JINGLE: JCMT dust and gas In Nearby Galaxies Legacy Exploration
—Status update and science highlights

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Image Credit:
William Montgomerie

Science Motivation

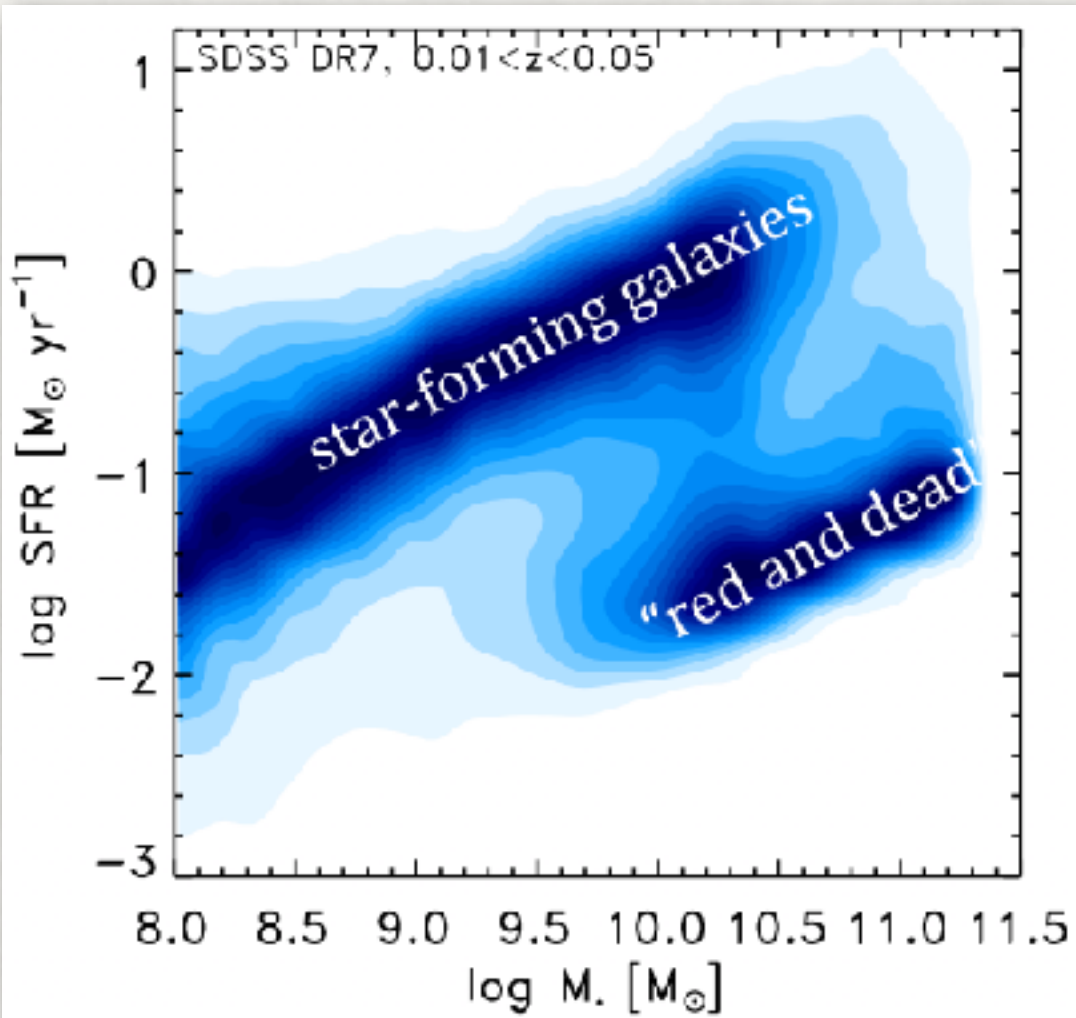


Image Credit: A. Saintonge

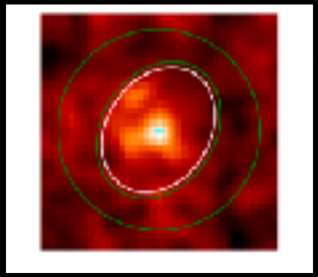
- The gas fraction and star formation efficiency (SFR/M_{gas}) are the keys to understand the mode regulating the star formation in galaxies.

- Conventionally, the cold molecular gas mass M_{gas} can be derived from:
  - M_{co} via α_{co} (e.g., Saintonge+11; Tacconi+13; Sargent+14)
  - M_{dust} via dust-to-gas ratio (e.g., Israel 1997; Leroy+11; Magdis+11; Scoville+14)

Survey Objectives of JINGLE

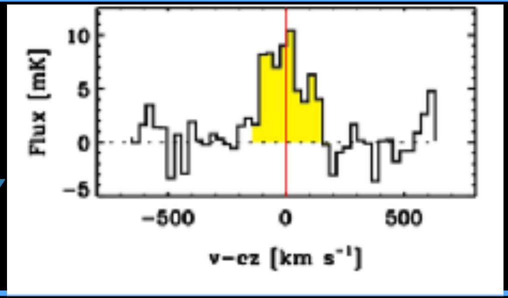
JINGLE
780h legacy survey

SCUBA-2
250 h, weather bands 2-4
850μm observations of 193 galaxies



Dust:
2) Dust mass and dust scaling relations

RxA3m
530 h, weather bands 4-5
CO(2-1) observations of 97 galaxies



Gas:
1) Star formation, star formation history and the total gas reservoir

Dust + Gas:
3) The relation between molecular gas and dust

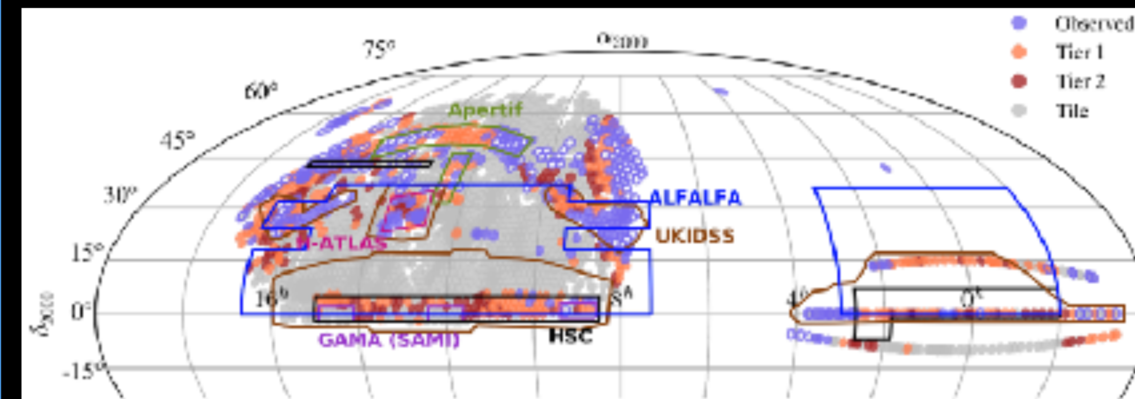
JINGLE: sample overview (2016 -)

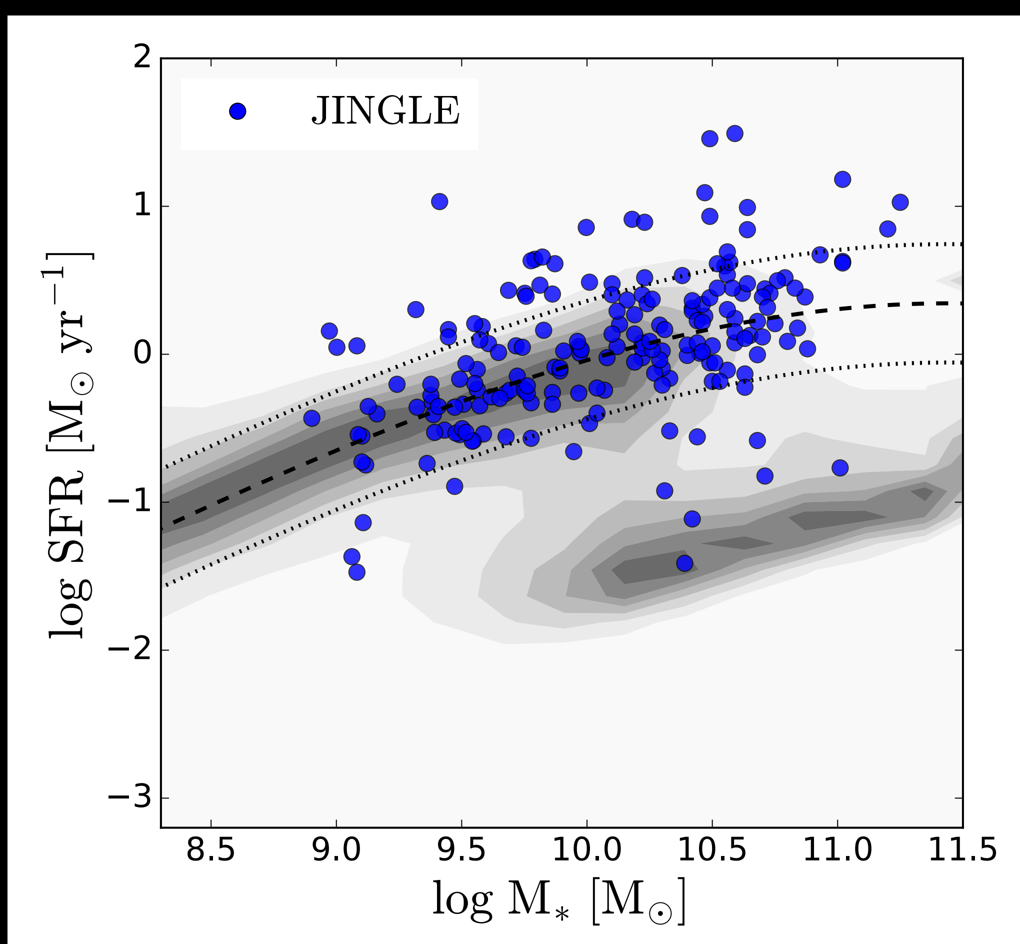
~200 nearby galaxies

Redshift range: $0.01 < z < 0.05$

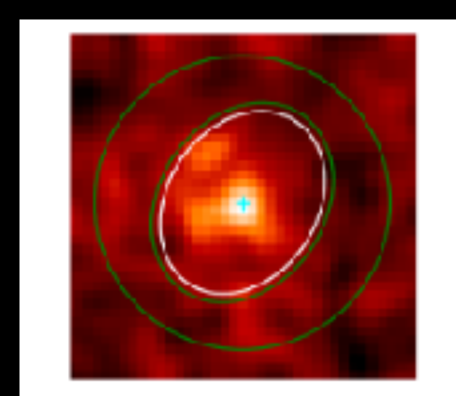
Multi-wavelength data:

- photometry: GALEX/SDSS/WISE/Herschel (H-ATLAS)
- optical IFU maps: MaNGA/SAMI
- HI maps: Apertif/ASKAP

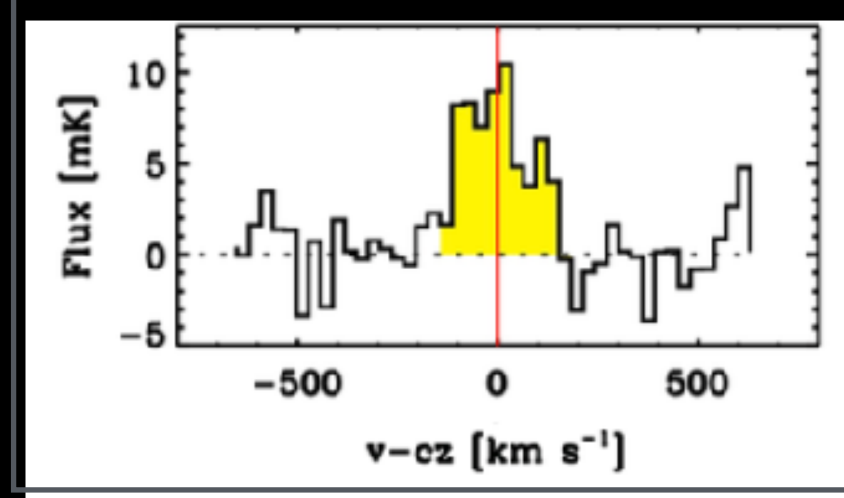




(SCUBA-2 instrument)



