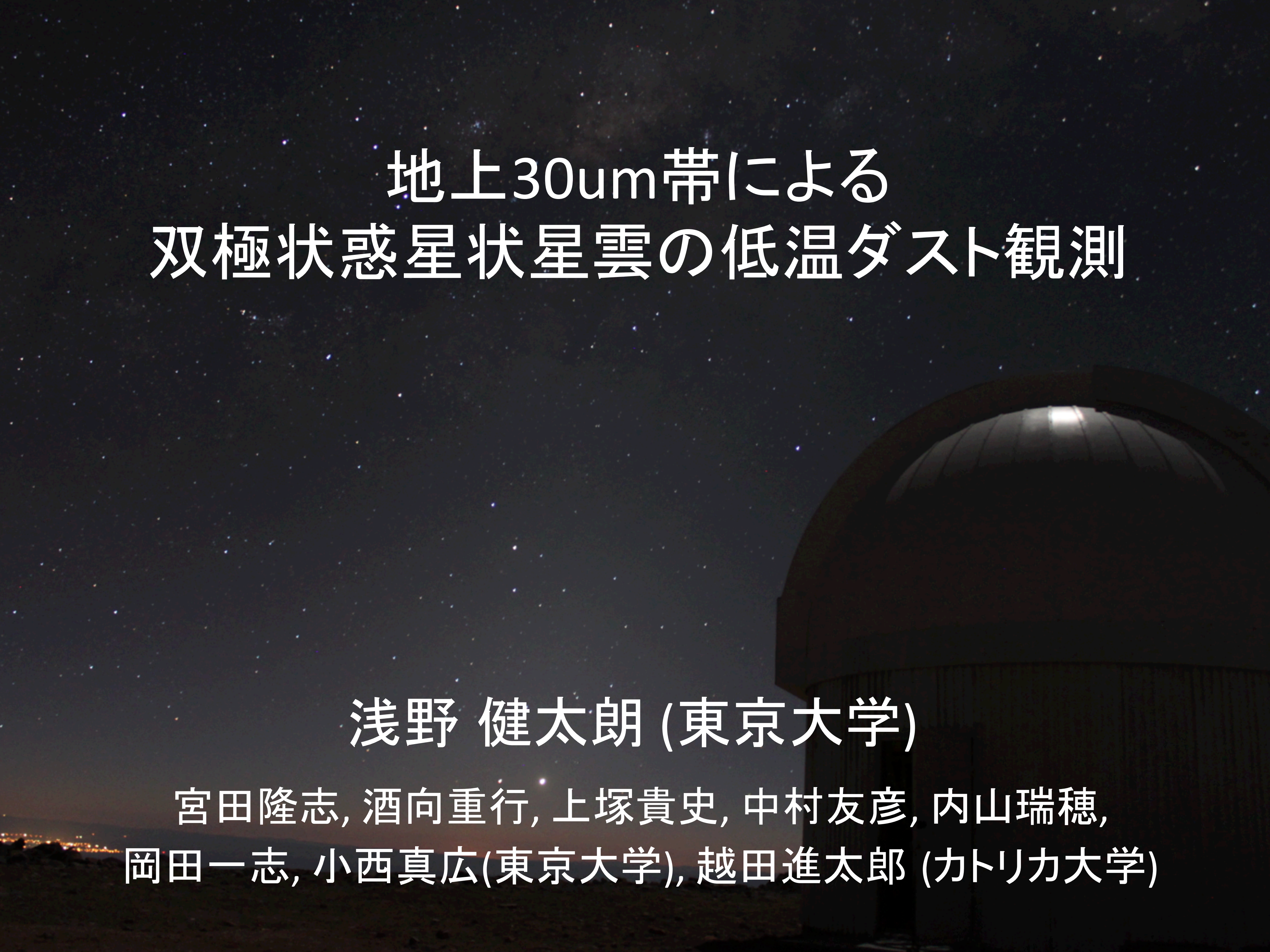

地上30um帯による
双極状惑星状星雲の低温ダスト観測

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宮田隆志, 酒向重行, 上塚貴史, 中村友彦, 内山瑞穂,
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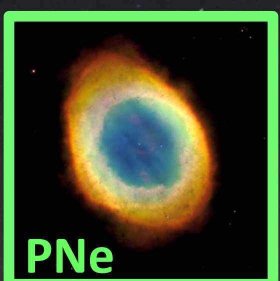
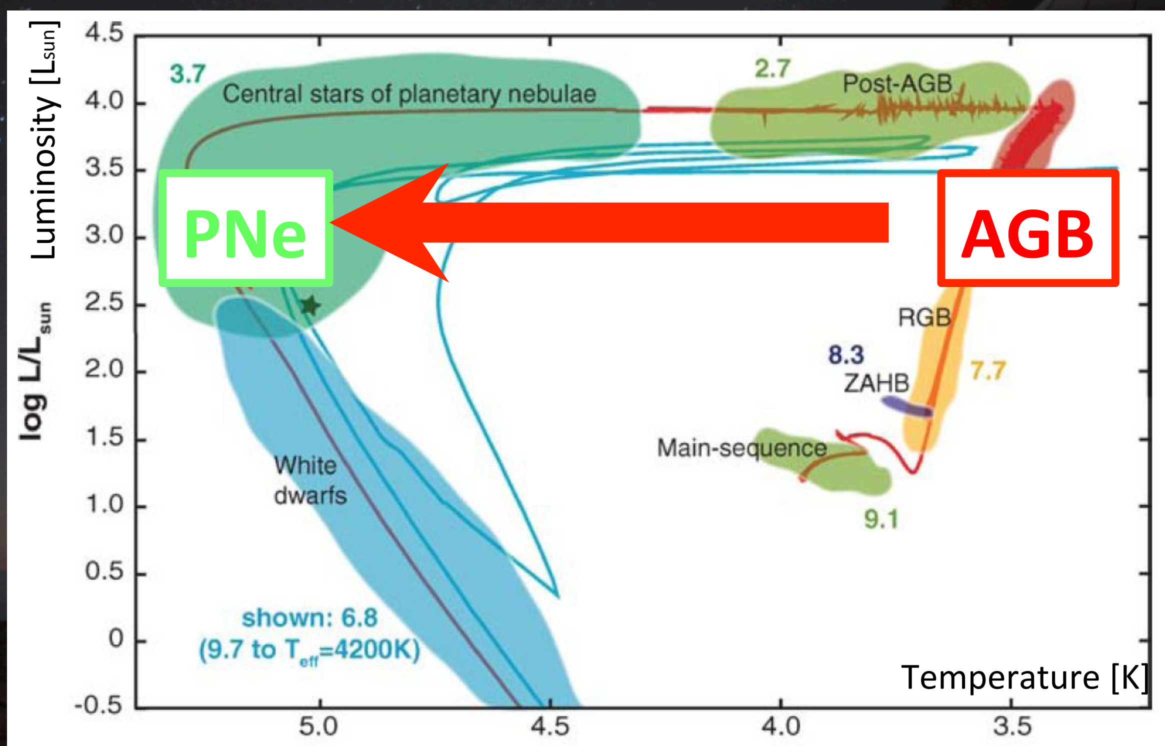
Introduction

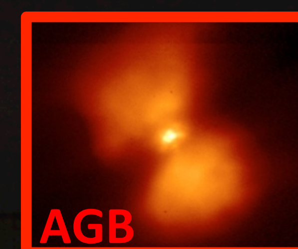
- What is the origin of dust in our galaxy?

