FIR Spectroscopic Imaging Study of Interstellar Medium

!

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Scientific Objectives

Investigation of dust and gas properties in various environments

Ionized Gas

Metallicity

UV field

Heating source

Morphology of galaxies

Activity of galaxies

Age

Dust

Molecular Gas

- Physical conditions of ISM in Galaxy
- Interpretation of dust and PDR model
- Dust heating mechanism
- Physical Processes connecting star-formation activities
- Star formation history and galaxy evolution
- Its extension to galaxies with different types
- Templates of typical galaxies

Scientific Objectives

Reveal of Hierarchical Structure of ISM

Spatial : scale of various structures

Time / Age : evolutional stages

Chemical Composition / Evolution
: correlation to spatial distribution,
age, energy sources, and etc…

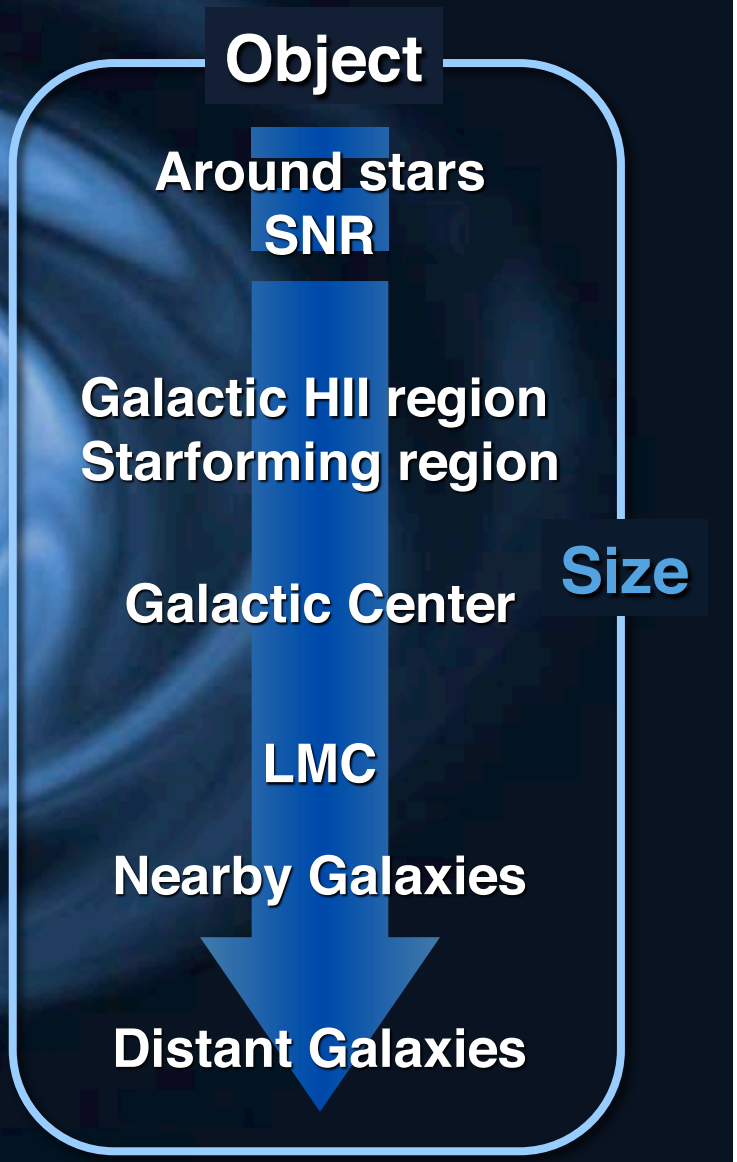
Hierarchical structure of ISM

Step 1 : Examinations on applicability of theoretical models for particular galactic targets in ideal environments

Step 2 : Application of theoretical models to ISM in various environment throughout our Galaxy

Step 3 : Application of knowledge on galactic ISM to nearby galaxies ISM in wider range of environments and to whole structure of ISM therein

Step 4 : Completion for archives: sizable catalog of nearby galaxies

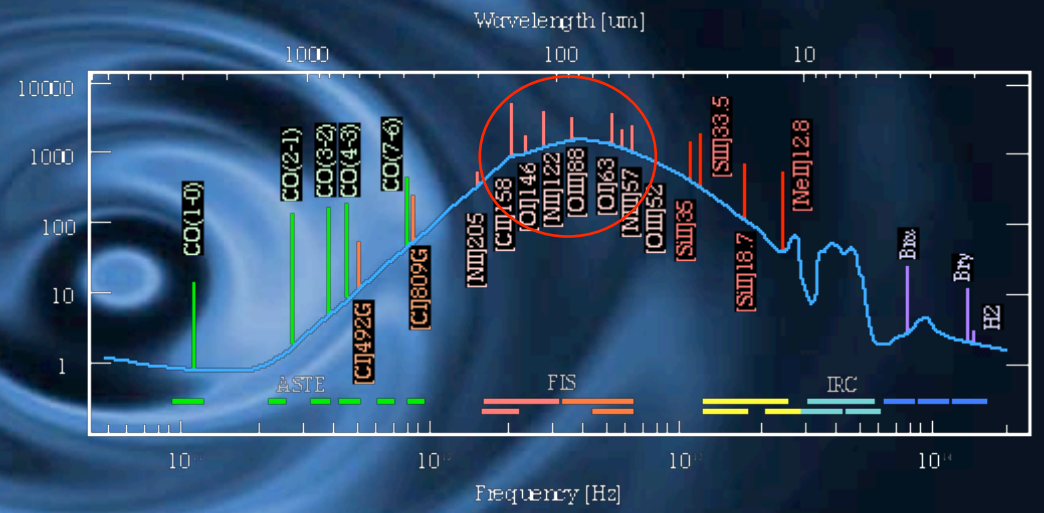


FIR fine-structure emission lines

[N III] 57um, [O I] 63um, [OIII] 52 & 88um, [NII] 122um, [CII] 158um….

Origins of each line :

- [O I] : Neutral Gas Cloud
- [N II], [N III] : Ionized Gas
- [C II] : Ionized & Neutral H gas region



Features of each line :

- [O I] : tracer of gas pressure
- [OI] / [CII] : decouple temperature and density in PDRs
- [OIII] 52um / 88um ratio : probe for gas density
- [NIII] / [NII] ratio : sensitive to the hardness of the ambient stellar UV radiation field

