「近傍銀河・銀河系」班の概要と ”stellar feedback”についての検討

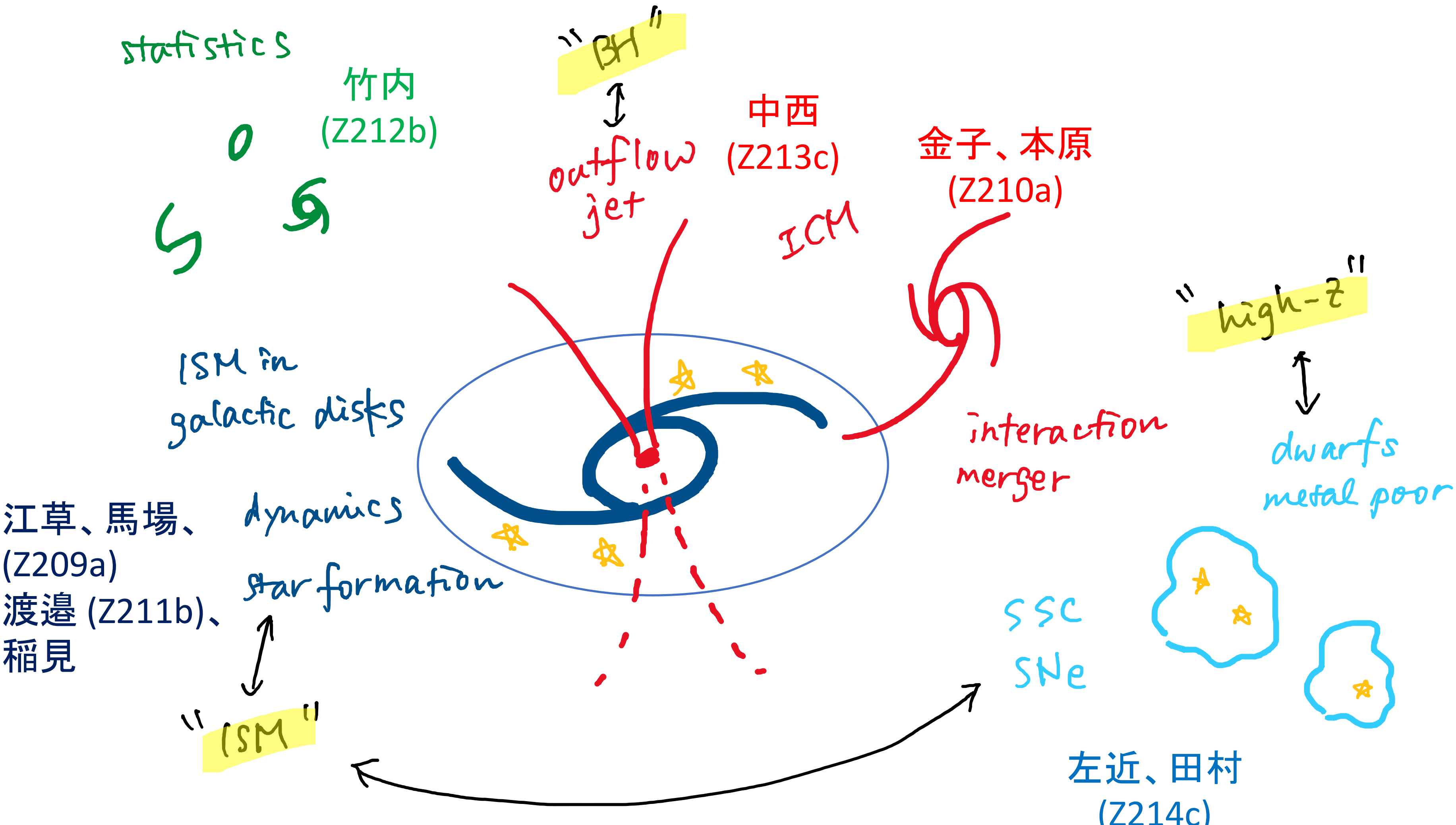
江草芙実（東京大学） on behalf of
SPICAサイエンス検討会「近傍銀河・銀河系」班

Members

- 江草芙実（東大）、光赤外＆電波、渦巻銀河（ESA近傍銀河）
- 馬場淳一（天文台JASMINE）、理論、円盤銀河、位置天文
- 渡邉祥正（日大）、電波、星間化学
- 稲見華恵（広島）、光赤外サブミリ波、LIRG（ESA銀河進化）
- 中西康一郎（天文台ALMA）、電波、スターバースト（遠方から近傍まで）
- 金子紘之（天文台野辺山）、電波、衝突銀河＆環境効果
- 本原顕太郎（東大）、光赤外、近傍の中でもちょっと遠方、銀河形成進化、星形成、化学進化（ESA銀河進化）
- 竹内努（名古屋）、理論＆光赤外、近傍銀河＆銀河進化、ダスト進化モデル（ESA銀河進化）
- 左近樹（東大）、光赤外、MW＆局所銀河、ダストの実験
- 田村陽一（名古屋）、電波、遠赤外線微細構造線、星間物理

Science Projects

"warm and ionized gas and dust in and around nearby galaxies"

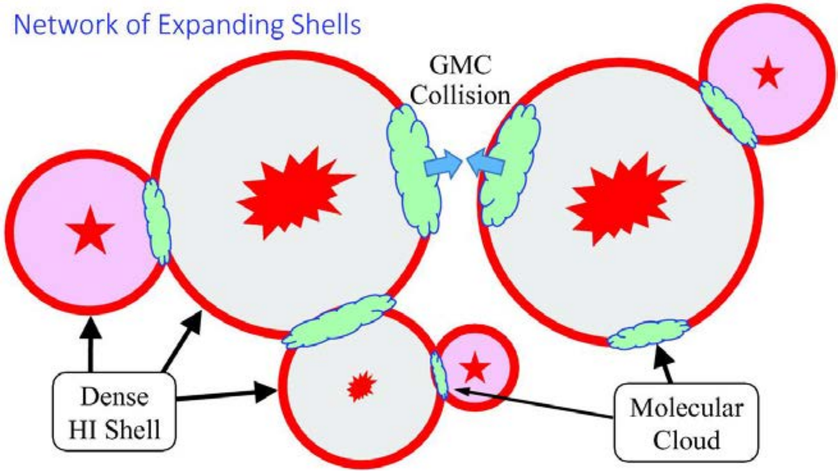


What is “stellar feedback”? ISM conditions in nearby galaxies with SPICA

Fumi Egusa (IoA, UT)

