Herschel Spatially Resolved Studies Of Extremely Metal Poor Galaxies

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1. Introduction

Extremely Metal Poor Galaxies (XMPGs, $Z<Z_{\odot}/10$):

- Testing current understandings of roles of metallicity in ISM physics and star formation at extreme low Z ($<Z_{\odot}/10$).

- A local laboratory to gain insights into galaxy formation in early Universe.

Spatially-resolved studies of nearby XMPGs by Herschel enable to probe the dependence of ISM physics and SF processes on local physical conditions.

2. Sample And Observations

Sample:

Table 1. The Proposed Sample

name	D [Mpc]	12+alog10(O/H)	Type	D_{25} [']	$\Sigma_{70\mu m}$ [MJy/sr]	$\Sigma_{160\mu m}$ [MJy/sr]
DDO 68	5.90	7.21	BCD	2.6	1.5	2.0
Sextans A	1.40	7.49	dI	5.0	2.5	3.0
ESO 146-G14	22.50	7.61	LSB	3.2	2.6	3.5

Solar 12+log(O/H)=8.65(Pettini & Pagel 2004)

Observations (PI: Y. Shi):

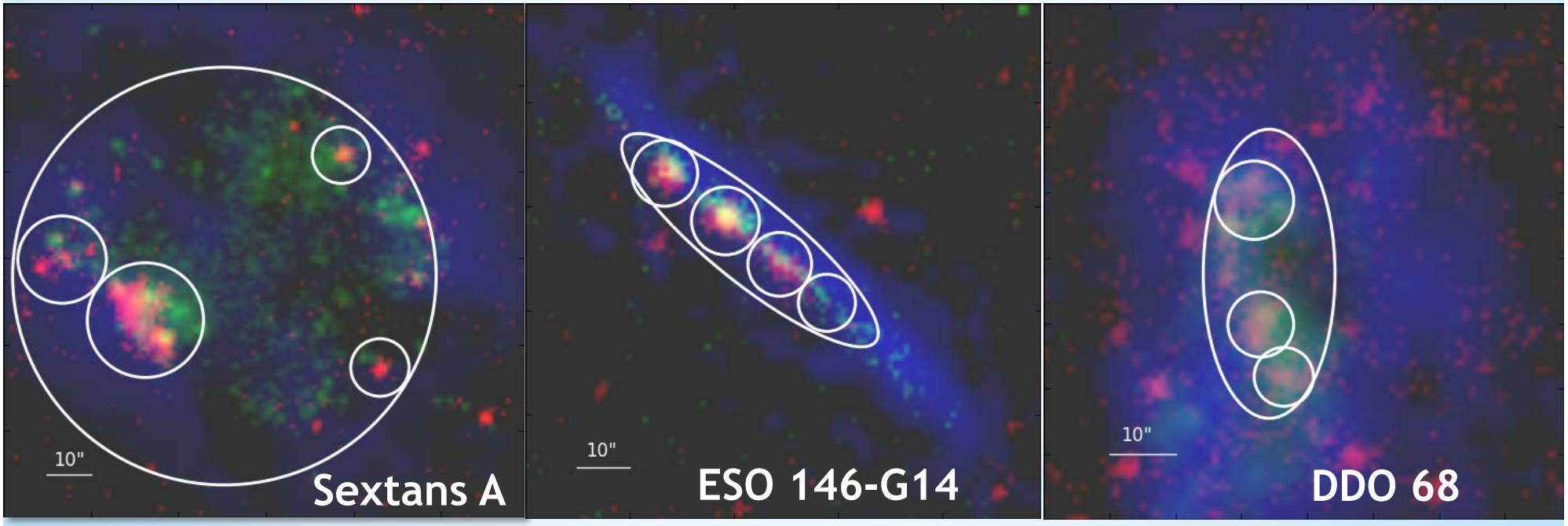
PACS (70 and 160 um) + SPIRE (250, 350, 500 um)

Reduction:

Unimap (Traficante+2011, Piazzo+2012)

3. RESULT: Spatial Distribution

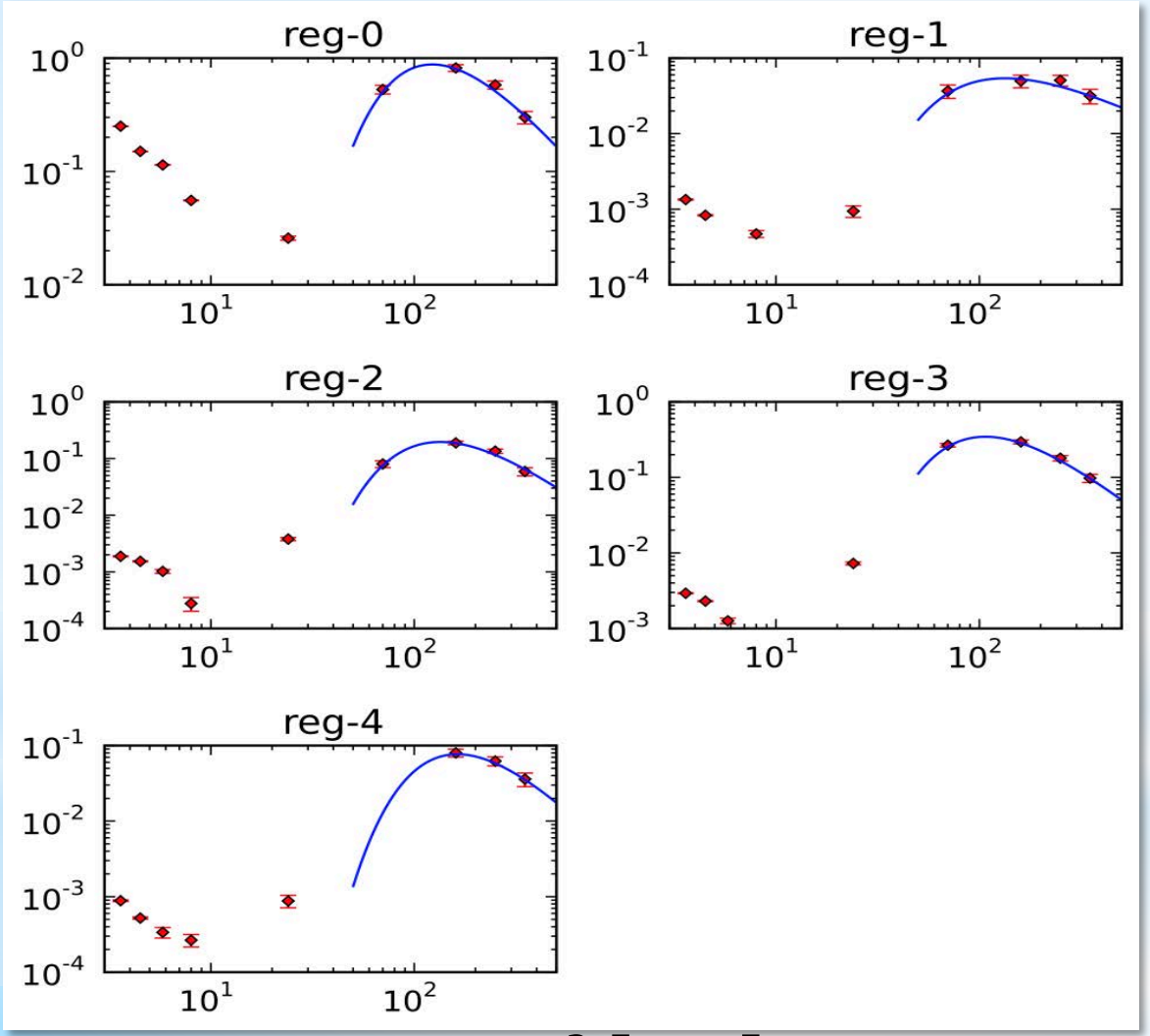
Dust emission is enhanced (detected) in SF clumps with high Σ^{UV}_{SFR}, similar to the case in spiral galaxies.

