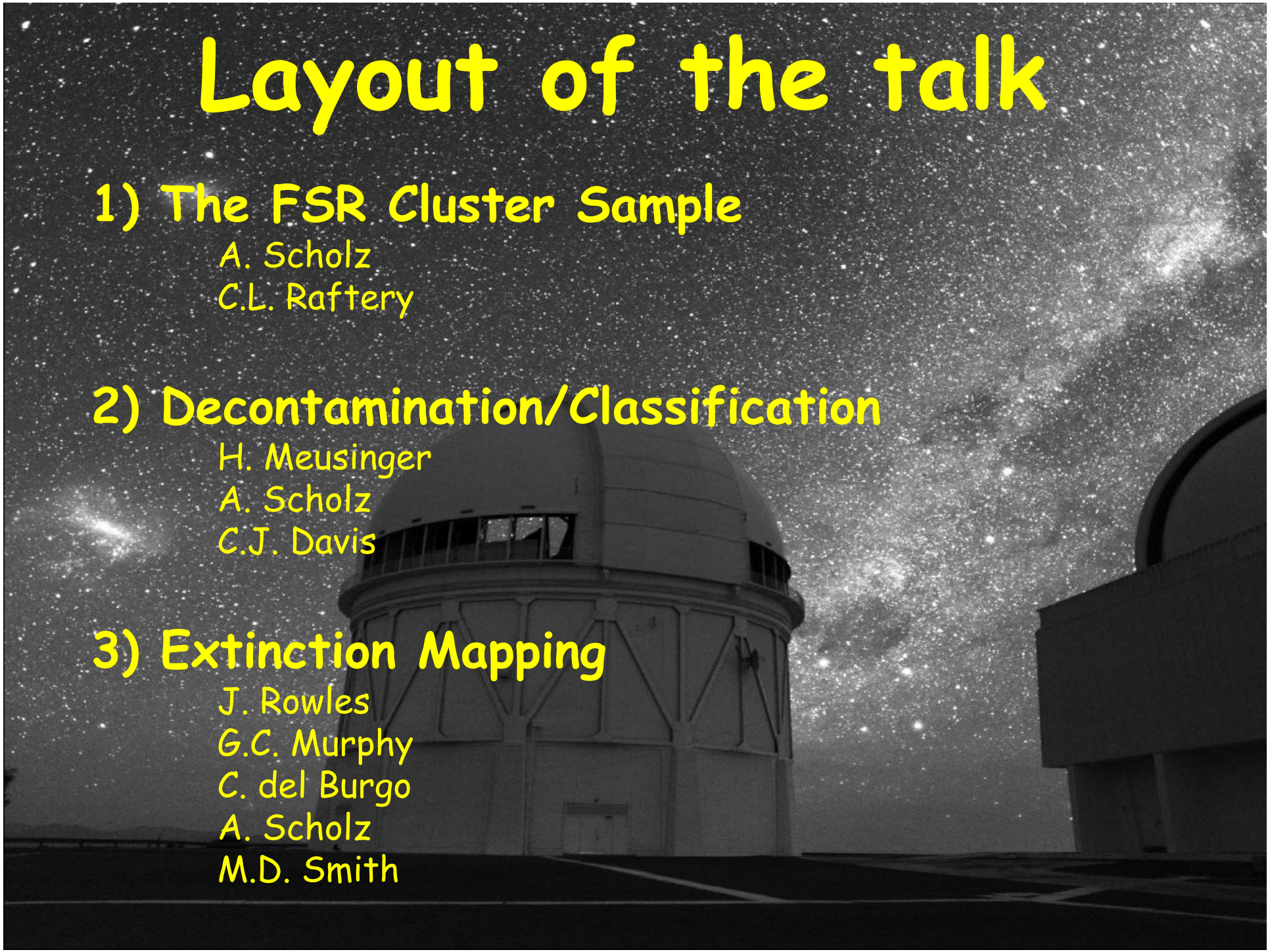
Exploiting 2MASS

A Systematic Search for and Discovery of new Galactic (Globular) Clusters

Dirk Froebrich

CENTRE FOR ASTROPHYSICS AND PLANETARY SCIENCE (CAPS)

UNIVERSITY OF KENT AT CANTERBURY



Layout of the talk

1) The FSR Cluster Sample

A. Scholz
C.L. Raftery

2) Decontamination/Classification

H. Meusinger
A. Scholz
C.J. Davis

3) Extinction Mapping

J. Rowles
G.C. Murphy
C. del Burgo
A. Scholz
M.D. Smith

Why bother?

Most (~90%) stars are formed in clusters.

Lada & Lada (2003)

Why bother?

Most (~2/3) stars are formed in clusters.

Megeath et al. (2008)

Why bother?

there is no prefered size/mass scale for clusters

Megeath et al. (2008)

Why bother?

i.e. star clusters are the building blocks of galaxies

Why bother?

(most) star clusters die young (infant mortality)

i.e. they dissolve into the field star population

Why bother?

star clusters are samples of stars with (almost) identical distance, reddening, age and metallicity

Why bother?

they are hence ideal laboratories to study stellar evolution, star formation, galactic structure, formation and evolution of the Galaxy

OpCl vs. GlCl

distributed in Galactic Plane	concentrated towards Galactic Center
young stars	old stars
not gravitationally bound (mostly)	gravitationally bound
to study recent Galactic star formation	to study Galaxy formation, evolution, structure

OpCl vs. GlCl

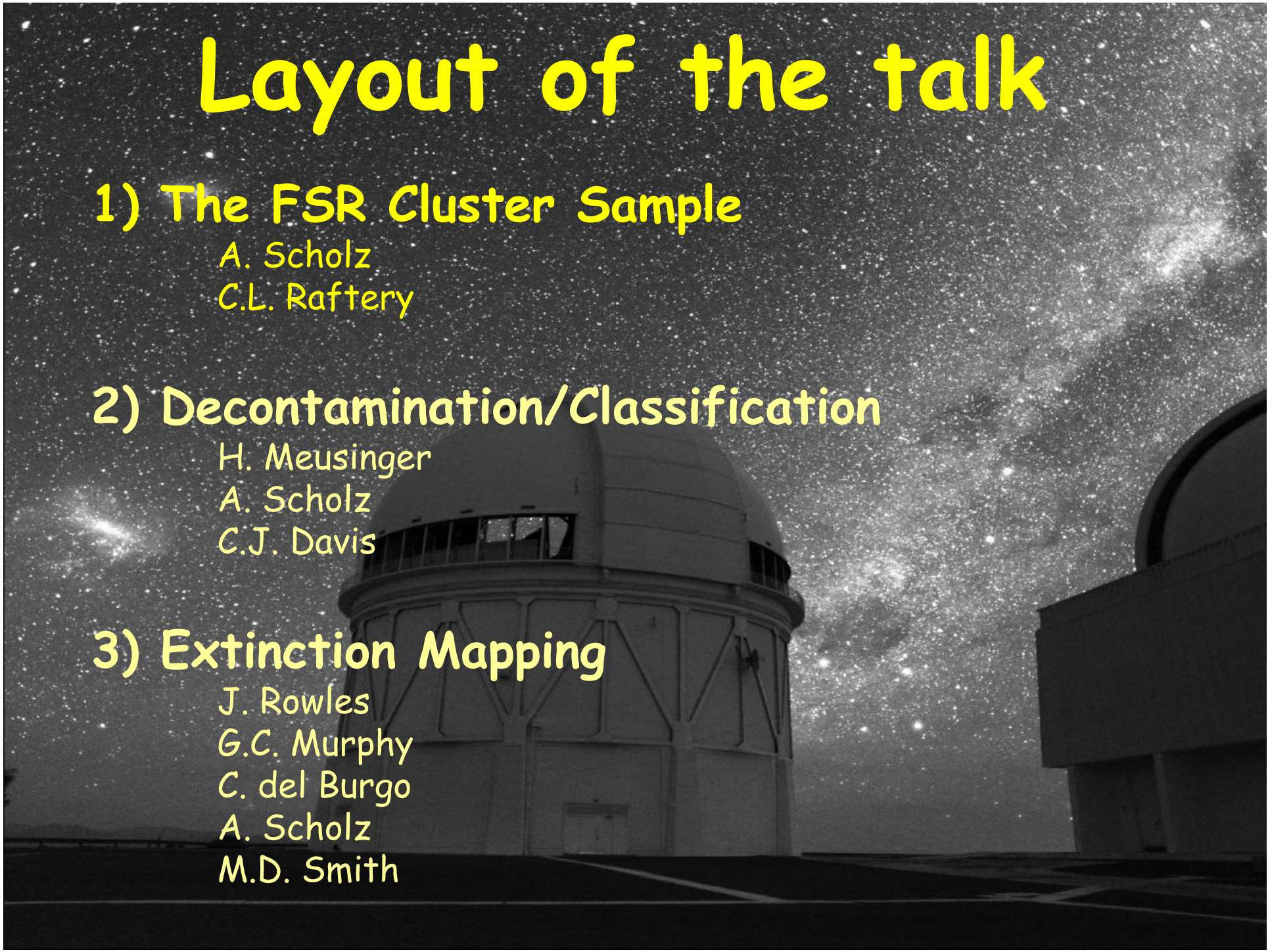
(pre-FSR sample)

1500-2000 kown

e.g.
Lynga (1995),
Carpenter et al. (2000),
Dutra & Bica (2000/2001),
Dias et al. (2002),
Ivanov et al. (2002),
Mermilliod & Paunzen (2003),
Dutra et al. (2003),
Bica et al. (2003),
Kronberger et al. (2006),
Froebrich et al. (2007a),
...

158 kown

Harris (1996, 2003) lists 150,
+
Glimpse-C01 (Kobulnicky et al. 2005),
GC Whiting1 (Carraro et al. 2005),
SDSS J1049+5103/J1257+3419
(Willman et al. 2005),
AL3 (Ortolani et al. 2006),
GC SEGUE1 (Belokurov et al. 2007),
Koposov1/2 (Koposov et al. 2007)



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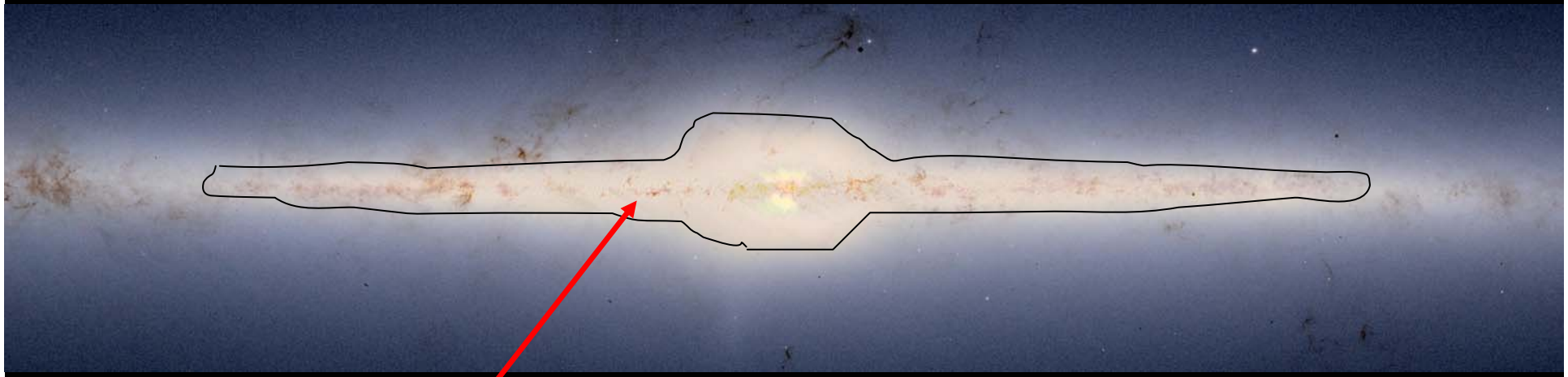
The FSR Cluster Sample



Zone of Avoidance

High extinction and star density →
low density contrast between cluster and background
distant clusters are obscured by dust

10±3 GlCl are 'missing' within 3kpc from the Galactic Center and near the Galactic Plane (Z<0.5kpc) (Ivanov et al. 2005)

Froebrich et al. (2007)

The FSR Cluster Sample

JHK star density maps
- 14400square degrees each
- 3.5' resolution
- 20"pixels → 0.5GigaPixel images

120hours computing time on
- 16node double processor Beowulf-type cluster

Froebrich et al. (2007)

The FSR Cluster Sample

Search for local enhancements in JHK star density maps

use ***SExtractor*** (Bertin & Arnouts 1996)

4σ above local (10°x5°) noise and >11square arcmin

+ manual search

cloud edges and spikes of bright stars rejected

fainter objects with cluster like appearance added

every cluster must be detected in H and (J or K)

2iterations between two people for validation!

Froebrich et al. (2007)

Classification

King (1962) radial density profile

$$\rho(r) = \rho_b + \rho_c \cdot r_{cor}^2 \cdot \left[\left(r_{cor}^2 + r^2 \right)^{-\frac{1}{2}} - \left(r_{cor}^2 + r_{tid}^2 \right)^{-\frac{1}{2}} \right]^2$$

Automatic fit at local completeness limit, excluding regions with source confusion (dense cluster centers)

Manual verification of validity via majority decision

Froebrich et al. (2007)

Classification

King (1962) radial density profile

$$\rho(r) = \rho_b + \rho_c \cdot r_{cor}^2 \cdot \left[\left(r_{cor}^2 + r^2 \right)^{-\frac{1}{2}} - \left(r_{cor}^2 + r_{tid}^2 \right)^{-\frac{1}{2}} \right]^2$$

Number of stars:

$$x \equiv r_{tid} / r_{cor}$$

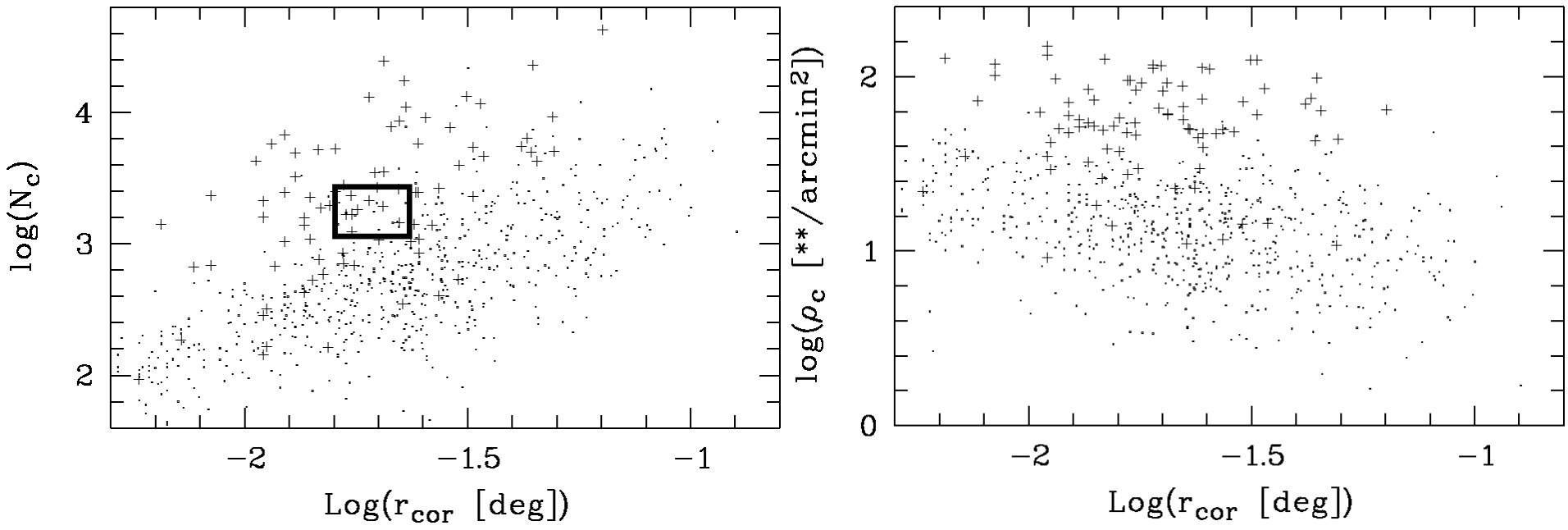
$$N = \pi \cdot \rho_c \cdot r_{cor}^2 \cdot \left[\ln(1 + x^2) - 4 + \frac{4 \cdot \sqrt{1 + x^2} + x^2}{1 + x^2} \right]$$

