RR LYRAE IN THE GALACTIC BULGE

VVV

VISTA VARIABLES IN THE VIA LACTEA

Dante Minniti &
VVV Science Team

Universidad Andrés Bello

Centro de Astrofísica y Tecnologías Afines

MILLENNIUM INSTITUTE OF ASTROPHYSICS

SPECOLA VATICANA

The VVV Science Team

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]

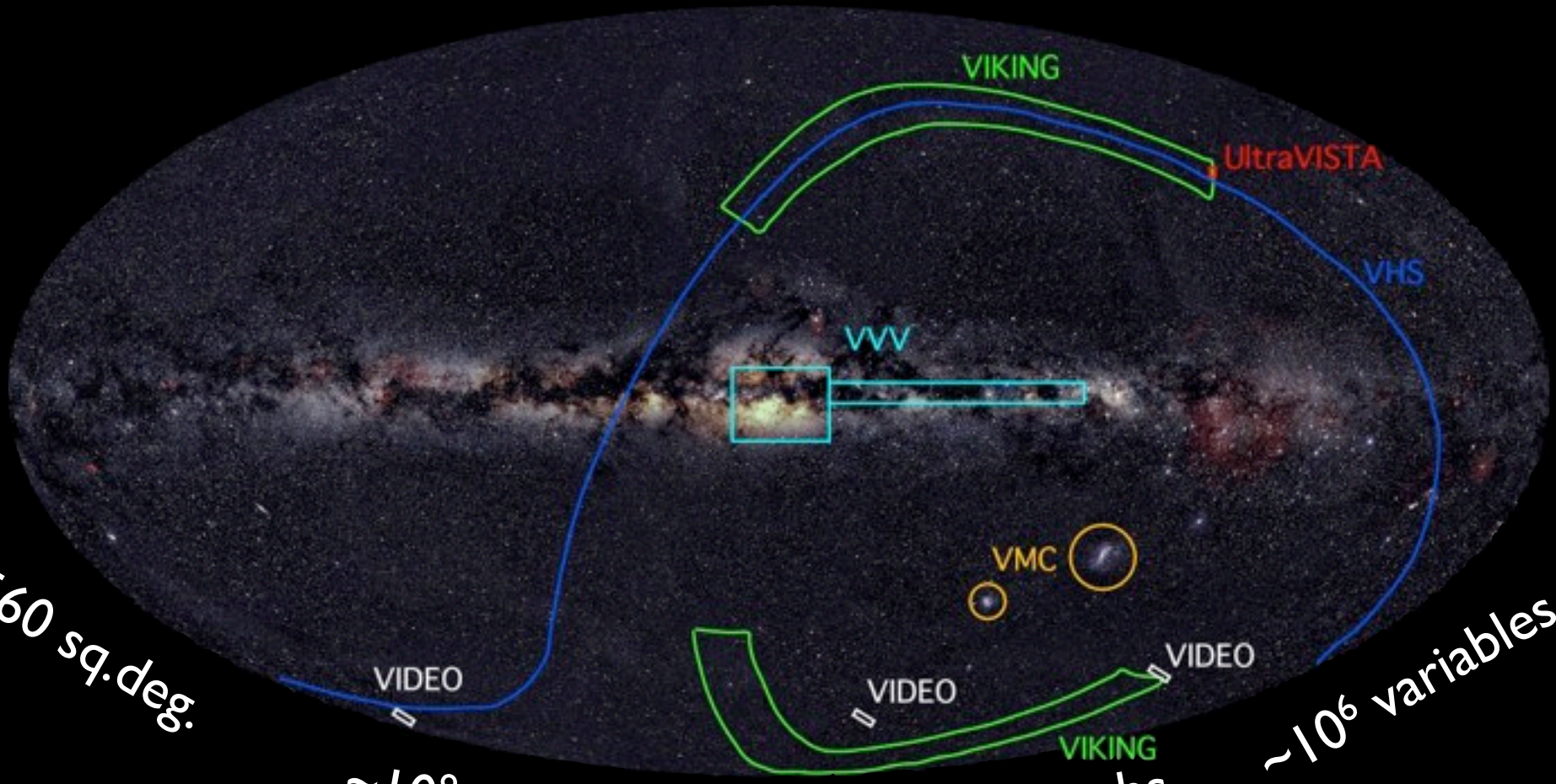
VISTA Telescope

- 4m diameter
- IR optimized
- large field

vvvsurvey.org

VISTA PUBLIC SURVEYS
VISTA VARIABLES IN THE VIA LACTEA

VVV

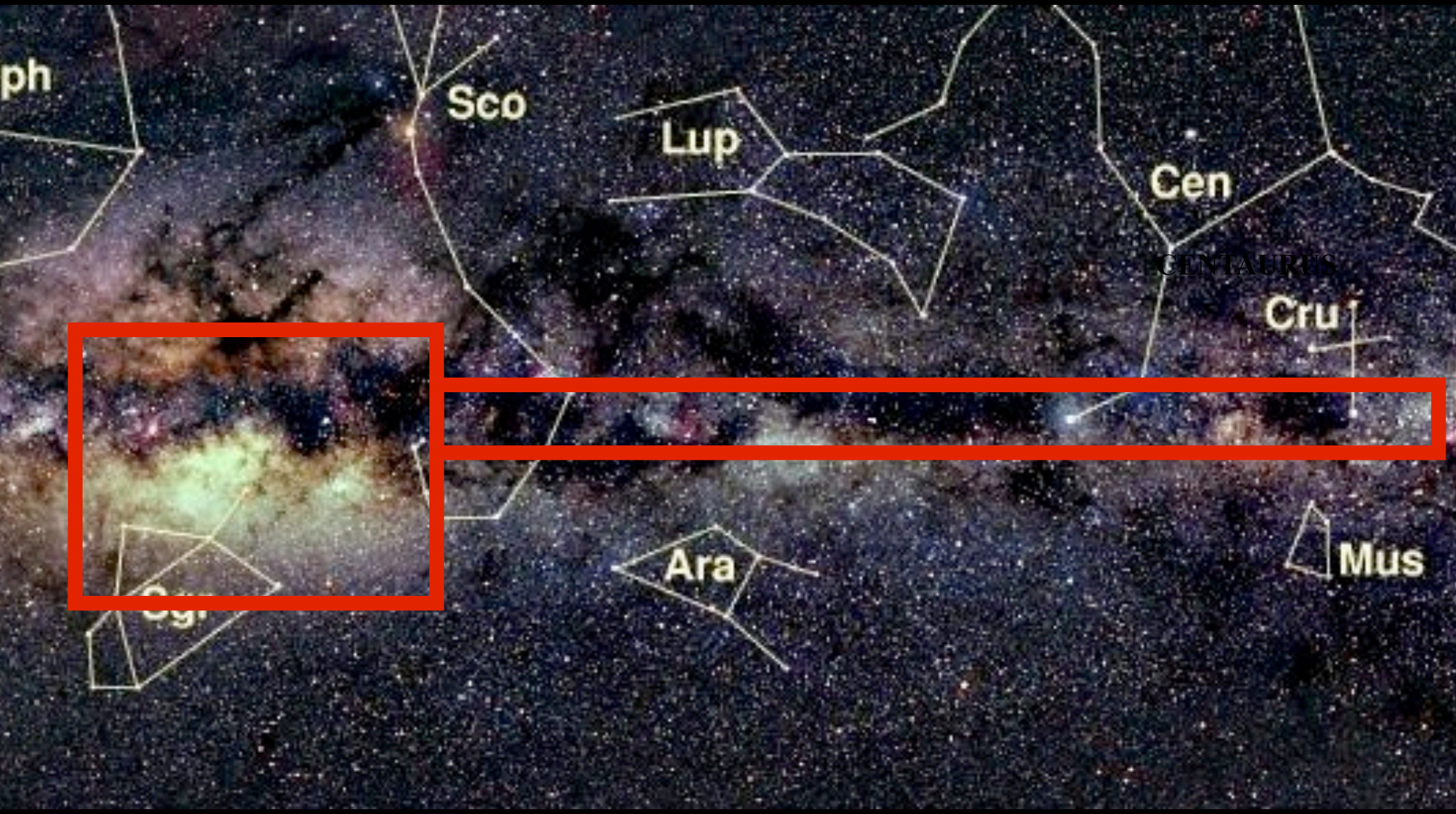


560 sq.deg.

~10^9 stars

~100 epochs

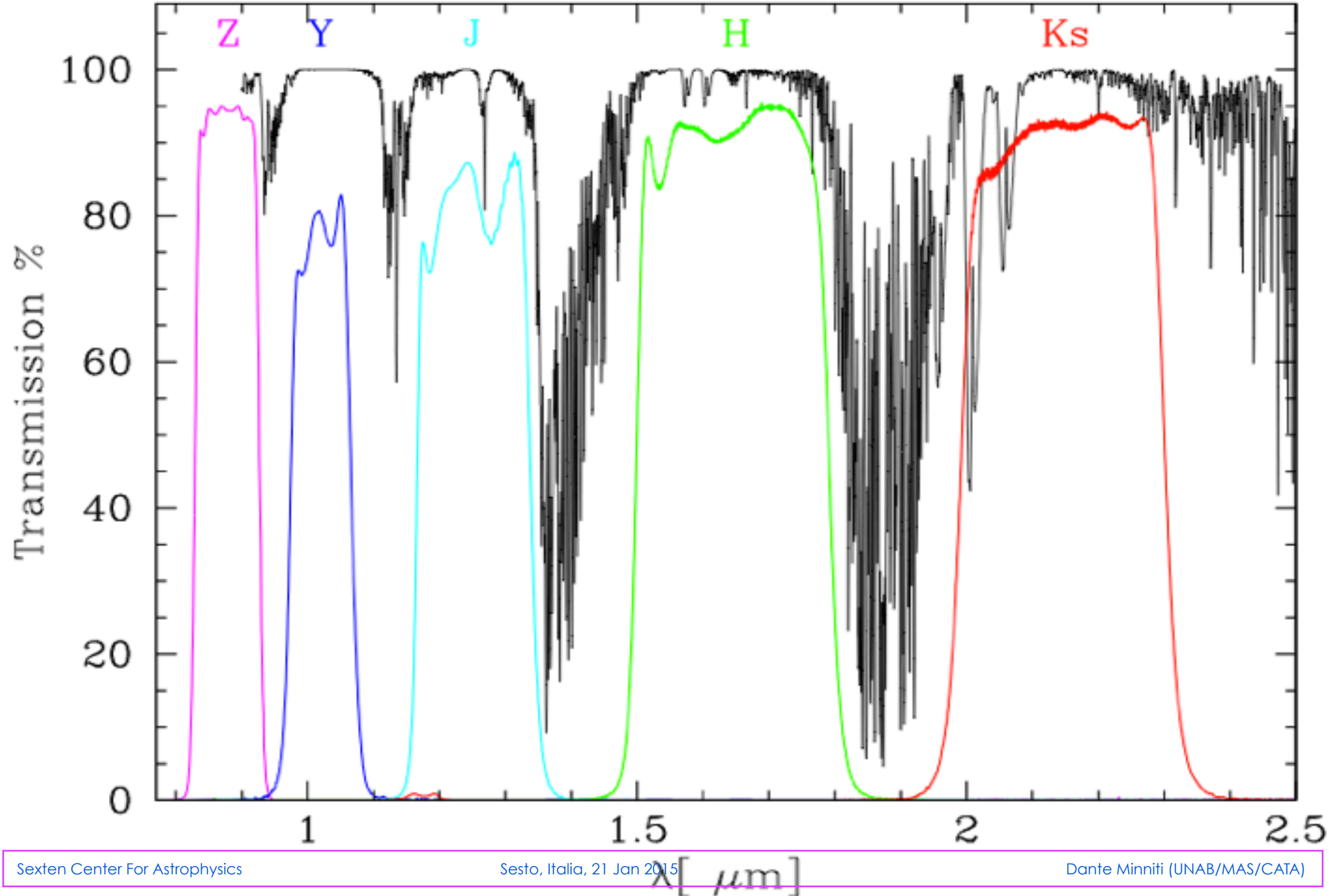
~10^6 variables



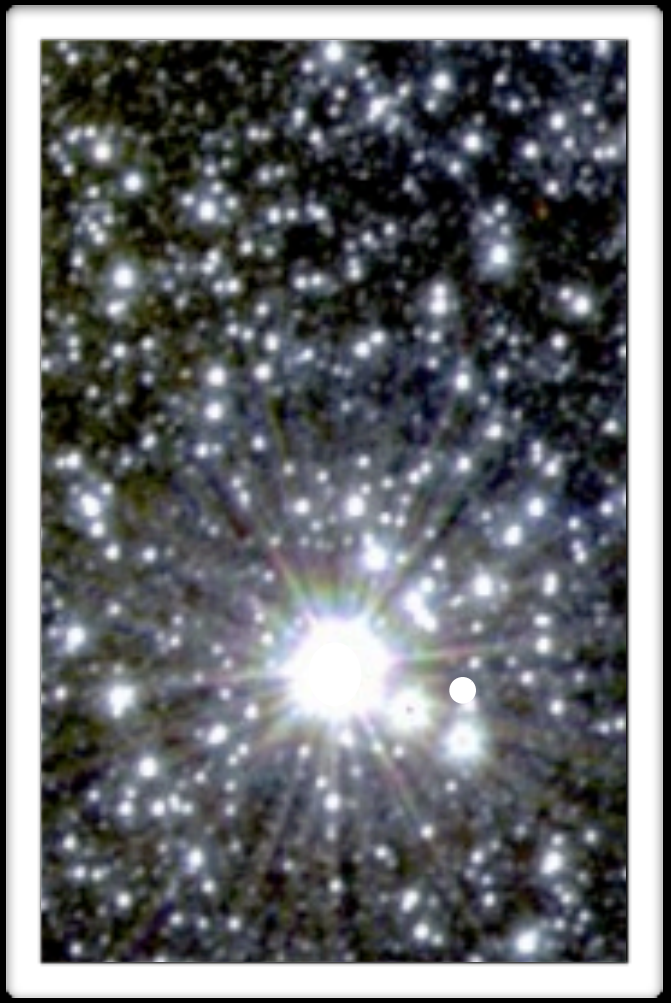
VVV maps 560 sqdeg in the central region of the MW.

The most difficult region of our galaxy...

VISTA filter transmissions



DEEPER AND HIGHER RESOLUTION



Main differences with 2MASS

2MASS covers the whole sky, VVV only 1.3%

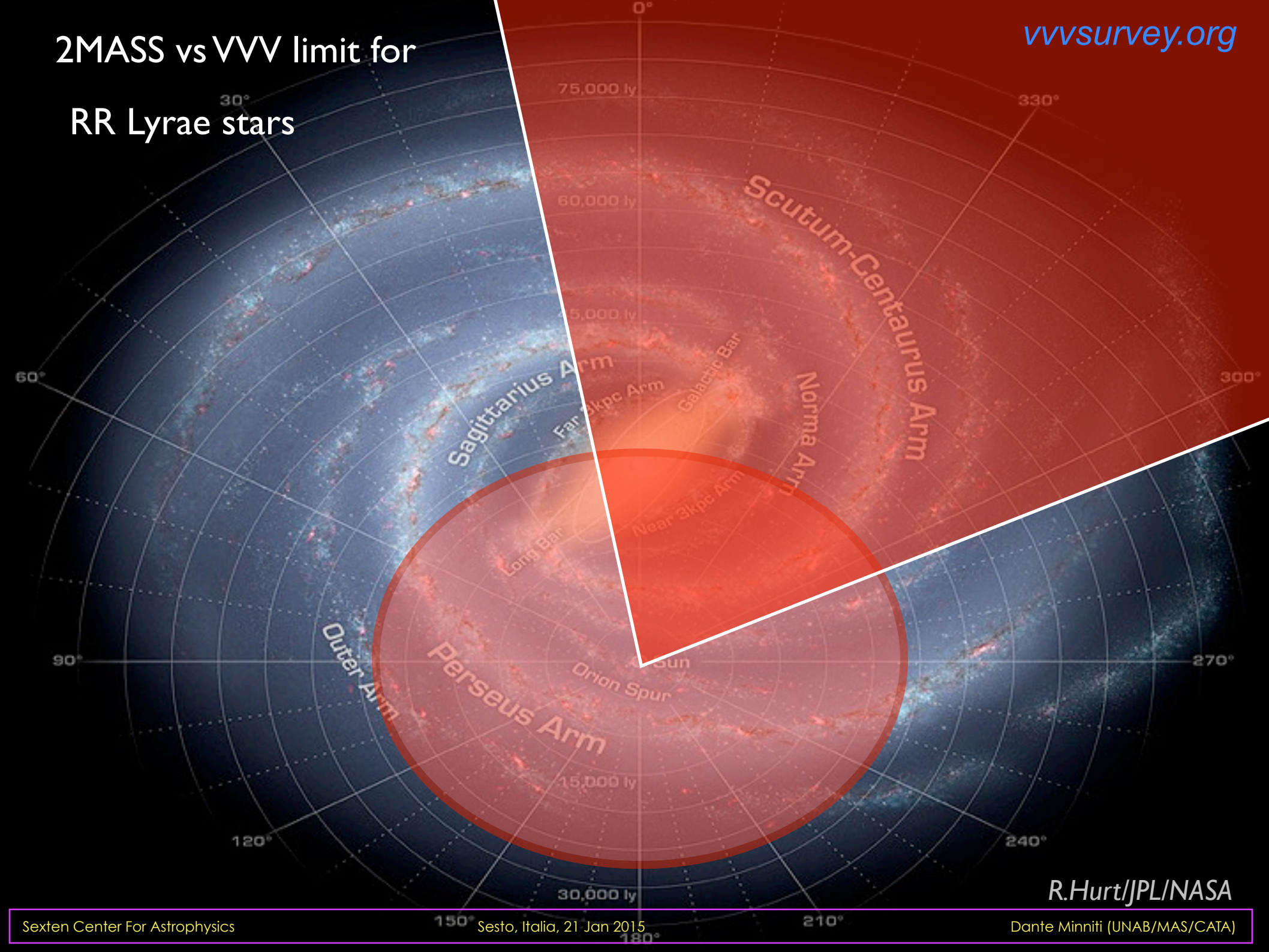
VVV has higher resolution (0.34”/pix)

VVV is deeper (Ks<18)

VVV has 5 filters (ZYJHKs)

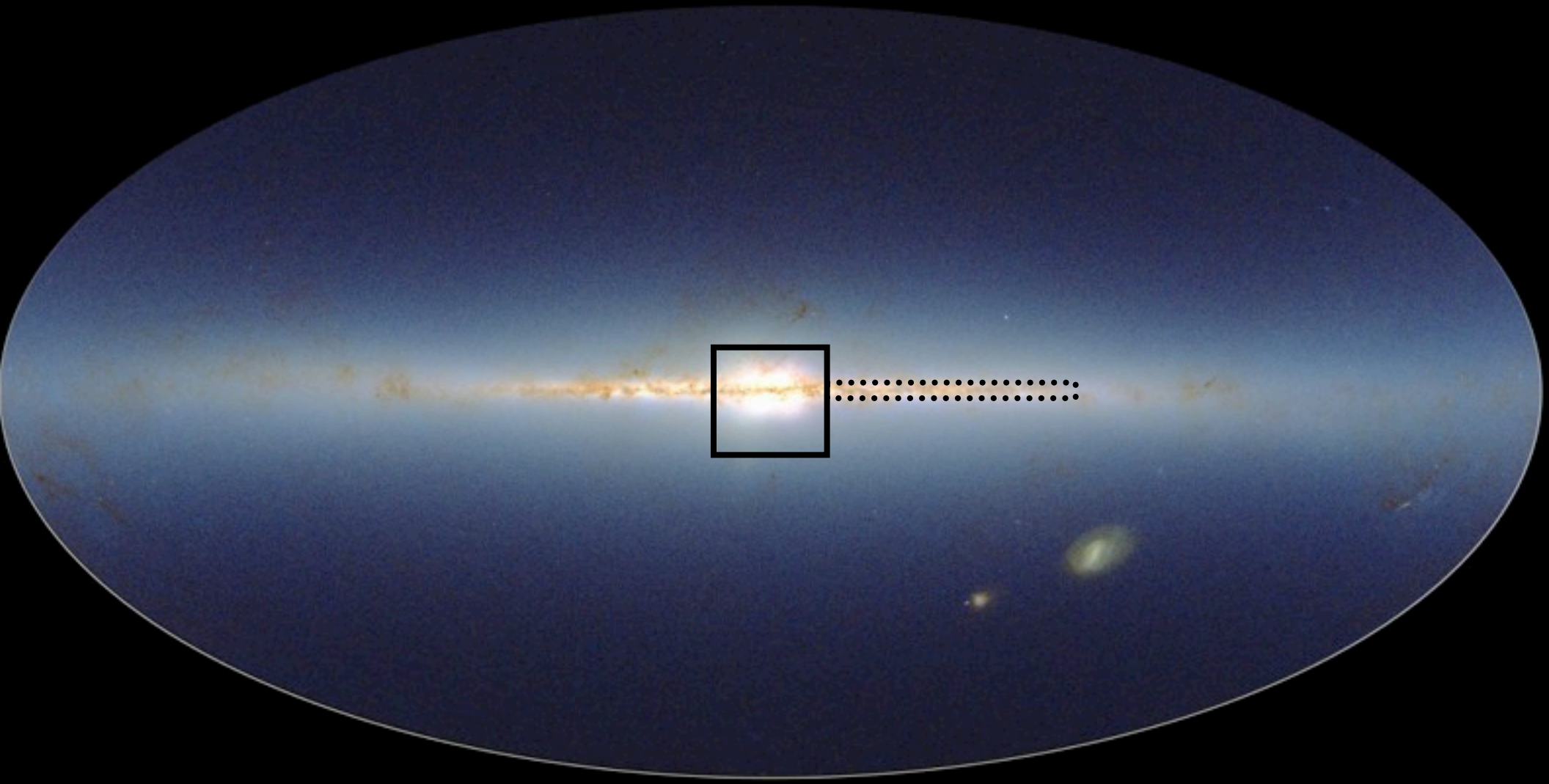
VVV is a multiepoch survey (~100 epochs)