FIR Spectroscopic Observation

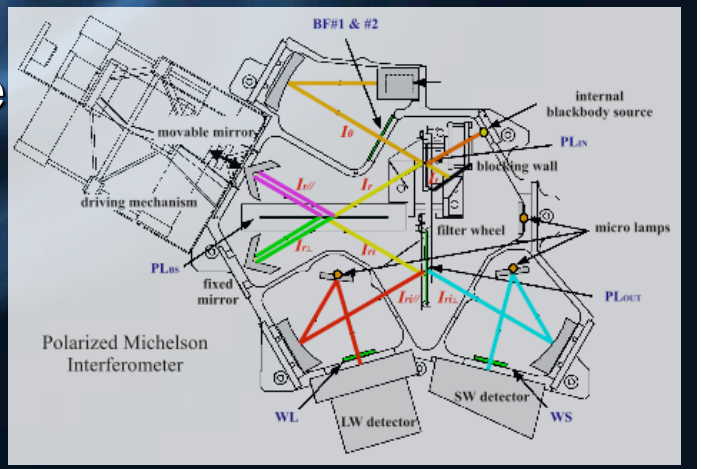
About AKARI FIS-FTS

- Spectroscopic mode of AKARI FIS
- Martin-Puplette type Michelson Interferometer
- Usage same detector arrays (WIDE band) for photometric mode
  → Wide range spectroscopy (55-200cm^{-1})
  → Imaging spectroscopy

Observation with FIS-FTS

- Spectroscopic mode of AKARI FIS : AOT03
- Pointing observation
- Selectable Low / high resolution mode
  (1.2cm^{-1} / 0.19cm^{-1})

- ~600 pointings
- ~100 hours
- ~80 objects



Observations

- Period : 2006.4.19 – 2007.8.25
- Total Number of Observations: **597** points *(12 minutes each)*
  - PV phase : 30 points
  - Primary obs. : 115 points (MP: 62, OT-ISAS: 7, OT-ESA: 24, DT: 22)
  - Parallel obs. : 452 points (MP-FISS3)

  - SED mode : 259 points (PV: 21, Primary / Parallel: 50 / 188)
  - Full res. Mode : 338 points (PV: 9, Primary / Parallel: 65 / 264)

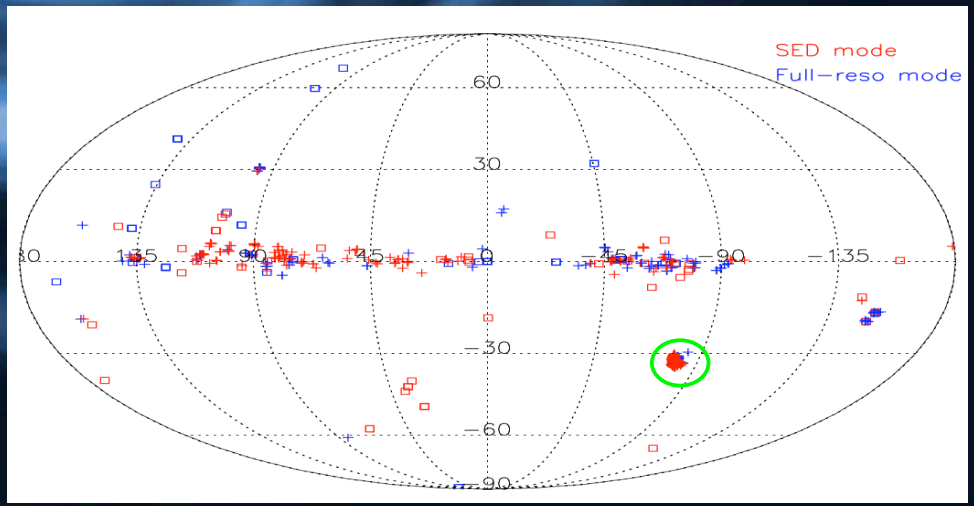
(data for several obs. are lost by downlink troubles)

- Observed Area

the Galactic plane (~ 55%)

Large Magellanic Cloud (~30%)

188 points (SED/Full =58/130)



┼: Parallel Observations
□: Primary Observations
SED mode / Full-res. mode

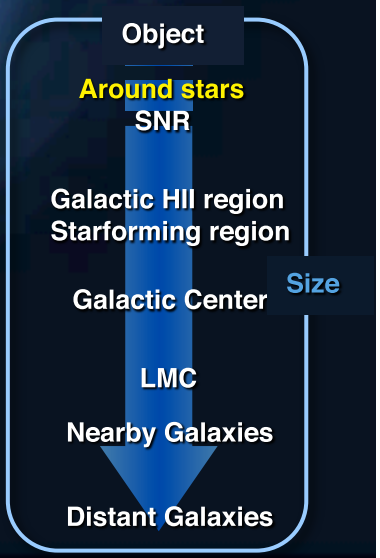
Sciences of eta-Carinae

Matsuo et al. 2009

- eta-Carinae is a massive star with its mass exceeding 100 solar mass!
- making study of **mass loss**
- the effect to the interstellar material around super massive star

FIR continuum：trace **dust** distribution
Radio lines：**molecular cloud** around eta Carinae
⇅
FIS line：Physical Information at **Ionized / shocked regions**

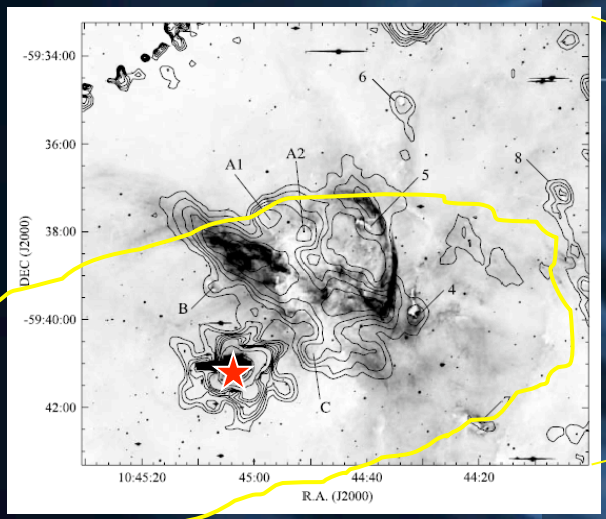
* **Interaction** of molecular cloud
* **heating source <---> ionizing source**
* Which wavelength are the feature as the tracer of ionizing source ?



Comparison with other observations

CO(3-2) 345GHz 40'x40' (color)

