Gas phase metallicities in CALIFA (like) galaxies

F. Fabián Rosales-Ortega

on behalf of the CALIFA team

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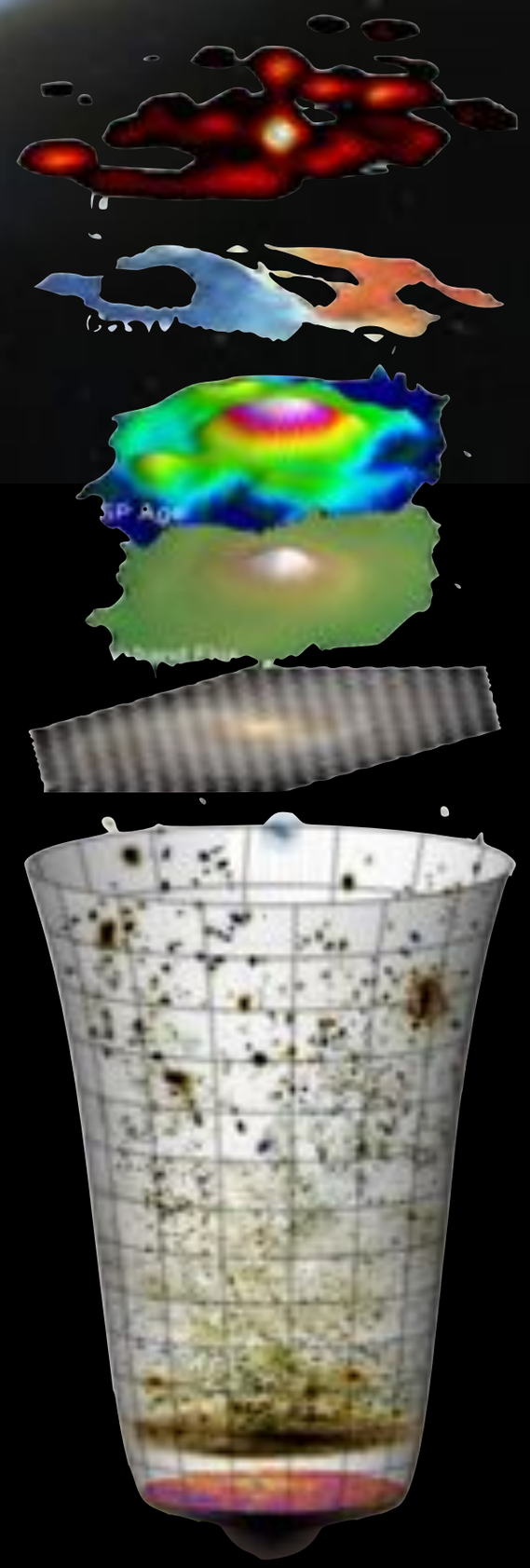

CALIFA Survey

Calar Alto

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Outline

Outline

- CALIFA: brief introduction and status update
- Study of the gas phase with IFS:
  - Mass-metallicity relation explored with CALIFA: is there a dependence on the star-formation rate?
  - The effects of spatial resolution with redshift in IFU-based surveys
  - The N2 and O3N2 metallicity calibrations revisited

CALIFA Survey

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CALIFA in brief...

Calar Alto Legacy Integral Field spectroscopy Area survey

CALIFA in brief...

Calar Alto Legacy Integral Field spectroscopy Area survey

- Integral Field Spectroscopy Survey of galaxies in the Local Universe (Calar Alto 3.5m telescope, Spain)
- 250 dark nights in 3 years (started July 2010, ~100 left)
  - ~ 2.5 Million Euros in telescope time
- Statistical and representative sample of ~600 galaxies
- Spatially resolved spectroscopic properties of galaxies in the Local Universe
- Legacy character: reduced data delivered publicly

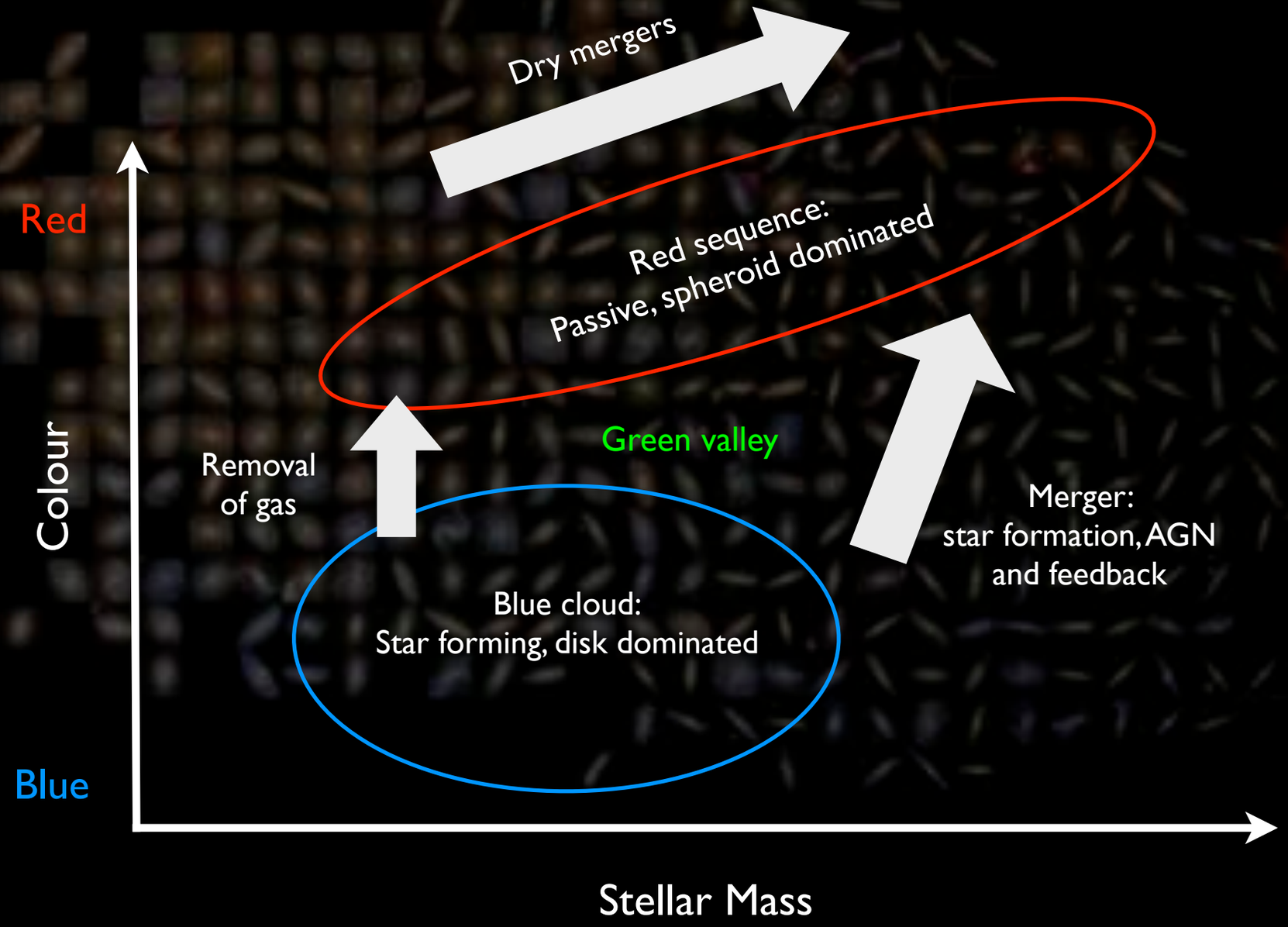
CALIFA Survey

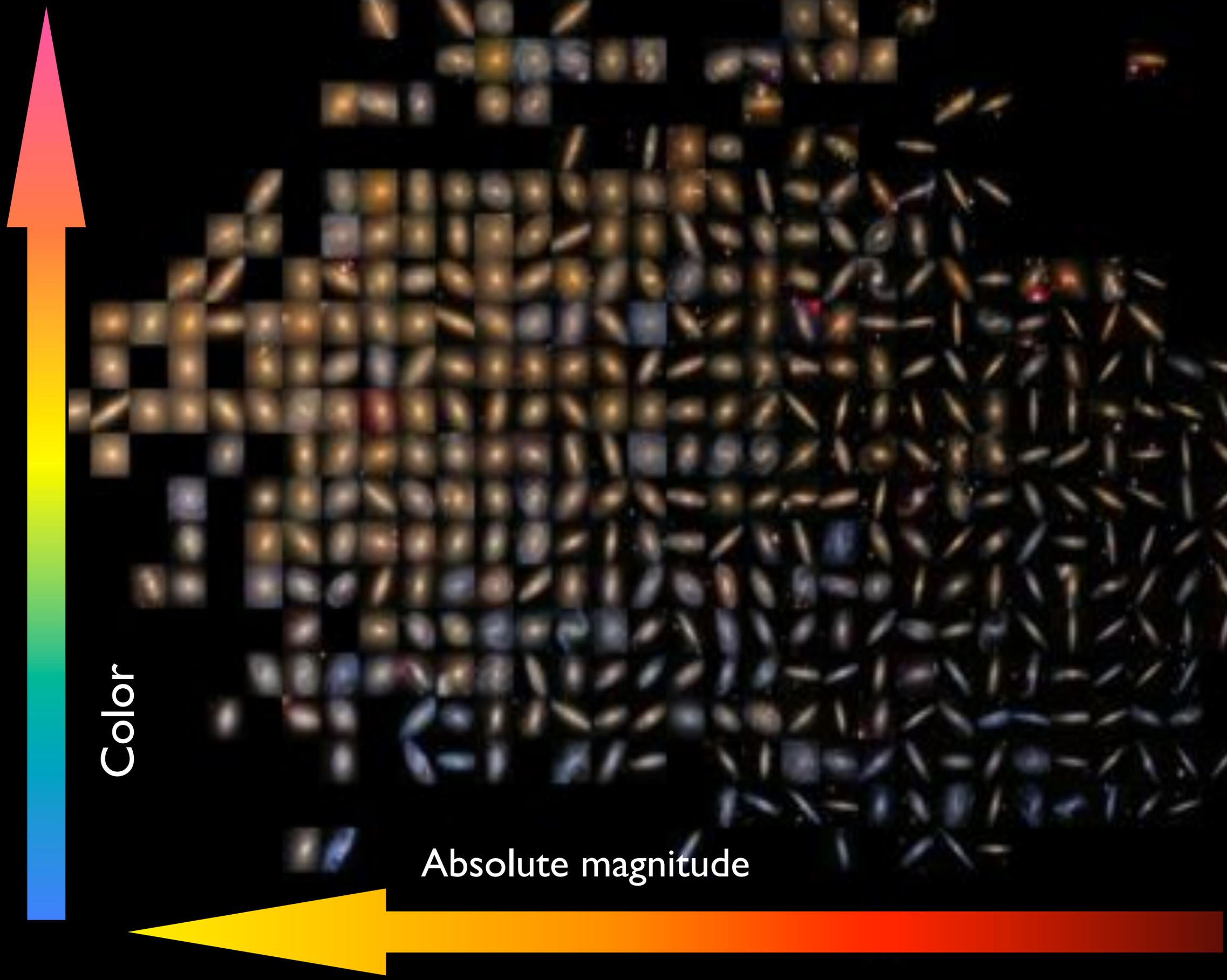
CALIFA: Science Drivers

- Nearby galaxies as:
  - End-result of galaxy evolution
  - "Fossil records" of the formation and evolution of galaxies
- Which is the origin of the observed diversity and bimodality of galaxies?
- How galaxies evolve with time?
  - Secular evolution vs. interaction
- Interrelated properties: chemistry, kinematics of ionized gas, stellar populations, morphology, etc.

CALIFA Survey

CALIFA: Science Drivers




Color
Absolute magnitude

CALIFA: The Team

- 82 members, 13 countries, 25 institutes
  - PI: Sebastián F. Sánchez (IAA-CAHA)
  - PS: Jakob Walcher (AIP, Postdam)
  - Board chair: Lutz Wisotzki (IAP)
  - Mostly young researchers (~ 35 years)

- Gathered by expertise and science interest

- Large experience
  - 3D spectroscopy
  - Large surveys
  - Stellar populations
  - Ionised gas
  - Kinematics

CALIFA Survey

CALIFA collaboration

2010

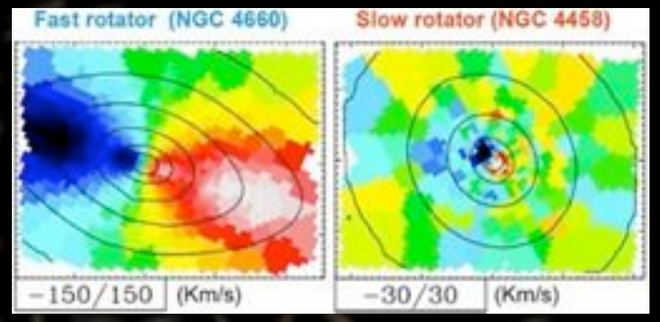
2011

2012

CALIFA: IFS Precedents

- SAURON (Atlas^{3D})
  - 72 (~200) E-type galaxies
  - z < 0.01 (large projected sizes)
  - Limited Field-of-View (FoV) and spectral coverage

SAURON



- PINGS (Rosales-Ortega+, 2010)
  - 12 L-type galaxies
  - z < 0.01 (large projected sizes)
  - Full optical size by mosaicing

VENGA

Blanc et al. 2013

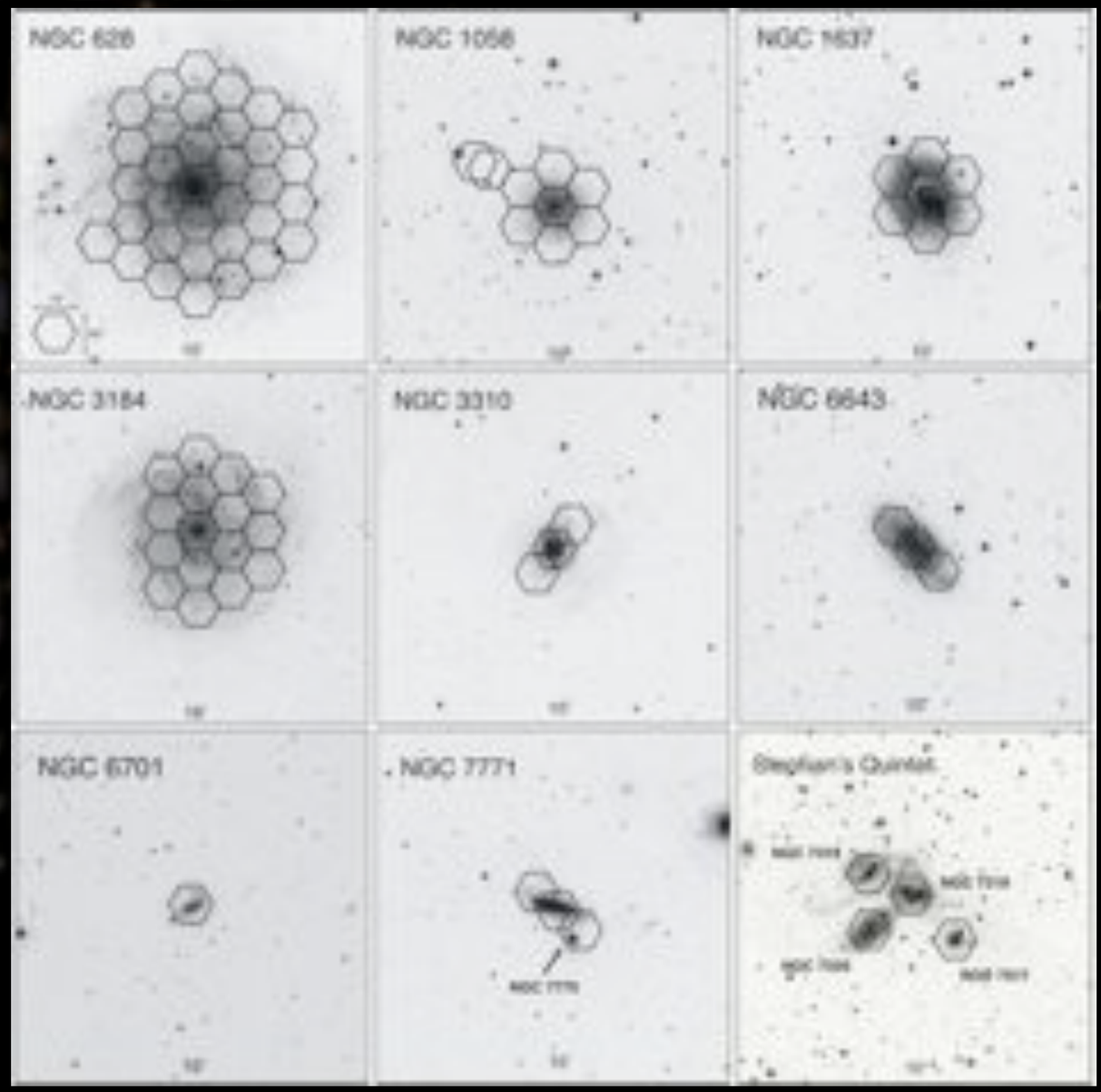
- DiskMass: 30 galaxies, kinematics
- VENGA: 30 spirals, SFR studies
- VIXENS: 15 interacting galaxies

CALIFA Survey

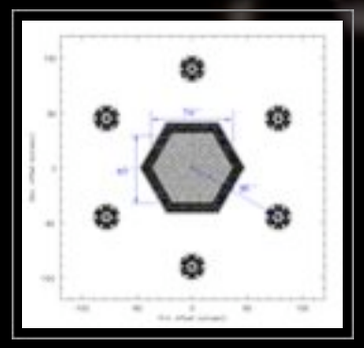
PINGS
PPAK IFS Nearby Galaxies Survey

Rosales-Ortega PhD Cantab 2009
Rosales-Ortega et al. 2010

(first) Wide-Field Integral Field Spectroscopy Survey of Nearby Galaxies (< 100 Mpc)

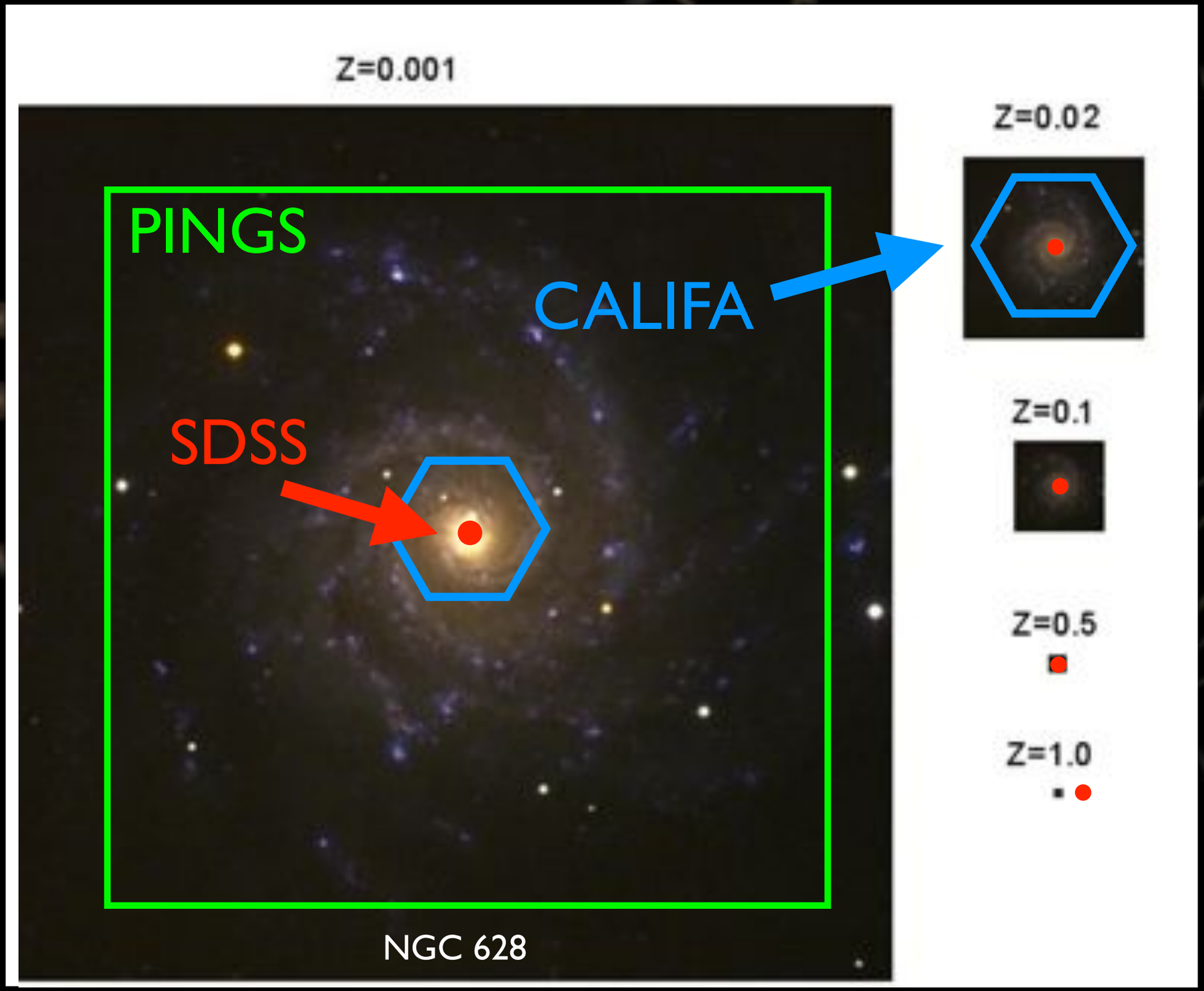


- PMAS/PPAK instrument at CAHA
- Continuous coverage spectra: λ3700-7000 Å
- All bright lines for chemical empirical calibrations: [OII] λ3727 - [SII] λλ6717,31



