The Plateau de Bure Interferometer

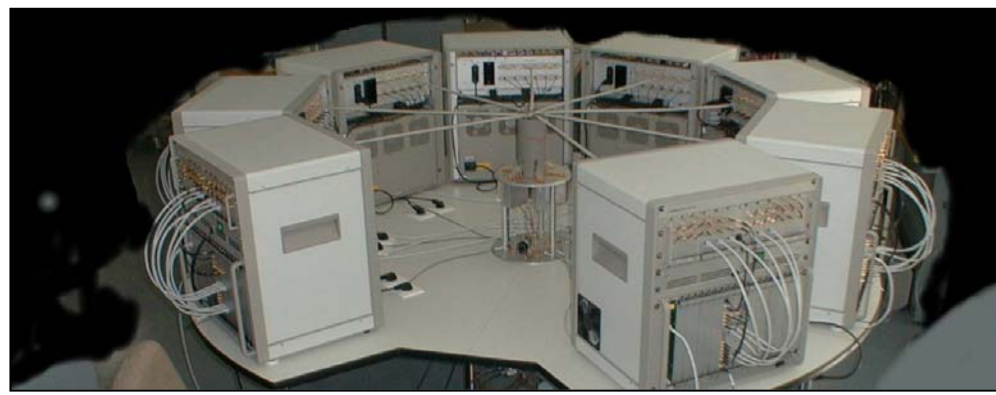
VIIth Interferometry School

Roberto Neri, IRAM

The Plateau de Bure Observatory

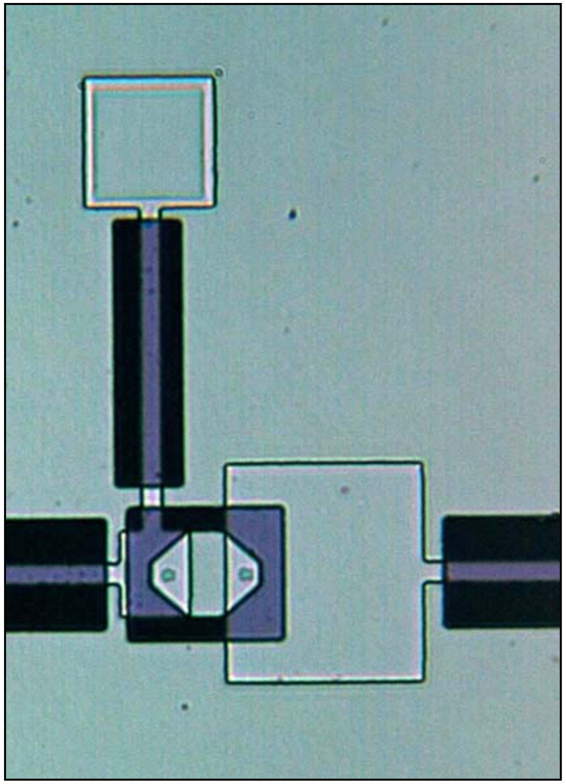
- IRAM = two observatories : Plateau de Bure Array + Pico Veleta 30m
- Three partners: CNRS, MPG, IGN
- Open to the international astronomical community → RadioNet

IRAM's expertise: pictures worth a thousand words



- Telescope design (~35 um), construction and operation
- Receiver design and development e.g. ALMA Band7, AMSTAR(+)
- HS-digital backends + LO systems e.g. Dual 4 GHz correlator

IRAM’s expertise: pictures worth a thousand words



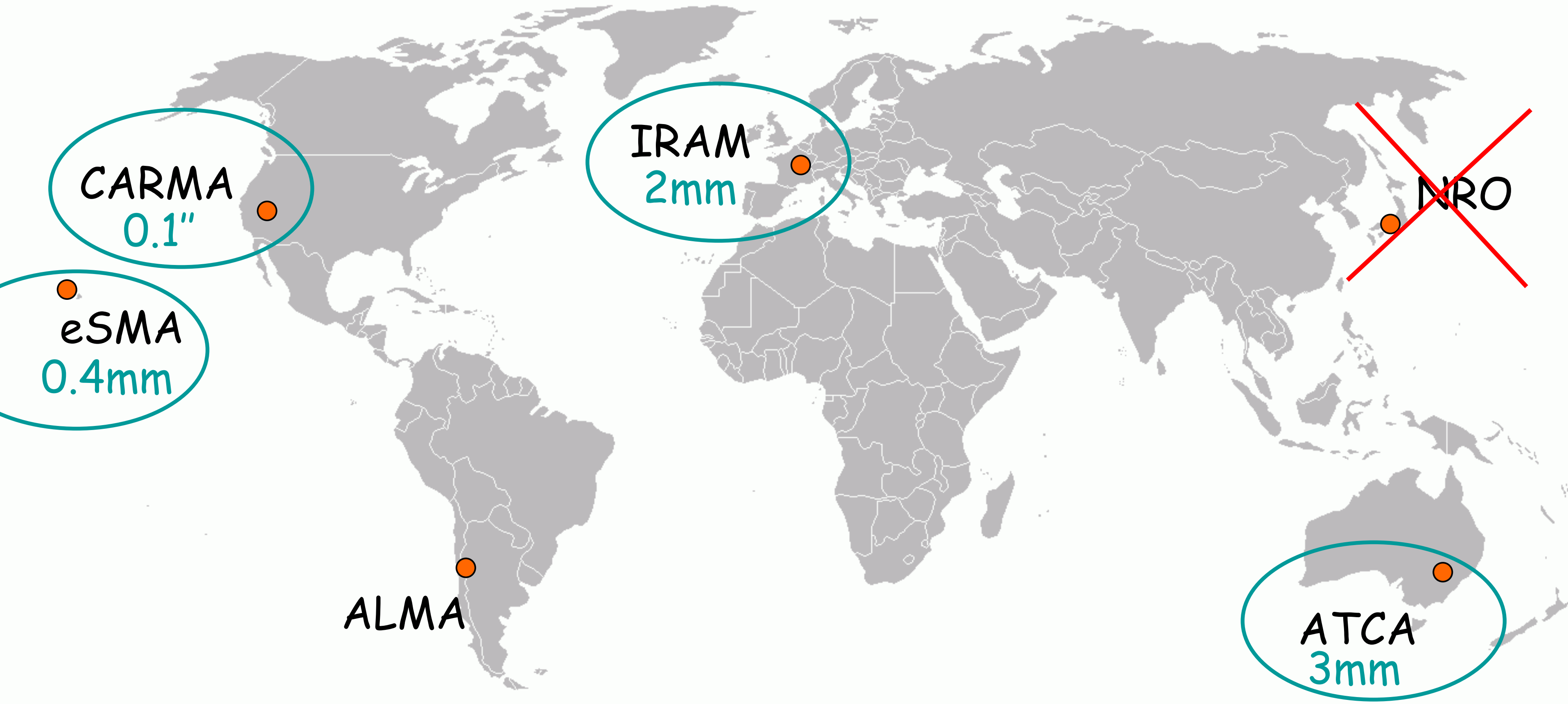
- Class 100 clean room for thin film technology
- Complete mm/THz-wave technology laboratory
- Developments for e.g. Herschel

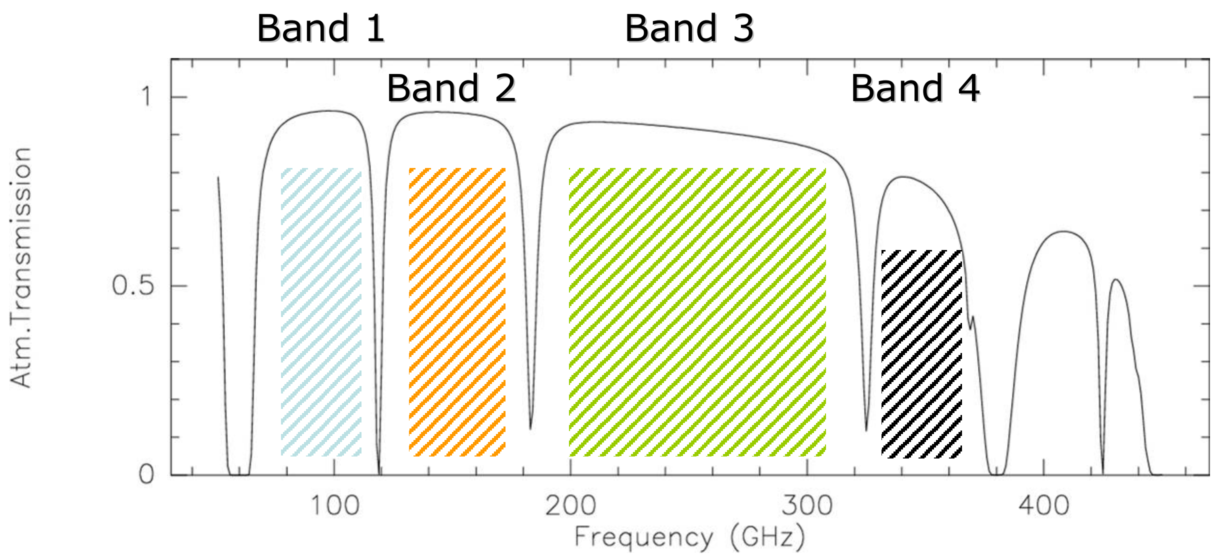
PdBI high impact upgrades

Semester	Upgrade	Done
W05/06	Track Extensions	✓
W06/07	FE: Band 1 and Band 3	✓
W07/08	FE: Band 2	✓
W09/10	BE: wideband correlator	✓
W10/11	FE: Band 4	
W11/12	Polarization, OTF	
W12/13	NOEMA	

(sub)mm-interferometers worldwide

(sub)mm-interferometers worldwide



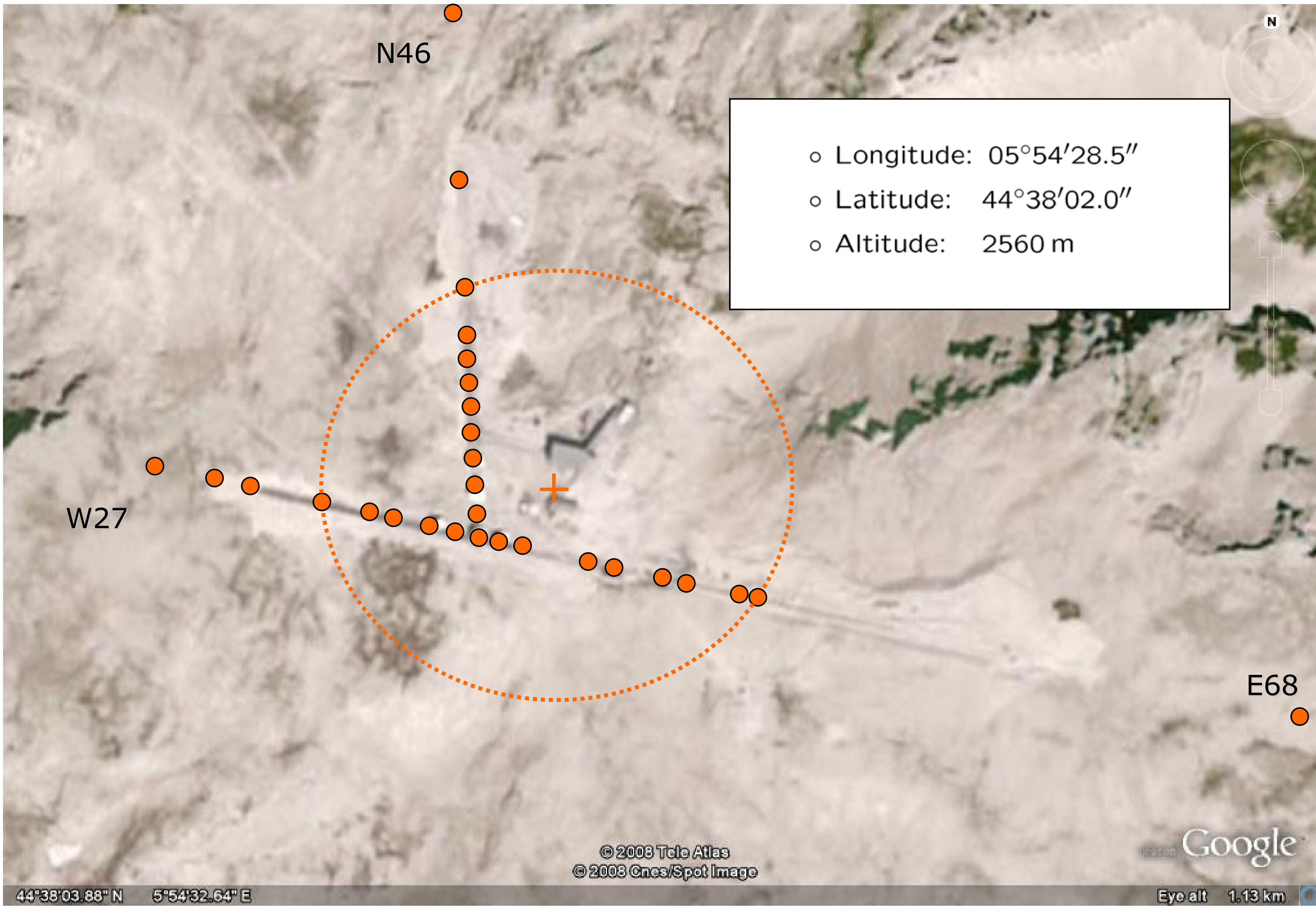


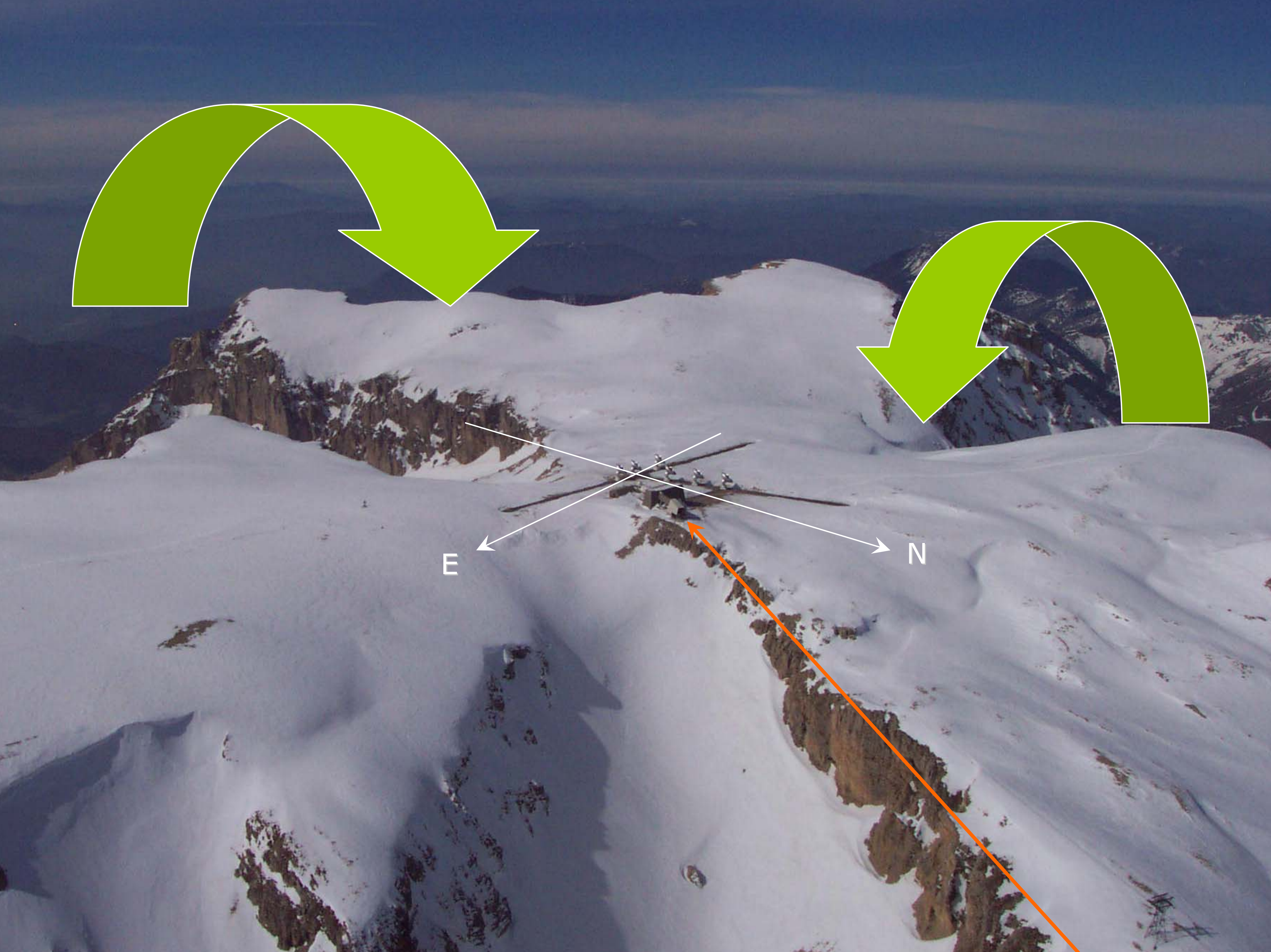
3mm = 100 GHz   2mm = 150 GHz   1mm = 300 GHz   0.8mm = 350 GHz

Interferometer	Atmospheric window	Ang.Resolution
ATCA	3mm	1.6″
PdBI	3mm, 2mm, 1mm, 0.8mm	0.3″
SMA	1mm-0.7mm, 0.4mm	(0.15″)
CARMA	3mm 1mm	(0.1″)

Large differences !

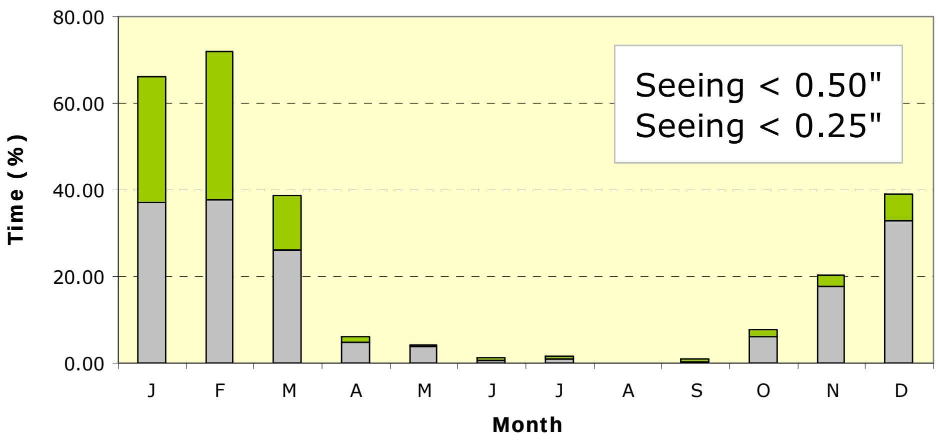
Rhône-Alpes
Grenoble
100 km
Plateau de Bure
© 2008 Cnes/Spot Image
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
© 2008 Europa Technologies
Google
44°55'45.84" N
5°46'08.41" E
Eye alt 146.69 km

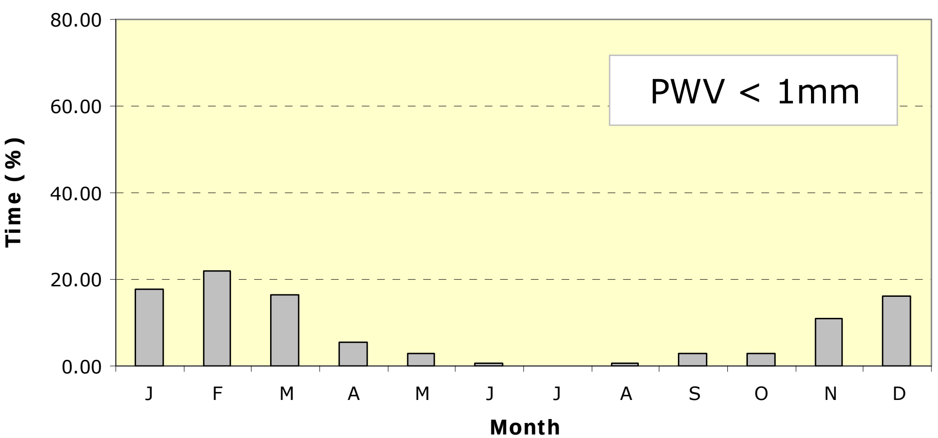

N46
W27
E68
○ Longitude: 05°54′28.5″
○ Latitude: 44°38′02.0″
○ Altitude: 2560 m
© 2008 Tele Atlas
© 2008 Cnes/Spot Image
Google
44°38'03.88" N 5°54'32.64" E
Eye alt 1.13 km

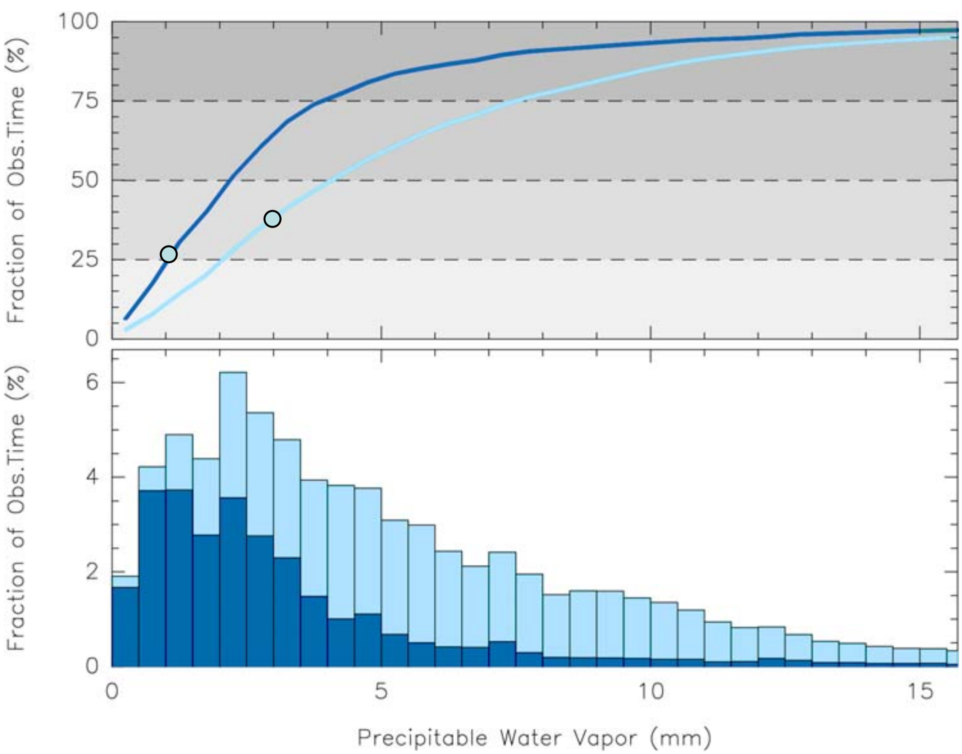

E
N


IRAM
Plateau de Bure
2004

some weather statistics (Jan 2001 >)







⇨ 2009: 80% of the observing time invested @ 3mm and 2mm

Plateau de Bure Interferometer Site

- Latitude : 05°54’28.5”
- Longitude : 44°38’02.0”
- Altitude : 2560 m
- RFI protection : terrain shielding + NRQZ (30 km)

- Water vapor : 40% (<3mm); 25% (<1mm) in winter
  down to 0.3mm in best winter conditions
  submm conditions ~5 % of the time

Plateau de Bure Interferometer Site

- Latitude : 05°54'28.5"
- Longitude : 44°38'02.0"
- Altitude : 2560 m
- RFI protection : terrain shielding + NRQZ (30 km)

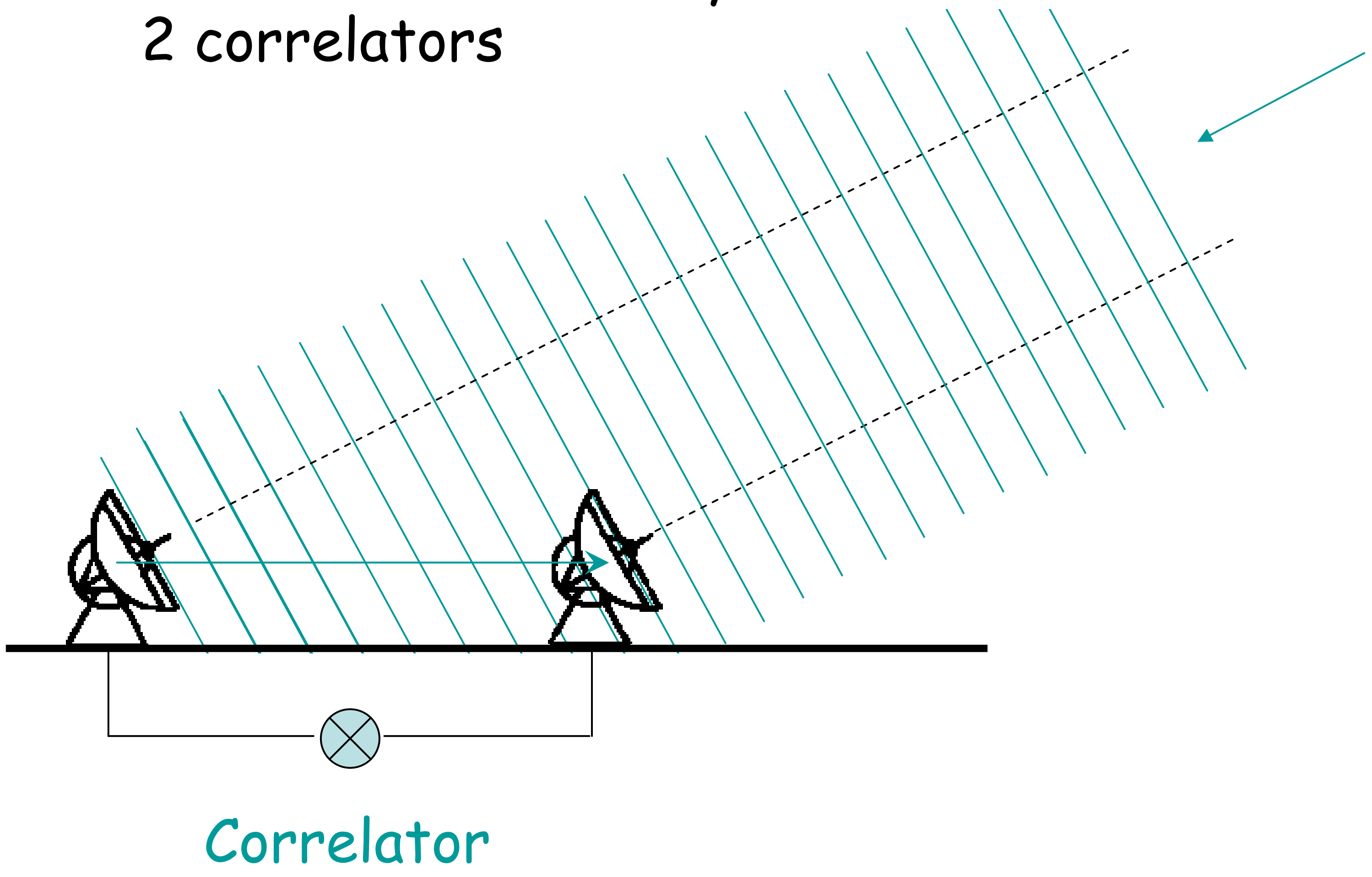
- Water vapor : 50% (<3mm); 25% (<1mm) in winter
- Weather downtime : 25 - 35%

