

# **Integrated Photometric Parameters of Galactic Open Clusters**

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## Intro



- ✓ from an OC sample with well defined statistical properties;
- ✓ based on reliable membership (pm, photometry, projected density distribution), homogeneous cluster parameters, and uniform methods of parameter determination

### Project team:

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# Constructing a Sample of Open Clusters (1)

## Basic survey

All-Sky Compiled Catalogue  
of 2.5 mln stars (**ASCC-2.5**):  
positions, proper motions,  
BV photometry,  
2MASS photometry,  
spectral types (0.5 mln),  
radial velocities (55,000)  
complete to  $V < \sim 11.5$  mag

Kharchenko N.V. 2001, KPCB 17, 409 (CDS id: I/280A)

**Cluster membership**  
kinematic, photometric,  
and spatial criteria

## Cluster parameters (650 OCs)

position of centre, apparent size,  
mean pm, Vrad (430 OCs),  
distance,  $E(B-V)$ ,  
age,  
tidal radius, tidal mass,  
ellipticity,  
integrated magnitudes (B,V,J,H,K),  
integrated colours

# Constructing a Sample of Open Clusters (2)

- 520 known clusters identified
- Search for new clusters around every star with  $V < 9.5$ :  
130 unknown clusters were discovered

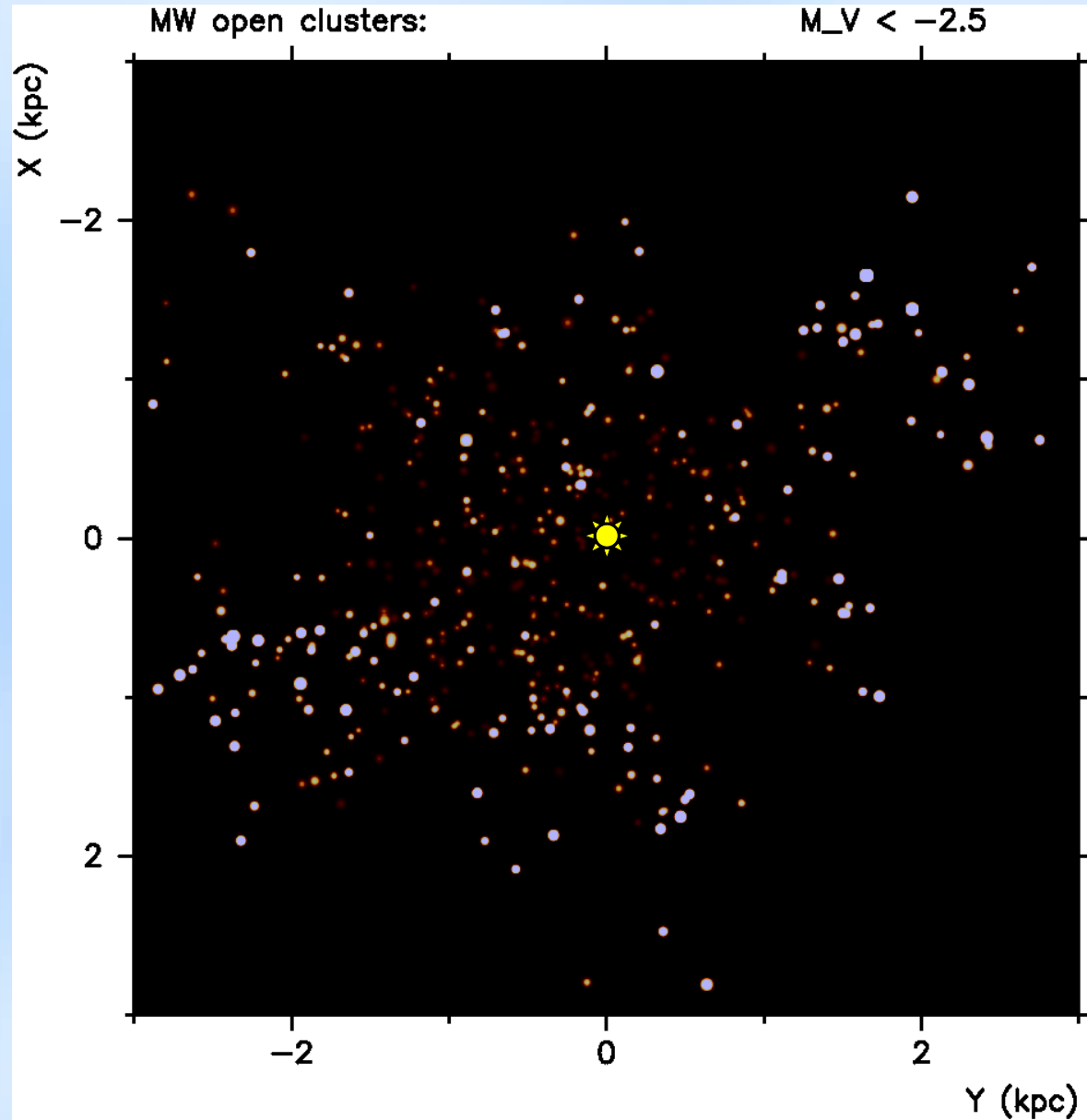


**650** objects total

To be compared to

**~1800** MW optical clusters  
or cluster candidates

650 OCs



# Selection of Results \*

Galactic OCs: more numerous (per unit of volume), larger,  
more massive, more long-lived as believed before  
.....  
from distributions:

spatial .....▶ completeness: 850 pc (259 OCs),  $\Sigma = 114 \text{ kpc}^{-2}$ ,  
 $N(R_G \leq 15 \text{ kpc}) = 93,000 \text{ OCs}$ ;

velocity .....▶ 4 OCCs (incl. Gould Belt): a tendency to higher  
hierarchical clustering

age .....▶ average age at present: 260 Myr;  
average lifetime: 330 Myr;

mass .....▶ average mass at present:  $700 M_{\odot}$ ,  
average mass at birth:  $4500 M_{\odot}$ , CFR:  $0.4 \text{ kpc}^{-2}$ ,  
CIMF is flat (more mass in massive clusters at 4-8 Myr),  
OCs provide ~35% mass input to the Galactic disk,