Normalised to magnitude m_{all}

$$N_c = N \cdot 10^{-\frac{C}{2.5} \cdot (m_{cl} - m_{all})}$$

Froebrich et al. (2007)

Classification



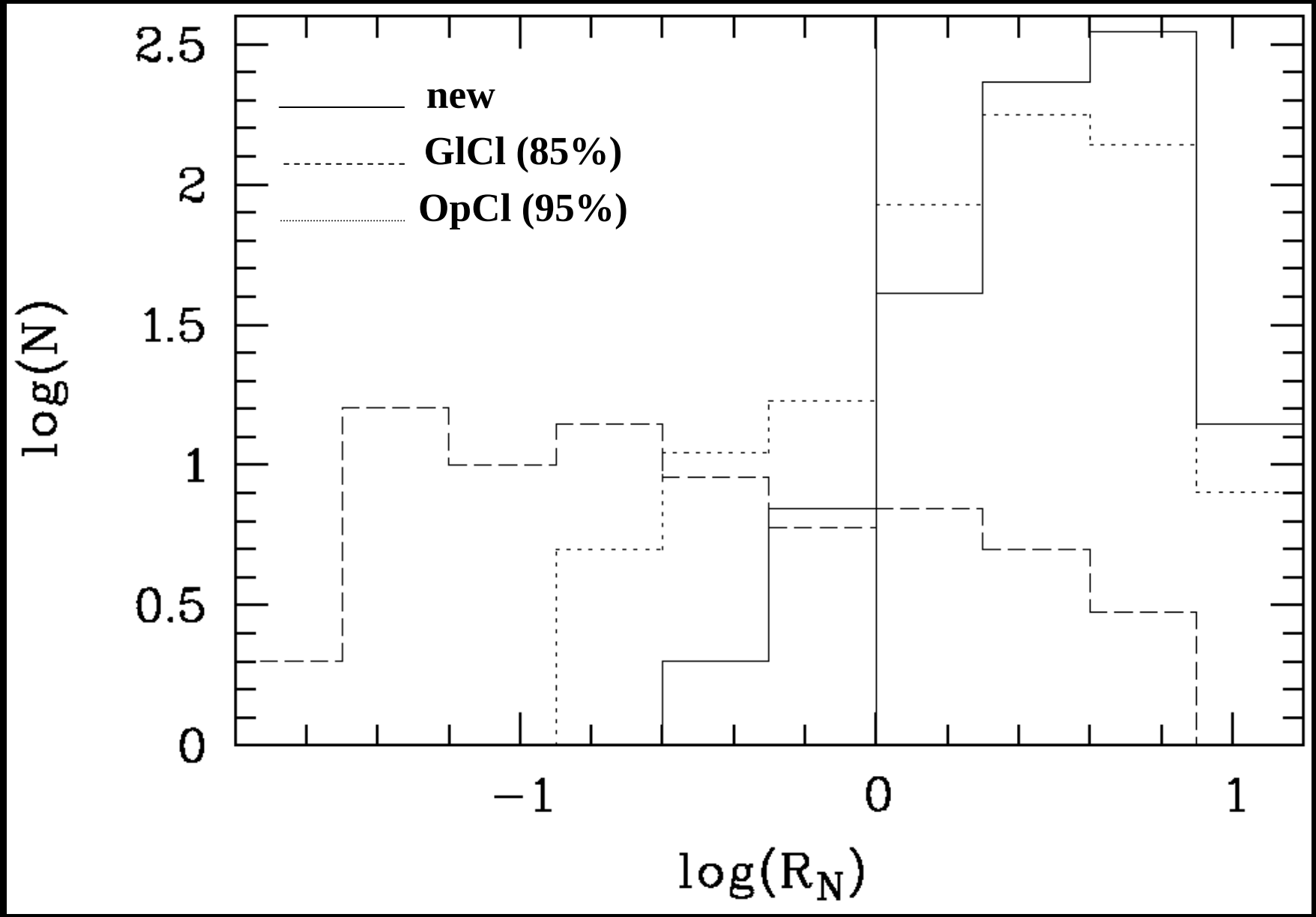
$P^{Op/Gl}_{plot_i} = N^{Op/Gl} / (N^{Op} + N^{Gl})$ for each plot and cluster

$$P^{Op/Gl} = \left(\prod_{i=1}^{9} P^{Op/Gl}_{plot_i} \right)^{1/9}$$

$$R_N \equiv (P^{Op} / P^{Gl}) \,/(681/86)$$

Froebrich et al. (2007)

Classification

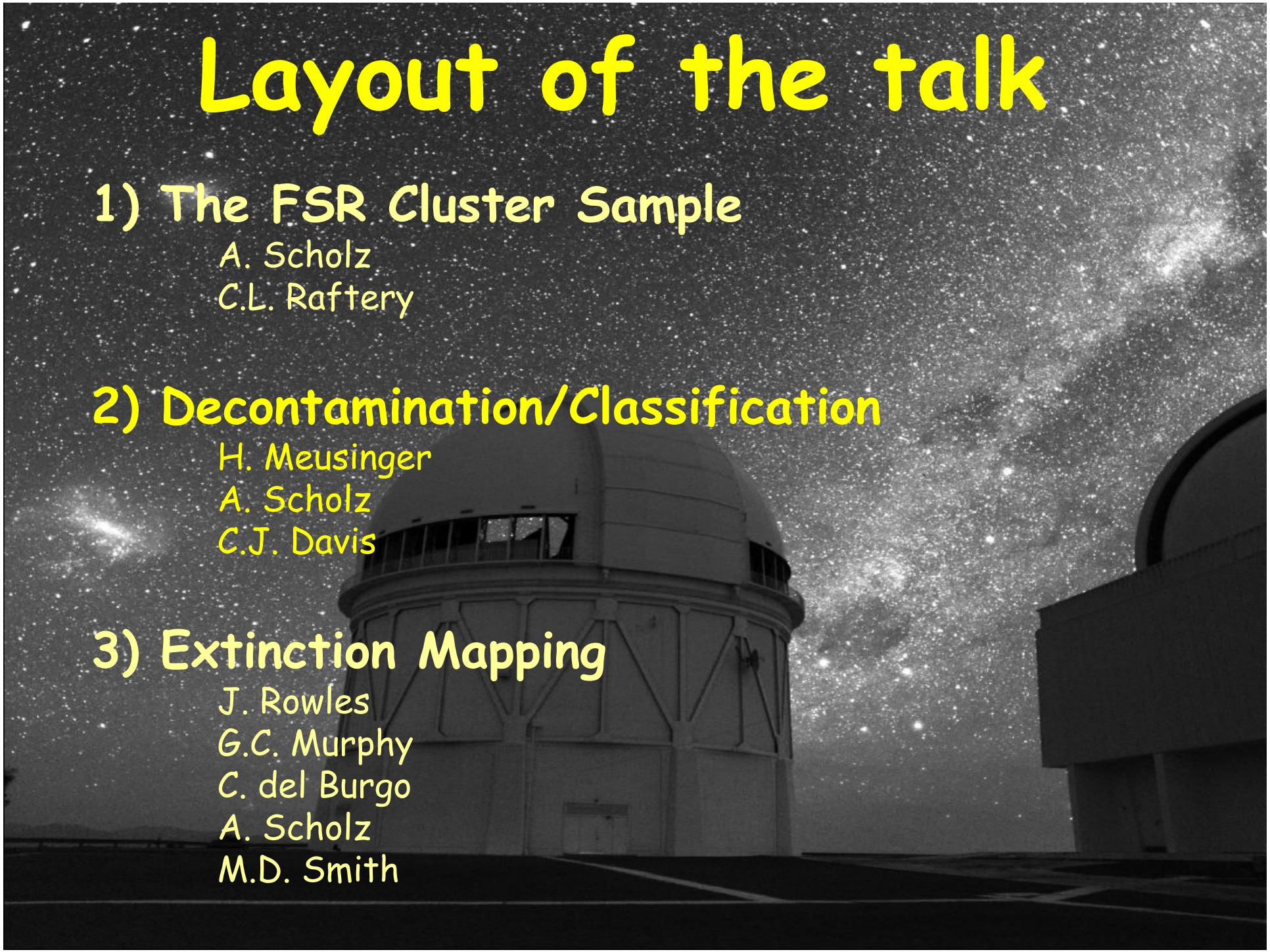


Froebrich et al. (2007)

The FSR Cluster Sample

http://astro.kent.ac.uk/~df/clusters/index.html

Froebrich et al. (2007)



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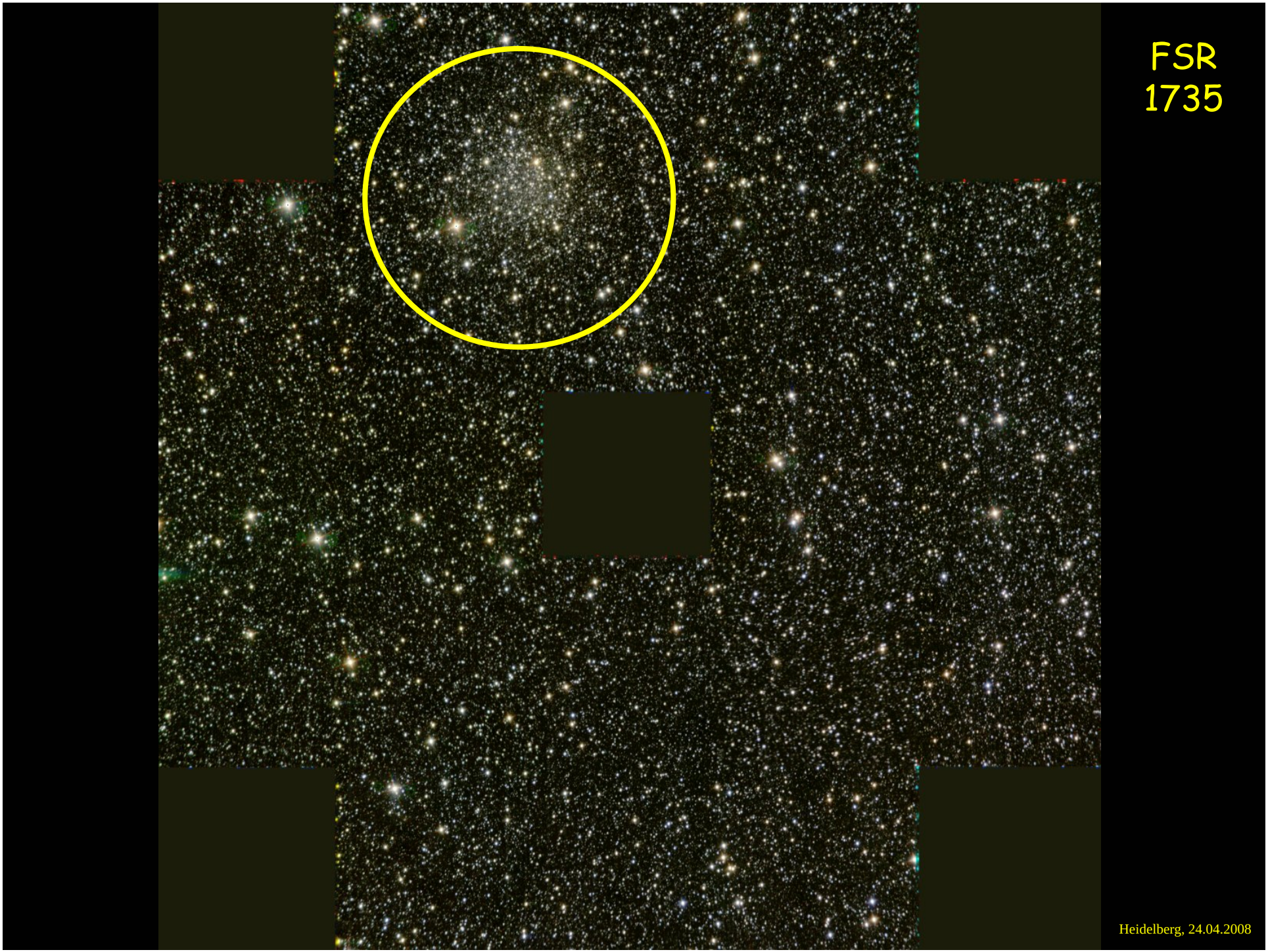
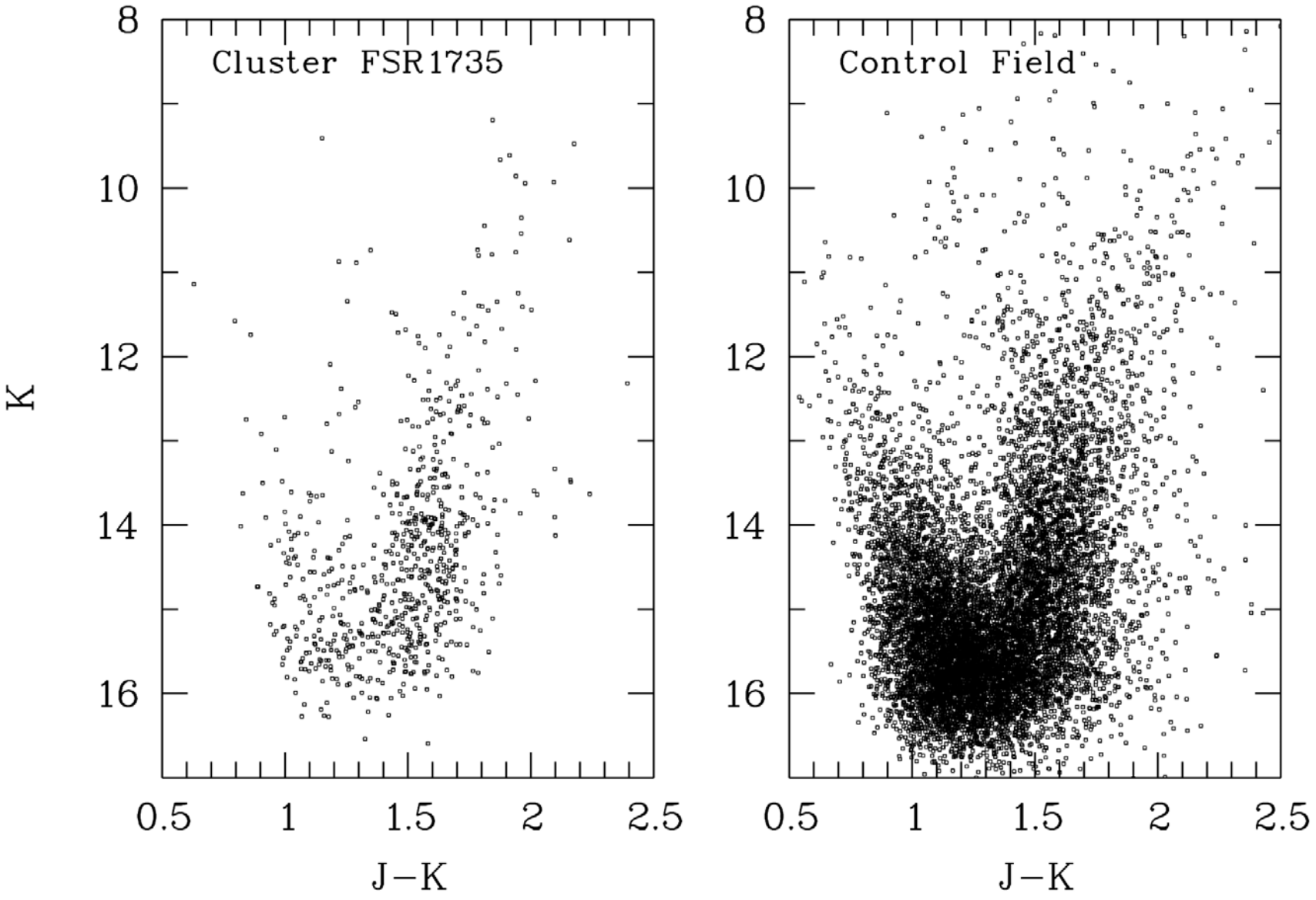

FSR
1735
Heidelberg, 24.04.2008

FSR
1735

The Cluster FSR1735
(SofI/NTT)