Plateau de Bure Interferometer Observatory

▷ Operation :	24 hrs, 365 days, service mode staff @ Bure + SOG @ Grenoble
▷ Team @ site :	6 staff members (+ 1 astronomer)
▷ Working schedule :	1 team per week, every 3 weeks
▷ VLBI @ 3mm :	5 days sessions, twice a year 1mm intercontinental planned (+ ALMA)

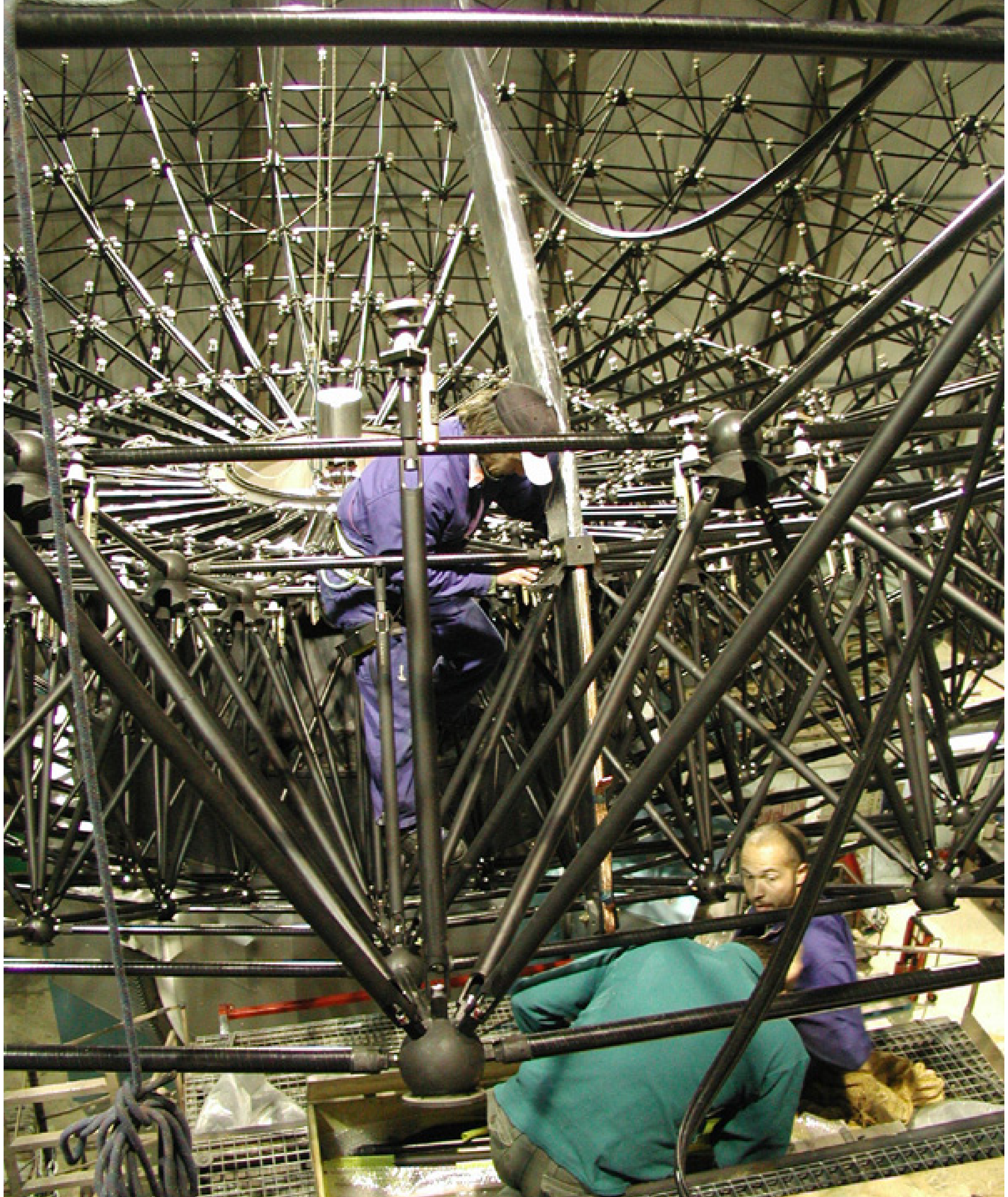
The Plateau de Bure Interferometer

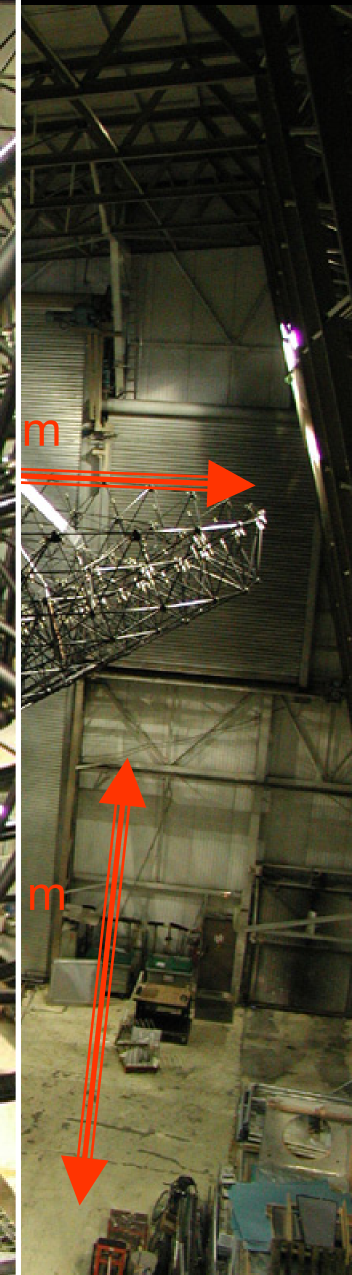
= ensemble of 6 antennas +
6 receivers + 12 delay lines +
2 correlators

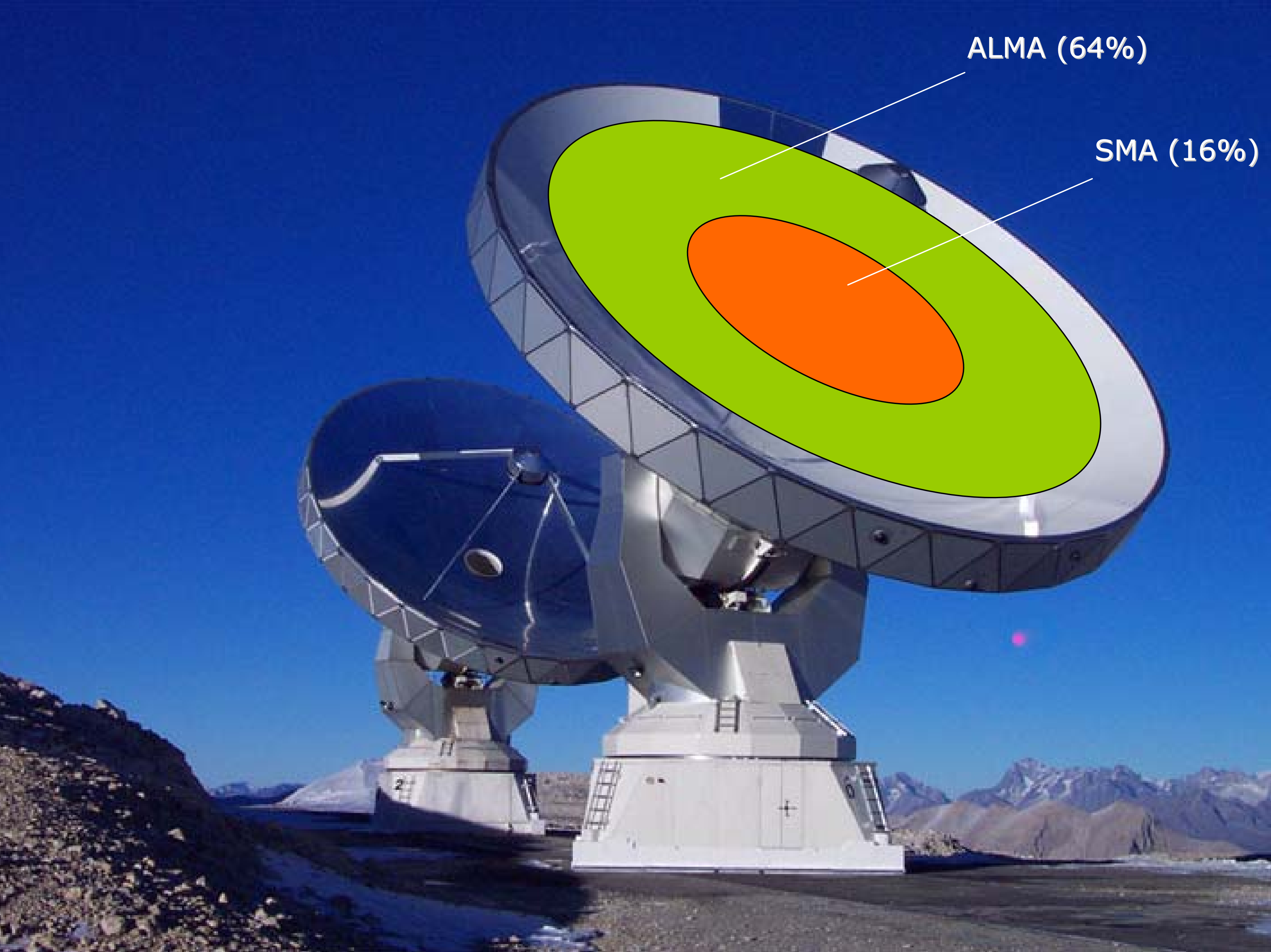


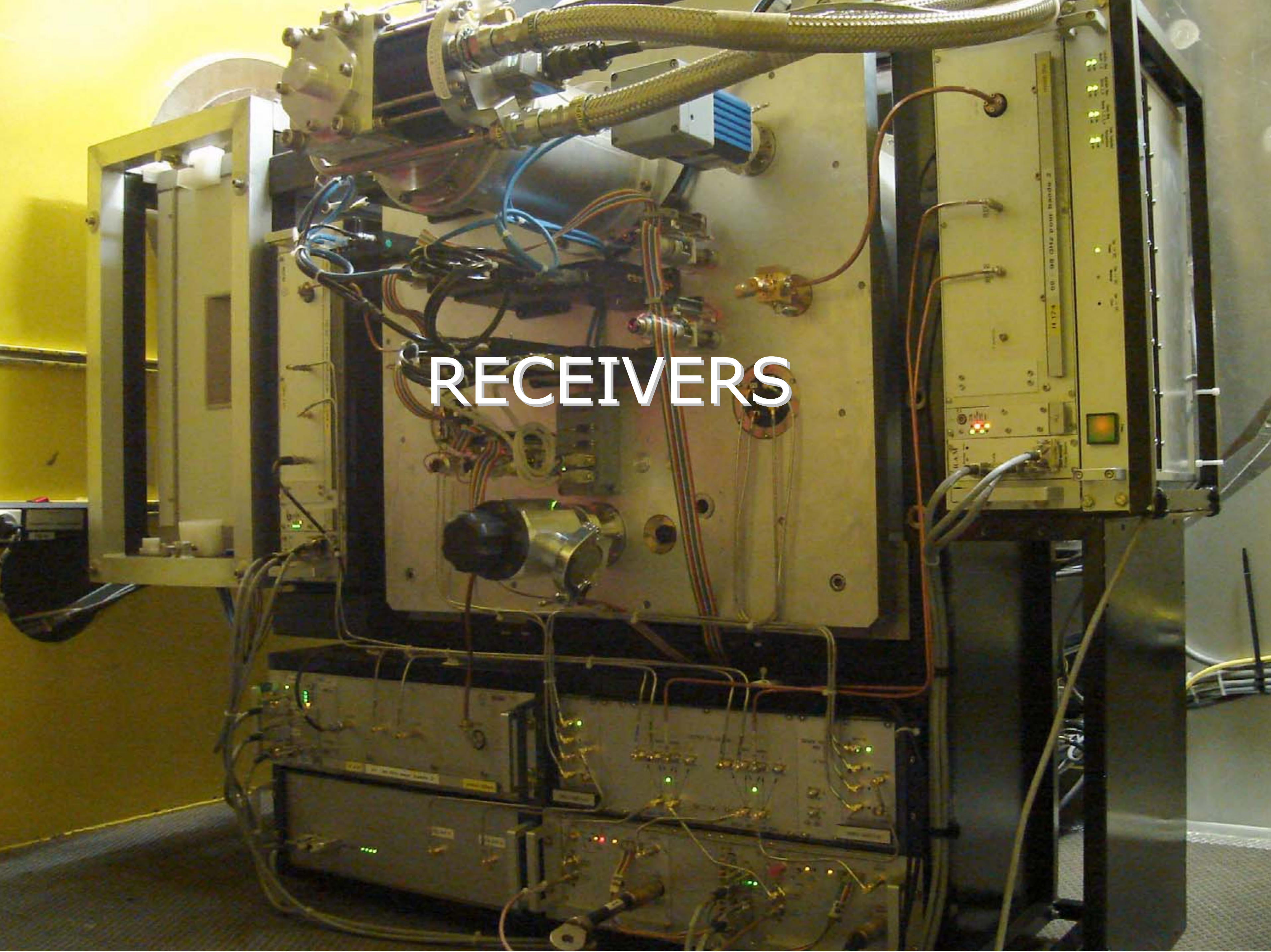
Plateau de Bure Interferometer Observatory

▷Antennas :	6, Cassegrain Type
▷ Collecting area :	$177m^2$ x 6 = $1060m^2$
▷ Surface panels :	176, aluminum
▷ Surface accuracy :	35 - 50 µm
▷ Aperture efficiency :	0.65 @ 230 GHz
▷ Primary beam :	21” @ 230 GHz
▷ Pointing / tracking RMS :	1.5” / 0.2”
▷ Wind speed (max) :	14 m/s




m
m


ALMA (64%)
SMA (16%)


RECEIVERS

PdBI State of the art receiver technology

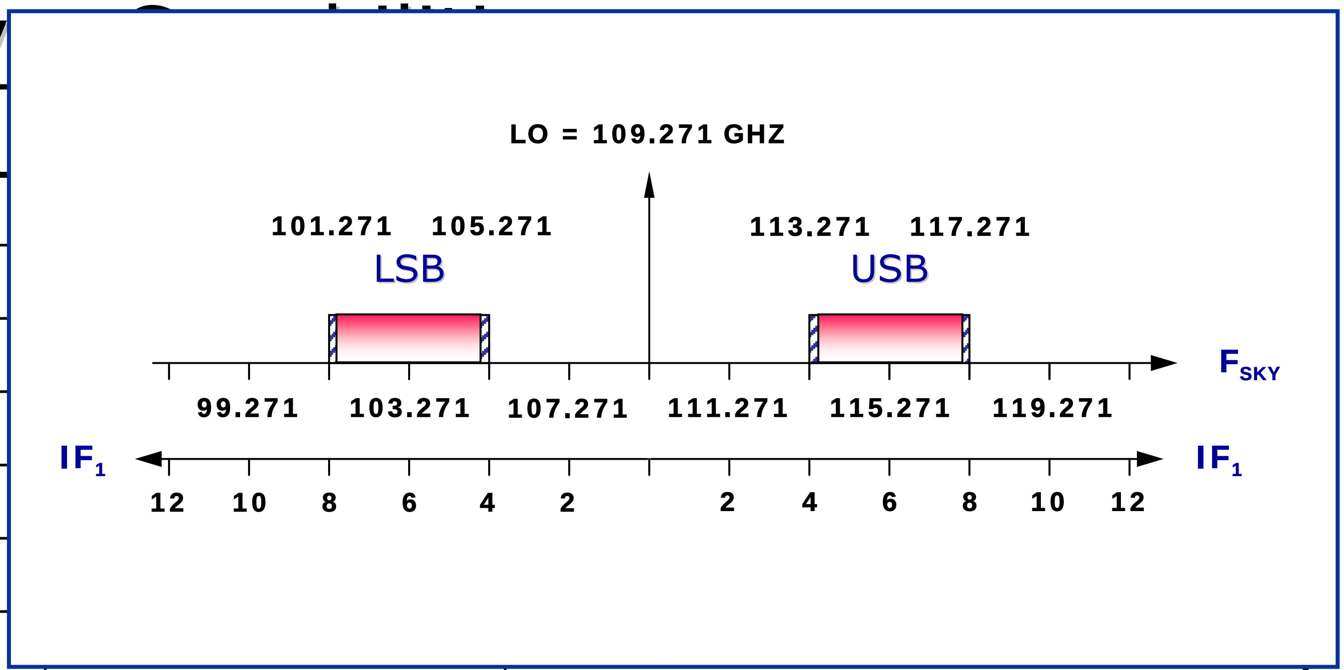
> Jan 2007

- Closed cycle cryocoolers ⇨ no liquid He refills
- SIS mixers in full-height waveguide ⇨ wideband, allow USB or LSB operation
- Fully reflective optics ⇨ lower loss
- New Design ⇨ higher density, better EMI control, simplified wiring

> Dec 2010

- Tuneless mixers and LOs for band 4 ⇨ simplified frequency tuning and switching

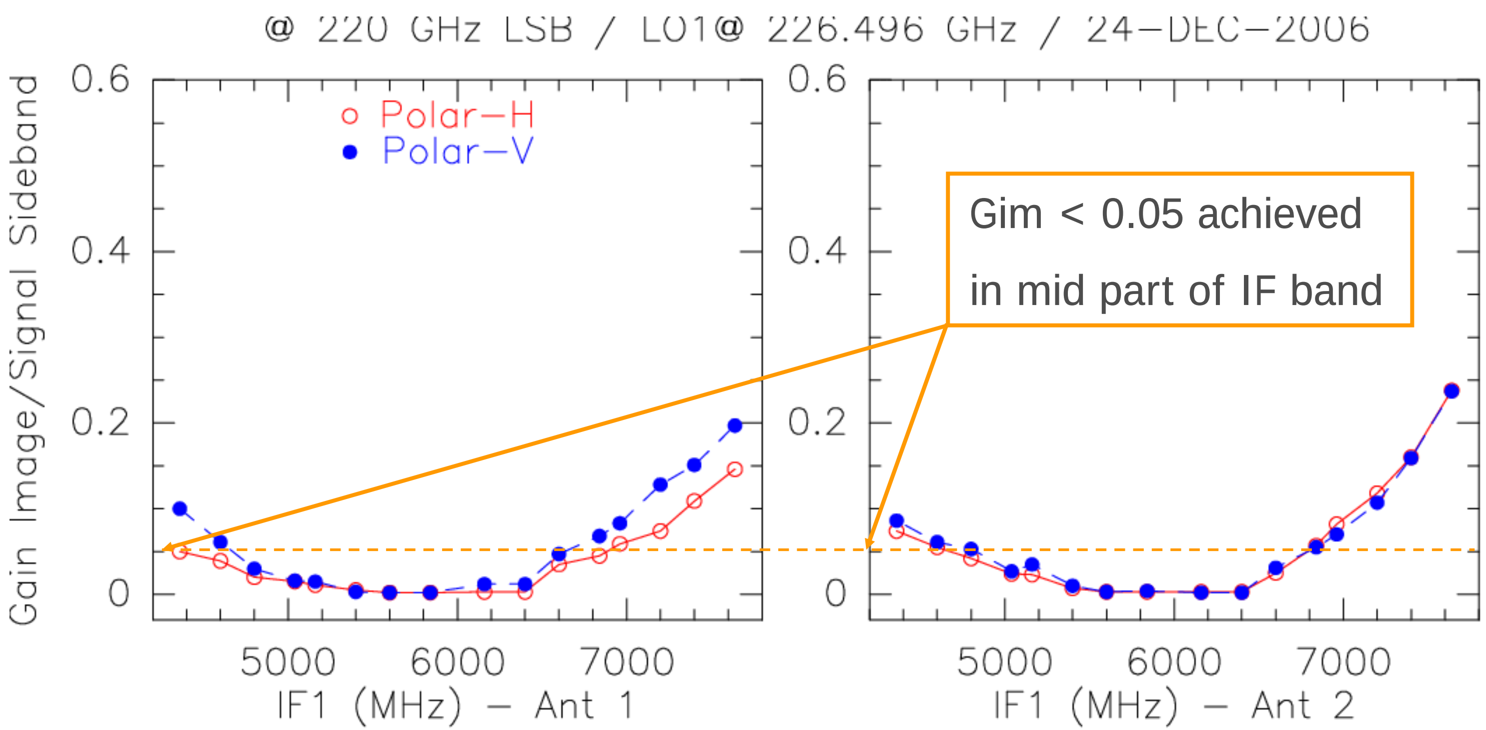
PdBI Receiv



Item		
RF bands		
1 = ALMA Band 3		
2 = ALMA Band 4		
3 = ALMA Band 6		
4 = ALMA Band 7		
RF response	SSB	LSB or USB Image Gain <-10dB
IF band	4 – 8 GHz	
Polarization	Dual linear	Circular also possible
Observing mode	Single frequency Dual polarization	Second band in standby Potential for Dual freq, Dual pol

PdBI Receiver Image Rejection

- Optimized for center of IF band
- Usually better than 10dB over 50% of IF band

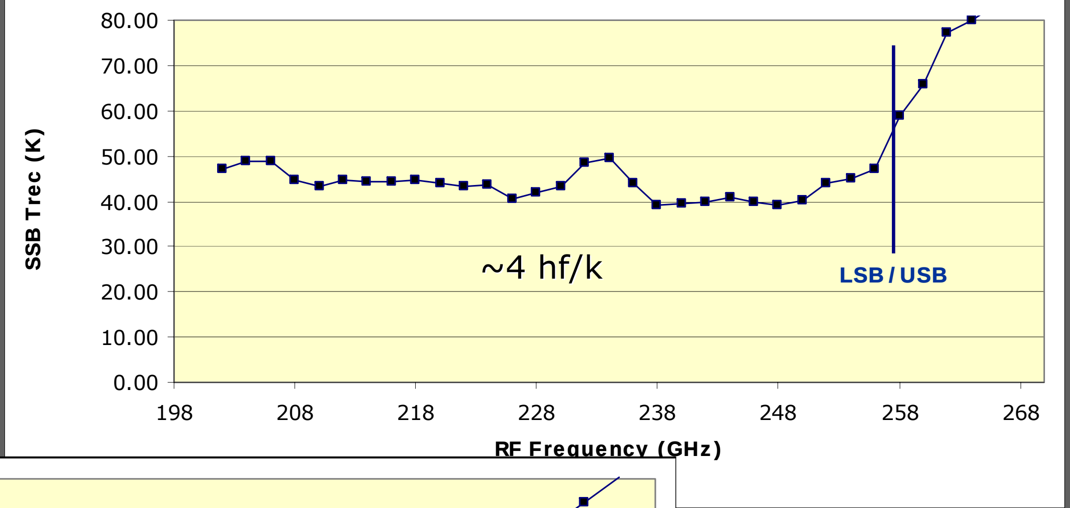


$X_{dB} = 10*\log10(Gim)$

Band3

12 mixers

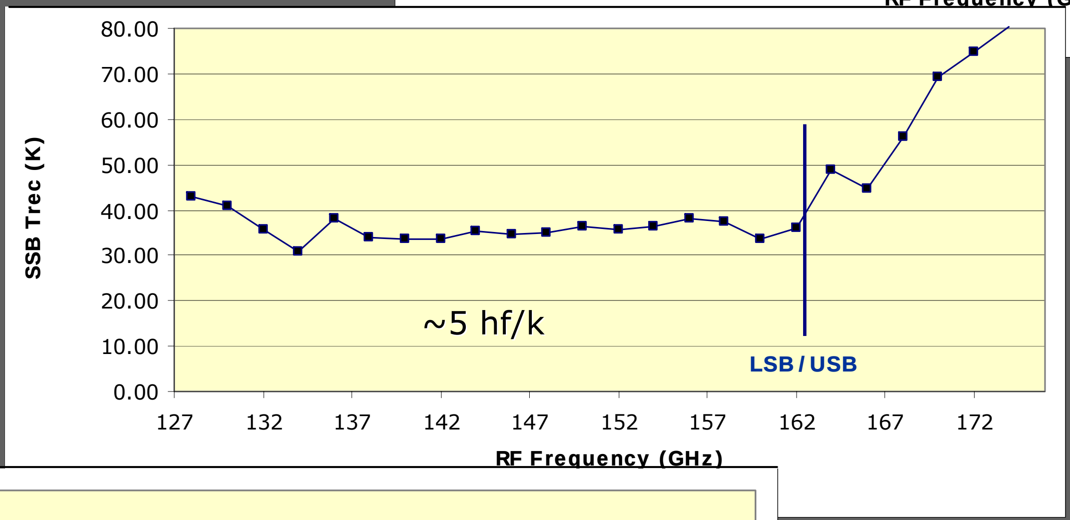
(June 2010)