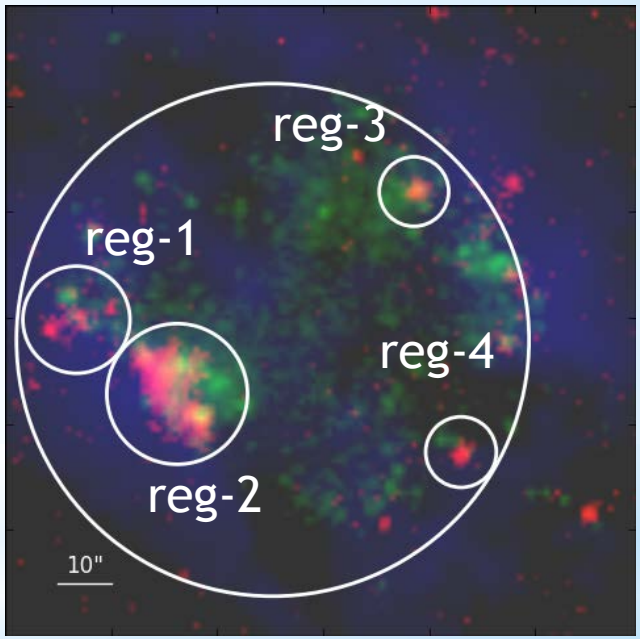


Blue: HI gas, Green: Far-UV, RED: 70+160 um

3. RESULT: A Single MBB Fit

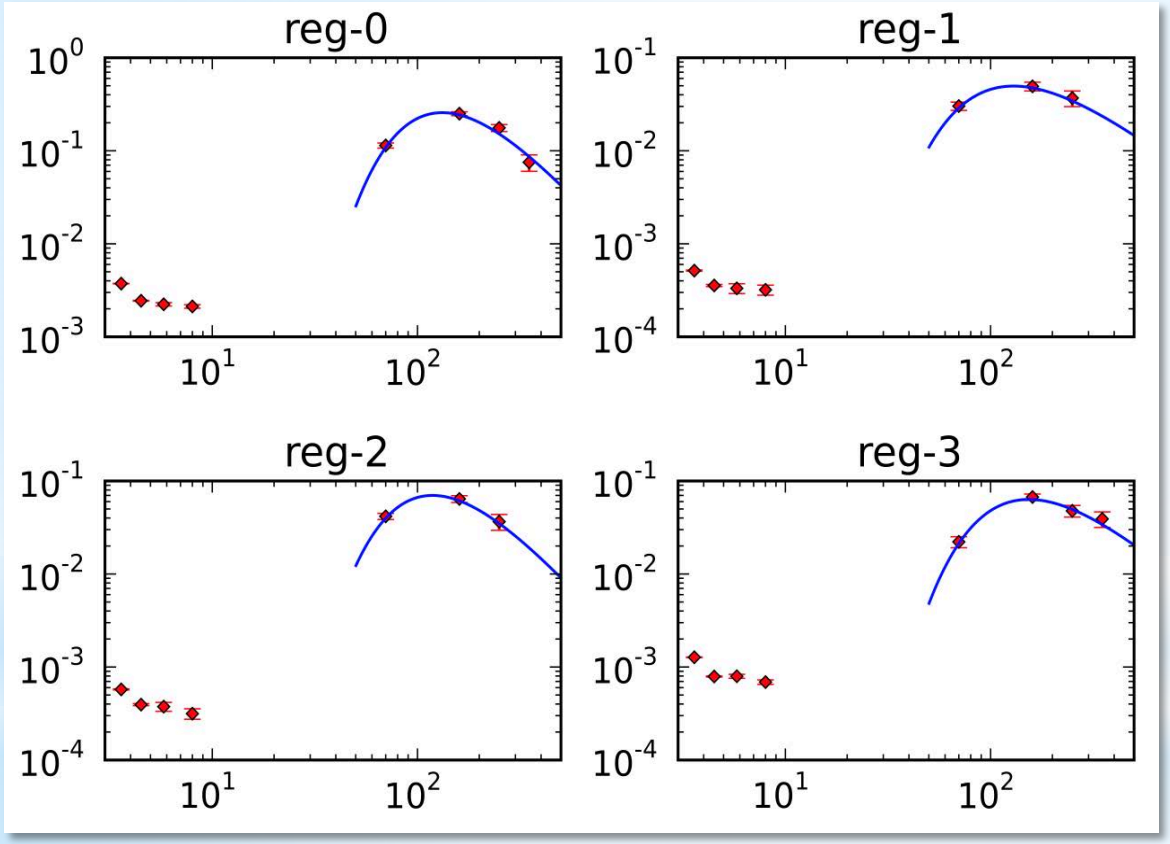
A Single MBB Fit To ≥ 70 um of Sextans A:

