Star formation rates in the local universe from CALIFA integral field spectroscopy

CALIFA Survey

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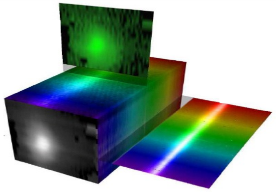
Gas, Dust and Star-Formation in Galaxies from the Local to Far Universe

May 27th, 2015

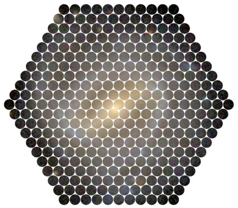
Relevance of the IFS data in the study of the SFR in nearby galaxies

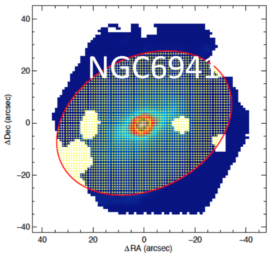


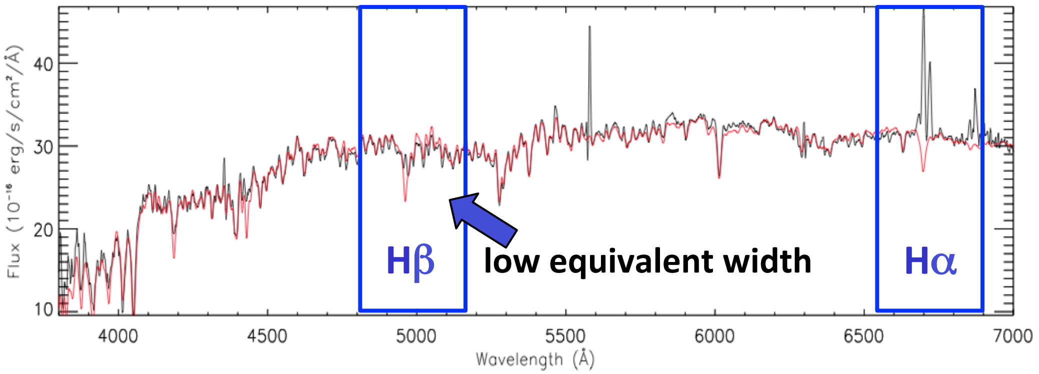
✧ **IFS data** combine advantages of **imaging** & **spectroscopy**:

- Separate Hα & [NII] flux contributions without assuming a relation (vs. narrow band imaging)
- Cover the whole galaxy avoiding problems associated with long-slit spectroscopy

✧ **IFS data** allows to properly determine **Hα** & **Hβ fluxes** → important for galaxies with **low EW in emission**, especially in Hβ (many objects in the Local Universe)







✧ **Integrated** measurements (particularly interesting use of IFS): whole galaxy + high S/N integrated spectra

✧ For the previous reasons, we use the Balmer Decrement attenuation-corrected Hα luminosity as the SFR tracer reference in our sample.

Multi-wavelength study of the SFR

GALEX
Galaxy Evolution Explorer

CALIFA Survey

WISE

IRAS
Infrared Astronomical Satellite

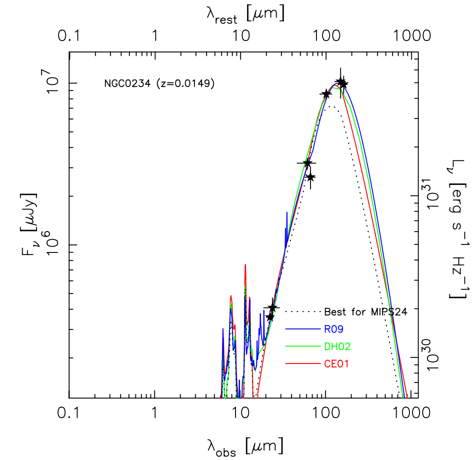
AKARI
ISAS/JAXA

GALEX → FUV: Aperture photometry

CALIFA → Hα & Hβ: Optical IFS

WISE → 22 μm : Aperture photometry

TIR: **WISE** 22 μm +
IRAS 12, 25, 60 and 100 μm +
AKARI 140 and 160 μm
SED fitting



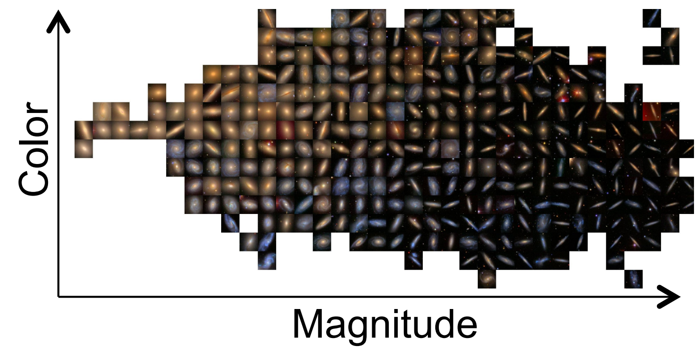
CALIFA IFS Survey

- ~ 550 galaxies observed until now (380 in this work)
- Limits: volume (0.005<z<0.03) & size (45”<D25<80”)
- Wavelength coverage:

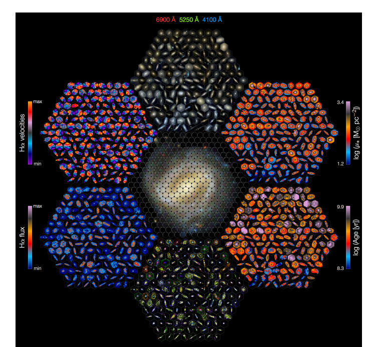
  V1200 setup (3650-4840 ÅÅ) , R~1650

  V500 setup (3745-7500ÅÅ), R~850 **Hβ & Hα**

The galaxies span the CMD

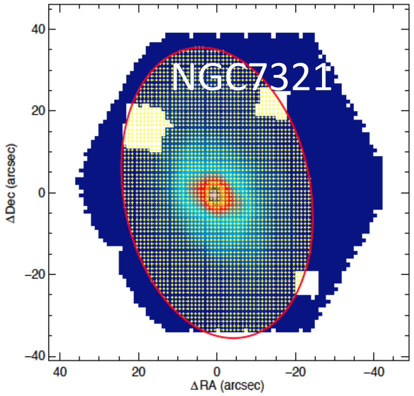


- Instrument: PPAK IFU/PMAS (Roth et al. 2005) @ CAHA 3.5m
- DR2 (200 galaxies in each setup) - October 2014 (García-Benito et al. 2015)



