銀河進化研究会 2016年 6月 3日 東北大学

AGN key sciences enabled by TMT/MICHI

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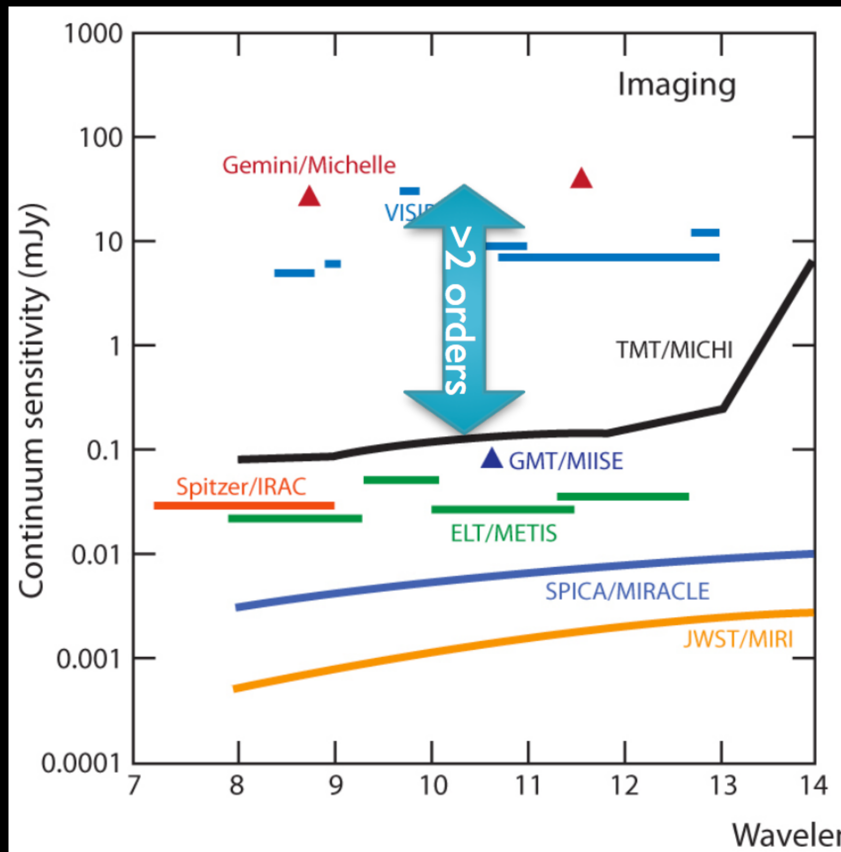
JSPS fellow (PD) at NAOJ
and co-PI of TMT AGN/BH physics group

What is MICHI (未知)?

mid-IR (MIR) band imaging/spec (+IFU/pol?)

One of the TMT 2nd gen. instruments (CfP in 2017?)

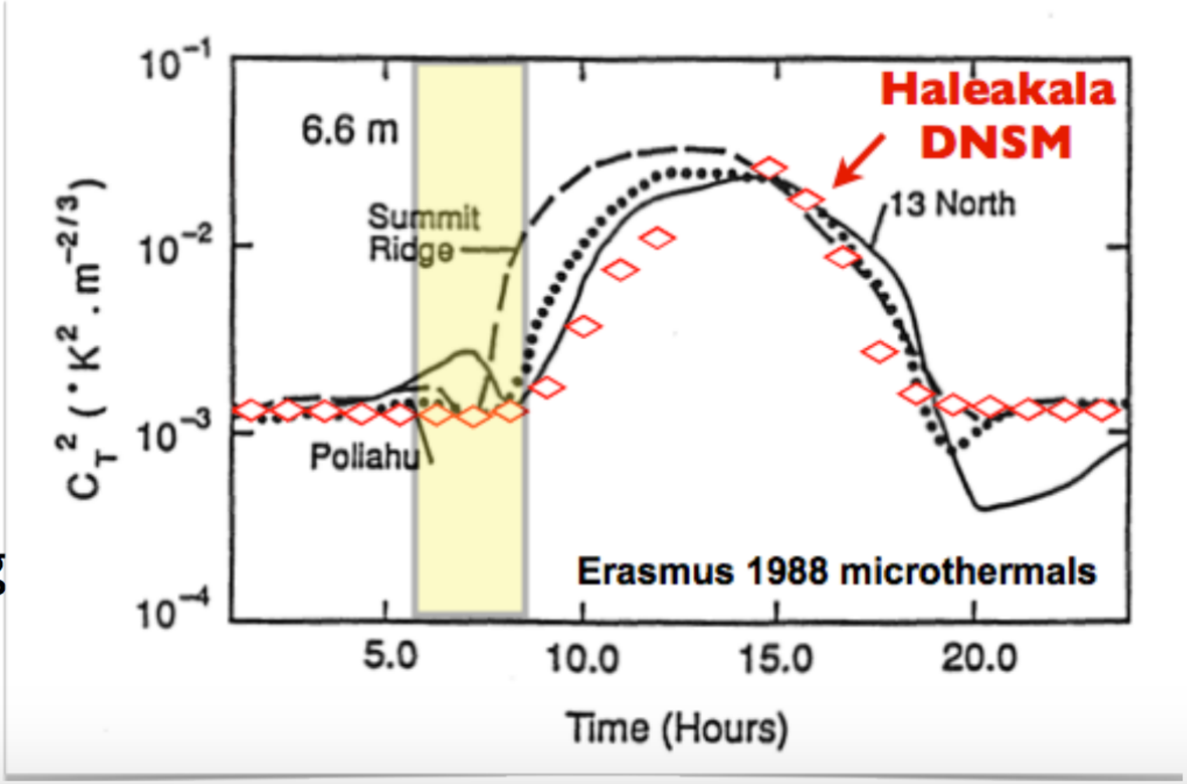
co-PIs in US/Japan
C. Packham (UT San Antonio)
M. Honda (Kurume Univ.)
tight collaboration between US and Japan



- ☑ Wavelength: 3-13 (-25um) um : L, M, N, (and Q?)
- ☑ 0.1 mJy @ 10 um imaging w/ 1hr elapsed time
- ☑ <0.1” @N (~0.03” @ L)

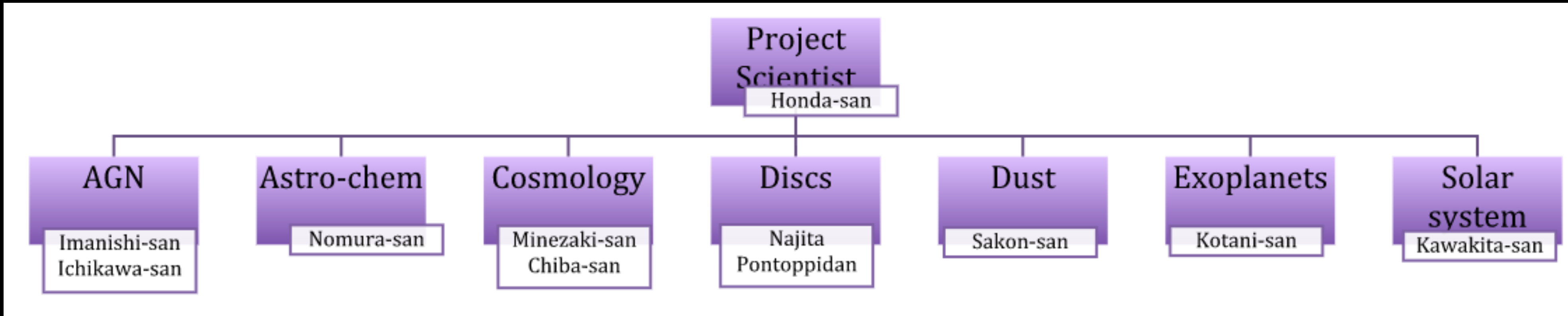
MIRAO & Daytime Observing

- Daytime observing
  - MIRAO/MICHI could exploit best seeing conditions in early morning hours
  - Appears feasible with no loss in performance and affords an extra **1-2 hours per night** (at minimal cost) of *TMT* observing time
  - R&D efforts
    - We appreciate the help of the Subaru AO team (especially Hayano-san)
    - Testing using Subaru's AO system is on-going



MICHI science group

7 categories and PIs of each science group



Each group has completed initial science cases (2016 May)

Dust, molecules are the key

Great synergies w/ ALMA, JWST

Studies of galaxies are still missing

MICHI AGN/BH group

16 members (as of May 2016)

A. Alonso-Herrero, P. Gandhi, K. Ichikawa (co-PI), M. Imanishi (co-PI), H. Inami, T. Izumi, N. Kawakatu, T. Kawamuro, M. Kishimoto, N. Levenson, E. Lopez-Rodriguez, K. Matsuoka, T. Nagao, N. Oi, C. Packham, M. Shirahata

☑ Group w/ IR, ALMA, X-ray, polarimetry, and theory backgrounds

☑ We welcome new members anytime!
contact => kohei.ichikawa@nao.ac.jp

11 science cases in total (as of May 2016)

3 science goals

☑ Resolving the AGN tori
☑ Peering AGN torus origins/fueling
☑ Revealing jet properties of black hole (BH) binaries

TMT/MICHI

~~3~~ 2 goals of AGN/BH sciences with MICHI

1. Resolving the AGN tori

2. Peering the torus origins and fueling

~~3. Jet properties of Black Hole (BH) binaries~~
~~(*not AGN but tight connection to AGN feedback*)~~

TMT/MICHI

2 goals of AGN/BH science with MICHI

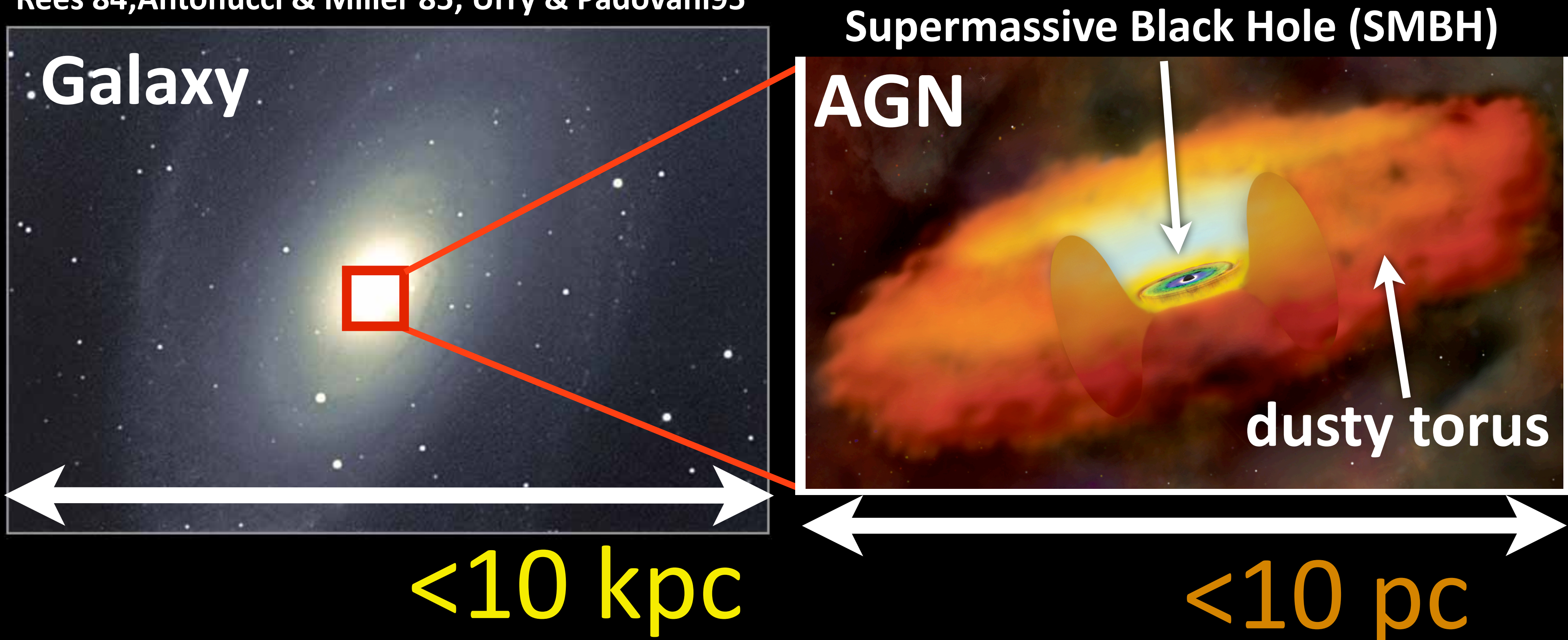
1. Resolving the AGN tori

2. Peering the torus origins and fueling

~~3. Jet properties through Black Hole (BH) binaries (*not AGN!*)~~

Active Galactic Nuclei (AGN)

