A WISE Study of Clusters

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What is the wise way of studying clusters?

WISE!

(Wide-field Infrared Survey Explorer)

Clusters?

Our Clustering?

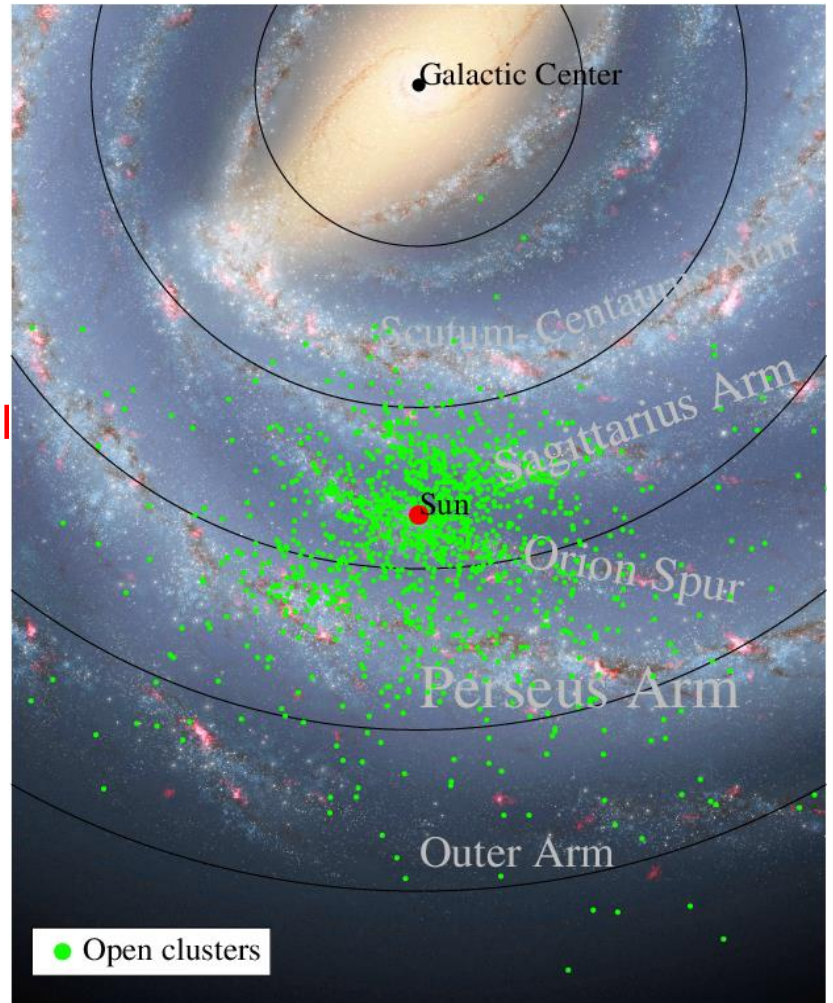
Part 1. A WISE Study of Star Clusters

(Jinhyuk Ryu et al. 2015, in prep)

Where are they?

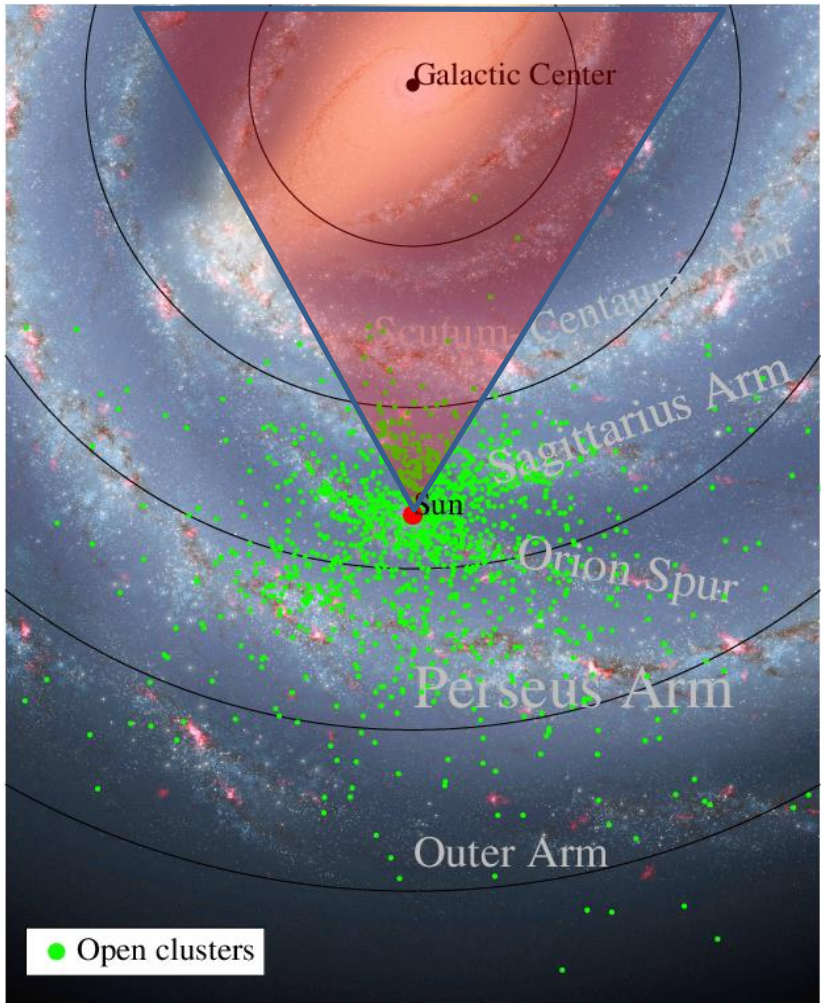
- Star clusters are a good tracer to study structures of the Milky Way. However, known clusters are mostly located in the solar neighborhood.
- Open clusters: N= 2,168
  (Dias+02, 2014 ver.)
- Globular clusters: N= 157
  (Harris 1996, 2010 ver.)
- Embedded clusters: N~ 200
  - Bica+03, Mercer+05, Borrisova+11, Morales+13, and more refs.
- **An estimated number of enti**
  open clusters in the MWG
  ~ 100,000 (Roeser+10)

- **Then, where are those unknown clusters?**



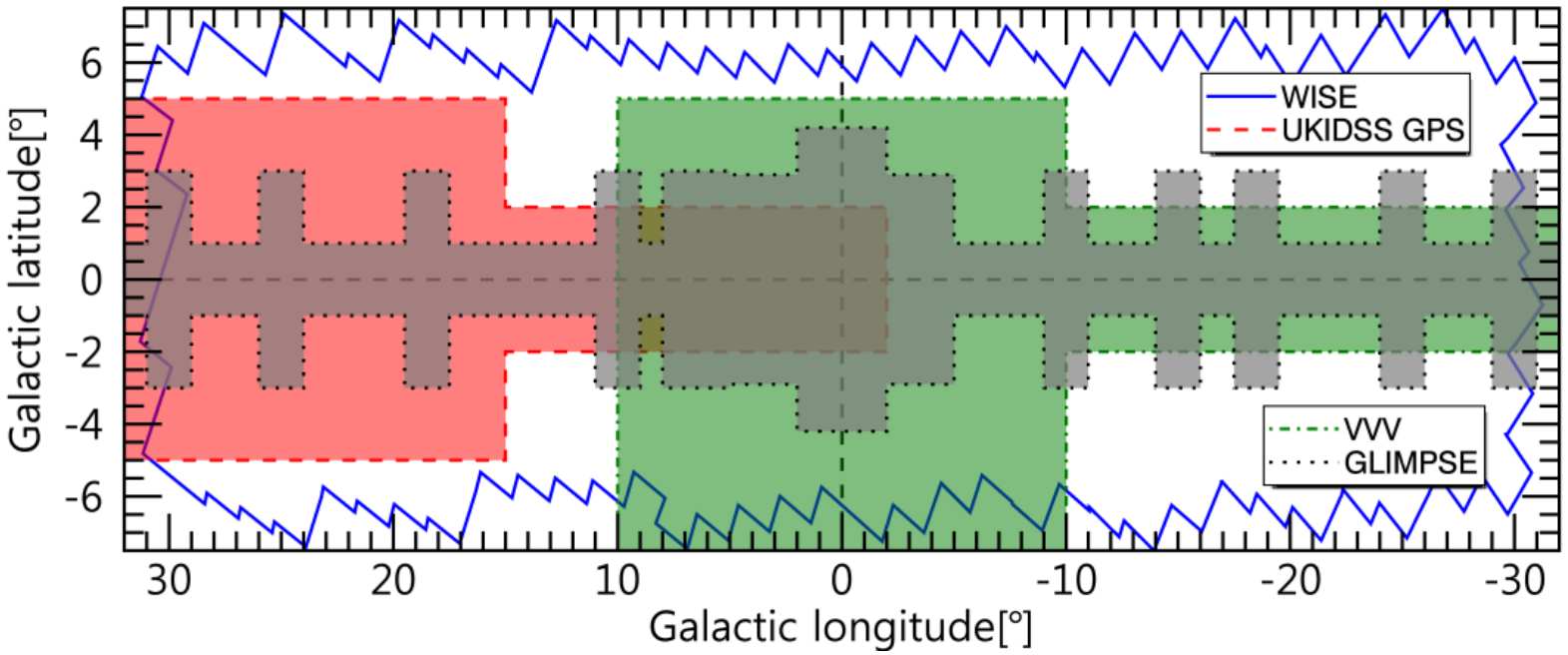
Where to find?

- The Galactic center direction
  - There are 2-3 arms, a bar, and the bulge.
  - The number density of star clusters is high.
  - It is impossible to see deep inside through the Galactic plane in optical.