1.2mm continuum
and Ha image



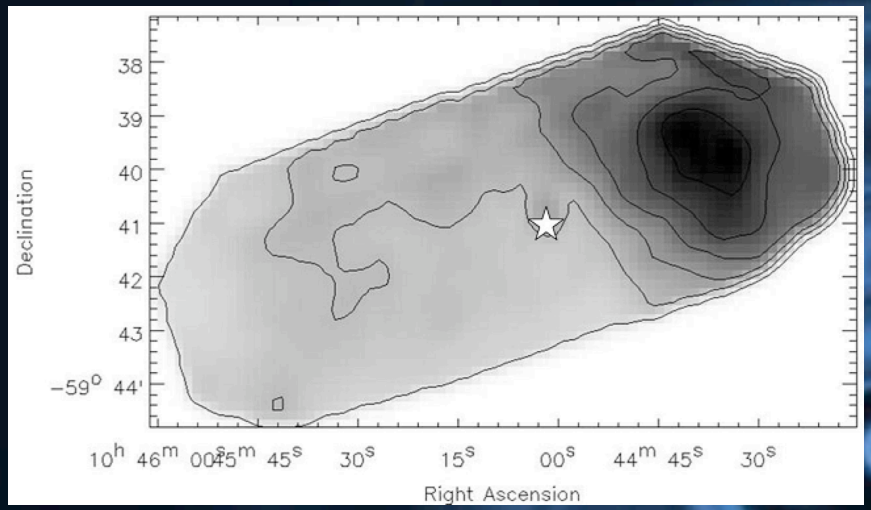
Brooks et al. 2005

Molecular Cloud

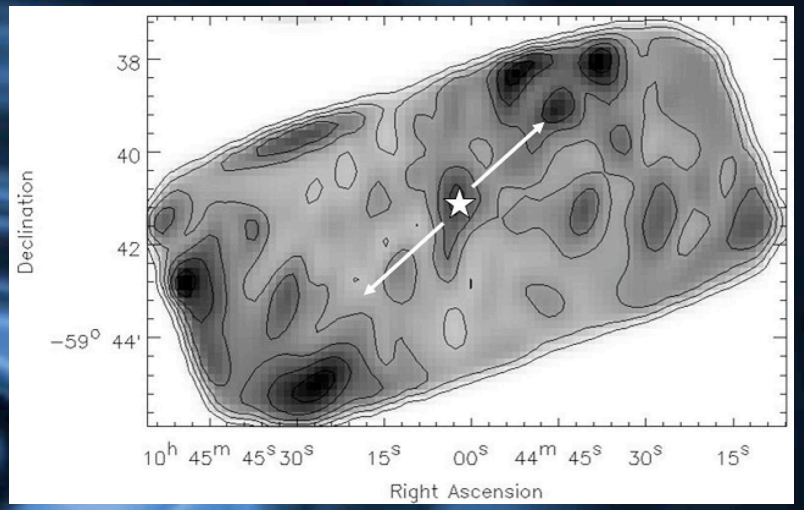
AKARI 90um continuum image (contour)

Yamaguchi et al. 2003

[O III] 88um image



[C II] 158um image

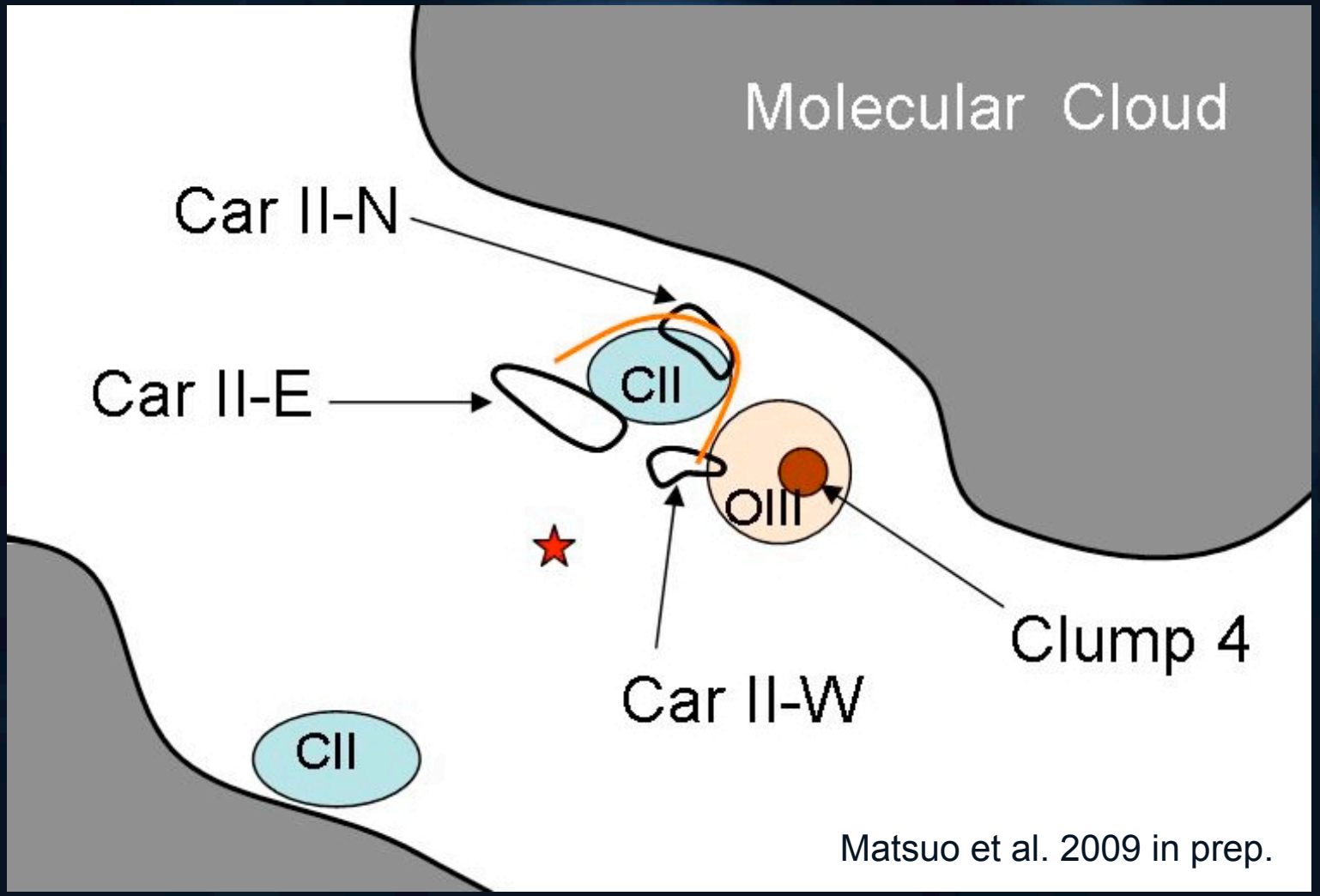


[O III] line seems to be excited at the interface region with the Carinae nebula.

[C II] line is enhanced to the direction aligned to the Homunculus Nebula elongation.

Matsuo et al. 2009 in prep.

Schematic View around eta Carinae



Matsuo et al. 2009 in prep.

Sciences of Galactic Starforming Regions

Okada et al. 2009

- Investigation of the structure of ISM
- possible embedded emission source from FIR lines and MIR continuum maps
  → necessary of imaging observations
- MIR & radio + FIR

MIR continuum：trace hot dust heated by heating source
Radio continuum：ionized region by ionizing source
⇅
FIS line：Physical Information at PDR and Ionized gas

* **Correlation or no-correlation** of distribution on each wavelength
* **heating source <---> ionizing source**
* Which wavelength are the feature as the tracer of ionizing source ?

