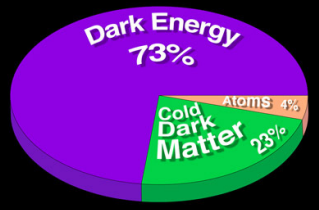
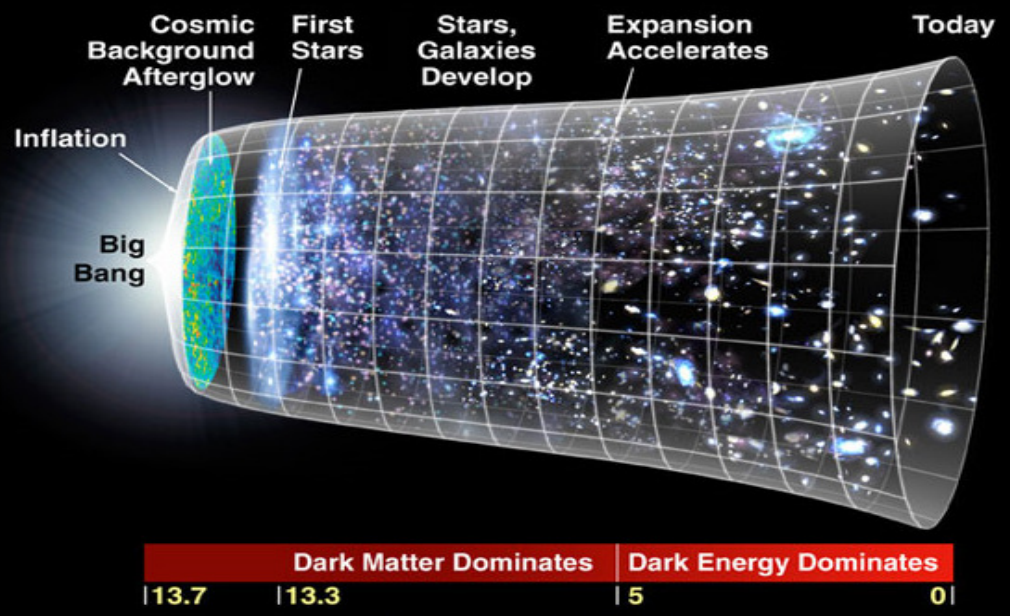

The Formation of Galaxies
ACTIVIDADES COMPLEMENTARIAS DE
INVESTIGACIÓN, Dep. Astro. + IAC, 2009
J. Sánchez Almeida,
C. Muñoz-Tuñón,
J. A. Aguerri

Summary

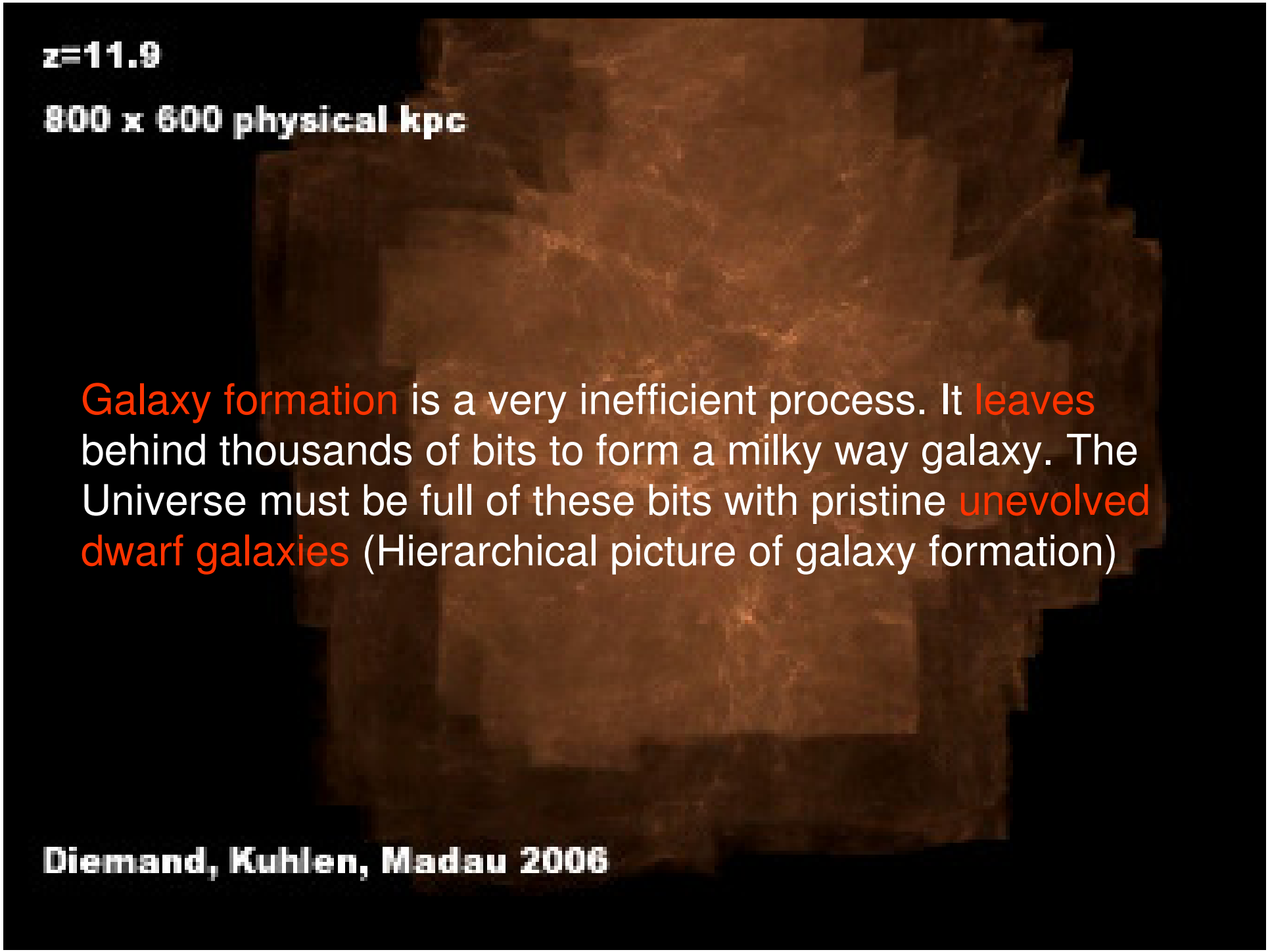
- **B**rief intro to hierarchical galaxy formation
- **T**he group : estallidos etc.
- **S**elected topics of research
- **ASK**: unsupervised spectral classification of galaxies
- **C**onclusions

Brief on Hierarchical Galaxy Formation



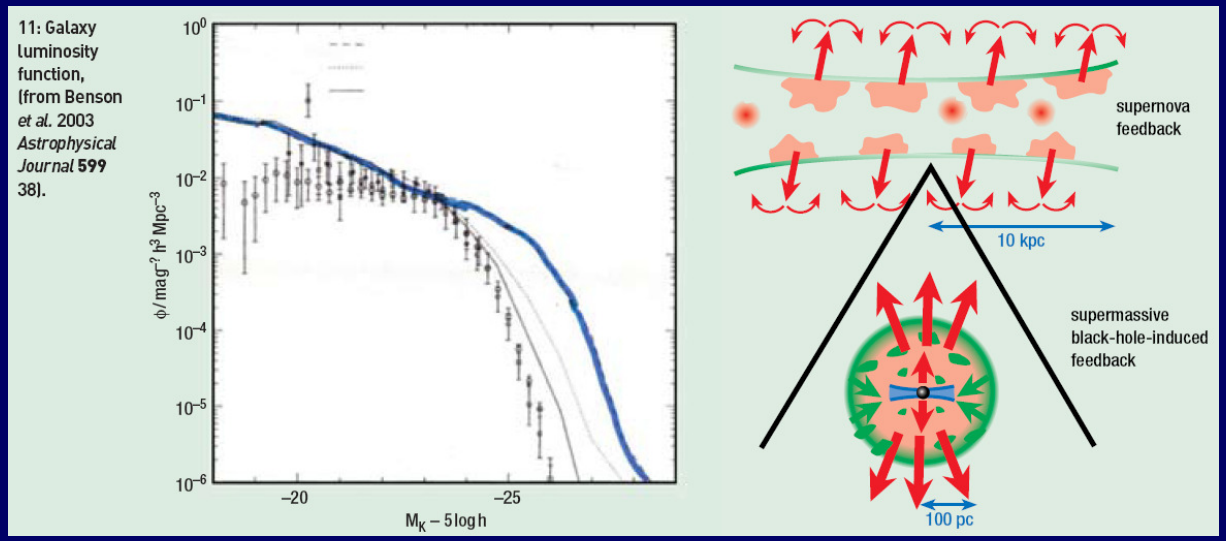


- Galaxy formation is dominated by gravity
- Dark matter plays a key role. There is no time for the galaxies to form unless there is plenty of dark matter!
- However, we just see atoms!


z=11.9
800 x 600 physical kpc
Galaxy formation is a very inefficient process. It leaves behind thousands of bits to form a milky way galaxy. The Universe must be full of these bits with pristine unevolved dwarf galaxies (Hierarchical picture of galaxy formation)
Diemand, Kuhlen, Madau 2006

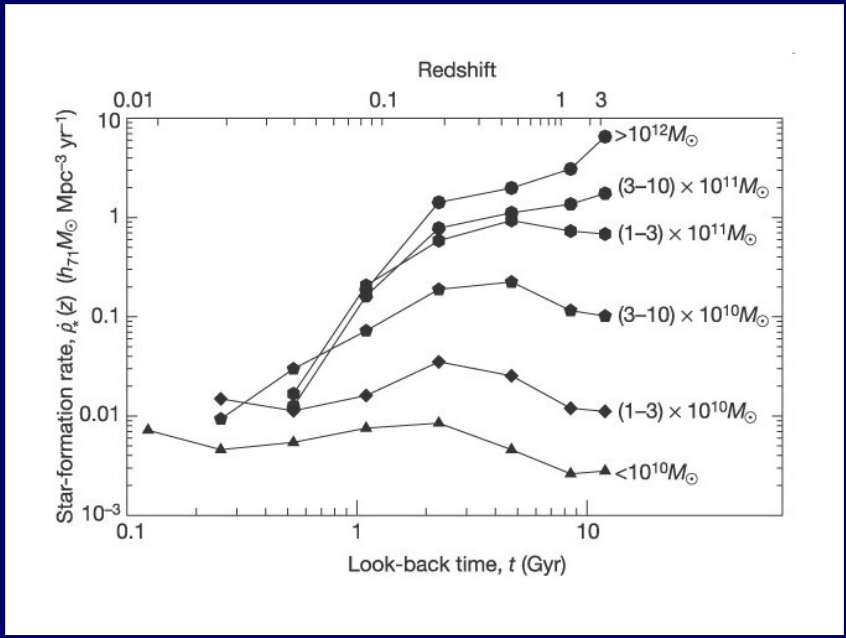
Plenty of successes, but plenty of unknowns as well,

- Where are the bits? Supernova feedback
- Where are the monsters? Black Holes feedback



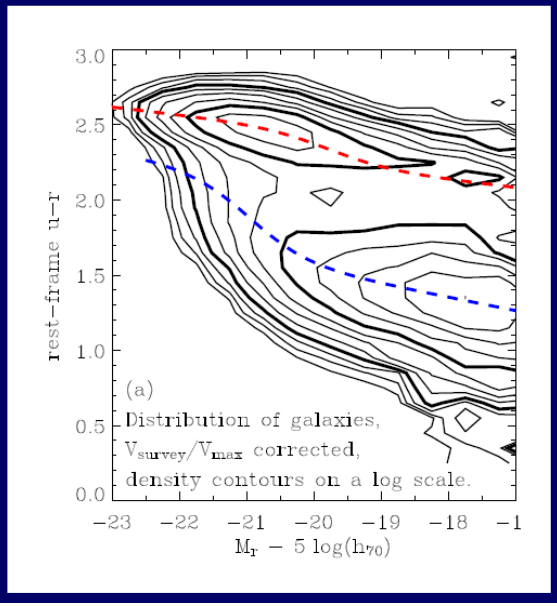
❑ Why small galaxies are younger than big galaxies? Downsizing

Star formation history ⟶



Heavens et al. (2004)

❑ Why galaxies follow a color sequence? Mergers, harassment and passive evolution.