→ AGB stars are one of the important sources of interstellar dust.

- PNe are the final stage of stellar evolution.
- PNe record the mass-loss history in the AGB phase.
- It is important to observe the dust around planetary nebulae.





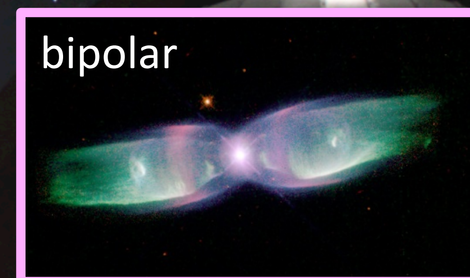


Dust souces of bipolar PNe

- Massive AGB creates a mount of dust.
- Initial mass (Pottasch+ 2006) :

1~4 $M_\odot$ → round, elliptical PN

4~8 $M_\odot$ → bipolar PN

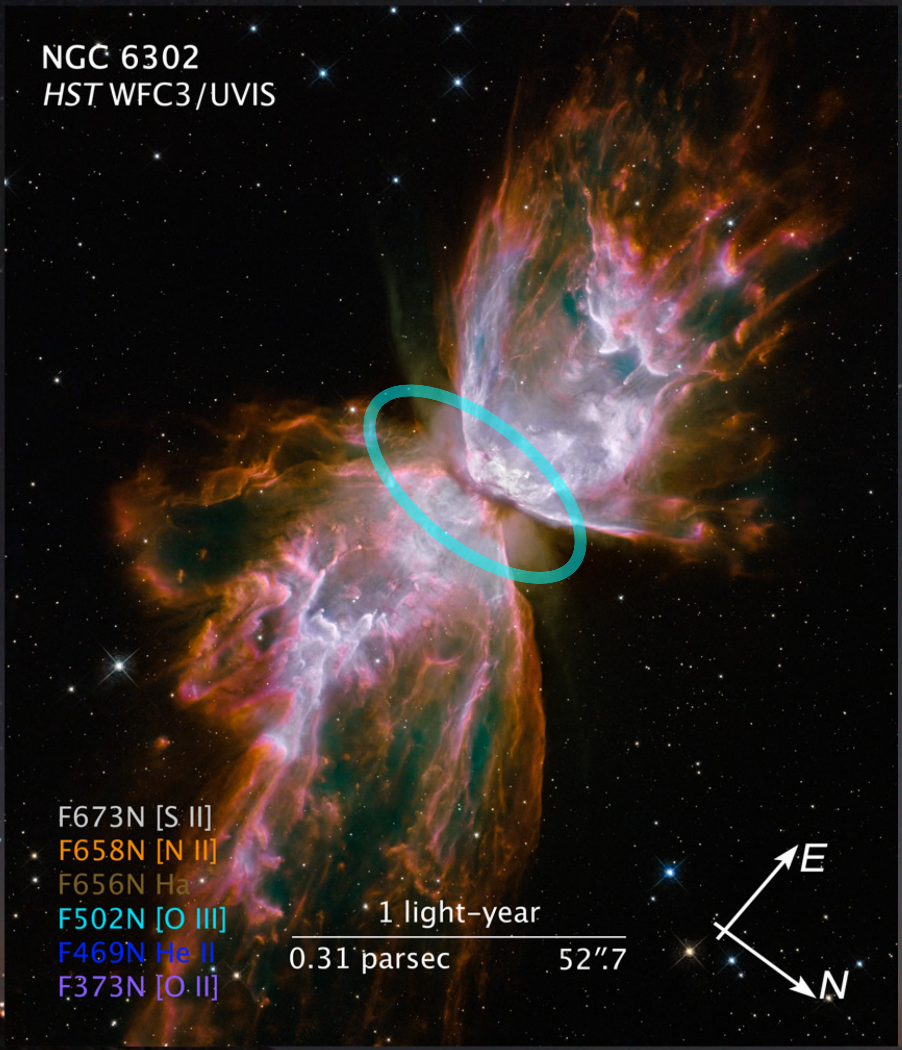


- Bipolar PNe are important dust sources.

→ Where is the dust in massive AGB phase?

The spatial distribution of cold dust in the bipolar PN have not been well understood so far.

Massive torus in the bipolar PN



- NGC 6302 is one of the most studied bipolar PNe (e.g. Matsuura+ 2005)
- Initial mass : $5M_\odot$
- A dark lane (a dust torus) can be seen in the central region.

