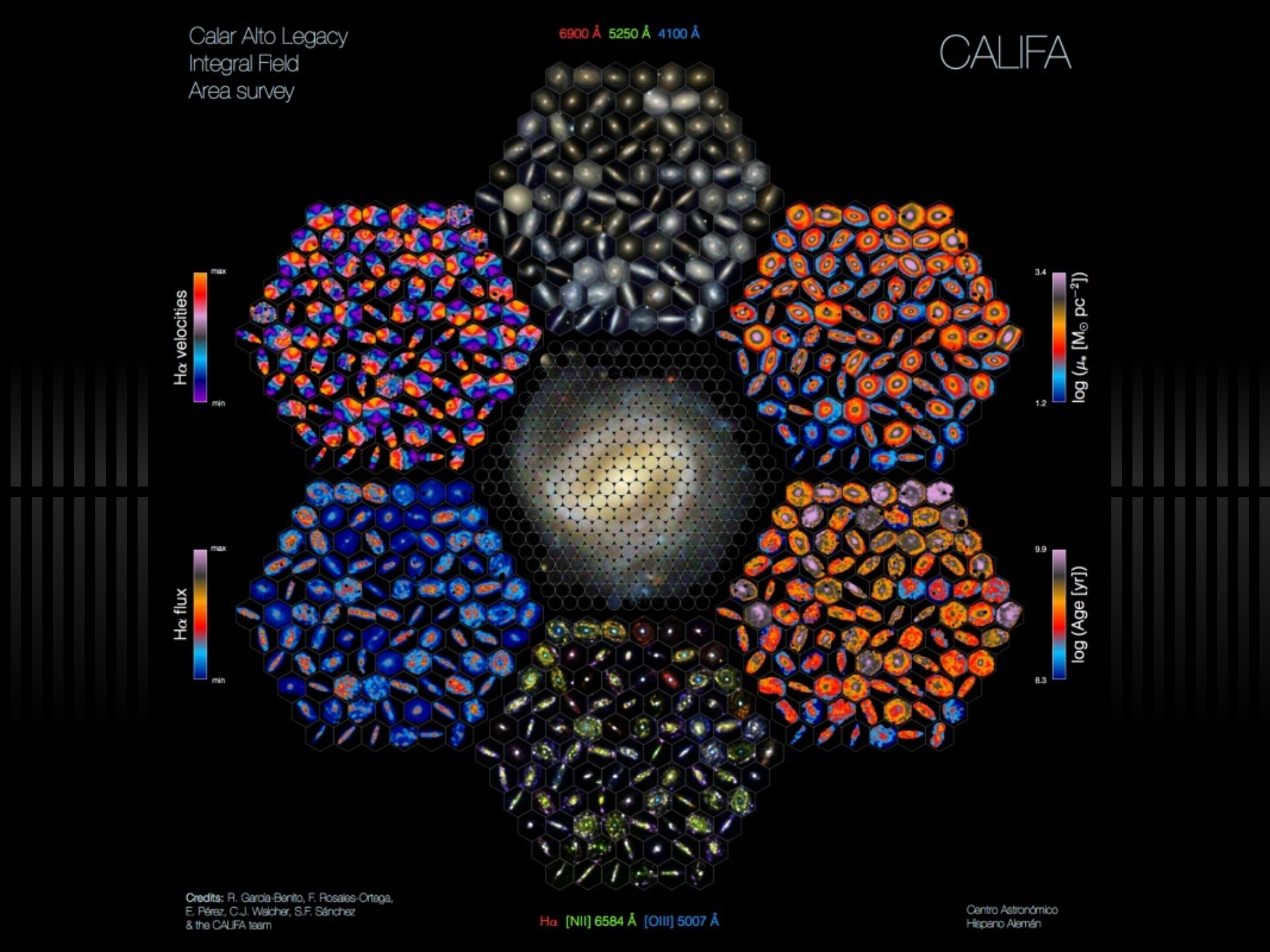
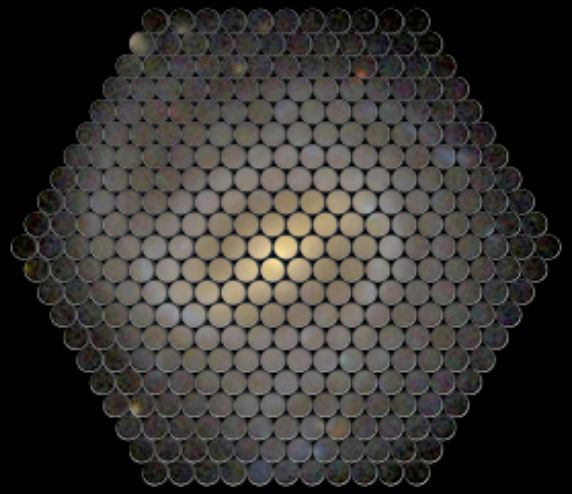

Calar Alto Legacy
Integral Field
Area survey
6900 Å 5250 Å 4100 Å
CALIFA
Hα velocities
max
min
3.4
1.2
log ($\mu_*$ [$M_\odot$ pc$^{-2}$])
Hα flux
max
min
9.9
8.3
log (Age [yr])
Hα [NII] 6584 Å [OIII] 5007 Å
Credits: R. García-Benito, F. Rosales-Ortega, E. Pérez, C.J. Walcher, S.F. Sánchez & the CALIFA team
Centro Astronómico Hispano Alemán



# CALIFA Survey

## The Calar Alto Legacy Integral Field Area Survey

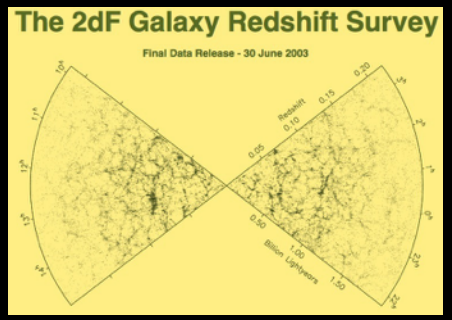
califa

Damián Mast
OAC

FoF Meeting
March 2016

# Caliphate of Córdoba (929 - 1031)

# Introduction




Understanding the Universe

Sloan Digital Sky Survey
Mapping the Universe

- ✓ 2dFGRS (Folkes et al. 1999)
- ✓ SDSS (York et al. 2000)
- ✓ GEMS (Rix et al. 2004)
- ✓ VVDS (Le Fèvre et al. 2004)
- ✓ COSMOS (Scoville et al. 2007)

GEMS STScI MPIA

VVDS
The VIMOS VLT Deep Survey (VVDS)

# Introduction

Understanding the Universe

- Linked global quantities with properties of individual galaxies
  - (Morphological type, stellar masses, metallicities)
- Recent generation surveys:
  - large samples (statistical analysis, control samples, broad coverage of environment and types)
  - homogeneity of data adquisition, reduction and analysis

# CALIFA precedents

- ✓ Imaging surveys:

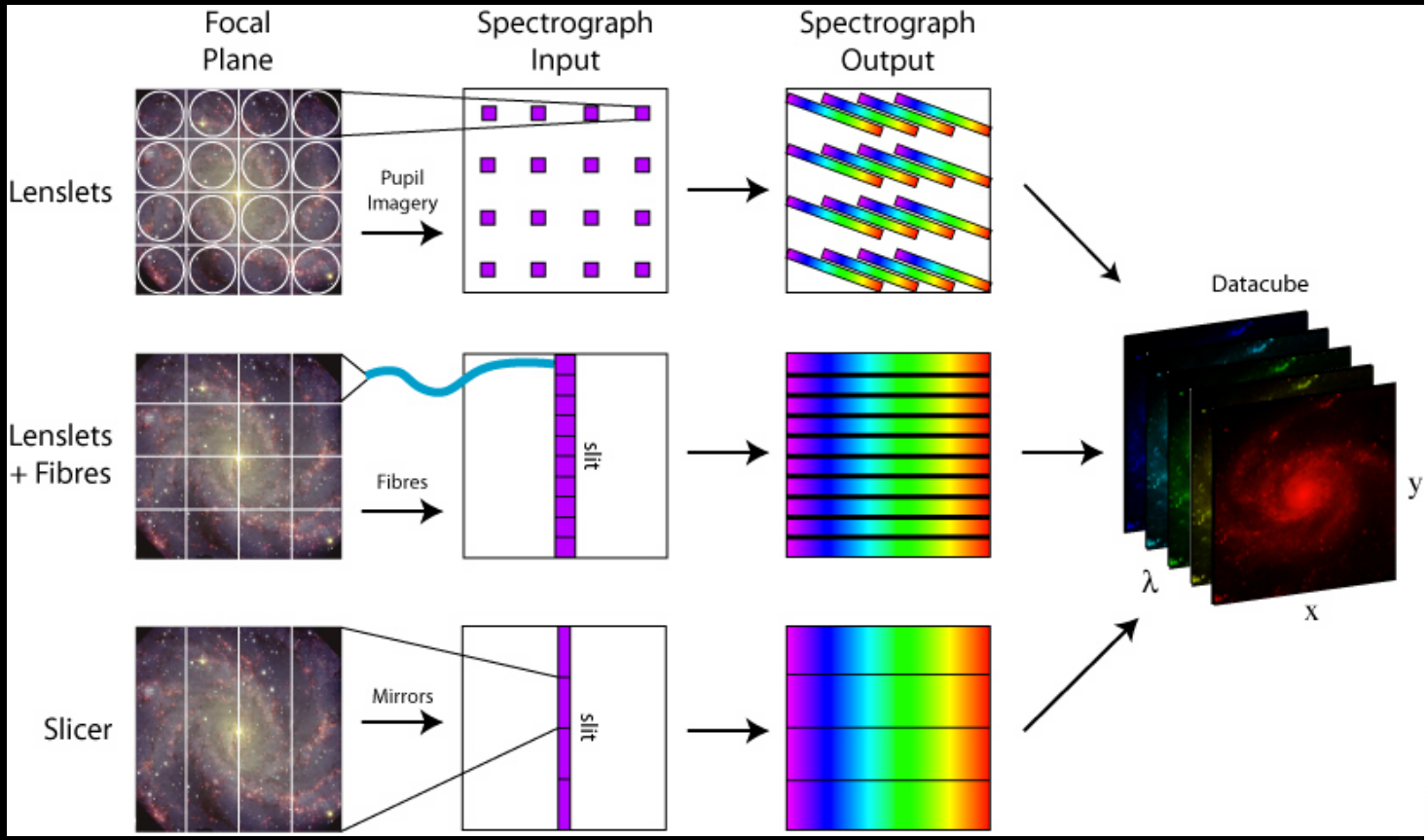
  COMBO-17, Alhambra, COSMOS

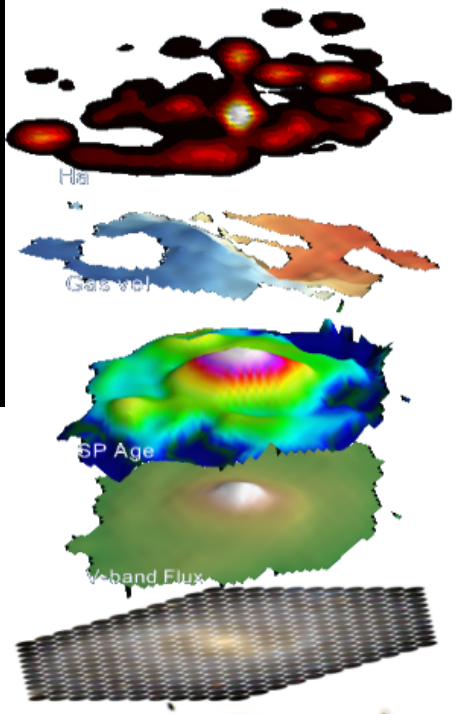
  - ✓ 2D coverage but info in SEDs limited
  - ✓ Better precision in redshift, mean ages, stellar masses

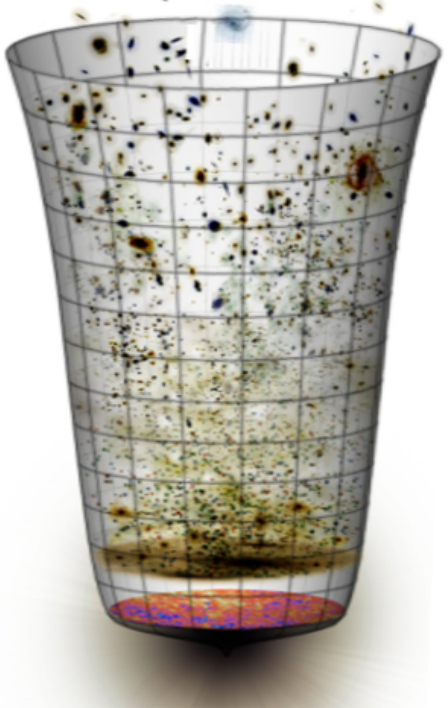
- ✓ Spectroscopic surveys: zCOSMOS, SDSS

  - ✓ Detailed astrophysical information
  - ✓ Limited to one spectrum per galaxy

# Integral Field Spectroscopy



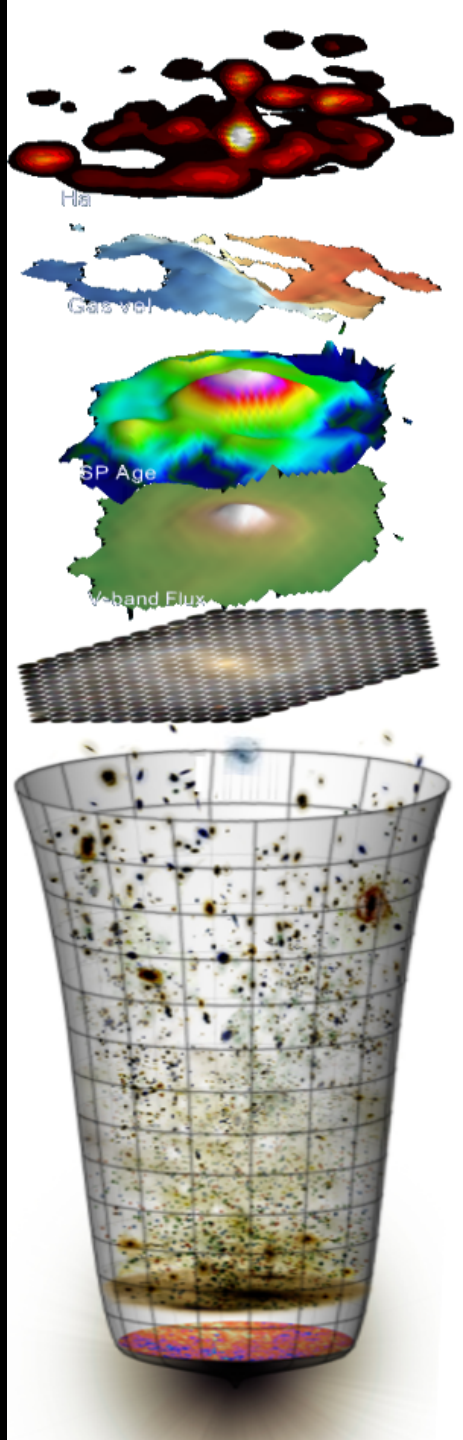



# Integral Field Spectroscopy

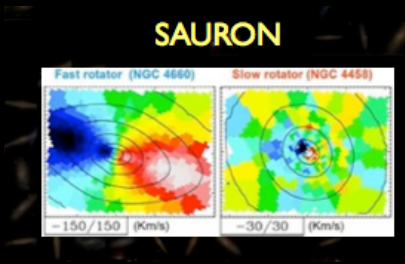
- ✓ the importance and consequences of merging, major and minor
- ✓ internal dynamical processes, such as bars, spiral arms, stellar migration
- ✓ environmental effects, such as tidal forces, stripping
- ✓ AGN feedback
- ✓ occurrence, spatial and temporal extent and trigger of star formation.