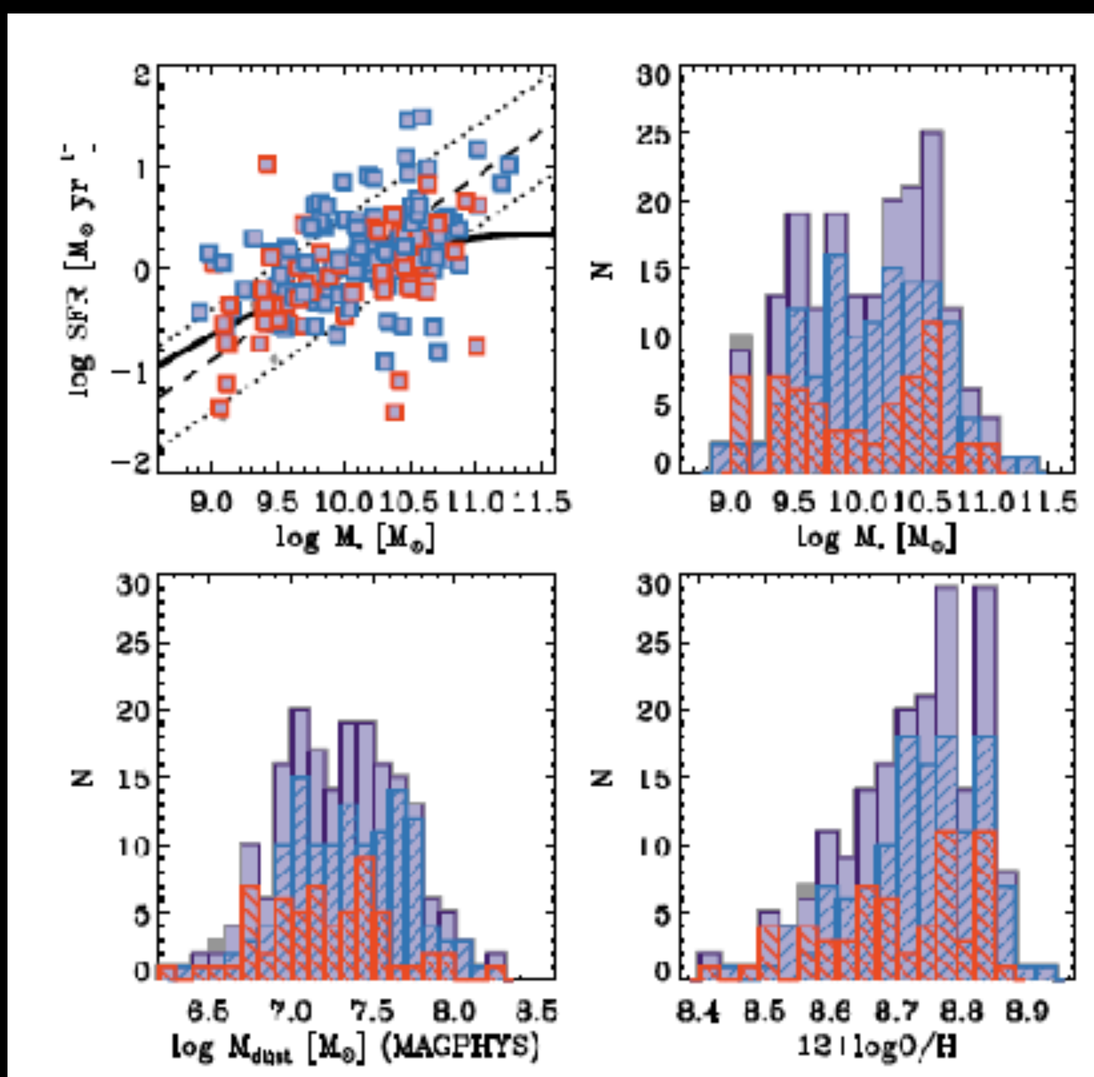
(RxA instrument)



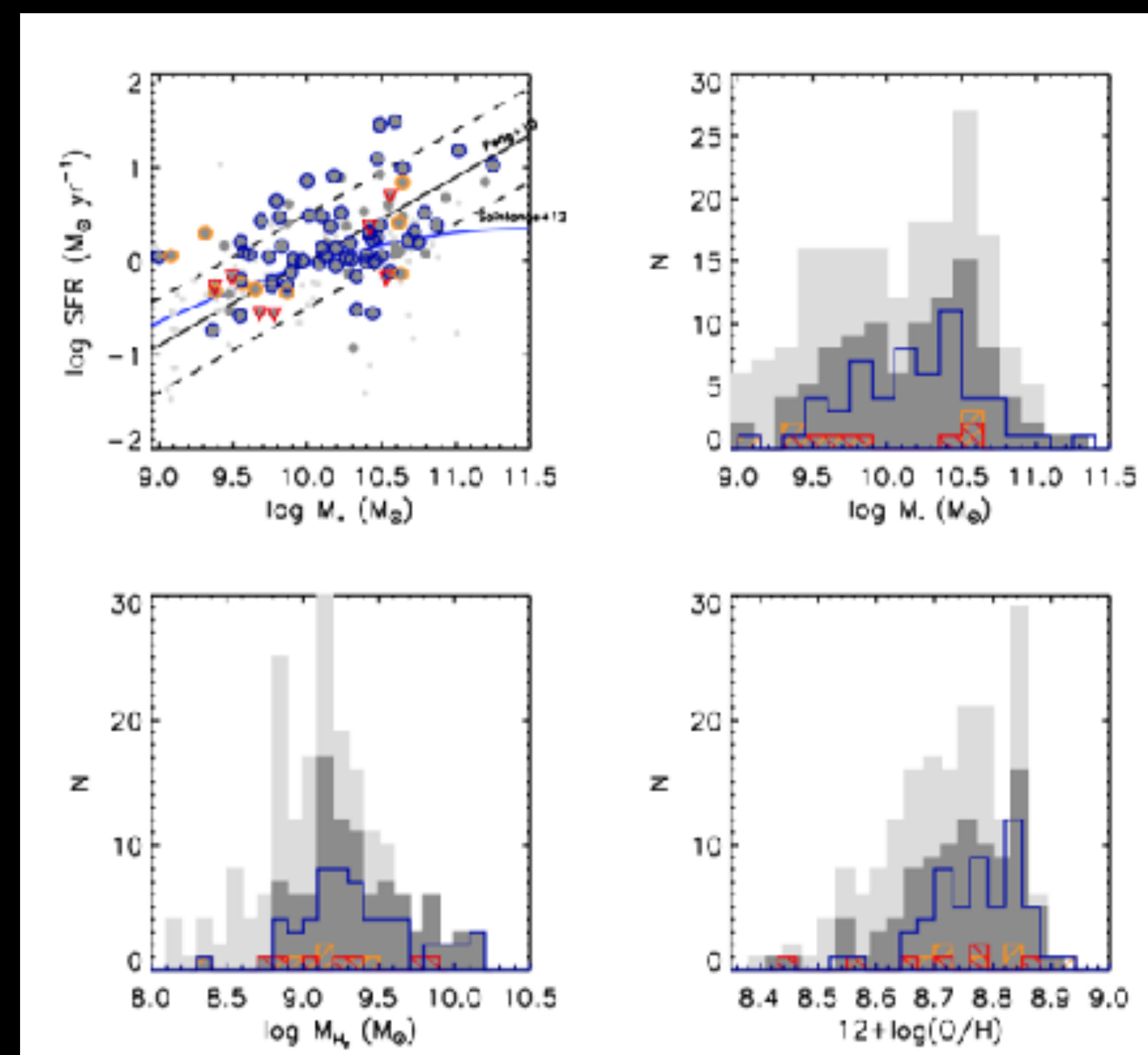
Status of JINGLE 1 Observations (as of Nov. 6, 2019)

- ★ SCUBA-2: 100% complete [193/193 galaxies observed]
- ★ RxA:
  - ✦74% complete [72/97 observed]
  - ✦79% complete for MaNGA galaxies [52/66]; 26 non-MaNGA galaxies to observe as "priority 2"
  - ★After the retirement of RxA, we started using Namakanui ("Big-Eyes") receiver

SCUBA-2 (193 galaxies)



RxA (72 galaxies)



Complete and Active Science Papers

Data Products

★ 4 papers published, 1 submitted, 1 to be submitted, 1 in prep.

- JINGLE I: Survey overview and first results (Saintonge+2018) - MNRAS, 481, 3497
- JINGLE II: SCUBA-2 data reduction and flux catalogs (Smith+2019) - MNRAS, 486, 4166
- JINGLE III: Molecular gas properties and scaling relations (Xiao+.) - in preparation
- JINGLE V: Dust properties from hierarchical Bayesian SED fitting (Lamperti+2019) - MNRAS, 489, 4389
- The effect of galaxy interactions on molecular gas properties (Pan+2018) - ApJ, 868, 132
- Molecular gas scaling relations in the JINGLE pilot sample (Gao et al.) - ApJ submitted
- JINGLE IV: Dust and HI scaling relations (De Looze+) - to be submitted

Approved JINGLE follow-up programmes

- **ALMA/ACA (C grade, cycle 6, 2018):**
Mapping CO emission in galaxies from the JINGLE survey - PI: C. Wilson (McMaster)

- **IRAM 30m/NIKA2 (20.9 hrs, 2018):**
Characterizing the millimeter emission in nearby galaxies using NIKA-2 - PI: I. Lamberti (UCL)

- **JCMT/SCUBA2 (60 hrs, Nov. 2017):**
Dust Properties of Starbursts and Green Valley Galaxies in the Local Universe - PI: H. S. Hwang (KIAS)

- **JCMT/RxA (100 hrs, Nov. 2017):**
Extending the JINGLE RxA Samples to Include" Red Mist" Galaxies - PI: R. Chown (McMaster)

- **ALMA (cycle 5):**
Snapshots of 6 Ultra-Red z>6 SCUBA2 sources from the JINGLE survey - PI: J. Greenslade (Imperial)

- **IRAM 30 m/NIKA2 (3 hrs, May 2017):**
The Brightest SPIRE dropout to date? Confirming a F850=18.9 mJy source not detected in Herschel - PI: J. Greenslade (Imperial)

- **Arecibo (37.6 hrs, Dec. 2016):**
Atomic Gas Content of JINGLE Galaxies - PI: M. Smith (Cardiff)

Science Highlights 1: JINGLE Overview + Galaxy SEDs

Saintonge+18:

> 30 aperture matched photometry (UV to FIR) and derived products of all 193 JINGLE galaxies

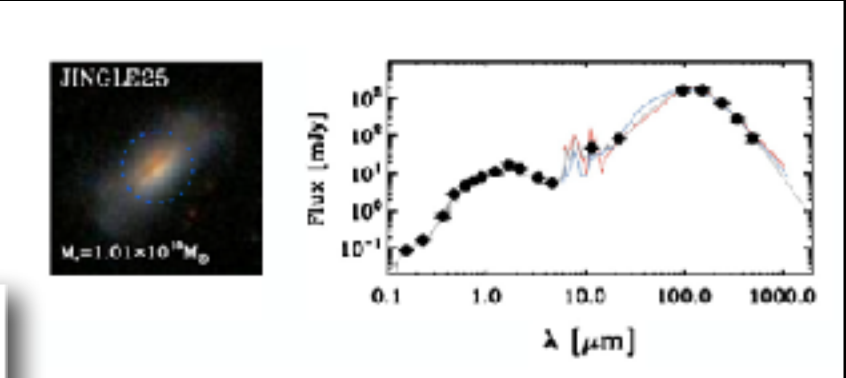


Table 1. Details of each band for which we produced CAAPR photometry. For FUV–K_s bands, we refer to each band by its listed 'Band name'; otherwise we refer to bands by wavelength. The 'Photometry present' column gives the number of galaxies in each band for which we present photometry (not counting photometry excluded due to image artefacts or insufficient sky coverage). References for calibration uncertainties and data archives are provided in the table footnotes.