Rees 84;Antonucci & Miller 85; Urry & Padovani95

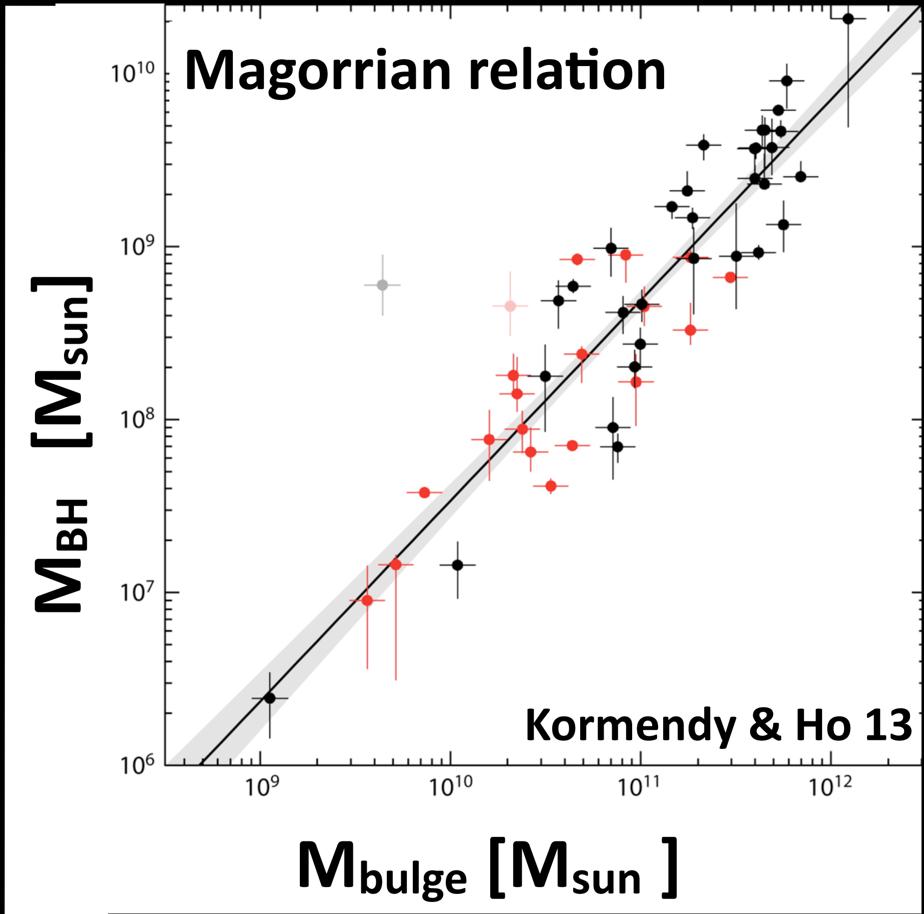


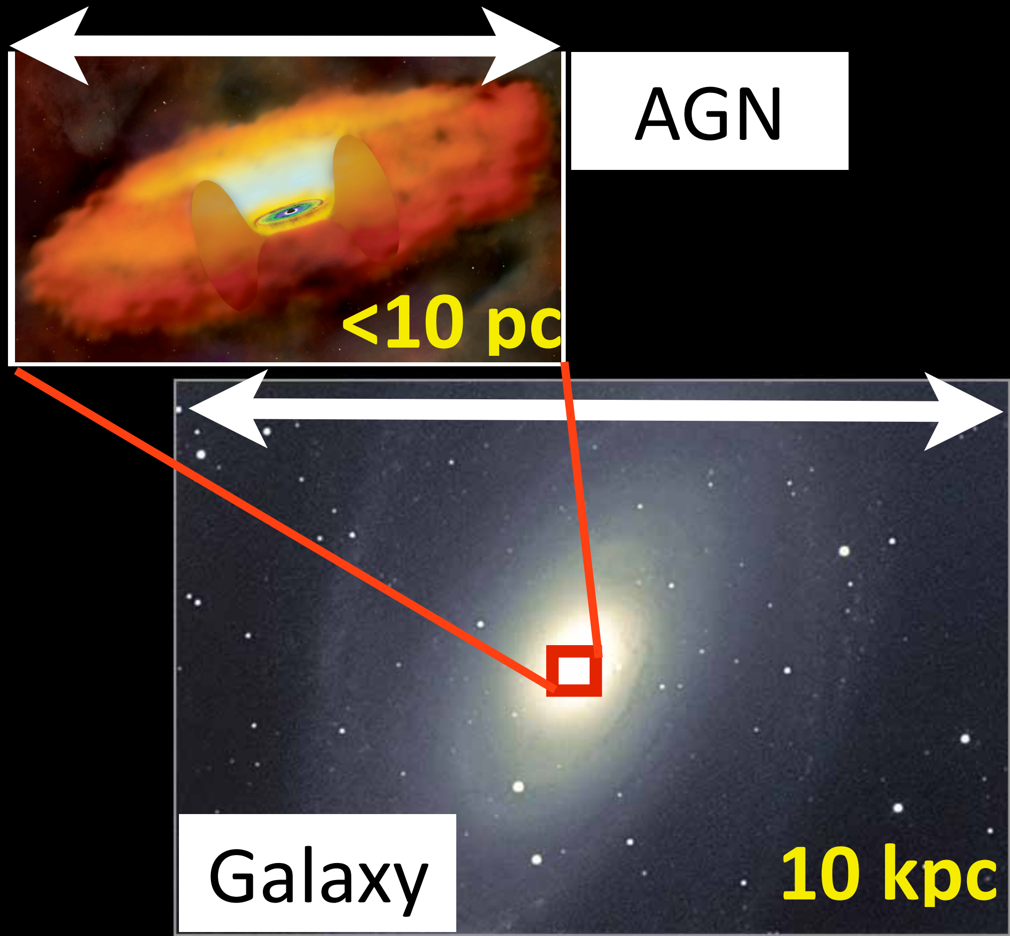
AGN Unified Model

- ☑ optical-UV: accretion disk
- ☑ X-ray: hot electron corona
- ☑ **Infrared (IR): dusty torus (dust/gas provider to SMBH)**

Co-evolution of SMBH and host galaxies

Tight correlation between M_{BH} and M_{bulge}





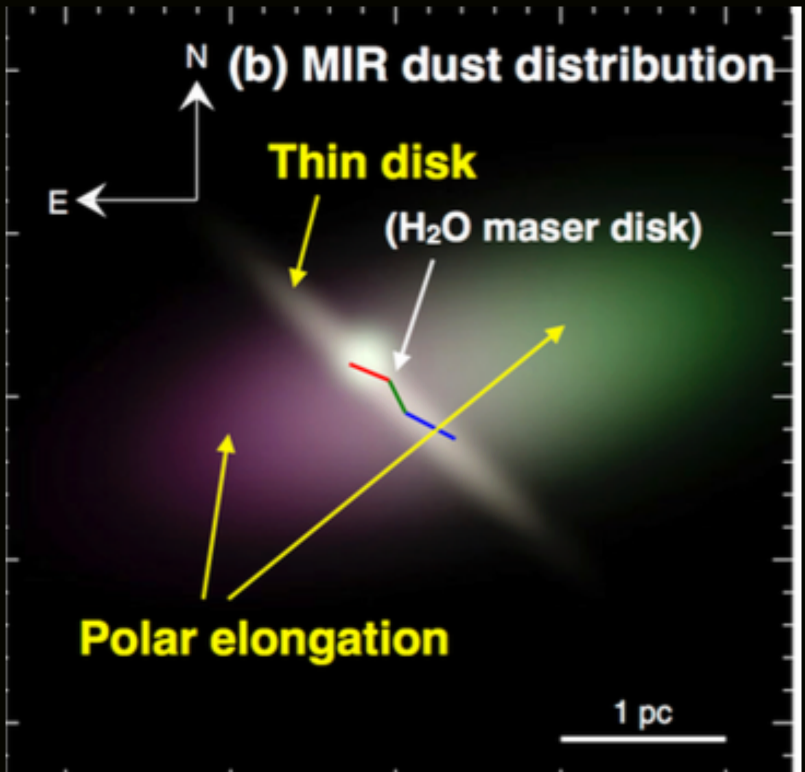
AGN torus bridges SMBH and the host galaxies

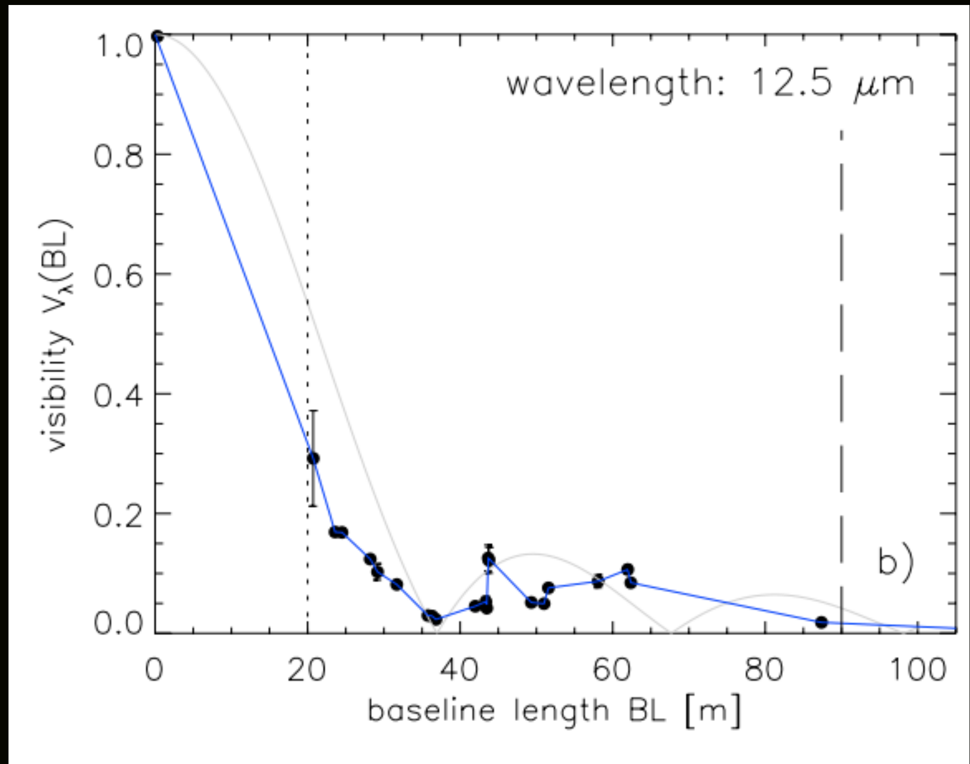
☑ **Knowing Torus => Understanding SMBH/galaxies**

Torus: very compact in MIR

☑ **MIR interferometry constrained torus (emission) size**

☑ torus size: **< 10 pc-scale ⇔ < 0.1'' @z>0.005**





Tristram+07,14

☑ **V ↓ when Baseline (BL) ↑ => sign of resolved torus?**

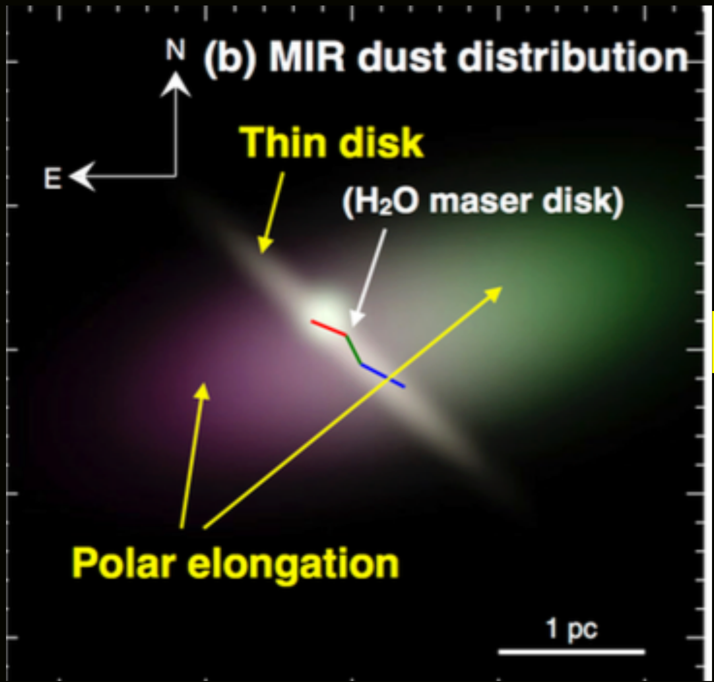
☑ **MIR emission is elongated in polar direction?**

