PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE
UNIVERSIDAD DE VALPARAÍSO
THE MILKY WAY MILLENNIUM NUCLEUS

# Milky Way demographics with the VVV survey: the 84 million star CMD of the Galactic bulge

*Science from the Next Generation Imaging and Spectroscopic Surveys*

*ESO Garching, 16 Oct, 2012*

**Roberto K. Saito**

in collaboration with D. Minniti, B. Dias, M. Hempel, M. Rejkuba, J. Alonso-García, B. Barbuy, M. Catelan, J. P. Emerson, O. Gonzalez, P. W. Lucas and M. Zoccali

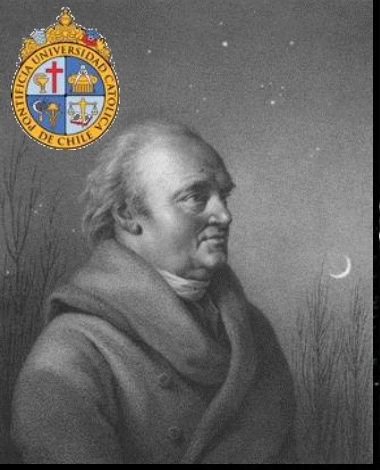
INICIATIVA CIENTIFICA MILENIO • ICM •

MWM

Centro de Astrofísica y Tecnologías Afines

CENTRO DE ASTROFISICA FONDAP

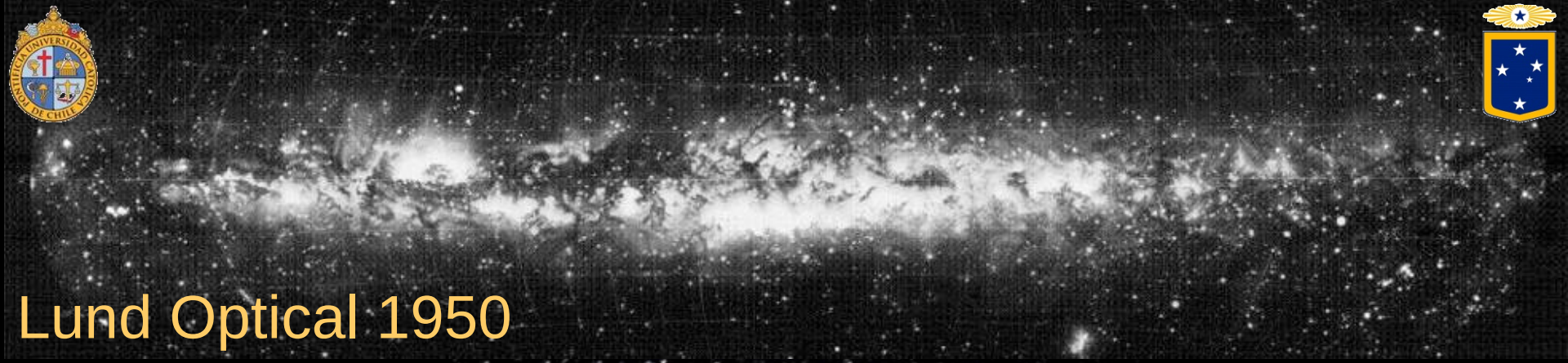
CONICYT COMISIÓN NACIONAL DE INVESTIGACIÓN CIENTÍFICA Y TECNOLÓGICA



# William Herschel 1785

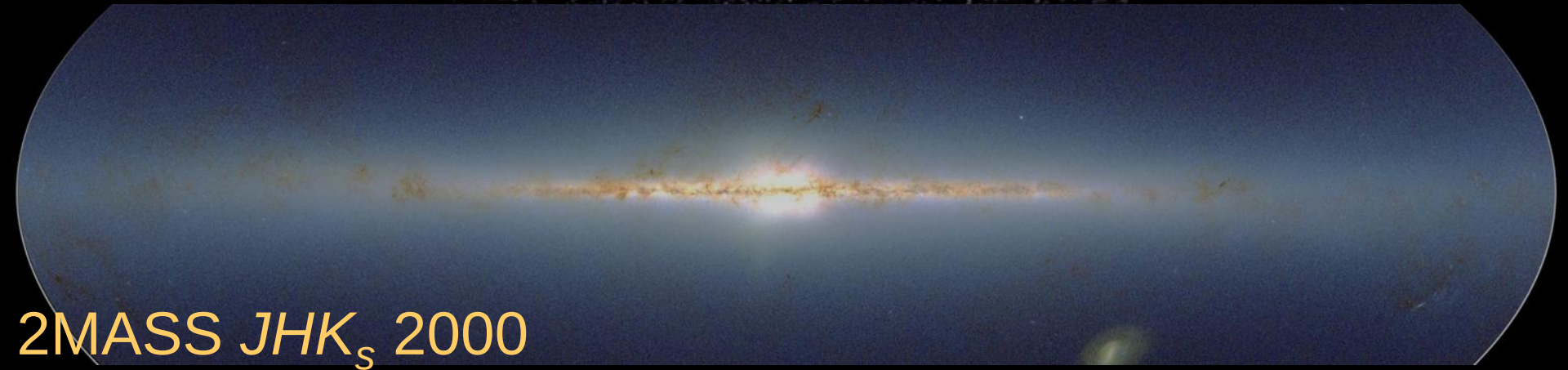
*On the Construction of the Heavens*


*Smithsonian National Air and Space Museum (Washington, DC)*



Lund Optical 1950

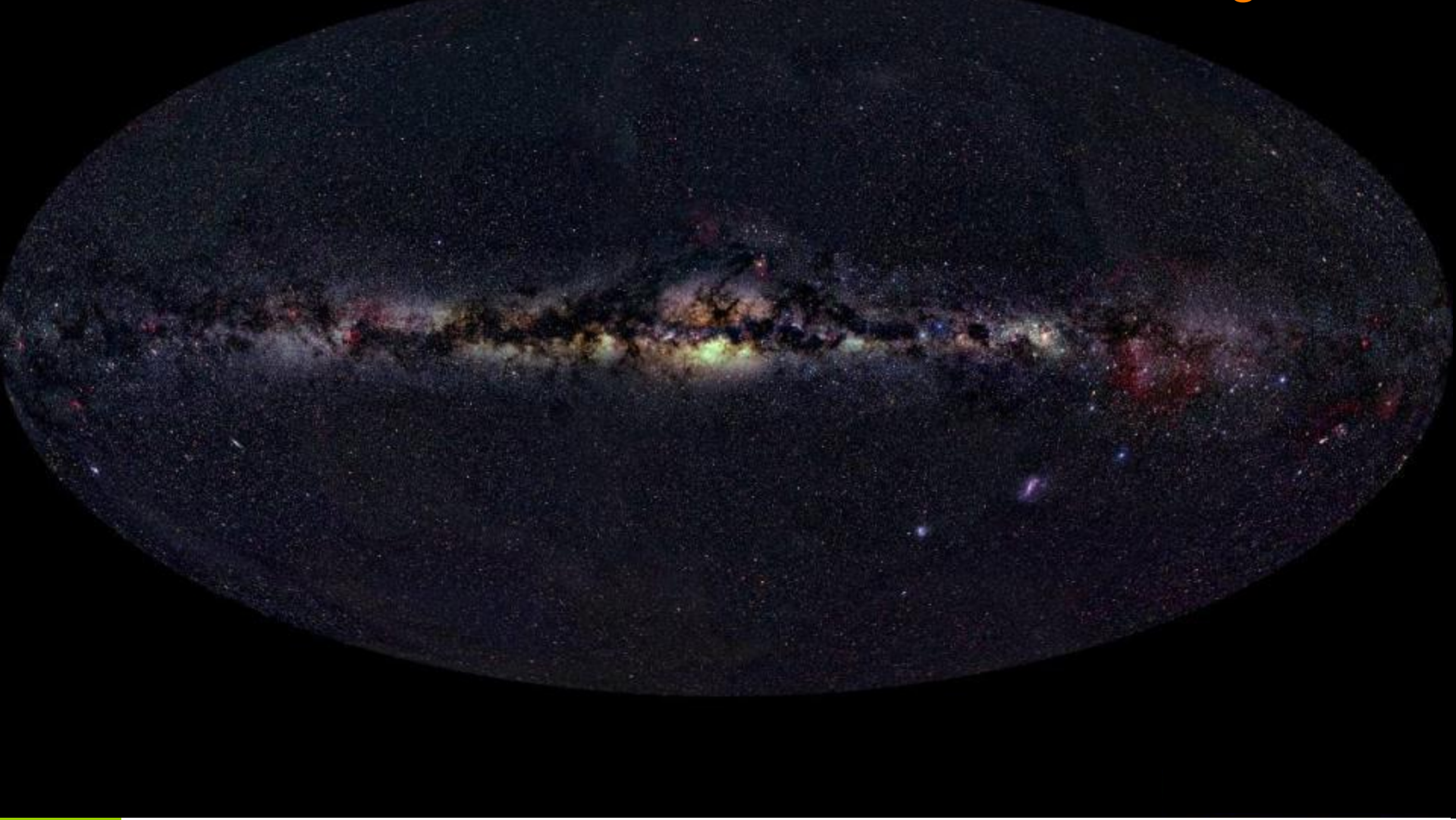
Cobe/Dirbe 1994



2MASS $JHK_s$ 2000

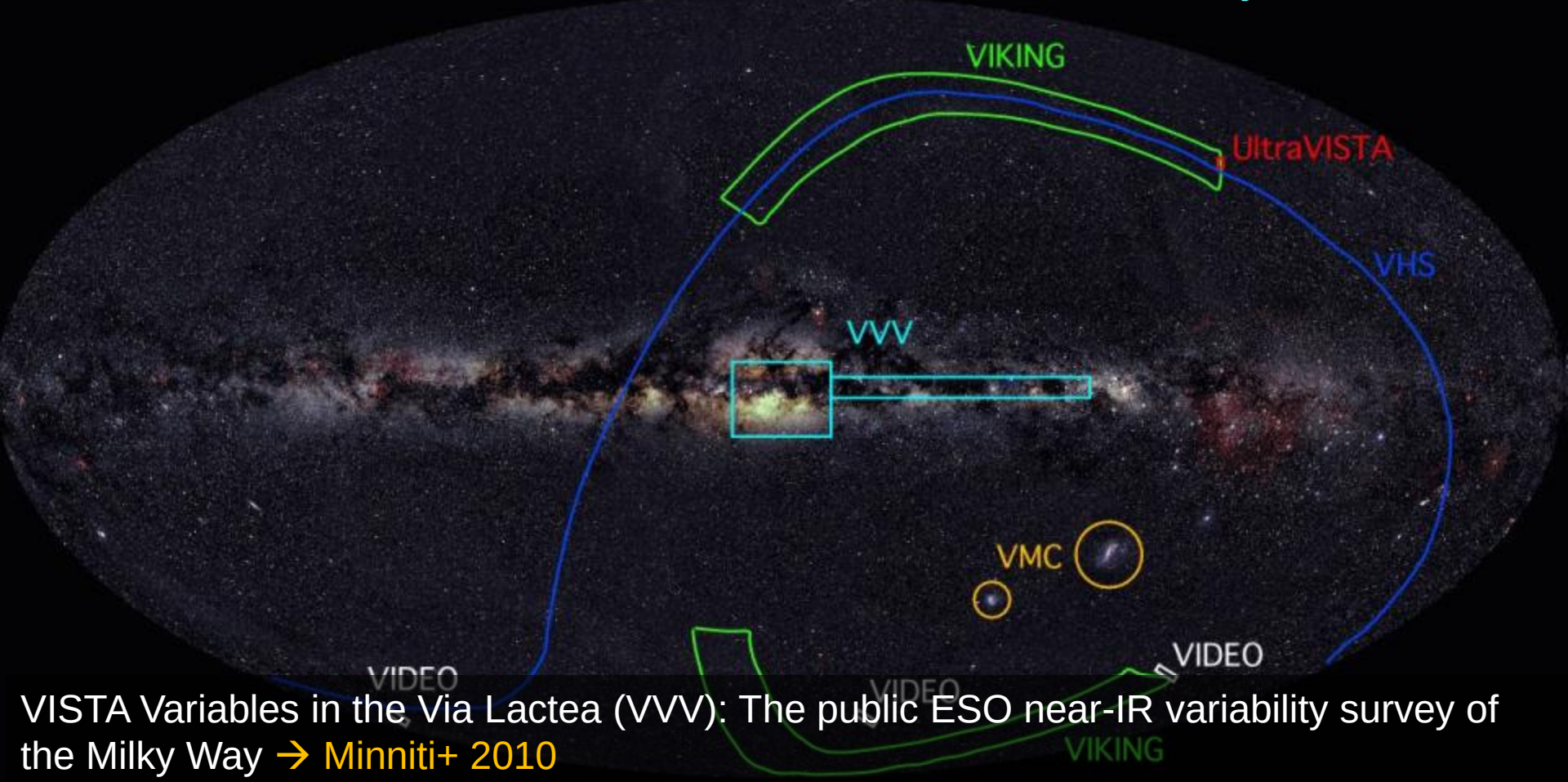
# How did the Milky Way form?

- What is the structure of the inner Galactic bulge?



