(Sub)mm-wave galactic astronomy in Chile: an historical perspective

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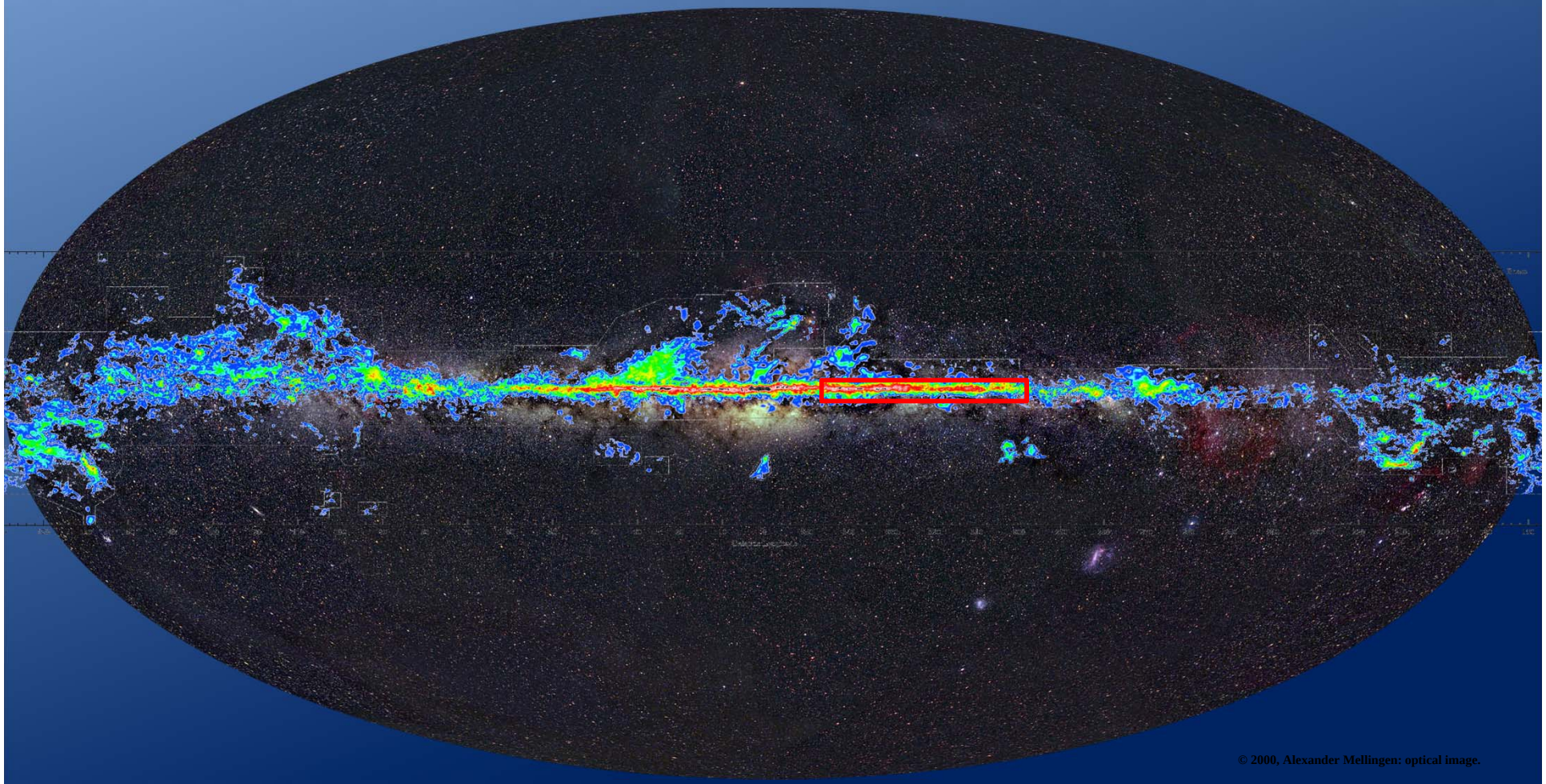
30 September 2015

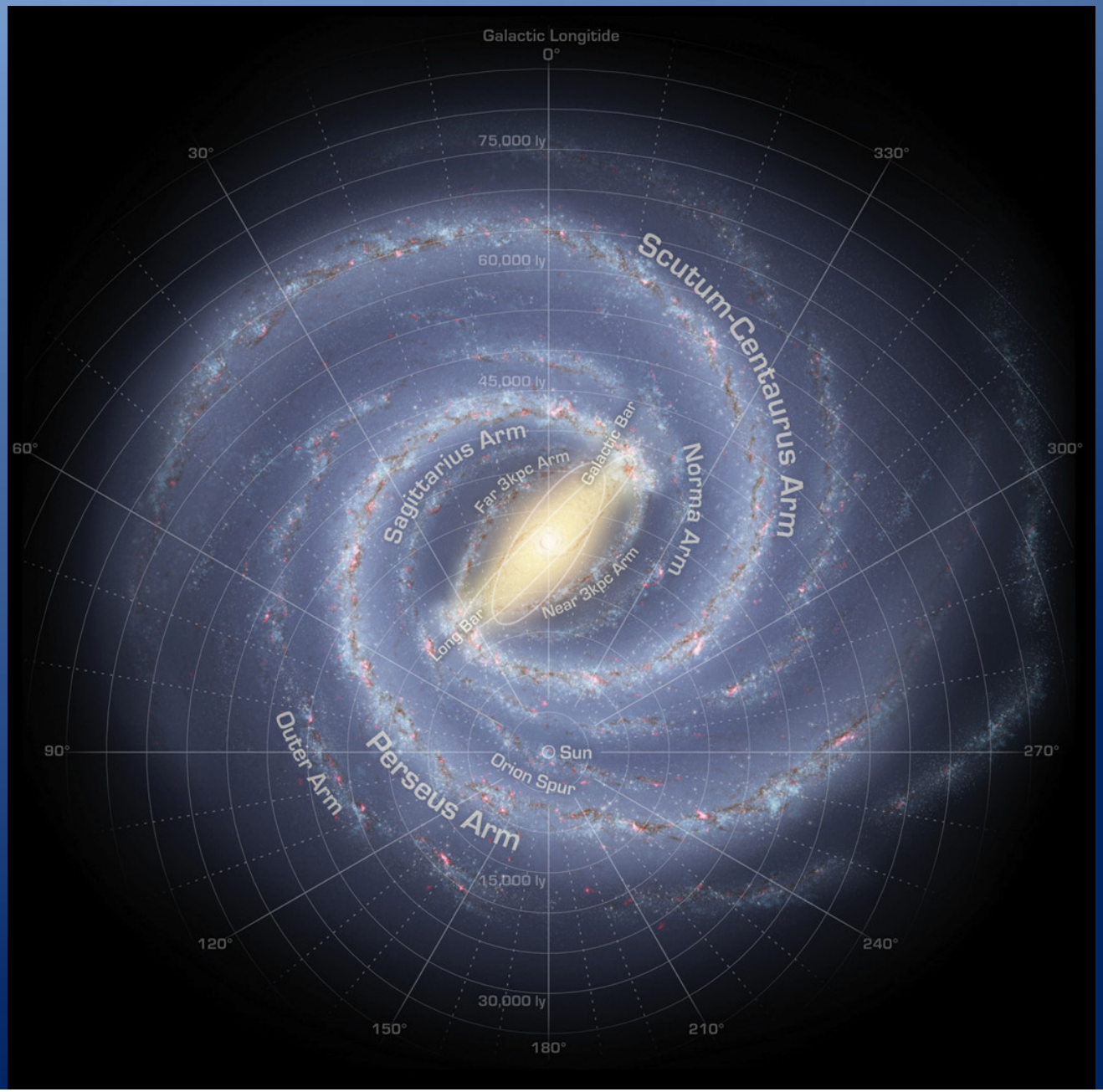
Giant Molecular Clouds and Massive Star Formation in the Southern Milky Way



Barnard's dilemma (1900)
Holes in the heavens or obscuring matter?

Face-on sketch view of the Galaxy obtained from optical, infrared, and mm data

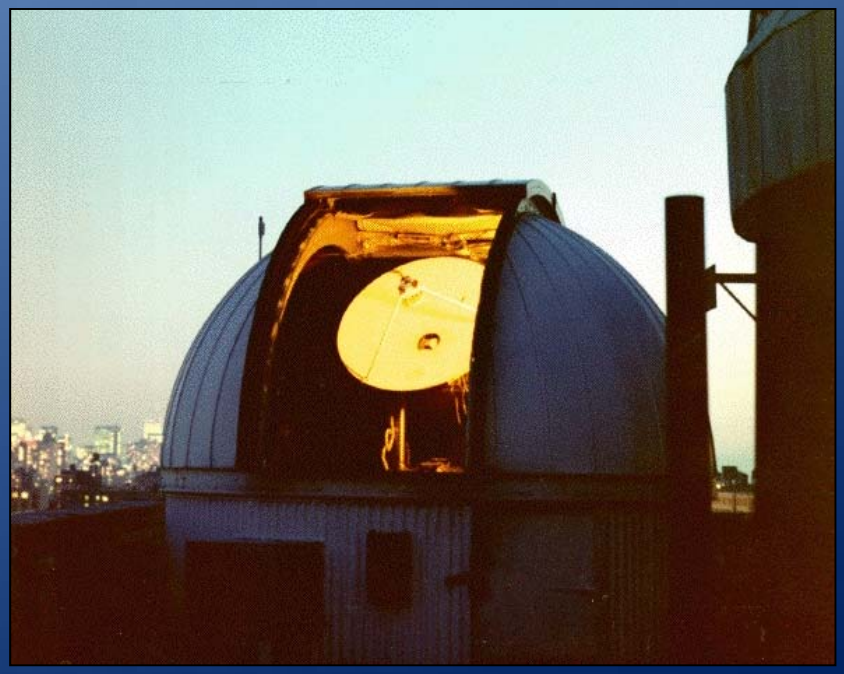
(Churchwell et al. 2009)



1.2m mm-wave Telescopes: Molecular Clouds in the Milky Way

(P. Thaddeus, Columbia University)

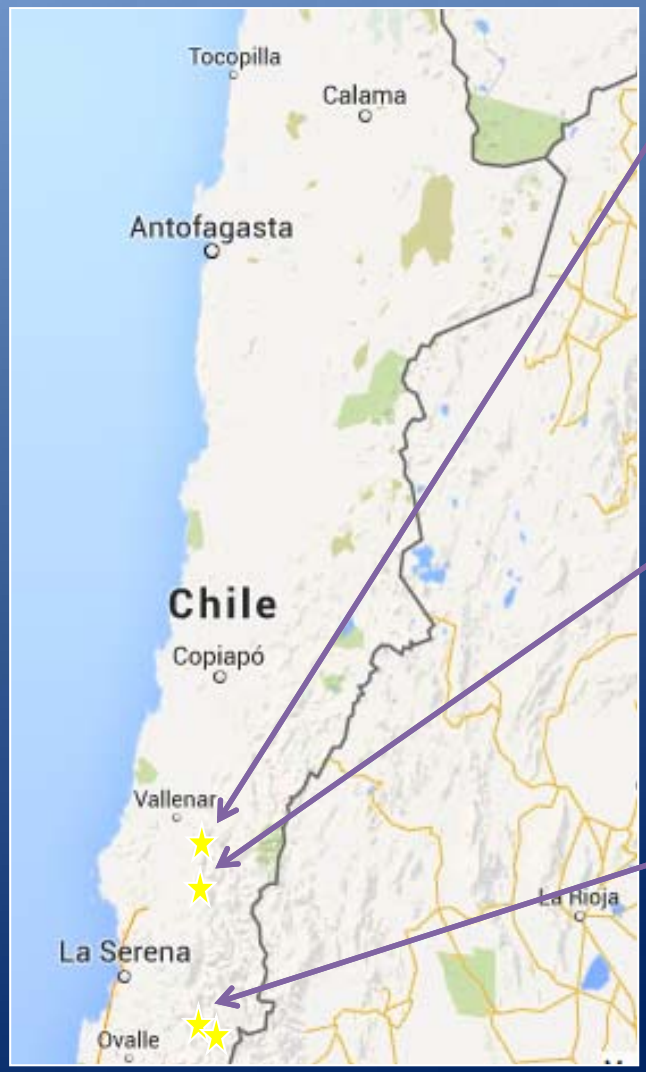
- Twin telescopes built at Columbia University (1976-1982)
- Southern Mini to Cerro Tololo, Chile (1982)
- Northern Mini to CFA (1986)
- Resolution = 8.3´ @ 115 GHz



