Searching for and Characterization of Galactic Open Clusters toward the Galactic Anti-Center with Pan-STARRS1

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Pan-STARRS
PS1 Science Consortium

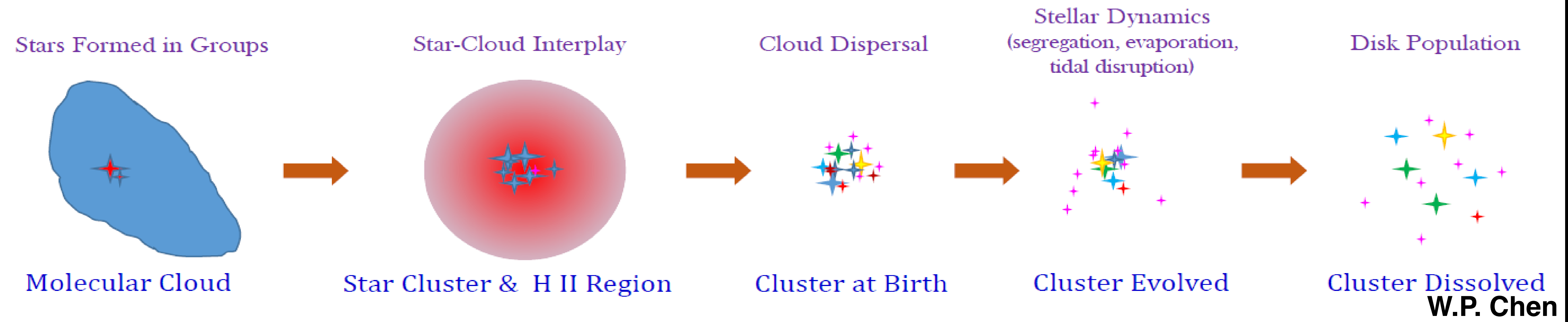
(Nigel Metcalfe) NGC2158

Outline

- Introduction and Motivation
- The Pan-STARRS project
- Search Algorithm
- Characterization Procedures
- Results and Discussions
- Summary and Future Works

Star Clusters

- Stars are formed in a clustered environment
- Members with different masses in a star clusters are at the same distance, with the same chemical composition and the same age.
- Star clusters serve as a good test bed for star formation and evolution theories.
- Star clusters serve to probe the Galactic structure and evolutionary history.

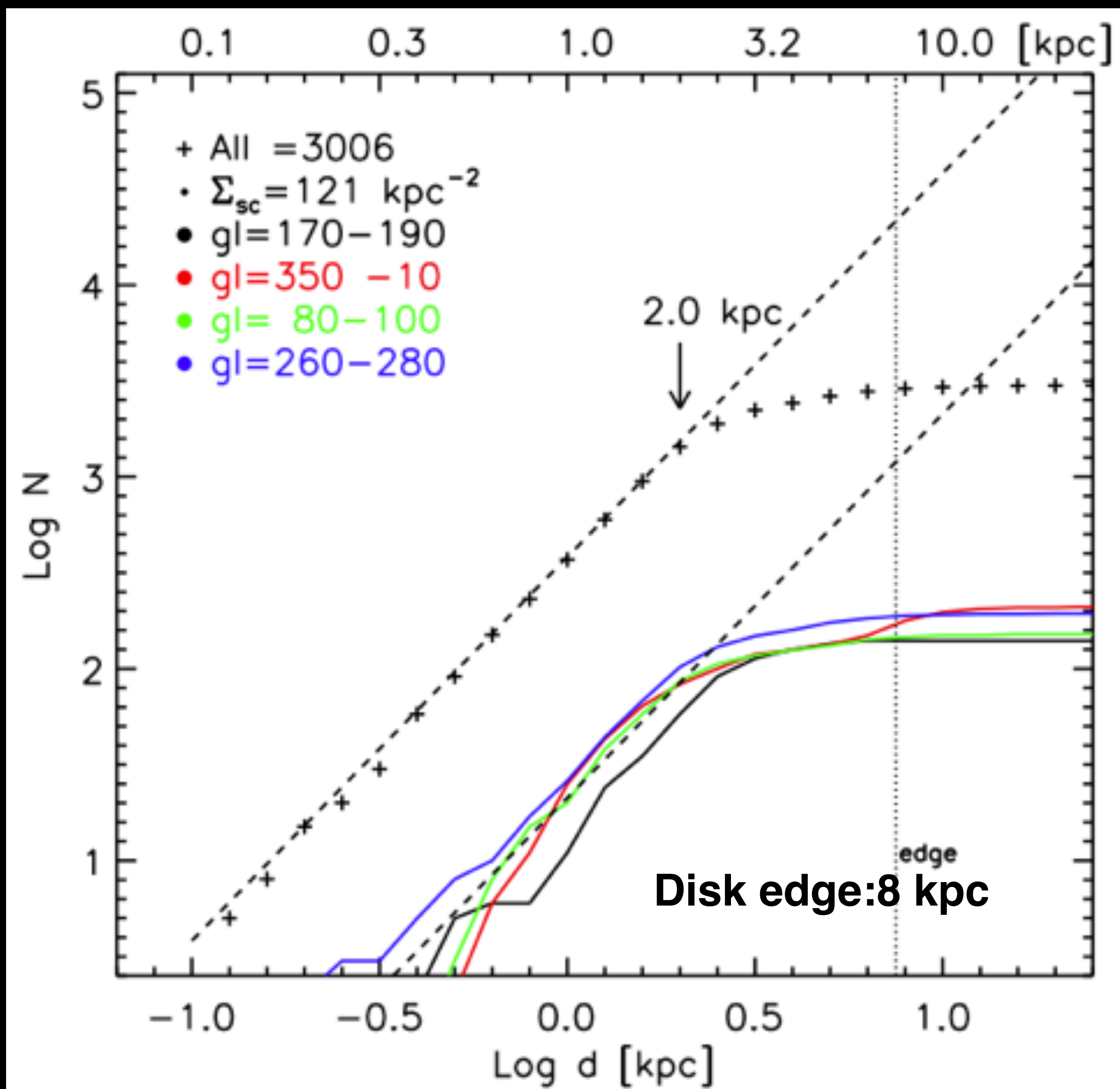


- Stars are formed in groups out of molecular clouds, and at the same time as the stellar birth planets are formed in circumstellar disks.
- Massive stars are centrally concentrated and low-mass stars ‘evaporated’ as the result of mutual gravitational interactions among members (+ external tidal perturbation)
- A cluster eventually dissolves.
- Do galactic environments influence the origin of stellar masses?

Study of Star Clusters

- Historically, one of the oldest subjects in astronomy, next to stars and planets, e.g., the Messier objects …
- Progress paused for a few decades because CCD sizes did not catch up.
- Interest revived because of sky surveys and OIR wide-field imaging
- Current census: 3000+ open clusters, 100+ globular clusters in the Milky Way
- Special interests in massive star clusters, low-mass star in star clusters, and dynamics of star clusters

Star cluster sample is incomplete



Lin et al. in prep (2014)

- 10^5 expected (Piskunov et al. 2006), but current sample is only a few 10^3 catalogued (Kharchenko et al, 2013, mostly < 2 kpc)
- Largely because of dust extinction in the solar neighborhood and lack of systematic search
- We therefore attempt to conduct a comprehensive search for star clusters with Pan-STARRS data

Pan-STARRS (PS1) 泛星計劃

Panoramic Survey Telescope And Rapid Response System

To detect hazardous asteroids…

Haleakala, Maui, Hawaii, USA

PS1 consortium members

JOHNS HOPKINS UNIVERSITY

Department of Physics and Astronomy

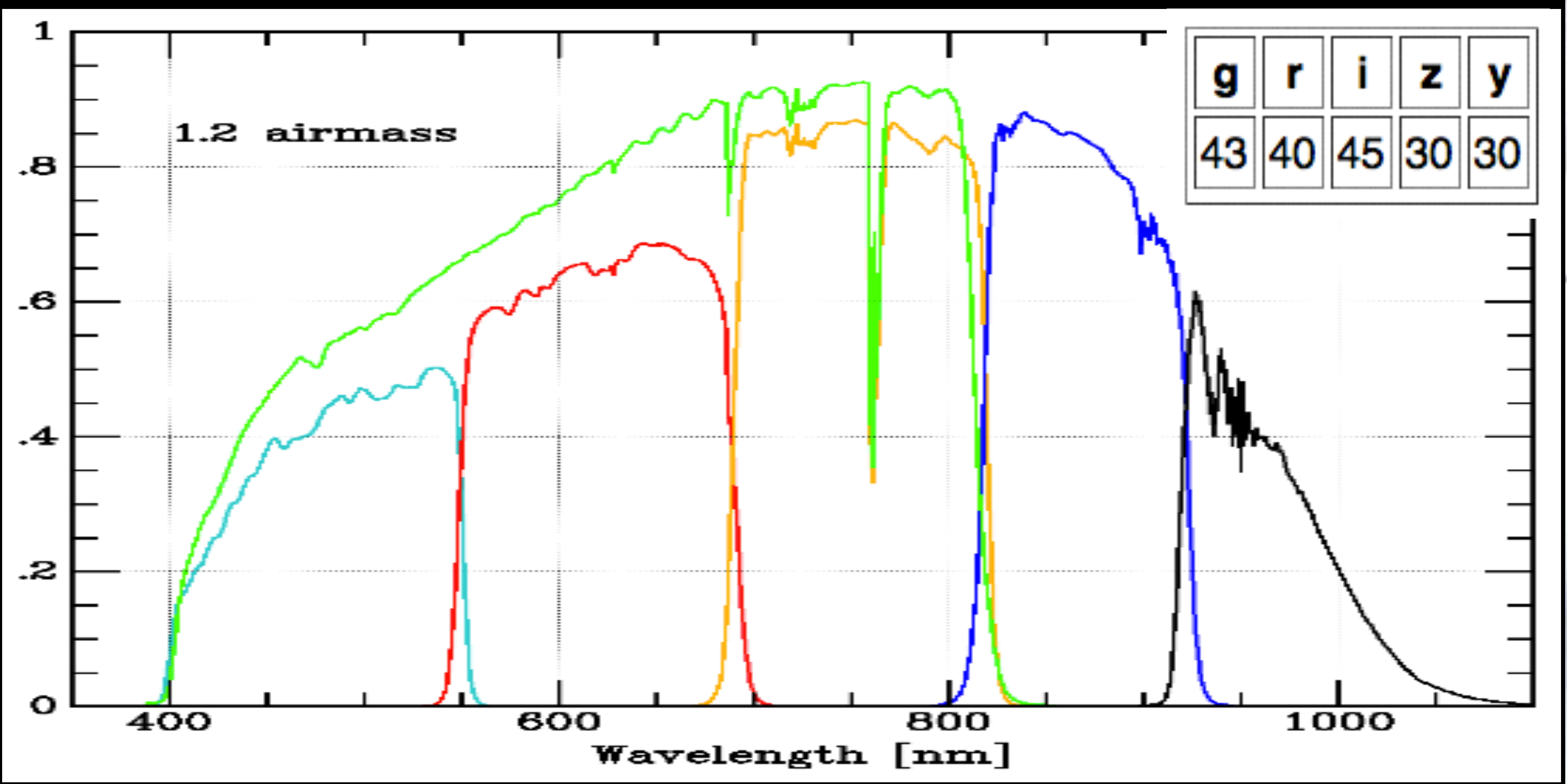
Durham University

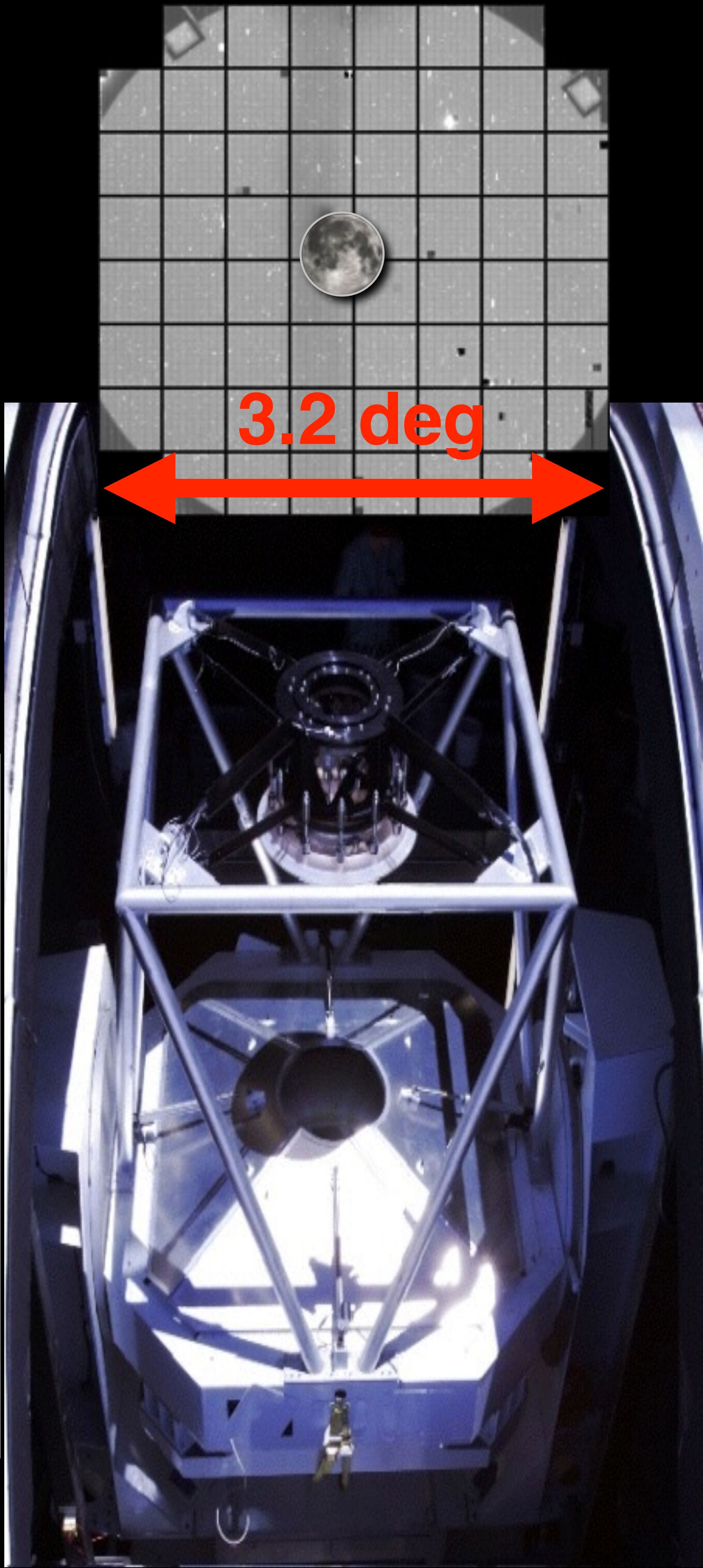
SPACE TELESCOPE SCIENCE INSTITUTE

Operated for NASA by AURA

PS1 Features

1. patrolling 3/4 sky several times a month
2. 1.8 m telescope at f/4.4 with 3.2 deg FOV
3. 1.4 Gigapixel camera, 10μm, 0.245”/pixel
4. reaching g,r,i ~24-27, z,y ~21-24 mag

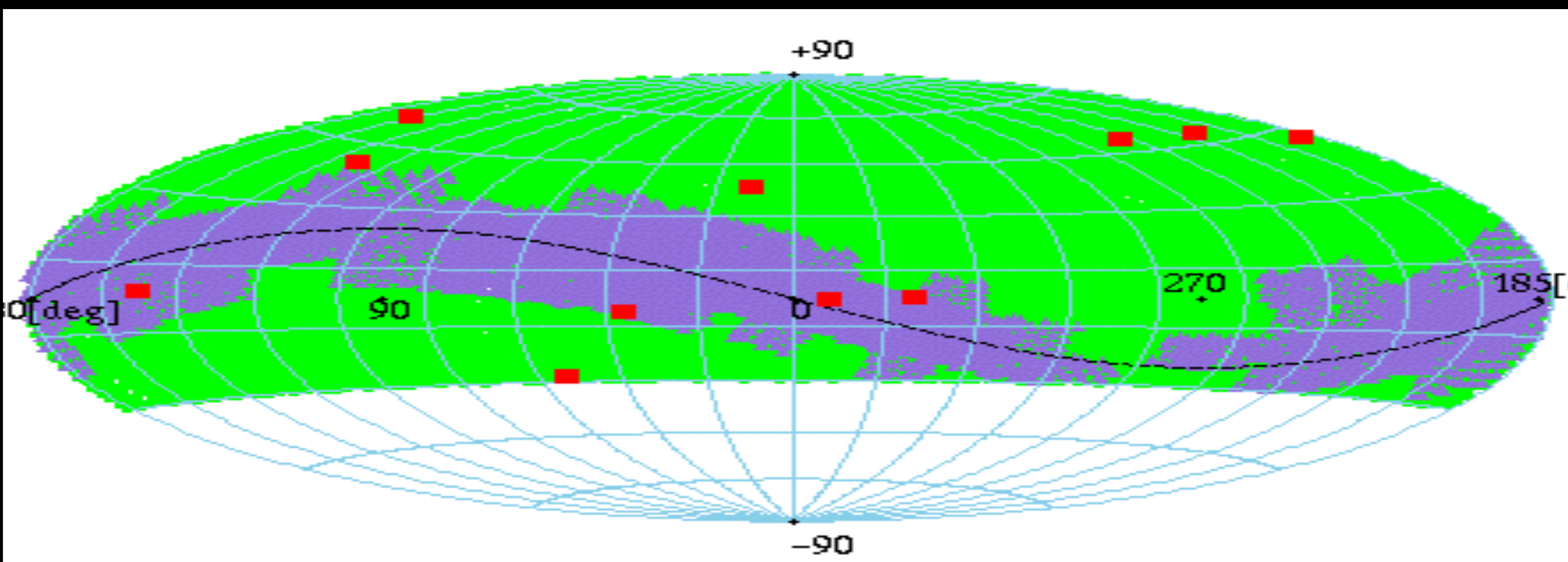




Tonry et al. 2012, ApJ

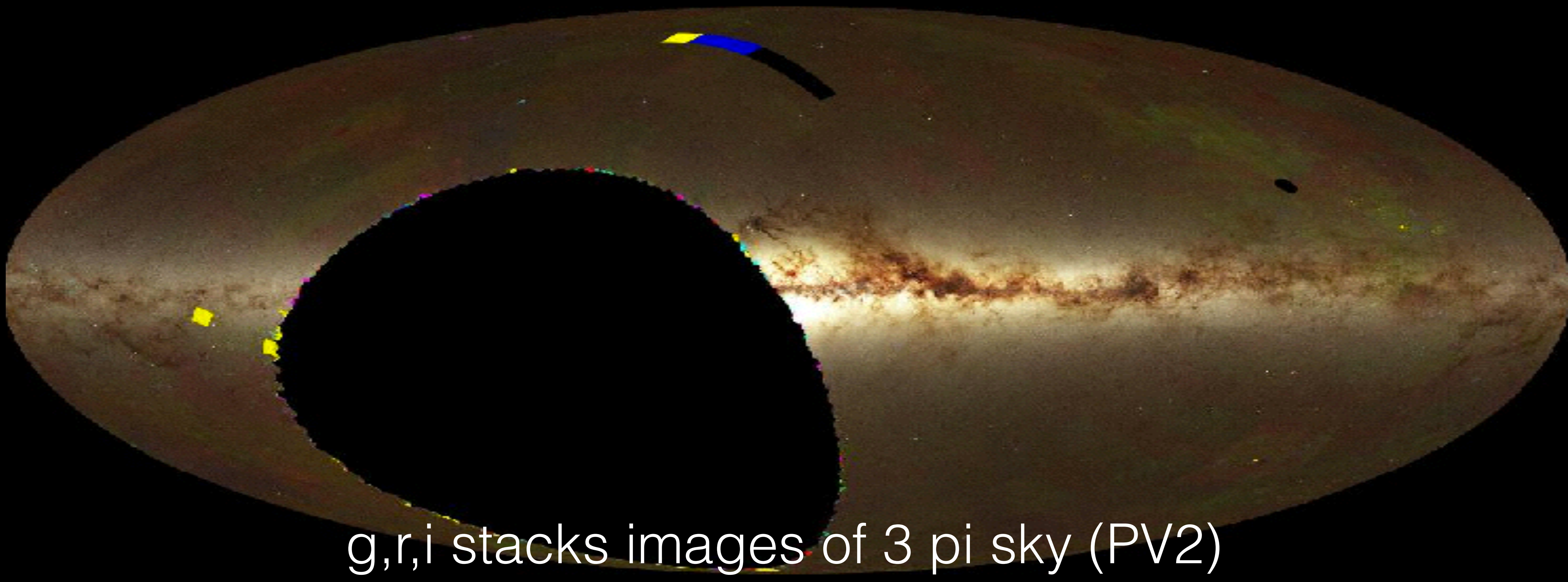
PS1 Surveys

1. 3π survey: 56% (low-mass stars, brown dwarfs, star clusters, structure of the Milky Way)
2. medium deep: 25 % (extragalactic, cosmology, large scale structure, etc.)
3. solar system: 11% (KBOs, asteroids, comets, etc.)
4. others: 8% (M31)



