Measuring star-formation and AGN activity at high redshifts

AST 524 seminar

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We found them, what's next

- Questions we want to ask:
  - We found something. Who are they in the galaxy evolution history.
  - When and how galaxies build up their stellar mass (luminosity function)
  - When and how black holes build up their mass?
  - Are they two correlated?

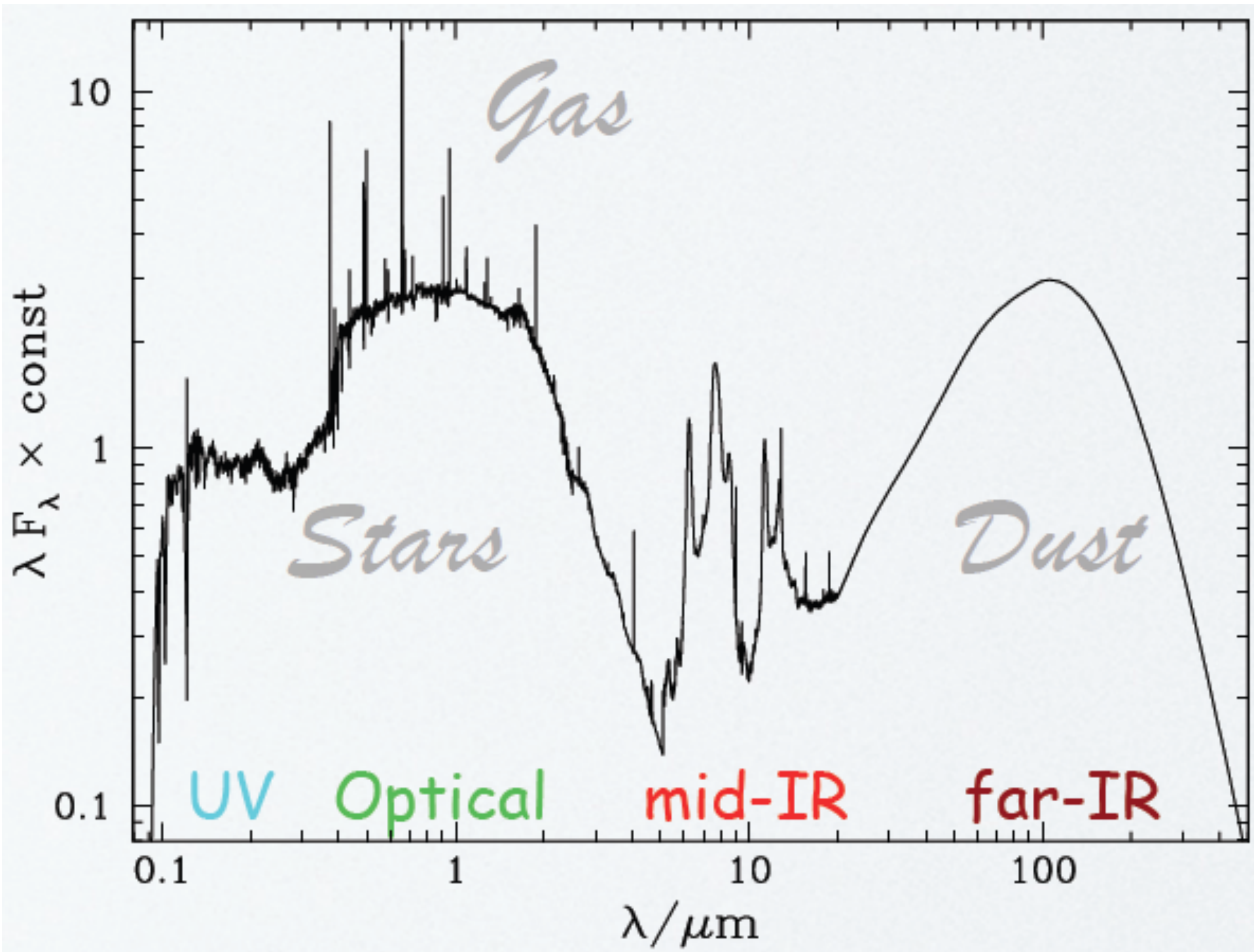
Outline

- How to measure star formation rate
  - SFR diagnostics
- Star formation rate at z~2
  - UV slope correction
  - Inferring IR luminosity from MIR
  - Star forming galaxy main sequence and starbursts
- AGN activity
  - Distinguish AGN from star forming galaxies
  - AGN activity related to star formation rate