Atacama: The driest desert in the world

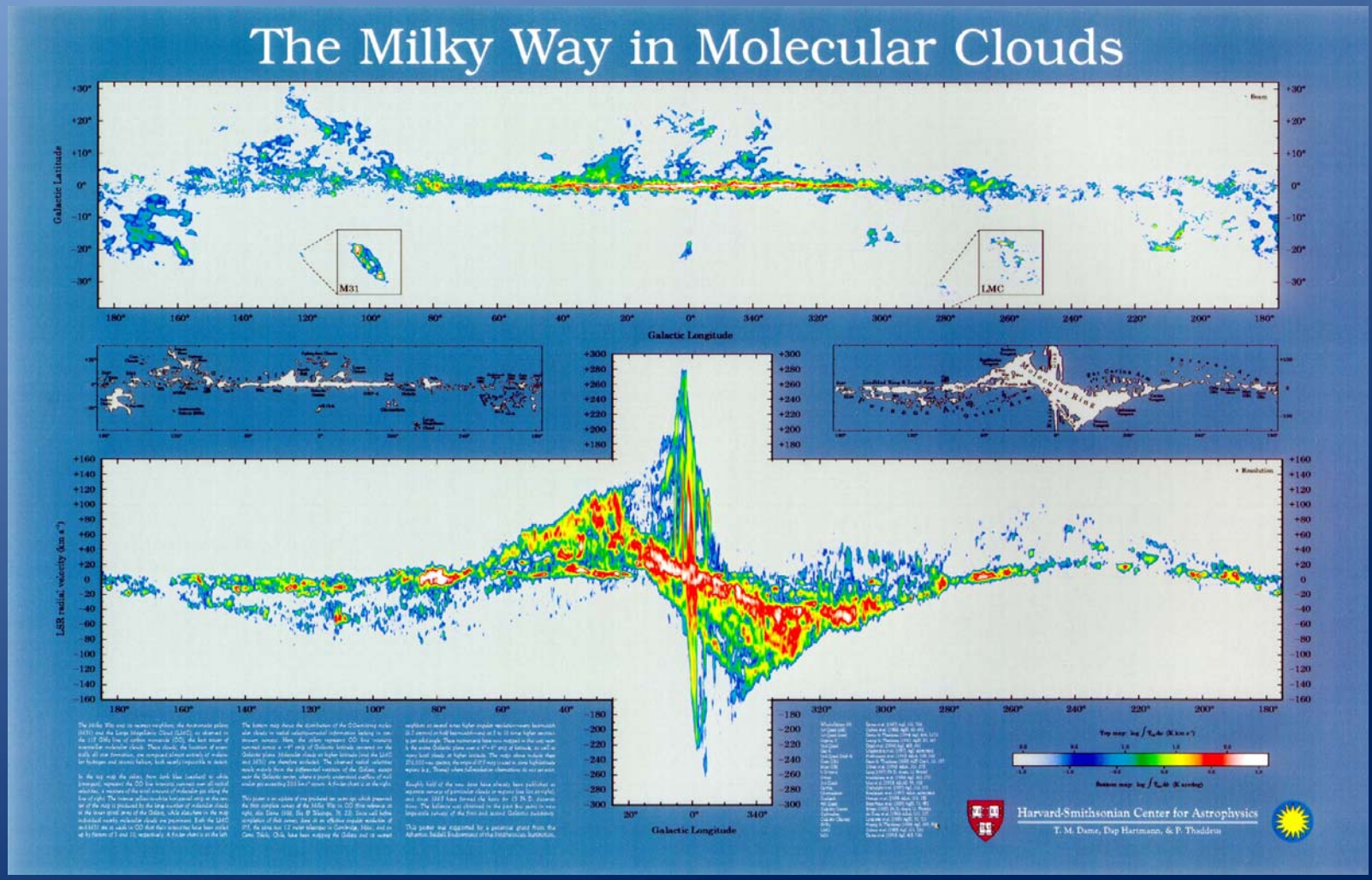
Mars Rover Test

Astronomical Observatories in northern Chile; 1980



Early radio astronomy in Chile : Maipú Observatory (1959-2000)
43-46 MHz; 528 dipoles in 10.000 m2; first in Latin America
(J. May, Universidad de Chile)

First complete CO survey of the Galaxy



The Norma G331.5 molecular complex
Among the most massive in the Galaxy (1985)

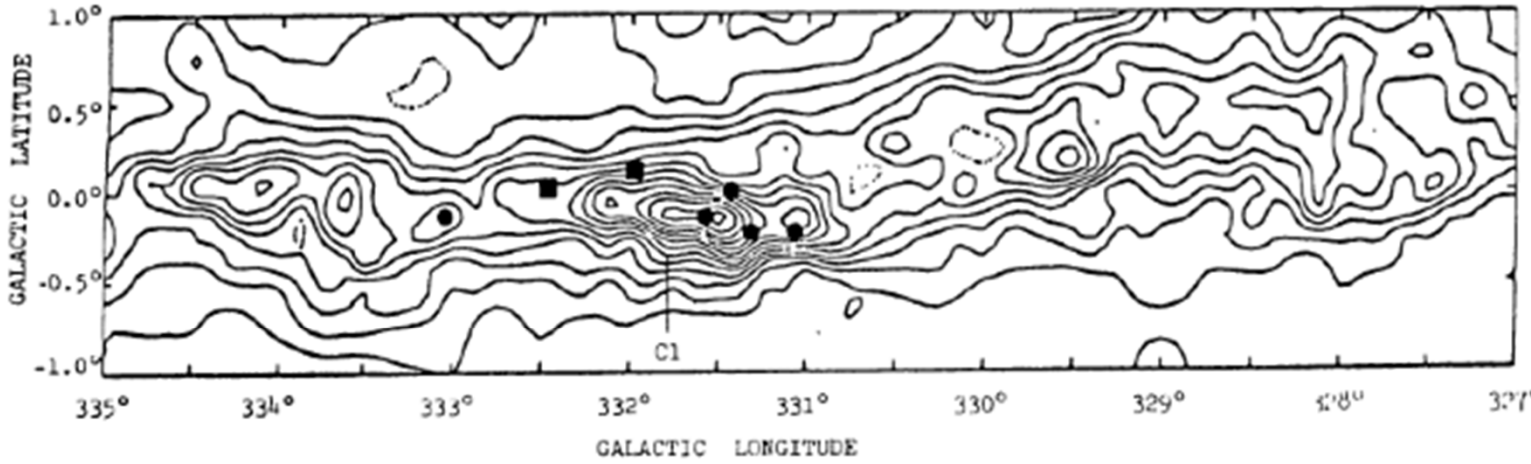
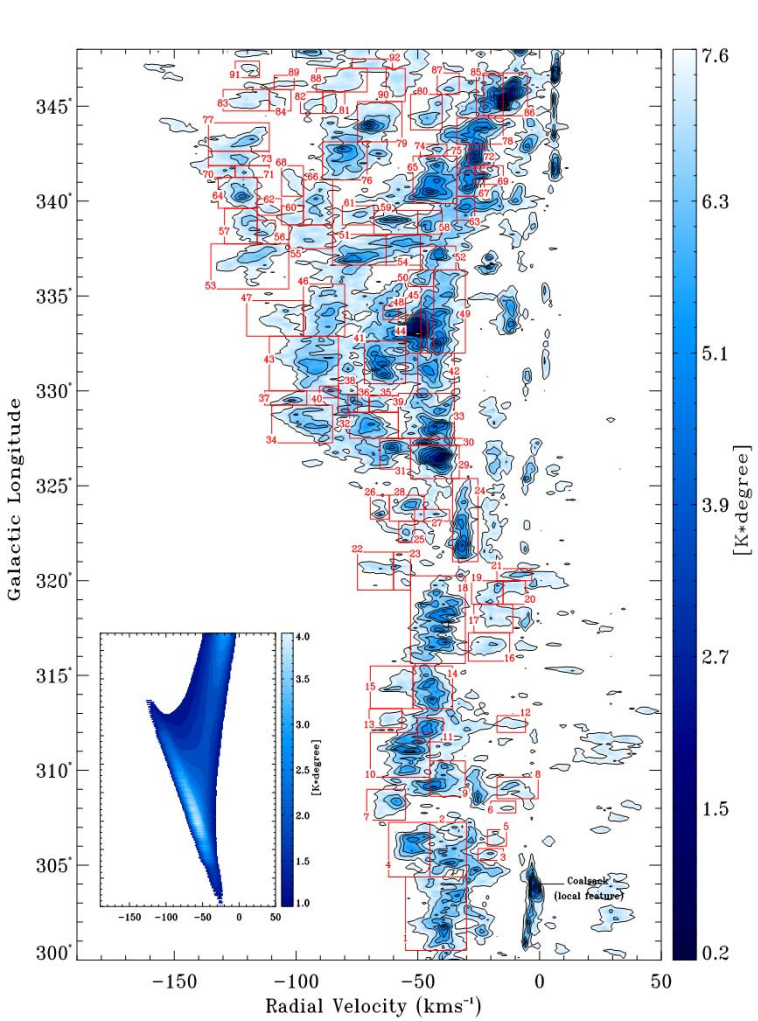


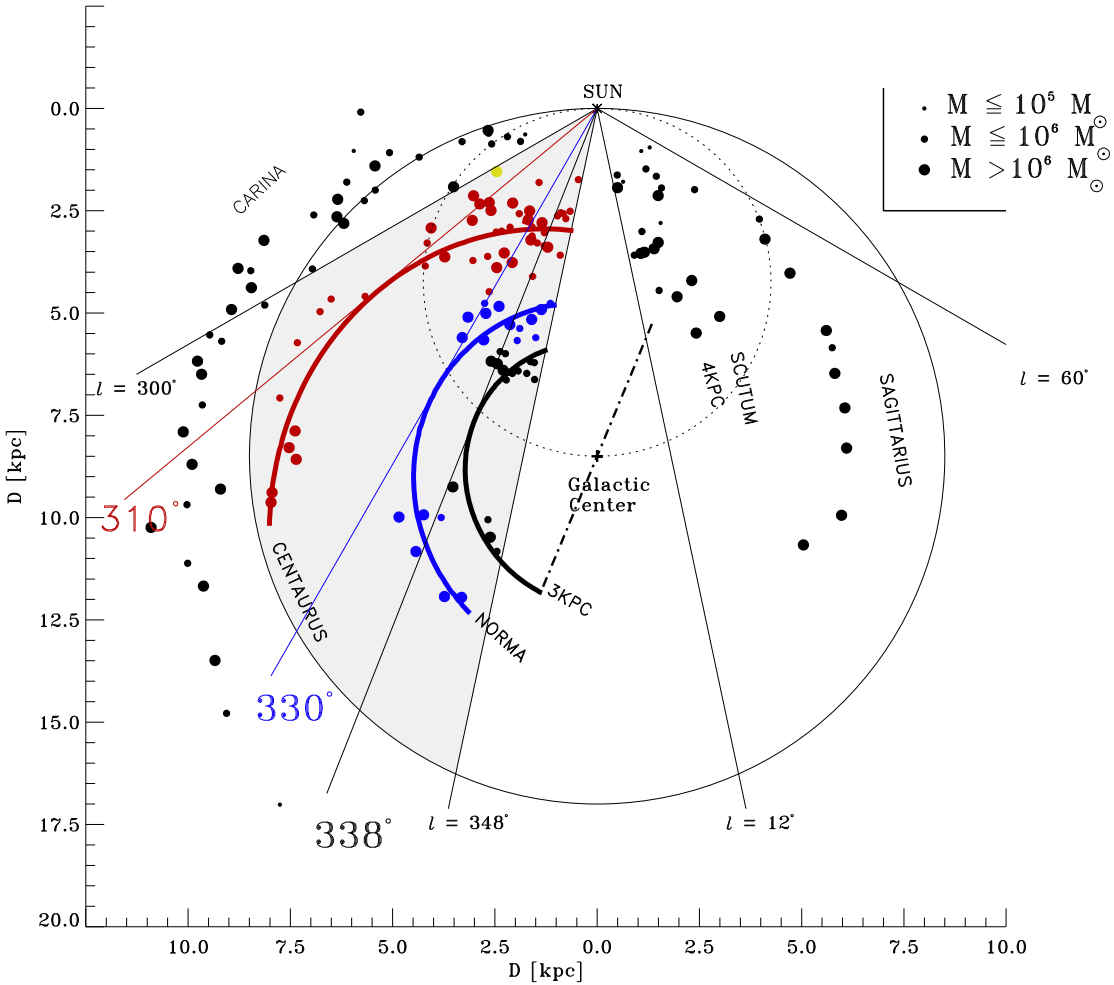
Figure 3. ℓ, v map of CO emission integrated over the highest velocity range (-120 < v < -80 km/s). Complex 1, in the figure, has a kinematical (near) distance of about 7 kpc. HII regions in the area are shown as filled circles, and SNRs as filled squares.

INDIVIDUAL CLOUD ANALYSIS:

