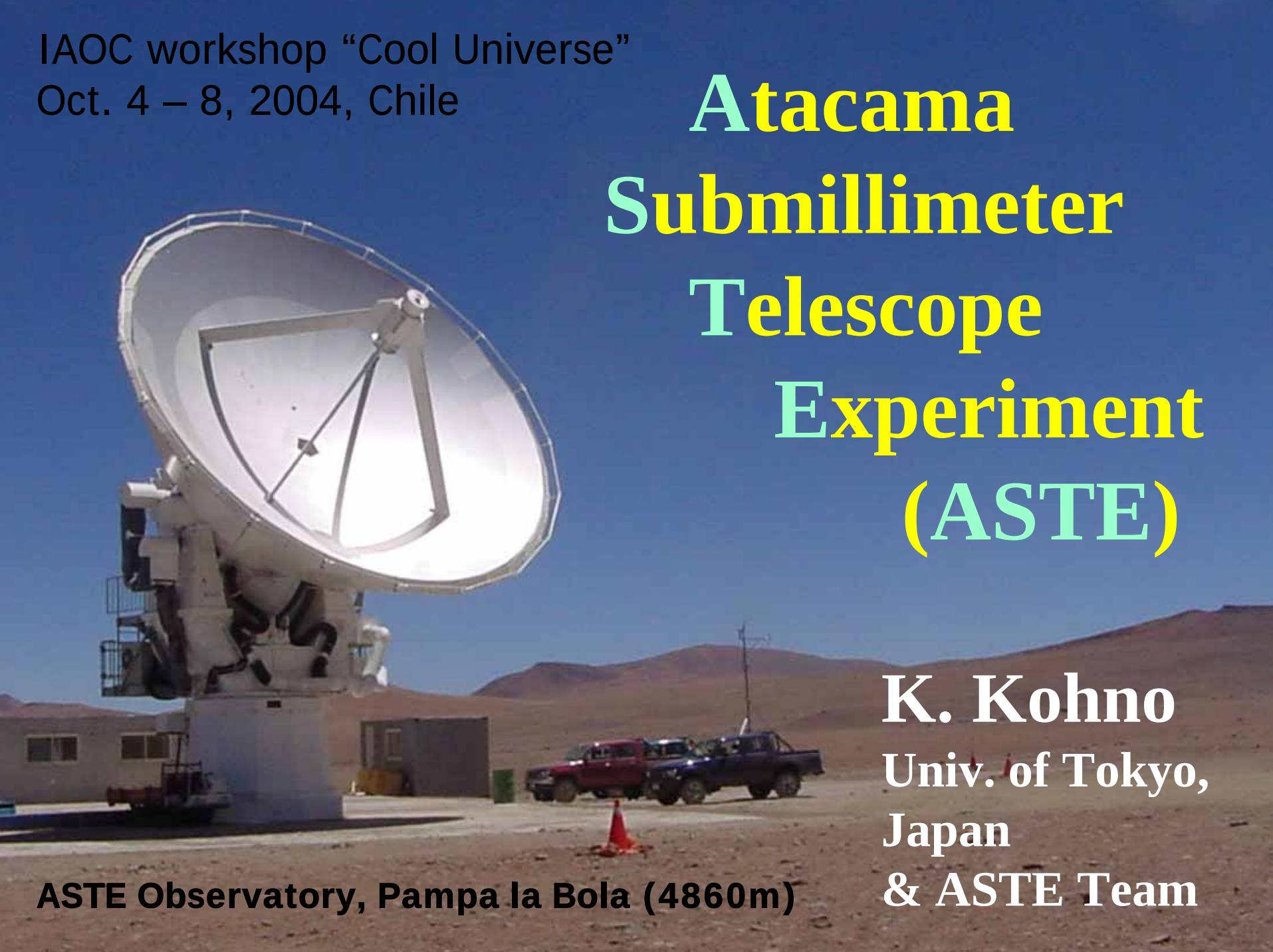
IAOC workshop “Cool Universe”
Oct. 4 – 8, 2004, Chile

Atacama Submillimeter Telescope Experiment (ASTE)



ASTE Observatory, Pampa la Bola (4860m)

K. Kohno
Univ. of Tokyo, Japan
& ASTE Team

Outline

- What is ASTE?
  - Overview of the project
  - Why submm ? – a case of active galaxies -
  - A brief history & current view of the site
- Instrumentation
  - Antenna: improvement of the surface
  - Receivers: cartridge type SIS receivers & bolometers
- Early science program & initial results

The ASTE Project

- A joint project
  - between Japan and Chile
  - to install and operate a 10 m high precision telescope
  - at Pampa la Bola (4860 m) in northern Chile.
- Collaboration:
  - NAOJ/Univ. of Tokyo/Nagoya Univ./Osaka- Pref. Univ./Ibaragi Univ. in Japan
  - Univ. of Chile, in Chile

The ASTE Project

- Project director: K. Kohno (Univ. of Tokyo)
- Project manager: H. Ezawa (NAOJ)
- Project scientist : S. Yamamoto (Univ. of Tokyo)
- Time Allocation Committee (Japanese side)
  - S. Yamamoto (Univ. of Tokyo; Chair)
  - R. Kawabe, H. Ezawa (NAOJ)
  - T. Ohnishi (Nagoya Univ.)
  - K. Kohno (Univ. of Tokyo)
- Univ. of Chile: L. Bronfman, M. Rubio, J. Cortez et al.

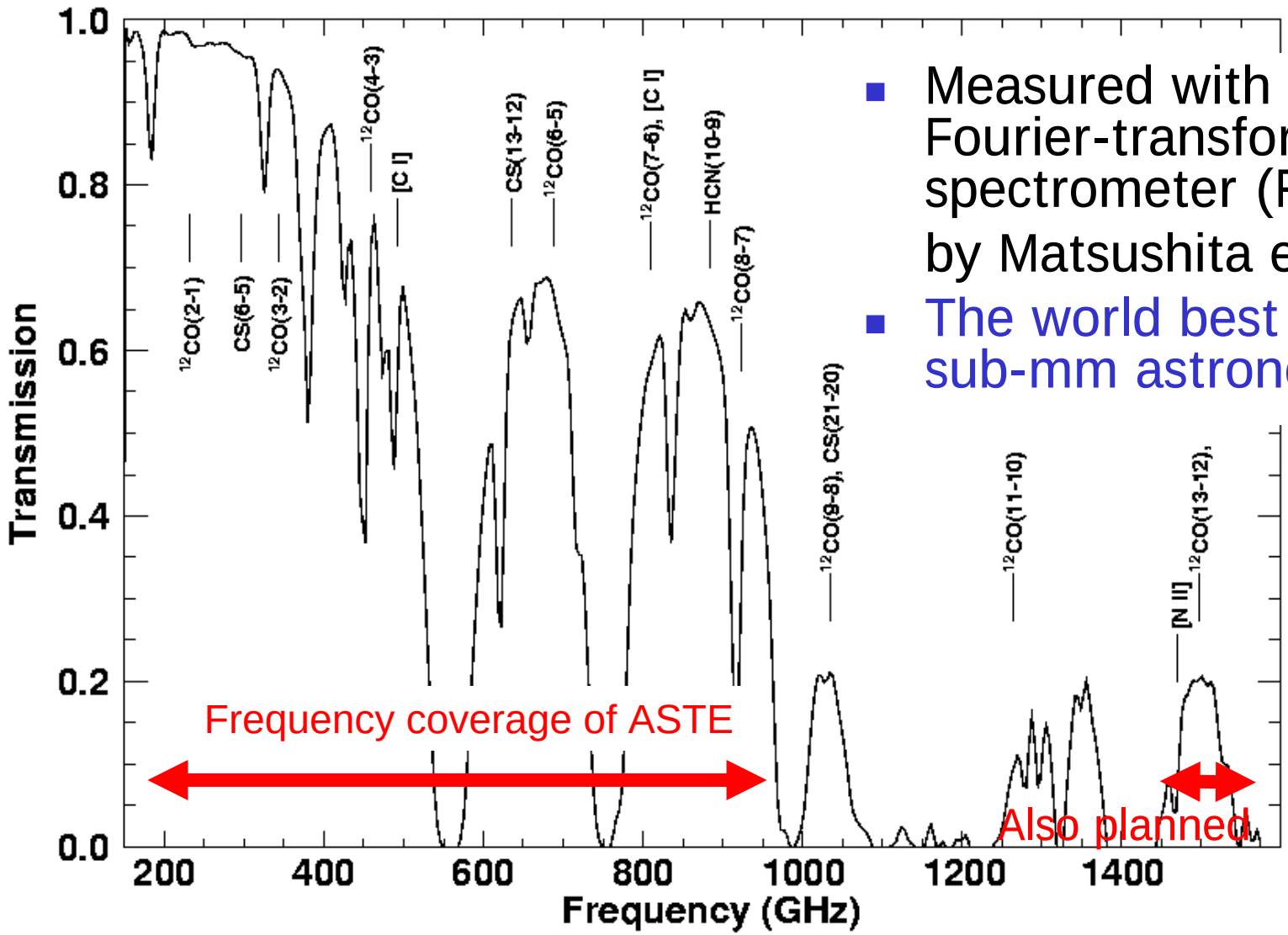
The ASTE Project

- Two goals:
  - On-site evaluation of high precision telescope and receiver systems, developed toward the ALMA project.
  - Astronomical exploration of the Southern sky at submm wavelengths.

Good preparation for ALMA,

technically & scientifically.

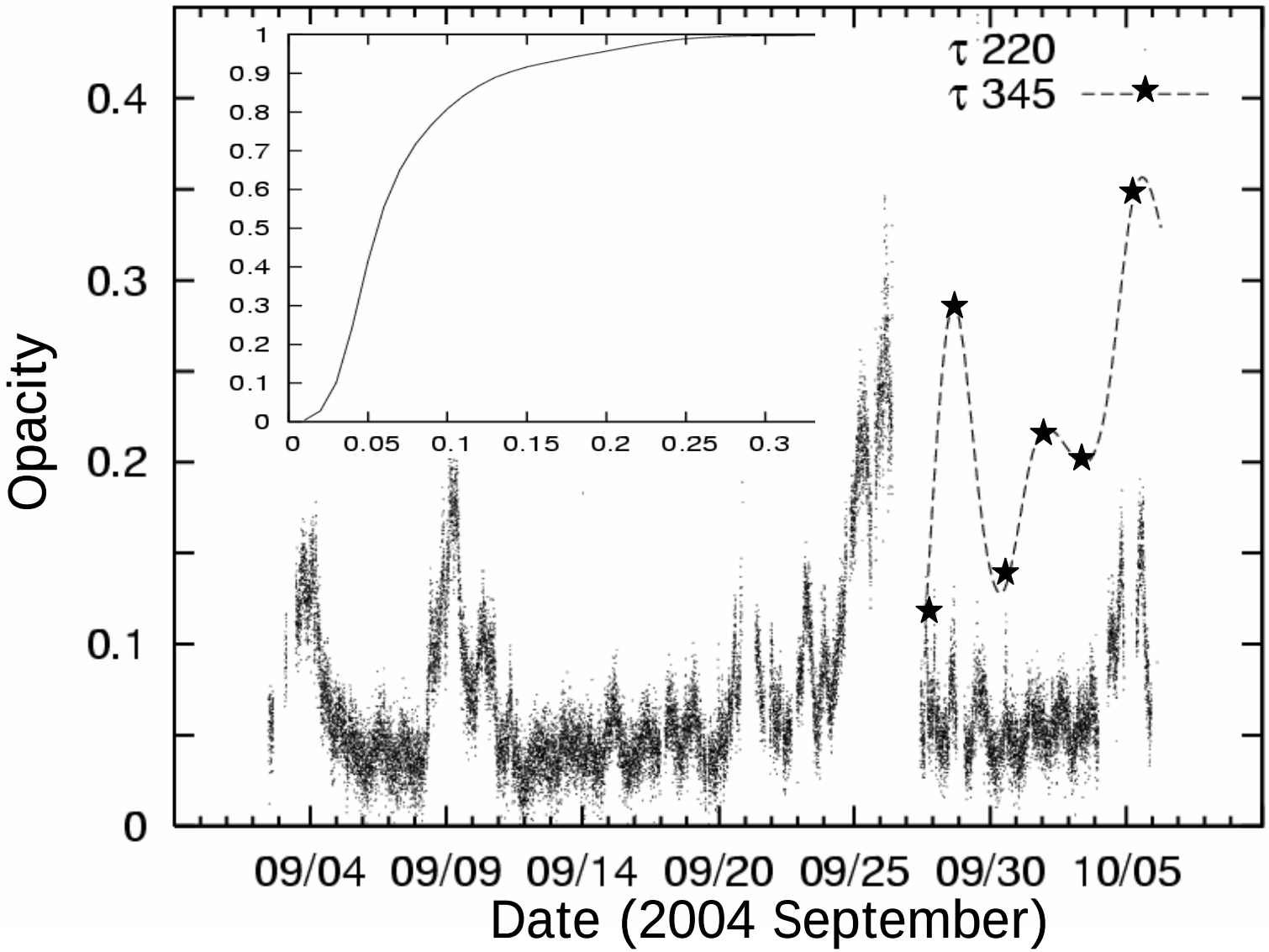
ASTE Atmosphere



- Measured with the Fourier-transform spectrometer (FTS) by Matsushita et al.
- The world best site for sub-mm astronomy!

Super-THz Windows

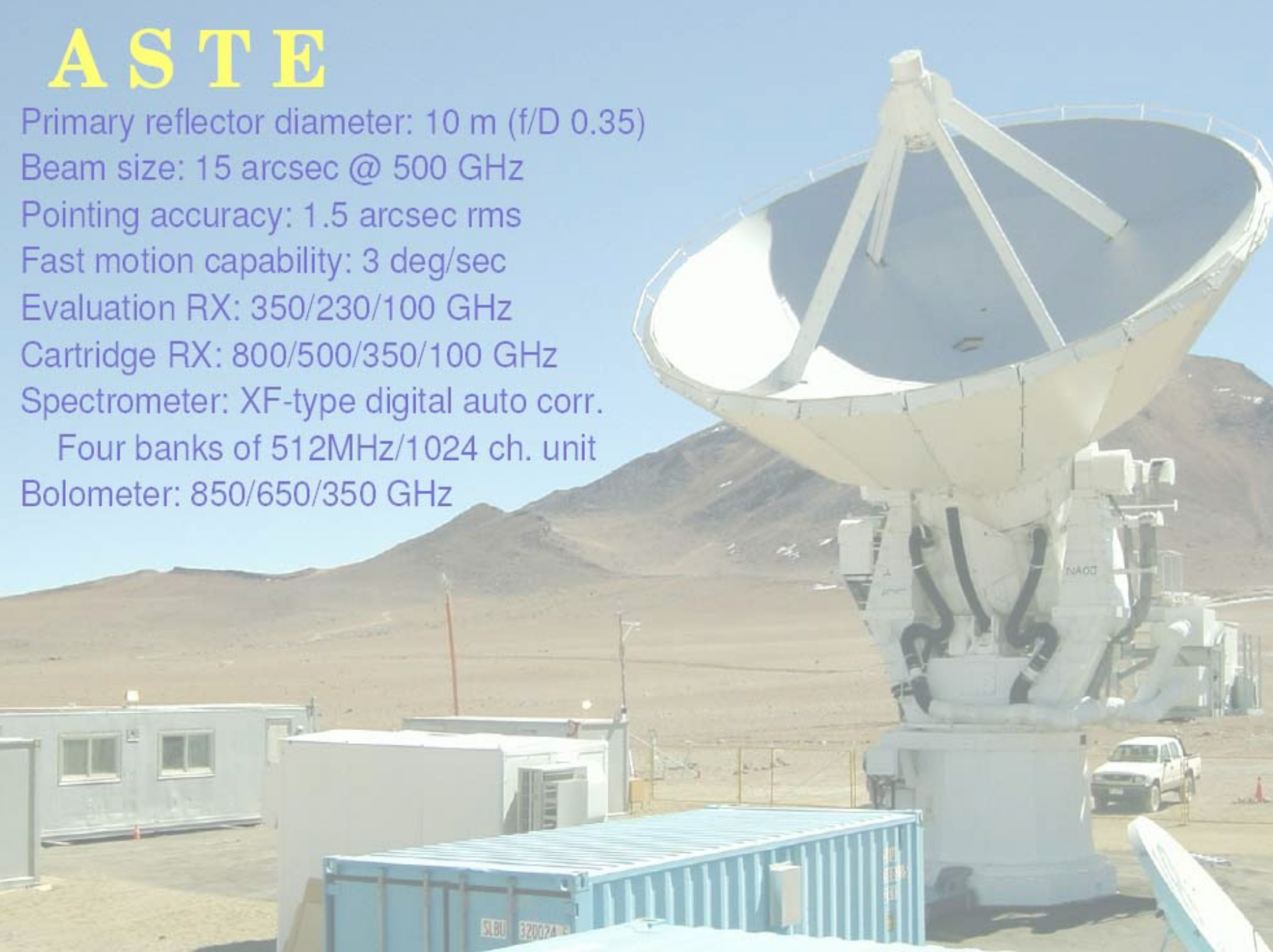
An example of measured opacities at 220 & 350 GHz



$$\frac{\tau\,350}{\tau\,220} \sim 4$$

ASTE

Primary reflector diameter: 10 m (f/D 0.35)
Beam size: 15 arcsec @ 500 GHz
Pointing accuracy: 1.5 arcsec rms
Fast motion capability: 3 deg/sec
Evaluation RX: 350/230/100 GHz
Cartridge RX: 800/500/350/100 GHz
Spectrometer: XF-type digital auto corr.
Four banks of 512MHz/1024 ch. unit
Bolometer: 850/650/350 GHz

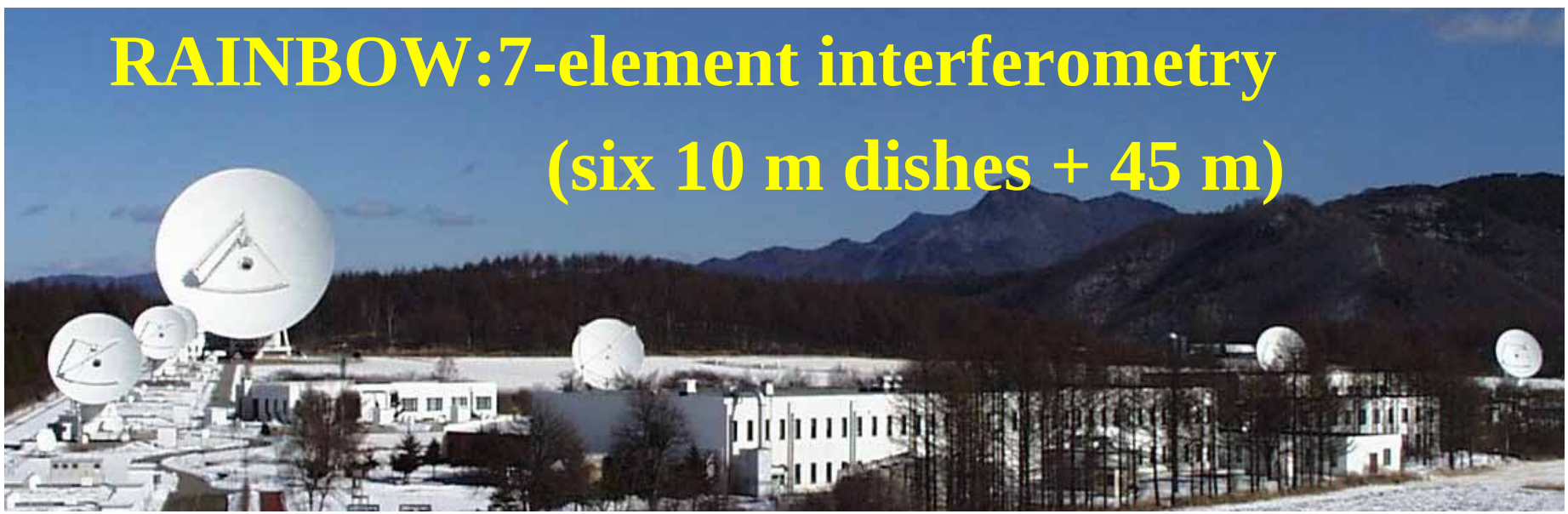


Why submm?