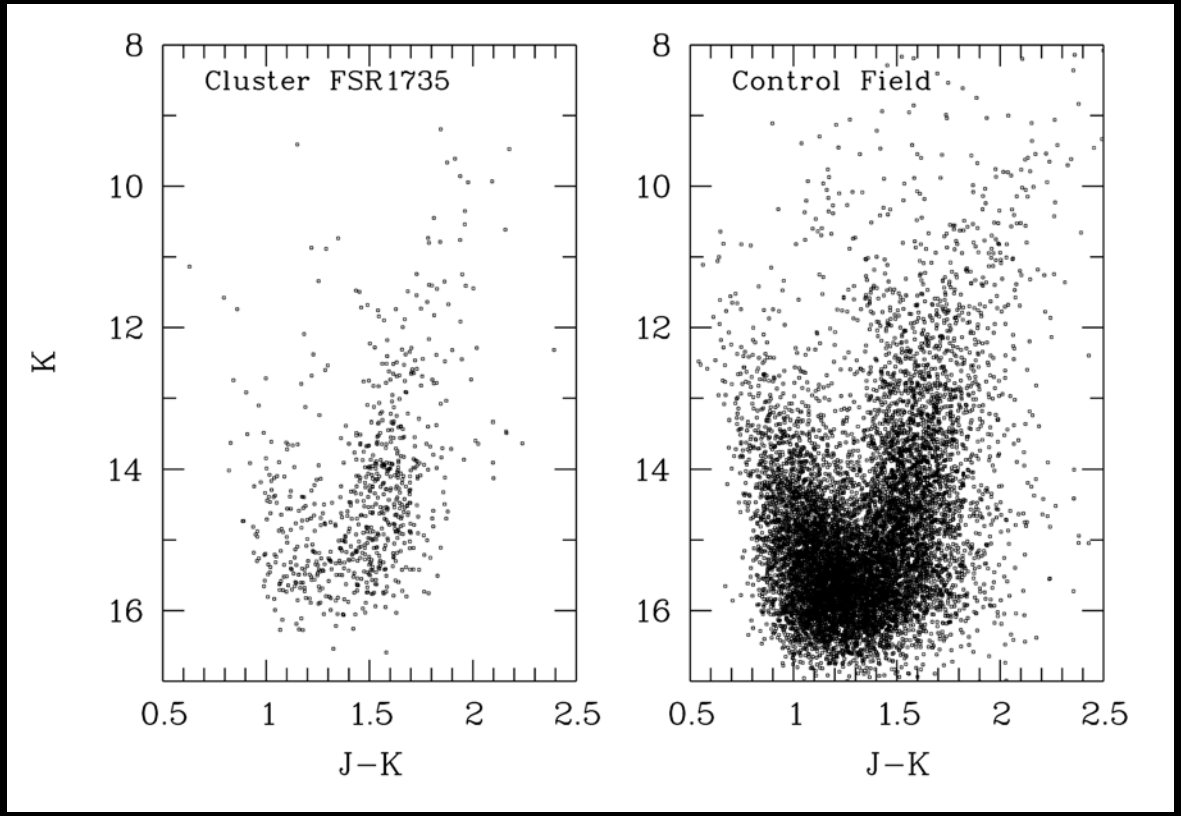
ESO Press Photo 12/07 (13 March 2007)

Fore/Background decontamination



Fore/Background decontamination

Stars in cells in J, (J-H) and (J-K) space in cluster and control field are counted and stars are randomly removed according to statistics (Bonatto & Bica 2007).
Cells vary in size according to stellar density. Typically they are ΔJ=0.5mag, Δ(J-H)=0.2mag and Δ(J-K)=0.2mag.



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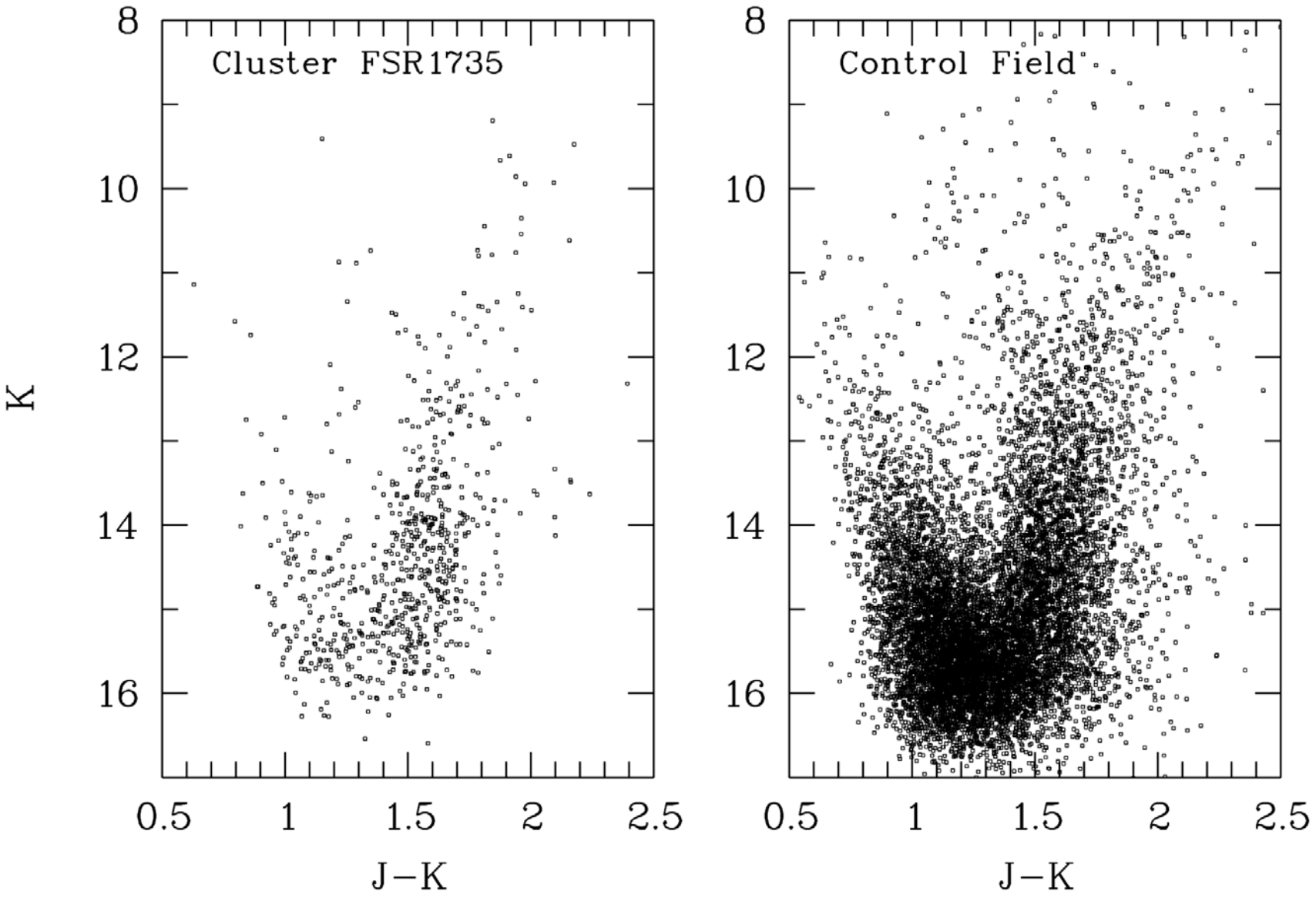

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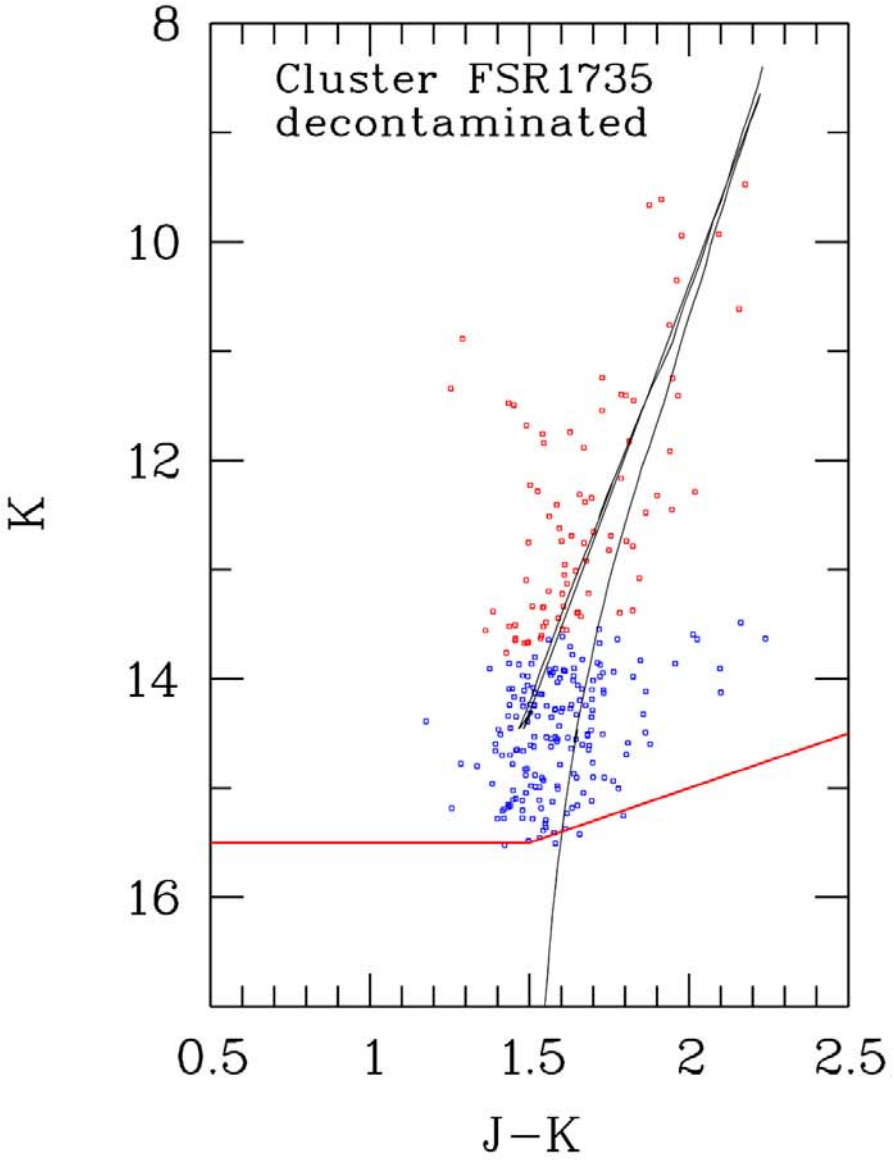

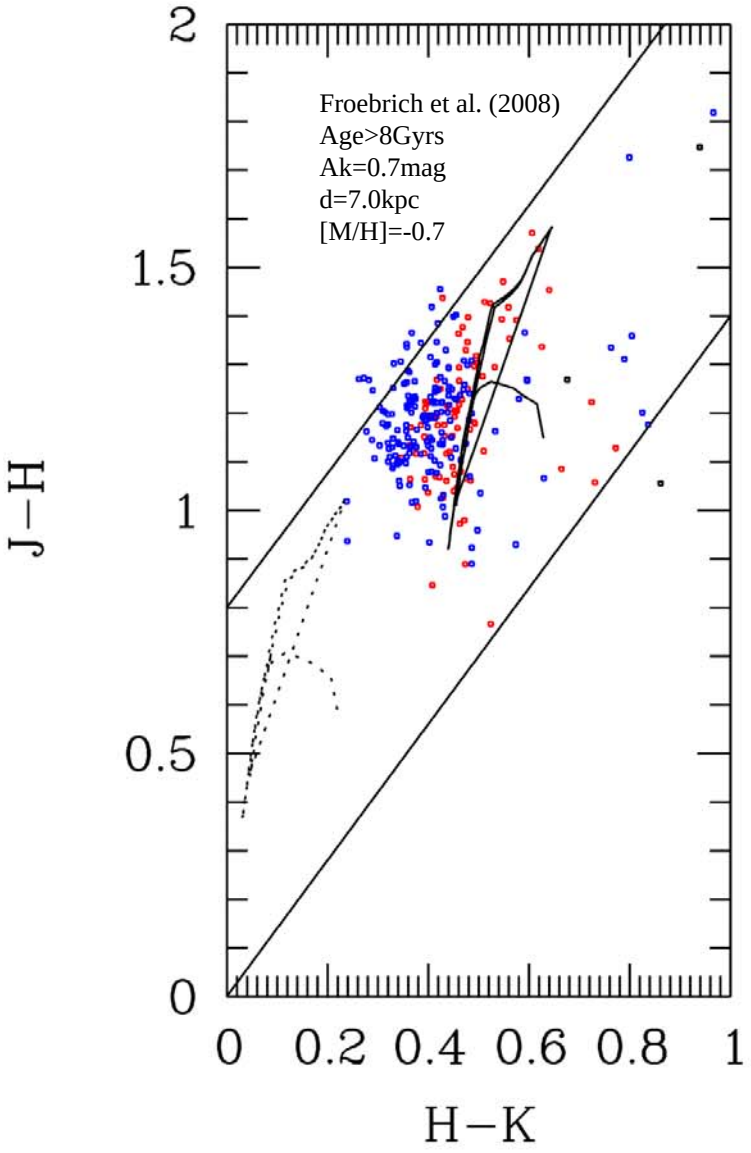

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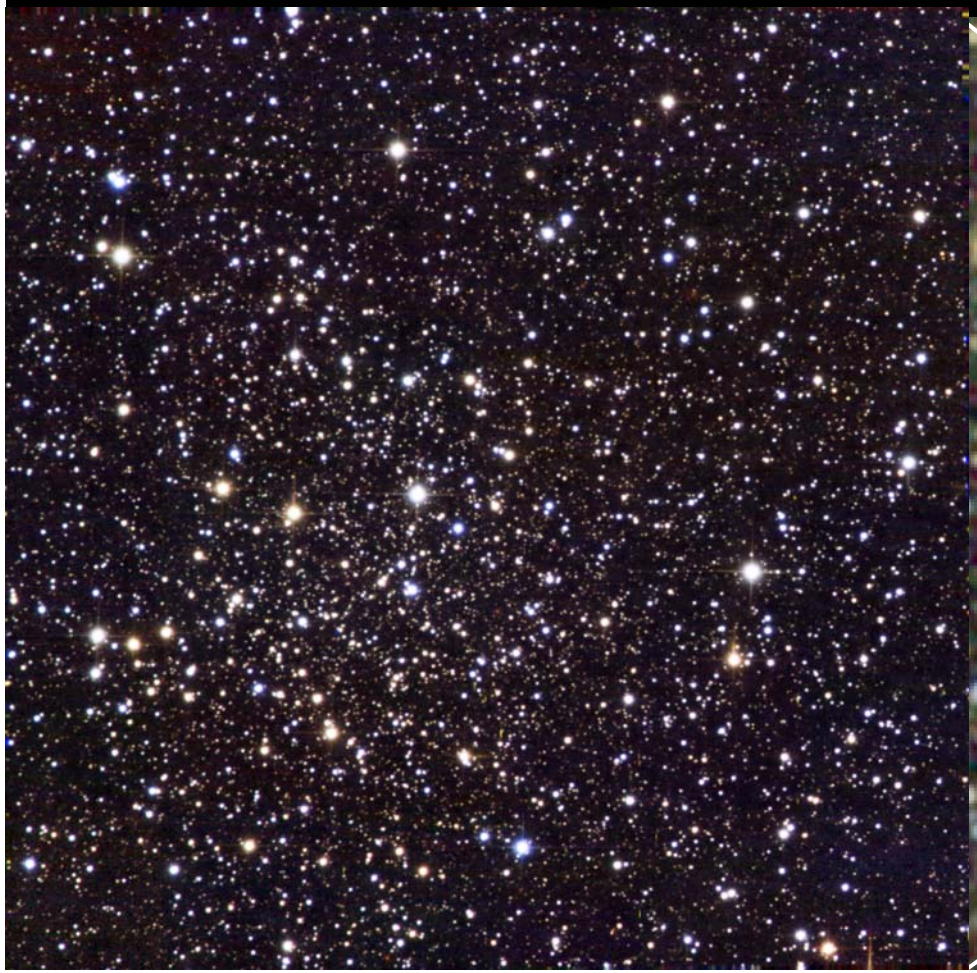
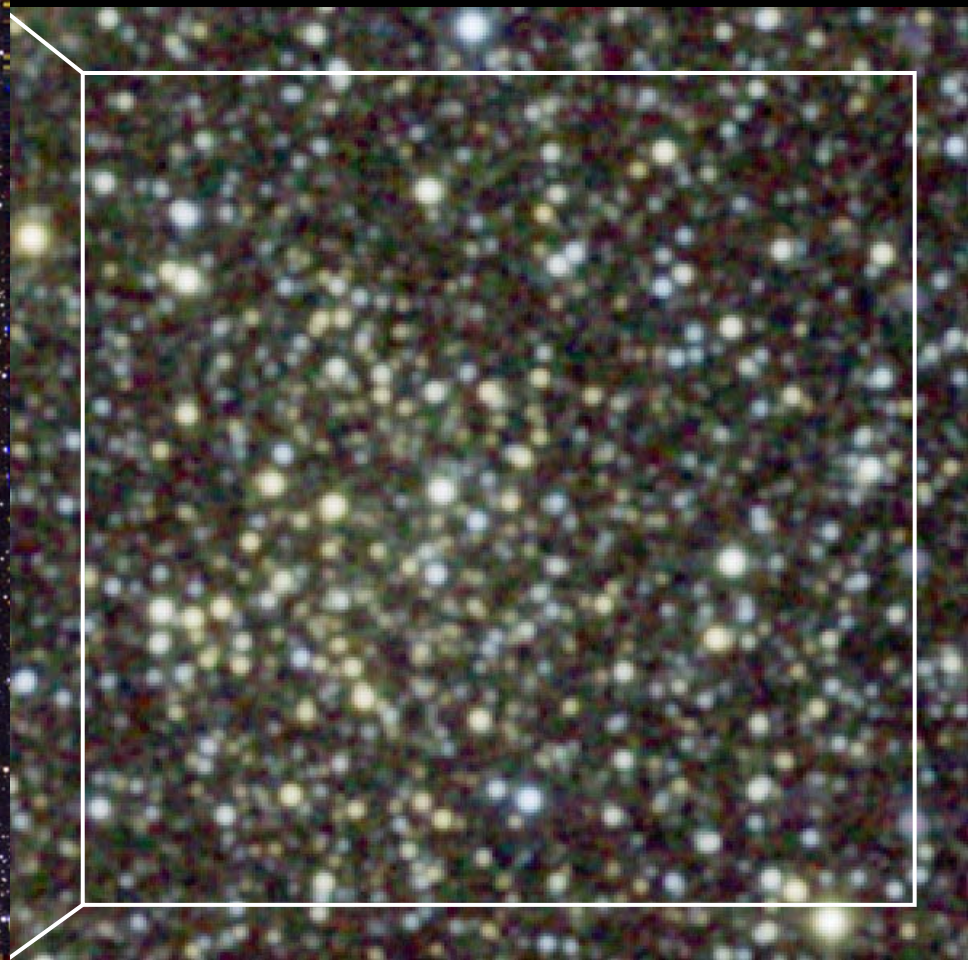
2MASS





