The CALIFA contribution to SFR studies

Cristina Catalán Torrecilla, Armando Gil de Paz, Africa Castillo Morales
Universidad Complutense de Madrid
Jorge Iglesias Páramo
Instituto de Astrofísica de Andalucía – CSIC
CALIFA team

Star Formation in the Local Universe from the CALIFA sample

I. Calibrating the SFR using IFS data

C. Catalán-Torrecilla[1], A. Gil de Paz[1], A. Castillo-Morales[1], J. Iglesias-Páramo[2,3], and CALIFA collaboration

[1] Departamento de Astrofísica y CC. de la Atmósfera, Universidad Complutense de Madrid, E-28040, Madrid, Spain
e-mail: ccatalan@ucm.es

[2] Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía, 18008 Granada, Spain
e-mail: jiglesia@iaa.es

[3] Centro Astronómico Hispano Alemán, 04004 Almería, Spain

ABSTRACT

Context. The Calar Alto Legacy Integral Field Area survey (CALIFA survey) has been designed to be the first survey to provide Integral Field Spectroscopy (IFS) data in the entire optical window for a large sample of all types of galaxies (~ 600 objects) in the Local Universe (0.005<z<0.03). One of the main goals of this survey is to explore the spatial distribution of the star formation in nearby galaxies with an unprecedented level of precision.
Aims. The objective of this work is to derive and compare integrated SFR measurements using the recipes found previously in the literature and provide updated SFR tracers for the entire sample using not only the CALIFA IFS data but also a number of different tracers at other wavelengths, including Ultraviolet (UV) and infrared (IR) data. The comparison between these tracers will allow us to determine whether or not the extinction-corrected Hα luminosities provide a good measure of the total current SFR and, in general, to explore the origin of the discrepancies between different single-band and hybrid SFR tracers. We provide updated calibrations referred to Hα, both global and split by properties.
Methods. We first derive integrated extinction-corrected Hα fluxes from CALIFA datacubes by fitting the stellar continuum using a set of evoluationary synthesis models. We also measure UV surface and asymptotic photometry and integrated WISE 22μm fluxes and make use of IRAS fluxes from the literature when available.
Results. Our analysis shows that in the vast majority of cases the extinction-corrected Hα luminosity agree with the different hybrid SFR estimators based on UV$_{obs}$+22μm, UV$_{obs}$+TIR, Hα_{obs}+22μm, or Hα_{obs}+TIR data over the full range of SFRs (~ 0.03 – 20 M$_\odot$ yr^{-1}). We provide updated calibrations for both single-band and hybrid SFR tracers (with and without type-2 AGN included in the sample) that are effectively tied to the SFR measured from the extinction-corrected Hα luminosity. Although the coefficients that multiply the IR term in hybrid SFR tracers show a large dispersion, they do not became increasingly small at high ionized-gas attenuations, as one would expect should a significant fraction of the Hα emission being missed. On the other hand, red, massive, lenticulars and early-type spirals together with type-2 AGN show somewhat smaller coefficients, which we interpret as consequence of the larger contribution of optical photons and AGN to dust heating.
Conclusions. At least in the Local Universe the Hα luminosity derived from observations of the CALIFA IFS survey can be used to trace the SFR once all effects are properly accounted for, namely stellar continuum absorption in Balmer lines and dust attenuation effects. Finally, in future communications we will make use of the CALIFA sample to derive the current SFR in the Local Universe with spatial resolution.

Key words. galaxies: evolution, galaxies: spiral, galaxies: star formation, techniques: photometric, techniques: spectroscopic

Star Formation in the Local Universe from the CALIFA sample

I. Calibrating the SFR using IFS data

C. Catalán-Torrecilla[1] A. Gil de Paz[1], A. Castillo-Morales[1], J. Iglesias-Páramo[2,3], and CALIFA collaboration

[1] Departamento de Astrofísica y CC. de la Atmósfera, Universidad Complutense de Madrid, E-28040, Madrid, Spain
e-mail: ccatalan@ucm.es
[2] Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía, 18008 Granada, Spain
e-mail: jiglesia@iaa.es
[3] Centro Astronómico Hispano Alemán, 04004 Almería, Spain

ABSTRACT

Context. The Calar Alto Legacy Integral Field Area survey (CALIFA survey) has been designed to be the first survey to provide Integral Field Spectroscopy (IFS) data in the entire optical window for a large sample of all types of galaxies ($\sim$ 600 objects) in the Local Universe (0.005<z<0.03). One of the main goals of this survey is to explore the spatial distribution of the star formation in nearby galaxies with an unprecedented level of precision.
Aims. The objective of this work is to derive and compare integrated SFR measurements using the recipes found previously in the literature and provide updated SFR tracers for the entire sample using not only the CALIFA IFS data but also a number of different tracers at other wavelengths, including Ultraviolet (UV) and infrared (IR) data. The comparison between these tracers will allow us to determine whether or not the extinction-corrected Hα luminosities provide a good measure of the total current SFR and, in general, to explore the origin of the discrepancies between different single-band and hybrid SFR tracers. We provide updated calibrations referred to Hα, both global and split by properties.
Methods. We first derive integrated extinction-corrected Hα fluxes from CALIFA datacubes by fitting the stellar continuum using a set of evoluationary synthesis models. We also measure UV surface and asymptotic photometry and integrated WISE 22μm fluxes and make use of IRAS fluxes from the literature when available.
Results. Our analysis shows that in the vast majority of cases the extinction-corrected Hα luminosity agree with the different hybrid SFR estimators based on UV_{obs}+22μm, UV_{obs}+TIR, Hα_{obs}+22μm, or Hα_{obs}+TIR data over the full range of SFRs ($\sim$ 0.03 – 20 $M_{\odot}$ yr^{-1}). We provide updated calibrations for both single-band and hybrid SFR tracers (with and without type-2 AGN included in the sample) that are effectively tied to the SFR measured from the extinction-corrected Hα luminosity. Although the coefficients that multiply the IR term in hybrid SFR tracers show a large dispersion, they do not became increasingly small at high ionized-gas attenuations, as one would expect should a significant fraction of the Hα emission being missed. On the other hand, red, massive, lenticulars and early-type spirals together with type-2 AGN show somewhat smaller coefficients, which we interpret as consequence of the larger contribution of optical photons and AGN to dust heating.
Conclusions. At least in the Local Universe the Hα luminosity derived from observations of the CALIFA IFS survey can be used to trace the SFR once all effects are properly accounted for, namely stellar continuum absorption in Balmer lines and dust attenuation effects. Finally, in future communications we will make use of the CALIFA sample to derive the current SFR in the Local Universe with spatial resolution.

Key words. galaxies: evolution, galaxies: spiral, galaxies: star formation, techniques: photometric, techniques: spectroscopic

Introduction

The SFR accounts for the number of stars recently formed in a galaxy during a given time lapse (i.e. the timescale).

Observational proxies for the SFR:

- UV luminosity: from massive stars.
- Hα luminosity: the recombination emission line of the photoionized hydrogen surrounding massive stars.
- IR luminosity: the emission from dust heated by stellar light.
- Radio-continuum: the free-free component from the ionized gas.
- X-ray: from X-ray binaries, supernovae, supernovae remnants, massive stars.

Introduction

The SFR accounts for the number of stars recently formed in a galaxy during a given time lapse (i.e. the timescale).

Observational proxies for the SFR:

- UV luminosity: from massive stars.
- Hα luminosity: the recombination emission line of the photoionized hydrogen surrounding massive stars. **CALIFA niche**
- IR luminosity: the emission from dust heated by stellar light.
- Radio-continuum: the free-free component from the ionized gas.
- X-ray: from X-ray binaries, supernovae, supernovae remnants, massive stars.

Introduction

The SFR accounts for the number of stars recently formed in a galaxy during a given time lapse (i.e. the timescale).

Observational proxies for the SFR:

- UV luminosity: from massive stars.
- Hα luminosity: the recombination emission line of the photoionized hydrogen surrounding massive stars.

CALIFA niche

- IR luminosity: the emission from dust heated by stellar light.
- Radio-continuum: the free-free component from the ionized gas.
- X-ray: from X-ray binaries, supernovae, supernovae remnants, massive stars.

INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CALIFA Survey

Introduction

These luminosities are proportional to the recent SFR (in the last ~10^8yr) under the assumptions:

a) All the Lyman continuum photons are converted to Hα emission photons that escape from the galaxy.

b) All the UV photons escape from the galaxy.

c) The bolometric luminosity from the young stars is absorbed by dust and re-emited at IR (~ 8µm – 1000µm) wavelengths.

$$\mathrm{SFR} = \begin{cases} \text{a)} \quad C(\mathrm{H}\alpha)*L(\mathrm{H}\alpha) \\ \text{b)} \quad C(\mathrm{UV})*L(\mathrm{UV}) \\ \text{c)} \quad C(\mathrm{IR})*L(\mathrm{IR}) \end{cases}$$

C(Hα), C(UV) and C(IR) are estimated from stellar evolutionary synthesis models, assuming your favorite IMF.

See reviews by **Calzetti (2013)** and **Kennicutt & Evans (2012).**

SFRs from CALIFA

The sample: 380 CALIFA galaxies (Oct. 2013).

- Observed at 3.5m Telescope Calar Alto (Almería, Spain)
- $0.005 < z < 0.03$, $45'' < D_{25} < 80''$ (SDSS-DR7)
- [3745,7500]Å, R ~ 850

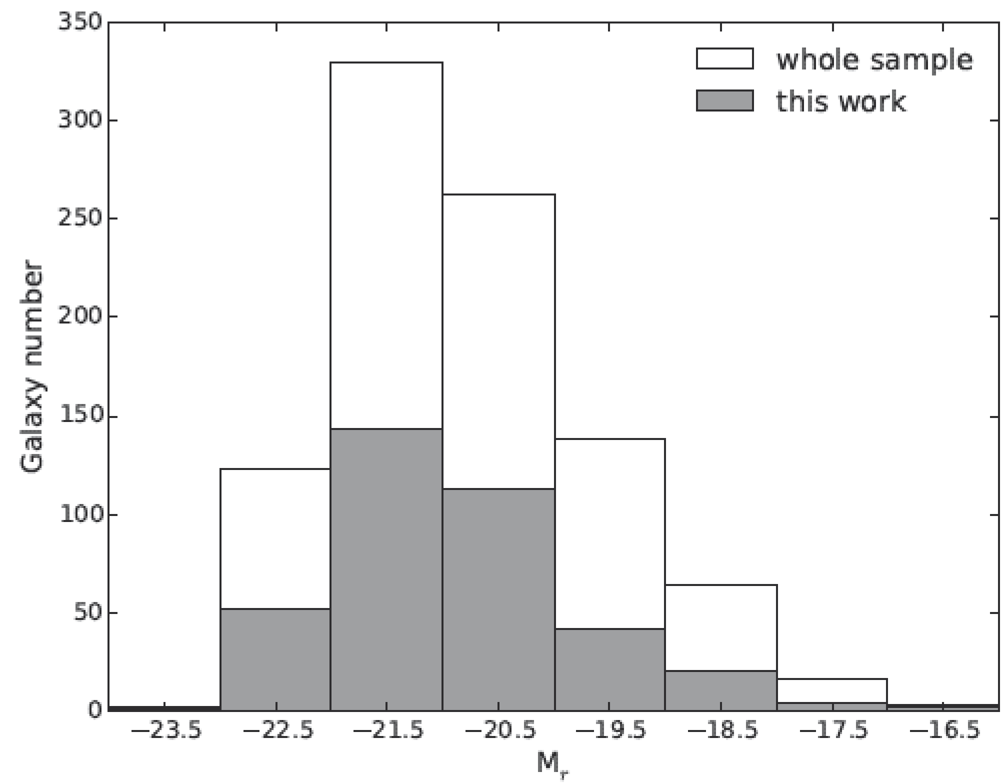
(enough to deblend the Hα-[NII] lines and to fit the underlying Balmer stellar absorptions)

SFRs from CALIFA

The sample: 380 CALIFA galaxies (Oct. 2013).