SED of Star Forming Galaxies and AGN

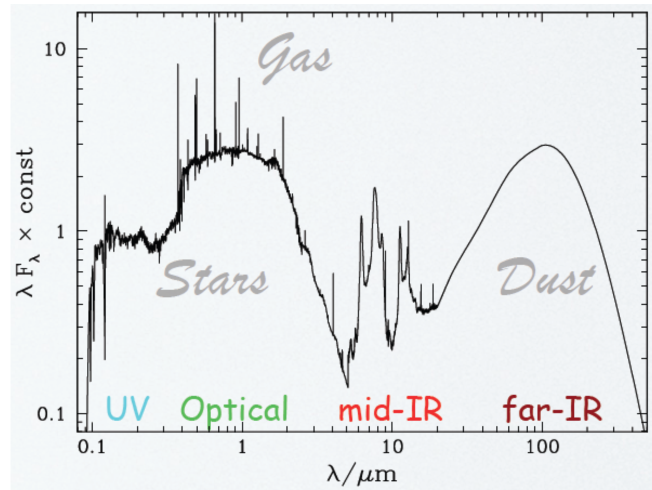
- Galaxy Spectrum – continuum
  - Stellar - optical peak
    - Multi temperature black body
  - Dust – FIR peak
    - ~Black body + warm dust and PAH lines in MIR
- AGN Spectrum
  - Flat power law – Synchrotron from X-ray to radio
    $F_\nu = C\,\nu^{-\alpha}$ with $0 <\sim \alpha <\sim 1$
    $\nu F_\nu \sim$ const if $\alpha = 1$

Star formation diagnostics



From S. Charlot

Star formation diagnostics



- **UV continuum** directly from young stars
  - 1250 – 2500 A
  - Observable from ground for z=1-5
  - Suffers from dust extinction
  - Reddening correction fails if
- **Total infrared continuum** from dust
  - 8 – 1000 μm
  - Cold dust component can be contaminated by old star
  - UV escape fraction has to be assumed
  - FIR flux > 20μm free from AGN contamination (Netzer et al. 2007)
- **Recombination lines (ex: Hα)** from HII region
  - Good instant SFR tracer
  - Suffers from dust extinction

How to measure star formation rate

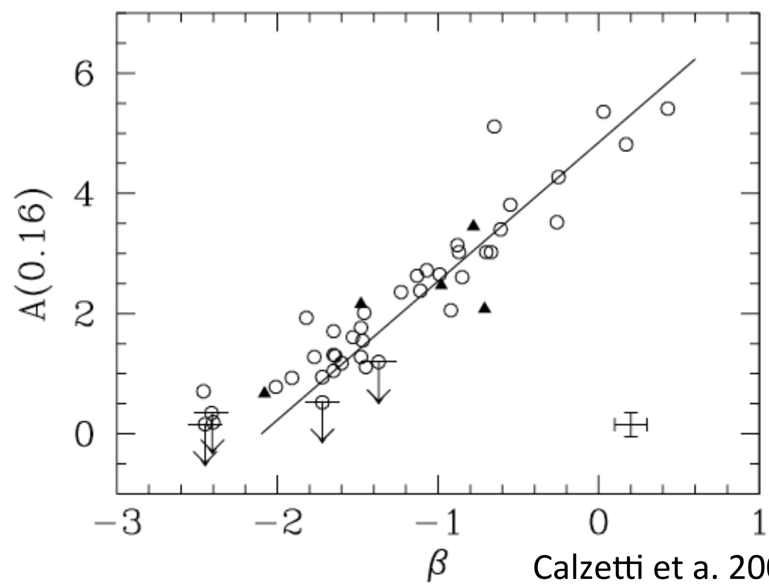
- UV continuum + FIR continuum

$$\mathrm{SFR_{UV+IR}}\ [M_\odot\ \mathrm{yr}^{-1}] = 1.09 \times 10^{-10}\ (L_{\mathrm{IR}} + 3.3\ L_{2800})/L_\odot$$