PS1 status

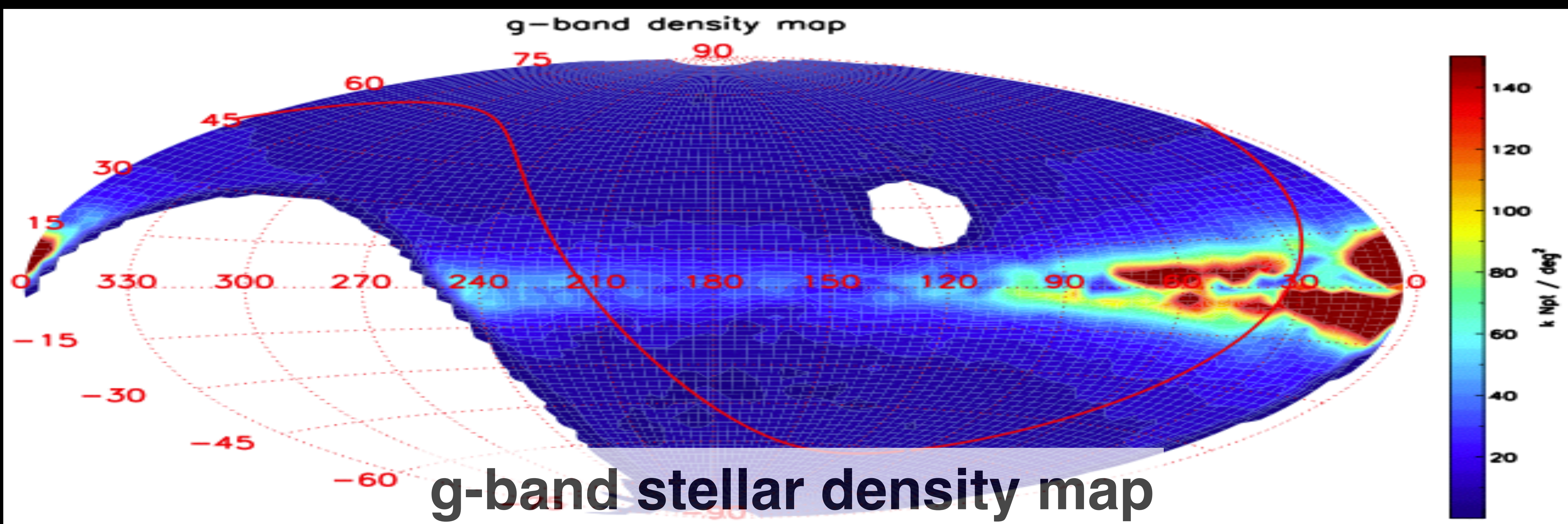
1. Full survey stared in May 2010, for duration of ~4 years.
2. Included ~5 billion objects and ~120 billion detections
3. Observations were end in March 2014
4. Data will be released to public in April 2015



g,r,i stacks images of 3 pi sky (PV2)

PS1 3π Data

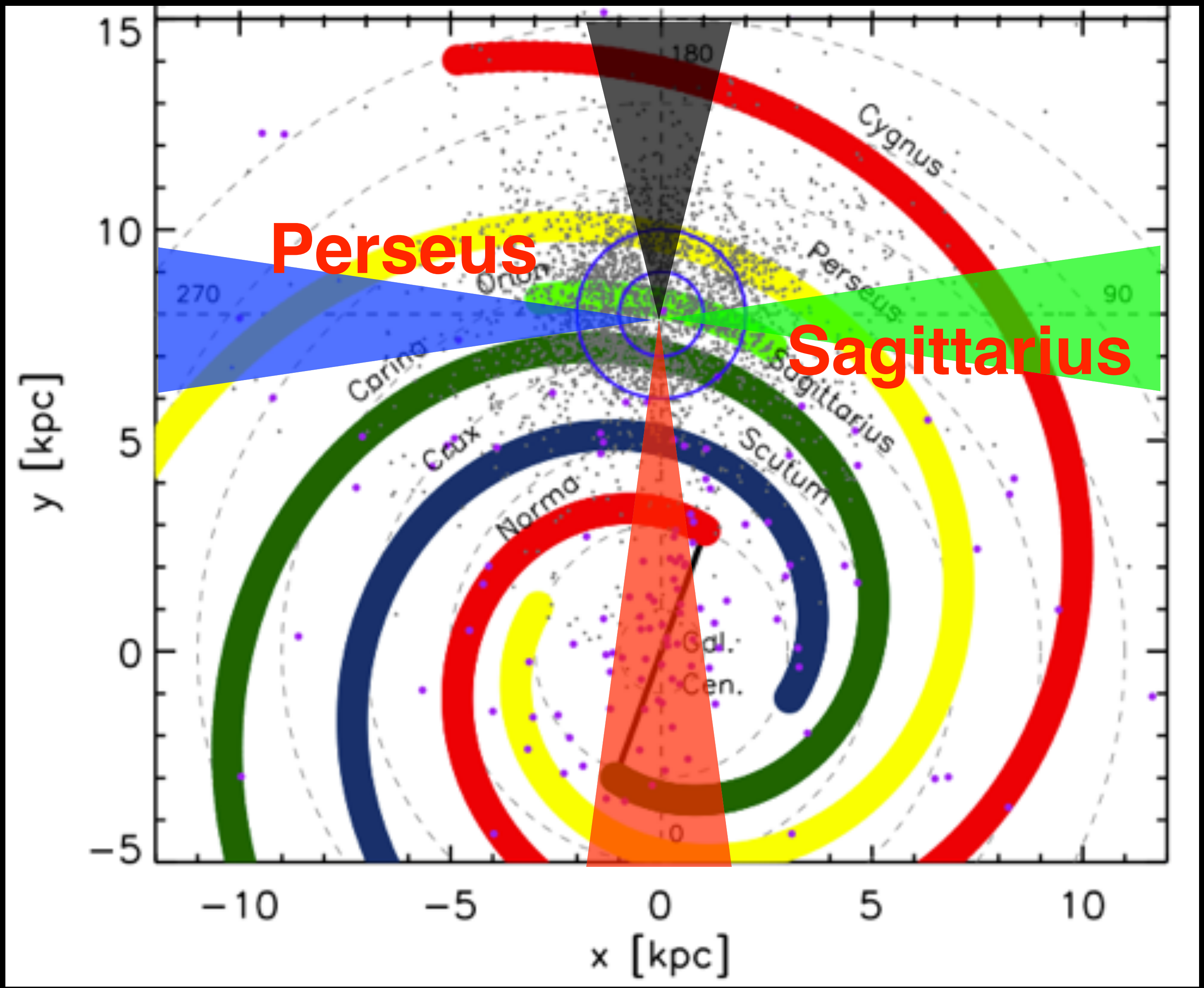
- Stellar objects are selected with PS1 object flags
  - exclude S/N < 5, psf quality < 0.85, and extend objects
  - measurements > 4
- Total of 1.3 billion stellar objects are in 3π sky (1 billion, USNO)
- The 5σ limit. mag. are at 22.30, 22.22, 21.99, 21.29, 20.22 mag

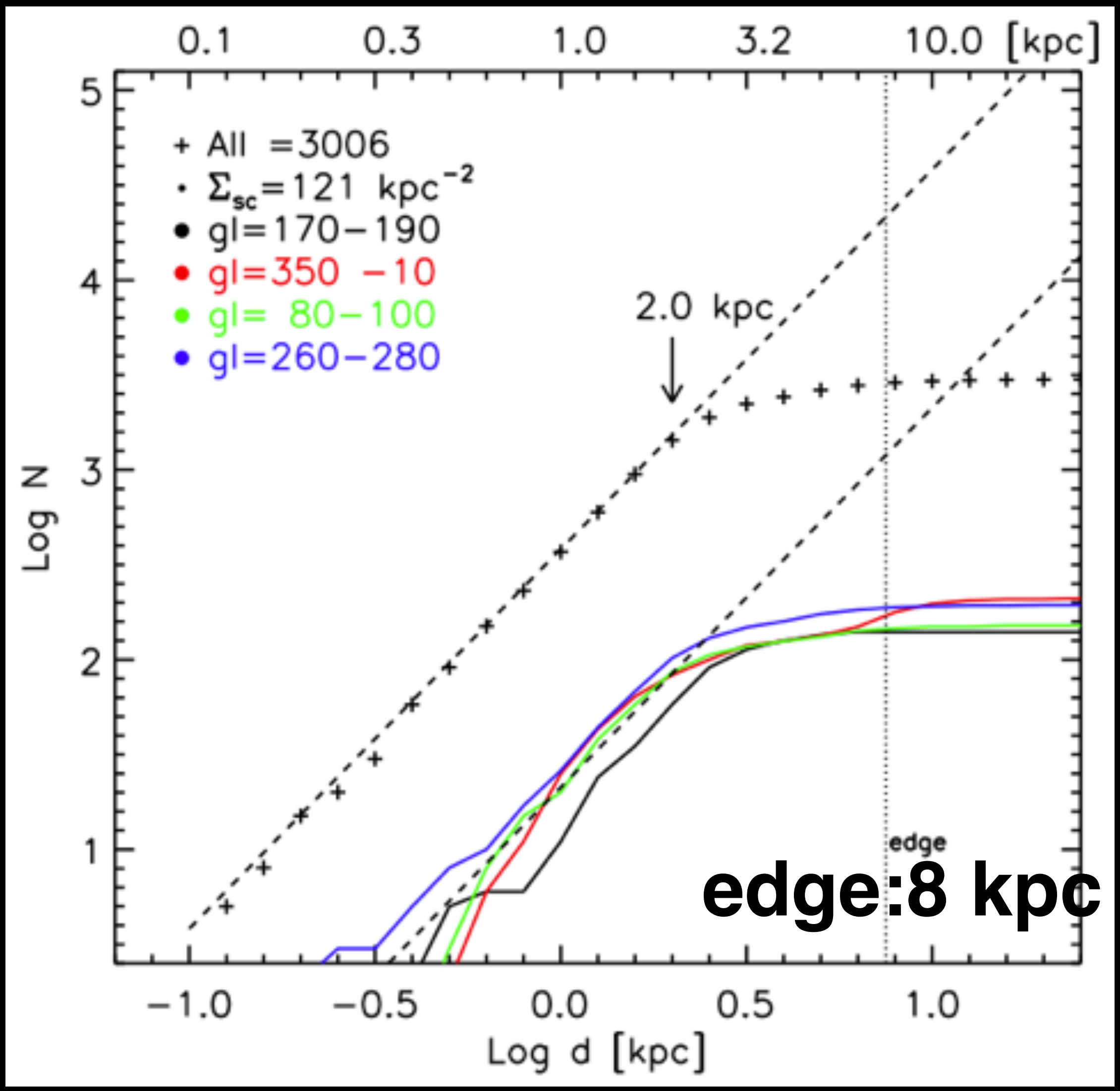


g-band stellar density map

A Pilot Study : Galactic Anti-Center

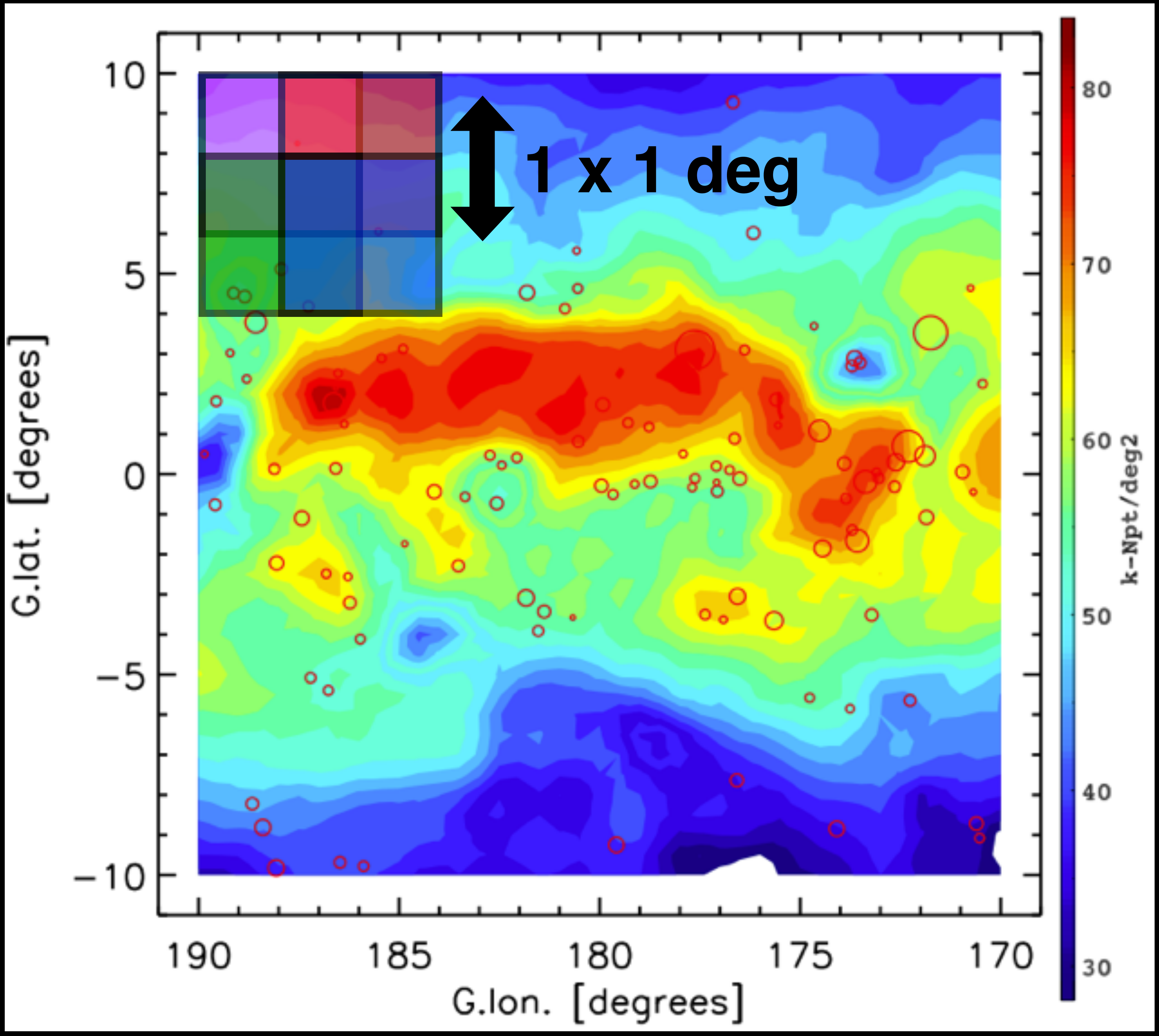
- A 20x20 deg² region with 30 million stellar objects
  - Contain lower dust extinction than other parts of Galactic plane
  - Reveal the galactocentric distribution of star clusters
  - Probe the structures of the outer disk