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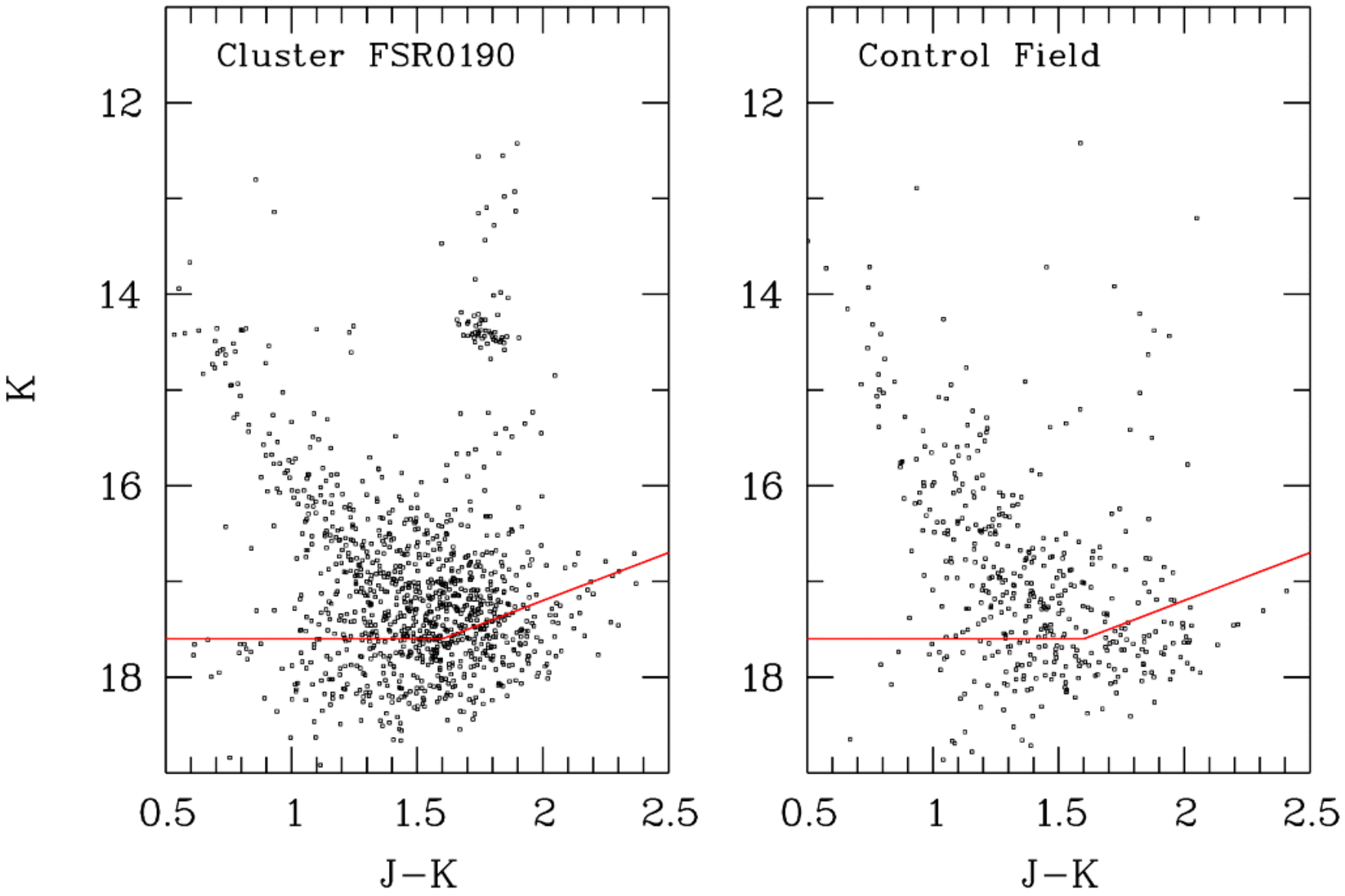

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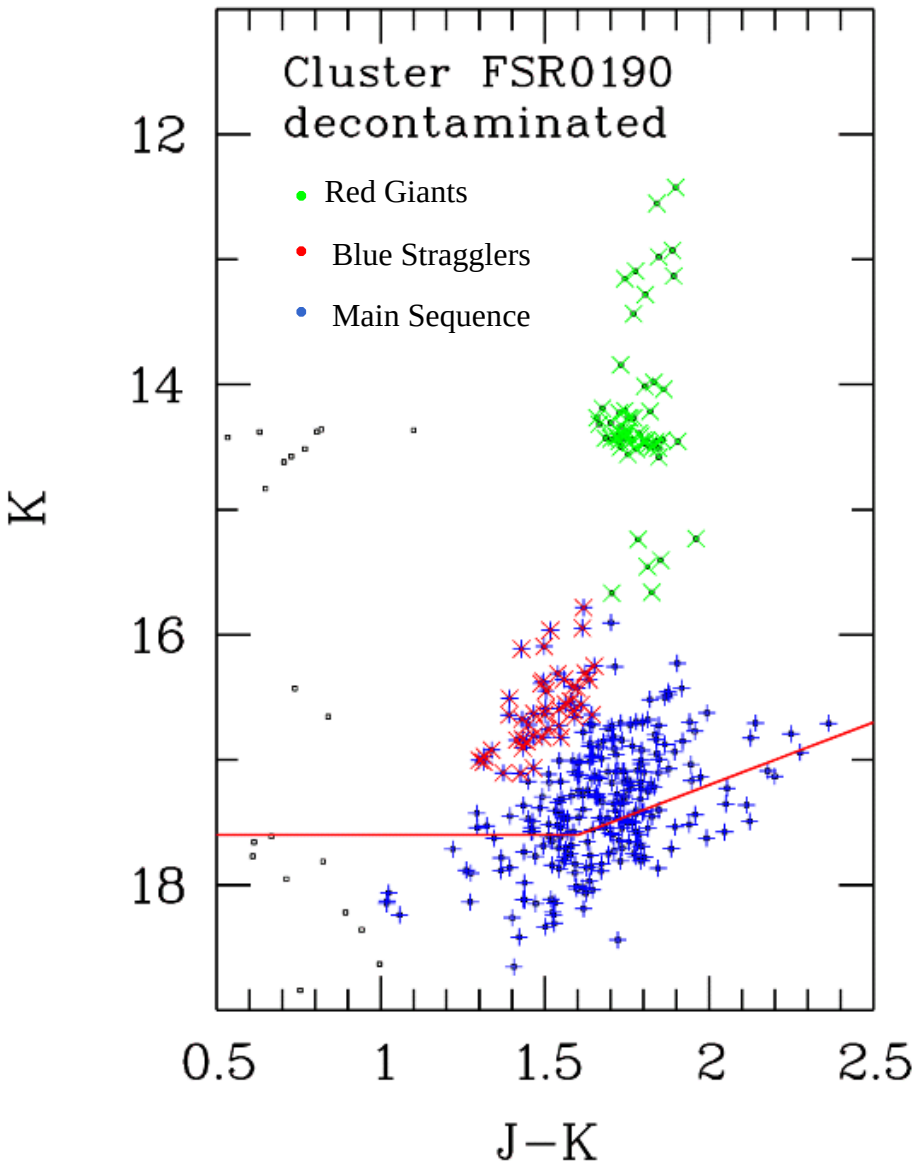

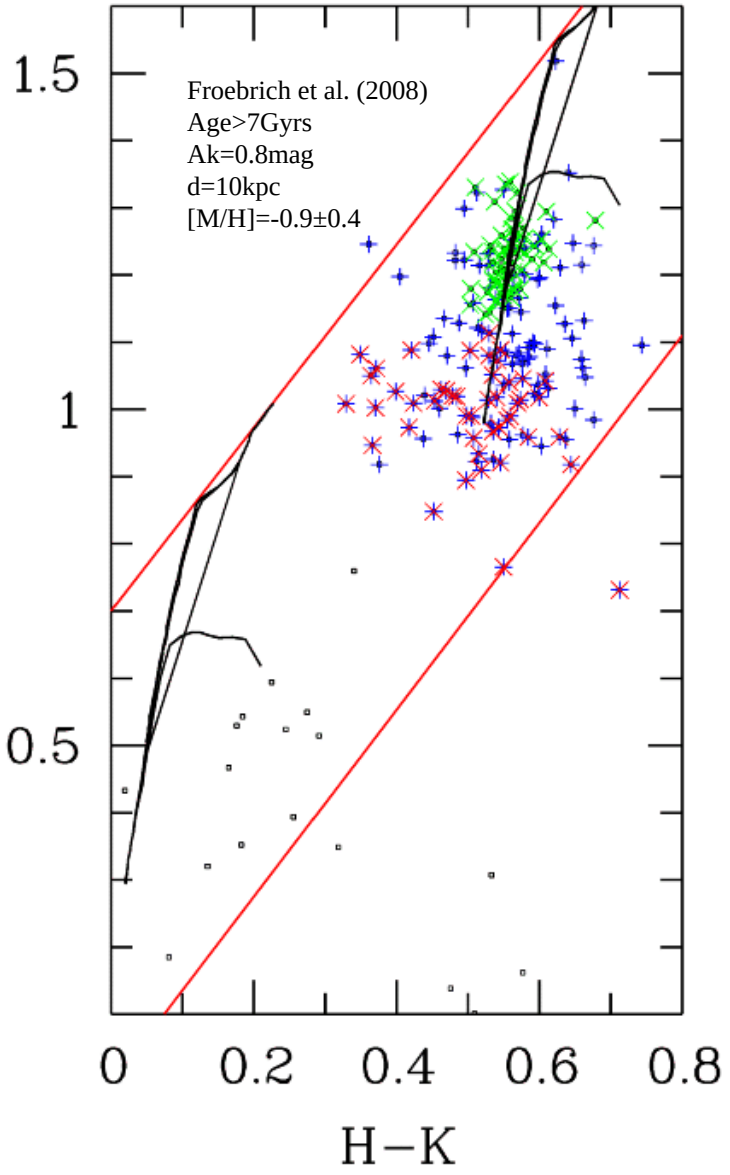

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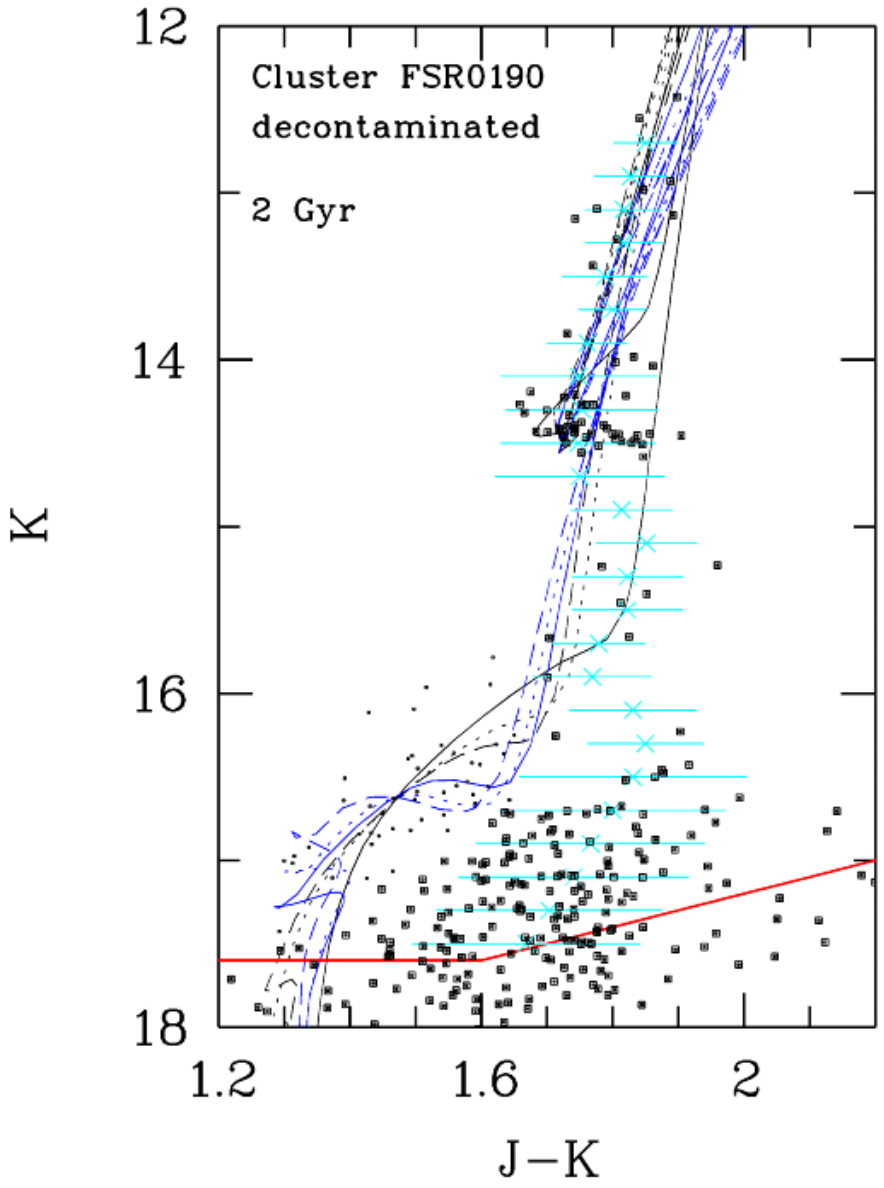