.....▶ .... and have a good chance to survive ejections of O-stars

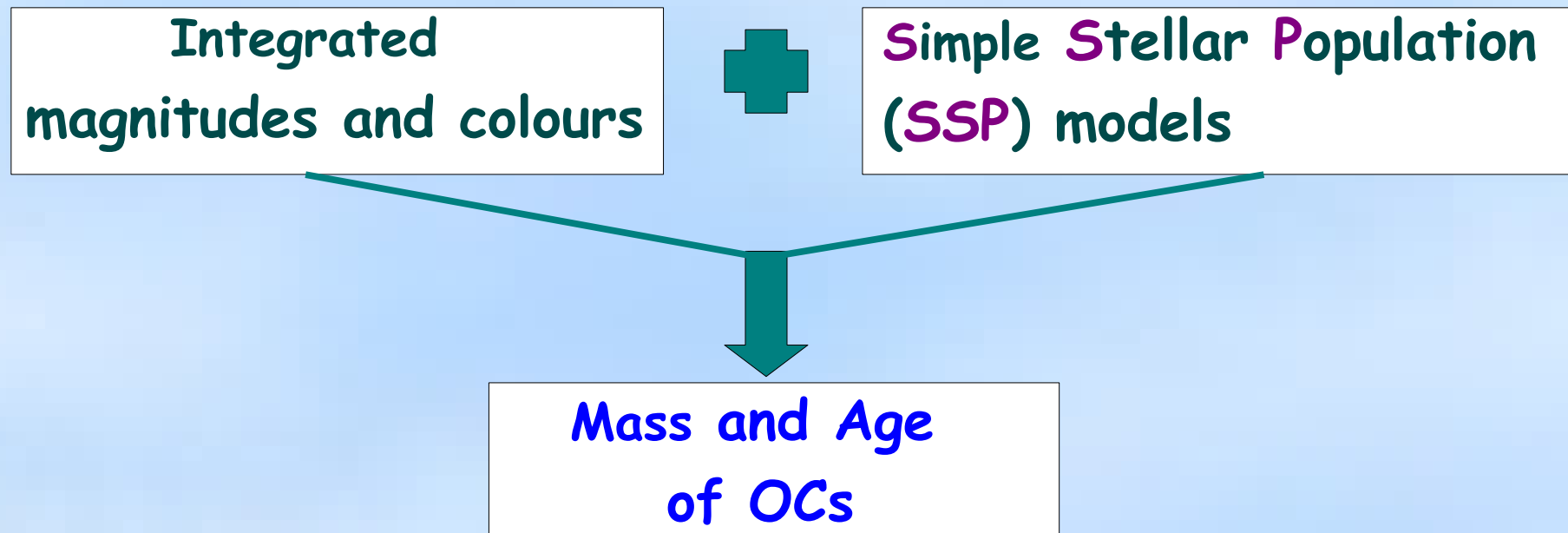
\*already published

# Integrated magnitudes of Open Clusters (1)

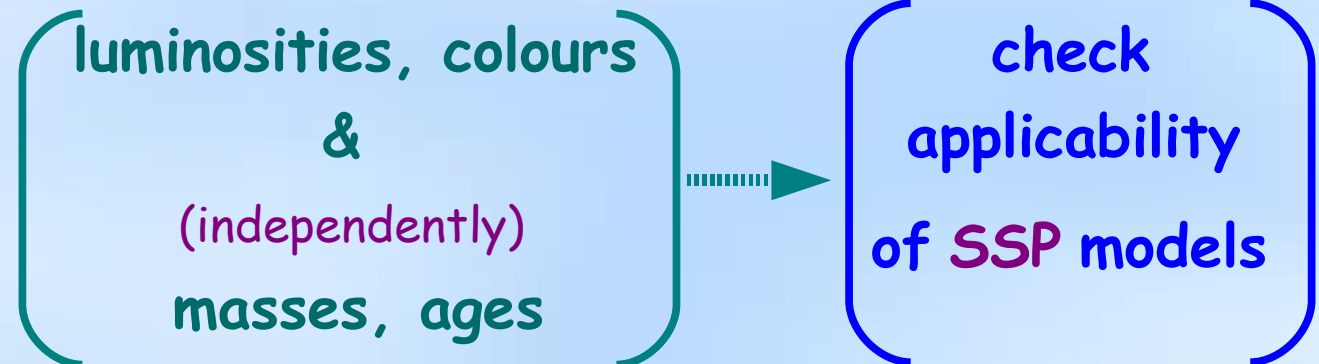
Integrated magnitudes  $\rightarrow$  LF of OCs: the basic observable statistical descriptor of the cluster population

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Usual approach for extragalactic open clusters:



Galactic OCs:



# Integrated magnitudes of Open Clusters (2)

Input:

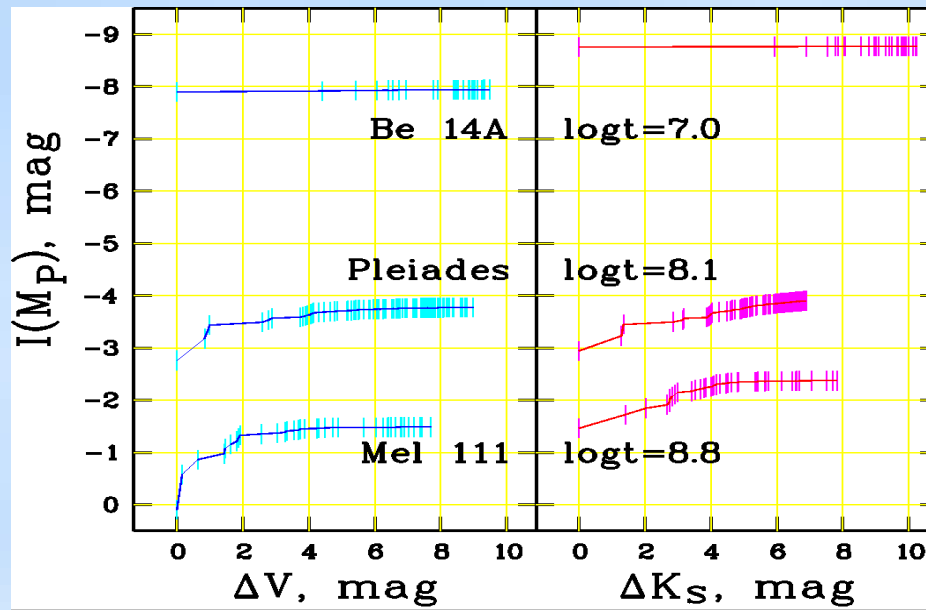
membership,  
app. magnitudes of  
individual members

Approach:

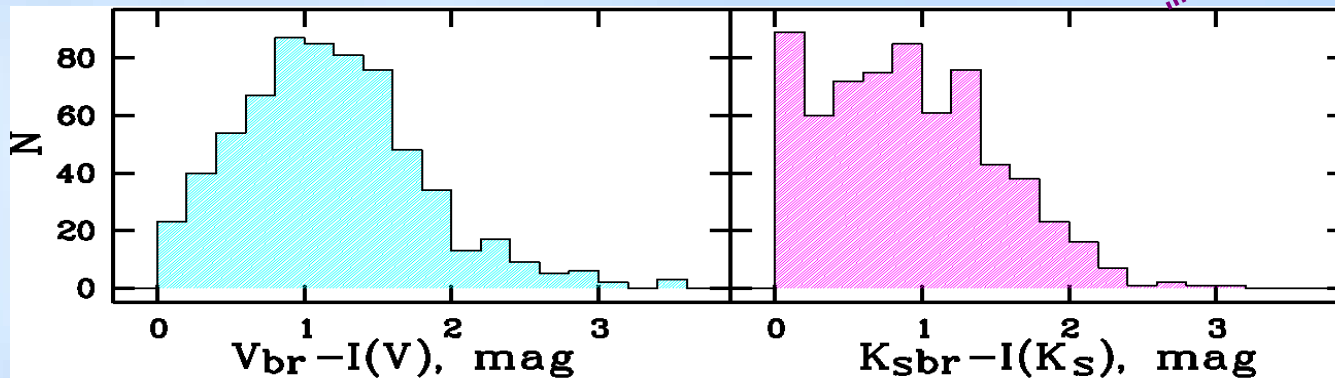
summing up individual  
luminosities of cluster  
members

Output:

integrated magnitudes  
in 5 passbands  
(B,V,J,H,Ks)



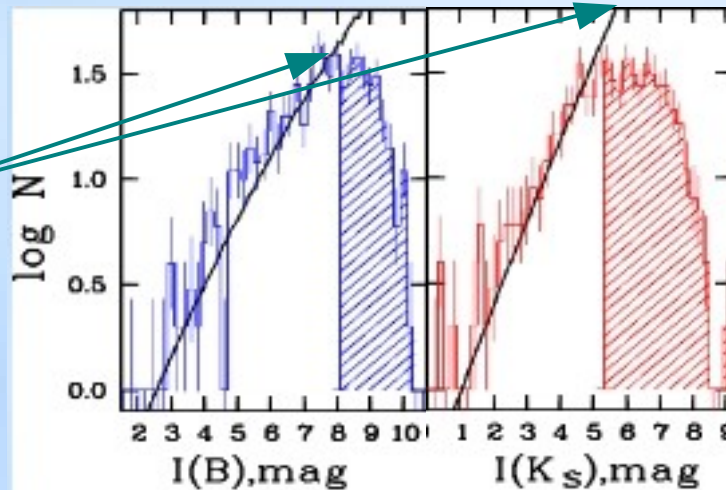
Integrated magnitudes  
of an open cluster  
are defined by the 1-3  
brightest members



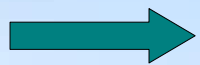
# Luminosity Function of Galactic Open Clusters (1)

## (a) Completeness of the cluster sample

cluster count model



Compl.mag	N clusters
B = 8.1	405
V = 7.7	406
J = 6.1	340
H = 5.3	255
Ks = 5.3	272



Magnitude limited sample of open clusters

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## (b) Absolute integrated magnitudes