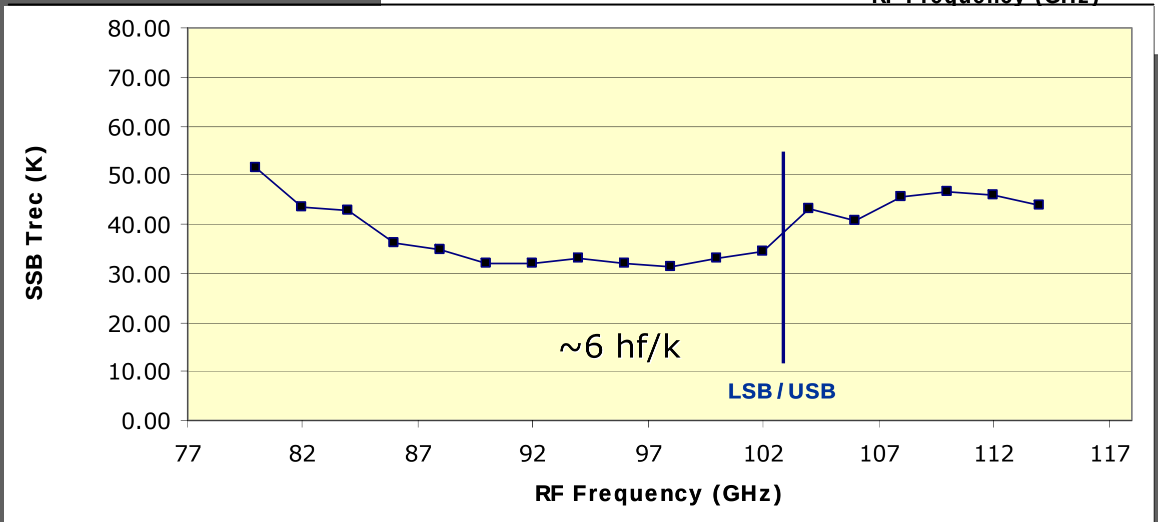


Band2

12 mixers

(June 2010)



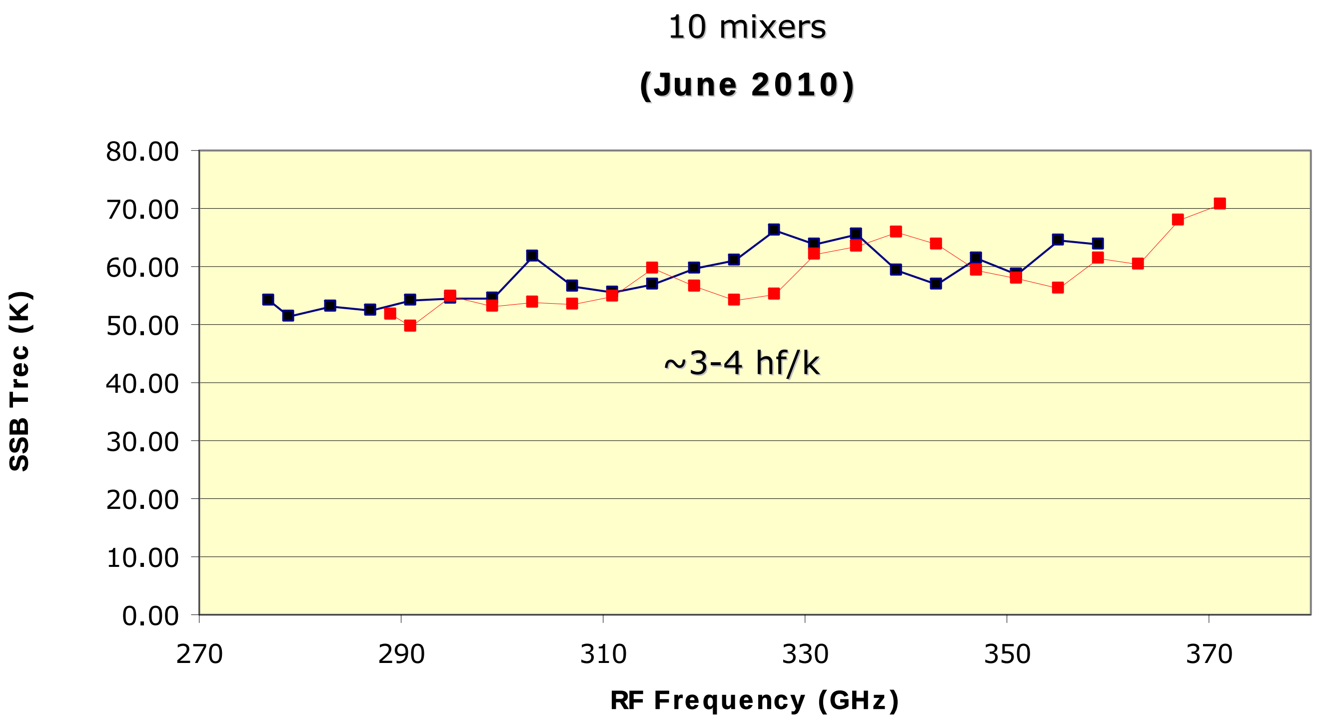


Band1

12 mixers

(June 2010)

PdBI Receiver Band 4

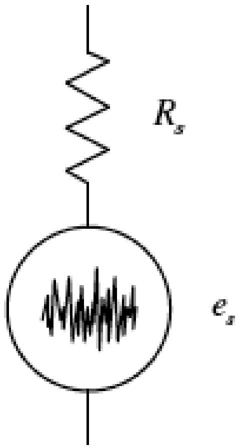


⇨ Winter 2010/2011

Noise Power

The output power of a …

… Resistor :



$$P_N = kT\Delta\nu$$

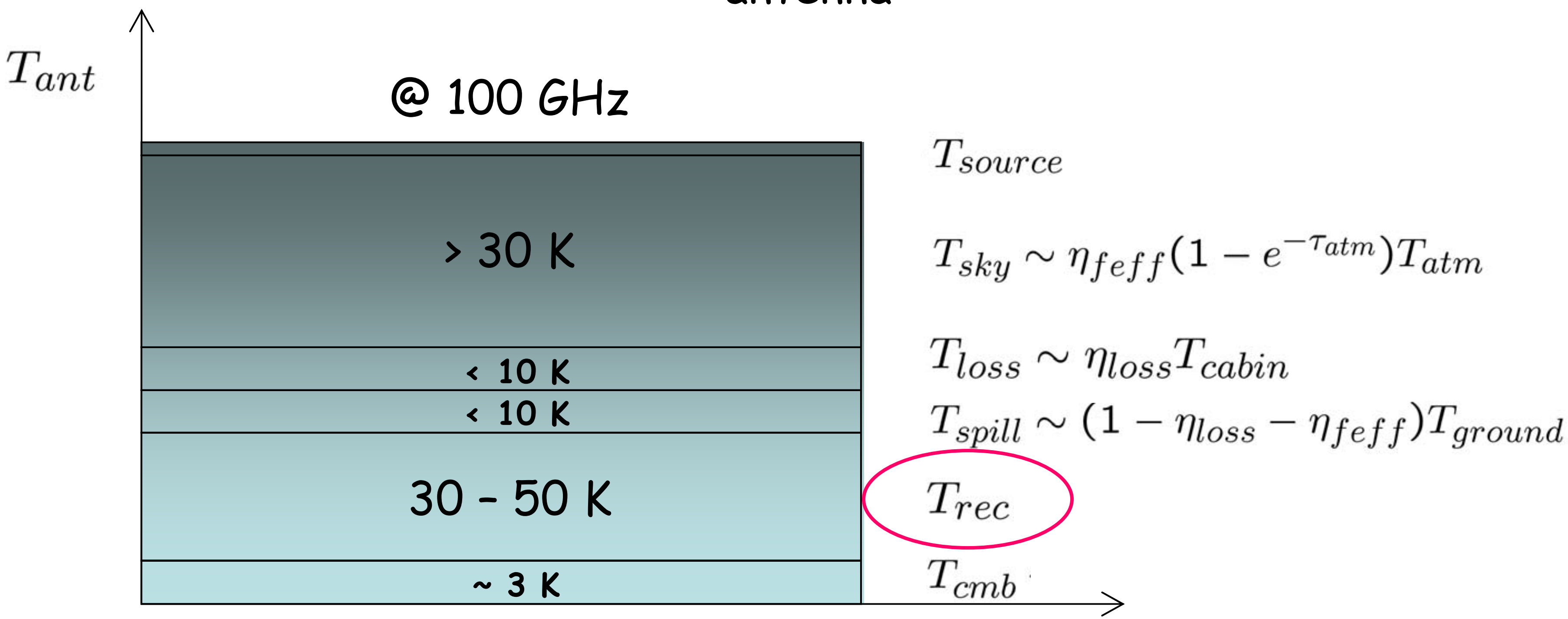
… Receiving System :

$$P_N = kT_{ant}\Delta\nu$$

Antenna System Temperature

Antenna System Temperature

is the temperature of the equivalent blackbody observed by the antenna



$$T_{ant} = T_{cmb} + T_{sky} + T_{spill} + T_{loss} + T_{rec}$$

We refer the System Temperature

Noise Power →

$$T_{sys} = \frac{e^{\tau_{atm}}}{\eta_{feff}} T_{ant}$$

and the Antenna Temperature

Astronomical Signal →

$$T_A^\star = \frac{e^{\tau_{atm}}}{\eta_{feff}} T_{source}$$

$$= \frac{\eta_A A}{2k} S$$

to an ideal antenna located outside the atmosphere.

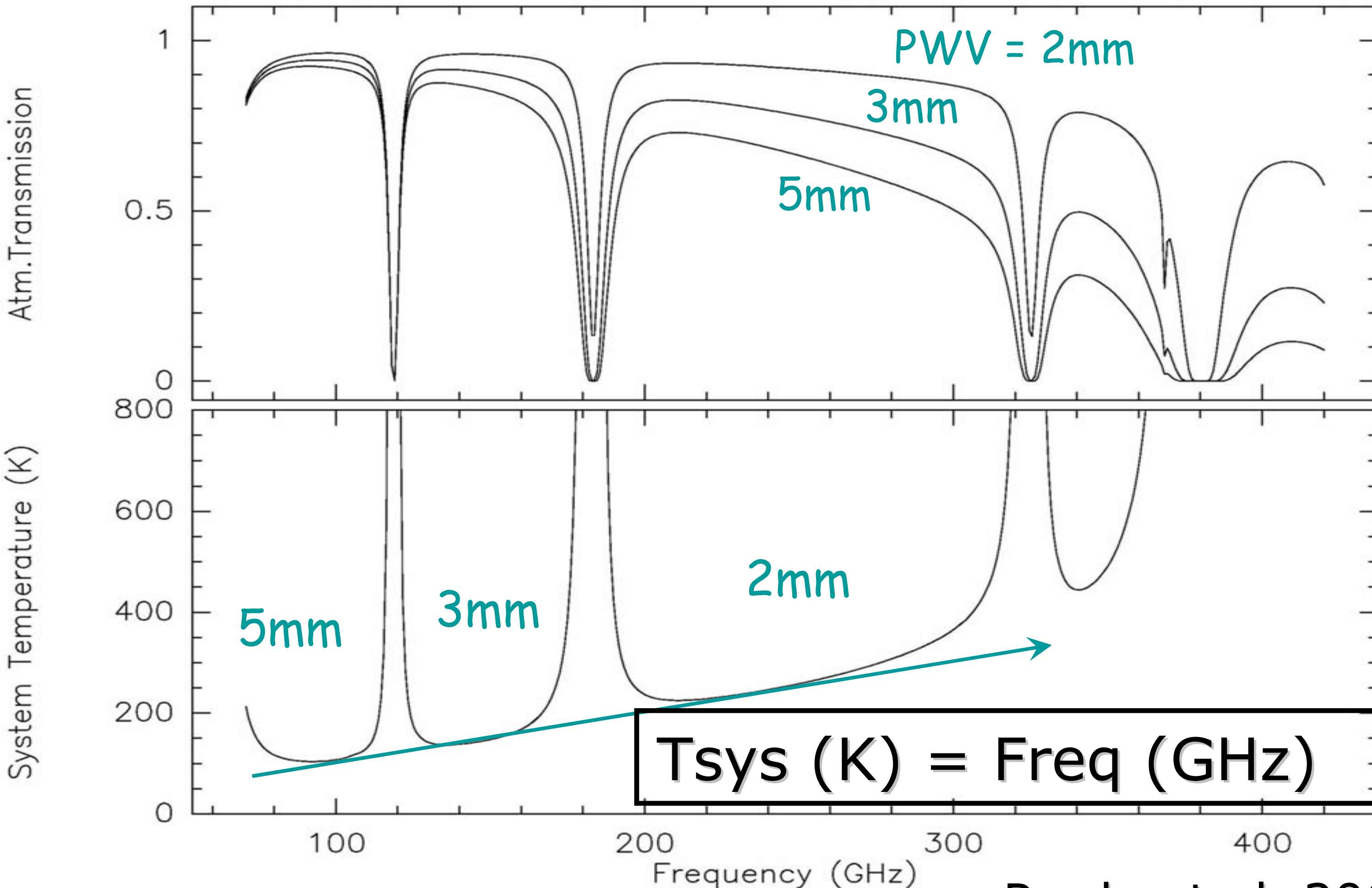
PdBI System Temperatures

Winter values: Tamb=273K, A=1.4 airmass

ATM (Cernicharo, Pardo)

	PWV	G	η_{eff}	Trec	τ	Tsys
100 GHz	3	0.05	0.95	32	0.07	77
150 GHz	3	0.05	0.92	35	0.10	113
230 GHz	1	0.05	0.87	50	0.07	141
350 GHz	1	0.05	0.84	60	0.27	336

PdBI System Temperatures



Pardo et al. 2007

The point source sensitivity

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{< T_{\mathsf{SYS}} >}{\eta_C \eta_J \eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

A	Collecting Area of a Single Antenna (177 m^2)
η_A	Aperture Efficiency (0.70 @ 3mm; 0.45 @ 1mm)
η_C	Correlator Efficiency (0.88)
η_J	Instrumental Jitter $\exp(-\sigma_J^2/2) \simeq 0.95$
η_P	Atmospheric Decorrelation $\exp(-\sigma_P^2/2) \leq 0.95$
N_P	Linear Polarizations (1 - 2)
T_{SYS}	System Temperature (K)
$\Delta\nu$	Spectral Bandwidth (39 kHz - 3600 MHz)
Δt	Integration Time On-Source (sec)

ATMOSPHERE (SITE)

Seeing Transparency

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{< T_{\mathrm{SYS}} >}{\eta_C \eta_J \eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

Receivers

Antenna

Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE

Single Dish Efficiency (Jy/K)

ATMOSPHERE (SITE)

Seeing Transparency

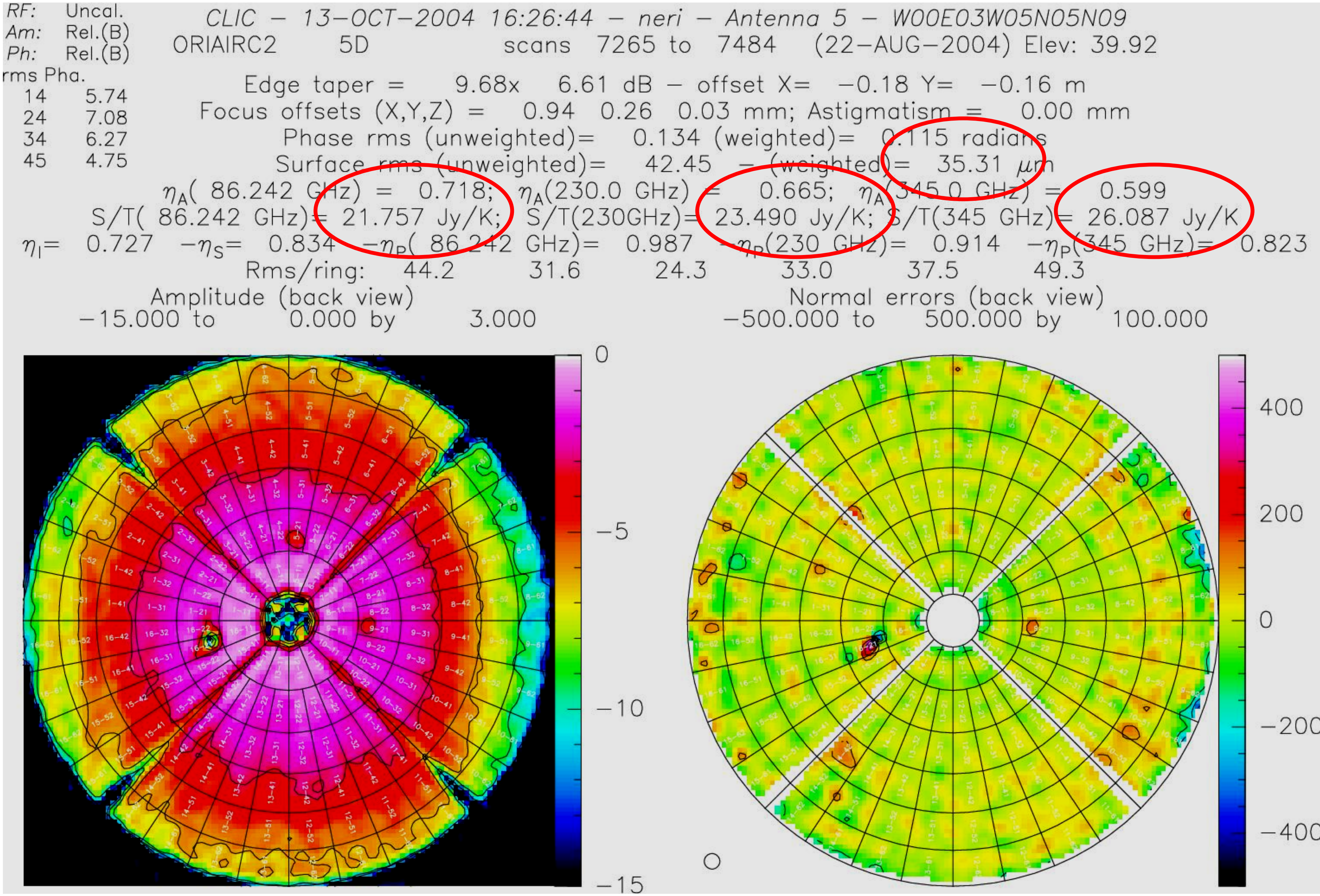
$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{< T_{\mathrm{SYS}} >}{\eta_C \eta_J \eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

$$\eta_A = \eta_{\mathrm{Blocage}} \cdot \eta_{\mathrm{Spillover}} \cdot \eta_{\mathrm{Receiver}} \cdot \eta_{\mathrm{Ruze}}$$

Antenna Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE


RF: Uncal.
Am: Rel.(B)
Ph: Rel.(B)
rms Pha.
14 5.74
24 7.08
34 6.27
45 4.75
CLIC – 13-OCT-2004 16:26:44 – neri – Antenna 5 – W00E03W05N05N09
ORIAIRC2 5D scans 7265 to 7484 (22-AUG-2004) Elev: 39.92
Edge taper = 9.68x 6.61 dB – offset X= -0.18 Y= -0.16 m
Focus offsets (X,Y,Z) = 0.94 0.26 0.03 mm; Astigmatism = 0.00 mm
Phase rms (unweighted)= 0.134 (weighted)= 0.115 radians
Surface rms (unweighted)= 42.45 – (weighted)= 35.31 μm
ηA(86.242 GHz) = 0.718; ηA(230.0 GHz) = 0.665; ηA(345.0 GHz) = 0.599
S/T(86.242 GHz)= 21.757 Jy/K; S/T(230GHz)= 23.490 Jy/K; S/T(345 GHz)= 26.087 Jy/K
ηI= 0.727 -ηS= 0.834 -ηP(86.242 GHz)= 0.987 -ηP(230 GHz)= 0.914 -ηP(345 GHz)= 0.823
Rms/ring: 44.2 31.6 24.3 33.0 37.5 49.3
Amplitude (back view)
-15.000 to 0.000 by 3.000
Normal errors (back view)
-500.000 to 500.000 by 100.000
0
-5
-10
-15
400
200
0
-200
-400

Interferometric Efficiency (Jy/K)

ATMOSPHERE (SITE)

Seeing Transparency

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{< T_{SYS} >}{\eta_C \eta_J \eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

Receivers

Antenna

Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE

Point source sensitivities:

$$\sigma_S = \frac{2k}{\eta_A A \times \eta_C \eta_J} \times \frac{< T_{\mathsf{SYS}} >}{\eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

$$= \frac{2k}{\eta_A A \times \eta_C \eta_J} \times \sigma_T$$

$\rightarrow 22 \times \sigma_T$ [Jy] @ 3mm Calibration precision $\leq 10\%$

$\rightarrow 26 \times \sigma_T$ [Jy] @ 2mm Calibration precision $\leq 15\%$

$\rightarrow 35 \times \sigma_T$ [Jy] @ 1mm Calibration precision $\leq 20\%$

ATMOSPHERE (SITE)

Seeing Transparency

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{< T_{\mathrm{SYS}} >}{\eta_C \eta_J \eta_P \sqrt{N(N-1)\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}}$$

Receivers

Antenna

Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE

One baseline, two antennas:

$$\sigma_S \simeq \frac{2k}{\eta_a A} \times \frac{< T_{\mathsf{SYS}} >}{\sqrt{2\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}} = \frac{\sqrt{T^1_{\mathsf{SYS}} \times T^2_{\mathsf{SYS}}}}{\sqrt{2\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}} \quad [\mathsf{Jy}]$$

$$\mathsf{Ex\,@\,100GHz:}\quad \sigma_S \simeq 22 \times \frac{100}{\sqrt{2 \times 3600\,10^6 \times 1}} \times \frac{1}{\sqrt{2}} \simeq 19\,\mathsf{mJy}$$

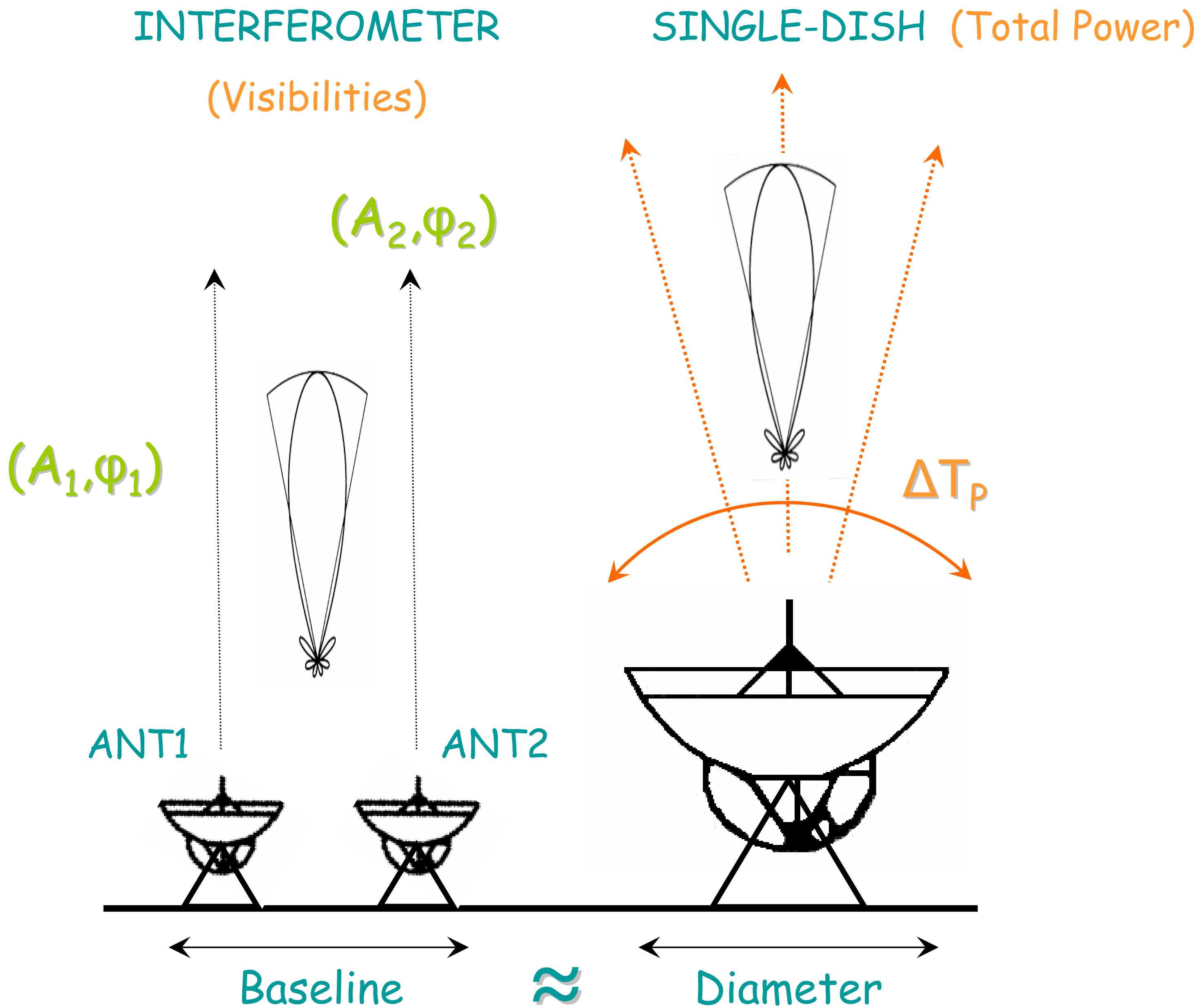
The PdBI array:

$$\mathsf{Ex\,@\,100GHz:}\quad \sigma_S \simeq 22 \times \frac{100}{\sqrt{30 \times 3600\,10^6 \times 1}} \times \frac{1}{\sqrt{2}} \simeq 4.7\,\mathsf{mJy}$$