Target List

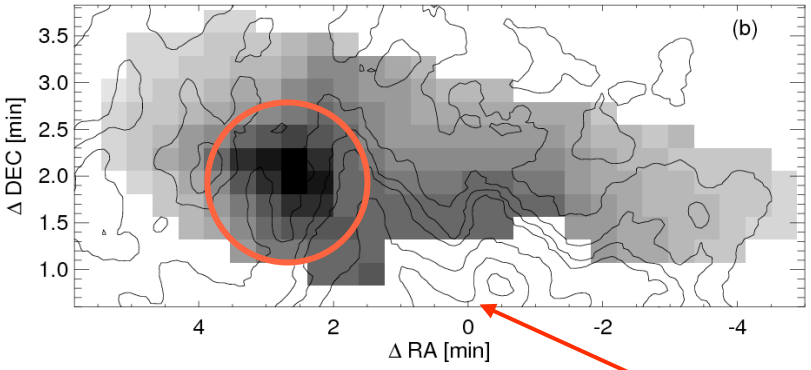
- Active Galactic starforming regions : 4 targets
- bright and extended source
  → enough S/N to derive wide region and multiple FIR lines

Target	# of pntg	Date	AOT	Reset	Mode
G3.270-0.101	1	2007.3.20	FIS03	0.25	full
G333.6-0.2	2	2007.3.3-4	FIS03	0.1	full
NGC3603	3	2007.7.21-23	FIS03	0.1	full
M17	1	2006.9.27	FIS03	0.1	full

- MIR : AKARI IRC, MSX
- radio : NRAO VLA Sky Survey, the Sydney Univ. Molonglo Sky Survey

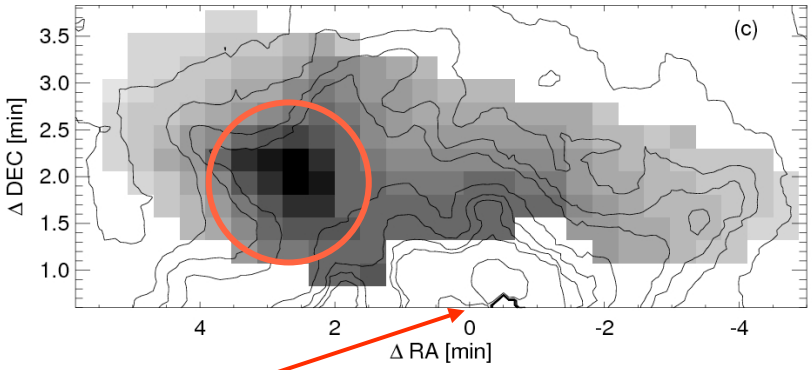
[O III] 88um image of G333.6-0.2

IRC survey 9um



hole

IRC survey 18um



peak

Center of Cluster

→ **Ionization source is in local peak.**

Okada et al. 2009 submitted

Sciences of Galactic Center Region

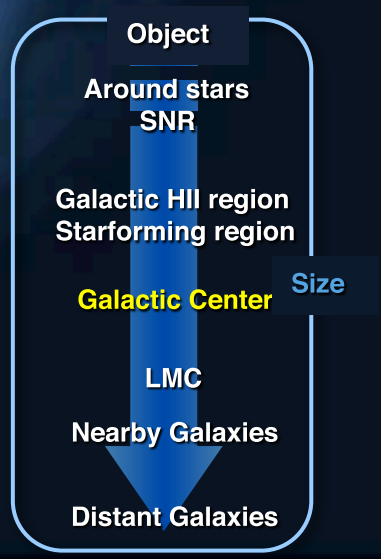
Yasuda et al. 2009

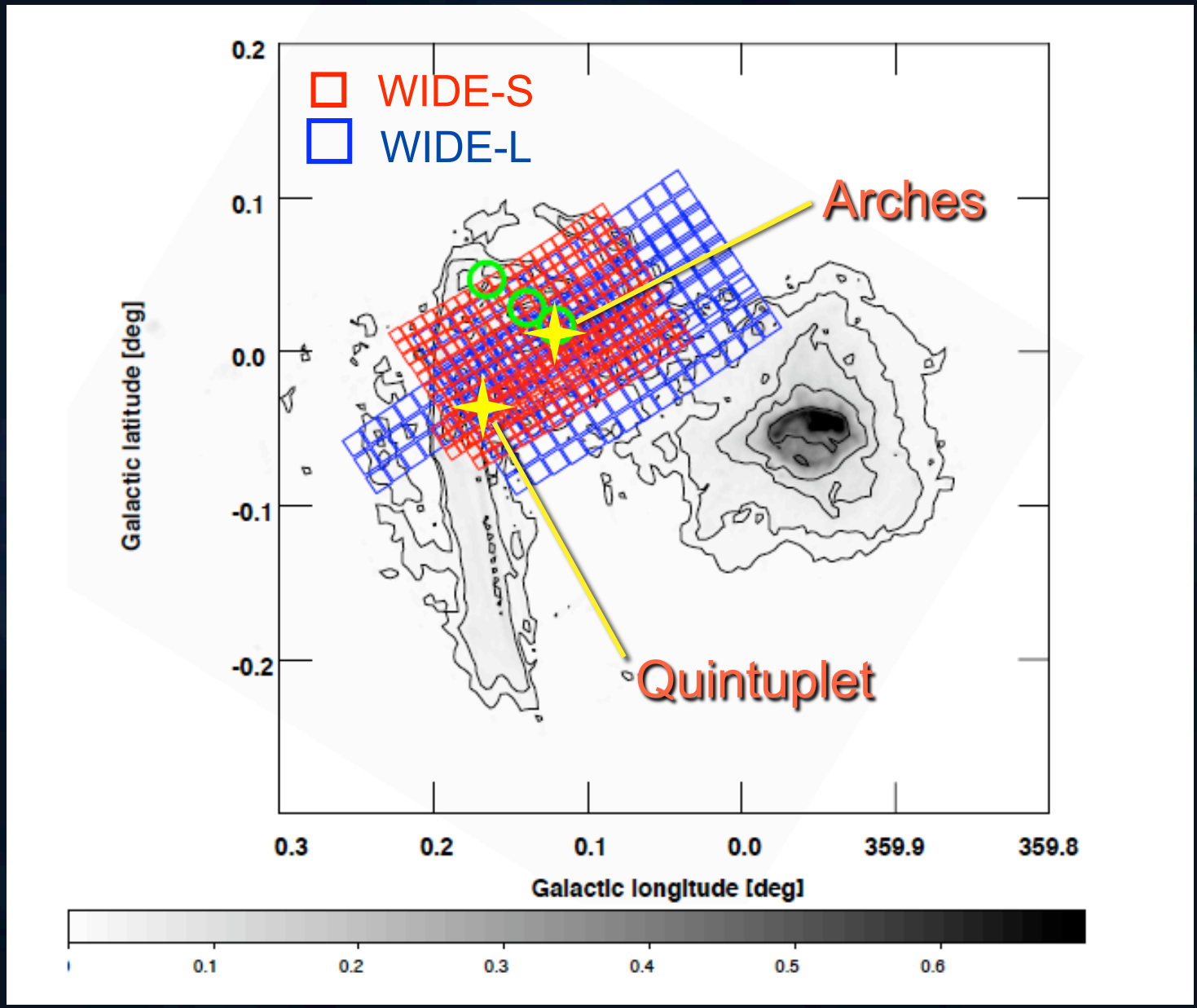
- Observation of Quintuplet- and Arches-cluster in GC
- Investigation of the structure of ISM near the **clusters of young massive stars**
  → high ionized region
- MIR & radio + FIR