IFU observed area ~ 80 arcmin^2

The FoV *issue*



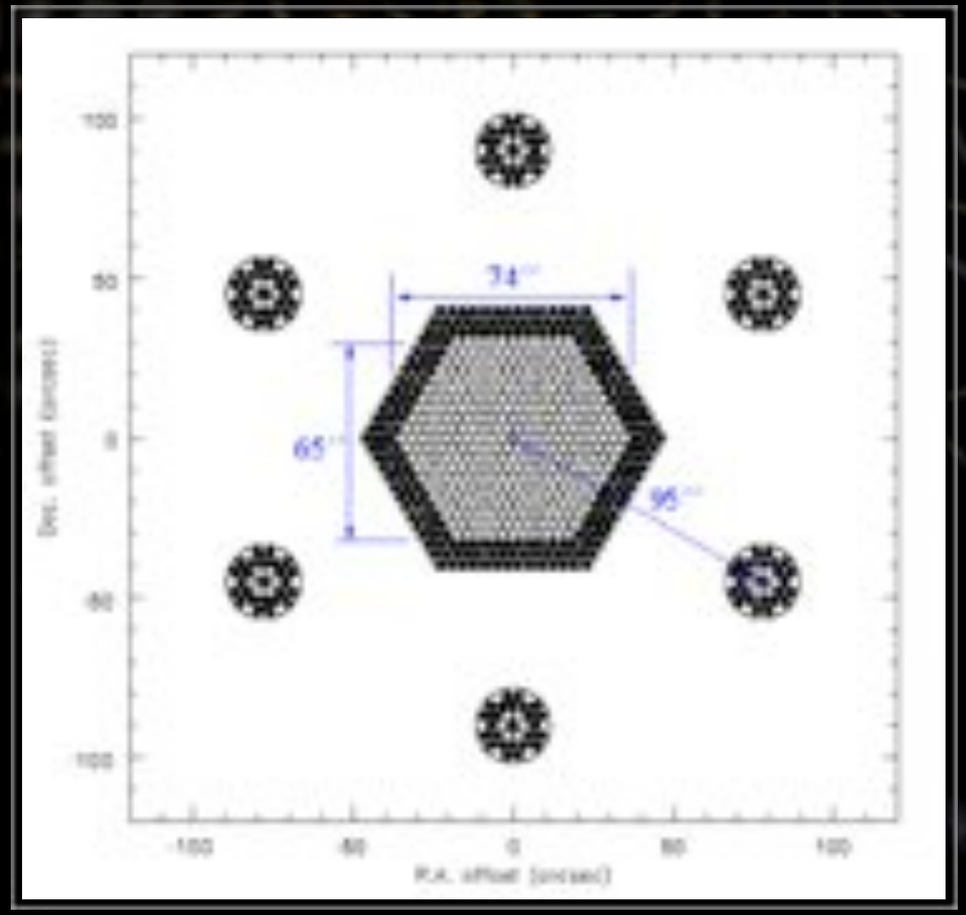
CALIFA: Methodology

- Integral Field Spectroscopy
  - PPAK@3.5m CAHA
  - Full optical wavelength range covered: 3700-7000 A
  - ~ 2000 spectra per object
  - Two instrumental setups: high (V1200) - mid (V500) resolution

PPAK: **P**MAS fiber **PA**c**K**

PMAS: Postdam Multi-Aperture Spectrophotometer

- Central hexagonal bundle of 331 optical fibres
- 2.7 arcsec per fibre
- Dithered observations



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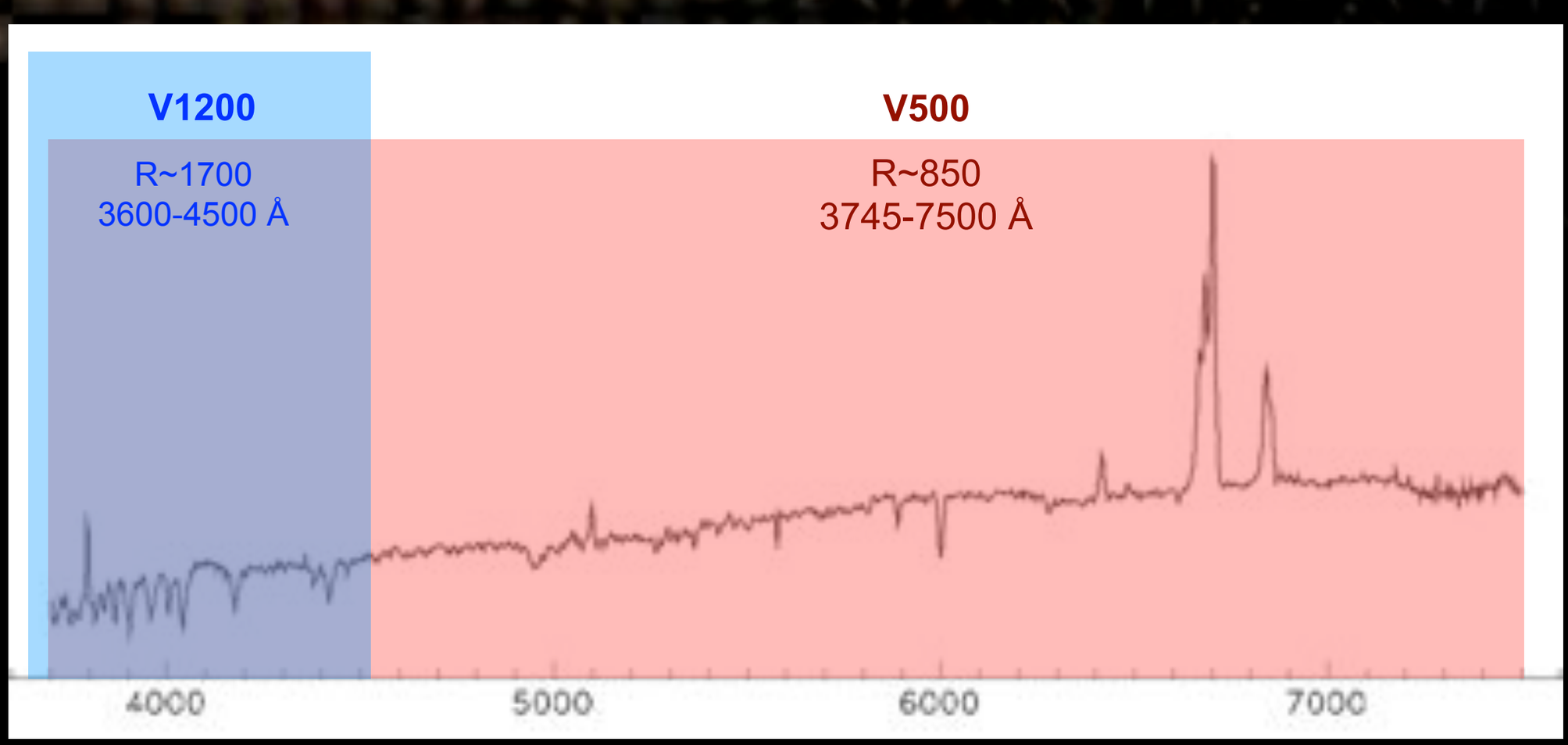
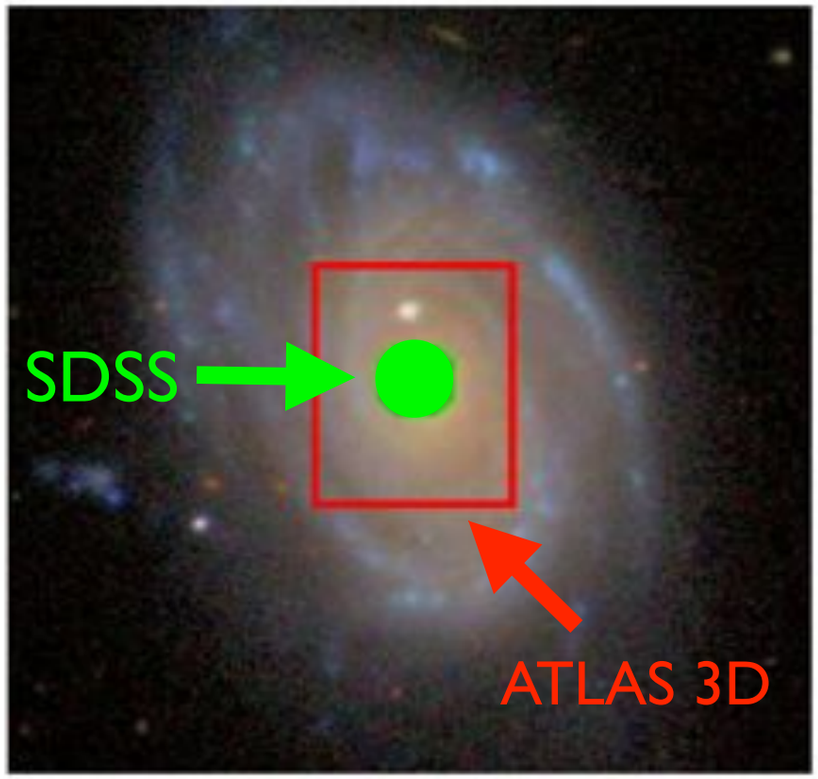


CALIFA Survey



CALIFA Survey

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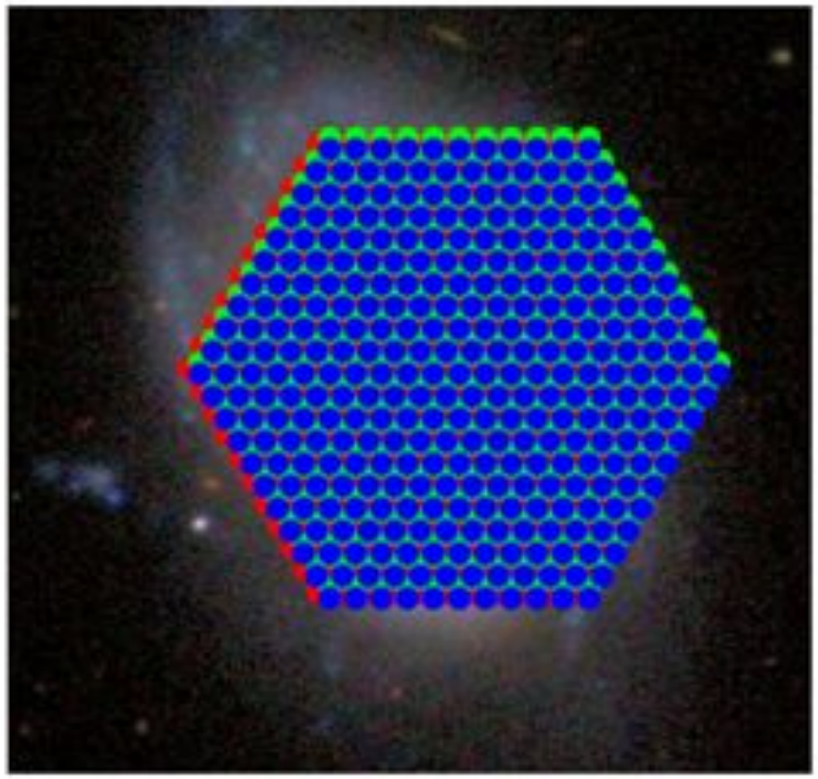
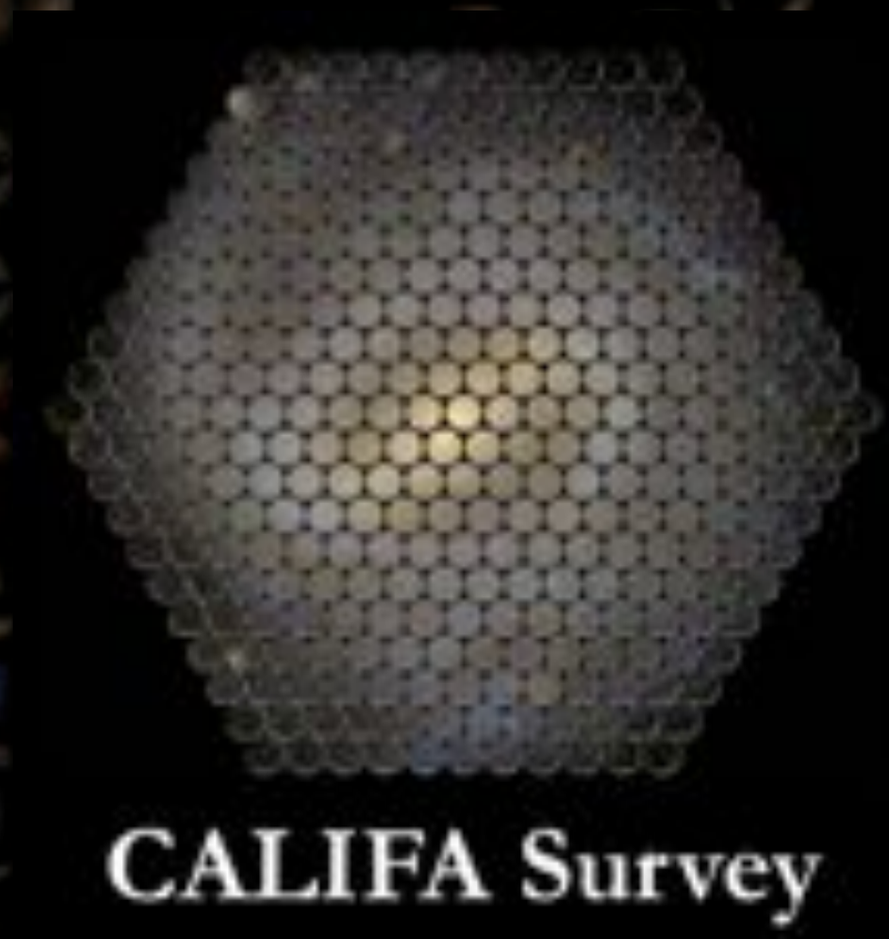
CALIFA



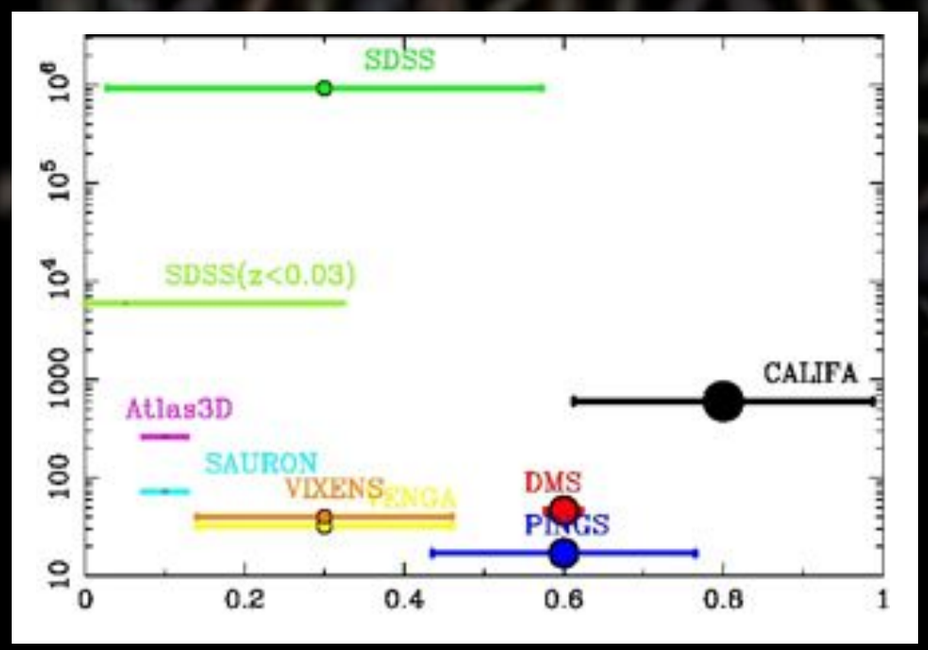
CALIFA Survey

fibre size = 2.7 arcsec
1 fibre ~ 0.9 kpc
FoV > 2*r_e



CALIFA Survey

Number of Galaxies



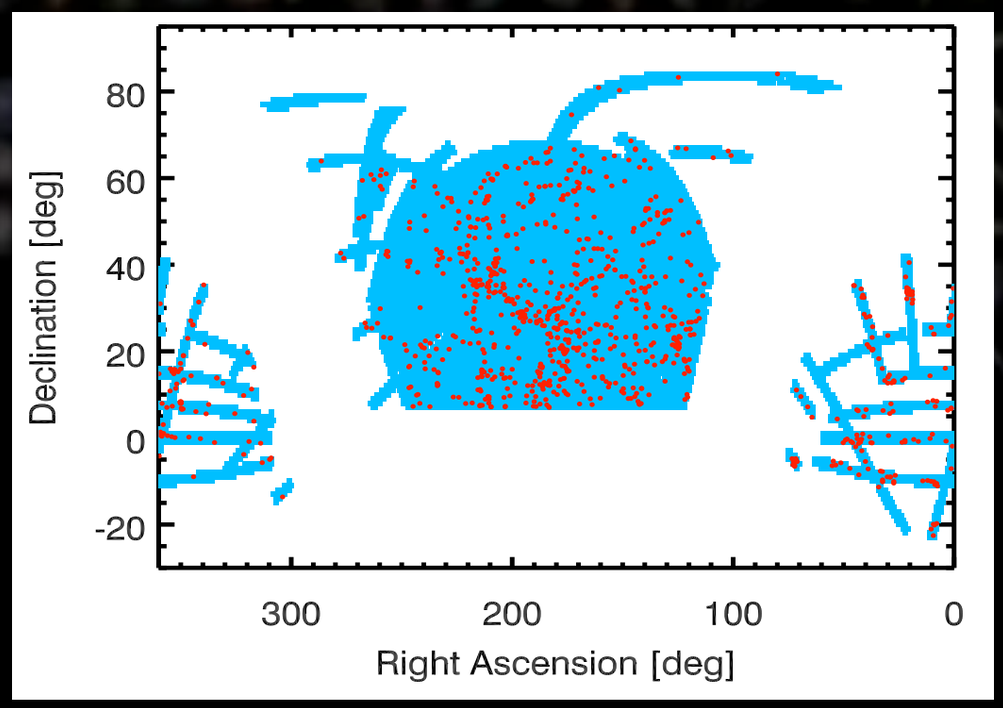
Field-of-View

Optical Size

CALIFA: sample selection

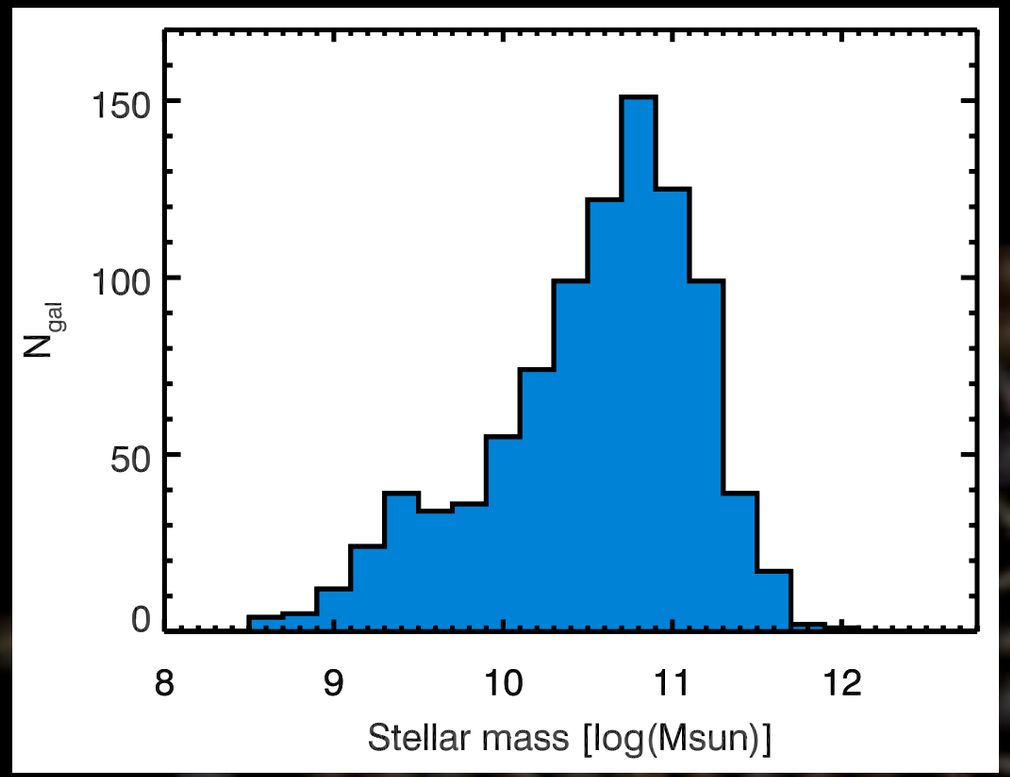
Goal: 600 galaxies will be observed out of:

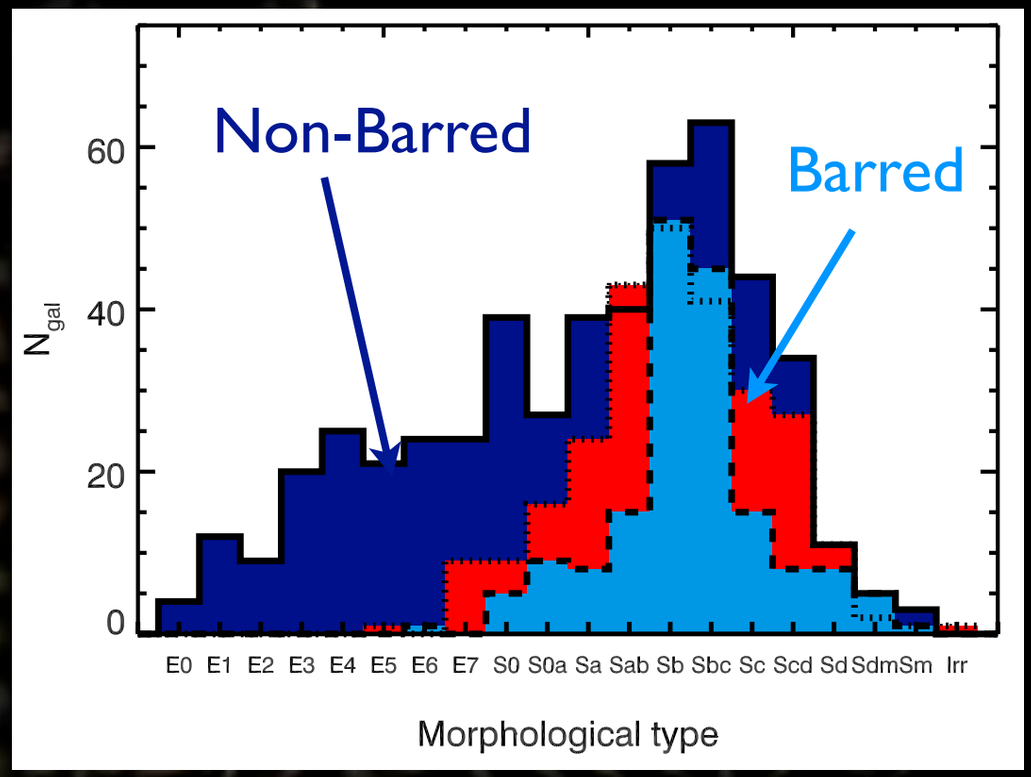
- Mother sample selected from SDSS
  redshift range: $0.005 < z < 0.03$ ~6000 galaxies
- Diameter selection
  $45'' < R_{25} < 80''$ isophotal radius at 25 mag/arcsec^2
- ~20 galaxies per Colour-Magnitude (1x1) bin
- No type selection, full coverage of the CM diagram
- Final spatial resolution: 2" ~ 0.5-1 kpc

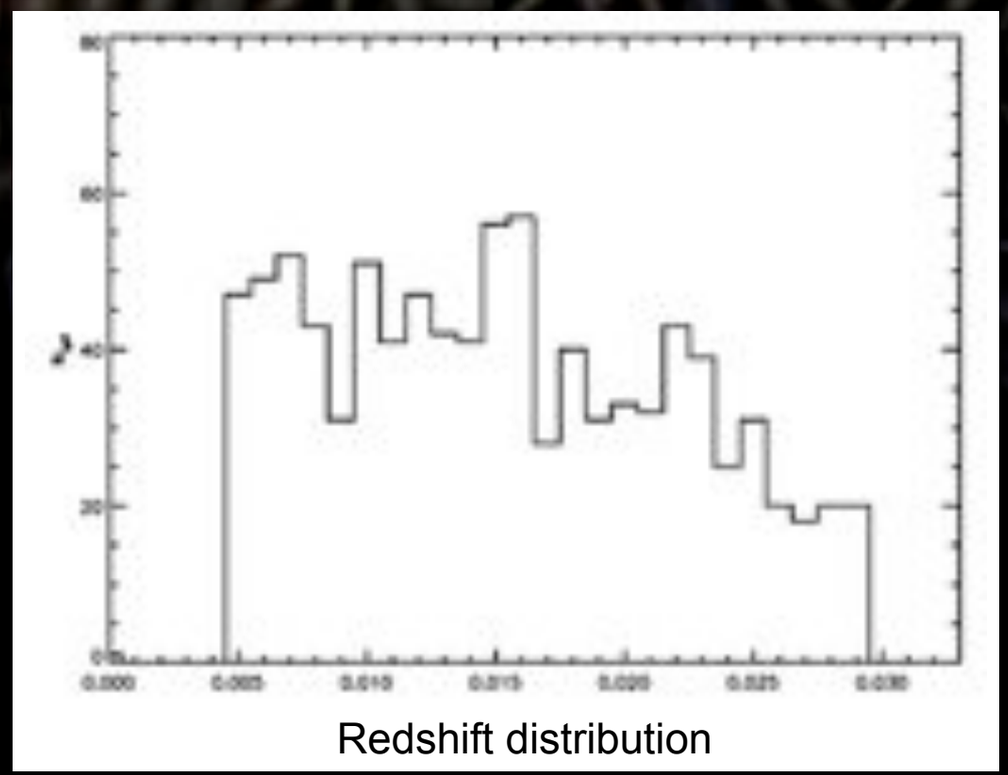


Walcher et al., in prep.