see Tristram+09,+11,+14; Kishimoto+11; Hoenig+12,+13; Lopez-Gonzaga+16a,b

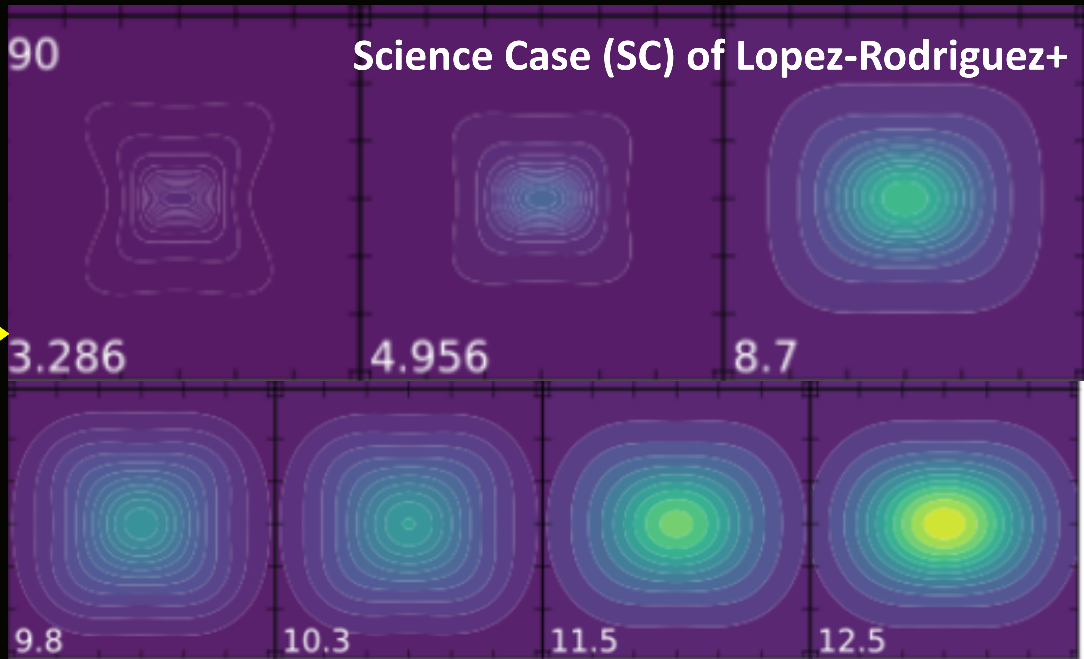
TMT era with MICHI

☑ MICHI could directly (partially) resolve torus @L, M, N band

VLTI



TMT (simulation)



We can obtain

1. dust distribution (polar direction or not?)

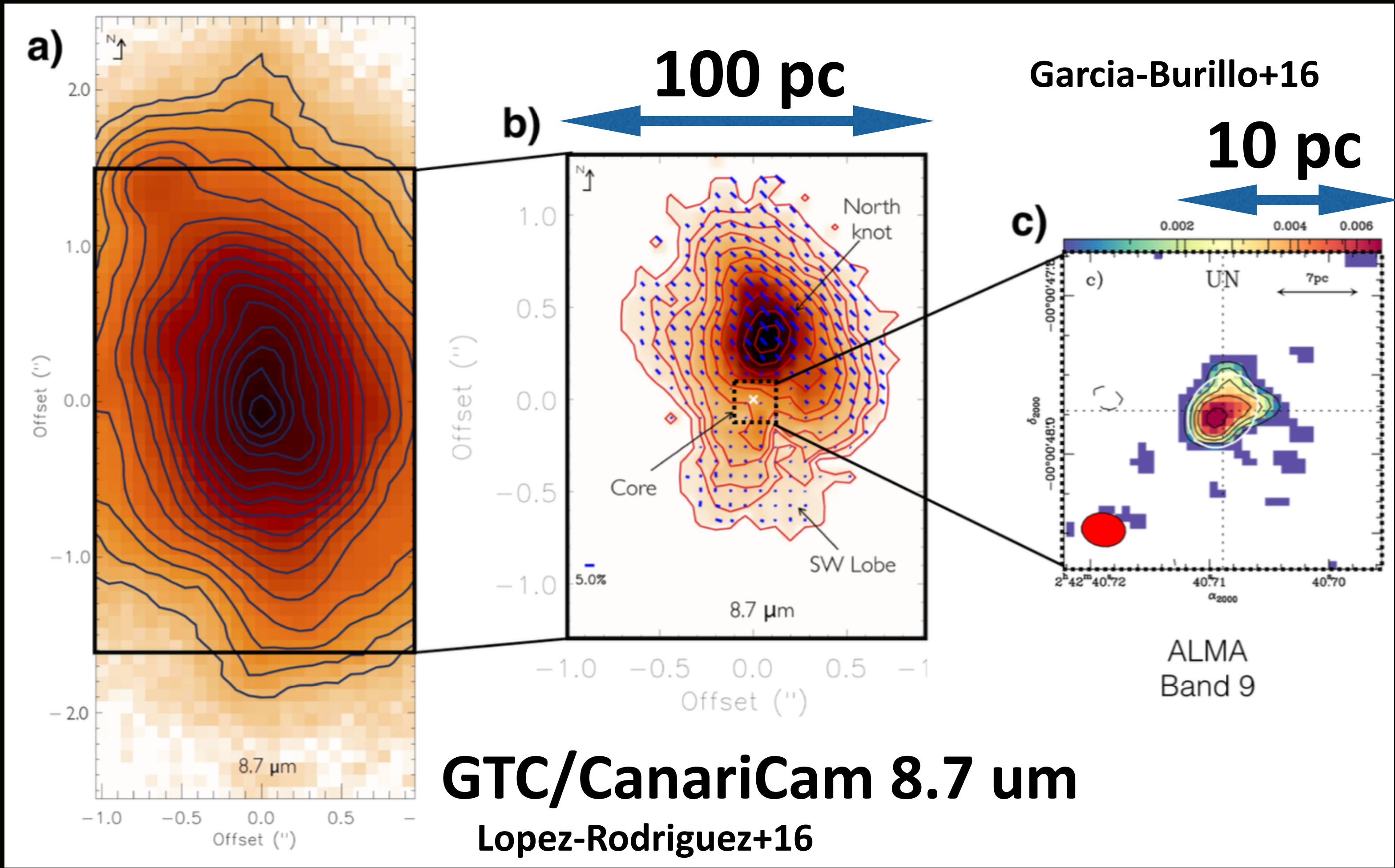
+ with the help of (clumpy) torus model,

2. physical parameters (M_{dust}, inclination)

→ see SCs of Lopez-Rodriguez, Izumi

Polarimetry

☑ Polarimetry tells dust structure more than total flux image



☑ Polarimetry could tell the torus morphology

(see SCs of Kishimoto, Lopez-Rodriguez)

TMT/MICHI

2 goals of AGN/BH science with MICHI

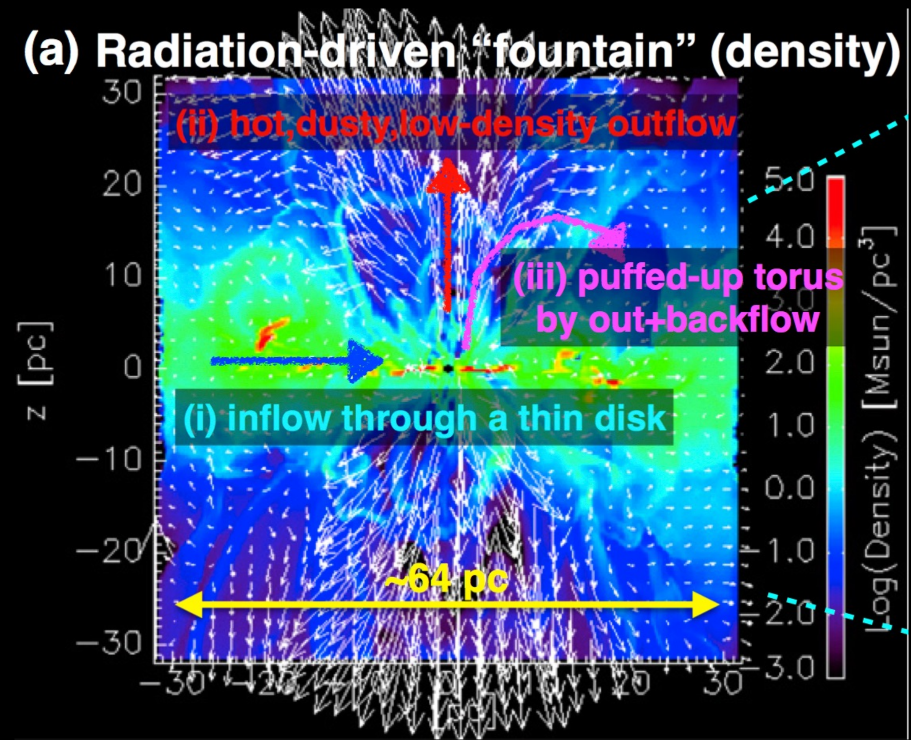
1. Resolving the AGN tori
   - ☑ **L, M,** and **N** band direct **imaging**
   - ☑ **L, M**, and **N** band imaging **polarimetry**
2. Peering the torus origins and fueling

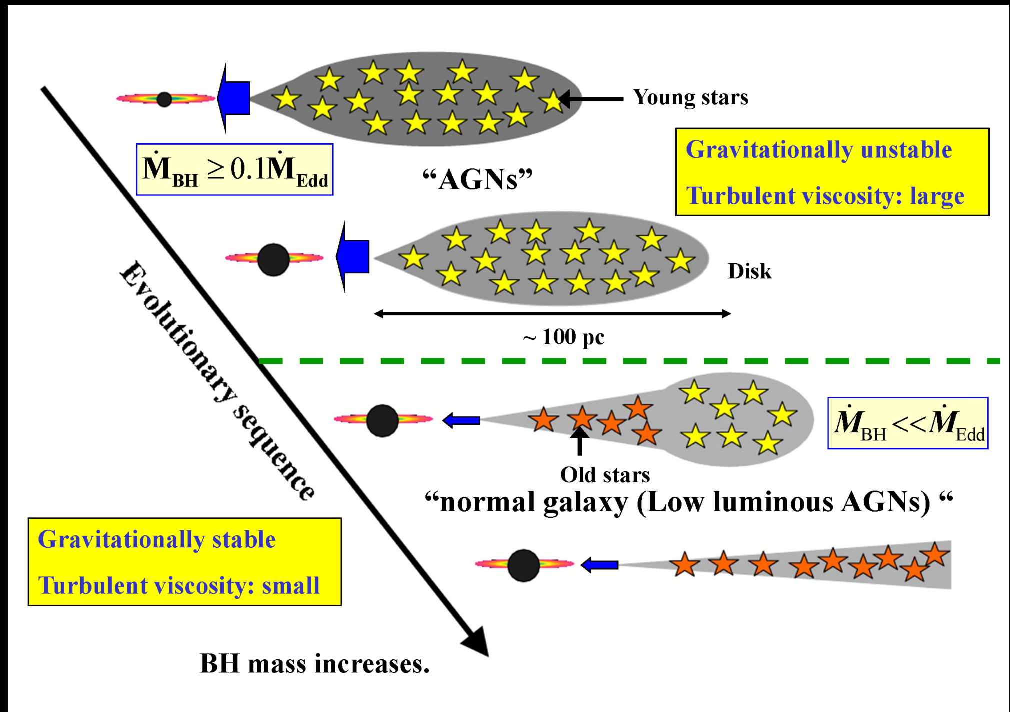
3. Jet properties through Black Hole (BH) binaries (*not AGN!*)

How does the torus feed SMBH?