Optical spectroscopy

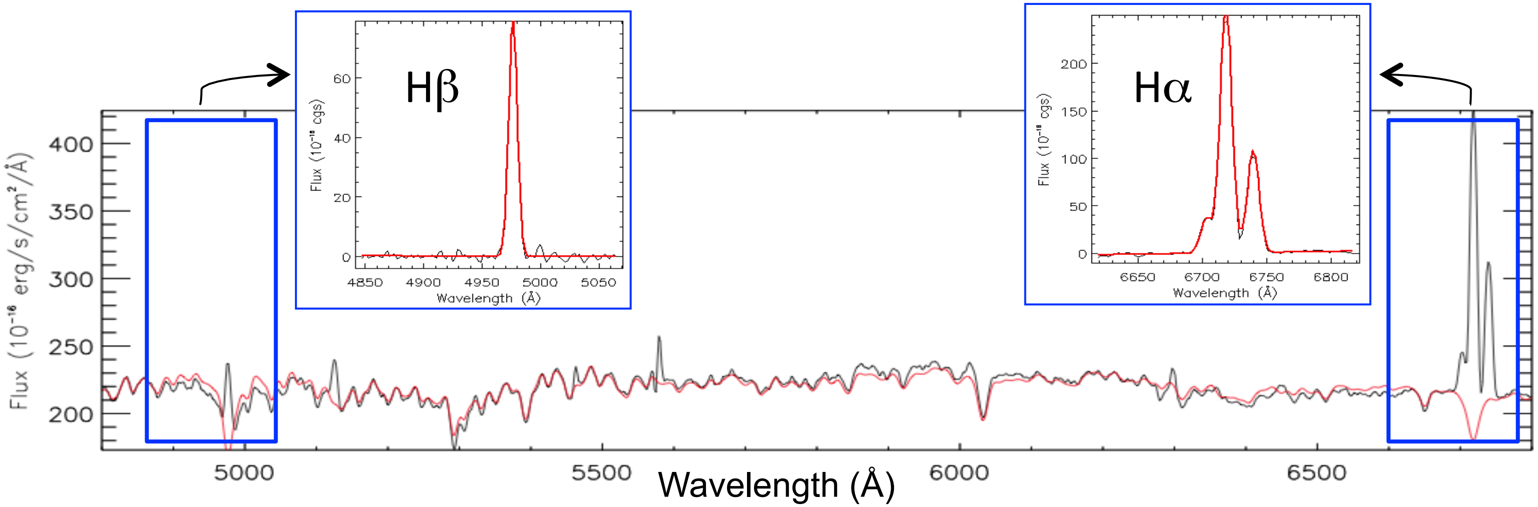
(1) Aperture extraction



(2) Stellar continuum subtraction

Multiple SSP models (Vazdekis et al. 2010)
+
MILES stellar library (Sánchez-Blázquez et al. 2006)
+
Kroupa IMF (Kroupa 2001)

(3) Hβ & Hα emission line fluxes



AIM: to provide **updated calibrations for SFR** in external galaxies

Based on a simply **ENERGY BALANCE approach**
(e.g., Kennicutt et al. (2009), Hao et al. (2011))

⇩

linear combinations of Hα emission-line (or FUV continuum) observed + IR (22μm or TIR)

⇩

attenuation-corrected SFRs

The attenuated luminosity in Hα or UV is re-radiated in the IR with a ***SCALE FACTOR*** (calibrated **empirically**)

Anchoring the data to a **reference SFR tracer**: **extinction-corrected Hα**
(obtained for the 1st time from IFS data)

$$\underbrace{SFR = 5.5\times10^{-42}\times L(H\alpha_{corr})}_{\text{extinction-corrected H}\alpha} = \underbrace{5.5\times10^{-42}\times[L(H\alpha_{obs})+a_{IR}\times L(IR)]}_{\text{hybrid SFR tracer (H}\alpha_{obs}\text{ + IR)}} \Rightarrow a_{IR} = \frac{L(H\alpha_{corr})-L(H\alpha_{obs})}{L(IR)}$$

SCALE FACTOR

$$\underbrace{SFR = 5.5\times10^{-42}\times L(H\alpha_{corr})}_{\text{extinction-corrected H}\alpha} = \underbrace{4.6\times10^{-44}\times[L(FUV_{obs})+a_{IR}\times L(IR)]}_{\text{hybrid SFR tracer (FUV}_{obs}\text{ + IR)}} \Rightarrow a_{IR} = \frac{cte_{H\alpha,FUV}\times L(H\alpha_{corr})-L(FUV_{obs})}{L(IR)}$$

Attenuation correction

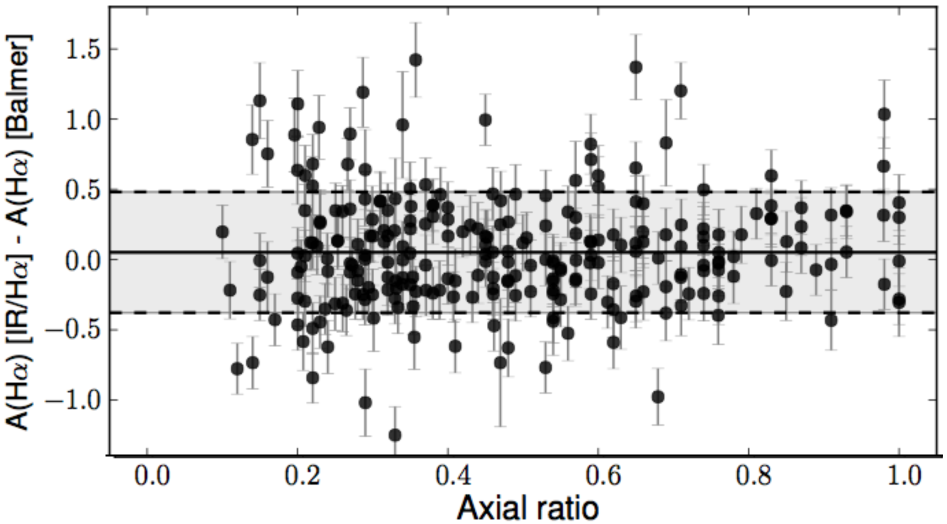
✧ As we use attenuation-corrected Hα as the SFR reference in our sample, we will first verify that our attenuation correction yields proper results.

- In present-day disk galaxies the typical dust attenuations varies from zero to several magnitudes. This work A(Hα) = 0.0 to 2.6 mag
- Reference attenuation corrections based on **Balmer Decrements** with a **Galactic extinction curve** (MW law, R_v=3.1) and a **foreground dust screen geometry**.

$$A(H\alpha)_{IR/H\alpha} = 2.5 \times \log_{10}\left(1 + a_{IR} \times \frac{L(IR)}{L(H\alpha_{obs})}\right)$$

$$A(H\alpha)_{Balmer} = \frac{K_{H\alpha}}{-0.4 \times (K_{H\alpha} - K_{H\beta})} \times \log_{10}\left(\frac{F_{H\alpha}/F_{H\beta}}{2.86}\right)$$

$A(H\alpha)_{IR/H\alpha} - A(H\alpha)_{Balmer} = 0.05 \pm 0.43$ mag



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L(22μm)

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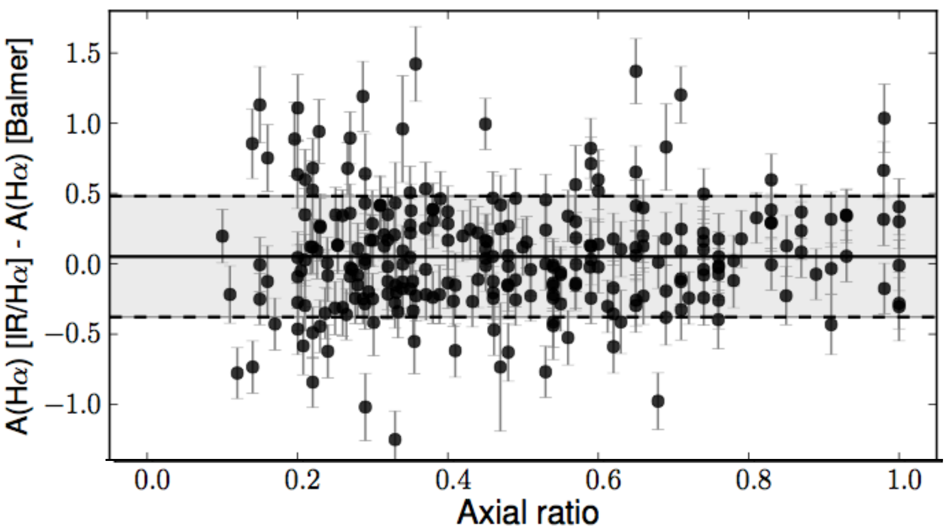
$A(H\alpha)_{IR/H\alpha} - A(H\alpha)_{Balmer}$ = 0.05 ± 0.43 mag