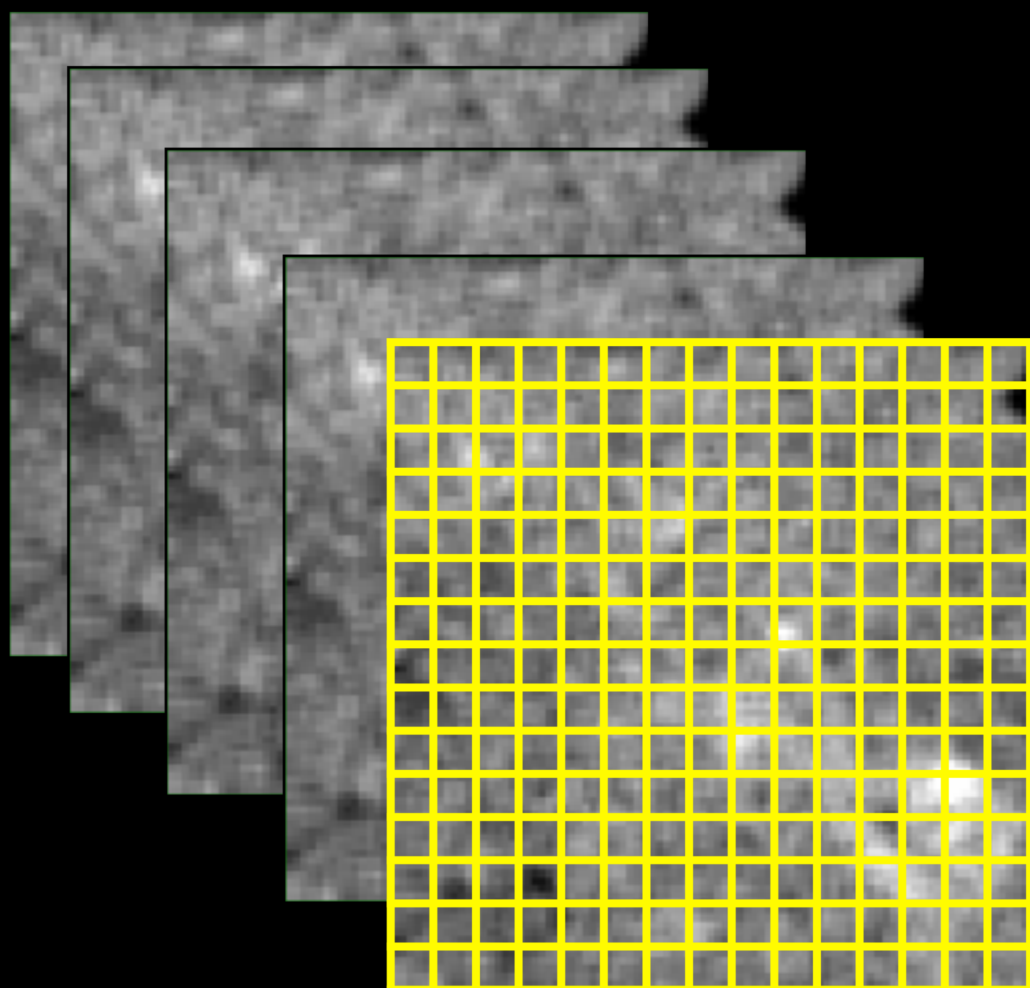


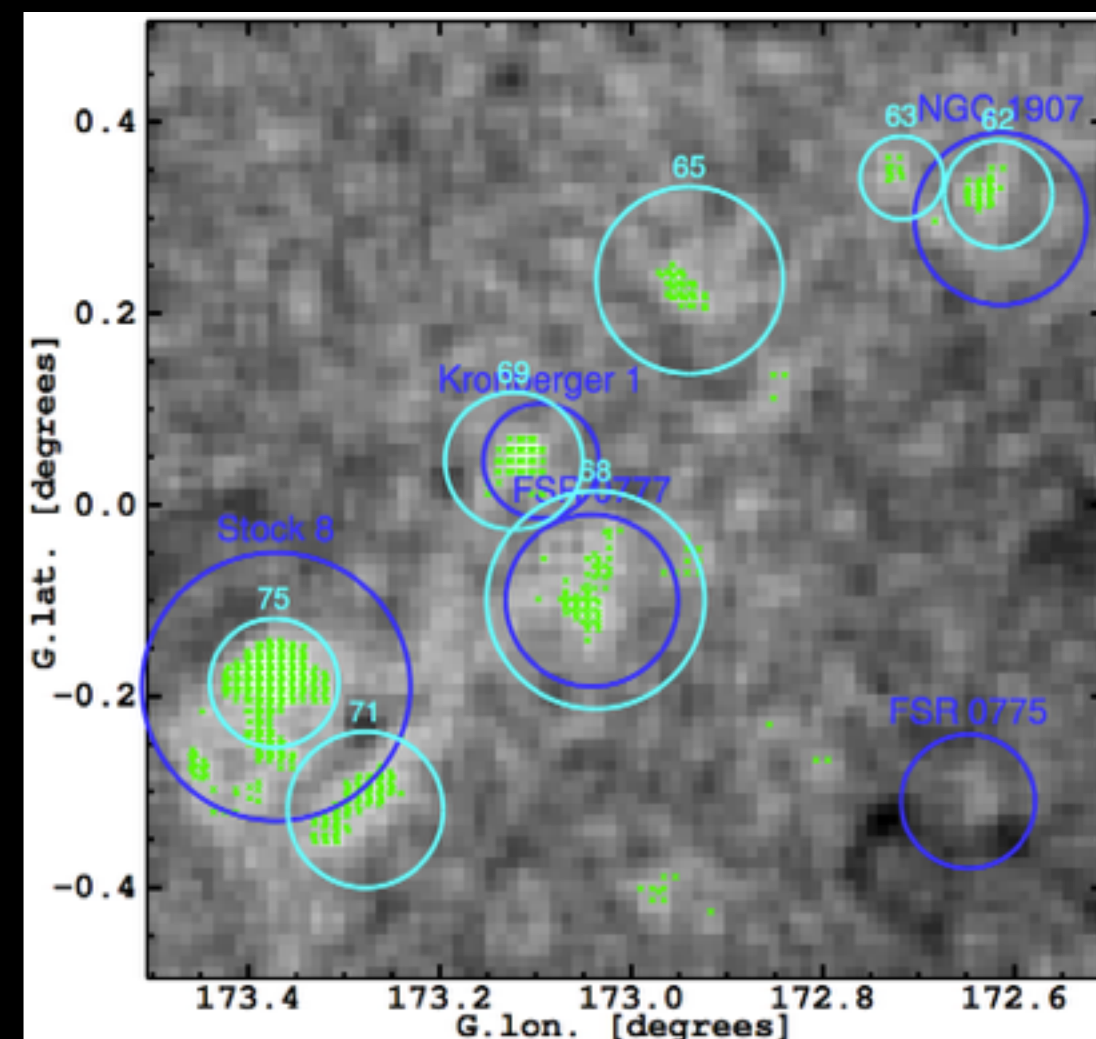
Search Method

Star Counting to Search for Stellar Density Enhancement Regions



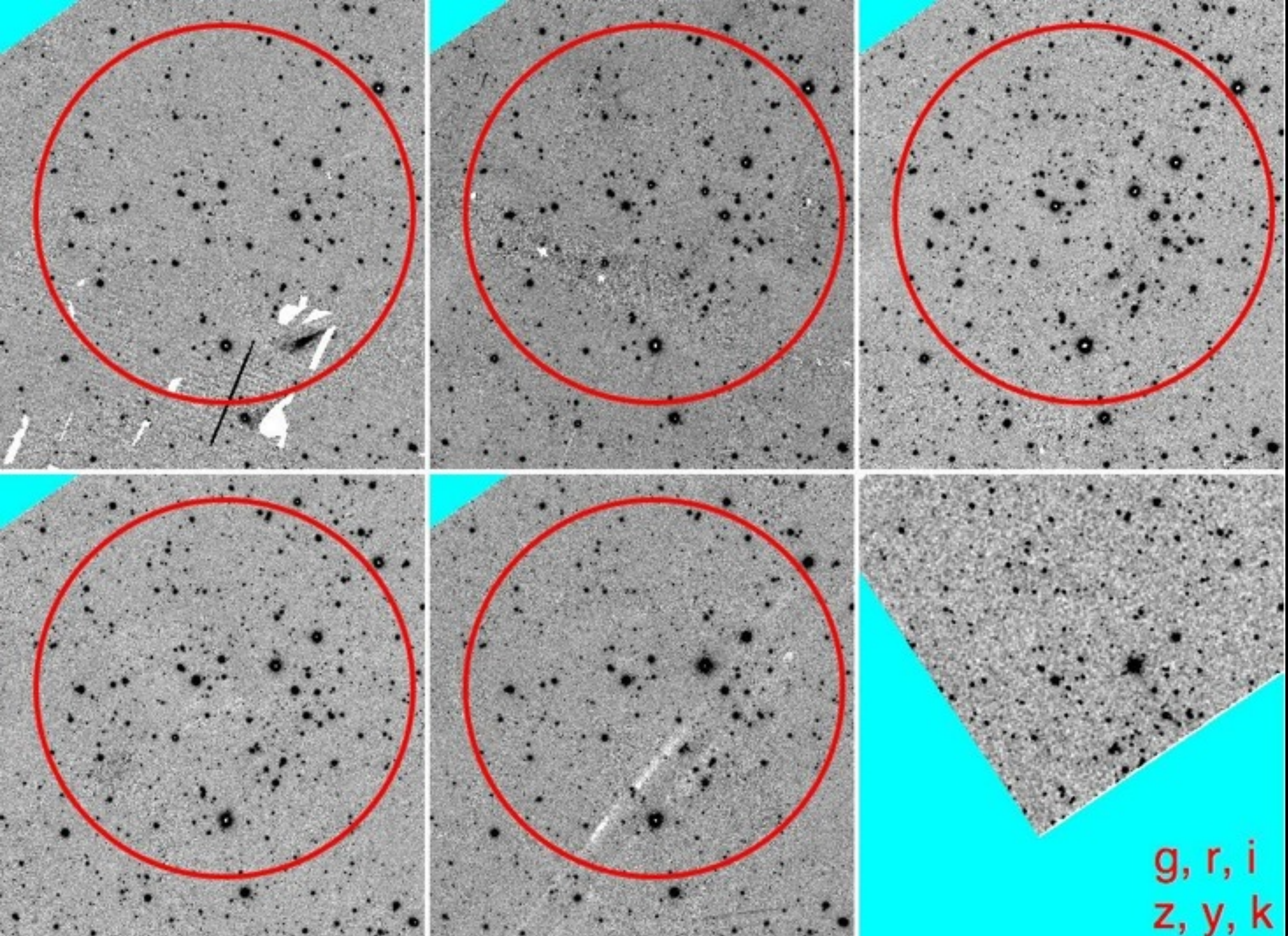
Star Counting to Search for Stellar Density Enhancement Regions

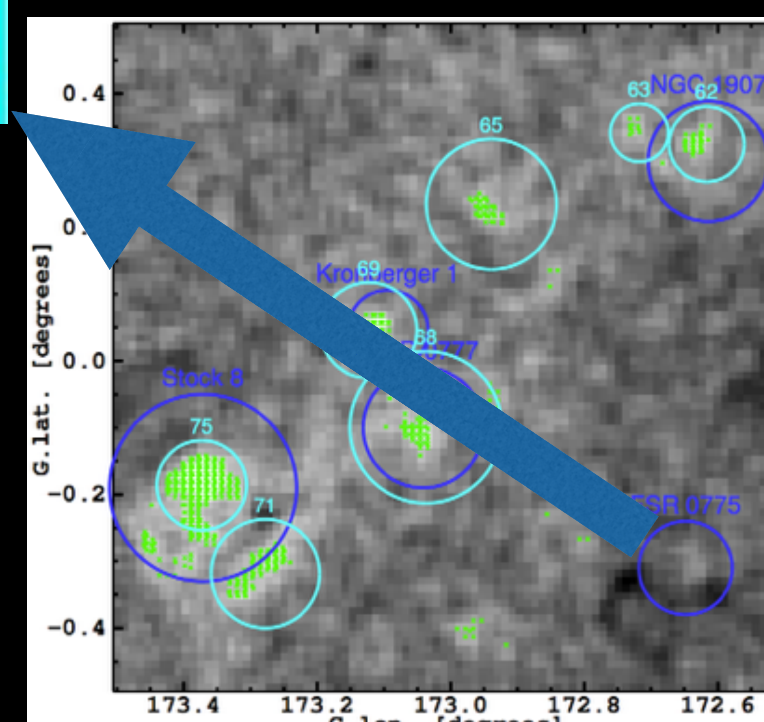




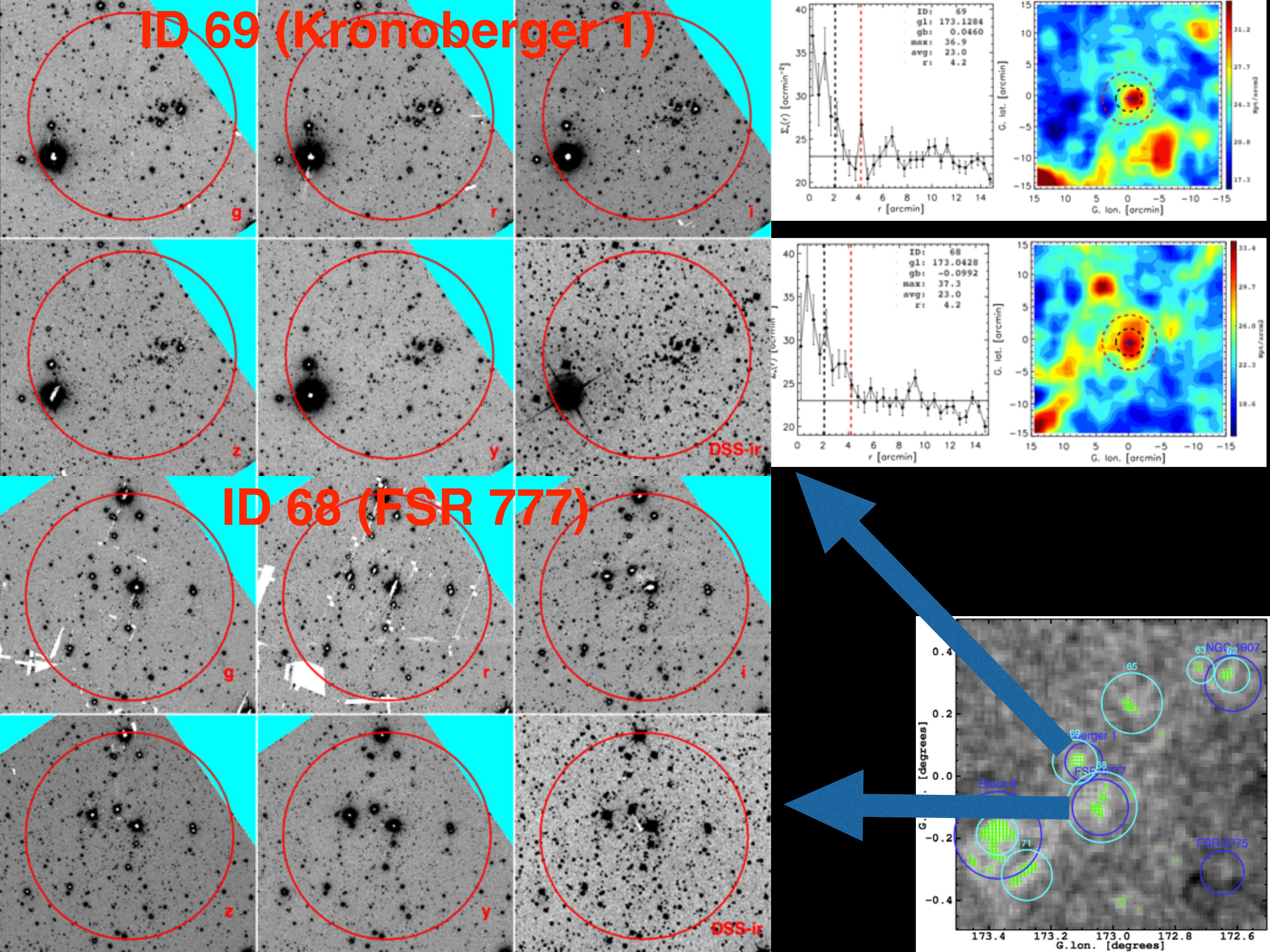
G173.0+0.0

- Density Map: grid size contains ~10 stars, smoothing with 3x3 boxes, subtracting median value, dividing standard deviation
- Cluster candidate: contains at least 3 adjacent grids, with each gird $\geq 3\sigma$, and > 3 times detections in different fields





Why no FSR 755?
Not a star cluster anymore
(Camargo et al., 2010)