- Observed at 3.5m Telescope Calar Alto (Almería, Spain)
- $0.005 < z < 0.03$, $45'' < D_{25} < 80''$ (SDSS-DR7)
- [3745,7500]Å, R ~ 850

(enough to deblend the Hα-[NII] lines and to fit the underlying Balmer stellar absorptions)



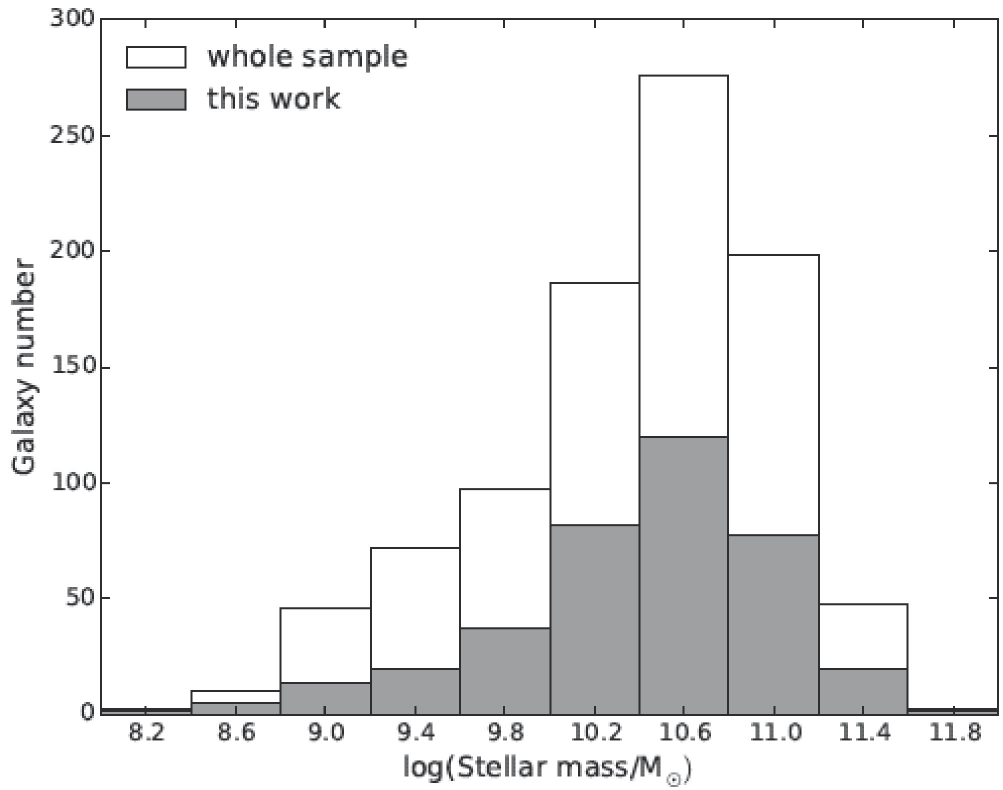
CALIFA Survey

SFRs from CALIFA

The sample: 380 CALIFA galaxies (Oct. 2013).

- Observed at 3.5m Telescope Calar Alto (Almería, Spain)
- $0.005 < z < 0.03$, $45'' < D_{25} < 80''$ (SDSS-DR7)
- [3745,7500]Å, R ~ 850

(enough to deblend the Hα-[NII] lines and to fit the underlying Balmer stellar absorptions)



SFRs from CALIFA

The sample: 380 CALIFA galaxies (Oct. 2013).

- Observed at 3.5m Telescope Calar Alto (Almería, Spain)
- $0.005 < z < 0.03$, 45" < D_{25} < 80" (SDSS-DR7)
- [3745,7500]Å, R ~ 850

(enough to deblend the Hα-[NII] lines and to fit the underlying Balmer stellar absorptions)

Hα (+ Hβ) luminosities: CALIFA spectra

SFRs from CALIFA

The sample: 380 CALIFA galaxies (Oct. 2013).

- Observed at 3.5m Telescope Calar Alto (Almería, Spain)
- $0.005 < z < 0.03$, 45” < D_{25} < 80” (SDSS-DR7)
- [3745,7500]Å, R ~ 850

(enough to deblend the Hα-[NII] lines and to fit the underlying Balmer stellar absorptions)

Hα (+ Hβ) luminosities: CALIFA spectra

UV luminosities: GALEX FUV(1530Å) and NUV(2310Å)

IR luminosities:

- WISE Mid-IR imaging: 22μm
- IRAS Mid-to-FIR IR imaging: 12μm, 25μm, 60μm, 100μm
- AKARI Far-IR imaging: 140μm, 160μm

SFRs from CALIFA

AIM OF THIS WORK:

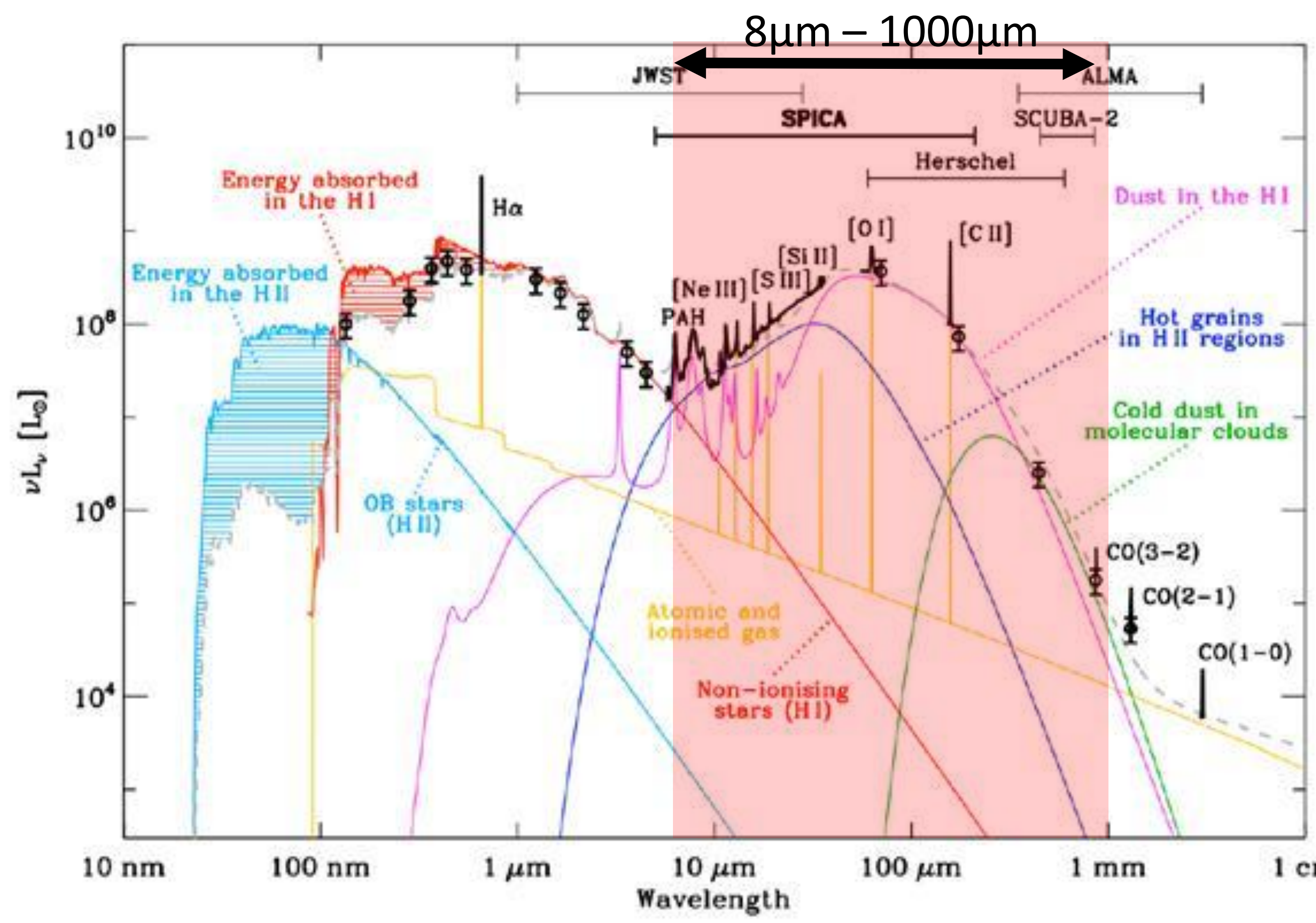
A comprehension of the relative contributions of Hα, UV and IR luminosities to the **global** SFR in CALIFA spiral galaxies.

Calibration of the SFR indicators.

SFRs from CALIFA

SFR(IR)

The IR SED (~ 8µm – 1000µm) has several components associated to dust in different conditions.



SFRs from CALIFA

<u>SFR(IR)</u>

The IR SED (~ 8µm – 1000µm) has several components associated to dust in different conditions.

We use Pérez-González et al. (2008) fits to theoretical models of:

- Chary & Elbaz (2001)
- Dale & Helou (2002)
- Rieke et al. (2009)

using our WISE, IRAS & AKARI photometry.

L(TIR), total luminosity from 8µm to 1000µm.

In addition to this, the SFR can be empirically calibrated using monochromatic luminosities at different wavelengths:

L(22µm) from WISE.

SFRs from CALIFA

<u>SFR(IR)</u>

WARNING!

• In general not all the bolometric luminosity of the young stars is absorbed by dust (we “see” the galaxies in UV and/or Hα).

Dusty mergers vs. Dwarf irregulars

• We know that also old stars produce photons capable to heat the dust.

