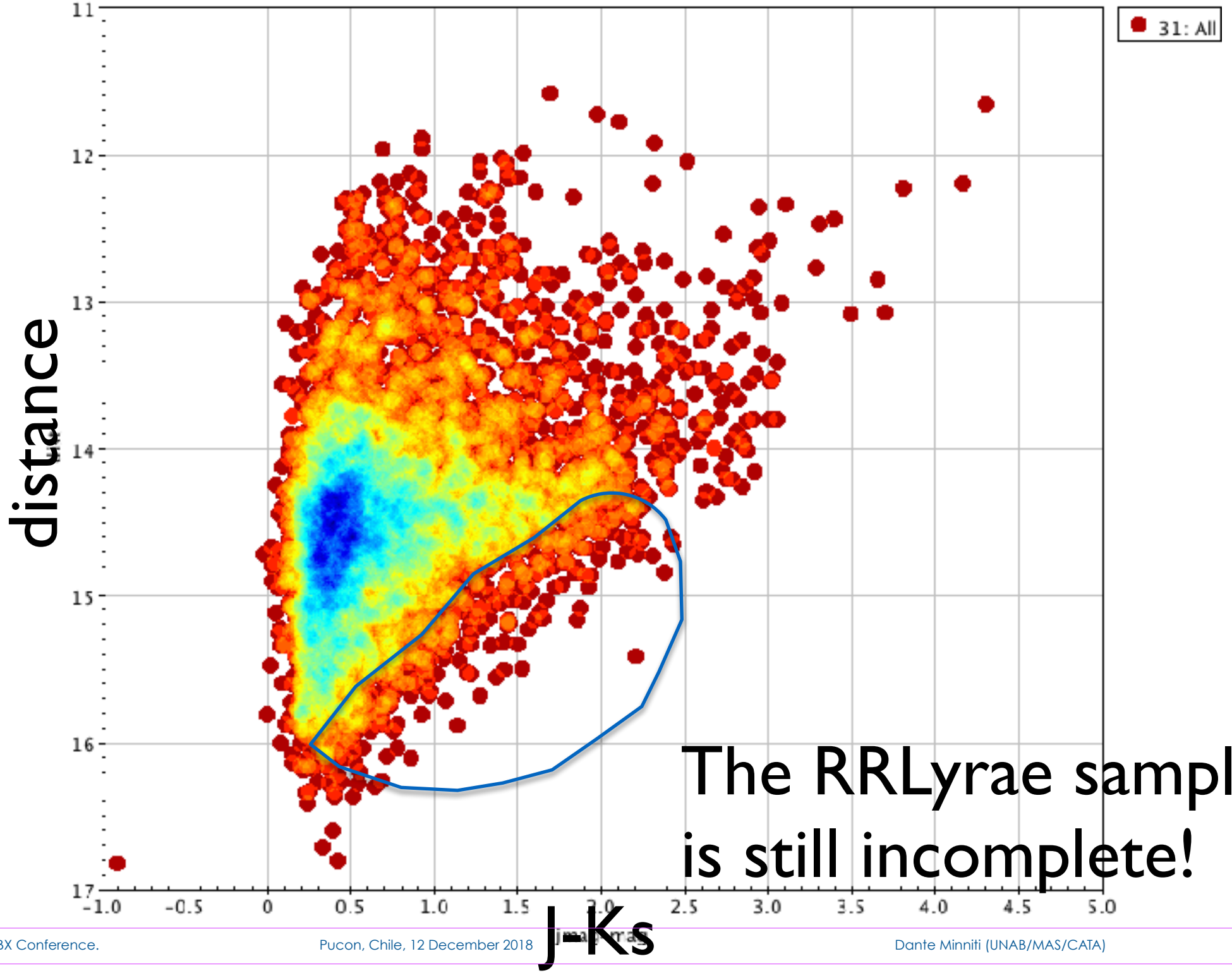
VVVall

Daniel Majaess et al. 2018



VVVall

Daniel Majaess et al. 2018

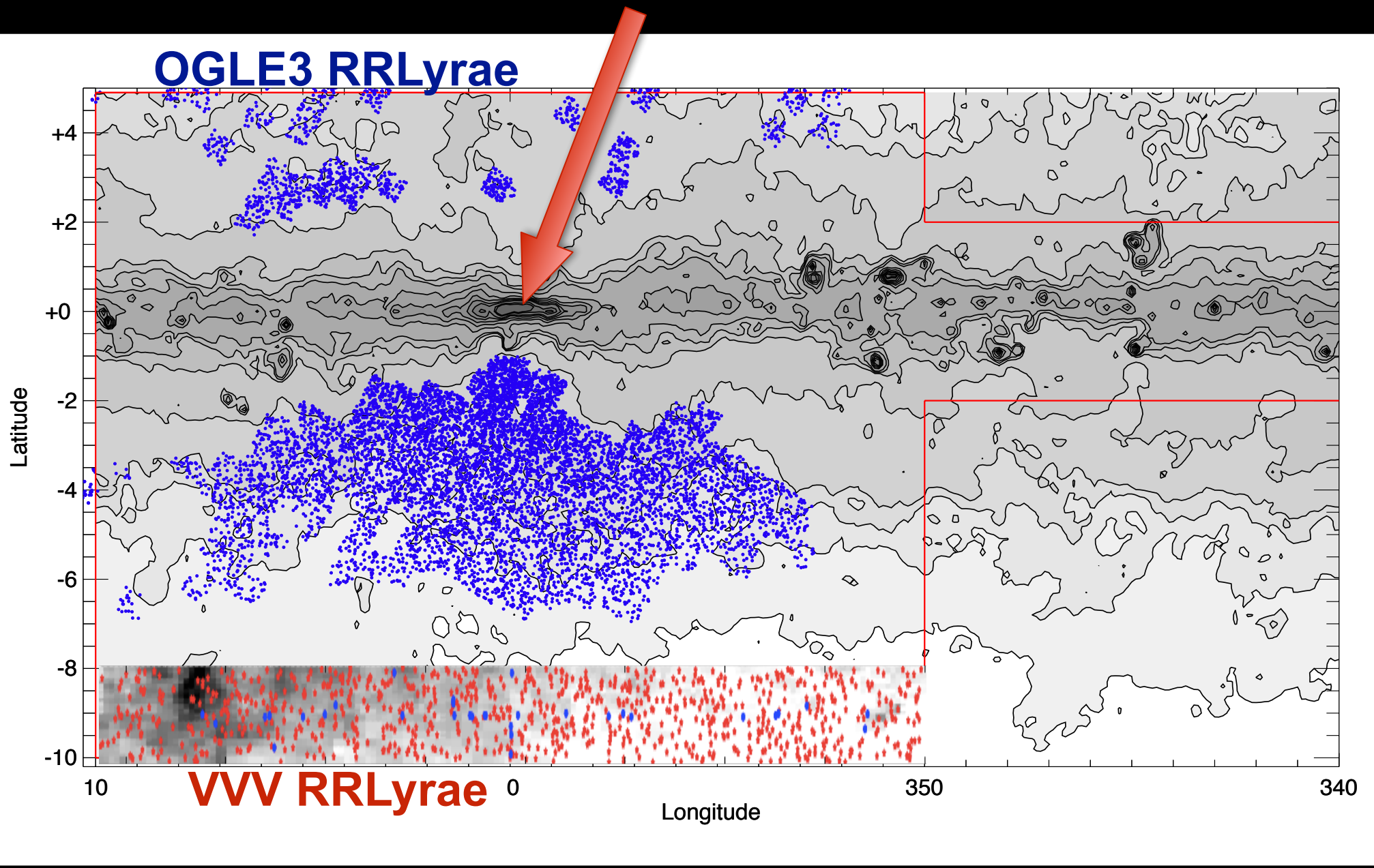


The RRLyrae sample is still incomplete!

Rodrigo Contreras et al. (2018 ApJ)
Dante Minniti et al. (2016 ApJL)