☑ Hydro+radiative transfer simulations suggest inflow/outflow into the SMBH (fountain model)

Schartmann & Wada 14 based on Wada 12's radiative code





Kawakatu+08: inflow induced by nuclear SB (and SN)

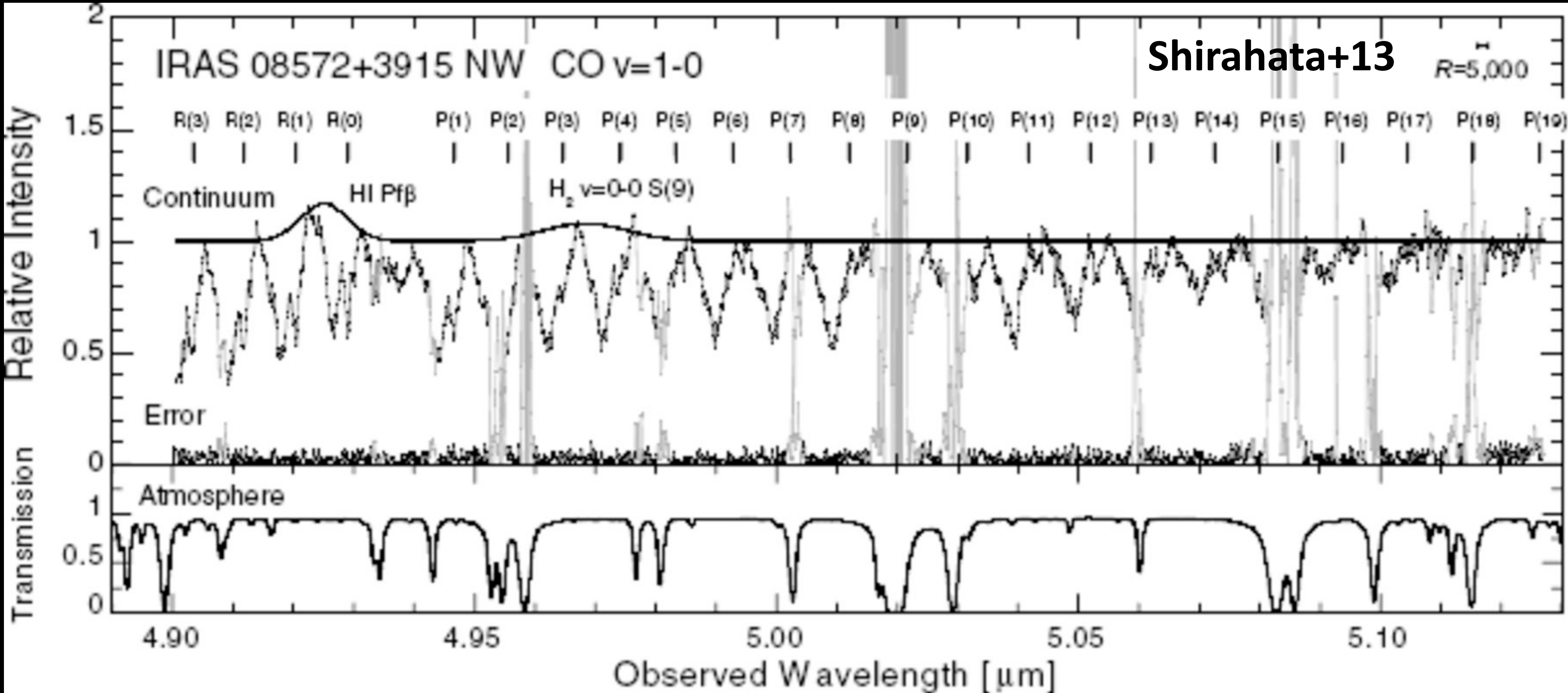
1. nuclear inflow/outflow

2. nuclear SB

are the keys of AGN fueling

CO high-J absorption: inflow/outflow tracer

☑ CO 4.7um absorption: ro-vibrational line with J=0->1



☑ Good to know density, temperature, and velocity!

☑ It is available from the ground

☑ high spec. resolution is necessary **(R>5000@M band)**

☑ 50 mJy => 10 mJy @M band w/ TMT (see SC of Ichikawa, Shirahata+)

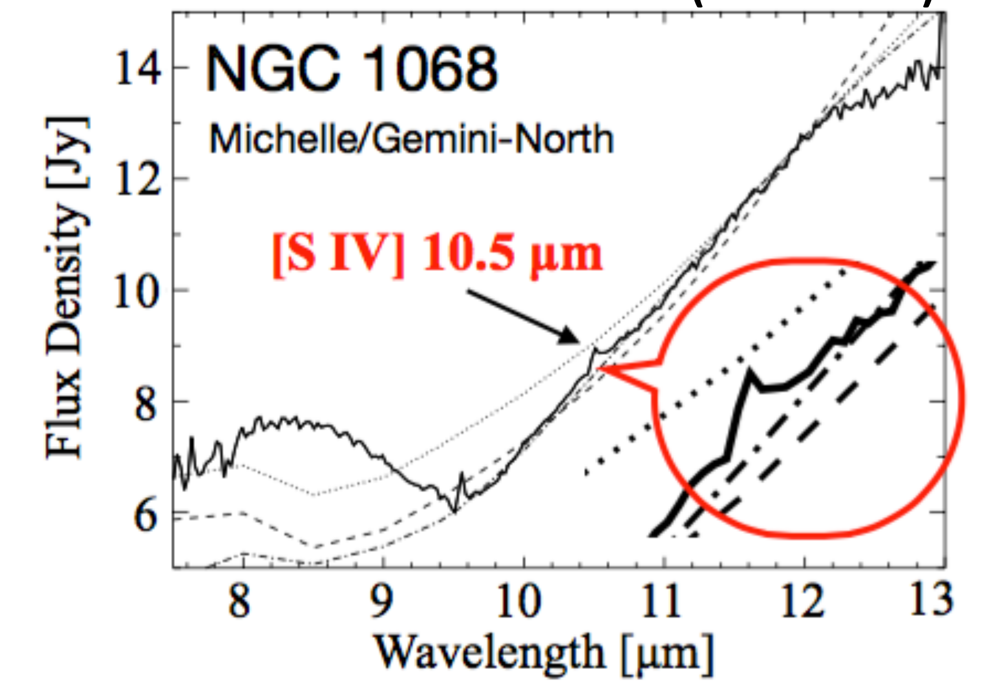
Ionized nuclear outflow: [SIV]10.5um

☑ ionized line [SIV]10.5um (and/or [NeII]12.8um)

- ☑ good tracer of nuclear outflow (high energy potential)
- ☑ strong against extinction

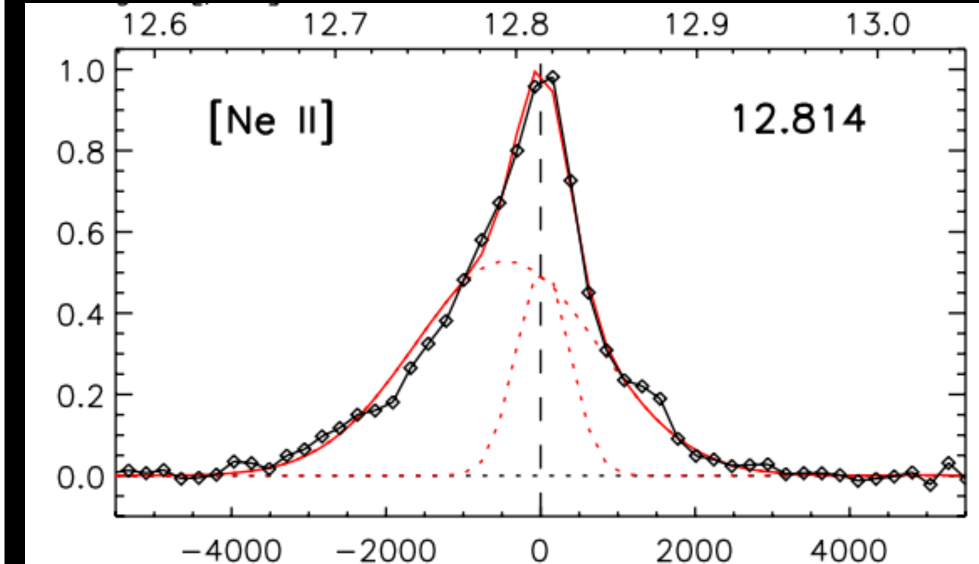
Not achievable w/ ALMA bands, optical, but IR!

(Mason+06)



IRAS F00183

(Spoon+09)



N band IFU will reveal nuclear gas kinematics

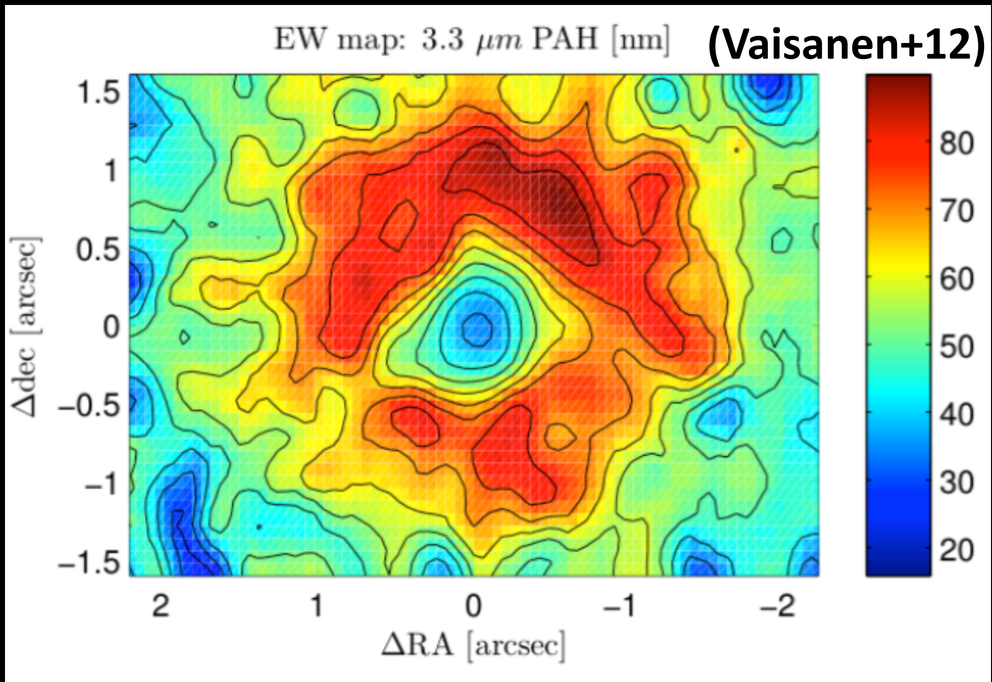
(to check fountain model) (see SC of Izumi, Nagao)

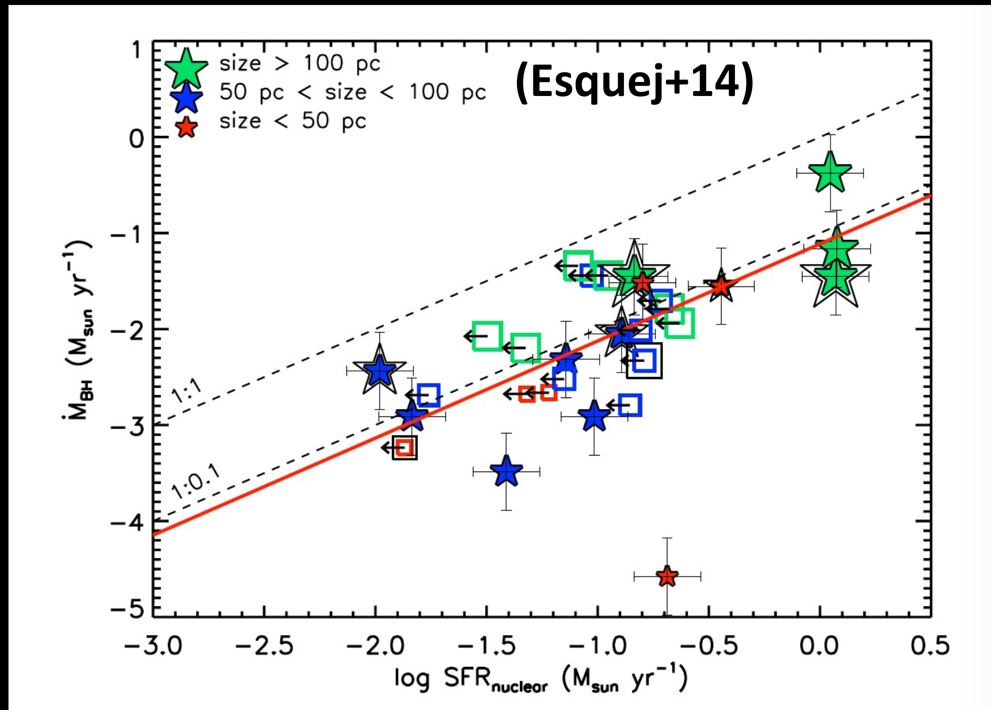
L_{AGN} vs L_{SF} : 100 pc => 10 pc scale

☑ MICHI can resolve nuclear SB w/ 10 pc scale

☑ PAH 3.3 and/or 11.3 um: pure SB tracer

☑ L or N band continuum : AGN torus dust tracer





☑ L and N band IFU are crucial for this study!