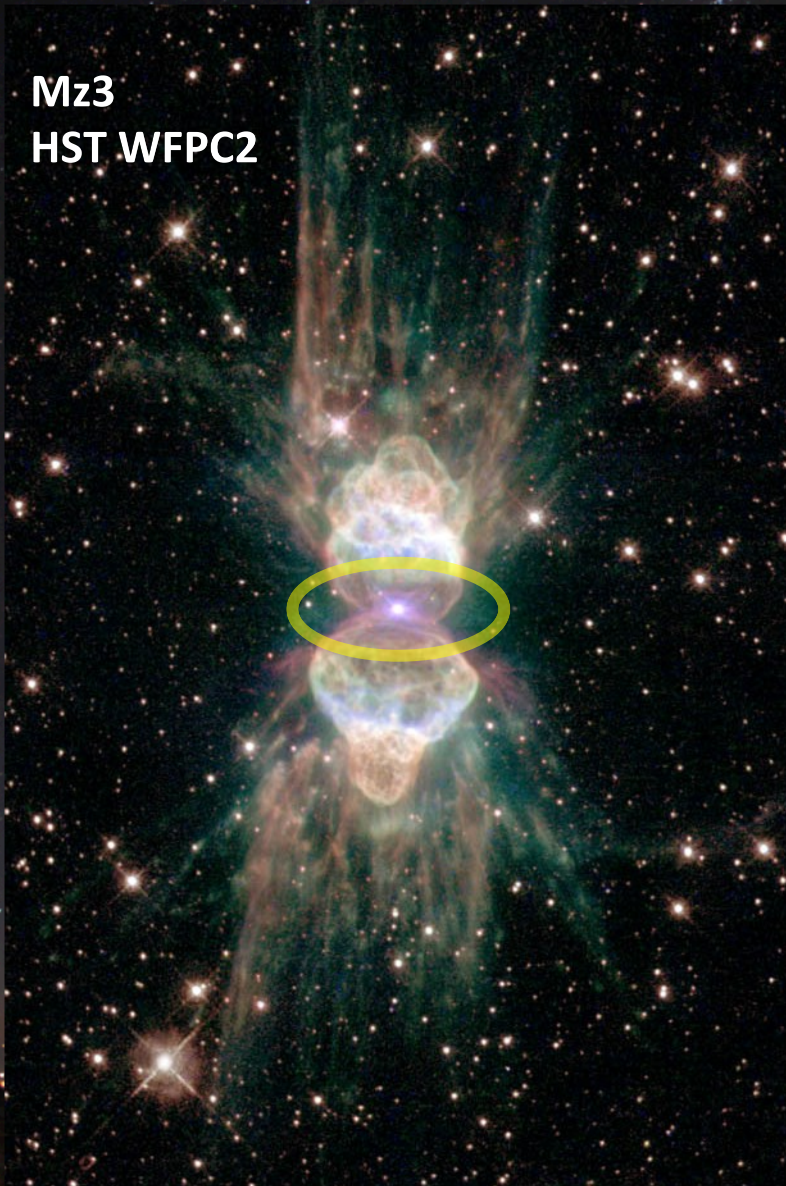
  → Massive dust torus

  $M_{dust} = 3.0 \times 10^{-2} M_\odot$

  $T_{dust} \sim 70K$

All bipolar PNe have massive dust torus?

Mz3 has a massive torus?



- Initial mass > $4M_{\odot}$ (Pottasch+ 2005)

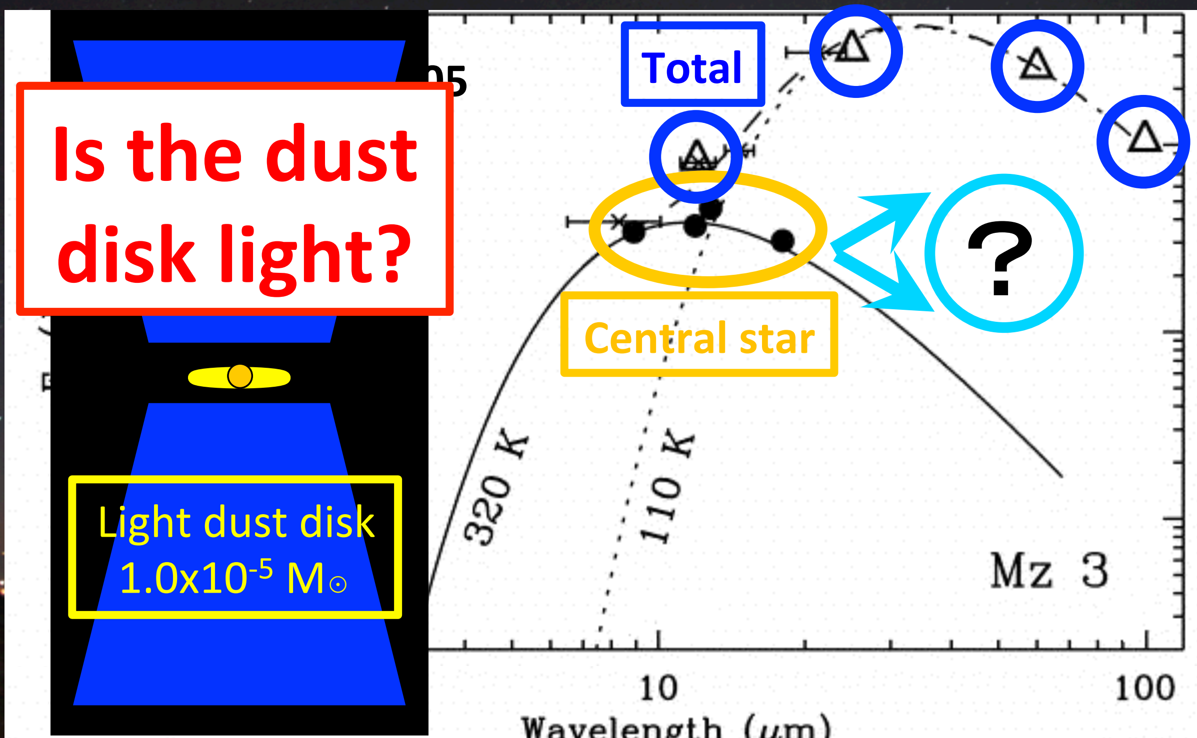
- No dark lanes at the center of Mz3.
  → A massive or light dust torus?
  Or not?

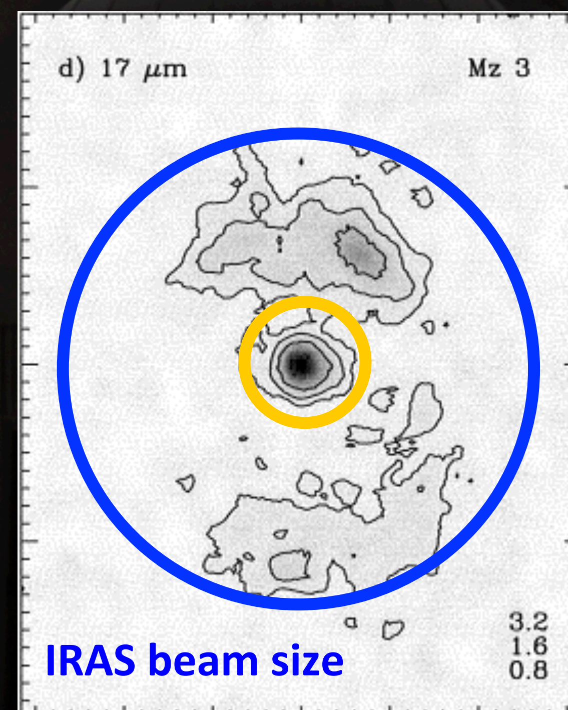
Previous studies of Mz3

- Warm component in the central region : $M_{dust} = 1.1\times10^{-6}\ M_\odot$ (Smith+ 2005, with ESO3.6m)
  - A light dust disk in the central region : $M_{dust} = 0.9\times10^{-5}\ M_\odot$ (Chesneau+ 2007, with MIDI)

- Cold components in the lobes : $M_{dust} = 2.6\times10^{-3}\ M_\odot$ (Smith+ 2005, with IRAS)

  → IRAS can't resolve the central disk (torus) and the lobes.