Galactic Center RRLyrae

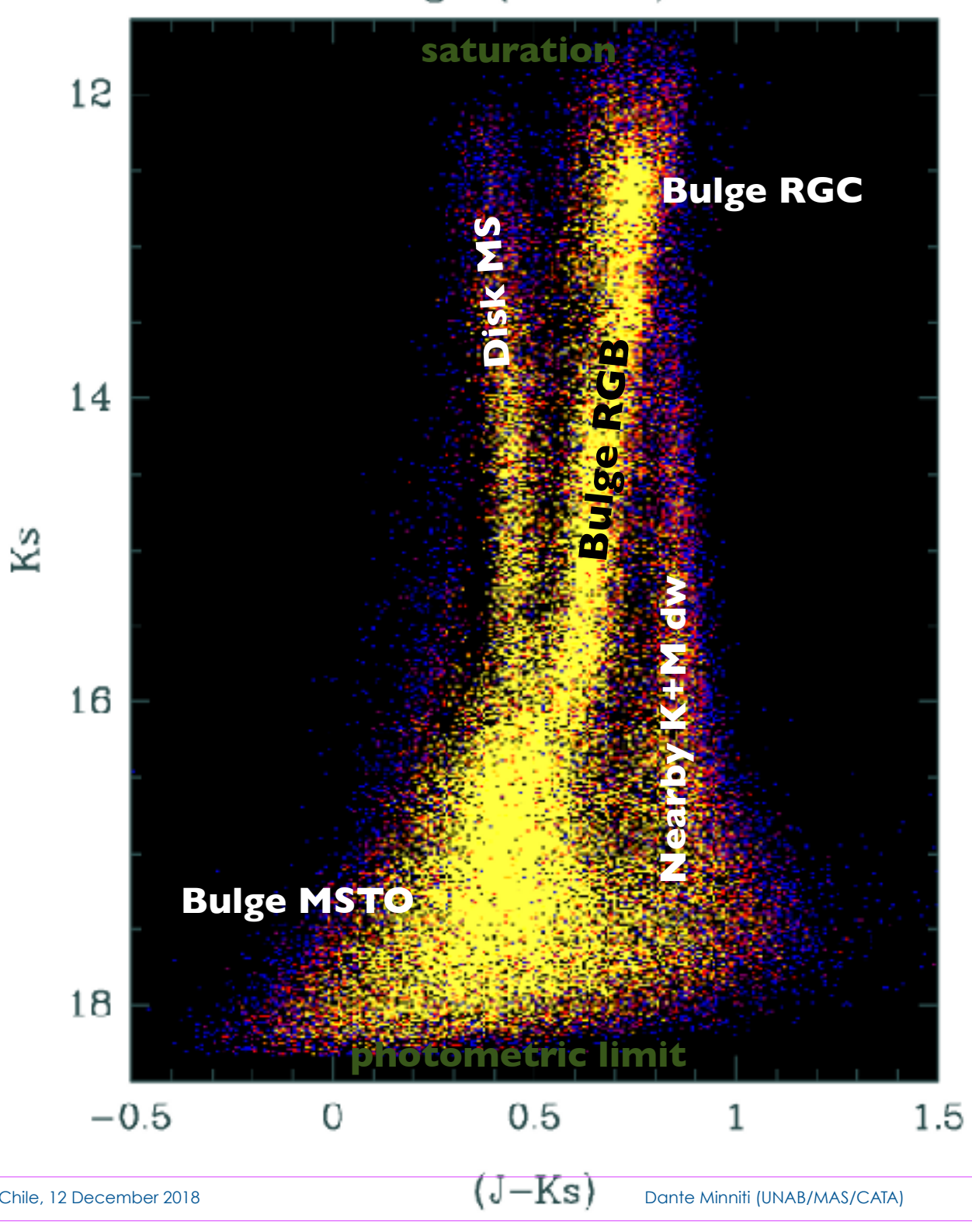
Galactic Center RR Lyrae

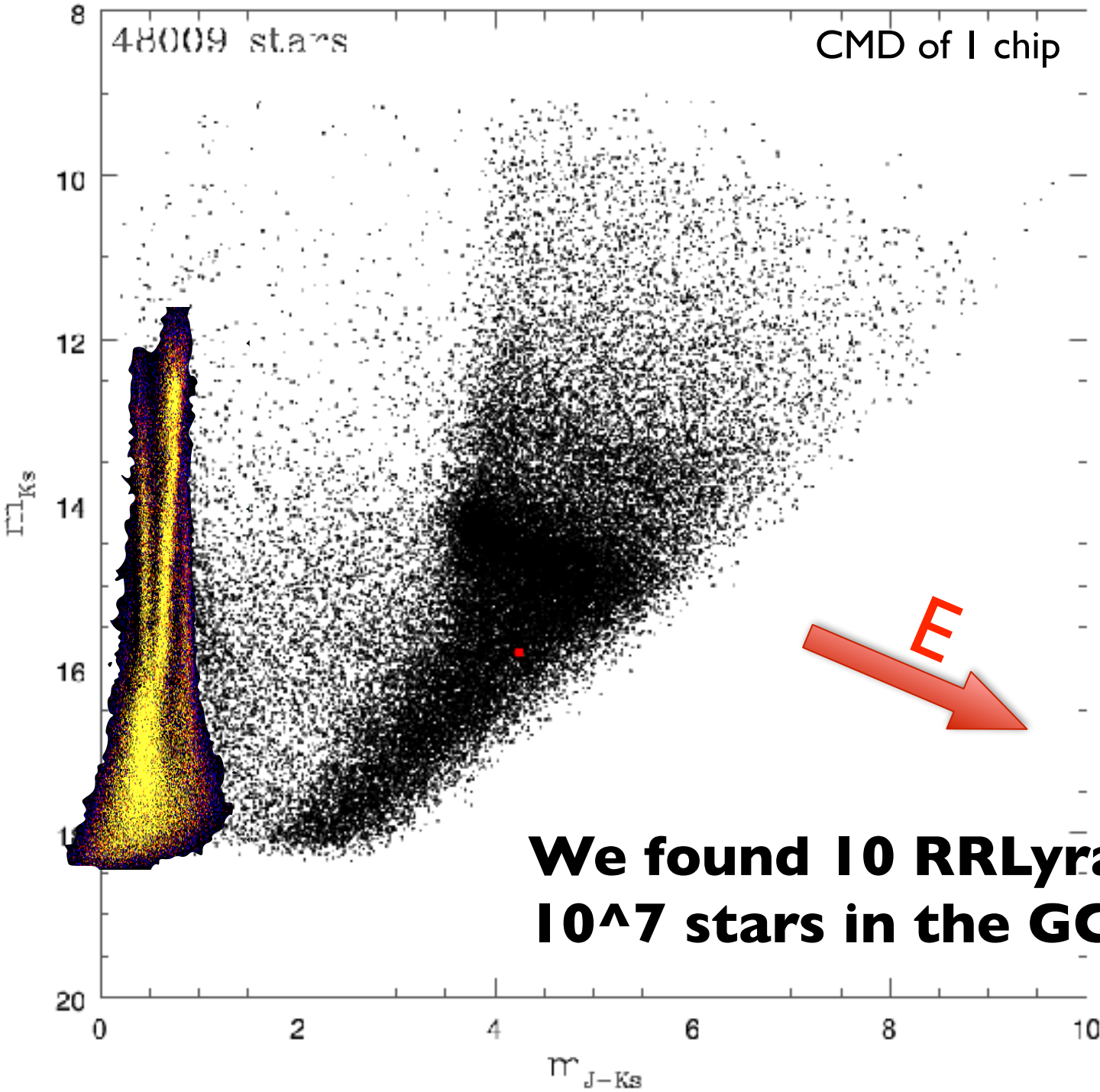


VVV Image of the Galactic center

outer bulge fields
b209-b211

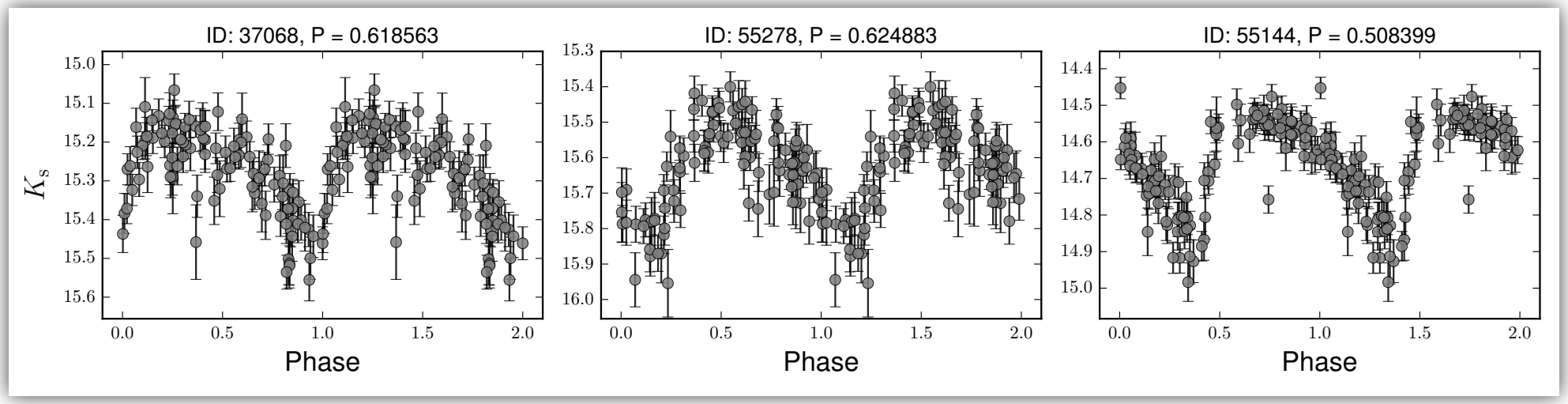
VVV STARS CMD





We found 10 RRLyrae out of 10^7 stars in the GC region

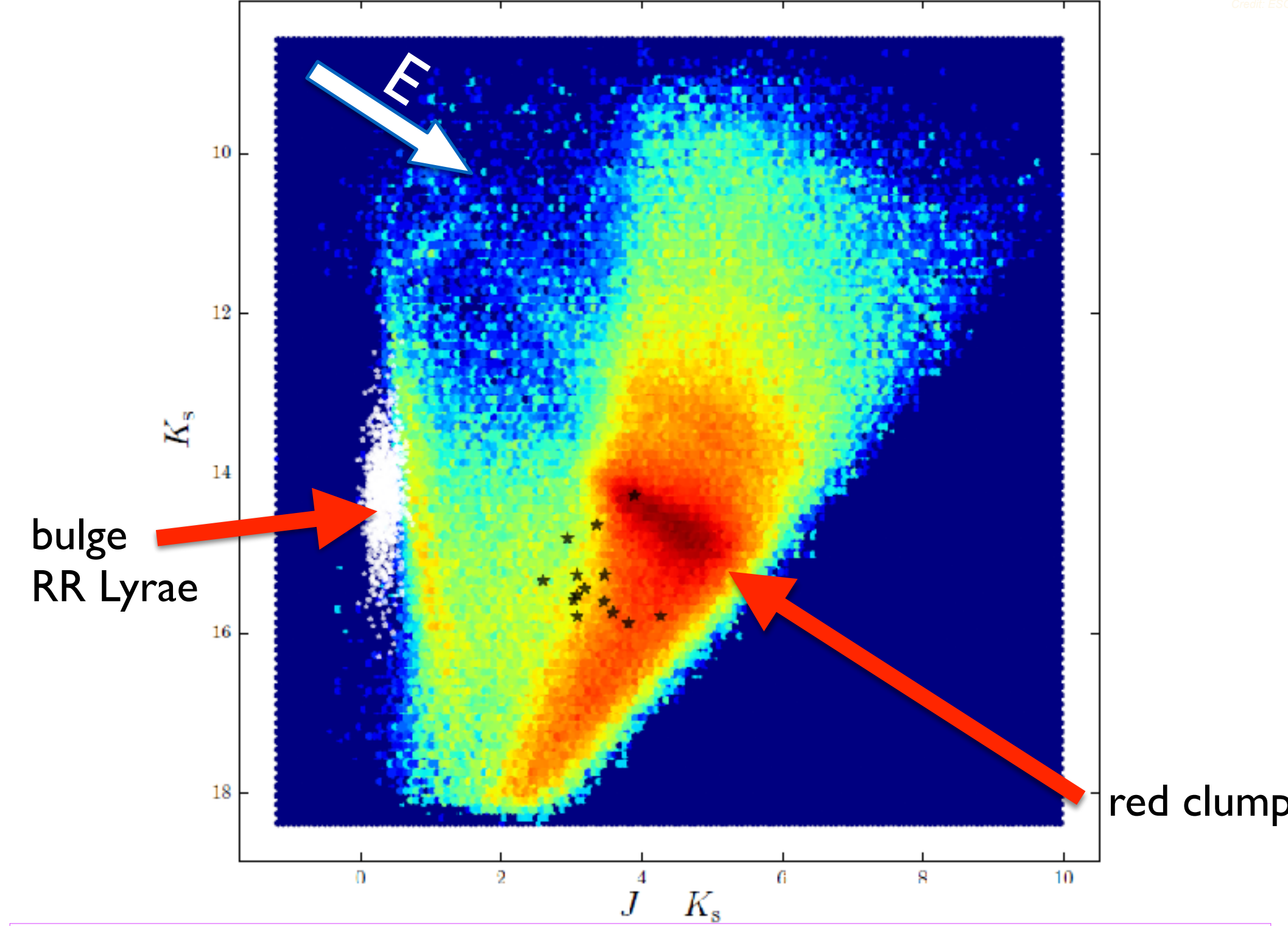
Galactic Center RR Lyrae

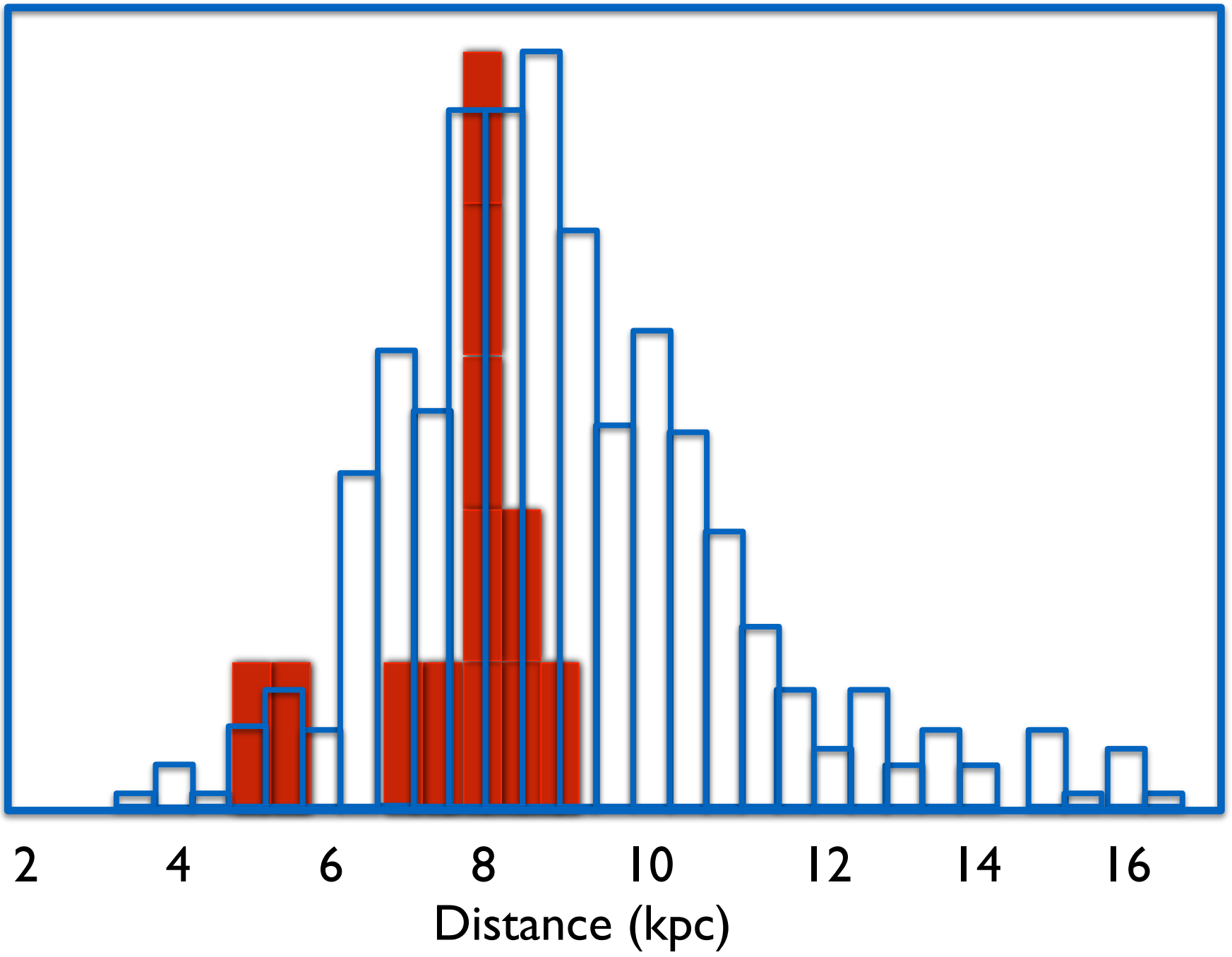


Typical light curves

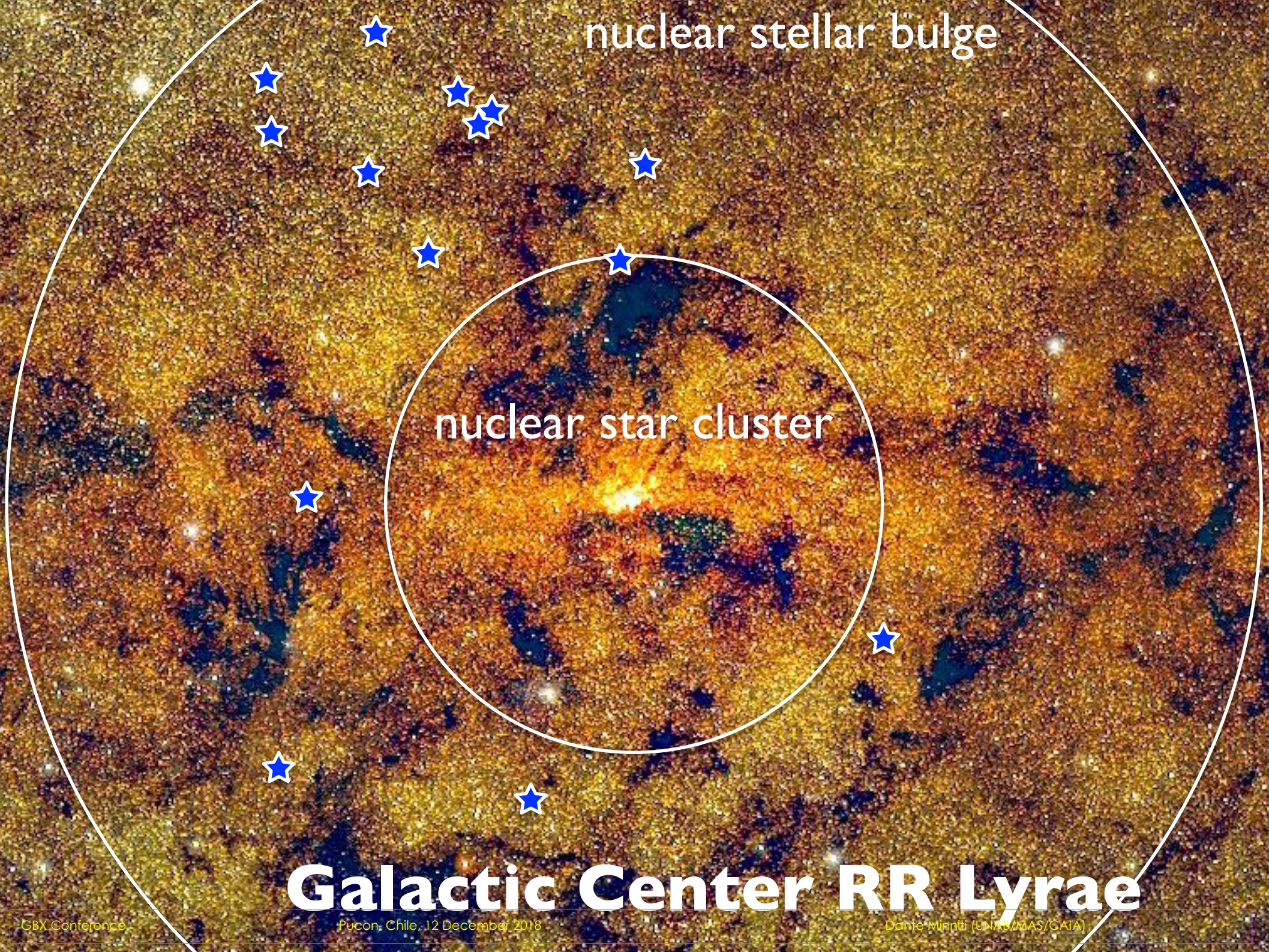
- clear discrimination from contact binaries
- somewhat noisier than typical VVV bulge RR Lyrae
- period distribution indicates an Oosterhoff type I population

Galactic Center RR Lyrae


E
bulge
RR Lyrae
red clump
10
12
14
16
18
K_s
0
2
4
6
8
10
$J \quad K_s$



Galactic Center RR Lyrae



Galactic Center RR Lyrae

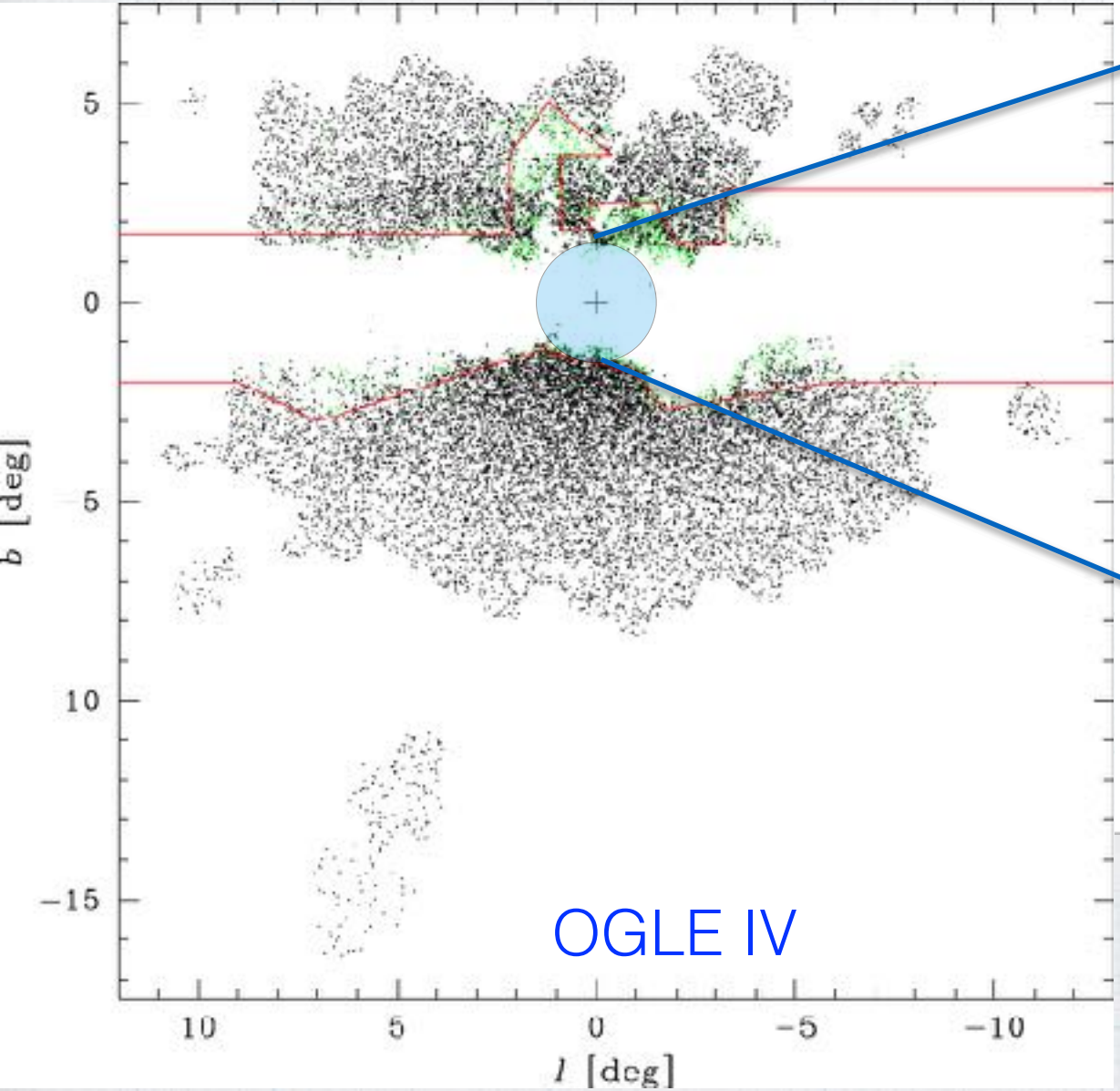
Galactic Center RR Lyrae

- We report the discovery of a dozen RR Lyrae ab-type stars in the nuclear stellar bulge of the Milky Way.
- This suggests that Galactic center contains an old and metal-poor population, detected here for the first time.
- One implication is that the Galactic center is very old.
- The merger of primordial globular clusters may have contributed to building up the high stellar density in the Galactic center, as proposed by R. Capuzzo-Dolcetta (1993).
- What next?
  - 1. Make a full census.
  - 2. Measure proper motions.
  - 3. Obtain spectra.