MIR continuum：trace hot dust heated by heating source
Radio continuum：ionized region by ionizing source
⇅
FIS line：Physical Information of Ionized gas by **high energy source**

Observation log

Target ID	Position (l)	Position (b)	AOT	Mode	Date
5110023	0.1285	-0.0042	FIS03	full	2006.9.19
5110042	0.1365	0.0089	FIS03	full	2007.5.17
5110043	0.1229	-0.0114	FIS03	full	2007.5.18
5110054	0.1051	-0.0387	FIS03	Full	2007.5.18
5110055	0.1497	0.0294	FIS03	Full	2007.5.18



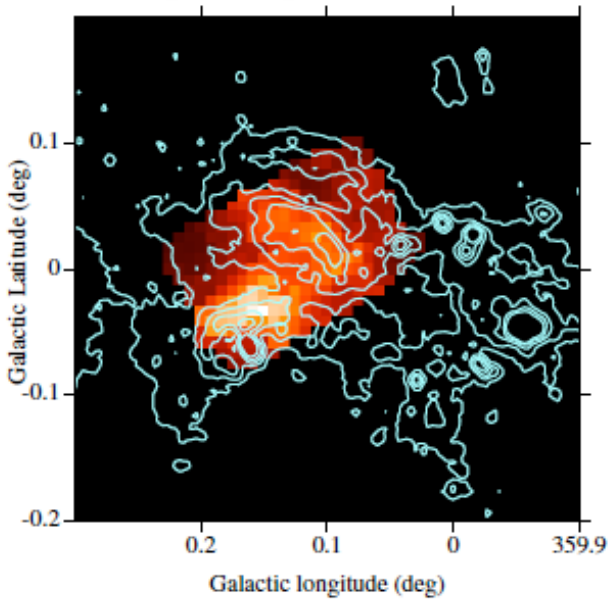


Yasuda et al. 2009

Results

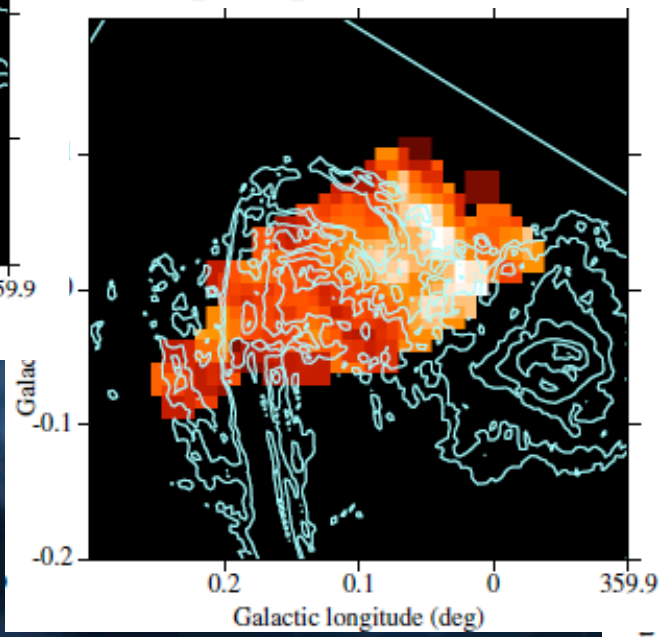
Yasuda et al. 2009

[O III] on 12um



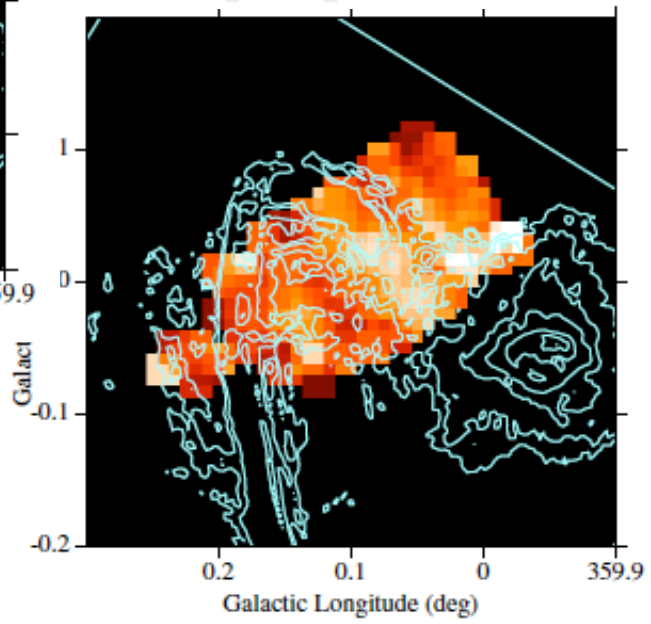
♻ trace the hot dust

[N II] on 20cm



♻ good correlation with arched filaments

[C II] on 20cm



[O III] / [N II]

→ Effective temperature **~ 34,000K**

88 / 122um continuum

→ Dust color temperature ~ **30K**

Sciences of LMC

Kawada et al. 2009

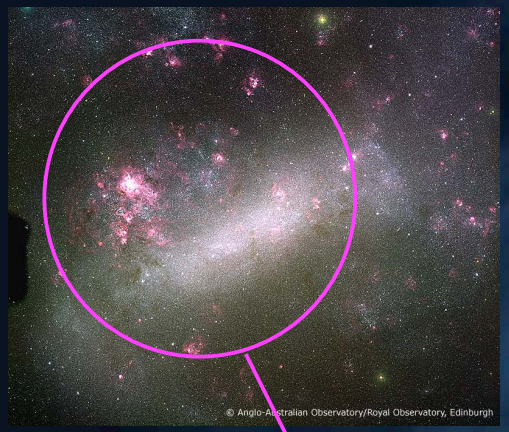
- Wide field observation =
  → **spatial distribution of ISM** around the galaxy
- Comparison with multi wavelength observation

Sub-mm & radio：Temperature and density of molecular gas
Optical : results of starformation
⇅
FIS [CII] line：Physical Information at PDR and Ionized gas

Observations

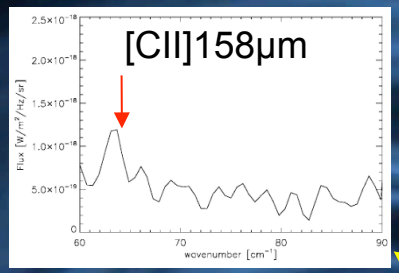
- Basically parallel observation with IRC
- 188 observing points (~50 pixels for each points)
- SED / full resolution mode

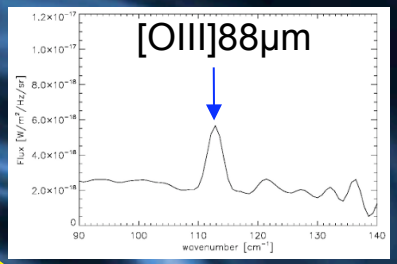
AKARI/FTS Observations at the LMC region

