Young open clusters in VVV ESO Public Large Survey.

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VVV view of G305 star forming region

Outline

- ✓ Census.
- ✓ Methods of analysis.
- ✓ Constraining the Galactic structure with stellar clusters in obscured HII regions.
- ✓ Young massive clusters, young massive stars.
- ✓ Exotic objects.
- ✓ Star forming regions.
- ✓ Distance scales – OC + Cepheid.
- ✓ Work in progress.

Goals

- Build a database of a great number (~100?) of open clusters observed with the VVV with homogeneously derived fundamental parameters.
- Provide a distribution map of these star clusters throughout the Galaxy.
- Constrain the fundamental parameters on the very early stages (up to 10 Myr).
- Study the effect of Galactic position on cluster evolution.
- Trace the structure of the Galactic disk.

Census of Galactic open clusters.

Wide Infrared Milky Way Surveys

Survey	Area, square deg	Bands / 5-sigma Sensitivity	Cluster Searches	Status and Data Products
2MASS	all sky	J / 16.5 mag H / 15.8 mag Ks / 15.1 mag	Hundreds new clusters: Dutra & Bica (2000, 2001), Ivanov et al. (2002), Bica et al. (2003), Borissova et al. (2003), Dutra et al. (2003), Froebrich et al. (2007, 2010)	Completed (1997-2001); last DR Mar 2003;~471 million PSC + 2 arcsec resolution JHKs atlas
DENIS	16700	Gunn I / 18.5 mag J / 16.5 mag Ks / 14.0 mag	2 new clusters (Reylé & Robin 2002)	Completed (1995-2001); as of DR3 from Sept 2005: ~355 million PSC + IJKs atlas
UKIDSS GPS	- 1800 in JHK - 300 in H2	J / 19.8 mag H / 19.0 mag K / 18.1 mag H2 / ...	~170 new clusters (Lucas et al., in prep.)	in progress (2006-2013), as of DR6 (Oct 2009): ~604 million PSC + ~1 arcsec resolution JHK atlas
VVV	- 300 in the bulge - 220 in the disk	Z / 21.5 mag Y / 20.7 mag J / 20.2 mag H / 19.3 mag K / 19.3 mag (disk)	search in progress 153	- raw paw-prints public via the ESO Data Archive - first v. 1.0 tiles+catalogs recently available to the team via CASU
GLIMPSE I+II+3D+360	220+60+ 134+290 =~700	[3.6] / 0.2 mJy [4.5] / 0.2 mJy [5.8] / 0.6 mJy [8.0] / 4.0 mJy	59 new clusters (Mercer et al. 2005)	In progress (2003-2012); ~100 million PSC (up to G-3D) + <=2 arcsec resolution atlas

From Ivanov et al. 2010

- Upper limit of star clusters in the Galaxy - 30000-35000 (Portegeis Zwart et al. 2010)
- We know about 5-10% of these (currently in the online list of Dias et al. 2002)

Cluster Lists/Databases

WEBDA - 681 - (http://www.univie.ac.at/webda/navigation.html)

Dias list - 2135 - (http://www.astro.iag.usp.br/~wilton/)

Kharchenko - 650 – (http://adsabs.harvard.edu/abs/2009A%26A...504..681K)

SAI catalogue - 200 - (http://ocl.sai.msu.ru/catalog/)

FSR list - 1788 - (http://astro.kent.ac.uk/~df/clusters/index.html)

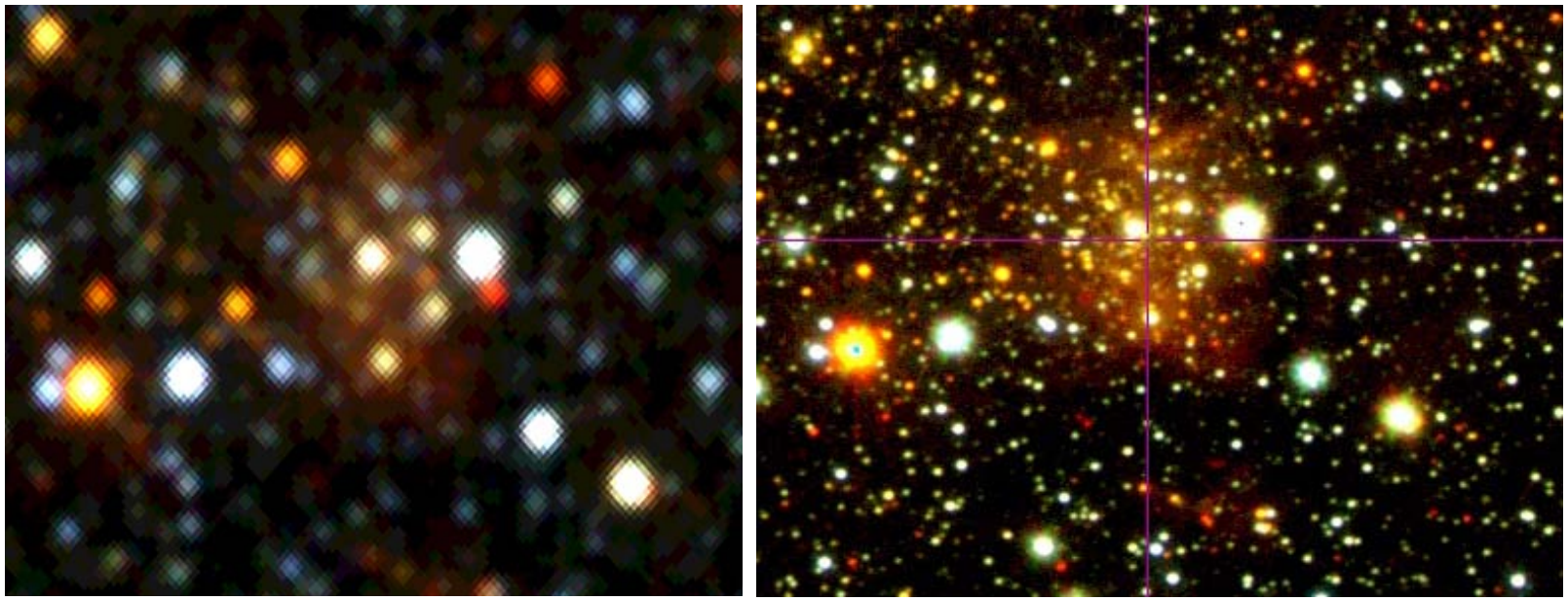
Harris - 157 - (http://adsabs.harvard.edu/abs/2010arXiv1012.3224H)

Lada & Lada - 76 - (http://adsabs.harvard.edu/abs/2003ARA%26A..41...57L)

From Froebrich 2012

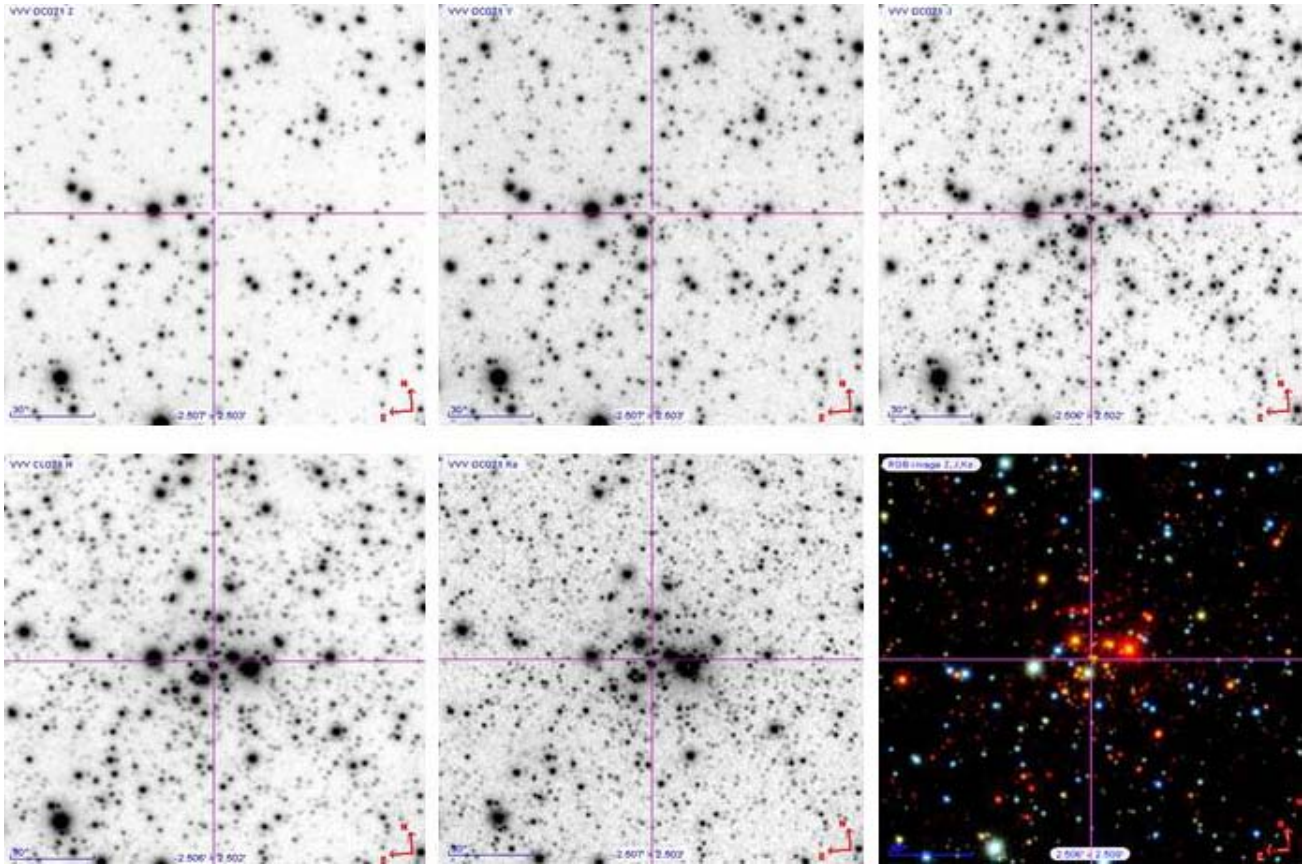
Census

- Less than half have been studied properly (Dias et al. 2002)
- **This sample is especially biased in the highly obscured and central regions of the Galaxy, because of the reddening, crowding, pixel size and limiting magnitudes of existing surveys (BEFORE VVV).**



The 2MASS and VVV composite *J,H,Ks* color image of VVV-CL062 . The field of view is approximately 2.2x1.8 arcmin. (Borissova et al. 2011).