THE CO EMISSION IS DOMINATED BY GMCs WHICH TRACE THE SPIRAL ARMS

MSc. P. García et al. 2013: new 4th quadrant analysis

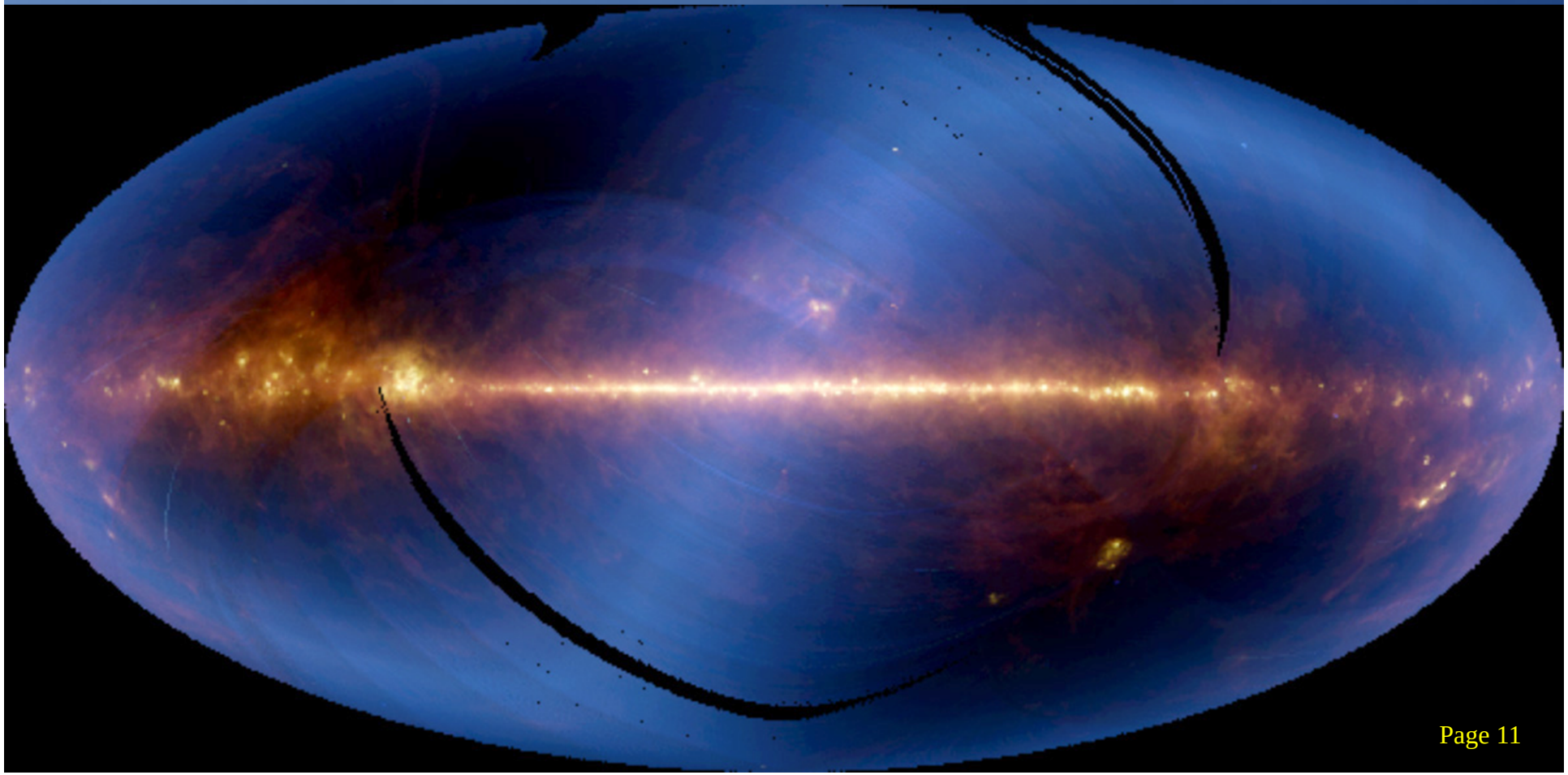




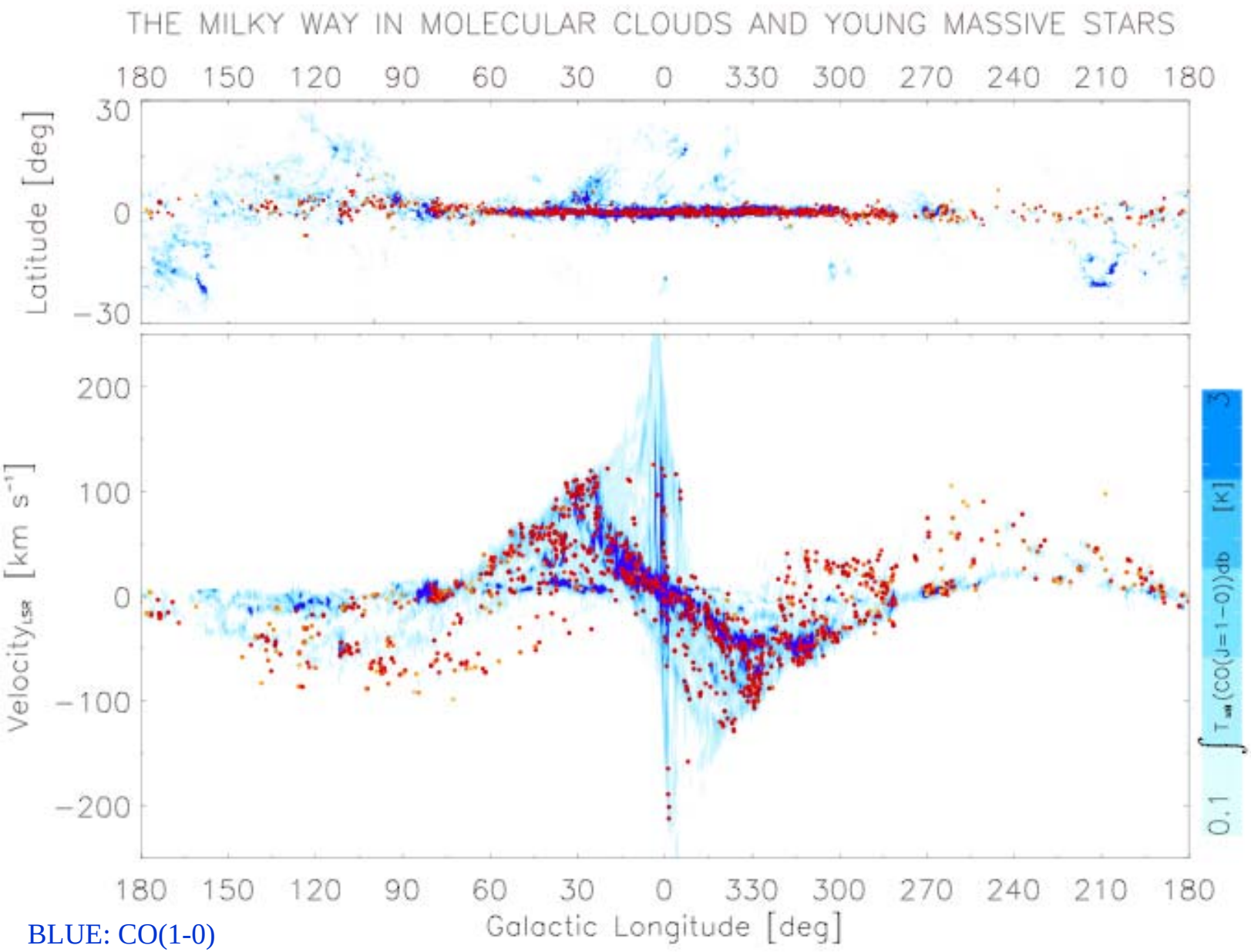
IRAS
BLUE = 12 um
GREEN = 60 um
RED = 100 um

FAR INFRARED (FIR) CONTINUUM EMISSION MAP OF THE MILKY WAY; DUST IS HEATED BY YOUNG MASSIVE STARS (30 K); MOLECULAR GAS IS ASSOCIATED WITH THE DUST

MOLECULAR LINE EMISSION CAN BE OBSERVED TOWARD BRIGHTEST FIR POINT-SOURCES TO DETERMINE THE DISTANCES TO THE EMBEDDED MASSIVE STARS; 1 ARCMIN RESOLUTION NEEDED



SEST (Swedish ESO Sub-millimeter Telescope); La Silla Observatory, 1988
15m diameter antenna; 100 – 345 GHz frequency range; Res. = 50” @ 100 GHz



BLUE: CO(1-0)

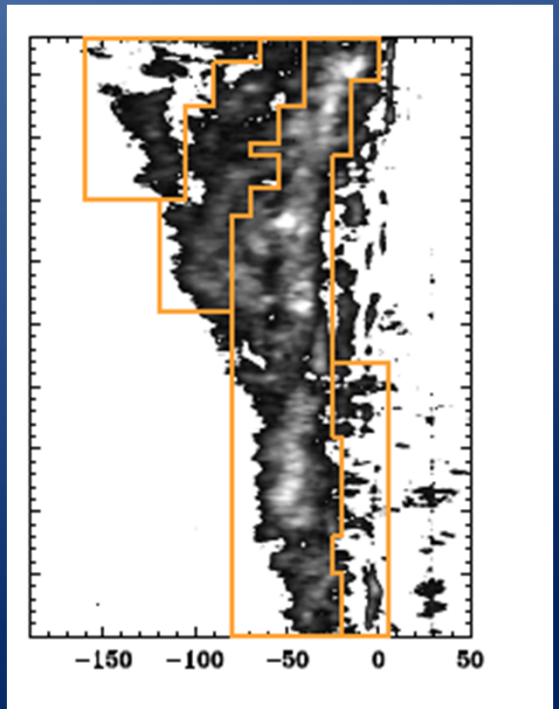
RED: CS(2-1): 1200 UC H II REGIONS FROM IRAS PSC OBSERVED WITH SEST AND ONSALA 20M

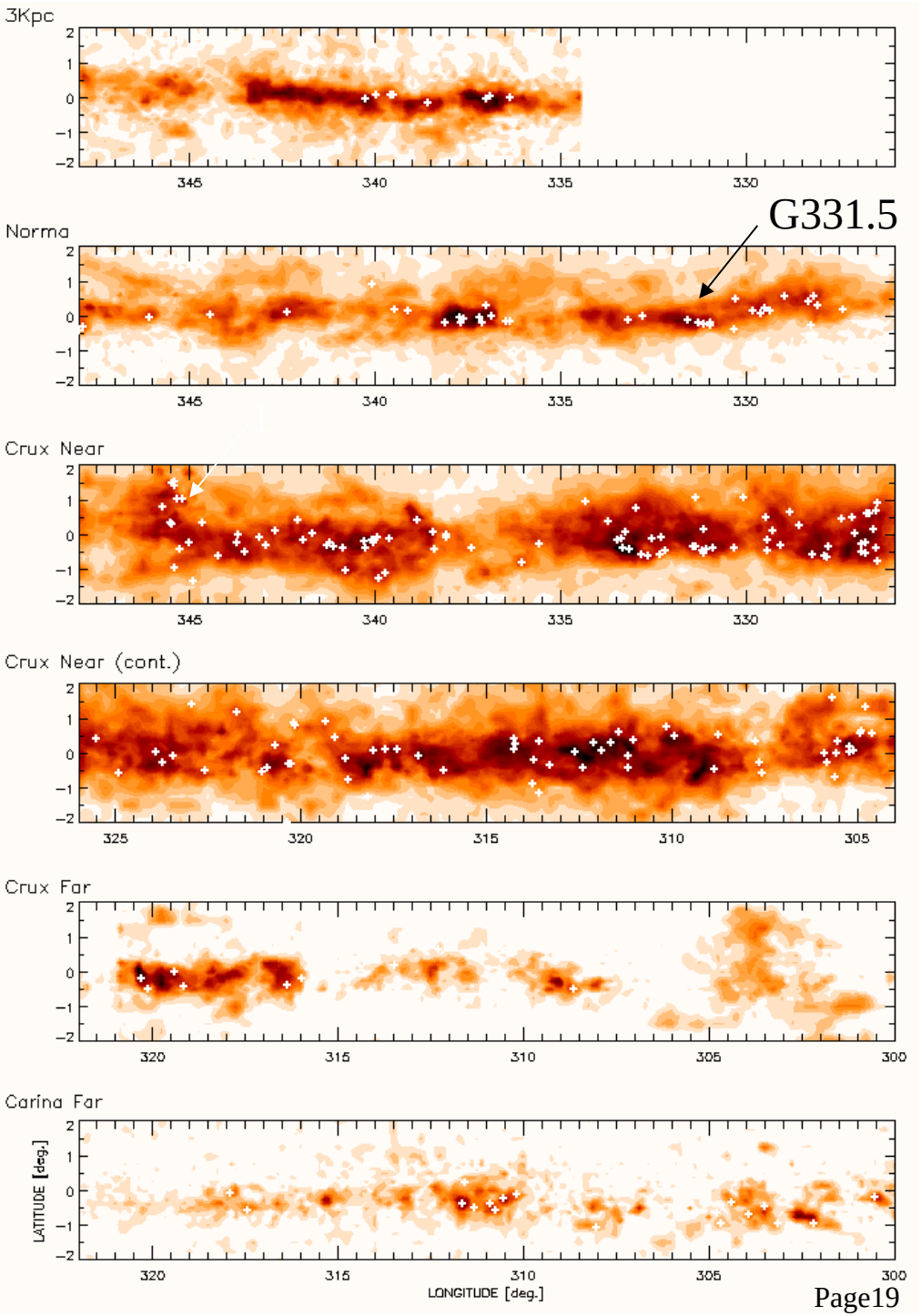
MASSIVE STARS FORM IN THE DENSE CORES OF GIANT MOLECULAR CLOUDS

COLOR: CO(1-0) INTEGRATED IN VELOCITY, WITHIN RANGES OF PROPOSED SPIRAL ARMS

CROSSES: MASSIVE STAR FORMING REGIONS DETECTED IN CS(2-1) WITH SEST.

NORMA G331.5: D = 7.4 KPC IN TANGENT OF NORMA SPIRAL ARM.

