Star forming Knots in Grand Design Spiral Galaxies: NIR view

Spiral Structure-Star Formation Connection

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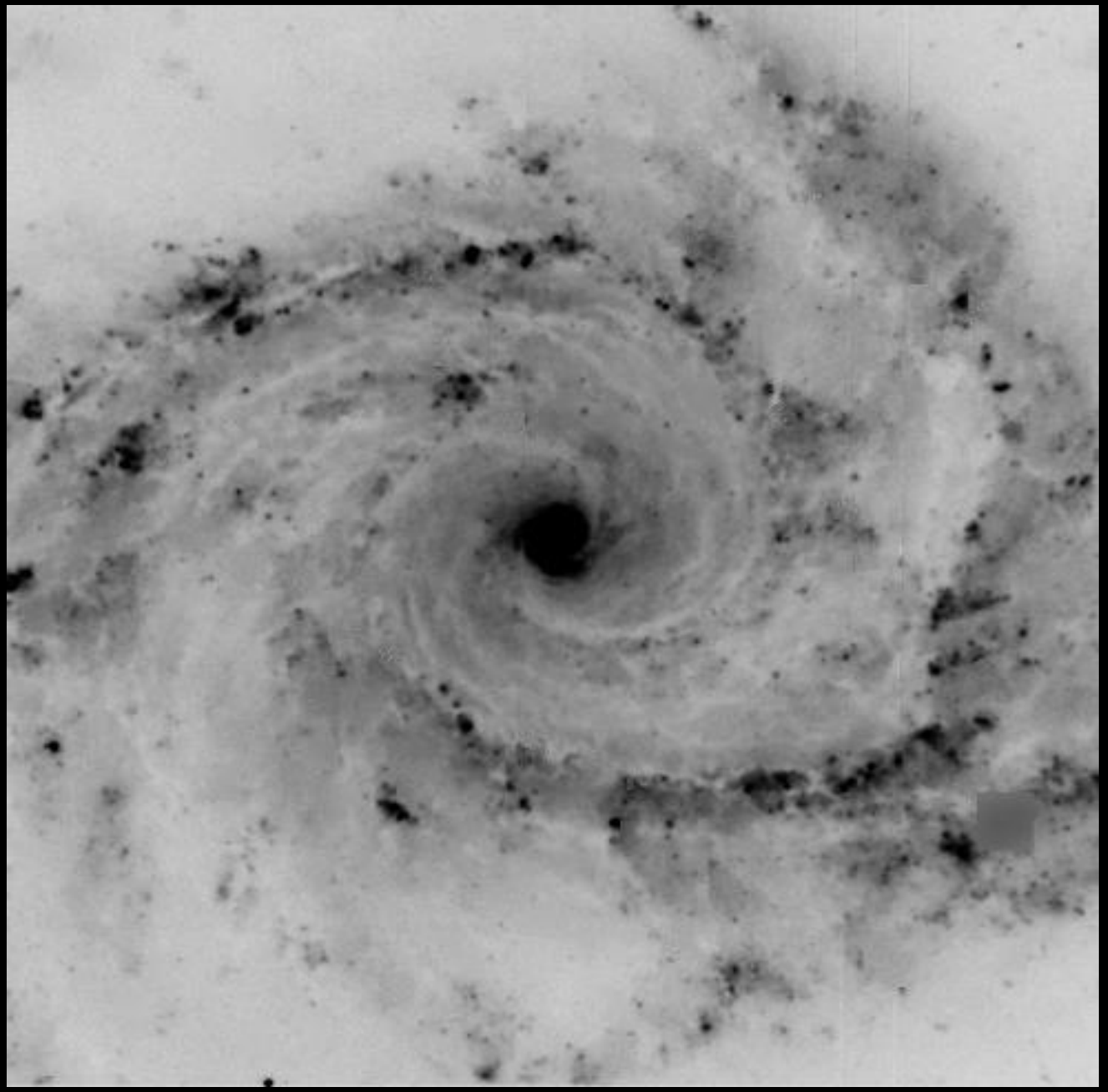
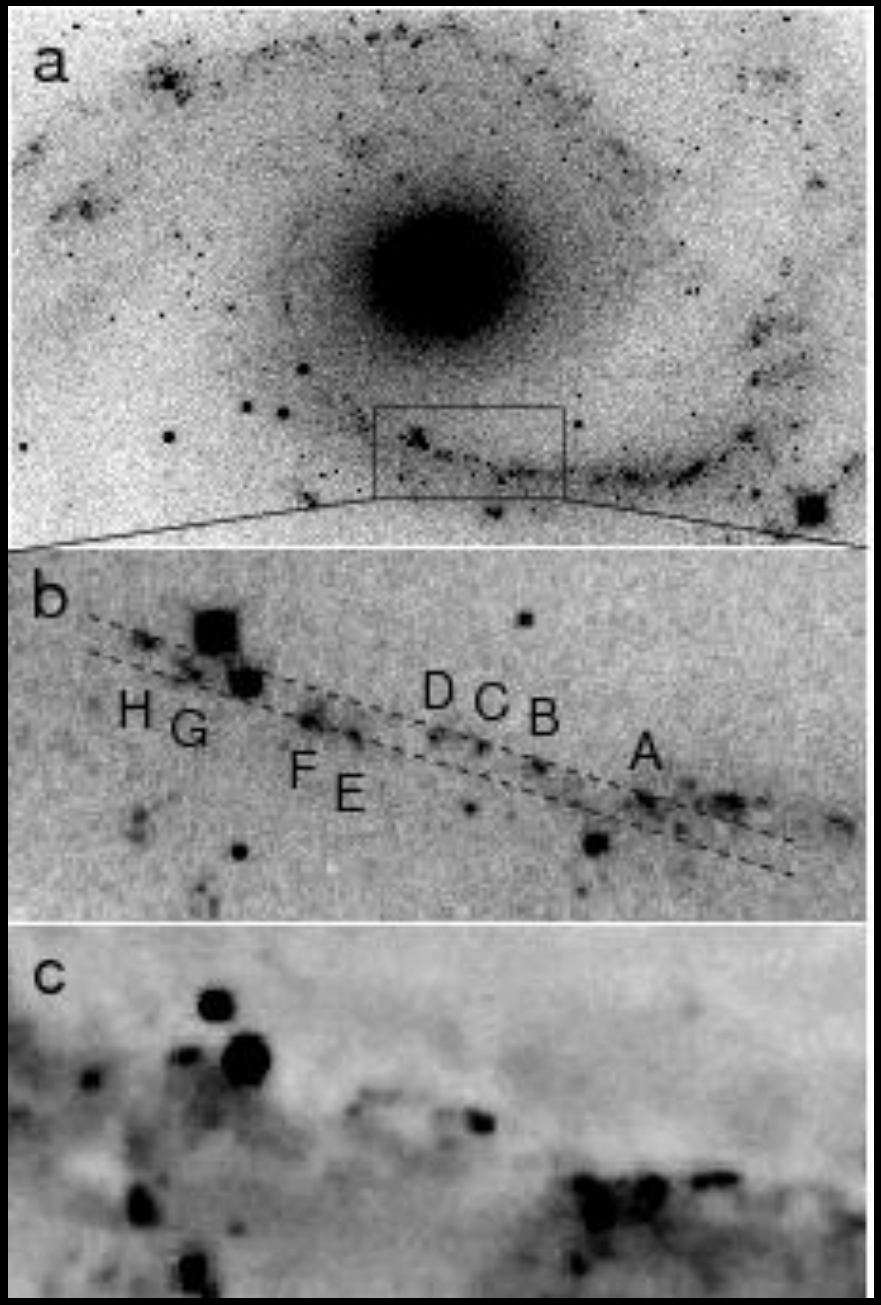
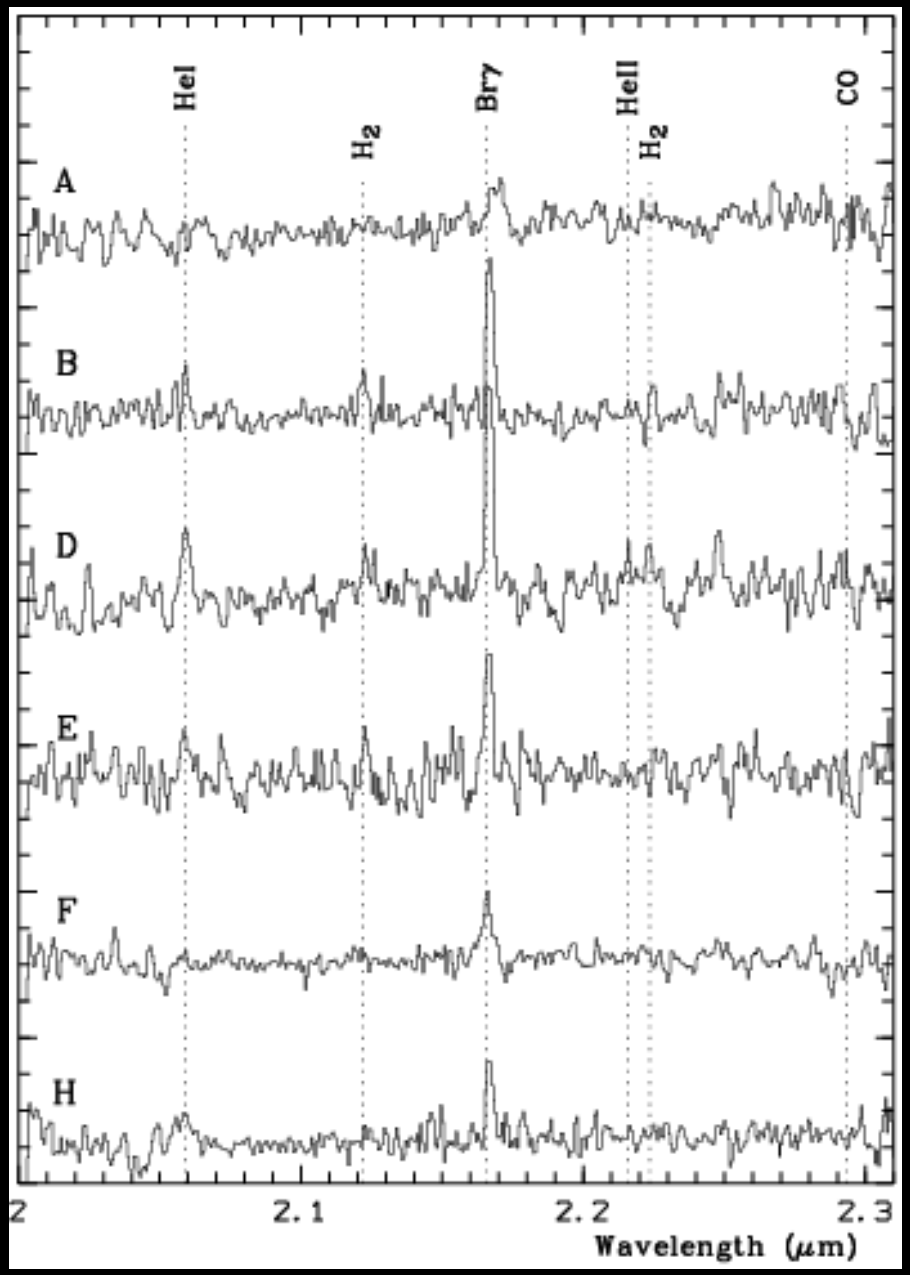
Objectives and Observations

