Credit: ESO

The VVV Survey:

Charting the Milky Way's Bulge and Disk

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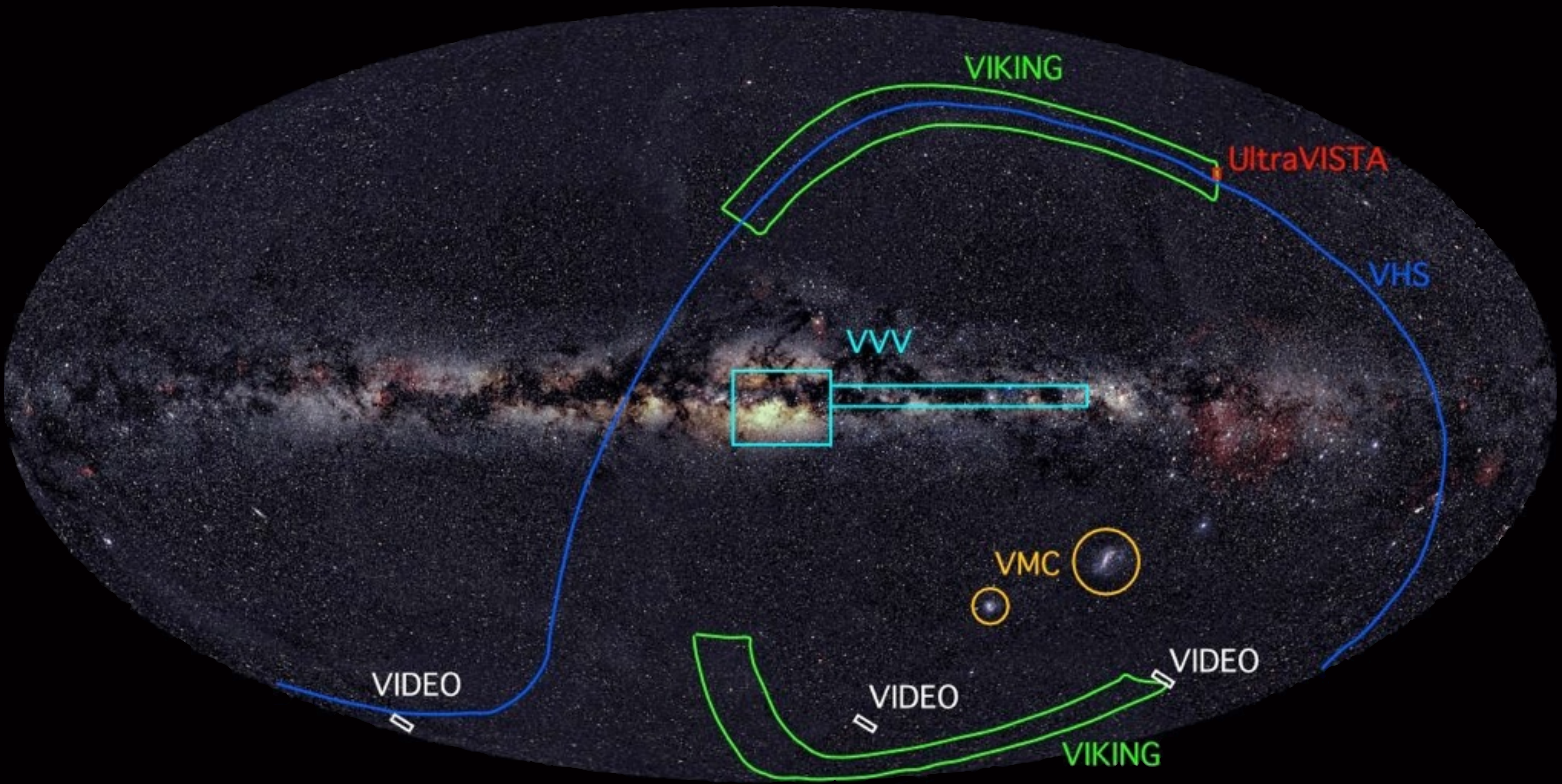
Millennium Institute for Astrophysics, Santiago, Chile

Pontificia Universidad Católica de Chile

VISTA Public Surveys

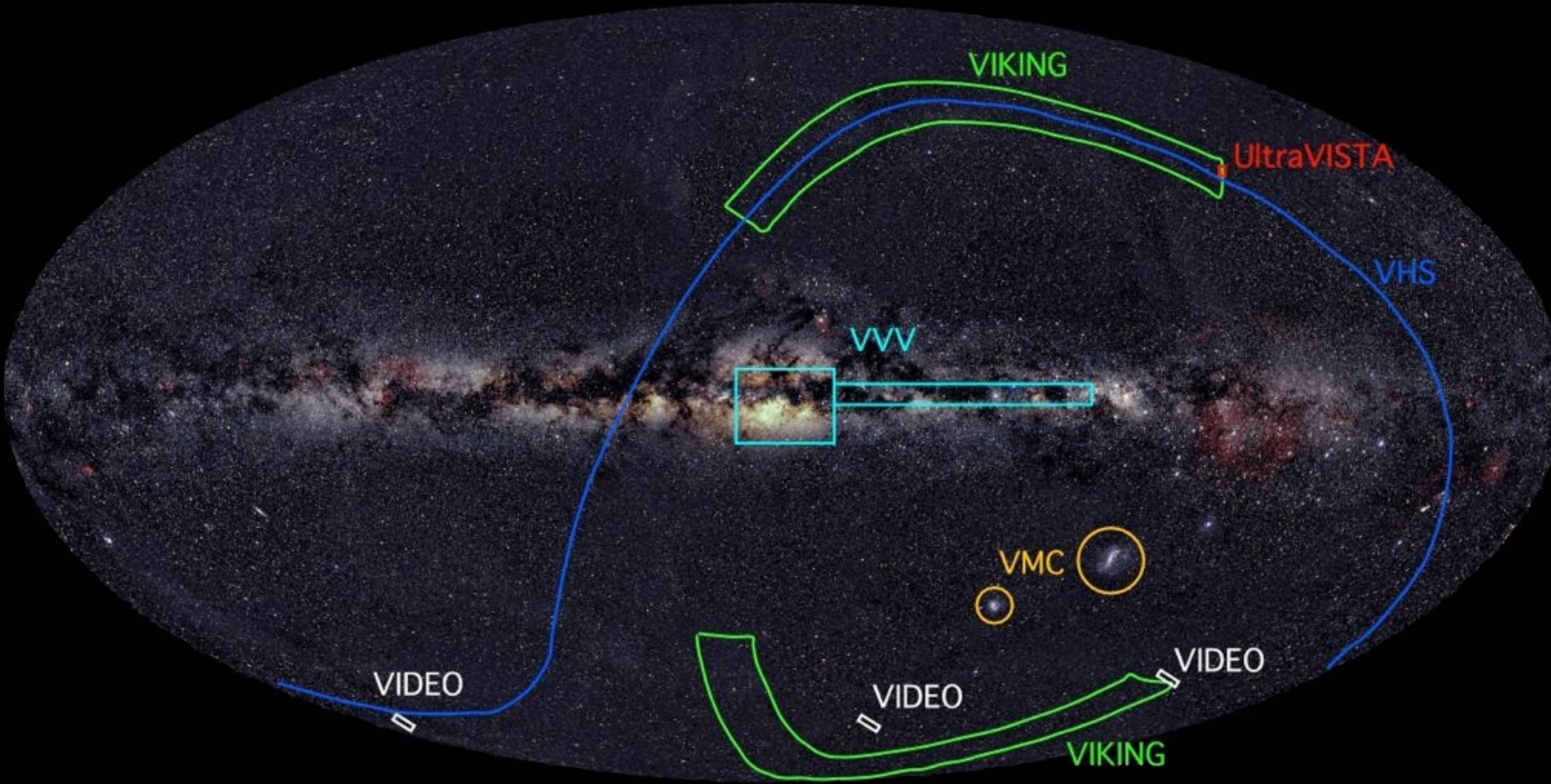


VISTA PUBLIC SURVEYS

VVV: VISTA Variables in the Vía Láctea

Near-IR time-domain photometric survey of the Galactic bulge and inner disk

PI: Dante Minniti, Chile co-PI: Philip Lucas, UK



VISTA PUBLIC SURVEYS

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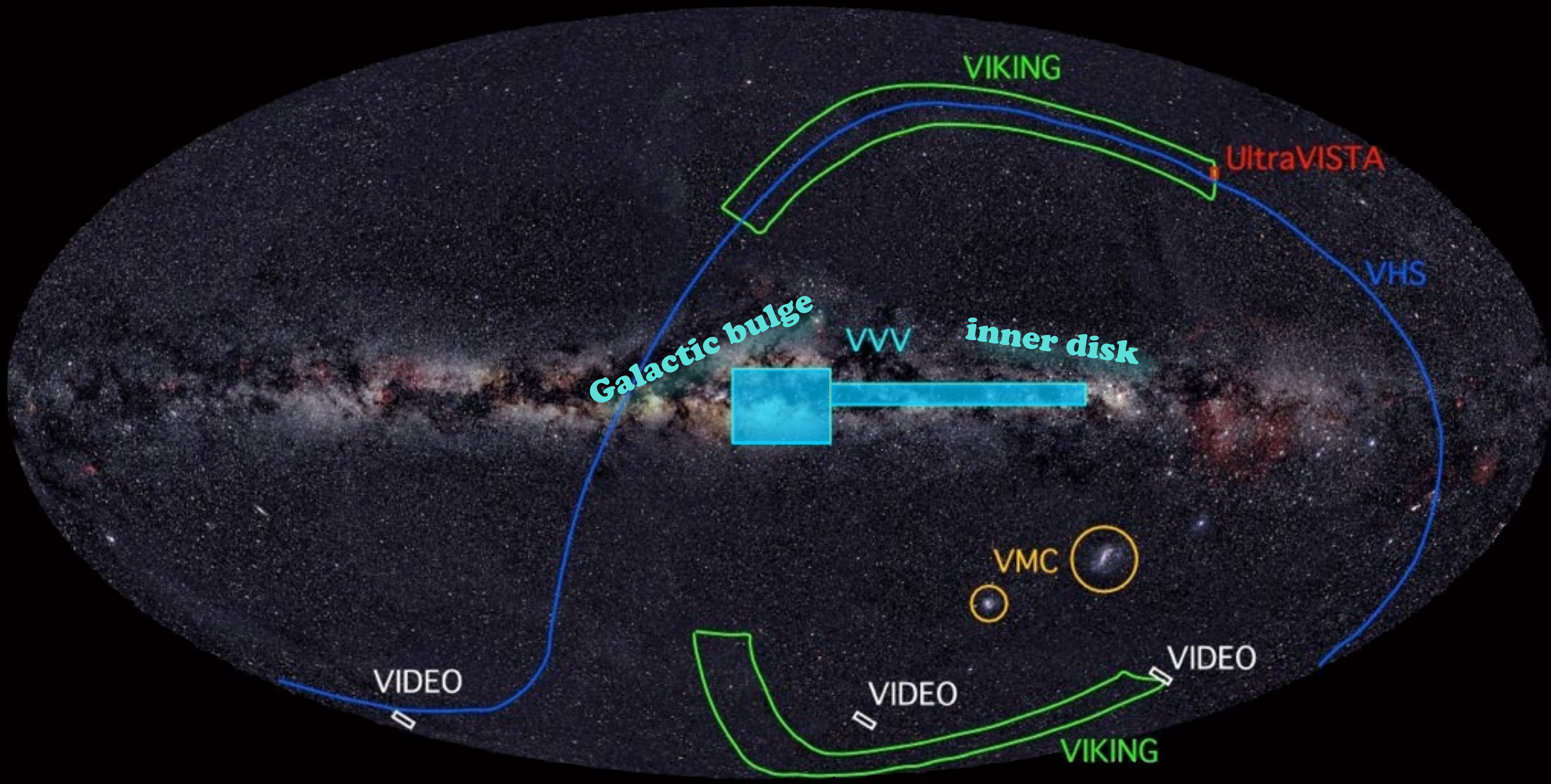
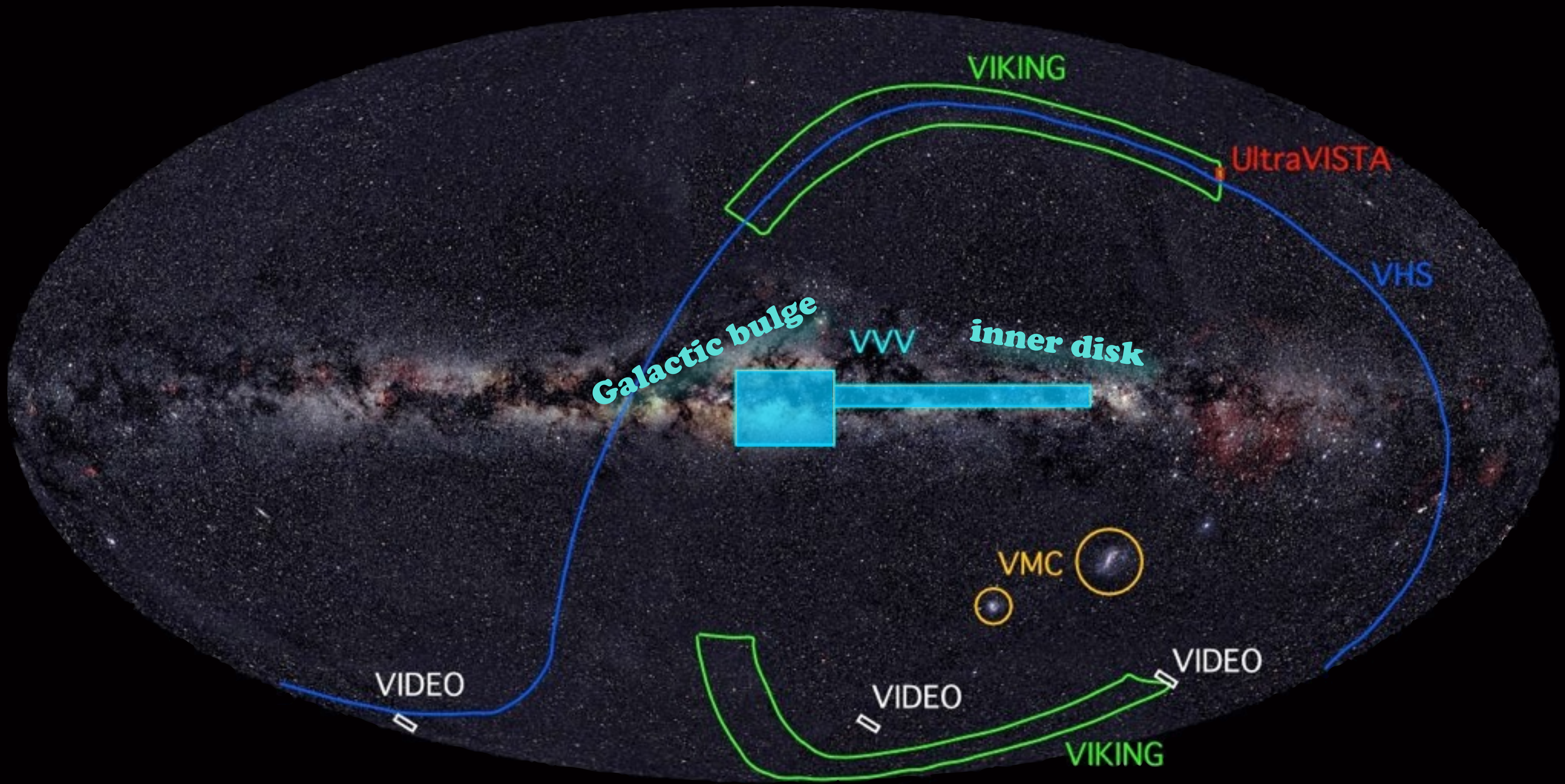


VISTA PUBLIC SURVEYS

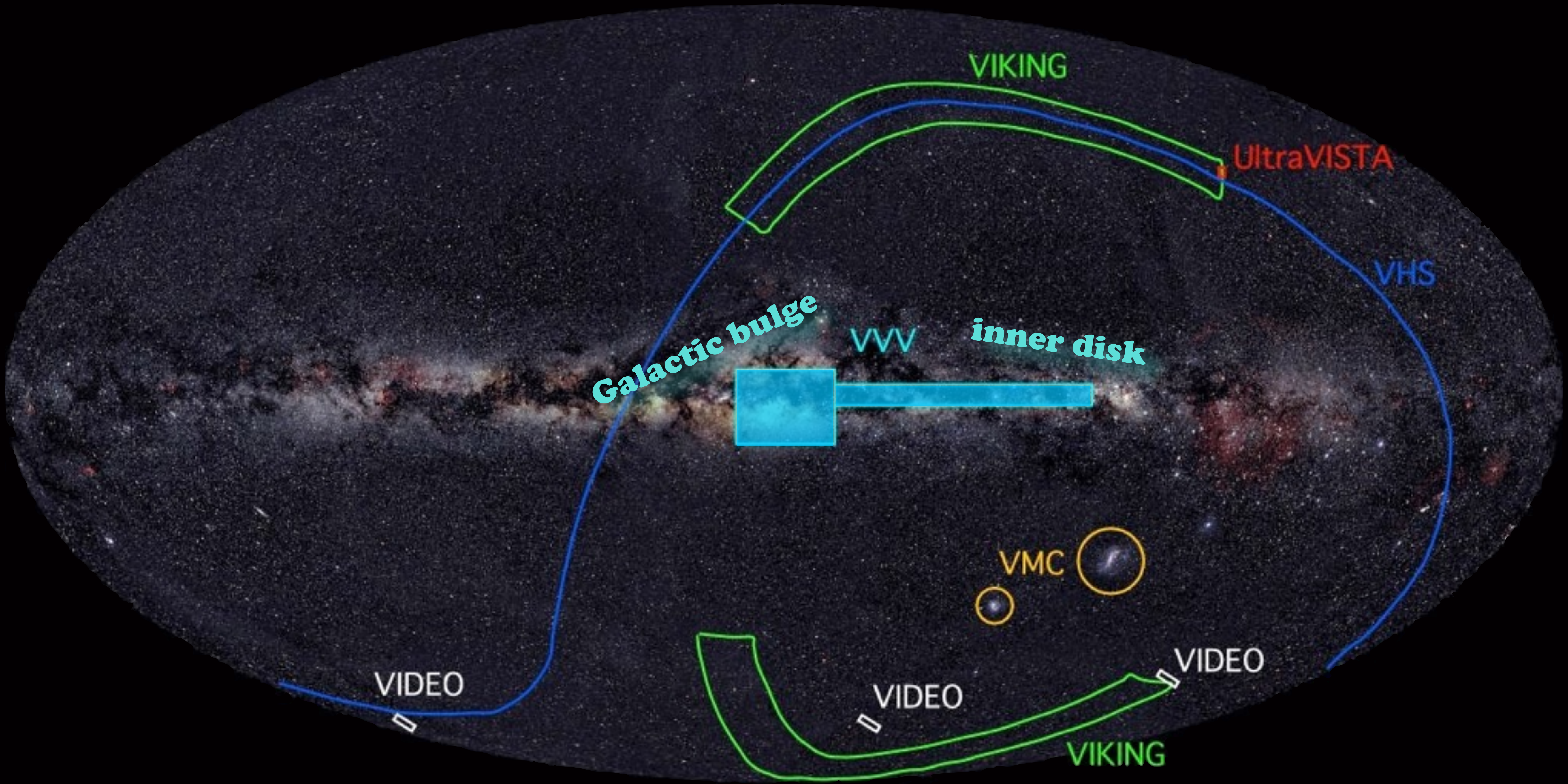
VVV: 520 square degrees
2000 hours
7 years



VISTA Public Surveys

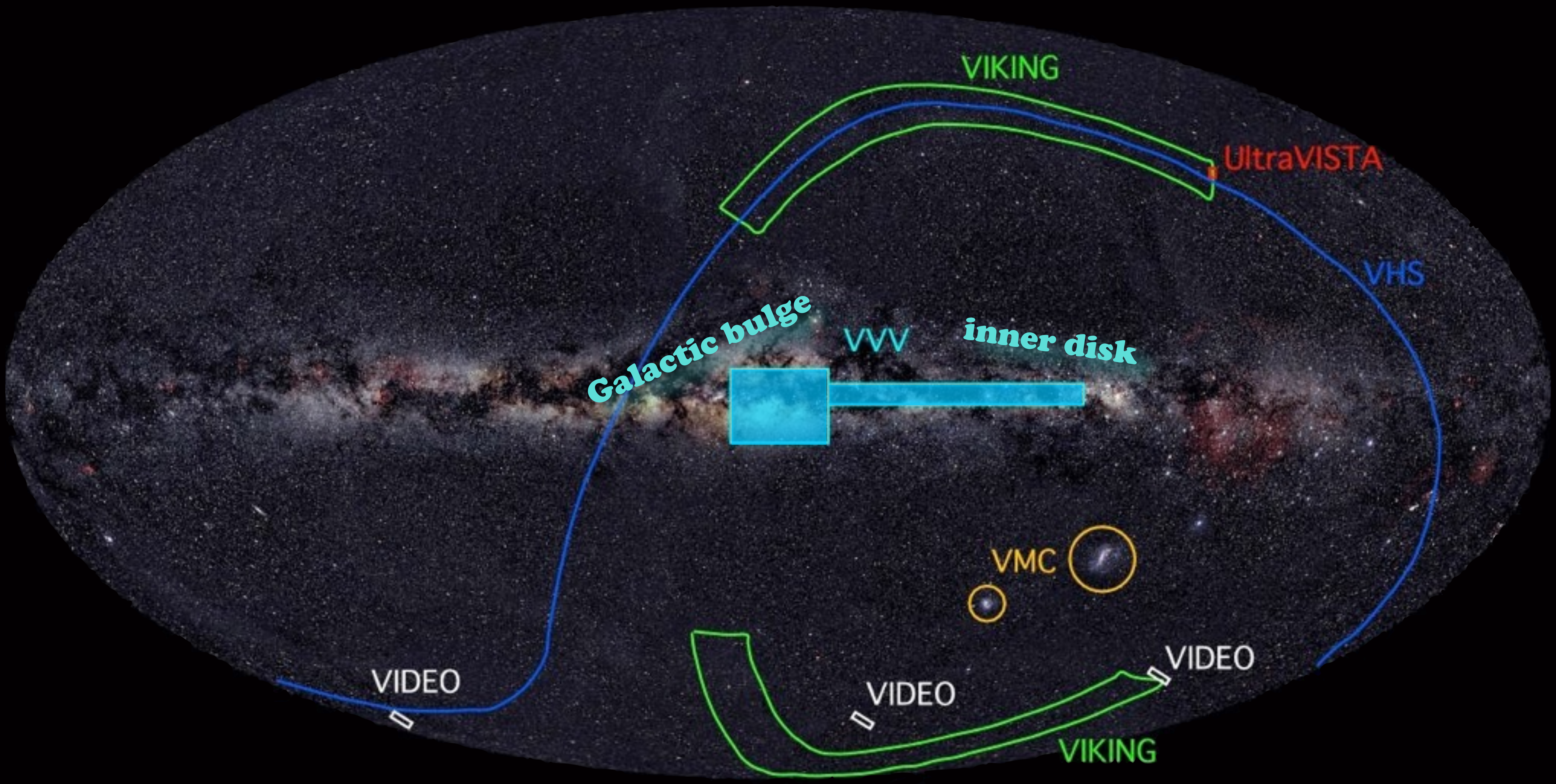
VVV:

520 square degrees	ZYJHKs atlas (single epoch)
2000 hours	up to ~100 epochs in Ks
7 years	1 billion objects, 1 million variables



VISTA PUBLIC SURVEYS

VVV: the *first* and *only* near-IR time-domain survey of the bulge and southern disk



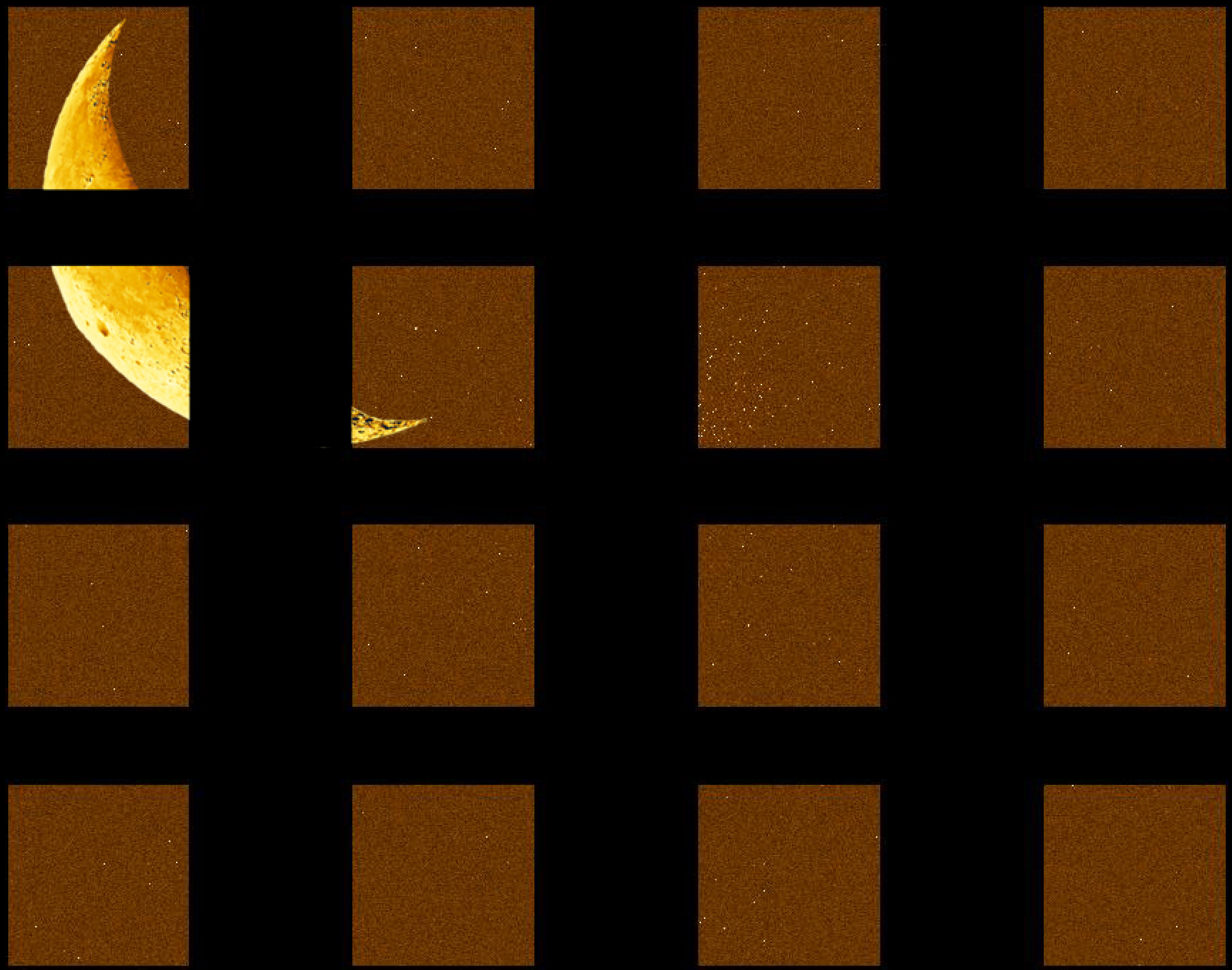
VISTA (Visible and Infrared Survey Telescope for Astronomy)