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$a_{IR} = 0.015$ L(22μm)

$$A(H\alpha)_{IR/H\alpha} = 2.5 \times \log_{10}\left(1 + a_{IR} \times \frac{L(IR)}{L(H\alpha_{obs})}\right)$$

$$A(H\alpha)_{Balmer} = \frac{K_{H\alpha}}{-0.4 \times (K_{H\alpha} - K_{H\beta})} \times \log_{10}\left(\frac{F_{H\alpha}/F_{H\beta}}{2.86}\right)$$

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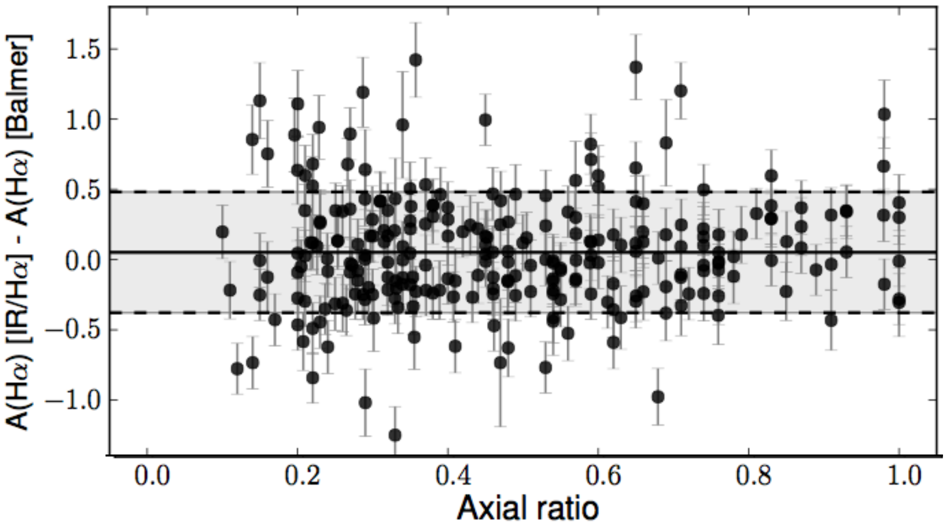
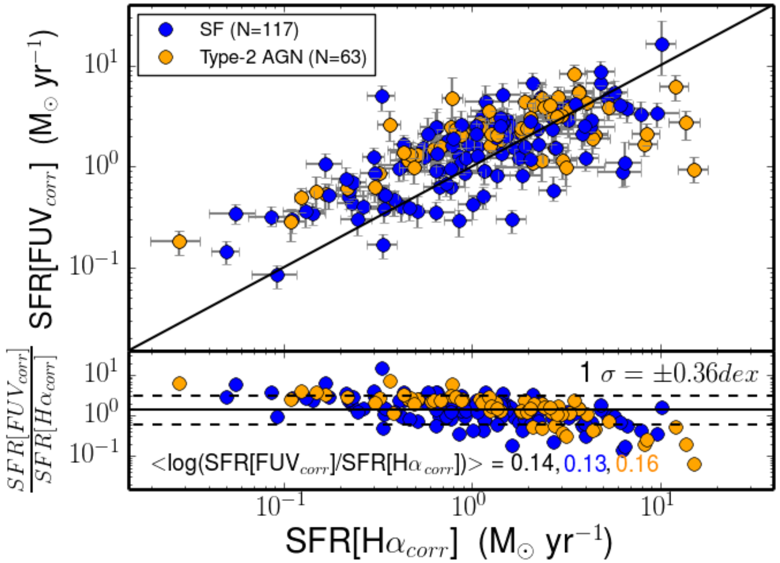
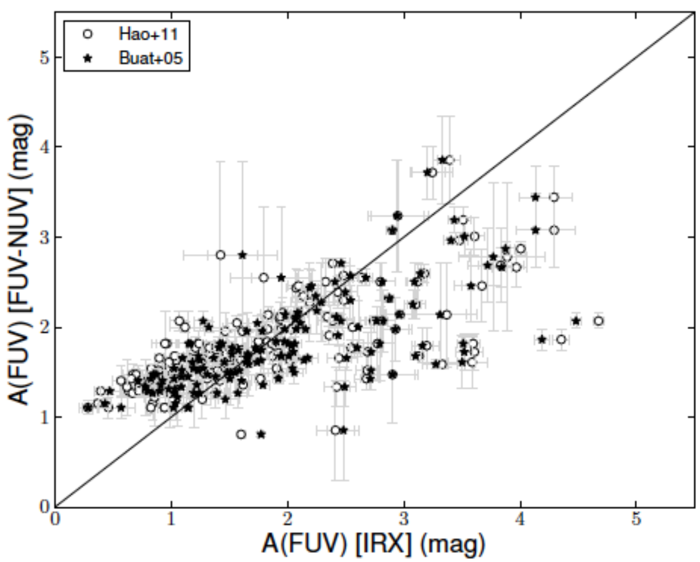