# ESO/VISTA Public Surveys

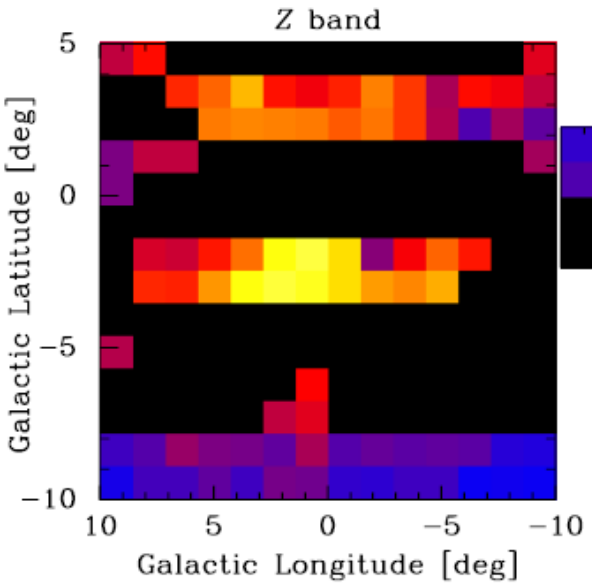
## VISTA Variables in the Vía Láctea Survey

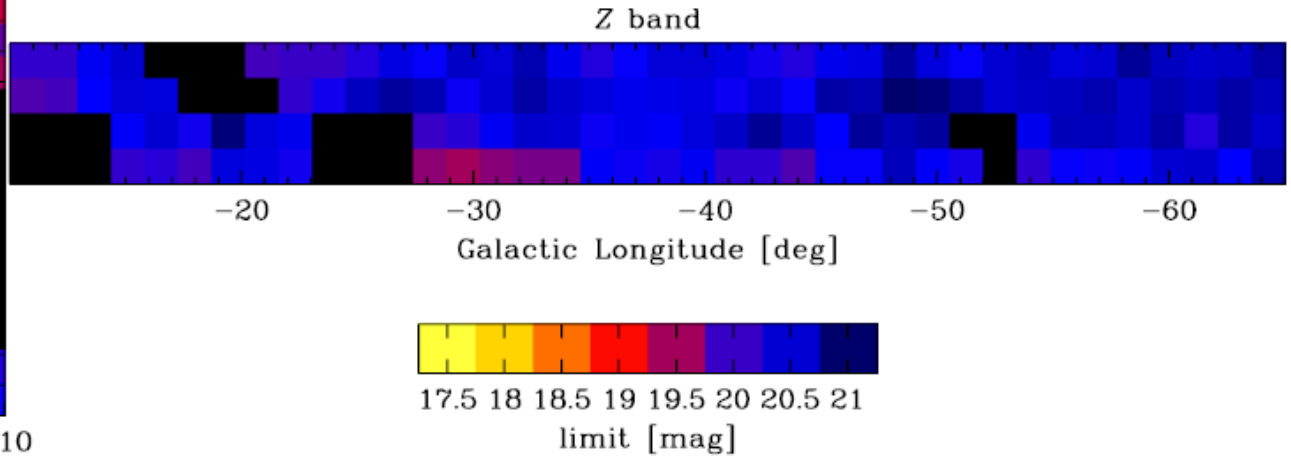


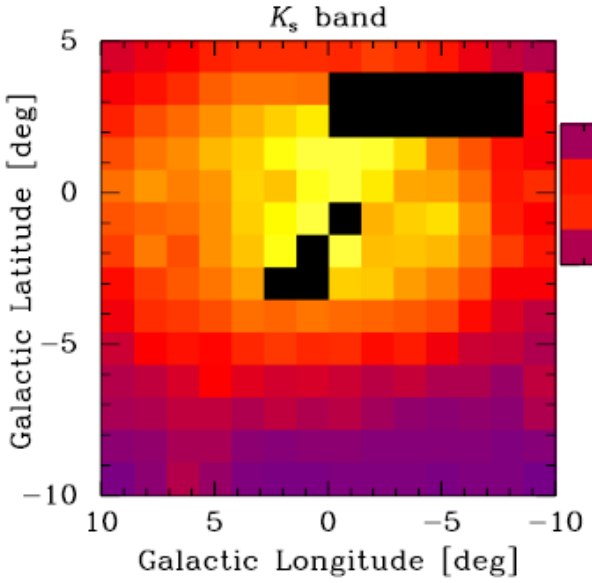

VISTA Variables in the Via Lactea (VVV): The public ESO near-IR variability survey of the Milky Way → Minniti+ 2010

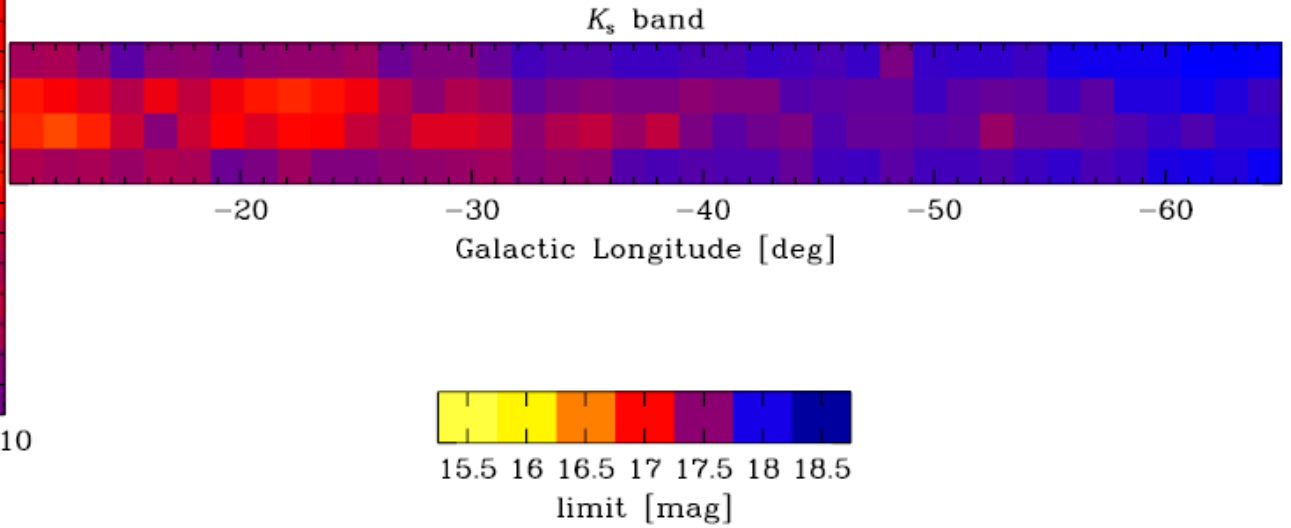
VVV DR1: The First Data Release of the Milky Way Bulge and Southern Plane from the Near-Infrared ESO Public Survey VISTA Variables in the Vía Láctea → Saito+ 2012a

