Membership analysis in the Gamma Velorum cluster

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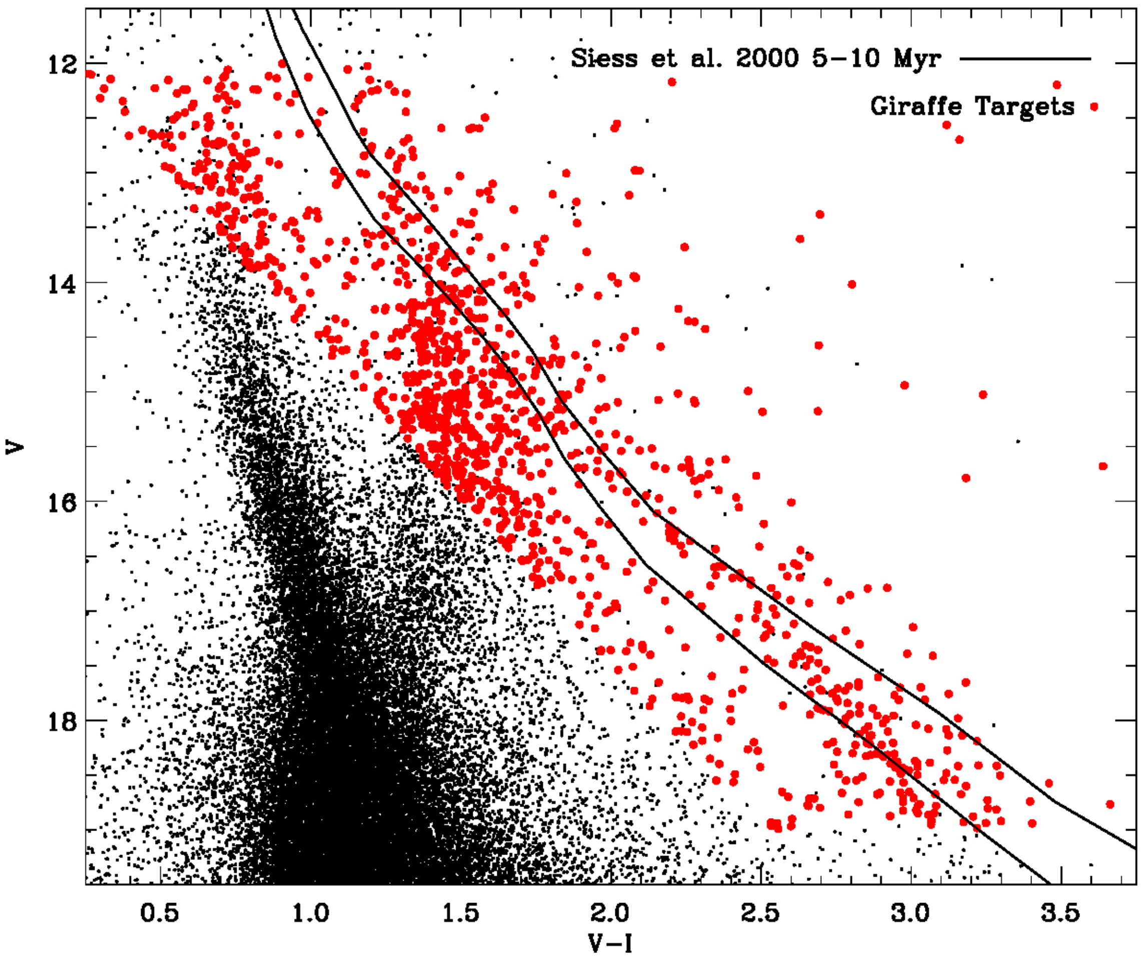
R. Jeffries and the GES Consortium

The Gamma Vel cluster

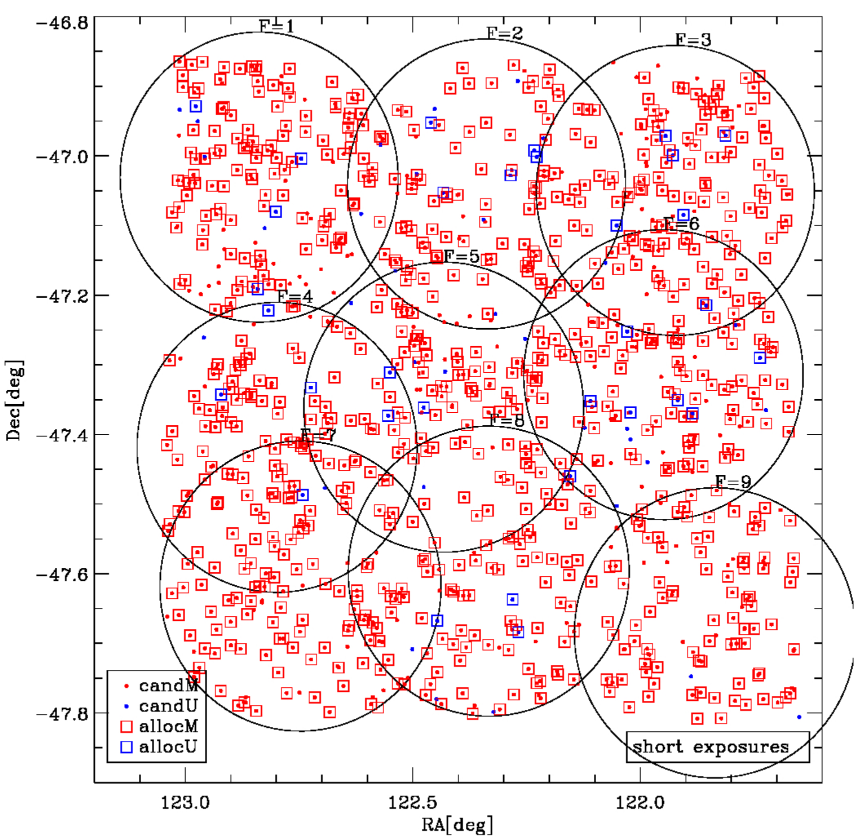
- Age: 5-10 Myr
  - no evidence of ongoing star formation
- Distance: 356±11 pc
  - quite sparse on the sky

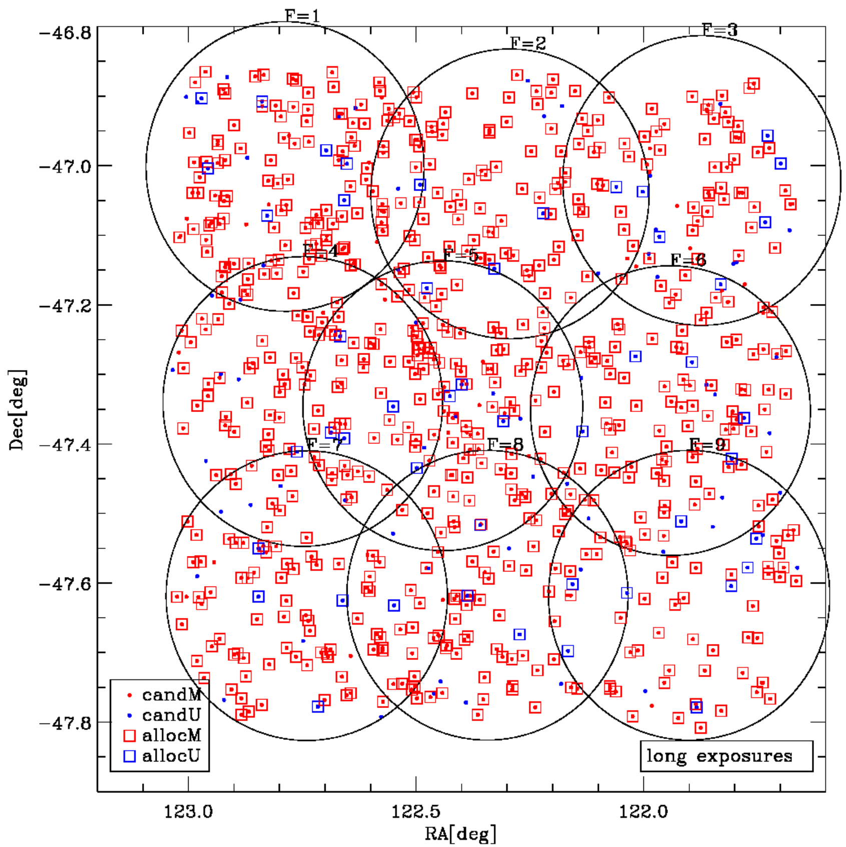
Ideal cluster for stellar evolution and dynamical studies!

1242 Giraffe targets
Many targets outside the cluster region!



GES OBSERVATION STRATEGY



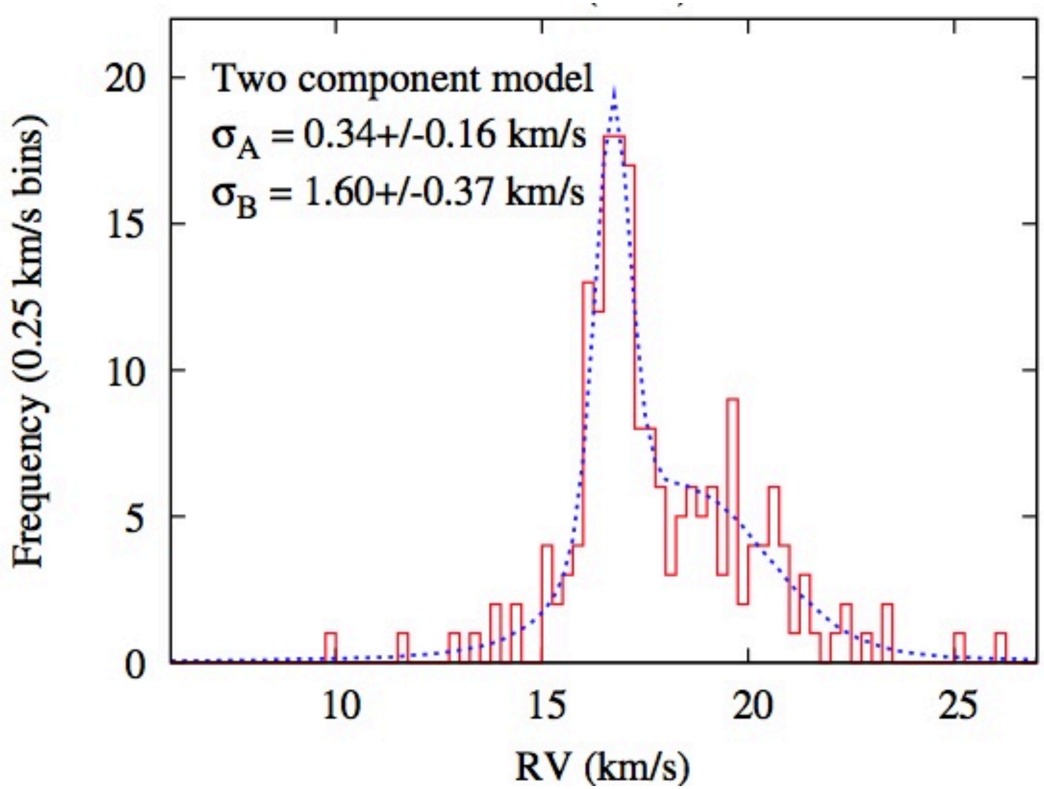


Cluster within a 1 deg x 1 deg field of view →
9+9 FLAMES pointings were required.
Many spare fibres were used to allocate objects around the CMD cluster locus… a large number of contaminants are expected

Context

- The cluster is embedded within the Vela OB2 Association
- The RV cluster distribution suggests the presence of two kinematically distinct BUT SIMILAR populations, A & B

  (Jeffries et al 2014)
- Pop. A & B are also of similar age



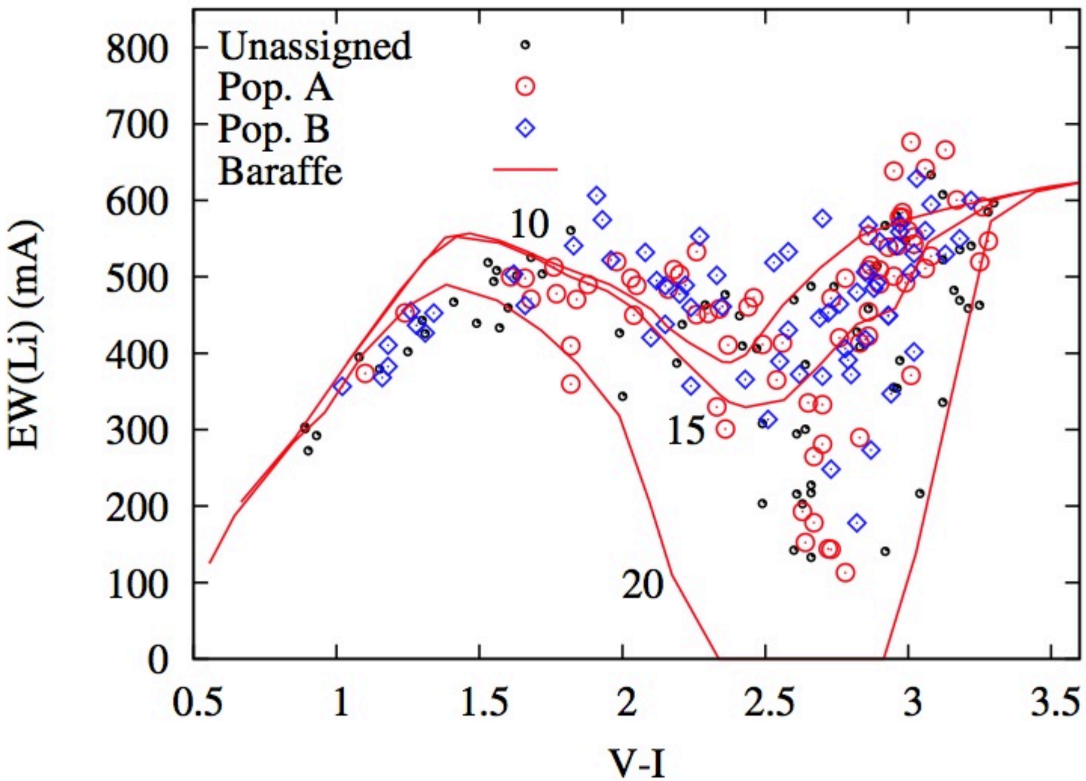
Cluster membership definition

- Radial velocity analysis is the only kinematic membership criterion
- Lithium, Halpha, X-rays are indicators of youth