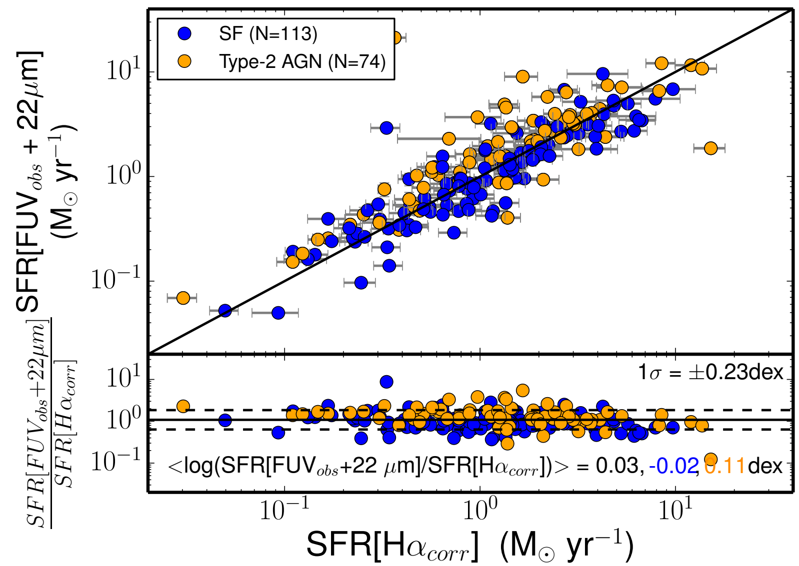
Discrepancies among SFR tracers

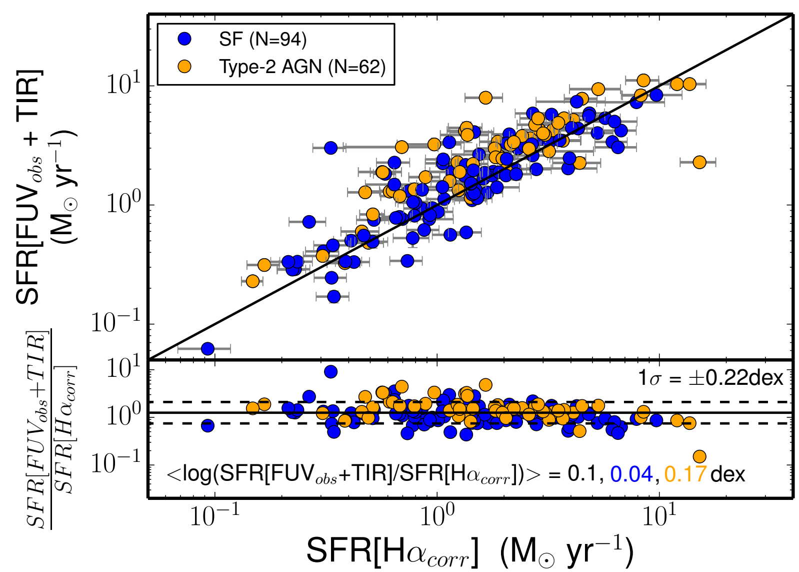
Single-band (e.g. β-corrected FUV)





Hybrids tracers (e.g. FUV observed + IR)





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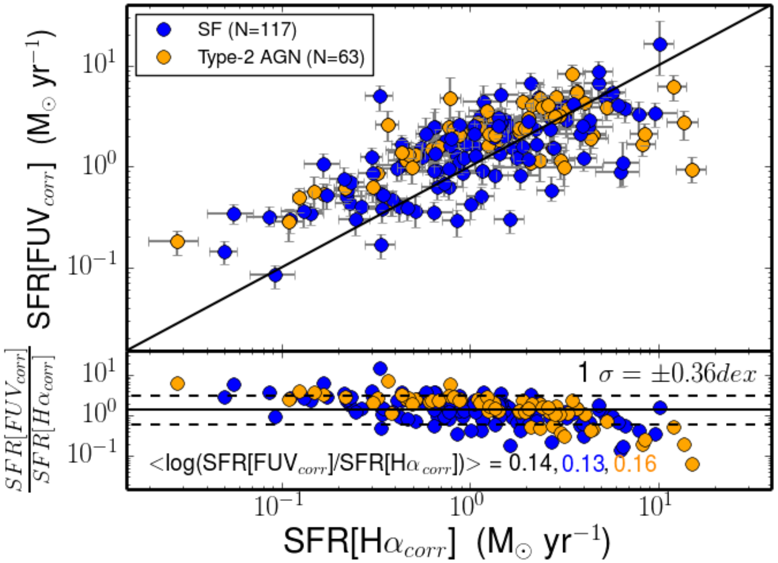
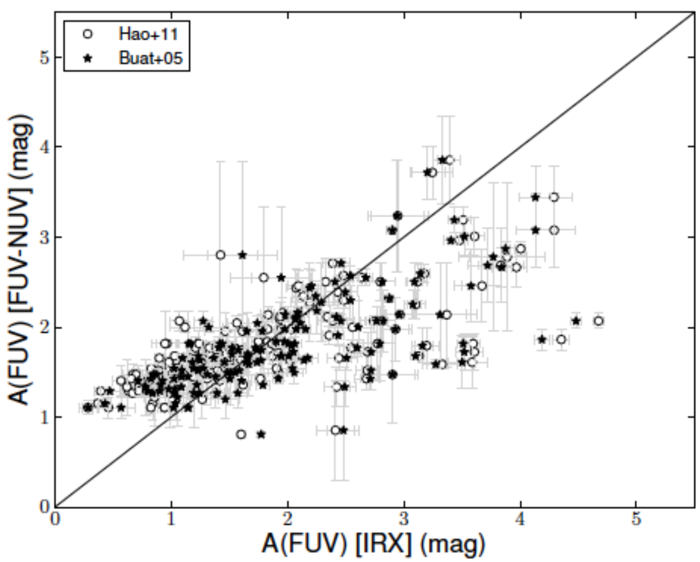
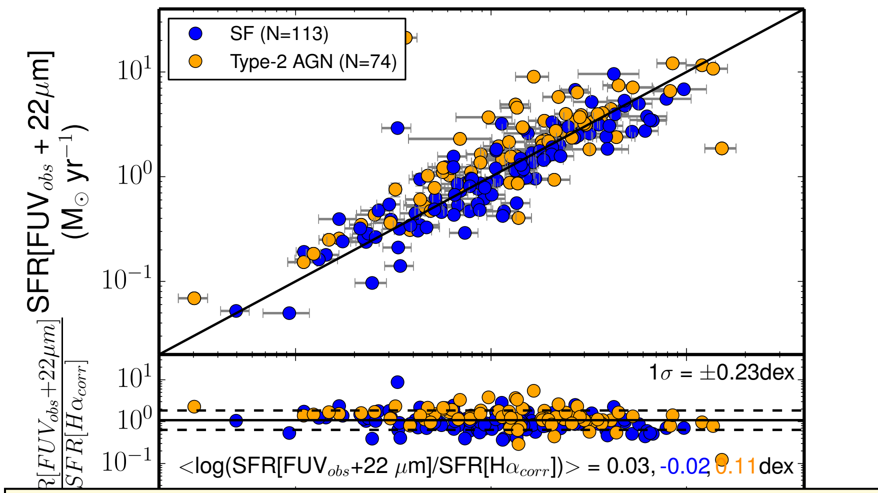
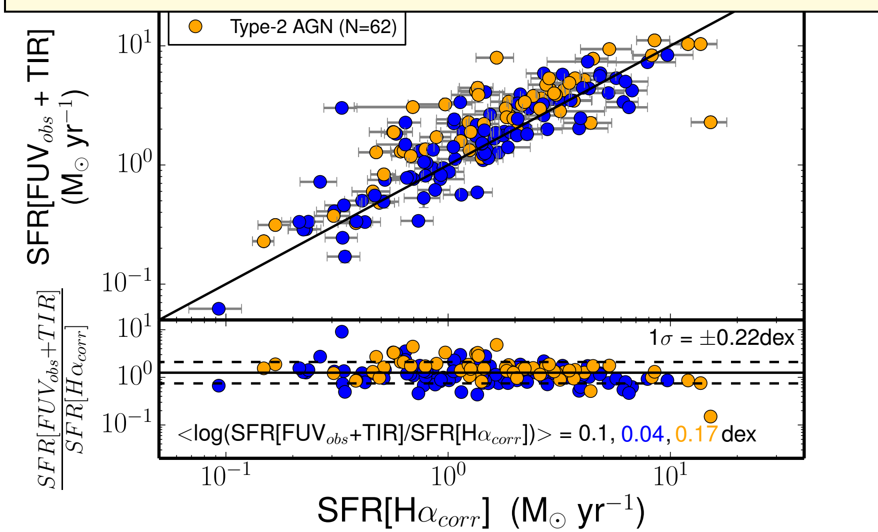




Hybrids tracers (e.g. FUV observed + IR)

