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COMING

CO MULTI-LINE IMAGING OF NEARBY GALAXIES

COMING-TAO Collaboration

"COMING-PLUS"

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& COMING-PLUS team

NINS National Institutes of Natural Sciences

国立天文台 NAOJ

Nobeyama Radio Observatory

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Nobeyama Radio Observatory

- One of brunches of National Astronomical Observatory of Japan
- Operates the 45-m radio telescope

- One of the largest radio telescopes in mm reign
- 20GHz(15mm)-115GHz(2.7mm)

What's COMING?

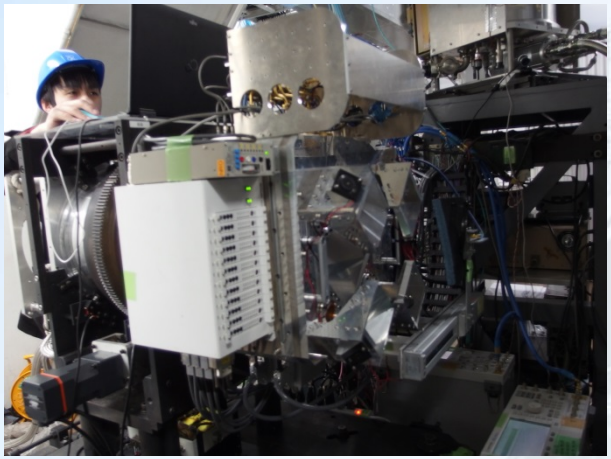
- COMING: CO Multiline Imaging of Nearby Galaxies
- One of Legacy Projects of the observatory

COMING
CO Multi-line Imaging of Nearby Galaxies

- Targets: Nearby Galaxies (P.I.: Sorai [Hokkaido Univ.])
- Simultaneous observations of molecular lines:
  ^{12}CO(J=1–0), ^{13}CO(J=1–0) and C^{18}O(J=1–0)

with new receiver FOREST

FOREST

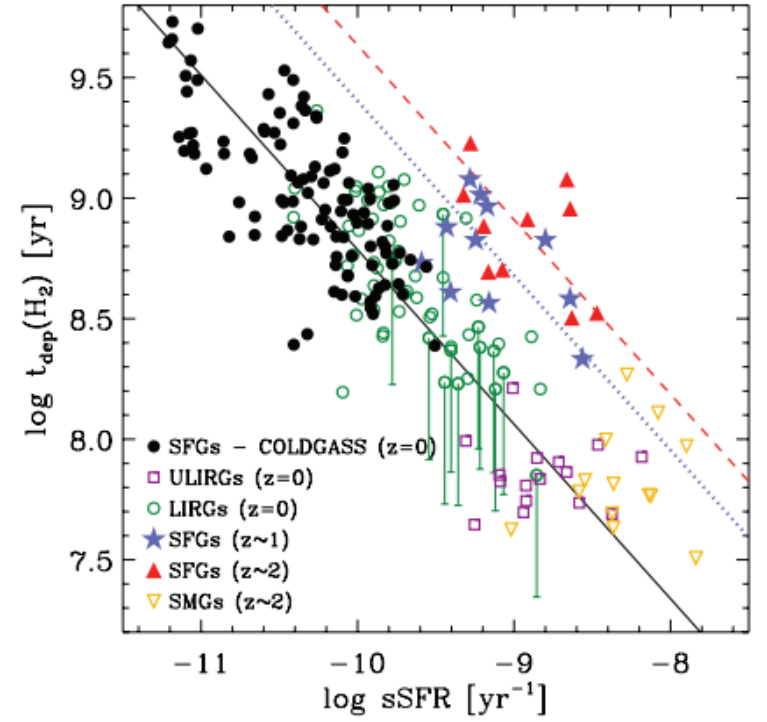


What's COMING?

- CO molecular lines: basic tracers of molecular gas
- Fuel of star formation

⇒ fundamental process of evolution of galaxies

- Star formation mechanism (where and how?)



