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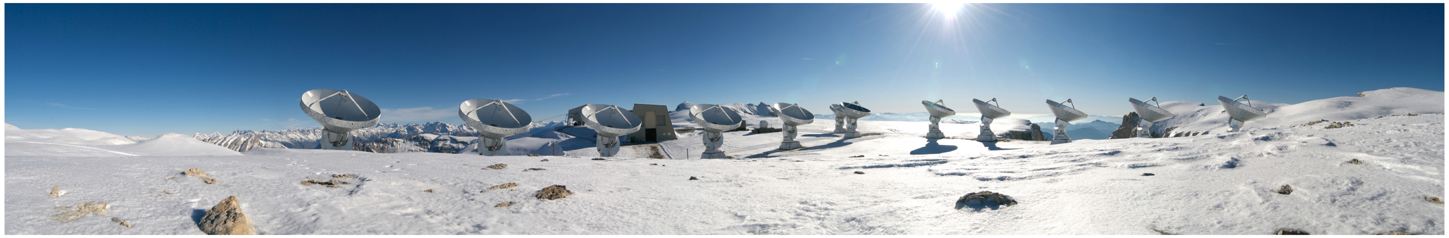
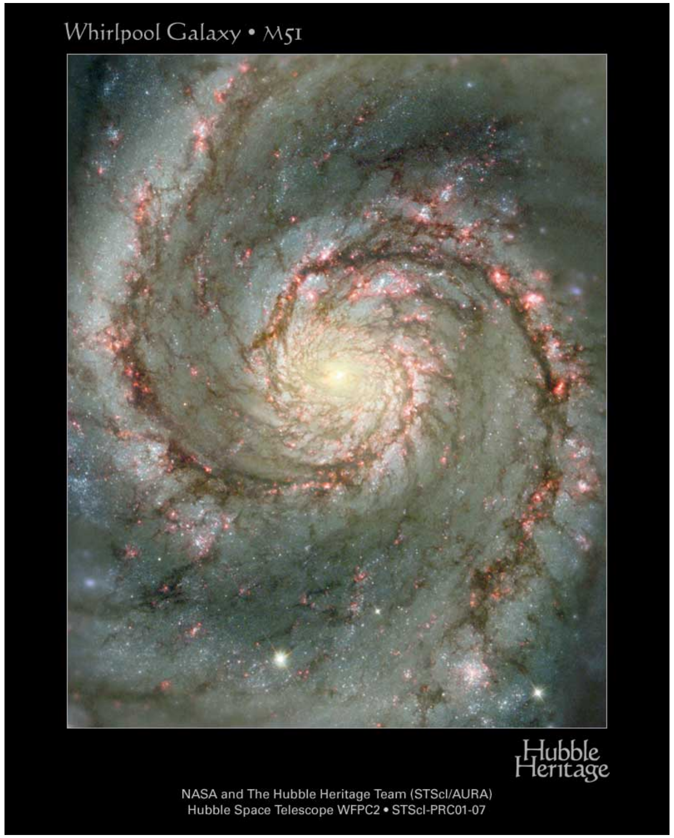
Directeur de l'Action Spécifique ALMA

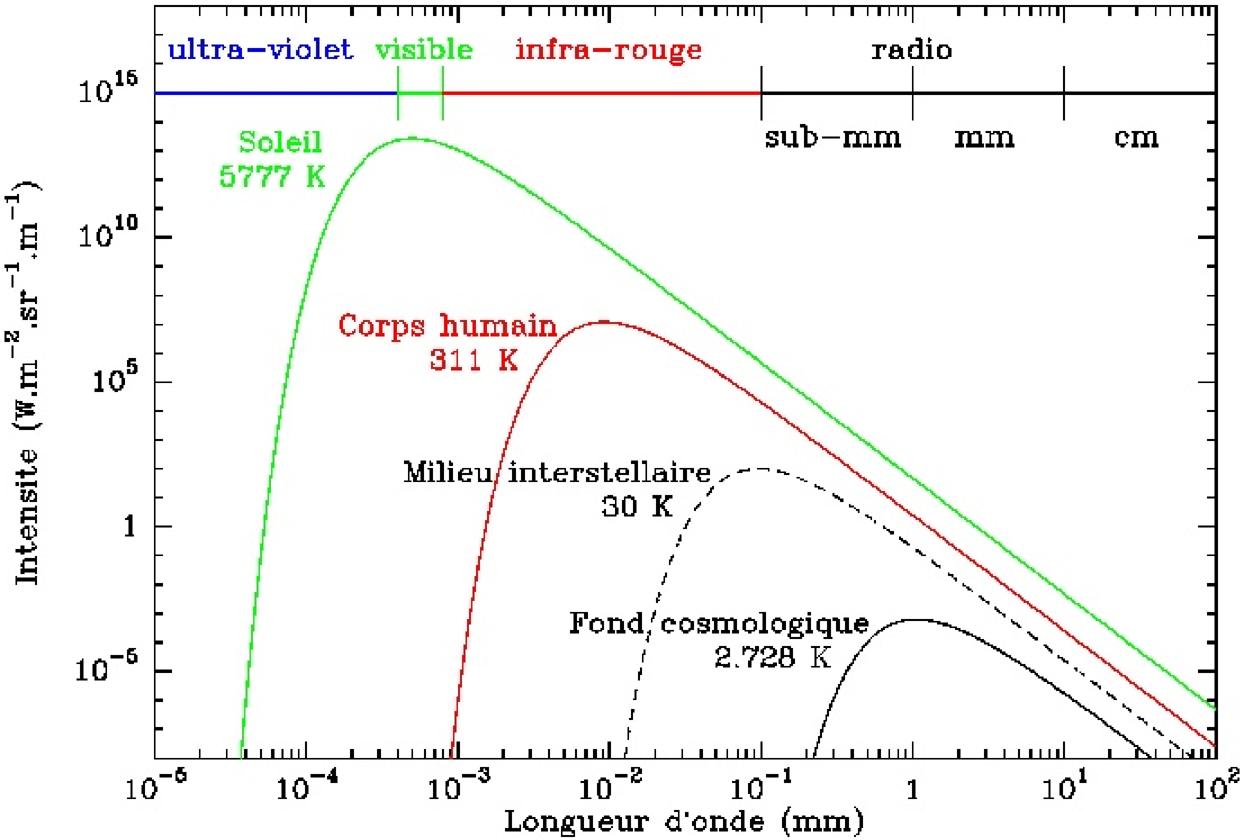
Radioastronomie (sub)-millimétrique du futur : IRAM/NOEMA et ALMA



CEA, 16 janvier 2012

Why doing (sub-)radio-astronomy?





Towards Higher Resolution: I. Problem

Telescope resolution:

- $\sim \lambda/D$;
- IRAM-30m: $\sim 11''$ @ 1 mm.

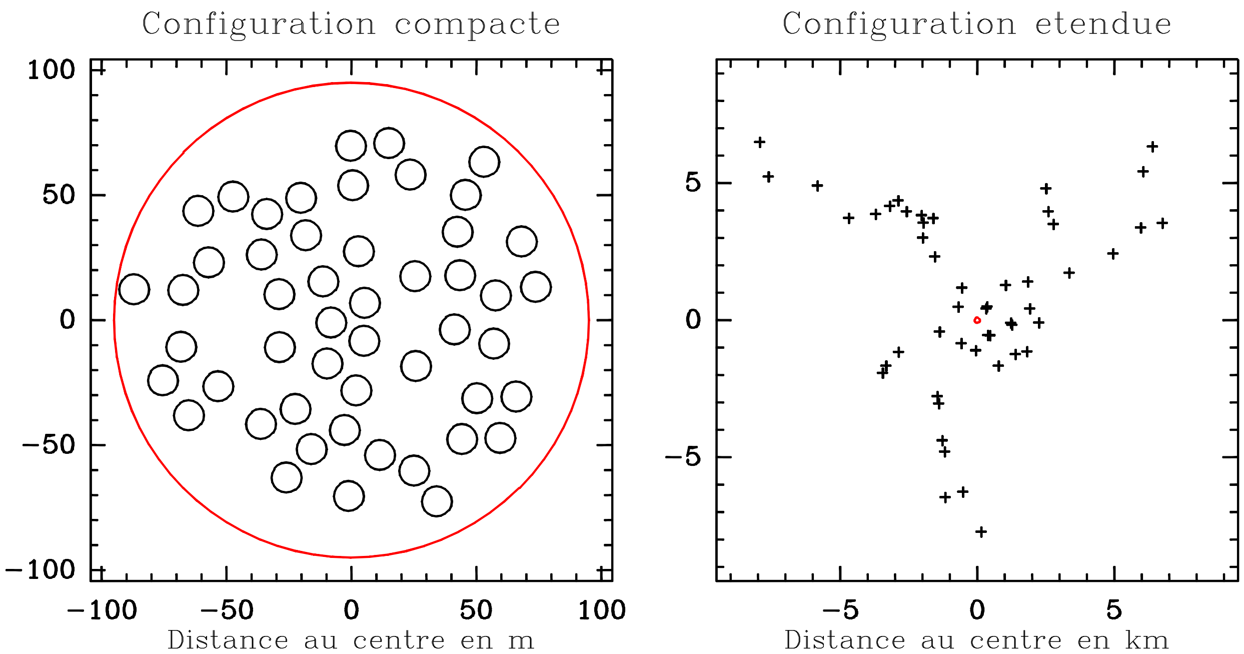
Needs to:

- increase D;
- increase precision of telescope positionning;
- keep high surface accuracy.

$\Rightarrow$ Technically difficult (perhaps impossible?).

Towards Higher Resolution:
II. Solution

Aperture Synthesis: Replacing a single large telescope by a collection of small telescope "filling" the large one.
⇒ Technically difficult but feasible.



Vocabulary and notations:

Baseline Line segment between two antenna.

b_{ij} Baseline length between antenna i and j.

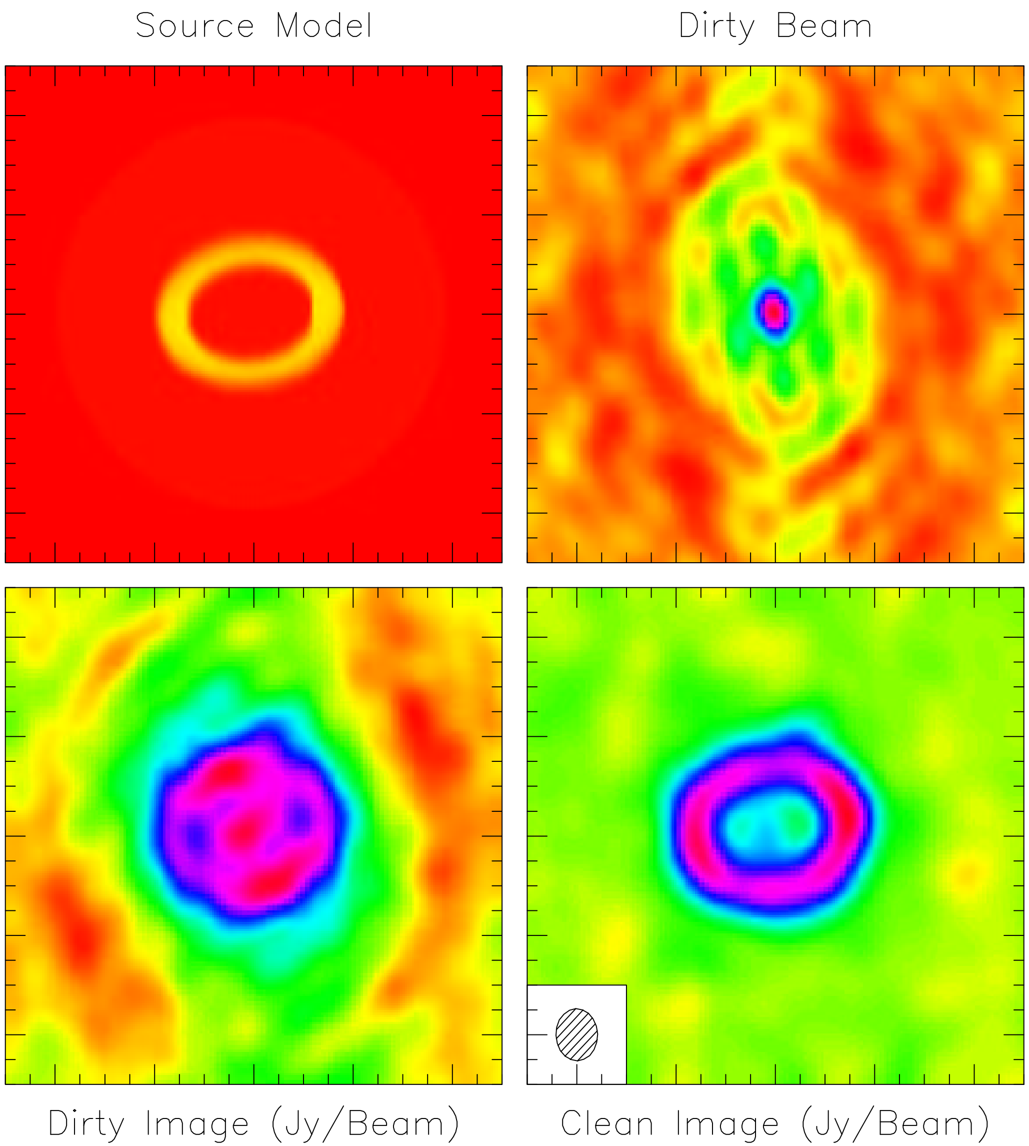
Configuration Antenna layout (*e.g.* compact configuration).

D configuration size (*e.g.* 150 m).

Primary beam resolution of one antenna (*e.g.* 27″ @ 1 mm).

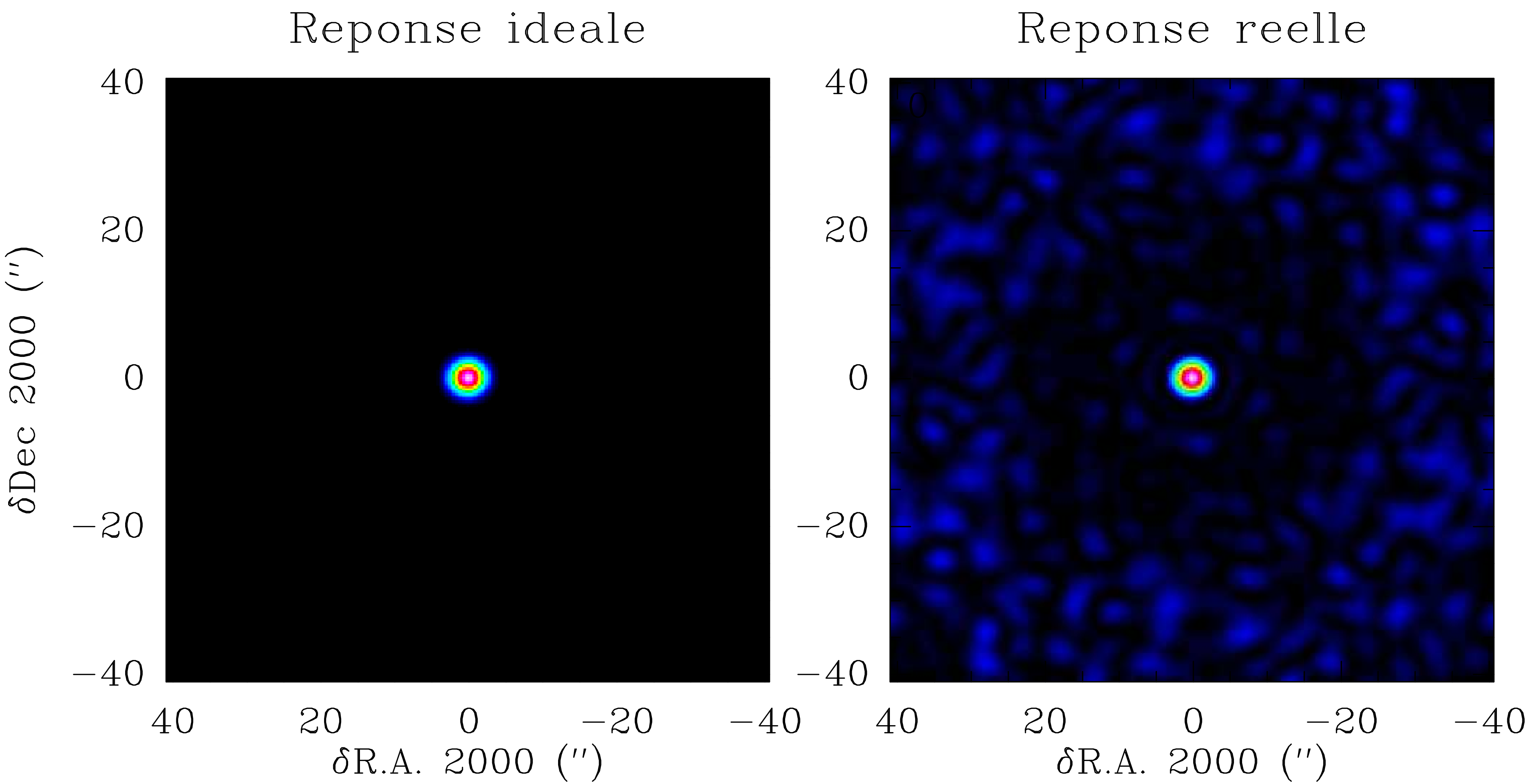
Synthesized beam resolution of the array (*e.g.* 2″ @ 1 mm).

On the need of deconvolution: I. Current interferometers



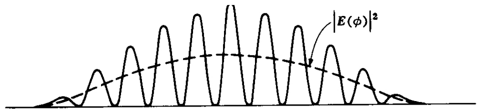
- Difficult to do science on dirty image.
- Deconvolution ⇒ a clean image compatible with the sky intensity distribution.

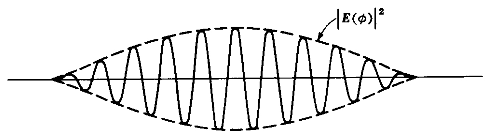
On the need of deconvolution: II. Future interferometers



Optic vs Radio Interferometer: I. Measurement Method

		Optic	Radio
Detector	Kind	Quadratic	Linear (Heterodyne)
	Observable	$I = \|EE^\star\|$	$\|E\| \exp(i\psi)$
Measure	Method	Optical fringes	Electronic correlation
	Quantity	$\|C\| = \frac{I_{\max}-I_{\min}}{I_{\max}+I_{\min}}$	$\|V\| \exp(i\phi_V) = < E_1.E_2 >$
Interferometer kind		Additive	Multiplicative



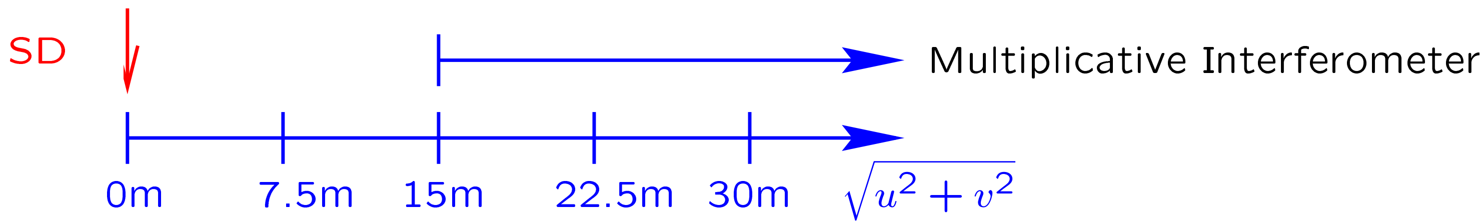


Multiplicative Interferometer

Avantage: all offsets are irrelevant $\Rightarrow$ Much easier;

Inconvenient: Radio interferometer = bandpass instrument;

$\Rightarrow$ Low spatial frequencies are filtered out.



Optic vs Radio Interferometer: II. Atmospheric Influence

Atmosphere emits and absorbs:

Signal = Transmission * Source + Atmosphere.

- Optic: $\left.\begin{cases} \text{Source} \gg \text{Atmosphere} \\ \text{Transmission} \sim 1 \end{cases}\right\} \Rightarrow$ transparent;
- Radio: $\left.\begin{cases} \text{Source} \ll \text{Atmosphere} \\ \text{Transmission can be small} \end{cases}\right\} \Rightarrow$ fog.

Good news: Atmospheric noise uncorrelated

$\Rightarrow$ Correlation suppresses it!

Bad news: Transmission depends on weather and frequency.

$\Rightarrow$ Astronomical sources needed to calibrate the flux scale!

Atmosphere is turbulent: $\Rightarrow$ Phase noise.

Timescale of atmospheric phase random changes:

- Optic: 10-100 milli secondes;
- Radio: 10 minutes.

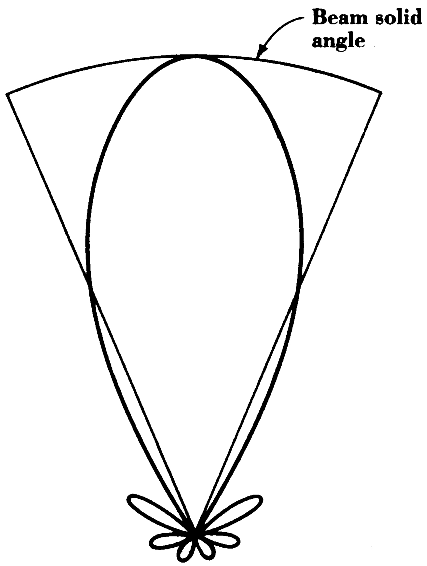
$\Rightarrow$ Radio permits phase calibration on a nearby point source (*e.g.* quasar).

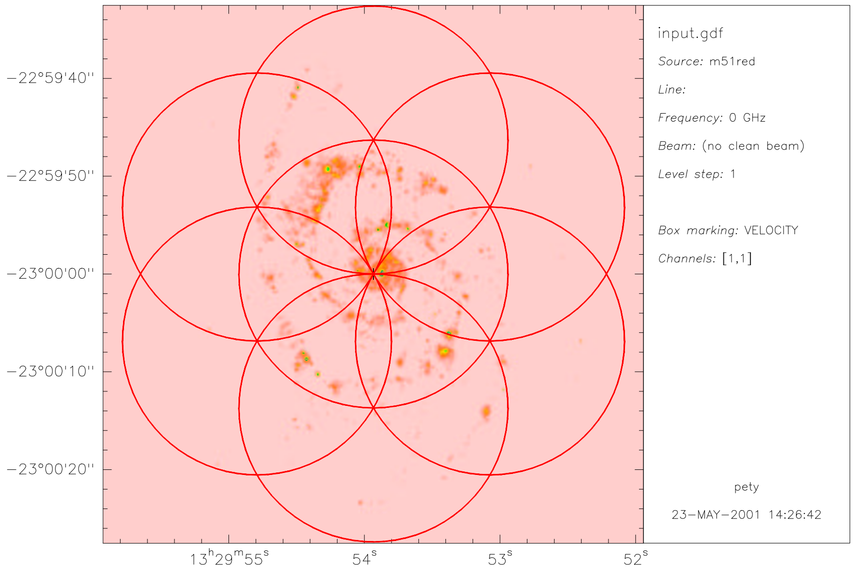
Instantaneous Field of View

One pixel detector:

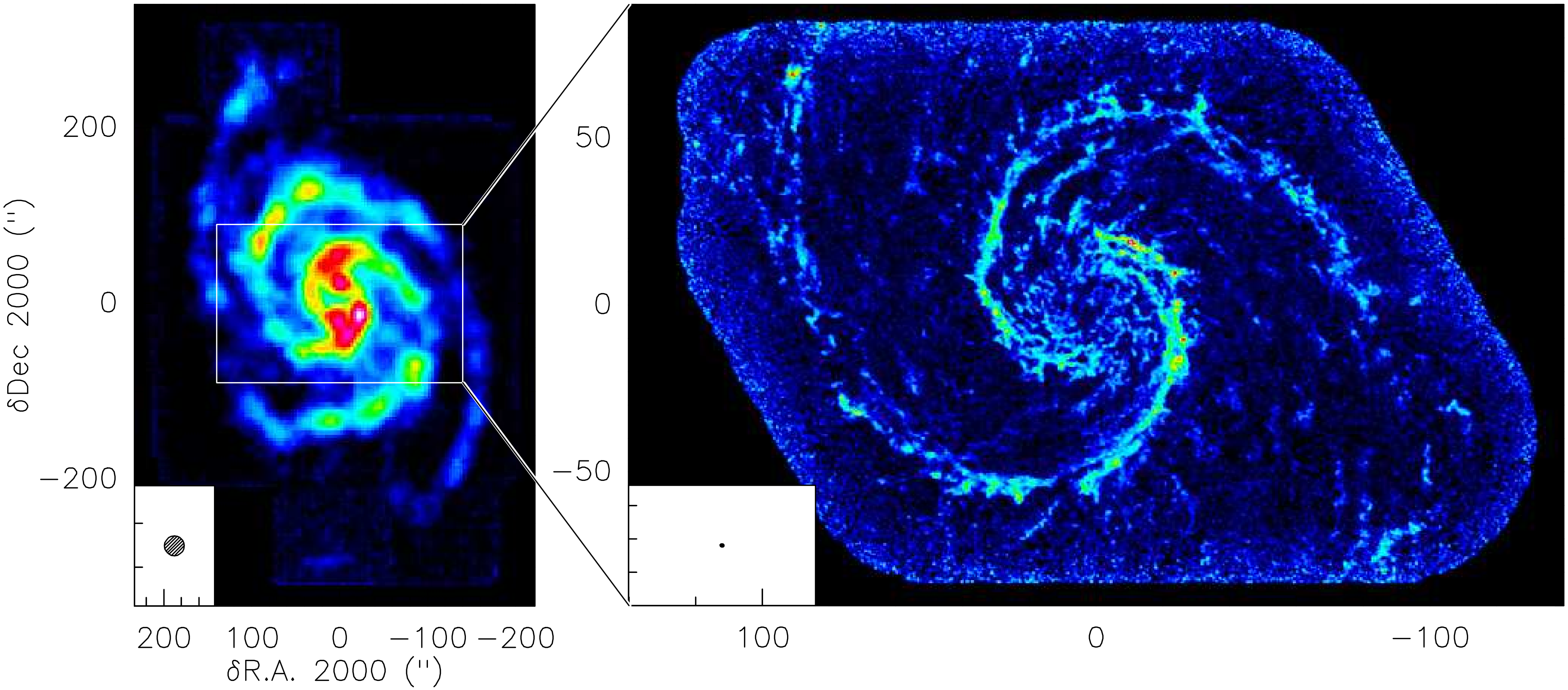
- Single Dish: one image pixel/telescope pointing;
- Interferometer: numerous image pixels/telescope pointing
  - Field of view = Primary beam size;
  - Image resolution = Synthesized beam size.

