THE ROLE OF MASSIVE STARS IN STAR FORMATION

DISK PHOTOEVAPORATION AND STAR FORMATION HYSTORY IN THE EAGLE NEBULA

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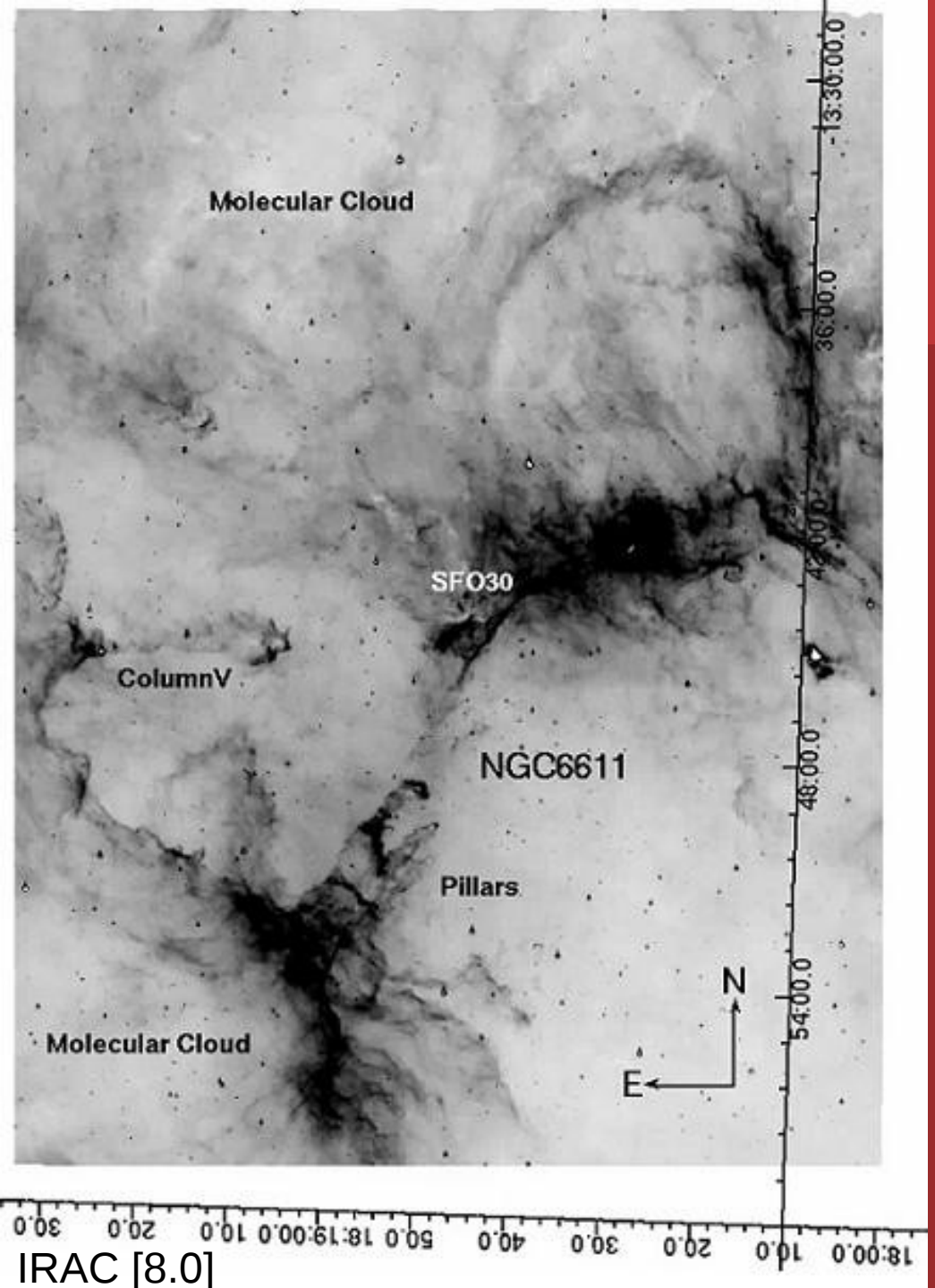
AIMS OF THE STUDY

- **EVIDENCES OF PHOTOEVAPORATION OF CIRCUMSTELLAR DISKS INDUCED BY NEARBY MASSIVE STARS**

- **HISTORY OF STAR FORMATION IN MASSIVE STARS FORMING REGIONS (SFR)**



THE EAGLE NEBULA (M16)

An active SFR in the Sagittarius arm

Distance: 1800-2400 parsec

NGC6611 in the central cavity, with:

54 OB stars
(Hillenbrand et al. 1997)

A population of YSOs (~1-2Myear)

STRATEGY

- MULTIWALENGTH APPROACH (BVIJHK[3.6], [4.5], [5.8], [8.0], X-RAYs)
- DISK-BEARING YSOs SELECTED BY INFRARED EXCESSES
- DISK-LESS YSOs SELECTED BY THE X-RAY EMISSION AND OPTICAL COLORS

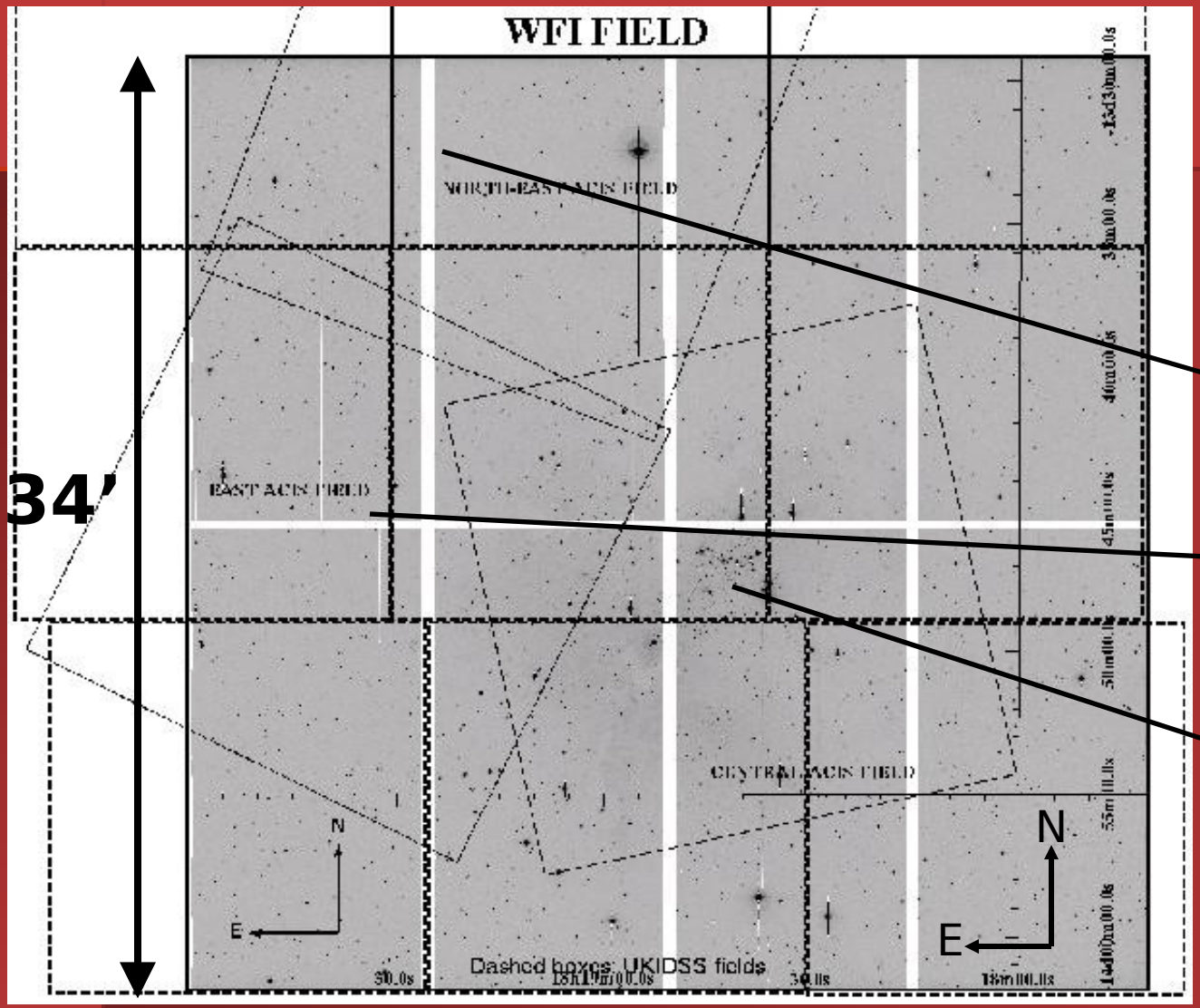
- PHOTOEVAPORATION: SPATIAL VARIATION OF DISK FREQUENCY IN NGC6611
- SF HISTORY: CHRONOLOGY OF STAR

ANALYZED DATA

Data	References
Optical in *BVI* bands	Guarcello et al. (2007)
Infrared in *JHK* bands	Bonatto et al. (2006); Guarcello et al. (2007), Guarcello Ph.D. thesis
Infrared between 3.6μm-8.0μm	Indebetouw et al. (2007); Guarcello et al. (2009)
X-rays 0.5-8 keV	Linsky et al. (2007), Guarcello Ph.D. thesis

- **28827 OPTICAL SOURCES DOWN TO V=23**
- **25920 2MASS/PSC SOURCES DOWN TO J=16**
- **159999 UKIDSS/GPS SOURCES DOWN TO J=19**
- **41985 IRAC SOURCES DOWN TO [3.6]=13**

