Billions of stars: the near infrared view of the Plane with the UKIDSS GPS

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Outline

1) Intro to the UKIDSS Galactic Plane Survey.
2) Combination with other surveys: Glimpse, IPHAS
3) Clusters in the GPS
4) New high amplitude variables

UKIDSS GPS Strategy

- Observing strategy (see Lucas et al.2008, MNRAS 391,136)
  - Observe at JHK in photometric conditions.
  - 3 band data taken near simultaneously (within a 20 minute period).
  - Integration times are 80s, 80s, 40s at JHK.
  - 2x2 microstepping is used to improve resolution -> 0.2” pixels.

- A 2nd epoch of imaging at K only is also in progress to detect high amplitude variables and proper motions.

GPS Depth

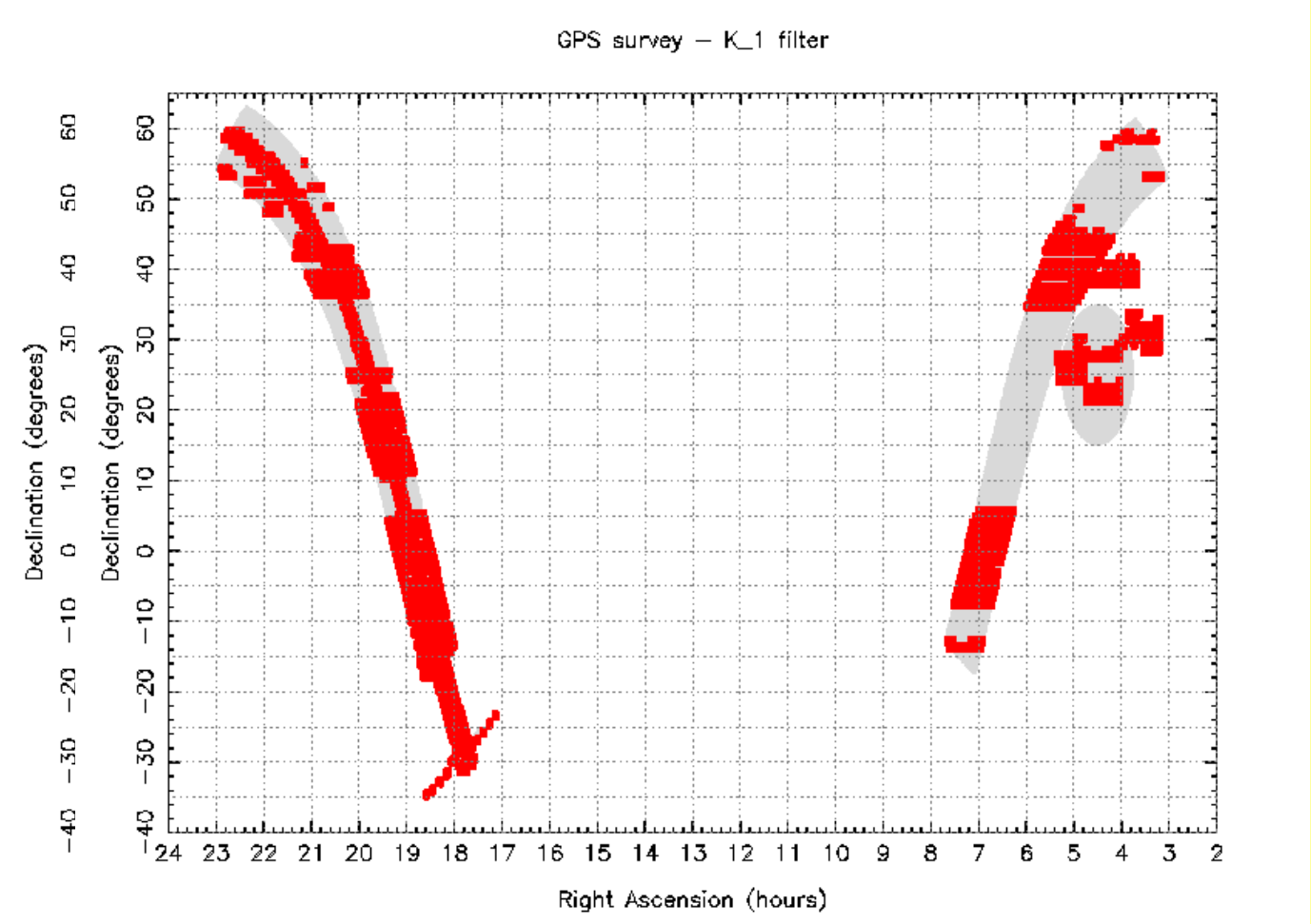
In uncrowded fields the modal (Vega) magnitudes are typically:

J=19.4 to 19.65
H=18.5 to 18.75
K=17.75 to 18.0.

The GPS is confusion limited in the inner Galaxy. Only a large wide field space telescope could go much deeper there.

UKIDSS GPS

Sky coverage in DR5 (now public to ESO states)



UKIDSS GPS Progress

DR5: 561 deg^2 at JHK. 1135 deg^2 at K_1 band.
31 deg^2 at K_2 band.

591 million unique sources. 1 to 2 billion expected at completion.

No. of sources with 2 epoch K band data: 22,760,901

Observed to 30 July 2009: ~800 deg^2 at JHK.

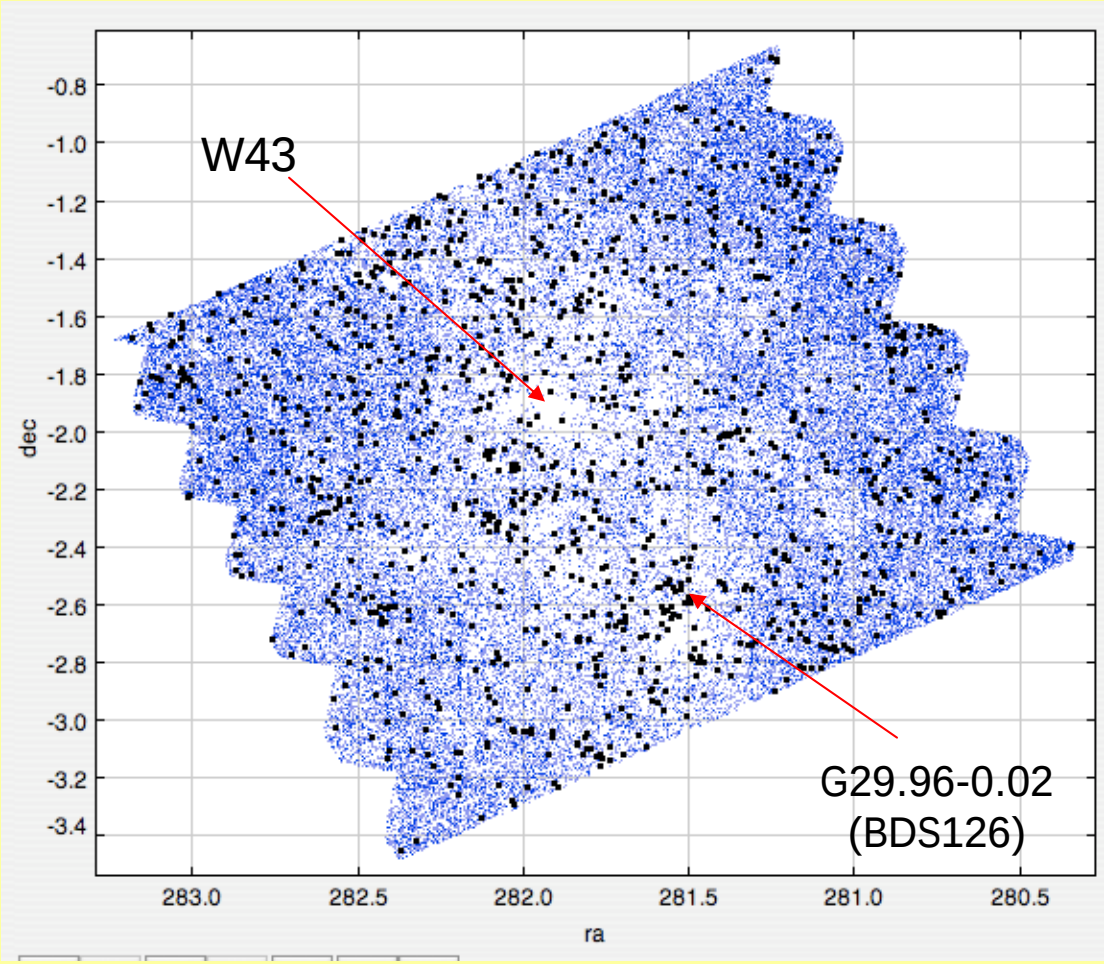
GPS/Glimpse cross match at l=29.6 to 31.6

Blue dots: normal stars

Black dots: YSO candidates

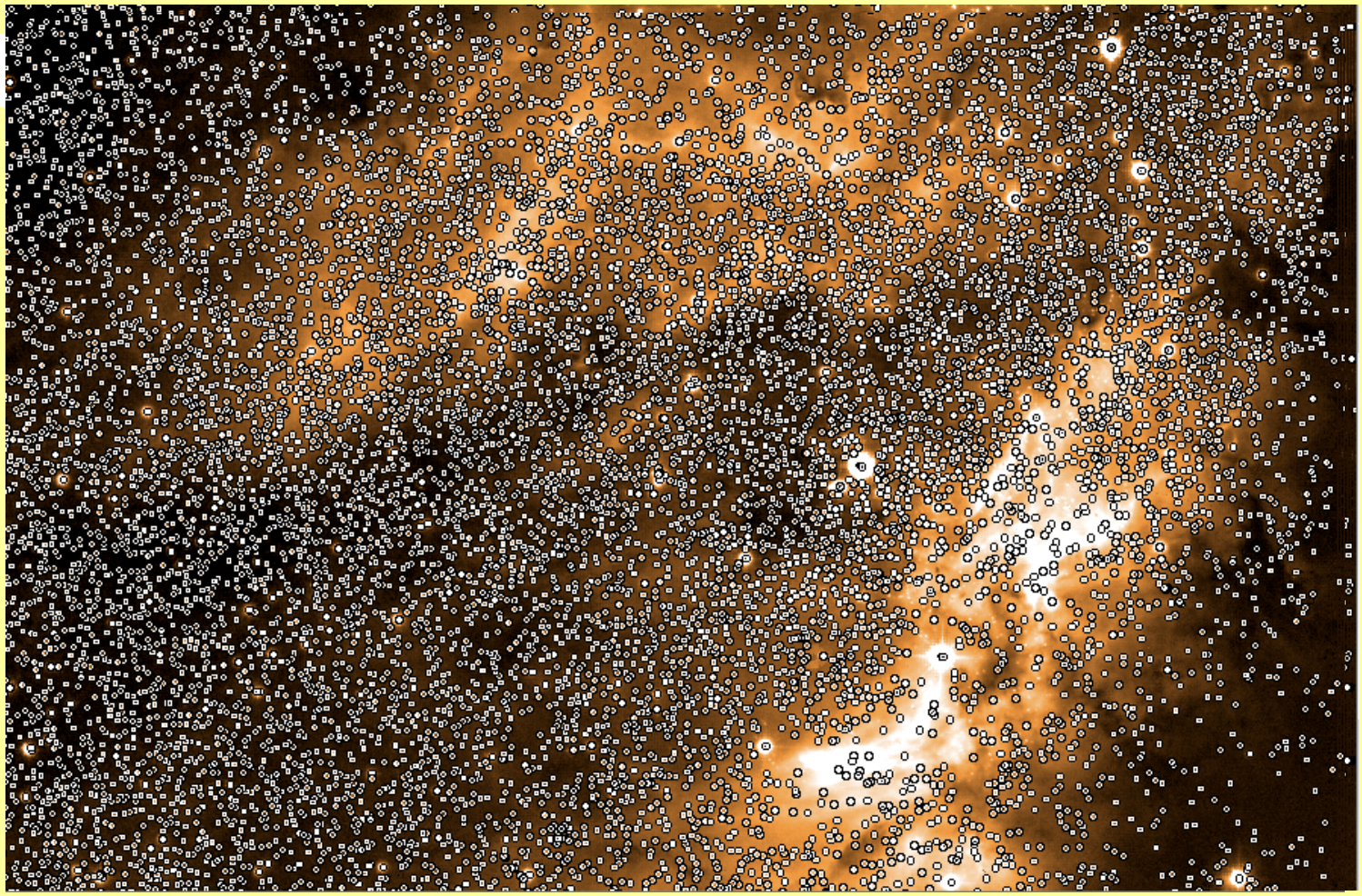
A problem is incompleteness in nebulous star formation regions in GLIMPSE.