Wide-field imaging: ⇒ mosaicing & on-the-fly (Pety & Rodriguez-Fernandez, A&A, 2010).



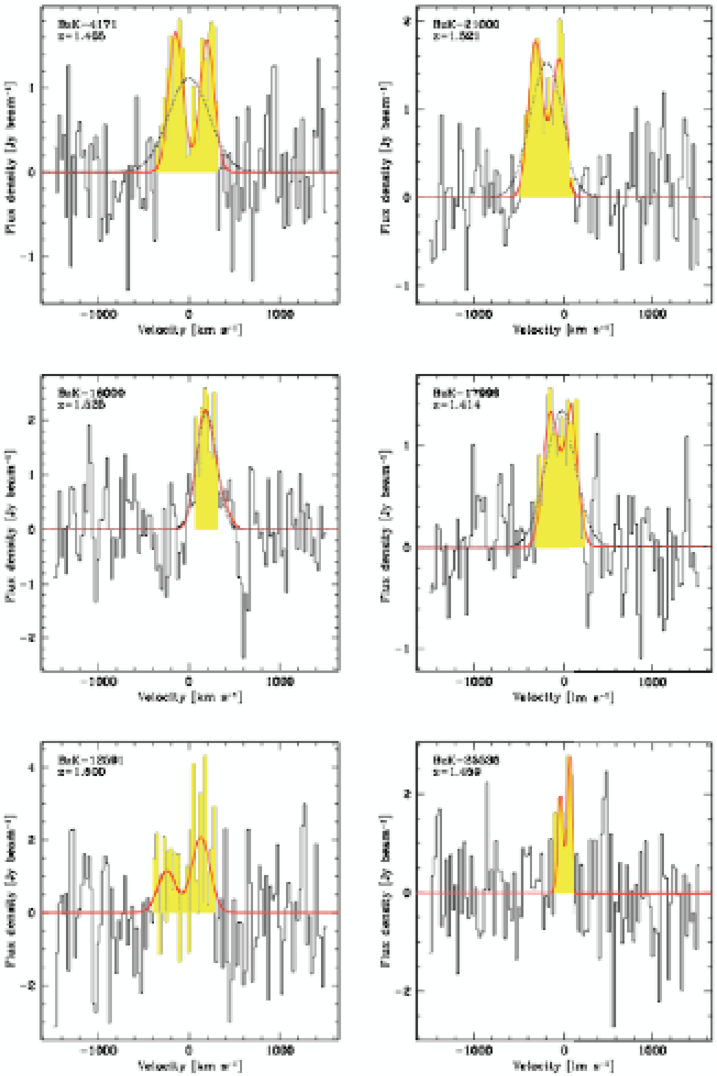


It works! Molecular gas of M51 mapped in ^{12}CO (J=1–0) at the IRAM-30m and the PdBI

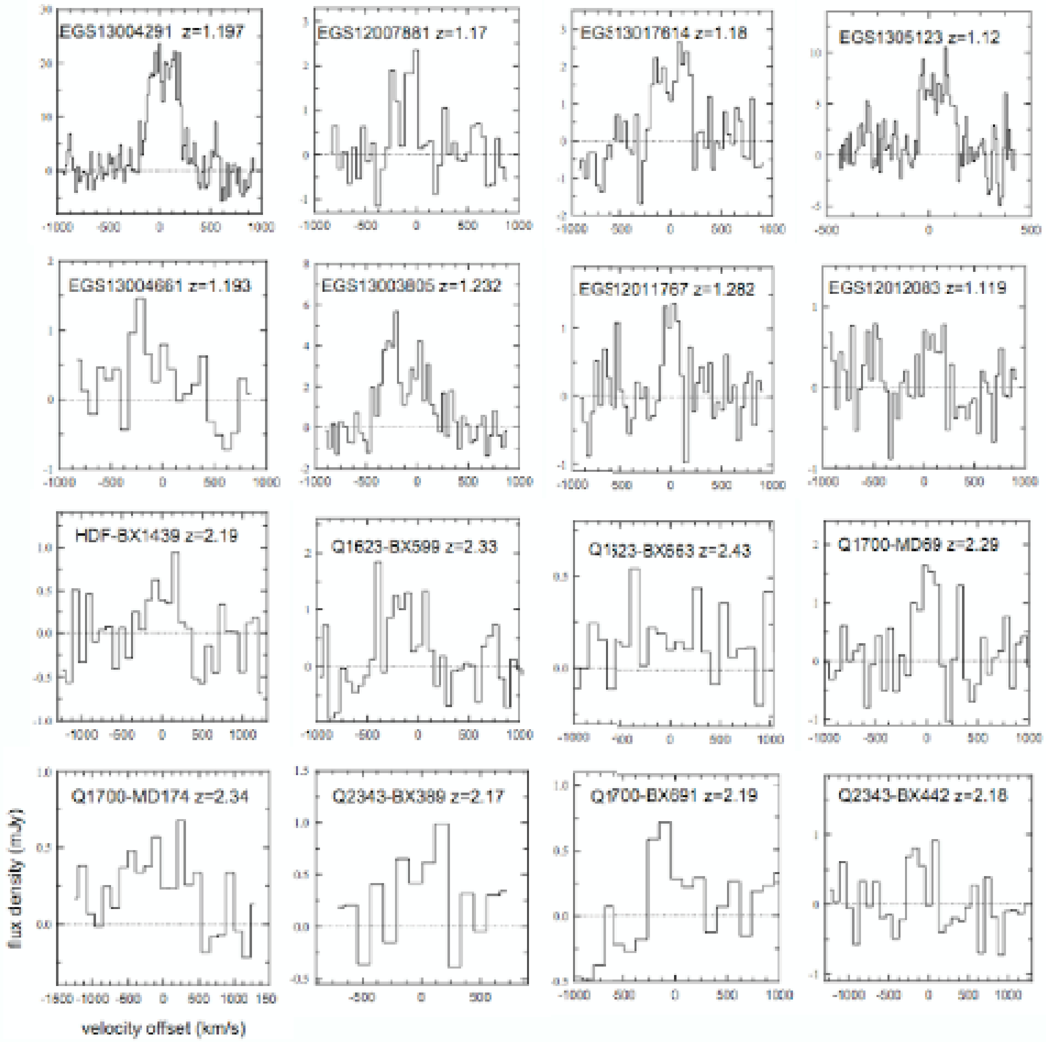


Pety et al., in prep as part of the PAWS project (PI E.Schinnerer).

Science with PdBI: I. Molecular gas in massive galaxies at $z = 1.5 - 2.5$

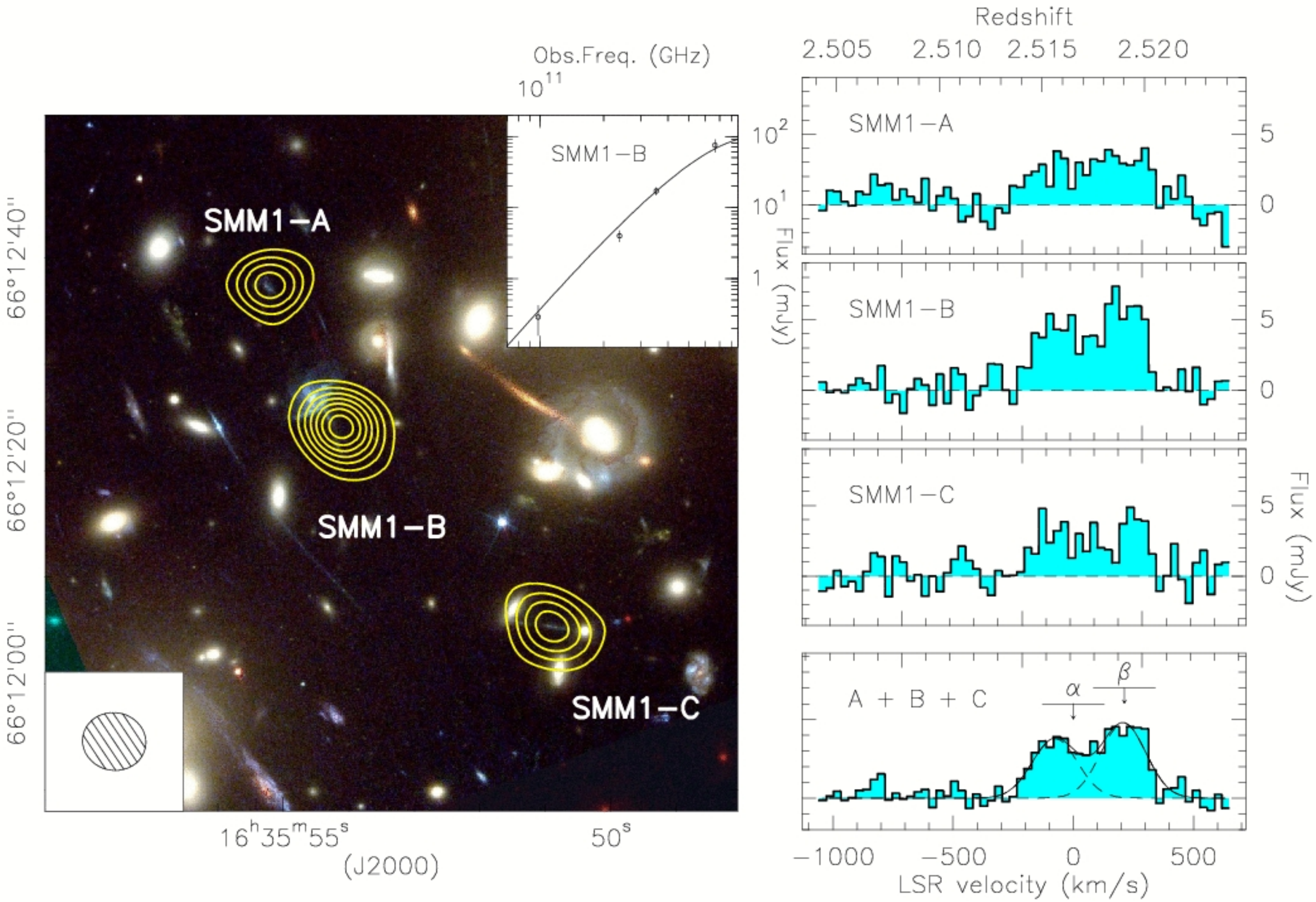


Daddi et al. 2008; 2010



Tacconi et al. 2010

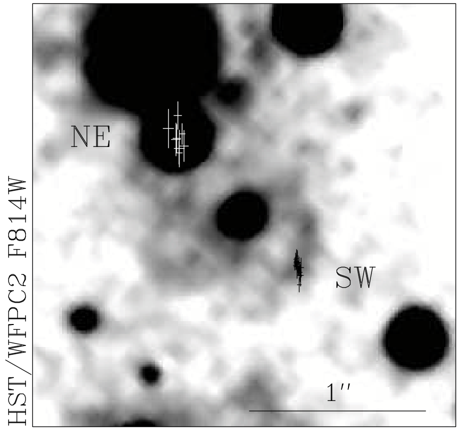
Science with PdBI: II. Molecular gas at $z \sim 2.5$
Kneib et al., 2005, A&A



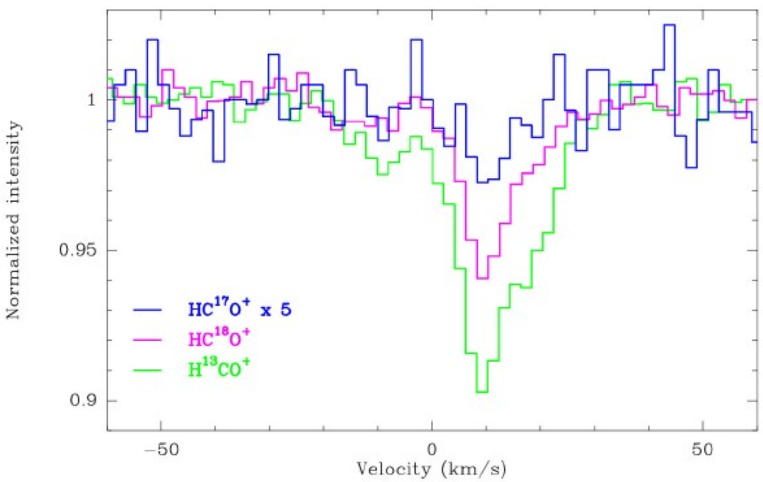
- CO (3-2) emission line.
- SMMJ16359+6612 at $z \sim 2.5$ lensed by Abell 2218 cluster.
- Magnification factor: 45.
- Intrinsically faint galaxy: 0.8 mJy at 0.850 mm.
- Likely a compact merger of 2 typical star-forming galaxies separated at most by 3 kpc.

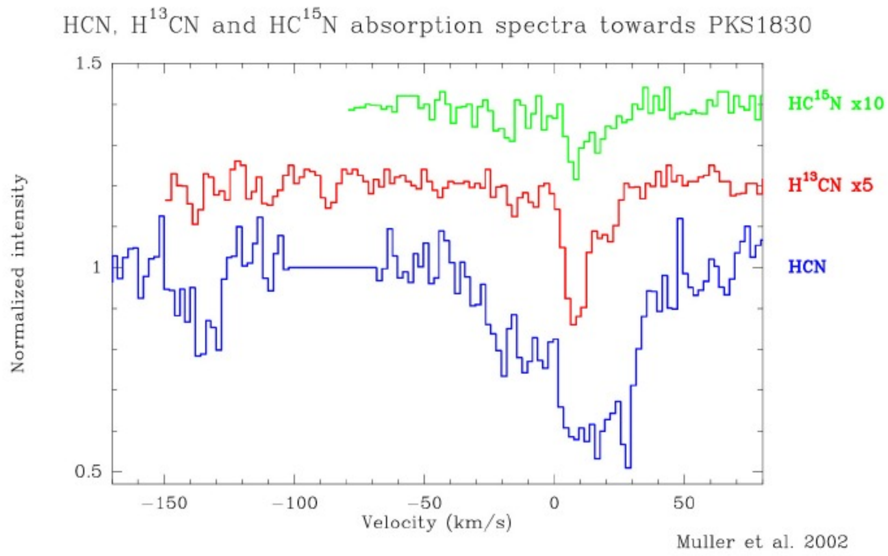
⇒ Probe of an object contributing to the far-infrared cosmic background.

Science with PdBI: III. Nucleosynthesis at z=0.89
Muller et al., 2006 & 2007, A&A

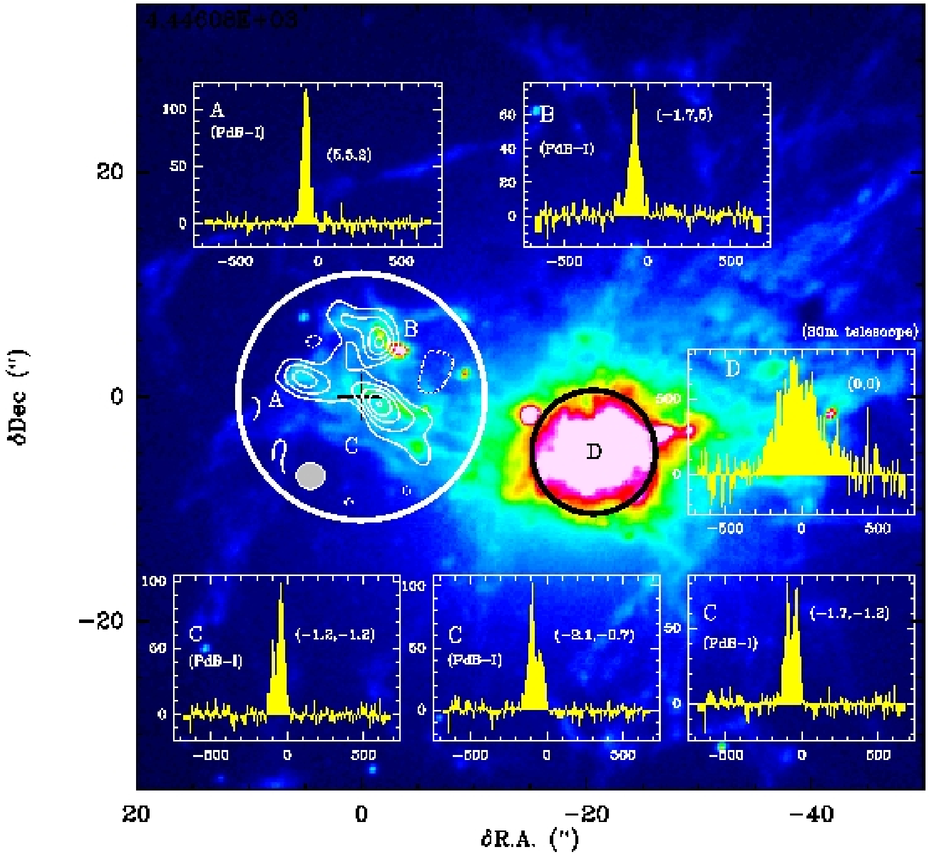


	^{12}C / ^{13}C	^{14}N / ^{15}N	^{16}O / ^{18}O	^{18}O / ^{17}O	^{32}S / ^{34}S
z = 0.89 galaxy	**27 ± 2**	**130** $^{+20}_{-15}$ †	**52 ± 4** †	**12** $^{+3}_{-2}$	**10 ± 1**
Solar System (a)	89	270	490	5.5	22
Local ISM (b)	59 ± 2	237 $^{+27}_{-21}$	672 ± 110	3.65 ± 0.15	19 ± 8
Galactic Center (c)	25 ± 5	900 ± 200	250 ± 30	3.5 ± 0.2	18 ± 5
IRC+10216 (d)	45 ± 3	> 4400	1260 $^{+315}_{-240}$	0.7 ± 0.2	21.8 ± 2.6
LMC (e)	62 ± 5	114 ± 14	> 2000	1.8 ± 0.4	18 ± 6
NGC 253 (f)	40 ± 10	–	200 ± 50	6.5 ± 1	8 ± 2
NGC 4945 (g)	50 ± 10	105 ± 25	195 ± 45	6.4 ± 0.3	13.5 ± 2.5



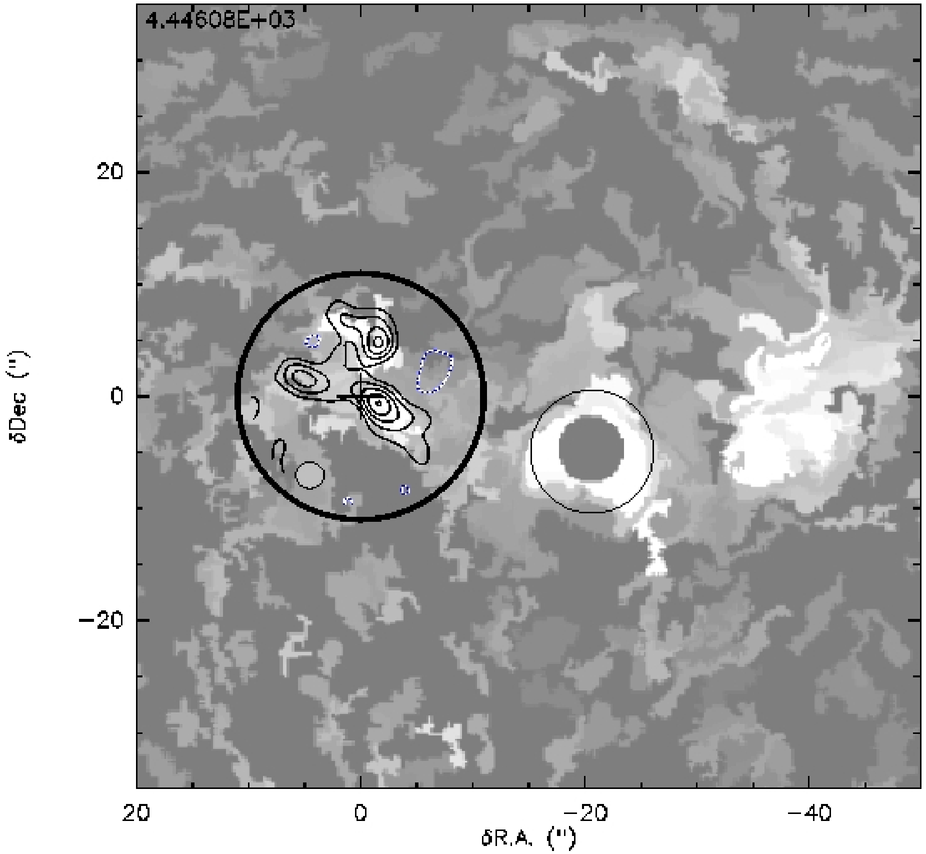


Science with PdBI: IV. Cooling flows in Perseus
Salome et al., 2008, A&A



CO(2-1) PdBI over Hα

(Conselice et al. 2001)

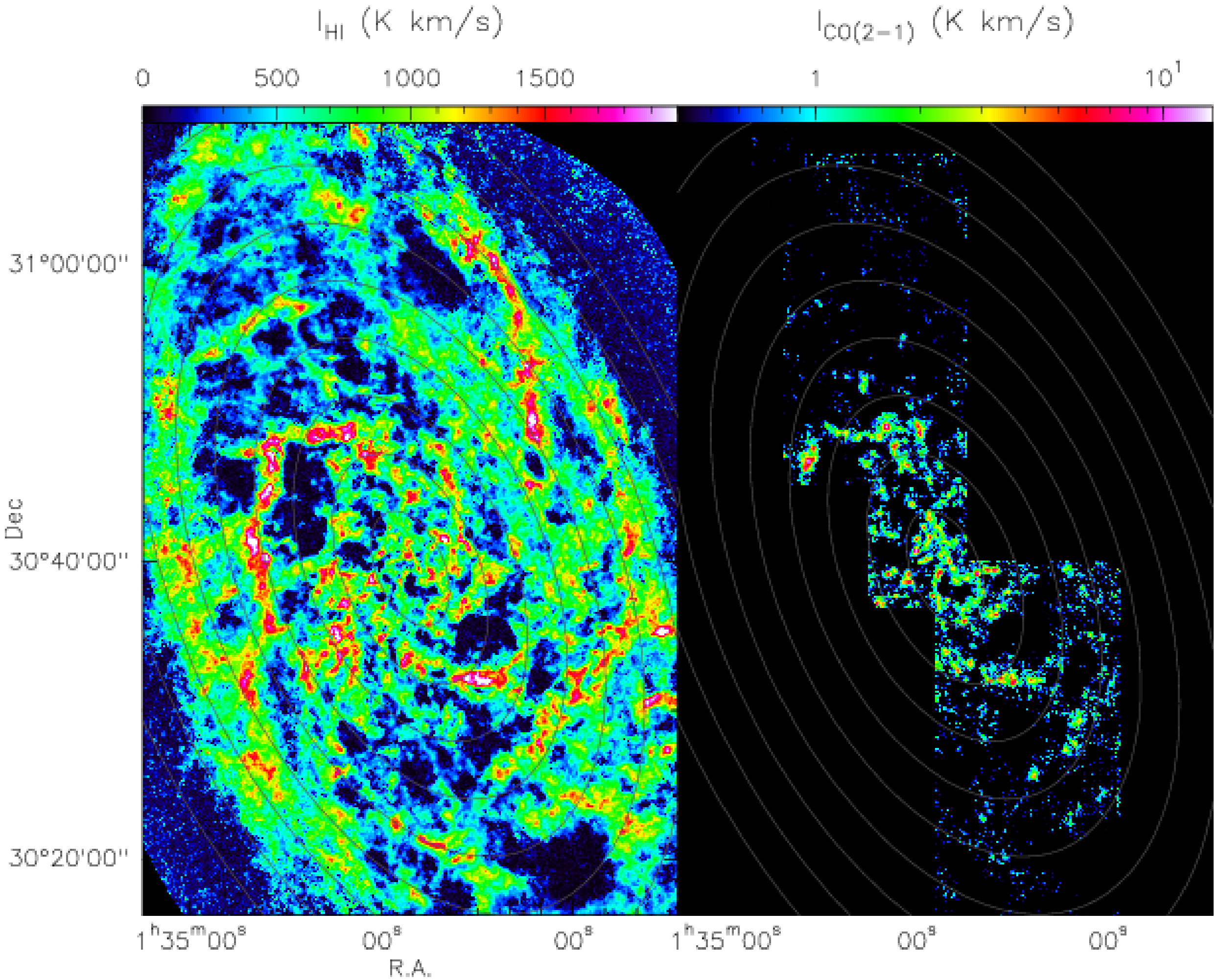


CO(2-1) PdBI over 0.5 KeV X-ray

(Fabian et al. 2006)

PdBI line much narrower than 30m lines.
Consistent with virialized GMCs falling back towards NGC1275.