INSTRUMENTS FIELD OF VIEWS



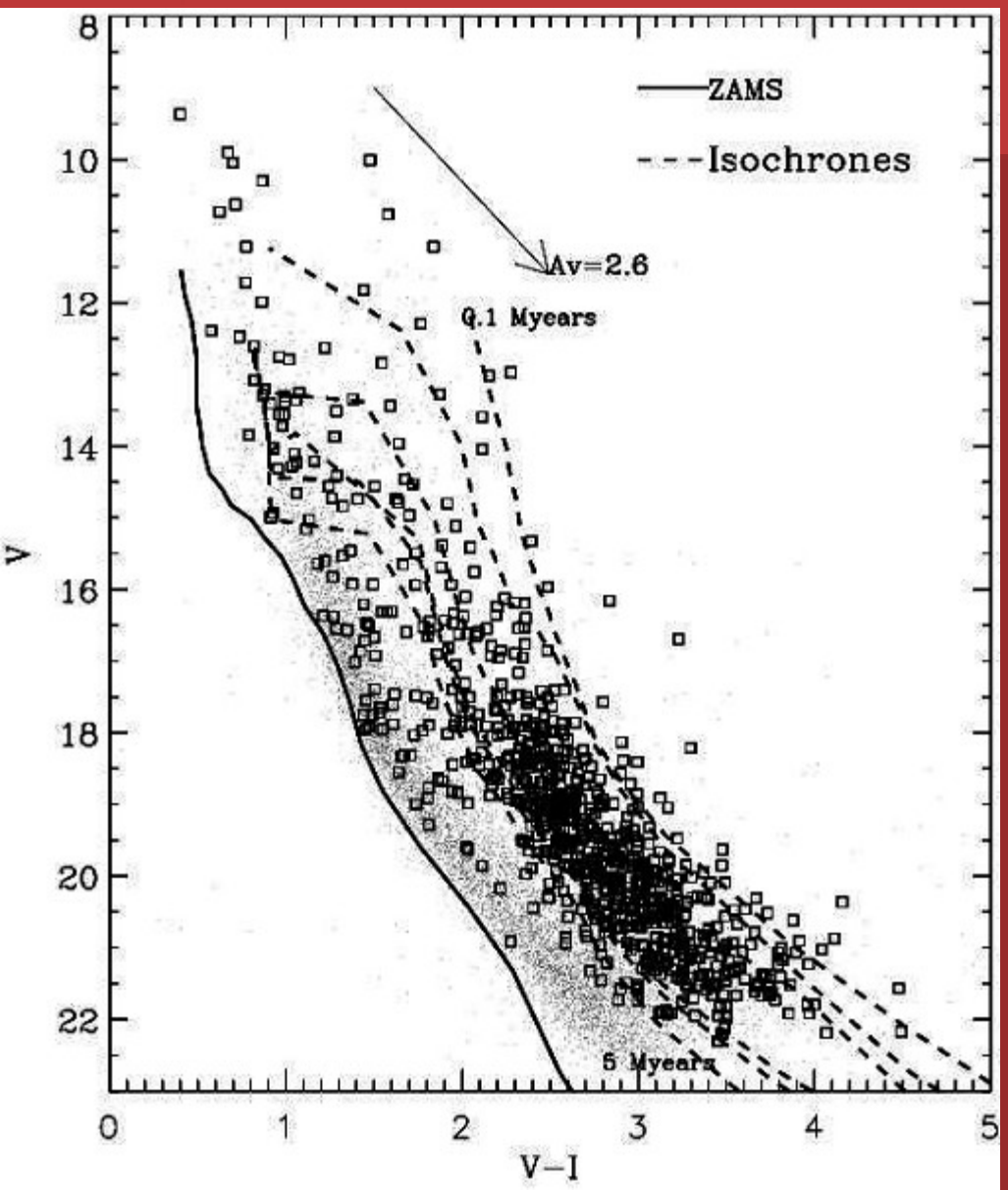
ACIS-I fields:

NE field (NE embedded cluster)

Est field (ColumnV)

Central field (NGC6611)

NGC6611 PARAMETERS (Guarcello et al.



from X-ray sources and MS turn-off in V vs. V-I diagram

- DISTANCE: 1750pc
- AGE: <1 – 3 Myears
- Av=2.6; in M16 increases N and E
- Core radius: 1.30 pc
- Relax.Time: 5.2Myears

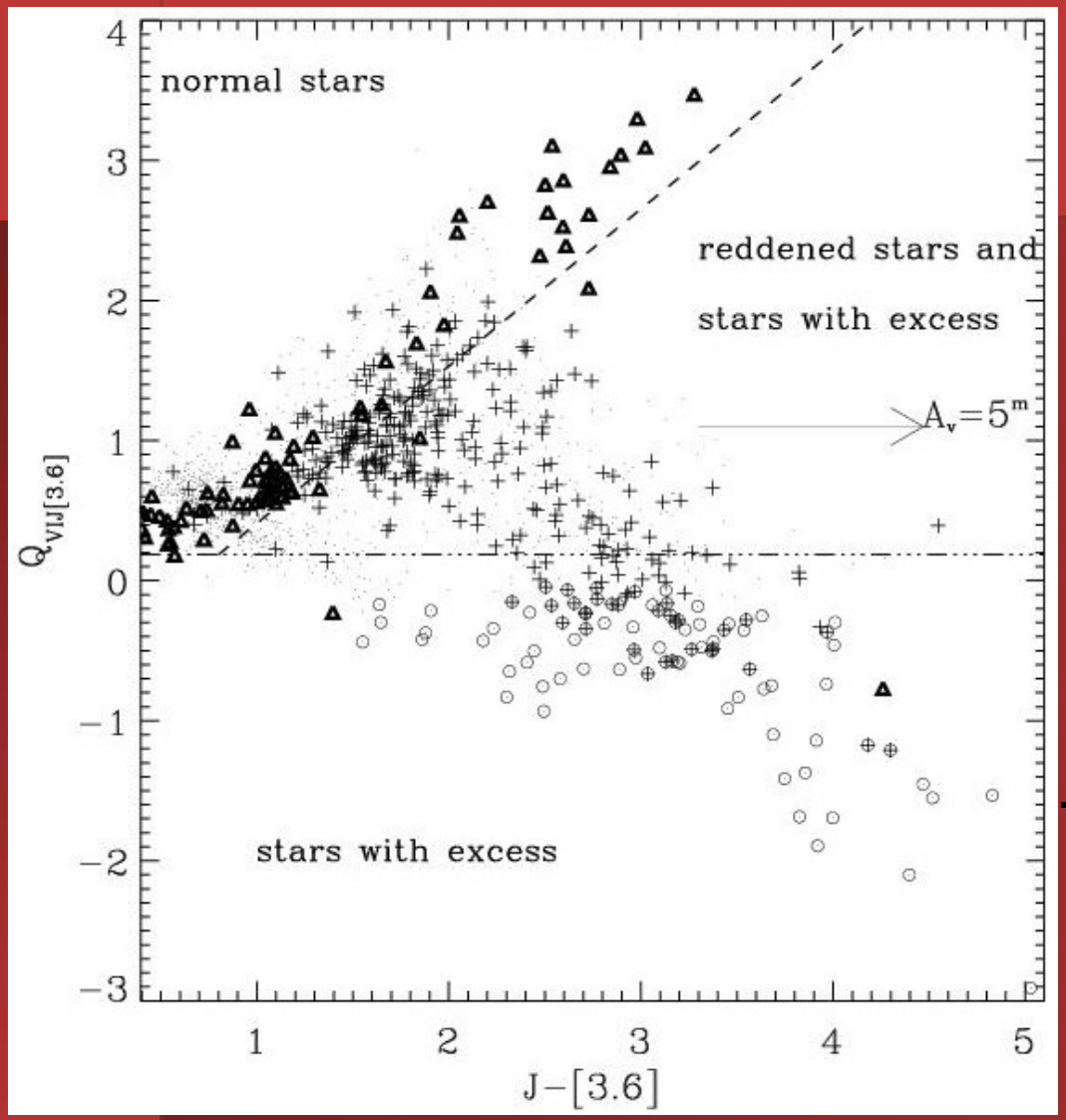
DISK DIAGNOSTICS: REDDENING FREE Q INDICES

$$Q_{VIAB} = (V - I) - (A - B) \times E_{V-I}/E_{A-B}$$

- A-B is an NIR color (from J to [8.0]);
- $E_{V\text{-}I}$ and $E_{A\text{-}B}$ are the reddening;
- V-I rappresents photospheric colors;
- Indices are reddening free

$$Q_{JHHK} = (J - H) - (H - K) \times E_{J-H}/E_{H-K}$$

EXAMPLE: QVIJ[3.6] vs. J-[3.6]



TOTAL OF STARS SELECTED IN M16 WITH Q INDICES:

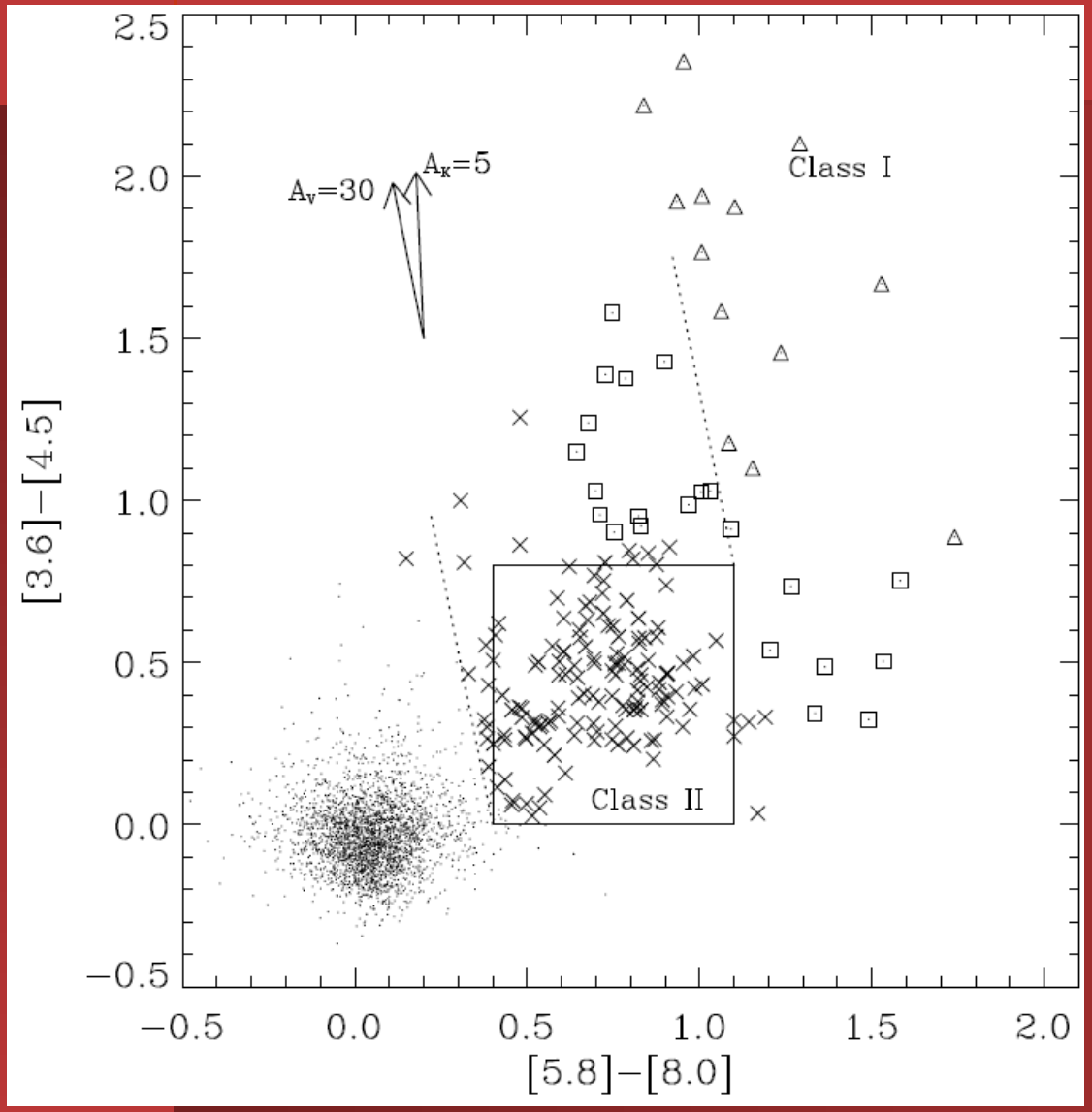
- 660 down to 0.2 solar masses
- 290 fainter probable cluster members