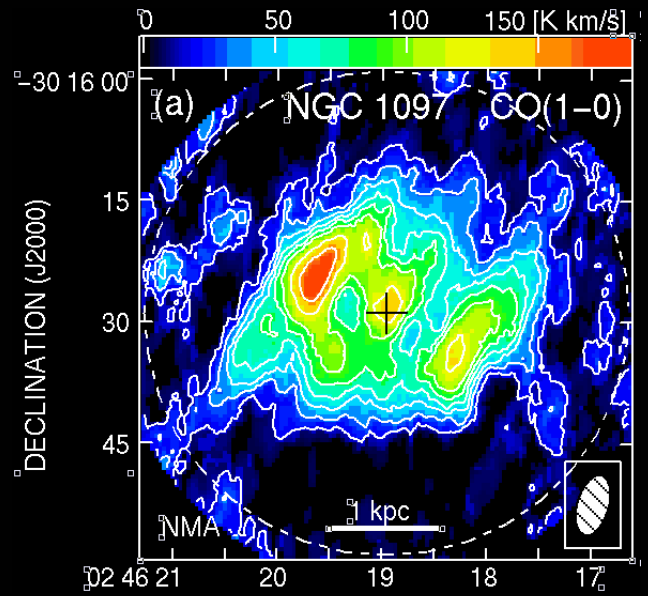
- a case of local active galaxies -

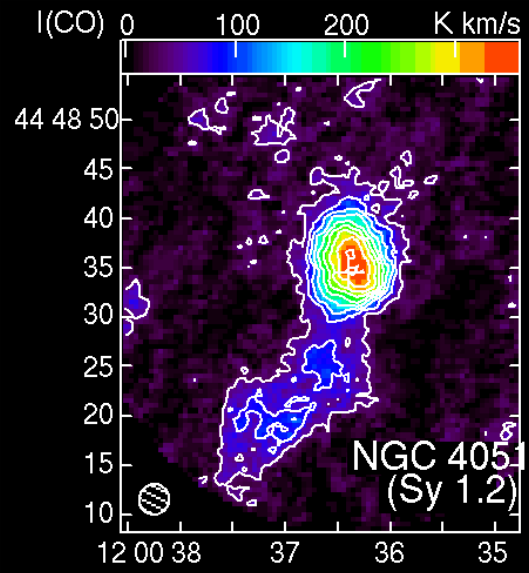
NMA/RAINBOW survey of local Seyfert & starburst galaxies

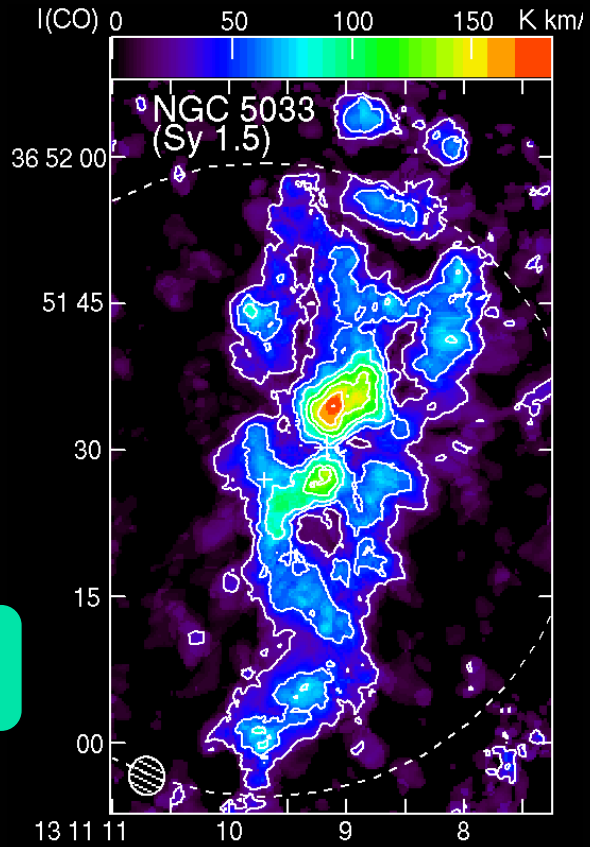
- High resolution (a few arcseconds) imaging
  ⇒ a few 100 pc scales at D ～ a few 10 Mpc
- CO(1-0): total molecular gas (n_{H2}>10^2 H_2 cm^{-3})
- HCN(1-0) & HCO+(1-0): dense molecular gas (n_{H2}>10^4 H_2 cm^{-3})

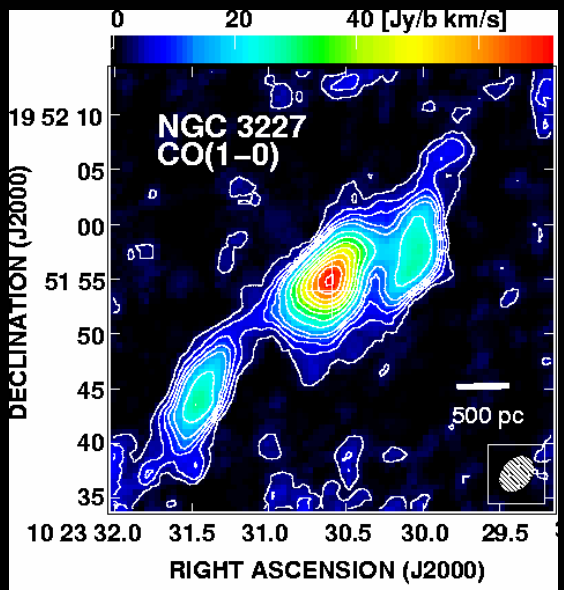


Nobeyama CO(1-0) Survey: type 1 Seyfert galaxies

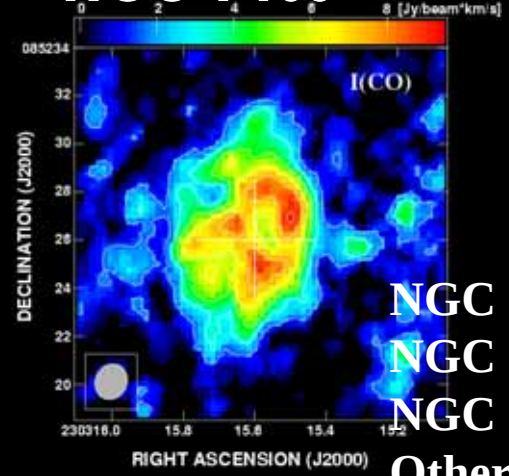








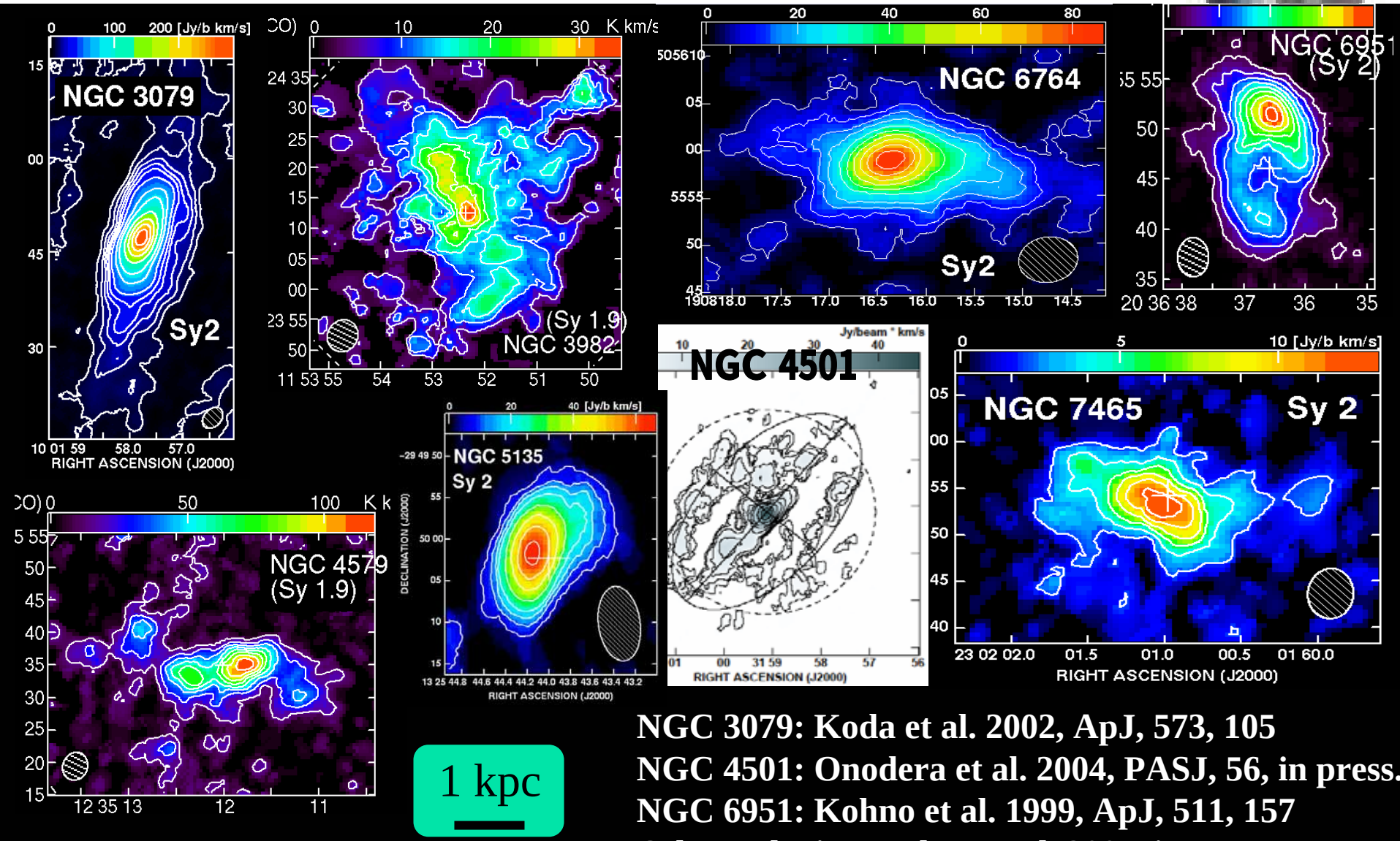
NGC 7469



1 kpc

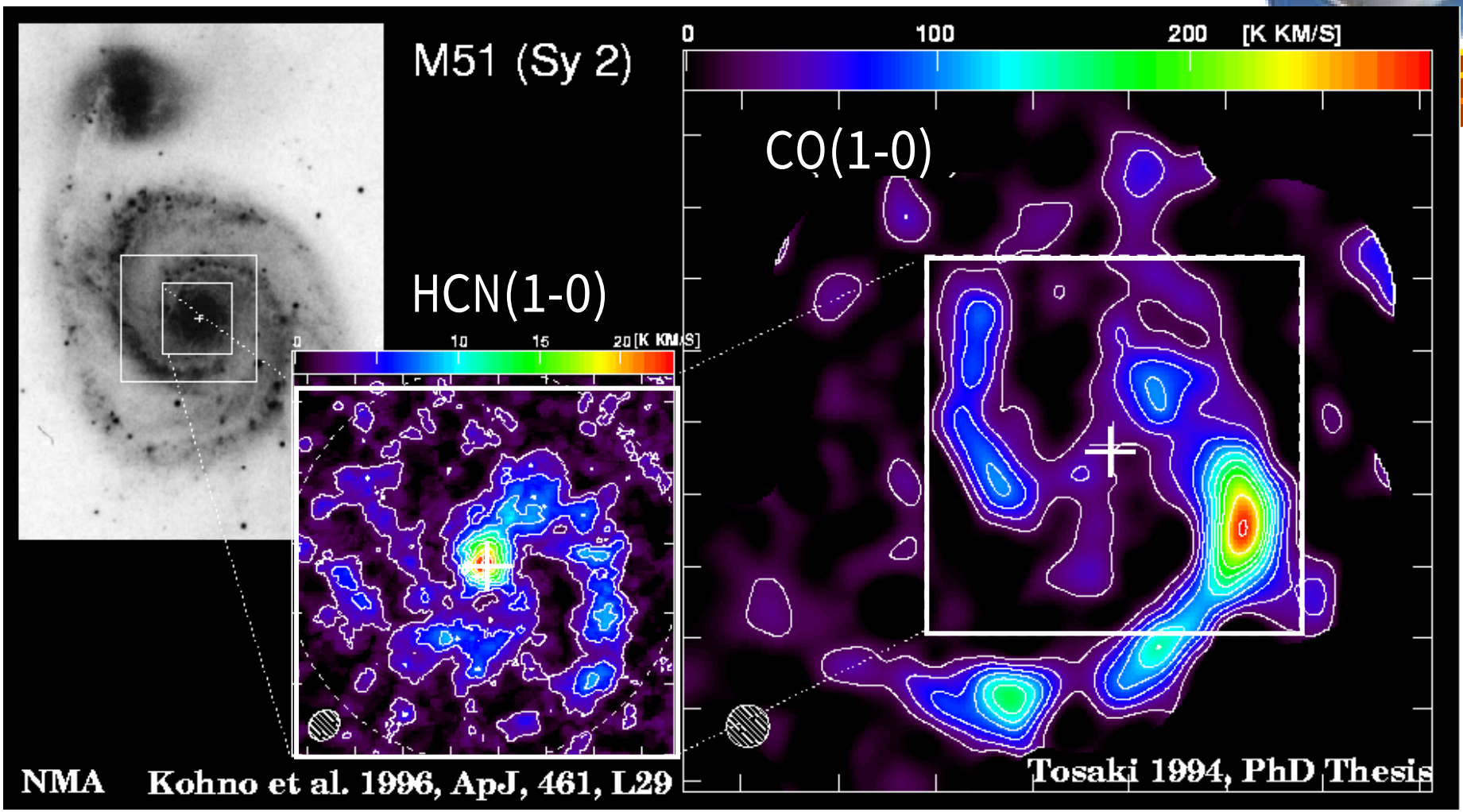
NGC 1097: Kohno et al. 2003, PASJ, 55, L1
NGC 5033: Kohno et al. 2003, PASJ, 55, 103
NGC 7469: Okiura et al. 2004, PASJ, in prep.
Other galaxies: Kohno et al. 2004, in prep.

Nobeyama CO(1-0) survey: type 2 Seyfert galaxies



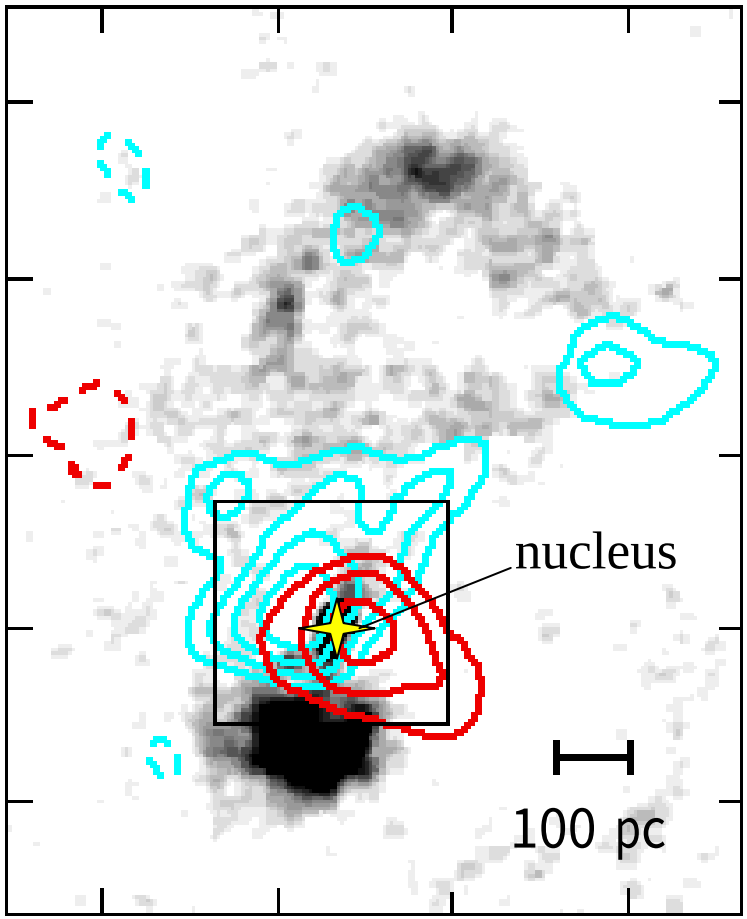
NGC 3079: Koda et al. 2002, ApJ, 573, 105
NGC 4501: Onodera et al. 2004, PASJ, 56, in press.
NGC 6951: Kohno et al. 1999, ApJ, 511, 157
Other galaxies: Kohno et al. 2004, in prep.