Census - we need to go deeper in the dust.



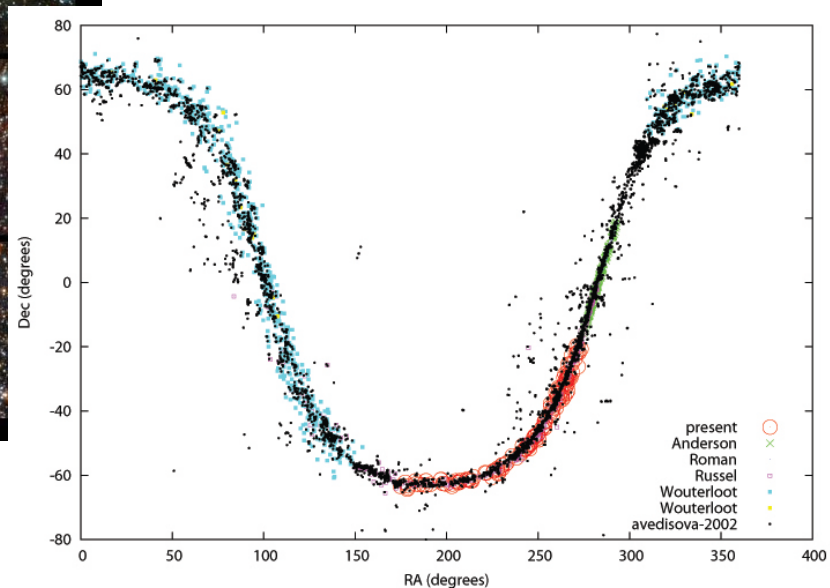
We will go even deeper by the end of the VVV survey.

The VVV ZYJHKs images and ZJKs true color image of VVV CL036. The field of view is 2.5x2.5 arcmin (Borissova el al. 2011).

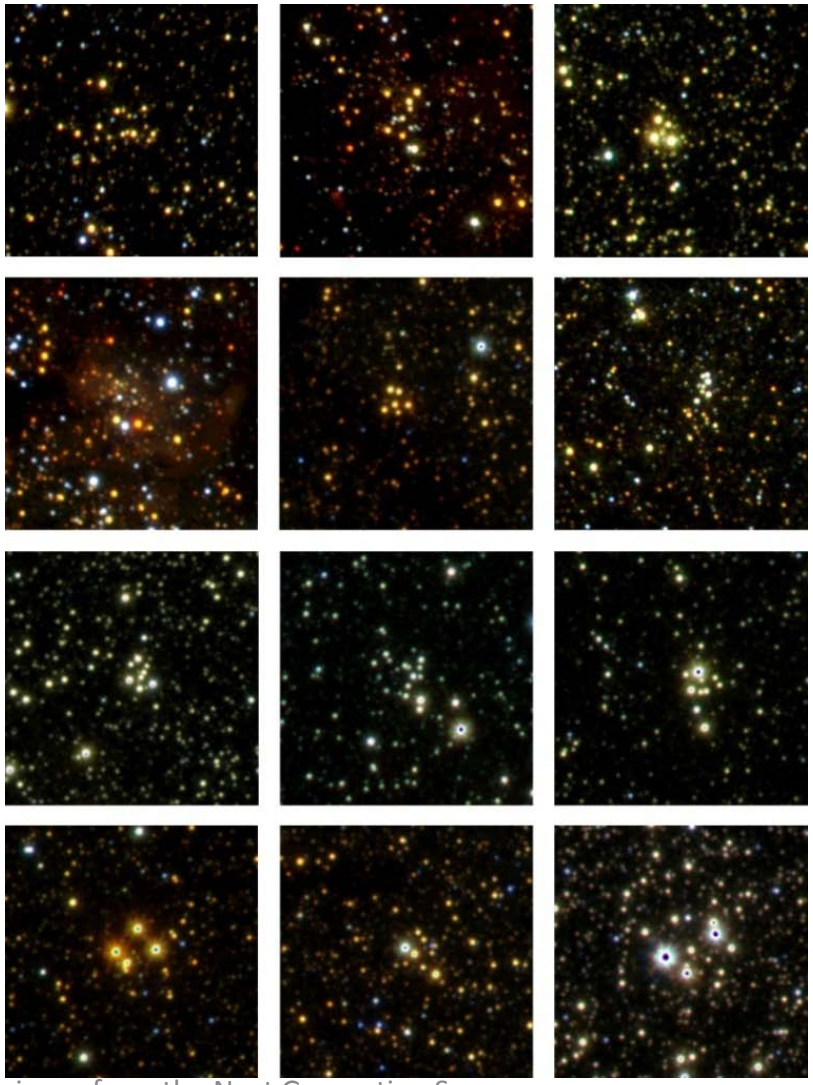
Pointed visual inspection of the VVV area.

Goal: to trace the early epochs of star cluster evolution.

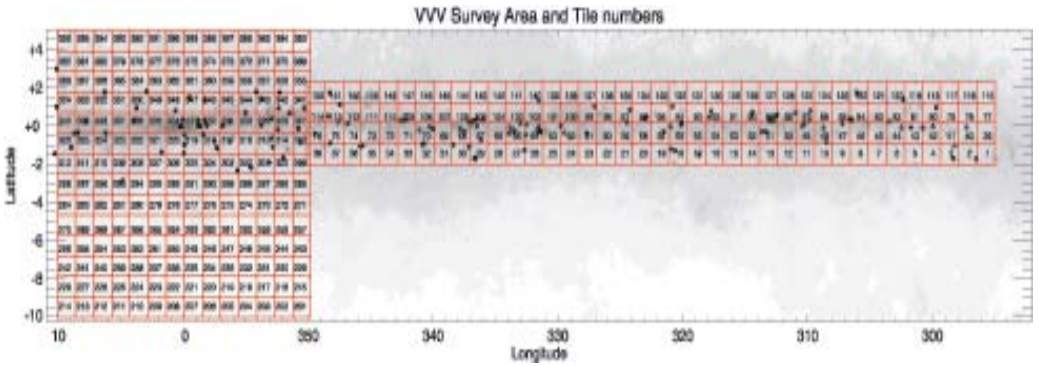
96 new star clusters in the Galactic disk (Borissova el al. 2011; ESO 1128).



Visual inspection of the VVV central area



57 new star clusters in the inner 10 degrees around Galactic center. (Borissova el al. 2012, in preparation).



Science from the Next Generation Surveys, 16.10.2012, ESO.

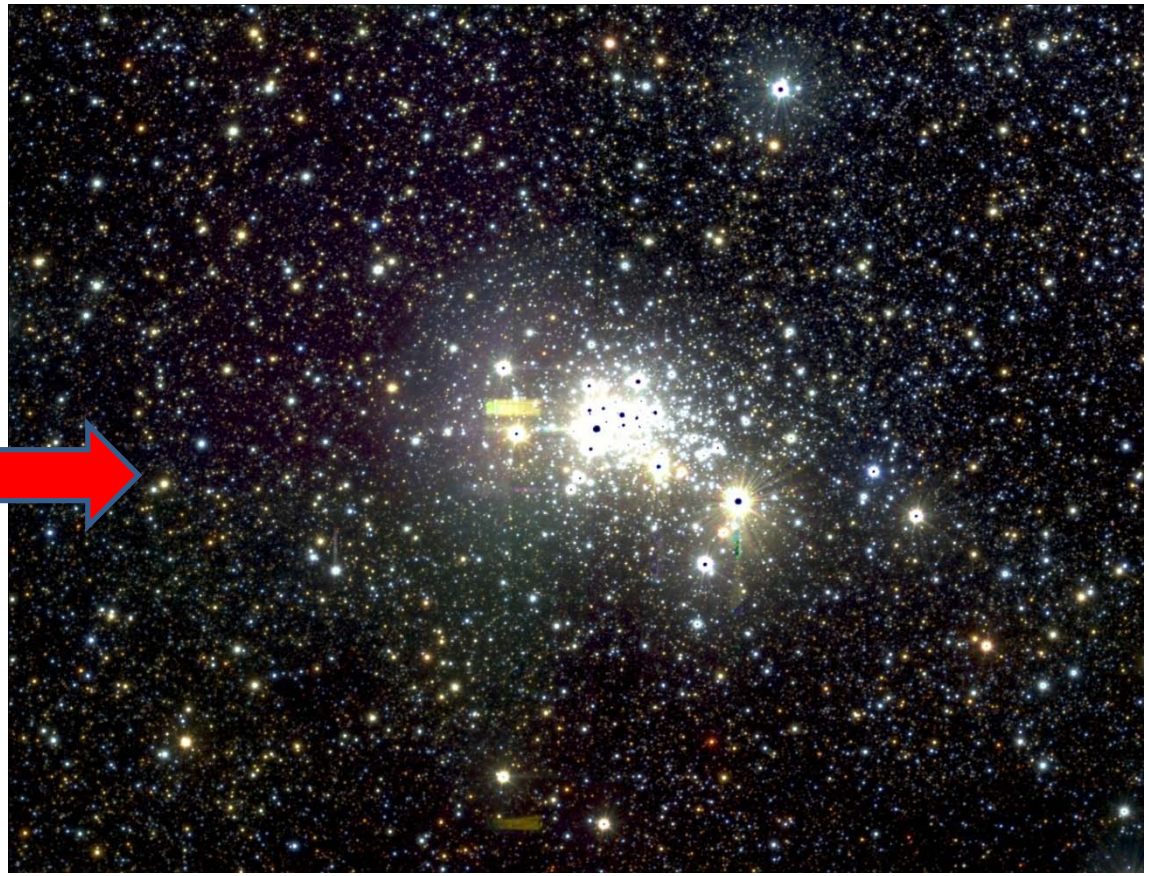
Visual inspection of the VVV area

"It is highly likely that we already know a large fraction of the super massive clusters (Mcl> 10^5 M⊙) in the Galaxy." Froebrich, 2012.

There are no new cluster candidates like this:

But, around 80 clusters between 10^4 M⊙ and 10^5 M ⊙ are predicted (Larcen 2006, Hanson 2010).

23 known clusters in latest Davies et al. 2012 catalog.