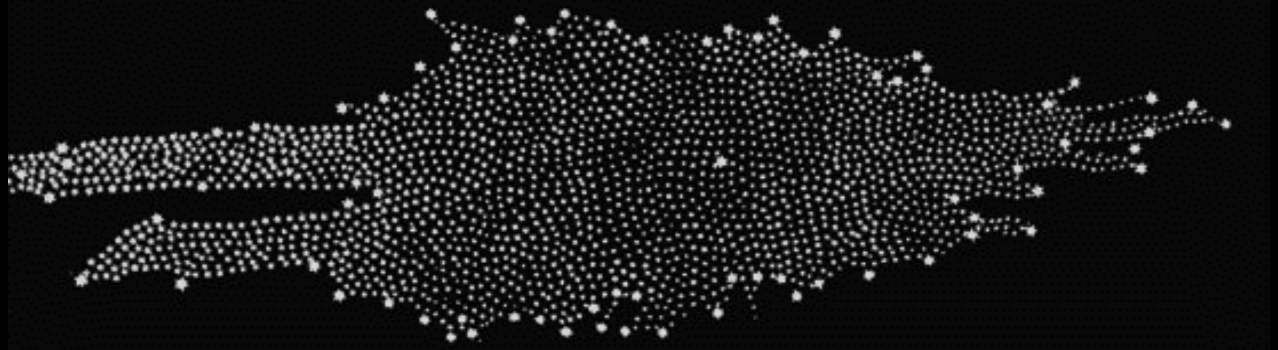
# VVV DR1: 128M + 168M = 296M sources



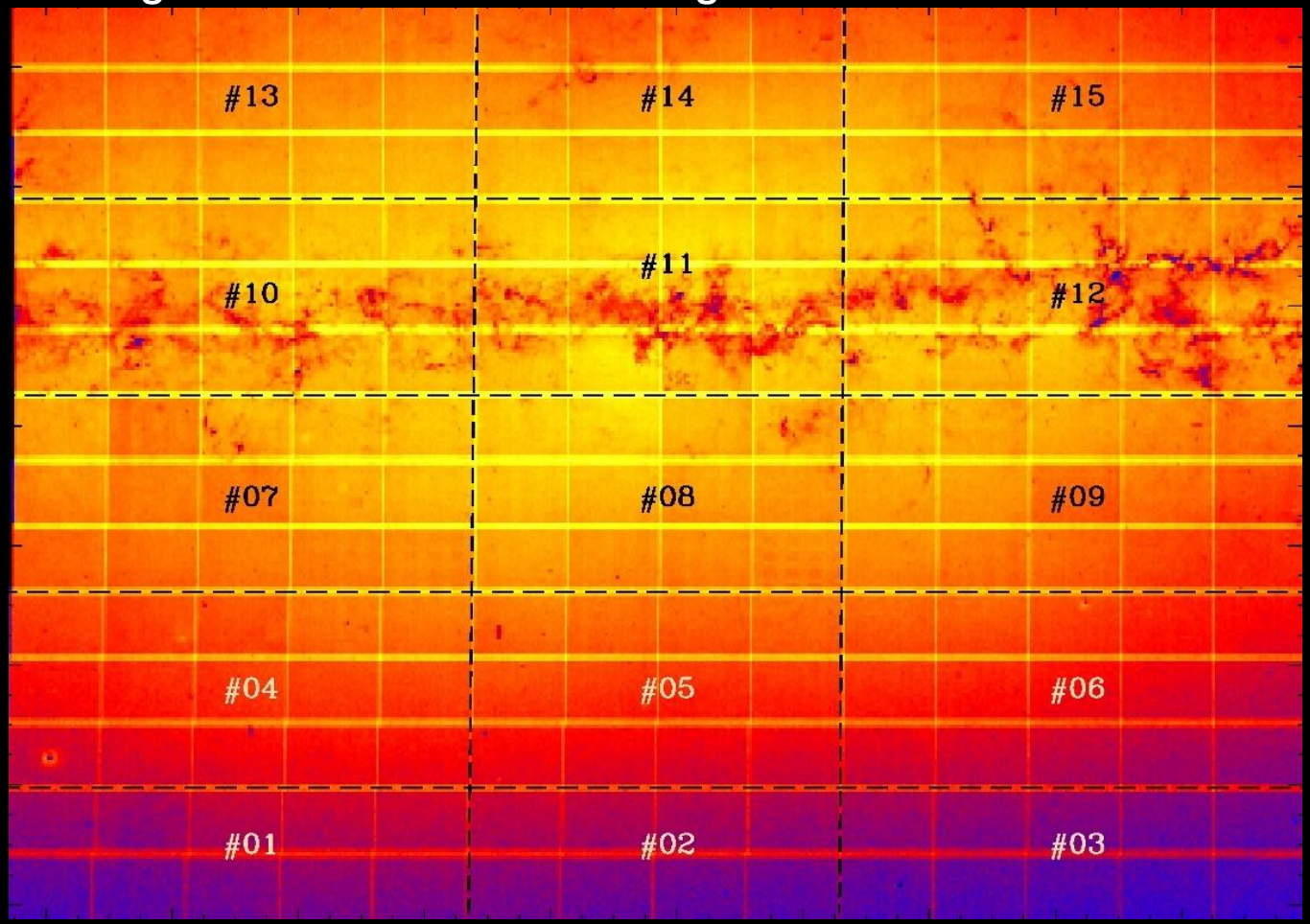





**$JHK_s$ → 173,150,467  $K_s$<16.5 → 128,660,076**



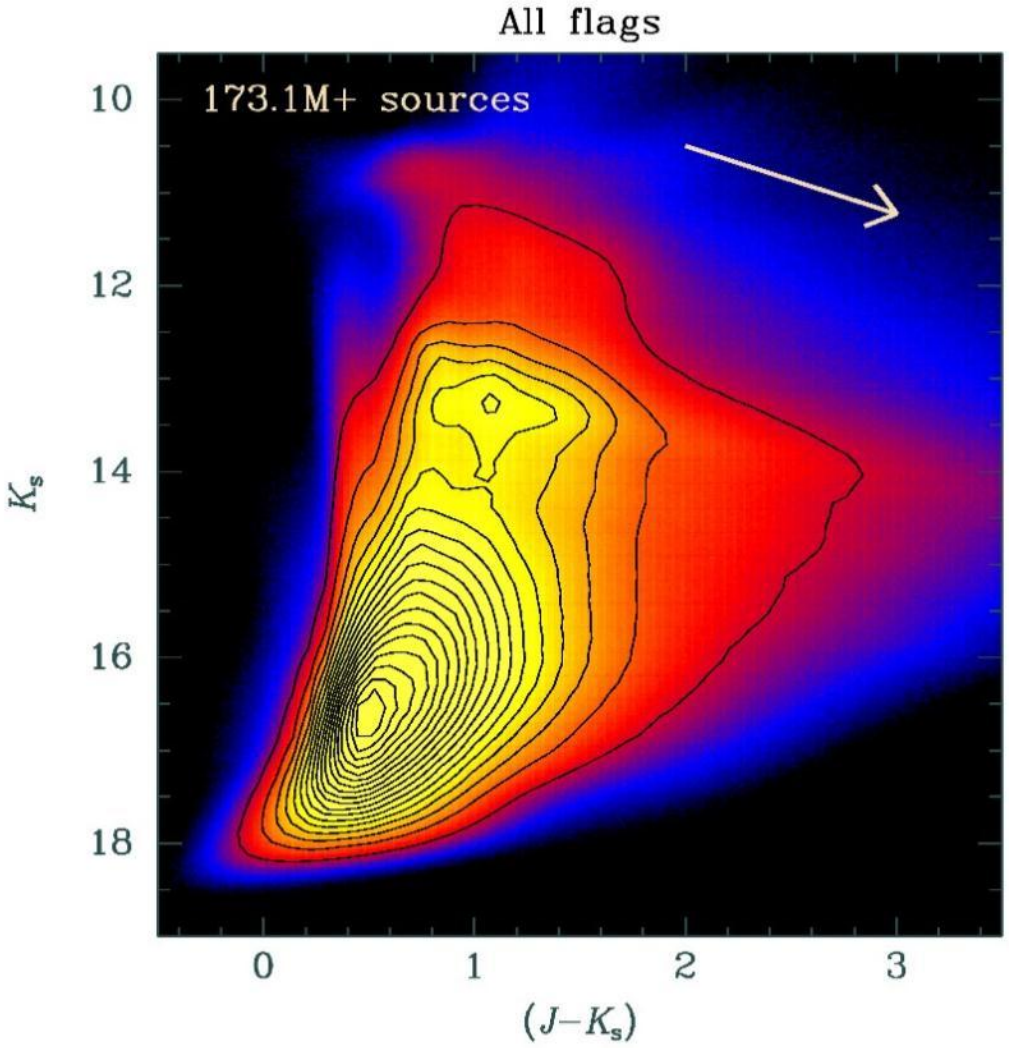

*Powered by*

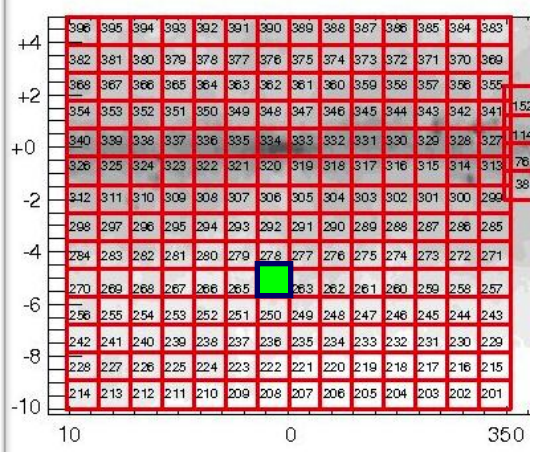
asu

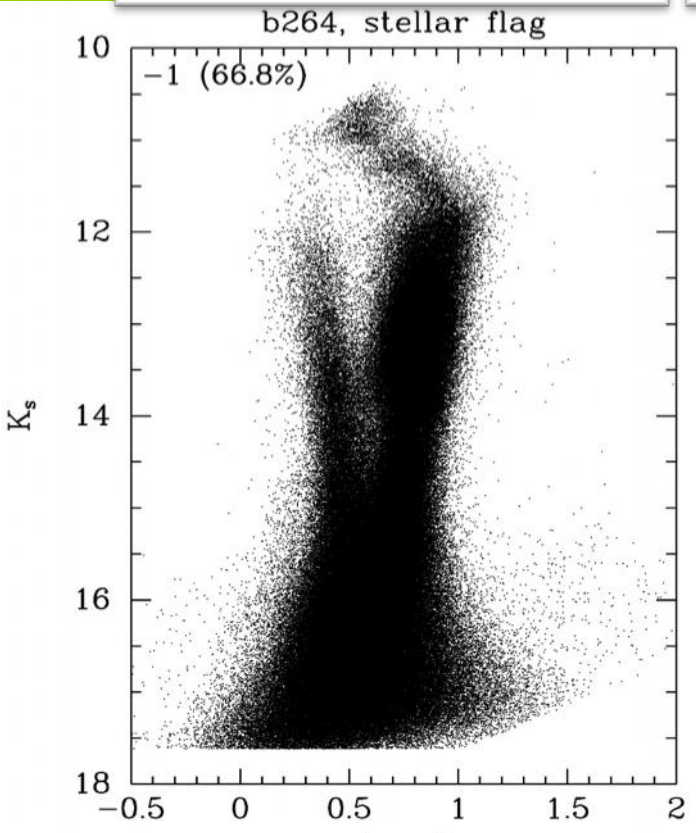
STILTS

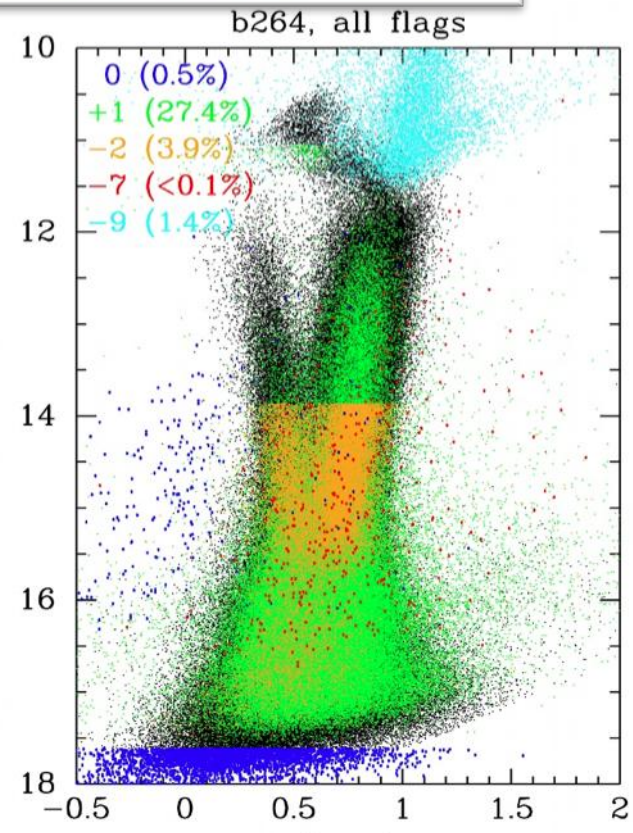
TOPCAT

awk Programming


All flags
173.1M+ sources
10
12
14
16
18
$K_s$
0
1
2
3
$(J-K_s)$




–1 → stellar

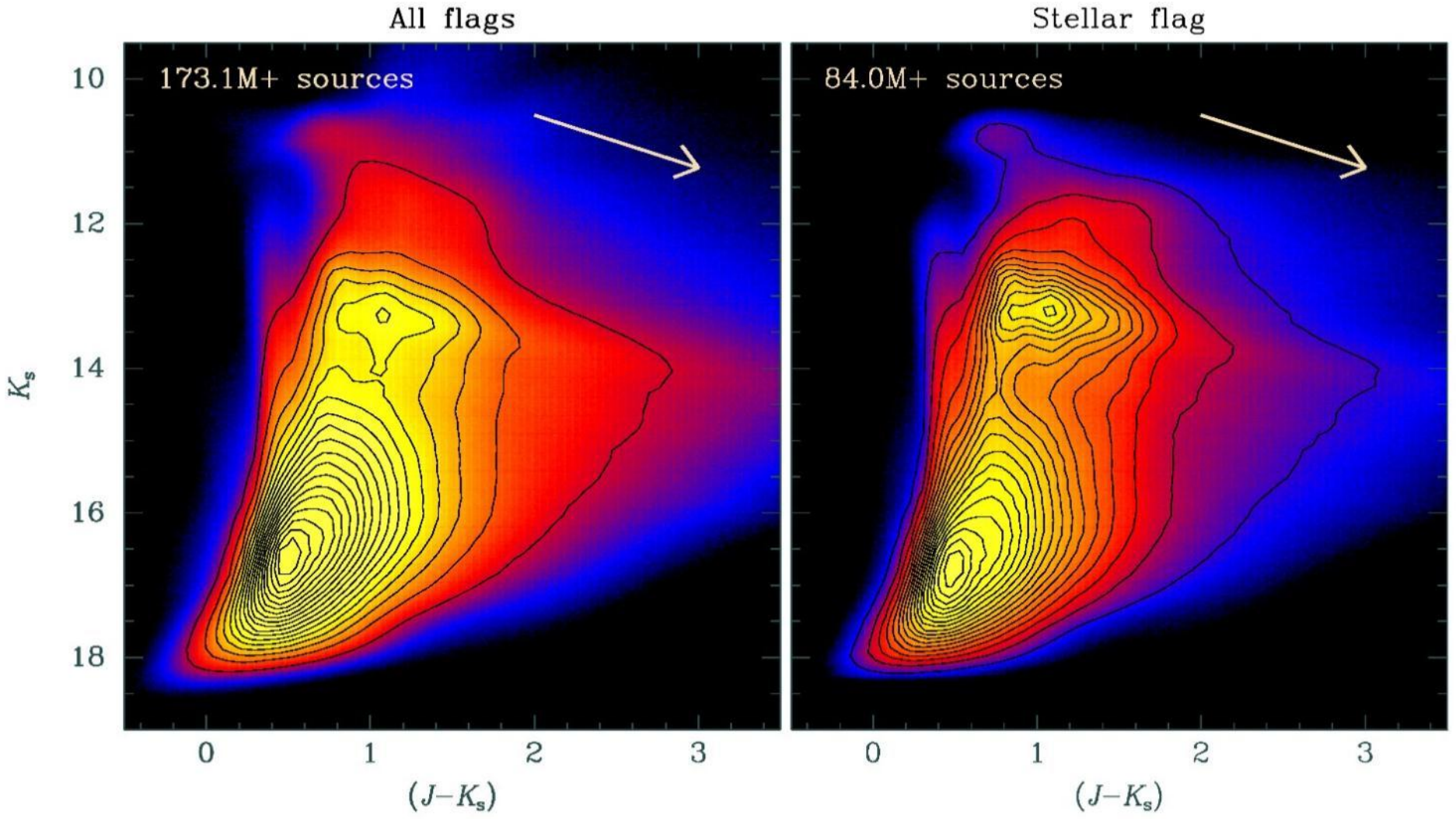
0 → noise

+1 → non–stellar

–2 → borderline stellar

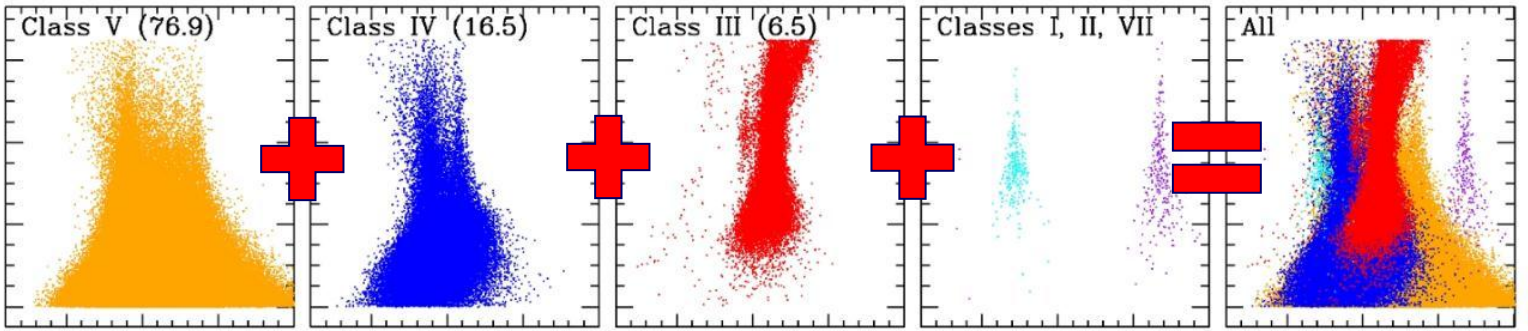