App. integrated mag.,  
distance,  
reddening



Absolute integrated magnitude,  
intrinsic integrated colours

# Luminosity Function of Galactic Open Clusters (2)

## Cluster Present Day Luminosity Function (CPDLF)

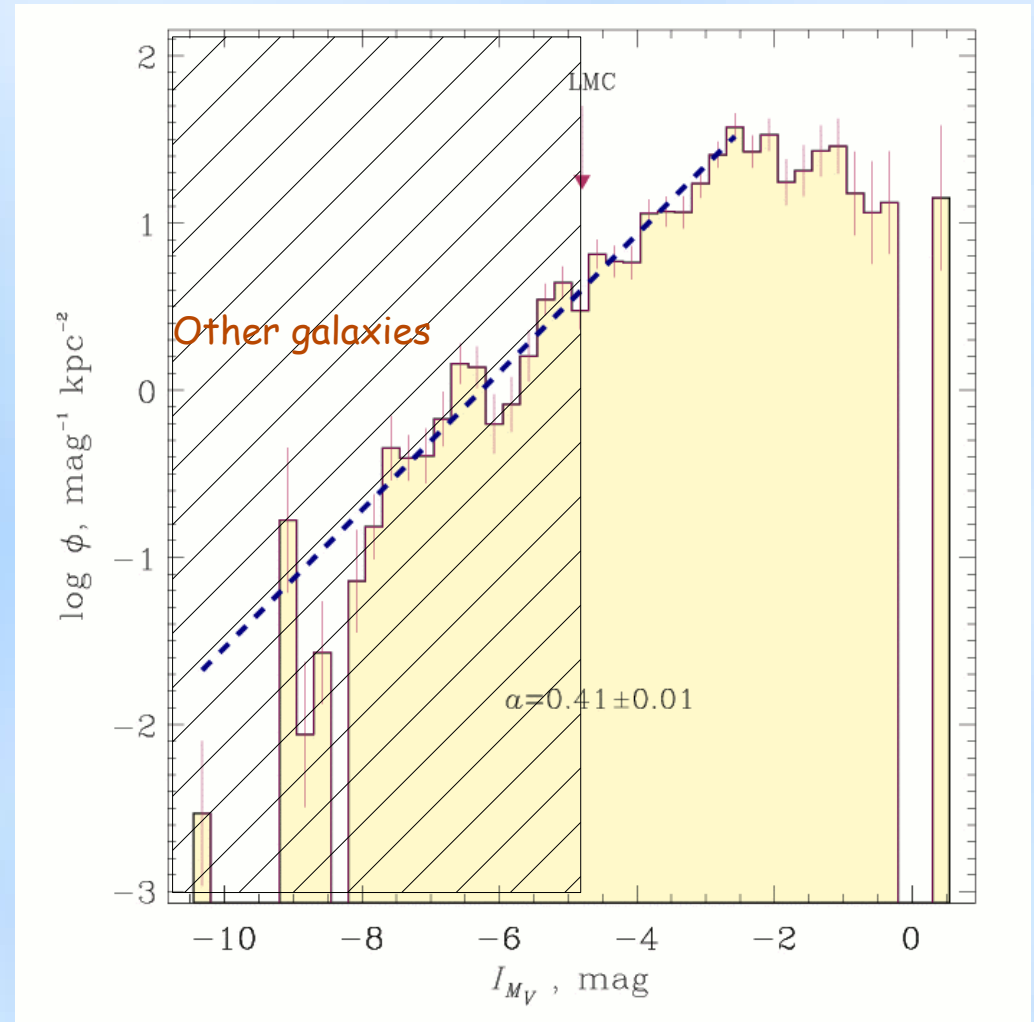
$$\phi(I_{M_V}) = \frac{1}{\Delta S} \frac{\Delta N}{\Delta I_{M_V}}$$

$$\log \phi = b + a I_{M_V}$$

$$a = 0.41 \pm 0.01$$

In **other** galaxies  
(usually with active SF and  $I_{M_V} \leq -7$  mag):

$$a \sim 0.4 \dots 0.6$$



The CPDLF in the MW comparable to that in other galaxies,  
but can be observed much deeper (and more reliable) !

# Luminosity Function of Galactic Open Clusters (3)

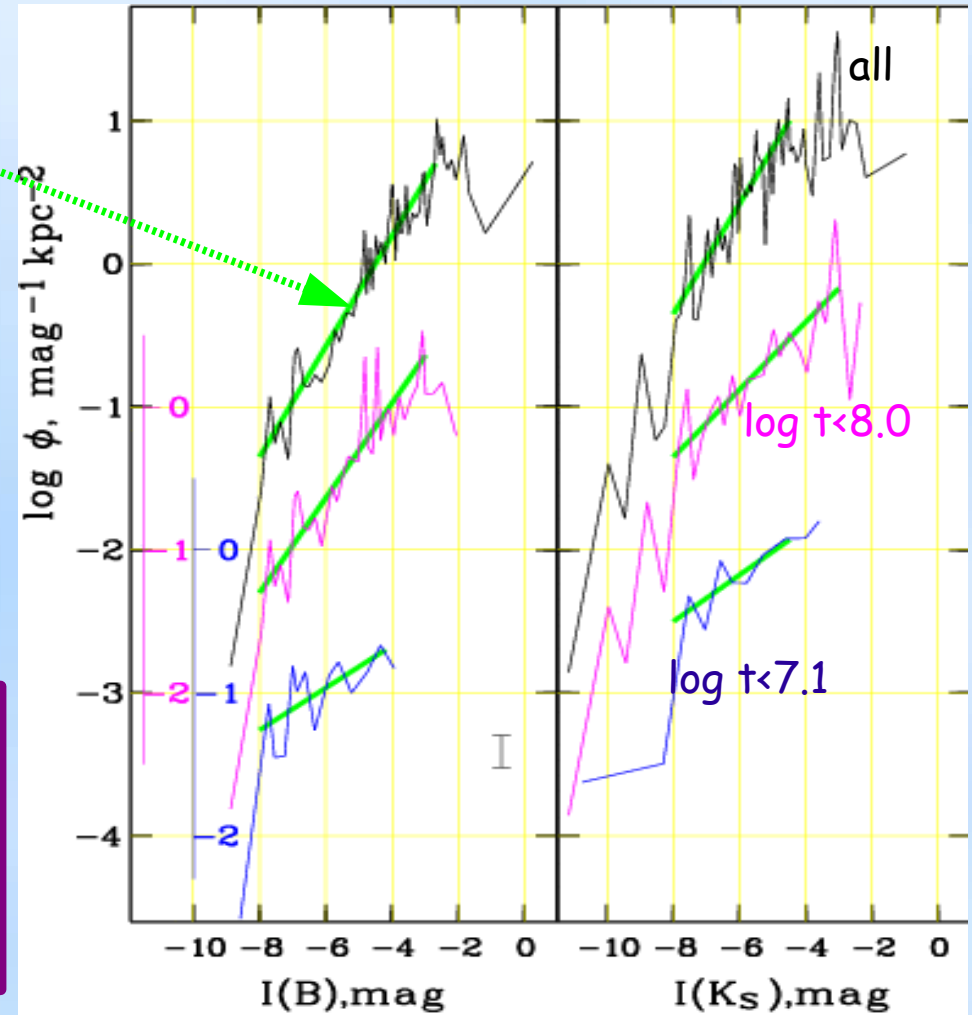
CLF evolution in the optical and NIR

$$\log \phi = p I(M_P) + q.$$

The CLF steepens with age:  
CPDLF  $\neq$  CILF!