- ***Objectives***
- Study relation between star-formation and spiral arms
- Properties of stellar clusters in grand-design spiral galaxies
- Unbiased sample of bright cluster complexes
- NIR photometry to reduce effects of dust lanes along arms
- ***Sample***
- 10 grand-design spiral galaxies
- Near face-on to allow good view of spiral structure
- Nearby to resolve star-forming complexes (i.e. <100pc)
- ***Observations***
- JHK maps using HAWK-I/VLT with 7' field
- Typical seeing 0.4″ with 0.1″/pixel
- Limiting magnitude K ~ 20 for >90% completeness

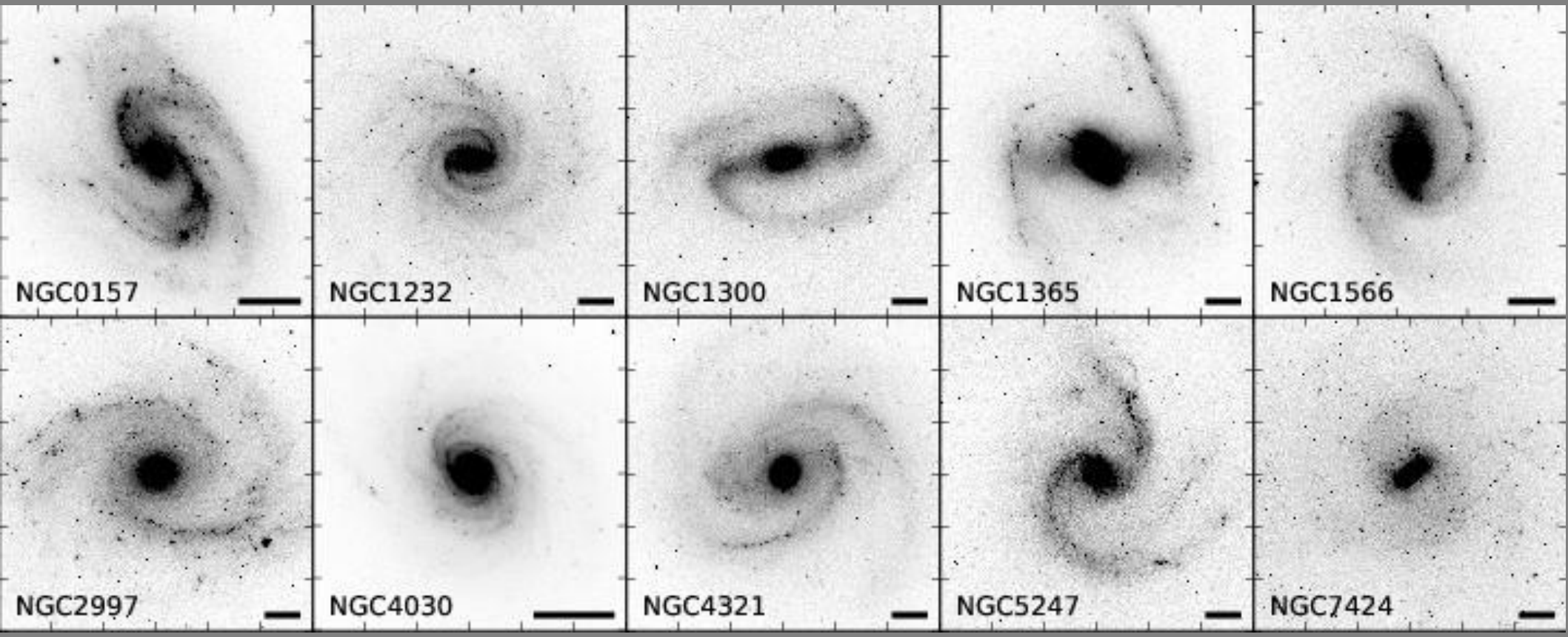
NGC 2997



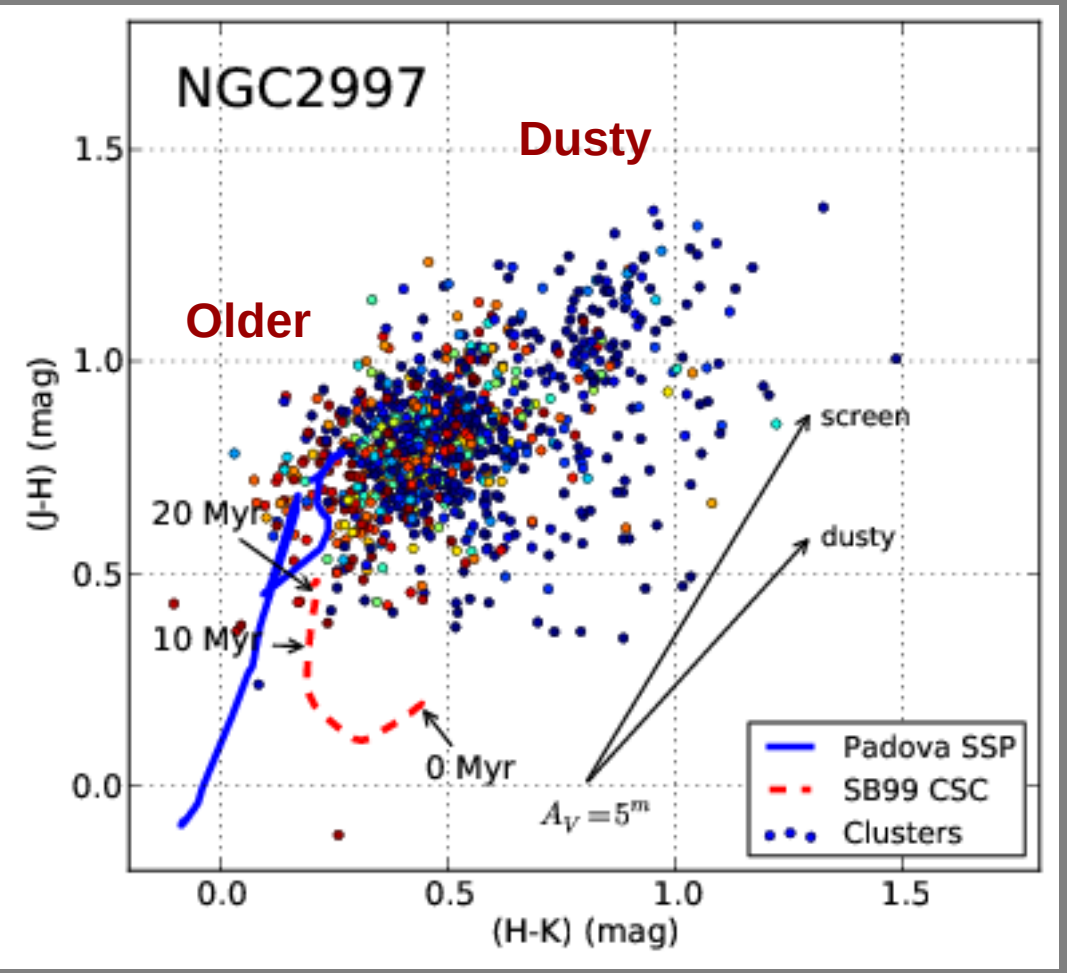

a
b
H
G
F
E
D
C
B
A
c


HeI
H2
Brγ
HeII
H2
CO
A
B
D
E
F
H
2
2.1
2.2
2.3
Wavelength (μm)

The Sample (VLT+HAWK-I



Color-Color Diagram



Two groups of clusters

Older clusters – low extinction

Dusty clusters - high extinction

All galaxies have both

But with different ratios

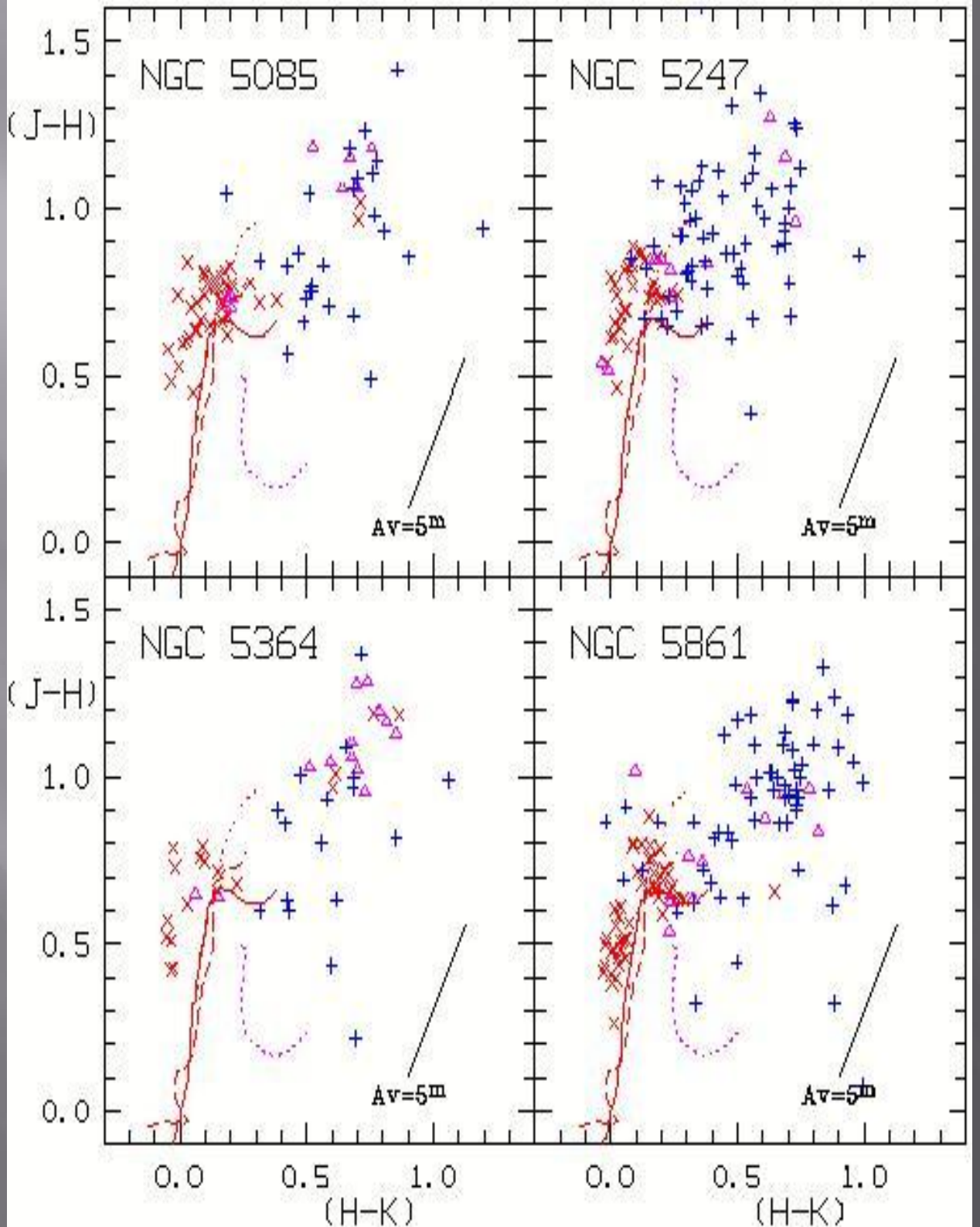
Scatter to high (H-K)