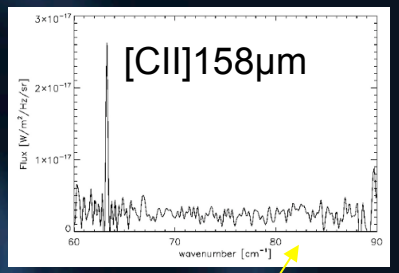


SED mode

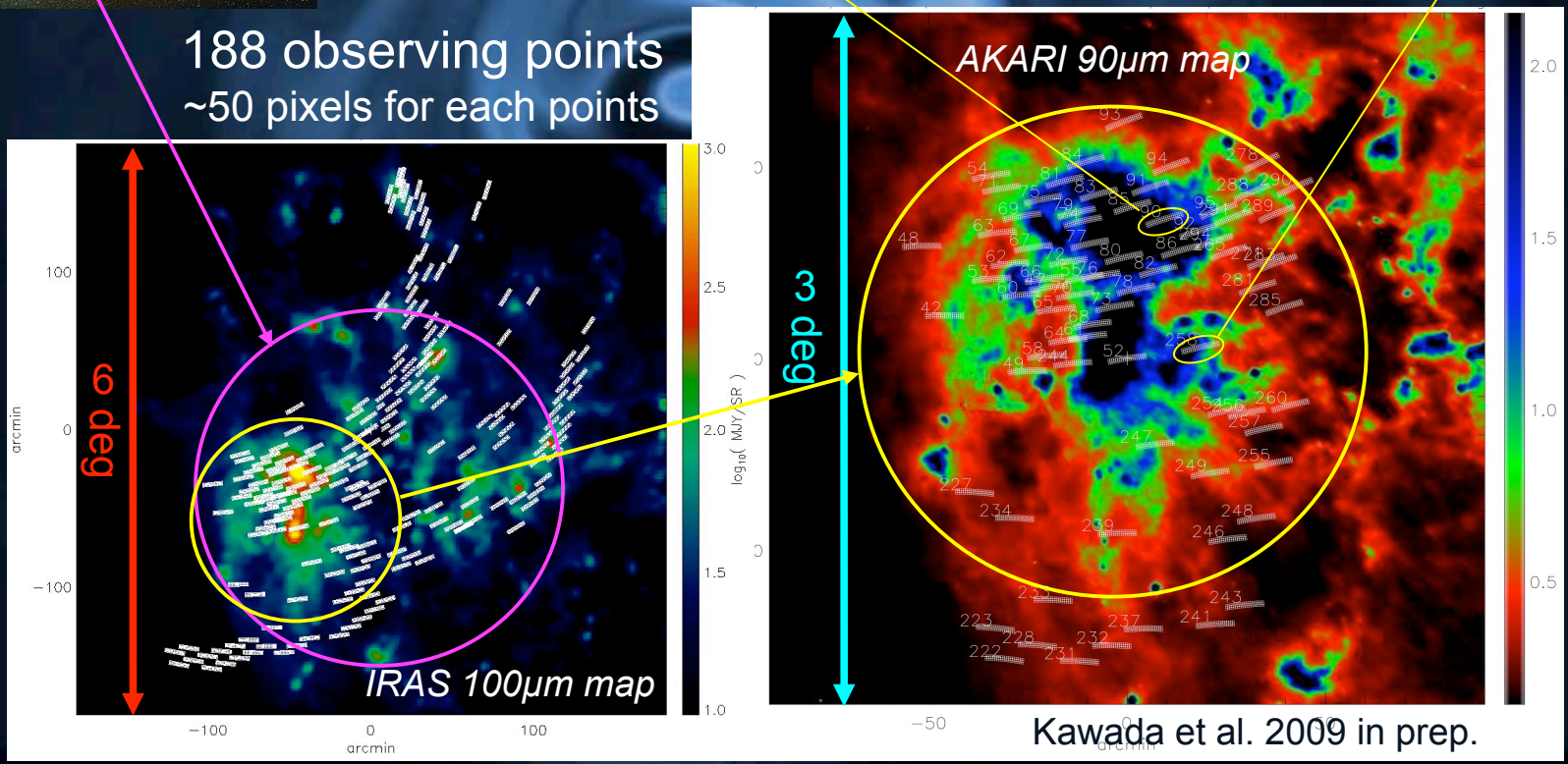
Full-res. mode







188 observing points
~50 pixels for each points



Kawada et al. 2009 in prep.

Sciences of NBGs

Takahashi et al. 2009

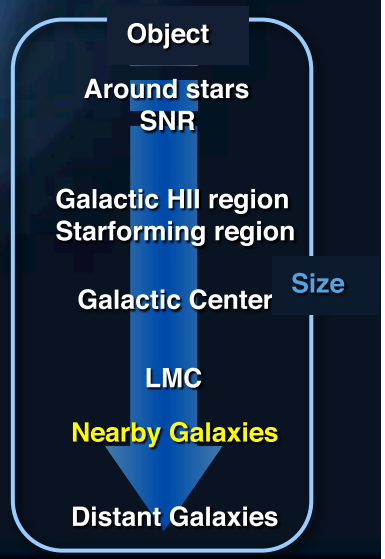
- Current observation of Sub-mm and radio (ASTE or NAO45m)
  (Multiple transition lines of CO)
  → relation of the variation of physical condition of molecular gas and the **starformation** within disk
- Sub-mm & radio + FIR

Sub-mm & radio：Temperature and density of molecular gas which is extended around disk

⇅

FIS [CII] line：Physical Information at PDR and Ionized gas

* **Correlation or no-correlation** of distribution on Sub-mm / FIR !?
* Limitation to structure of interstellar (molecular) gas !?
* Temperature and density of molecular gas is correlated to **starformation rate** !?