4.1 m telescope

f / 3.25

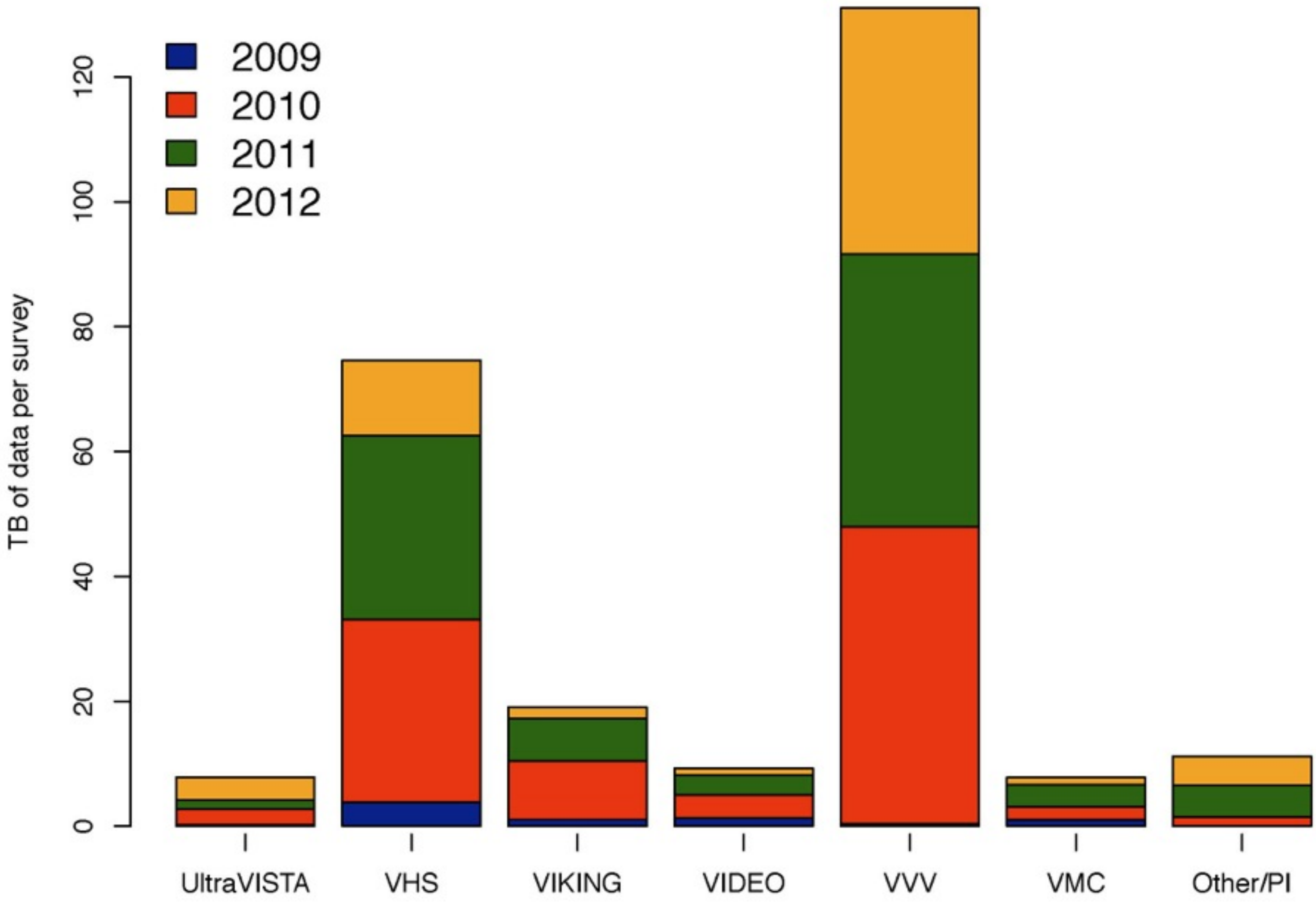
1.5 sq. deg. FOV

VIRCAM (VISTA InfraRed Camera)



Data Volumes produced by CASU

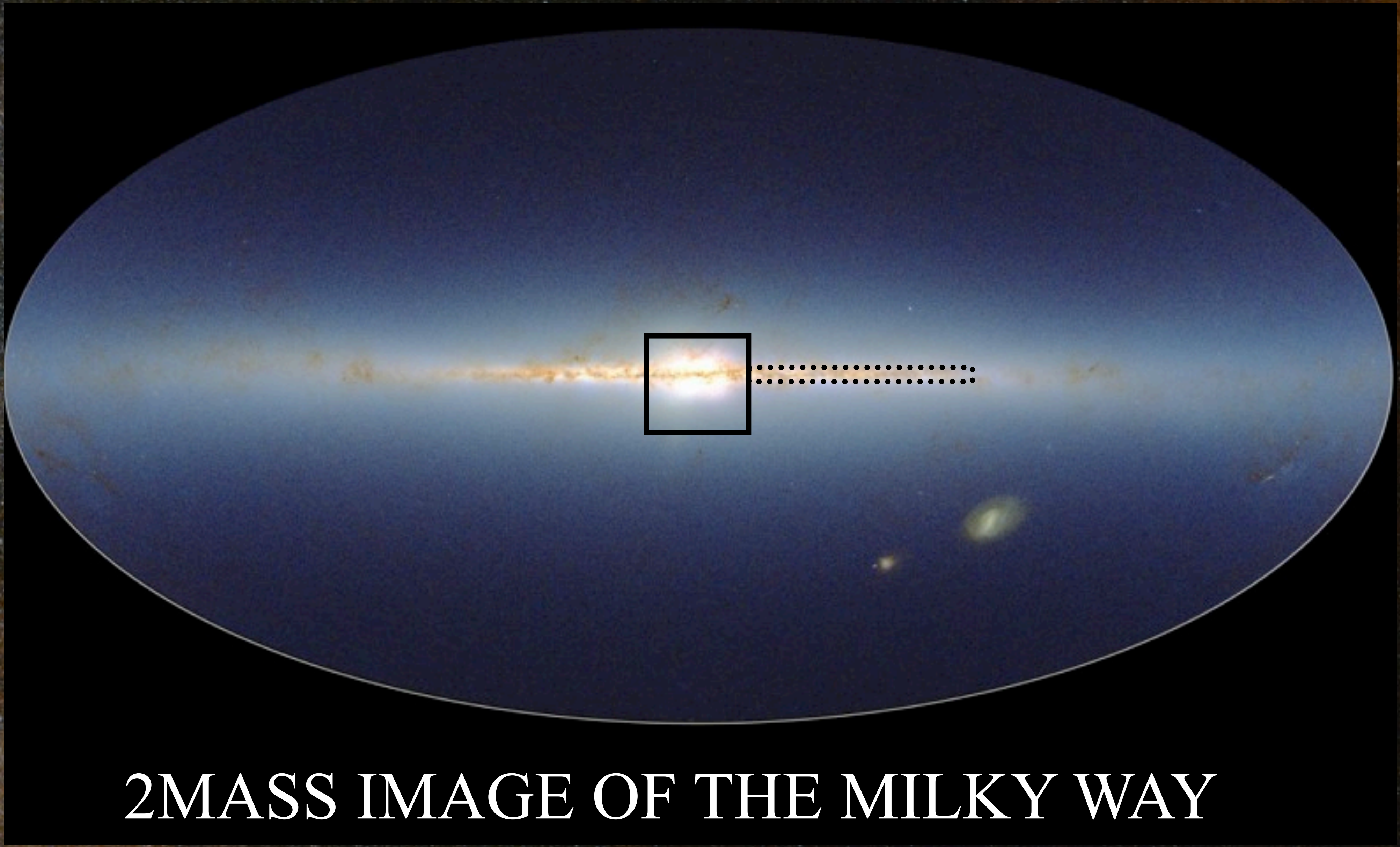
Jim Emerson



VVV AND 2MASS

VVV builds on the 2MASS legacy: Science cases given by 2MASS

WFIRST can build on the VVV legacy: Science cases from VVV



VVV is calibrated by 2MASS

VVV system != 2MASS system

Credit: ESO

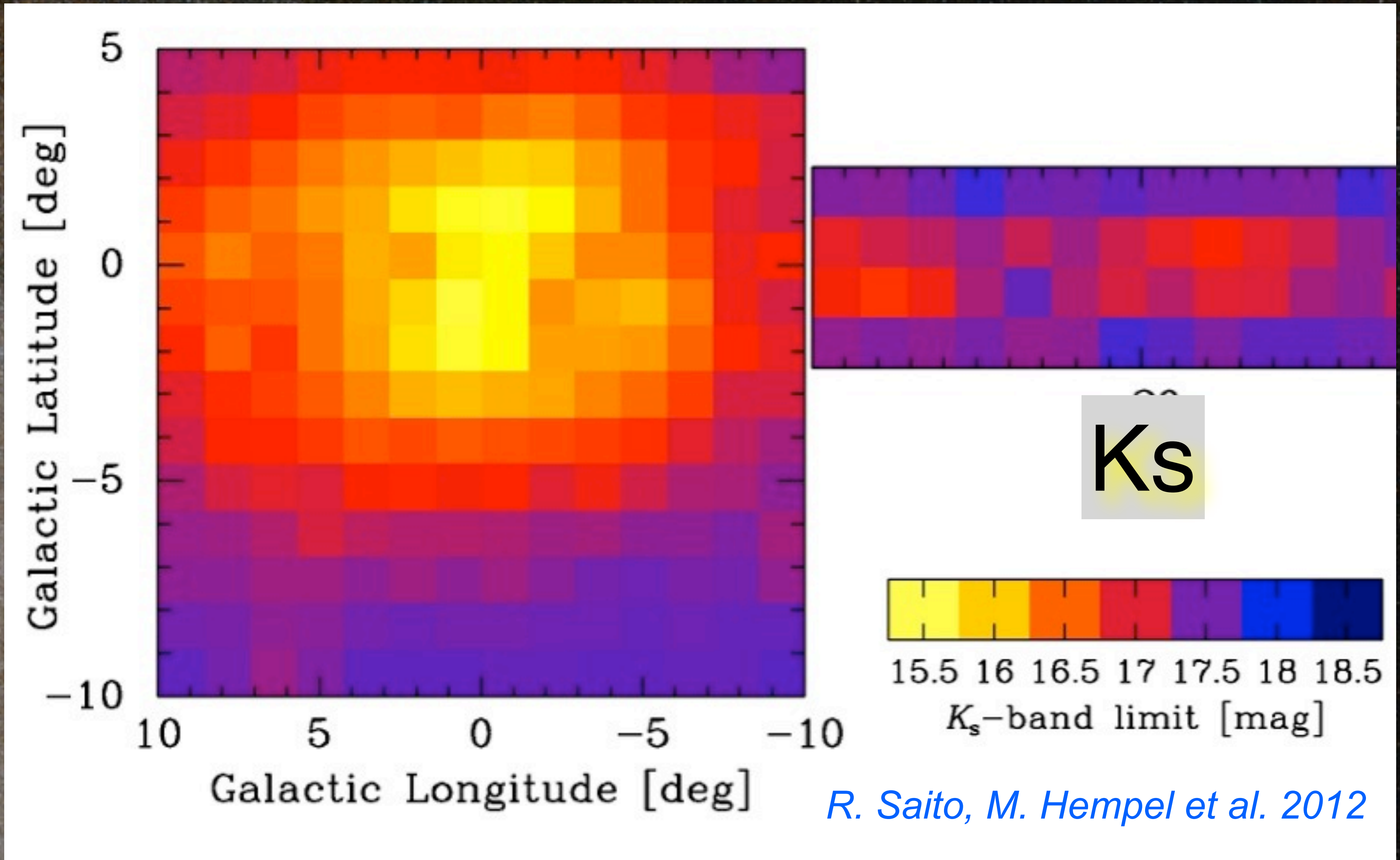
VVV AND 2MASS

Main differences with 2MASS

2MASS covers the whole sky, VVV only 1.3%

VVV has higher resolution (0.34''/pix)

VVV AND 2MASS



R. Saito, M. Hempel et al. 2012

Main differences with 2MASS

2MASS covers the whole sky, VVV only 1.3%

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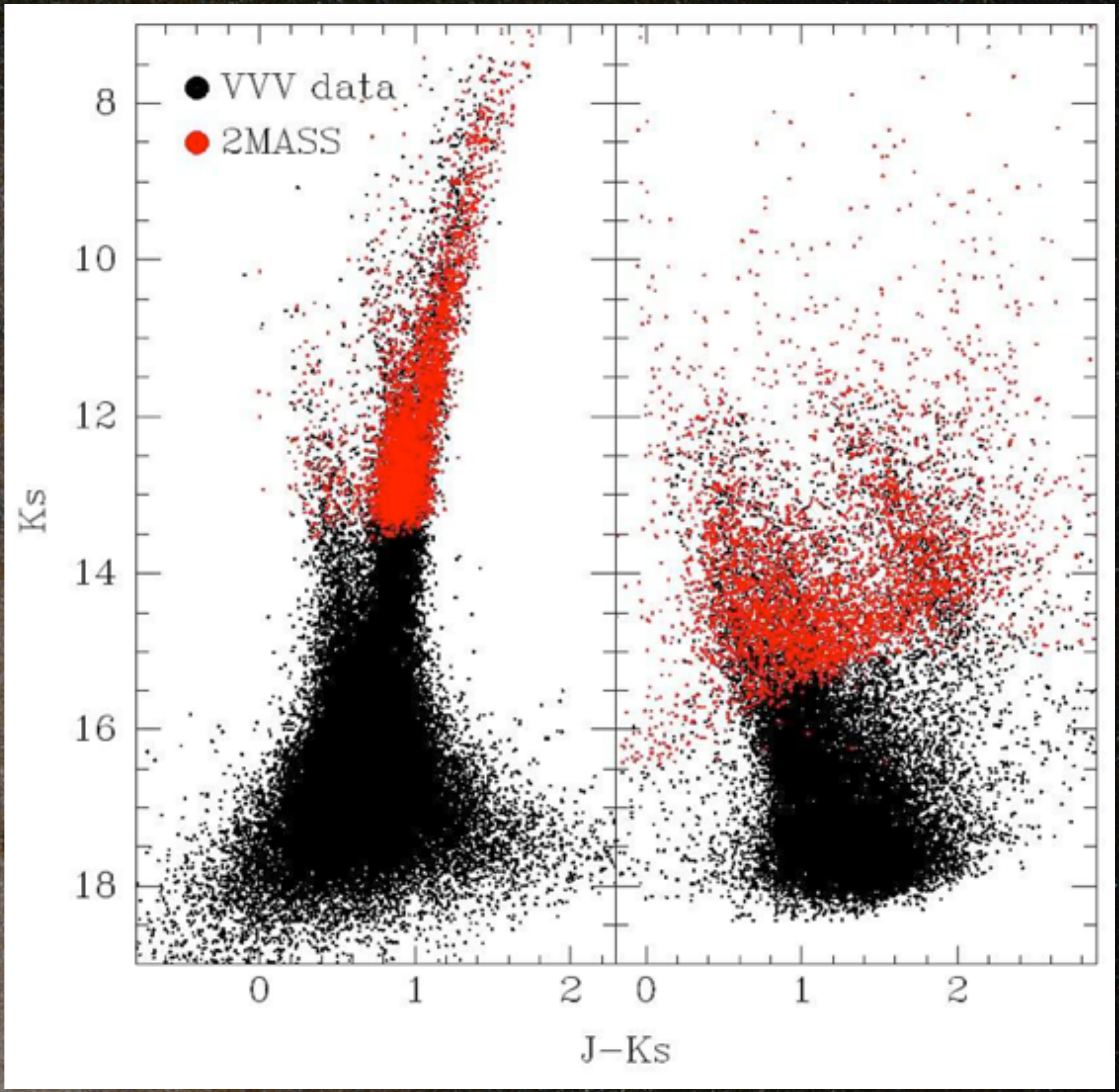
VVV is deeper (Ks<18)

VVV AND 2MASS



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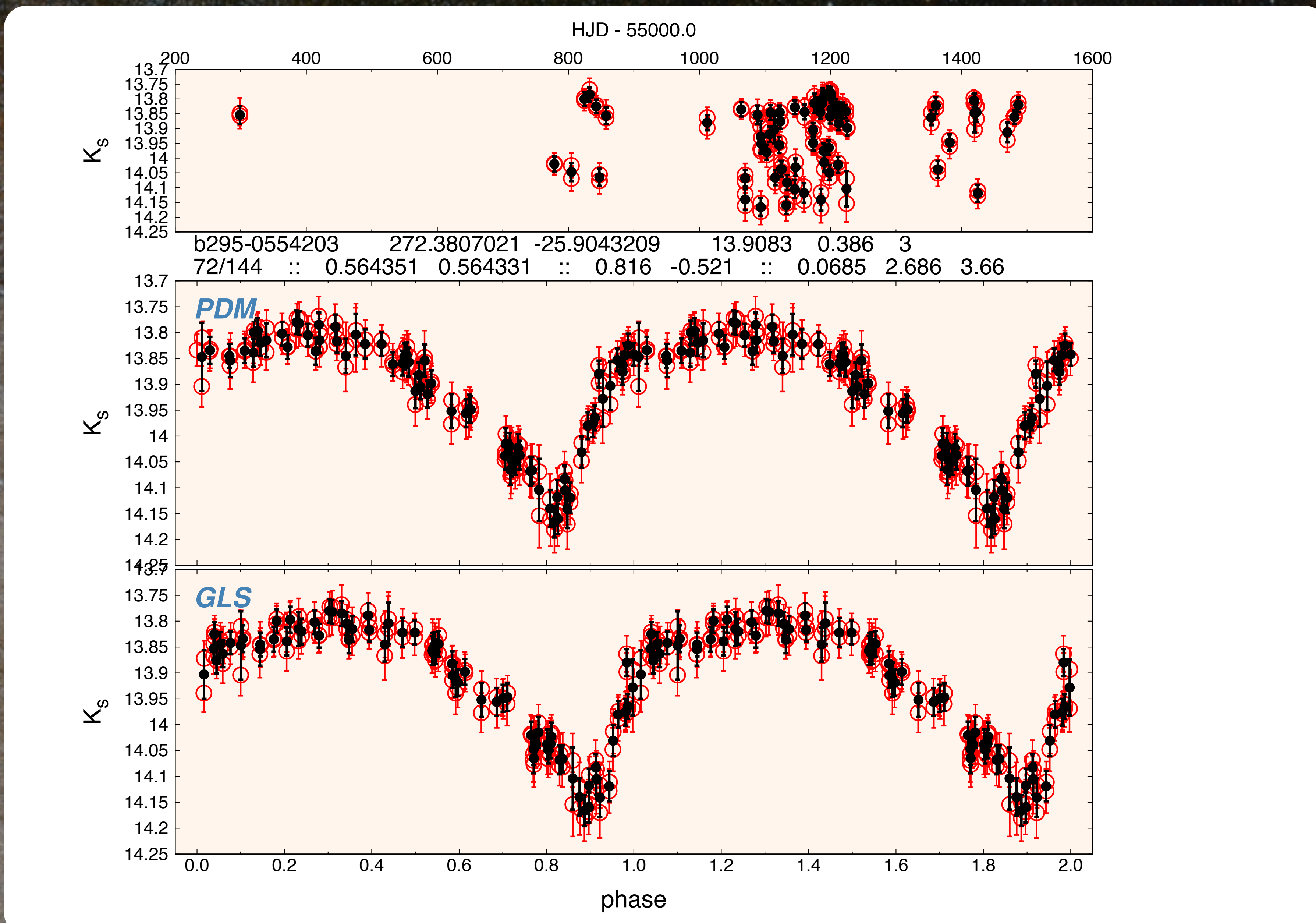
VVV AND 2MASS



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)

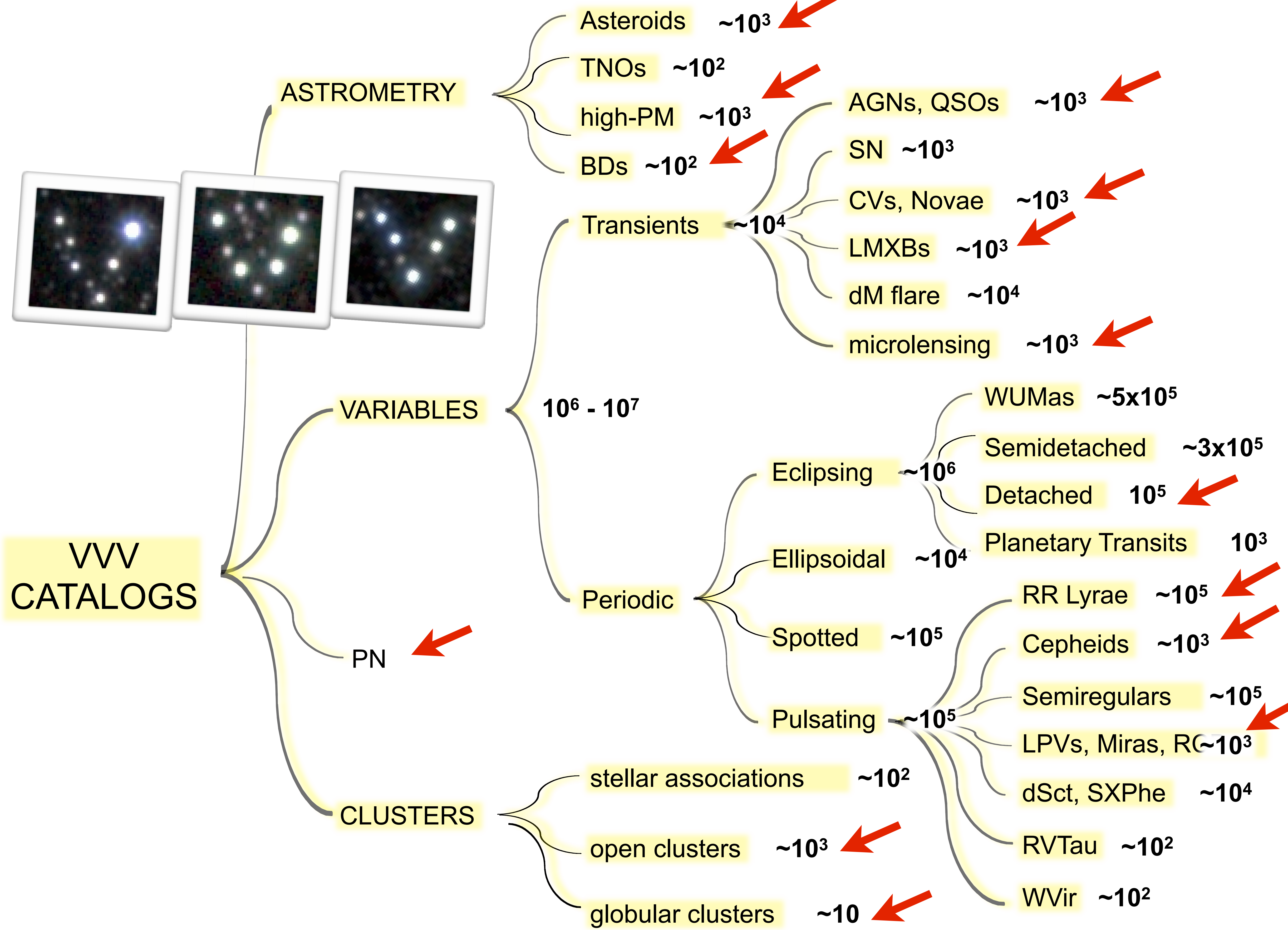
VVV is a time-domain survey (in Ks)