Sa/Sab vs. Sdm

SFRs from CALIFA

SFR(UV)

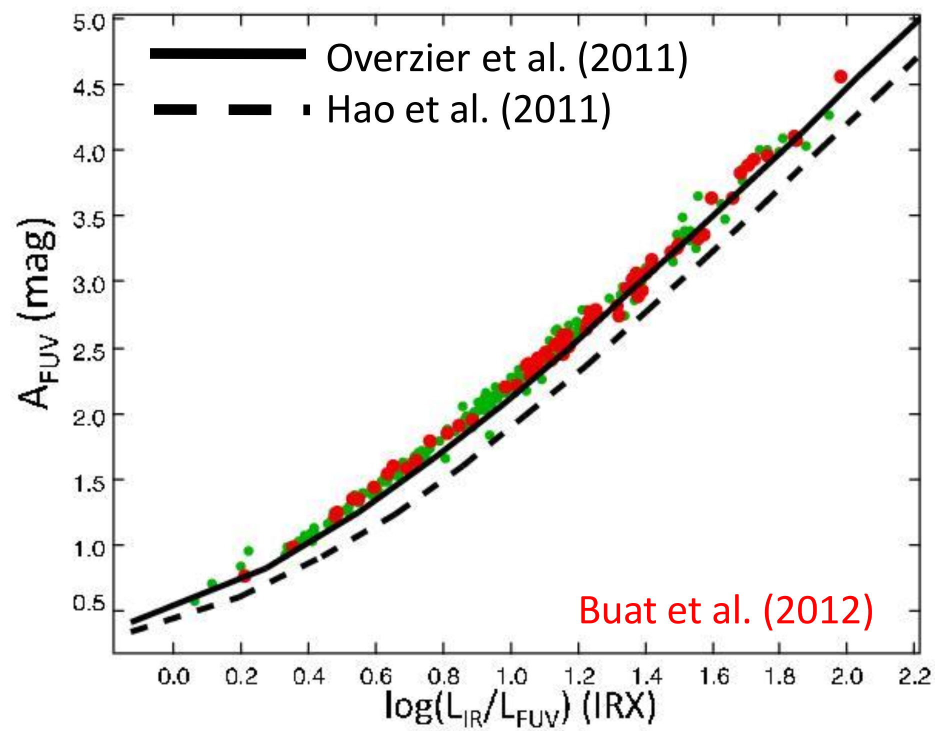
WARNING!

• Many UV photons are absorbed by dust, thus a correction for this "lost UV luminosity" is required: attenuation correction.

A(FUV) = f(L(TIR)/L(FUV))

Very robust estimation.

Almost indepent of the Relative geometry of dust and stars.



CALIFA Survey

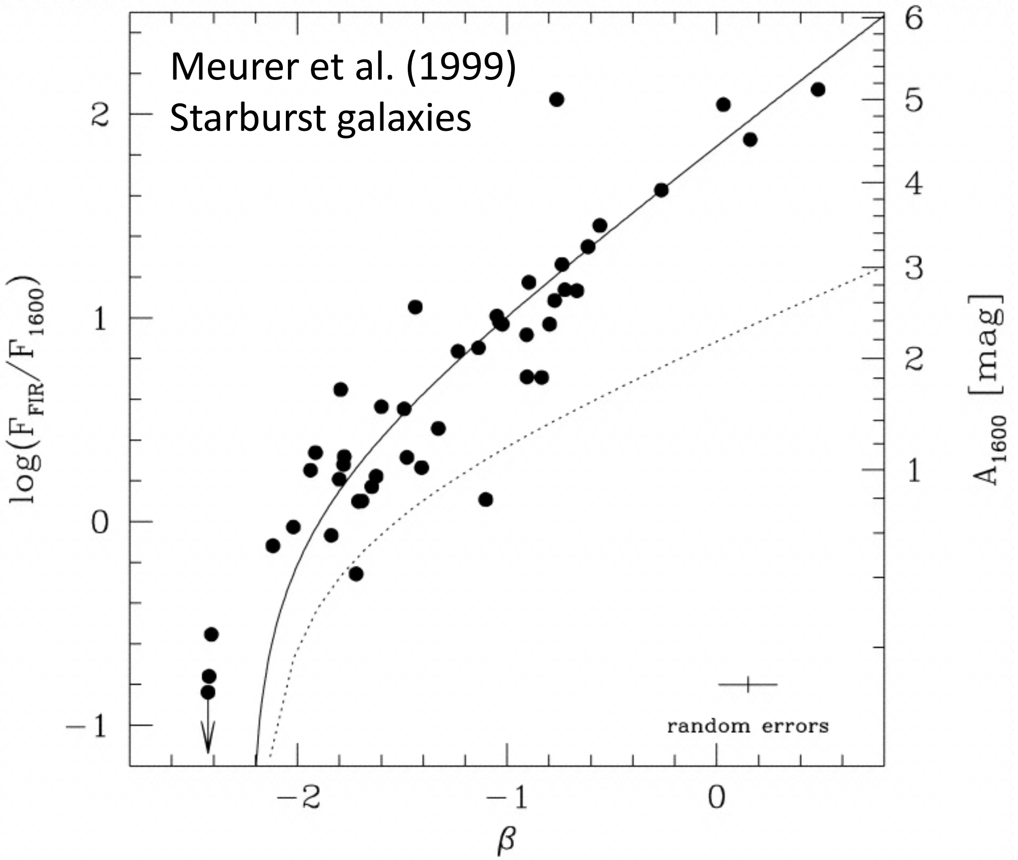
SFRs from CALIFA

<u>SFR(UV)</u>

UV fluxes from GALEX images: FUV @ 1530Å

When only UV flux available (not IR):

FUV-NUV color traces
The UV attenuation?



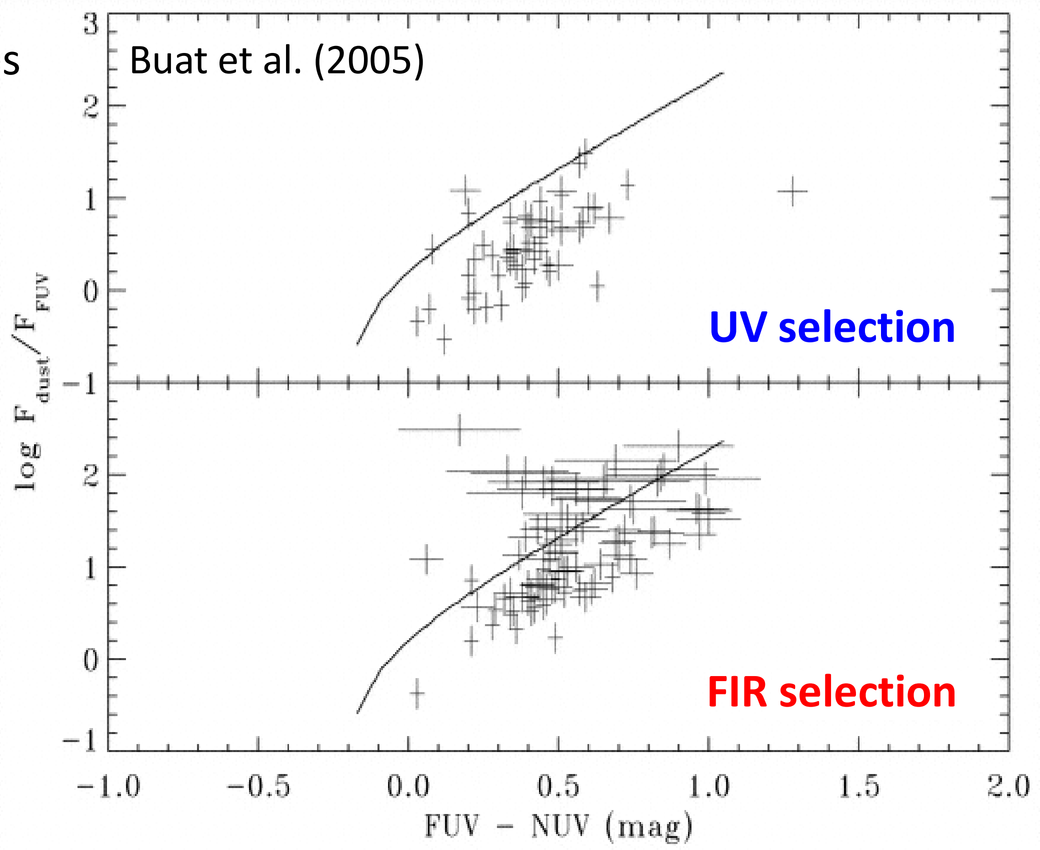
SFRs from CALIFA

<u>SFR(UV)</u>

UV fluxes from GALEX images: FUV @ 1530Å

When only UV flux available (not IR):

FUV-NUV color traces
The UV attenuation?



SFRs from CALIFA

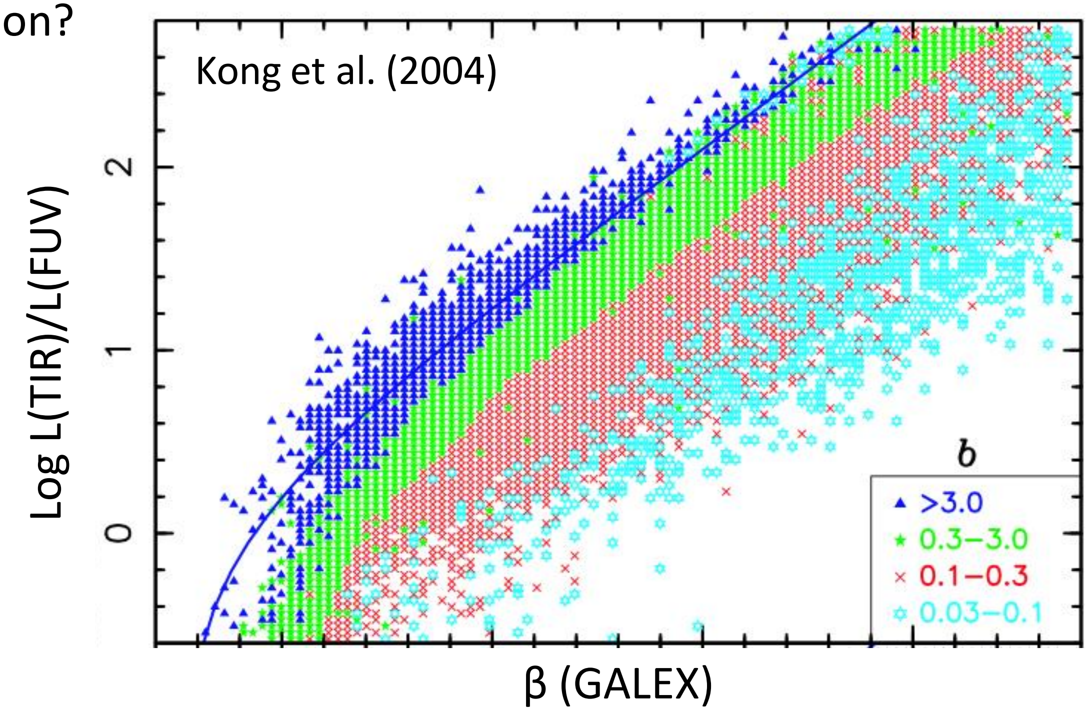
CALIFA Survey

SFR(UV)

UV fluxes from GALEX images: FUV @ 1530Å

When only UV flux available (not IR):

FUV-NUV color traces
The UV attenuation?