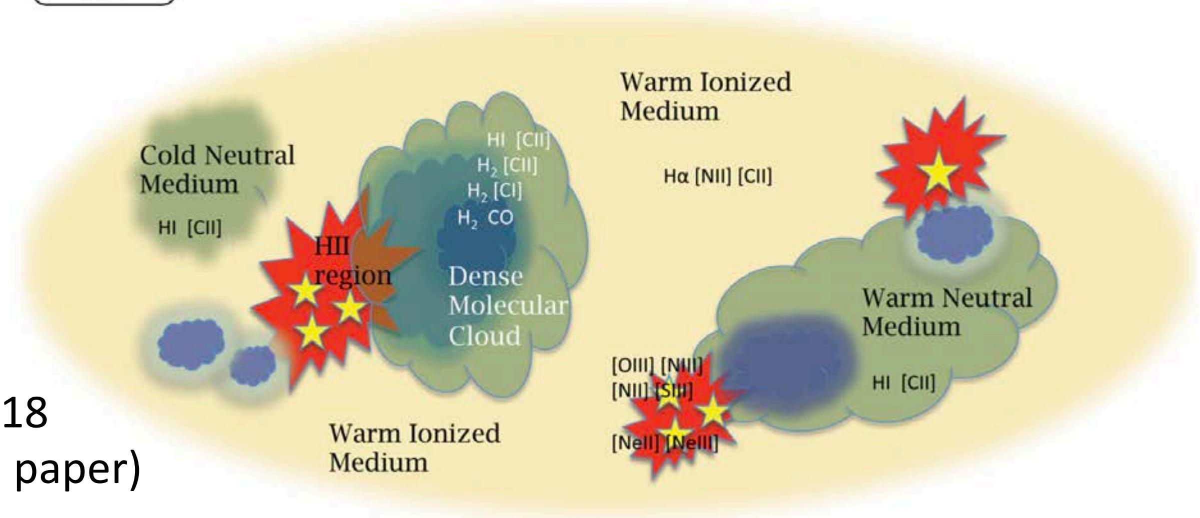
Junichi Baba (NAOJ)

ISM Pictures



Inutsuka+15

Multi-phase ISM controlled by stellar feedback



van der Tak+18 (SPICA white paper)

Stellar Feedback

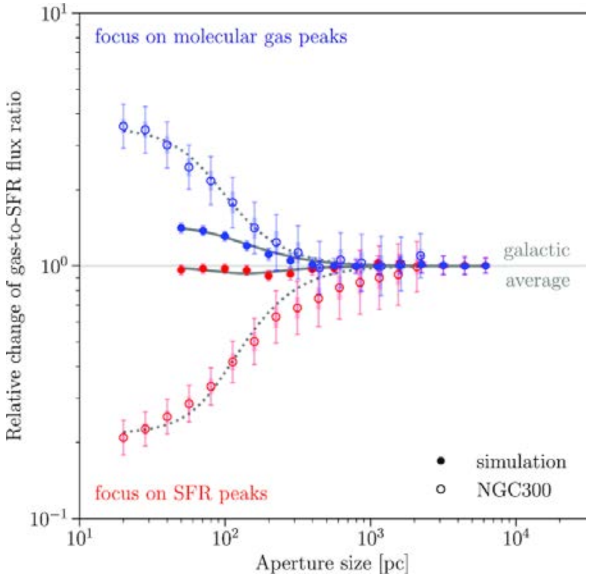
- In simulations, feedback is important to stop run away collapse of molecular clouds.
- HII regions: photoionization (+shock)
  - implemented as heating surrounding gas?
- Type II SN: 1e51 erg per SN
  - implemented as thermal energy and/or momentum
  - delay ~ 5 Myr after star formation
  - binary effect? impact of Type I??
- (winds/jets/outflows from individual stars)

Stellar Feedback

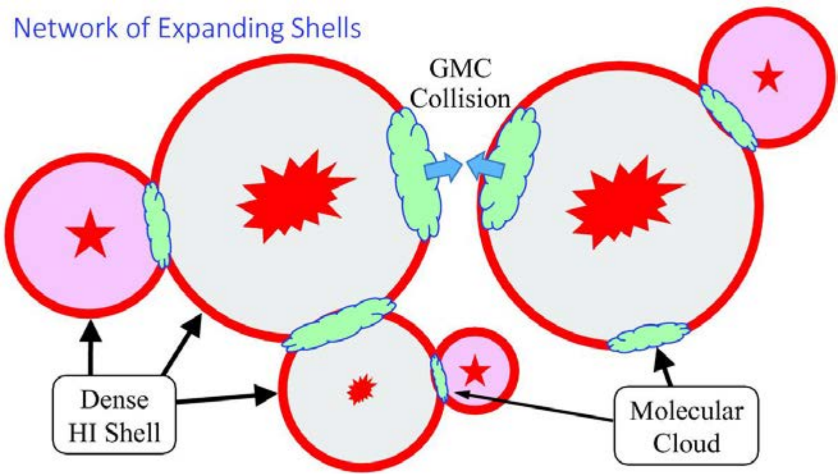
- Global effect
  - suppress early collapse -> abundant hot/warm gas -> form gas disk at a later phase -> larger disk
- Local effect
  - suppress collapsing remaining molecular gas to reproduce observed low (~1%) SFE
  - other factors (e.g. magnetic field, shear, cloud-cloud collisions) could also be important

HII region feedback does not completely destroy a natal GMC but breaks it up into smaller clouds (Baba+17).
... but do we see this many bubbles??

feedback not strong enough to reproduce observed GMC-HII region offsets?
(Fujimoto+19)