The GLIMPSE-360 and Cygnus-X teams are tackling this for their surveys.



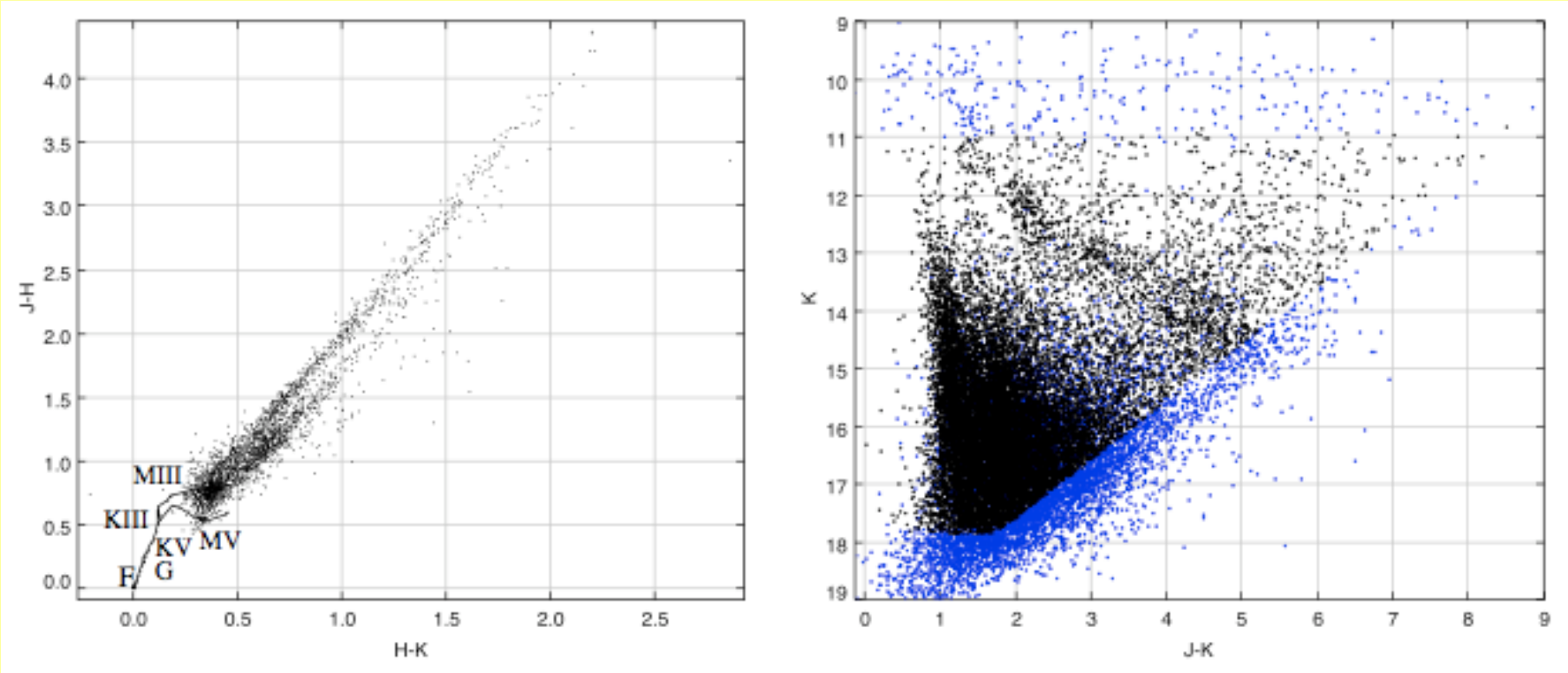
Improved photometry in bright nebulae

M17 in DR5



Spectro-photometric typing

l=31, b=0

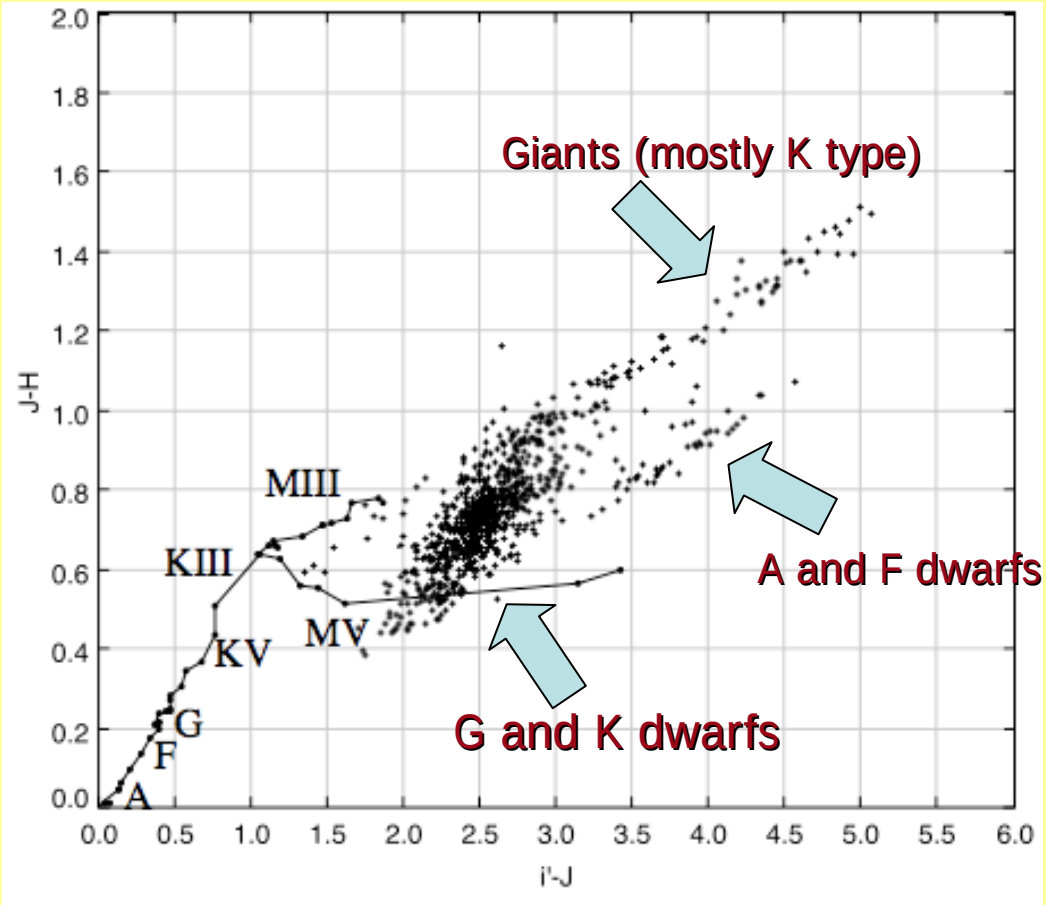


An IPHAS/GPS cross match

IPHAS data from the IPHAS Initial Data Release: see www.iphas.org

and

Gonzales-Solares et al.2008, MNRAS 388, 89



(from Lucas et al.2008, MNRAS 391,136)

Cluster Detection in the GPS

The Milky Way contains >10^4 clusters.

Large lists of clusters have been published by….

1) Bica & Dutra (2003 papers) using a biased eyeball search of 2MASS.
2) Mercer et al.(2005) using a Bayesian search of Spitzer/GLIMPSE.
3) Froebrich et al.(2007) by searching for statistical overdensities in 2MASS.

We are using several methods to search the UKIDSS GPS

1) A Bayesian search following Mercer et al. (Samuel & Lucas).
2) An eyeball search of the jpeg images during quality control.

3) An unbiased Spitzer/GPS search for objects with the colours of YSOs.

Bayesian search: Expectation Maximisation (EM) Method

For each field (i.e. each 13 arcminute WFCAM array) do:

E step - determine ln(L) given cluster parameters

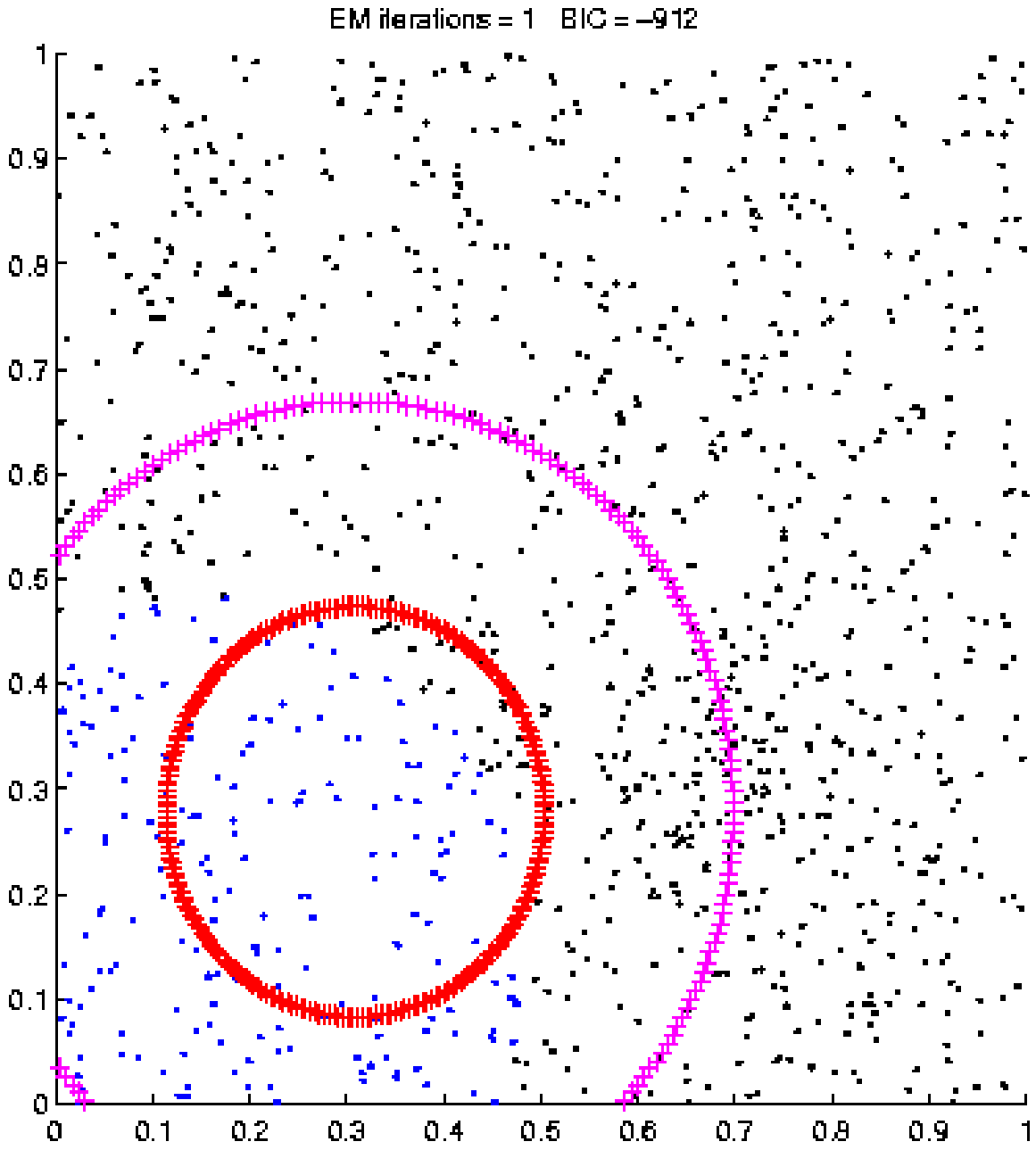
M step - calculate new cluster parameters by applying the current model. The contribution of each star to position, cluster size etc. is weighted by the probability for each star to be a cluster member. This shifts the parameters in the direction of increased likelihood.

Iterate E and M steps to convergance.

Maximise the Bayesian Information Criterion (BIC)

$$BIC = \ln(L) - m \ln(N)$$

Start with 1 cluster, repeat the process with 2, 3, 4 clusters.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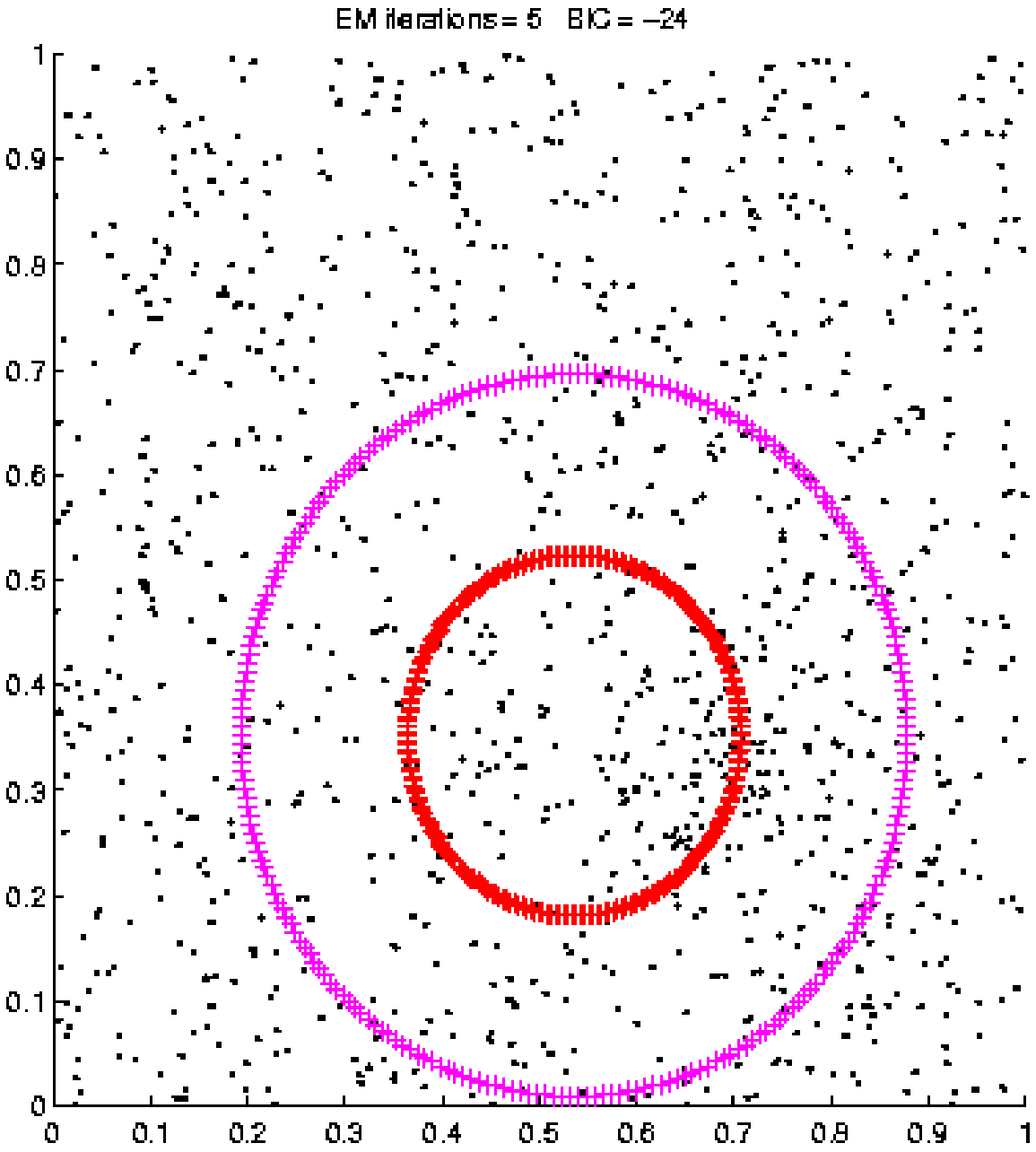
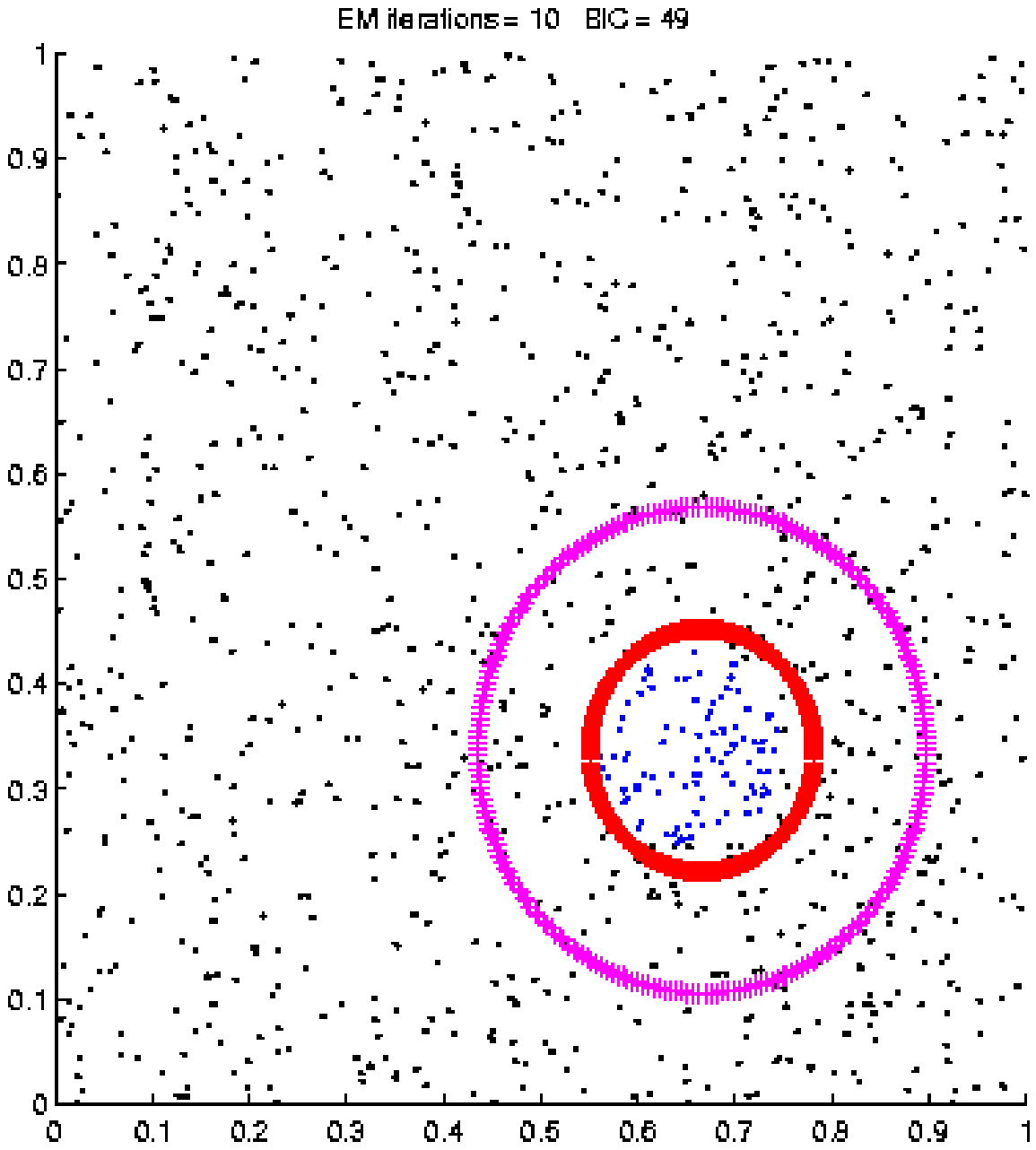
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


