Far-IR counterparts of SDSS galaxies:

Analysis of commonly used Star Formation Rate estimates

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The SFR is one of the key parameters for understanding galaxy evolution. The SFR can be derived through different indicators in a wide wavelength range, e.g., X-rays (tracing X-ray binary emission), UV (emission from recently formed massive stars); optical wavelengths (from the recombination lines of the young massive population), FIR (absorption and reemission by dust of UV light in the infrared) or radio wavelengths (supernova activity). Due to the different physical mechanisms and assumptions made to estimate the SFR it is of great importance to see how these SFRs indicators compare to each other and which galaxy properties have a more important impact. One of the major problems when deriving SFR at shorter wavelengths is that they must be corrected by dust extinction. The main advantage of the SFR from the FIR emission is that it is not affected by dust extinction. In this work we compare various SFR indicators with each other (UV, Hα, IR, SDSS, total) by combining for the first time deep IR data from the latest PEP (PACS Evolutionary Probe, Lutz et al. 2011) *Herschel* public data release (which sample the IR peak of the galaxy spectra, helping to derive accurate L_{IR} values) with the optical spectroscopic ancillary data from the Sloan Digital Sky Survey - DR7 (Abazajian et al. 2009) and the Galaxy Evolution Explorer satellite (*GALEX*, Martin et al. 2005; FUV, NUV). We study a sample of ~ 100 galaxies up to z ~ 0.4 in the COSMOS and Lockman Hole fields divided into 4 spectral types (star forming (SF), composites, active galactic nuclei (AGN) and unclassifiable galaxies) and 4 morphological types (E, S0, Sab, Scd). For the SF and unclassifiable galaxies we calculate dust extinctions from the UV slope, the Hα/Hβ ratio and the L_{IR}/L_{UV} ratio. We find a tight correlation between the dust extinction and both the L_{IR} and the metallicity. The agreement between the SFR indicators is very good for the bulk of the galaxies, and dispersions are smaller than typical SFR uncertainties (σ ~ 0.30). The galaxies follow the prescriptions of the Fundamental Plane (M-Z-SFR) derived by Lara-López et al. 2013.

Data and sample selection:

- FIR: *Herschel* PEP (100 and 160 μm) public DR1
- Optical: *SDSS*-DR7, galaxy spectra analysis by the MPA-JHU group: mass, SFR, metallicity, emission lines
- UV: *GALEX* DR6/DR7

Galaxy Classification:

- Spectral classification from Brinchmann + 2004 (BPT diagram): SF, AGN, composite, unclassified
- Morphological classification (Huertas-Company + 2011): E, S0, Sab, Scd

Dust extinction:

- UV slope (β)
- Hα/Hβ ratio (R)
- L_{IR}/L_{UV} ratio (IRX)

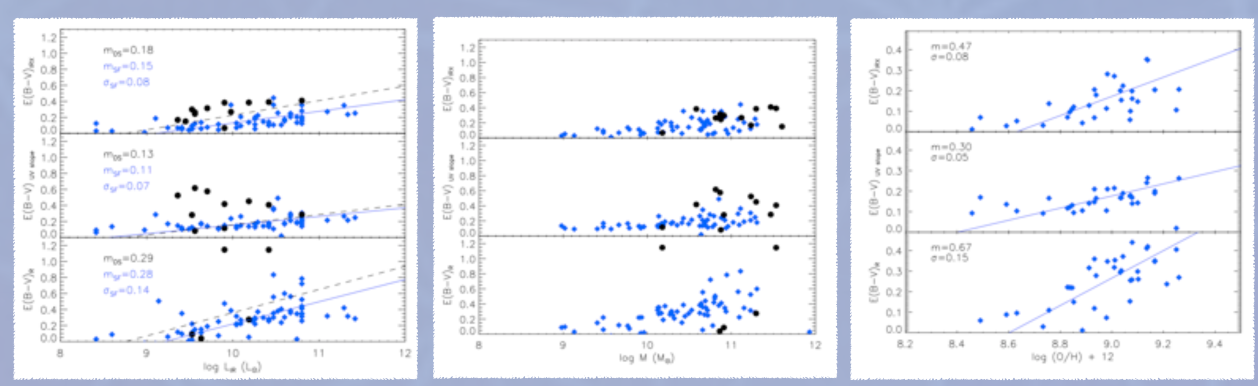

Fig 1. Left: E(B-V) versus L_{IR} for the SF (blue diamonds) and the unclassifiable samples (black circles). The blue thick line is the best- fitting slope to the SF sample, while the black dashed line is the relation obtained by Domínguez Sánchez + 2012. Middle: E(B-V) versus mass. Right: E(B-V) versus metallicity for SF galaxies.