Optical sources with normal colors: Δ

X-ray sources: +

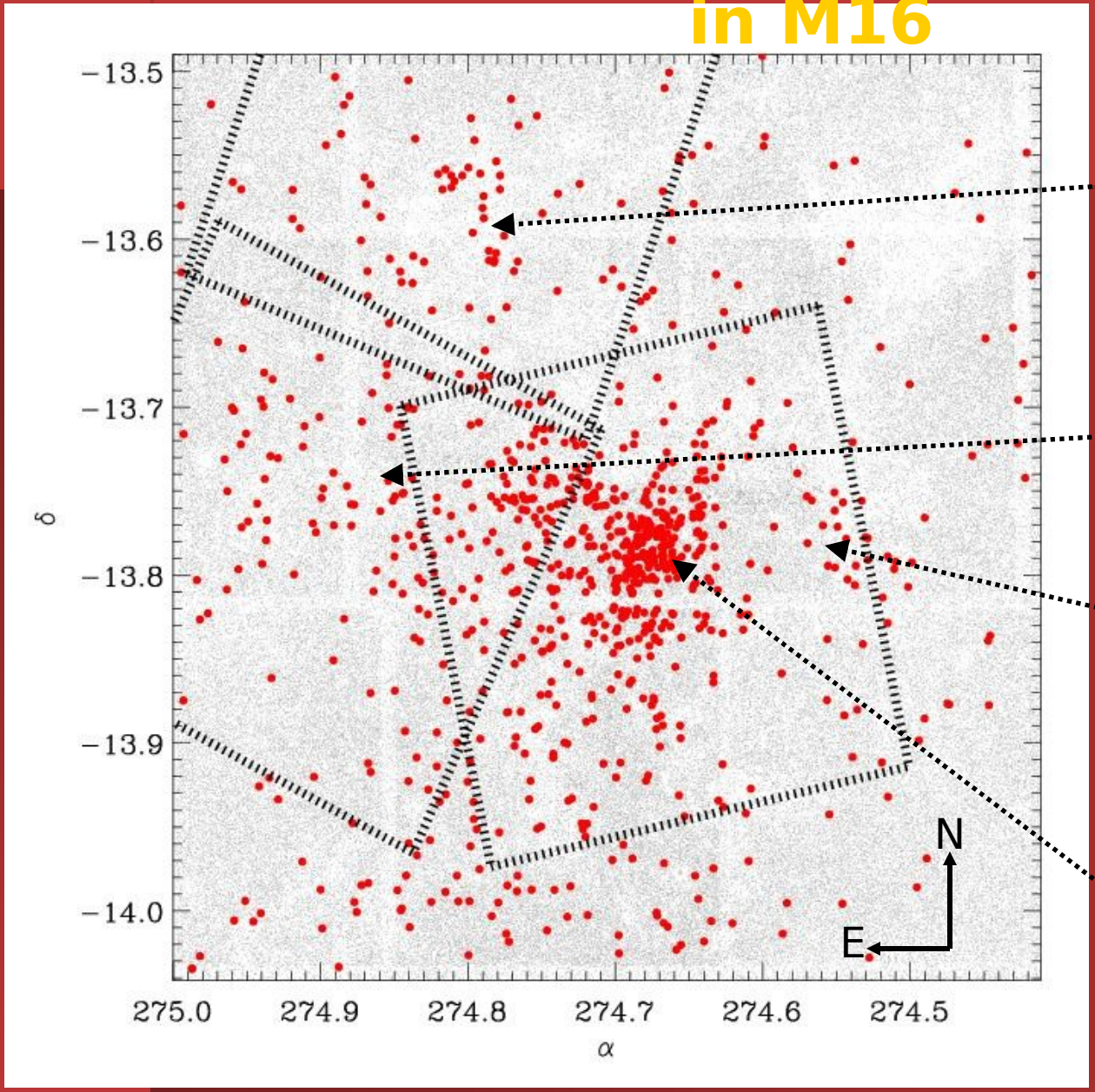
Stars with excess in [3.6]:

T-Tauri stars from the IRAC color-color diagram



- 172 TTS IN M16 (124 not Q-excesses), with:
- 147 ClassII TTS ×
- 13 ClassI TTS Δ
- 22 not class.

Spatial distribution of disk-bearing YSOs in M16



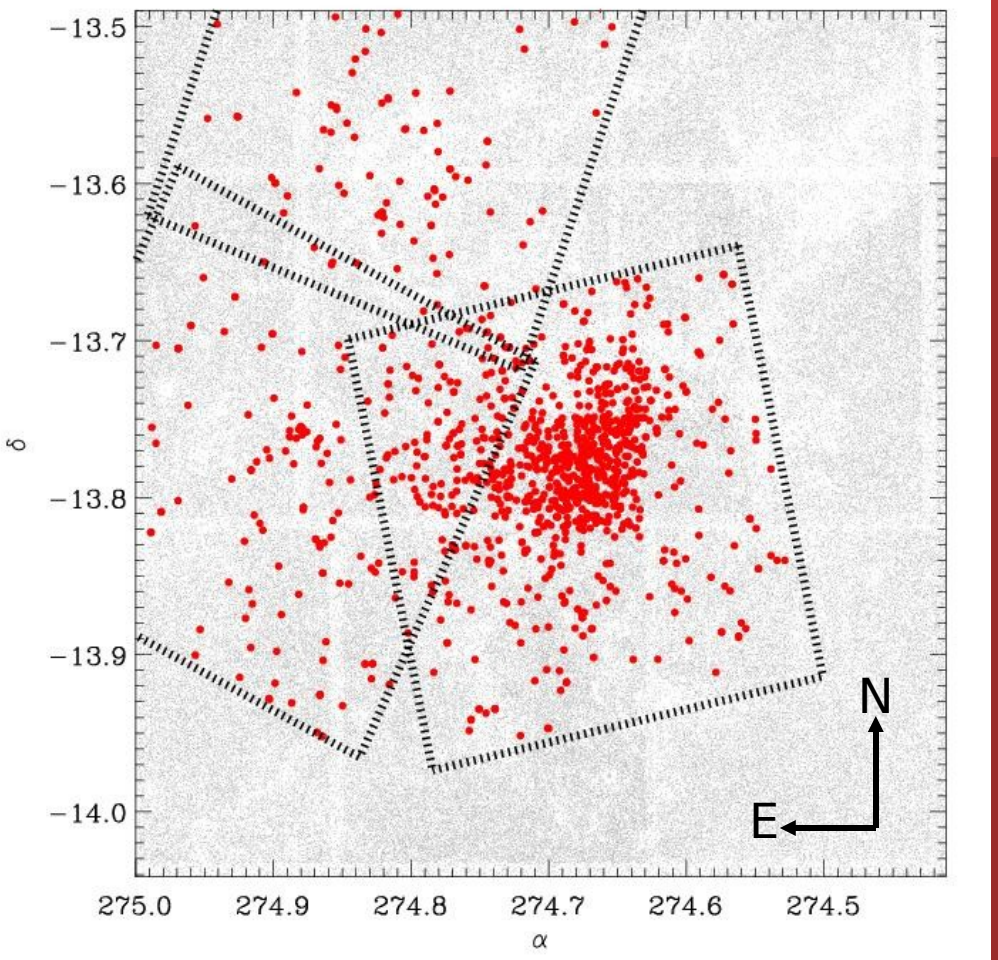
NE embedded cluster

ColumnV

Massive SF

NGC6611

DISK-LESS CANDIDATE MEMBERS IN M16



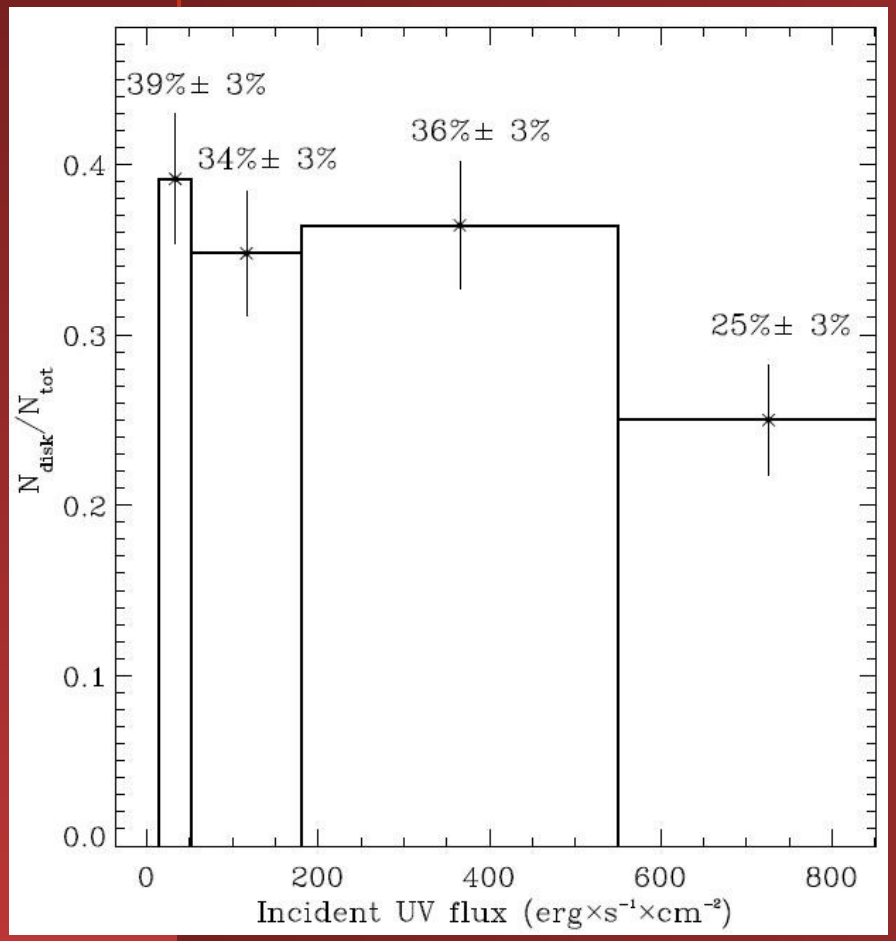
- X-ray sources with:
  - ➢ 1 stellar counterpart
  - ➢ colors compatible with the cluster
  - ➢ no NIR excesses

1117 stars selected

Central Field: 910 disk-less, 532 disk-bearing

DISKS PHOTOEVAPORATION IN NGC6611

- Flux emitted from OB stars and incident on disk-bearing and disk-less members.
- Average disk frequency in 4 flux bins.