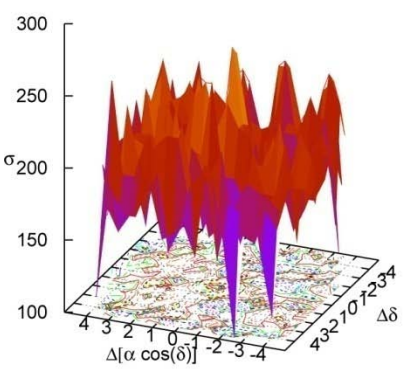


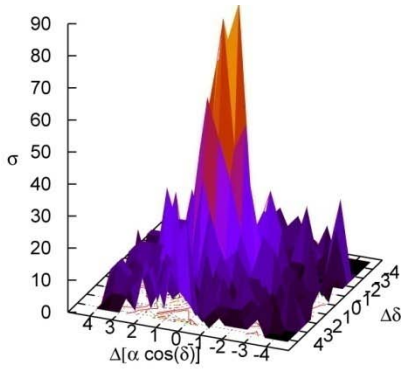
VVV true color image of Westerlund 1. The field of view is approx. 14x11 arcmin.

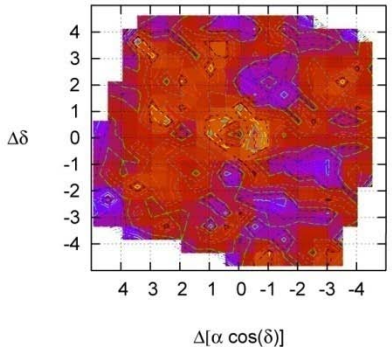
Cluster Characterization Methods.

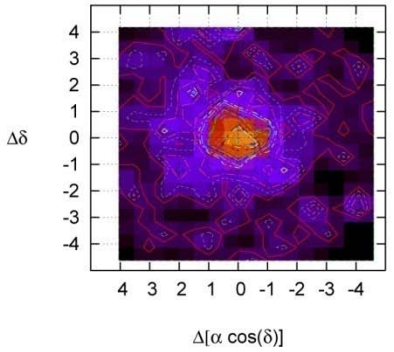
PSF photometry (Mauro et al. 2012) +

Photometric Membership Probabilities (statistical decontamination of field stars Bonnato et al. 2010 method).







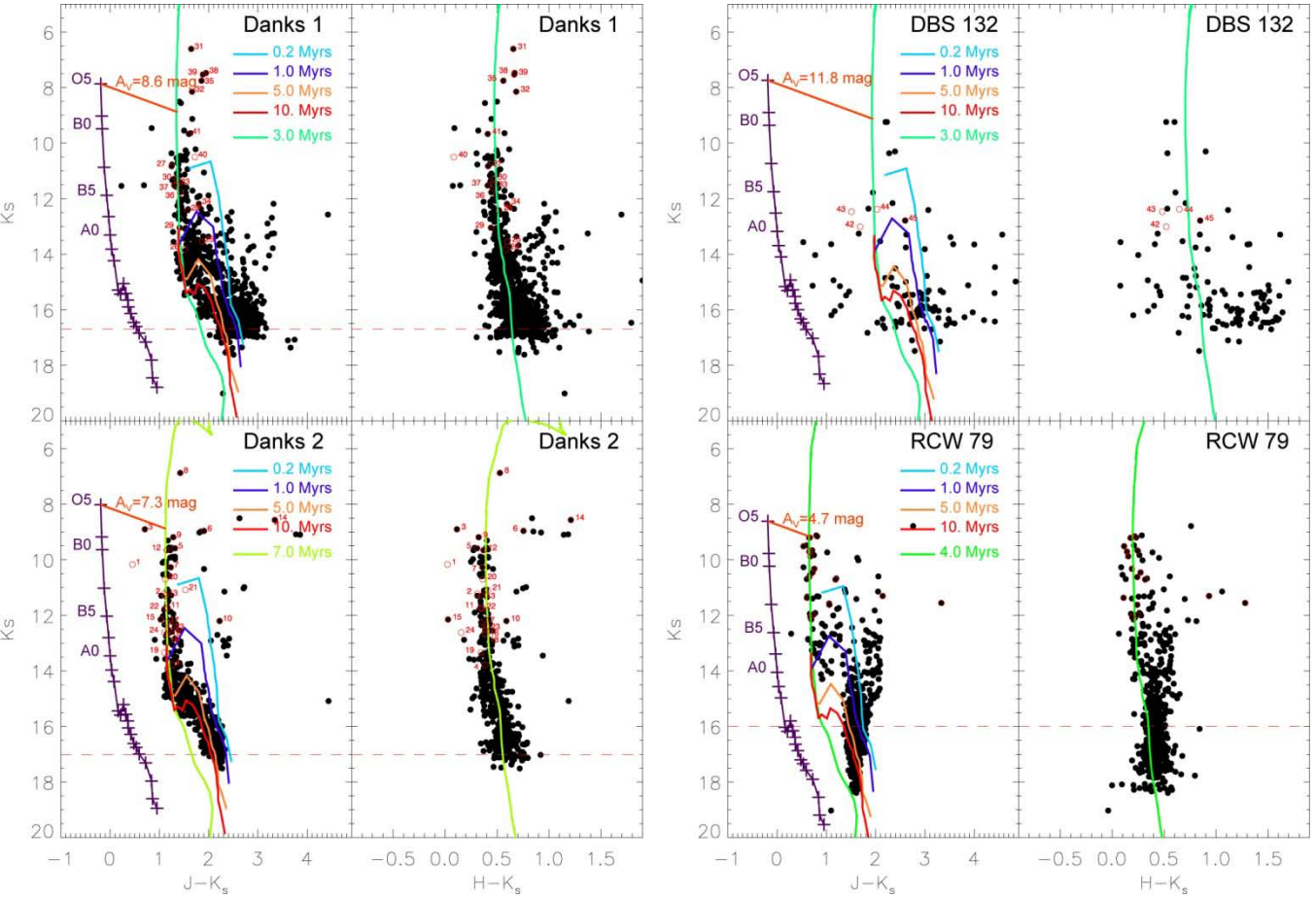


VVV CL036

Stellar surface-density σ(stars arcmin^2) of VVV CL036. The radial density profile produced with the raw photometry is shown to the left and the right images show the field after statistical decontamination. (Borissova et al. 2011).

Cluster Characterization Methods.

Reddening, distance, age
Photometric Parallax: Isochrone fitting of color-magnitude diagrams.
Best solution of Main sequence isochrones + PMS set.



Color-magnitude diagrams of Danks1, Danks2, RCW 79 and DBS2003 132 (Chenè et al. 2012).

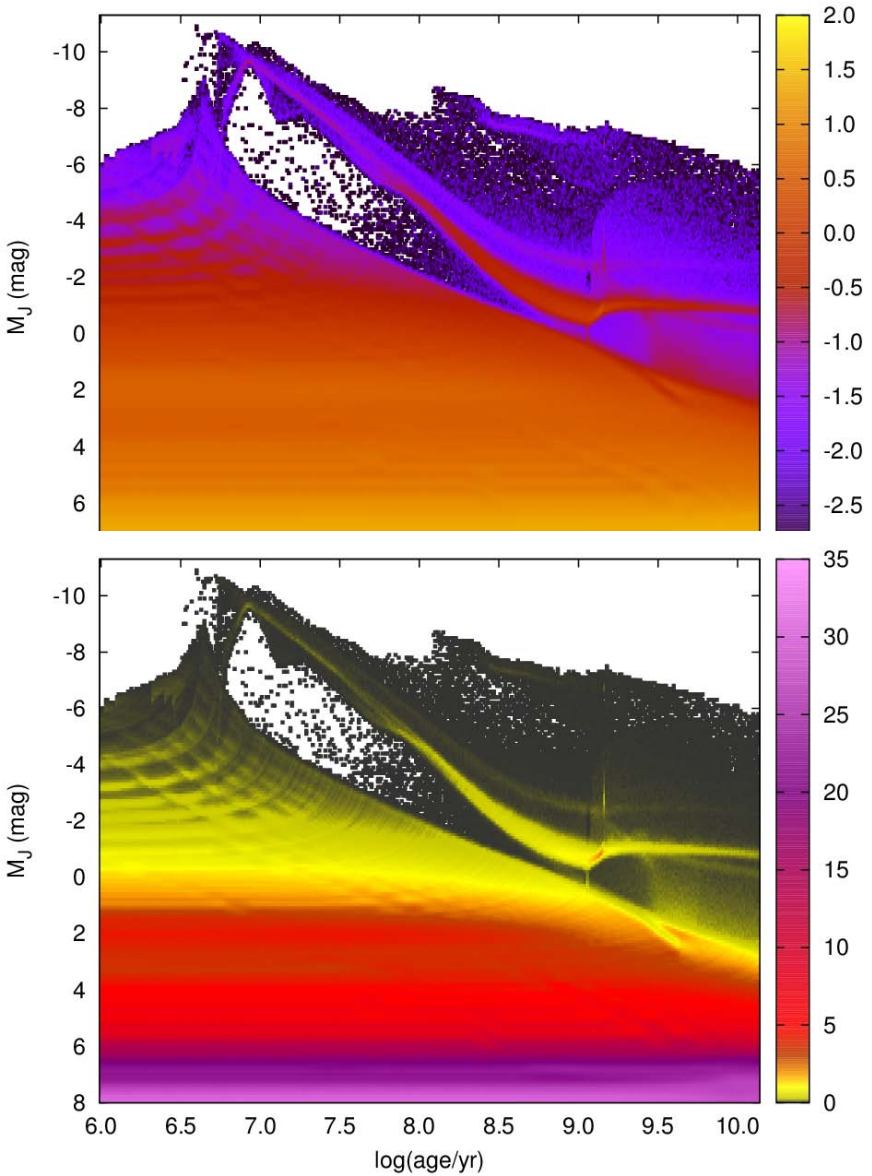
Geneva isochrones: Lejeune & Schaerer 2001; Ekström et al. 2012.
Padova isochrones for the VISTA system (Girardi et al. 2012).
PMS isochrones: Seiss et al. 2000.
Problems with age determination – vertical lines, no main sequence turnoff, very few PMS stars.

Another approach: Age Determination of VVV Clusters from 4 Million Monte Carlo Simulations.