SFRs from CALIFA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
CALIFA Survey

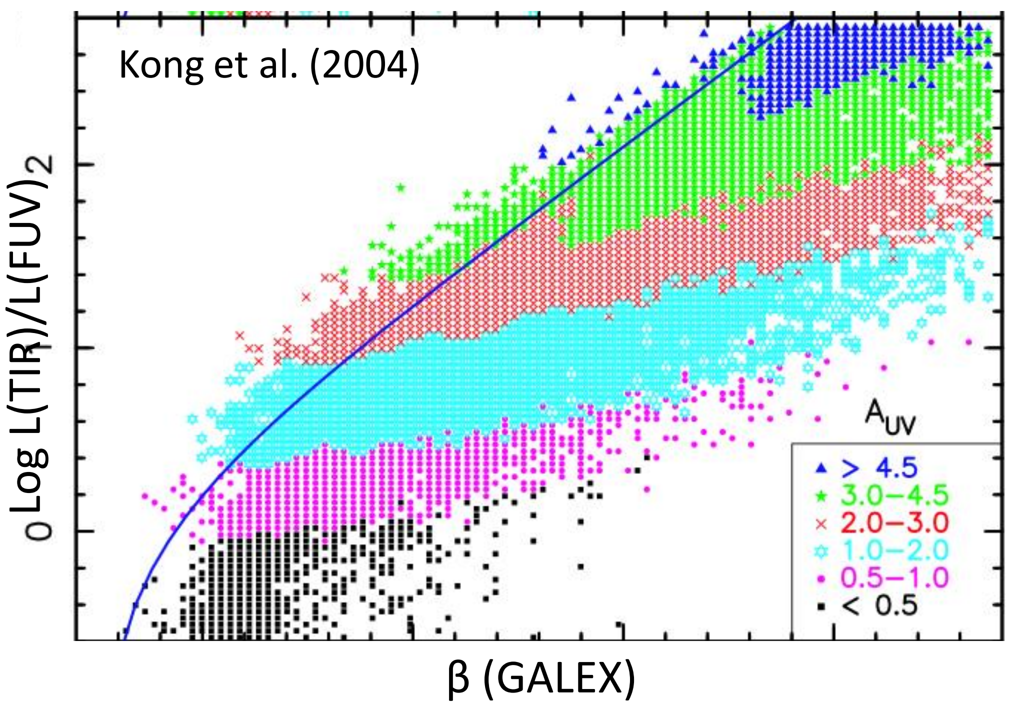
SFR(UV)

UV fluxes from GALEX images: FUV @ 1530Å

When only UV flux available (not IR):

FUV-NUV color traces
The UV attenuation?

UV attenuation from FUV-NUV increases scatter in the SFR derivation.



SFRs from CALIFA

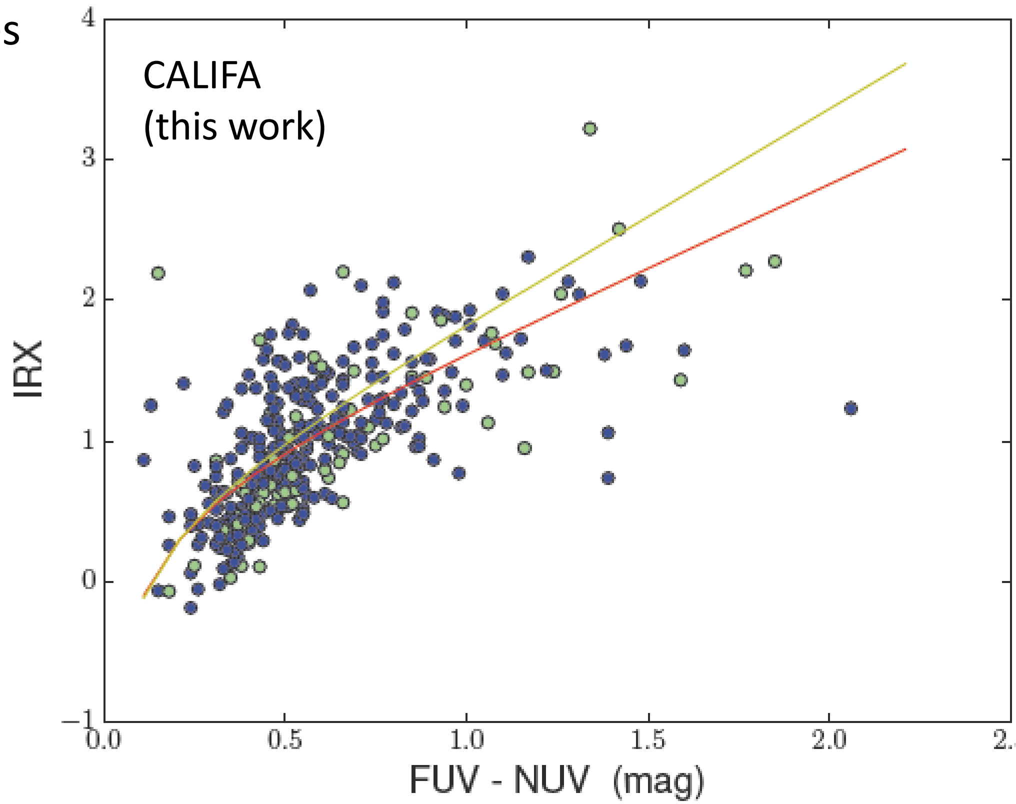
SFR(UV)

UV fluxes from GALEX images: FUV @ 1530Å

When only UV flux available (not IR):

FUV-NUV color traces
The UV attenuation?

UV attenuation from
FUV-NUV increases
scatter in the SFR
derivation.



SFRs from CALIFA

SFR(Hα)

WARNING!

• Many Hα photons absorbed by dust, so an extinction correction is required.

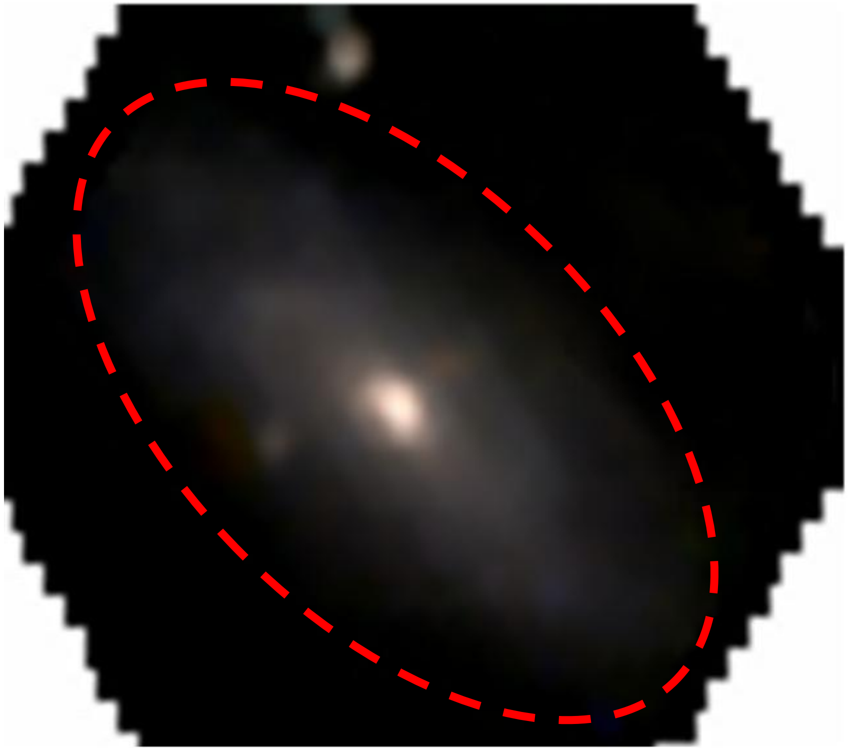
A(Hα) = f(Hα/Hβ)

SFRs from CALIFA

SFR(Hα)

Starting point: CALIFA datacubes (R.A., Dec., λ)

For each galaxy we integrate the spectrum within the elliptical aperture containing all the UV flux.



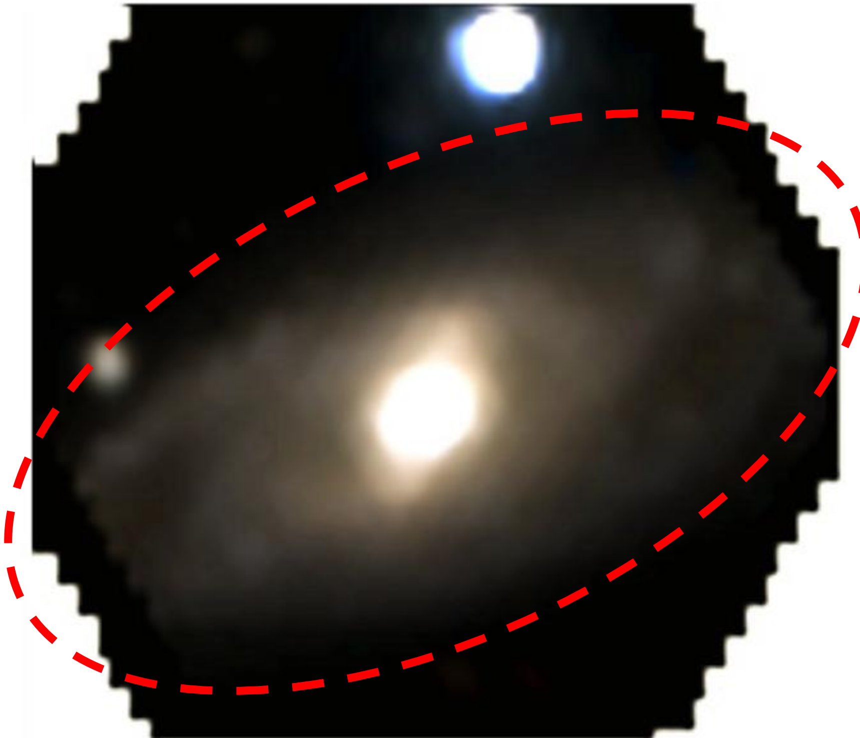
SFRs from CALIFA

<u>SFR(Hα)</u>

Starting point: CALIFA datacubes (R.A., Dec., λ)

For each galaxy we integrate the spectrum within the elliptical aperture containing all the UV flux.