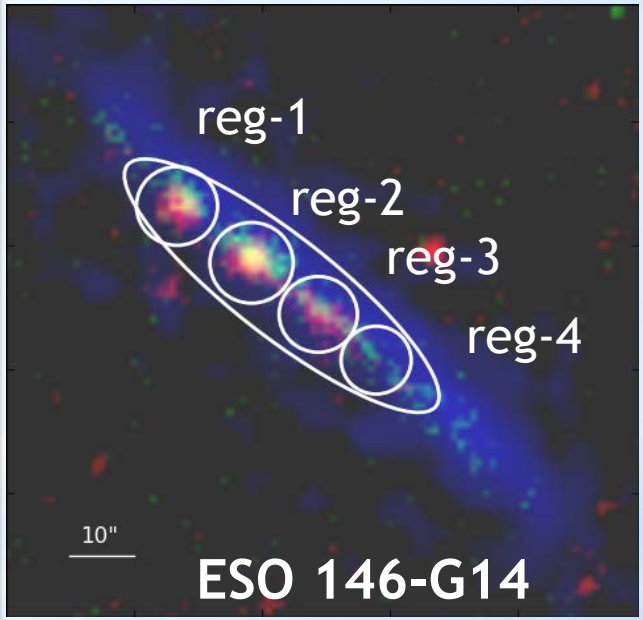




3. RESULT: A Single MBB Fit

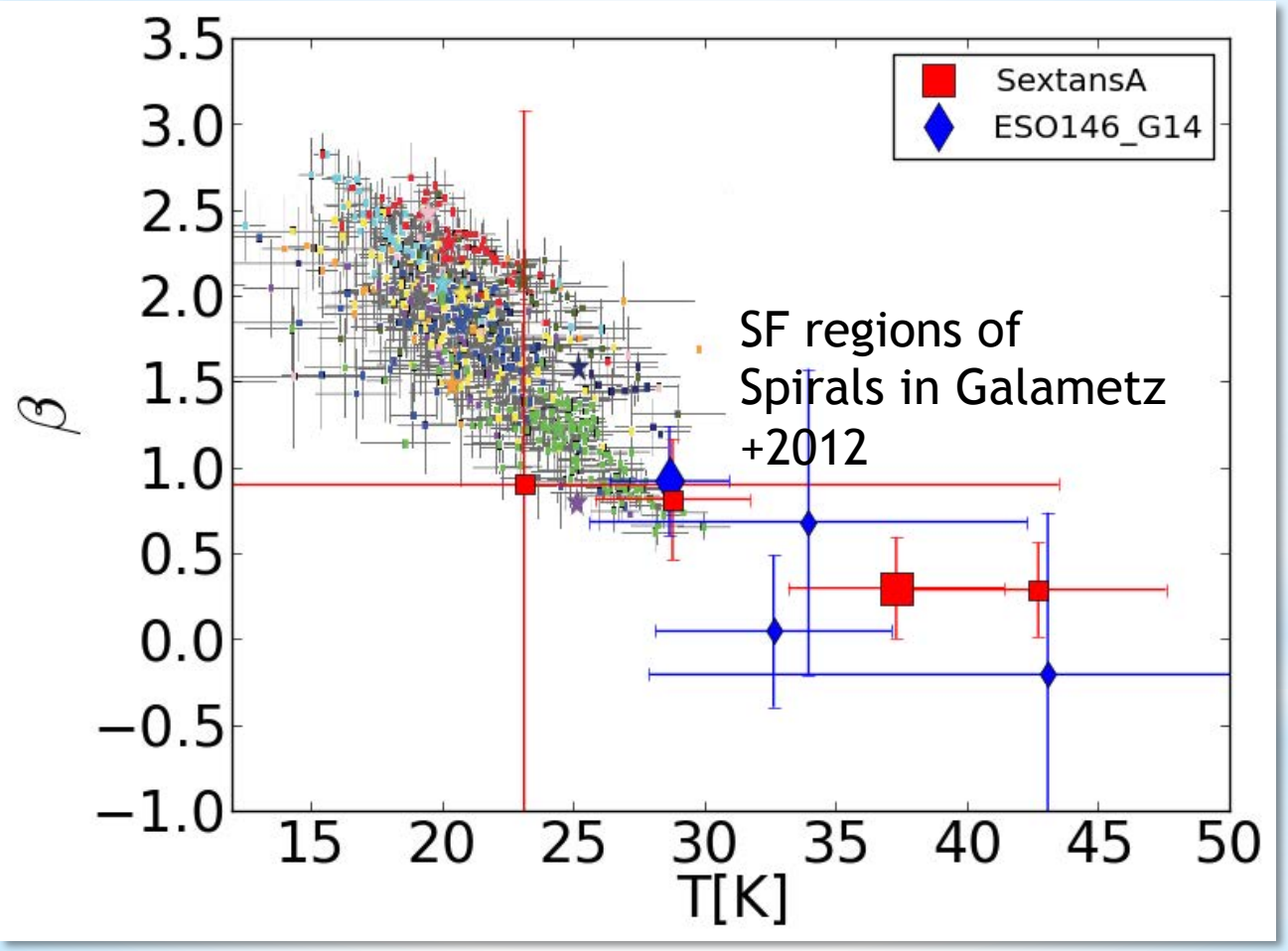
A Single MBB Fit To ≥ 70 um of ESO 146-G14:





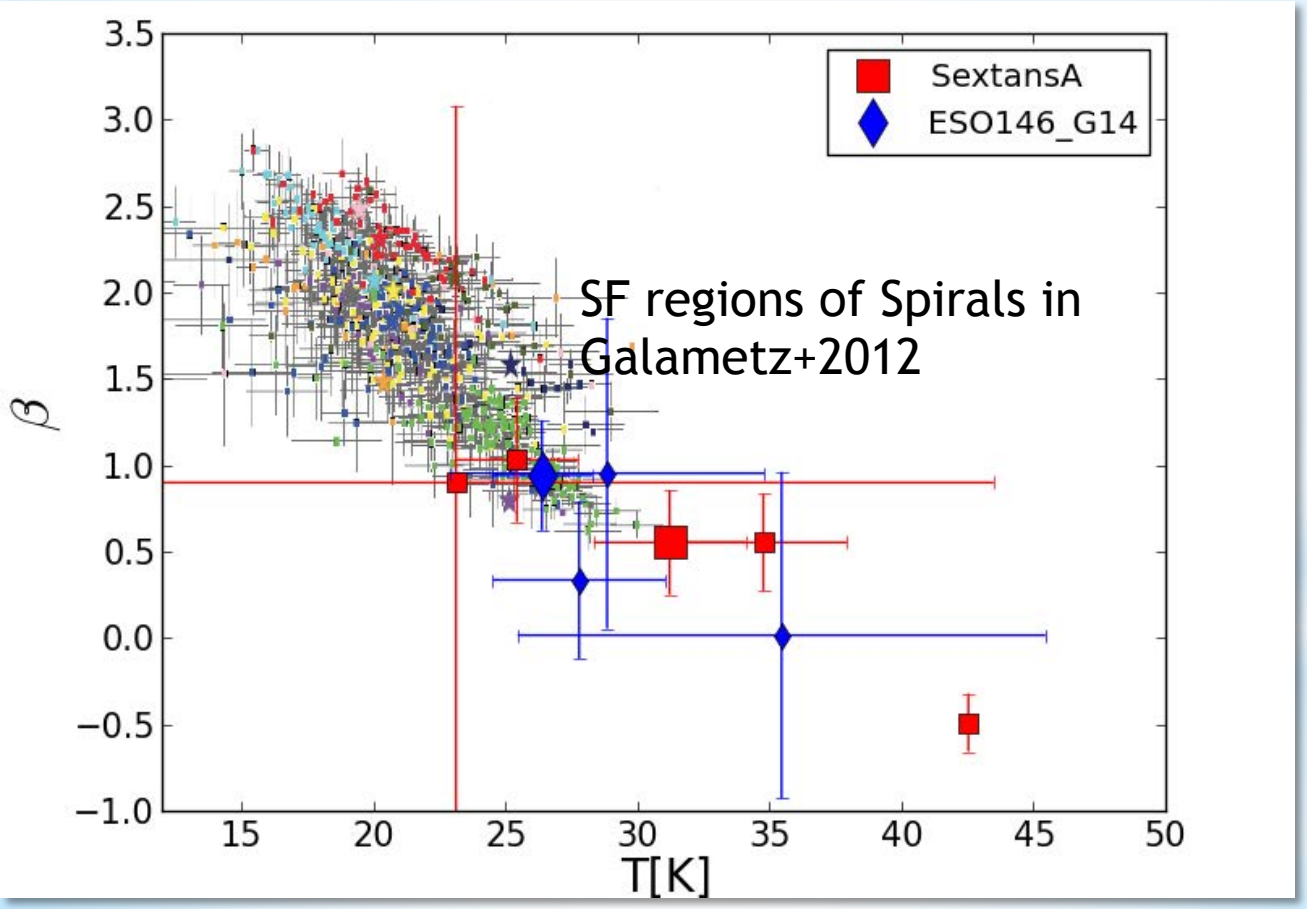
3. RESULT: A Single MBB Fit

All dusty clumps prefer high temperature and low emissivity, as compared to spiral galaxies!



3. RESULT: A Single MBB Fit

Possible warm dust contaminations at 70 um (Galametz+2012) -- reducing 70 um emission by 30 % and re-fit. The basic trend holds.



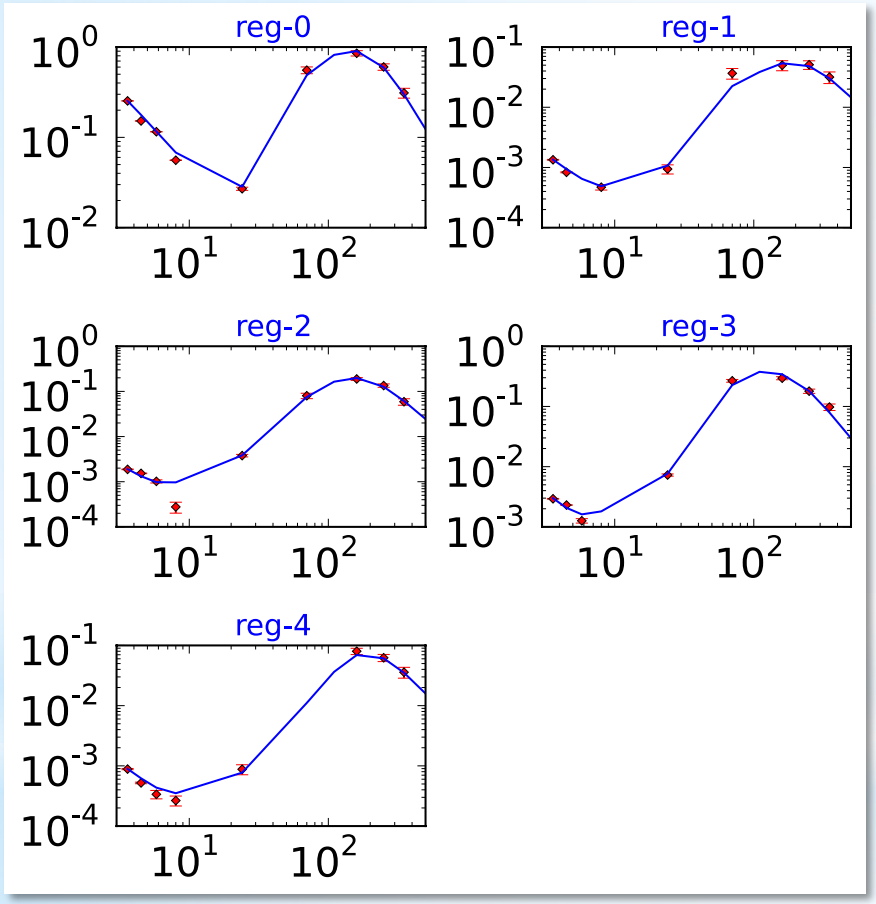
3. RESULT: A Single MBB Fit

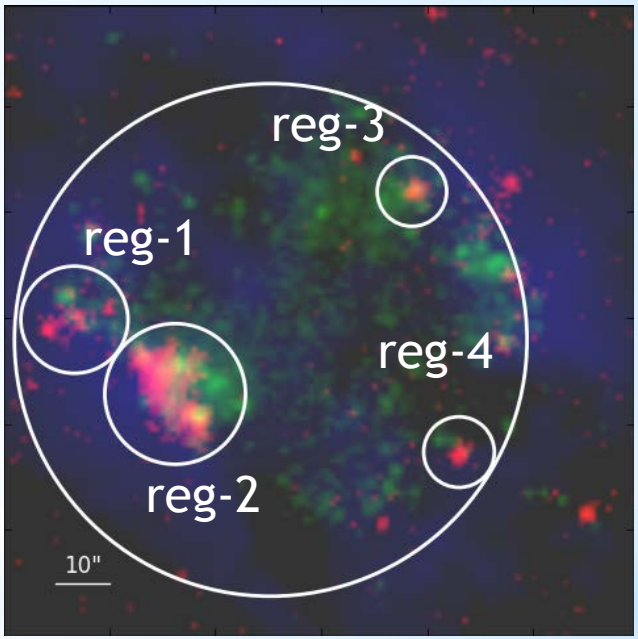
Comparisons of x^2 between fixing emissivity (a standard value of 2) and setting it as free.