Enhanced HCN in NGC 5194



- I(HCN)/I(CO) enhanced up to ~ 0.5
- (cf. Milky Way ~ 0.08 with similar spatial extent)

Dense gas disk around Sy2 nucleus of NGC 5194



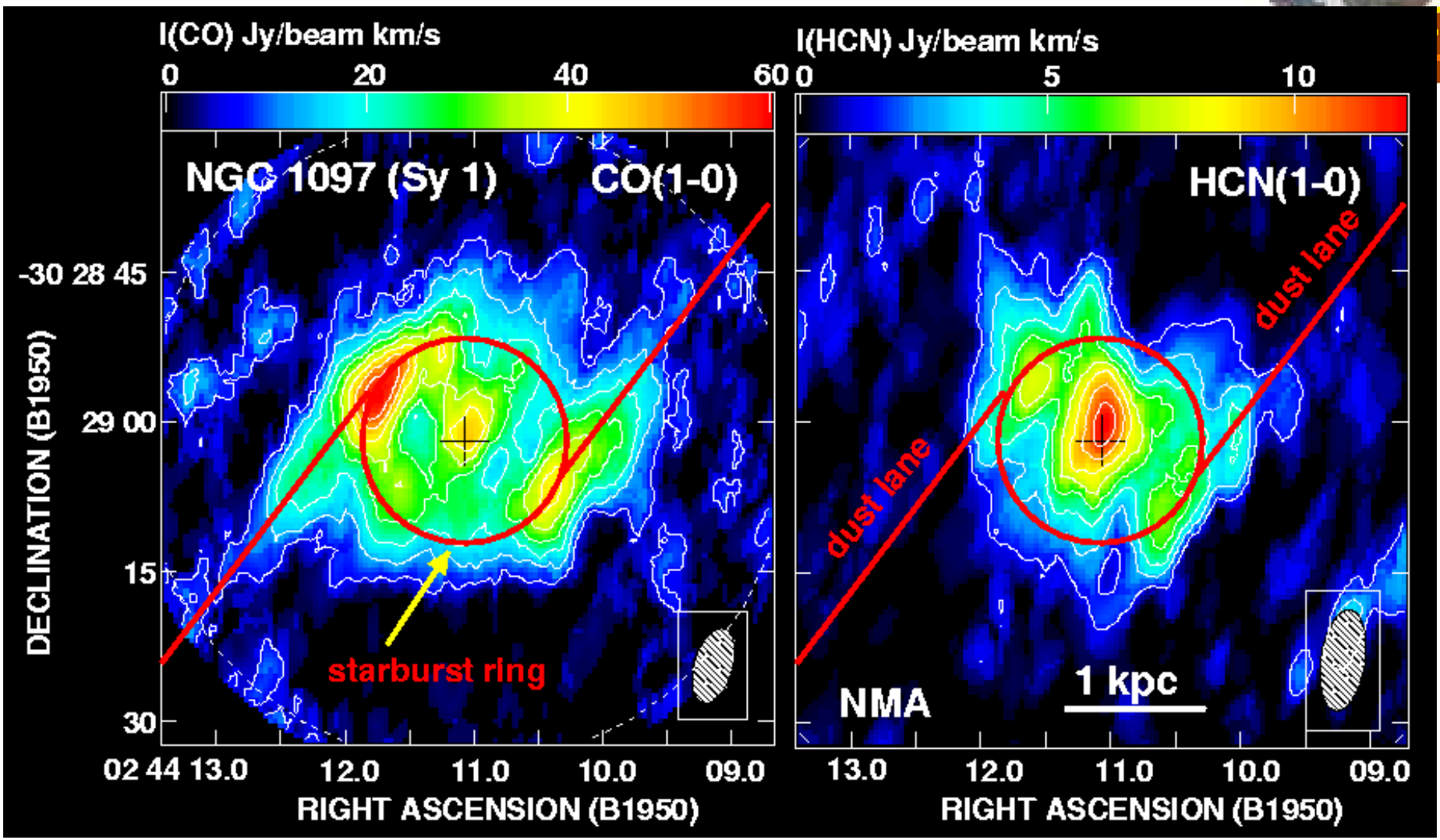
Contour: HCN blue & red shifted components (NMA)
Grey scale: radio jet @ 6 cm (VLA)

- Dense (n_{H2}>10^4cm^{-3}) rotating gaseous disk with a radius of ~ 70 pc
- Rotation axis is aligned to the radio jet, not aligned to the galactic disk rotation
- Column density from HCN observations (N_H~10^{24} cm^{-2}) is consistent with that from X-ray observations (Terashima et al. 2000 etc.)

⇒ outer envelope of dense obscuring material ?

Kohno et al. 1996, ApJ, 461, L29

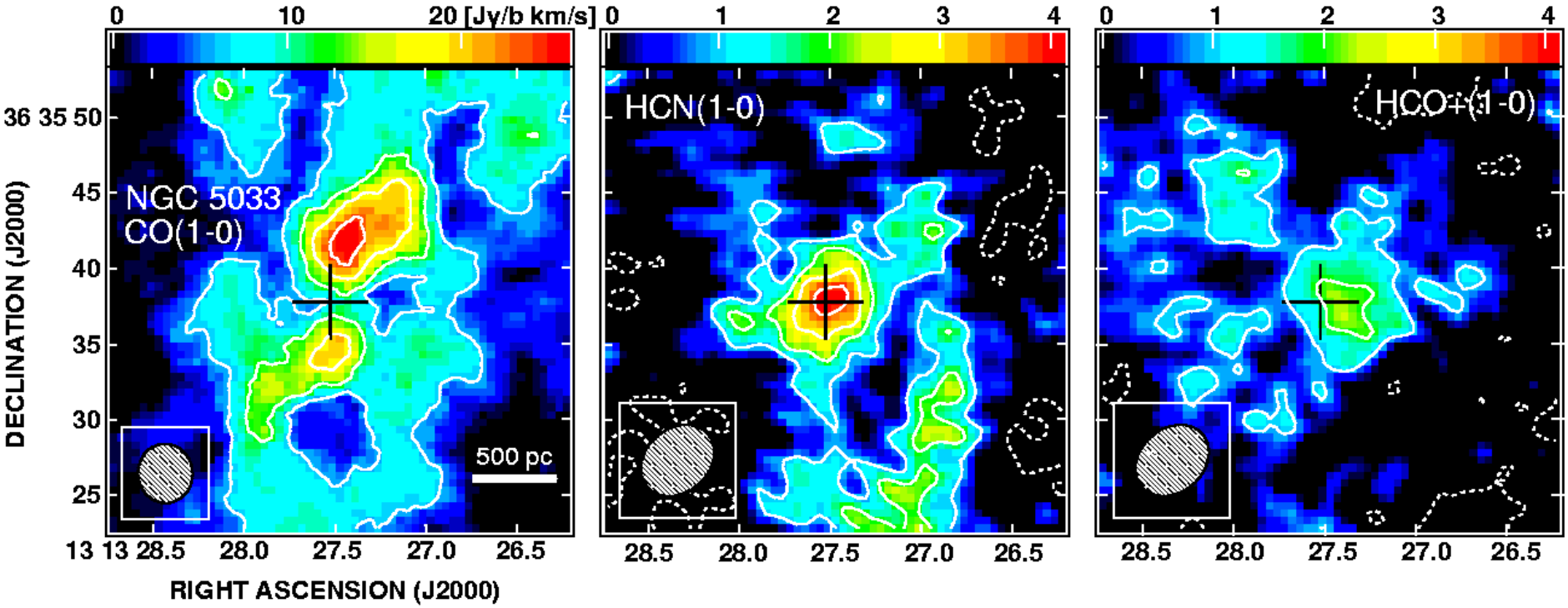
Enhanced HCN in NGC 1097



- I(HCN)/I(CO) in Tb scale is ~ 0.36

Kohno et al. 2003, PASJ, 55, L1

New HCN enhanced Seyfert: NGC 5033



Flux at the nucleus: 31 ± 2 Jy/b km/s 4.3 ± 0.63 Jy/b km/s 2.3 ± 0.63 Jy/b km/s

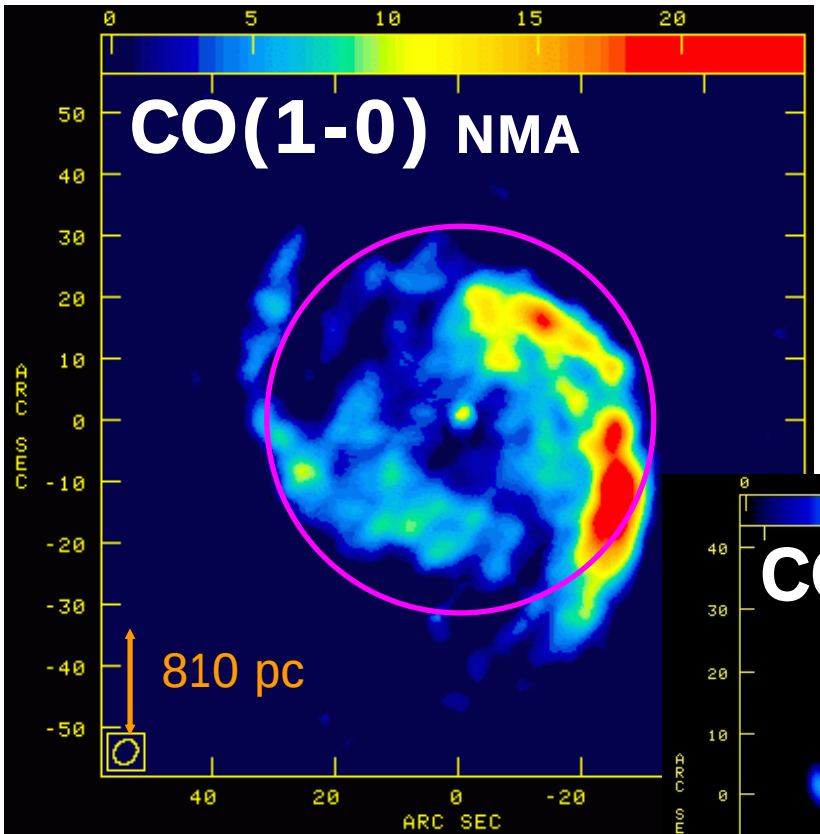
- HCN and HCO+: central concentration; no clear counterpart to CO twin peaks

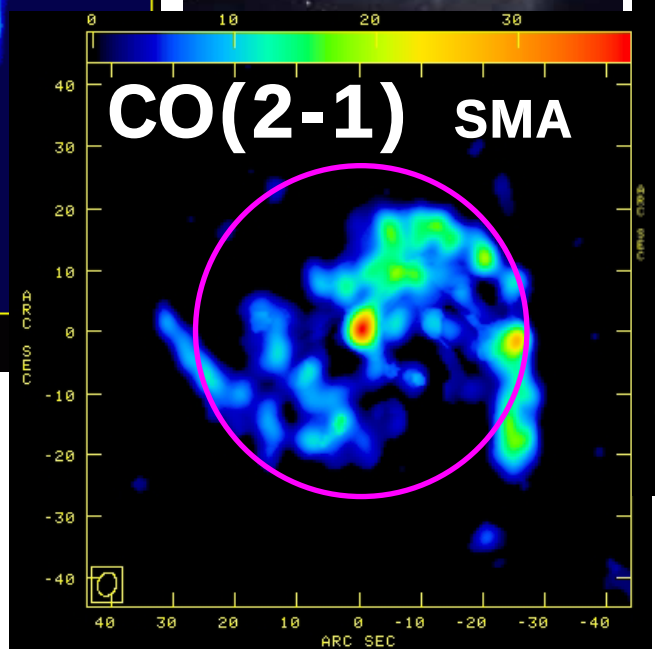
See poster by Kohno et al.

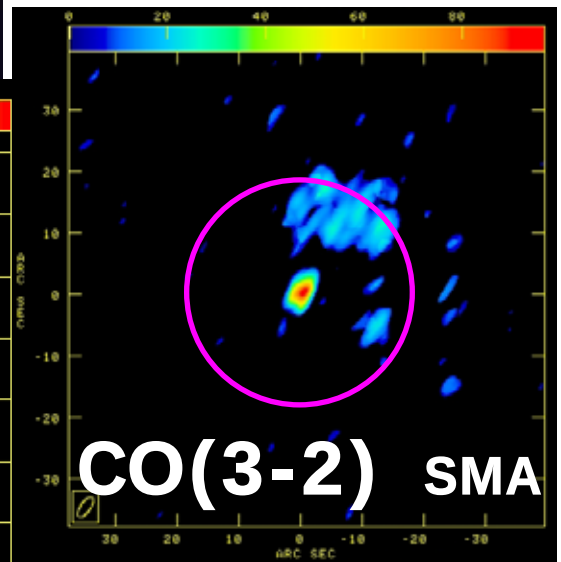
- I(HCN)/I(CO)$\sim$0.23 in Tb, I(HCN)/I(HCO+)$\sim$1.9

$\Rightarrow$ This is the 4th "NGC 1068", i.e., HCN enhanced Seyfert.

Multi-J CO Line observations of Seyfert 2 Galaxy M51







Sakamoto et al.
(1999, ApJS, 124, 403)

Matsushita et al.
(2004, ApJL, in press)

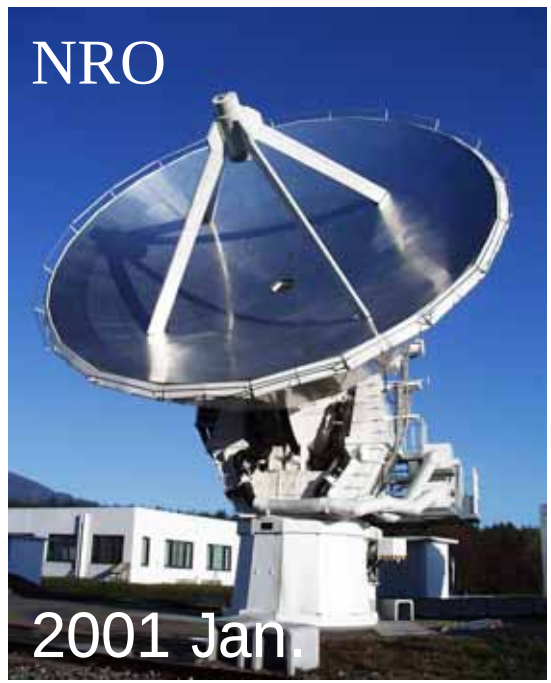
Sawada-Satoh et al.

A brief history

From Nobeyama to Chile

- 2000/02 — 2001/05 : Evaluation at NRO
- 2001/05 — 2002/03 : Relocation to Chile
- 2002/03 — : Start evaluation in Chile

Relocate



Assembly at San Pedro

Transportation

Transportation with two trailers (cruising speed ~ 3 km/hr)

Current view of the site

ASTE Facilities

Univ. of Chile

- RX Laboratory
- Communication
- Operation

Satellite Communication
64 kbps

Internet
128 kbps

National Astronomical Observatory of Japan and Universities

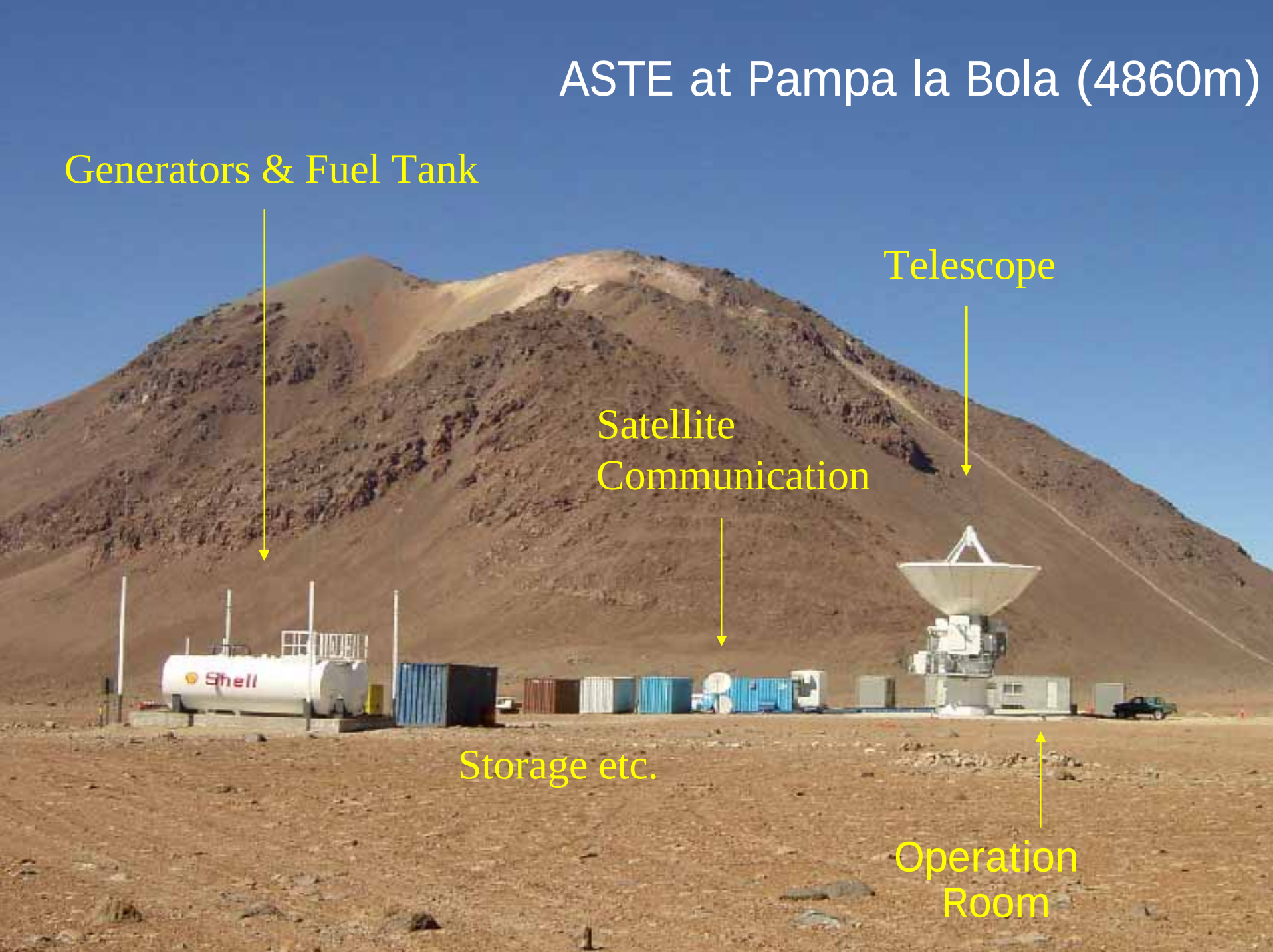
Pampa la Bola (4860 m)

- 10 m antenna
- RX, Backends
- Computers
- Holography TX

- Operation/ Maintenance
  - Control room
  - stock room
  - small lab.