Spatially resolved spectroscopic properties of a statistical sample of nearby galaxies

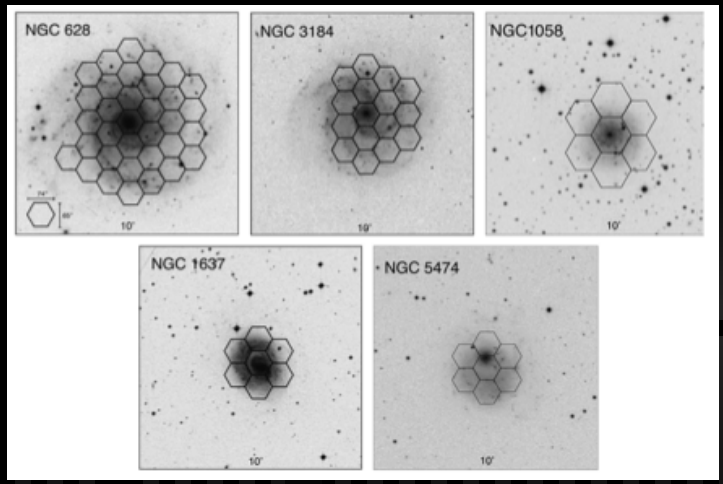


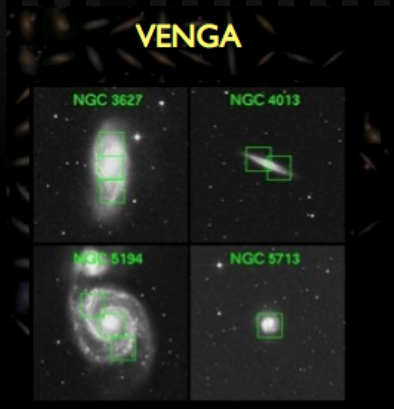
# IFS precedents

- ✓ SAURON (Atlas 3D)
  - ✓ 72 (~200) E-type galaxies
  - ✓ z < 0.01
  - ✓ Limited FoV
- ✓ PINGS
  - ✓ 12 L-type galaxies
  - ✓ z < 0.01
  - ✓ Full optical size by mosaicing
- ✓ VENGA: 30 Spirals
- ✓ DiskMass: 30 Spirals
- ✓ VIXENS: 15 interacting galaxies




PINGS



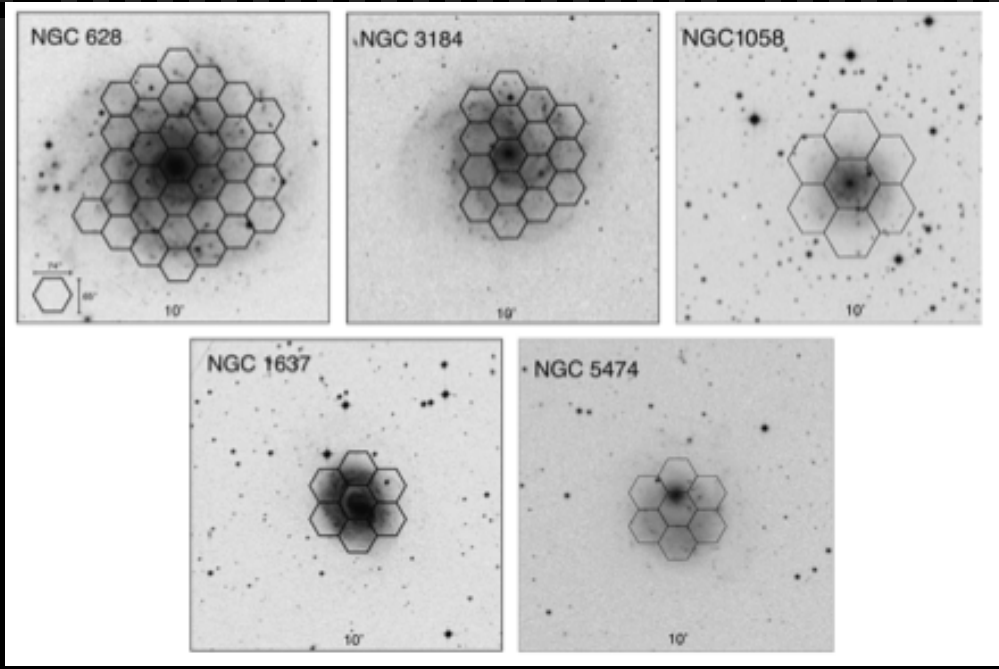




Blanc et al. 2013

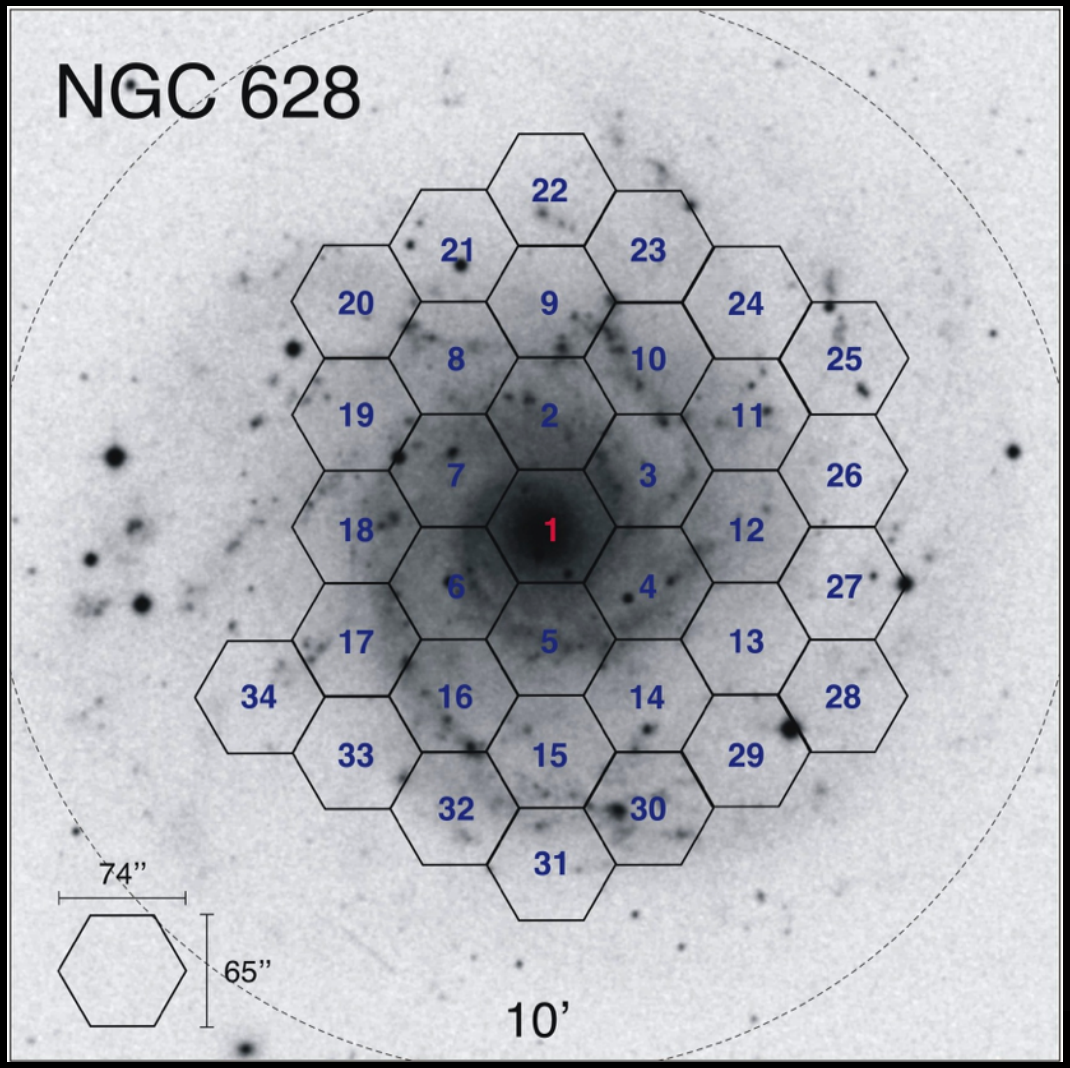
# IFS precedents

- ✓ PINGS (Rosales-Ortega et al. 2010)
  - ✓ 12 L-type galaxies
  - ✓ z < 0.01
  - ✓ Full optical size by mosaicing

PINGS
PPAK IFS Nearby Galaxies Survey



✓ PINGS (Rosales-Ortega et al. 2010)



# IFS precedents

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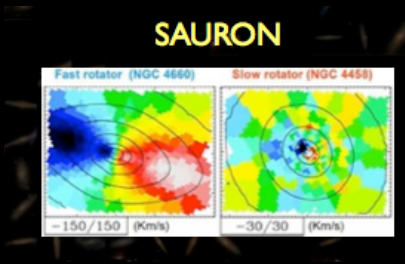
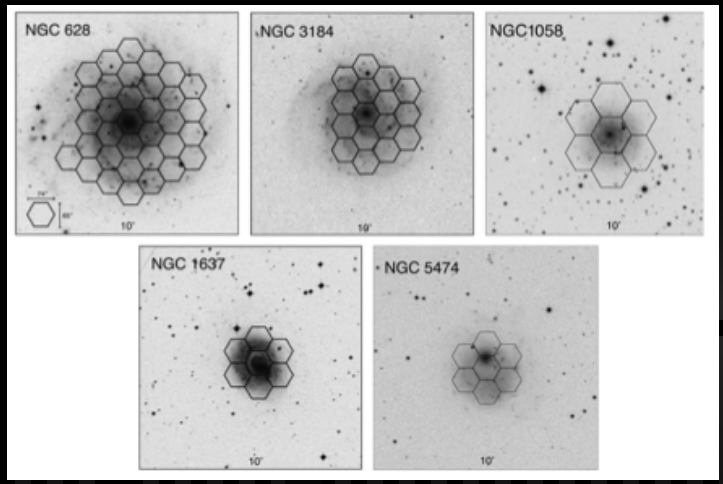
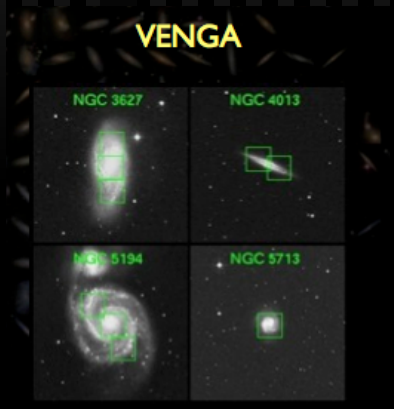