	Sextans A					ESO 146-G14			
	REG-0	REG-1	REG-2	REG-3	REG-4	REG-0	REG-1	REG-2	REG-3
X^2/dof free β	1.5	1.1	2.5	0.3	0.1	3.2	0.1	0.0	0.6
X^2/dof β=2	29	17	13	30	0.1	13	4.5	1.7	13

3. RESULT: DL07 Model Fit

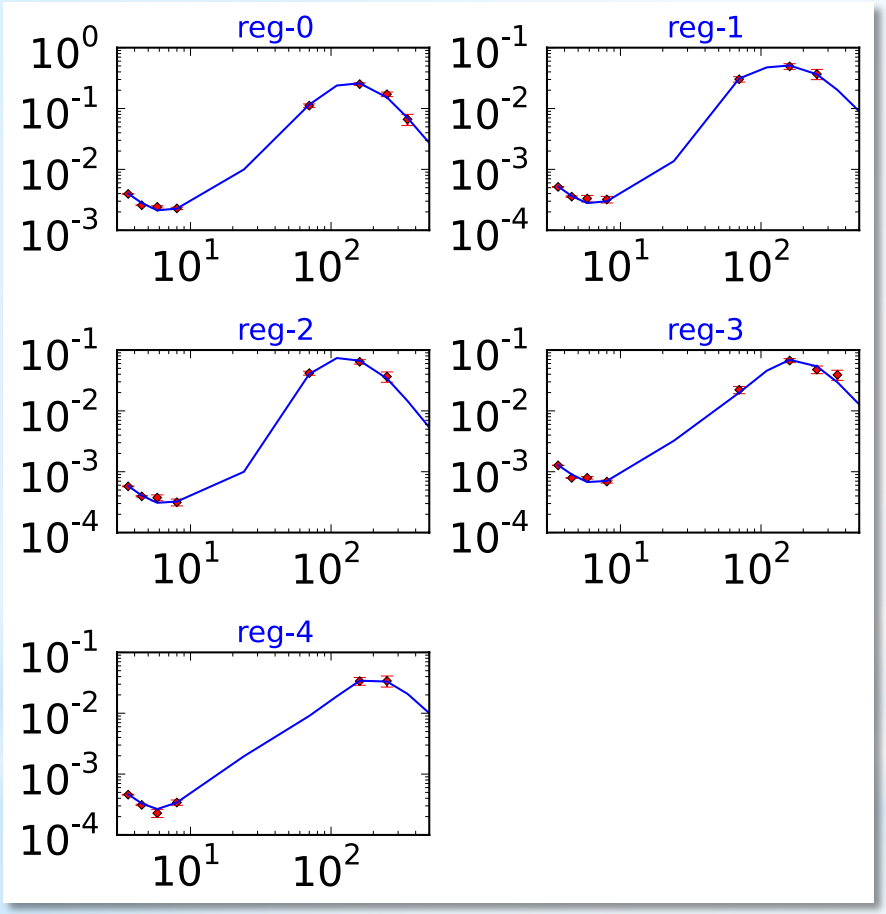
Fit To Spitzer+Herschel Photometry of Sextans A:

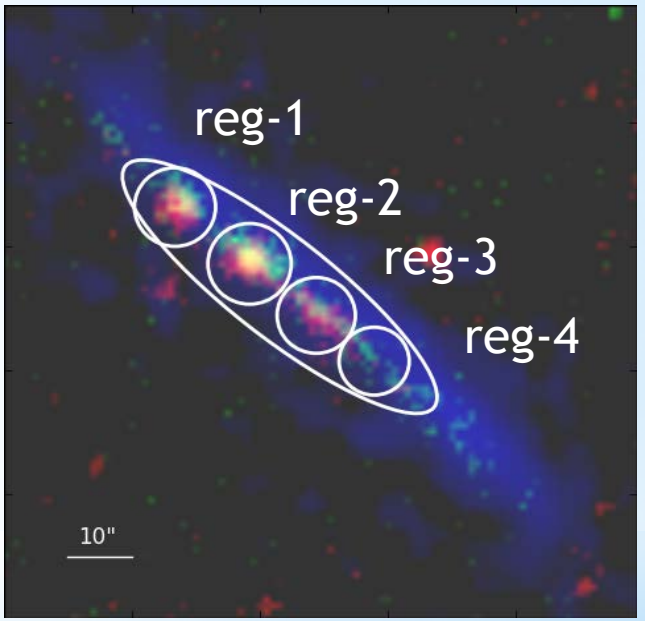




3. RESULT: DL07 Model Fit

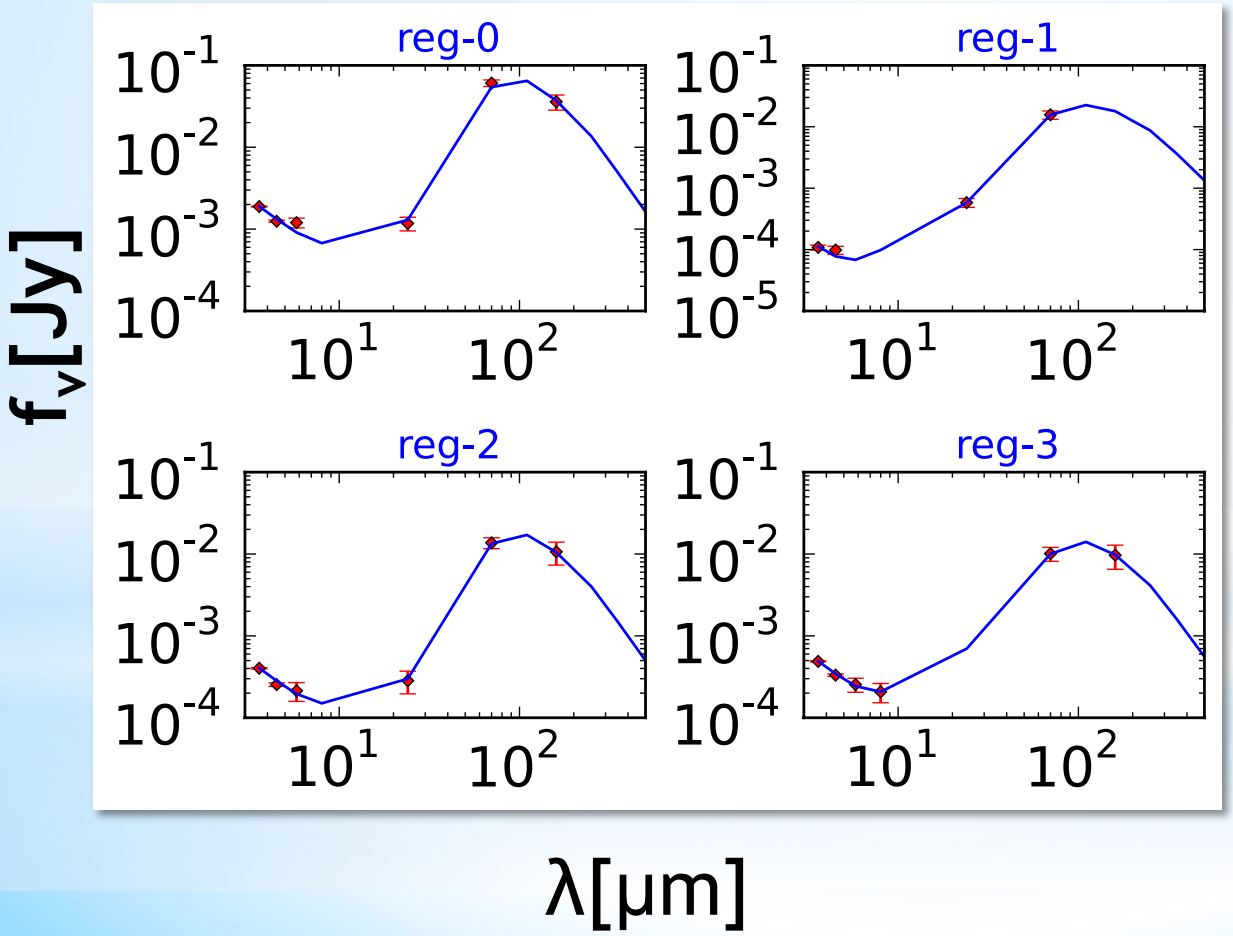
Fit To Spitzer+Herschel Photometry of ESO146-G14:

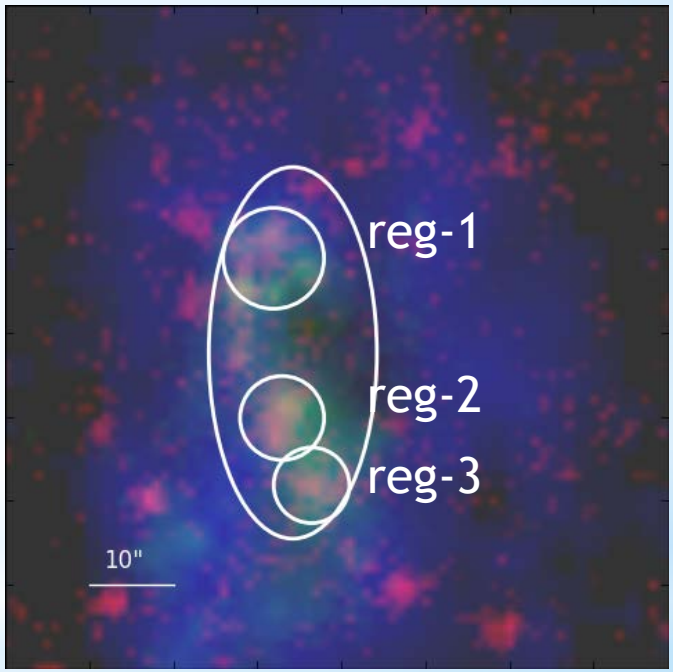




3. RESULT: DL07 Model Fit

Fit To Spitzer+Herschel Photometry of DDO 68:

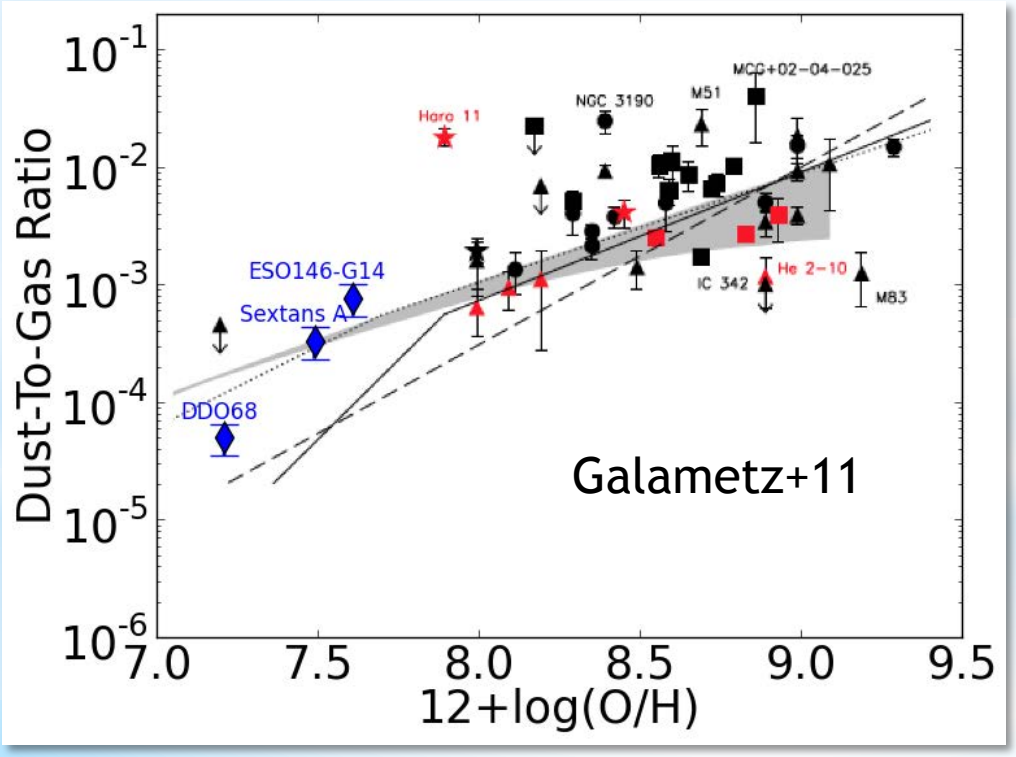


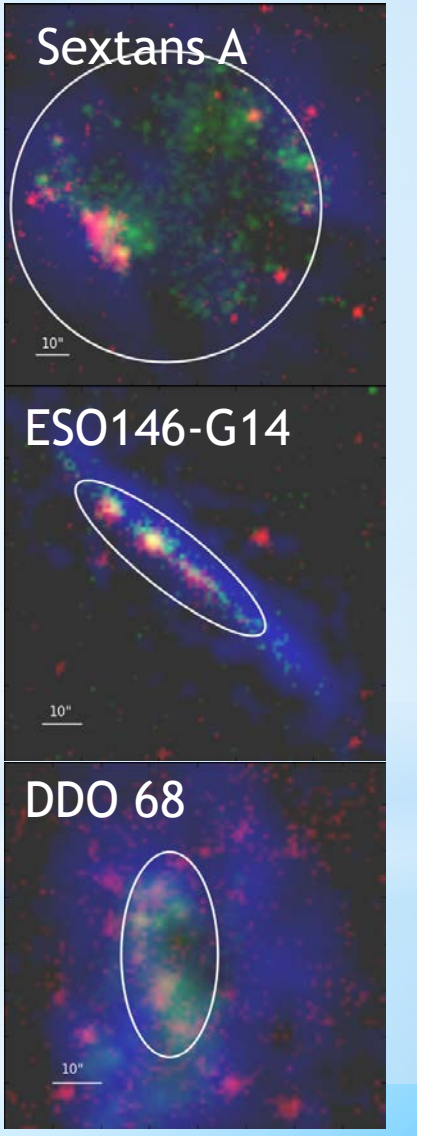


3. RESULT: DGR Of SF Disks

With spatially resolved images, we can derive the integrated DGR of star-forming disks (c.f. Draine+2007).