Nebular emission, hot dust

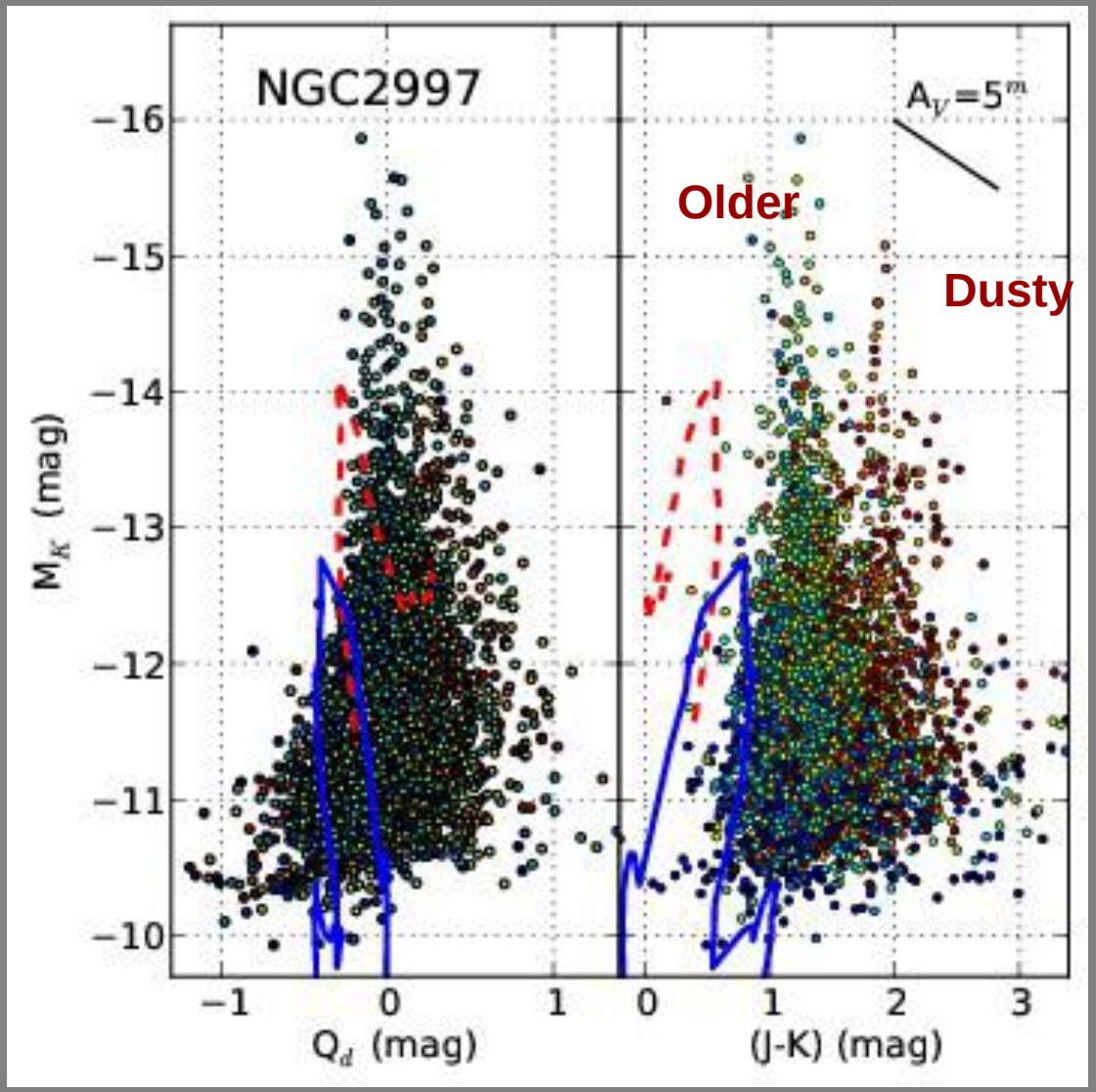
Younger clusters Higher extinction AV ~ 3-8m

Older clusters, Less dust extinction

Influence of AGB stars


NGC 5085
NGC 5247
NGC 5364
NGC 5861
(J-H)
(H-K)
1.5
1.0
0.5
0.0
Av=5m

Color-magnitude Diagrams



Reddening 'free' index

Q = (H-K) – 0.88*(J-H)

Correlates with Brg for 0.1<Q

Brightest clusters MK ~ -15m

Aperture photometry (dia: 1”)

Total mass >10^5 Mo

(J-K) – Mk diagram

Separation older-dusty branch

Dusty branch – young <10Myr

Gap suggests abrupt change

e.g. Dust expulsion after SN

Sharp left edge

Agree with models

Rightwards scatter due to dust.

Luminosity Function of clusters

Power law fit NdL = f L^-αdL

Range of α: 1.7 – 2.3

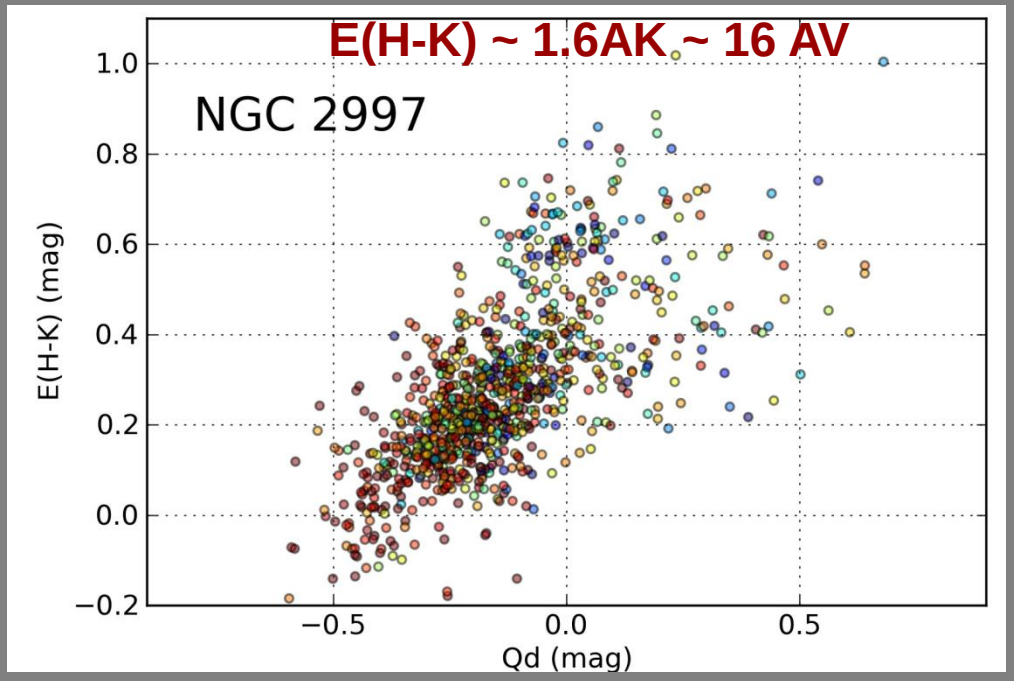
Issues of fixed aperture for bright sources.