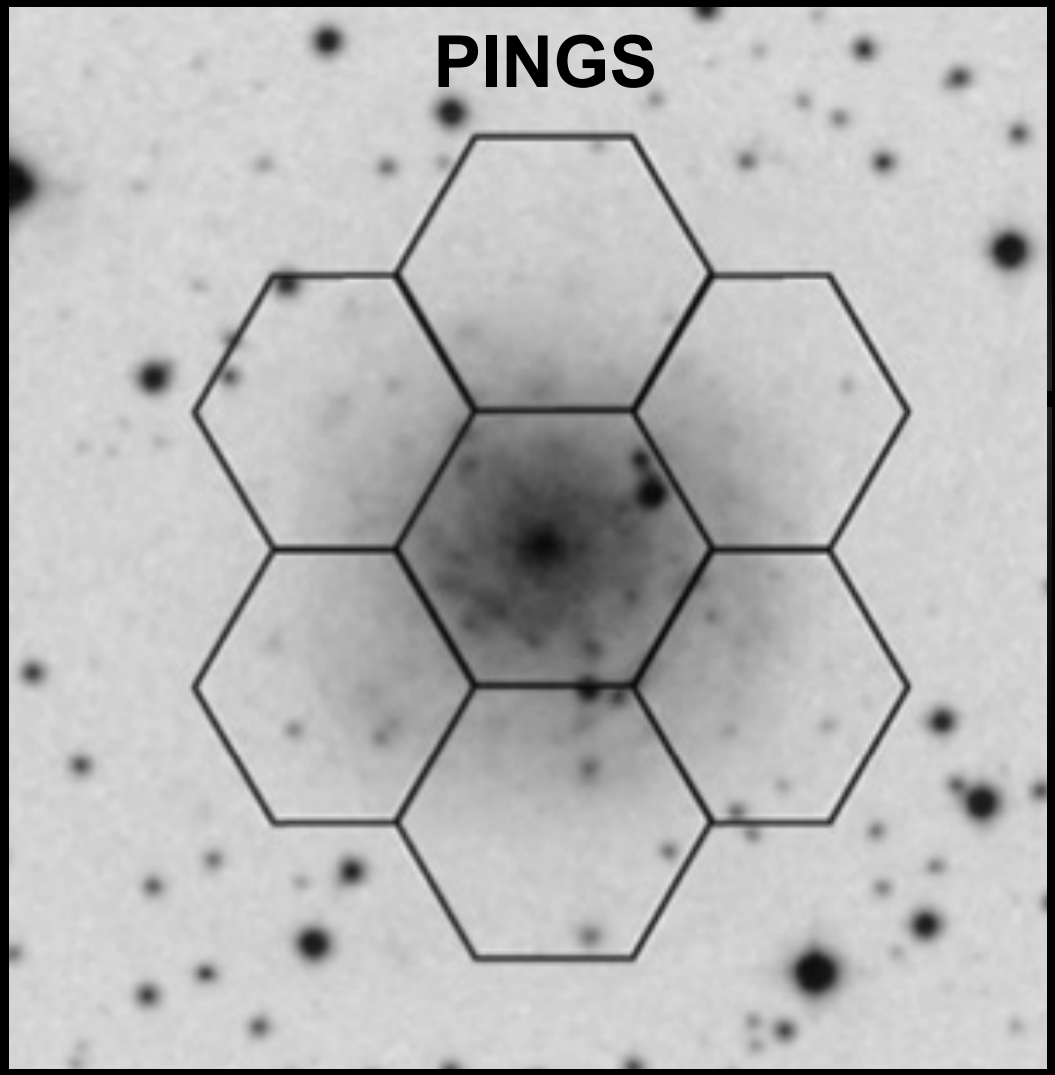

PINGS



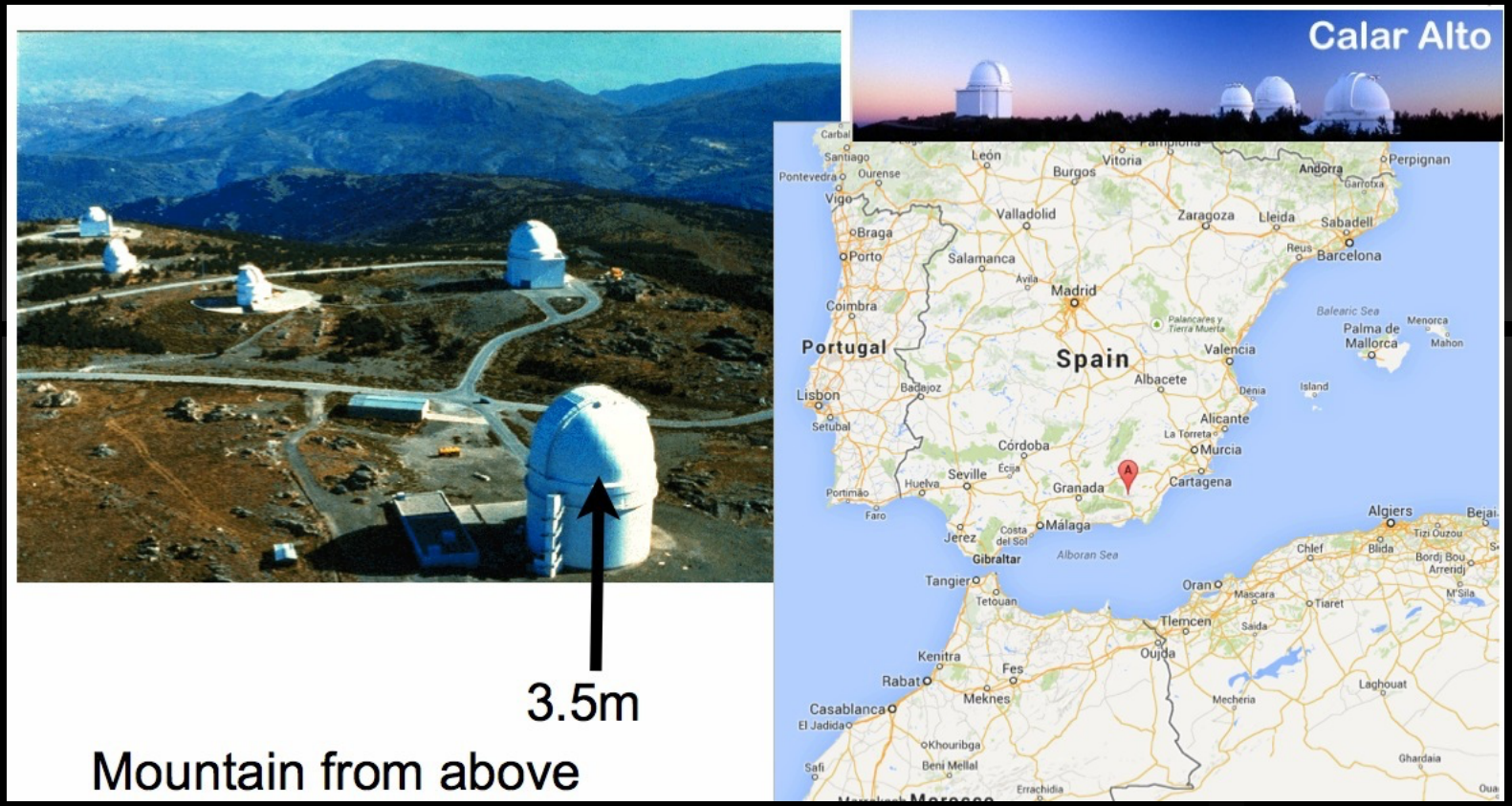




Blanc et al. 2013

# CALIFA wants to fill the gap...

# CALIFA in brief...




- ✓ Integral Field Spectroscopy Survey of galaxies in the Local Universe (Calar Alto 3.5m telescope, Spain)

# CALIFA in brief...

- ✓ 250 dark nights in 5 years started July 2010
- ✓ ~ 2.5 Million Euros in telescope time
- ✓ Statistical and representative sample of ~600 galaxies
- ✓ Legacy character: reduced data delivered publicly

# CALIFA collaboration

✓ 90 members

✓ 14 countries

✓ 26 institutes

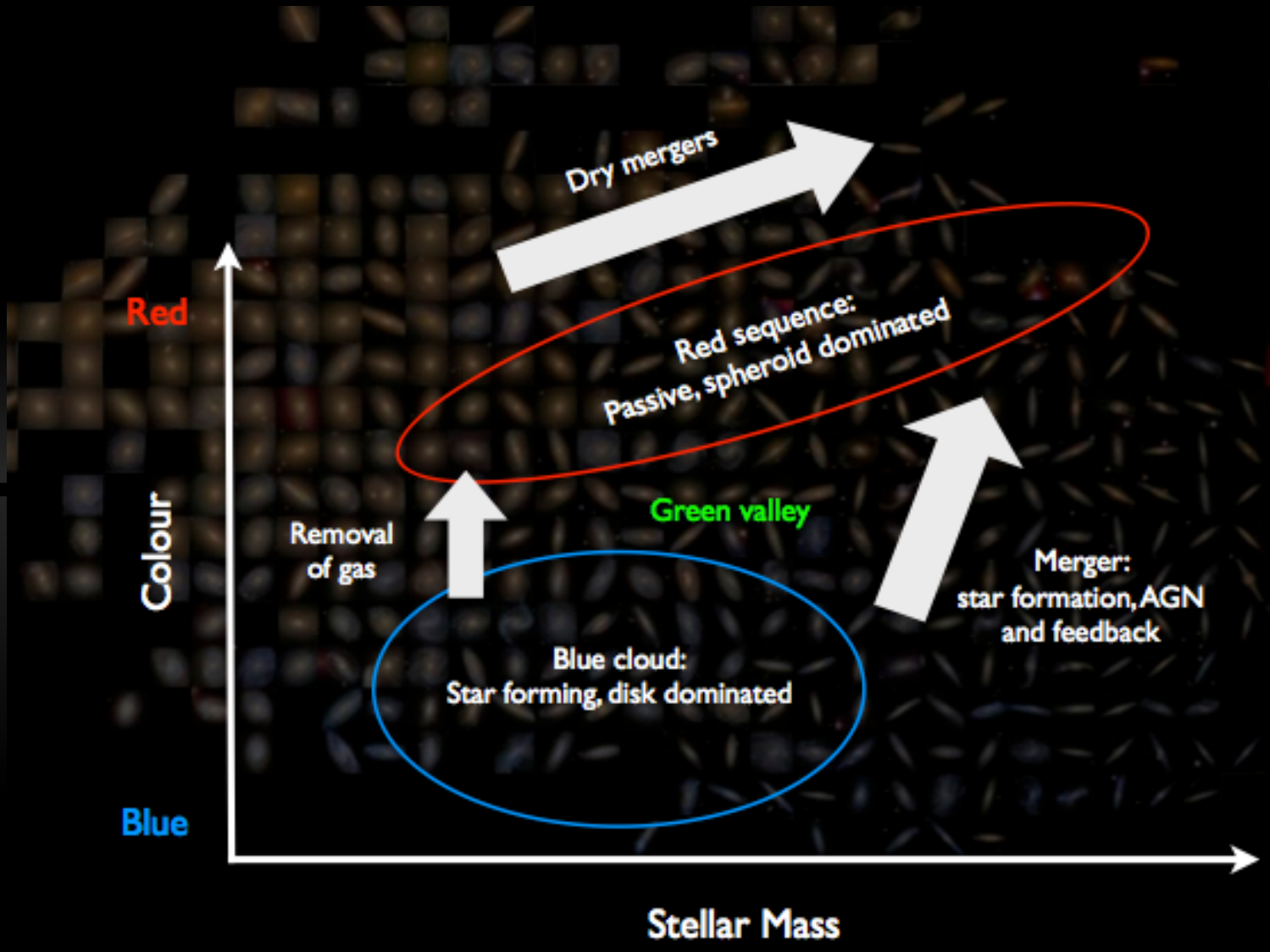
PI: Sebastián Sánchez (UNAM, Mexico)

# Science drivers

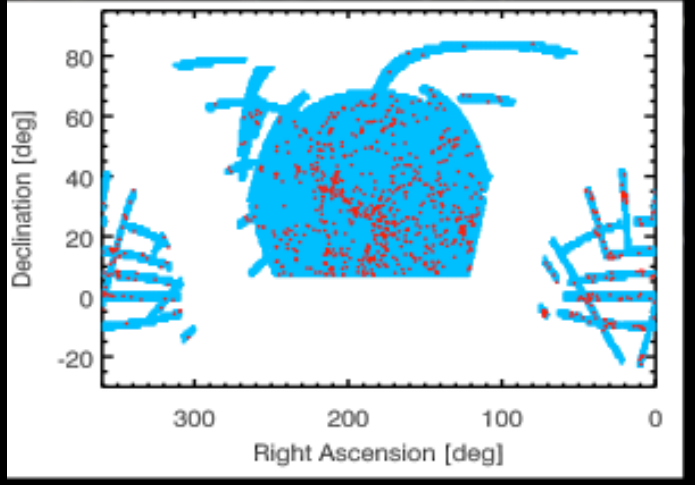
- ✓ Nearby galaxies as:
  - ✓ “Fossil records” of the formation and evolution of galaxies
- ✓ Which is the origin of the observed bimodality of galaxies?
- ✓ How galaxies evolve with time?

  Secular evolution vs. interaction
- ✓ Interrelated properties: chemistry, kinematics of ionized gas, stellar populations, morphology, etc.

# Science drivers



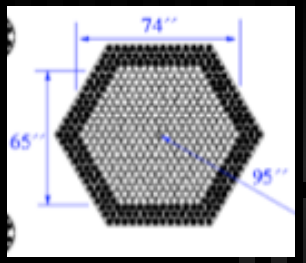
# The mother sample

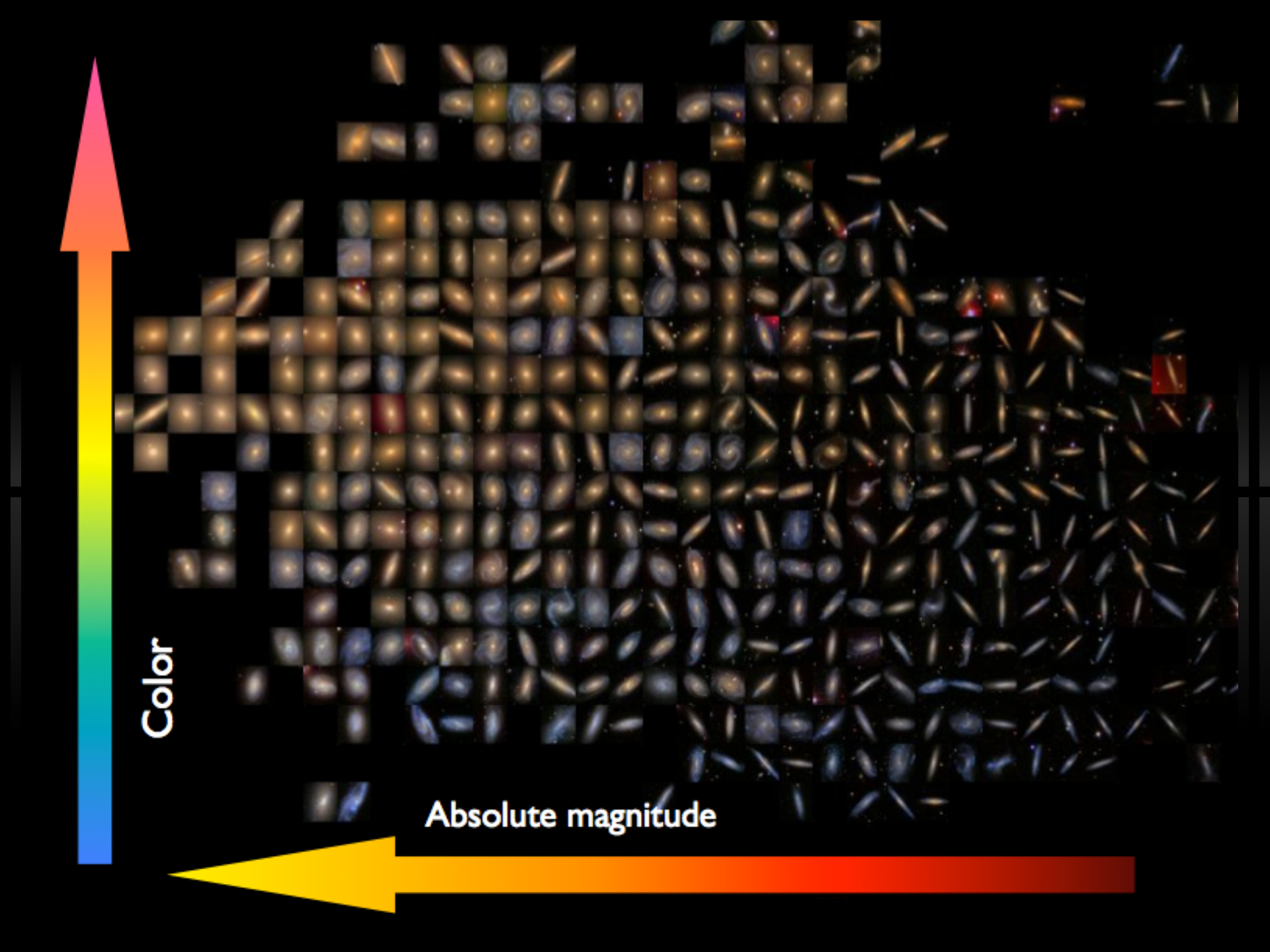



Walcher et al. 2014

- ✓ 600 galaxies were observed out of 939
  - ✓ Selected from SDSS DR7
  - ✓ Redshift range 0.005 < z < 0.03
  - ✓ Diameter 45” < R25 < 80” (isophotal radius at 25 mag/arcsec$^2$)
  - ✓ Final spatial resolution: 2” ( ~0.4-1 kpc)
  - ✓ No type selection (full coverage of the CMD)

PPak FoV





Color
Absolute magnitude

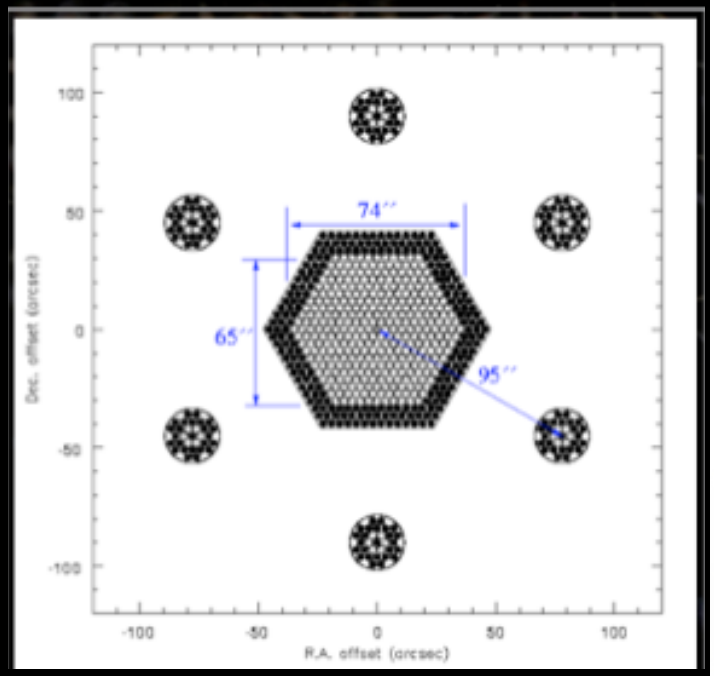
# Methodology

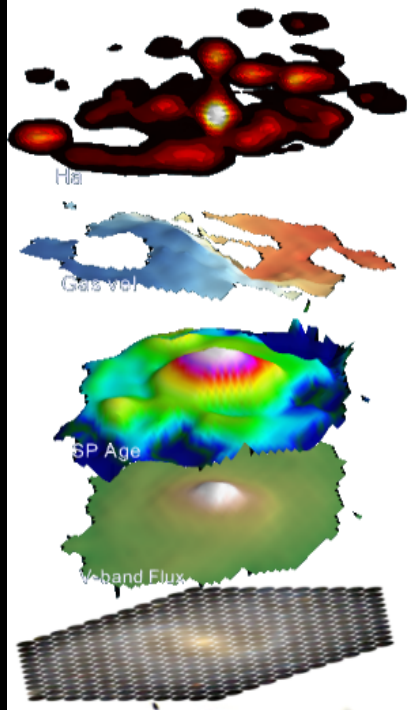
- ✓ PPAK@3.5m CAHA

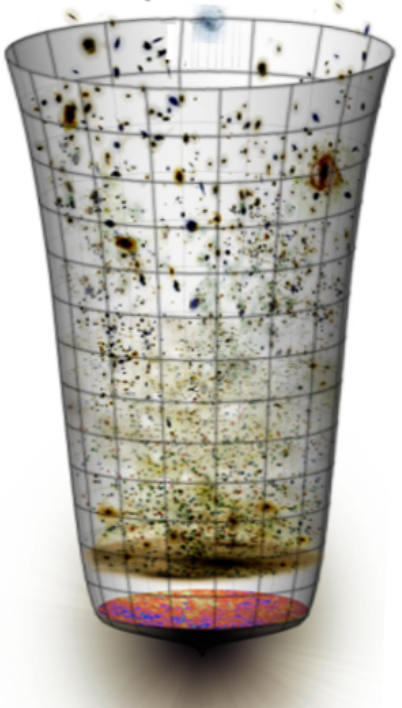
- ✓ PPAK:

  **P**MAS (Postdam Multi-Aperture Spectrophotometer) fiber **PA**c**K**

  - ✓ central hexagonal bundle of 331 optical fibres
  - ✓ 2.7 arcsec/fibre
  - ✓ Dithered observations

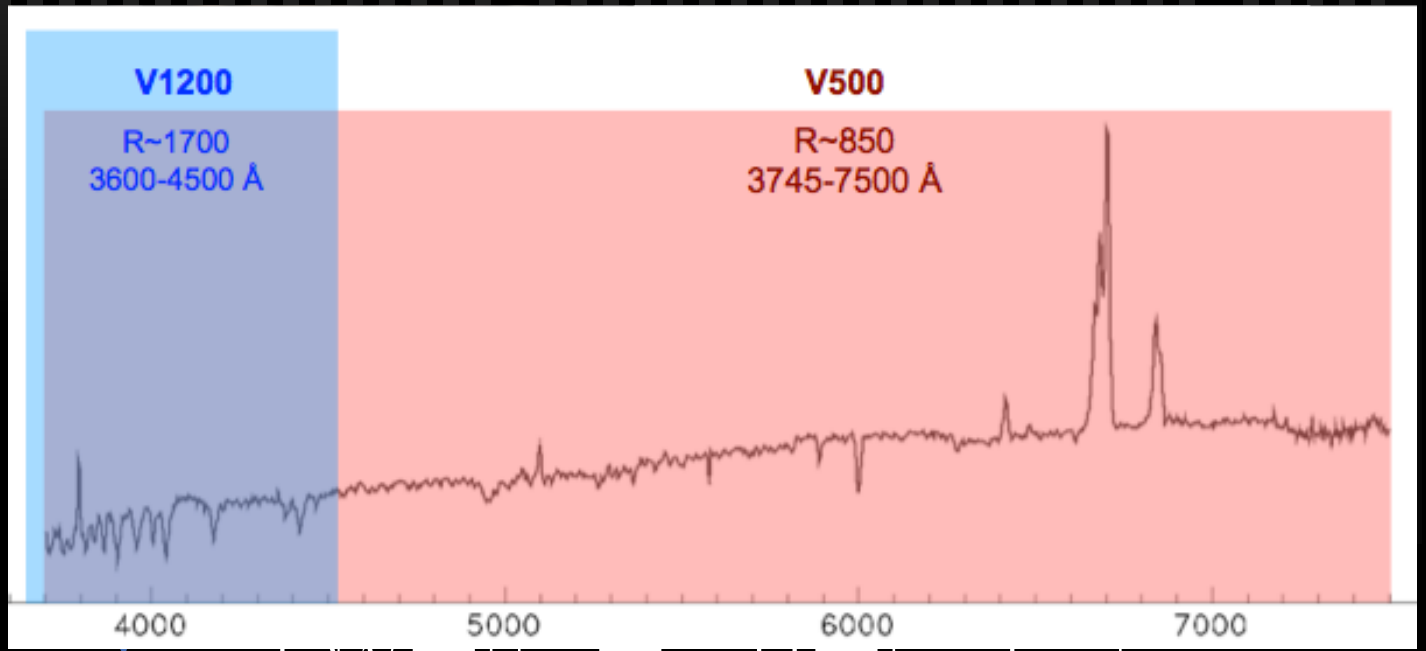


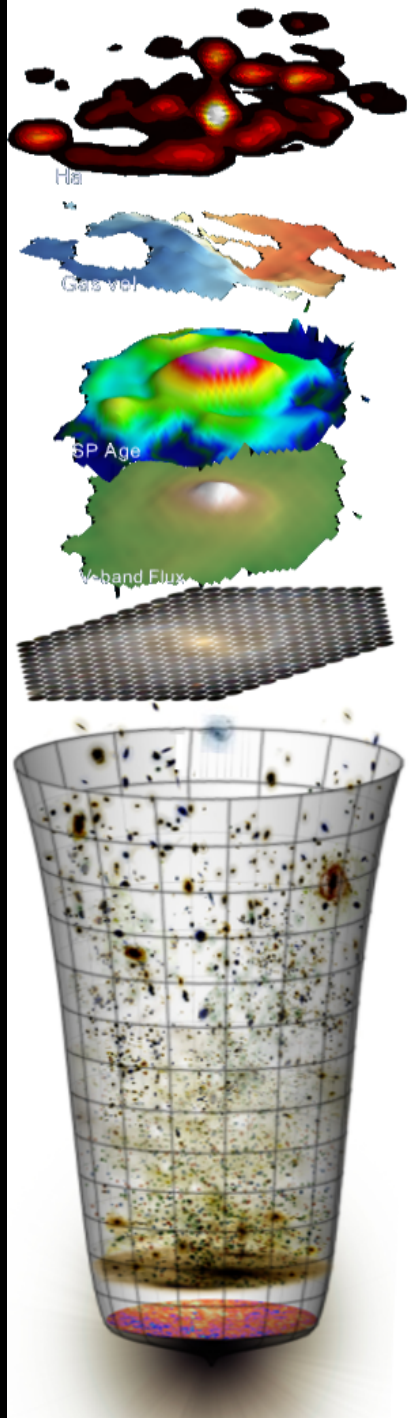



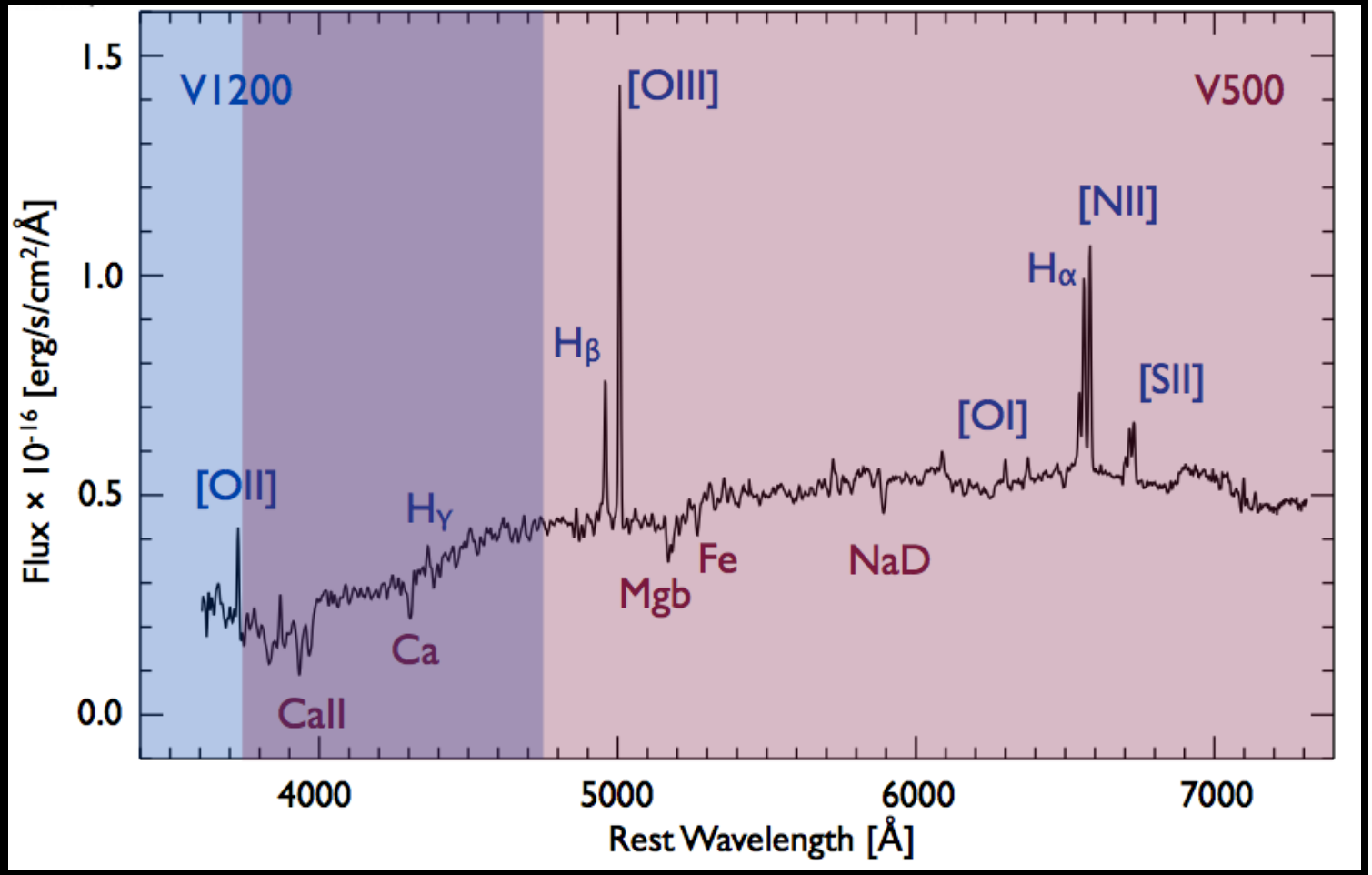
# Methodology

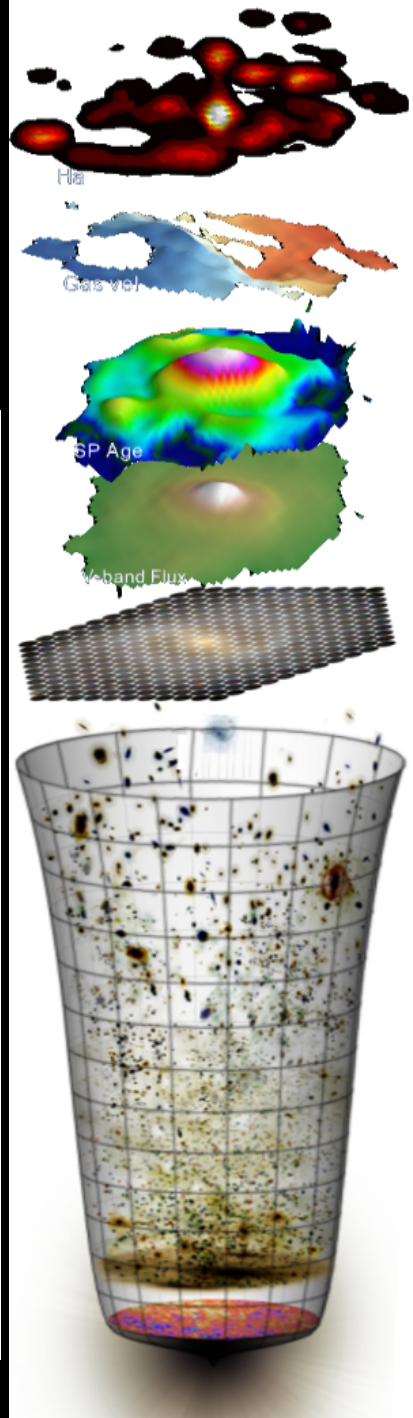
- ✓ PPAK@3.5m CAHA
- ✓ Wavelength range: 3700-7000 Ang
- ✓ ~2000 spectra per object
- ✓ Two instrumental setups:
  - ✓ high (V1200), mid (V500) resolution



# Methodology



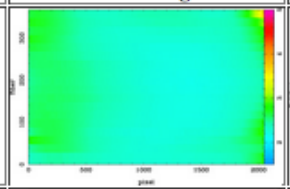
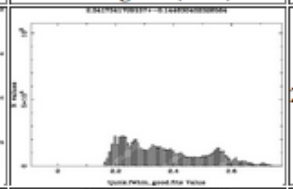
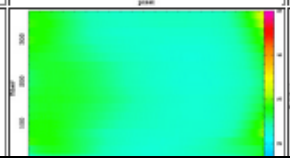
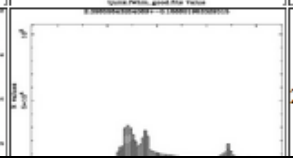



# Semi-Automatic reduction Pipeline

| DATA PRODUCTS | | | | |
|---|---|---|---|---|
| CUBE | RSS | Pos. Table | Reconst. V-band image | 20" Aperture Spectrum |
| IC2402.V500.rscube.fits.gz | mos_IC2402.V500.rss.fits.gz | mos_IC2402.V500.pt.txt |  |  |
| UGC6249.V500.rscube.fits.gz | mos_UGC6249.V500.rss.fits.gz | mos_UGC6249.V500.pt.txt |  |  |
| NGC3600.V500.rscube.fits.gz | mos_NGC3600.V500.rss.fits.gz | mos_NGC3600.V500.pt.txt |  |  |
| UGC6320.V500.rscube.fits.gz | mos_UGC6320.V500.rss.fits.gz | mos_UGC6320.V500.pt.txt |  |  |
| SN2002ji.V500.rscube.fits.gz | mos_SN2002ji.V500.rss.fits.gz | mos_SN2002ji.V500.pt.txt |  |  |

## AUTOMATIC QUALITY CONTROLS

| FIBERFLAT | | | | | |
|---|---|---|---|---|---|
| FITSFILE | MEAN | MEDIAN | STDDEV | MIN | MAX |
| fiberflat.20131212.fits | 0.92 | 0.98 | 0.147 | 0.3 | 1.301 |

| SPATIALLY RESOLVED INSTRUMENTAL CROSS-DISPERSION WIDTH | | | | | | |
|---|---|---|---|---|---|---|
| Cont Object | RSS Image | Histrogram (ALL) | MEAN FHWM | STDDEV FWHM | MIN FWHM | MAX FWHM |
| IC2402 |  |  | 2.373 | 0.144 | 2.165 | 3.349 |
| NGC3600 |  |  | 2.453 | 0.168 | 2.235 | 3.178 |