Kennicutt 1998

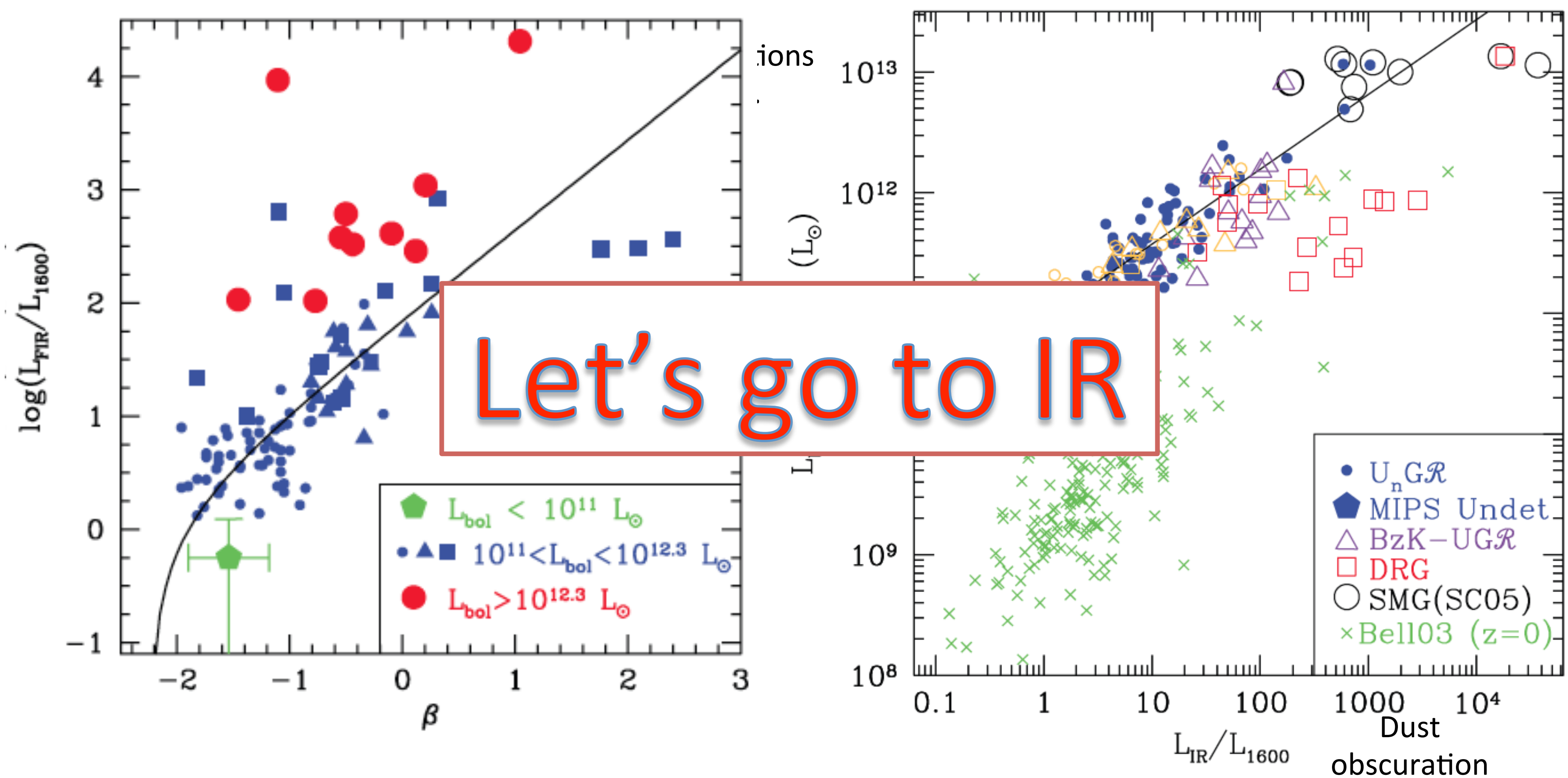
- UV continuum + IR flux inferred from 24 µm flux

- SED modeling
- UV + extinction correction
- Hα + extinction correction hard for z>2



Calzetti et a. 2000

UV slope and extinction correction



SFR cannot be inferred from UV luminosity and slope for SMC and DRGs

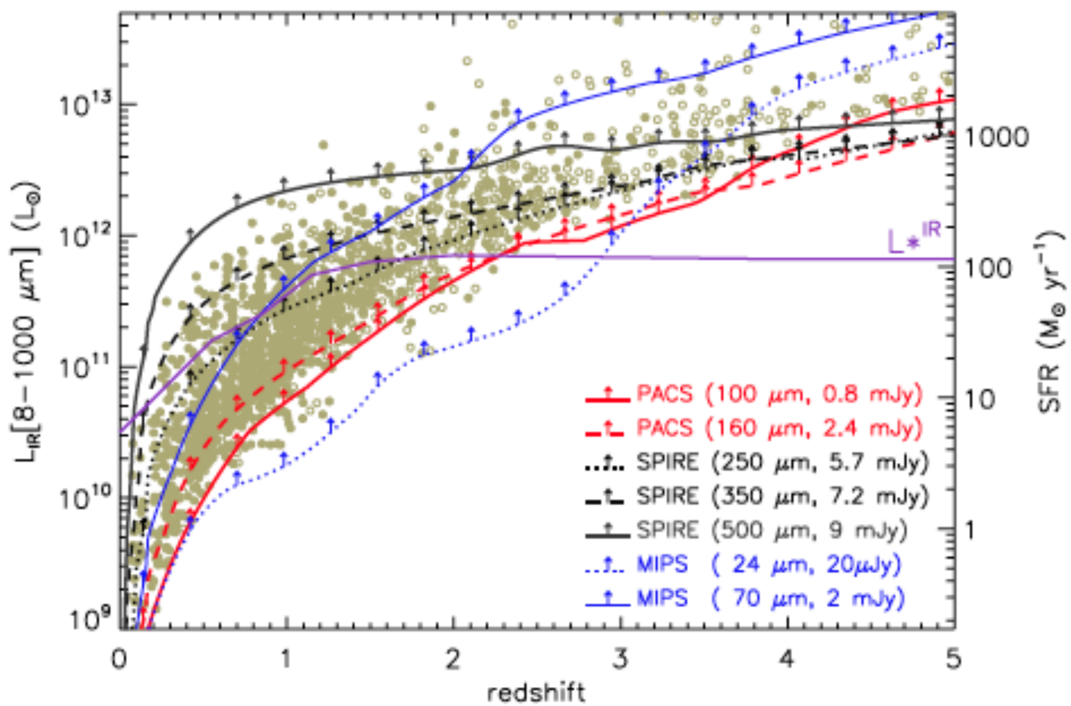
Dust obscuration - UV slope β conversion depends on luminosity