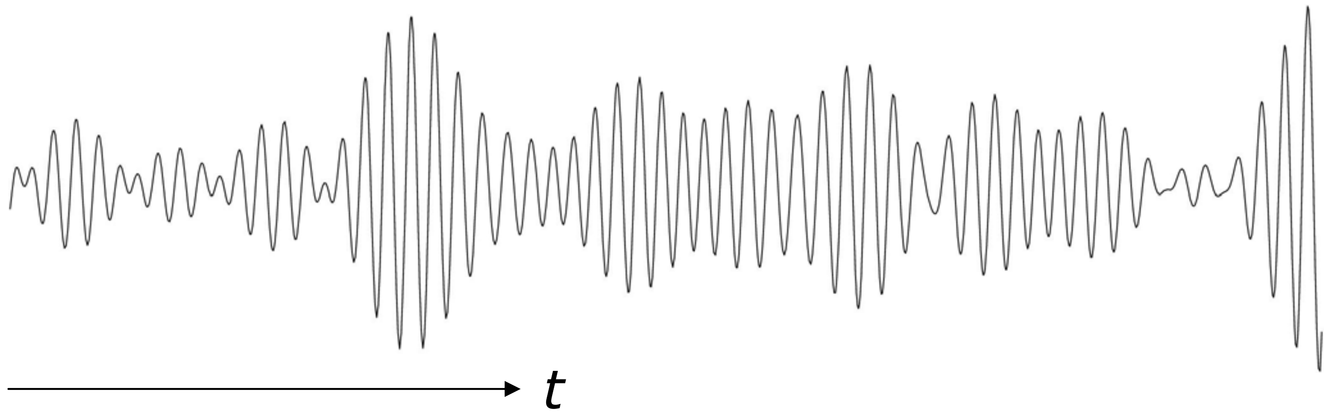
mm-interferometers : a comparison

	ATCA		CARMA		IRAM		SMA	
Altitude	220		2200		2600		4200	
Antennas	5		15		6		8	
	3mm	1mm	3mm	1mm	3mm	1mm	3mm	1mm
Sensitivity	0.51	—	0.41	0.36	1.00	1.00	—	0.36
Speed	0.23	—	0.17	0.13	1.00	1.00	—	0.13

$$\text{Sensitivity} = \frac{\eta_A D^2 \sqrt{N(N-1)}}{T_{\text{sys}}}, \quad \text{Speed} = \left[\frac{\eta_A D^2 \sqrt{N(N-1)}}{T_{\text{sys}}}\right]^2$$


INTERFEROMETER
(Visibilities)
SINGLE-DISH (Total Power)
(A_2,φ_2)
(A_1,φ_1)
ΔT_P
ANT1
ANT2
Baseline
≈
Diameter

Temporal coherence function

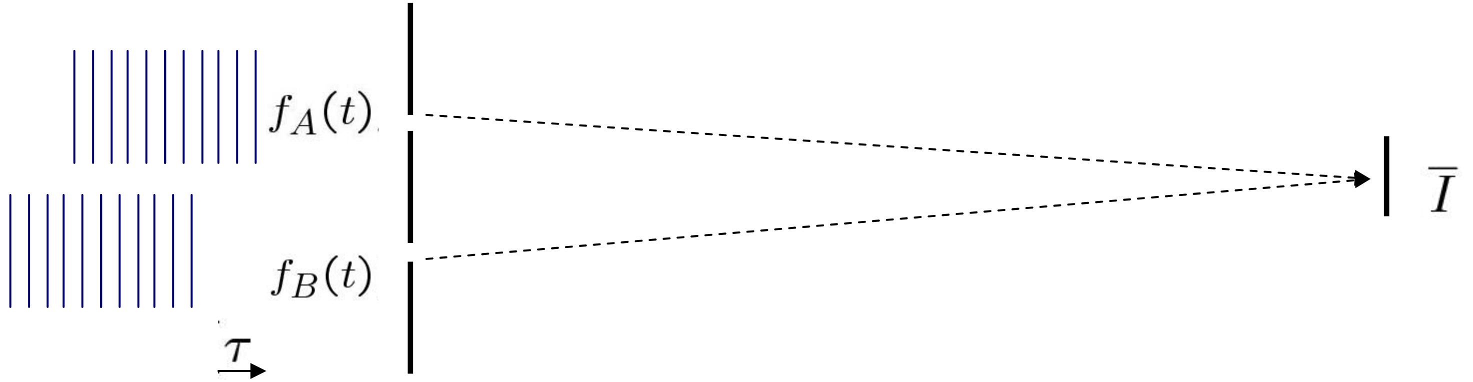


Correlation coefficient:

$$\gamma(\tau) = f(t) f^*(t+\tau) / \overline{|f(t)|^2}$$

$$f(t) = A\, e^{i\omega t} \quad \Rightarrow \quad \gamma(\tau) = e^{-i\omega\tau} \quad \Rightarrow \quad |\gamma(\tau)| = 1$$

Temporal coherence



Correlation coefficient:

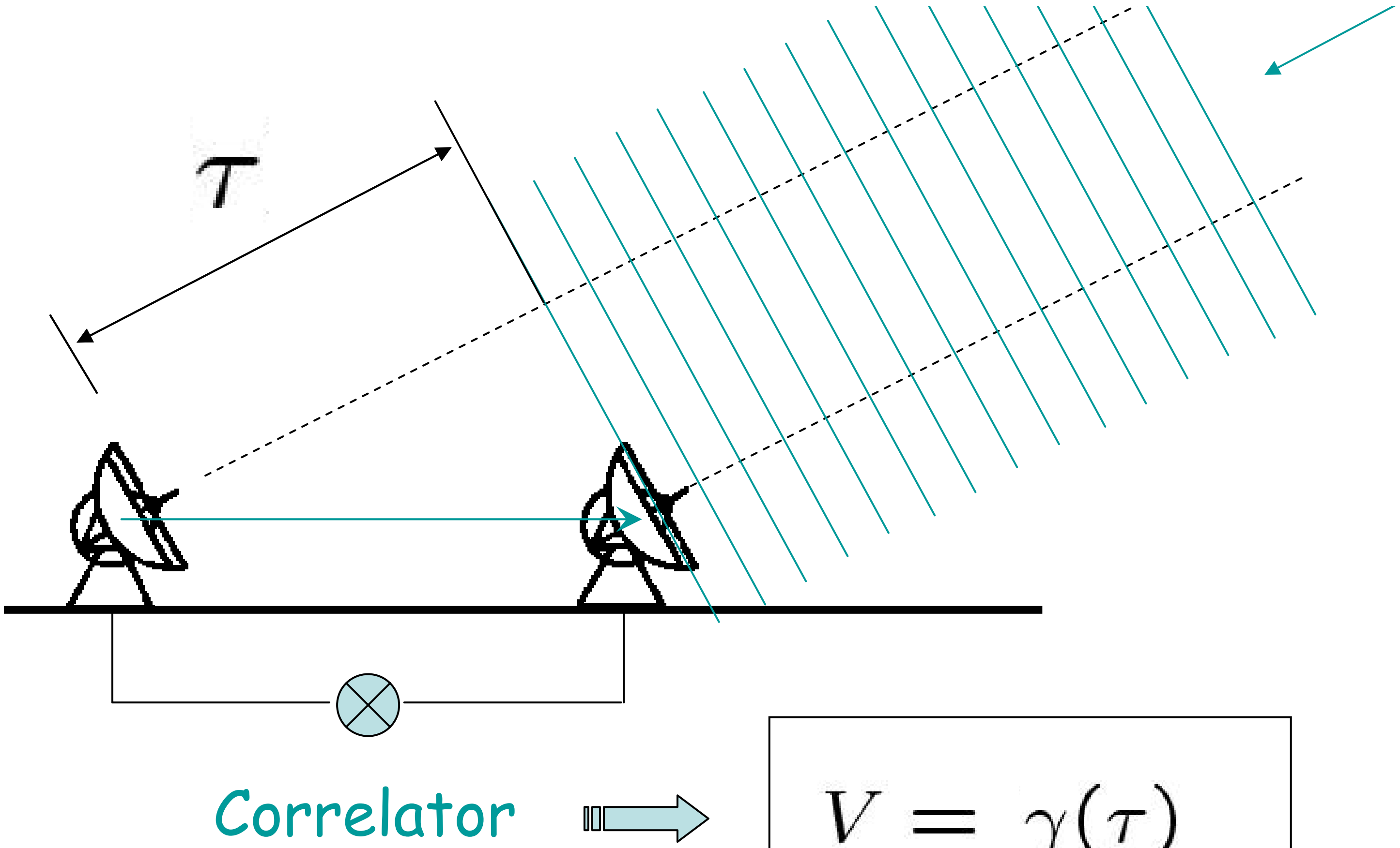
$$\gamma_{AB} = \overline{f_A(t) f_B^*(t+\tau)} / (\overline{|f_A(t)|^2}\ \overline{|f_B(t)|^2})^{\frac{1}{2}}$$

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = 2|\gamma_{AB}|(\overline{I}_A \overline{I}_B)^{\frac{1}{2}} / (\overline{I}_A + \overline{I}_B)$$

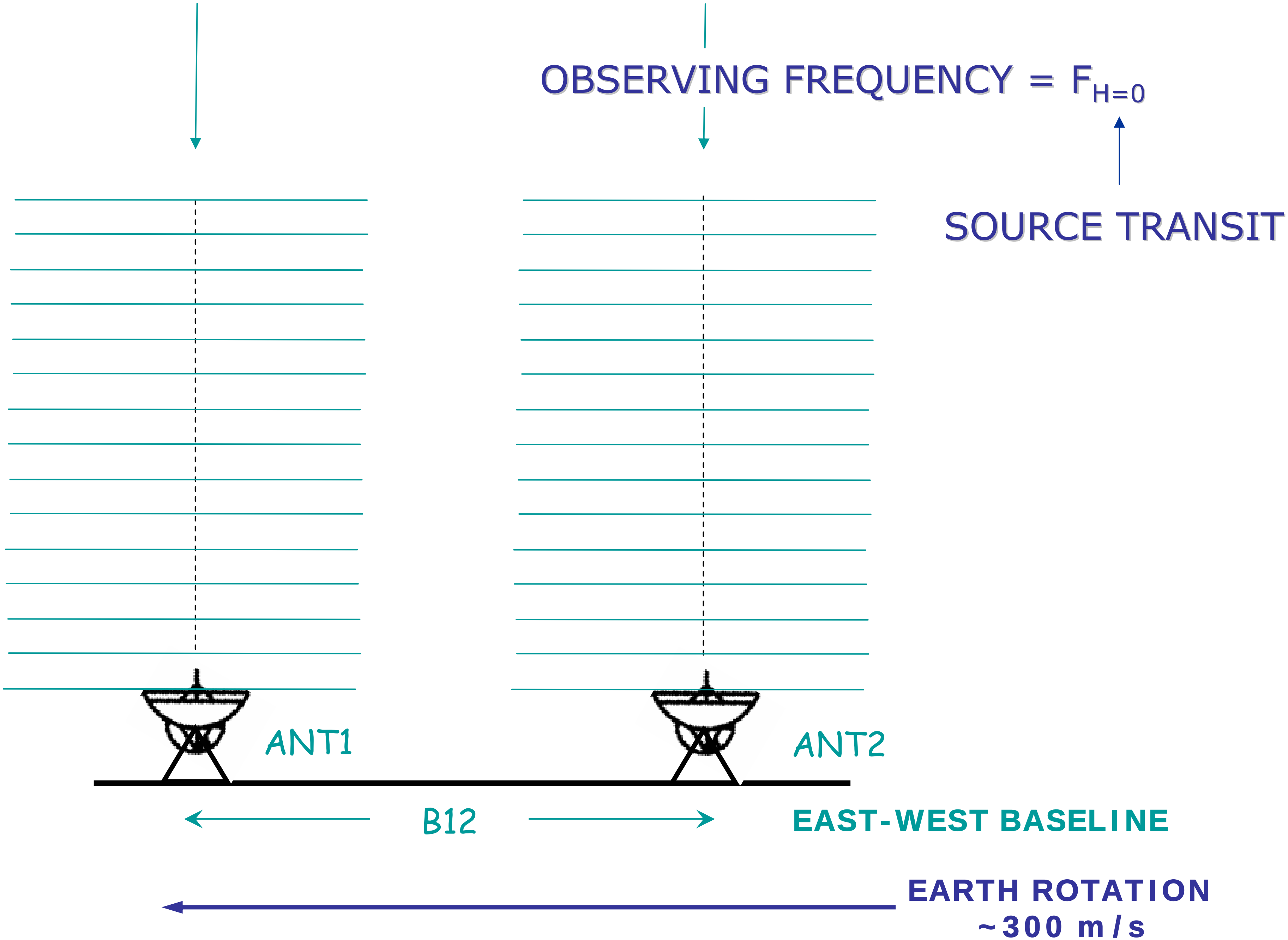
$\overline{I}_A = \overline{I}_B \quad \Rightarrow \quad \boxed{V = |\gamma_{AB}|}$

An interferometer

measures the temporal coherence of the incoming wavefront



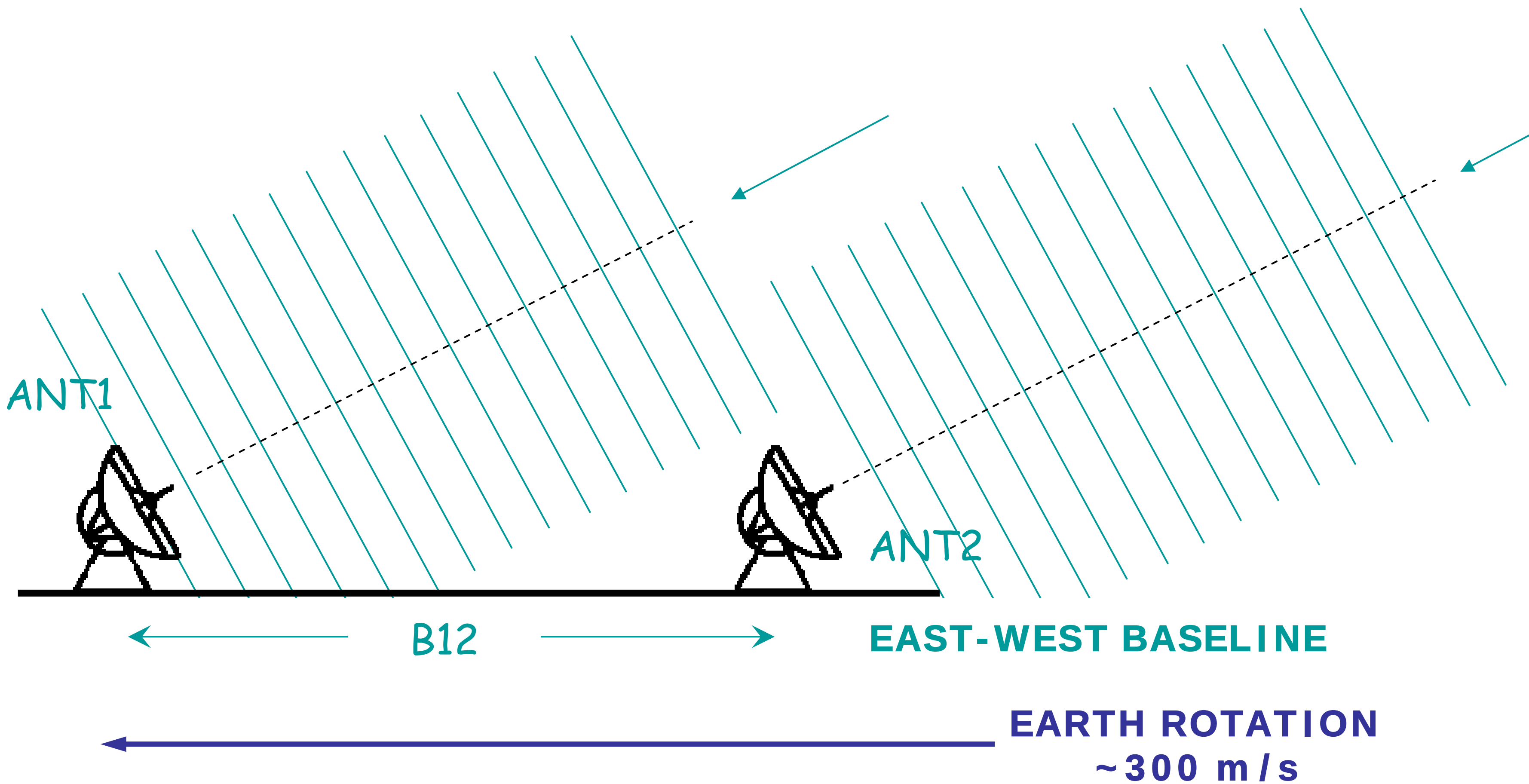
$$V = \gamma(\tau)$$

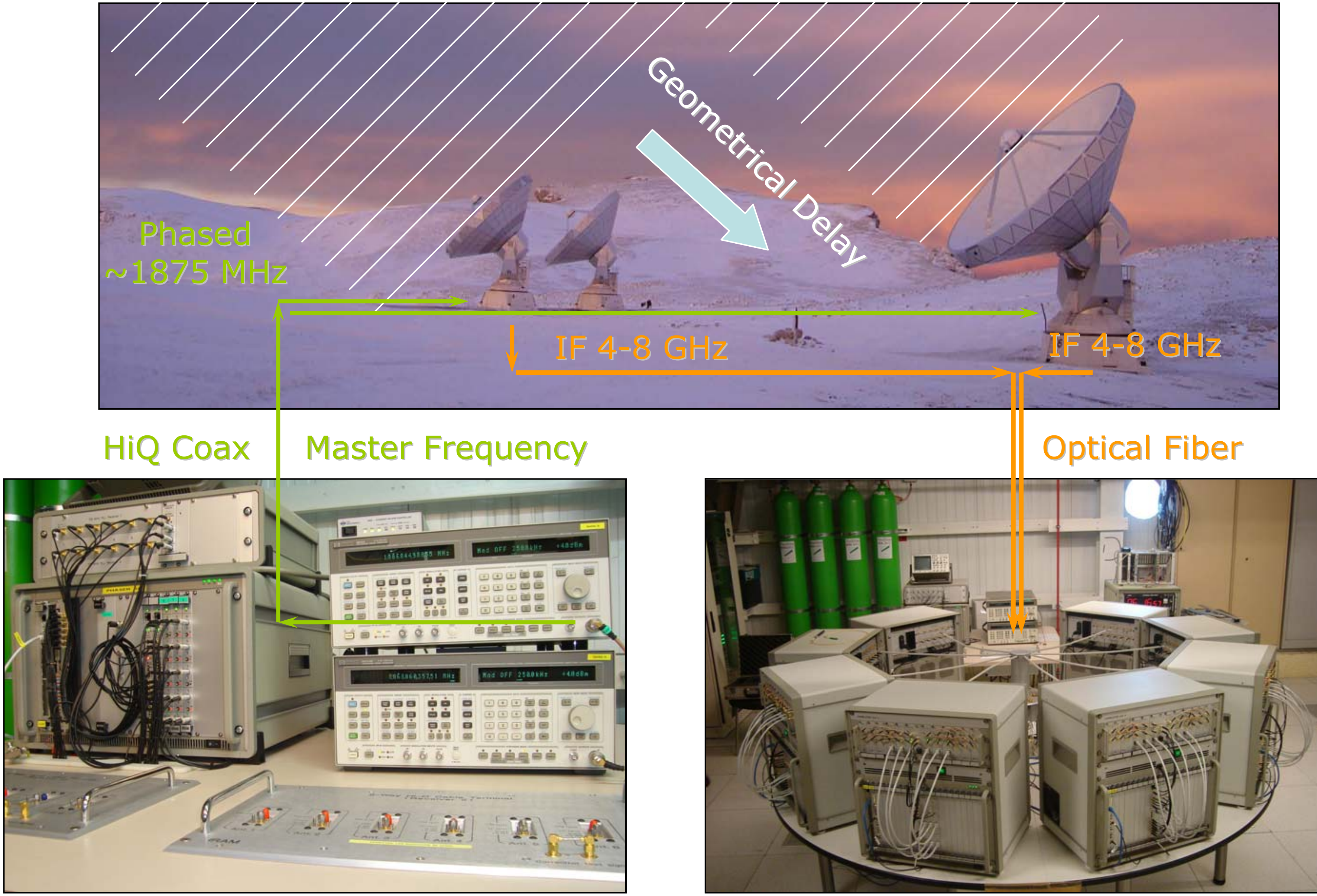

OBSERVING FREQUENCY = $F_{H=0}$
SOURCE TRANSIT
ANT1
ANT2
B12
EAST-WEST BASELINE
EARTH ROTATION
~300 m/s

SOURCE TRANSIT

SOURCE RISES $F_{H<0} > F_{H=0} > F_{H>0}$ SOURCE SETS

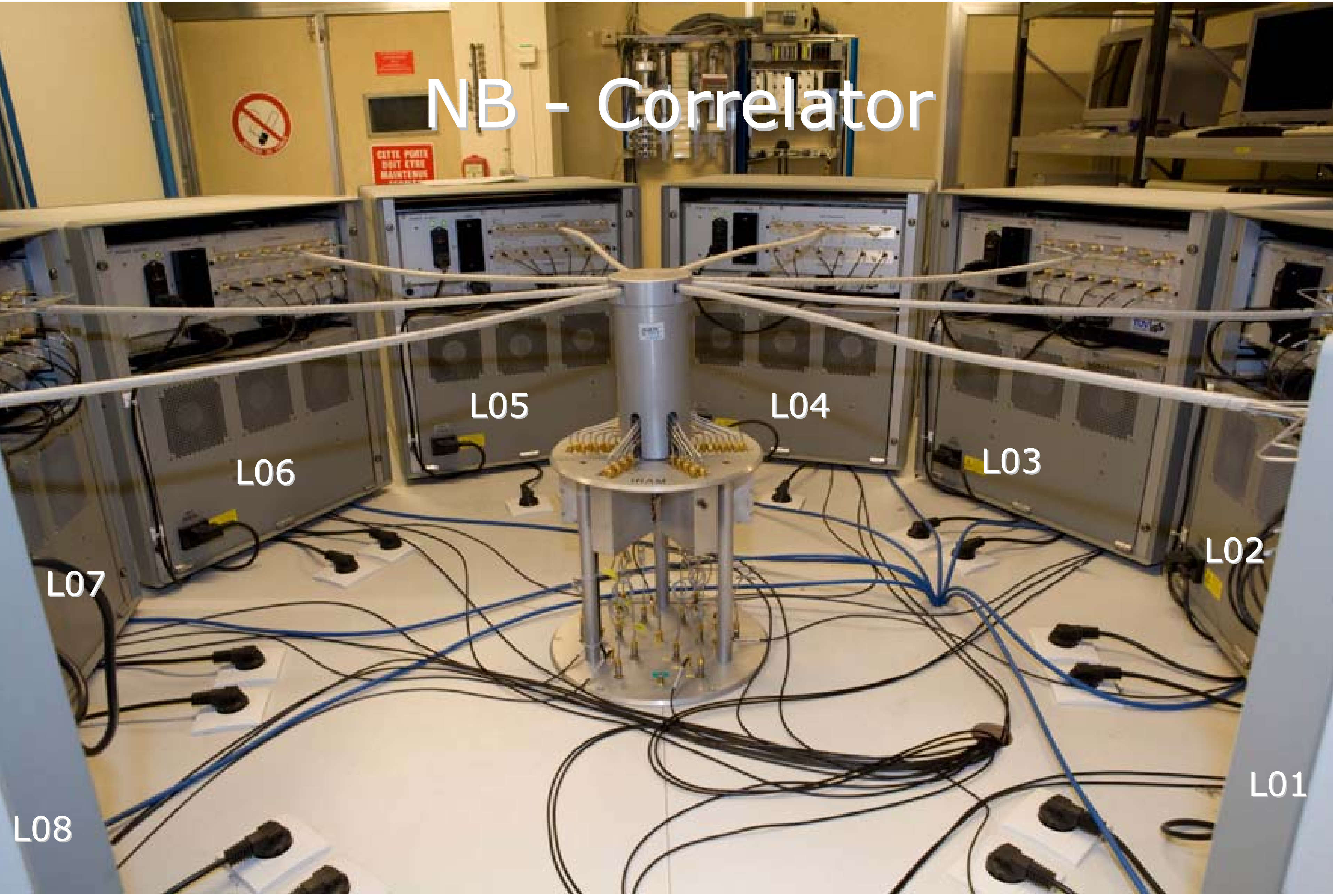
⇒ DEPENDS ON THE SKY POSITION





Geometrical Delay
Phased
~1875 MHz
IF 4-8 GHz
IF 4-8 GHz
HiQ Coax
Master Frequency
Optical Fiber