Pop. A and B are similar in their motion and in age
-> available membership criteria do not allow us to distinguish them

In this work "cluster members" belong to either Pop. A & B

EXAMPLE:



Adopted cluster membership criteria

- PHOTOMETRIC CRITERIA:
- Color-magnitude diagram position (P)
• X-ray detection (X)

- SPECTROSCOPIC CRITERIA:
• Radial velocity (R)
• EW(Li) (L)
• Hα core index (A) (Damiani et al. 2014)
• ϒ gravity index (G) (Damiani et al. 2014)

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Necessary condition

PHOTOMETRIC CANDIDATES

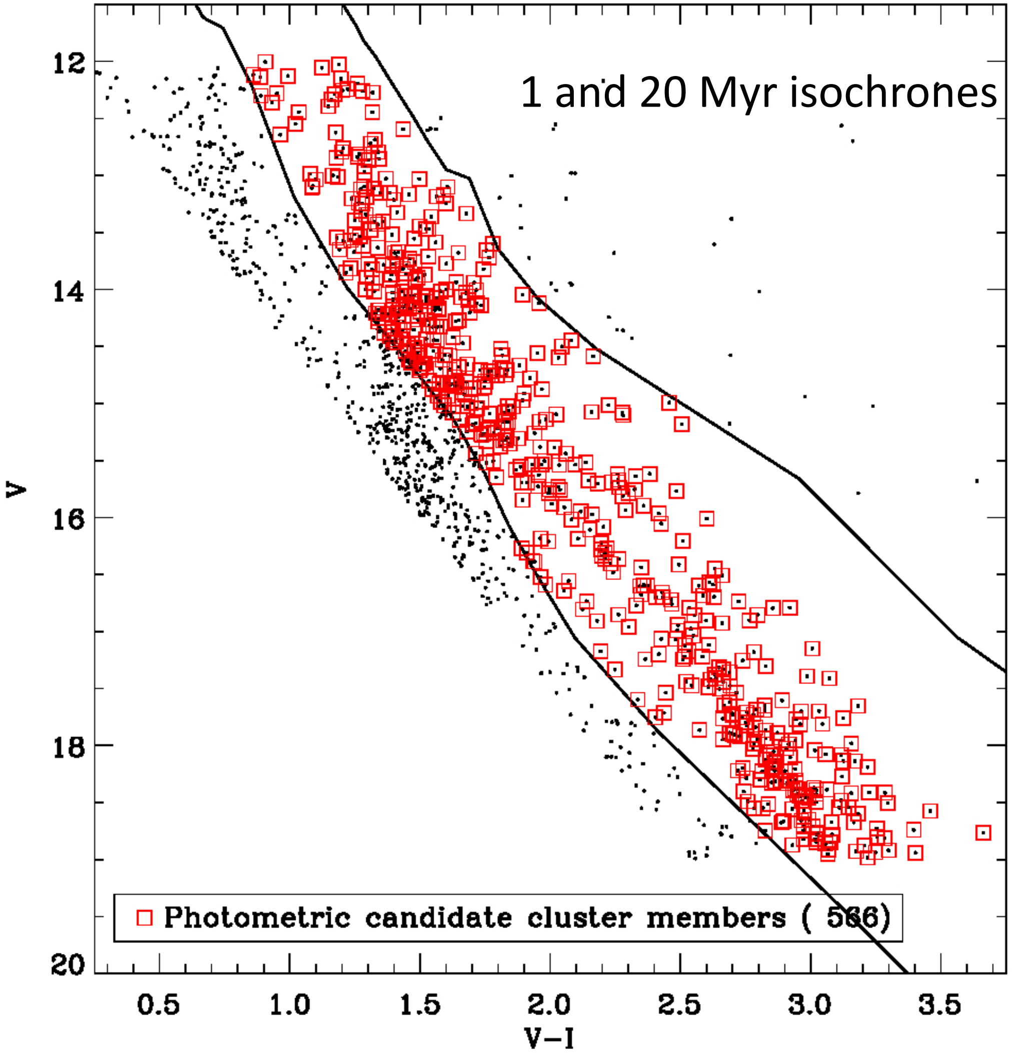
ASSUMPTIONS:

CLUSTER AGE RANGE:
1-20 Myr
(inclusive selection)

Siess et al. 2000 Isochrones

Distance modulus: 7.76
A_V=0.131
(from Jeffries et al. 2009)

586 candidate members

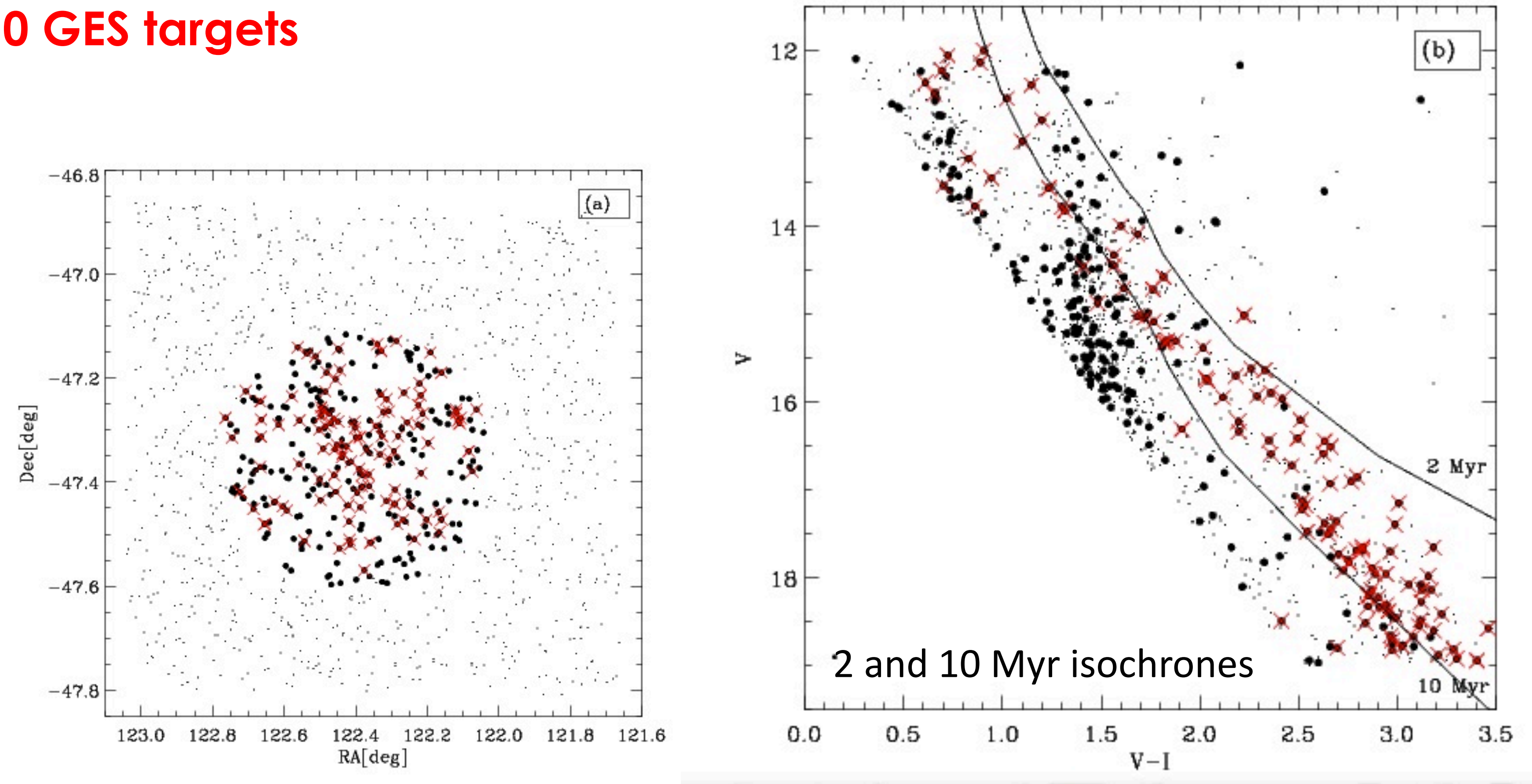


X-RAY CANDIDATES

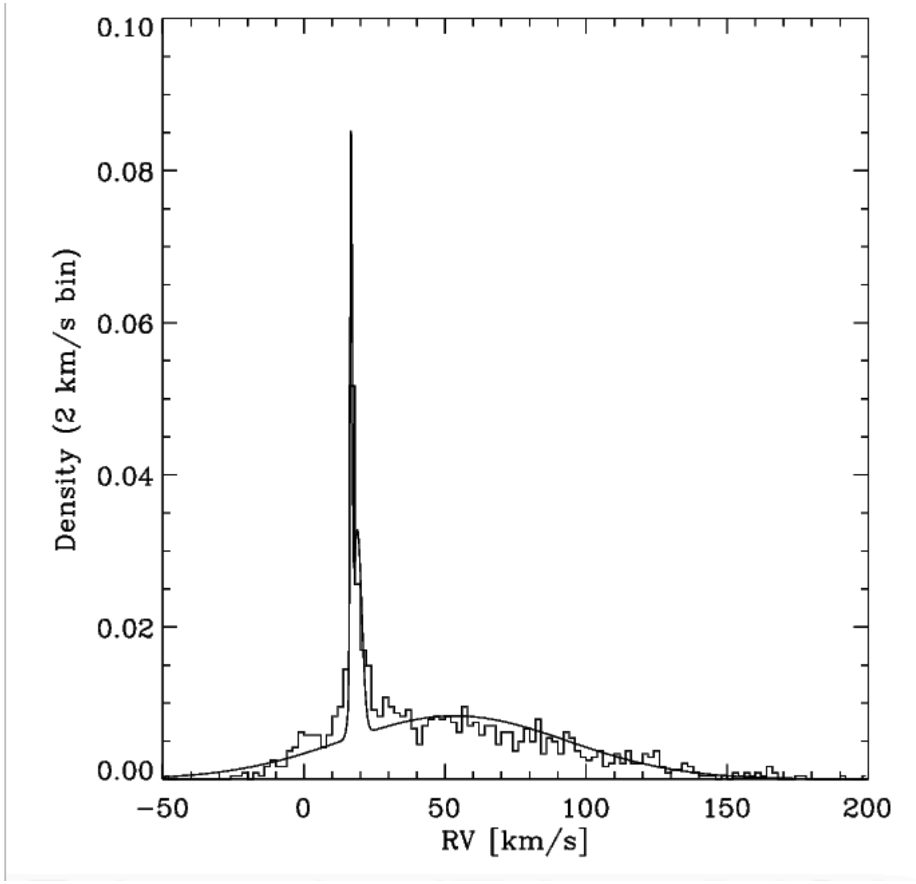
EPIC-XMM obs. FOV ~30 arcmin diameter

(260 X-ray sources, Jeffries et al. 2009)