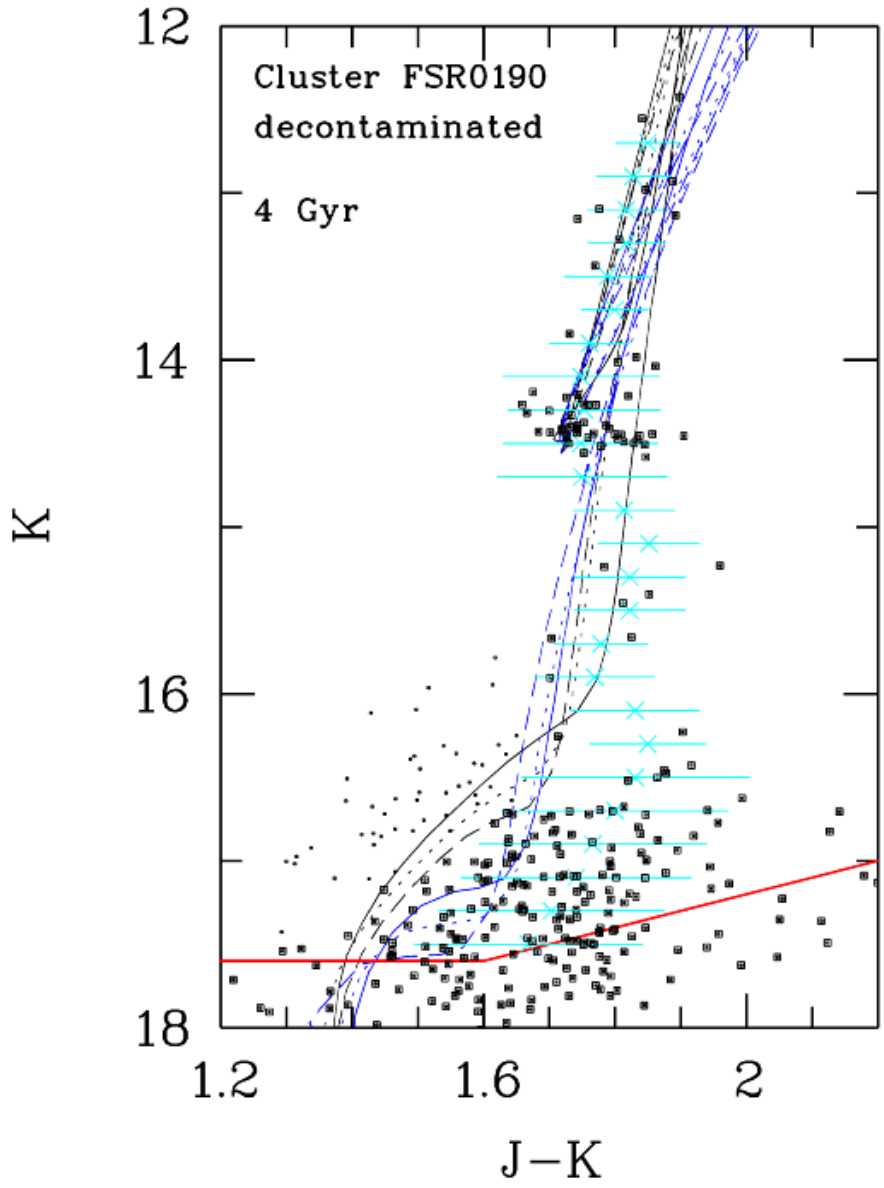

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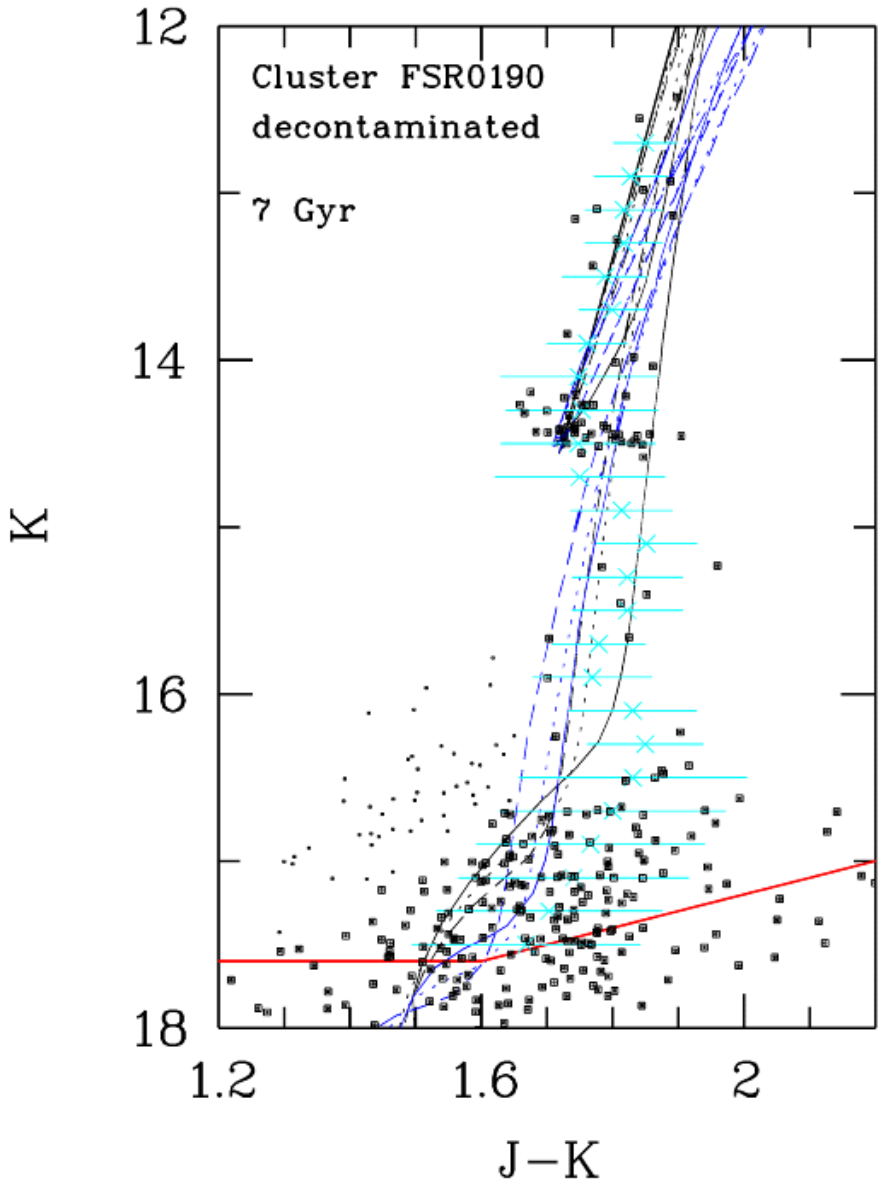

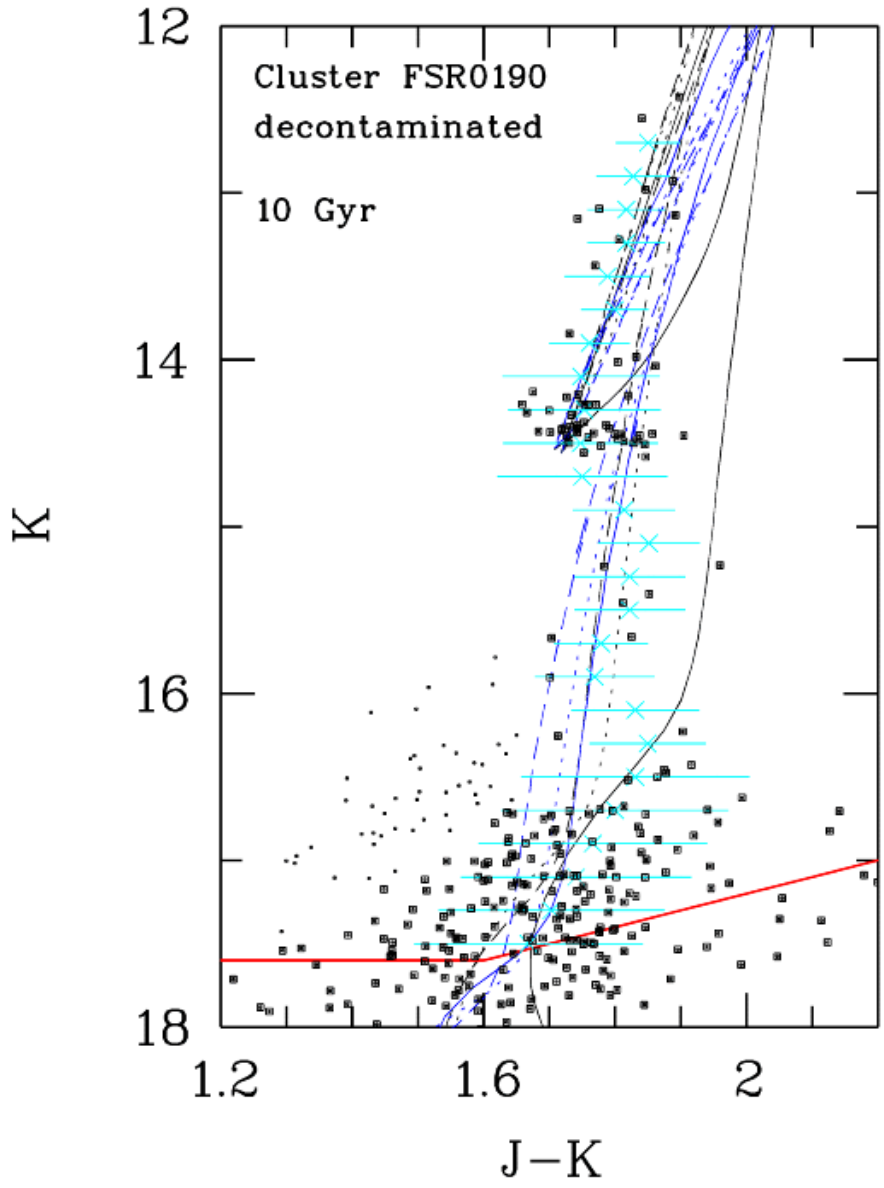


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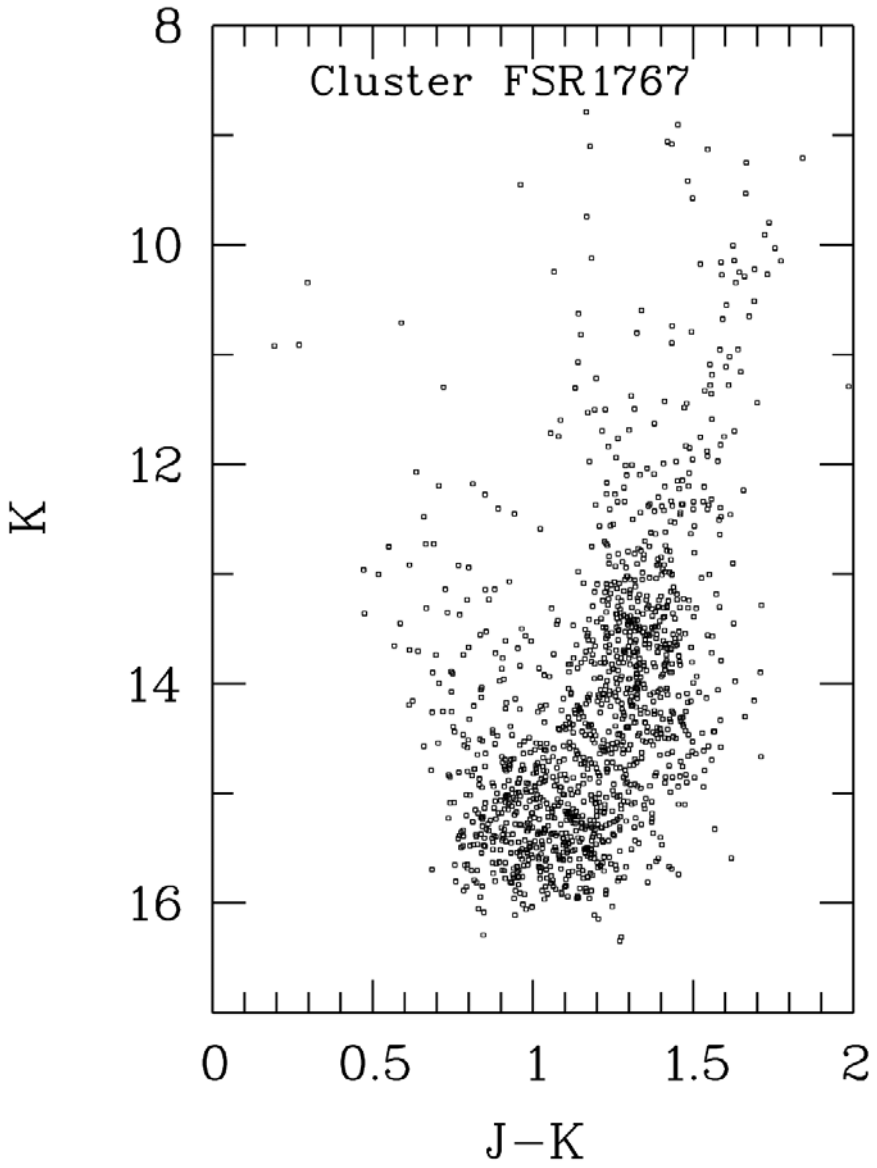
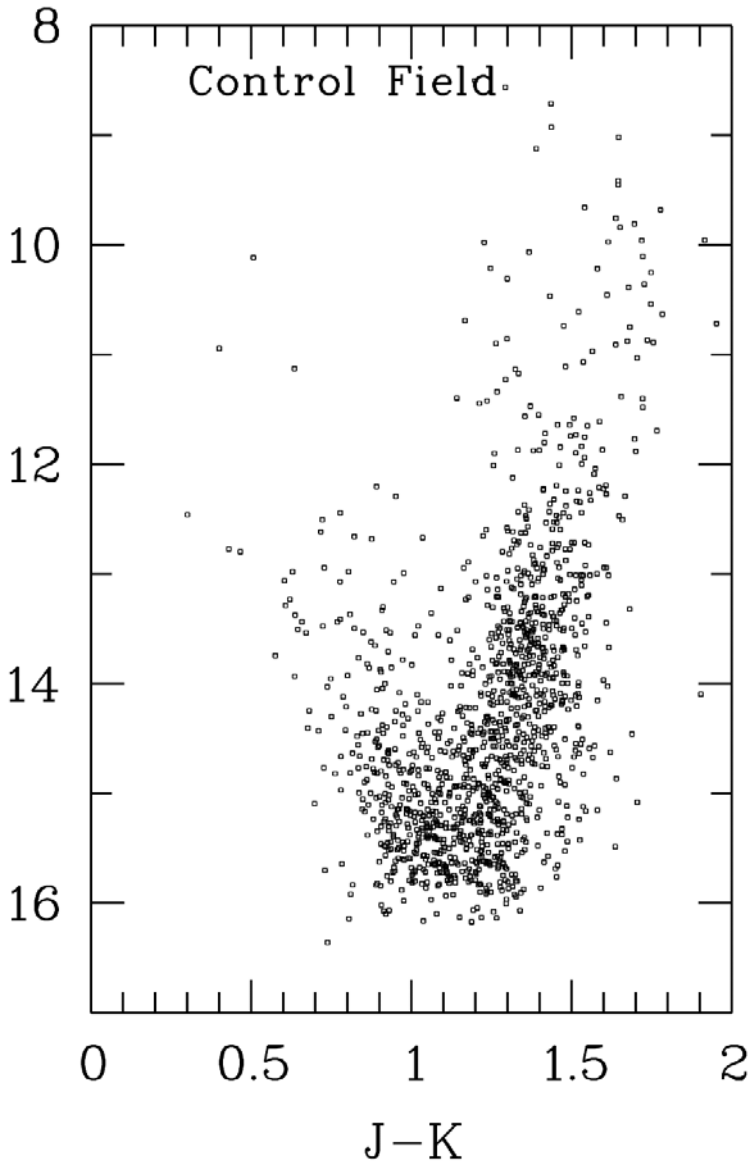
Heidelberg, 24.04.2008