2MASS vs VVV limit for RR Lyrae stars



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

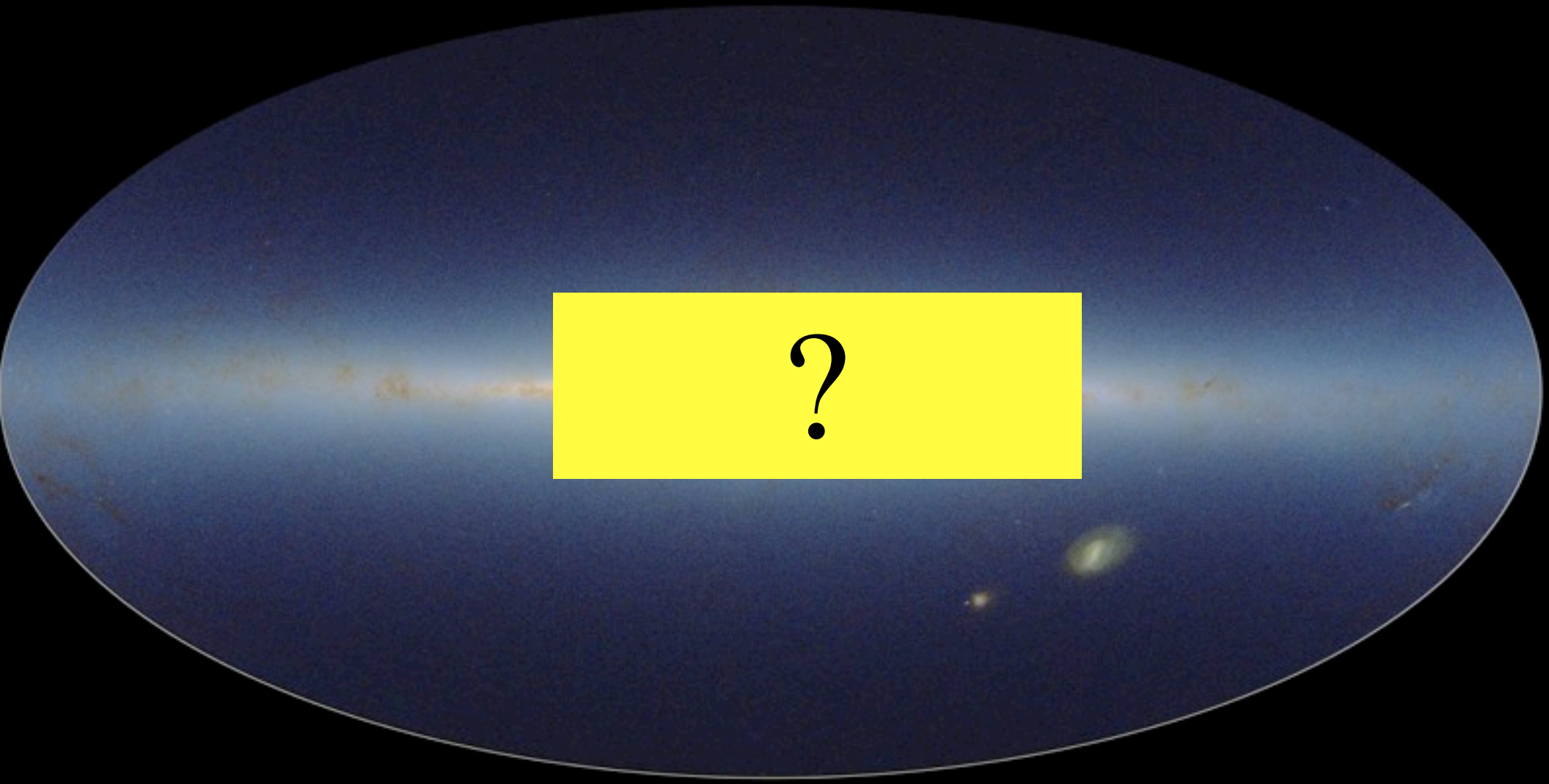
vvvsurvey.org



2MASS IMAGE OF THE MILKY WAY

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

vvvsurvey.org



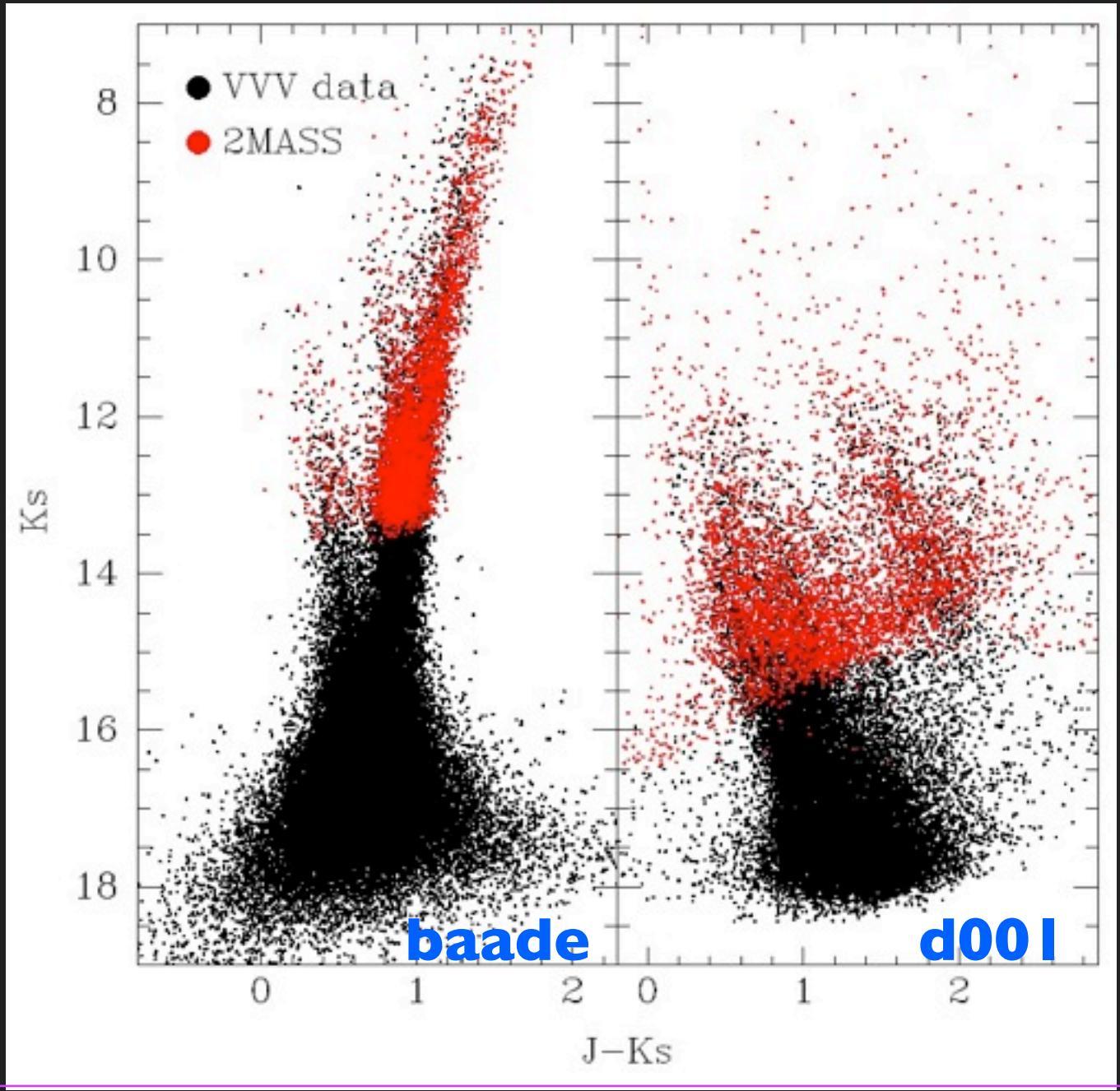
2MASS IMAGE OF THE MILKY WAY

VVV Goal

What is the 3-D structure of the Milky Way

VVV CMDs

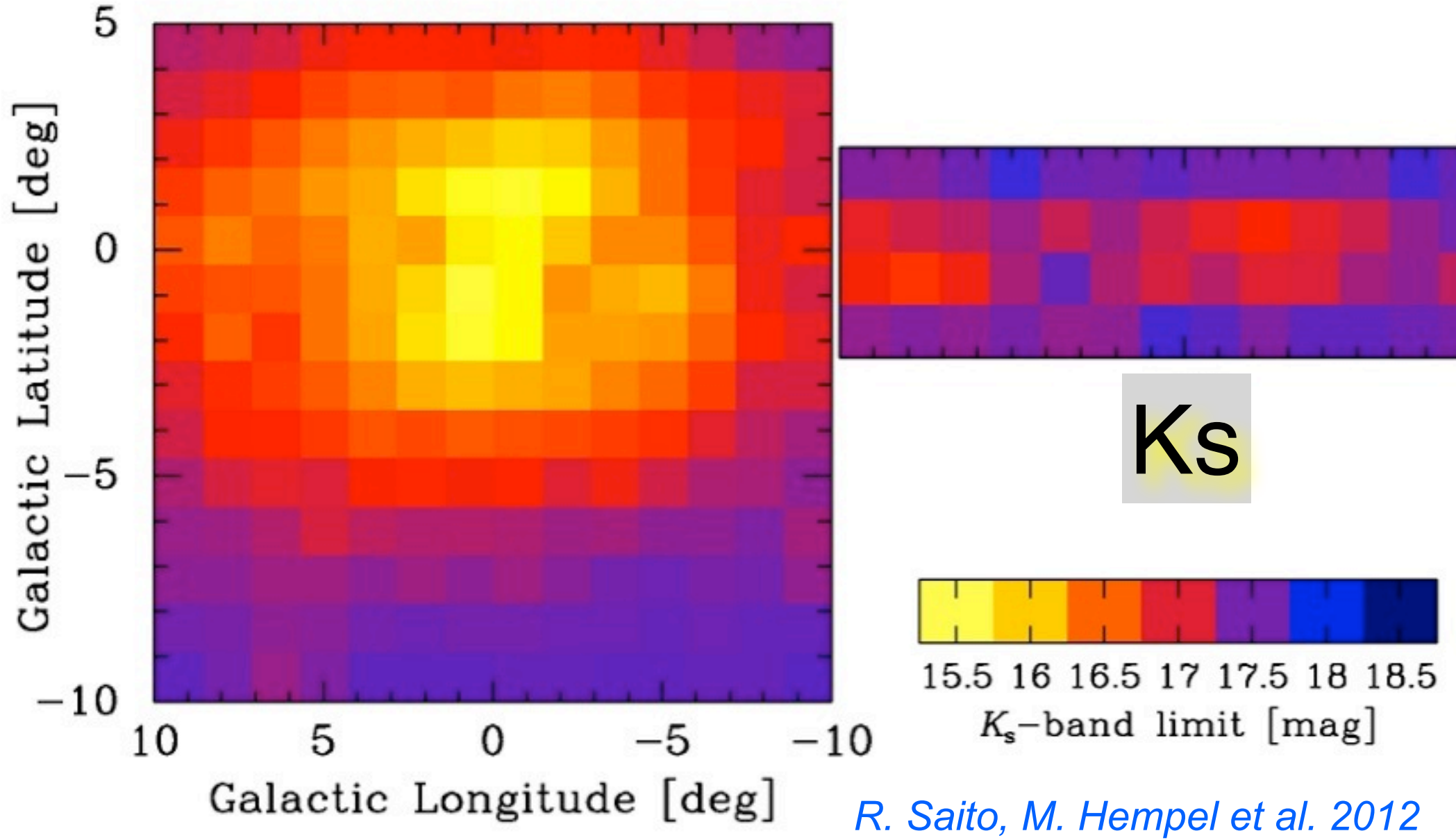
Color-magnitude diagrams of bulge and disk fields compared with 2MASS.



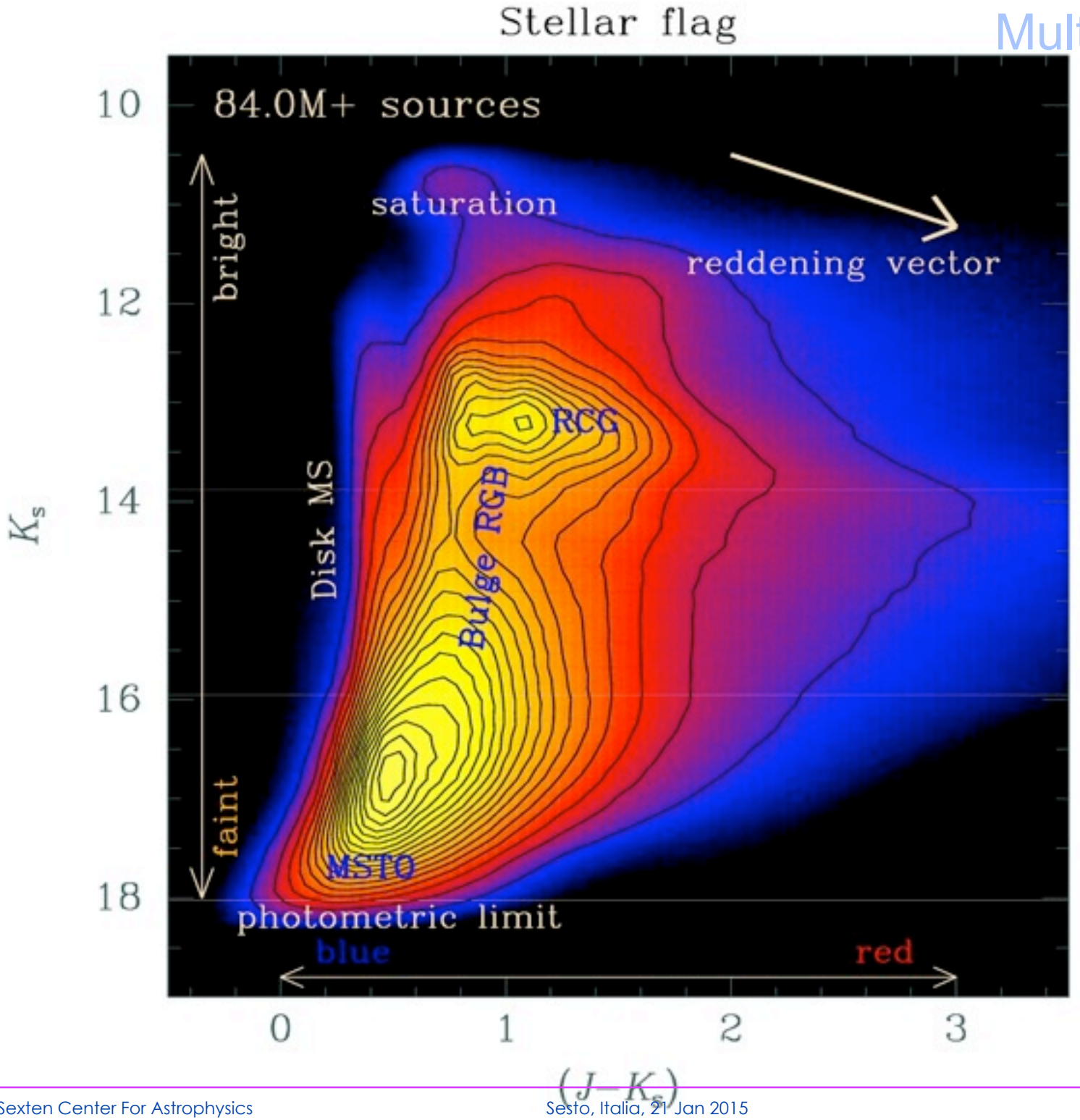
Oscar Gonzalez

VVV limiting magnitudes

vvvsurvey.org



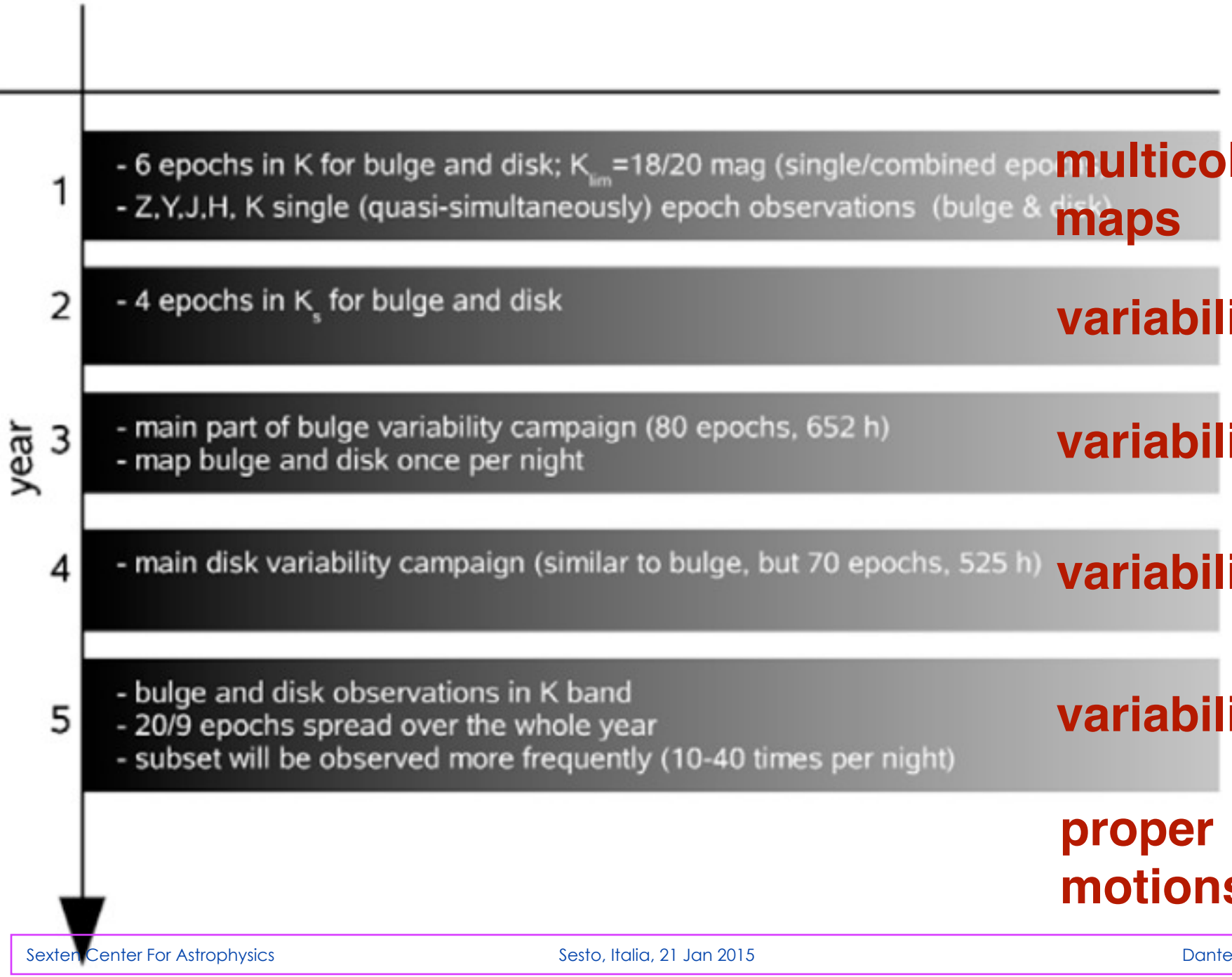
R. Saito, M. Hempel et al. 2012



VVV 84M STARS BULGE CMD

R. Saito et al. 2012

The VVV Survey: Timeline



The VVV Stages

Multicolor Photometry: ZYJHKs

Star clusters, stellar pops, extinction, metallicities, galaxies...

