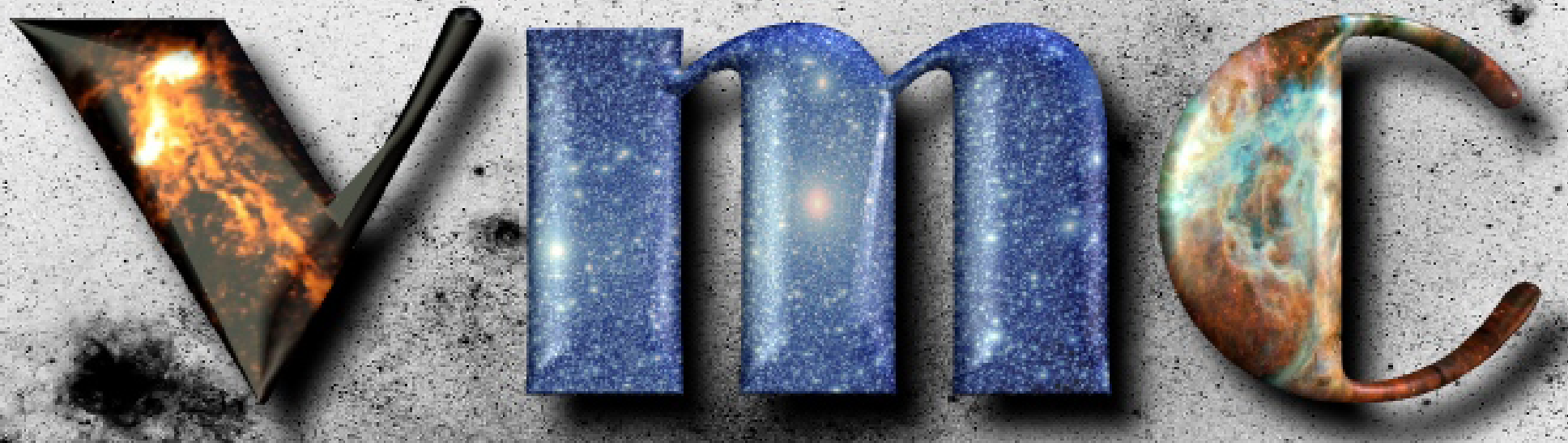
The Star Formation History of the Magellanic Clouds from VMC data



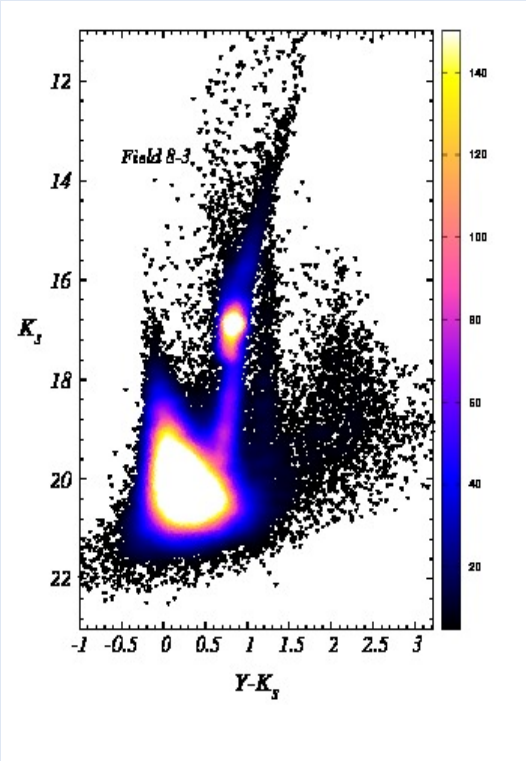
Léo Girardi – OAPadova

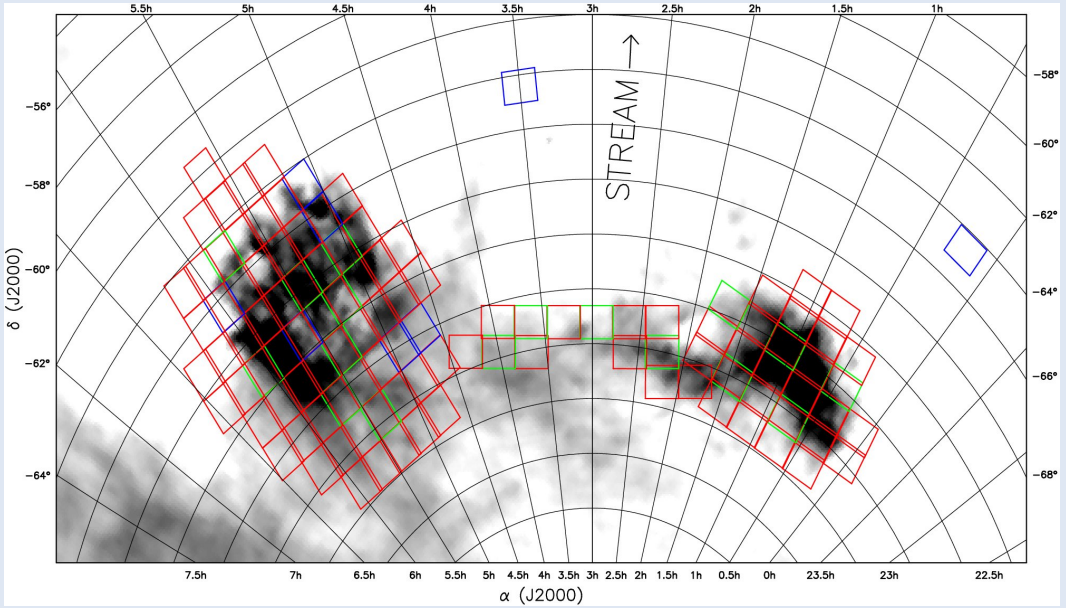
for the VMC Team and its SFH task group, especially Stefano Rubele and Leandro Kerber

The VMC Survey

ESO Public Survey using VISTA 4m telescope at Paranal

- Area: 180 sqrdeg over LMC + SMC + Bridge and Stream
- Depth: 21.9 in *Y*, 21.4 in *J*, 20.3 in K_s (S/N =10)
  ~5 mags deeper than 2MASS!
- Designed to reach oldest main sequence turnoff even in LMC bar





Why is the space-resolved SFH important?

1) **Basic history of Local Group and factors driving star formation** (*near-field cosmology*):

• Are the MCs in their first passage around MW? (Kalivayalil, Besla et al.), or were they accreted ~3 Gyr ago? Do peaks in SFR reveal close galaxy-galaxy encounters (van den Bergh, Harris & Zaritsky, Bekki et al.)?

• Why so many massive star clusters at ages ~0.1 and 1.5-3 Gyr? Why many have multiple populations?

• Are there extended MC halos (Saha et al. 2012)? Origin of LMC bar and SMC stars accreted on LMC (Olsen et al. 2011)?

2) LMC+SMC contain hundreds to thousands of fundamental ”stellar tools” like RR Lyrae, Cepheis, PNe, Miras + LPVs of all kinds, RSGs, C and S stars, Li-rich giants, extreme-AGBs, SNRs, X-ray sources

All mixed in field in proportions determined by the local SFH

• **Knowing the SFH(r) is essential to constrain their formation mechanisms and intrinsic properties – lifetimes, masses, etc.**

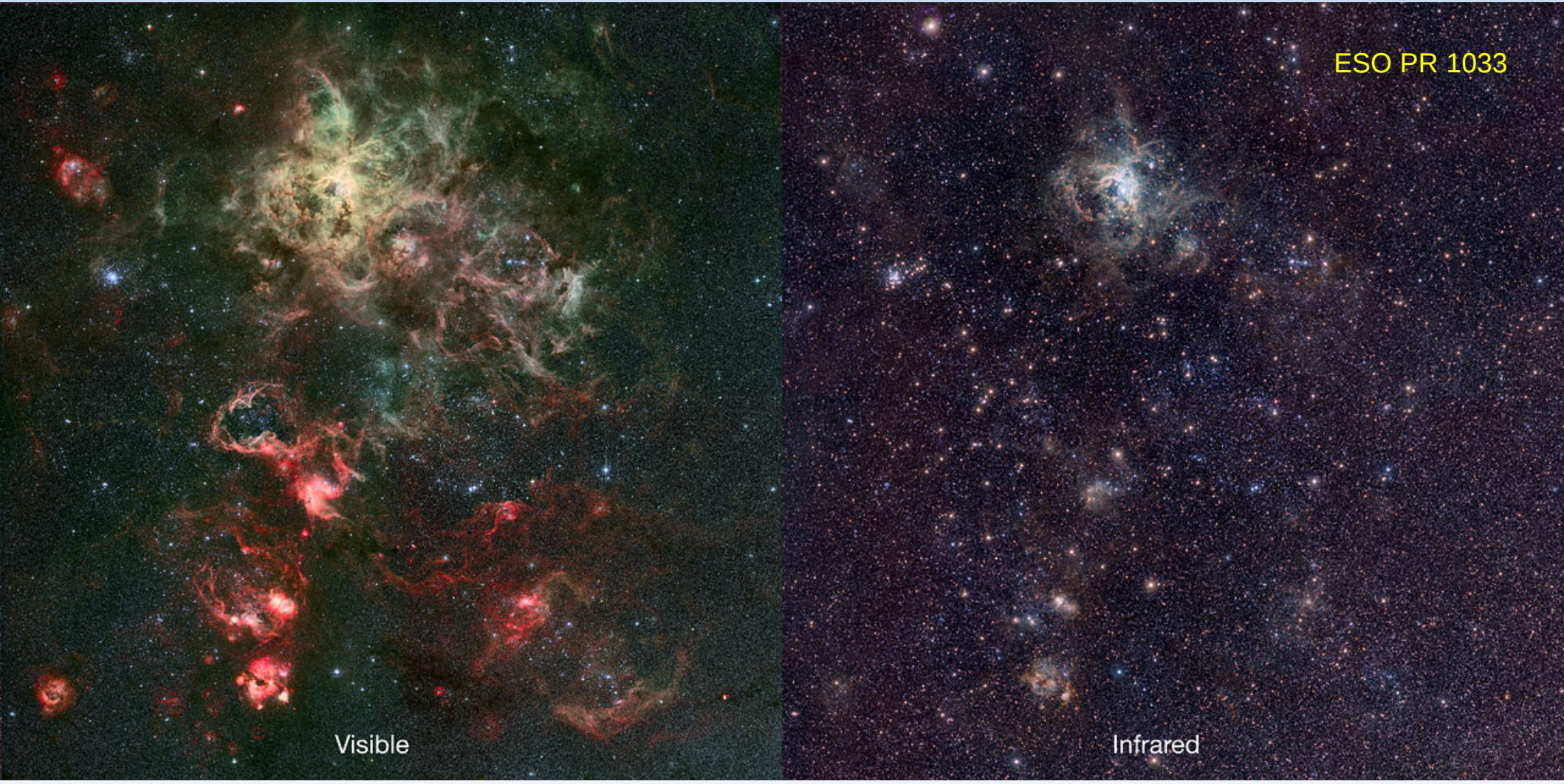
Previous SFH maps (Harris & Zaritsky 2001-2010) severely affected by reddening and crowding, and HST-based for >3-Gyr

What do we gain in the NIR?