- Power generators ~ 200 kW x 2

San Pedro de Atacama (2600 m)


ASTE at Pampa la Bola (4860m)
Generators & Fuel Tank
Telescope
Satellite
Communication
Storage etc.
Operation
Room
Shell

Inside view of observing room

Dining room

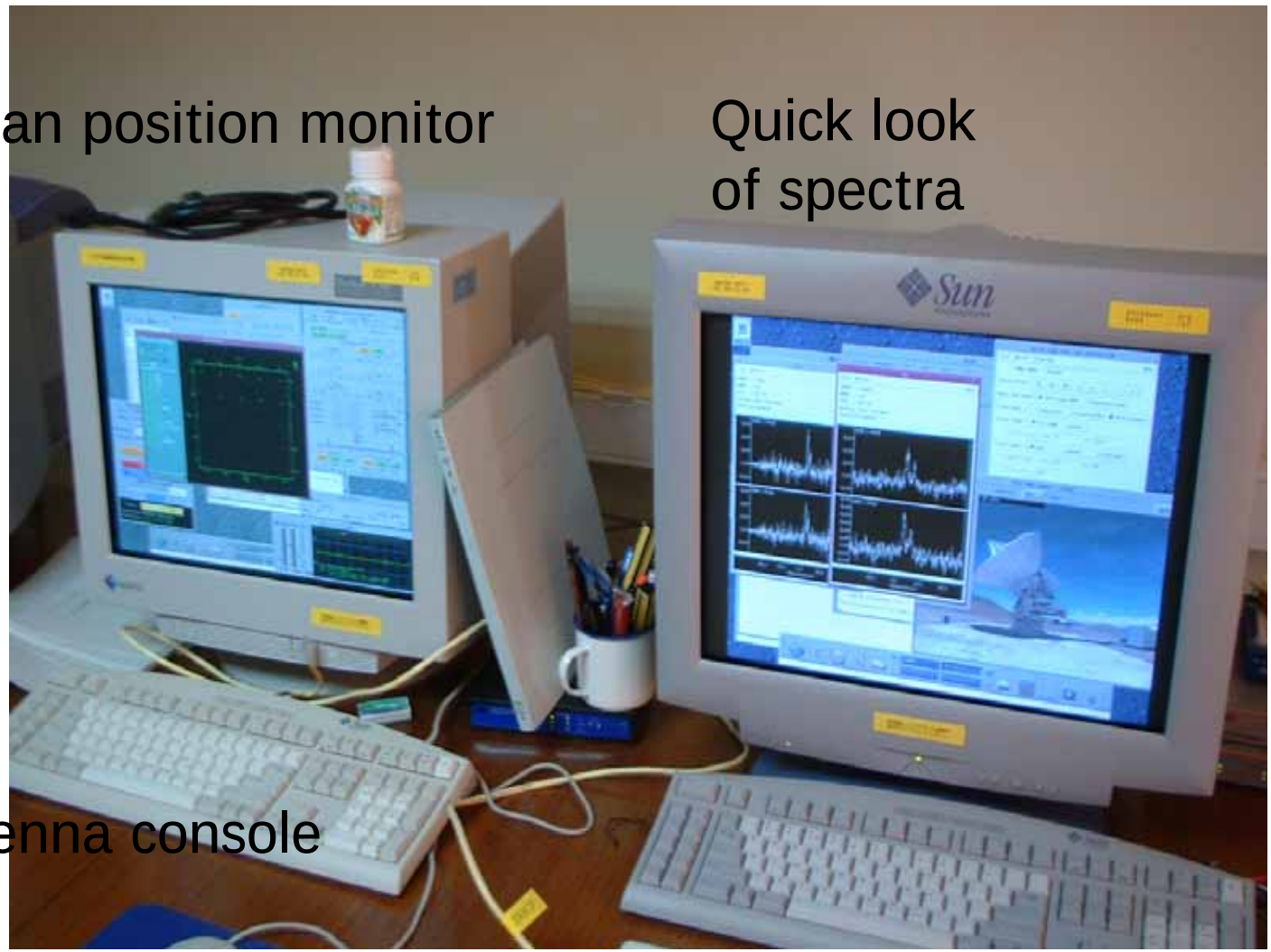
- Air conditioner
- O_2 enrichment system
- With *tatami* mat

Feel at home !

Power generators & fuel tanks

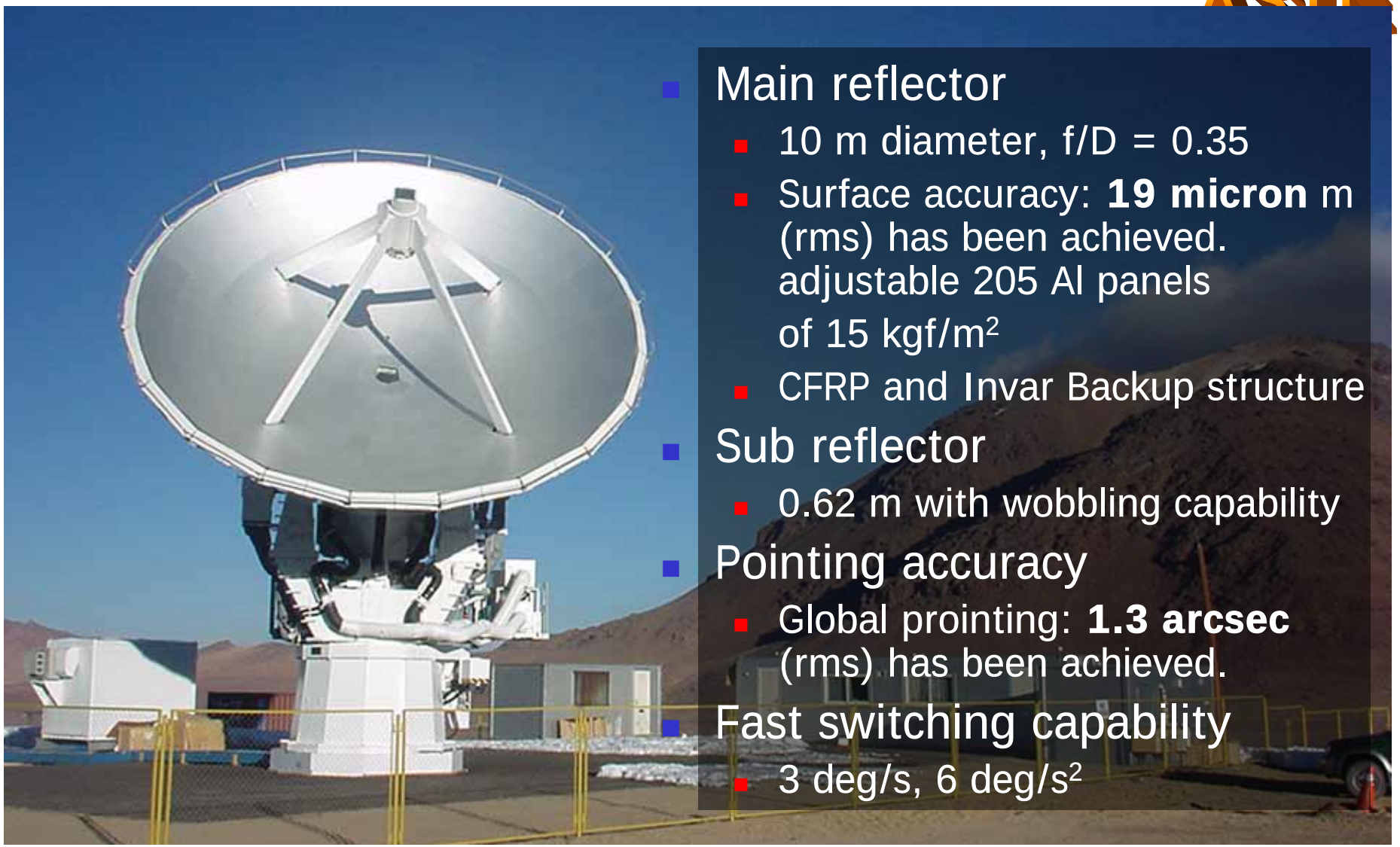
200 kW,
15000 litters
×2

Remote observations from San Pedro de Atacama



Instruments:
1. antenna

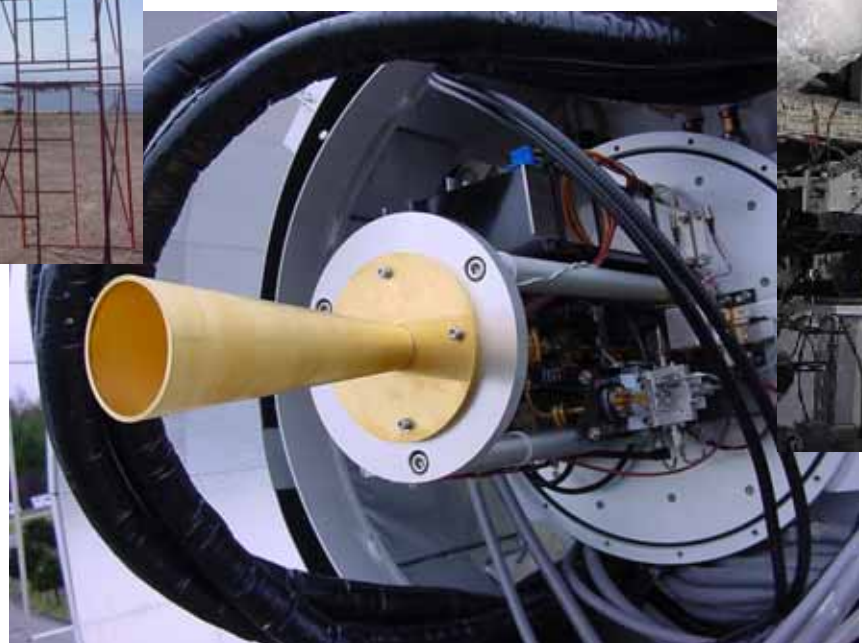
ASTE 10 m Antenna



- Main reflector
  - 10 m diameter, f/D = 0.35
  - Surface accuracy: **19 micron** m (rms) has been achieved. adjustable 205 Al panels of 15 kgf/m^2
  - CFRP and Invar Backup structure
- Sub reflector
  - 0.62 m with wobbling capability
- Pointing accuracy
  - Global pointing: **1.3 arcsec** (rms) has been achieved.
- Fast switching capability
  - 3 deg/s, 6 deg/s^2

Holography RX (95 GHz)

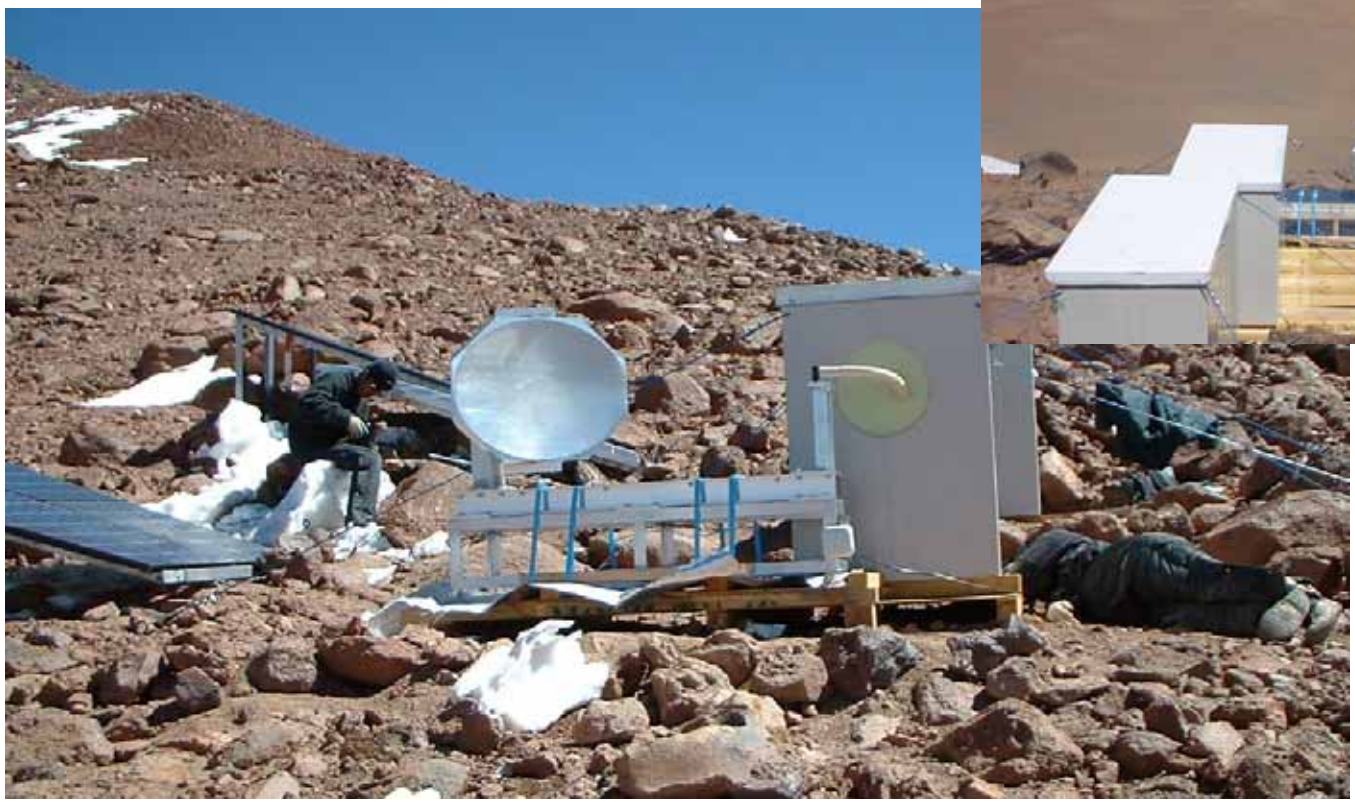
Installation of RX
(reference RX
@ subreflector)



Reference
RX at sub ref.

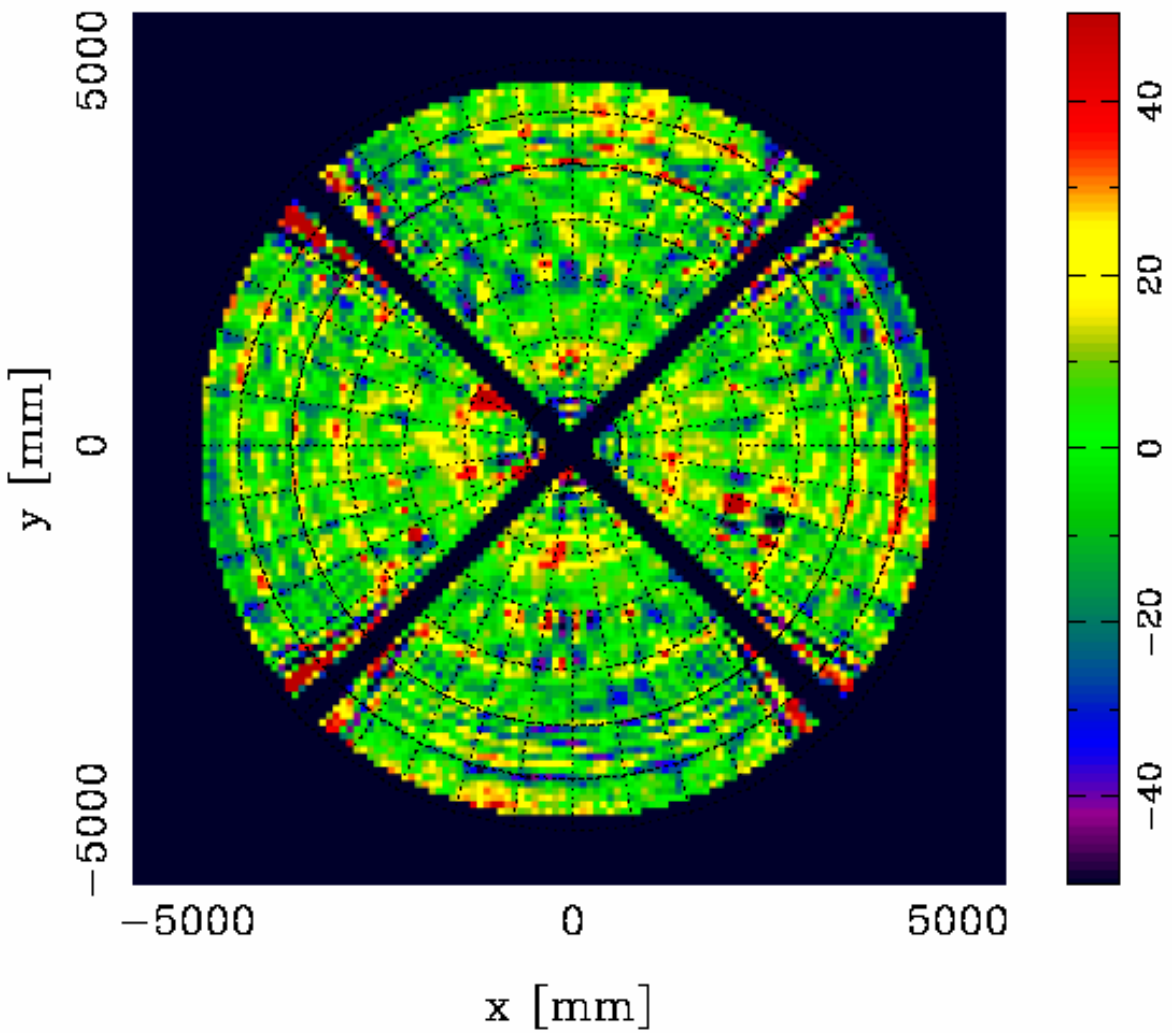
RX for
main reflector

Holog. TX site



- 5200 m, solar power, remote control of Gunn
- EL ~ 5 deg., 3.4 km between TX and ASTE

Current ASTE surface: 19 μm

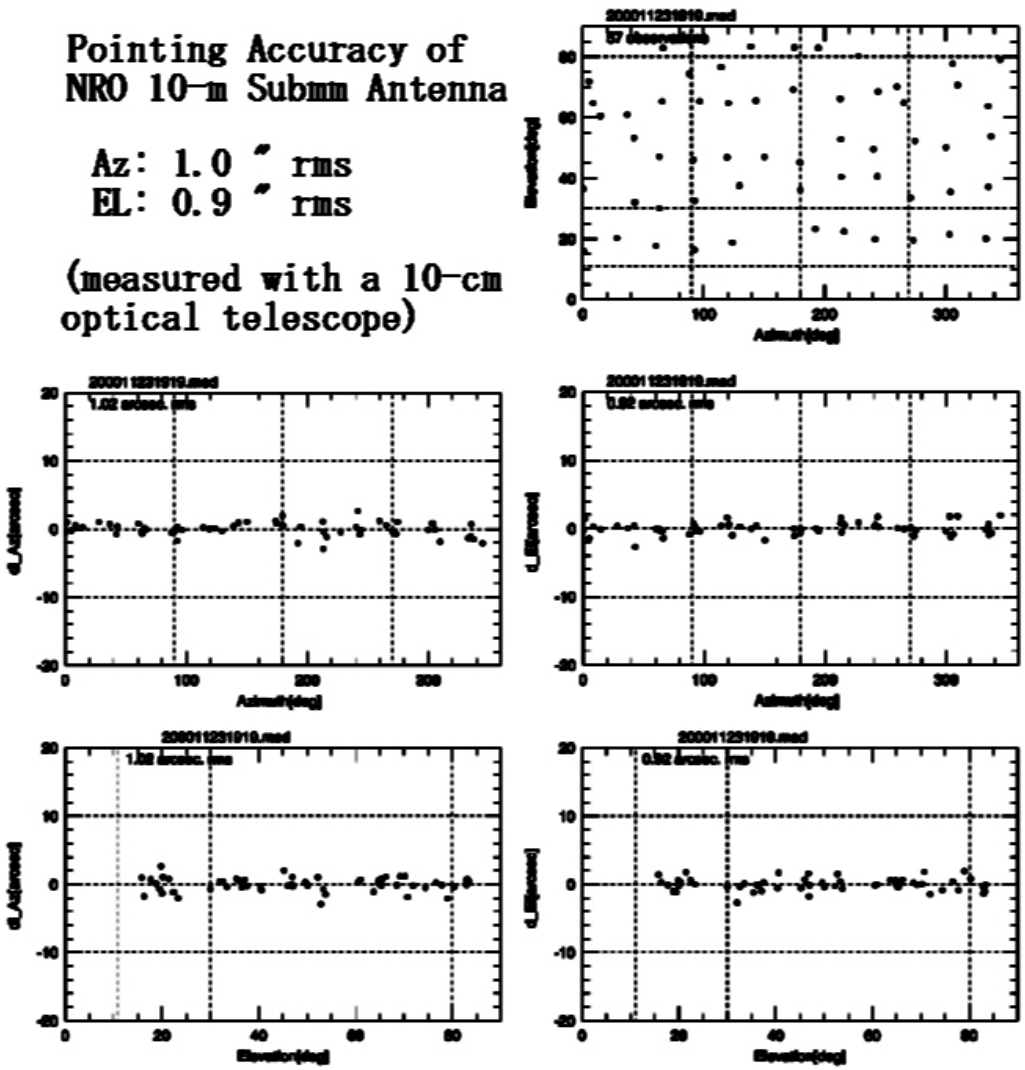


- 19 micron rms has been achieved (June 2004)

Measured efficiencies at 350 GHz: (September 2004)

- Aperture efficiency ~0.65
- Main beam efficiency~0.80

Pointing accuracy of ASTE



- ASTE Absolute pointing measured with the optical pointing telescope.
  - 1.3” rms (night time): already achieved.
  - Radio pointing is an another issue.., however.