110 GES targets

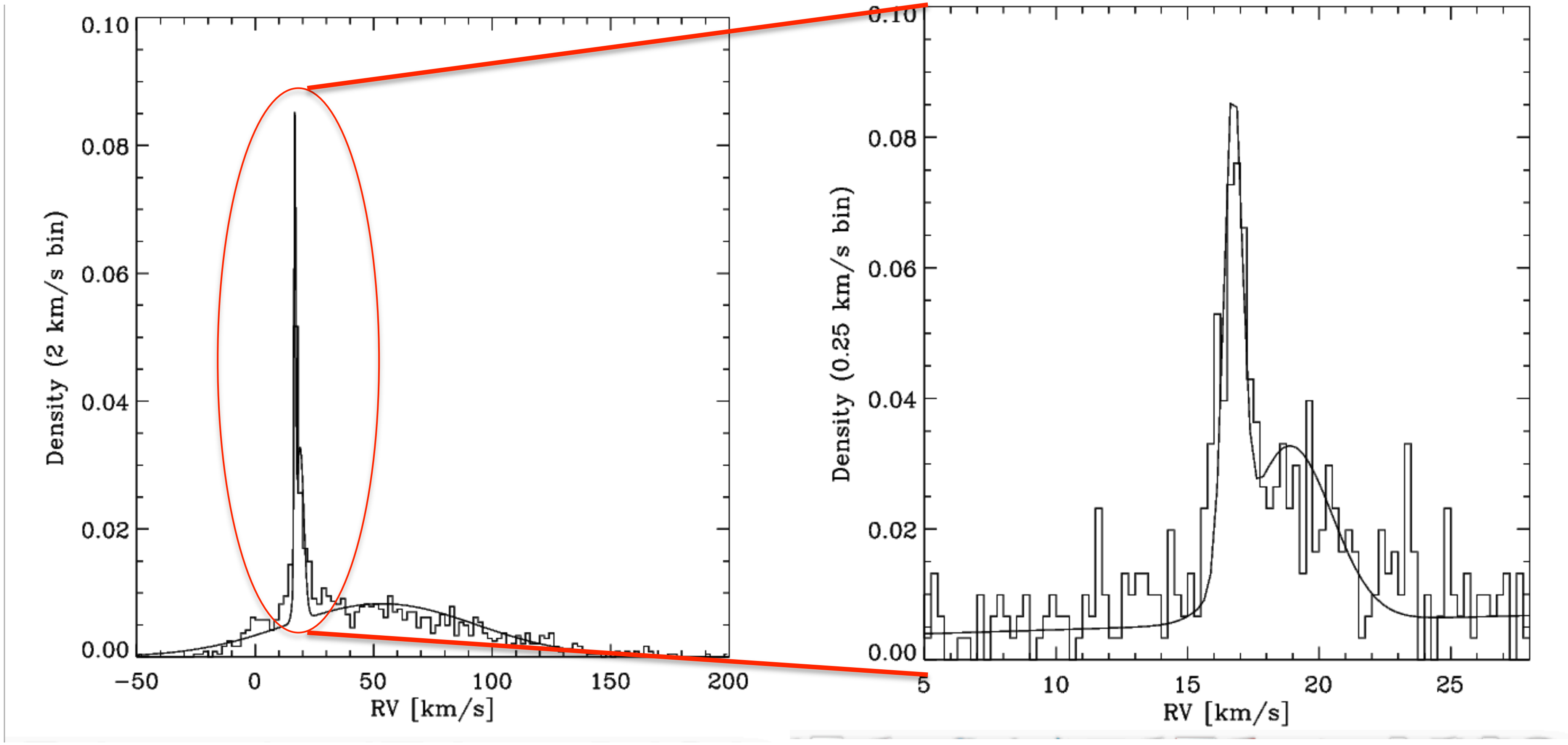


RADIAL VELOCITY MAXIMUM LIKELIHOOD FITTING



We used the entire data set (1202 targets with S/N>5)

RADIAL VELOCITY MAXIMUM LIKELIHOOD FITTING



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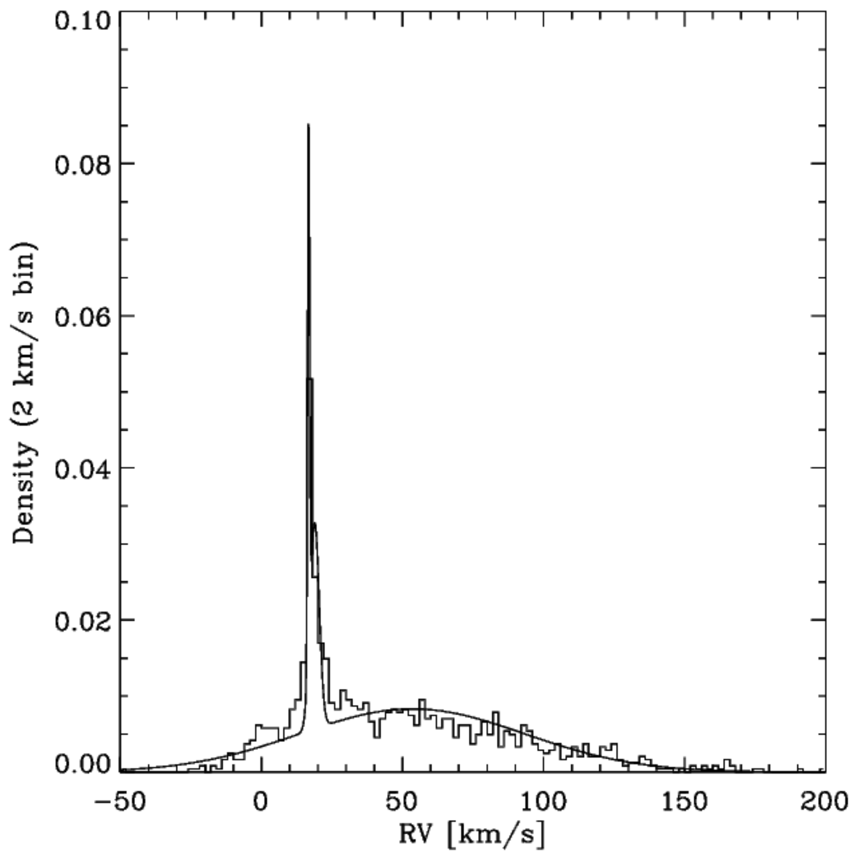
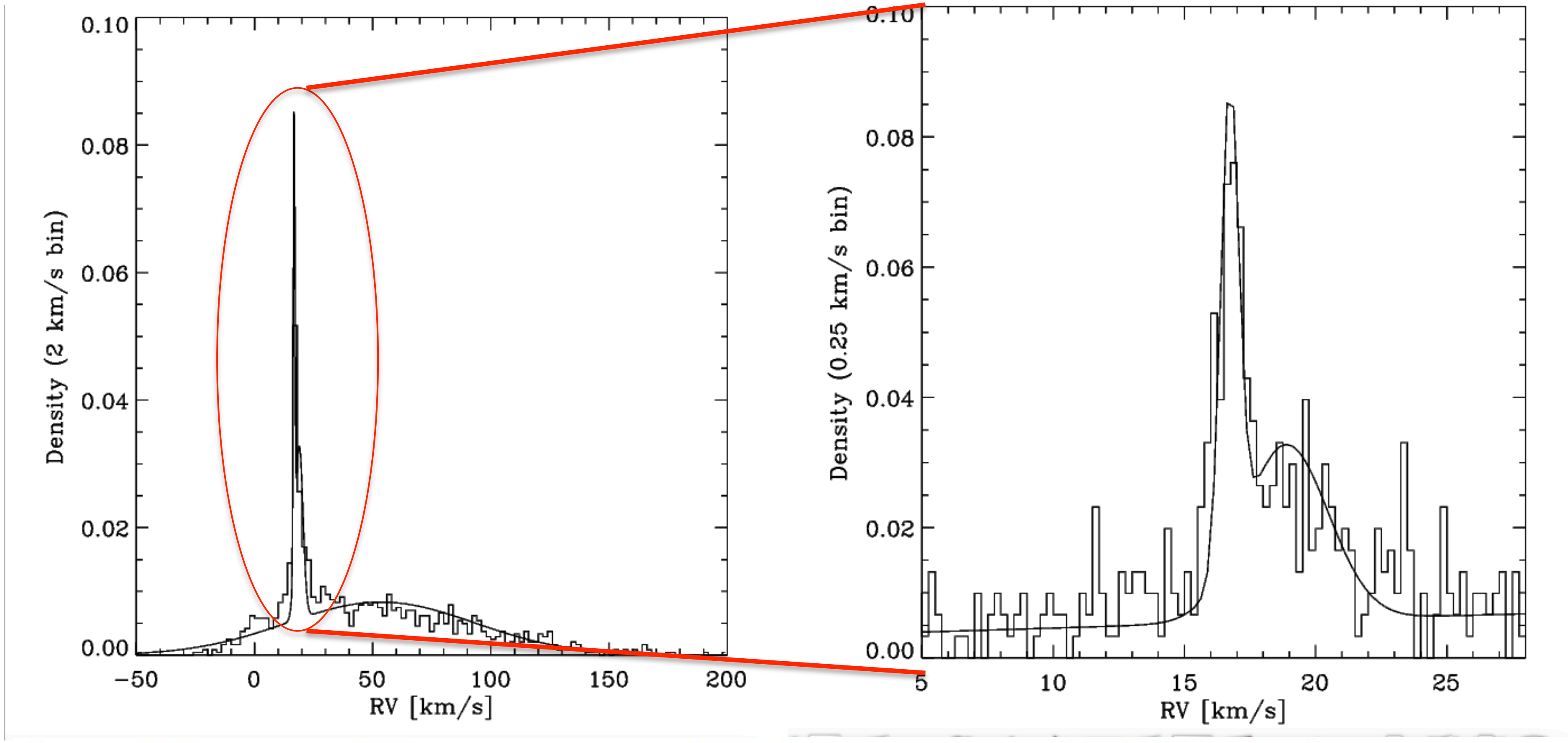


Three gaussian component model with RV mean and RMS for pop. A & B
from Jeffries et al. 2014

$$F(x) = F_A(x) + F_B(x) + F_F(x) =$$

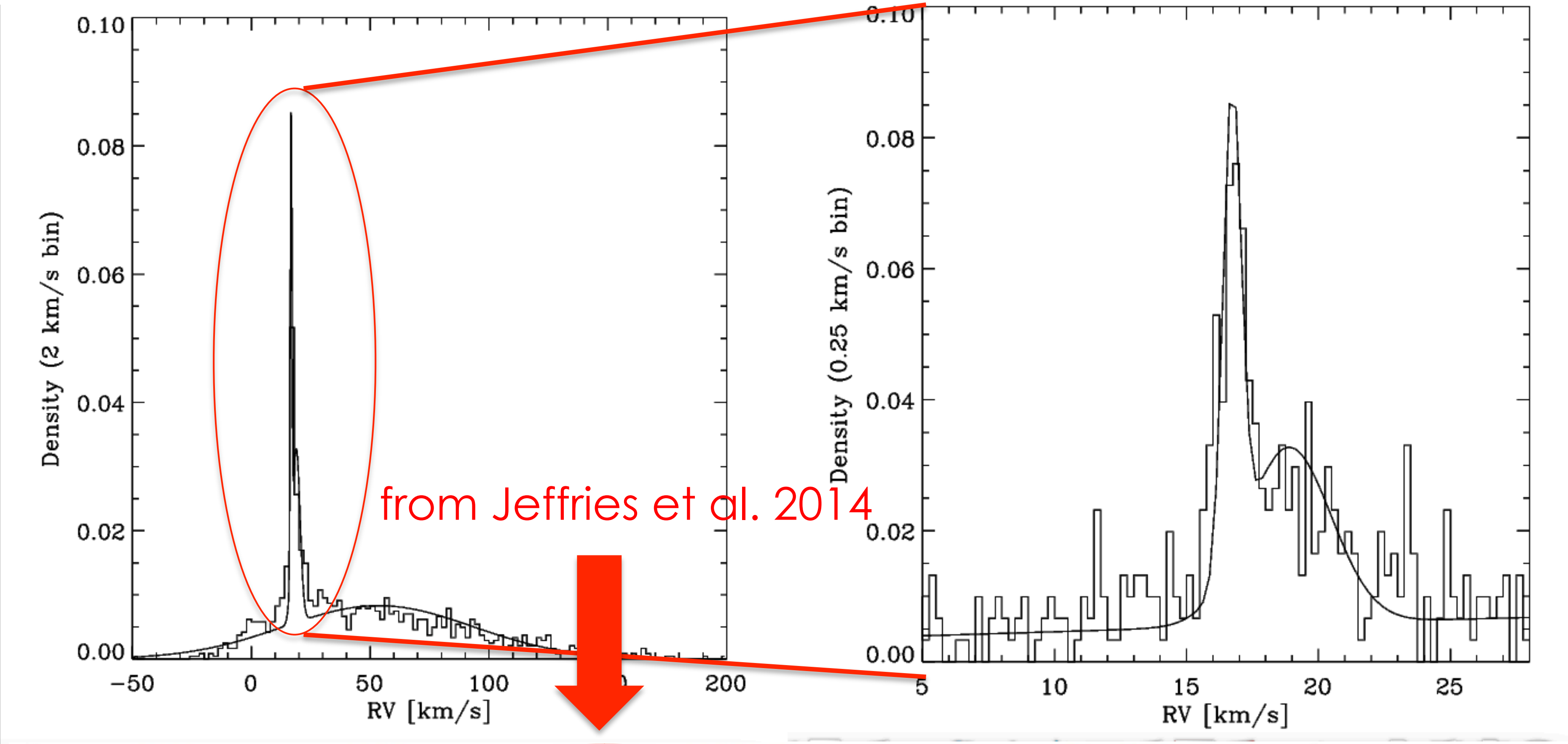
$$= \frac{f_A}{\sigma_A\sqrt{2\pi}} e^{-\frac{(x-\mu_A)^2}{2\sigma_A^2}} + \frac{f_B}{\sigma_B\sqrt{2\pi}} e^{-\frac{(x-\mu_B)^2}{2\sigma_B^2}} + \frac{f_F}{\sigma_F\sqrt{2\pi}} e^{-\frac{(x-\mu_F)^2}{2\sigma_F^2}}$$

RADIAL VELOCITY MAXIMUM LIKELIHOOD FITTING



population	RV mean	RV sigma	fraction
A	μ_A =16.73	σ_A = 0.34	f_A = **0.062± 0.009**
B	μ_B =18.88	σ_B = 1.60	f_B = **0.109± 0.012**
Field	μ_F =**53.45± 1.29**	σ_F =**39.80± 0.89**	f_F = **0.829± 0.015**