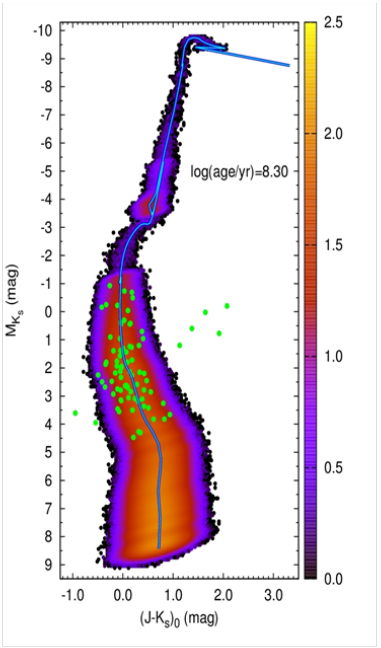
Bogdan Popescu, M. Hanson.

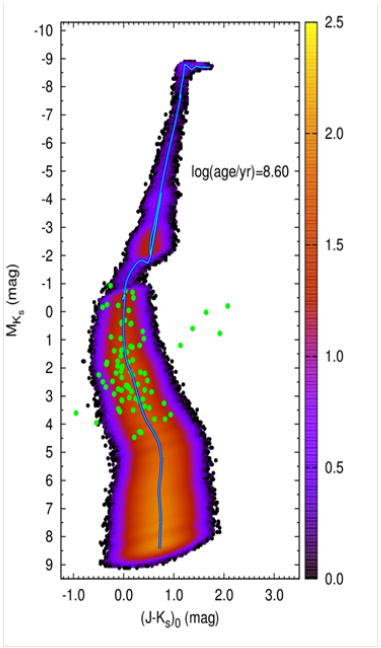
The MASSCLEAN package to perform 4 million Monte Carlo simulations in order to generate CMD templates.

Density of stars in the CMD plane.
~300 000 MASSCLEAN Monte Carlo Simulations
M_J vs. log(age/yr)
$M_{cluster} = 1000\ M_\odot$
Top: Logarithmic color scale; *Bottom*: Linear color scale.

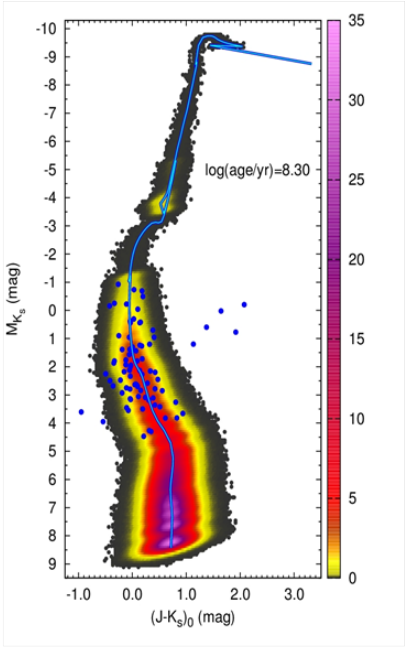


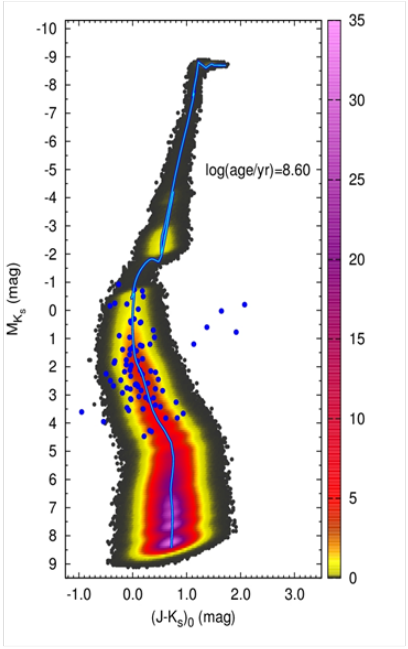
VVV CL042





30 000 MASSCLEAN Monte Carlo Simulations, logarithmic color scale. (all stars above 0.15 $M_\odot$)

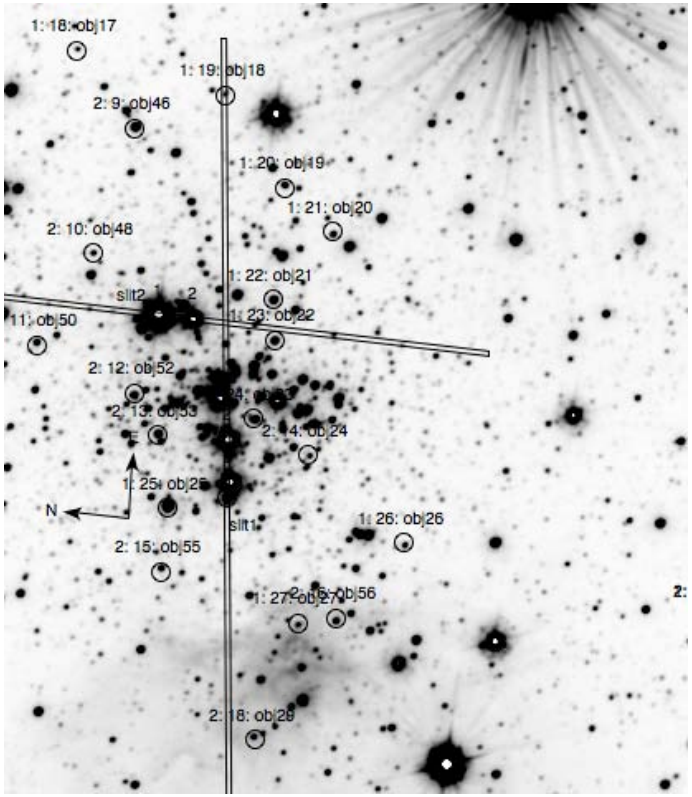


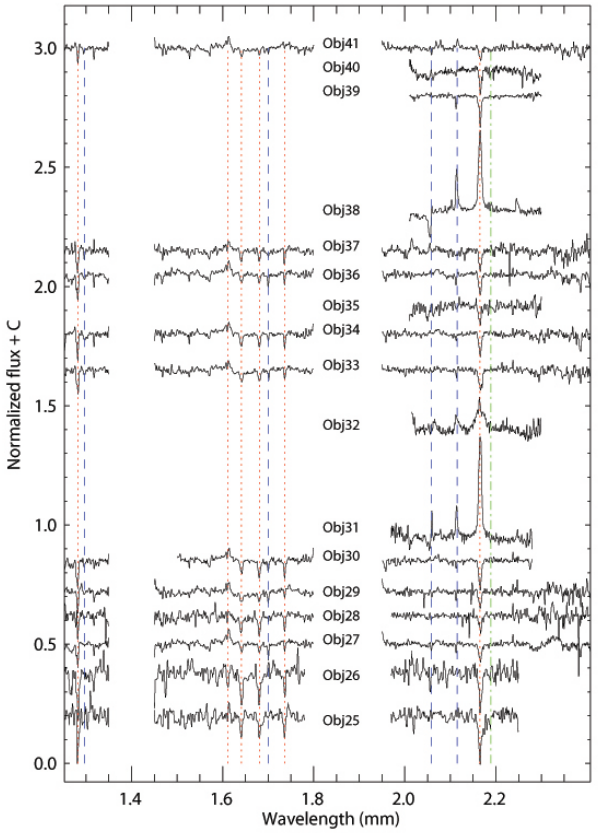


Same as previous, linear color scale. (normalized per 1000 $M_\odot$ cluster per 0.1 mag)

Cluster Characterization Methods

Reddening, distance: Spectroscopic parallax:
Low resolution spectra in K, and J+H (when available) bands –
ISAAC, VLT, SofI, NTT, ESO;
SOAR, MMIRS, Clay, Magellan, LCO.

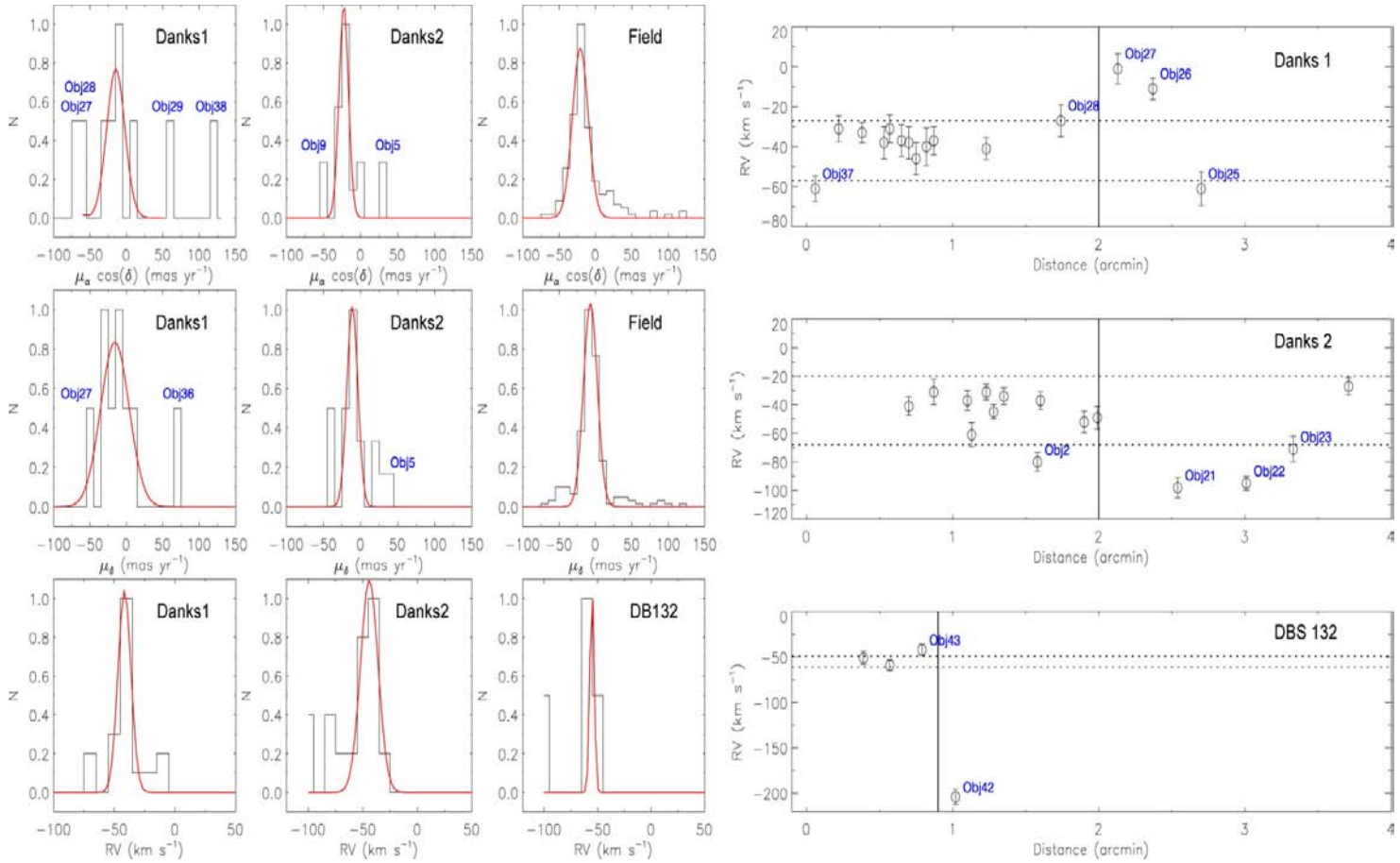




Low resolution spectra of Danks1 (Chenè 2012)