Instruments:
2. receivers

ASTE Receivers

- Submm heterodyne receivers
  - Evaluation receivers: 100, 230, & 350 GHz
    ※ used from May 2002 to Nov. 2003
  - ALMA prototype (cartridge type) receivers:
    Engineering models of band 3 (100 GHz), band 7 (350 GHz), band 8 (490 GHz) & band 10 (810 GHz)

Already operating

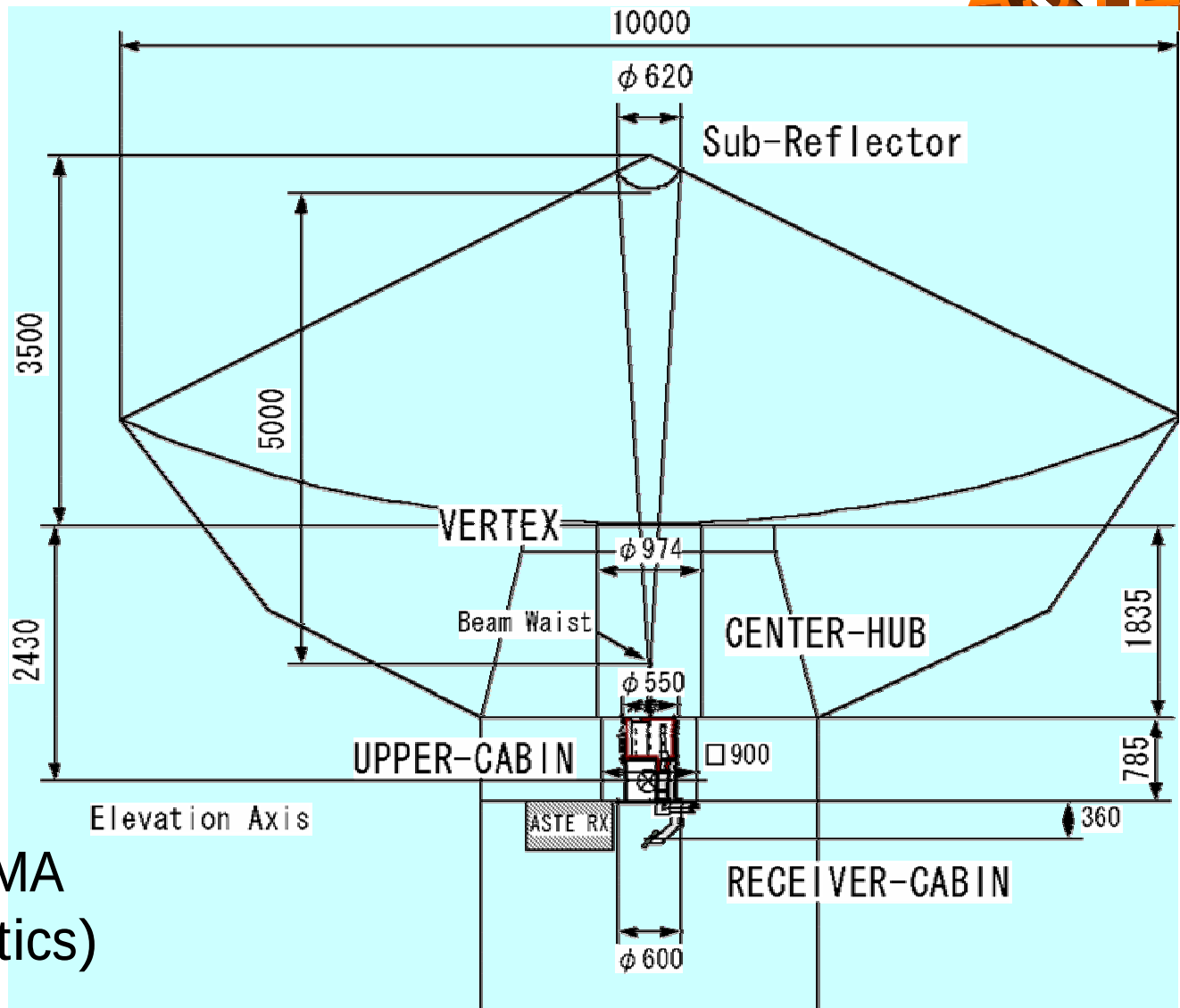
- Submm continuum sensors
  - 3 color bolometer @ 850, 450, 350 micron
  - SIS photon detector array for 850 & 460 micron

Under construction

ASTE 10m optics layout

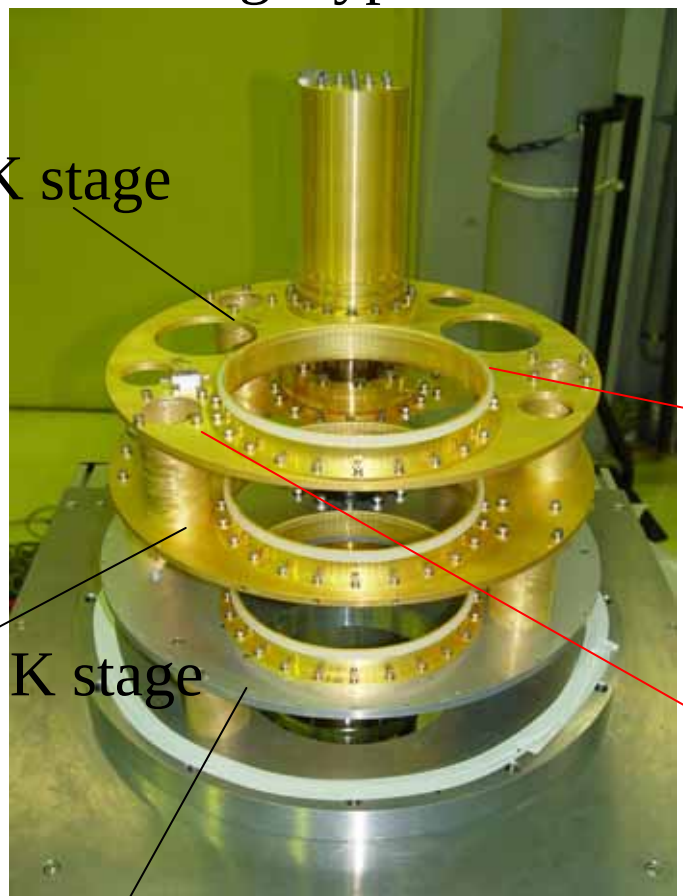
ALMA-type RX at Cassegrain focus, called “upper cabin”

Final focal length is the same as ALMA 12m (same RX optics)



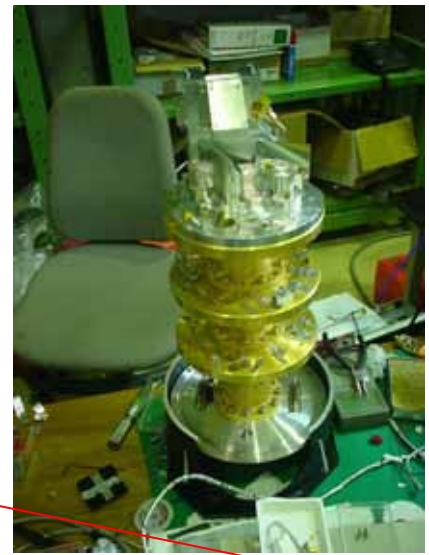
Cartridge type receiver unit

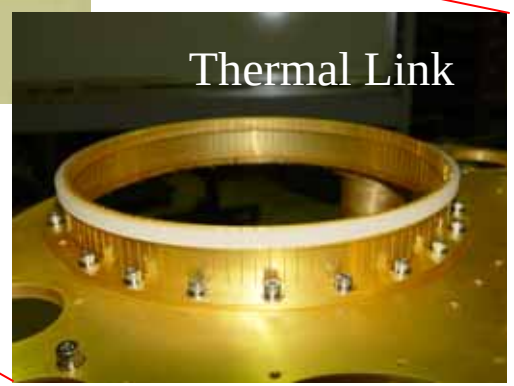
Cartridge type dewar



NAOJ-Cartridge

ALMA Band-10

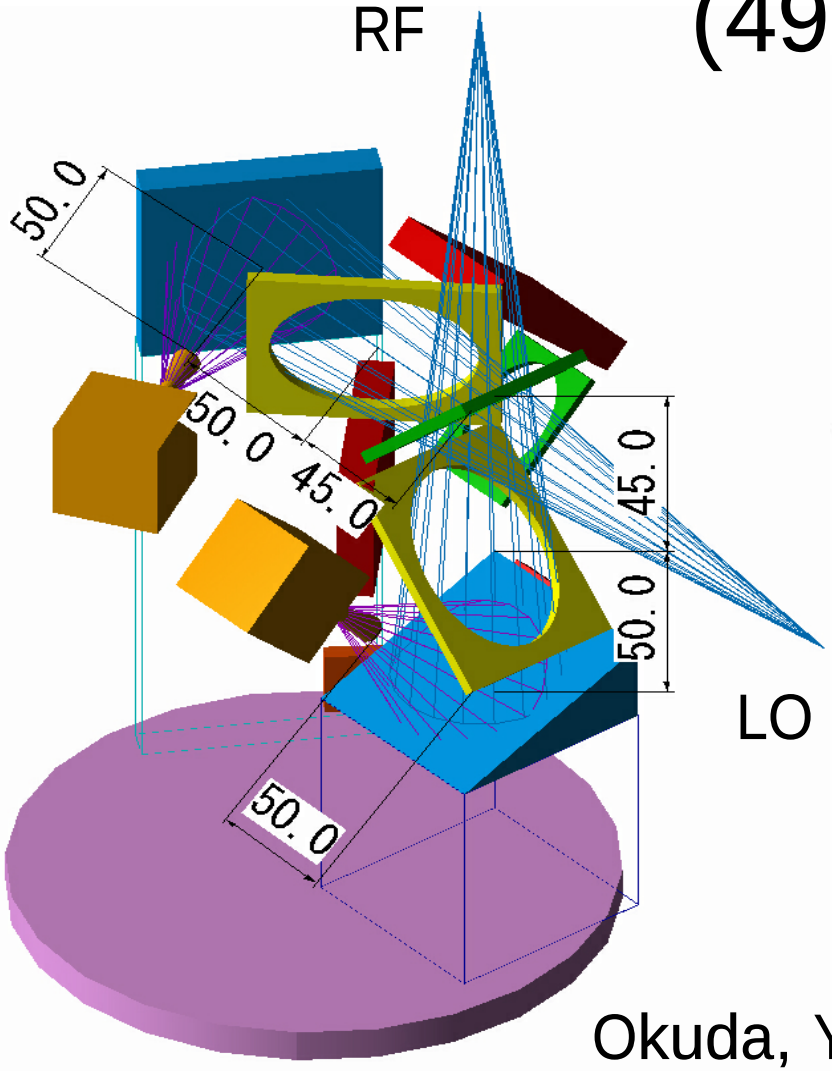


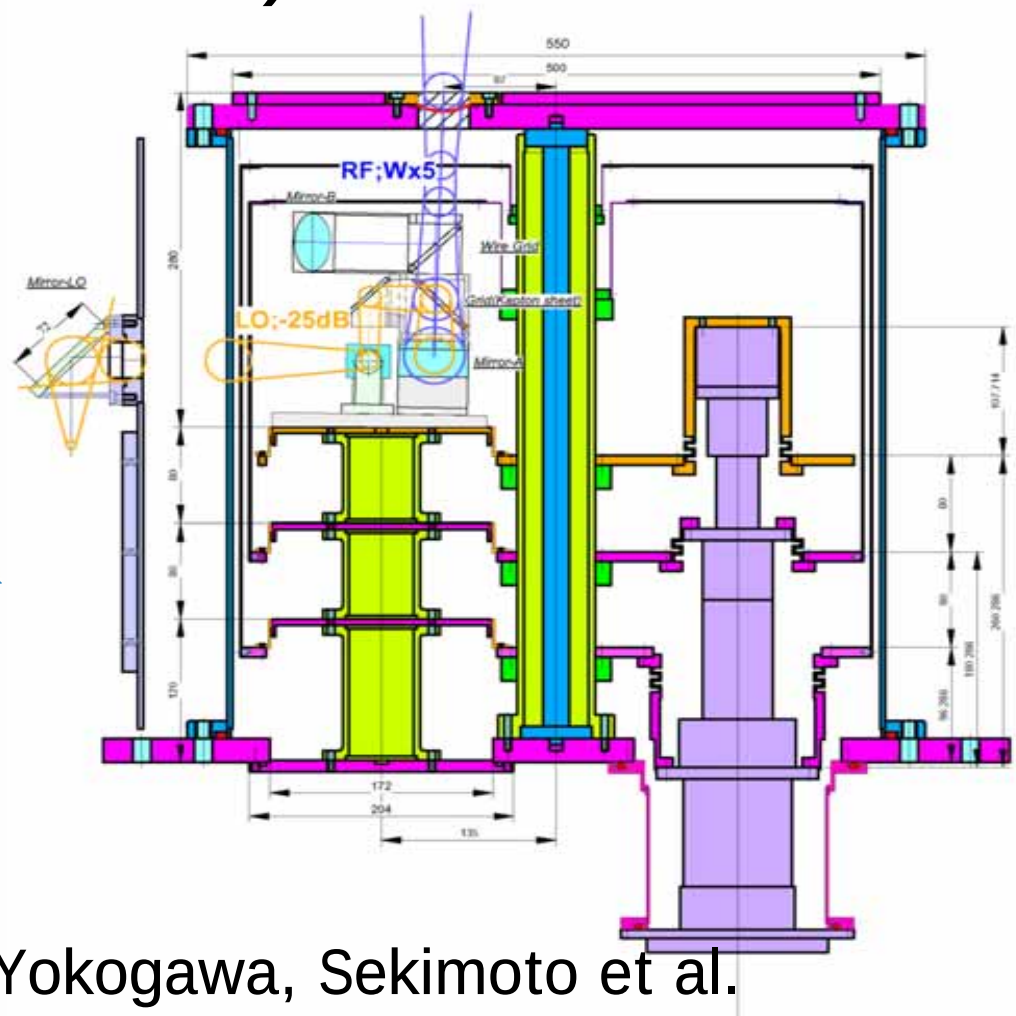


Sekimoto et al. 2003 (ALMA memo 455)

ALMA Band 8 RX optics

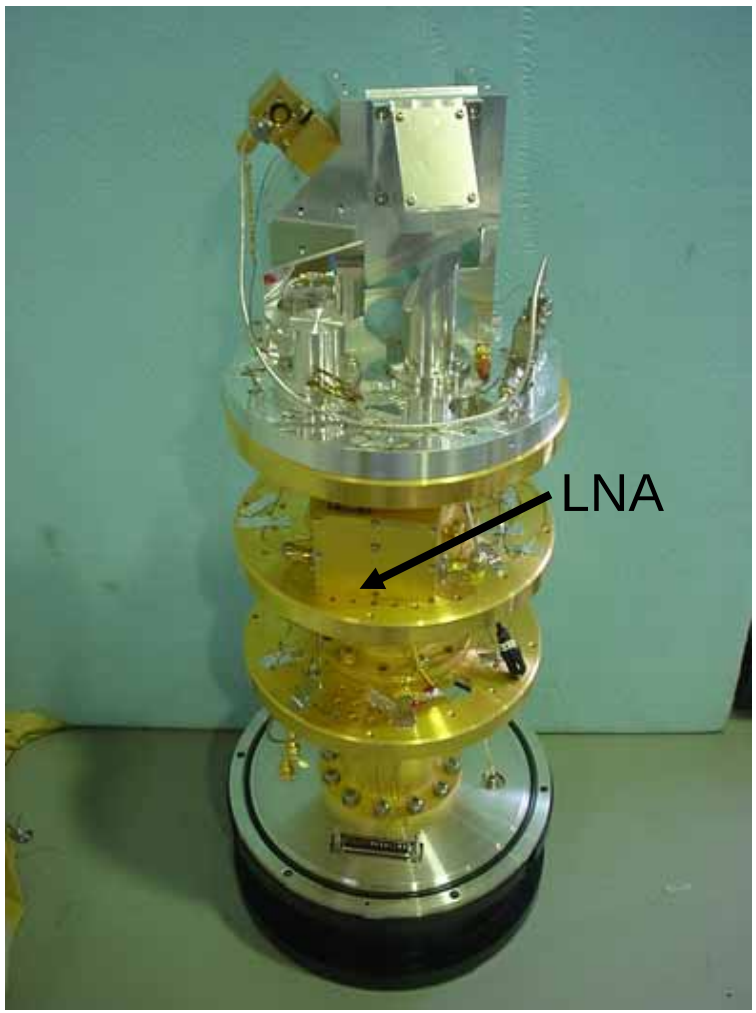
(490 GHz)



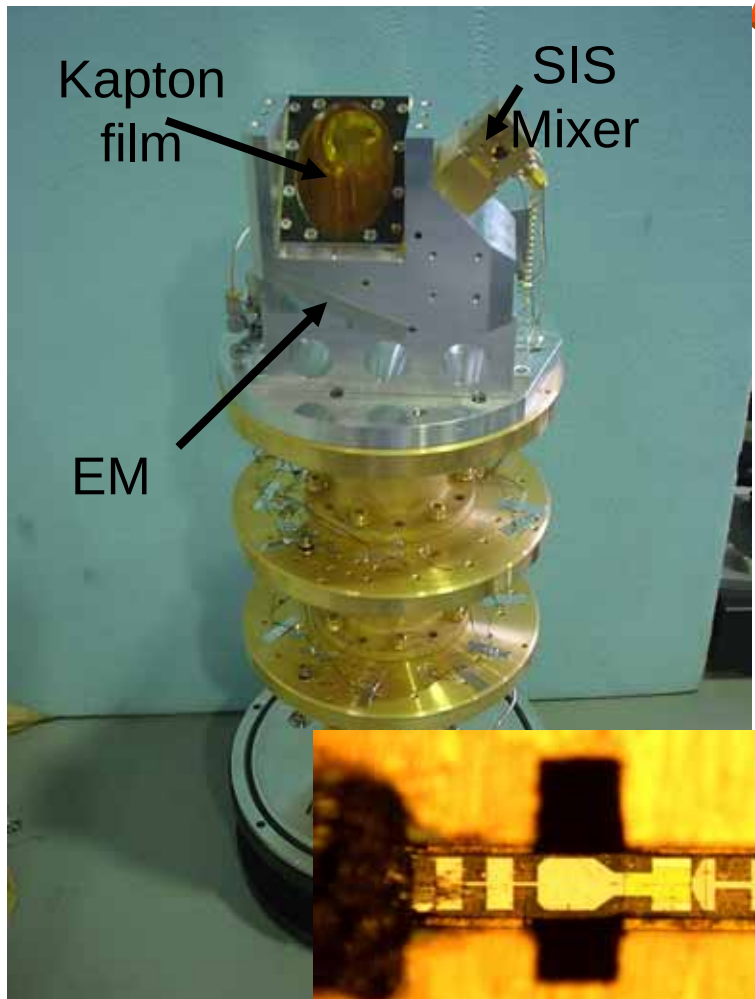


Okuda, Yokogawa, Sekimoto et al.

