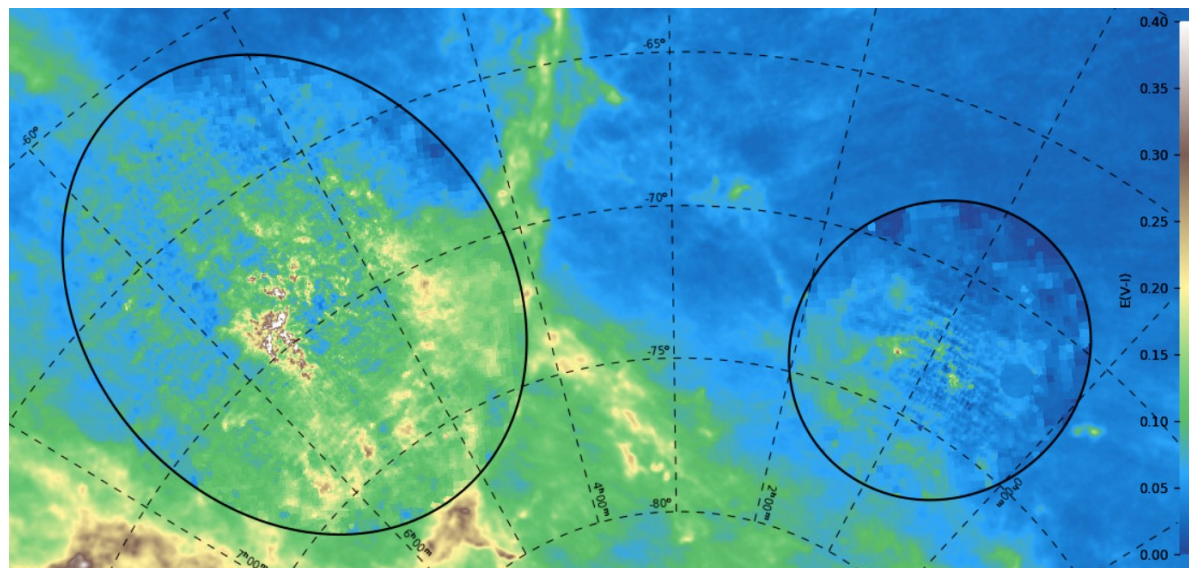


Reddening Maps of the Large and Small Magellanic Cloud based on OGLE-IV Red Clump Stars



Dorota Skowron

Astronomical Observatory, University of Warsaw

Based on the publication: **Skowron et al. 2021, ApJS, 252, 23**

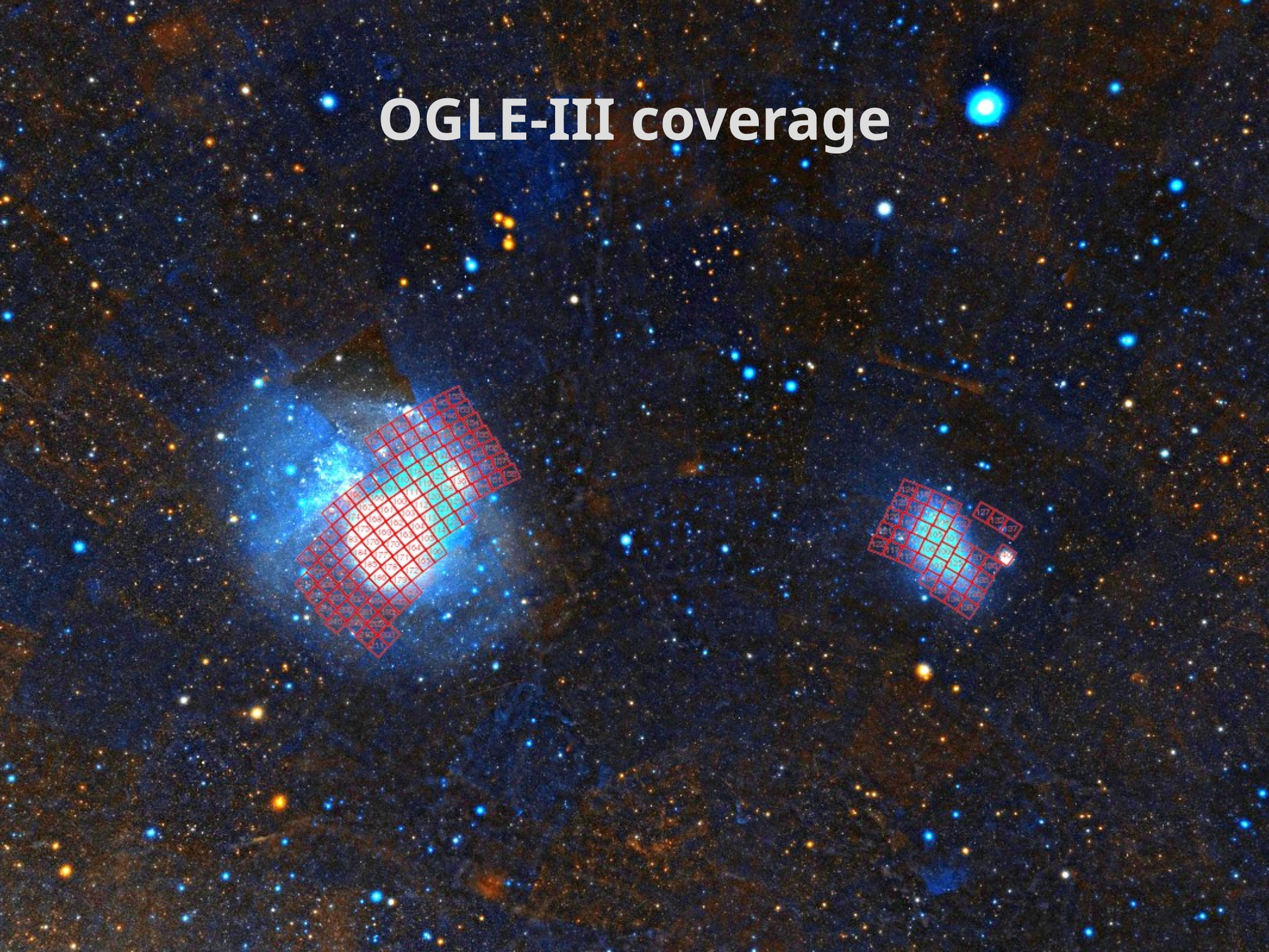
The motivation

- knowing **reddening** is essential in practically all astrophysical studies that involve calculating distance
- knowing **reddening** in the Magellanic Clouds is especially important, as they are used to calibrate the cosmological distance scale
- **THE PROBLEM** – widely used **reddening** maps cover only a small central area of the Magellanic Clouds ([Haschke et al. 2011](#), recently recalibrated by [Górski et al. 2020](#))

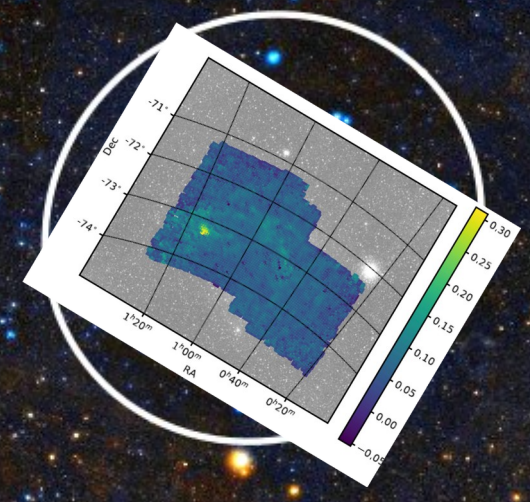
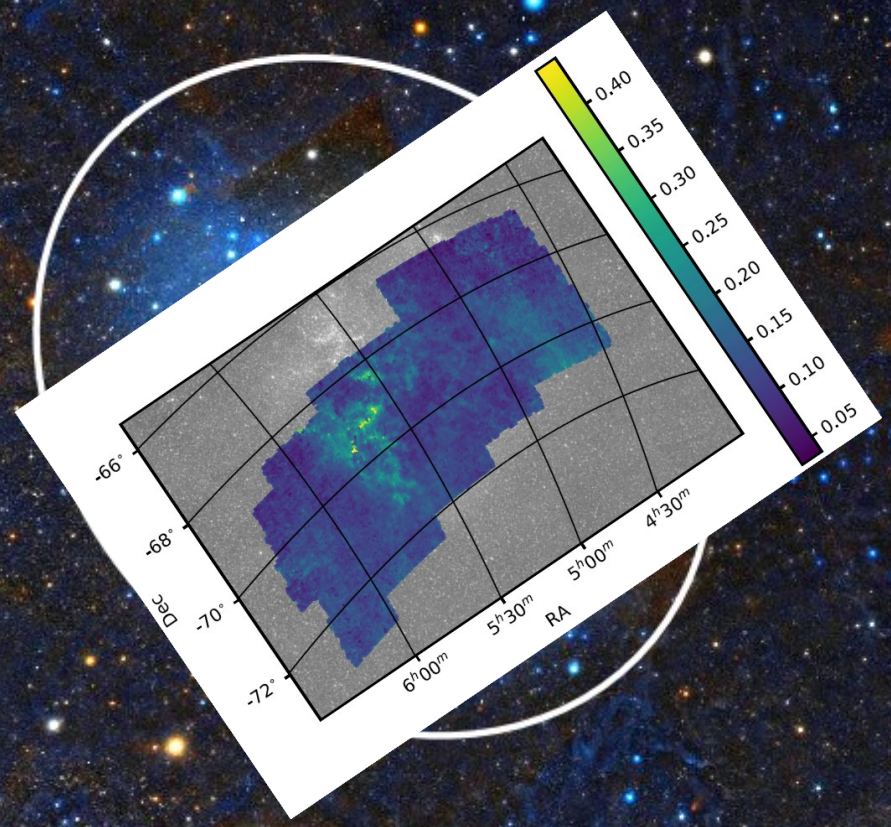
Large and Small Magellanic Clouds