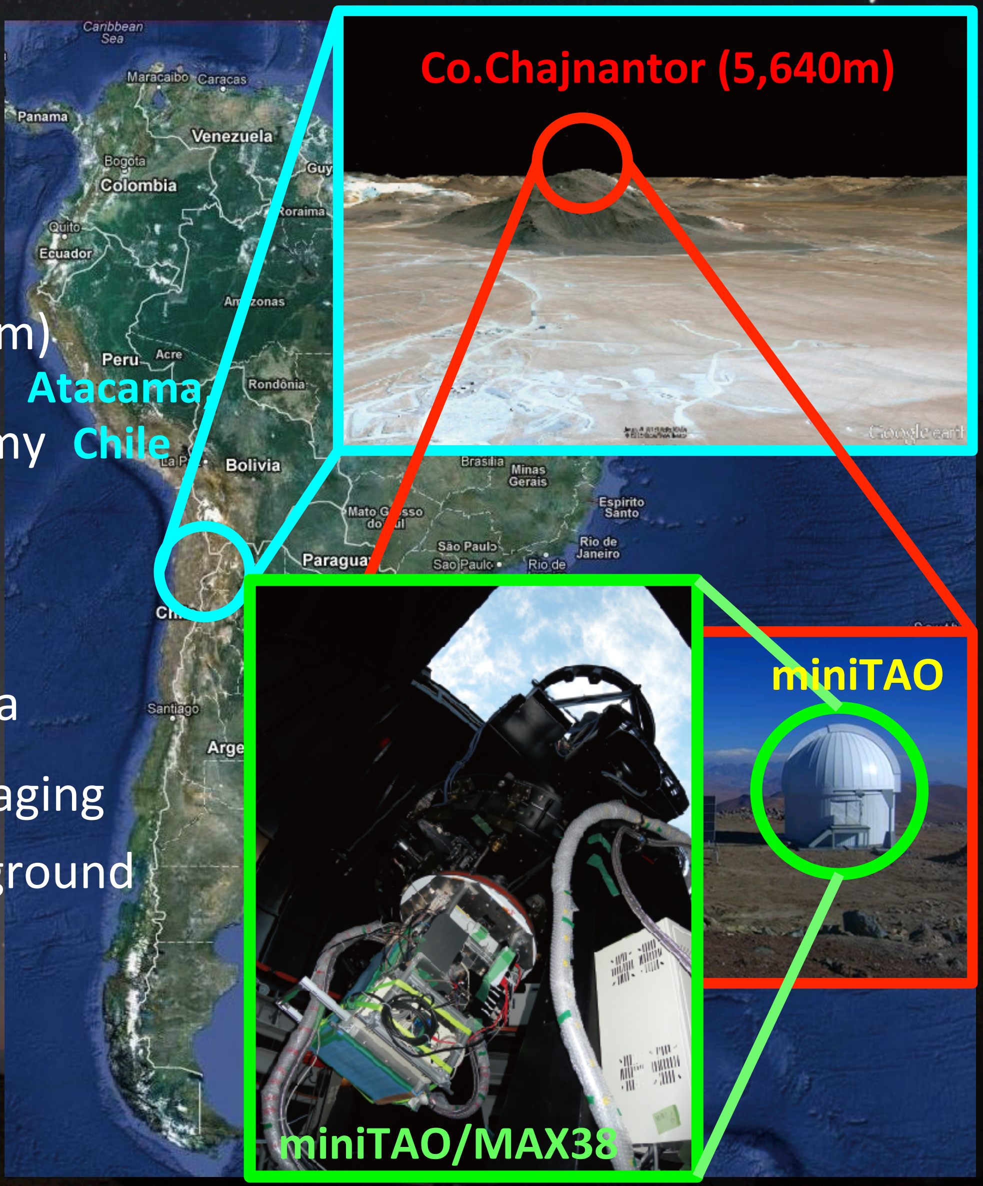
Observations

- Object : bipolar PN Mz3
- Instrument : miniTAO / MAX38
- Wavelength : 18.7, 25, 31.7 um

Wavelength [um]	date	Intergration Time [s]
18.7	2011.5.28	400
25.0	2012.10.21	1000
31.7	2011.5.28	3000