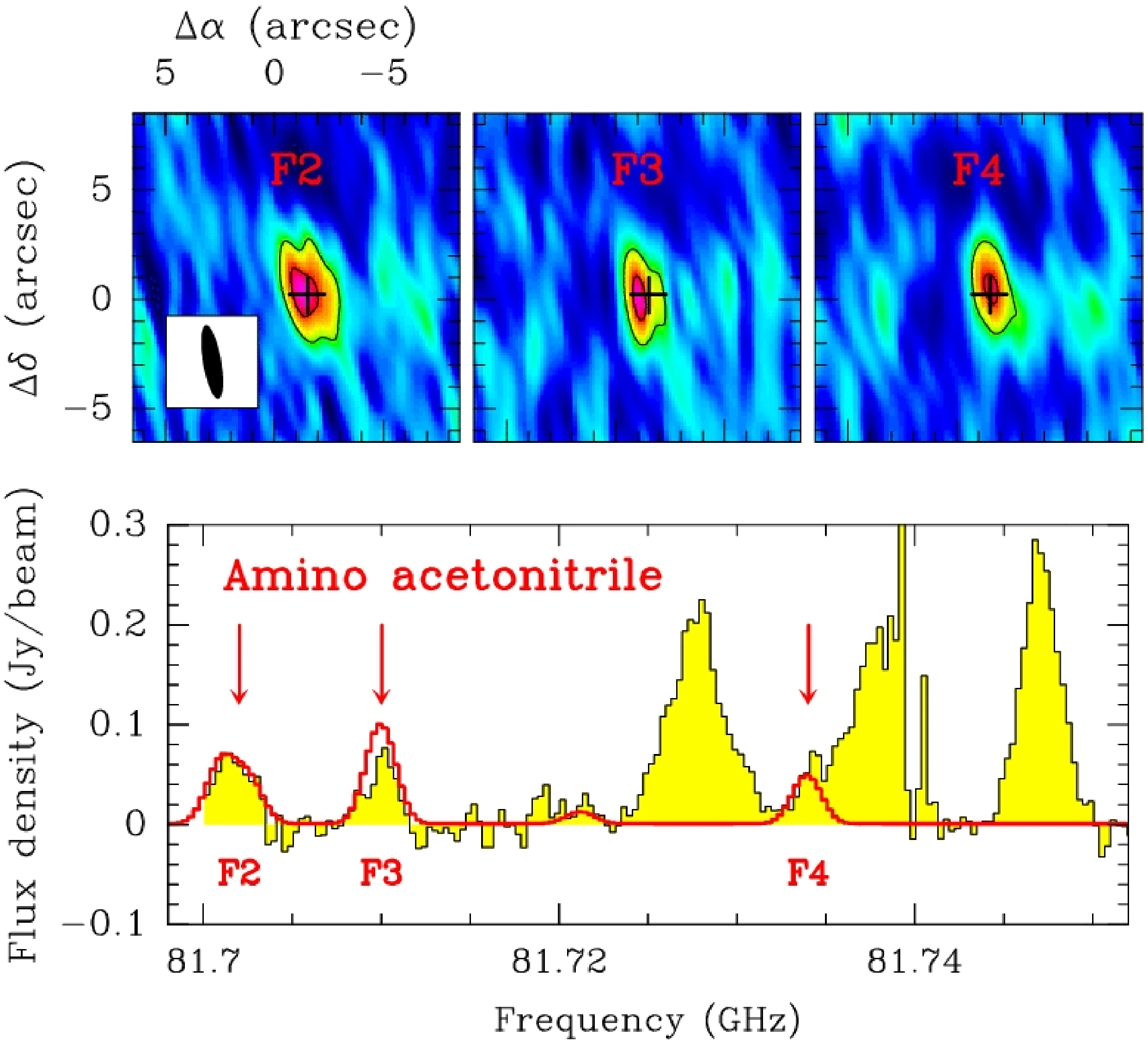
Science with IRAM: V. Characterizing GMCs in M33
Gratier et al., 2010, A&A



Left: HI from VLA. Right: ^{12}CO from IRAM-30m.

Science with PdBI: VI Dectection of amino-acetonitrile in Sgr B2(N)

Belloche et al., 2008, A&A

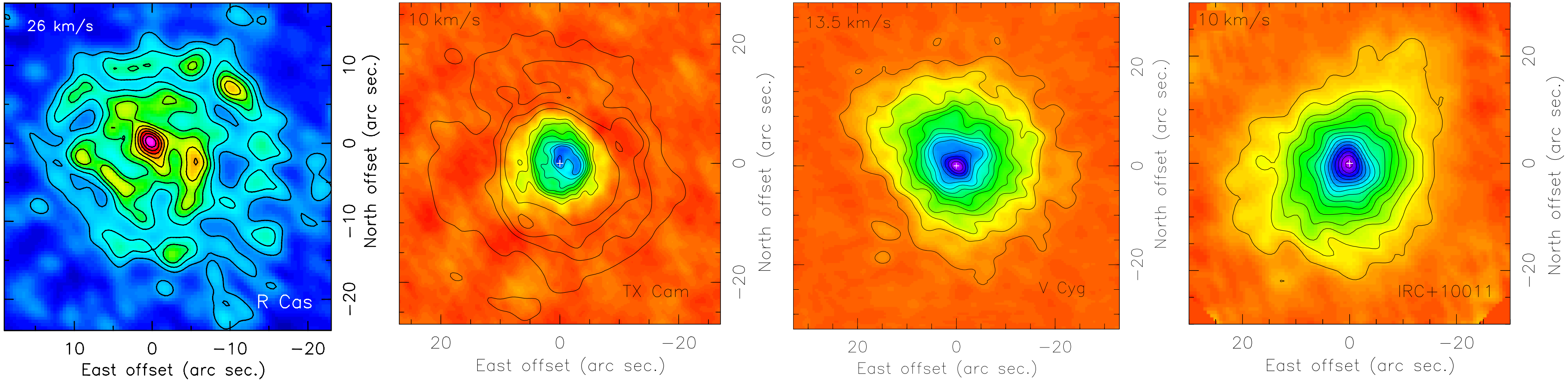


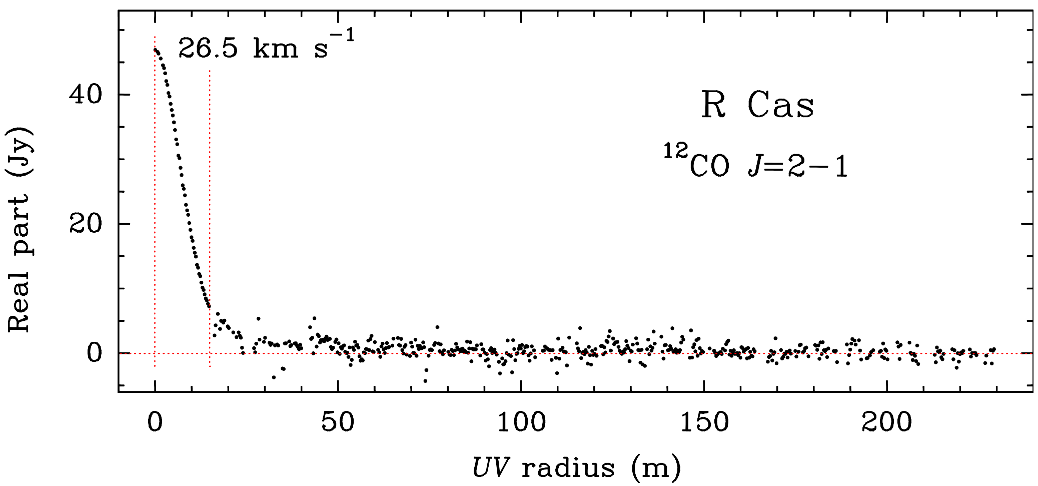
- Amino-acetonitrile: NH_2CH_2CN.
- Precursor of glycine (NH_2CH_2COOH), the simplest amino-acid.
- 51 weak 3mm features detected with the 30m and modelled with a unique rotation temperature of 100 K.
- 3 lines confirmed at PdBI from a 2″ region.

⇒ Glycine likely below the 3mm confusion limit in Sgr B2(N).

Science with PdBI: VII AGB mass loss

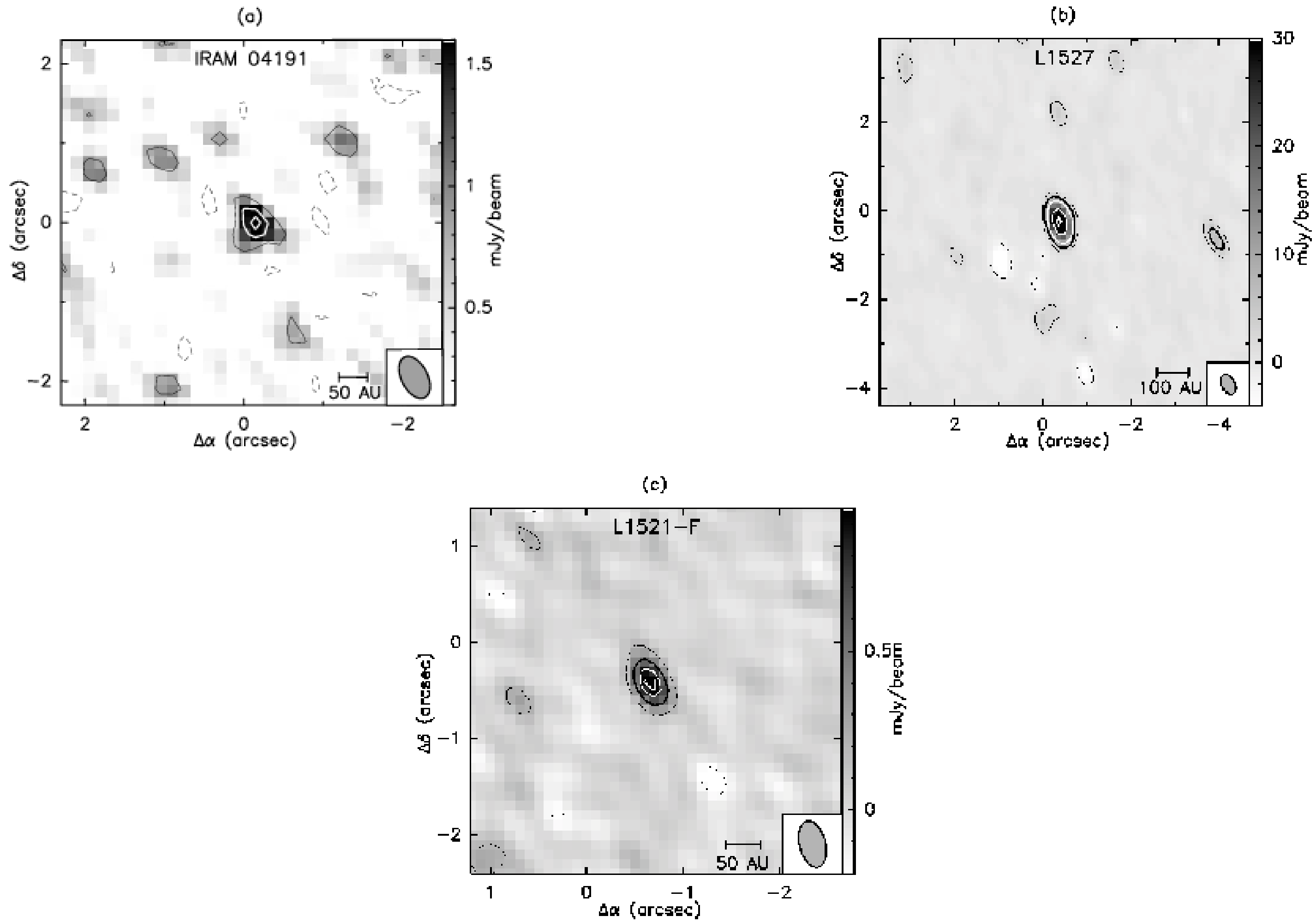
Arancha Castro-Carrizo et al., 2007, ASPC, 378, 199





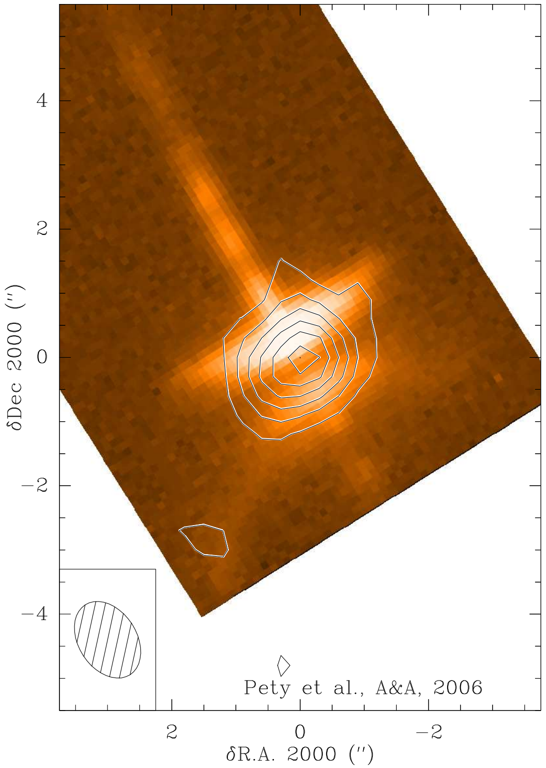
- 45 sources observed, in CO J=2-1 and J=1-0, in track sharing.
- Short-spacings from 30m essential.
- Clear asymmetries at different scales ⇒ Temporal variations of mass loss $<$ 1000 yrs.
- Axial winds are also detected in AGB circumstellar envelopes.

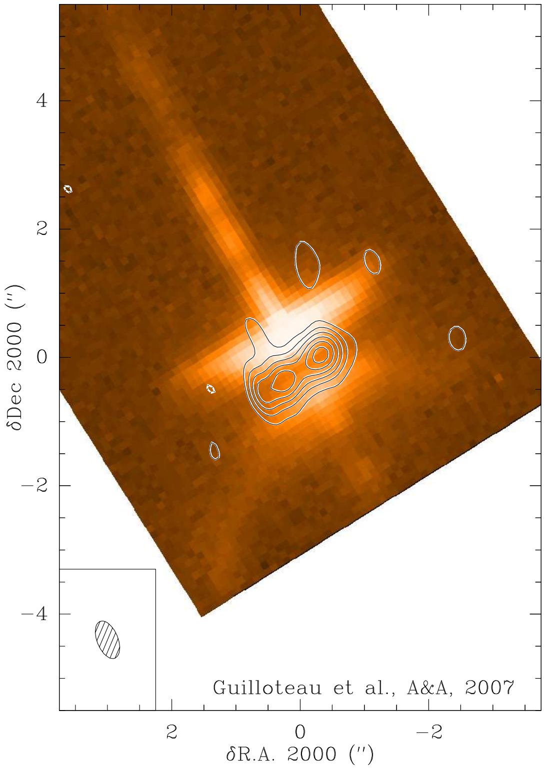
Science with PdBI: VIII Characterizing the formation of multiple system
Maury et al., 2010, A&A



No multiplicity detected in 3 Taurus class 0 objects.

Science with PdBI: IX Proto-planetary disks
Pety et al., 2006, A&A and Guilloteau et al., 2008, A&A



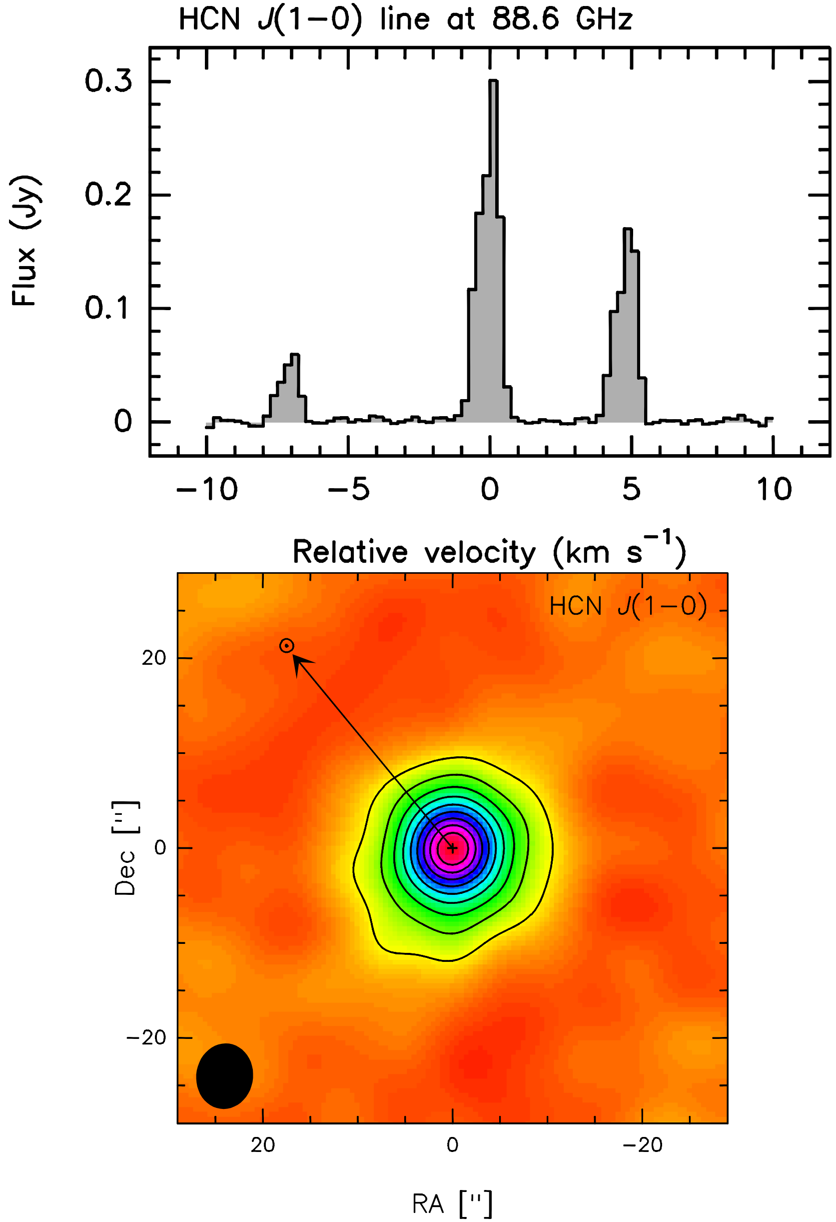


- HH30 1mm continuum before and after:
  - The doubling of the track extension.
  - The change of receiver generation (increase in sensitivity: ∼2).

  ⇒ Beam:
  From $1.29'' \times 0.91''$, PA 33 deg to $0.66'' \times 0.33''$, PA 22 deg
- HH30 is a binary system.

Boissier et al., A&A 2010

- Visible intensity gain of 14 magnitude on Oct. 24th, 2008.
- Snapshot at IRAM-30m to check gas detectability.
- HCN(1-0), HNC(1-0) + continuum observed during 8 hrs on Oct. 27th and 28th at PdBI, 2008. Typical resolution 6″.
- Discovered 200 years ago due to a similar outburst at approximately the same position of the orbit.



ALMA Summary: I. Politics

Web pages:
http://www.almaobservatory.org/
http://www.eso.org/sci/facilities/alma/index.html
http://www.alma.nrao.edu
http://www.nro.nao.ac.jp/alma/E/

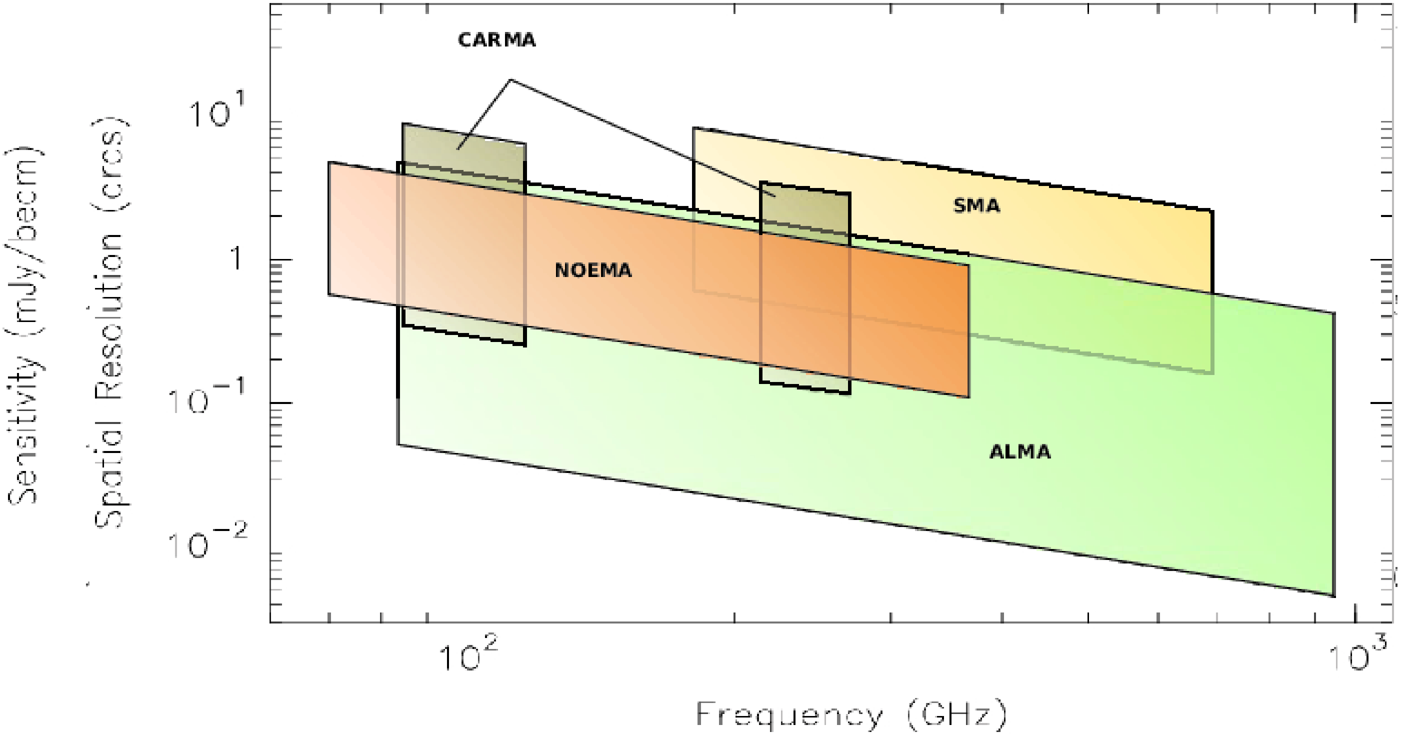
- Participants: Europe (ESO), North America, Asia (Japan, Taiwan), Chili.
- Budget:
  - Construction: $\sim$ \$800M (+\$250M for Japan);
  - Operation: \$65M per year ramping from 2007 to 2012.
- Schedule: Final delivery: 2013.
- Responsabilities:
  - Director: T. De Graauw.
  - Project Scientist: R.Hills (ALMA), L.Testi (ESO), A.Wooten (NRAO), R.Kawabe (Japan).
  - F.Gueth (IRAM) in ASAC, R.Moreno (LESIA) in ESAC.
- France is "entitled" to $\sim$ 5% of the time.
- Time allocation:
  - One worldwide committee;
  - No provision for legacy programs.
- User support: ALMA Regional Centers.

ALMA Summary: II. Technics

http://www.almaobservatory.org/
http://www.eso.org/sci/facilities/alma/index.html
http://www.alma.nrao.edu
http://www.nro.nao.ac.jp/alma/E/

- Location: Atacama, Northern Chili, Altitude 5000 m.
- Instrument kind: High-fidelity, high-angular resolution, submm interferometer.
  - 50 (to 64) 12m–antennas;
  - 4 12m-antennas for zero-spacing;
  - 12 7m-antennas for short-spacings.
- Configuration size: 150 m to 16 km.
- Antenna characteristics:
  - Surface accuracy: 25 μm rms;
  - Pointing accuracy: $0.6''$ rms in 9 m/s wind, $2''$ absolute in all sky.
- Spectral coverage:
  - Goal: all atmospheric windows between 80 GHz (4 mm) and 900 GHz (300 μm).
  - Budgeted: receivers for 6-7 out of the 10 possible bands.
- Instantaneous bandwidth: 8 GHz per polarization.
- Correlator: 4096 channels, full Stokes parameters.
- Water vapor radiometers: 183 GHz.
- Calibration accuracy goal: 3 to 5%.
- Data rate: 6 MB/s average; 64 MB/s peak.
- Archive: Raw + Pipeline images.

The NOEMA project: I. Which future for IRAM in the ALMA era?