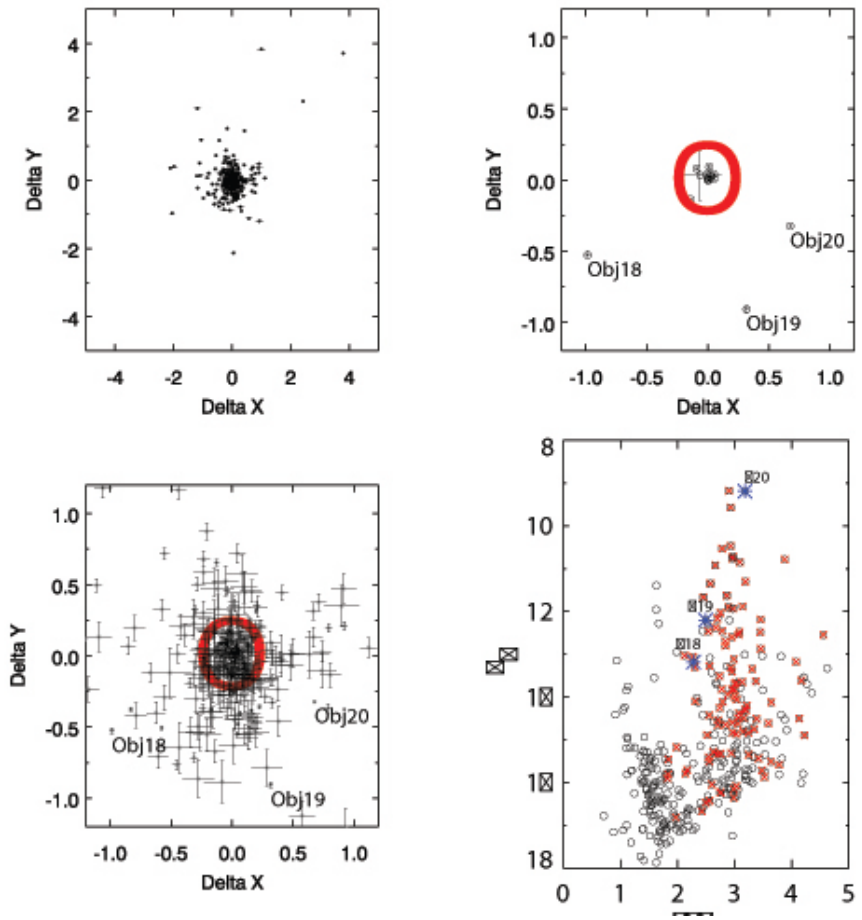
Cluster Characterization Methods

•Proper motion – memberships – for the moment: PM catalogs
•Radial velocities – memberships and RV of the cluster – binary clusters like Danks1/Danks2 (Chenè et al. 2012)



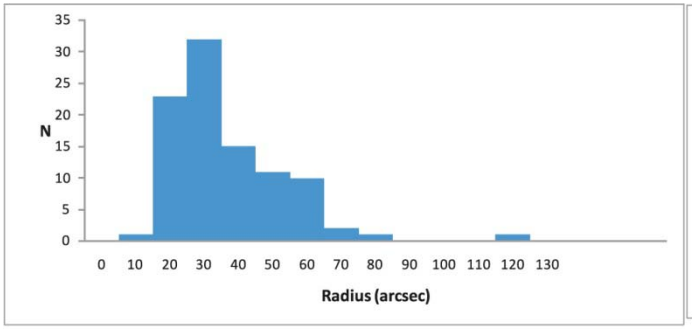
Left: Histograms and distributions of μα cos δ, μδ and RV of Danks1, Danks2 and comparison field. *Right:* Radial velocities as a function of distance from the Danks 1 (top), Danks 2 (middle) and DBS 132 (bottom) cluster centers (Chenè et al. 2012).

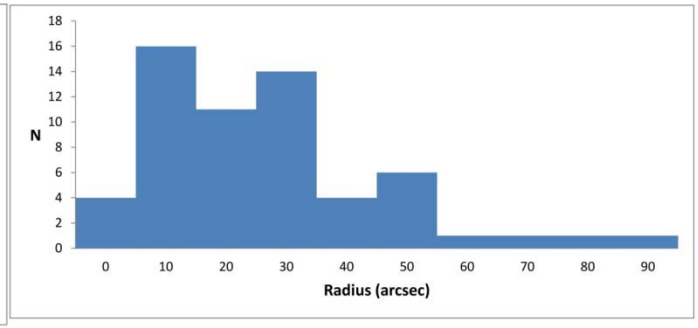
Relative proper motions with 5-6 years baseline

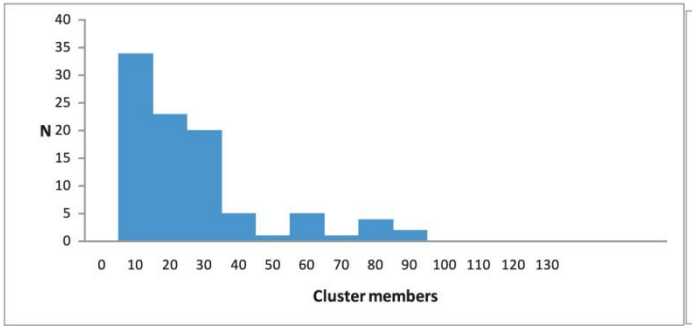


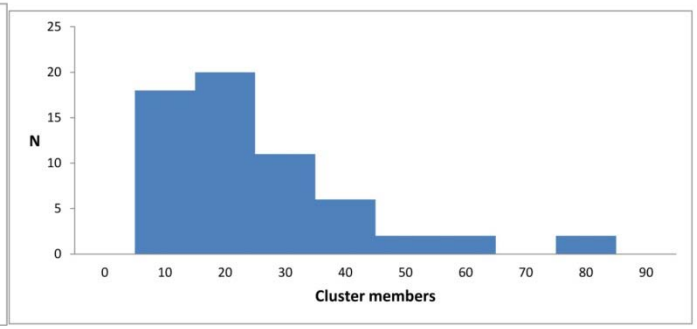
We will be more efficient with PM by the end of the VVV Survey.
Example: Relative proper motion of DBS2003 179 – distance 8-9 kpc, 5 years baseline (Borissova et al. 2012).

Characteristic of the sample: 153 newly discovered clusters.









Upper panel: Distribution of the disk and central area clusters (Borissova et al 2011).
Lower panel: Histogram of the cluster sample by number of most probable cluster members (Borissova el al. 2012).

The mean radius of the disk sample is 34”±18
The mean radius of the central area clusters 26”±14.

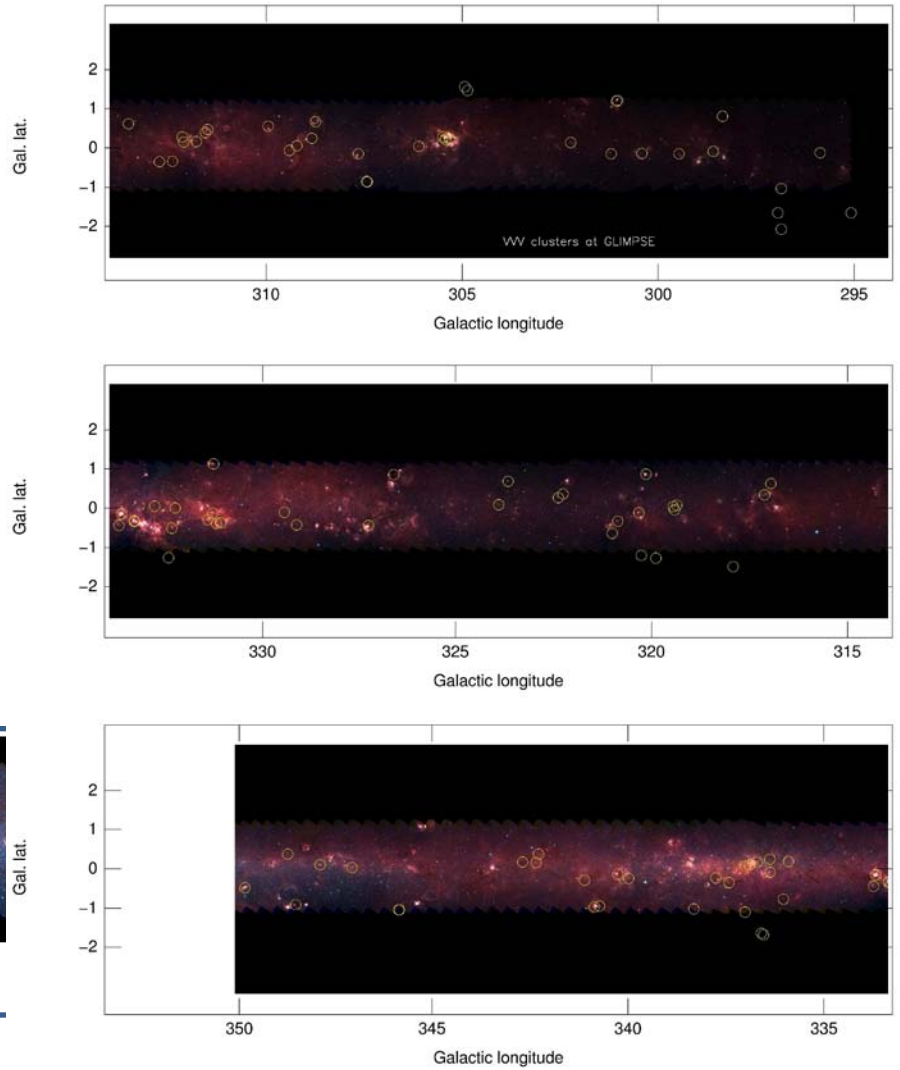
Smaller than the mean values of 47” ± 17 , and 42” ± 22 From Dutra et al. (2003) and Mercer et al. (2005) clusters for the VVV area.