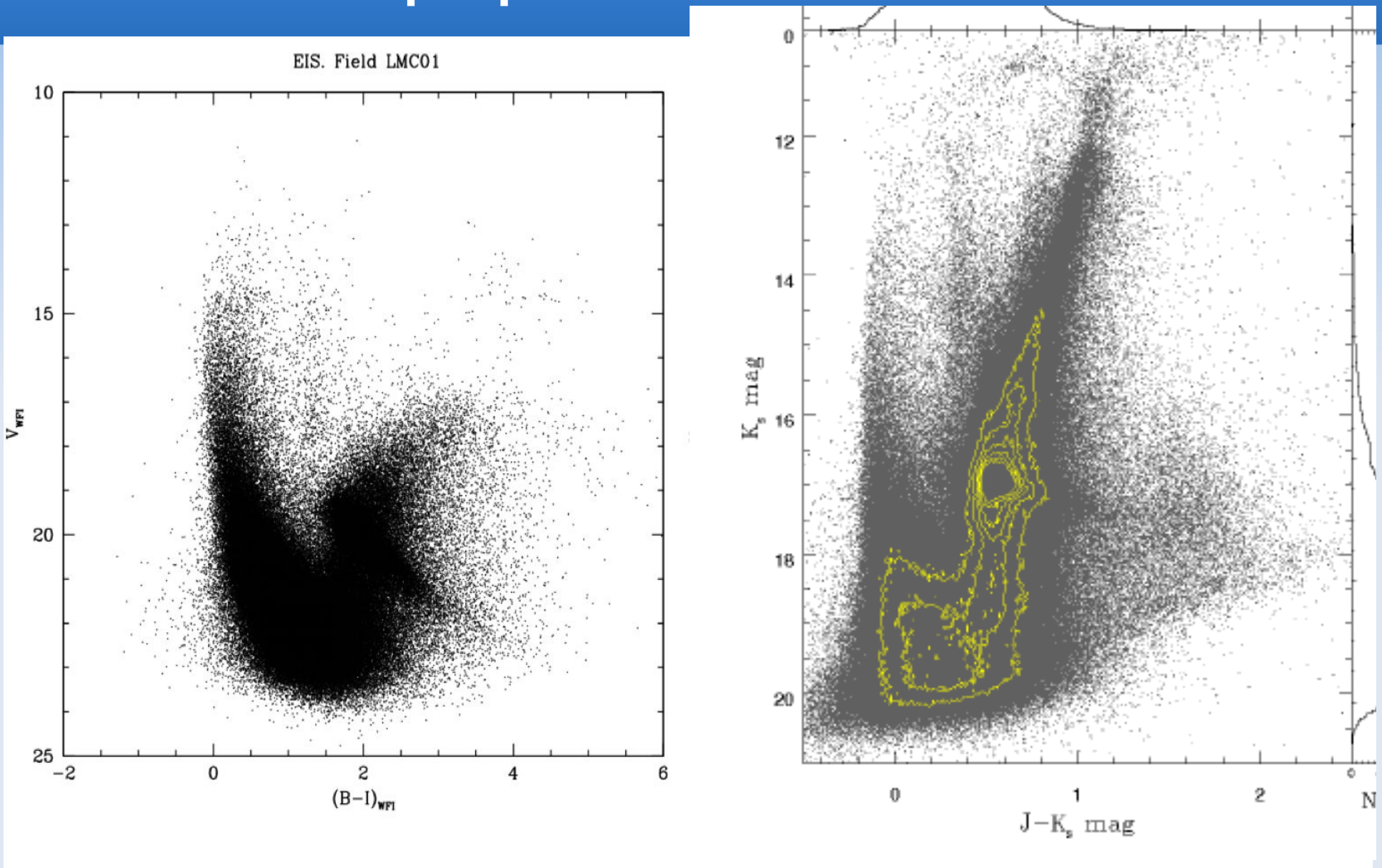
- Largely reduced extinction:

  $A_H = 0.18\ A_V$ → in A_v=5 regions, 1/100 of *V* flux, ½ of *H* flux

- Seing $\alpha\ \lambda^{-0.2}$ → up to 40 % reduction in seeing

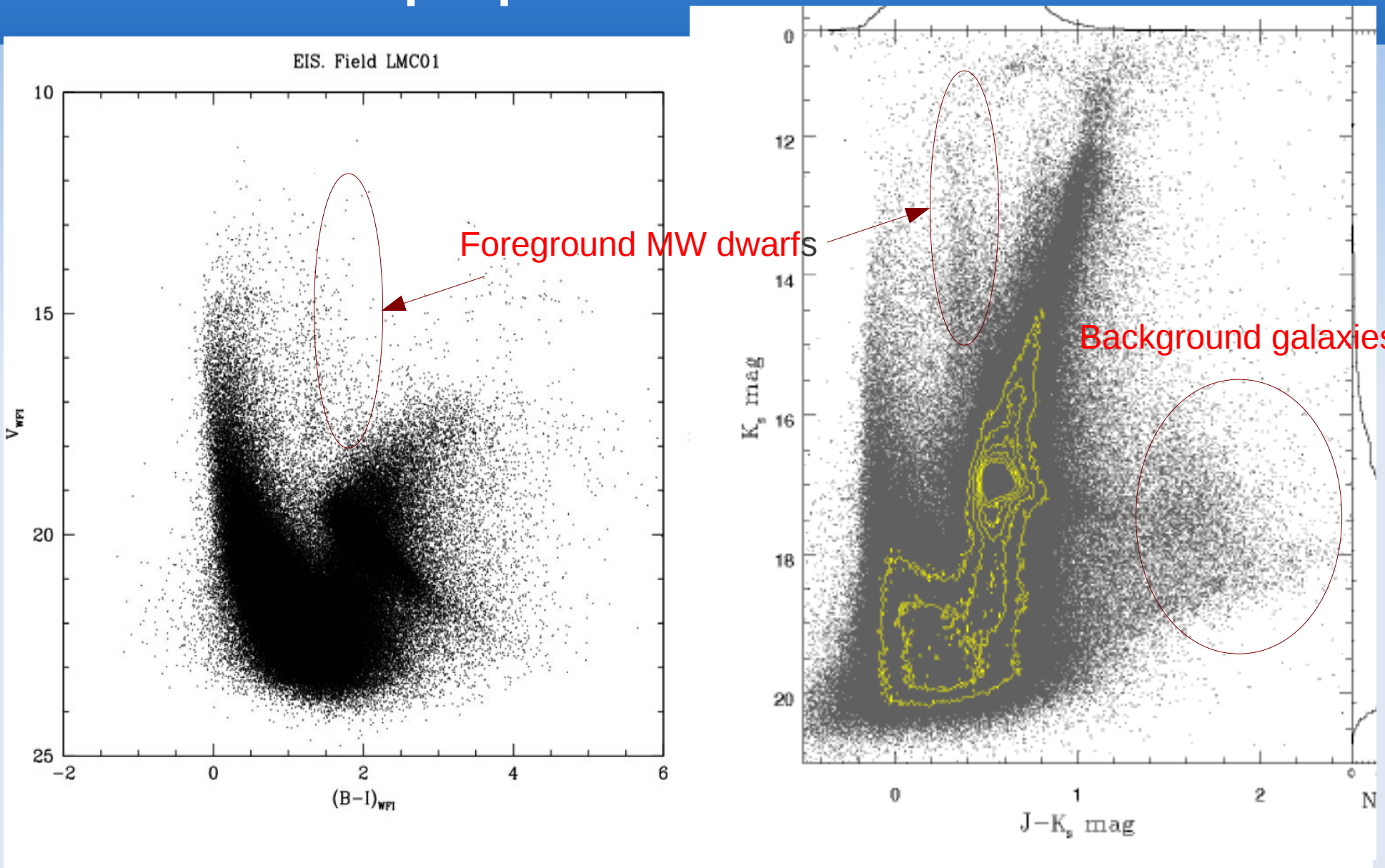


Stellar populations in the NIR



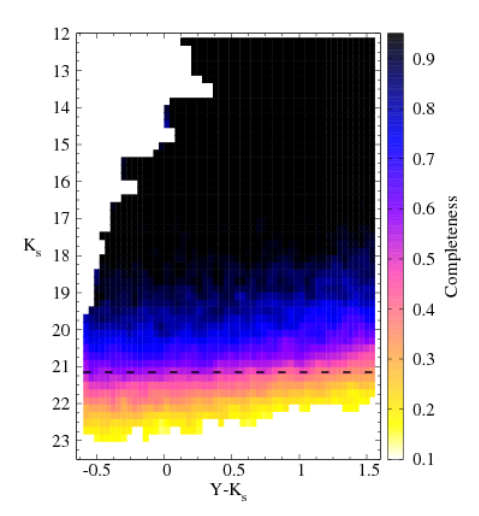
30 Dor in the LMC, optical X NIR (Zaggia et al., Tatton et al. 2012)

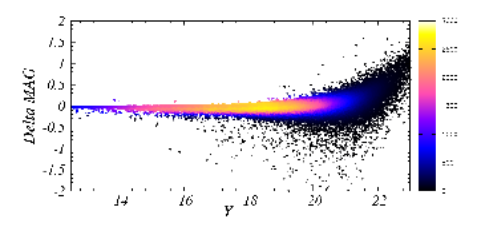
Stellar populations in the NIR

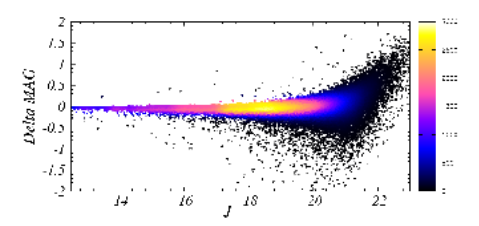


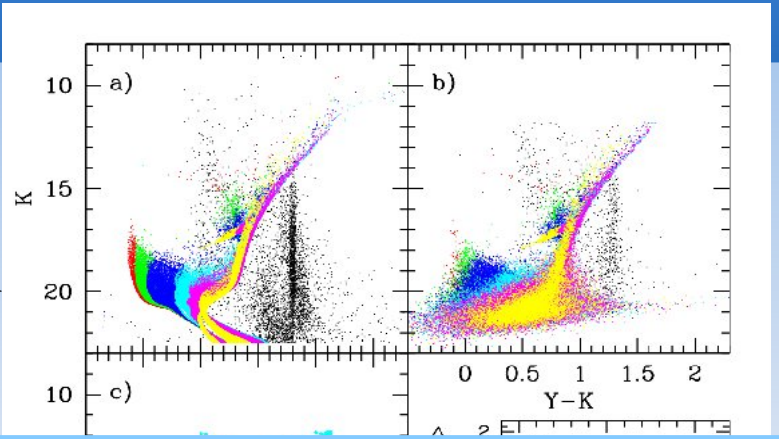
30 Dor in the LMC, optical X NIR (Zaggia et al., Tatton et al. 2012)

How SFH-recovery works





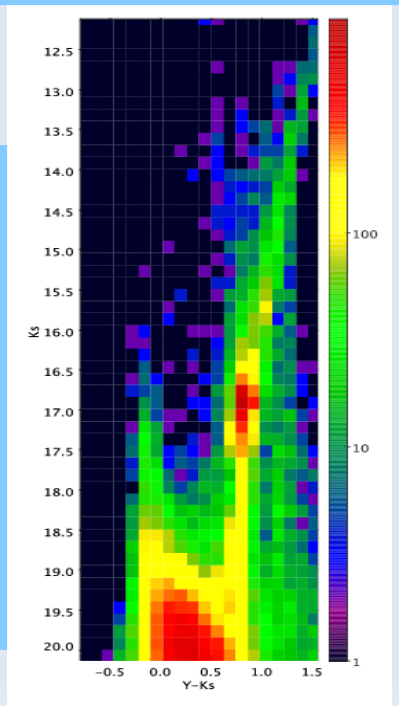




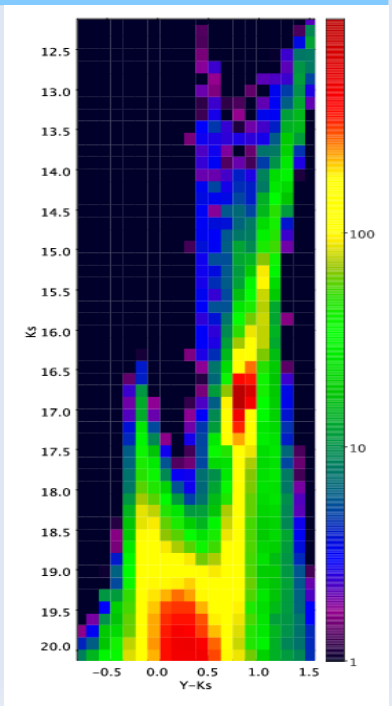
>10^6 artificial stars → Completeness + error maps

Models of ”single-burst populations” of all possible ages and metallicities, degraded to observational conditions

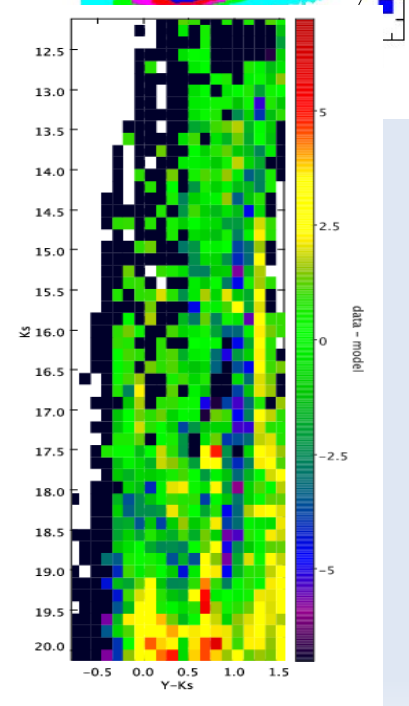
Run StarFISH (Harris & Zaritsky 2001) to find linear combination that minimizes a χ^2-like statistics: that's the SFH