miniTAO / MAX38

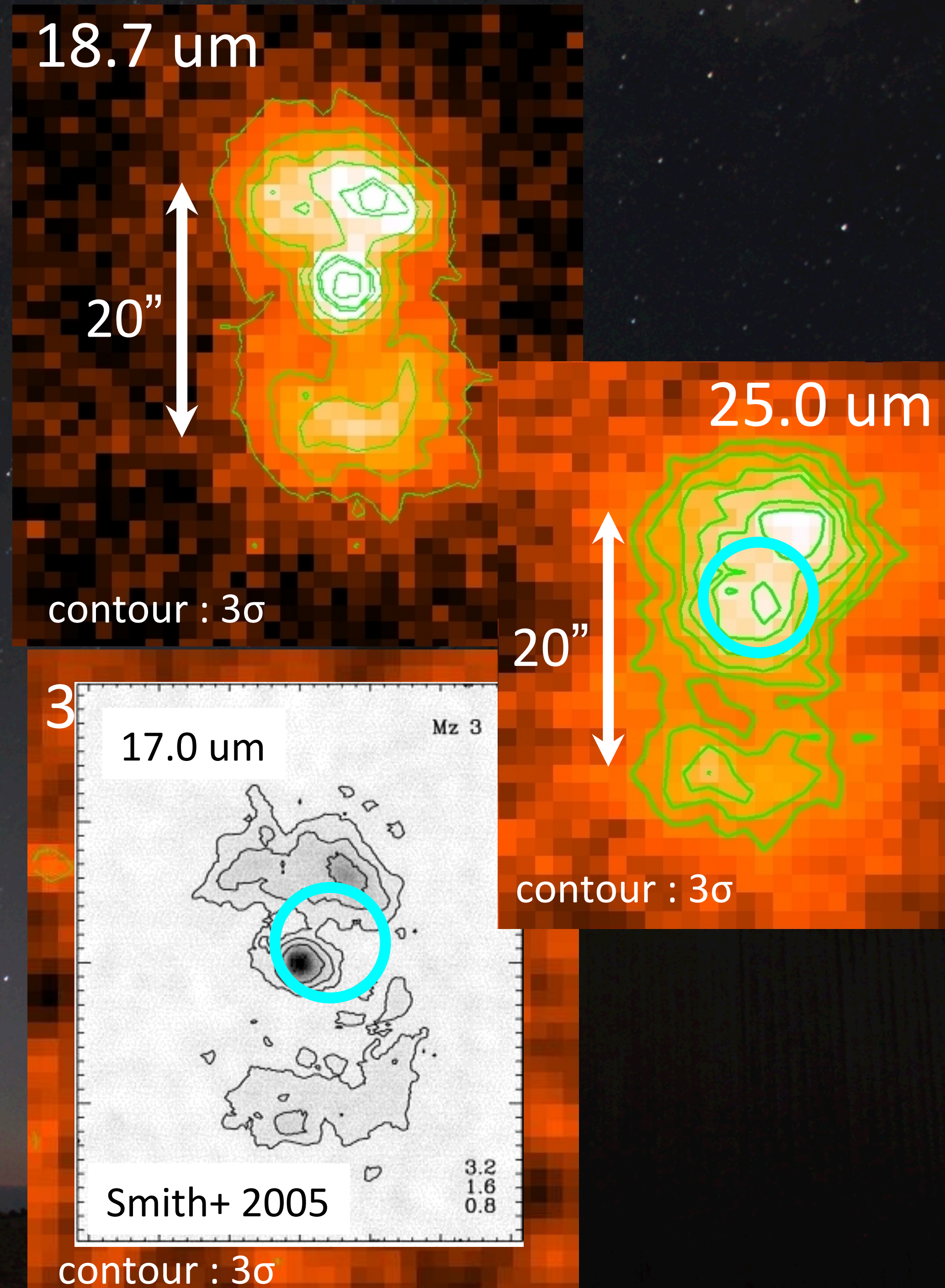
- miniTAO
  - 1.0m telescope
  - Atacama desert in northern Chile
  - The summit of Cerro Chajnantor (5,640m)
    - → The best site for infrared astronomy



- MAX38
  - Our own developed mid-infrared camera
  - The unique instrument which has an imaging capability at 30 micron bands from the ground
  - Wavelength coverage : 8 – 38 um
  - Spatial resolution : 8” at 30 um

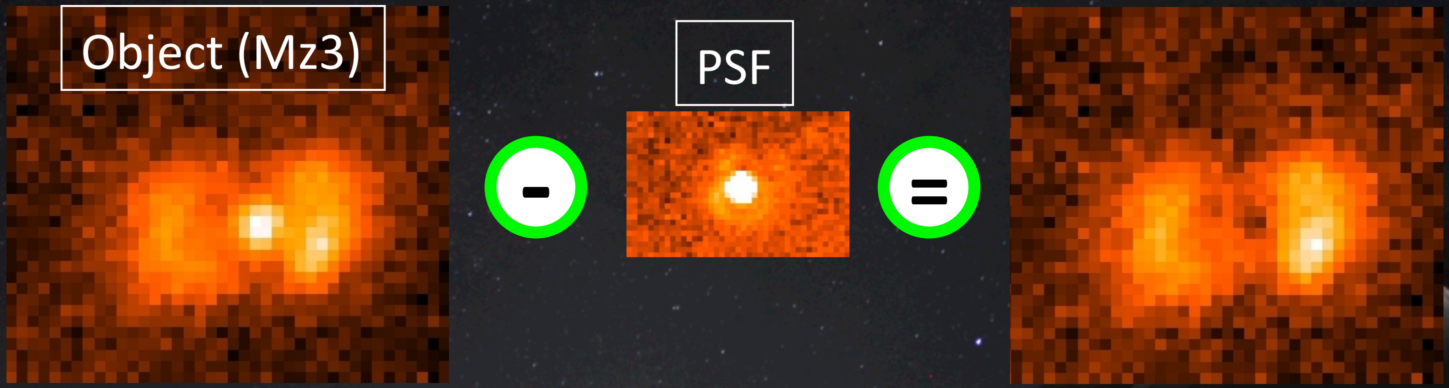
Results

- Spatially resolved images of Mz3 at 18 and 25, 31 um were obtained.
- A bright peak is seen at the center of the 18 um image.
- The 18-um image well resembles the 17-um image obtained by Smith (2005).
- The central region is also bright in the 25,31-um image.



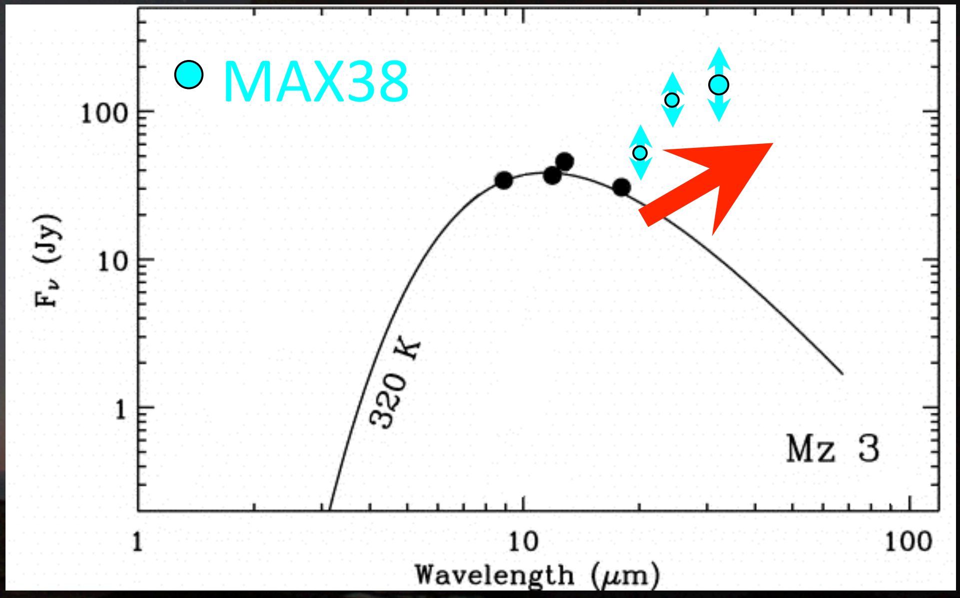
Analysis : psfphotometry

- PSF photometry : the fluxes of the central region at 18, 25, 31 um



- The 31um flux of the central region is much larger than the expected value.