Galaxies of a given bolometric luminosity are less dust obscured at z ~ 2 than present

Reddy et al. 2006

Inferring total IR flux from MIR flux

- UV + IR (peak at FIR) is the most direct SFR indicator. However, FIR (160 μm) observation for z~2 galaxies was not possible until *Herschel*, and is not as easy as NIR observation.
- Local observation found tight correlation between MIR (24 μm) and total IR luminosities at z < 1.5 (Ex: Chary & Elbaz 2001). Therefore local SED templates can be used to extrapolate total IR from MIR.
- Deep field FIR survey (ex: Elbaz +2011) suggest for z > 1.5 similar technique can be used if one rest-frame PAH feature is traced throughout all z.

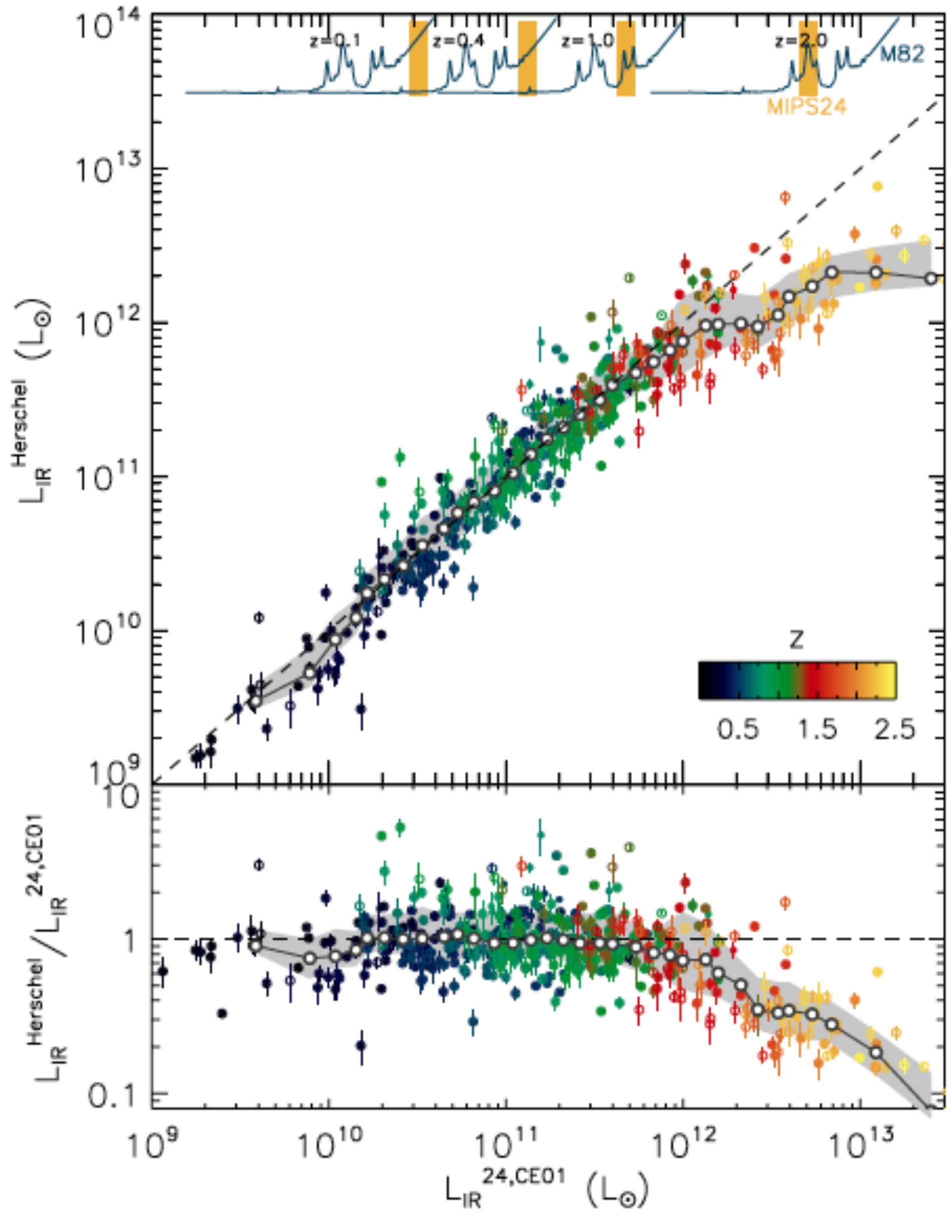


Elbaz et al. 2011

Elbaz et al. 11

with IR SED 3-500 µm from Goods-Herschel + IRAS, ISO, Spitzer, and AKARI.