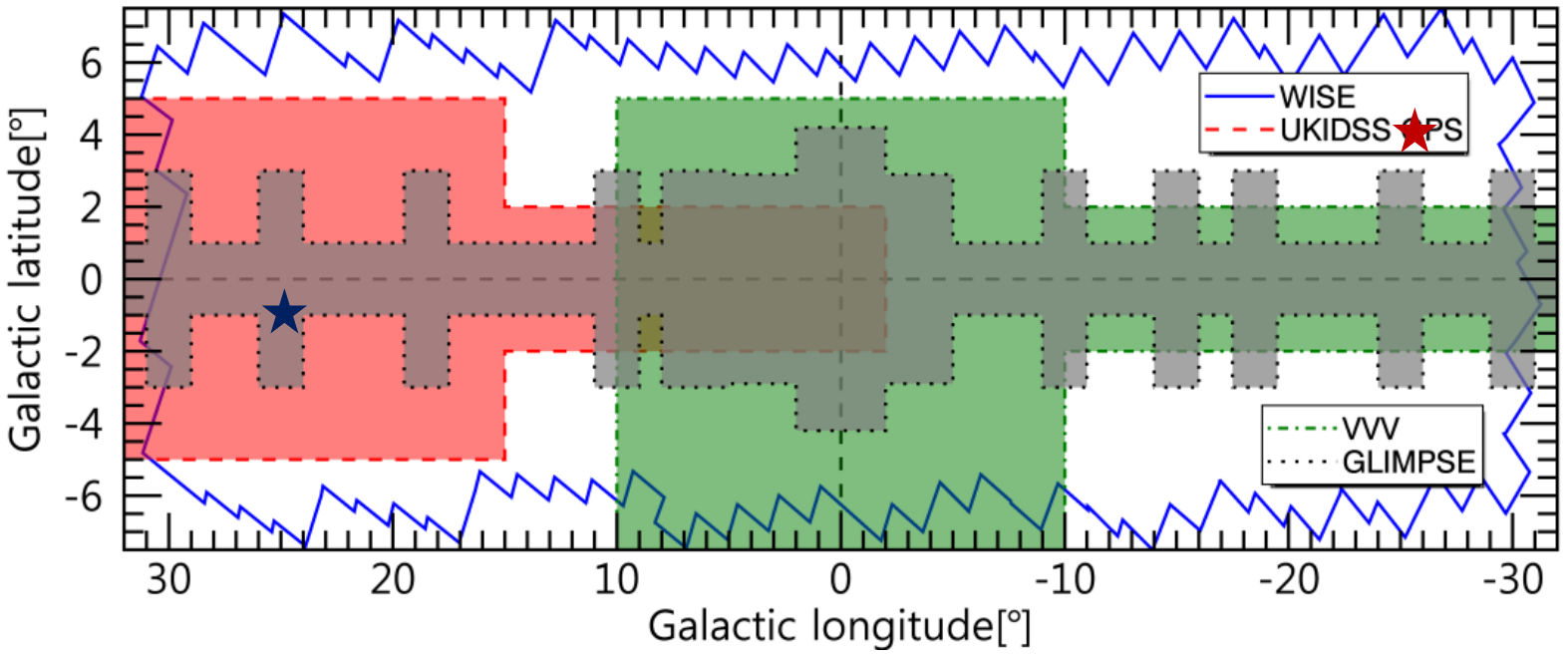
-**NIR/MIR all sky survey data in WISE is a tool to find them.**

Survey sky coverage and data



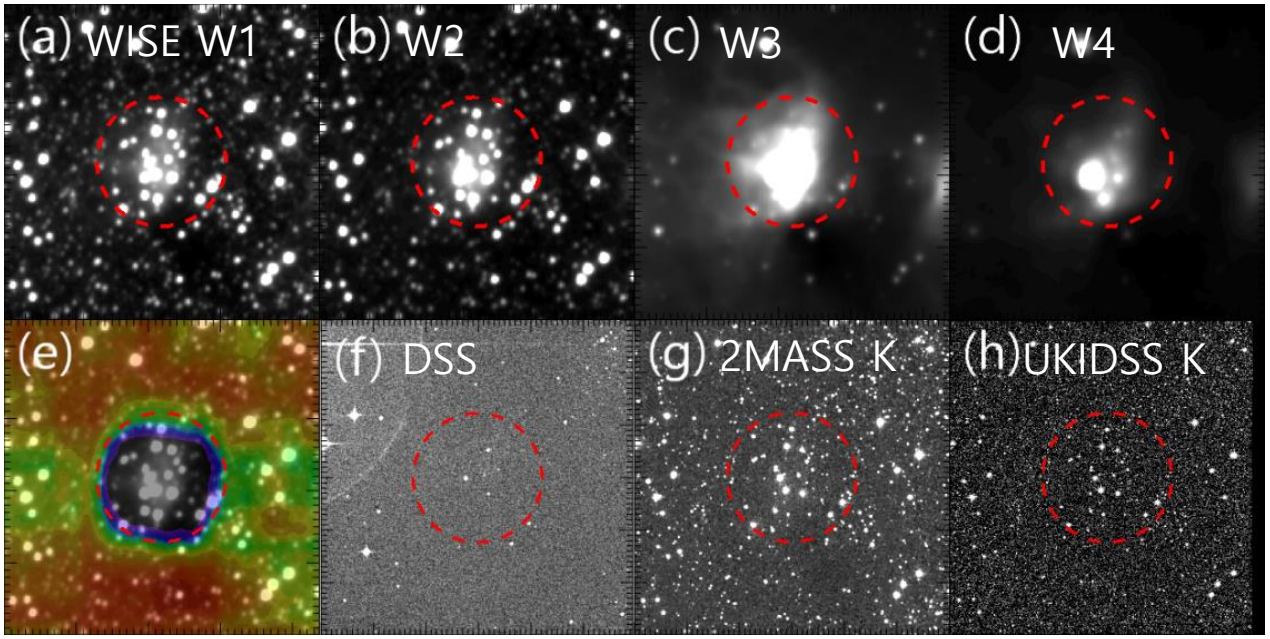
- A 720-deg^2 area ($|l| \leq 30^\circ$ & $|b| \leq 6^\circ$), consists of 334 fields. (90′×90′)
  - +2MASS (K~15)
  - +UKIDSS GPS (Galactic Plane Survey; K~18)
  - +VVV (Vista Variables in the Via Lactea; K~18)
  - +GLIMPSE

Results: New Clusters

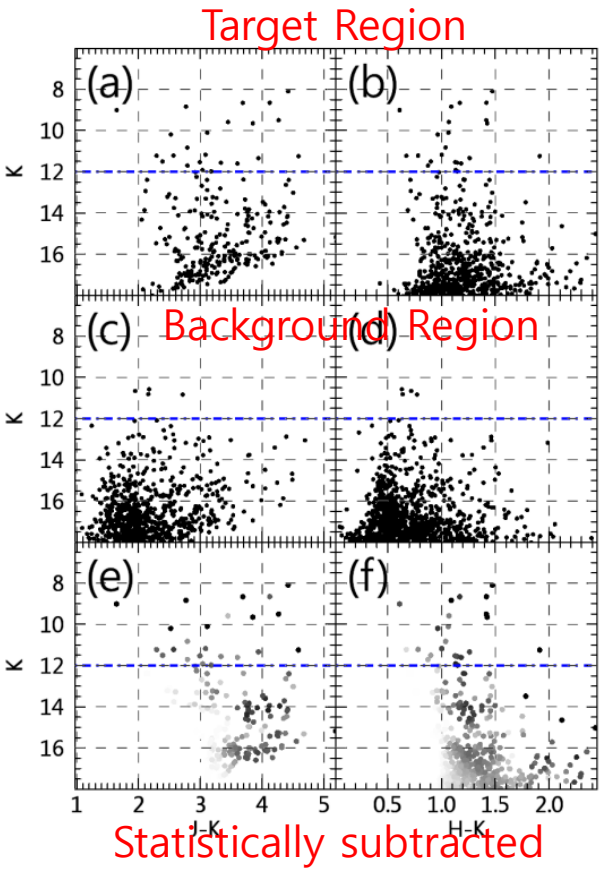


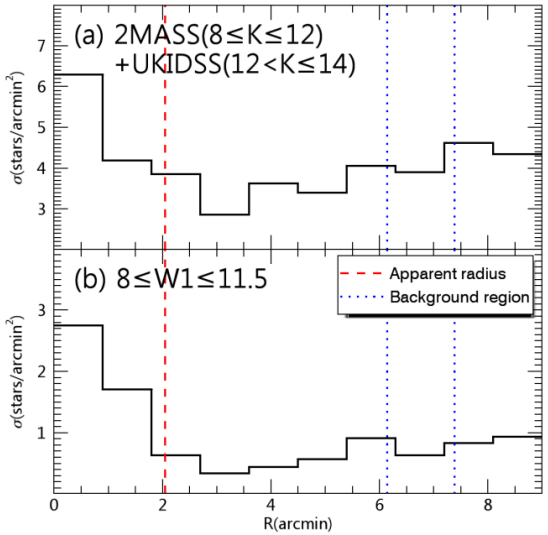
- (Method) automatic selection & visual search
- (Output) 1835 preliminary cluster candidates.
  - 163 (class A: 23, class B: 140) probable star cluster candidates.
  - 758 possible candidates (class C).
  - Two globular cluster candidates.

Sample : RL 022: embedded cluster?