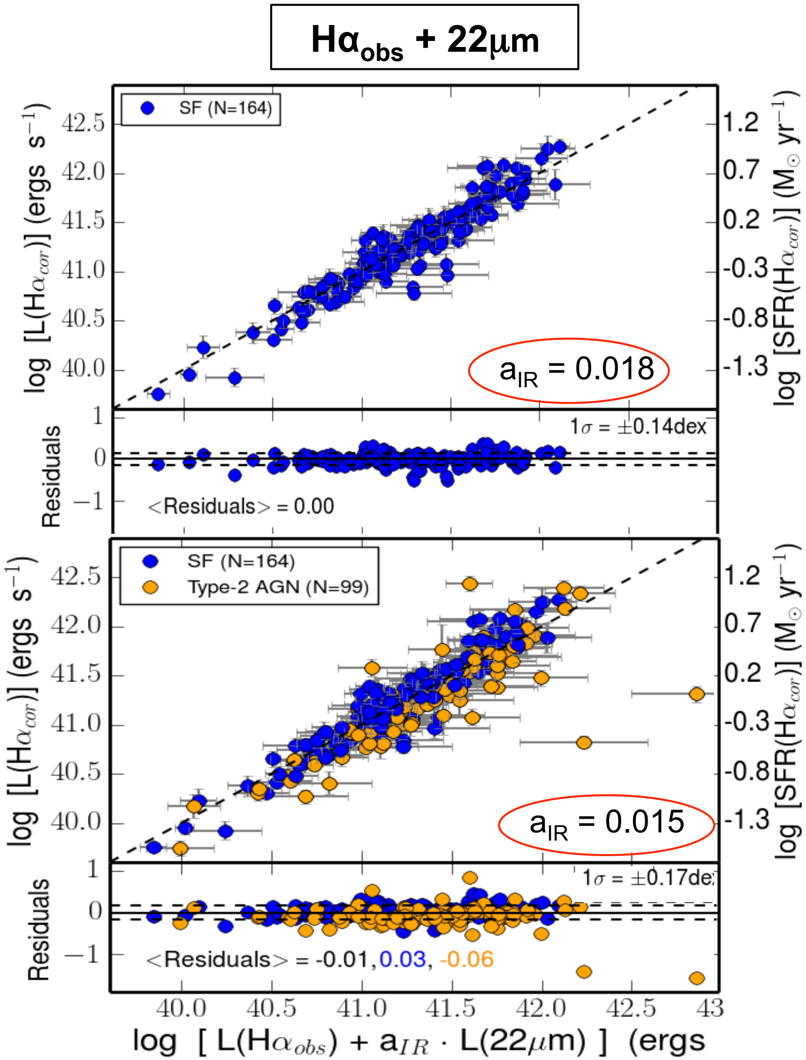


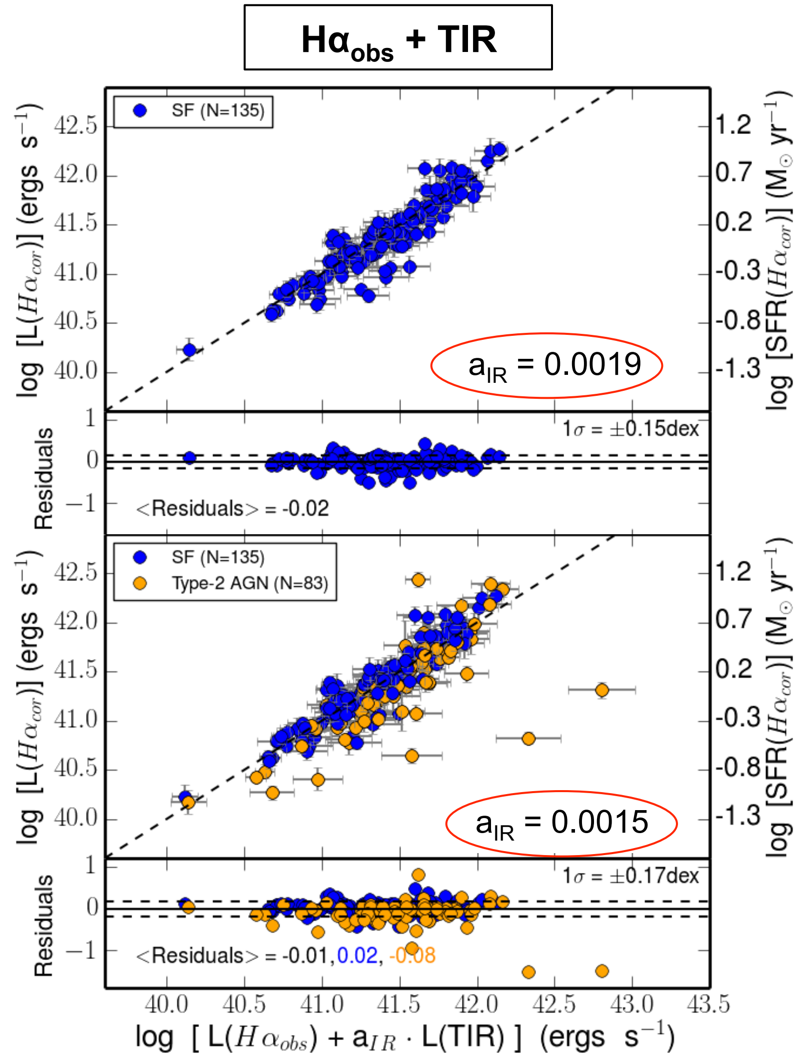
The composite tracers reduce the dispersion when comparing with FUV or IR (22µm or TIR) single-band tracers alone



Composite tracers comparison

$$SFR(M_{\odot}yr^{-1}) = 5.5 \cdot 10^{-42} L(H\alpha_{corr}) = 5.5 \cdot 10^{-42} [L(H\alpha_{obs}) + a_{IR} \cdot L(IR)]$$