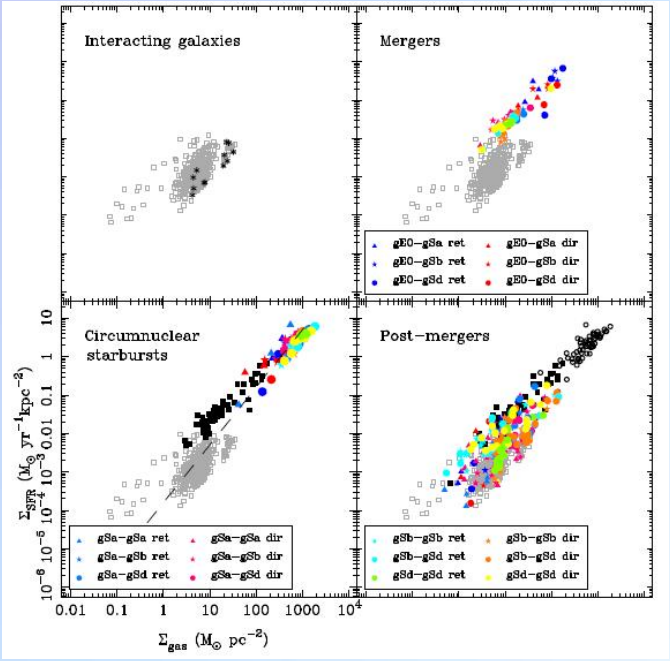
Saintonge et al. (2011)

What's COMING?

- CO molecular lines: basic tracers of molecular gas
- Fuel of star formation

⇒ fundamental process of evolution of galaxies

- Relationship btw gas properties and environments (bar, AGN, starburst, interactions, cluster, etc.)



Matteo et al. (2008)

What's COMING?

- Comparison to previous CO imaging surveys

- BIMA SONG: 44 galaxies @ 6"
- Nobeyama CO atlas: 40 galaxies @ 16"
- STING: 23 IR-bright galaxies@ 3-5"

⇒ few # of samples, low spatial resolution

What's COMING?

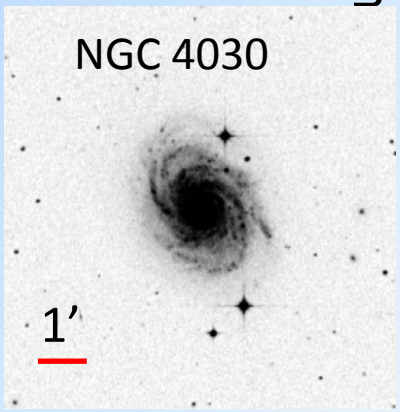
- galaxies with the distance of < 35 Mpc
- # of targets: 238 galaxies

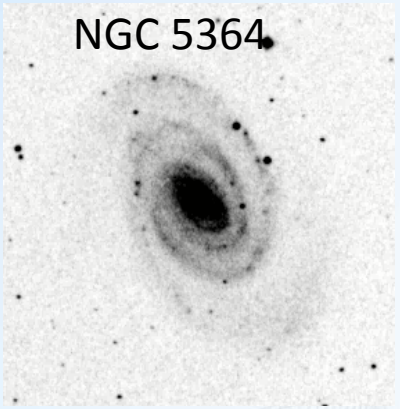
…more than the # of galaxies ever imaged (~100)

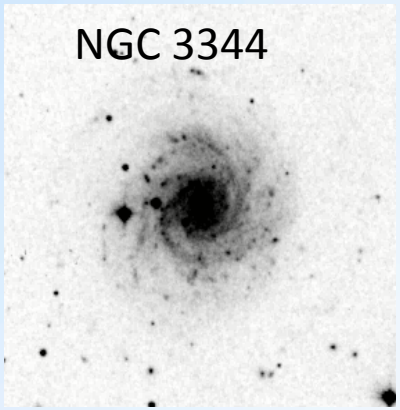
- Typical galaxy size : 5'
- Imaging area: 70% of D_{25}
- Velocity res.: 10 km/s
- Spatial res.: 19" @^{12}CO(1–0)

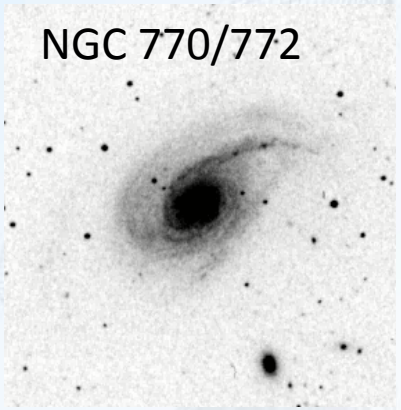
- ^{12}CO(J=1–0), ^{13}CO(J=1–0) and C^{18}O(J=1–0)

→gas density and temperature









What's COMING?

- From low-z to high-z
- If a target at z~1 is observed w/ ALMA's highest res.