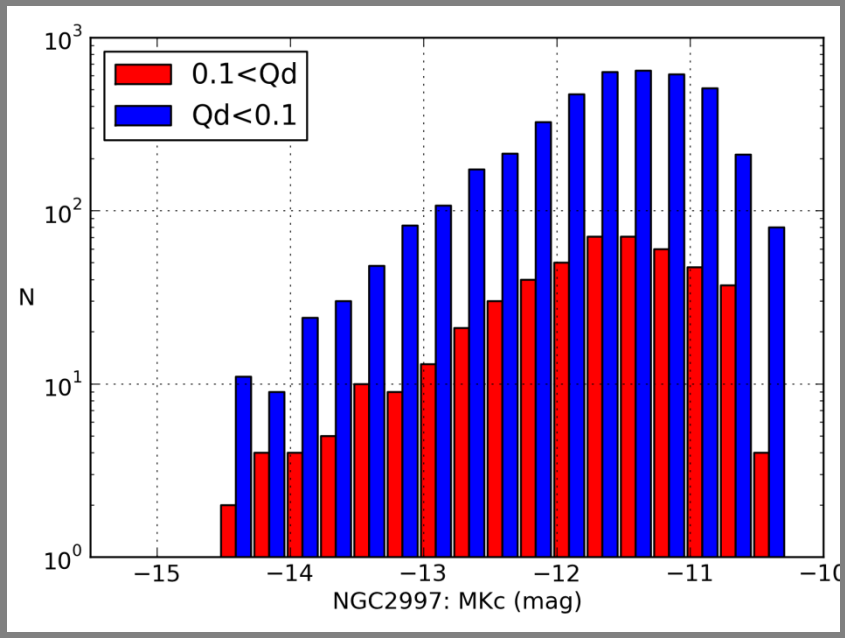
Extinction correction for K important

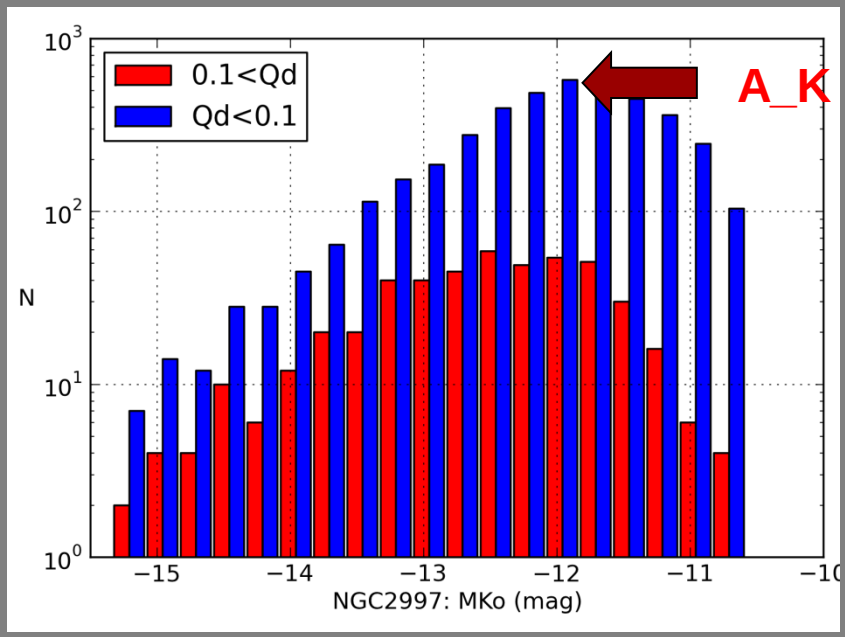
Correction somewhat model dependent

Luminosity Function of MK0

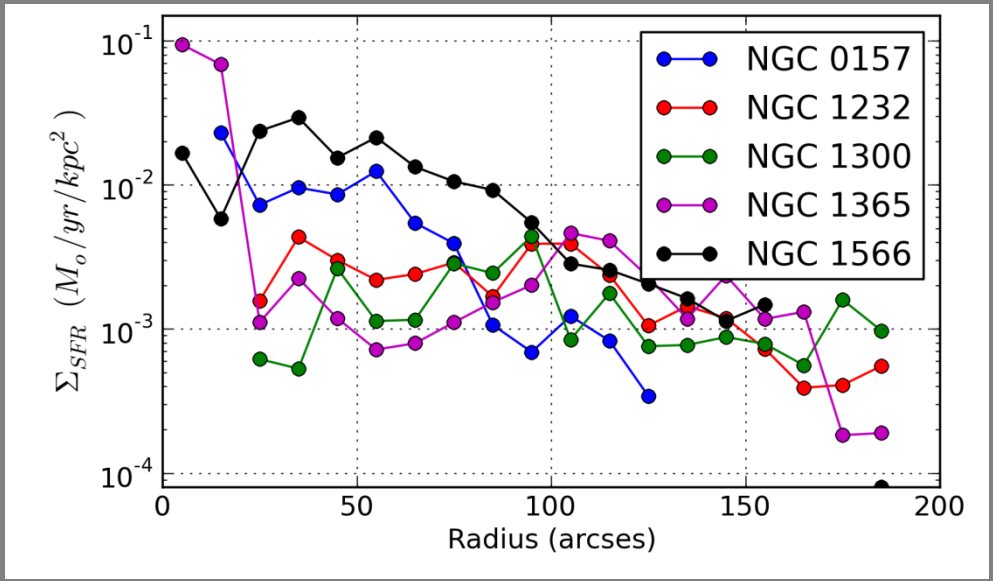
Marginal shallower than for uncorrected MK

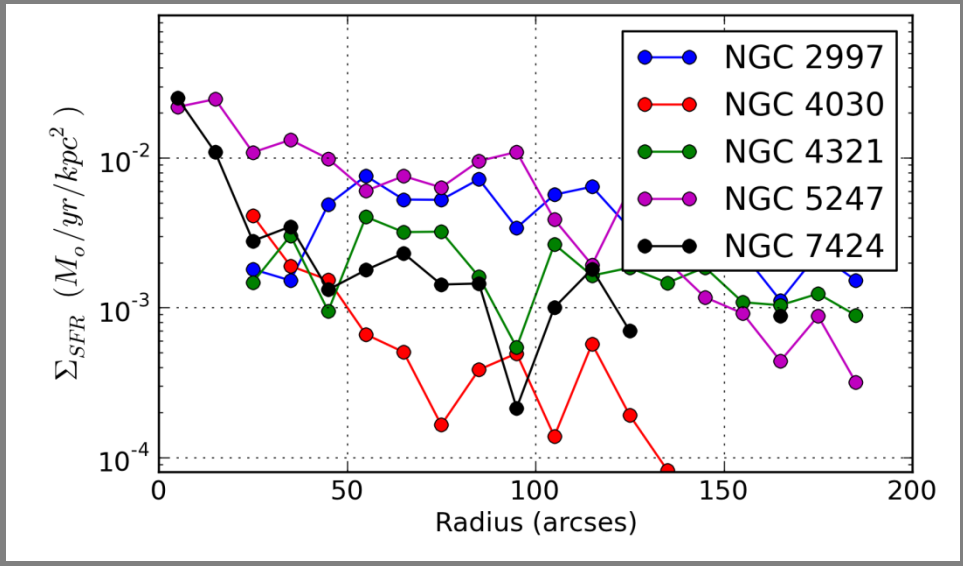






Stars-Formation rate





Star-Formation rate within last 10Myr (0.1<Q)

Assume MK0 = -15.5m ⟶ 10^6 Mo

Models dependent , mainly on Mu and IMF

Two type of radial variation within main disk

Declining outwards (e.g. NGC157, NGC1566, NGC 4030)

Constant SFR (e.g. NGC 1232, NGC 1365, NGC 2997)

No strong correlation with radial extent of main, two-arms spiral pattern

Galaxy	SFR (Mo/yr)
NGC 157	1.4
GNC 1232	1.6
NGC 1300	1.4
NGC 1365	2.9
NGC 1566	5.0
NGC 2997	3.6
NGC 4030	0.5
NGC 4321	2.9
NGC 5427	5.4
NGC 7424	0.2

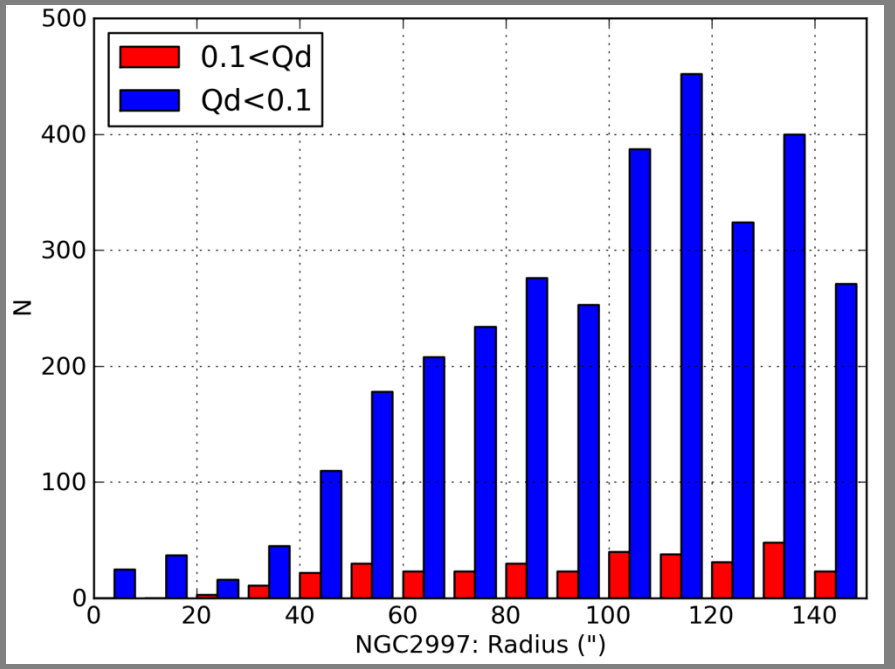
Radial distribution of clusters

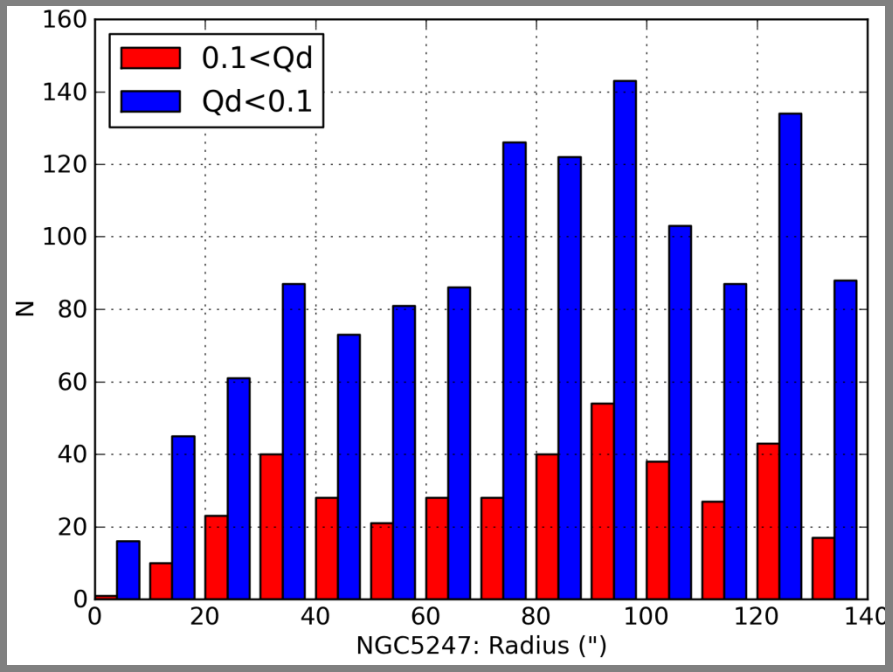
No. of clusters per radial bin

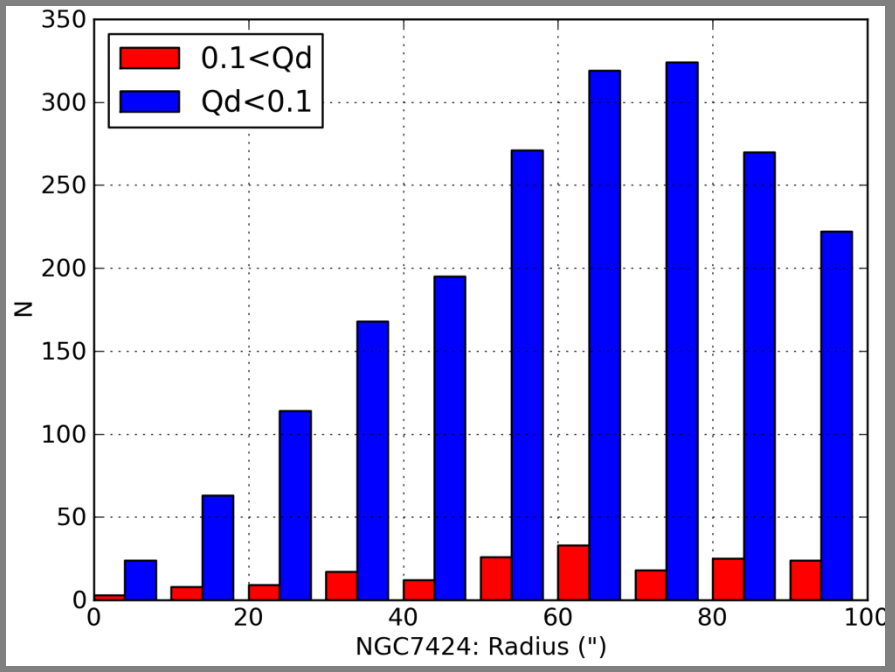
- Young cluster (0.1<Q)
- Almost constant over disk