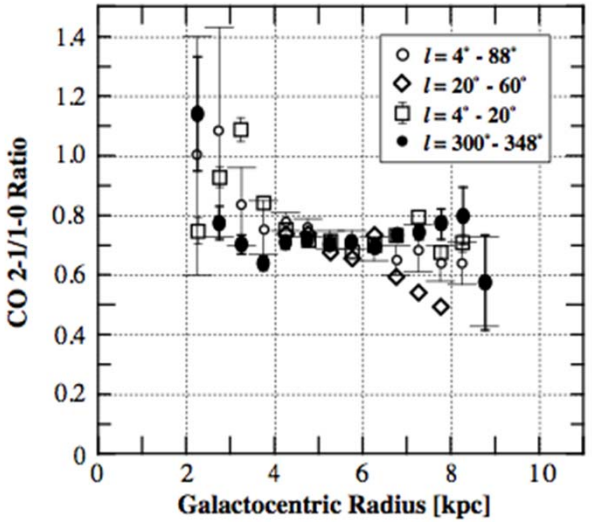




Tokyo-Onsala-ESO-Calán Galactic CO survey T. Hasegawa, 1995

CO J=2-1 line @ 1.3 mm (230 GHz) 60 cm survey telescope,

Resolution = 9´
= wavelength/diameter



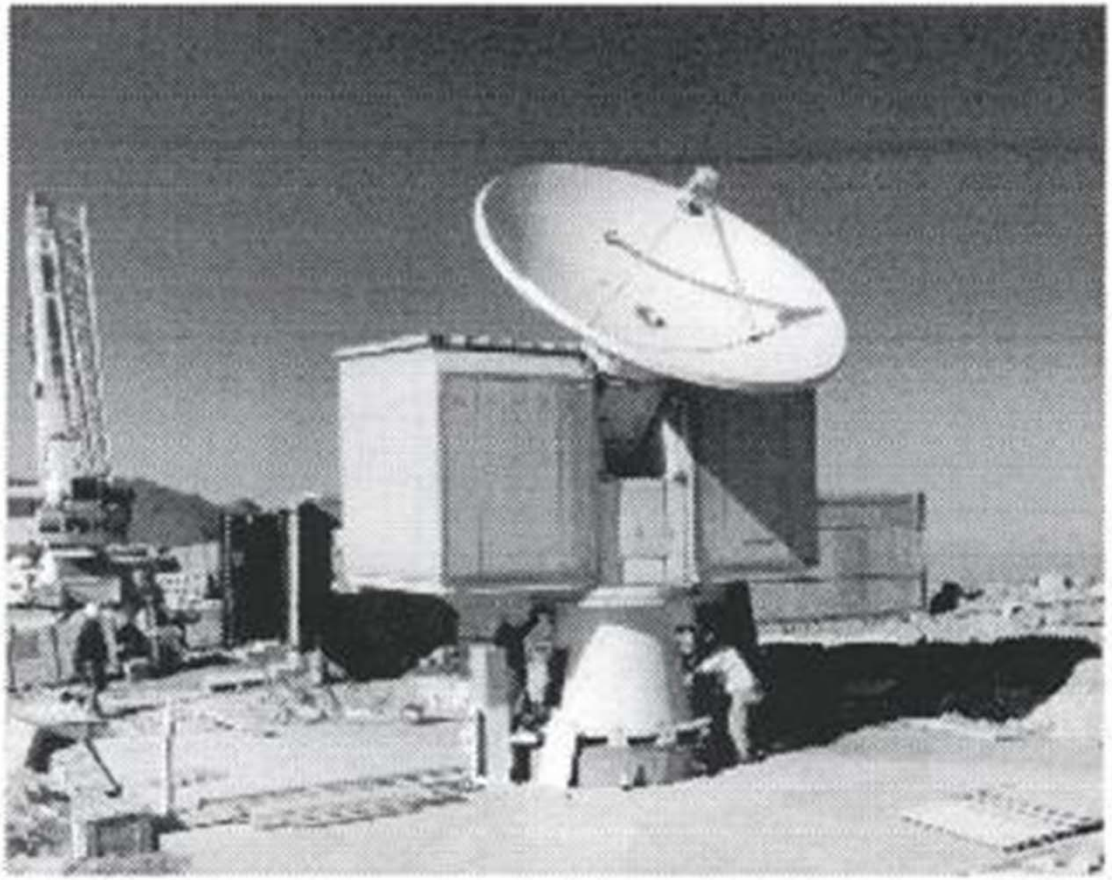
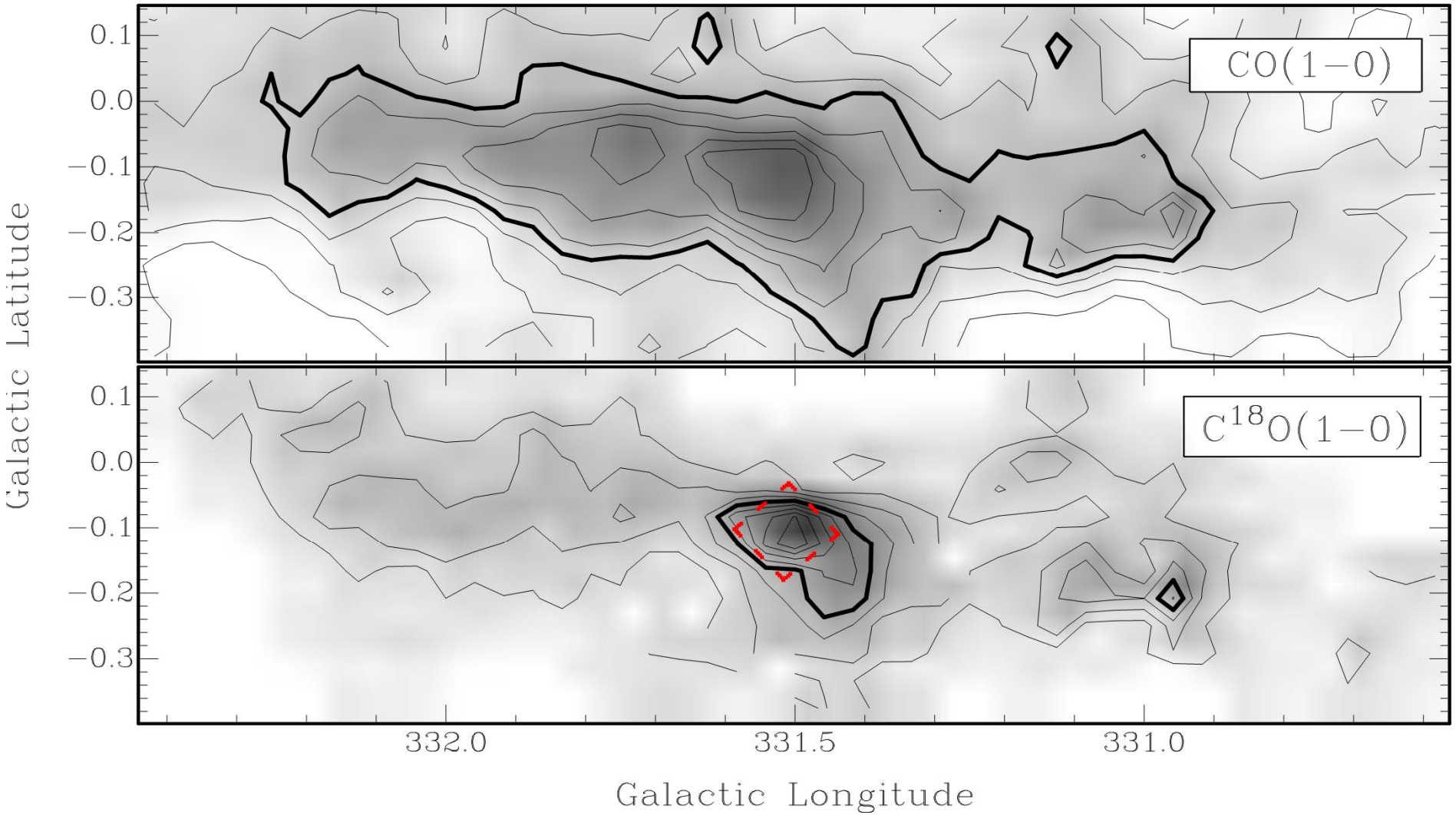
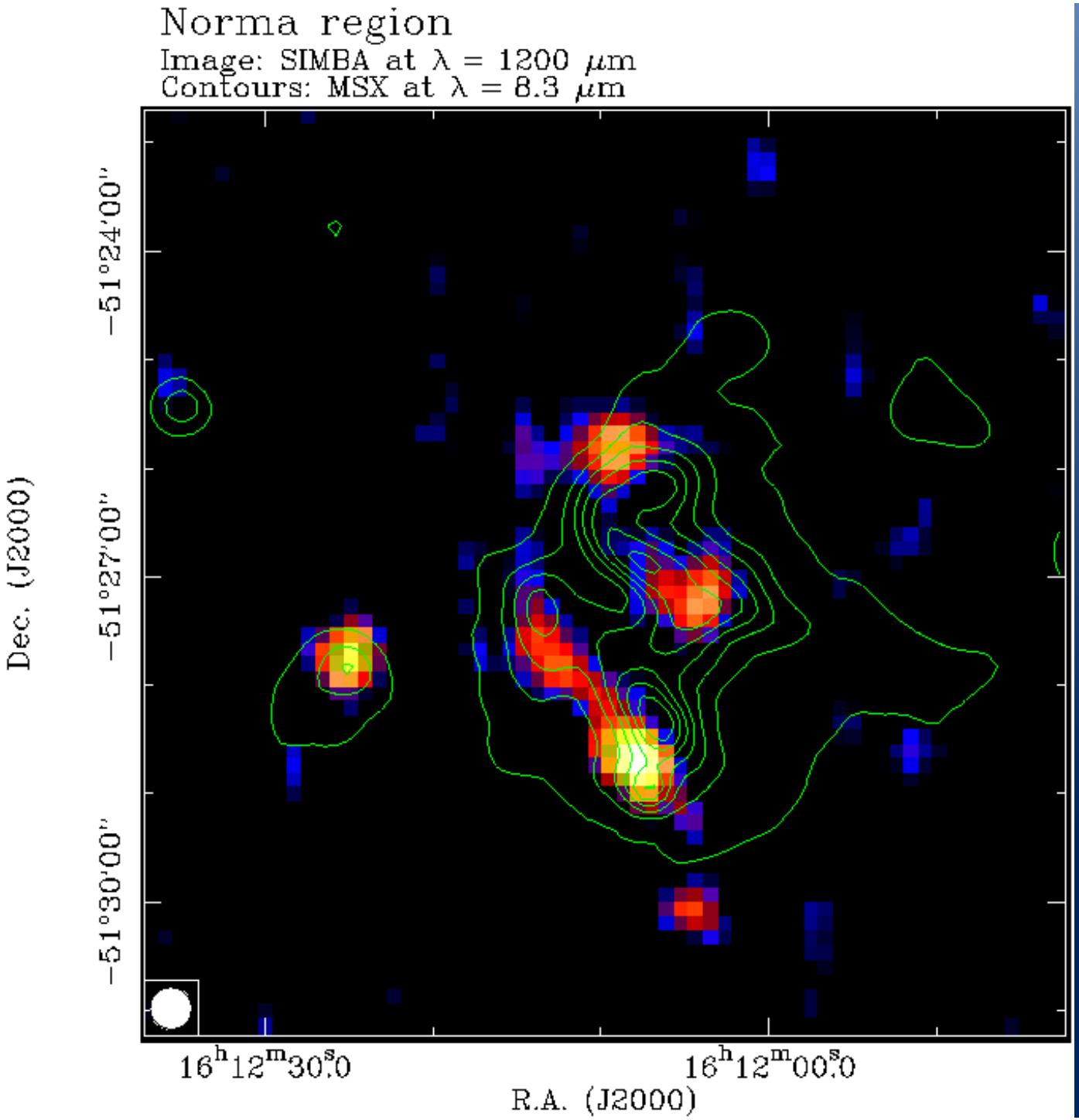


Figure 2. The 4-meter millimeter-wave telescope named NANTEN (=southern sky in Japanese) installed at Las Campanas Observatory in Chile.

Nagoya University NANTEN Telescope (Y. Fukui, 1995)
86 – 115 GHz coverage, 4m antenna, Las Campanas Observatory

NANTEN MAP OF NORMA G331.5; RESOLUTION 2.5 arcmin
3.5 MILLION SOLAR MASSES





ZOOMING IN WITH SEST 15 m TELESCOPE RES. = 22 arcsec .

SIMBA BOLOMETER (2001)

G331.5 MOLECULAR CLOUD CORE:

CONTINUUM EMISSION FROM COLD DUST HEATED BY PROTO AND FORMING STARS

IN THE MEANTIME: THE ALMA SITE AT 5000 m, ATACAMA, CHILE

GENERAL VIEW OF PAMPA CHAJNANTOR, 1995

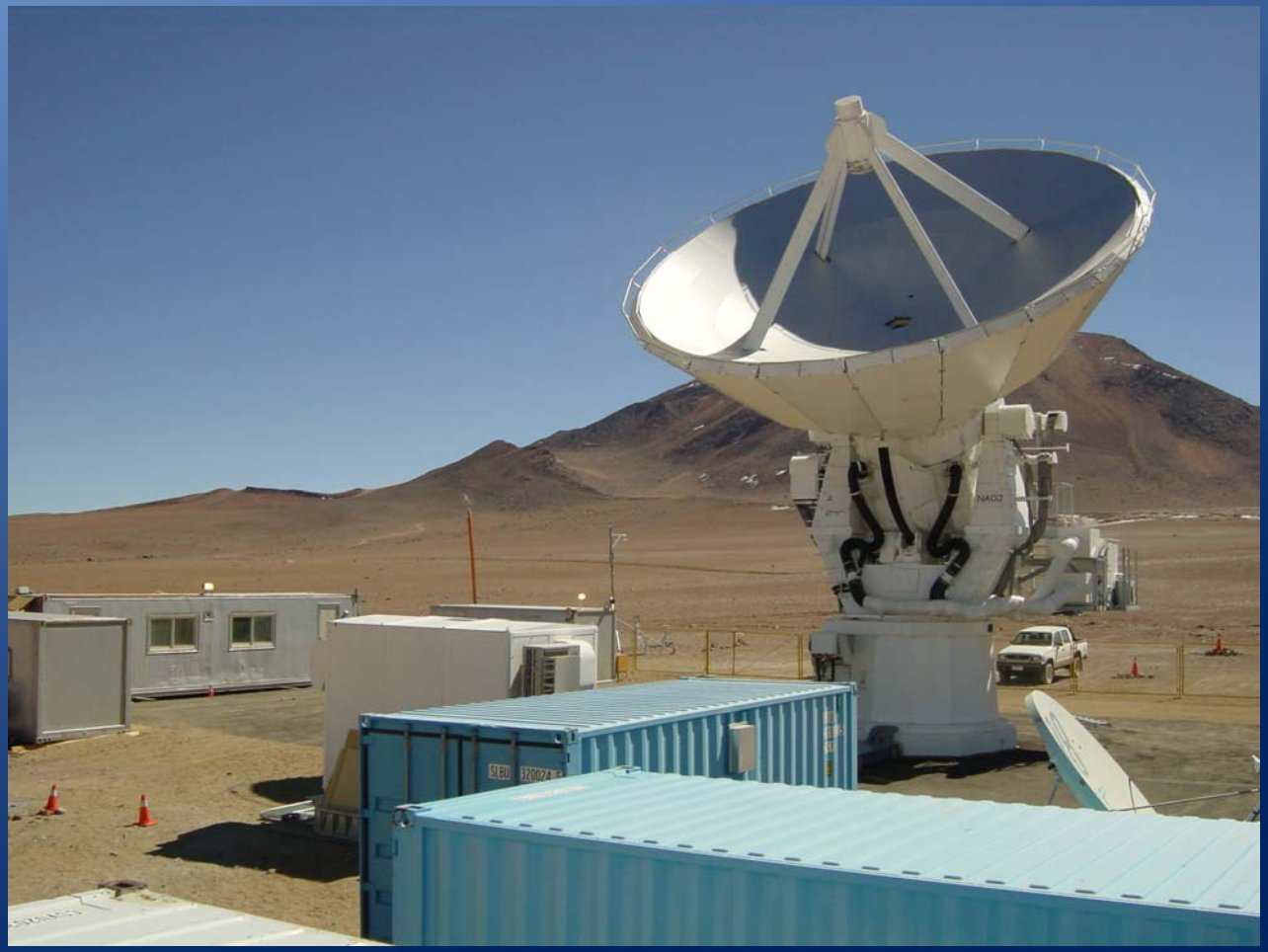
70 km from San Pedro town; 170 km from Calama, major mining city