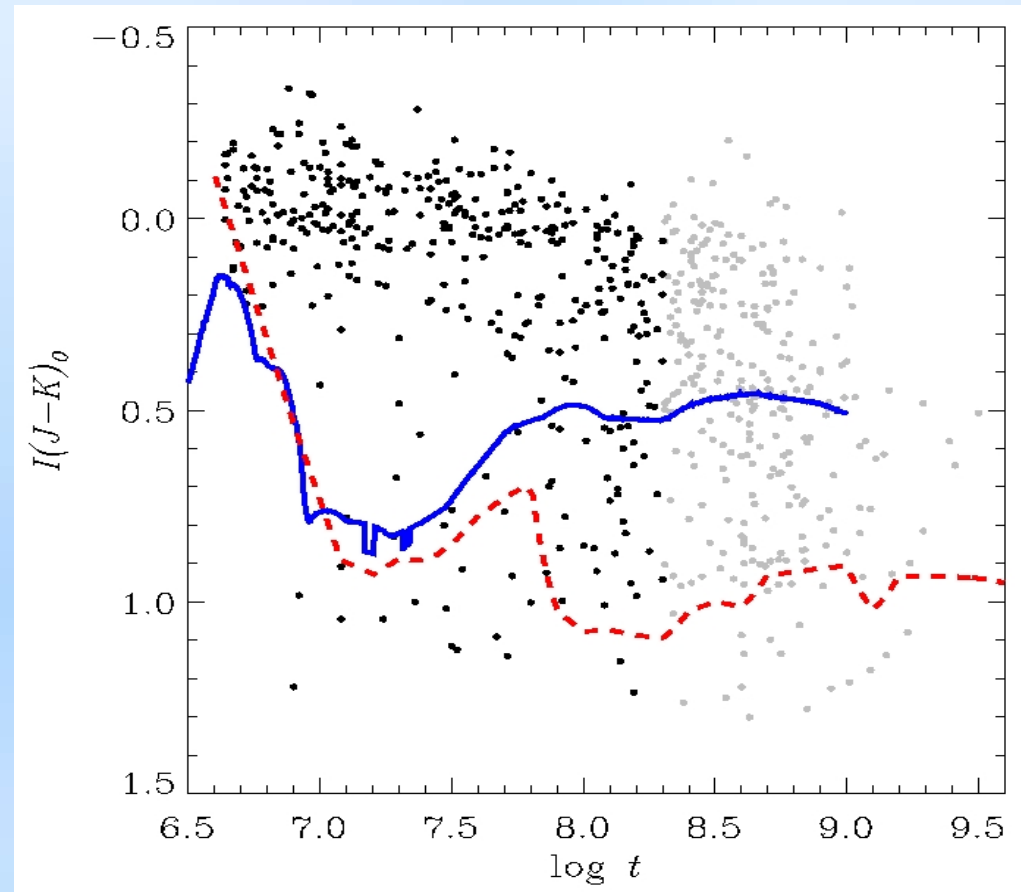
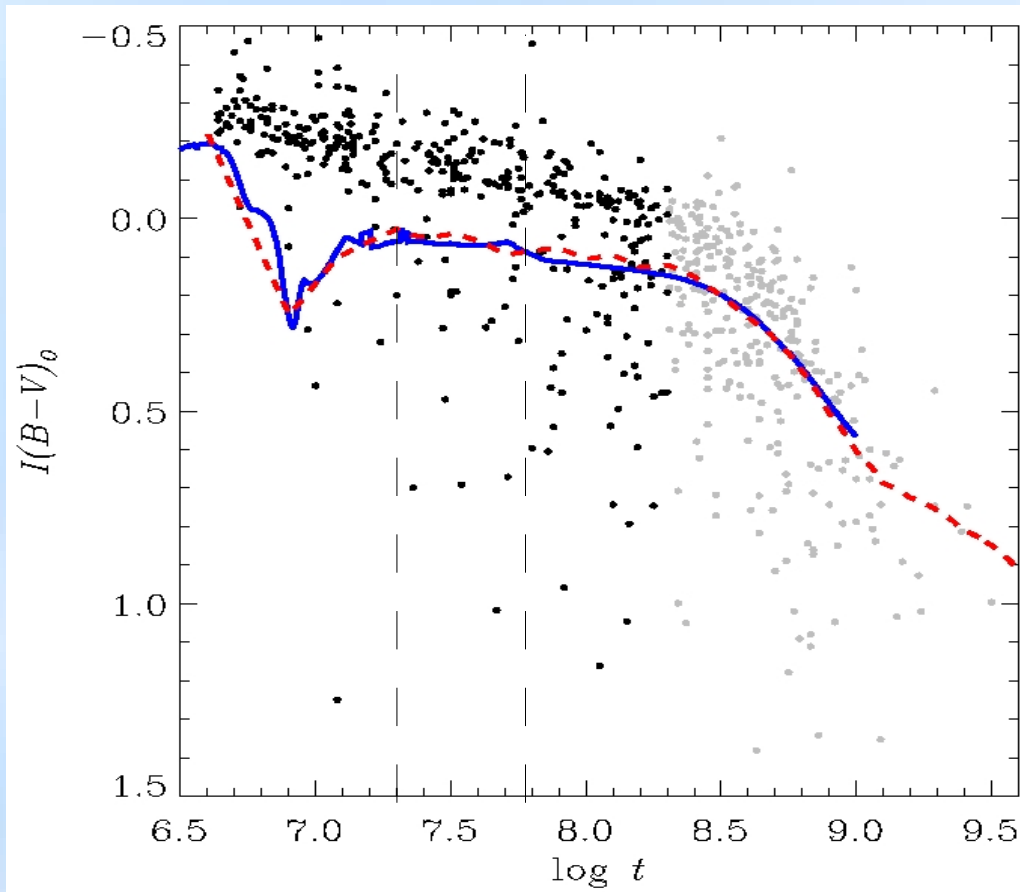
a hint to star cluster evolution:  
«fading» + dynamical mass loss  
resulting in «cluster disruption»



To derive CILF one needs a cluster sample as young as possible!

# Comparison with «standard» SSP models(1)

## Colour distribution of Galactic open clusters



Evolutionary  
synthesis models:  
(Simple Stellar Population)

### Starburst 99

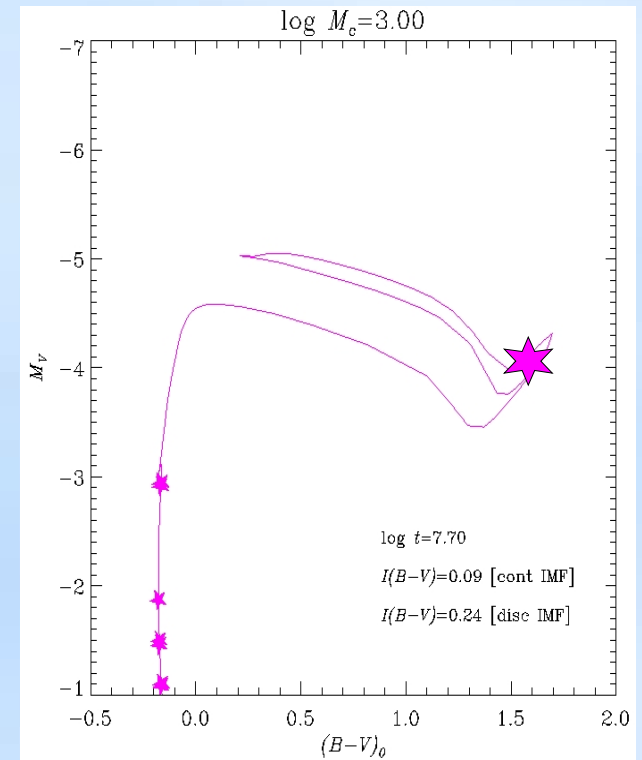
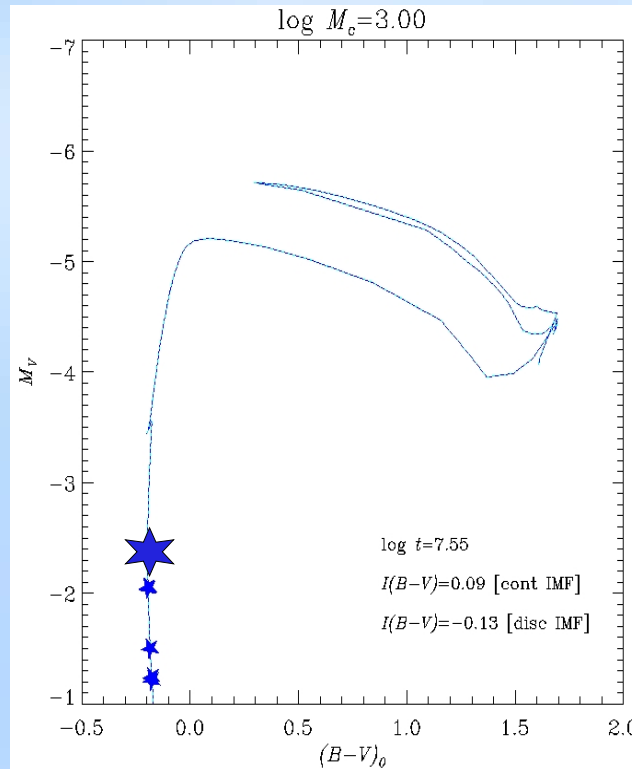
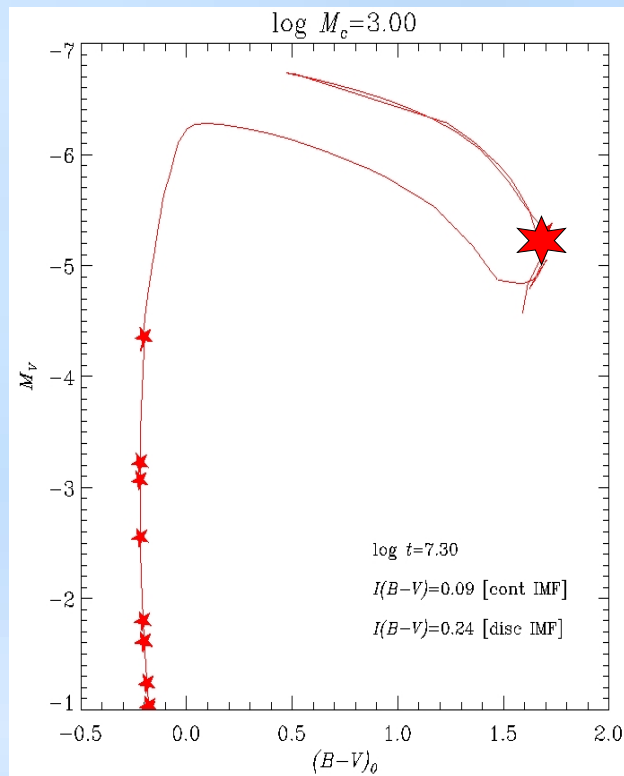
(Vazquez & Leitherer  
2005, ApJ 621, 695)