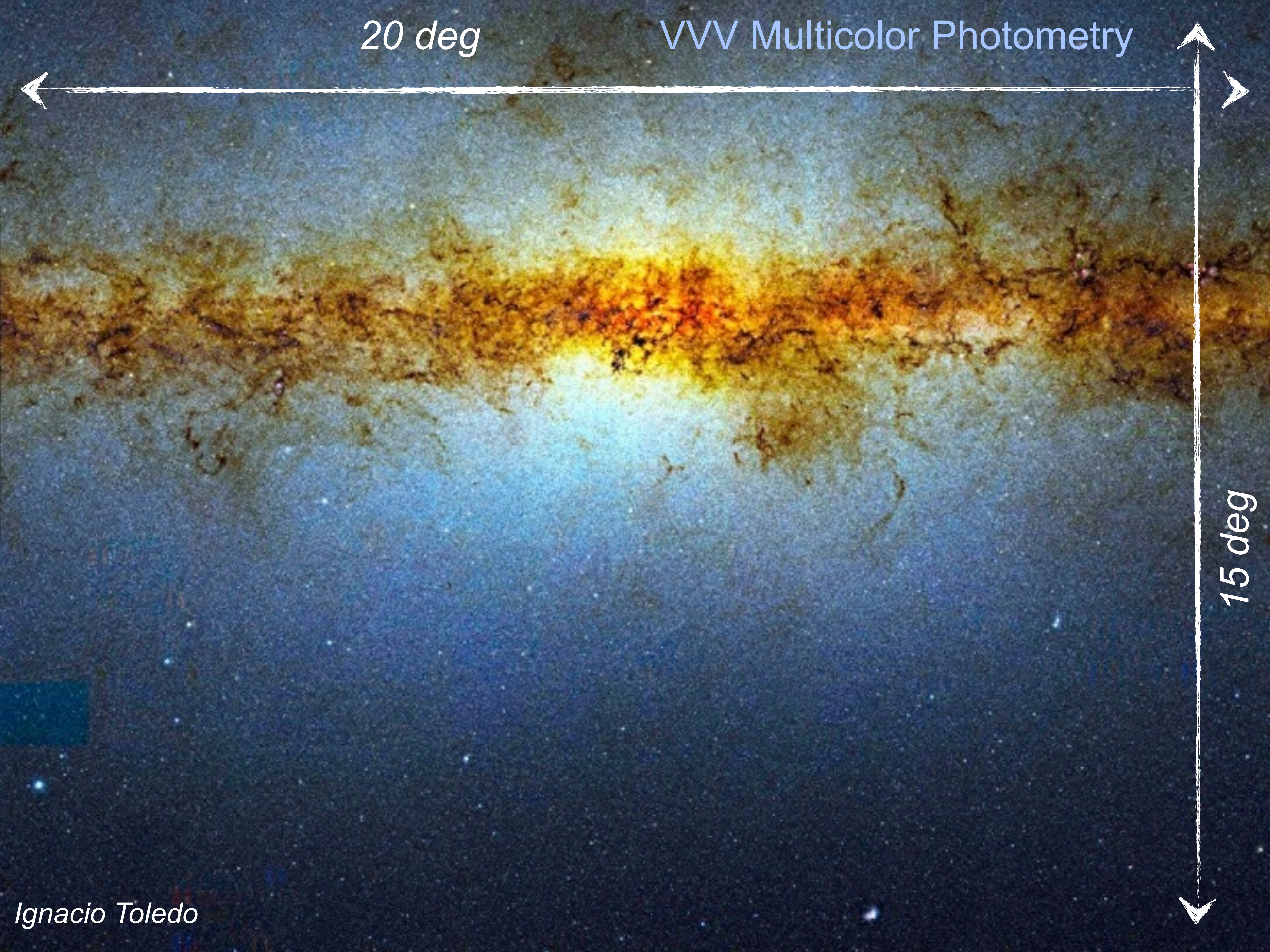
VVV Goal

What is the 3-D structure of the Milky Way

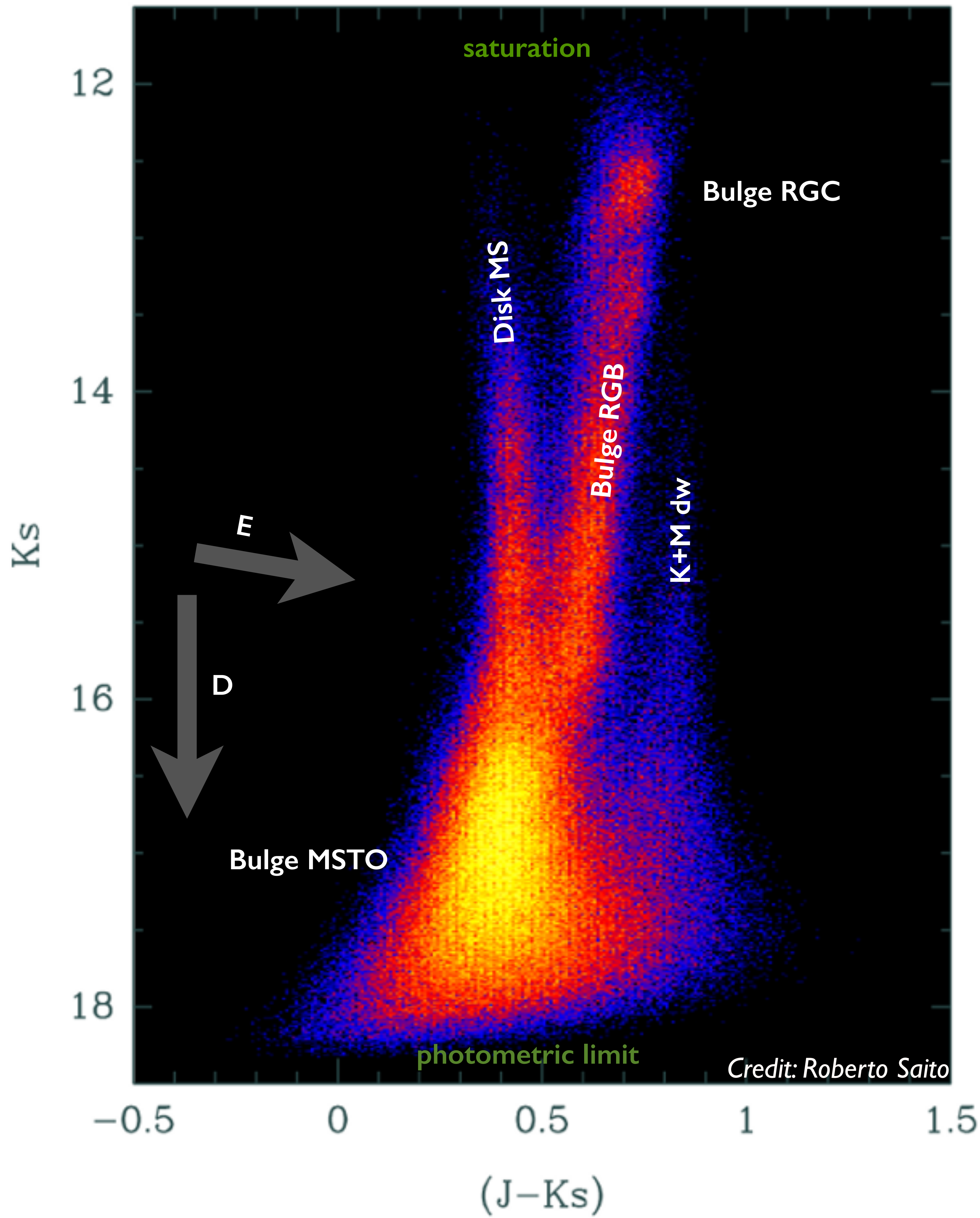
VVV Goal

How did it form

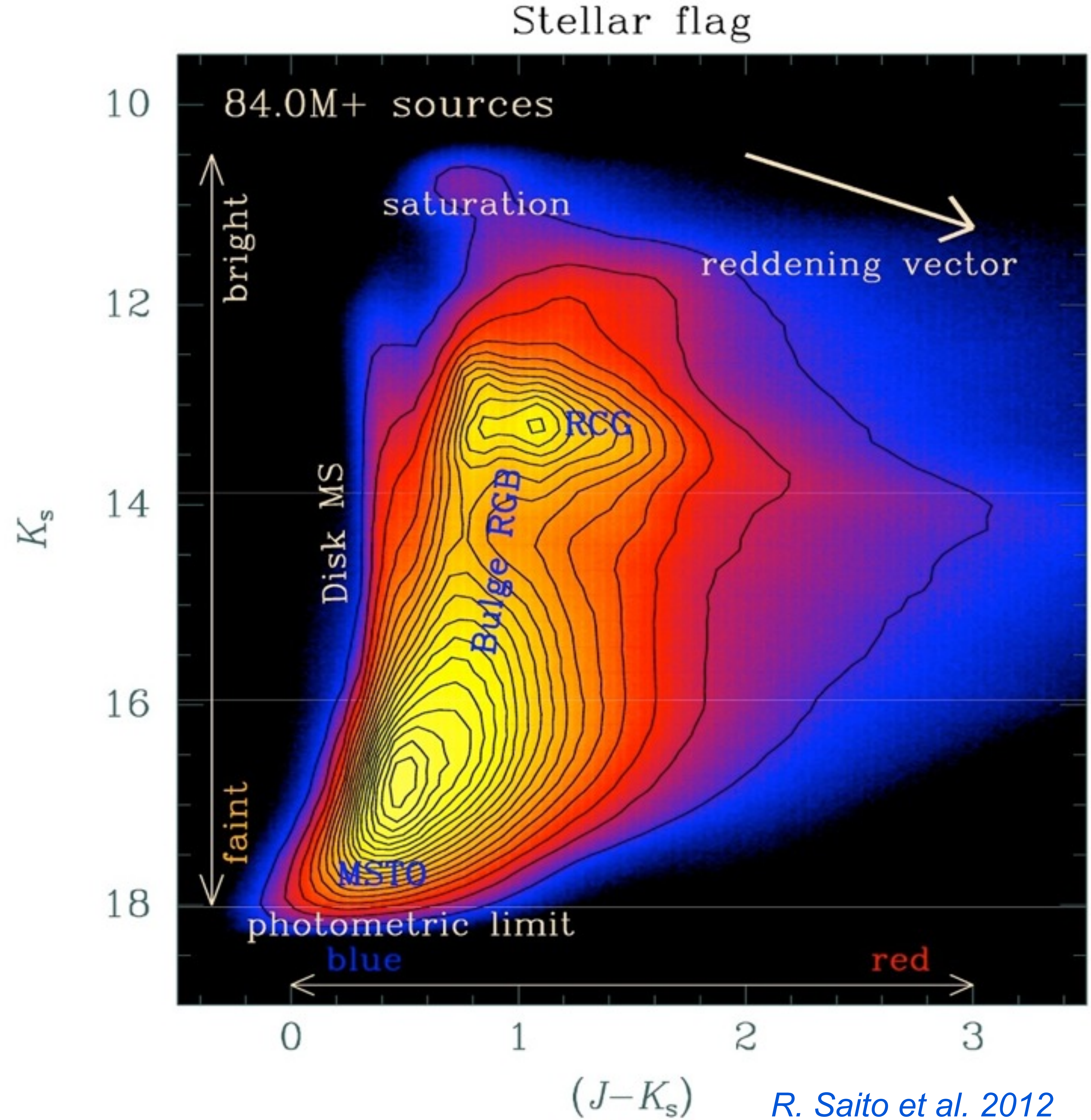

VVV CATALOGS
ASTROMETRY
Asteroids $\sim10^3$
TNOs $\sim10^2$
high-PM $\sim10^3$
BDs $\sim10^2$
VARIABLES
10^6 - 10^7
Transients $\sim10^4$
AGNs, QSOs $\sim10^3$
SN $\sim10^3$
CVs, Novae $\sim10^3$
LMXBs $\sim10^3$
dM flare $\sim10^4$
microlensing $\sim10^3$
Periodic
Eclipsing $\sim10^6$
WUMas $\sim5x10^5$
Semidetached $\sim3x10^5$
Detached 10^5
Planetary Transits 10^3
Ellipsoidal $\sim10^4$
Spotted $\sim10^5$
Pulsating $\sim10^5$
RR Lyrae $\sim10^5$
Cepheids $\sim10^3$
Semiregulars $\sim10^5$
LPVs, Miras, RC $\sim10^3$
dSct, SXPhe $\sim10^4$
RVTau $\sim10^2$
WVir $\sim10^2$
PN
CLUSTERS
stellar associations $\sim10^2$
open clusters $\sim10^3$
globular clusters ~10


20 deg
VVV Multicolor Photometry
15 deg
Ignacio Toledo

VVV 0.3M SINGLE TILE BULGE CMD

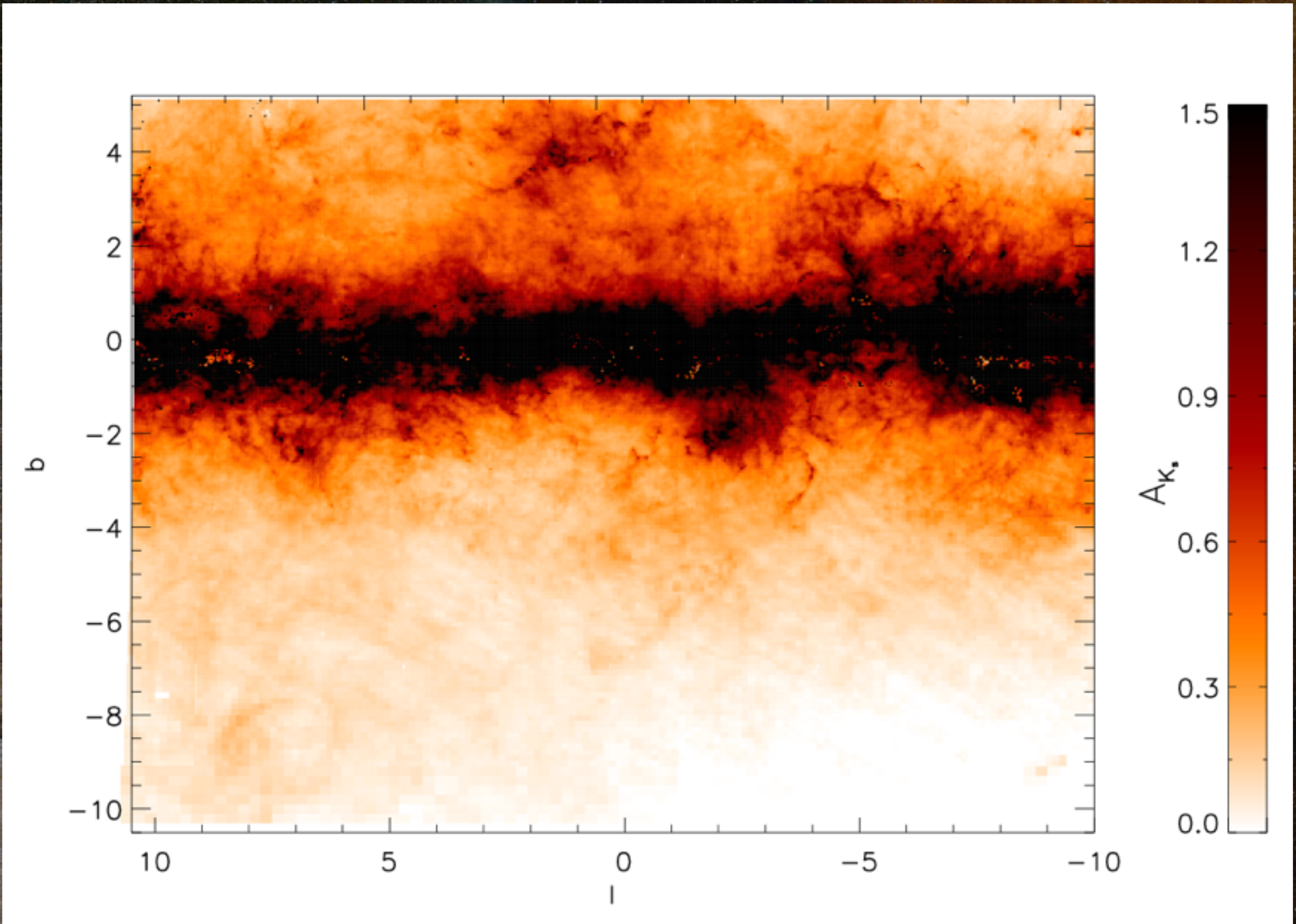


VVV 84M STARS BULGE CMD



R. Saito et al. 2012

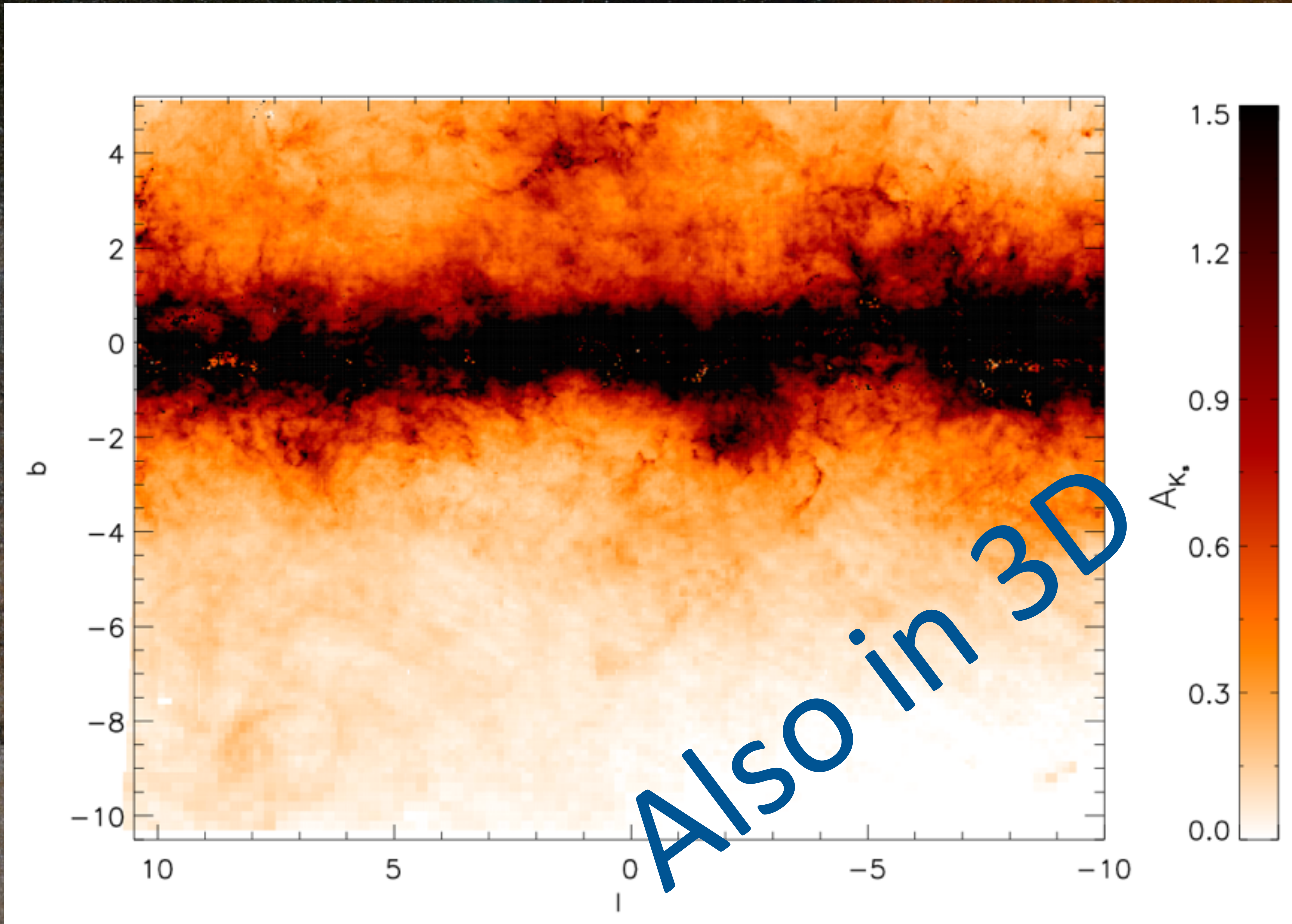
EXTINCTION MAP



O. Gonzalez, et al. A&A 2012, B. Chen et al. A&A 2013

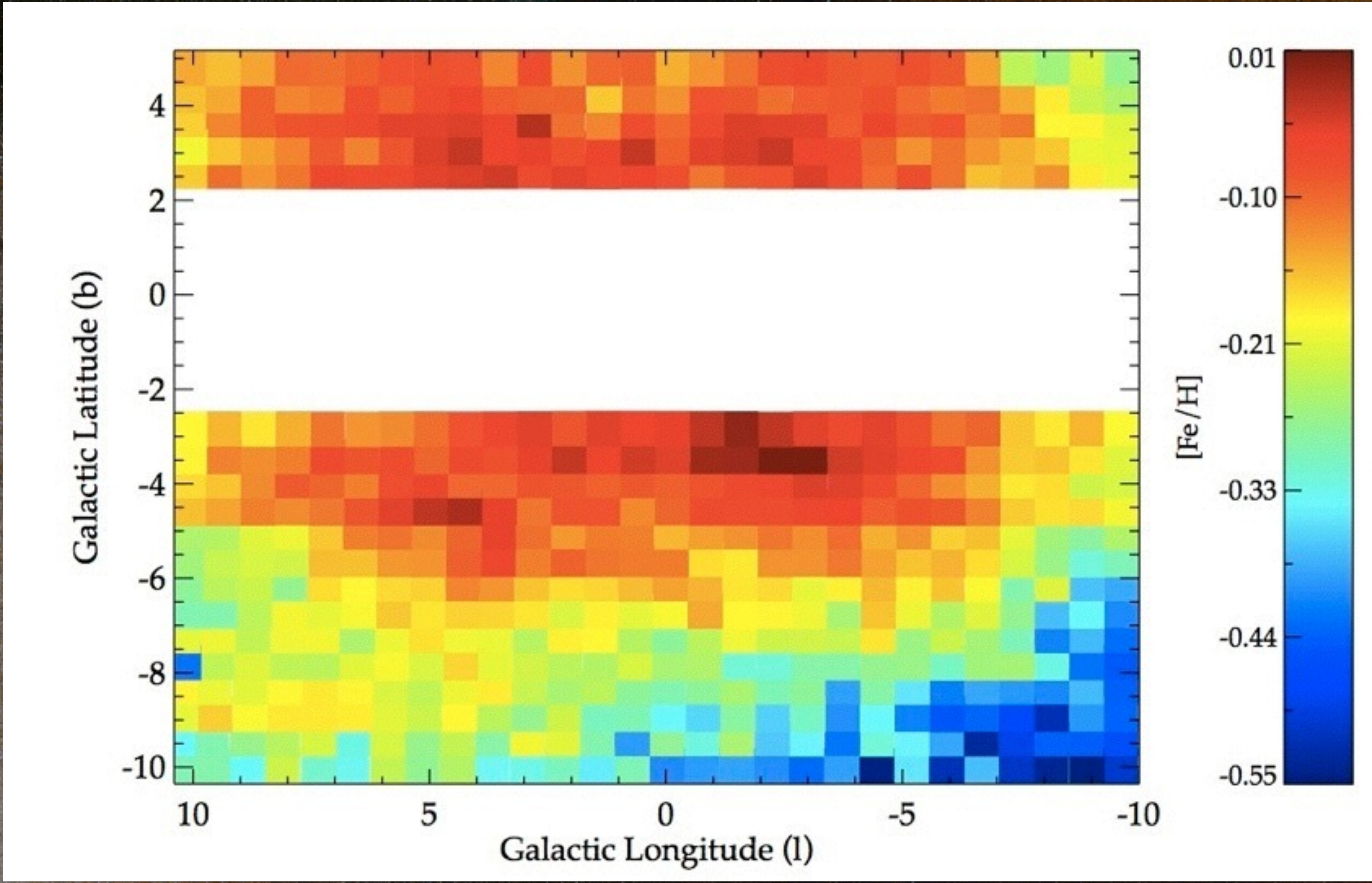
Credit: ESO

EXTINCTION MAP



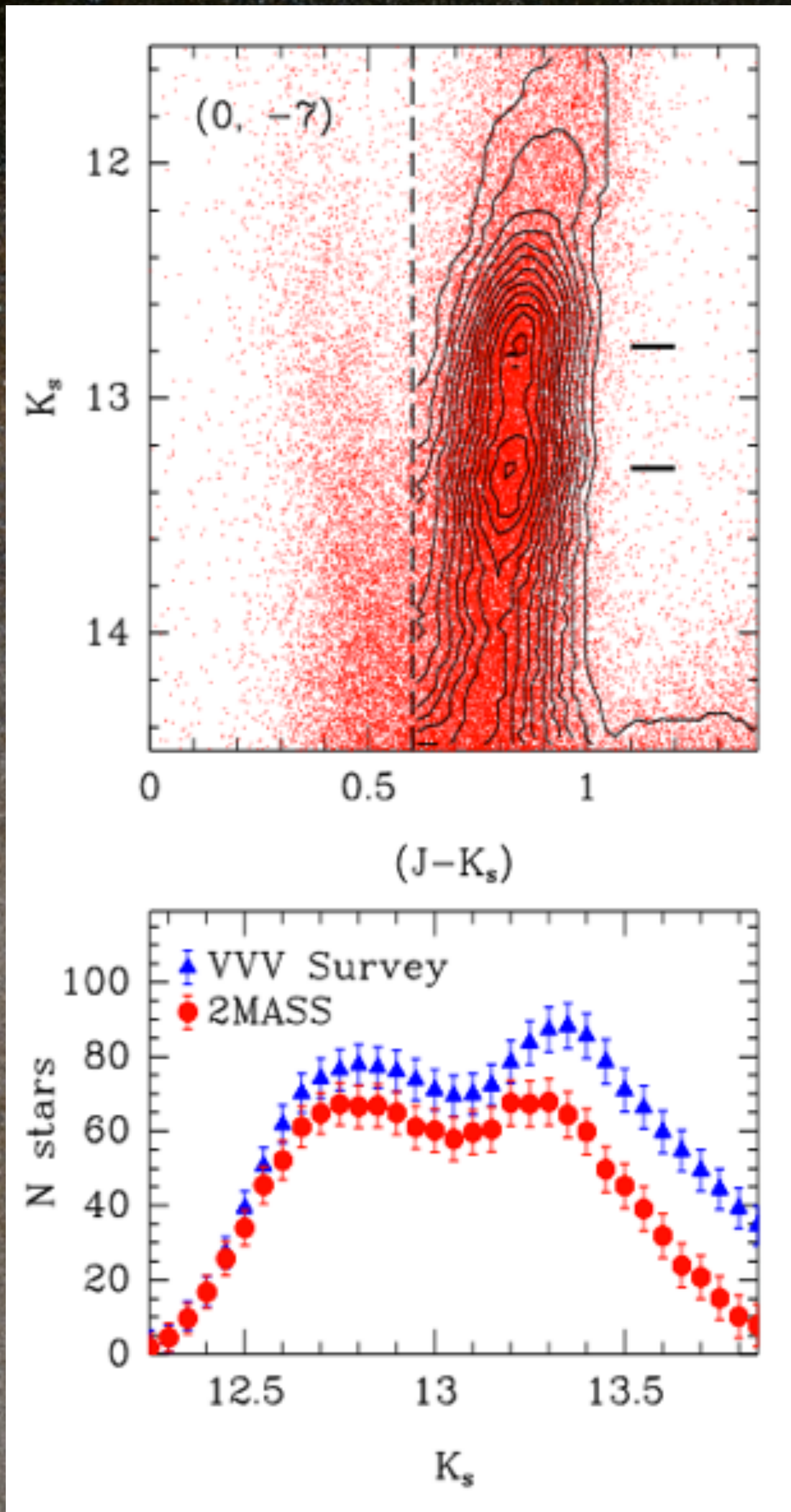
O. Gonzalez, et al. A&A 2012, B. Chen et al. A&A 2013

METALLICITY MAP



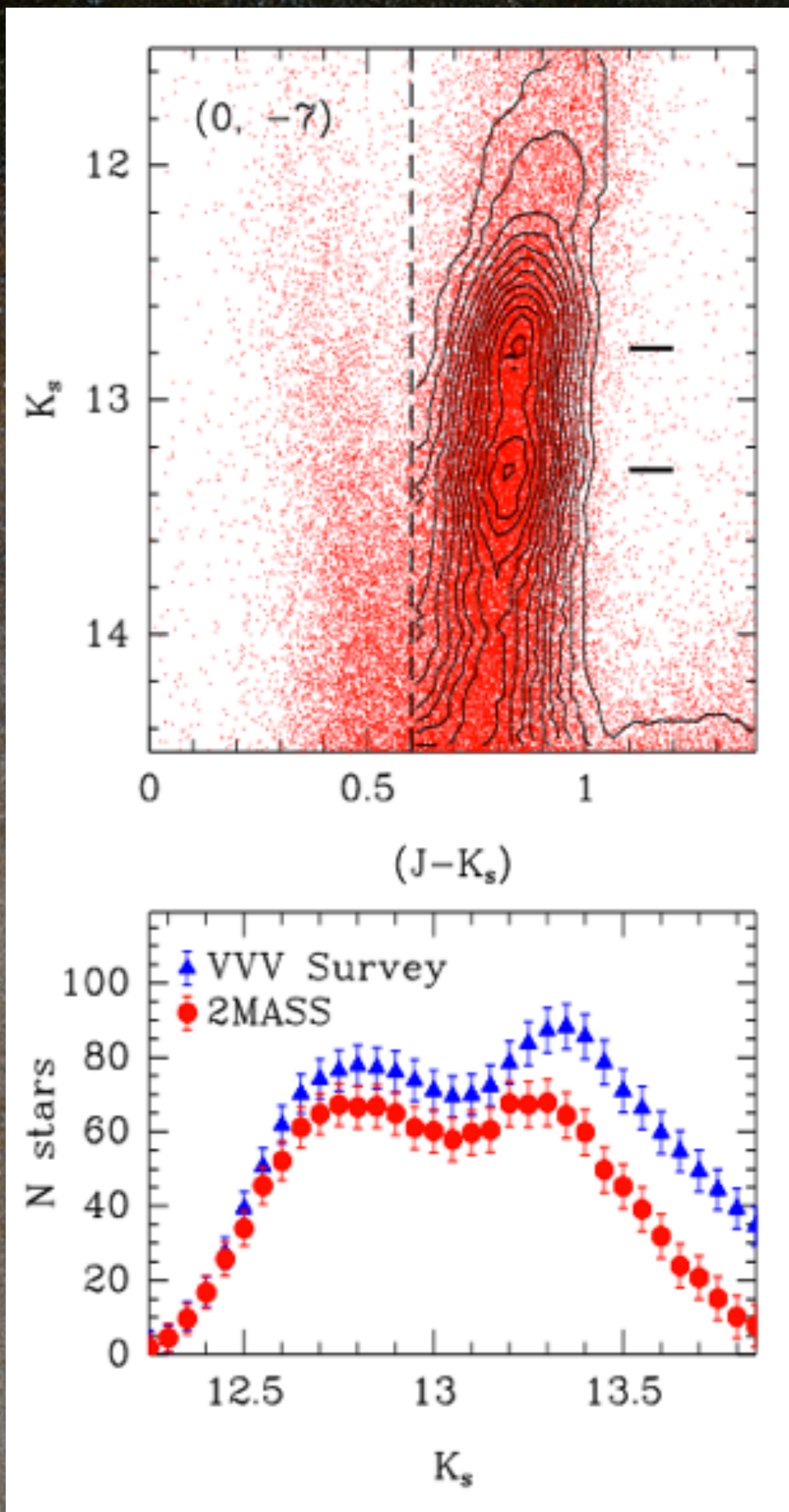
O. Gonzalez, et al. A&A 2012

BULGE MAPPING



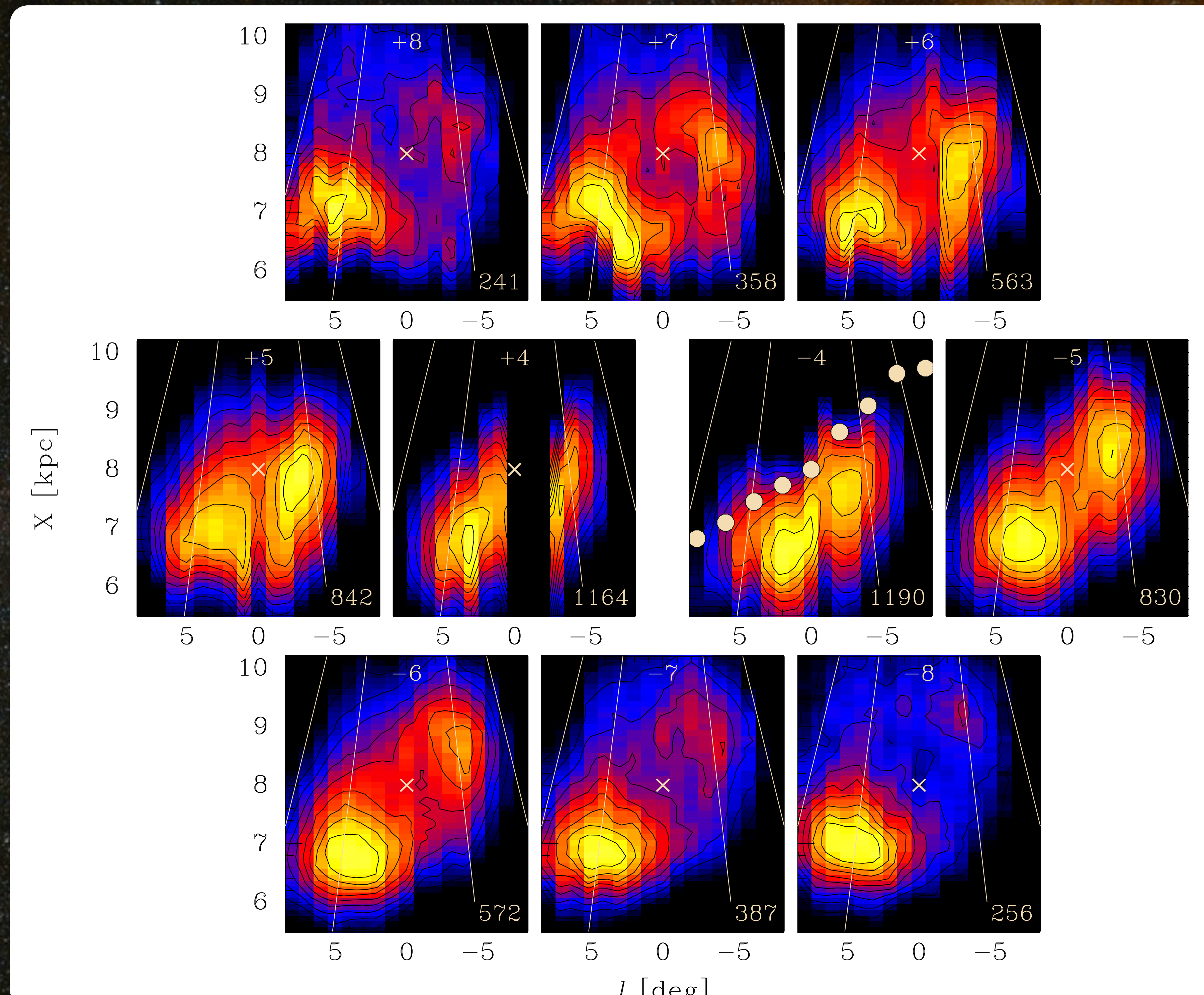
A double red clump is seen along different directions towards the bulge. This is present in 2MASS and VVV data.