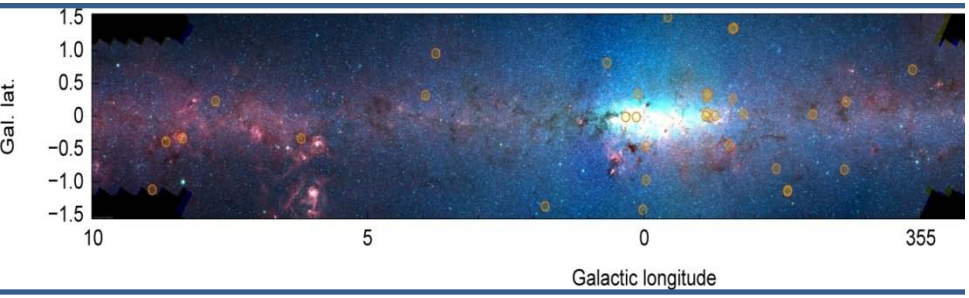
Most of the clusters have a radius between 20 and 30”

Faint and compact clusters.

Constraining the Galactic structure with stellar clusters in obscured HII regions.

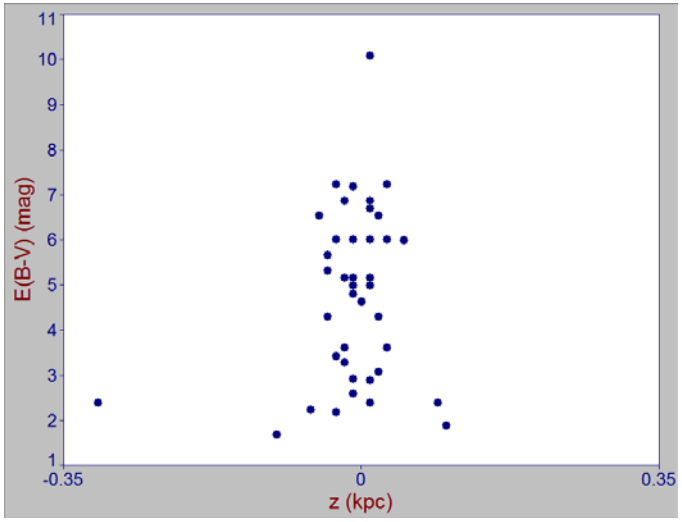
Correlation between GLIMPSE dust structures and projected position of our star cluster candidates.
Sample: 153 newly discovered clusters.





The VVV survey area, overplotted on the GLIMPSE 3.6, 4.5 and 8.0 μm true color image, with the new star cluster candidates positions(Borissova el al. 2011, plot R. Barba).

Galactic structure: Reddening, age

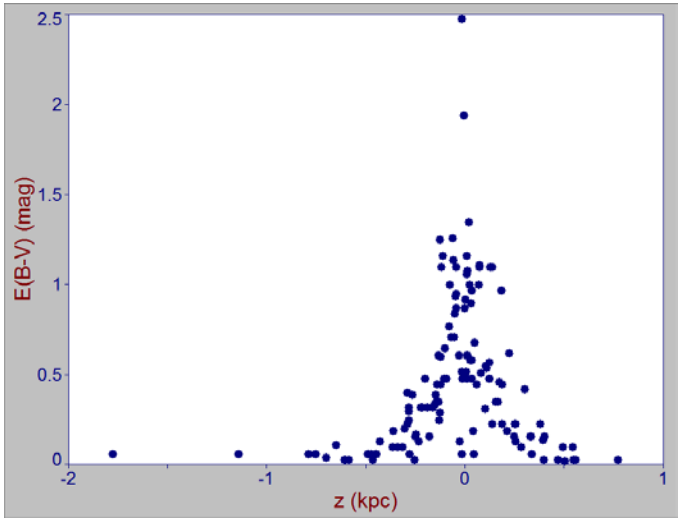


VVV sample

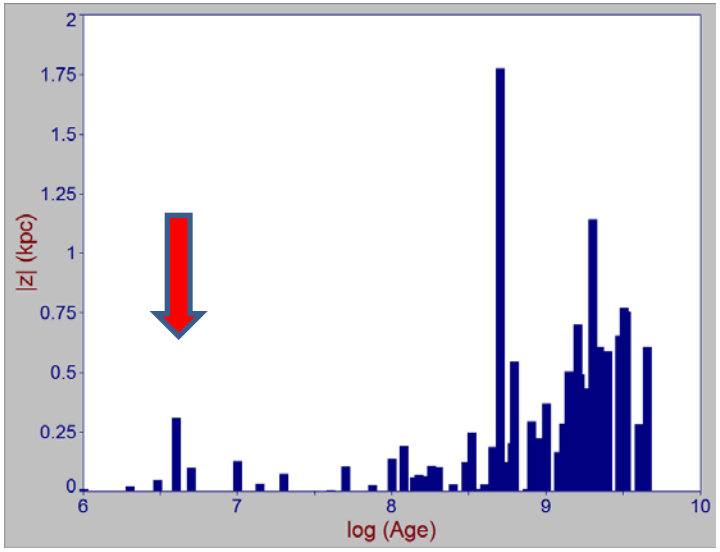
VVV sample
43 clusters
age < 10 Myr
Location: within Z±0.1
Average reddening:
E(B-V)=4.8 ±1.9

- Comparison with Bukowiecki et al. 2011 – homogeneous sample of 754 open clusters in 2 MASS
  E(B-V)=0.68
- Comparison with Tadross et al. 2011- homogeneous sample of 134 optically visible open clusters.
  E(B-V)=0.46 ±0.42.

The same trend in all samples: E(B-V) decreases with increasing |z| in our case like $E(B-V)=a+b|z|^2$

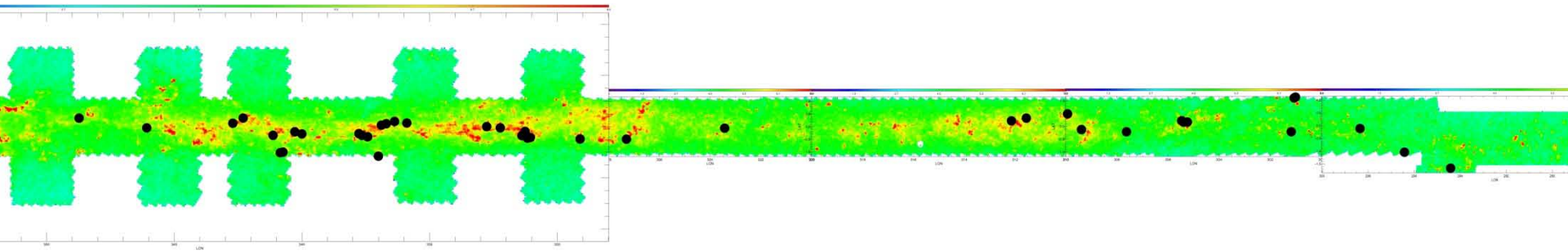


Tadross (2011) sample



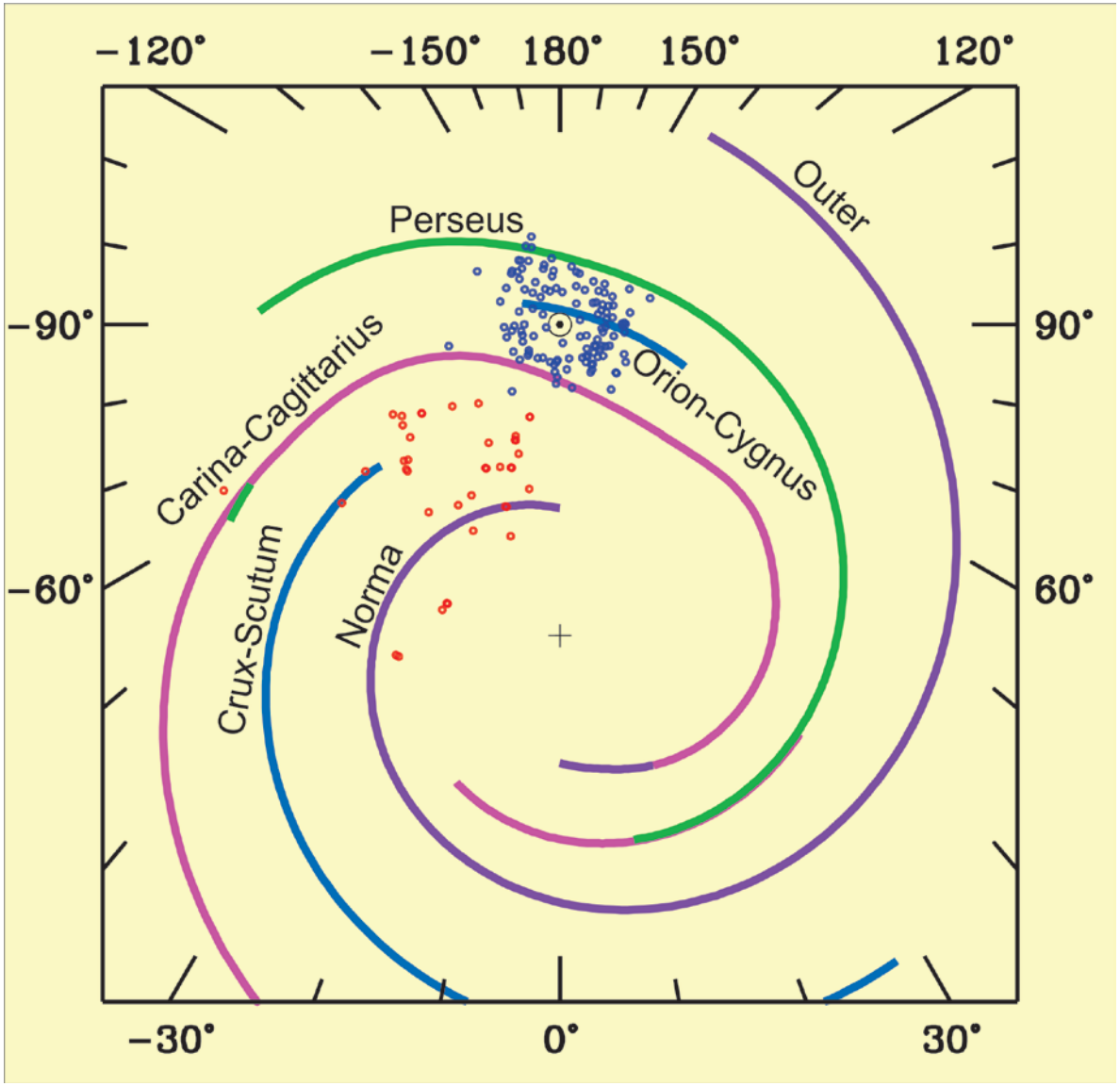
Tadross (2011) +VVV sample

Two dimensional Extinction Maps of the Galactic Midplane.