### Galev

(Anders & Fritze-v.Alvensleben  
2003, A&A 401, 1063)

Why do **SSP**- models not  
fit the observations?

# Comparison with «standard» SSP models(2)



$\Delta=(B-V)_d - (B-V)_s \rightarrow +0.15\text{mag}$

$\rightarrow -0.22\text{mag}$

$\rightarrow +0.15\text{mag}$

Main reason for the «observations-model-conflict»: discreteness of the real IMF in typical open clusters (small number statistics in OC)

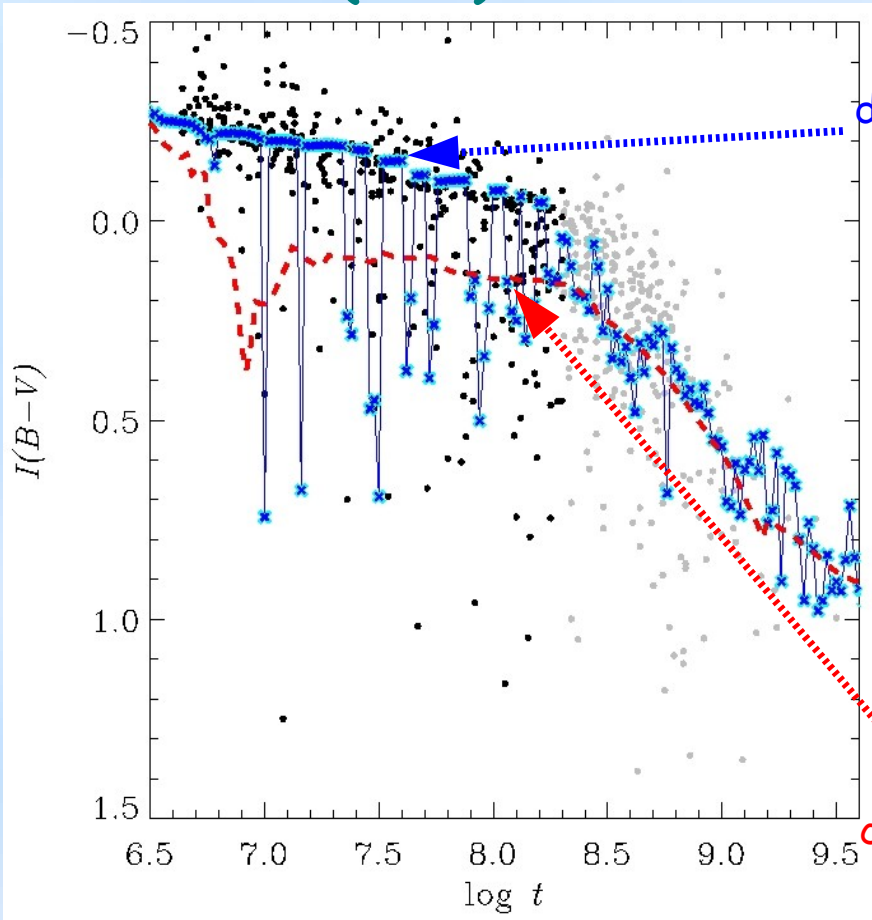


**«Discrete» SSPmodel:**

- Padova isochrones
- Salpeter IMF
- Monte-Carlo-generated cluster population

# Comparison with «standard» SSP models(3)

$I(B-V)_0$



discrete-IMF SSP

The model

IMF: Salpeter

$\alpha = 2.35$

$m_j = 0.08 m_\odot$

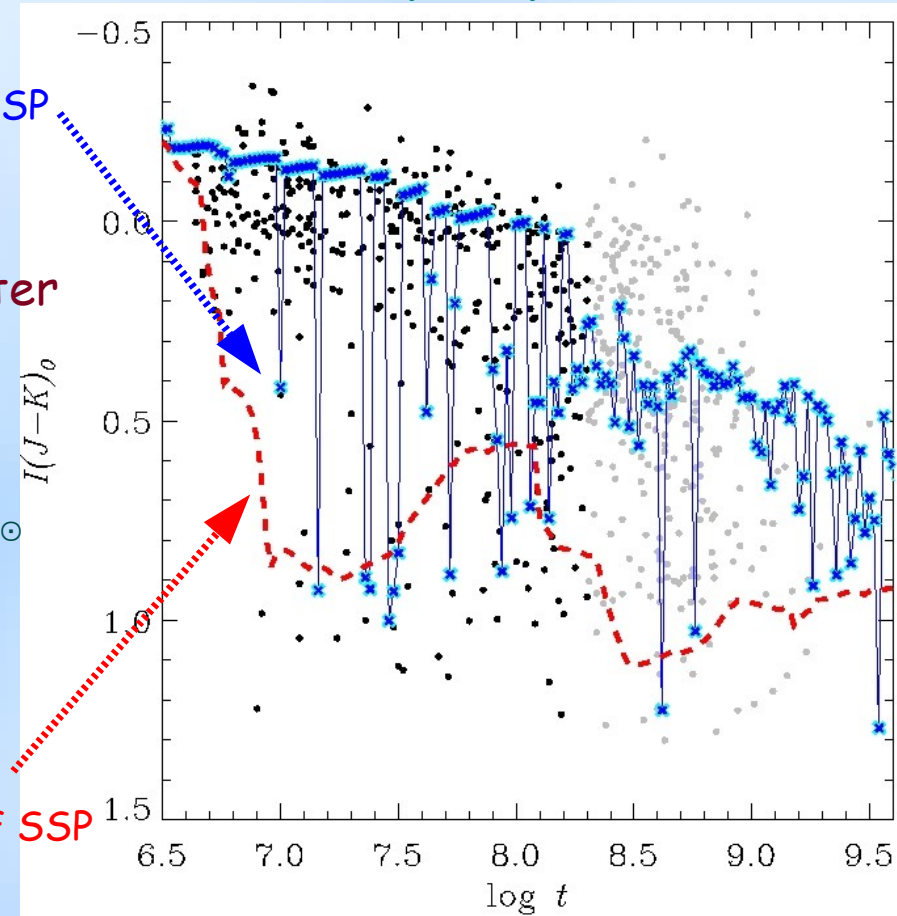
$M_c = 1000 m_\odot$

$Z = 0.02$

«standard»