Facility	Effective wavelength	Band name	Photometry present	Pixel width (arcsec)	Resolution FWHM (arcsec)	Calibration uncertainty (per cent)		Data archive
GALEX	153 nm	FUV	183	2.5	4.3	4.5	a	b
GALEX	227 nm	NUV	185	2.5	5.3	2.7		
SDSS	353 nm	*u*	193	0.4	1.3	1.3		
SDSS	475 nm	*g*	192	0.4	1.3	0.8		
SDSS	622 nm	*r*	193	0.4	1.3	0.8	c	d
SDSS	763 nm	*i*	192	0.4	1.3	0.7		
SDSS	905 nm	*z*	193	0.4	1.3	0.8		
VISTA	877 nm	*Z*	45	0.4	0.8	2.7		
VISTA	1.02 μm	*Y*	44	0.4	0.8	2.7		
VISTA	1.25 μm	*J*	12	0.4	0.8	2.7	e	f
VISTA	1.65 μm	*H*	45	0.4	0.8	2.7		
VISTA	2.15 μm	K_s	47	0.4	2.0	2.7		
2MASS	1.24 μm	*J*	192	1	2.0	1.7		
2MASS	1.66 μm	*H*	191	1	2.0	1.9	g	
2MASS	2.16 μm	K_s	192	1	2.0	1.9		
WISE	3.4 μm	(W1)	182	1.375	6.1	2.9		h
WISE	4.6 μm	(W2)	183	1.375	6.4	3.4	i	
WISE	12 μm	(W3)	193	1.375	6.5	4.6		
WISE	22 μm	(W4)	193	1.375	12	5.6		
Spitzer	4.5 μm	(IRAC-2)	28	0.6	1.72	3		
Spitzer	5.8 μm	(IRAC-3)	17	0.6	1.88	3	j	
Spitzer	8.0 μm	(IRAC-4)	16	0.6	1.98	3		
Spitzer	24 μm	(MIPS-1)	25	2.45	6	5		k
Spitzer	70 μm	(MIPS-2)	18	4	18	10	l	
Spitzer	160 μm	(MIPS-3)	18	8	38	12		
Herschel	100 μm	(PACS-Green)	190	3	11	7	m	
Herschel	160 μm	(PACS-Red)	190	4	14	7		
Herschel	250 μm	(SPIRE-PSW)	193	6	18	5.5		n
Herschel	350 μm	(SPIRE-PMW)	193	8	25	5.5	o	
Herschel	500 μm	(SPIRE-PLW)	193	12	36	5.5		

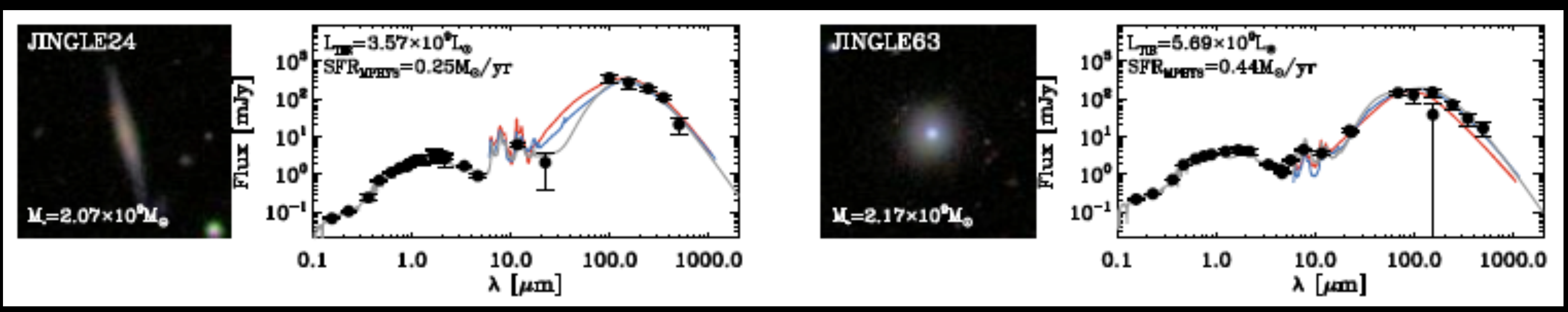
Science Highlights 1: JINGLE Overview + Galaxy SEDs

Saintonge+18:

> 30 aperture matched photometry and derived products of JINGLE galaxies

Table 2. Properties of the JINGLE galaxies (the full table is available electronically)

JINGLE ID	SDSS name	α_{J2000} [deg]	δ_{J2000} [deg]	z_{spec}	$\log M_*$ [$M_\odot$]	r_{50} [kpc]	$\log \mu_*$ [$M_\odot$kpc^{-2}]	C	M	logSFR [$M_\odot$yr^{-1}]	12+ log(O/H)	BPT	Env
JINGLE0	J131616.82+252418.7	199.07012	25.40522	0.0129	10.31 ± 0.08	3.78	9.15	2.78	1	-0.92 ± 0.05	8.75	3	2
JINGLE1	J131453.43+270029.2	198.72264	27.00812	0.0154	9.95 ± 0.10	5.70	8.47	2.78	1	-0.66 ± 0.12	8.78	1	1
JINGLE2	J131526.03+330926.0	198.85848	33.15724	0.0162	9.12 ± 0.12	3.44	8.11	2.57	1	-0.75 ± 0.06	8.64	1	1
JINGLE3	J125606.09+274041.1	194.02541	27.67810	0.0165	9.00 ± 0.01	2.23	8.10	2.44	1	0.05 ± 0.02	8.56	1	3
JINGLE4	J132134.91+261816.8	200.39549	26.30467	0.0165	9.86 ± 0.05	2.73	8.95	2.63	1	-0.26 ± 0.02	8.82	1	1
JINGLE5	J091728.99-003714.1	139.37082	-0.62058	0.0166	9.97 ± 0.07	7.09	8.37	2.59	1	0.01 ± 0.02	8.76	1	3
JINGLE6	J132320.14+320349.0	200.83396	32.06361	0.0167	9.49 ± 0.08	6.00	7.85	2.25	1	-0.54 ± 0.04	8.68	1	3
JINGLE7	J132051.75+312159.8	200.21563	31.36661	0.0168	9.55 ± 0.04	5.13	8.03	2.44	1	-0.58 ± 0.05	8.68	1	3
JINGLE8	J091642.17+001220.0	139.17575	0.20556	0.0169	9.68 ± 0.07	3.29	8.90	2.69	1	-0.56 ± 0.05	8.65	2	1
JINGLE9	J131547.11+315047.1	198.94630	31.84642	0.0170	9.86 ± 0.18	5.87	8.07	2.36	1	0.41 ± 0.23	8.68	1	2
JINGLE10	J091750.80-001642.5	139.46168	-0.27848	0.0175	10.45 ± 0.05	7.98	8.78	2.41	1	0.01 ± 0.01	8.72	1	2
JINGLE11	J131020.14+322859.4	197.58392	32.48319	0.0176	9.75 ± 0.06	9.16	7.94	2.42	1	-0.25 ± 0.02	8.65	-1	1
JINGLE12	J132251.07+314934.3	200.71281	31.82622	0.0178	9.38 ± 0.05	6.49	7.68	2.15	1	-0.32 ± 0.02	8.62	1	1
JINGLE13	J114253.92+000942.7	175.72470	0.16187	0.0185	8.97 ± 0.01	3.02	8.11	2.25	1	0.16 ± 0.29	8.49	1	3



Science Highlights 2: IR & submm Data

Smith et al. 2019: 850 um data reduction

Monthly Notices of the Royal Astronomical Society
MNRAS 486, 4166–4185 (2019) doi:10.1093/mnras/stz1102
Advance Access publication 2019 April 17

JINGLE, a JCMT legacy survey of dust and gas for galaxy evolution studies: II. SCUBA-2 850 µm data reduction and dust flux density catalogues

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ABSTRACT

We present the SCUBA-2 850µm component of JINGLE, the new JCMT large survey for dust and gas in nearby galaxies, which with 193 galaxies is the largest targeted survey of nearby galaxies at 850 µm. We provide details of our SCUBA-2 data reduction pipeline, optimized for slightly extended sources, and including a calibration model adjusted to match conventions used in other far-infrared (FIR) data. We measure total integrated fluxes for the entire JINGLE sample in 10 infrared/submillimetre bands, including all WISE, *Herschel*-PACS, *Herschel*-SPIRE, and SCUBA-2 850 µm maps, statistically accounting for the contamination by CO(J = 3–2) in the 850 µm band. Of our initial sample of 193 galaxies, 191 are detected at 250 µm with a $\geq 5\sigma$ significance. In the SCUBA-2 850 µm band we detect 126 galaxies with $\geq 3\sigma$ significance. The distribution of the JINGLE galaxies in FIR/sub-millimetre colour–colour plots reveals that the sample is not well fit by single modified-blackbody models that assume a single dust-emissivity index (β). Instead, our new 850 µm data suggest either that a large fraction of our objects require $\beta < 1.5$, or that a model allowing for an excess of sub-mm emission (e.g. a broken dust emissivity law, or a very cold dust component $\lesssim 10$ K) is required. We provide relations to convert FIR colours to dust temperature and β for JINGLE-like galaxies. For JINGLE the FIR colours correlate more strongly with star-formation rate surface-density rather than the stellar surface-density, suggesting heating of dust is greater due to younger rather than older stellar-populations, consistent with the low proportion of early-type galaxies in the sample.

Key words: galaxies: ISM – galaxies: photometry – galaxies: spiral – submillimetre: ISM.

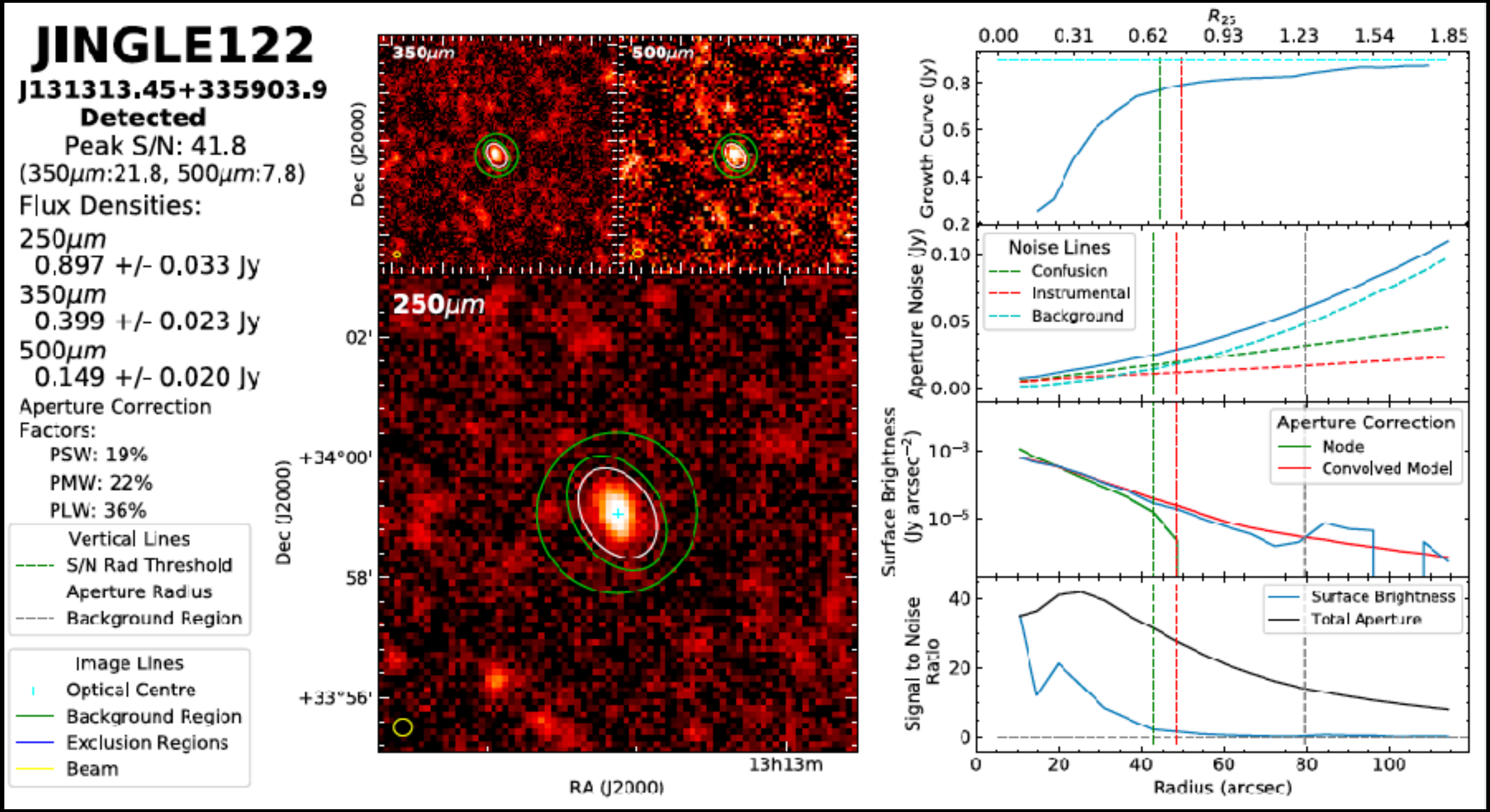
Table 1. Individual band parameters.