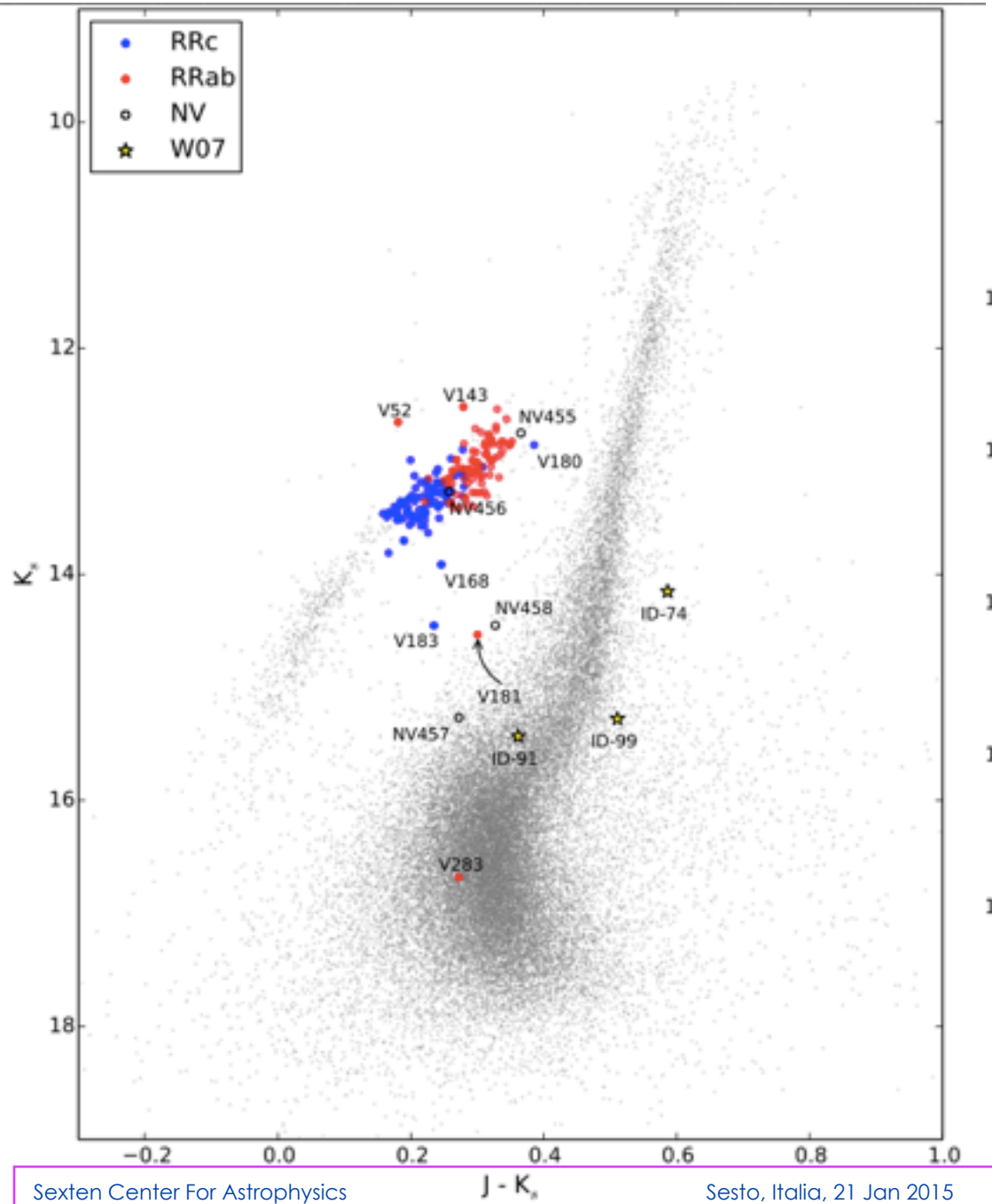
Variability: Ks

LPVs, Cepheids, RR Lyrae, Binaries, Novae, Microlensing...

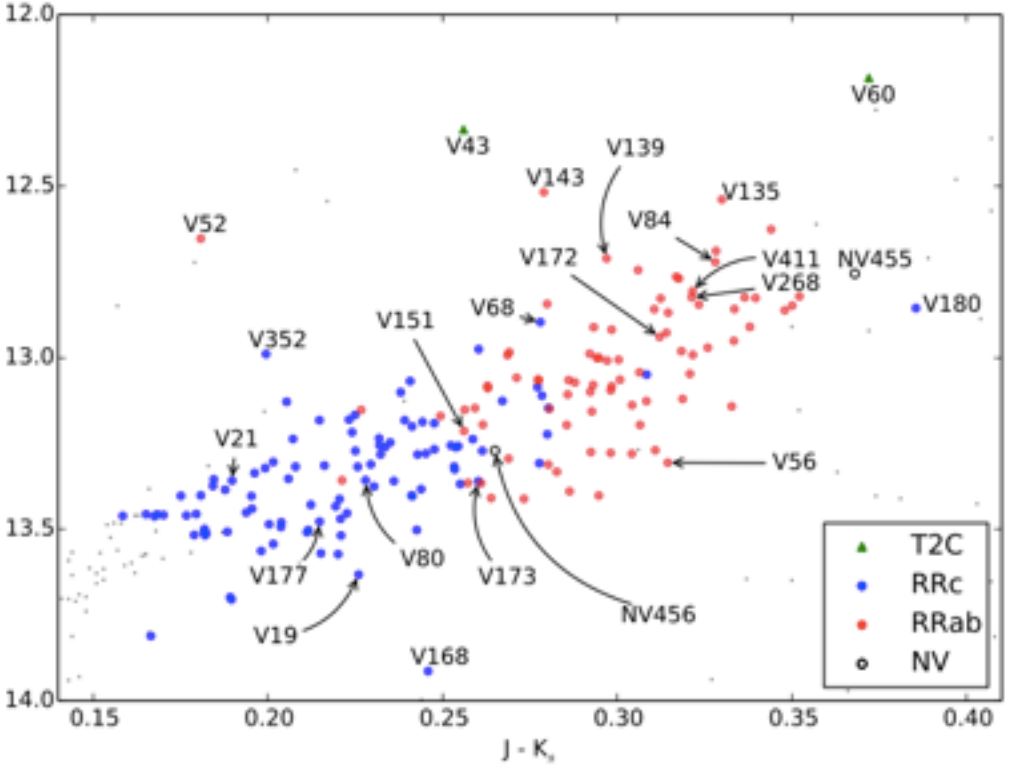
Proper Motions: Ks

Nearby stars, BDs, WDs, Asteroids, Hyper-Velocity Stars...

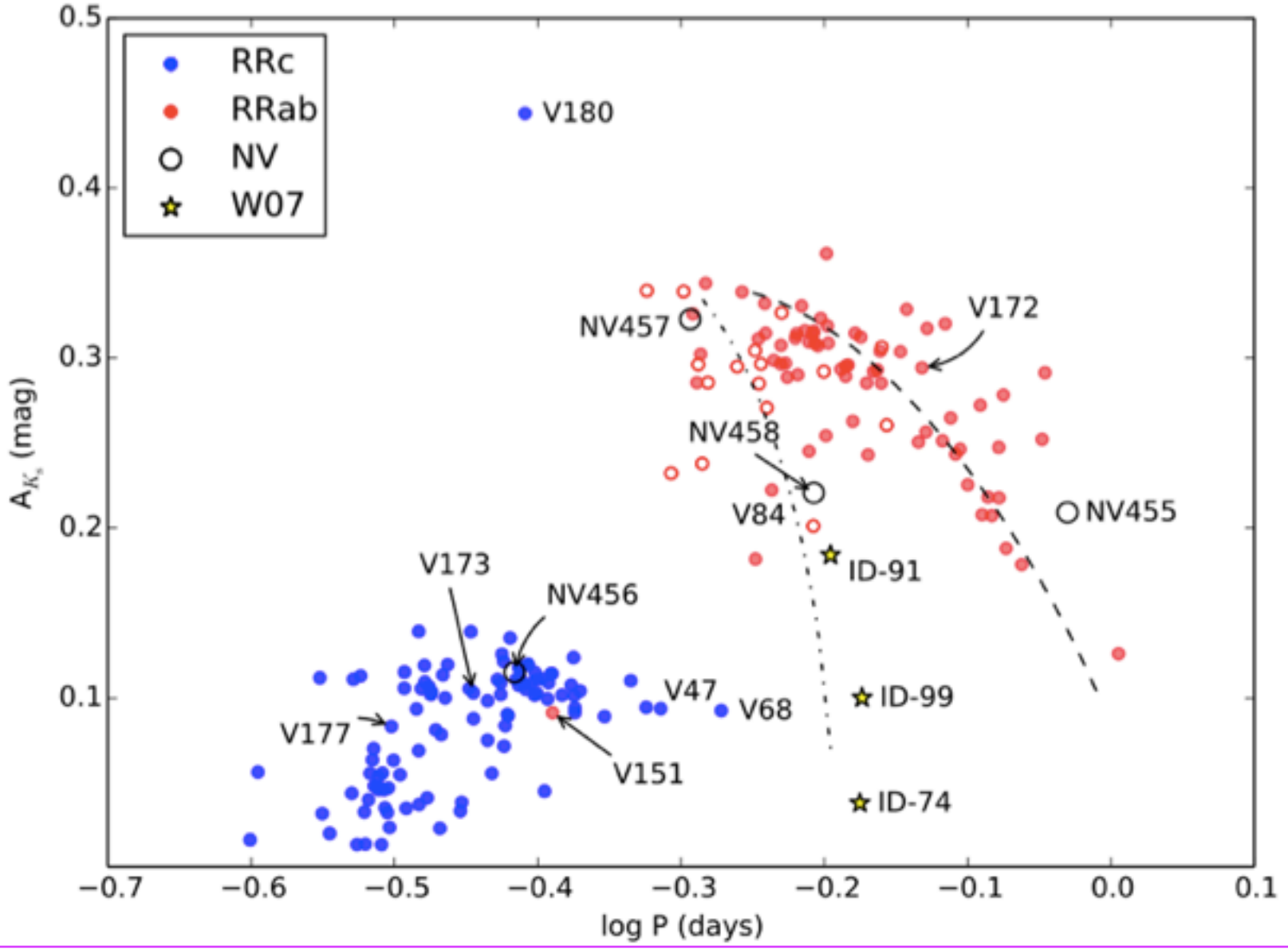
A complete census of RR Lyrae Stars in Omega Centauri in the near-IR: 88 RRab and 101 RRc (C. Navarrete et al. A&A 2015)



RR Lyrae in GCs

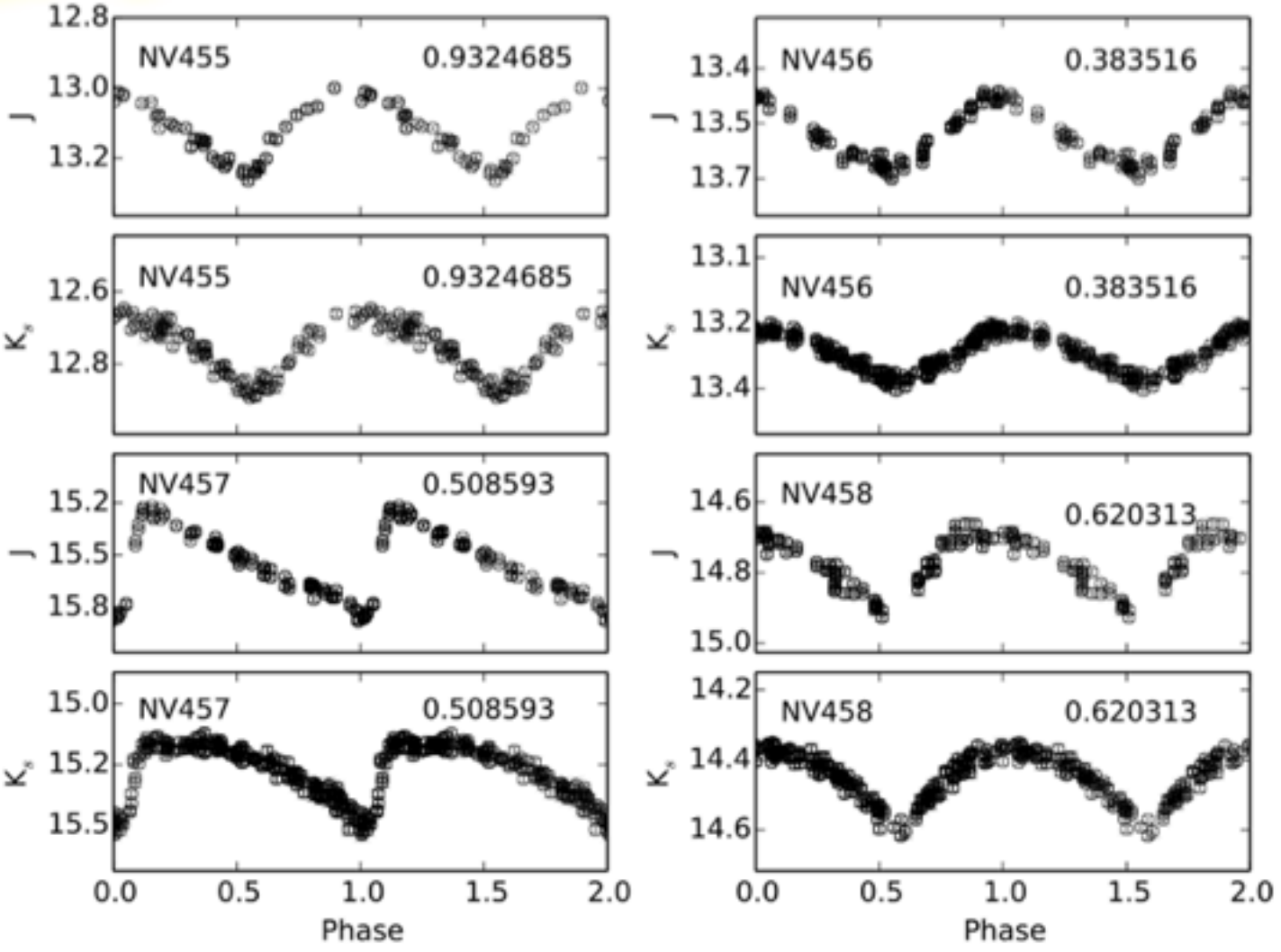


A complete census of RR Lyrae Stars in Omega Centauri in the near-IR: 88 RRab and 101 RRc (C. Navarrete et al. A&A 2015)



A complete census of RR Lyrae Stars in Omega Centauri in the near-IR: 88 RRab and 101 RRc (C. Navarrete et al. A&A 2015)

good template light curves!

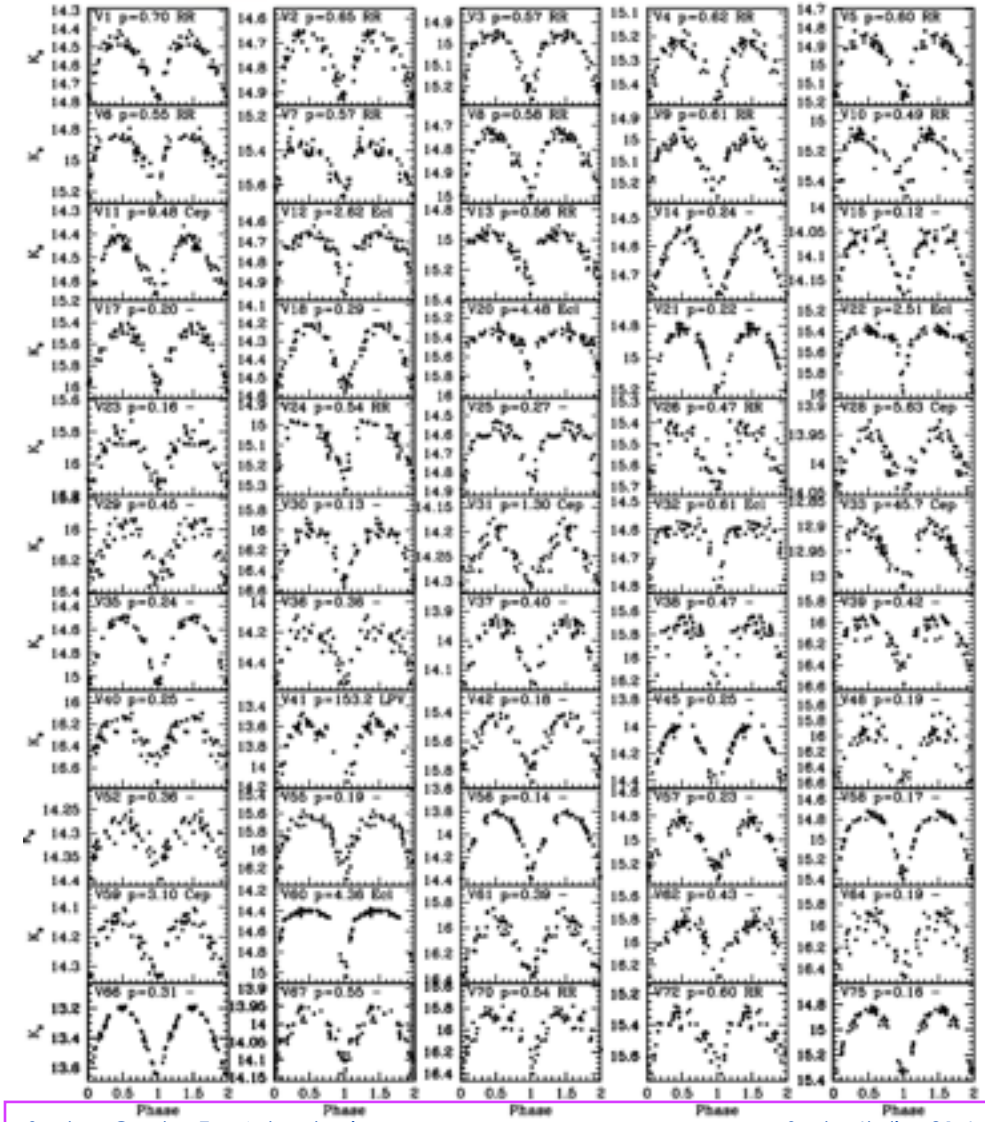


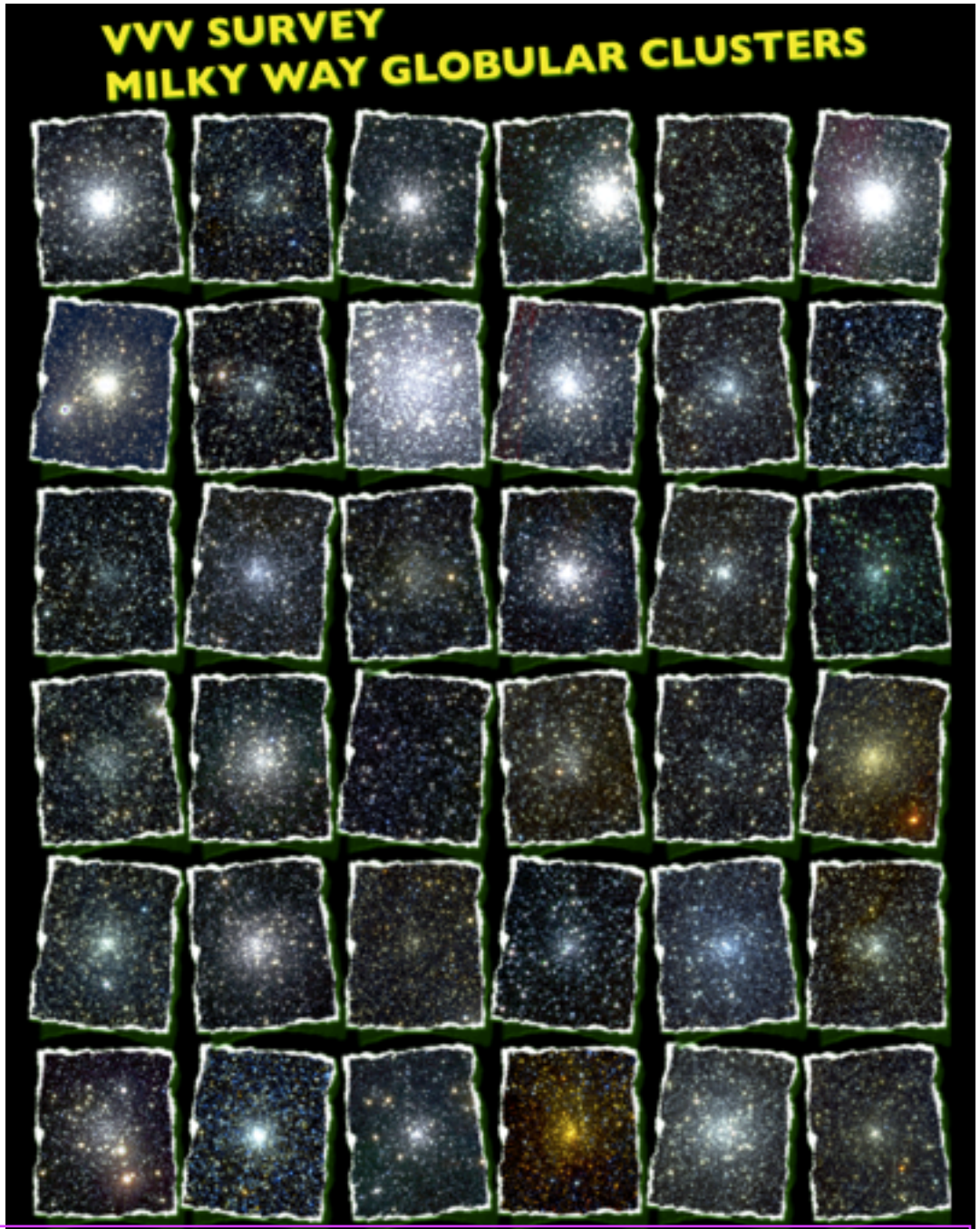
J and K_S-band light curves of the newly discovered RRL stars that are likely cluster members.