BULGE MAPPING

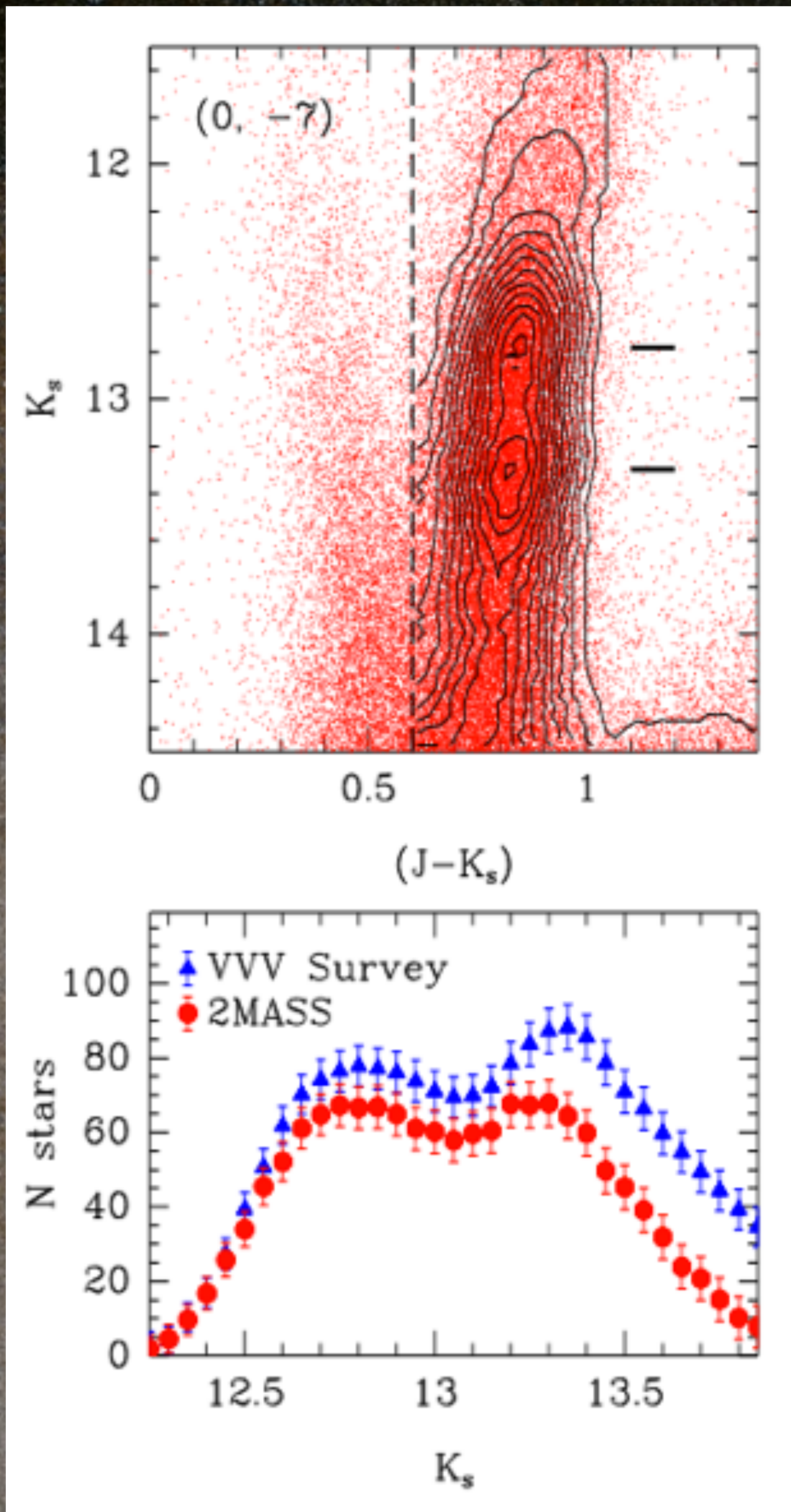


Saito et al. 2011, AJ

The Milky Way bulge is X-shaped.
Two independent datasets and analyses (2MASS, VVV).



BULGE MAPPING



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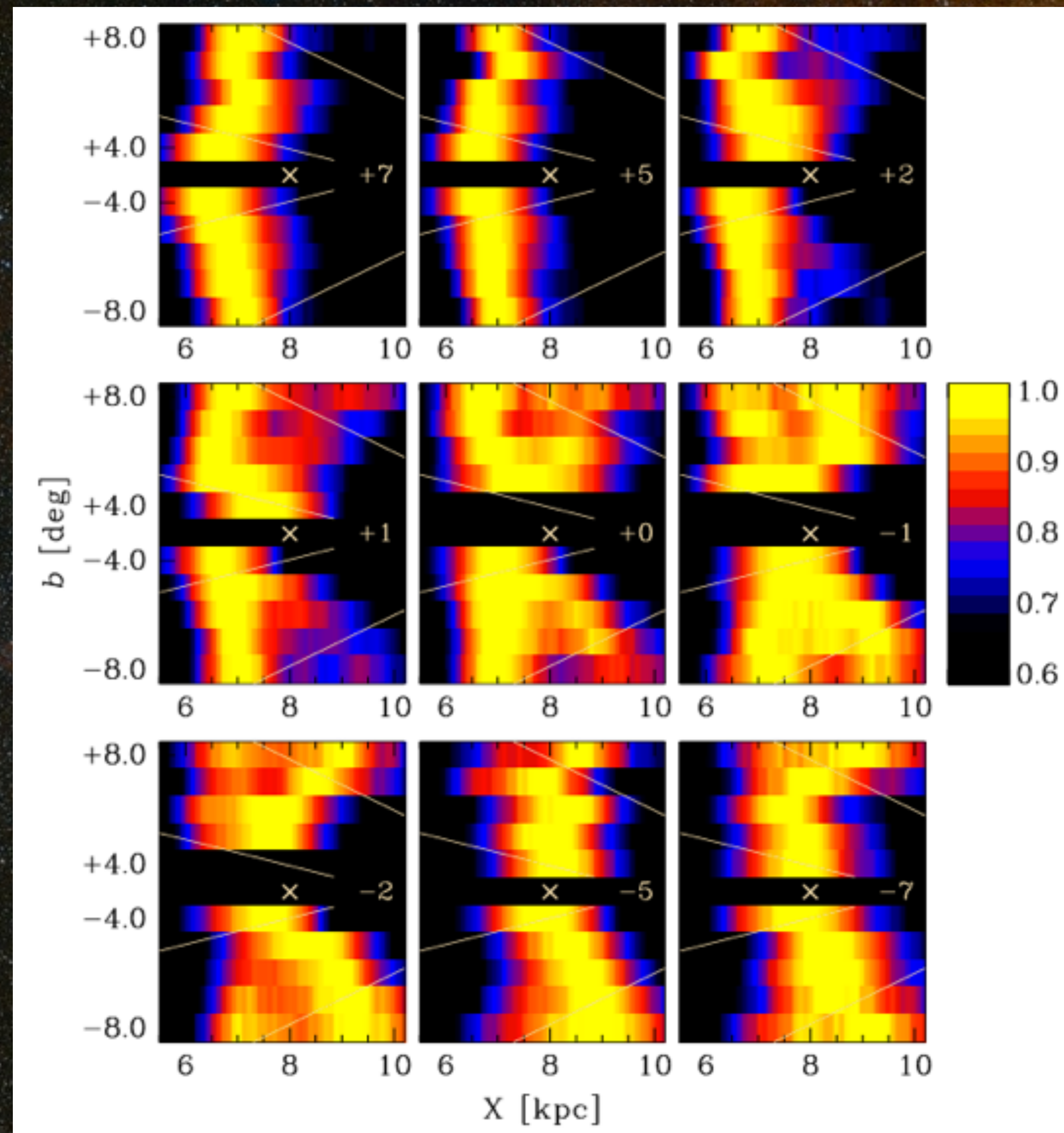


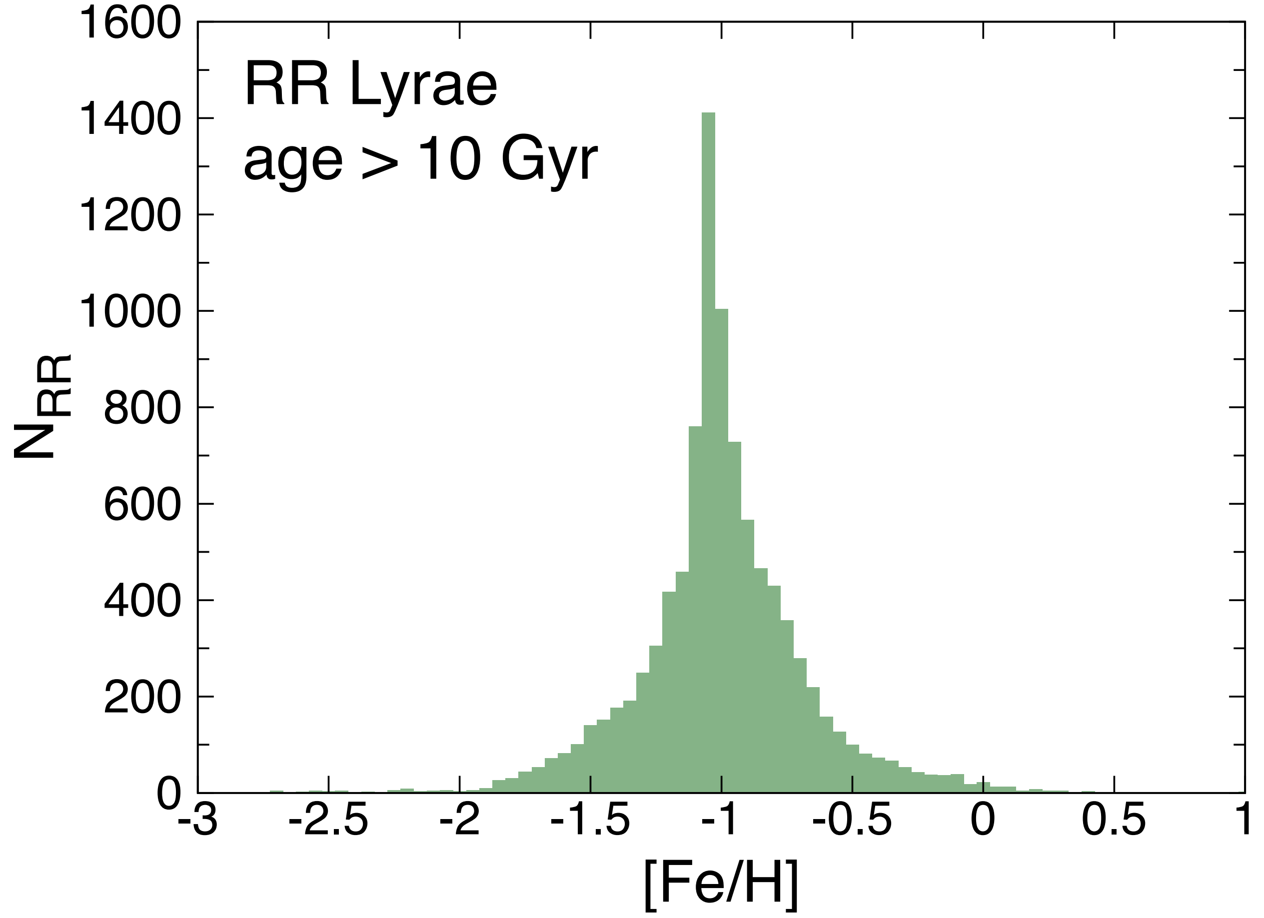
BULGE MAPPING

The peanut-shaped bulge formed from the disk via buckling instability.

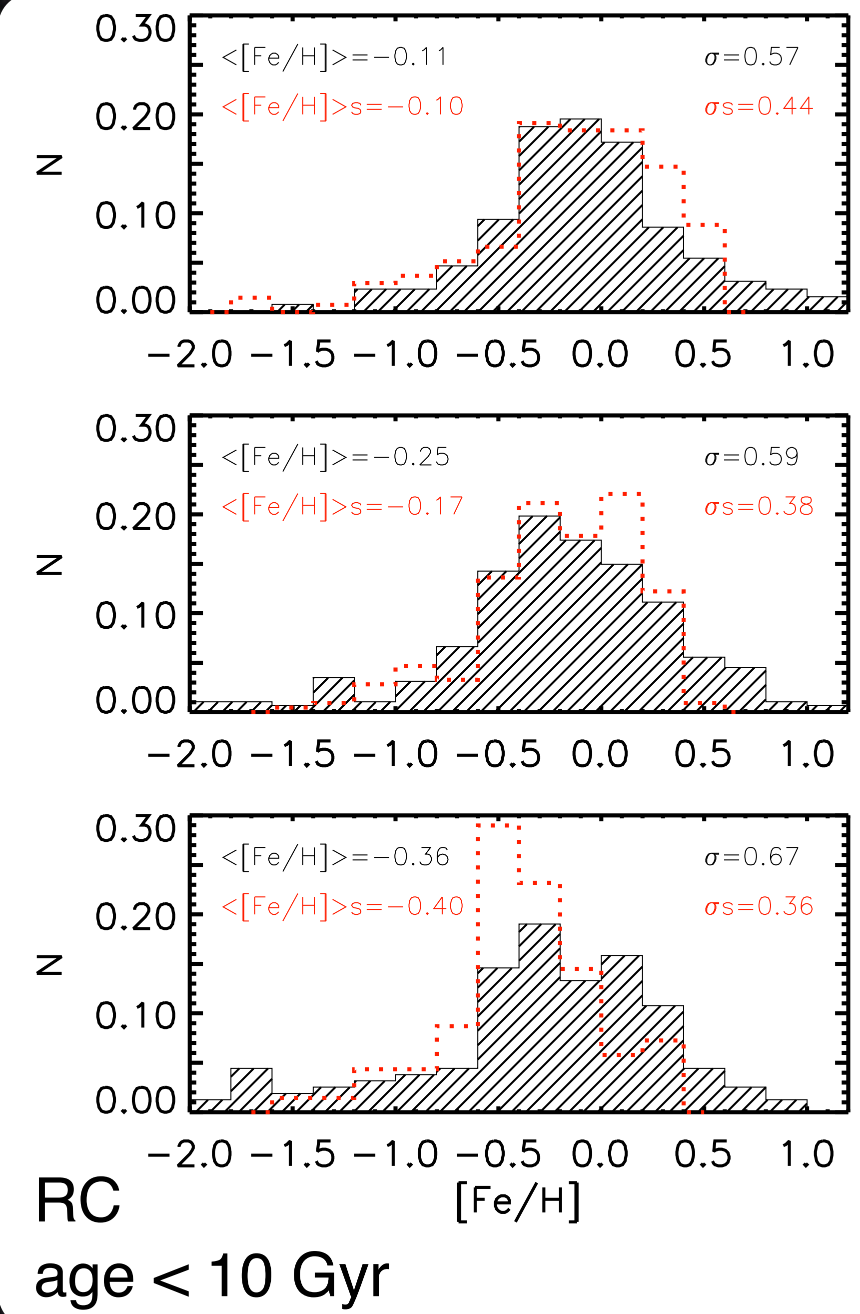
theory: see, e.g., Wegg & Gerhard (2013)

BULGE MAPPING

Red clump (RC) and RR Lyrae stars trace different populations.

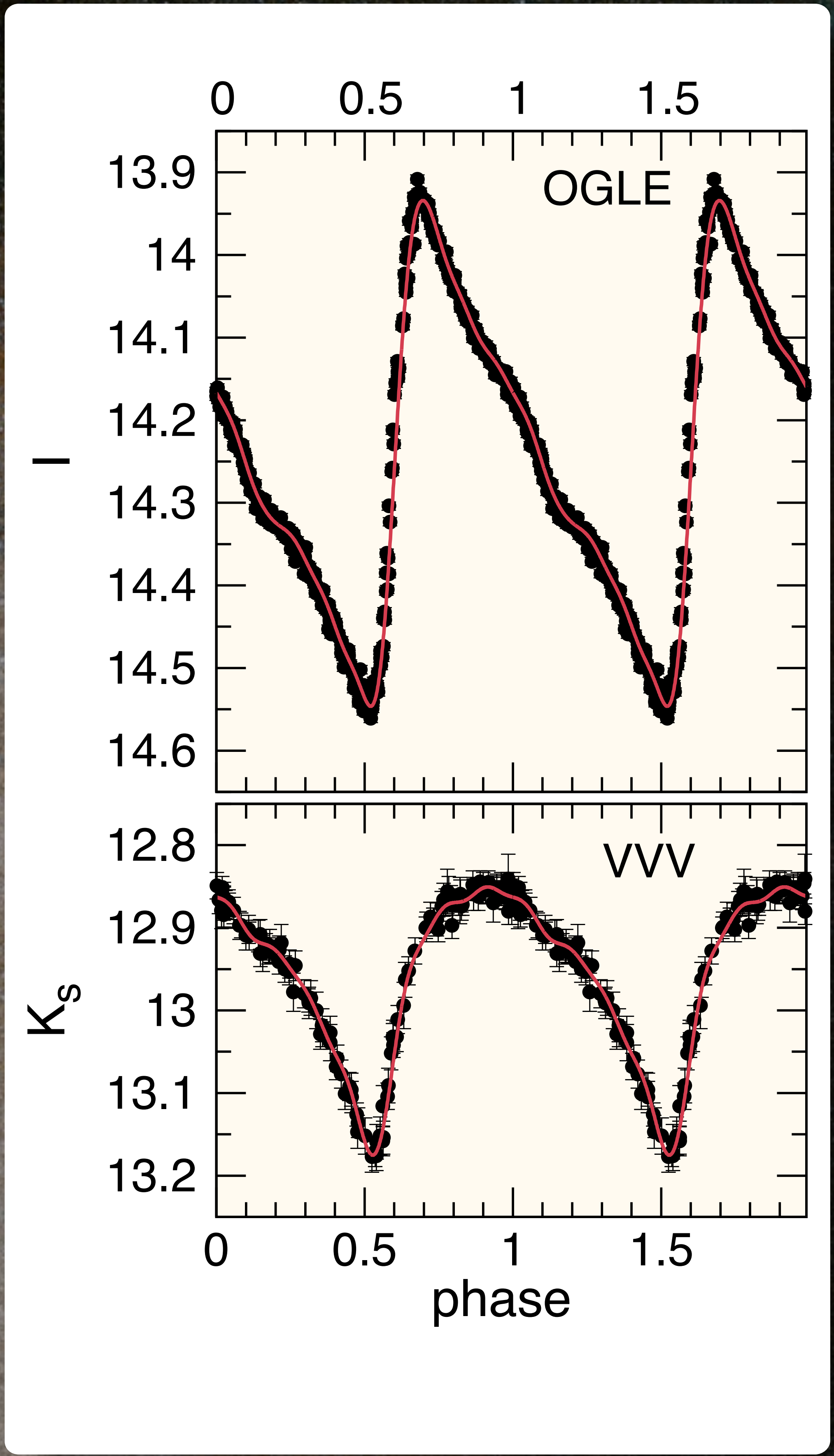


Pietrukowicz et al. 2012, ApJ

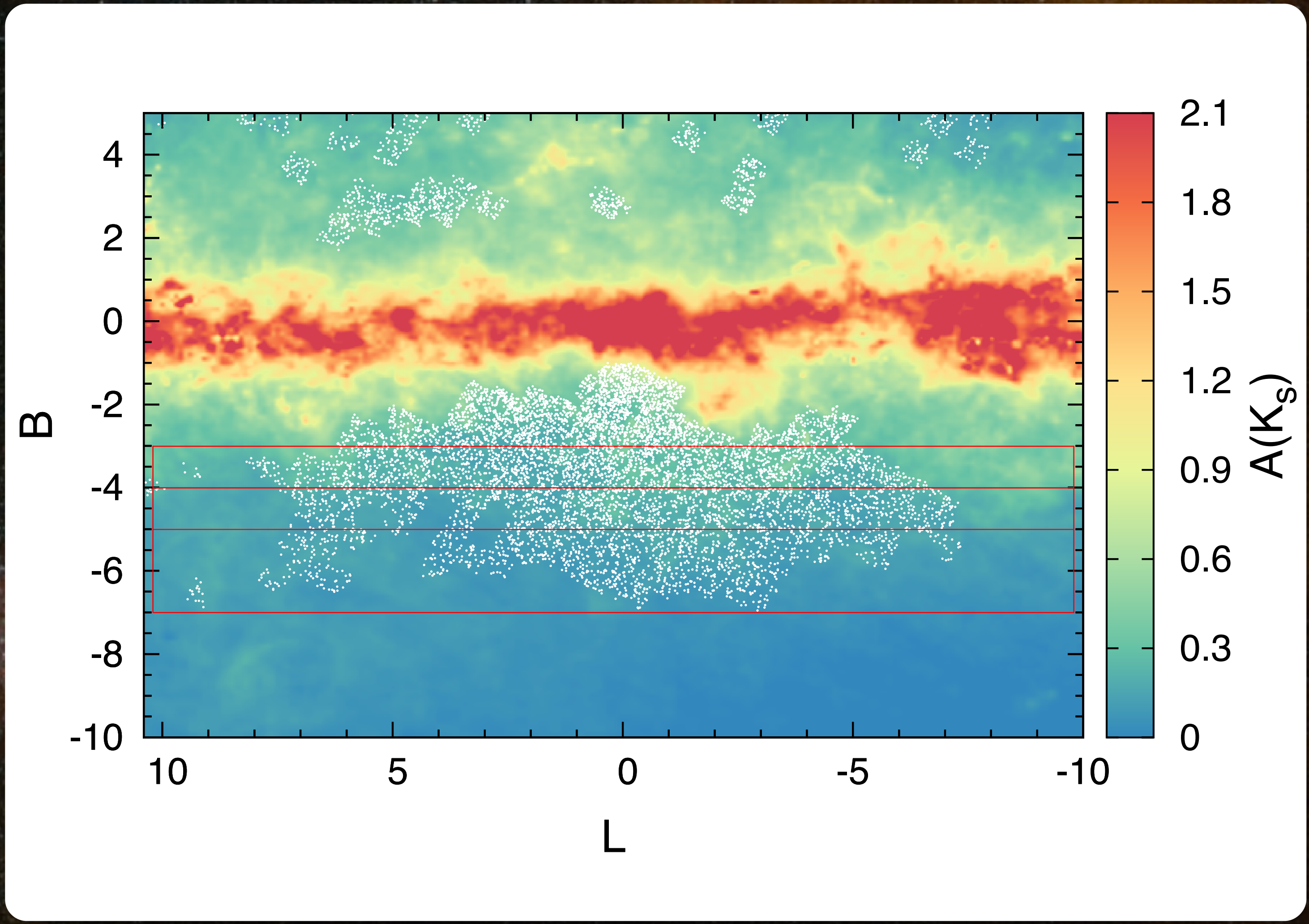


Zoccali et al. 2008, A&A
Gonzalez et al. 2011, A&A

BULGE MAPPING

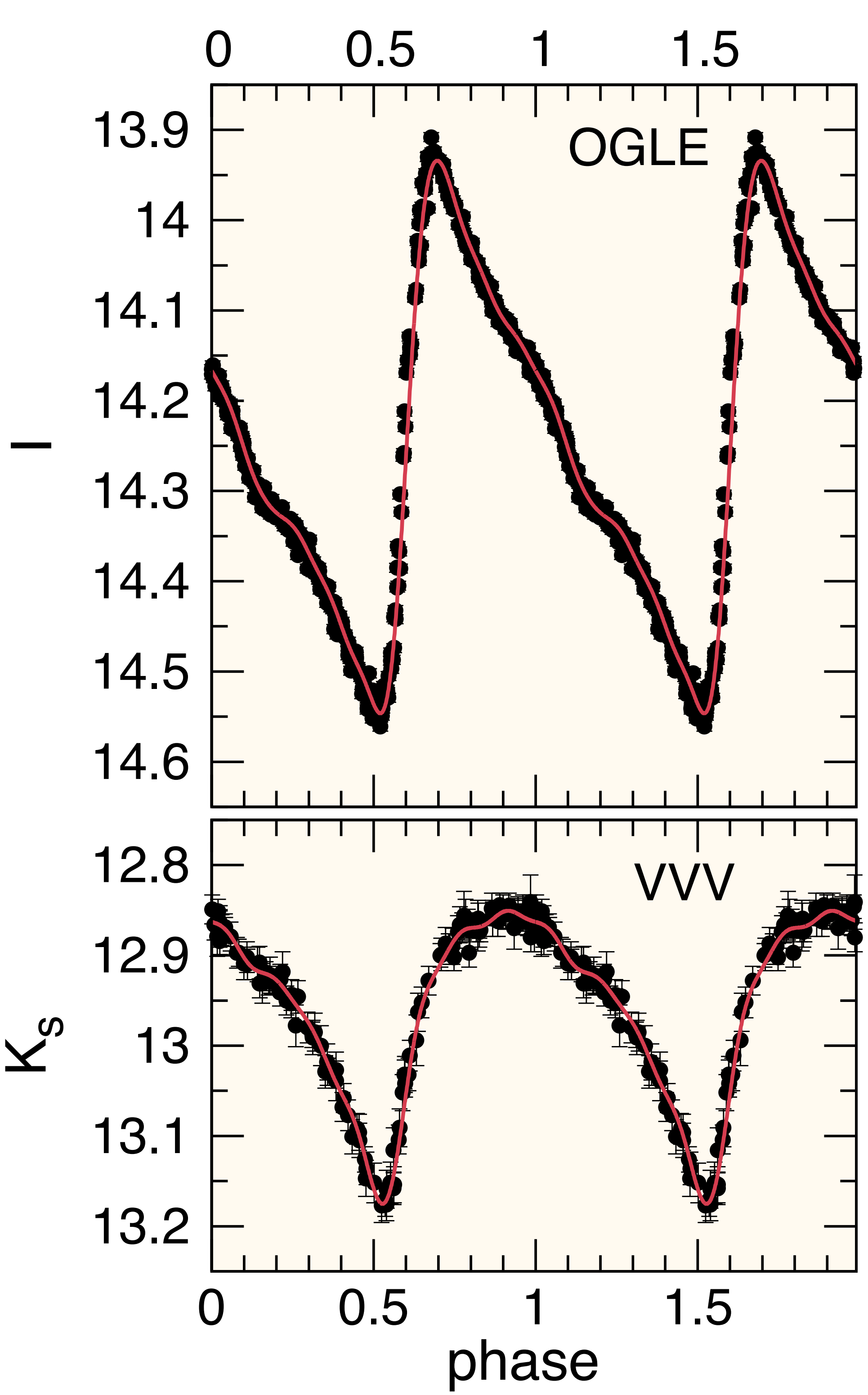


Combined OGLE + VVV (I + Ks) distance analysis of bulge RR Lyrae stars.
Advantage: accurate distances and reddenings on a star-by-star basis by precise PL-relations.