NB - Correlator

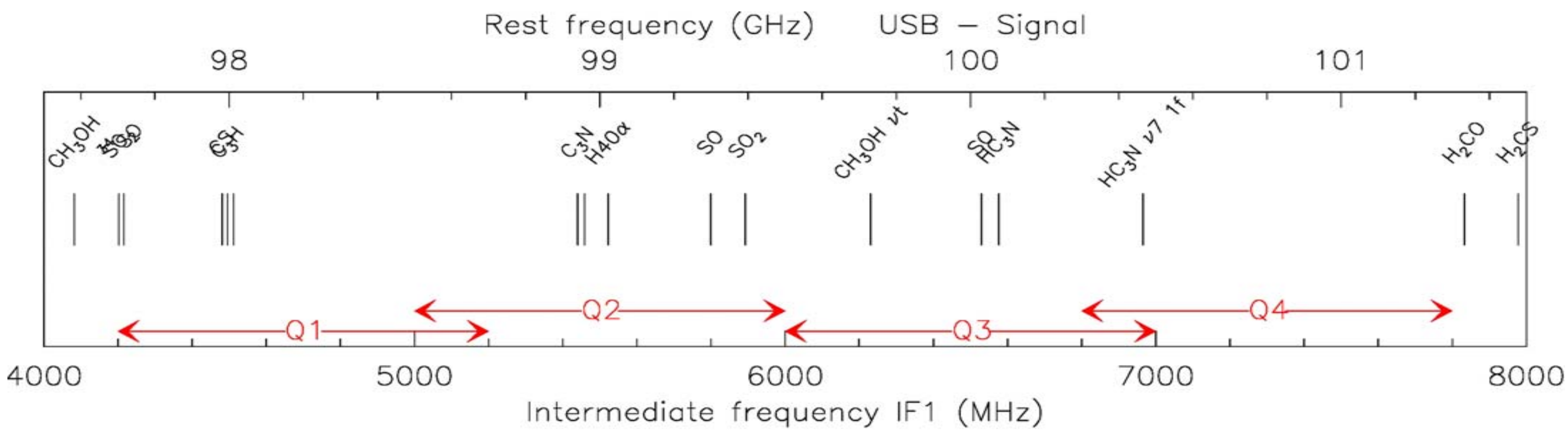


NB-Correlator Modes

http://www.iram.fr/IRAMFR/TA/backend/cor6A/index.html

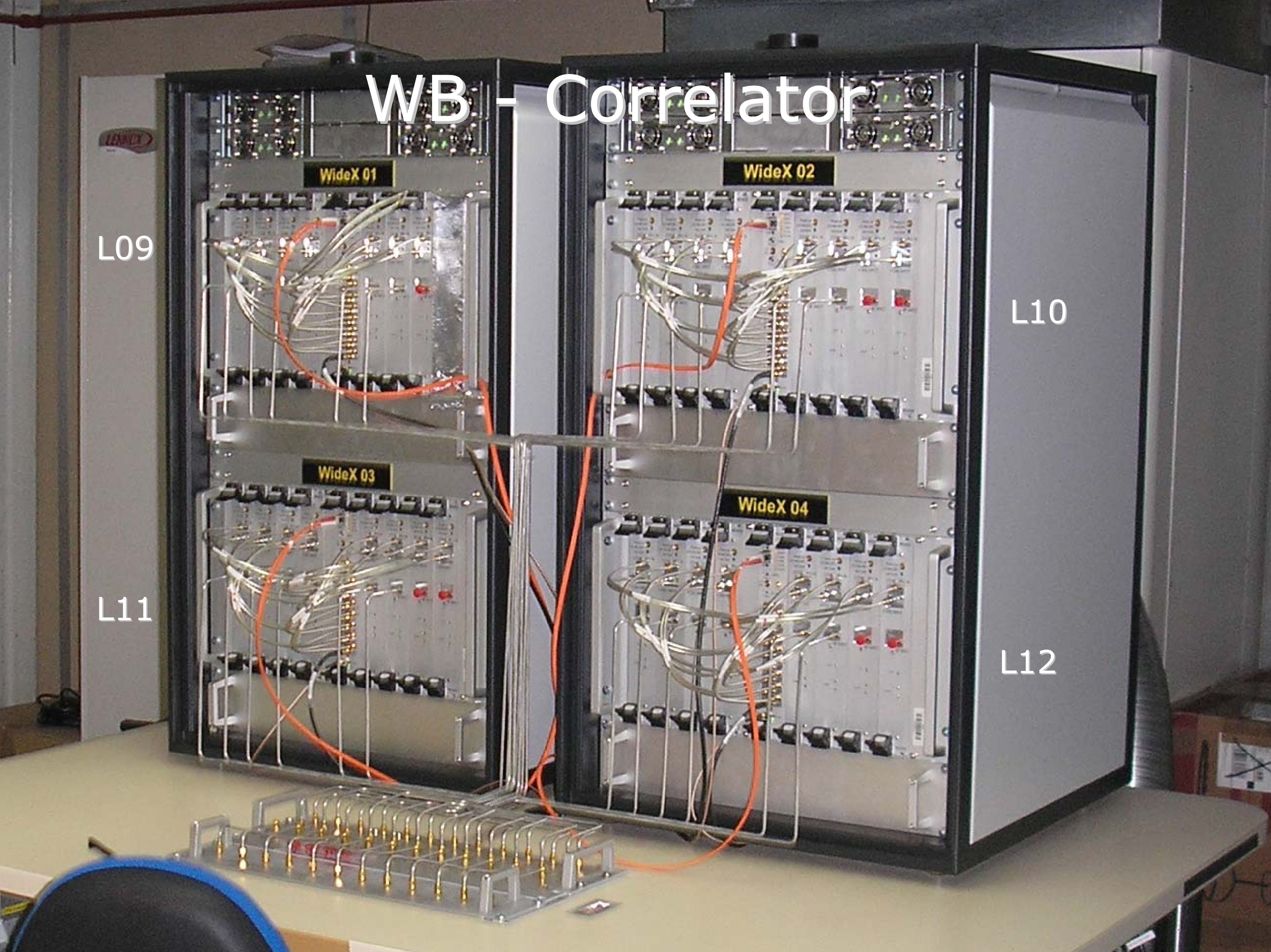
Bandwidth	Mode	Channels	Spacing
320 MHz	DSB	2 x 64	2.5 MHz
160 MHz	SSB	1 x 128	1.25 MHz
160 MHz	DSB	2 x 128	0.625 MHz
80 MHz	SSB	1 x 256	0.312 MHz
80 MHz	DSB	2 x 256	0.156 MHz
40 MHz	SSB	1 x 512	0.078 MHz
20 MHz	SSB	1 x 512	0.039 MHz

A 4 GHz RF but …



- correlator accepts only 2 quarters ; max bandwidth = 2 x 1 GHz
- eight (8) correlator units : 20 … 320 MHz (40 KHz … 2.5 MHz)

Band (MHz)	Effective (MHz)	Channel (MHz)	Δv (100 / 230) (km/s)	Sensivity (100 / 230) (mJy after 1 hr)
320	2000	2.5	7.5 / 3.3	5 / 12
160	1000	0.6	1.9 / 0.8	9 / 25
80	500	0.3	0.9 / 0.4	12 / 35


WB - Correlator
WideX 01
WideX 02
WideX 03
WideX 04
L09
L10
L11
L12

PdBI backends

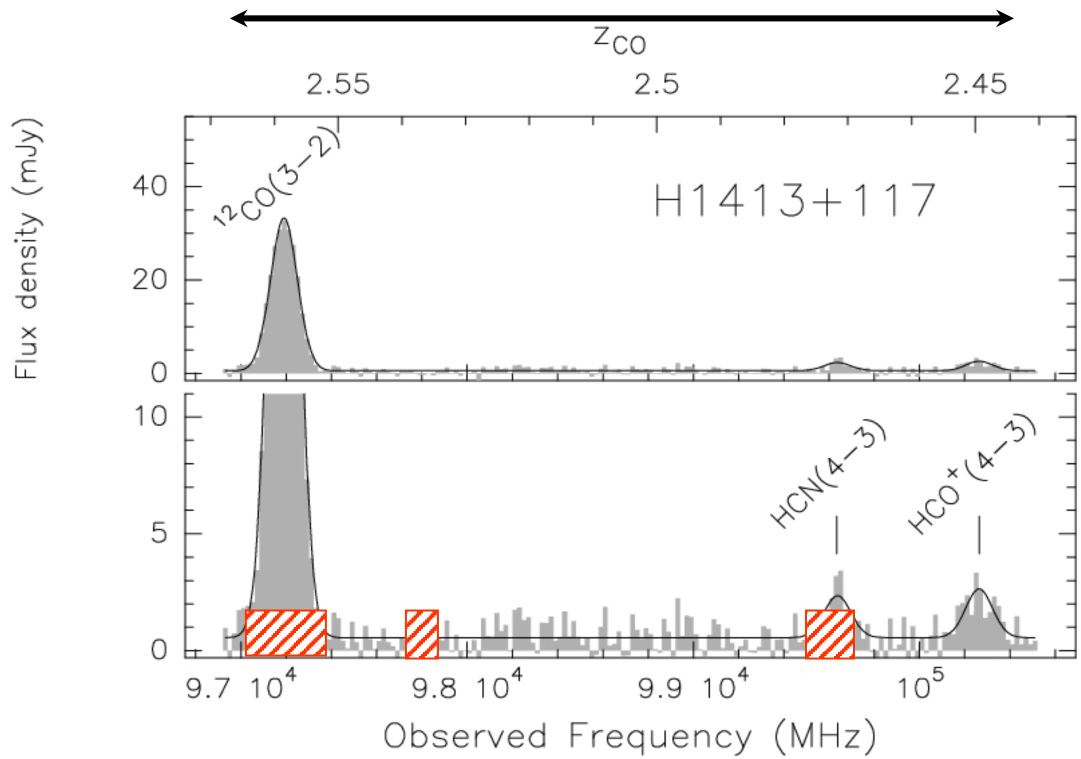
Item	Value	Notes
Correlator		
1 = Narrow Band	8 Units : 20 – 320 MHz	Freq.res : 0.039 – 2.5 MHz
2 = Wide Band	4 Units : 2 GHz	Freq.res : 2 MHz Fixed
IF band	4.2 – 7.8 GHz	IF processor limited
Polarization	Dual linear	Full Stokes in 2011

⇒ line searches (@ high redshift)

⇒ improved relative line intensity calibration

⇒ sensitive continuum ⇒ calibration, polarization, spectral index

3.6 GHz in each polarization



spect.cover. = 3.6 GHz
chan.sampl. = 20 MHz
integra.time = 3.6 hrs

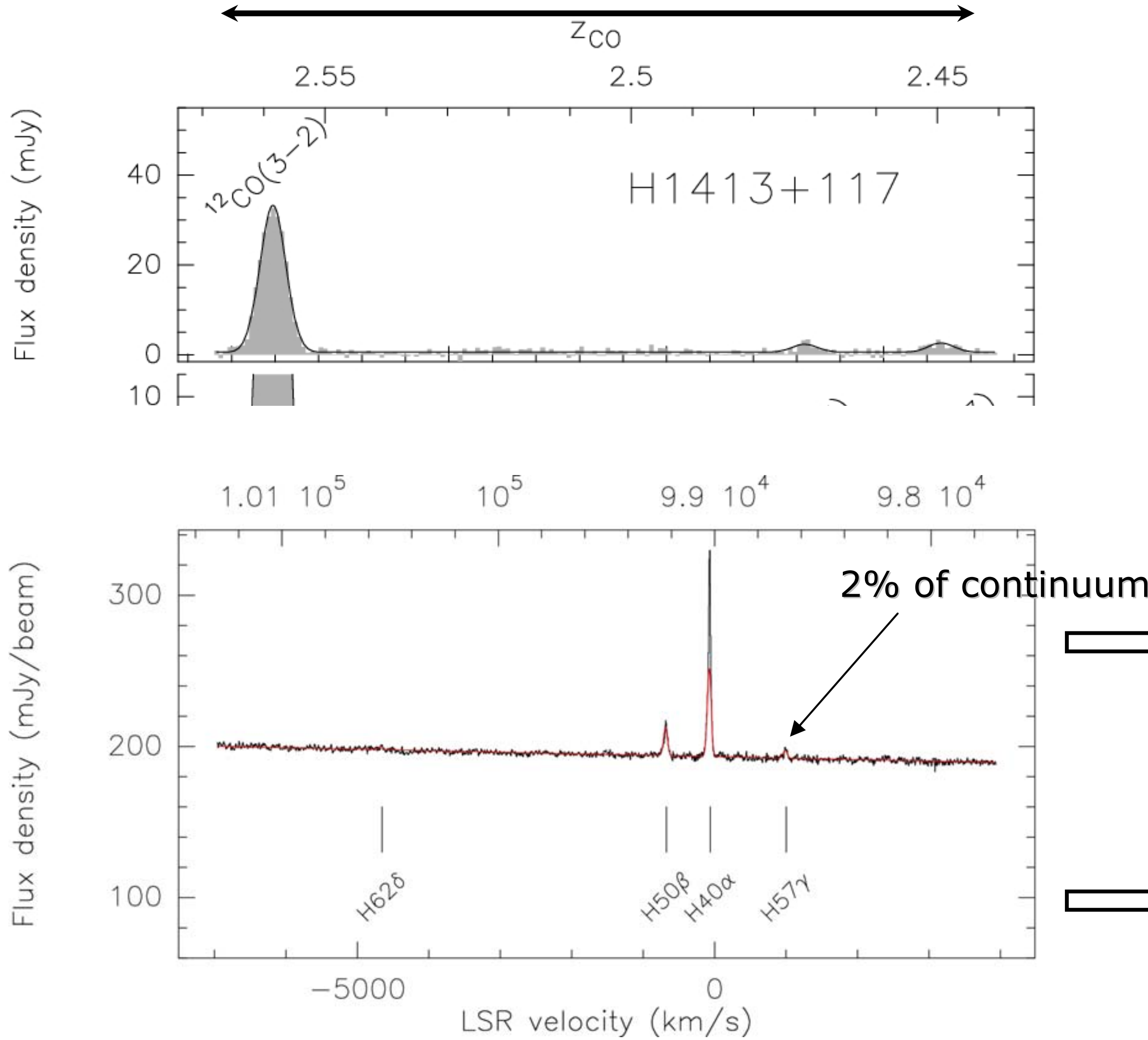
r.m.s. = 0.66 mJy

⇒ line searches

Guélin et al. in prep

Narrow Band Correlator Units (up to 8)

3.6 GHz in each polarization



spect.cover. = 3.6 GHz
chan.sampl. = 20 MHz
integra.time = 3.6 hrs

r.m.s. = 0.66 mJy

⇨ line searches

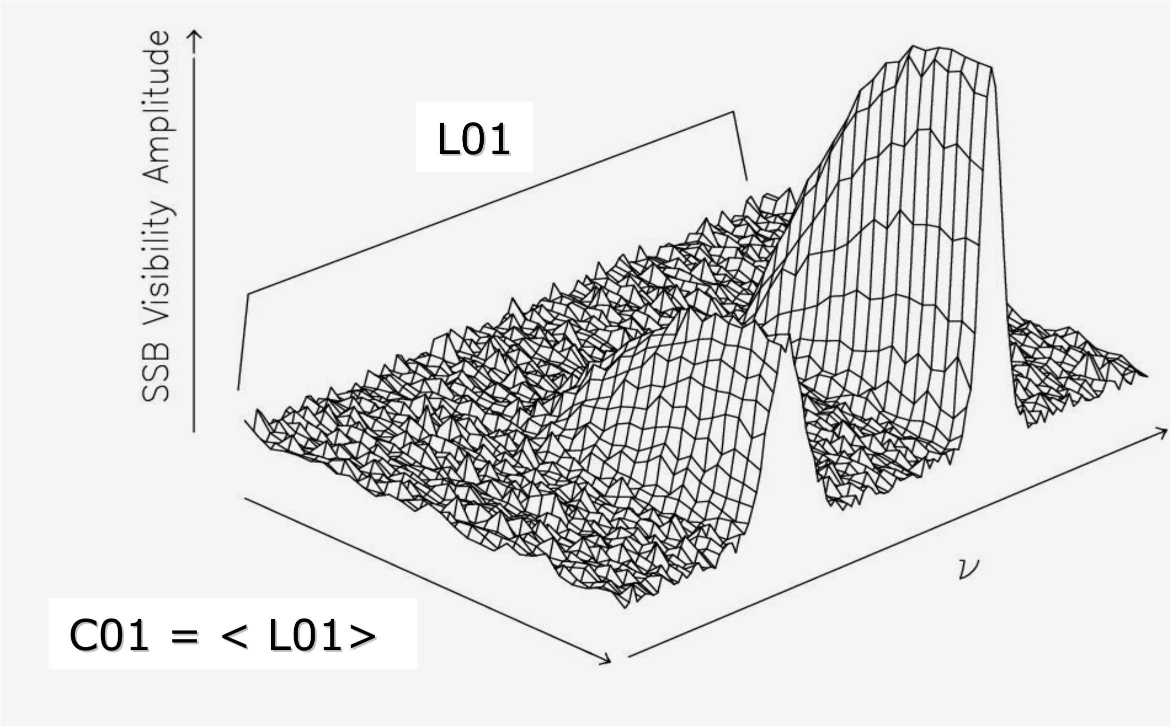
⇨ improved relative line intensity calibration

Thum et al. in prep

Each correlator unit produces Line and Continuum data:

⇨ L01, ..., L12 : one visibility spectrum per SCAN (mostly 45 sec)

⇨ C01, ..., C12 : one spectral averaged visibility per RECORD (1 sec)



Bandwidth	Mode	Channels	Spacing
20 MHz	SSB	1 x 512	0.039 MHz
320 MHz	DSB	2 x 64	2.5 MHz

One baseline, two antennas:

$$\sigma_S \simeq \frac{2k}{\eta_a A} \times \frac{< T_{\mathrm{SYS}} >}{\sqrt{2\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}} = \frac{\sqrt{T^1_{\mathrm{SYS}} \times T^2_{\mathrm{SYS}}}}{\sqrt{2\Delta\nu\Delta t}} \times \frac{1}{\sqrt{N_P}} \quad [\mathrm{Jy}]$$

Ex @ 100 GHz:

$$\sigma_S \simeq 22 \times \frac{100}{\sqrt{2 \times 0.039\, 10^6 \times 45}} \times \frac{1}{\sqrt{1}} \simeq 1.2\,\mathrm{Jy}$$

$$\sigma_S \simeq 22 \times \frac{100}{\sqrt{2 \times 2.5\, 10^6 \times 45}} \times \frac{1}{\sqrt{1}} \simeq 150\,\mathrm{mJy}$$

$$\sigma_S \simeq 22 \times \frac{100}{\sqrt{2 \times 3600\, 10^6 \times 1}} \times \frac{1}{\sqrt{2}} \simeq 18\,\mathrm{mJy}$$

Scan types:

- **IFPB:** auto- and cross-correlations on white noise $\rightarrow$ backend calibration.
- **AUTO:** auto-correlations on the sky $\rightarrow$ backend calibration.
- **CALI:** auto-correlations (total power measurements) on a cold load (15K), table (290K) and on the sky $\rightarrow$ interferometer temperature scale.
- **CORR:** on-target cross-correlations $\rightarrow$ complex visibilities (K) in the uv–plane.
- **POIN = CORR** $\rightarrow$ antenna pointing (Az$\pm$, El$\pm$)
- **FOCU = CORR** $\rightarrow$ antenna focus (ΔF)
- **GAIN = CORR** $\rightarrow$ receiver image to signal sideband calibration $\rightarrow$ interferometer temperature scale.
- **FLUX = CORR** $\rightarrow$ visibility flux density calibration scale (W/m^2/Hz/K)

CALIBRATOR 1

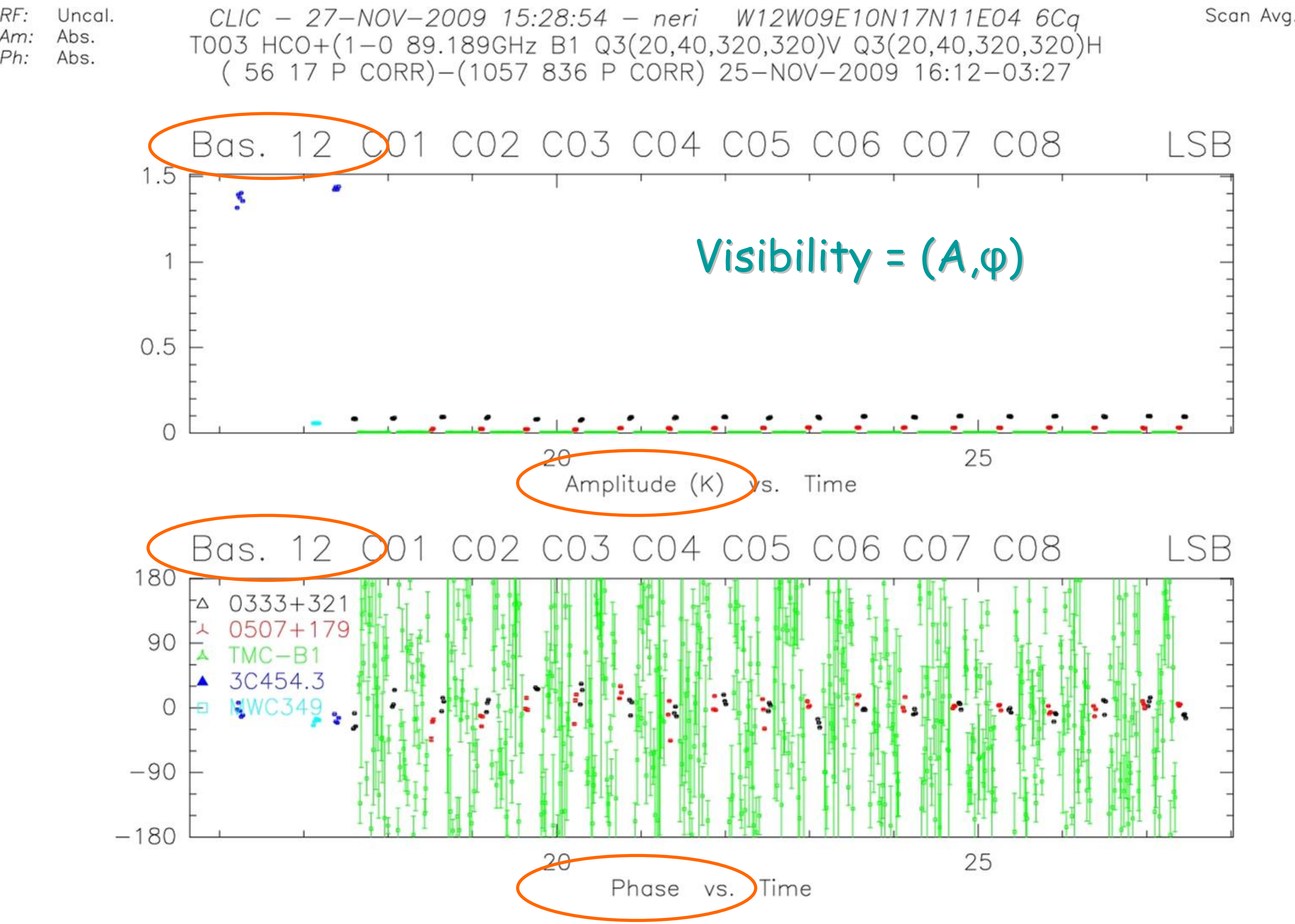
BANDPASS CALIBRATION	→ IFPB	(2x 5 sec)
TABLE / SKY CALIBRATION	→ CALI	(1→2x 5 sec)
ANTENNA POINTING	→ POIN	(2x 60 sec)
ANTENNA FOCUS	→ FOCU	(5x 15 sec)
CORRELATIONS	→ CORR	(3x 45 sec)

(CALIBRATOR 2)

(BANDPASS CALIBRATION	→ IFPB)
(TABLE / SKY CALIBRATION	→ CALI)
(CORRELATIONS	→ CORR)

SOURCE

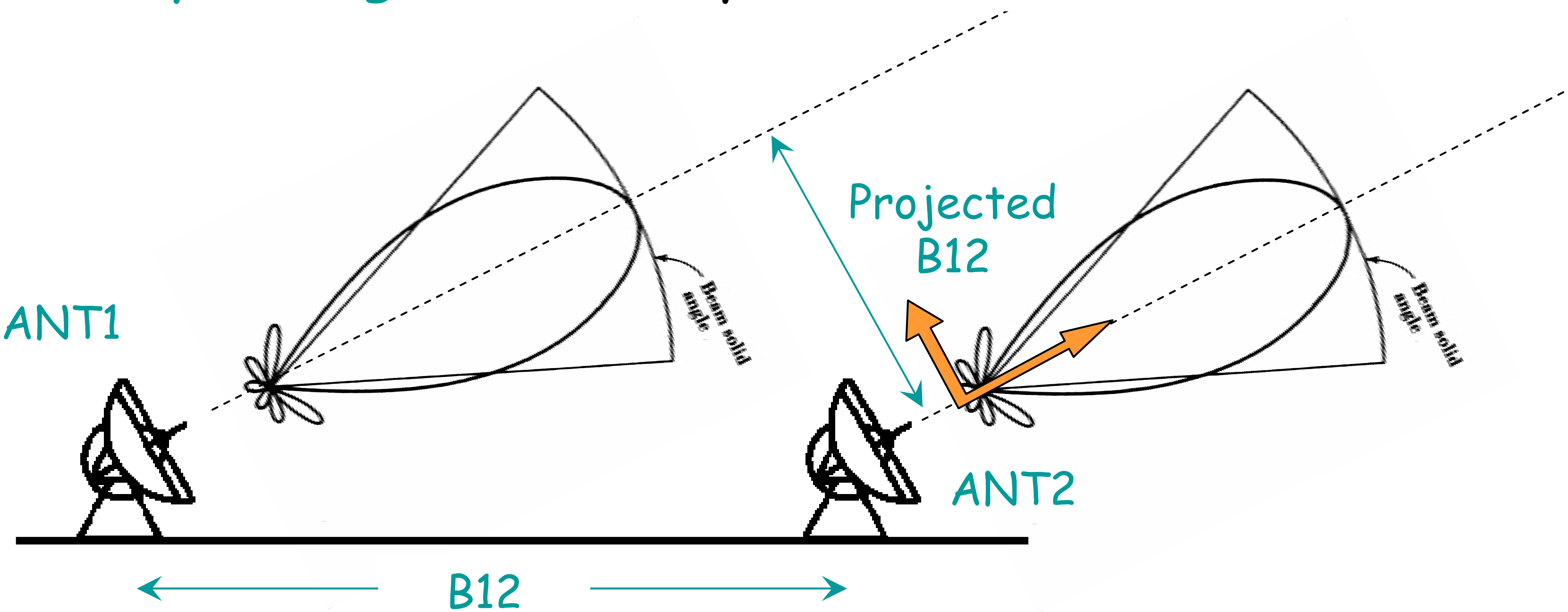
BANDPASS CALIBRATION	→ IFPB	
TABLE / SKY CALIBRATION	→ CALI	
CORRELATIONS	→ CORR	(30x 45 sec)