In some cases the galaxy is larger than the CALIFA aperture.



SFRs from CALIFA

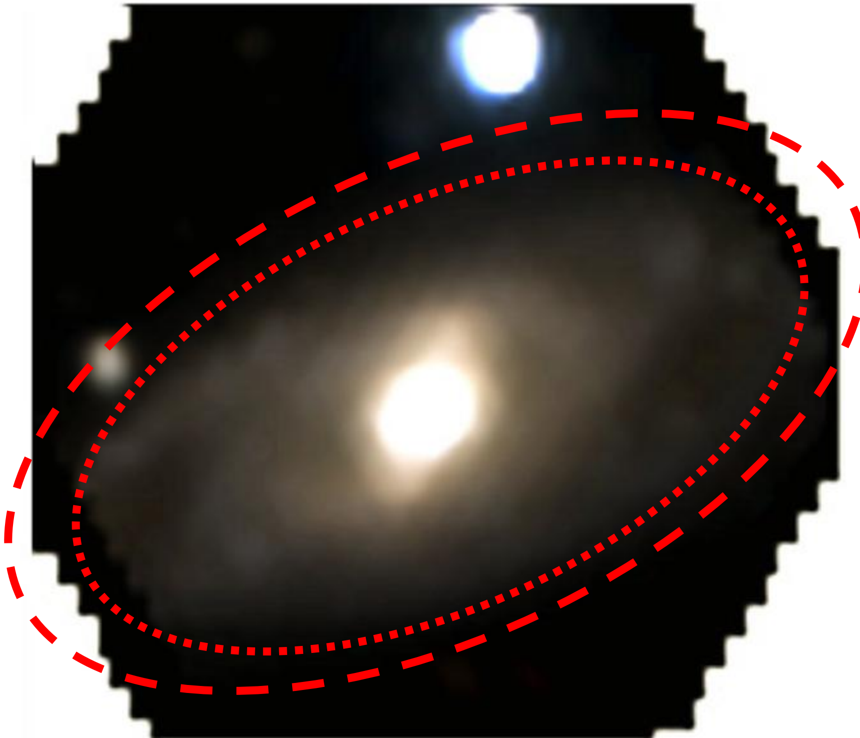
SFR(Hα)

Starting point: CALIFA datacubes (R.A., Dec., λ)

For each galaxy we integrate the spectrum within the elliptical aperture containing all the UV flux.

In some cases the galaxy is larger than the CALIFA aperture.

We reduce the size of our aperture to the maximum contained in the CALIFA field of view and proceed as for the small galaxies.
(GALEX images are 0.5deg radius)



SFRs from CALIFA

<u>SFR(Hα)</u>

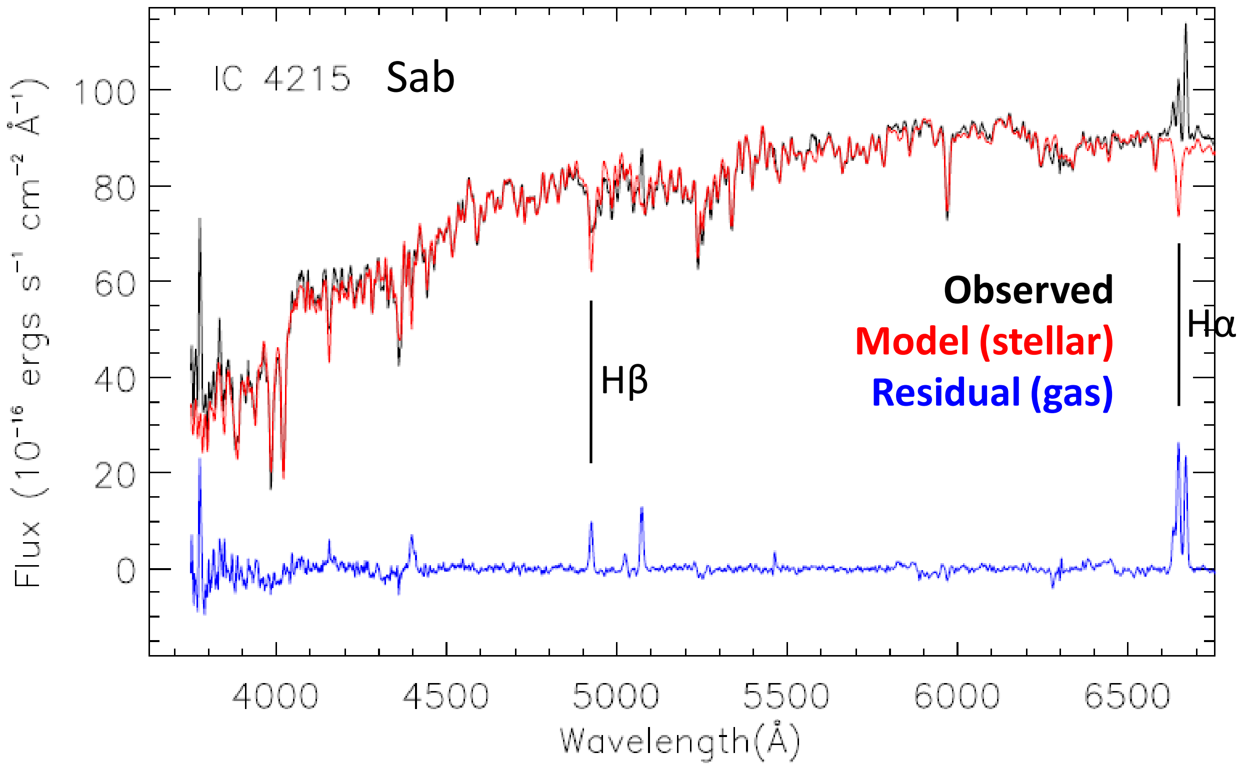
Then we subtract the contribution of the stellar population using evolutionary synthesis models of Vazdekis et al. (2010) based on the MILES stellar library (Sánchez-Blázquez et al. 2006).

Kroupa IMF
Two ages: 0.10-0.79Gyr and 2-14.13Gyr
Metallicities: [Z/H] -> 0.20, 0.00, -0.40, -0.71, -1.31

SFRs from CALIFA

SFR(Hα)

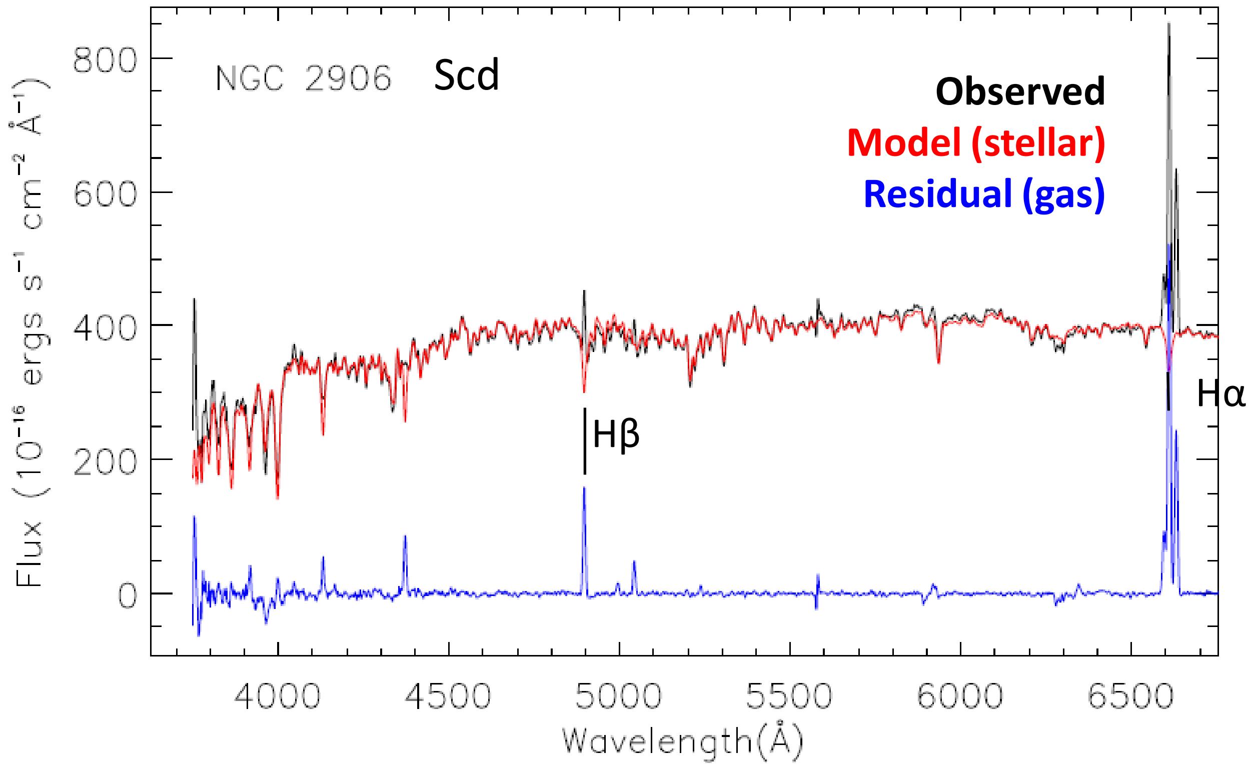
Then we subtract the contribution of the stellar population using evolutionary synthesis models of Vazdekis et al. (2010) based on the MILES stellar library (Sánchez-Blázquez et al. 2006).