Instrument	Band	FWHM (arcsec)	Beam area (arcsec^2)	Confusion noise (mJy beam^{-1})	NEBULISER median filter (arcsec)
SPIRE	250 µm	17.6	469.7	5.8	90
	350 µm	23.9	831.7	6.3	90
	500 µm	35.2	1793.5	6.8	90
PACS	100 µm	11.4	147.2^a	0.27	60
	160 µm	13.7	212.7^a	0.92	60
WISE	3.4 µm	6.1	42.2^a	–	60
	4.6 µm	6.4	46.4^a		60
	12 µm	6.5	47.9^a	–	60
	22 µm	12.0	163.2^a		60
SCUBA-2	850 µm	13.0	229.5	($m = 1.22$, $c = -0.61$)^b	60

126 out of 193 galaxies (64%) are detected in 850um with S/N > 3

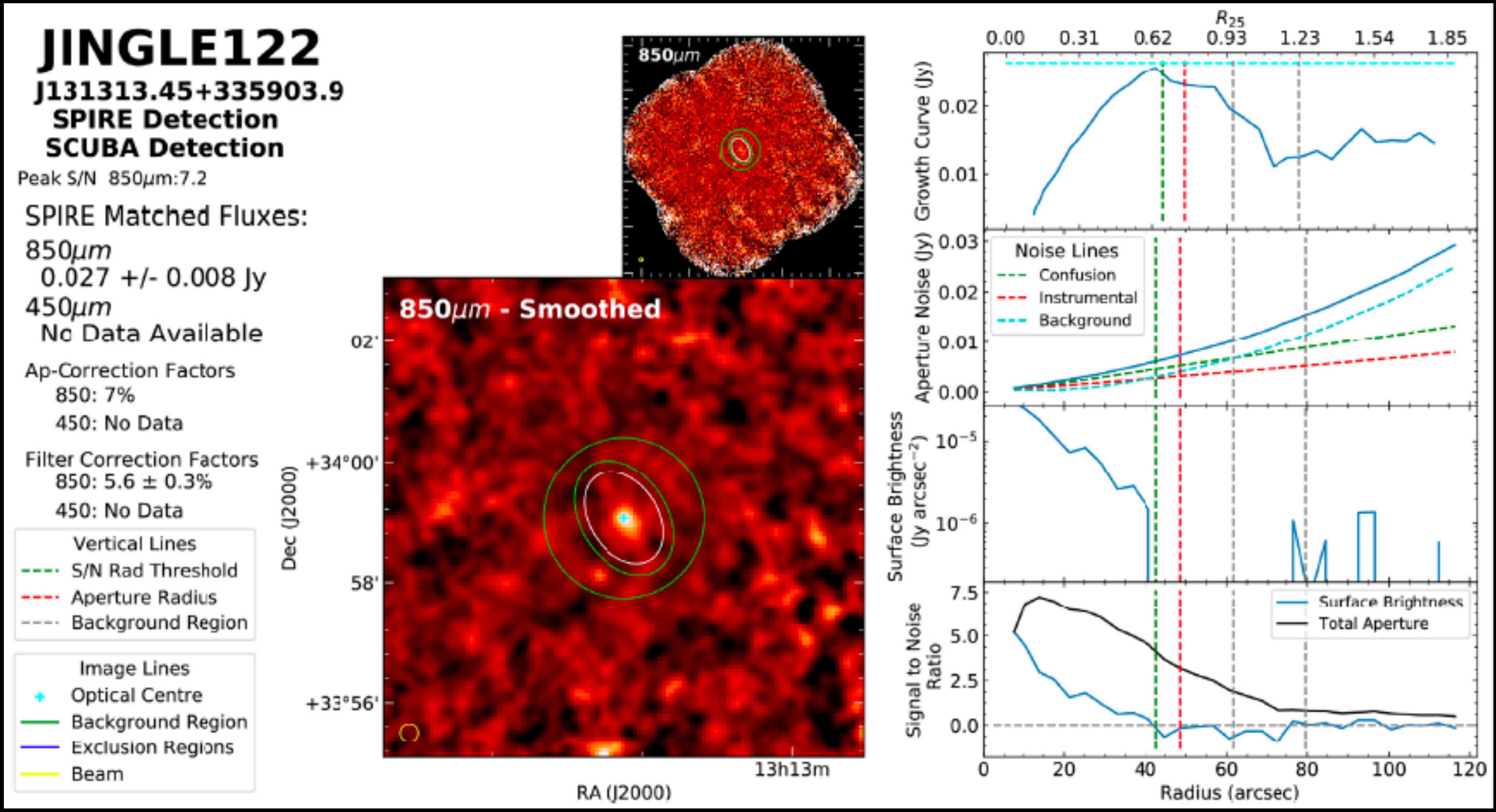
Science Highlights 2: IR & submm Data

Smith et al. 2019



Science Highlights 2: IR & submm Data

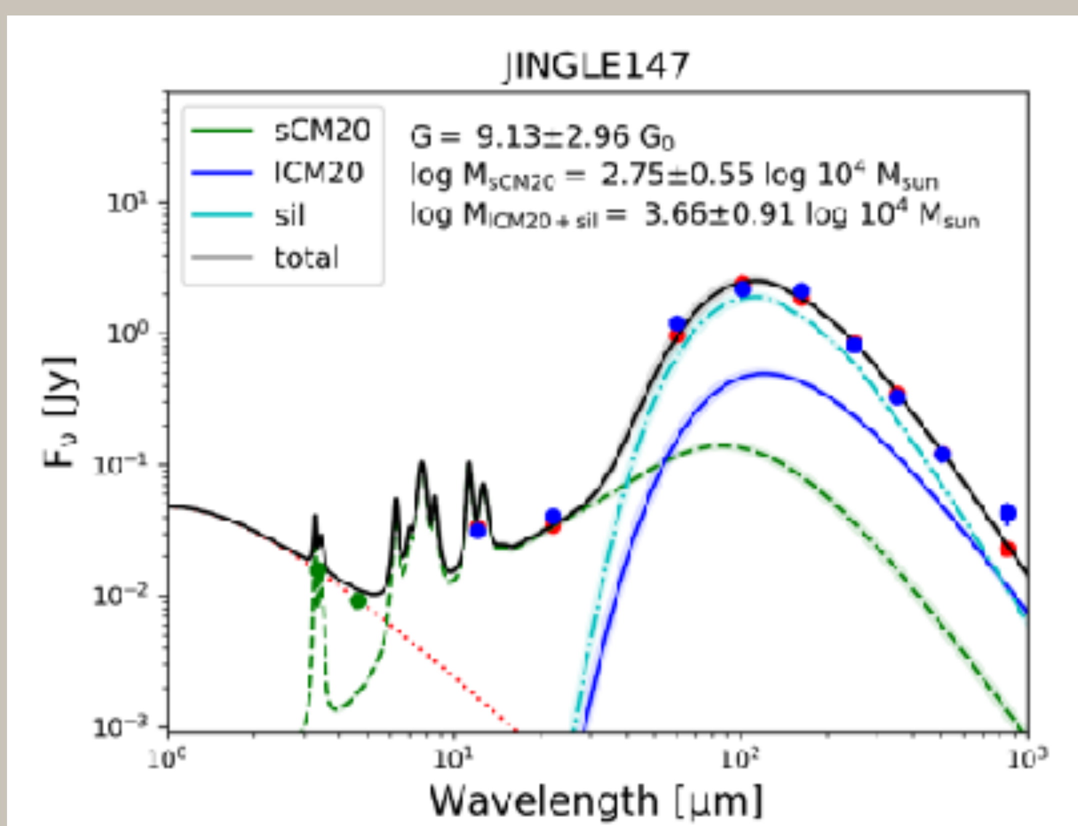
Smith et al. 2019



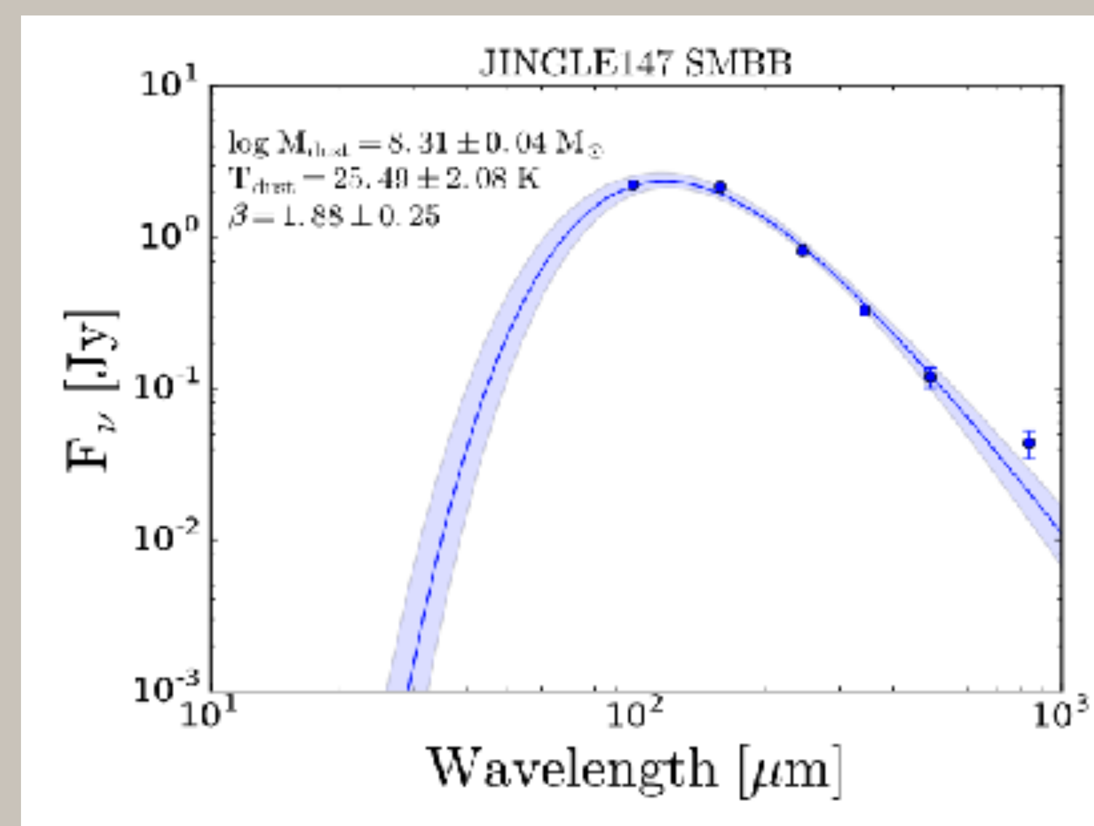
Science Highlights 3:
Dust Properties from more sophisticated SED fitting

THEMIS models
physically motivated dust models

MBB: modified black-body
analytical functions



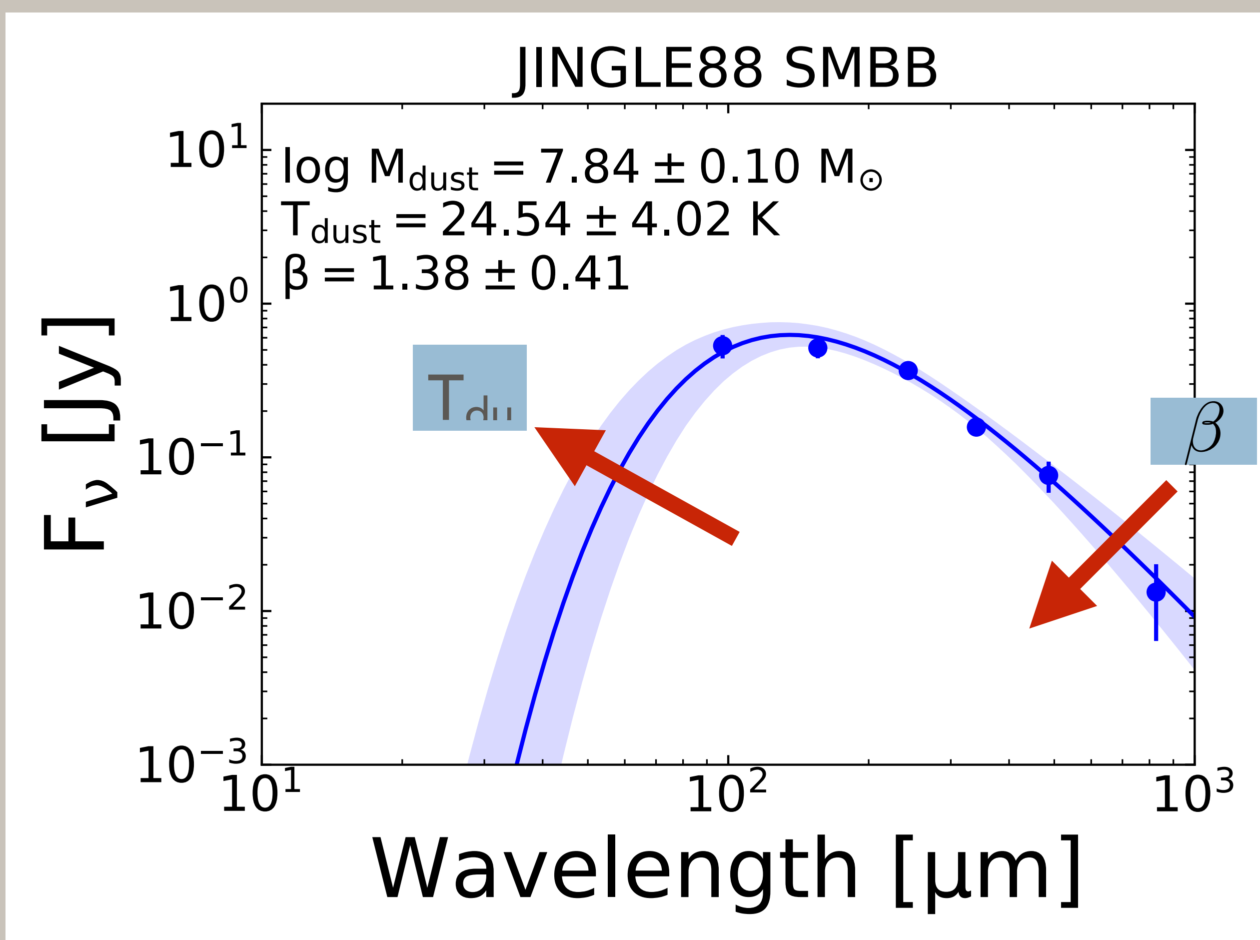
De Looze et al., in prep.