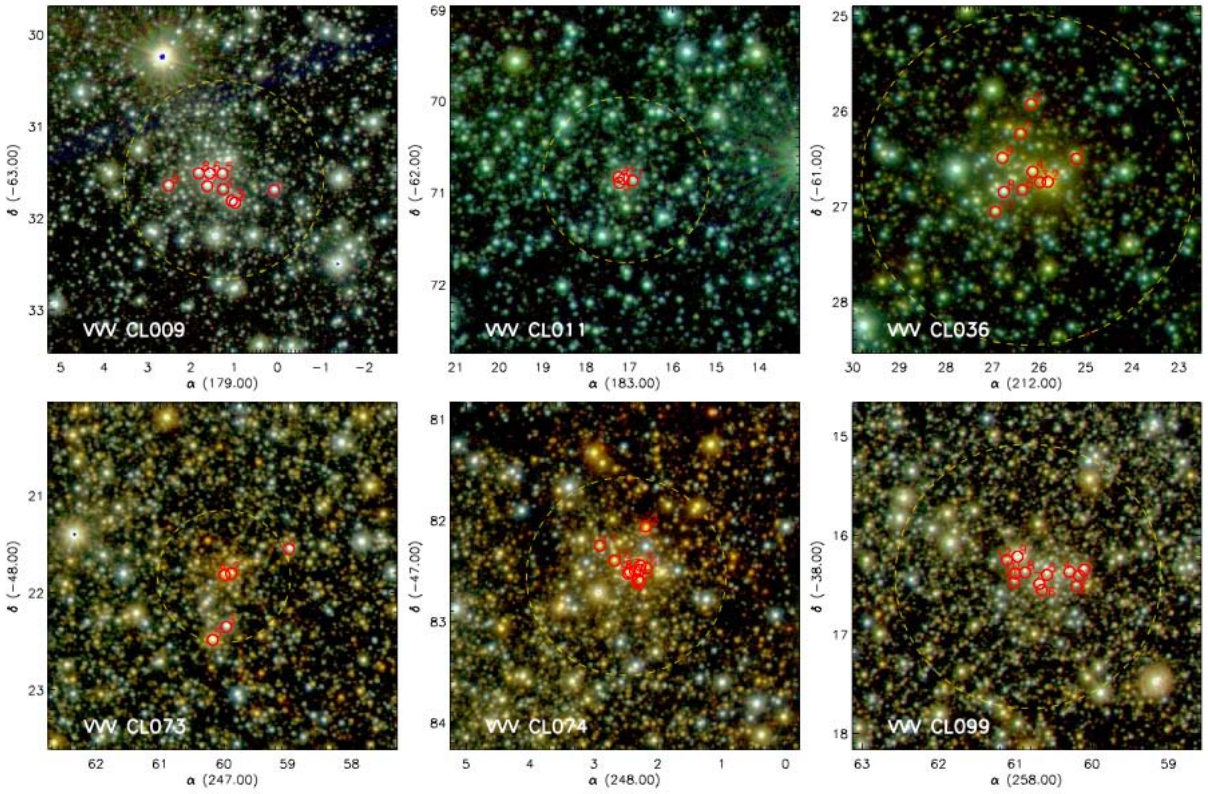
The extinction maps are in units of A(Ks) derived from all stars counts using GLIMPSE-I/-II/-3D and Vela-Carina Data.
from Nidever, Zasowski & Majewski 2012, ApJS, 201,35.
Dots: 43 VVV clusters.

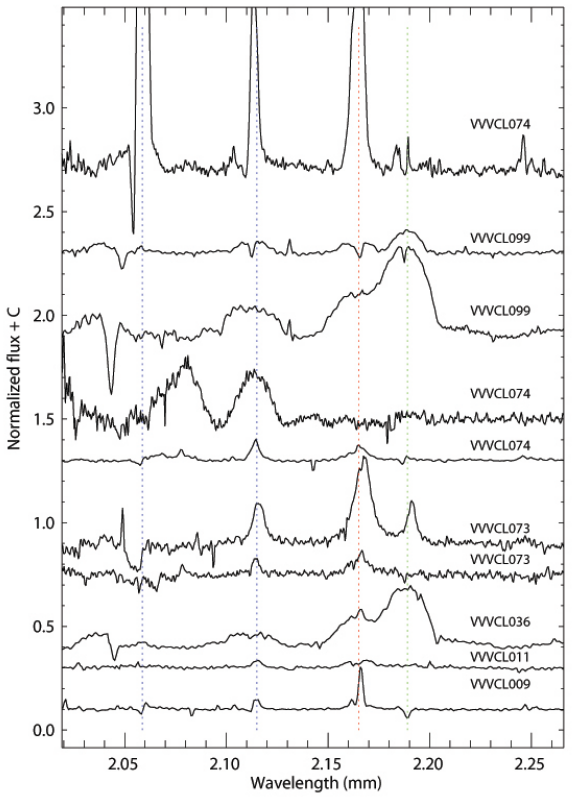
Tracing the spiral structure



VVV 43 clusters + Tadross 2011 sample.

Six new clusters containing WR stars





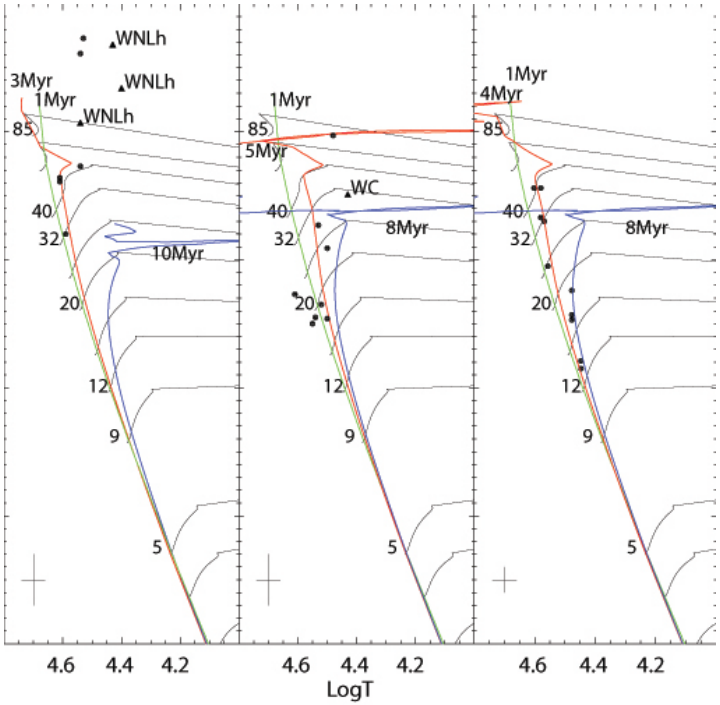
According to Galactic WR catalog ver1.3, Oct. 2012 there are 37 clusters containing WR stars – 16% more.

Chené et al. (2012)

Massive stars themselves

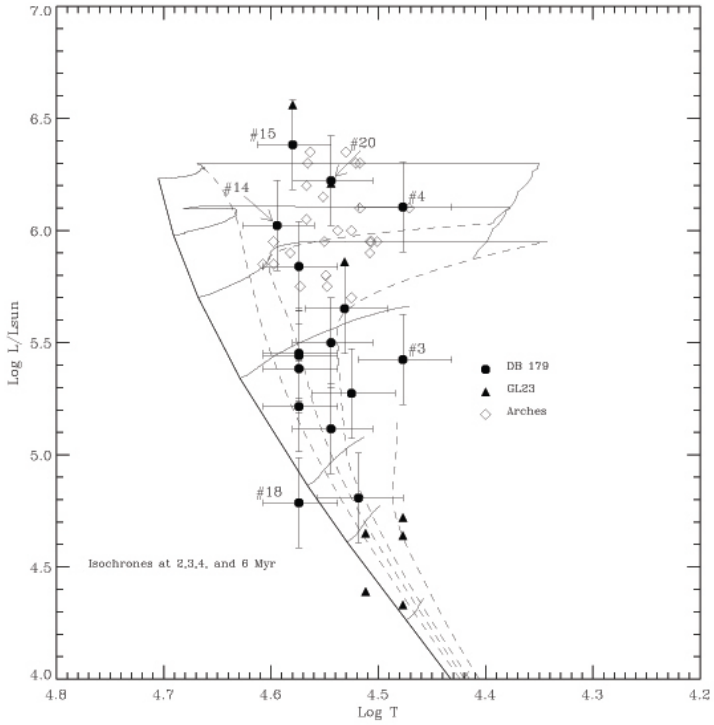
Massive stars are rare objects - more exoplanets are known than WR stars!

The most massive stars OIf and WR are younger by approx 2 Myr from OB Main Sequence stars.



The HR diagram for Dank1, Danks2 and RCW 79.

The same trend was reported by Liermann et al. 2012 for Quintuplet cluster.