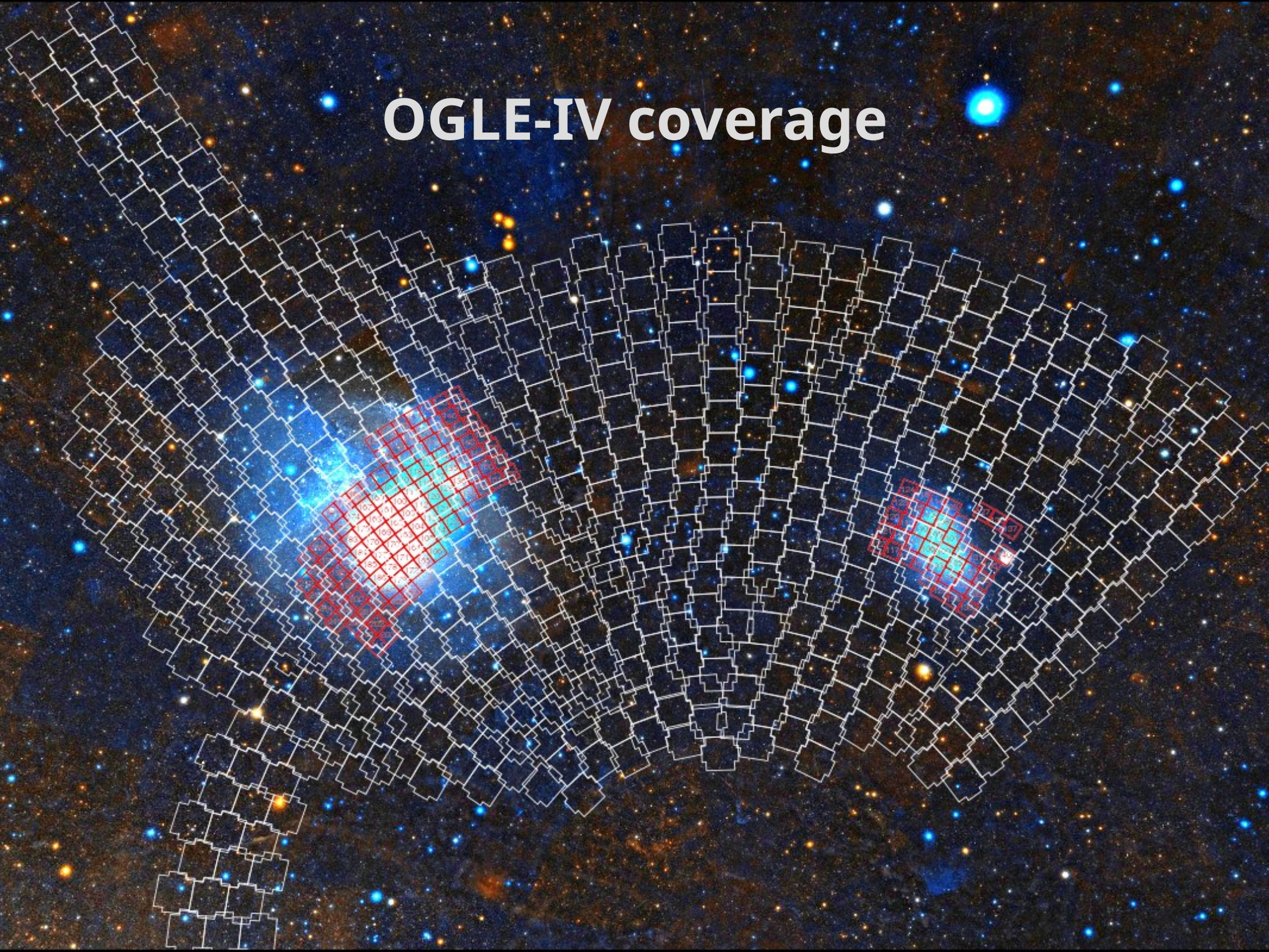
OGLE-III coverage



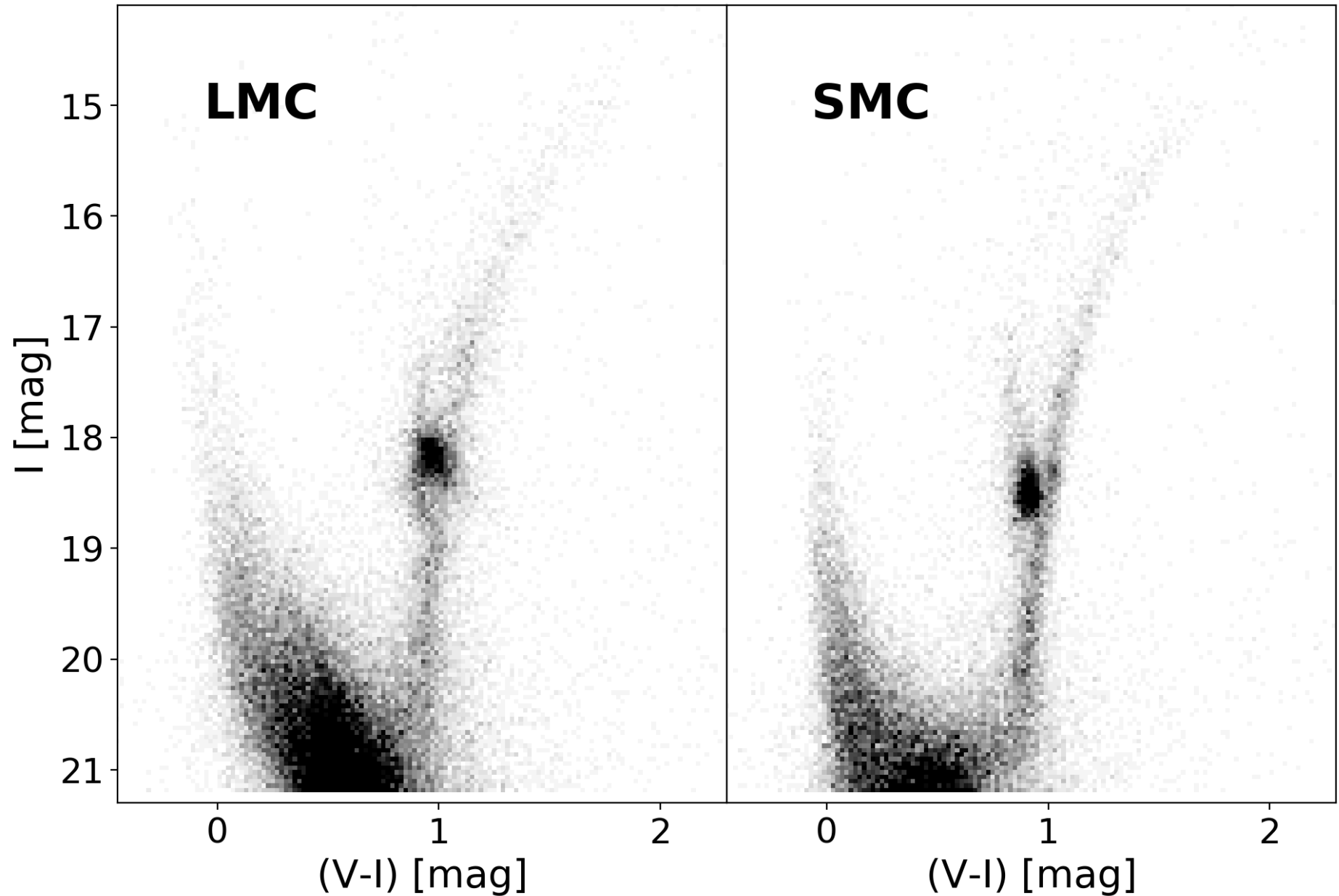
OGLE-III coverage



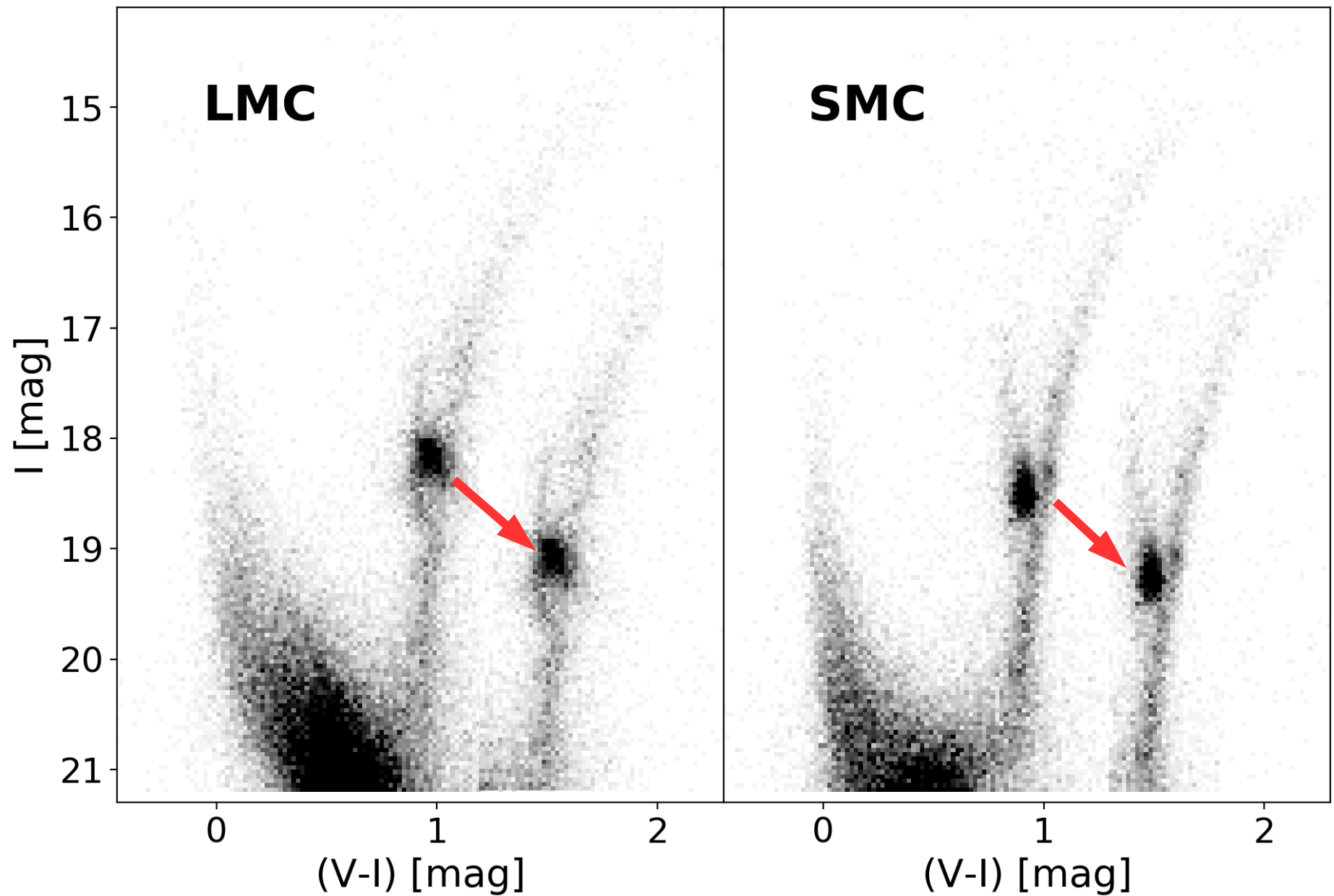
OGLE-IV coverage



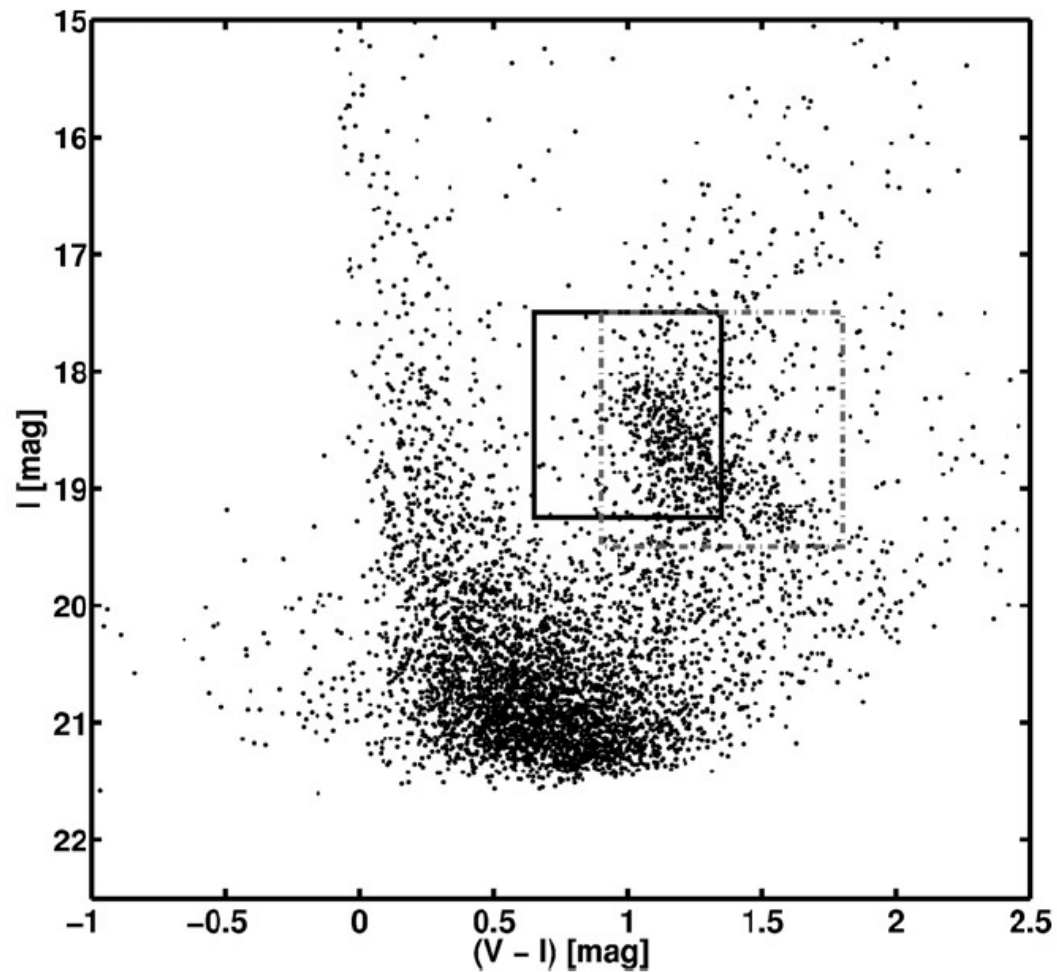
Reddening tracer – Red Clump stars



Reddening by dust in front of the Magellanic Clouds



Differential reddening caused by dust within Magellanic Clouds



Reddening from the Red Clump

$$E(V-I) = (V-I) - (V-I)_0$$



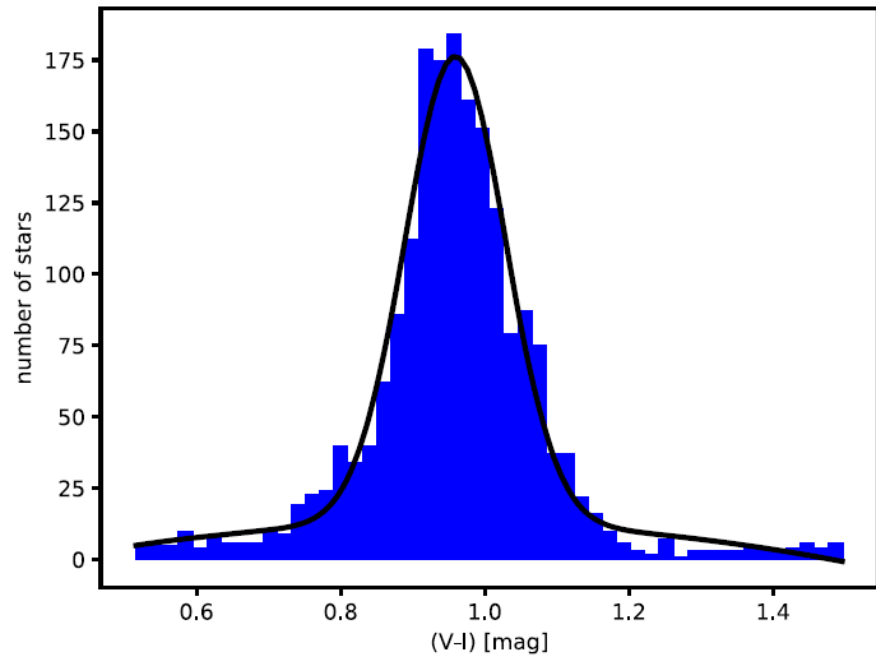
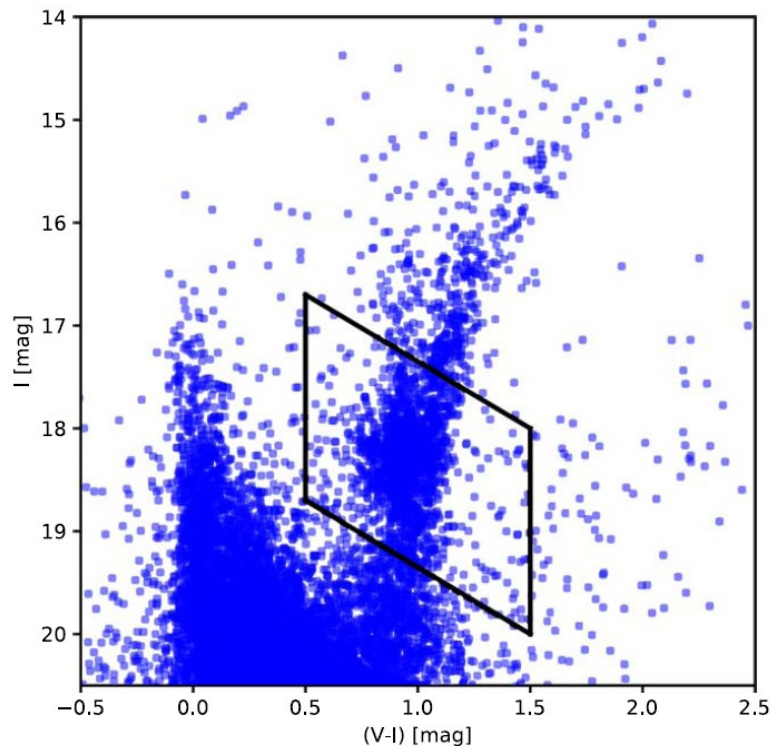
REDDENING

**OBSERVED
COLOR**

**INTRINSIC
COLOR**

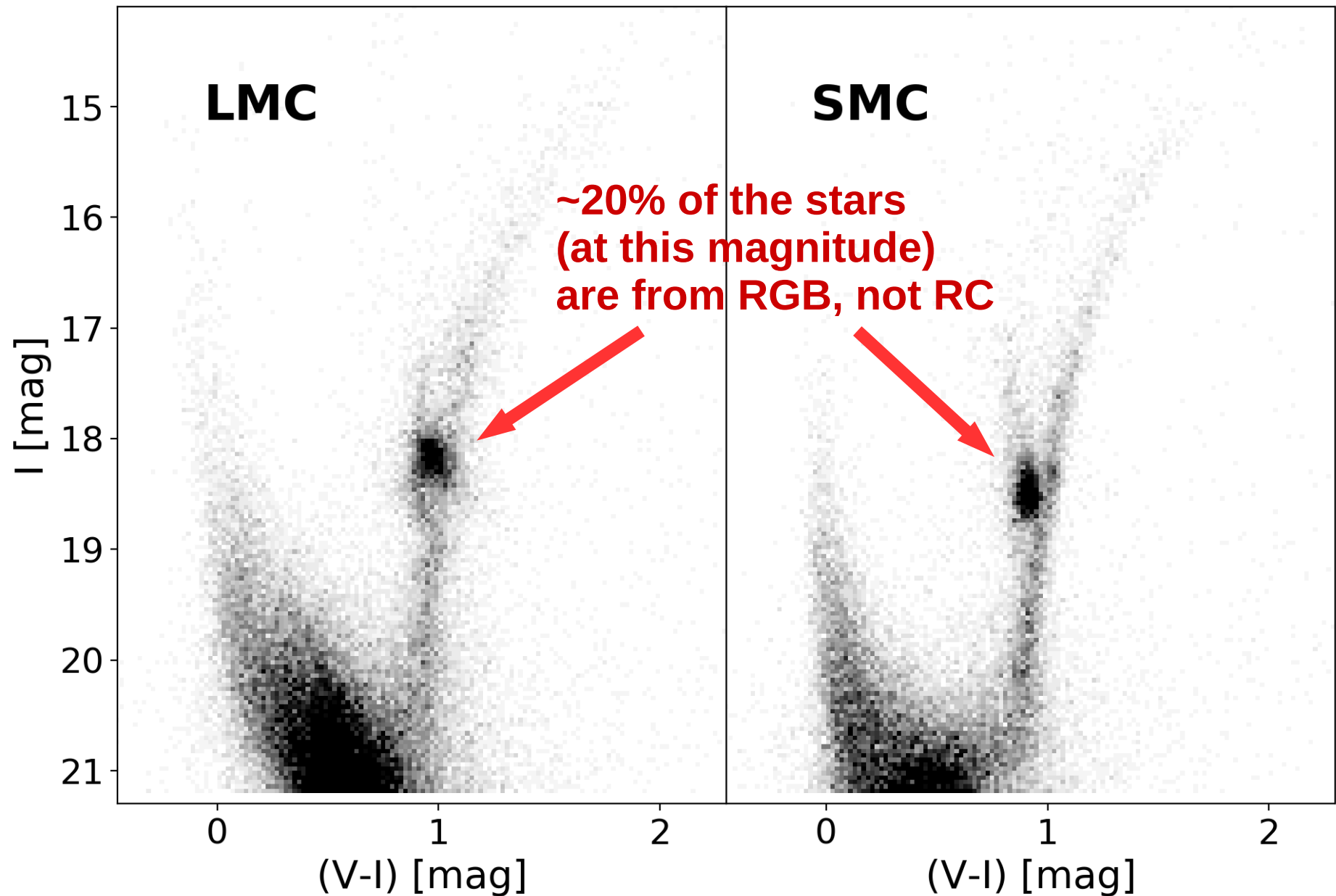
Measuring the color of the Red Clump

- Previous studies used a Gaussian-fit + parabola as a model of the color distribution



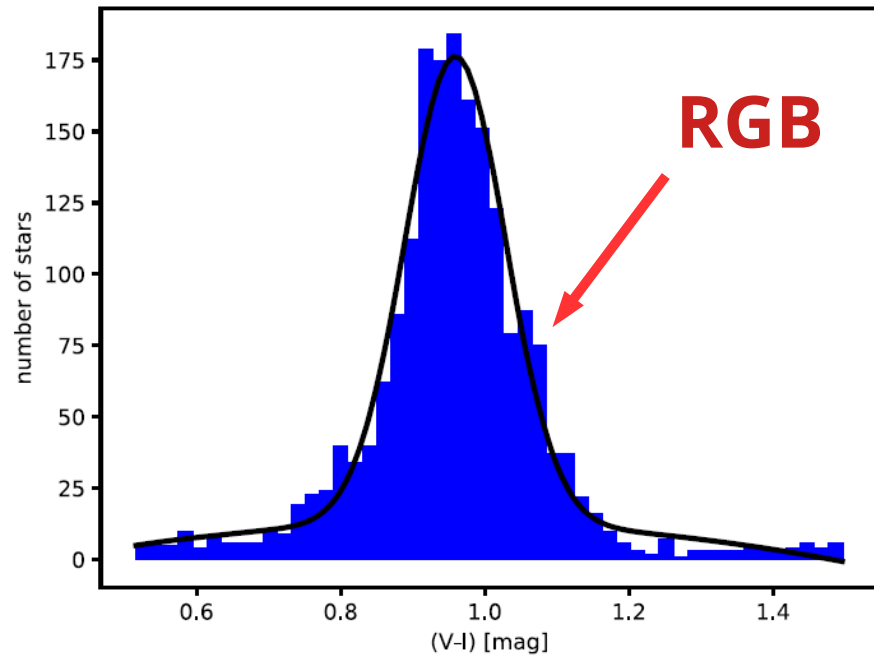
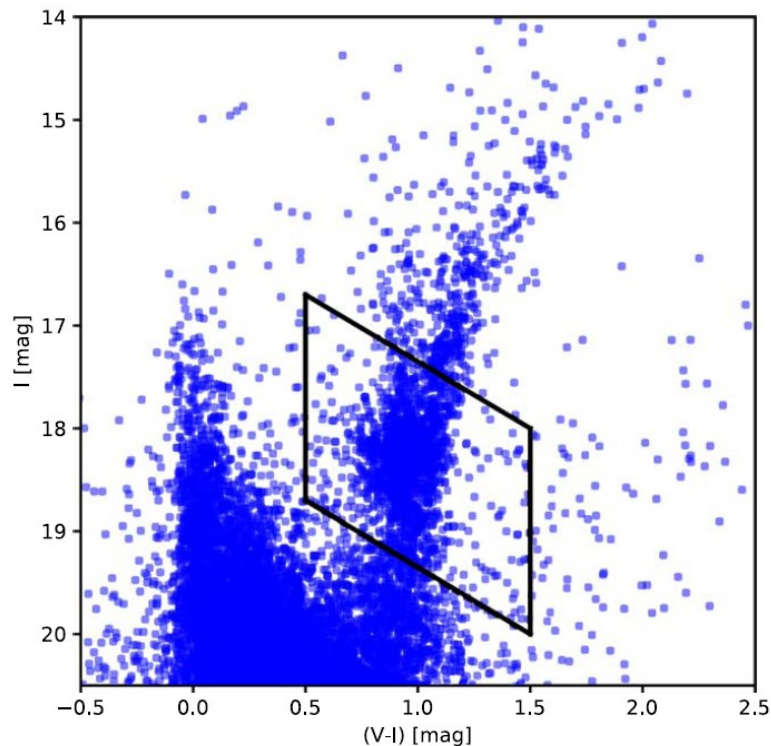
Górski et al. 2020

What about the RGB?



Measuring the color of the Red Clump

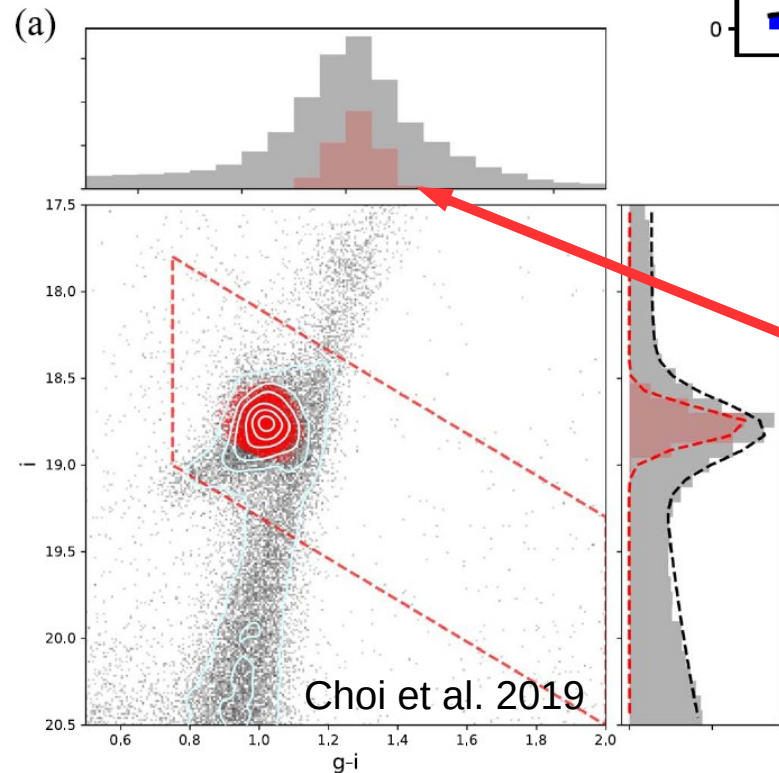
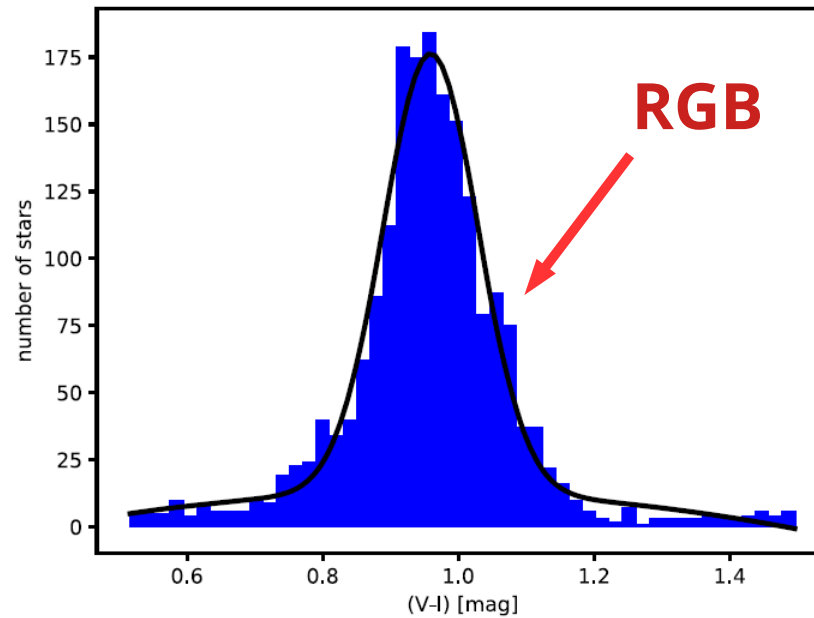
- Previous studies used a Gaussian-fit + parabola as a model of the color distribution



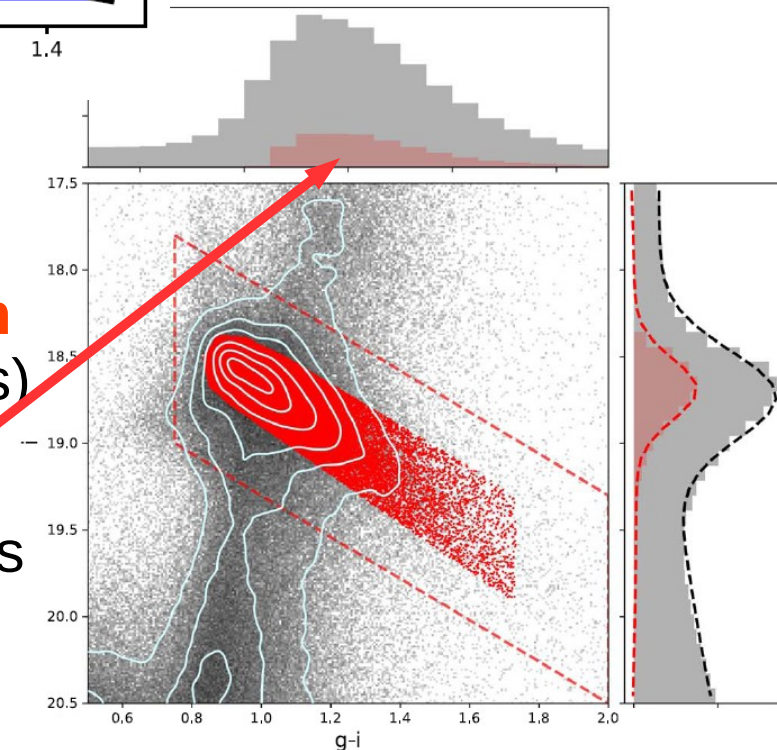
Górski et al. 2020

Problems with previous studies (Gaussian fits, means, medians, etc.)