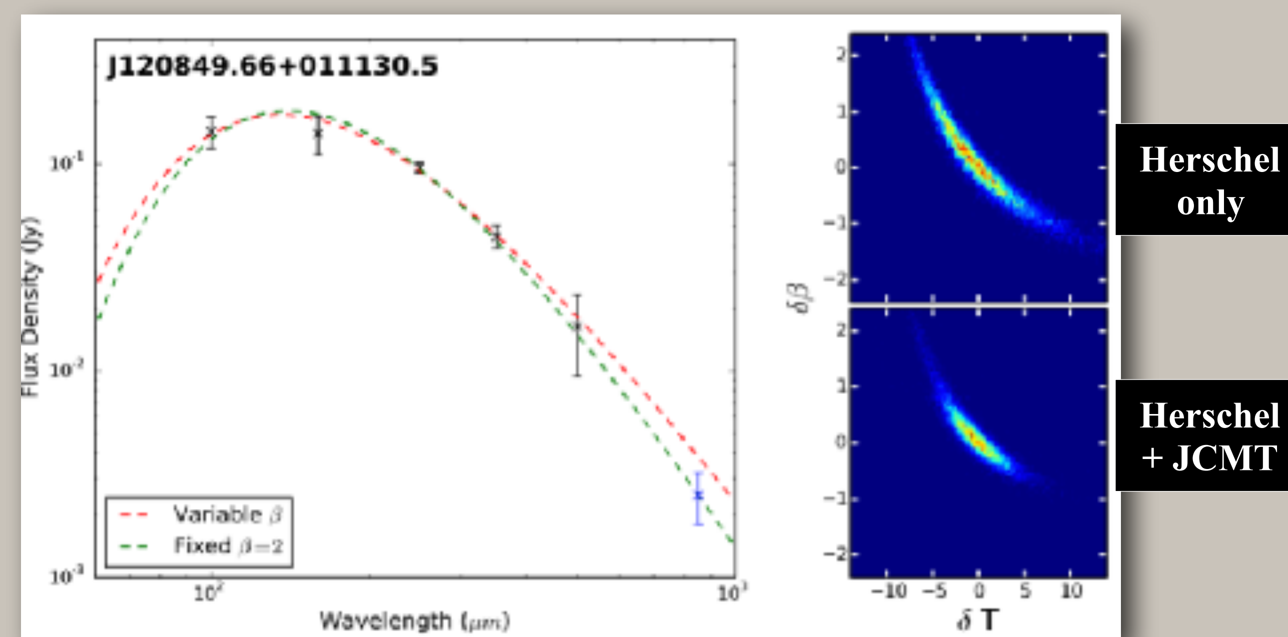


Lamperti et al., 2019.

Single Modified Black Body (SMBB)

$$F_\lambda(M_{\rm dust}, T_{\rm dust}, \beta) = \frac{M_{\rm dust}}{D^2}\kappa_0 \left(\frac{\lambda_0}{\lambda}\right)^{\beta} B_\lambda(T_{\rm dust})$$

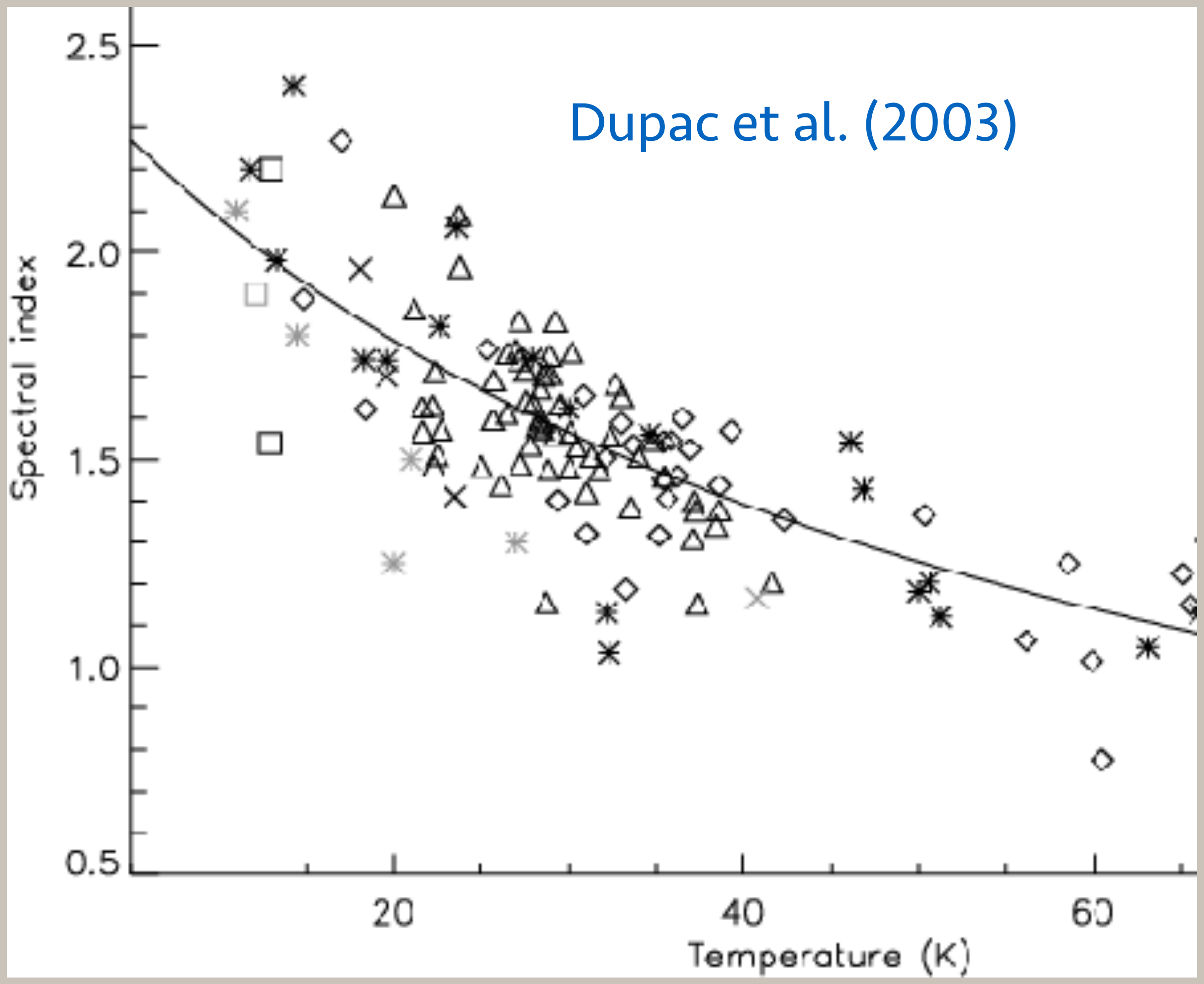




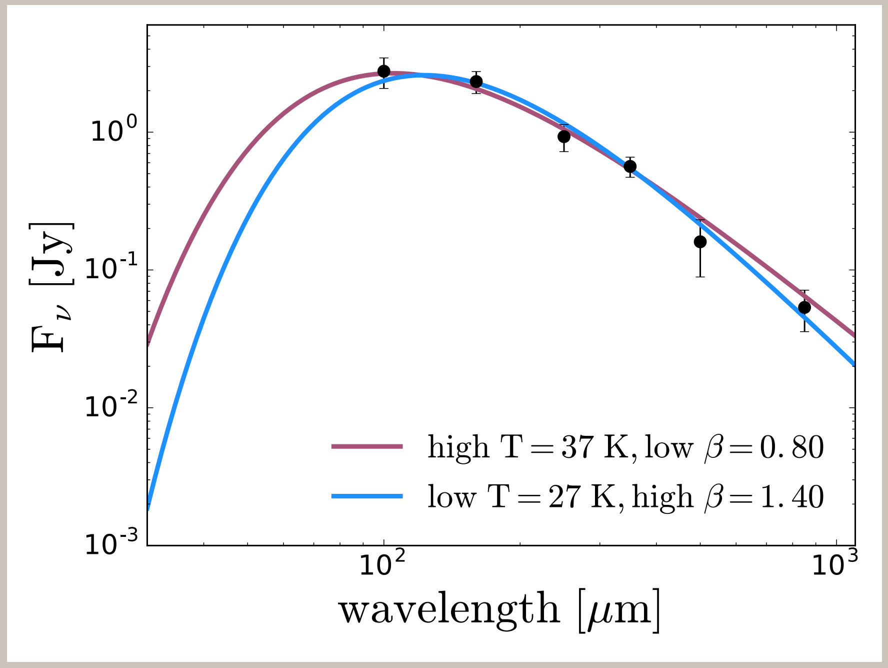
By adding SCUBA-2 850um data, we can fit better for dust temperature ($T_{\rm dust}$) and dust emissivity index (β).

Correlation between T_{dust} and β :
Is it intrinsic correlation or degeneracy?

β



Temperature [K]



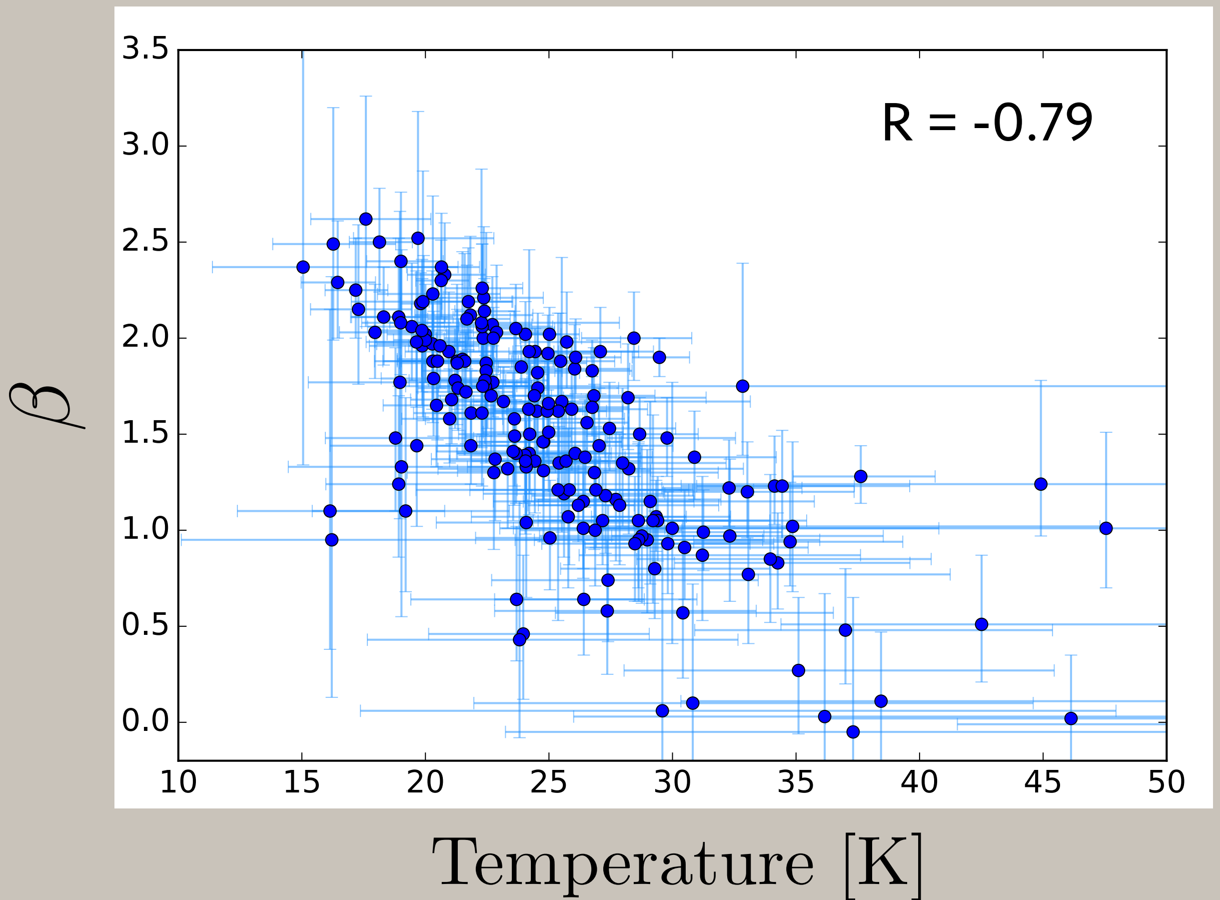
Reference: Shetty et al. 2009a,b

See also Désert et al. (2008), Paradis et al. (2010), Baracco et al. (2011), Smith et al. (2012)