continuous-IMF SSP

$I(J-K)_0$

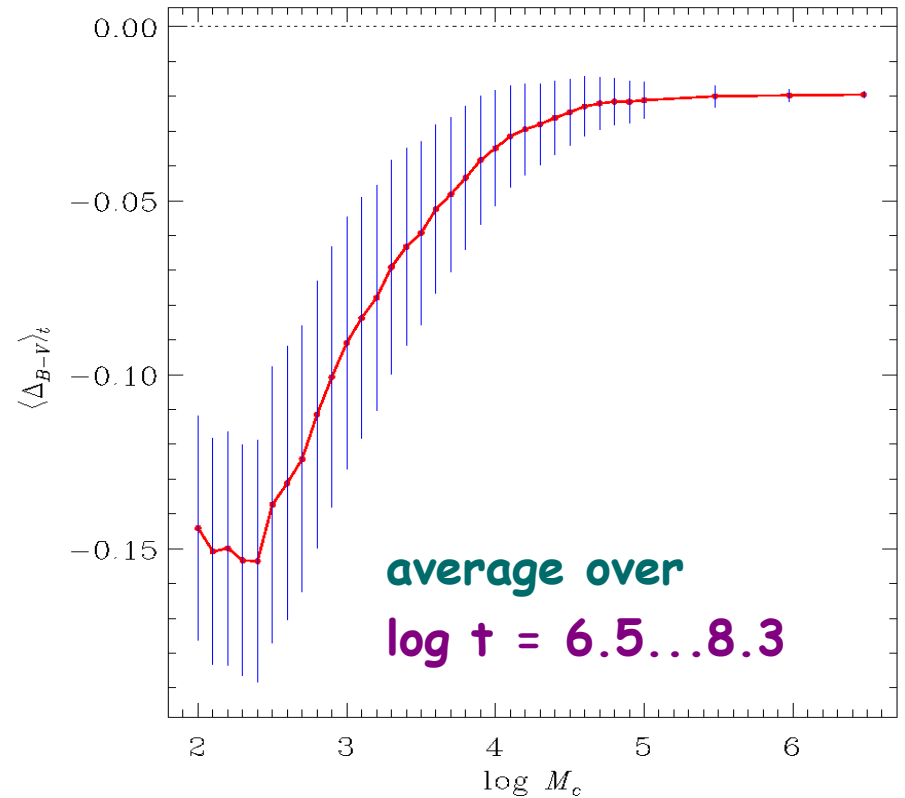
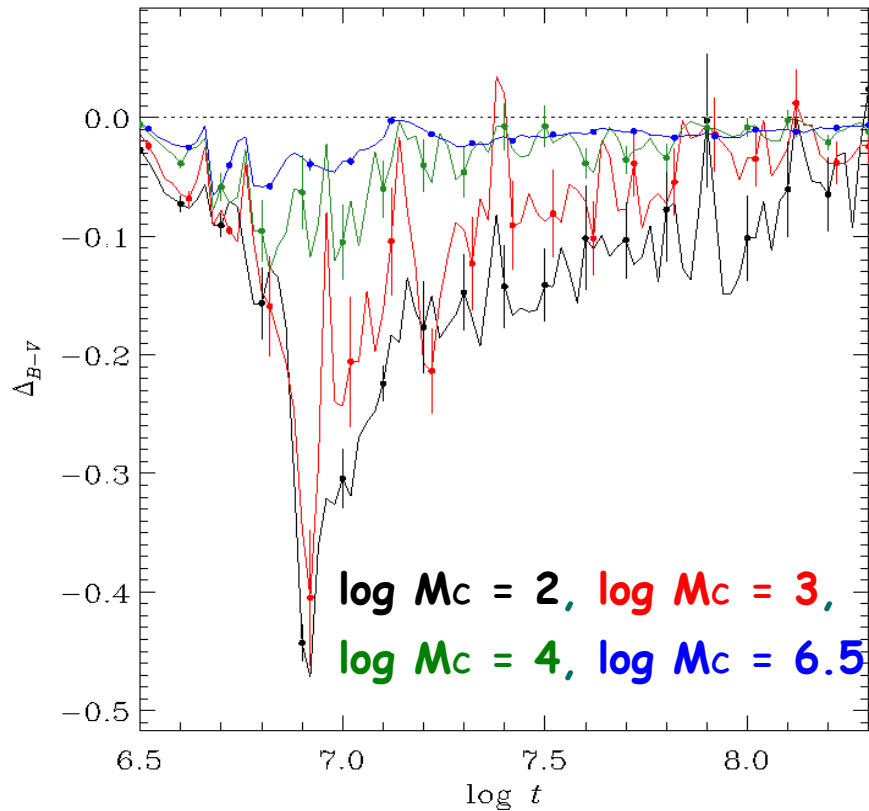


A typical OC ( $M_c < 10^4 m_\odot$ ) is «blue» ( $I(B-V) < 0$ ) during the first 250 Myr of its life, except for a few very short «RG-events» ( $I(B-V) > 0$ )

# Comparison with «standard» SSP models(4)

Monte Carlo simulation  
of the Salpeter IMF

$m_1 = 0.08 m_{\odot}$ ,  $\log M_c = 2, \dots 6.5$ ,  
N=50 realizations for every cluster mass

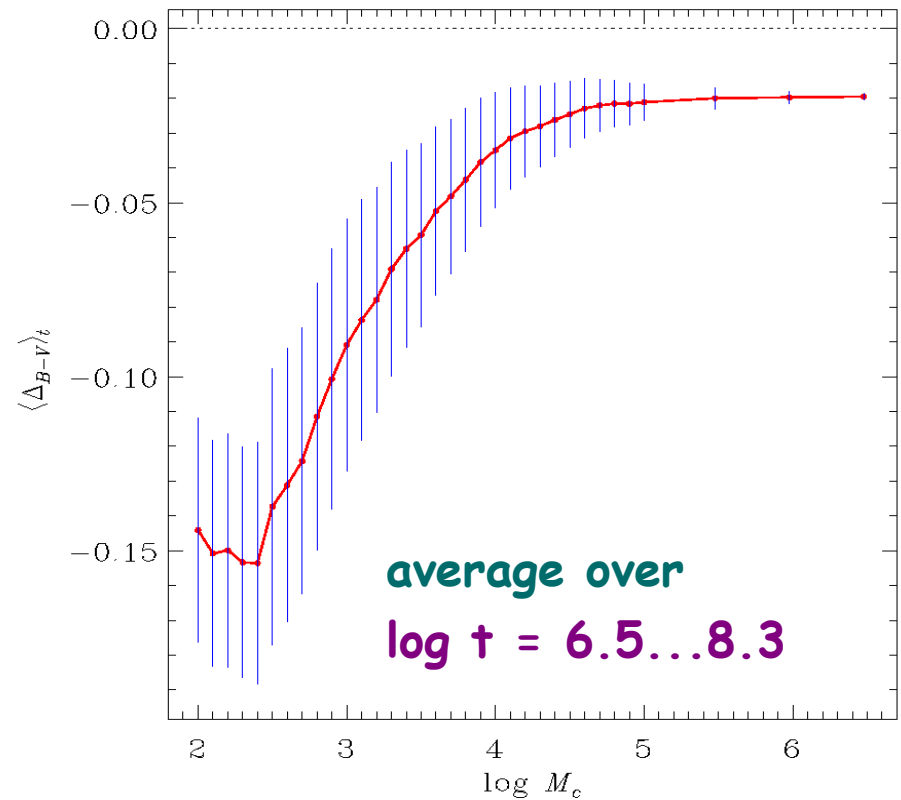
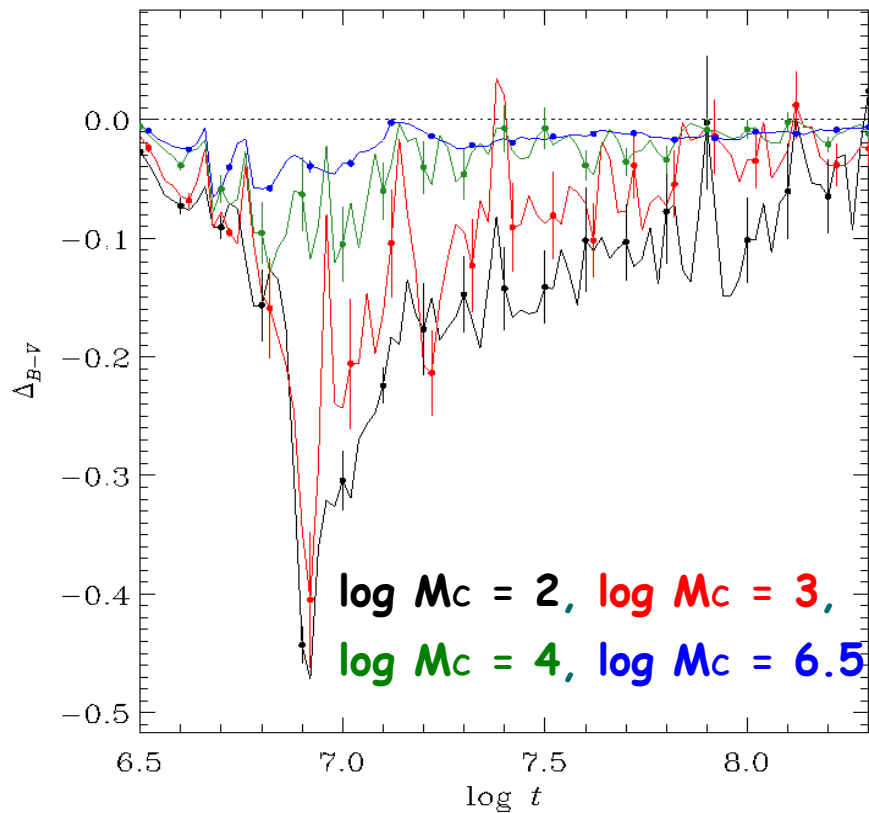