CALIFA: mother sample







Walcher et al., in prep.

CALIFA: Methodology

- Automatic Reduction Pipeline (v1.3)

  Developed along 2009-2010, after PINGS experience

Characteristic performance:	V500	V1200	
– Surface brightness 3σ:	23.0	22.8	mag/arcsec^2
– Wavelength calibration:	5	10	km s^{-1}
– Wavelength resolution:	150	85	km s^{-1}

– Flux calibration: ~ 5% relative (blue-to-red)
~ 15% absolute (tied to SDSS)

Primary products:

– Resampled data cubes with 1sq arcsec spaxels

– Meaningful noise cubes!

CALIFA Survey

CALIFA is unique!

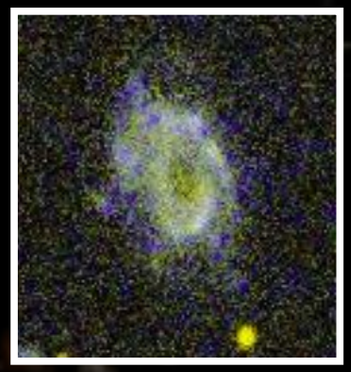
- Large, homogeneous sample
  - Statistics, classification, rare objects
  - Will allow comparison between different types
- Large wavelength coverage and resolution:
  - Full diagnostic (BPT) diagrams
  - Extended view on stellar populations
  - Suitable for kinematic analysis
- Spatial coverage and sampling
  - Full optical size of galaxies
  - ~1 kpc resolution
- Vast ancillary data

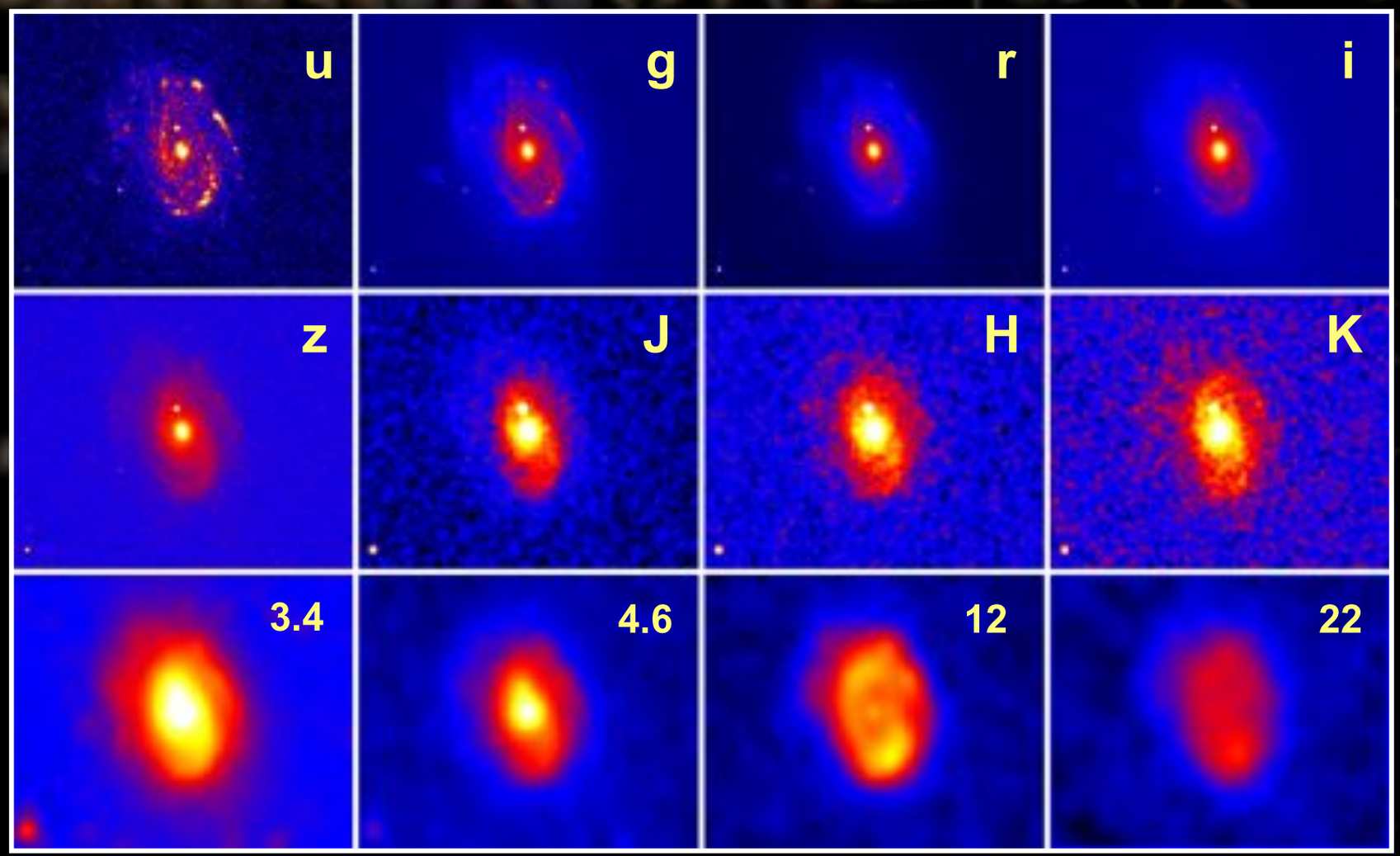
CALIFA ancillary data

CALIFA

SDSS

GALEX





Spitzer

WISE

CALIFA Survey

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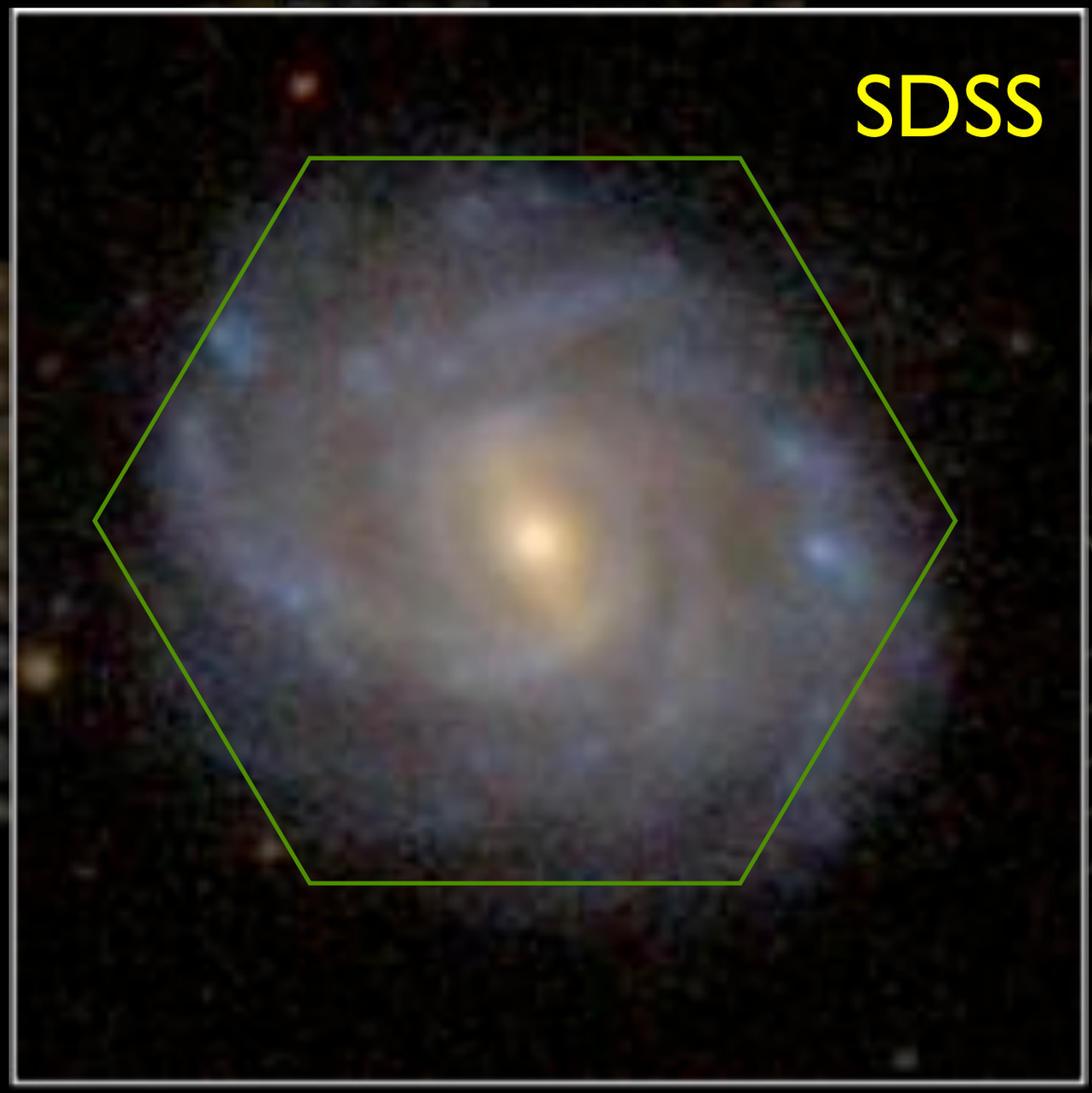
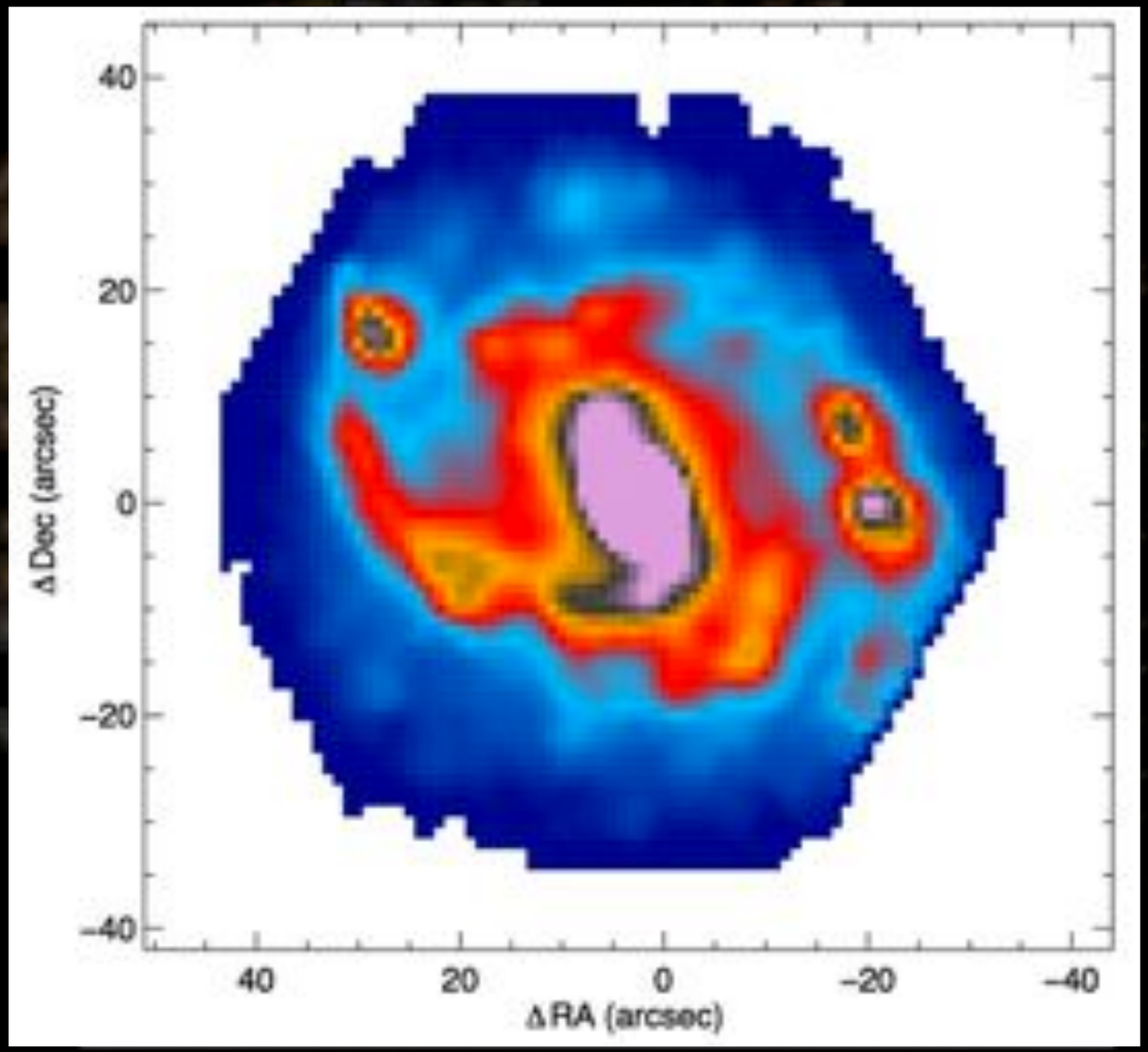
NGC 5947



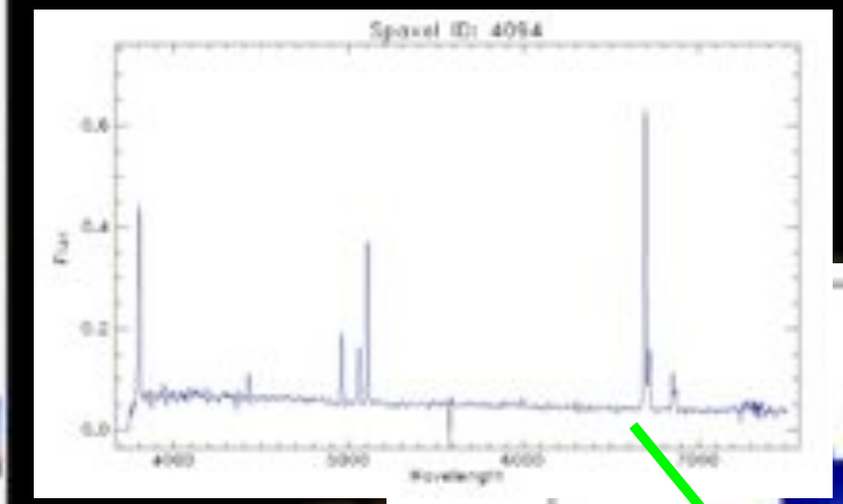
CALIFA Survey

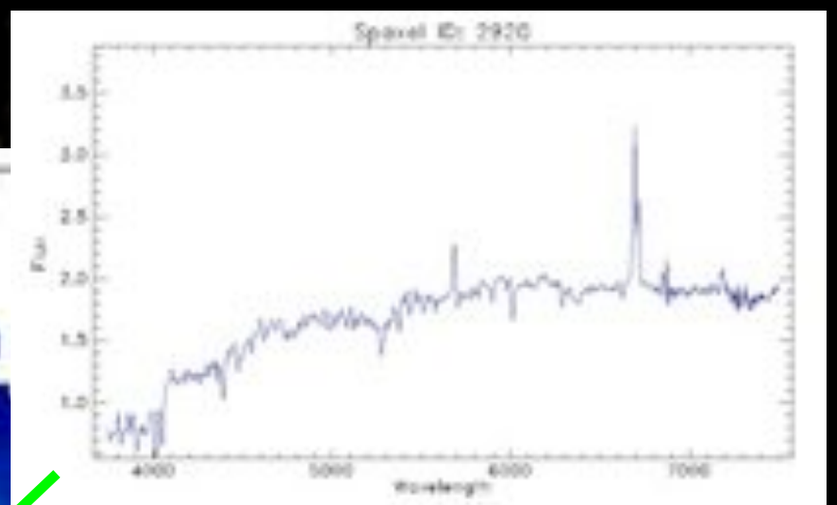
NGC 5947

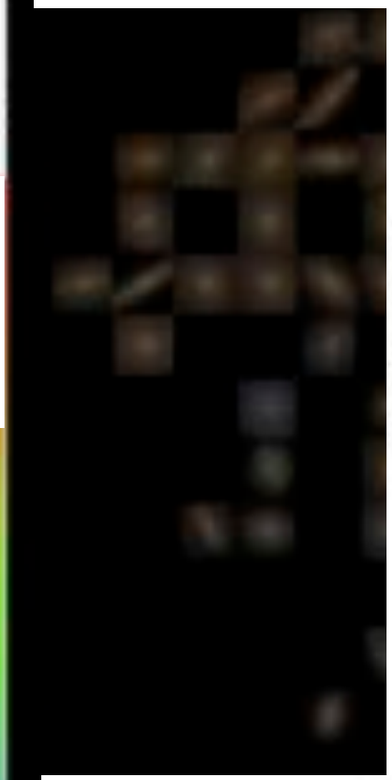


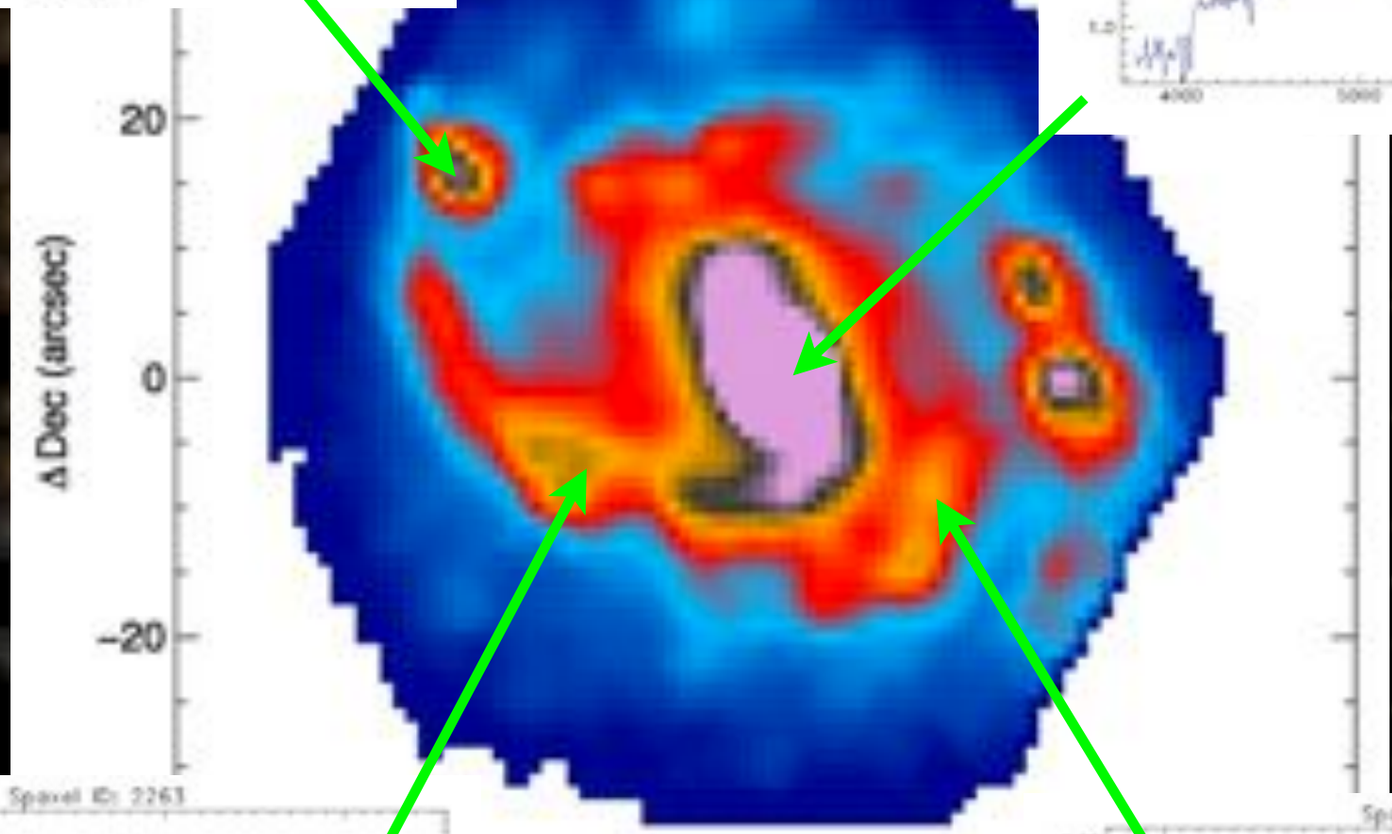
CALIFA Survey

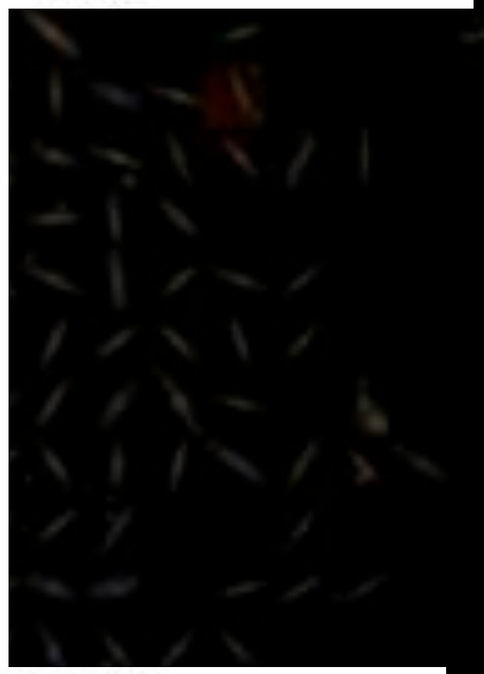
NGC 5947

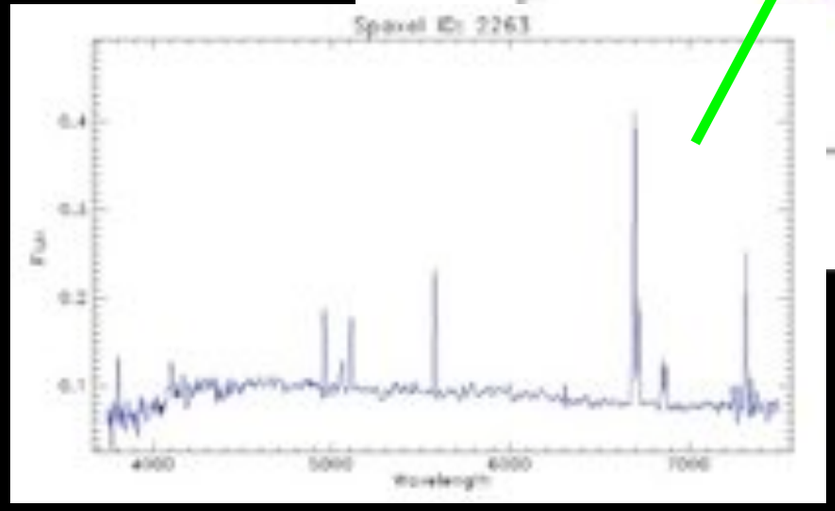


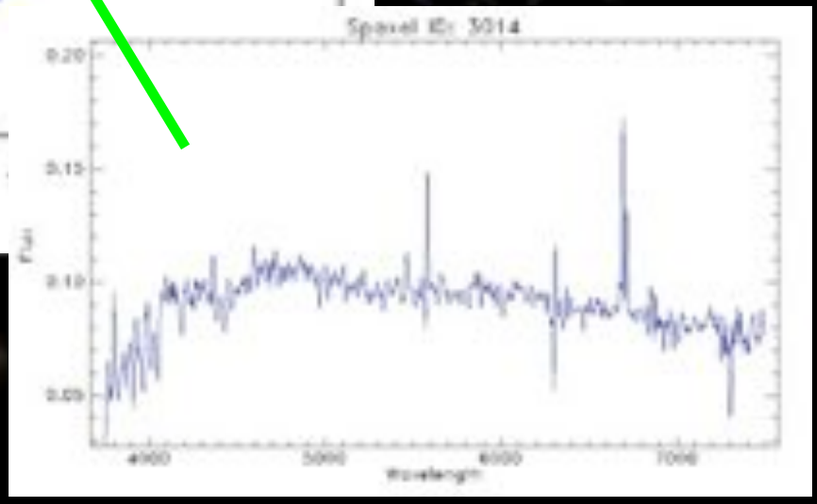












1st CALIFA Data Release

- 1st November 2012
- 100 objects
- 200 cubes (both resolutions)
- 400,000 individual spectra!
- Fully reduced and QC tested

http://califa.caha.es/DR1

CALIFA, the Calar Alto Legacy Integral Field Area survey:

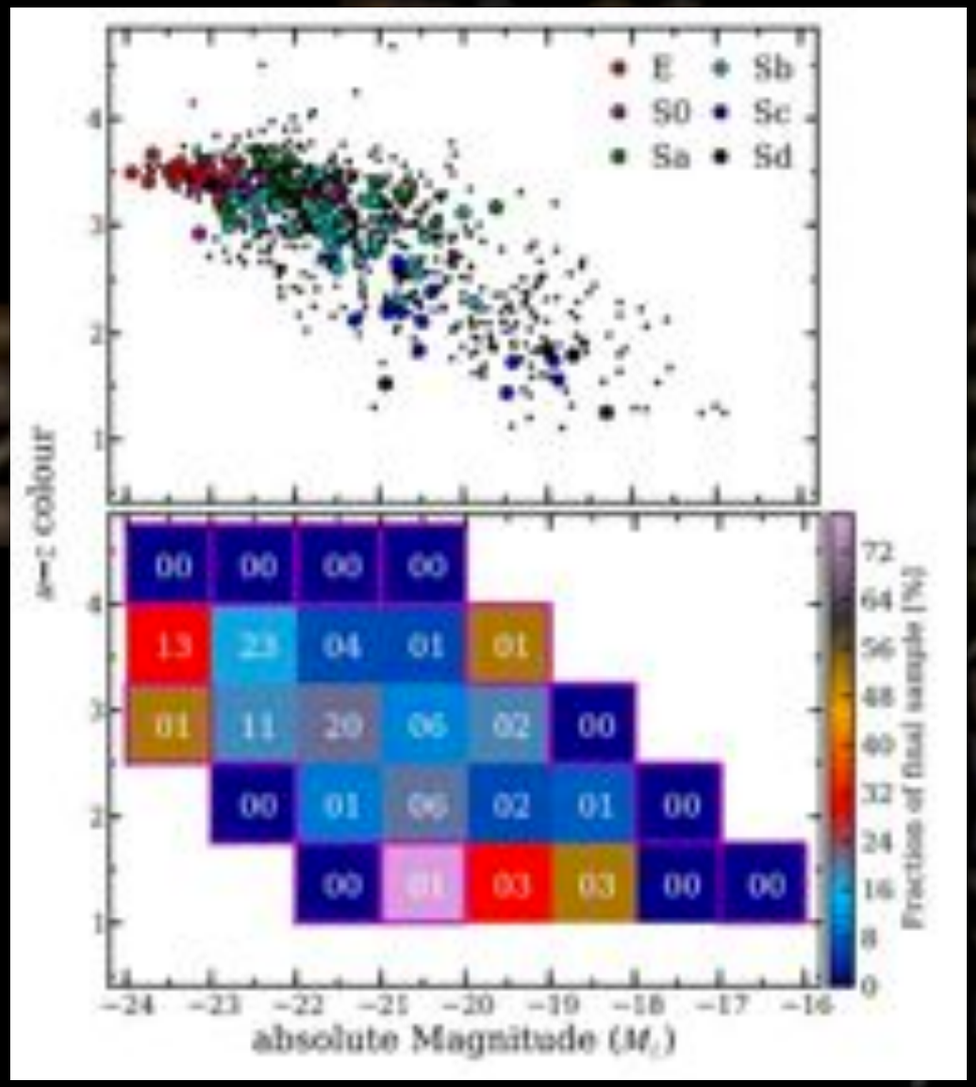
II. First public data release*

B. Husemann[1], K. Jahnke[2], S. F. Sánchez[3,4], D. Barrado-Navascues[4], S. Bekeraité[1], D. J. Bomans[5,6], A. Castillo-Morales[7], C. Catalán-Torrecilla[7], R. Cid Fernandes[8], J. Falcón-Barroso[9,10], R. García-Benito[3], R. M. González Delgado[3], J. Iglesias-Páramo[3,4], B. D. Johnson[11], D. Kupko[1], R. López-Fernandez[3], M. Lyubenova[1], R. A. Marino[12], D. Mast[4], A. Miskolczi[5], A. Monreal-Ibero[3], A. Gil de Paz[7], E. Pérez[3], I. Pérez[13,14], F. F. Rosales-Ortega[15], T. Ruiz-Lara[13], U. Schilling[5], G. van de Ven[2], J. Walcher[1], J. Alves[12], A. L. de Amorim[8], N. Backsmann[1], J. K. Barrera-Ballesteros[8], J. Bland-Hawthorn[17], R.-J. Dettmar[5,6], M. Demleitner[18], A. I. Díaz[16], H. Enke[1], E. Florido[13,14], H. Flores[19], L. Galbany[20], A. Gallazzi[21], B. García-Lorenzo[9,10], J. M. Gomes[22], N. Gruel[23], T. Haines[24], L. Holmes[25], B. Jungwiert[26], V. Kalinova[1], C. Kehrig[3], R. C. Kennicutt Jr[27], J. Klar[2], M. D. Lehnert[19], Á. R. López-Sánchez[28,29], A. de Lorenzo-Cáceres[10], E. Mármol-Queraltó[9,10], I. Márquez[3], J. Mendez-Abreu[9,10], M. Mollá[12], A. del Olmo[3], S. E. Meidt[2], P. Papaderos[22], J. Puschnig[15], A. Quirrenbach[30], M. M. Roth[1], P. Sánchez-Blázquez[16], K. Spekkens[25], R. Singh[2], V. Stanishev[20], S. C. Trager[31], J. M. Vílchez[3], V. Wild[32], L. Wisotzki[2], S. Zibetti[33], and B. Ziegler[15]

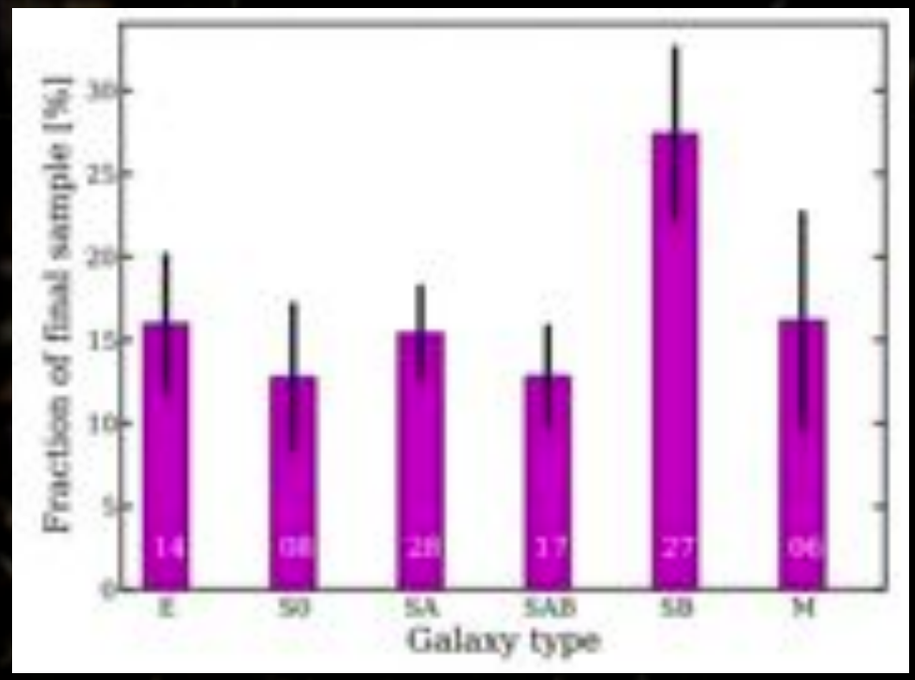
(Affiliations can be found after the references)

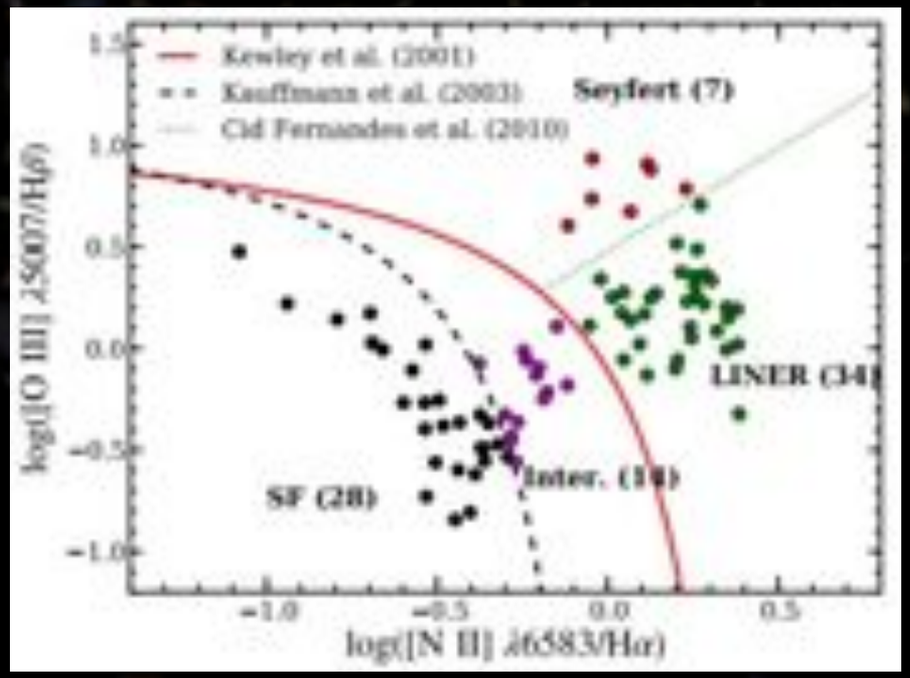
November 1, 2012

CALIFA Data Release 1



Husemman et al. 2013



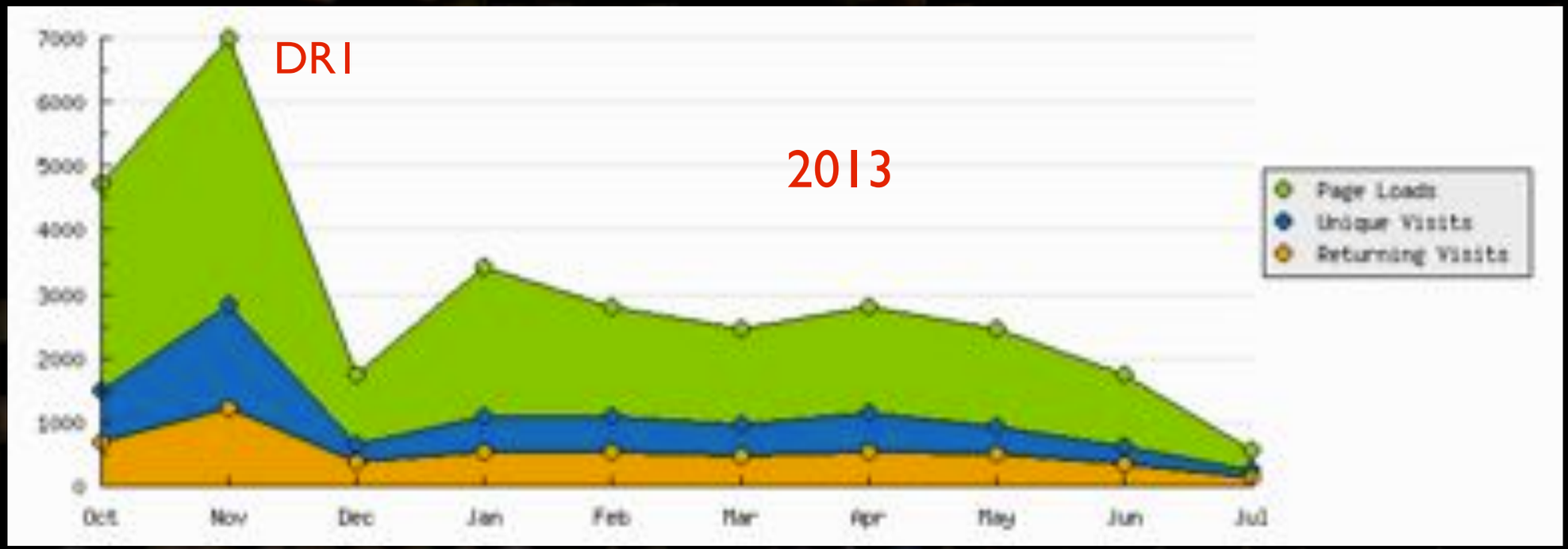


nuclear spectra

CALIFA Survey

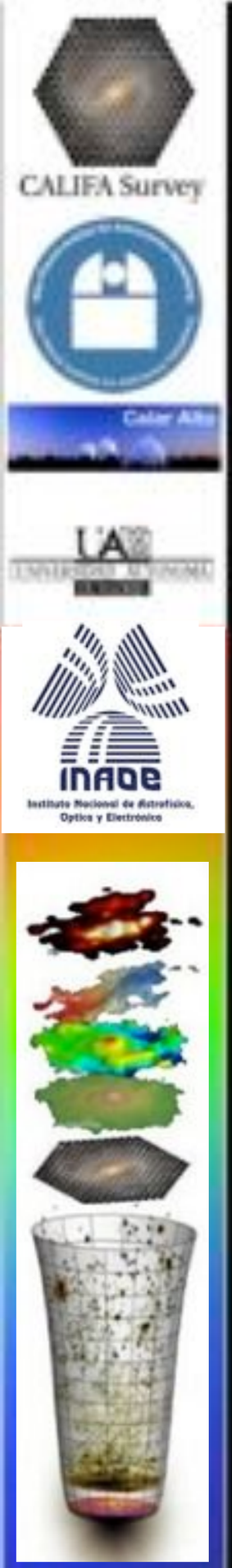
CALIFA Data Release 1

11000+ visits since DR1: 5000 downloaded cubes!