Digression: Brightness noise and integration time

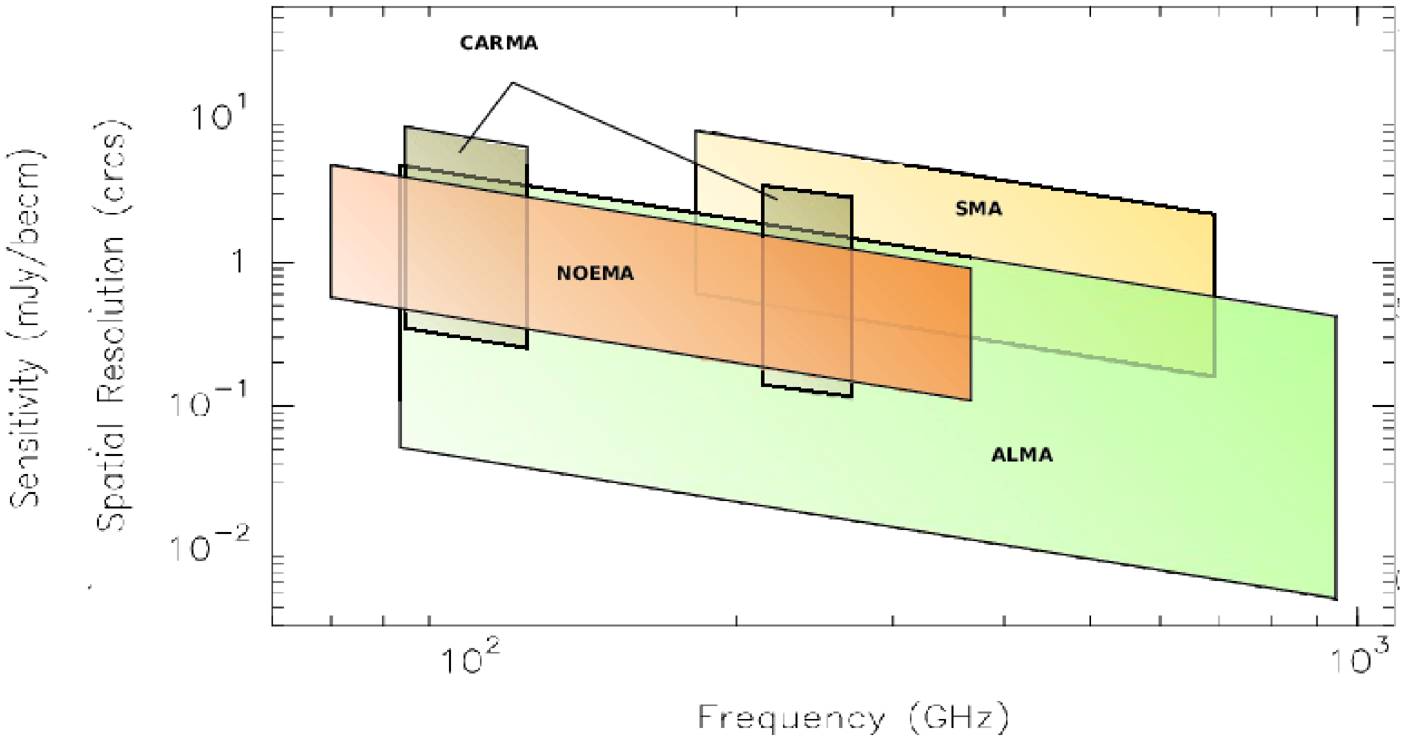
$$\delta T = \frac{\lambda^2}{2k}\frac{\sigma}{\Omega} \qquad \text{with} \qquad \sigma = \frac{2k}{\eta}\frac{T_{\text{sys}}}{\sqrt{\Delta t \Delta \nu}\sqrt{N_{\text{ant}}(N_{\text{ant}}-1)}A}$$

Channel width: $0.8\,\text{km}\,\text{s}^{-1}$. Wavelength: 1 mm. Decorrelation = 0.8.

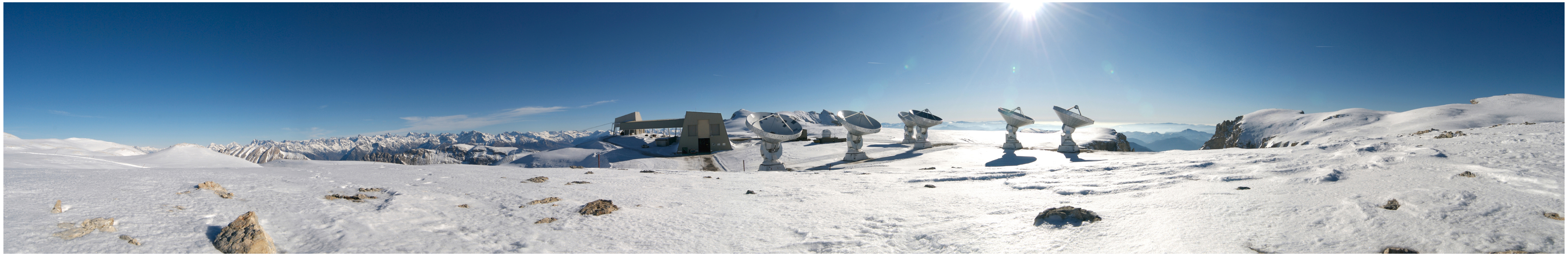
Instrument	Resolution	δT	On-source time	Comment
PdBI now	$1''$	0.3 K	2 hrs	
ALMA 2013	$1''$	0.3 K	3.5 min	Same line, many objects
ALMA 2013	$1''$	0.05 K	2 hrs	Fainter lines, same object
ALMA 2013	$0.1''$	0.3 K	575 hrs	6.5% of a civil year!
ALMA 2013	$0.1''$	5 K	2 hrs	Intermediate sensitivity
ALMA 2013	$0.4''$	0.3 K	2 hrs	Intermediate resolution

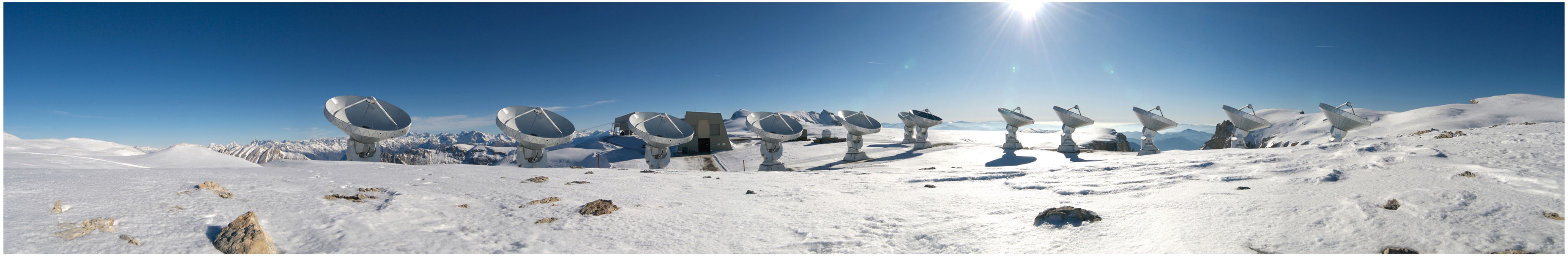
A factor $\sim$ 6 sensitivity increase
$\Rightarrow$A factor $\sim$ 2.4 resolution increase
(same integration time, same noise level).

The NOEMA project: I. Which future for IRAM in the ALMA era?



The NOEMA project: II. From 6 to 12 antennas





- Doubling the collecting area.
- Better uv instantaneous coverage (4.4 more baselines).
- Less configuration changes.

The NOEMA project: III. From 8 GHz to 32 GHz bandwidth:
3. Future 2SB receivers

Instrument	Bandwidth	σ	On time	Comments
PdBI 2005	1 GHz	1.0 mJy/Beam	96 min	
PdBI 2008	2 GHz	1.0 mJy/Beam	12 min	New receivers
PdBI today	8 GHz	1.0 mJy/Beam	3 min	New correlator
ALMA 2013	16 GHz	1.0 mJy/Beam	3 sec	
NOEMA 2016	32 GHz	1.0 mJy/Beam	11 sec	

The NOEMA project: IV. Cost and schedule

Support

- French astronomy prospective ranked NOEMA 1st in the medium size projects.
- 10 Meuros funded through EQUIPEX.
- 10 Meuros from MPG.
- 1 Meuros from IGN.
- 5 Meuros from IRAM investment budget.

Cost 44 Meuros, well determined as all components (except the correlator) were already built by IRAM.

Baseline

- 4 additional antennae.
- New receivers for all antennae.
- 12 antennae correlator.

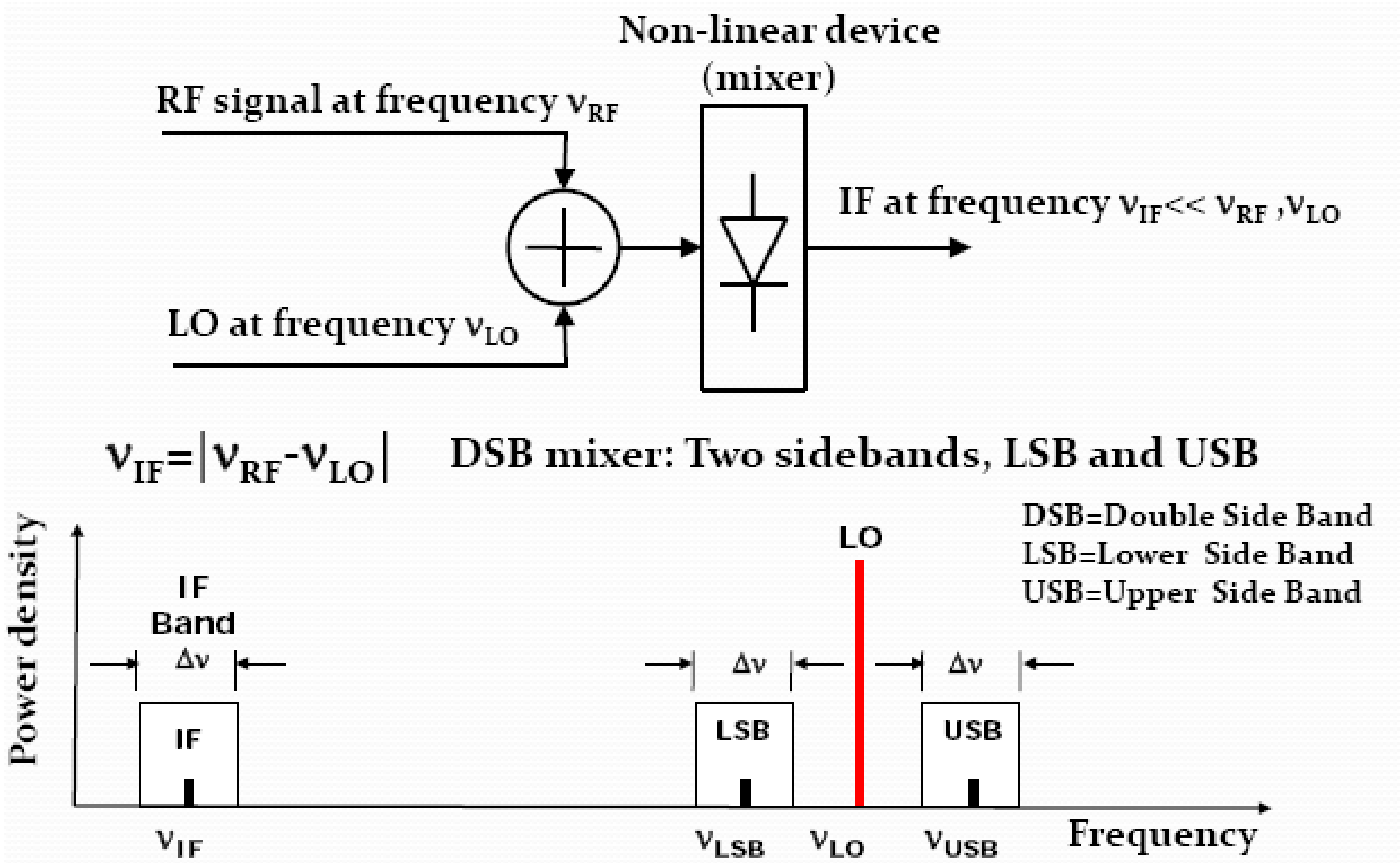
Schedule

- Design almost finished.
- Antenna construction will start in 18 months with a rate of 1 antenna added every 12 months.
- Project completion: in 5 years.

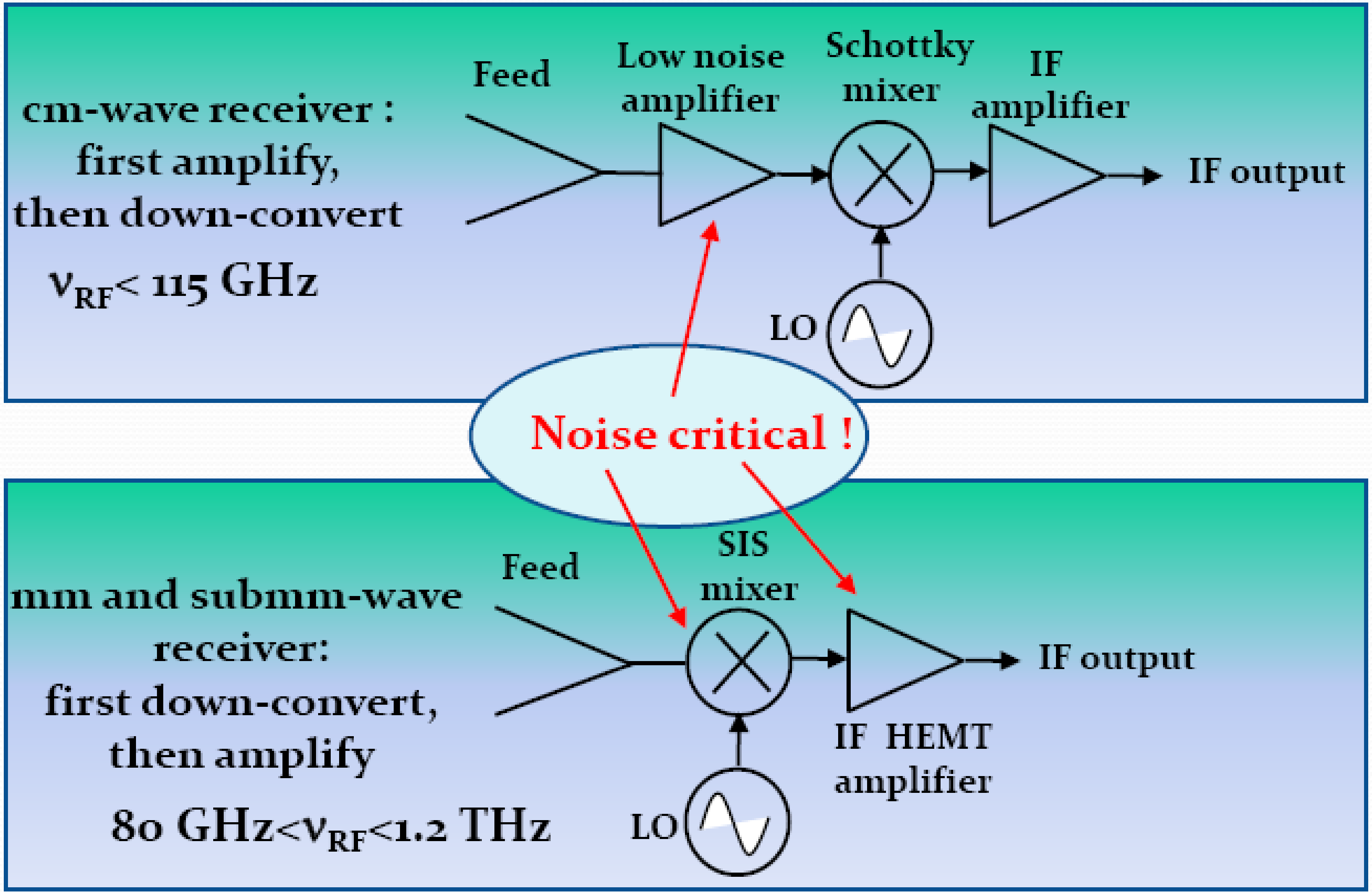
The NOEMA project: V. A project evolving over the decade 2011-2020

- Frequency extension to include 70-80 GHz range.
- Array phasing for VLBI.
- Dichroics for dual band observations (32 GHz per band).
- Multibeam receivers.

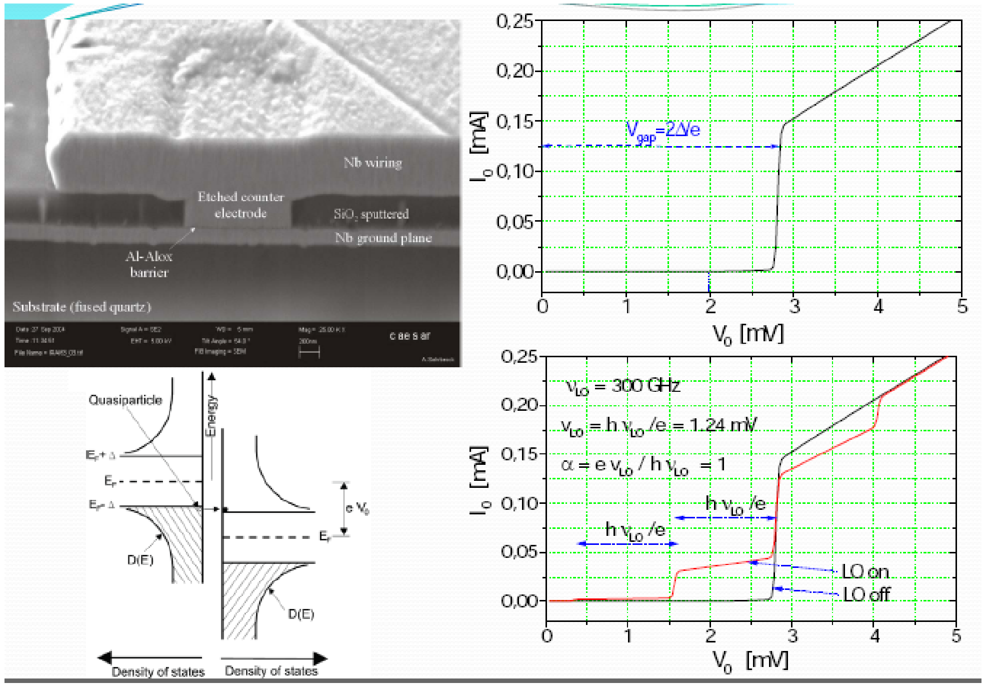
Receivers: I. Heterodyne frequency down-conversion
(Navarrini & the IRAM frontend group)



Receivers: II. cm versus mm receivers
(Navarrini & the IRAM frontend group)



Receivers: III. Superconductor-Isolator-Superconductor mixers (Navarrini & the IRAM frontend group)



SIS junction Nb/AlO$_x$/Nb.

AlO$_x$ barrier Thickness $\sim$ 1 nm, area $\sim$ 1 μm.

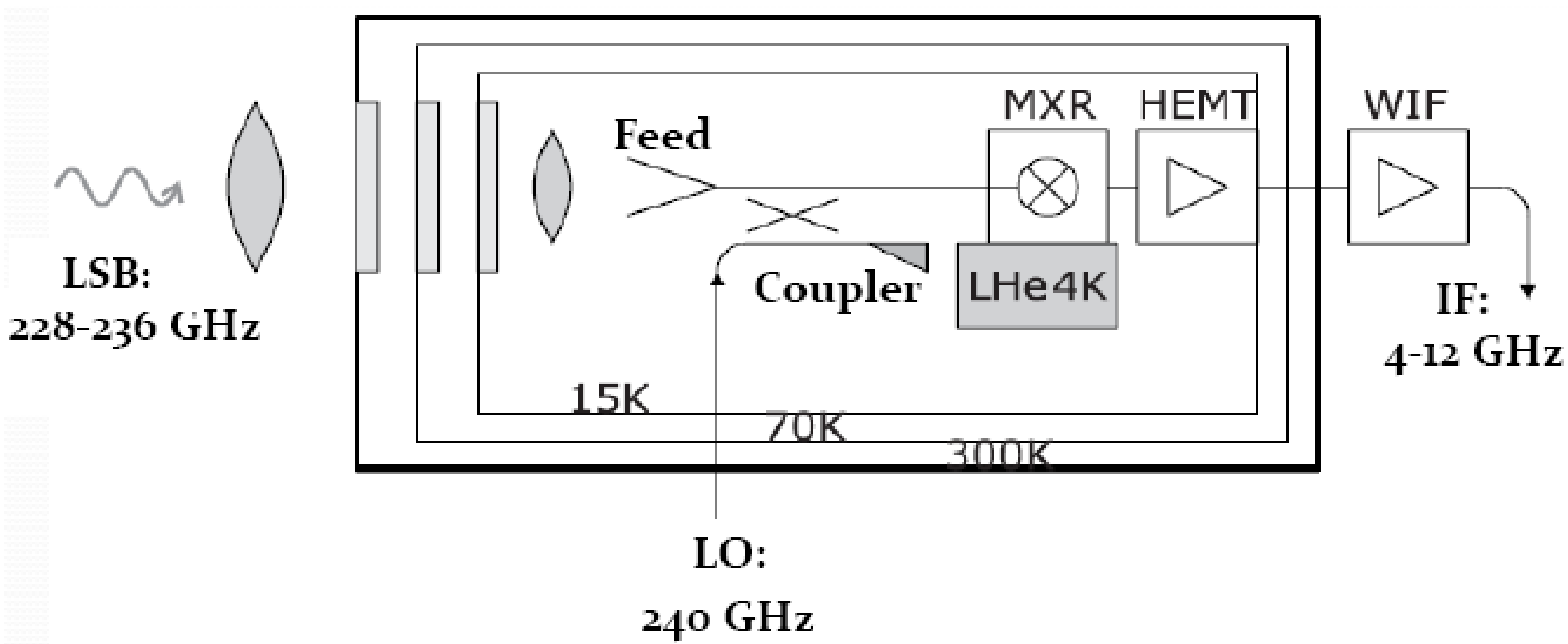
Principle Photon-assisted tunneling.

- Two kinds of particles in a superconductor: Cooper pairs & quasiparticles.
- Cooper pairs produced the "parasite" Josephson current $\Rightarrow$ Suppression using a permanent magnetic field.
- The photons assist the tunneling of quasi-particles through the junction.

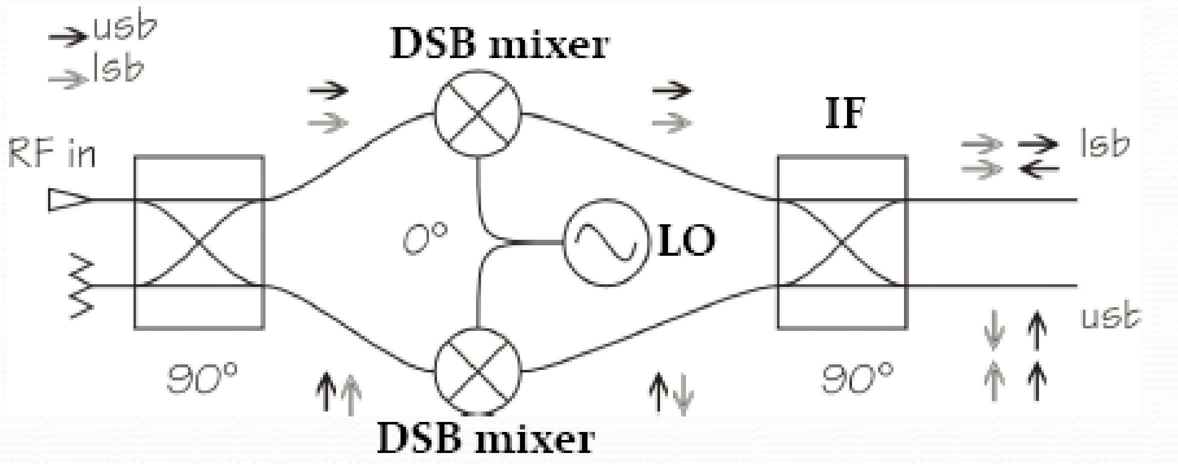
Receivers: IV. Low temperature cryostat (Navarrini & the IRAM frontend group)

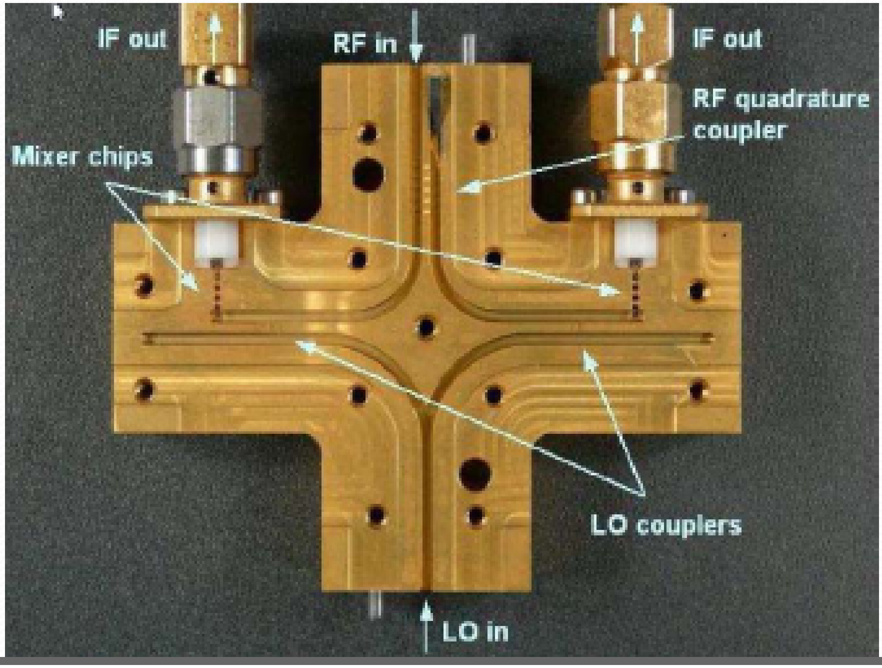
- SIS mixers work at 4K.