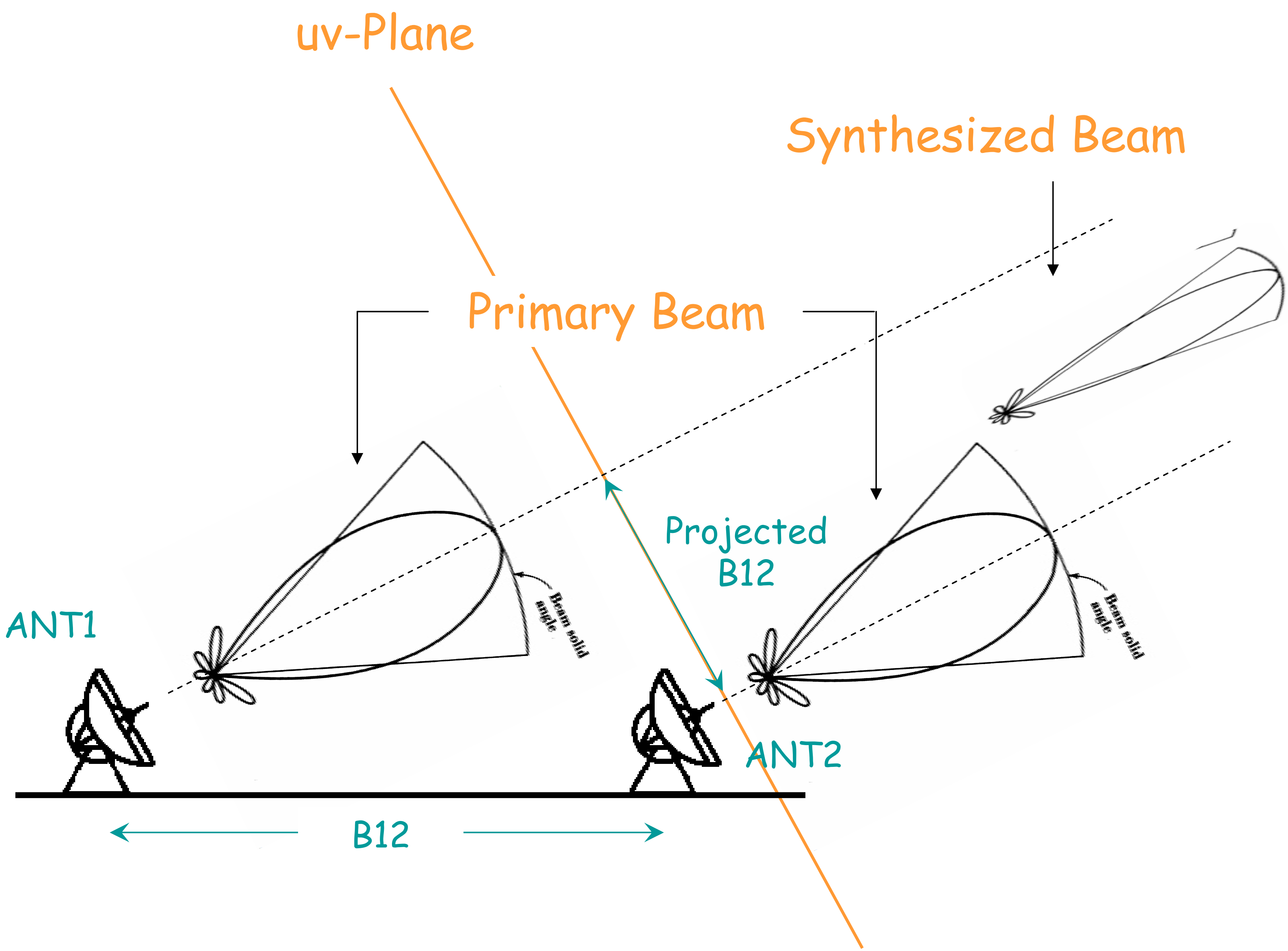

RF: Uncal.
Am: Abs.
Ph: Abs.
CLIC – 27–NOV–2009 15:28:54 – neri W12W09E10N17N11E04 6Cq
T003 HCO+(1–0 89.189GHz B1 Q3(20,40,320,320)V Q3(20,40,320,320)H
(56 17 P CORR)–(1057 836 P CORR) 25–NOV–2009 16:12–03:27
Scan Avg.
Bas. 12 C01 C02 C03 C04 C05 C06 C07 C08 LSB
Visibility = (A,φ)
Amplitude (K) vs. Time
Bas. 12 C01 C02 C03 C04 C05 C06 C07 C08 LSB
0333+321
0507+179
TMC–B1
3C454.3
MWC349
Phase vs. Time

Baseline Bij : distance between two antennas

Projected Baseline Bij : distance between two antennas as seen from the sky

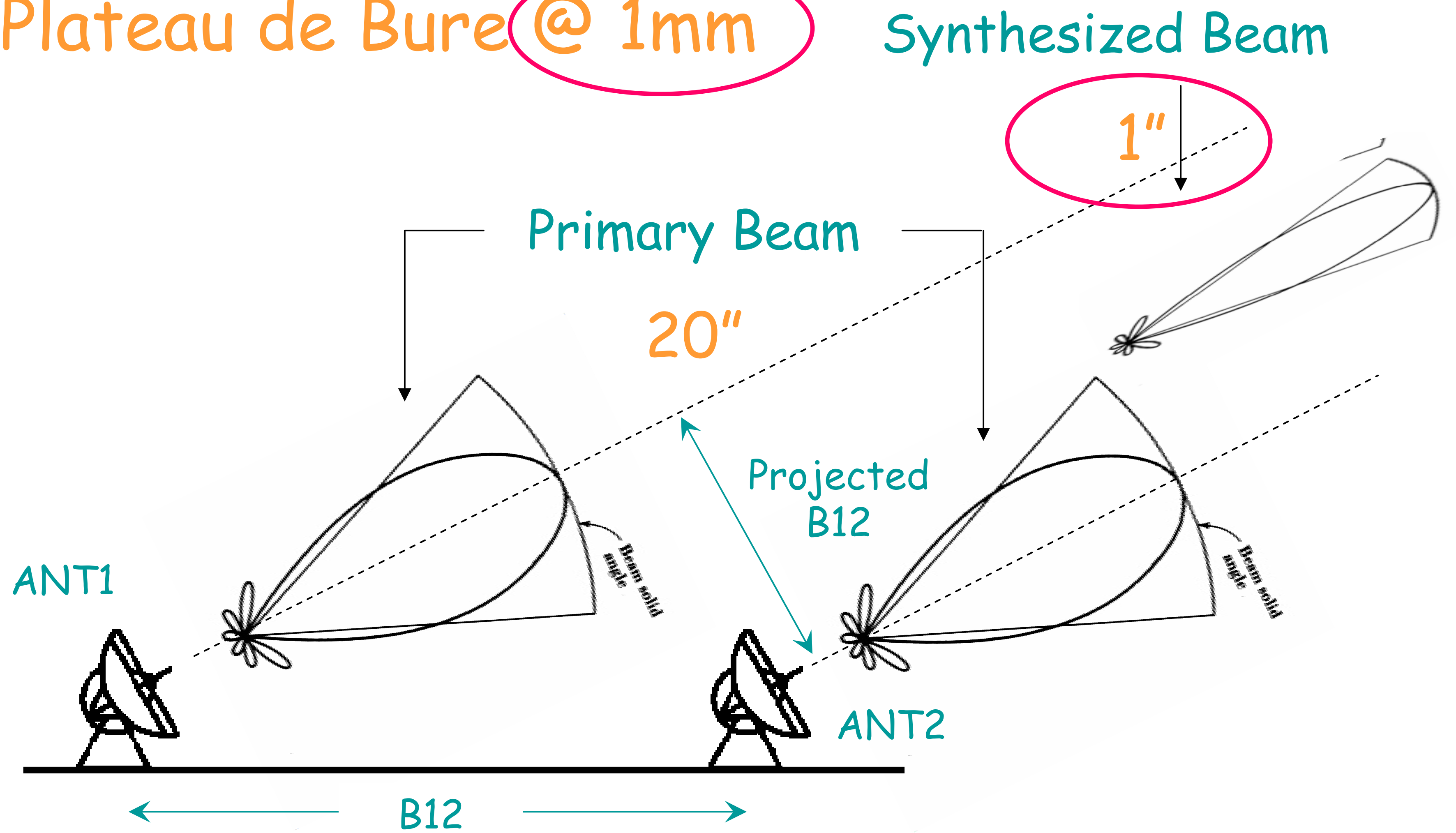
Array Configuration : layout of the antenna stations





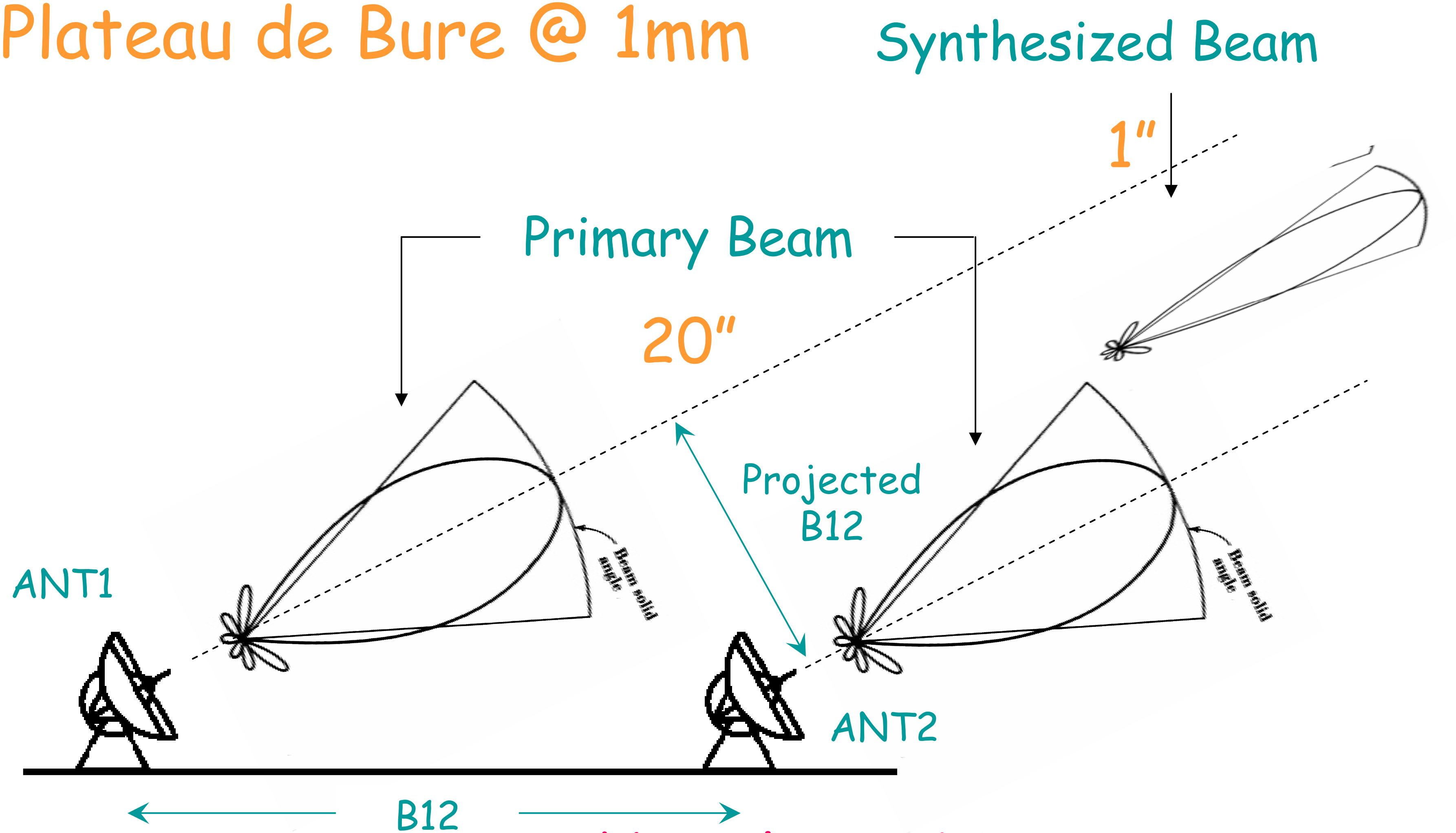
uv-Plane
Synthesized Beam
Primary Beam
Projected
B12
ANT1
ANT2
Beam solid
angle
Beam solid
angle
B12

Plateau de Bure @ 1mm



C configuration = 200m

Plateau de Bure @ 1mm



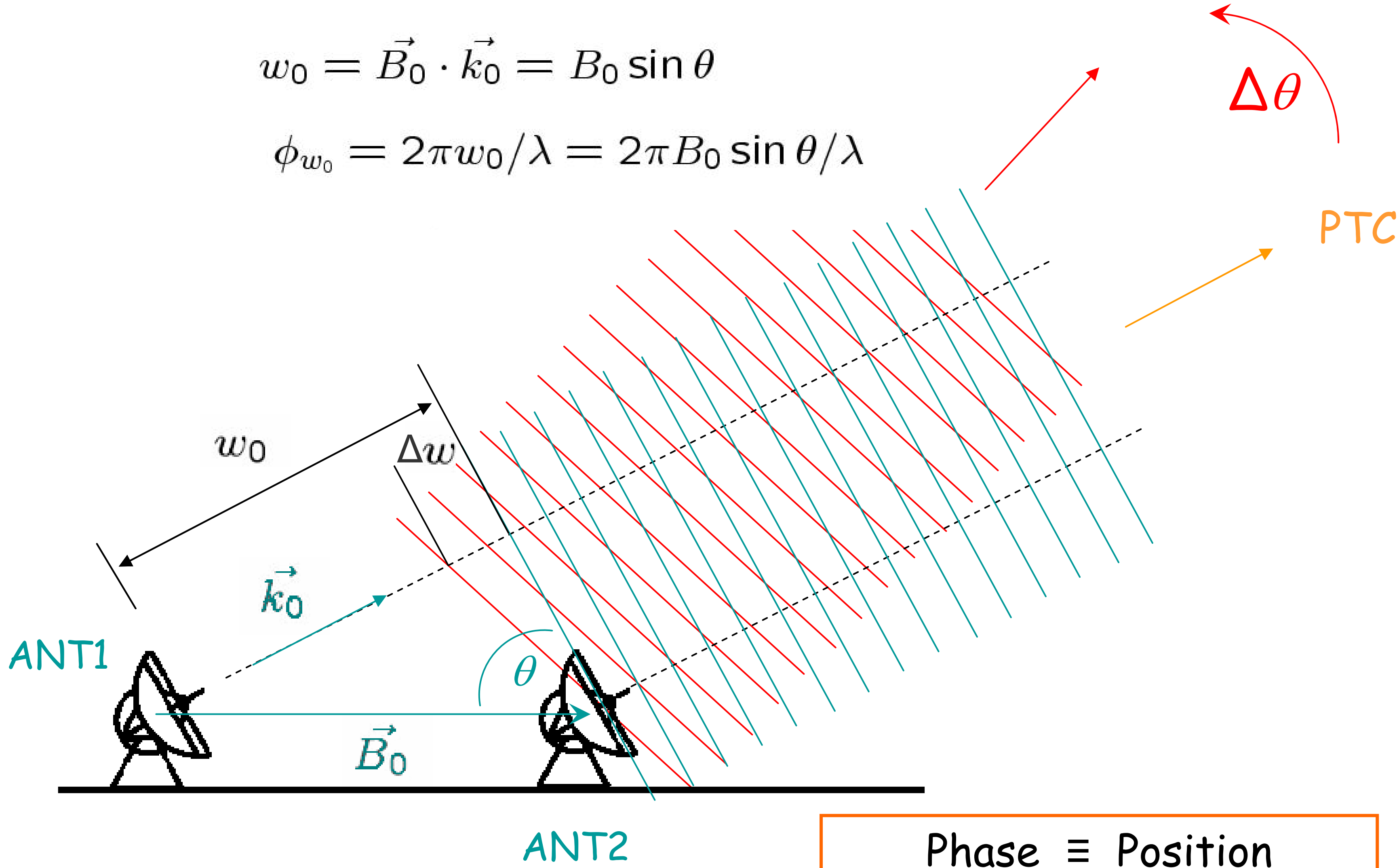
Minimum projected baseline = 15m

SHORT SPACINGS ⇒ 30m Telescope

The phase equation

$$w_0 = \vec{B}_0 \cdot \vec{k}_0 = B_0 \sin\theta$$

$$\phi_{w_0} = 2\pi w_0/\lambda = 2\pi B_0 \sin\theta/\lambda$$

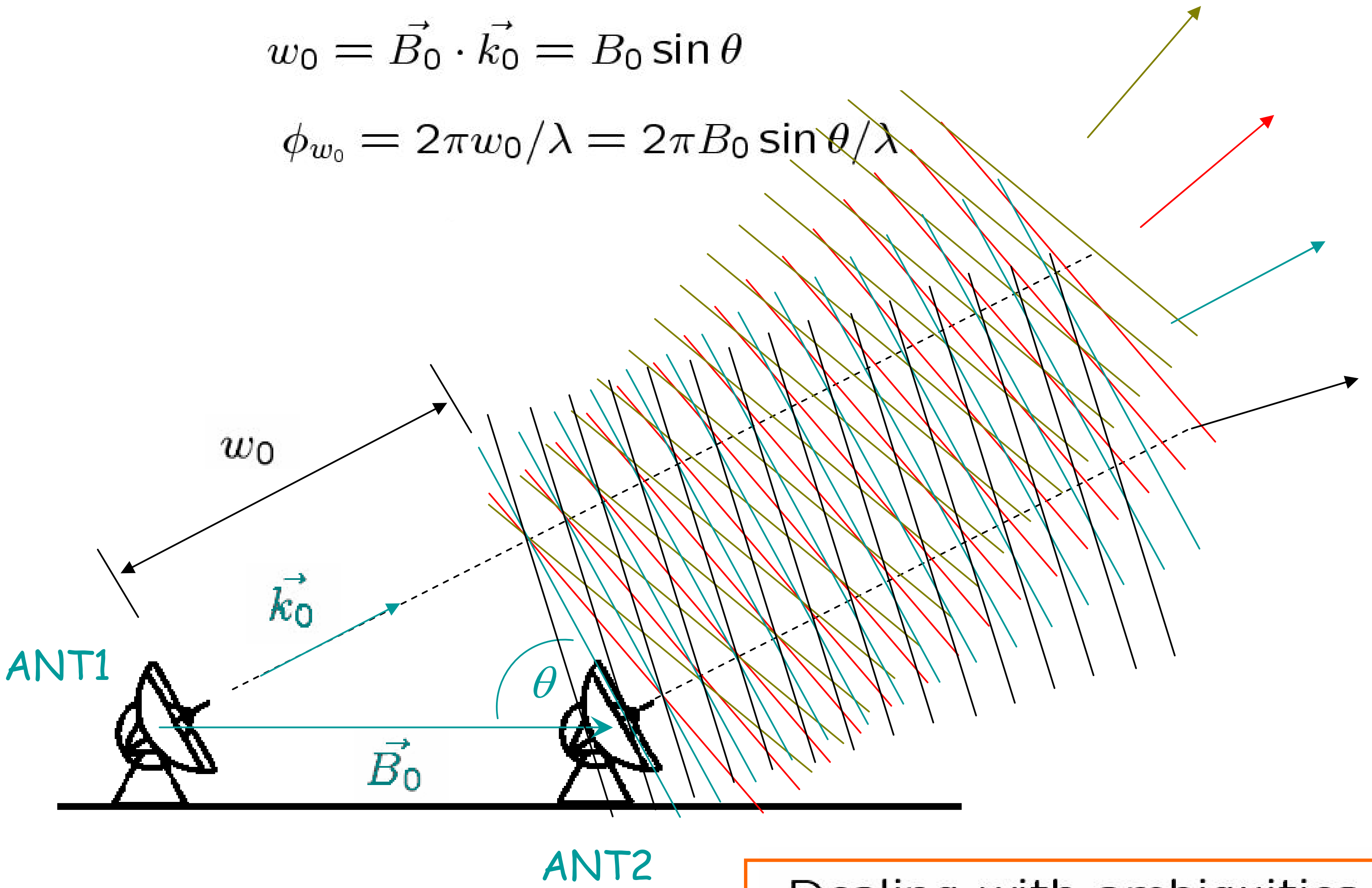


Phase ≡ Position

The phase equation

$$w_0 = \vec{B_0} \cdot \vec{k_0} = B_0 \sin\theta$$

$$\phi_{w_0} = 2\pi w_0/\lambda = 2\pi B_0 \sin\theta/\lambda$$



Dealing with ambiguities ...

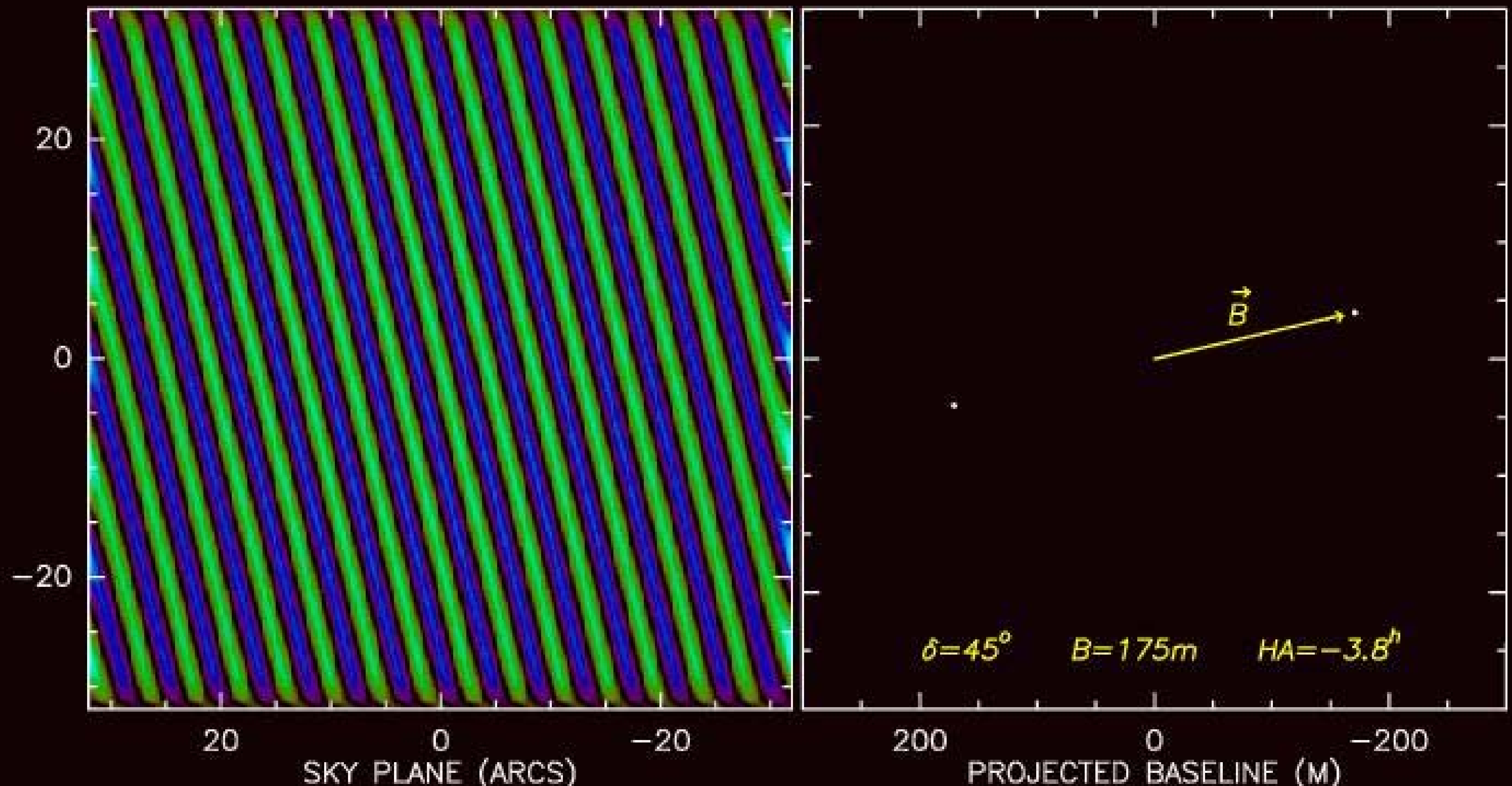
Dealing with $\omega_0 = \vec{k_0} \cdot \vec{B_0}$

$$\rightarrow 2\pi\omega_0/\lambda = 2\pi B_0 \sin\theta/\lambda = \pm 2\pi N$$

Ex: with $B_0 = 300\,\mathrm{m}$ and $\lambda = 3\,\mathrm{mm}$, the positional ambiguity on the skyplane becomes:

$$\theta_N = \lambda/B_0 \times N = \pm 2'' \times N$$

Ex: a source displaced by a single beam $\theta = \lambda/B_0$ shows an offset of 360° in the signal phase.