$L_{8\,\mu m\,rf}$ can be traced by IRAC 8 µm IRS 16 µm and MIPS 24 µm from z=0-2.5, and K-corrected by local template



Elbaz et al. 2011

Elbaz et al. 11

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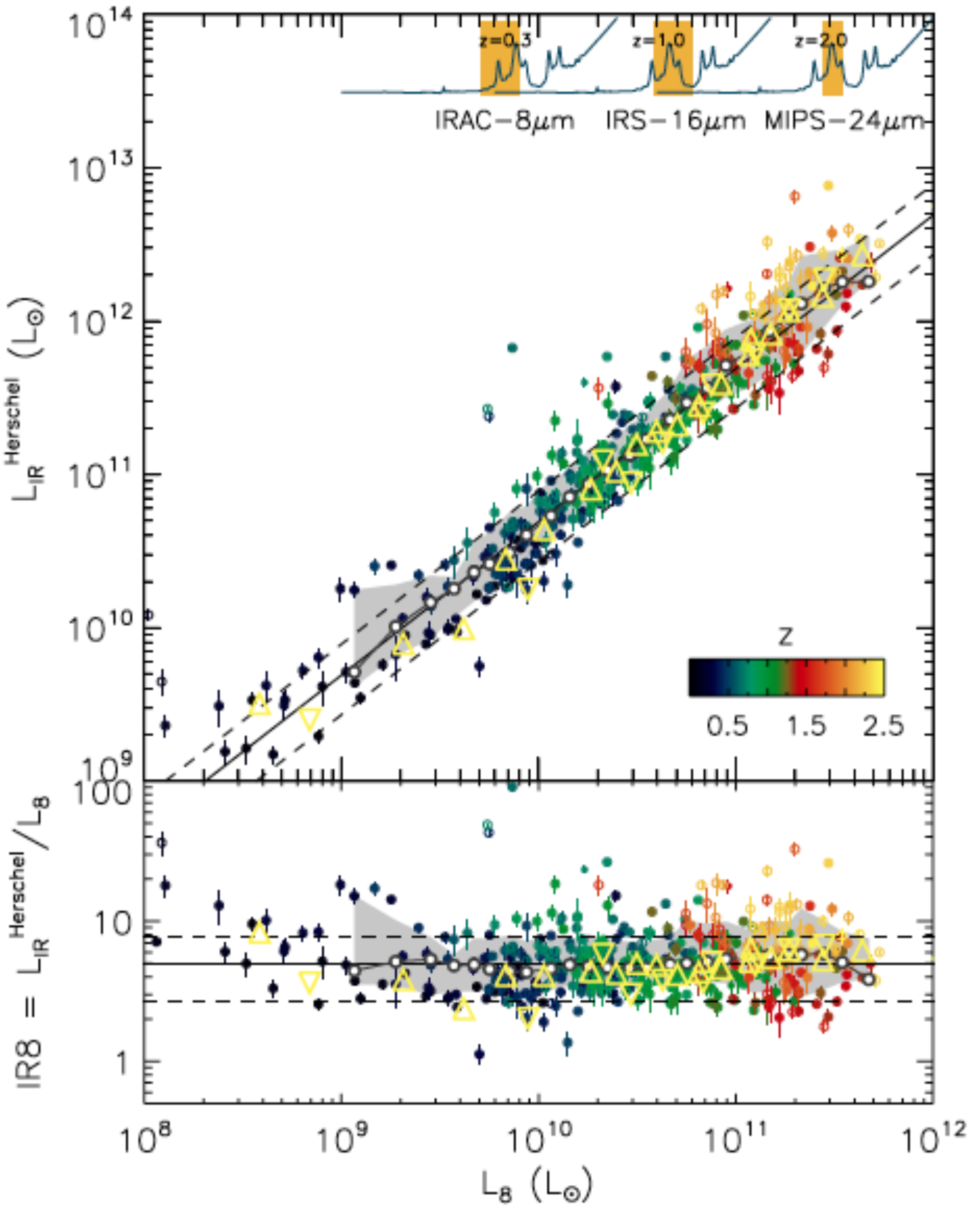


Elbaz et al. 2011

Wuyts 2011 A

Comparing SFR estimated from different SFR indicators out to z~3 using three deep fields.