EM iterations = 5 BIC = −24
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1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1
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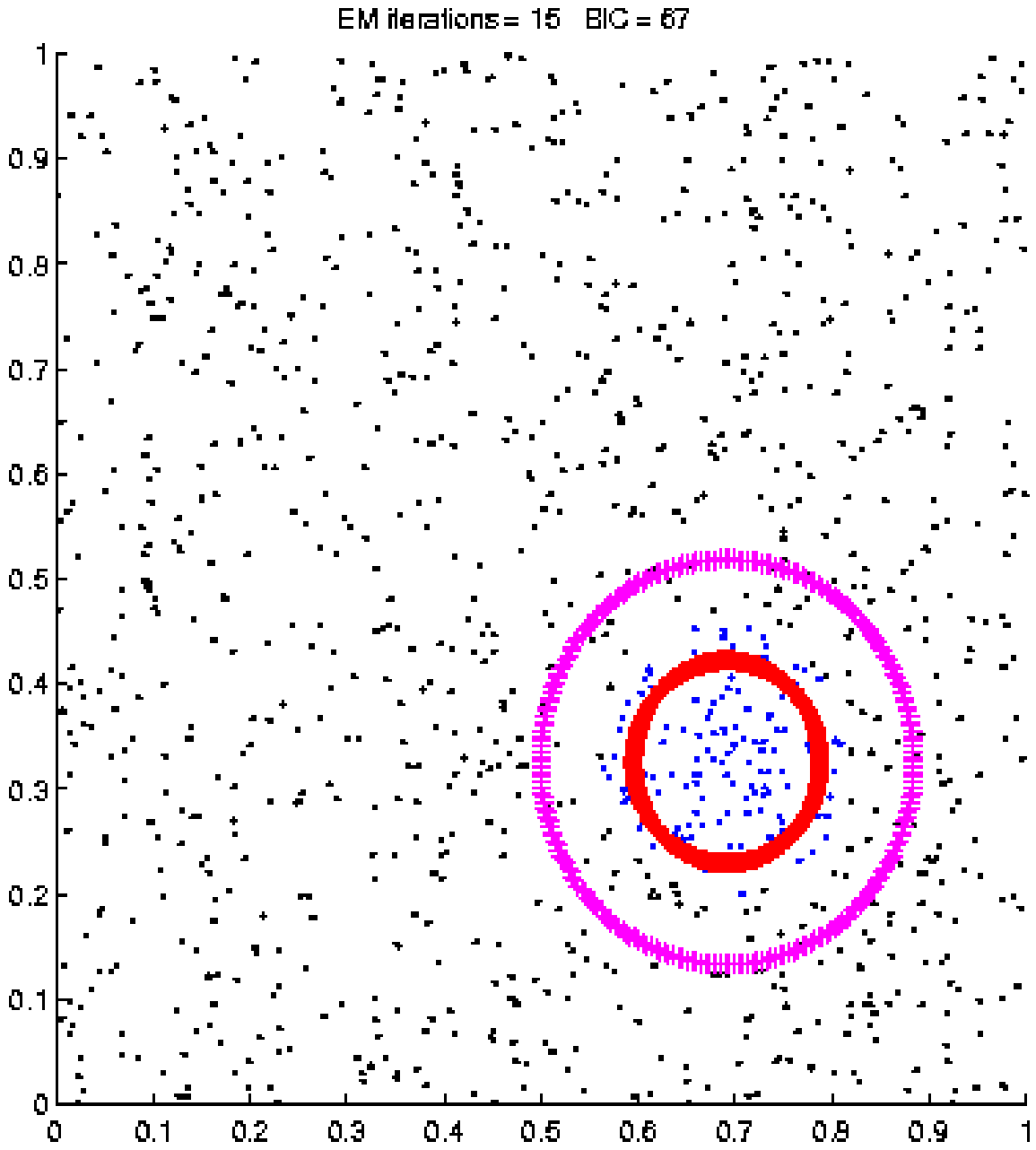
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1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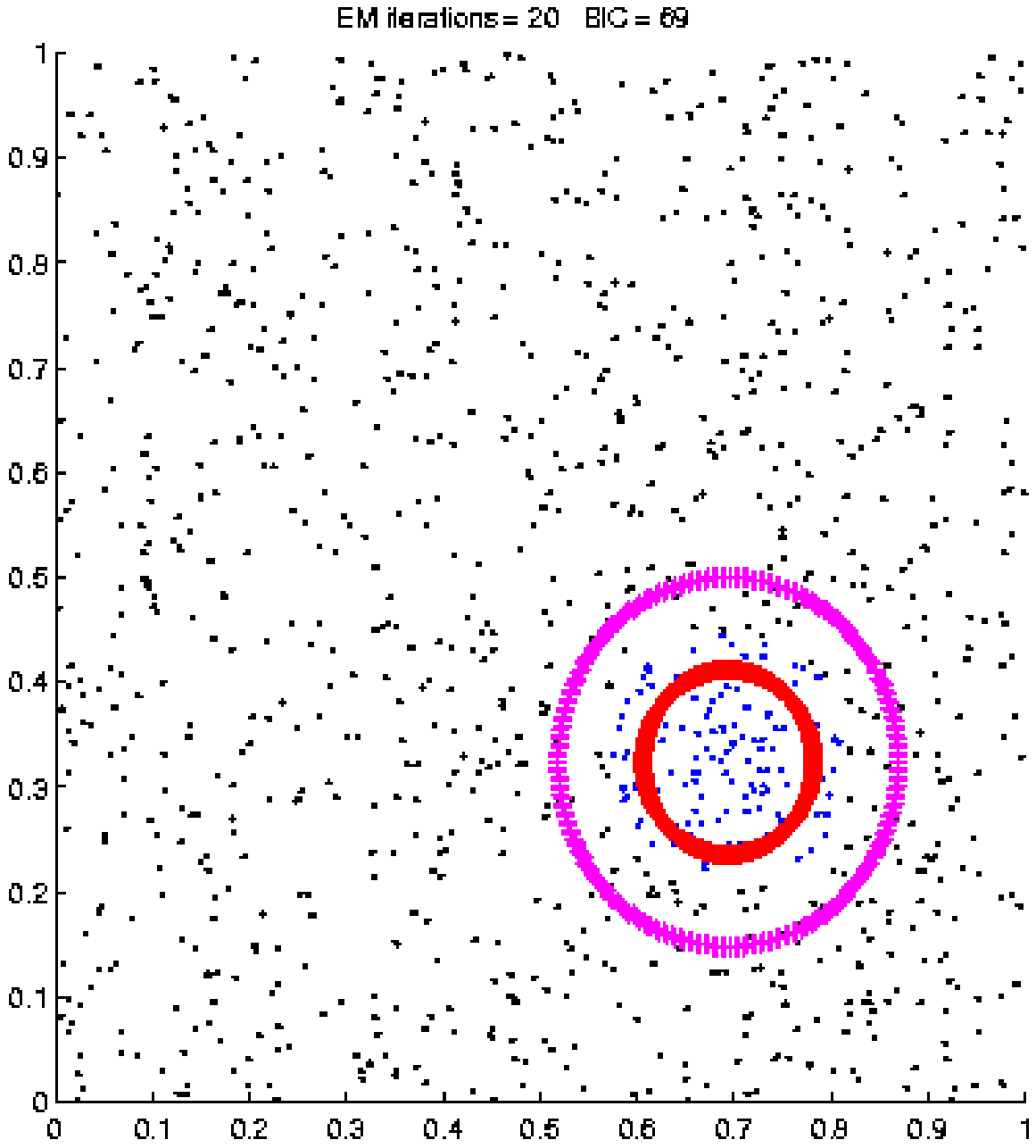
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1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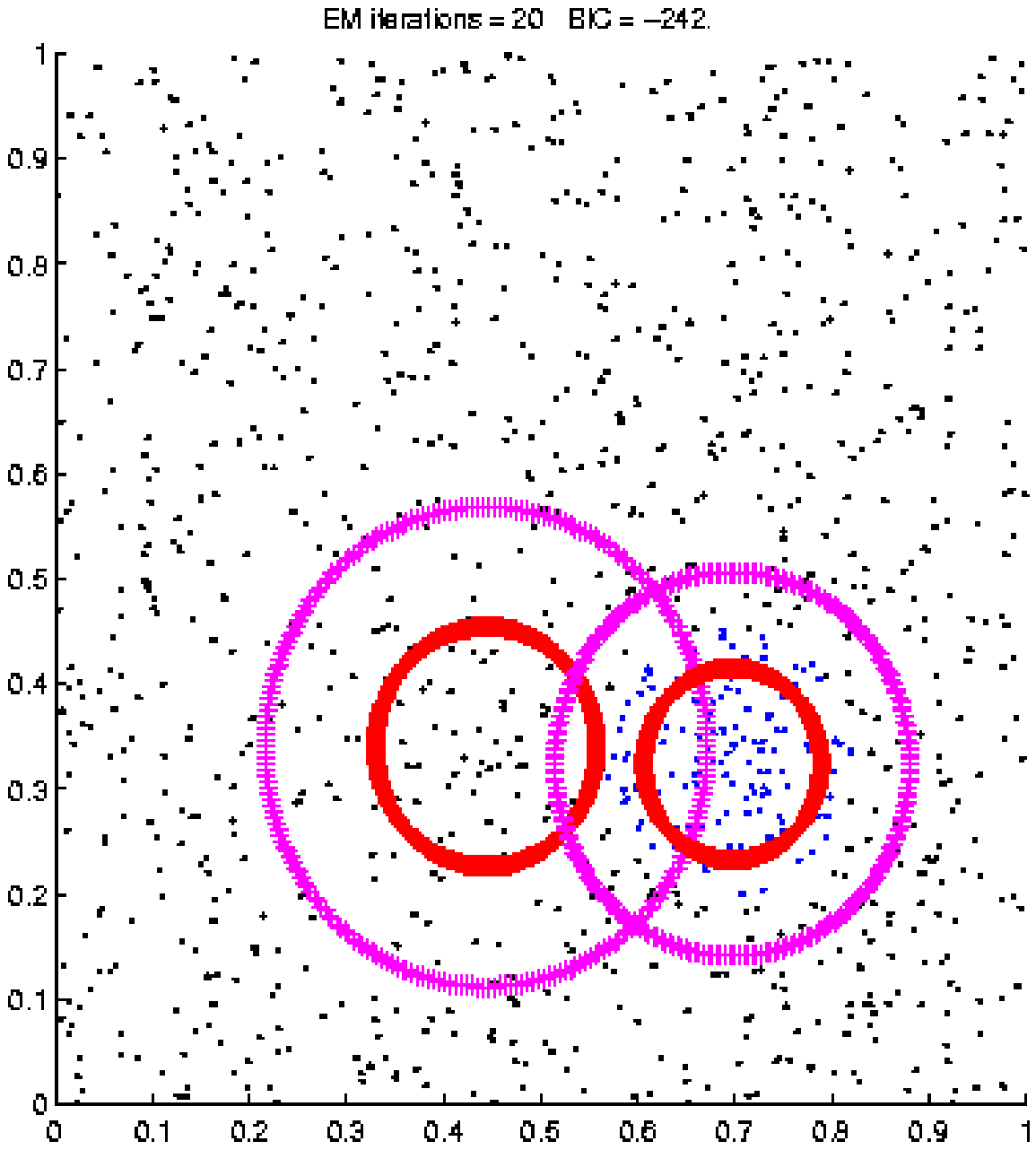
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


EM iterations = 20 BIC = −242.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Results from David Samuel's MATLAB Code

- We ran it on DR4, using a local copy of gpsSource that contains only FramesetID, RA, Dec, J, H, K, MergedClass for each of the ~555 million sources.