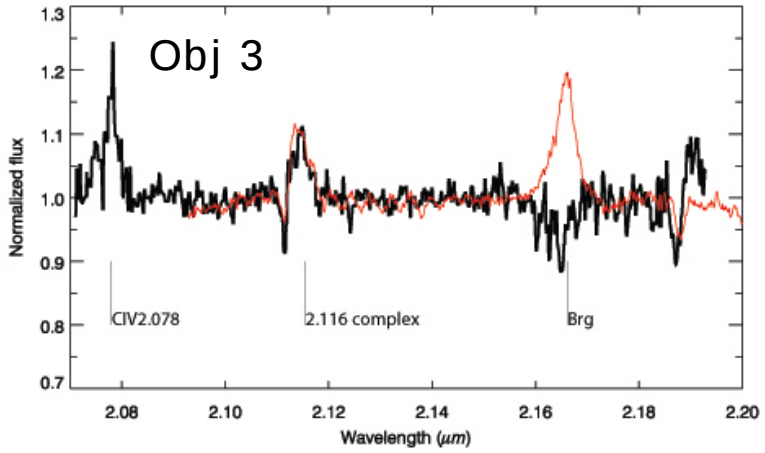
The HR diagram for DB2003 179, Mercer 23 and Arches.

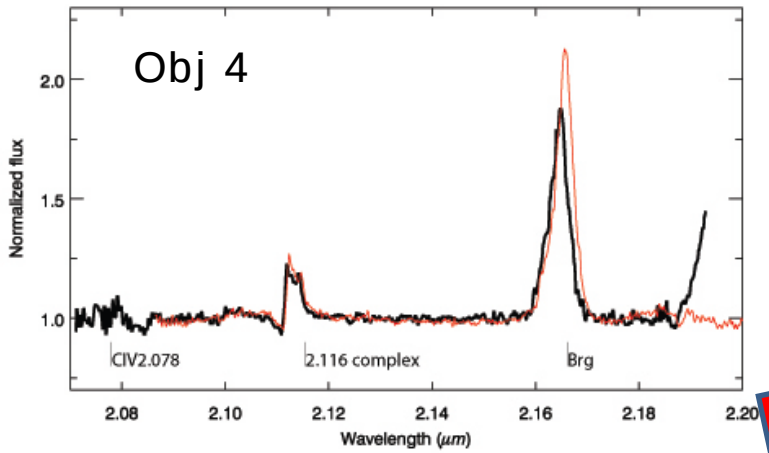
The most massive stars are formed in a different way as a second generation?

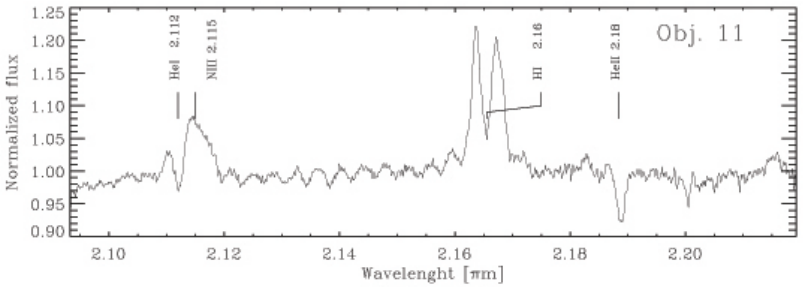
For example, the stars are formed by merging of less massive stars rather than from interstellar material?

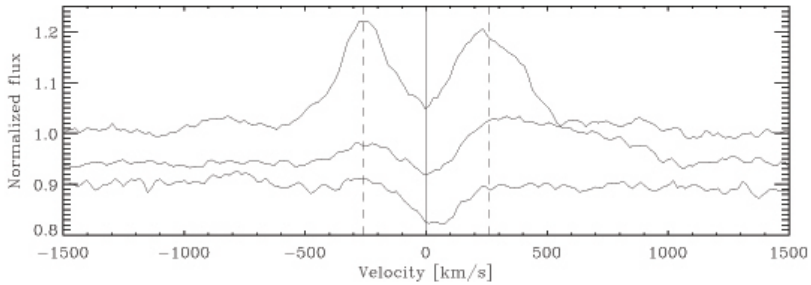
Or we have to constrain the models?

Exotic Post-MS objects:
Many of these clusters contain rare Post-MS stars (Ofpe, WR, RSGs).

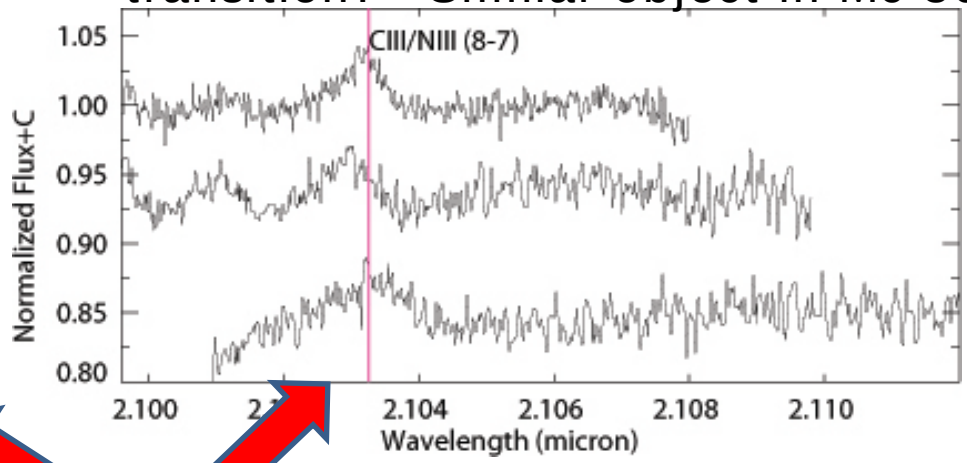








Obj11 – binary or a star in transition? Similar object in Mc 30.



Obj3: a star in transition? Like Of?p stars (Walborn & Howarth 2007), only 5 in Galaxy. (Borissova et al. 2012)

Obj 4, Ofpe/WN9 – binary?

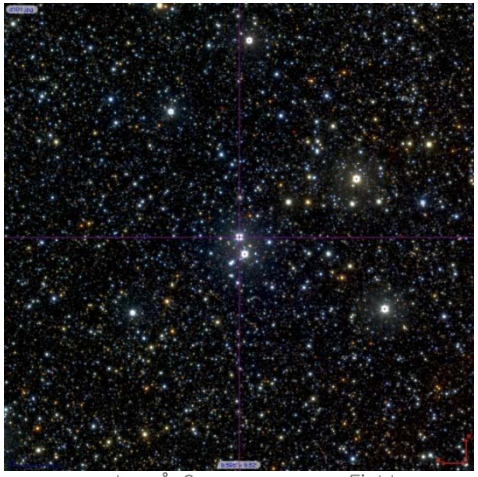
Star forming regions – exploring large VVV FOV.

- G305:12 early B stars with distances that are comparable with Danks 1 and Danks 2 - runaway stars or larger association of young stars surrounding Danks 1 and 2, formed within the same molecular cloud? Three new young star clusters and/or stellar groups: VVV CL023, VVV CL022, VVV CL021.
- G347.6+00.2: several early OB stars around – association? PMS and IR - excess stars, triggered star formation? No new clusters.
- G345: DBS 110, DBS 111, DBS 112, DBS 113, DBS 114, DBS 115 and DBS 117.

From Borissova et al 2012, Chenè et al. 2012, Baume et al. 2011.

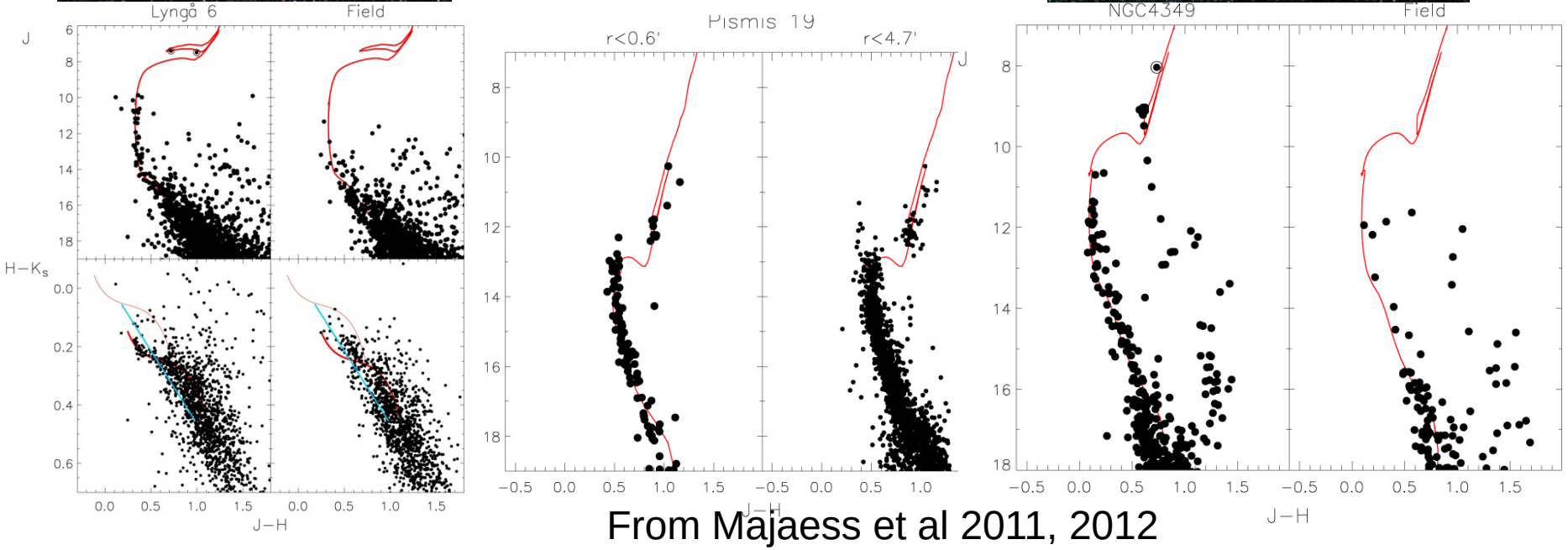
Cepheid distance scale in the Galaxy.

Linga 6



Pismis 19

NGC 4349



From Majaess et al 2011, 2012

Future work:

Automatic search for least concentrated and older clusters.

Completing the sample (~100) with HOMEGENIOUSLY derived fundamental parameters.

Time domain:

- for variability (+ proper motions)
- runaway stars

Thank you.

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