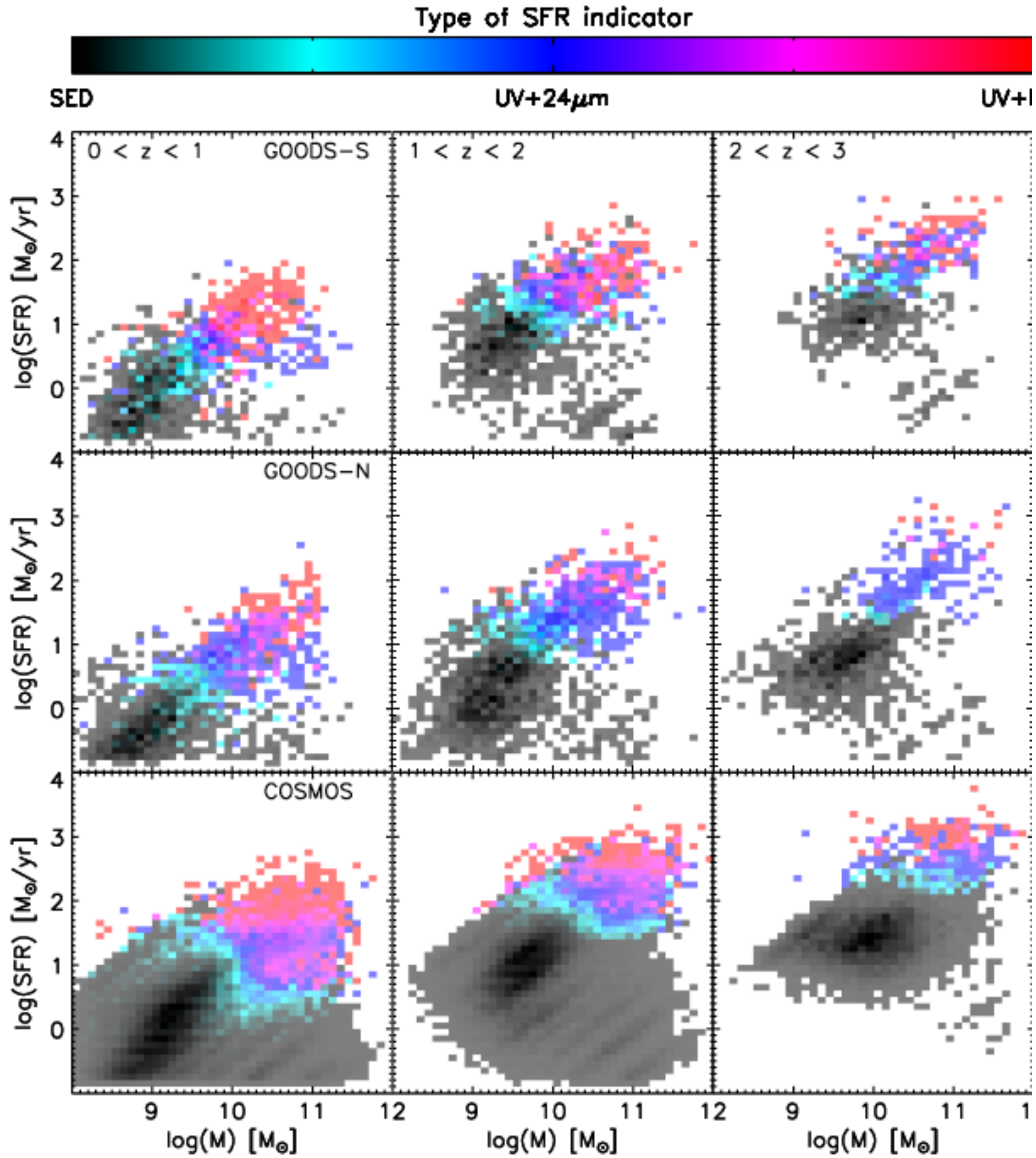
UV + IR (Herschel PACS)

UV + 24 µm (Spitzer MIPS)

SED (U -8 µm SPS modeling)
(integrated photometry underestimate age)

Hα (SINS)
(extinction correction failed for high SFR due to patchy dust)

To explore the entire population of star forming galaxies, combination of indicators is required



IR Main Sequence

IR main sefquence

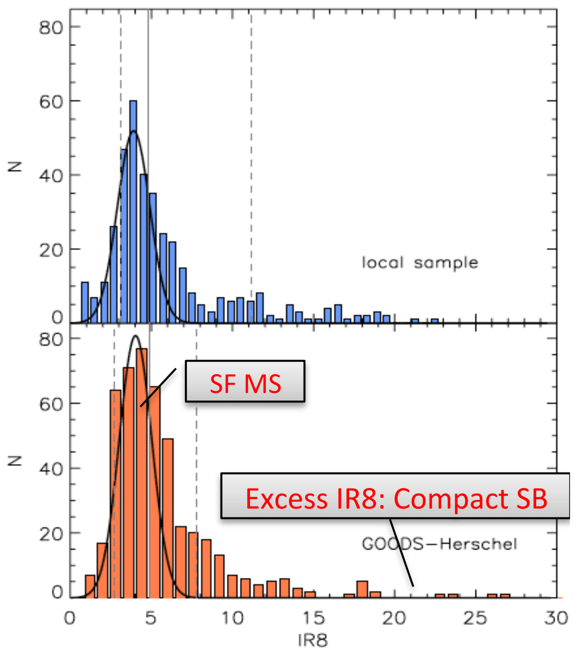
$L_{tot\,IR}/L_{8\,\mu m\,rf}$ follows a Gaussian distribution independent of redshift and luminosity