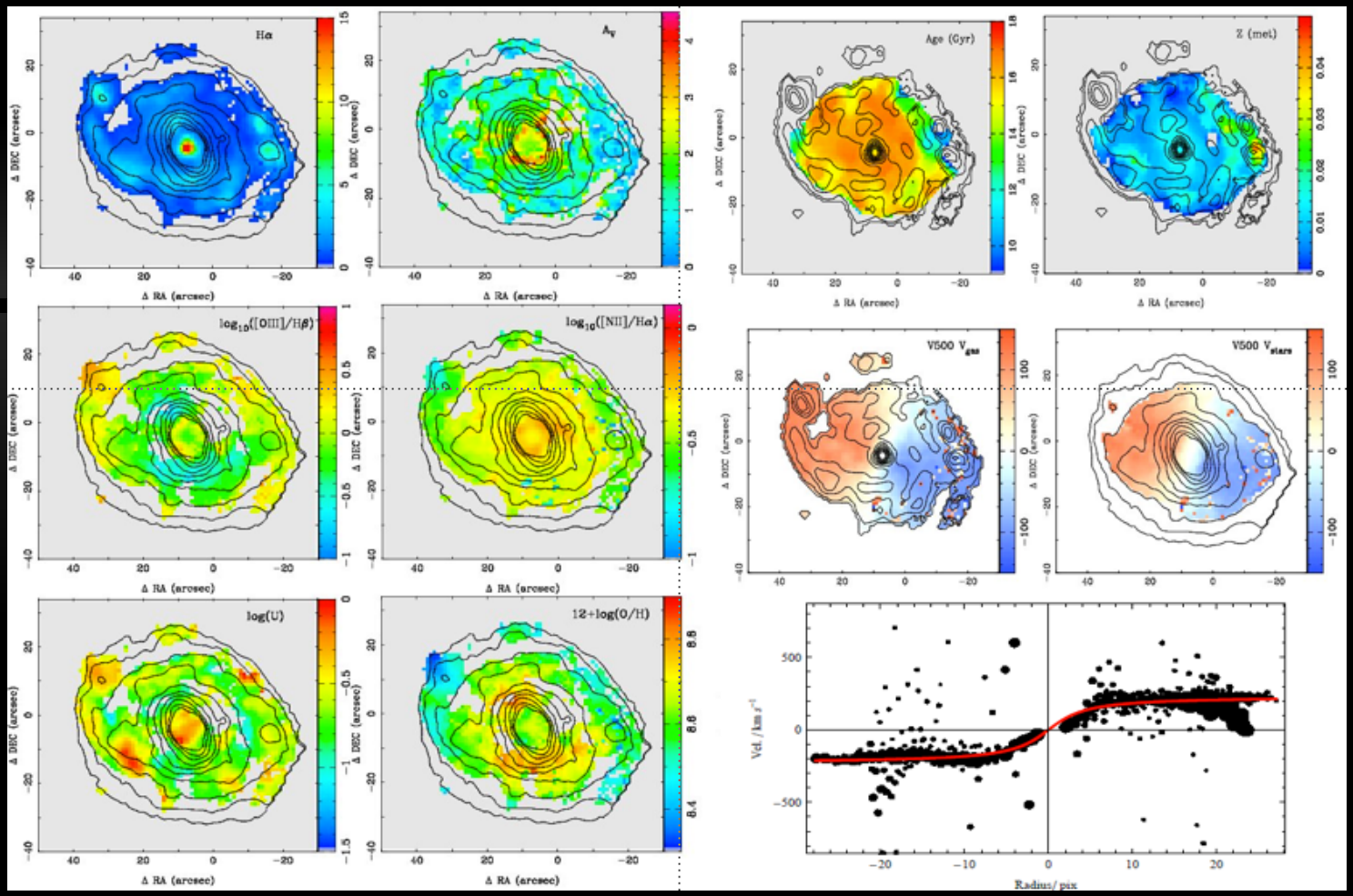
# Semi-Automatic reduction Pipeline

- ✓ v1.2 (Perl/R3D, Sánchez et al 2012)
- ✓ v1.3c (DR1, Perl/Python/Py3D, Husemann et al 2013)
- ✓ v1.5 (DR2, García-Benito et al 2015)
- ✓ v2.2 (DR3, Sánchez et al., in prep.)

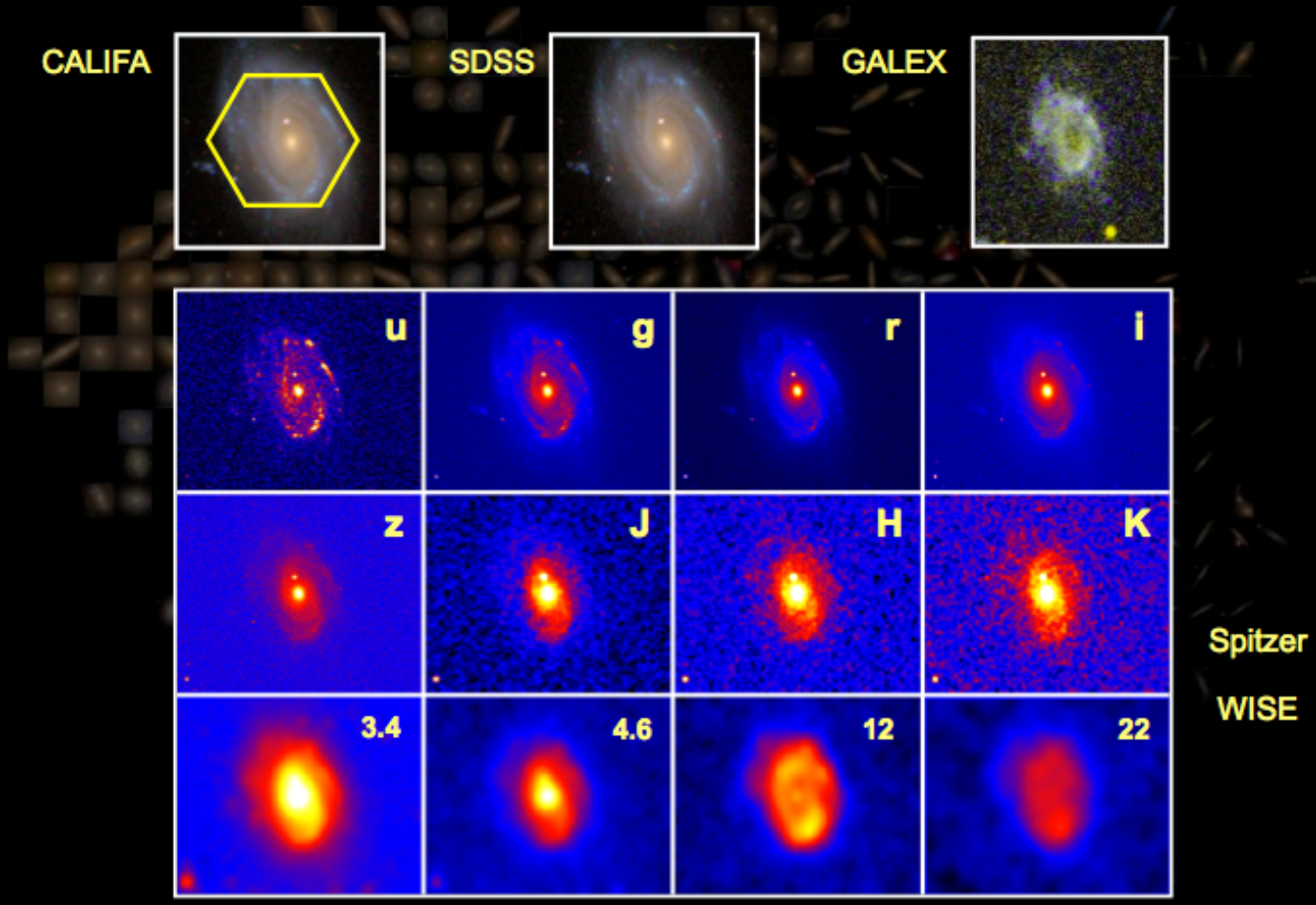
**Quality Control**

- ✓ Automatic QC performed by the reduction
- ✓ Detailed QC performed by an independent group

# Analysis pipeline



# Ancillary data



# CALIFA DATA Releases

- ✓ DR1, 100 galaxies, 200 cubes. Oct. 2013, Husemann et al. 2013
- ✓ DR2, 200 galaxies, 400 cubes. Oct. 2014, Garcia-Benito et al. 2015
- ✓ DR3, ~650 galaxies, ~1200 cubes. Apr. 2016. Sanchez et al., in prep.

**http://califa.caha.es/DR3**

# CALIFA Explorer

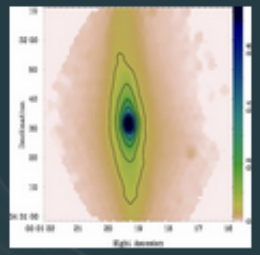
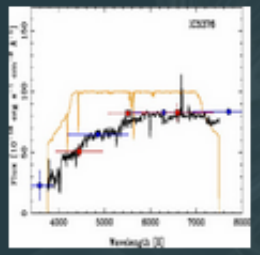
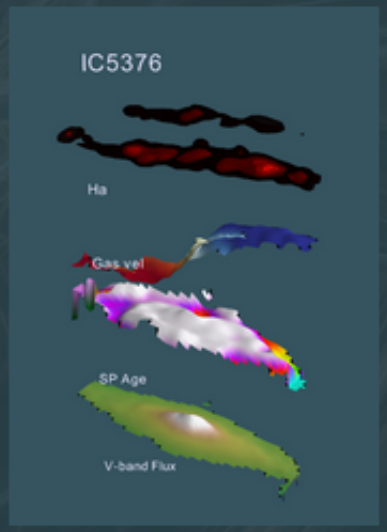
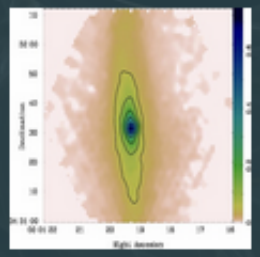
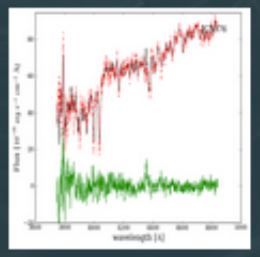
## CALIFA EXPLORER V1.0

Tue, 11/22/2011 - 15:31

| NAME (1) | RA | DEC | CALIFAID |
|---|---|---|---|
| IC5376 | 00:01:19.77 | +34:31:32.40 | 1 |

| BASIC PARAMETERS | VALUE | REF. |
|---|---|---|
| Name | IC5376 | NED |
| Redshift | 0.016792 | SDSS |
| Petrosian Mags (u,g,r,i,z) | (16.4068 ,14.4858 ,13.6274 ,13.1605 ,) | SDSS |
| Galactic Extinctions (u,g,r,i,z) | (0.369168 ,0.27163 ,0.197009 ,0.149386 ,0.105916) | SDSS |

### CALIFA OBSERVATIONS

| | | | | |
|---|---|---|---|---|
| V500 | 20110825 V500 Cube |  |  |  |
| V1200 | 20110828 V1200 Cube |  |  | |




### CALIFA Morphological Classification

| PARAMETER | VALUE | PARAMETER | VALUE |
|---|---|---|---|
| hubble_type | S | hubble_subtype | b |
| minimum_hubble_type | S | minimum_hubble_subtype | a |


✓ 10000 individual downloads

# Science highlights

# Publication statistics

## CALIFA in NASA-ADS

**Last update: March 2016**

| Direct links to ADS search | Number |
|---|---|
| Publications with the string "CALIFA" in the title | **93** |
| Publications with the string "CALIFA" in the abstract | **121** |
| Citations to the survey presentation article [1)] | **218** |
| Citations to the DR1 article [2)] | **68** |
| Citations to the DR2 article [3)] | **31** |
| Citation history the survey presentation article | |
| Citation history of the DR1 article | |
| Citation history of the DR2 article | |

1) Sánchez et al. 2012, A&A, 538
2) Husemmann et al. 2013, A&A, 549
3) García-Benito et al. 2015

4 PhD Thesis

17 (future) PhD Thesis

6 Master Thesis

7 (future) Master Thesis

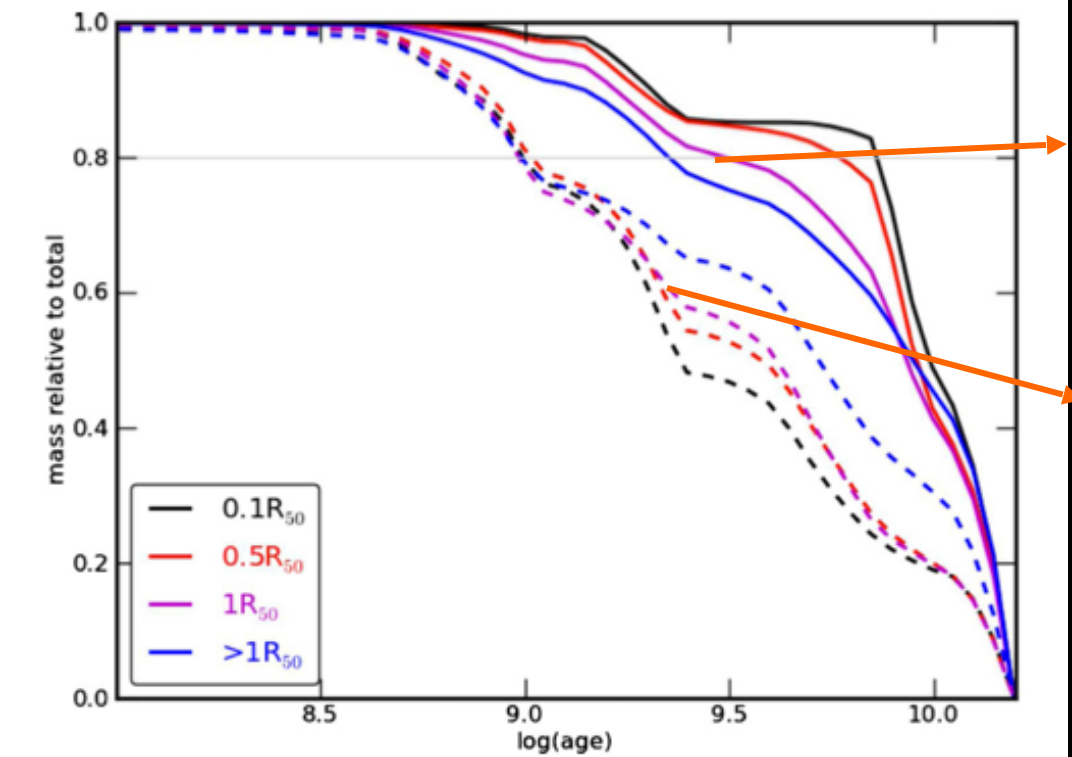
1 Bachelor Thesis

# Sales pitch!

Science highlights

Pérez et al. ApJL 2013

✓ Mass growth curve




Galaxies with M~5-7 x$10^{10}$ Msun)