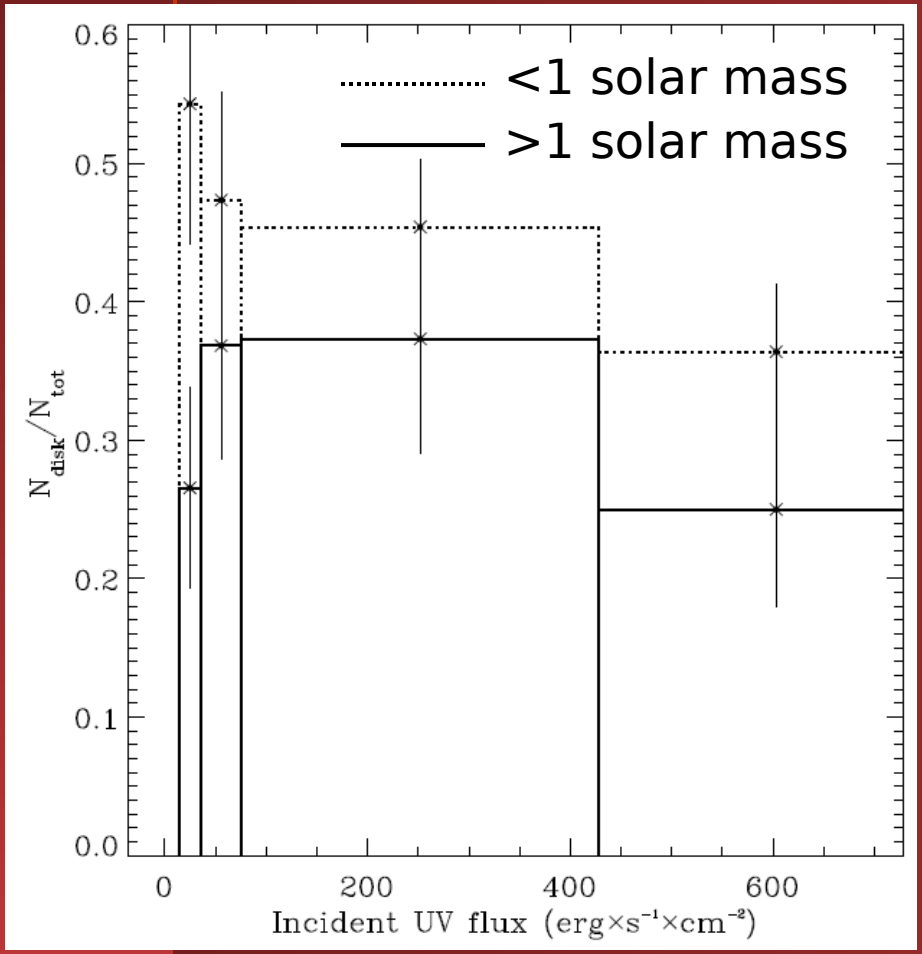


DISK FREQUENCY DROPS CLOSE TO HIGH MASS STARS:

DISKS ARE LESS FREQUENT AT HIGH UV FLUXES:

INDUCED PHOTOEVAPORATION?

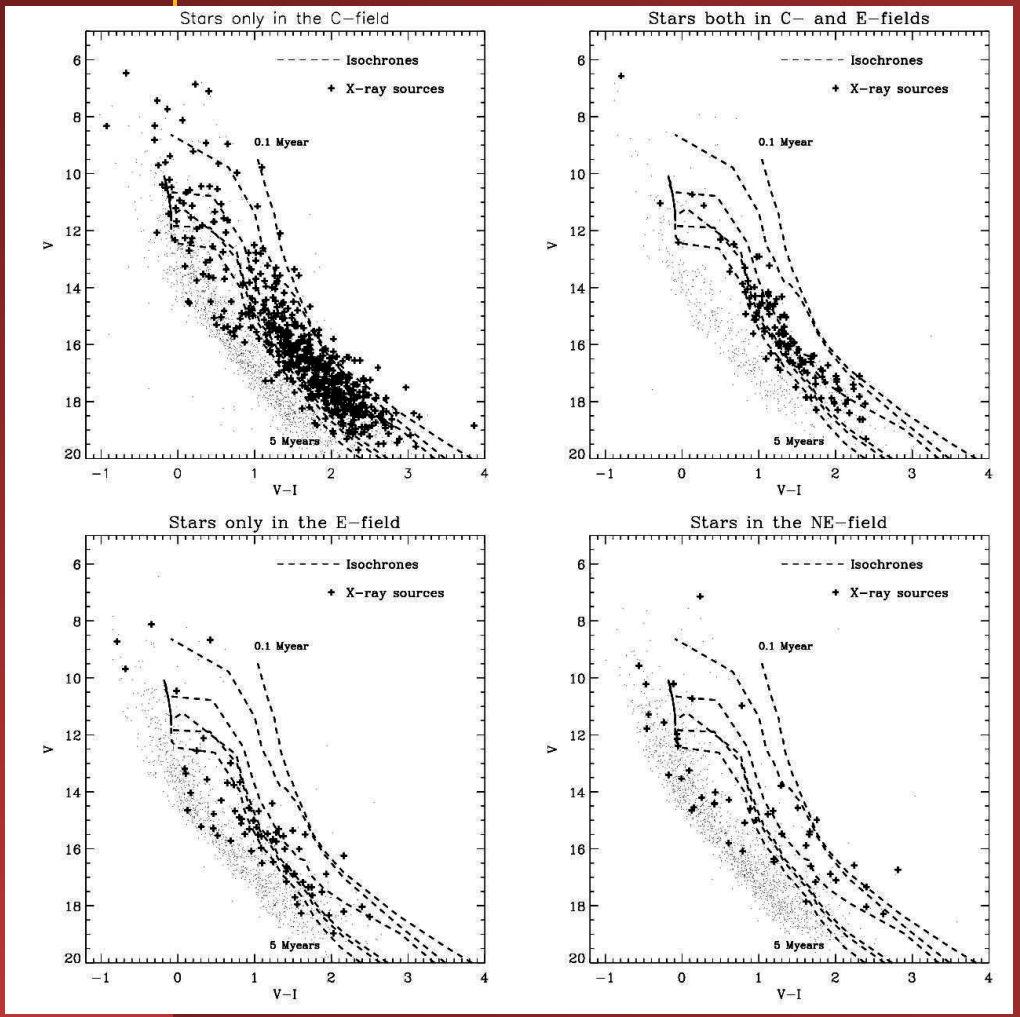
- members mass obtained from dereddened col-mag diagrams and tracks of Siess et al. 2000
- no effects of photoevaporation for high-mass stars
- disks in low-mass stars more frequent than high-mass at low incident flux



- **photoevaporation dissipates disks in low-mass stars more quickly than in high-mass stars** (Adams et al. 2004)
- **far away from massive stars disks have normal evolution**

SF HISTORY IN THE EAGLE NEBULA

Members age obtained from dereddened col-mag diagrams and isochrones of Siess et al. 2000

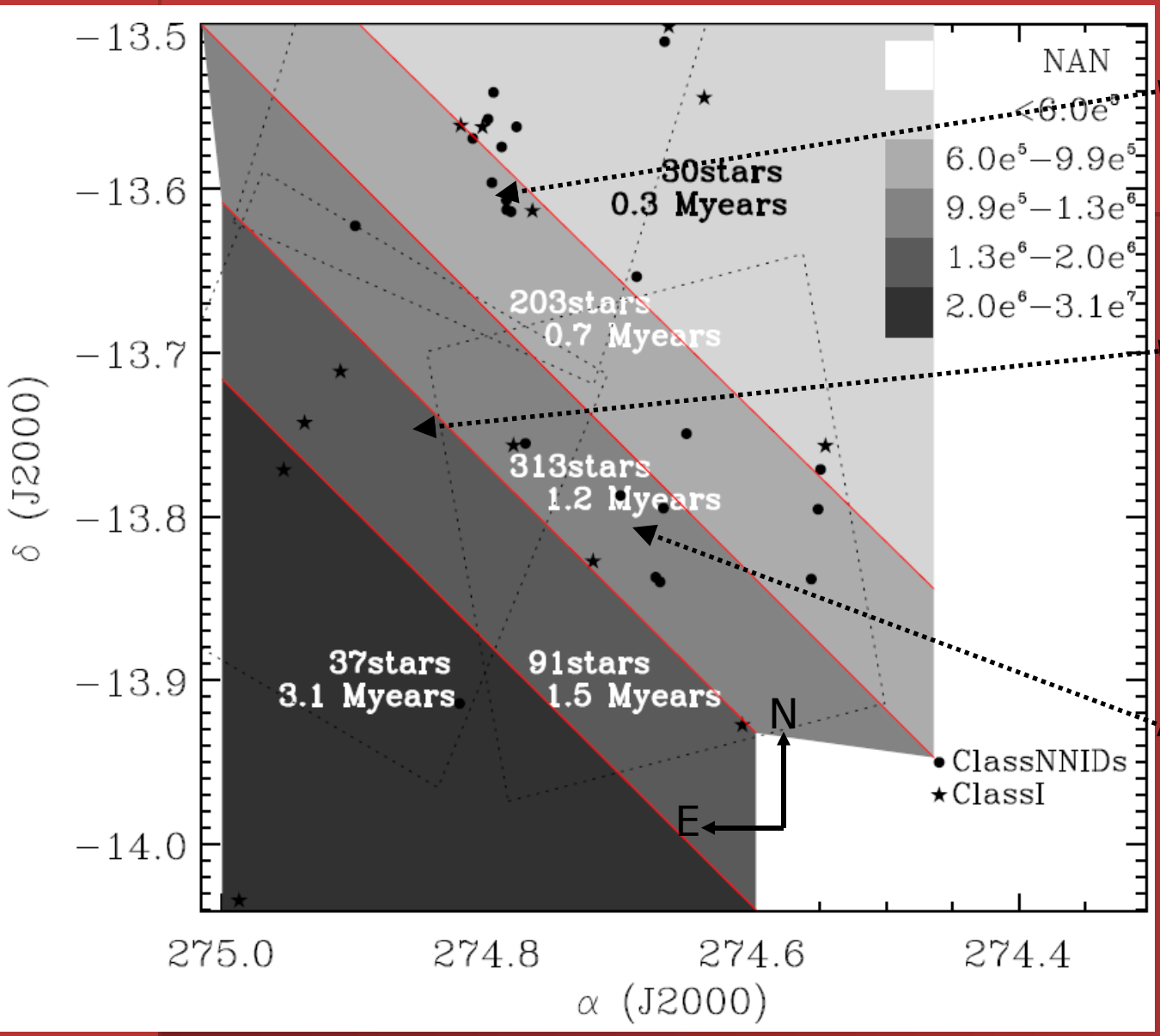


MEDIAN AGES:

- Central-field: 1 Myear
- common C-E field: 1.4 Myears
- E field: 2 Myears
- NE field: sparse, mostly younger than 1 Myears