Wavelength [um]	Flux [Jy]	Instrument
8.9	34.3	ESO3.6/TIMMI2
11.9	36.9	ESO3.6/TIMMI2
17.0	30	ESO3.6/TIMMI2
18.7	55±7	miniTAO/MAX38
25.0	117±15	miniTAO/MAX38
31.7	157±40	miniTAO/MAX38



Analysis : mass estimation

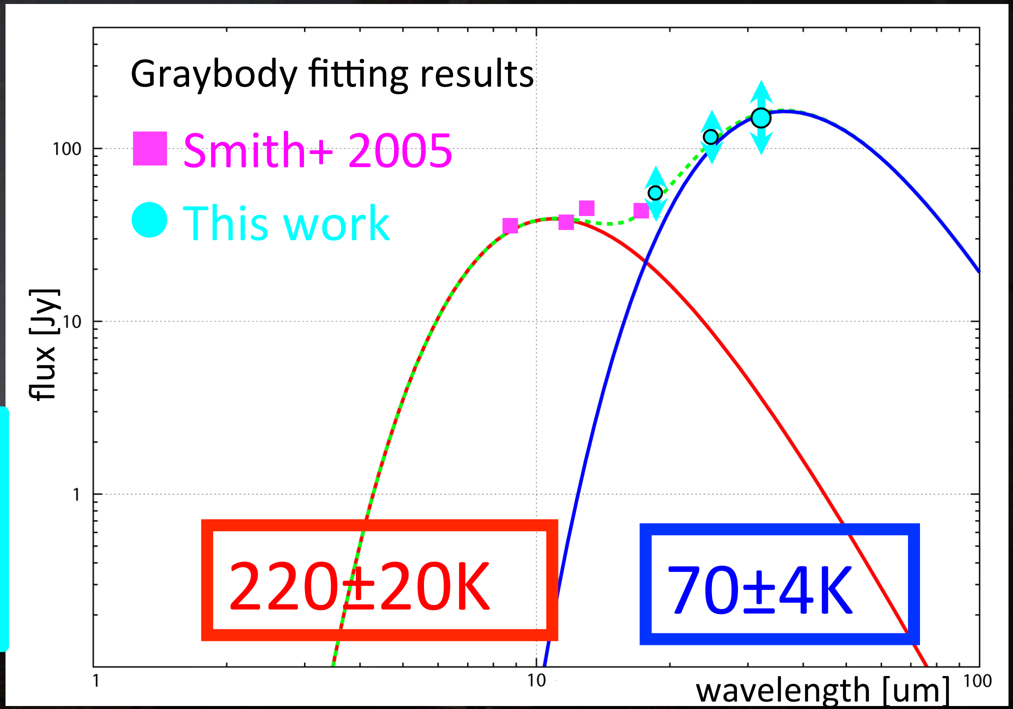
- Masses of the warm/cold component at the center are estimated by a graybody fitting with λ^{-1} emissivity.

  - We apply the equation of Smith (2005) to this results.

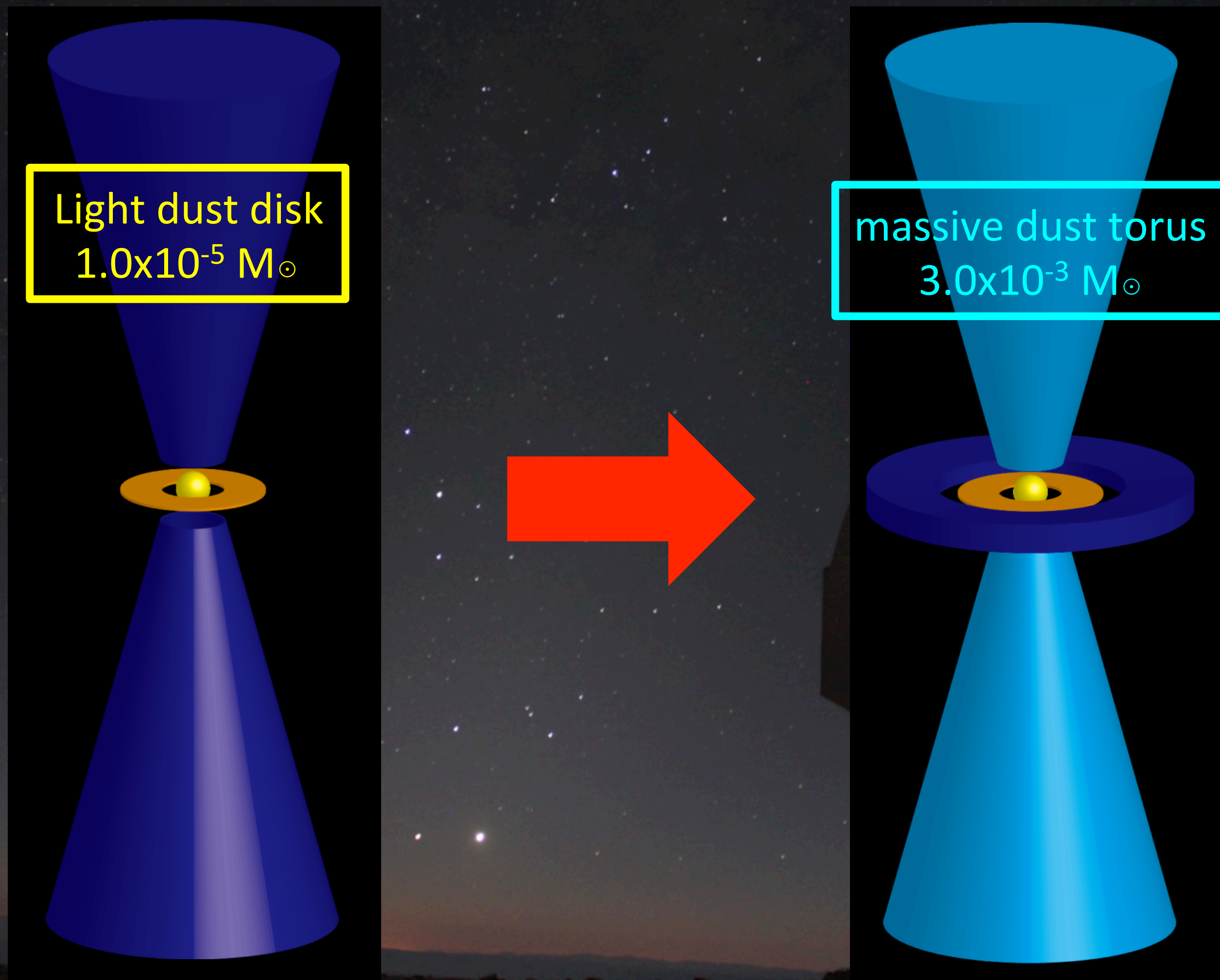
$$M_{dust} = \left(\frac{a\rho}{3\sigma Q_e (T_{dust})^4}\right) L_{dust}$$