Site survey expedition for NAOJ LMSA (proto ALMA); 1994

ALMA Site in Chile

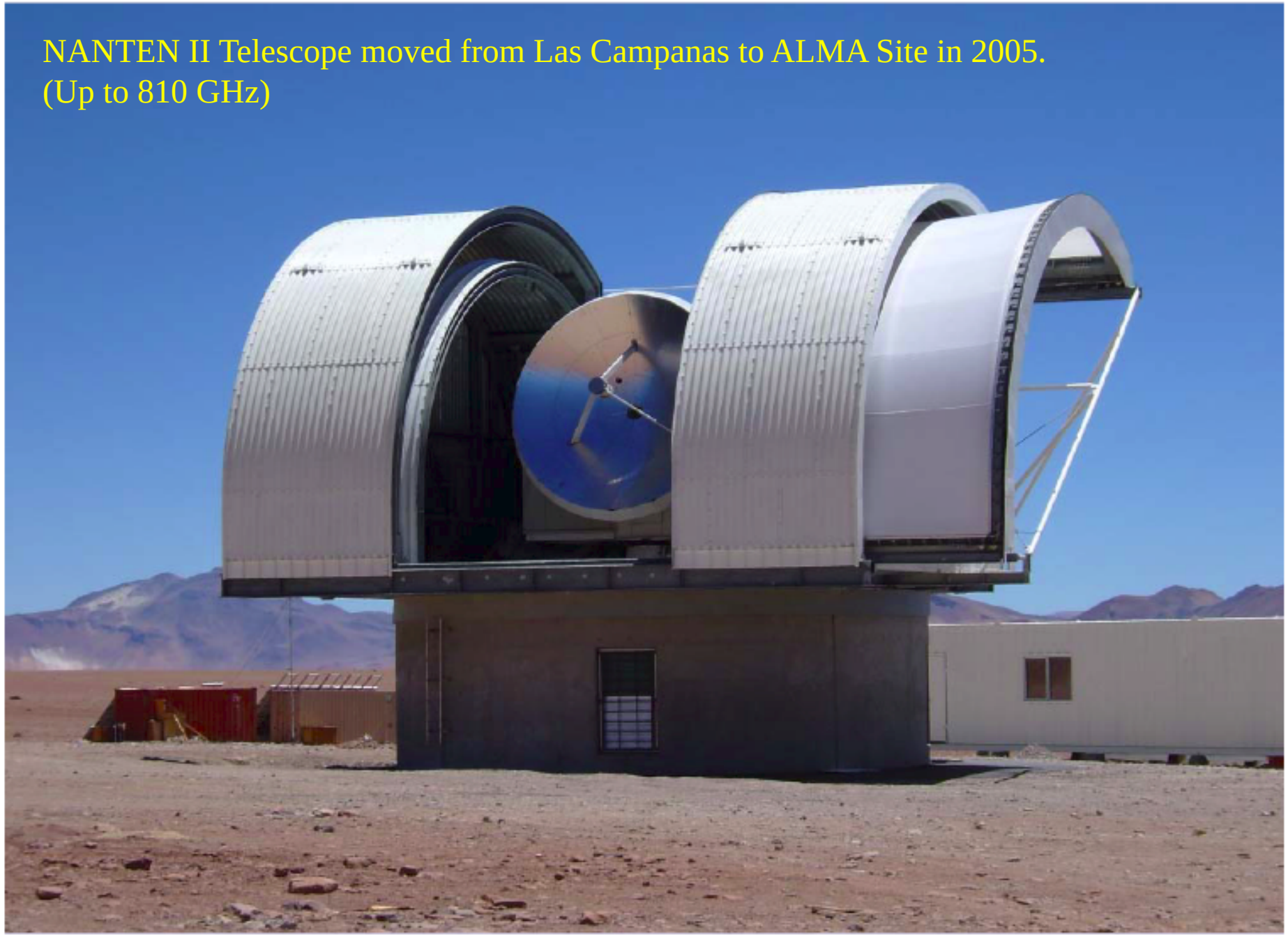
NAOJ Test Interferometer (1996)

Atacama Submillimeter Telescope Experiment (Japan ASTE 10 m Telescope, NAOJ , 2004) Frequency range up to 800 GHz



TRANSPORT OF ASTE TO PAMPA LA BOLA AT 4850 M , CHILE , ALMA SITE, MARCH 2002 (S. SAKAMOTO)

NANTEN II Telescope moved from Las Campanas to ALMA Site in 2005.
(Up to 810 GHz)



Atacama Pathfinder Experiment (APEX 12 m Telescope)

Chajnantor (ALMA site, Chile, 5.050 m)

MPIfR, ESO, Onsala (2005)

230 Ghz to 1 THz

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ATOMIC CARBON IN THE SOUTHERN MILKY WAY

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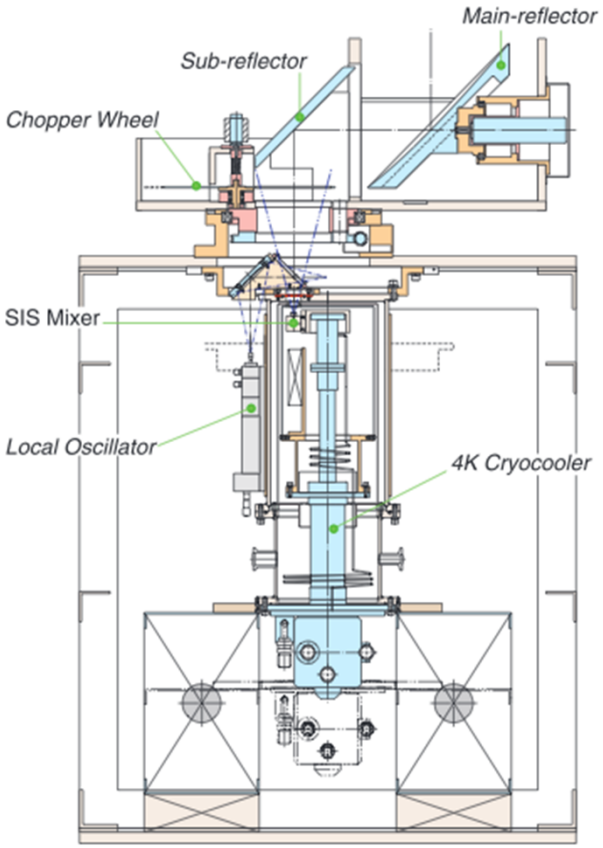


FIG. 1.—Schematic drawing of the Portable 18 cm Submillimeter-wave Telescope.

TABLE 1

THE PARAMETERS OF POST18 AT 492 GHz

Parameter	Value
Main Reflector	
Optics	Offset paraboloid
Diameter	18 cm
Focal length	420 mm
HPBW	13′.6
Receiver	
Cryocooler	Two-stage GM
Mixer type	SIS PCTJ
IF frequency	1.8–2.5 GHz
Receiver temperature	140 K (DSB)
Spectrometer	
Type	AOS
Channel number	1728 ch
Bandwidth	700 MHz (430 km s^{-1})
Resolution	1.0 MHz (0.6 km s^{-1})

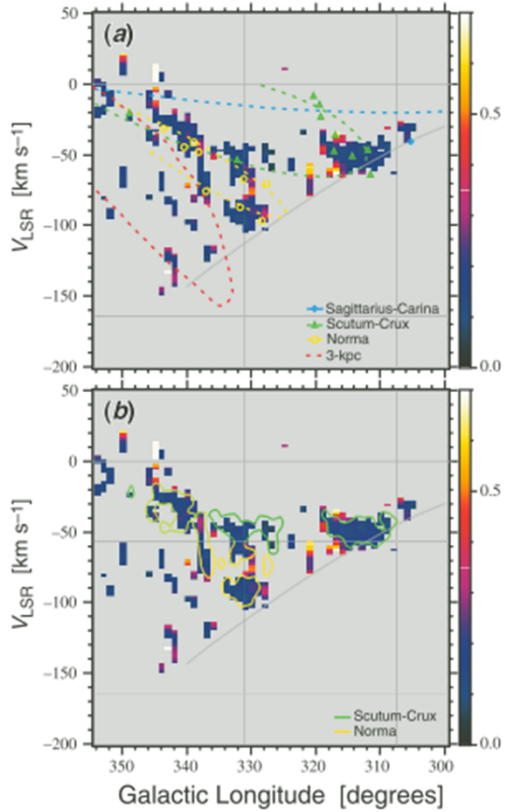
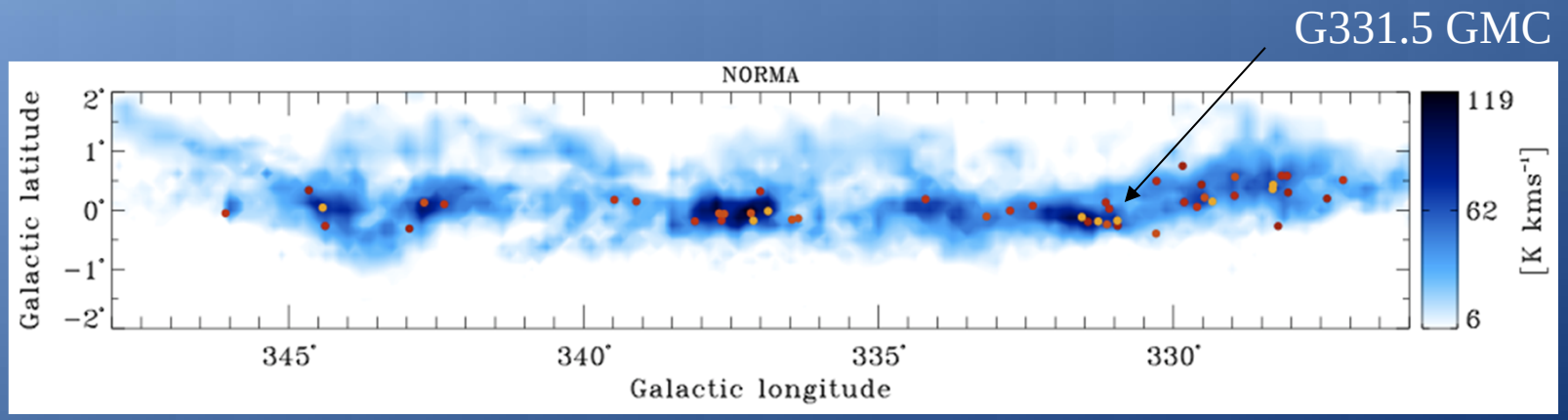
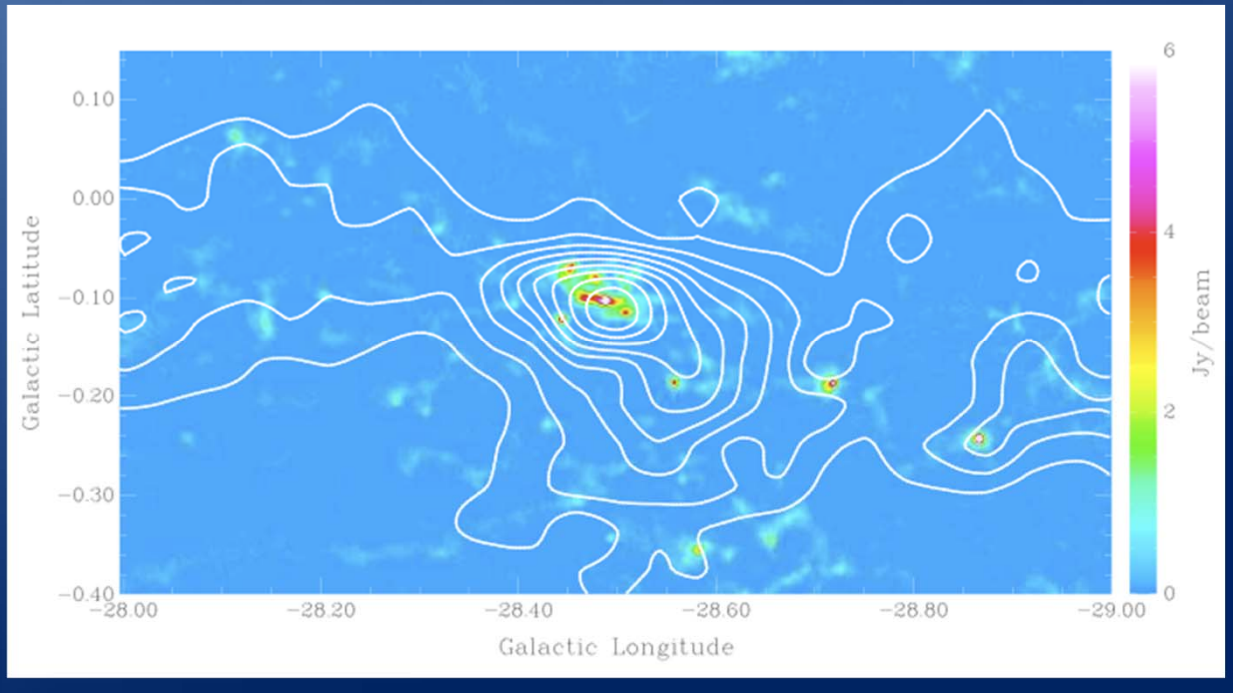


FIG. 9.—Longitude-velocity map of the antenna temperature ratio $R_{C\,I/CO}$: (*a*) with loci of the arms and of giant H II regions, and (*b*) with CO complexes that may be associated with the Scutum-Crux and Norma arms. Both data sets were smoothed to a 2 km s^{-1} resolution, and data with T_{MB}(C I) < 0.25 K were excluded. Thin gray lines show the zero velocity line and the terminal velocity line for $r \geq 3$ kpc.

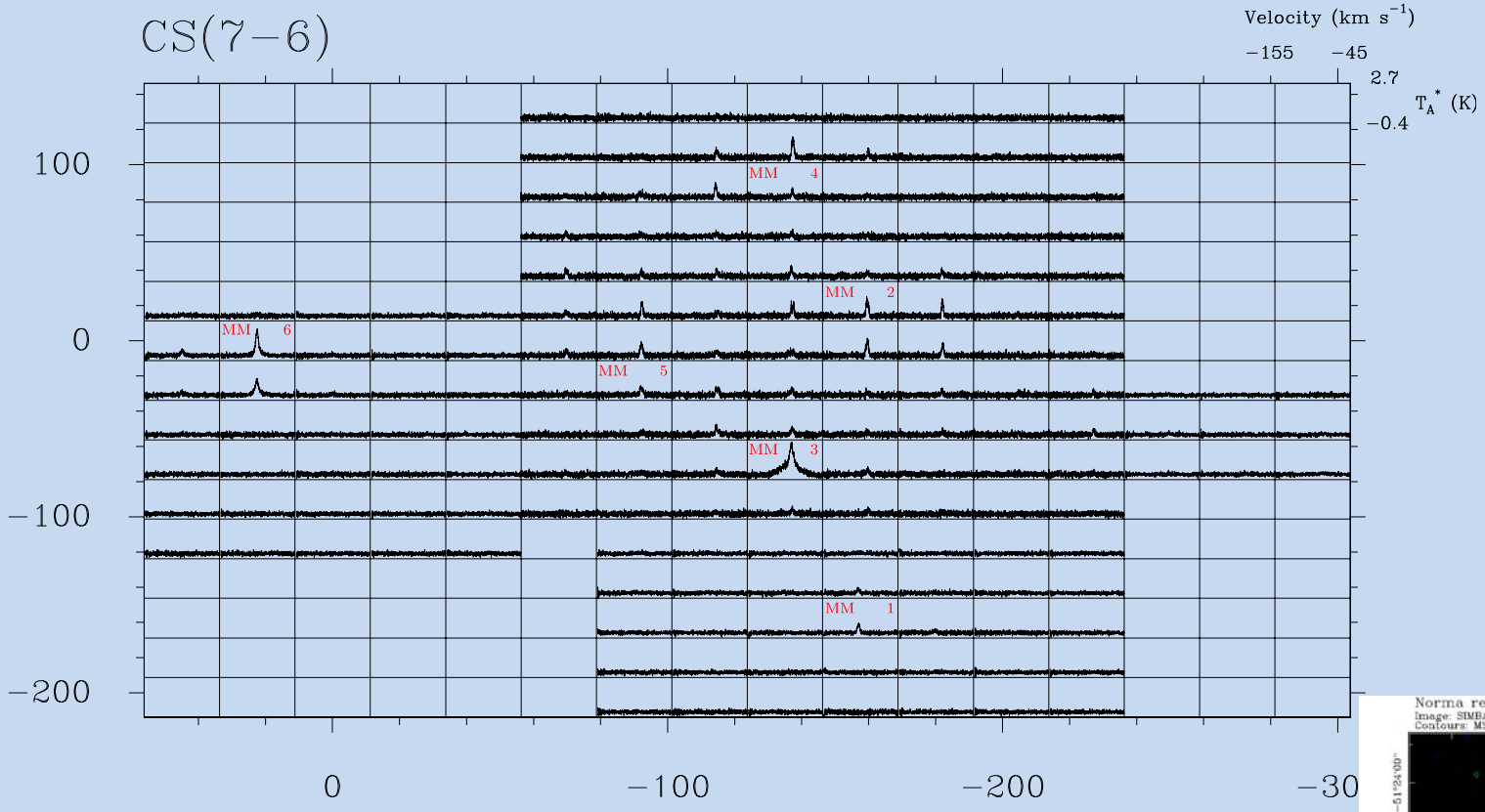
Back to science: The G331.5 GMC/Massive Star Forming Region observed with APEX LABOCA camera at 0.87 mm