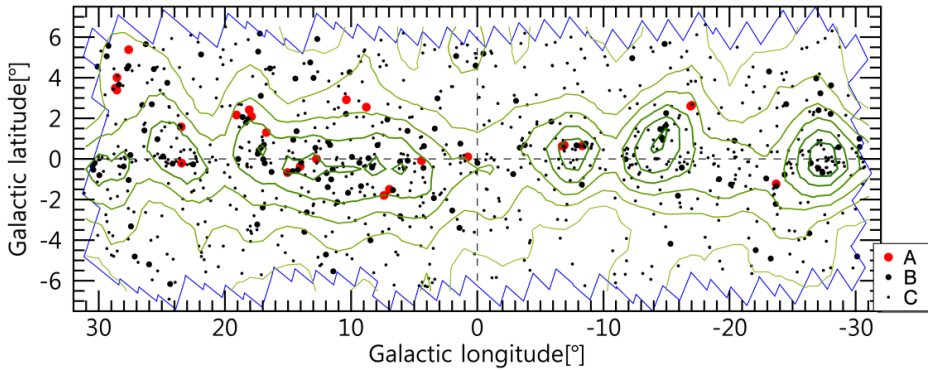
Brightness density map (W1)



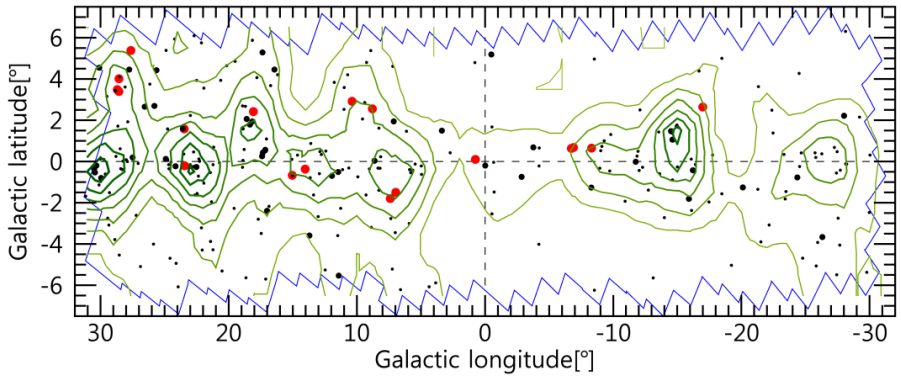


Radial Number Density Profile

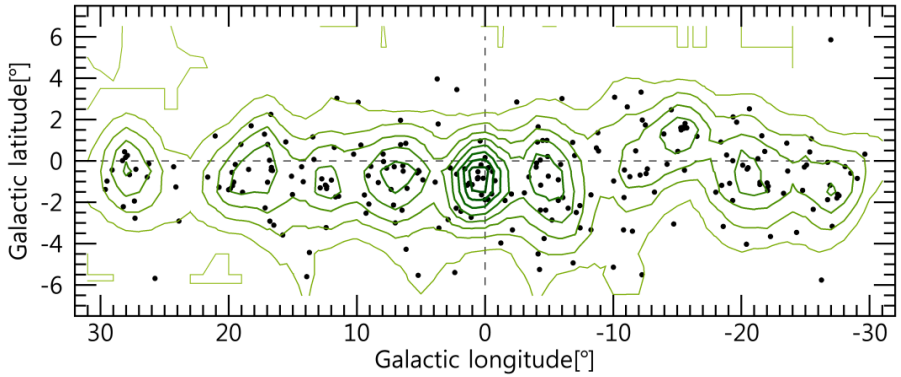
Spatial distribution of candidates



- Entire candidates (A+B+C=921)

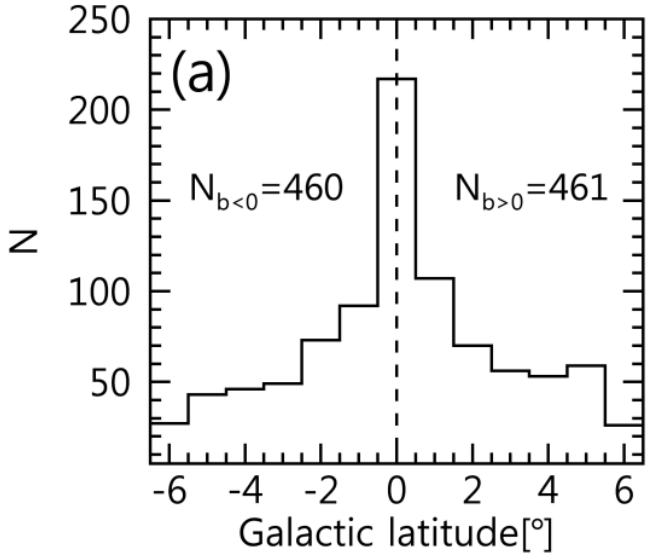


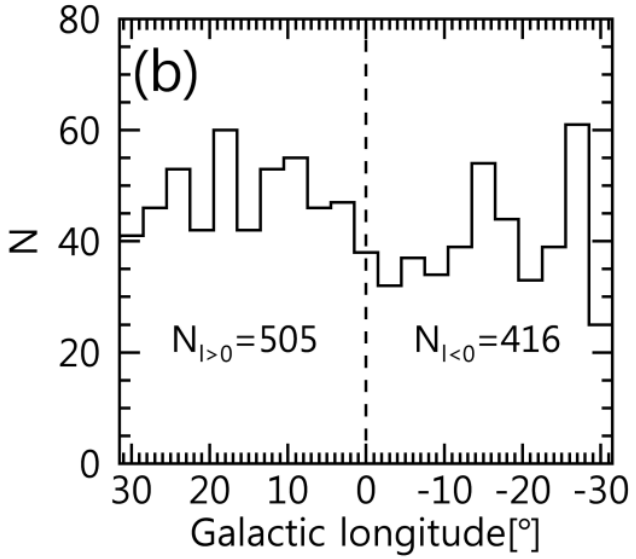
- Embedded cluster candidates (258)



- Known Open clusters

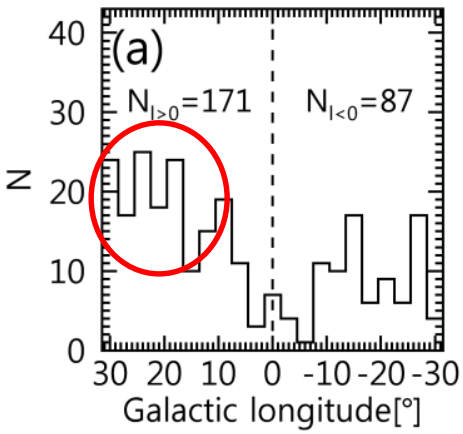
Spatial distribution of star cluster candidates



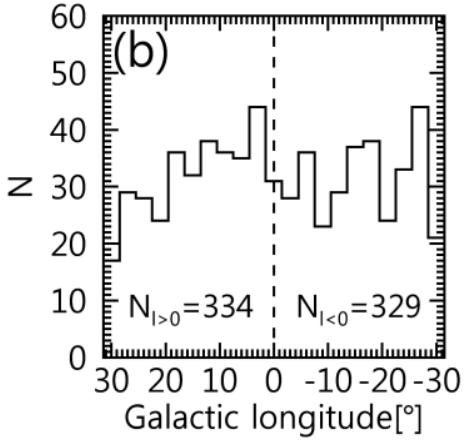


This number difference comes from embedded clusters.