ID 69 (Kronoberger 1)
ID 68 (FSR 777)
g
r
i
z
y
DSS-ir
ID: 69
gl: 173.1284
gb: 0.0460
max: 36.9
avg: 23.0
r: 4.2
ID: 68
gl: 173.0428
gb: -0.0992
max: 37.3
avg: 23.0
r: 4.2
r [arcmin]
G. lat. [arcmin]
G. lon. [arcmin]
G.lon. [degrees]
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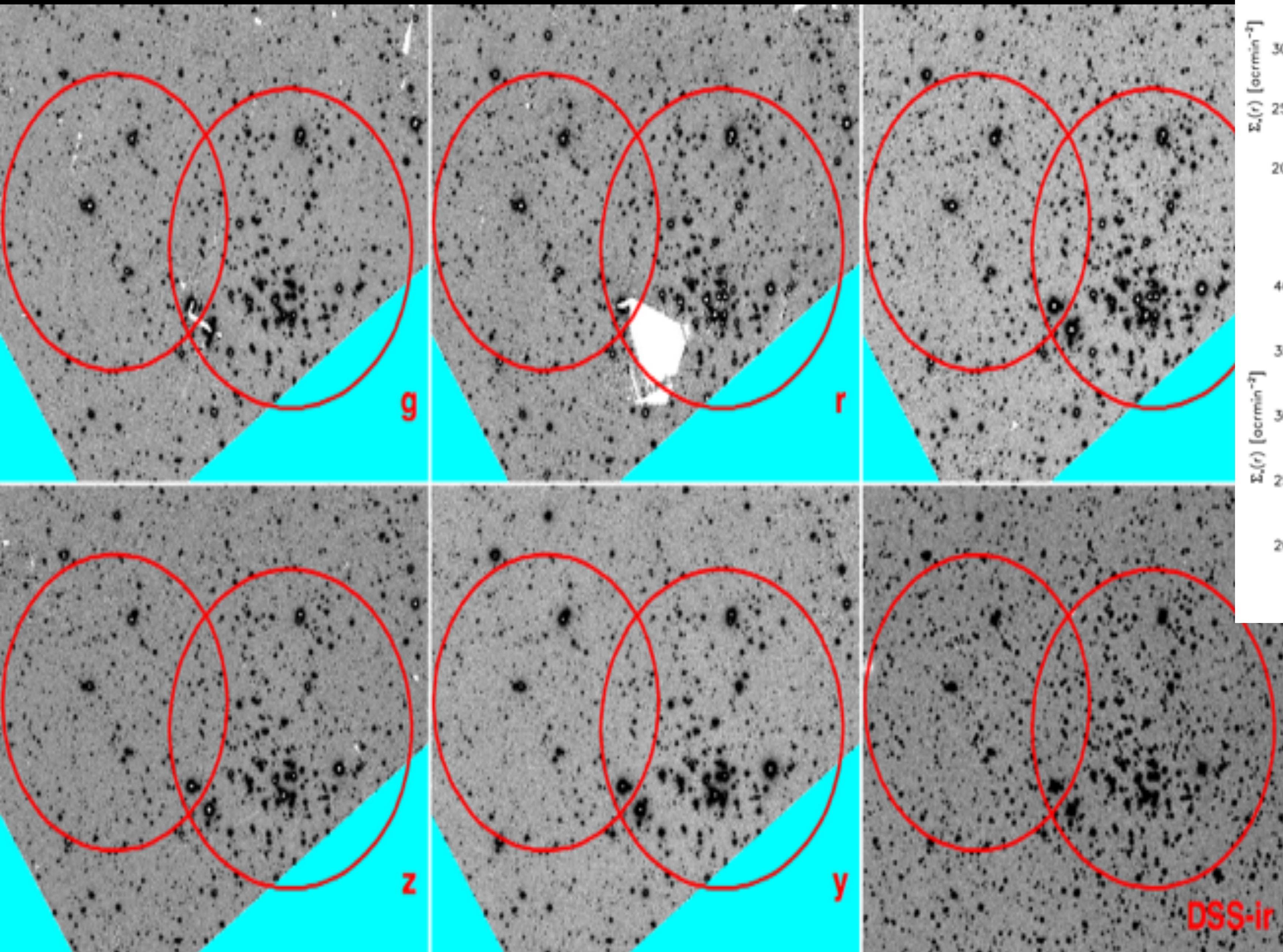
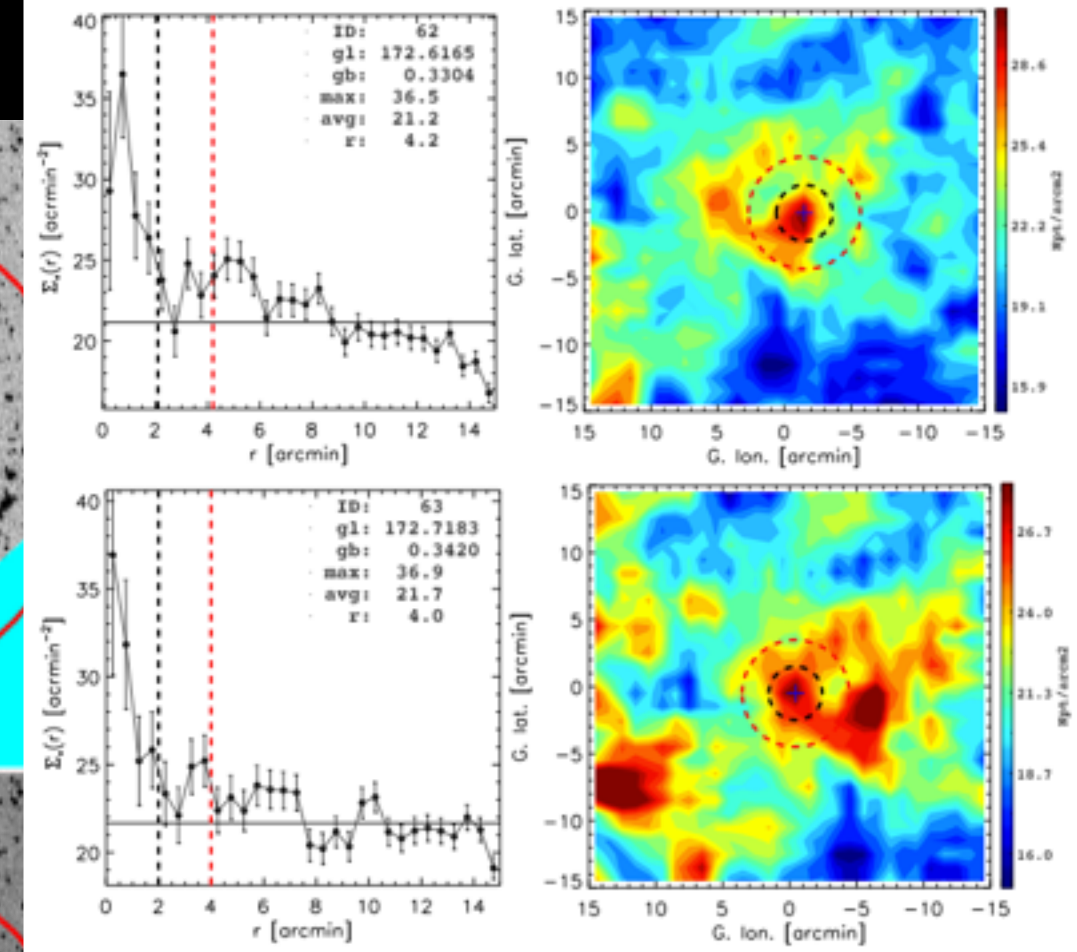
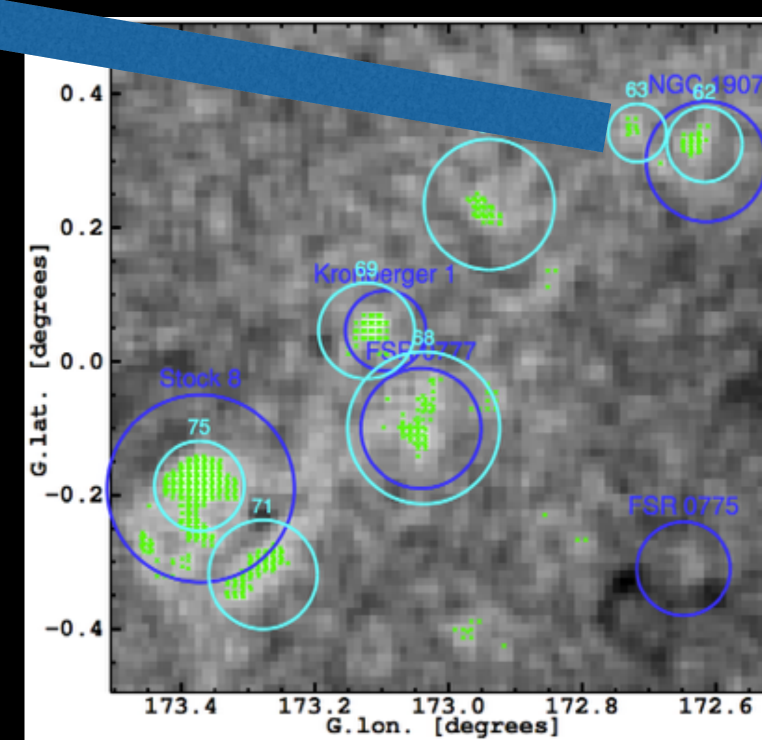
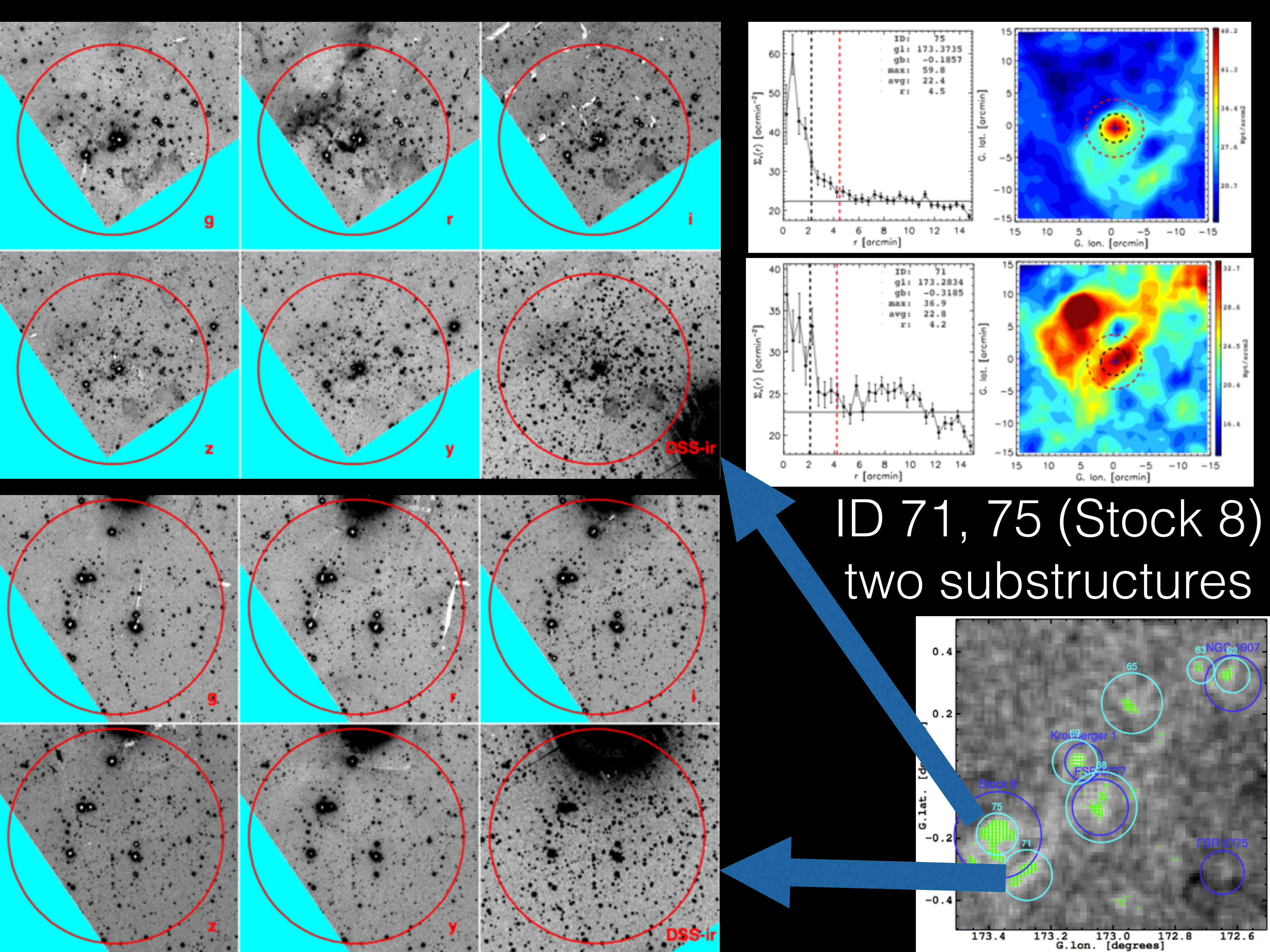
NGC 1907
Stock 8
FSR 0775
63
62
65
71
68
69



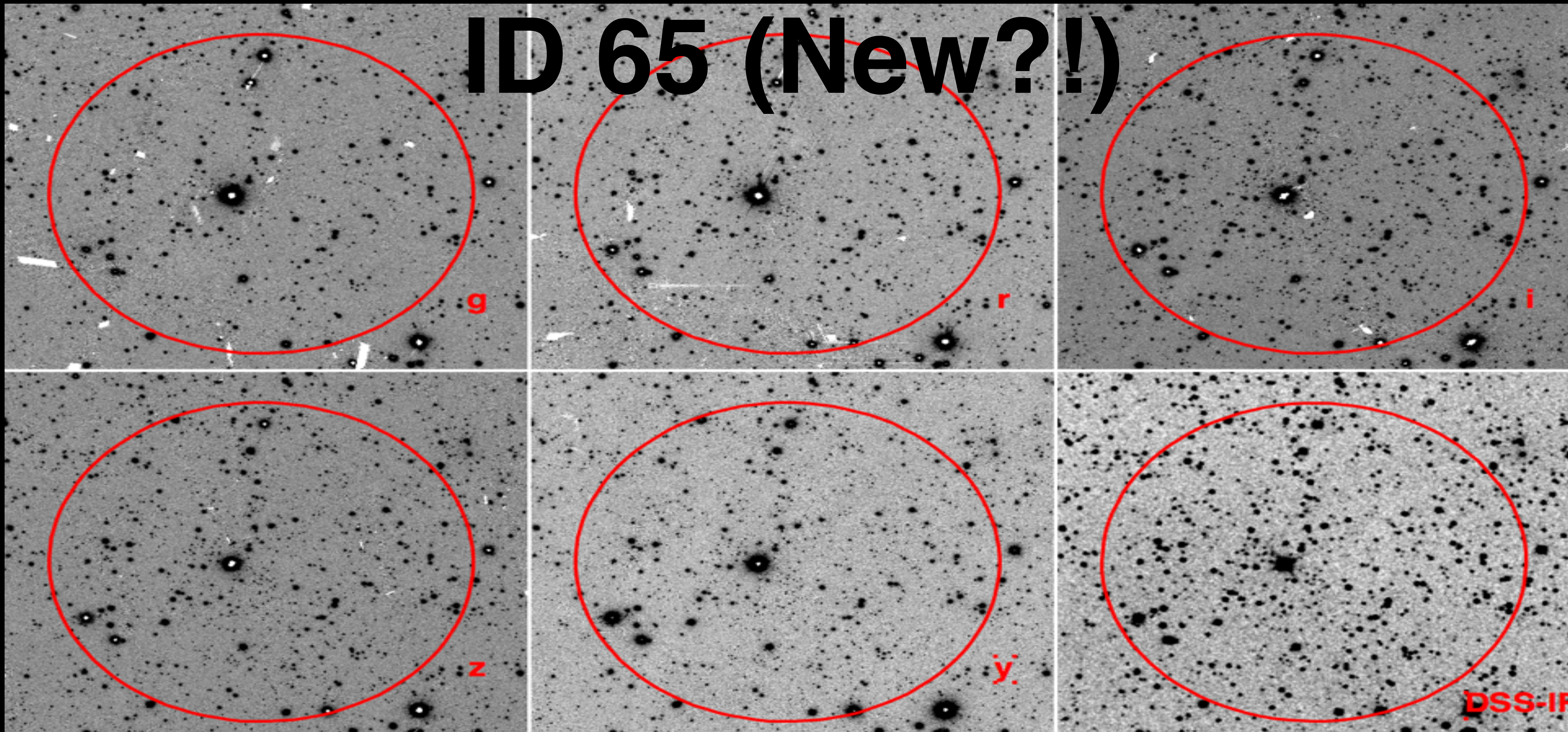


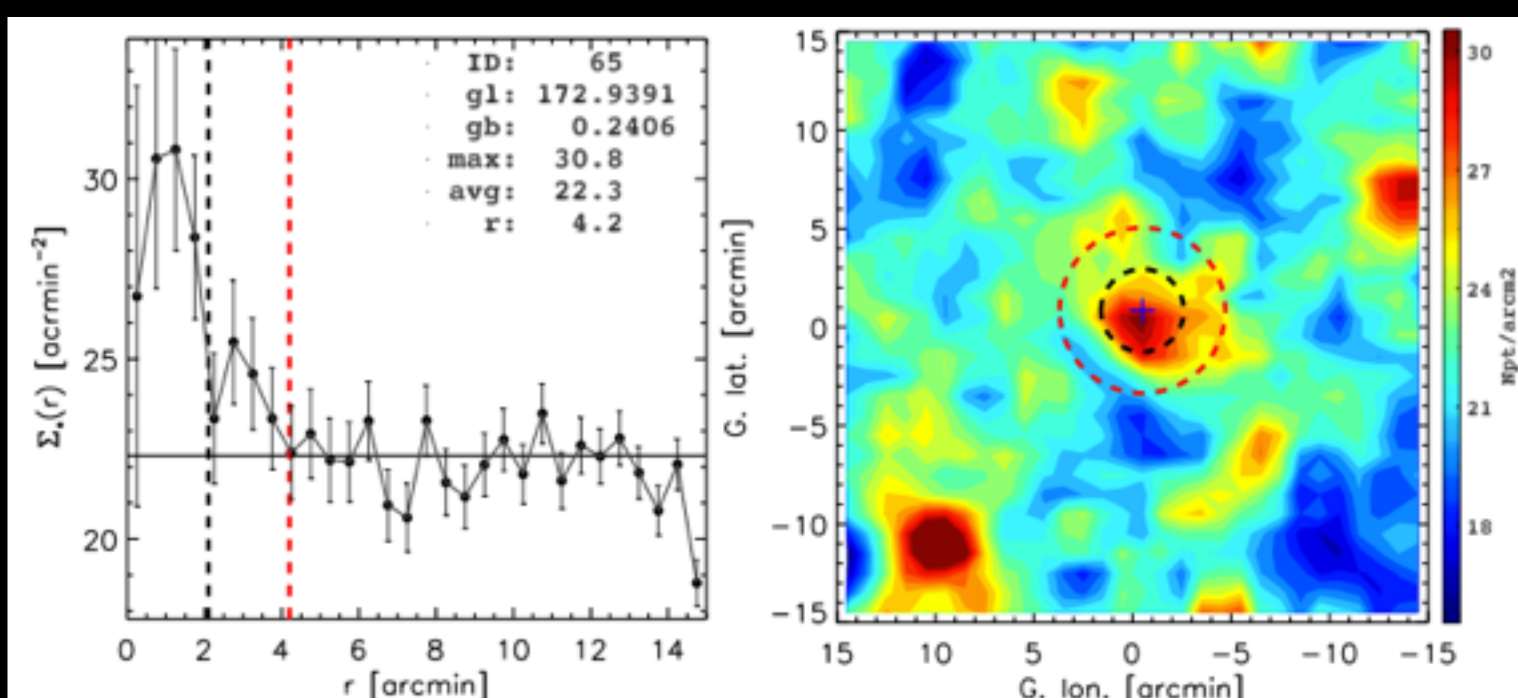


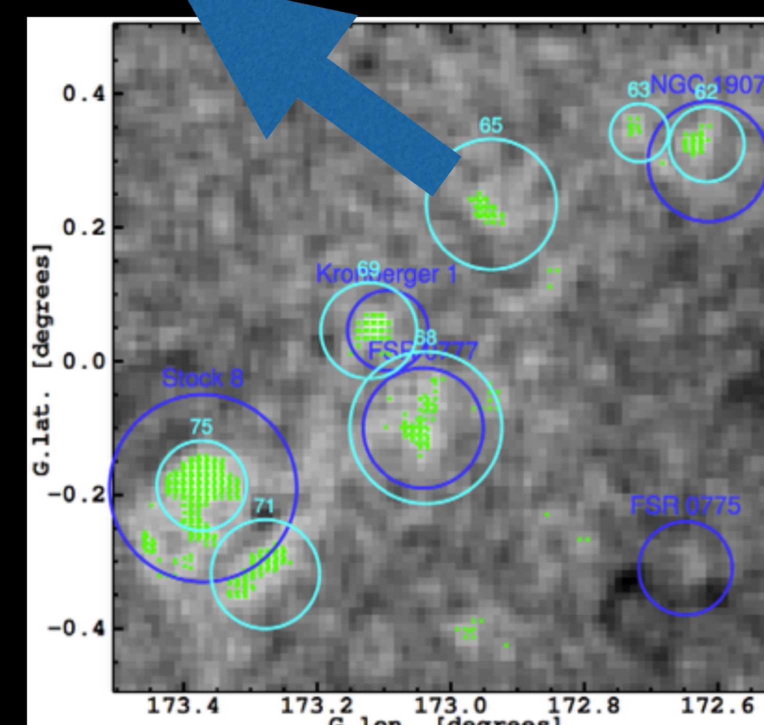
ID 62, 63
(two substructures of NGC1907)