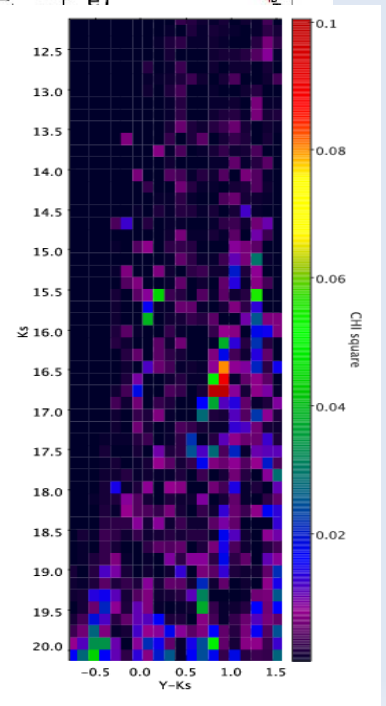
data



model



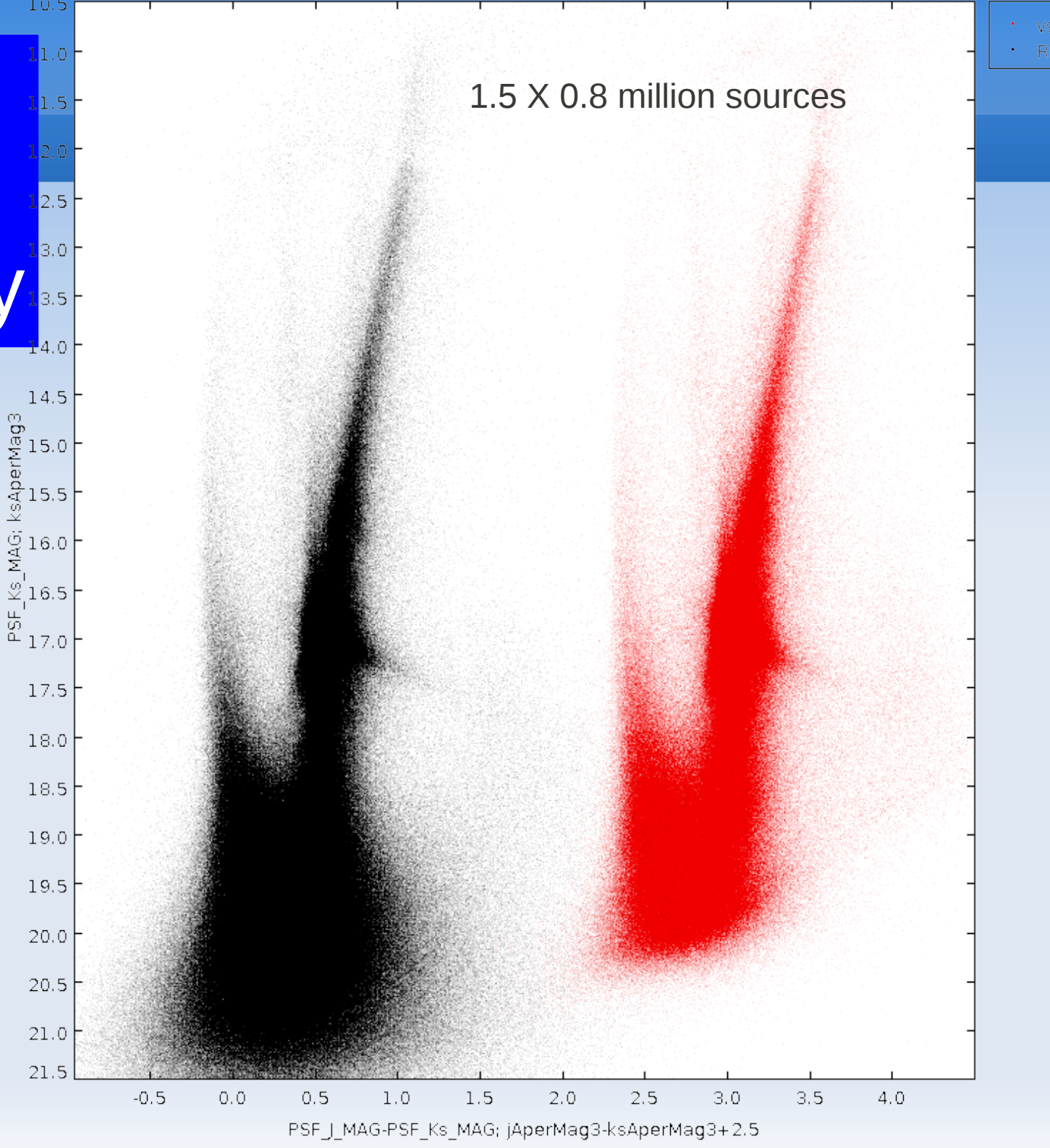
difference



χ^2 map

PSF vs. VSA photometry

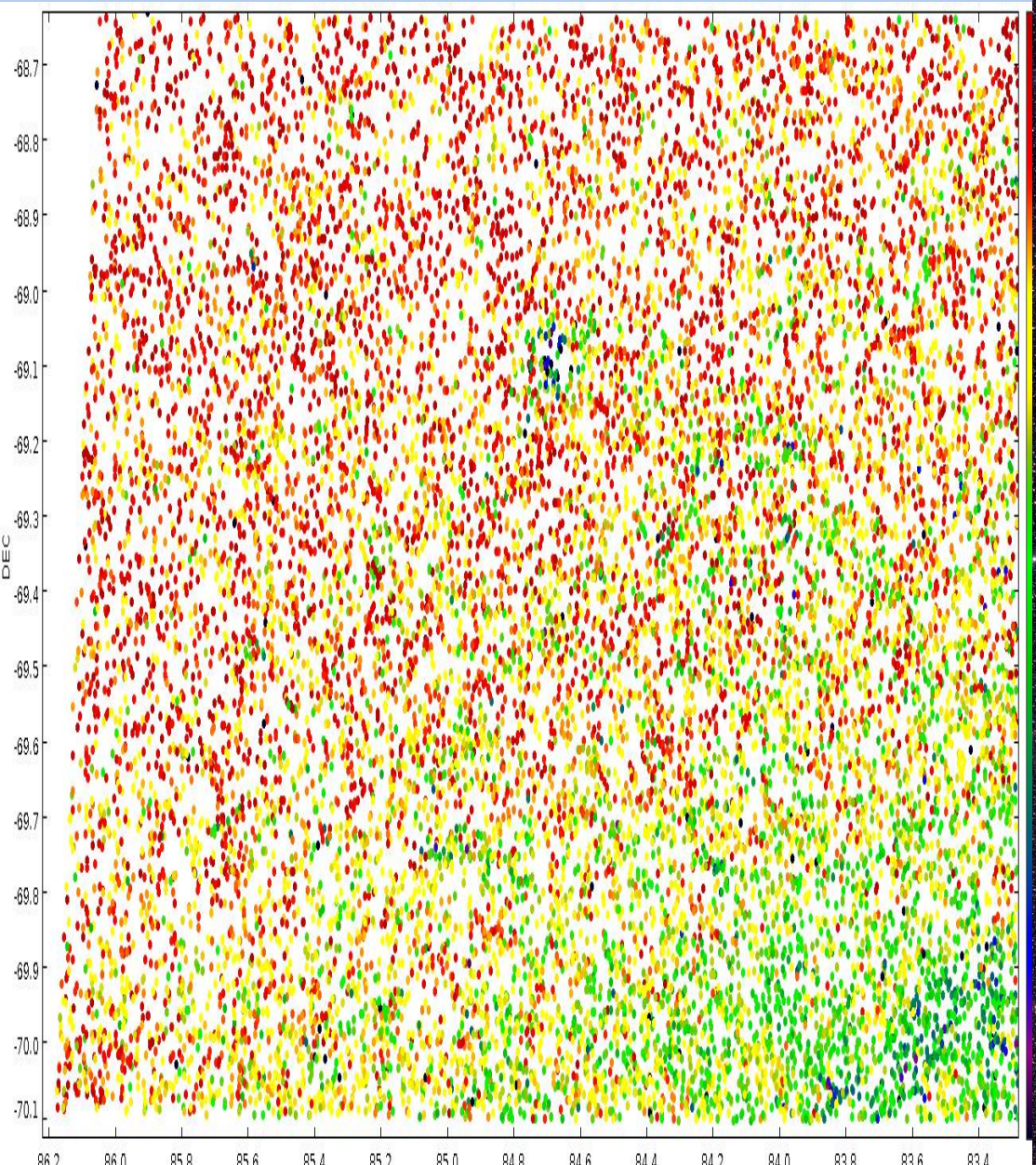
- PSF photometry being redone, Stefano Rubele's pipeline
- Catalogues being released through ESO archive