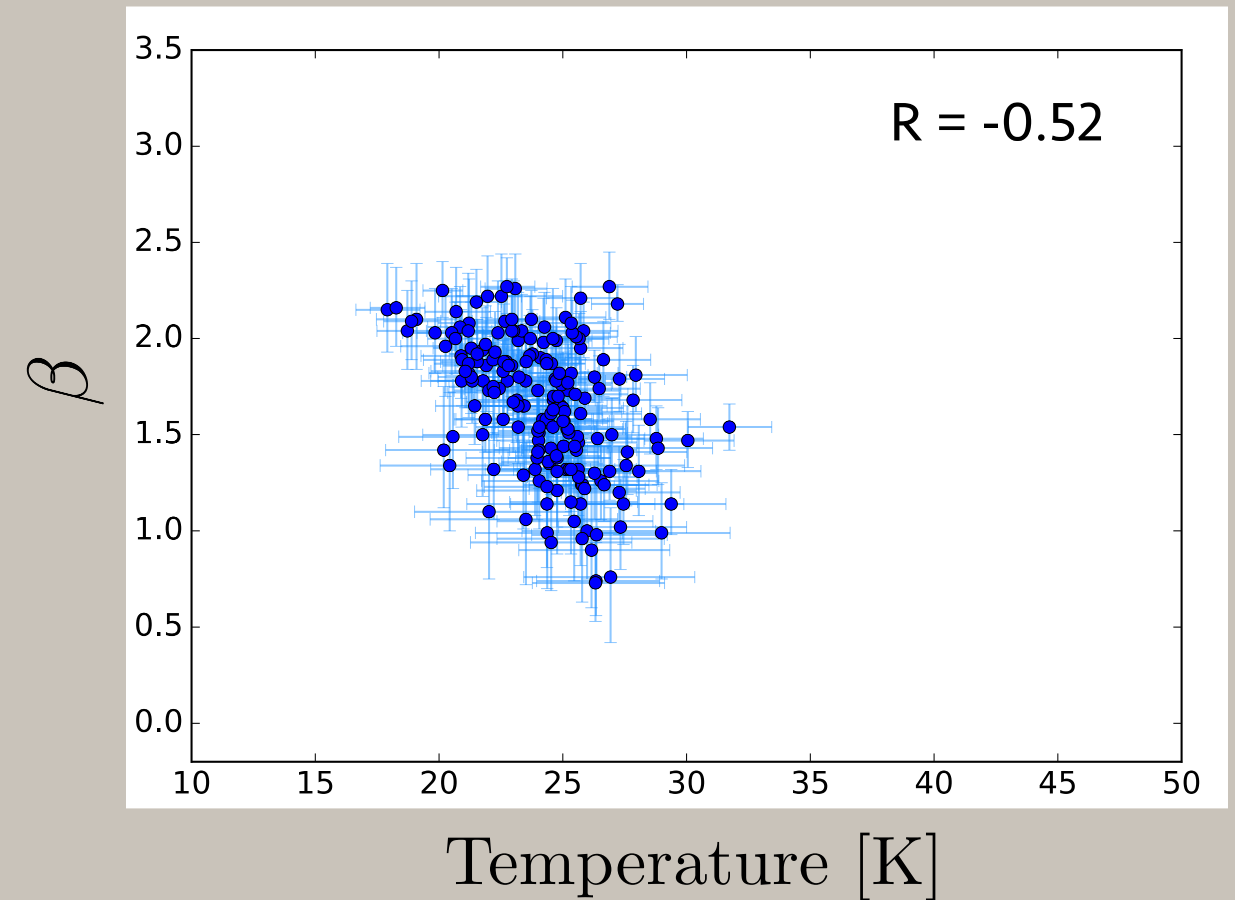
Application to the JINGLE sample

Lamperti et al., 2019

non-hierarchical



hierarchical

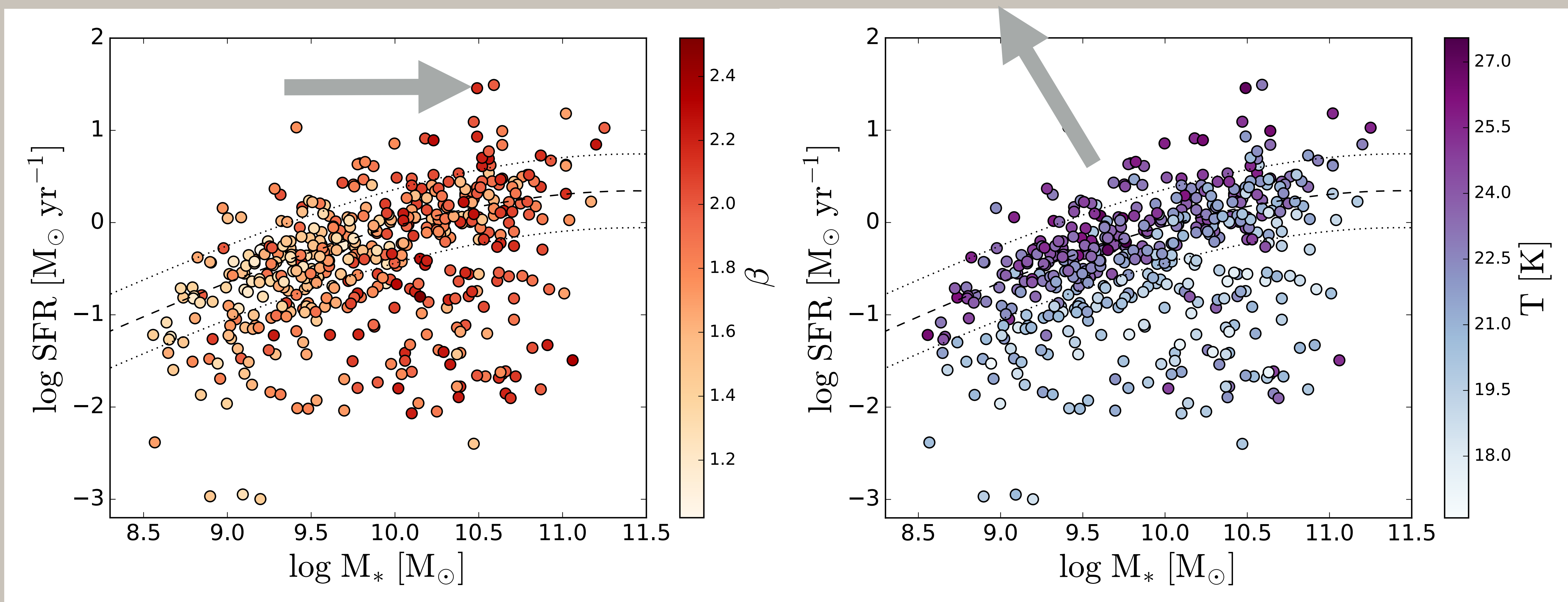


The hierarchical method reduces the T_{dust} - β anti-correlation in the JINGLE sample!

Dust Properties On the SFR-M* plane in JINGLE and HRS

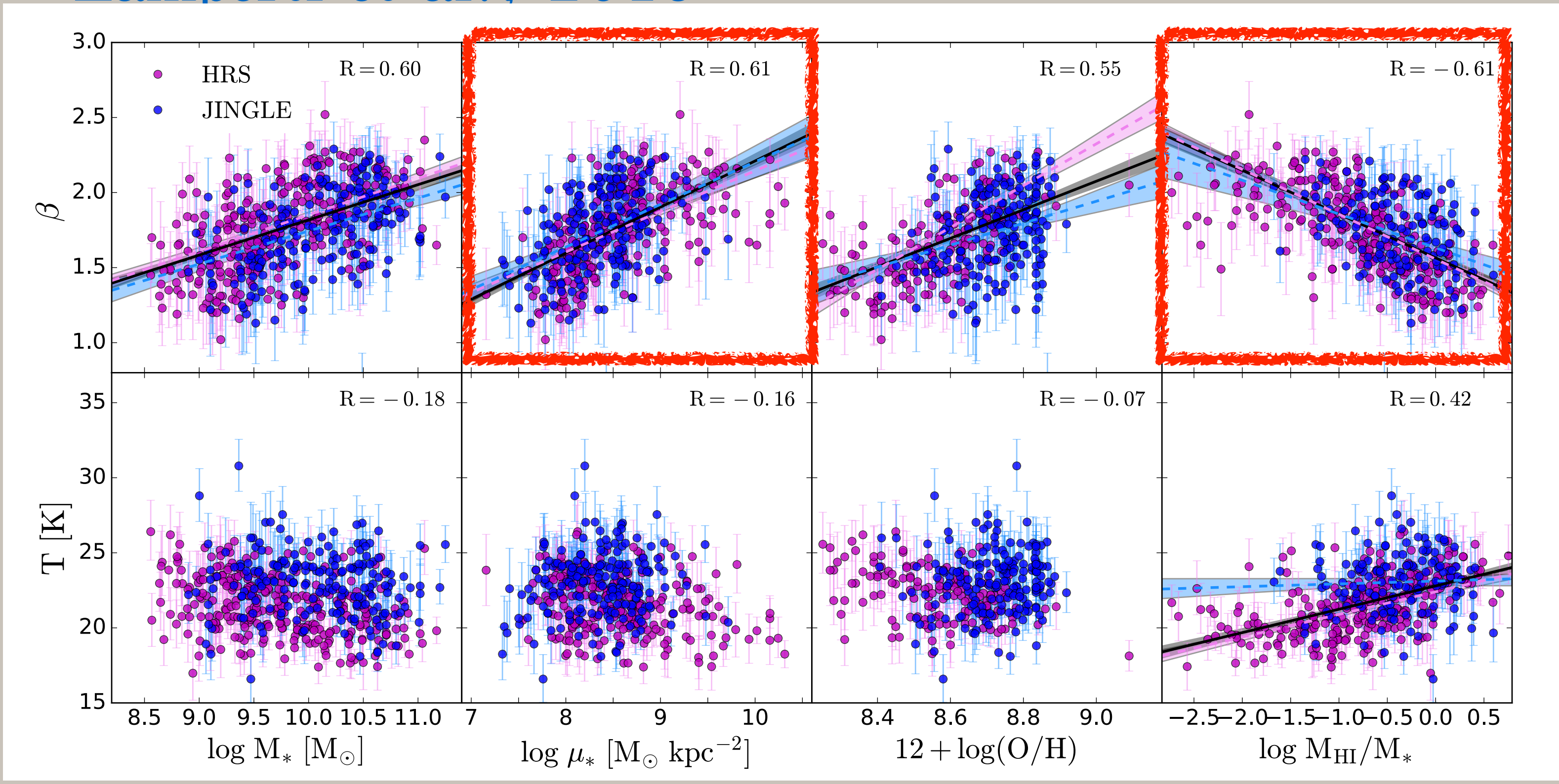
Lamperti et al., 2019

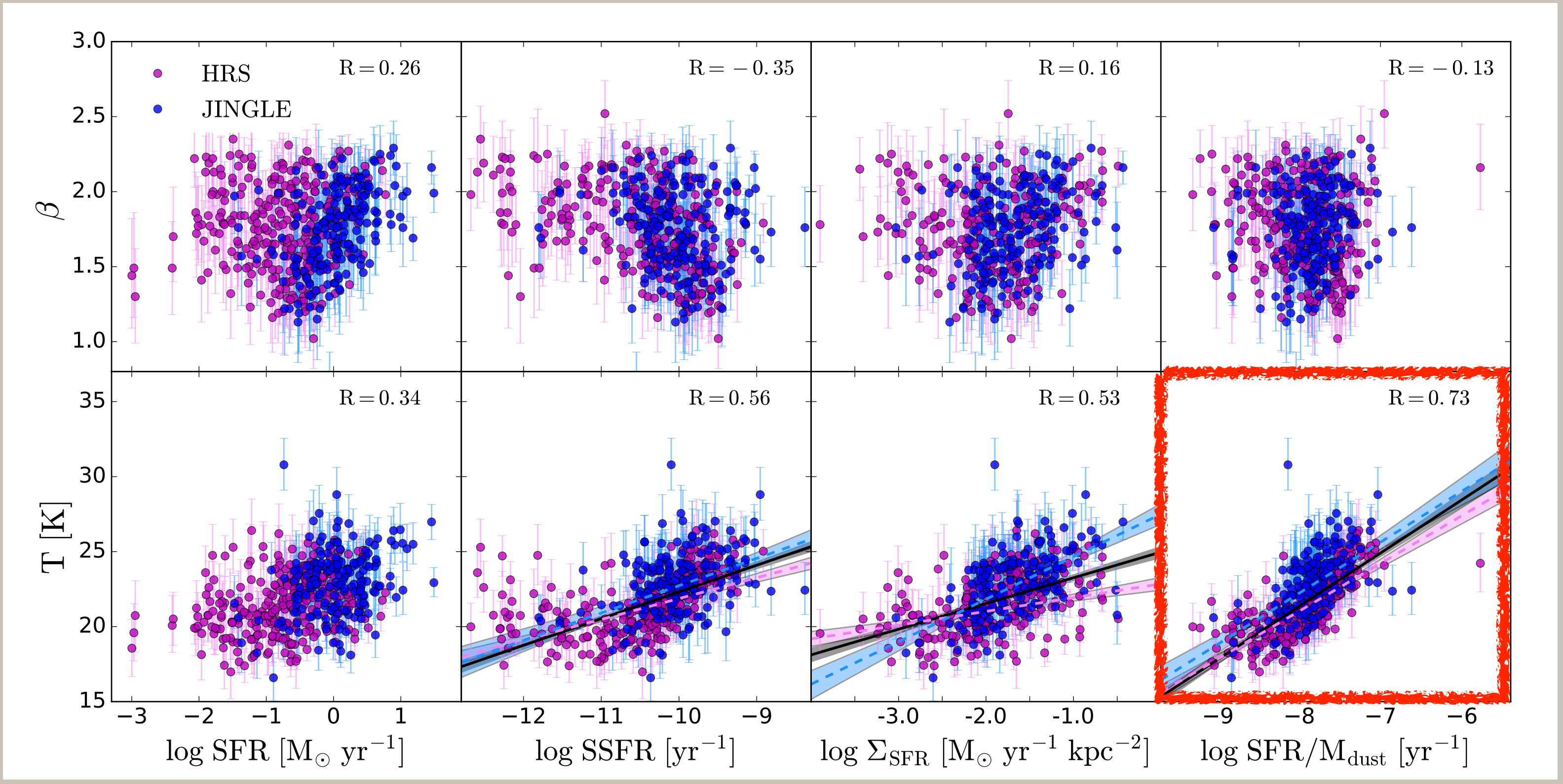
dust emissivity index β dust temperature T_{dust}



Scaling Relations

Lamperti et al., 2019





Dust scaling relations can be applied to derive dust properties for samples were fewer photometric data are available, for example at higher redshift.