The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
http://sings.stsci.edu/

Ellipticals

Irregulars

Strong Bulge

Strong Bulge

Unbarred Spirals

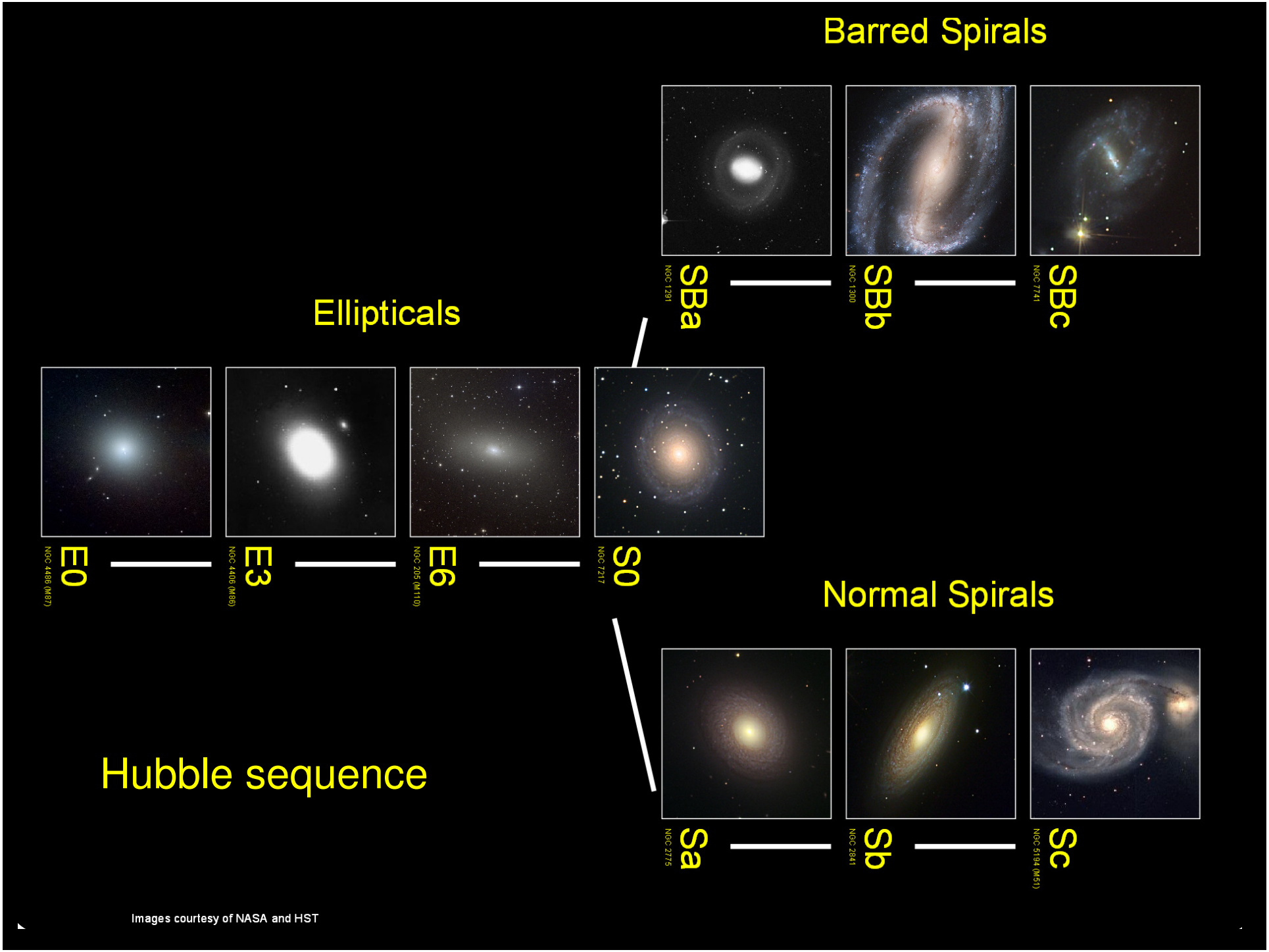
Weak Bulge

Intermediate Spirals

Weak Bulge

Barred Spirals

SINGS Team


Barred Spirals
SBa
NGC 1291
SBb
NGC 1300
SBc
NGC 7741
Ellipticals
E0
NGC 4486 (M87)
E3
NGC 4406 (M86)
E6
NGC 205 (M110)
S0
NGC 7217
Normal Spirals
Sa
NGC 2775
Sb
NGC 2841
Sc
NGC 5194 (M51)
Hubble sequence
Images courtesy of NASA and HST

The group : estallidos etc.

Large old group at IAC, … elsewhere (spain, mx, us, germany, …)

Proven expertise in supervising theses.

CMT leading the Estallidos collaboration (consolider project)

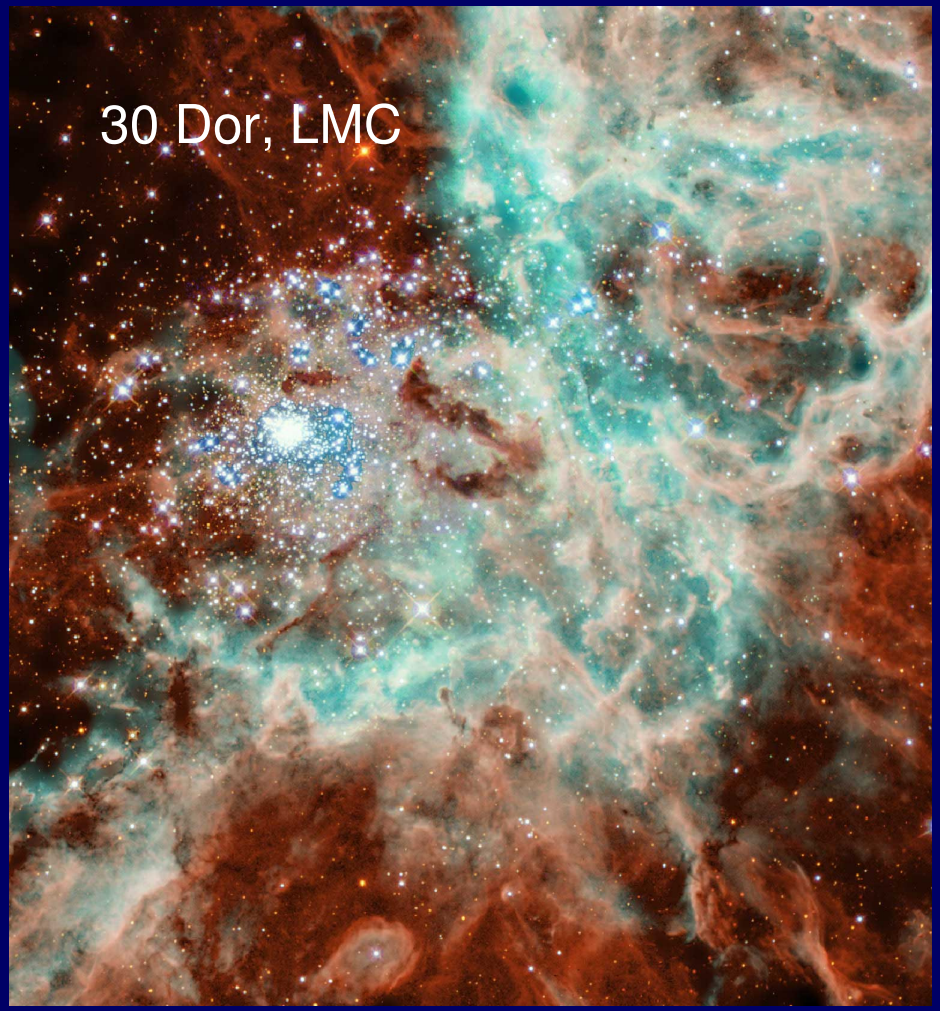
http://estallidos.iac.es/estallidos/

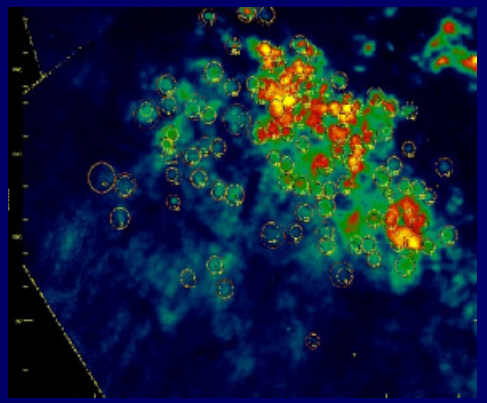
Also in consolider ingenio GTC,

http://www.iac.es/consolider-ingenio-gtc/

Selected topics of research

- Massive starbursts and their impact on galaxies. Super Stellar Clusters. Star Formation, SNe driven winds, and feedback mechanisms.