Tight correlation between E(B-V) and L_{IR} (dust extinction increasing with L_{IR}, Fig.1-left) and metallicity (metal rich galaxies have higher dust extinctions, Fig.1-right). Relation between E(B-V) and stellar mass shows a very large dispersion, specially at large masses. The dispersion of the relations always takes the smallest values for $E(B-V)_{\beta}$.

Main galaxy sample = 105 galaxies from SDSS with UV and FIR detection

SFR estimates (Kennicutt 1998):

- SFR from L_{UV} (dust correction using UV slope)

$$SFR(M_\odot\ yr^{-1}) = 1.4 \times 10^{-28}\ L_{UV}\ (erg\ s^{-1}\ Hz^{-1})$$

- SFR from Hα (dust correction using Hα/Hβ)

$$SFR(M_\odot\ yr^{-1}) = 7.9 \times 10^{-42}\ L(H\alpha)\ (erg\ s^{-1})$$

- SFR from L_{IR} (NO dust correction)

$$SFR(M_\odot\ yr^{-1}) = 4.5 \times 10^{-44}\ L_{IR}\ (erg\ s^{-1})$$

- SFR total (obscured+unobscured)

$$SFR_{total} = SFR_{UV,Uncorr} + SFR_{FIR}$$

SFR comparison:

- Excellent agreement between the SFR indicators for the whole sample of SF galaxies (Fig. 2).
- Late type galaxies behave similar to the SF sample.
- Unclassified galaxies show larger dispersions than SF galaxies.
- Important difference (~ 1dex) between SFR_{total} and $SFR_{H\alpha}$ at high mass.