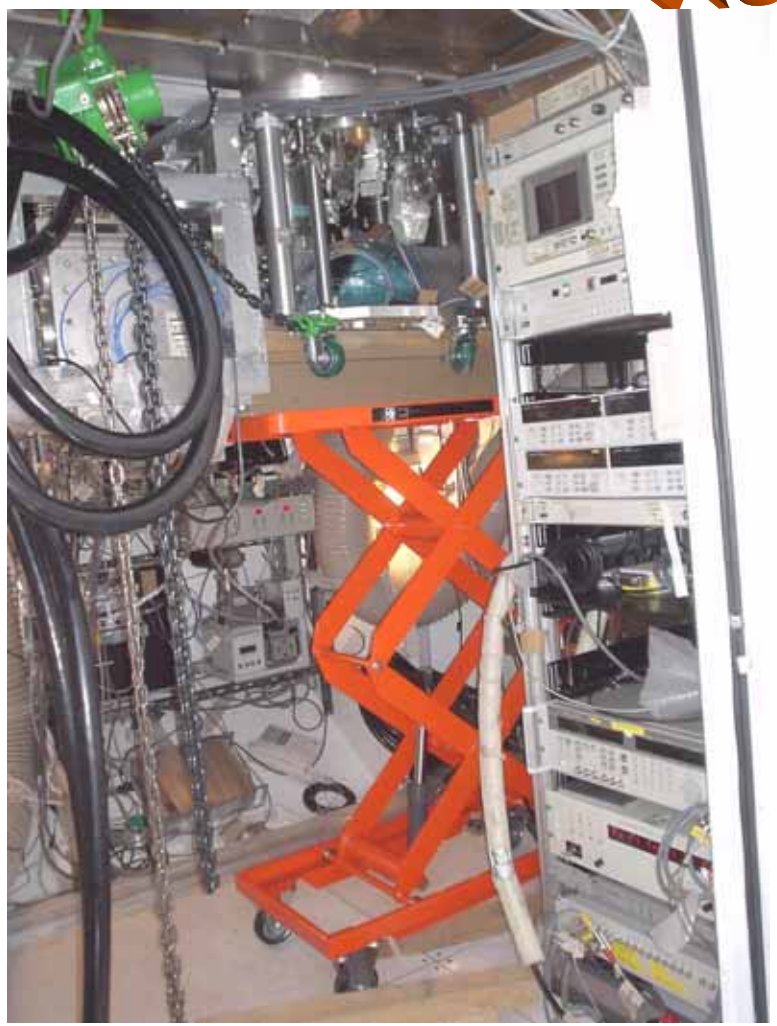
Band 8 (490 GHz) cartridge



NAOJ

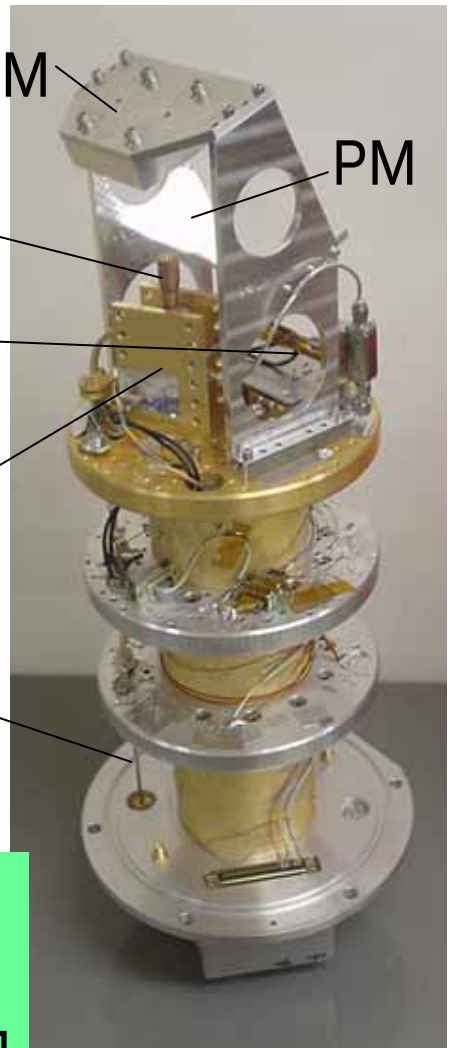


Installation of dewar



ALMA type RX attached

New 345 GHz RX (Sep. 2004 ~)



- Cartridge type
- Cool optics
- IF frequency: 4 – 8 GHz, DSB
- T(RX) ~ 90 K or 5.5 times quantum noise limit ($h\nu/k_B$)
- T(sys) < 200 K when $\tau_{220} \sim 0.03$

Univ. of Tokyo
Osaka Pref. Univ
Nagoya Univ. & NAOJ

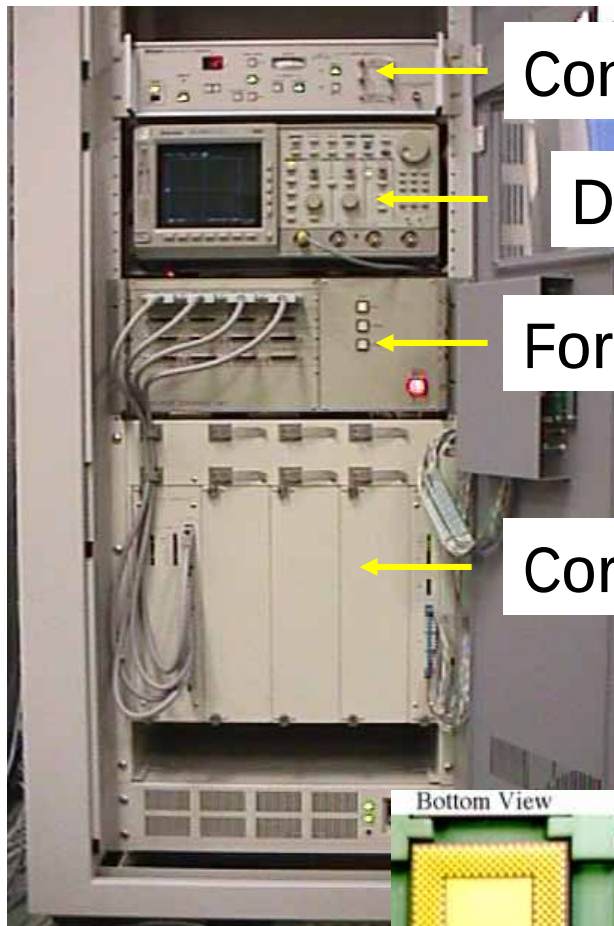
ASTE receivers performance

- ALMA Prototype Receivers
  - Band 7 (350 GHz): 2004
    T(RX) ~ 90 K (~ 5.5 hν/k) in DSB
  - Band 8 (490 GHz): 2003
    T(RX) ~ 100 K (〜4 hν/k) in DSB
  - Band10 (810 GHz): 2003
    T(RX) ~ 1200 K in DSB
  - Fabritacion of 2SB/dual pol. recievers in progress.
- Good atmosphere ⇒ good Tsys even in submm!
  - Tsys ~ 200 K (DSB) at 350 GHz
  - Tsys ~ 1000 K (DSB) at 490 GHz
  - Tsys ~ 3000 – 8000 K (DSB) at 810 GHz

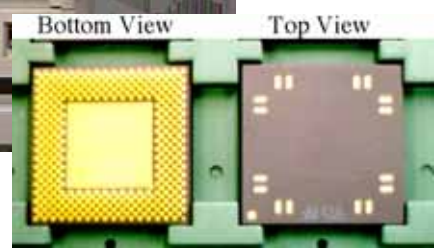
Instruments:
3. spectrometer

ASTE Spectrometer

- XF-type digital auto-correlators
  - spectral channels: 1024
  - width: 512 MHz or 32 MHz
  - frequency resolution:
    31.25 kHz (32 MHz/1024 ch)
    ~ 0.03 km/s @ 350 GHz
- 2 GHz system with 4 correlator units
  - total velocity coverage:
    740 km/s @ 810 GHz

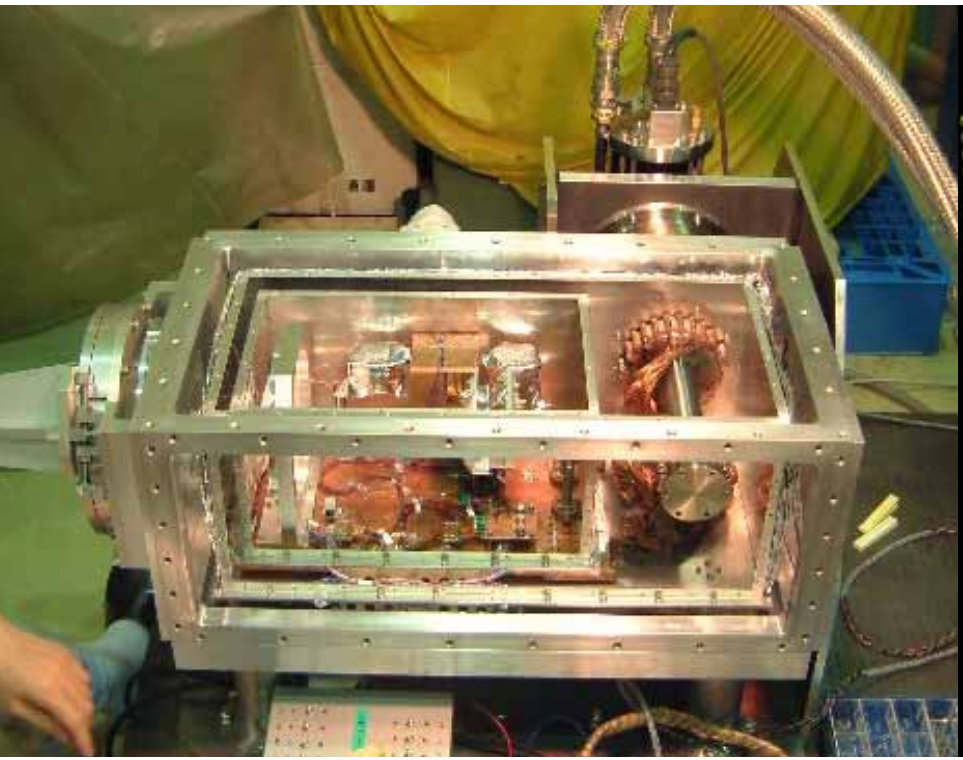


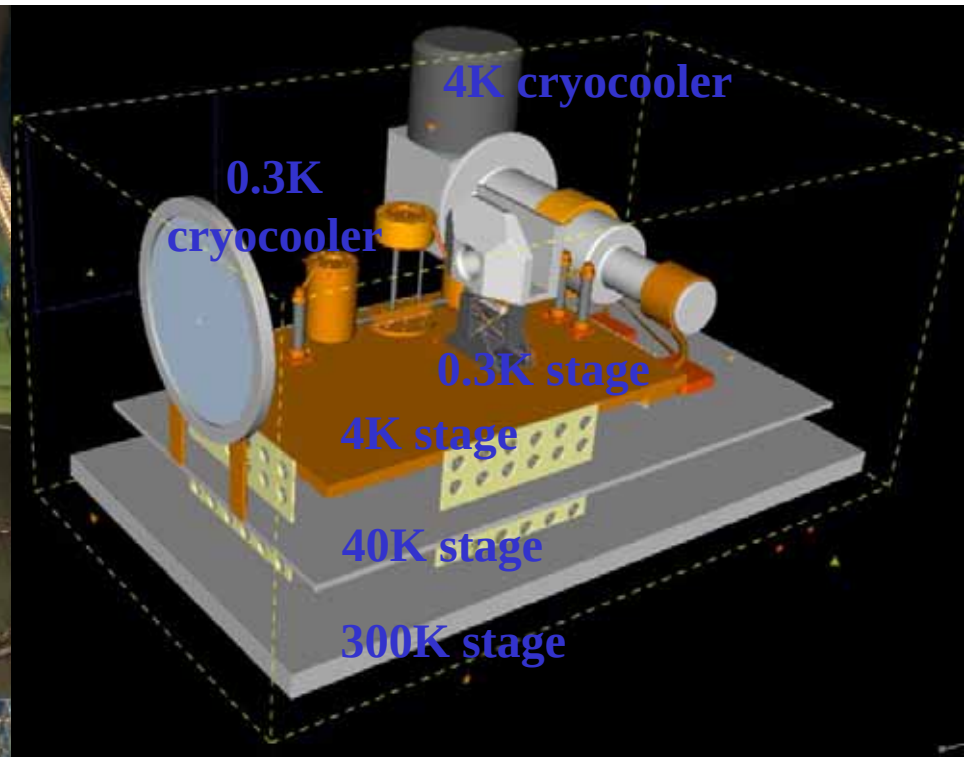
Correlator LSI



Instruments:
4. continuum observations

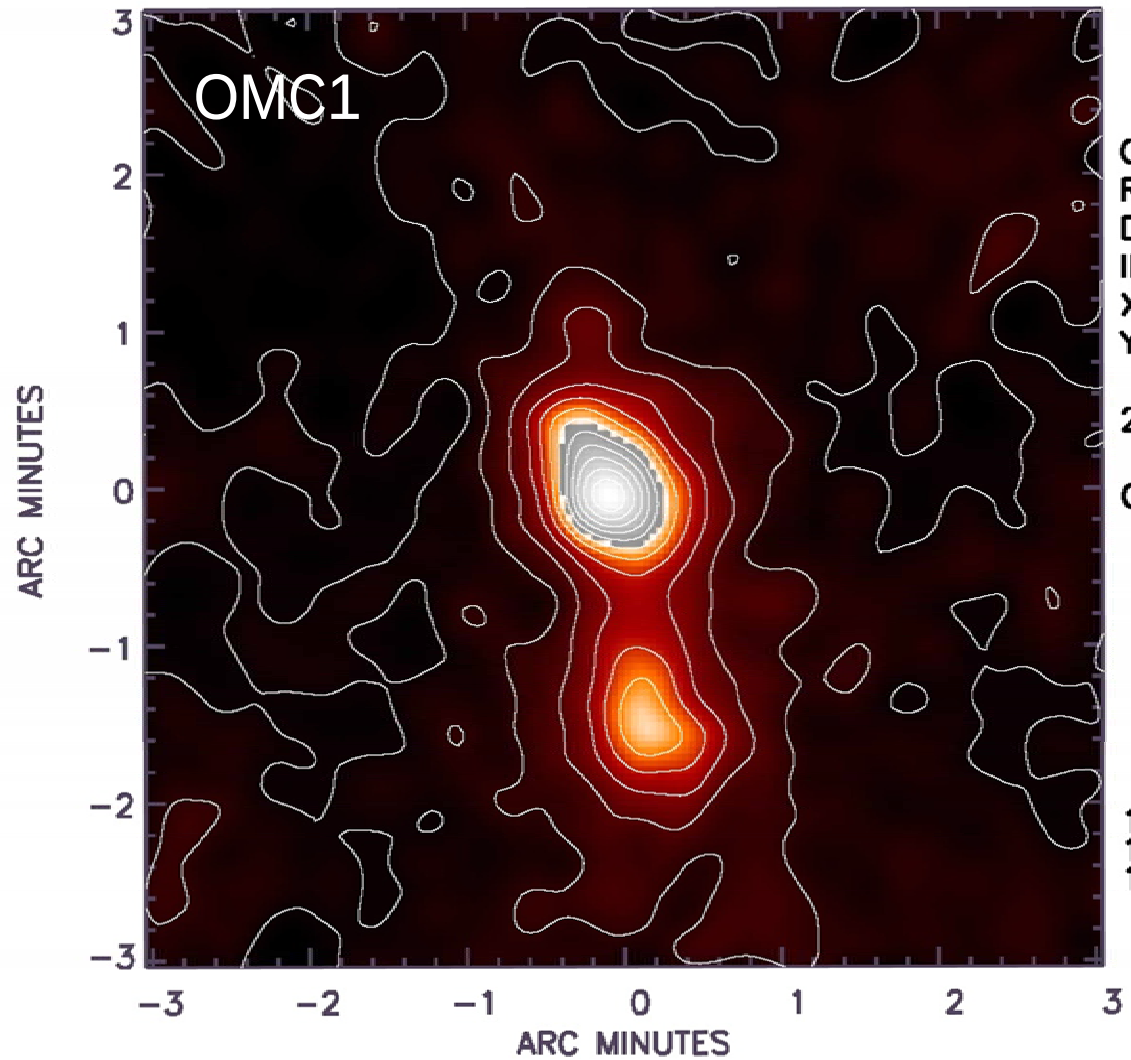
ASTE 3 color bolometer





- Low vibration mechanical 0.3 K cryocooler
- 350/650/850 GHz, single pix., remote obs.