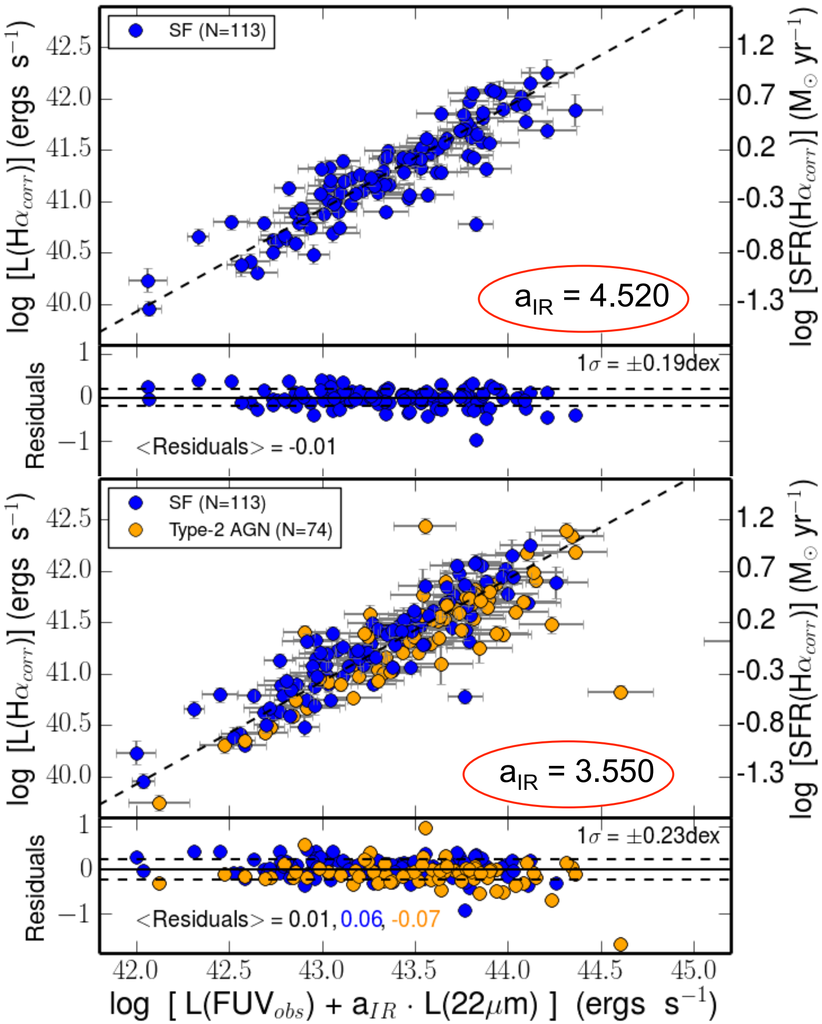


(Catalán-Torrecilla et al., submitted)

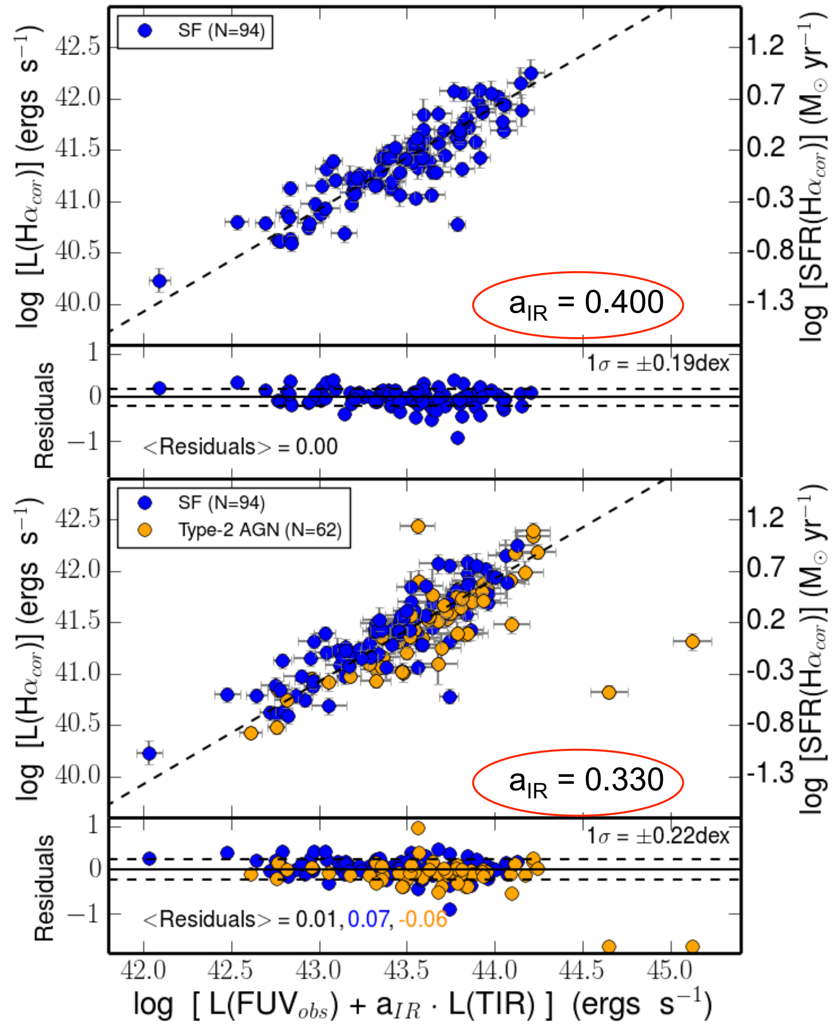
Composite tracers comparison

$$SFR(M_{\odot}yr^{-1}) = 5.5 \cdot 10^{-42} L(H\alpha_{corr}) = 4.6 \cdot 10^{-44}[L(FUV_{obs}) + a_{IR} \cdot L(IR)]$$

FUV_{obs} + 22μm



FUV_{obs} + TIR

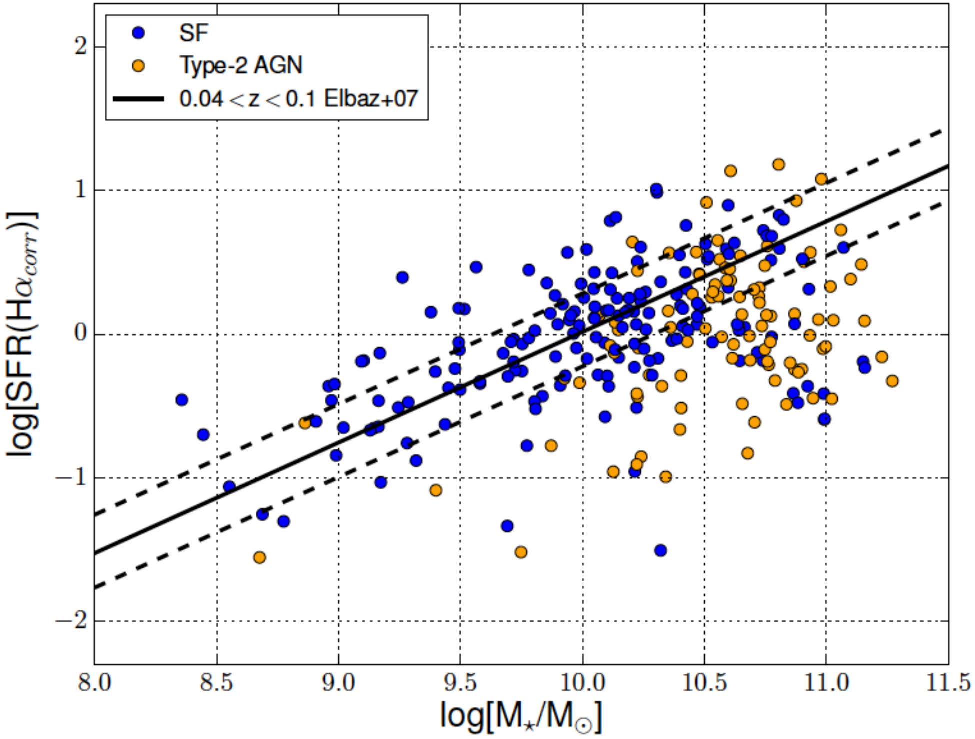


(Catalán-Torrecilla et al., submitted)

The presence of an **AGN** makes the a_{IR} coefficient lower

$$SFR(M_{\odot}yr^{-1}) = 5.5 \cdot 10^{-42} L(H\alpha_{corr}) = 5.5 \cdot 10^{-42}[L(H\alpha_{obs}) + a_{IR} \cdot L(IR)]$$