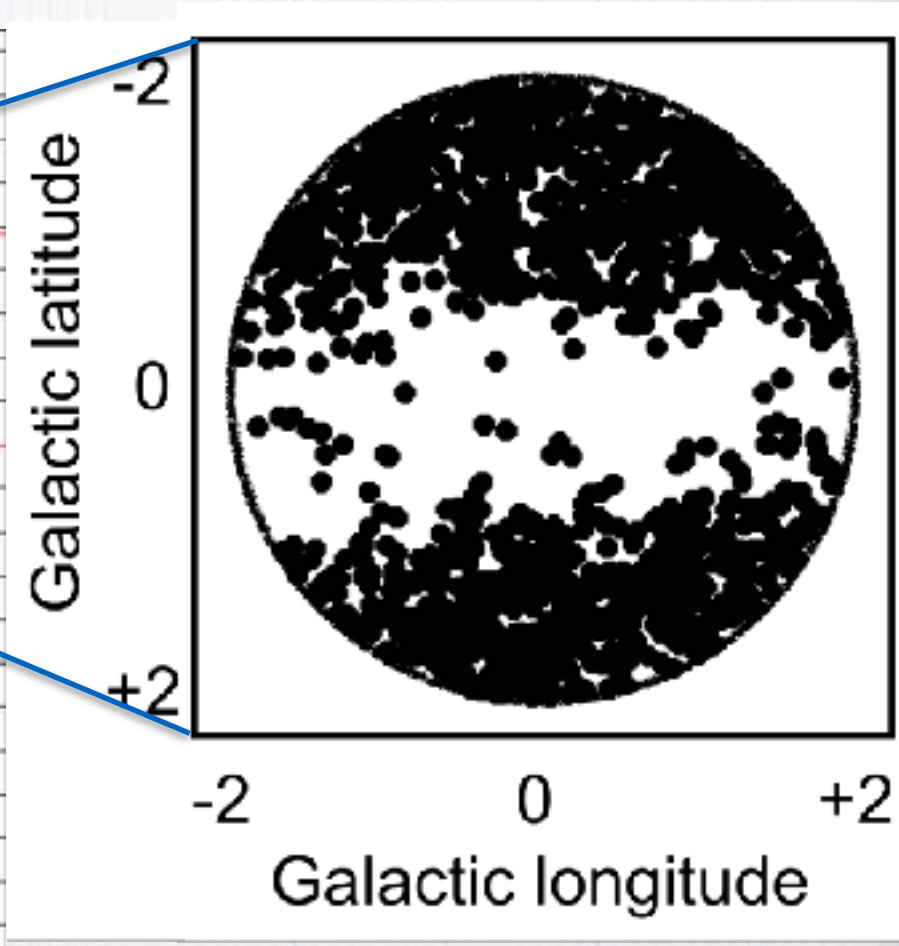
D. Minniti, et al. 2016, ApJL

see also Dong et al. 2017, ApJ

R. Contreras-Ramos, et al. 2018, ApJ

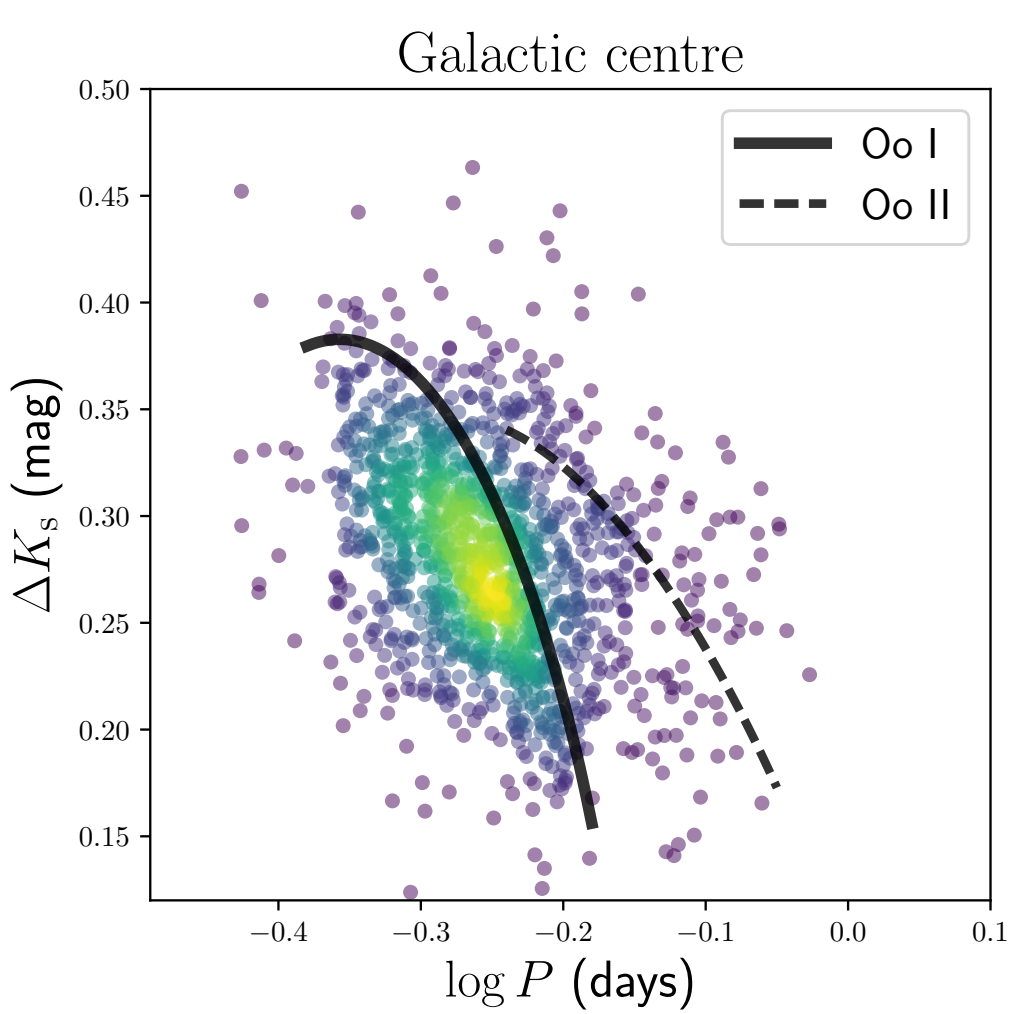


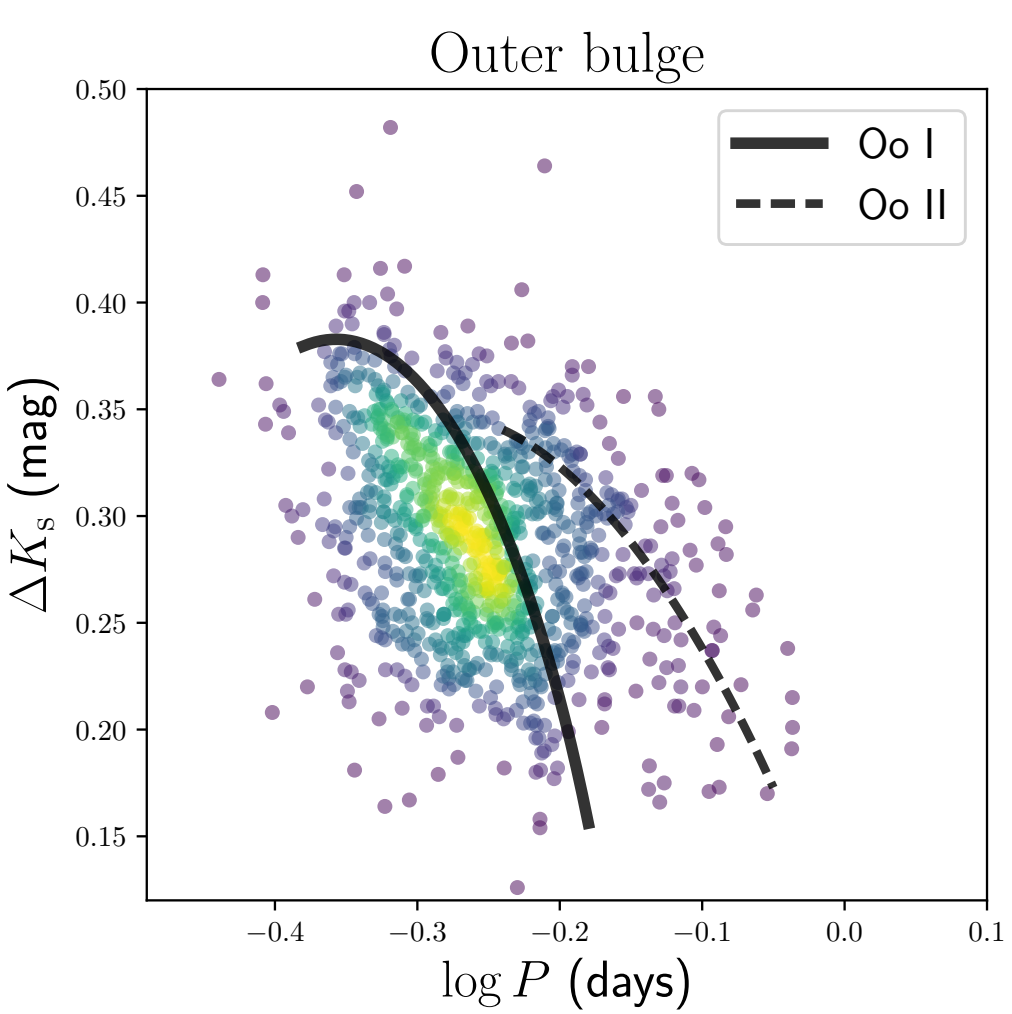
OGLE IV



Completing the census of Galactic centre RR Lyrae: ~1000 new RRab (Contreras Ramos et al. 2018)

The Galactic centre RR Lyrae appear to belong to an extreme OoI population (Contreras Ramos et al. 2018)



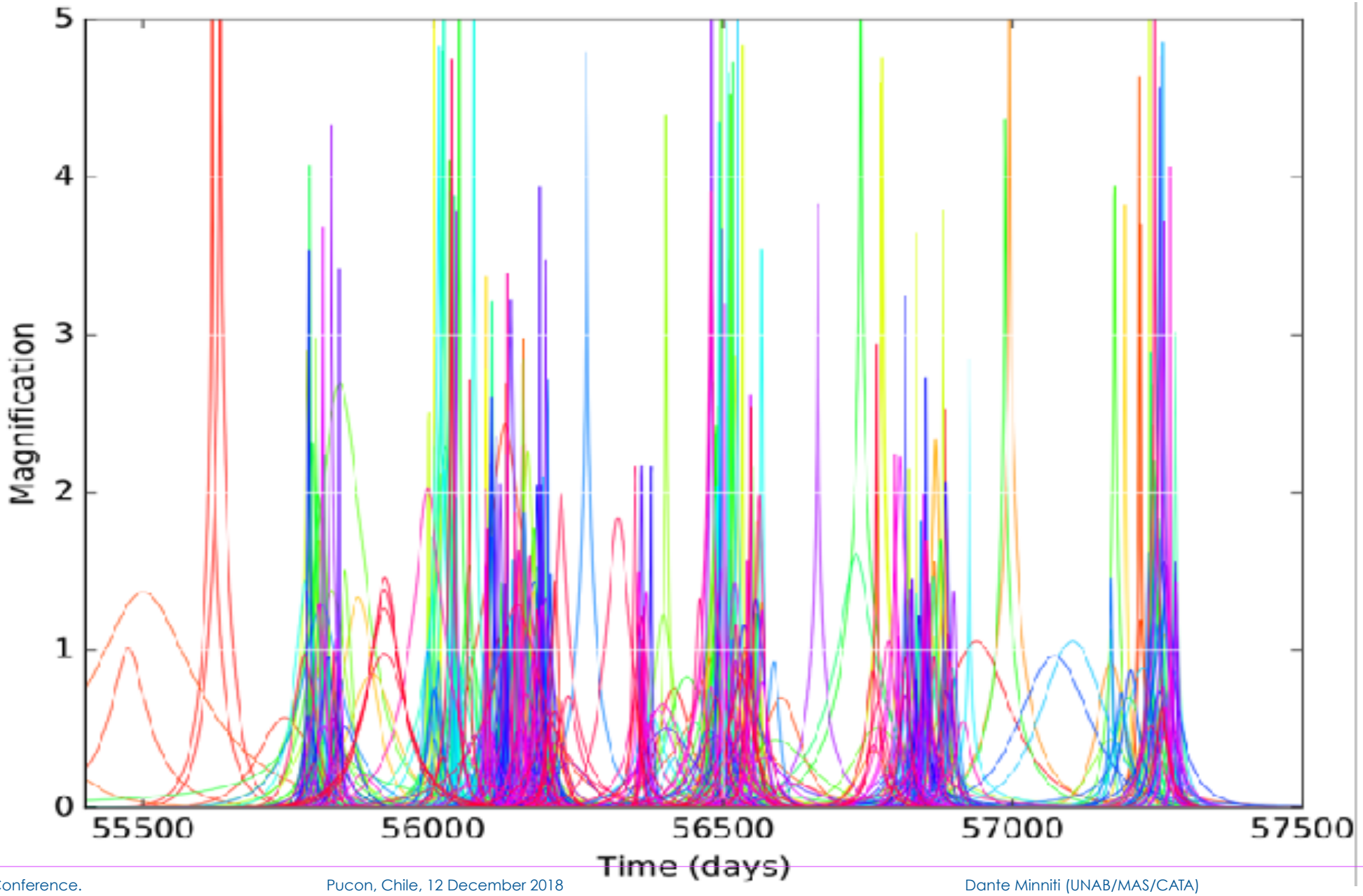


See talk by Gabriela Navarro

Microlensing

Microlensing events

G. Navarro et al. 2016 ApJL,
G. Navarro et al. 2017 ApJL,
G. Navarro et al. 2018 ApJ submitted



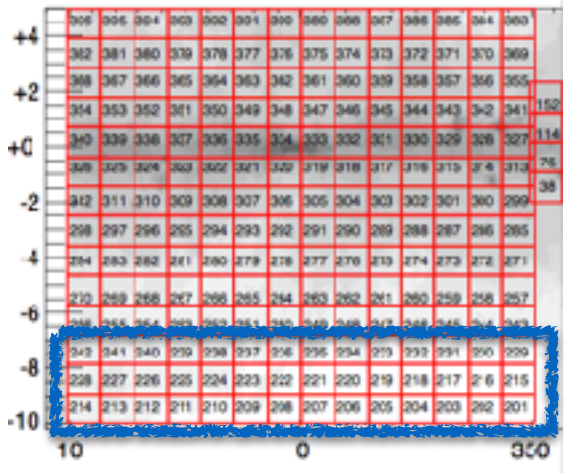
see talk by V. Braga

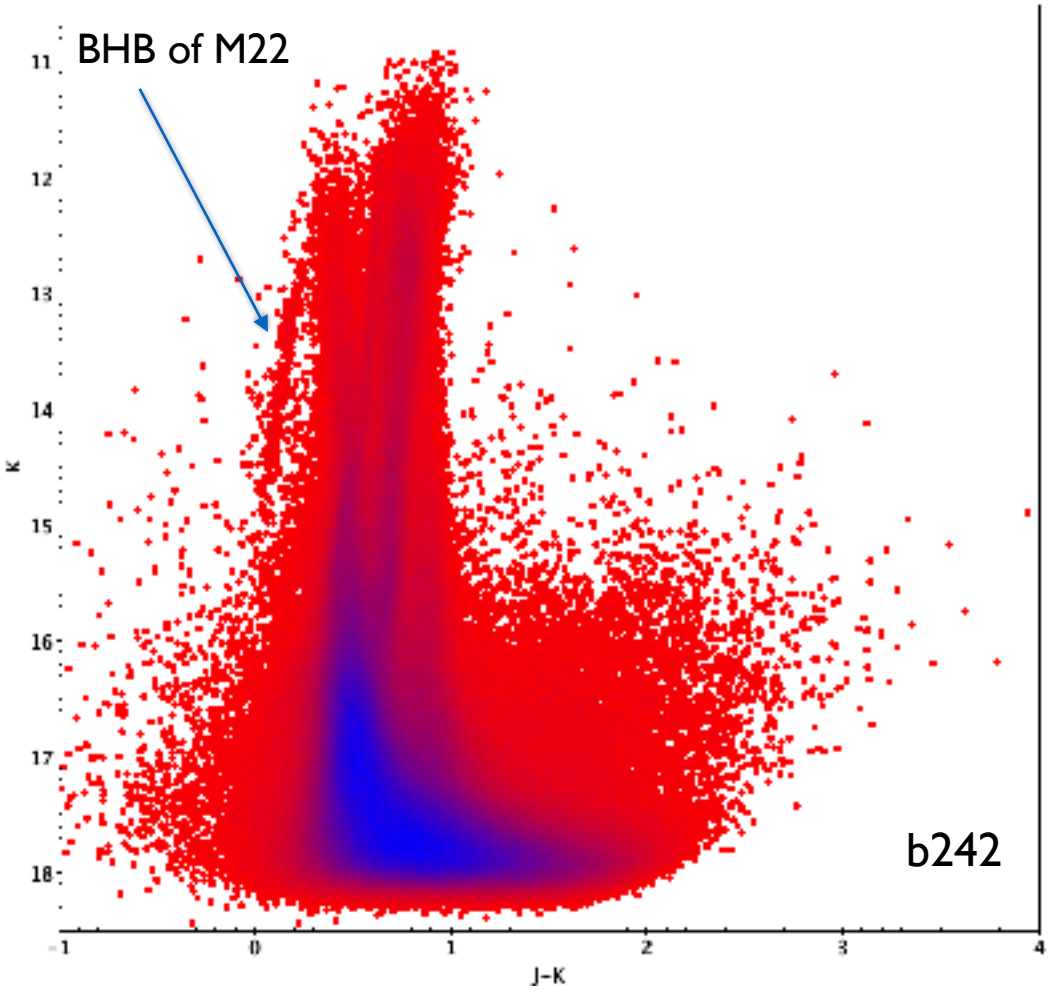
Miras and LPVs

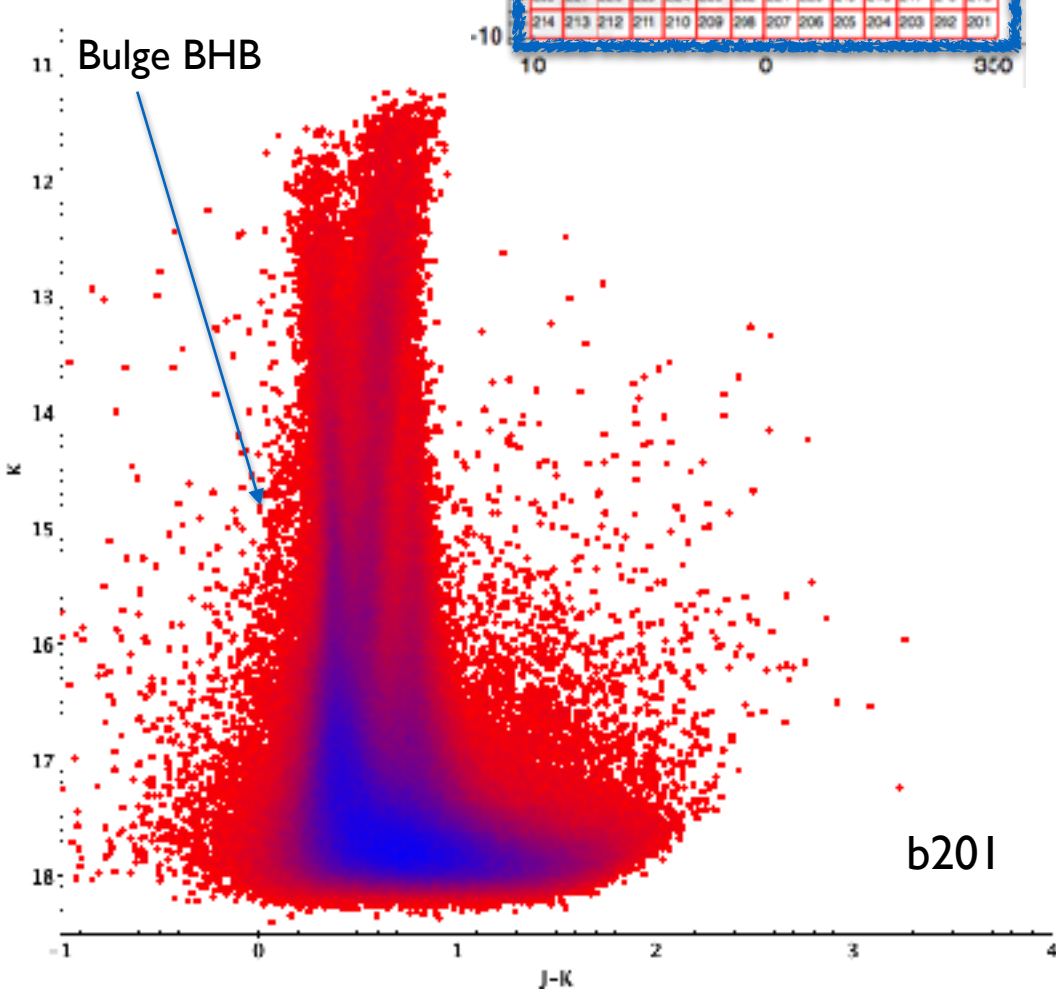
K. Montenegro et al. 2018
see poster by L. Gramajo