Fore/Background decontamination





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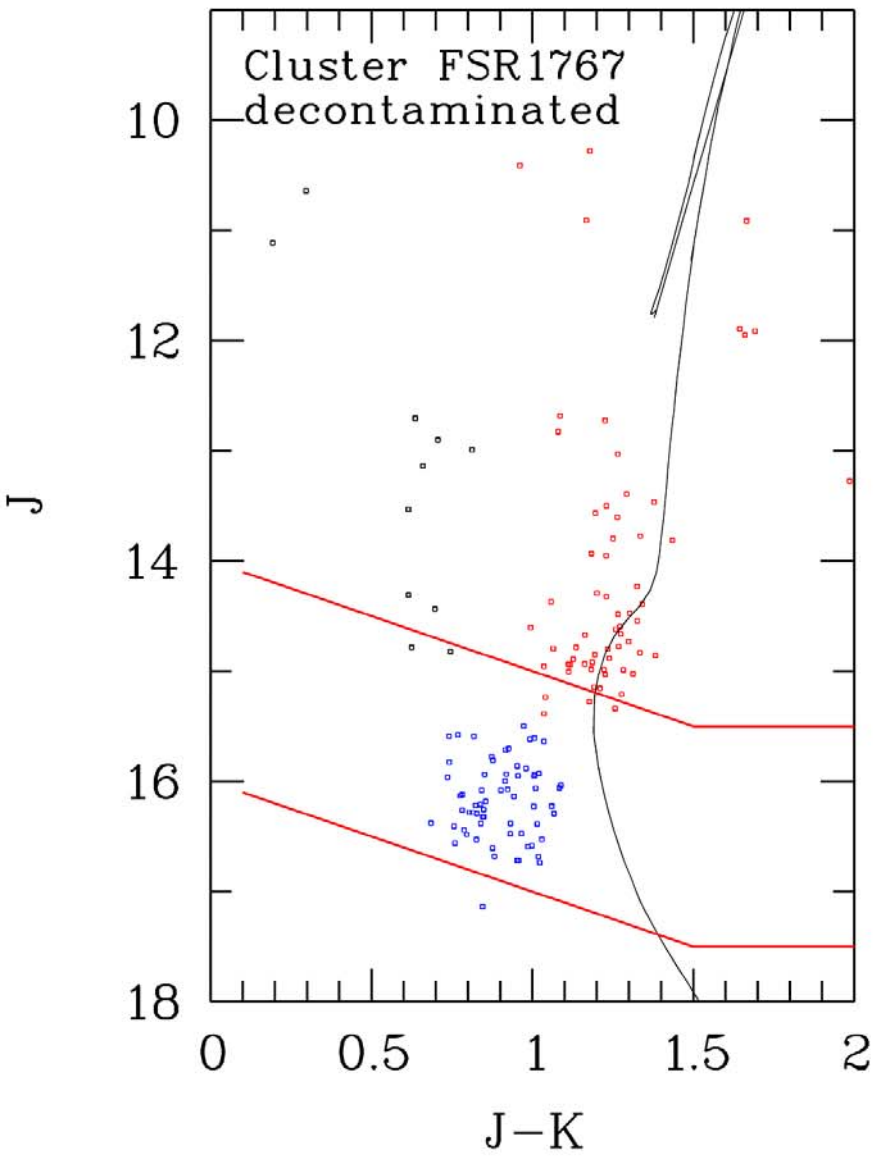

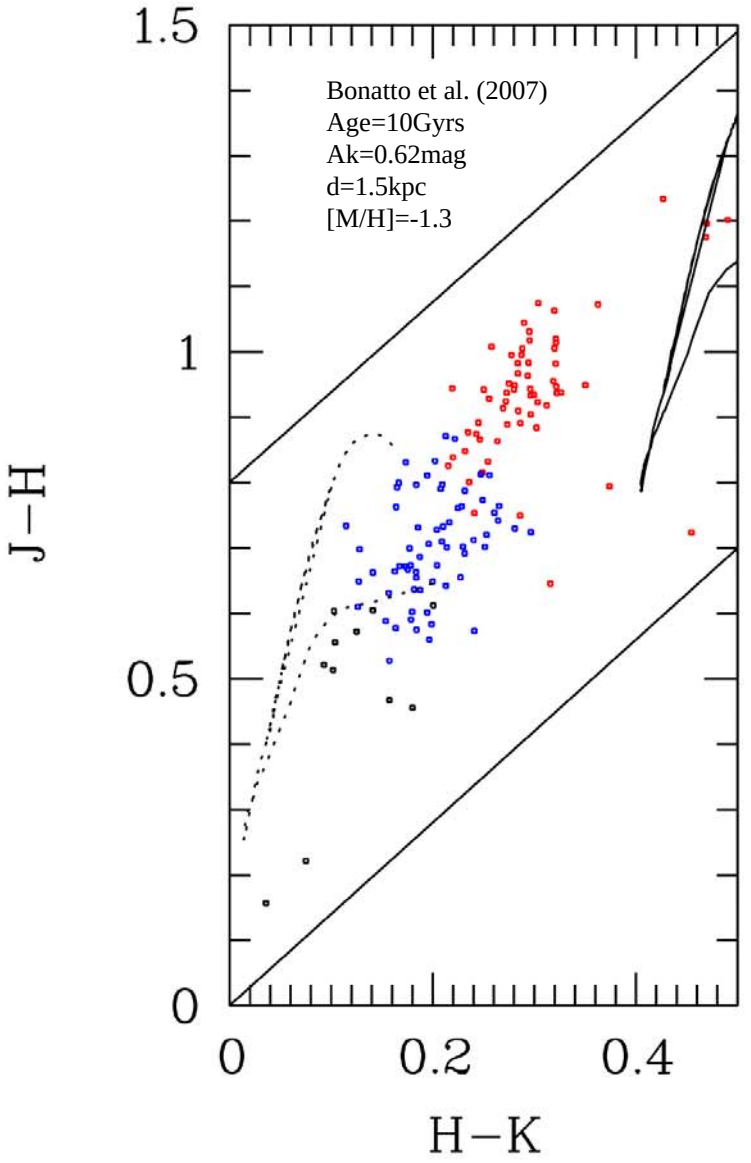

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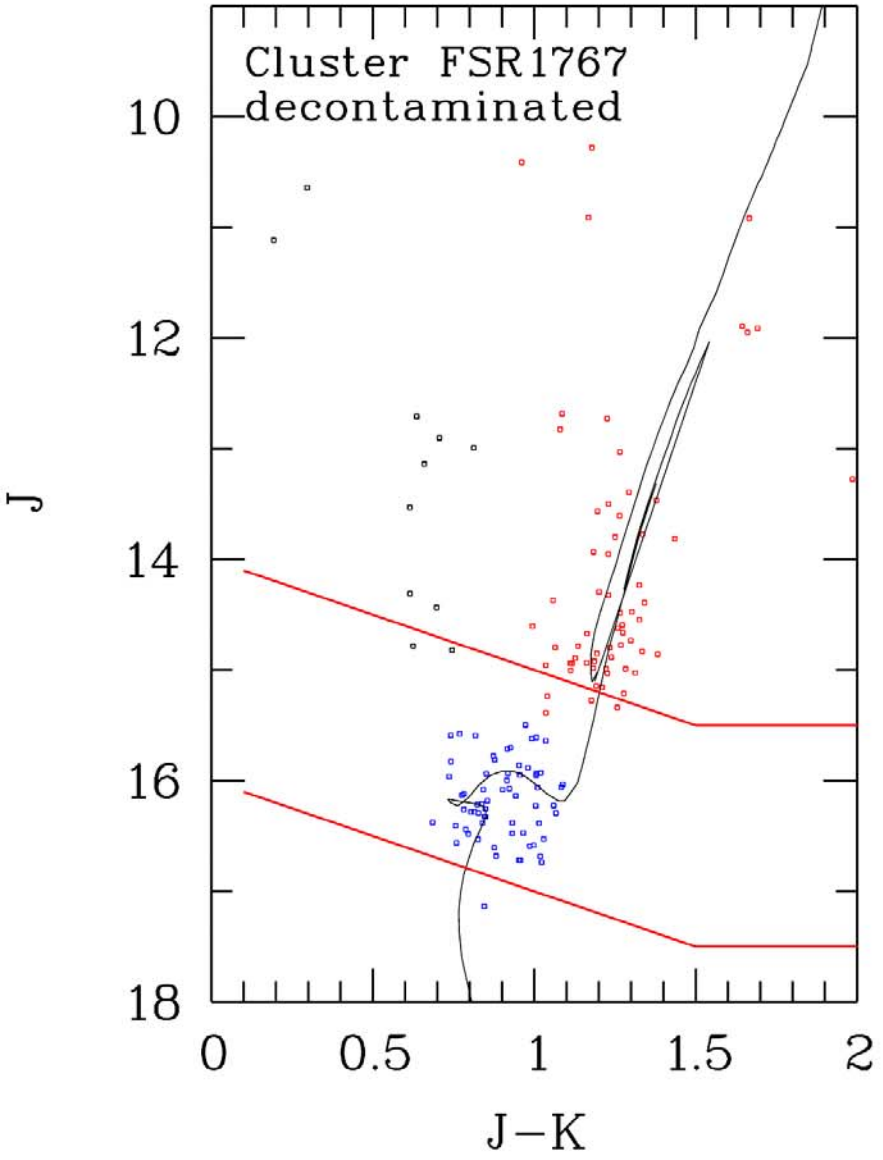

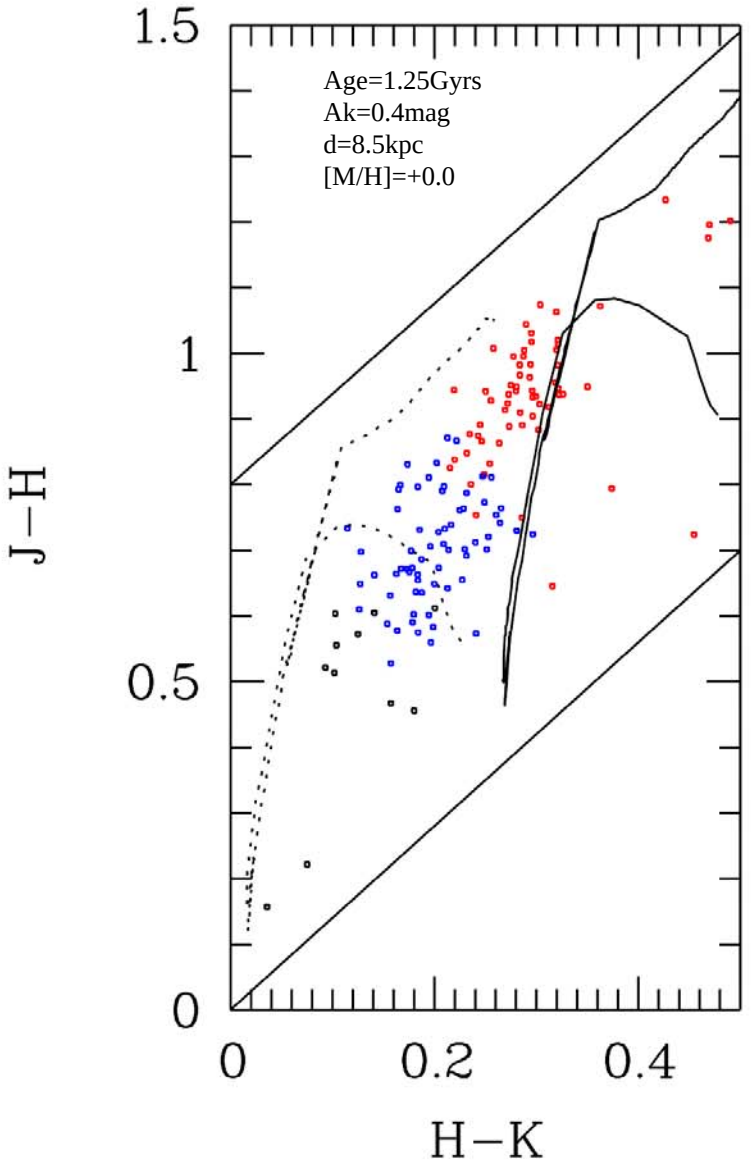


FSR
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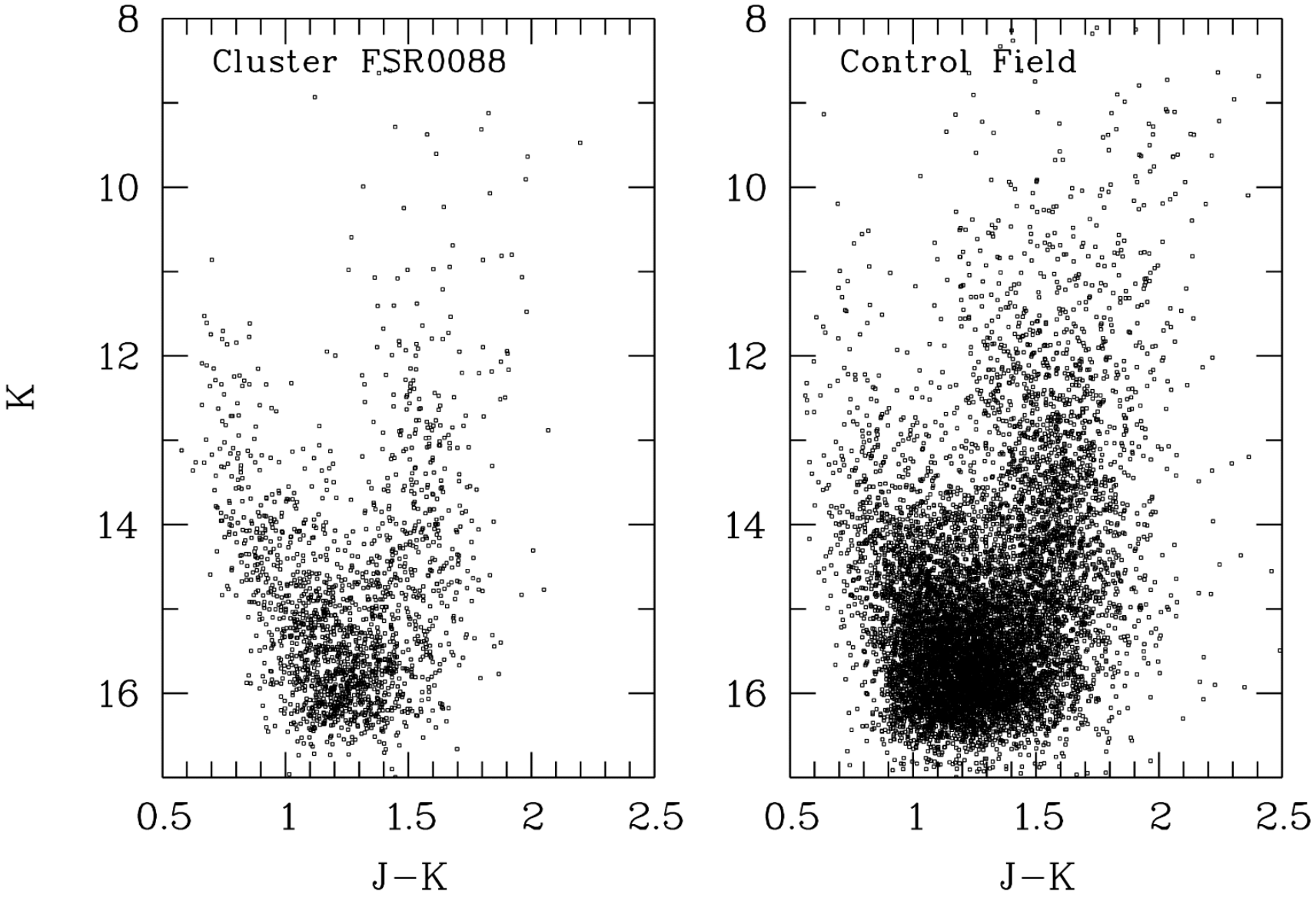