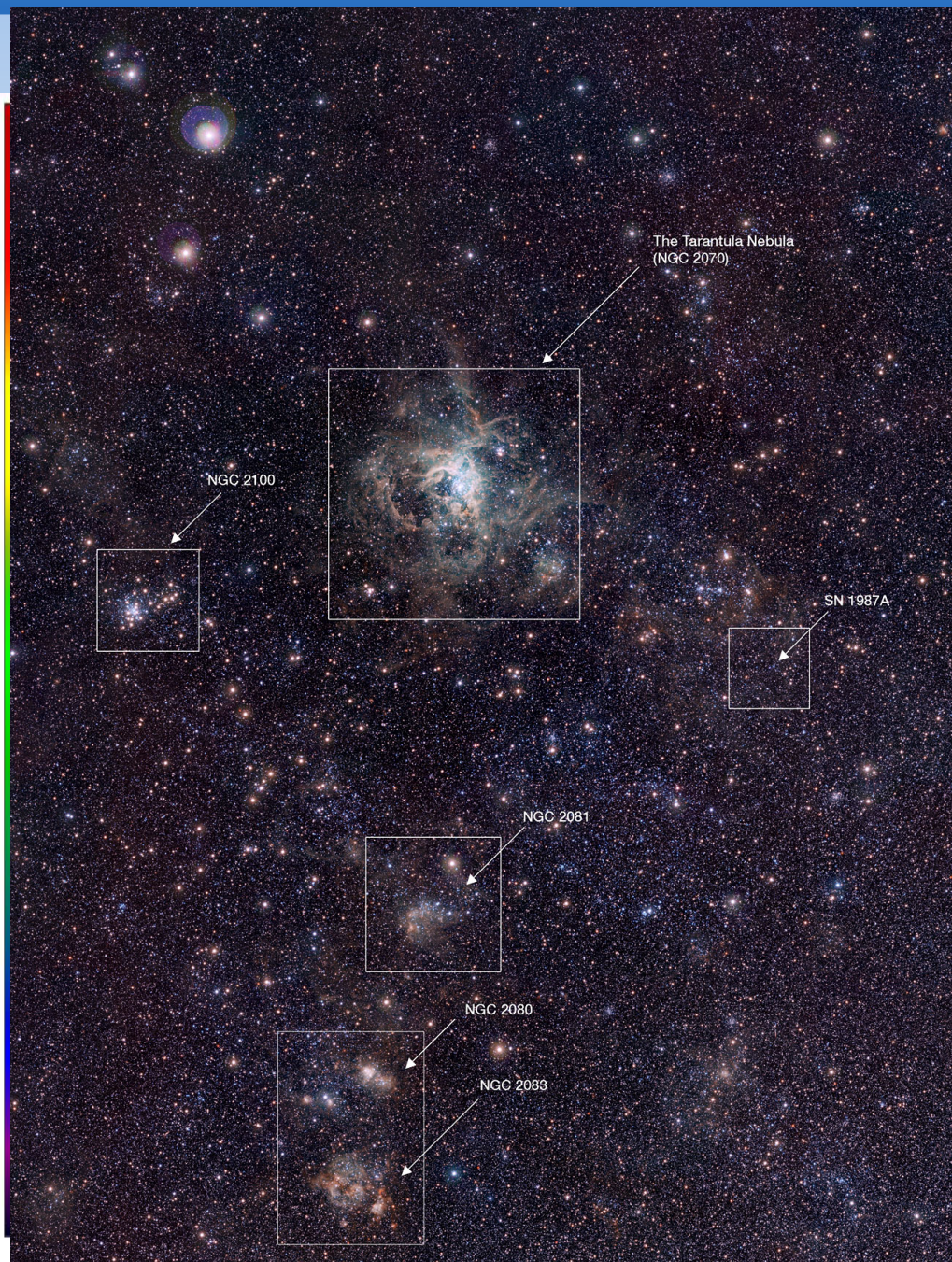


”Star-by-star” completeness

- ESO PR 1033

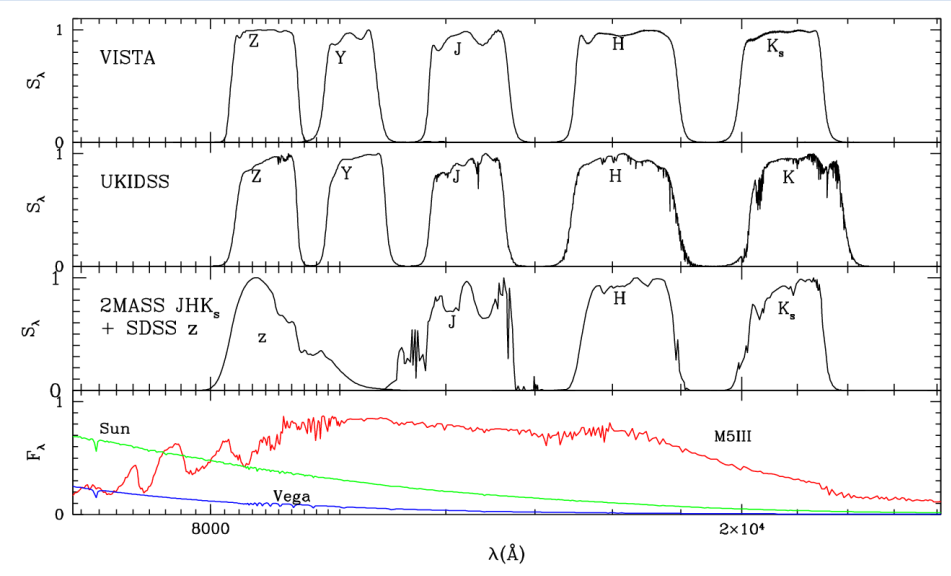
•1.5 deg x 1.18 deg

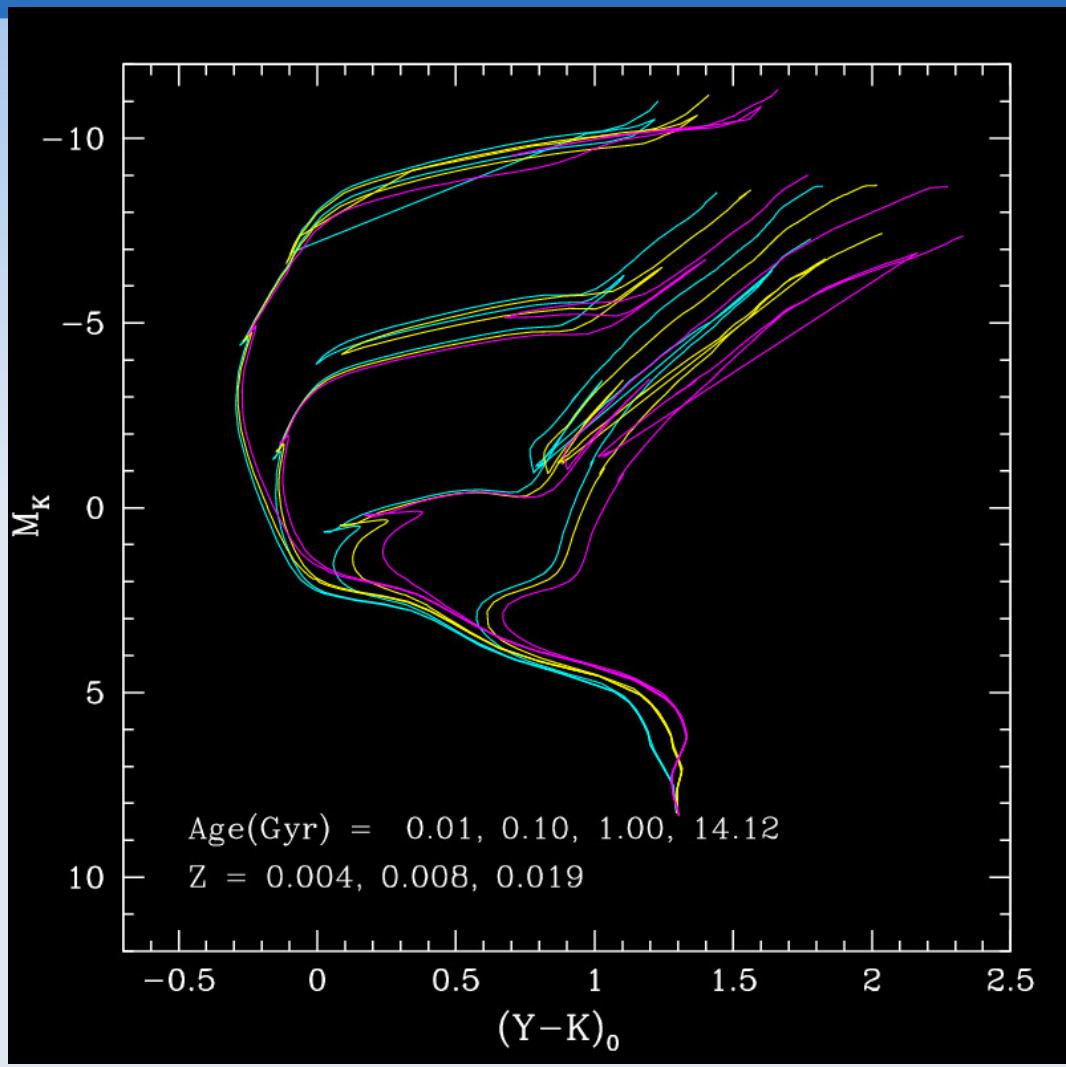




Isochrones in VISTA Vegamag system

(+ extinction coefficients Alambda/Av)

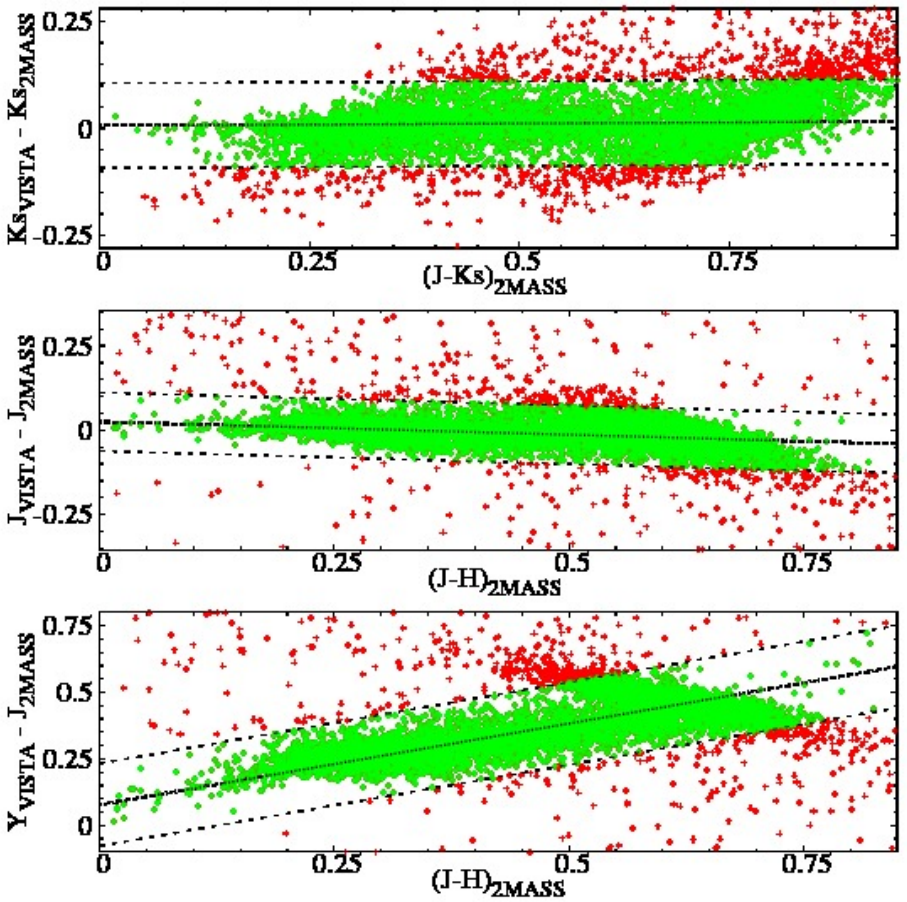




Available at http://stev.oapd.inaf.it/cmd since early-2011
And also in TRILEGAL MW model http://stev.oapd.inaf.it/trilegal

Offsets between VSA photometry calibration (v1.1) and Vegamags

- Simulate a section of MW in VISTA + 2MASS system, using TRILEGAL
- Correct with 2MASS error distribution (Bonatto et al. 2001).
- Derived the Zero Point offset → the difference between VSA and Vegamag VISTA system



$$Y_{VISTA} - J_{2MASS} = 0.610 * (J-H)_{2MASS}$$

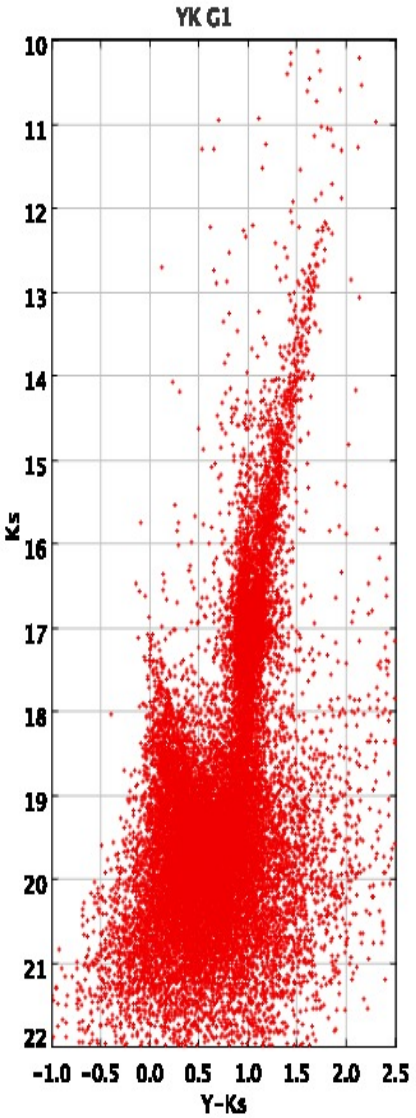
$$J_{VISTA} - J_{2MASS} = -0.077 * (J-H)_{2MASS}$$

$$Ks_{VISTA} - Ks_{2MASS} = 0.010 * (J-Ks)_{2MASS}$$

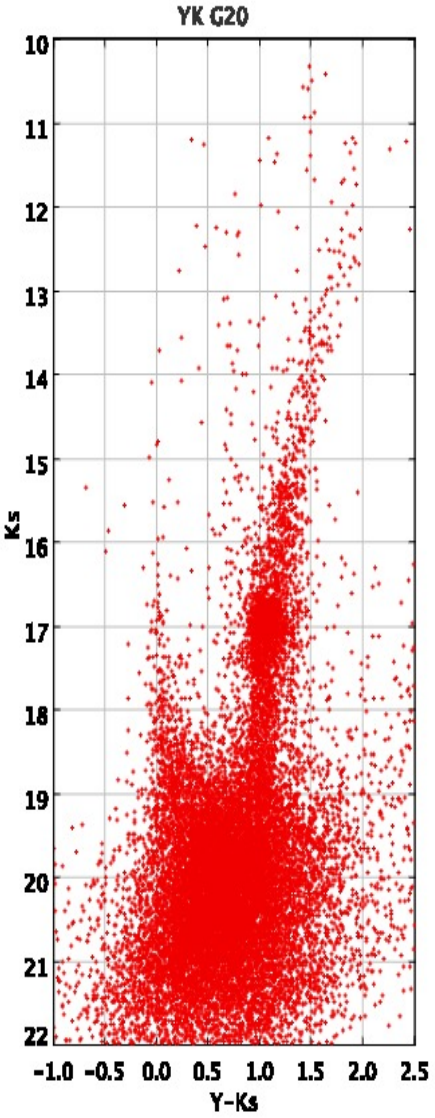
Derived ZP offsets (in VSA v1.1)
0.006 in Ks
0.027 in J
0.081 in Y