Eclipsing BinarieS

Bulge BHB star selection from deep VVV bulge photometry by Javier Alonso-García

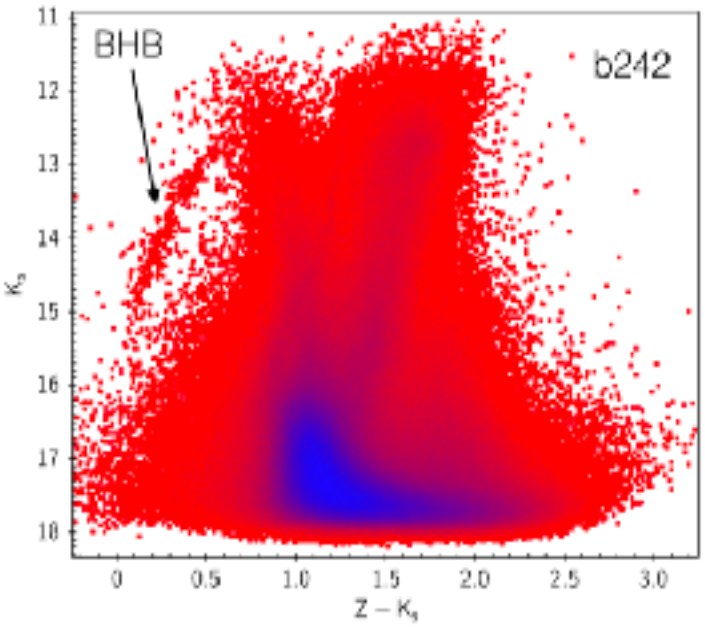


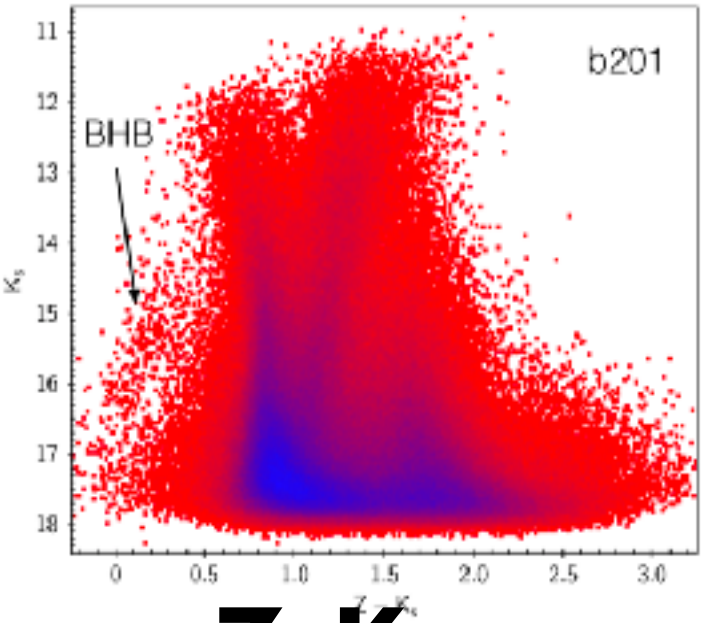




J-Ks

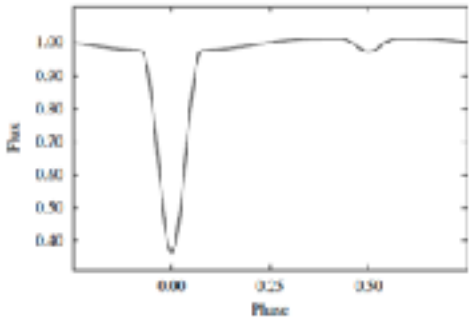
EBs among bulge BHB stars
K. Montenegro et al. 2018 ApJ

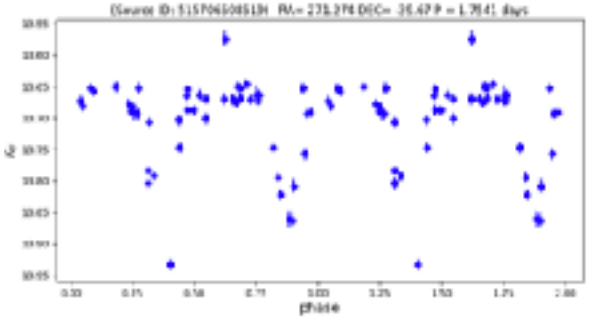




Z-Ks

- EA (Algols): This type of eclipsing binary exhibits a flat light-curve in the regions where we cannot see eclipses, because they have spherical or slightly ellipsoidal components. From inspection of the light-curve it is possible to clearly see the beginning and end of the eclipses, although the secondary eclipse may be less visible.

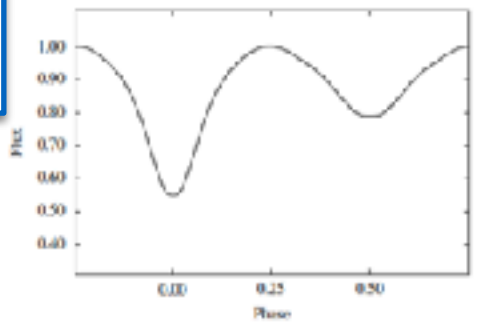




gure 13. EA eclipsing binaries. A synthetic light-curve tained from ?) in the top panel can be compared with of our EA light-curves shown in the bottom panel.

- EB (β Lyrae): The light-curve is continuously variable, with a large difference in the depths of the eclipses due to their components being ellipsoidal. The secondary eclipse is always clearly observed.

- EW (W Ursae Majoris): The ellipsoidal compo- [illegible] in contact, and present very similar eclipses. They have a light-curve that is contin-



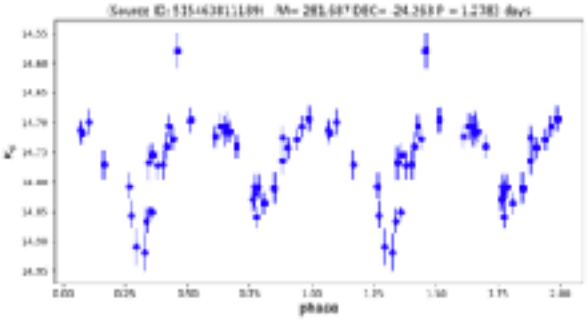
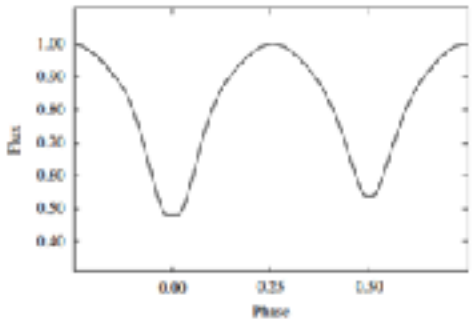
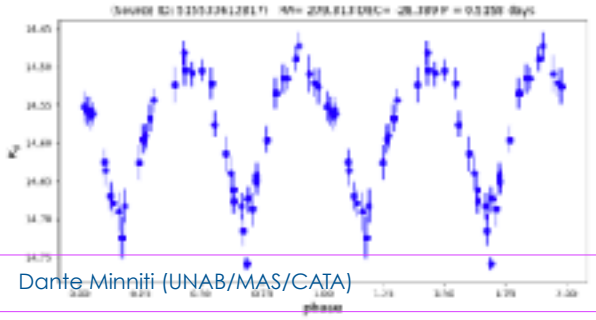


Figure 14. EB eclipsing binaries. A synthetic light-curve (obtained from ?) in the top panel can be compared with one of our EB light-curves in the bottom panel.





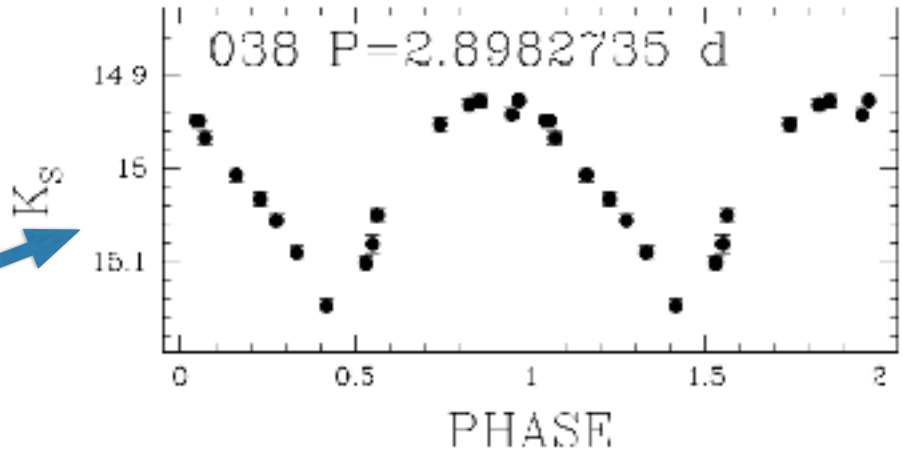
see talk by J. Minniti, A. Bhardwaj

VVV Classical Cepheids

Galactic structure,
stellar evolution,
star clusters,
…

Classical Cepheids

- Classical Cepheids are pulsating variable stars.
- They have 1.0<P<200 days
- Their characteristic periods and light curves make them easy to identify.
- They represent a very young and metal-rich population.
- They are present in young open clusters.
- They follow a P-L relation
- They are primary distance indicators.



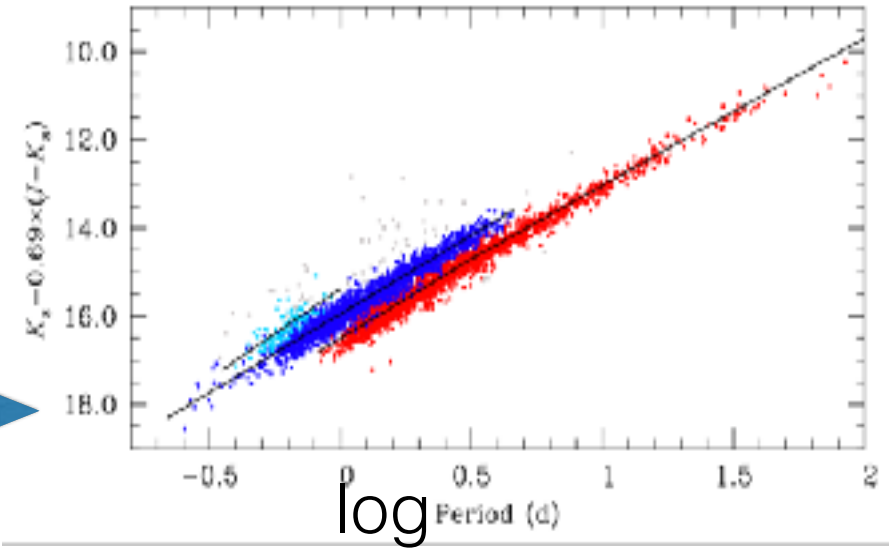


Figure credit Ripepi/Cioni/Moretti 2017

Three Classical Cepheids in the Galactic Bulge
Noriyuki Matsunaga, et al., Nature 2016

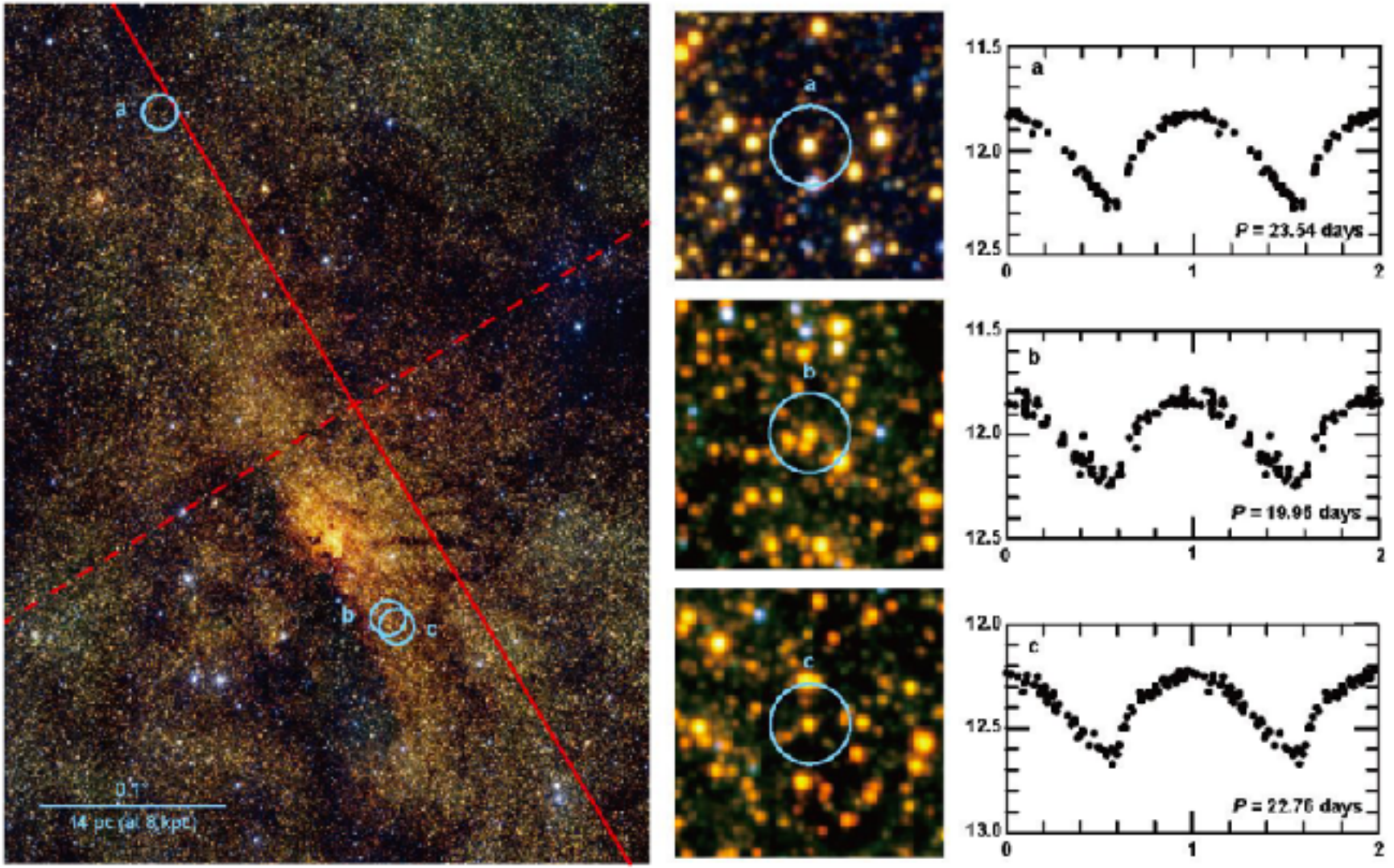
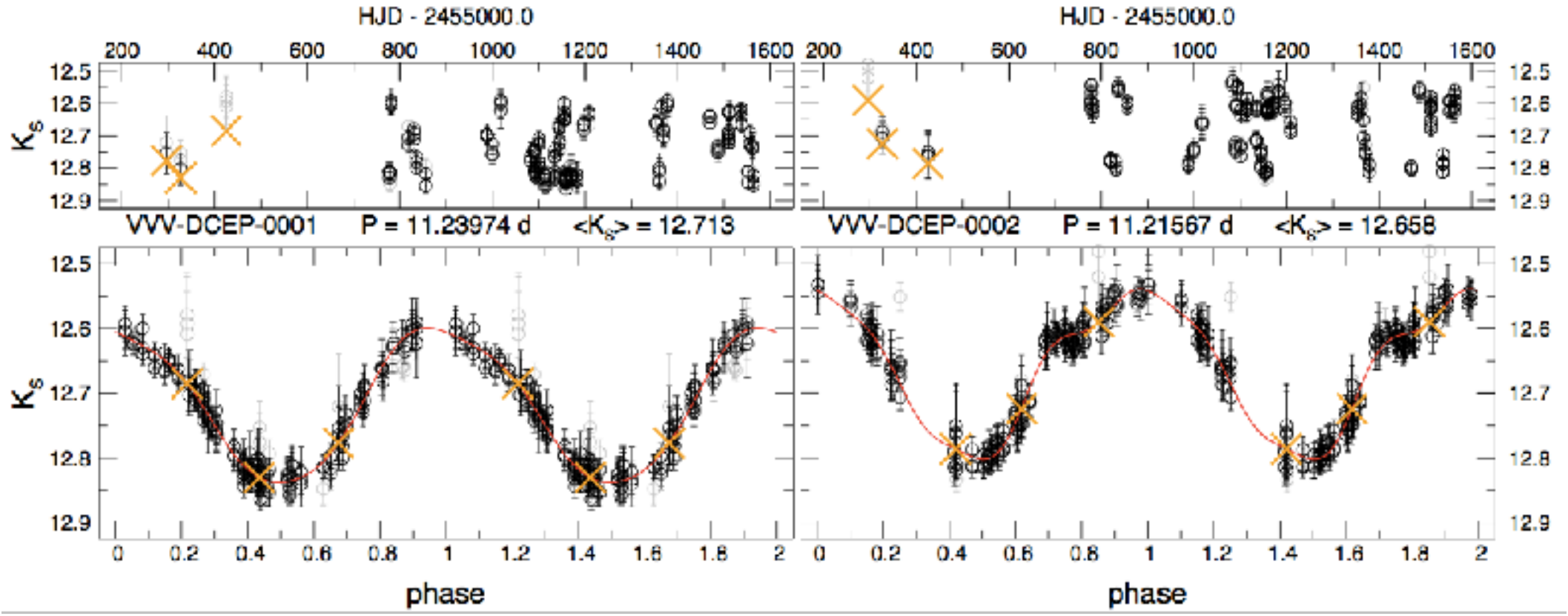


Figure1 | The classical Cepheids discovered in the nuclear bulge.