worldwide visitors

CALIFA Survey

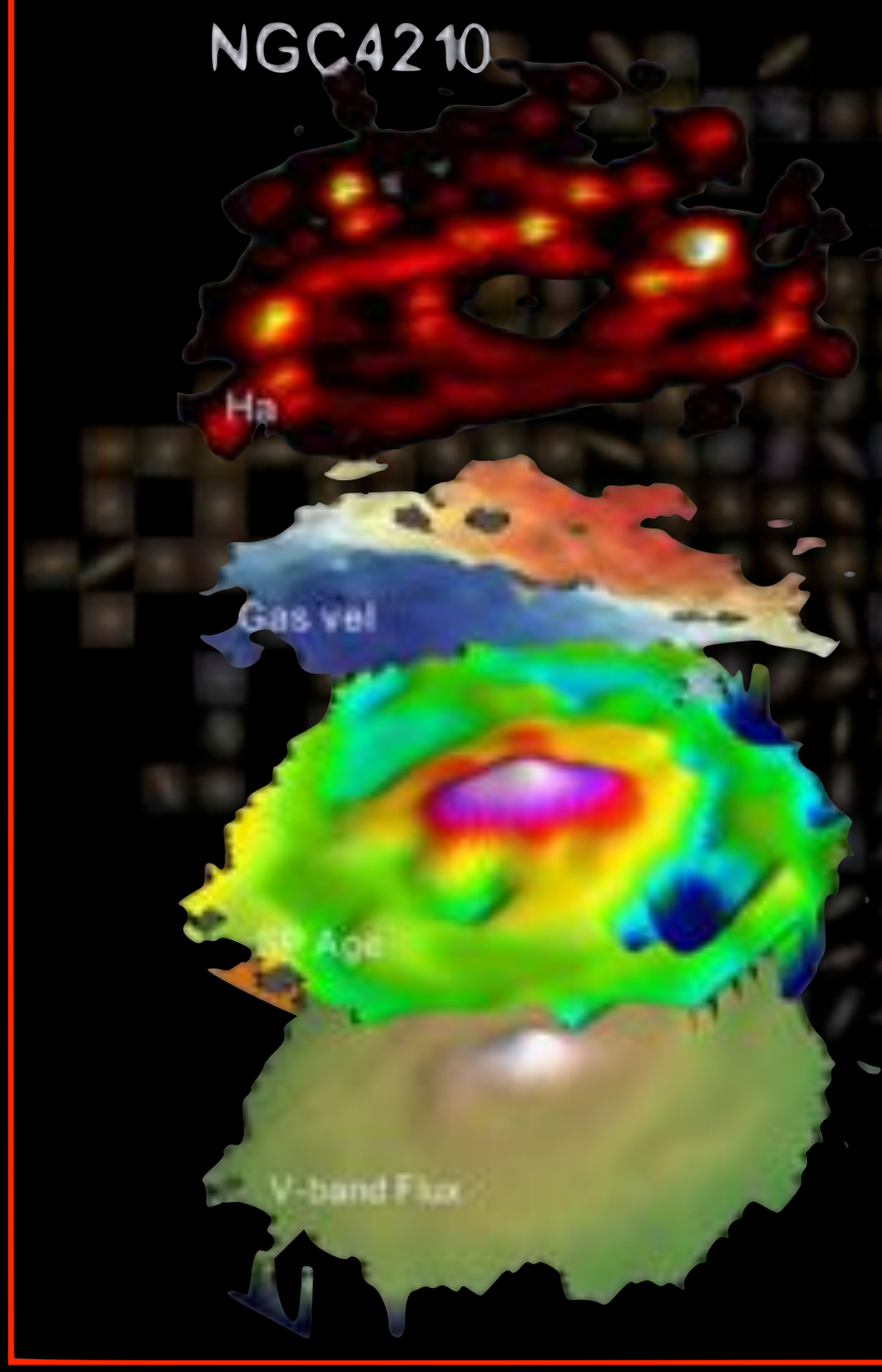


CALIFA so far:
+340 objects observed

Color

Absolute magnitude

CALIFA Survey



Hα emission

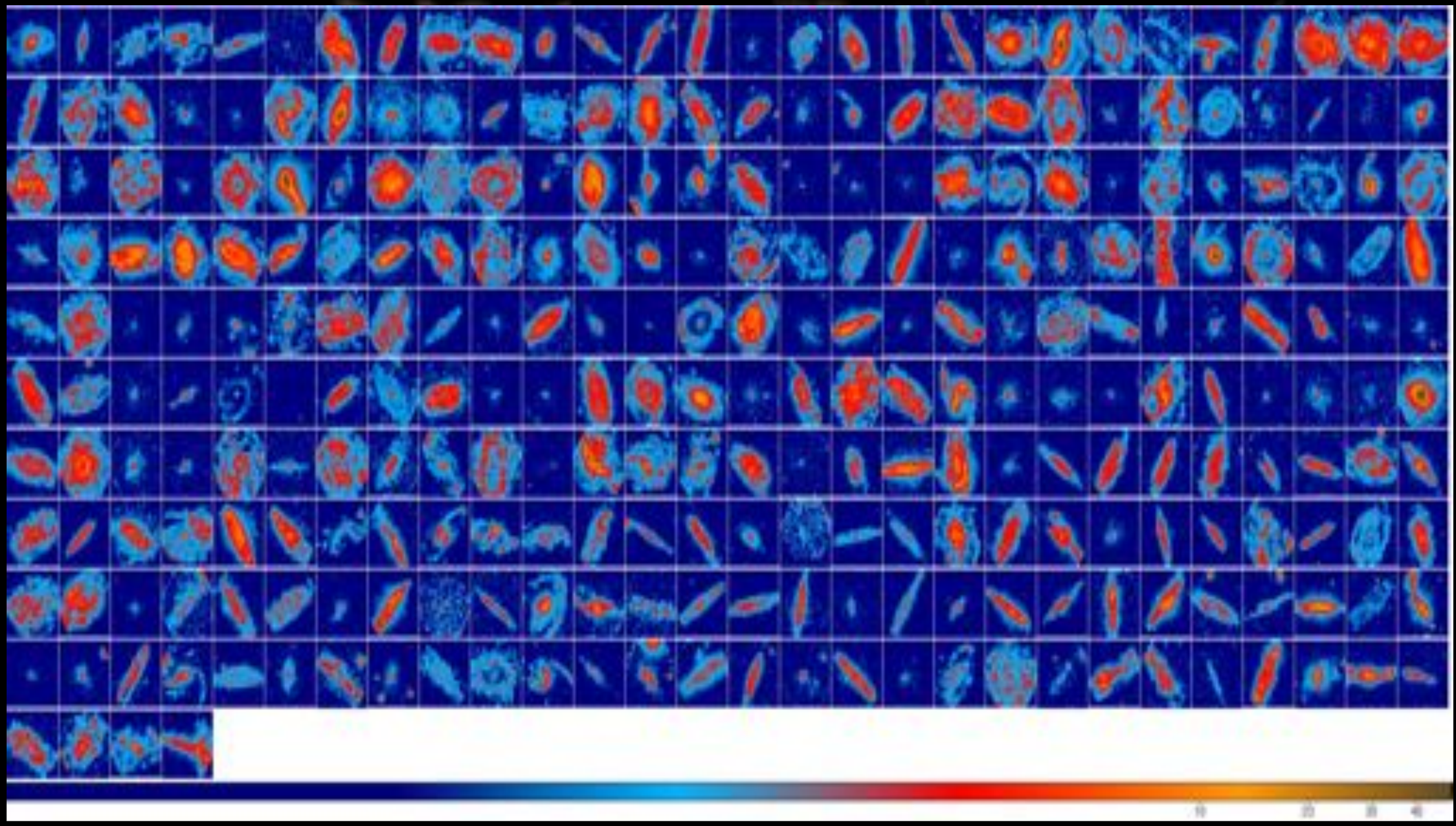
Gas velocity

SP Age

V-band flux

CALIFA Survey

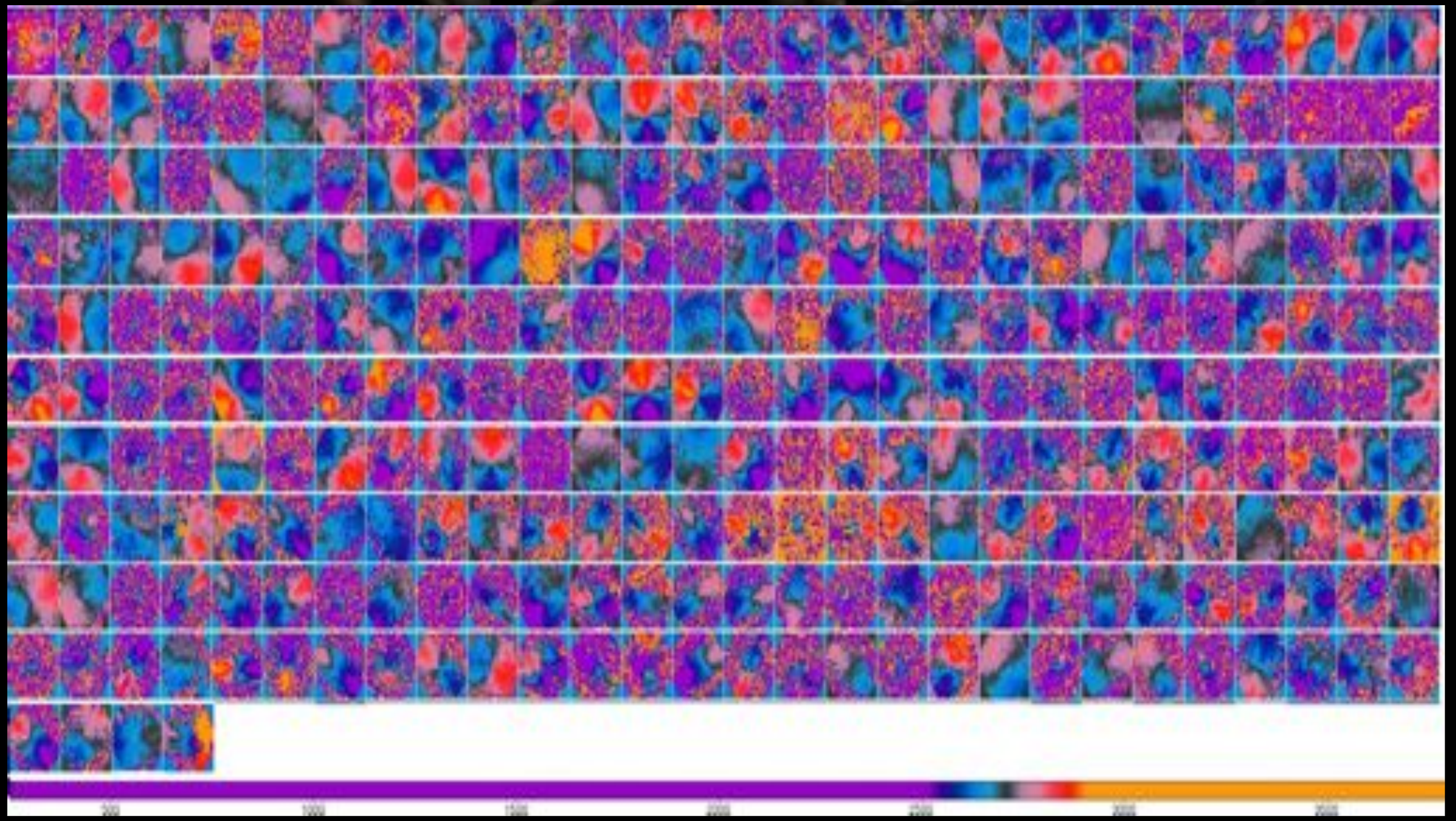
285 Hα emission line maps

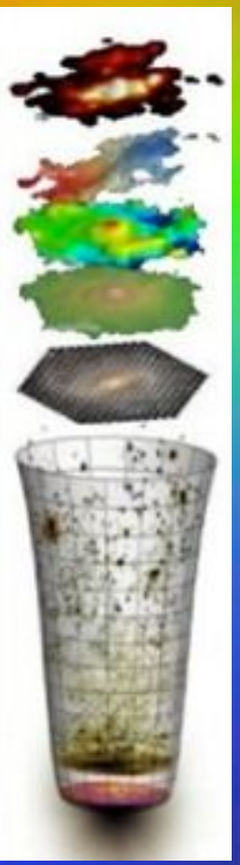


gas emission in ALL galaxy types !!!

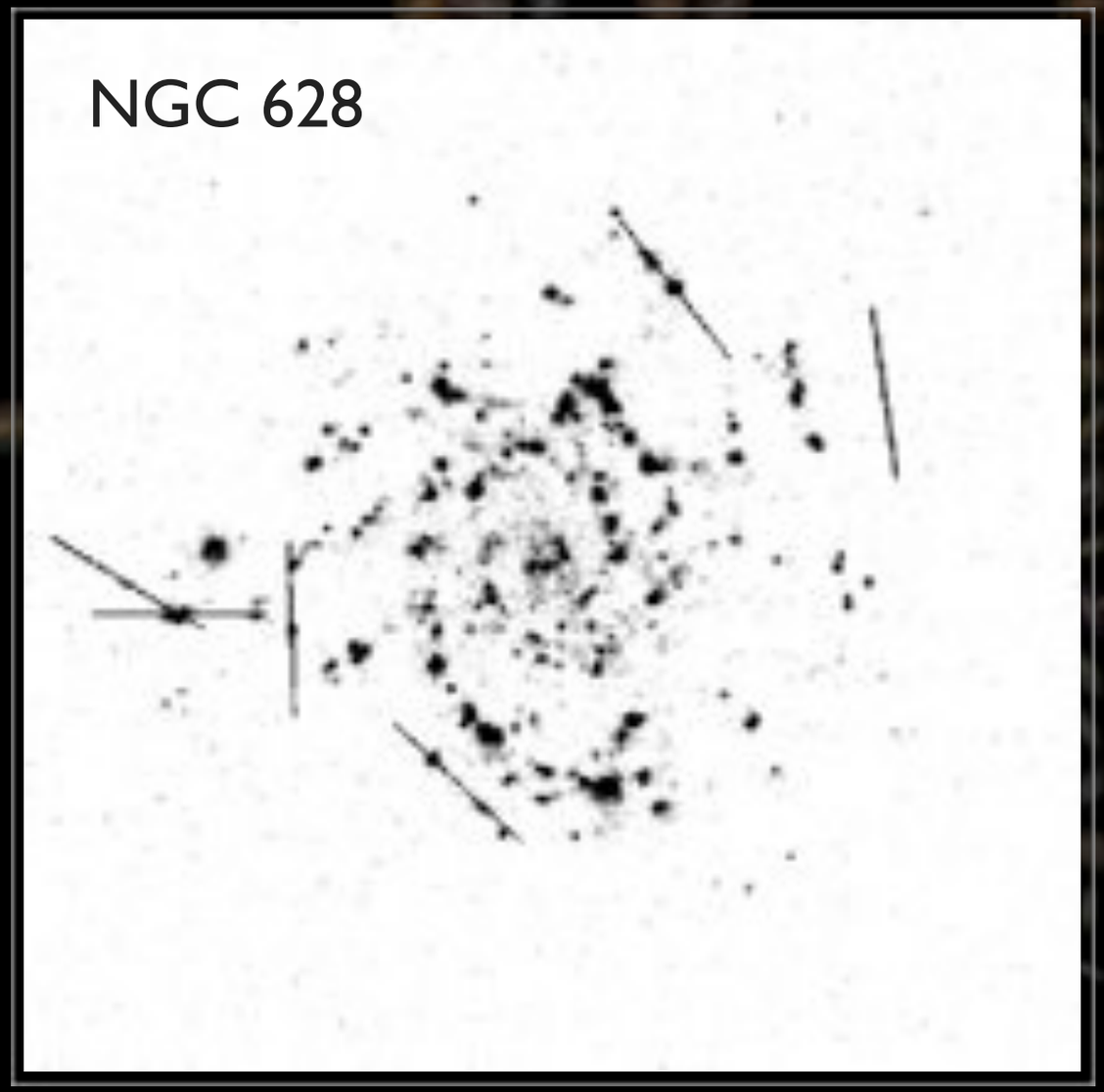
CALIFA Survey

285 Hα velocity maps



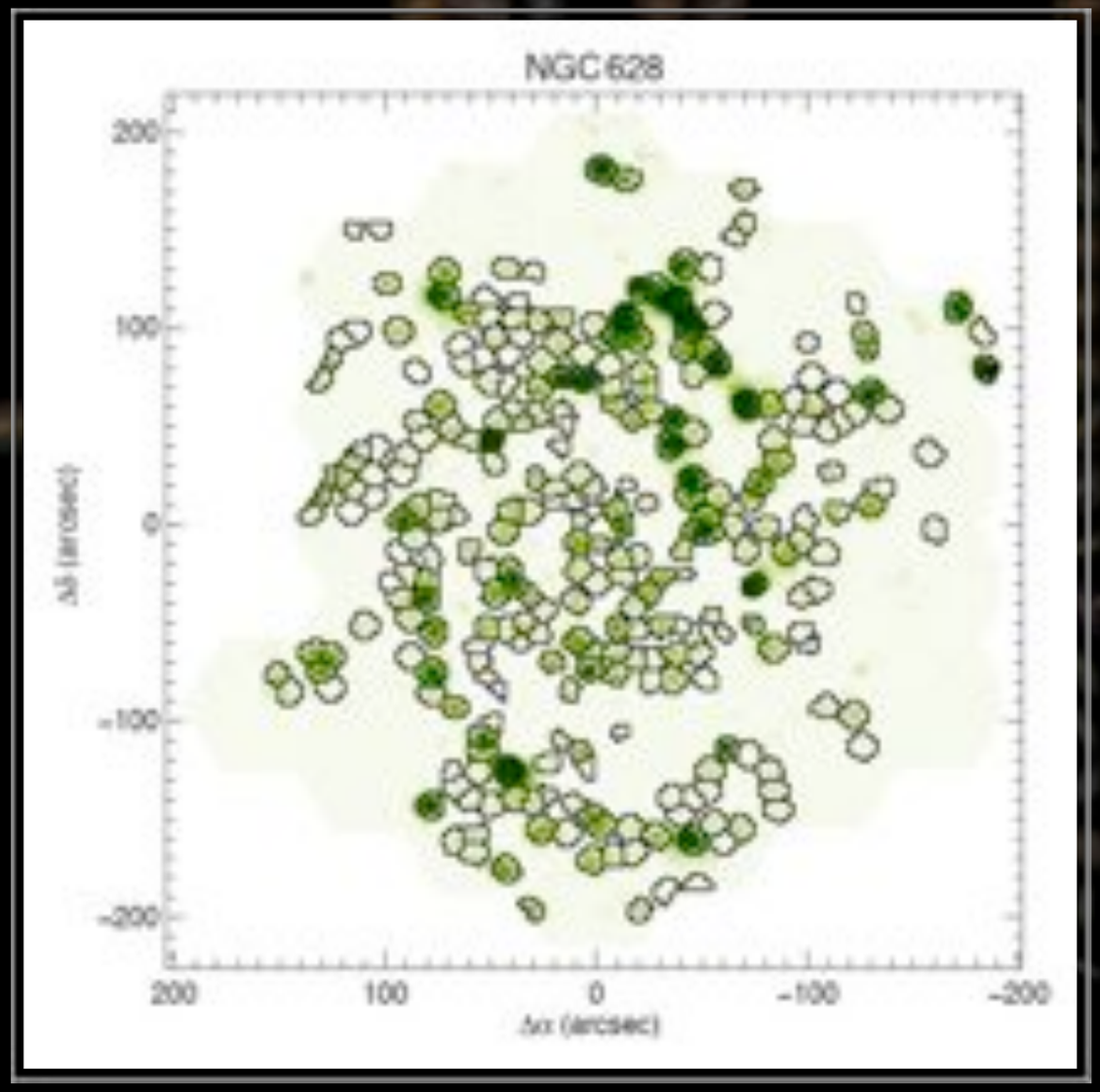


Devising the methodology for IFS emission-line studies



- ★ Classic HII regions identification via Hα narrow-band images
- ★ Previous experience with IFS:
  - ★ PINGS, Marino et al. 2012, etc.
  - ★ HII regions selected BY HAND!
  - ★ Not feasible for many objects & survey-mode IFS
- ★ Tests with SExtractor, REGION, HIIPhot, etc
  (unsuccessful due to low spatial resolution & depth of IFS data)

Devising the methodology for IFS emission-line studies



PINGS IFS mosaic - 37 pointings

Sánchez et al. 2010, Rosales-Ortega et al. 2011

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- ★ Previous experience with IFS:
  - ★ PINGS, Marino et al. 2012, etc.
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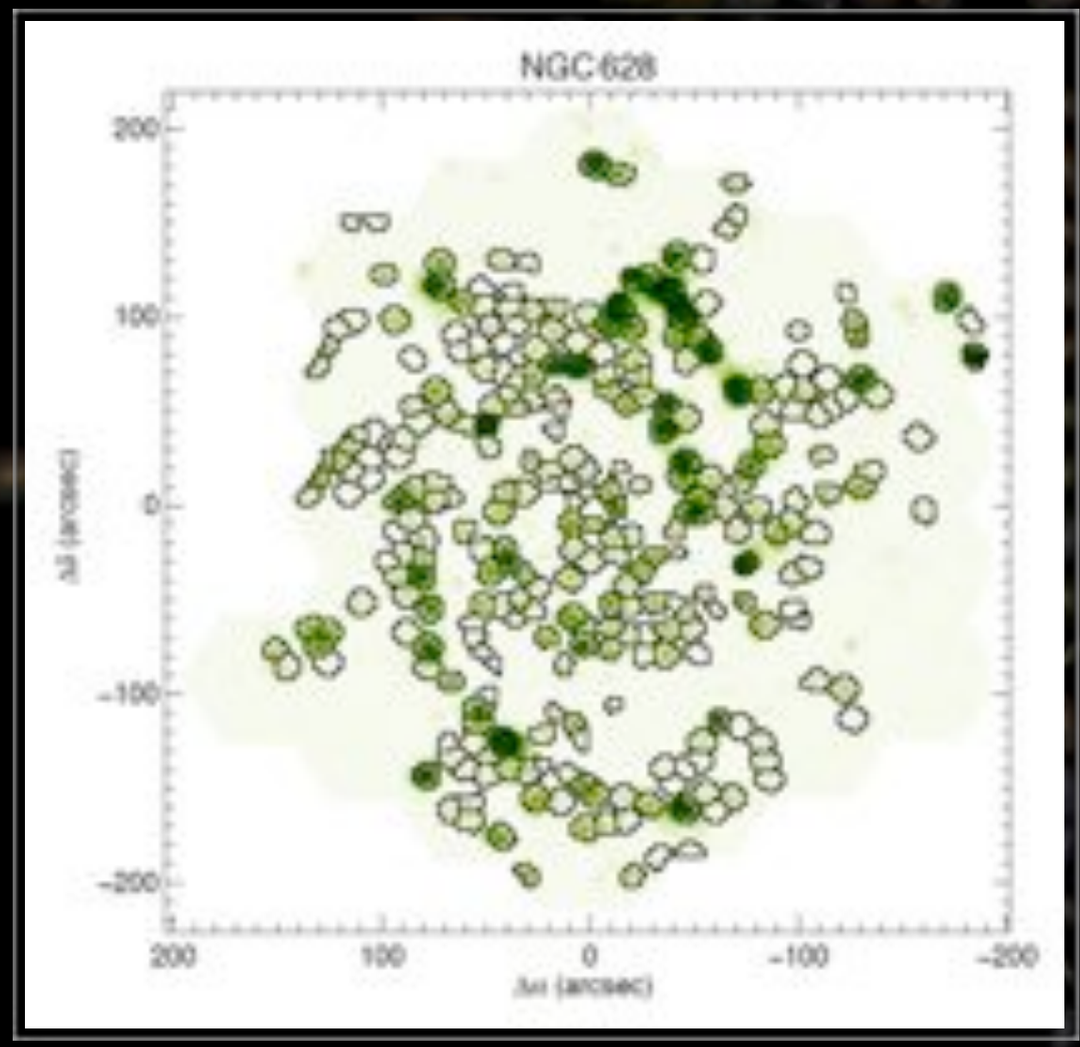
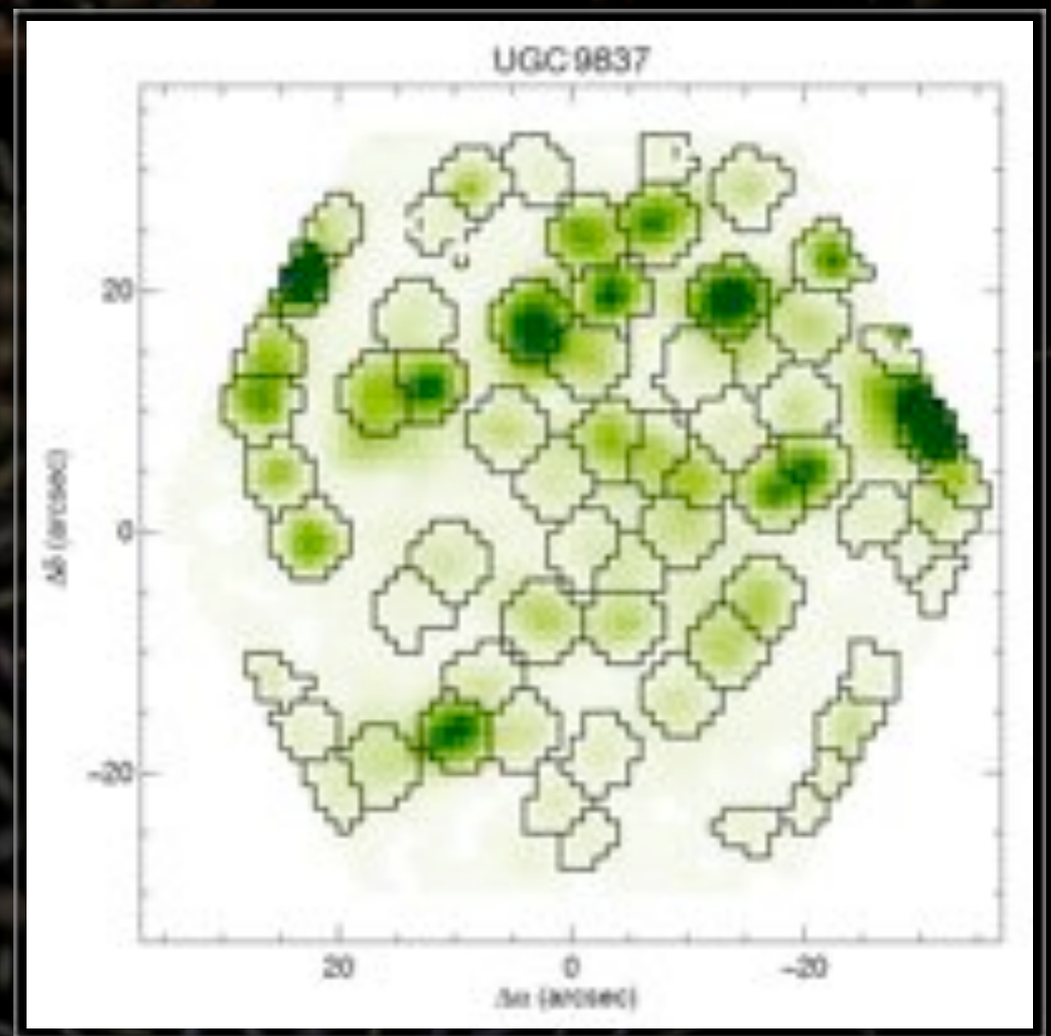
- ★ Tests with SExtractor, REGION, HIIPhot, etc
  (unsuccessful due to low spatial resolution & depth of IFS data)
- ★ HIIexplorer
  Sánchez et al. 2012b

IFS-based HII region extraction

HIIexplorer (Sánchez et al. 2012b)





pre-CALIFA: ~2500 high S/N, spectra of HII regions (aggretations)