Science Highlights 4: Galaxy Interactions and Molecular Gas Properties

The Astrophysical Journal, 868:132 (20pp), 2018 December 1 https://doi.org/10.3847/1538-4357/aaeb92

The Effect of Galaxy Interactions on Molecular Gas Properties

Hsi-An Pan[1], Lihwai Lin[1], Bau-Ching Hsieh[1], Ting Xiao[2,3], Yang Gao[3], Sara L. Ellison[4], Jillian M. Scudder[5], Jorge Barrera-Ballesteros[6], Fangting Yuan[3], Amélie Saintonge[7], Christine D. Wilson[8], Ho Seong Hwang[9], Ilse De Looze[7,10], Yu Gao[11], Luis C. Ho[12,13], Elias Brinks[14], Angus Mok[15], Toby Brown[8], Timothy A. Davis[16], Thomas G. Williams[16], Aeree Chung[17], Harriet Parsons[18], Martin Bureau[19], Mark T. Sargent[20], Eun Jung Chung[21], Eunbin Kim[21,22], Tie Liu[18,21,23], Michał J. Michałowski[24], and Tomoka Tosaki[25]

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Abstract

Galaxy interactions are often accompanied by an enhanced star formation rate (SFR). Since molecular gas is essential for star formation, it is vital to establish whether and by how much galaxy interactions affect the molecular gas properties. We investigate the effect of interactions on global molecular gas properties by studying a sample of 58 galaxies in pairs and 154 control galaxies. Molecular gas properties are determined from observations with the JCMT, PMO, and CSO telescopes and supplemented with data from the xCOLD GASS and JINGLE surveys at ^{12}CO(1–0) and ^{12}CO(2–1). The SFR, gas mass (M_{H_2}), and gas fraction (f_{gas}) are all enhanced in galaxies in pairs by ~2.5 times compared to the controls matched in redshift, mass, and effective radius, while the enhancement of star formation efficiency (SFE ≡SFR/M_{H_2}) is less than a factor of 2. We also find that the enhancements in SFR, M_{H_2} and f_{gas}, increase with decreasing pair separation and are larger in systems with smaller stellar mass ratio. Conversely, the SFE is only enhanced in close pairs (separation <20 kpc) and equal-mass systems; therefore, most galaxies in pairs lie in the same parameter space on the SFR–M_{H_2} plane as controls. This is the first time that the dependence of molecular gas properties on merger configurations is probed statistically with a relatively large sample and a carefully selected control sample for individual galaxies. We conclude that galaxy interactions do modify the molecular gas properties, although the strength of the effect is dependent on merger configuration.

Key words: galaxies: interactions – galaxies: ISM – ISM: molecules – galaxies: star formation

Science Highlights 4: Galaxy Interactions and Molecular Gas Properties

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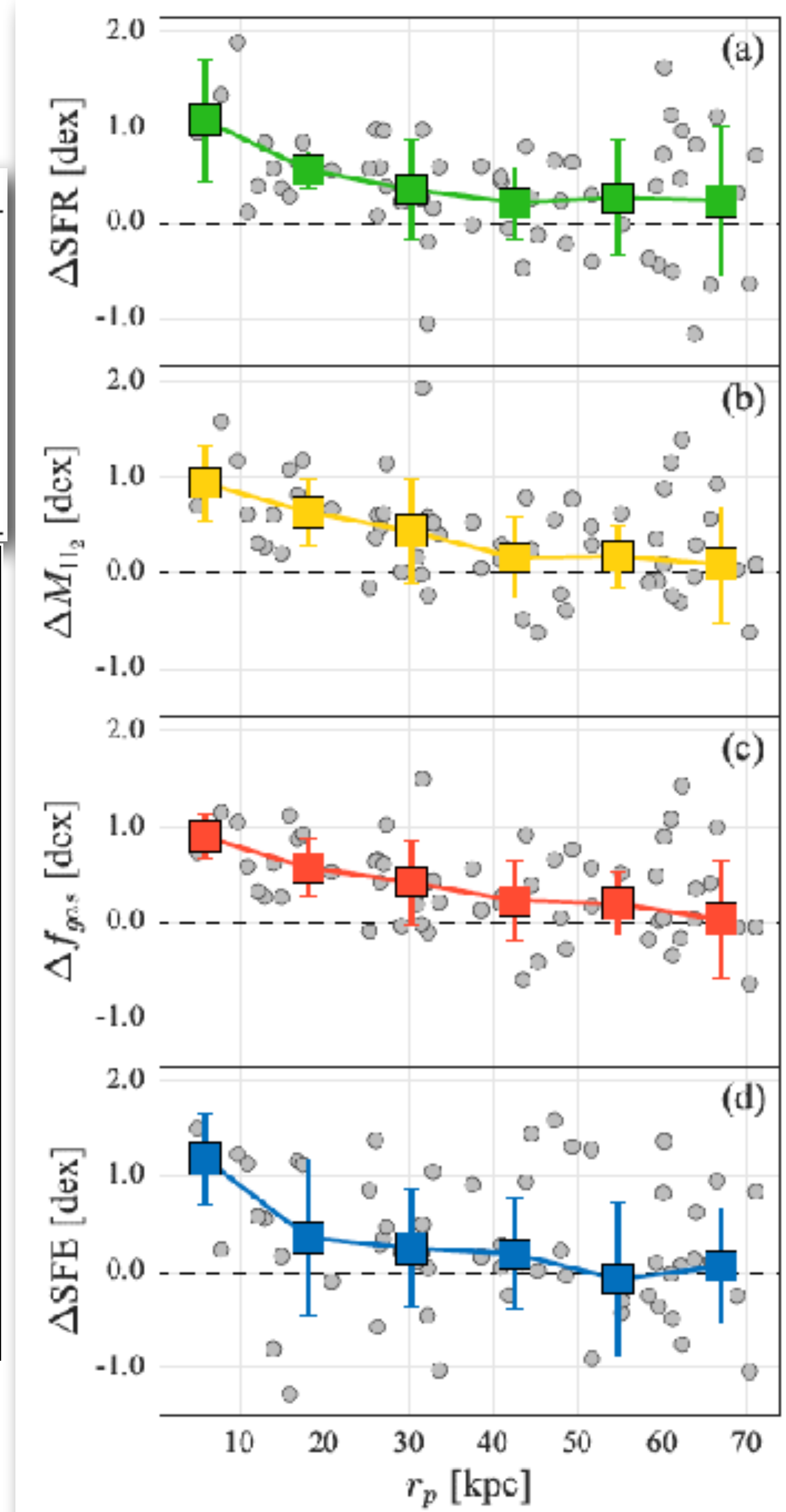
Table 1. Summary of the molecular gas data used in this work.

	paired				isolated
project	JCMT PI programs	JINGLE	JINGLE pilot	xCOLD GASS	xCOLD GASS
observing period	2016 – 2018	2016	2015	2009 – 2017	2009 – 2017
telescope	JCMT 15 m	JCMT 15 m	JCMT 15 m/PMO 14 m/CSO 10.4 m	IRAM 30 m	IRAM 30 m
transition	^{12}CO(2–1)	^{12}CO(2–1)	^{12}CO(2–1)/(1–0)/(2–1)	^{12}CO(1–0)	^{12}CO(1–0)
beamsize	22″	22″	22″/51″/30″	22″	22″
number	21	5	2/2/1	28	154
M_* range	9.43 – 10.74	10.11 – 10.84	9.97 – 11.15	9.28-11.11	9.01 – 11.33
redshift range	0.021 – 0.054	0.023 – 0.039	0.020 – 0.039	0.010 – 0.048	0.010 – 0.049

Hubble Space Telescope



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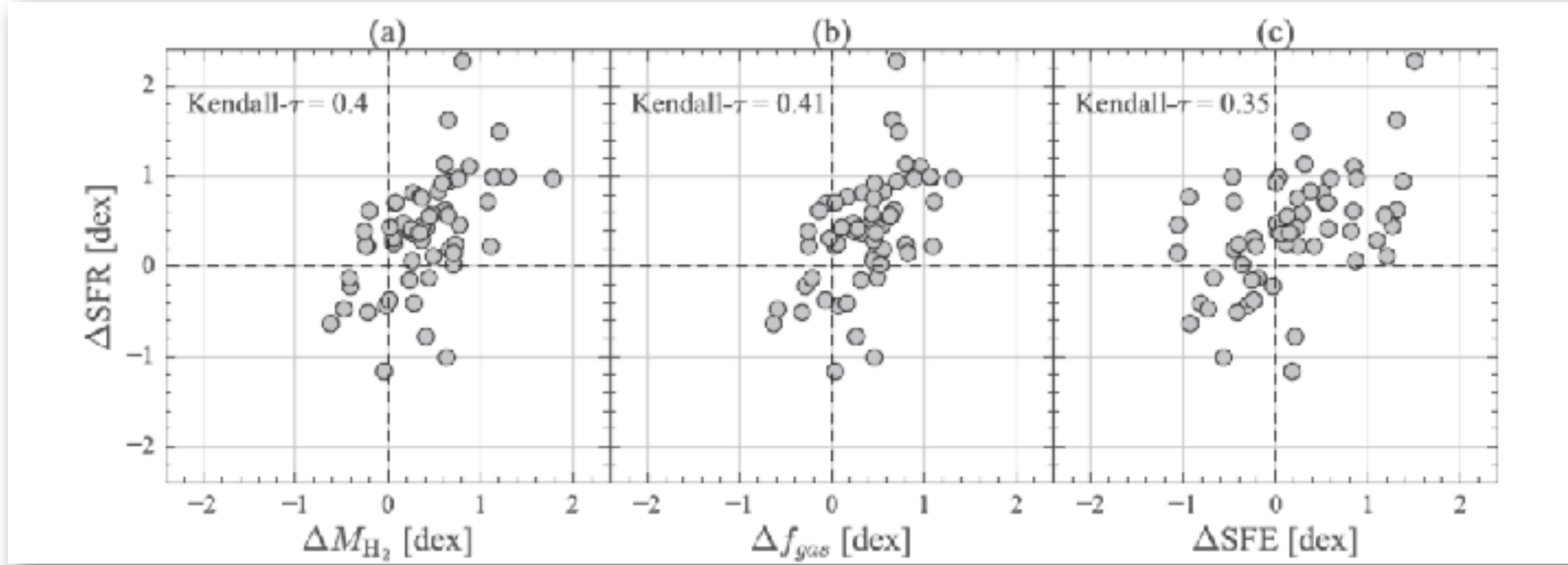
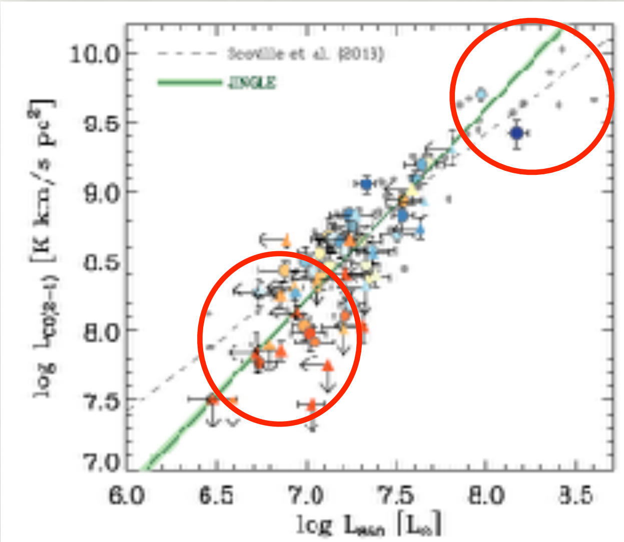