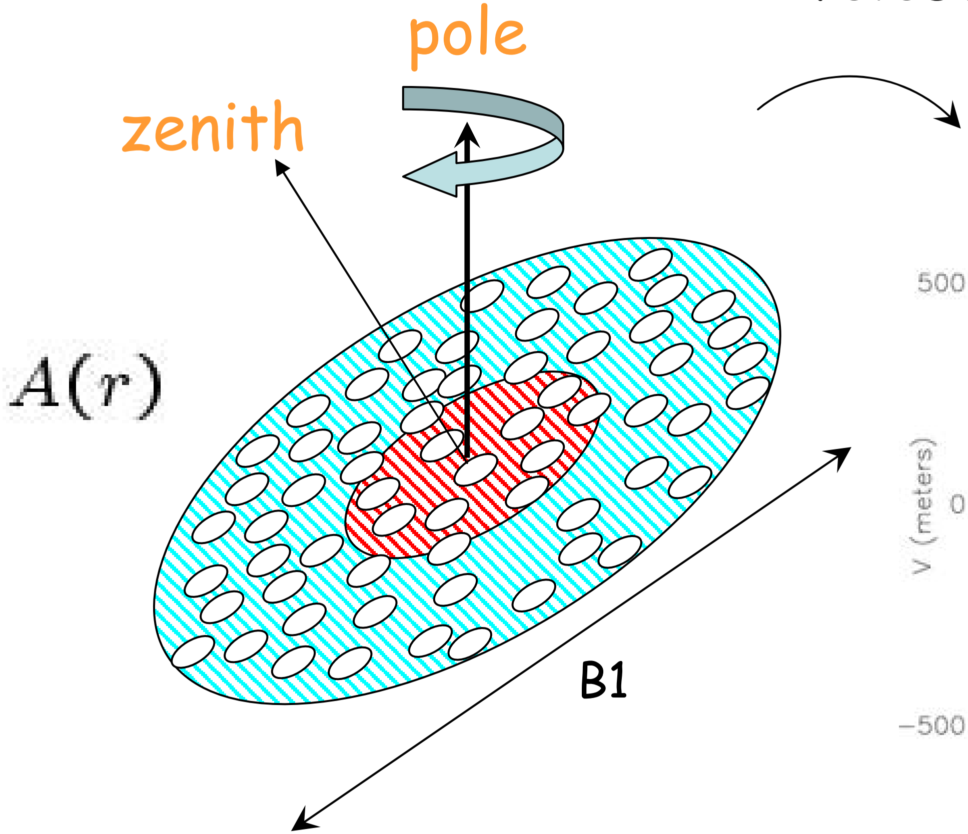


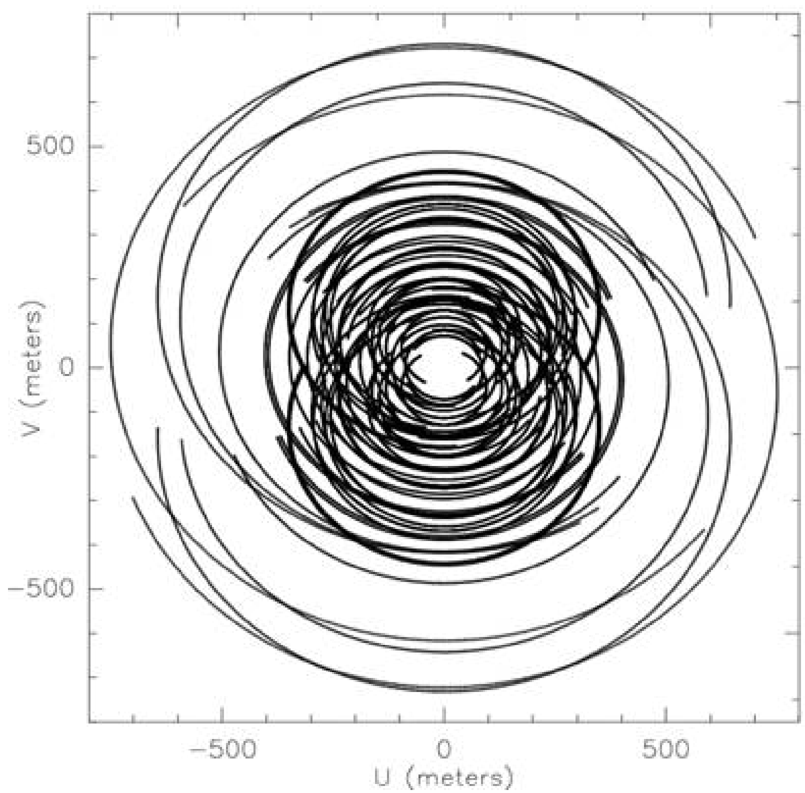
20
0
−20
20
0
−20
SKY PLANE (ARCS)
$\vec{B}$
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)

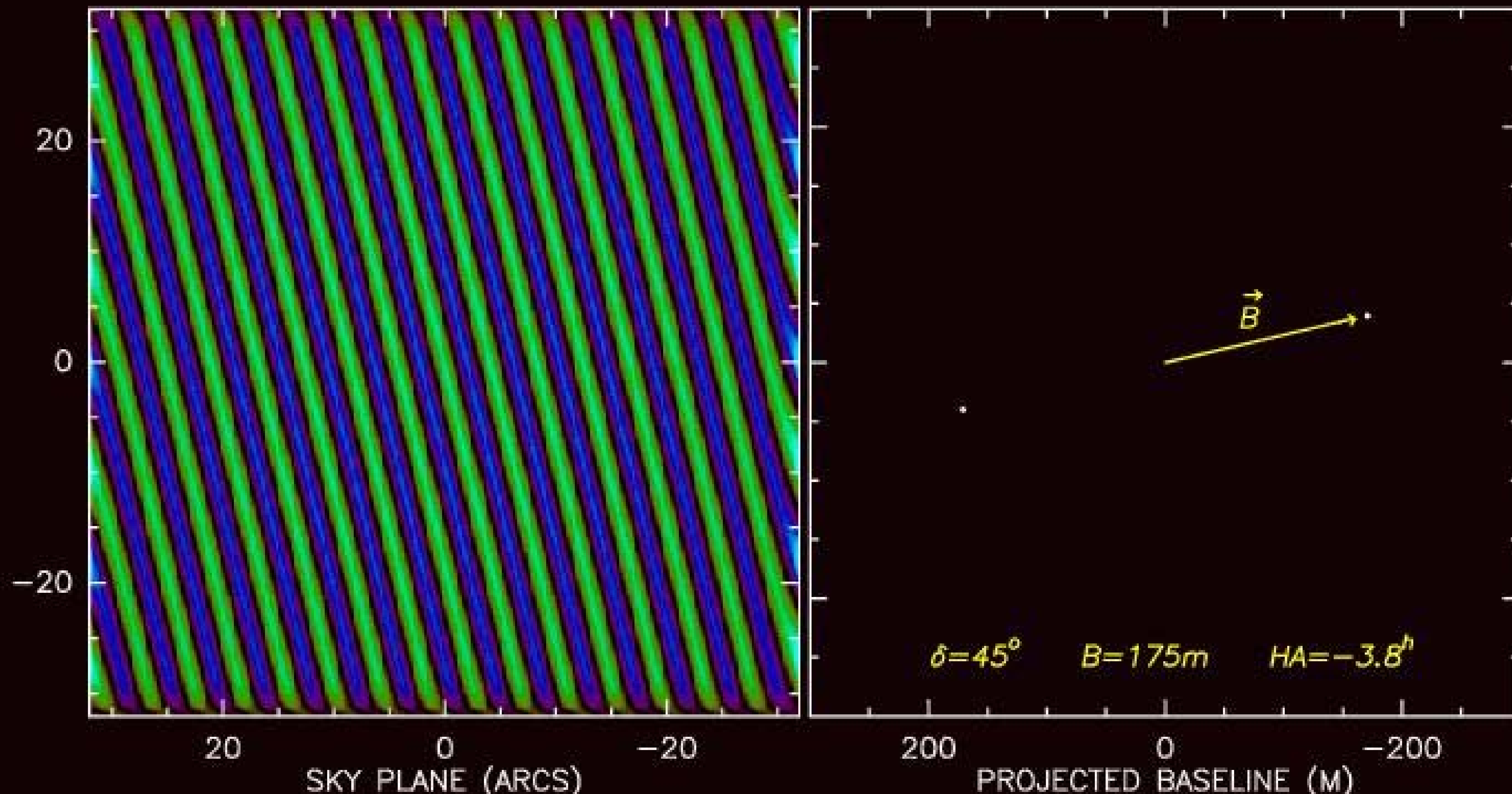
Super-Synthesis or Earth Rotation Synthesis

is the technique by which the elements of an interferometer sweep out the aperture of a large telescope

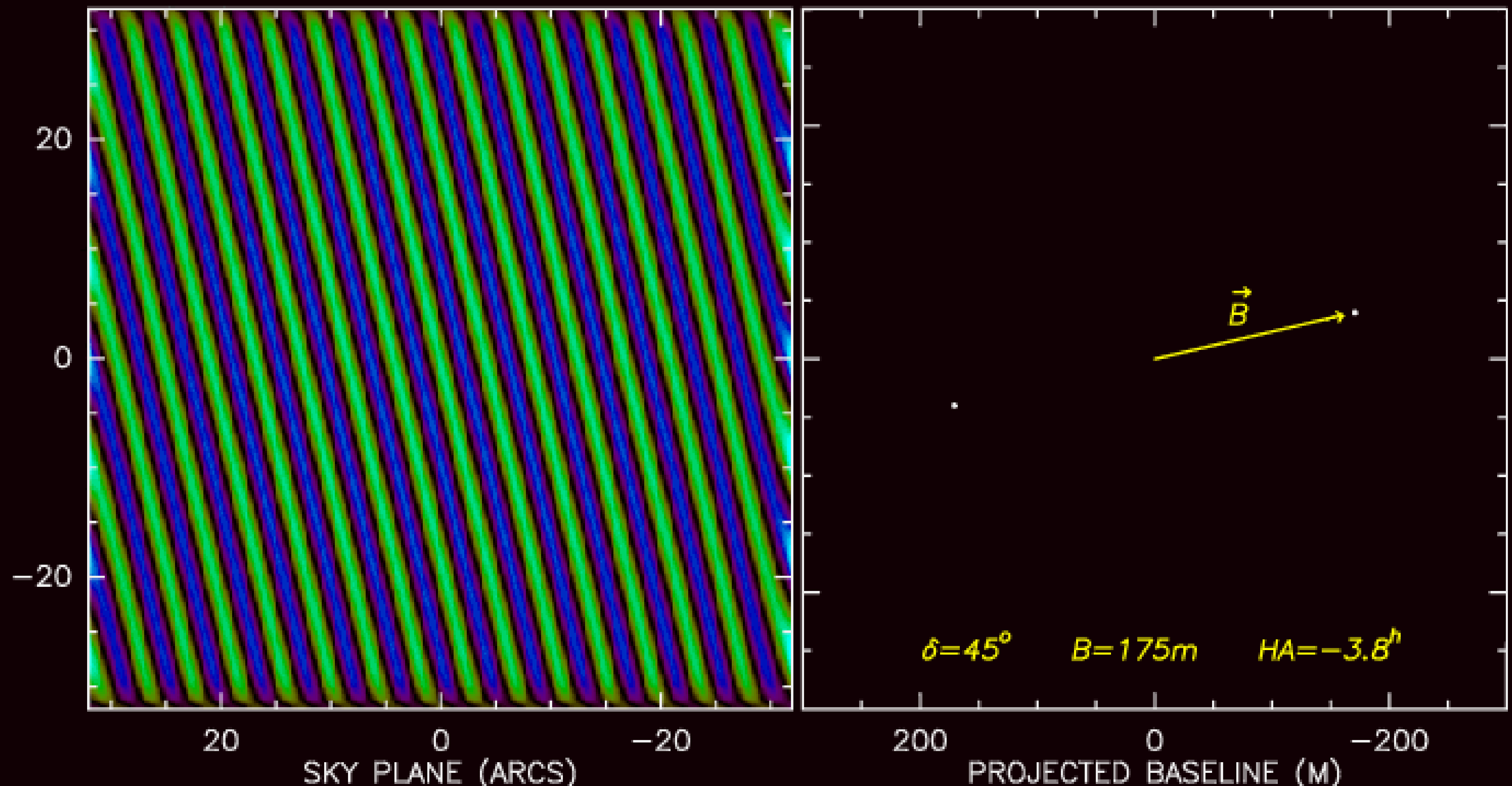
$$\mathrm{OTF} = A(r) \star A(r)$$

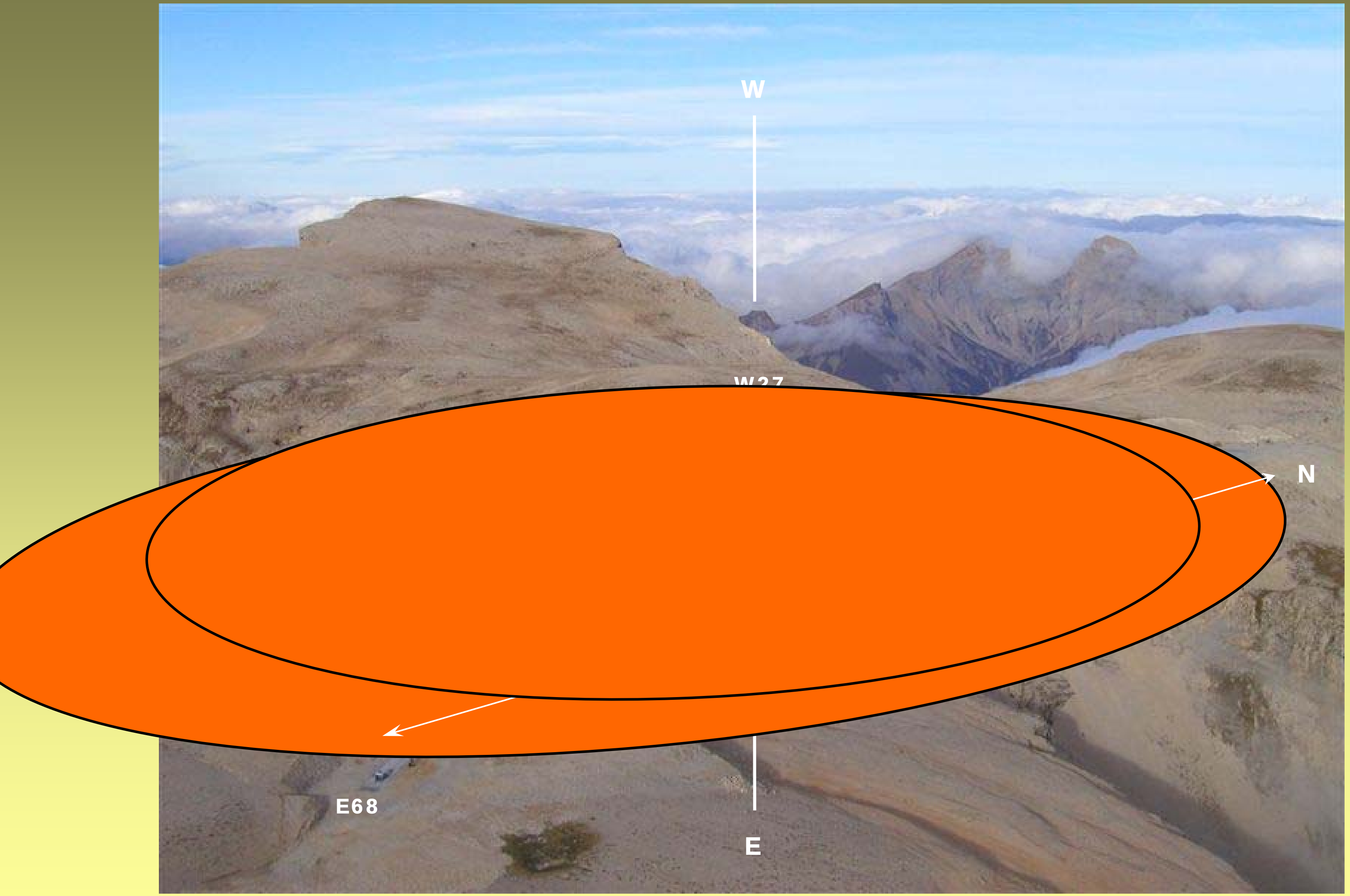






20
0
−20
20
0
−20
SKY PLANE (ARCS)
$\vec{B}$
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)


20
0
−20
20
0
−20
SKY PLANE (ARCS)
B
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)

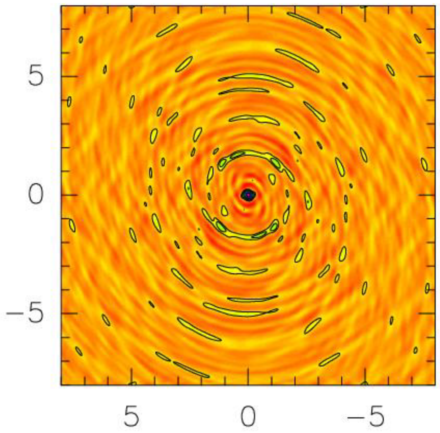

W
W27
N
E68
E

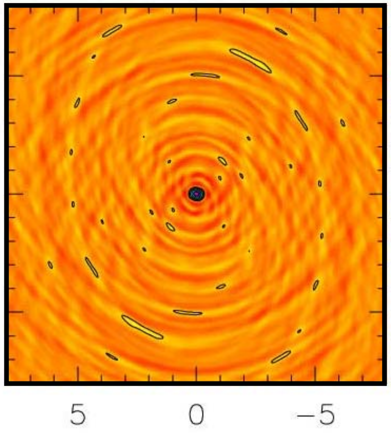
Array configurations

Design: 4 configurations, optimization 20° decl.

Karastergiou et al. 2006

A @ 230 GHz

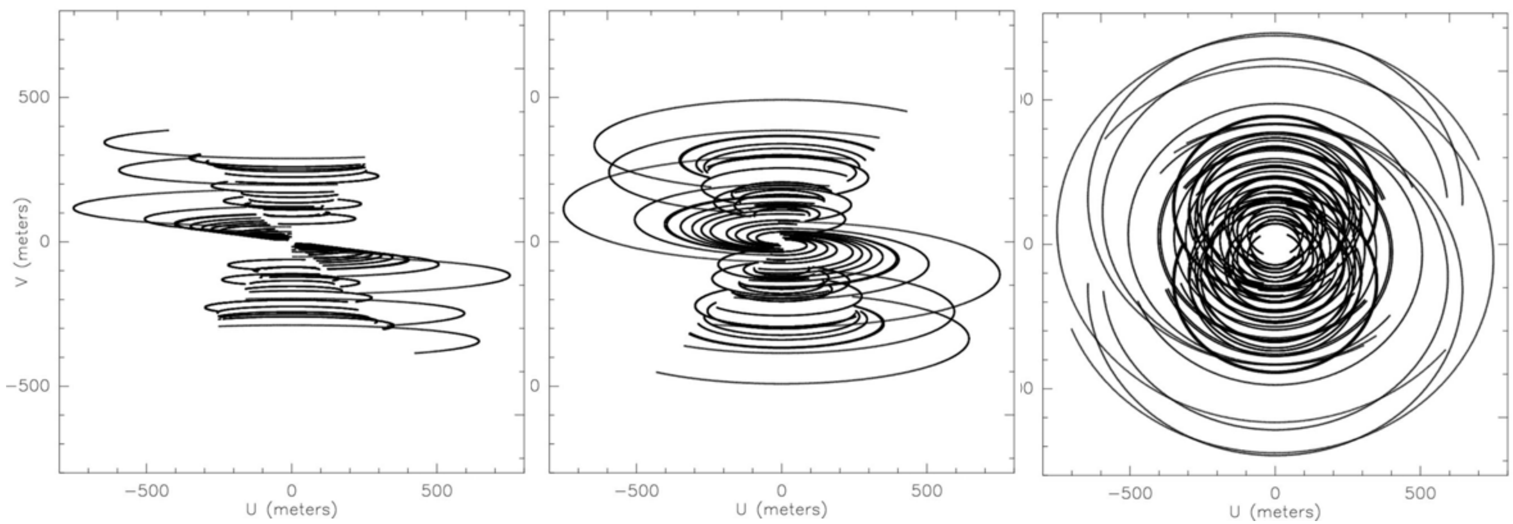




AB @ 230 GHz

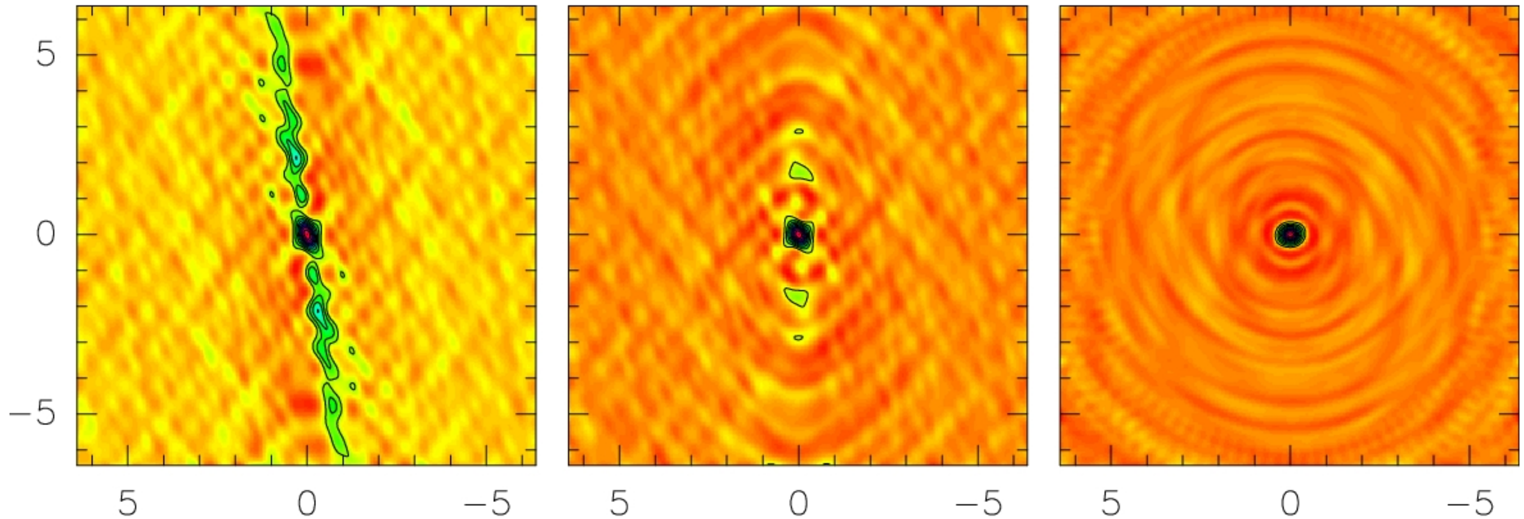
Configurations	D	C	B	A
Months	Apr – Nov	Mar - Apr Nov - Dec	Jan - Mar	Jan - Mar
Resolution @ 230 GHz	3″			0.3″

PdBI's AB configurations @ 230 GHz
Three Examples



	Orion @ -5°	W51N @ 14°	S140 @ 63°
Δt	8 hrs	9 hrs	10 hrs

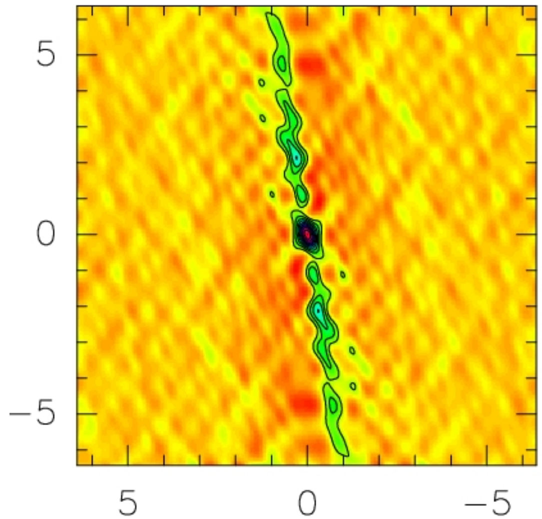
PdBI's AB configurations @ 230 GHz
Three Examples