Dékány et al. 2013, ApJL

BULGE MAPPING



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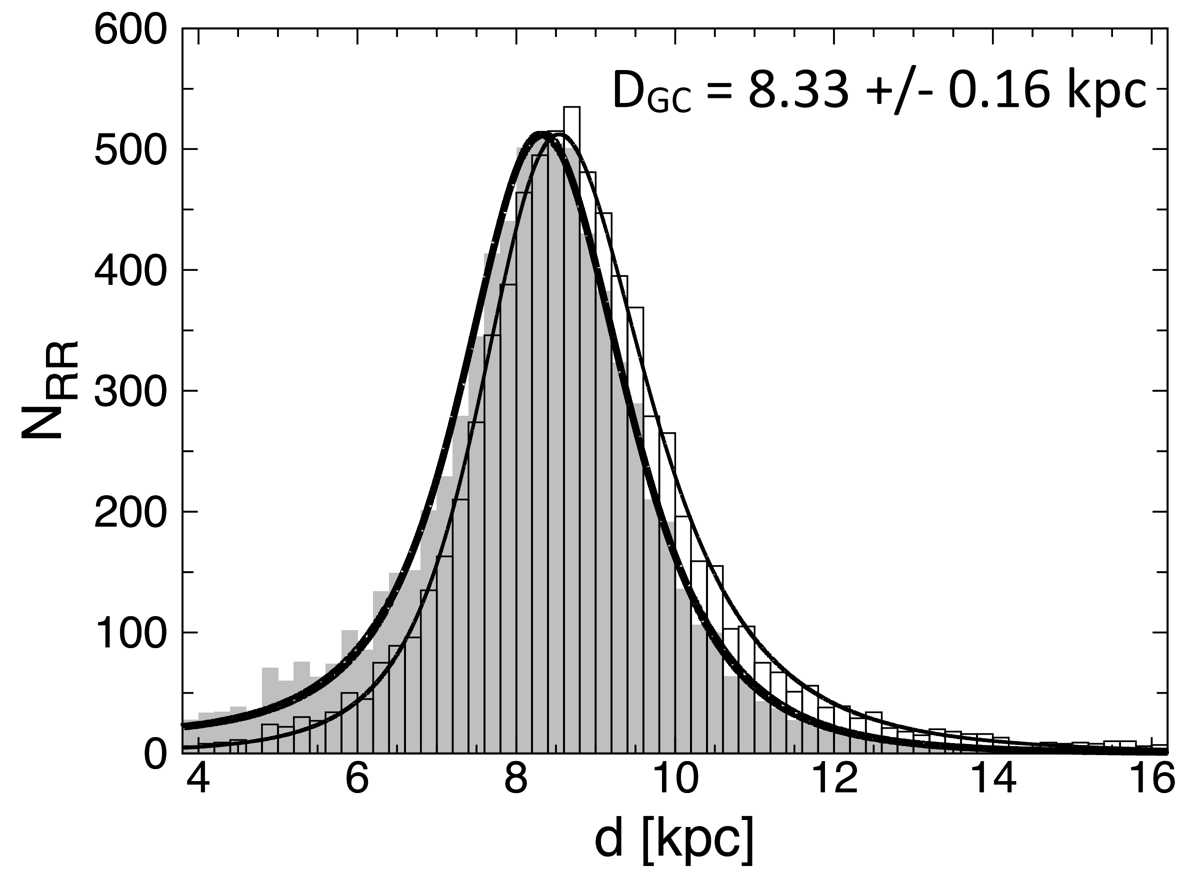
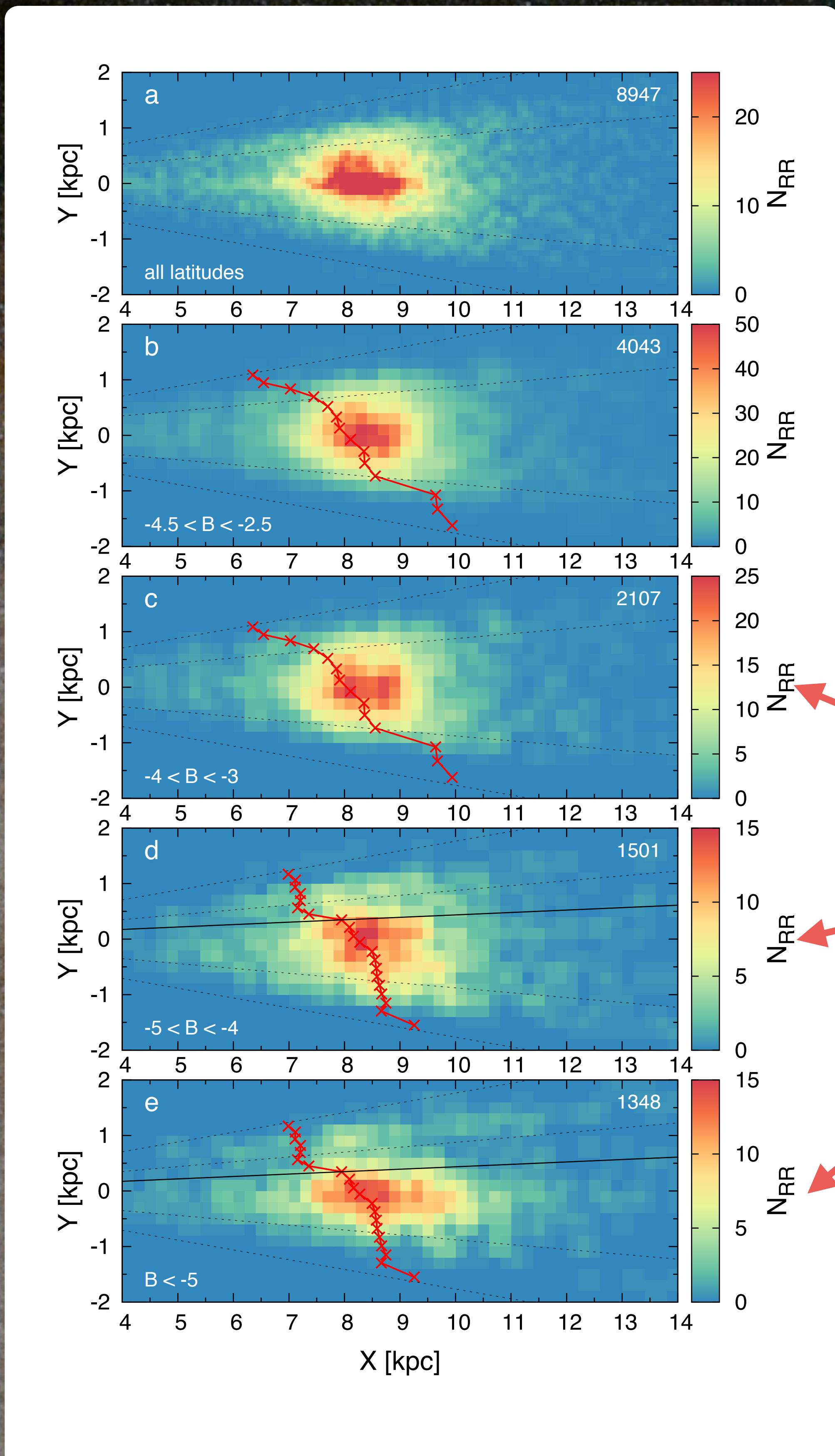


Dékány et al. 2013, ApJL

BULGE MAPPING



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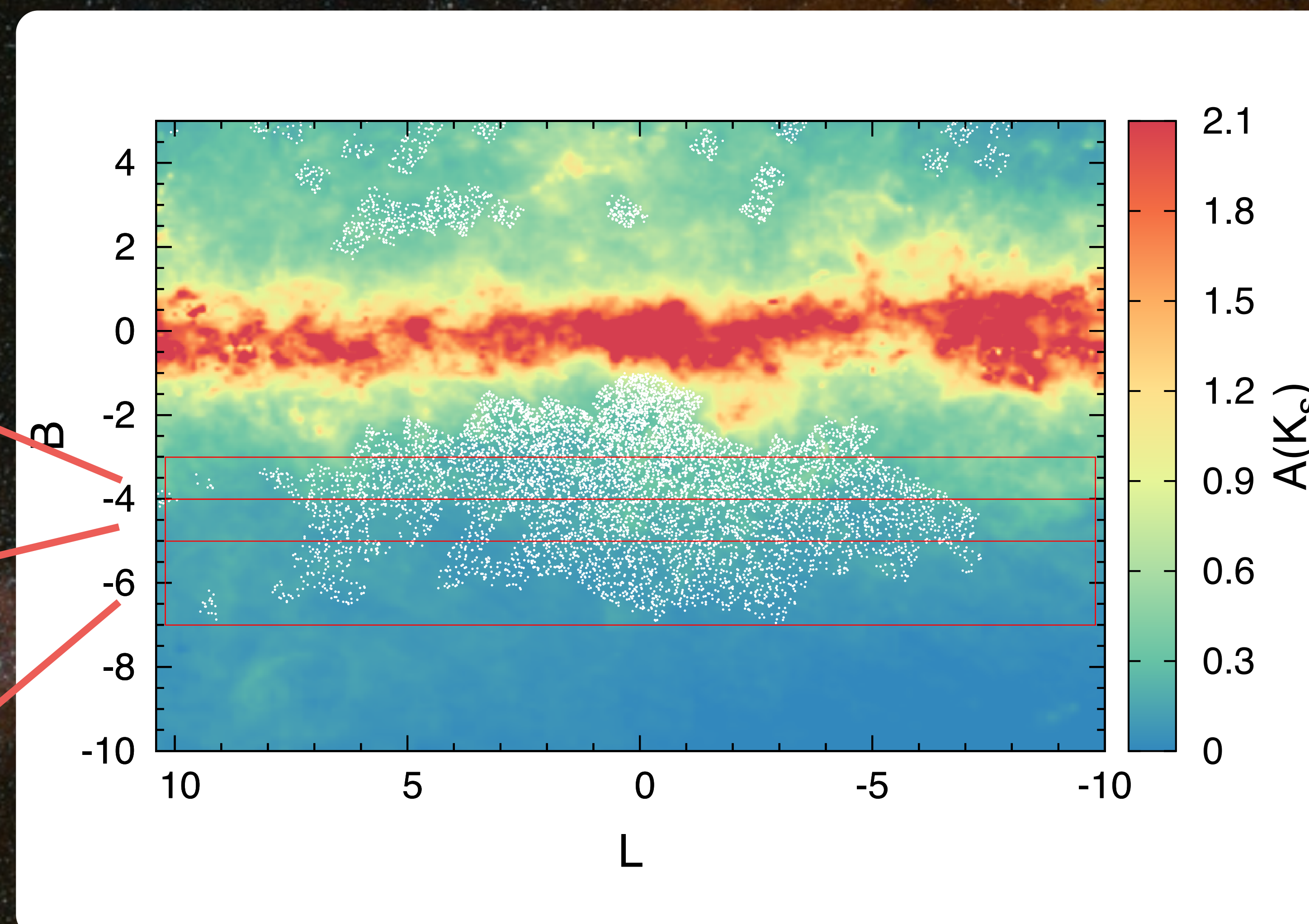
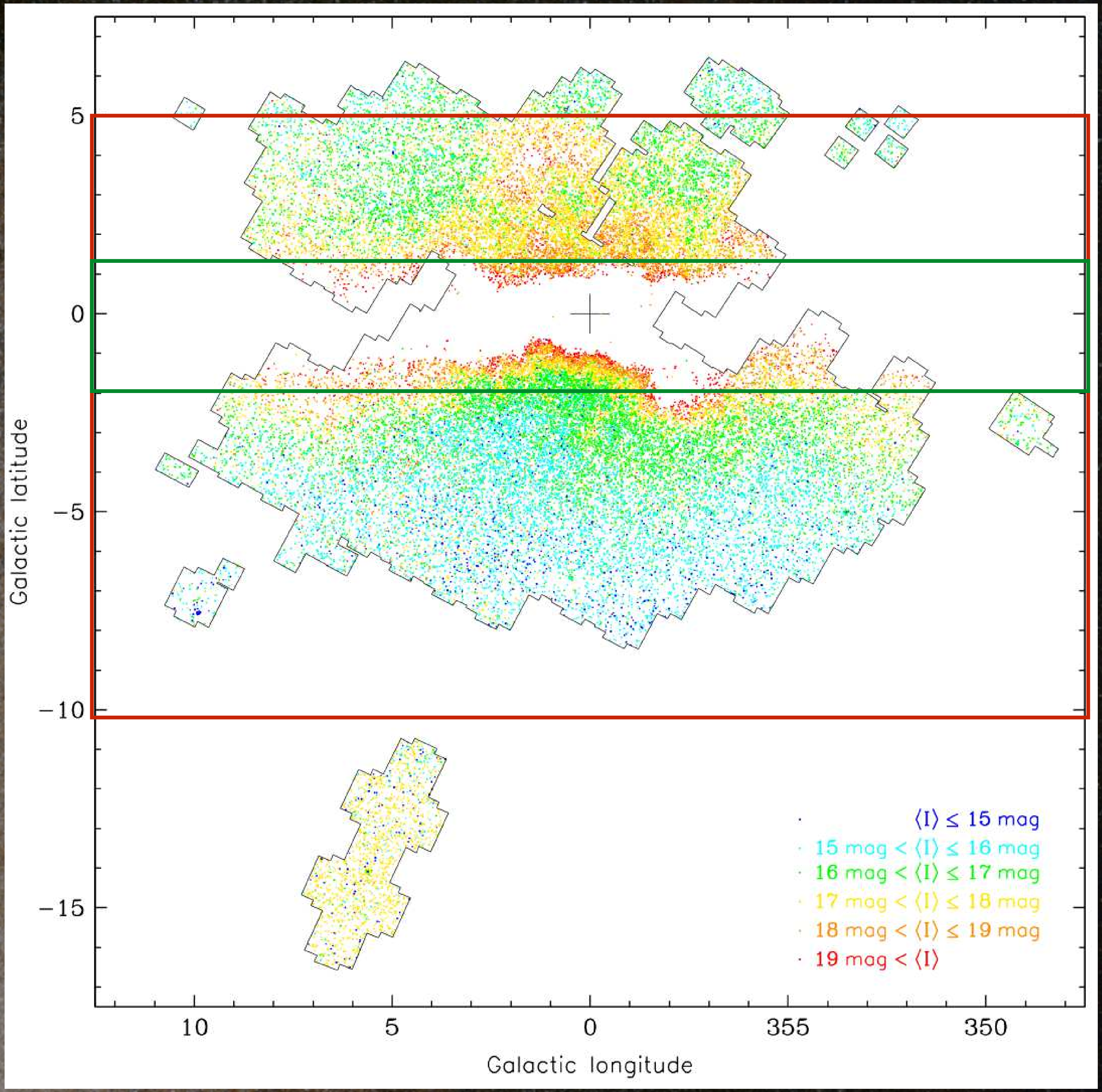


Dékány et al. 2013, ApJL

BULGE MAPPING



Up next:
extended I+Ks analysis of OGLE-IV sample.
Near-IR data extraction almost complete.

Dékány et al. 2015, in prep.

Up next:
explore the rest with VVV.
Challenge:
identifying RR Lyrae n the near-IR.
Time-series analysis underway, automatic classifier ready.

Soszynski et al. (2014)

BULGE MAPPING

The old (> 10 Gyr) bulge is not X-shaped and not even barred.
The Milky Way has a composite bulge:

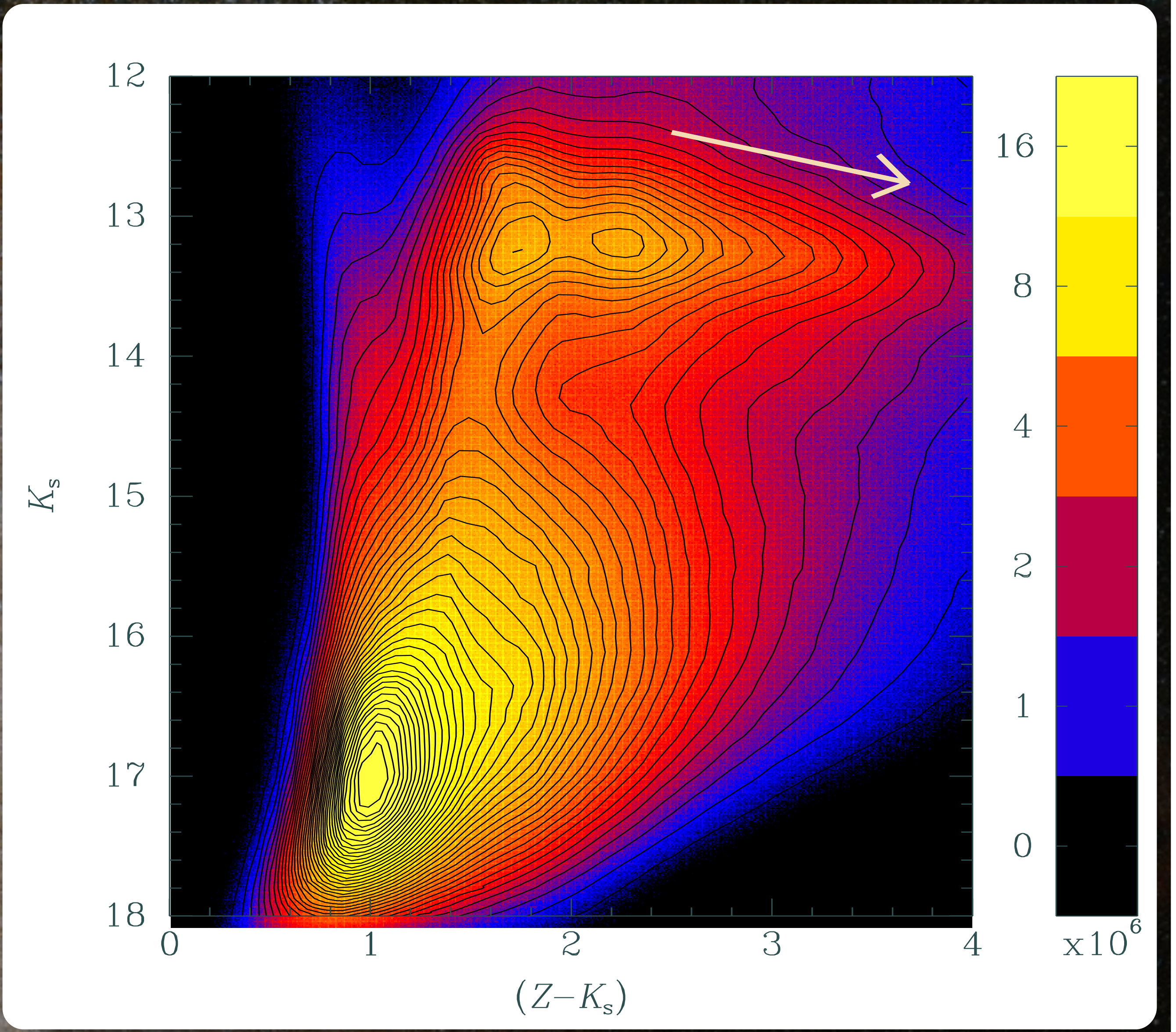
BOXY PEANUT + SPHEROID

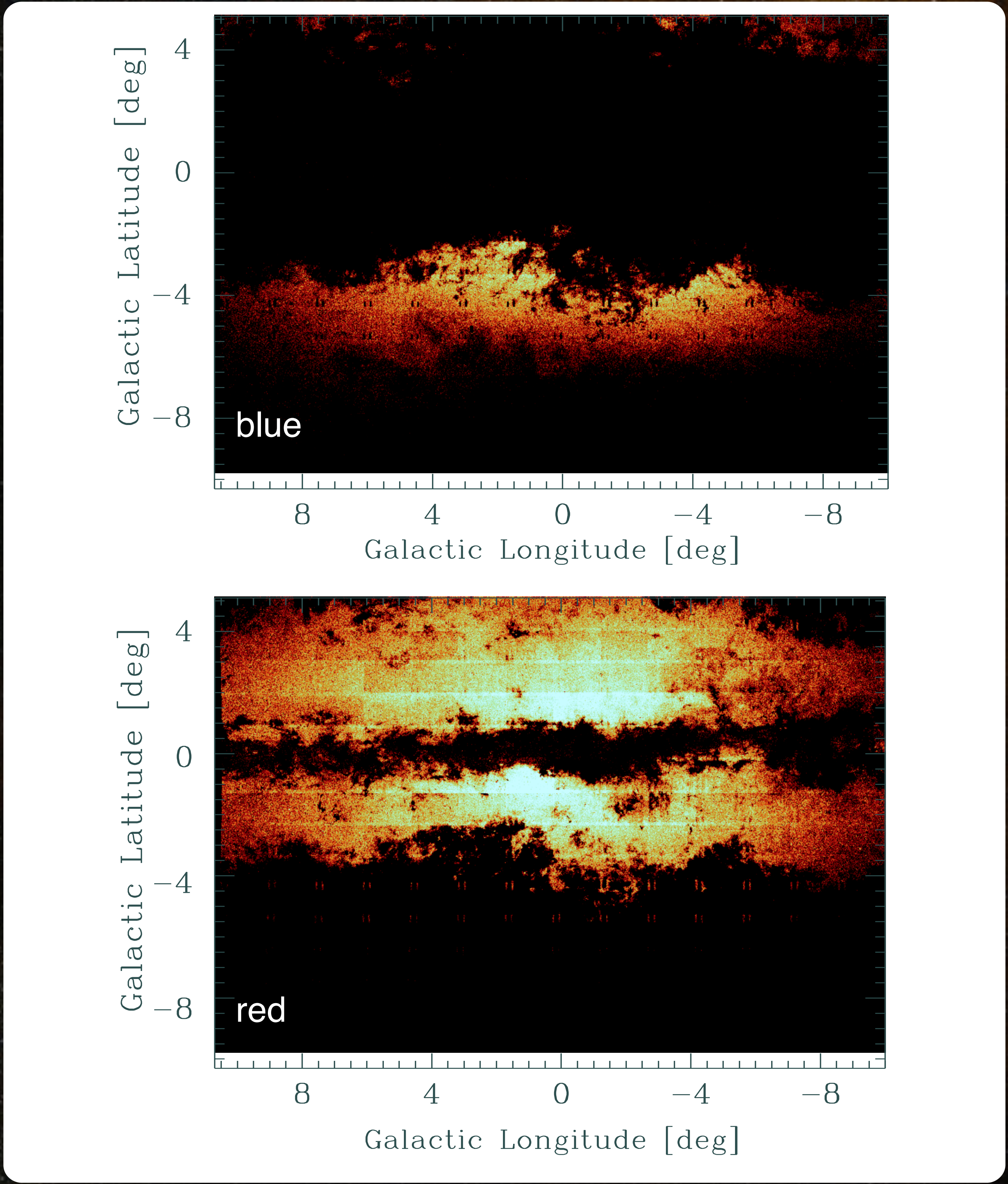
The MW formed first inside-out, then grew a boxy peanut shaped bulge.

Samland & Gerhard 2003, A&A
Obreja et al. 2013, ApJ
Saha & Gerhard 2013, MNRAS

THE GREAT DARK LANE

A split red clump is seen along the reddening vector towards the bulge.