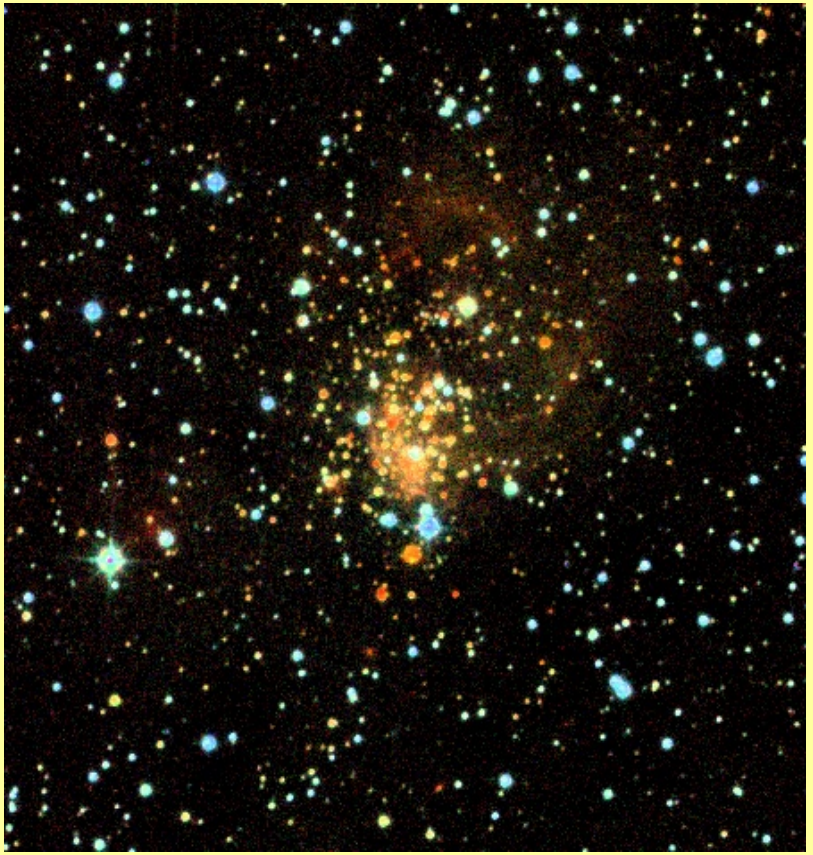
- Search parameters: K mag<17, **mergedClass=+1**, AlertBIC<0,
  Then repeated with any mergedClass and BIC<0.
- Repeated with K mag <16 threshold.
- So far 248 candidate clusters are confirmed as real, based on my eyeballs.
- About 127 of these (50%) are new. These show some bias toward small angular size and large Galactic longitudes.

- Searches with K<15, K<14, K<13 thresholds suggest we'll have ~400 clusters in DR4 by this method and a further 100 from my eyeball search. **Total ~500**.

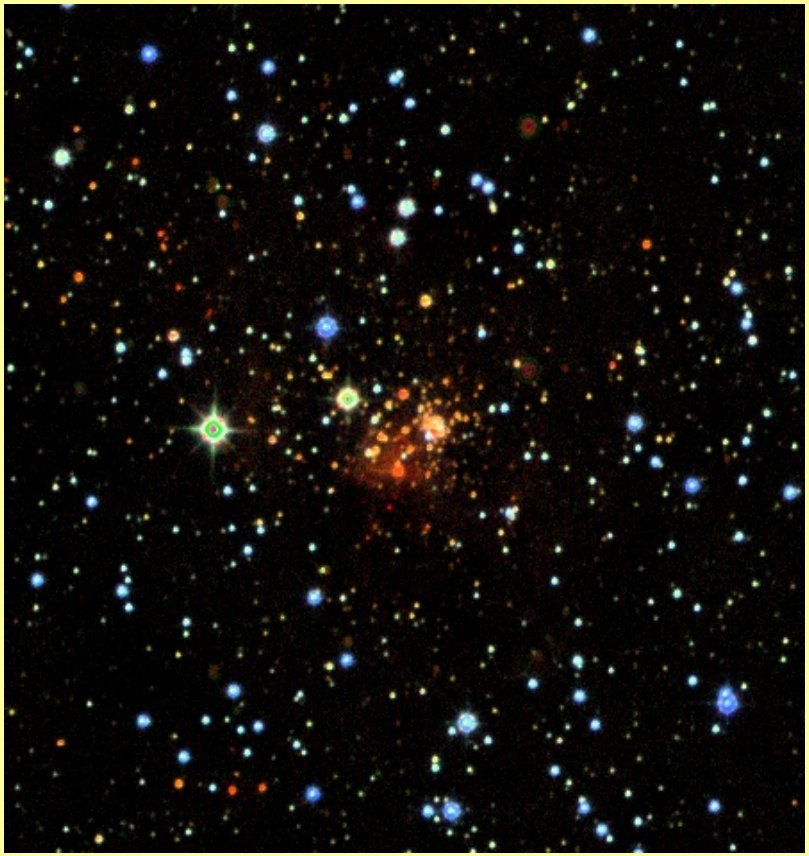
- A large proportion are star formation regions. The AlertBIC is assisted by the spurious detection of nebulosity as a group of extended sources. Clusters also naturally contain blended stars misclassified as extended sources in 1 or more passbands.

New cluster - No.28
3 arcmin JHK colour image from the WSA

New cluster - No.30
3 arcmin JHK colour image from the WSA



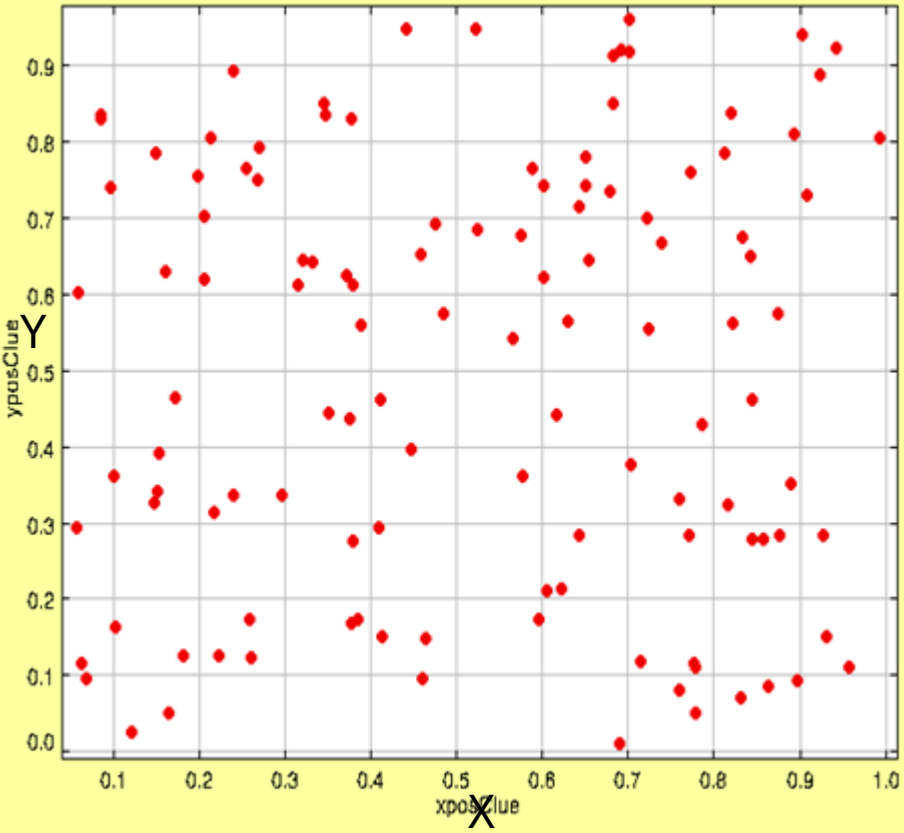
New cluster - No.33
3 arcmin JHK colour image from the WSA



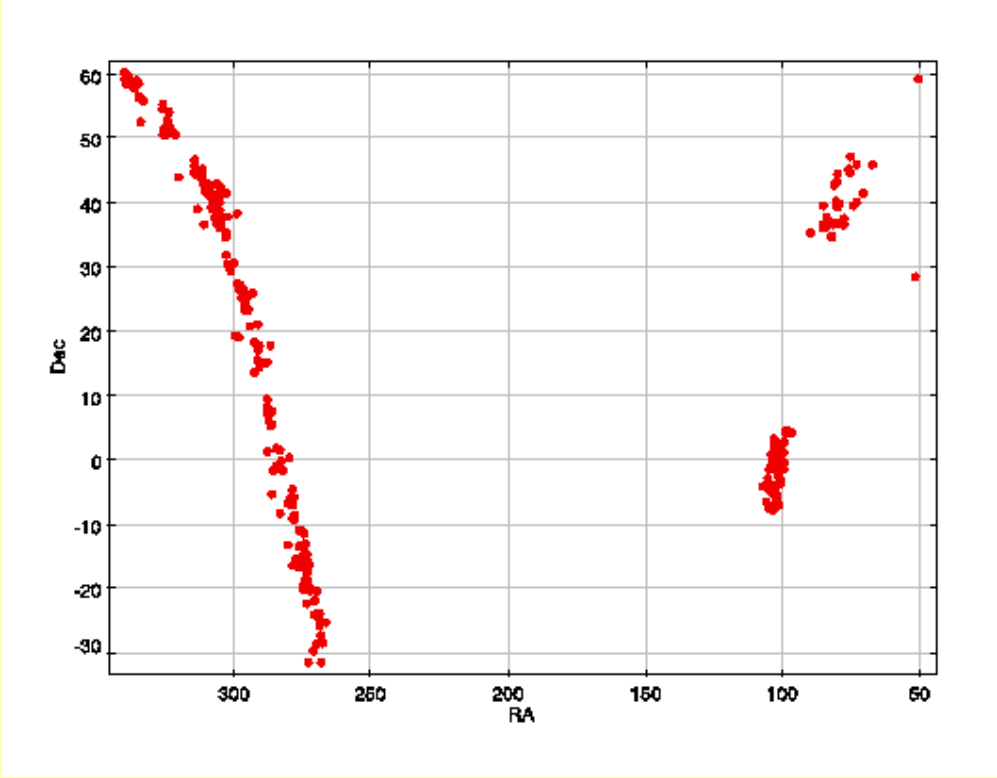
New cluster - No.36
2 arcmin JHK colour image from the WSA

Properties of the Bayesian Cluster Sample(1)