RADIAL VELOCITY MAXIMUM LIKELIHOOD FITTING



from Jeffries et al. 2014

population	RV mean	RV sigma	fraction
A	$\mu_A = 16.73$	$\sigma_A = 0.34$	$f_A = \mathbf{0.062 \pm 0.009}$
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Field	$\mu_F = \mathbf{53.45 \pm 1.29}$	$\sigma_F = \mathbf{39.80 \pm 0.89}$	$f_F = \mathbf{0.829 \pm 0.015}$

RADIAL VELOCITY MAXIMUM LIKELIHOOD FITTING

Probability that the *i*th star belongs to pop. A or B:

$$P_{AB,i}=(F_{A,i}+F_{B,i})/F_i$$

$F_{A,i}$, $F_{B,i}$ and F_i are computed from the adopted model at the RV of the *i*th star

325 stars (including 87contaminants) with $P_{AB}>0.003$

(3σ from the RV mean: 12.8<RV<24.9 km/s)

+ **23** SB2 or fast rotators from inspection of the CCF

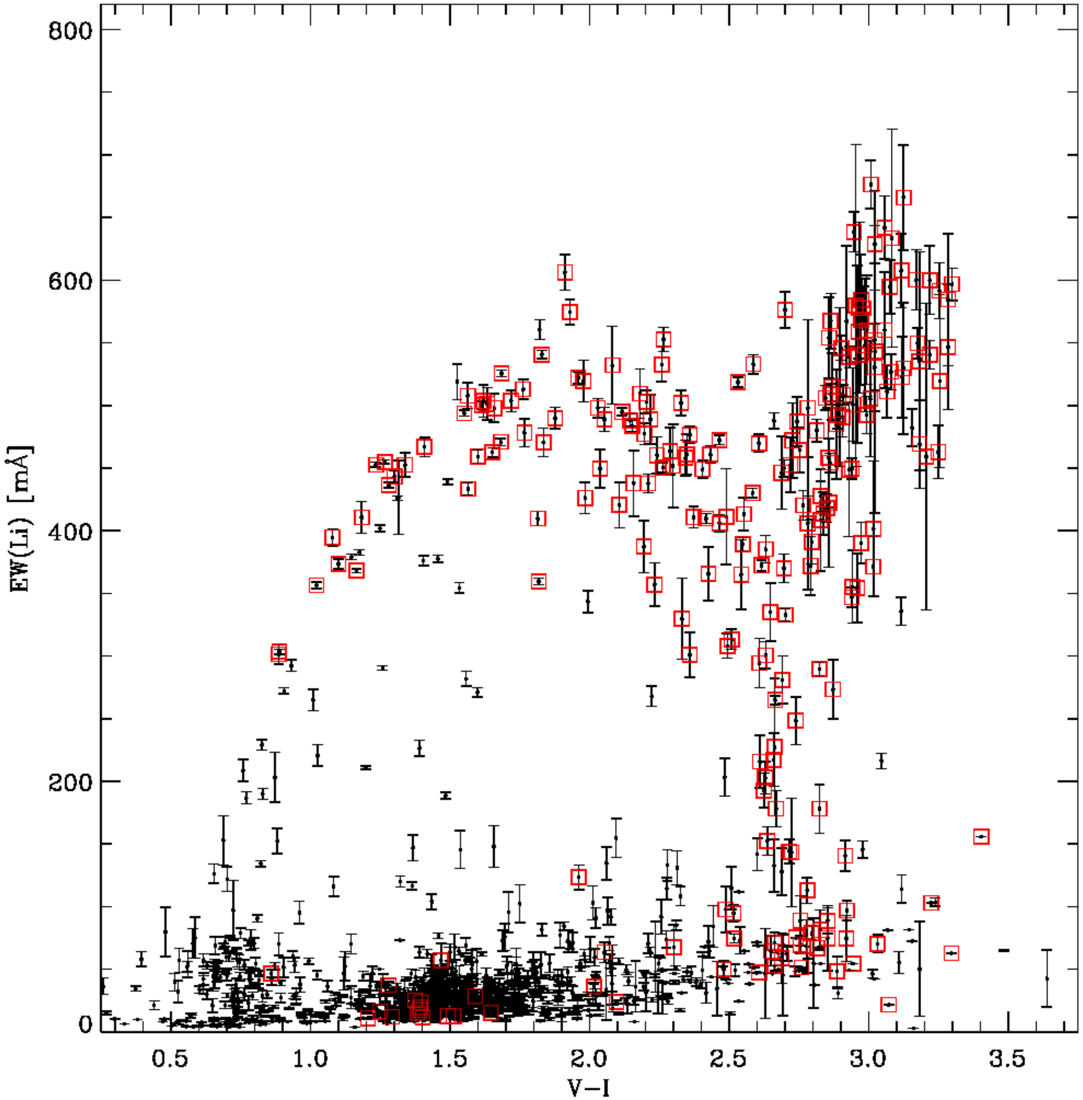
LITHIUM CANDIDATES

STEP 1

DEFINING LOCUS

Reference sample:

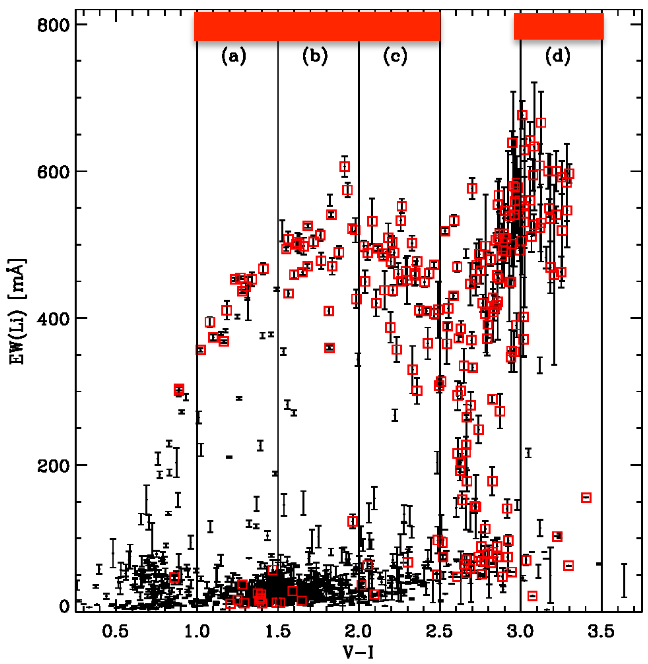
236 photometric & RV candidates (red empty squares)

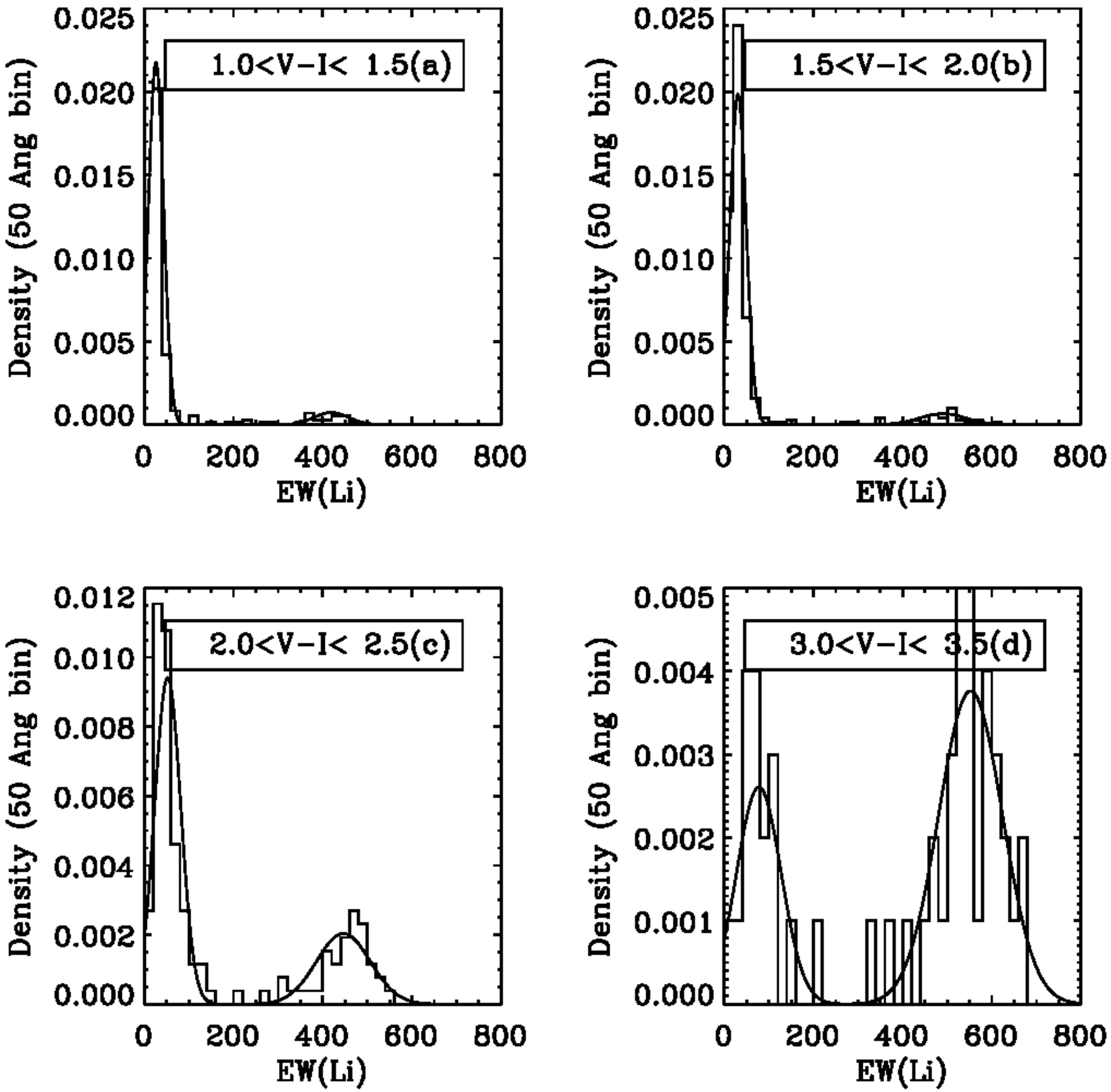


LITHIUM CANDIDATES: FITTING

STEP 2

- Breakdown in four V-I ranges
- maximum likelihood fitting technique -two gaussian components (L_C and L_F)