ASTE 1st 850 μm image



OMC1

CENTER:
R.A. 00 00 0.00
DEC 00 00 0.0
IMAGE SIZE
X: 148
Y: 148

21−Mar−2004 23:54

CONTOUR LEVELS:

0:	−0.112500
1:	−0.0250000
2:	0.0625000
3:	0.150000
4:	0.237500
5:	0.325000
6:	0.412500
7:	0.500000
8:	0.587500
9:	0.675000
10:	0.762500
11:	0.850000
12:	0.937500

Matsuo, Nagata, Sekiguchi et al. 2004

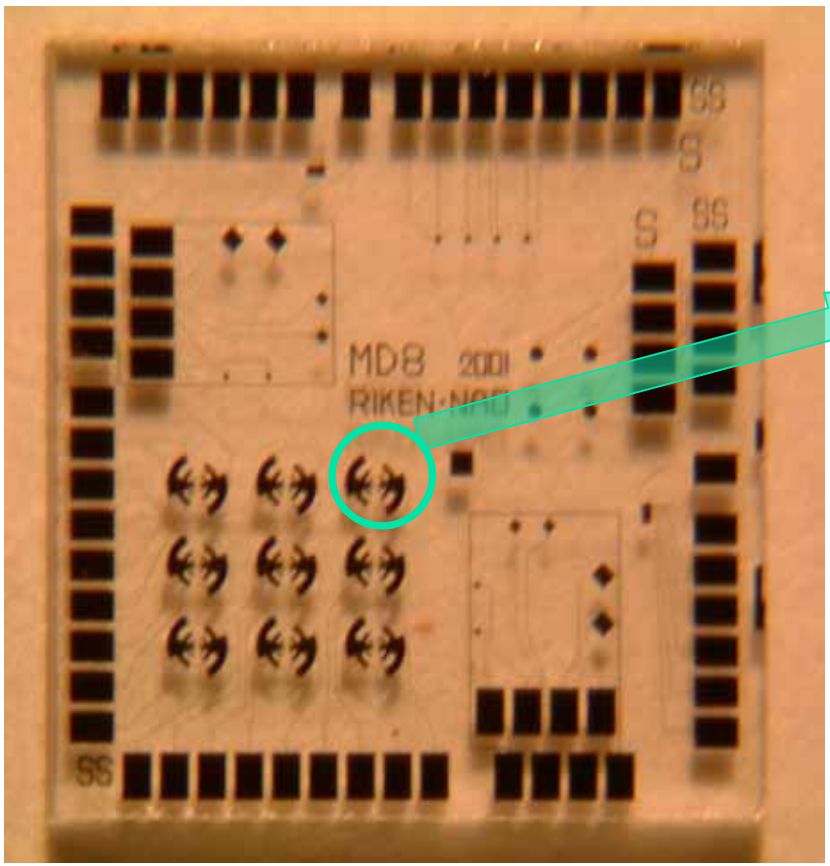
ASTE submm camera

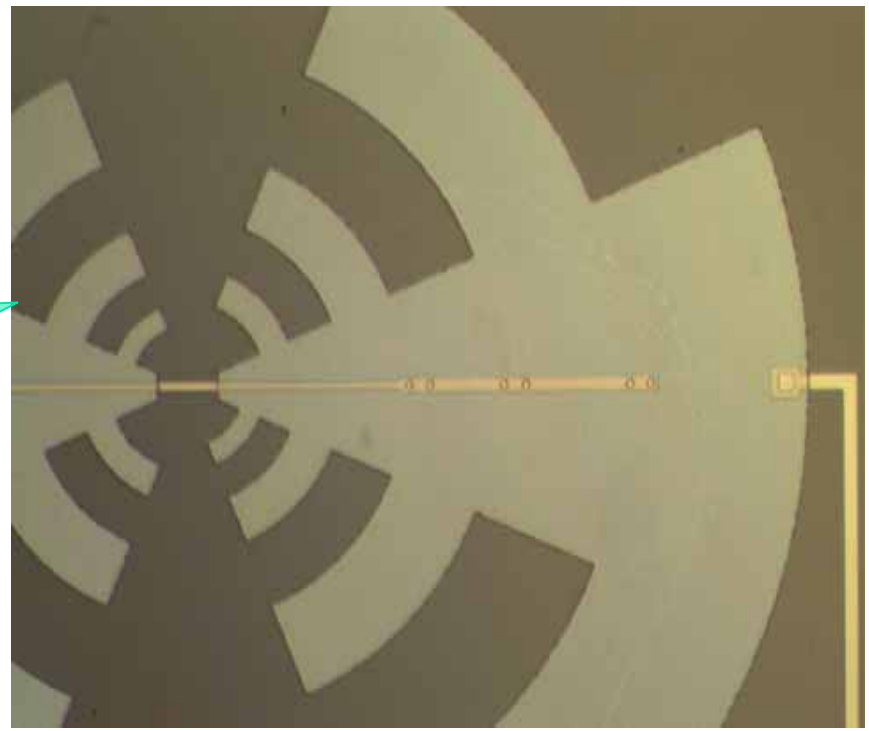
- Large format direct detector (SIS photon detector) array for 850 & 460 micron bands
- Beam size: 11 arcsec @ 460 micron
- Field of view: 10 arcmin
- NEP ~ 10^{-16} W/$\sqrt{\text{Hz}}$

Focal plane array
10x10 → 32x32

Distributed SIS junctions
with Log-periodic antenna patterns

An engineering model of photon detectors array





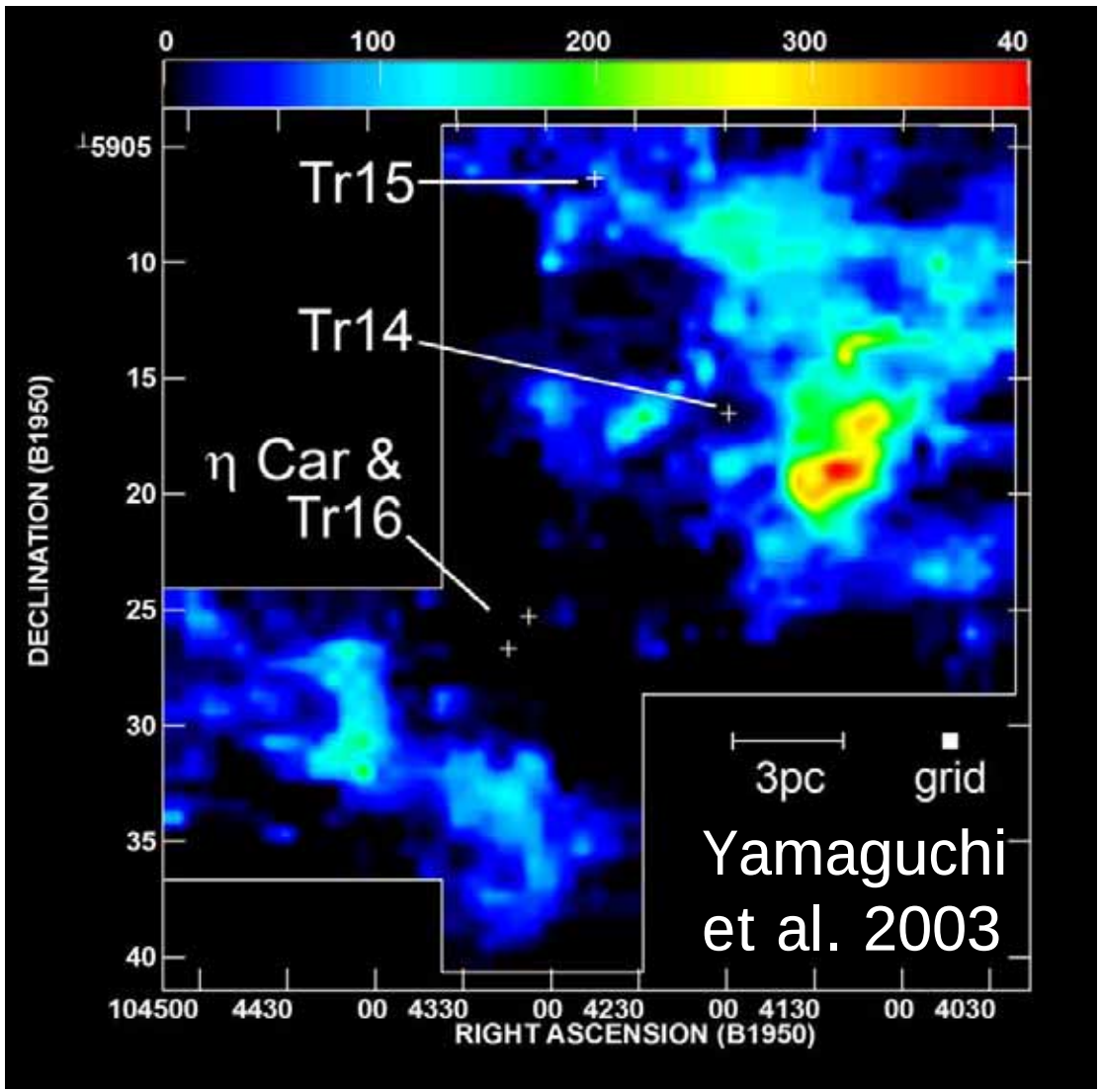
Distributed Junctions and log-periodic antenna

Early Science Program & Initial Results

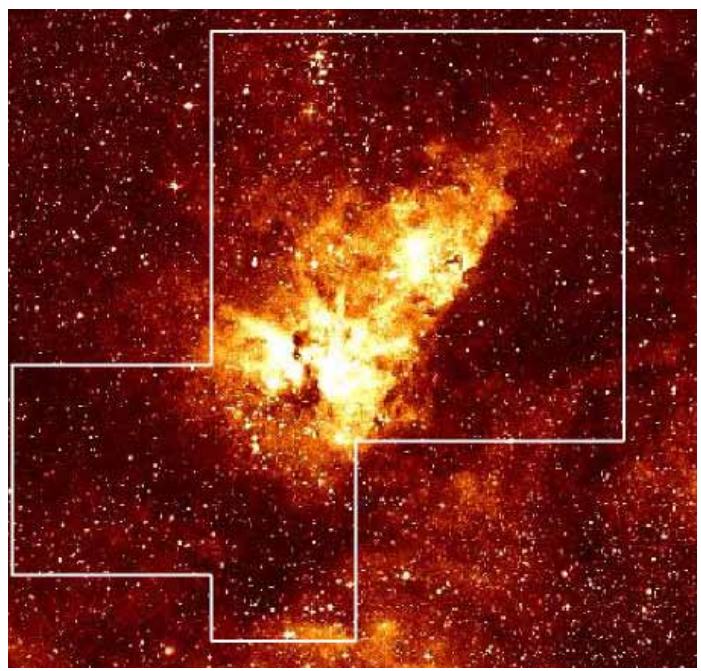
Early Science Programs

- Executable even in “initial phase” & important
- Seven Early Science Projects
  - Magellanic Clouds [Ohnishi, N. Mizuno, Hasegawa et al.]
  - Low mass star forming regions [Hayakawa、Hiramatsu, Hasegawa et al.]
  - High mass star forming regions [Yamaguchi, Sunada, Yonekura et al.]
  - The Galactic center [Oka et al.]
  - Spectral line survey [Sugimoto, Sekimoto, Hasegawa et al.]
  - Proto-planetary disks [Sekiguchi, Yokogawa, Kawabe et al.]
  - Nearby galaxies [Kohno, Nakanishi, Okuda, et al.]
- Individual programs
  - **ρ** - Oph [Kamazaki et al.]; SNRs [Tatematsu et al.], etc.

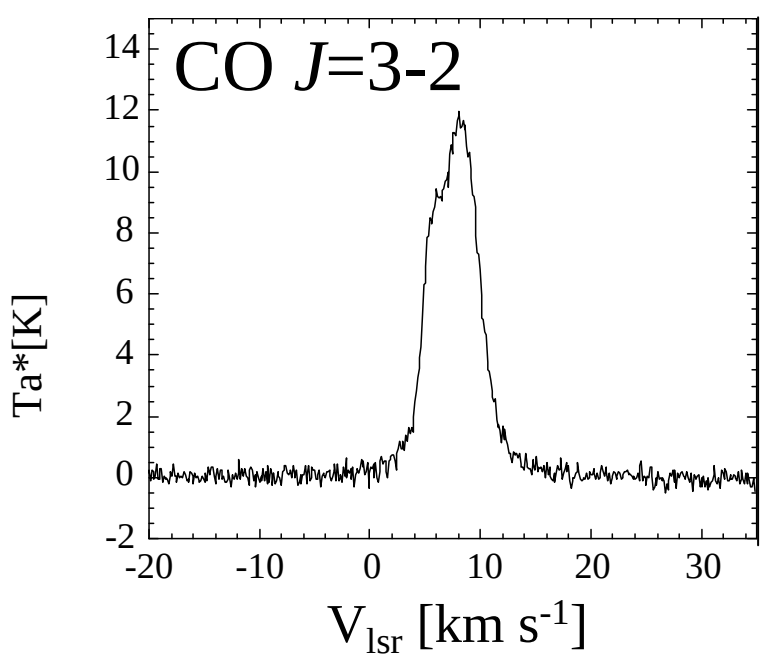
Carina nebula CO(J=3-2)

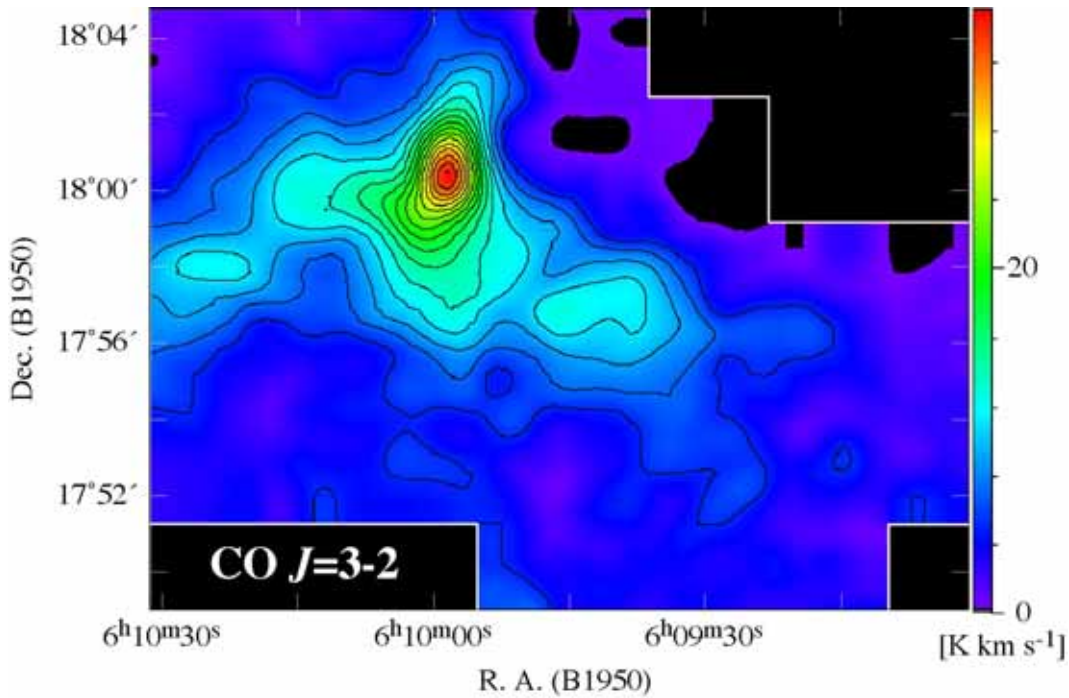


- (left) More than 3000 spectra were obtained. (bottom) Optical image of Carina nebula. Mapped area with ASTE is indicated.