(see SCs of Imanishi, Oi for L band, and
Alonso-Herrero, Kawakatu for N band)

Summary: Instrument Requests

2 goals of AGN/BH science with MICHI

1. Resolving the AGN tori (II: compelling)
   - ☑ **L, M,** and **N** band direct **imaging**
   - ☑ **L, M**, and **N** band imaging **polarimetry**
2. Peering the torus origins and fueling (III: excellent)
   - ☑ **L, N** band IFU
   - ☑ **M** band high spec. resolution

Summary: Instrument Requests

2 goals of AGN/BH science with MICHI

1. Resolving the AGN tori
   - ☑ direct check of the polar elongated emission
   - ☑ direct check of the torus models
2. Peering the torus origins and fueling
   - ☑ tracing 10 pc scale SB, inflow/outflow

MICHI will be…

the MICHI (道; path) to the MICHI (未知; unknown)

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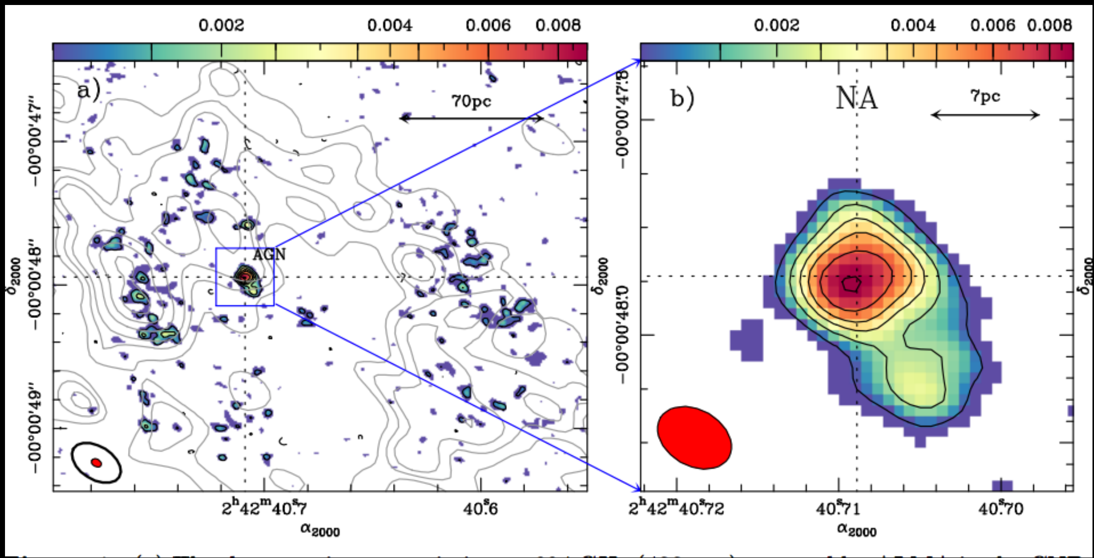
Appendix

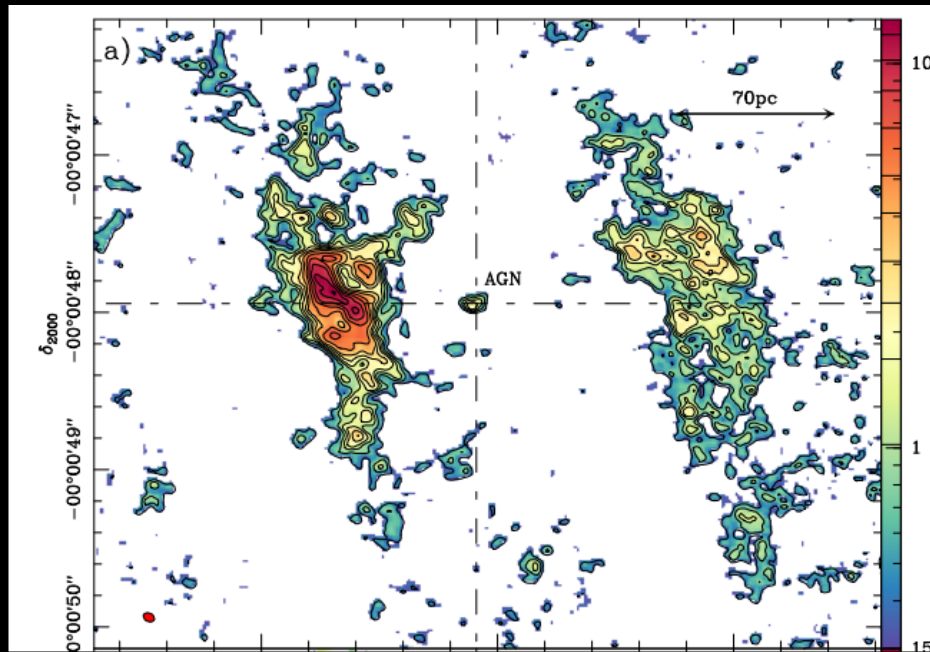
Synergy with ALMA

☑ MICHI can resolve torus in MIR

☑ ALMA reveal molecular gas/cold dust structure (CND)

Garcia-Burillo+16





Combination of MICHI and ALMA will reveal whole dust/gas structure in the central 100 pc of AGN

(see SC of Izumi)

TMT/MICHI

3 goals of AGN/BH science with MICHI

1. Resolving the AGN tori

2. Peering the torus origins and fueling

3. Jet properties through Black Hole (BH) binaries (*not AGN!*)

Jet properties of BH binary w/ MICHI

When outburst occurs in BH binary, synchrotron peak (ν_{break}) appears in MIR

Very few follow-ups (Gandhi+11; Russell+13) due to the limited sensitivity

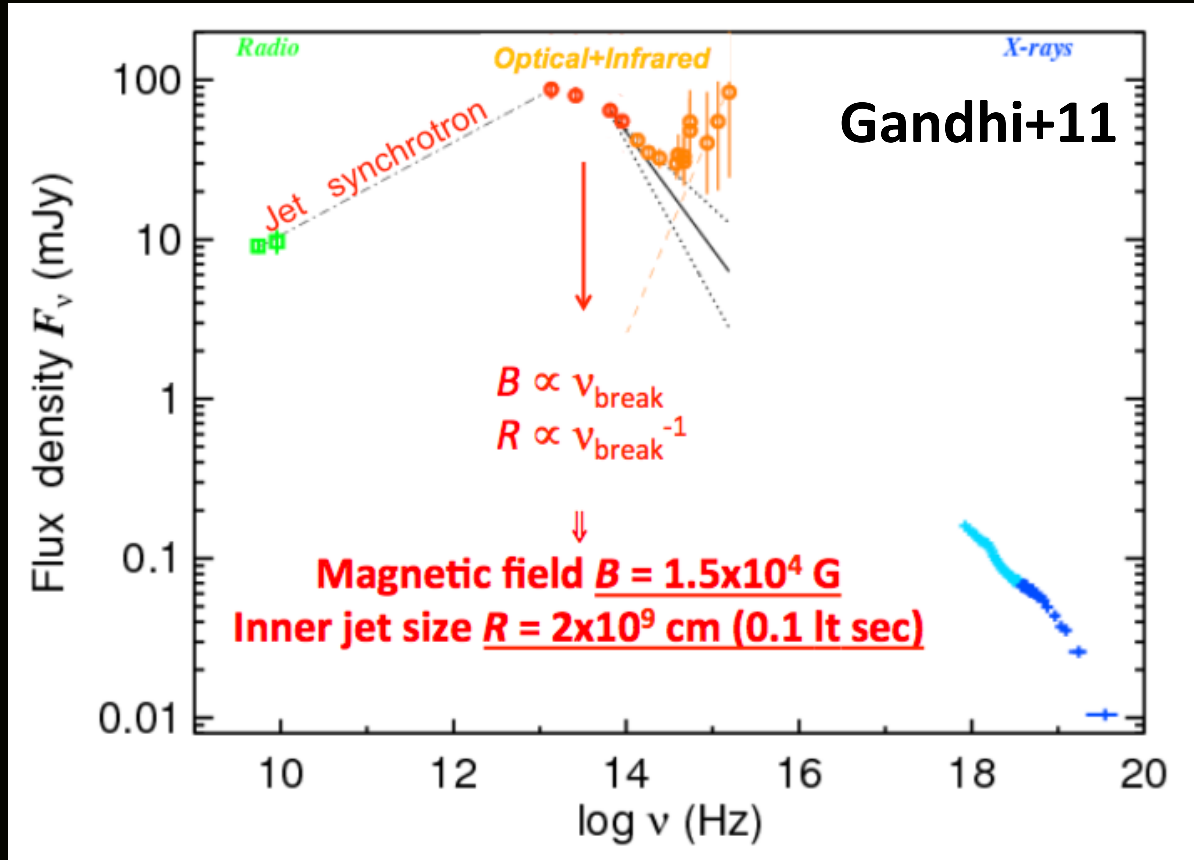
Locating Jet break ν_{break}

ν_{break} changes w/ 10 sec scale

B (magnetic field)

R (the size of the jet base)

changes rapidly



Requirement:

1. prompt follow-up (< 1 week) once outburst occurs (>10 events/yr)
2. covering wide IR coverage (quasi-)simultaneously to locate break
3. Polarization monitor is also good to trace synchrotron activities

instrument summary

Blu-MICHI Summary

Wavelength Range	
Wavelength Range	L (3.42-4.12μm)[1], M (4.57-4.79μm), N band (7.3-13.8μm) [Q band (16.0-25.0μm) TBC]
Imager	
Field of View	24.4x24.4" at L&M bands 28.1x28.1" at N [&Q TBC] band
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N [&Q TBC] band
Spectral Resolution	R~10-100
Long-Slit Moderate Dispersion Spectrometer	
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N [&Q TBC] band
Wavelength Range	L, M, & N bands [Q band TBC]
Spectral Resolution	R~600 L, M, & N bands [Q band TBC]
Slit	28.1" length, diffraction limited to ~0.1"
High Dispersion Spectrometer	
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N band
Wavelength Range	L, M, & N bands
Spectral Resolution	R~120,000 at L&N, R~100,000 at M, [R~60,000 at Q TBC]
Slit	2" length, diffraction limited to ~0.1"
Slit Viewer	Imager used as slit viewer
IFU Spectrometer	
Wavelength Range	N band (only)
Field of View	~0.175" (length) x ~0.07" (width), 10 slices
Pixel Scale	35.0 mas per pixel
Spectral Resolution	R~1,000
Disperser	Reflective gratings
Slicing Mirror Unit	10 spaxels
Polarimetry (TBC)	
Operational Modes	Imaging- and spectro-polarimetry, both modes TBC
Methodology	Dual-beam (Wollaston and Half Wave Retarder)
Wavelength Range	L, M, & N bands
MIR Adaptive Optics System	
Field of View	10" with 1 arcmin goal
Wavefront Quality	Requirement wavefront rms phase < 750nm, goal < 350nm rms
Sky Coverage	"All sky" and limited only by natural tip-tilt stars
Strehl Ratios	L & M Bands up to 80% N & Q Band 80%

[1] We have defined our L band transmission following Tokunaga, Simons & Vaca (2001), but recognize that the L band atmospheric window it partially transmissive ~2.8-4.1 μm. We will invite requests for special filters to cover specific features (i.e. water ice at 2.9 μm) within the L band atmospheric window.

Sensitivity: imaging

Imaging Sensitivity Estimates

The imager has a 5-sigma, 1-hour on-target sensitivity shown in Table 1.

lambda	3	5							
F_nu	0.0078	0.095							
lambda	8	9	10	11	12	13	14		
F_nu	0.075	0.081	0.11	0.12	0.14	0.23	0.73		
lambda	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*
F_nu	*0.81*	*0.40*	*0.43*	*0.48*	*0.67*	*0.80*	*0.89*	*1.6*	*2.8*

(lambda in microns; F_nu in mJy; bandpass is for whole of L&M windows or 1 micron for N and Q bands)