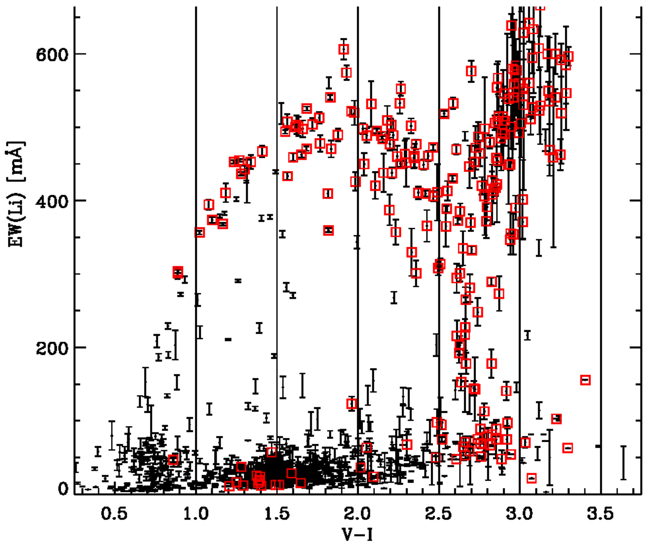
LITHIUM CANDIDATES: PROBABILITIES

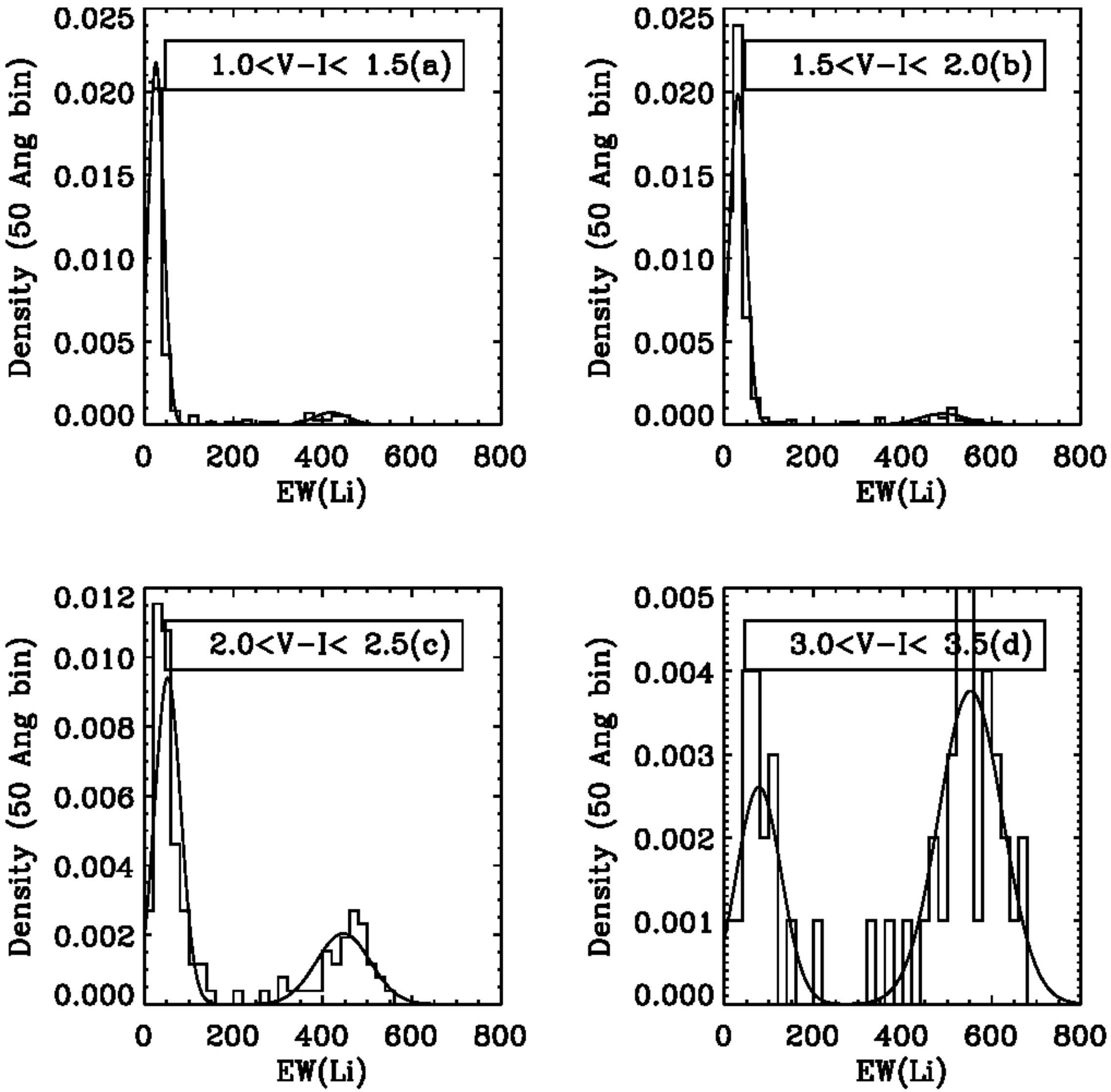
STEP 3

Probability that the *i*th star belongs to the cluster

$P_{C,i} = L_{C,i} / (L_{C,i} + L_{F,i})$

$L_{C,i}$ and $L_{F,i}$ are computed from the adopted model at the EW(Li) of the *i*th star





LITHIUM CANDIDATES: Li GAP

Considering EW(Li)<100 mÅ

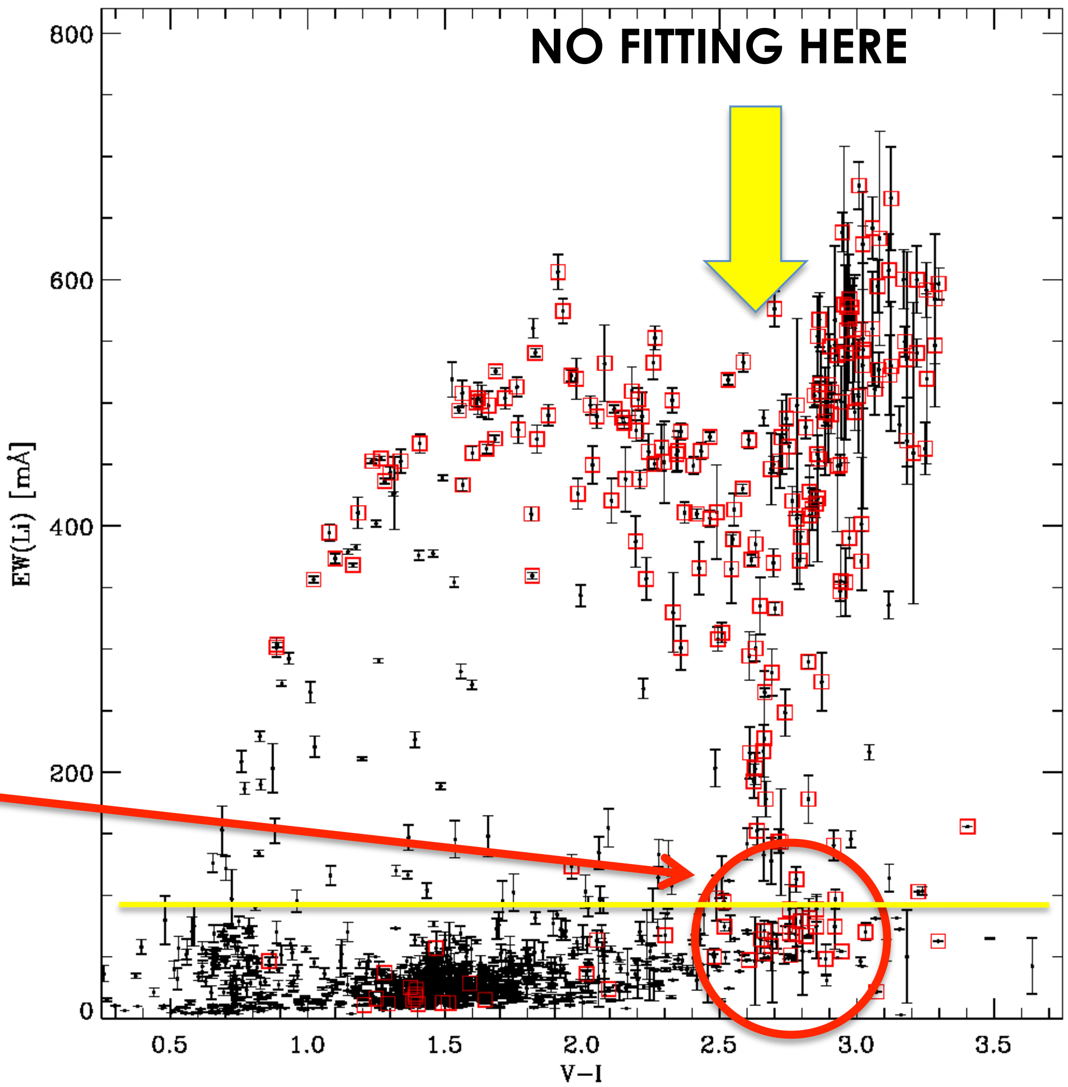
V-I	Candidate fraction
1.0- 1.5	12/327 (4%)
1.5-2.0	3/317 (1%)
2.0-2.5	6/84 (7%)
2.5-3.0	21/50 (42%) excess!
3.0-3.5	3/12 (25%)

1-2.5 21/728 (3%) →

2.5-3.0 0.03*50=1.5 spurious

19.5 ARE EXPECTED TO BE CANDIDATE MEMBERS

TO BE CONFIRMED STAR BY STAR BY OTHER METHODS

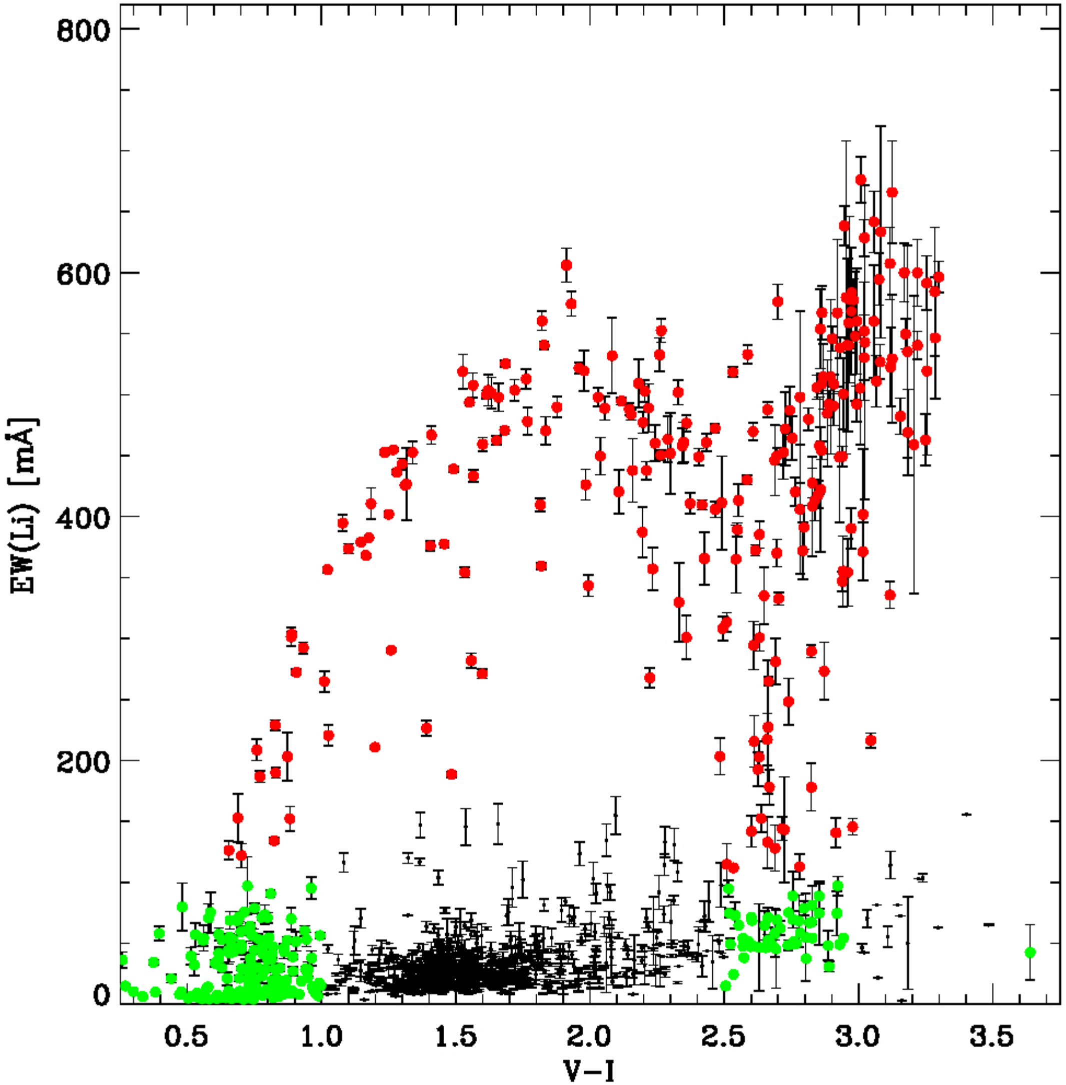


LITHIUM CANDIDATES: RESULTS

235 Li candidate members (red dots)

247 UNDEFINED for Li (green dots)

760 non members



Hα CANDIDATES: ACTIVE STARS

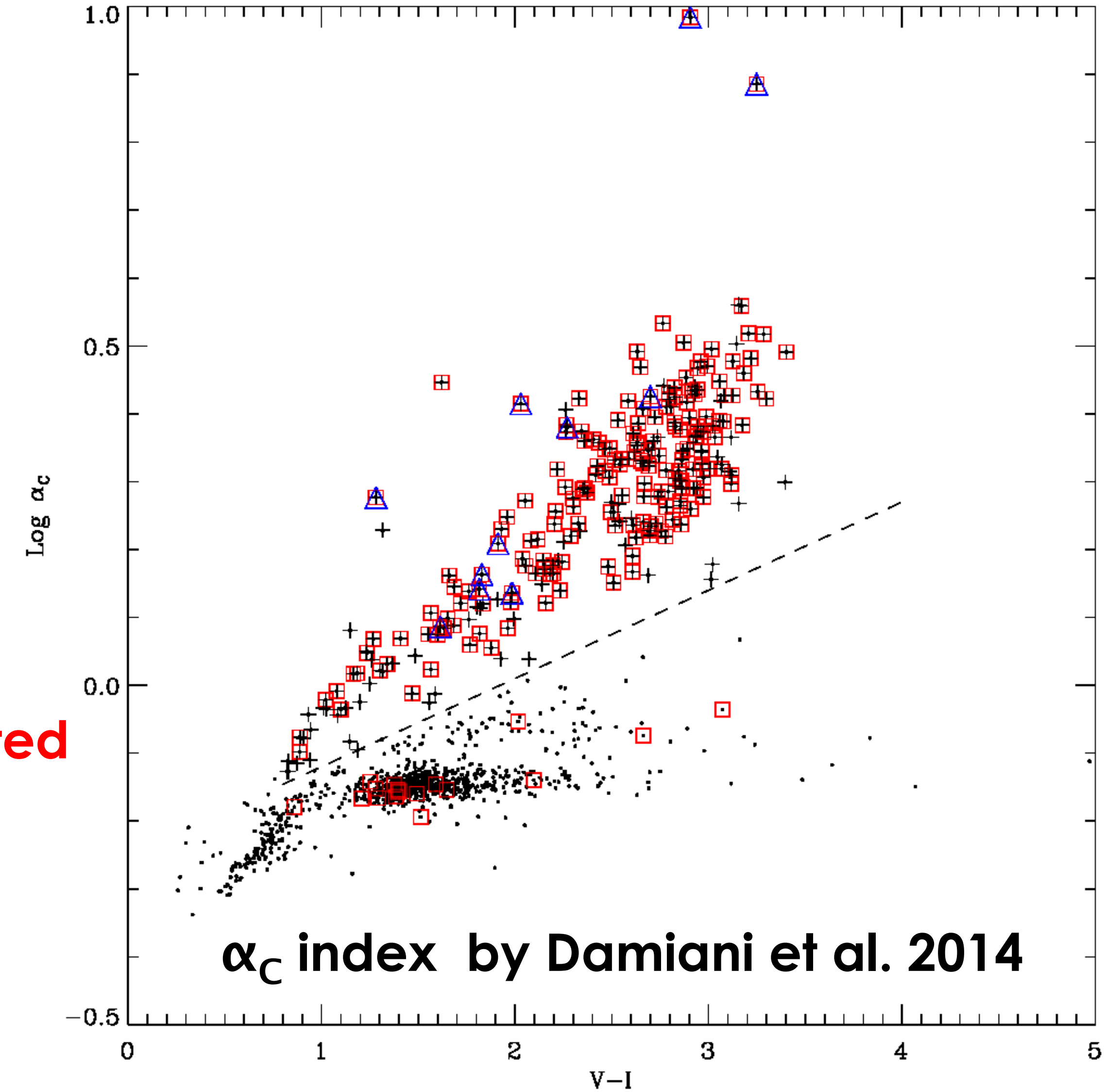
- Reference sample:
  photometric and RV
  candidate members
  to trace the locus
  (red squares)