…linear res. ~ kpc

⇒ comparable to the observation of nearby galaxies (~few 10 Mpc) w/ the 45-m telescope

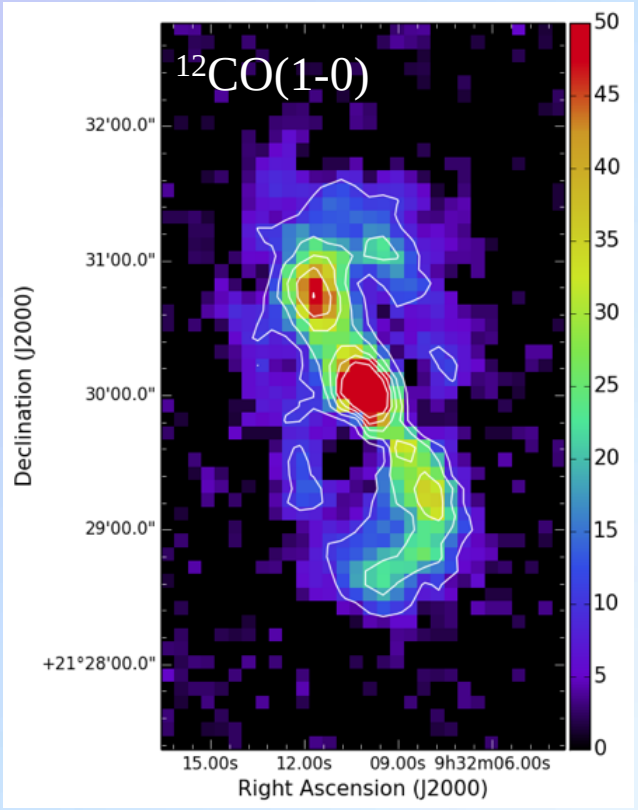
- Enable us to direct comparison

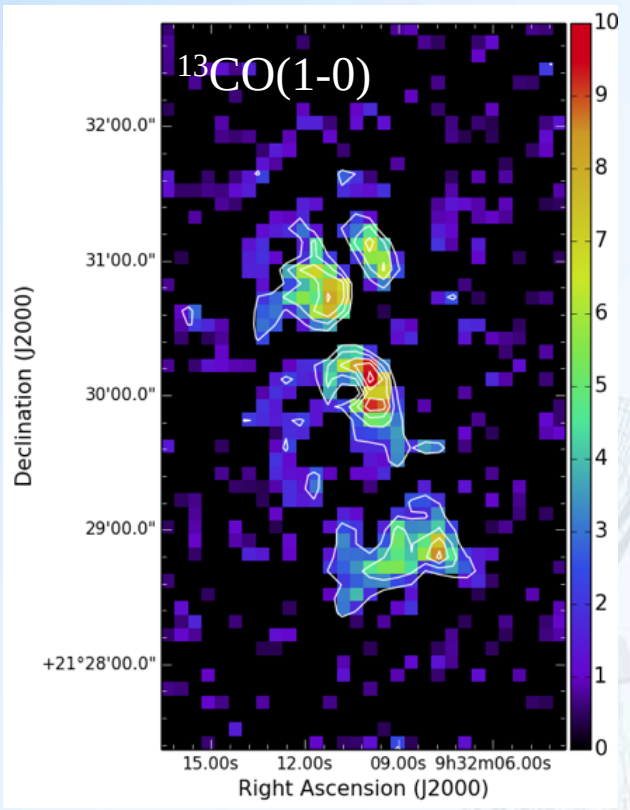
- Important to understand the statistical properties of low-z galaxies with resolving their structures

"COMING" has come!

- From this spring, scientific data has obtained
- Successfully obtained ^{12}CO(1–0) & ^{13}CO(1–0) maps simultaneously!!