Variable stars in the VVV globular clusters. I. 2MASS-GC02 and Terzan 10

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

RR Lyrae in GCs





Variable stars in the VVV globular clusters. I. 2MASS-GC02 and Terzan 10

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

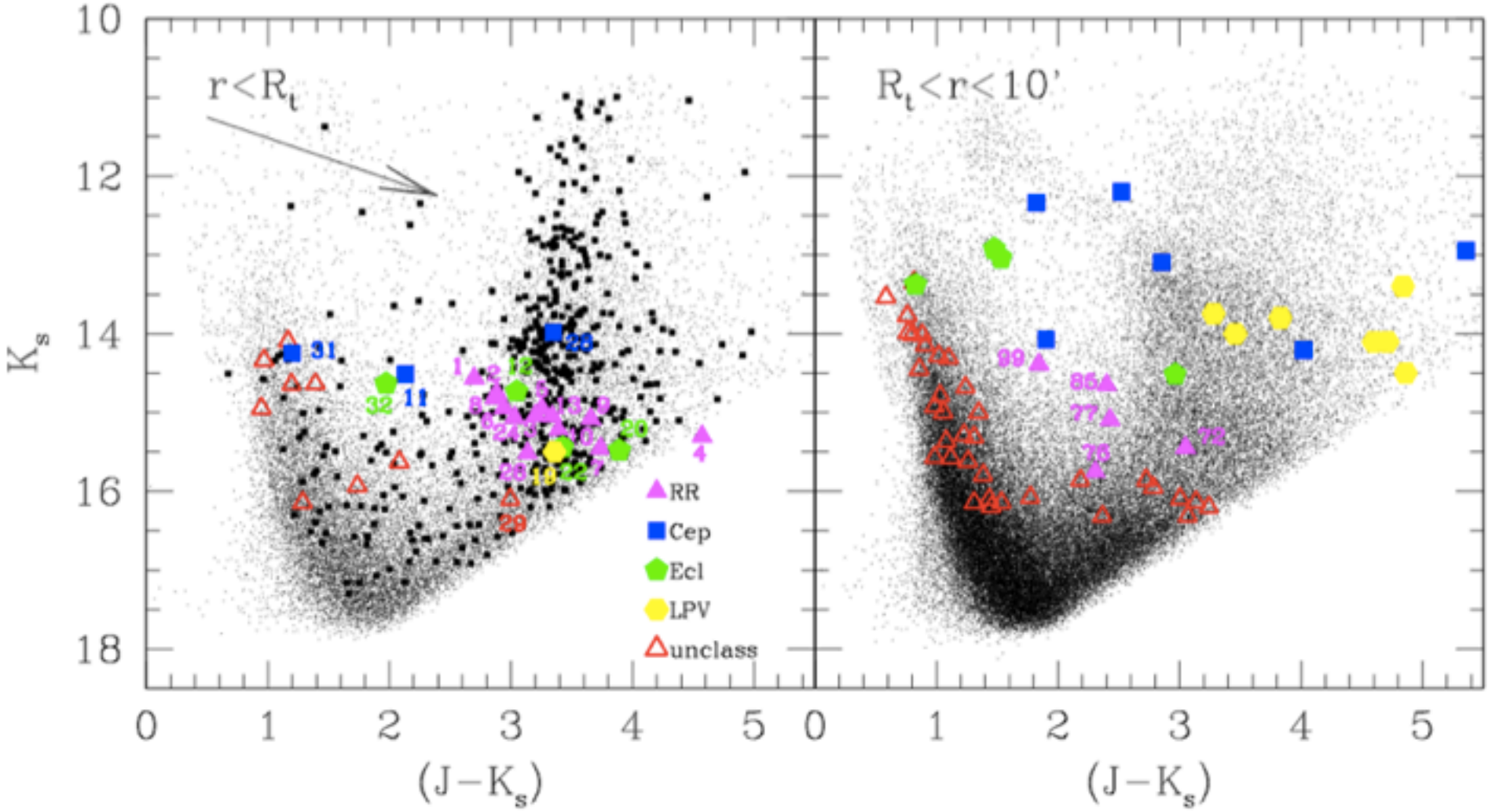


Fig. 1.— $J-K_s$ vs. K_s CMDs of 2MASS-GC02, out to its tidal radius $r_t = 4.9'$ (left), and of its surrounding region (right). The arrow shows the reddening vector according to Nishiyama

Variable stars in the VVV globular clusters. I. 2MASS-GC02 and Terzan 10

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

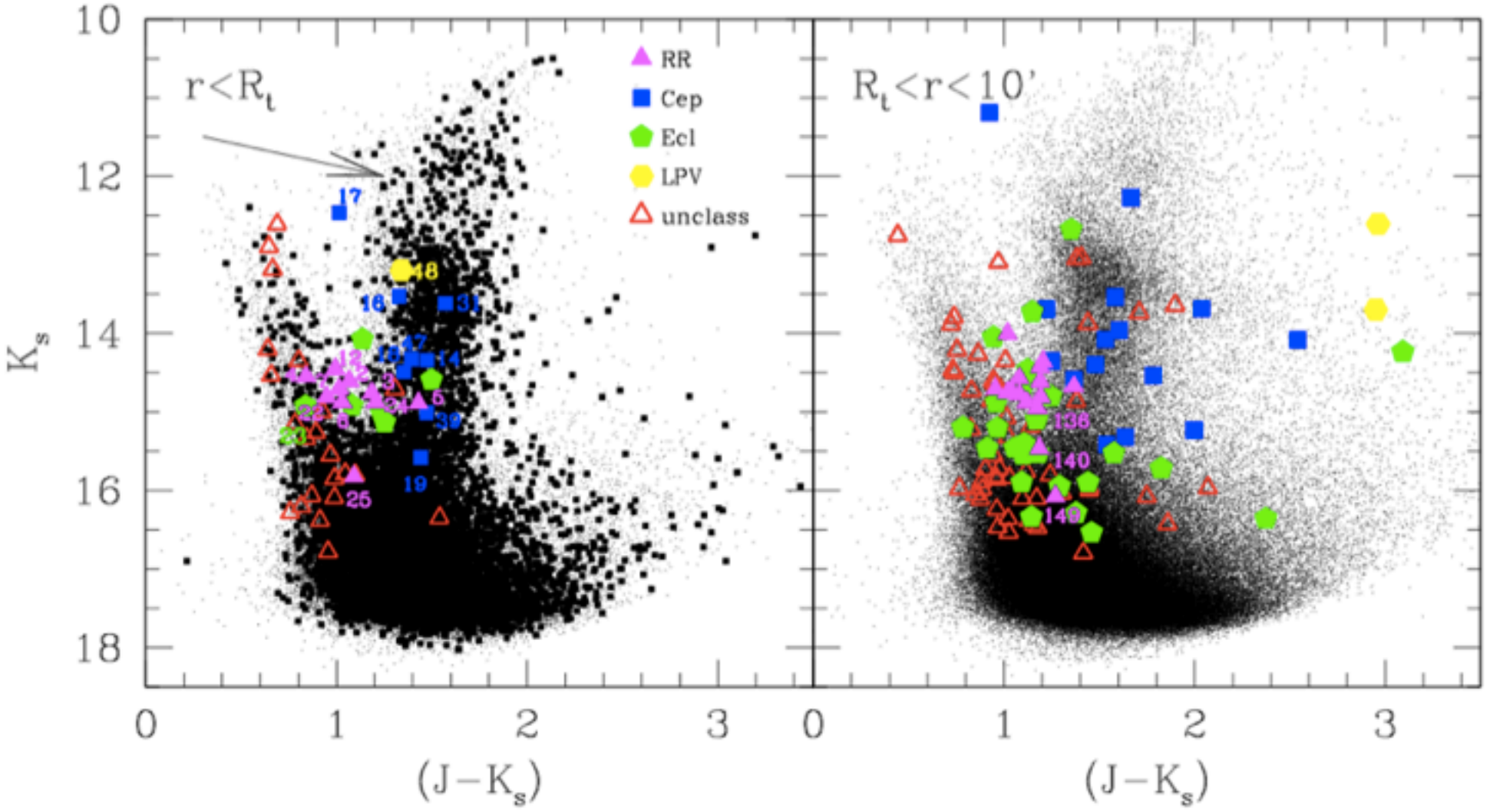


Fig. 6.— As in Figure 1, but for Terzan 10 and its surroundings. In the left panel we have plotted with bigger solid squares the objects out to the cluster's half-light radius, $r_h = 1.55'$.

Variable stars in the VVV globular clusters. I. 2MASS-GC02 and Terzan 10

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

RR Lyrae in GCs

Table 5. Distances and extinctions to the studied clusters

	$R_{\odot,\mathrm{Harris96}}$ (kpc)	$R_{GC,\mathrm{Harris96}}$[1] (kpc)	$E(B-V)_{\mathrm{Harris96}}$	$R_{\odot,\mathrm{derived}}$ (kpc)	$R_{GC,\mathrm{derived}}$[1] (kpc)	$E(J-K_s)_{\mathrm{derived}}$
2MASS-GC02	4.9	−3.2	5.16	$7.1\pm0.5\pm0.9$	$-1.6\pm0.2\pm^{0.6}_{0.2}$	2.92
Terzan 10	5.8	−2.3	2.40	$9.8\pm0.2\pm0.5$	$+2.0\pm0.2\pm0.4$	0.82

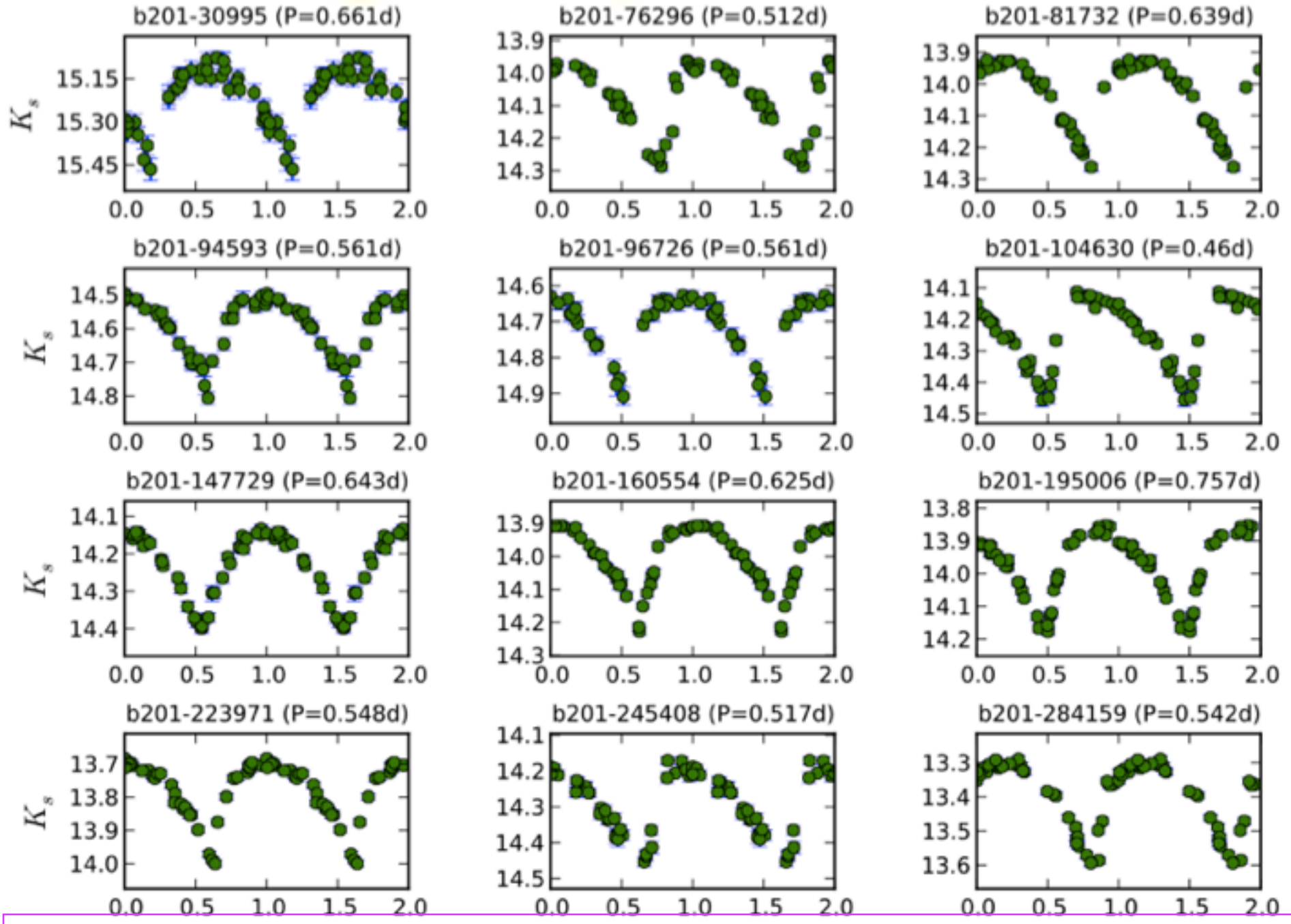
[1]The minus sign indicates location on the near side of the bulge, and the plus sign indicates location on the far side of the bulge. Distances obtained assuming a Galactocentric distance for the Sun of 8 kpc.