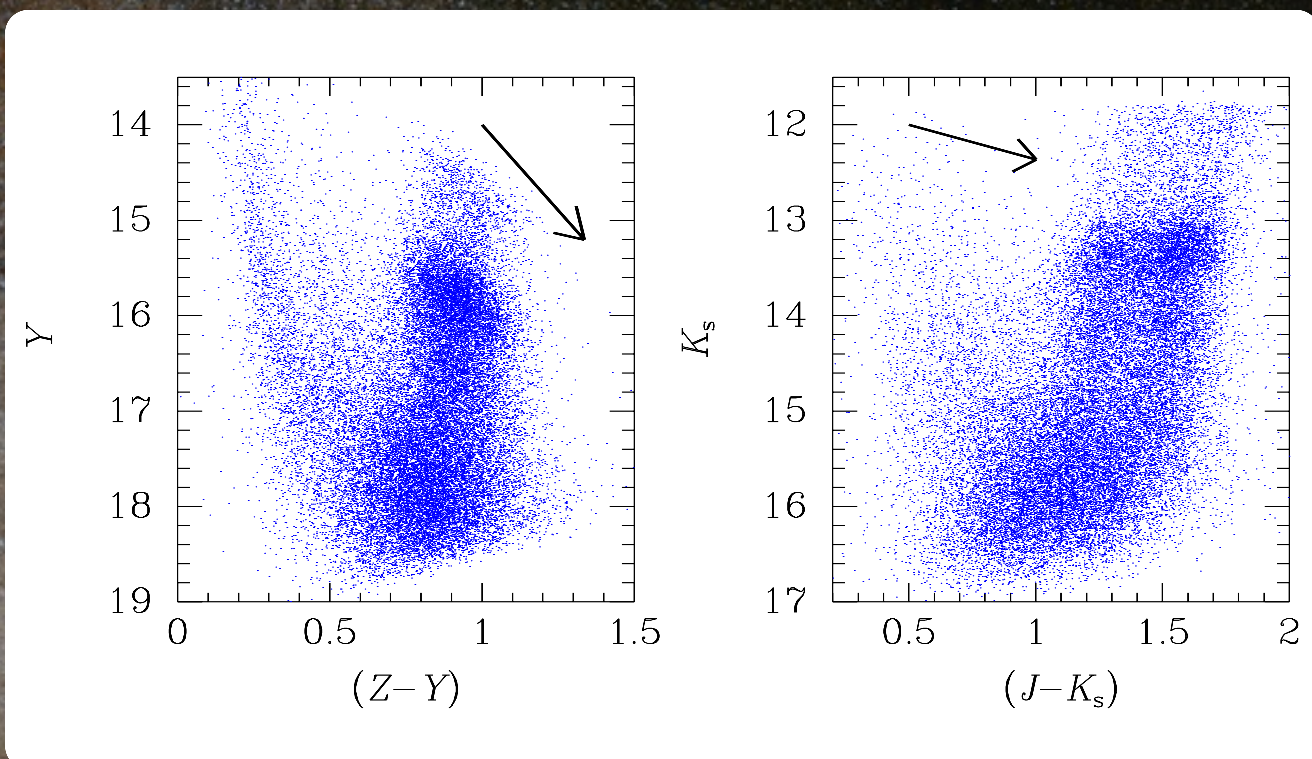


66 million stars

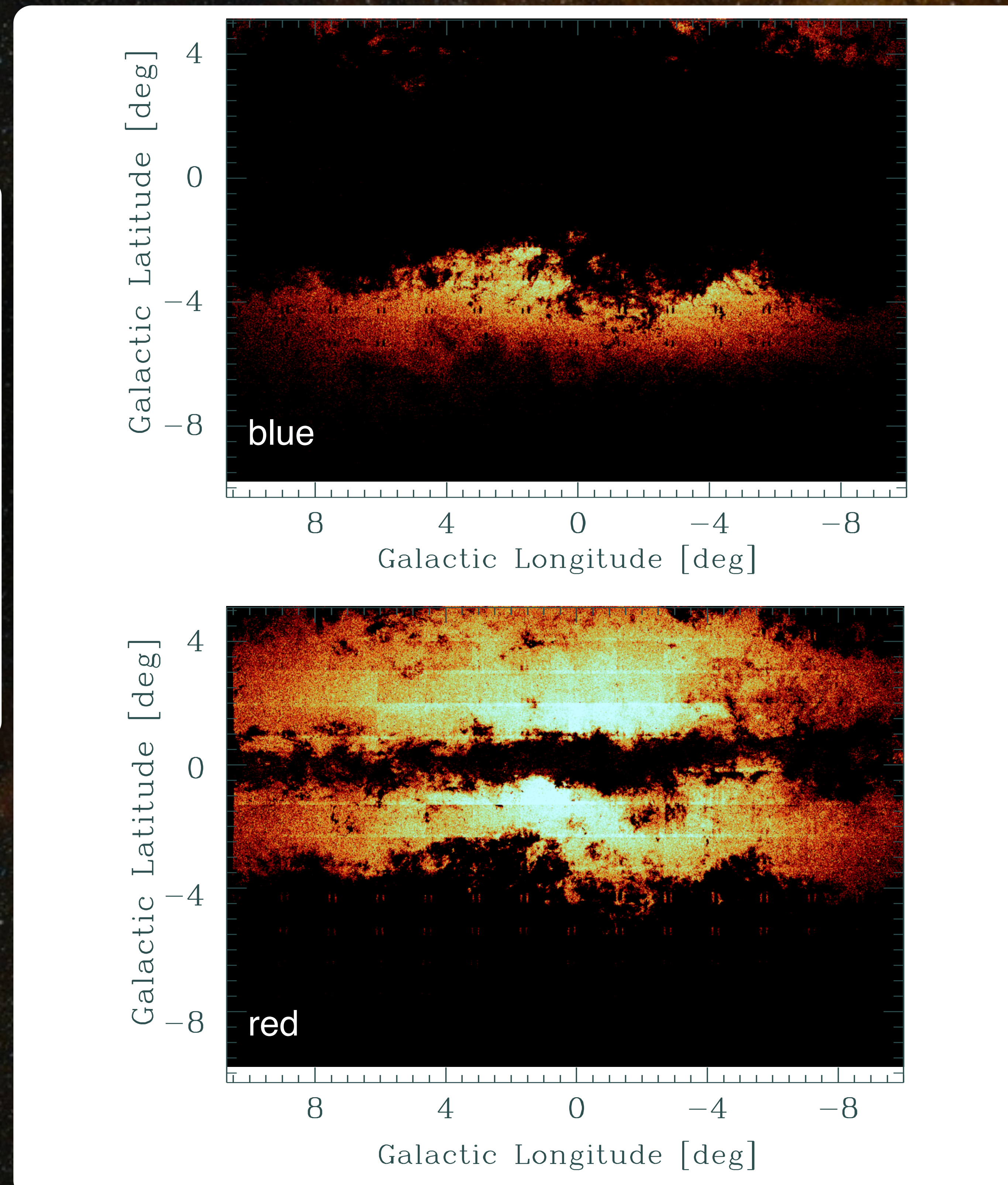
Minniti et al. 2014, A&A

THE GREAT DARK LANE

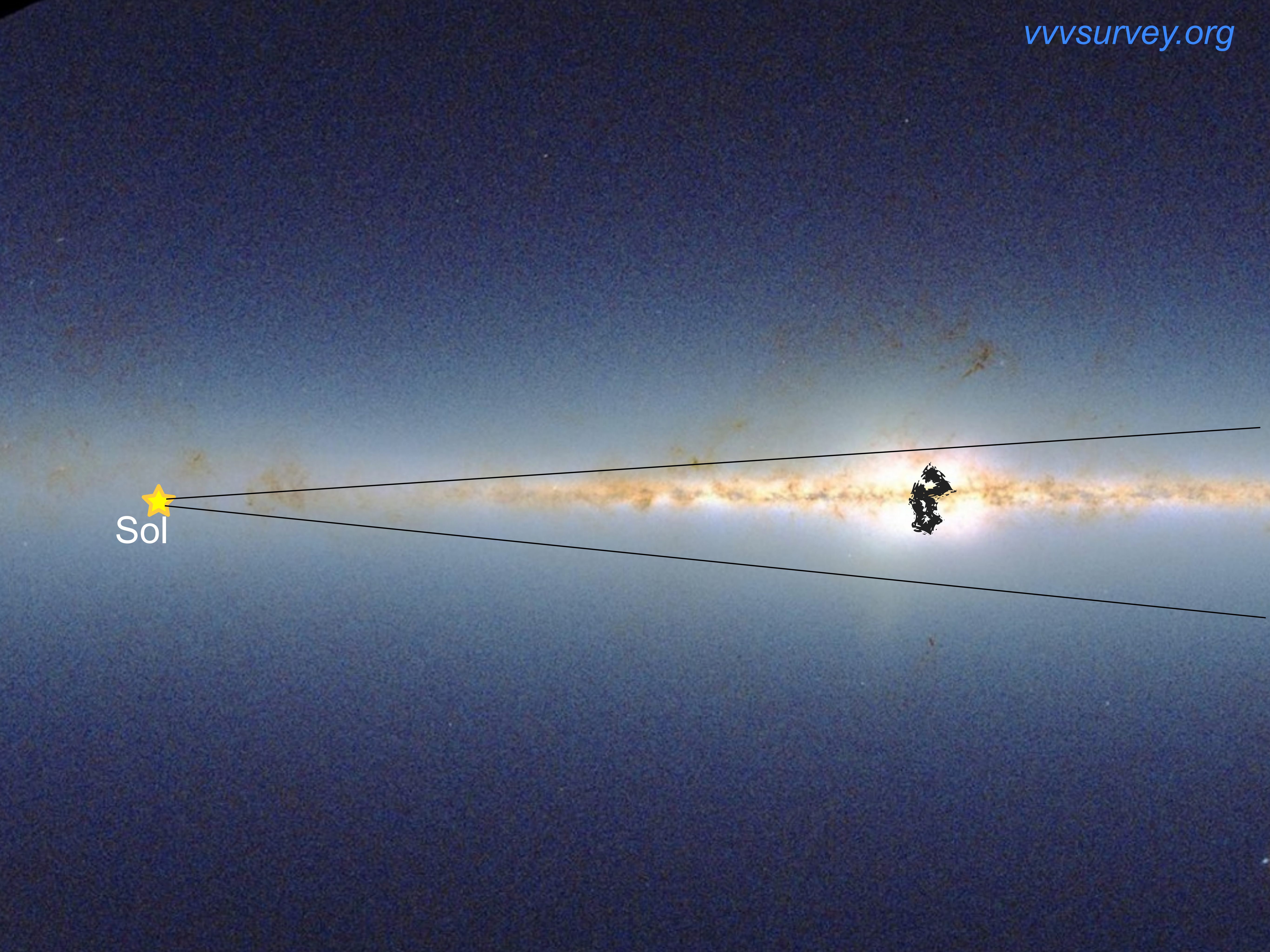
A split red clump is seen along the reddening vector towards the bulge.



small field at the dark lane's edge



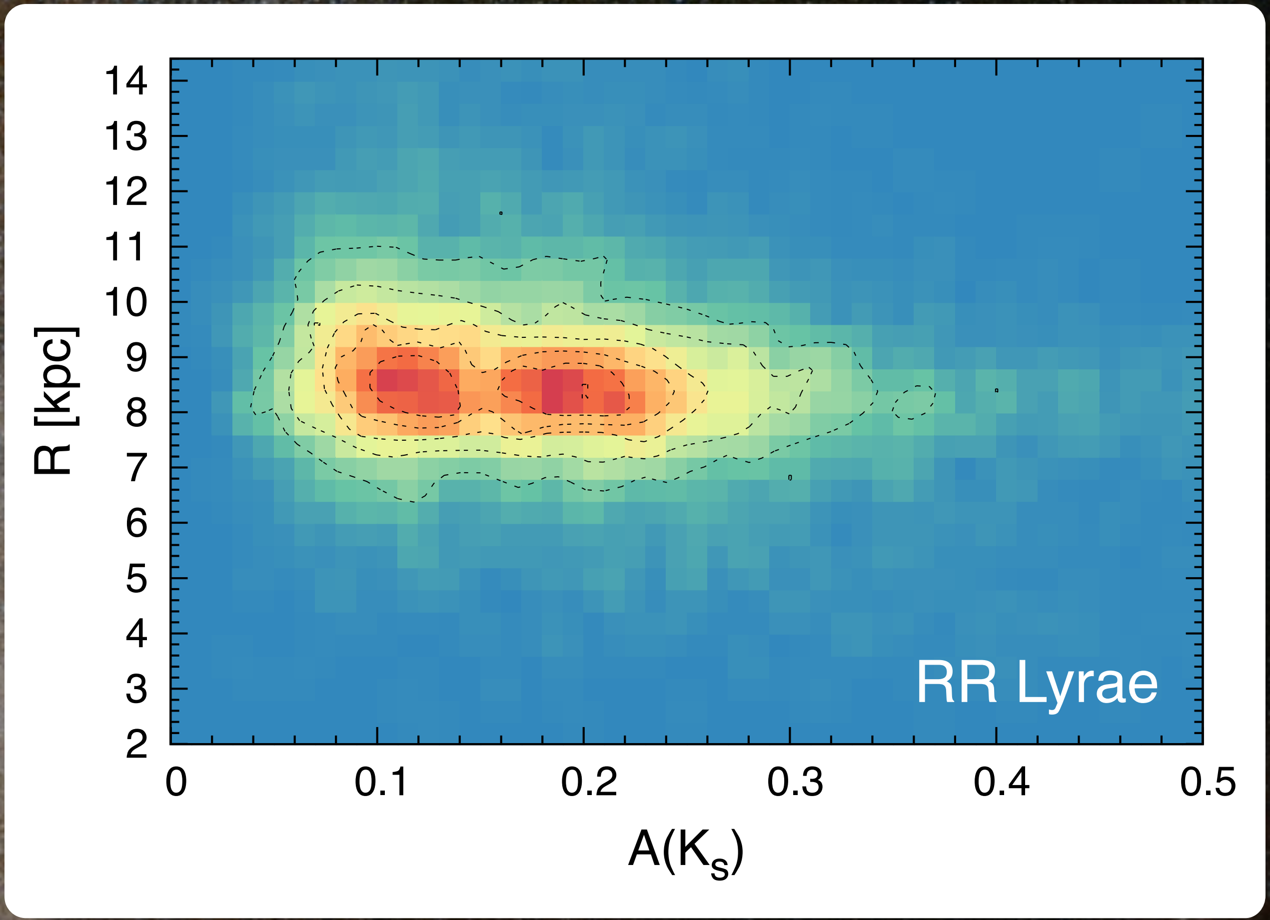
Minniti et al. 2014, A&A

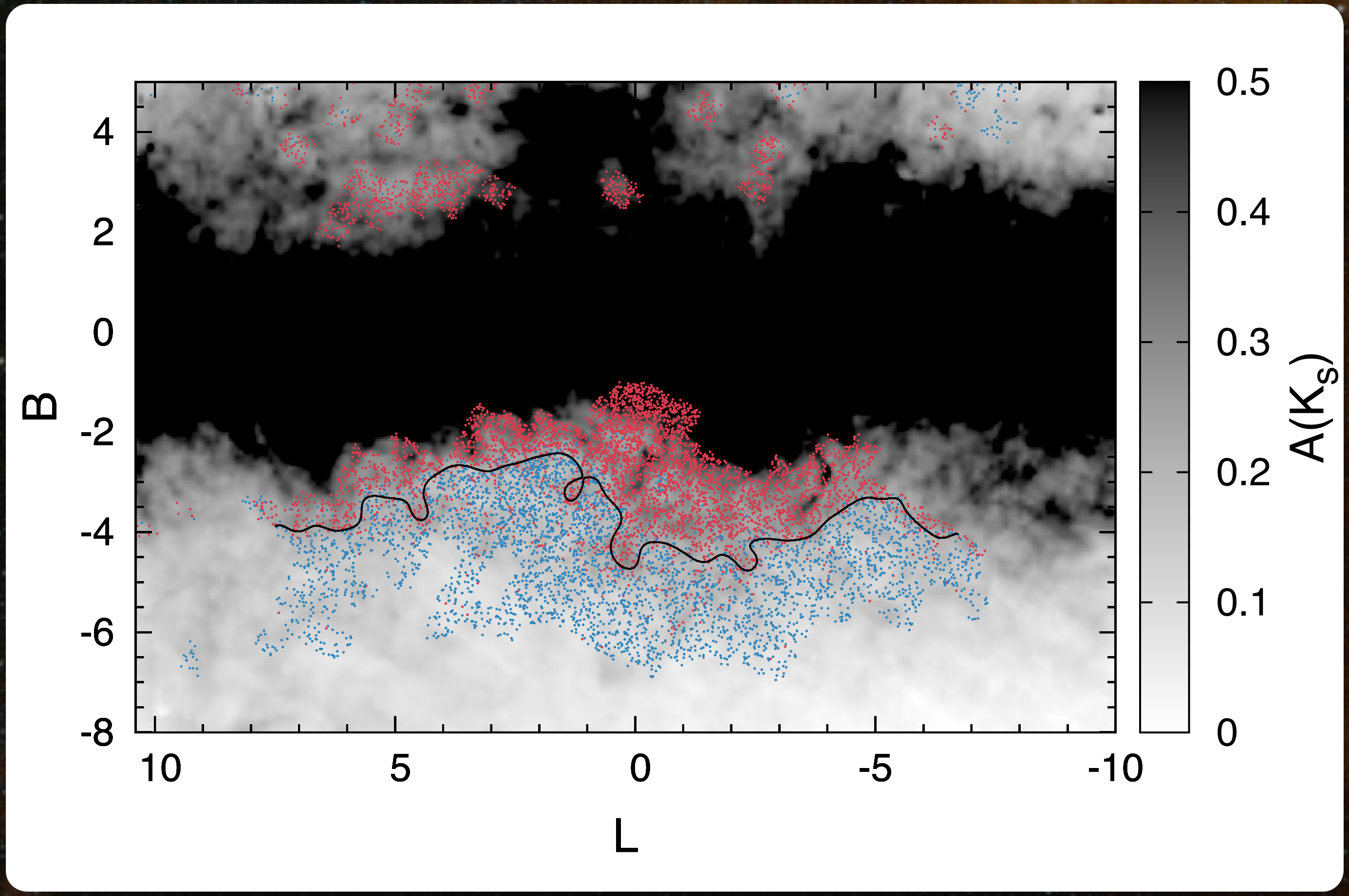

vvvsurvey.org
Sol

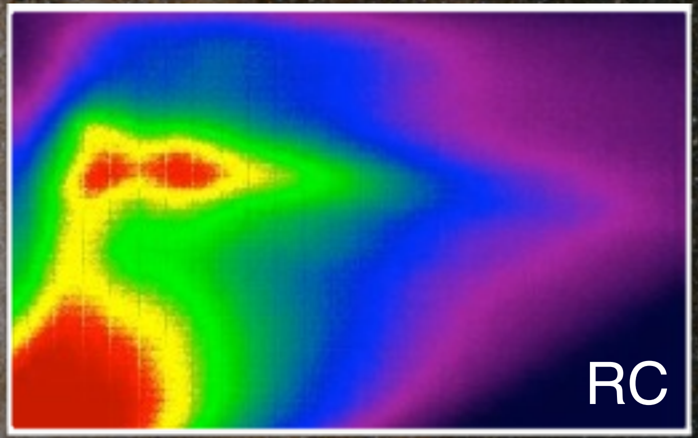

NGC1365: two nested bars with two arms
HST OPTICAL
theory: see, e.g., Athanassoula (1993, MNRAS)

THE GREAT DARK LANE

RR Lyrae distance-reddening distribution: the Great Dark Lane is indeed real.





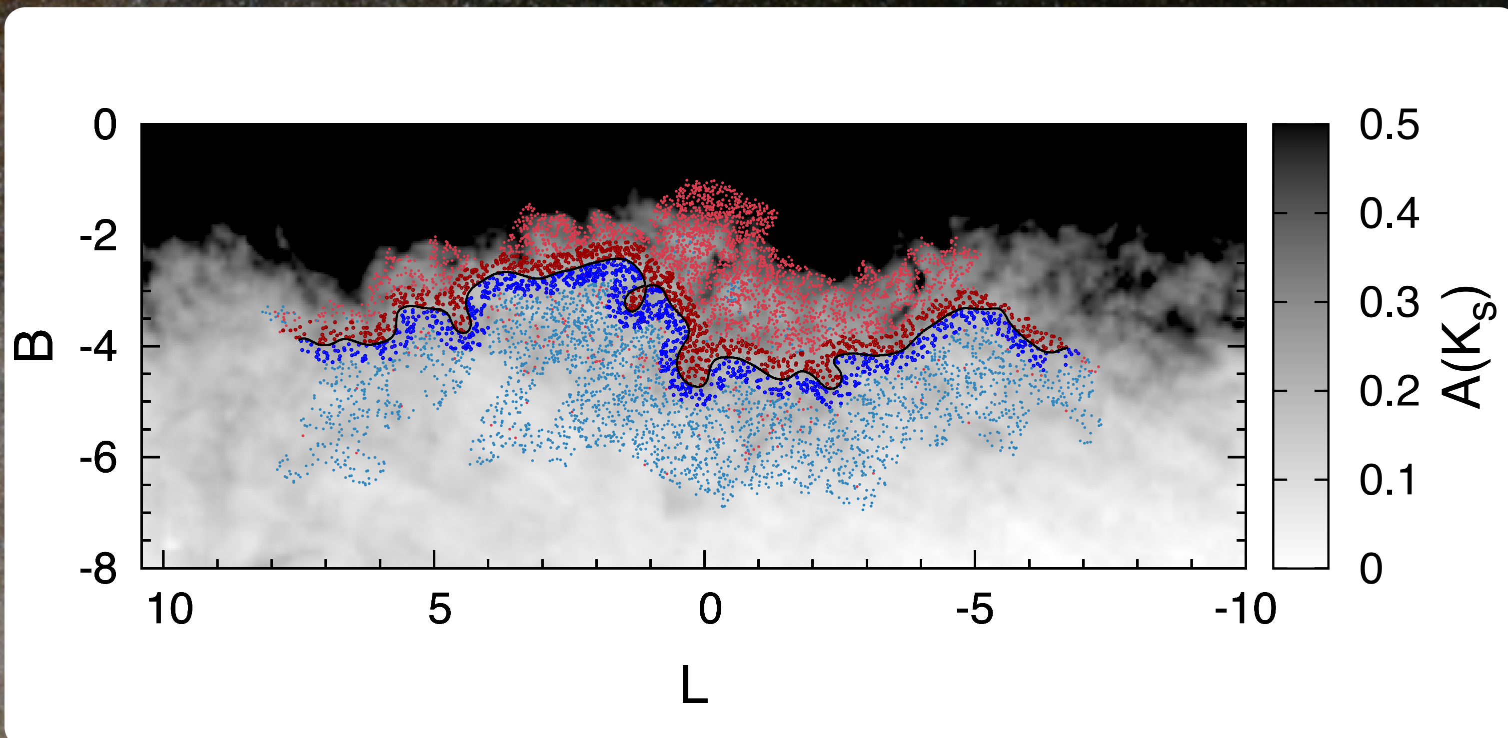


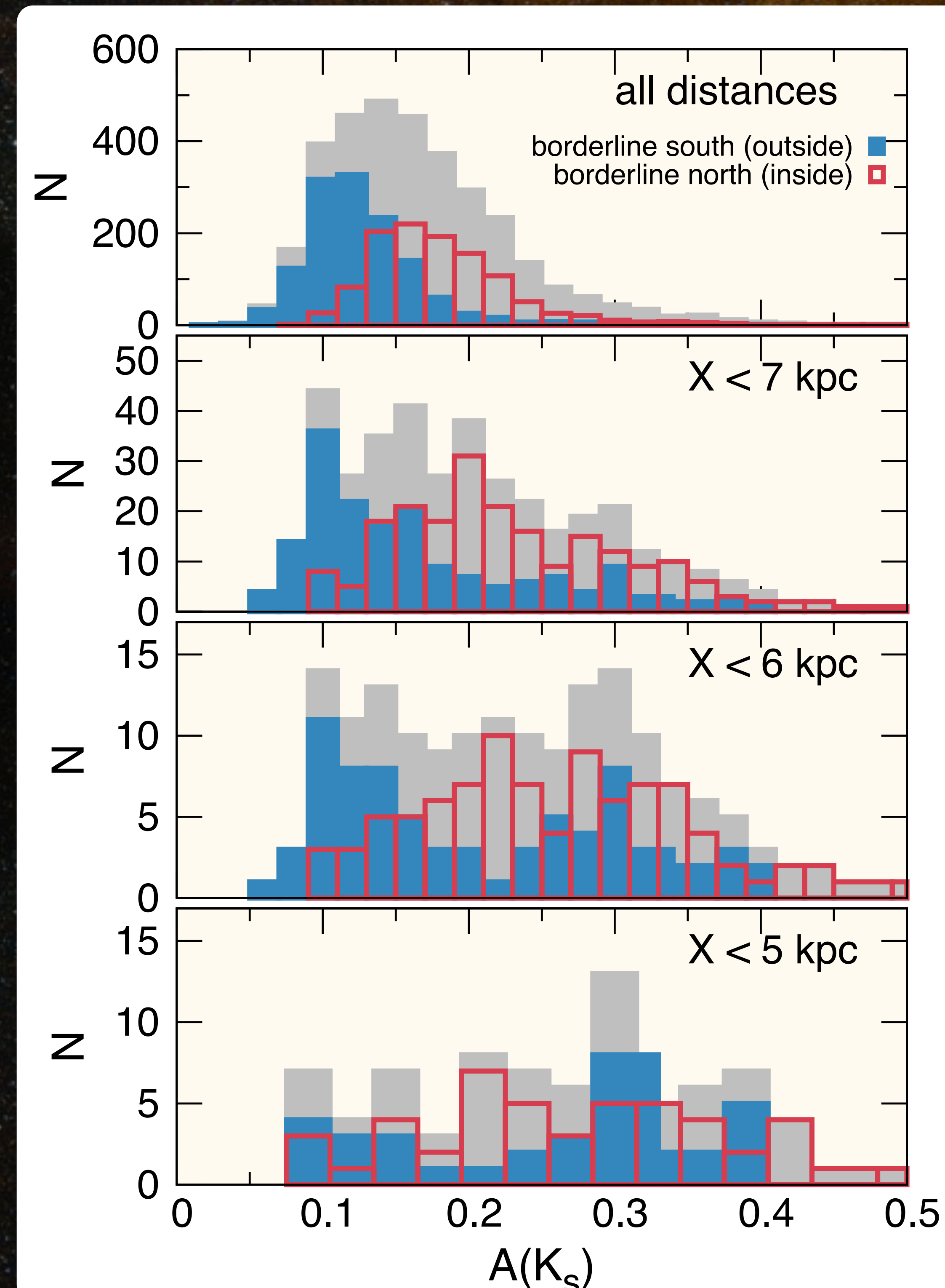
Dékány et al. (in prep.)

Credit: ESO

THE GREAT DARK LANE

RR Lyrae distance-reddening distribution:
the Great Dark Lane is NOT in the bulge.

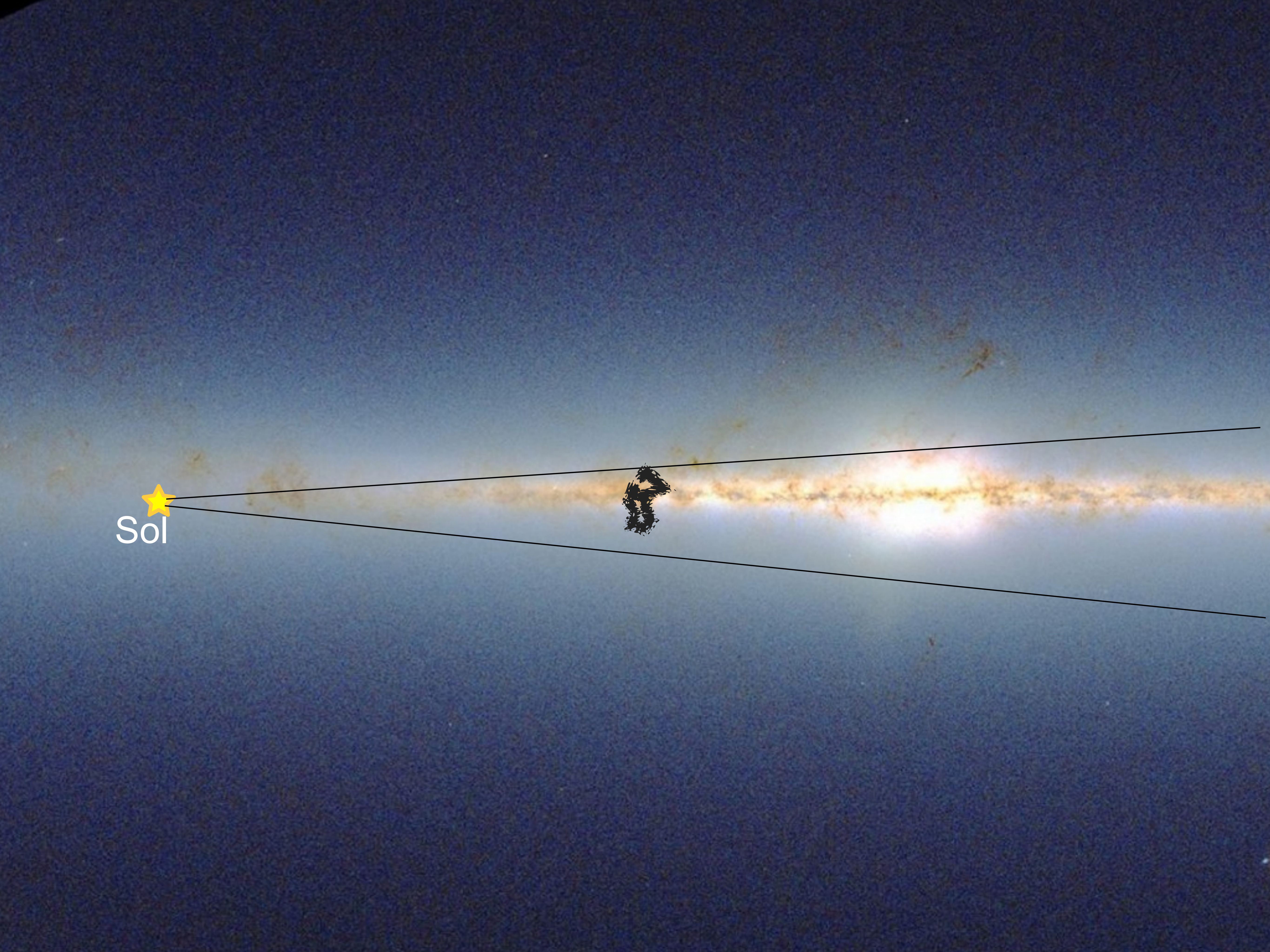


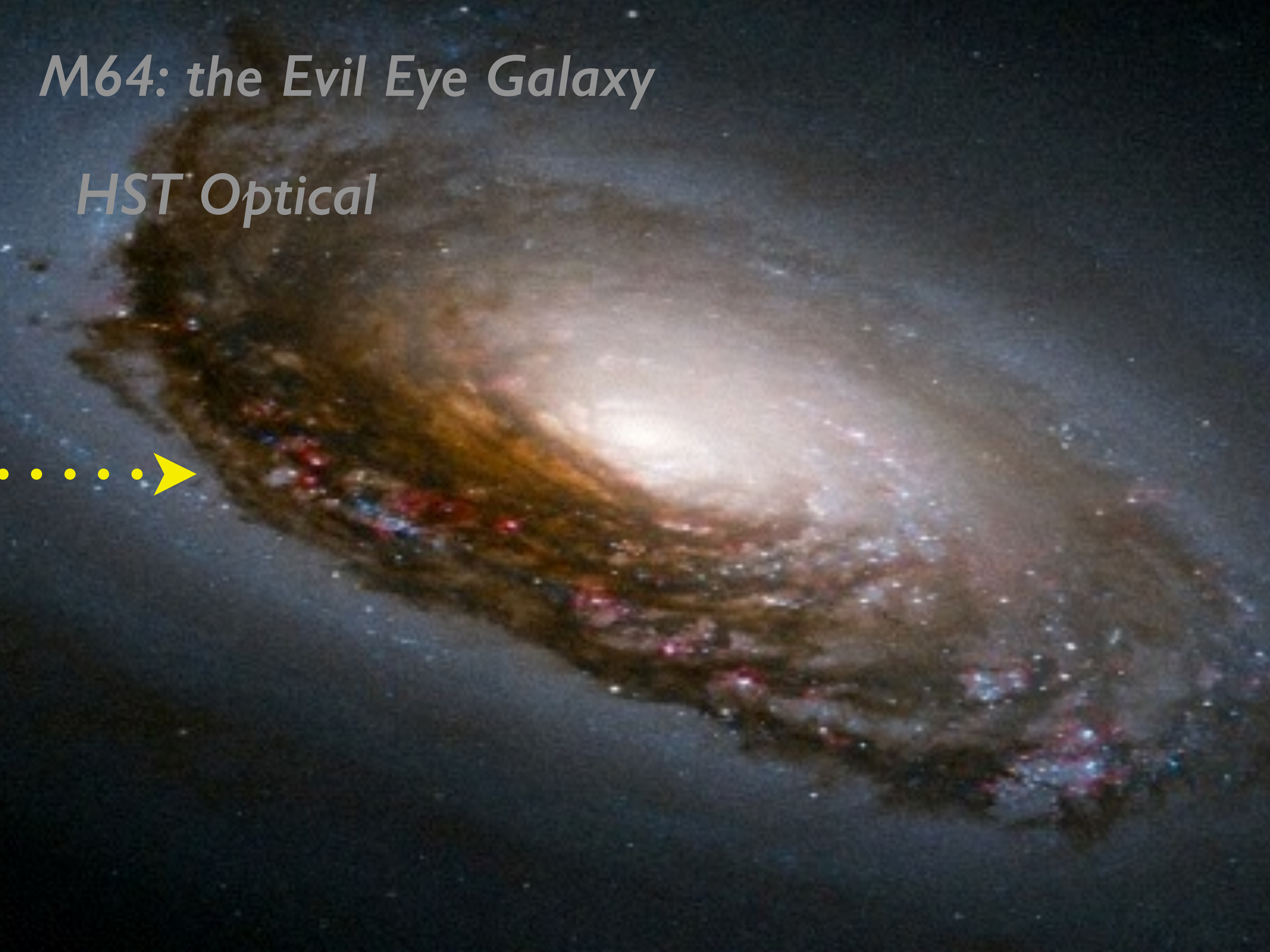


Sample is limited in short distances,
but gives an upper limit of ~6 kpc for the
Dark Lane's distance.