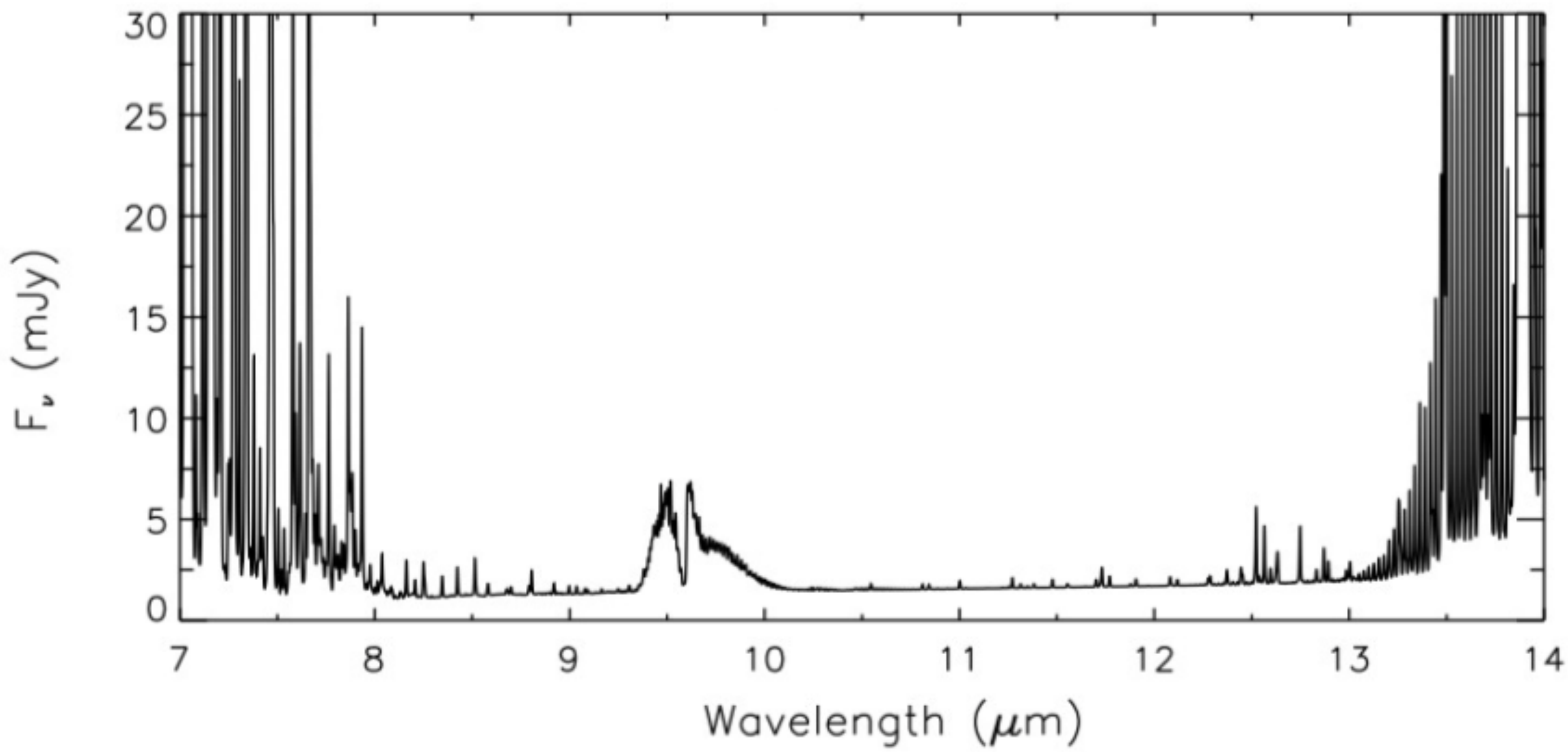
Table 1. 5-sigma, 1-hour on-target sensitivity for the imager.

Sensitivity: spectroscopy (R=600)

N band

Spectroscopy Sensitivity Estimates

For moderate spectral resolution, N band and Q band, the 5 sigma, 1 hour integration flux densities are shown in Figure 1.



Sensitivity: spectroscopy (R=600)

Q band

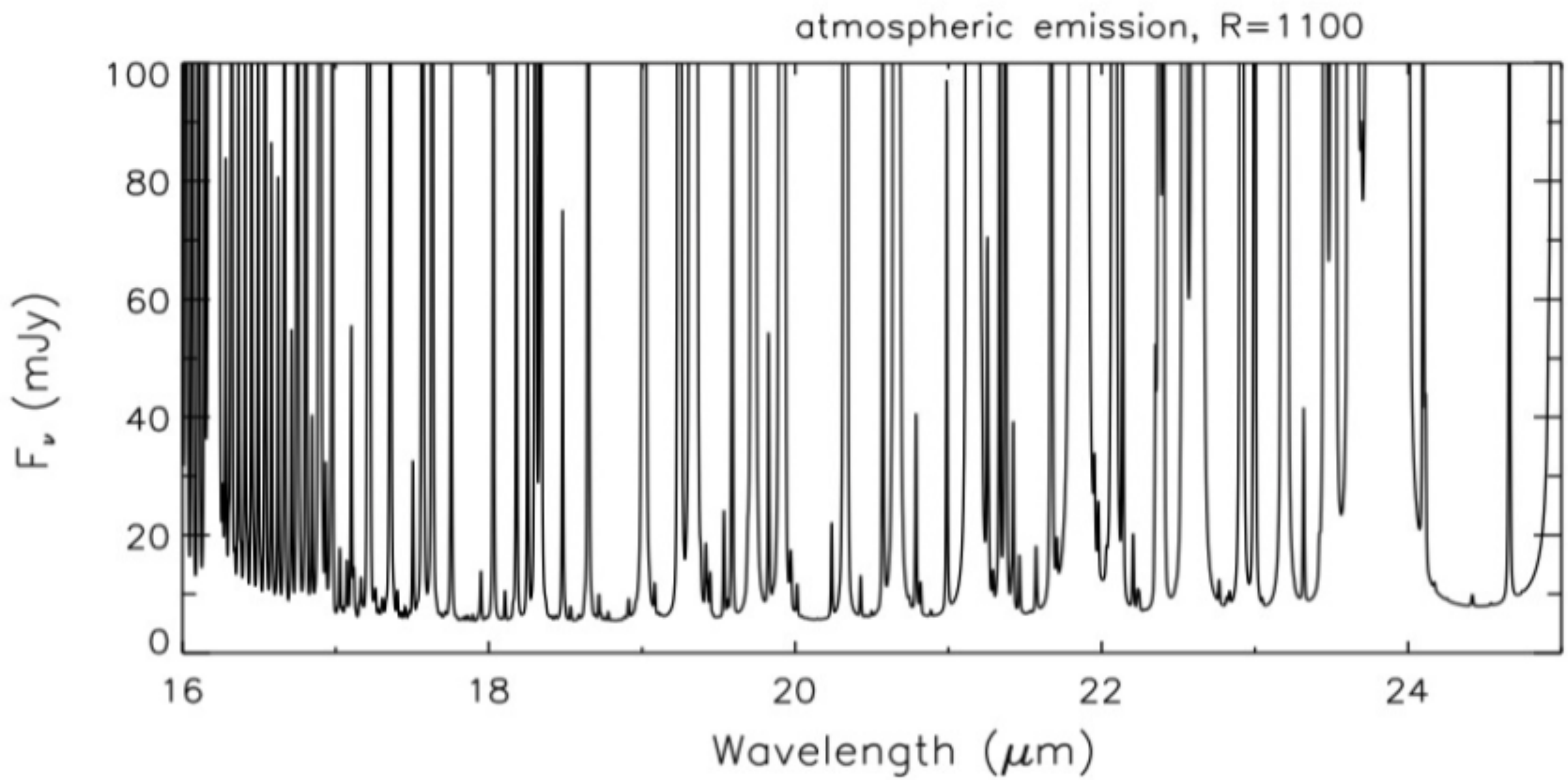


Figure 1: Moderate resolution 5-sigma, 1 hour sensitivity limits for the N and Q bands.

The sensitivity of the high-resolution spectrograph (R=120,000) depends highly on the specific wavelength of interest. This shown in Figure 2.

Sensitivity: spectroscopy (R=120,000)

N band

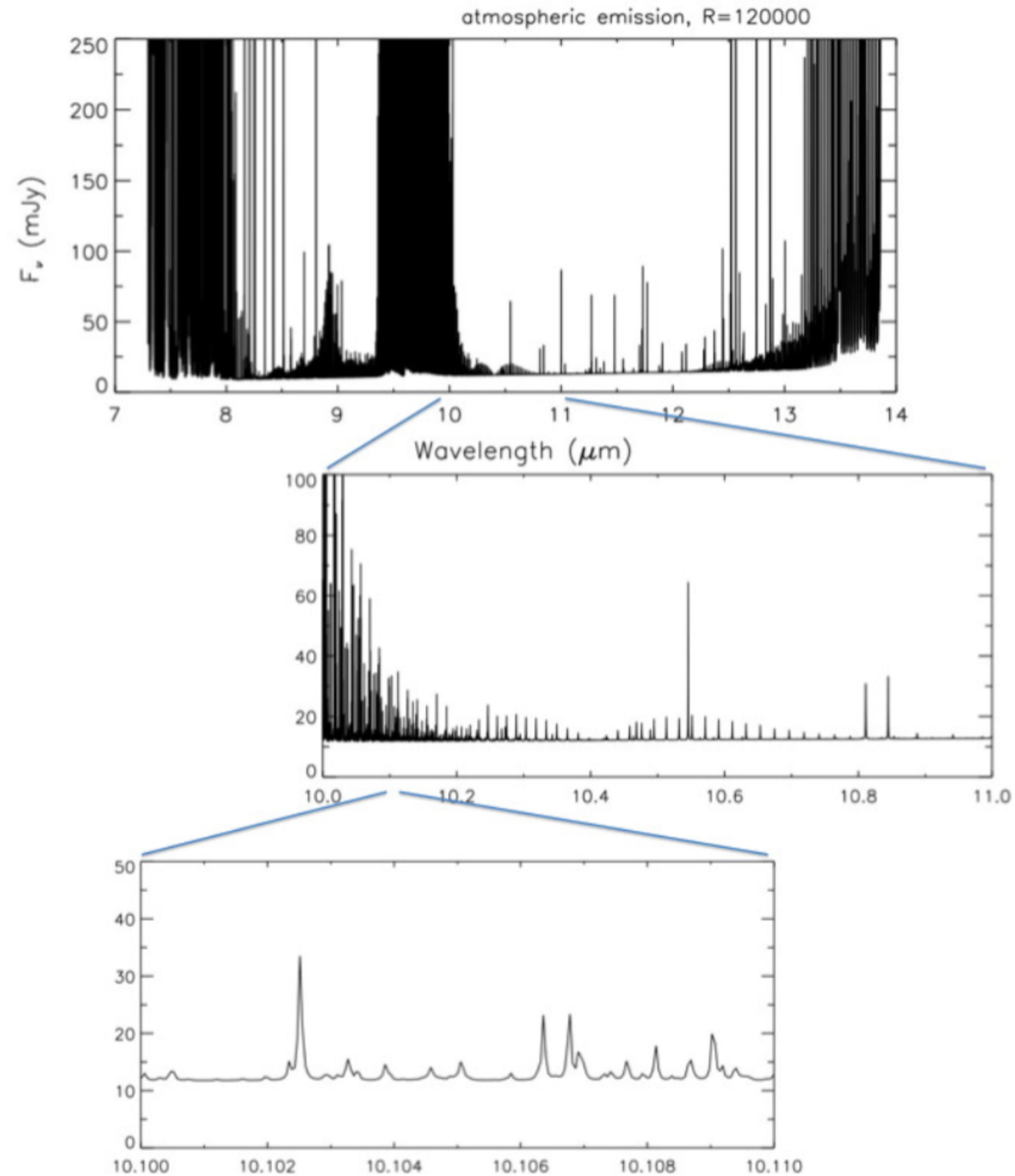
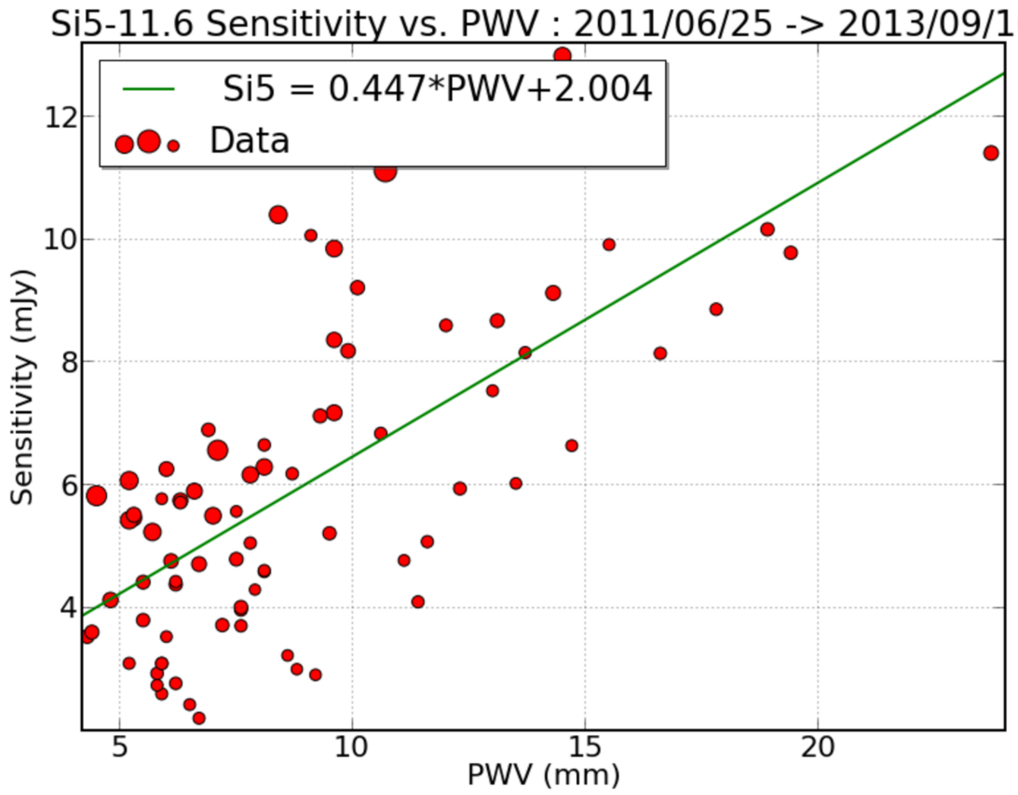