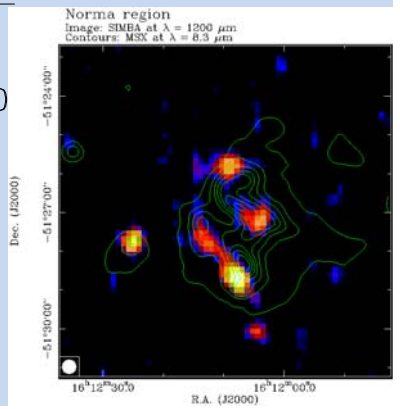




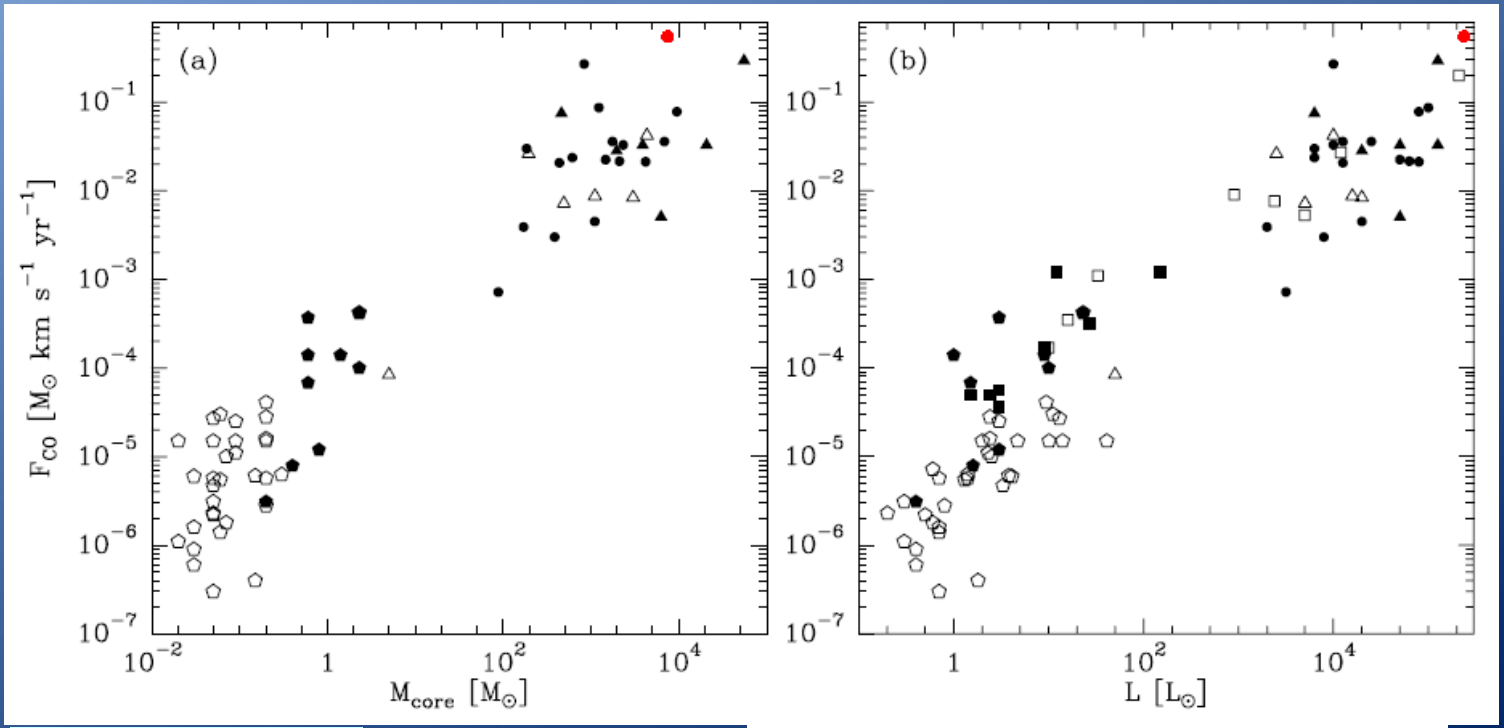
- Distance: 7.5 kpc
- FIR luminosity: $3.6 \times 10^6 L_\odot$
- Contours: NANTEN $C^{18}O$ GMC mass: $3.5 \times 10^6 M_\odot$
- Color: APEX/LABOCA 0.87 mm dust continuum emission

CS(7-6) OBSERVED WITH ASTE AT 343 GHz (22” res)
DISCOVERY OF A MASSIVE MOLECULAR OUTFLOW
AT G331.5 GMC CORE IN NORMA SPIRAL ARM





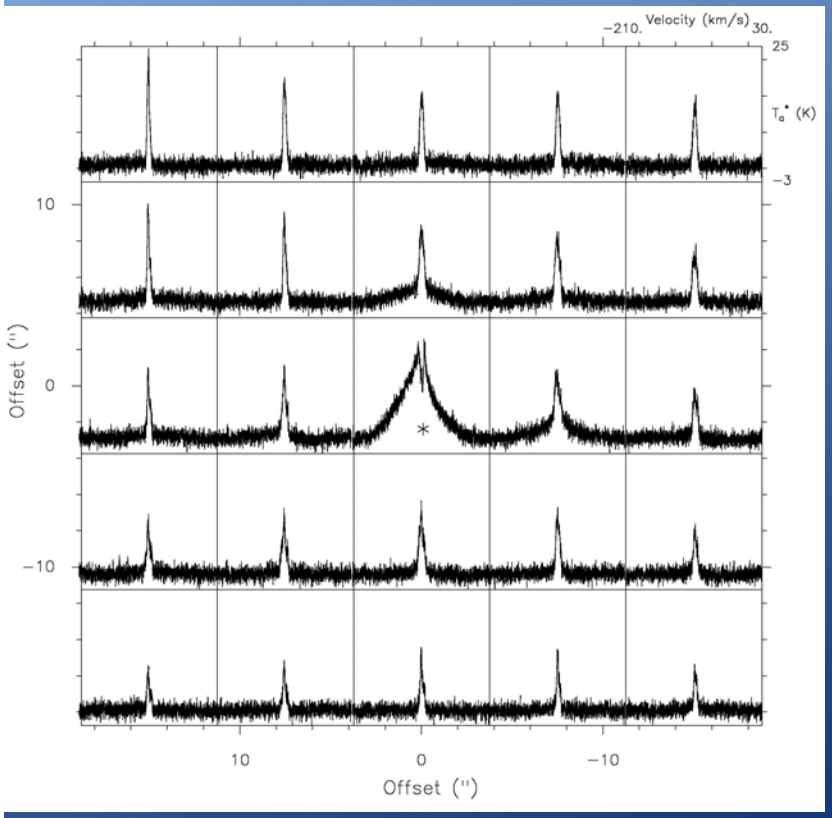
VERY MASSIVE AND LUMINOUS HIGH VELOCITY MOLECULAR OUTFLOW; INFANCY OF A HIGH MASS STAR

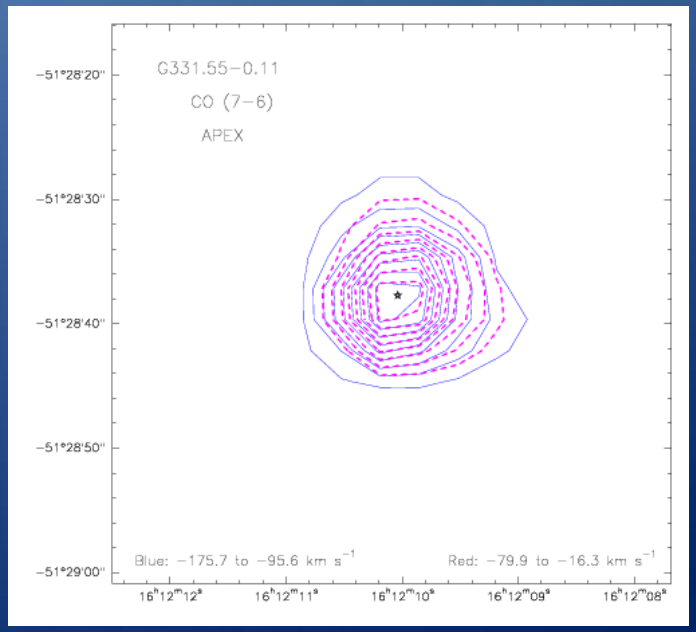


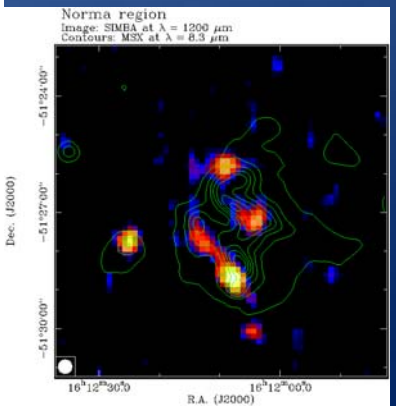
Beuther et al.2002b

$$\dot{M}_w \sim 3 \times 10^{-4}\ M_\odot\ \mathrm{yr}^{-1}$$

A massive molecular outflow in G331.5-0.1: Unresolved with available single dish telescopes

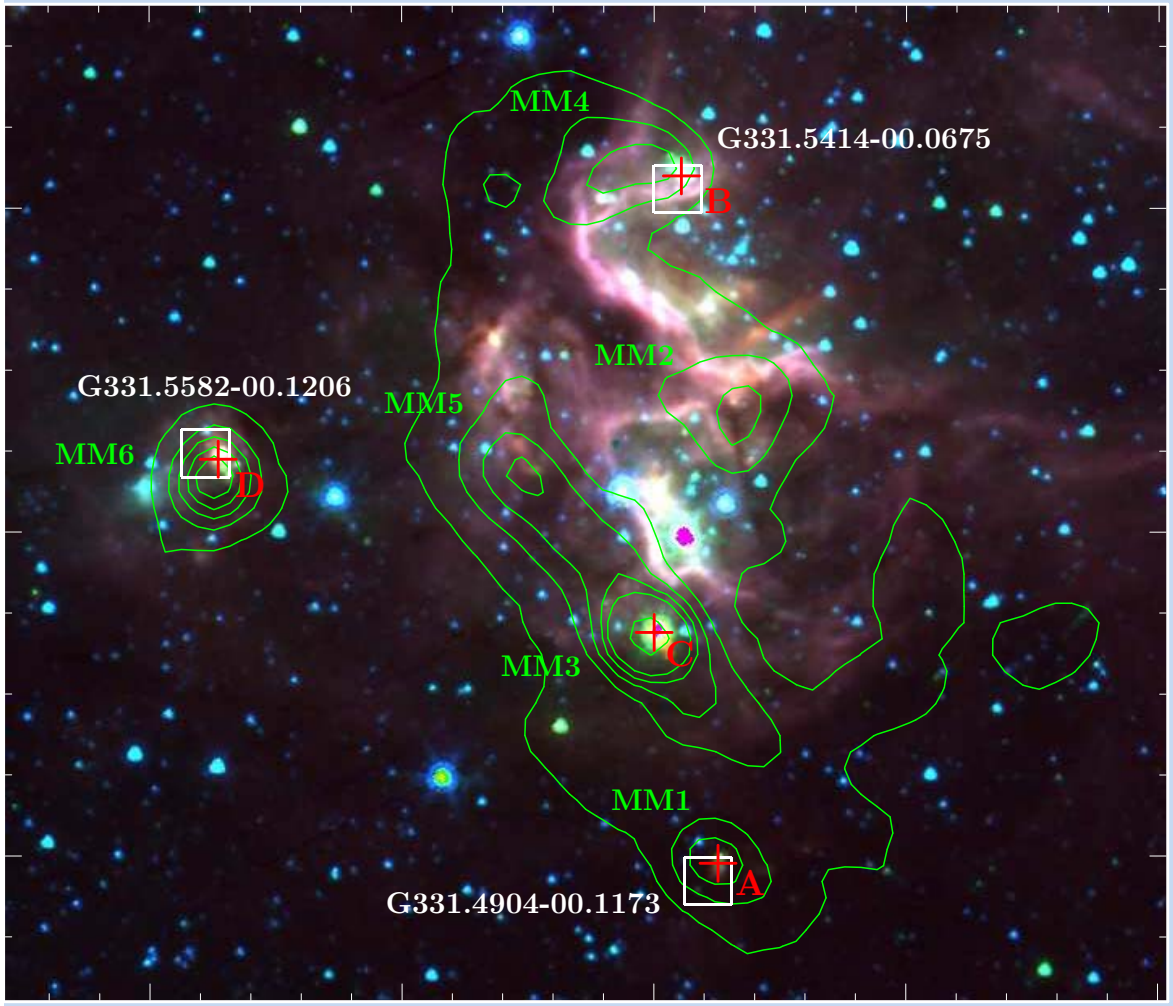




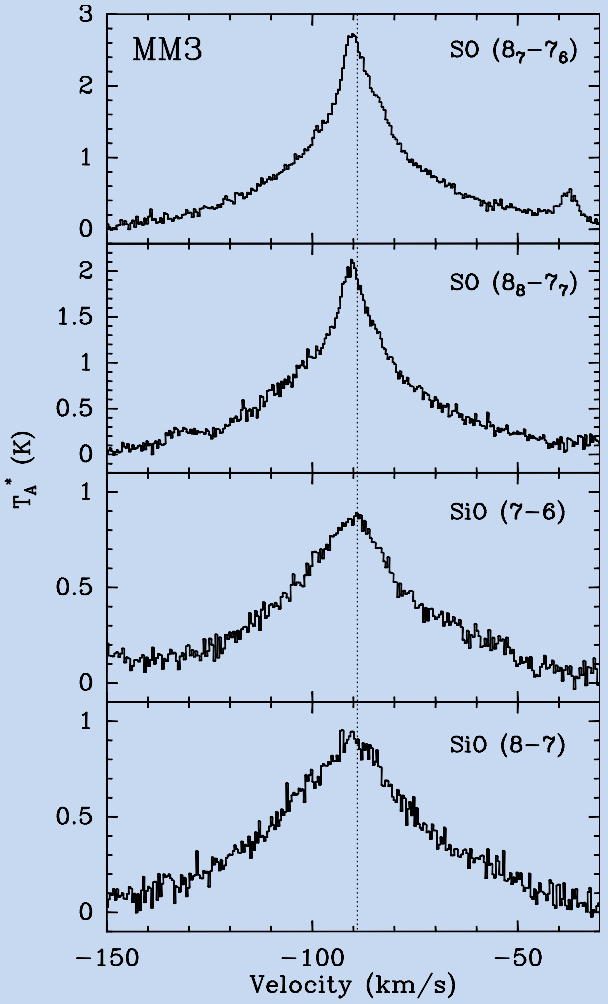


- APEX CO (7-6): Res 7.7" @ 800 GHz
- Velocity width (ZP)160 km/s
- Dynamic timescale: less than 3×10^3 yrs.