- Low noise HEMT amplifiers work at 15K.



Receivers: V. 2SB receivers (Navarrini & the IRAM frontend group)





Double Side Band Lower and Upper SB are down converted and superimposed at the Intermediate Frequency (IF).

Single Side Band Either the LSB or the USB is rejected before down-conversion ⇒ No line confusion, less noise but twice as less bandwidth (line and continuum) as DSB.

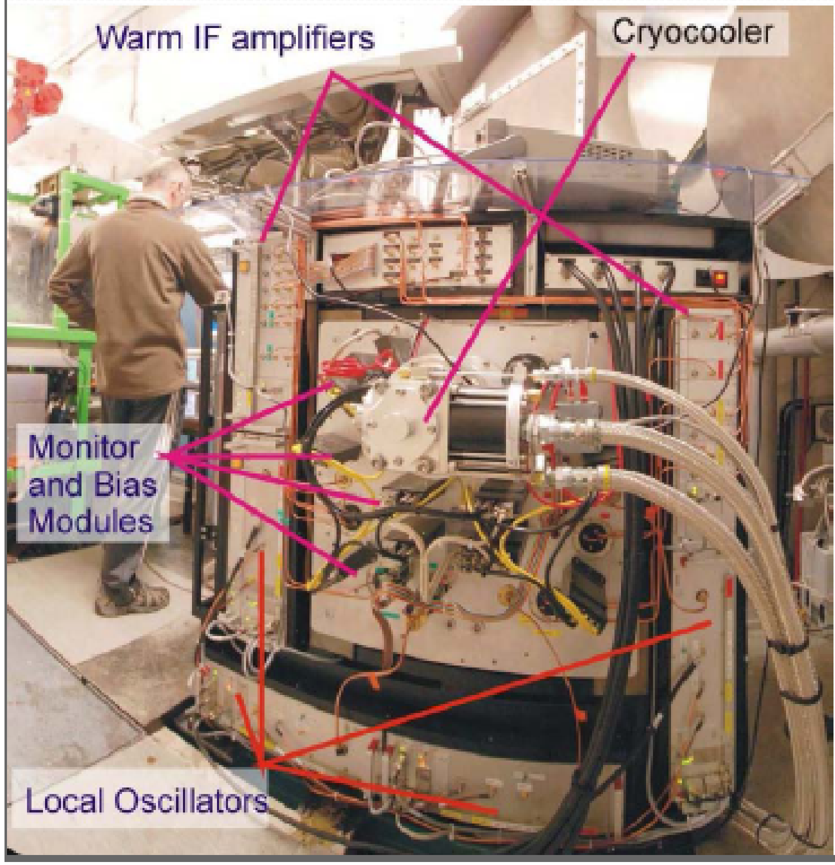
2 Side Bands LSB and USB downconverted and separated to two different IF outputs ⇒ Best of both worlds.

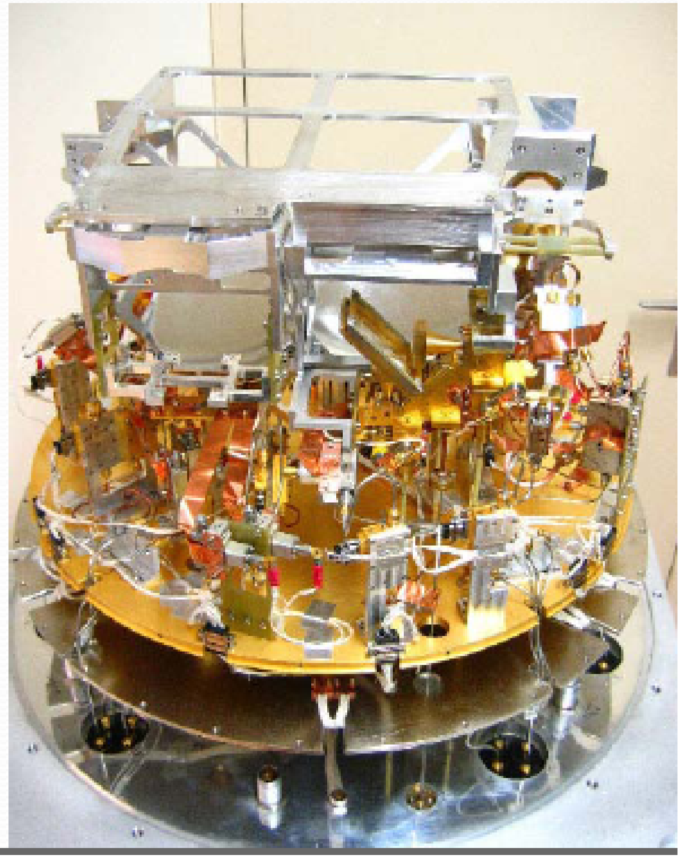
Receivers: VI. Example (1)
(Navarrini & the IRAM frontend group)

EMIR: Multi-band mm-wave SIS receiver for IRAM 30 m telescope

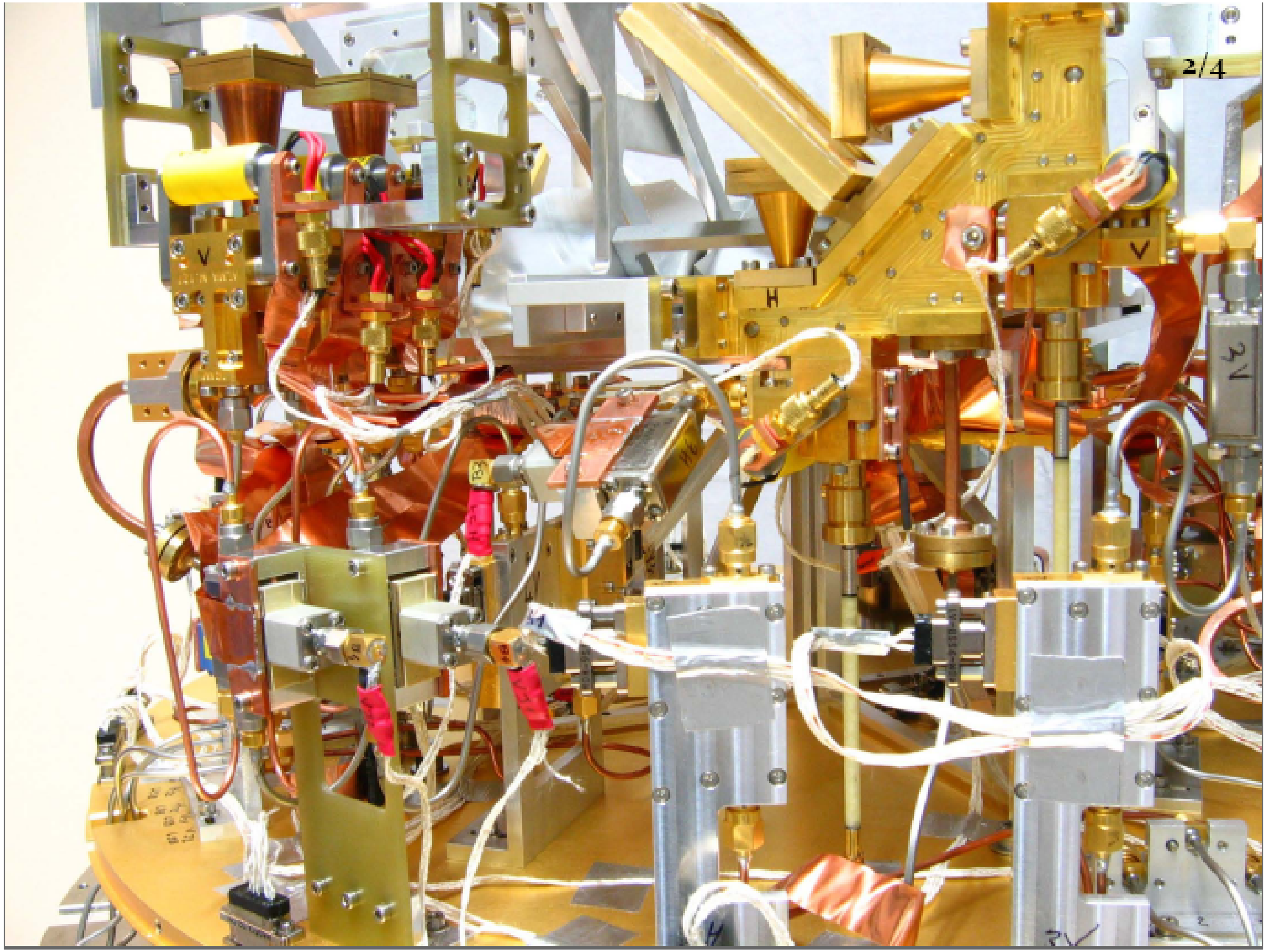
1/4

Band#	RF coverage (GHz)	Mixing scheme	IF config. Pol× Sb× BW(GHz)
B1	83 – 117	2SB	2 × 2 × 8
B2	129 – 174	SSB	2 × 1 × 4
B3	200 – 267	SSB	2 × 1 × 4 [a]
B4	260 – 360	2SB	2 × 2 × 4 [b]



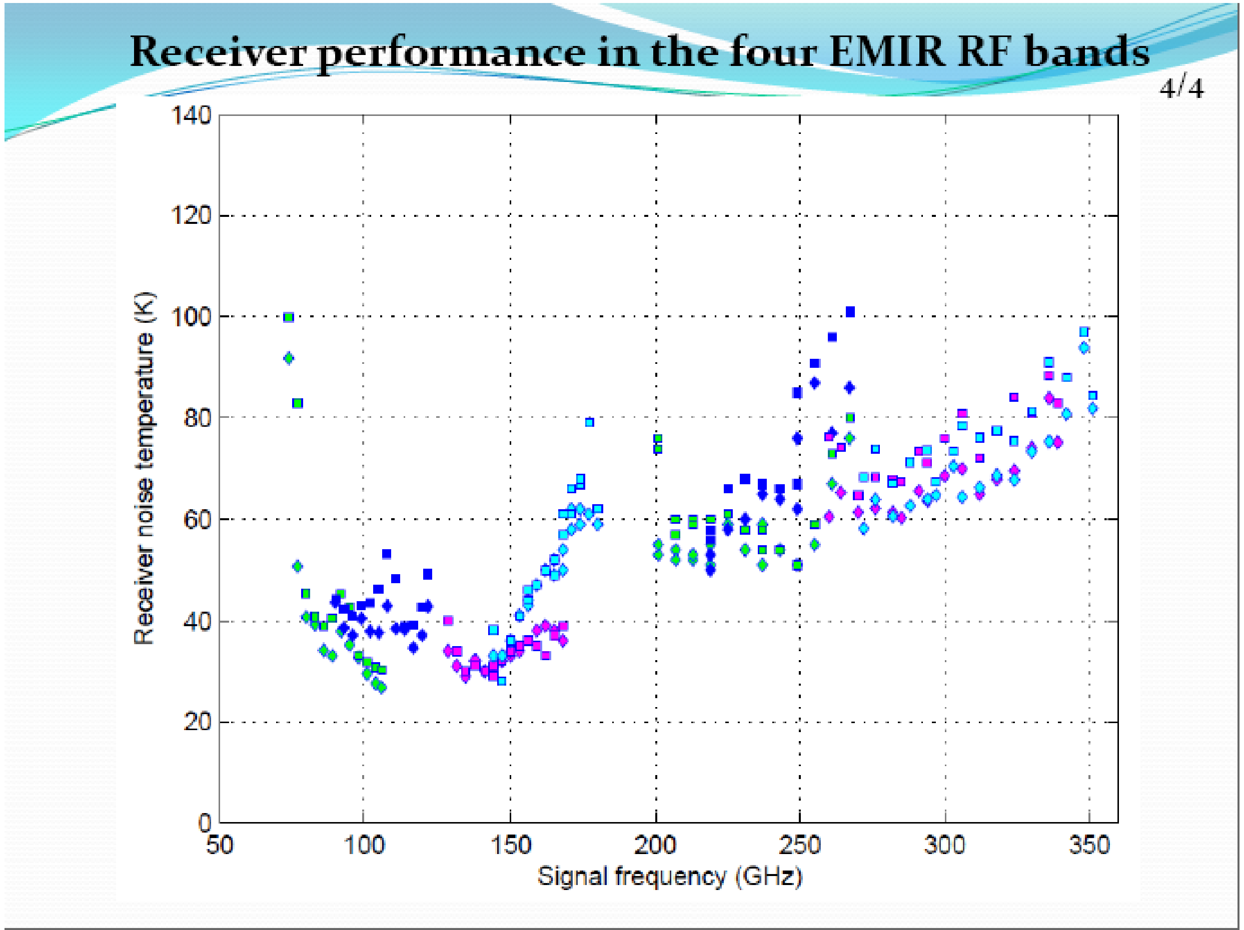


Receivers: VI. Example (2)
(Navarrini & the IRAM frontend group)



Receivers: VI. Example (3)
(Navarrini & the IRAM frontend group)

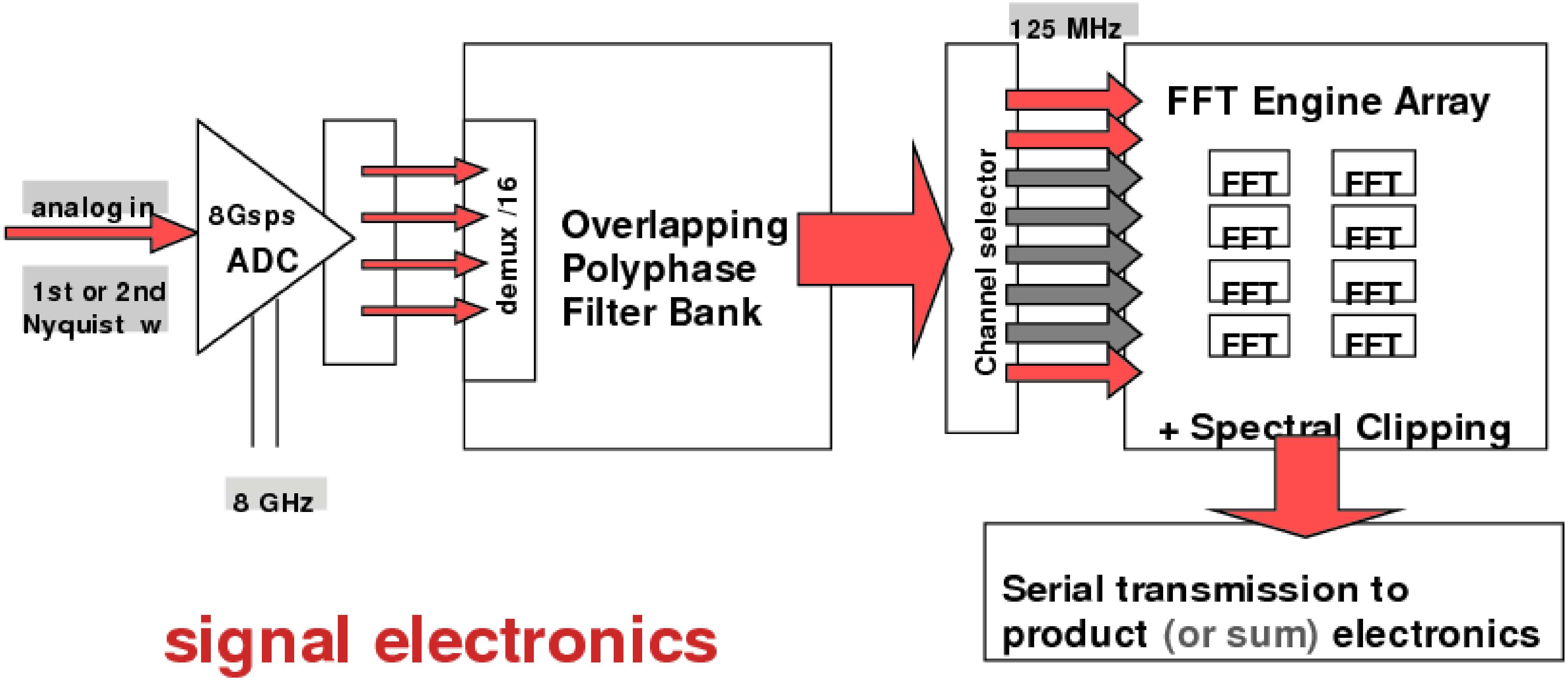
Receivers: VI. Example (4)
(Navarrini & the IRAM frontend group)



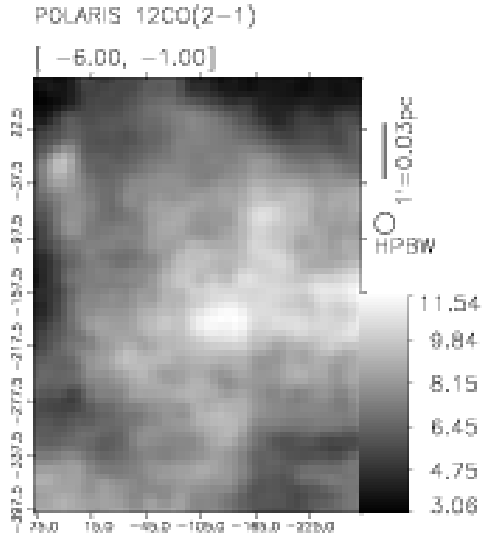
Quantum noise limit: $T = \frac{h\nu}{k} \sim 5\,\mathrm{K}\frac{\nu}{100\,\mathrm{GHz}}$.

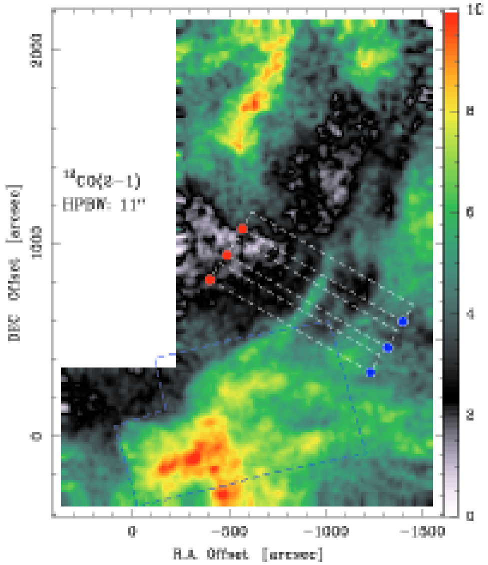
Typical receiver performances: $T = 4\frac{h\nu}{k}$.

Digital spectrometers
NOEMA raw data rate: 2 TB/s



Recent, current and foreseen revolutions in radio-astronomy: I. Wide-field imaging at 30m: 1) Spectroscopy





Top: Falgarone et al. 1998
Bottom: Hily-Blant et al. 2009

Past:

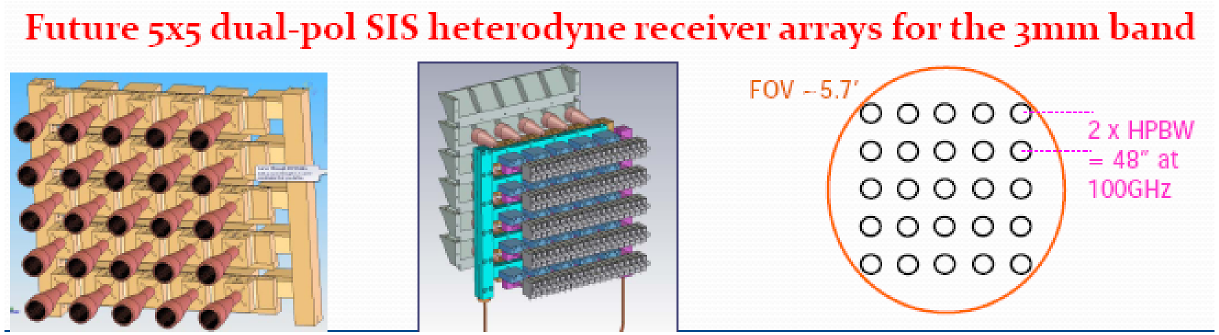
- Revolution 1 (1995-2000): On-The-Fly.
- Revolution 2 (2002-2007): Multi-Beams (HERA1 and HERA2).

Present:

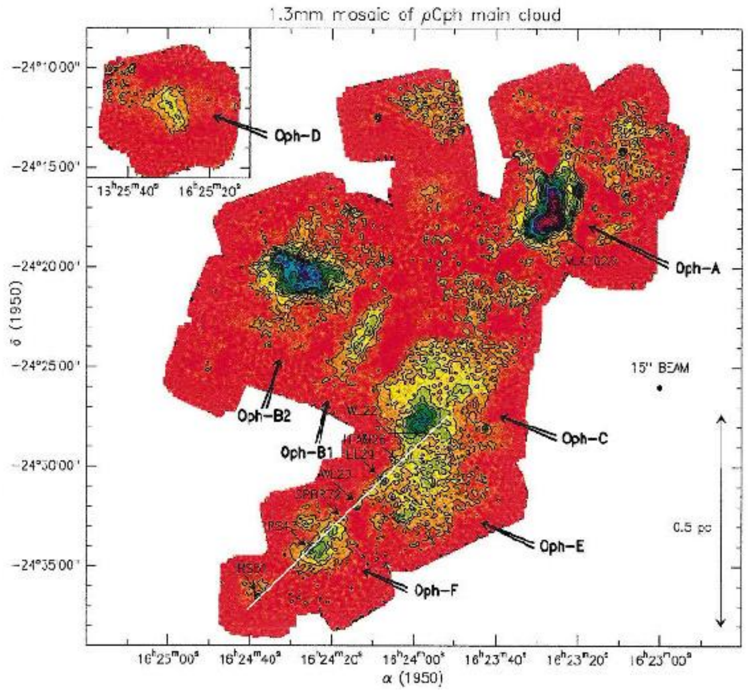
- HERA: 18 heterodyne pixels surveying the focal plane at 1mm.
- $1^{\circ 2}$ in 50 hours
  $\Rightarrow$ Typical sensitivity 0.5 K (T_A^*, in 0.25 km s^{-1})
  $\Rightarrow$ 10^6 raw spectra and 2.10^5 reduced spectra ($\sim$ 1000 channels each).

Future:

- New generation mixers:
  - 2SB receivers with much better sensitivity than HERA mixers.
  - Wide IF bandwidth.
  - Miniaturization $\Rightarrow$ Larger number of pixels.
- ???: 50 pixels at 3mm.
  $1^{\circ 2}$ in 5 hours $\Rightarrow$ Typical sensitivity 0.2 K (T_A^*) in 0.25 km s^{-1}.
- SHERA: 98 pixels at 1mm $\Rightarrow$ 5 times more pixels than today.
  $1^{\circ 2}$ in 10 hours $\Rightarrow$ Typical sensitivity 0.2 K (T_A^*) in 0.25 km s^{-1}.



Recent, current and foreseen revolutions in radio-astronomy: II. Wide-field imaging at 30m: 1) Bolometer



Motte et al.

Past:

- Revolution 1 (1995-2001): MAMBO1 (37 pixels).
- Revolution 2 (2001-2011): MAMBO2 (117 pixels).
  $1^{\circ 2}$ in 50 hours $\Rightarrow$ Typical sensitivity: 3 mJy/Beam.

Present:

- Experimental field arrays (GISMO = TES and NIKA = KIDS).

Future:

- New instrument.
  - 2 colors.
  - Field arrays.
  - Larger number of pixels to fully sample a field of view of radius 20′.

Recent, current and foreseen revolutions in radio-astronomy: II. Line surveys at 30m

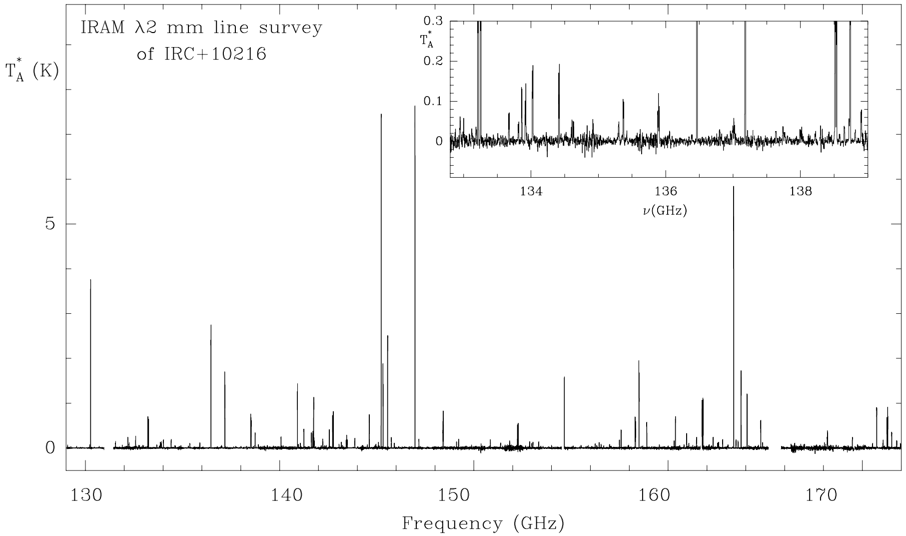
Past:

- Revolution 1 (2002-Today): VESPA correlator.
- Revolution 2 (2004-Today): WILMA correlator.
- Revolution 3 (2008-Today): EMIR receivers.