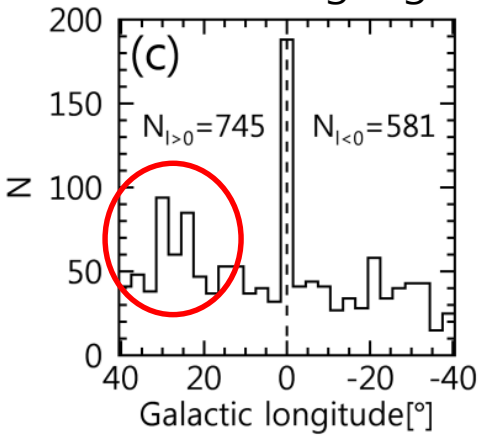
Embedded clusters



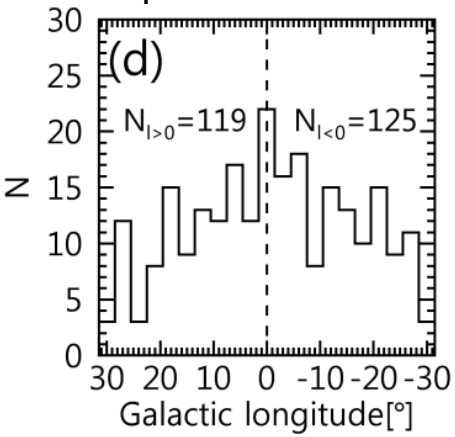
Non-embedded



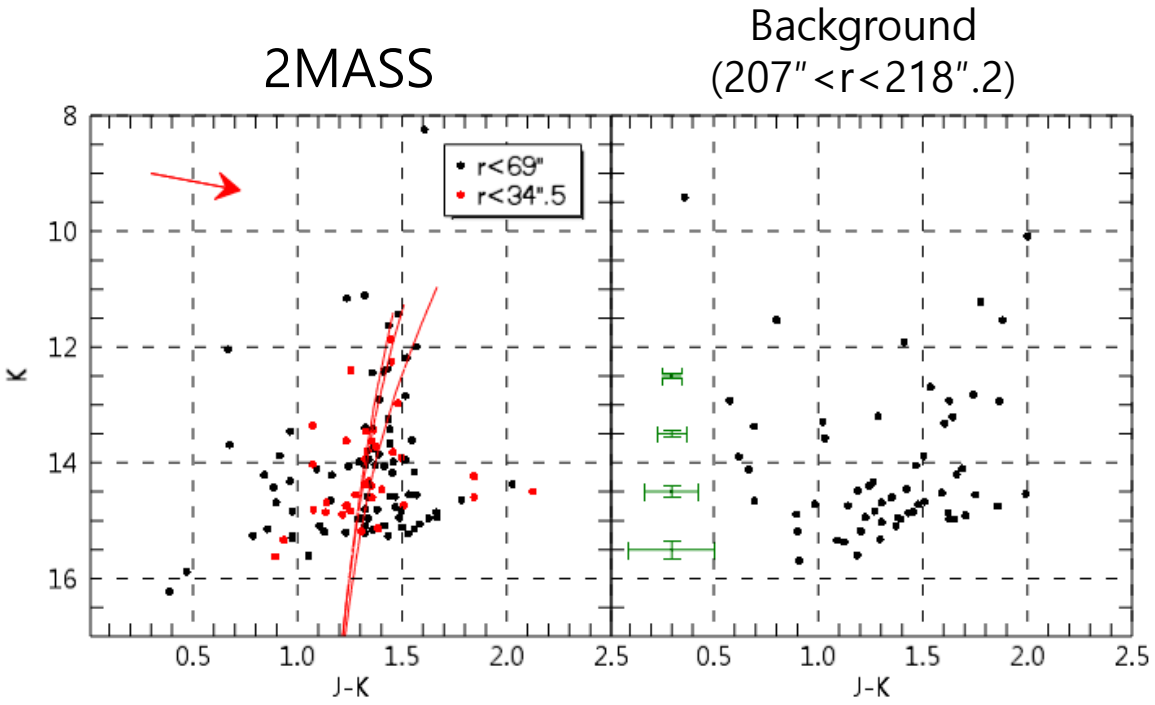
Star forming regions

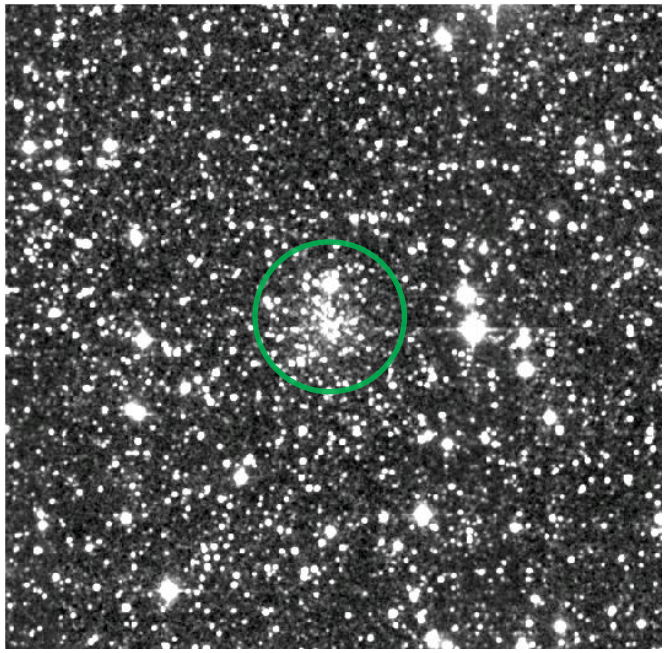


Open clusters



Globular Cluster Candidate #1





2MASS K band
(10′X10′)

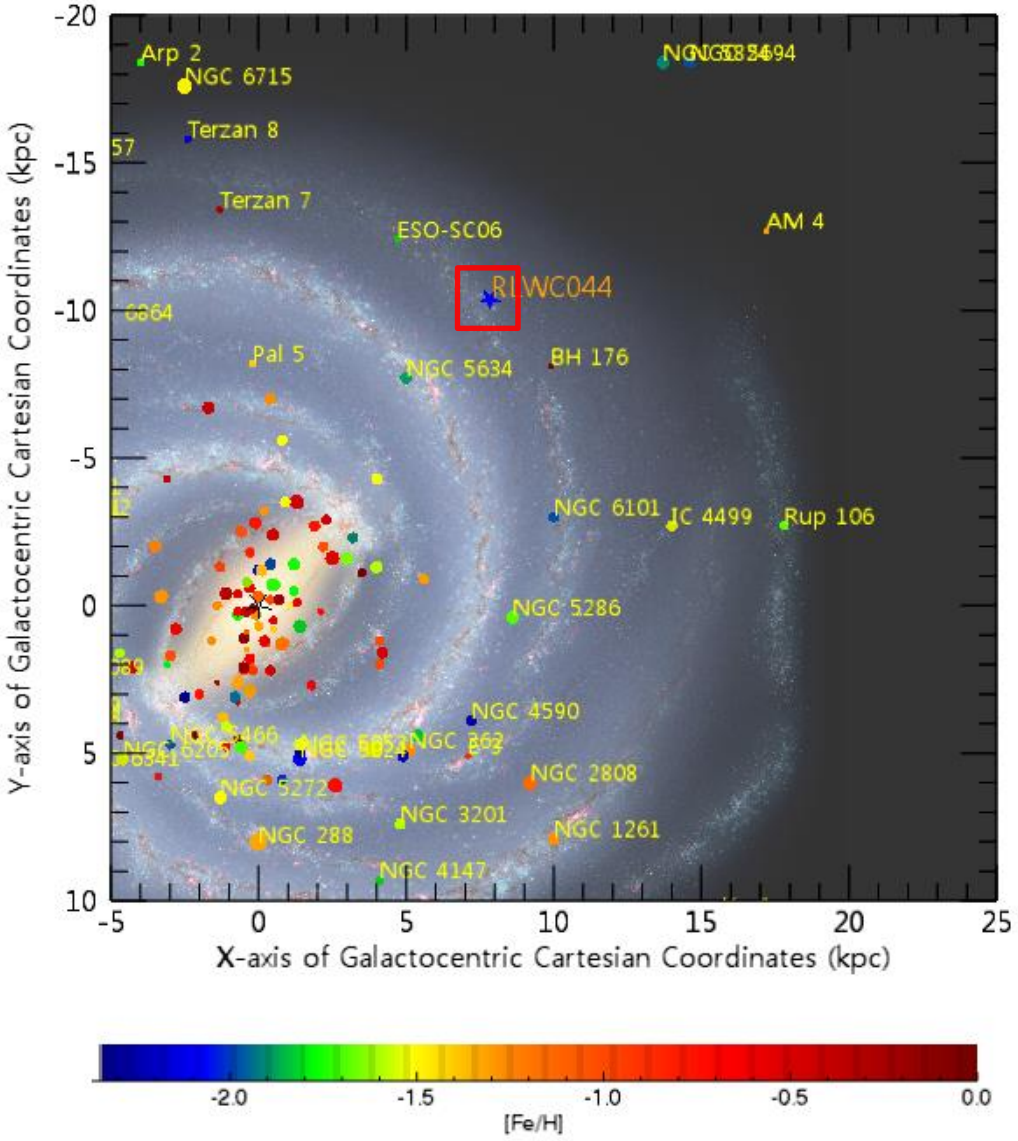
E(B-V) = 1.4

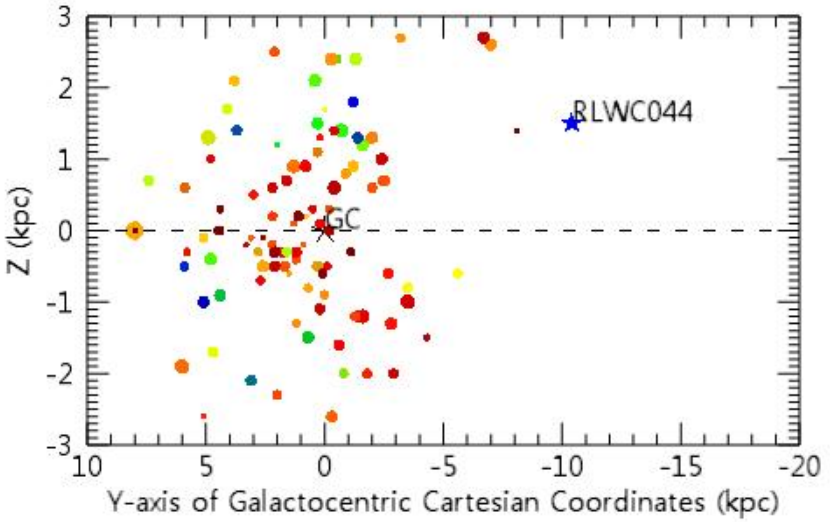
[Fe/H] = -2.0

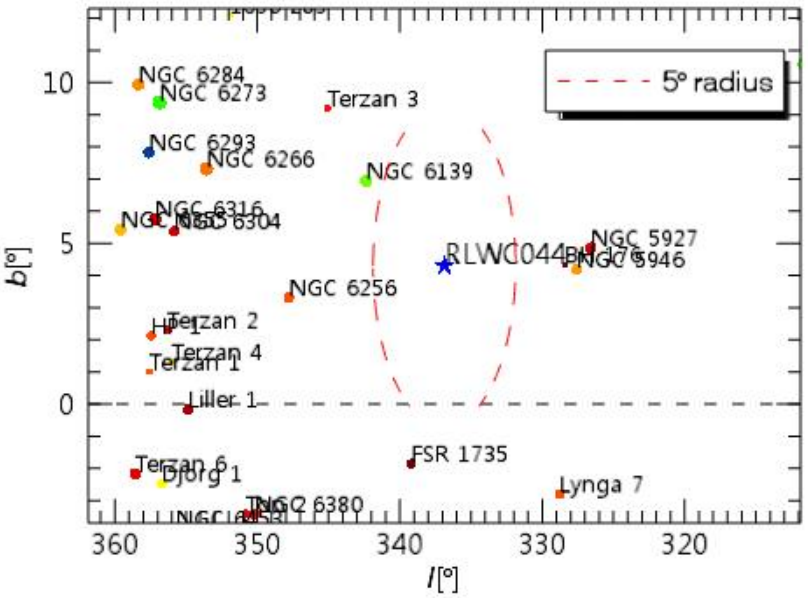
d = 20 kpc

r_H = 40″.85 (=3.88 pc)