Simple gaussian fit **overestimates** Red Clump color, due to inclusion of RGB



Manual cuts:
either cut **too much**
(bias to lower colors)
or cut **too little** (bias
to larger colors)

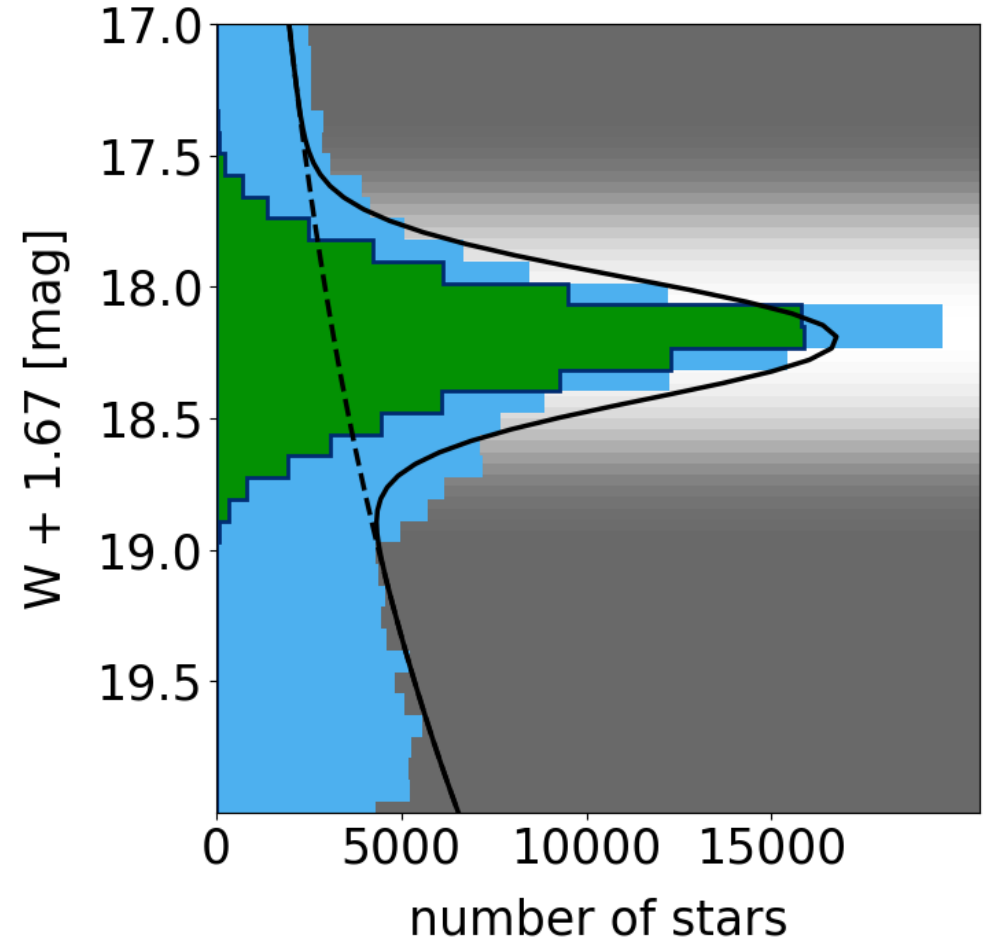
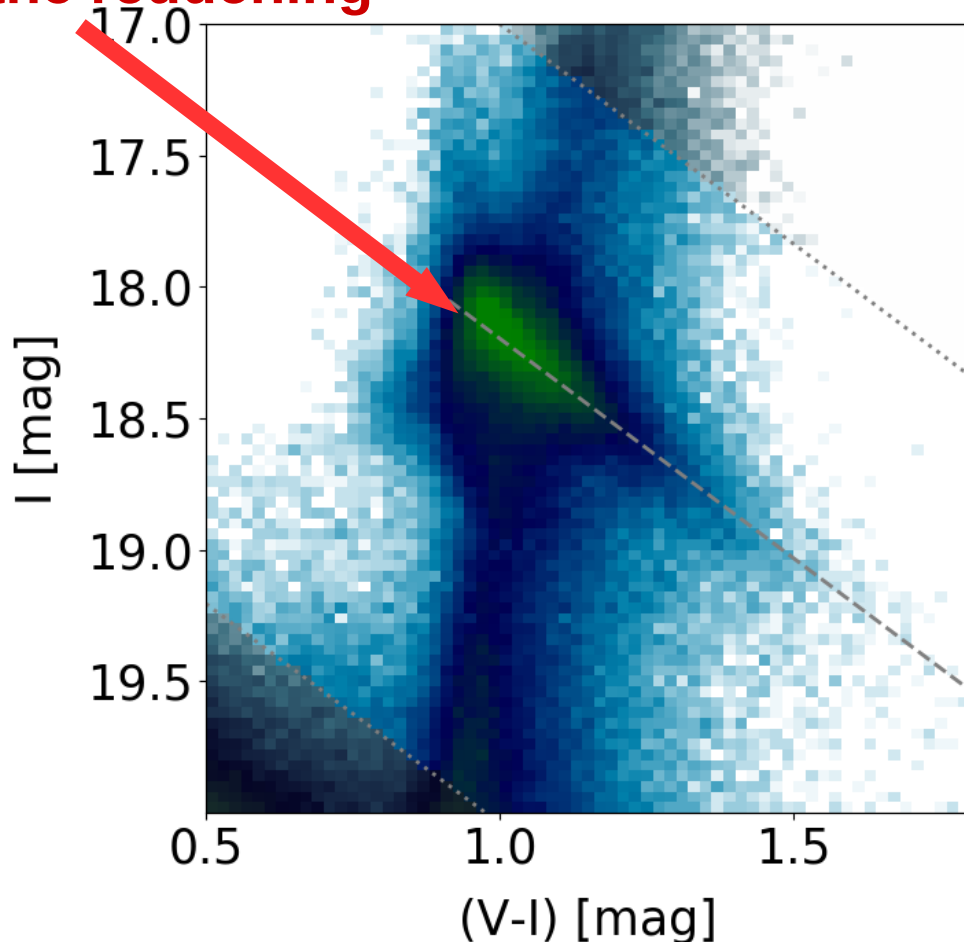


Measuring the color of the Red Clump

- Refine the method of calculating the RC color to properly account for the RGB contribution

Luminosity function fit

direction of
the reddening

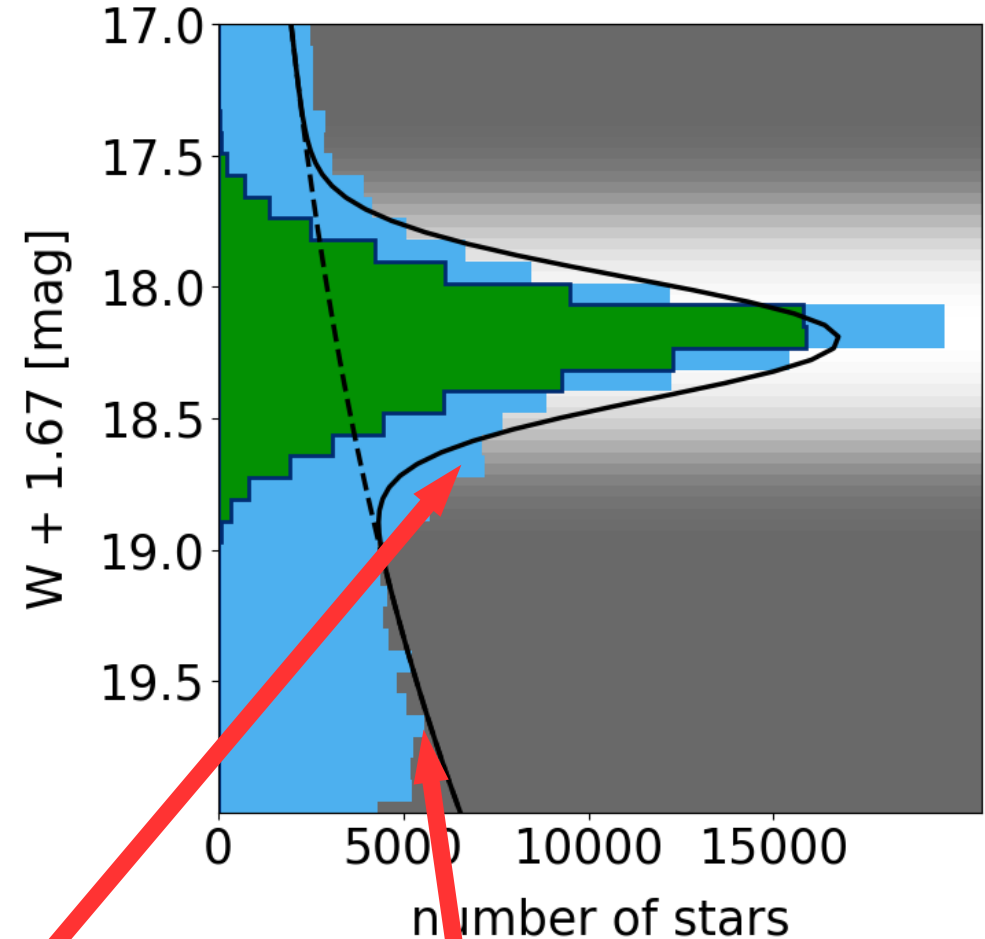
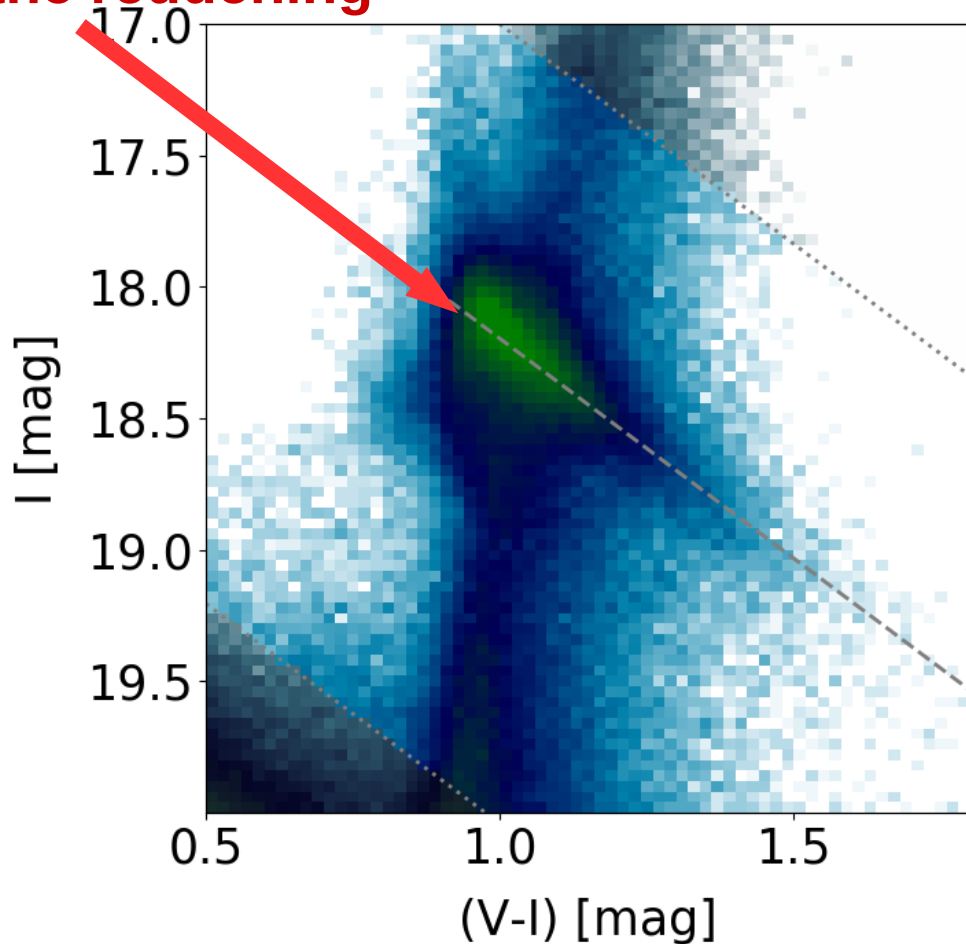


The magnitude axis is defined
using a Wesenheit index:

$$W = I - 1.67 (V-I) \quad \text{in the LMC}$$
$$W = I - 1.74 (V-I) \quad \text{in the SMC}$$

Luminosity function fit

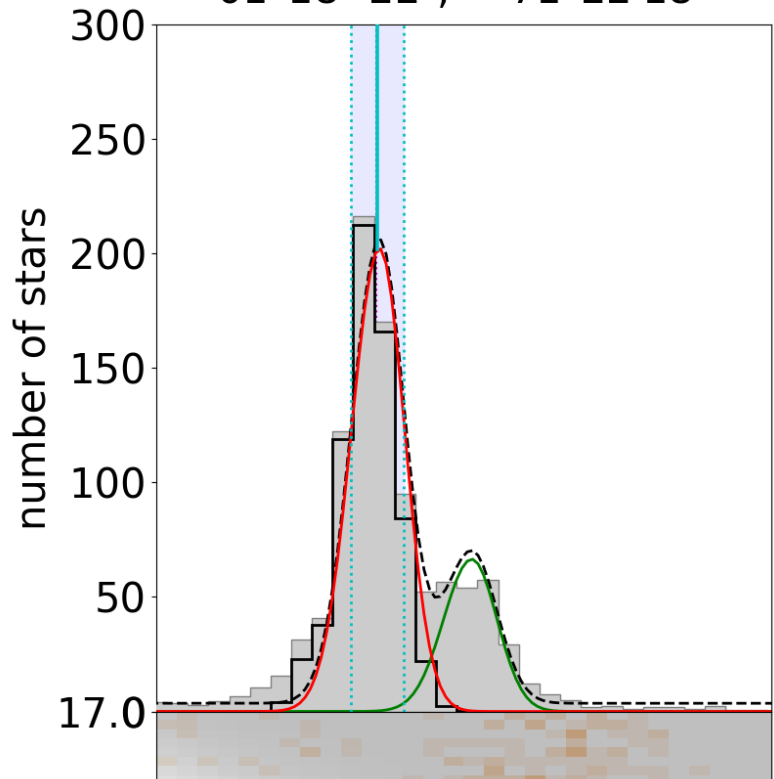
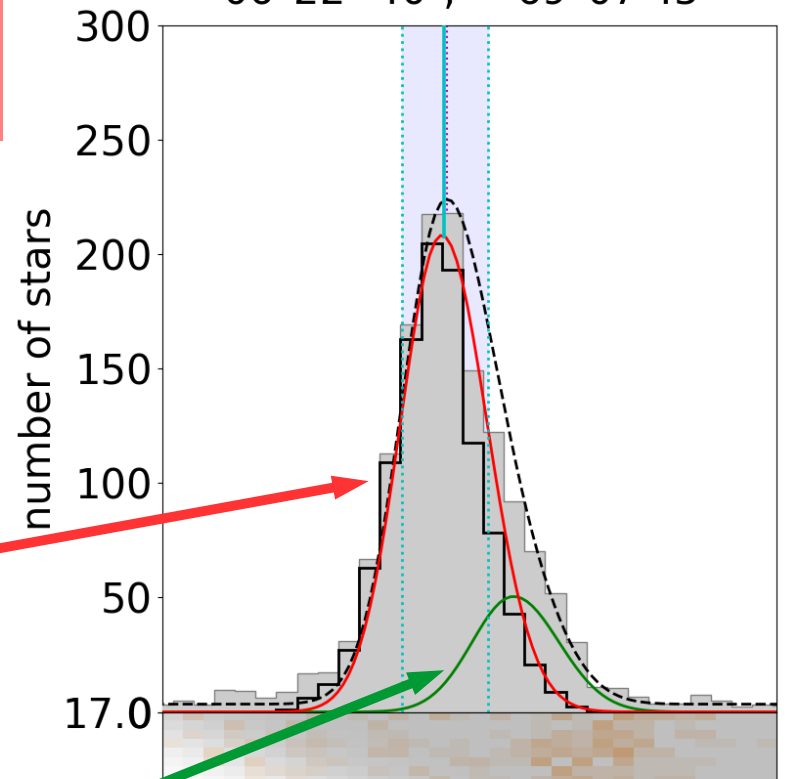
direction of
the reddening



$$LF(W) = LF_{RC}(W) + LF_{RGB}(W) \sim \exp\left(-\frac{1}{2} \left(\frac{W - \bar{W}}{\sigma_W}\right)^2\right) + A \exp\left(\frac{W}{2.5}\right)$$

LMC 27.5' x 27.5'
06^h22^m40^s, -69°07'45"

SMC 27.5' x 27.5'
01^h18^m22^s, -71°22'18"



RC

RGB

I [mag]

0.8 1.0 1.2

(V-I) [mag]

I [mag]

0.8 1.0 1.2

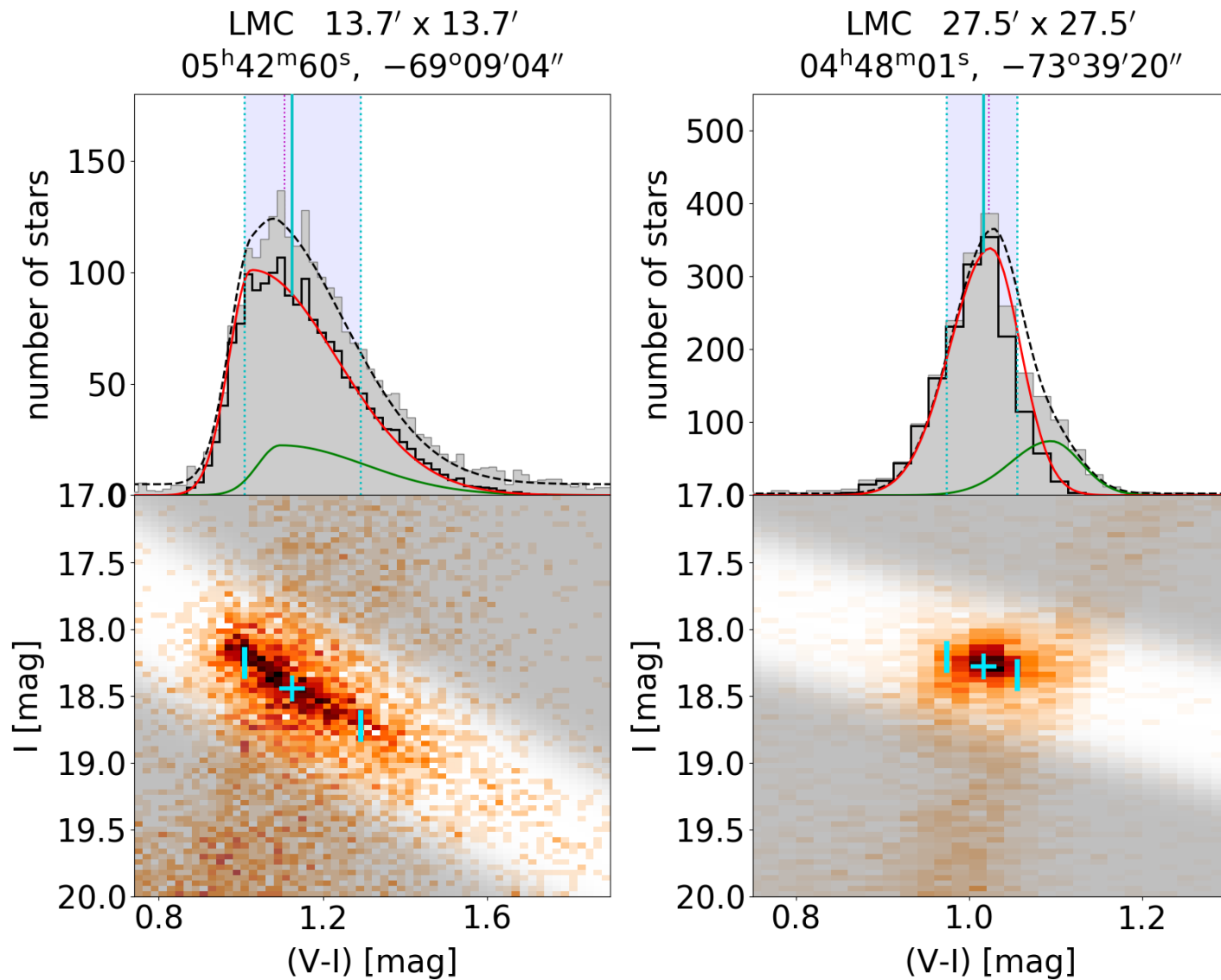
(V-I) [mag]