ID 71, 75 (Stock 8)
two substructures
g
r
i
z
y
DSS-Ir
ID: 75
gl: 173.3735
gb: -0.1857
max: 59.8
avg: 22.4
r: 4.5
ID: 71
gl: 173.2834
gb: -0.3185
max: 36.9
avg: 22.8
r: 4.2
r [arcmin]
G. lon. [arcmin]
G. lat. [arcmin]
G.lon. [degrees]
Stock 8
75
71
65
63
62
NGC 1907
Kronberger 1
FSR 0777
FSR 0775

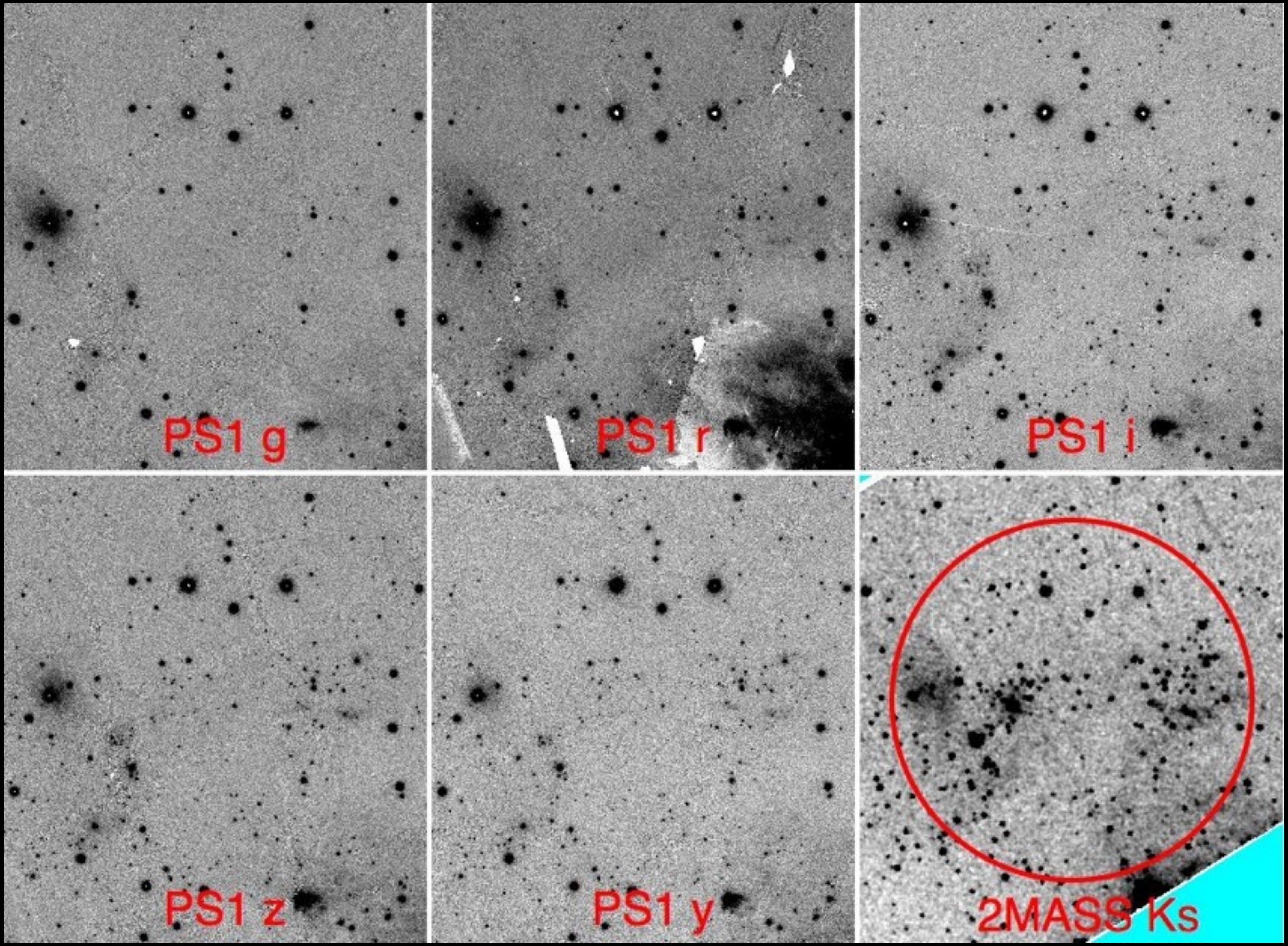
ID 65 (New?!)


g
r
i
z
y
DSS-IR

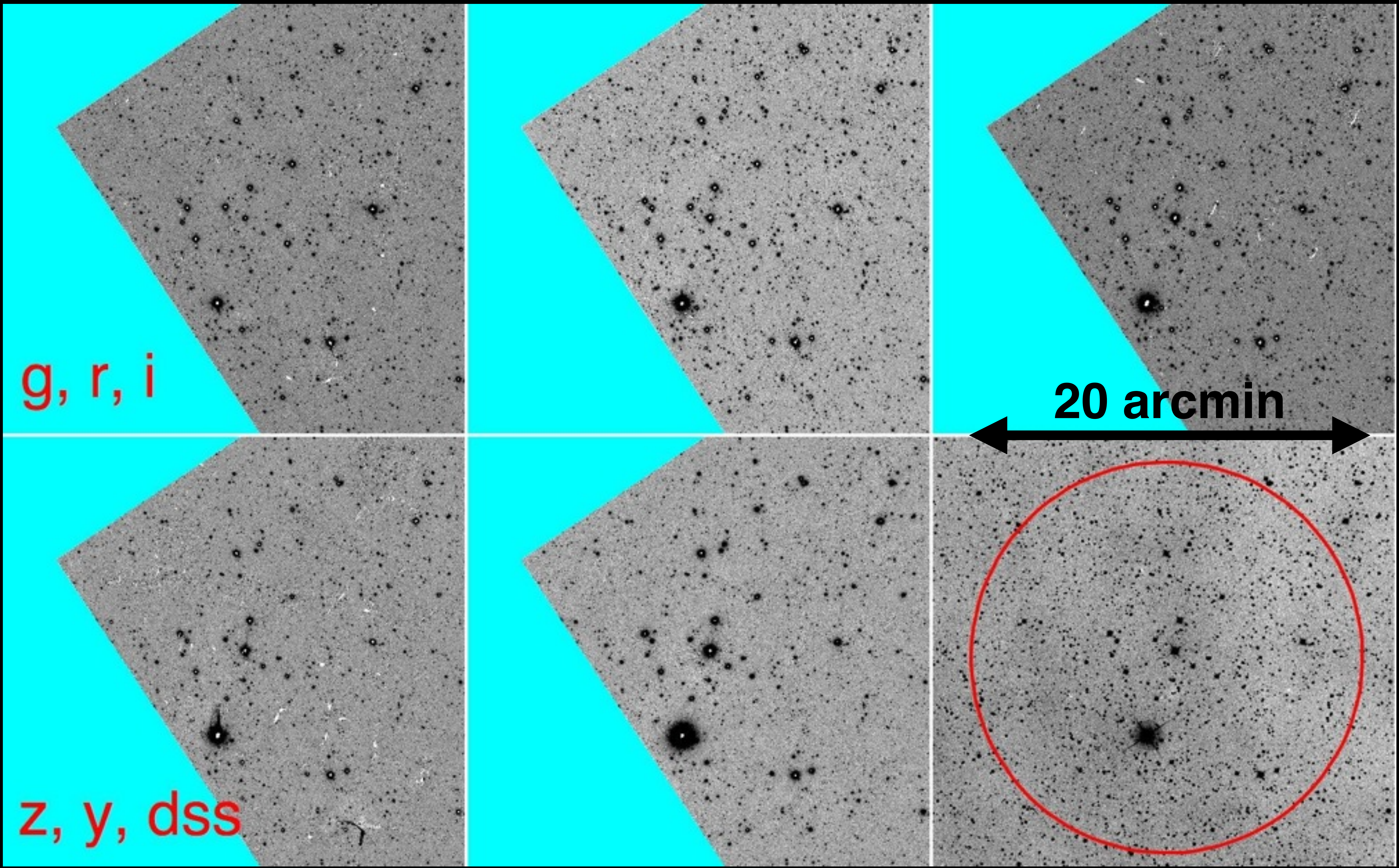

ID: 65
gl: 172.9391
gb: 0.2406
max: 30.8
avg: 22.3
r: 4.2
Σ*(r) [arcmin⁻²]
r [arcmin]
G. lat. [arcmin]
G. lon. [arcmin]
Npt/arcm2


NGC 1907
63
62
65
Kronberger 1
69
FSR 0777
68
Stock 8
75
71
FSR 0775
G.lat. [degrees]
G.lon. [degrees]

Failed on Embedded Clusters (BDSB 73)



Failed on Large Radii Clusters (NGC 1896)



Capability of the Search Algorithm

- 50 of 109 known star clusters were re-found
  - 30 are probably not star clusters
  - 13 are too large > 10’
  - 2 are embedded clusters
  - 4 are in HII regions
  - 10 are detected twice (three times required)
- Detection rate of the search method is 50/60 ~ 83%
- 491 star cluster candidates were identified

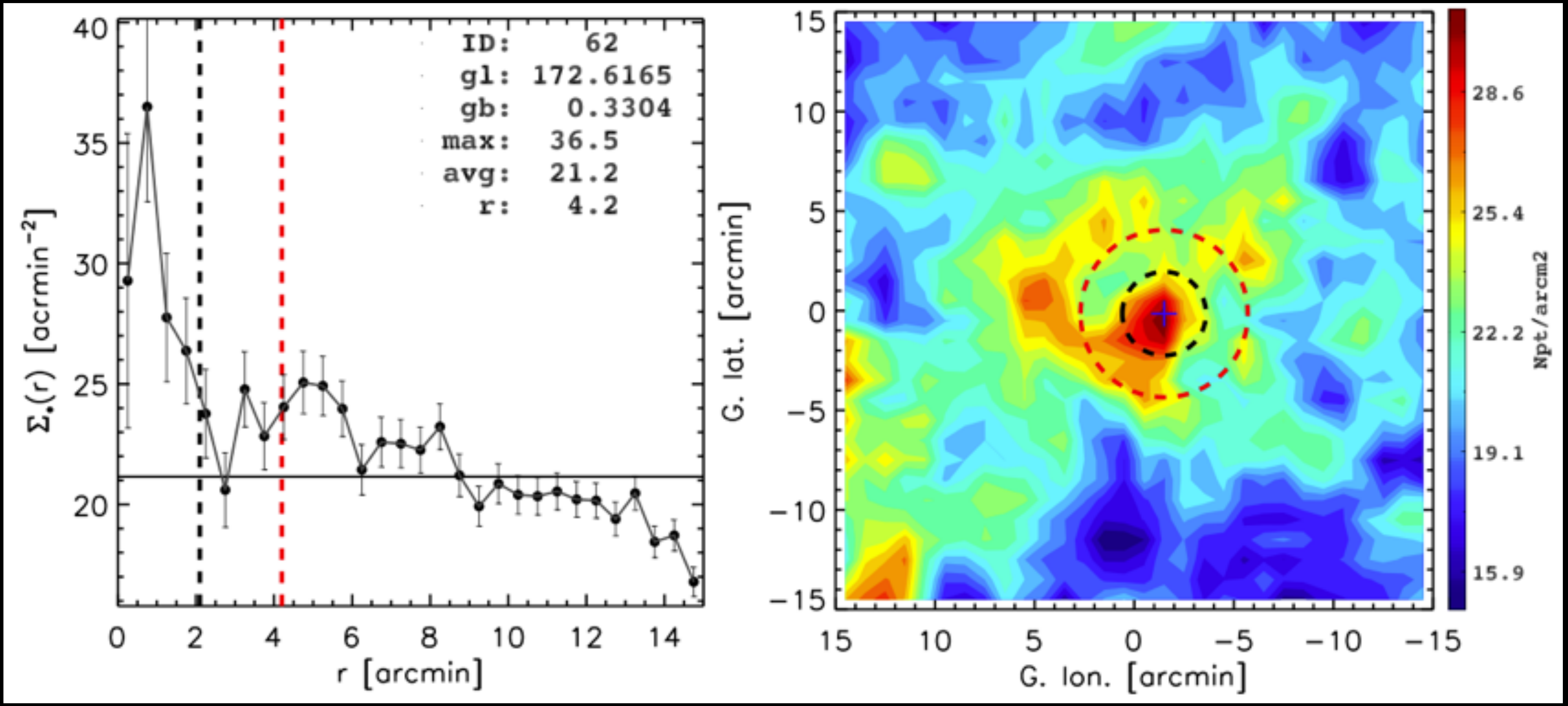
Characterization

Characterization

- 491 star cluster candidates were identified
- coordinate and radius
- highly probable members
- reddening, distance, age
- low mass members

Coordinate and Radius

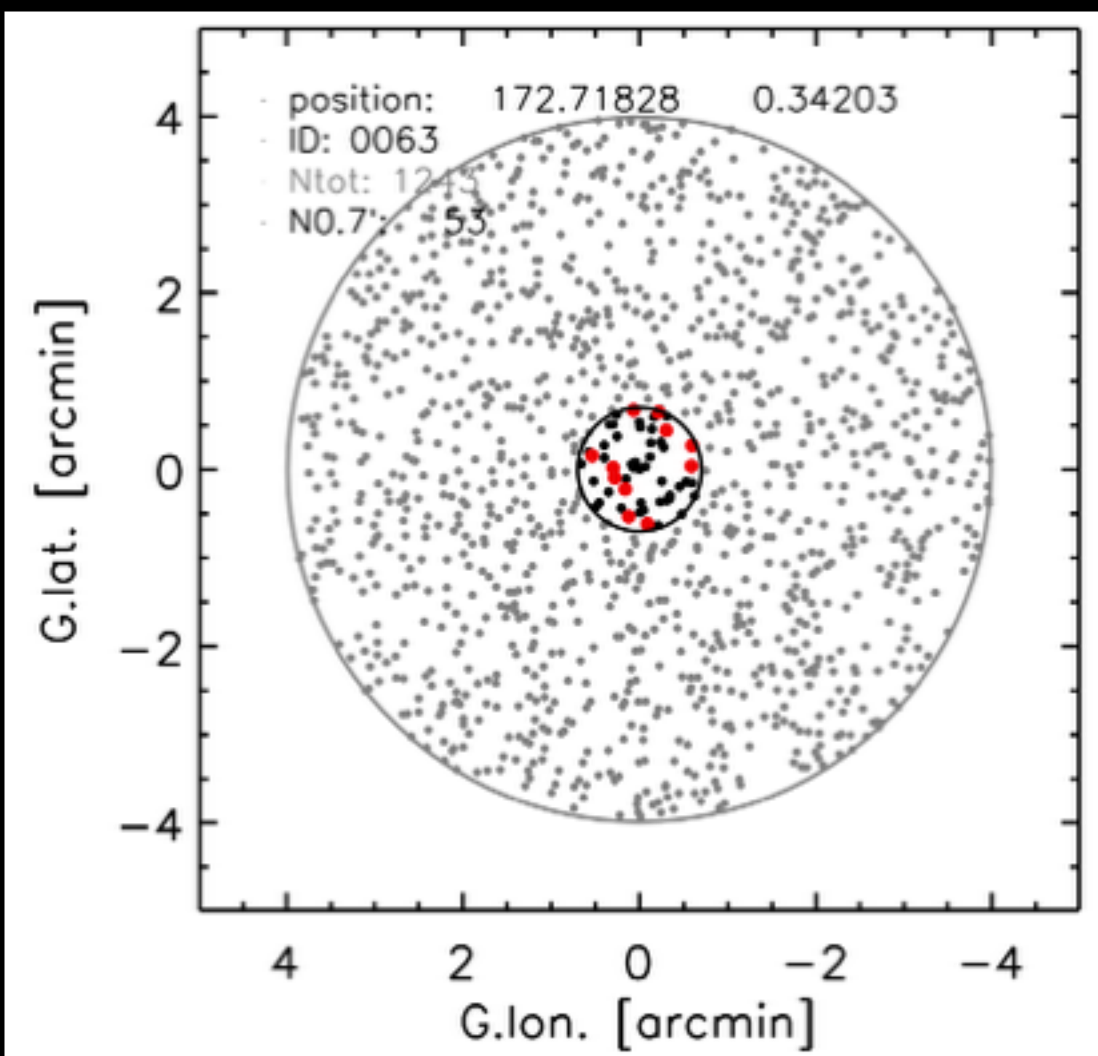
- The center coordinate: position of density peak
- Core radius: half of density peak (Gaussian profile)
- Effective radius (r_e): 2 x core radius