VVV Cepheids

Cepheids in the Inner Bulge

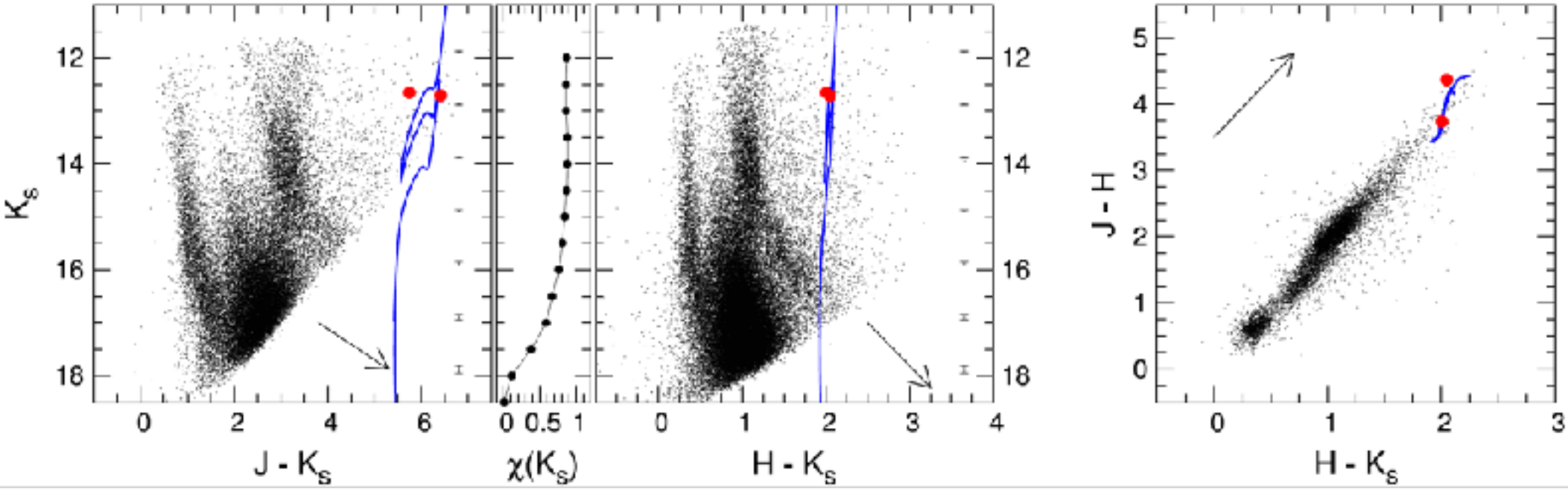
Star	α [hms]	δ [dms]	l [deg]	b [deg]	period [d]
C1	18:01:24.49	-22:54:44.6	6.99047	0.00055	11.23974
C2	18:01:25.09	-22:54:28.3	6.99555	0.00079	11.21567



The VVV Survey reveals a couple of classical Cepheids that trace a young and massive stellar cluster located behind the Galactic bulge.

Cepheids in the Inner Bulge

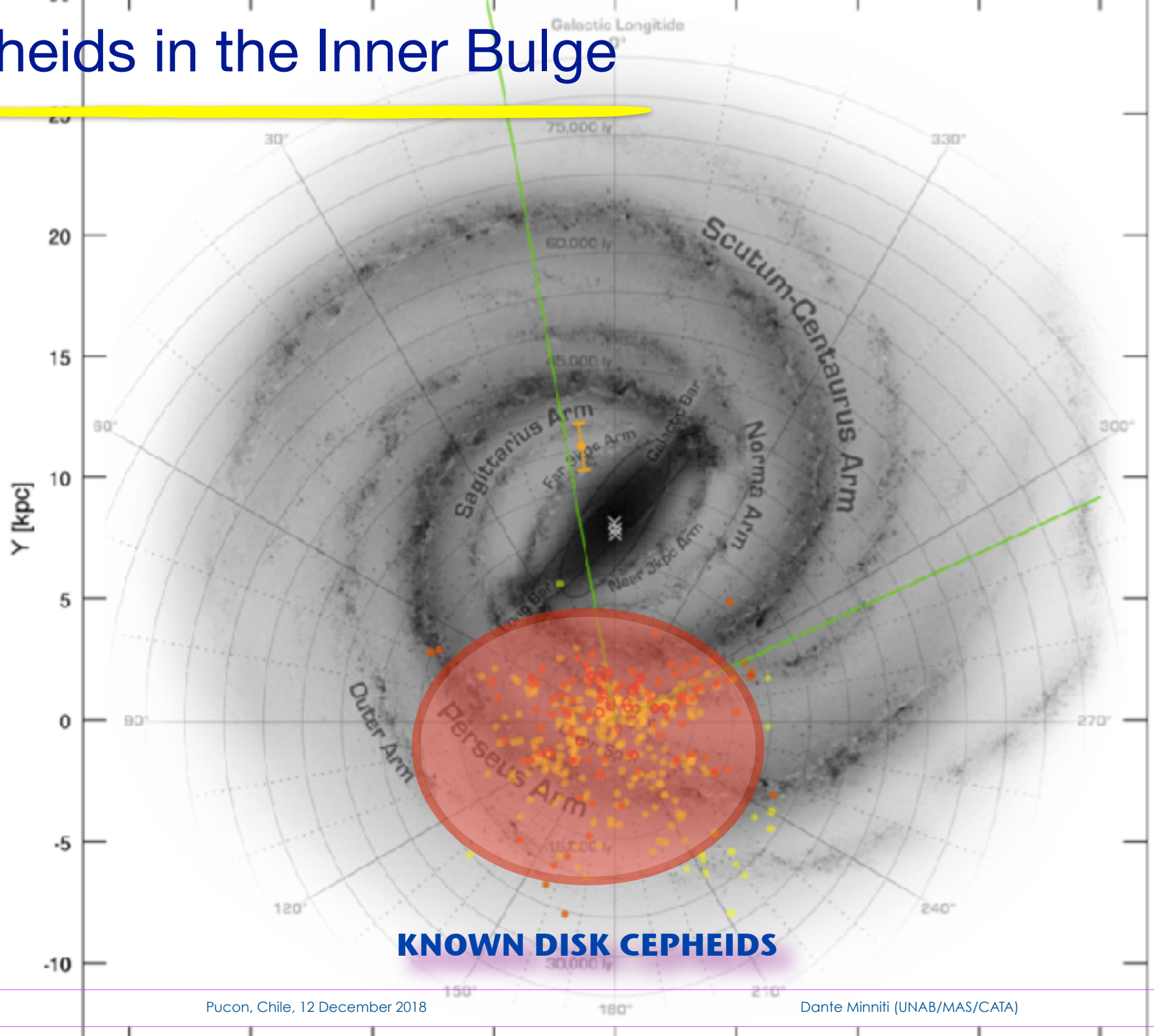
Star	α [hms]	δ [dms]	l [deg]	b [deg]	period [d]
C1	18:01:24.49	-22:54:44.6	6.99047	0.00055	11.23974
C2	18:01:25.09	-22:54:28.3	6.99555	0.00079	11.21567



The VVV Survey reveals a couple of classical Cepheids that trace a young and massive stellar cluster located behind the Galactic bulge.

Dekany et al. 2015 ApJL

Cepheids in the Inner Bulge

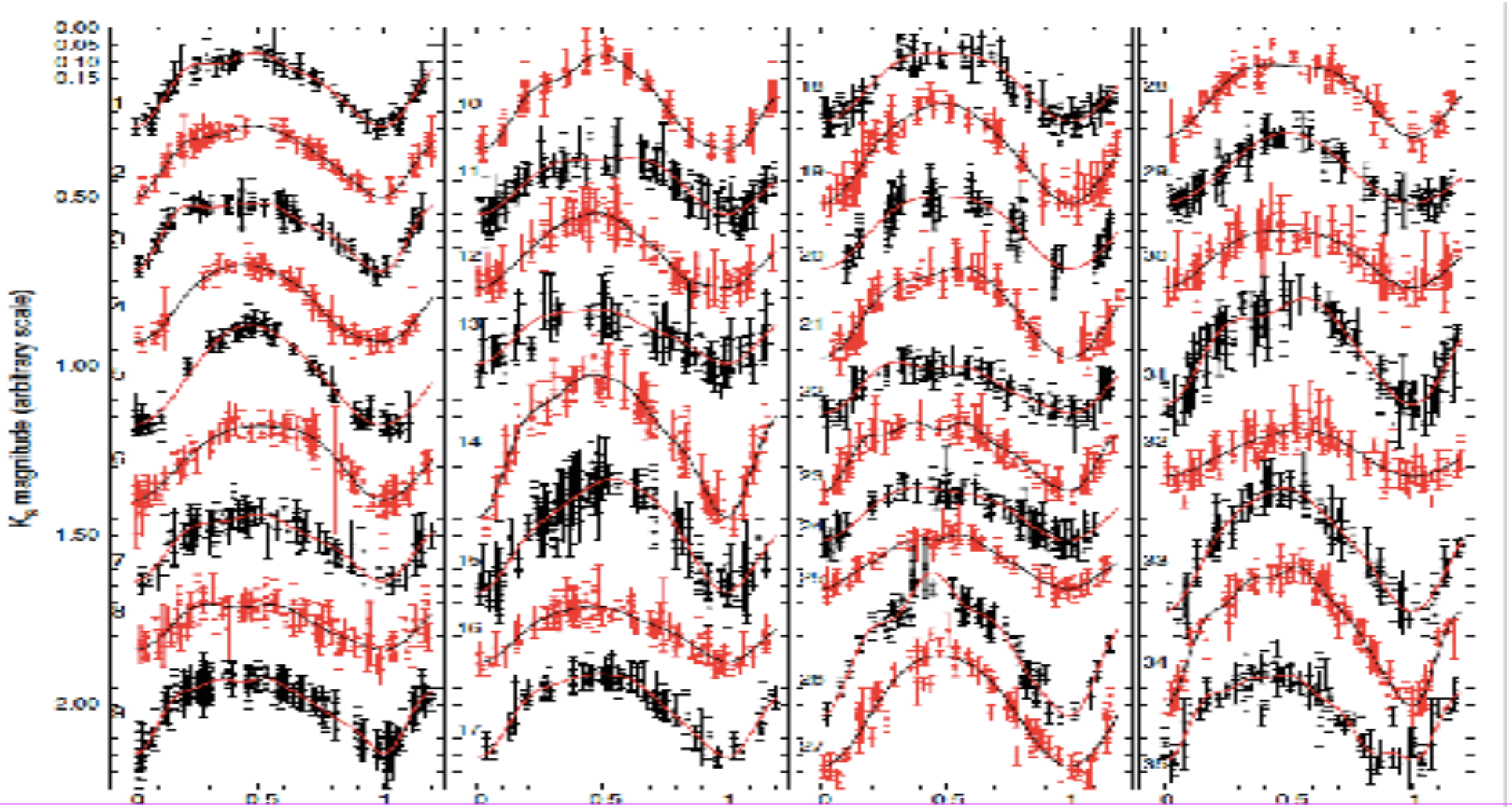


Cepheids in the Inner Bulge

Dekany et al. 2015 ApJL (arXiv:1509.08402)

Main problem:

To separate Classical Cepheids from Type 2 Cepheids



see talks by V. Braga, A. Bhardwaj, G. Hagdu

Type 2 Cepheids

Classical Cepheids

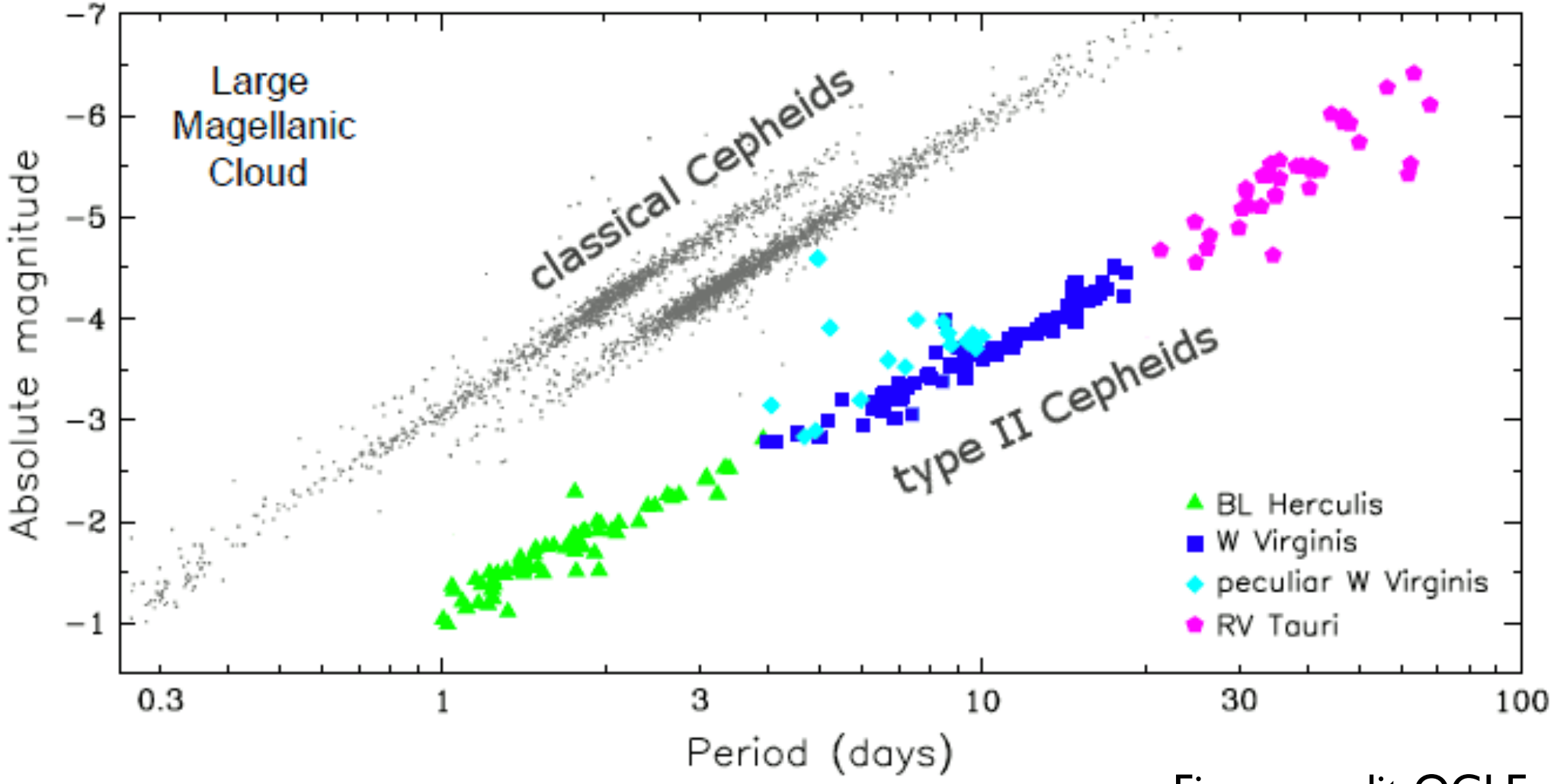
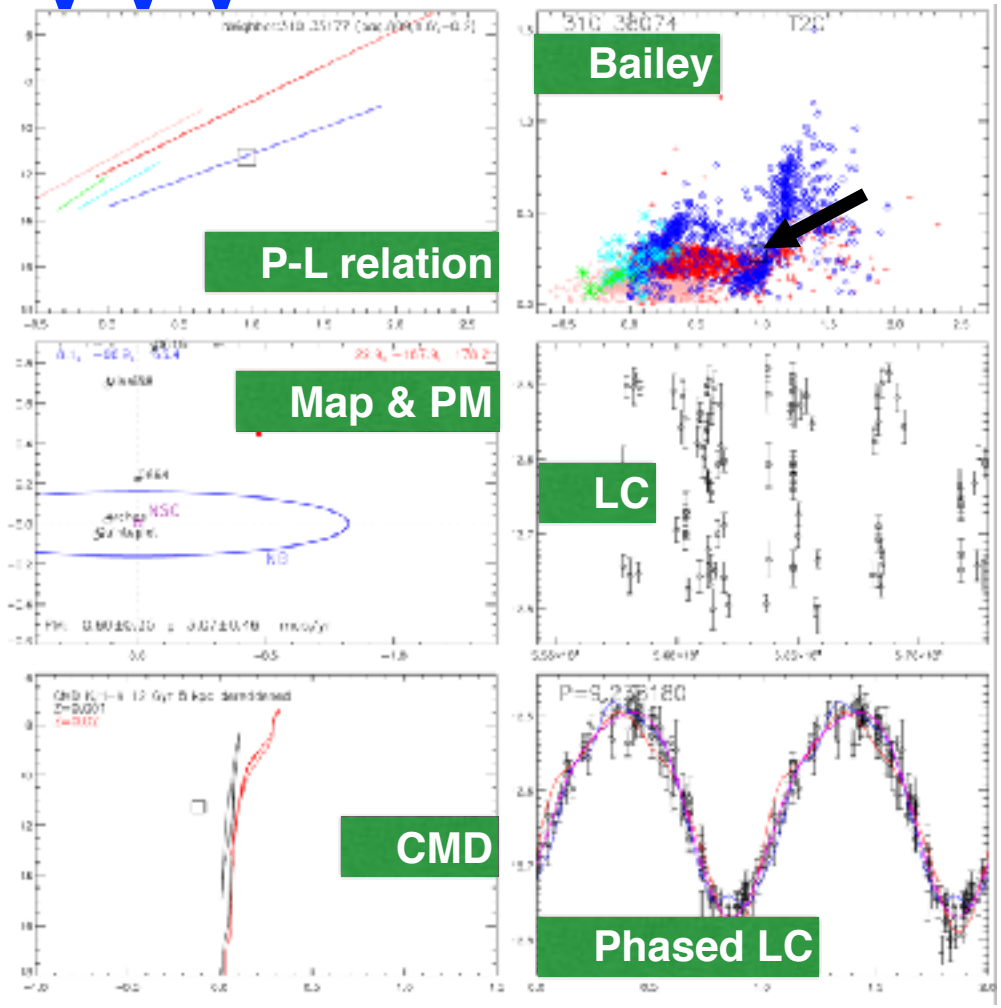