**each star is weighted with
the probability of
belonging to the RC**

$$p_{\text{LF}}(W) = \text{LF}_{\text{RC}}(W) / \text{LF}(W)$$

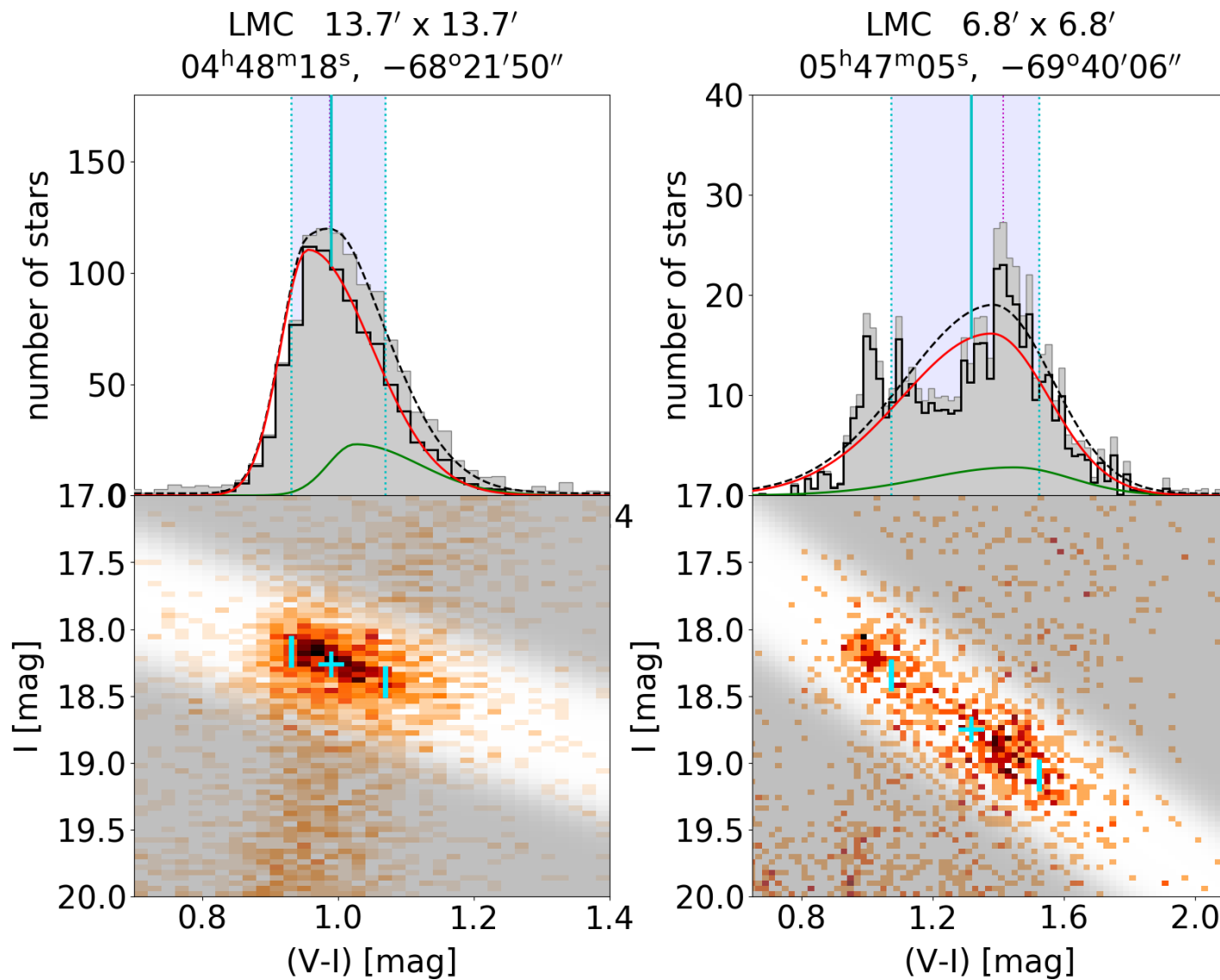
+

„Two-sigma“ Gaussian

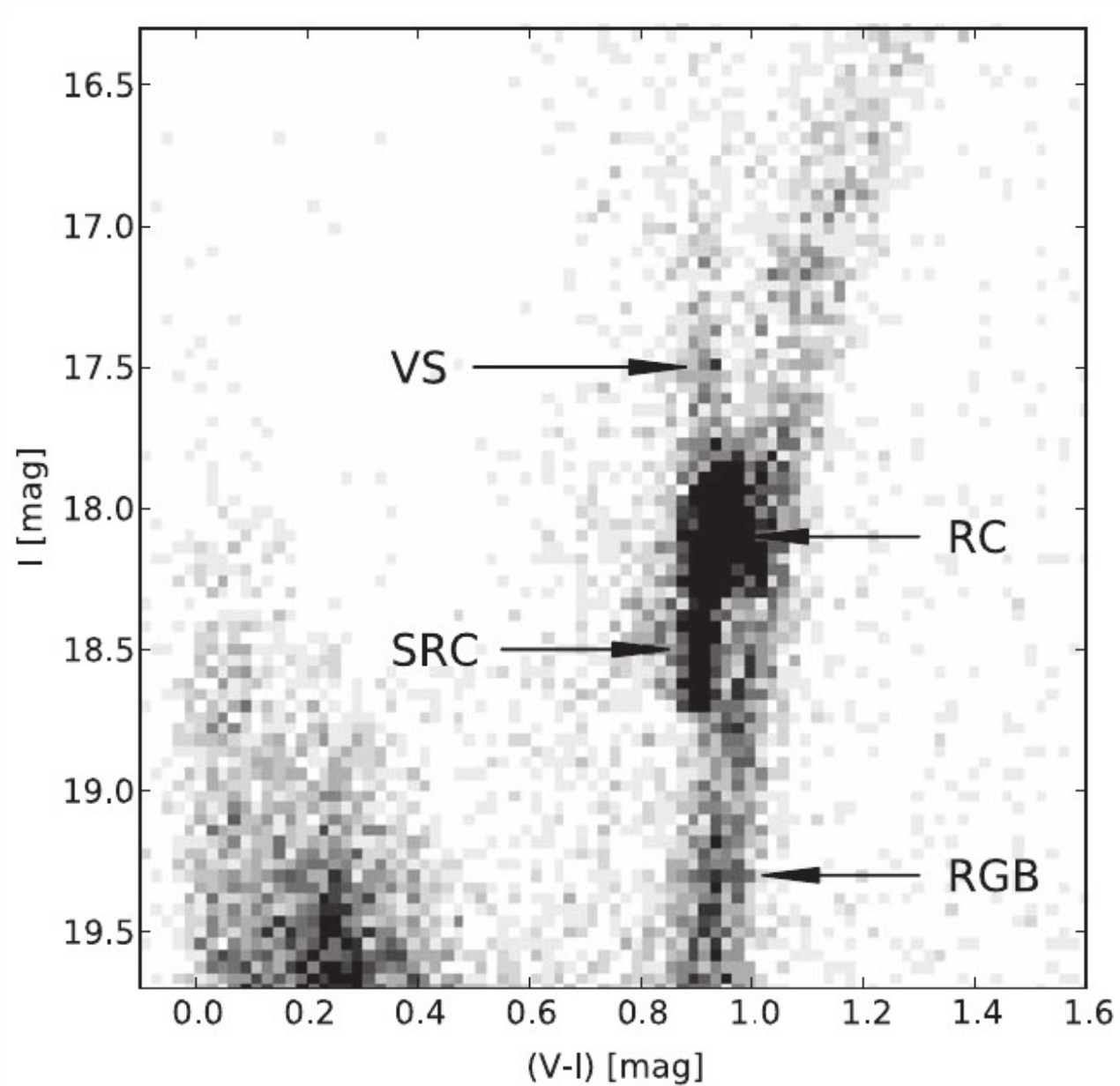


$$\mathcal{N}_2(\overline{V-I}, \sigma_L, \sigma_H) = \begin{cases} \frac{2\sigma_L}{\sigma_L + \sigma_H} \mathcal{N}(\overline{V-I}, \sigma_L), & \text{for } (V-I) < \overline{V-I} \\ \frac{2\sigma_H}{\sigma_L + \sigma_H} \mathcal{N}(\overline{V-I}, \sigma_H), & \text{for } (V-I) > \overline{V-I} \end{cases}$$

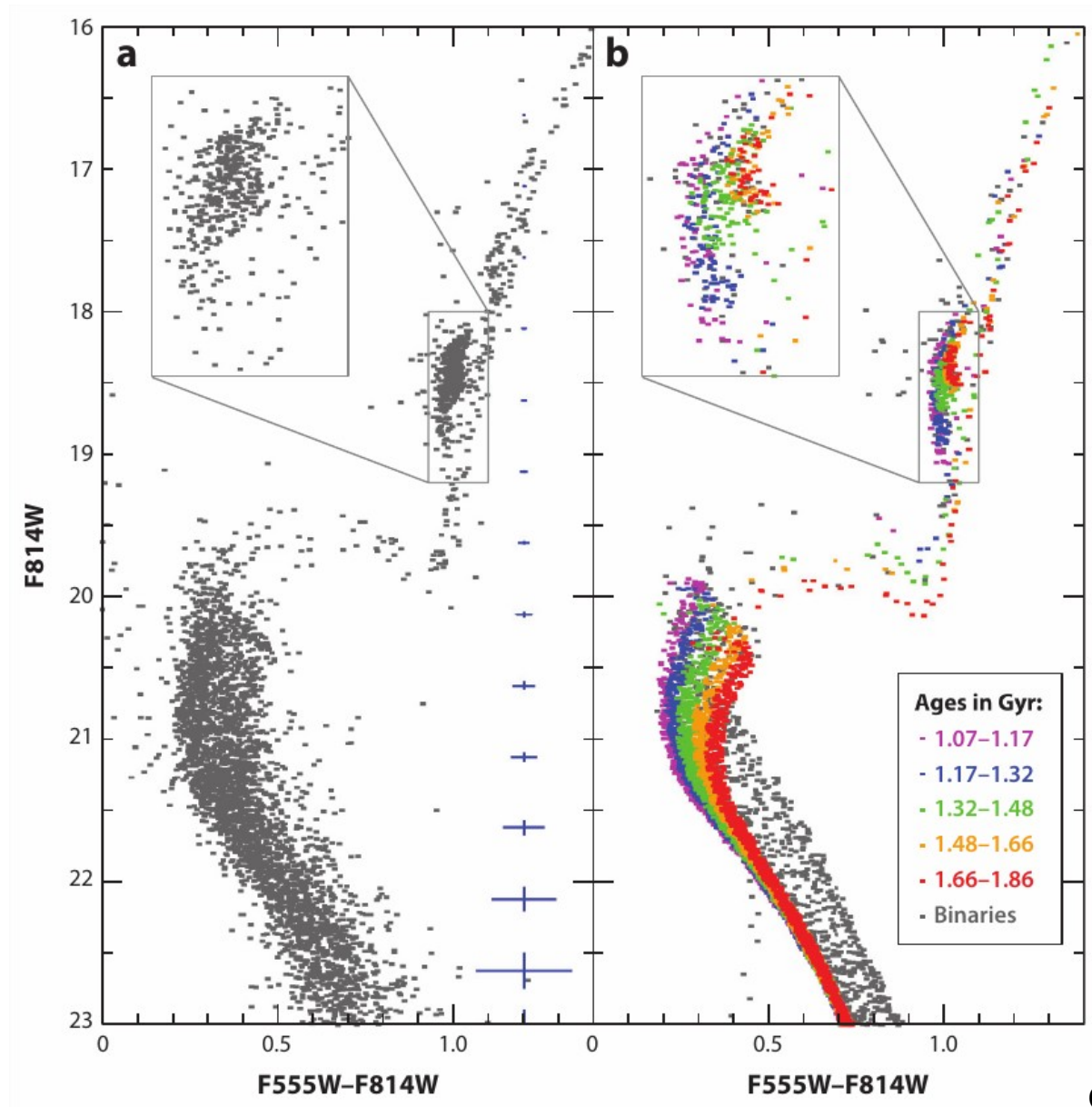
„Two-sigma“ Gaussian



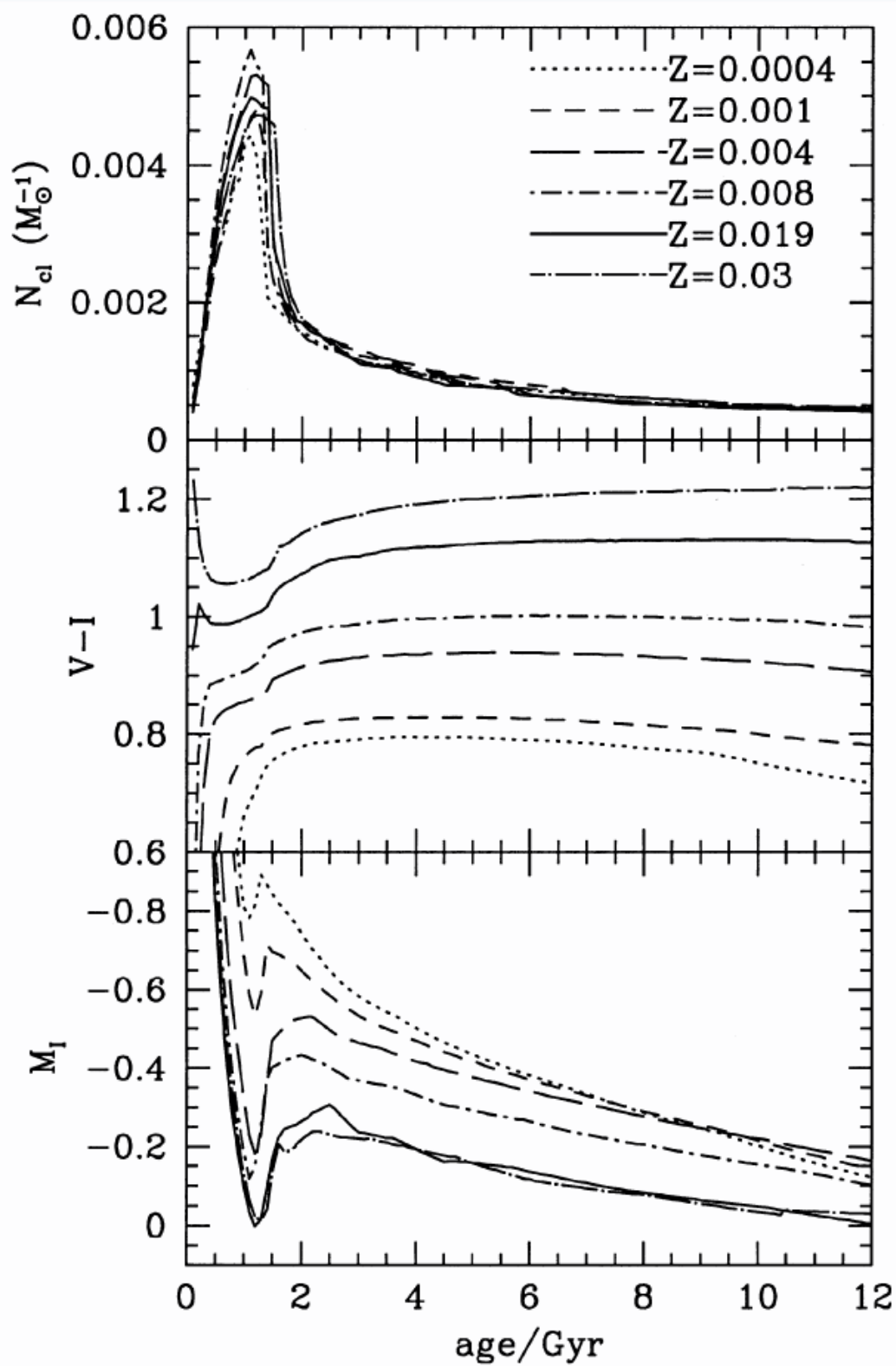
Red Clump complexity



Red Clump complexity

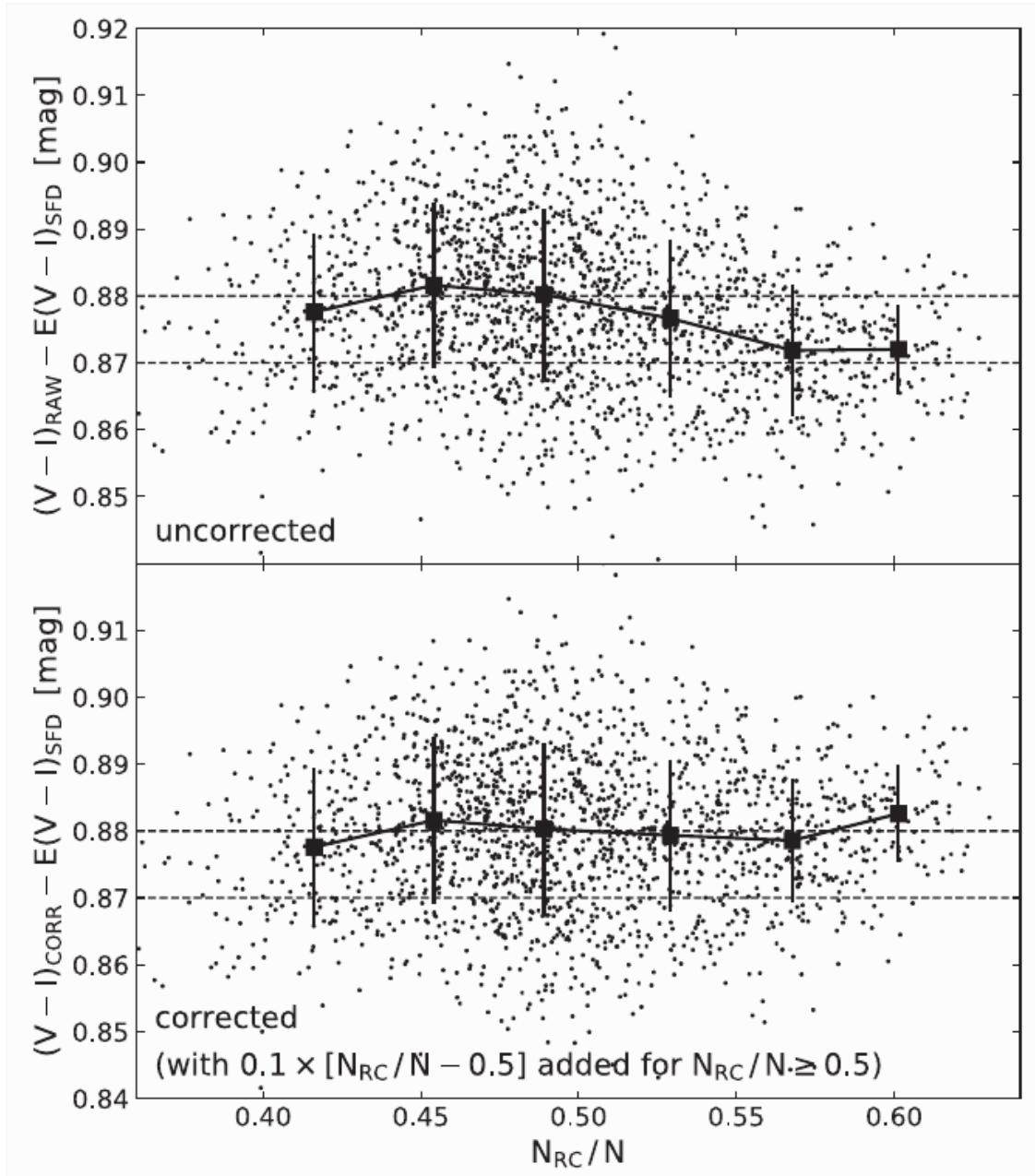


Girardi (2016)

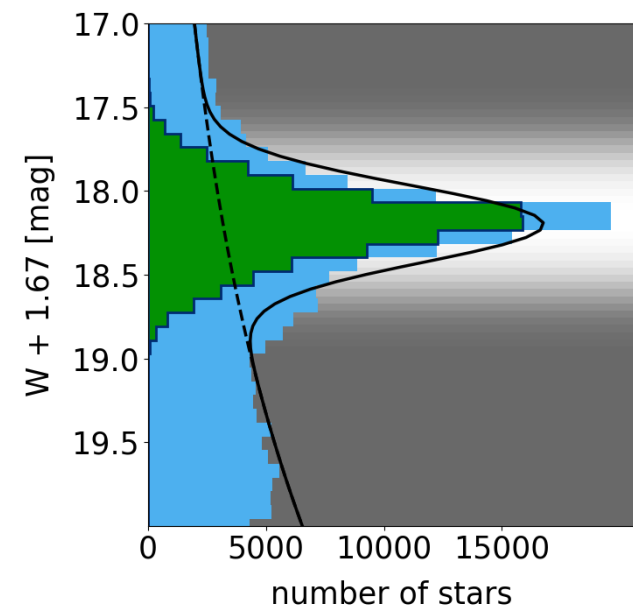


Girardi & Salaris (2001)