NGC 2903



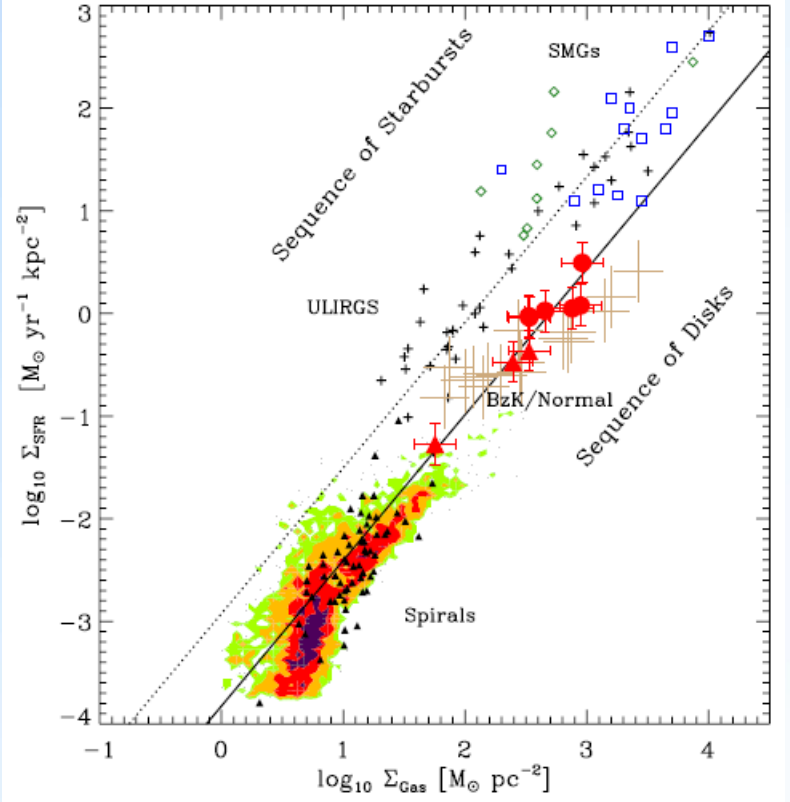


COMING-PLUS

- Relationship btw molecular gas and star formation
- Kennicutt-Schmidt law (e.g., Kennicutt, 1998)
- One of the important topics in the studies of evolution of galaxies

$$\Sigma_{SFR} \propto \Sigma_{gas}^{N}$$

- N~1-2
- N differs in galaxies and structures (e.g., Daddi et al. 2010)



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- Example of CO and Paα

…for science w/ imaging data, Hα is mostly used

- Problem: dust extinction

→correction w/ dust re-radiation (e.g., Calzetti et al. 2008)

Worse in spatial res. (3-4")

Needs of two data set (Hα & dust [24 μm, etc.])

- When science w/ ALMA, resolution is NOT enough

…Paα should be a clue.

miniTAO/ANIR and TAO/SWIMS are the best answer

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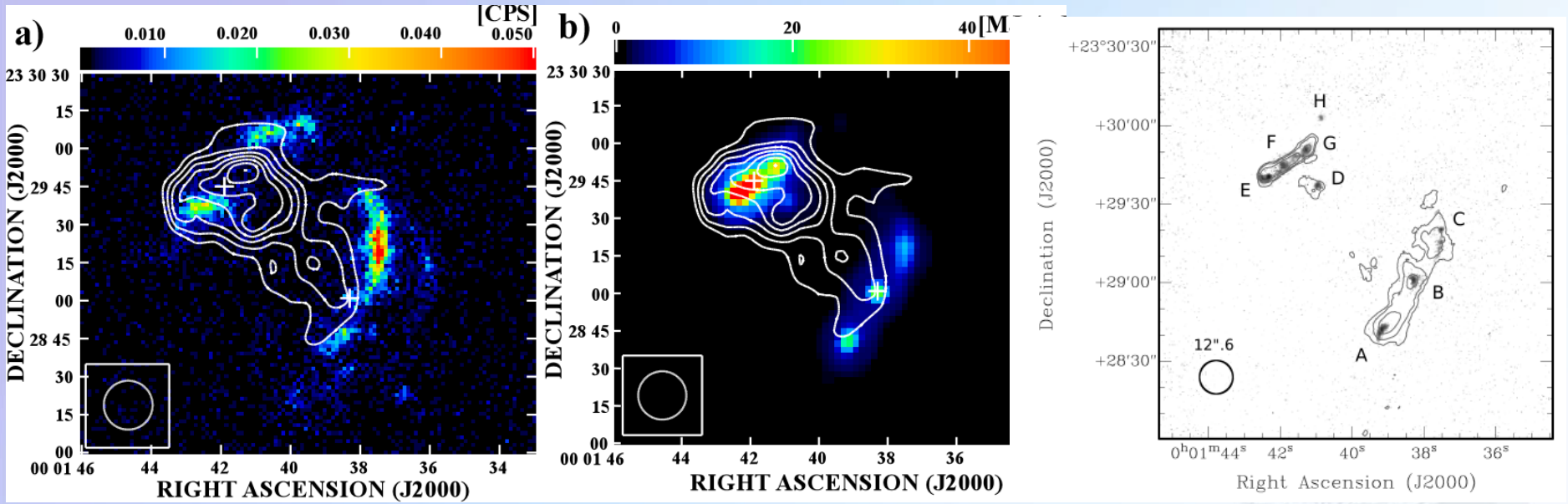
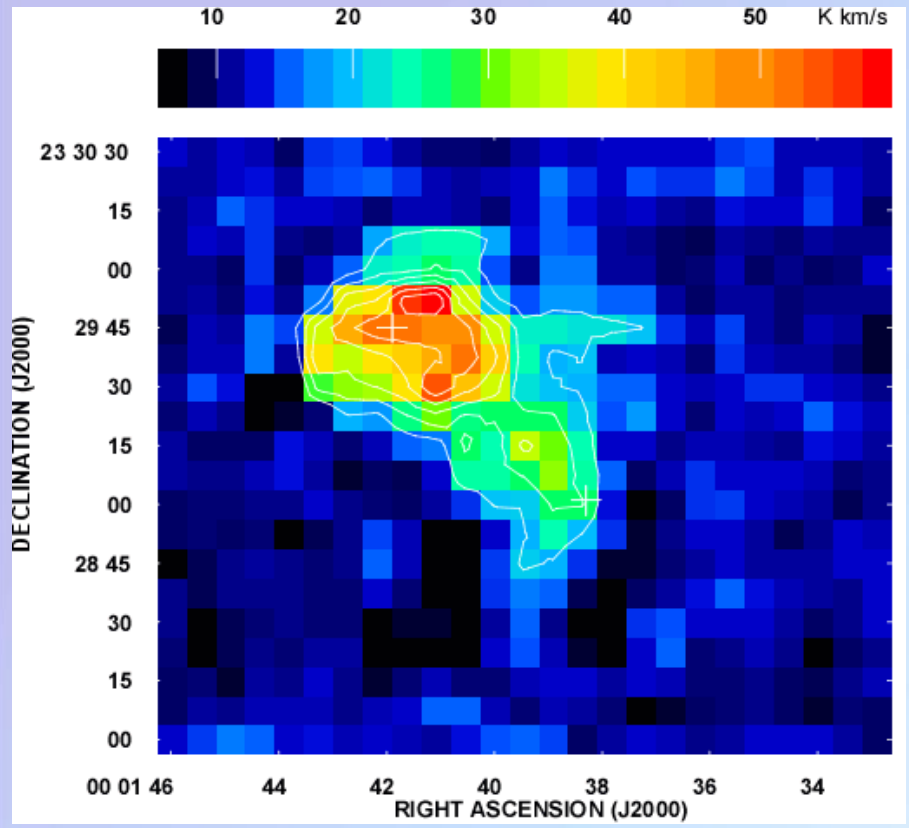
- Tracers of star formation
- Interacting galaxies VV 254