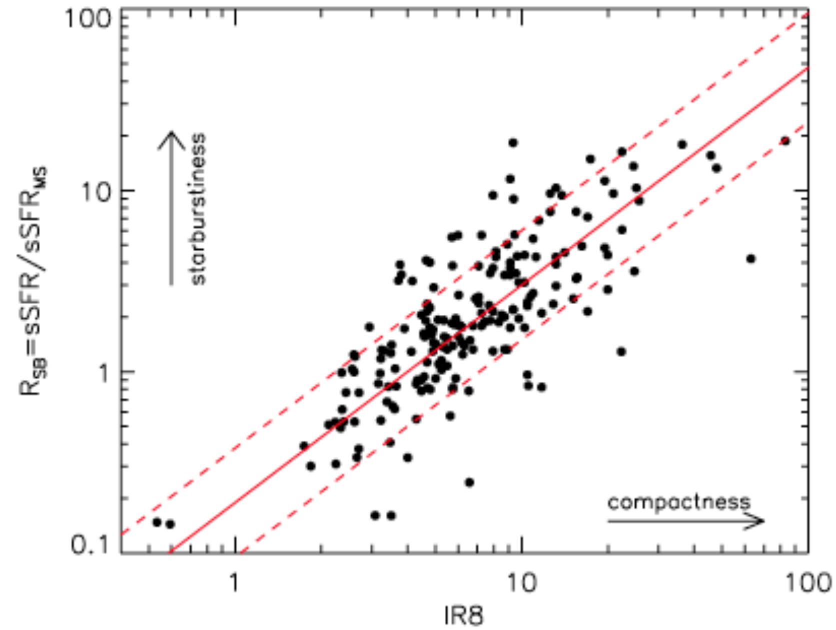
This IR MS is related to star forming galaxy MS

Starburst galaxies

~20% outliers with high $L_{8\,\mu m\,rest}$ are consistent with compact dusty starbursts

AGN do not play an important role in changing IR SED





Elbaz et al. 2011

IR Main sequence SF galaxies	Star burst galaxies
$L_{IR}/L_{8\mu m}$ universal independent of z or L_{IR}	$L_{IR}/L_{8\mu m}$ excess
Moderate sSFR	Starbusrts (sSFR > 2* MS sSFR)
Moderate compactness	More compact than MS galaxies
Follow Schmidt-Kennicutt law $\Sigma_{SFR} \simeq 0.017 \Sigma_{gas}\, \Omega_{gas}$	SFR is one order of magnitude more efficient than SK law

Daddi+ 2010; Genzel + 2010

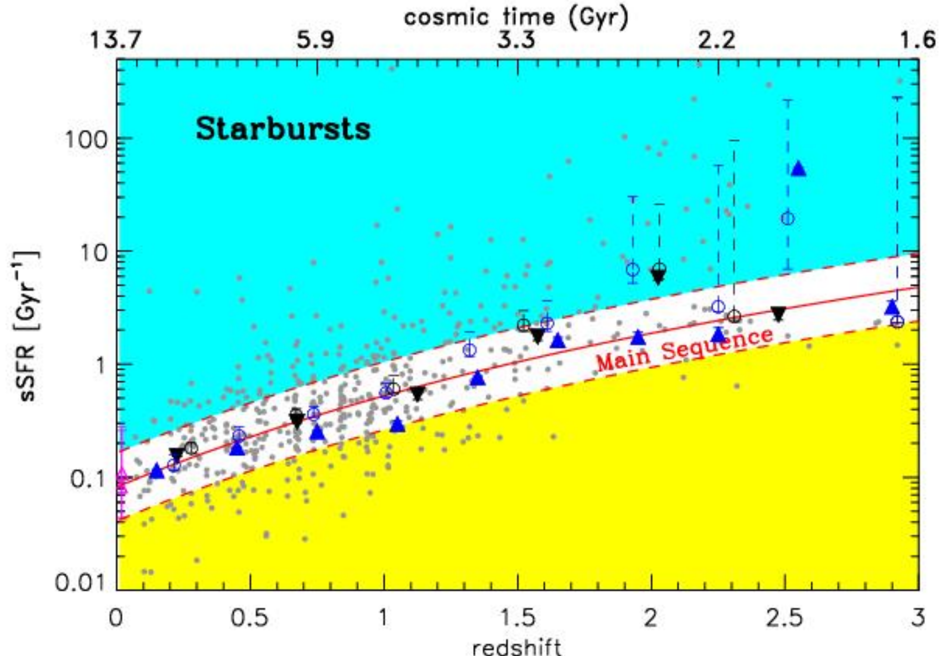
Ho

Evolution of sSFR

- Medium sSFR, representing the MS sSFR, increases as z increases

$$sSFR_{\rm MS}\,[{\rm Gyr}^{-1}] = 26 \times t_{\rm cosmic}^{-2.2}$$

- Local starbursts are mostly related to merger, while high z starbursts can be sustained in other way