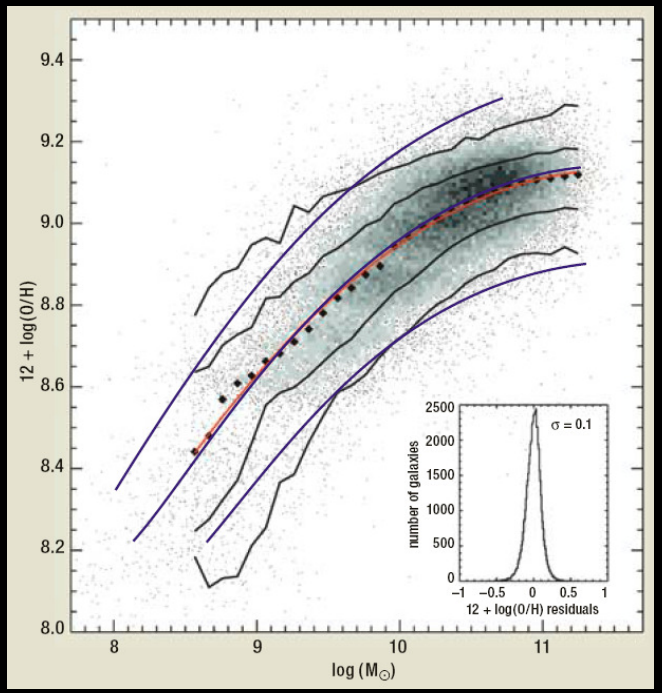


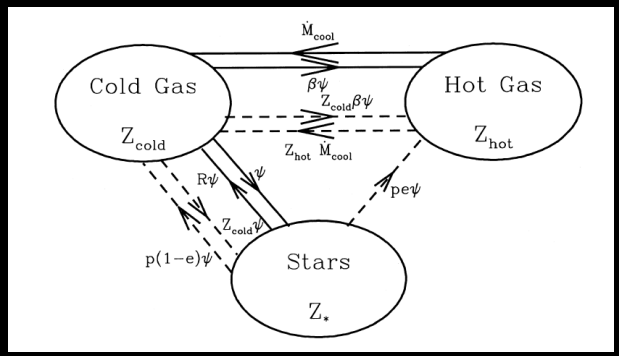


- Local Universe Survey (LUS): Mapping of all local group galaxies (distance < 3 Mpc) using narrow-band tuning filters chosen so that they can provide the star formation history of all galax in 2D. OSIRIS/GTC

- FOssil Groups Origins (FOGO): Muli-frequency studies of fossil galaxy groups. Physical properties of the central galaxy, the intergalactic medium and the group.

- The most metal poor galaxies. BCDs. Metal poor means unevolved. Nearby left overs of massive galaxy formation? Metallicity. Pop III stars





ASK: unsupervised spectral classification of galaxies

Rationale:

- K-means worked to separate galaxies in the green valley. Can we separate all the galaxy evolution steps using it?

- SDSS/DR7 provides a unique database comprising as many as 930000 galaxy spectra.

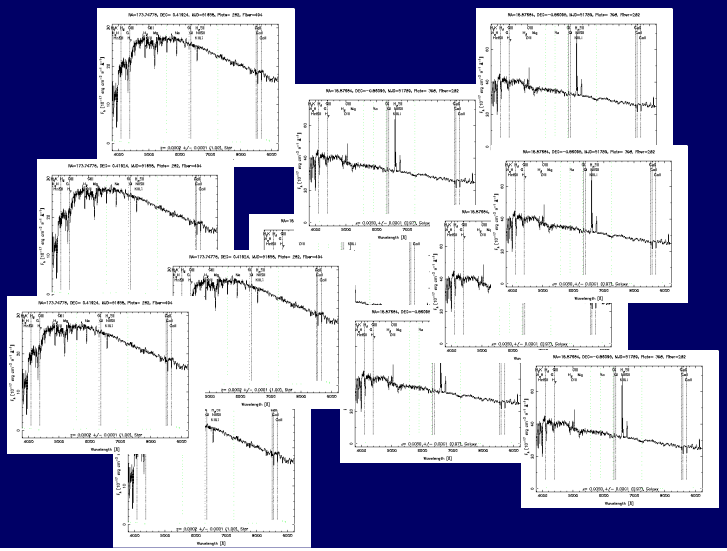
- Can we classify all local galaxies in a small number of types?

The classification method: k-means clustering algorithm

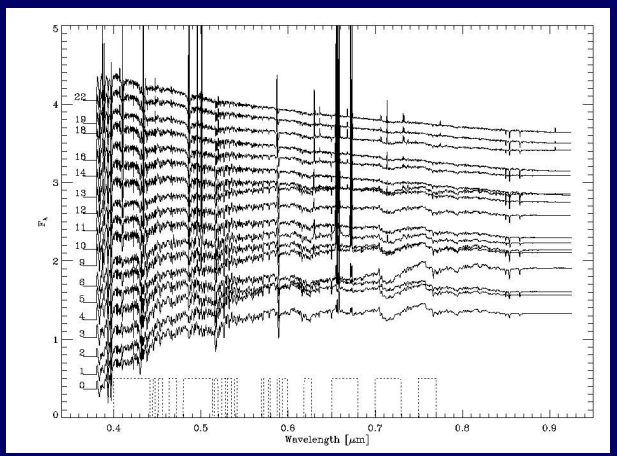
Original image

pixels properties
cluster around 10 ⟶
RGB classes

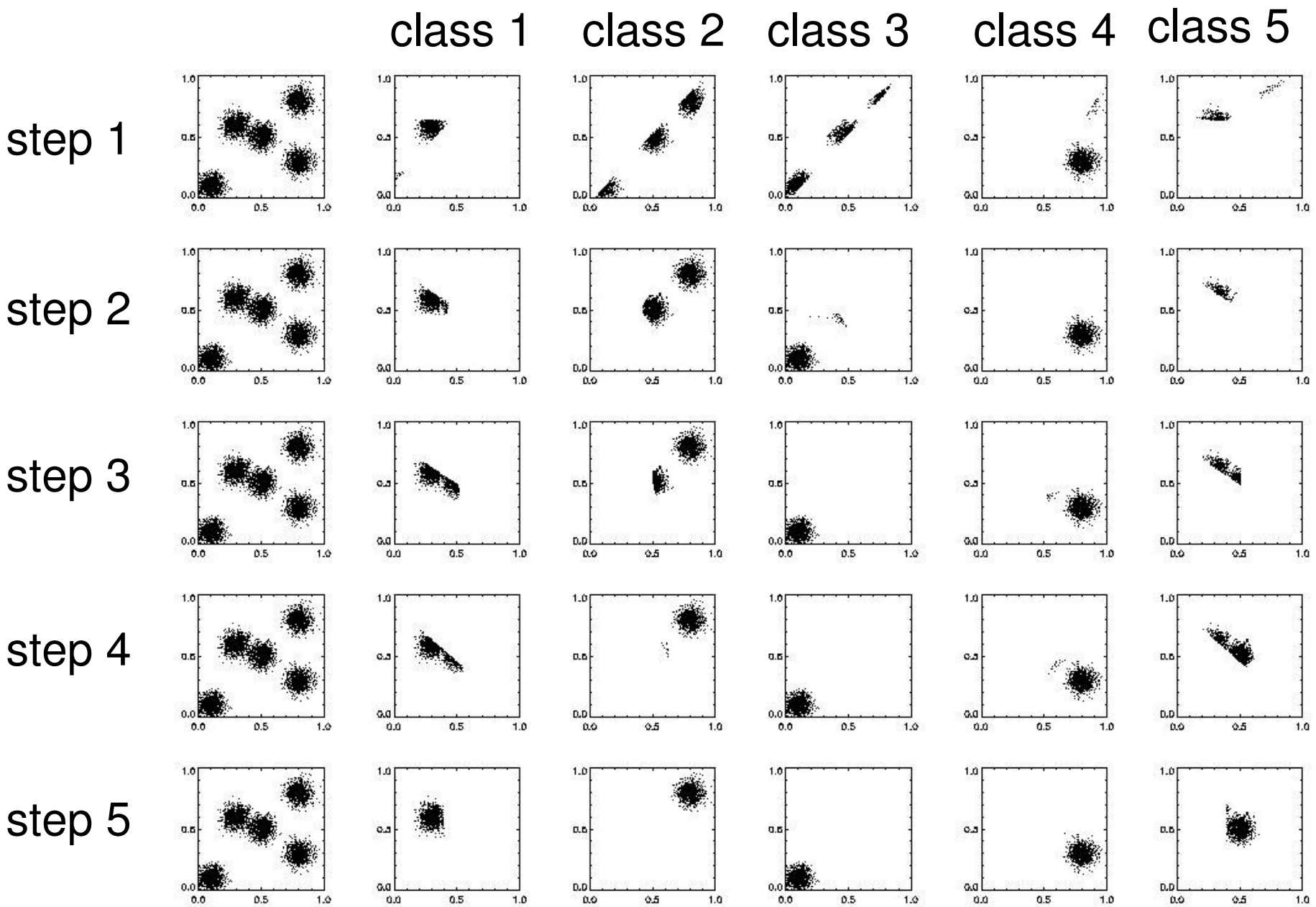
$K = 10$



?



How does k-means work?