Number of Epochs: Bulge

Maren Hempel

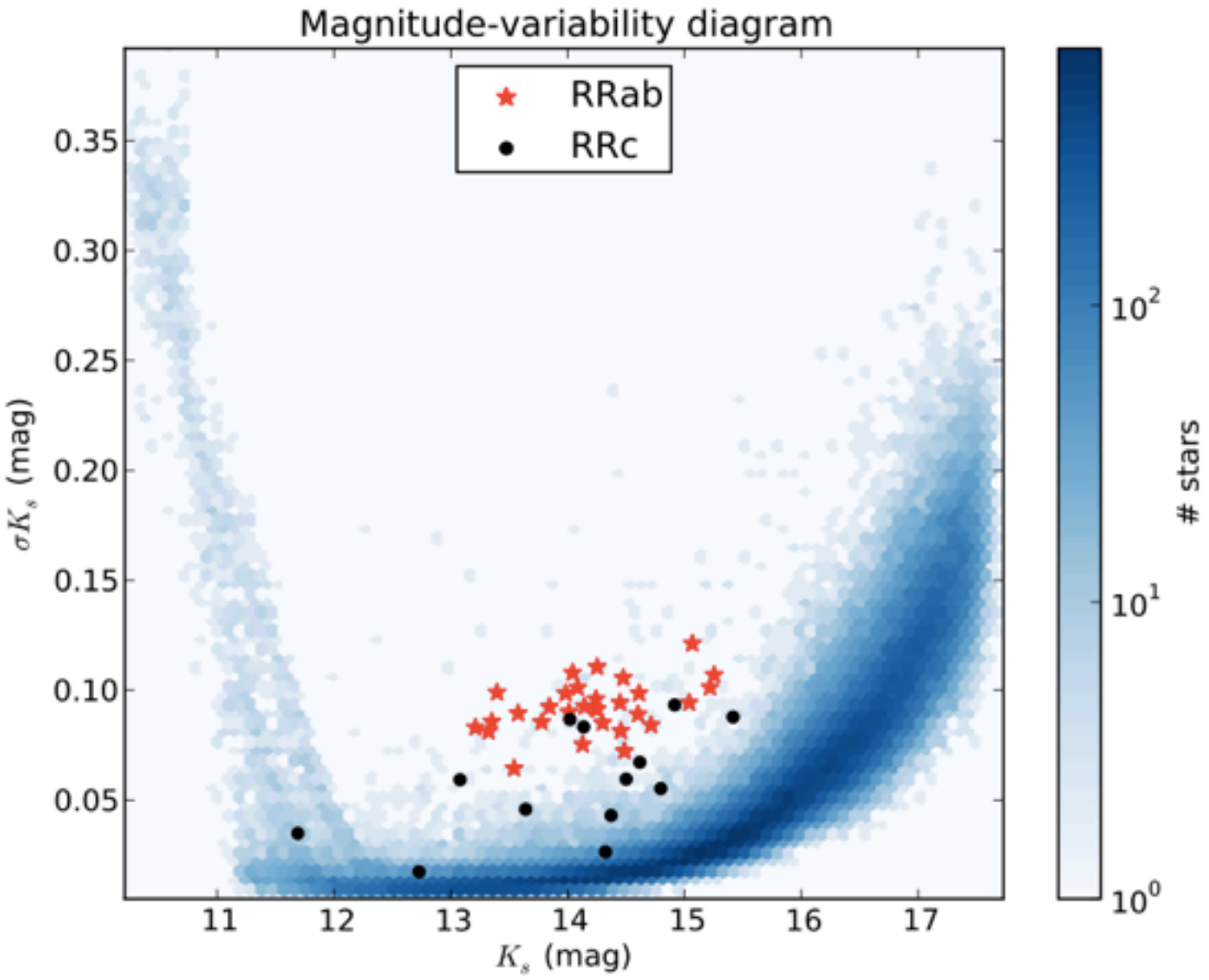
Bulge RR Lyrae

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



Bulge RR Lyrae

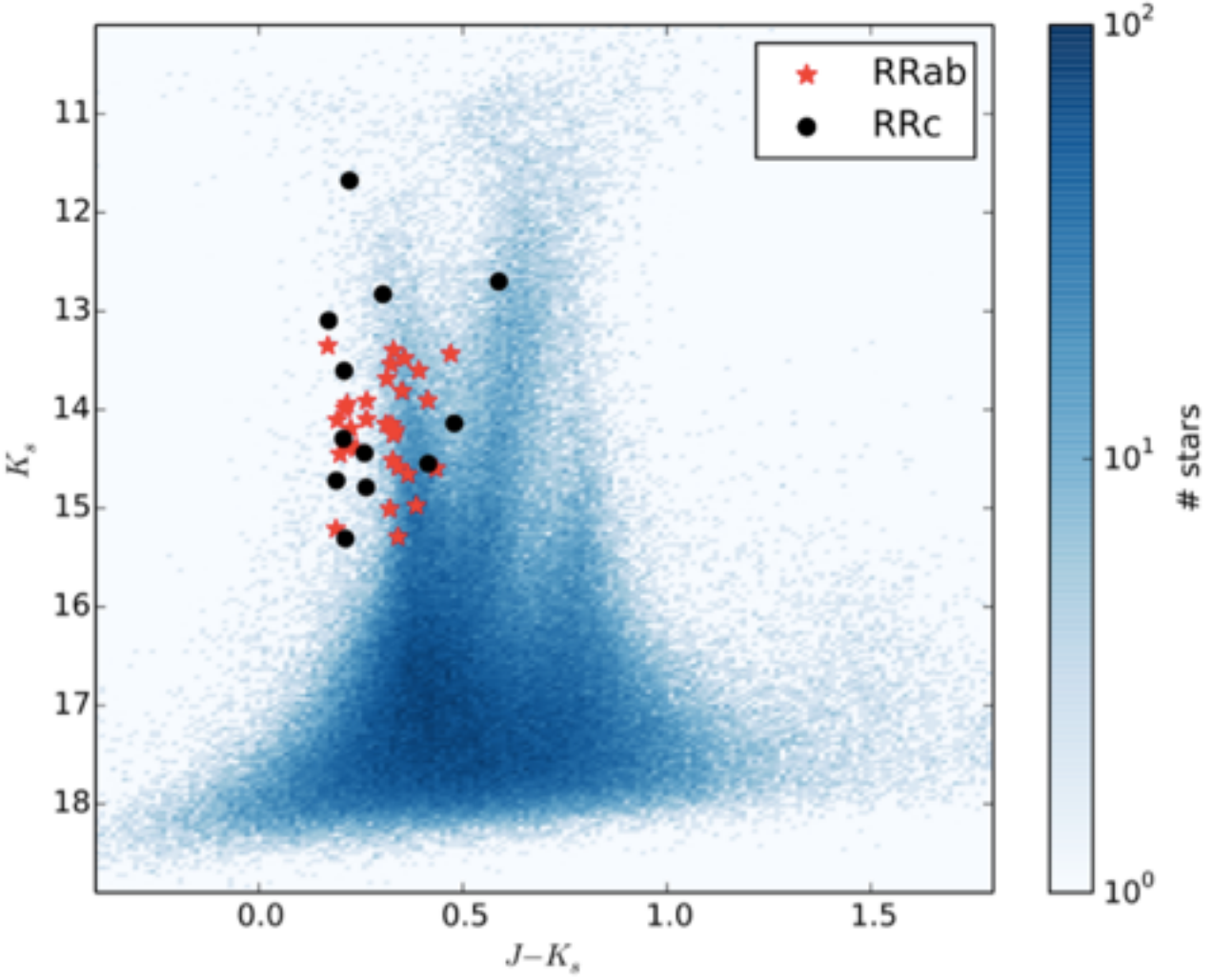
F. Gran, et al. 2014, A&A



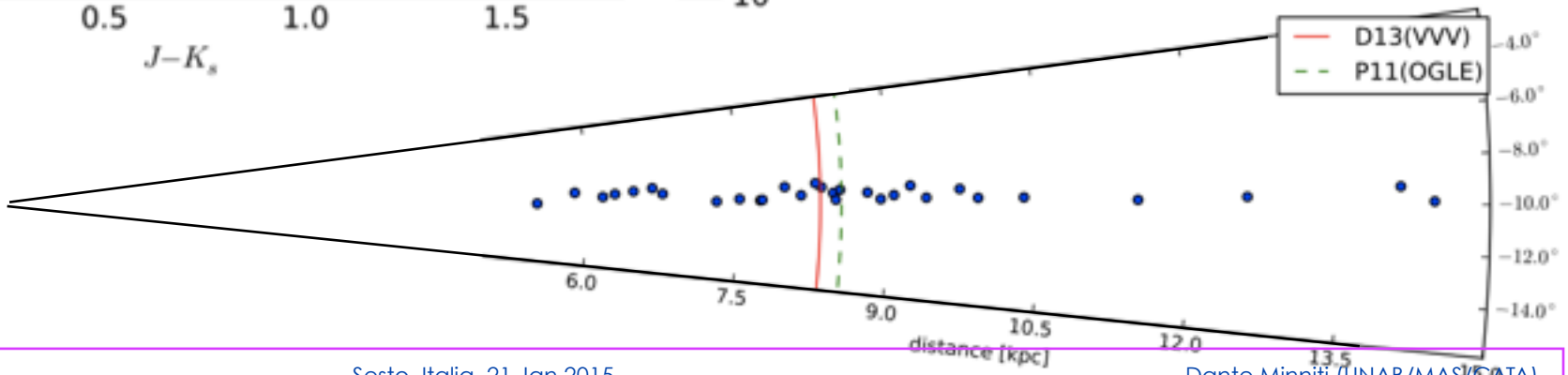
We find ~1 RR Lyrae variable star for every 10,000 stars measured.

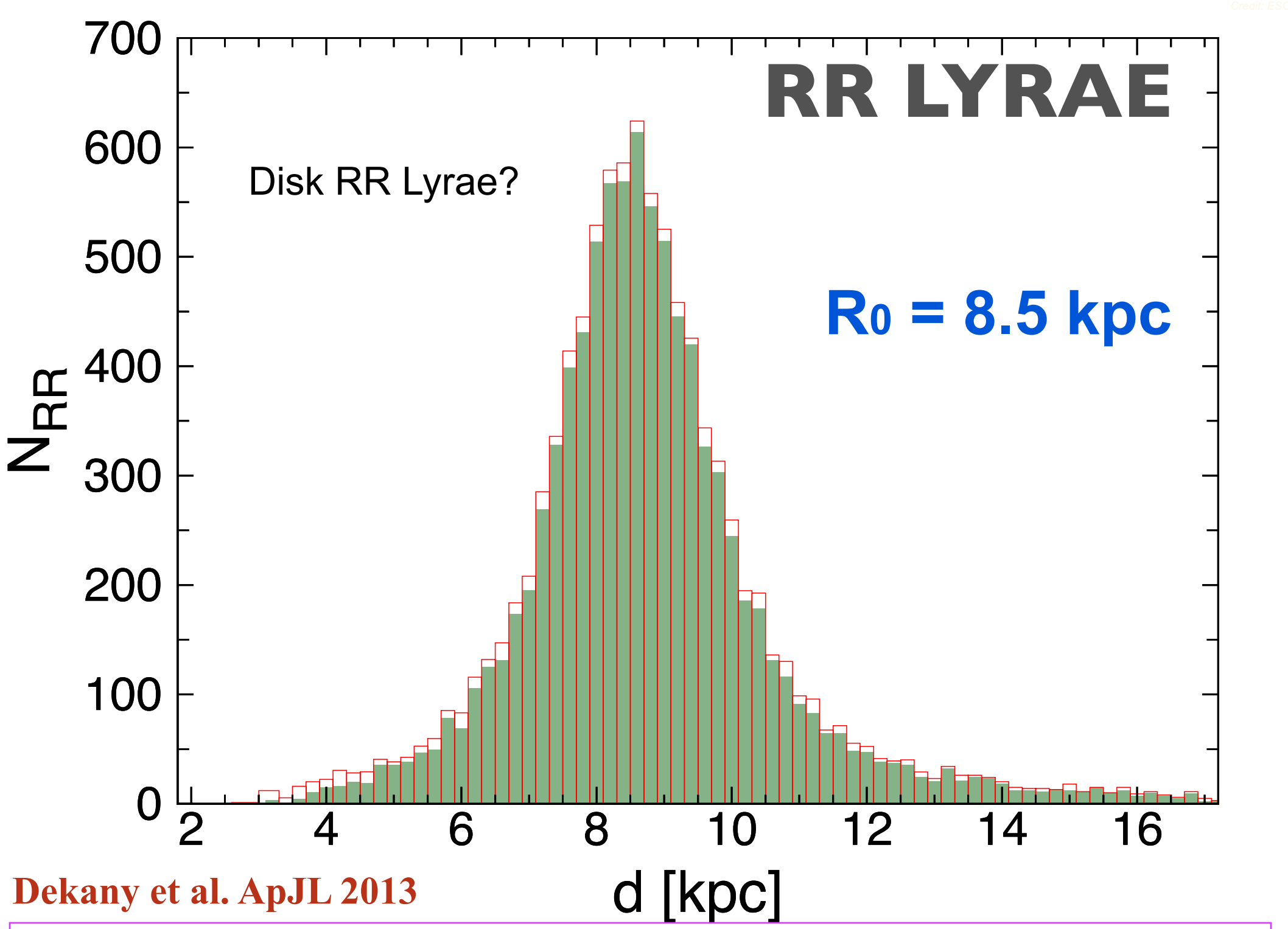
Bulge RR Lyrae

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



- RR Lyrae are metal-poor, and represent the oldest stellar populations.
- RR Lyrae stars are excellent primary distance indicators.

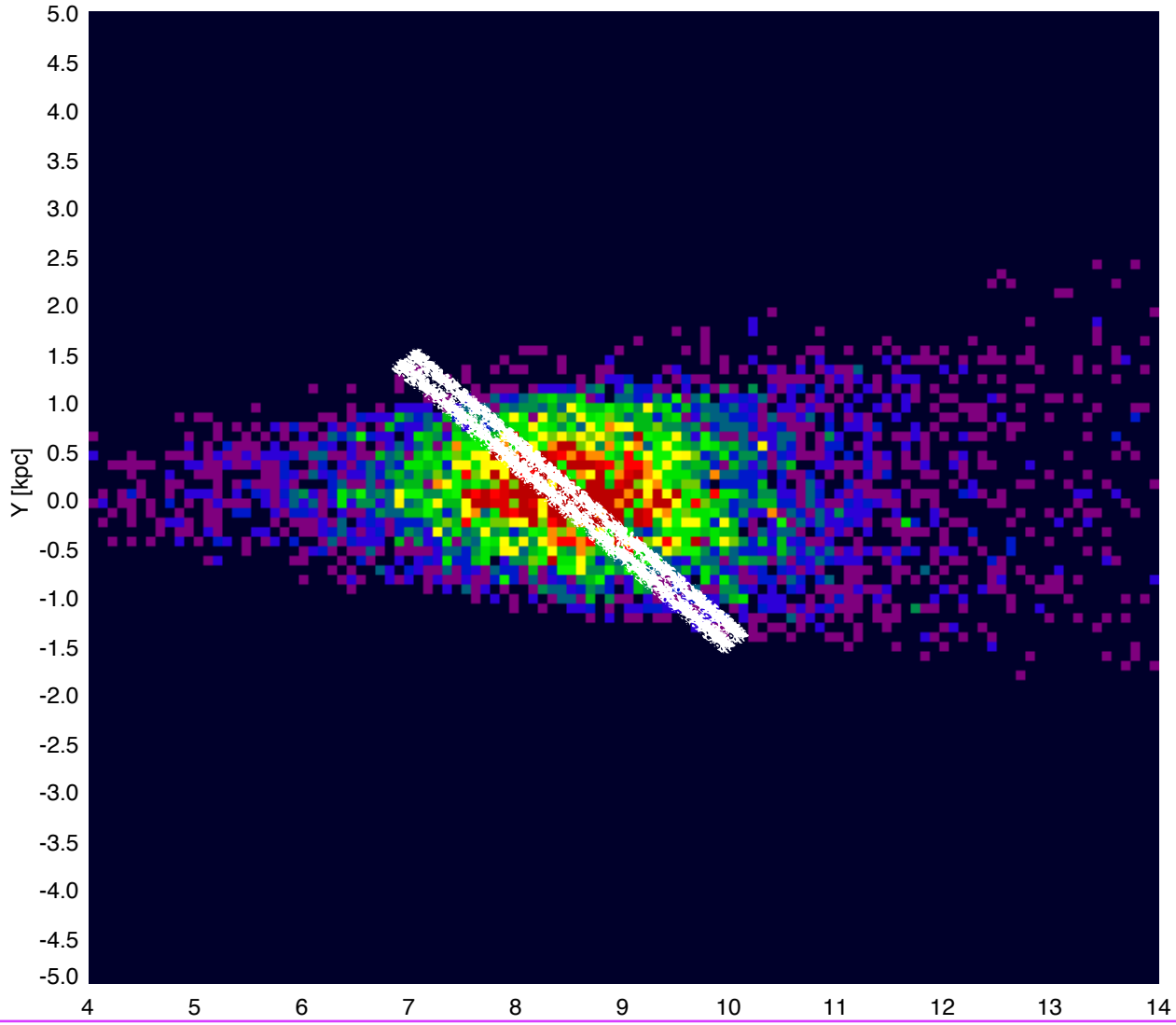




Dekany et al. ApJL 2013

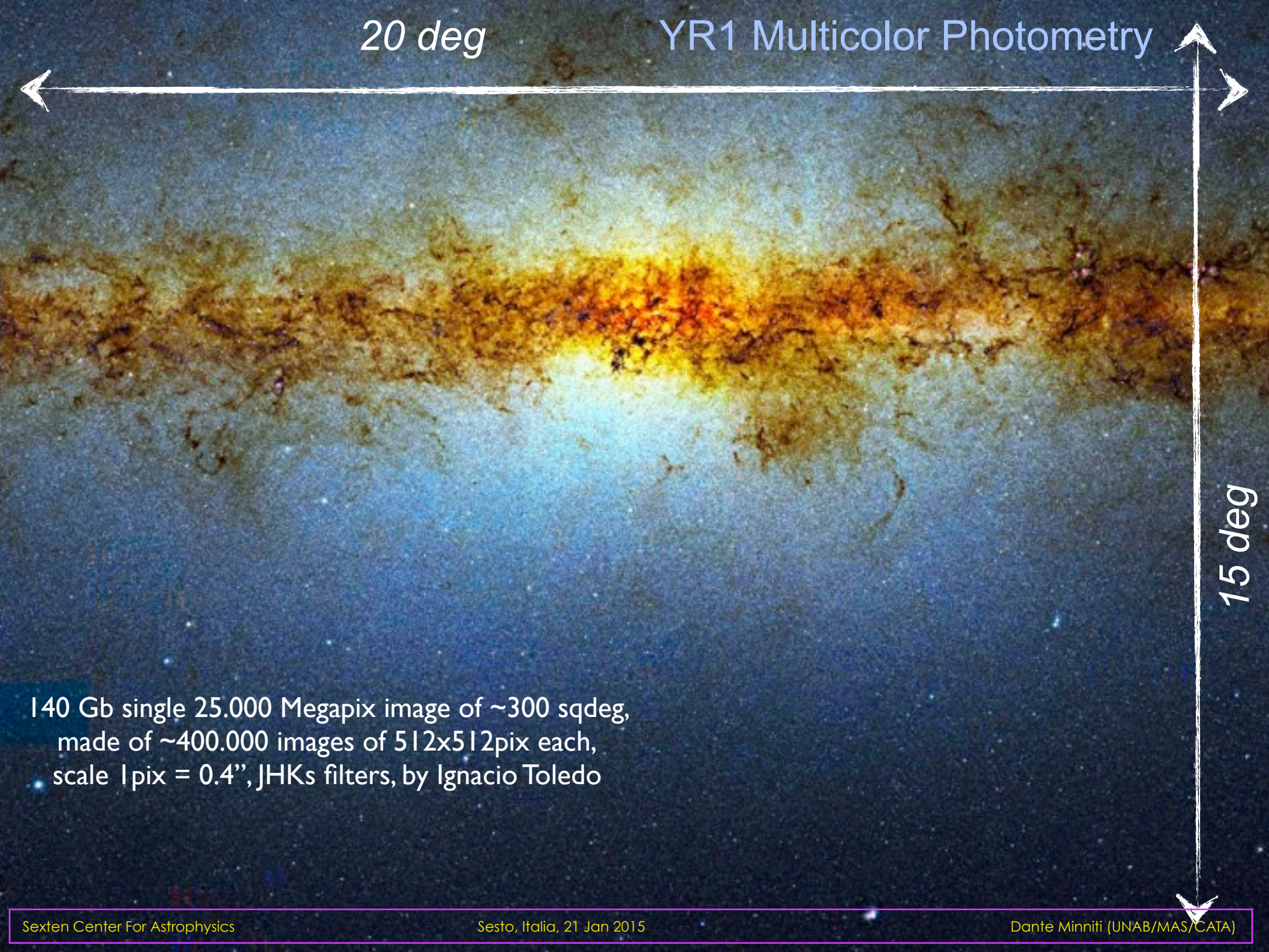
Bulge RR Lyrae

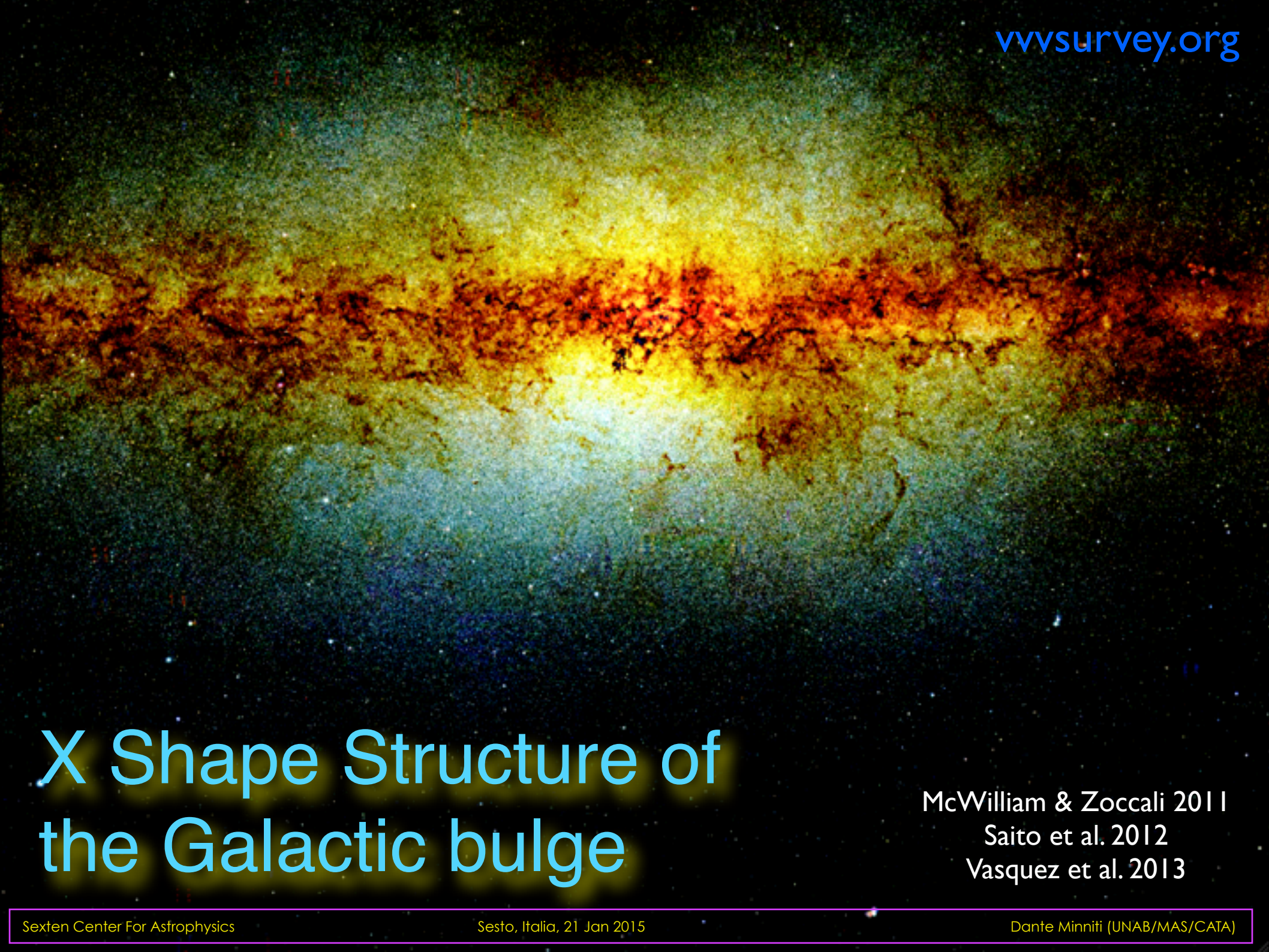
The VVV distance distribution of known bulge RR Lyrae is different from the clump giants!