Present:

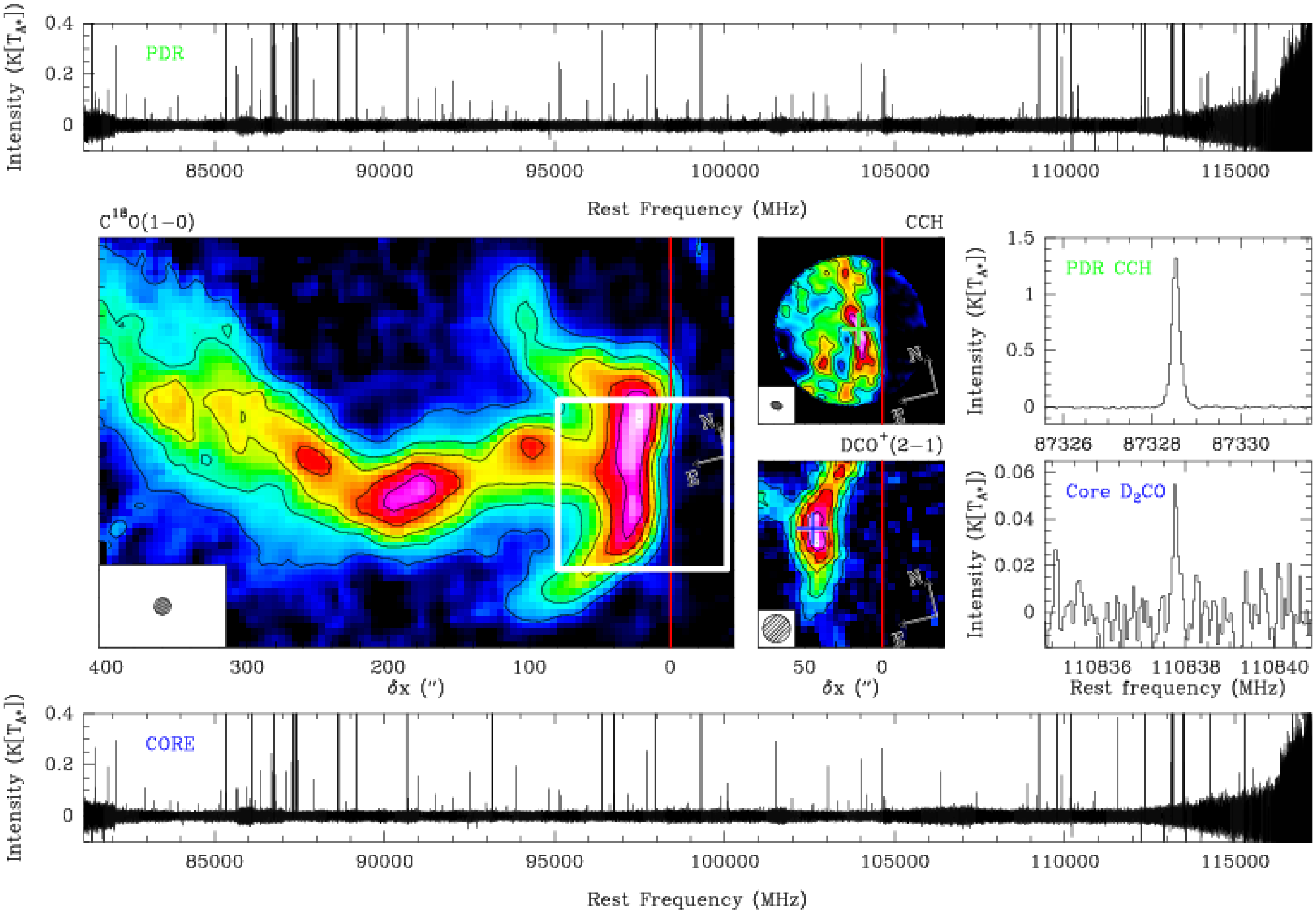
- The IF cables can transport 8 times 4 GHz bandwidth.
- WILMA can process 4 times 4 GHz with a channel spacing of 2 MHz. ⇒ 8 000 channels.

- Fourier Transform Spectrometers:
  - 212 kHz channel spacing ⇒ ∼ 20 000 channels per 4 GHz.
  - 150 000 channels in total.



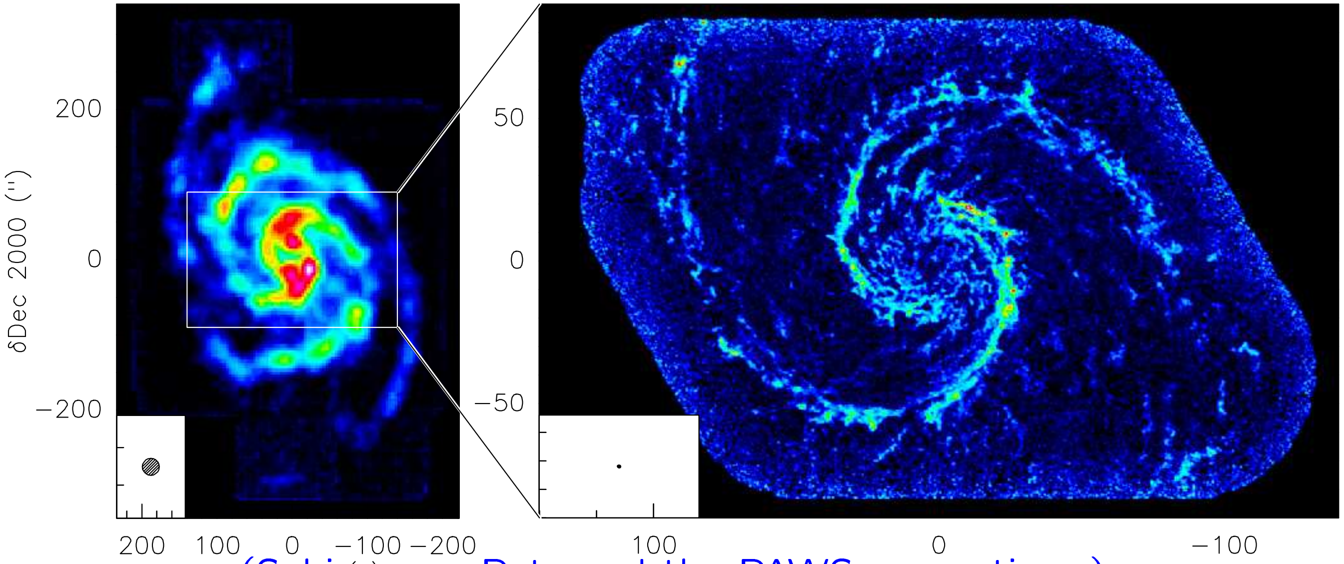
- Cernicharo et al. 2000.
- 40 000 channels.
- 380 detected lines.

Recent, current and foreseen revolutions in radio-astronomy: II. Line surveys at 30m



Two 3mm line surveys in Horsehead (Pety, Guzman, Gratier et al., in prep)

Recent, current and foreseen revolutions in radio-astronomy: III. Wide-field imaging at PdBI



(Schinnerer, Pety and the PAWS consortium.)

Past:

- Revolution 1 (1997-2007): Mosaicking.
- Revolution 2 (2009-Today): Large programs.

Present:

- Mosaic of 60 fields at 3 mm ⇒ Field of view: $3.5' \times 2.8'$.
- 8 hr in D, 15 hr in C, 43 hr in B and 60 hr in A ⇒ 454 000 visibilities × 1024 channels and a final resolution of $\sim 1''$.
- Imaging and deconvolution require images of 2 Mpixels (in fine: only 36 000 fully independant pixels).
  ⇒ 400 CPU-hours to deconvolve 120 channels (320 000 components per channel).

Present:

- Mosaicking ∼ Raster mapping for a single-dish.
  ⇒ 8-9 seconds lost when moving from one field to the next one.

Future:

- Interferometric On-The-Fly.
  - New observing mode + new imaging algorithm.
  - Pety & Rodriguez-Fernandez 2010, *A&A*.
- NOEMA ⇒ 4.4 times more baselines.

Recent, current and foreseen revolutions in radio-astronomy: IV. Continuum and line surveys at PdBI

Past:

- Revolution 1 (2001): Narrow band correlator.
- Revolution 2 (2007): New generation of receivers.
- Revolution 3 (2010): WIDEX.

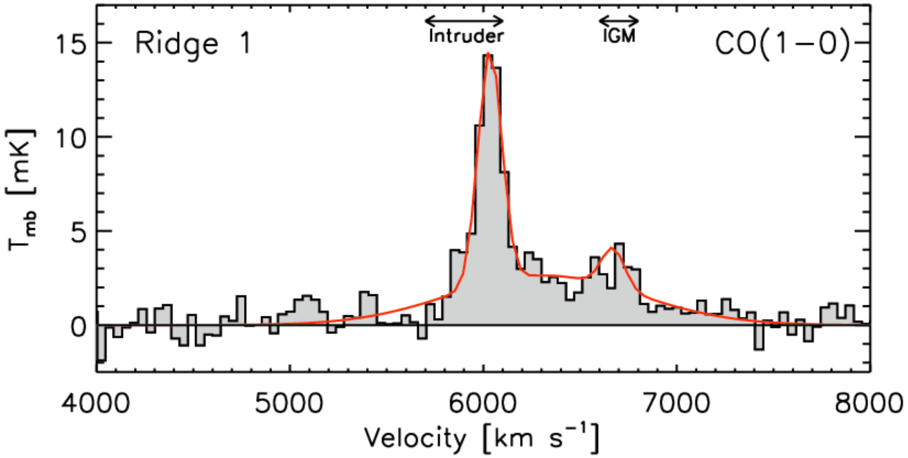
Present:

- Narrow band correlator: up to 8 times 20 MHz with 39 kHz channel spacing.
- WIDEX: 2 times 4 GHz with a channel spacing of 2 MHz (up to 8 antennas).
  $\Rightarrow \sim$ twice the narrow band correlator continuum sensitivity.

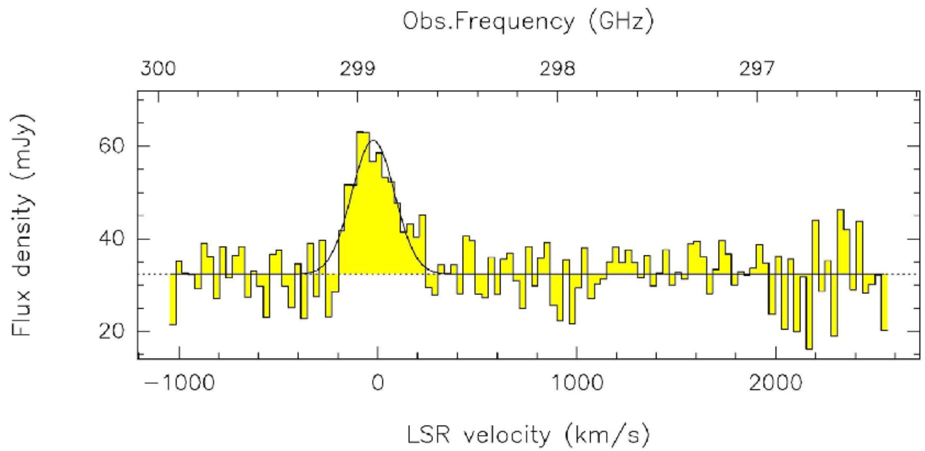
$\Rightarrow$ 4 096 + 4 096 channels.

Future:

- NOEMA:
  - New receivers $\Rightarrow$ 32 GHz of instantaneous bandwidth.
    $\Rightarrow$ At least 16 000 channels with a 2 MHz channel spacing.



CO in the Stephan's Quintet
(Guillard et al. submitted to A&A).



Water detected at 299 GHz in one of the
H-ATLAS high z source (Omont et al. in prep).

Consequences:

I. "Large" data quantities: 1) Examples

Memory size:

- $N_{\text{spectra}} = 32\,768$
  - $N_{\text{channel}} = 1\,024 \Rightarrow 150$ MB;
  - $N_{\text{channel}} = 16\,384 \Rightarrow 2$ GB;
  - $N_{\text{channel}} = 262\,144 \Rightarrow 32$ GB.
- $N_{\text{spectra}} = 524\,288$
  - $N_{\text{channel}} = 1\,024 \Rightarrow 2.3$ GB;
  - $N_{\text{channel}} = 16\,384 \Rightarrow 32$ GB;
  - $N_{\text{channel}} = 262\,144 \Rightarrow 0.5$ TB.
- Bure or 30m:
  - Today: $\sim$ 20-100 GB;
  - Tomorrow: $\sim$ 0.5-1 TB (up to 20 TB);
  - Raw data. Processing $\Rightarrow$ Tenfold size of scratch space...

Read/Write data rates:

- Constant independant of N_{spectra};
- Varies linearly with N_{channel}:

spectra/sec	N_{channel}
10 000	128
1 200	16 384
100	262 144

- System limitation.

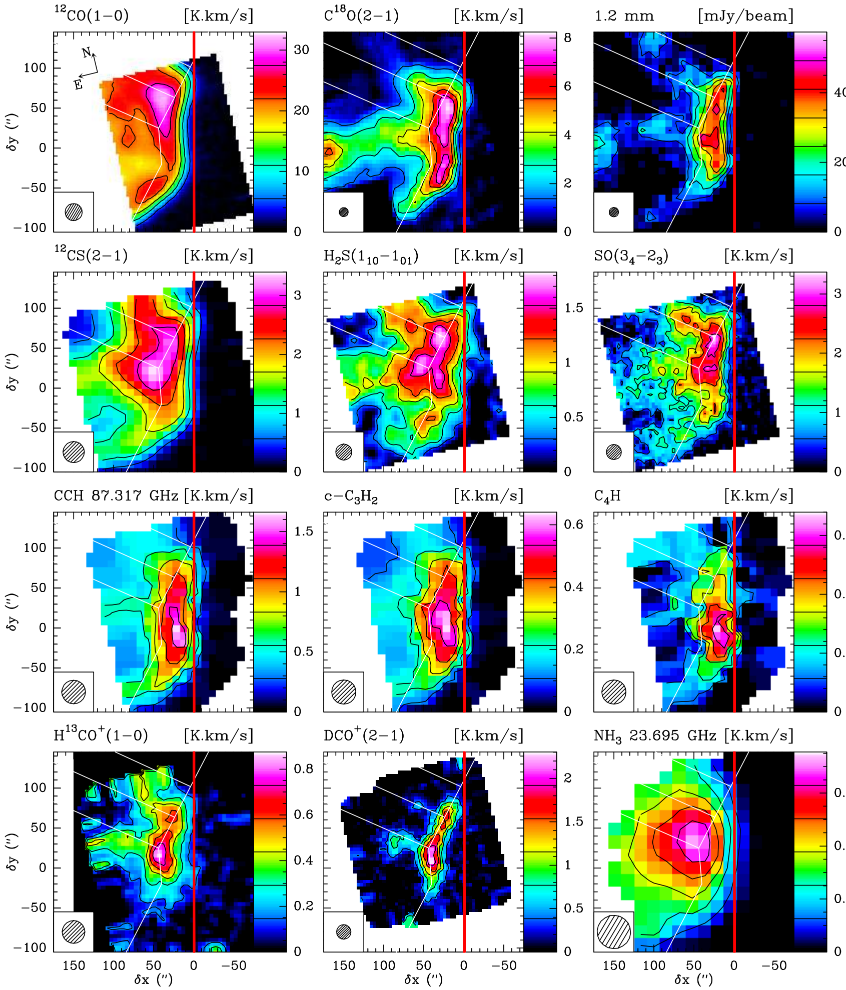
Consequences:
I. Large data quantities: 2) Implications for softwares

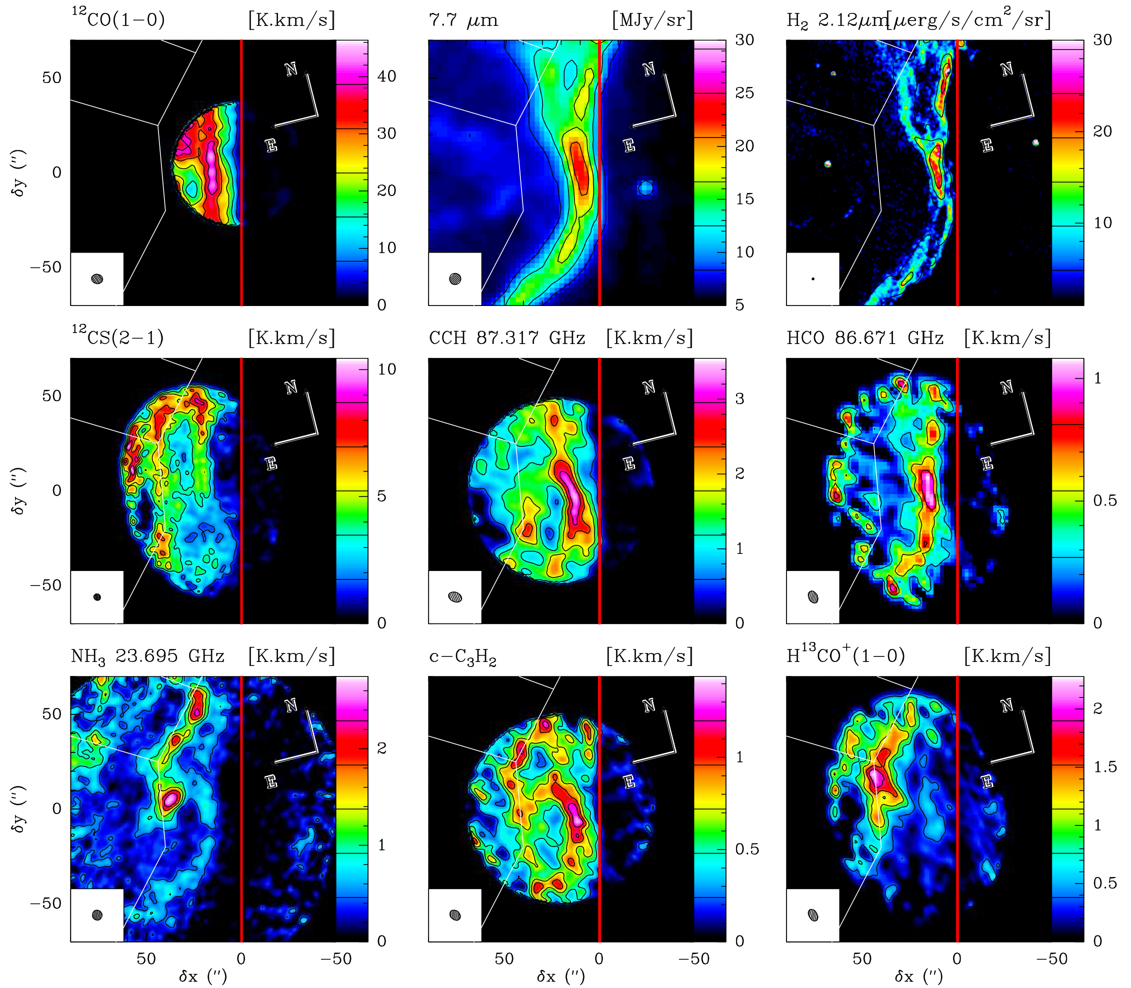
- Best use of available hardware:
  - Make use of all available RAM: Get prepared to divide your problems in tiny chunks fitting inside it.
  - Multi-core processors ⇒ (tricky) multi-threading.
- Chase out N^2 algorithms... ⇒ Code profiling.
- Flexible data access:
  - Most of the parameter space probably empty, but serendipitous discoveries must be easy.
    ⇒ What is the granularity of the data format?
  - Interface to a priori information; *i.e.*, line catalogs (weeds) or regions where the signal is expected.
    ⇒ Processing may depend on data analysis.

Consequences:
II. New kind of data sets

Past decade From spectra to spectra cubes or image sets.

Next decade From line surveys to cube surveys.





Pety et al., 2004-today

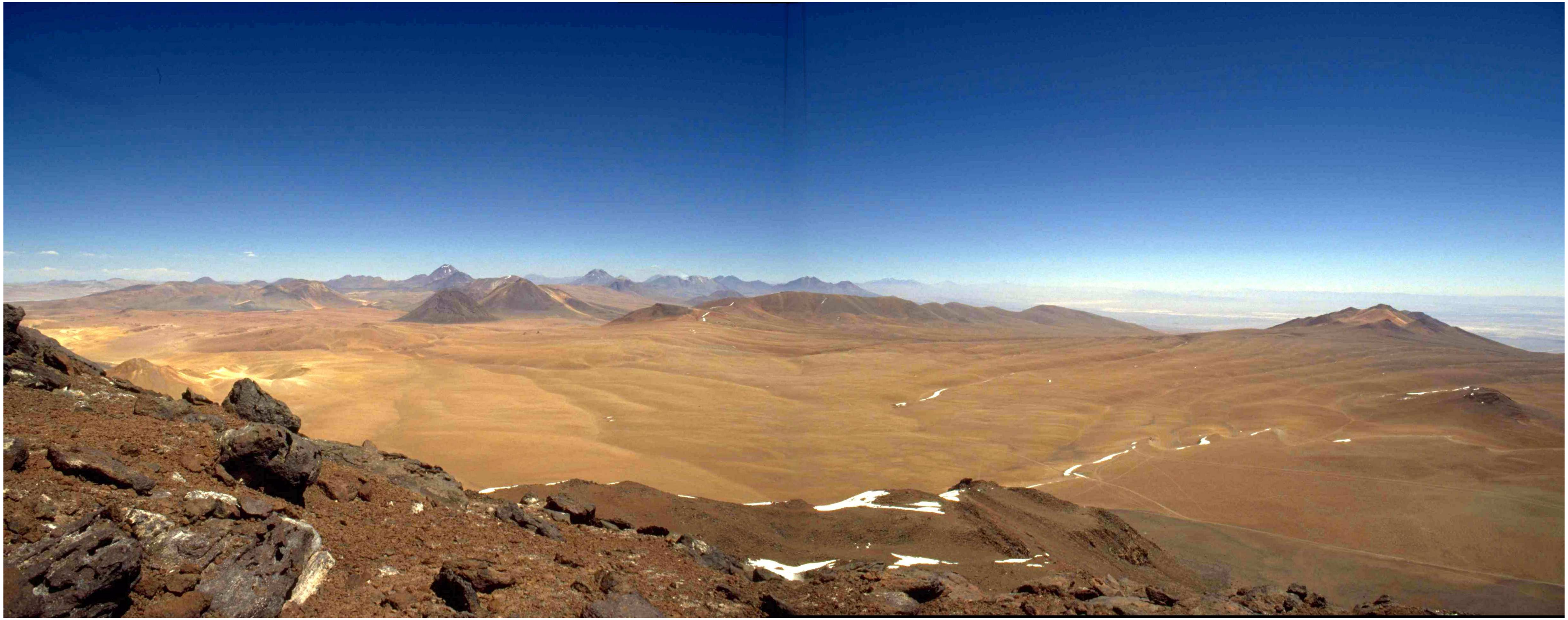
Consequences:
III. From an individual to a collective practice

- Very few and expansive observatories ⇒ Worldwide competition.
- Sensitive receivers and high data rate backends ⇒ Large data sets with subtle artifacts.
- Complex observations (large samples or very high angular resolution) needed to reach many single scientific goals ⇒ Needs matching micro-physics parameters (gas phase and solid phase) and modelling (radiative transfer, chemistry, dynamics).