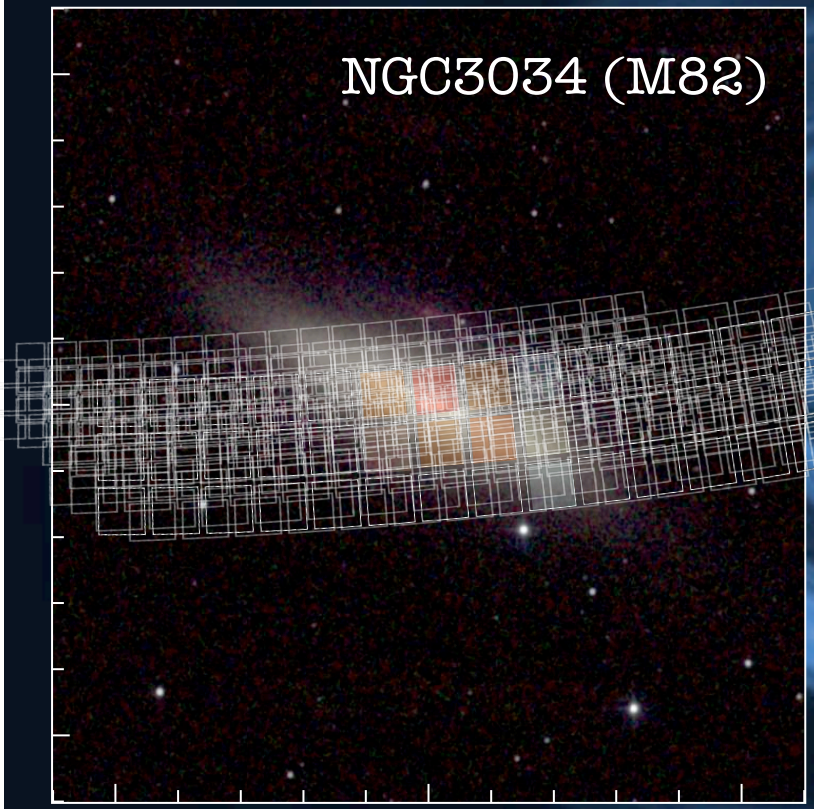
Quick Results and Remarks

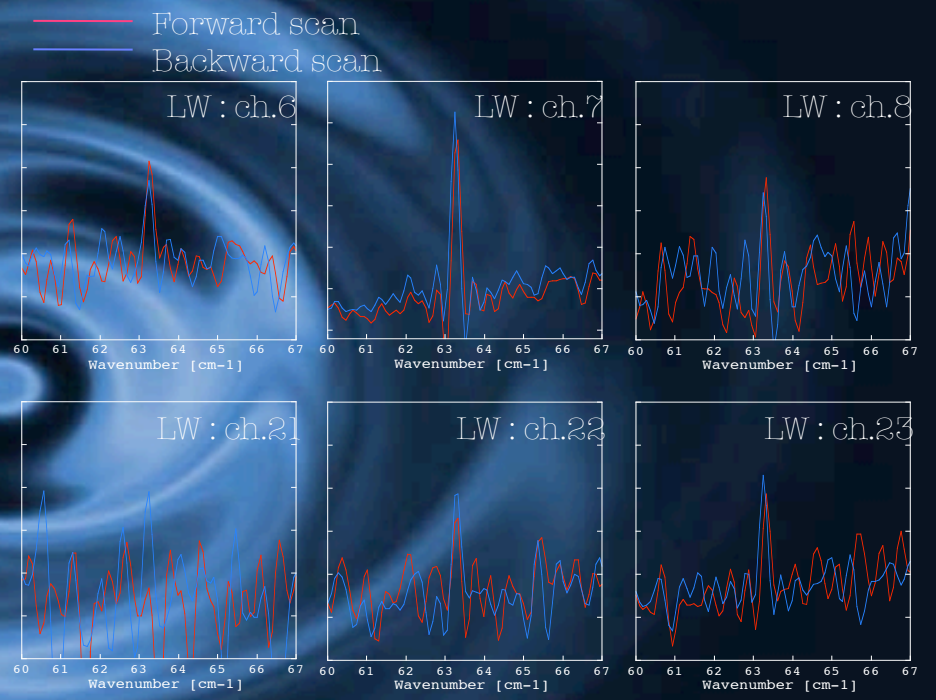
- Total observed targets : 9 targets
- Some targets are detected on multiple pixels.
- Multiple FIR lines are detected on several targets.

Target	Type	Size (")	FTS mode	# of pntg	ISO	SST	Others
NGC 253	SAB(s)c; HII, Sbrst	27.5 x 6.8	Full	3	264 x 84		ASTE, 45m, NMA
IC 342	SAB(rs)cd	21.4 x 20.9	Full	2	284 x 184		45m, NMA
NGC 3034	I0, Sbrst	11.2 x 4.3	Full	5	384 x 84	SINGS	45m, NMA
NGC 6946	SAB(rs)cd	11.5 x 9.8	Full	1	584 x 384	SINGS	45m, NMA
Maffei2	SAB(rs)bc	5.82 x 1.57	Full	1	P		45m, NMA
NGC 5236	SAB(s)c; HII, Sbrst	12.9 x 11.5	Full	2	399 x 219		ASTE, 45m, NMA
NGC 5457	SAB(rs)cd	28.8 x 26.9	Full	3	684 x 84		45m, NMA
NGC 1569	Ibm; Sbrst	3.6 x 1.8	SED	1	P		
NGC 2146	SB(s)ab pec, HII	6.0 x 3.4	Full	1	P		NMA

- with IRC : wide range SED
- with ISO, SST : cross calibration, spatial structure…
- with sub-mm and radio : as follows…