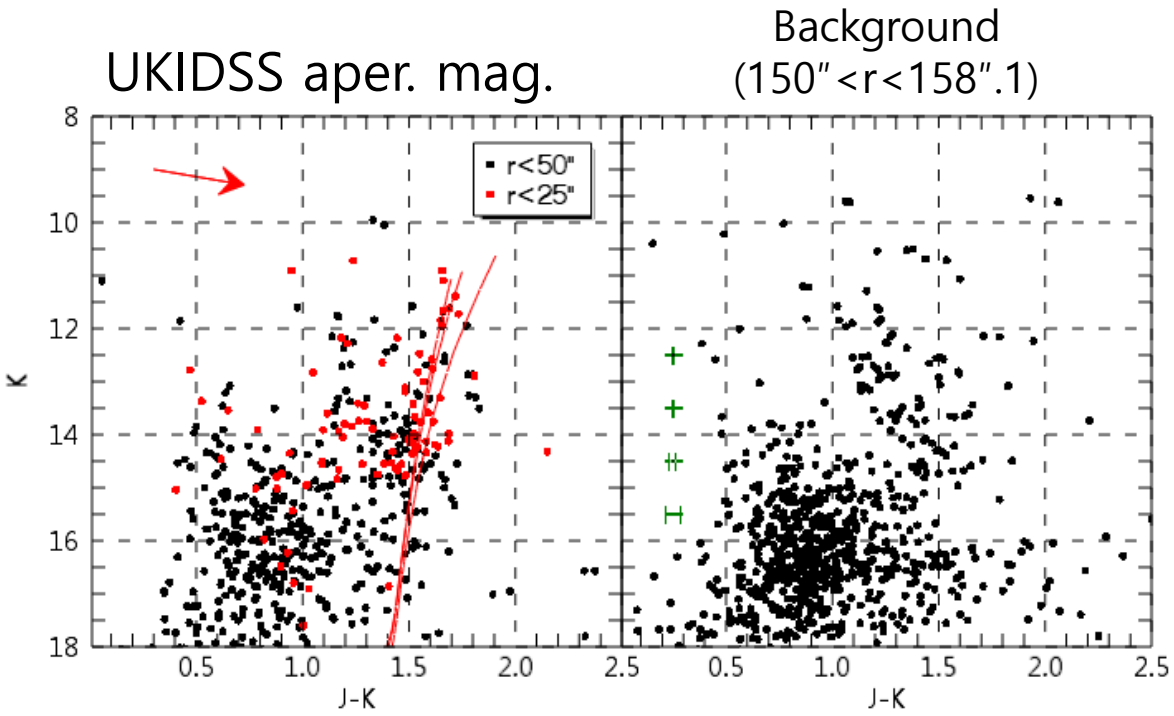
GC Candidate #1

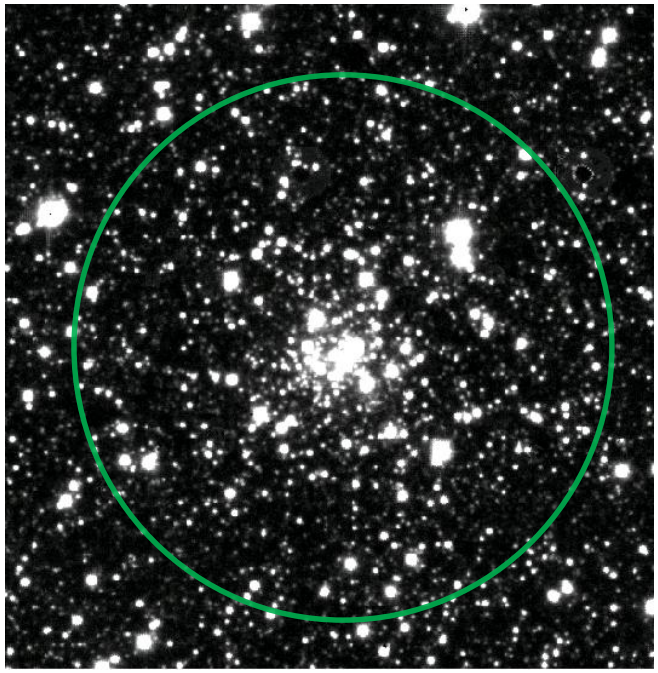






GC Candidate #2





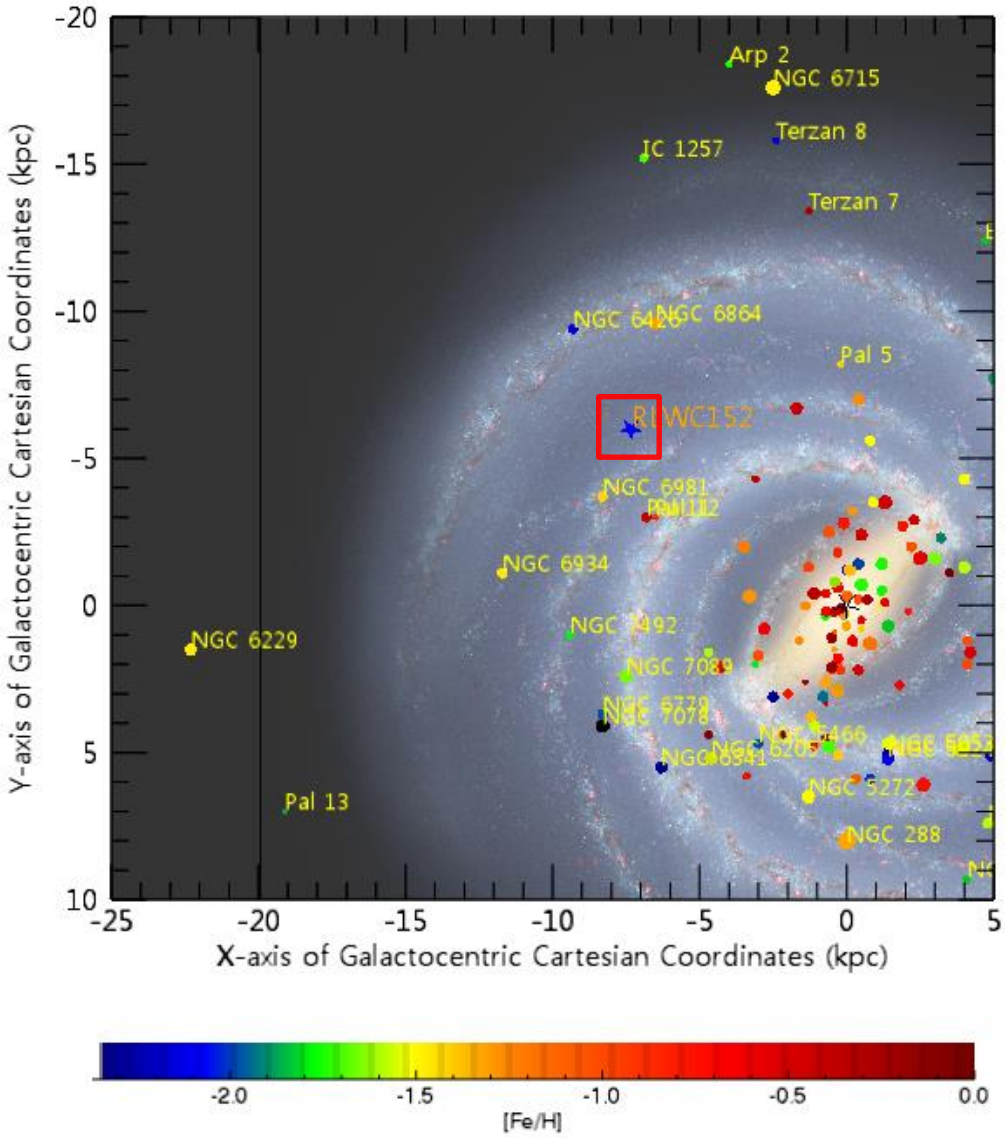
UKIDSS K band
(2′X2′)