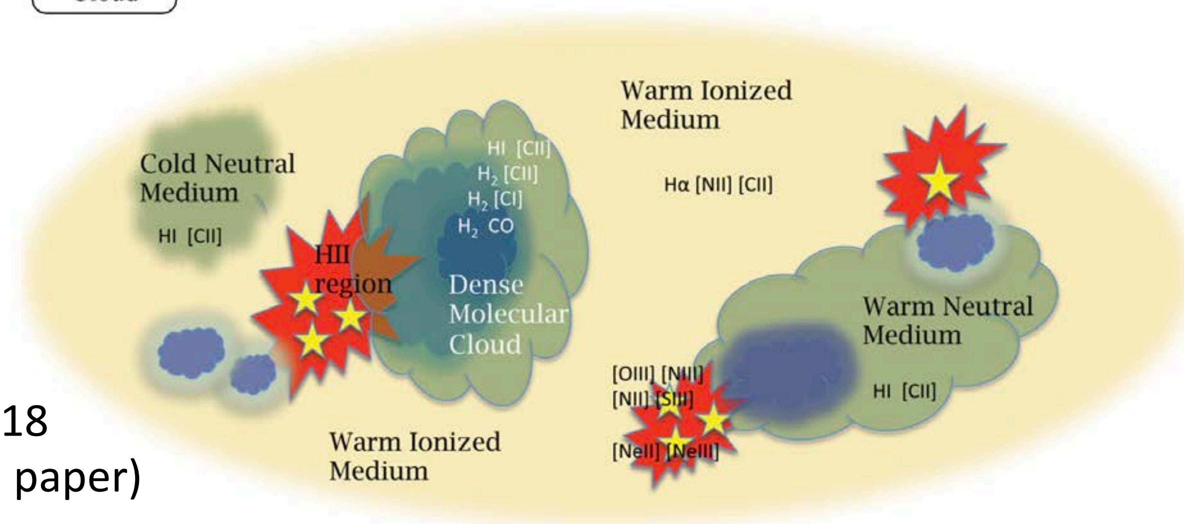


Goal of this Project



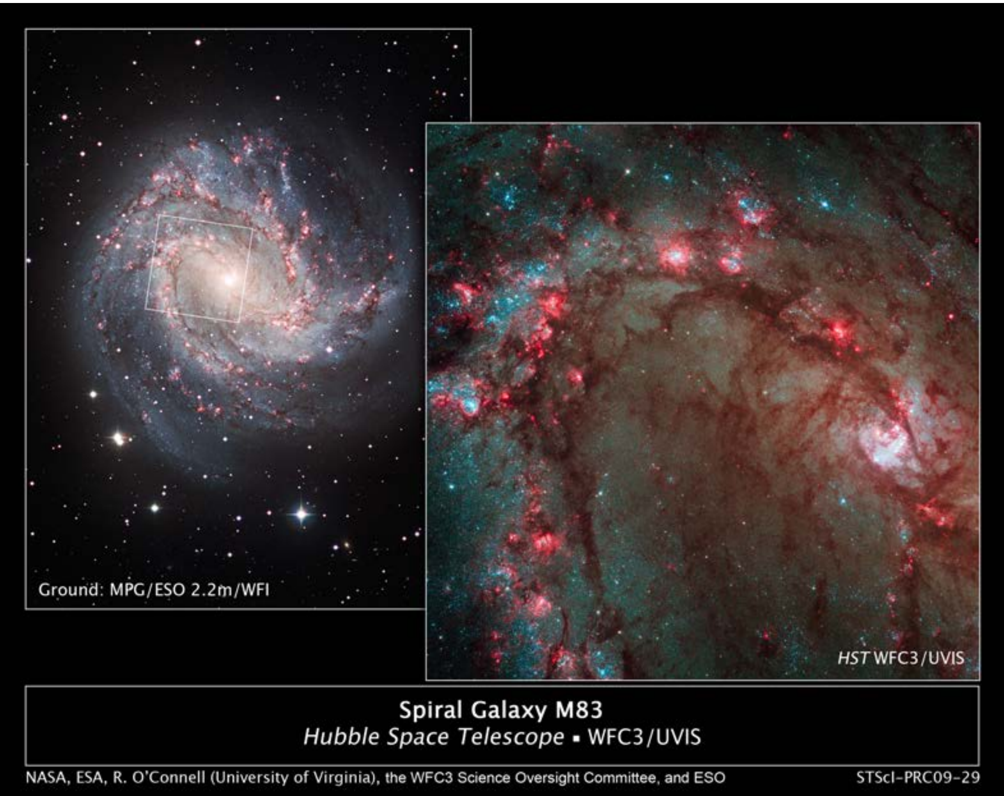
Inutsuka+15

We aim to explore ISM conditions based on IR emission lines emitted from different phases of ISM, and to assess the impact of stellar feedback on ISM.



van der Tak+18
(SPICA white paper)

Why Spiral Galaxies?



ISM evolution (molecular gas -> HII regions -> star clusters) can be seen across a spiral arm.

Strategy for SPICA

- Dish size similar to Herschel and SOFIA
  - PSF ~ 1.8—23” (70—800 pc at M51) at 18—230 μm
    - HII regions and SNRs ~ 40 pc or less
    - spiral arm width ~ 500 pc
  - small-scale structures can be studied at shorter wavelengths
- Sensitivity >10 times better than Spitzer, Herschel and SOFIA

- “Going deeper and wider” is the basic strategy

Fact Sheet Summary

	SMI/MR	SAFARI/SW	/MW	/LW	/LLW
wavelength [μm]	18--36	34--56	54--89	87--143	140--230
R*	1400--1100	11000--6000	6000--4000	4000--3000	3000--1500
FoV	60” x 3.7”				
band center PSF	2.7”	4.5”	7.2”	12”	19”
sensitivity**	4e-10	2e-11	1e-11	9e-12	6e-12

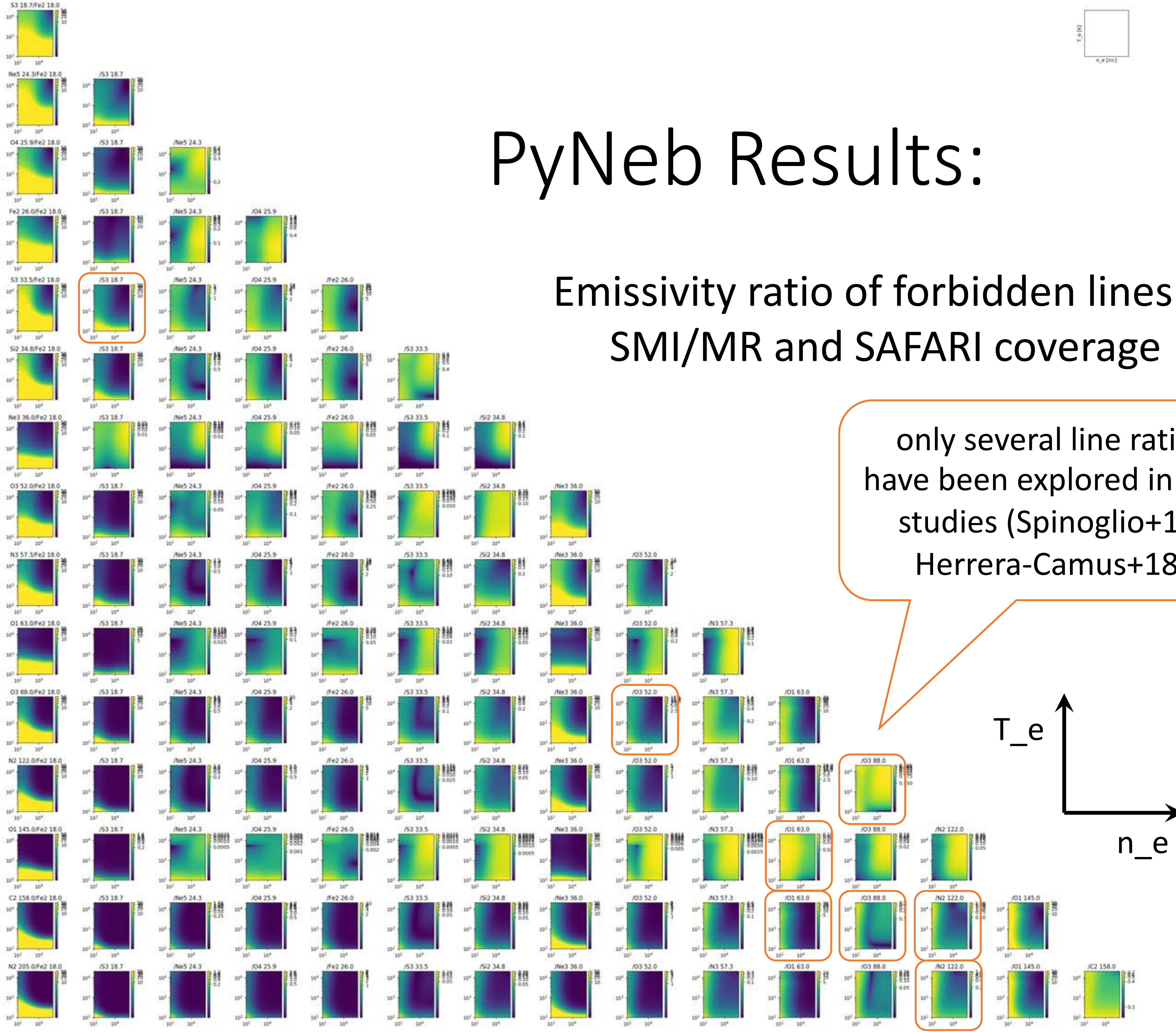
*: for diffuse for SMI/MR
**: diffuse source sensitivity for line (5 sigma, 1 hr, for 1’x1’) [W/m2/sr]