–7 → sources with bad pixels

–9 → saturated stars

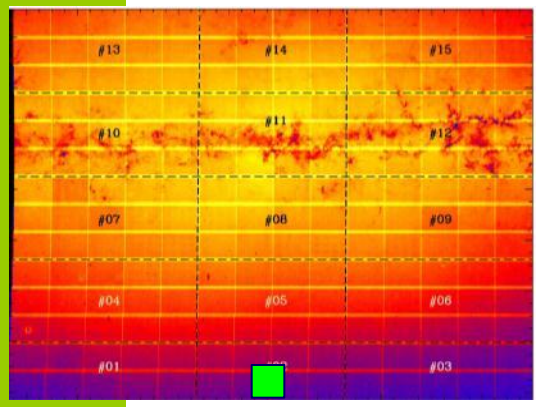


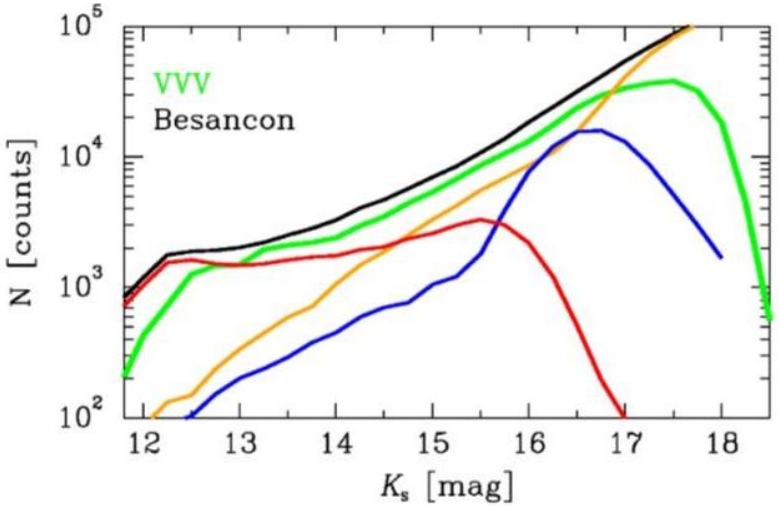

# The largest CMDs published to date
# 173,150,467 and 84,095,284 sources (Saito+ 2012b)

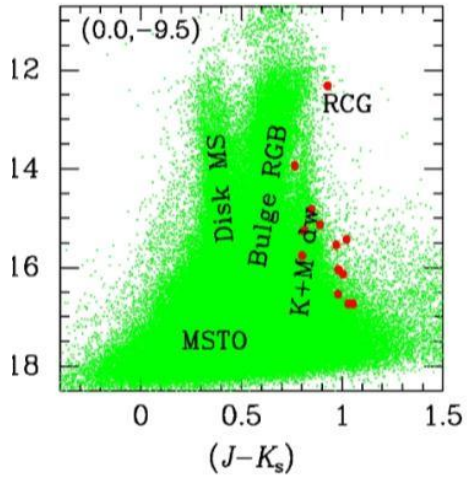
# Comparison with models

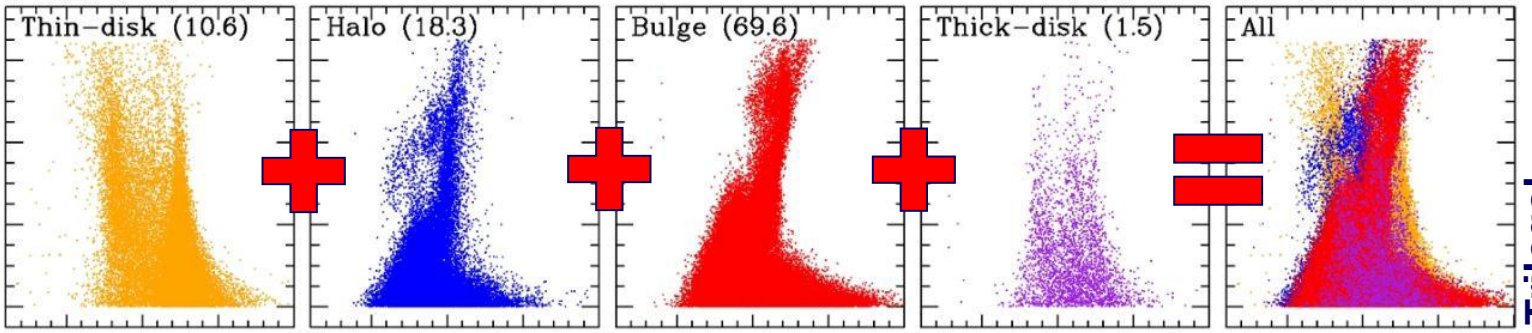



Besançon



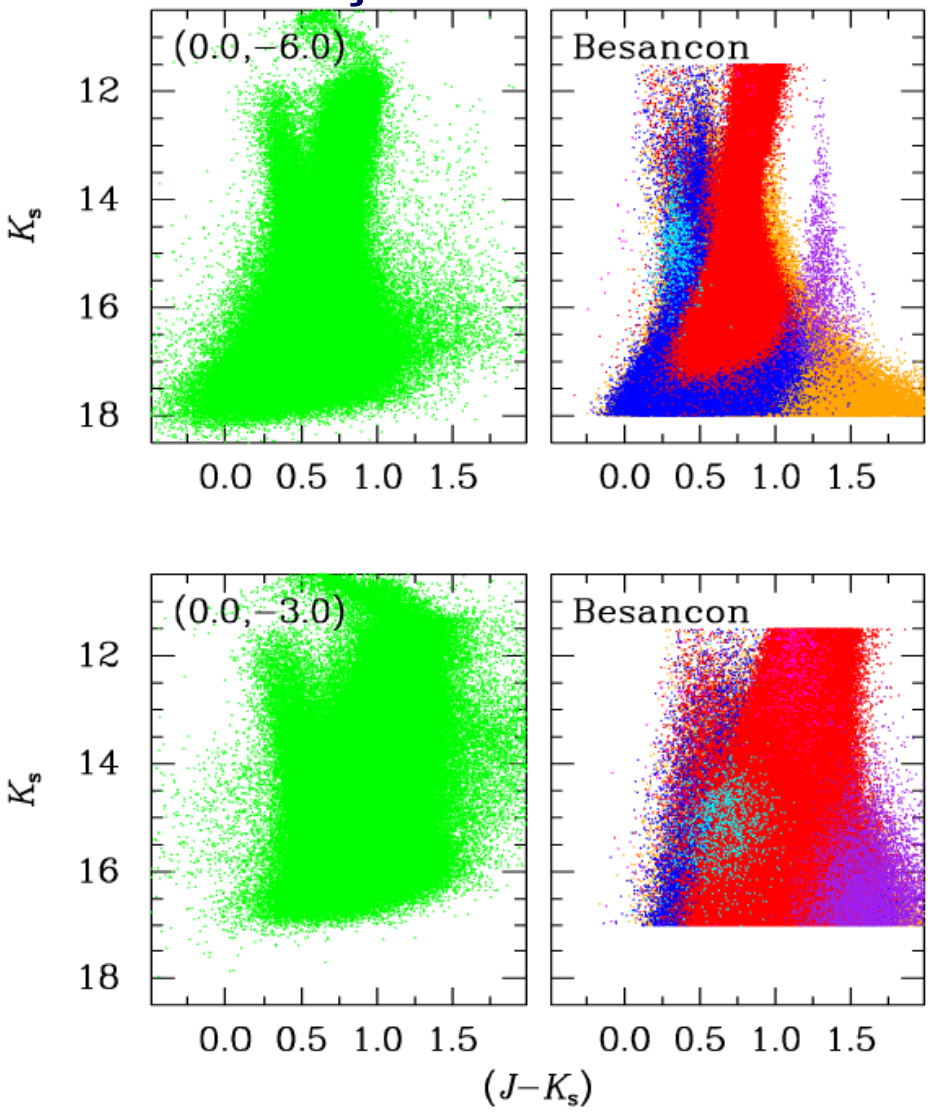



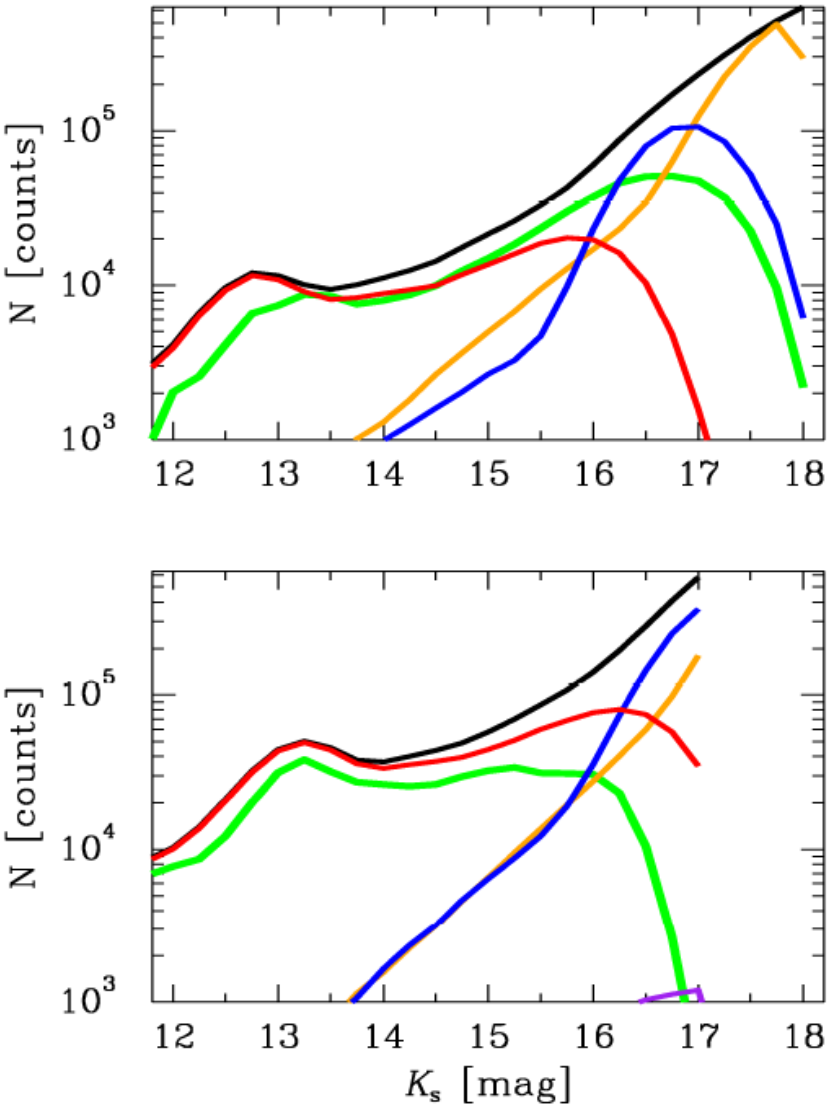



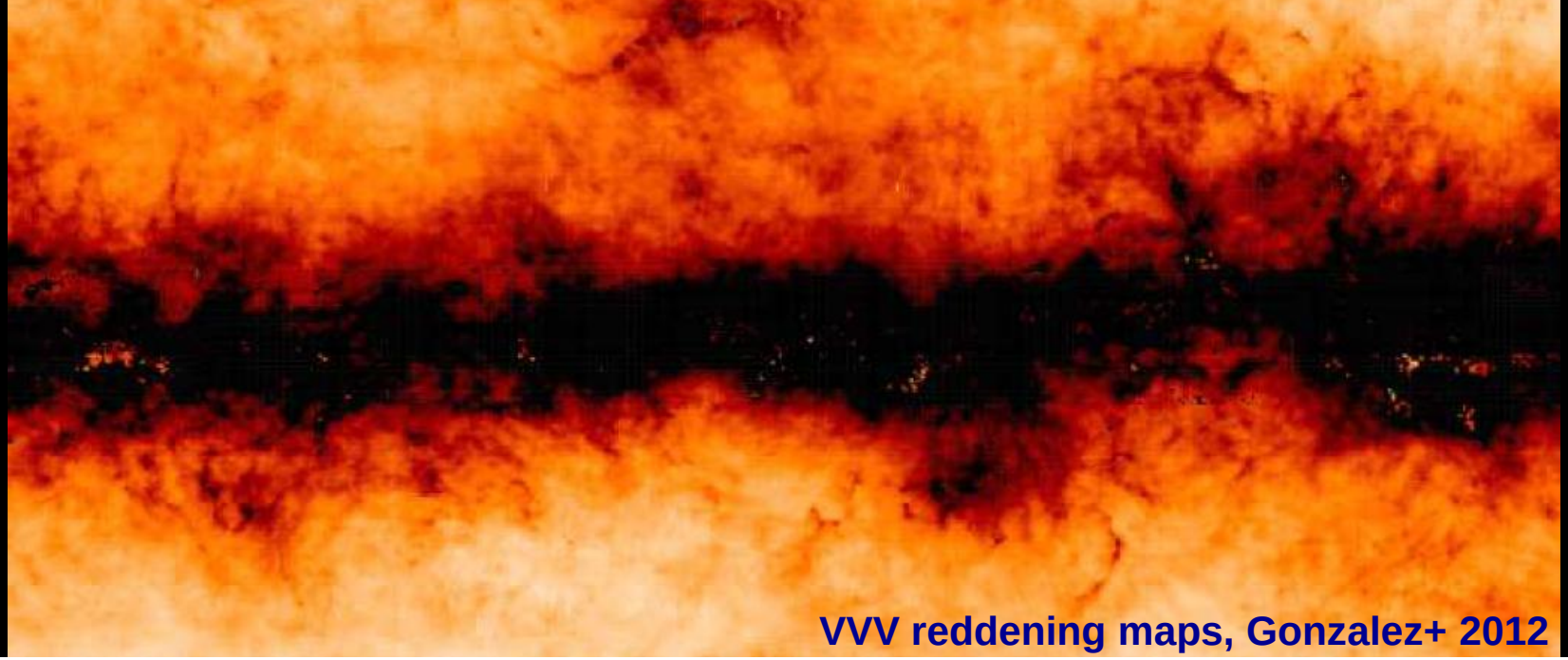




Trilegal

# Besançon

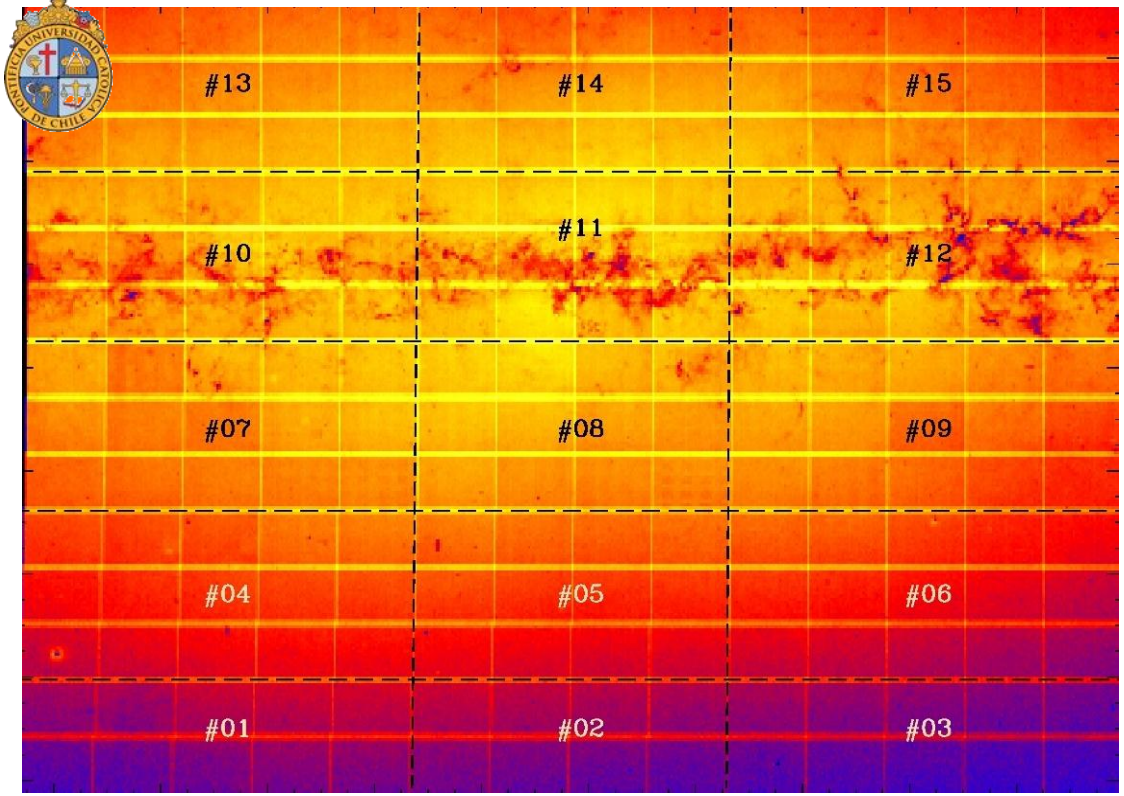

(0.0,−6.0)
Besancon
(0.0,−3.0)
Besancon
$K_s$
12
14
16
18
0.0 0.5 1.0 1.5
$(J-K_s)$