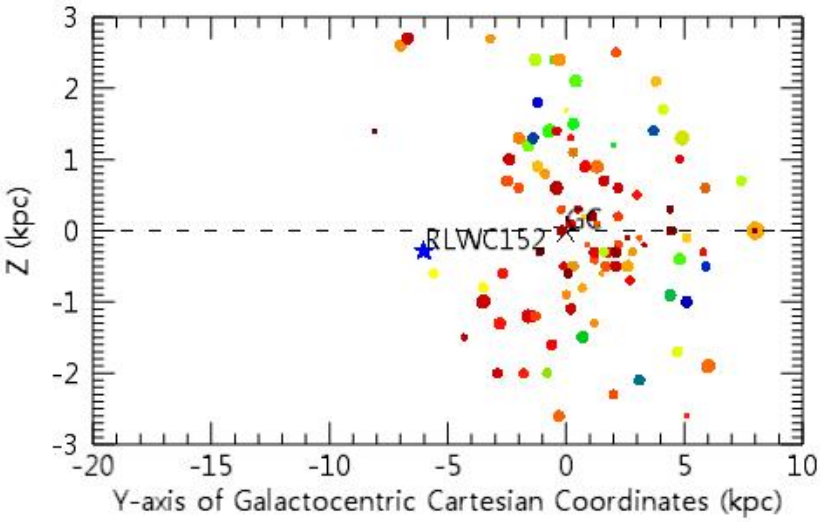
E(B-V) = 1.85

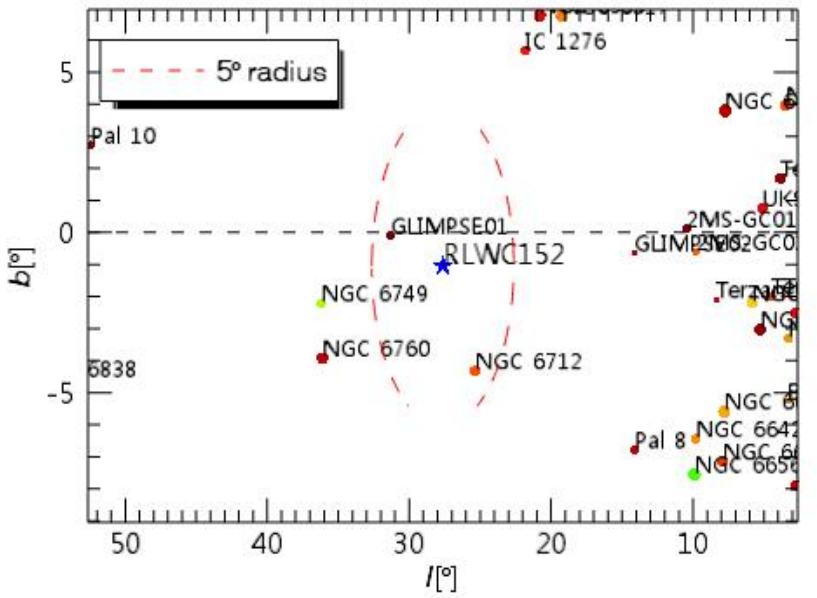
d = 15.8 kpc

[Fe/H] = -2.0

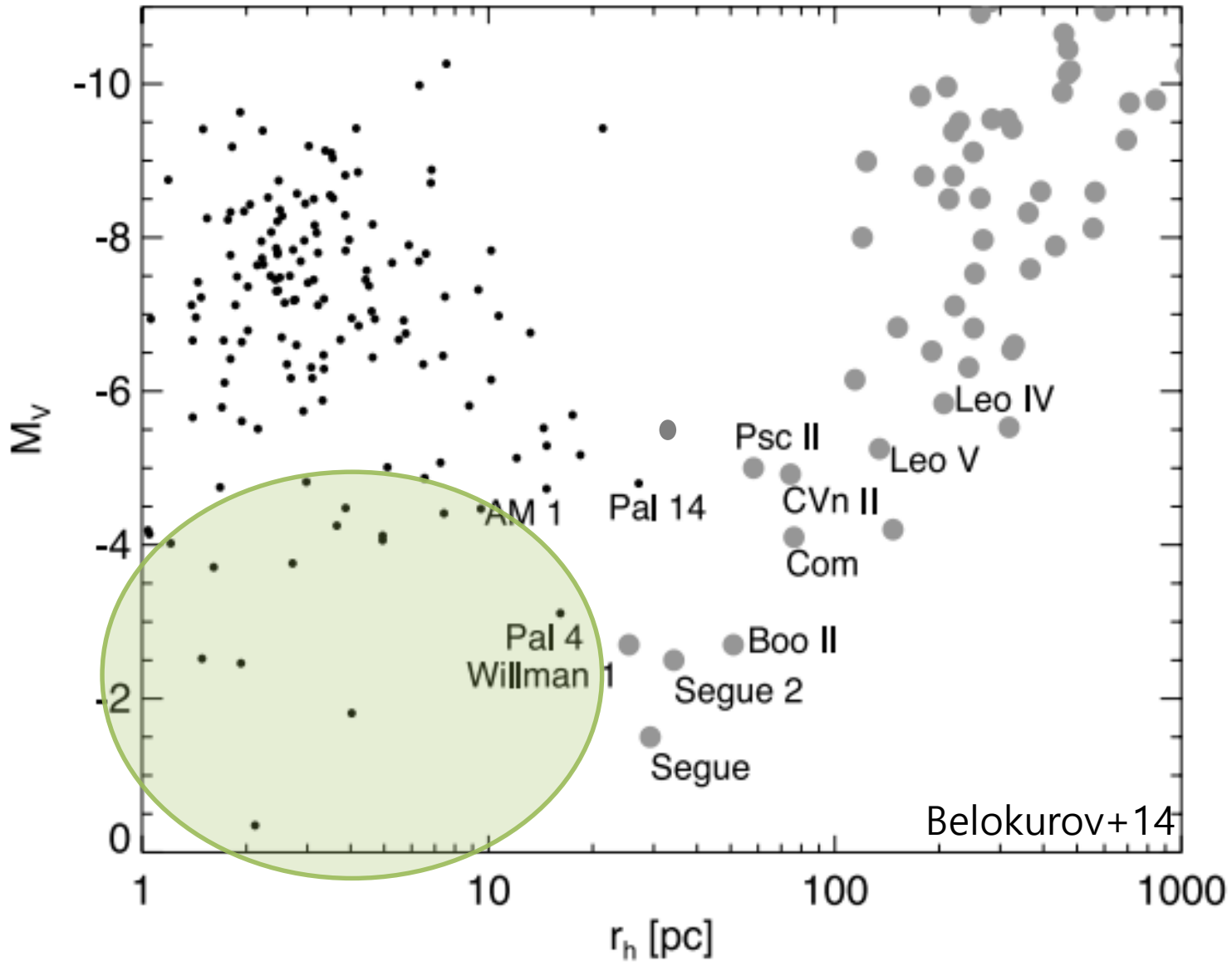
GC Candidate #2







They are not ‘typical’ GCs



Summary

- We find and investigate visually 1835 star cluster candidates using the WISE, 2MASS, UKIDSS, VVV, and GLIMPSE data at the central region of the Milky Way.

- 25 candidates are probably genuine star clusters. 16 are embedded; young clusters and 9 seems to be old.
  - The WISE data has advantage to find very young clusters, or old clusters.
  - Two of them are GC candidates.

- These two candidates are likely to be **halo GCs**, (old and metal-poor) but they are located at close to the Galactic plane.

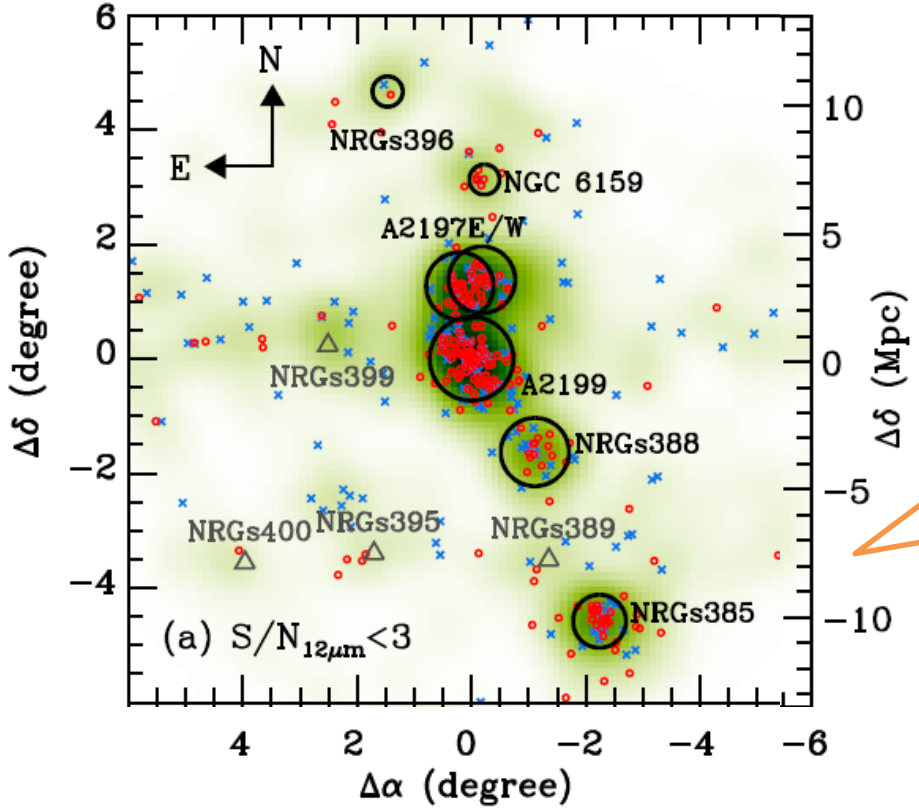
- The asymmetric Galactic longitude distribution is originated mainly by embedded candidates. The Galactic bar end may be related to this.

Part 2. A WISE Study of Galaxy Clusters

Galaxy evolution in the mid-infrared green valley: a case of the A2199 supercluster (Gwang-Ho Lee et al. 2015, ApJ)

Abell 2199 Supercluster (z=0.03)

- ✓ *A galaxy catalog of Hwang+12 for Abell 2199*
- ✓ ***SDSS DR7*** *spectroscopic data*
- ✓ ***WISE*** *provides all sky survey data in four MIR bands (3.4, 4.6, 12, 22 μm)*
- ✓ *1529 member galaxies = 559 early types (E/S0) + 970 late types (S/Irr)*