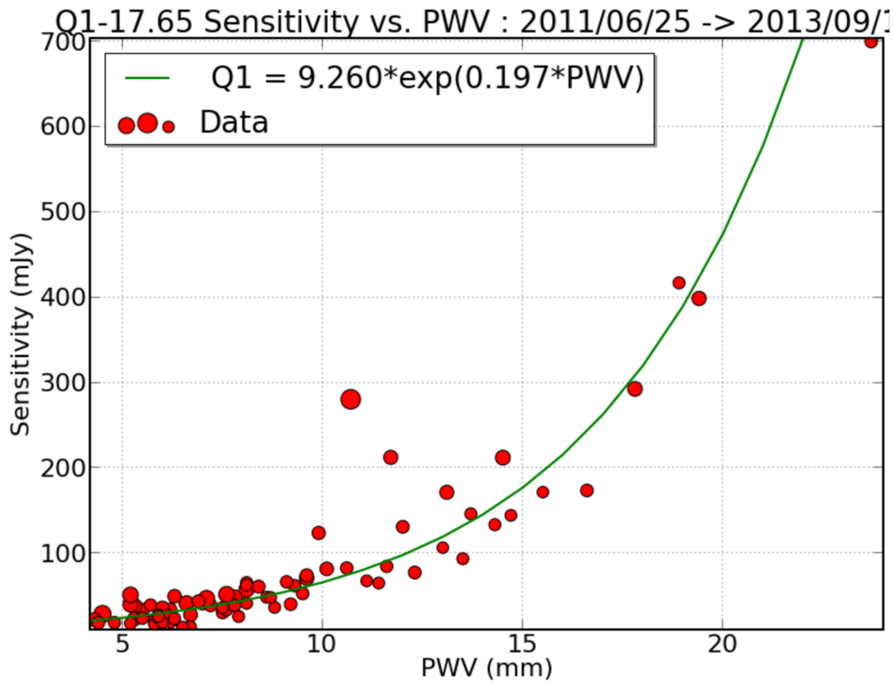
Figure 2: High resolution 5-sigma, 1 hour sensitivity limits for the high-resolution spectrograph. This illustrates that at high spectral resolution clear regions of the atmosphere can be exploited.

Spatial resolution of TMT/IRIS, MICHI

TMT	30	IRIS	2.2	0.018
		MICHI	3.45	0.029
			4.75	0.040
			8.7	0.073
			10.3	0.086
			11.6	0.097

Sensitivity vs. PWV





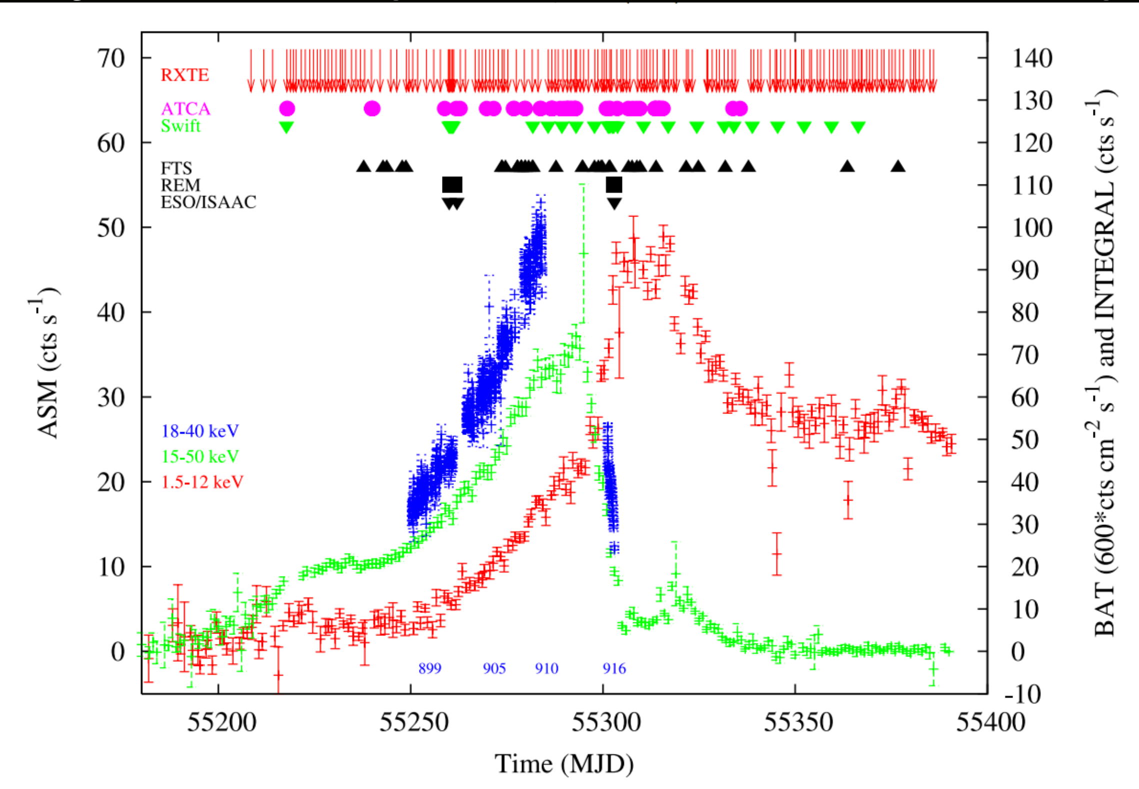
Sensitivity (5σ in 30 minutes on-source) in the Q1-17.65 filter based on observations of mi stars taken in the period from June 2011 to January 2013. The size of the symbols is propc FWHM of the PSF. A exponential fit to the data is shown as a solid green line

What does "outburst" in Gandhi+11 mean?

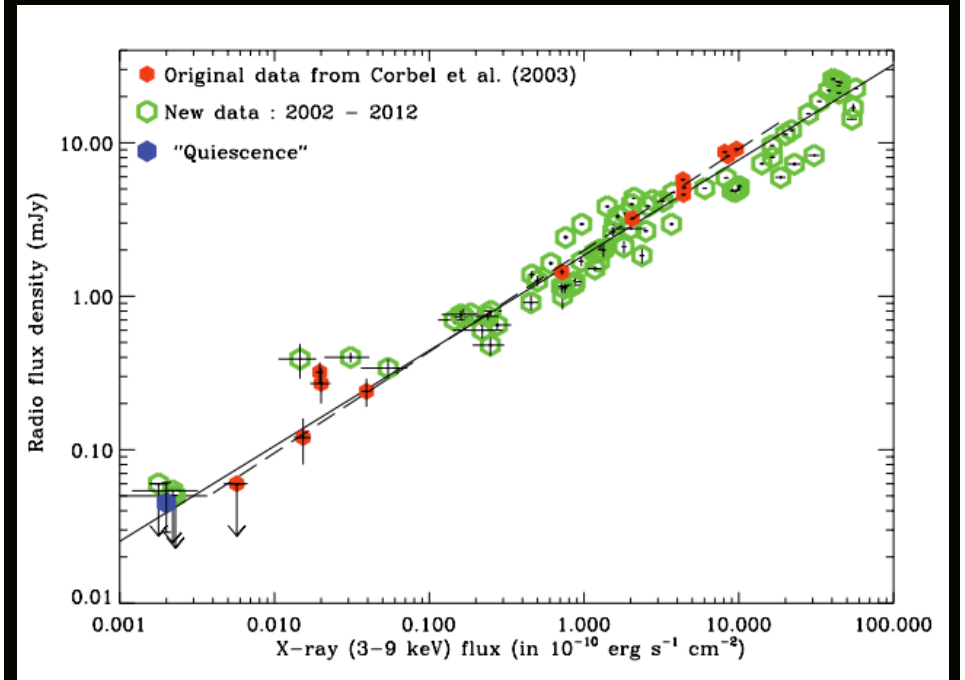
outburst means the bright epoch in "X-ray"

But the state must be "low-hard" state, not high-soft state

Cajole Bel+11 (2010 outburst of GX 339-4)



Corbet+13 (Lx vs Lradio | $L_{corona+disk}$ vs. L_{jet})



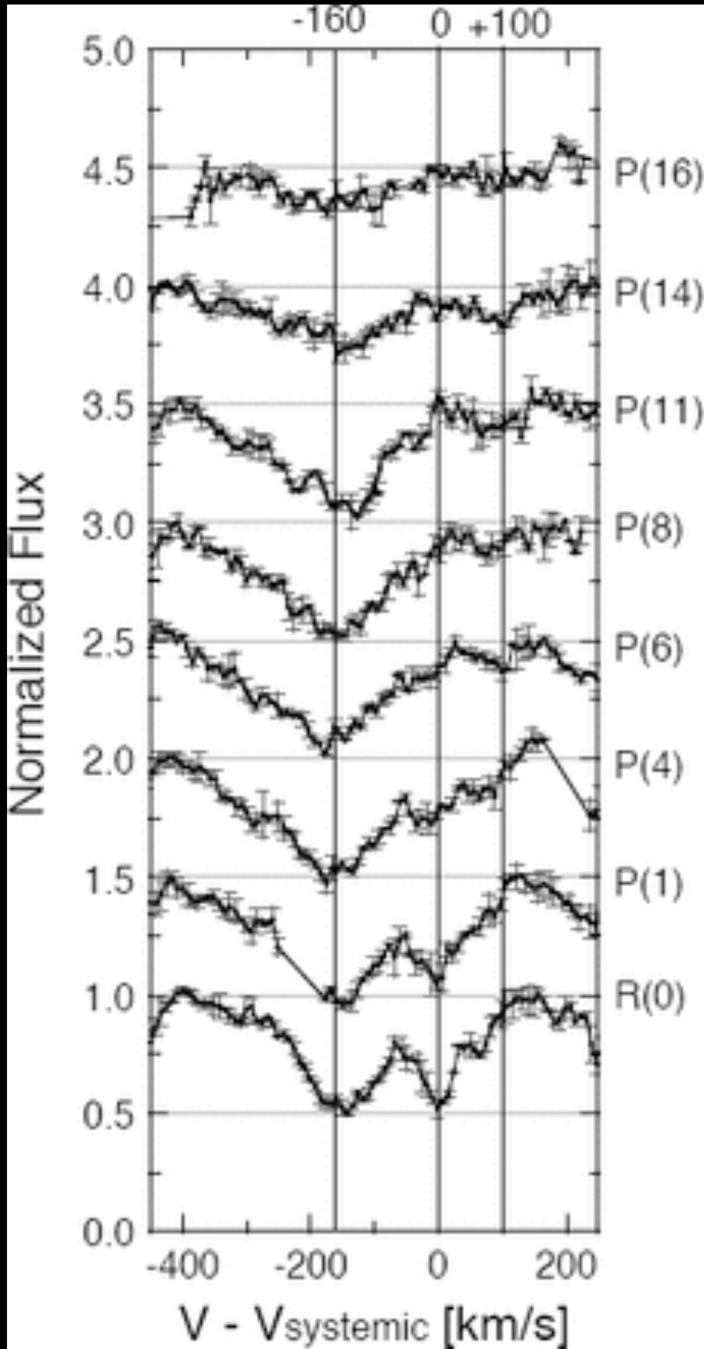
TMT/MICHI w/ high R>5000

☑ Using 4.7um CO abs., Shirahata+13 detected **three velocity components** from ULIRG

1. blue (v=-160km/s) w/ 270K
-> outflow from the accretion disk?
2. red (v=+100km/s) w/ 700 K
-> inflow to the accretion disk
3. v=0km/s w/ 20K