Dékány et al. (in prep.)

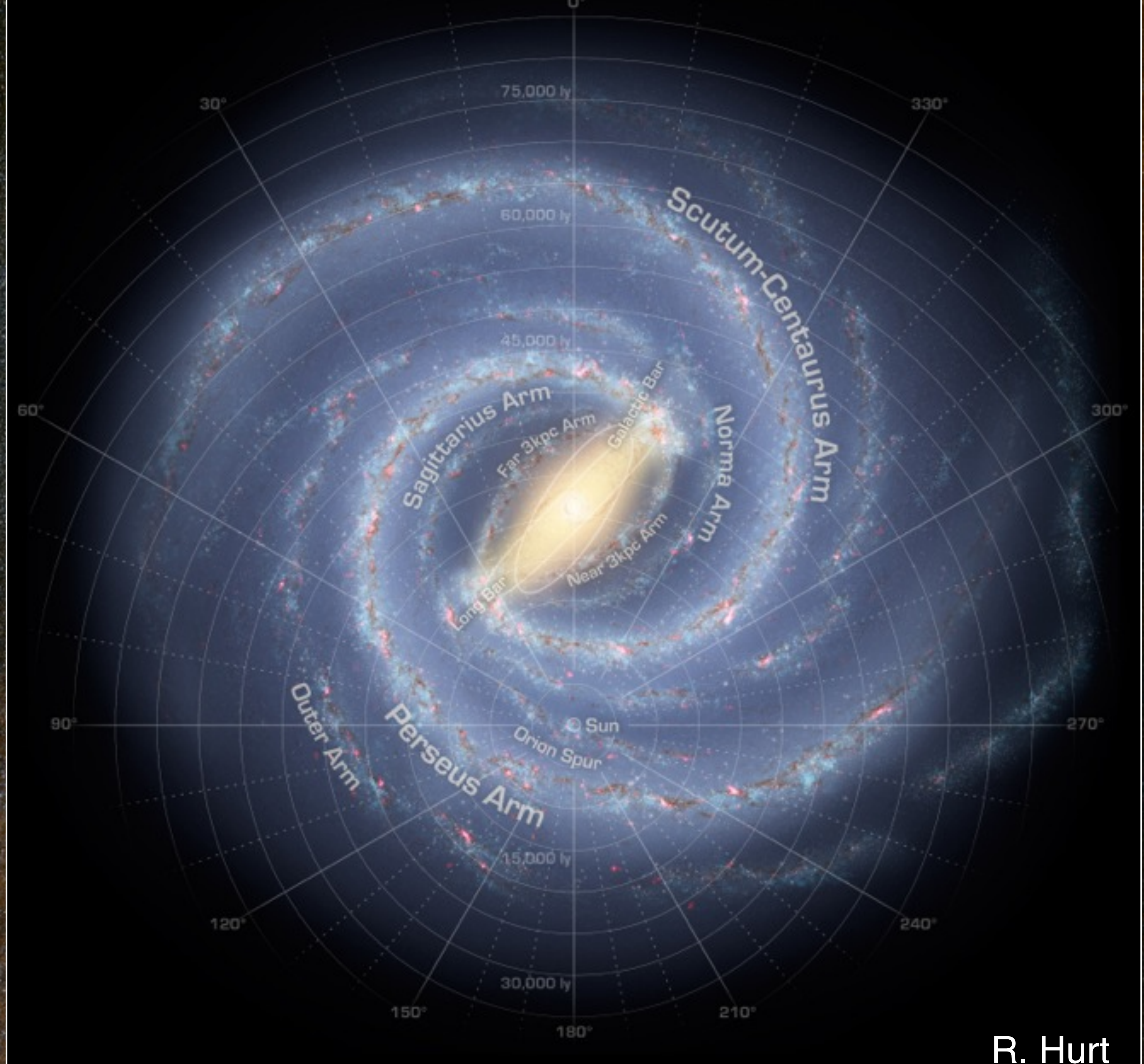
Credit: ESO


Sol


M64: the Evil Eye Galaxy
HST Optical

THE OTHER SIDE OF THE MW.

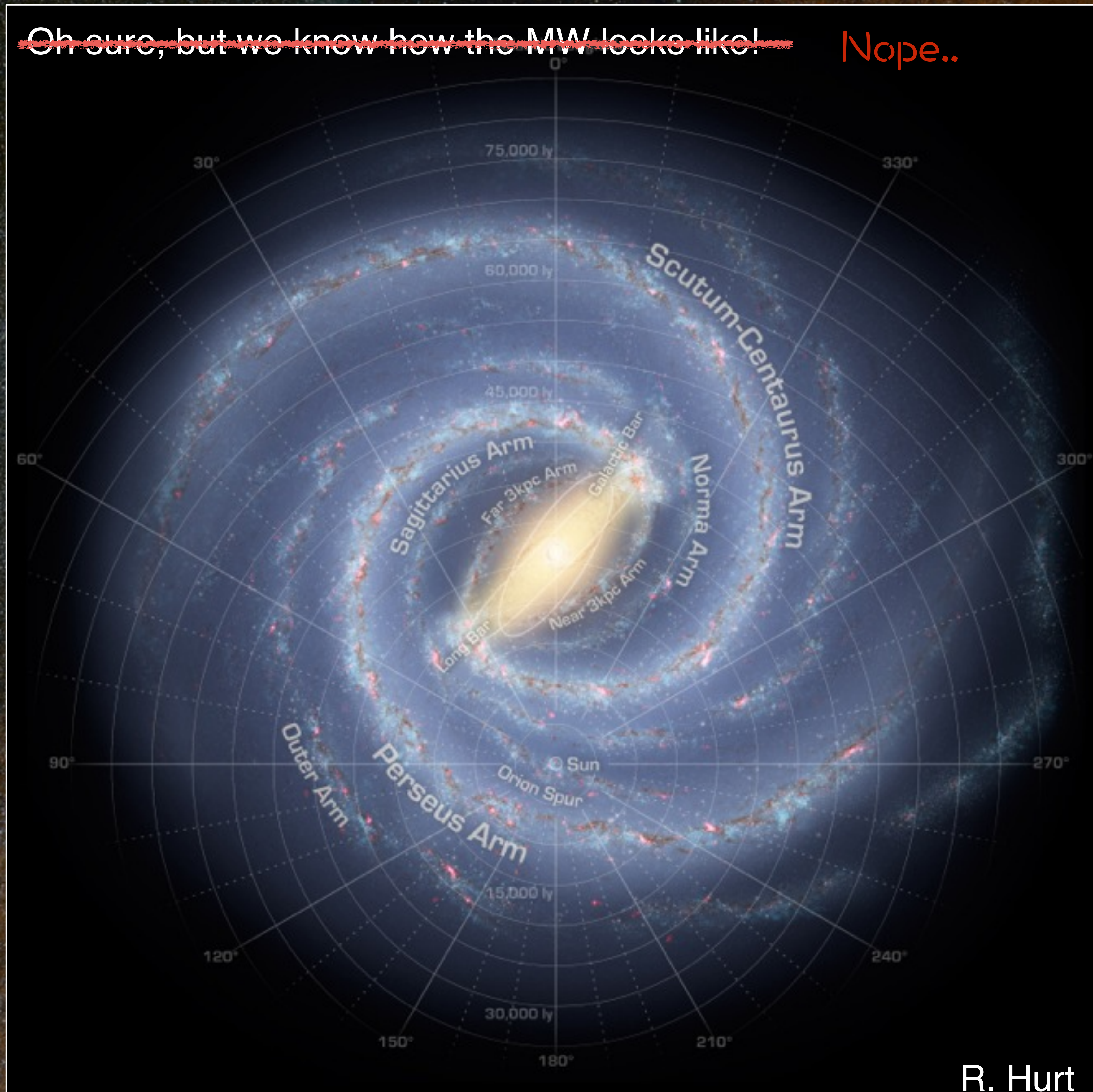
Oh sure, but we know how the MW looks like!



R. Hurt

Credit: ESO

THE OTHER SIDE OF THE MW.



THE OTHER SIDE OF THE MW.

(Pre-2MASS)

Ptolemy et al. (150)

Credit: ESO

Credit: ESO

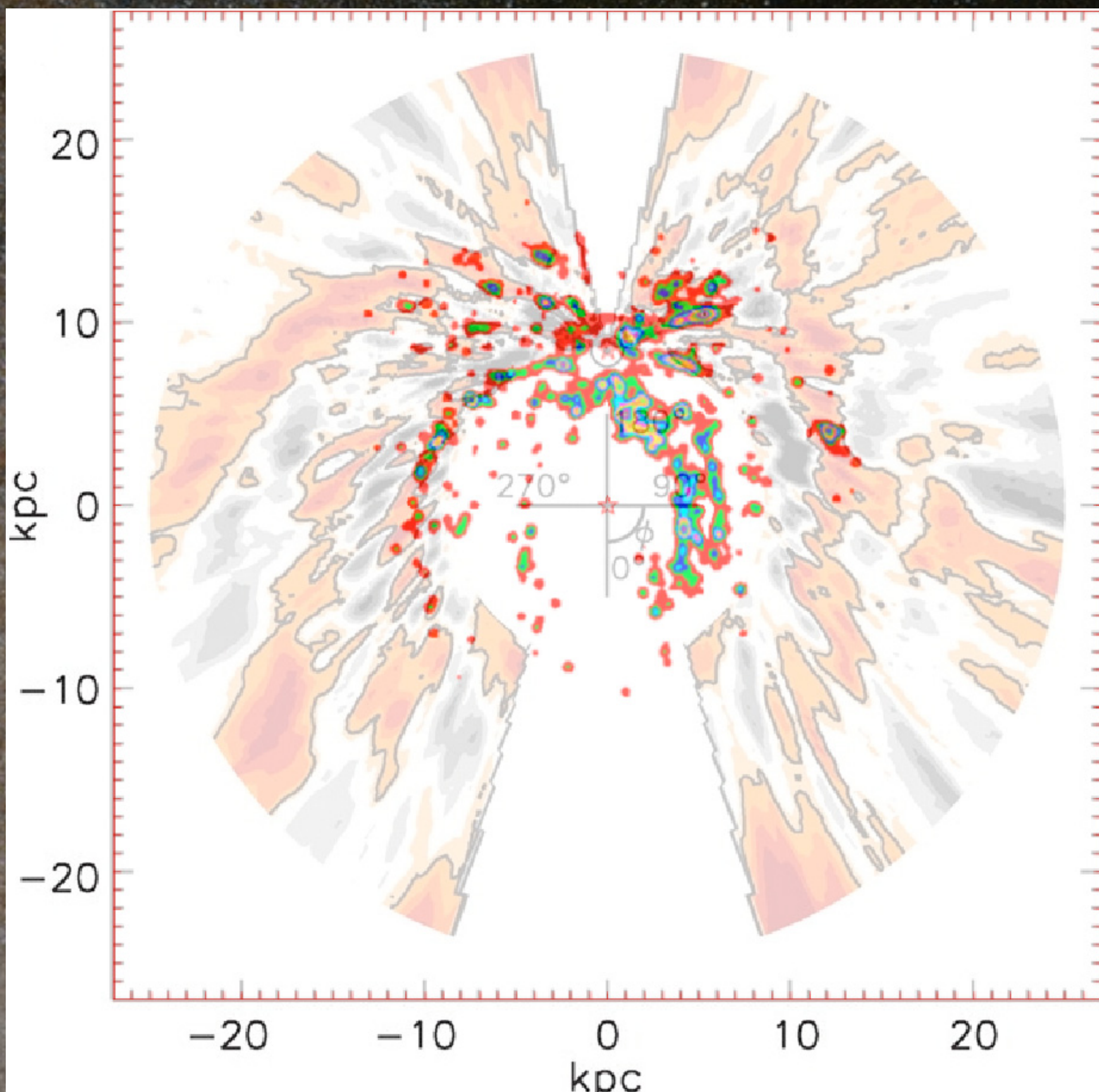
THE OTHER SIDE OF THE MW.

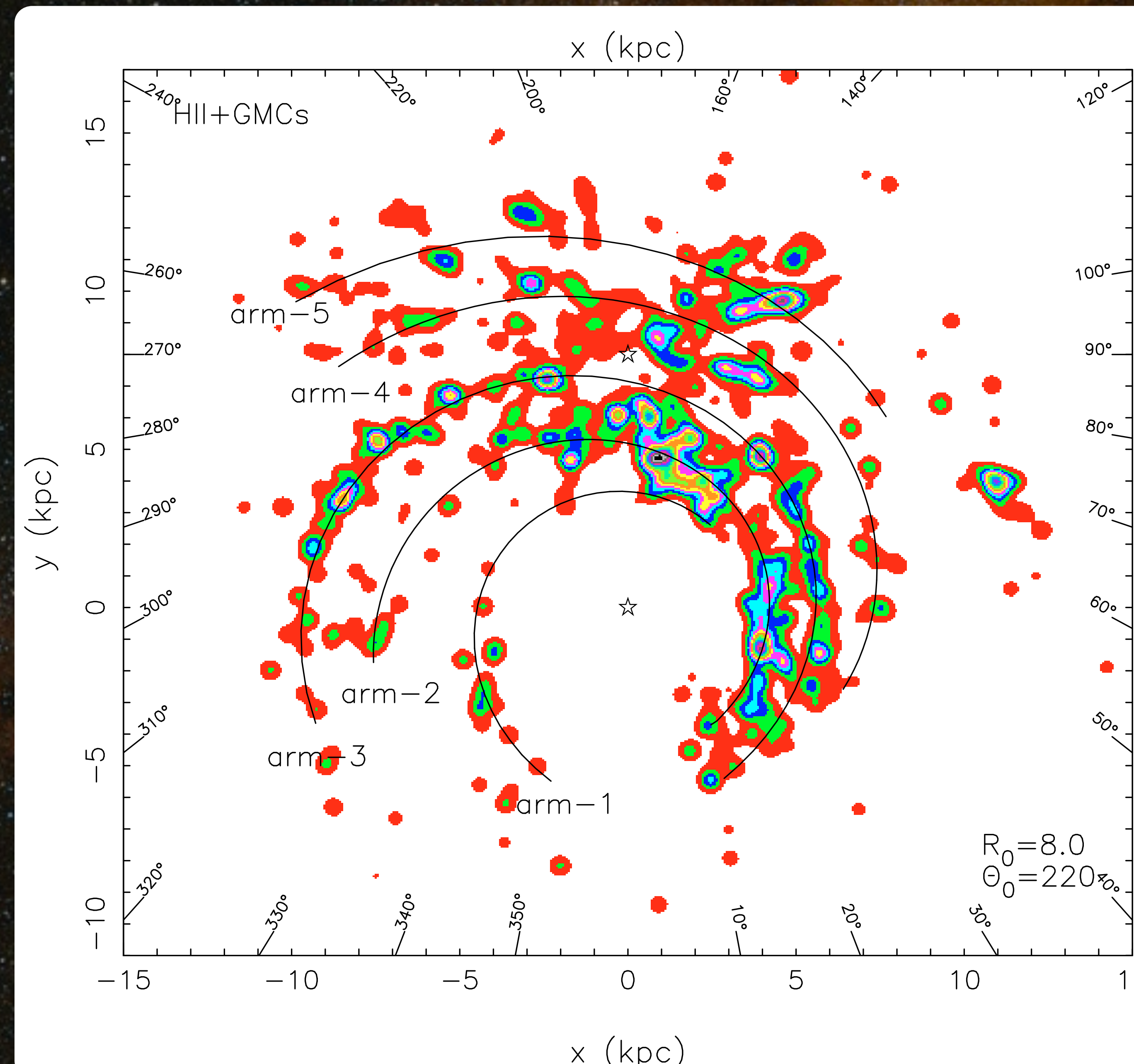
(Post-Spitzer)

Ortelius et al. (1570)

THE OTHER SIDE OF THE MW.

Velocity mapping (HI, HII, CO, masers, …)
Drawback: kinematic assumptions, blind towards GC, GAC

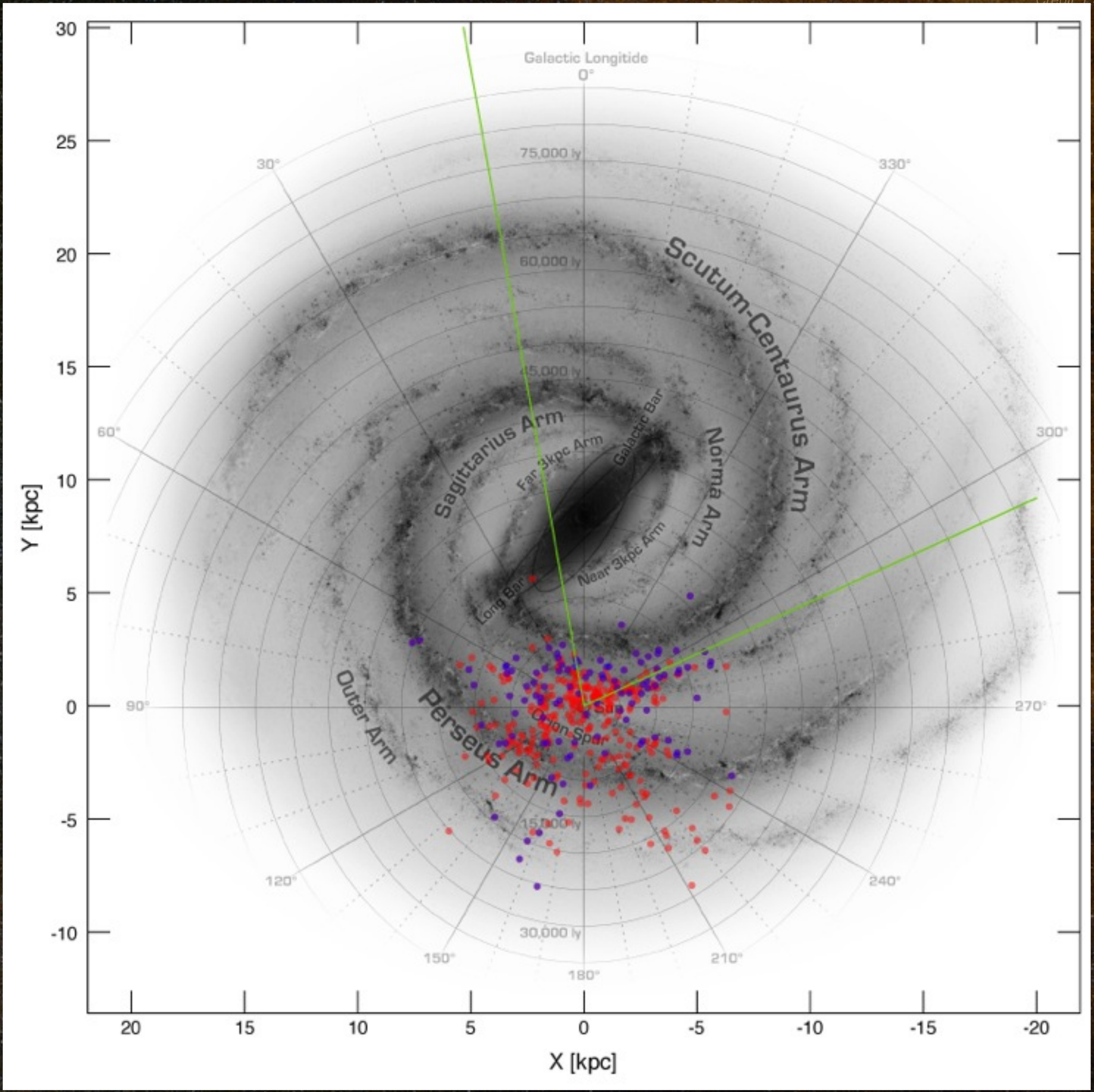




Hou et al. (2009, A&A)

Stellar tracers (Cepheids, YOC, OB stars, …)

Drawback: limited to near side

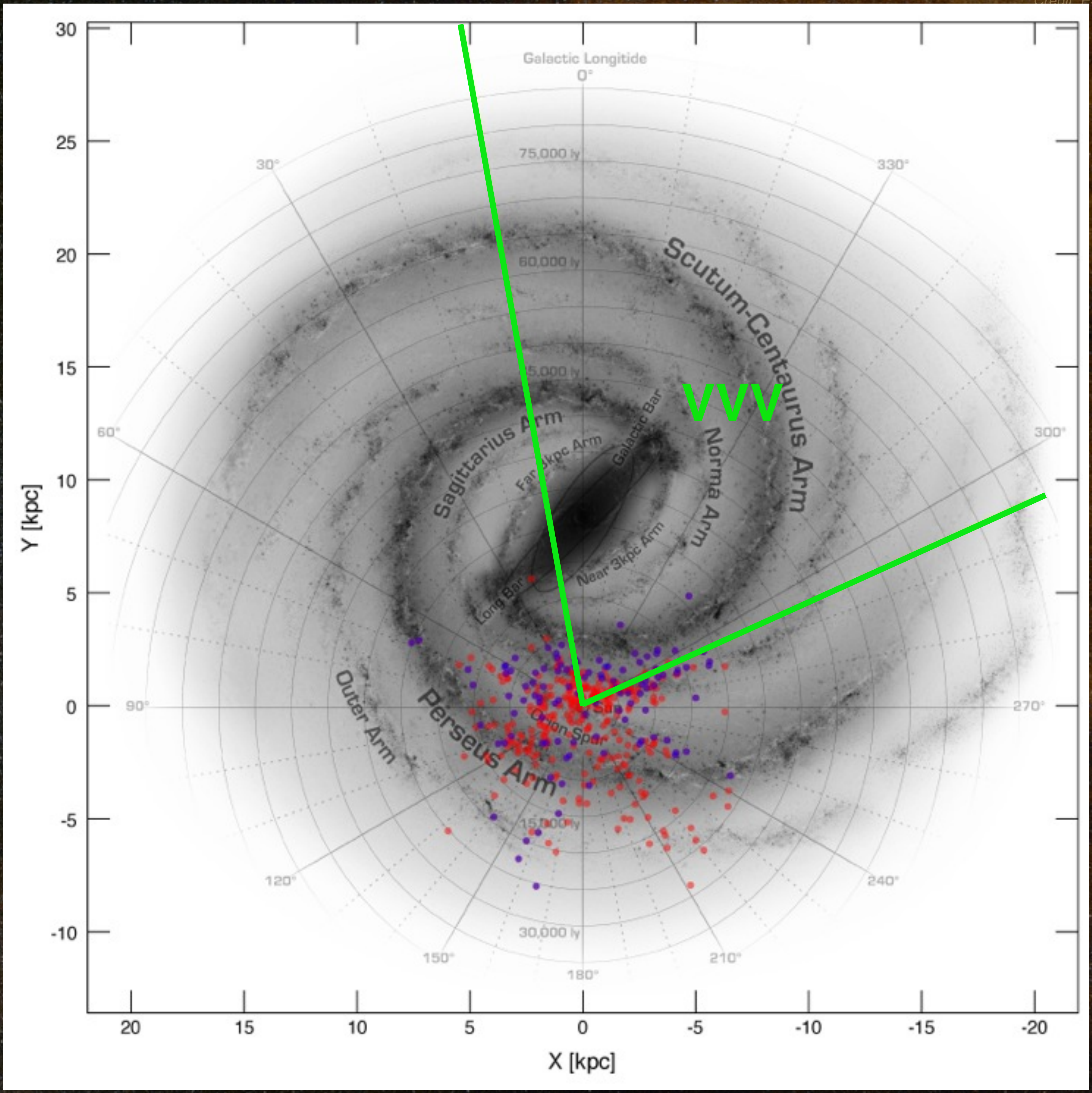


DDO Cepheid database

Stellar tracers (Cepheids, YOC, OB stars, …)

Drawback: limited to near side

BUT: VVV

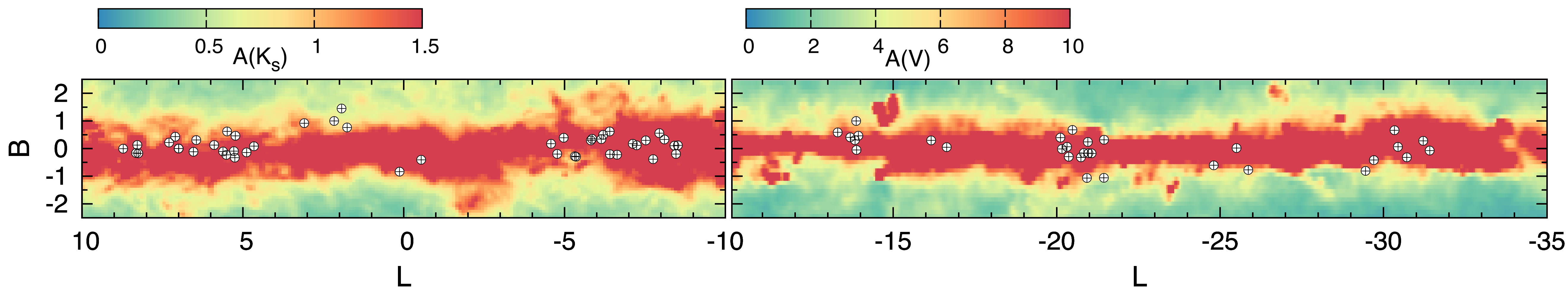


DDO Cepheid database

Credit: ESO

THE OTHER SIDE OF THE MW.

VVV Galactic Cepheid Program (VGCP): up to A(V)~50



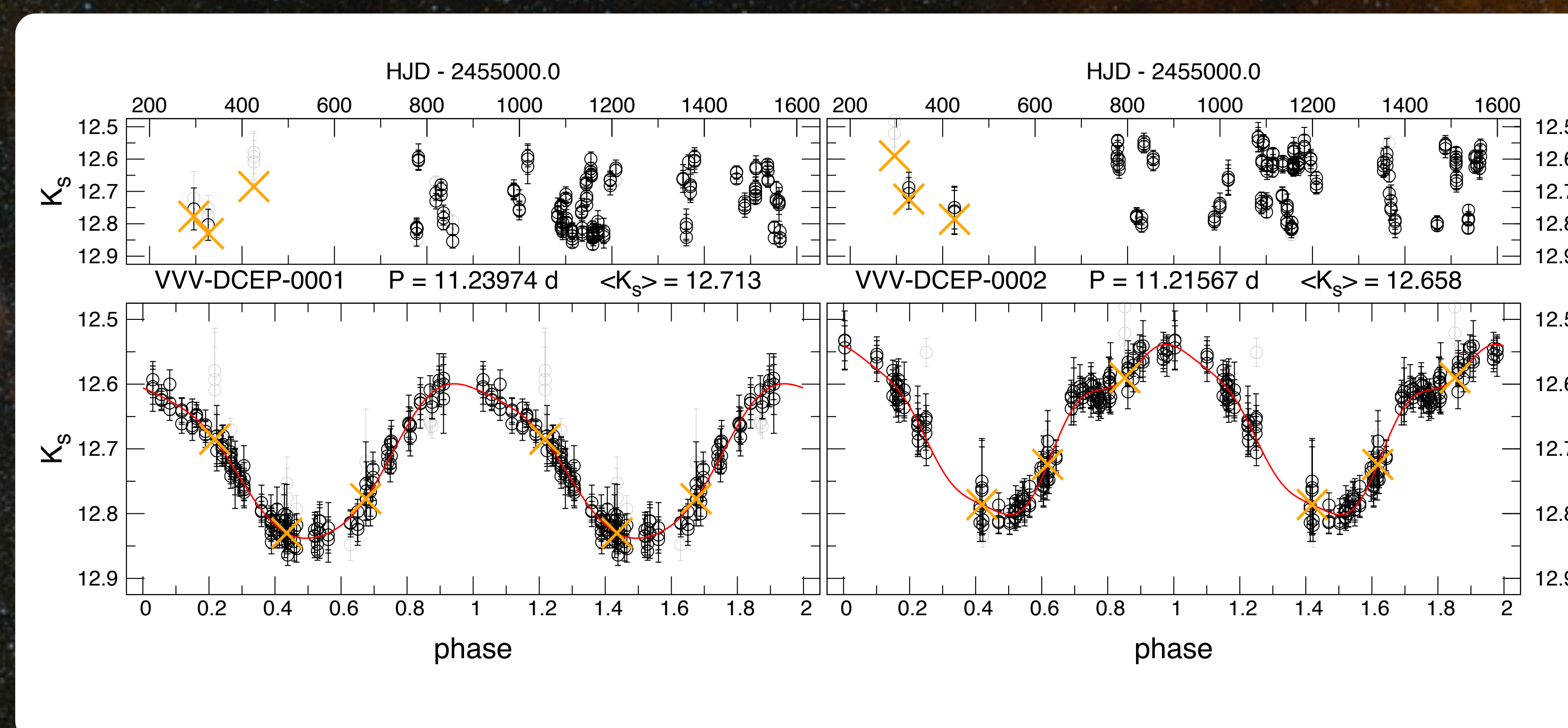
SO FAR:
analysis of ~35 million light-curves in -2º < b < 2º , -70º < l < 10º
~5 % of the low-latitude are searched for Cepheids
~400 candidates found
problem: confusion with type II Cepheids (due to near-IR light-curves)
solution: spectroscopic follow-up
~80 best targets proposed for FIRE/Baade, X-Shooter/VLT

Credit: ESO

THE OTHER SIDE OF THE MW.