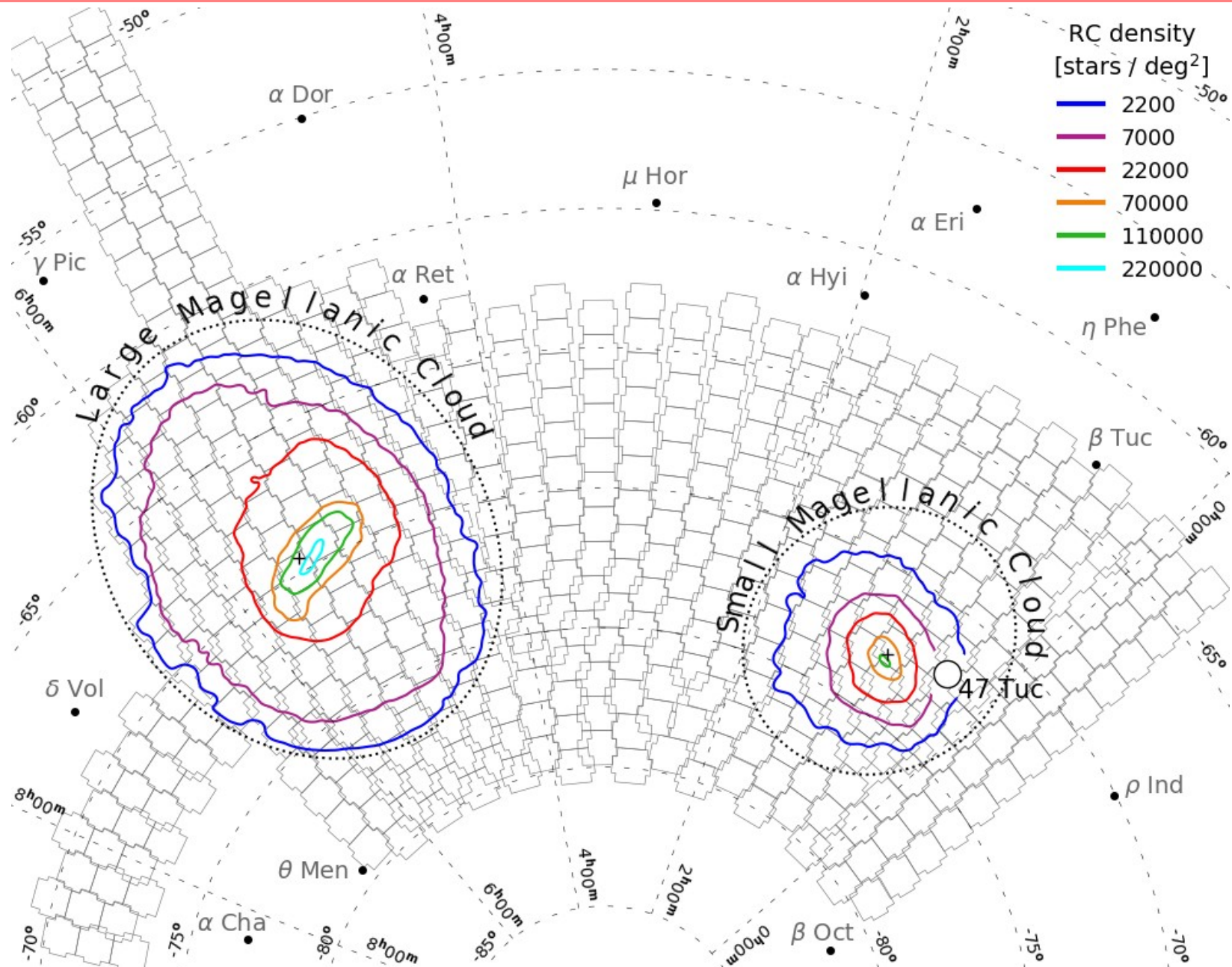
Red Clump complexity



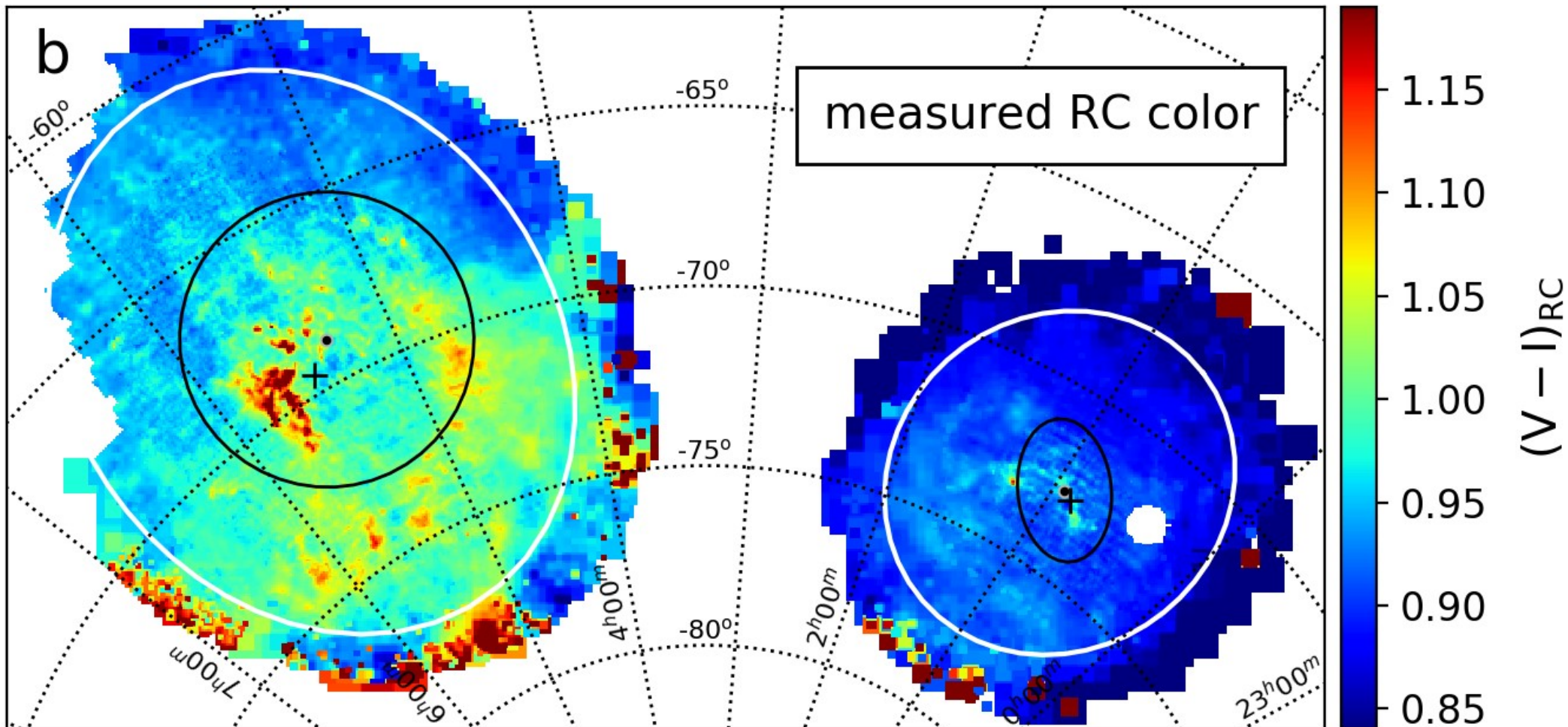
N_{RC}/N parameter –
relative number of RC
stars to all stars around
the measured RC
brightness