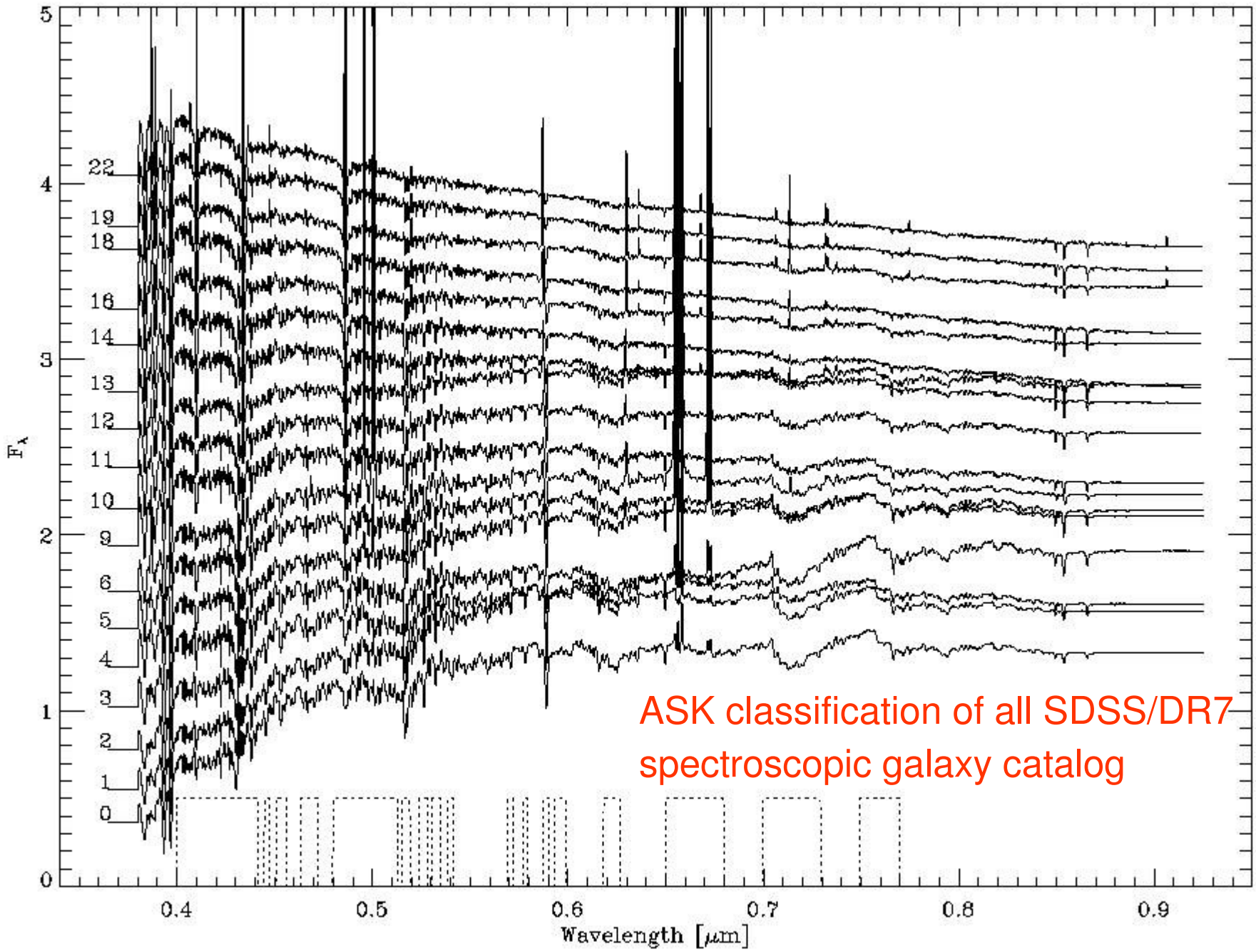
ASK classification

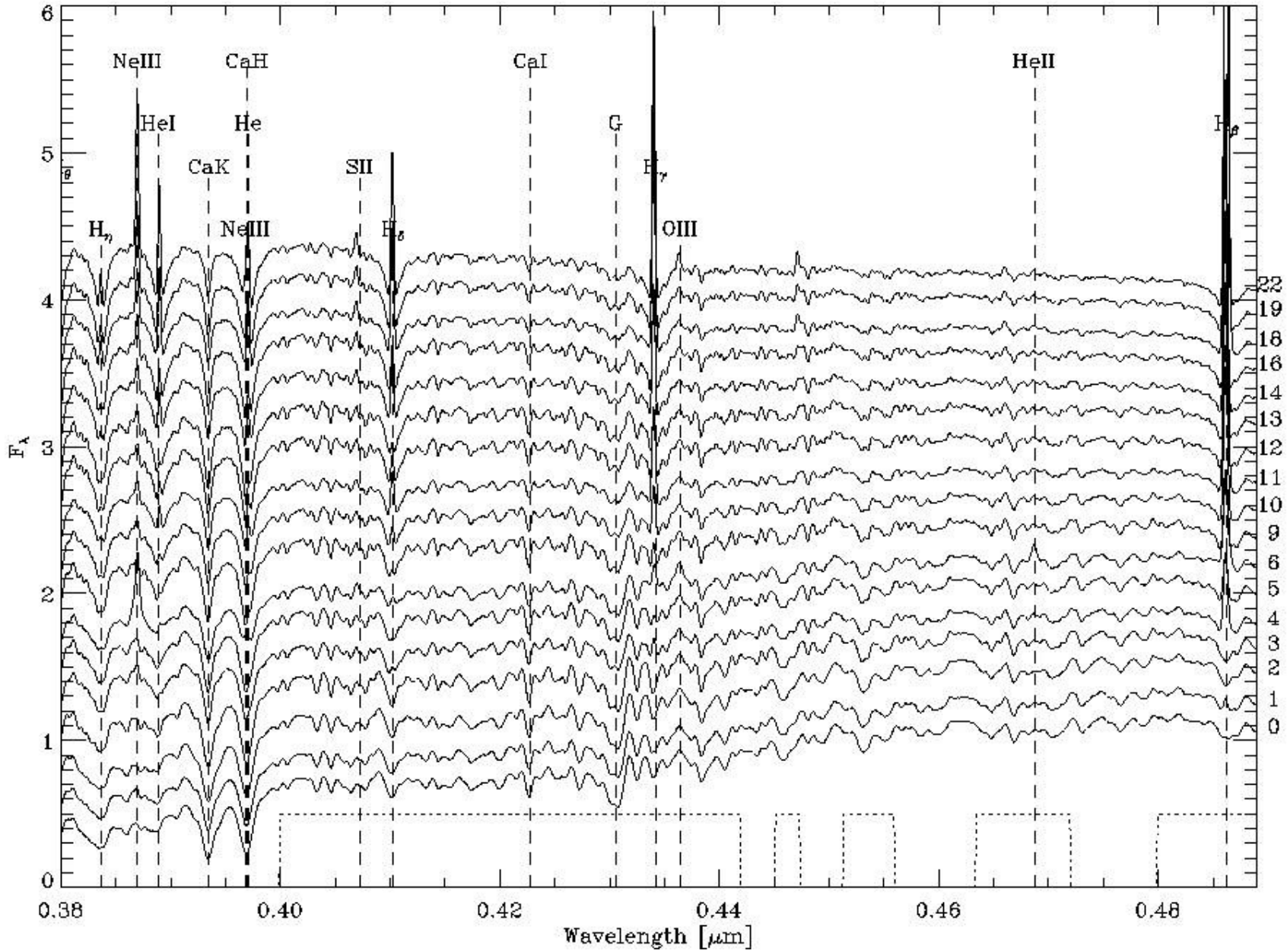
- It works for SDSS spectra. 3800 – 9300 Å, ≈1.5 Å pixels, selected spectral regions, normalized to the mean flux in the *g*-band.
- Computationally intensive: 788677 spectra x 1637 pixels (≈11.6 Gb). 50 iterations. 150 initiallizations.

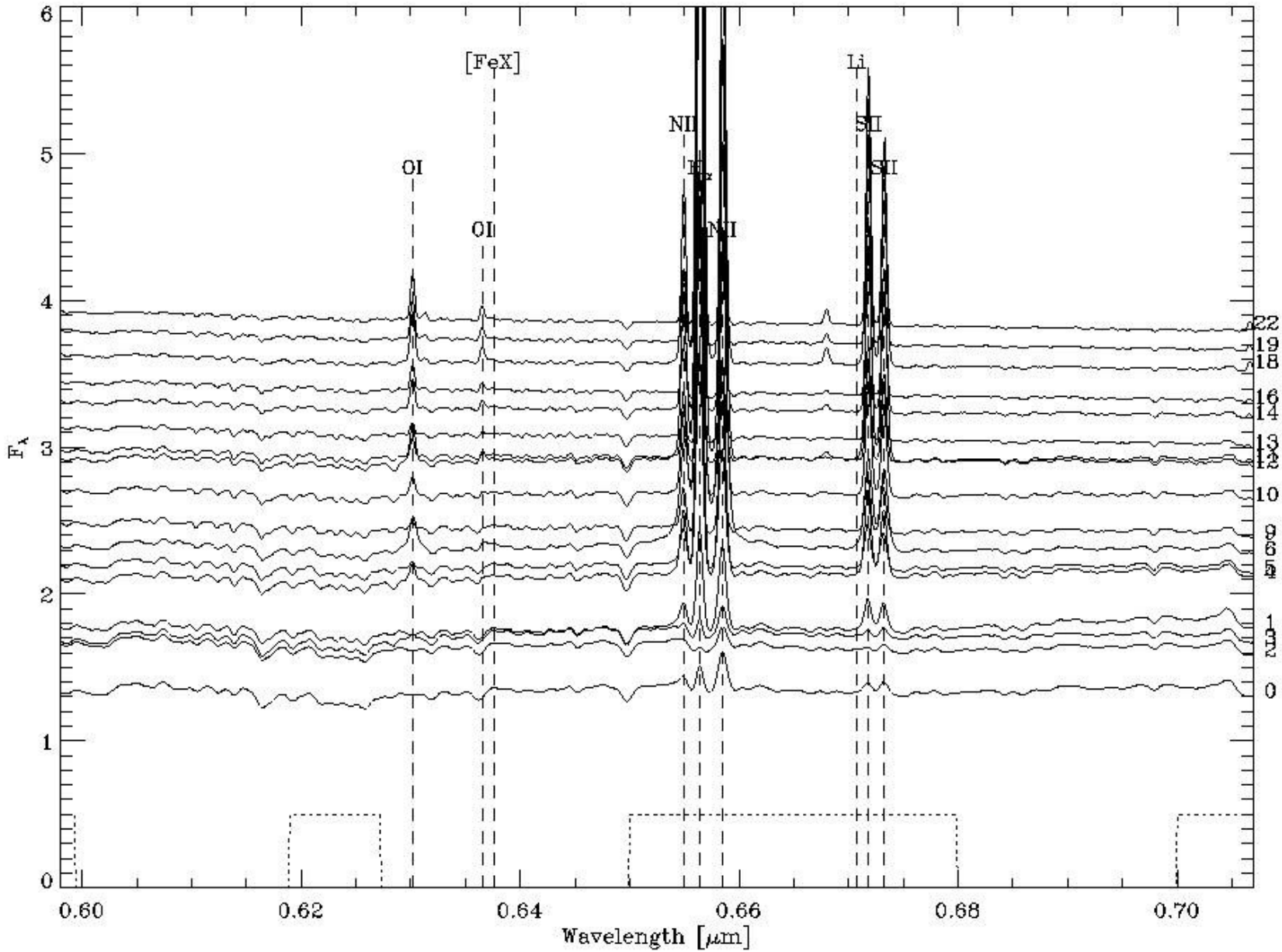
  IDL 300 min/ classification (31 days for 150) using a fast 8-core Intel Xenon 2.66GHz 32Bb RAM.