FIR [CII] line map

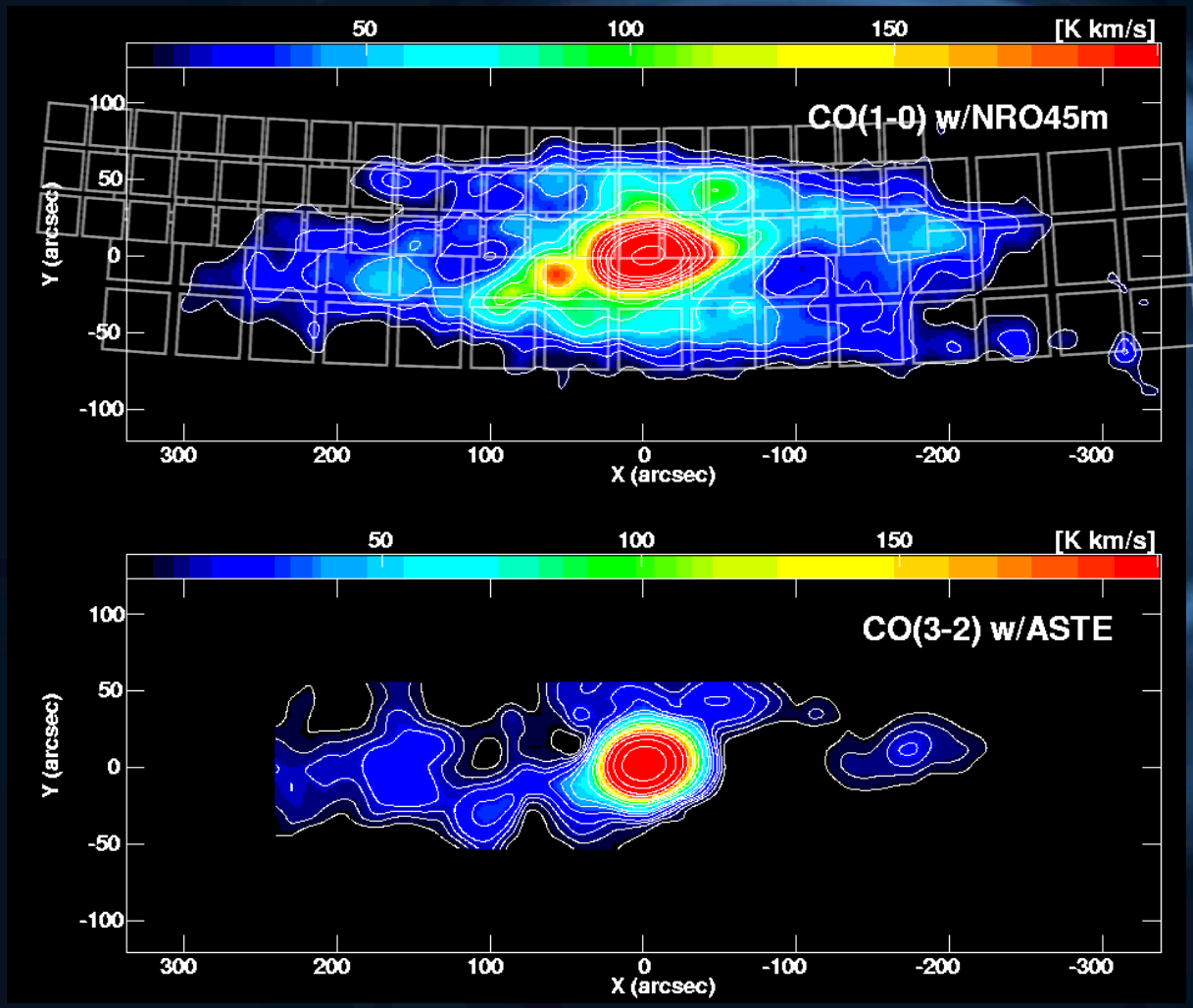




- [CII] 158um forbidden line
- Widely spread detection
  → compare to submm & mm

Takahashi et al. 2009 in prep.

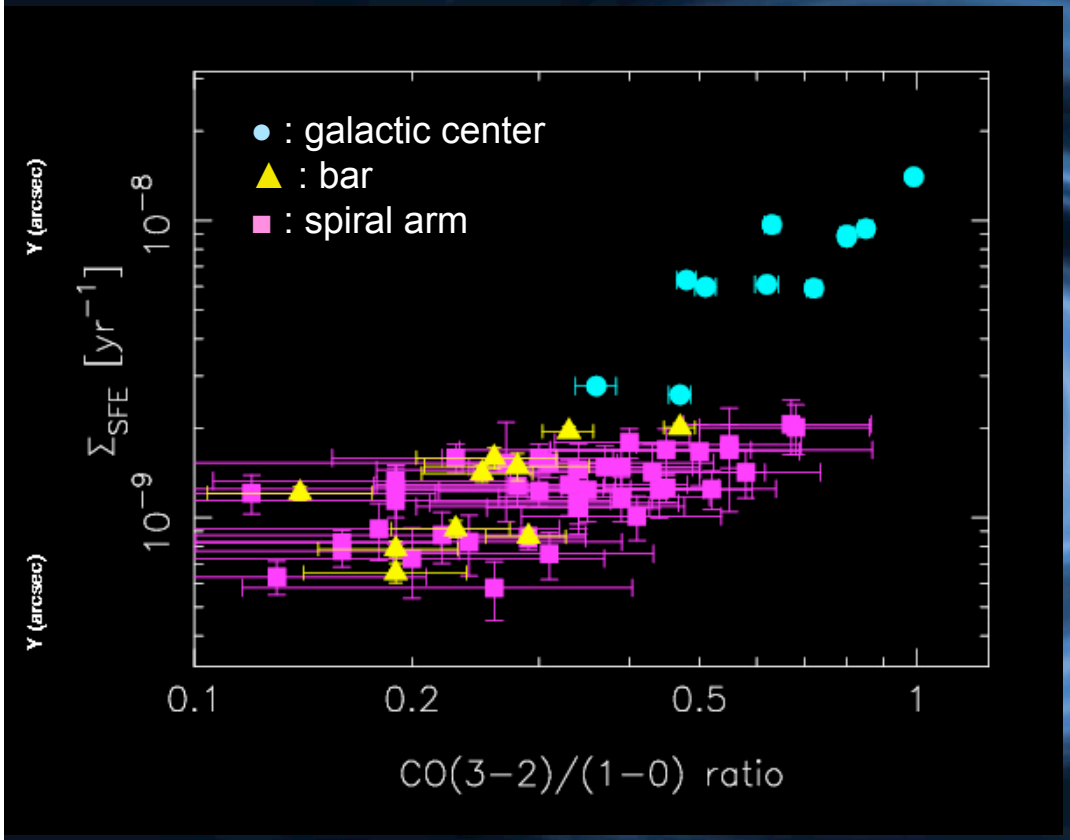
^{12}CO(1-0) and (3-2) maps on NGC253



- Center : Disk (r<500pc) = 1:2.6
- Center : Disk = 1:0.7

Nakanishi et al. 2009 in prep.

CO line ratio vs SFE (6cm/CO)



Nakanishi et al. 2009 in prep.

★ Star formation efficiency(SFE) is star formation rate per unit molecular gas mass

★ SFE ∝ 6cm/CO(1-0)

★ 3-2/1-0 ratio have correlation with SFE?

♻ How is the spatial distribution of the correlation ??

“Diagnosis of the age of starformation and the evolutionally stage on central core or disk of galaxies separately”

FIR Spectroscopic Observation toward future missions

Problems and Items on data analysis about FIS-FTS

- Spectral correction factor
- Transient correction of photoconductor
- Fringe correction
- Practical spectral resolution
- Absolute calibration
- PSF of spectroscopy mode
- etc…

Problems on observation with AKARI FIS-FTS

- **Limited pointings**
  → narrow spatial coverage
  → limited sample
- **less sensitivity**
  → detection only few lines
- **poor spatial resolution**

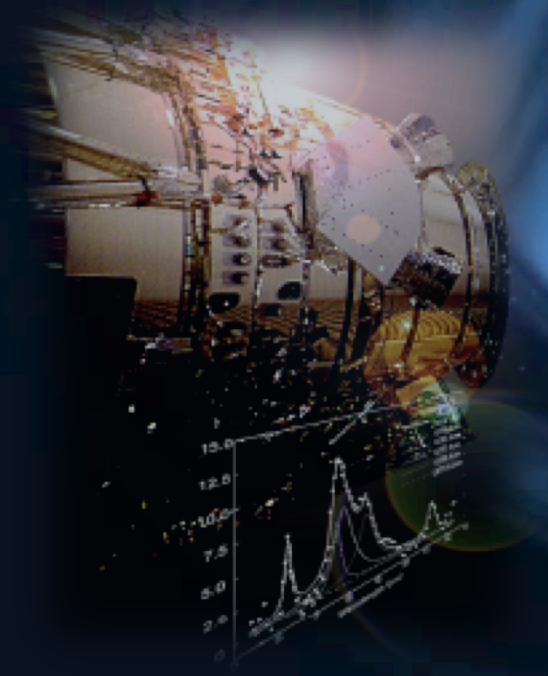
FIR Spectroscopic Observation toward future missions

- **High sensitivity**
  - → multiple lines
  - → wide range of physical condition
- **High spatial resolution**
  - → reveal spatial distribution in different physical condition
- **Wide spatial coverage**
  - → detailing research within each target
- **Multiple sample**
  - → comparison to various environments
  - → statistical and systematic study

FIR Spectroscopic Study

From

AKARI



toward

SPICA

to be discussed …..