AGE TREND FROM THE CENTER TO EAST

CHRONOLOGY OF SF IN THE WHOLE M16



NE embedded cluster

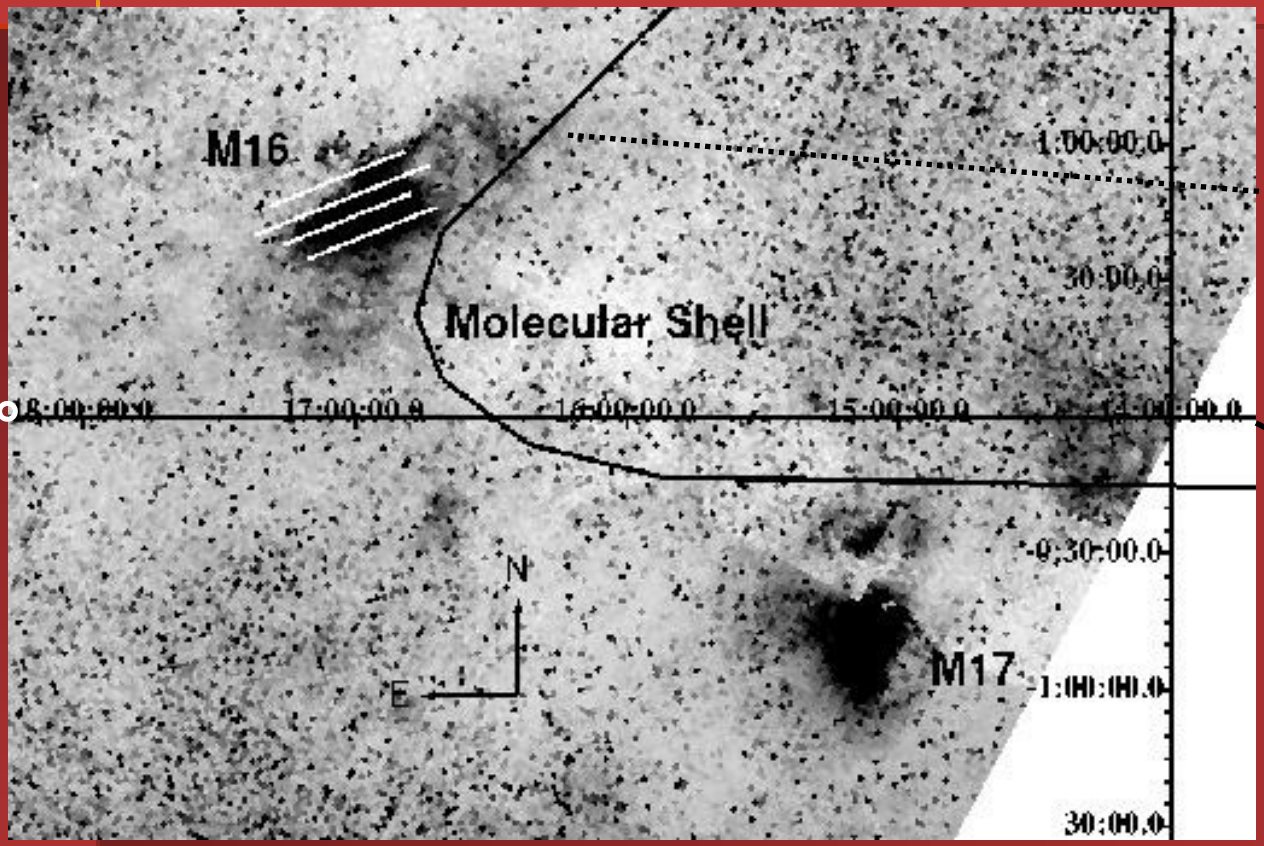
ColumnV

NGC6611

NO CLEAR EFFECTS DUE TO MASSIVE STARS

Possible External Triggering

DSS-I image:



3°

4°

Giant Molecular Shell (Moriguchi et al. 2002)