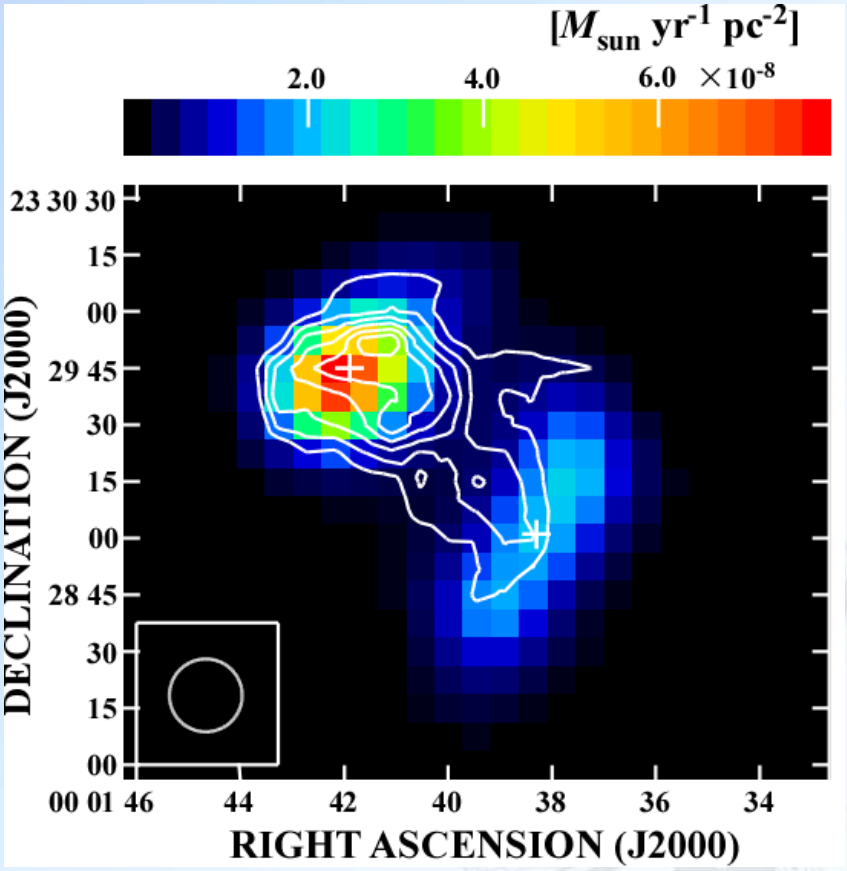


FUV(GALEX) Spitzer 24 um Komugi et al. (2012)