☑ Good support of clumpy torus

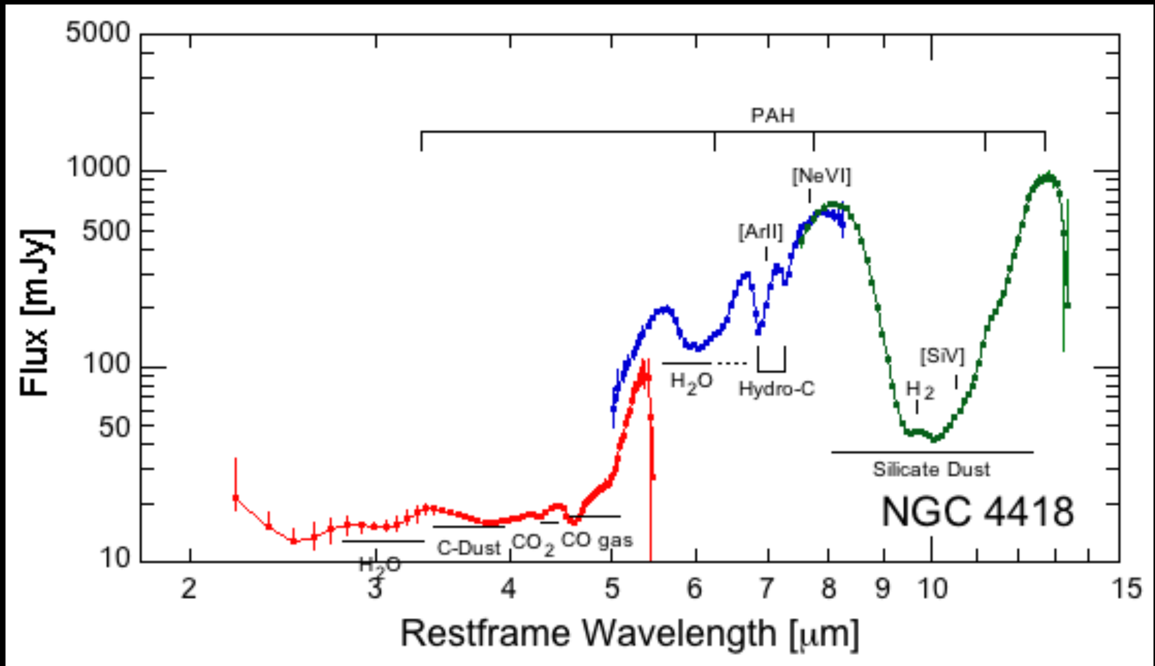
☑ first robust inflow/outflow detection in buried AGN

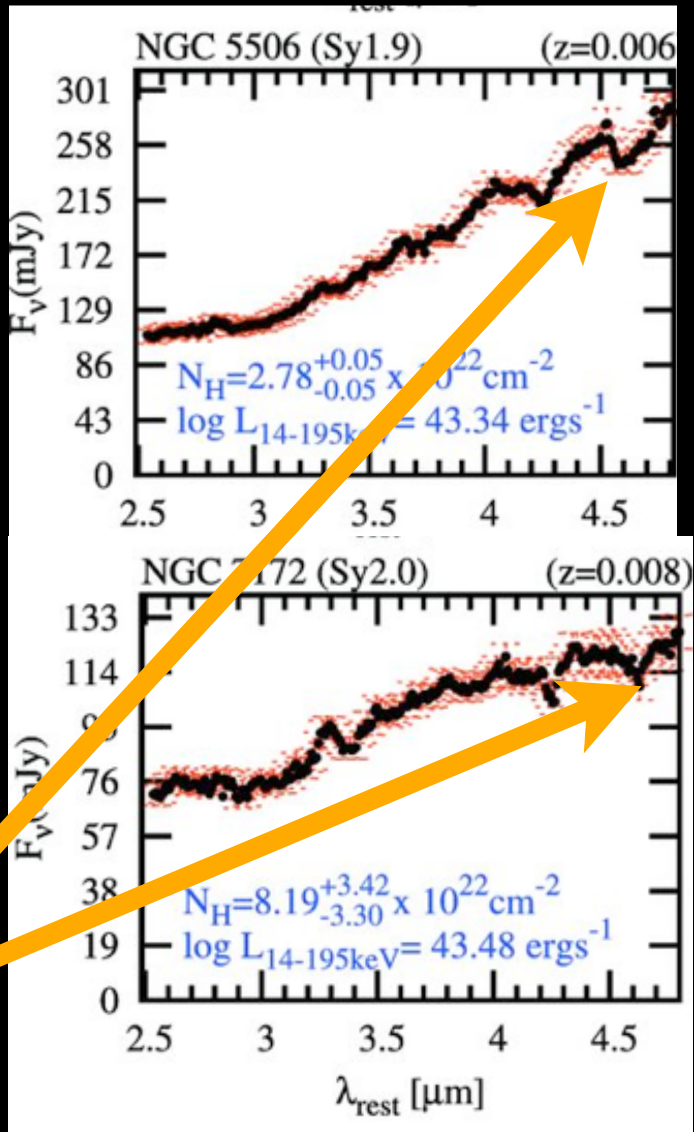


Shirahata+13

Candidates: AKARI CO detected BAT AGN

☑ AKARI discovered CO detected(?) candidates of type-2 AGN (Shirahata+14; Castro+14)





CO?

☑ $N_H > 10^{23}$ cm: one criterion? (e.g., Meijerink+05)

☑ ~10 candidates from AKARI observed BAT/AGN sources

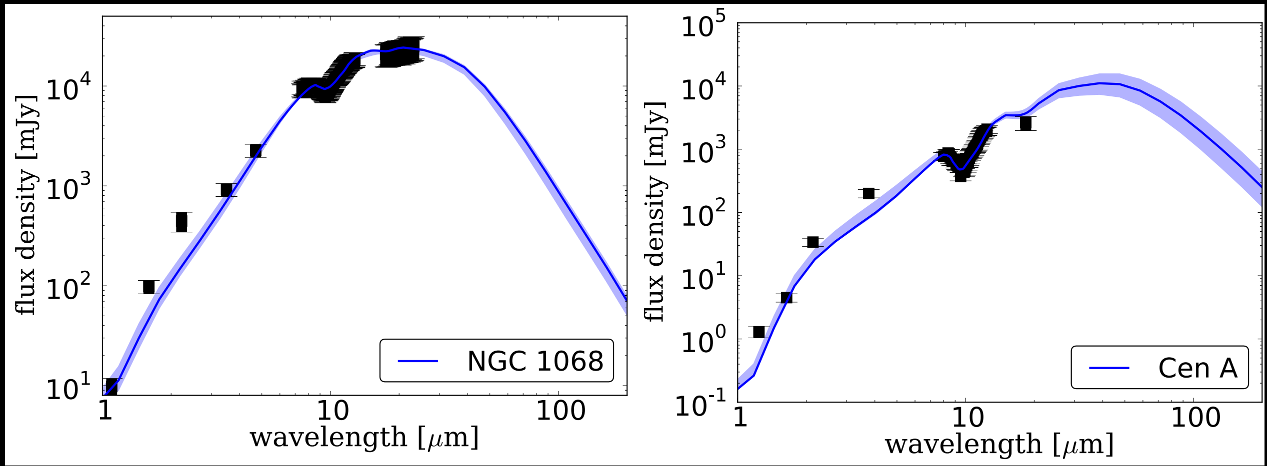
Torus models on the market

☑ torus is clumpy! (**clumpy model; Krolik & Begelman 86, Nenkova+02**)

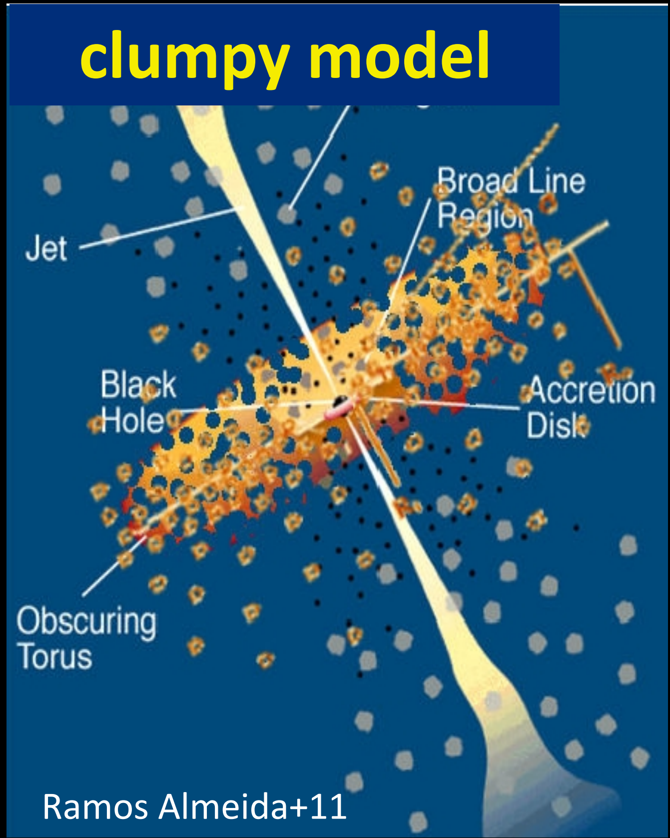
radiative code (e.g., CLUMPY) enable us to

✓ Get torus geometry from the observations

(see Ramos Almeida+11; Alonso-Herrero+11; Ichikawa+15)



Ichikawa+15



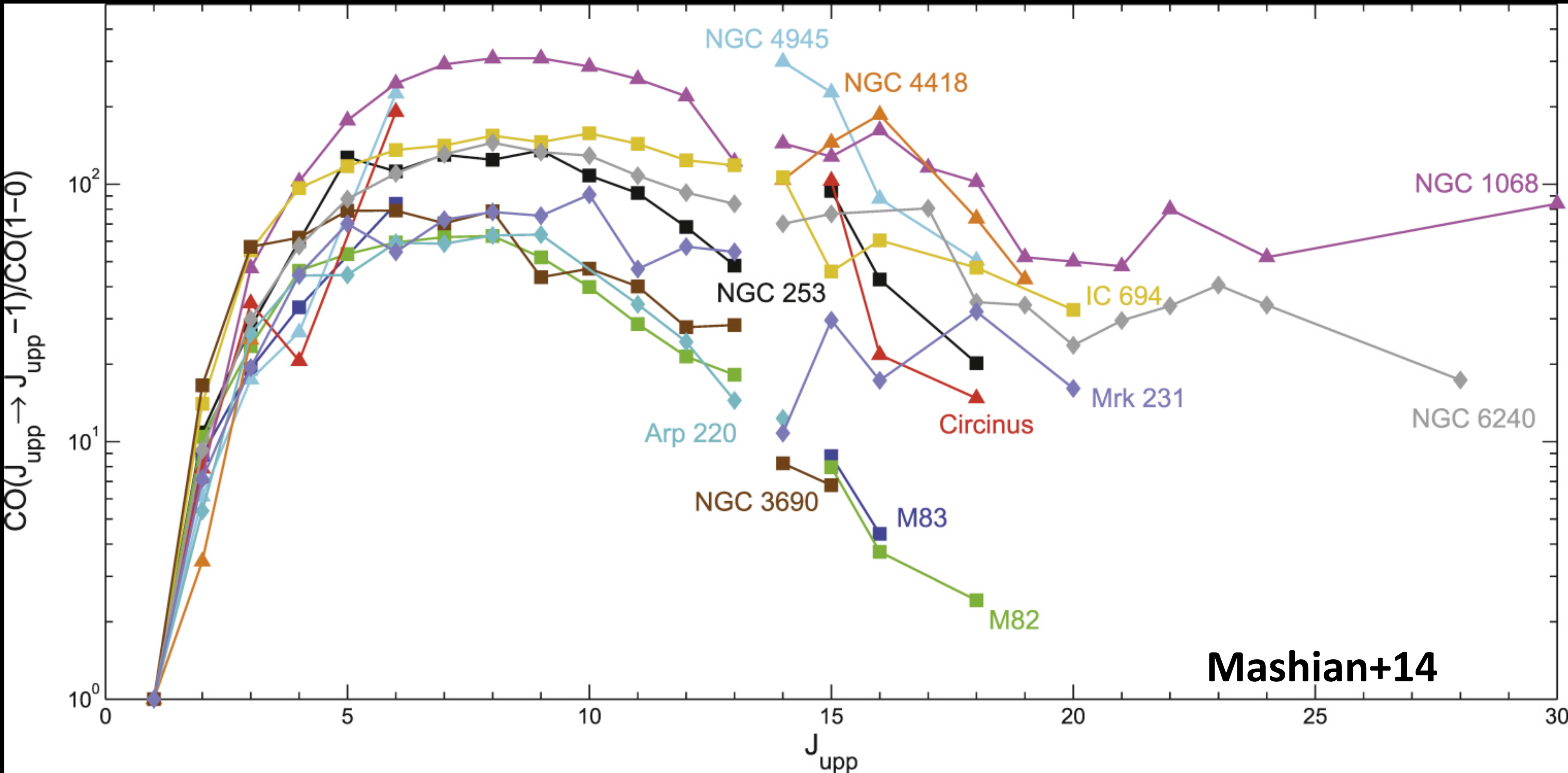
But, the model is static (no-inflow/outflow)

model does not tell us the torus origin (and SMBH growth)

How and when does the torus feed SMBH?

Herschel study of CO high-J lines

☑ CO high J (J>10) lines is a good AGN indicator



☑ Good to know density, mass, and temperature

☑ spatial resolution is limited (due to Herschel)

☑ Not available currently