Contours: APEX-LABOCA 0.87 mm continuum
Colors: SPITZER-IRAC mid infrared

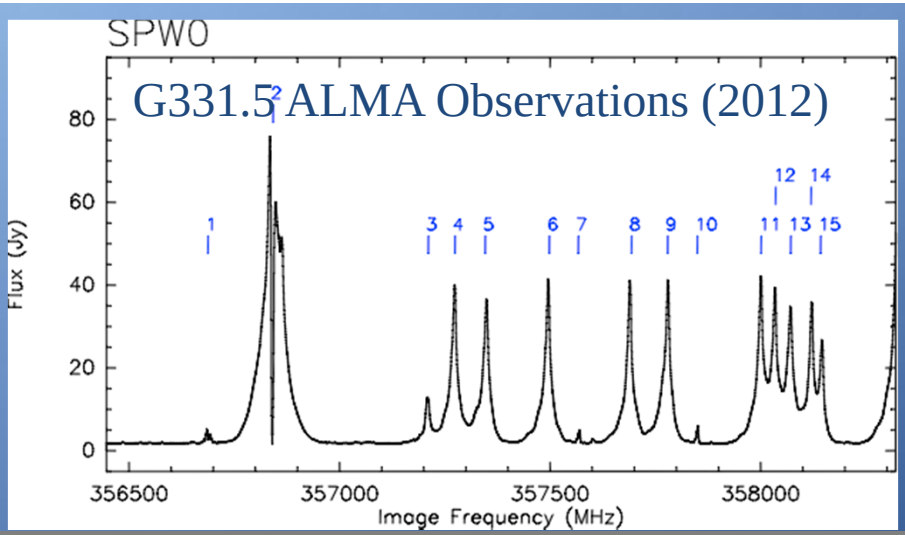


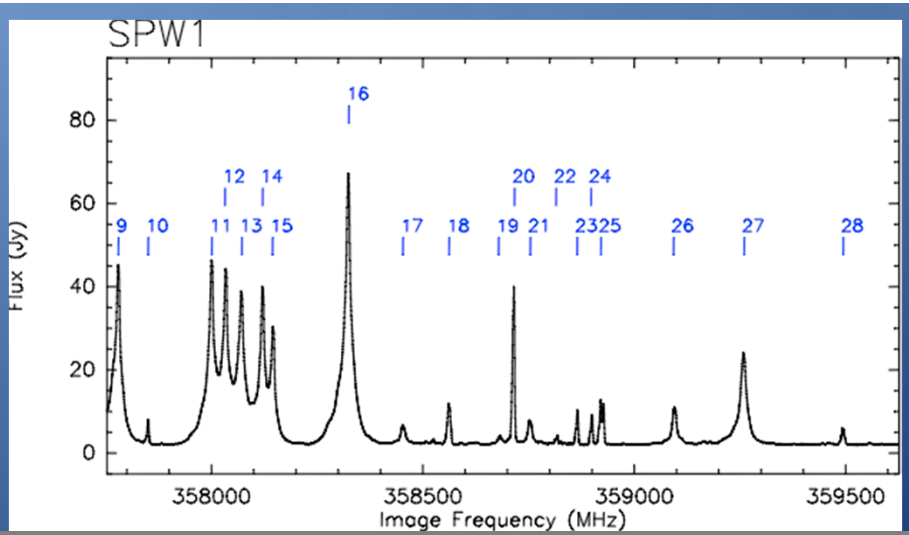
APEX spectra of shocked gas in clump MM3; High velocity molecular outflow G331.512-0.103



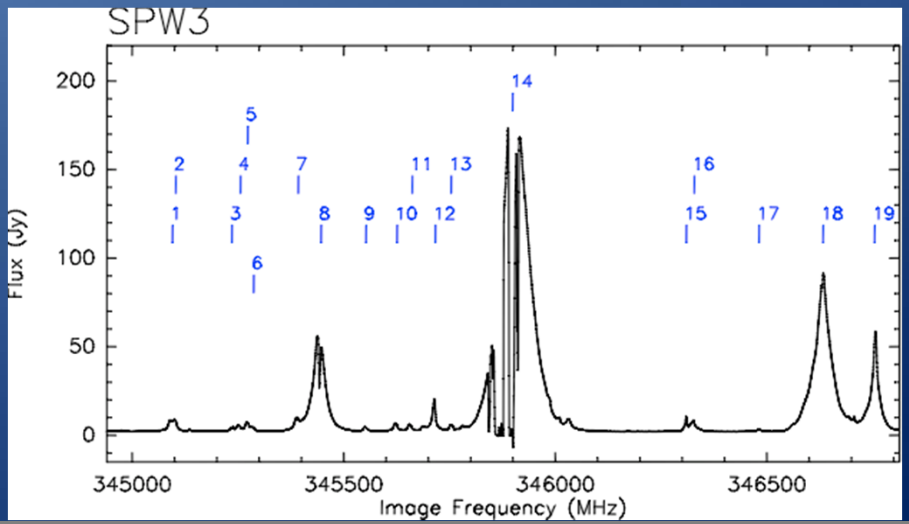
The Atacama Large (sub)Mm Array
Largest radio telescope in the world.
66 antennas: 54x12m + 12x7m, 35 to 950 GHz.
North America, Europe, East Asia collaboration in Chile

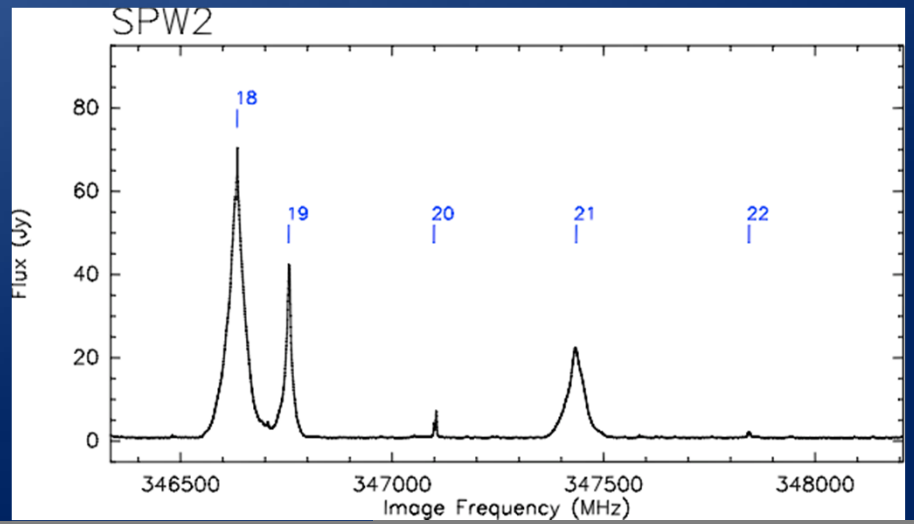
G331.5 ALMA Observations (2012)





1 CH3OCH3 8(4,5)-7(3.4)
2 HCO+ v=0 4-3
3 34SO2 v=0 20(0,20)-19(1,19)
4 SO2 v=0 13(4,10)-13(3,11)
5 SO2 v=0 15(4,12)-15(3,13)
6 SO2 v=0 11(4,8)-11(3,9)
7 CH3OCH3 18(2,17)-17(1,16)
8 SO2 V=0 8(4,4)-8(3,5)
9 SO2 v=0 9(4,6)-9(3,7)
10 Unidentified
11 SO2 v=0 7(4,4)-7(3,5)
12 SO2 v=0 6(4,2)-6(3,3)
13 SO2 v=0 17(4,14)-17(3,15)
14 SO2 v=0 5(4,2)-5(3,3)
15 SO2 v=0 4(4,0)-4(3,1)
16 SO2 v=0 20(0,20)-19(1,19)
17 34SO2 v=0 23(4,20)-23(3,21)
18 Unidentified
19 CH3OCHO v=0 29(12,18)-28(12,17)A
20 CH3OHv t=0 4(1,3)-3(0,3)
21 S18O 9(9)-8(8)
22 Unidentified
23 CH3CCH v=0 21(3)-20(3)
24 CH3CCH v=0 21(2)-20(2)
25 CH3CCH v=0 21(1)-20(1) / CH3CCH v=0 21(0)-20(0)
26 Unidentified (possible 34SO2 v=0 15(2,14)-14(1,13))
27 SO2 v=0 25(3,23)-25(2,24)
28 CH3OCH3 12(3,10)-11(2,9)





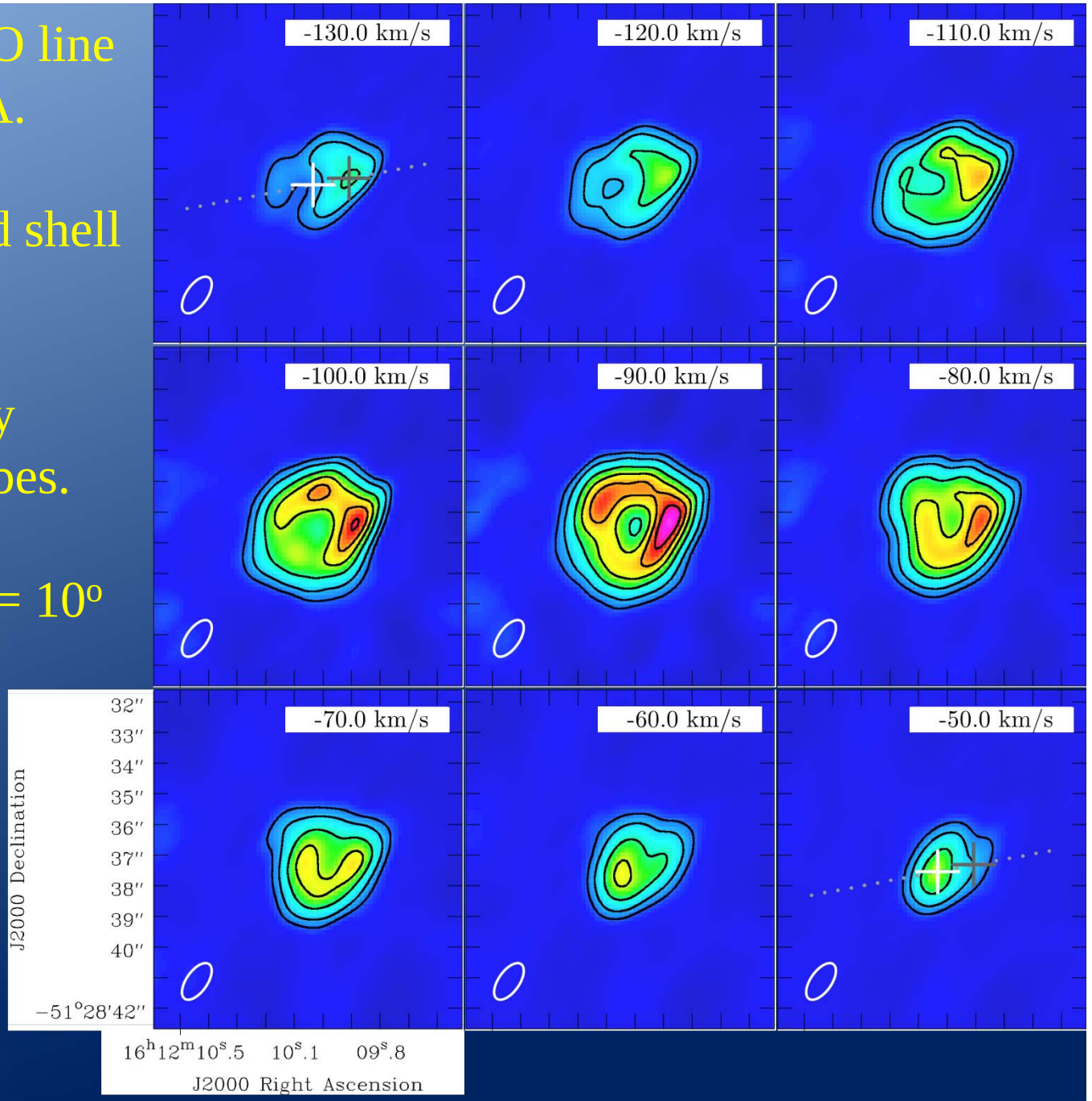
1 34SO2 v=0 15(4,12)-15(3,13)
2 34SO2 v=0 11(4,8)-11(3,9)
3 CH3OCH3 35(2,33)-35(1,34)
4 Possible SO2 v=0 5(5,1)-6(4,2)
5 34SO2 v=0 8(4,4)-8(3,5)
6 NH2CHO 17(0,17)-16(0,16)
7 Unidentified (possible 34SO2 v=0 9(4,6)-9(3,7))
8 H13CN v=0 J=4-3
9 SO2 v=0 26(9,17)-27(8,20)
10 34SO2 v=0 7(4,4)-7(3,5)
11 34SO2 v=0 6(4,2)-6(3,3)
12 HC3N v=0 J=38-37
13 34SO2 v=0 6(4,2)-6(3,3)
14 CO v=0 3-2
15 CH3OHv t=0 5(4,2)-6(3,3)-- / CH3OHv t=0 5(4,1)-6(3,4)++
16 NS J=15/2-13/2,Omega=1/2,F=17/2-15/2,I=f
17 SO2v2=1 19(1,19)-18(0,18)
18 SO2 v=0 16(4,12)-16(3,13)
19 SO2 v=0 19(1,19)-18(0,18)
20 H13CO+ 4-3
21 SiO v=0 8-7
22 SO+ J=15/2-13/2,Omega=1/2,I=e

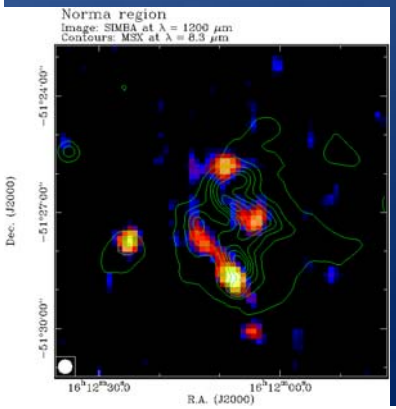
*Channel maps of SiO line obtained with ALMA.