→ Massive dust torus in Mz3

	parameter	value
a	Grain size	0.05-1.0 [um]
ρ	Density	2.25 [g/cm^3]
σ	Stefan-Boltzman	5.7e-8 [W/m^2/K^4]
Q_e	Emissivity	Gilman+ 1974
T_{dust}	Temperature	70 [K]
L_{dust}	Luminosity	540 [L⊙]



Massive dust torus in Mz3



Previous

This work

Similar torus in bipolar PN:M2-9

- Bipolar PN : M 2-9
  - Similar structure to Mz3
  - initial mass > $2M_\odot$ (Palla+ 1999)
  - No dark lanes at the center region
  - A light disk in the central region : $M_{dust} = 1.5\times10^{-5} M_\odot$
    (Lykou+ 2011, with MIDI)

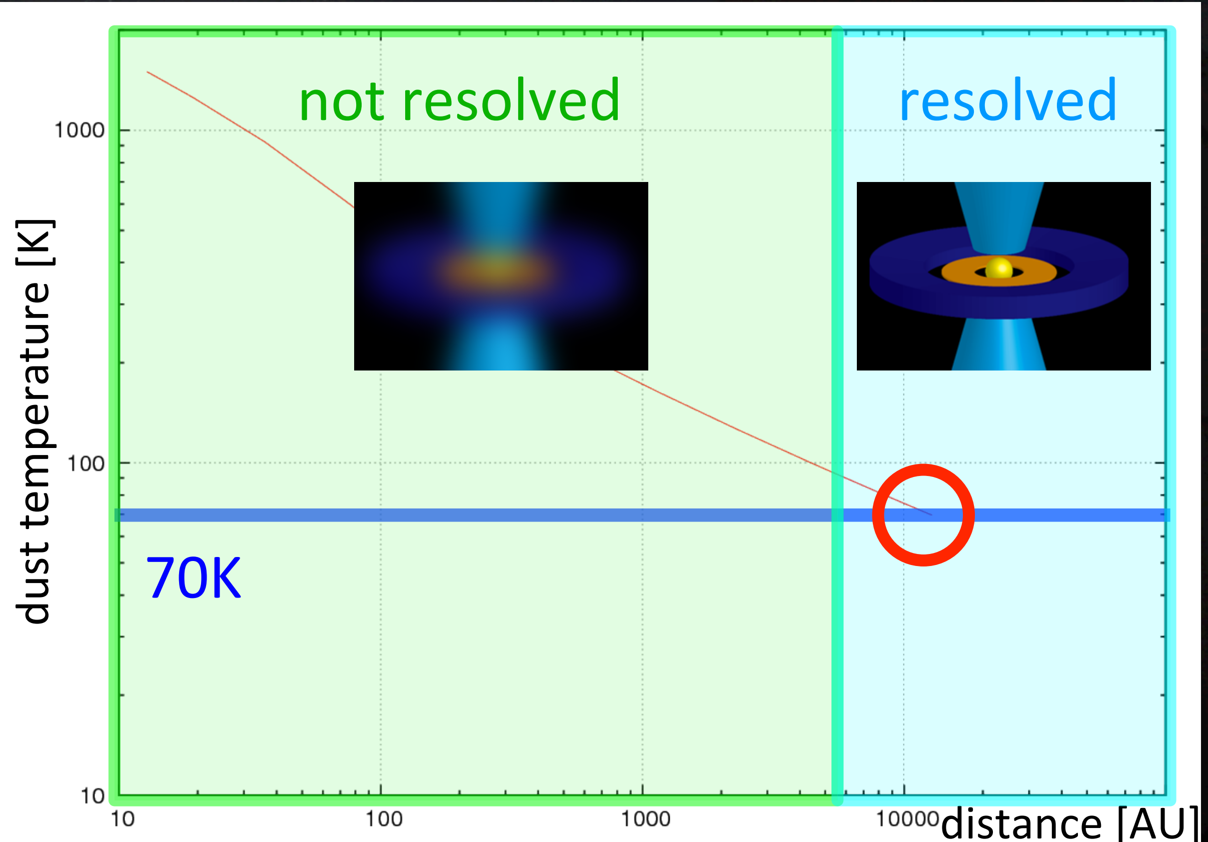
- Double ^{12}CO 2-1 ring were detected (Castro2012)

- Outer ring : $M_{gas}=1.0\times10^{-2}\ M_\odot$

Discussion : cold torus

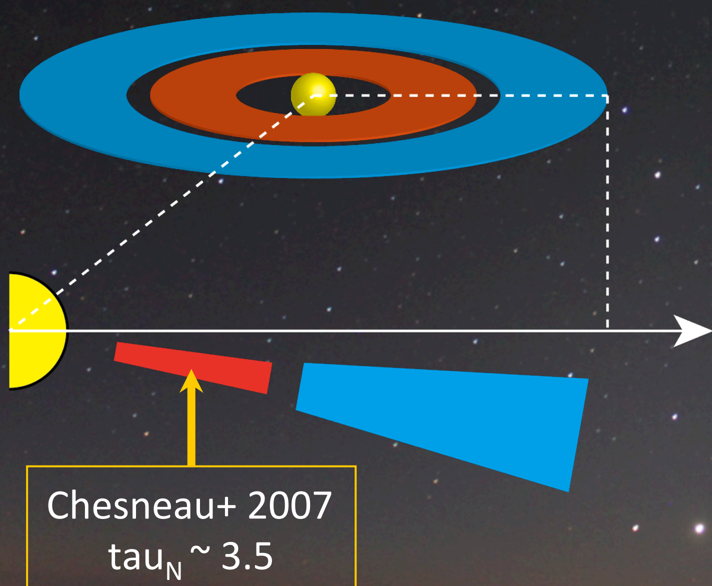
- Observation … MAX38 couldn't resolve the cold torus with 31um
  - MAX38 31um resolution : 8 arcsec ~ 10000 AU
    - → cold torus < 5000 AU
- Thermal equilibrium : the cold torus distance from the central star ~ 11000 AU
  - optically thin
  - normal size dust

parameter	Value
Dust	Astronomical silicate (Draine & Lee 1948)
Grain shape	Spherical
Grain size	0.005-0.25 [um]
Size distribution	$a^{-3.5}$
Dust temperature	70 [K]
Luminosity of star	10000 [L⊙]