Assuming HI dominates the total cold gas over the SF disks (likely reasonable for this low Z, e.g. Elmegreen +2013), the dust-to-gas ratio roughly follows 1/Z.





3. RESULT: SF Efficiency

Making an assumption that the DGR is constant across the disk given following three reasons:

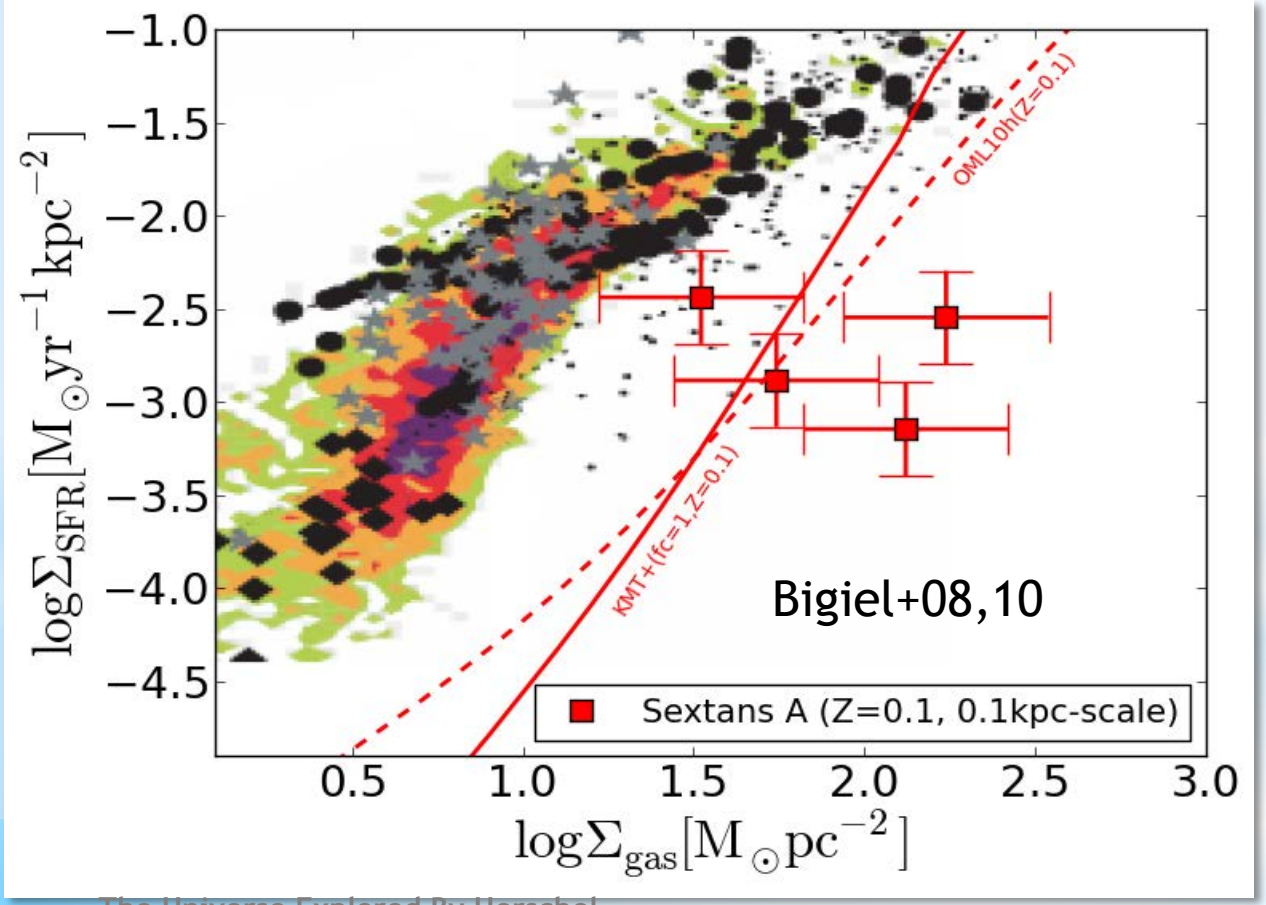
- Dust temperature and emissivity are similar for different regions, implying similar ISM conditions in different regions.
- Studies of ~ 30 spiral disks show pretty flat DGR profiles, after removing the effect of metallicity gradient (Sandtrom +2012).
- [O/H] of several HII regions in Sextans A are quite constant (Kniazev+05), as well as in DDO 68 (Pustilnik+05).

With the above assumption, we estimate the total cold gas of SF clumps with the integrated DGR and derived dust masses of SF clumps.

3. RESULT: SF Efficiency

Sextans A [0.1 kpc-scale]:

SF efficiency is lower by > 10, consistent with KMT+ model (Krumholz+2013) and OML10h model (Ostriker +2010; Bollatto+12).