IR Line Ratios to Derive ISM Conditions

- Ionized gas:
    - key: electron density and temperature (+abundance)
- Photo-Dissociation Region (PDR):
    - key: UV intensity, H density, metallicity
- Advantage over the optical IFU
    - less affected by extinction
    - can probe ISM with lower density and temperature
    - (wider FoV)

PyNeb Results:

Emissivity ratio of forbidden lines in SMI/MR and SAFARI coverage



only several line ratios have been explored in past studies (Spinoglio+15, Herrera-Camus+18)

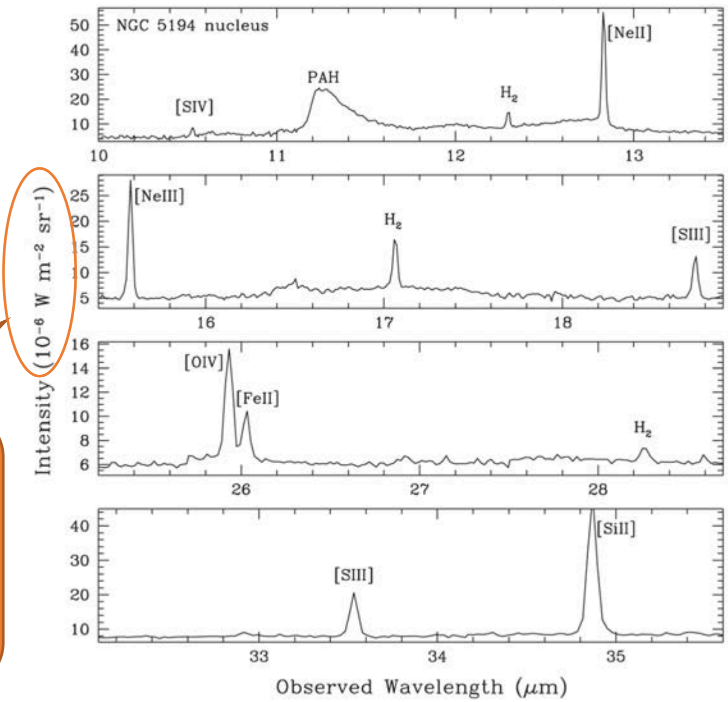
Summary of Past Studies

- MIR: Spitzer (SINGS)
- FIR: Herschel (KINGFISH, VNGS, SHINING), SOFIA

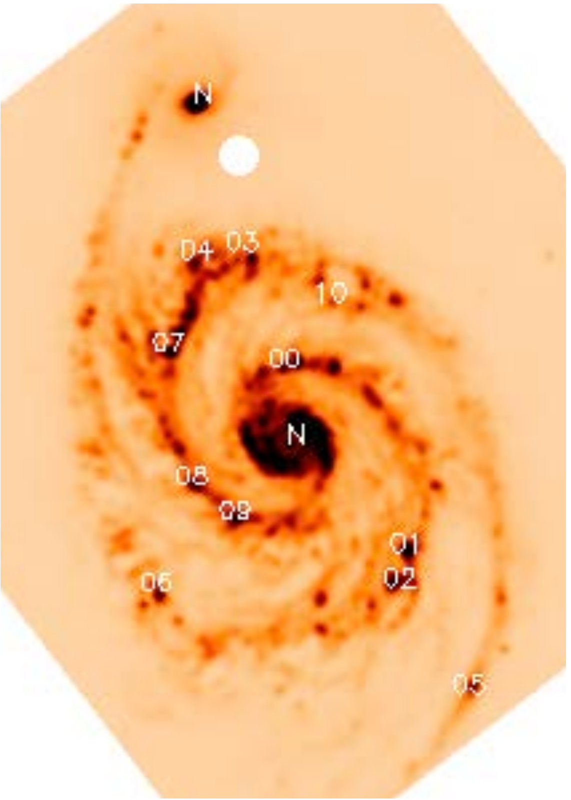
- M51 as (likely) the best case
  - nearby: D ~ 7.6 Mpc (Sabbi+18, 1” ~ 37 pc)
  - face-on grand-design spiral
  - Sy 2 nucleus
  - interacting system

M51

- Spitzer spectra available only for selected positions



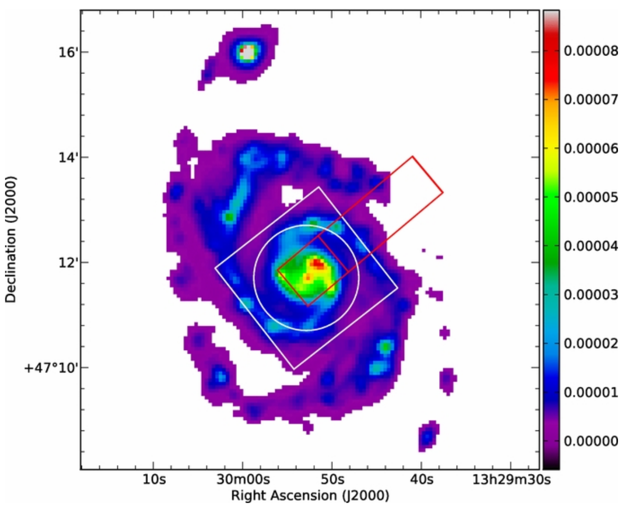
SMI/MR sensitivity: 4e-10 W/m2/sr for 5 sigma in 1 hr for 1'x1'