N [counts]
$10^5$
$10^4$
$10^3$
12 13 14 15 16 17 18
$K_s$ [mag]

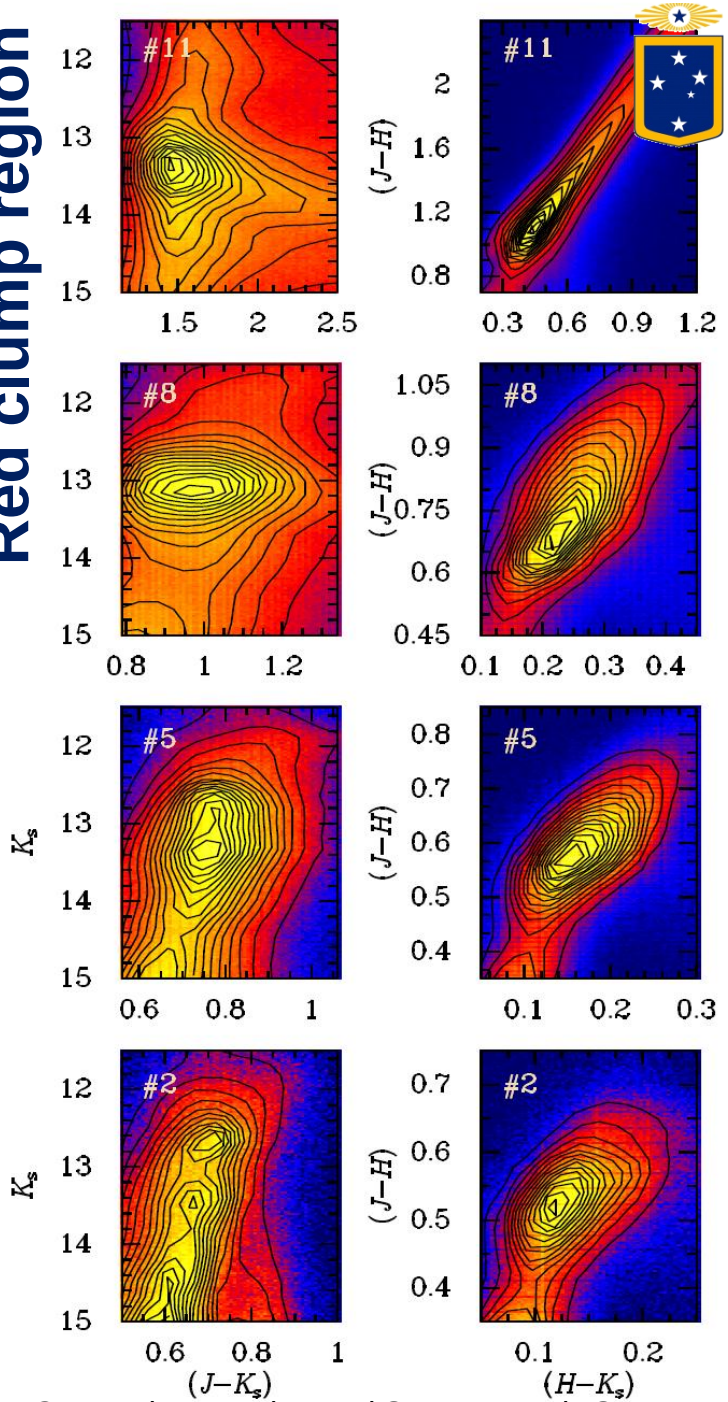


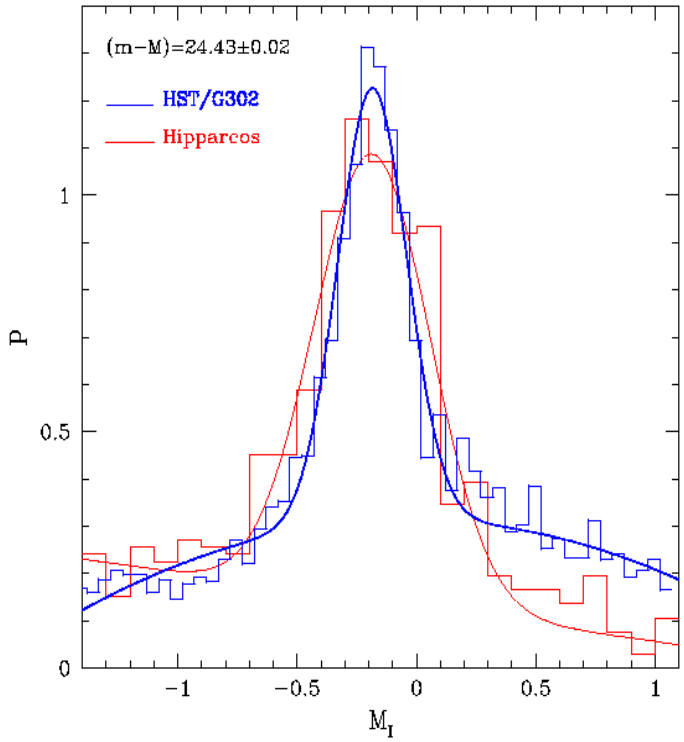
VVV reddening maps, Gonzalez+ 2012

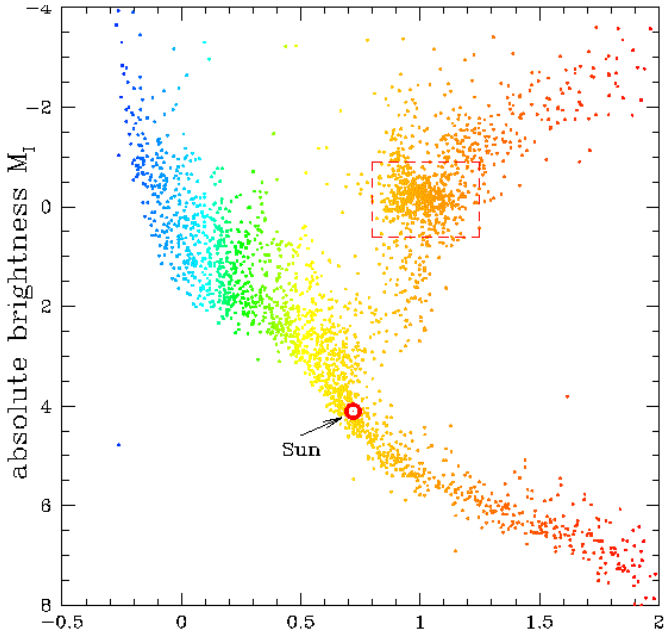
| Population | $E(B-V)=0$<br>$A_V=0$<br>$A_J=0$<br>$A_K=0$ | $E(B-V)=3.2$<br>$A_V=10.0$<br>$A_J=2.8$<br>$A_K=1.1$ | $E(B-V)=4.8$<br>$A_V=15.0$<br>$A_J=4.2$<br>$A_K=1.7$ | $E(B-V)=8.4$<br>$A_V=26.3$<br>$A_J=7.4$<br>$A_K=3.0$ |
|---|---|---|---|---|
| Bulge RGB tip | $K_s=8.0$[a] | $K_s=9.1$[a] | $K_s=9.7$ | $K_s=11.0$ |
| Sgr dSph RGB tip | $K_s=10.5$ | $K_s=11.6$ | $K_s=12.2$ | $K_s=13.5$ |
| Bulge RGB clump | $K_s=12.9$ | $K_s=14.0$ | $K_s=14.6$ | $K_s=15.9$ |
| Bulge RR Lyrae | $K_s=14.3$ | $K_s=15.4$ | $K_s=16.0$ | $K_s=17.3$ |
| Sgr dSph RGB clump | $K_s=15.4$ | $K_s=16.5$ | $K_s=17.1$ | $K_s=18.4$[b] |
| Sgr dSph RR Lyrae | $K_s=16.8$ | $K_s=17.9$ | $K_s=18.5$[b] | $K_s=19.8$[b] |
| Bulge MS turn-off | $K_s=17.0$ | $K_s=18.1$ | $K_s=18.7$[b] | $K_s=20.0$[b] |