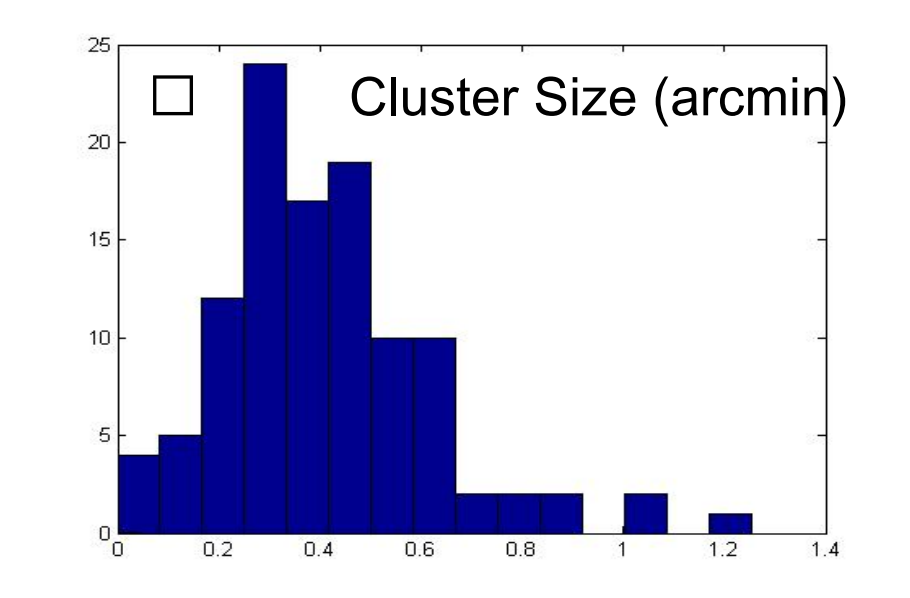
X-Y distribution on WFCAM array

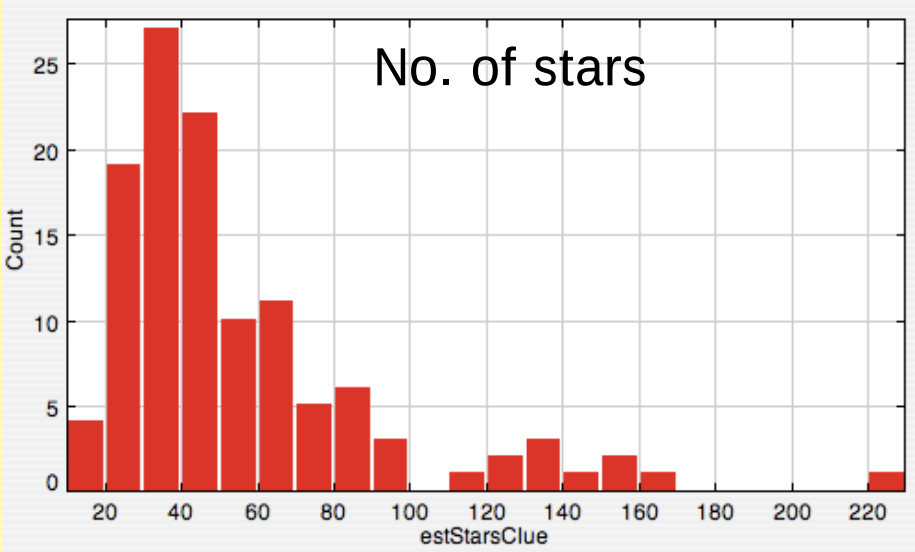


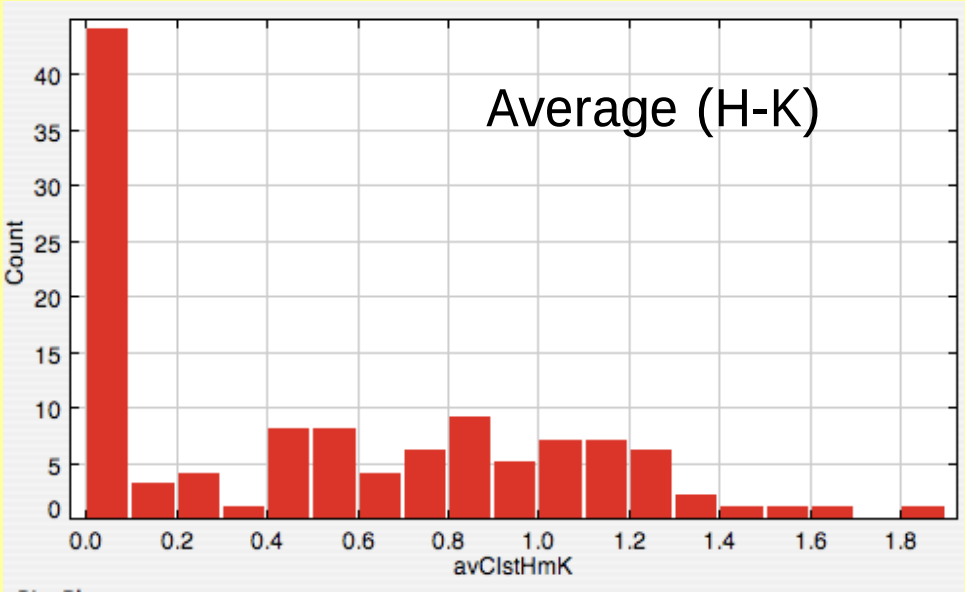
RA & Dec on sky



Properties of the Cluster Sample (2)







Results from my eyeball search

All jpegs from the EDR, and DR1 to DR6 data releases were searched during quality control.

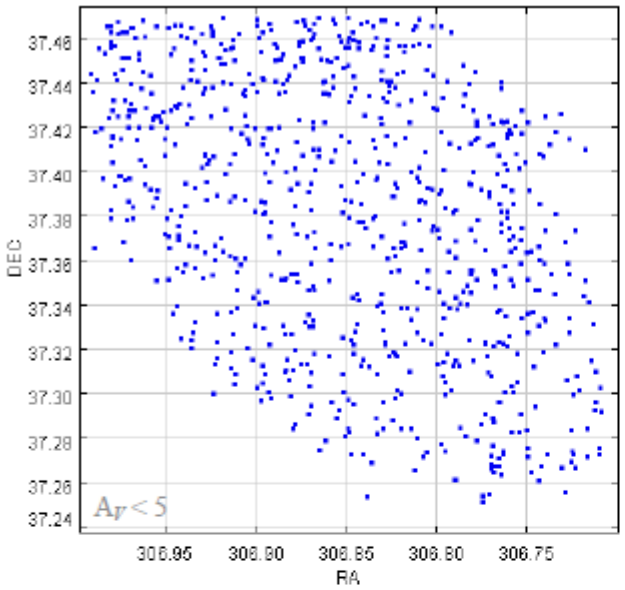
So far only about one third (from EDR and DR2) have been looked into, i.e. coordinates determined and a literature search done.

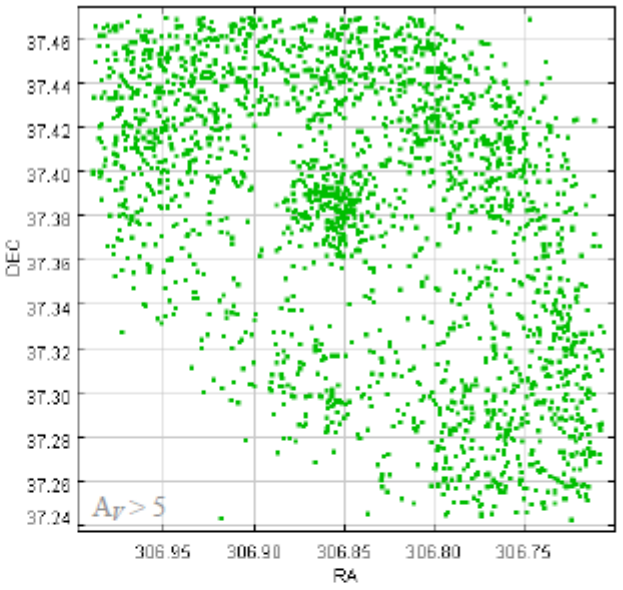
Results: 82 clusters found, of which 61 (75%) are new.

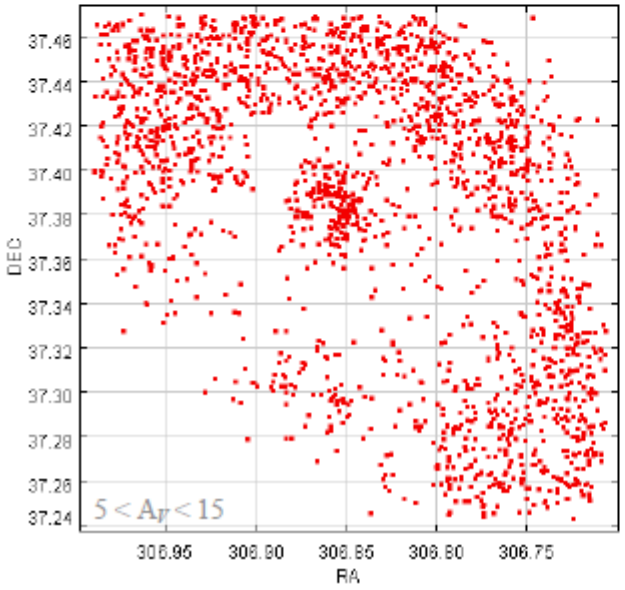
Also numerous star formation regions that lack a cluster have been found.

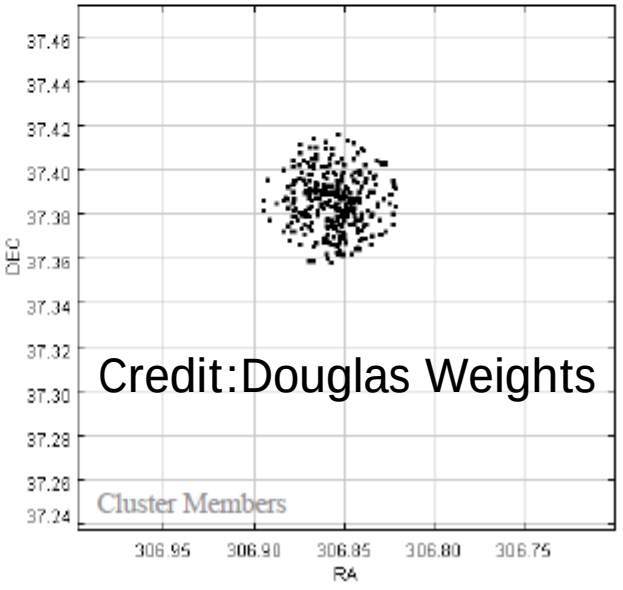
Approximate fraction not found already by the Bayesian search: 42%.

Identifying cluster members: S106









Credit: Douglas Weights

Variable stars in the GPS

- The first tranche of 2 epoch data was released on 1/9/09 in DR5.