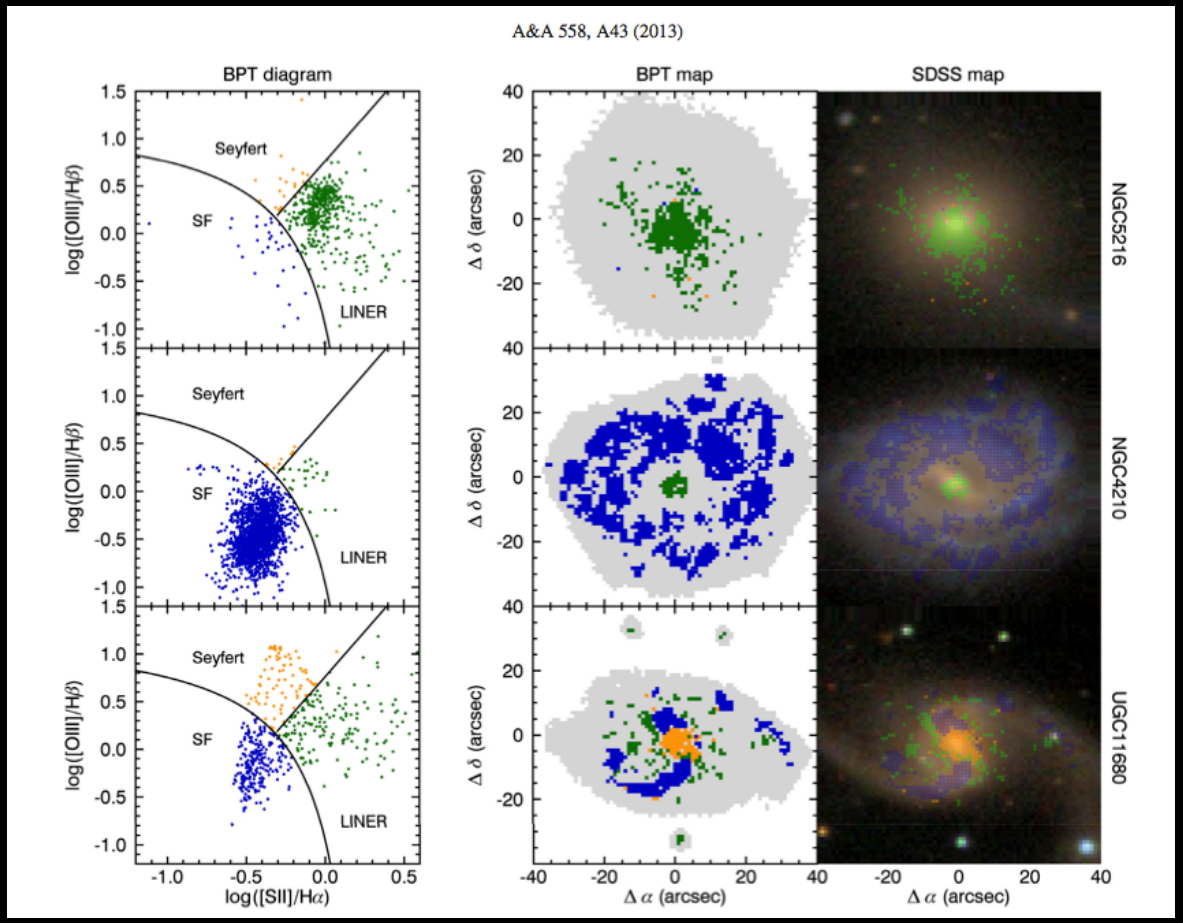
Low mass galaxies (<$10^{10}$ Msun)

Galaxies with Mass > $10^{10}$ (Msun): grow inside-out

Science highlights

Singh et al. A&A 2013

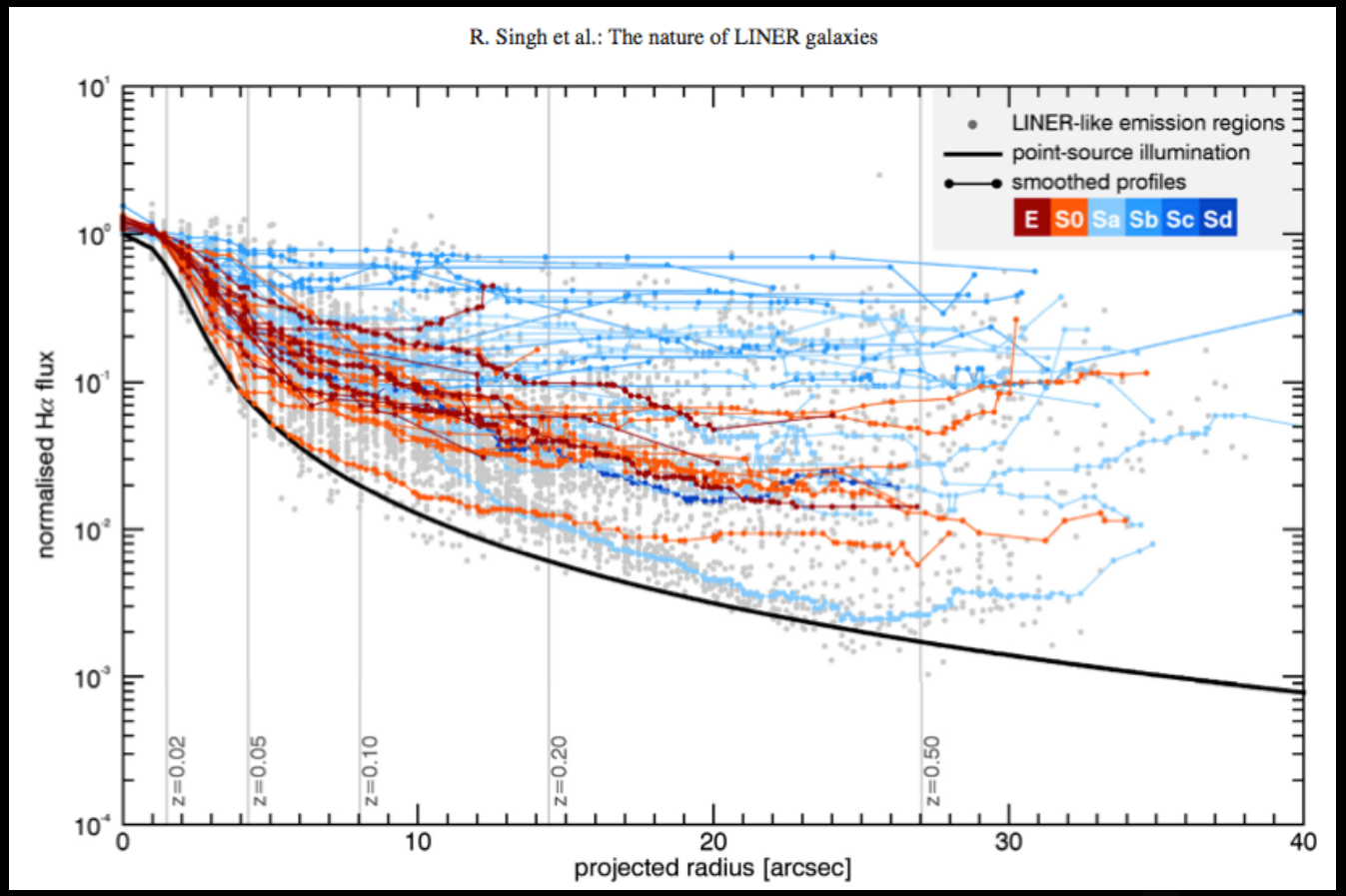
✓ Are LINERS powered by a low-luminosity AGN?




LINER: (Low ionization nuclear emission-line region), the largest AGN sub-population

Science highlights

Singh et al. A&A 2013

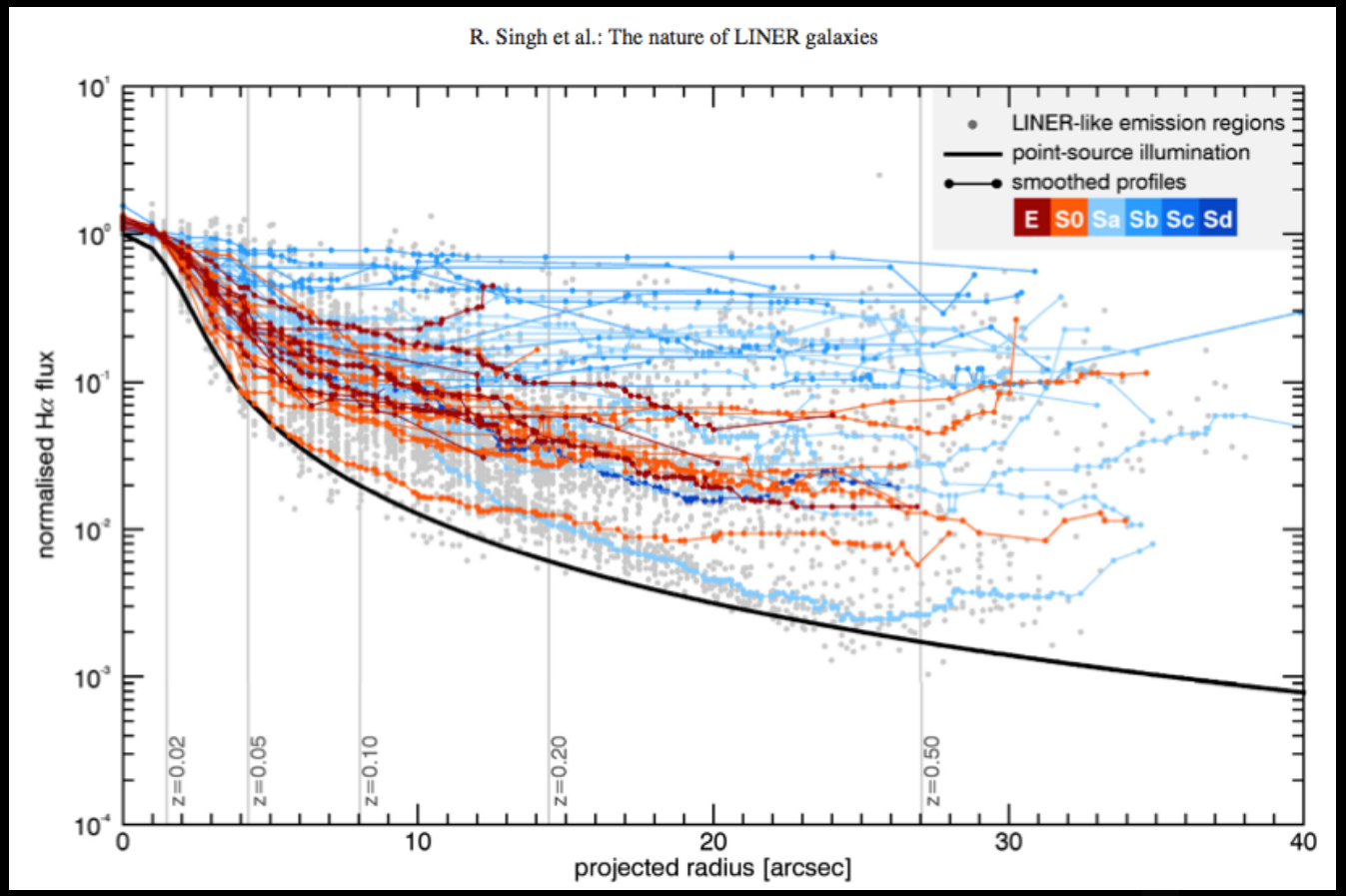



Powered by ubiquitous hot old stars

Science highlights

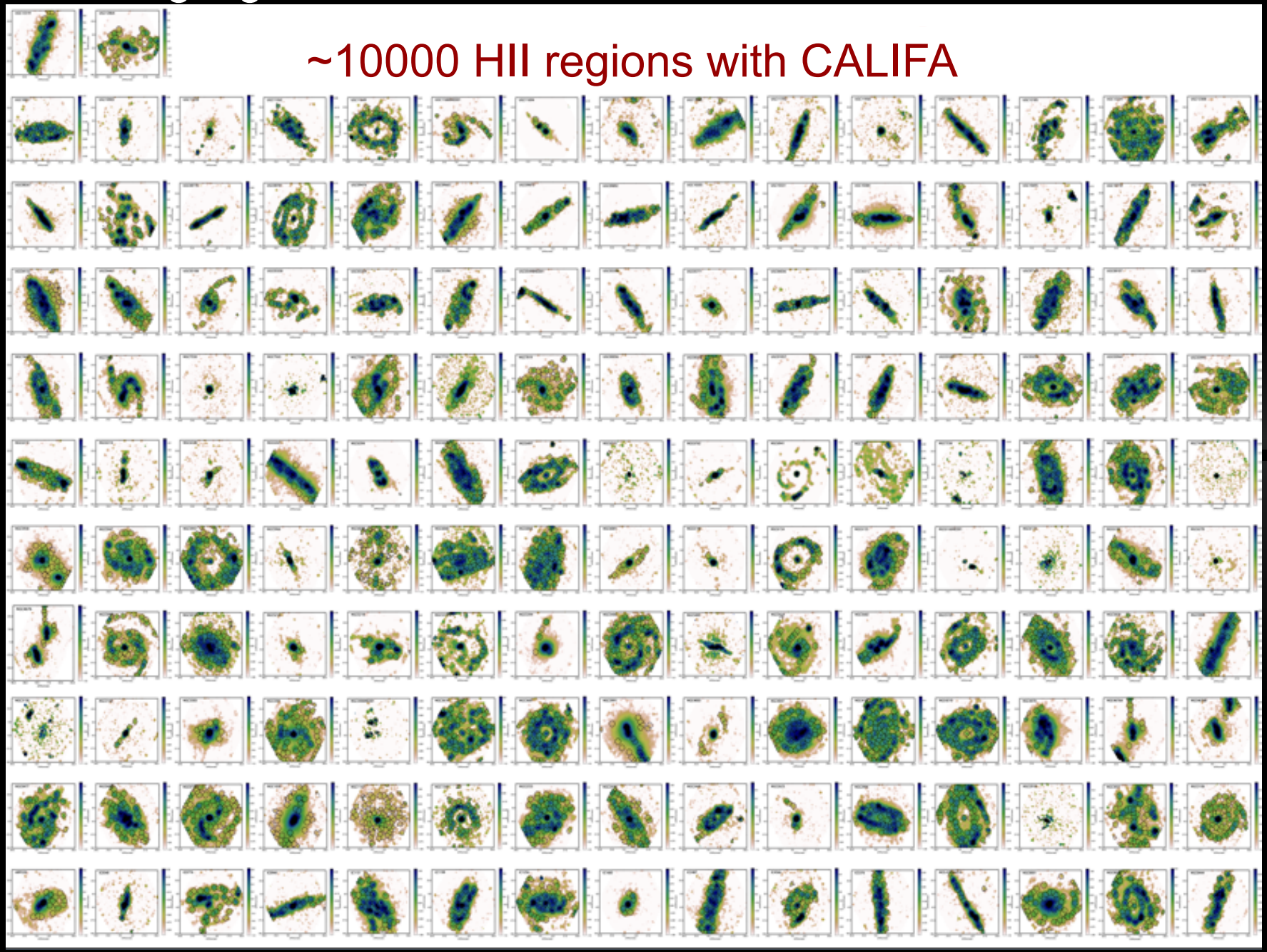
Singh et al. A&A 2013

✓ LINERS are LIERS!