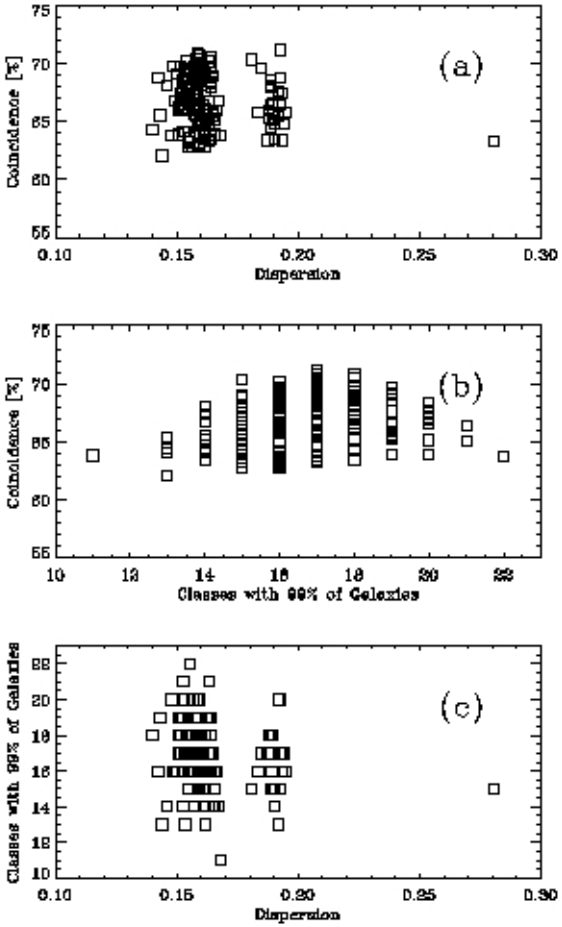
  Fortunately the algorithm can be parallelized. Fortran MPI 1 hour per 150 initializations using the cluster of 48 Intel Xenon CPUs (2.4 GHz) at IAC (de Vicente).

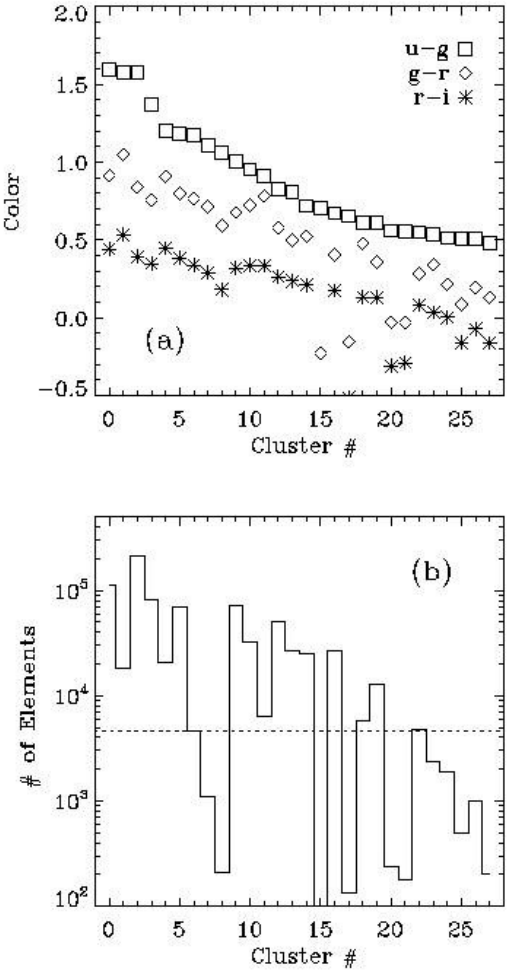
- 99% of the 78867 galaxies can be assigned to only 17 major classes. We order them by *u-g* color.


ASK classification of all SDSS/DR7
spectroscopic galaxy catalog
Wavelength [μm]
F_λ
0.4
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5
22
19
18
16
14
13
12
11
10
9
6
5
4
3
2
1
0

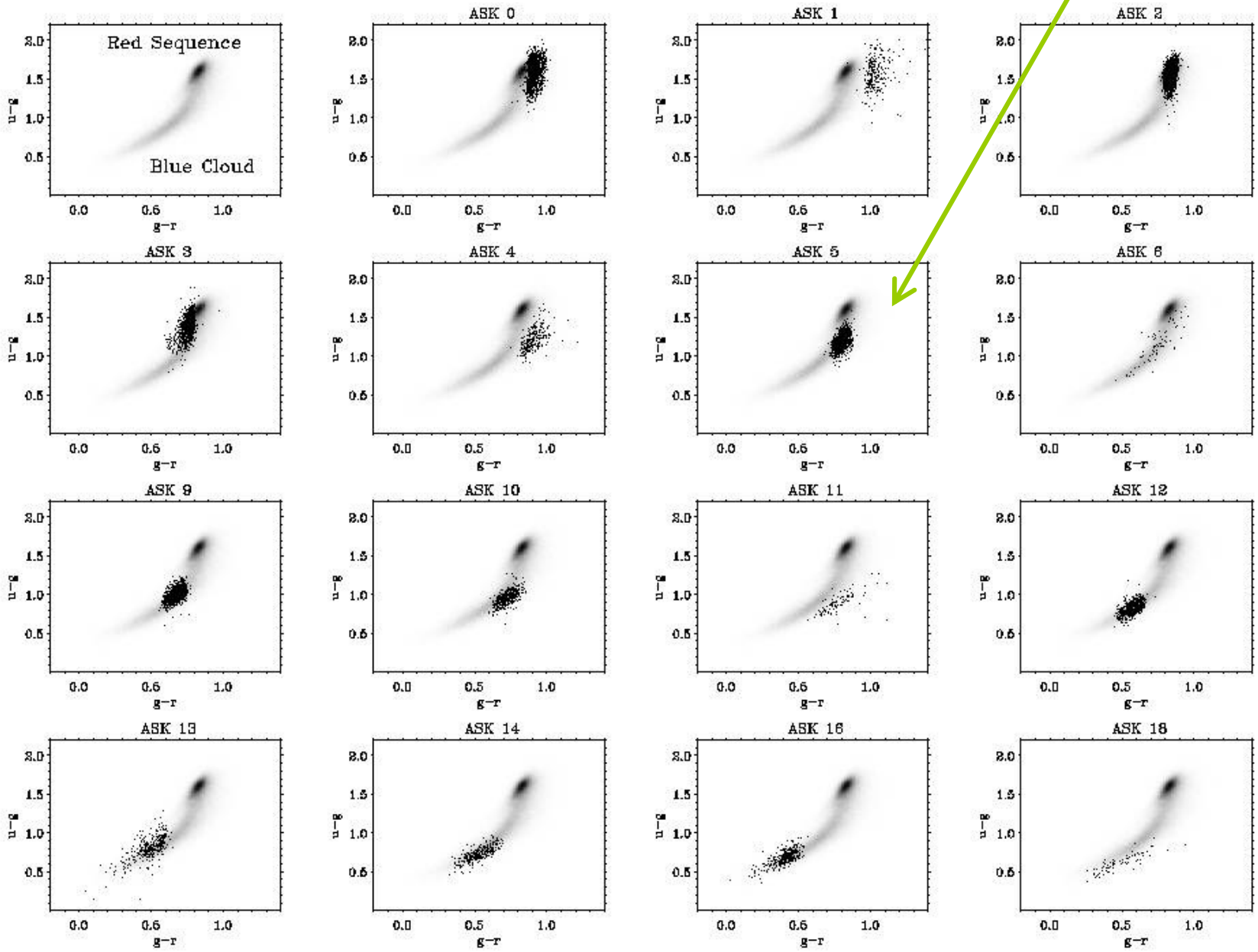

NeIII
CaH
CaI
HeII
HeI
He
G
CaK
SII
OIII
NeIII
22
19
18
16
14
13
12
11
10
9
6
5
4
3
2
1
0
0.38
0.40
0.42
0.44
0.46
0.48
Wavelength [μm]
F_λ

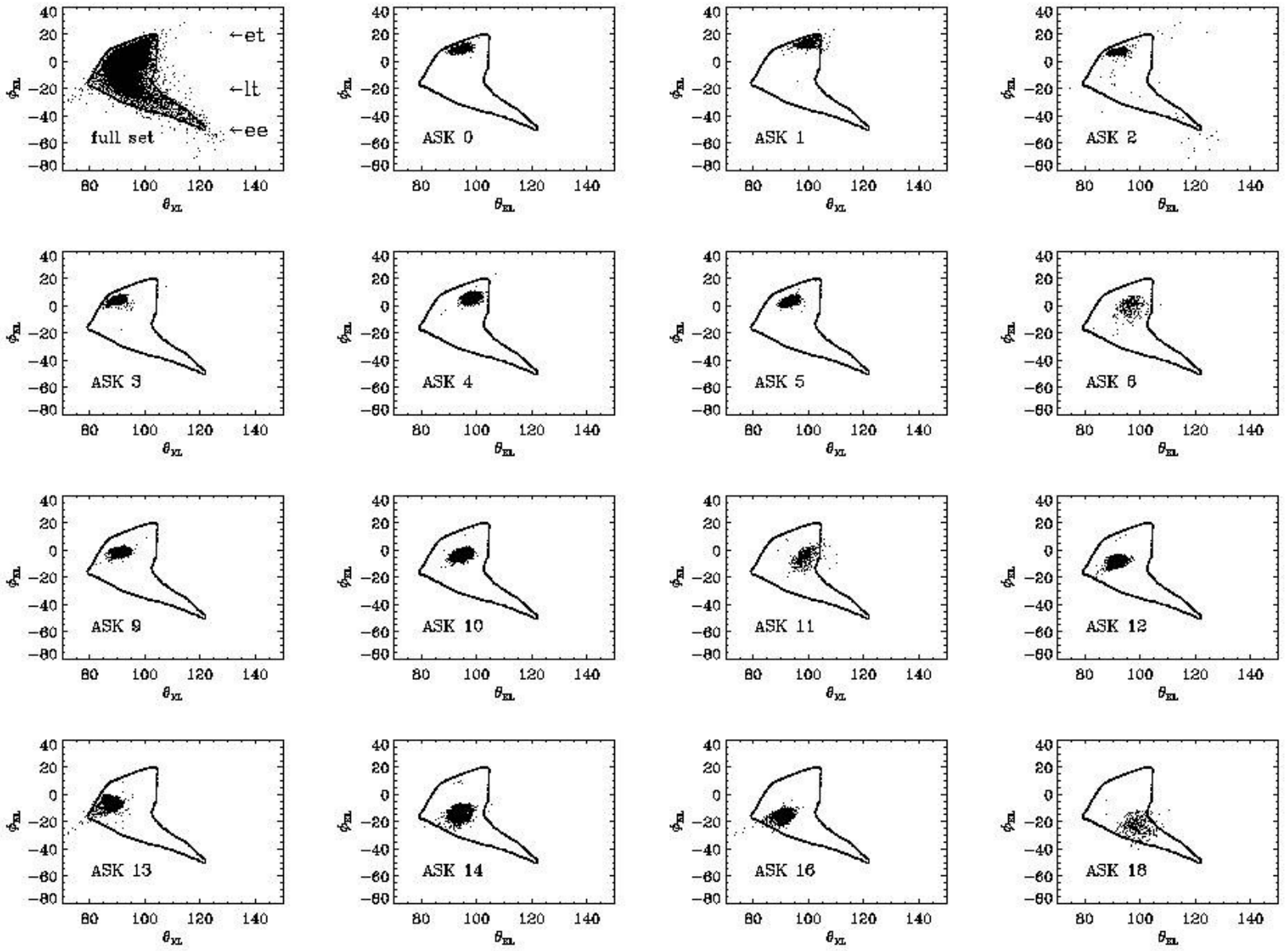

[FeX]
Li
NII
SII
OI
Hα
SII
OII
NII
F_λ
Wavelength [μm]
0.60
0.62
0.64
0.66
0.68
0.70
0
1
2
3
4
5
6
22
19
18
16
14
13
12
10
9
6
5
4
1
3
2
0