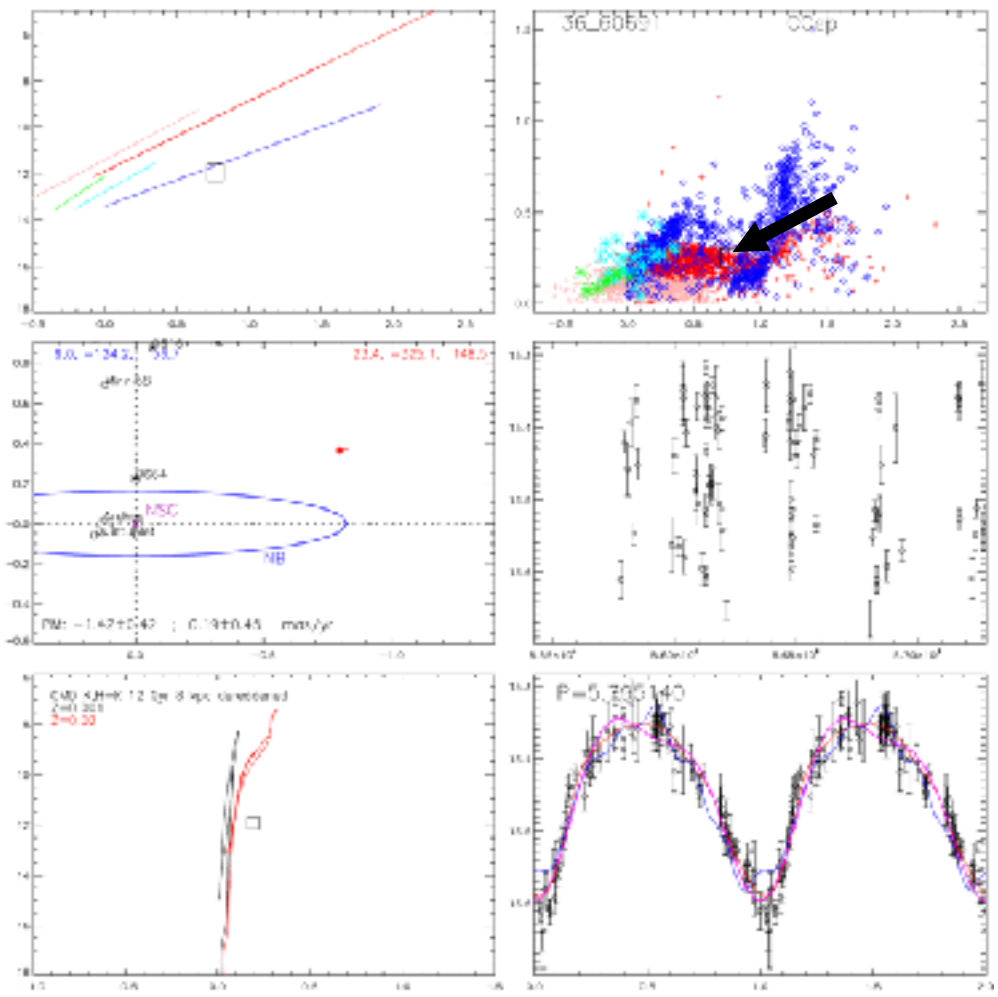
Figure credit OGLE

VVV

Type 2 Cepheid

Classical Cepheid

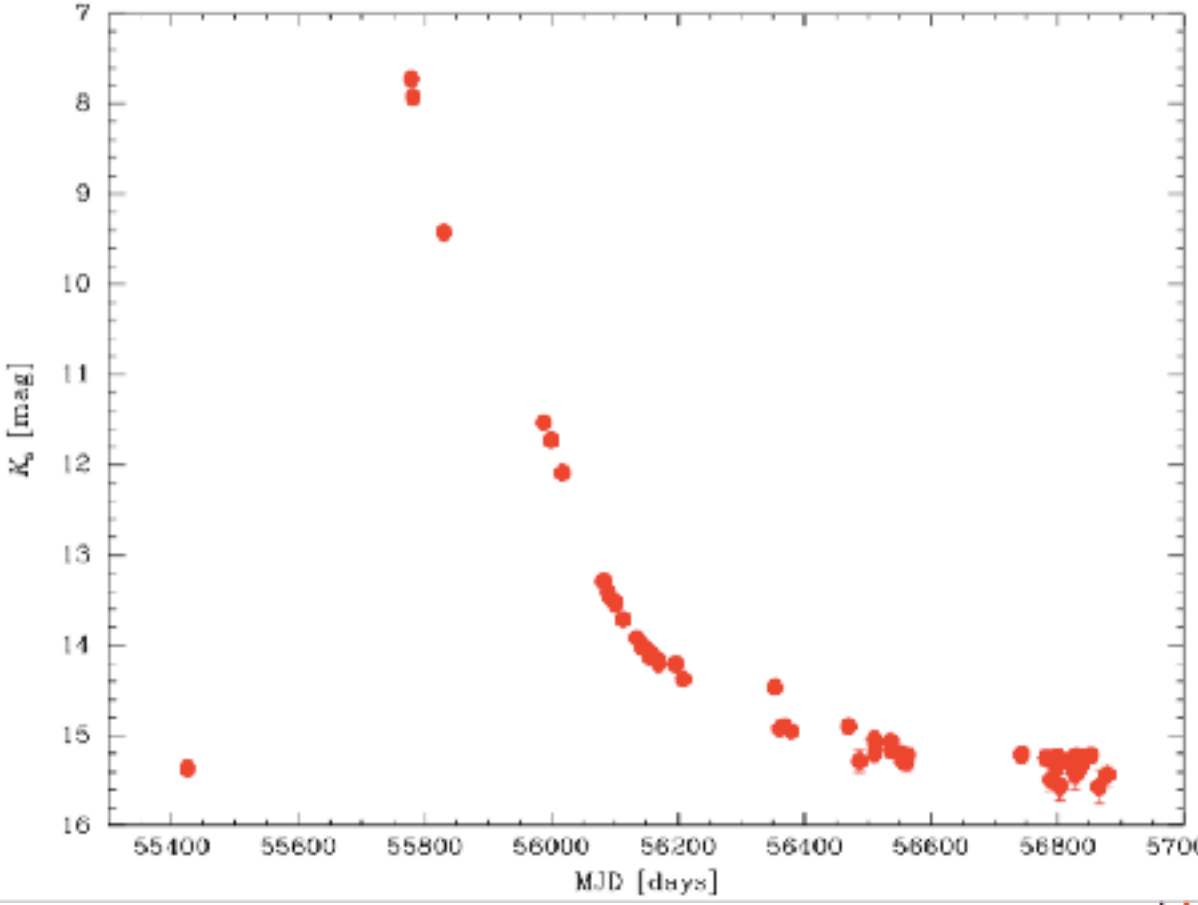




slide credit: Vittorio Braga

Novae

VVV NOVA Hunters



The Astronomer's Telegram

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6 Apr 2015; 02:19 UT

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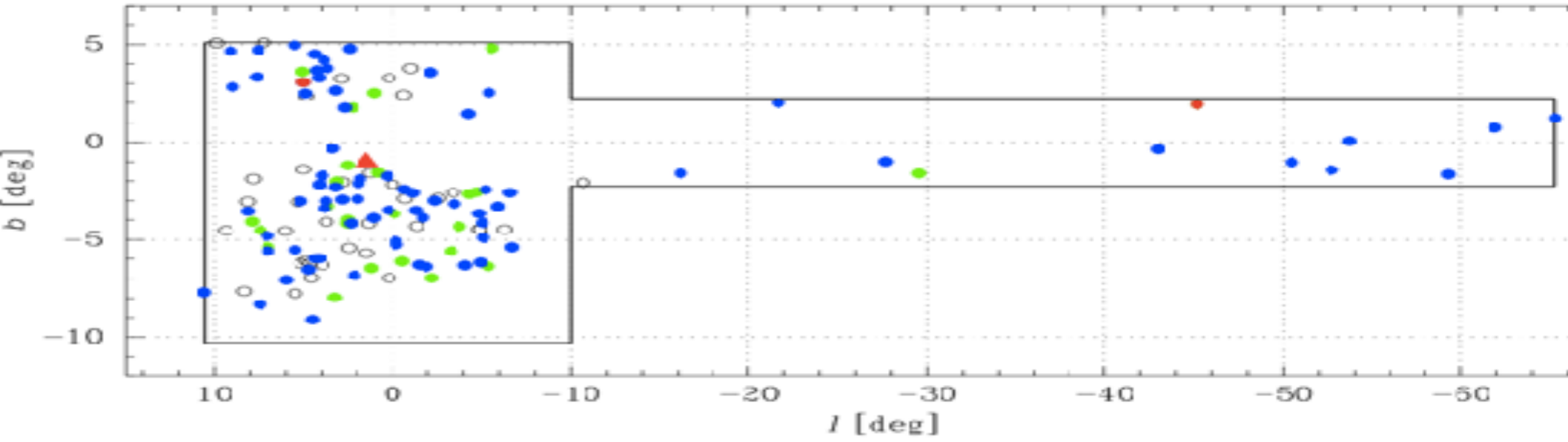
VVV-NOV-006: the sixth Galactic nova candidate discovered by the VVV Survey

ATel #7241; *K. Montenegro (Universidad Andres Bello), D. Minniti (Universidad Andres Bello, Vatican Observatory, Millennium Institute of Astrophysics), R. K. Saito (Universidade Federal de Sergipe)*

on 17 Mar 2015; 21:46 UT

VVV NOVA Hunters

Catalog of 138 Known Galactic Novae *Roberto Saito et al. A&A, 2013*



Spatial distribution of known Galactic novae in the VVV area.
They avoid the Galactic plane, where the extinction is highest.
We are discovering novae in the most obscured regions of the Milky Way.

N(VVVNovae) = 20 so far.

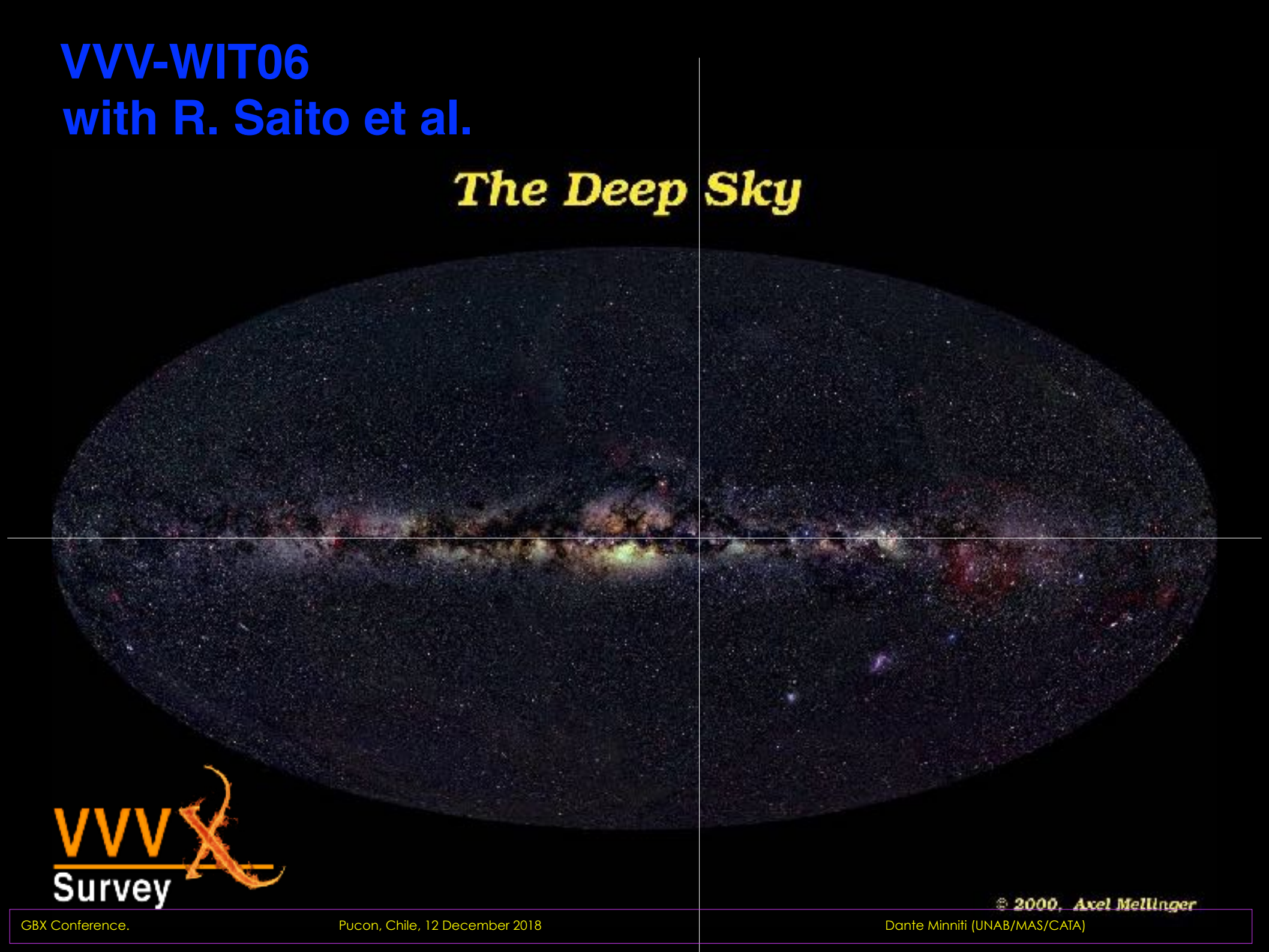
Roberto Saito, Nicola Masetti, Rodrigo Contreras Ramos, Daniel Majaess, Valentin Ivanov, Giuliano Pignata, Marina Rejkuba et al.

Transients/ Serendipity

WIT (What is This?)