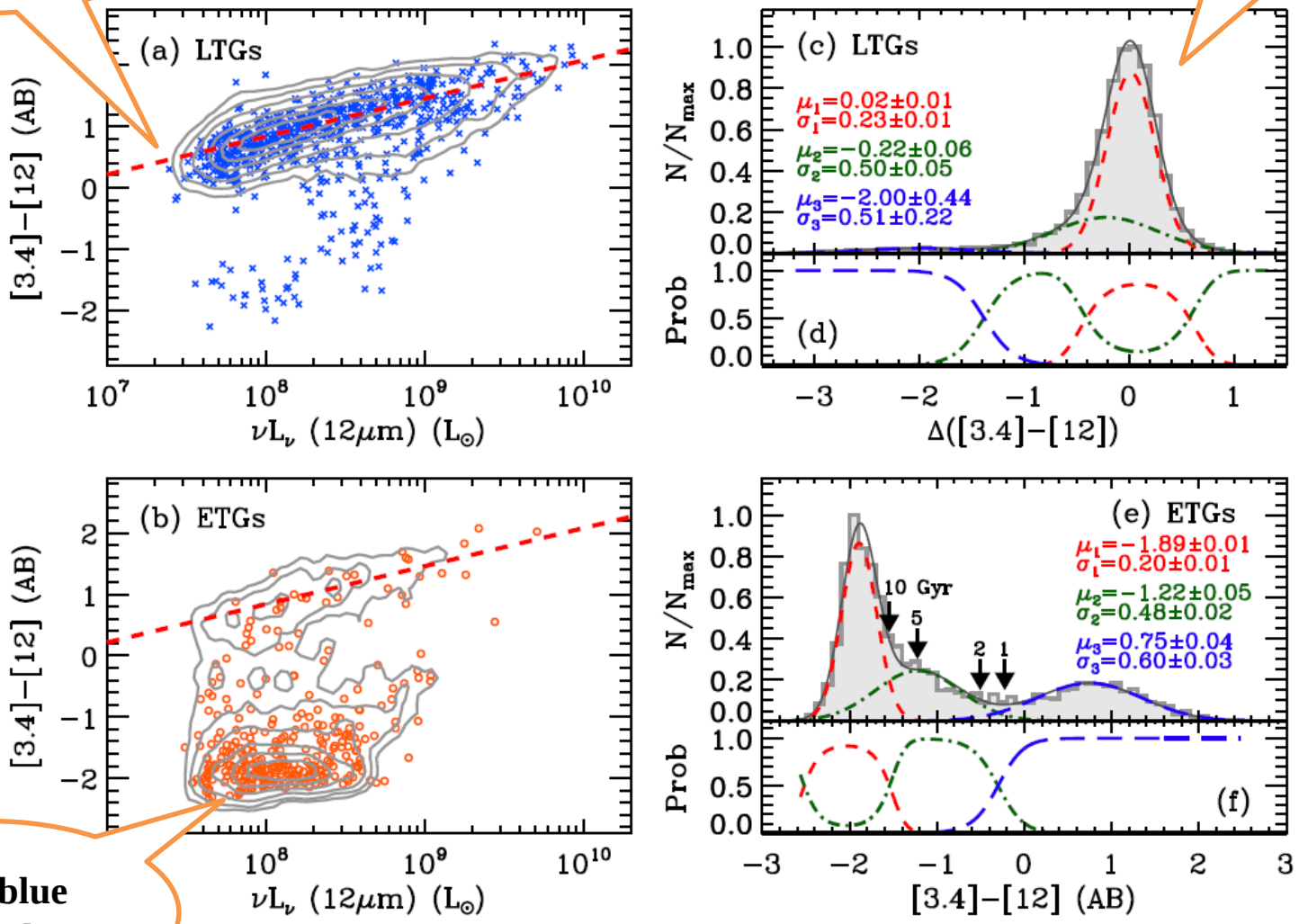
Morphology from KIAS VAGC

three galaxy clusters + four galaxy groups

MIR color-luminosity diagram

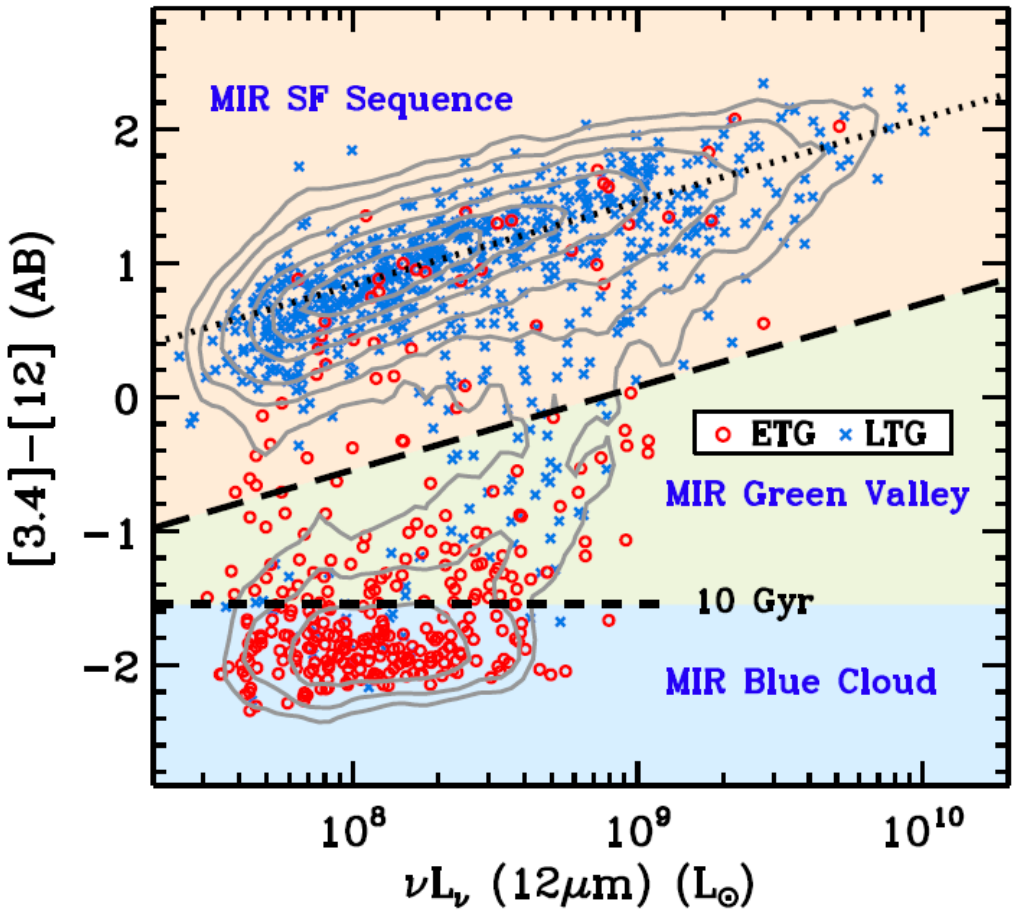
MIR SF sequence (Hwang+12)