(a)
Coincidence [%]
Dispersion
(b)
Coincidence [%]
Classes with 99% of Galaxies
(c)
Classes with 99% of Galaxies
Dispersion


u−g
g−r
r−i
(a)
Color
Cluster #
(b)
# of Elements
Cluster #

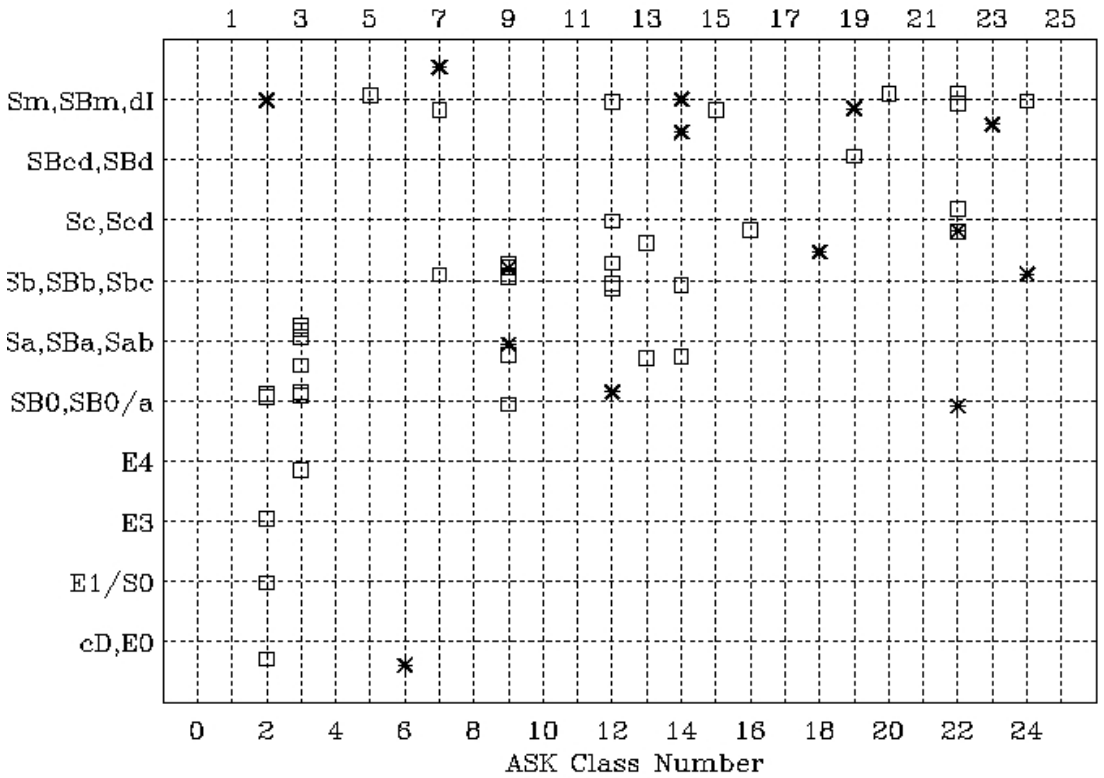
ASK classes distinguish galaxies in the green valley

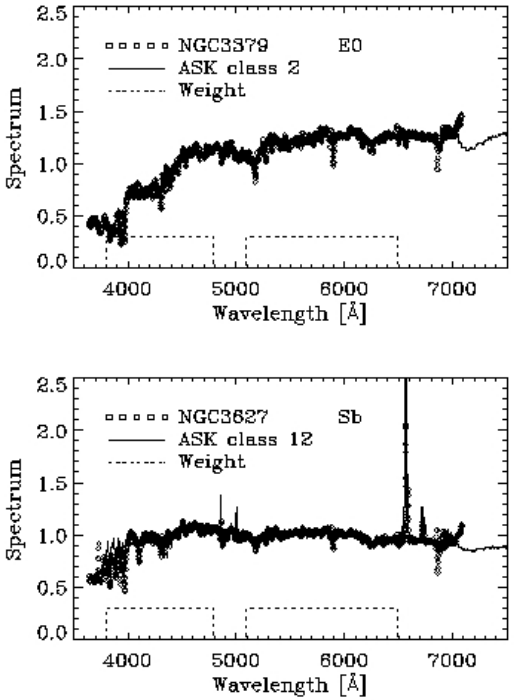




In agreement with, but finer than, PCA classification

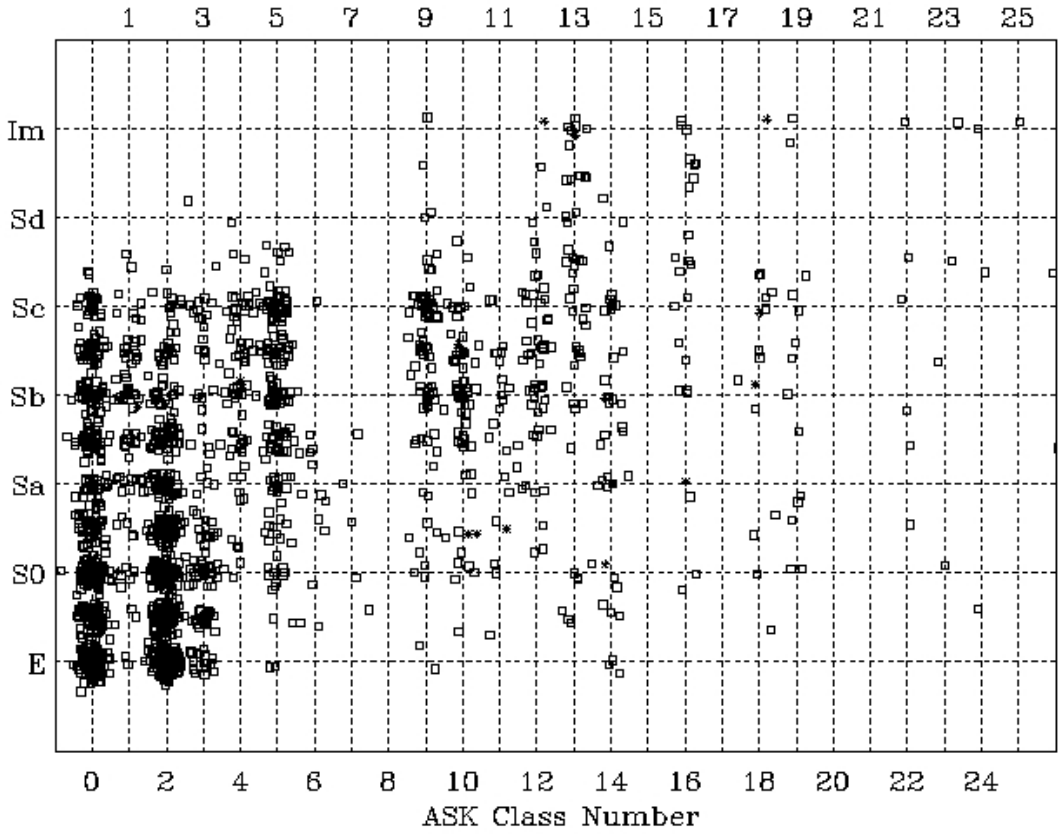
ASK class vs morphological classification





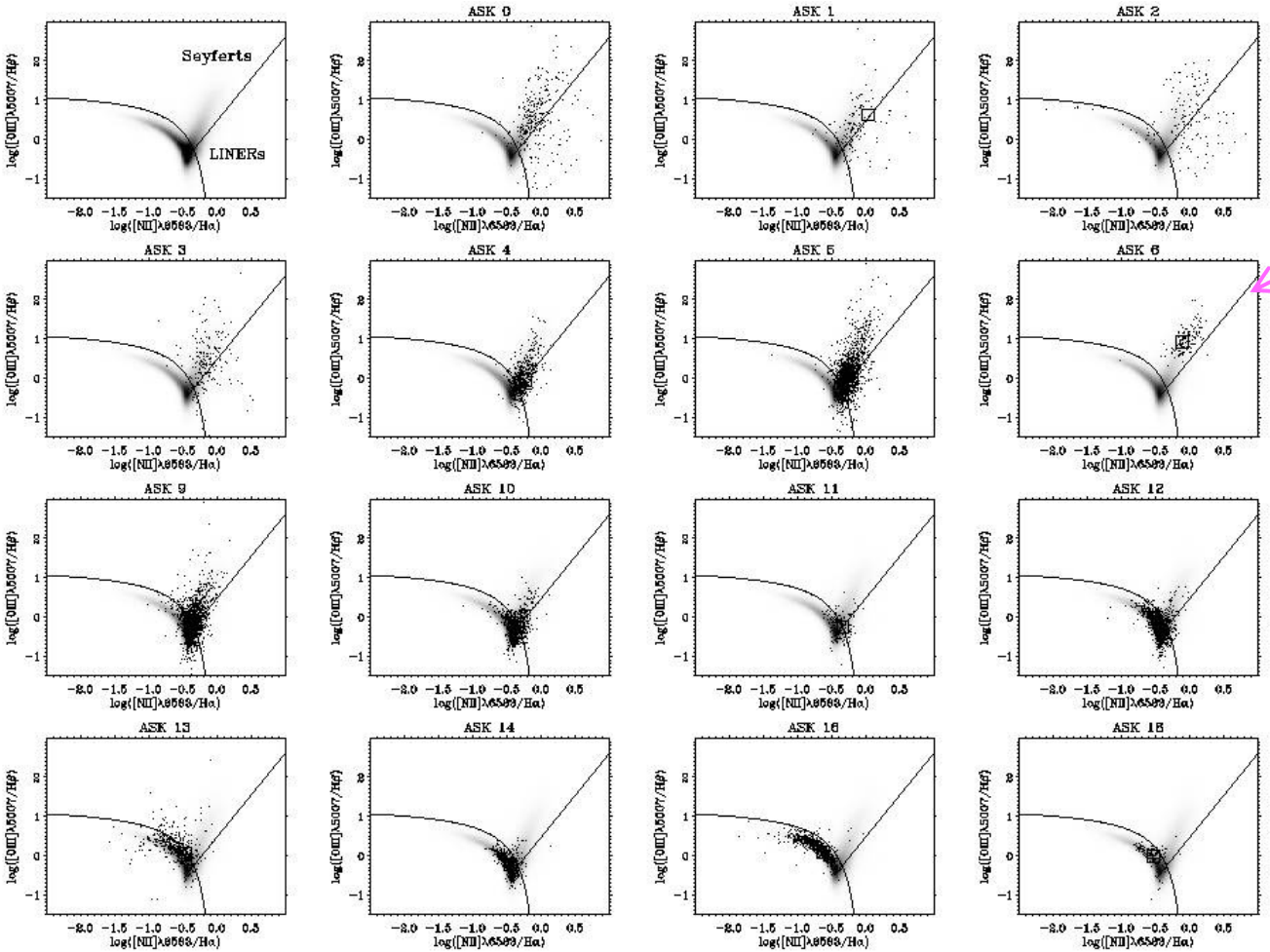
Kennicutt 02

There is a clear trend for the small ASK numbers (red galaxies) to be associated with the early-types, and vice versa. However the relationship presents a large intrinsic scatter.