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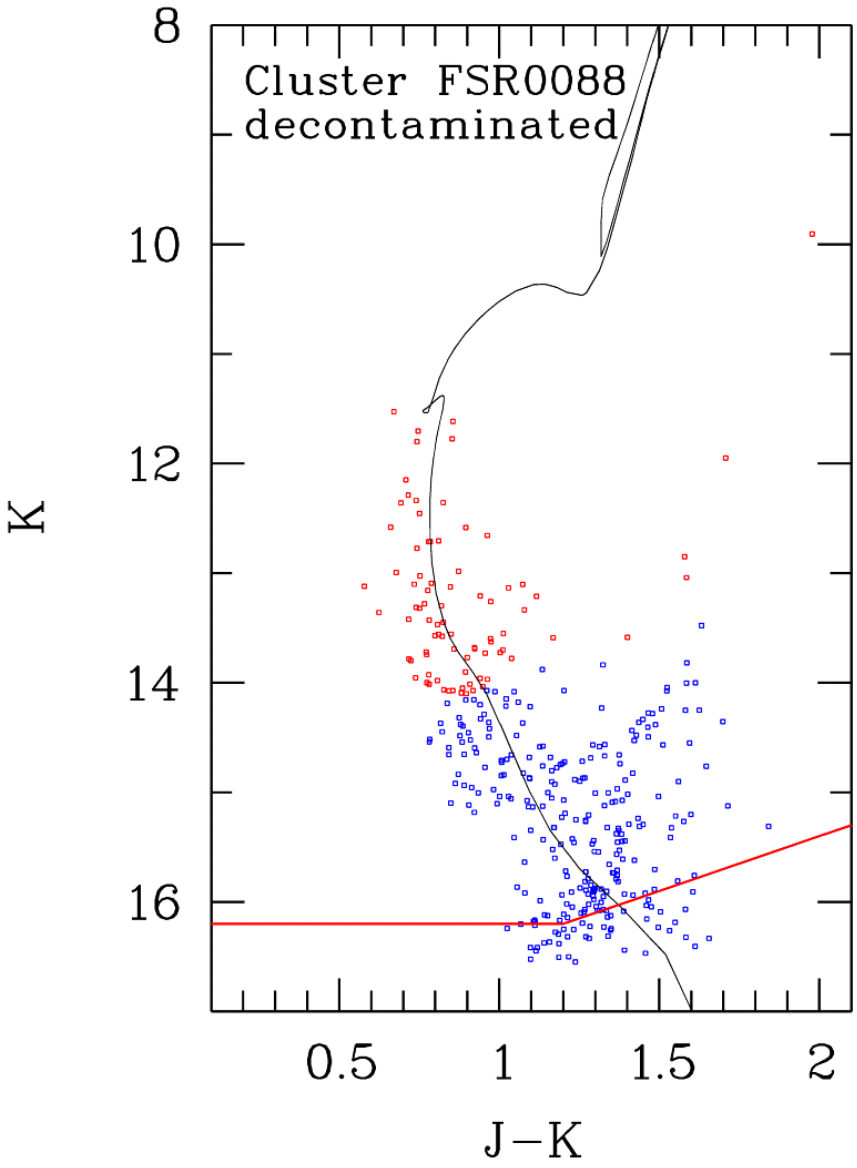

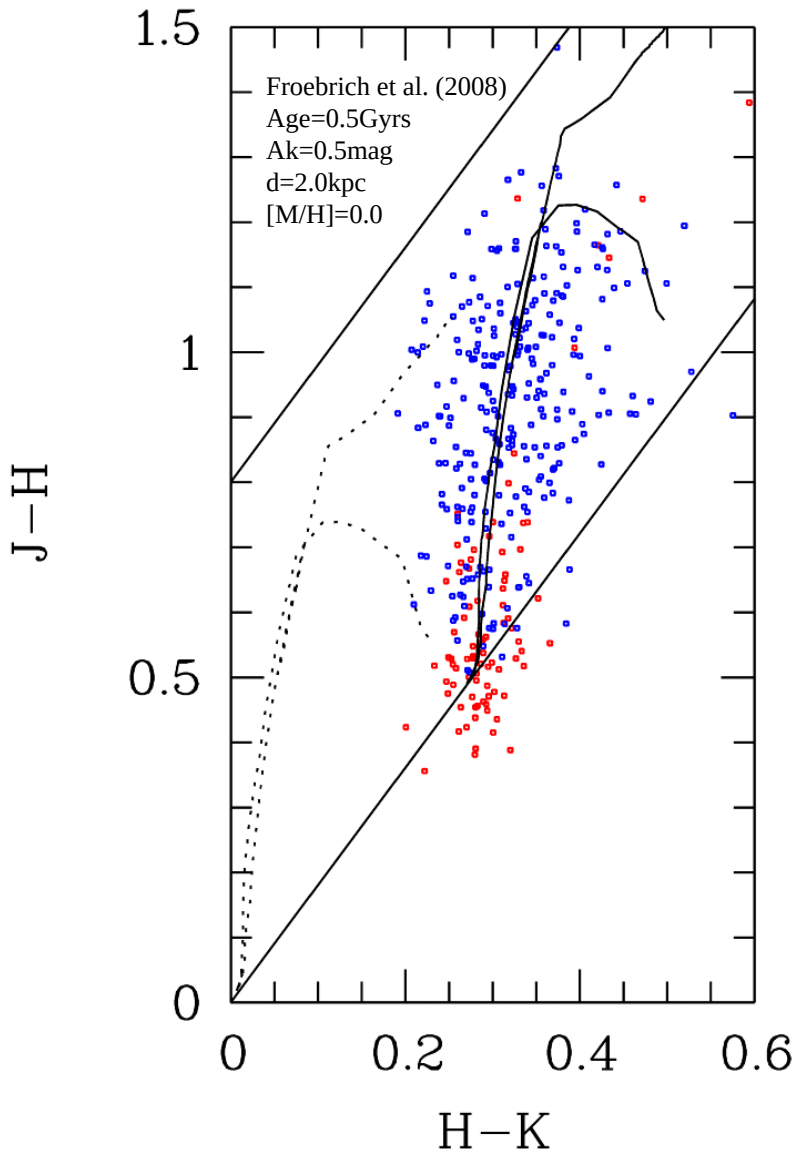

OpCl vs. GlCl

1500-2000 kown

e.g.
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Bica et al. (2003),
Kronberger et al. (2006),
Froebrich et al. (2007a),
...

(with new data)

163? kown

Harris (1996, 2003) lists 150,
+
Glimpse-C01 (Kobulnicky et al. 2005),
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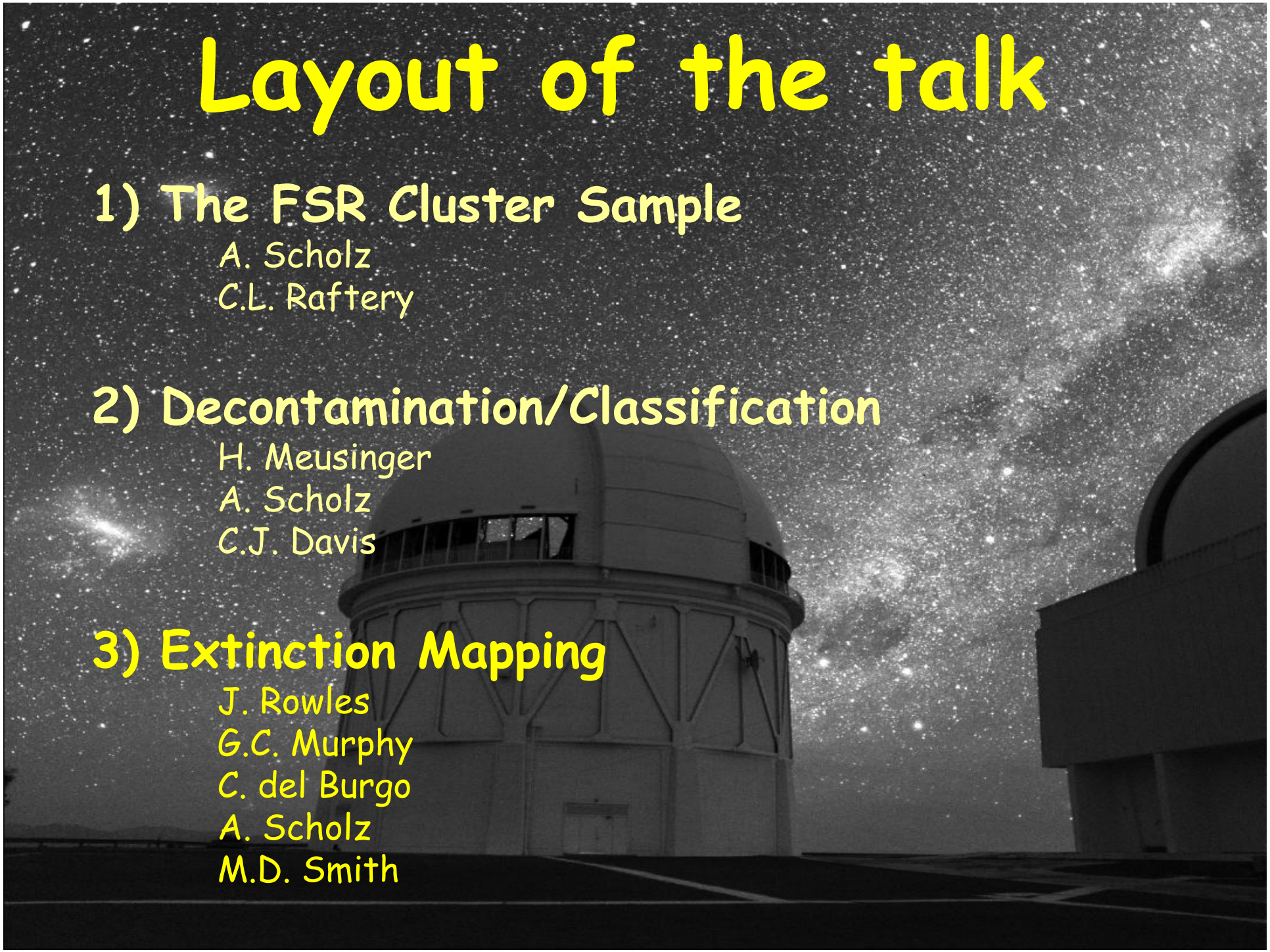
SDSS J1049+5103/J1257+3419
(Willman et al. 2005),
AL3 (Ortolani et al. 2006),
FSR1735? (Froebrich et al. 2007b),
GC SEGUE1 (Belokurov et al. 2007),
Koposov1/2 (Koposov et al. 2007),
~~FSR1767 (Bonatto et al. 2007),~~
FSR0584? (Bica et al. 2007),
FSR0190? (Froebrich et al. 2007c),
FSR1716? (Froebrich et al. 2008a),
FSR0358? (Froebrich et al. 2008b)



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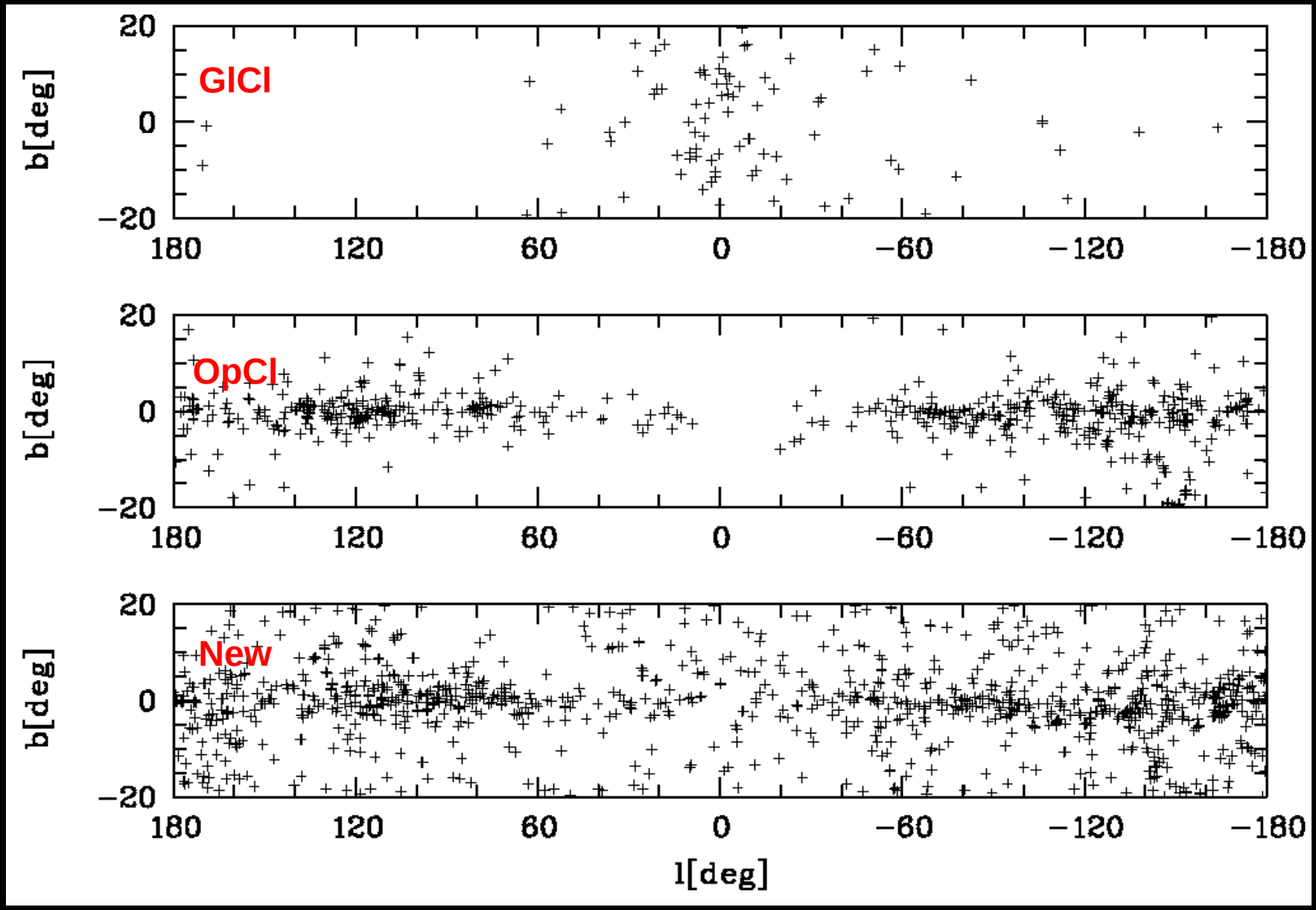
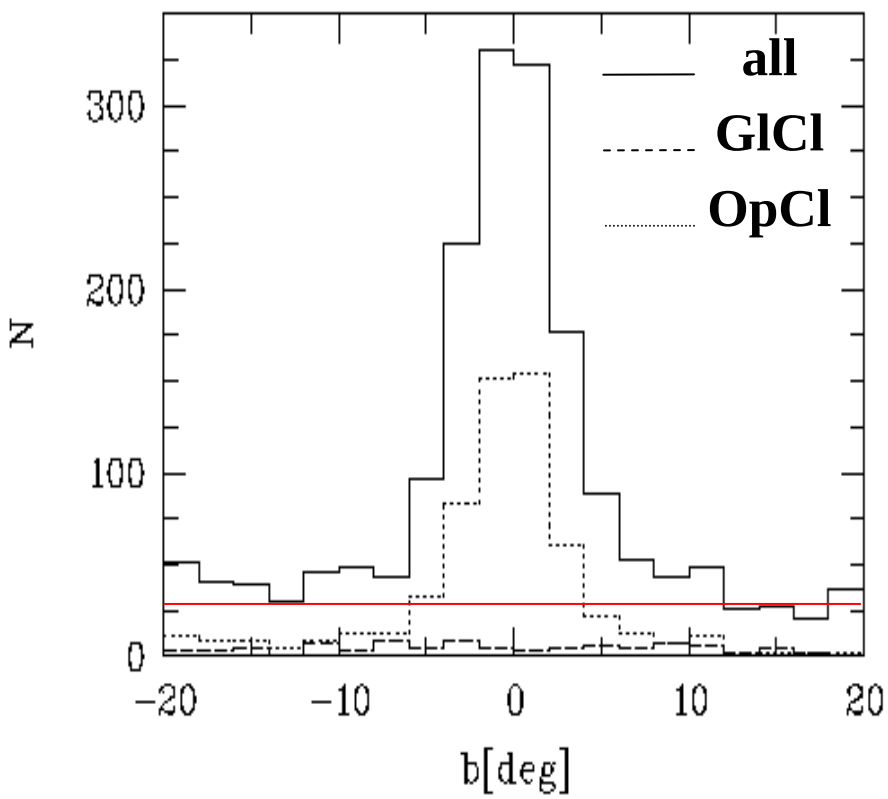
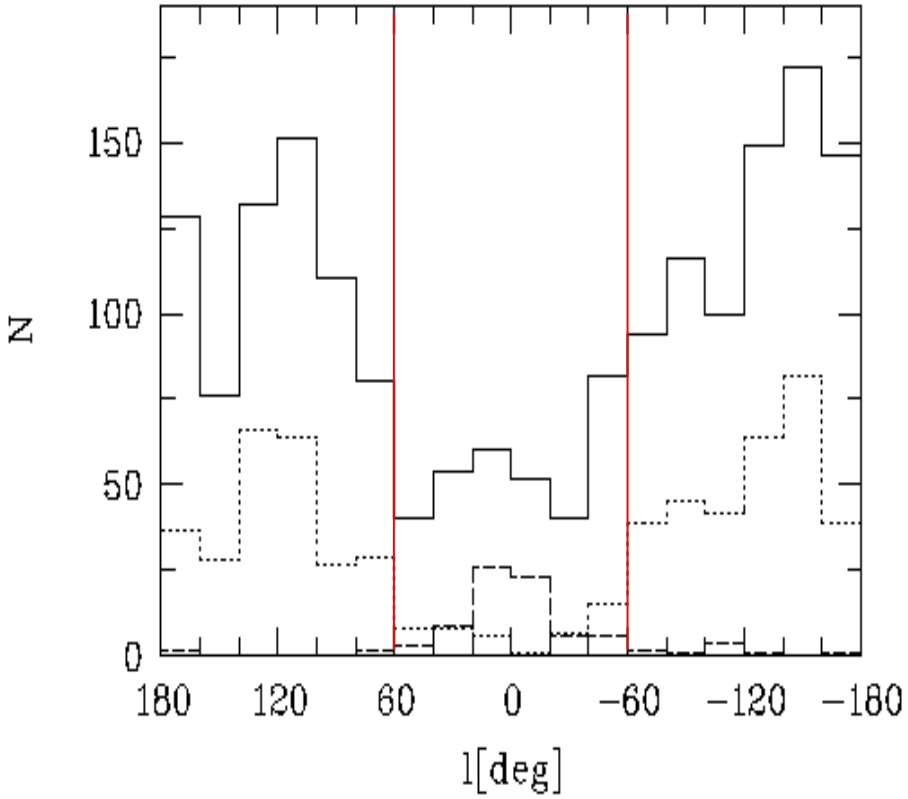
Distribution of FSR Clusters