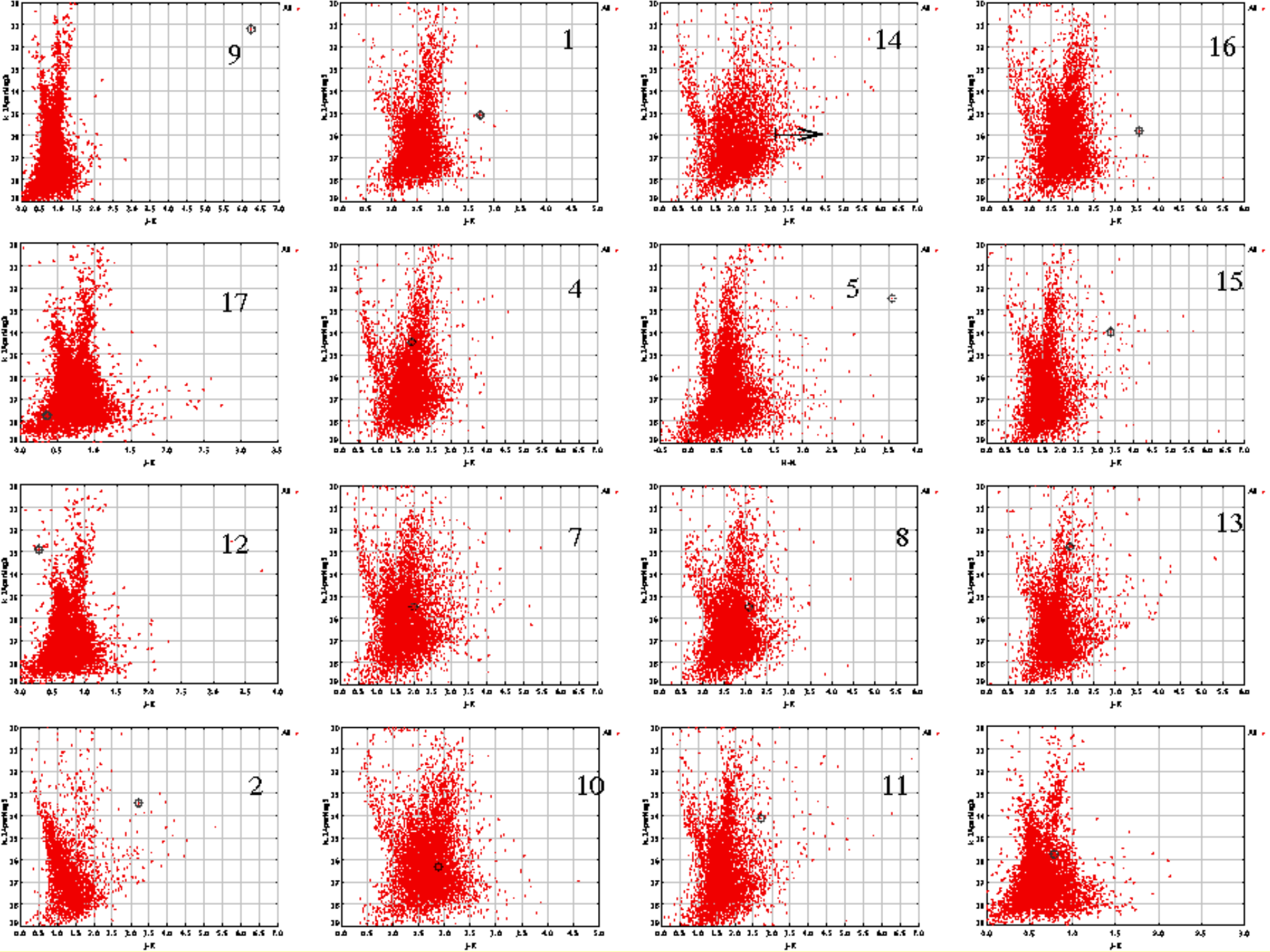
- Area covered: **31 deg^2, 22 million stars.** All at |b|=1 to 5.

- Epochs: K band in 05A, then JHK in early 08A.

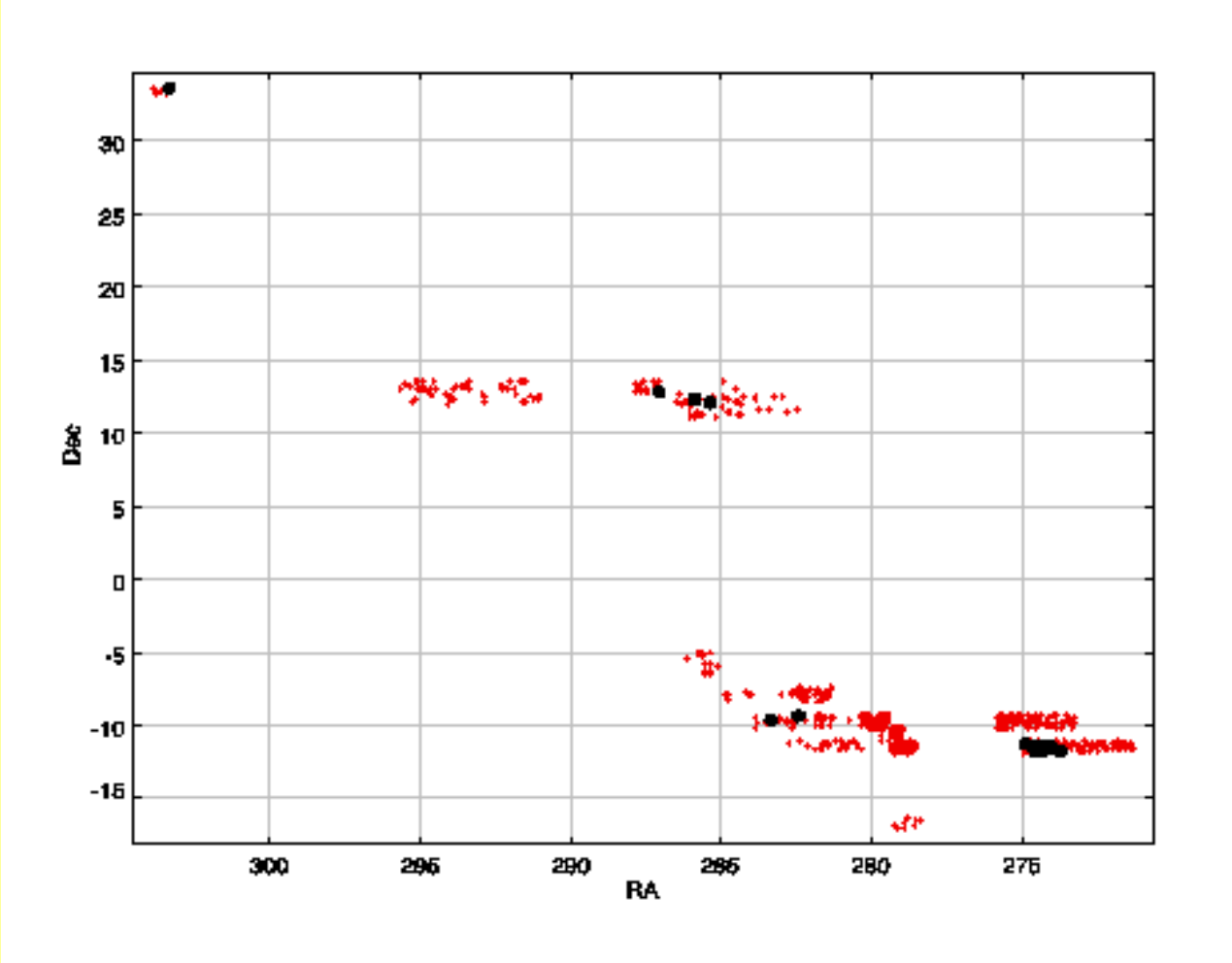
Search for stars with ΔK > 1 mag.

- First test field: 330,000 stars
  7 candidates quickly found in the catalogue at K<16.0.
  1 real variable confirmed by inspection of the images.

- In the full sample there are:
  17 real high amplitude variables at K<16.0, with ΔK =1.0 to 3.75.
  (after inspecting 672 image cut-outs).

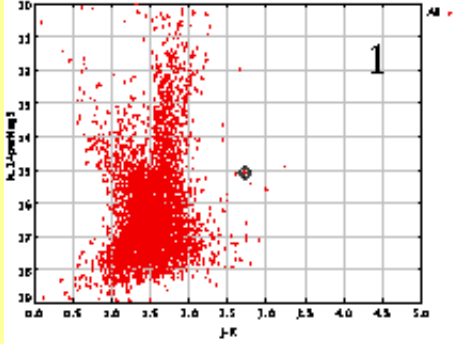

9
1
14
16
17
4
5
15
12
7
8
13
2
10
11

Location, location, location
The Serpens OB2 association
(contains 11/17 variables)



BUT only 1 source is in a dark cloud.