Colour difference  $\Delta_{B-V} = I(B-V)_d - I(B-V)_s$   
between the «discrete» and «standard» models

# Comparison with «standard» SSP models(4)

Monte Carlo simulation  
of the Salpeter IMF

$m_i = 0.08 m_{\odot}$ ,  $\log M_c = 2, \dots 6.5$ ,  
N=50 realizations for every cluster mass



$M_V = -11.89$  and  $V-I = 0.71$ . Because of noise in the distribution of stars, however, this population of clusters appears as a “smear” with  $\sigma_V = 0.08$  mag and  $\sigma_{V-I} = 0.07$  mag. This factor becomes extremely important for young clusters with lower masses, in which case the scatter from the distribution of stars becomes much larger than the photometric errors. (Dolphin & Kennicutt, 2002)

cf.: from the magnitude limited sample of OCs:  
present  $\langle M_c \rangle = 700 M_{\odot}$   
initial  $\langle M_c \rangle = 4500 M_{\odot}$

# Comparison with «standard» SSP models (5)

## Mass-Luminosity relation for open clusters

$L_c$  ← ..... the brightest (i.e., more massive) cluster members

$M_c$  ← ..... a large number of faint (i.e., low mass) cluster members

Two independent time scales:  
stellar evolution  
(responsible mainly for  $L_c$ ),  
dynamical evolution  
(responsible mainly for  $M_c$ )

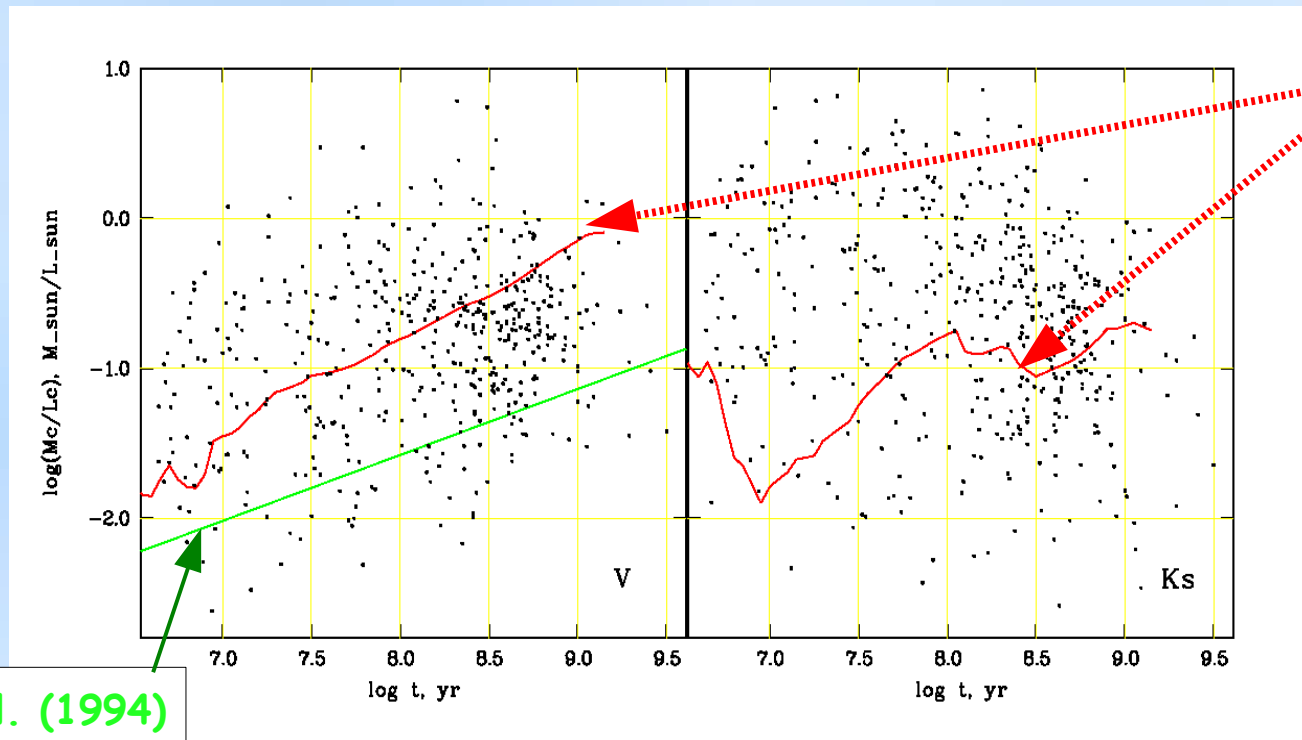
Advantage of our data - **masses** and **luminosities** of OCs are derived **independently** of each other



masses: from the observed **density distribution** of cluster members (tidal masses),

luminosities: from the observed **photometric data** of cluster members

# Comparison with «standard» SSP models (6)



Battinelli et al. (1994)

## The model

IMF: Salpeter  
continuous IMF

$\alpha = 2.35$

$m_f = 0.15 m_{\odot}$

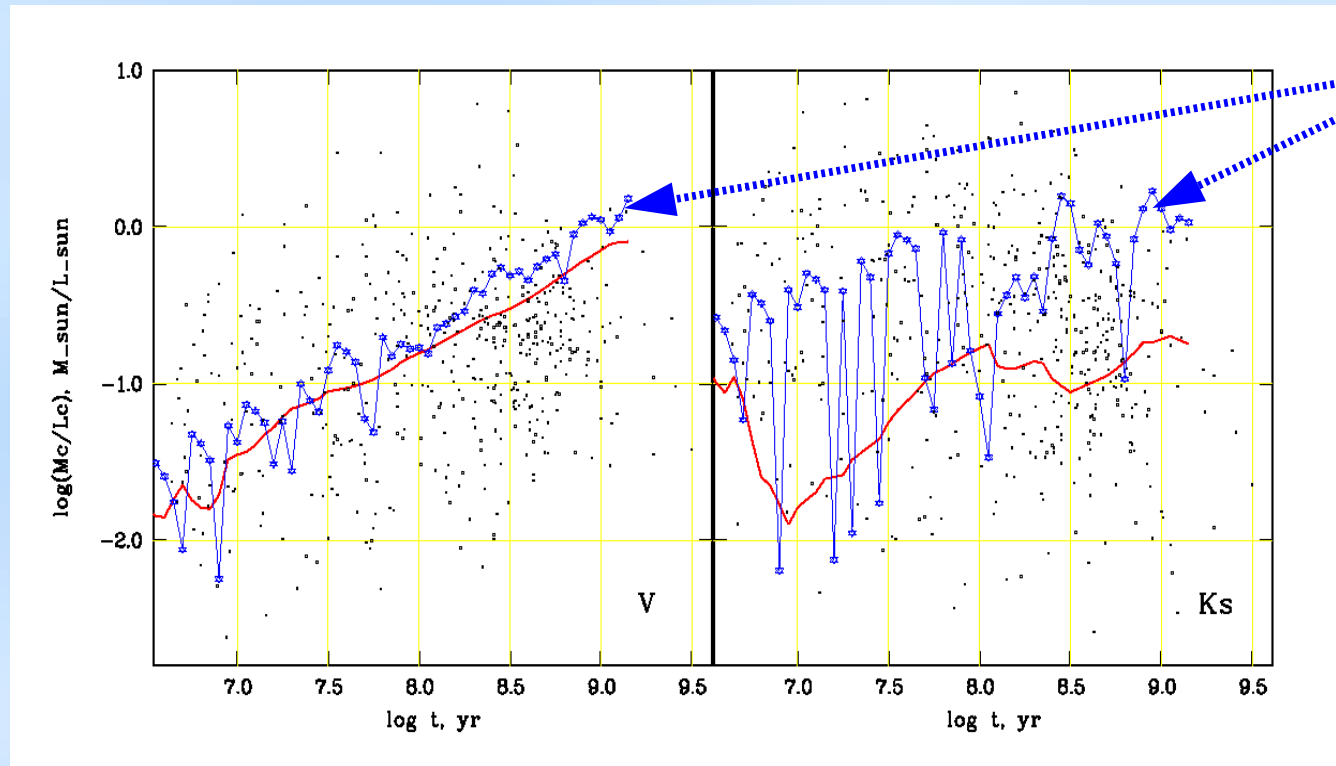
$M_c = 1000 m_{\odot}$

(Mc/Lc:  
independent of  $M_c$ )