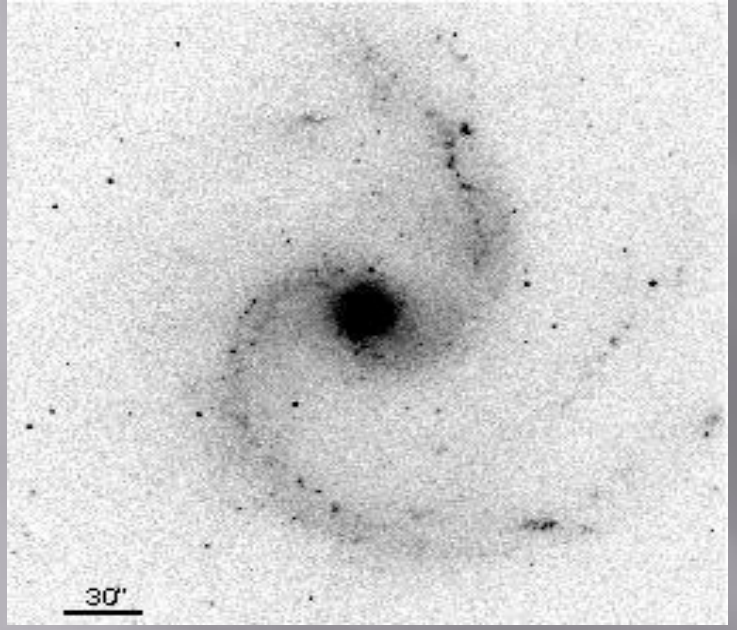
Older clusters (Q<0.1)

- Increase in inner parts
- Decline outside main spiral pattern

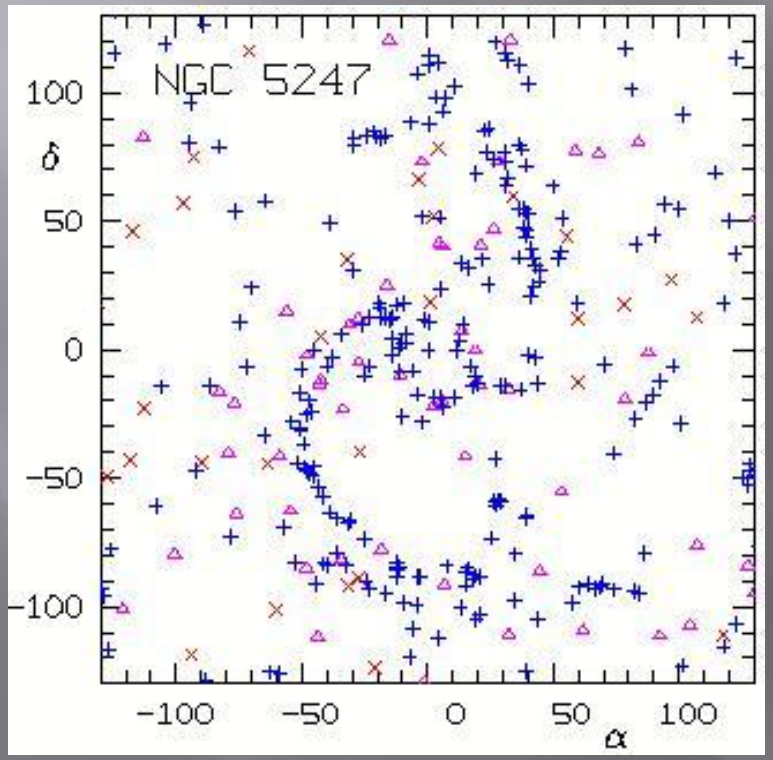






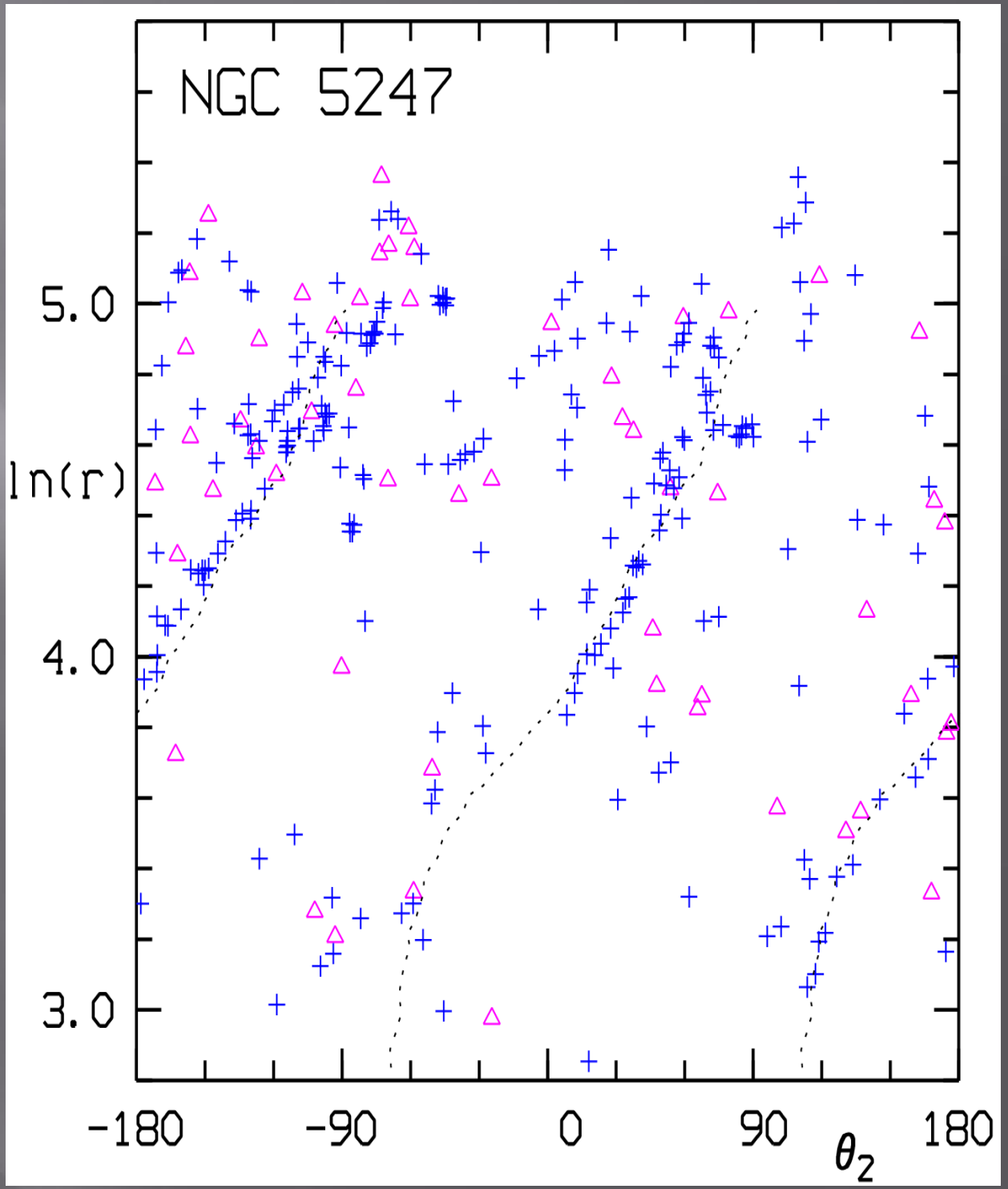


- NGC 5247: NTT K-image.



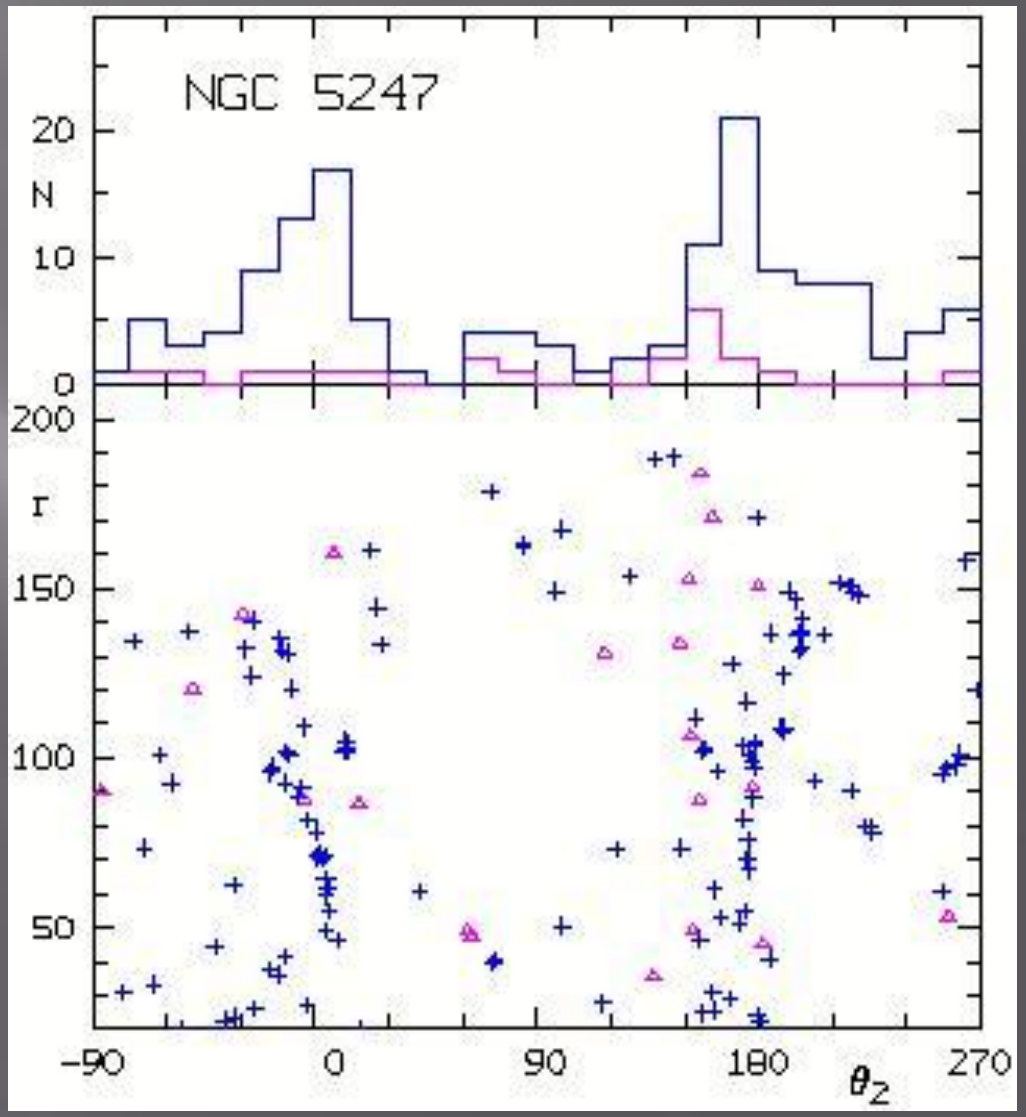
- Distribution of IR sources.