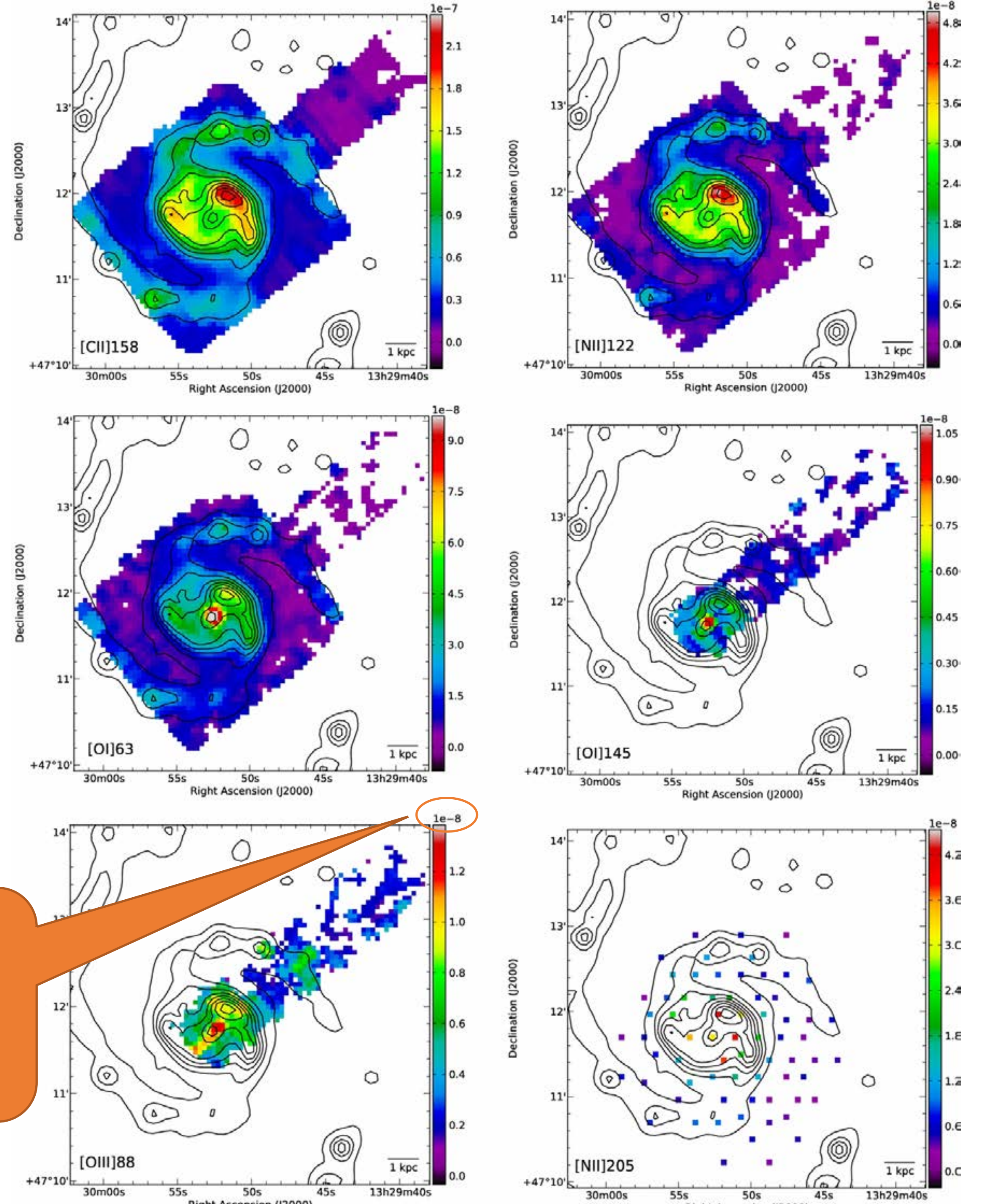


Labeled positions where spectra are available (Dale et al. 2009)

M51

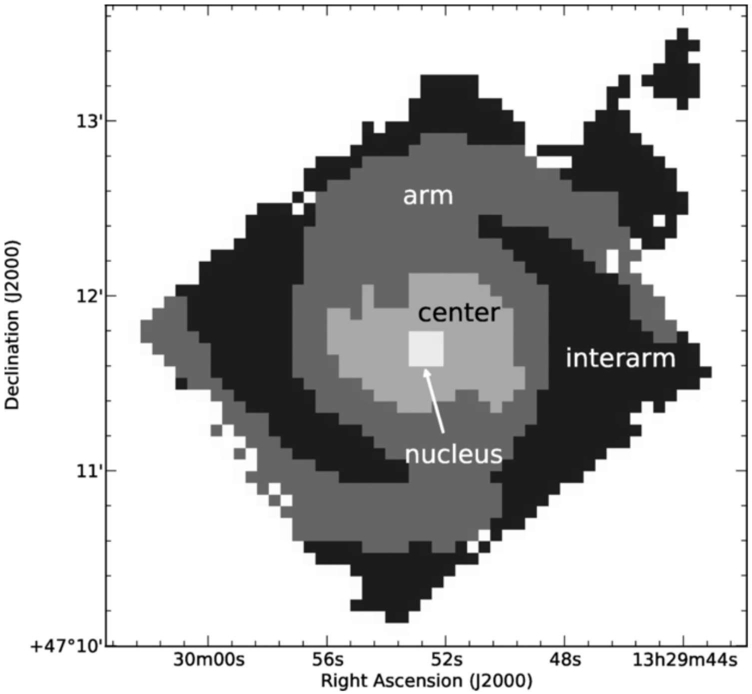
Herschel PACS + SPIRE FTS
(Parkin+13)

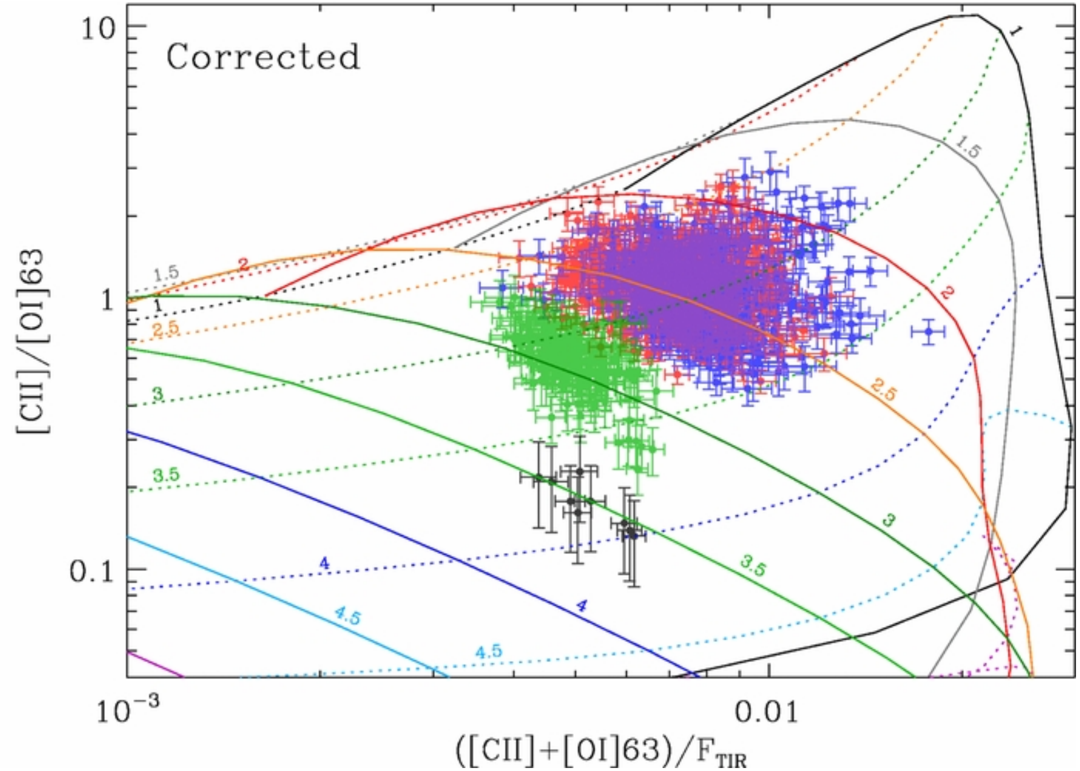




SAFARI/high-R sensitivity: <2e-11 W/m2/sr for 5 sigma in 1 hr for 1'x1'