- define the limit
- SELECTION:

259 candidate active stars (black plus) that include 11 Accretors previously selected

65 undefined (low S/N)

918 inactive stars



CANDIDATES FOR GRAVITY

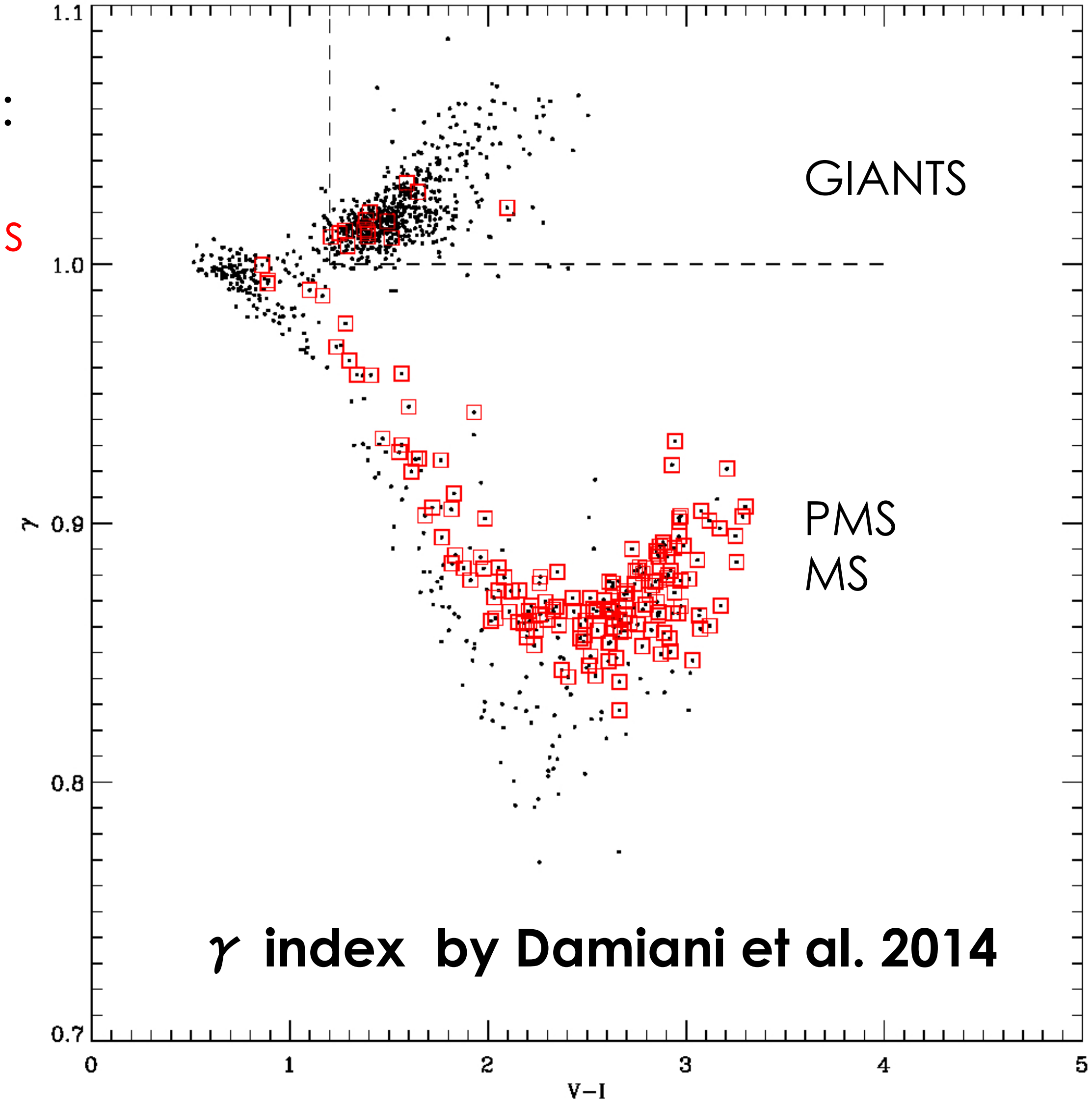
- STARTING FIDUCIAL SAMPLE:
  R and P candidate members to trace the locus

- define the limit
- SELECTION:

451 candidate MS or PMS

199 undefined

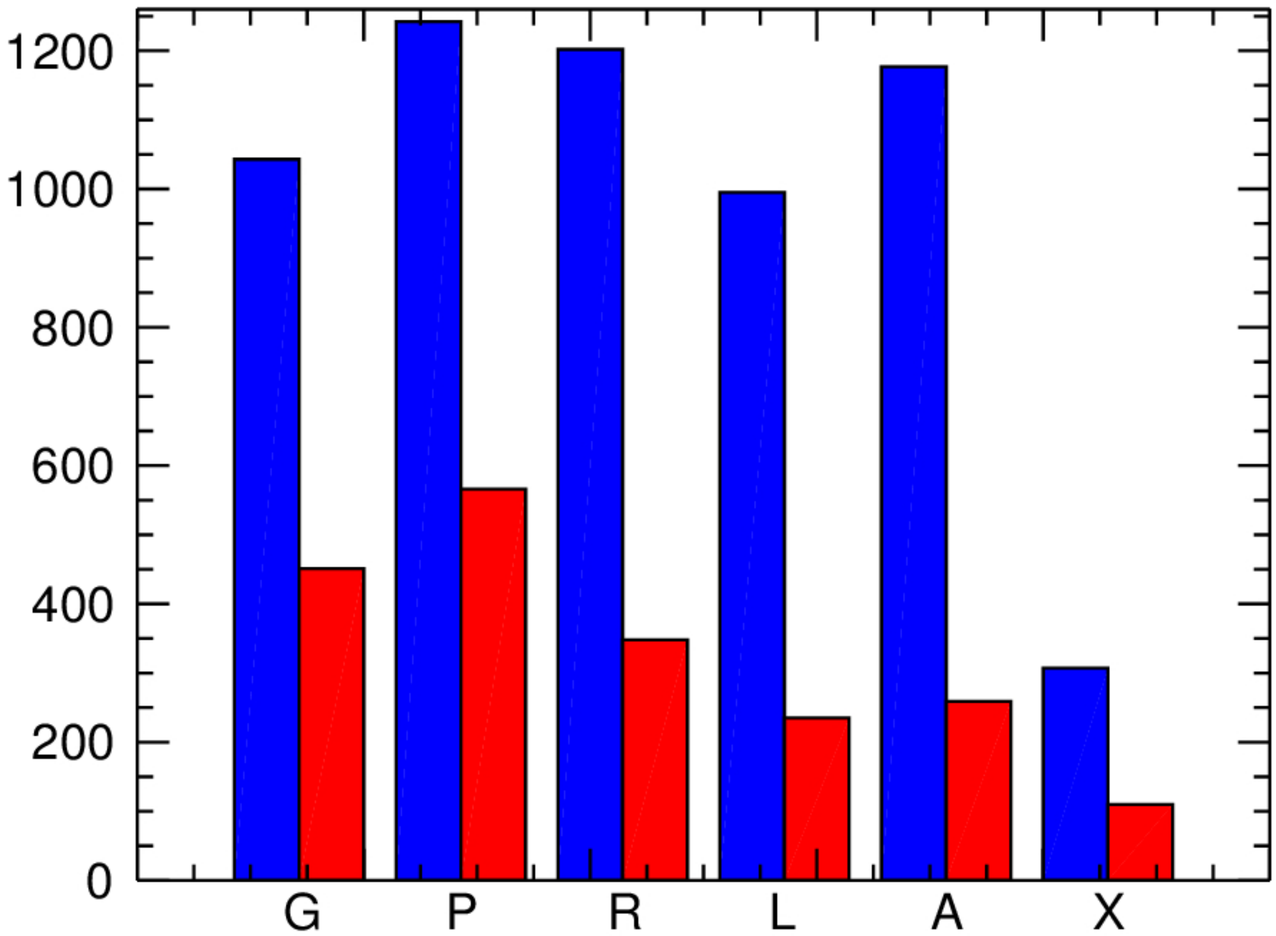
592 Giants



ALL CRITERIA

CANDIDATE MEMBERS / TOTAL

- **Grav. 592 / 1043**
- **Phot. 586 / 1242**
- **RV 348 / 1202**
- **Li 235 / 995**
- **Activ. 259 / 1177**
- **X-ray 110 / 307**



MEMBERSHIP REQUIREMENTS

For each star
N is the number of criteria with available membership indication
M is the number of criteria for which the membership is positive

CONFIRMED MEMBERS:
(238)

$M/N > 3/4$ and $N > 2$ and Phot-ok
OR
$M/N = 3/4$ and (ok-RV or ok-Li)

POSSIBLE MEMBERS or YOUNG STARS:
(44)

$1/2 < M/N < 3/4$
OR
$M/N = 3/4$ and no-RV and no-Li
OR
$M = 2$ and $N = 2$

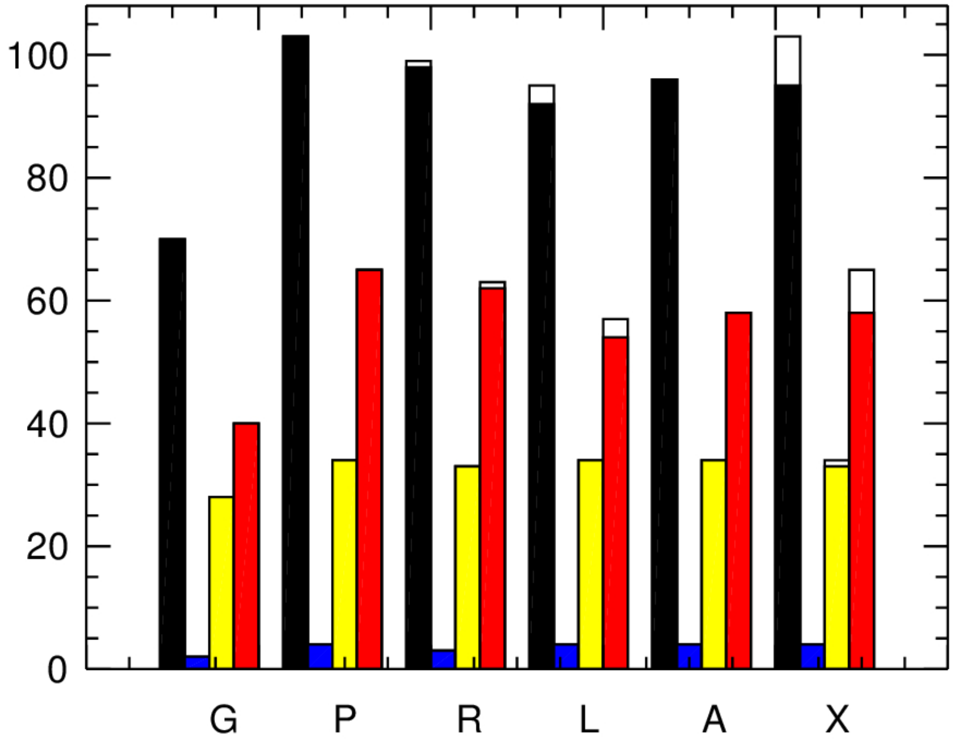
NON MEMBERS:
(960)

$M/N \leq 0.5$

MEMBERSHIP EFFICIENCY in the XMM FOV

Method	#members	#info	Fraction 1	Fraction 2
	all V-I range Tot. 103			
G	70	70	1.00	0.68
P	103	103	1.00	1.00
R	98	99	0.99	0.95
L	92	95	0.97	0.89
A	96	96	1.00	0.93
X	95	103	0.92	0.92
	0.3<V-I< 1.1 Tot. 4			
G	2	2	1.00	0.50
P	4	4	1.00	1.00
R	3	3	1.00	0.75
L	4	4	1.00	1.00
A	4	4	1.00	1.00
X	4	4	1.00	1.00
	1.1<V-I< 2.4 Tot. 34			
G	28	28	1.00	0.82
P	34	34	1.00	1.00
R	33	33	1.00	0.97
L	34	34	1.00	1.00
A	34	34	1.00	1.00
X	33	34	0.97	0.97
	2.4<V-I< 4.1 Tot. 65			
G	40	40	1.00	0.62
P	65	65	1.00	1.00
R	62	63	0.98	0.95
L	54	57	0.95	0.83
A	58	58	1.00	0.89
X	58	65	0.89	0.89