1866 galaxies with Hubble types from Fukugita et al. 07

ASK class vs AGN activity



ASK 6, pure Seyfert galax

red galaxies present AGN activity ASK 0,1,2

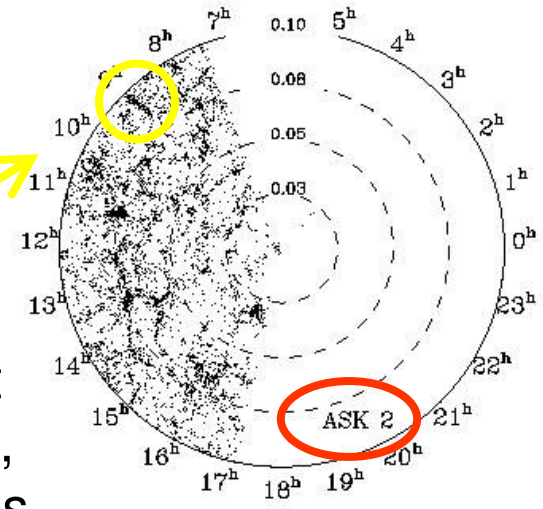
green galaxies also resent AGN activity ASK 3,4,5,6

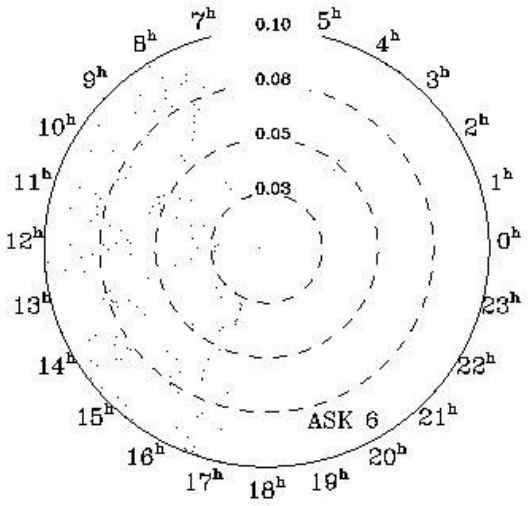
blue galaxies resent starburst activity ASK ≥ 7

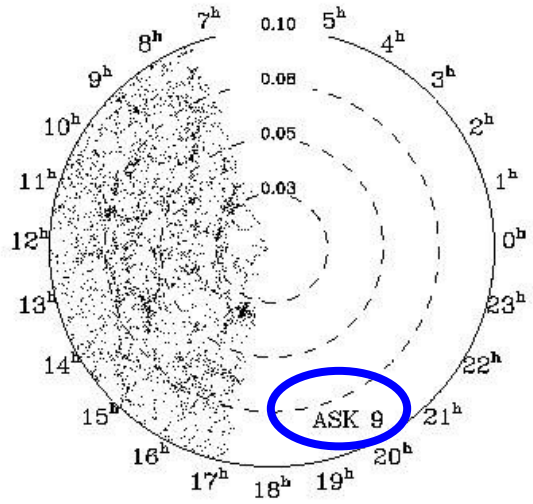
Cone diagram, redshift < 0.1

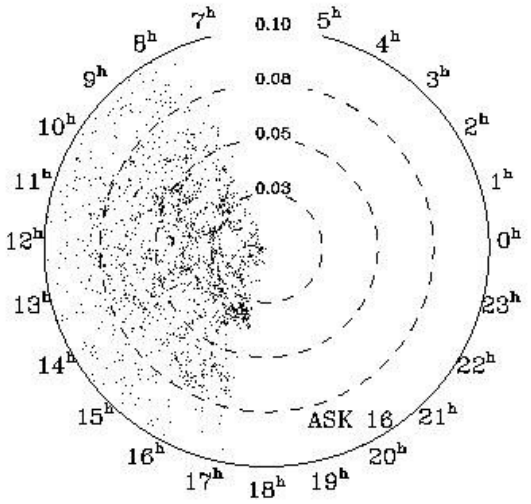
$35^{o} < DEC < 45^{o}$

Clear *finger of god* effect present only in red types, meaning that red galaxies tend to be in clusters, whereas blue types are more spread out.



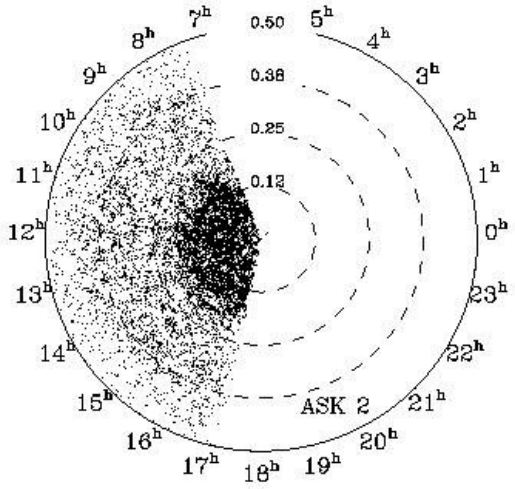


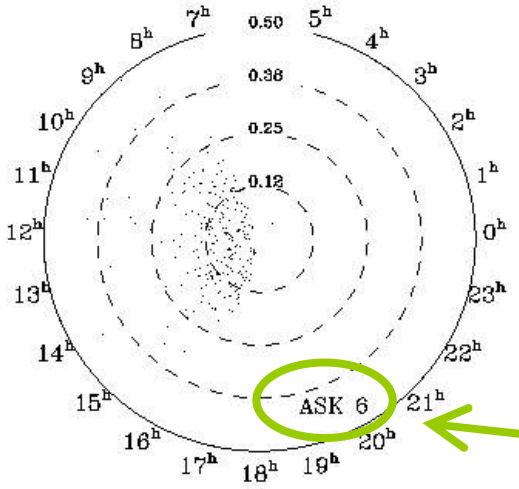


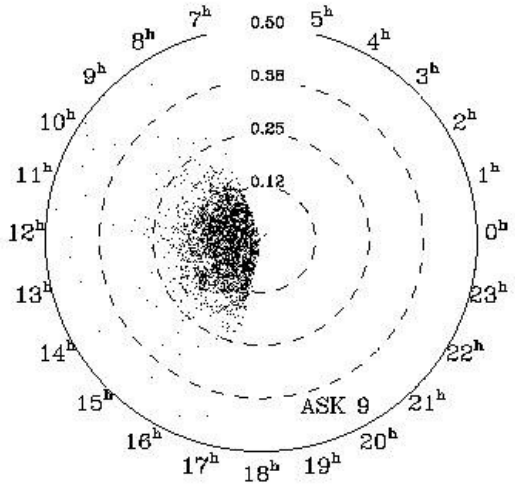


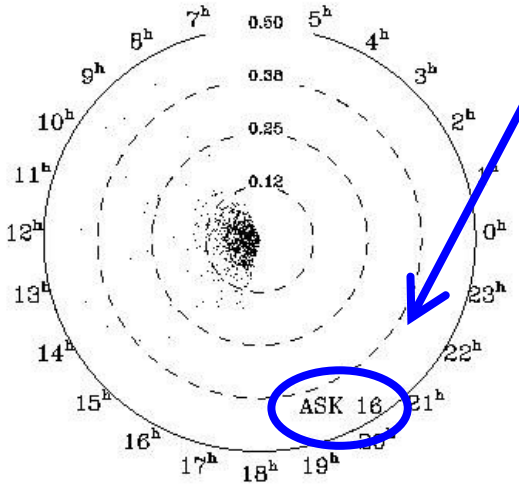
Cone diagram, redshift < 0.5

35^o < DEC < 45^o









- Seyferts (ASK 6) are spread out.
- Blue types are nearby.

Conclusions ++

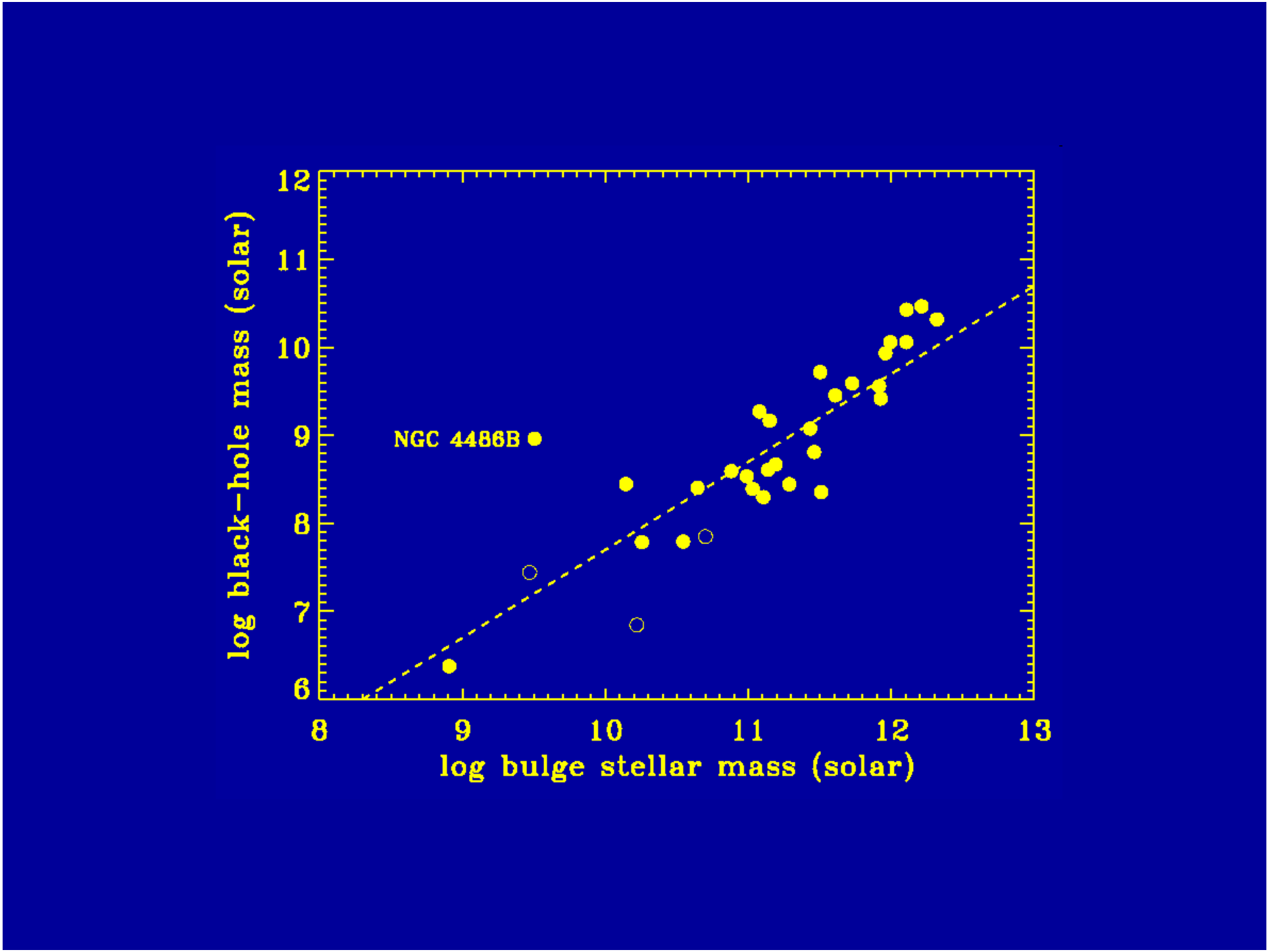
Galaxy formation is one of the most active fields of research in observational Cosmology.