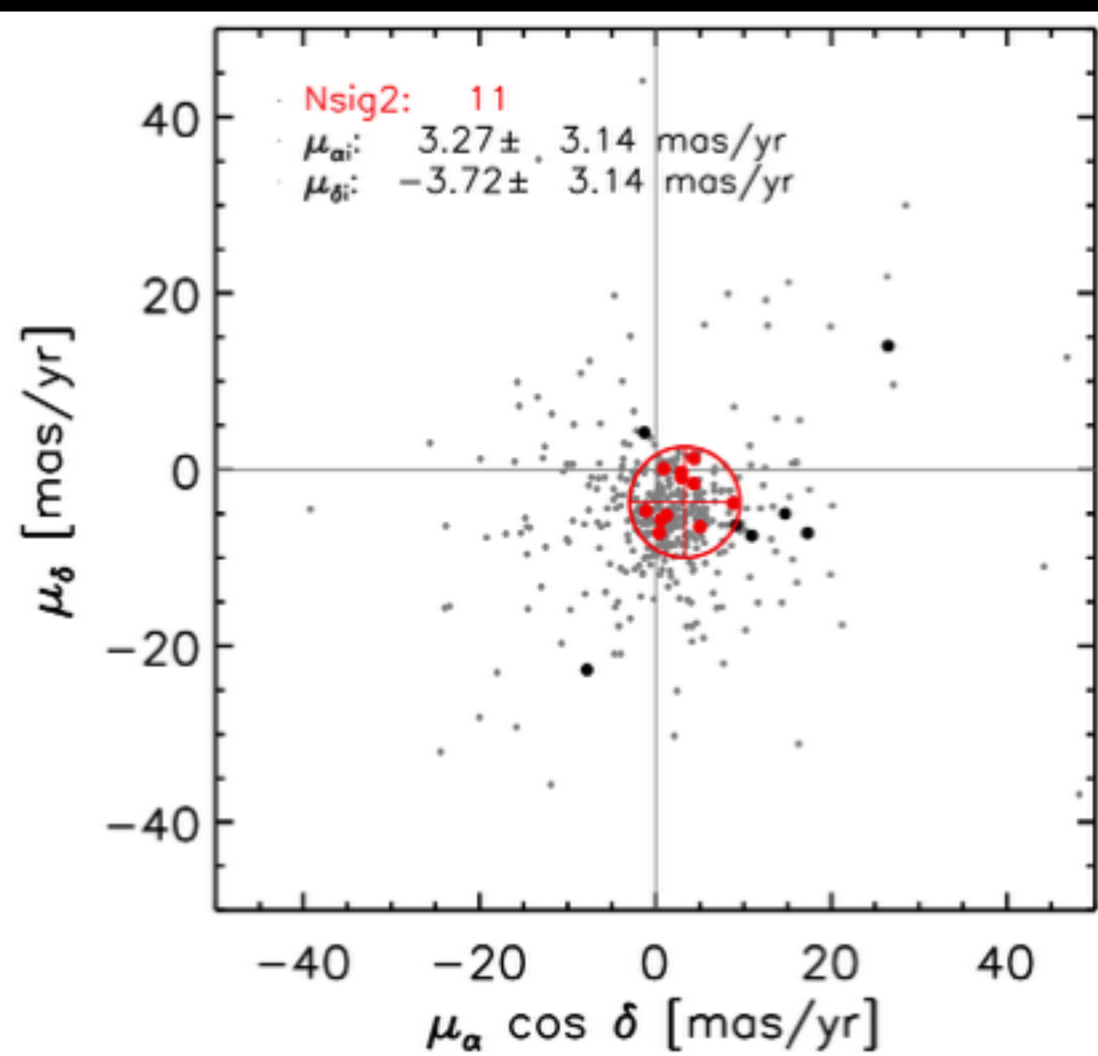
Radial Density Profile　　Zoomed in Density Map

Proper Motions

- secured members
- spatial (r < 0.7 arcmin)
- PPMXL proper motions (PM) within 2σ



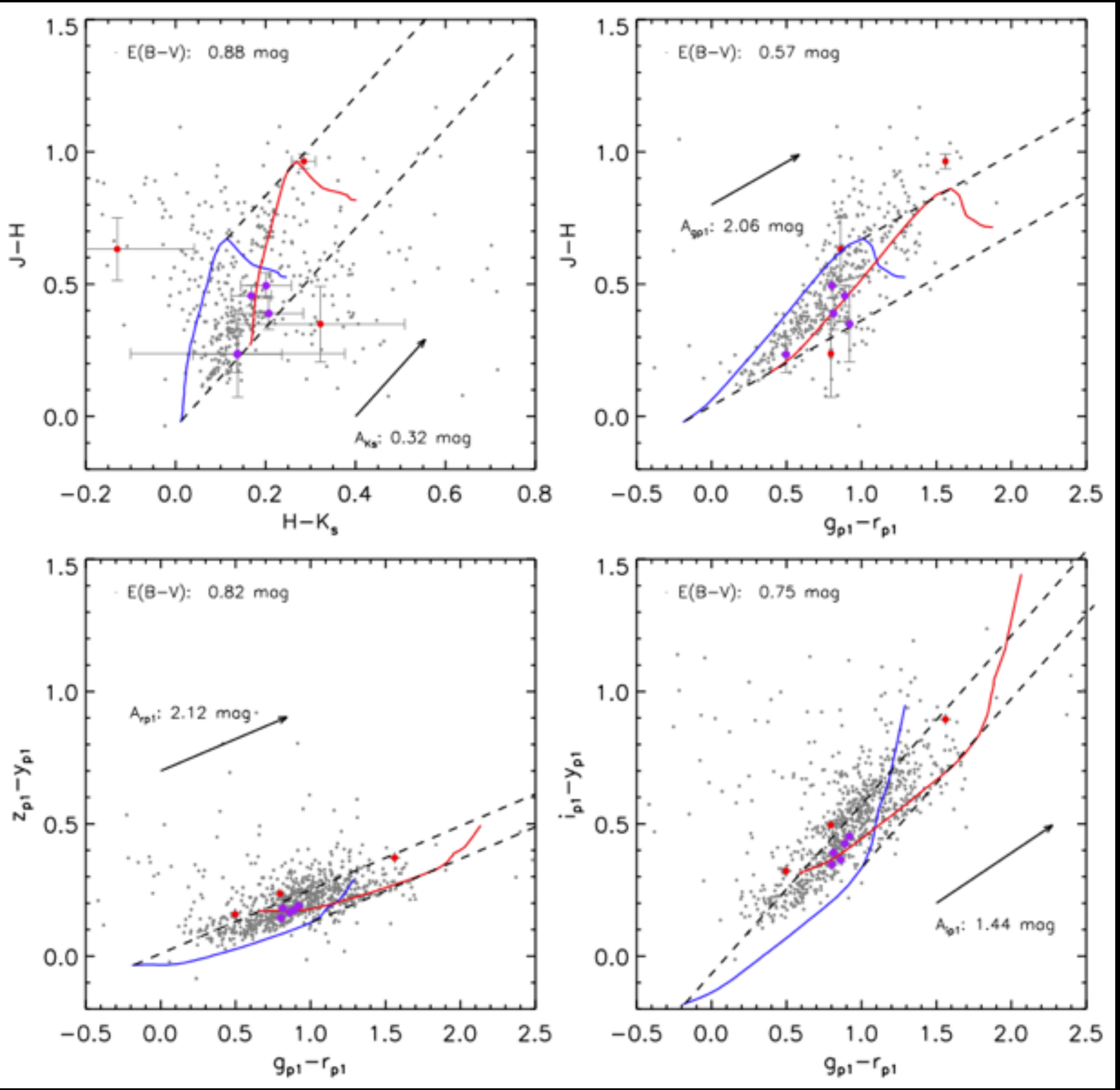
Spatial Distribution



Proper Motion Diagram

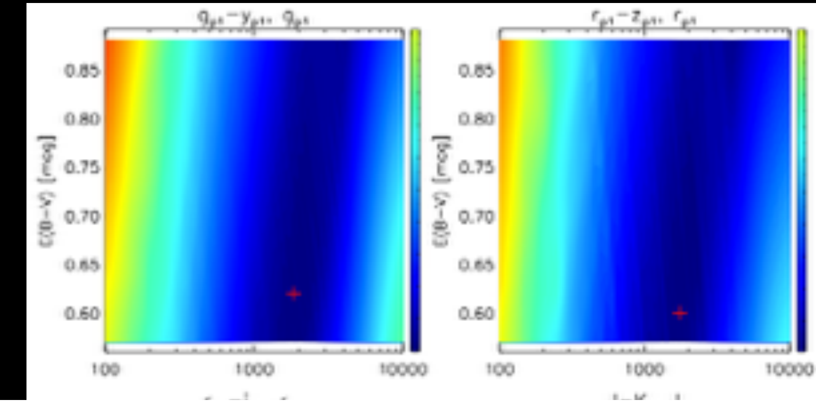
Reddening

- two-color diagram
  - (H−Ks, J−H)
  - (g−r, J−H)
  - (g−r, z−y)
  - (i−y, g−r)
- range of E(B-V)

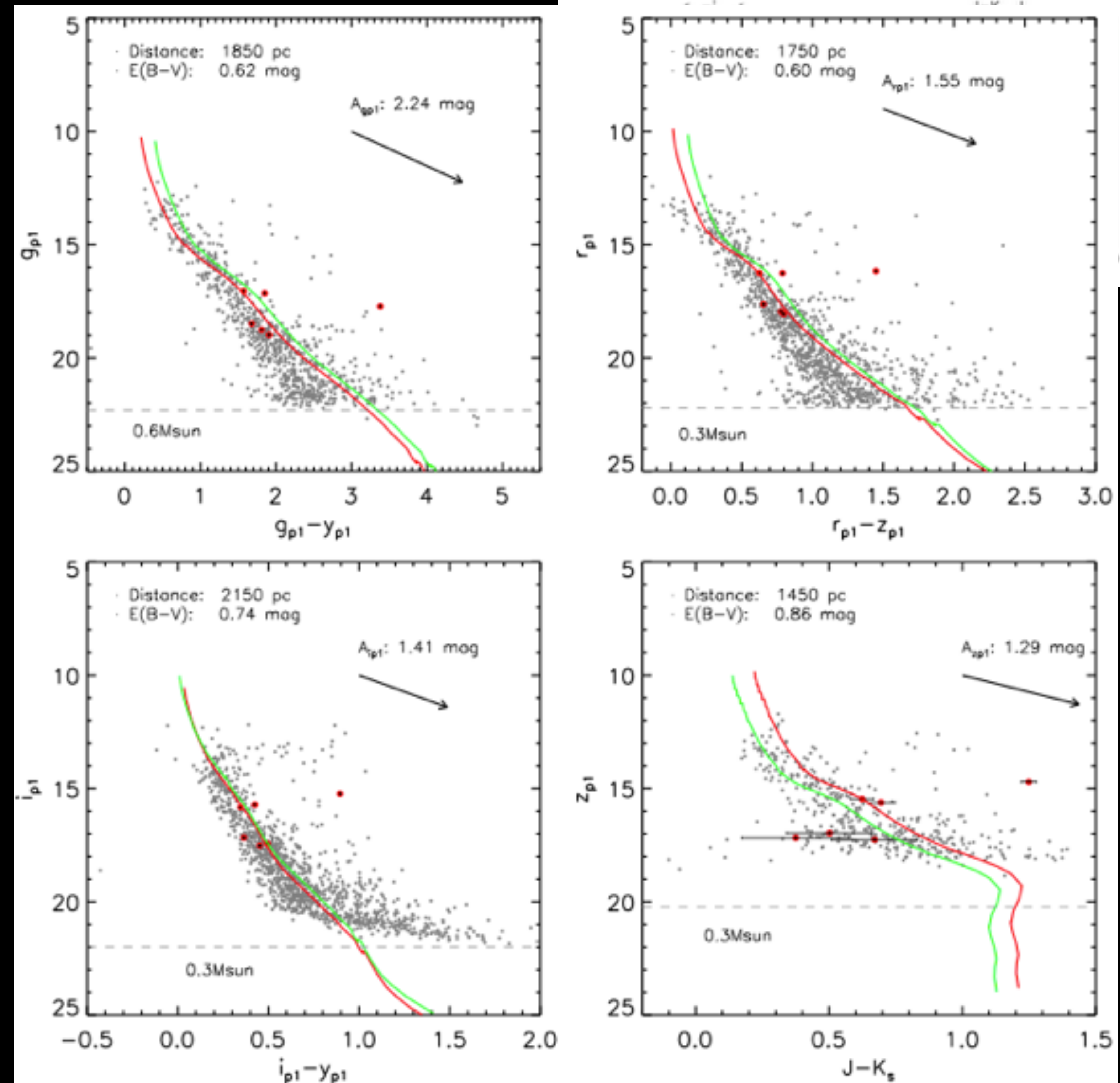


stellar loci: Tonry et al., 2012

Distance & Reddening



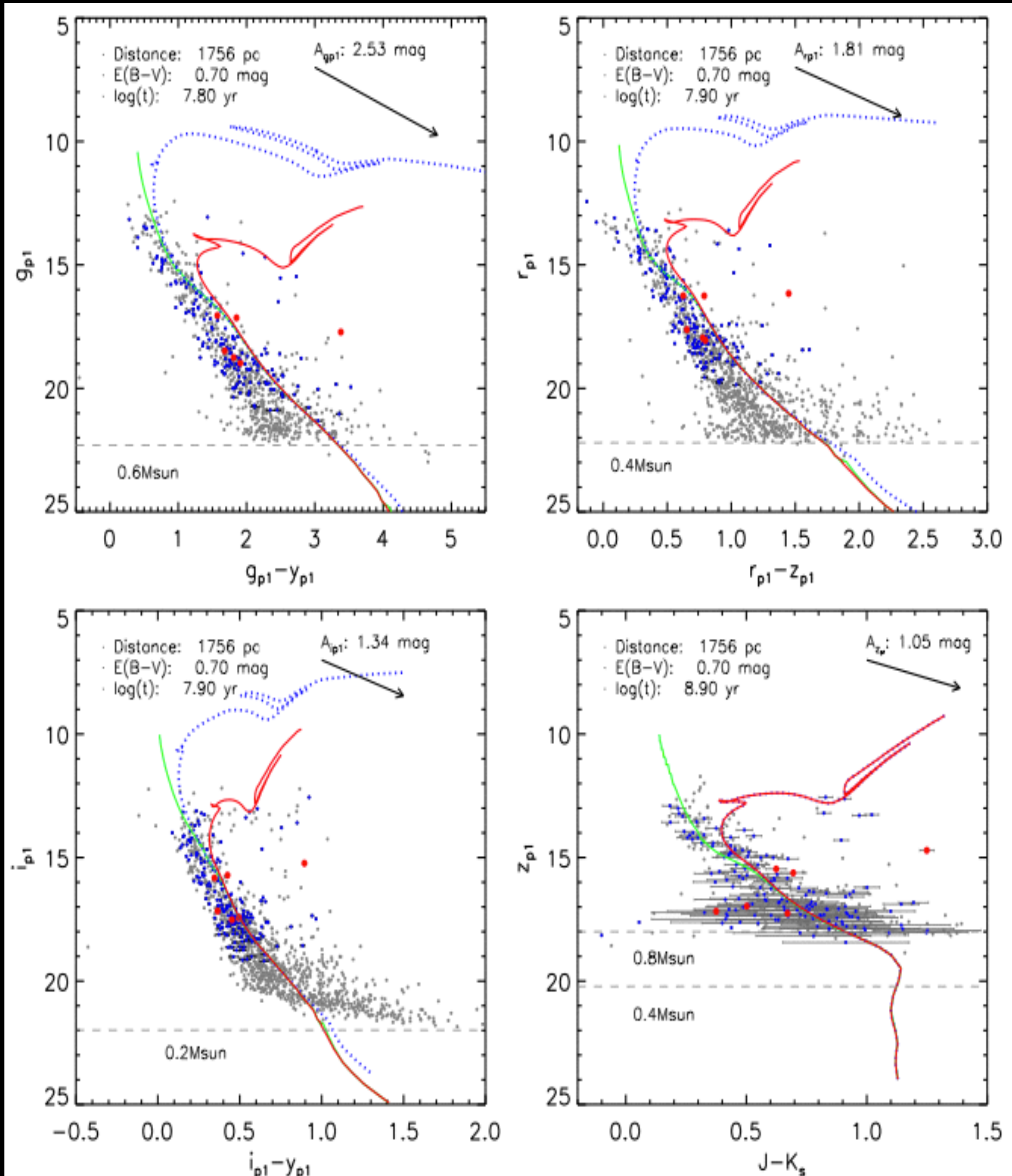
- ZAMS fitting
- color-magnitude diagram
  - (g-y, g), (r-z, r)
  - (i-y, i),(J-Ks, z)
- avg. distance
- avg. reddening



ZAMS: Marigo et al., 2008

Age

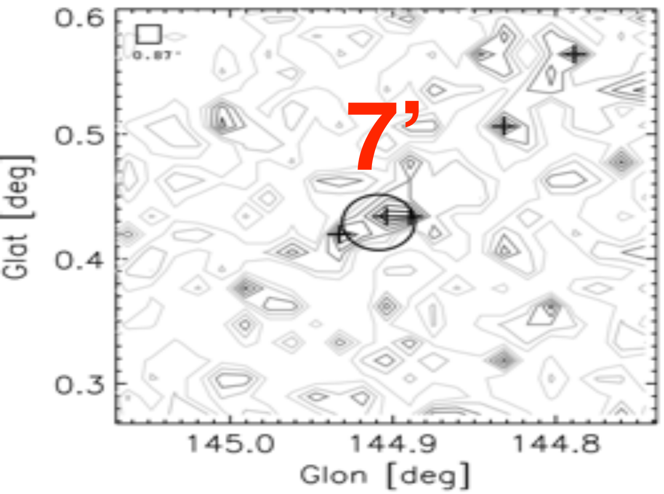
- secured members
  - within r_e
  - selected PMs
- color-magnitude
  - (g-y, g), (r-z, r)
  - (i-y, i),(J-Ks, z)
- avg. age
- Stellar masses
  - 0.25 $M_\odot$ at 1 kpc
  - 0.7 $M_\odot$ at 4 kpc