- **θ vs logR diagram:**
- distribution of objects vs ridge of the K-arms, obtained by FFT.
- remarkable:
- there is a shift in the alignment between emitting knots and K-arm.
- Knots formation is also detectable in the interarm region.
- A considerable part of the arms is a logarithmic spiral.



- Knots position with respect to the FFT K-arm.

- Bar diagram shows the spread of regions around the FFT arm.



(H-K)-(J-H) diagrams indicate two groups of clusters

Dusty, younger clusters with high extinction <10Myr

Older clusters with lower extinction

(J-K)-MK diagrams show gap between these groups

Suggesting an abrupt expulsion of dust at ages <10Myr

Possibly associated to explosion of first SN

Luminosity function with exponent α ~ 1.7 – 2.3

Extinction corrections important in K for young clusters

Radial distribution of young clusters is flat

Arm/inter-arm populations of clusters are different

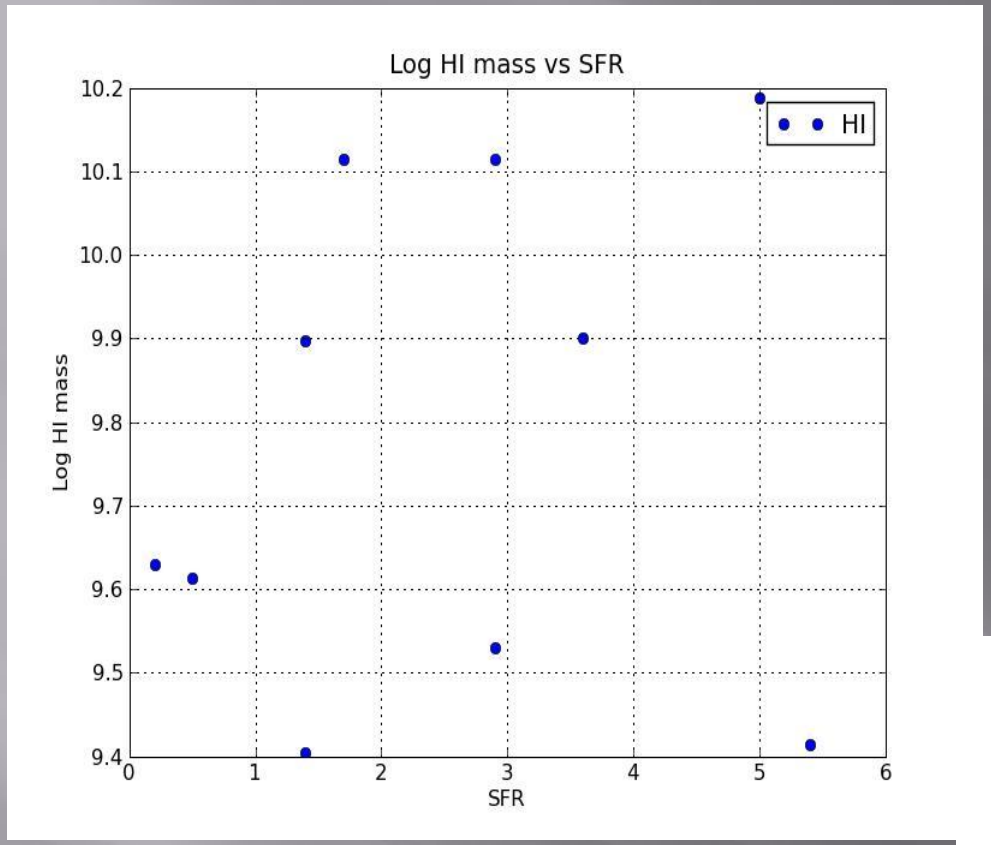
Youngest and brightest clusters are concentrated in arms

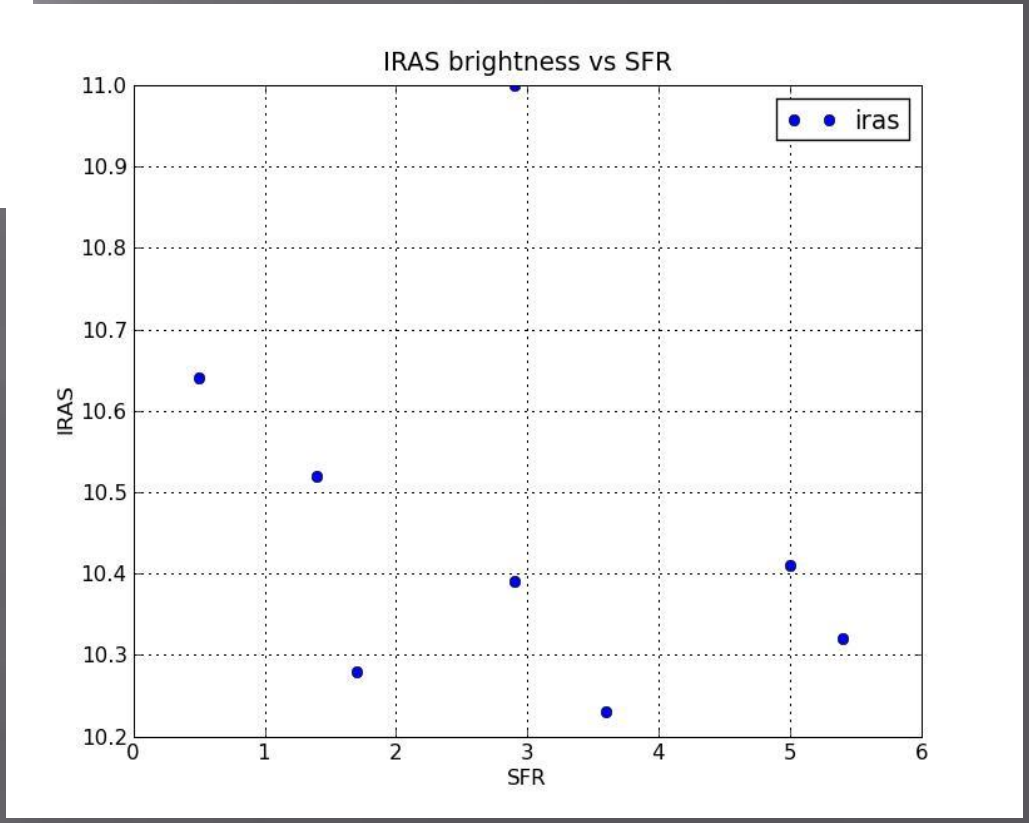
Young clusters are also seen in inter-arm regions

Older, fainter clusters are more uniformed distributed

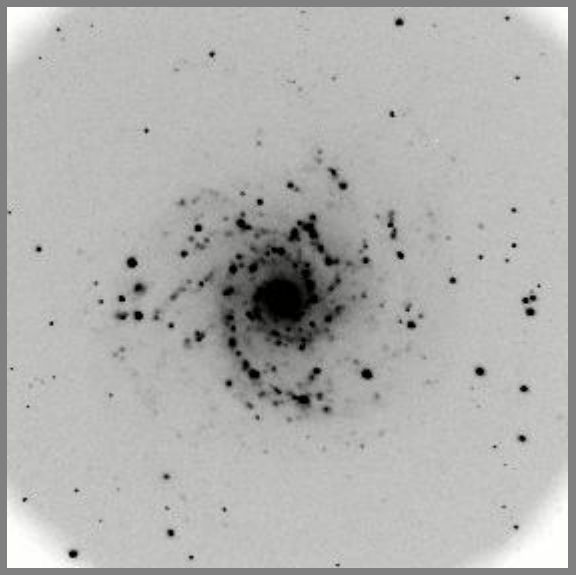
Outside main spiral pattern distribution more uniform

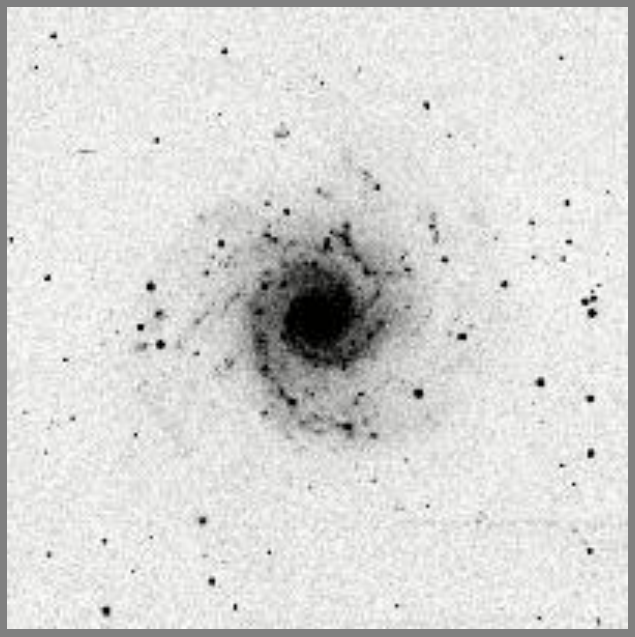
SFR vs. HI-mass, IRAS luminosity and CO.

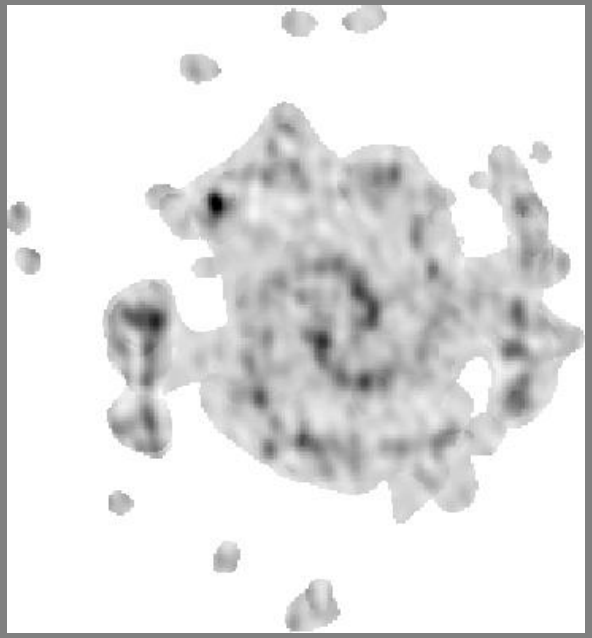

Log HI mass vs SFR
HI
Log HI mass
SFR
10.2
10.1
10.0
9.9
9.8
9.7
9.6
9.5
9.4
0
1
2
3
4
5
6


IRAS brightness vs SFR
iras
IRAS
SFR
11.0
10.9
10.8
10.7
10.6
10.5
10.4
10.3
10.2
0
1
2
3
4
5
6