COMING-PLUS

- Tracers of star formation
- Interacting galaxies VV 254





^{12}CO (45-m: Kaneko et al. 2013) SFR from FUV + 24um (Kaneko et al. in prep.)

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COMING-PLUS

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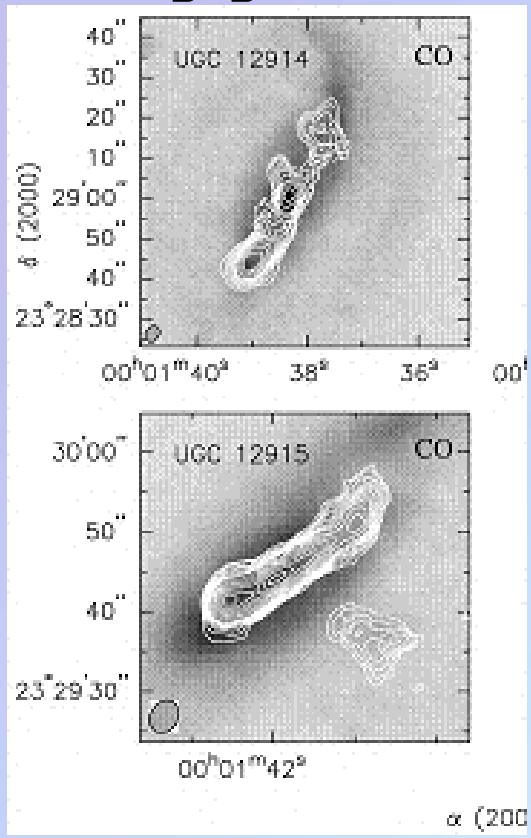
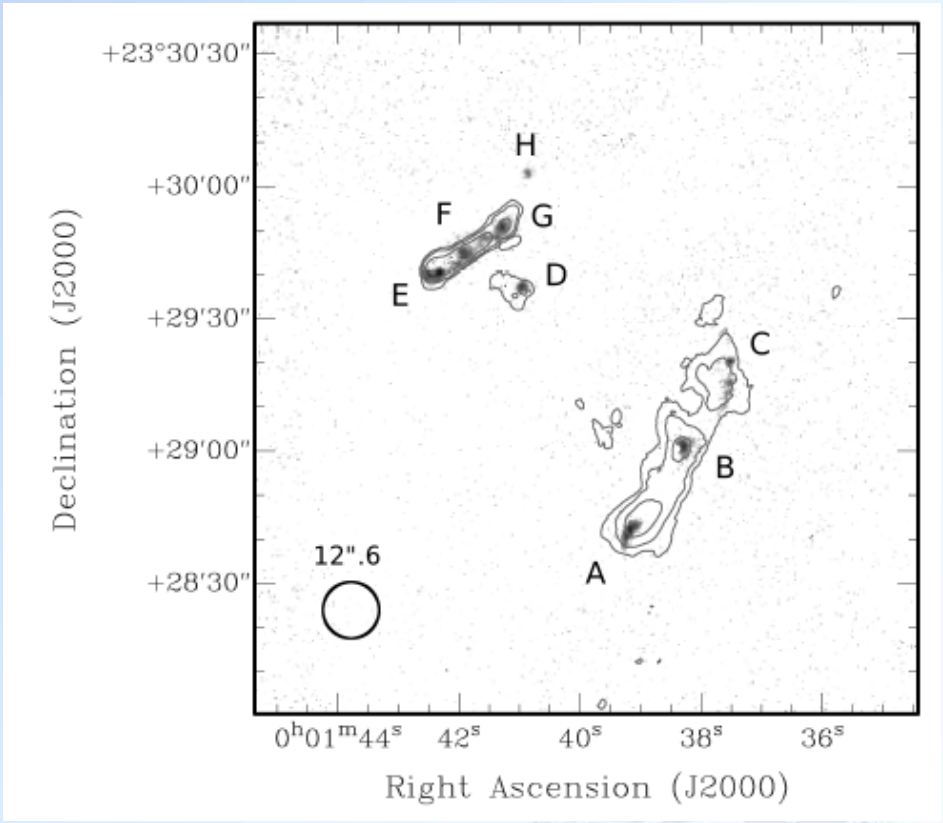
- Interacting galaxies VV 254



^{12}CO (OVRO: Iono et al. 2005)



Paα (Komugi et al. 2012)
contour :^{12}CO(Iono et al. 2005 as left fig.)