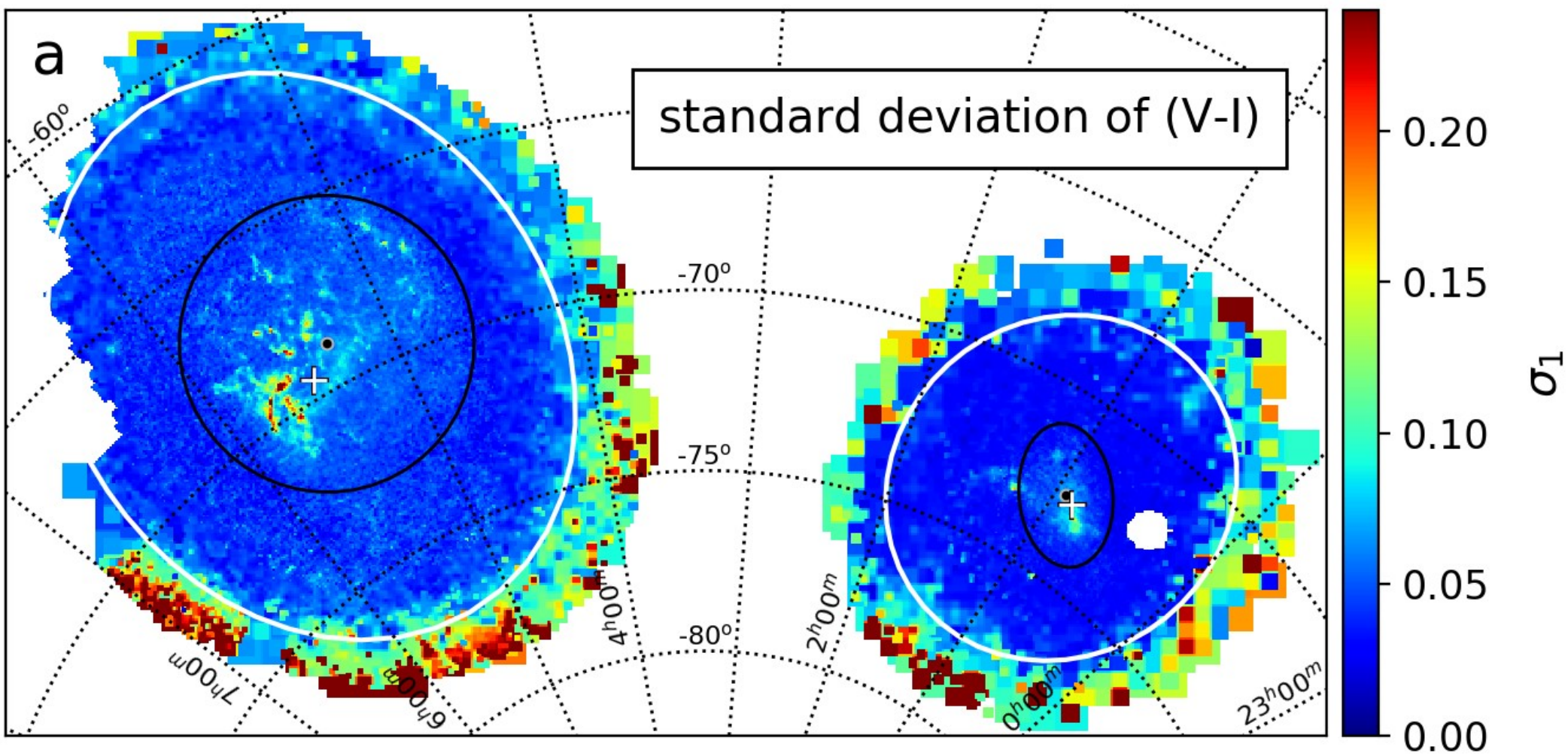
Results – density of RC stars



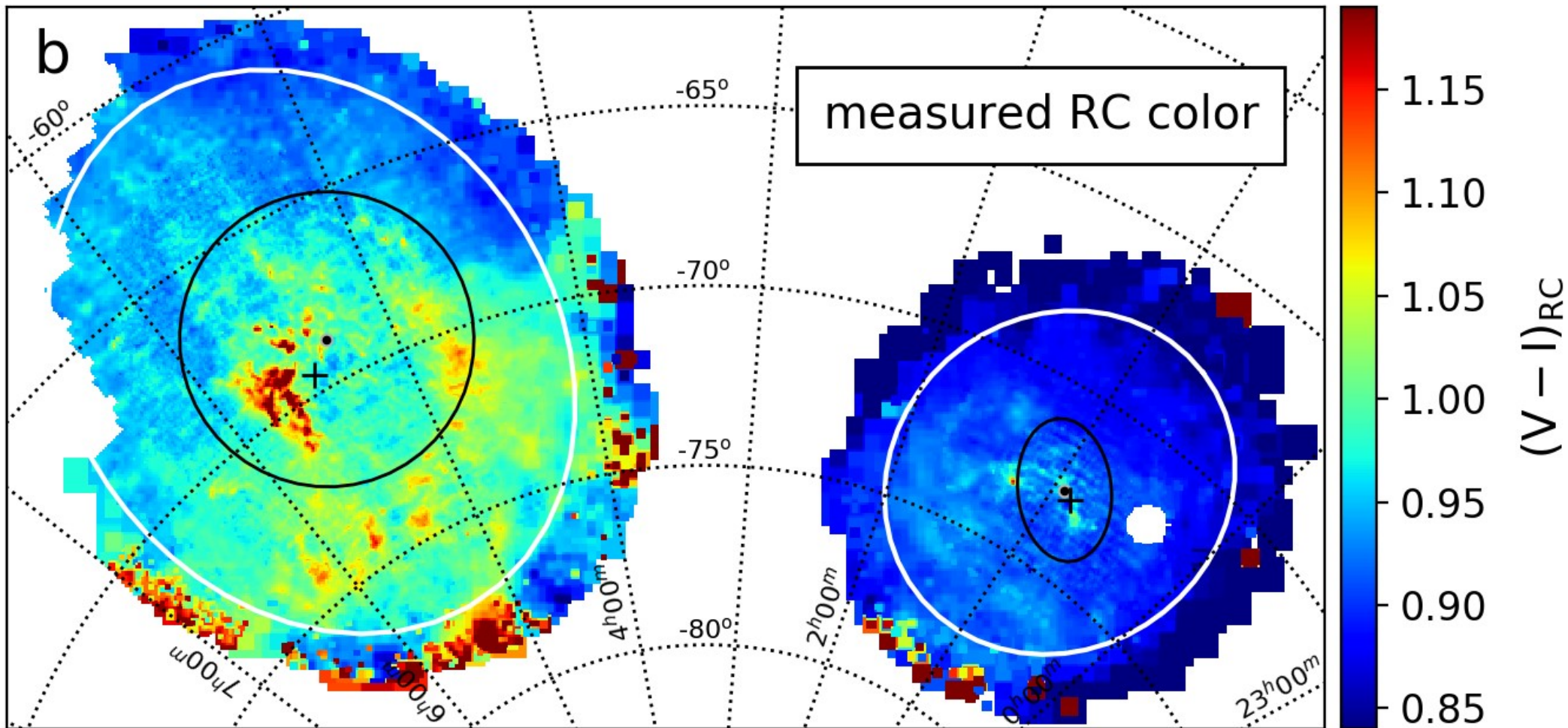
Measured RC color $(V-I)_{RC}$



Scatter of the measured color $\sigma_{(V-I)}$



Measured RC color $(V-I)_{RC}$



Reddening from the Red Clump

$$E(V-I) = (V-I) - (V-I)_0$$



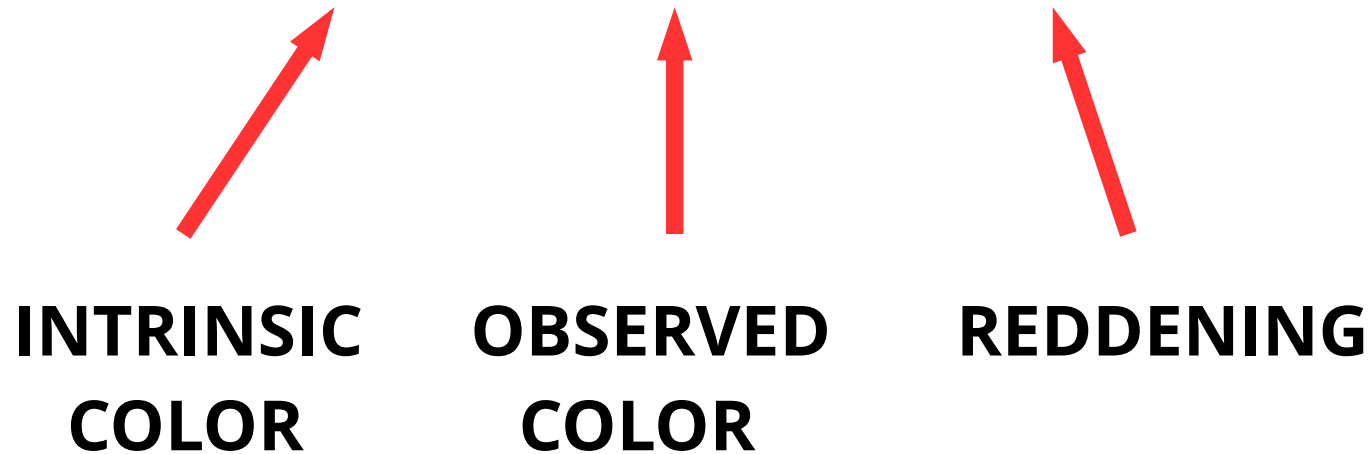
REDDENING

**OBSERVED
COLOR**

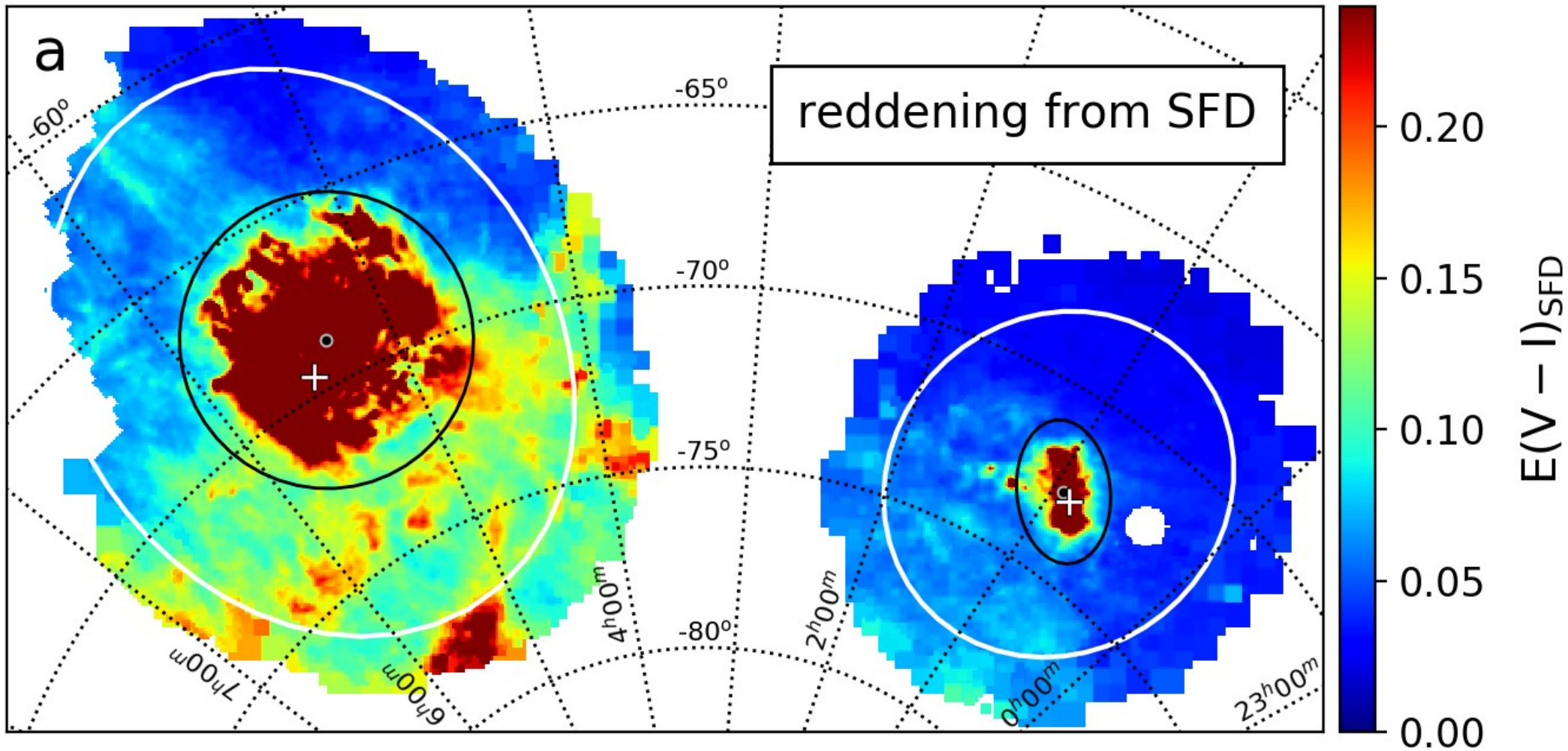
**INTRINSIC
COLOR**

Reddening from the Red Clump

$$(V-I)_0 = (V-I) - E(V-I)$$

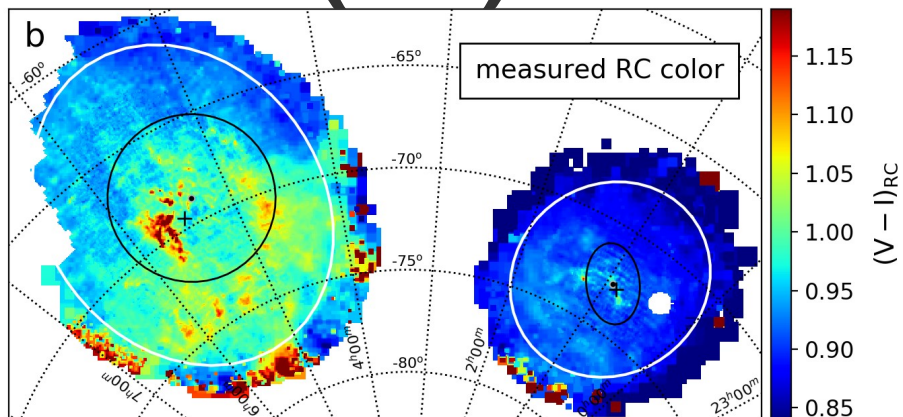


Reddening based on Schlegel, Finkbeiner, & Davis (1998) - $E(V-I)_{\text{SFD}}$

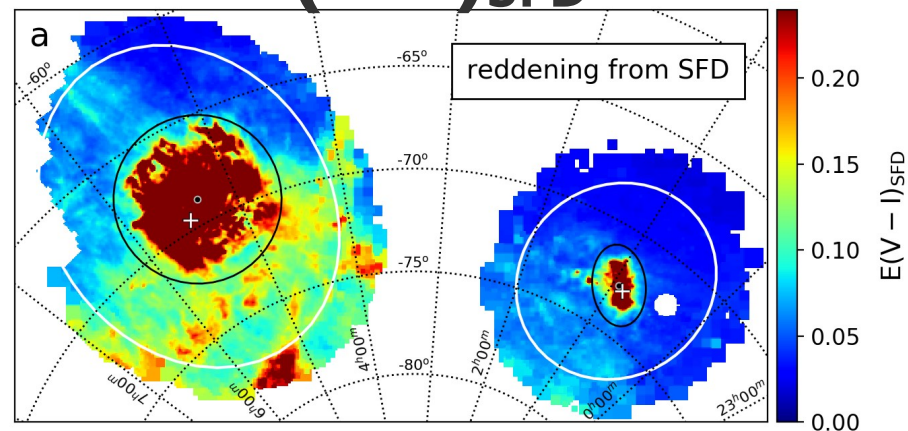


Intrinsic Red-Clump color $(V-I)_0$

$(V-I)$

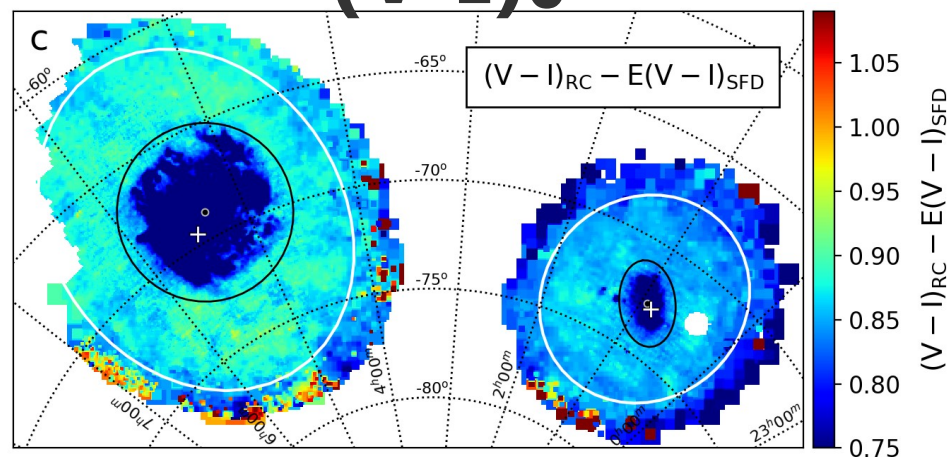


$E(V-I)_{SFD}$

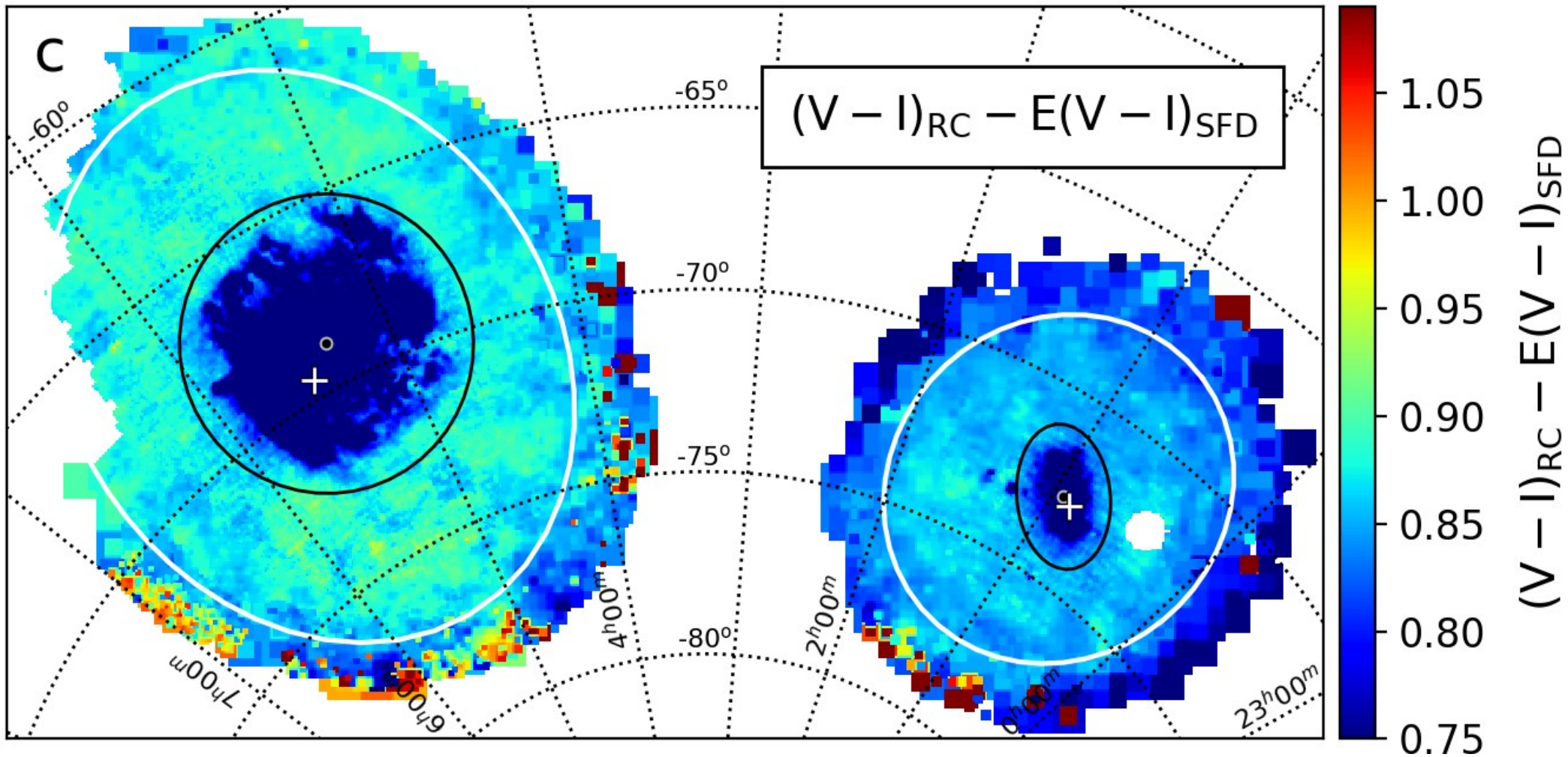


$(V-I)_0$

=

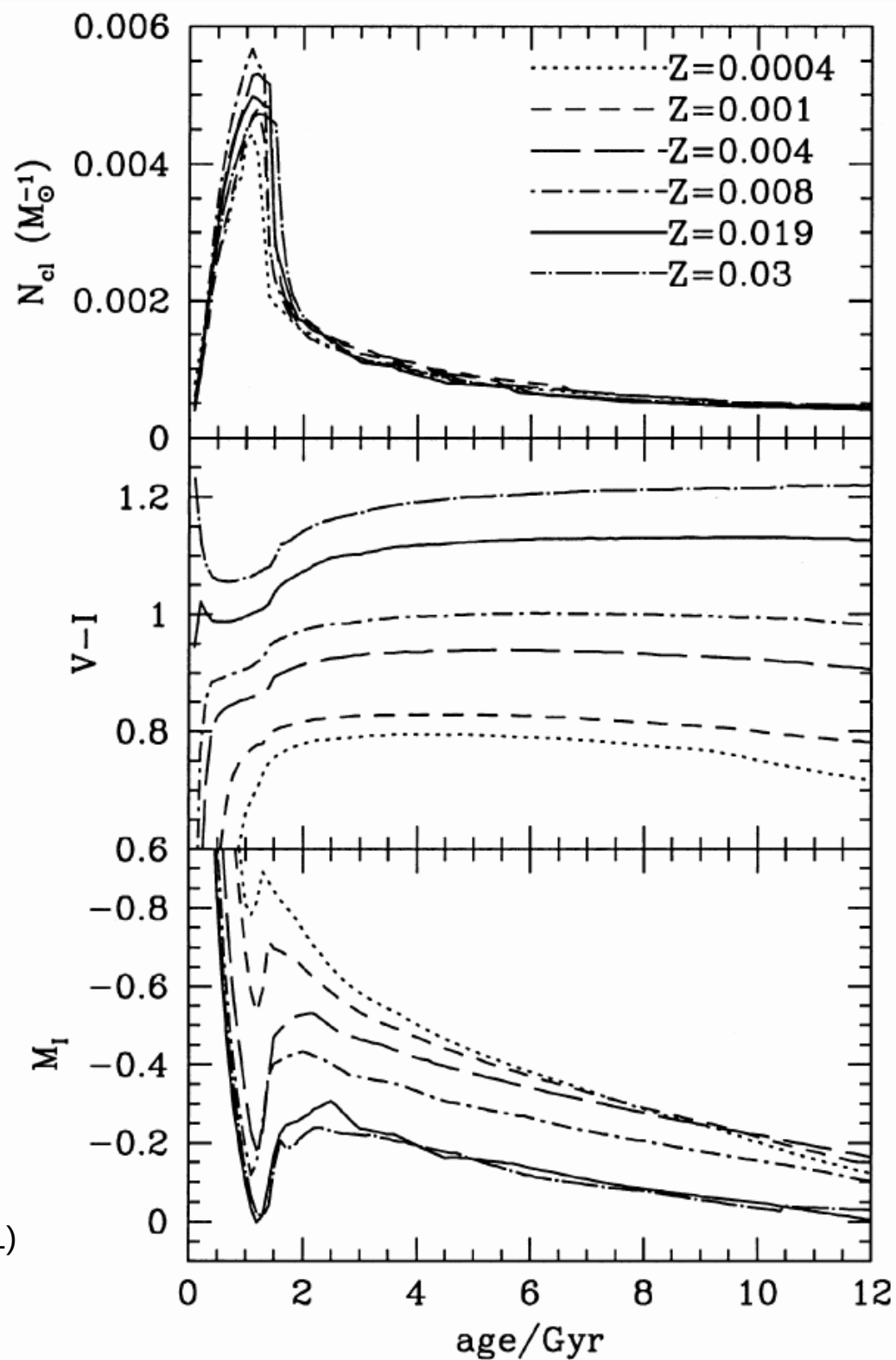


Intrinsic Red-Clump color $(V-I)_0$



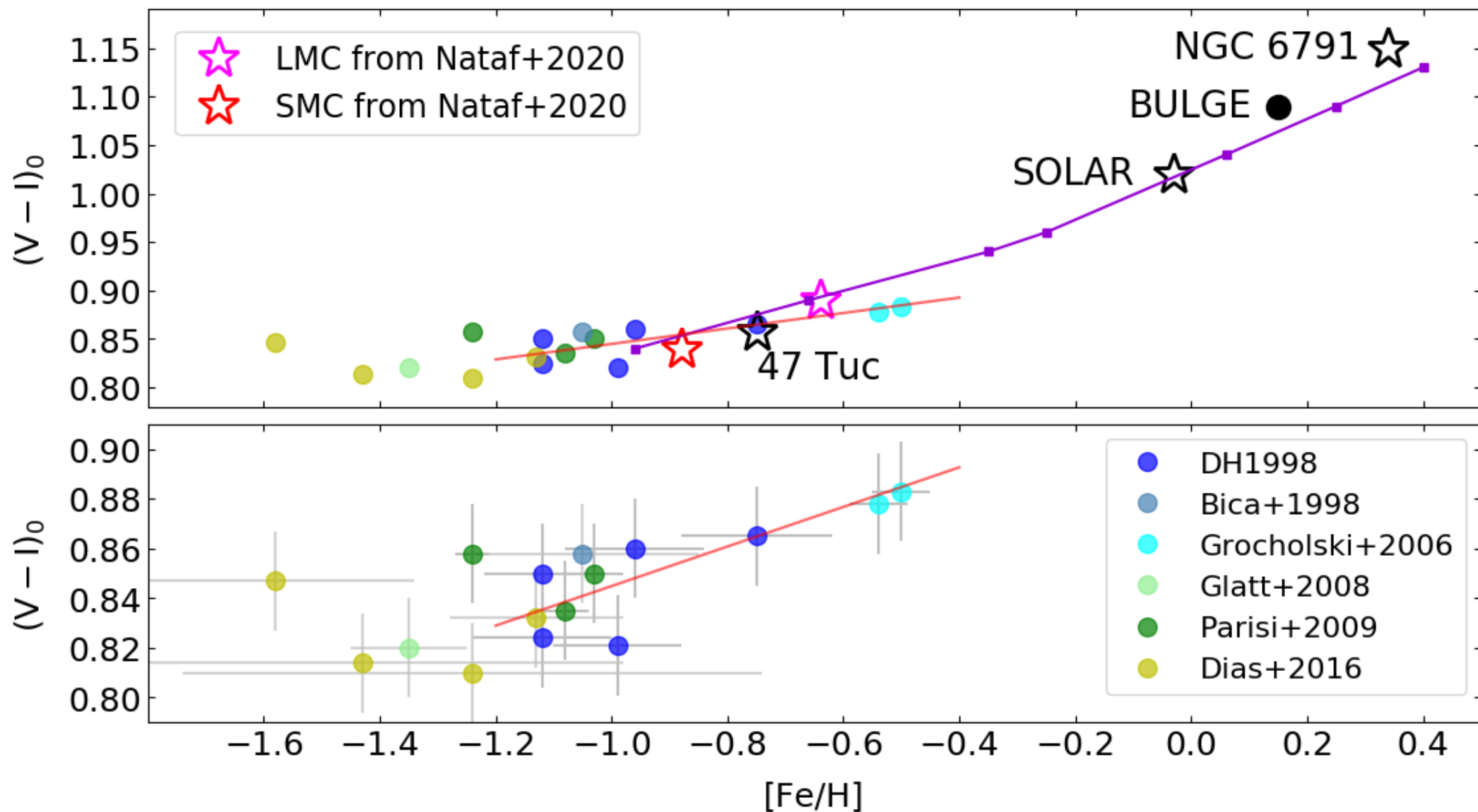
Intrinsic Red-Clump

- Depends on **age** and **metallicity**

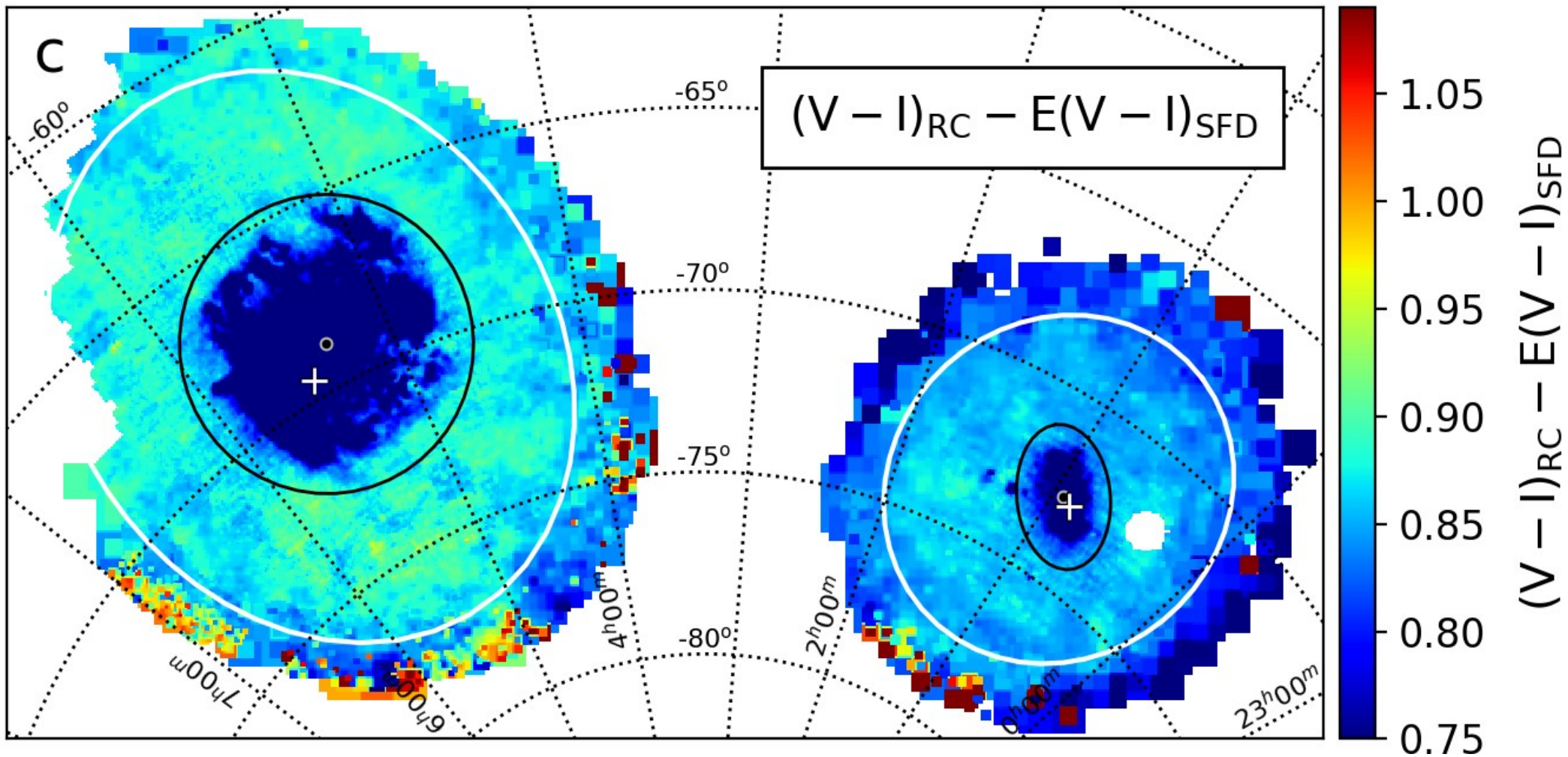


Girardi & Salaris (2001)

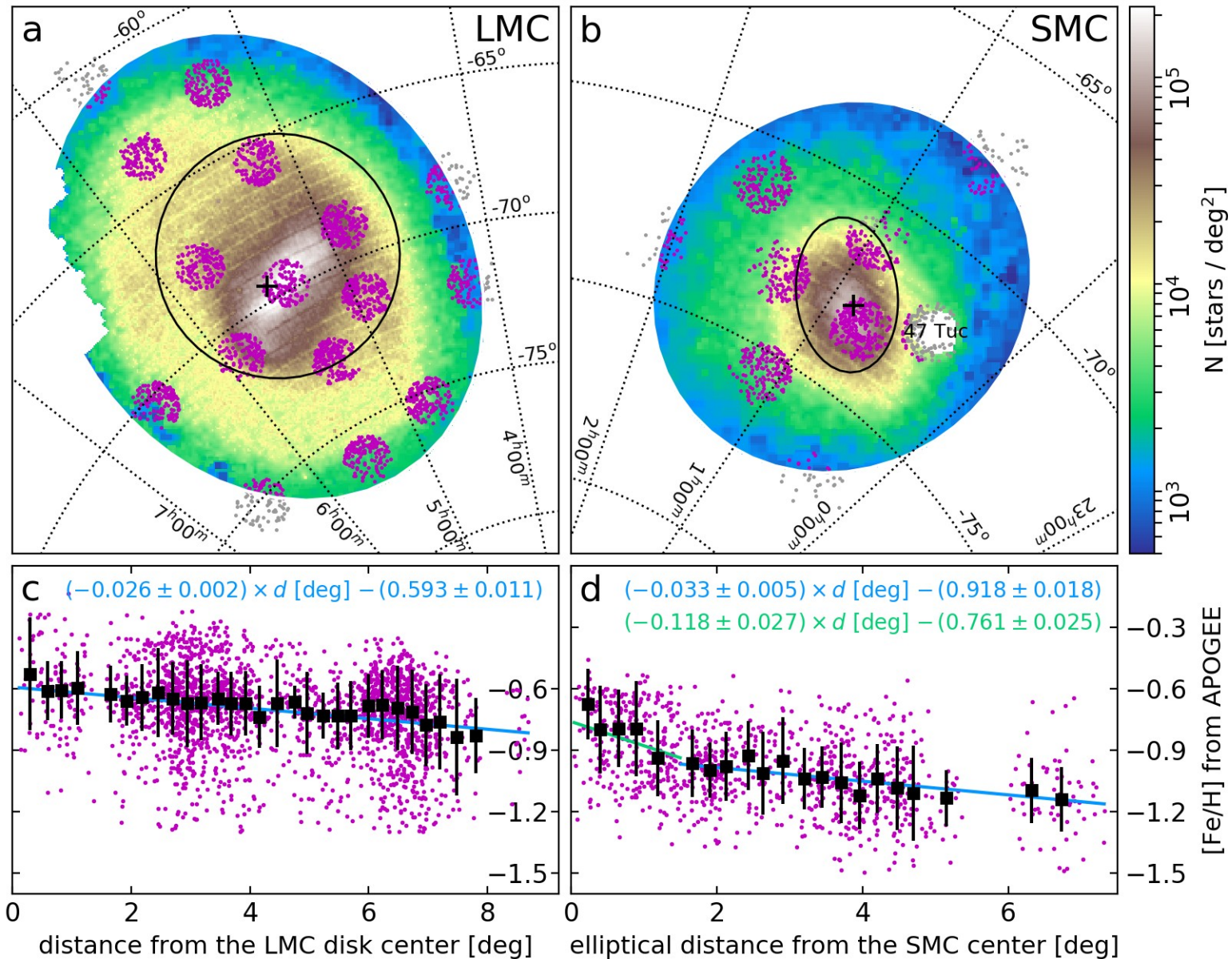
$(V-I)_0$ gradient may be due to metallicity