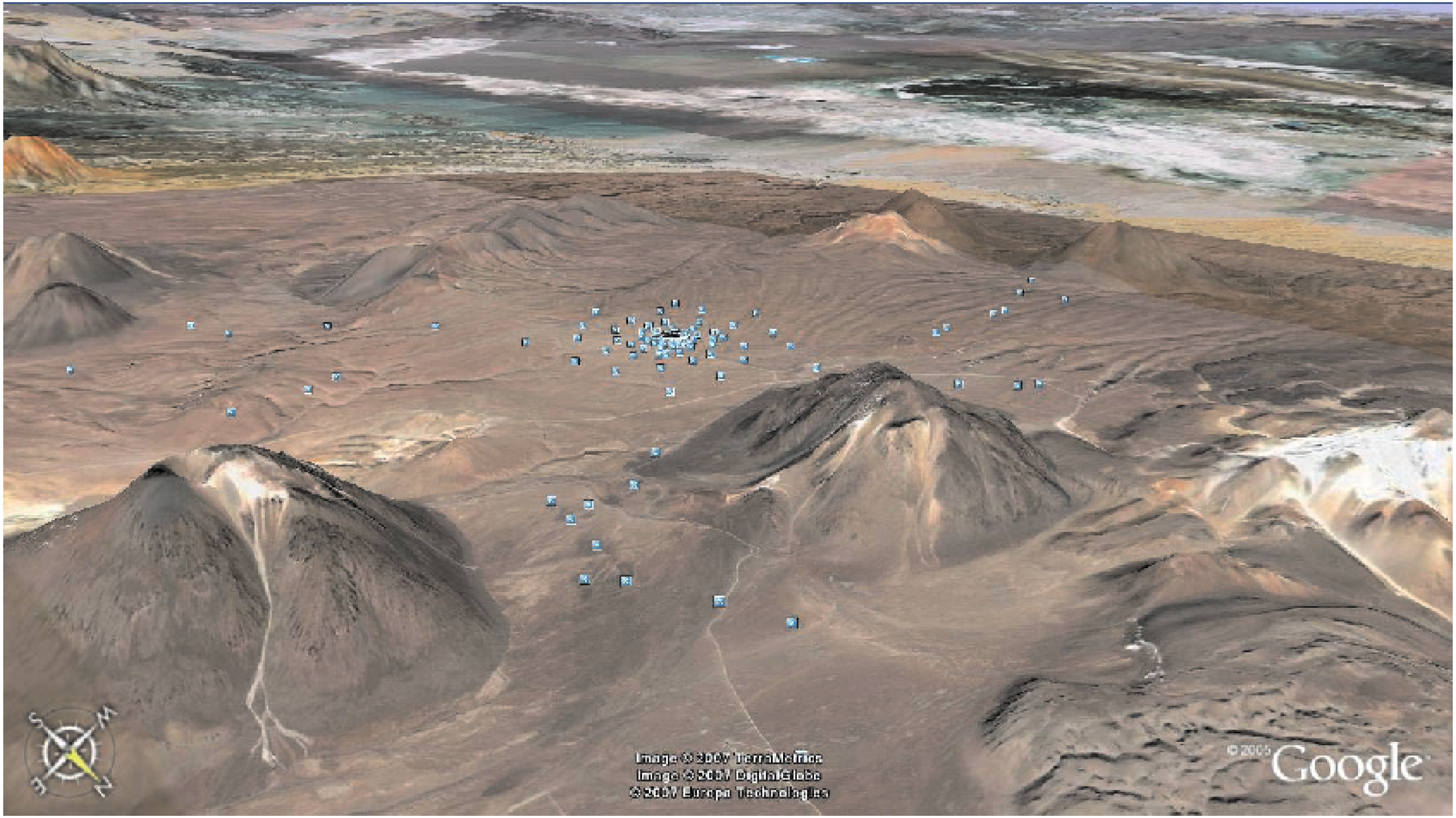
⇒ Consortium already needed at proposal time.

⇒ How individuals (*e.g.* students, post-docs) and groups (experimentalists, developers of data reduction softwares, modellers) will be rewarded?

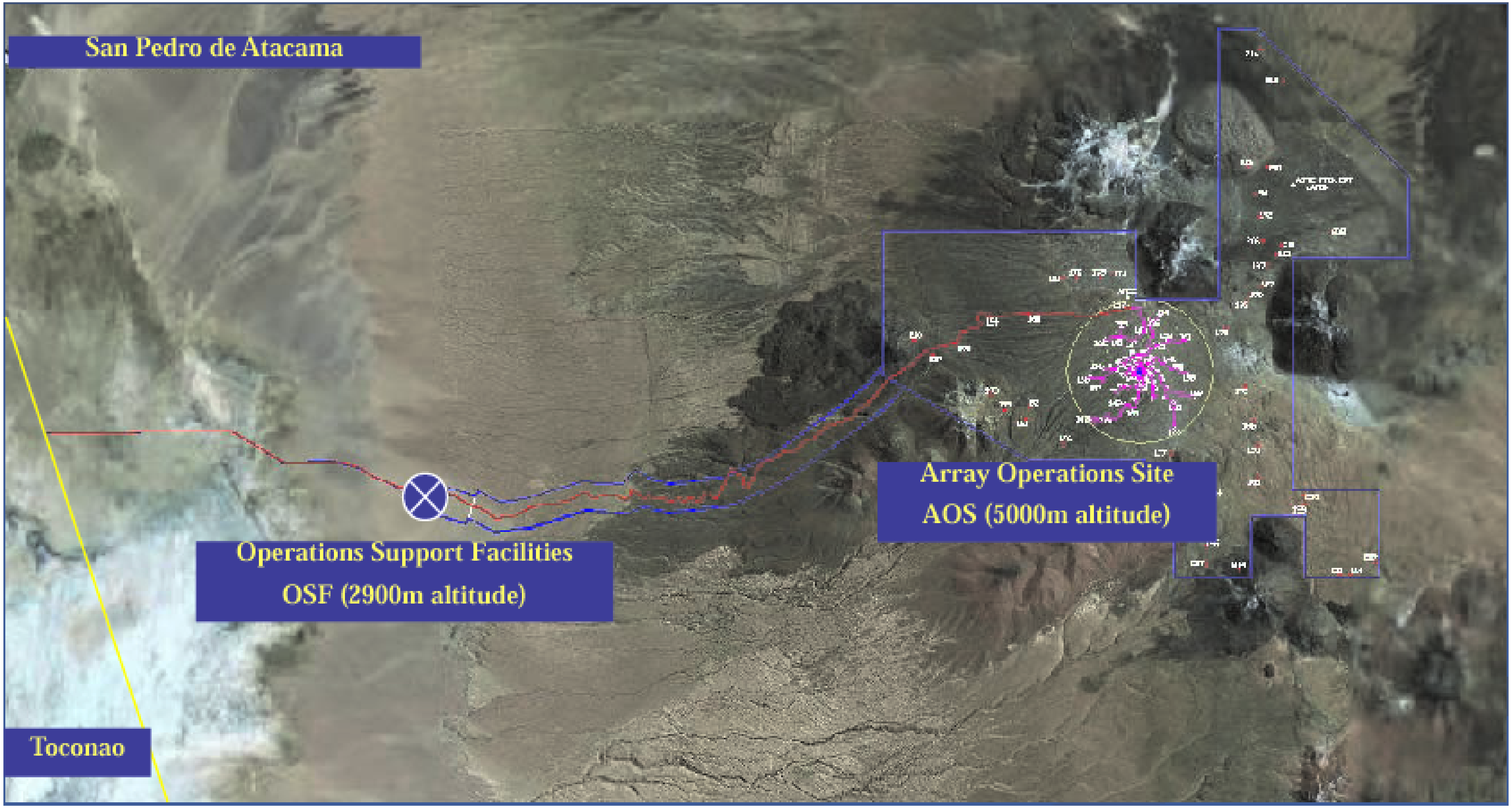
ALMA Status:
I. Site: Chajnantor, Atacama, Chili



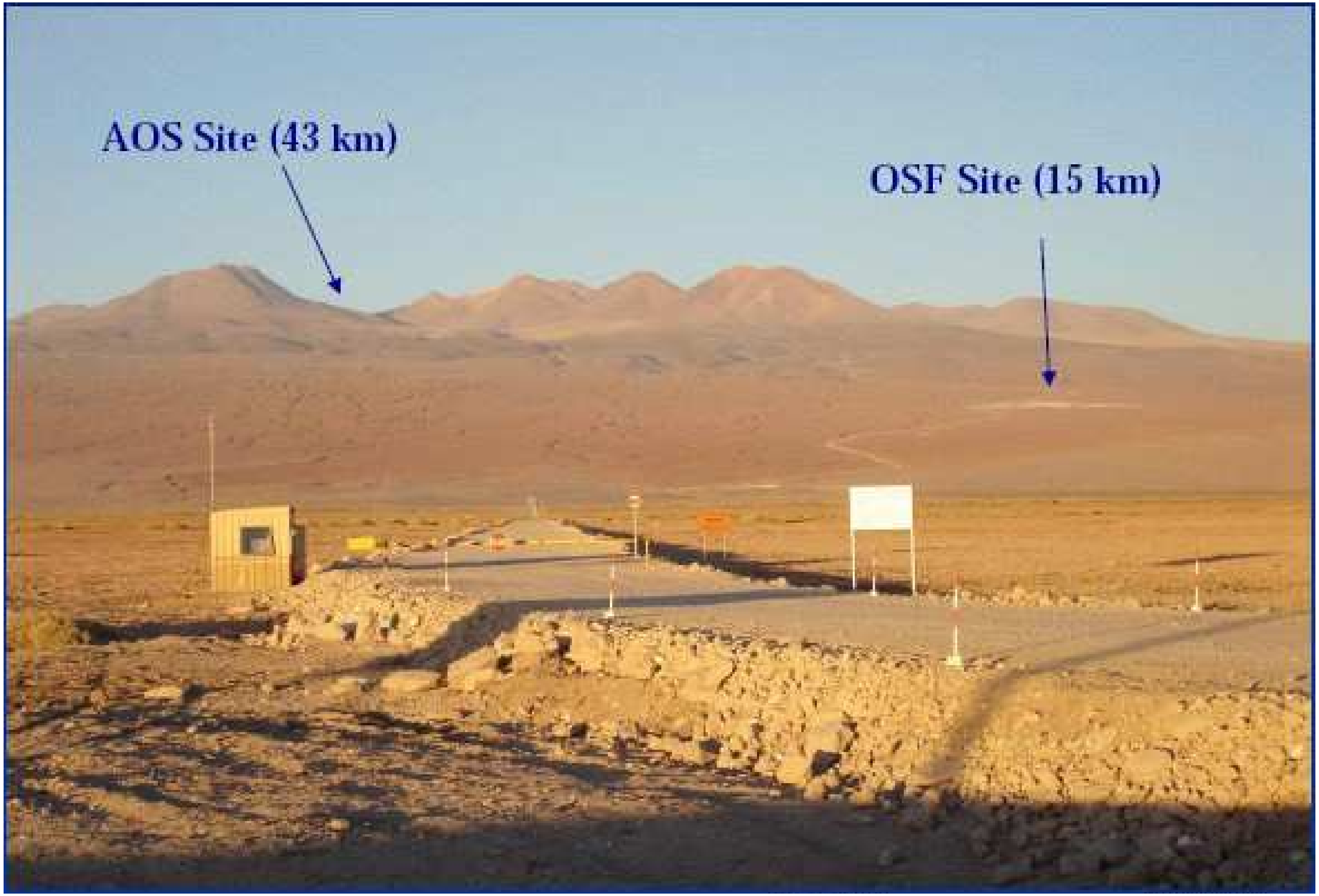
ALMA Status:
I. Site: Chajnantor, Atacama, Chili



ALMA Status:
I. Site: Chajnantor, Atacama, Chili

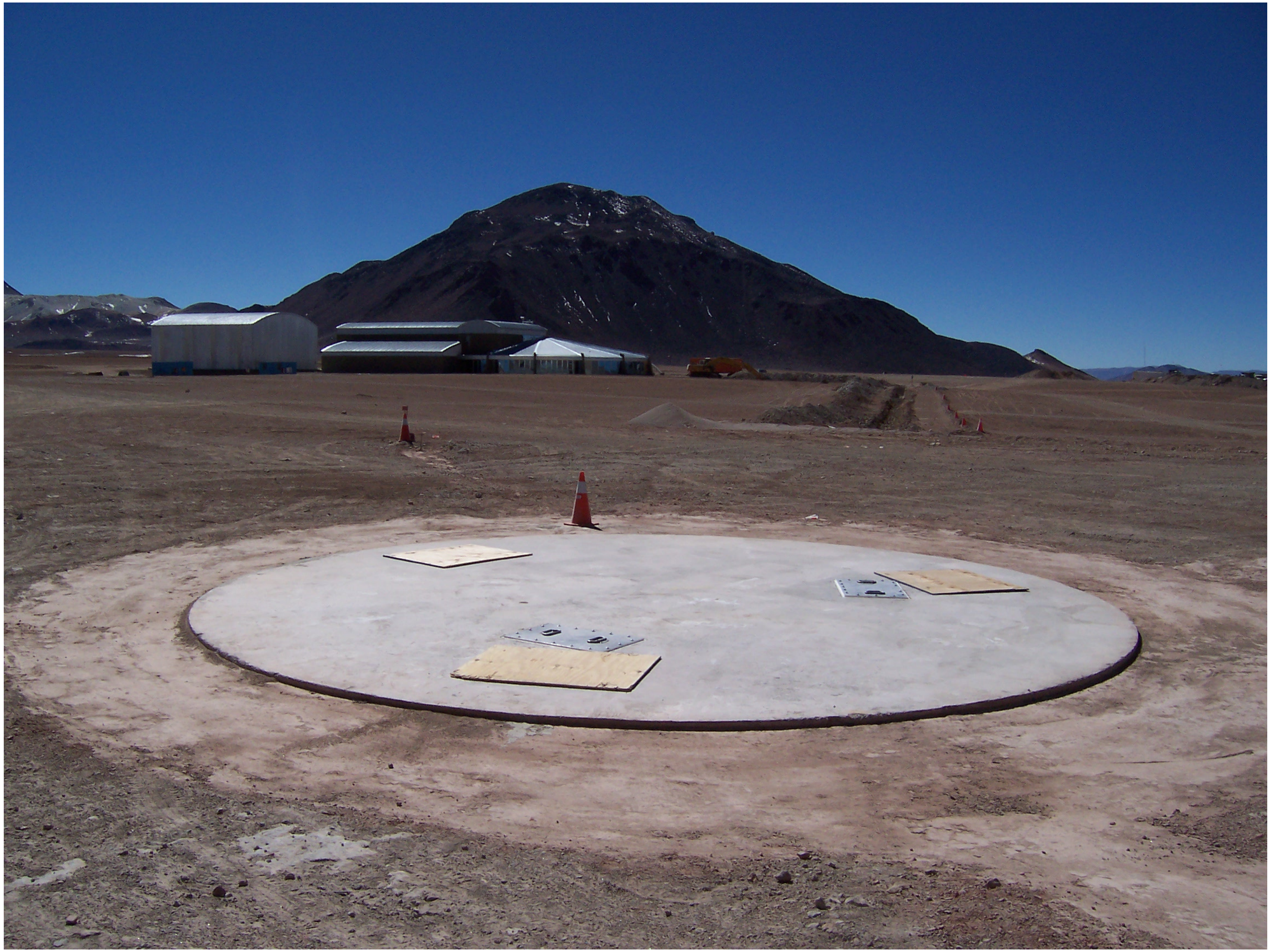


ALMA Status:
II. Private access road (width: 14 to 19m)



ALMA Status:
III. AOS, ALMA Operation Site (in Feb 2008)

ALMA Status:
III. AOS, ALMA Operation Site (mid 2009)



ALMA Status:
III. AOS, ALMA Operation Site (mid 2009)

ALMA Status:
III. AOS, ALMA Operation Site (mid-2010)

ALMA Status:
III. AOS, ALMA Operation Site (mid-2011)

ALMA Status:
IV. Correlator: Room and First Quadrant (beginning of 2008)

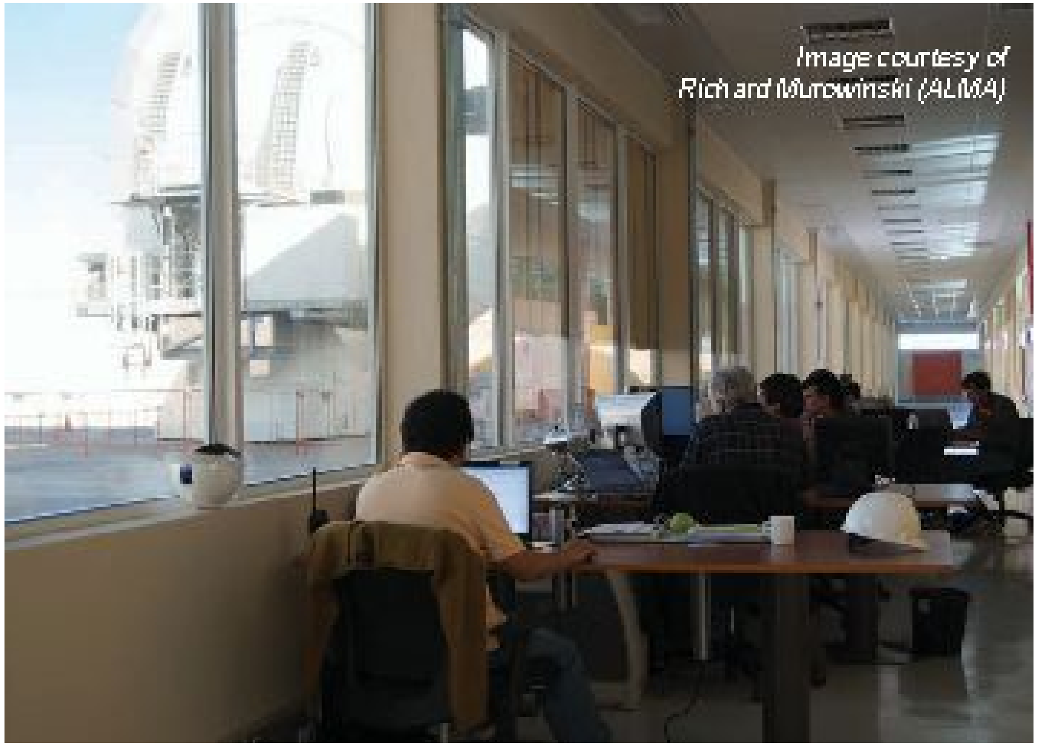
ALMA Status:
IV. Correlator: Room and First Quadrant (beginning of 2009)

ALMA Status:
IV. Correlator: ACA and ALMA (mid 2010)

ALMA Status:
V. OSF, Operation Support Facility (in Feb 2008)

ALMA Status:
V. OSF, Operation Support Facility (mid-2011)

ALMA Status:
V. OSF, Operation Support Facility (in Jun 2009)



ALMA Status:
V. OSF, Operation Support Facility (mid-2010)

ALMA Status:
VI. Power

Power need 7 MW.

Generation Fuel generators at OSF (2900 m) and transporter through buried cables to AOS (5000 m).

Smoothing system Fly wheel system at AOS.

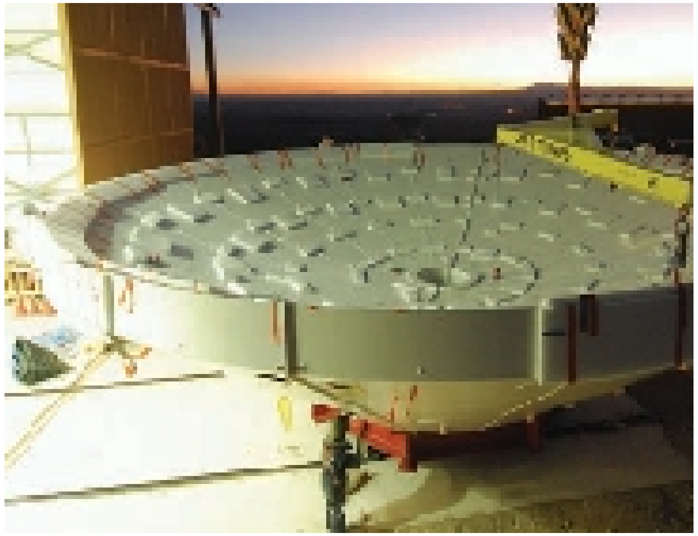
ALMA Status:
VII. Antennae (beginning of 2008)

ALMA Status:
VII. Antennae (mid-2010)

ALMA Status:
VII. Antennae (mid-2011)

ALMA Status:
VII. European antennae (mid-2009)

ALMA Status:
VII. European antennae (mid-2009)



ALMA Status:
VII. European antennae (mid-2010)

ALMA Status:
VII. Japanese and American antennae (Sep. 2010)

- 2 Japanese and 6 American antennae provisionnally accepted.

ALMA Status:
VII. Japanese 7m-antennae (mid-2011)

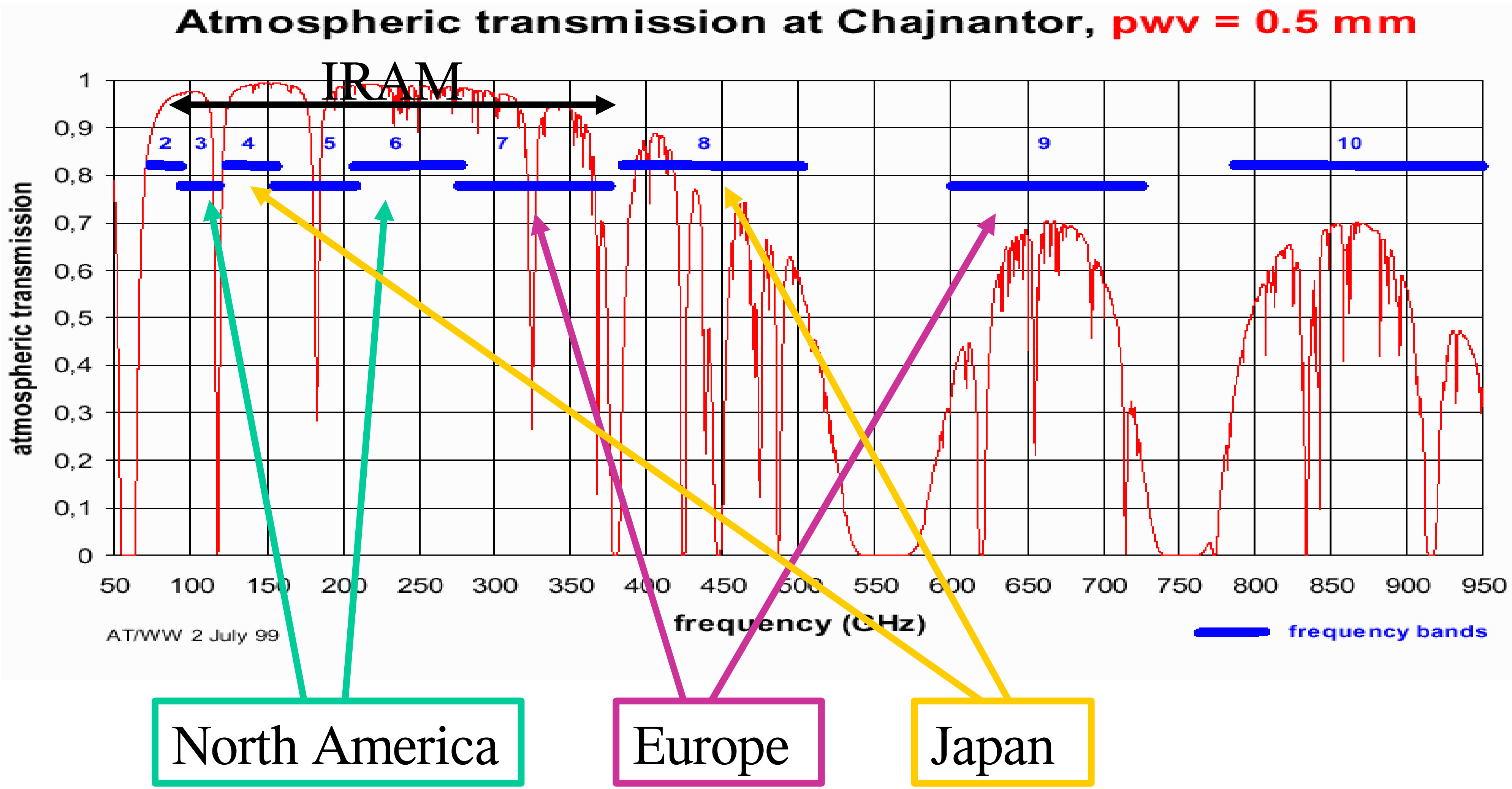
ALMA Status:
VIII. Transporter (mid-2008)

The ALMA Antenna Transporter

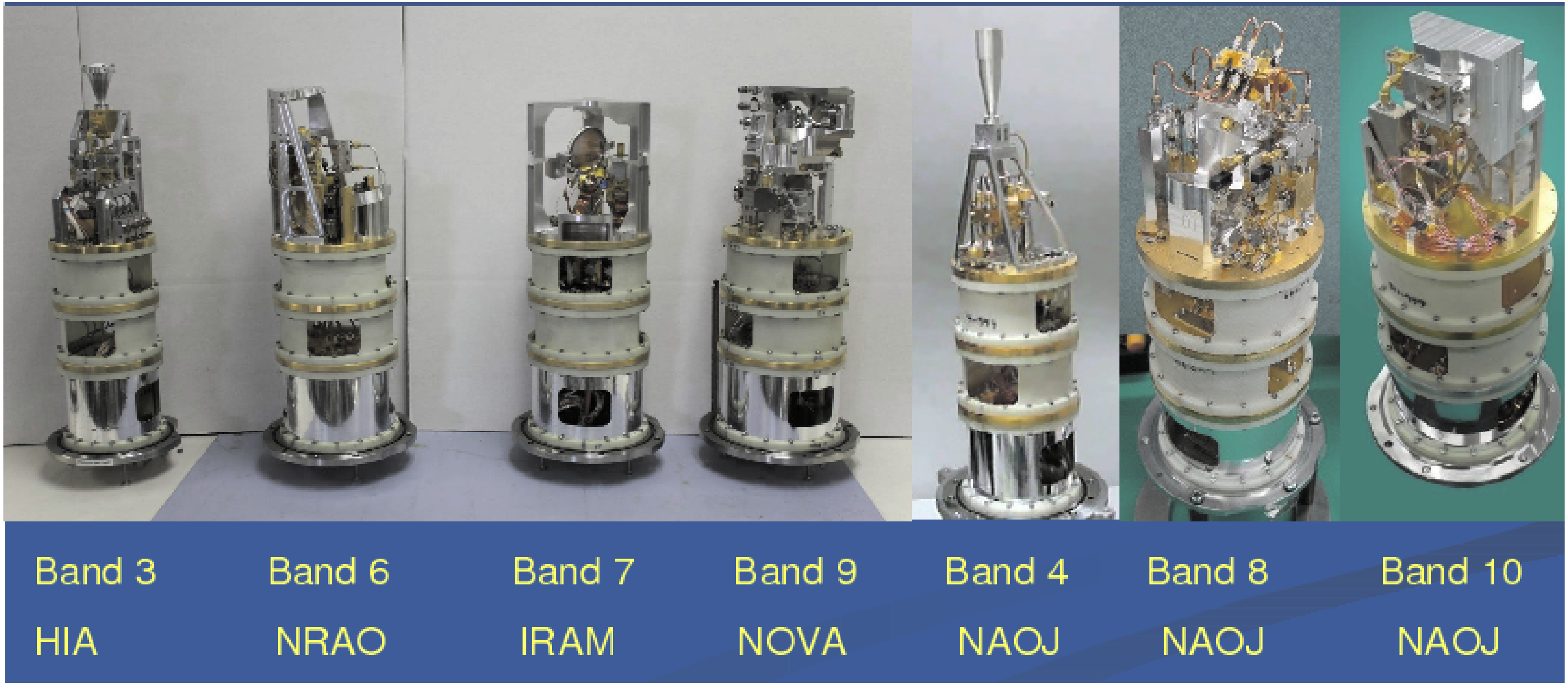
ESO Press Photo 45b/07 (5 October 2007)