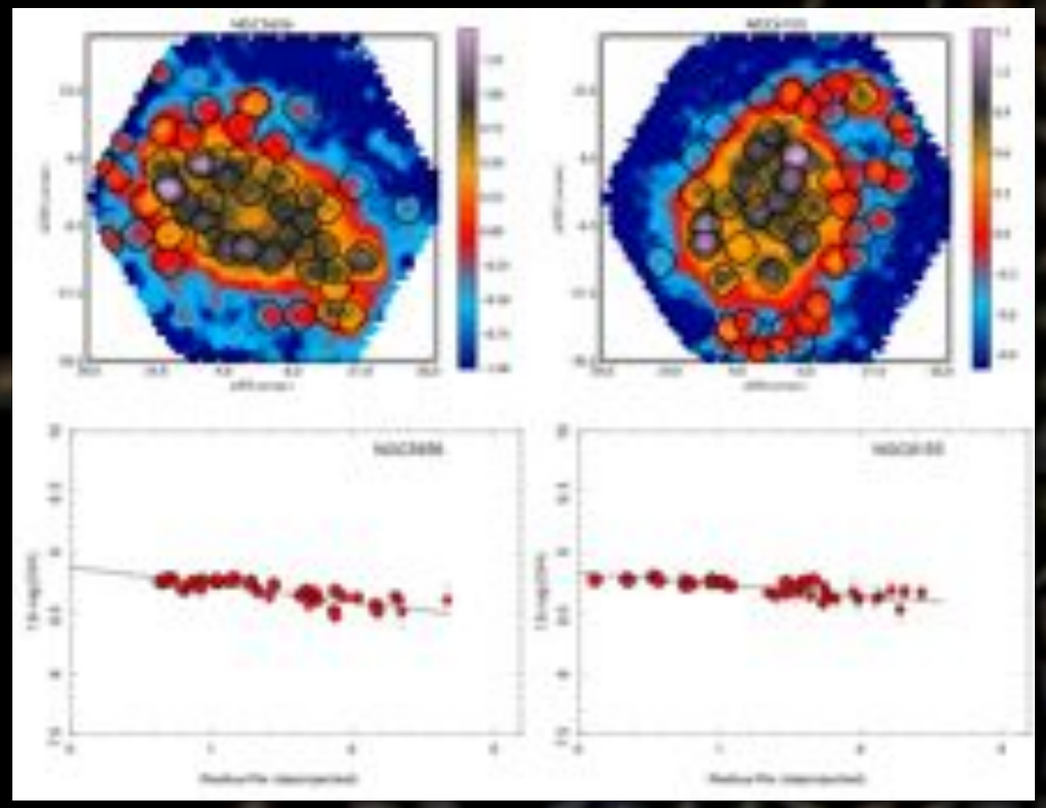
CALIFA: ~6000 regions

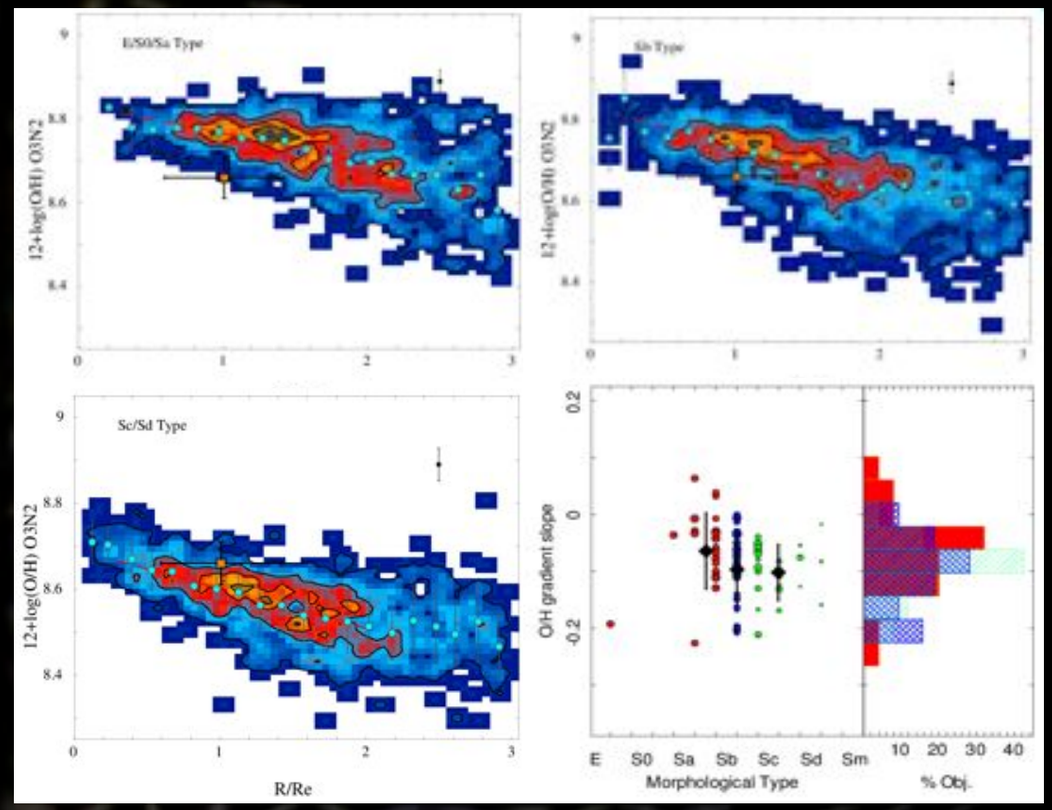
The largest spatially-resolved, nearby spectroscopic HII region survey ever accomplished

CALIFA: ionized gas

Gas phase metallicity

Sánchez et al. in preparation





- +4000 HII regions/aggregates in CALIFA
- All abundance gradients are compatible with being a subsample of Gaussian distribution.
- Slope ~ -0.12+-0.10 dex/Reff (using O3N2)
- No significant difference found by galaxy types: barred/unbarred, grand-design/flocculent

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Gas phase metallicity

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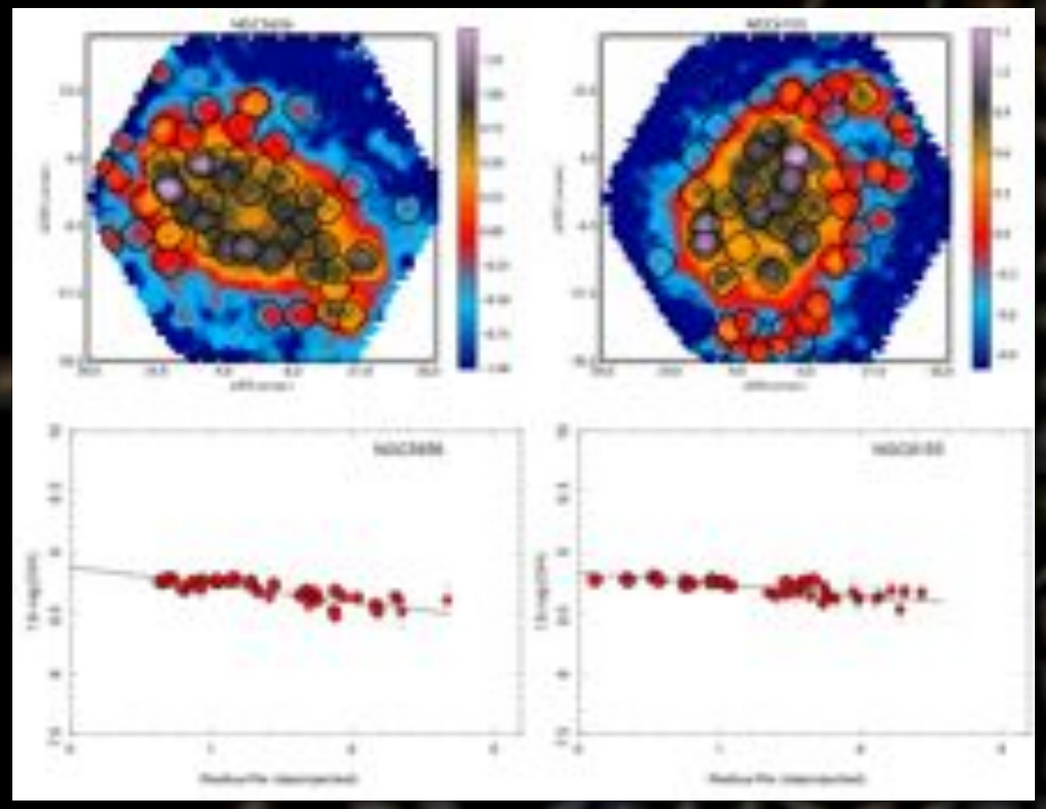

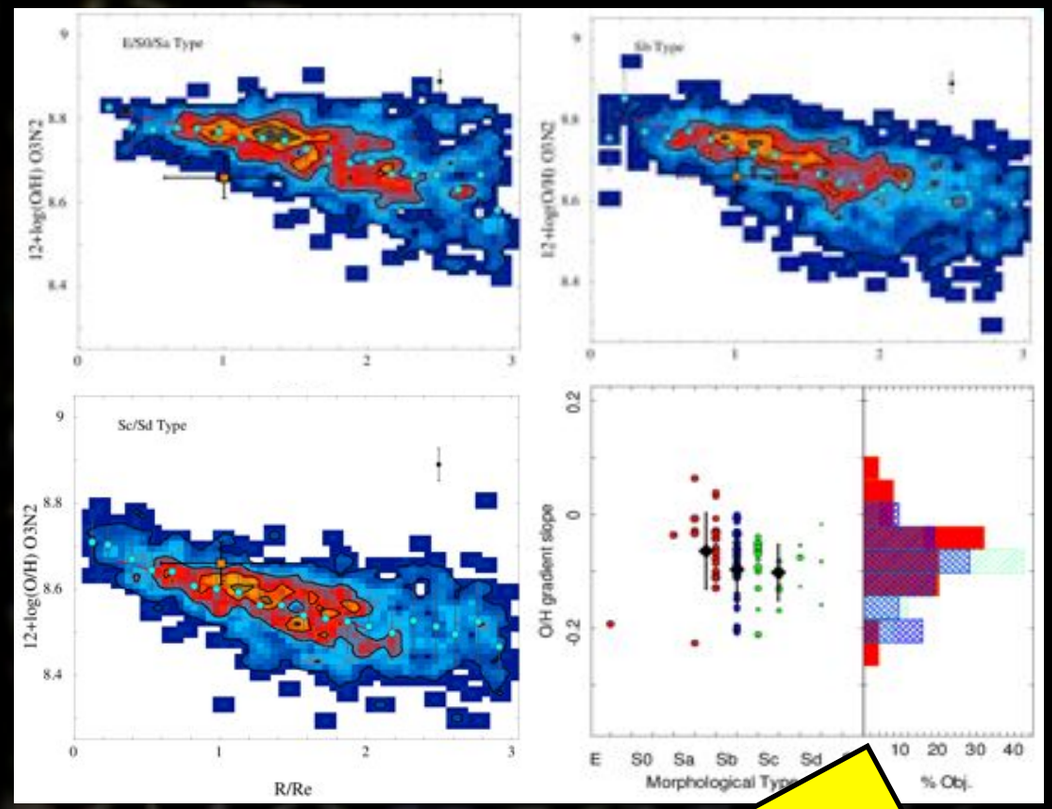

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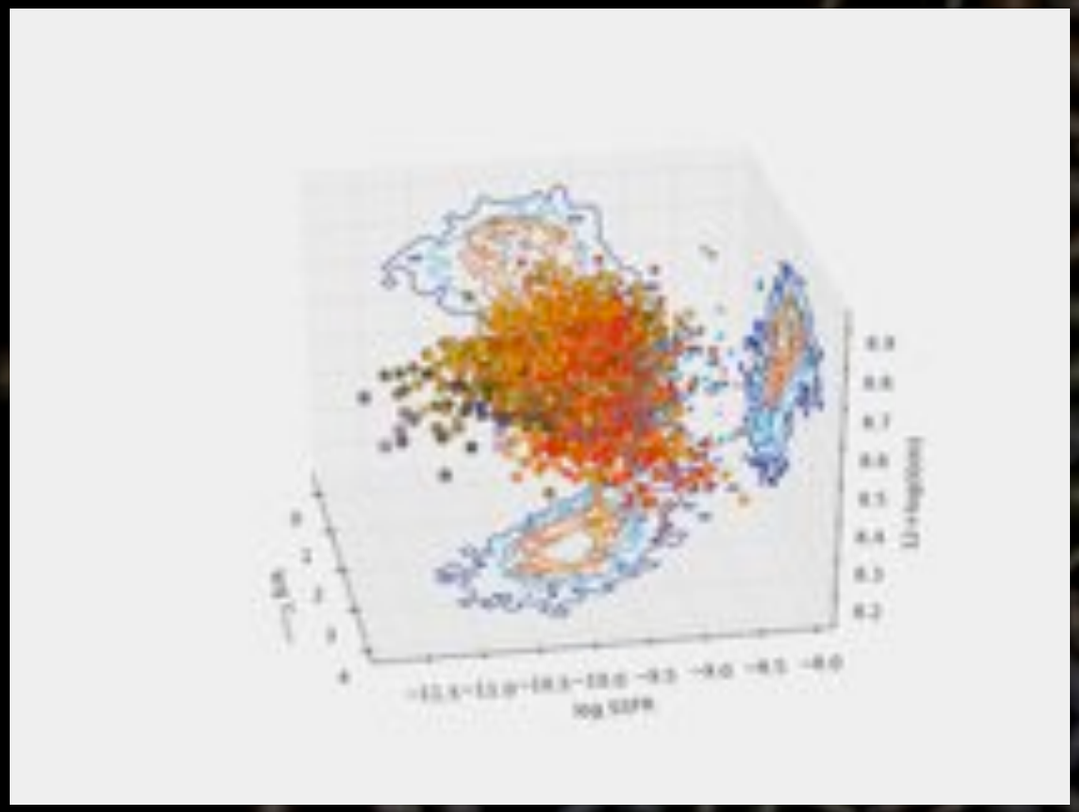
Sebastián's talk on Friday!

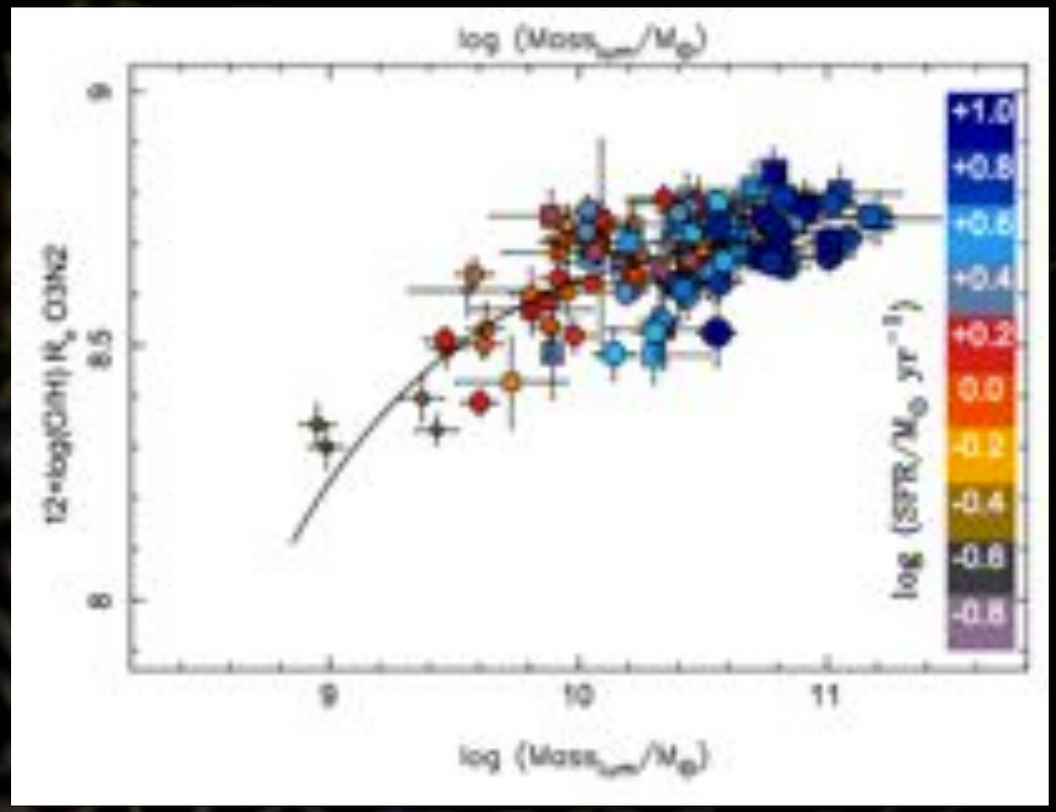
CALIFA: ionized gas

Rosales-Ortega et al. 2012
Sánchez et al. 2013

Local Mass-Metallicity relation



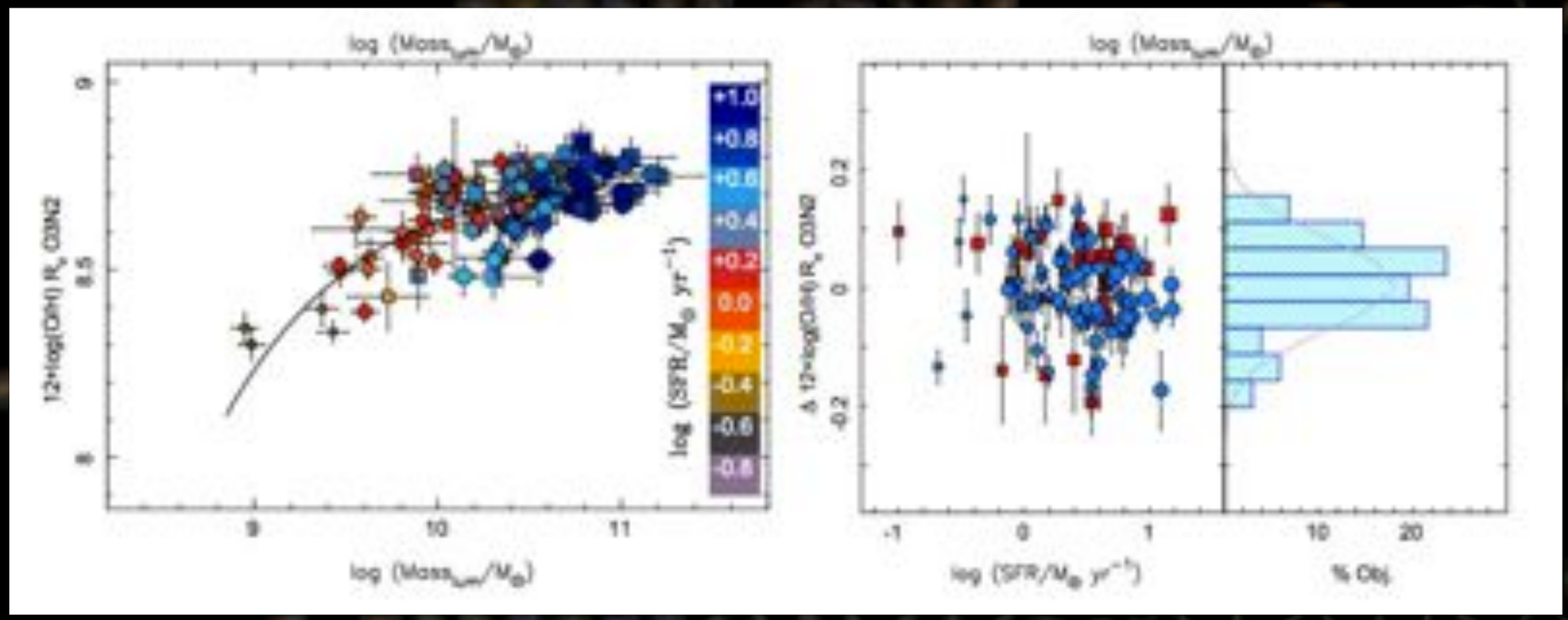
Global Mass-Metallicity relation



- CALIFA *global* M-Z relation: smaller dispersion than T04 SDSS ($\sigma_{\Delta\log(O/H)}$=0.07 dex)
- *Local* surface mass density - metallicity relation confirmed

Mass-metallicity relation explored with CALIFA: Is there a dependence on the star-formation rate?

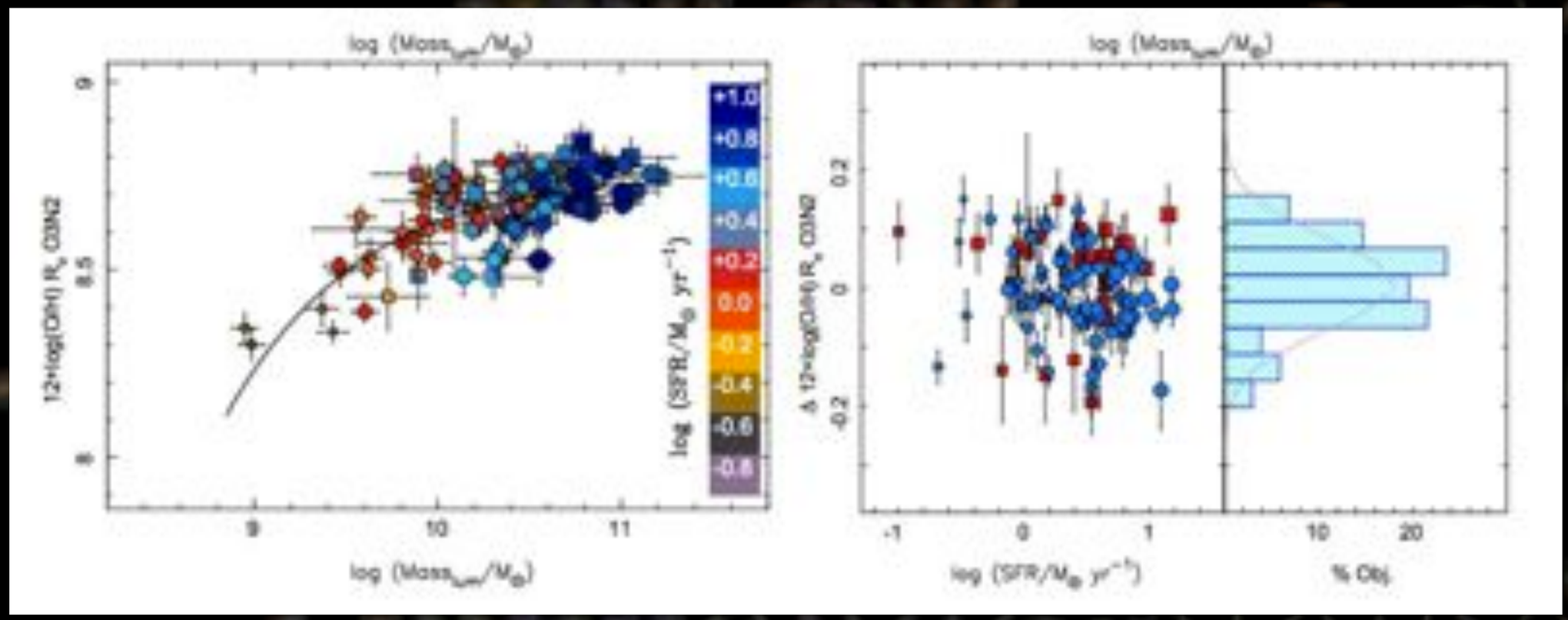
Sánchez et al. 2013



Distribution of the differential oxygen abundances at the effective radii, once the dependency with the stellar mass has been subtracted, as a function of the integrated SFR for the CALIFA galaxies

Mass-metallicity relation explored with CALIFA: Is there a dependence on the star-formation rate?