Istvan Dekany, et al. 2013, ApJL

although see Pietrukowicz et al. 2014 Acta Astronomica


20 deg
YR1 Multicolor Photometry
15 deg
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



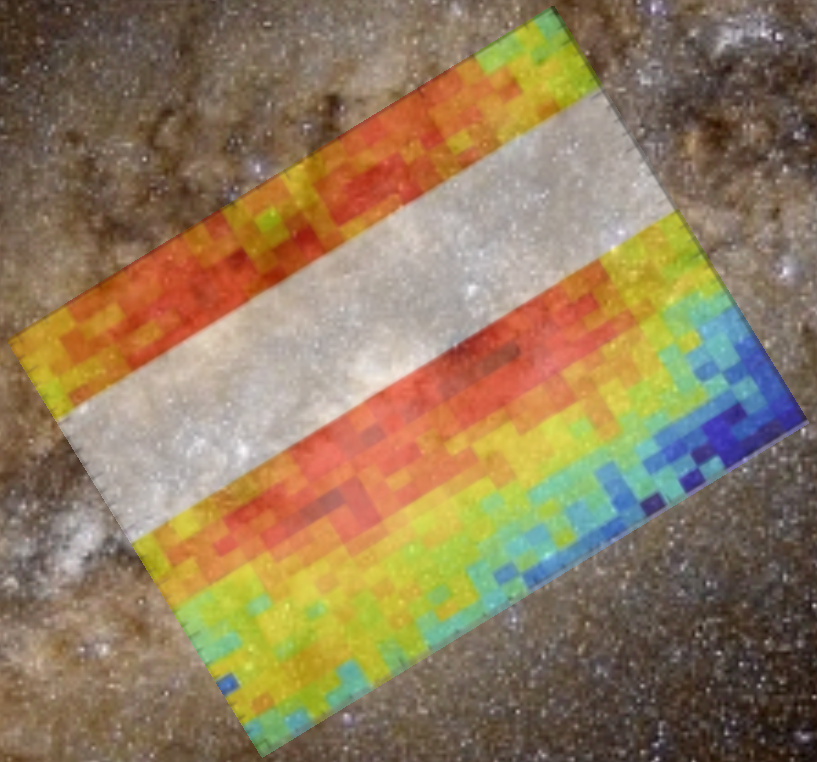
vvvsurvey.org

X Shape Structure of the Galactic bulge

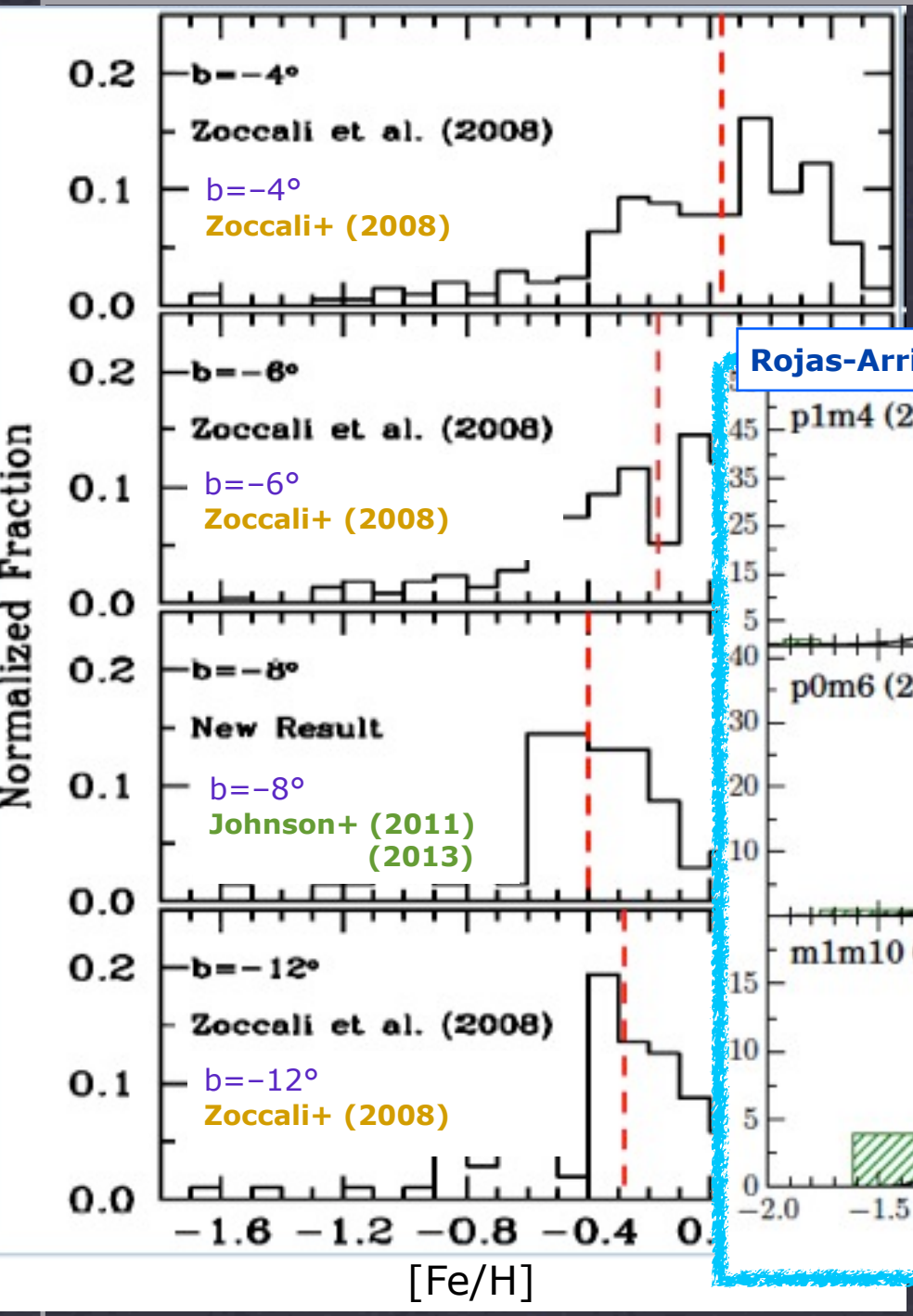
McWilliam & Zoccali 2011
Saito et al. 2012
Vasquez et al. 2013

The VVV global photometric reddening and metallicity maps of the Milky Way bulge

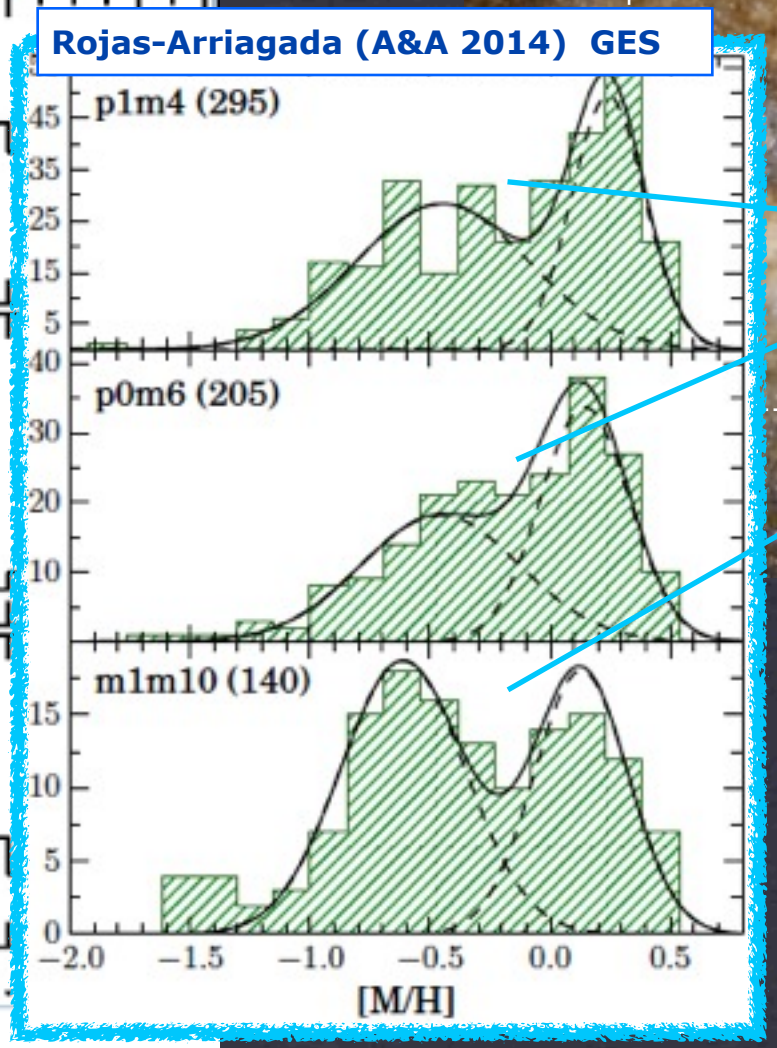
Gonzalez, Zoccali, et al. (2012, A&A)
Gonzalez, Rejkuba, Zoccali, et al. (2013, A&A)

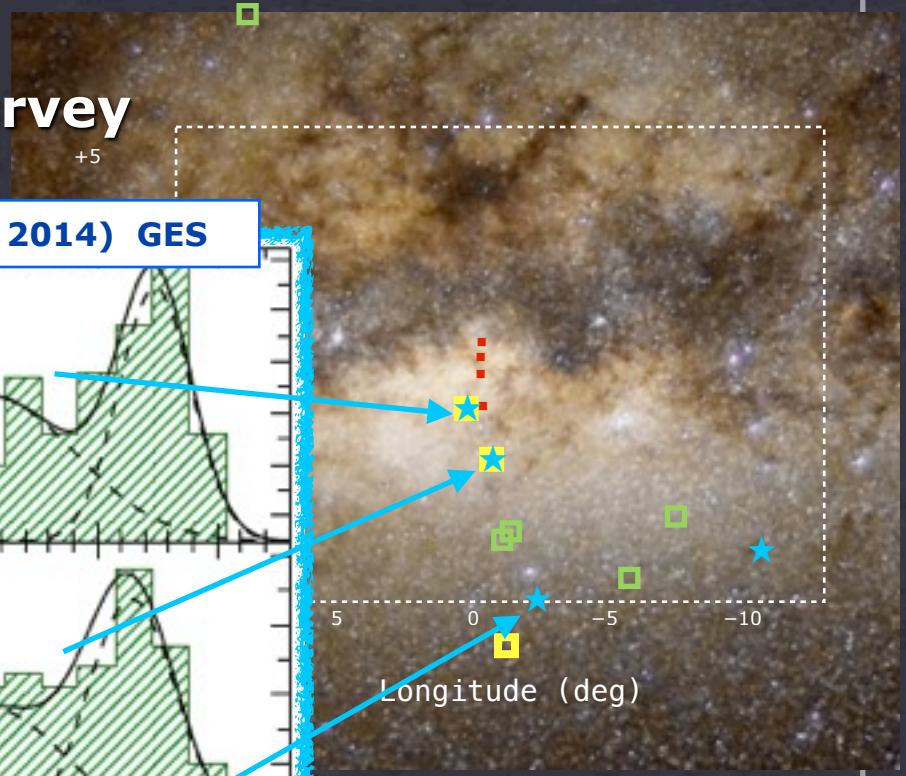


Bulge MDF



GES Survey

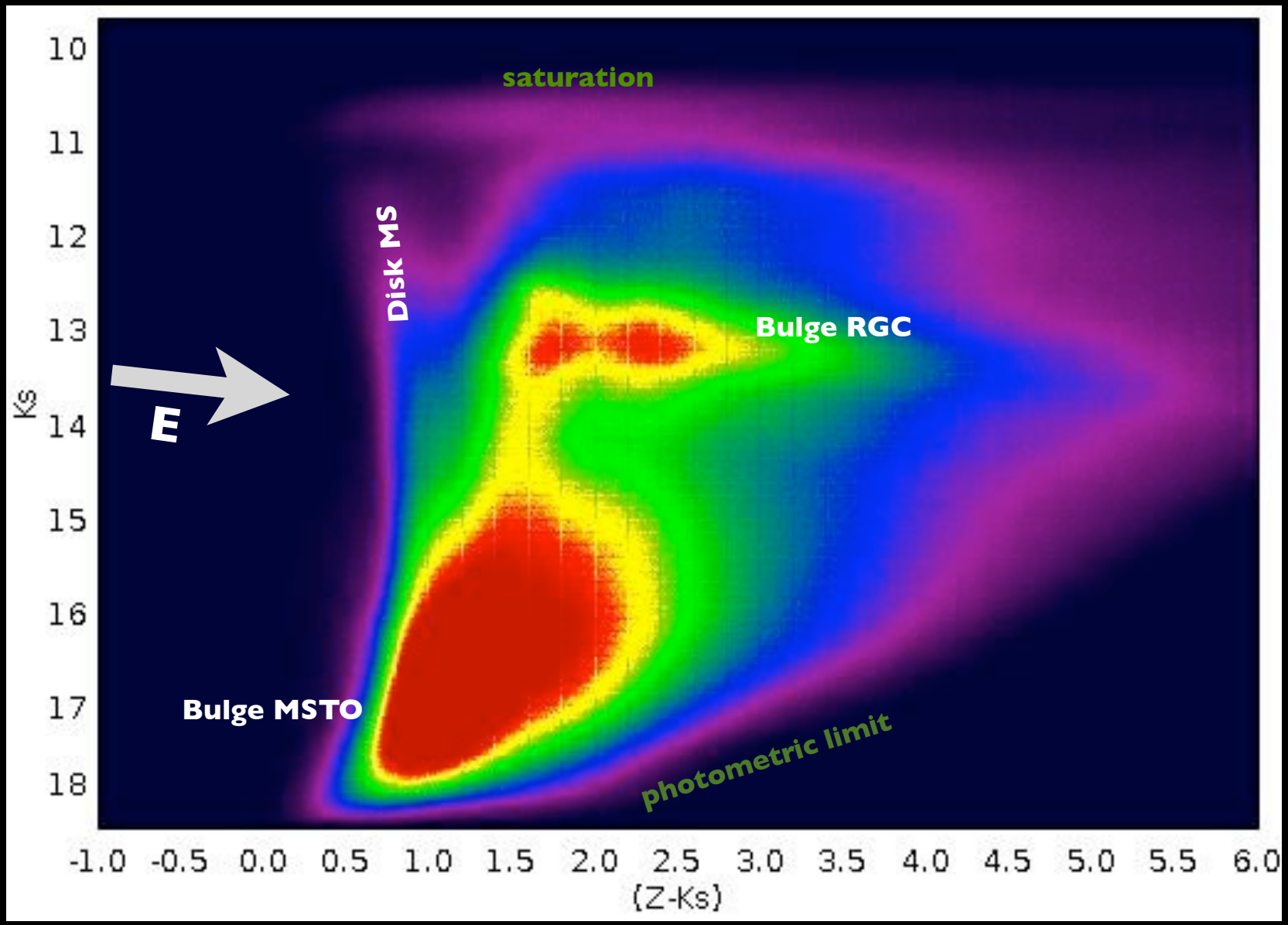




GIBS
GES
APOGEE
4MOST
…

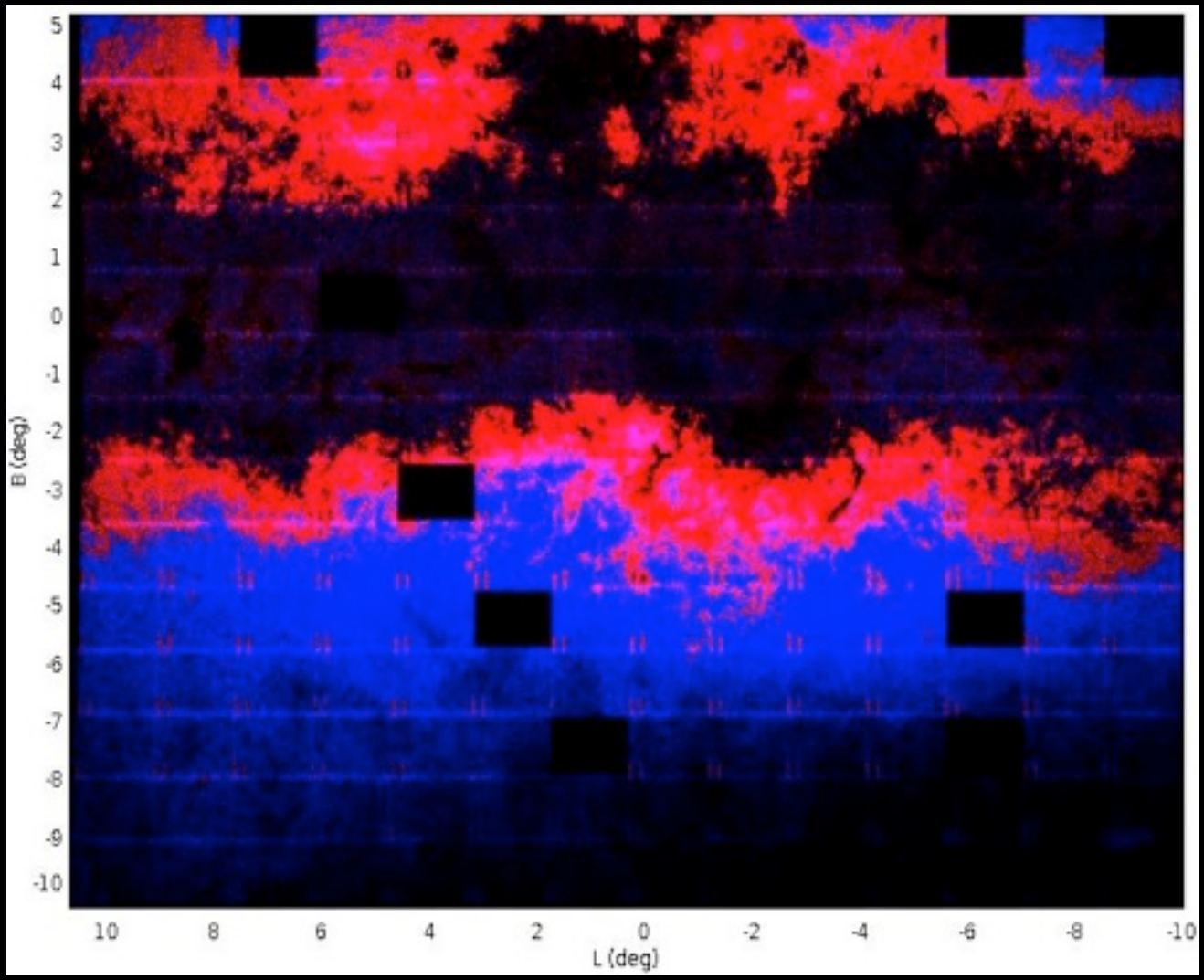
VVV feeding sources for spectroscopic surveys

VVV 157M STARS BULGE CMD



Mean red clump color difference (Z – Ks) = 0.55 mag, equivalent to AV = 2.0 mag

D. Minniti et al. 2014

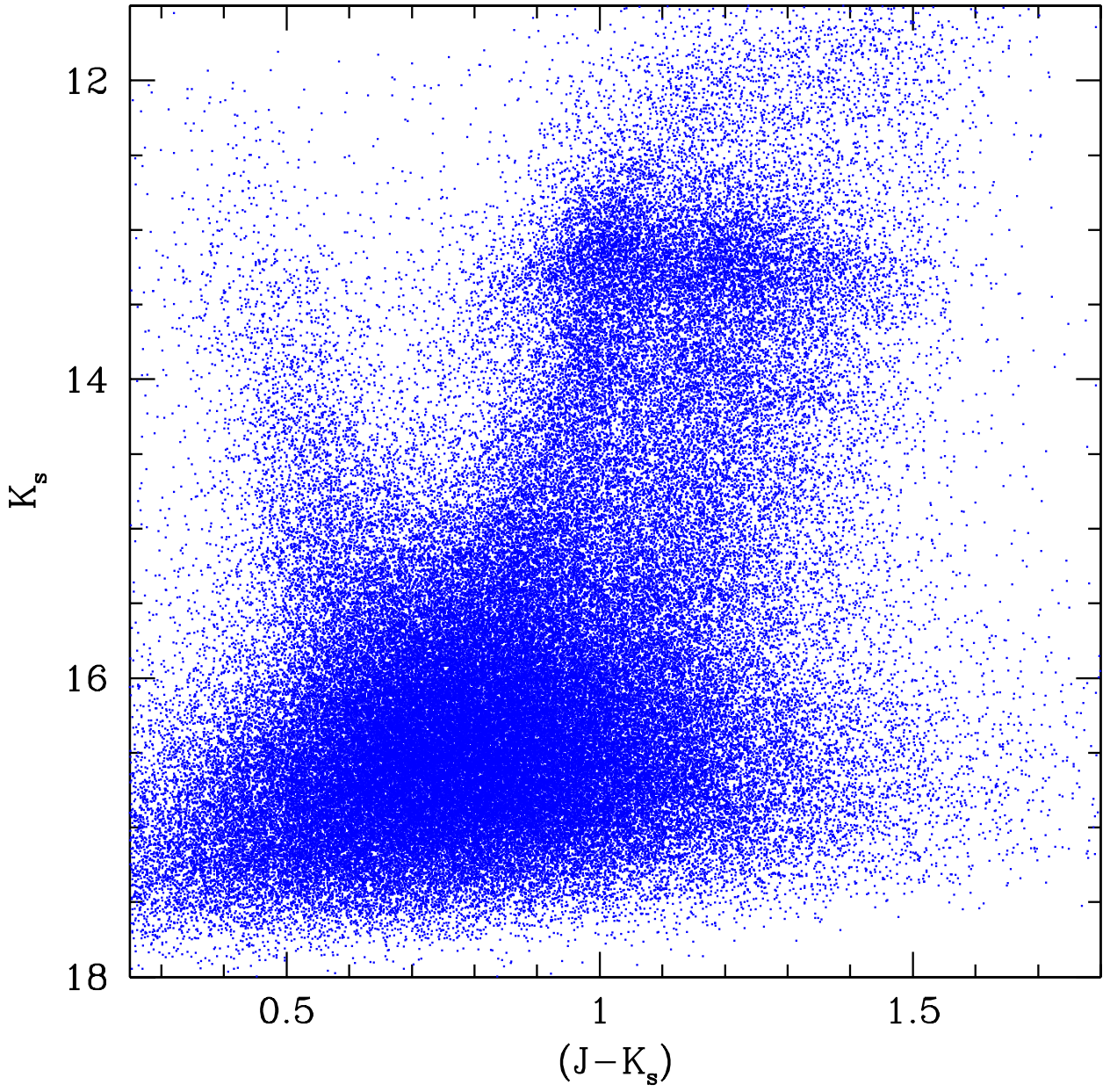


THE CMD REVEALS THE GALACTIC GREAT DARK LANE:

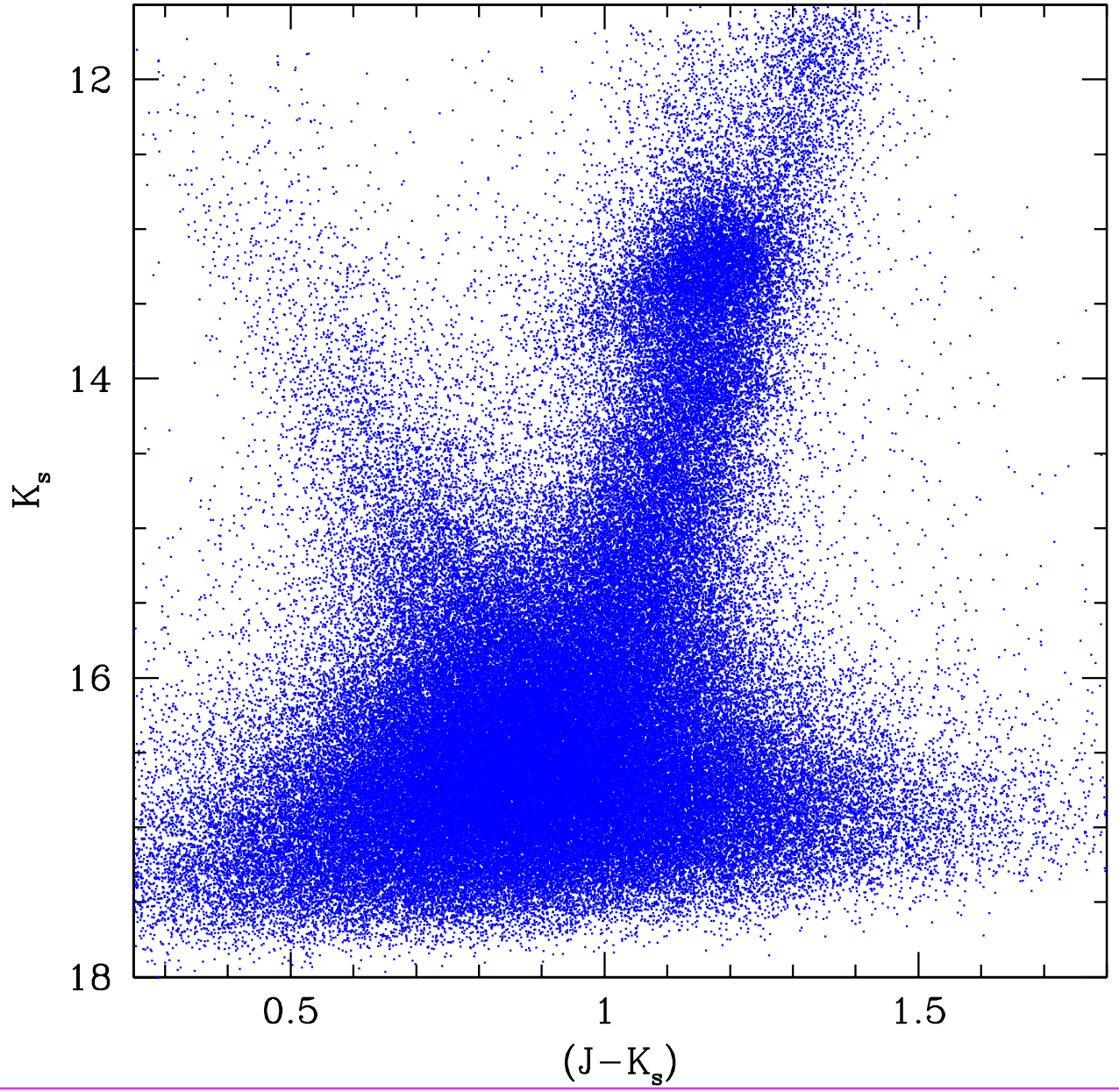
A COHERENT CLOUD STRUCTURE THAT STRETCHES FOR >20 DEG ABOVE AND BELOW THE PLANE OF THE MW

D. Minniti et al. 2014

VVV TILE B304 BULGE CMD



VVV TILE B248 BULGE CMD



The VVV Giga Bulge CMD

DoPhot PSF photometry of the bulge

J. Alonso, et al. 2015, in preparation

In Z, 667 million sources

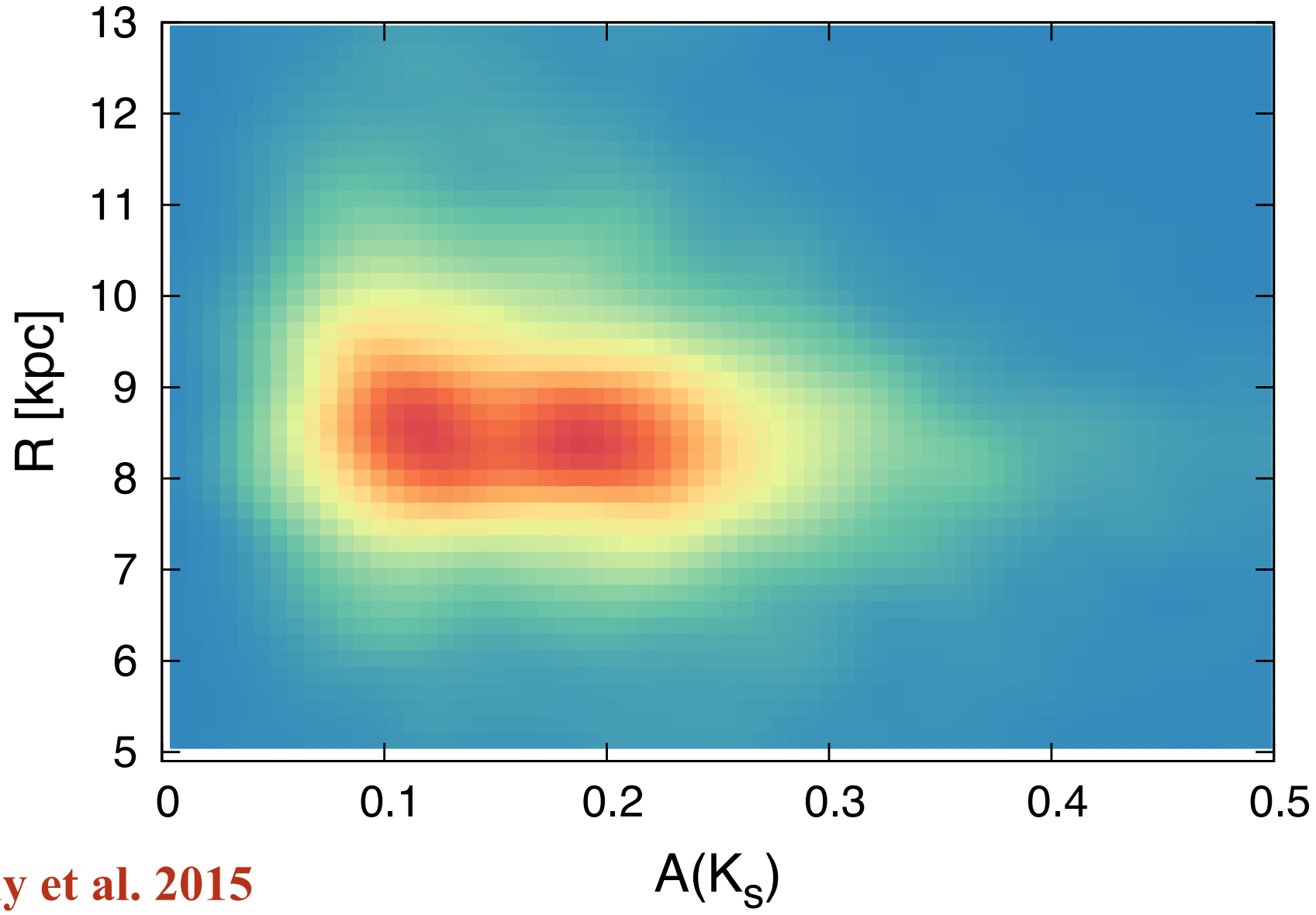
In Y, 707 million sources

In J, 922 million sources

In H, 990 million sources

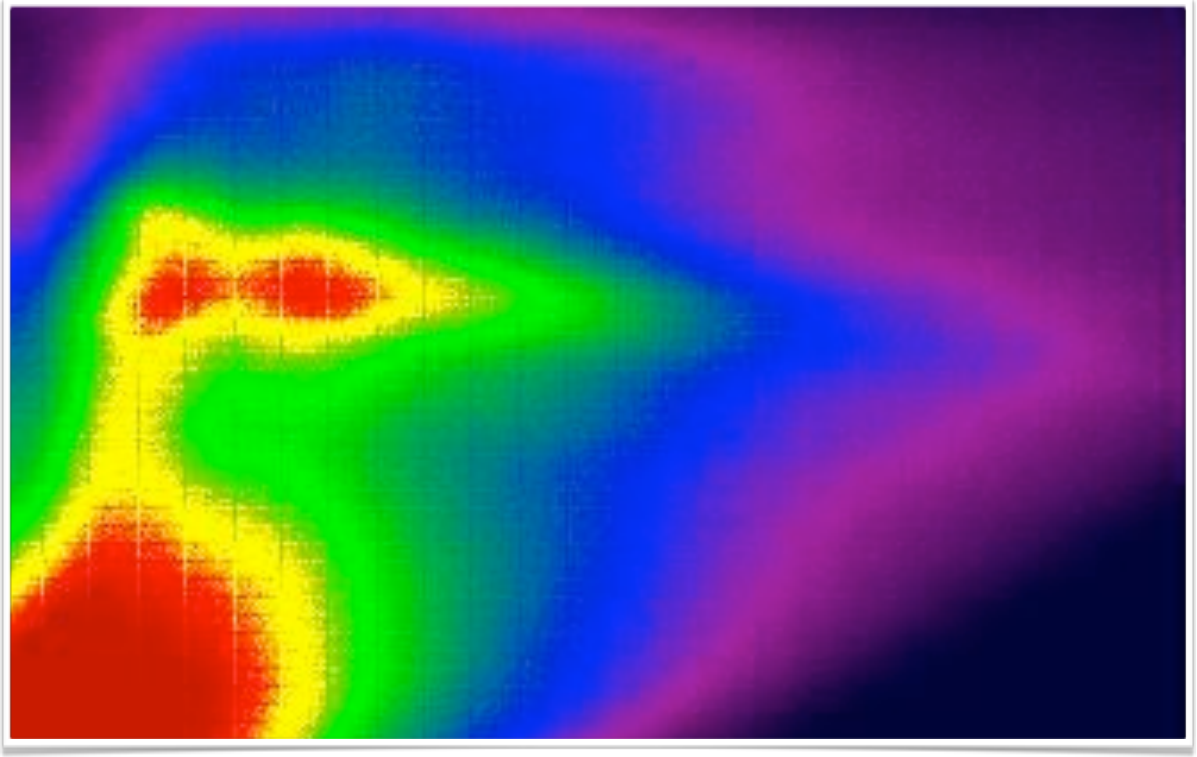
In Ks, 779 million sources

Ogle III RR Lyrae

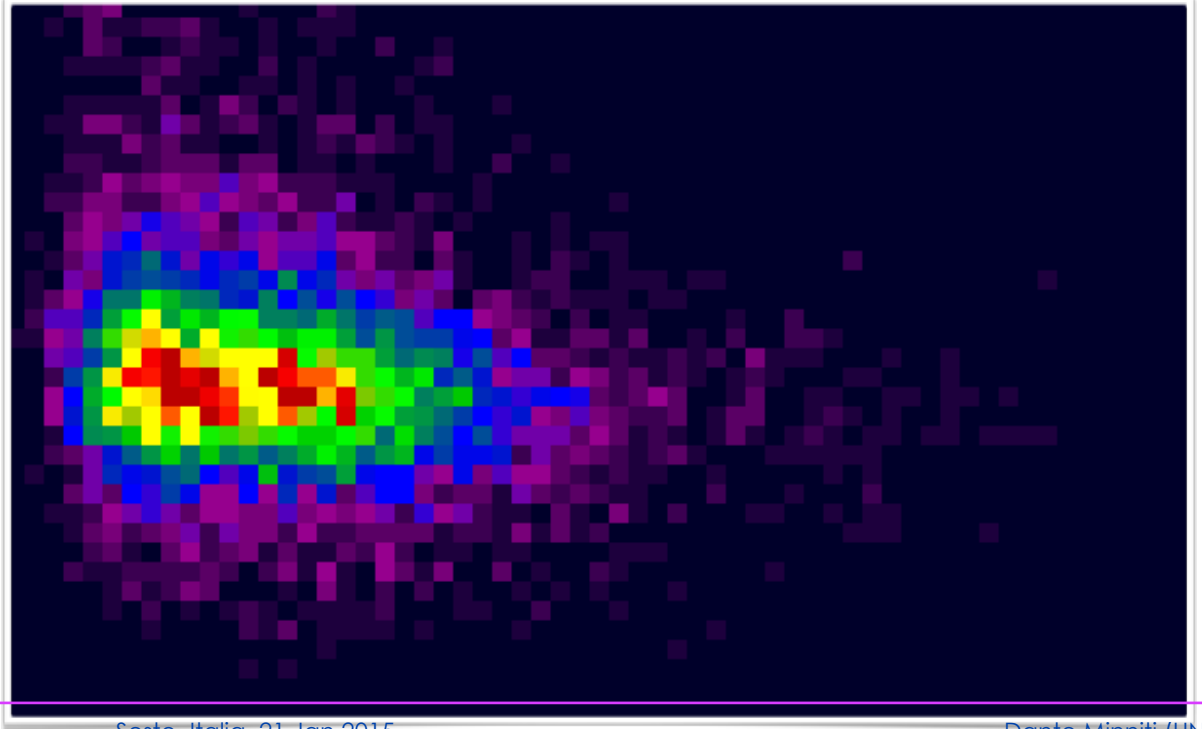


Dekany et al. 2015

Clump Giants



RR Lyrae

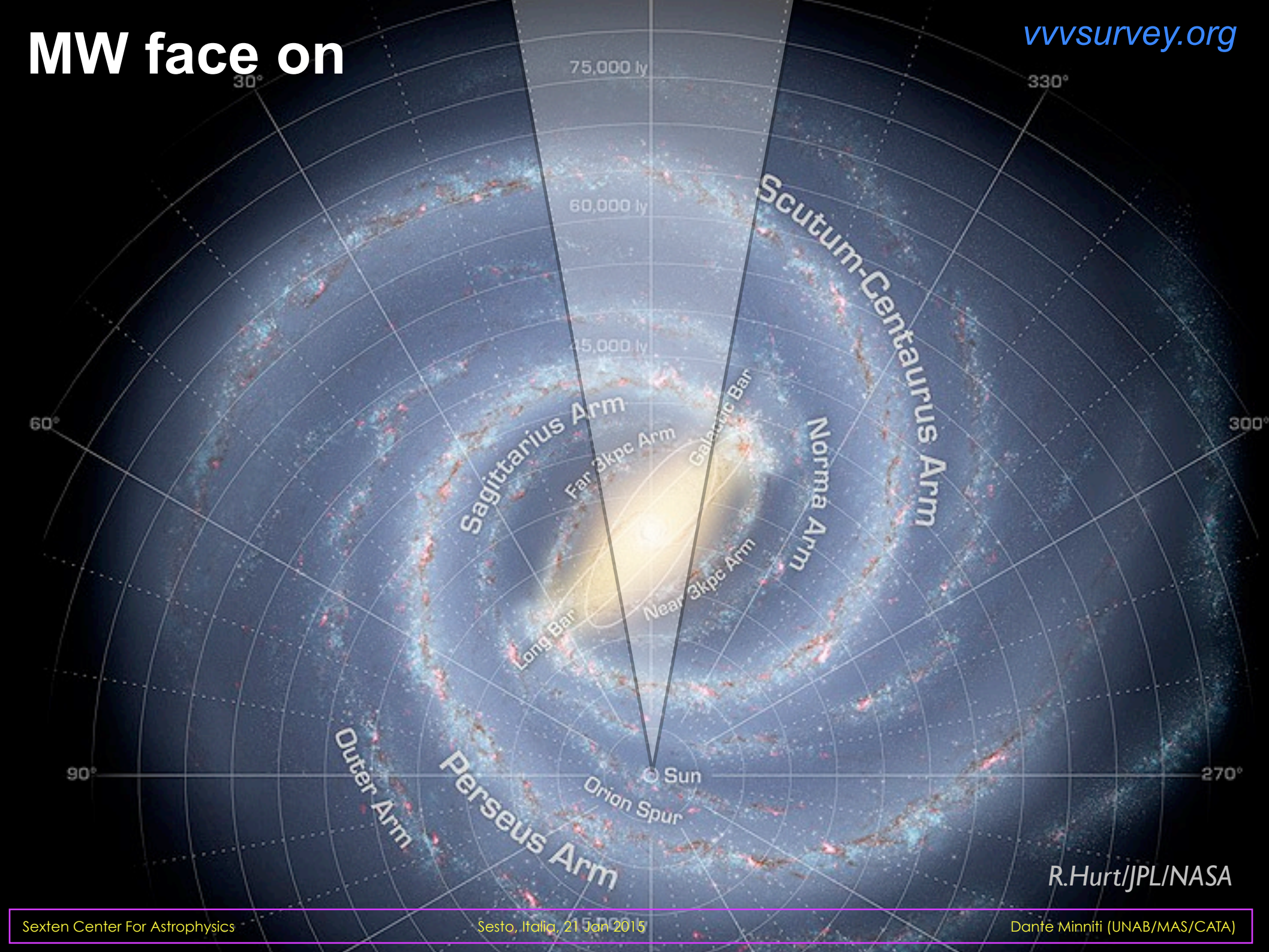


THIS IS REAL !