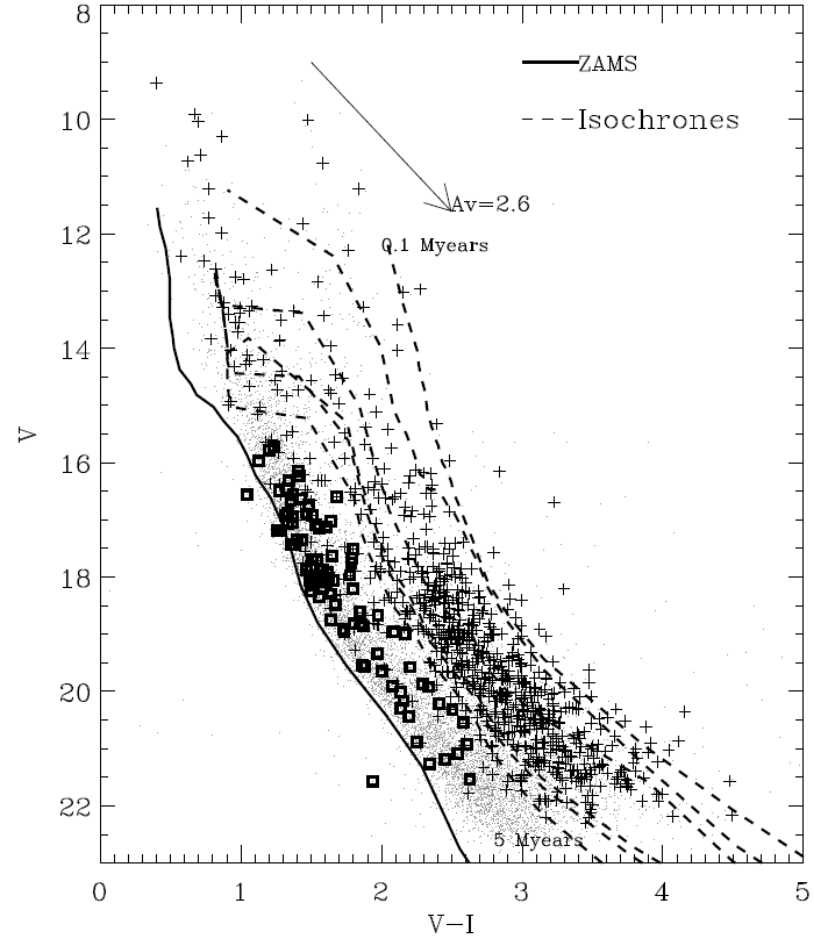
Galactic Plane

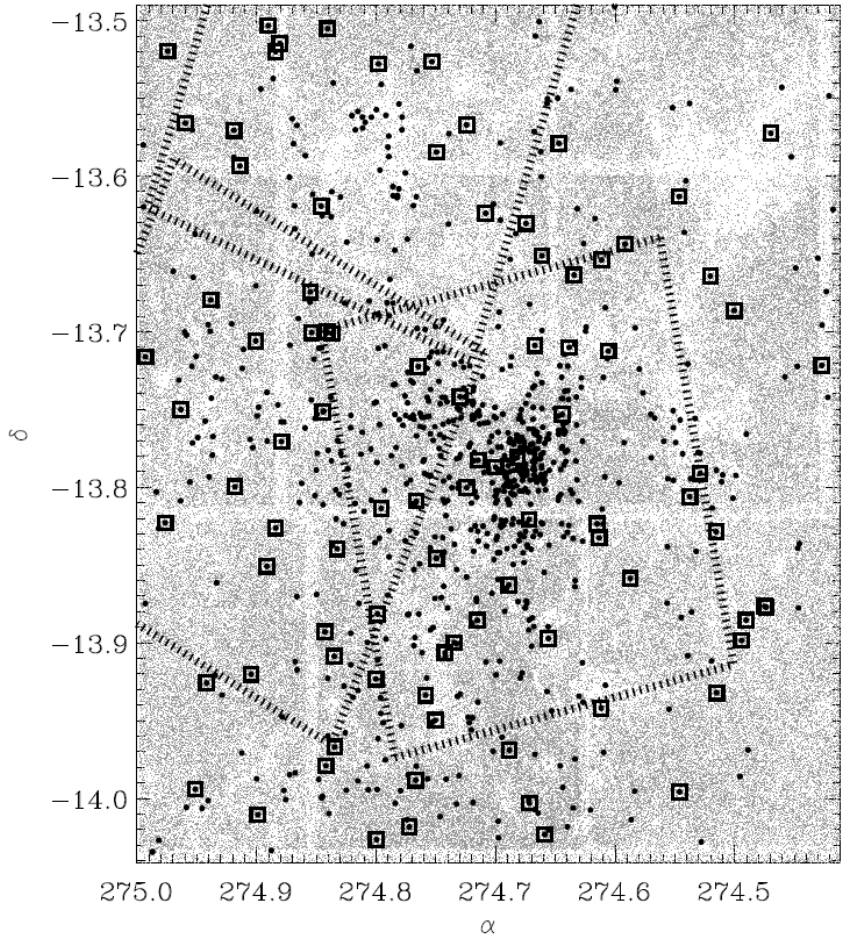
Galactic coordinate

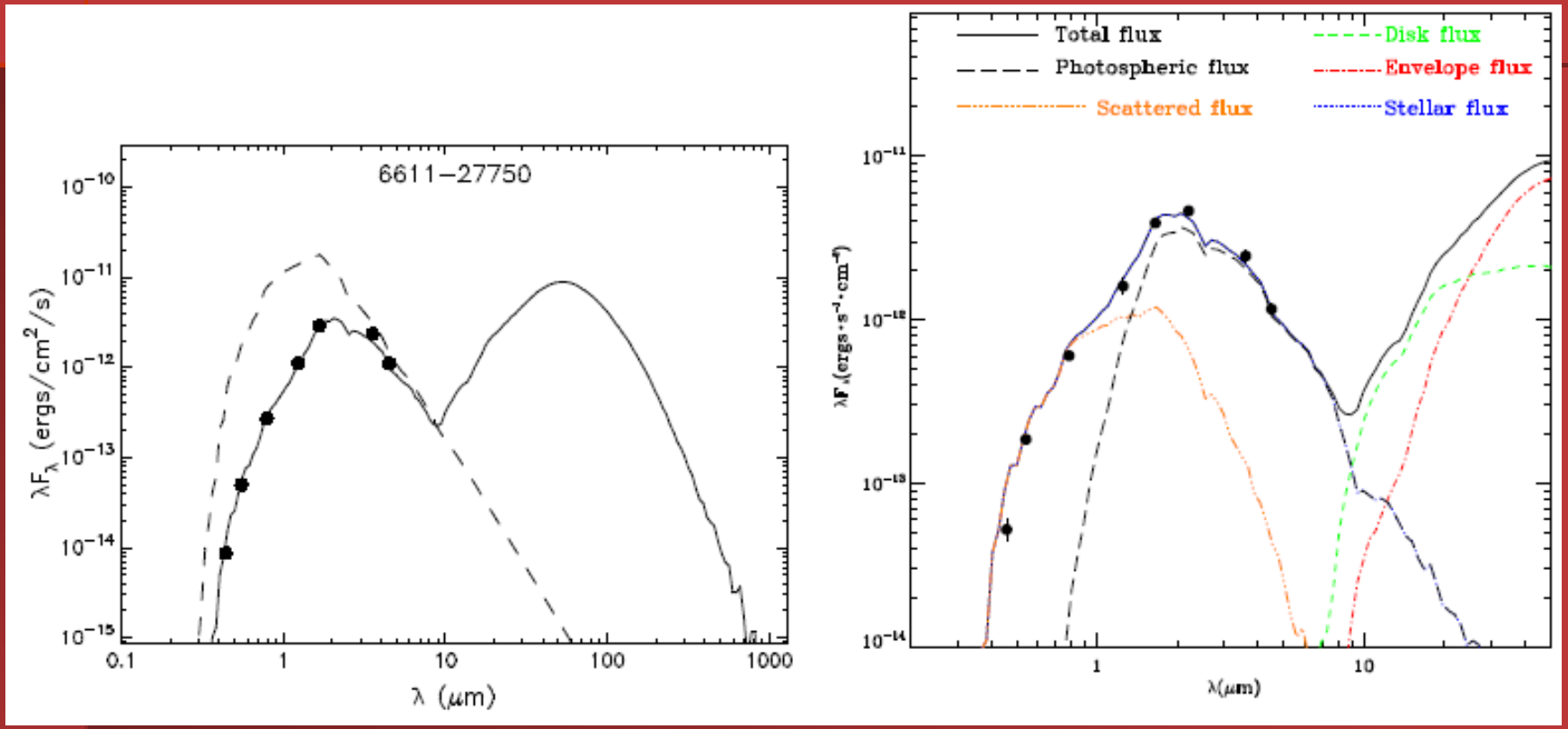
Summary and Conclusions

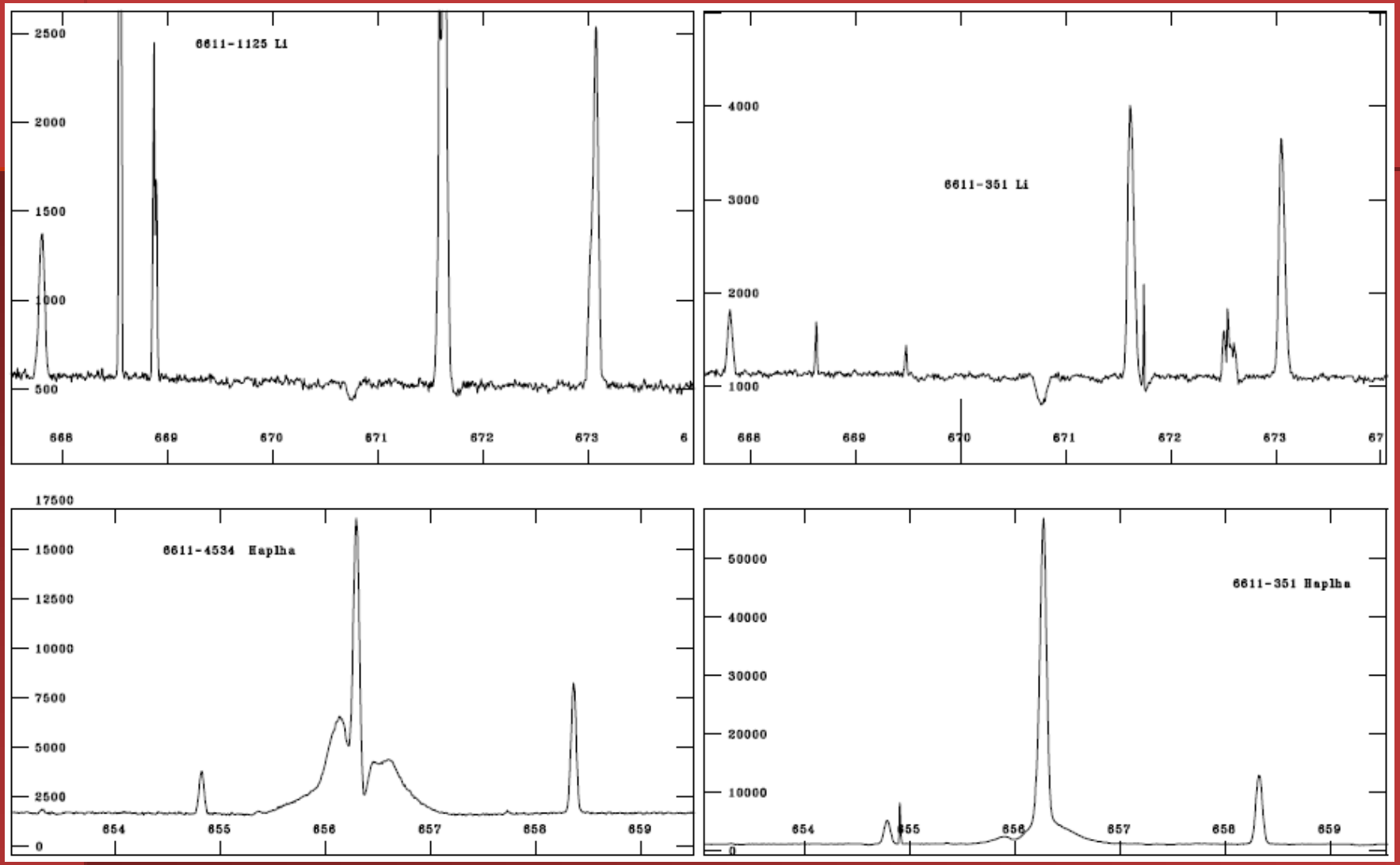
- Disk-bearing and disk-less YSOs identified in the whole Eagle Nebula
- Photoevaporation efficient in low-mass stars close to massive stars in NGC6611
- Chronology of SF not compatible with triggering by massive stars
- Externally induced SF first events at South-East by giant molecular shell?

BWE stars

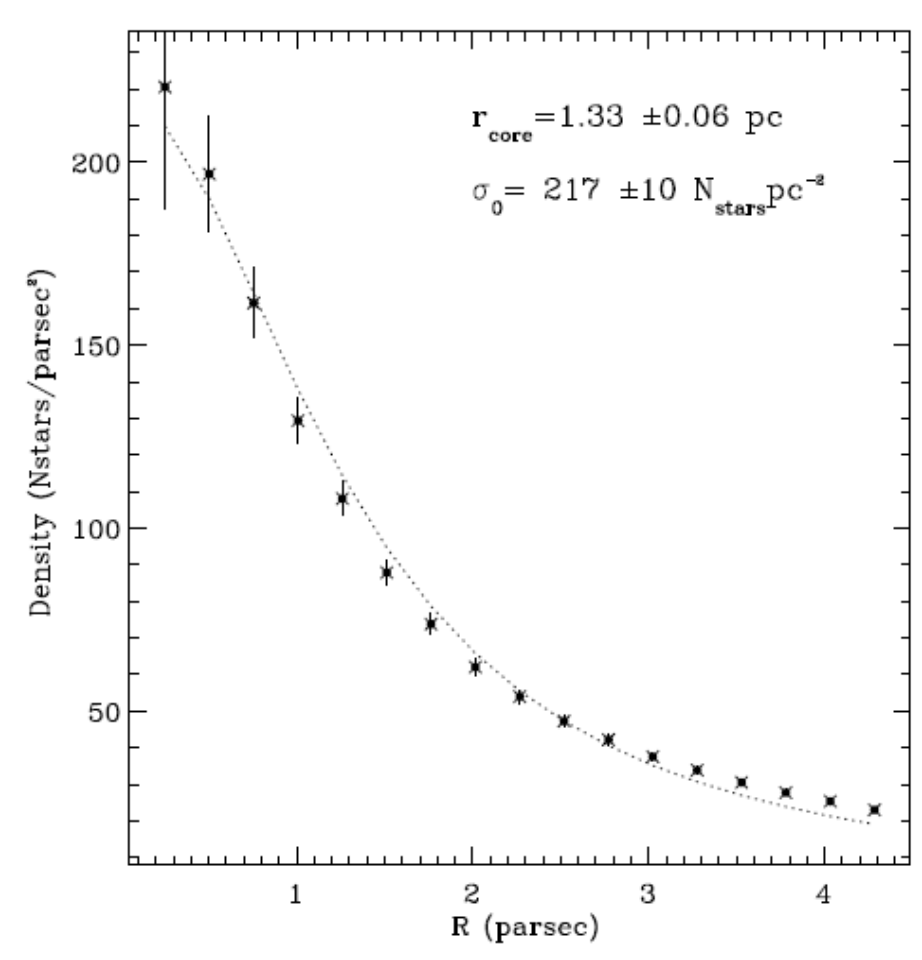

ZAMS
Isochrones
Av=2.6
0.1 Myears
5 Myears
V
V−I
8
10
12
14
16
18
20
22
0
1
2
3
4
5


δ
α
−13.5
−13.6
−13.7
−13.8
−13.9
−14.0
275.0
274.9
274.8
274.7
274.6
274.5


6611−27750
λF_λ (ergs/cm^2/s)
λ (μm)
Total flux
Photospheric flux
Scattered flux
Disk flux
Envelope flux
Stellar flux
λF_λ (ergs·s^{-1}·cm^{-2})
λ(μm)


6611-1125 Li
2500
2000
1500
1000
500
668
669
670
671
672
673
6
6611-351 Li
4000
3000
2000
1000
668
669
670
671
672
673
67
17500
15000
12500
10000
7500
5000
2500
0
6611-4534 Haplha
654
655
656
657
658
659
50000
40000
30000
20000
10000
0
6611-351 Haplha
654
655
656
657
658
659