Obvious SFH variations inside 30Dor tile

SW corner

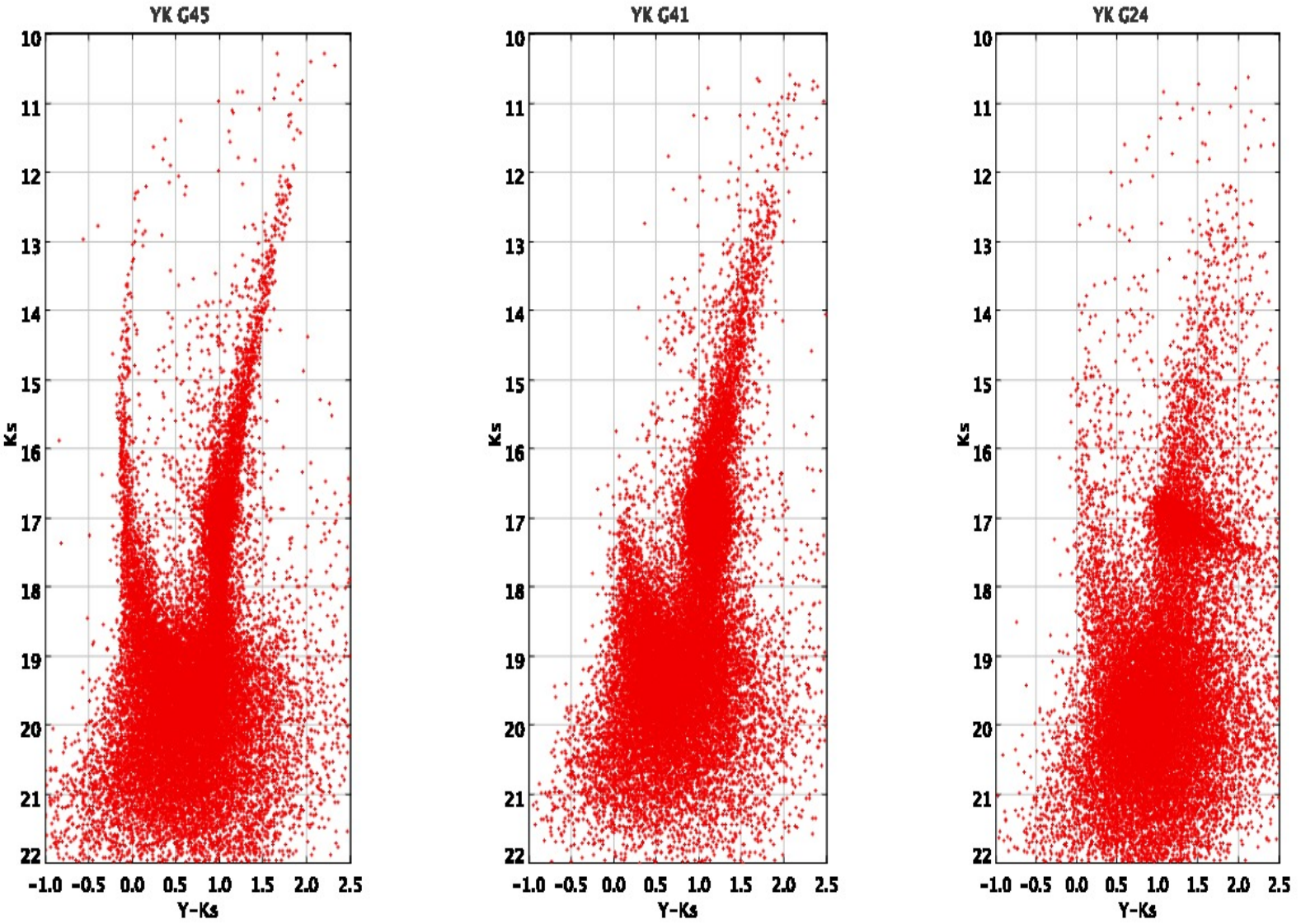


NE corner



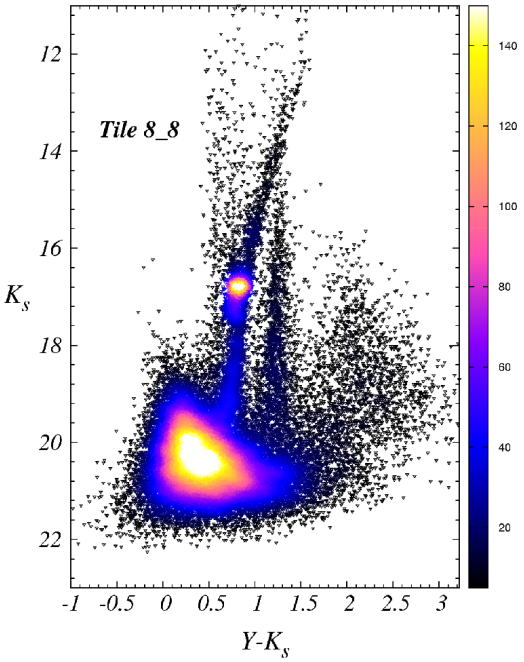
Obvious SFH variations inside 30Dor tile