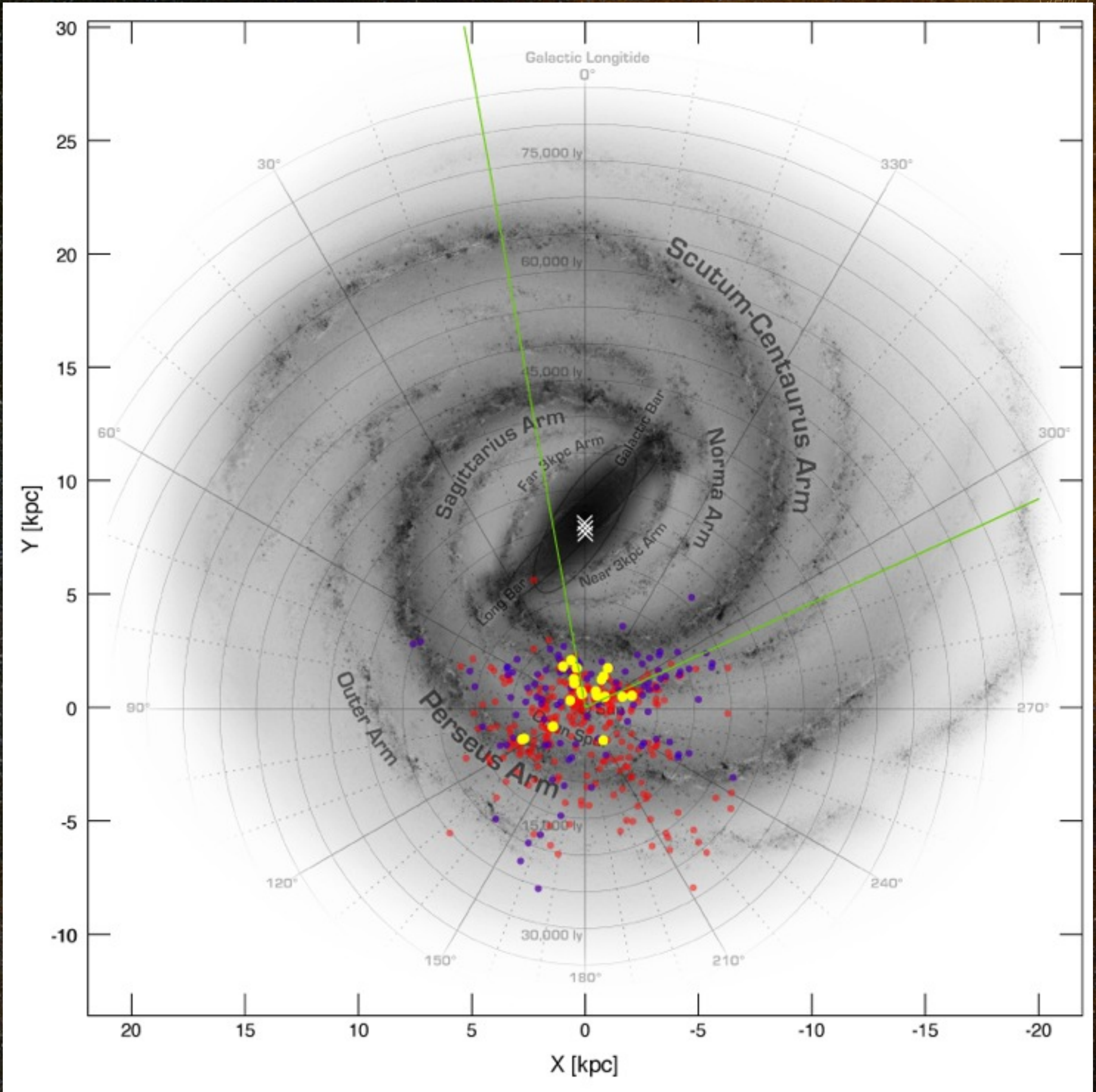
VGCP Proof of Concept: The Twin Cepheids

separation = 18.3”
b=0°
A(Ks)=3.2 mag, A(V)=32 mag
d=11.4 kpc
< 1pc from the Galactic plane
must be type I
must be in OC



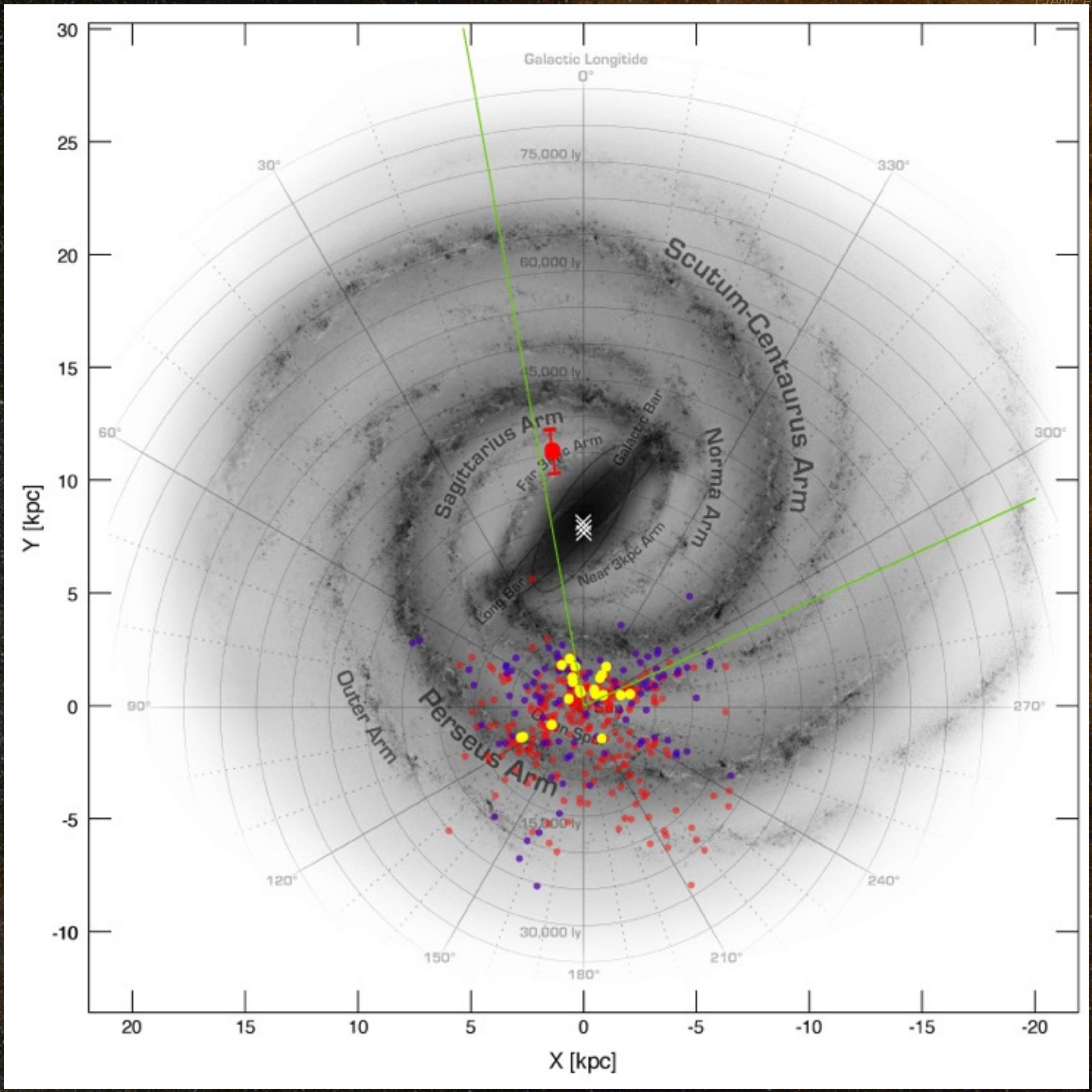
Dékány et al. (2014, ApJL, submitted)

VGCP Proof of Concept: The Twin Cepheids



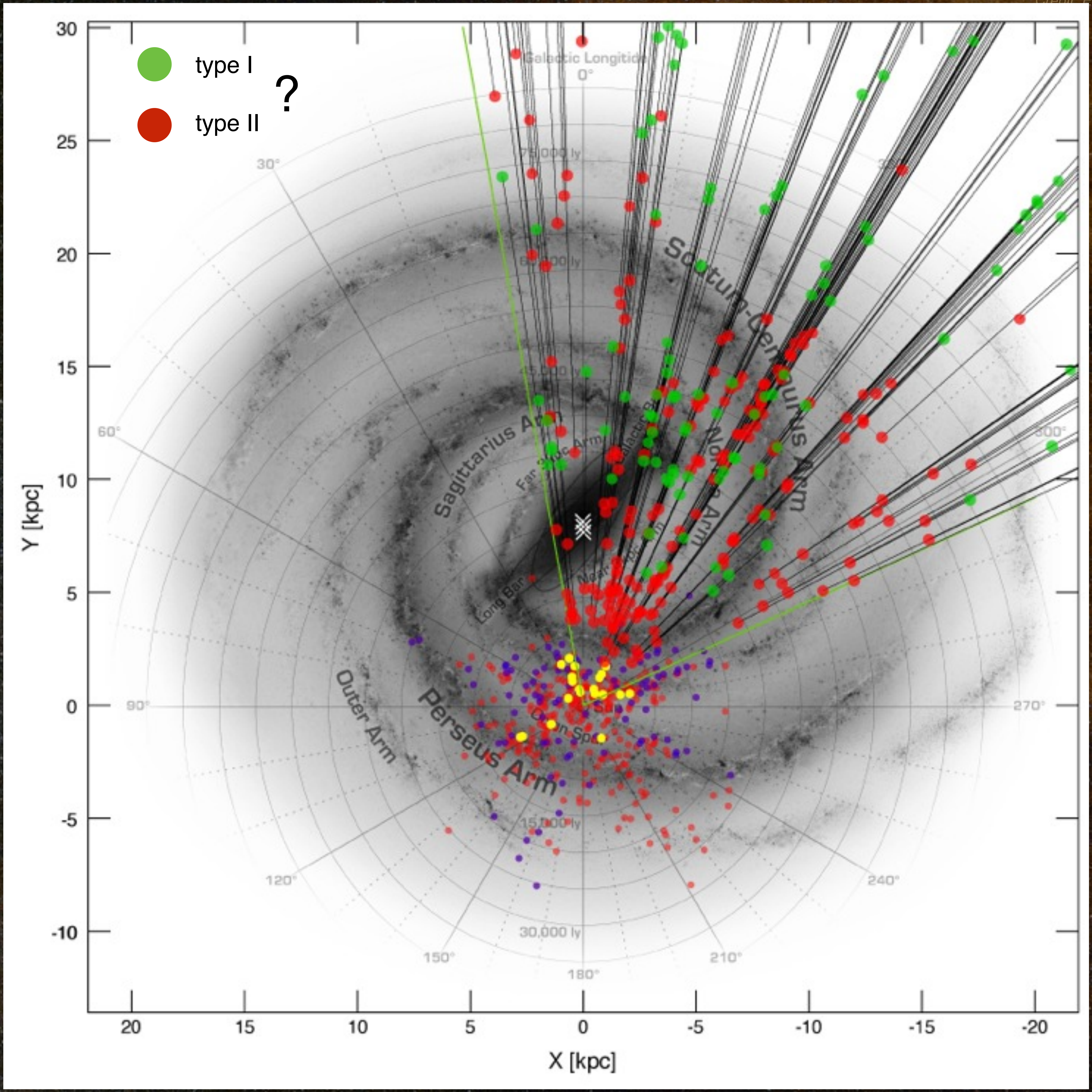
Dékány et al. (2014, ApJL, submitted)

VGCP Proof of Concept: The Twin Cepheids

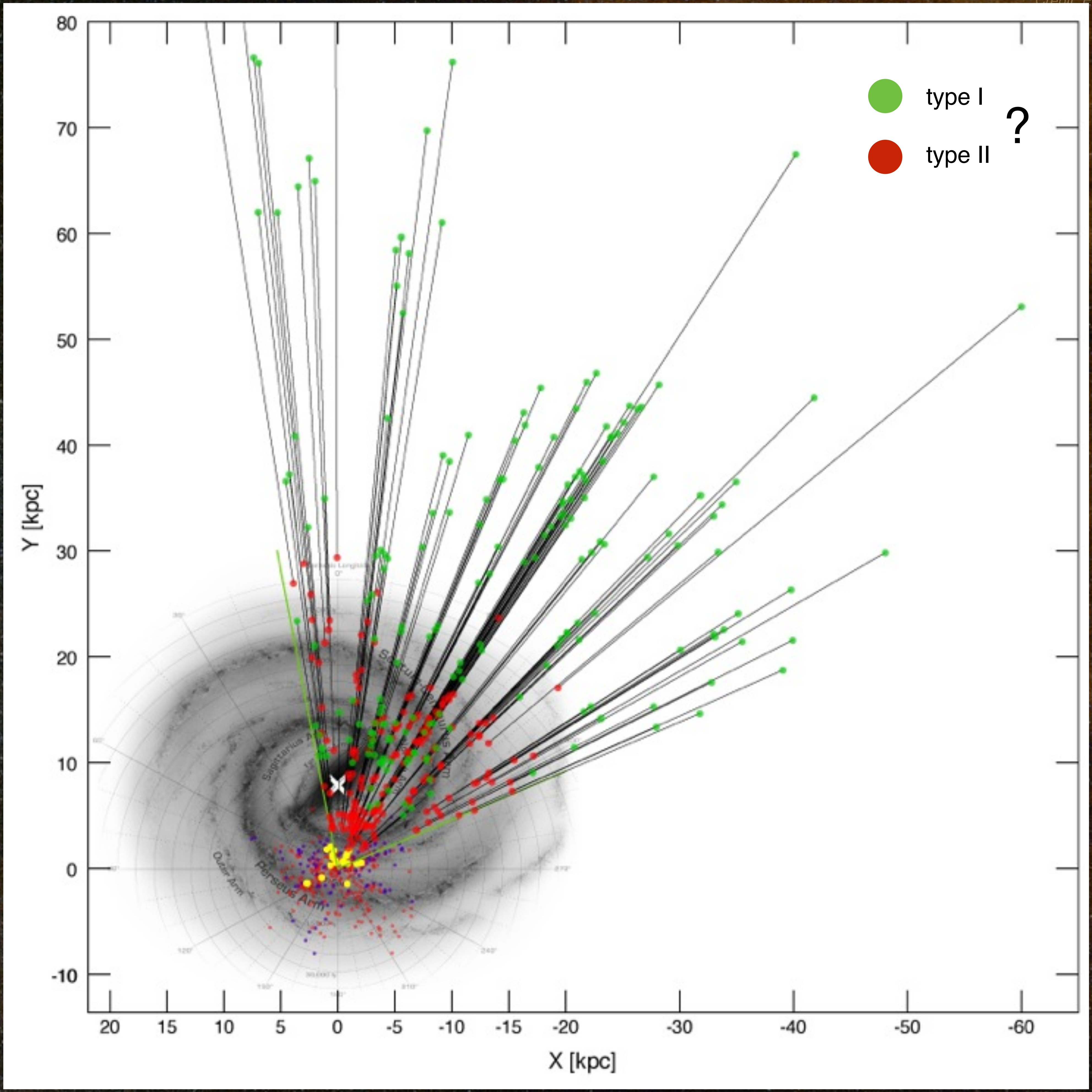


Dékány et al. (2014, ApJL, submitted)

VGCP: prospects

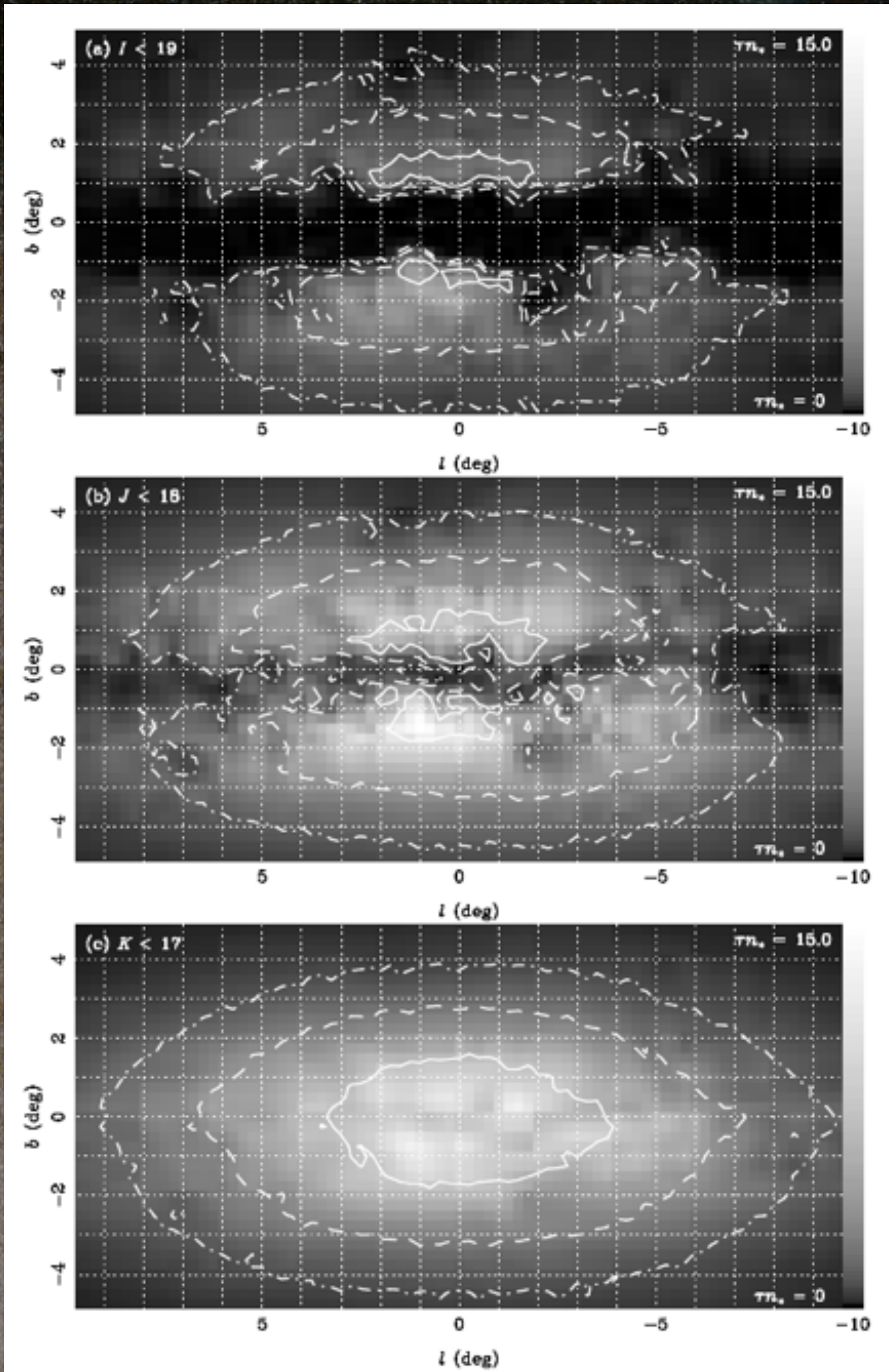


VGCP: prospects



Credit: ESO

VVV AND MICROLENSING



E. Kerins et al. (2008)

VVV was originally not designed for ML.

BUT: high-cadence program has been proposed for the inner bulge

VVV will search for reddened bulge microlensing events, and produce a **map of the optical depth**, tracing the 3D bulge mass distribution.

The near-IR advantage:

I, J and Ks-map event rates for sources with K<17.

Contours = 17.5, 35, 52.4 per sq.deg. per year.

Candidate Microlensing events from the VVV Survey

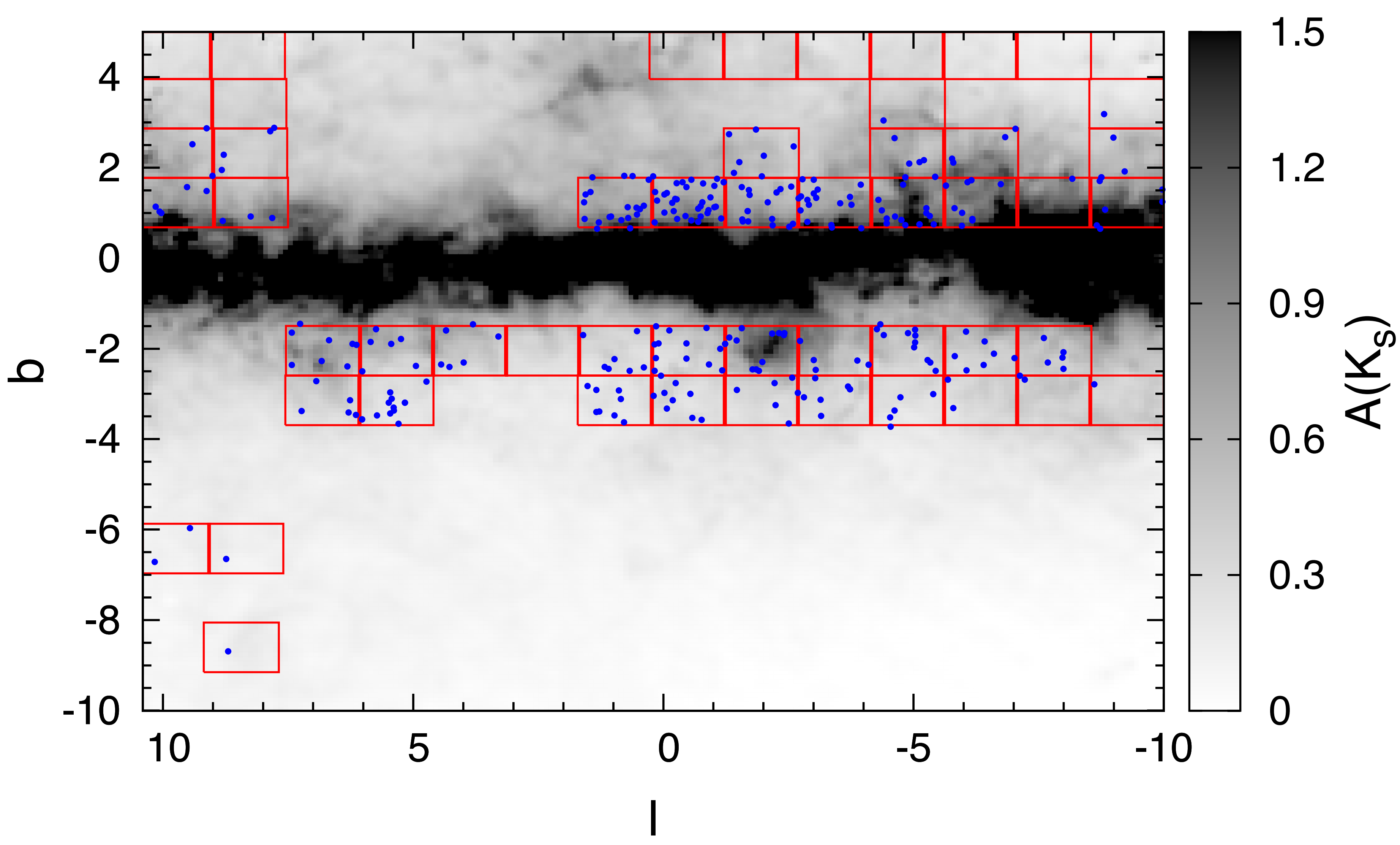
serendipitous discoveries

proof of concept that allows us to explore the parameter space covered and plan future strategies

complementary to optical surveys

István Dékány, Dante Minniti, Roberto Saito: ML search

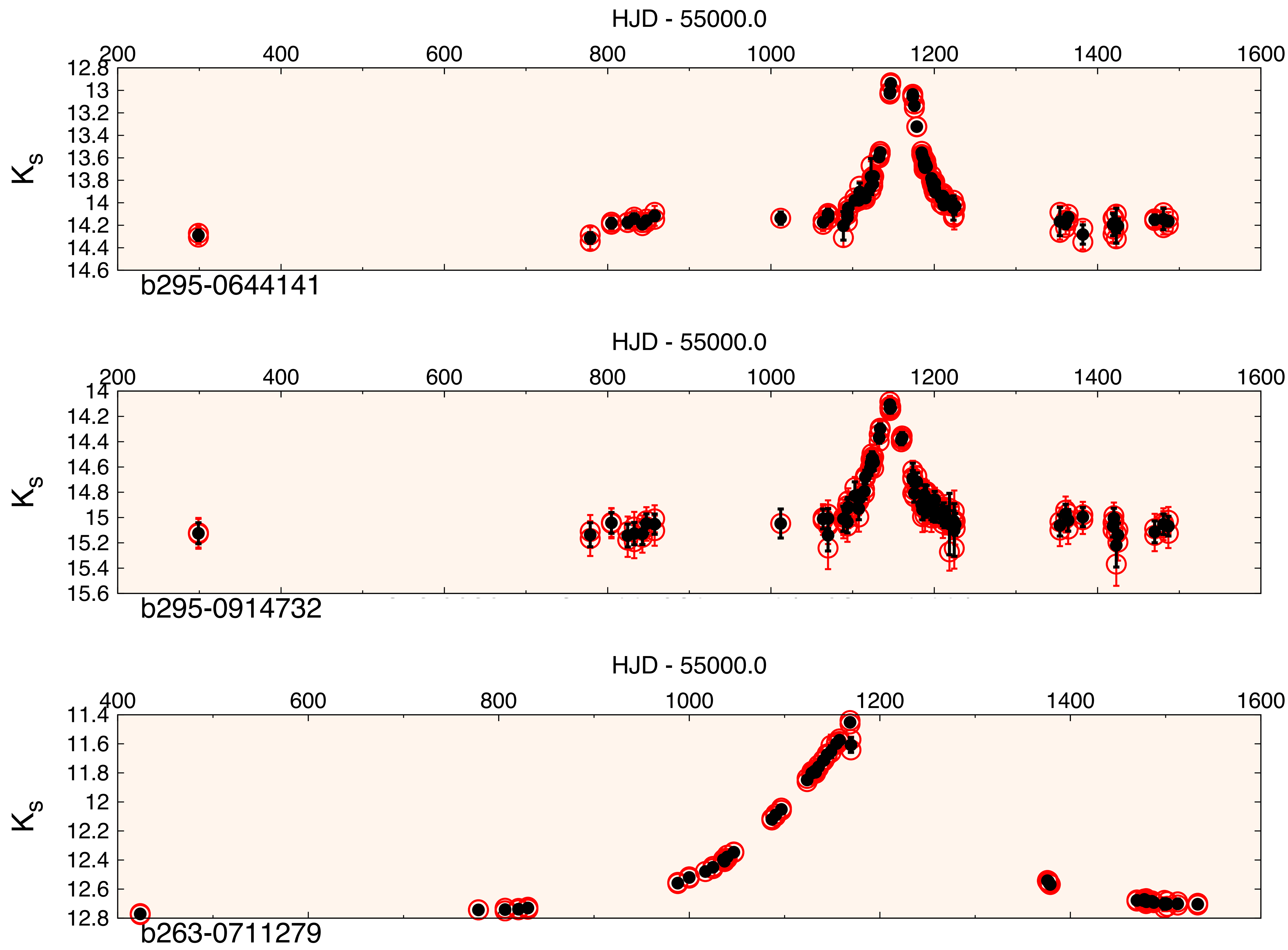
Eamonn Kerins: DIA pipeline development



N>200

Minniti, Dekany et al. (2014, A&A, submitted)

VVV AND MICROLENSING



VVV AND WFIRST

VVV: the *first* and *only* near-IR time-domain survey of the bulge and southern disk

This provides basic synergies with WFIRST:
VVV is pioneering for WFIRST
VVV lets us learn now how to use massive Galactic data
VVV prepares us to surf the WFIRST data tsunami

VVV for WFIRST:

provide science cases
input catalogs for followup

extended time baseline
QSOs
extended ML timescale

WFIRST for VVV:

recalibration
deblending
more epochs