Sánchez et al. 2013



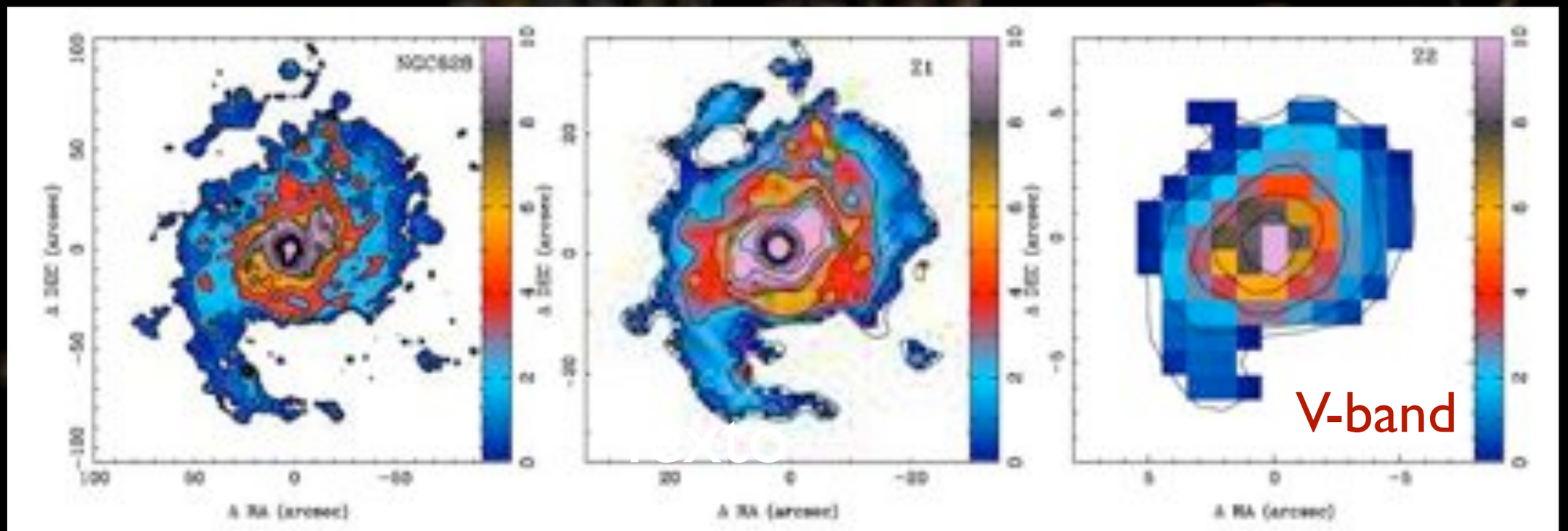
Distribution of the differential oxygen abundances at the effective radii, once the dependency with the stellar mass has been subtracted, as a function of the integrated SFR for the CALIFA galaxies

We do NOT find any secondary relation of mass and metallicity with the SFR

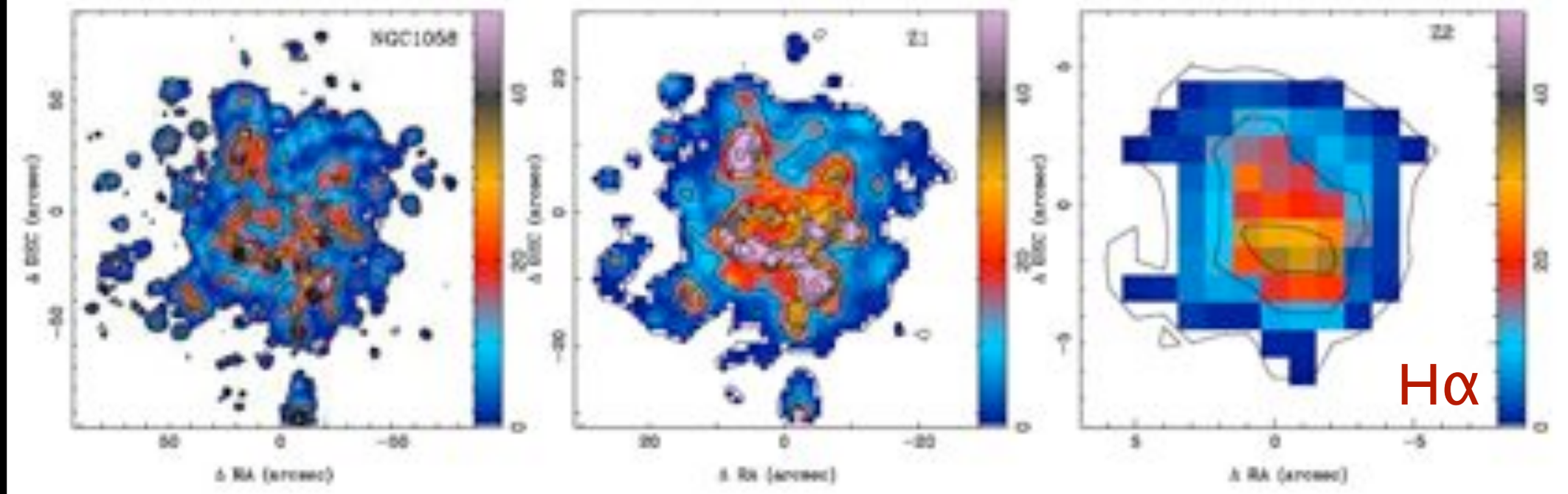
Escenario: gas recycling in galaxies, both locally and globally, is much faster than other typical timescales
(e.g. gas accretion by inflow and/or metal loss due to outflows)

The effects of spatial resolution on Integral Field Unit Surveys at different redshifts. The CALIFA perspective

Mast et al. A&A submitted



PINGS: z ~ 0 CALIFA: z ~ 0.02 z ~ 0.05



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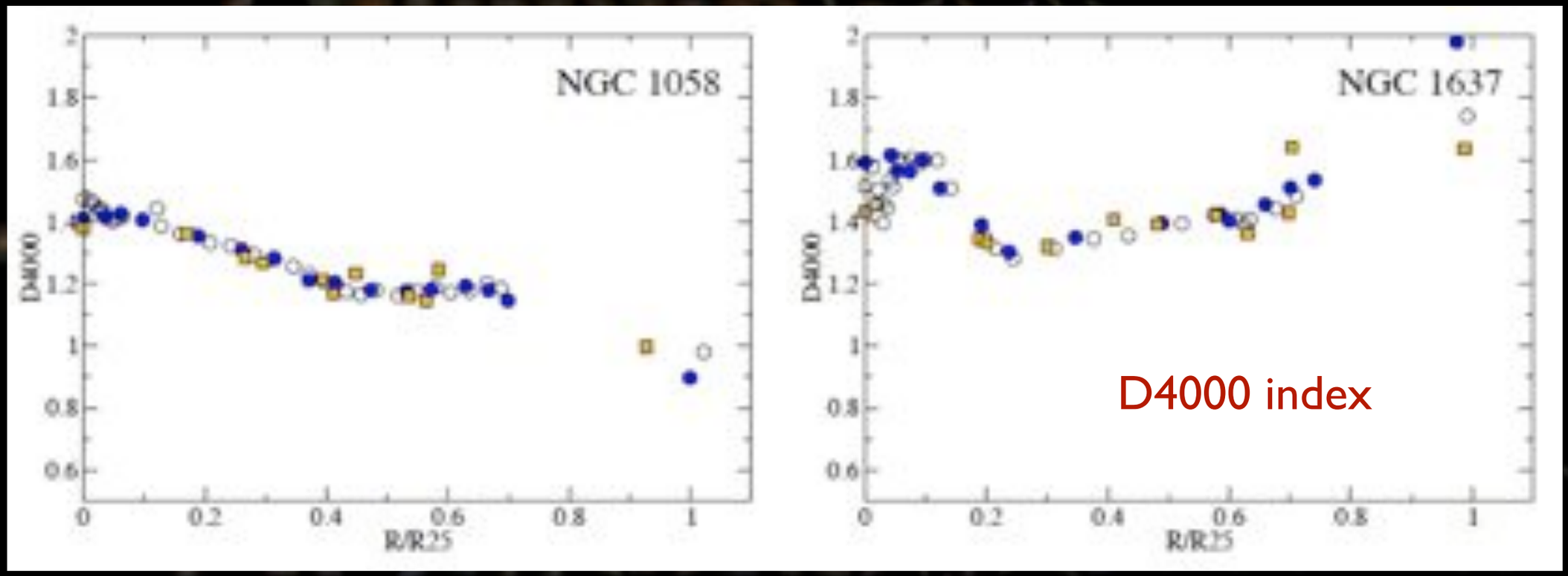
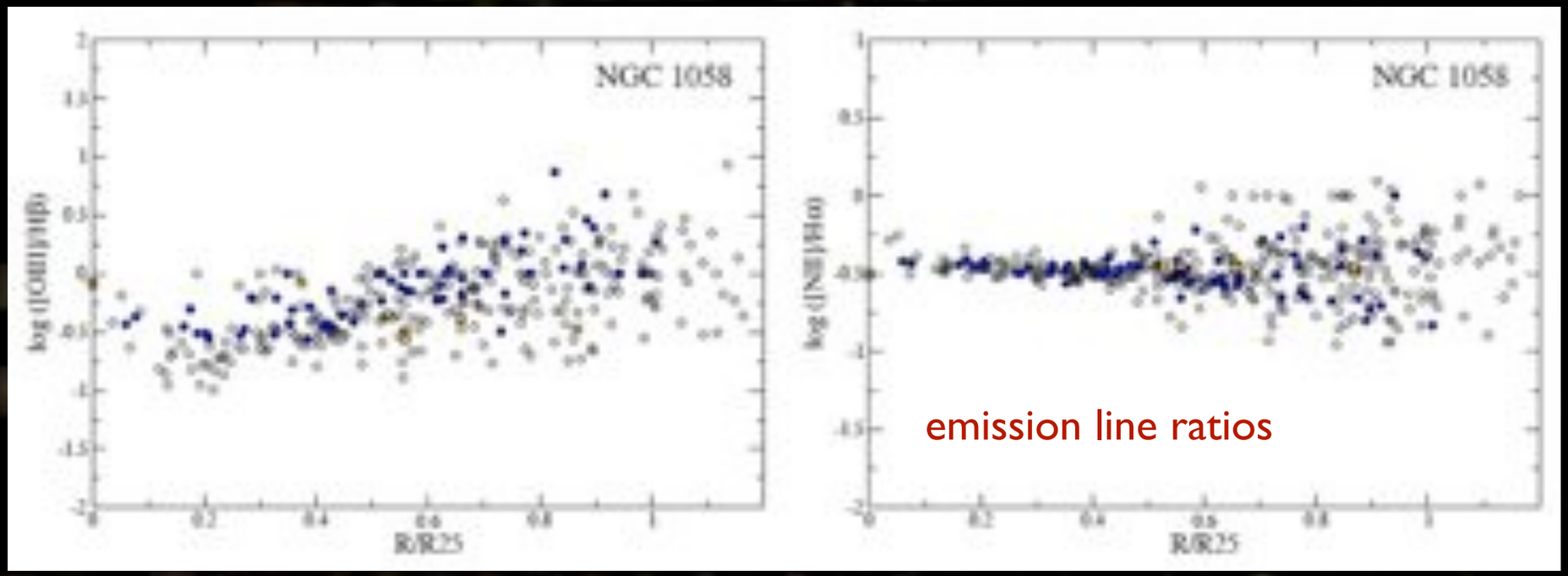


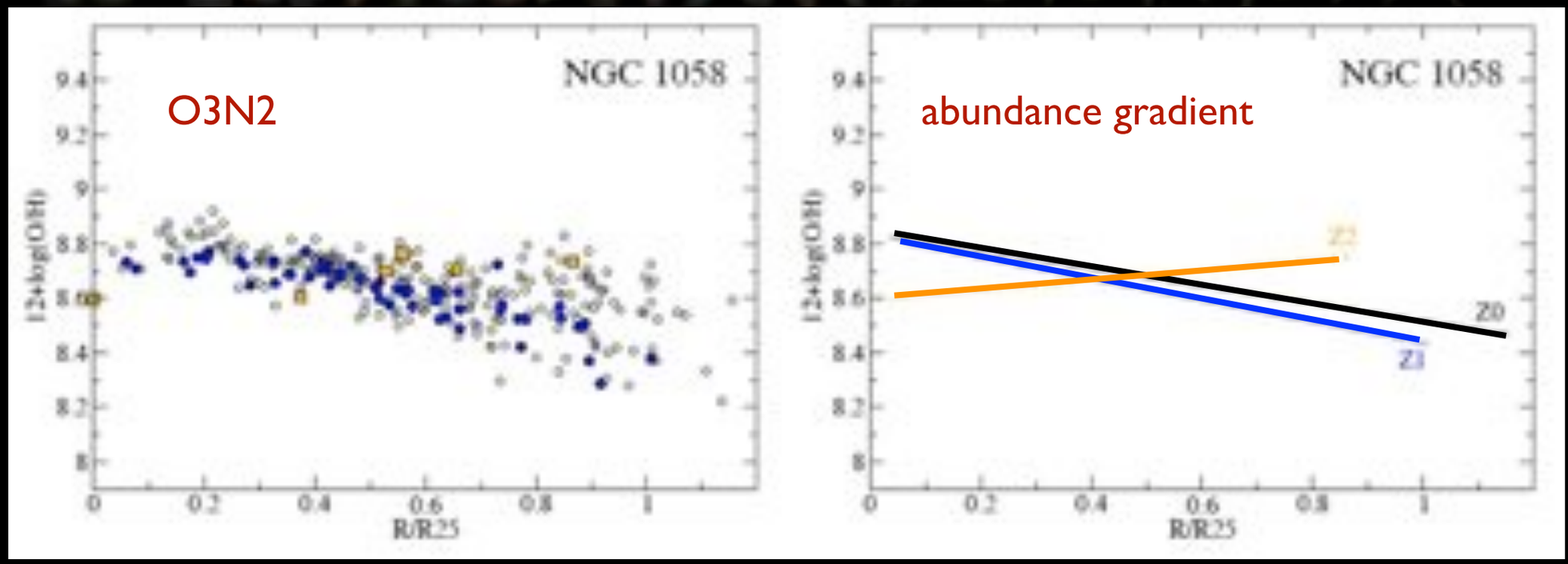
Spectral indices: global tendencies are correctly traced on both simulated cases, and **z1** is also capable, at some level, of reproducing fine structure of the **z0** distributions

The effects of spatial resolution on Integral Field Unit Surveys at different redshifts. The CALIFA perspective

Mast et al. A&A submitted



emission line ratios

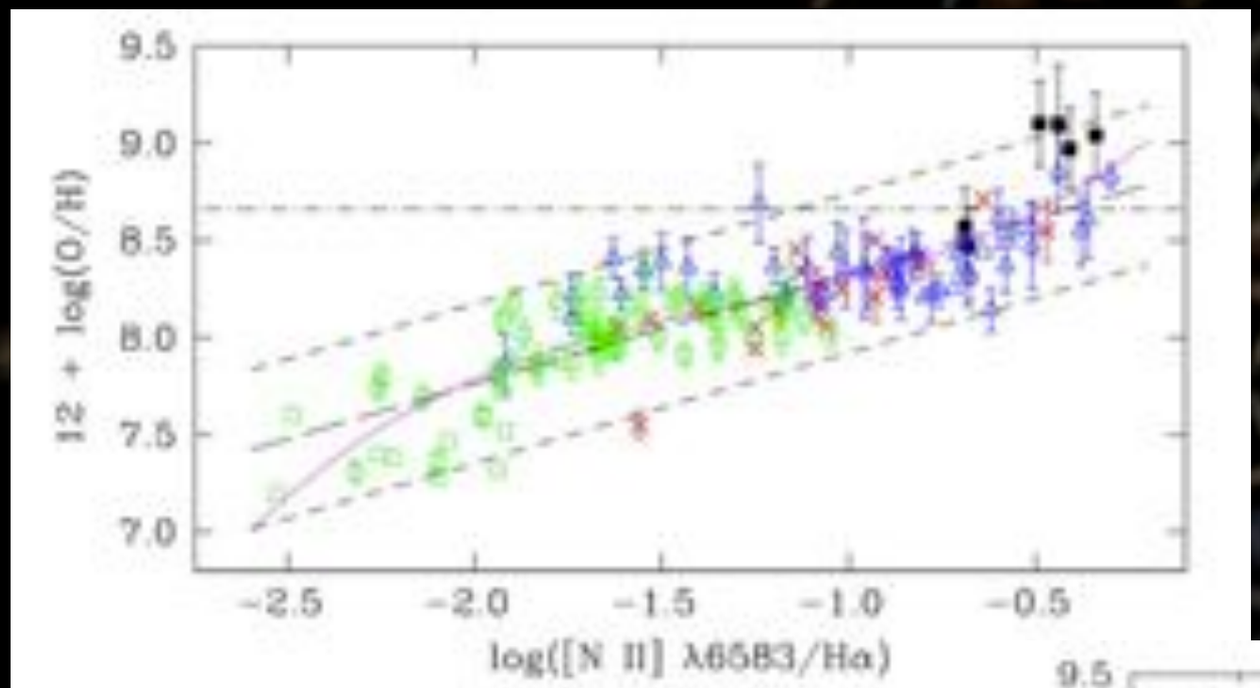


The effects of spatial resolution on Integral Field Unit Surveys at different redshifts. The CALIFA perspective

Mast et al. A&A submitted

- ★ At higher redshift, the coarse resolution adds diffuse gaseous component to what we are considering HII aggregates, with very different ionising structure than the original HII complexes at lower redshift regimes.
- ★ The spatial resolution degradation on the z~0.05 regime inhibits any possibility of measuring convincing radial abundance gradients or structures at that redshift.
- ★ The parameters studied for the gaseous phase show that, contrary to the naive picture, the effect of the resolution degradation is not intuitive as it would be if we were considering simple additive magnitudes.
- ★ Figure of merit: the ratio between the spaxel size and the typical scale-length at a certain redshift:
  - ★ CALIFA-like studies using VIMOS or GMOS, it has to be done at z~0.05 at most
  - ★ SINFONI with AO can be used up to z~0.1

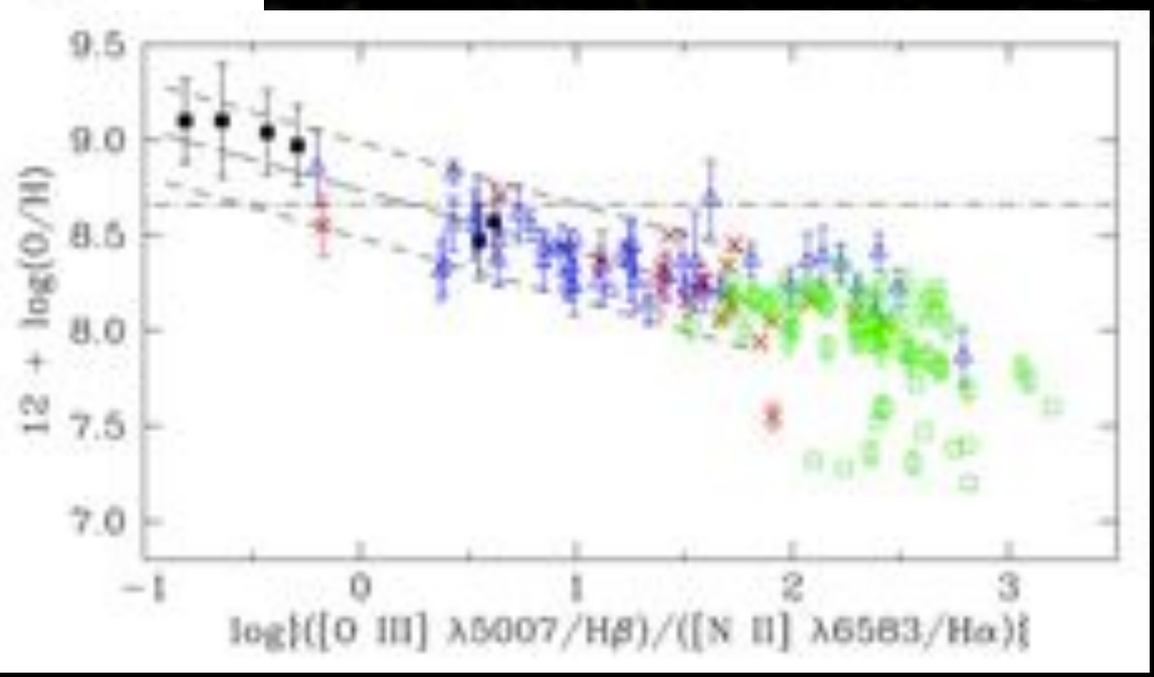
The N2 and O3N2 abundance indicators revisited: improved calibrations based on CALIFA and Te-based literature data



N2 calibration

Alloin et al. (1979)
Storchi-Bergmann, Calzetti & Kinney (1994)
Raimann et al. (2000)
Denicoló, Terlevich & Terlevich (2002)

O3N2 calibration



Pettini & Pagel 2004

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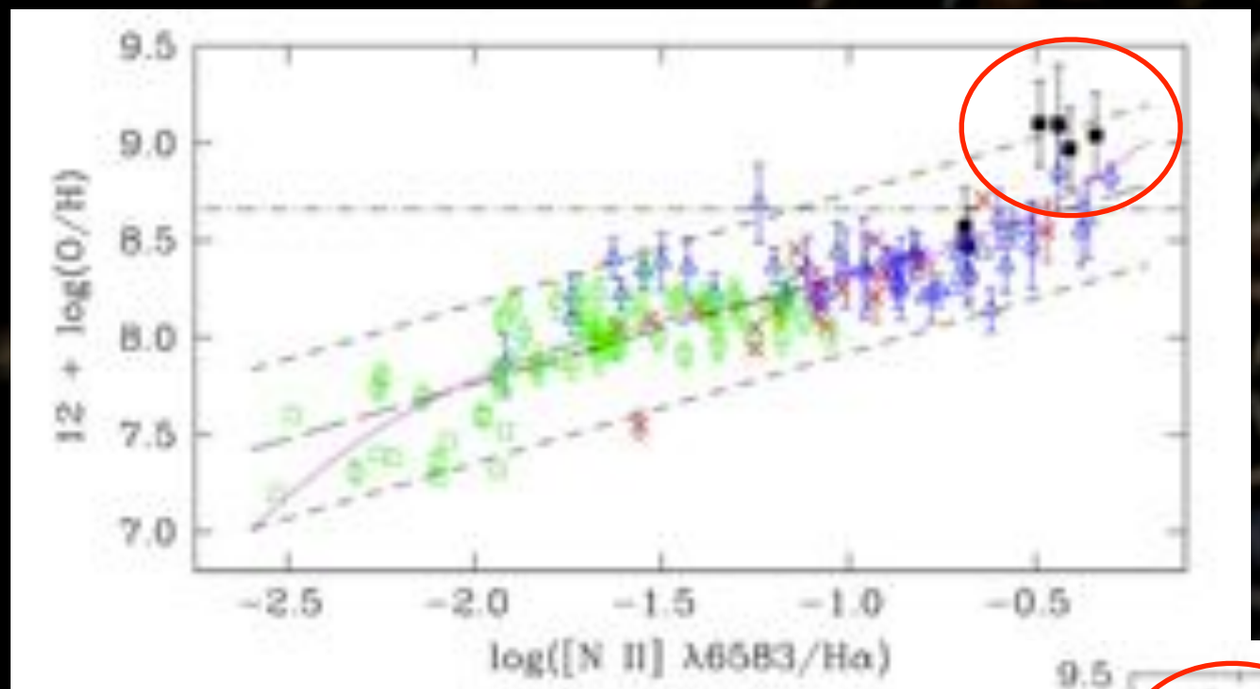

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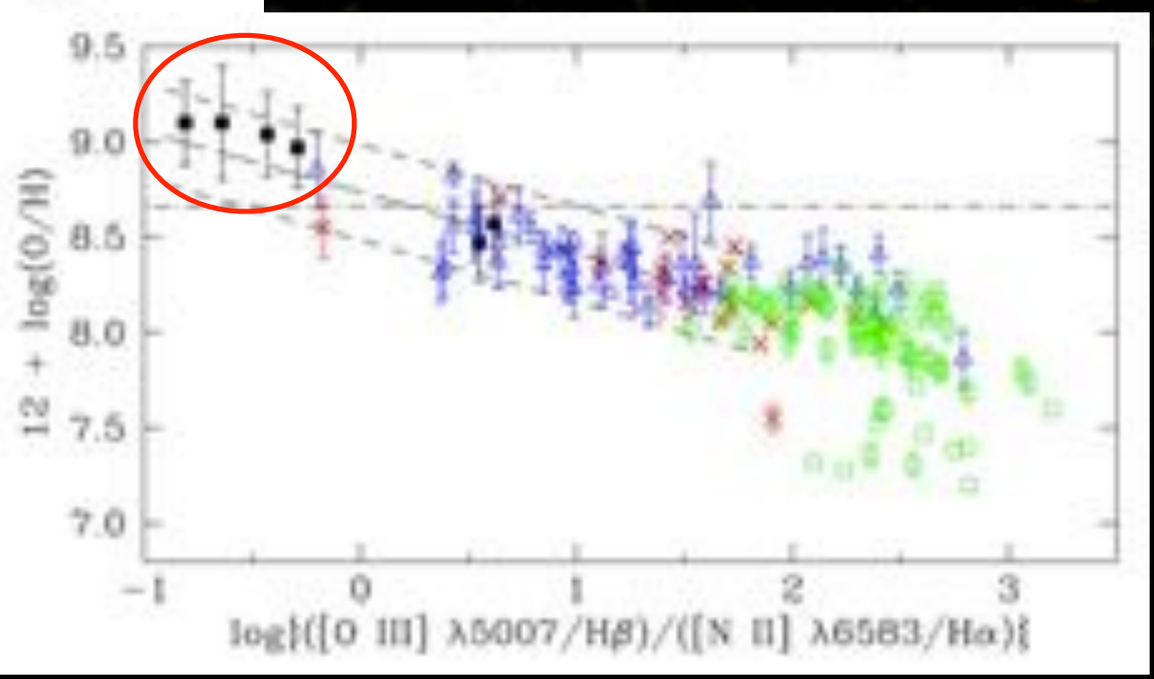