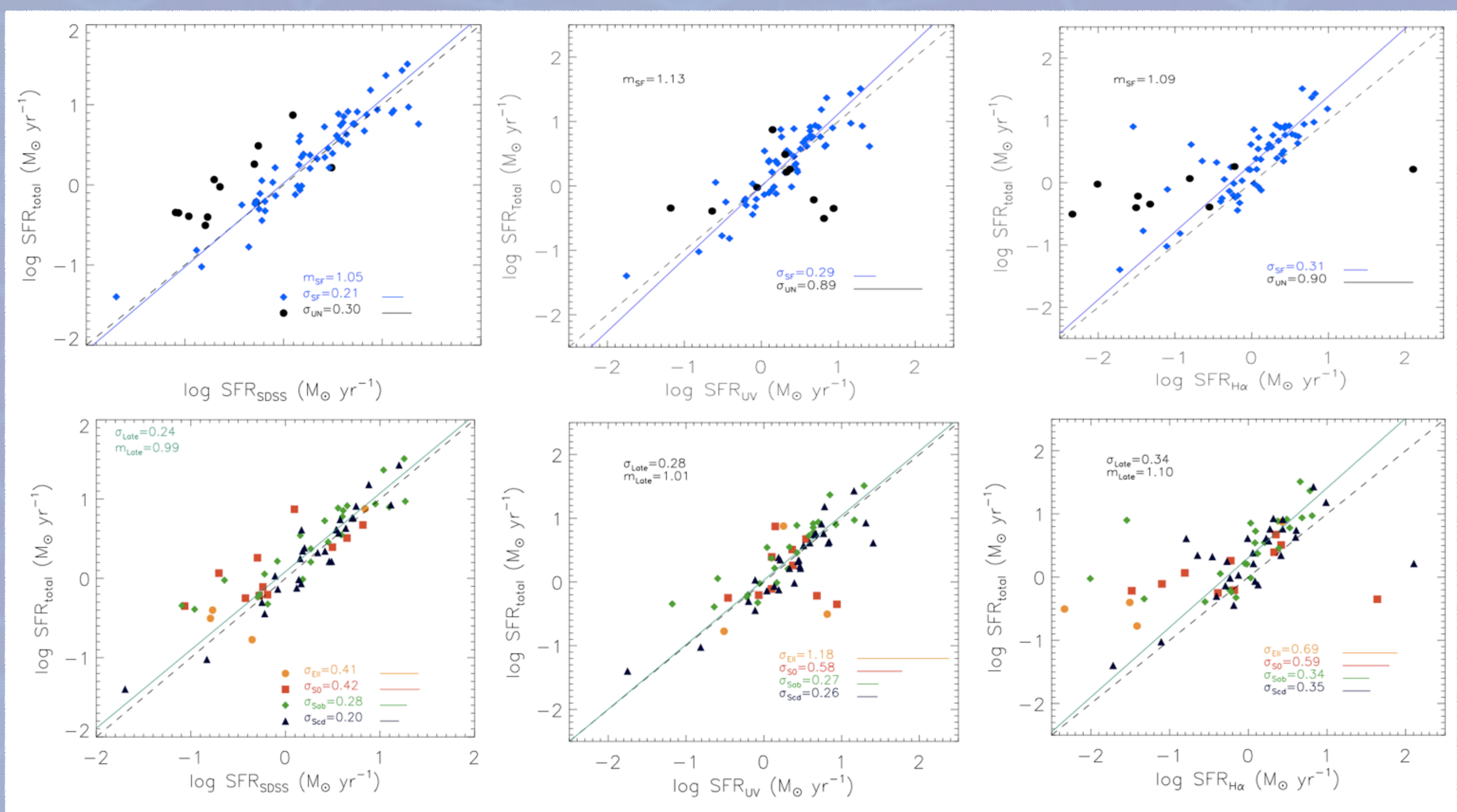

Fig. 2 Left upper panel: $SFR_{total}=SFR_{UV,uncorr}+SFR_{FIR}$ versus SFR derived by the MPA-JHU group for the SDSS DR7. The one to one relation is represented by the black dashed line, while the thick blue line is the best-fit to the SF sample. The obtained slope and dispersion for the SF sample are also shown, as well as the dispersion values for the unclassifiable galaxies. Left bottom panel: The colour code represents the morphological classification. The dark green line is the best-fit to the late type galaxies (Sab and Scd). Middle panels: SFRtotal versus SFR_{UV}. Right panels: SFRtotal versus $SFR_{H\alpha}$.

AGNs and composites: SFR vs LIR & LUV

SFRs and dust extinction recipes above are not valid for AGN and composite galaxies.

For these objects we compare SFR_{SDSS} vs L_{IR} and L_{UV} (Fig 3).

SFR seems to correlate very well with the L_{IR} for AGN and composite galaxies (σ=0.29).