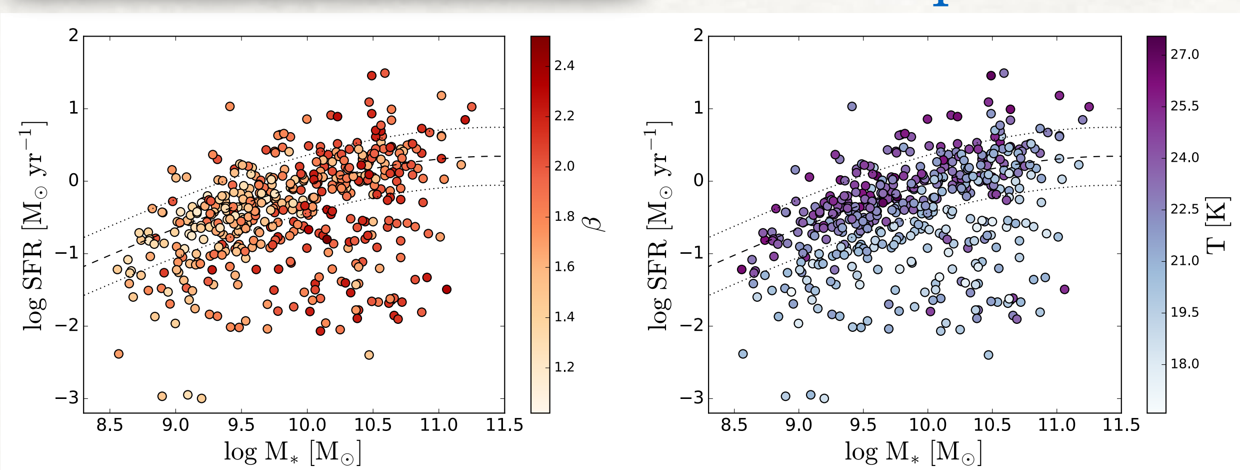
Hubble Space Telescope

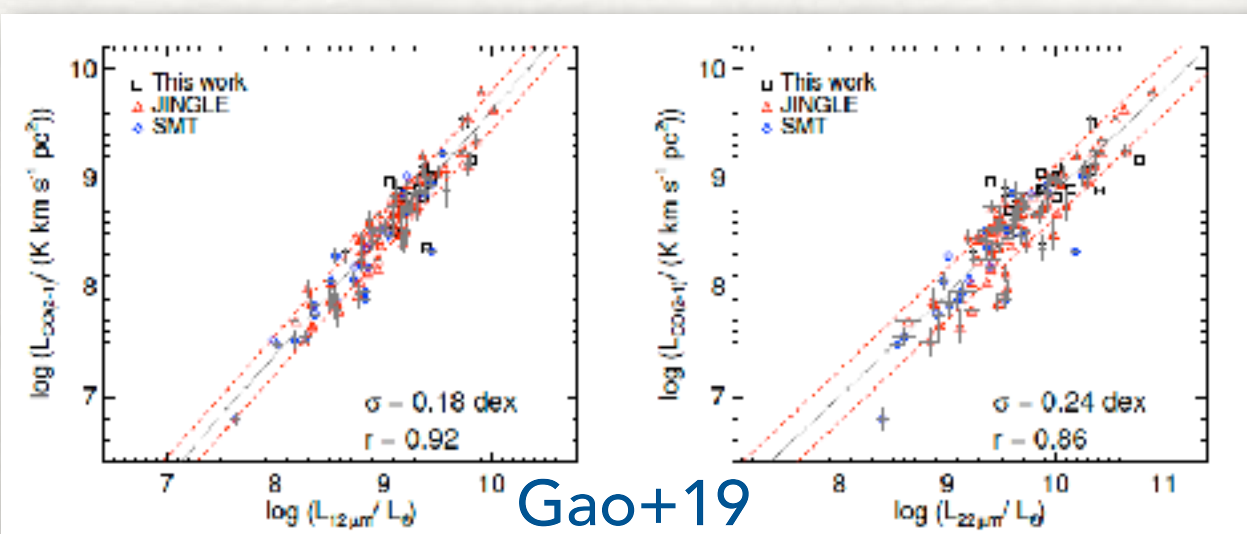
What's Next?



Saintonge+18

Lamperti+19





Gao+19

★ From JINGLE 1:

✦Not many galaxies with high and low sSFRs, which will the keys to fully calibrate the scaling relation for subsequent application at high redshift.

✦Variations in T_{dust} and β are seen across the SFR-M* plane.

✦CO(2-1) correlates well with L12um and L22um

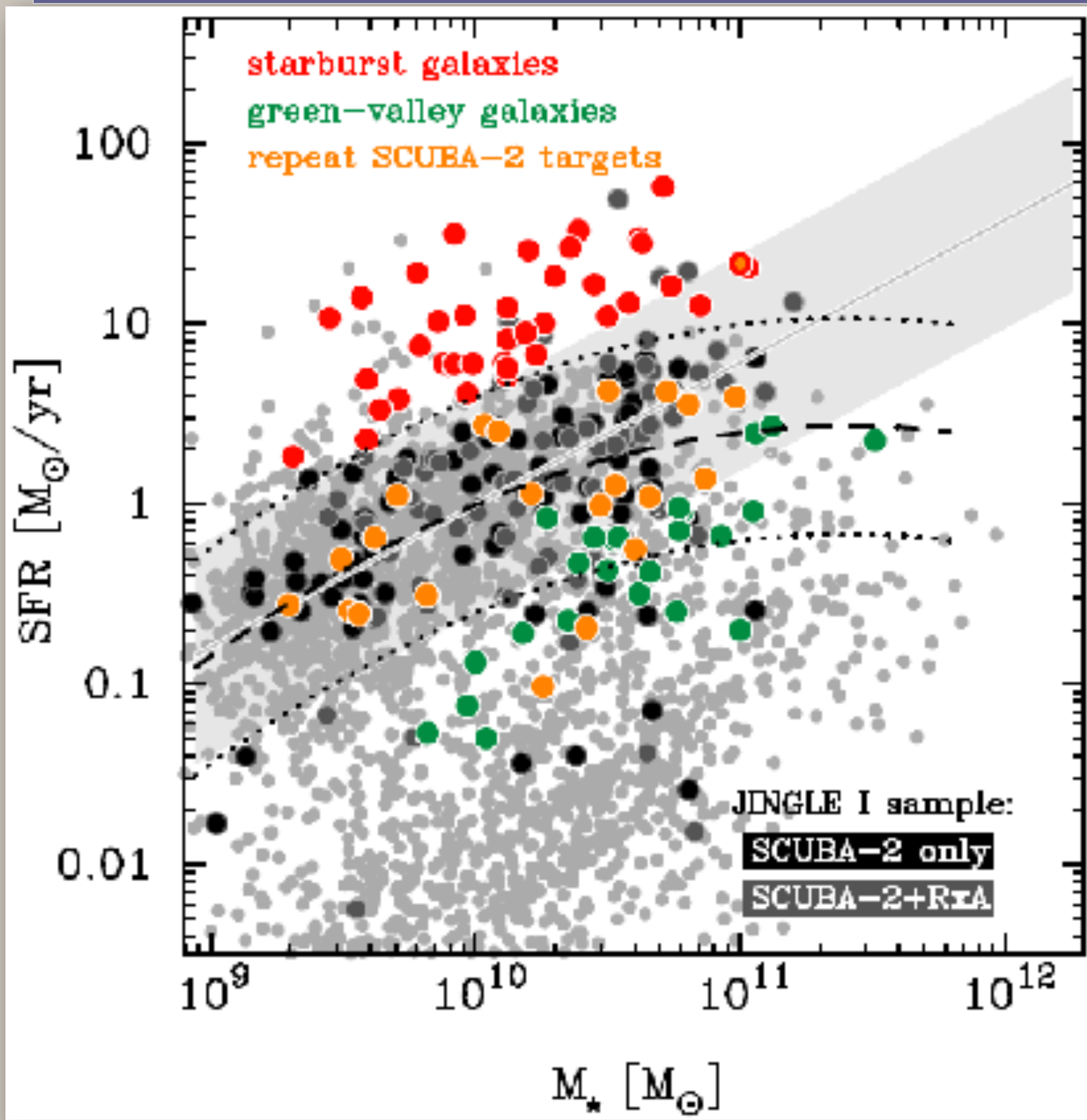
✦Unanswered Questions:

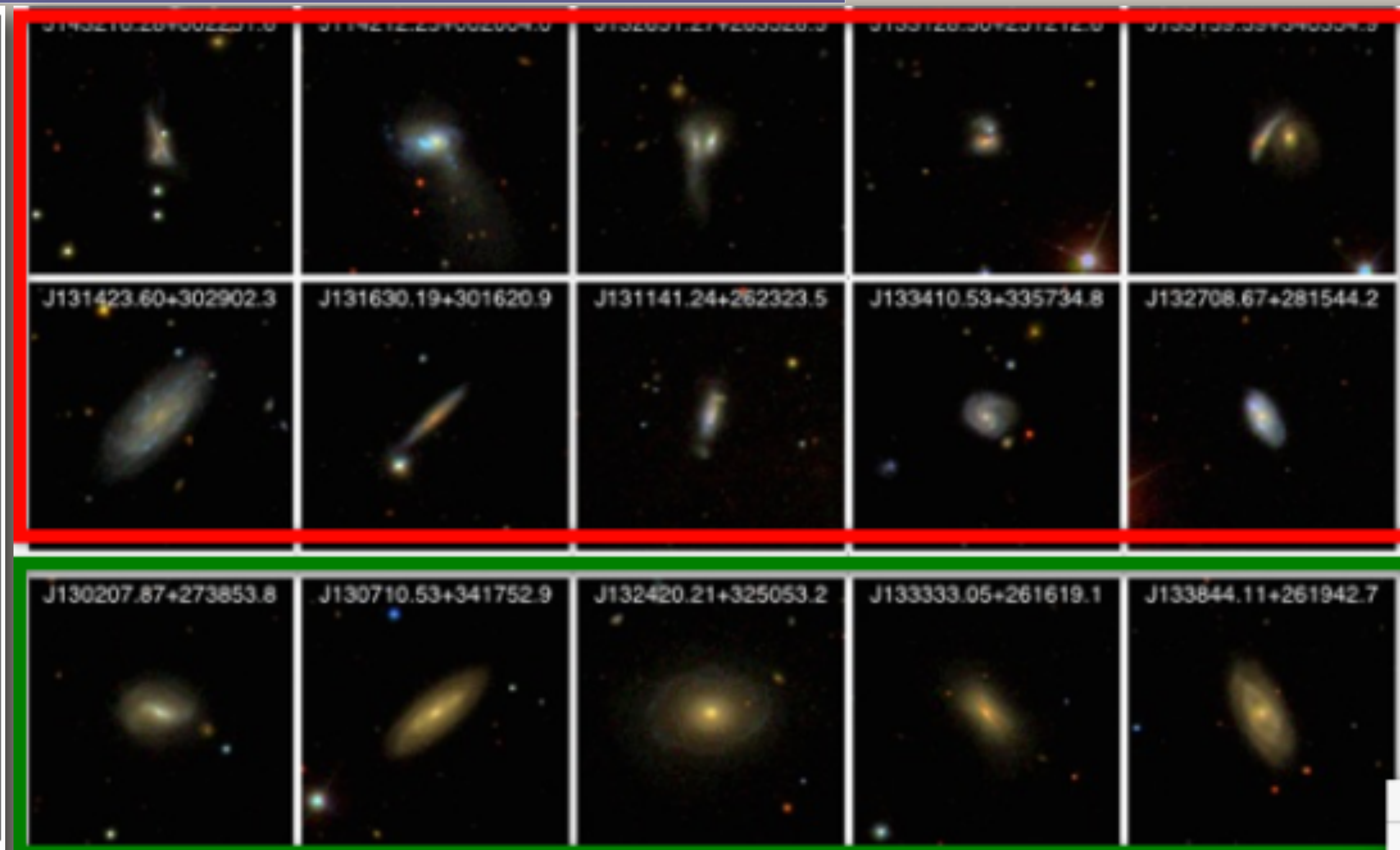
✦Do the scaling relations for main sequence galaxies hold for starburst or green valley galaxies?

✦How do molecular gas fraction and SFE vary with galaxy properties? Are the star formation modes similar across different populations?

Expand the sample to galaxies above and below the main sequence!

JINGLE 2 (Willson, Lin, Xiao, Hwang, Sargent, Koyama)





➢ B-ranked: Received only RxA3m time (2017.8 - 2020.1)

- ✦ Band 4: 285.0 hours
- ✦ Band 5: 169.0 hours
- ✦ Follow-up Proposal (PI: H.S.Hwang): 60 hours of SCUBA-2

➢ Targets

- ✦ 21 starburst galaxies
- ✦ 21 green-valley galaxies: 9 in MaNGA

➢ Requested Observations

- ✦ 185 hours of RxA3m observations
- ✦ 124 hours of SCUBA-2 observations

SUMMARY

- JINGLE represents the first and largest systematic survey of cold ISM in nearby star-forming main galaxies with both 850um and CO observations, enabling independent estimates of gas mass and improved constraints on the dust properties.
- JINGLE 850 data:
  - help constrain SED in combination with other NIR and submm data
  - reveal variations in T_{dust} and β across the main sequence
  - reveal strong correlation between 1) T_{dust} and SFR per unit dust mass; 2) β and HI gas fraction
- JINGLE 2 will expand the sample to starburst and green valley galaxies to complete the full picture in the role of dust and cold gas.