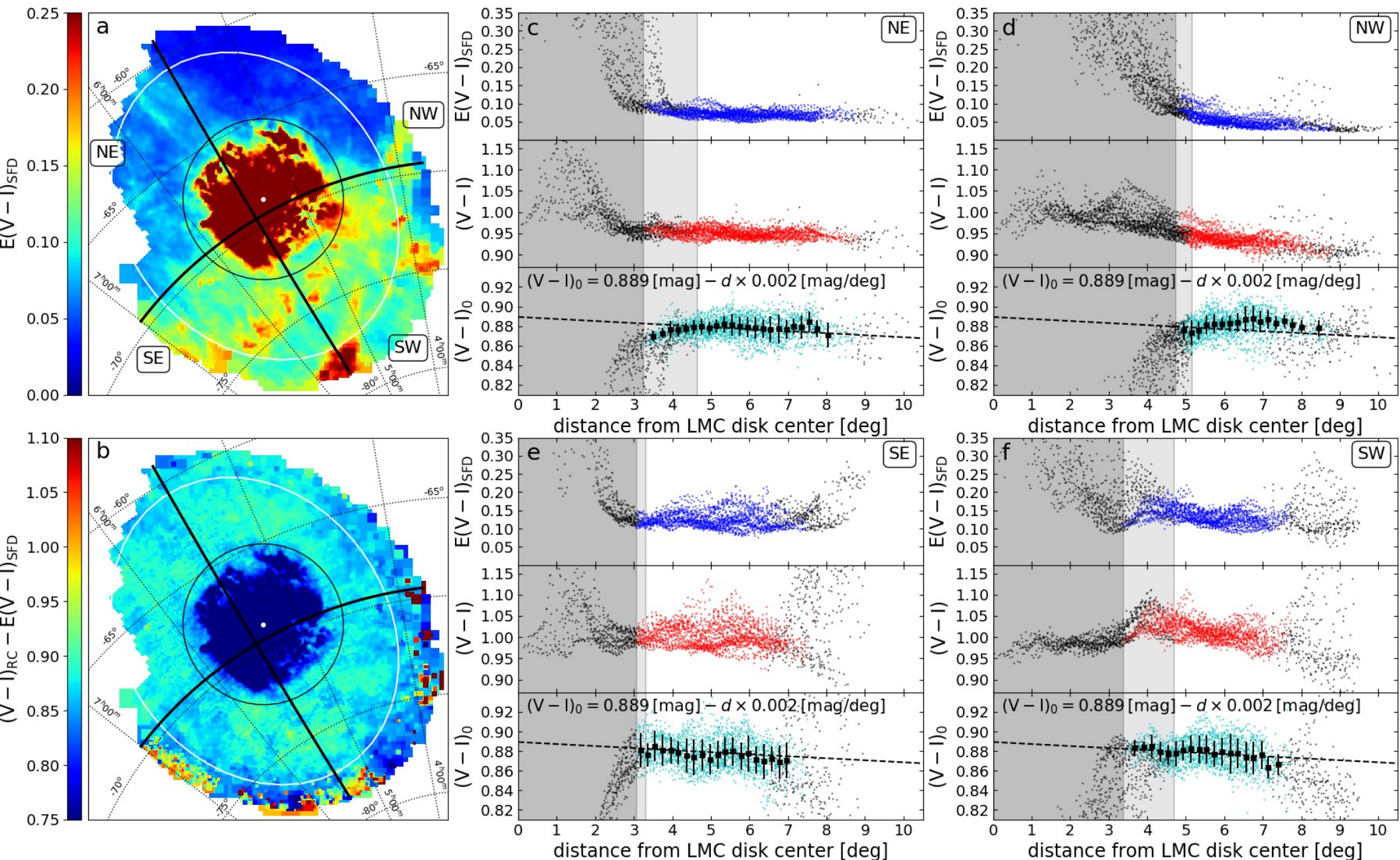
Intrinsic Red-Clump color $(V-I)_0$



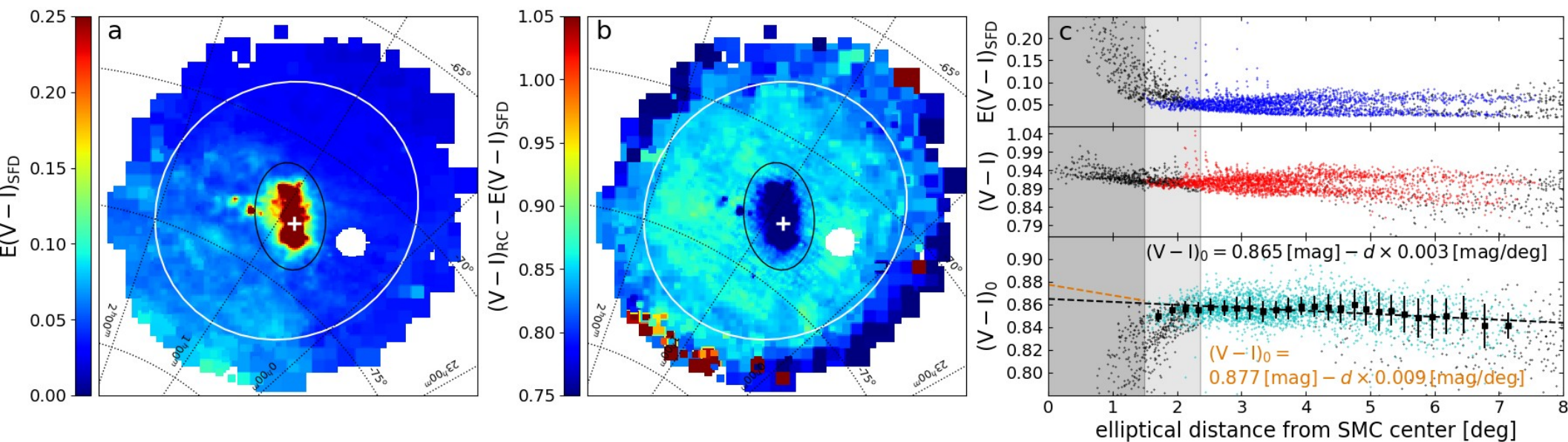
Red giant metallicity from APOGEE



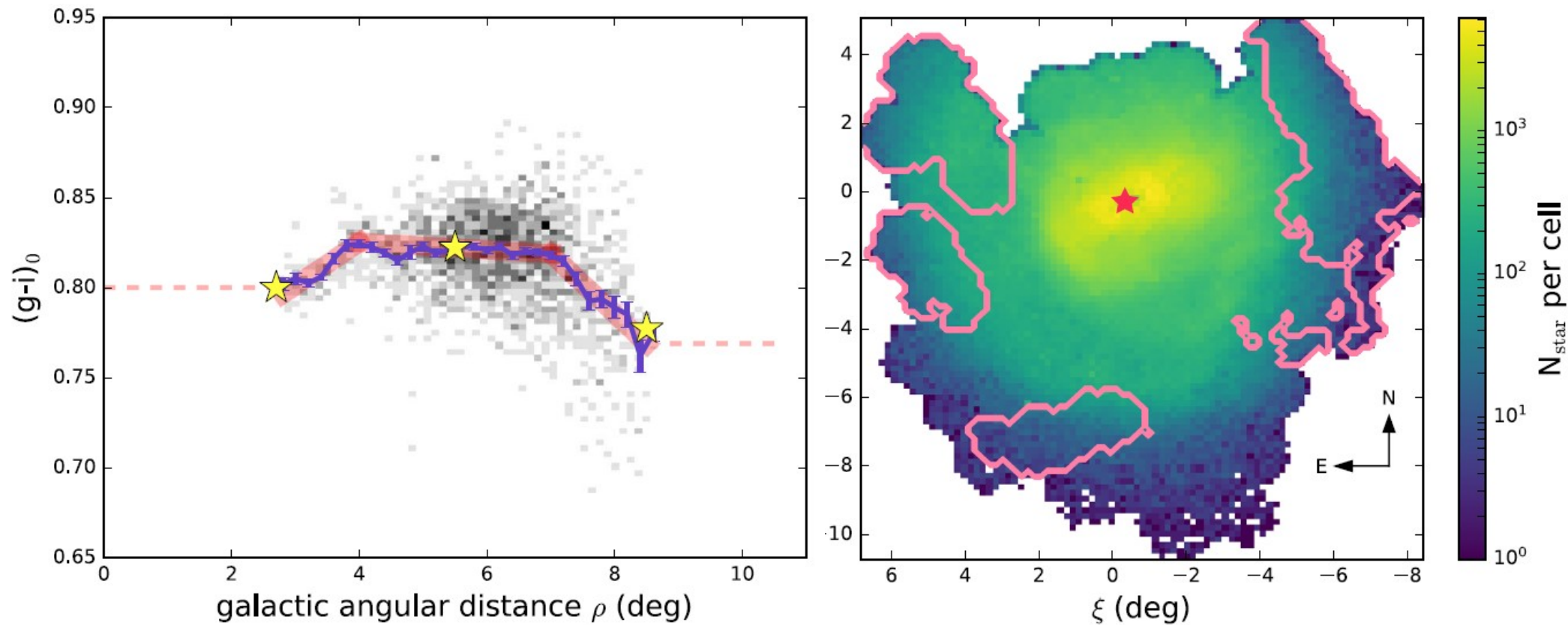
Intrinsic Red-Clump color $(V-I)_0$ in the LMC



Intrinsic Red-Clump color $(V-I)_0$ in the SMC



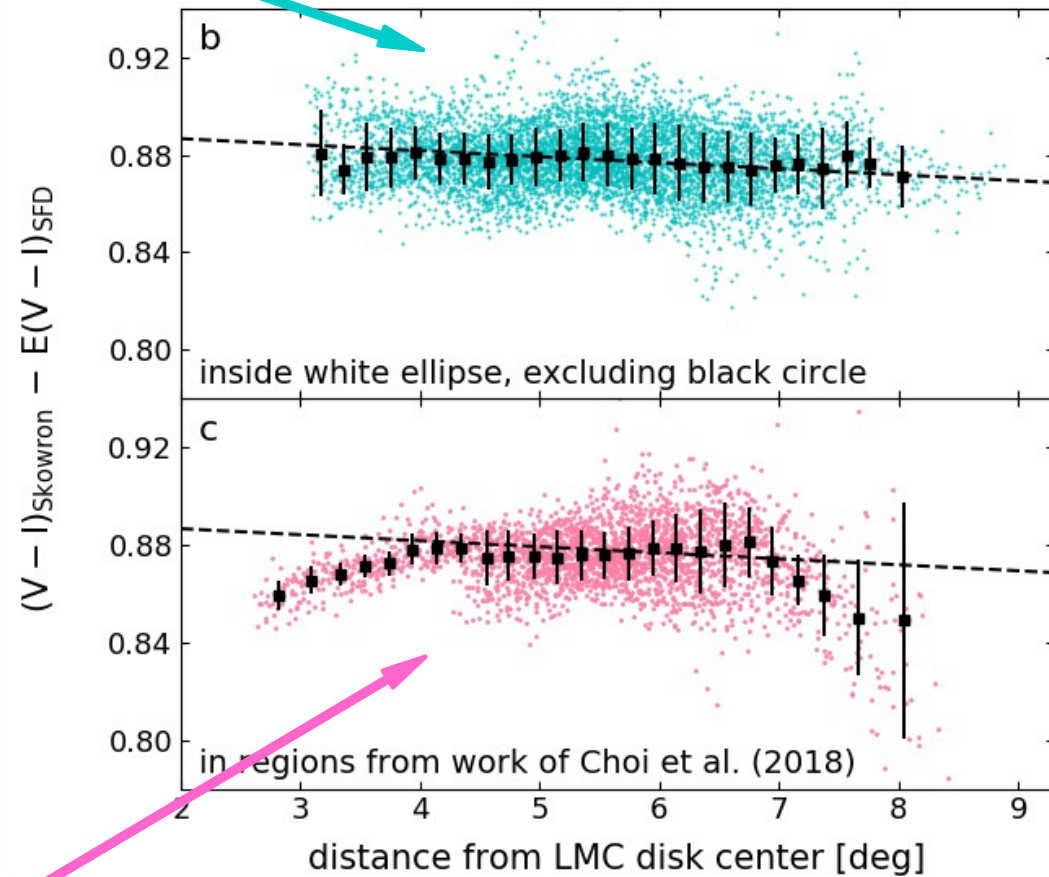
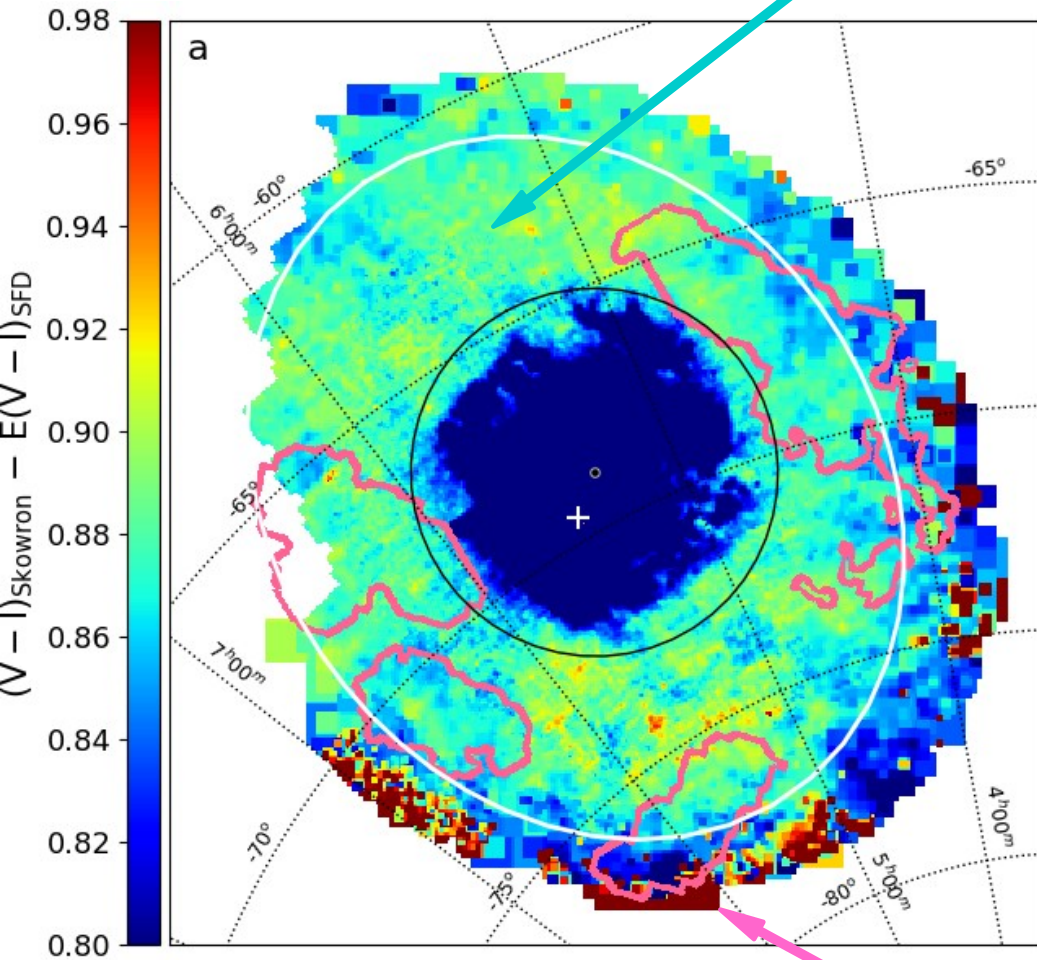
Varying $(V-I)_0$ of the Red Clump in the LMC?



Choi et al. (2019)

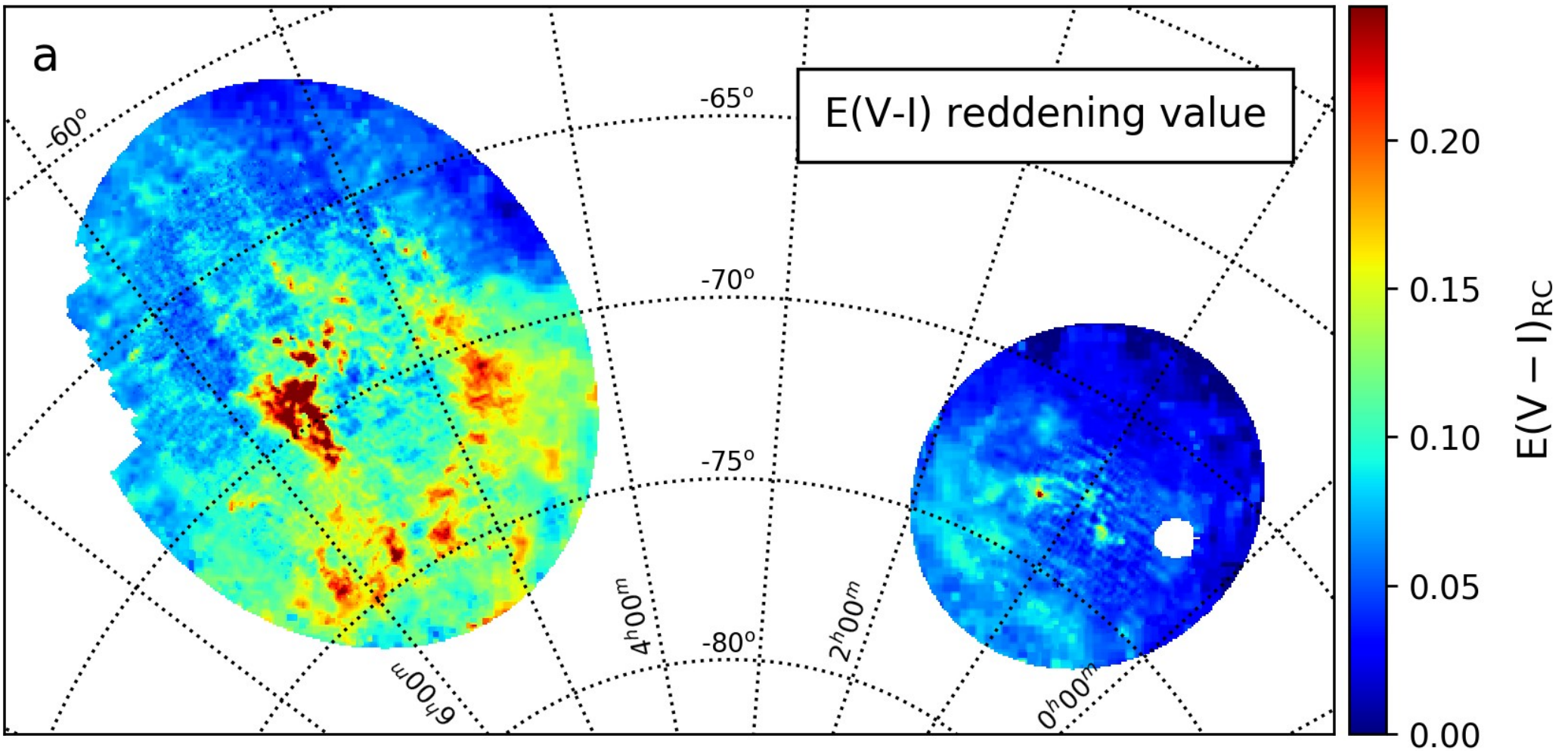
Varying $(V-I)_0$ of the Red Clump in the LMC?