Dekany et al. 2015

MW face on

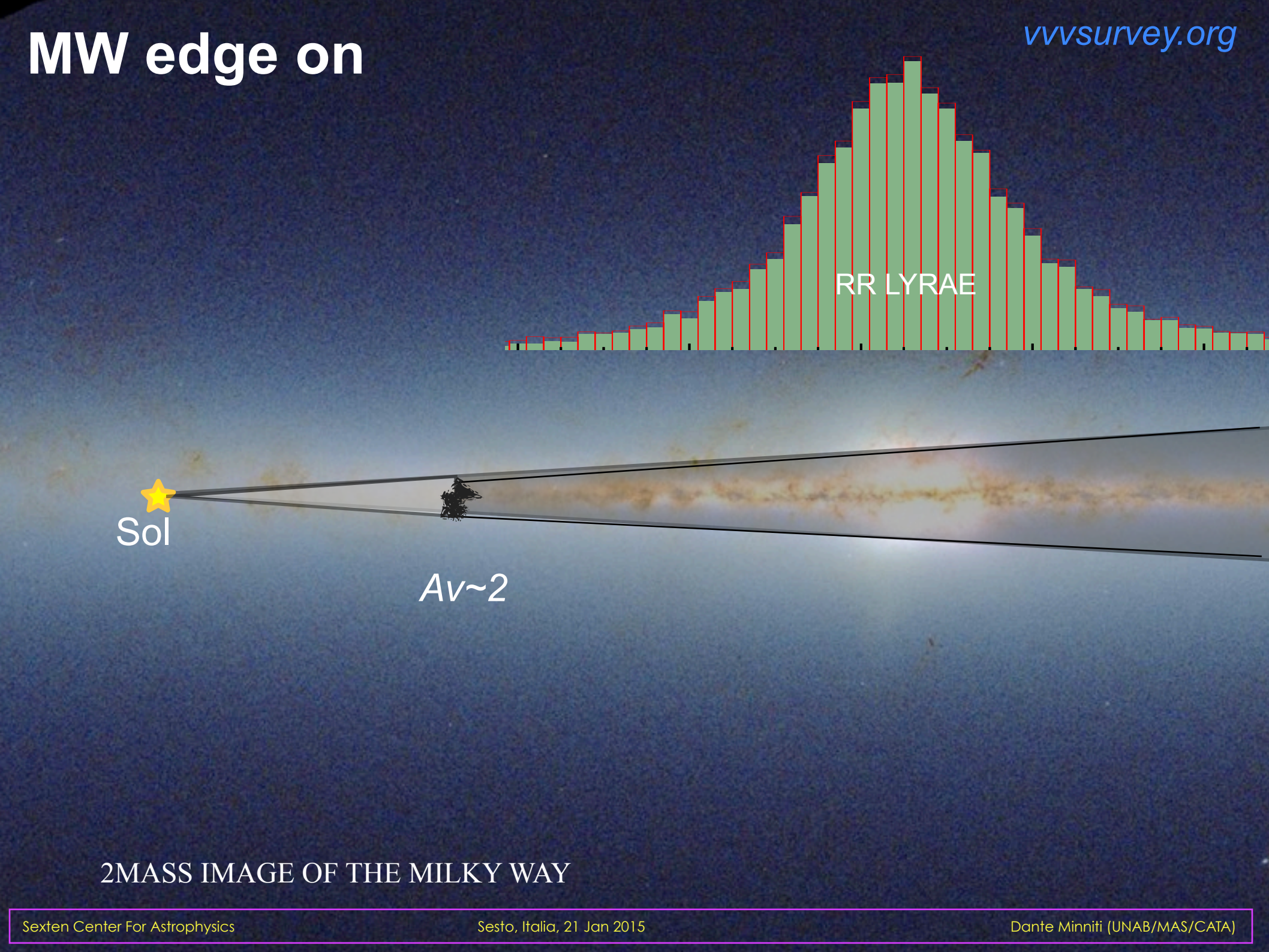
vvvsurvey.org



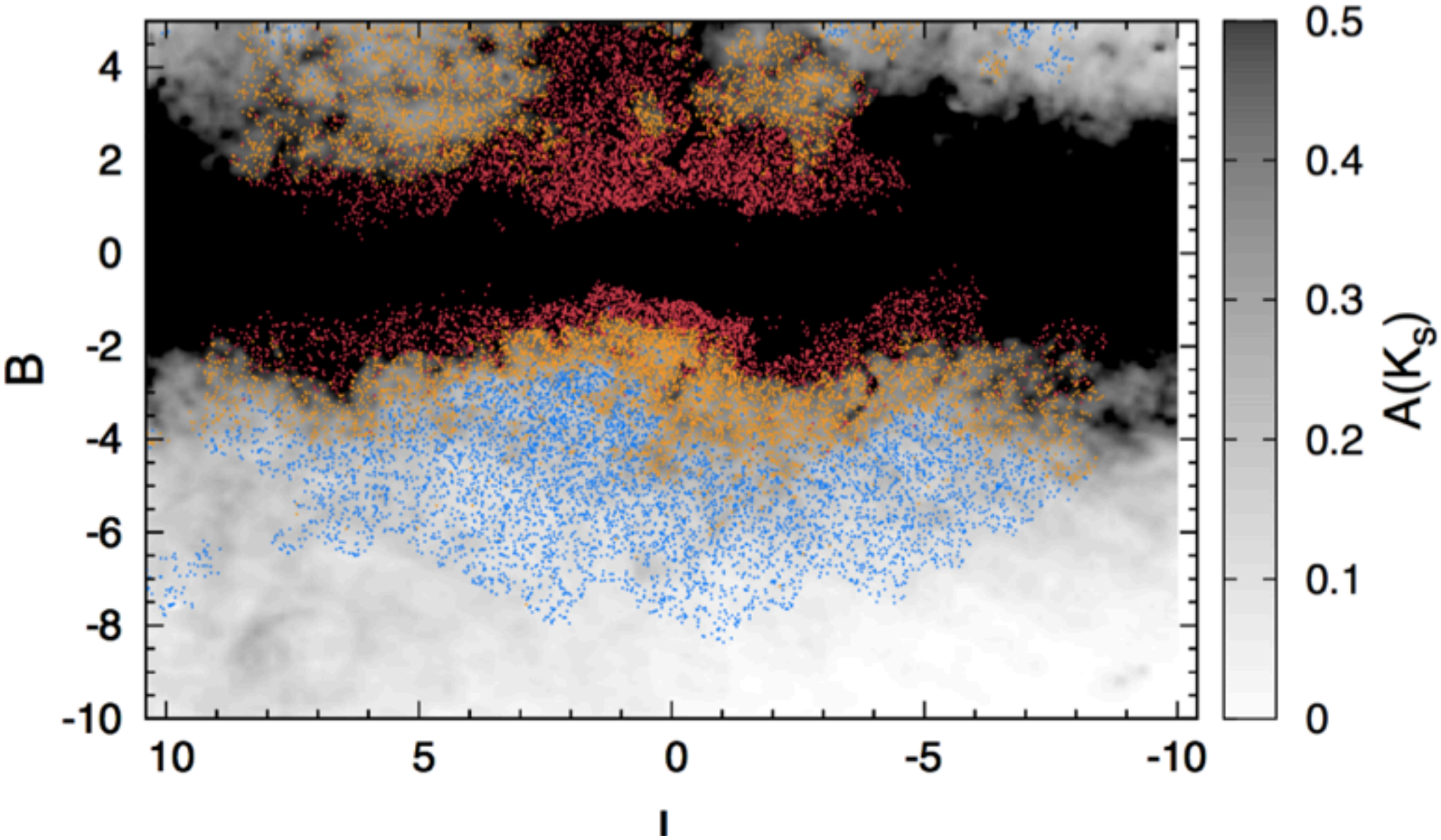
R.Hurt/JPL/NASA

MW edge on

vvvsurvey.org



Ogle IV RR Lyrae



Dekany et al. 2015

VVV Survey | Exploring the Milky Way bulge and southern disk on the near-IR with ESO´s VISTA Telescope

vvvsurvey.drupalgardens.com

ADS 2.0 - Index | Núcleo Milen... | Vía Láctea | Pre-generate...lanet Plots | Argentinos en Chile | UC | SAO/NASA ADS | Astrophysics | Gmail: Email from Google | Apple | Google Maps

CASU | Contact | ESO | Forums | Search

VVV Survey

VVV Survey

Exploring the Milky Way bulge and southern disk on the near-IR with ESO´s VISTA Telescope

Home | About | Team | Data Releases | Papers | Meetings | Outreach | VISTA

vvvsurvey.org

Search

The VVV Survey

VVV Science Meetings

Discoveries

Globular Clusters
Open Clusters (incl. WR clusters)
Galactic Novae and other transients
Nearby Brown Dwarfs
Companions to Nearby Stars
Galaxies & Clusters in the Avoidance Zone
IR Counterparts of High Energy Sources
Candidate microlensing events
Candidate extrasolar planetary transits
Variable stars in clusters

Conclusions

- We are more than half way through the VVV Survey, with everything working well.

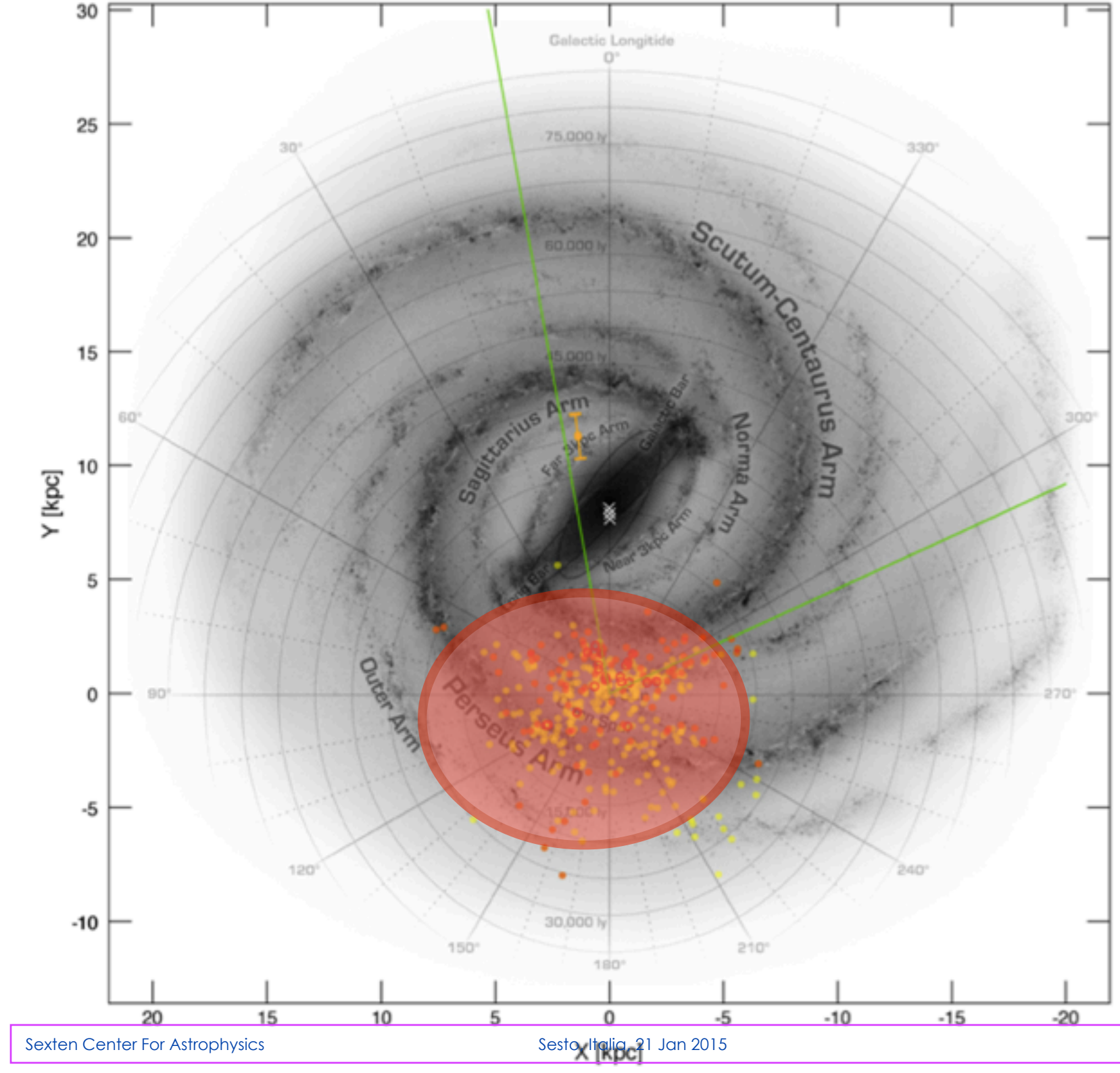
- Several discoveries have been made, with many more to come.

- We need help following up spectroscopically a wide variety of targets.

VVV
Survey

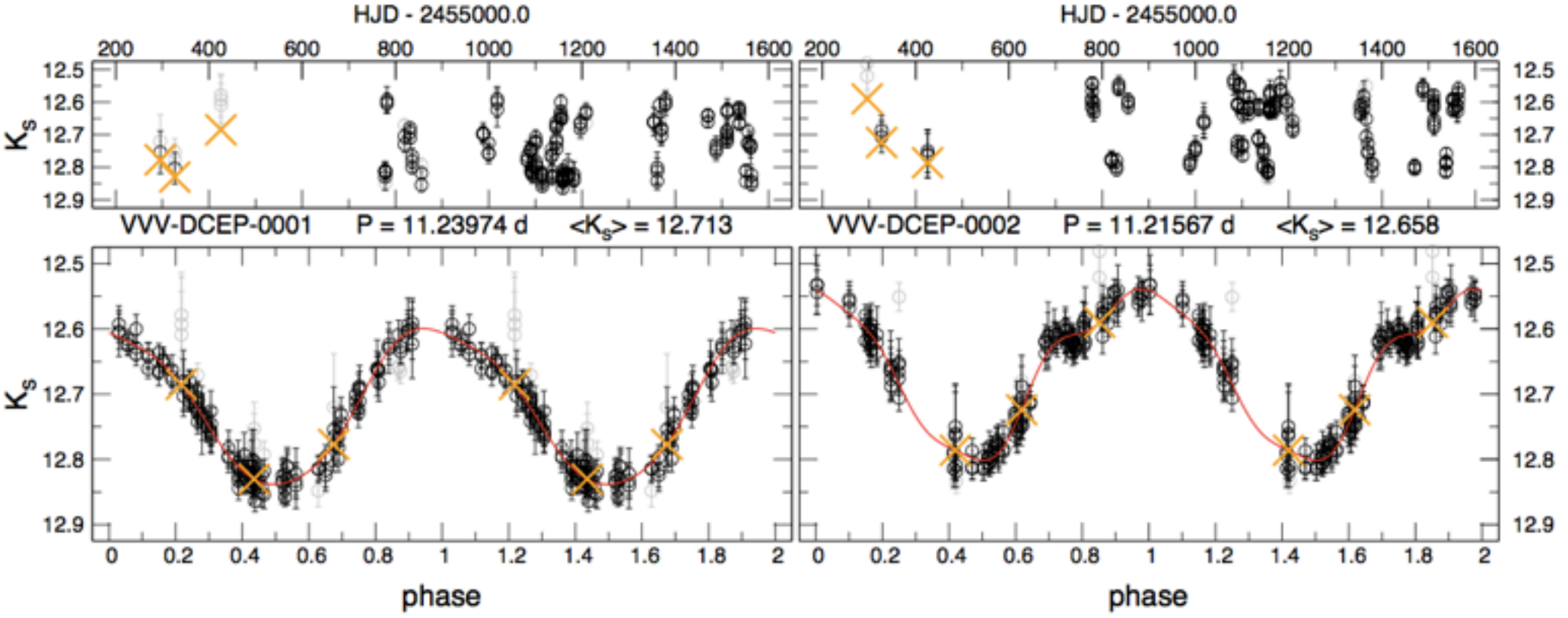
CEPHEIDS IN THE GALACTIC DISK

I. Dekany et al.
ApJL 2015



I. Dekany et al.
ApJL 2015

CEPHEIDS IN THE GALACTIC DISK

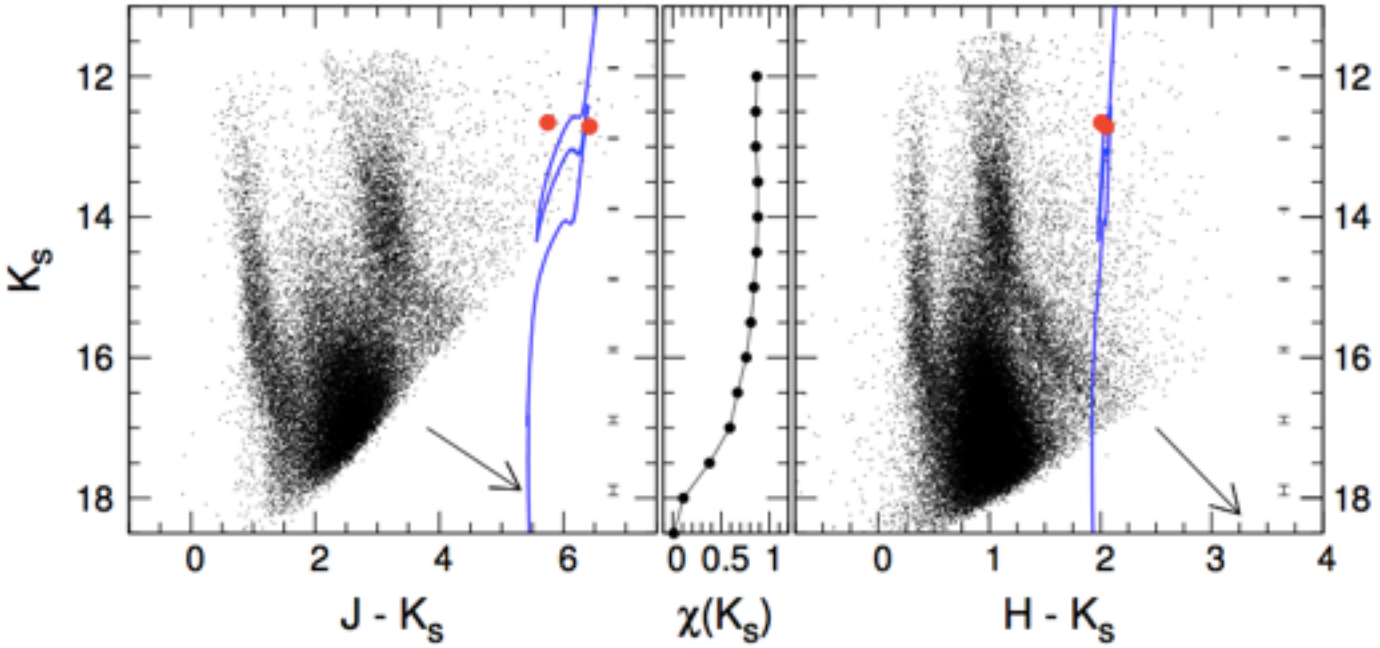


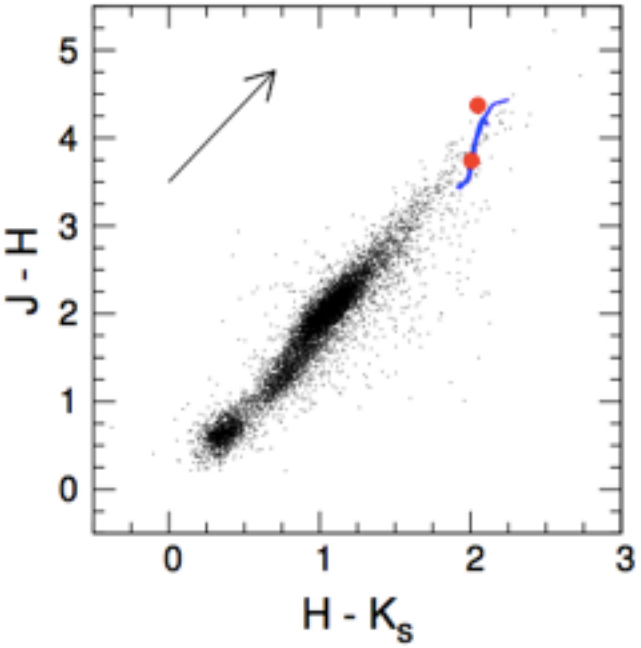
I. Dekany et al.
ApJL 2015

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

CEPHEIDS IN THE GALACTIC DISK

AN INVISIBLE MASSIVE OPEN CLUSTER HIDDEN BEHIND Av~32





I. Dekany et al.
ApJL 2015

Star	$a_{tot.}$[a] (K_s)	$\langle K_s \rangle$	$\langle H-K_s \rangle$	$\langle J-K_s \rangle$	$E(H-K_s)$	$A(K_s)$[b]	R [pc]
C1	0.24	12.71	2.05	6.42	2.00	3.27	11337
C2	0.26	12.66	2.01	5.75	1.96	3.20	11397

The VVV Survey: A New Exploration of the Milky Way

exploring our own galaxy,
fostering Southern collaborations,
promoting Astrophysics at all levels, &
securing resources for the future generations.