Froebrich et al. (2007)

Distribution of FSR Clusters





Froebrich et al. (2007)

Distribution of FSR Clusters

$$P(r) = \frac{1}{\mathcal{N}} \cdot \sum_{i=1}^{\mathcal{N}} P_i(r) = \frac{1}{\mathcal{N} \cdot (\mathcal{N}-1)} \cdot \sum_{i=1}^{\mathcal{N}} \frac{\mathcal{N}_i(r)}{2 \cdot \pi \cdot r \cdot \delta r}$$

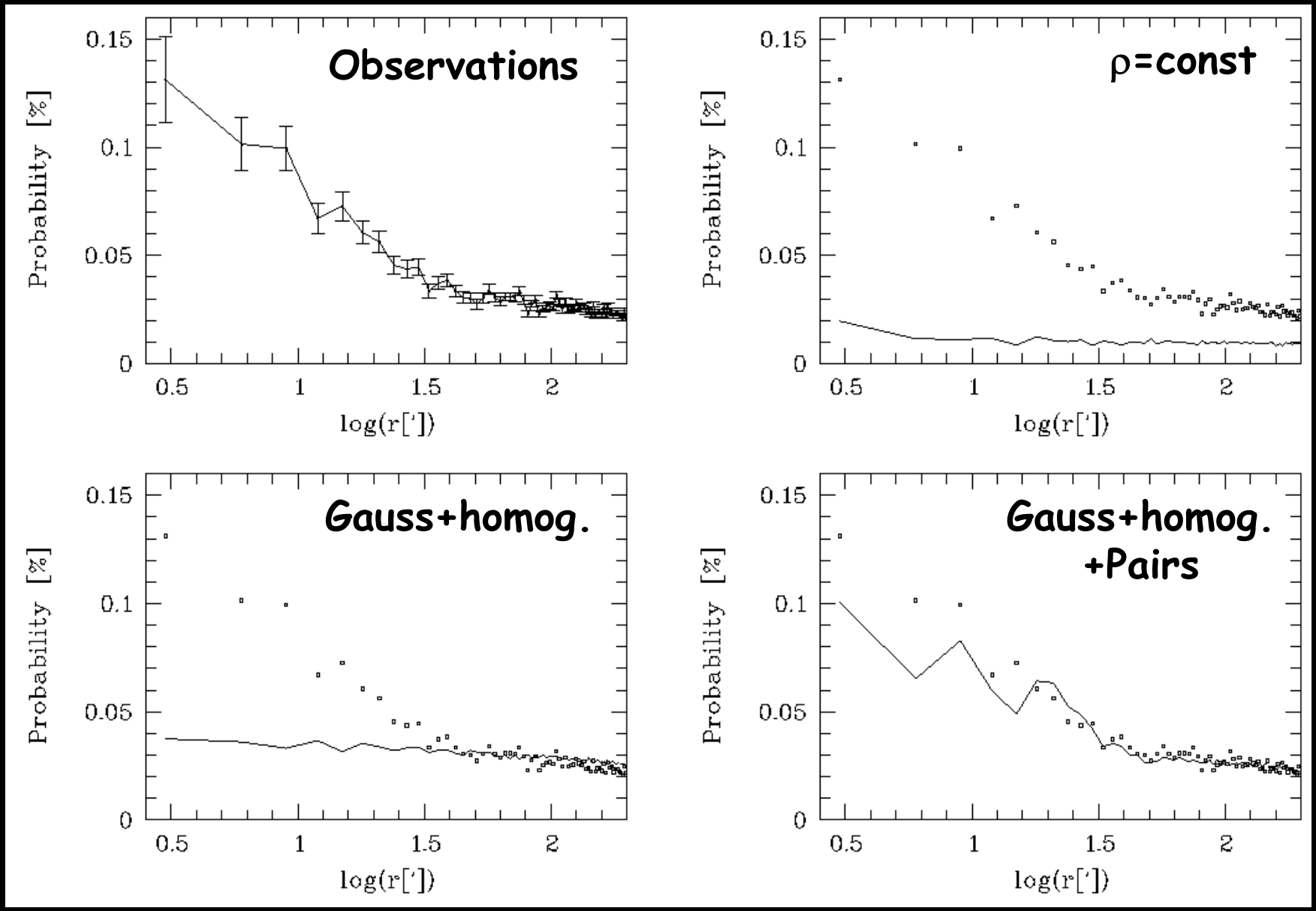
Probability to find cluster pairs with a separation r:

Count clusters in a ring with radius r and width δr, normalise to area and cluster number → $P_i(r)$

Average $P_i(r)$ over all clusters → $P(r)$

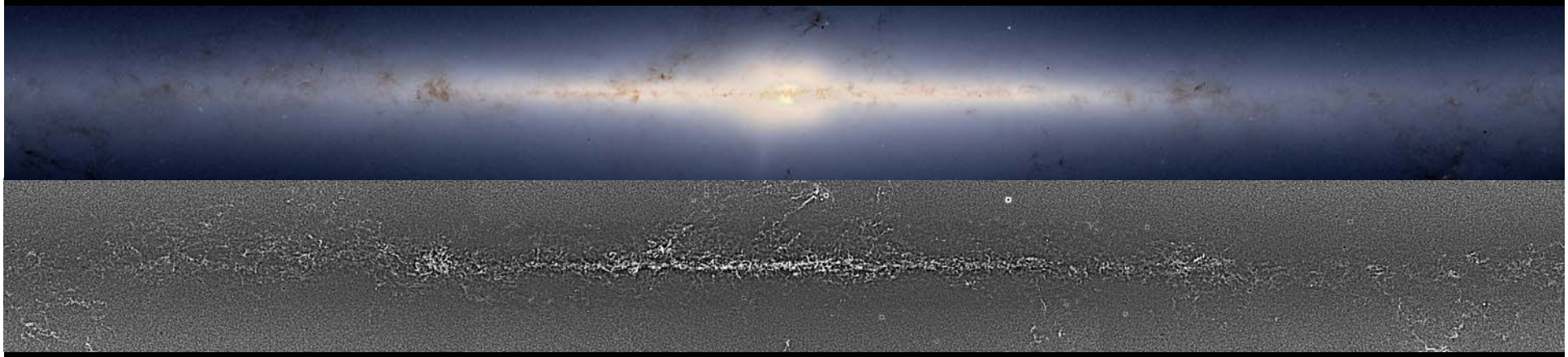
Froebrich et al. (2007)

Distribution of FSR Clusters



Froebrich et al. (2007)

Extinction Mapping



JHK star count relative extinction maps
- 14400 square degrees each
- 3.5' resolution
- 20" pixels → 0.5 GigaPixel images

120 hours computing time on
- 16 node double processor Beowulf-type cluster

Froebrich et al. (2005)

Colour Excess

Lada et al. (1994) - NICE

Difference between measured and intrinsic colour of stars as estimator for extinction

$$\langle \lambda_1 - \lambda_2 \rangle \equiv (m_{\lambda_1} - m_{\lambda_2}) - \left(m^{\mathrm{tr}}_{\lambda_1} - m^{\mathrm{tr}}_{\lambda_2}\right)$$

$$A_\lambda \propto \lambda^{-\beta}$$

$$A_{\lambda_2} = \frac{\langle \lambda_1 - \lambda_2 \rangle}{\left(\frac{\lambda_2}{\lambda_1}\right)^{\beta} - 1}$$

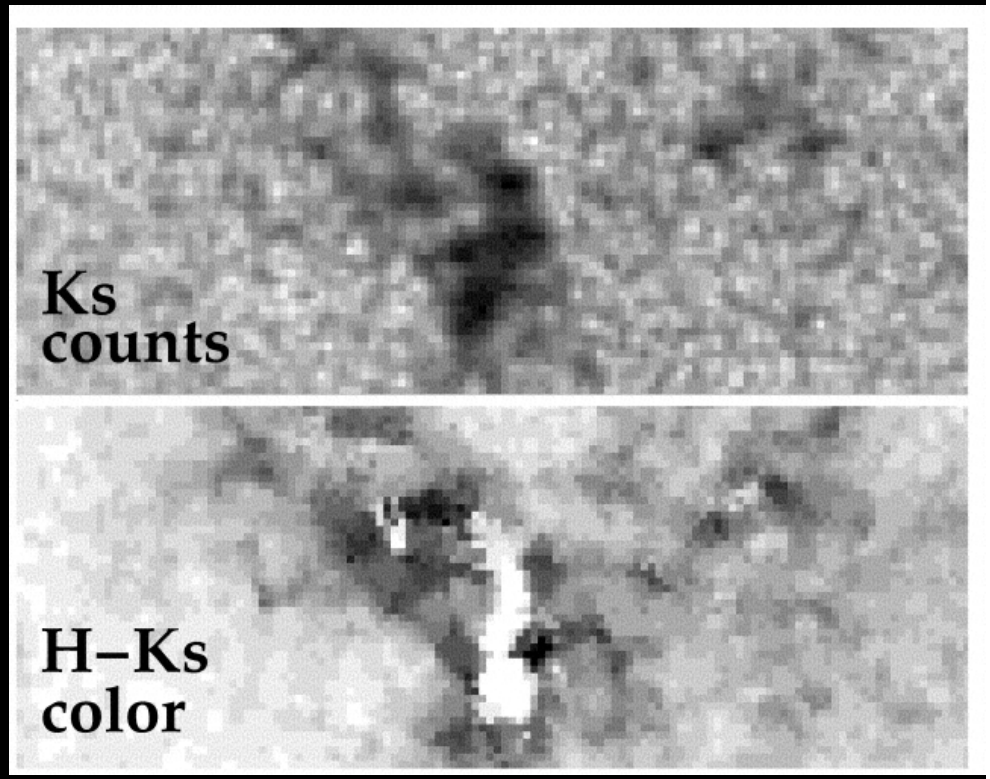
Lombardi & Alves (2001) - NICER

Optimised use of multi-band photometry

Combined Methods

Cambresy et al. (2002)

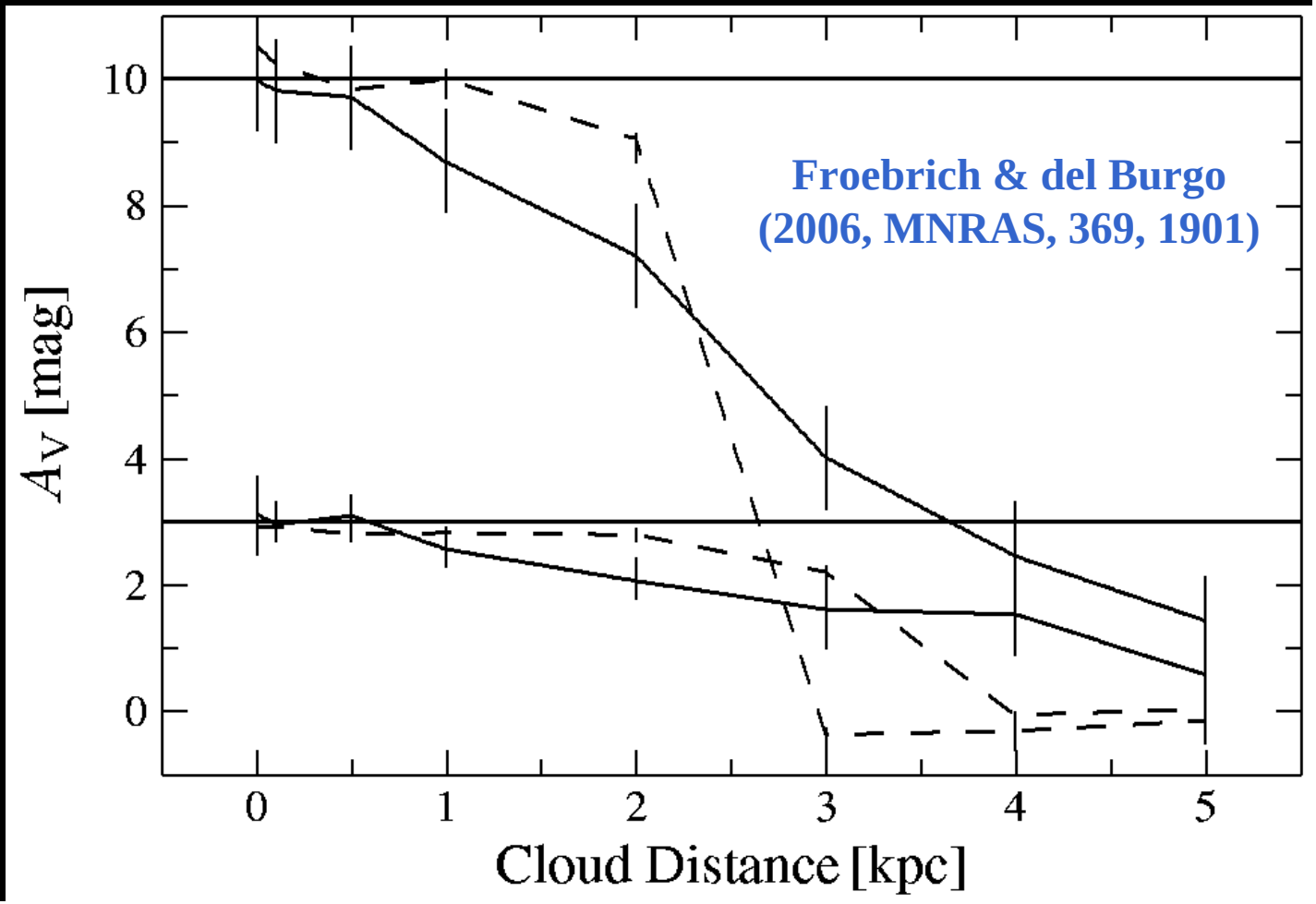
Use of colour excess and star counts simultaneously



Lombardi (2005)

Optimised use of star counts and colour excess

Combined Methods



Extinction Mapping

<J-H> + < H-K> colour excess extinction map of Galactic Anticenter

Froebrich et al. (2007)

Conclusions

We have identified 1021 new star cluster candidates with |b|<20° in star density maps (40-50% contamination rate)

Follow up observations/analyses have so far revealt 4 new galactic GlCl candidates, plus a number of old OpCl

Deep NIR imaging is at least required to verify their nature. 2MASS alone is insufficient in some cases (e.g. FSR1767)!

The FSR clusters are clustered on scales of 0.7° or about 25pc, a typical size for molecular clouds

A complete and homogeneous classification of all FSR cluster candidates, as well as All Sky extinction mapping will (hopefully) help to understand this → Do GMCs form more than one stars cluster?