Pettini & Pagel 2004

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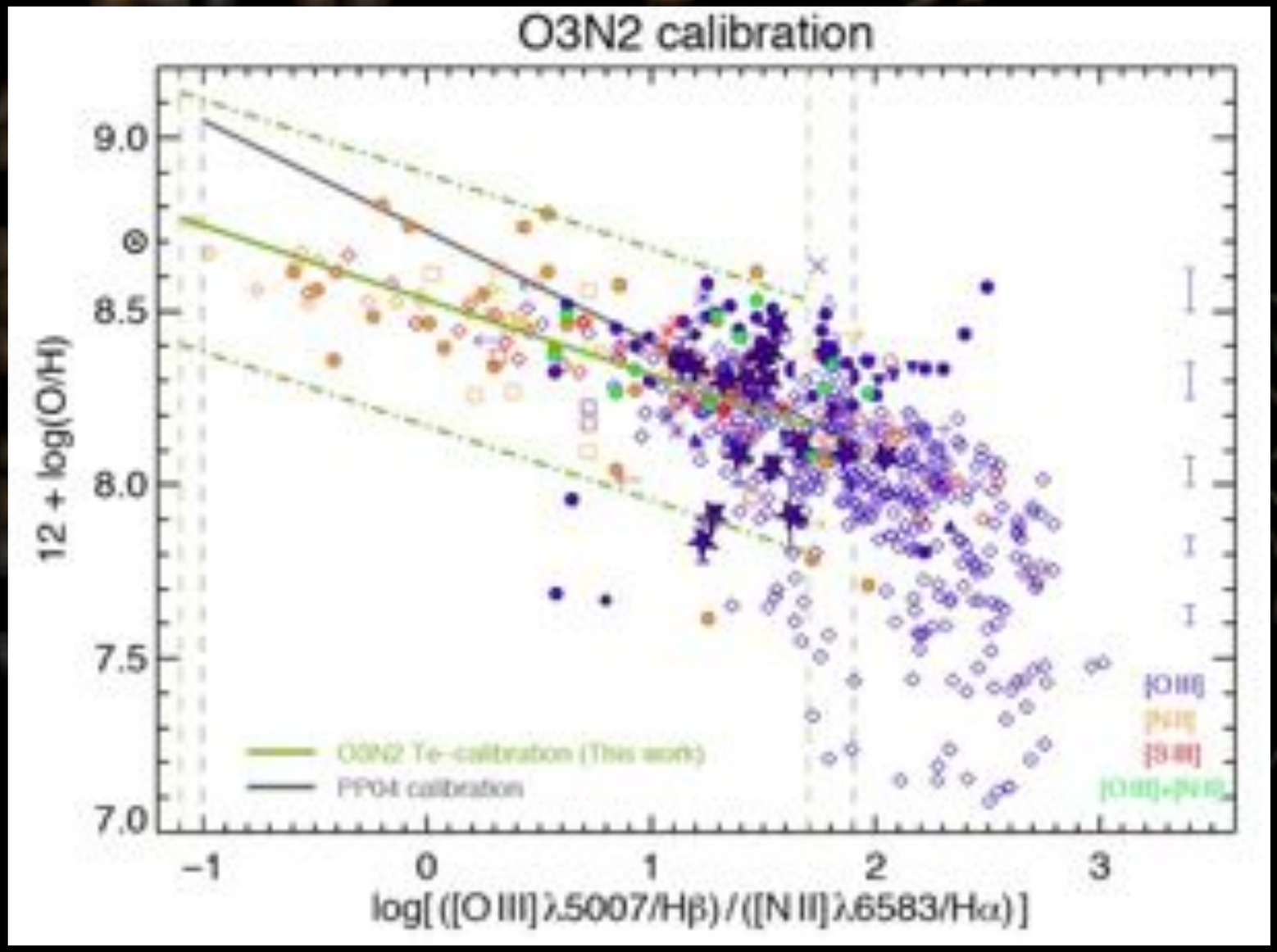
Marino et al. A&A submitted



New compilation of T**e**-based HII regions to date. This new dataset compiles the T**e**-based abundances of 603 HII regions extracted from the literature but also includes new measurements from the CALIFA survey.

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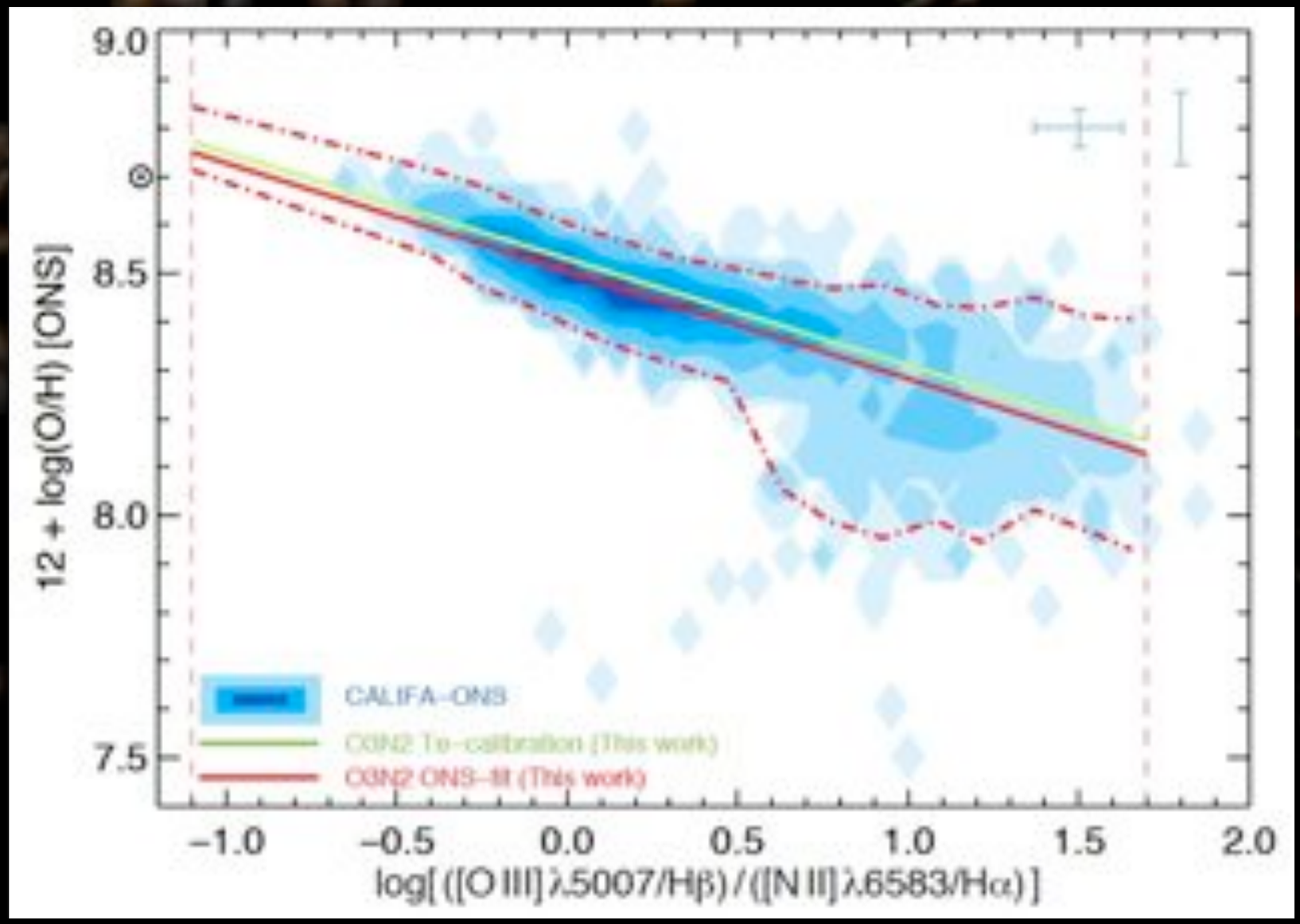
Marino et al. A&A submitted



New compilation of Te-based HII regions to date. This new dataset compiles the Te-based abundances of 603 HII regions extracted from the literature but also includes new measurements from the CALIFA survey.

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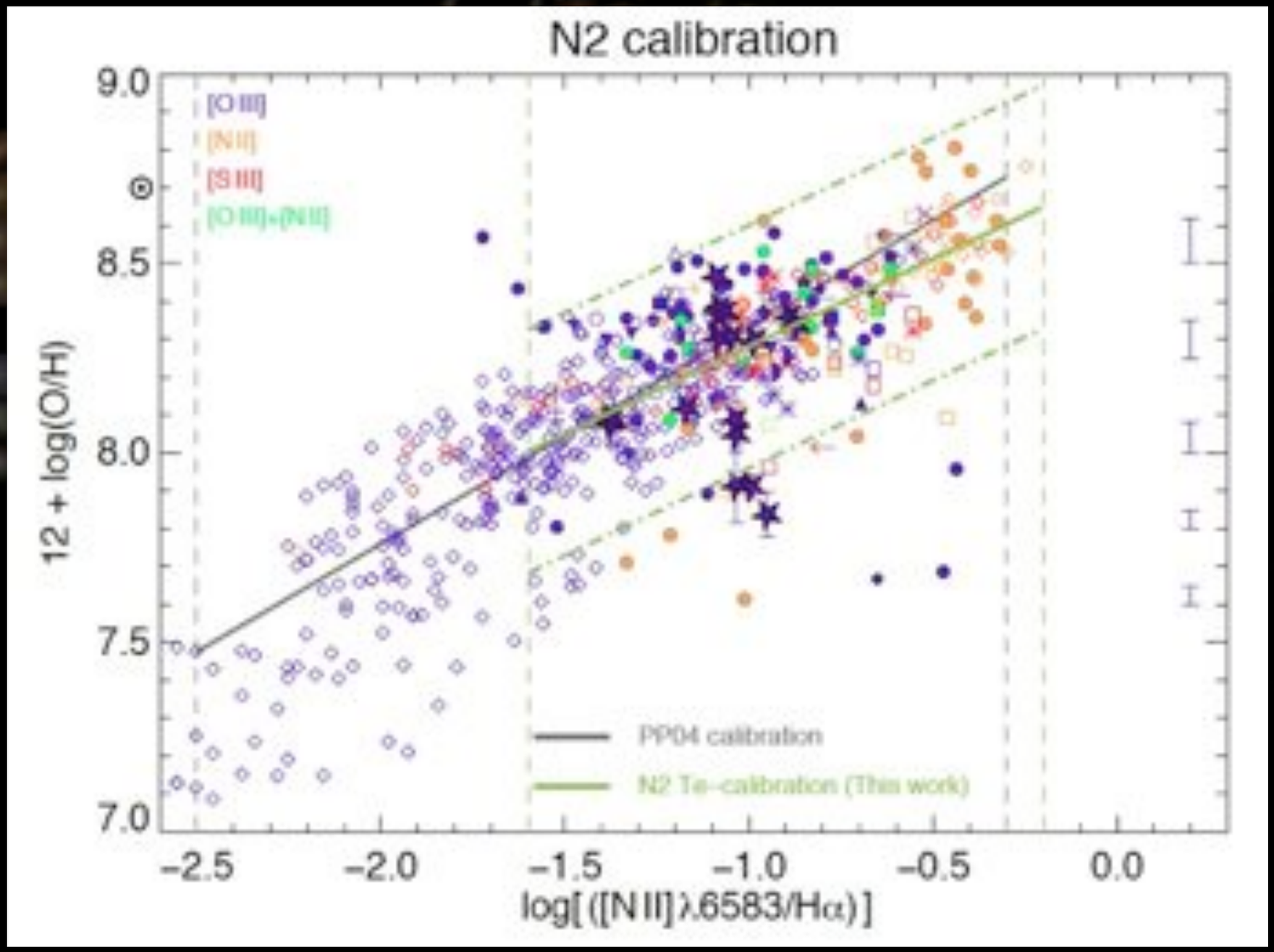

CALIFA Survey

Calar Alto

UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

INAOE
Instituto Nacional de Astrofísica, Óptica y Electrónica

CALIFA science highlights

NGC 4676

"The Mice" galaxies

Wild et al. A&A submitted

CALIFA Survey

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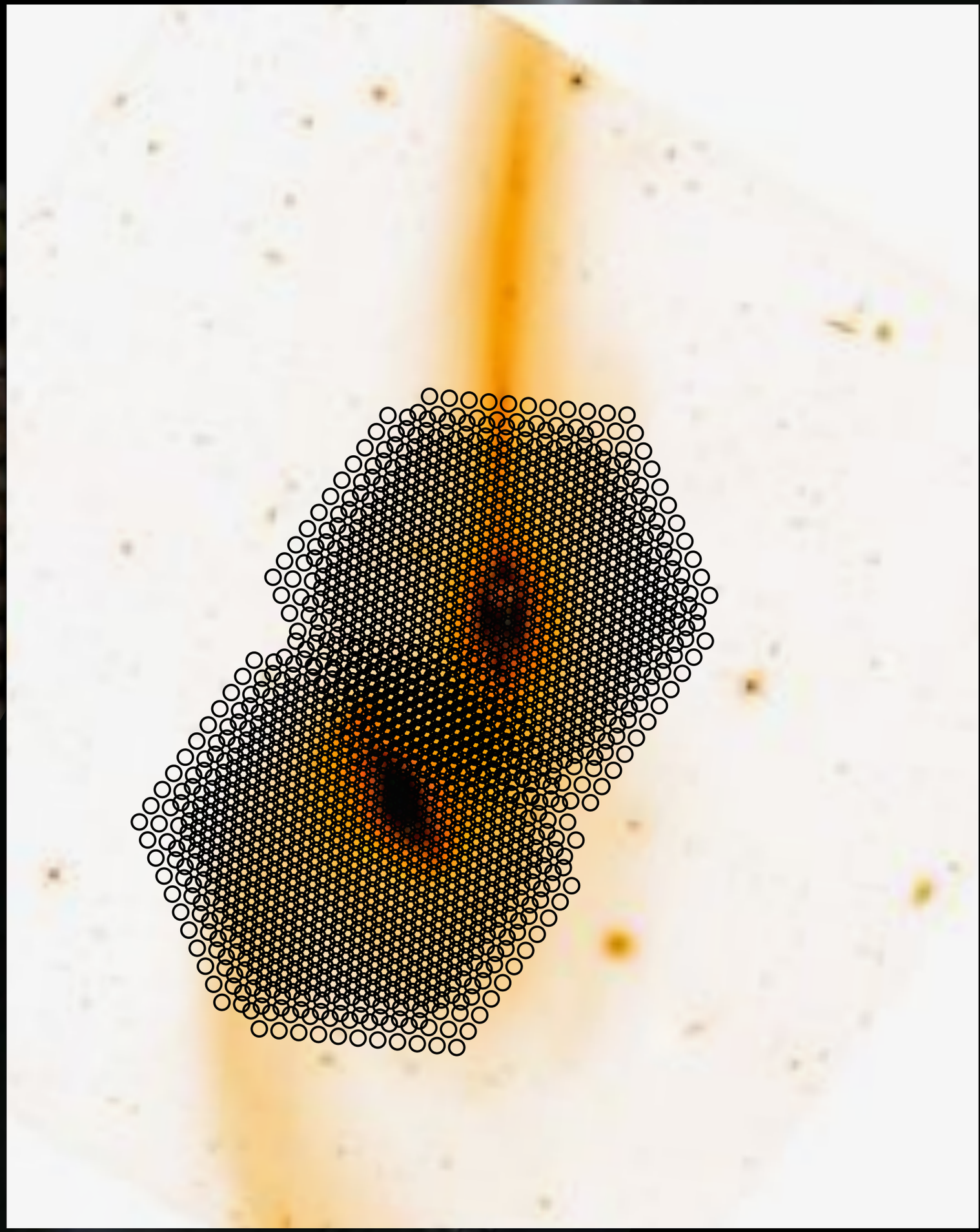
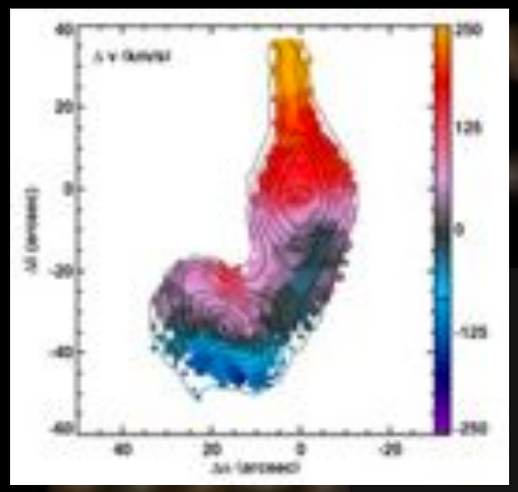
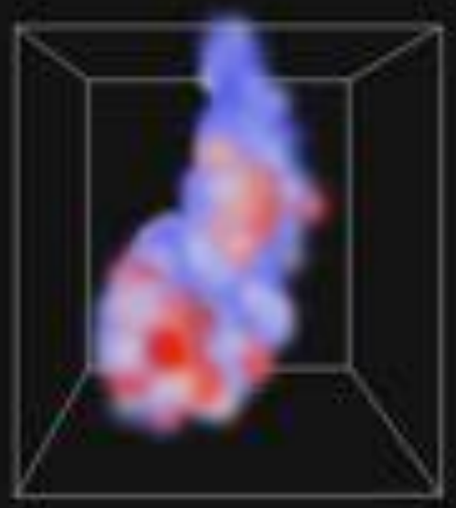


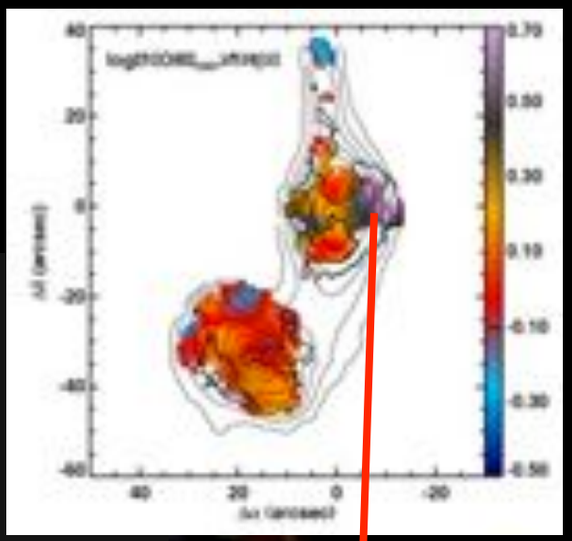
CALIFA science highlights

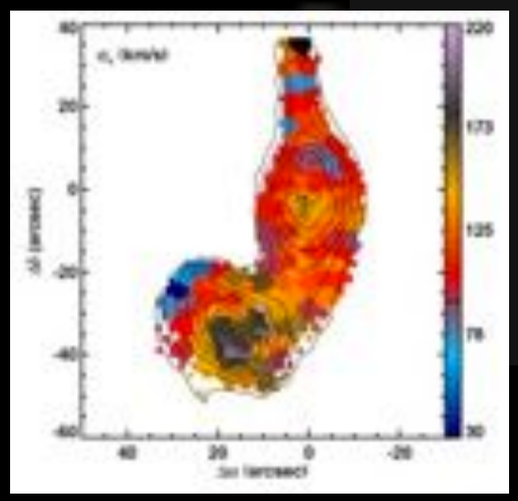
Mice galaxies



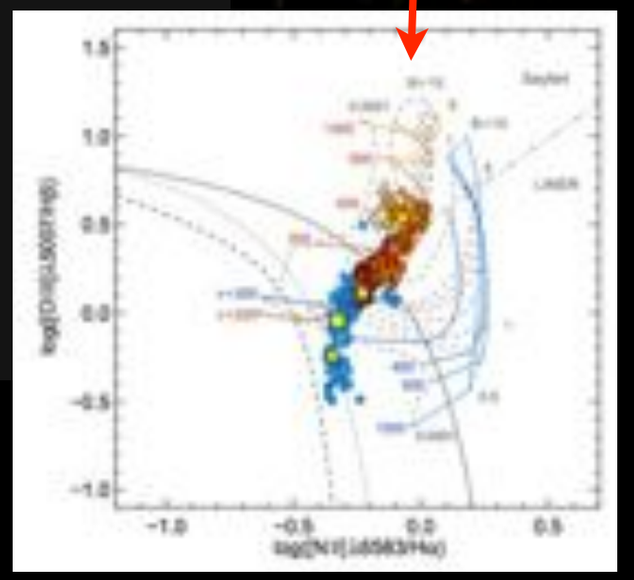


Mice galaxies: pure gas emission 3D cube





Wild et al. A&A submitted



SF-driven shocks V ~ 400 km/s

CALIFA ongoing projects

- Stellar metallicity gradients in disk galaxies
- The nucleosynthesis histories of local galaxies
- Enviromental effects on stellar populations acroos the Hubble sequence
- Tracing the evolution of galaxies from the blue to the red sequence
- Tracing the fuelling mechanisms of low luminous AGN
- Comparative studies of nearby Seyfert and normal galaxies Baryonic fractions
- LINERS physics
- ISM physics excitation
- Star formation vs. diffuse emission
- ISM outflows
- The (non-)effects of bars

PhD Theses

- The Tully-Fisher relation from CALIFA
- Stellar populations in the outskirts of galaxies
- The role of starburst and AGNs in the evolution of galaxies
- The mass distributions of galaxies
- Activity phenomena in interacting/ merging galaxies

and many more...!

CALIFA Survey

Calar Alto

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Instituto Nacional de Astrofísica, Óptica y Electrónica

CALIFA SURVEY

Calar Alto Legacy Integral Field spectroscopy Area survey

Conclusions

- CALIFA is to date, the largest Integral Field Spectroscopy survey ever proposed
- CALIFA represents a unique opportunity to understand the baryonic physics of galaxies using IFS
- CALIFA is a legacy survey, data are being collected, quality is excellent, and is public!
- CALIFA is producing the first, exciting results right now (and you can be part of it!)
- CALIFA will retain properties that make it interesting even after next generation IFS surveys are available (e.g. SAMI, MaNGA, MUSE, VIRUS, etc.)

califa.caha.es

CALIFA Survey

Guillermo Haro 2013 Workshop: Galaxy structure and evolution through Integral Field Spectroscopy: the next generation surveys

Welcome

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Instituto Nacional de Astrofísica, Optica y Electrónica

Have a nice and fruitful stay...!