Hierarchical galaxy formation driven by gravity seems to work, but there are plenty of open questions.

New possibilities open by large data sets, e.g., ASK classification

Personal webpage with talk + links
http://www.iac.es/galeria/jos

Proyecto master based on ASK? BH mass vs Galax mass (Magorrian diaggram)

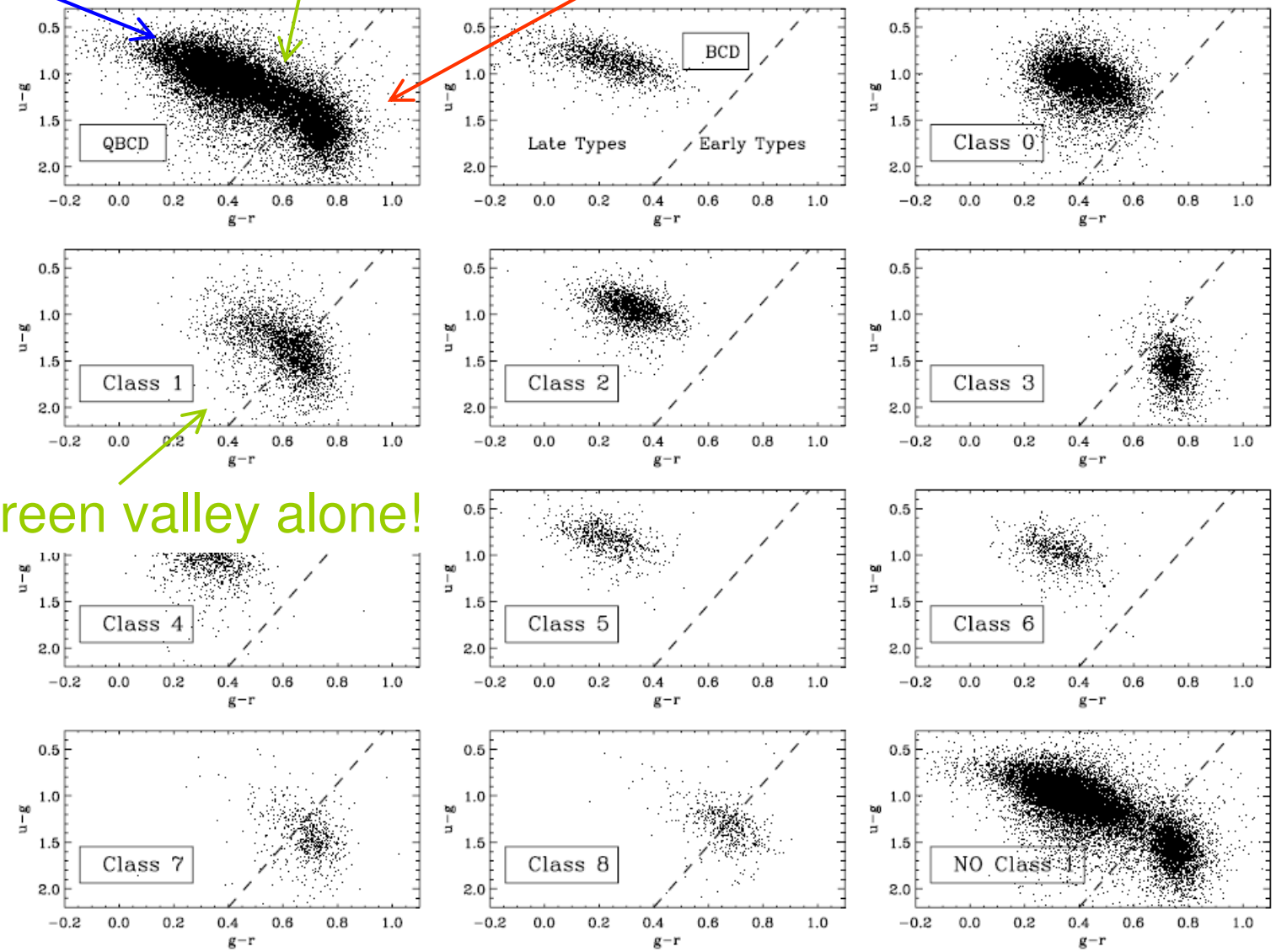

log black-hole mass (solar)
log bulge stellar mass (solar)
NGC 4486B
12
11
10
9
8
7
6
8
9
10
11
12
13

Flammarion woodcut

blue cloud

green valley

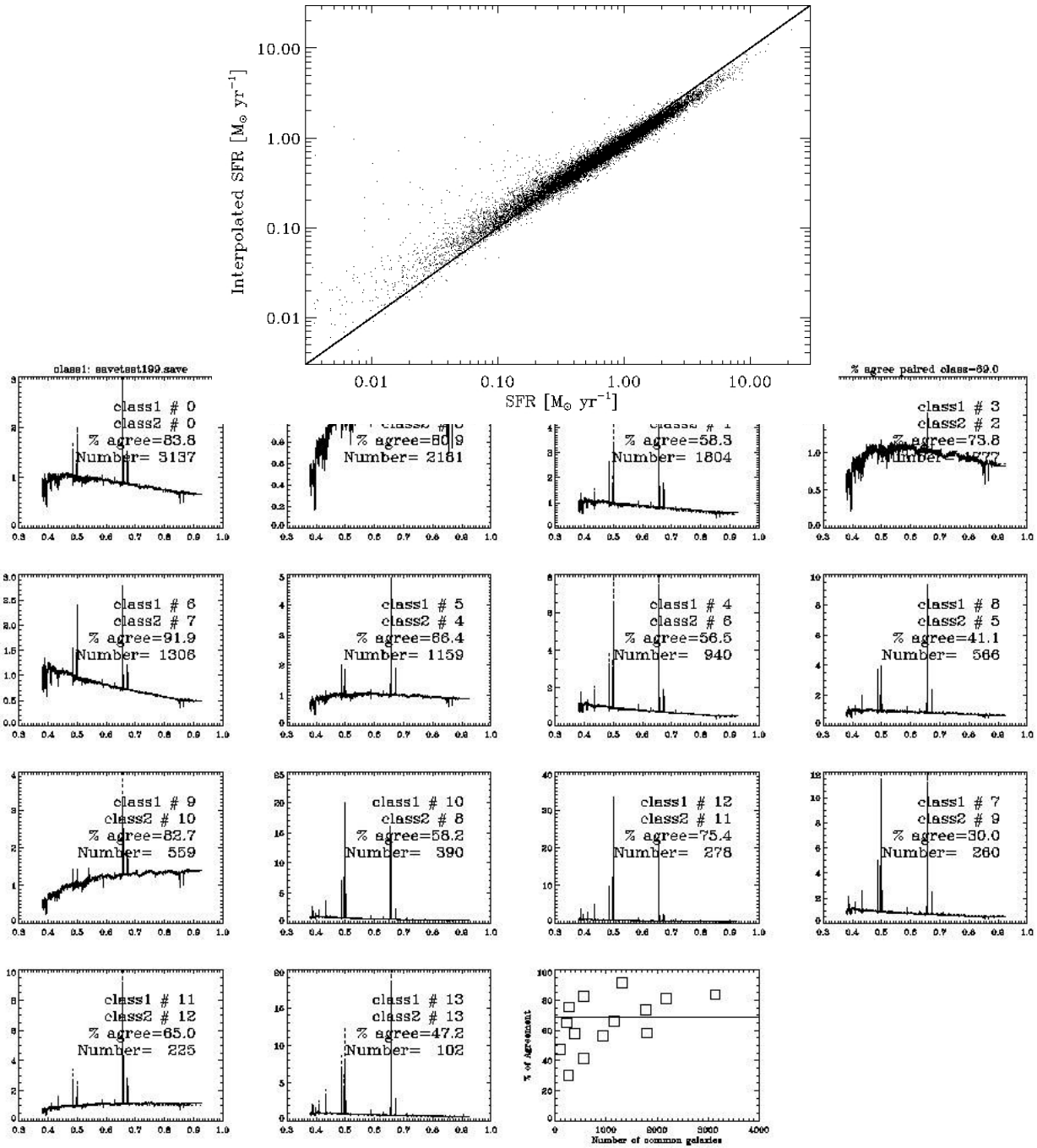
red sequence



green valley alone!

SA et al. 2009

Flammarion woodcut


Interpolated SFR [M$_\odot$ yr^{-1}]
SFR [M$_\odot$ yr^{-1}]
0.01
0.10
1.00
10.00
class1: savetest199.save
class1 # 0
class2 # 0
% agree=83.8
Number= 3137
% agree=80.9
Number= 2161
% agree=58.3
Number= 1804
% agree paired class=89.0
class1 # 3
class2 # 2
% agree=73.8
class1 # 6
class2 # 7
% agree=91.9
Number= 1306
class1 # 5
class2 # 4
% agree=66.4
Number= 1159
class1 # 4
class2 # 6
% agree=56.5
Number= 940
class1 # 8
class2 # 5
% agree=41.1
Number= 566
class1 # 9
class2 # 10
% agree=82.7
Number= 559
class1 # 10
class2 # 8
% agree=58.2
Number= 390
class1 # 12
class2 # 11
% agree=75.4
Number= 278
class1 # 7
class2 # 9
% agree=30.0
Number= 260
class1 # 11
class2 # 12
% agree=65.0
Number= 225
class1 # 13
class2 # 13
% agree=47.2
Number= 102
% of Agreement
Number of common galaxies