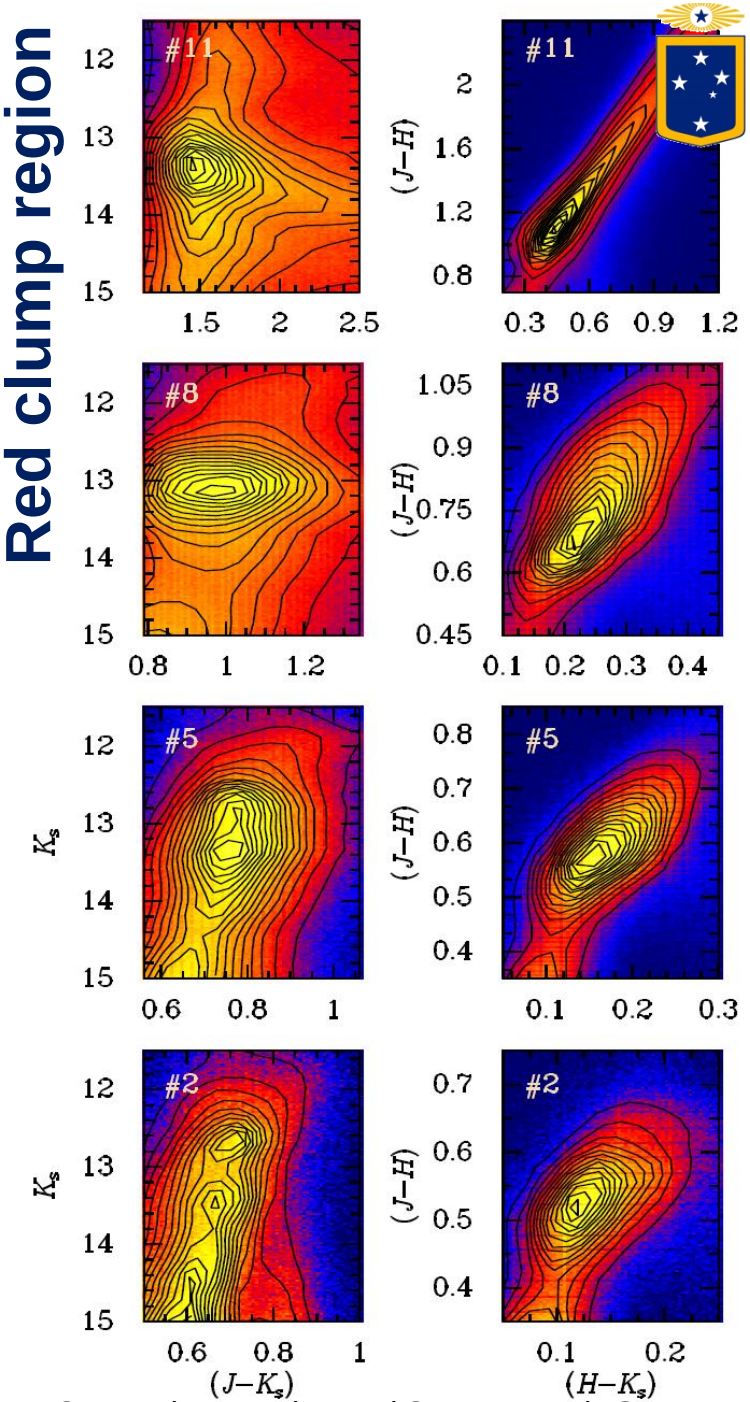

## Red clump region

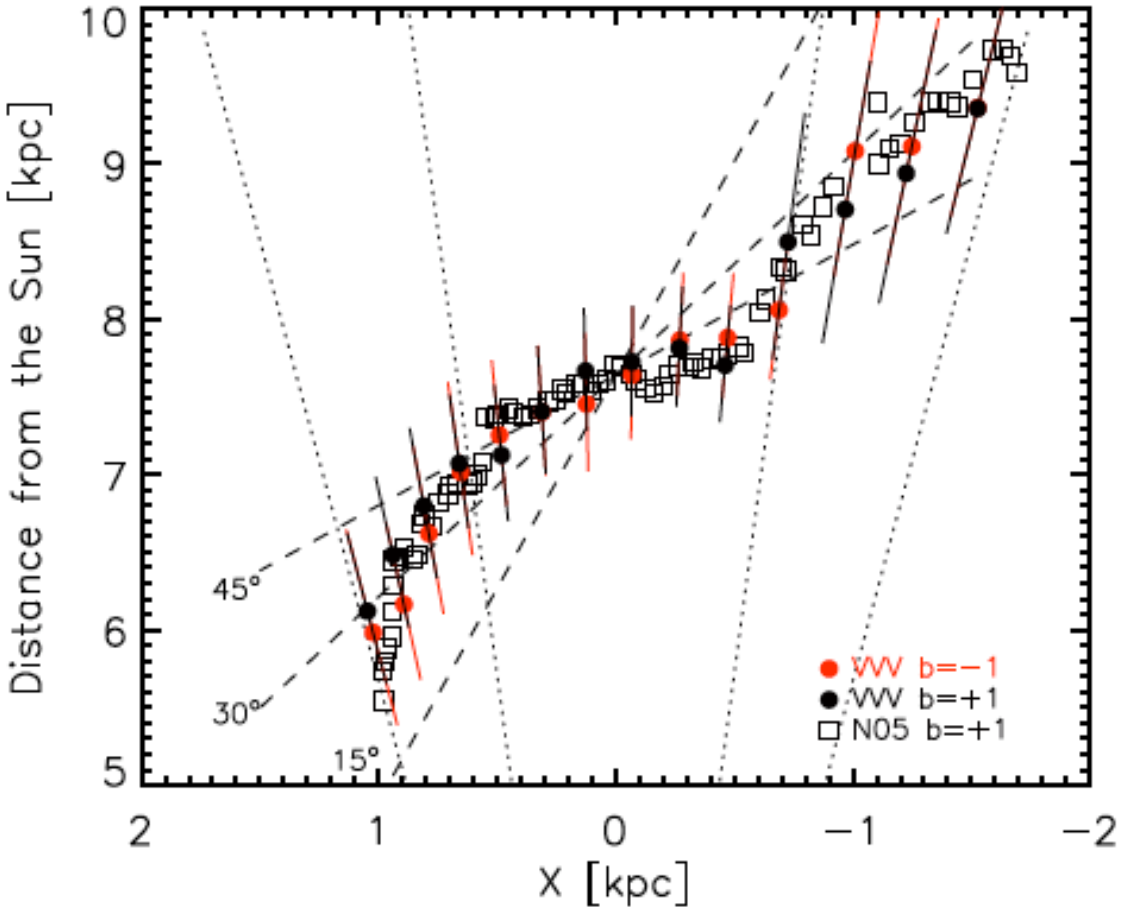


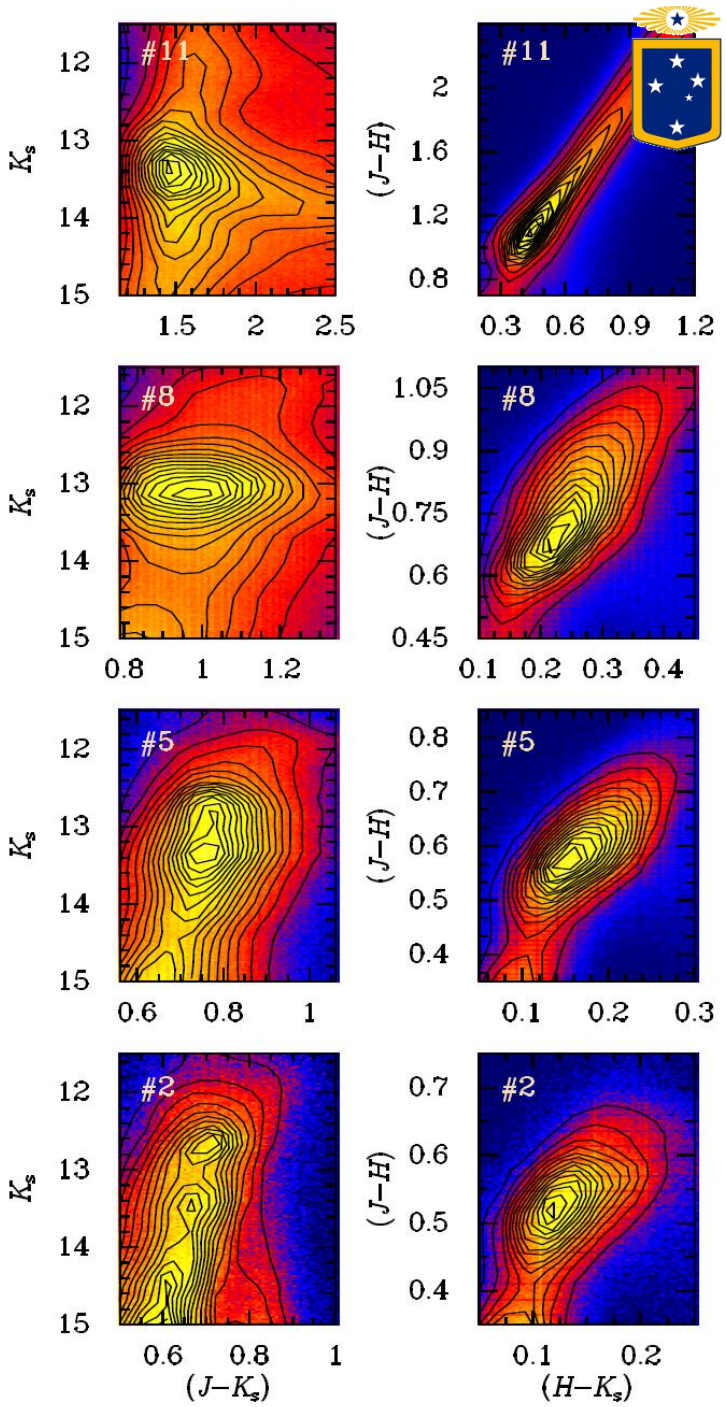



## Red clump region

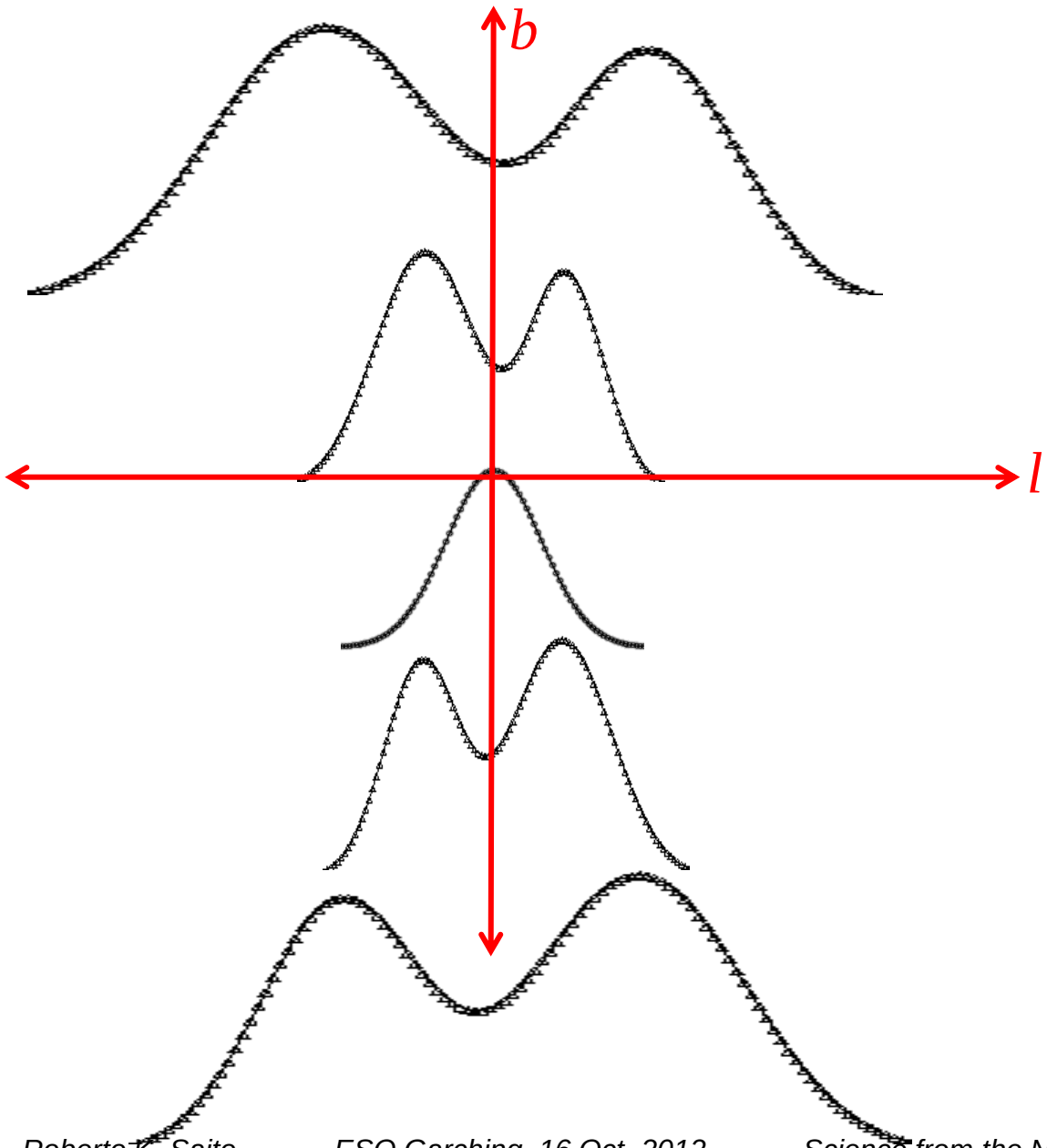


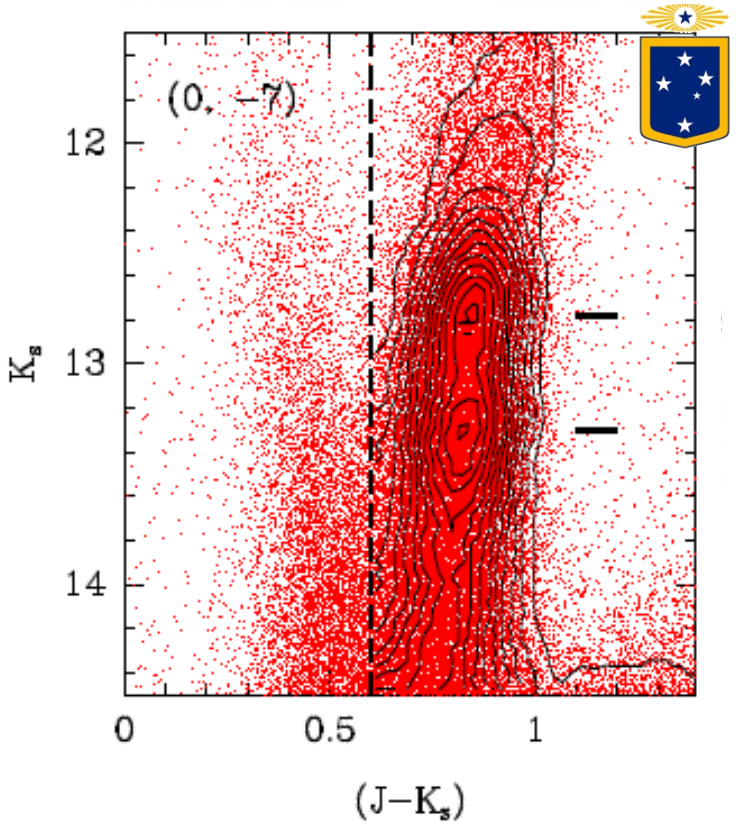


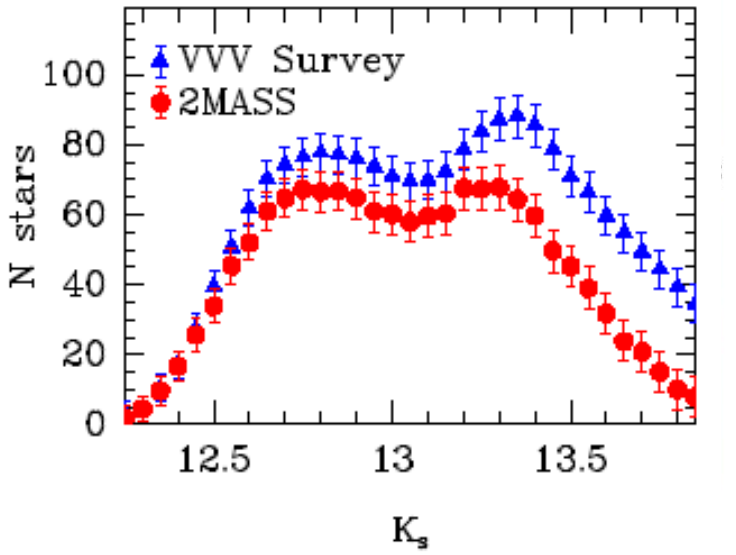




# The inner Galactic bar traced by the VVV Survey (Gonzalez+ 2011)

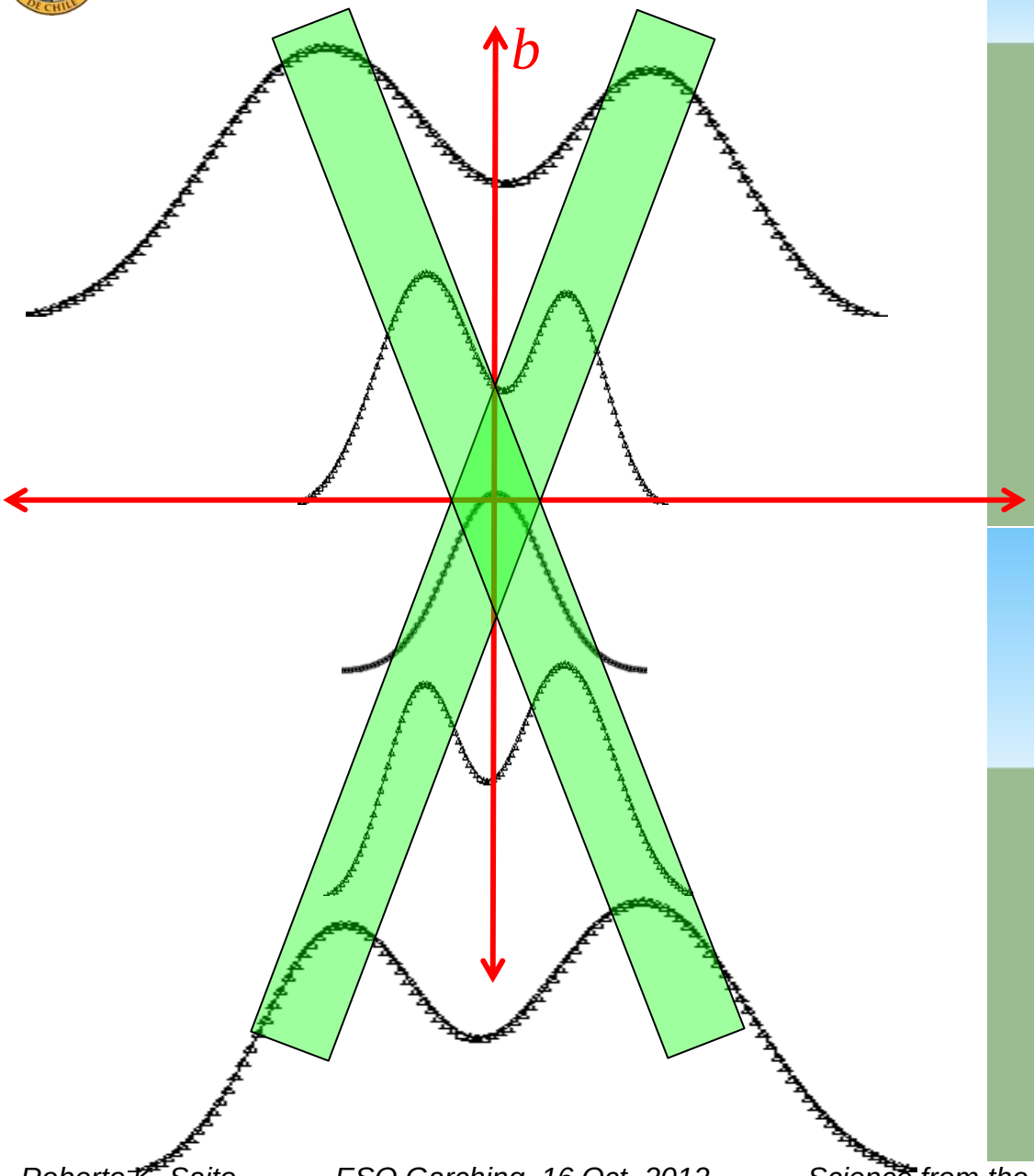
# Toy model

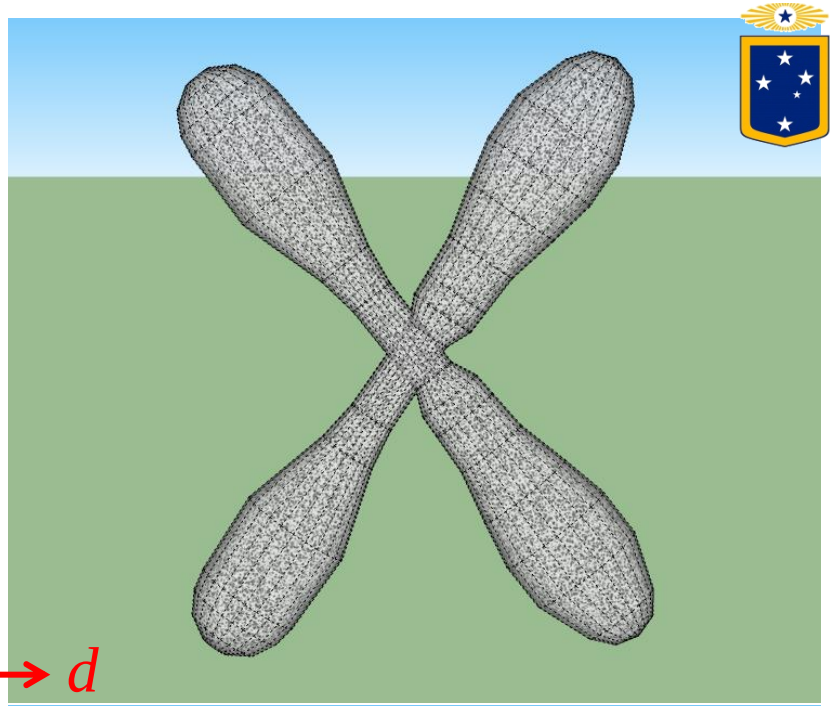