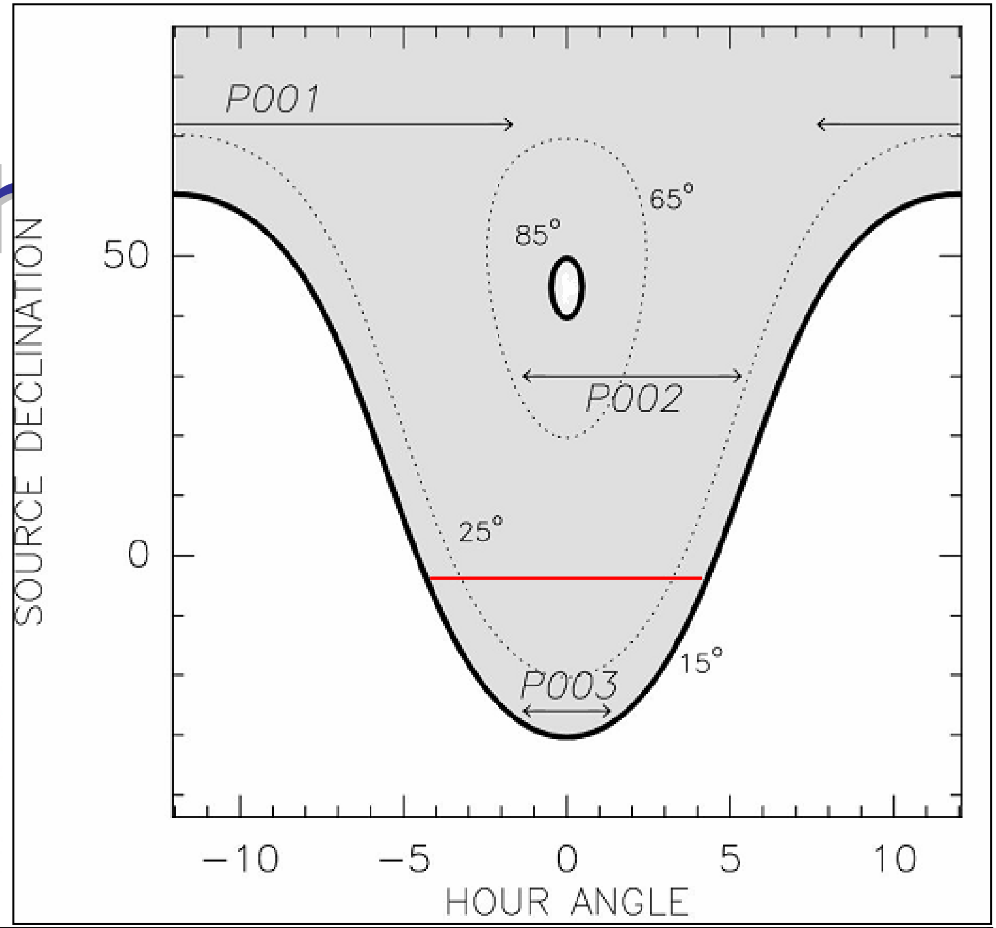


	Orion @ -5º	W51N @ 14º	S140 @ 63º
Δt	8 hrs	9 hrs	10 hrs
D	400 pc	8300 pc	910 pc
″	0.70″ x 0.41″	0.51″ x 0.45″	0.47″ x 0.40″

iram
Institut de Radioastronomie Millimétrique

Th





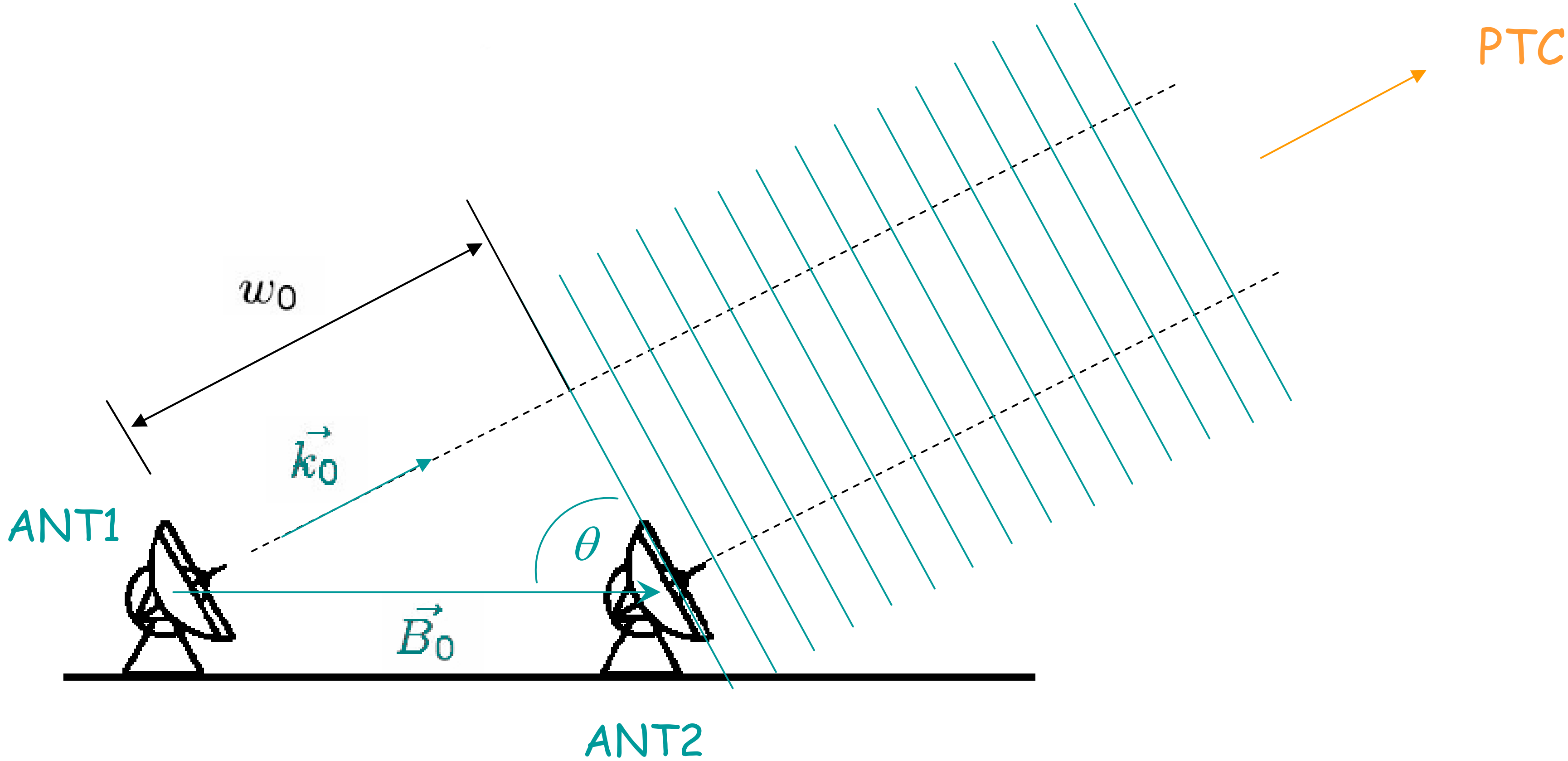
	Orion @ -5°	W51N @ 14°	S140 @ 63°
T	8 hrs	12 hrs	24 hrs
D	400 pc	8300 pc	910 pc
″	0.70″ x 0.41″	0.51″ x 0.45″	0.47″ x 0.40″

⇨ observing efficiency ~60%

The phase equation

$$w_0 = \vec{B}_0 \cdot \vec{k}_0 = B_0 \sin\theta$$

$$\phi_{w_0} = 2\pi w_0/\lambda = 2\pi B_0 \sin\theta/\lambda$$



$$\rightarrow \phi_{w_0} = 2\pi\,(B_x \cos H \cos\delta - B_y \sin H \cos\delta + B_z \sin\delta)/\lambda$$

$$
\begin{aligned}
\Delta\phi^{ij} = \; & 2\pi/\lambda \cdot \\
& [\Delta\alpha \cdot (B_x^{ij} \sin H \cos\delta + B_y^{ij} \cos H \cos\delta) + \\
& \Delta\delta \cdot (B_y^{ij} \sin H \sin\delta - B_x^{ij} \cos H \sin\delta + B_z^{ij} \cos\delta) + \\
& (B_x^{ij} \cos H \cos\delta - B_y^{ij} \sin H \cos\delta + B_z^{ij} \sin\delta) + \\
& (A^i - A^j) \cos \mathrm{El}]
\end{aligned}
$$

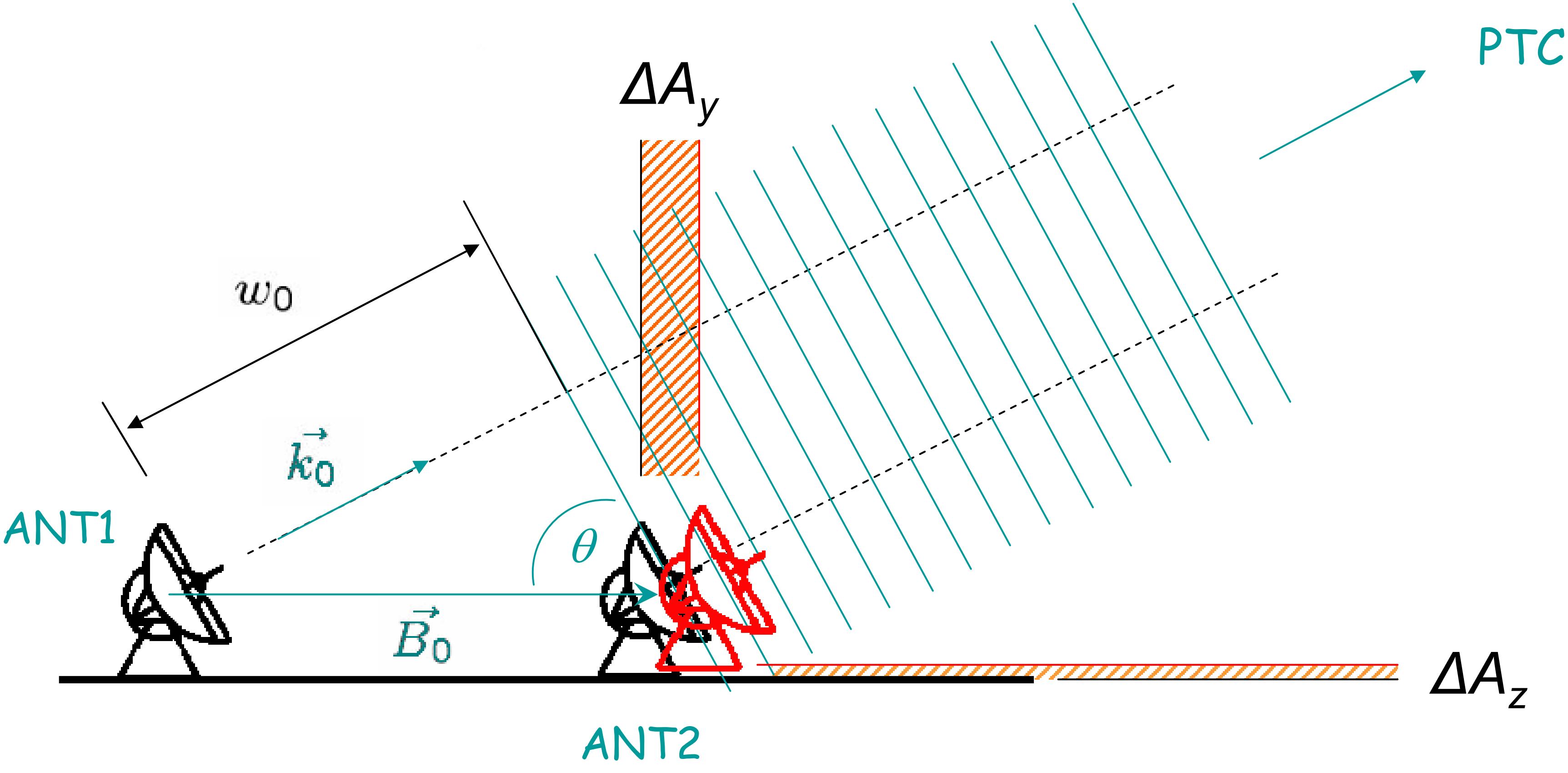
where A is the offset between the azimuth and elevation axis of an antenna.

In practice, an LSQ-analysis is used to derive the unknowns (B_x,B_y,B_z) from the meaurements of the many observed $\Delta\phi^{ij}$ at $10 - 15$ different hour angles H and declinations δ.

The phase equation

$$w_0 = \vec{B_0} \cdot \vec{k_0} = B_0 \sin\theta \simeq B_0 \cdot \theta$$

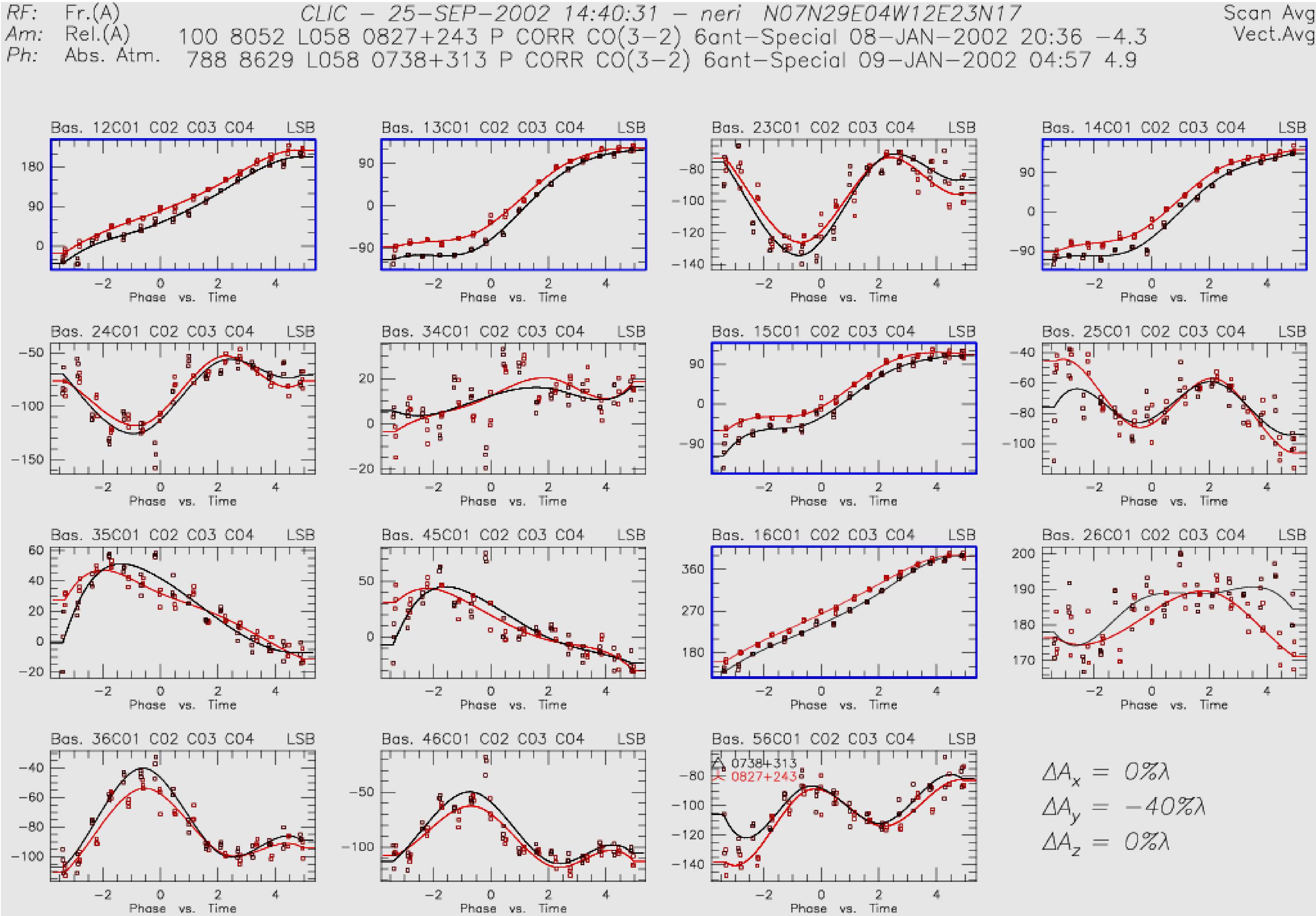
$$\phi_{w_0} = 2\pi w_0/\lambda = 2\pi B_0 \sin\theta/\lambda$$



$$
\begin{aligned}
\Delta\phi^{ij} = \; & 2\pi/\lambda \cdot \\
& [\Delta\alpha \cdot (B_x^{ij} \sin H \cos\delta + B_y^{ij} \cos H \cos\delta) + \\
& \Delta\delta \cdot (B_y^{ij} \sin H \sin\delta - B_x^{ij} \cos H \sin\delta + B_z^{ij} \cos\delta) + \\
& (B_x^{ij} \cos H \cos\delta - B_y^{ij} \sin H \cos\delta + B_z^{ij} \sin\delta) + \\
& (A^i - A^j) \cos \mathrm{El}]
\end{aligned}
$$

where A is the offset between the azimuth and elevation axis of an antenna.

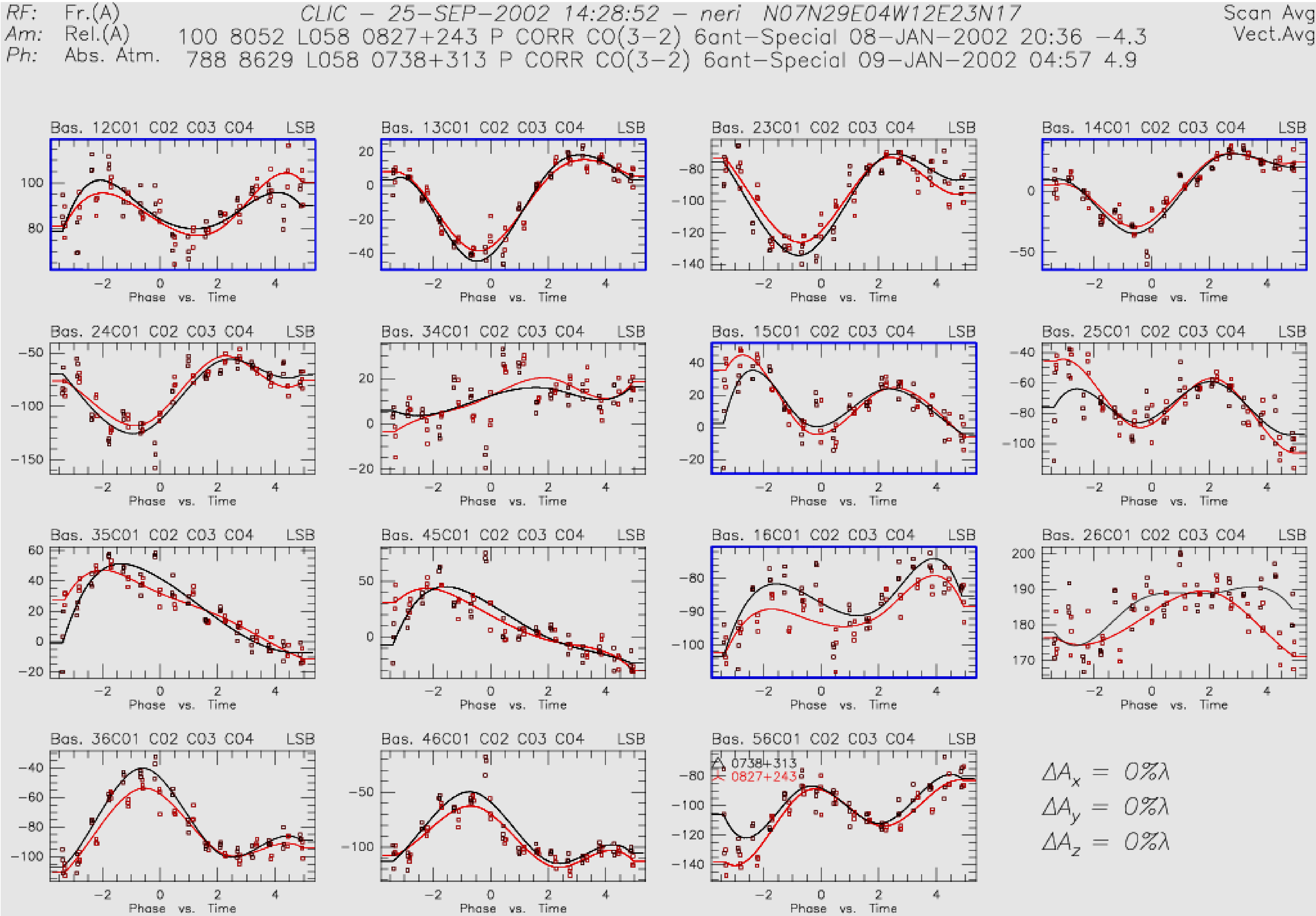
In practice, an LSQ-analysis is used to derive the unknowns (B_x,B_y,B_z) from the meaurements of the many observed $\Delta\phi^{ij}$ at $10-15$ different hour angles H and declinations δ.


RF: Fr.(A)
Am: Rel.(A)
Ph: Abs. Atm.
CLIC – 25-SEP-2002 14:40:31 – neri N07N29E04W12E23N17
100 8052 L058 0827+243 P CORR CO(3–2) 6ant–Special 08–JAN–2002 20:36 –4.3
788 8629 L058 0738+313 P CORR CO(3–2) 6ant–Special 09–JAN–2002 04:57 4.9
Scan Avg
Vect.Avg
Bas. 12C01 C02 C03 C04 LSB
Bas. 13C01 C02 C03 C04 LSB
Bas. 23C01 C02 C03 C04 LSB
Bas. 14C01 C02 C03 C04 LSB
Bas. 24C01 C02 C03 C04 LSB
Bas. 34C01 C02 C03 C04 LSB
Bas. 15C01 C02 C03 C04 LSB
Bas. 25C01 C02 C03 C04 LSB
Bas. 35C01 C02 C03 C04 LSB
Bas. 45C01 C02 C03 C04 LSB
Bas. 16C01 C02 C03 C04 LSB
Bas. 26C01 C02 C03 C04 LSB
Bas. 36C01 C02 C03 C04 LSB
Bas. 46C01 C02 C03 C04 LSB
Bas. 56C01 C02 C03 C04 LSB
0738+313
0827+243
Phase vs. Time
ΔAx = 0%λ
ΔAy = –40%λ
ΔAz = 0%λ

$$
\begin{aligned}
\Delta\phi^{ij} = \; & 2\pi/\lambda \cdot \\
& [\Delta\alpha \cdot (B_x^{ij} \sin H \cos\delta + B_y^{ij} \cos H \cos\delta) + \\
& \Delta\delta \cdot (B_y^{ij} \sin H \sin\delta - B_x^{ij} \cos H \sin\delta + B_z^{ij} \cos\delta) + \\
& (B_x^{ij} \cos H \cos\delta - B_y^{ij} \sin H \cos\delta + B_z^{ij} \sin\delta) + \\
& (A^i - A^j) \cos \mathrm{El}]
\end{aligned}
$$

where A is the offset between the azimuth and elevation axis of an antenna.

In practice, an LSQ-analysis is used to derive the unknowns (B_x,B_y,B_z) from the meaurements of the many observed $\Delta\phi^{ij}$ at $10-15$ different hour angles H and declinations δ.



RF: Fr.(A)
Am: Rel.(A)
Ph: Abs. Atm.
CLIC – 25-SEP-2002 14:28:52 – neri N07N29E04W12E23N17
100 8052 L058 0827+243 P CORR CO(3–2) 6ant–Special 08–JAN–2002 20:36 –4.3
788 8629 L058 0738+313 P CORR CO(3–2) 6ant–Special 09–JAN–2002 04:57 4.9
Scan Avg
Vect.Avg
Bas. 12C01 C02 C03 C04 LSB
Bas. 13C01 C02 C03 C04 LSB
Bas. 23C01 C02 C03 C04 LSB
Bas. 14C01 C02 C03 C04 LSB
Bas. 24C01 C02 C03 C04 LSB
Bas. 34C01 C02 C03 C04 LSB
Bas. 15C01 C02 C03 C04 LSB
Bas. 25C01 C02 C03 C04 LSB
Bas. 35C01 C02 C03 C04 LSB
Bas. 45C01 C02 C03 C04 LSB
Bas. 16C01 C02 C03 C04 LSB
Bas. 26C01 C02 C03 C04 LSB
Bas. 36C01 C02 C03 C04 LSB
Bas. 46C01 C02 C03 C04 LSB
Bas. 56C01 C02 C03 C04 LSB
Phase vs. Time
0738+313
0827+243
$\Delta A_x = 0\%\lambda$
$\Delta A_y = 0\%\lambda$
$\Delta A_z = 0\%\lambda$

Sources of phase errors

- Limited accuracy of baseline measurements
- Limited stability of an antenna station
- Thermal load on the antenna structure
- Atmosphere
- Time and delay errors
- Precision in the calibrators absolute position

PdBI – Sources of uncertainty

TELESCOPE	$\Delta\theta$	Calibration
Axes Non-Intersection	$\leq$ 0.20″	Yes
AzEl Bearings	$\leq$ 0.15″	Yes
OBSERVATION		
Focus Offset	$\leq$ 0.15″	Partially
Calibrator Distance	$\leq 8\,10^{-2}\,\theta_B$	No
Atmospheric Seeing	$\leq 6\,10^{-2}\,\theta_B$	No
Pointing Offset	$\leq 2\,10^{-2}\,\theta_B$	Partially

PdBI – Other sources of uncertainty

OBJECT	$\Delta\theta$	Calibration
Source Intensity	$\leq\ 10^{-1}\,\theta_B$	No
Calibrator Position	$\leq\ 0.02''$	No
MISCELLANEOUS		
Bandwidth smearing	$\leq\ 0.08''$	No
Visibility averaging	$\leq\ 0.06''$	No
Gravitational lensing	$\leq\ 0.02''$	No
Primary beam correction	$\leq\ 0.02''$	No

PdBI in a Nutshell

Frequency	80 to 271 GHz (371 GHz in 2010)
Bandwidth	3.6 GHz both polarizations, backshort tuning
Spectral resolution	39 KHz (50 m/s @ 230 GHz) – 3600 MHz
Angular resolution	0.3” – 3” @ 230 GHz
Continuum flux sensitivity	0.6 mJy/beam in 1 min @ 100 GHz
Dynamic range	1:100 (spectral), 1:50 (imaging) @ 100 GHz
Polarization	all cross-products (2011), sequential mode
Short spacings	30m telescope