Powered by ubiquitous hot old stars

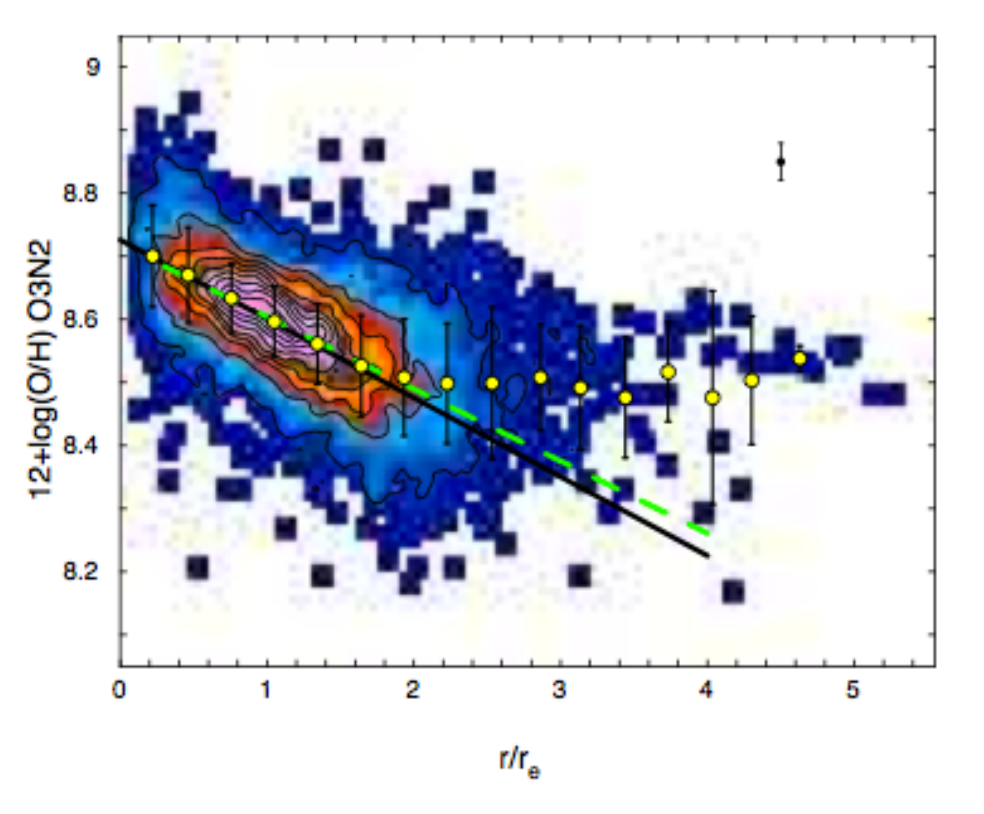
# Science highlights



Science highlights

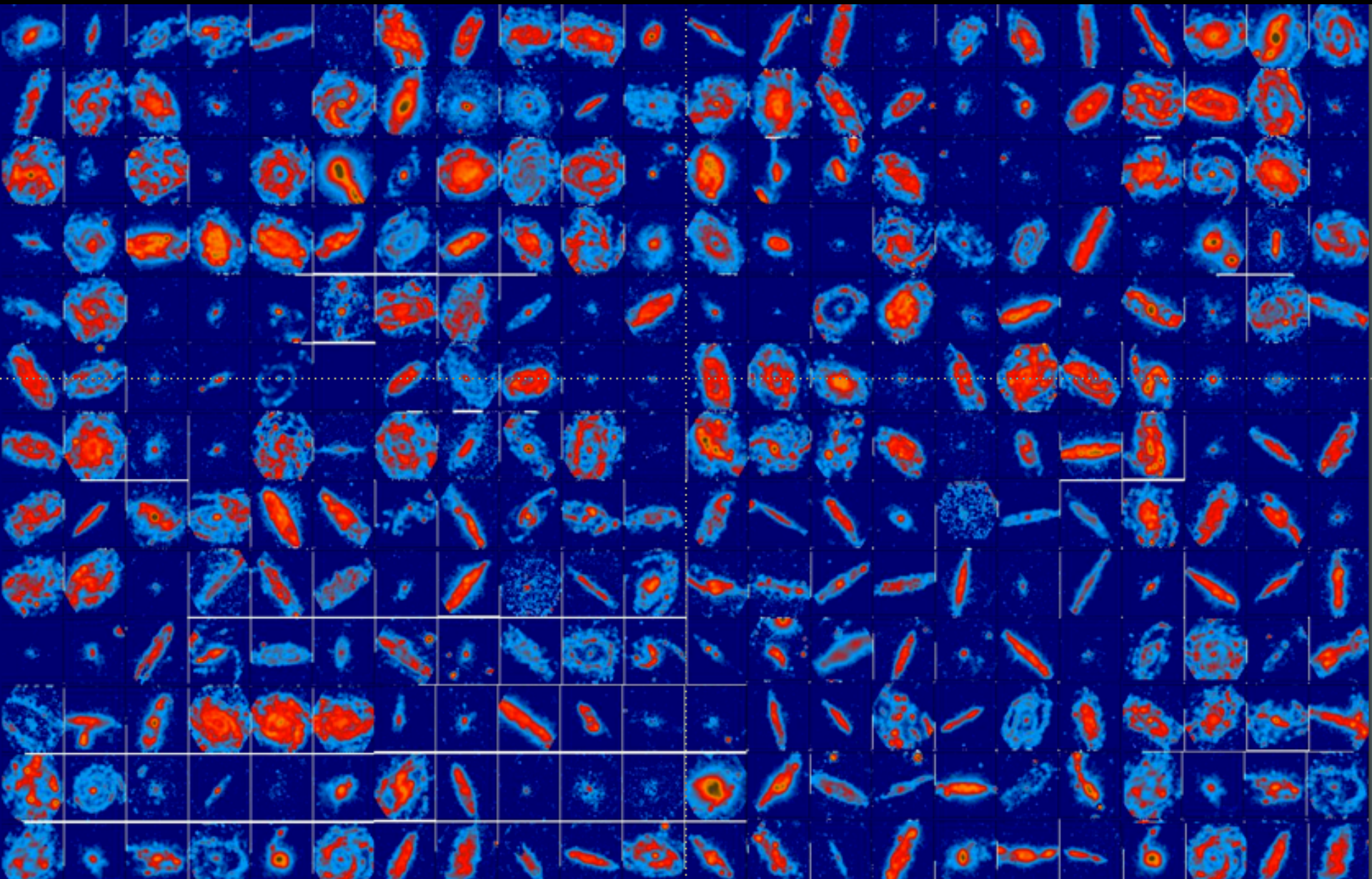
Sánchez et al. A&A 2013

✓ A common gradient in the oxygen abundance
✓ α(*O/H*) = –0.12 +/-0.1 dex/*re* between 0.3 and 2 disk effective radii (*re*)




The slope is independent of morphology, incidence of bars, absolute magnitude or mass.

# Ionized gas detected in all galaxies!



# Science highlights

- ✓ NGC 4676

"The Mice galaxies"

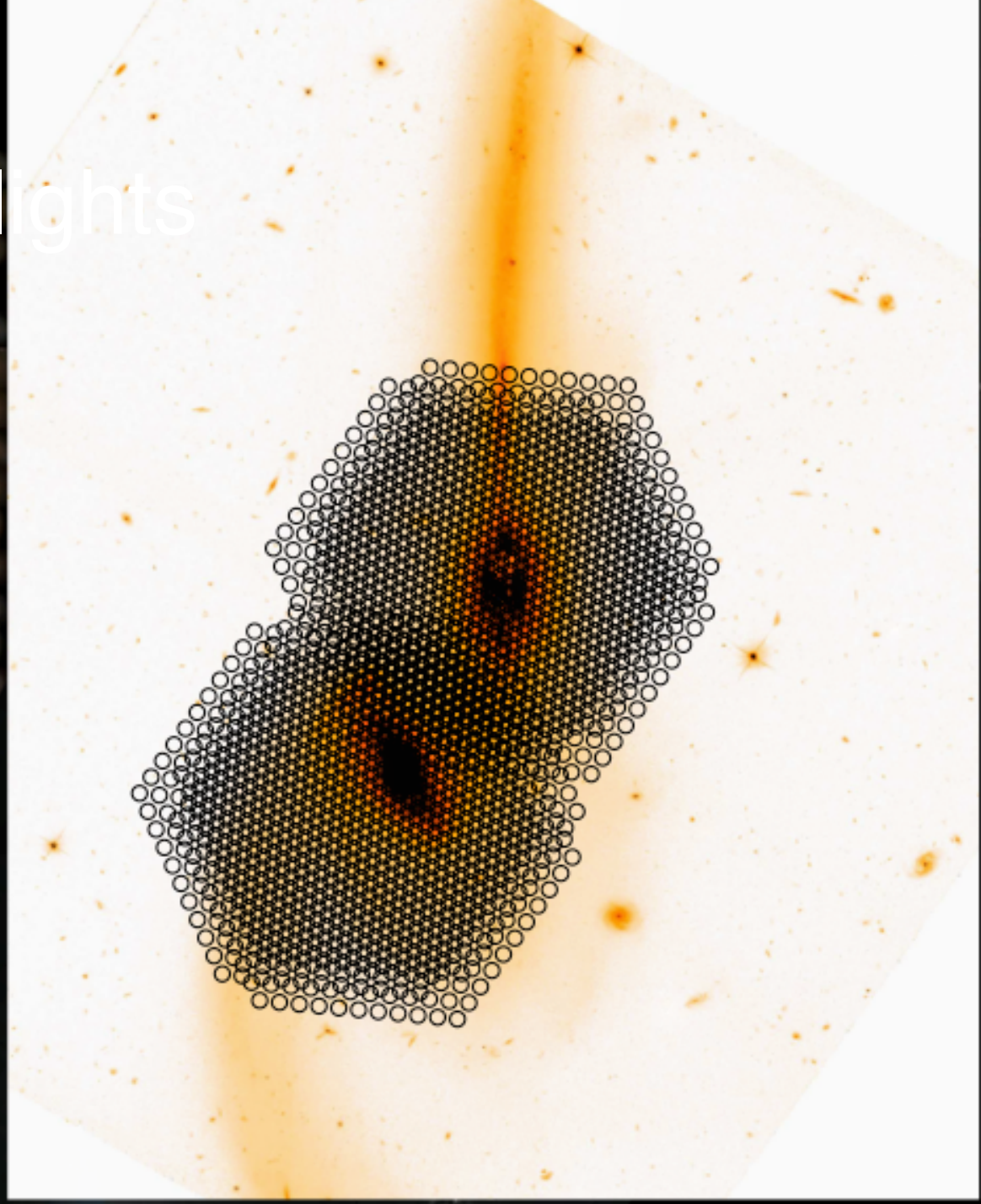
Wild et al. 2014

# Science highlights

- ✓ NGC 4676

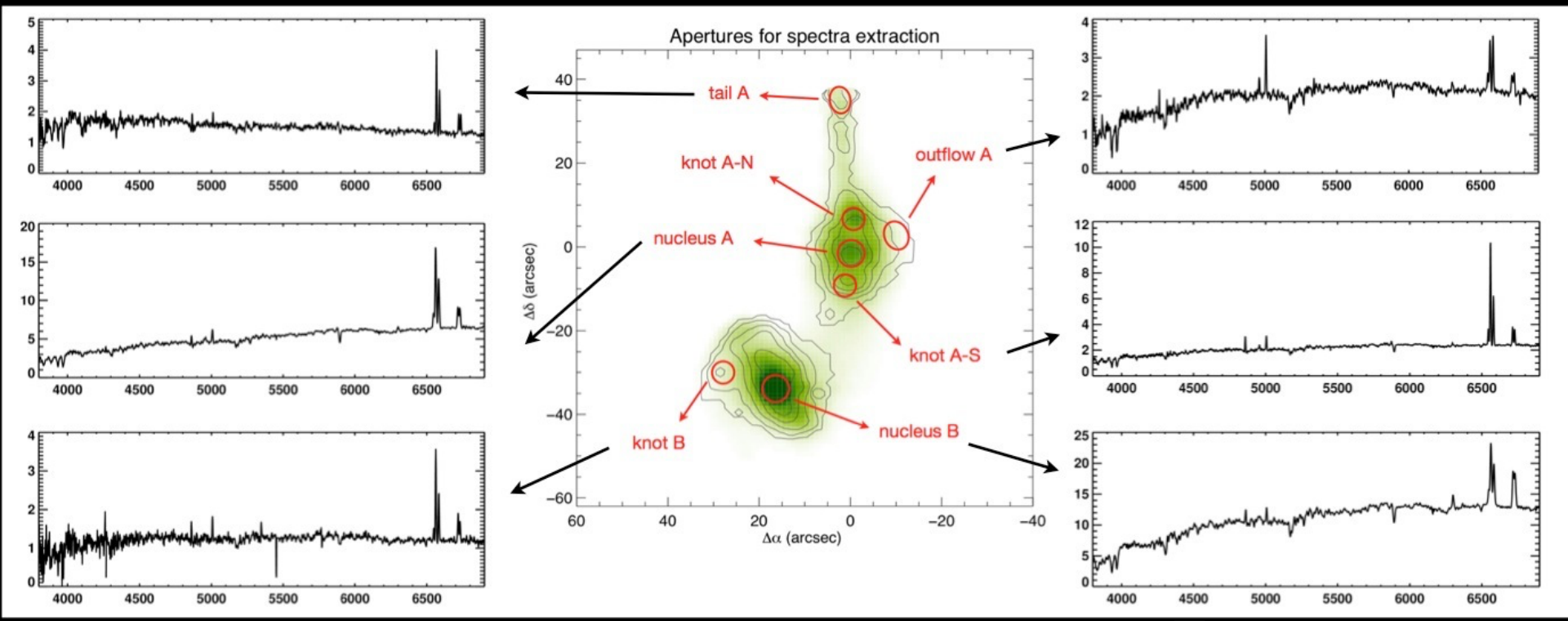
"The Mice galaxies"

Wild et al. 2014



# Science highlights

"The Mice galaxies"




Wild et al. 2014

# After CALIFA

- ✓ The next step after CALIFA is a larger sample
- ✓ Remaining questions that need statistics (>10kgalaxies)

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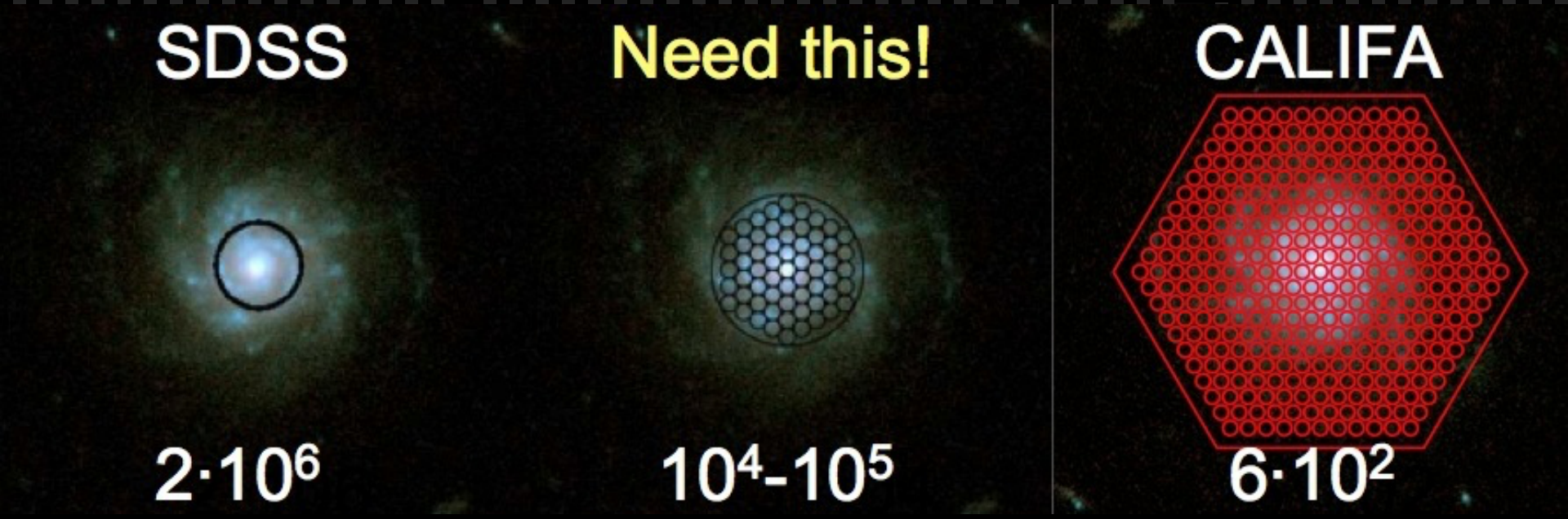
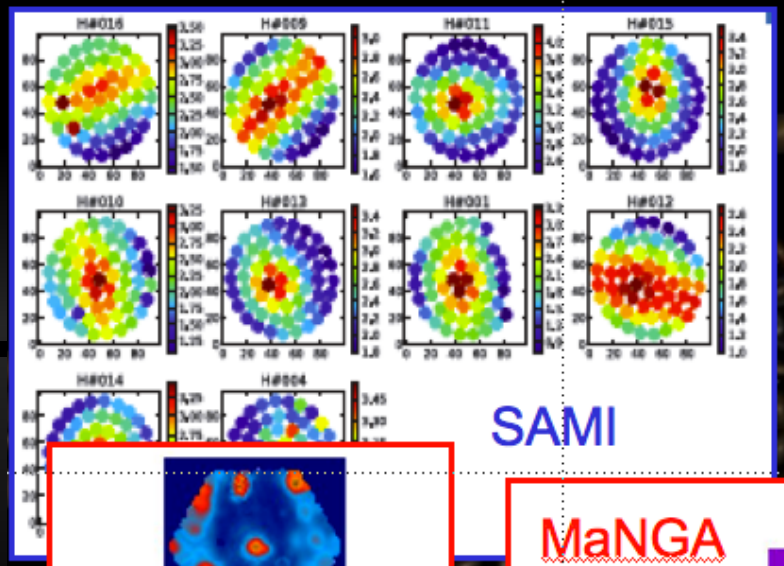
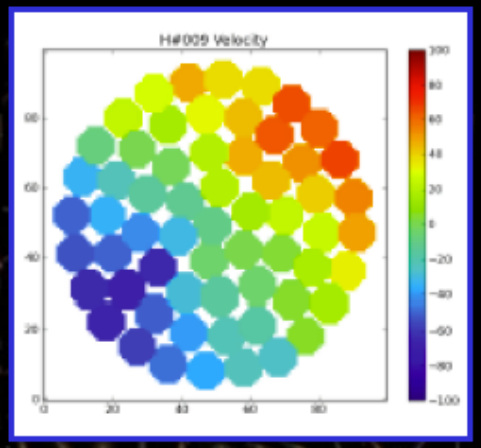
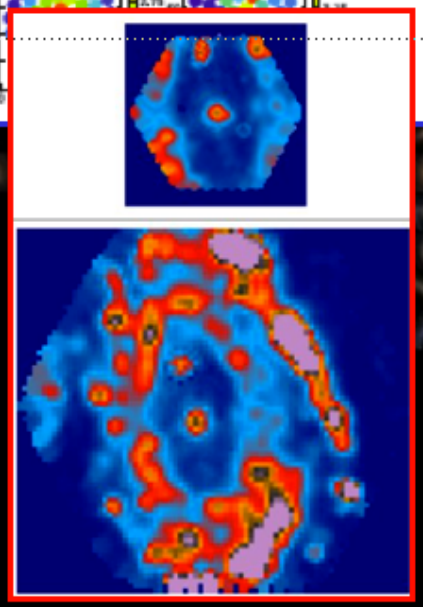