Our regions for determining intrinsic color (all inside ellipses)

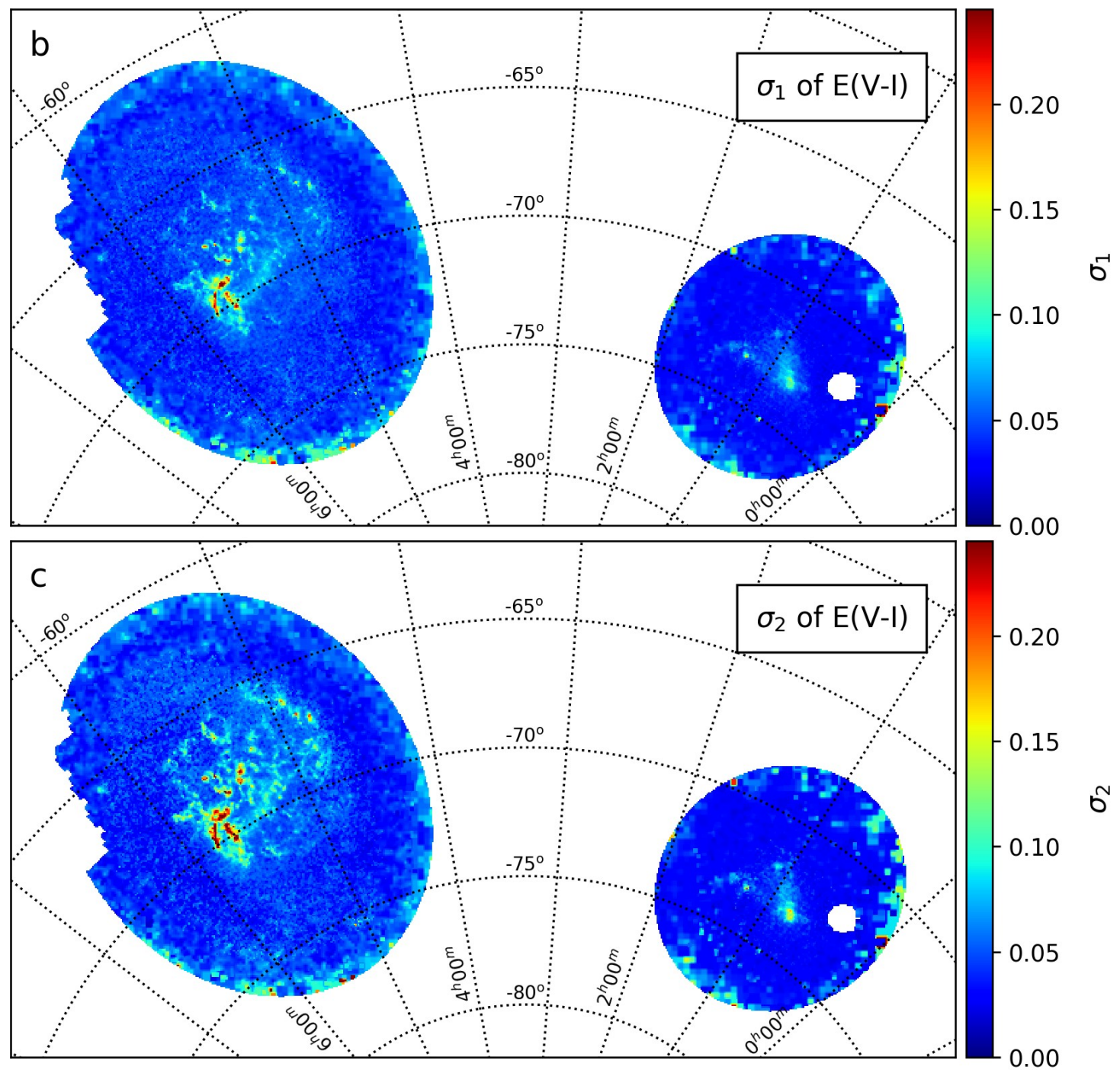


Choi et al. regions for determining intrinsic color (inside pink contours)

Final E(V-I) reddening map



Differential reddening



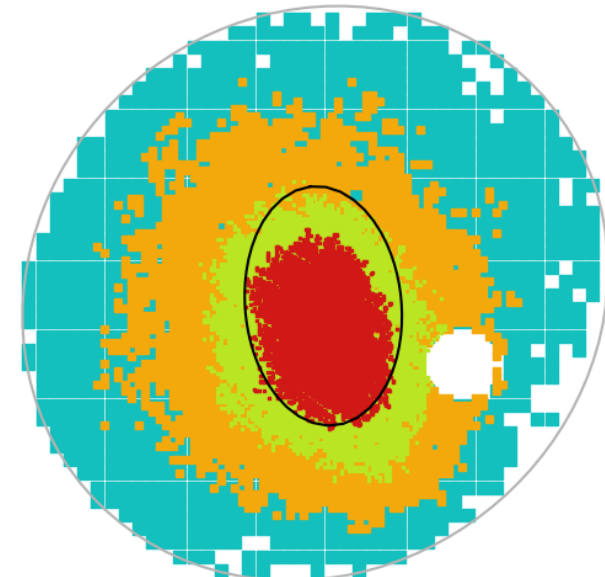
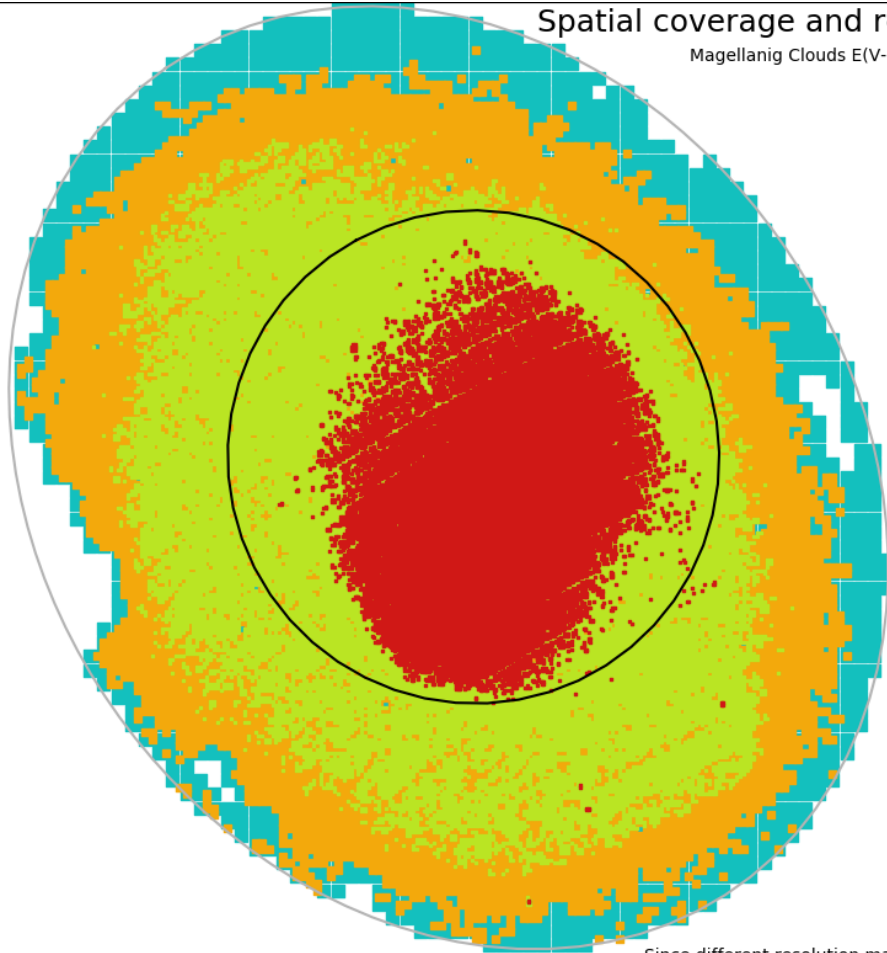
Resolution of the reddening map

Spatial coverage and resolution of the ASCII .txt tables

Magellanic Clouds E(V-I) reddening maps - Skowron et al. 2020

- 27.5 arcmin box, point every 13.8 arcmin
- 13.8 arcmin box, point every 6.9 arcmin
- 6.9 arcmin box, point every 3.4 arcmin

- 27.5 arcmin box, point every 13.8 arcmin
- 13.8 arcmin box, point every 6.9 arcmin
- 6.9 arcmin box, point every 3.4 arcmin
- 3.4 arcmin box, point every 1.7 arcmin



Since different resolution maps are overlapping, it is usually easier to use provided FITS file, where all maps have been joined together onto a single plane.

Website (an interactive interface)

- http://ogle.astrouw.edu.pl/cgi-ogle/get_ms_ext.py

OGLE Homepage

E(V-I) Reddening Map in the Magellanic System from OGLE-IV Red Clump stars

Skowron et al. 2020, arXiv:2006.02448 ([abstract](#))

Compute reddening value at RA/Dec: hrs deg

Coordinates may be entered in decimal (H.MMMMM, D.DDDDD), sexagesimal (HH:MM:SS.SS, HH MM SS.SS) format or any of [the following](#) ?.

Or upload coordinates file: No file selected. to or results.

The uploaded file should have coordinates in columns 1 and 2. Use drop-down menu above to choose RA/Dec in (hrs, deg) or (deg, deg), or galactic coordinates.

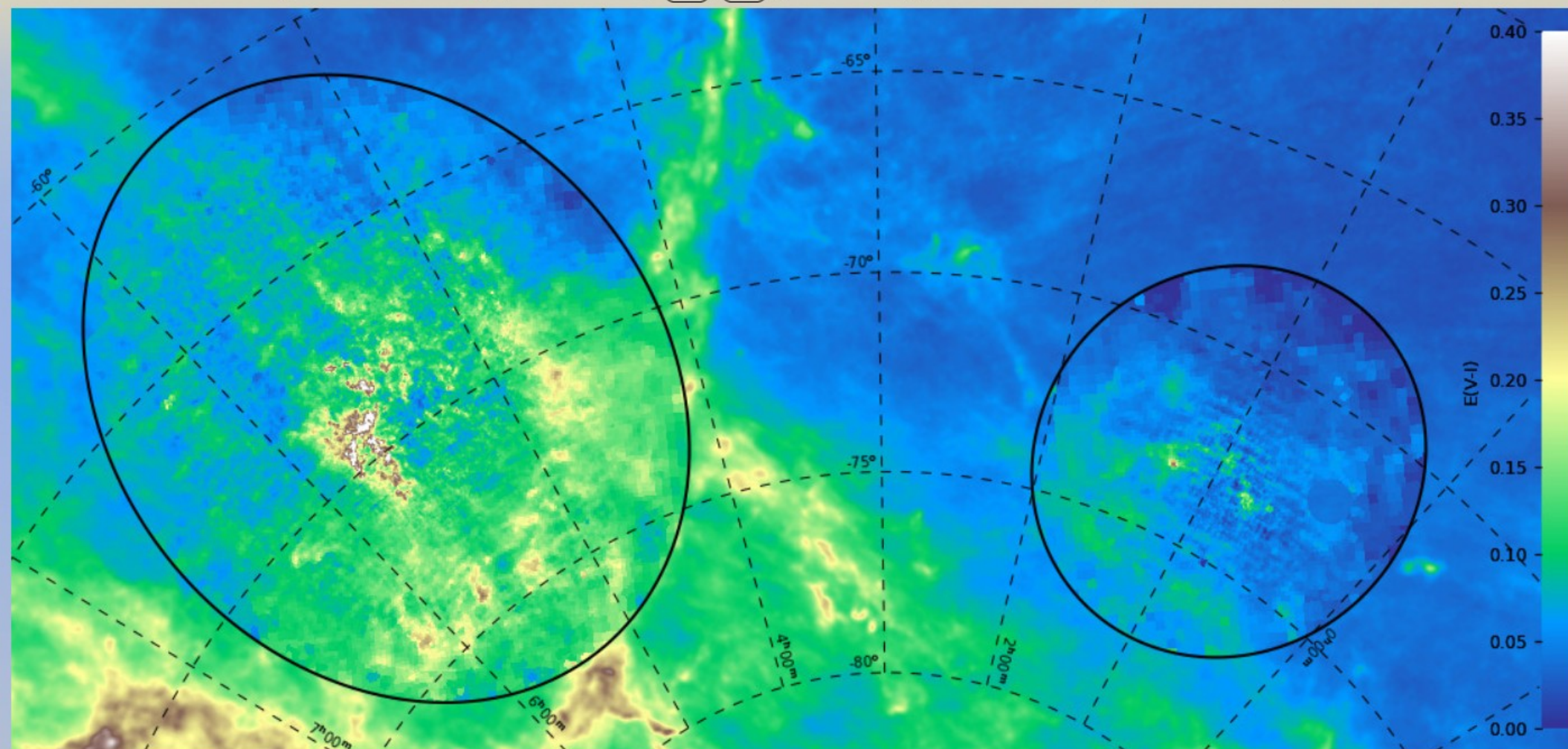
You can also **click** on the map below. More **download** options are provided at the bottom of the page.

Result:

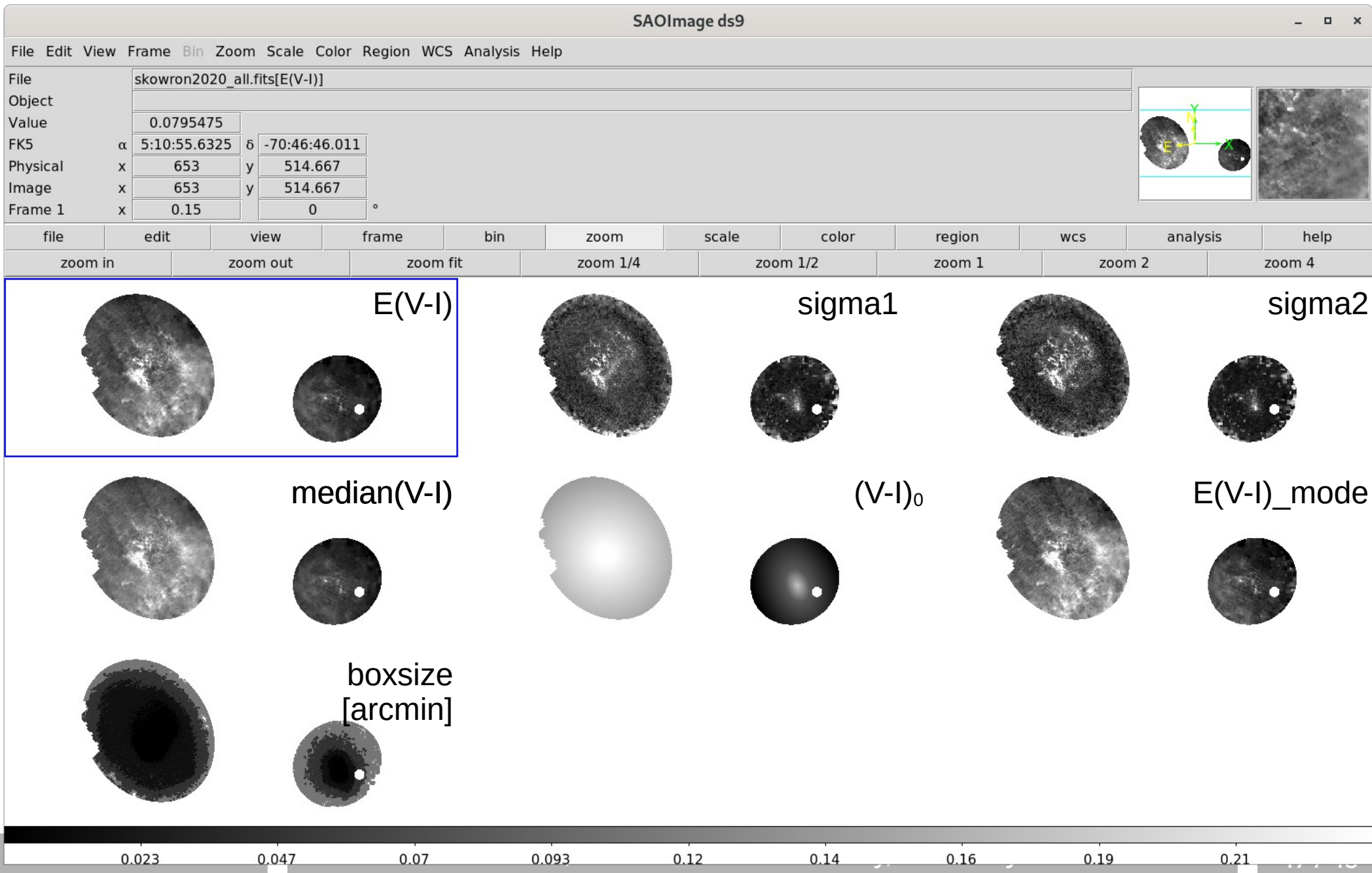
RA	Dec	RA	Dec	----- OGLE Red Clump stars -----								
[hr]	[deg]	[hr]	[deg]	E(V-I)	-sigma1	+sigma2	(V-I)_RC	(V-I)_0	E(V-I)peak	E(V-I)sfd	box	sep
				median	[-34%]	[+34%]	median	[mag]	mode	from SFD	arcmin	arcmin

Website (an interactive interface)

reddening map OGLE only σ_1 σ_2 SFD only IRAS infrared DSS2 photo

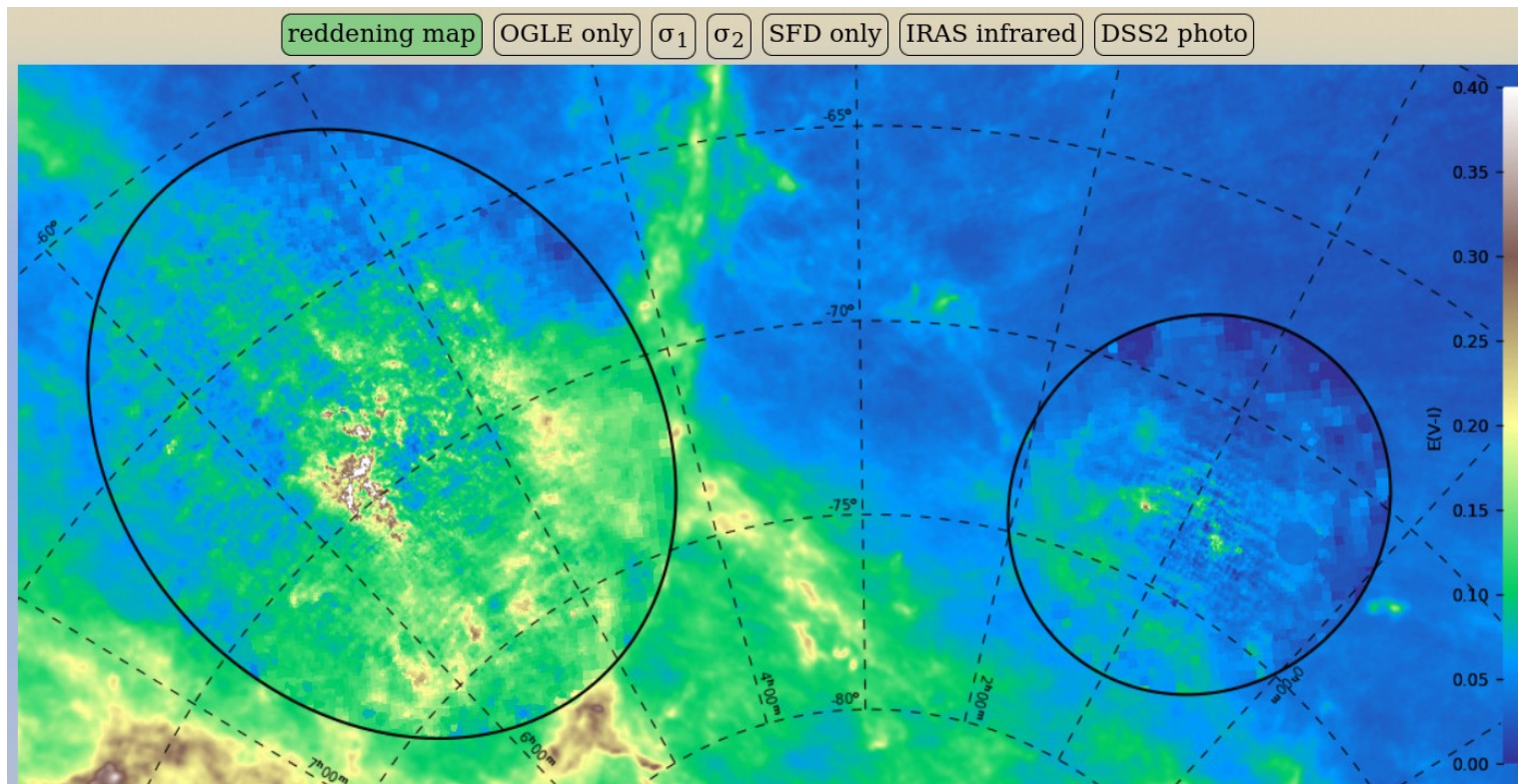


Data in FITS format



Reddening Maps of the Magellanic Clouds from OGLE-IV Red Clump Stars

- http://ogle.astrouw.edu.pl/cgi-ogle/get_ms_ext.py



Skowron et al. 2021, ApJS, 252, 23