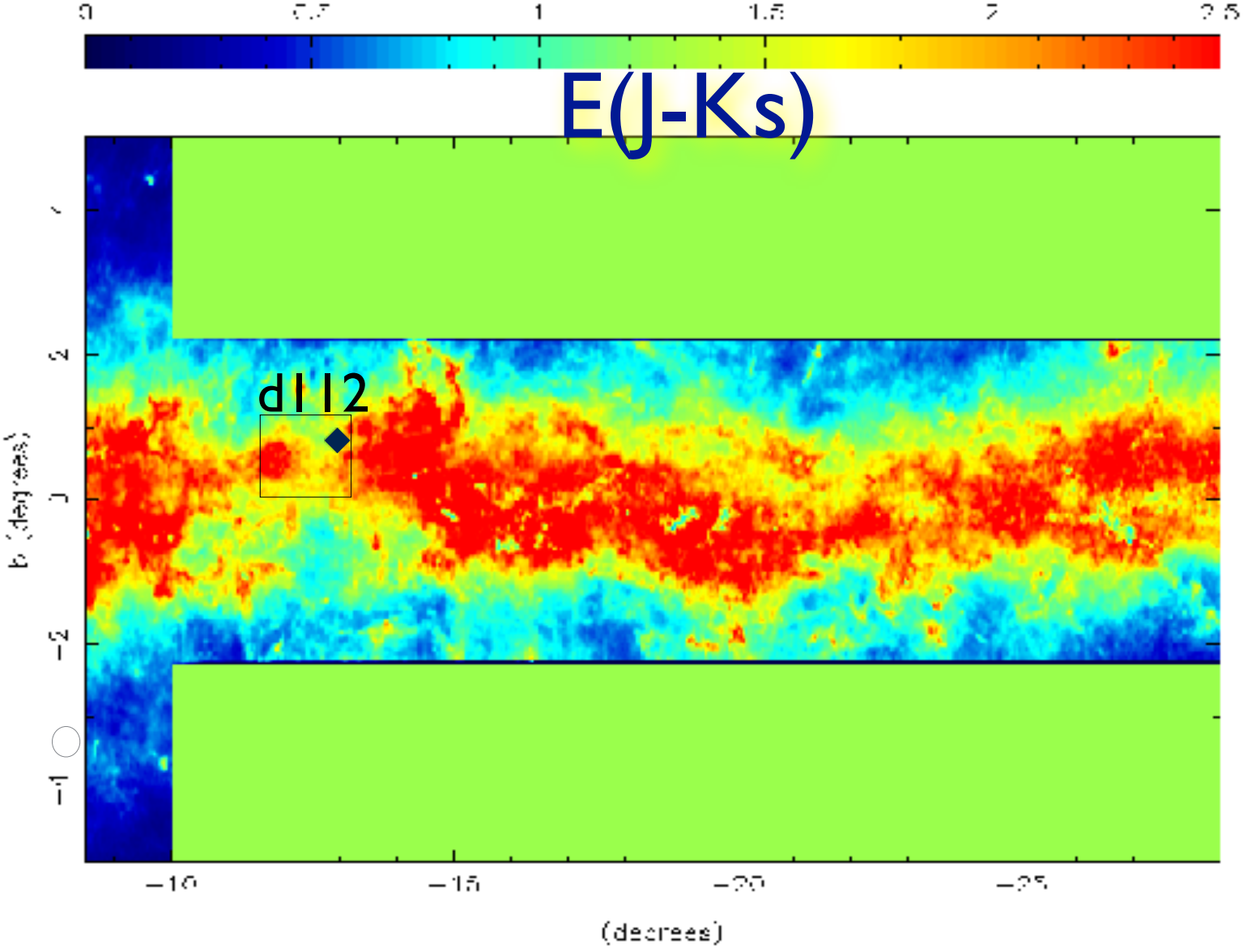
WIT (What is This?)

VVV-WIT06
with R. Saito et al.

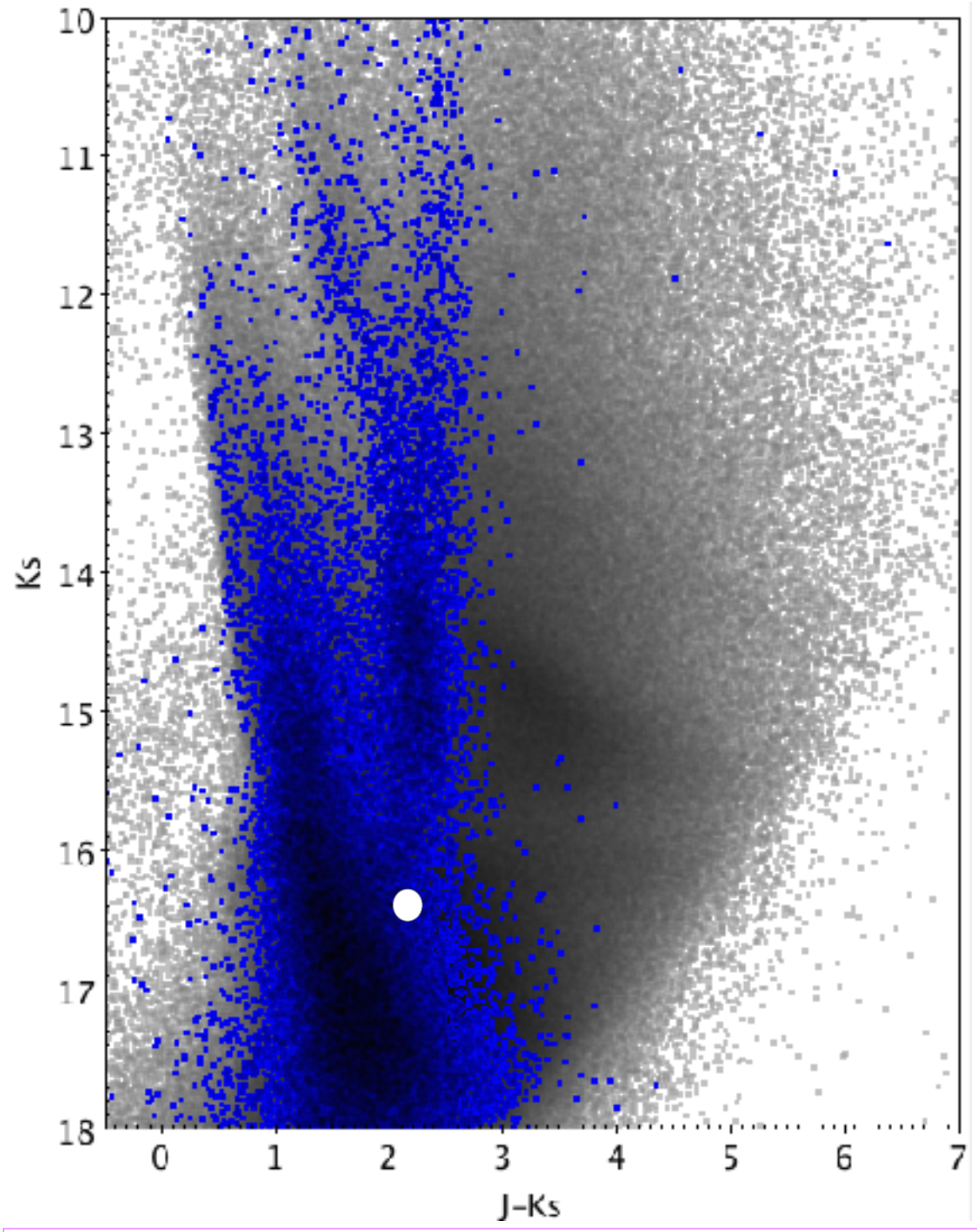


VVV Survey

VVV-WIT06
with R. Saito et al.



M. Irwin Reddening Map



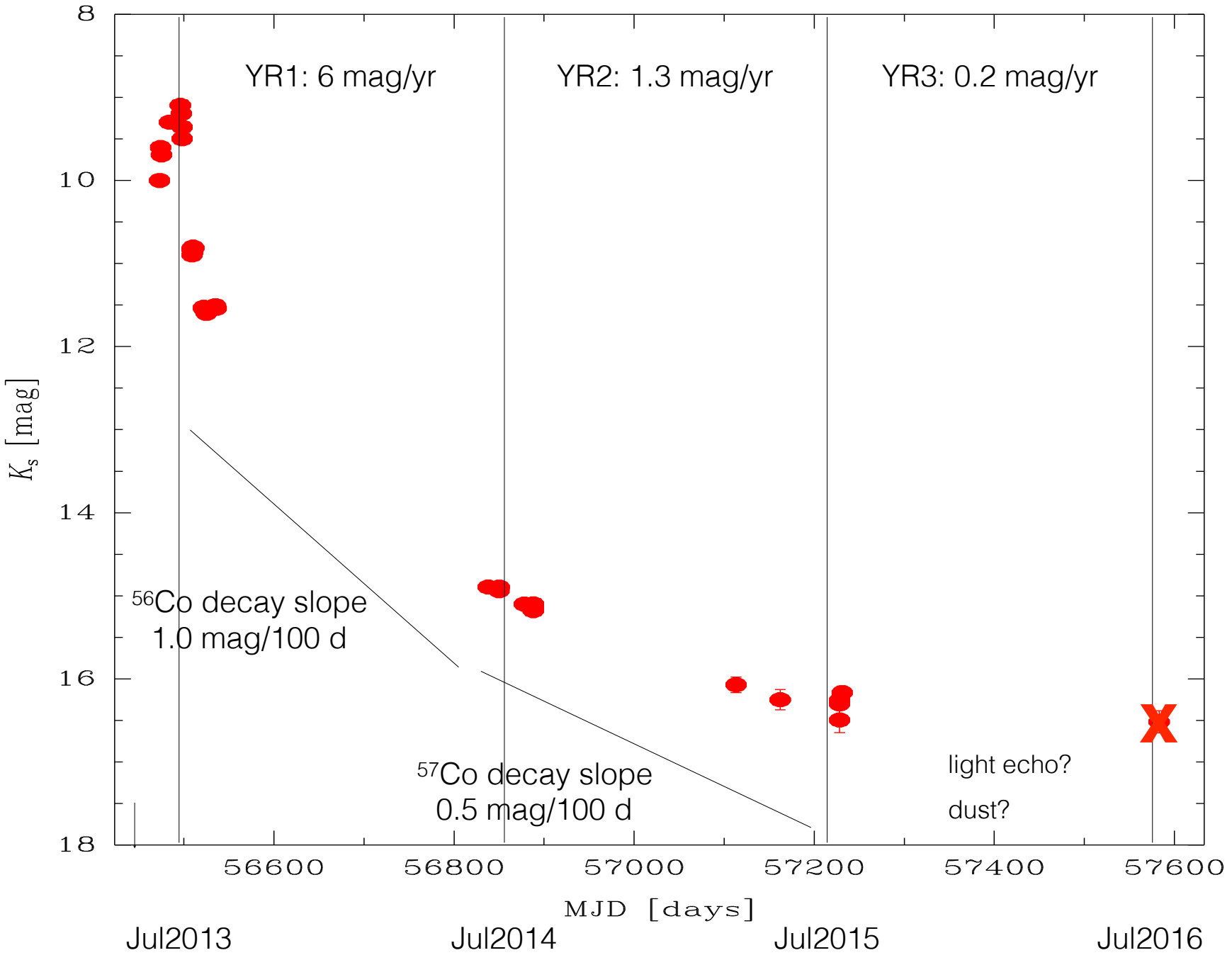
VVV-WIT06

Deep CMD

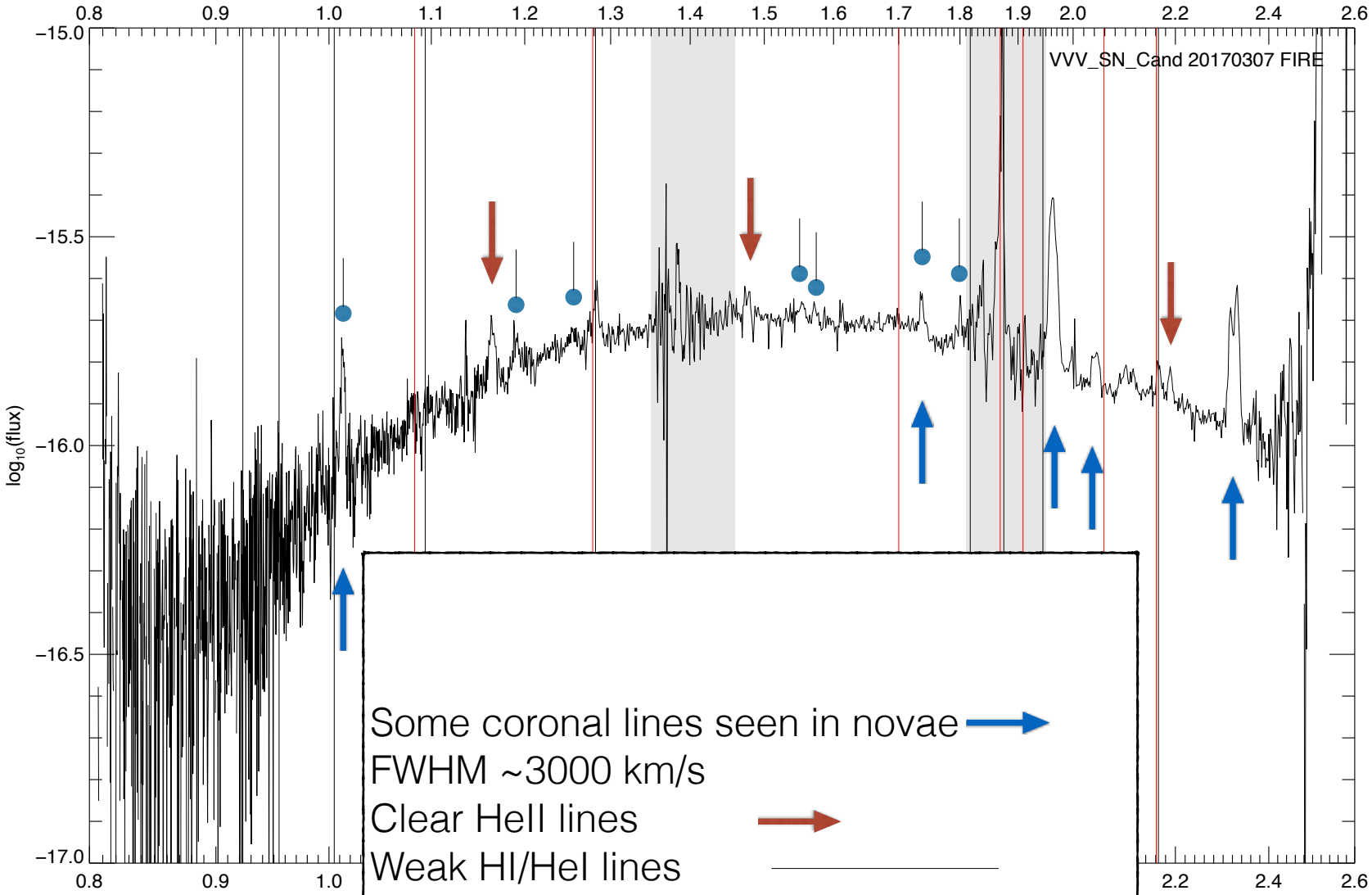
(Francisco Surot/
Elena Valenti)

VVV tile d112
1.5 sqdeg
(grey)

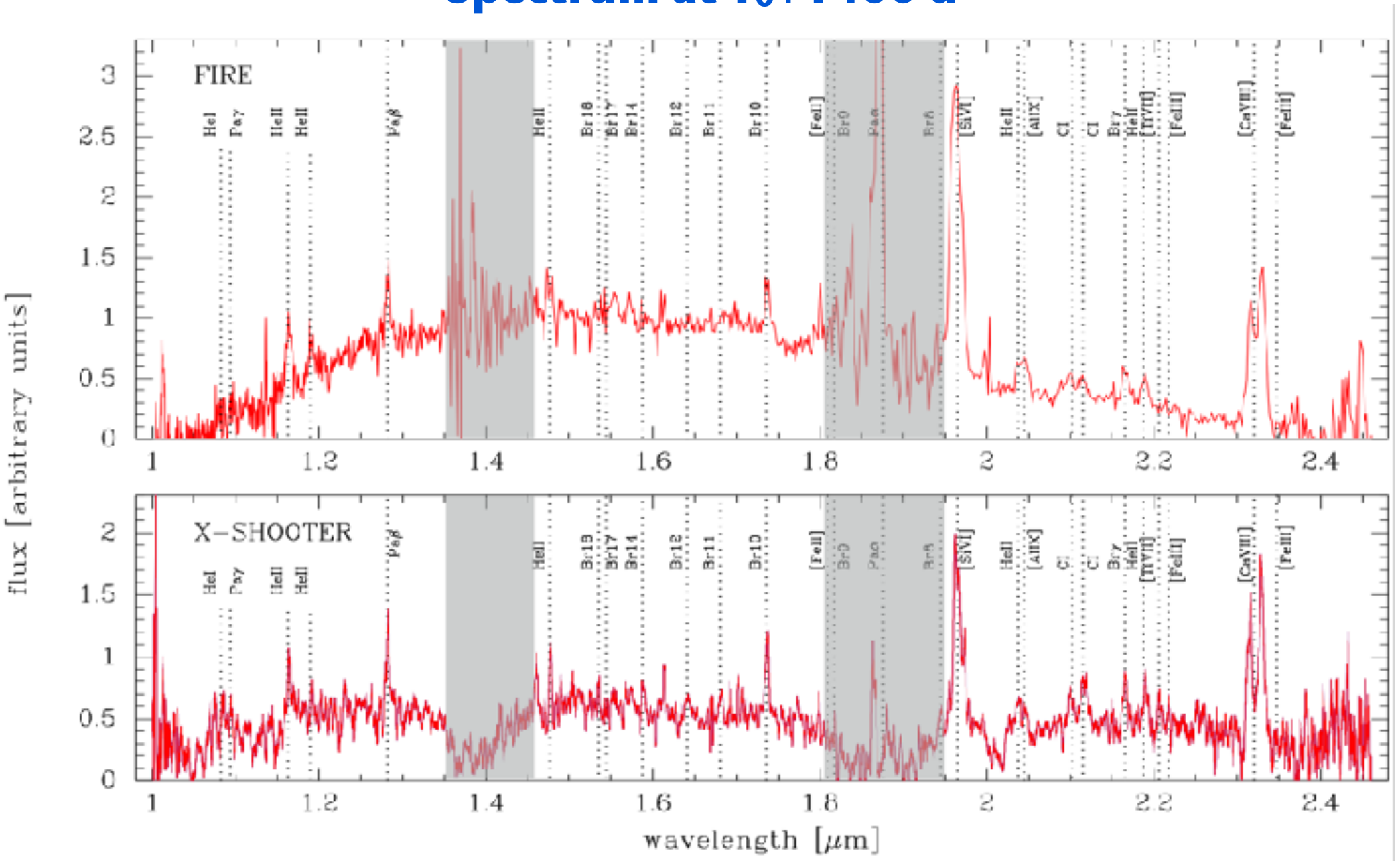
VVV-WIT06
5´x5´
(blue)


YR1: 6 mag/yr
YR2: 1.3 mag/yr
YR3: 0.2 mag/yr
^{56}Co decay slope
1.0 mag/100 d
^{57}Co decay slope
0.5 mag/100 d
light echo?
dust?
K_s [mag]
MJD [days]
Jul2013
Jul2014
Jul2015
Jul2016