## Weak dependence and large spread:

- uncertainties in the input data
- intrinsic spread due to IMF-discreteness and different evolutionary status of clusters
- «other» parameters not taken into account by SSP models

# Comparison with «standard» SSP models (7)



## The model

IMF: Salpeter

discrete IMF

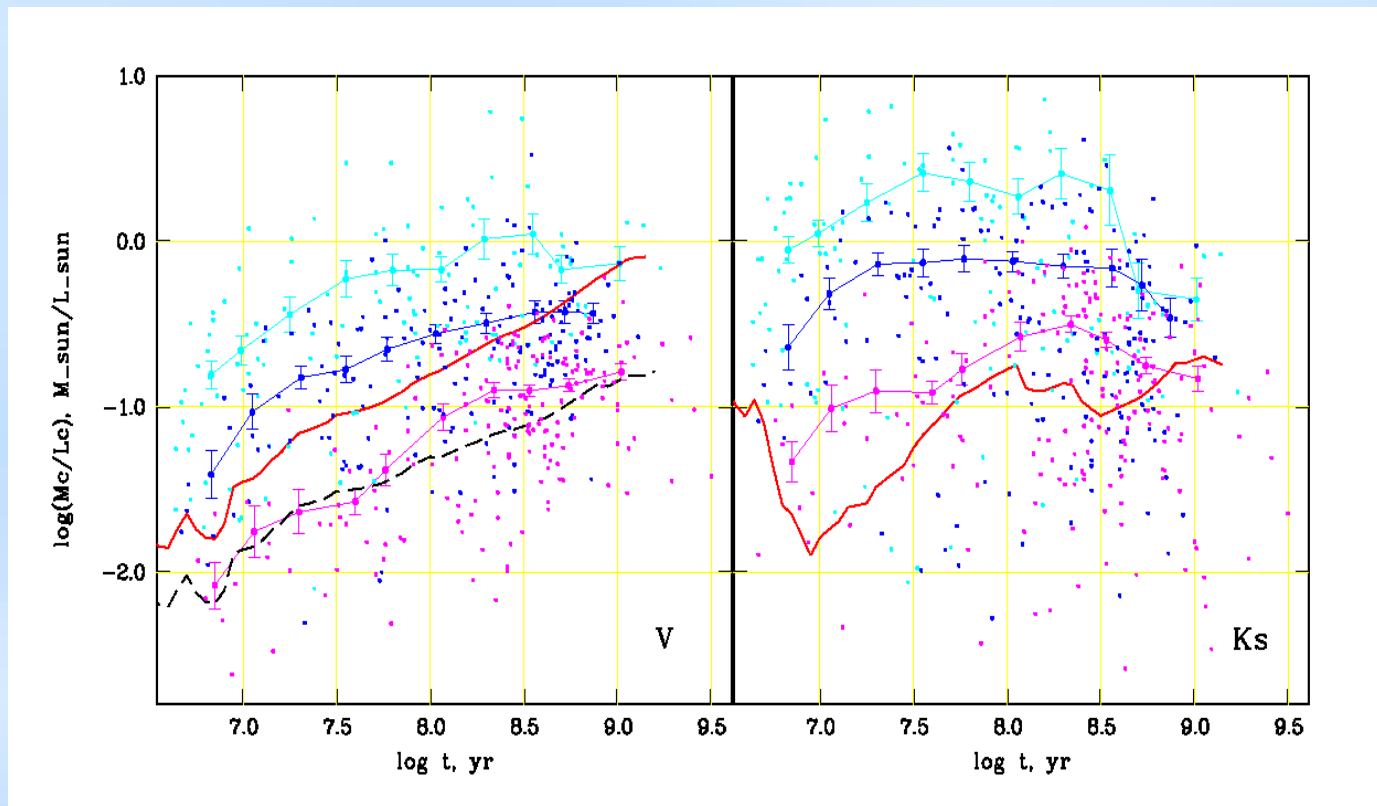
$\alpha = 2.35$

$m_l = 0.15 m_{\odot}$

$M_c = 1000 m_{\odot}$

IMF-discreteness causes spread in  
Mass/Luminosity relation of  
open clusters

# Comparison with «standard» SSP models (8)



Cluster mass (in  $M_{\odot}$ ):

$1000 < M_c < 8000$

$200 < M_c < 1000$

$M_c < 200$

«standard»

SSP model:

— —  $m_i = 1.00 M_{\odot}$

— —  $m_i = 0.15 M_{\odot}$

The observed  $M_c/L_c$  shows a dependence on the cluster mass  $M_c$ :

.....▶ different parameters of the IMF (e.g.,  $m_i$ ) play a role?

Flattening of the observed  $M_c/L_c$  at  $\log t > 8$ :

.....▶ dynamical evolution (i.e., a continuous loss of low mass members) of open clusters?

# Summary

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- based on reliable **membership** information, integrated magnitudes **BVJHK<sub>s</sub>** were determined for 650 Galactic OCs (for 422 OCs (BV) and 650 (JHK<sub>s</sub>) - for the first time);
- with a **magnitude limited sample** of OCs, the **CPDLF** and **CILF** were constructed;
- the **CILF** is flatter than the **CPDLF** → a hint to **star cluster evolution**;
- due to a **discrete-IMF**, the observed **colour/age** relation of Galactic OCs shows large spread and a systematic offset from the «**standard**» **SSP models** (in **B-V**, bias  $> 0.1$  mag for  $M_c < 10^4 m_\odot$ , and even stronger for **JHK<sub>s</sub>** passbands) → **incorrect estimates of cluster ages and masses** based on evolutionary grids of «**standard**» **SSP models**;
- **IMF-discreteness** causes **spread** in the cluster **M/L relation**;
- **M/L relation** seems to be **depending on the cluster mass** → different **parameters of IMF** of clusters of different masses?

# Summary

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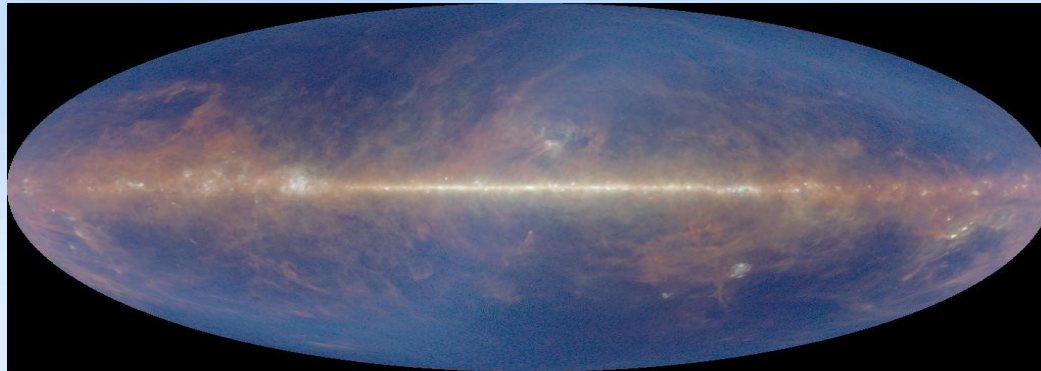
Take care in using integrated magnitudes and colours to determine masses and ages of extragalactic open clusters and with interpretation of the results



# Summary

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Take care in using integrated magnitudes and colours to determine masses and ages of extragalactic open clusters and with interpretation of the results



? The Milky Way ?