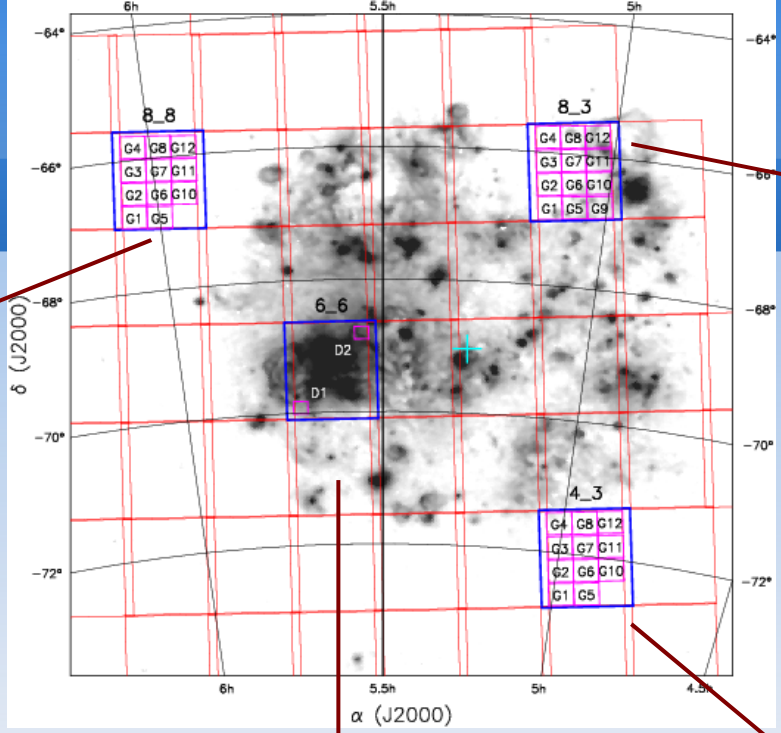
Extreme subregions

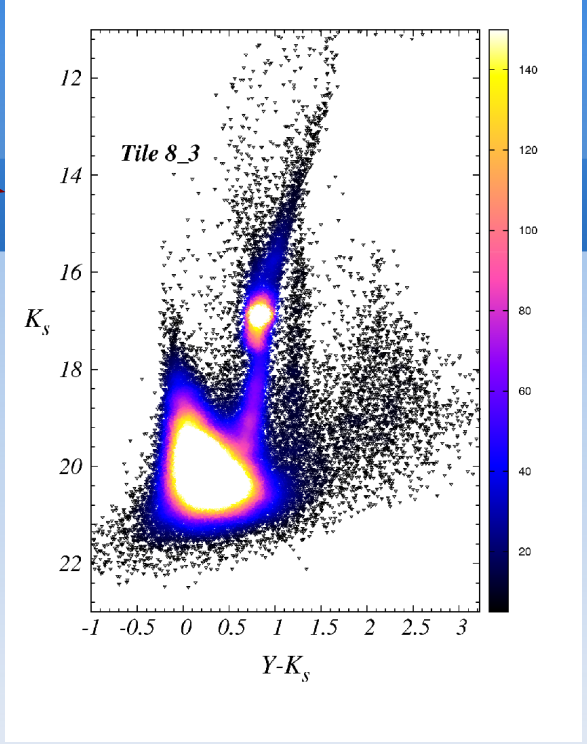


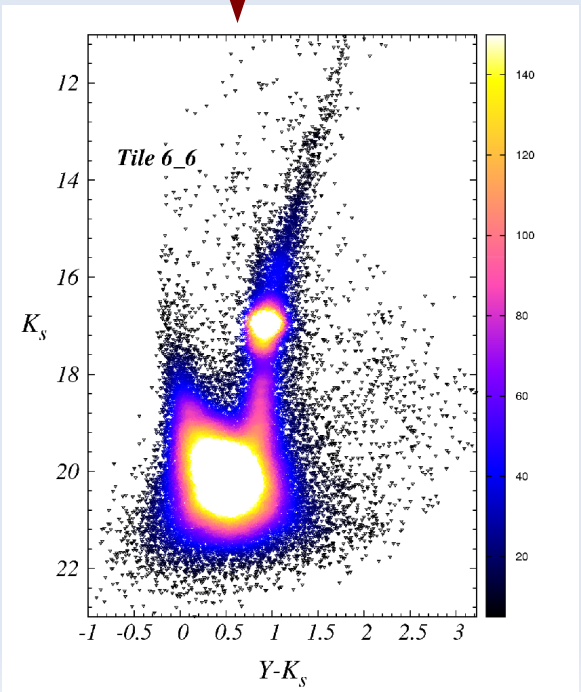
CMDs

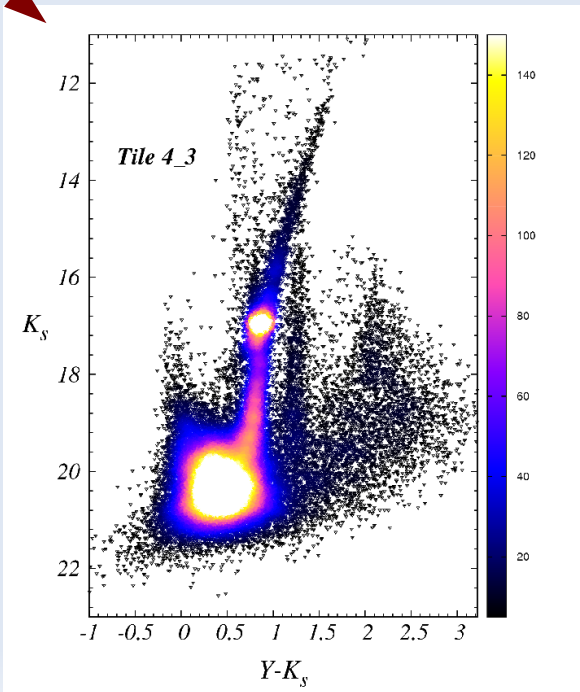
- Rubele et al. 2011







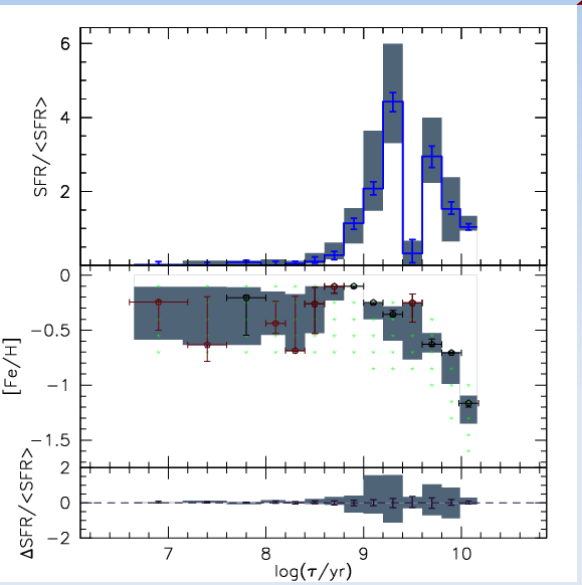


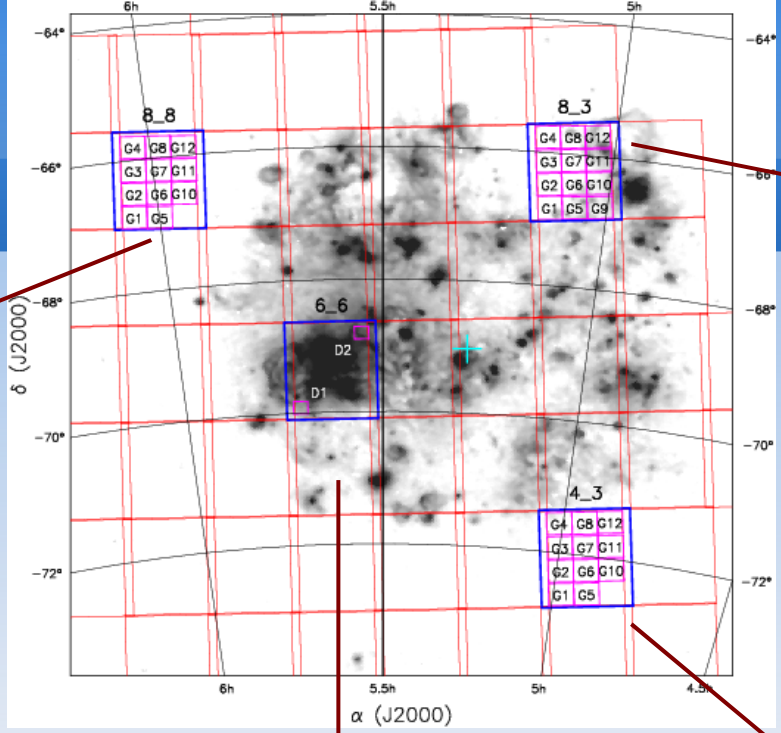


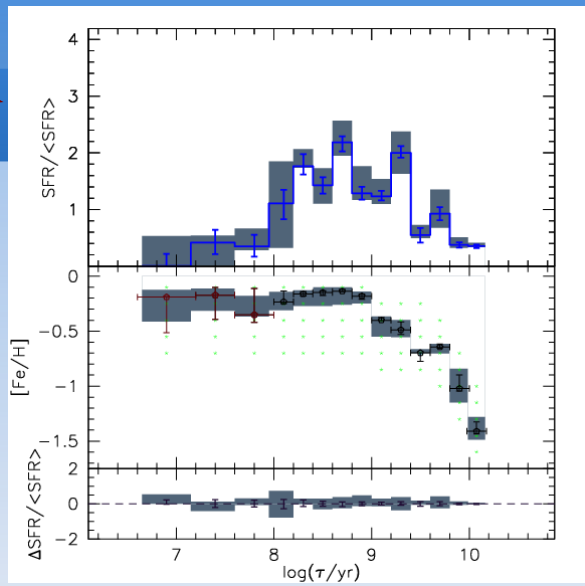
Available tiles divided into
~0.12 sq.deg sections
0.036 sq.deg in 30Dor

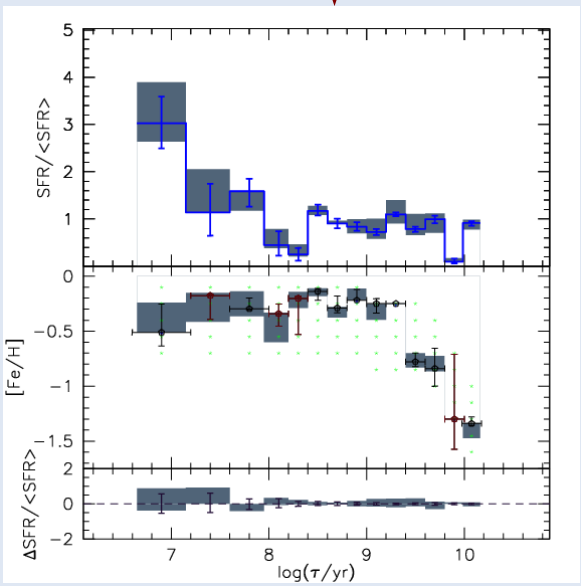
CMDs

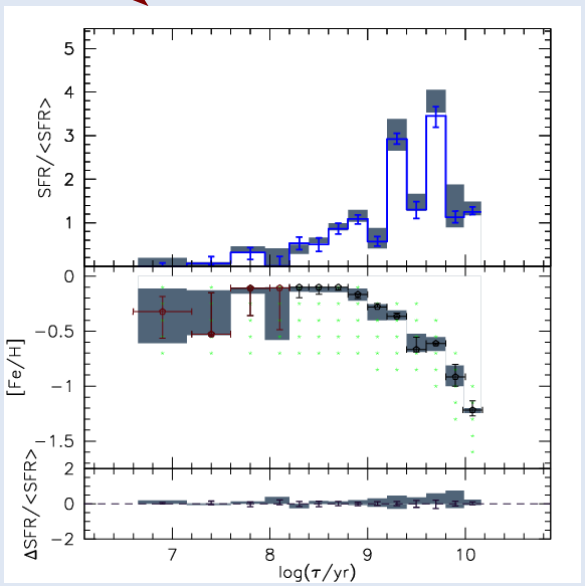
- Rubele et al. 2011





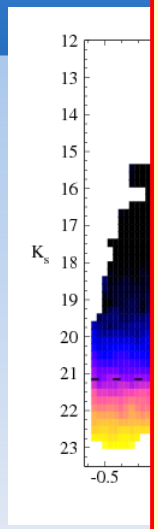






Derived SFR(*t*) and [Fe/H](*t*) for every subtile (0.12 deg², or 0.036 deg² next to 30 Dor)

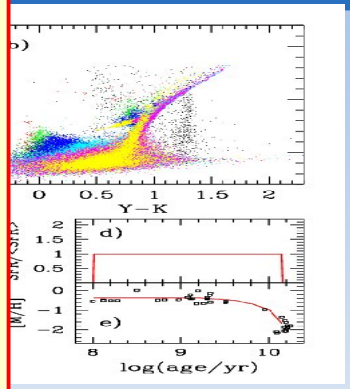
A closer look at the results



>10^6 ar

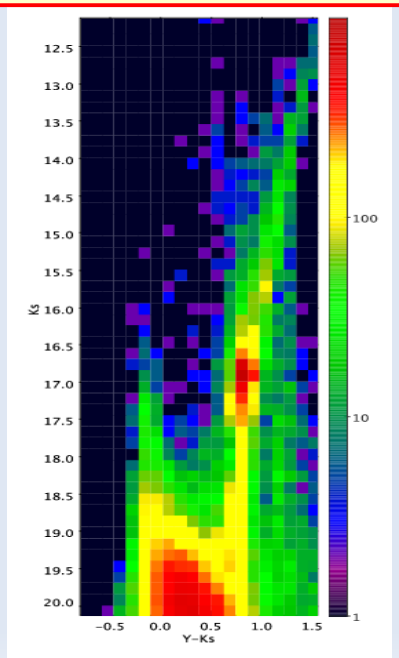
This is the largest persistent discrepancy we find: indicative of a ~<20% excess in the He-burning lifetimes for low-mass stars: Discrpancy partially solved with new PARSEC tracks, residuals easily fixed by adjusting overshooting+breathing pulses at end of He-burning lifetime (Bressan et al., in prep).

But overall, stellar models are very reliable in the near-infrared

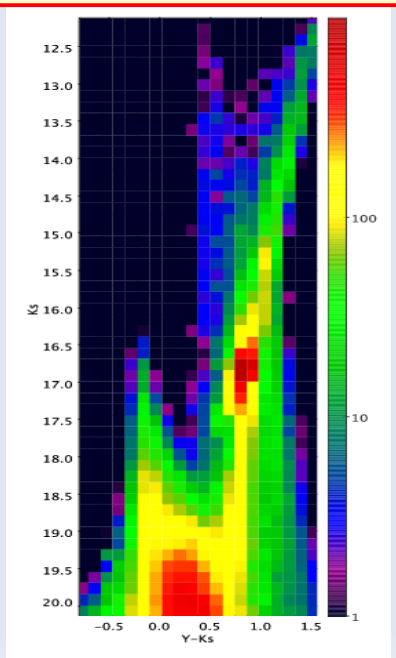


populations" of
etallicities

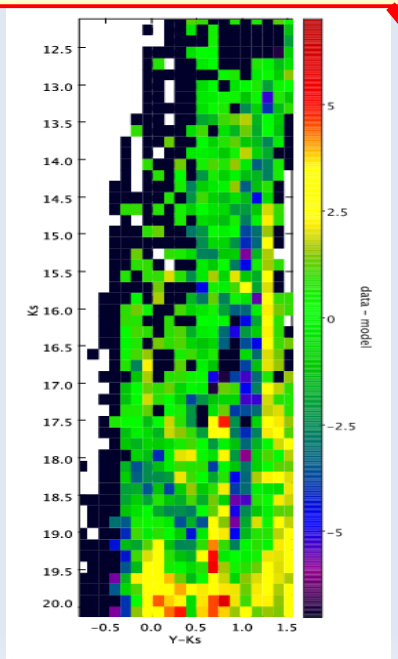
Run StarFISH (Harris & Zaritsky 2001) to find linear combination that minimizes a χ^2-like statistics: that's the SFH