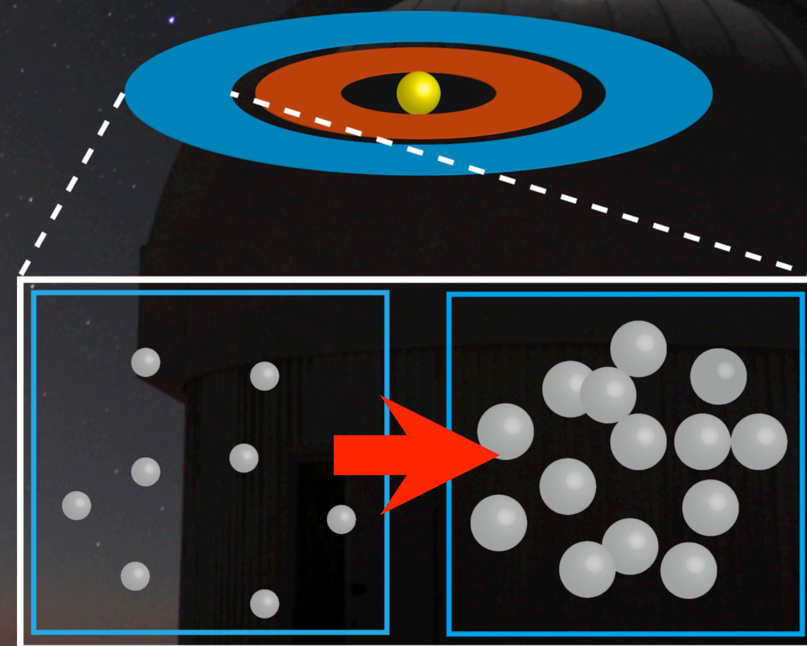


possible explanations

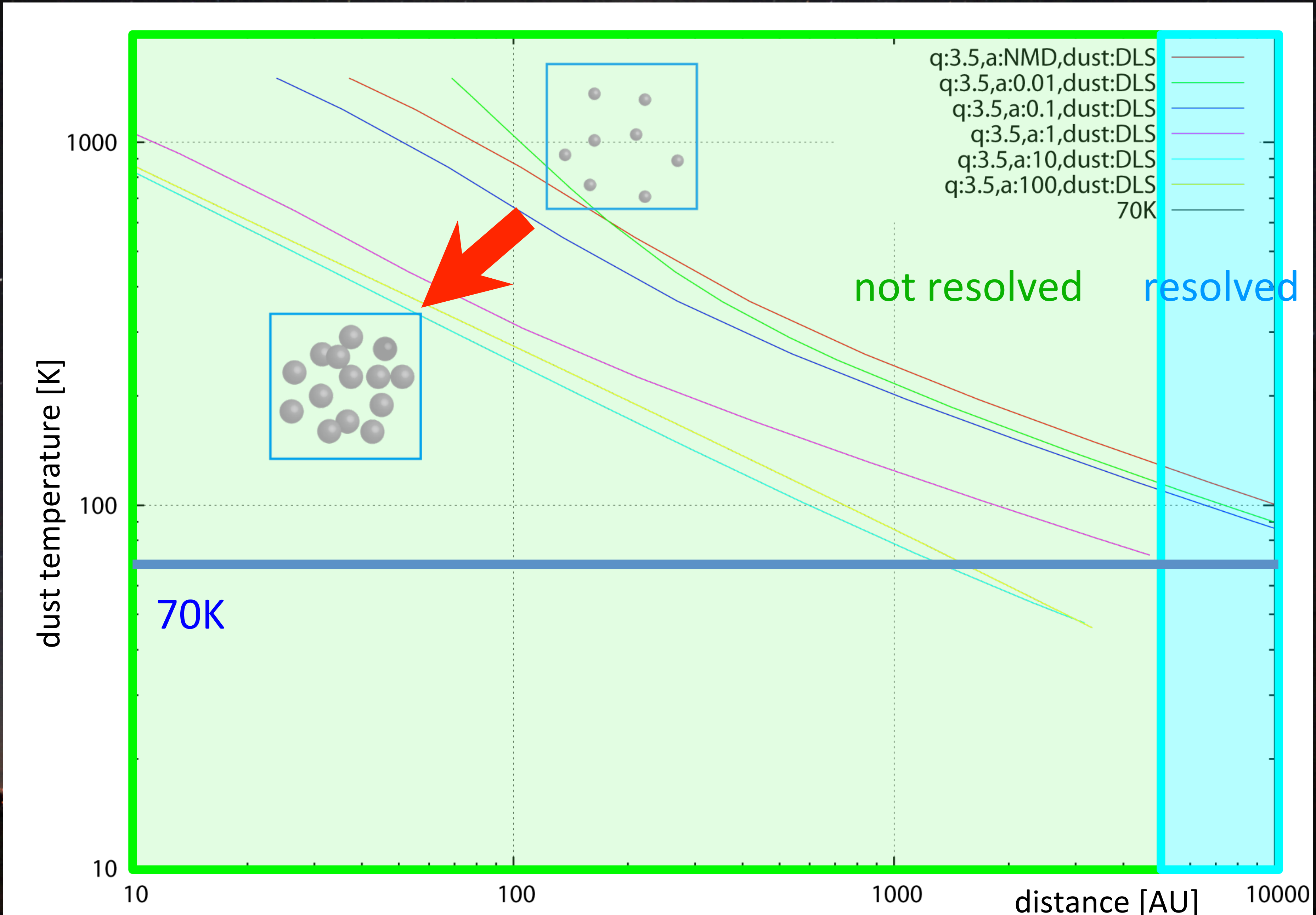
1) Extinction of stellar radiation by the inner disk



2) Growth of dust grains in the torus



2) Growth of dust grains in the torus ?



Summary

- We successfully obtained spatially resolved images of Mz3 at the 18.7 and the 20um, and the 31.7um bands.
- The cold component of T~70K was found at the central region.
- The mass of the torus ($1.0\text{x}10^{-3}$ $M_\odot$) is 100 times higher than the previous studies.
- Assumptions of the dust grain growth or the existence of optically thick inner disk can explain the unresolved dust torus with MAX38 / 31 micron.


end