ONLY CONFIRMED MEMBERS



FILLED: confirmed by the specific method
EMPTY: missed by the specific method

MEMBERSHIP EFFICIENCY in the XMM FOV

Method	#members	#info	Fraction 1	Fraction 2
	all V-I range Tot. 103			
G	70	70	1.00	0.68
P	103	103	1.00	1.00
R	98	99	0.99	0.95
L	92	95	0.97	0.89
A	96	96	1.00	0.93
X	95	103	0.92	0.92
	0.3<V-I< 1.1 Tot. 4			
G	2	2	1.00	0.50
P	4	4	1.00	1.00
R	3	3	1.00	0.75
L	4	4	1.00	1.00
A	4	4	1.00	1.00
X	4	4	1.00	1.00
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G	28	28	1.00	0.82
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R	33	33	1.00	0.97
L	34	34	1.00	1.00
A	34	34	1.00	1.00
X	33	34	0.97	0.97
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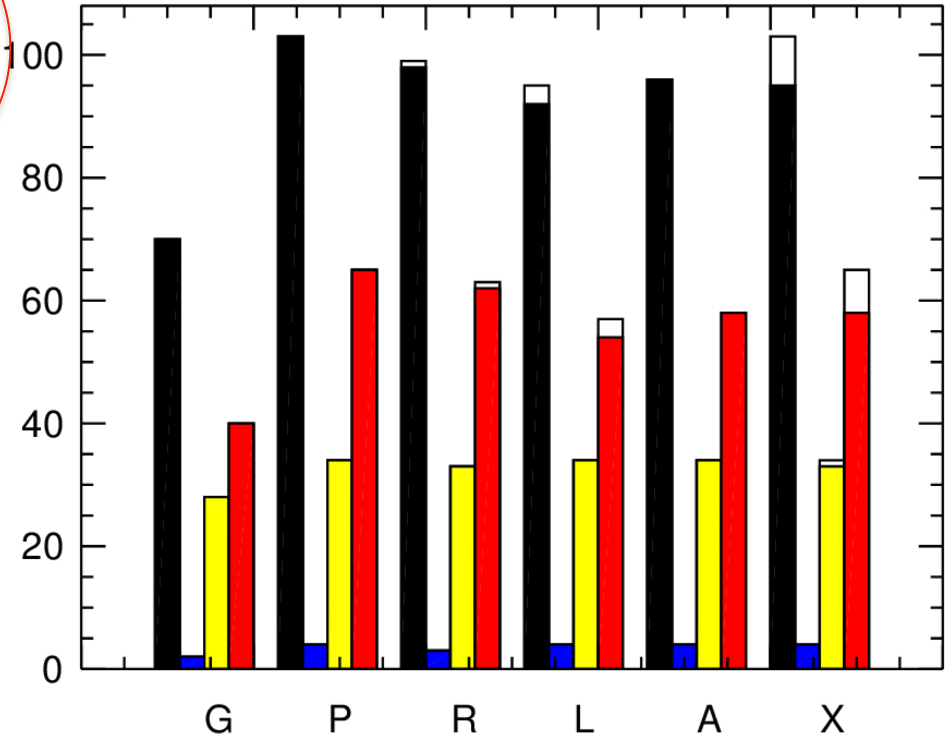
P	65	65	1.00	1.00
R	62	63	0.98	0.95
L	54	57	0.95	0.83
A	58	58	1.00	0.89
X	58	65	0.89	0.89

ONLY CONFIRMED MEMBERS

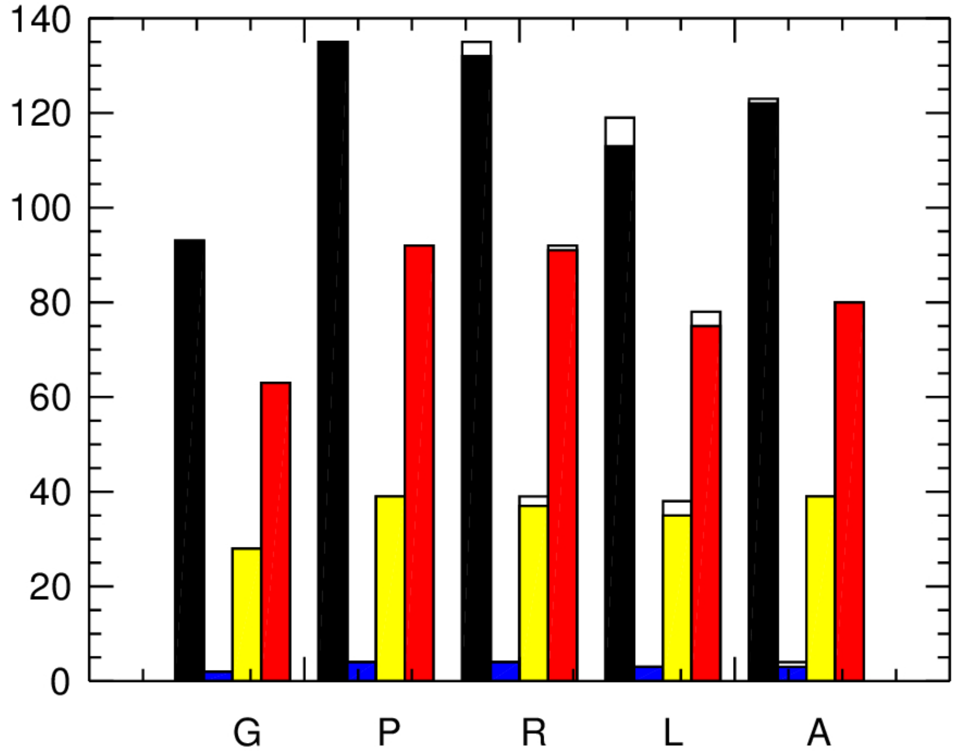


FILLED: confirmed by the specific method
EMPTY: missed by the specific method

MEMBERSHIP EFFICIENCY outside XMM FOV

Method	#members	#info	Fraction 1	Fraction 2
	all V-I range Tot. 135			
G	93	93	1.00	0.69
P	135	135	1.00	1.00
R	132	135	0.98	0.98
L	113	119	0.95	0.84
A	122	123	0.99	0.90
	0.3<V-I< 1.1 Tot. 4			
G	2	2	1.00	0.50
P	4	4	1.00	1.00
R	4	4	1.00	1.00
L	3	3	1.00	0.75
A	3	4	0.75	0.75
	1.1<V-I< 2.4 Tot. 39			
G	28	28	1.00	0.72
P	39	39	1.00	1.00
R	37	39	0.95	0.95
L	35	38	0.92	0.90
A	39	39	1.00	1.00
	2.4<V-I< 5.0 Tot. 92			
G	63	63	1.00	0.68
P	92	92	1.00	1.00
R	91	92	0.99	0.99
L	75	78	0.96	0.82
A	80	80	1.00	0.87

ONLY CONFIRMED MEMBERS



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MEMBERSHIP EFFICIENCY: CONCLUSIONS

- All members are above the threshold fixed for the method

WITH THE GES DATA OF GAMMA VEL CLUSTER:

- The **most helpful** method is based on **RV** (97%, 8 lost) regardless of spectral type

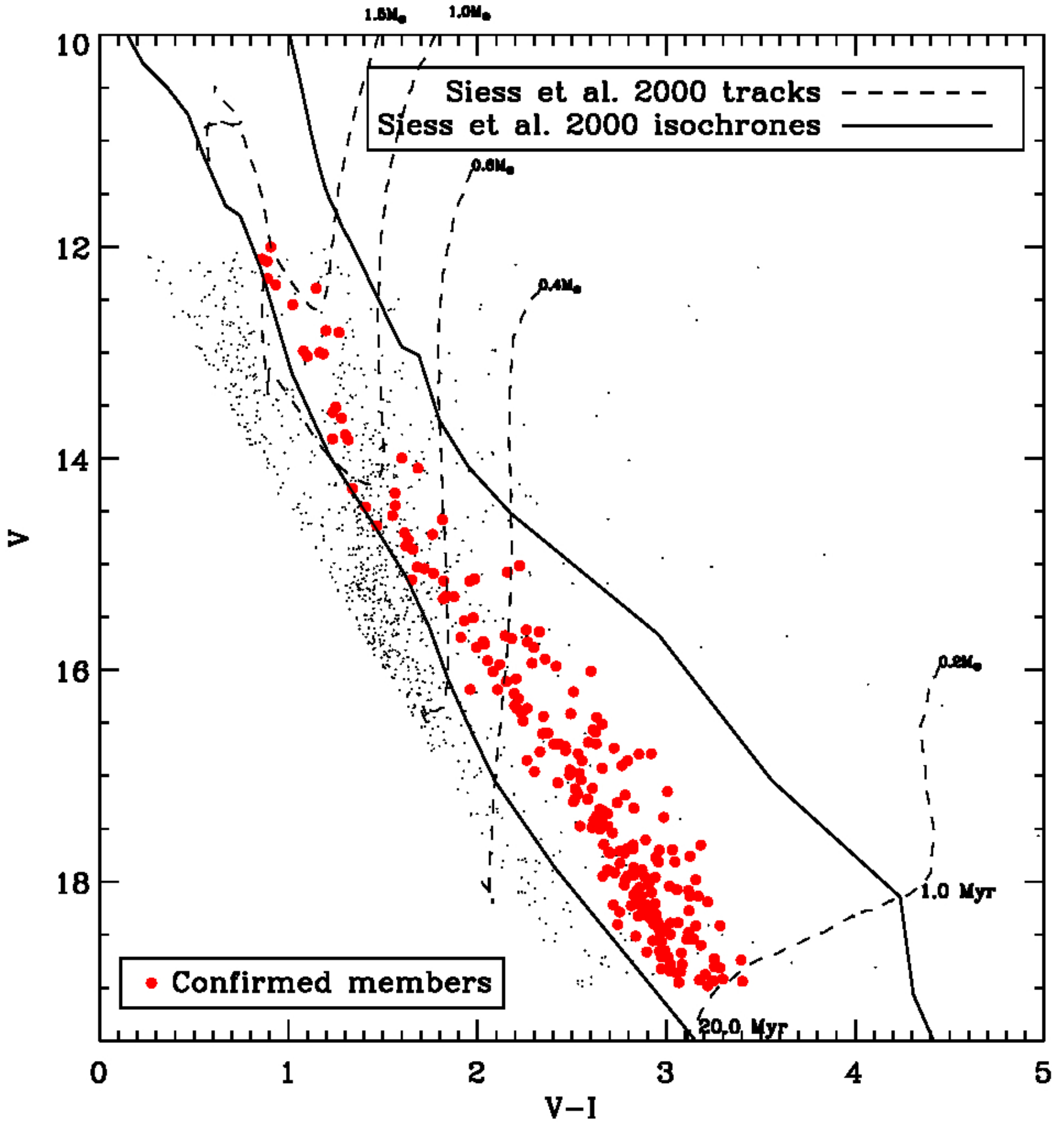
- The method based on the gravity and on the Hα can be applied only on the subsample of spectra with high S/N

- The Li method limit is due to the physics of the mechanism

- The Hα and gravity methods are very efficient for mid and late type stars

- The X-ray method is limited for the M-type stars because they are less bright in X-rays

INITIAL MASS FUNCTION (preliminary results)