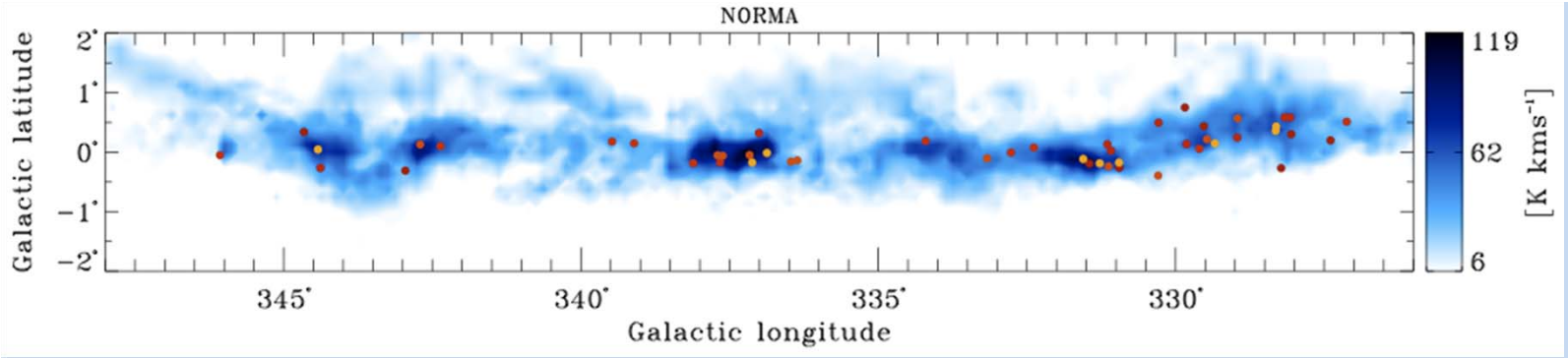
Cental map: projected shell structure

Crosses: high velocity molecular outflow lobes.

•Outflow inclination = 10^{o}





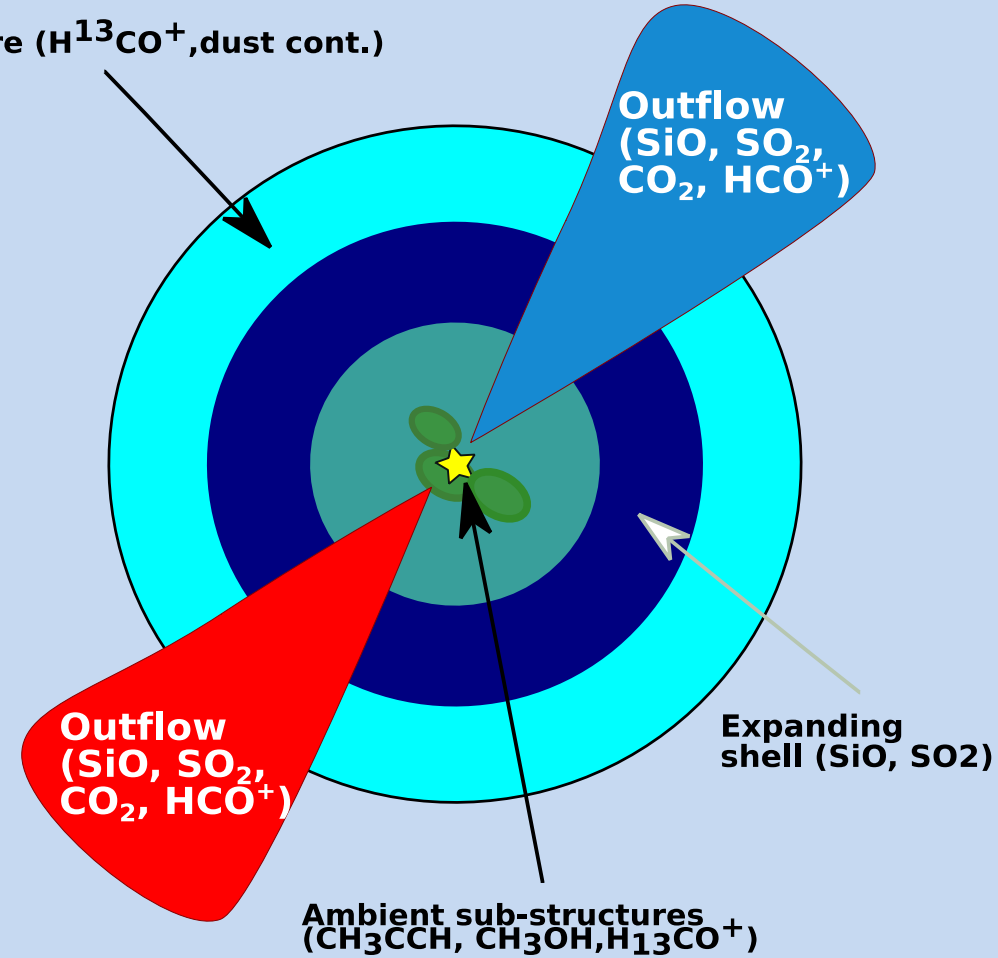


1985
MINI:
Resolution
8.3` (500¨)

Model of G331.5
Molecular Outflow

ALMA Resolution: 1”
(2012)

Timescale less than
1000 years
(Total life 1 MY)

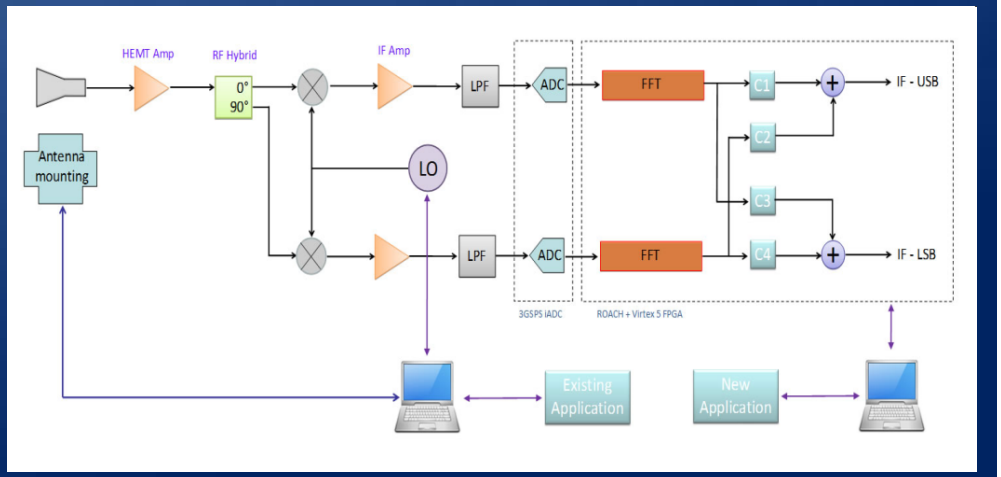


- In the meantime: relocation of the Southern MINI to Cerro Calán, (OAN Universidad de Chile, 2009)

The 1.2 m telescope at U. Chile OAN, Cerro Calán

- Hands-on training for Astronomy students
- Engineering graduate and undergraduate theses.
- Receiver upgraded using state-of-the-art digital technology

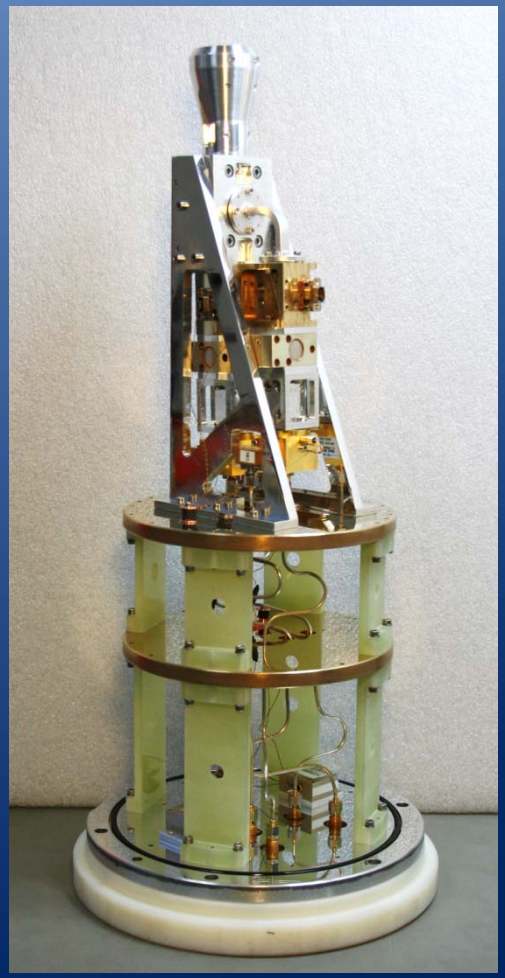
Southern Mini at Cerro Calán, July 2013



Digital sideband separating mixer using FPGA digital technology (ROACH).

ALMA Band 1 prototype receiver

Designed and built at U. Chile (NAOJ Cryogenics, Y. Sekimoto)



U. Chile Lab. Support for Tsukuba University Project

IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY

Development of a Transportable Telescope for Galactic Survey at 500 GHz in Antarctica

Shun Ishii, Masumichi Seta, Naomasa Nakai, Yusuke Miyamoto, Makoto Nagai, Hitoshi Arai, Hiroyuki Maezawa, Taketo Nagasaki, Naoki Miyagawa, Hideaki Motoyama, Yutaro Sekimoto, and Leonardo Bronfman

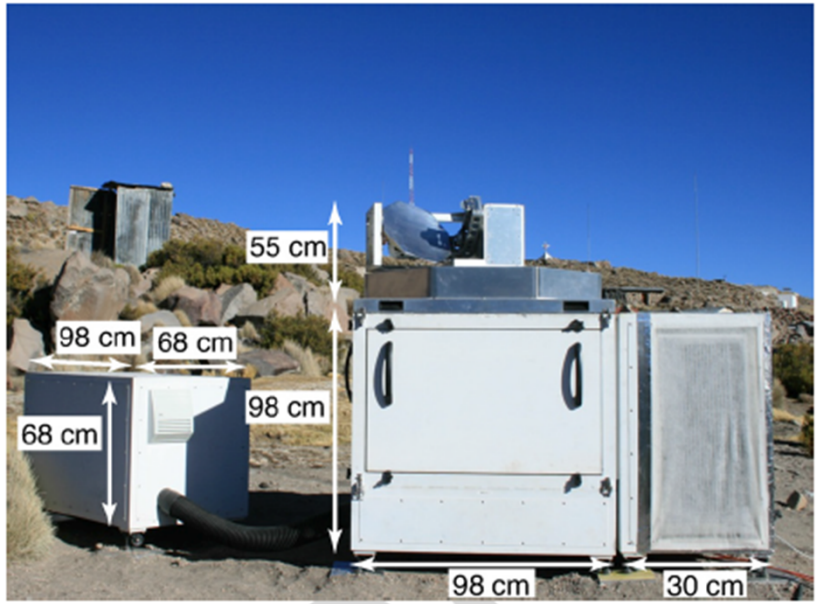


Fig. 9. Photograph of the 30-cm telescope in Chile with its size. The antenna subsystem is placed on 98 cm cube main box.

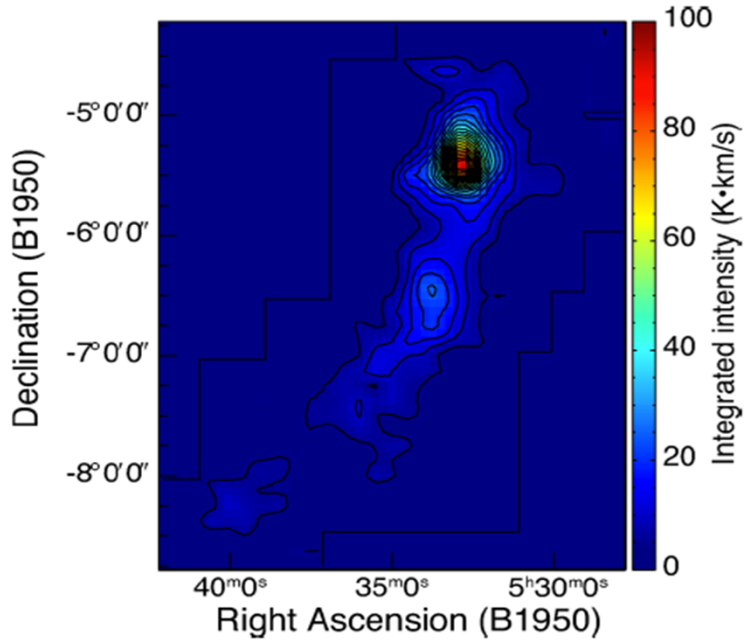


Fig. 15. Integrated intensity map of the CO ($J = 4 - 3$) toward Orion A GMC.

Thanks

2009 Setember

In memory of Prof. Jorge May (1936-2011)