Magellan FIRE Near-IR Spectrum at T_0+1350 d

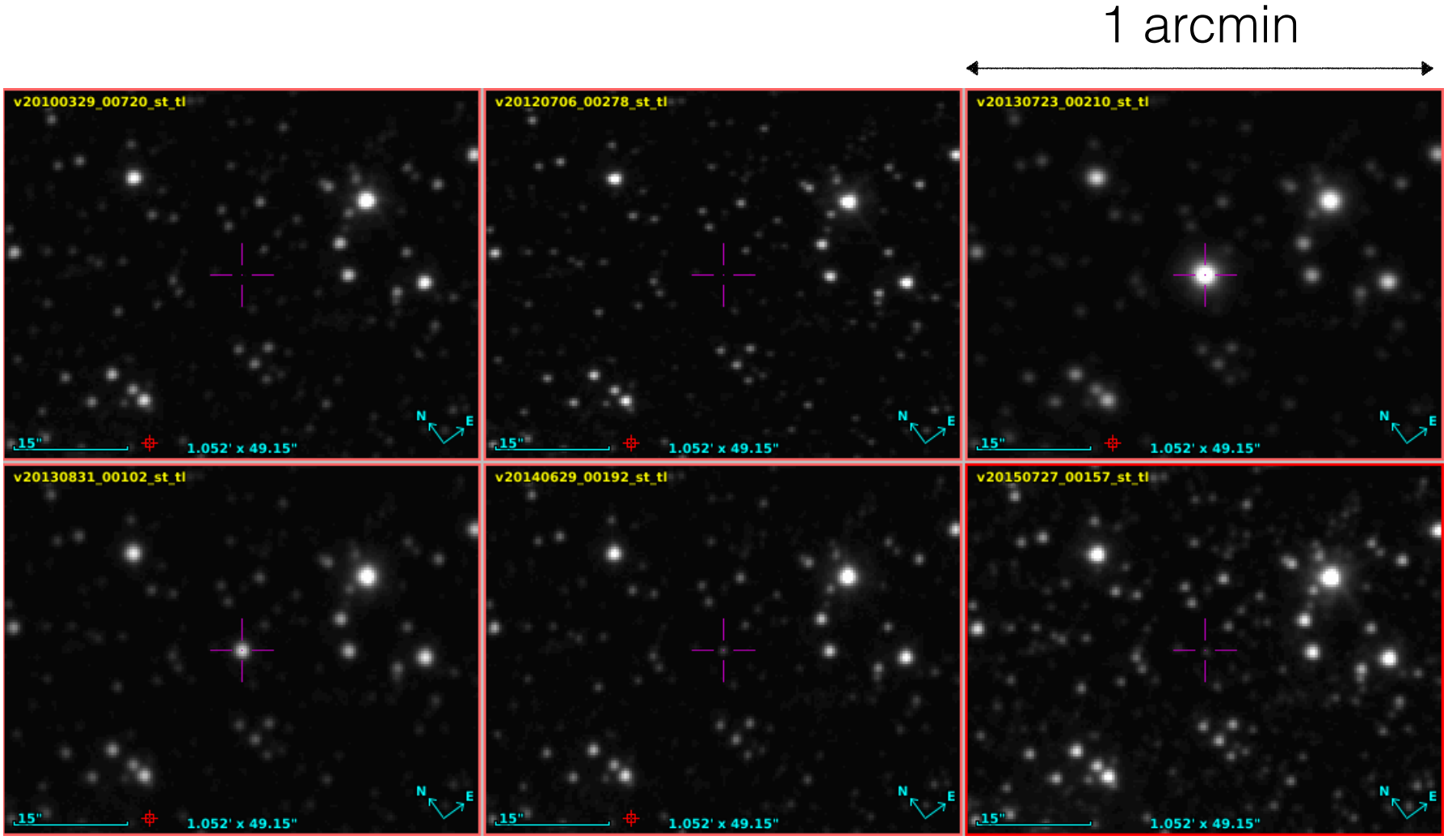


VLT XSHOOTER Near-IR Spectrum at T_0+1400 d



VVV-WIT06:

A Galactic SN, a Nova, or a Stellar Merger ???



D. Minniti, et al. 2017, ApJL

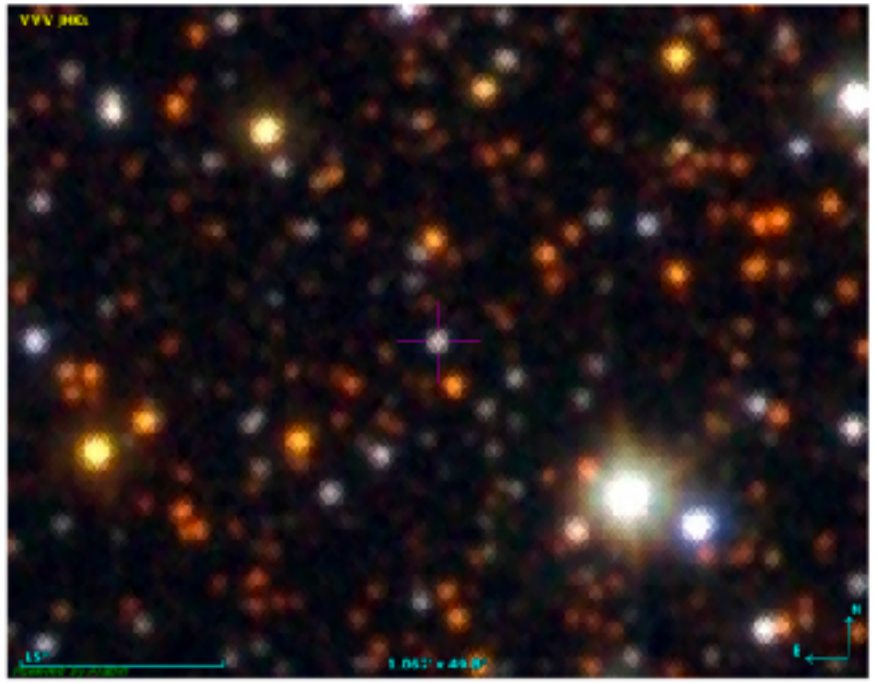
Big data

How to find the needle in the haystack?

VVV-WIT-07: another Boyajian's star or a Mamajek's object?

R. Saito et al.

MNRAS 2018



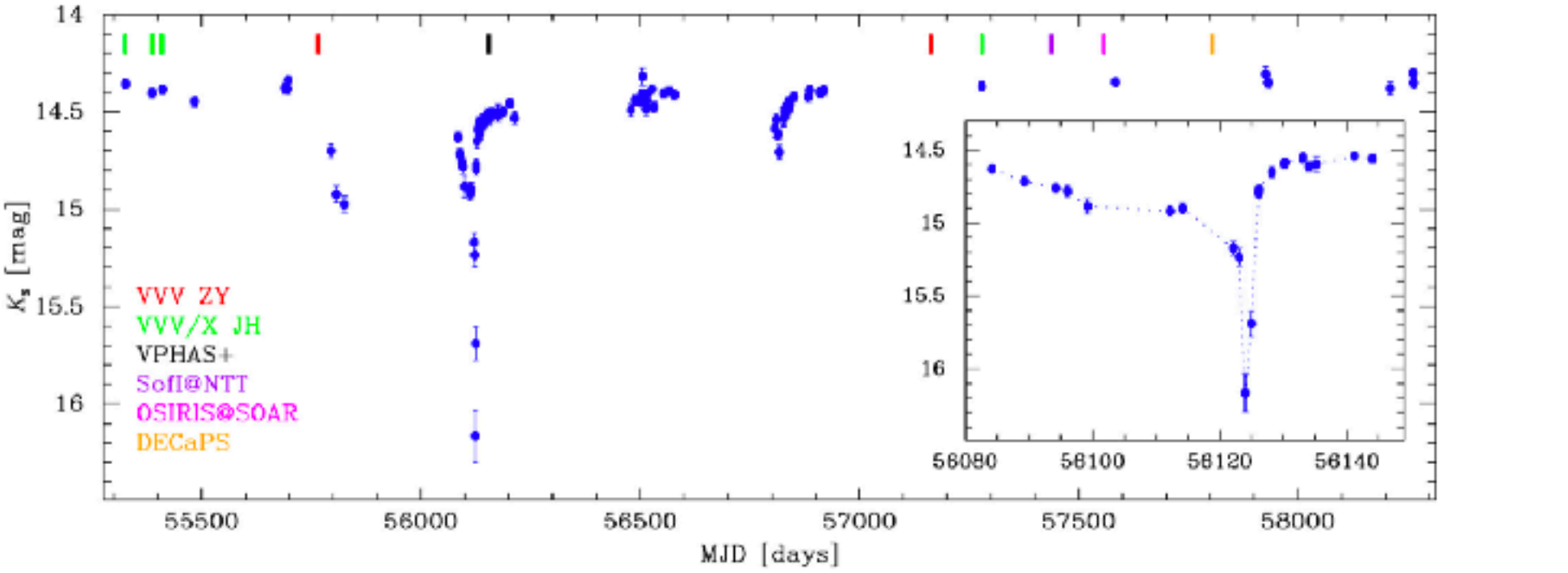
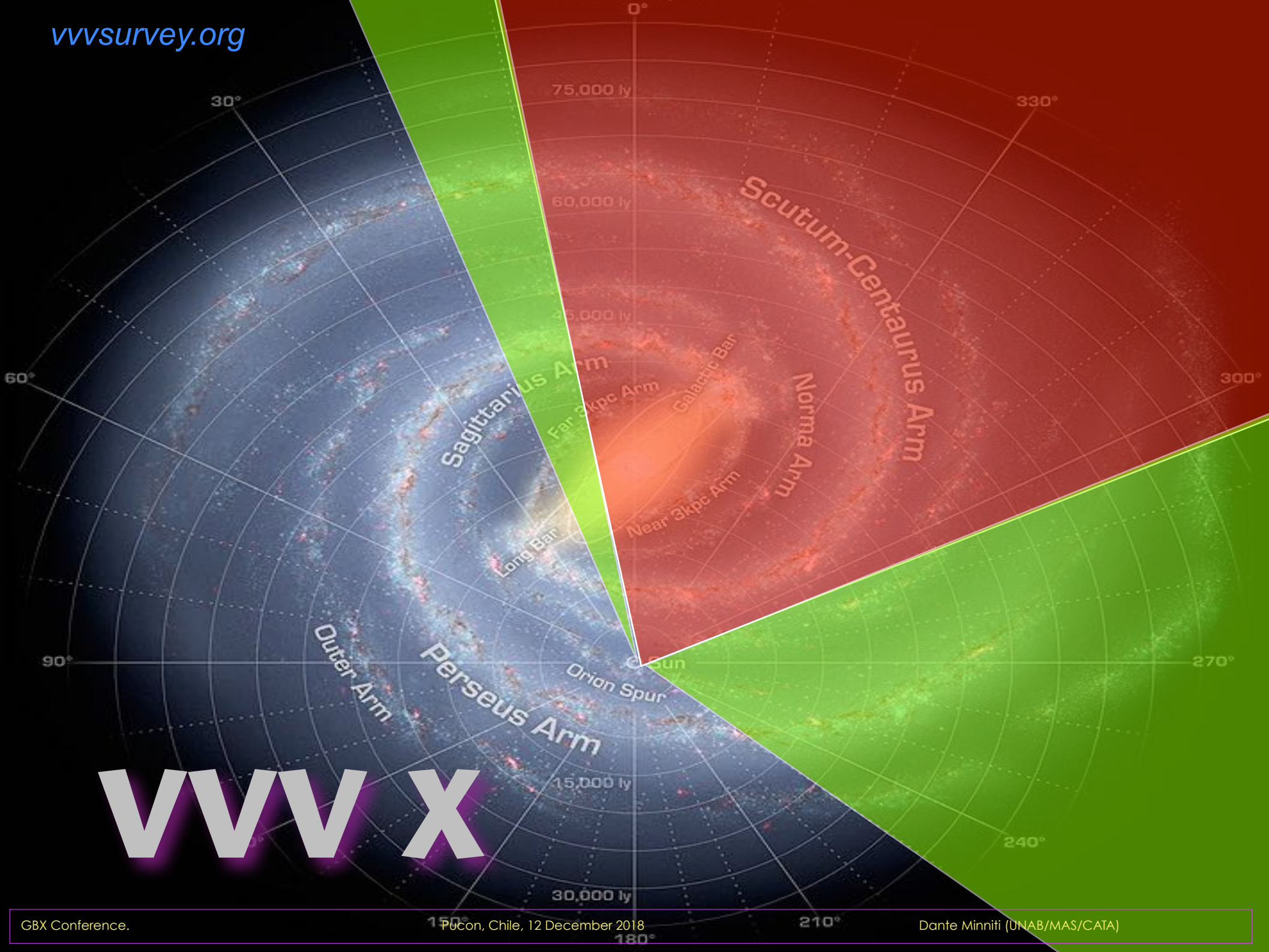


Figure 2. VVV K_s-band light curve of VVV-WIT-007. There is a total of 85 data points covering the 2010–2018 seasons, including data from the VVVX

vvvsurvey.org

archive.eso.org


vvvsurvey.org
0°
30°
330°
60°
300°
90°
270°
240°
210°
180°
150°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Norma Arm
Galactic Bar
Near 3kpc Arm
Far 3kpc Arm
Sagittarius Arm
Long Bar
Outer Arm
Perseus Arm
Orion Spur
Sun
VVV X

The VVV Extended Survey

Total Area 1700 sqdeg
Total Time 2000 hs

>50% of the MW

VVV X

Near-IR variability of the bulge stellar population

Wish List

gaia

Wish List

Gaia DR3

LSST Galactic plane/bulge survey

JWST census of Galactic Center RRLyrae

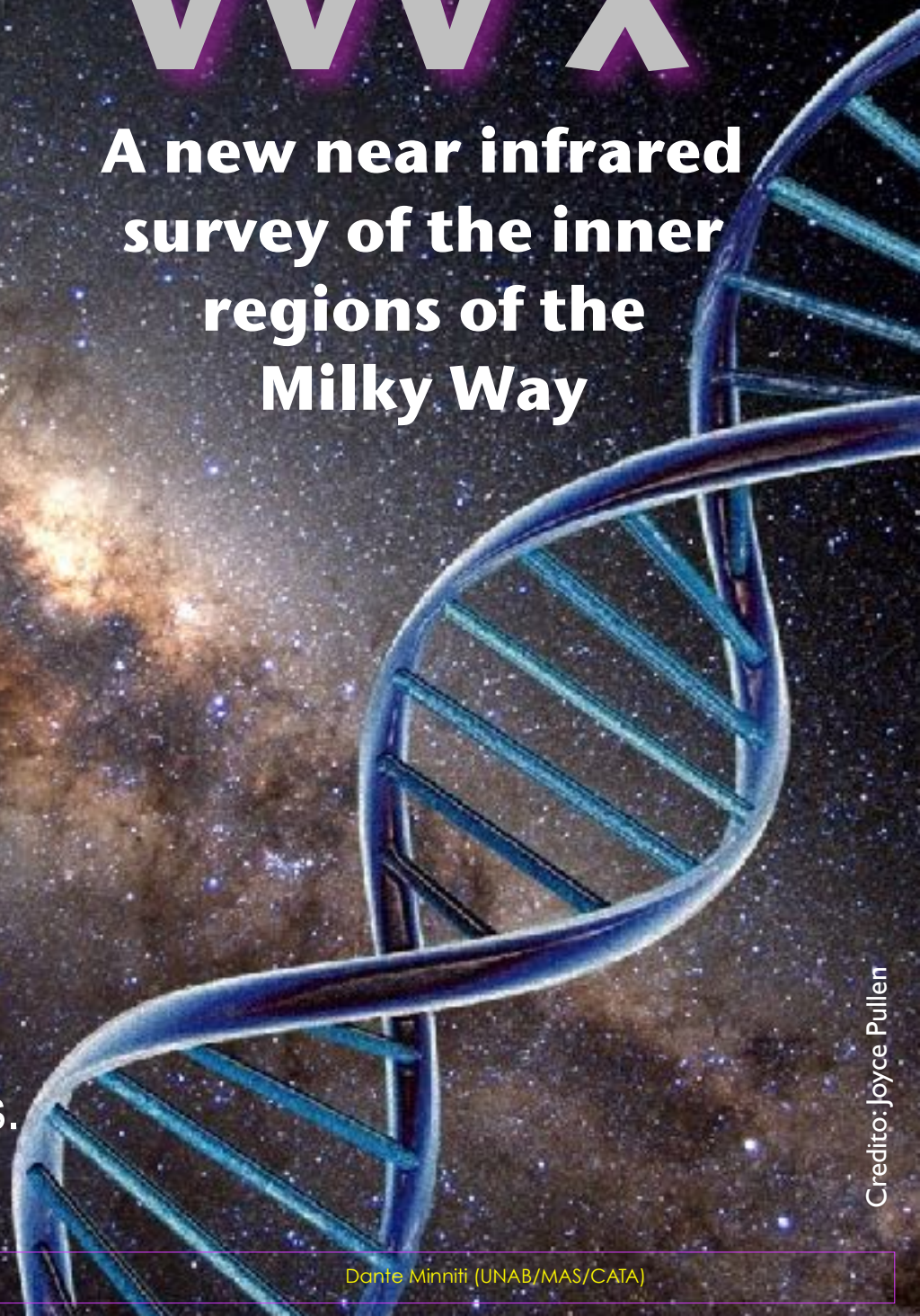
MOONS @ VLT

K-band filter for WFIRST

VVV X

A new near infrared survey of the inner regions of the Milky Way

Discovering our own galaxy,
fostering international collaborations,
promoting Astrophysics at every level, &
securing resources for the future generations.



Credito: Joyce Pullen


Questions?