The SFR_{SDSS}-L_{UV} dispersion is too large (σ=0.57) to derive any recipe,

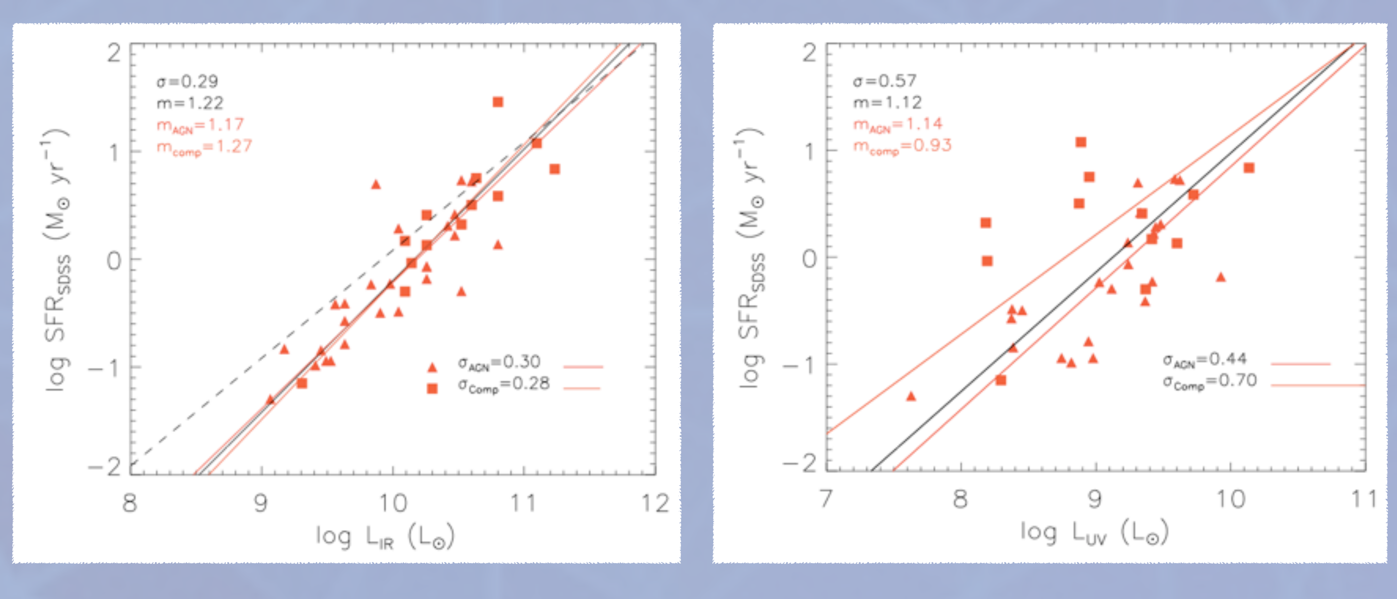

Fig. 3: SFR_{SDSS} versus L_{IR} (left panel) and L_{UV} (right panel) for AGNs (red triangles) and composite galaxies (orange squares). The black, red and orange thick line are the best fit to the AGNs plus composites, the AGNs only and the composites only, respectively. The dashed line is the K98 relation for SF galaxies. Also shown the best-fitting slopes and dispersions.

SFR vs Mass:

- The SF sample of FIR SDSS counterparts follows the MS relation obtained for the whole SDSS sample (m_{FIR}=0.79; m_{SDSS} =0.77, Brinchmann + 04)
- The AGNs, composites and unclassifiable galaxies are located below the MS (AGN preventing star formation or selection effects?).
- The best-fitting slope for the late type galaxies is larger (m_{late}=0.92) and shows an offset in the zero point due to the presence of late type galaxies with low sSFR.
- The majority of E and S0 galaxies lie below the MS.

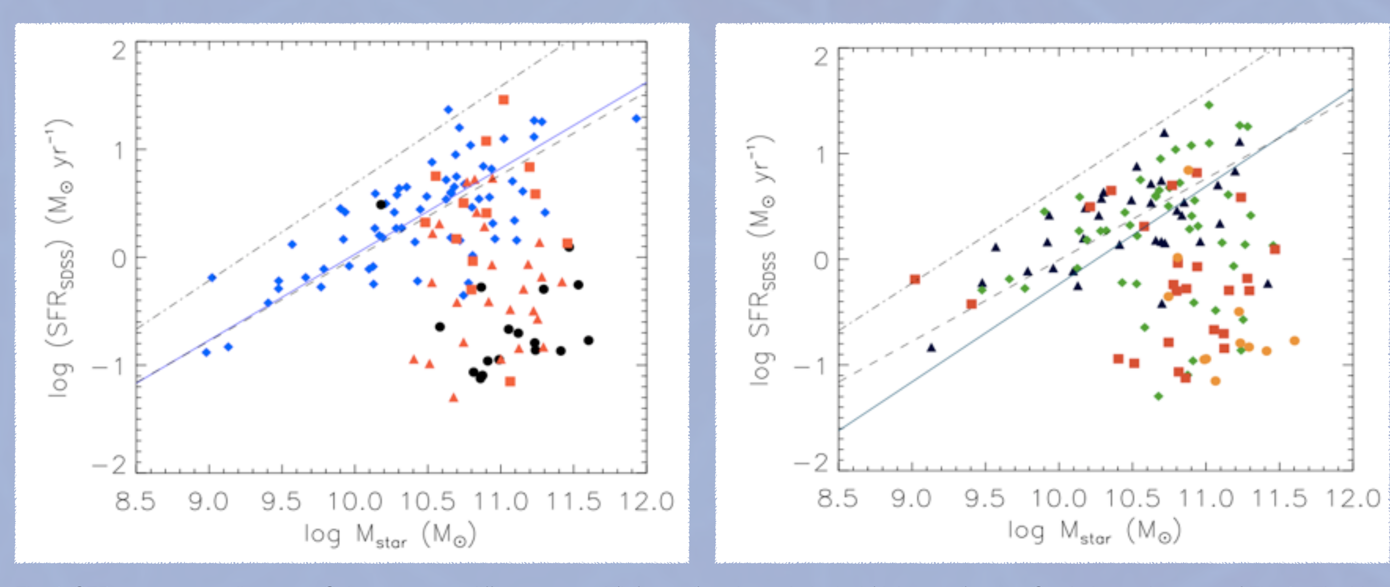

Fig. 4: SFR_{SDSS} versus stellar mass. Colors represent different spectral (left panel) and morphological (right panel) types. Symbols are the same of Fig. 2 . The blue and dark green thick lines are the best-fit to the SF and the late-type samples, respectively. Also shown the Main Sequence relations derived for the local SDSS sample (black dashed line, B04) and the one derived by Elbaz + 2007 at z ~ 1 (black dotted-dashed line).