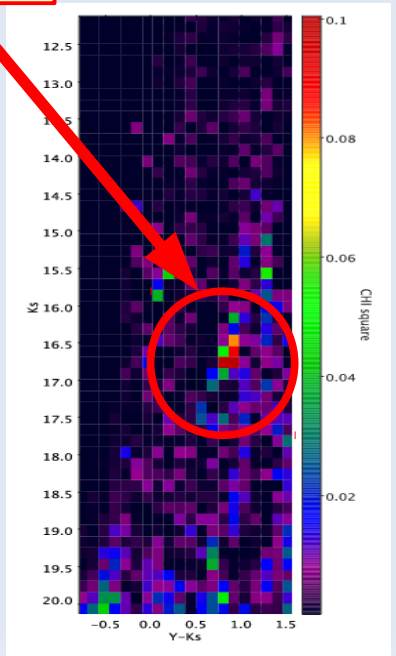
data



model

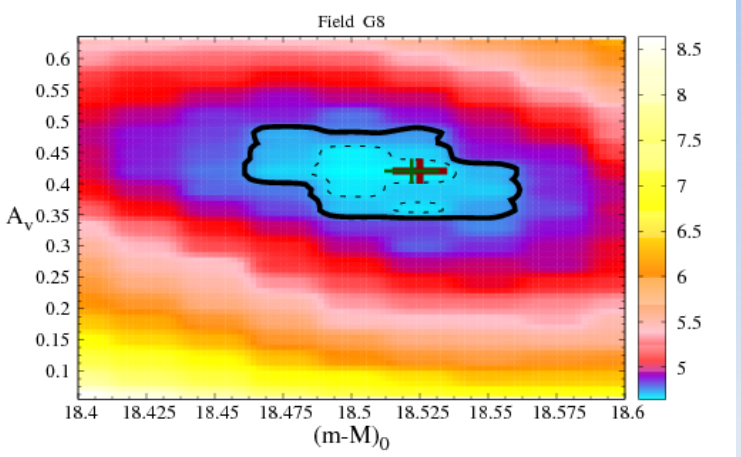


difference



χ^2 map

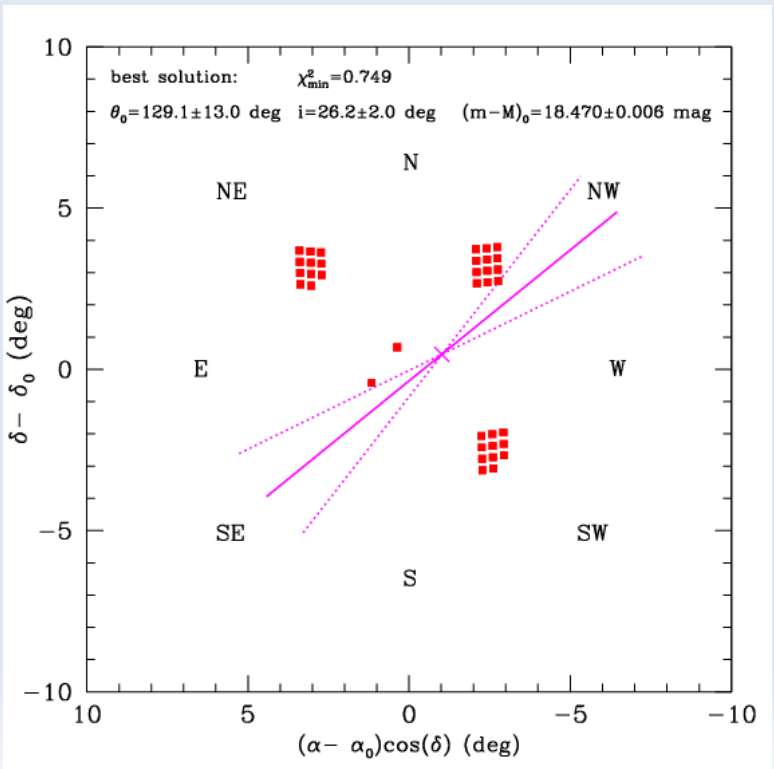
Evaluating distances and extinction

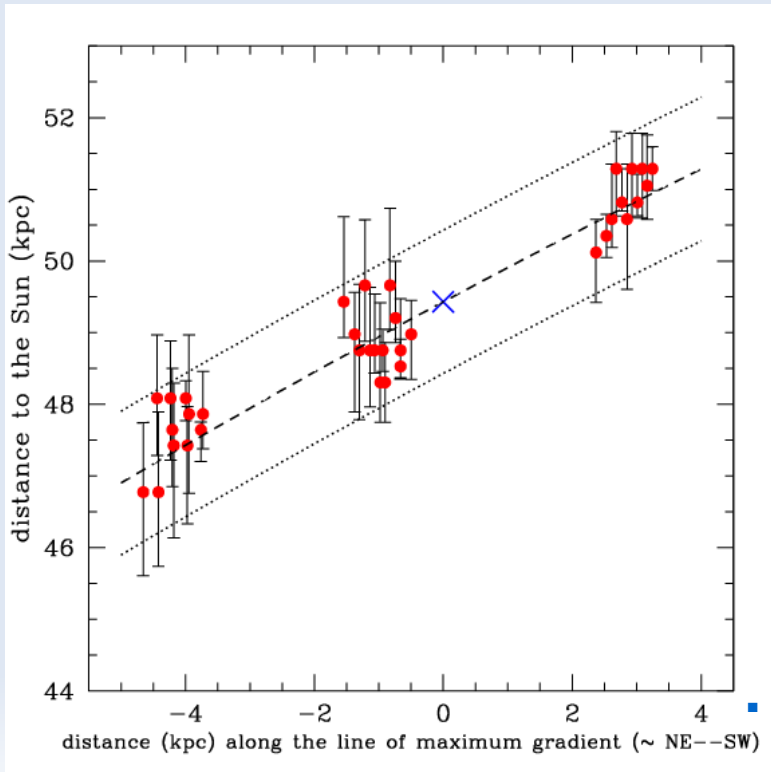


Map of χ^2 in distance vs. reddening plane: identifies best-fitting values and region for estimation of systematic errors

What a surprise: best-fitting LMC plane has

α_c (J2000) (deg)	δ_c (J2000) (deg)	i (deg)	θ_0 (deg)	$(m-M)_0^{centre}$	χ^2_{min}
79.40	−69.03	26.2 ± 2.0	129.1 ± 13.0	18.470 ± 0.006	0.749
82.25	−69.50	26.2 ± 1.9	126.4 ± 10.1	18.466 ± 0.006	0.785
81.90	−69.87	26.2 ± 2.0	130.9 ± 8.9	18.470 ± 0.005	0.750
79.91	−69.45	26.2 ± 1.7	129.6 ± 10.1	18.471 ± 0.006	0.769

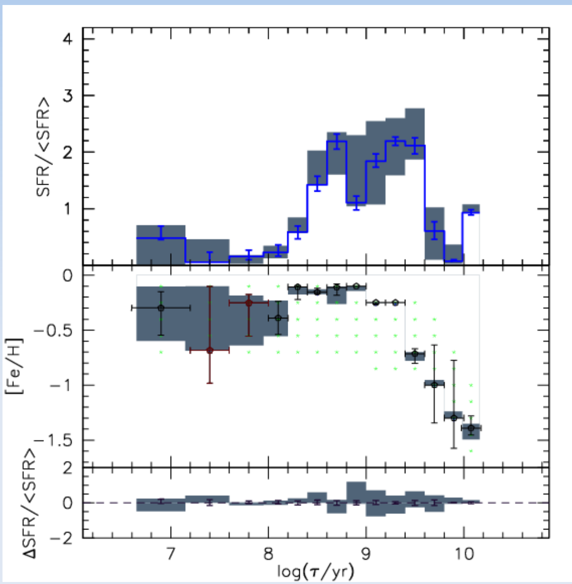


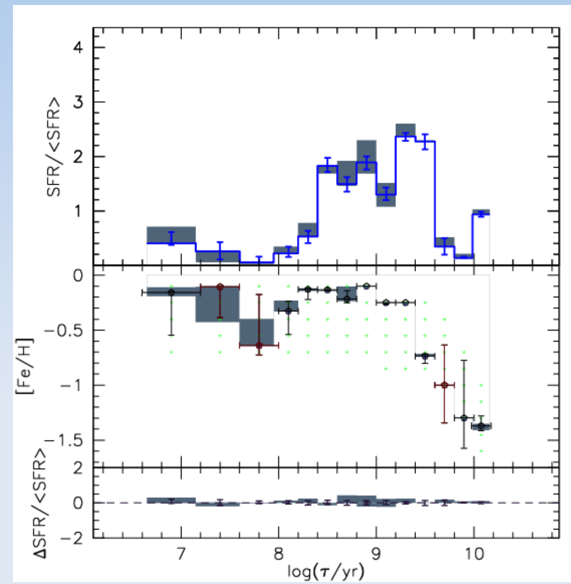


Rubele et al. 2011

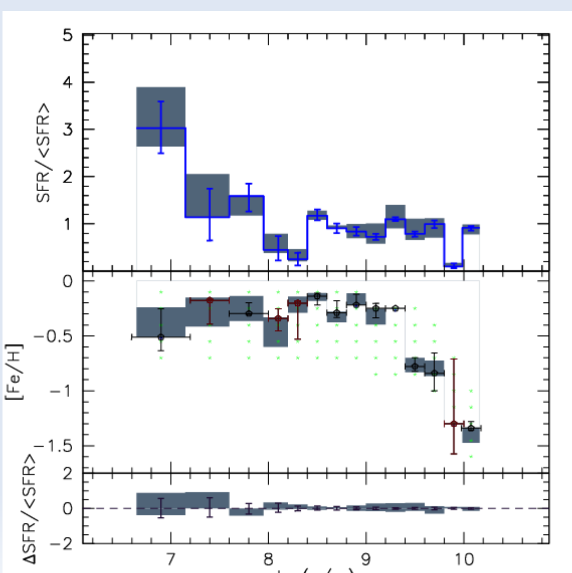
e.g. for the two 30 Dor / LMC bar fields (~1.2 kpc apart):

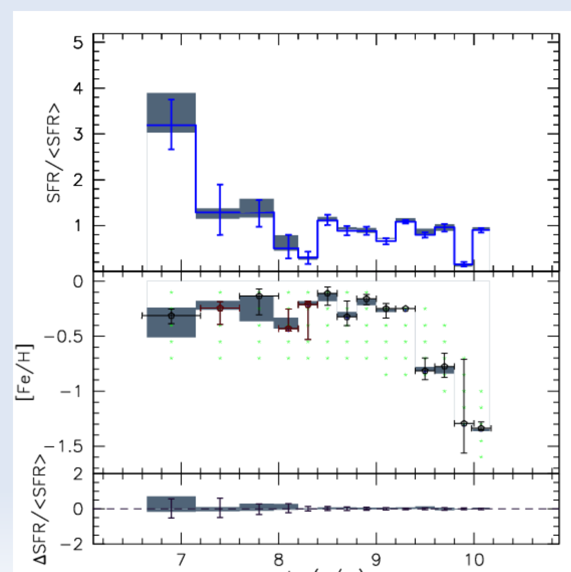
- Rubele et al. 2011





Strong reduction in error bars, when the distance is assumed equal to the best-fitting LMC plane

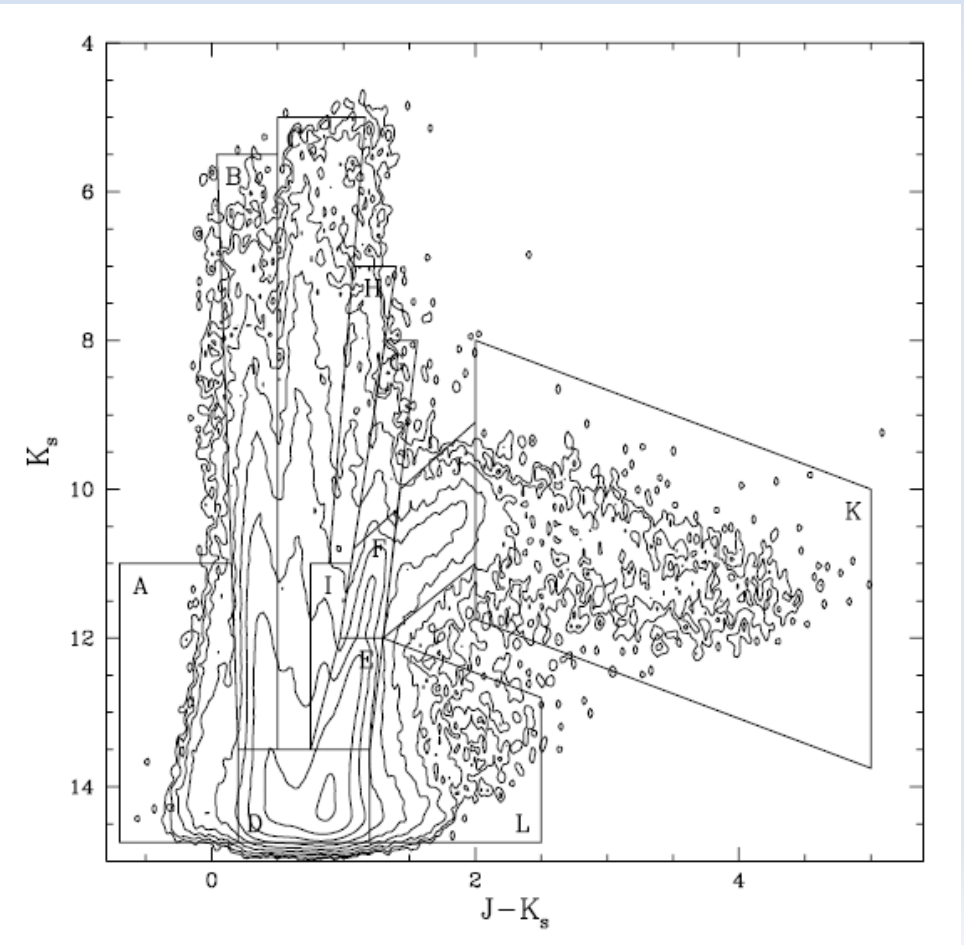


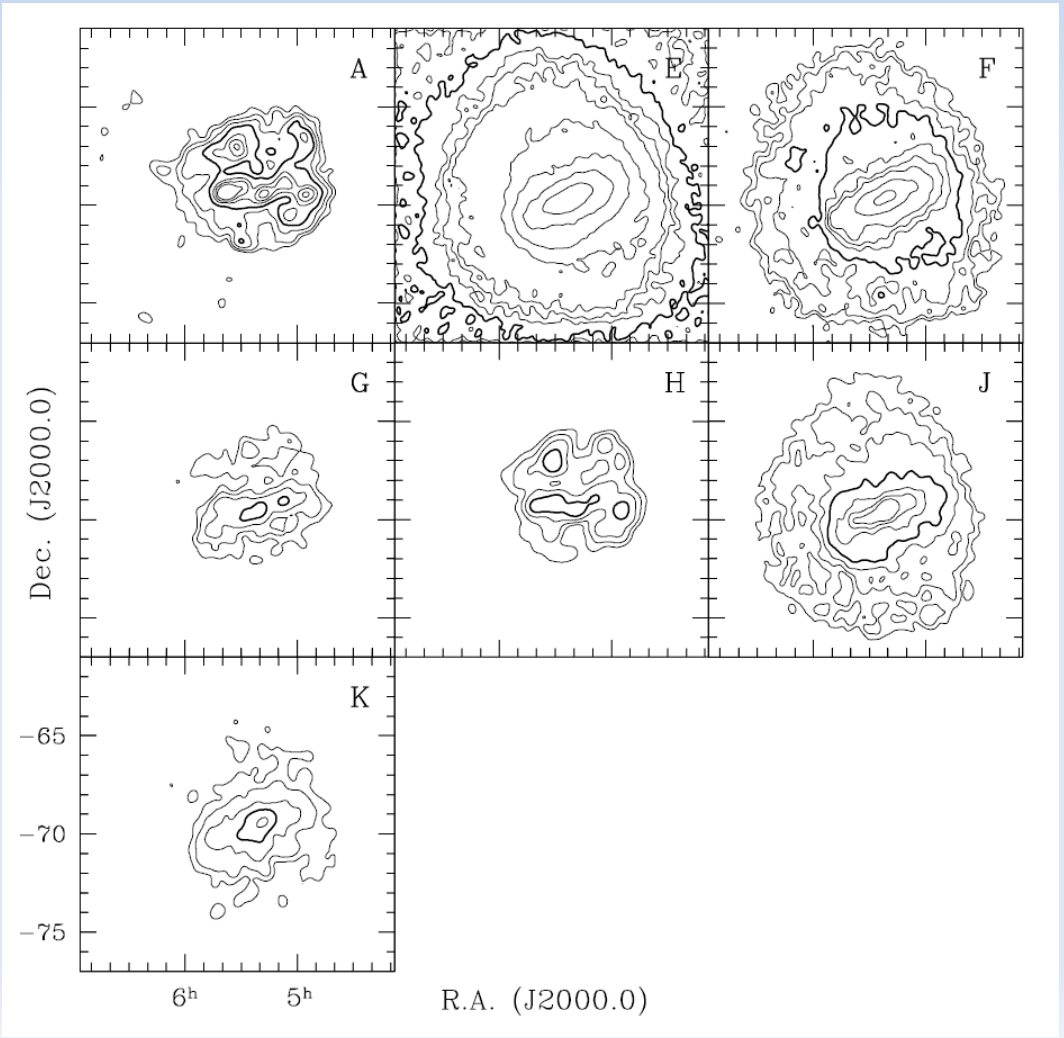


Notice similarity in the old SFH: the 10 Gyr population (present everywhere in the LMC), and the 0.5-6 Gyr plateau (the LMC bar?)