M51





data points: nucleus, center, arm, interarm
lines: solid (log(G_0)), dotted (log(n)) from PDR model of Kaufman+99, 06

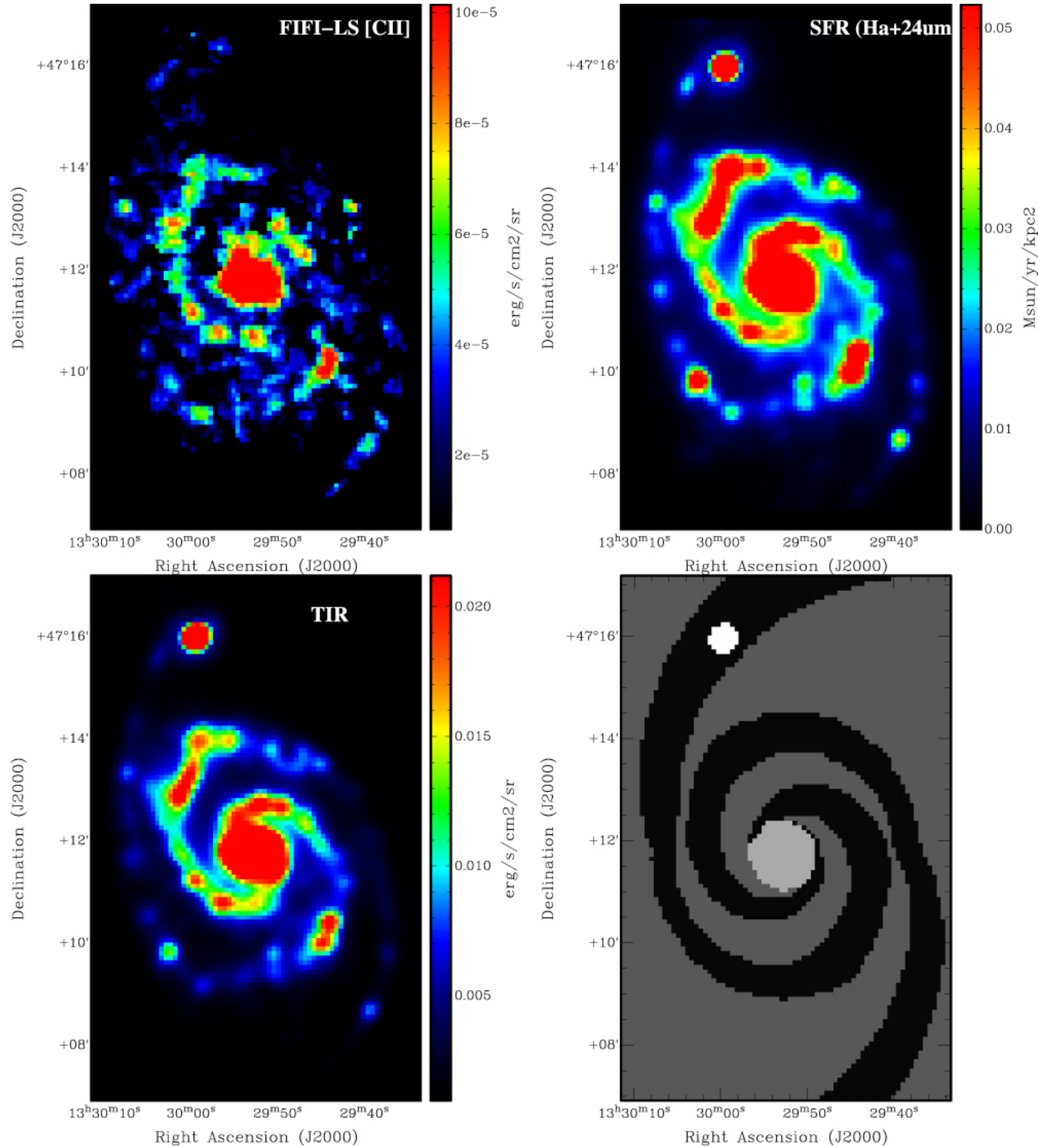
no clear difference between arm and interarm? needs wider FoV? (also better resolution ...)

M51

[C II] from SOFIA
PSF ~ 16"
(Pineda+18)

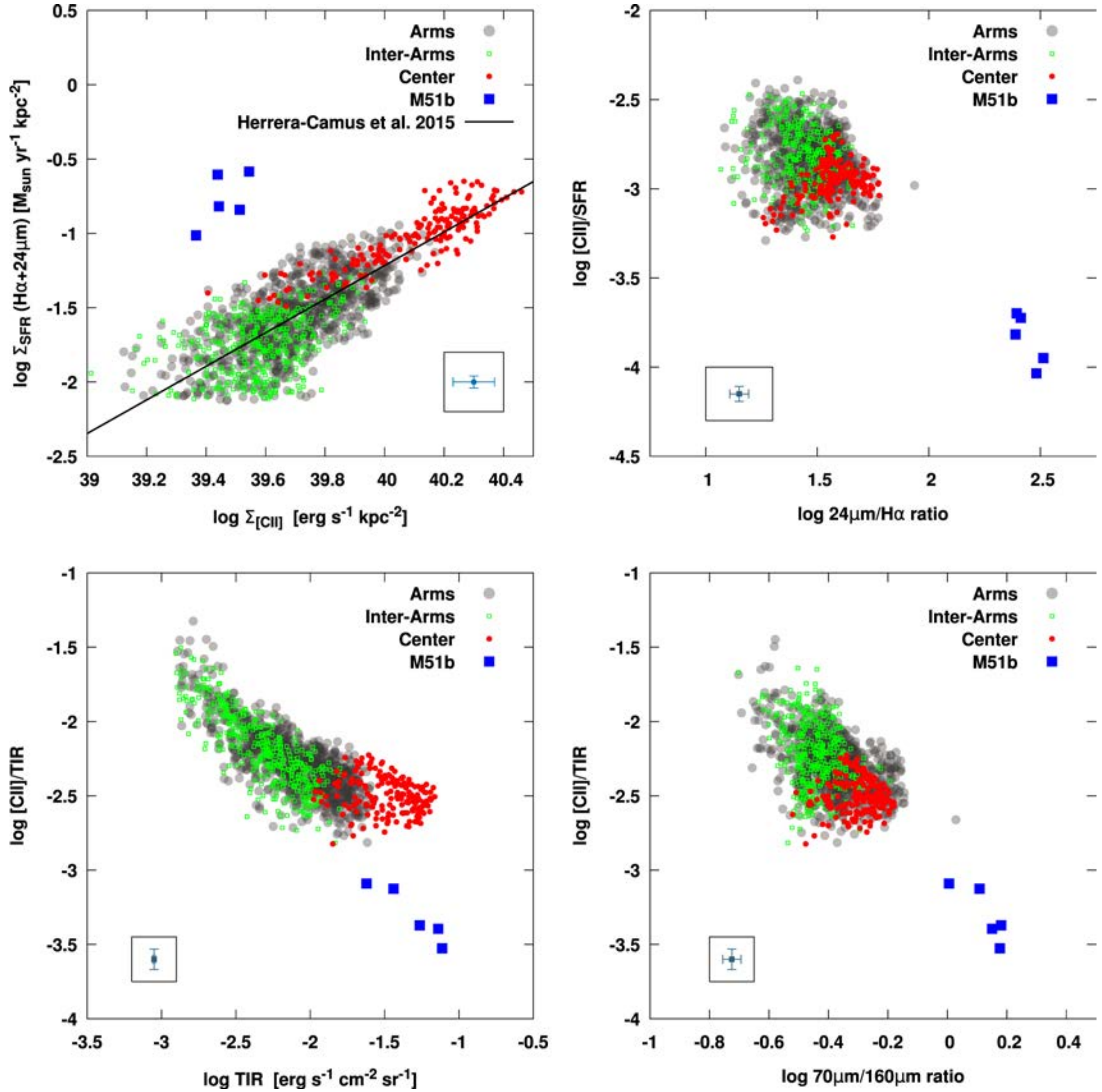
rms ~ 6.6e-6 erg/s/cm²/sr
-> 6.6e-13 W/cm²/sr
-> 6.6e-9 W/m²/sr