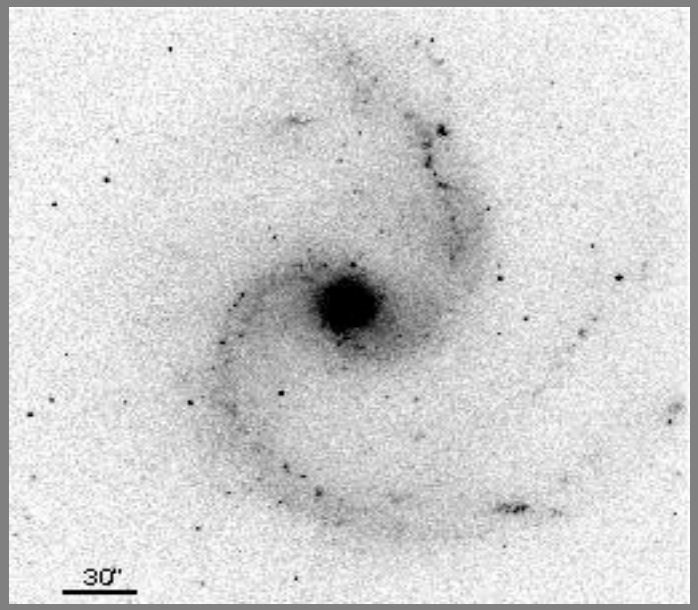
Optical, H_alpha and BIMA-SONGG NGC 628



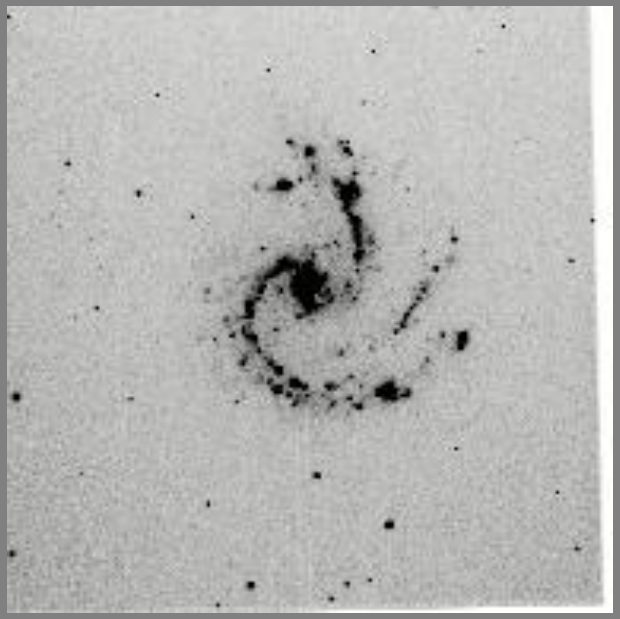




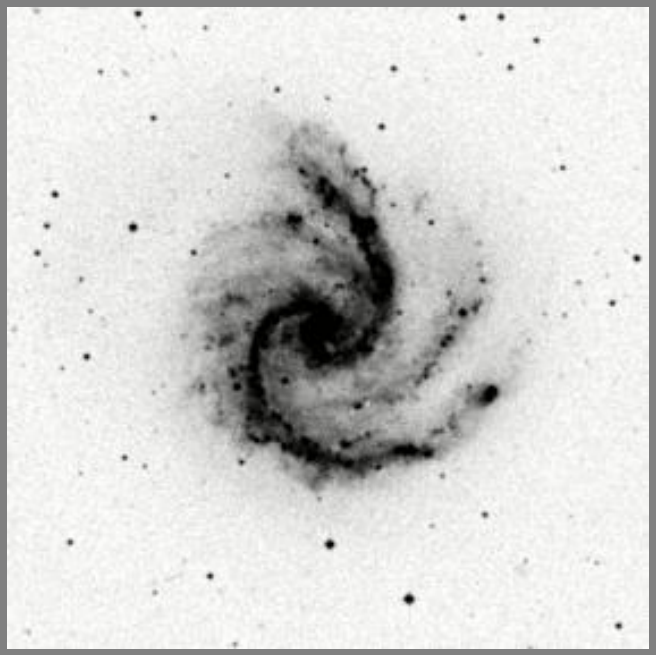
NGC 5247



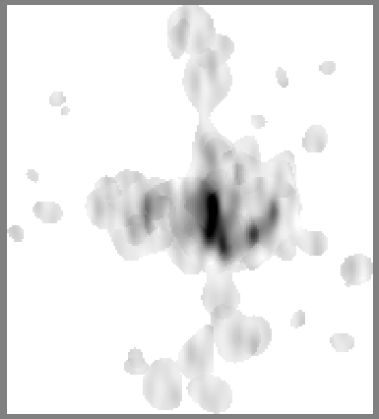
K-band, NTT



Halpha JKT



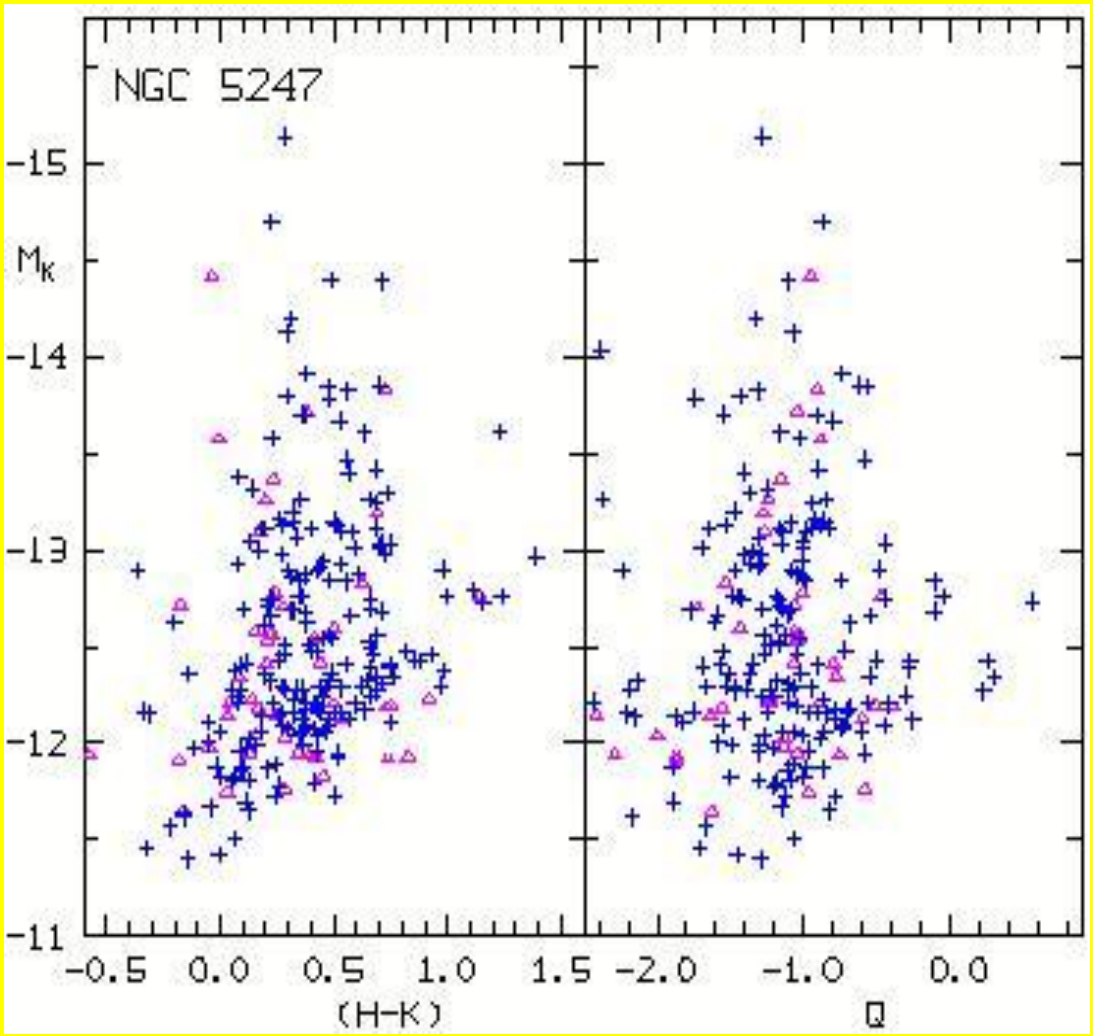
IIIaJ UK 48 Schmidt



CO BIMA-SONGG

Proposal for LLAMA-ALMA

- LLAMA spatial resolution to observe the disk of the galaxies in CO line.
- ALMA (+LLAMA) high spatial resolution to observe arms details and compare to the very young SFR.