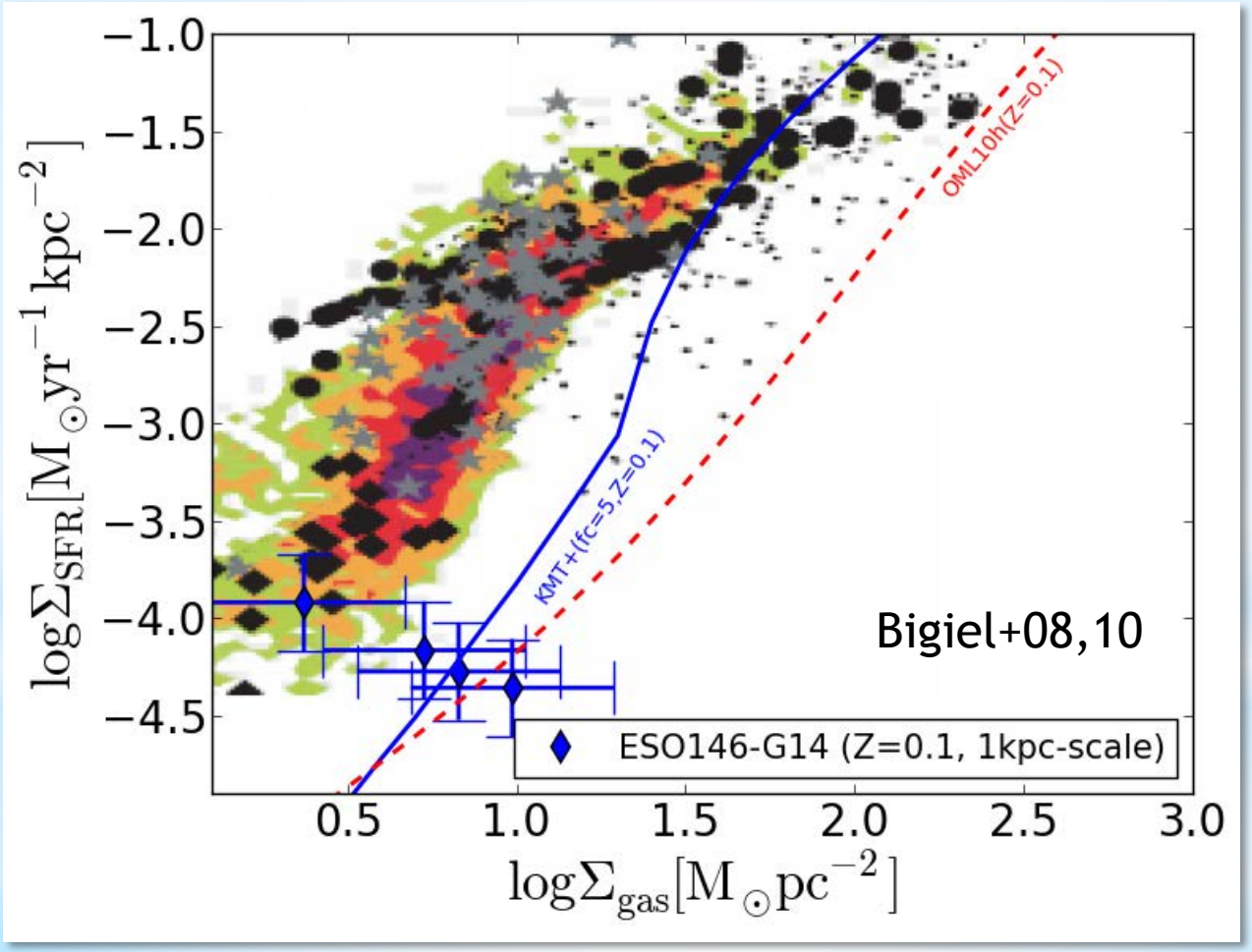


- Error on SFR:
  - UV photon noise
  - systematic uncertainty (0.2 dex)
- Error on gas:
  - The integrated DGR error.
  - The fluctuations of DGR across the disk based on spirals.
  - The derived dust mass error.

3. RESULT: SF Efficiency

ESO146-G14[1 kpc-scale]:

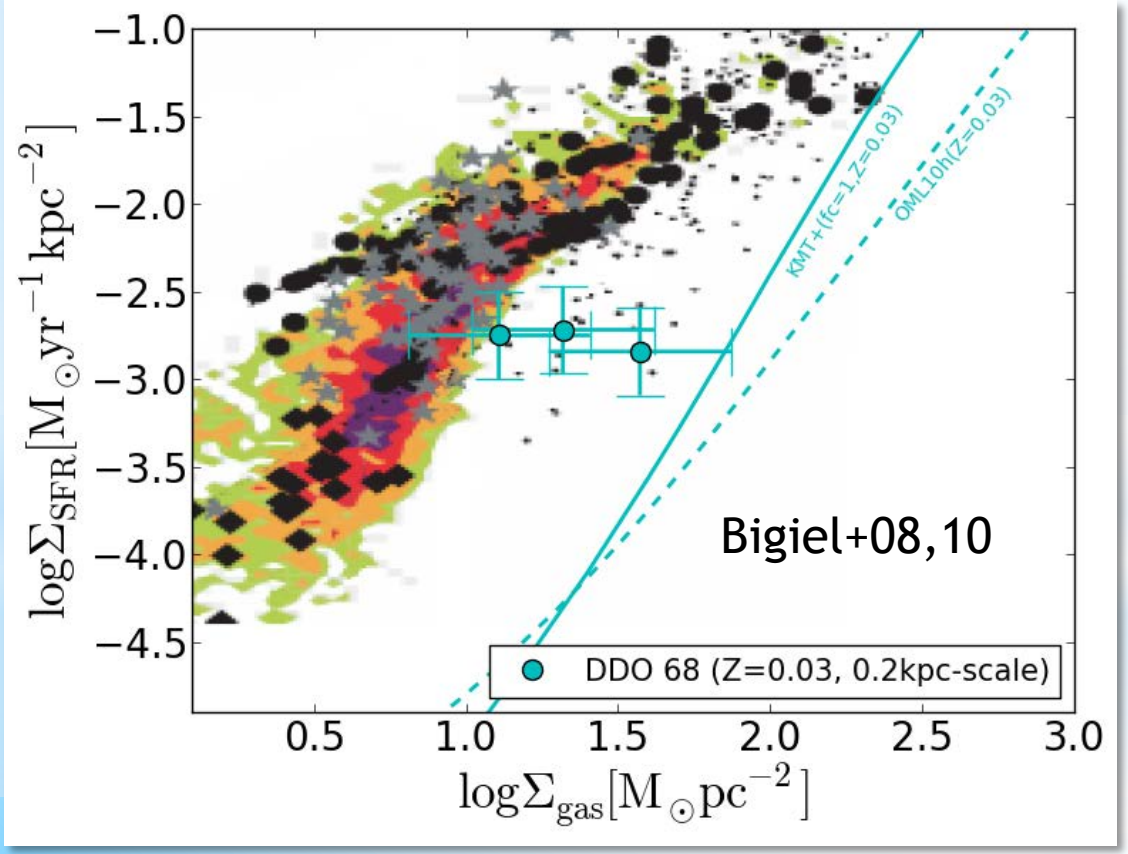
SF efficiency is lower by > 10, consistent with KMT+ model and OML10h model.



3. RESULT: SF Efficiency

DDO 68 [0.2 kpc-scale]:

SF efficiency is lower by 7, higher than predictions with KMT+ model and OML10h model.



Two Possible Reasons:

(1) Under-estimate of dust masses due to the lack of photometry > 160 um.

(2) Galaxy interactions may enhance SFE, similar to the case of massive galaxies (e.g. Daddi+2010).

4. Summary

We present Herschel spatially-resolved multi-band studies of three XMPGs. Preliminary results are:

- **Dust is enhanced (detected) in SF clumps at < $Z_{\odot}/10$, similar to the higher-Z case.**
- **The cold dust components of SF clumps of XMPGs have different FIR shapes compared to higher-Z.**
- **The integrated DGRs of SF disks of XMPGs roughly follow 1/Z.**
- **The SFEs of SF clumps of XMPGs are significantly lower (by > 10) compared to spiral galaxies at similar gas densities, demonstrating the predictions by theoretical models.**