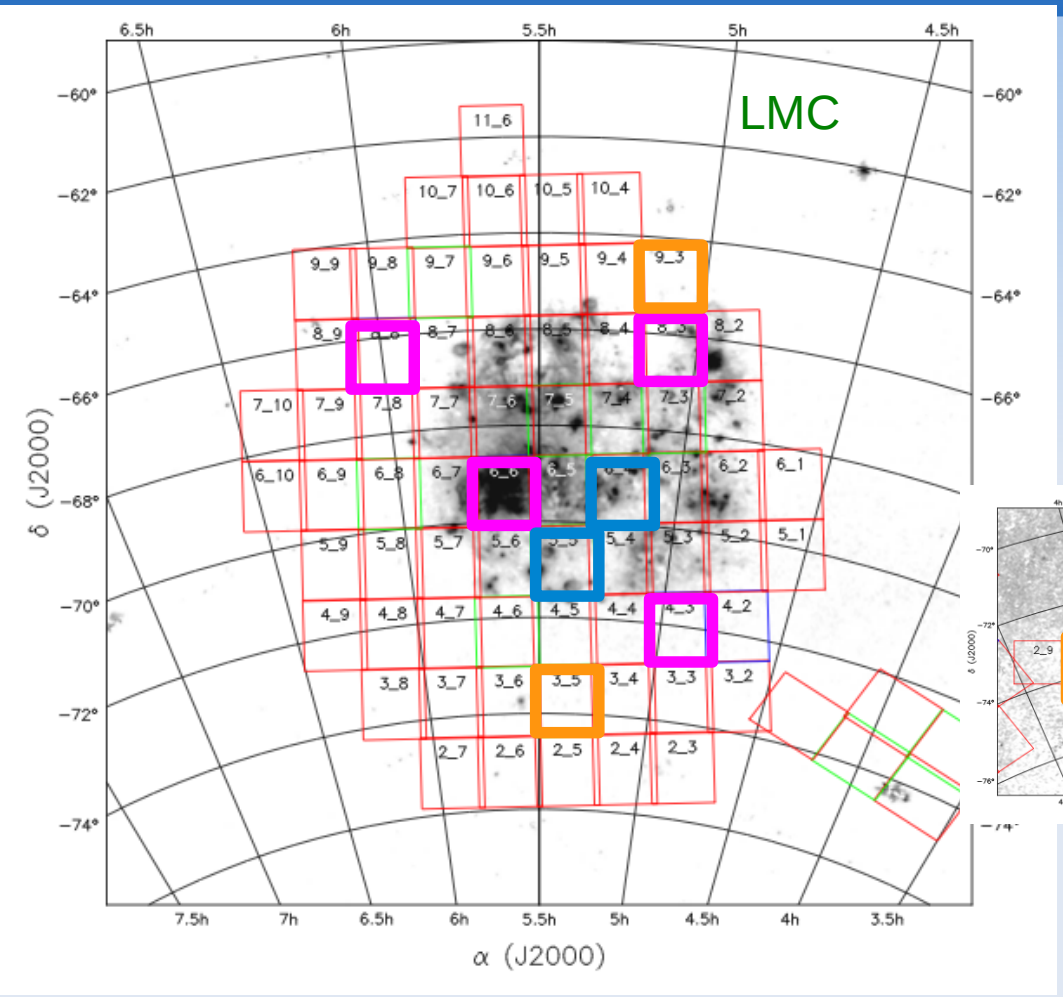
The MCs as seen by 2MASS

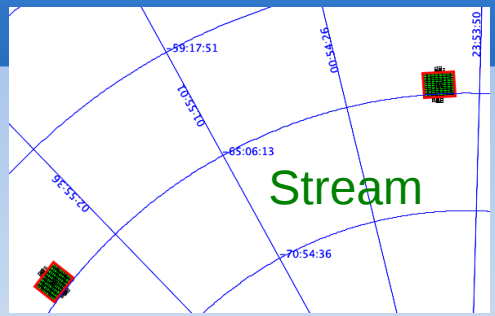
- Smooth distribution of intermediate-age and old populations, can even derive disk inclination from isophotal fitting (Weinberg & Nikolaev 2001)
- No surprise: 10 km/s in ~2 Gyr → 2 Kpc

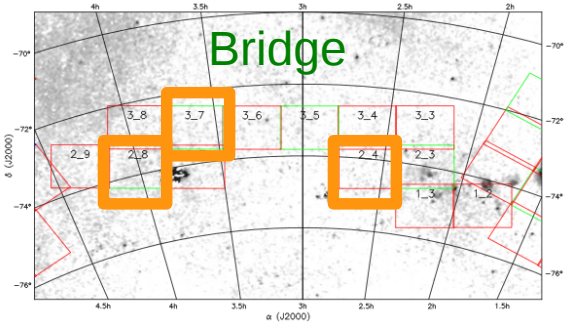


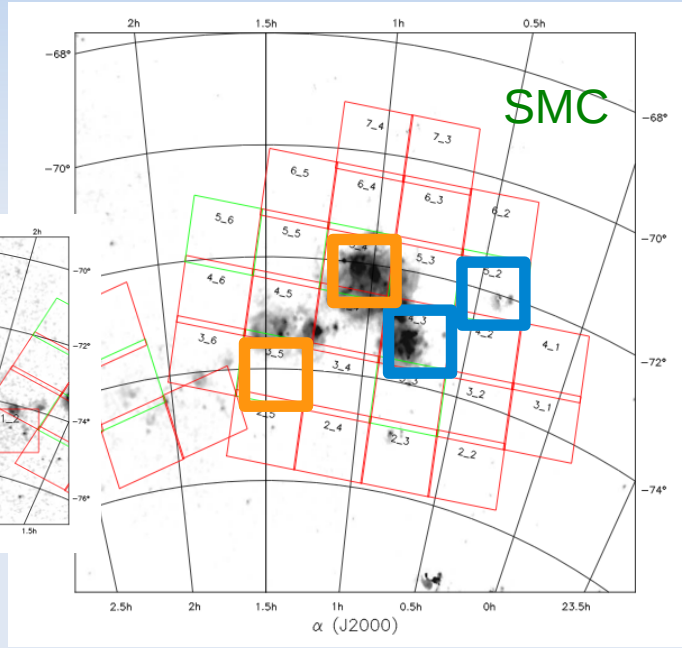


Status of AST + SFH work









Imaging: Completed Advanced (*YJ* mainly) Started/in queue

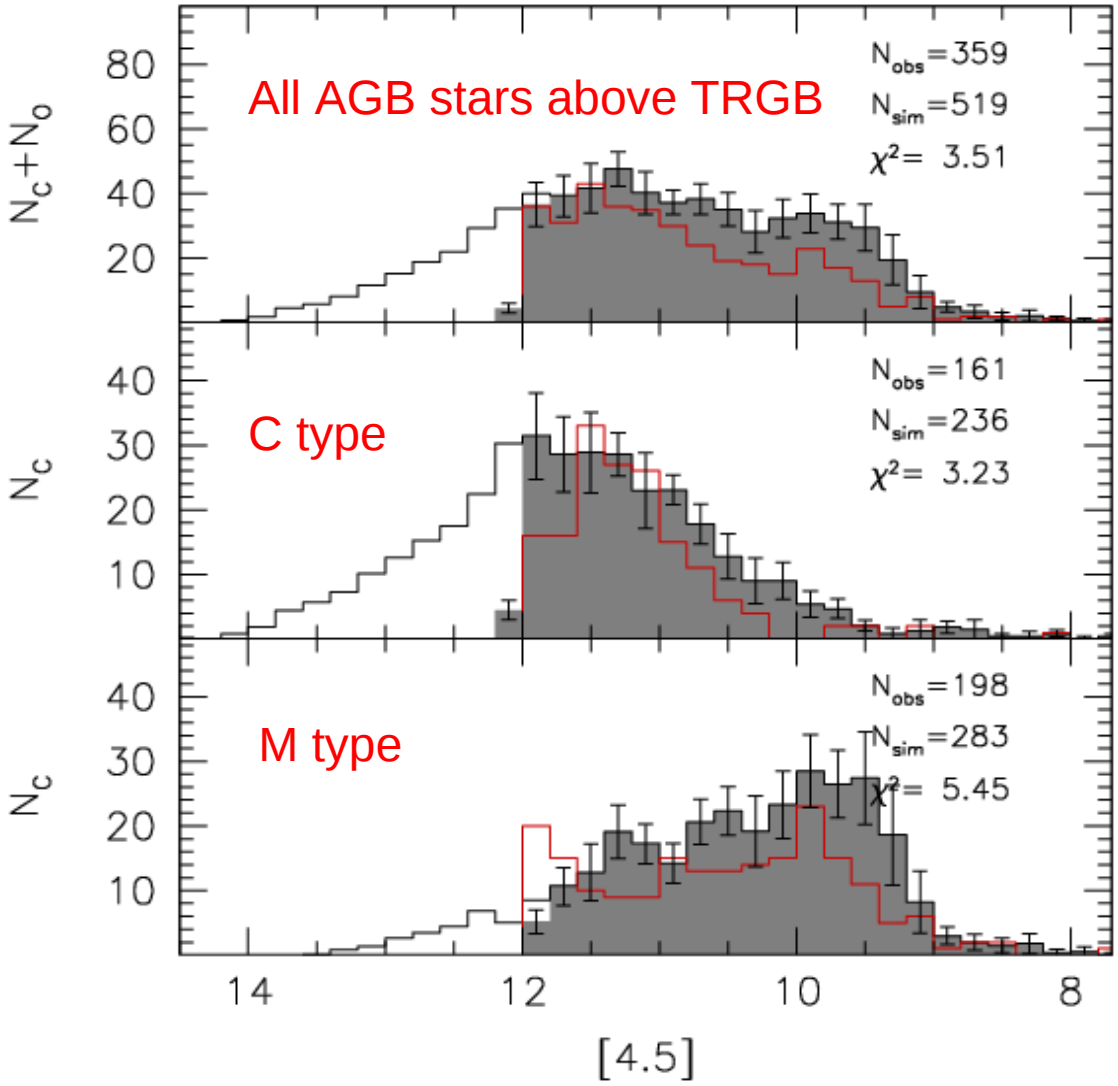
SFH work: Already done (but to be redone)

processing (ASTs almost ready)

starting

Using the SFH: calibrating TP-AGB models

- Take SFH in a tile
- Simulate TP-AGB population (TRILEGAL+ Marigo 2008-12 tracks)
- Compare with actual numbers/LFs (VMC+2MASS+Spitzer +OGLE)
- Adjust models, e.g. Increase mass-loss
- No better galaxies for this!



Gullieuszik et al. In prep

Basic messages from VMC:

Thanks to the deep & wide NIR photometry, we are about to map the SFH and distances all across the Magellanic System

The SFH quality is better than with

- *HST (fields are too small)*
- *wide optical surveys (affected by variable reddening+crowding),*

We're still not taking full advantage of field-to-field correlations between distances, and the very smooth variations in the old SFH

→ *results will improve a lot with contiguous VMC areas*

Accurate 3D+SFH mapping of entire galaxies is possible: Impact into stellar populations + LG galaxy evolution