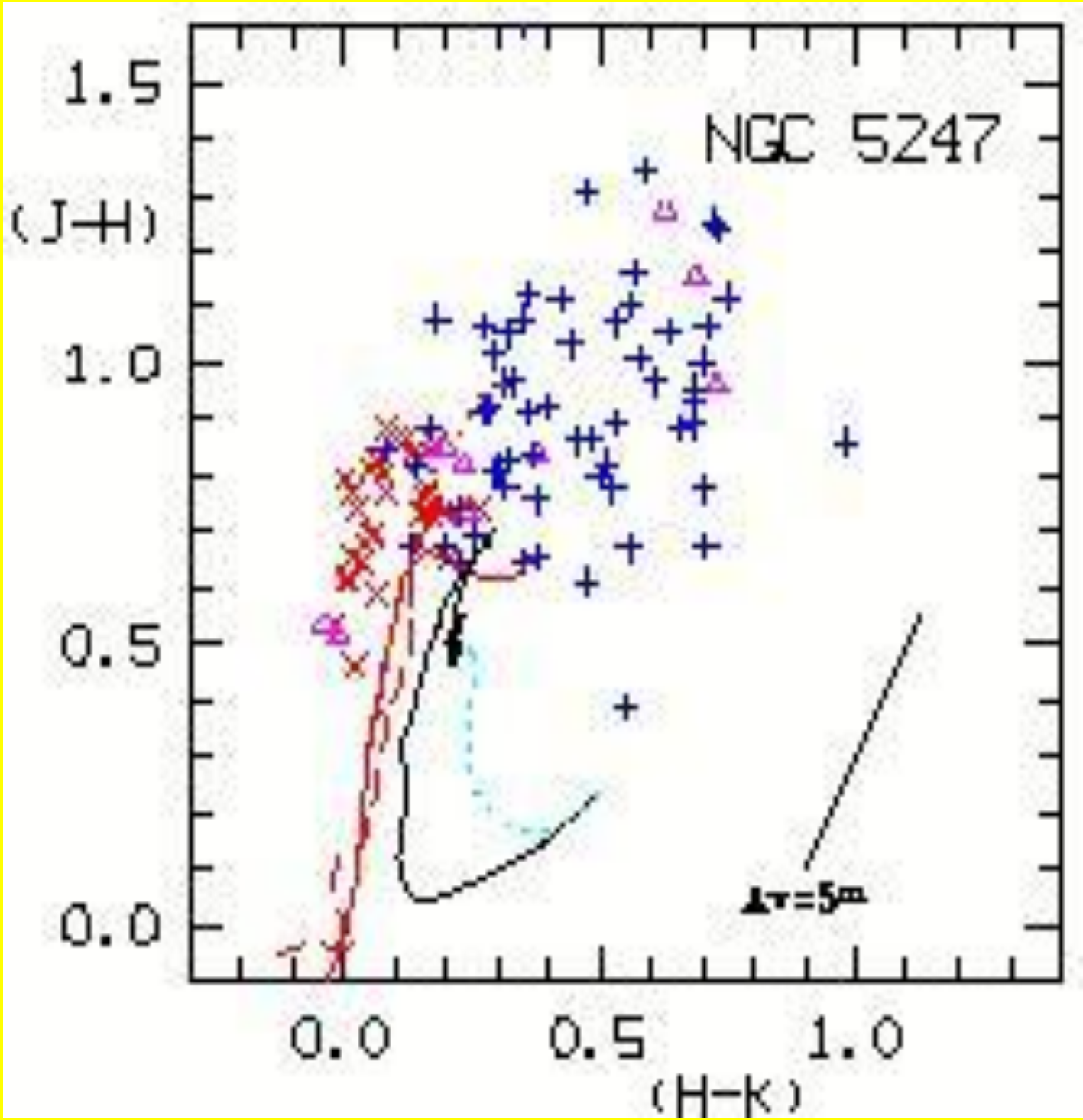


- CMD diagram
- Clusters with K< -14 requiere:
- old SB99 models with
- M>10^6Msol
- or young models with

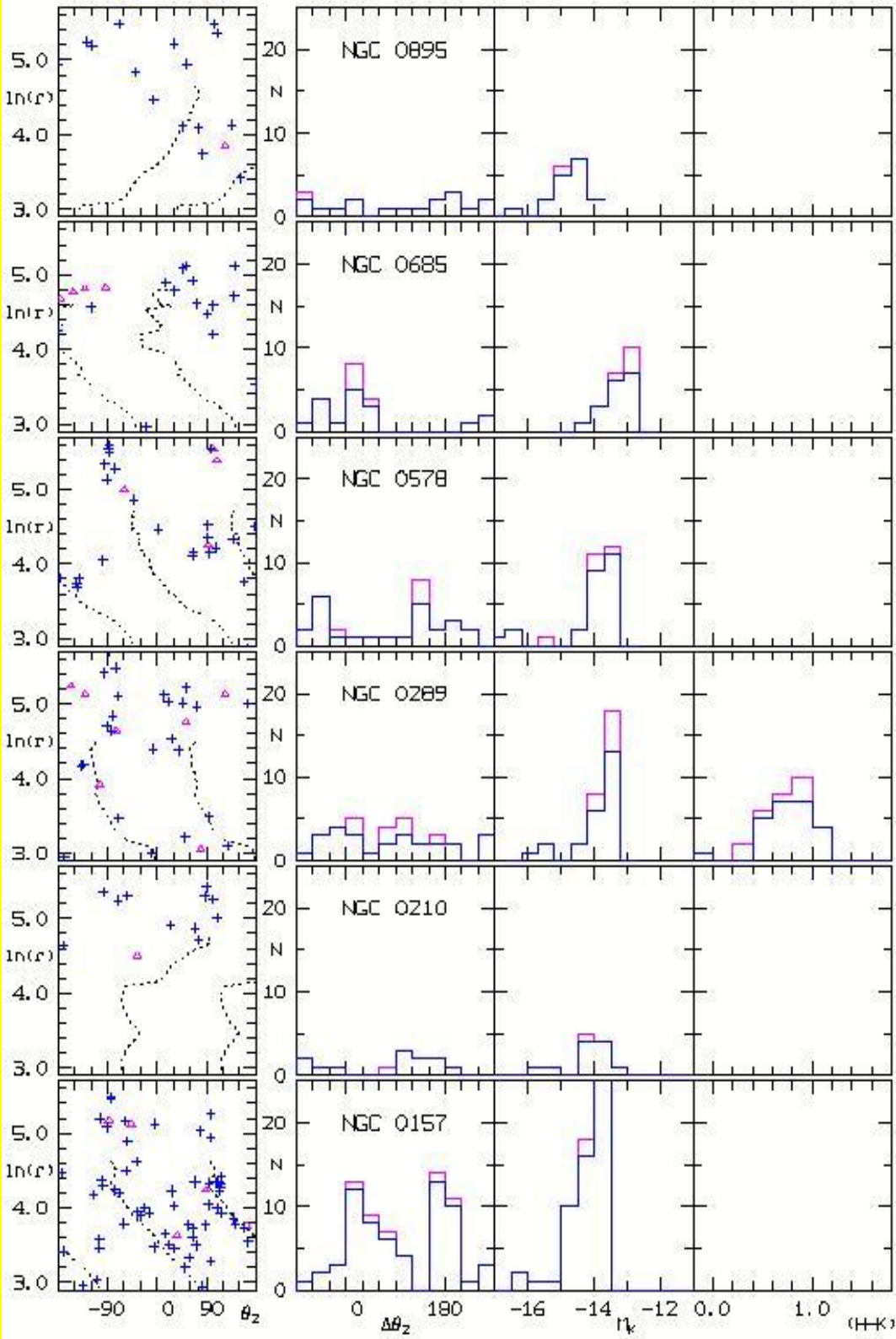
  M>several 10^6Ms

stars => small shift in calibr.

- knots position compatible with SB99 + abs.
- left, no absorption.
- right, Av>5.
- Knots don't reach models.
- SB99 models and * MS shown

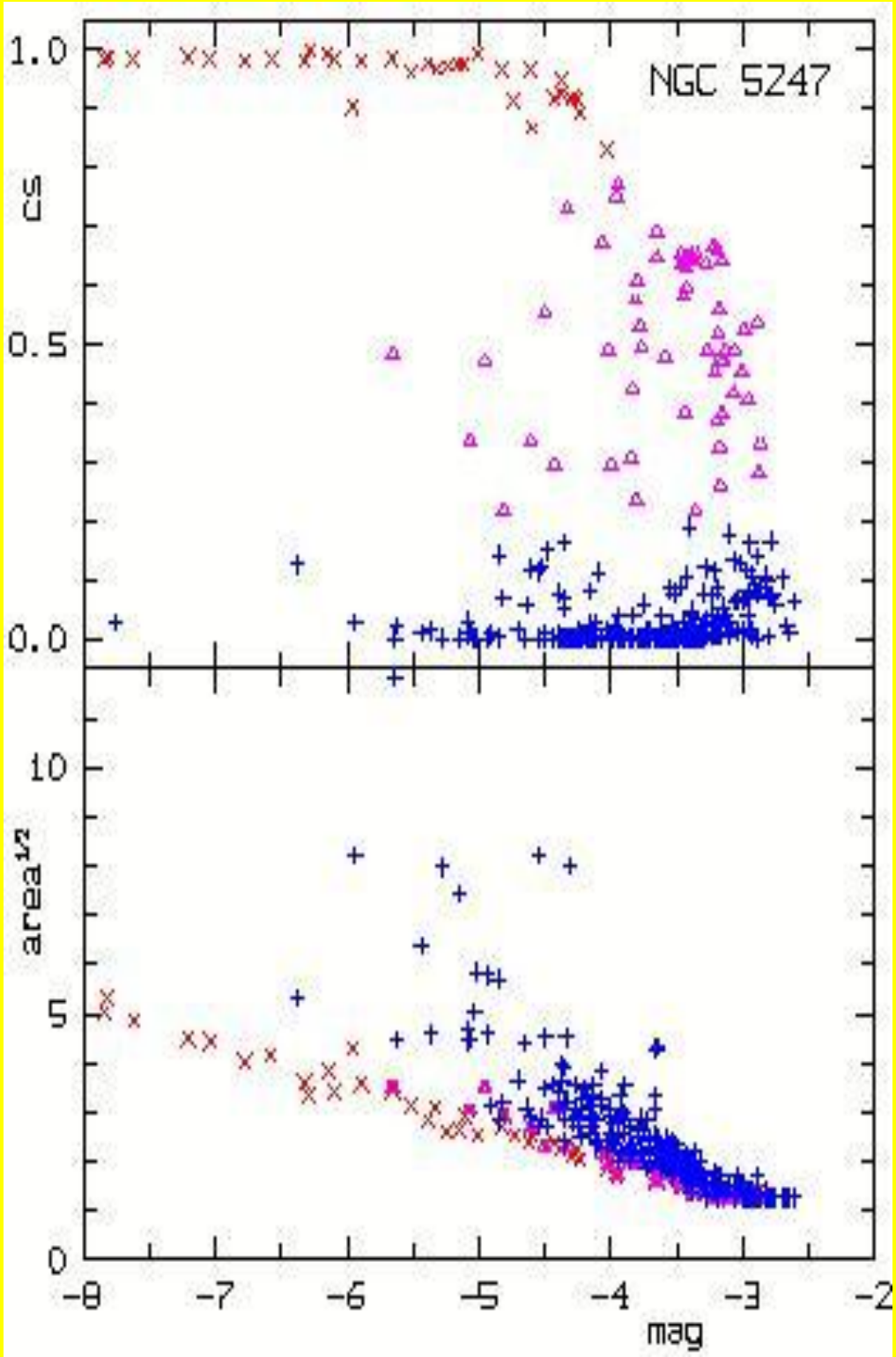


- Log R vs Theta
- Number of knots vs DTheta.
- Brightness histogram.
- Color histogram.



Conclusions

- The knots are mainly v. young embedded HII regions. ***11 out of 48 Spirals*** shows really clear link Arms Clusters-Formation.
- Masses are 10^4<M/Msol<10^6.
- ***Objects*** seems to be ***younger than*** deduced from ***SB99 models*** and certainly younger than the neighbour optical HII regions.
- Statistically, ***dust*** might be an ***age indicator***.
- Dust may process a large amount of the ionizing radiation, making the determination of ages through W(BrG) not so precise (Dopita, 2007).
- Distribution follows mainly the arms (angular momentum disipation), but there are ***knots not clearly linked to arms***.



- ***Sextractor*** ***(Bertin & Arnouts 1996)***
- separate objects by stellar class.
- ***Theoretical counts***
- Models of MW stars counts ***(Robin et al 2003)***
- Models of background galaxies counts (Ellis & Bland-Hawthorn 2006).
- ***Mean Color of MW GC***
- (J-H)~0.69+-0.09,
- (H-K)~0.24+-0.06

Motivations

- To know the origin of NIR emitting knots located mainly along spiral arms, shifted with respect to optical HII regions.

  To determine the physical characteristics and the evolutionary state.

- To complement or correct the rate of star formation derived by SINGG (Hannish 2006, Meurer 2006).