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- COMING containing Paα Line imaging by Using the telescopes in Southern hemi-sphere

- Paα imaging observations
- Targets: galaxies in the sample of COMING (238 galaxies) which can be observable from the TAO site (dec. < 30 degree)

→candidates : 140 galaxies

- Observing time per one galaxy (rough estimate FOR miniTAO)
  broad band (J , H + Ks): ~10 min x 2 band
  Paα, Paβ ~40 min

… ~1 hour/galaxy

→~140 hours

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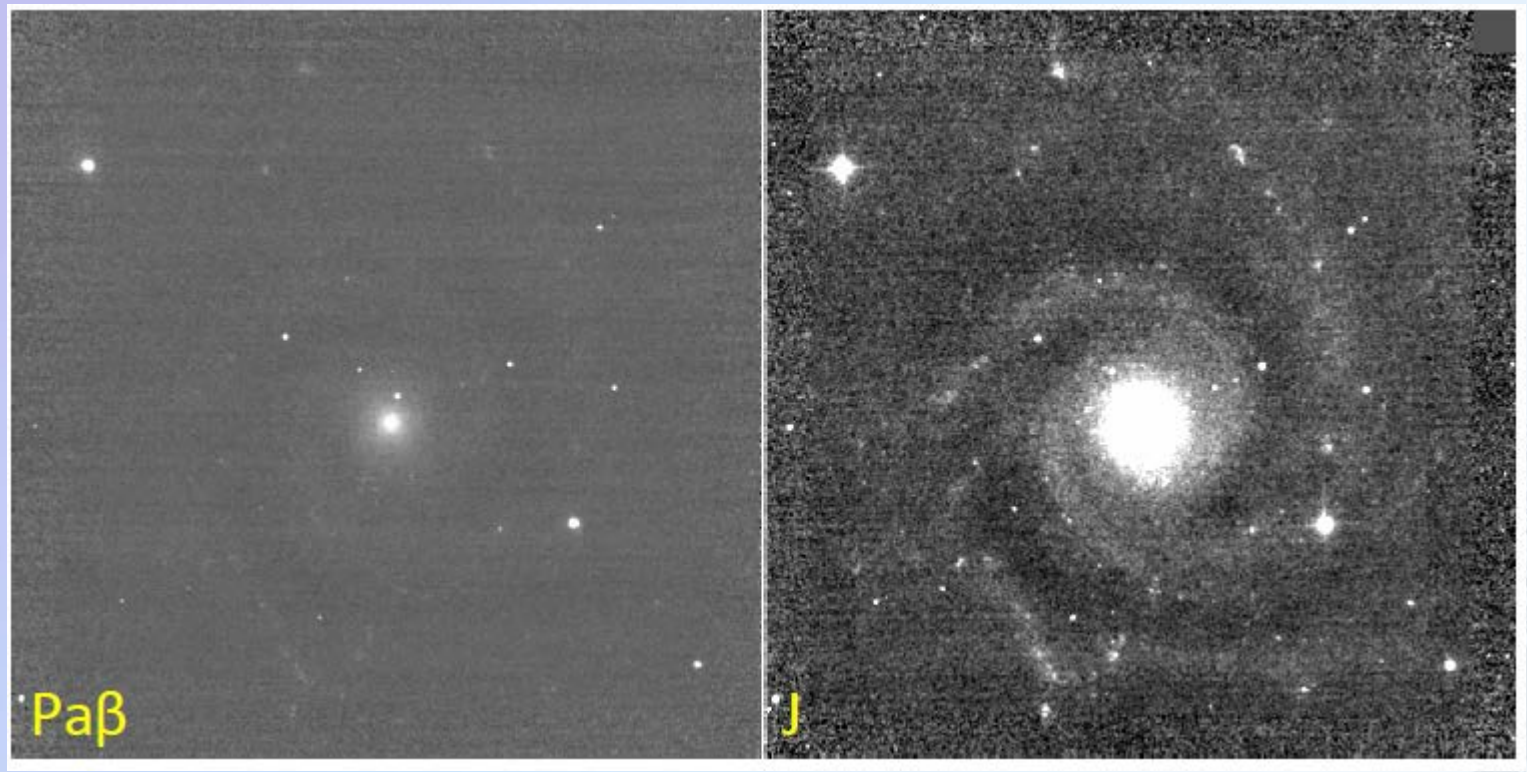
NAOJ NINS