Gaussian Mixture Modeling



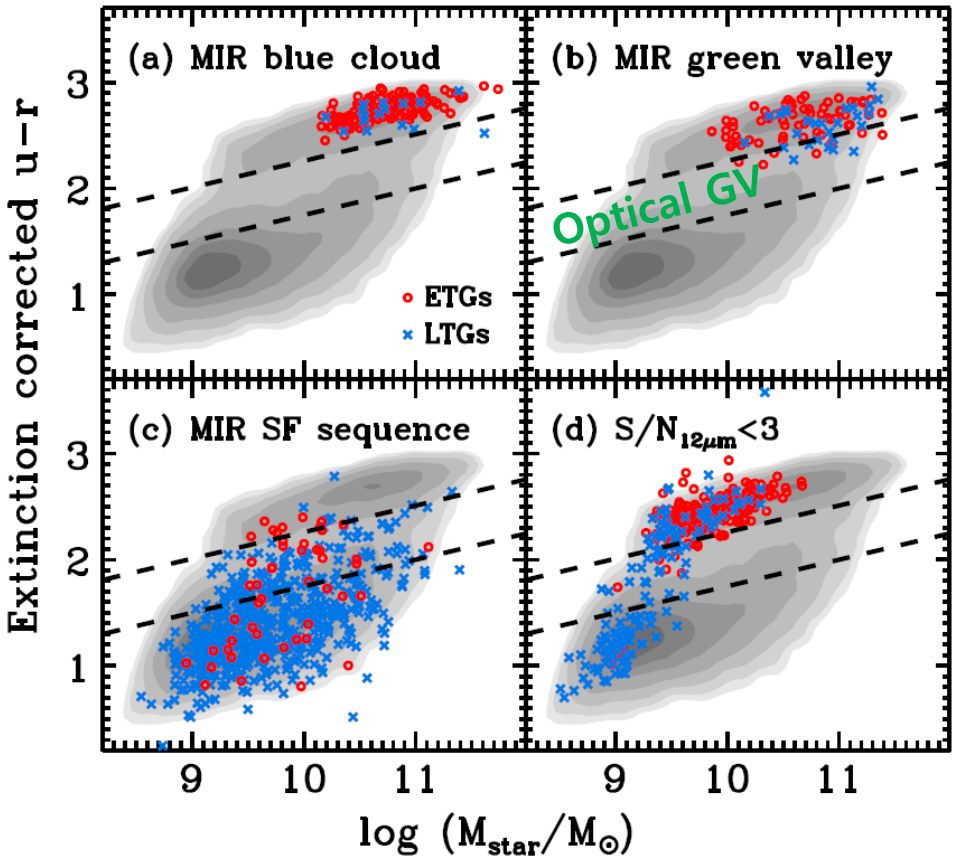
MIR blue cloud

MIR galaxy classification



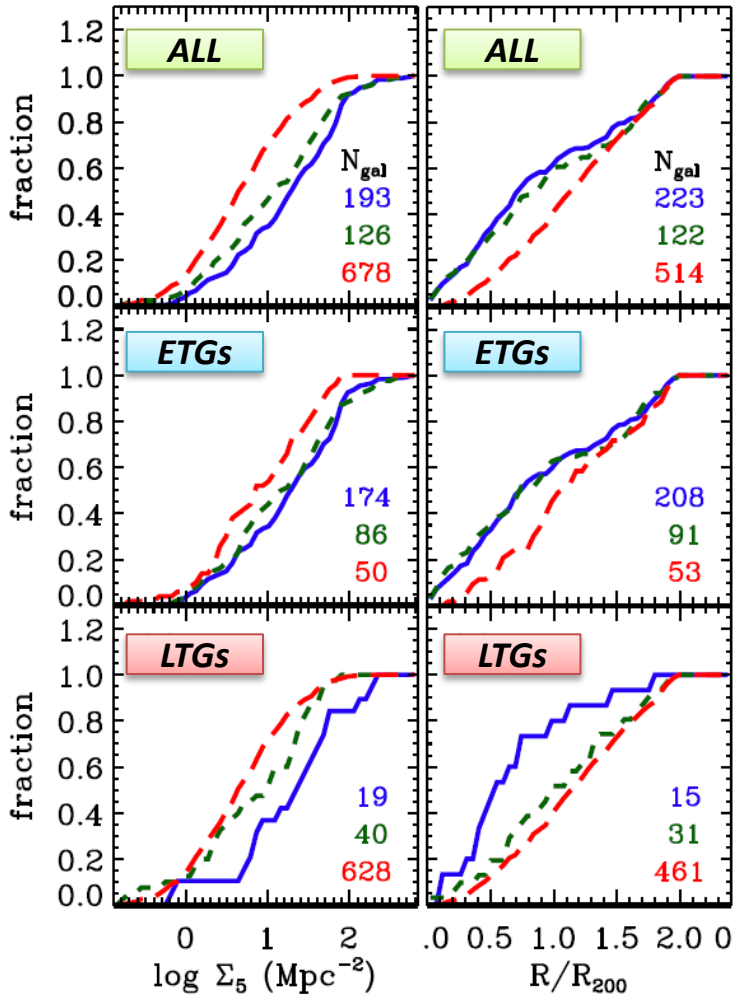
	f_{ETG}	f_{LTG}
MIR SF Sequence	0.07	0.93
MIR Green Valley	0.68	0.32
MIR Blue Cloud	0.90	0.10

The MIR green valley vs. The Optical green valley

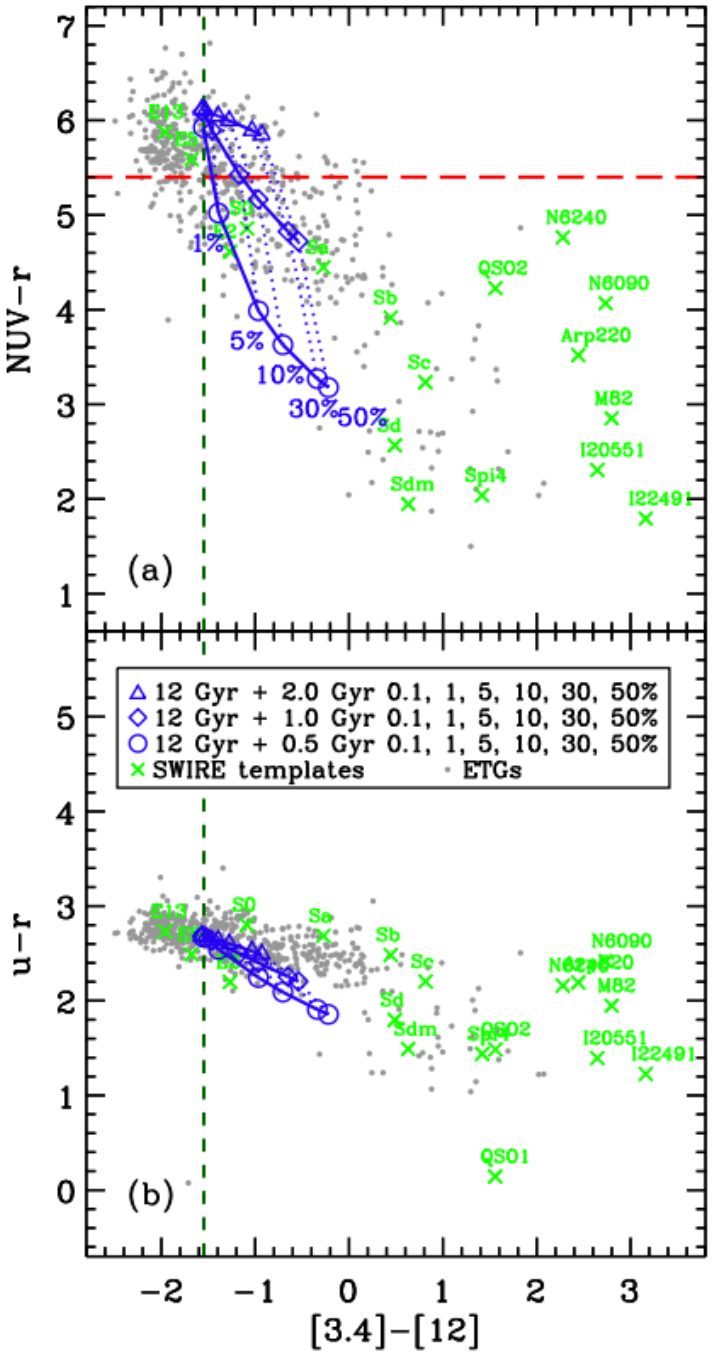


- ✓ ***The MIR green valley galaxies ≠ the optical green valley galaxies.***
- ✓ ***The MIR green valley galaxies belong to the optical red sequence.***
- ✓ *This figure suggests that* ***SF quenching mainly occurs before galaxies enter the MIR green valley.***

Environment dependence of MIR GV galaxies: The cumulative distributions of $\sum_5$ & R/R_{200}



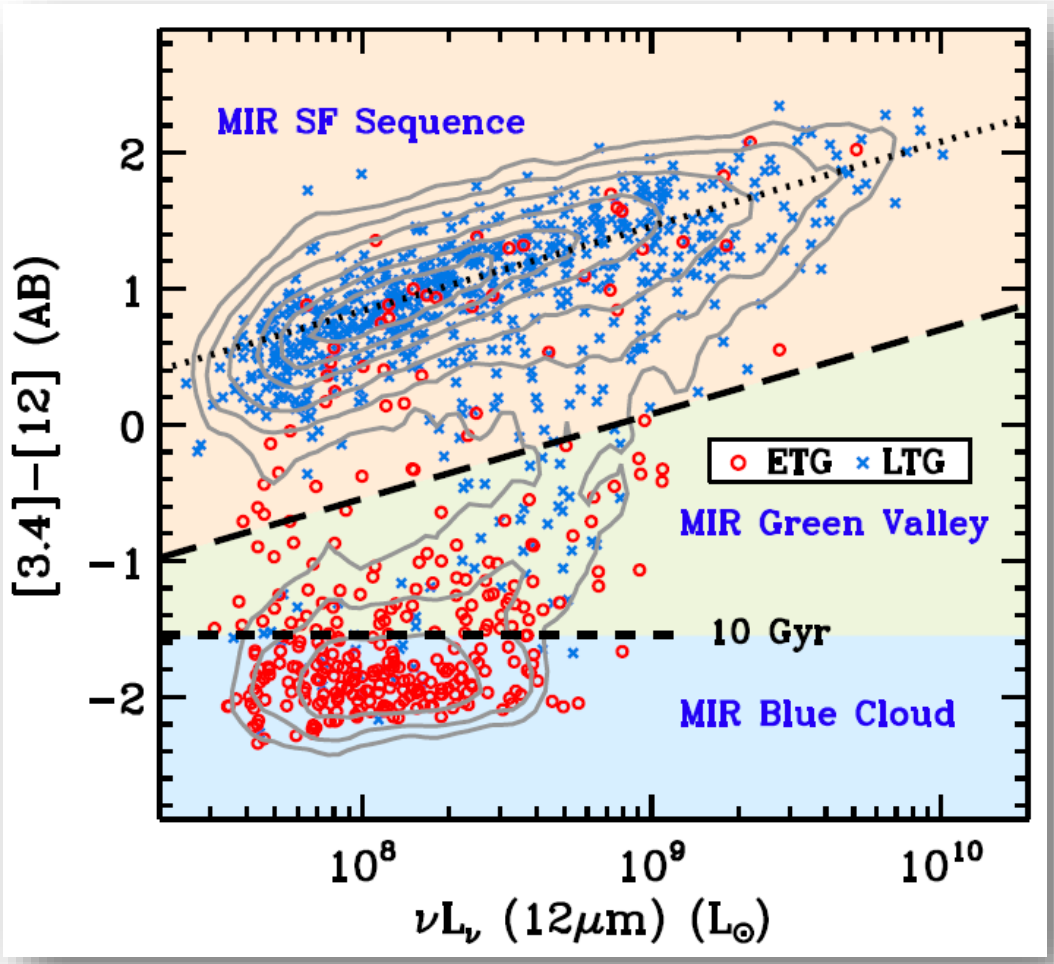
- ✓ *MIR green valley galaxies show the distributions between MIR blue cloud galaxies and MIR SF sequence galaxies.*
- ✓ *However, early-type galaxies show little difference between MIR blue cloud and MIR green valley galaxies.*
- ✓ *A unique difference between early-type MIR blue cloud galaxies and early-type MIR green valley galaxies is the MIR colors.*



MIR colors of ETGs

- ✓ *Two component SSP model (Piovan+03) 12Gyr + 0.5, 1, 2 Gyr stellar populations*
- ✓ *A small amount of young populations makes [3.4]-[12] colors green (> -1.55).*
- ✓ *50% of ETGs in the MIR green valley stopped forming stars at least 2 Gyr ago.*
- ✓ *The MIR traces SF over a longer timescale (> 2 Gyr) than the NUV and optical wavelengths (Ko +13).*

Conclusions



Late-type MIR SF sequence galaxies

Star formation quenching

Late-type MIR green valley galaxies

Morphology transformation

Early-type MIR green valley galaxies

several Gyr

Early-type MIR blue cloud galaxies

✓ *The MIR green valley is the site where the morphology transformation of galaxies mainly appears to occur.*

Summary

A wise? study
or A WISE study
of clusters.

FOREVER

(FORmation & EVolution of ClustERs)