Only 3 are within a few arcminutes of a dark cloud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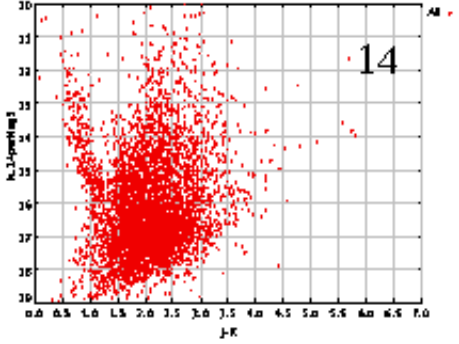
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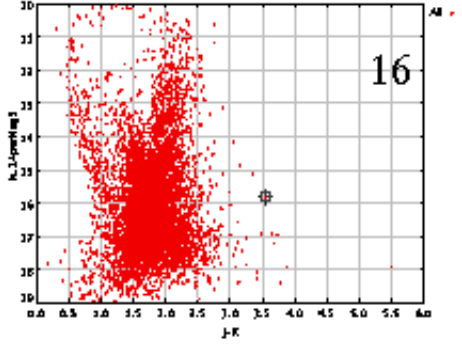
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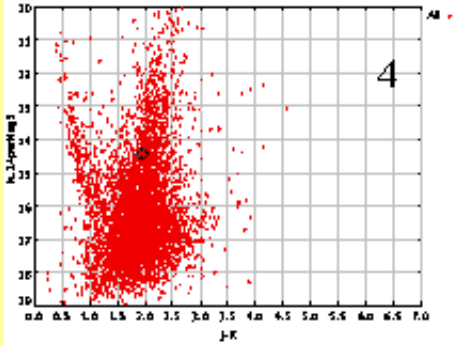
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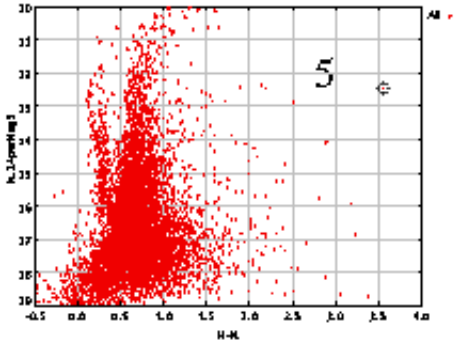
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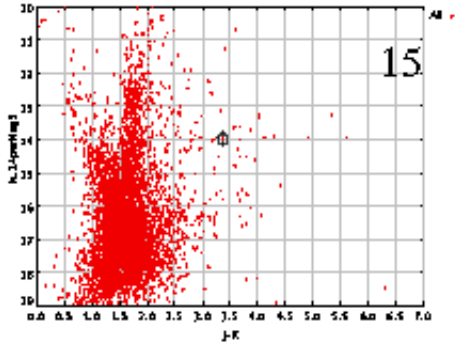
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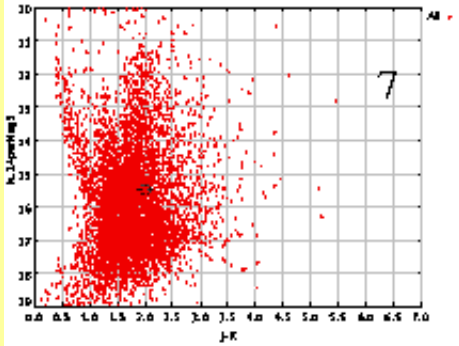
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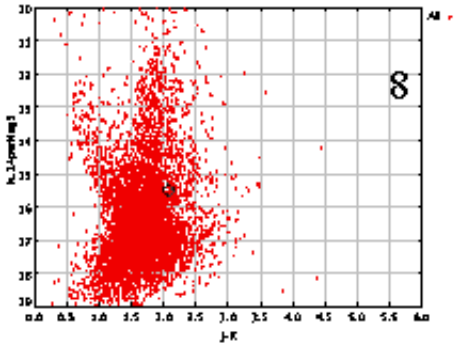
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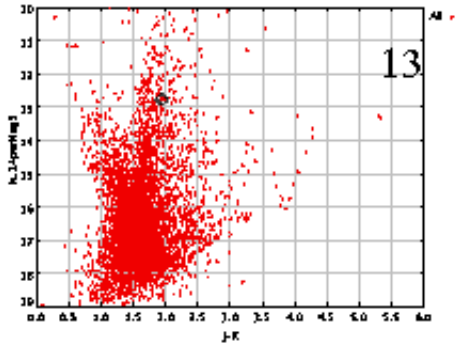
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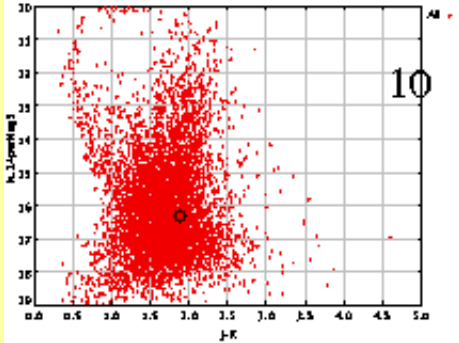
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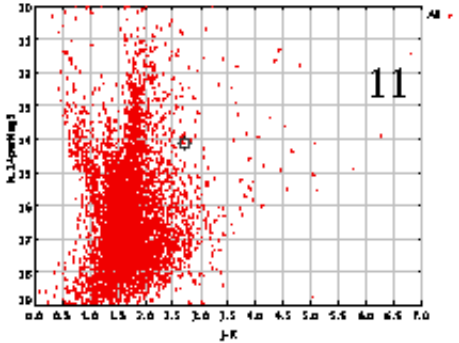
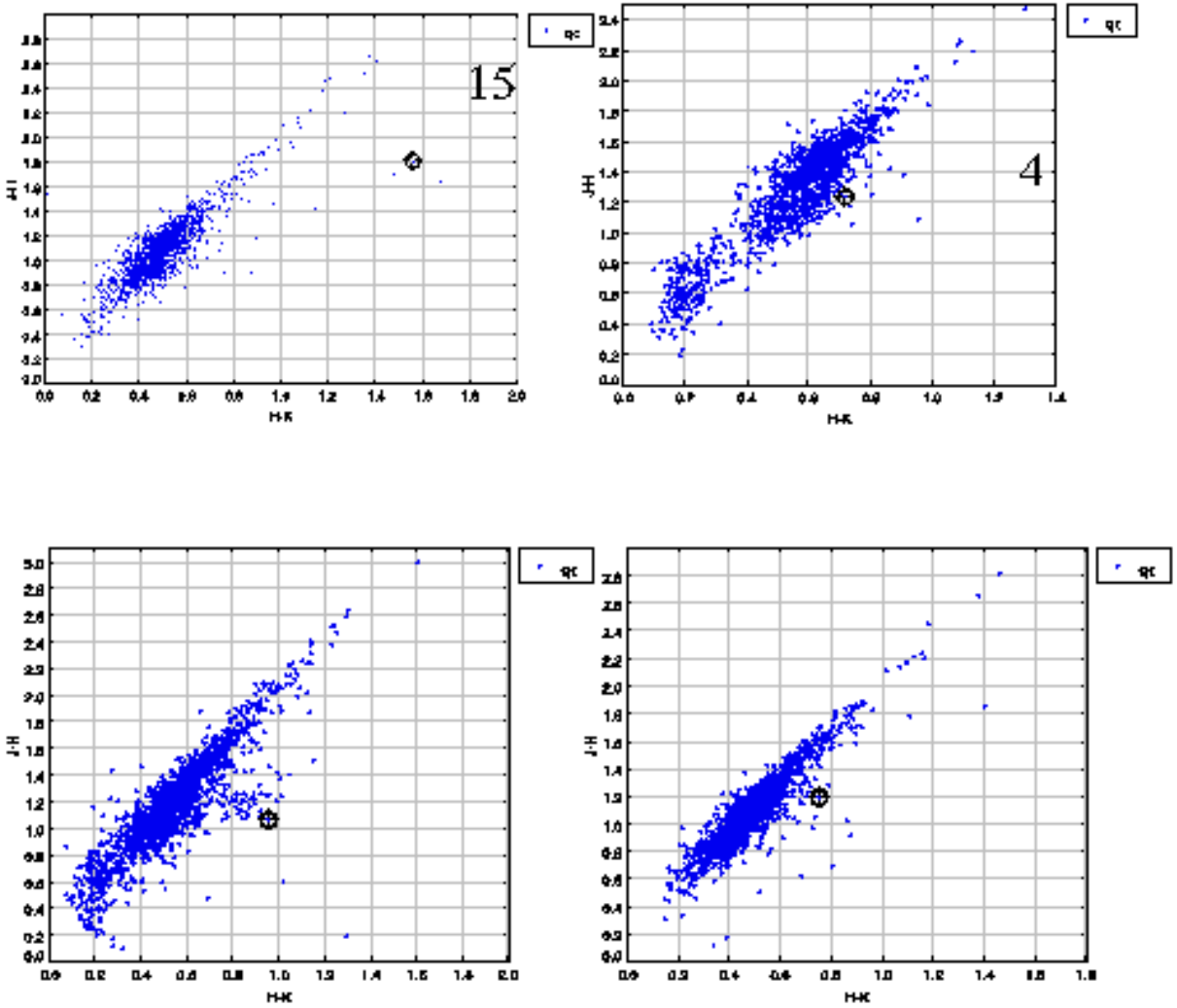
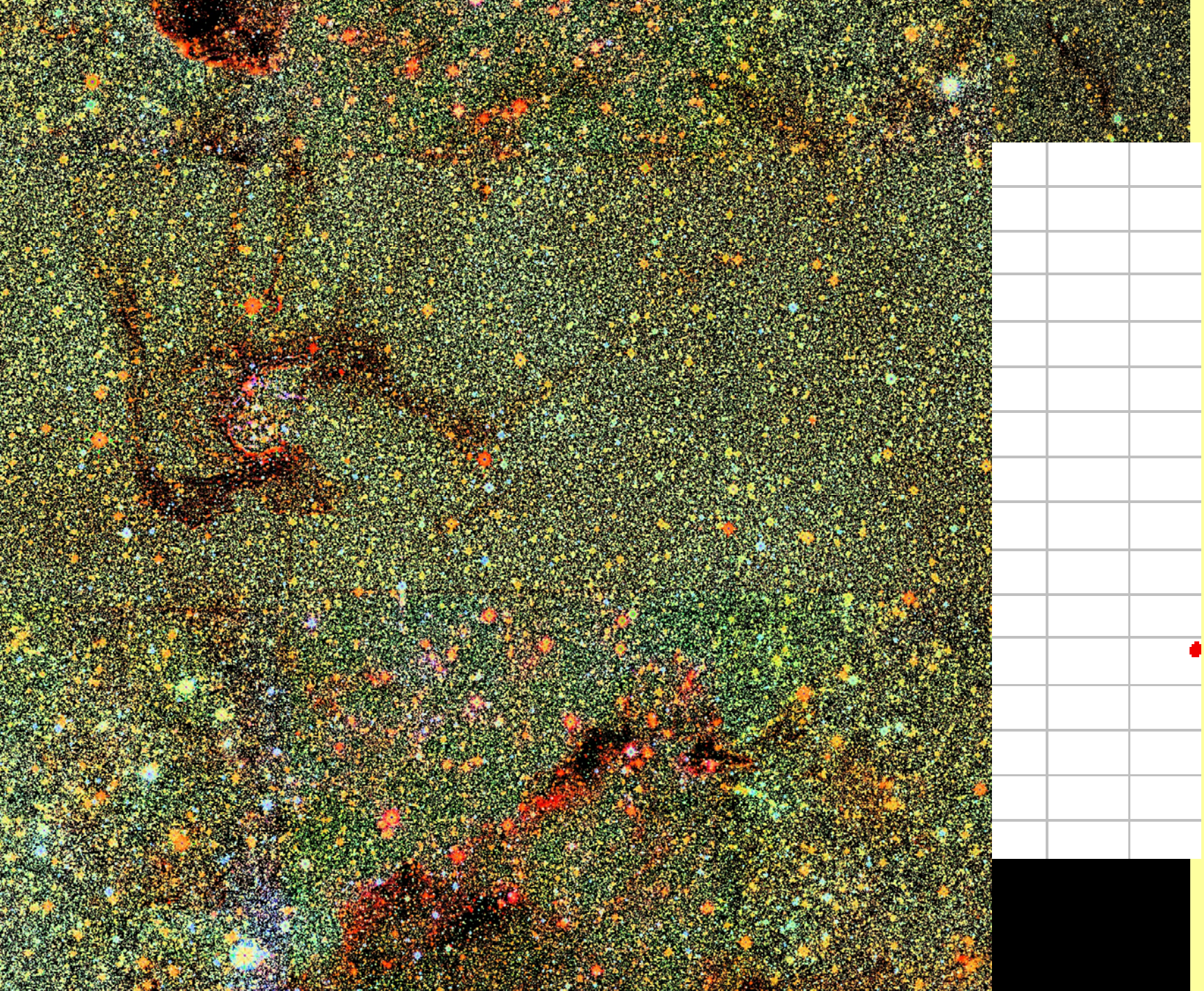

11

Two colour diagrams



The colours are consistent with pre-main sequence stars with hot accretion discs

T Tauri stars, Herbig Ae/Be stars, or Class I Young Stellar Objects.



Conclusion so far on variables

- 2 epoch photometry readily identifies unusual things.
- GPS will supply >1000 high amplitude variables at the end of the 2nd epoch, defined by (ΔK>1).

- Interesting new things are likely to be either very red or Population I sources in the plane, e.g. FUORs, helium flash objects, LBVs, or the unknown (V838 Mon).

- IR spectroscopy is required to confirm the nature of the candidate FUORs/DEOSs and place them in a context with optically identified FUORs.

Science to expect from the GPS

- 500 clusters and star formation regions from DR4 half of which are new.
- Tracing the formation of clusters from the earliest stages seen as IRDCs through to optically visible clusters, aided by environmental data from Scuba2, Herschel, Bolocam, VLA-CORNISH, Spitzer, IPHAS & VPHAS.
- Unbiased detection of protostars by matching with Spitzer-GLIMPSE, GLIMPSE-360 and Cygnus-X.
- Progress on the structure of the galaxy (the bar, the spiral arms, the warp and extinction maps) using the red giant clump and combination with IPHAS, e.g. Lopez-Corredoira et al.(2008).
- Redetermination of the near IR extinction law and its spatial variations (Gosling & Bandyopadhyay; Stead & Hoare).
- Mapping the structure of the local universe using galaxies in the Zone of Avoidance.
- Variability and proper motion catalogues: GPS^2, GPS-2MASS, GPS-IPHAS.
- A catalogue of IR counterparts to known Galactic X-ray sources.
- Identification of post-AGB stars & PPN with GPS+UWISH2.