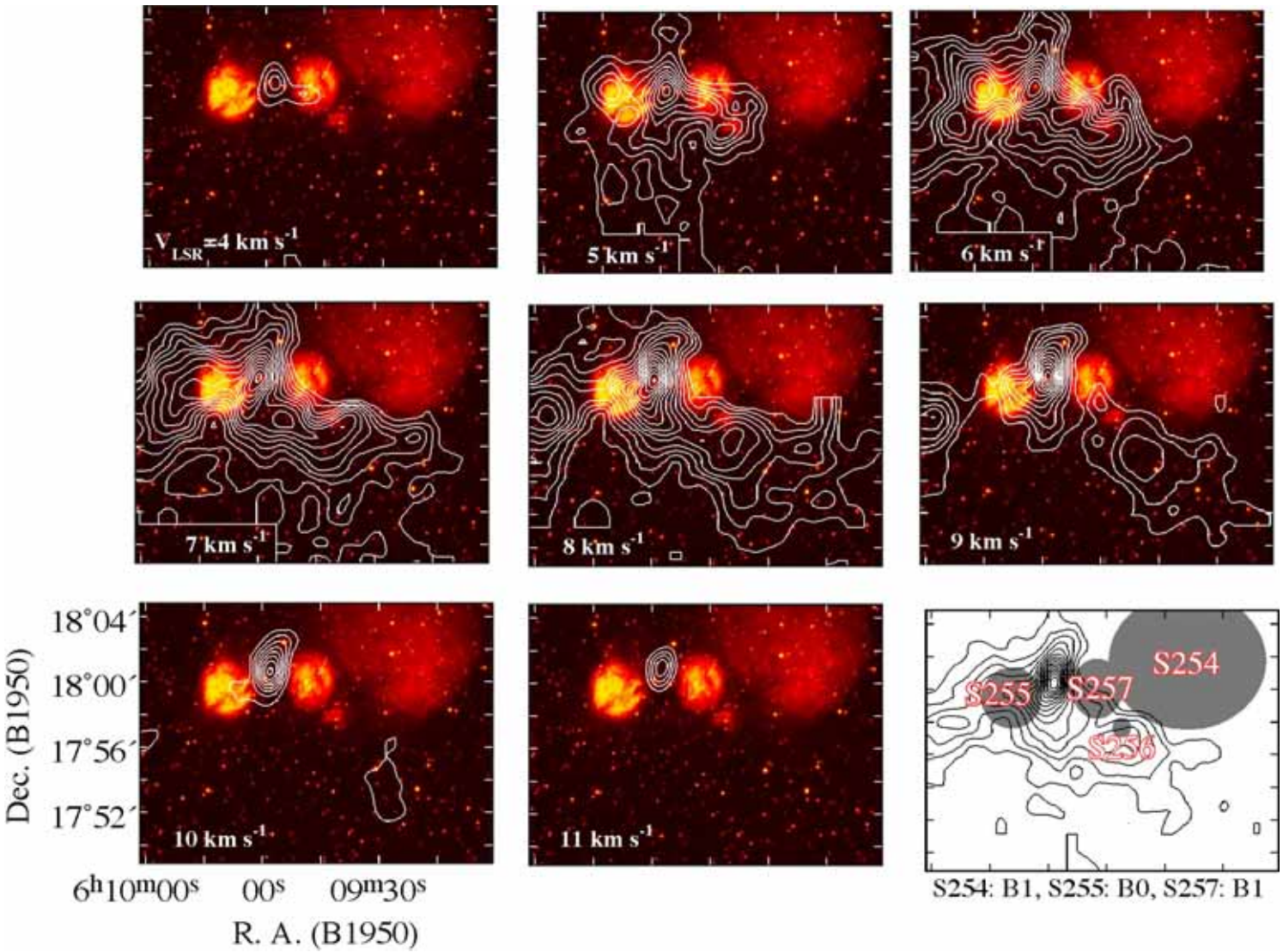
HII regions: S254-S257





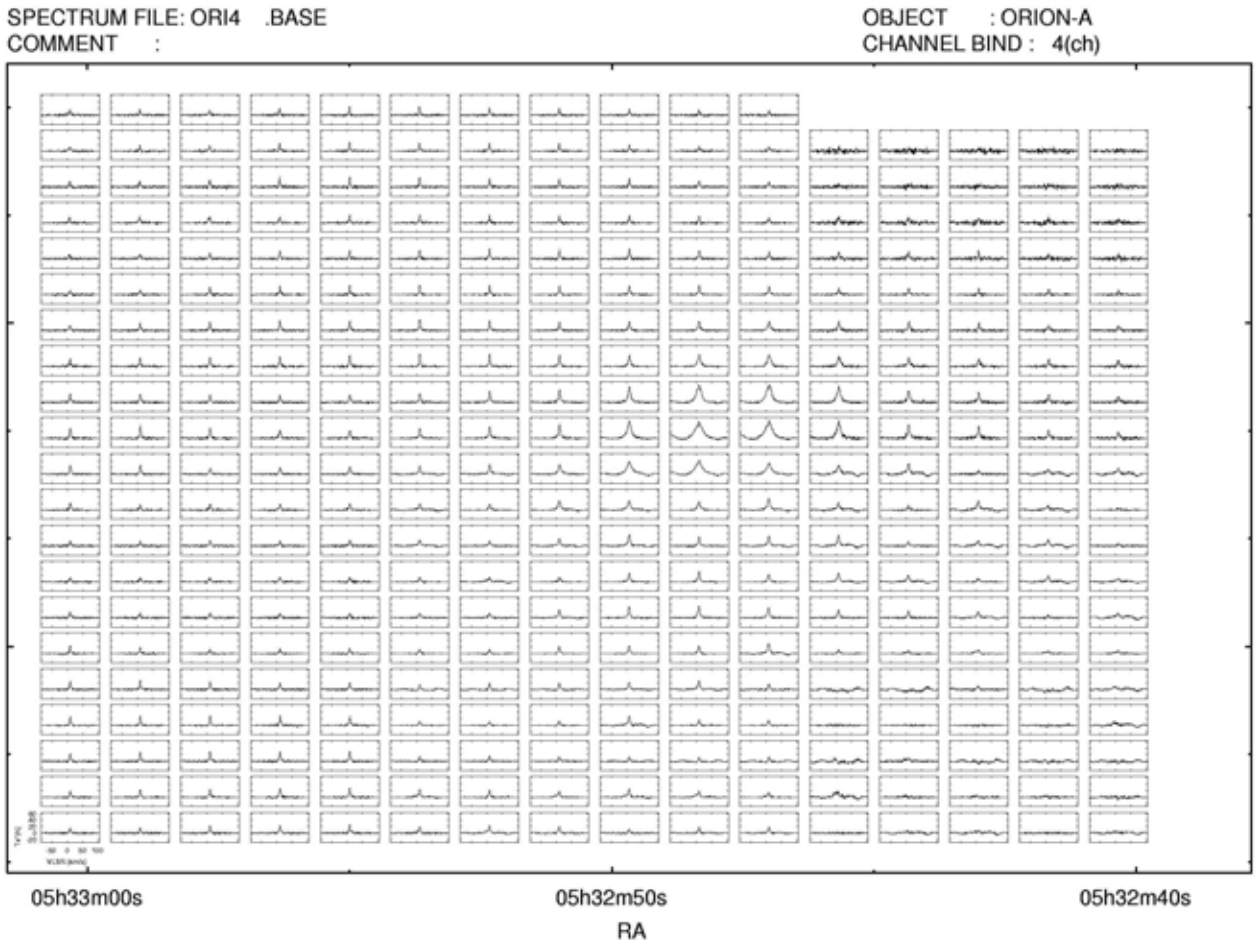
- Sakai et al. 2003 (in prep.)
- Using the 345 GHz evaluation receiver

ASTE CO(3-2) Channel maps vs HII regions



1st CO(J=7-6) map w/ ASTE

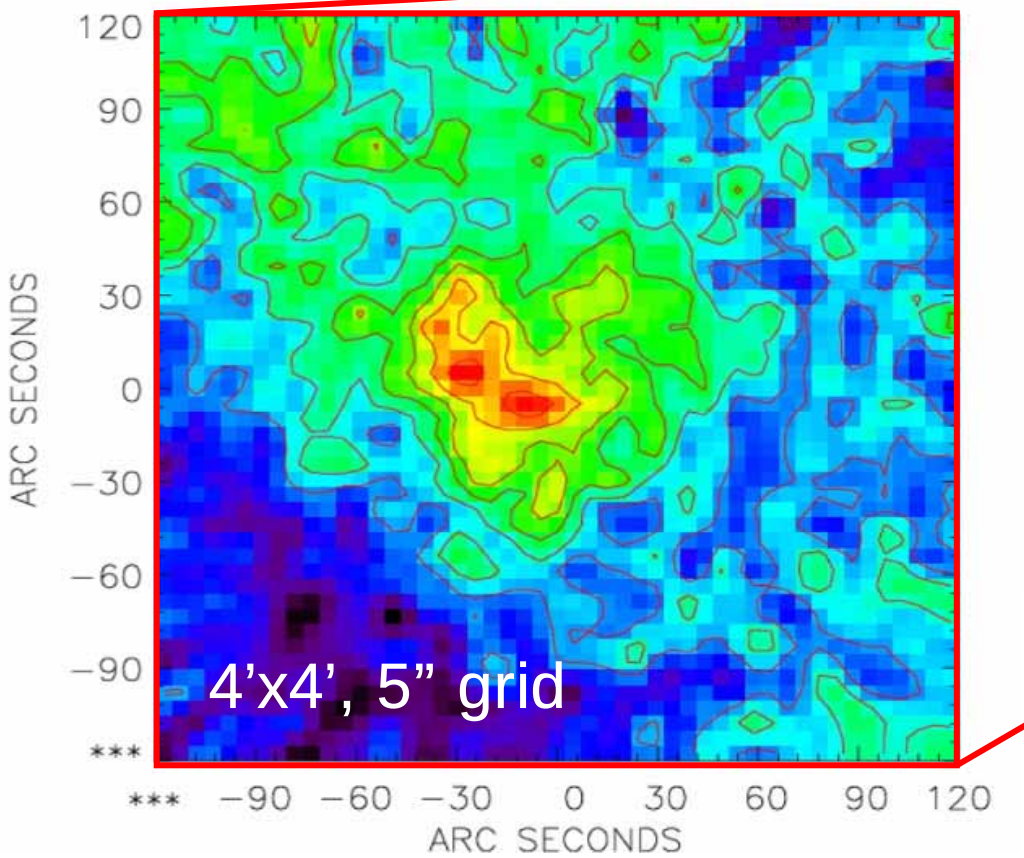
- **Wide field CO(7-6) mapping can be done very easily thanks to low noise SIS RX and excellent atmosphere**
- **16 x 21 pts, 10” grid, 10 – 30 sec integration per pts**
- **Tsys ～ 3000 - 6000 K (DSB) at EL ~ 60 deg !!!**

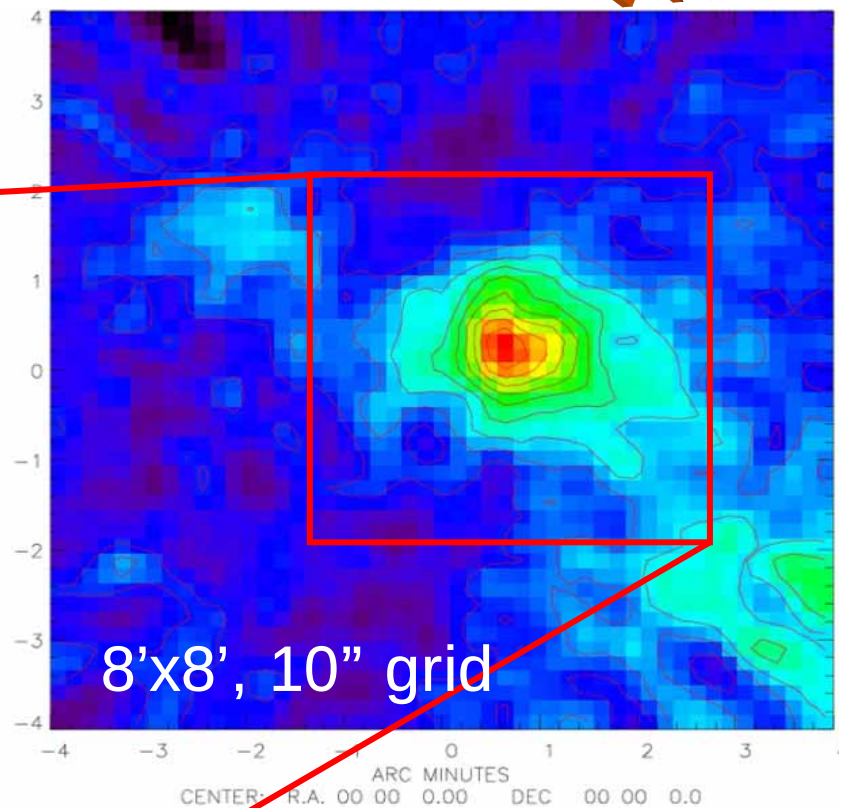


Sugimoto et al. 2003

Massive star forming regions

- NGC 3576; Southern star forming region

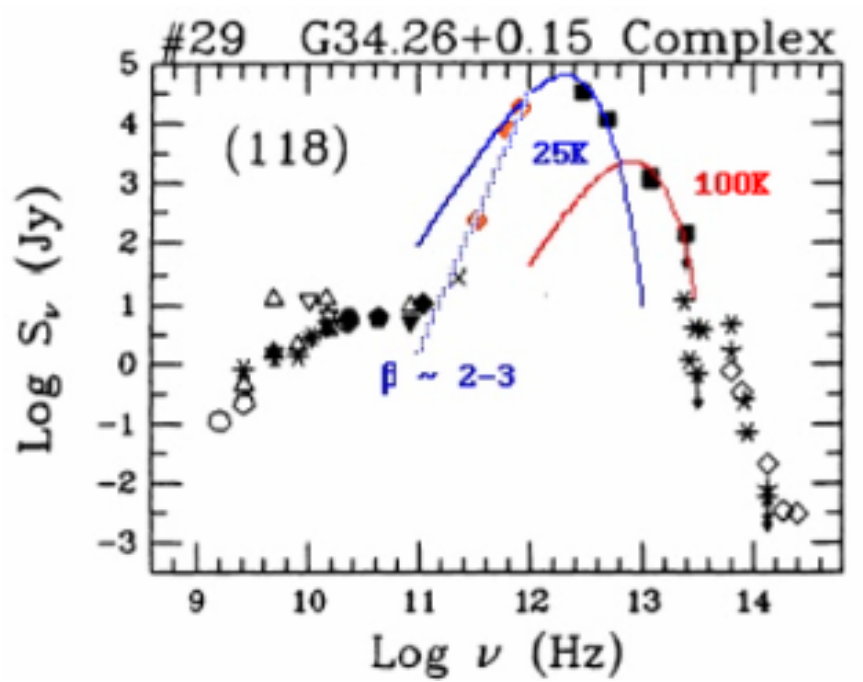


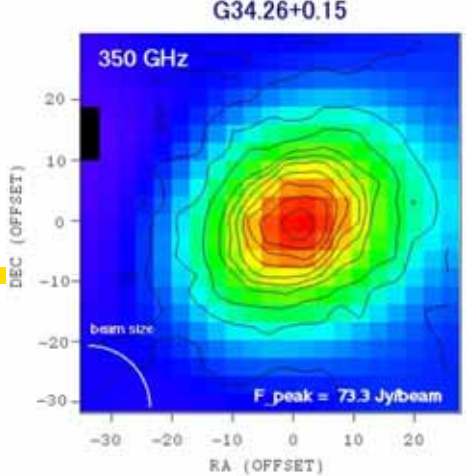


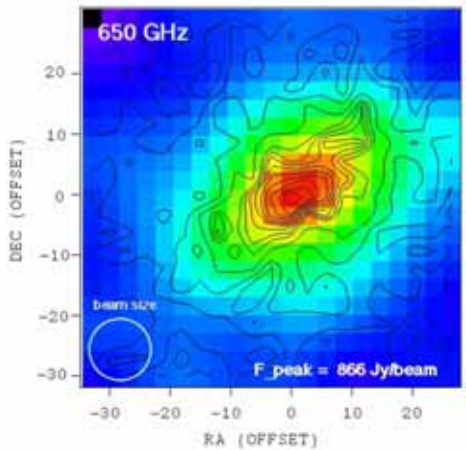
3 color bolometer
850 micron band
Kobayashi et al. 2004

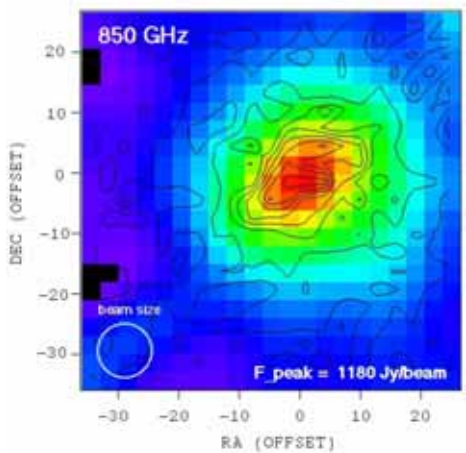
UCHII regions

- G34.26+0.15
- Submm SED at 3 frequencies was obtained.









1'x1'

3 color bolometer

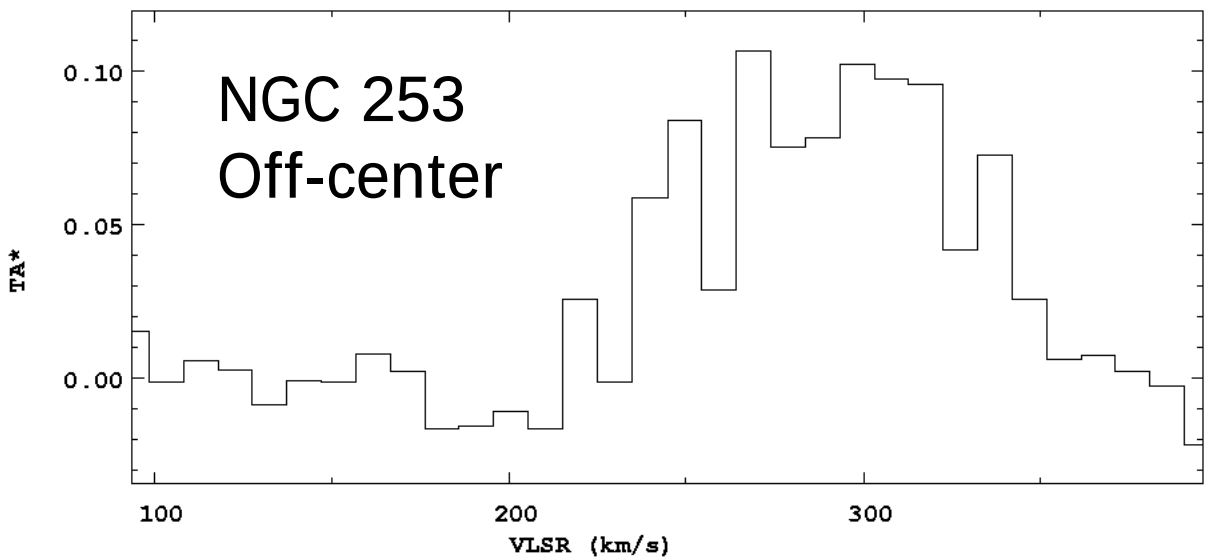
Takahashi et al. 2004

Extragalactic CI (1-0)

```
N253_55      NGC253                    N253M-A1.SMTHG
Comments
Spectrum-id = 00007 (            )     :  DATE(M D Y) = 08 24 03
Ref. coordinate = RA,DEC               :  P.A. =  51.000d
X offset = -00d00'11.7"                :  RA (1950) = +00h45m04.8s      :  l =  97.242D
Y offset = -00d00'09.4"                :  DEC(1950) = -25d33'49.9"      :  b = -87.965D
Center freq. = 492.160651(GHz)         :  AOS-A1
r.m.s. =   0.0054(K)                   :  Integ time = 00h13m40s
Baseline order = 02                    :  Scaling factor =  1.00

no.   peak T                x of peak                  half width                integ. int.
```

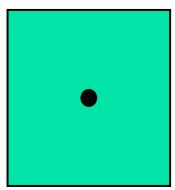
- Improvement of overall system performance is still required.



Nearby active galaxies in the Southern sky

CentaurusA
Radio galaxy

~ 10 arcmin



15”

ASTE beam @ 460 GHz

~ 8 arcmin

Summary

- The Atacama Submm Telescope Experiment (ASTE):
  - a joint project between Japan and Chile
  - to install and operate a 10 m high precision telescope
  - for exploration of the Southern sky through the submm.
- Technical achievements:
  - Main reflector surface accuracy of ~ 19 micron rms
  - Main beam efficiency of ~ 80 % at 350 GHz
  - System noise temperature of ~ 200 K at 350 GHz
- Commissioning phase is mostly finished:
  - CO(3-2) and CO(7-6) maps of star forming regions
  - Extragalactic CI(1-0) detections at 490 GHz
  - 850, 650, and 350 micron continuum maps of HII regions
  - ASTE will be in a fruitful phase soon !