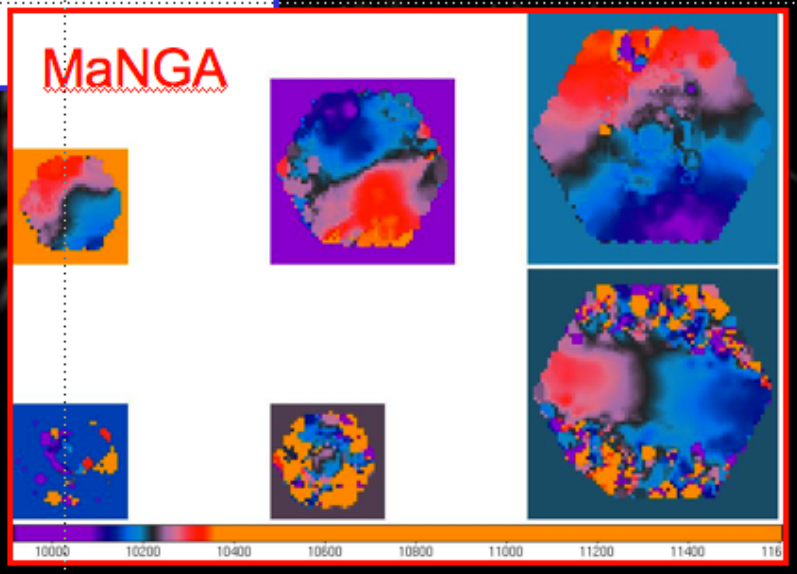
# After CALIFA

- ✓SAMI (AAT, observation started, ~3k galaxies)
- ✓MaNGA (SDSS extension, ~5k Galaxies)
- ✓HECTOR (AAO, in development, 100k galaxies)

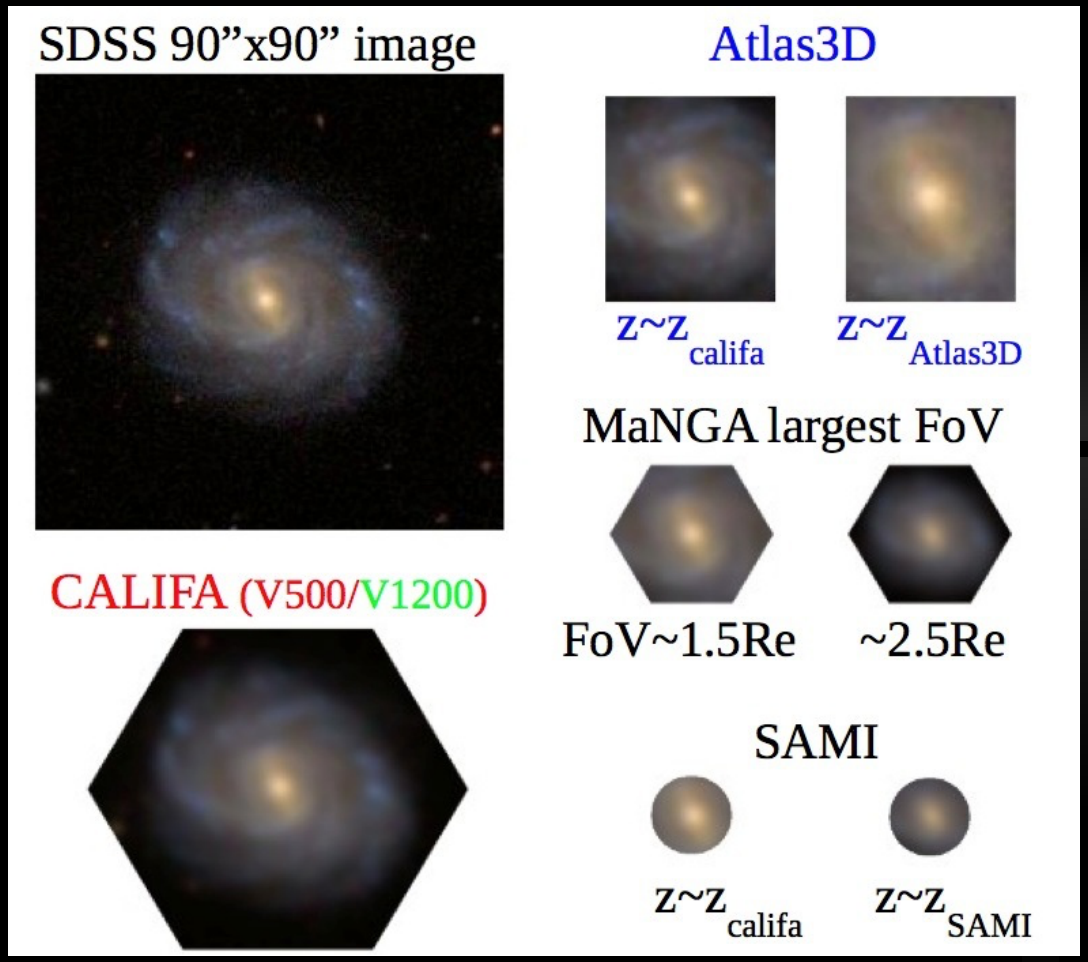




# Spatial coverage, spatial resolution and wavelength coverage

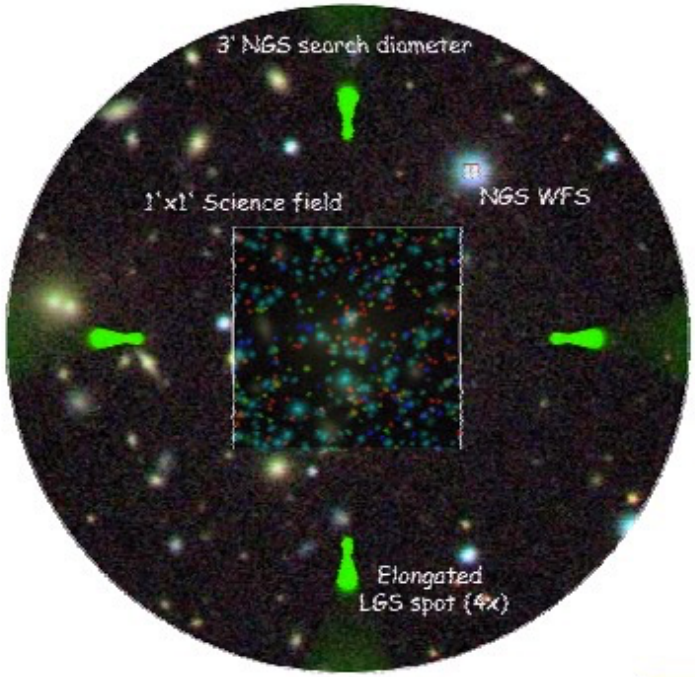



✓CALIFA will retain properties that make it interesting even after next generation IFS surveys are available.

# Spatial coverage, spatial resolution and wavelength coverage

muse
multi unit spectroscopic explorer

| Observational Parameters | |
|---|---|
| Spectral range (simultaneous) | 0.465-0.93 μm |
| Resolving power | 2000@0.46 μm |
| | 4000@0.93 μm |
| **Wide Field Mode (WFM)** | |
| Field of view | 1x1 arcmin$^2$ |
| Spatial sampling | 0.2x0.2 arcsec$^2$ |
| Spatial resolution (FWHM) | 0.3-0.4 arcsec |
| Gain in ensquared energy within one pixel with respect to seeing | 2 |
| Condition of operation with AO | 70%-ile |
| Sky coverage with AO | 70% at Galactic Pole |
| Limiting magnitude in 80h | $I_{AB}$ = 25.0 (R=3500) |
| | $I_{AB}$ = 26.7 (R=180) |
| Limiting Flux in 80h | 3.9 $10^{-19}$erg.s$^{-1}$.cm$^{-2}$ |
| **Narrow Field Mode (NFM)** | |
| Field of view | 7.5x7.5 arcsec$^2$ |
| Spatial sampling | 0.025x0.025 arcsec$^2$ |
| Spatial resolution (FWHM) | 0.030-0.050 arcsec |
| Strehl ratio | 10-30% |
| Limiting Flux in 1h | 2.3 $10^{-18}$erg.s$^{-1}$.cm$^{-2}$ |
| Limiting magnitude in 1h | $R_{AB}$ = 22.3 |
| Limiting surface brightness in 1h | $R_{AB}$ = 17.3 arcsec$^{-2}$ |



# Conclusions

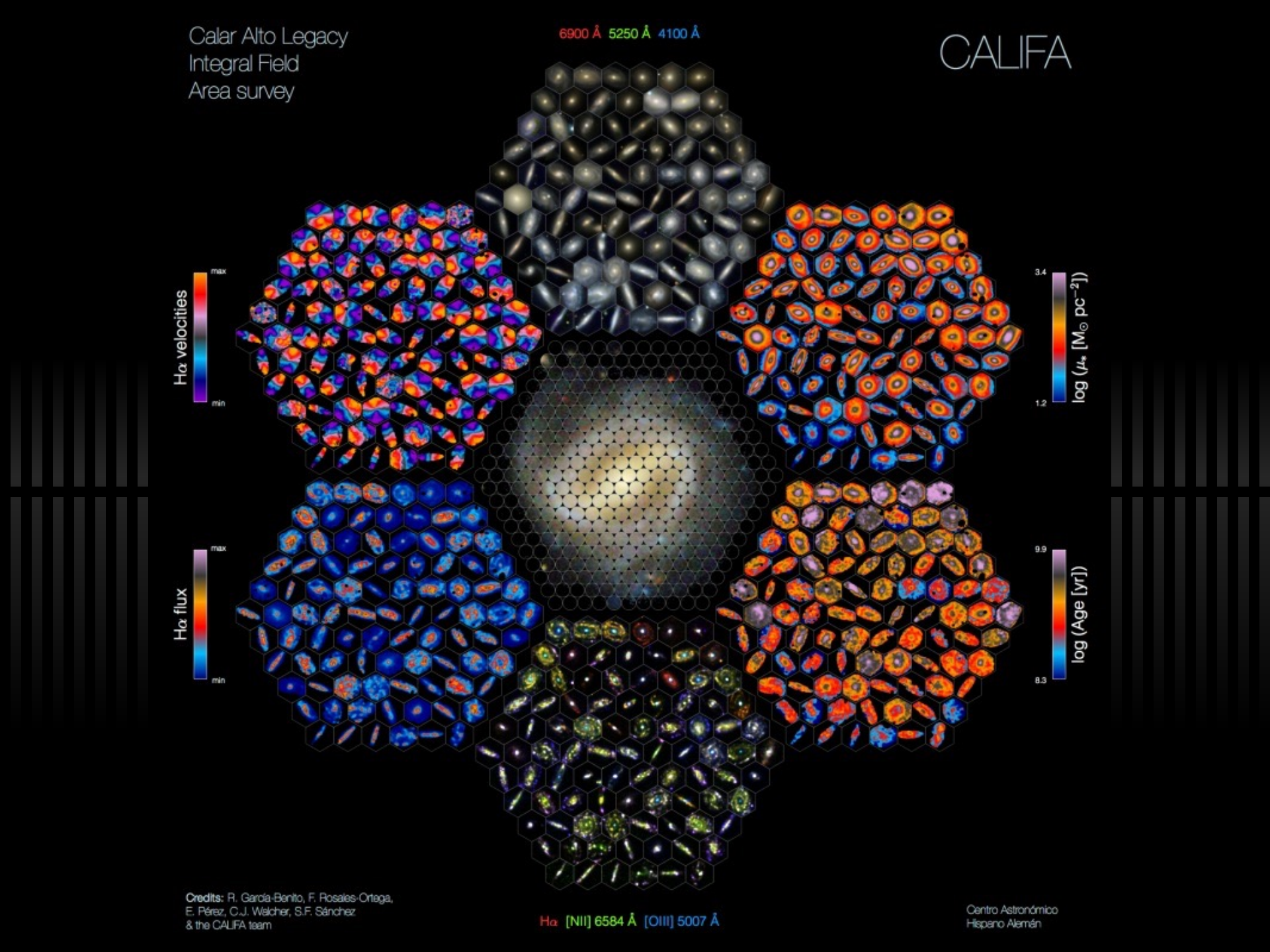
- ✓ CALIFA is unique **opportunity** to understand the baryonic physics of galaxies using integral field spectroscopy.
- ✓ CALIFA is a **legacy survey**, data are being collected, quality is excellent, and all will be public!
- ✓ CALIFA will retain properties that make it **interesting** even after next generation IFS surveys are available

# DR3 !!!!!!

✓

650 Objects
April 2016
Stay tuned!

CALIFA Survey


Calar Alto Legacy
Integral Field
Area survey
6900 Å 5250 Å 4100 Å
CALIFA
Hα velocities
max
min
3.4
1.2
log ($\mu_*$ [$M_\odot$ pc$^{-2}$])
Hα flux
max
min
9.9
8.3
log (Age [yr])
Hα [NII] 6584 Å [OIII] 5007 Å
Credits: R. García-Benito, F. Rosales-Ortega, E. Pérez, C.J. Walcher, S.F. Sánchez & the CALIFA team
Centro Astronómico Hispano Alemán