CMD: comparison with models

MASS ESTIMATES

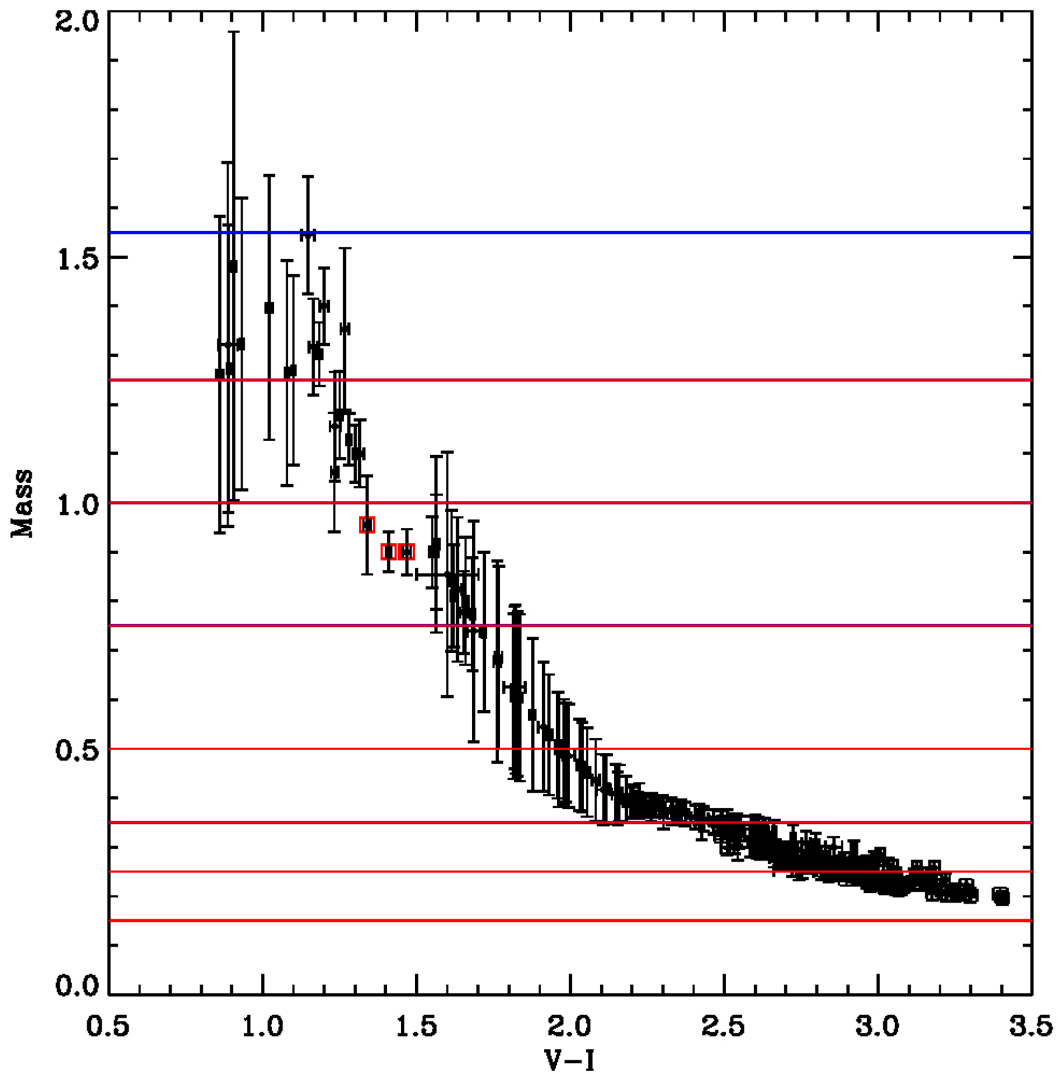
ERRORS on the MASSES

assuming the errors on

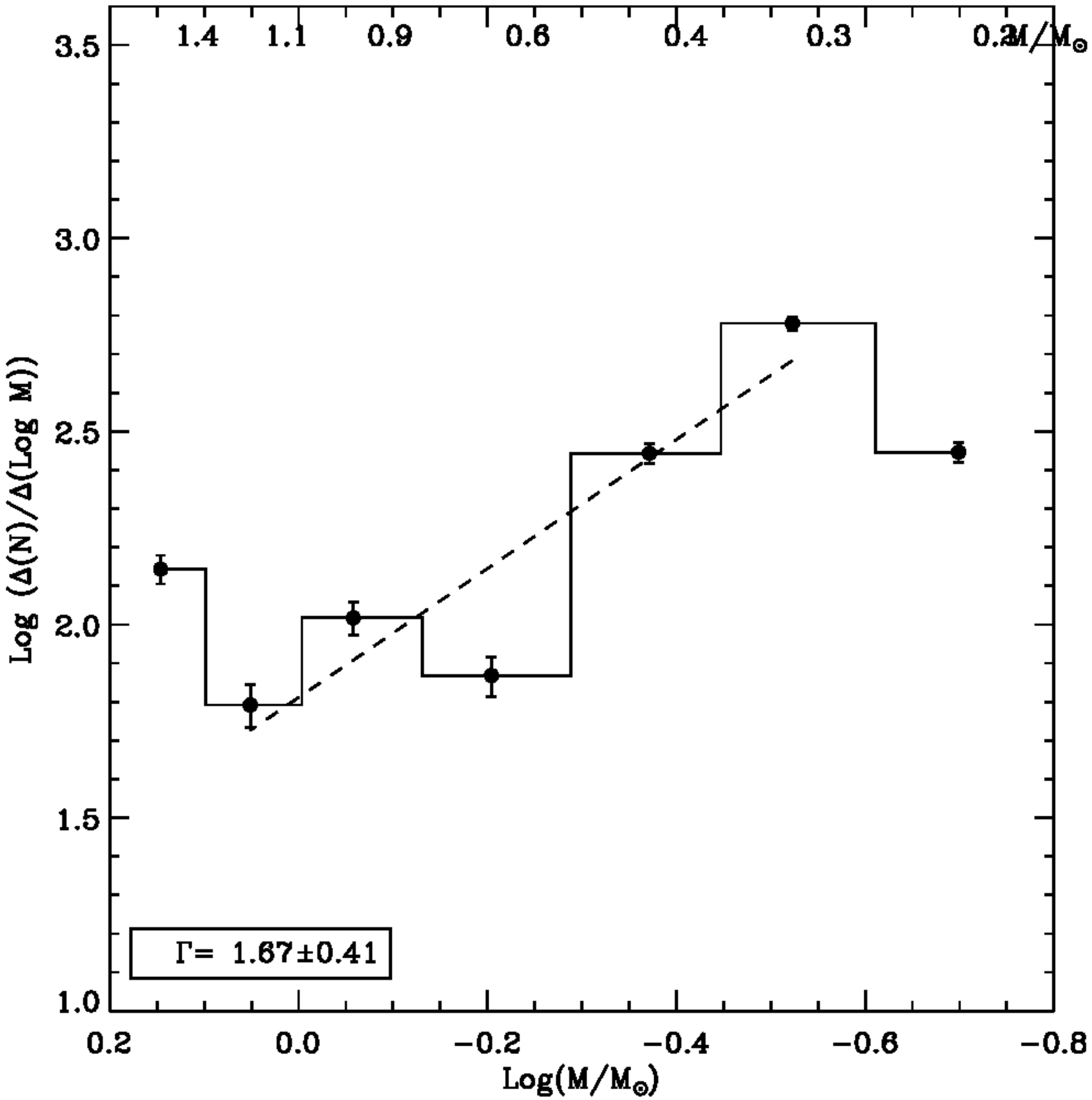
- distance modulus:7.76±0.07
(Jeffries et al. 2009)

- E(V-I)=0.131±0.084
 (Jeffries et al. 2009
 Damiani et al. 2014)

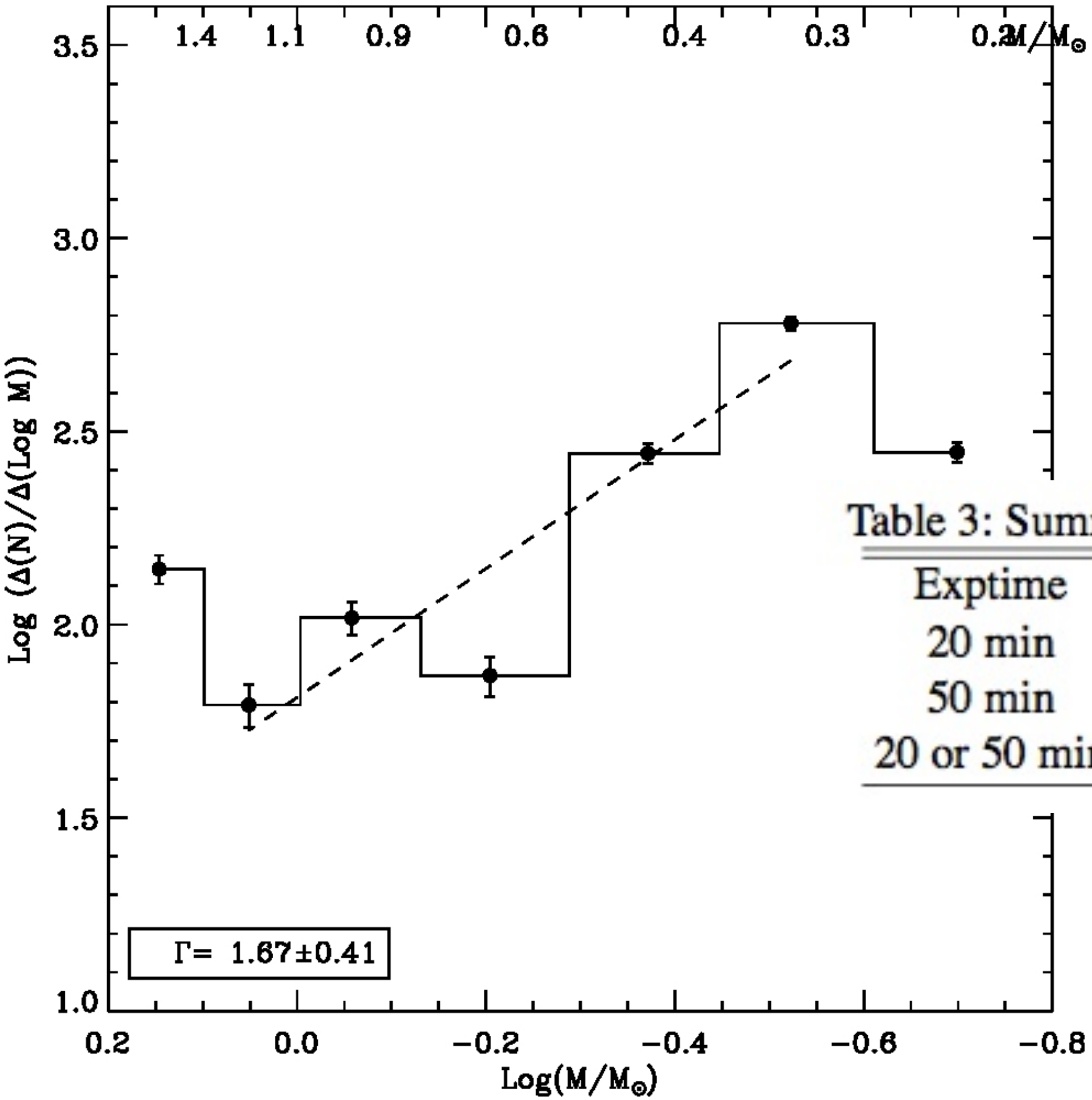
MASS BINS ~ MASS ERRORS



INITIAL MASS FUNCTION



PRELIMINARY IMF

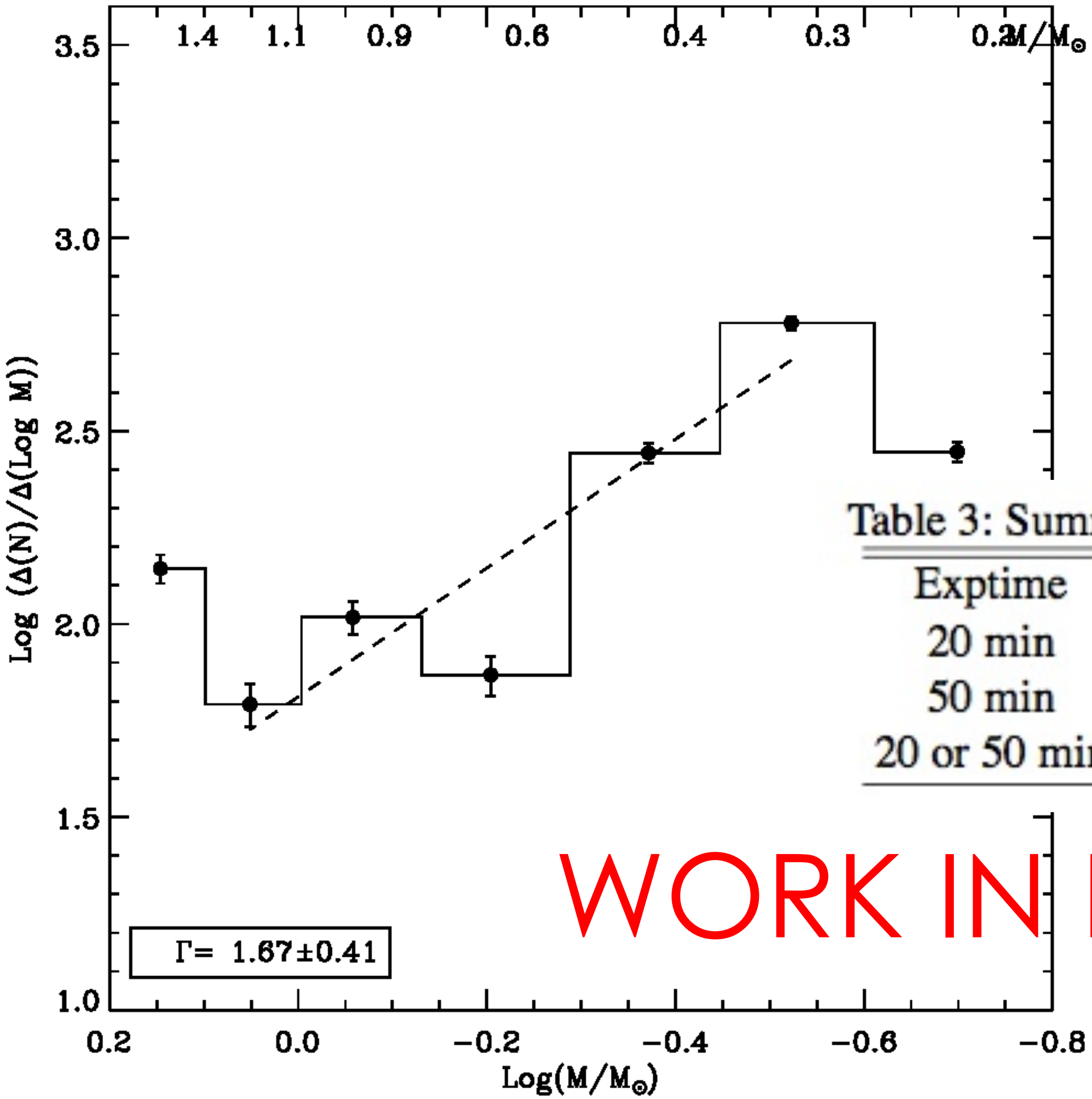


No correction for Incompleteness yet ... considering low and high priorities for the allocations

Table 3: Summary of Medusa target allocations

Exptime	Candidates	Cand. Alloc.	> 1
20 min	1029	834	145
50 min	748	680	169
20 or 50 min	1440	1263	463

PRELIMINARY IMF



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WORK IN PROGRESS!

X-ray UNOBSERVED WITH GES