Main sequence

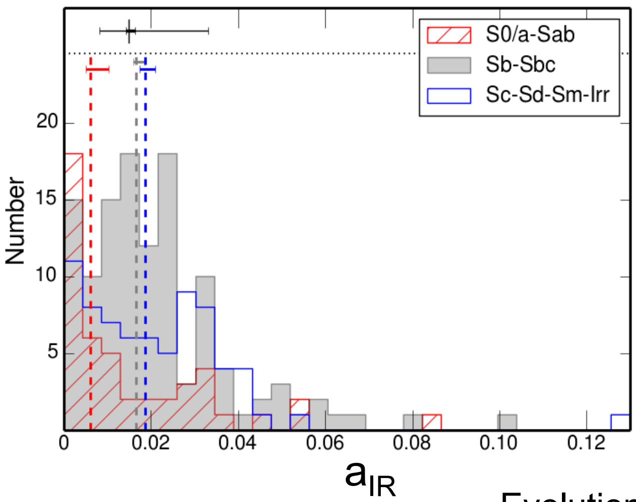


Possible explanations:

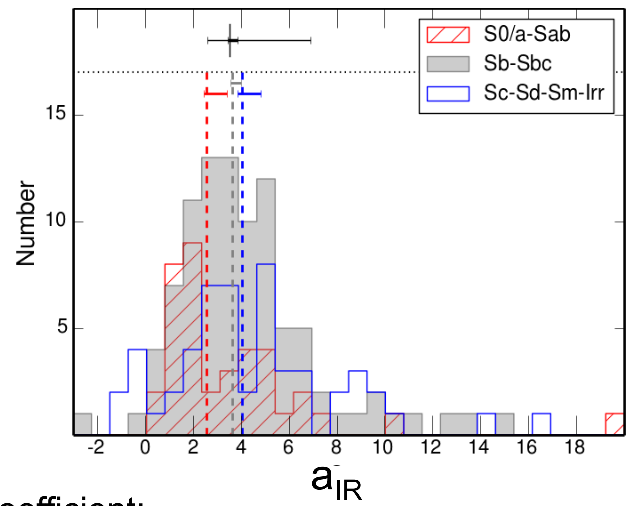
- A fraction of the L(Hα_corr) associated to circumnuclear SF could be missed, which implies that the actual SFR would be underestimated in these systems using only Hα measurements.
- Alternatively, the presence of an AGN influence the evolution of the galaxy by heating the dust, expelling the gas and finally, quenching the SF.

Composite tracers → Studying the value of the a_{IR} coefficient as a function of galaxy properties: **Morphological type**

22 + Hα



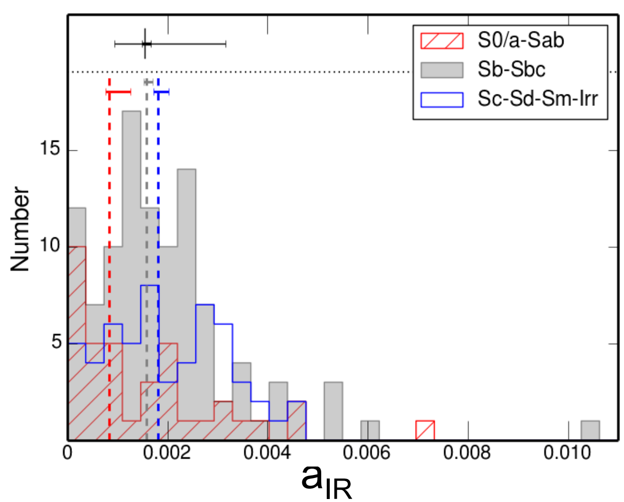
22 + FUV



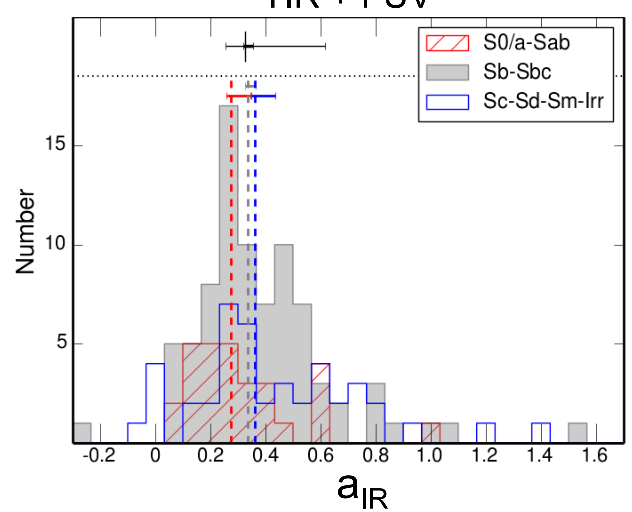
Evolution of the a_{IR} coefficient:

a_{IR}(S0/a-Sab) < a_{IR}(Sb-Sbc) < a_{IR}(Sc-Sd-Sm-Irr)

TIR + Hα

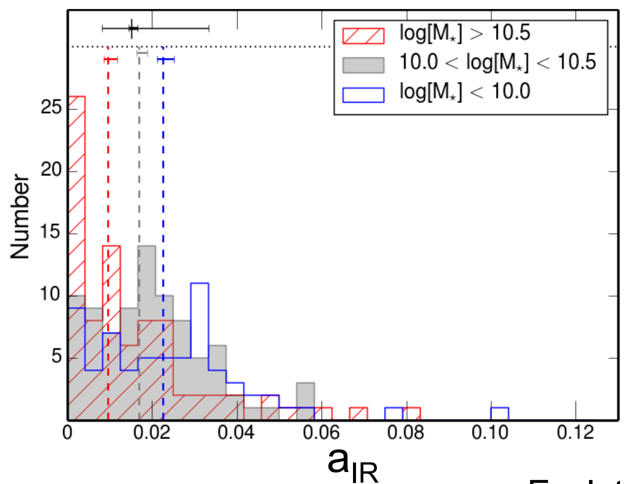


TIR + FUV

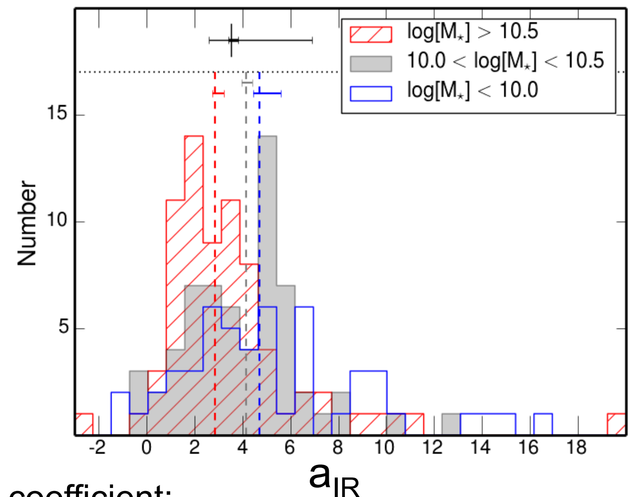


Composite tracers → Studying the value of the a_{IR} coefficient as a function of galaxy properties: **Stellar mass**