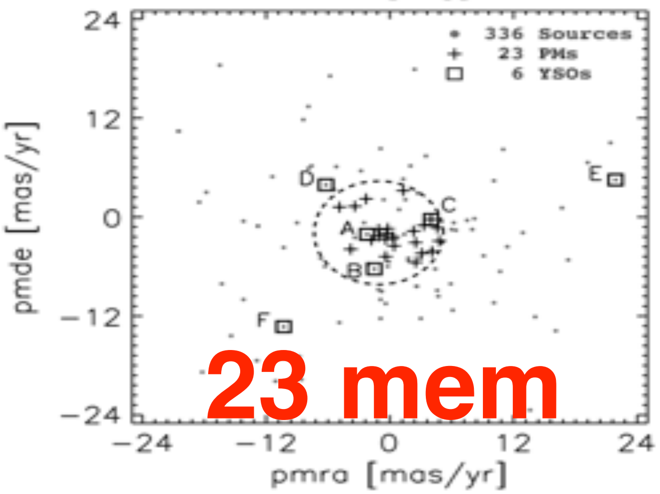


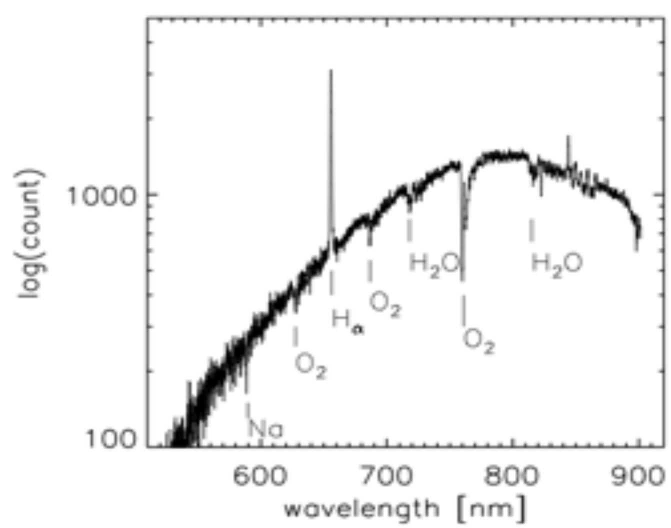
Isochrone: Marigo et al., 2008

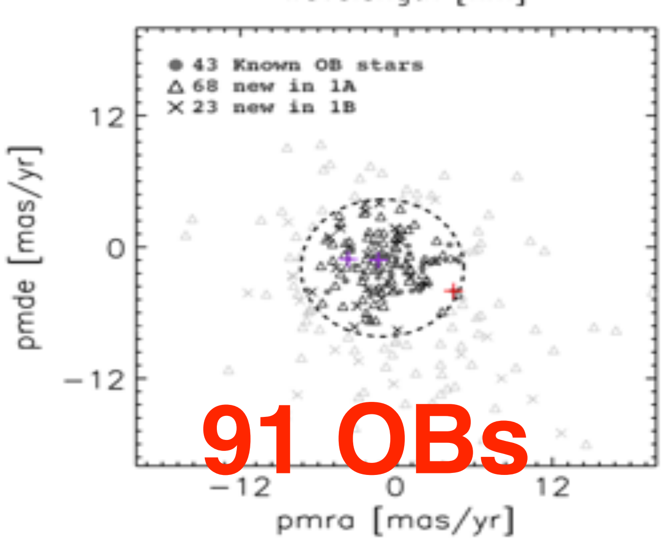
The similar procedures have been applied for two star clusters

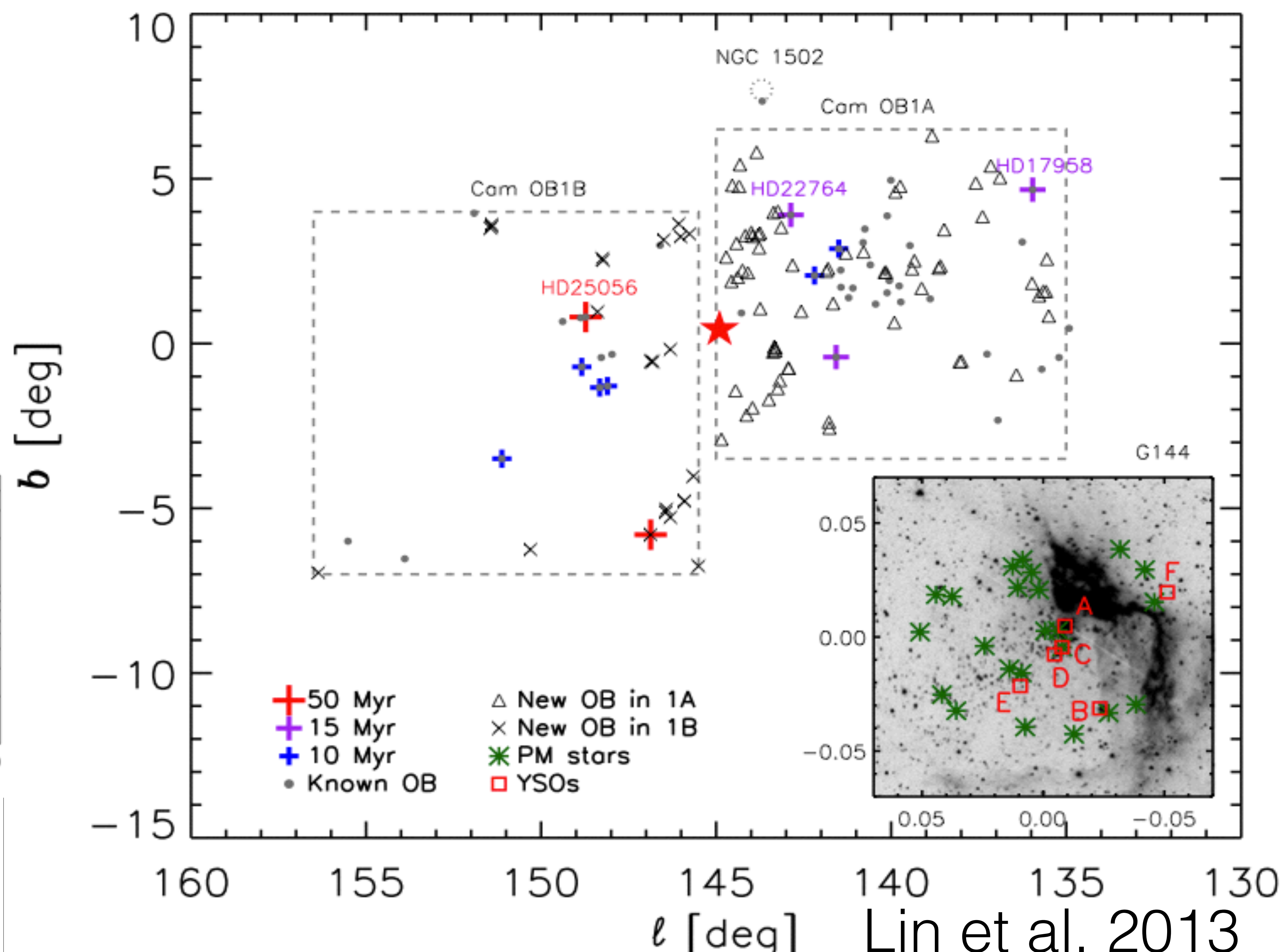
Characterization of a young star cluster G144





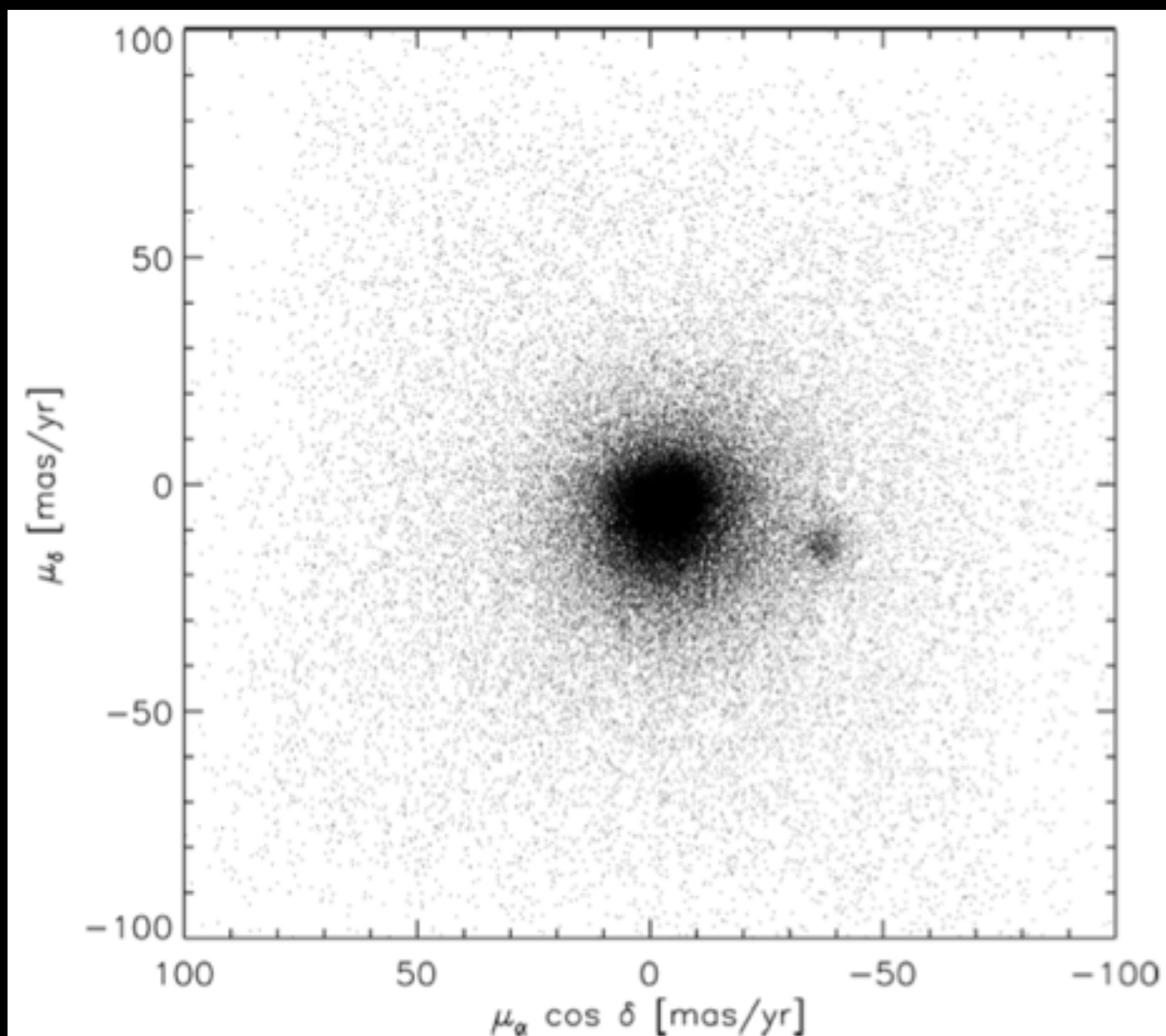




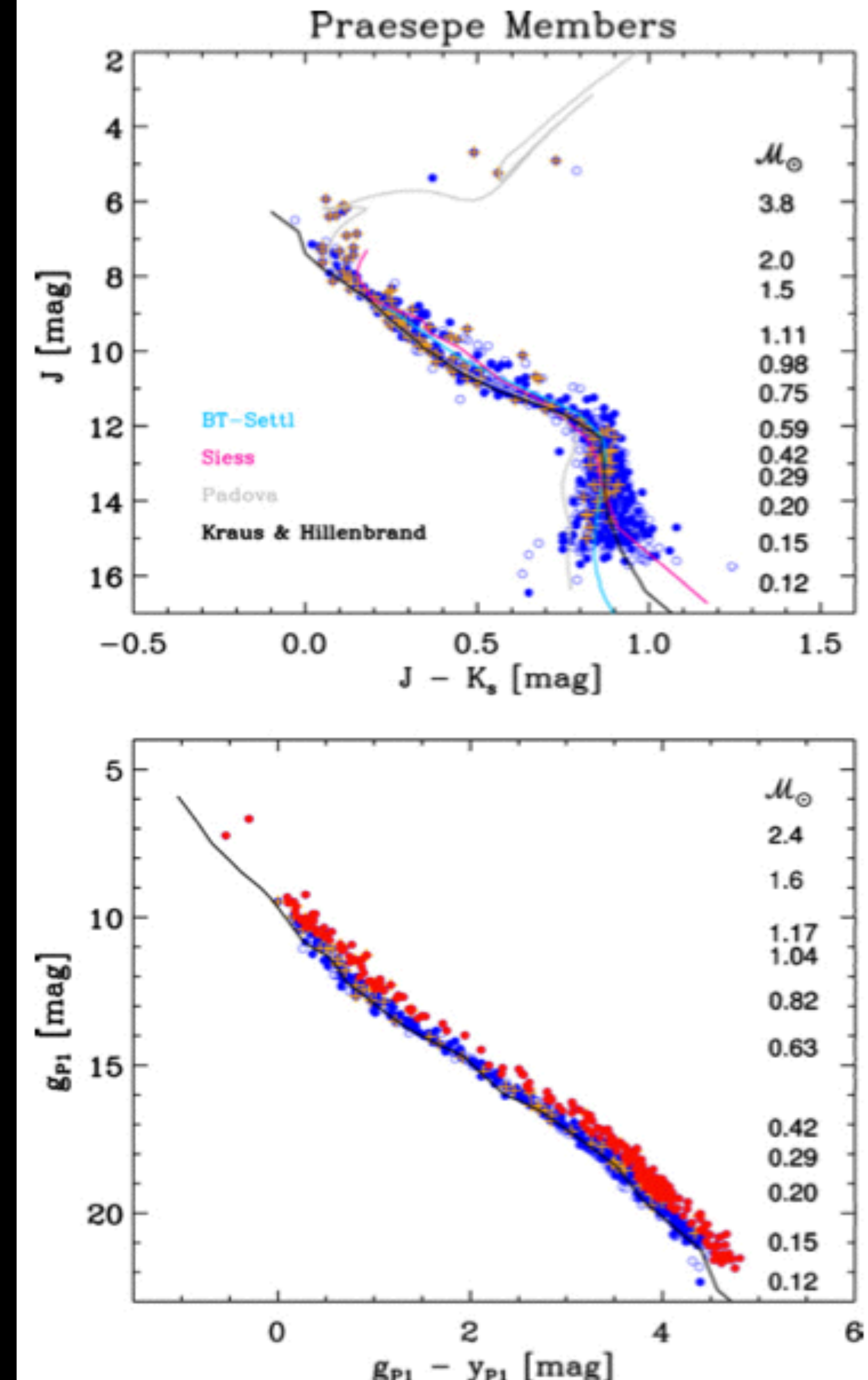


G144 represented the latest episode of sequential star formation in this cloud complex.

Characterization of an intermediate age cluster Praesepe (750 Myr)

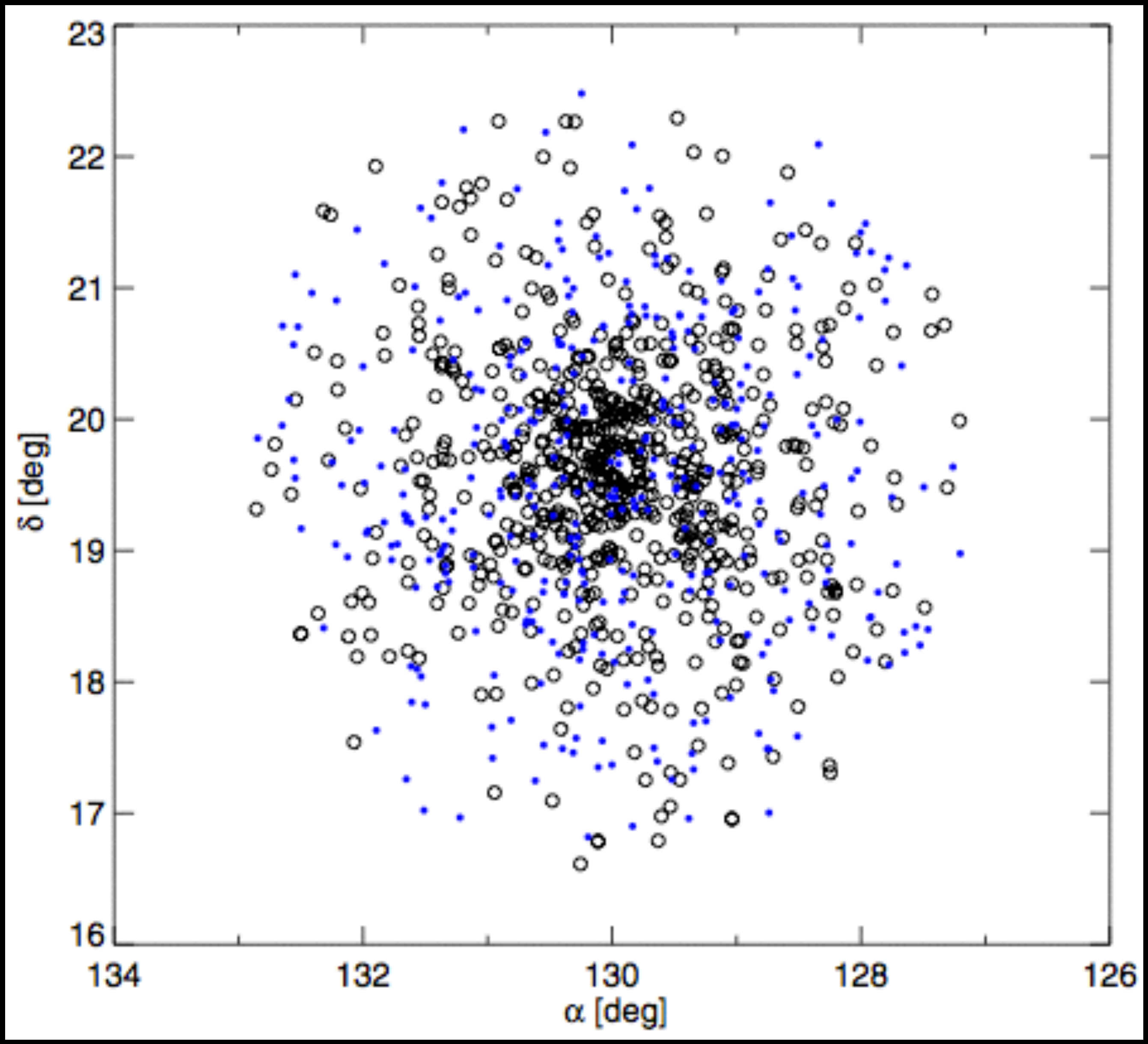


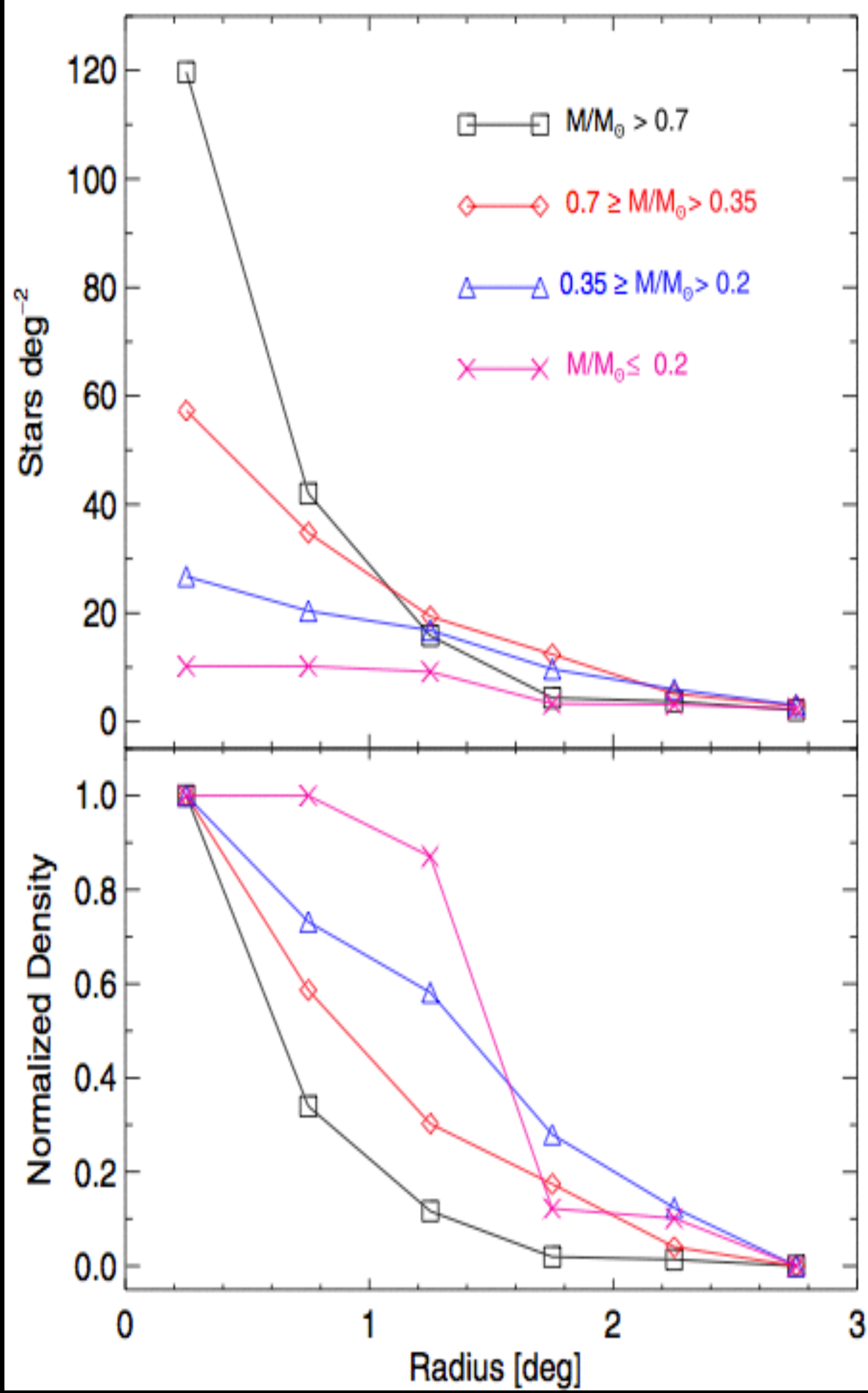
PPMXL + 2MASS + PS1
1040 member candidates
20-40% binary frequency
low-mass stars < 0.1 M⊙