SFRs from CALIFA

SFR(Hα)

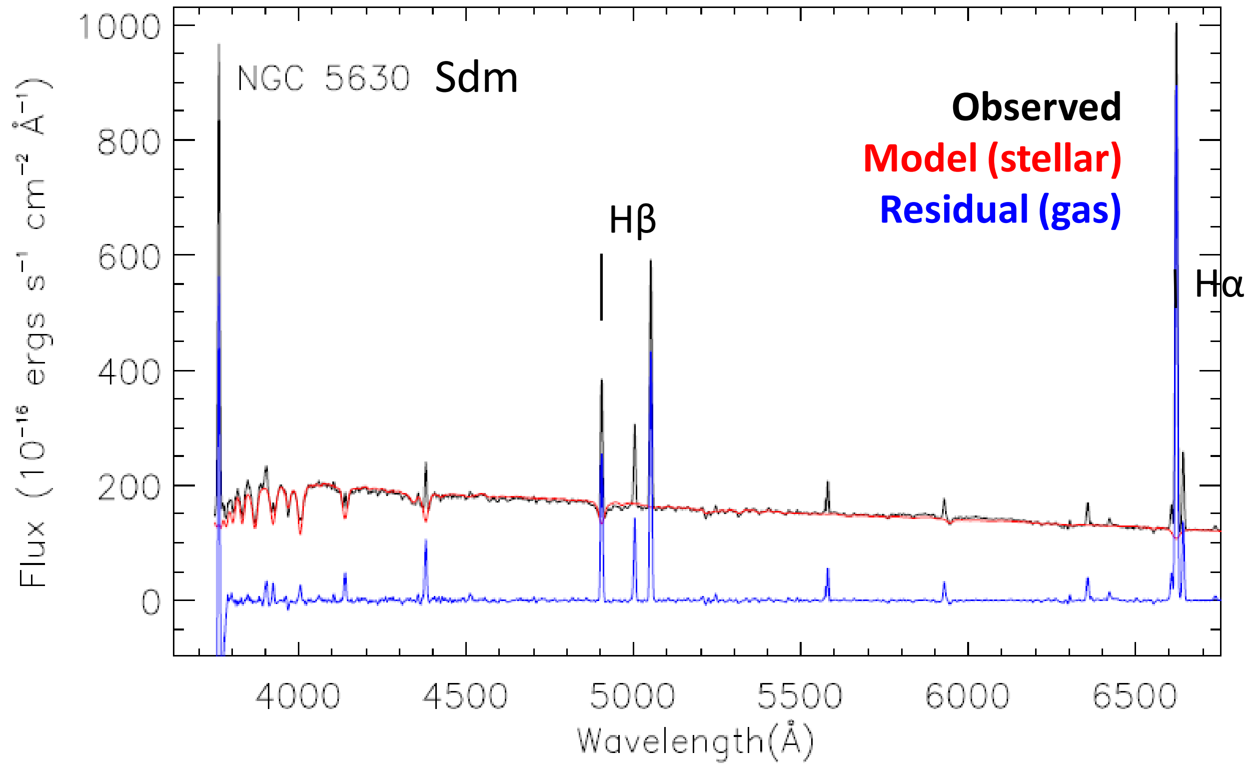
Then we subtract the contribution of the stellar population using evolutionary synthesis models of Vazdekis et al. (2010) based on the MILES stellar library (Sánchez-Blázquez et al. 2006).



SFRs from CALIFA

SFR(Hα)

Then we subtract the contribution of the stellar population using evolutionary synthesis models of Vazdekis et al. (2010) based on the MILES stellar library (Sánchez-Blázquez et al. 2006).



SFRs from CALIFA

SFR(Hα)

For the large galaxies we extrapolate the Hα luminosities assuming that the UV and the observed Hα emissions are equally distributed.

Extinction correction:

Balmer ratio of 2.86 from Case B recombination, T_e=10000K and n_e=100cm^{-3}

$$A_{H\alpha} = \frac{K_{H\alpha}}{-0.4 \times (K_{H\alpha} - K_{H\beta})} \times log_{10} \frac{F_{H\alpha}/F_{H\beta}}{2.86}$$

Where $K_{H\alpha}$ y $K_{H\beta}$ are from the Galactic extinction curve of Cardelli et al. (1989).

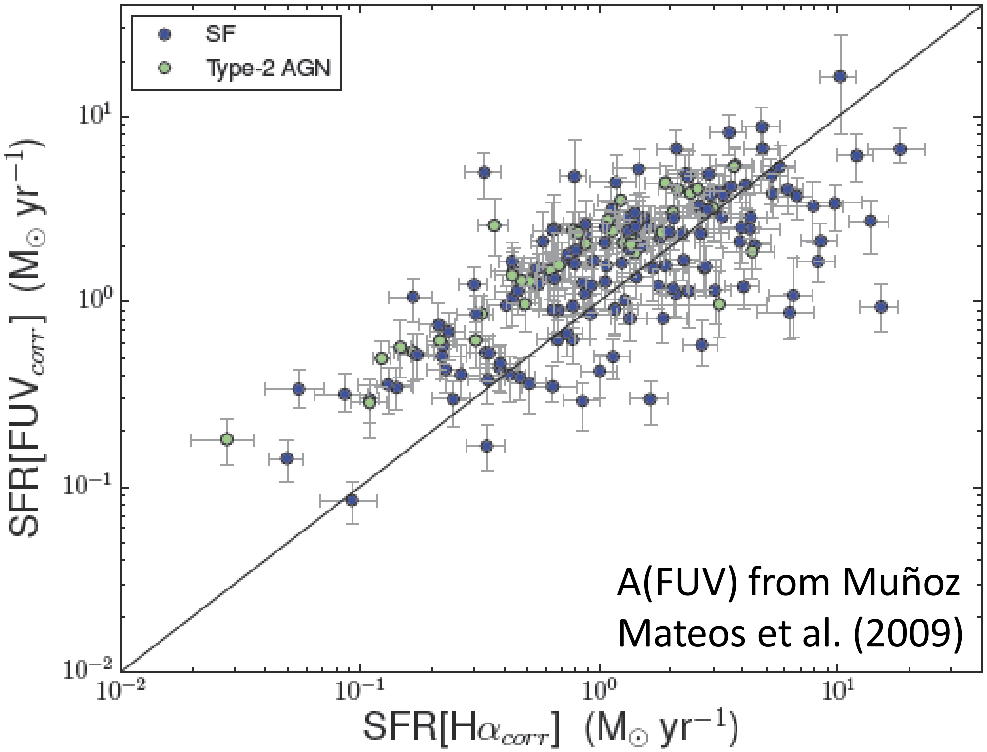
The final products are integrated Hα luminosities free from stellar absorption features and dust extinction.

SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

If only UV luminosity available: UV color is not a good tracer of A(FUV)…



INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

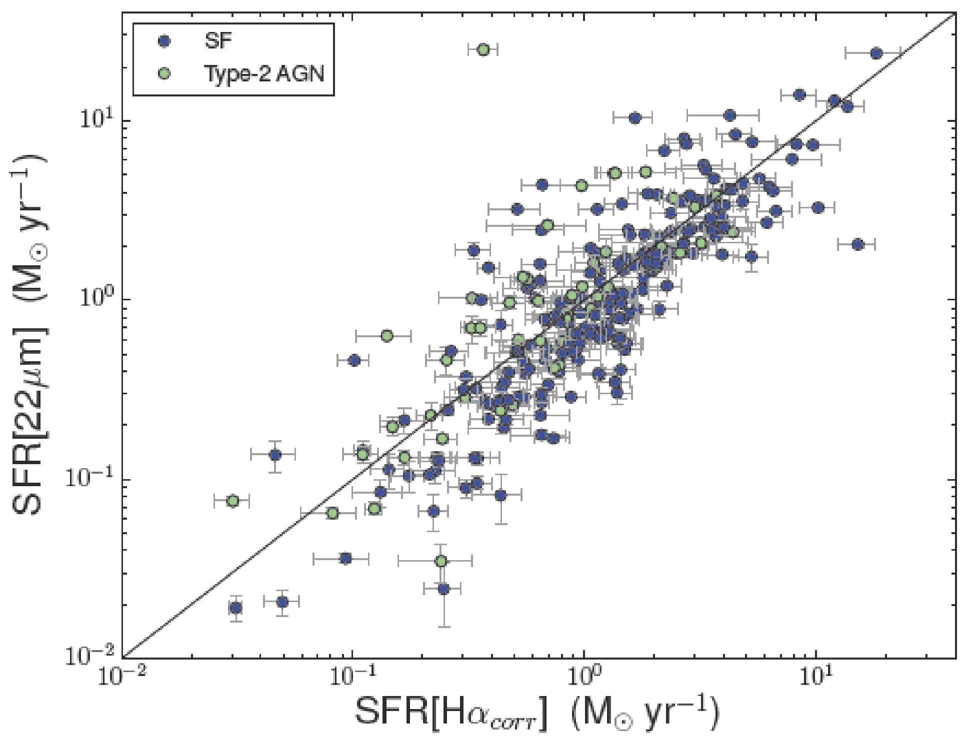
CALIFA Survey

SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

If only IR luminosity available: The Rieke et al. (2009) calibration for L(24μm) underestimates the SFR and is very dispersed.

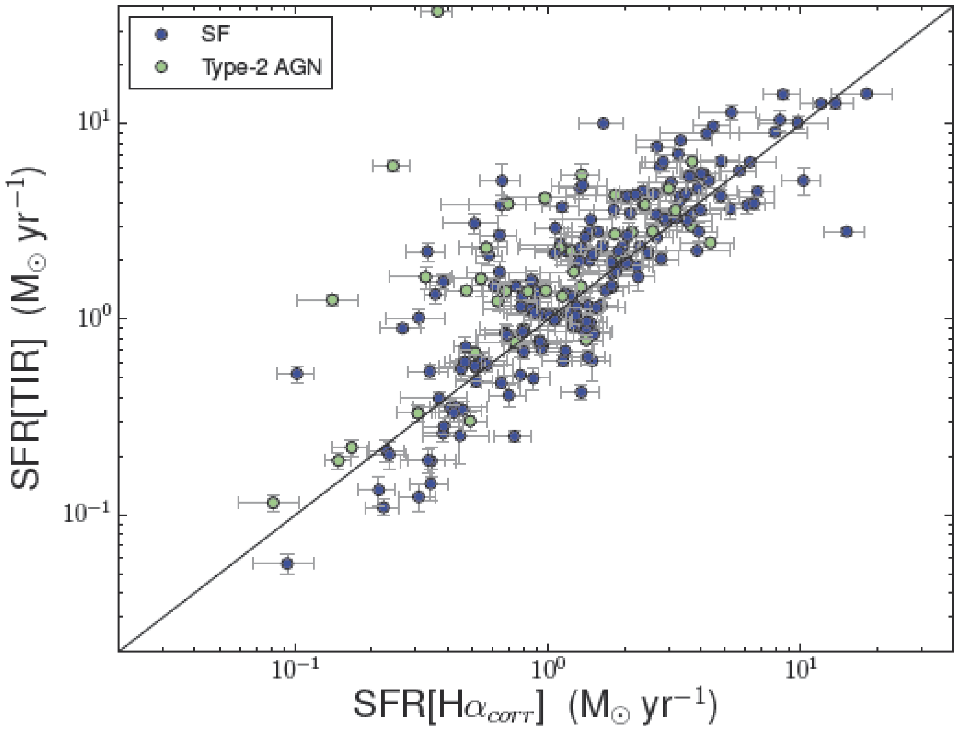


SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

If only IR luminosity available: L(TIR) calibration is very dispersed and underestimates the SFR for low luminosities.