b
l

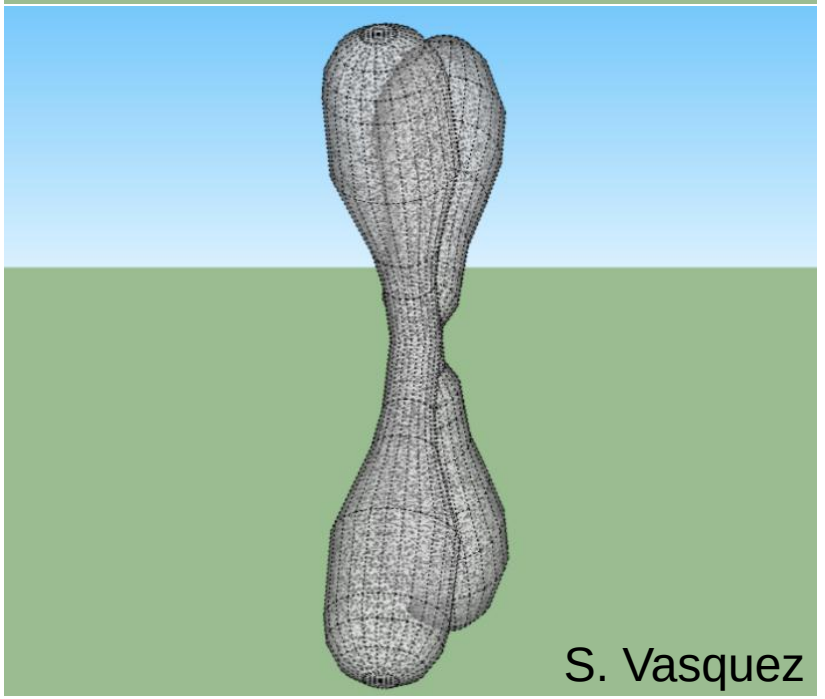

(0, −7)
12
13
14
$K_s$
0
0.5
1
$(J-K_s)$

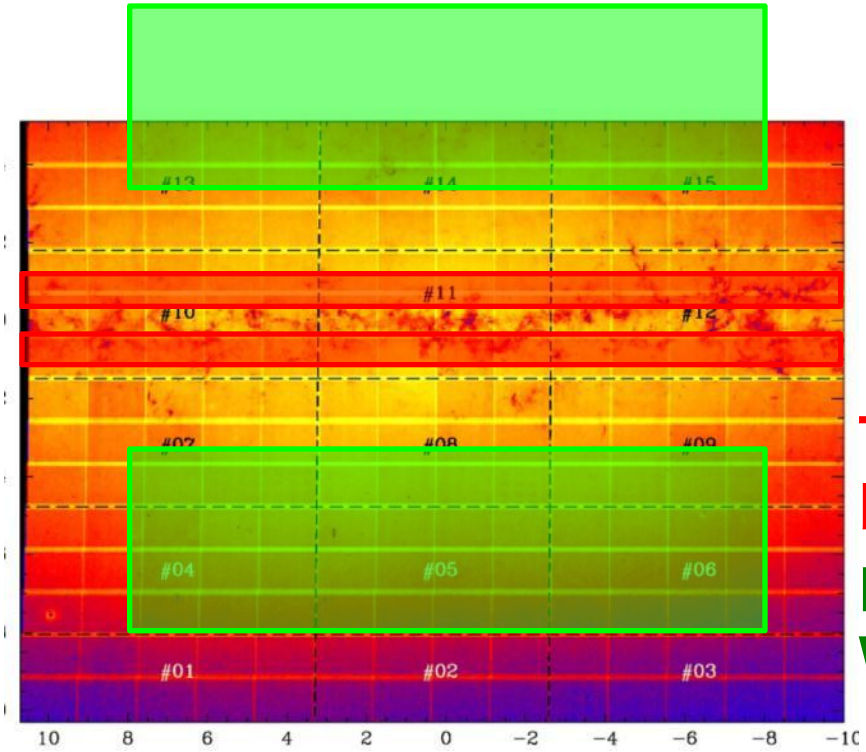

VVV Survey
2MASS
N stars
100
80
60
40
20
0
12.5
13
13.5
$K_s$

# Toy model



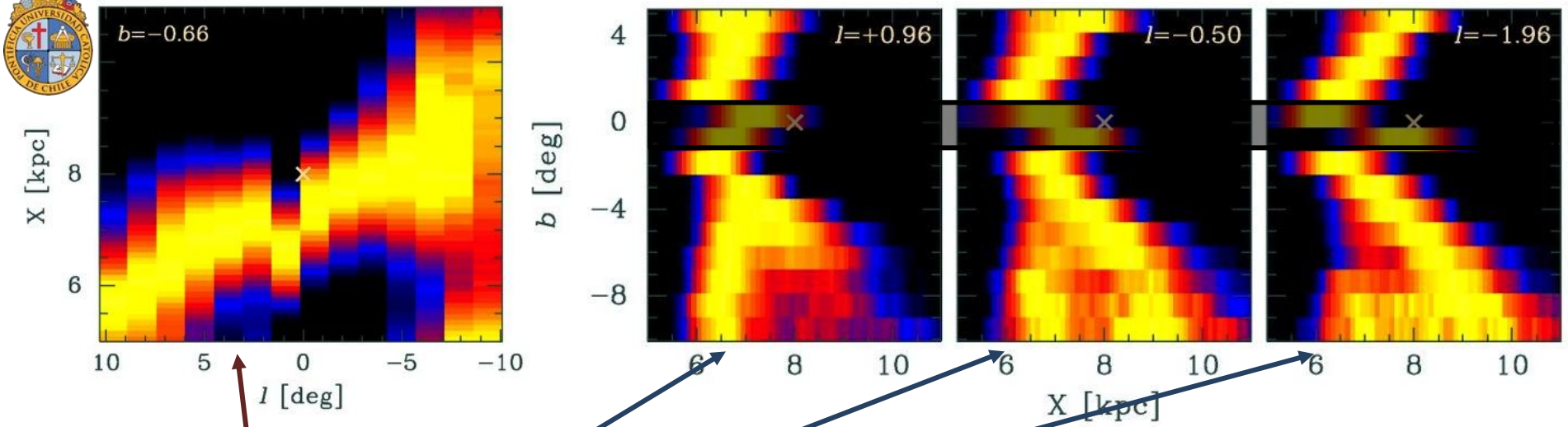








# The inner Galactic bar traced by the VVV Survey (Gonzalez+ 2011)

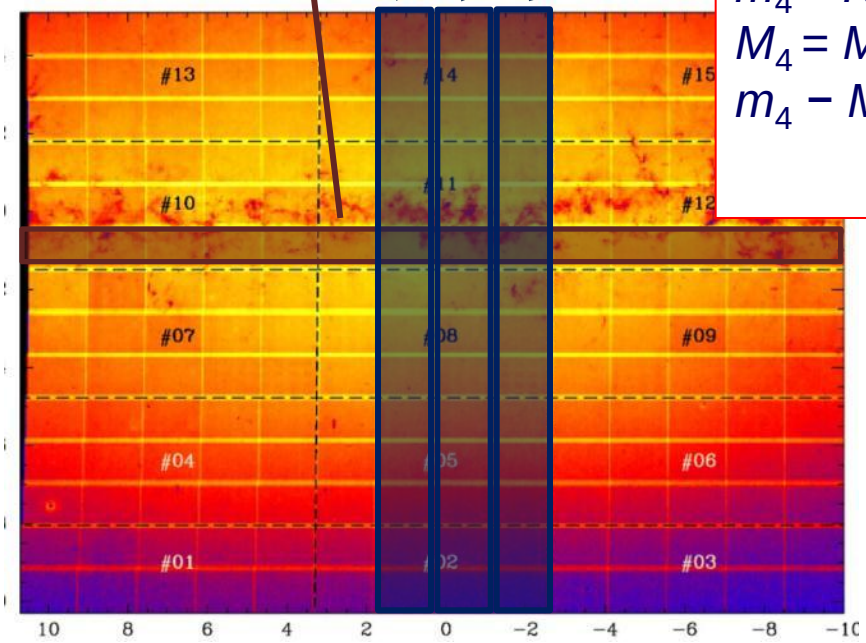
# Mapping the X-shaped Milky Way bulge (Saito+ 2011)