Wang et al. 2013

Characterization of an intermediate age cluster Praesepe (750 Myr)



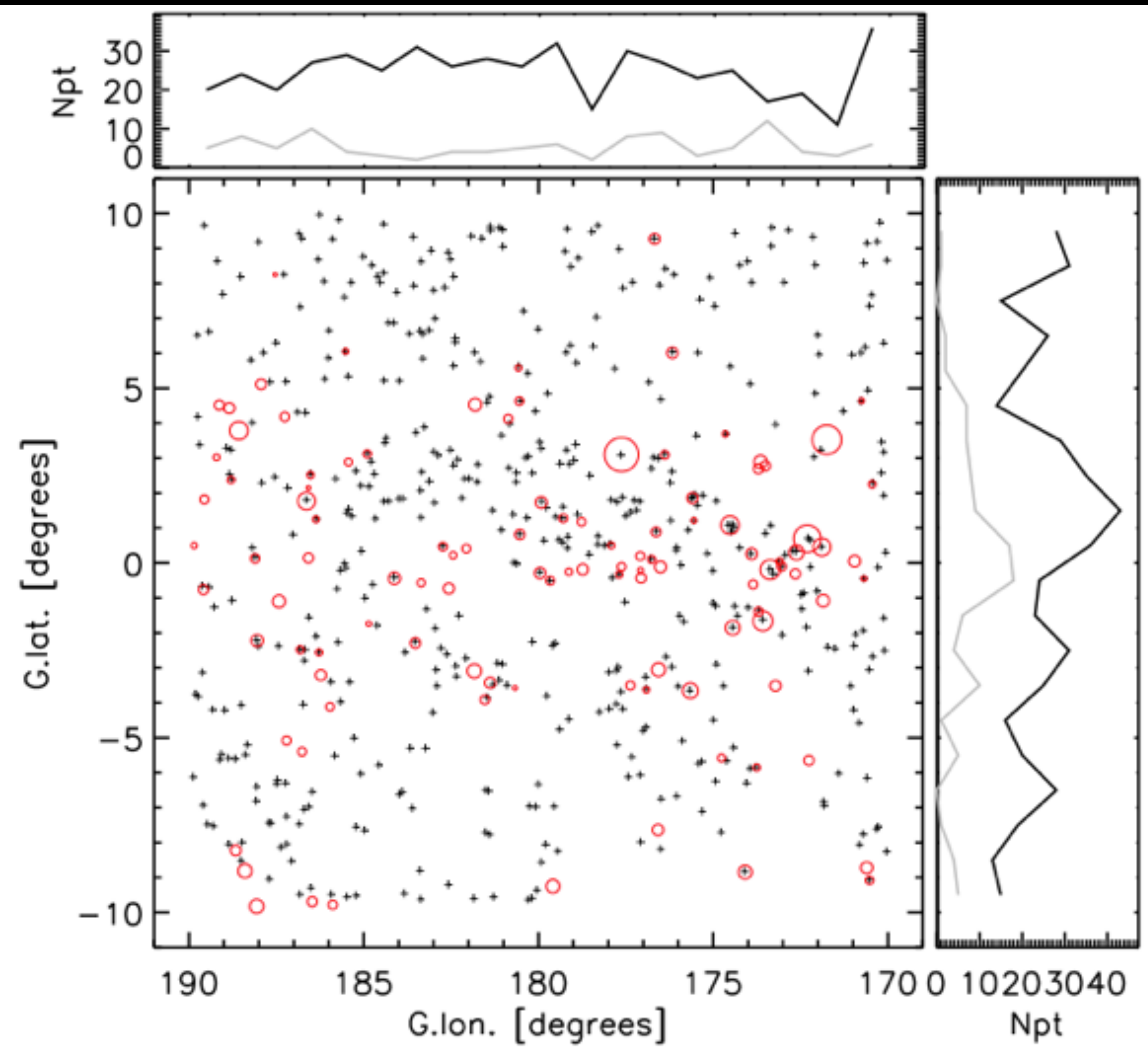


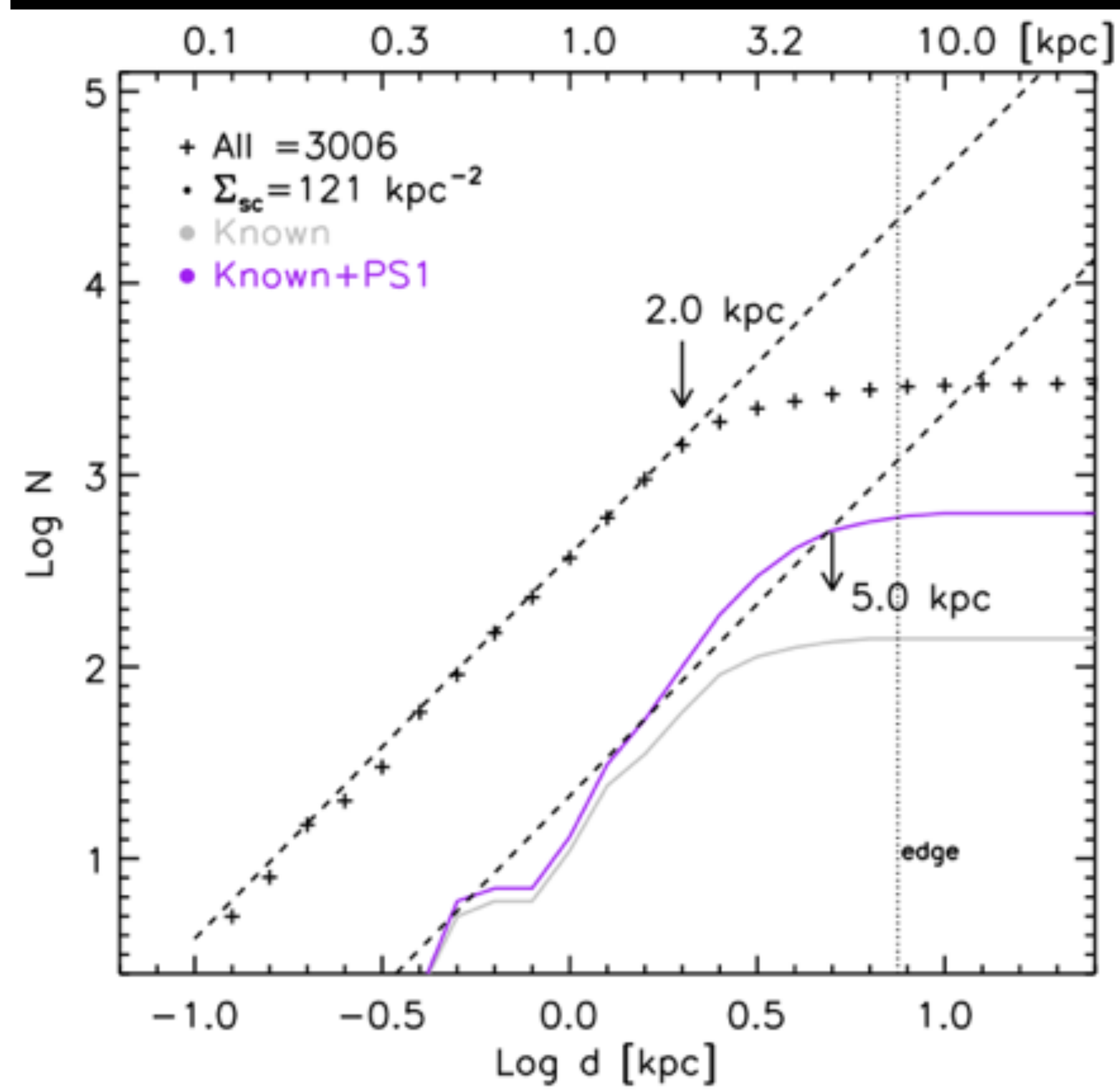
Mass segregation occurred
Low-mass members are escaping

Wang et al. 2013

Results

The completeness limit of revised sample ~ 5 kpc





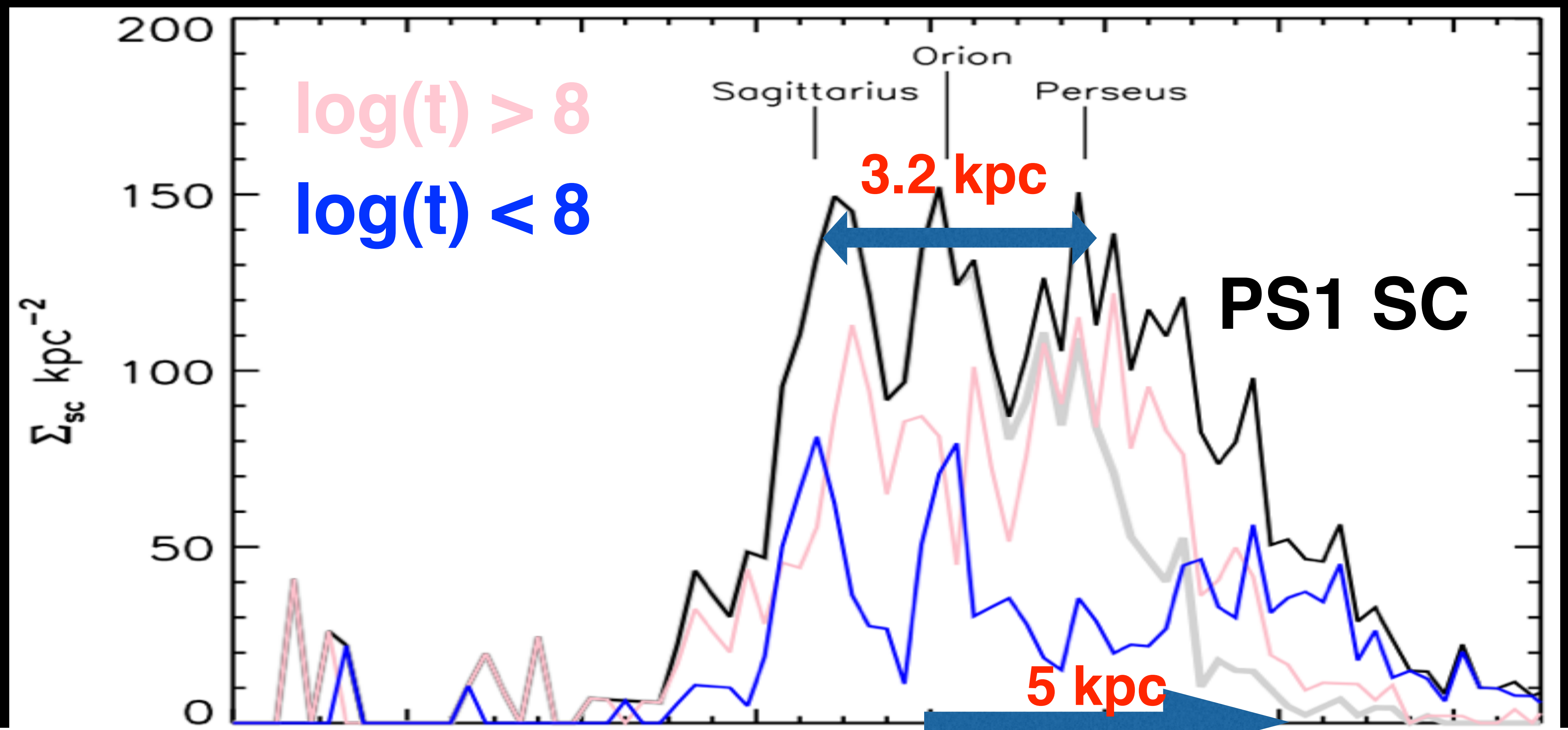
Spatial Distribution

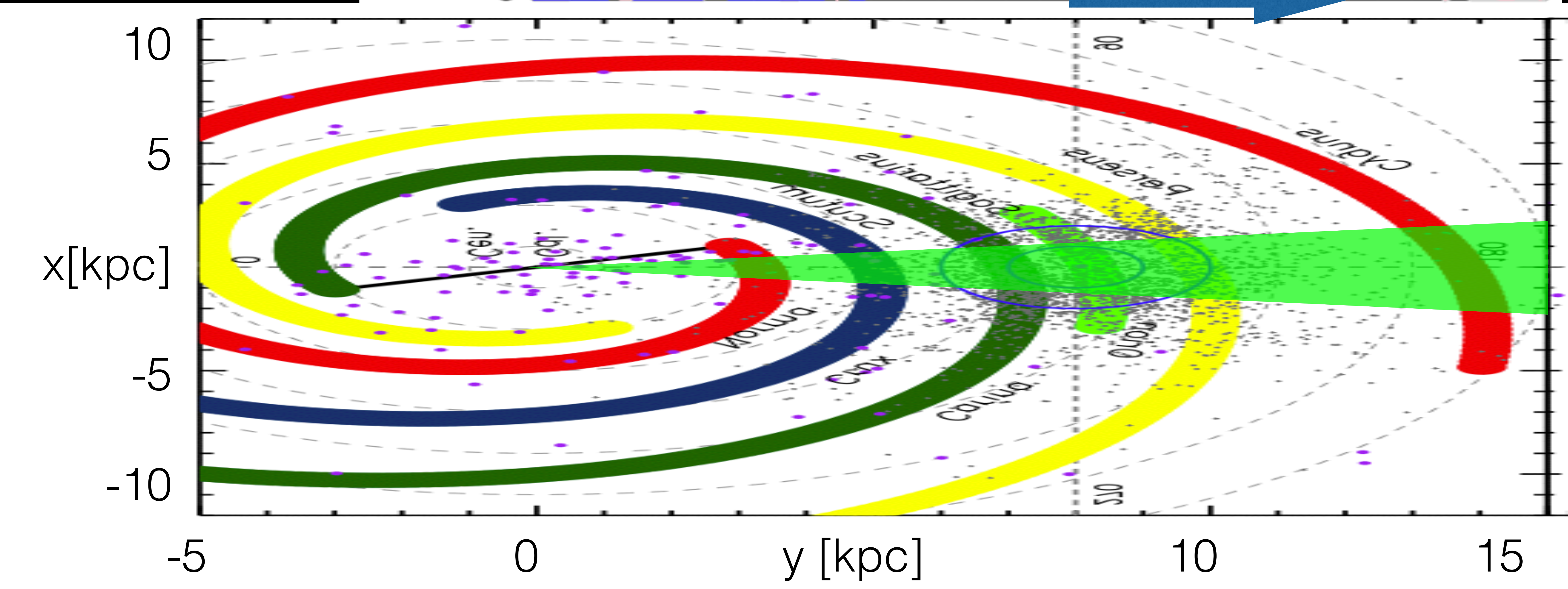
Cumulative distribution

Sagittarius:
450±50 pc

Orion:
400±50 pc

Perseus:
800±100 pc





Summary

- As a pilot program to search for star clusters from PS1 data, we developed the star-counting algorithm to identify 491 stellar density enhancements (50 are matched with known OCs) in a field of 20 x 20 deg^2 toward the Galactic anti-center.
- The detection rate of known OCs by the search method is ~ 83%.
- We characterized the star cluster candidates with RDP, PMD, TCD, and CMD to obtain coordinate, radius, mean proper motion, reddening, distance, and age, respectively.
- The completeness limit of revised star cluster sample is up to about 5 kpc toward the Galactic anti-center. The lowest mass of members can be identified down to 0.25 $M_\odot$ or 0.7 $M_\odot$ at ~ 1 kpc or 4 kpc with PS1 photometry.
- The separation between the Sagittarius and Perseus arms is estimated to be 3.2±0.5 kpc and the widths of Sagittarius, Orion, and Perseus arms to be 450±50, 400±50, 800±100 kpc. The metallicity gradient seems to decrease toward the Galactic anti-center.

Future Works

- We aim to provide a more complete sample of star clusters than current samples.
- Verification of newly found candidates either by PS1 image inspection or by follow-up observations.
- Improvements of characterization, in particular the age determination with different metallicities and models (Padova, BT-Settl).
- Expansion of the search area to other parts of the Galactic plane (|b| < 50 deg).
- Characterization with supplemental data, such as deep images (WIRCam, HSC), spectral data (SDSS or LAMOST), and proper motions (PS1).

Thanks