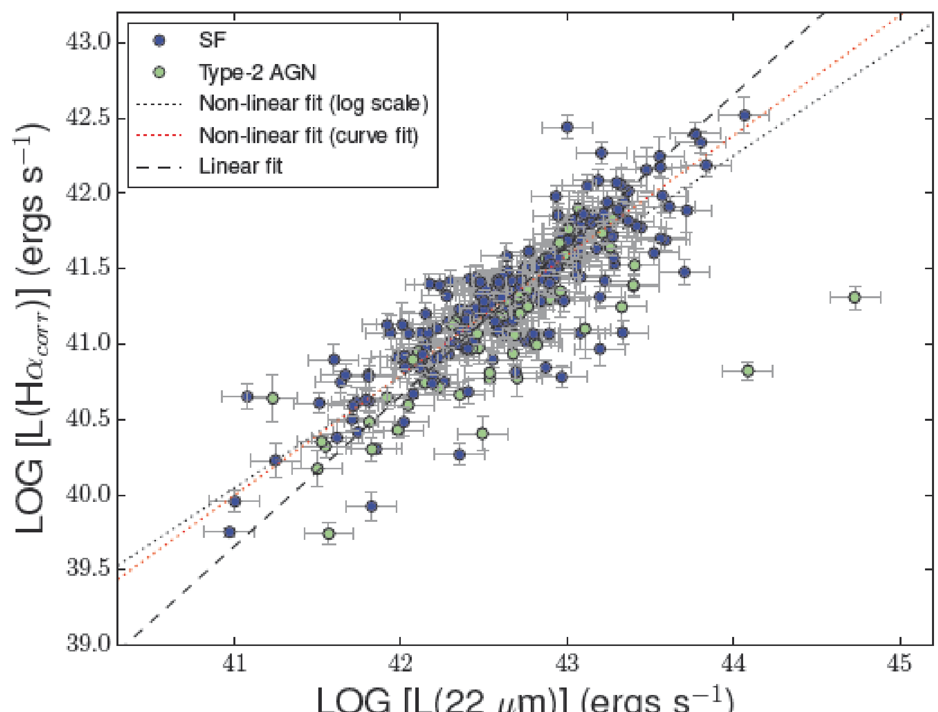


SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

If only IR luminosity available: new calibration of the L(22μm) and L(TIR) with L(Hα).

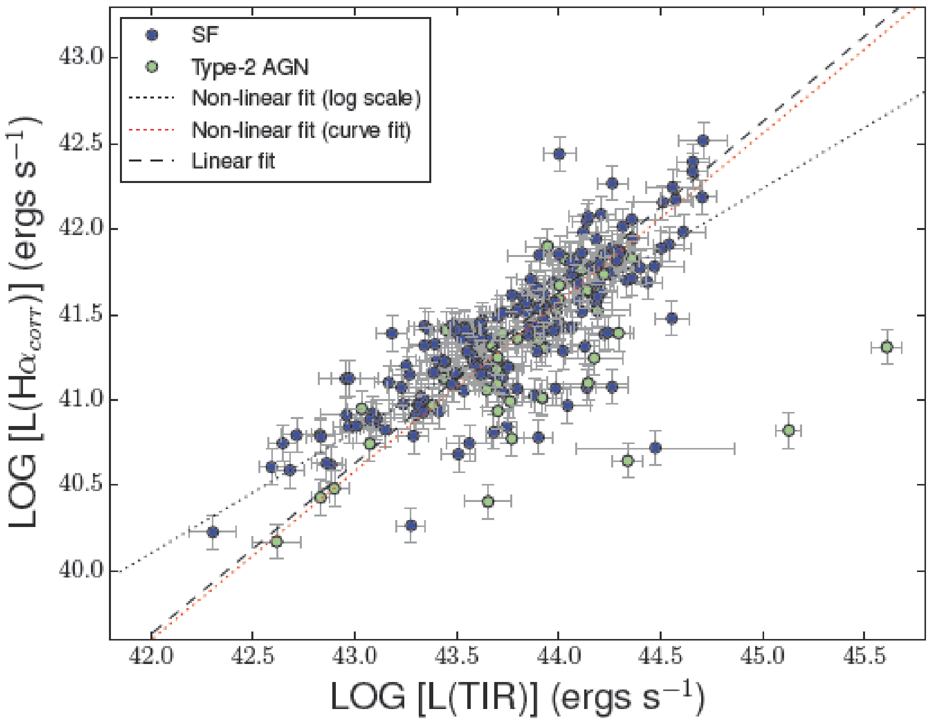


SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

If only IR luminosity available: new calibration of the L(22μm) and L(TIR) with L(Hα).



SFRs from CALIFA

Comparing Hα, UV and IR luminosities:

We assume that the (extinction corrected) Hα luminosity takes into account all the SFR, so…

Solution: combining the bright side of the star formation (Hα, UV) with the dark side of star formation (IR).

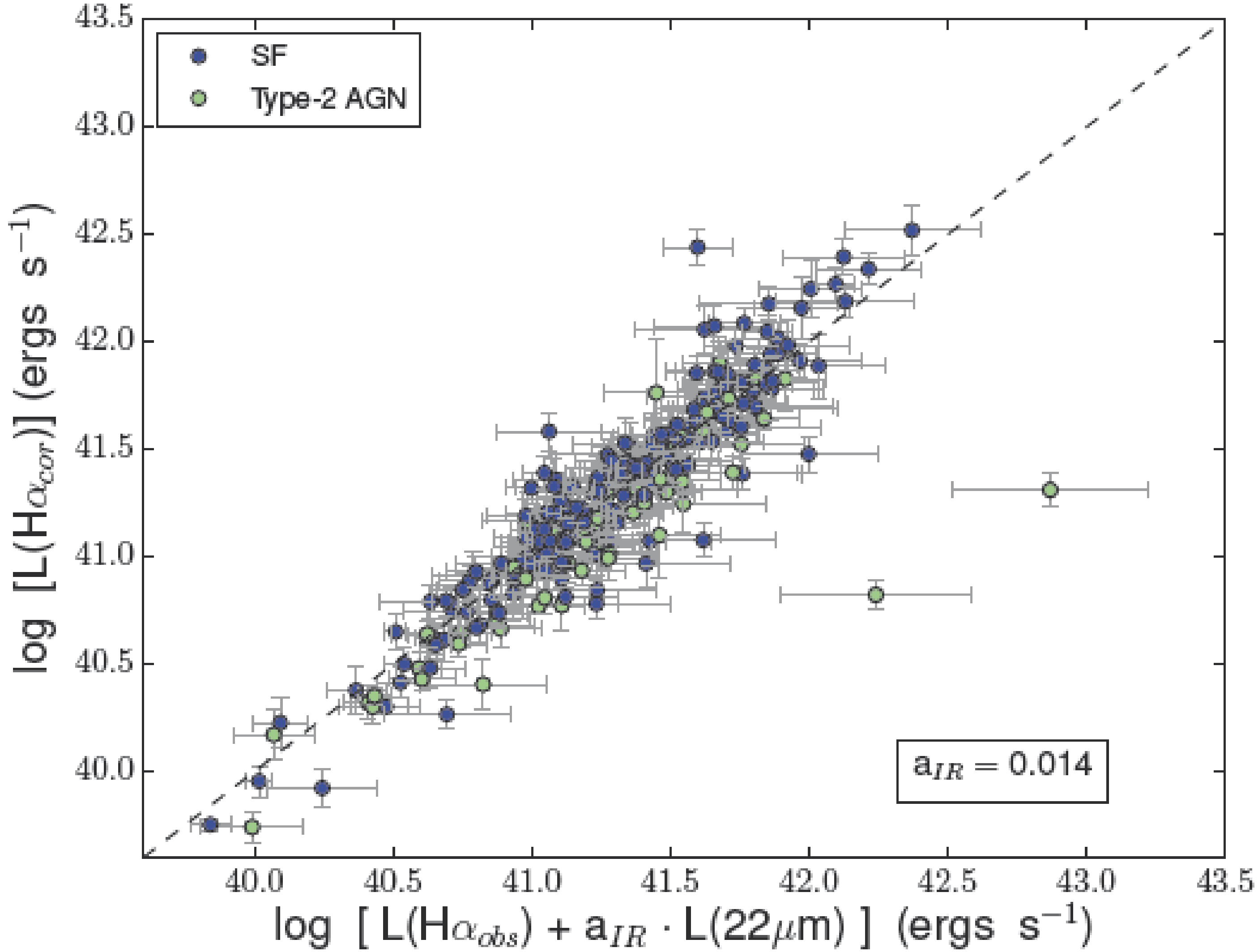
Hybrid calibrations (e.g. Kennicutt et al. 2009; Hao et al. 2011):

$$L(H\alpha)_{corr} = L(H\alpha)_{obs} + a(TIR)*L(TIR)$$

$$L(H\alpha)_{corr} = K * [L(FUV)_{obs} + a(TIR)*L(TIR)]$$

SFRs from CALIFA

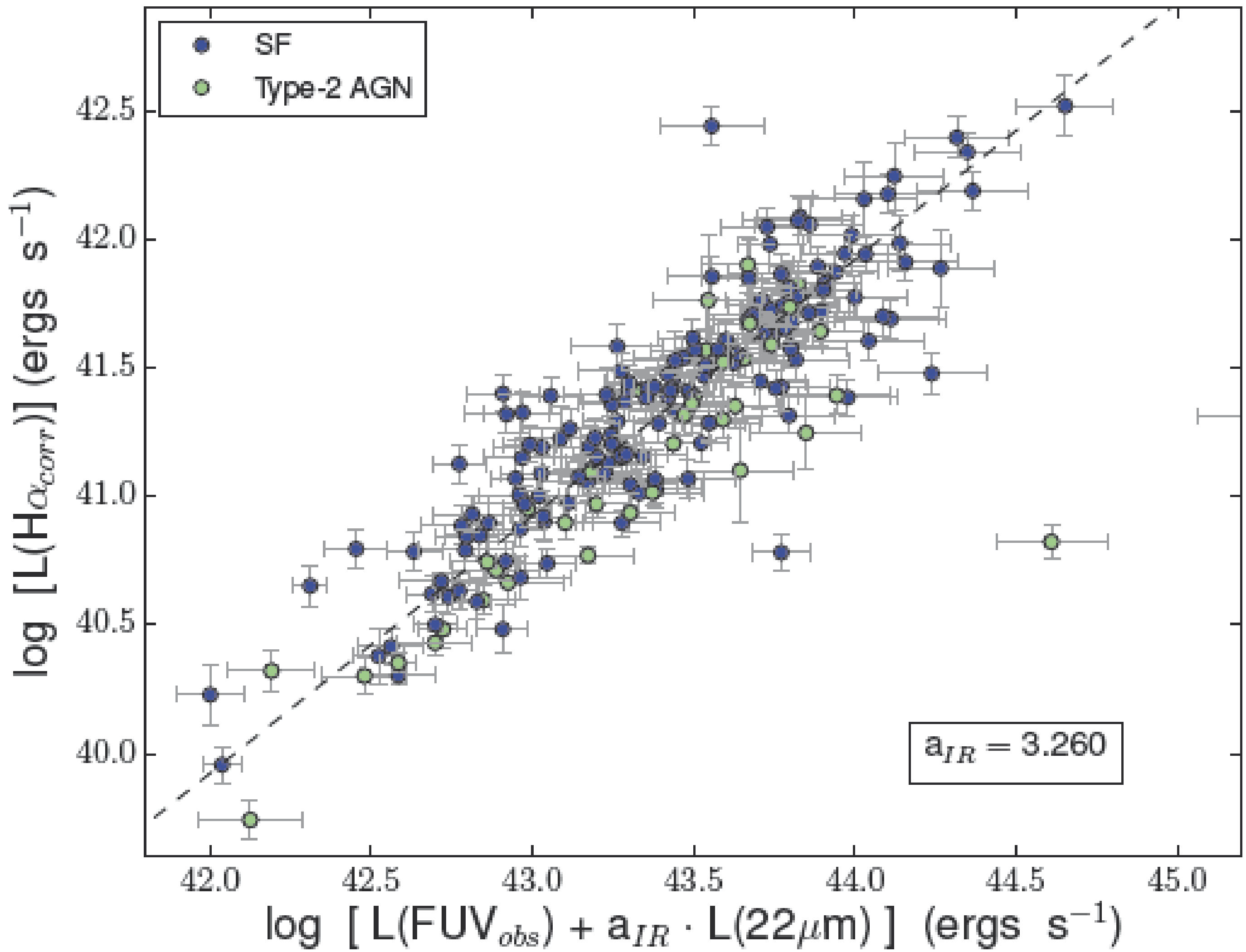
Results:



SFRs from CALIFA

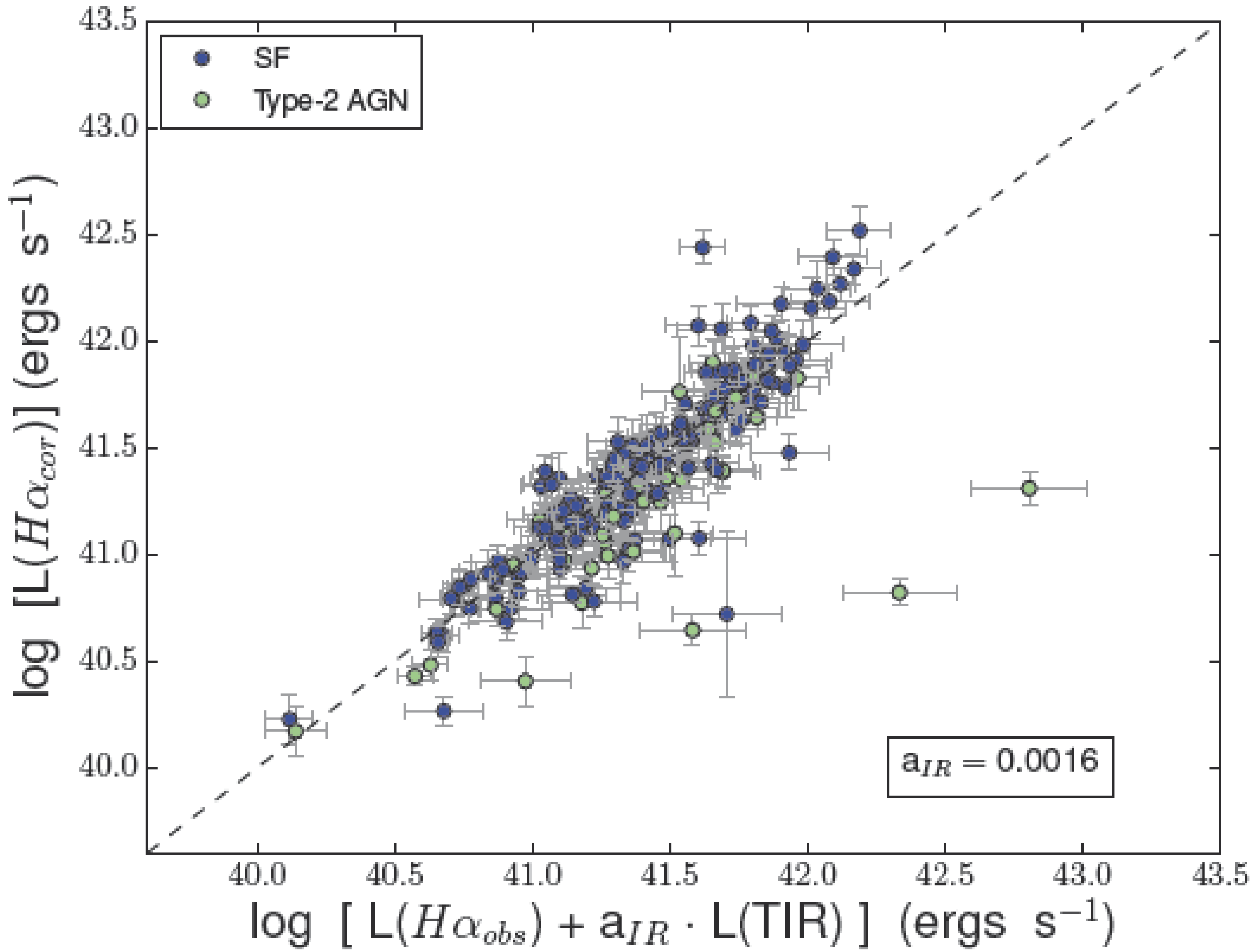
CALIFA Survey

Results:



SFRs from CALIFA

Results:



INSTITUTO de ASTROFISICA de ANDALUCIA

CSIC

I·A·A

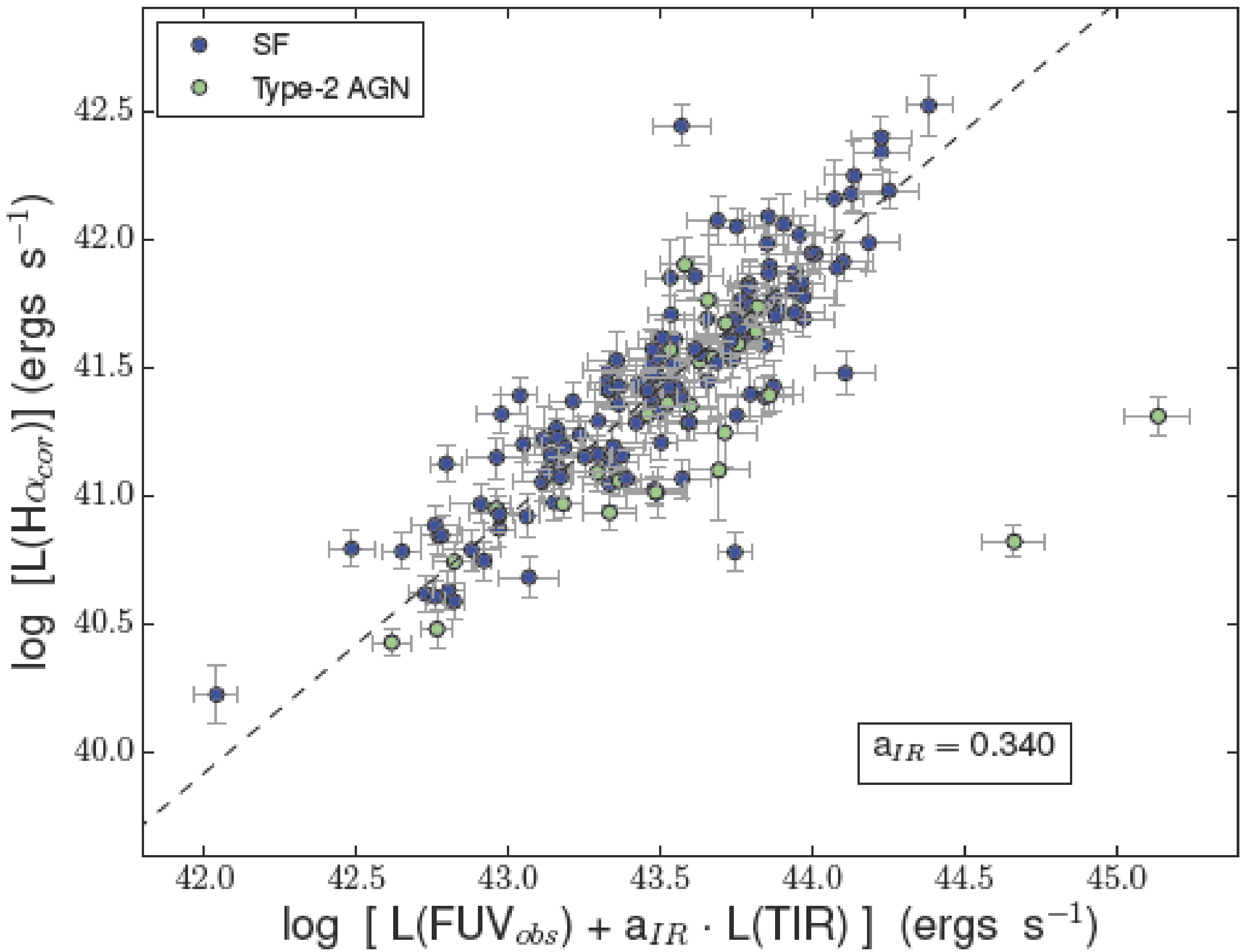
CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CALIFA Survey

SFRs from CALIFA

Results:



SFRs from CALIFA

Results:

	S0/a-Sab	Sb-Sbc	Sc-Irr
a(TIR) $L(H\alpha)_{corr}=L(H\alpha)+a(TIR)*L(TIR)$	0.0009	0.0016	0.0018
a(TIR) $L(H\alpha)_{corr}=L(FUV)+a(TIR)*L(TIR)$	0.30	0.34	0.36

INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CALIFA Survey

SFRs from CALIFA

Results:

	S0/a-Sab	**Sb-Sbc**	**Sc-Irr**
a(TIR) $L(H\alpha)_{corr}=L(H\alpha)+a(TIR)*L(TIR)$	0.0009	0.0016	0.0018
a(TIR) $L(H\alpha)_{corr}=L(FUV)+a(TIR)*L(TIR)$	0.30	0.34	0.36

	logM*> 10.5	**10<logM*< 10.5**	**logM*< 10**
a(TIR) $L(H\alpha)_{corr}=L(H\alpha)+a(TIR)*L(TIR)$	0.0010	0.0017	0.0024
a(TIR) $L(H\alpha)_{corr}=L(FUV)+a(TIR)*L(TIR)$	0.25	0.38	0.46

SFRs from CALIFA

More to be done…

• New estimates of L(TIR) using Herschel data (beyond 200µm): contribution of cold dust to SFR.

• Spatially resolved SFR: inside vs. outside star formation, radial trends.

• Starburst vs. Normal star formation activity in CALIFA galaxies.

• SFR vs. Environment (global/local).

• SFR vs. Gas (atomic + molecular).

…

INSTITUTO de ASTROFISICA de ANDALUCIA

CSIC

I·A·A

CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

CALIFA Survey