ALMA Status:
VIII. Transporter (mid-2009)

ALMA Status:
IX. Receivers (project)



ALMA Status:
IX. Receivers (mid-2010)

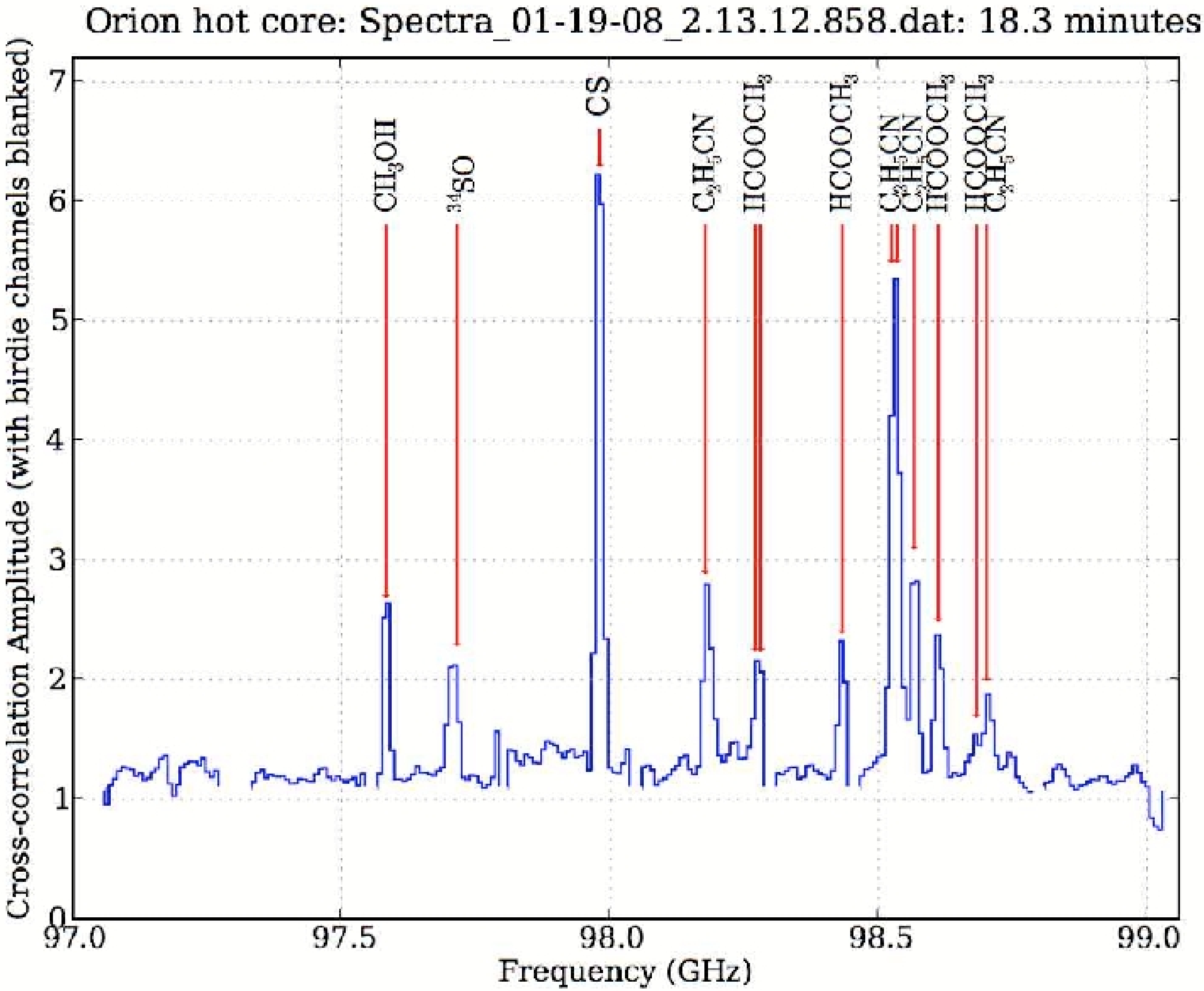


ALMA Status:
IX. Receiver assembly and tests (mid-2009)

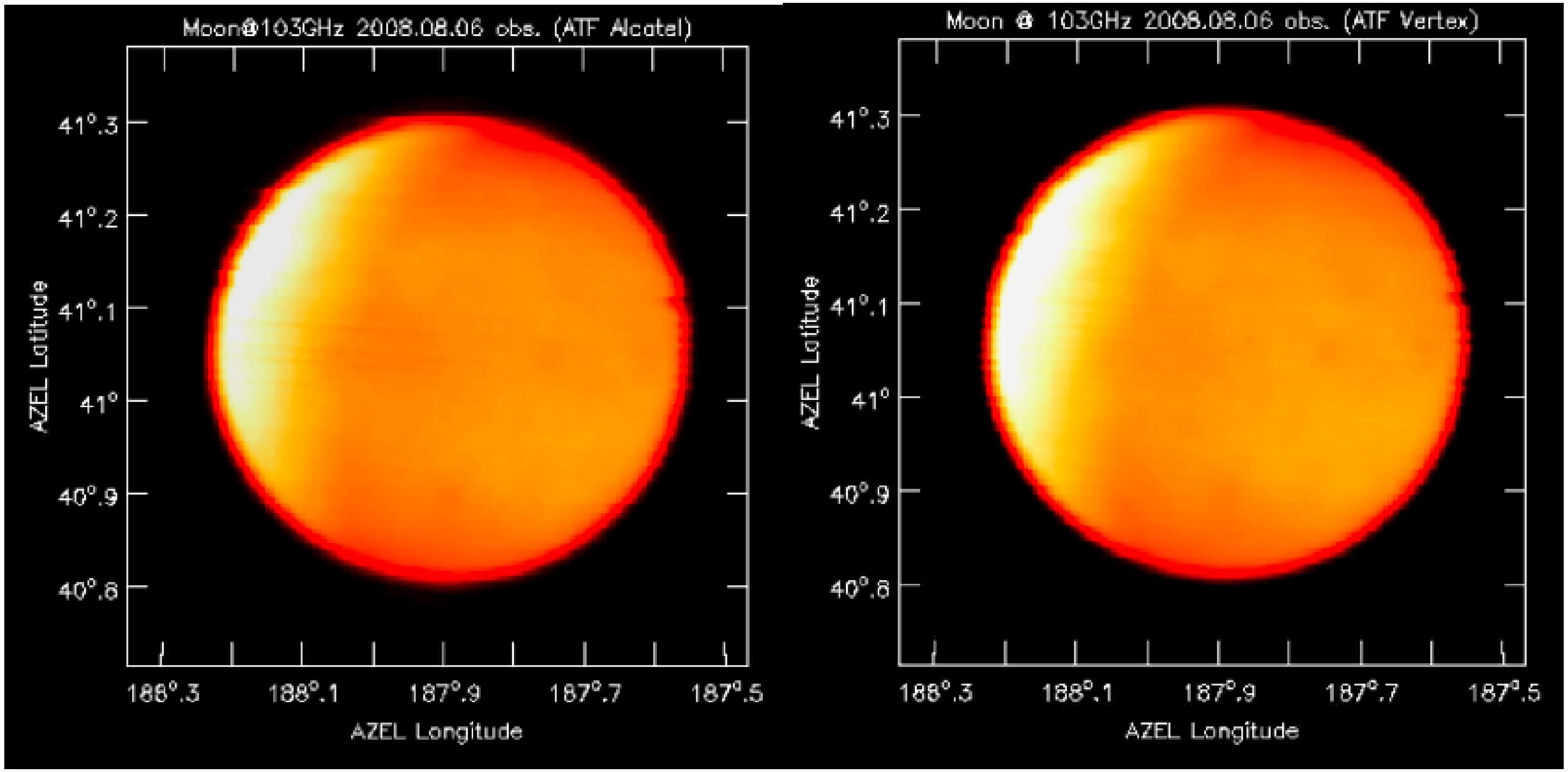
ALMA Status:
IX. Receiver installation

ALMA Status:
X. Santiago central office on the ESO campus (mid-2010)

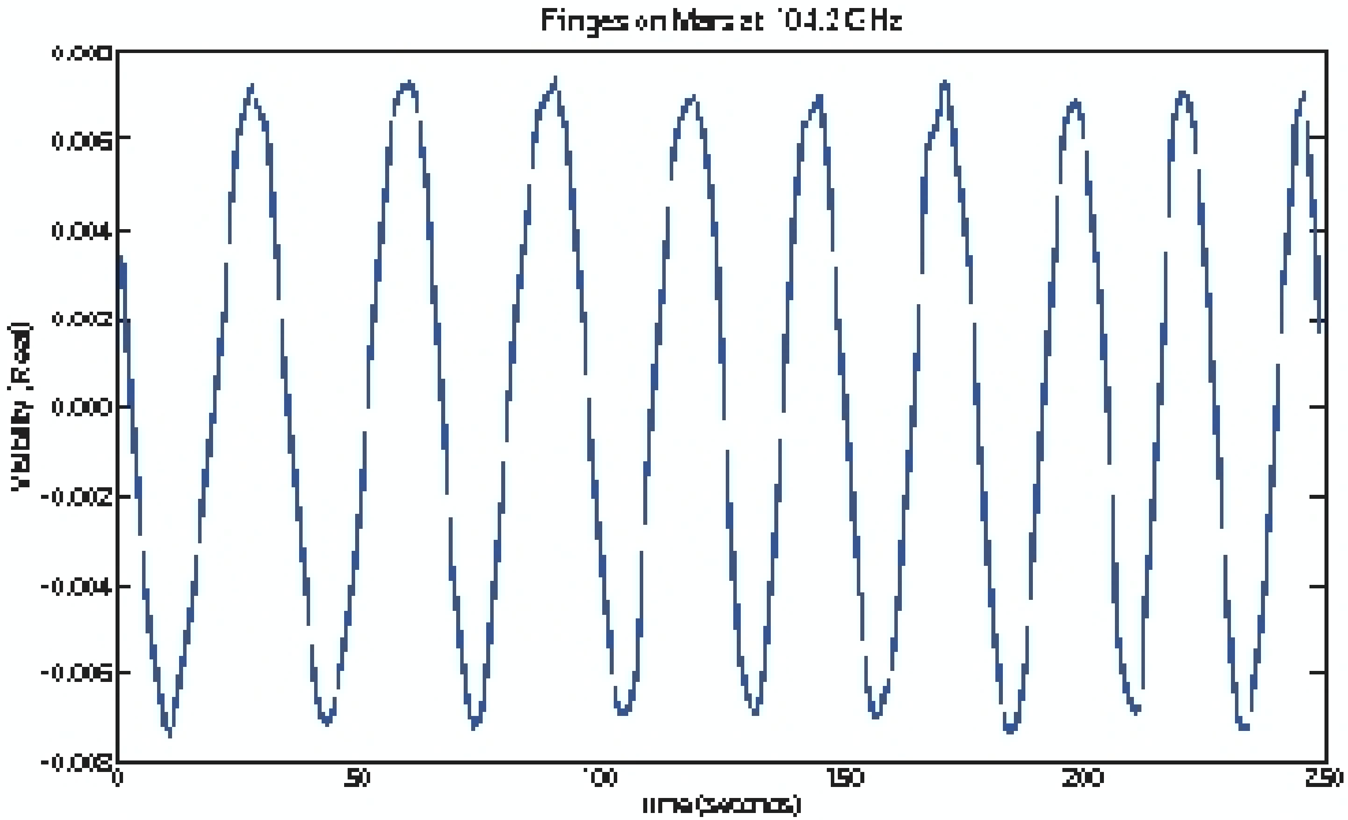
ALMA Status:
XI. First interferometric spectrum in Socorro, USA (mid 2008)



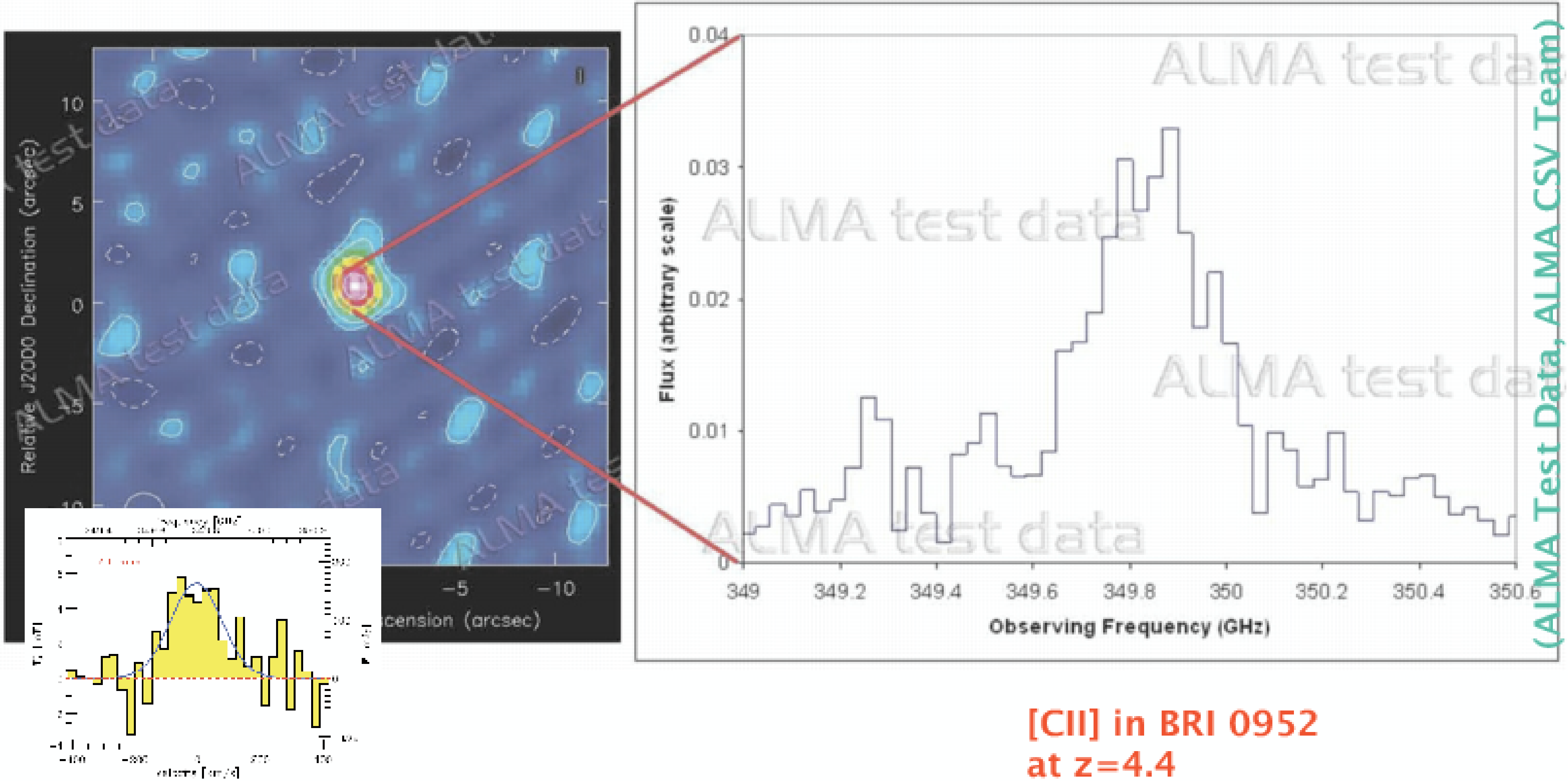
ALMA Status:
XI. First single-dish images on Moon at OSF, Chili (beginning 2009)



ALMA Status:
XI. First fringes on Mars at OSF, Chili (mid 2009)

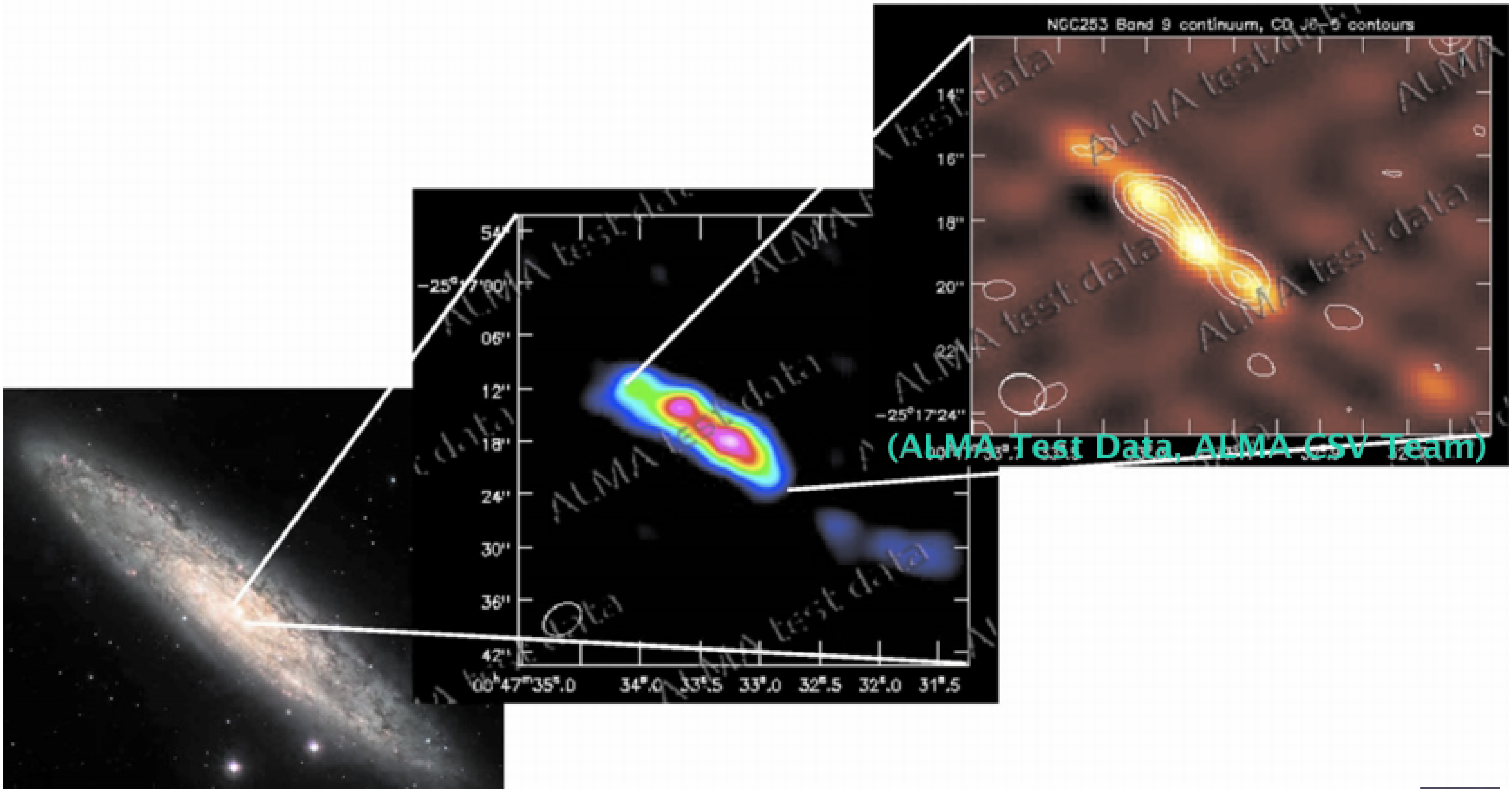


ALMA Status:
XI. First science verification data at OSF, Chili (Automn 2010)

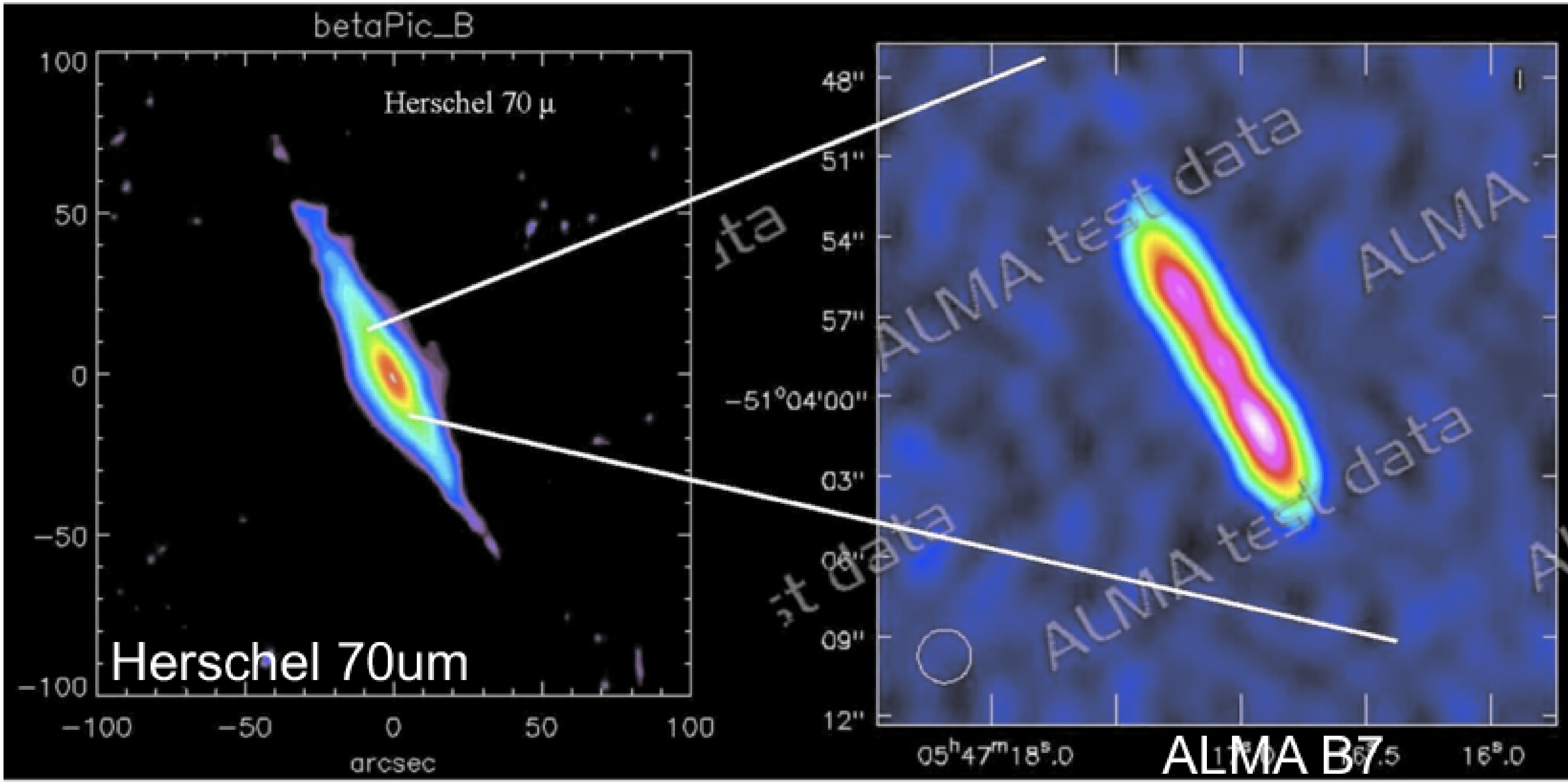


[CII] in BRI 0952
at z=4.4

ALMA Status:
XI. First science verification data at OSF, Chili (Automn 2010)



ALMA Status:
XI. First science verification data at OSF, Chili (Automn 2010)



(ALMA Test Data, ALMA CSV Team)

ALMA Status:
XII. Weather at OSF, Chili ("Unusually severe altiplanic winter")

ALMA Status:
XII. Weather at OSF, Chili

ALMA Status:
XIII. Schedule

- mid-2008: Start of commissioning and science verification.
- end-2009: 3 antennae interferometer.
- mid-2010: First interferometric data cube.
- 30-jun-2010: Early science (cycle 0) proposal deadline.
- end-2011: Early science start (At least 16 antennas with 4 bands of receivers).
- 2013: Full science operation.

⇒ Tomorrow!