SAFARI/high-R sensitivity:
6e-12 W/m2/sr for 5 sigma
in 1 hr for 1'x1'
PSF ~ 19" (fact sheet)



M51

arm-interarm difference is still not clear...
(due to sensitivity? or choice of lines??)



Pineda+18

2 Plans for SPICA

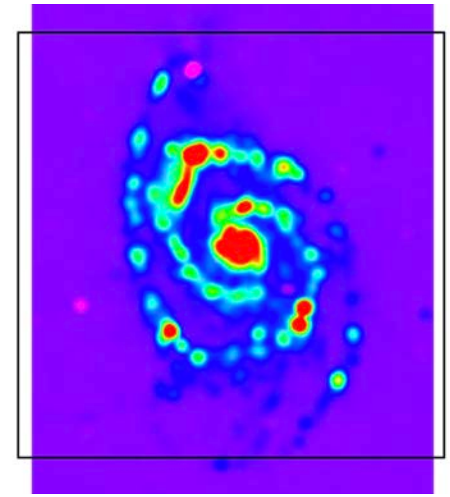
- 1-D
  - radial dependence with all (18—230 μm) data
  - PSF ~ 23” (~800 pc at M51)
  - inner/outer comparison
  - should cover the entire disk (or more)
  - D ≲ 10 Mpc for ~1 kpc resolution

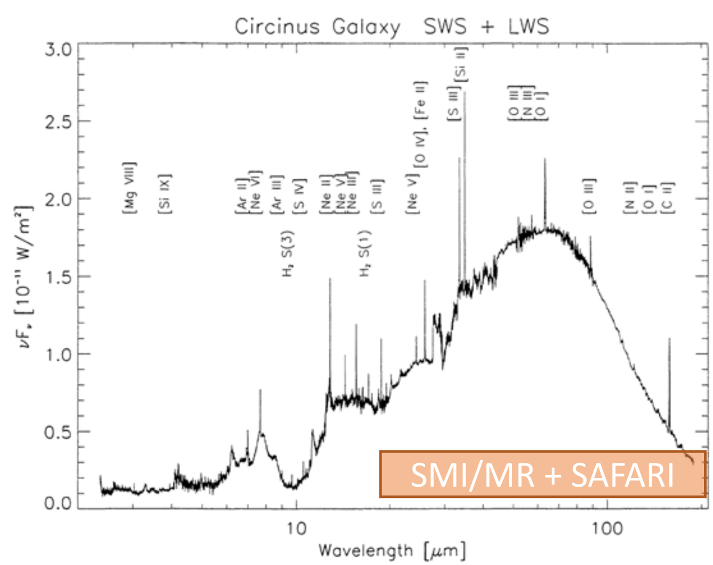
- 2-D
  - spatial distribution only with short-wavelength (e.g. <50 μm) data
  - PSF ~ 5” (~200 pc at M51)
  - arm/interarm comparison
  - D ≲ 5 Mpc for ~100 pc resolution?

1-D Case

- Radial dependence of ISM conditions
  - all data smoothed to 23”
  - all lines available
  - needed a wide radial coverage
- E.g.: 1 hr for 10’x10’
  - 36 sec for 1’x1’
  - 5σ sensitivity: from 4e-9 (SMI/MR) to 6e-11 (SAFARI/LLW) [W/m2/sr]
  - c.f. Circinus spectra: 1e-11 [W/m2] -> 1.3e-7 [W/m2/sr] assuming r=17’

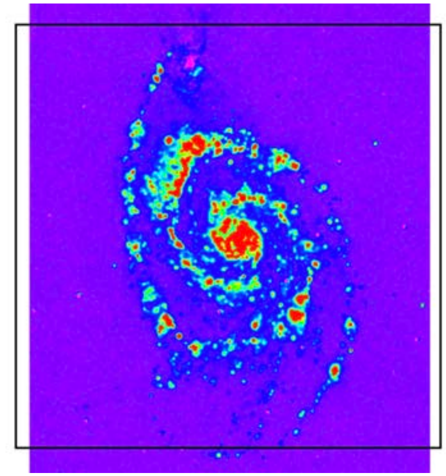
M51 Ha smoothed to 23”
(box = 10’x10’)