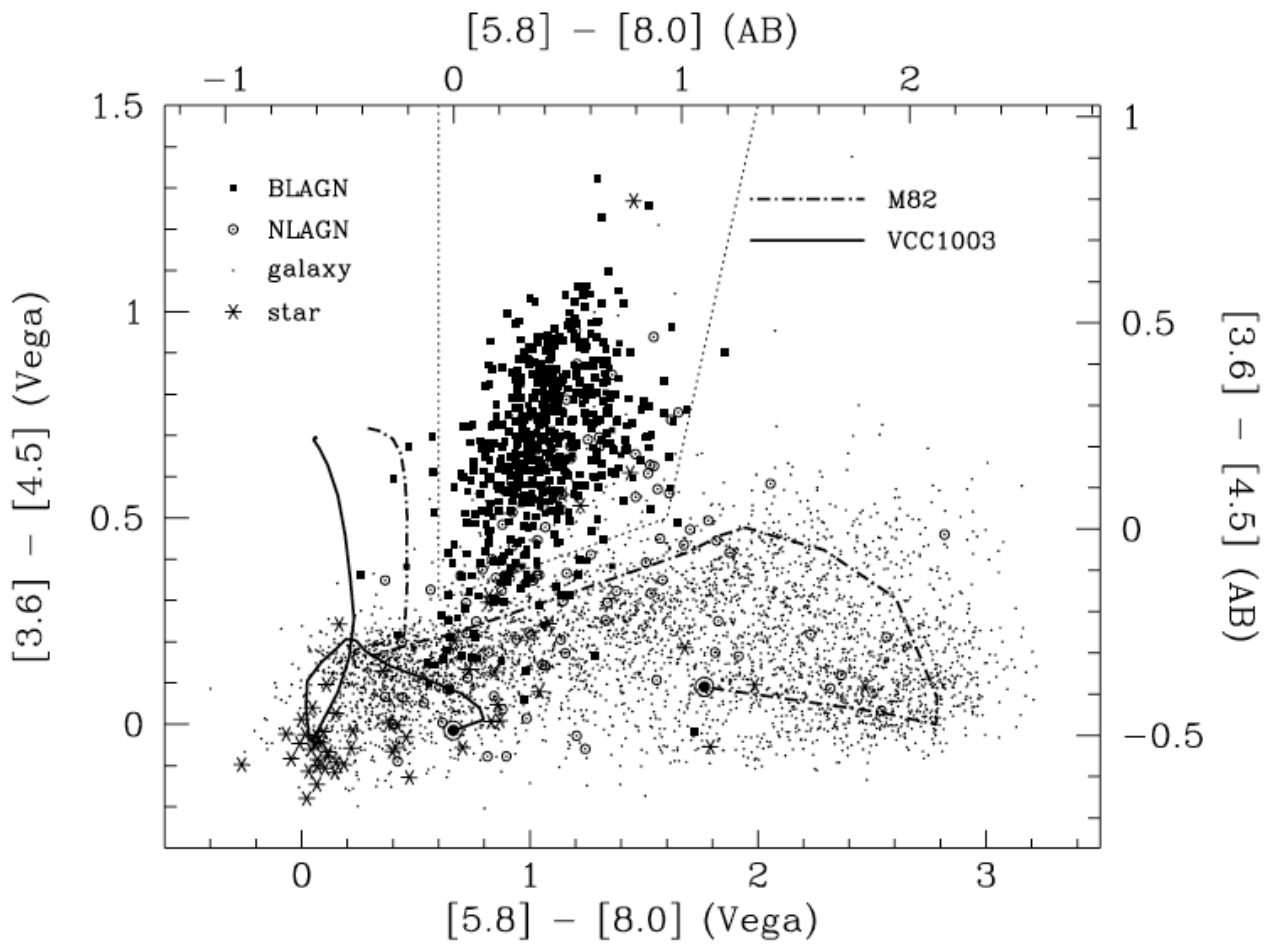
Elbaz et al. 2011

Complications – disentangle AGN from Star formation

- X-ray selection corona,
  - X-ray bright and hard, optically normal obscured quasar exists (Stern+02)
- UV color selection acc disk
  - Selection of QSO, law extinction, AGN dominate over galaxy, rare
  - Suffers from extinction
- MIR color selection hot dust (Stern+05)
  - Good at selecting obscured quasar

MIR color selection of AGN

- AGN has redder MIR [3.6]-[4.5] color
- Broad line AGN continuum dominates over PAH feature, which causes a wide spread of [5.8] - [8.0] color
- Select high Eddington ratio AGN
- Can pick up obscured AGN



Stern et al. 2005

What we've found

- Black hole growth (AGN activity) goes with SF
  - SFR in AGN hosts are higher than inactive galaxies (Santini+ 2012 w/ *Herschel*)
  - AGN fraction increases by 30-40% for galaxies with SFR ~1000 M_solar/yr (Rafferty+ 2011)
  - Different selection finds different AGN fraction
    - 1% LAEs, 3% LBGs, 30% red color selected, high in SMG
  - Mid-to-far IR emission of X-ray AGNs is dominantly produced by star formation (Elbaz+ 2011)

Summery

- UV+IR is the most reliable SF diagnostics
  IR luminosity can be inferred from MIR

- Most star forming galaxies are in the star formation main sequence, and the sSFR increases with z

- AGN activity is correlated with star formation activities

References

- Kennicutt, 1998, *ApJ*, v.498, p.541
- Stern et al. 2005, *ApJ*
- Reddy et al. 2006, *ApJ*
- Wuyts et al. 2011, *ApJ*
- Rafferty et al. 2011, *ApJ*
- Elbaz et al. 2011, *ApJ*
- Santini et al., 2012, A&A