- Few galaxies: already observed w/ miniTAO/ANIR
- NGC 628



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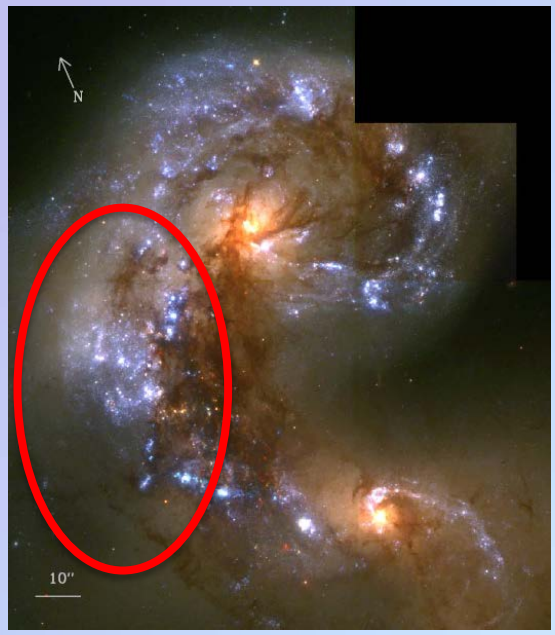
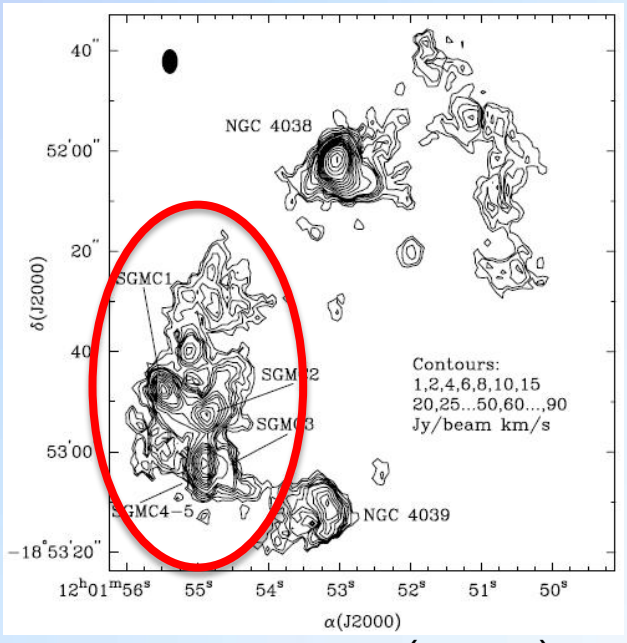
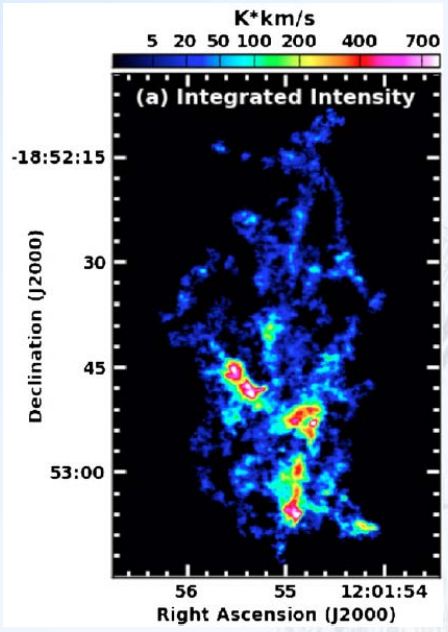
- Strength of COMING-PLUS
- molecular gas and star formation tracer images
- Easily leads to ALMA science
  - Giant Molecular Clouds scale (~100 pc) in nearby galaxies
  - kpc scale in High-z



Whitmore et al. (1999)



Wilson et al. (2000)



Whitmore et al. (2014)

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Summary

- CO multi-line imaging of nearby galaxies using the 45-m telescope, COMING, has been conducted
- Kennicutt-Schmidt law is one of clues to reveal evolution of galaxies
- Paα is the best star formation tracer
- miniTAO/ANIR Paα survey as a first step has started
- TAO/SWIMS & COMING collaboration will be one key to investigate the evolution of galaxies
- This collaboration leads to the science with ALMA in both local and high-z universe