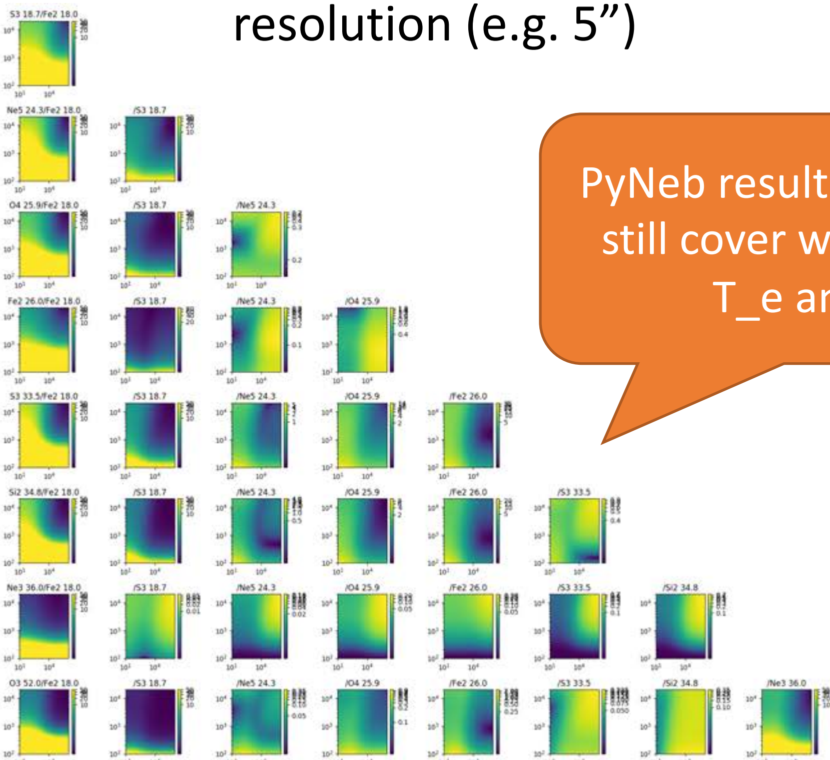
ISO spectra of Circinus galaxy
(Moorwood+99)

M51 Ha smoothed to 5”
(box = 10’x10’)

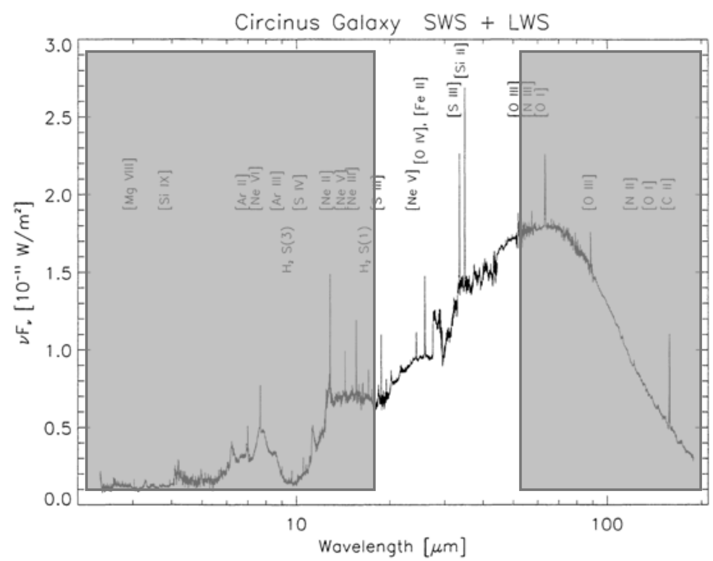


2-D Case

- Spatial distribution of ISM conditions
  - limited lines (e.g. <50 μm) for better angular resolution (e.g. 5”)



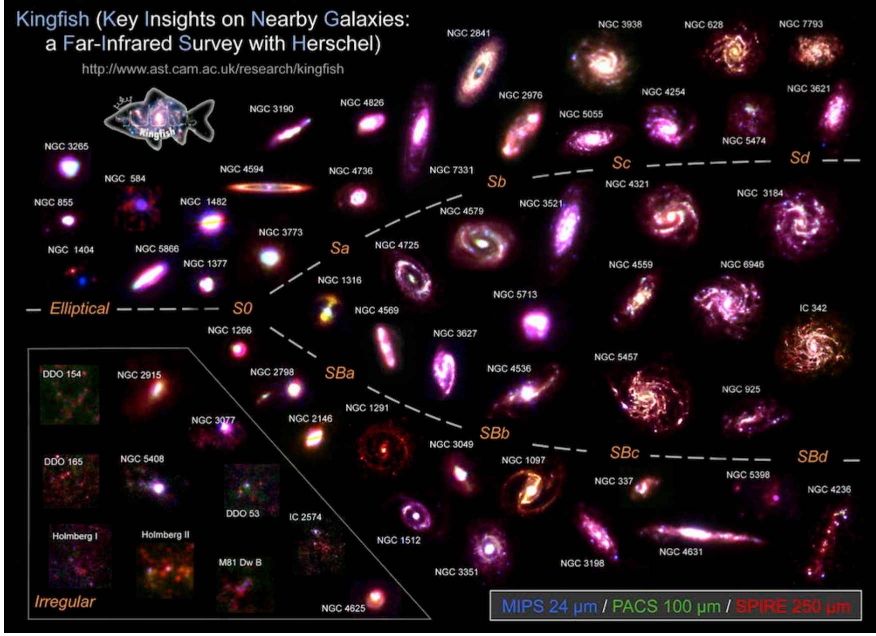
PyNeb results for <50 μm: still cover wide range of T_e and n_e

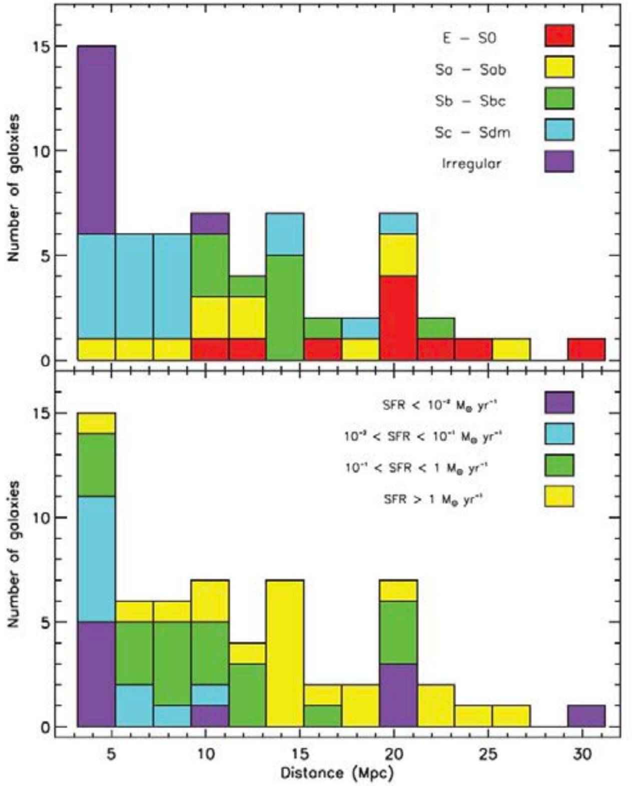


With shades outside 18—50 μm

Targets

- Based on KINGFISH sample
  - ~5 spirals at D<5 Mpc
  - ~20 spirals at D<10 Mpc
  - ~40 spirals at D<20 Mpc
- May need to exclude several edge-on galaxies





KINGFISH sample (Kennicutt+11)

Summary

- Spatially resolved spectra (i.e. IFU-like data) at IR are still limited
  - especially at MIR wavelengths
  - warm/ionized gas conditions not well constrained
- SPICA will provide
  - (almost) extinction-free data with unprecedented sensitivity
  - the first 3D cube data at MIR -> ISM conditions at ~200 pc scale
  - the first radial profiles of ISM conditions out to the optical radius (or more)
- Derived ISM conditions will help us constrain stellar feedback models