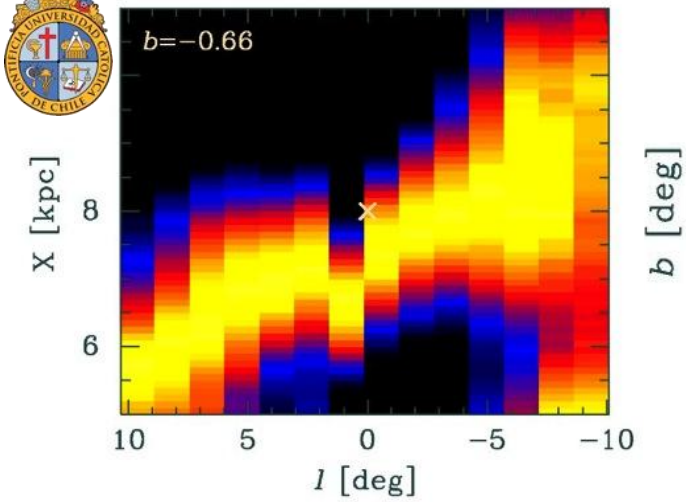


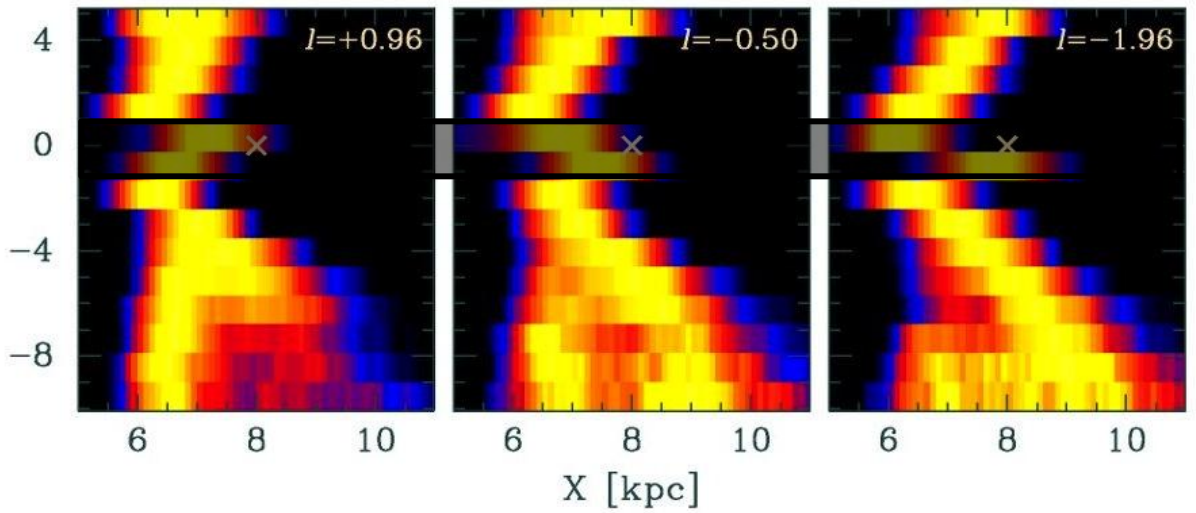

Reddening-free indices for VISTA Filter System*
Catelan et al. 2011

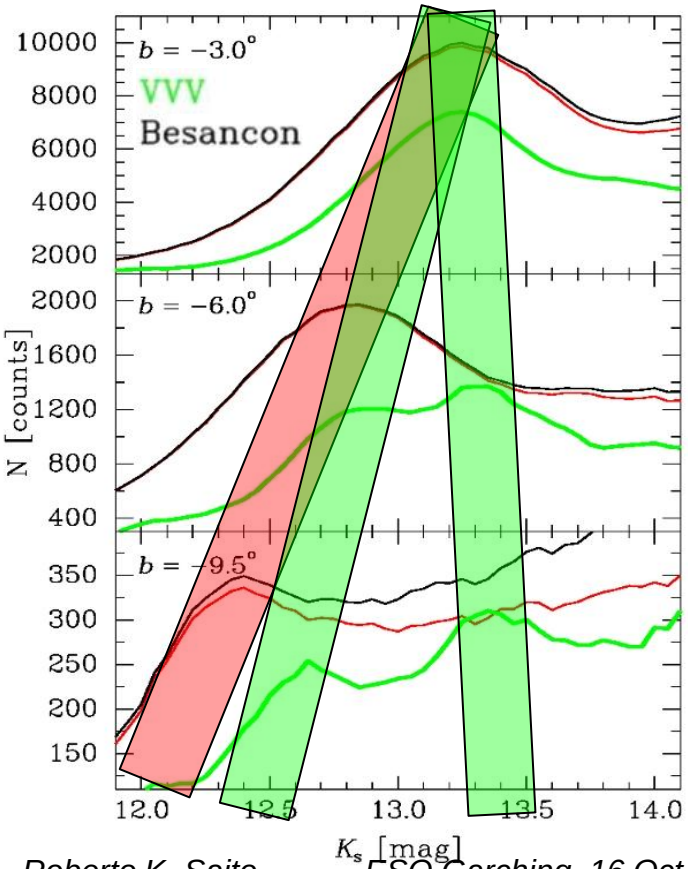
$m_4 = K_s - 1.22(J - H)$
$M_4 = M_{Ks} - 1.22(M_J - M_H)$
$m_4 - M_4 = 5\log d - 5$

*Standard extinction law from Cardelli et al. (1989)






## Reddening-free indices for VISTA Filter System*
## Catelan et al. 2011

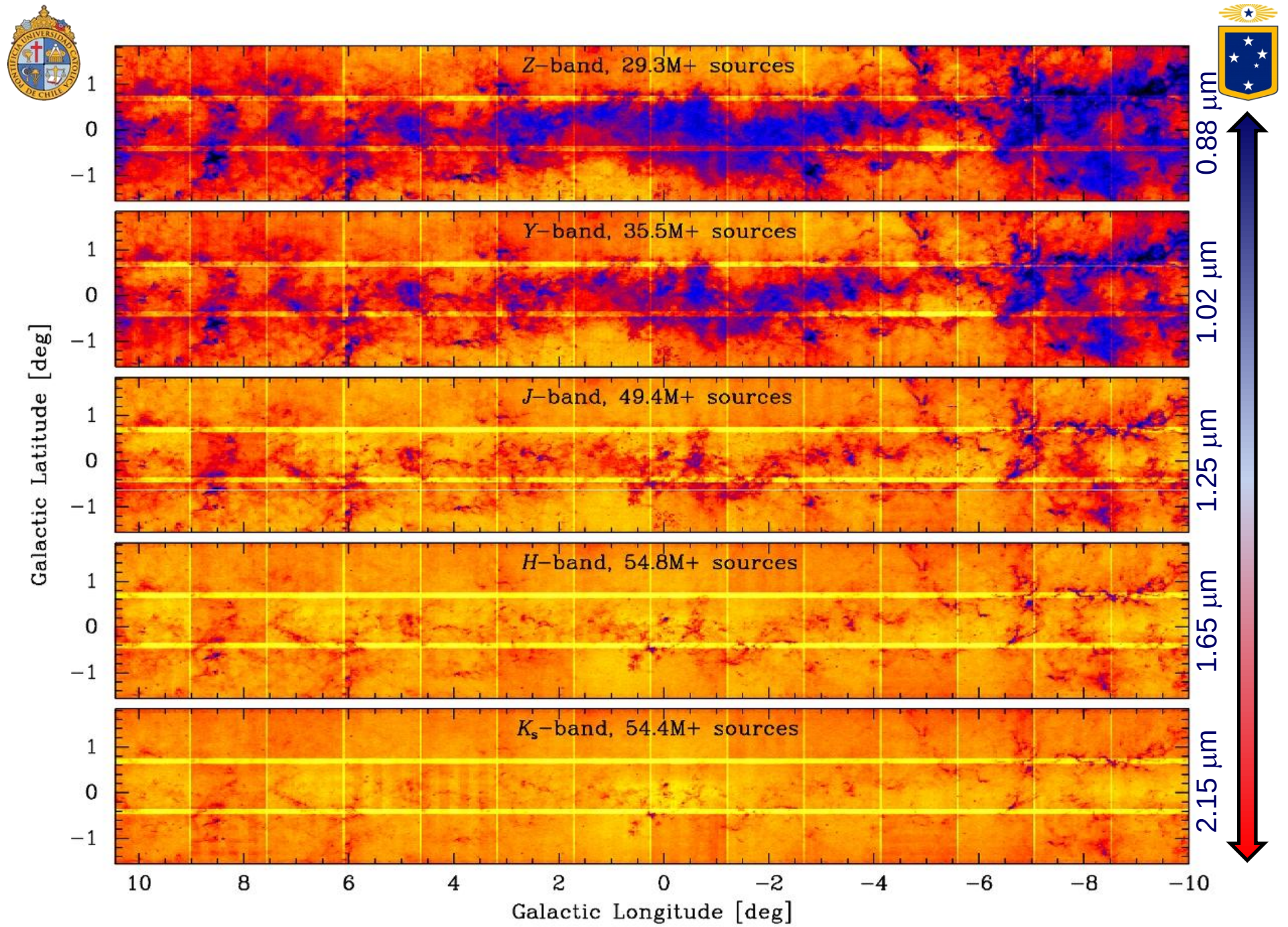
$m_4 = K_s - 1.22(J - H)$

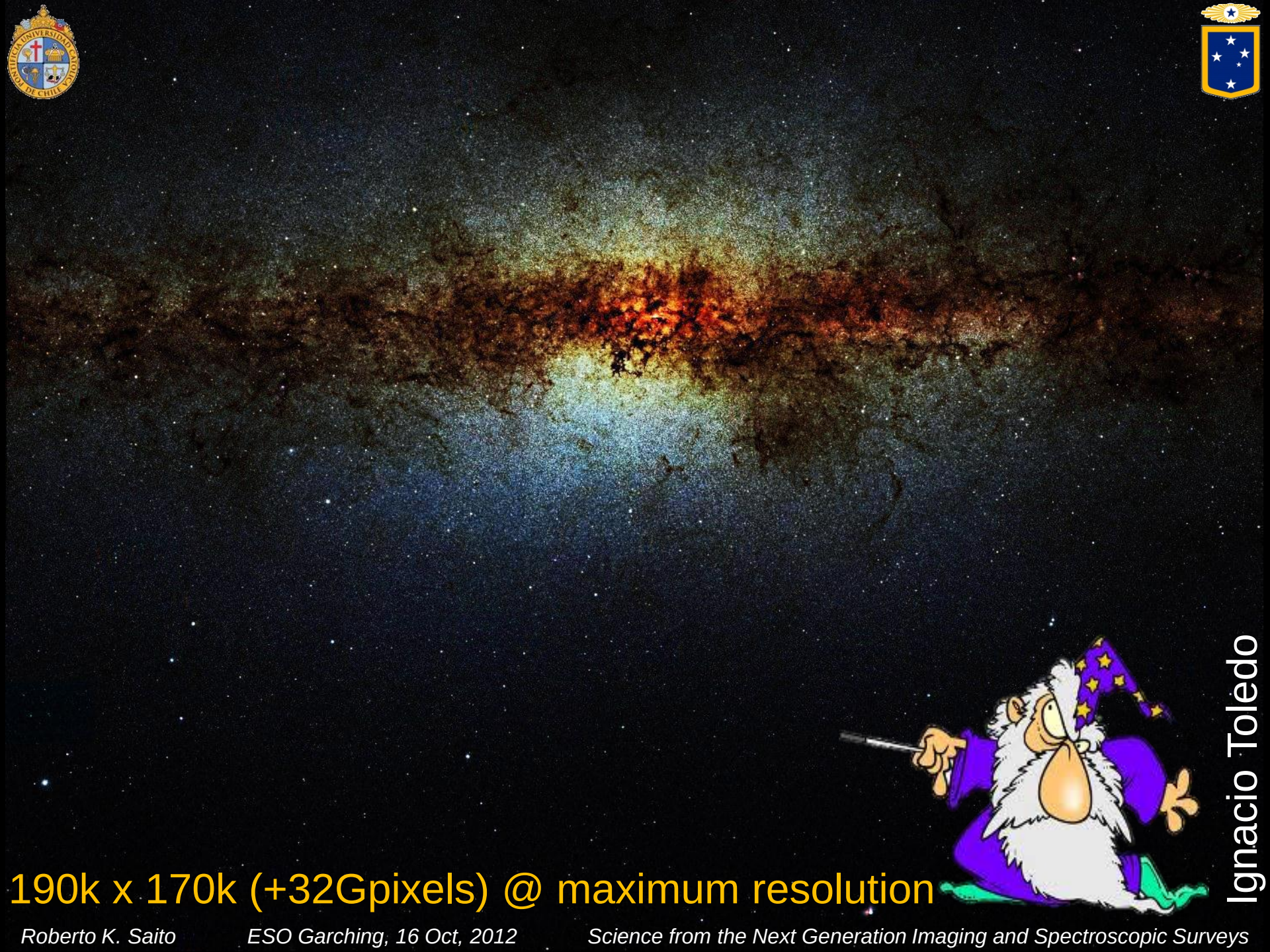
$M_4 = M_{Ks} - 1.22(M_J - M_H)$

$m_4 - M_4 = 5\log d - 5$

*Standard extinction law from Cardelli et al. (1989)

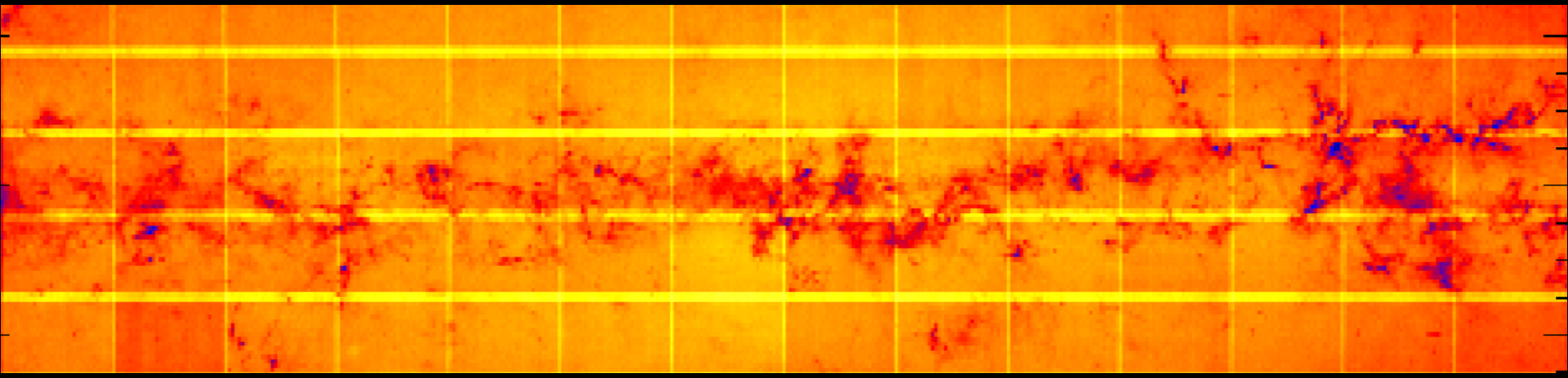
"Since the 2MASS data are not complete, we cannot perform a quantitative fit **(of the double clump)**… in a future paper we plan a more complete analysis of the shape of the flare **(flared bar)** using VVV data, for example, by comparing simulations with the density plots from Saito et al. (2011)." Robin+ 2012


Z−band, 29.3M+ sources
Y−band, 35.5M+ sources
J−band, 49.4M+ sources
H−band, 54.8M+ sources
$K_s$−band, 54.4M+ sources
0.88 μm
1.02 μm
1.25 μm
1.65 μm
2.15 μm
Galactic Latitude [deg]
Galactic Longitude [deg]
1
0
−1
10
8
6
4
2
0
−2
−4
−6
−8
−10




190k x 170k (+32Gpixels) @ maximum resolution

# Vielen dank!
# Thank you very much!



rsaito@astro.puc.cl

www.vvvsurvey.org