King's profile

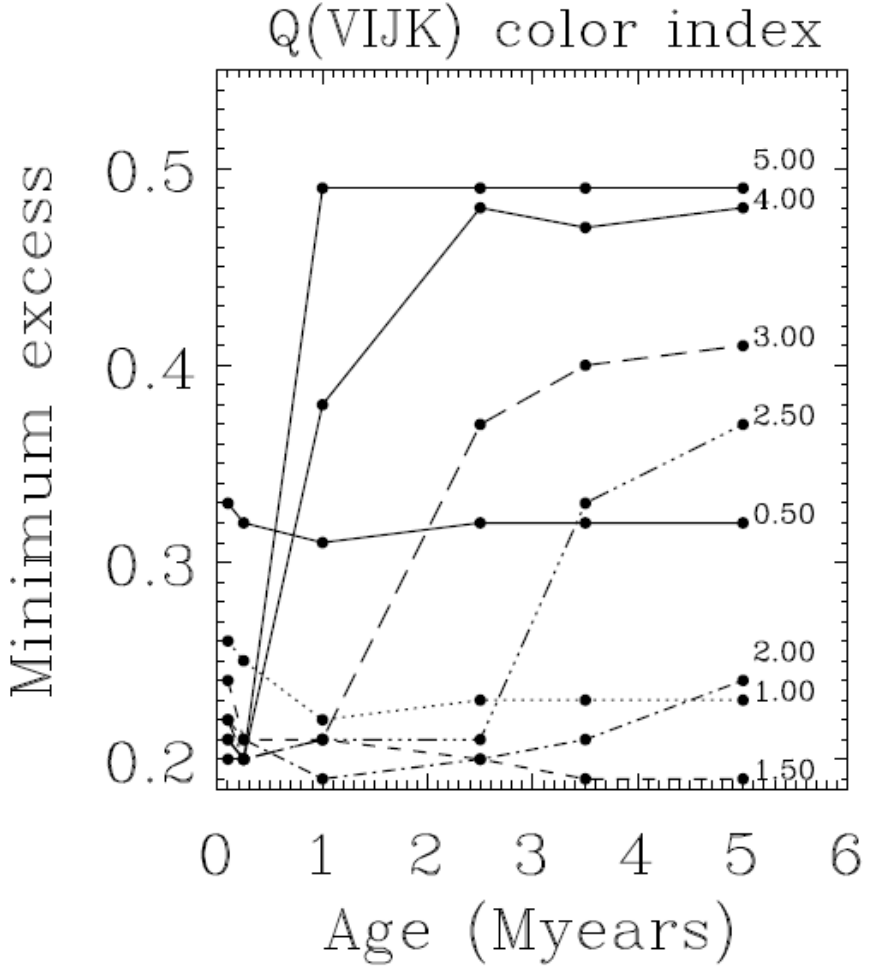


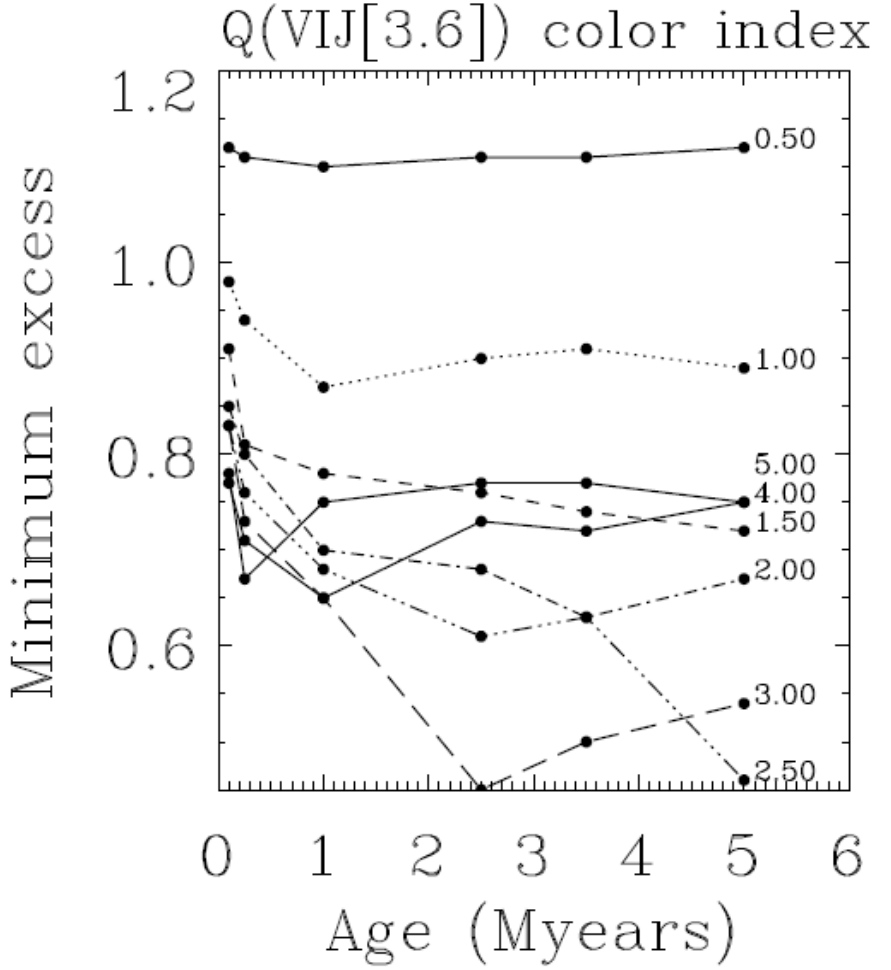
Multiband catalogs

Number of stars	WFI detection	2MASS detection	IRAC detection	X-ray sources
575	*no*	*no*	*no*	575
20063	*no*	*no*	*yes*	117
2732	*no*	*yes*	*no*	22
14636	*no*	*yes*	*yes*	78
18334	*yes*	*no*	*no*	288
1936	*yes*	*no*	*yes*	204
3122	*yes*	*yes*	*no*	136
5438	*yes*	*yes*	*yes*	480

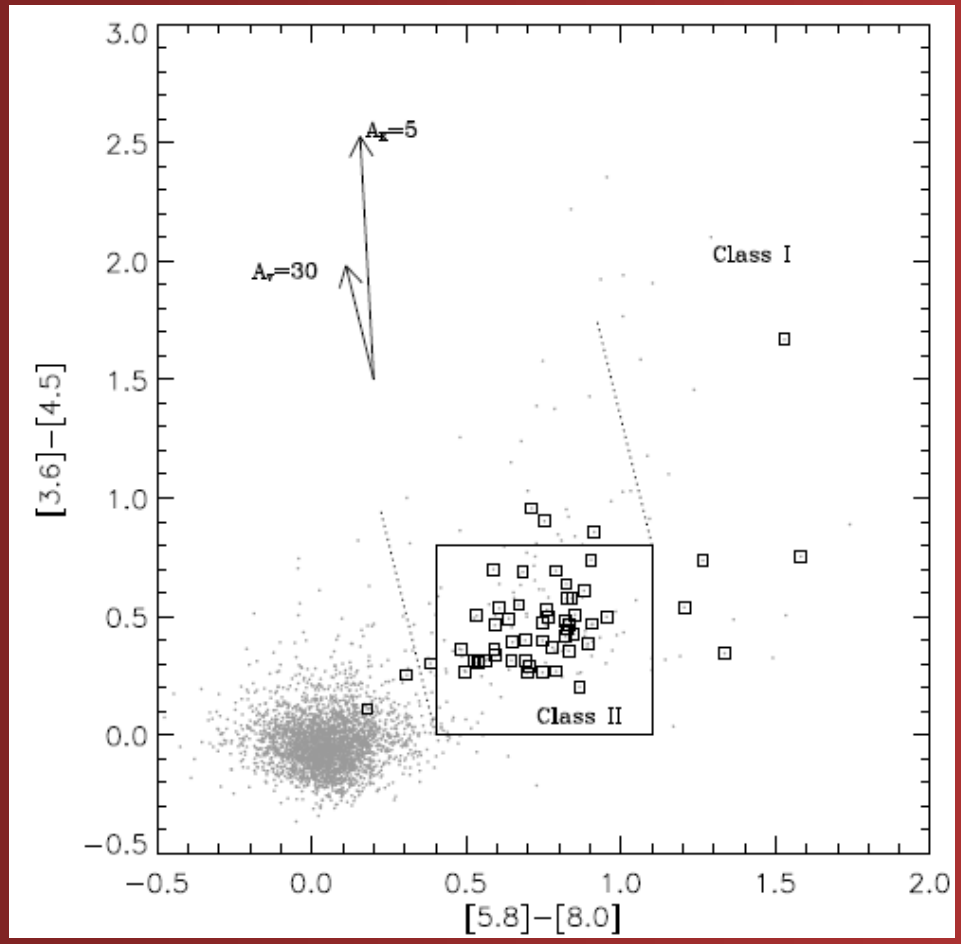
Number of stars	WFI detection	UKIDSS detection	IRAC detection	X-ray sources
504	*no*	*no*	*no*	504
9468	*no*	*no*	*yes*	89
126286	*no*	*yes*	*no*	116
25510	*no*	*yes*	*yes*	104
11378	*yes*	*no*	*no*	124
787	*yes*	*no*	*yes*	65
10100	*yes*	*yes*	*no*	298
6650	*yes*	*yes*	*yes*	624

Minima excesses

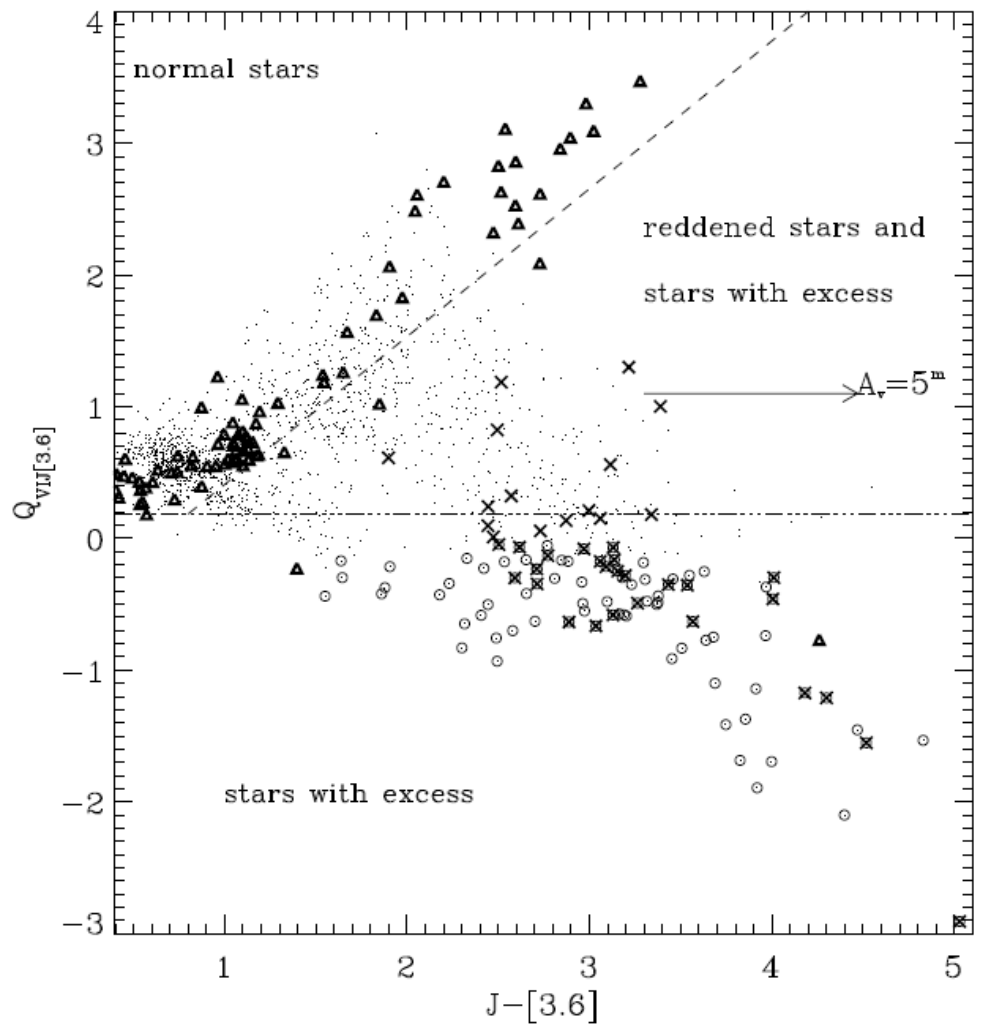




Qstars in CC IRAC:

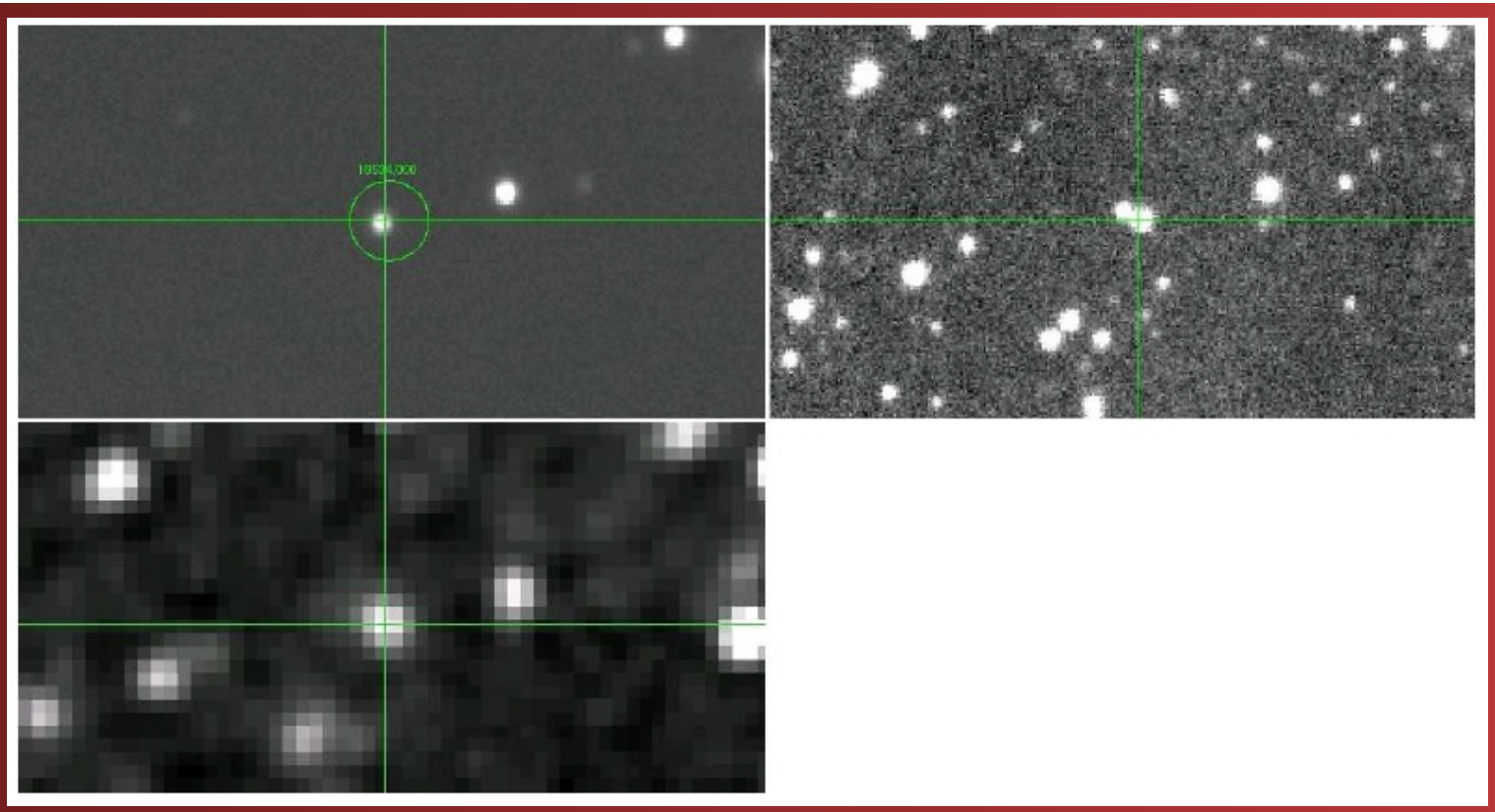


CCIRAC-excess stars in Q diagrams

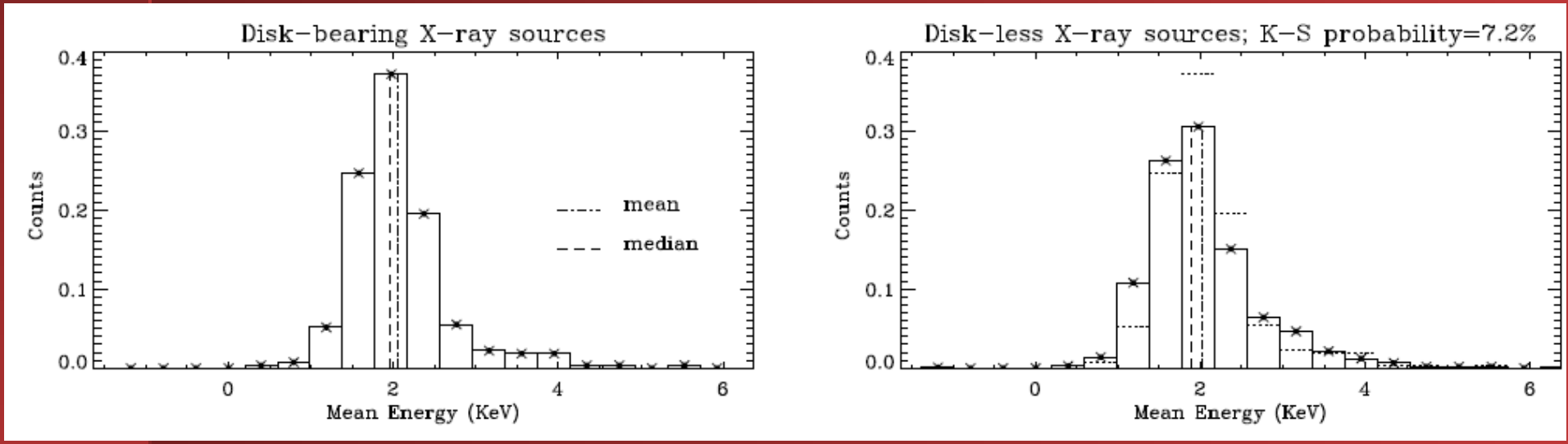


Qukidss and Q2mass

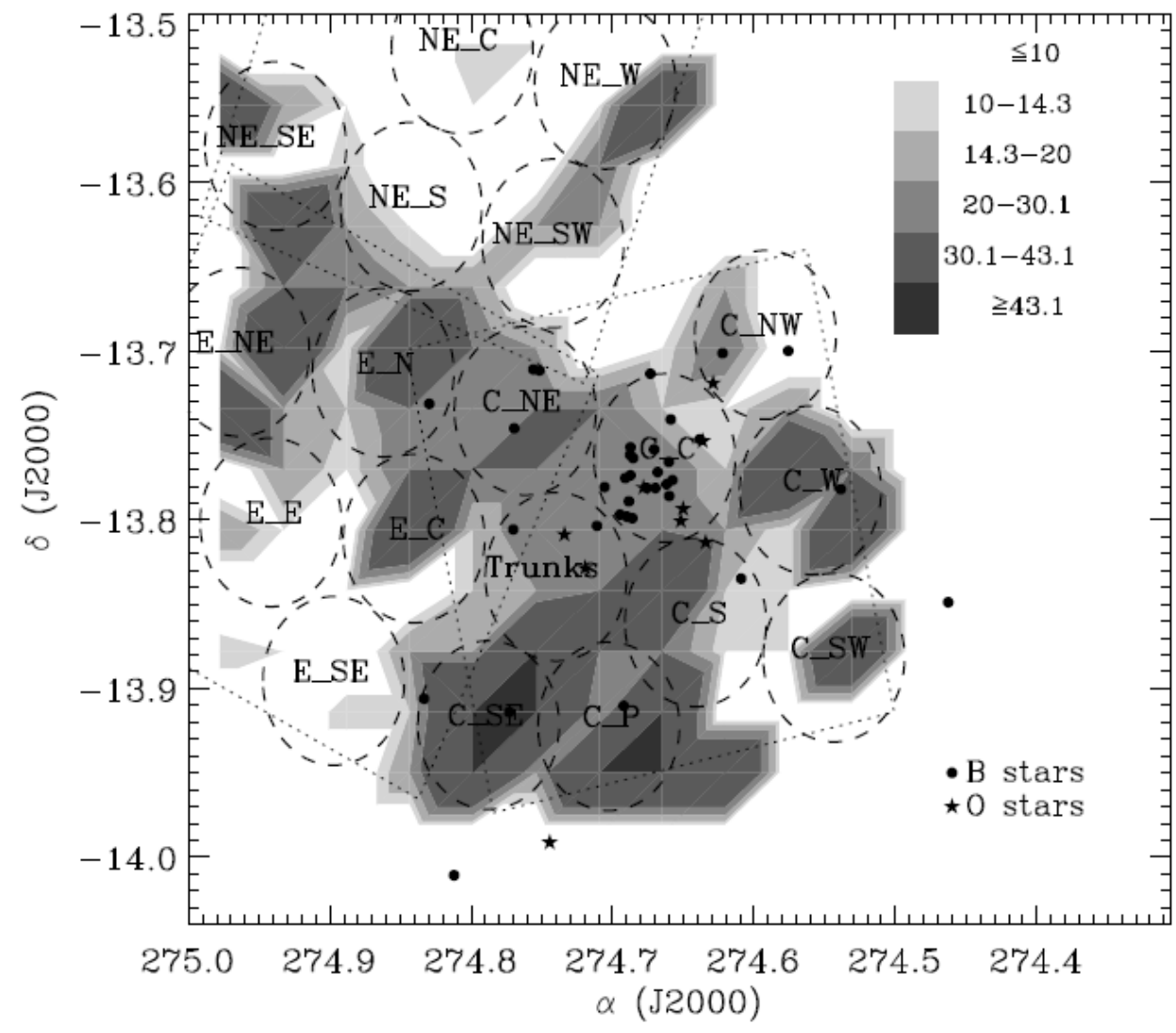
- 142 sources selected only with Q_{2MASS};
- 449 sources selected only with Q_{UKIDSS}, among which 181 are in the 2MASS Point Source Catalog;
- 317 sources in both lists.



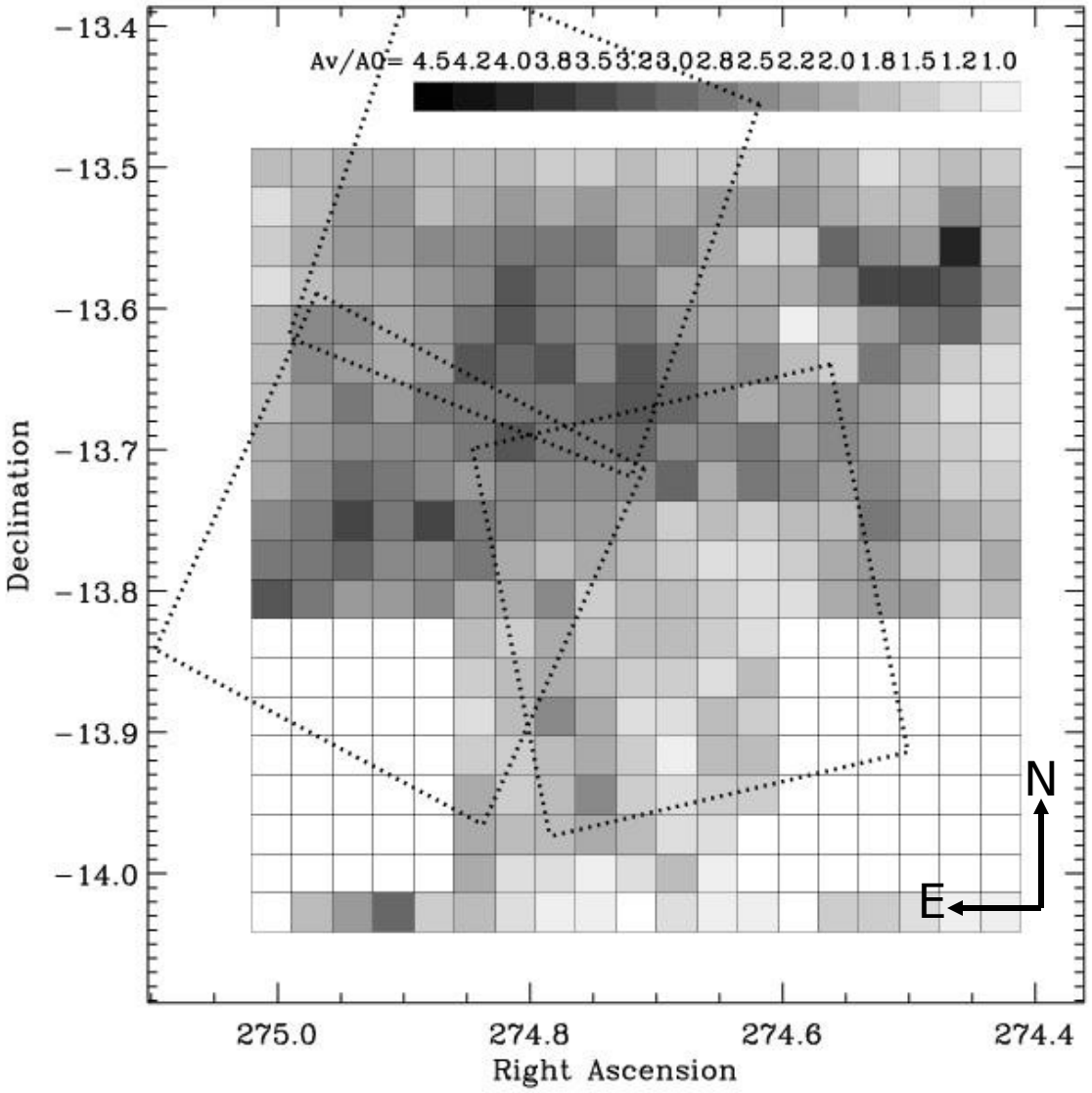
Xmedian energy for ClassIII and ClassI/II



Disk Frequency across M16



Absorption map



- obtained from UKIDSS sources without optical counterpart
- $E_{(H-K)} = (H-K)_{observed} - (H-K)_{giants}$

(Bessel&Brett et al. 1988)

- low Av in the central cavity
- Av increases northward up to Av~10