22 + Hα



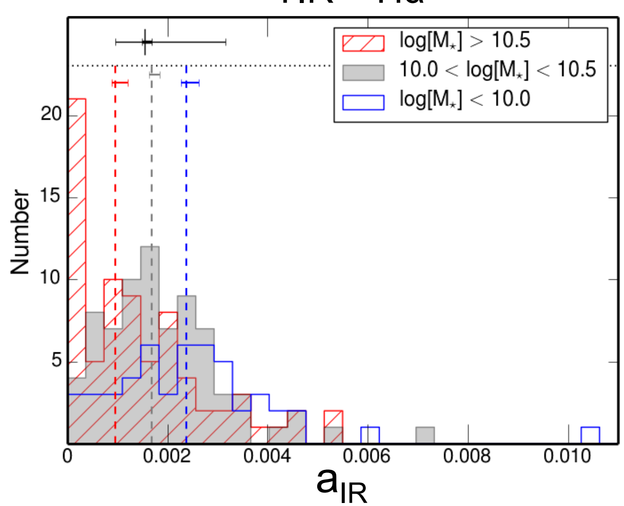
22 + FUV



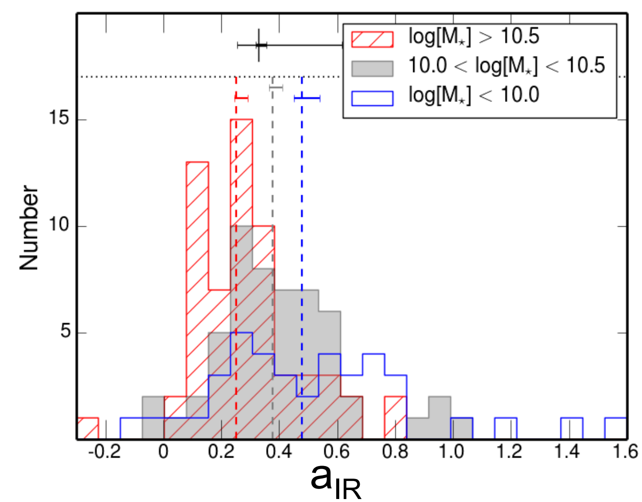
Evolution of the a_{IR} coefficient:

a_{IR}(more mass) < a_{IR}(intermediate mass) < a_{IR}(low mass)

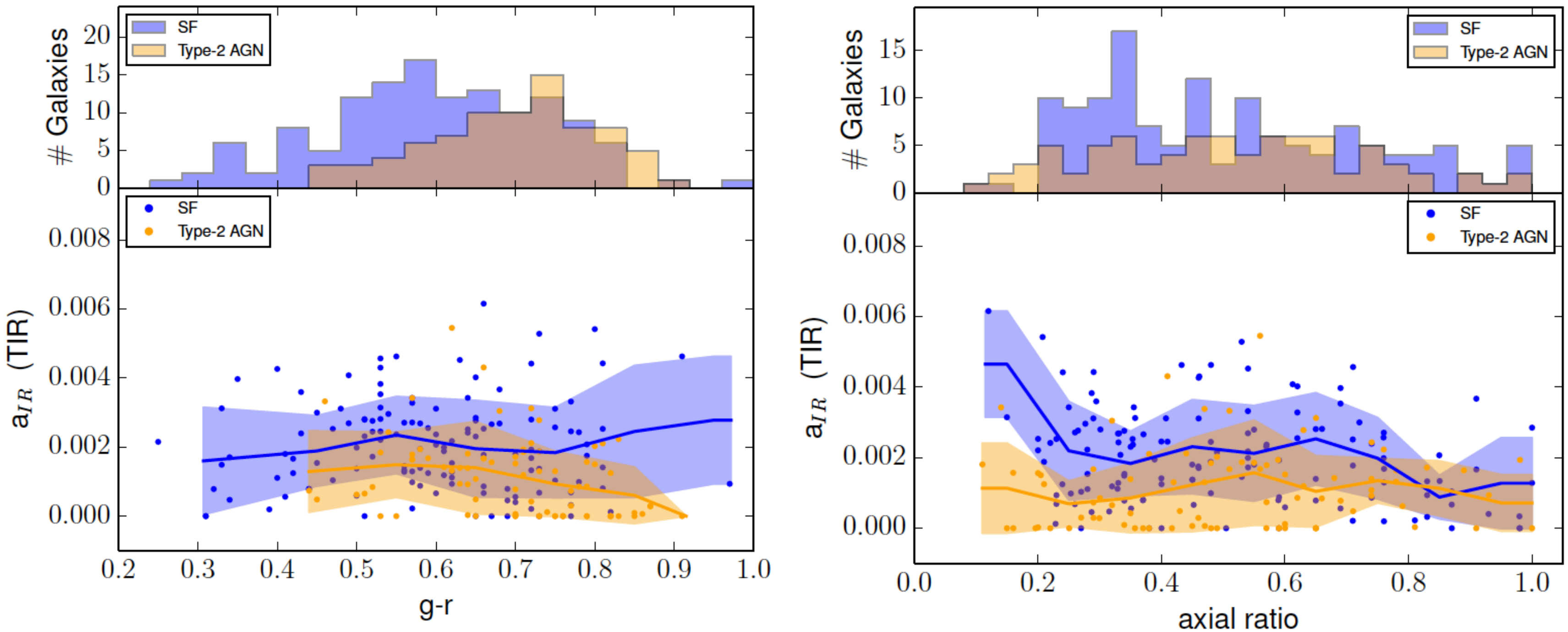
TIR + Hα



TIR + FUV



Composite tracers → Studying the value of the a_{IR} coefficient as a function of galaxy properties: **axial ratio & *g-r SDSS* color**



- ✓ Most of the decrease in a_{IR} with color and axial ratio is driven by type-2 AGN host galaxies
- ✓ SF objects with low axial ratios (where highly-inclined disk galaxies would be located) show similar a_{IR} values as the rest of the galaxies. Lower a_{IR} would be expected if a fraction of the Hα emission is completely obscured.

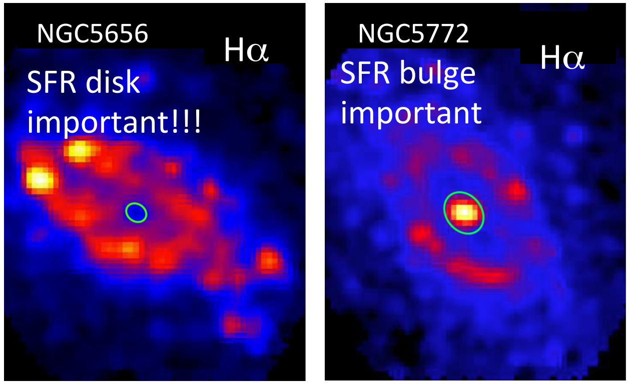
Summary & Conclusions

- ✧ We present the analysis of the SFR in a sample of 380 galaxies from the CALIFA survey. The availability of wide-field IFS ensures a proper determination of the underlying stellar continuum, leading to extinction-corrected Hα luminosities.
- ✧ We provide a new set of composite tracers anchored to the exitinction-corrected Hα luminosity. We determine the best fitting for the $\mathbf{a}_{\mathbf{IR}}$ scale factor using different combinations of observed (Hα or UV) and dust-reprocessed (22μm or TIR) luminosities.
- ✧ We study the variation of the scale factor with galaxy properties such as morphological type, stellar mass or (*SDSS g-r*) color. This analysis provides, for the first time, a set of hybrid calibrations for different morphological types and masses with and without type-2 AGN being considered.

Work in progress

AIM: study the spatially-resolved SFR maps using CALIFA IFS to understand in detail the patterns of SF in galaxies

(1) Determination of the Local Universe SFR density by galaxy components



(2) Radial profile analysis & SFR 2D distribution