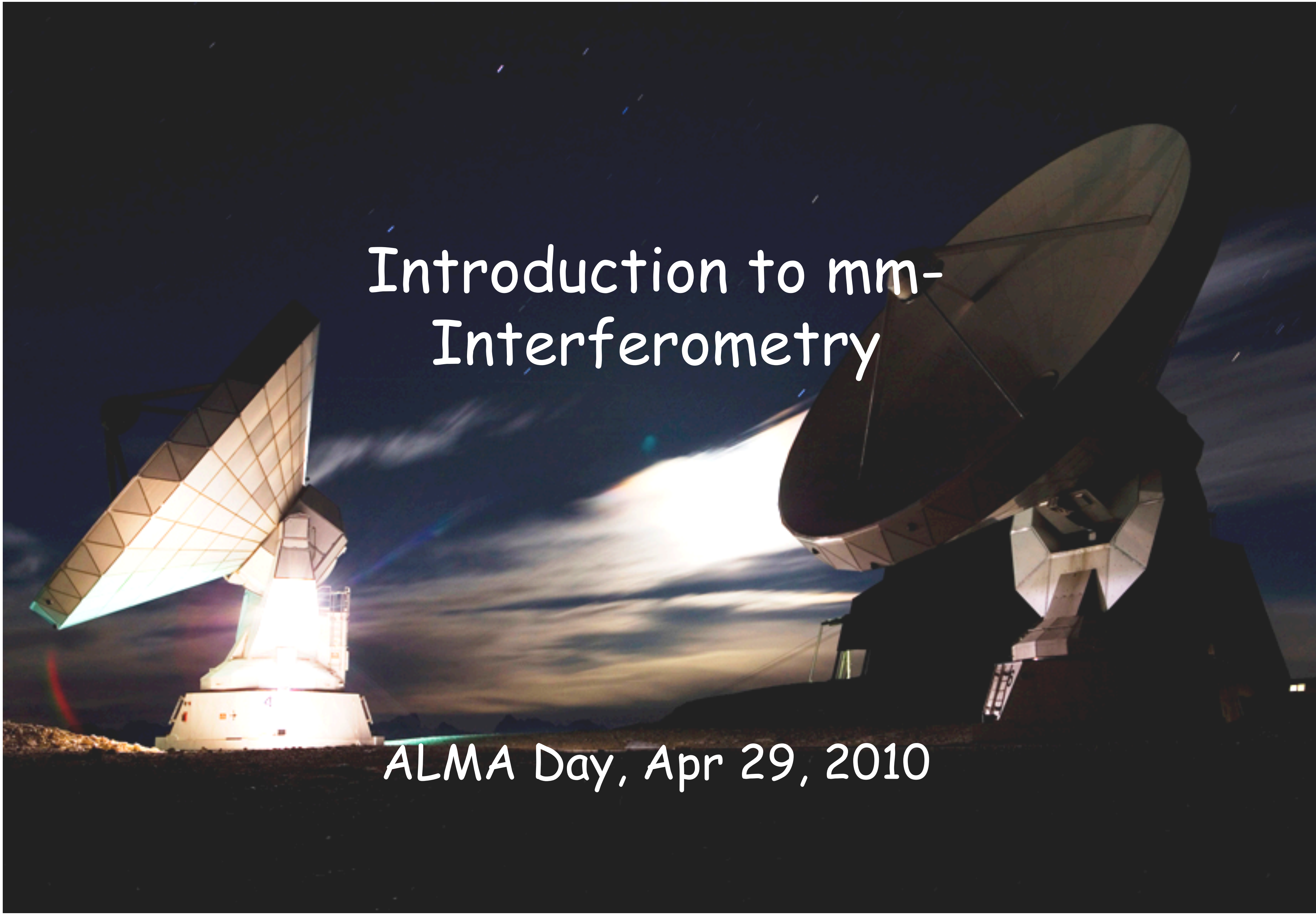

Introduction to mm-Interferometry
ALMA Day, Apr 29, 2010

Andreani, Arnaboldi, Bacciotti, Beltran, Benedettini, Benvenuti, Bettoni, Brand, Casasola, Caselli, Casu, Cesaroni, Cimatti, Clemens, Codella, Coffey, Comito, Crapsi, Cristiani, Danese, Danziger, de Ruiter, De Zotti, D'Odorico, Felli, Ferrara, Fontani, Franceschini, Frontera, Furuya, Gallerani, Galletta, Galli, Gavazzi, Gentile, Gervasi, Gregorini, Habart, Hunt, Isella, Kawakatu, Leone, Lopez-Sepulcre, Mack, Magliocchetti, Maiolino, Mazzotta, Melchiorri, Molinari, Molendi, Molinari, Moscadelli, Murgia, Nagao, Nagar, Natta, Navarrini, Olmi, Paladino, Palla, Parma, Polletta, Pompei, Porceddu, Prandoni, Salucci, Santangelo, Scappini, Scodeggio, Sironi, Spinelli, Tarchi, Tartari, Testi, Tofani, Trigilio, Umana, Verley, Vig, Vigotti, Viti, Walmsley, Zannoni, Zucconi

→ have observed with the IRAM array (or hoped to) !

Interferometer Science @ PdB

Science Drivers 2005 ›	Allocated Time	Keyword
Galaxies @ high-z : LBG, SMM, ERO, RG	30%	"CSF history"
Nearby Galaxies : Spirals, (U)LIRGs	30%	"dynamics + structure"
YSO : Prestellar Clouds → T-Tauri Stars	30%	"SF + evolution"
Evolved Stars	5%	"mass loss"
Chemistry, Solar System, …	5%	

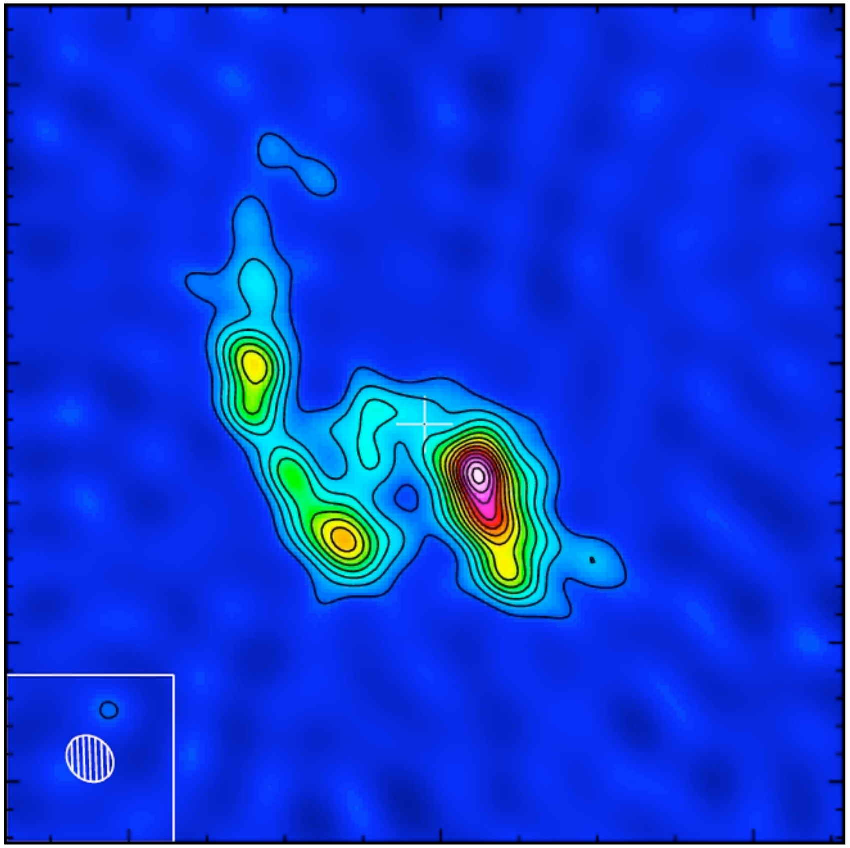
VLBI	10 days	

mm-interferometry …

⇒ … not anymore in a proof-of-concept stage

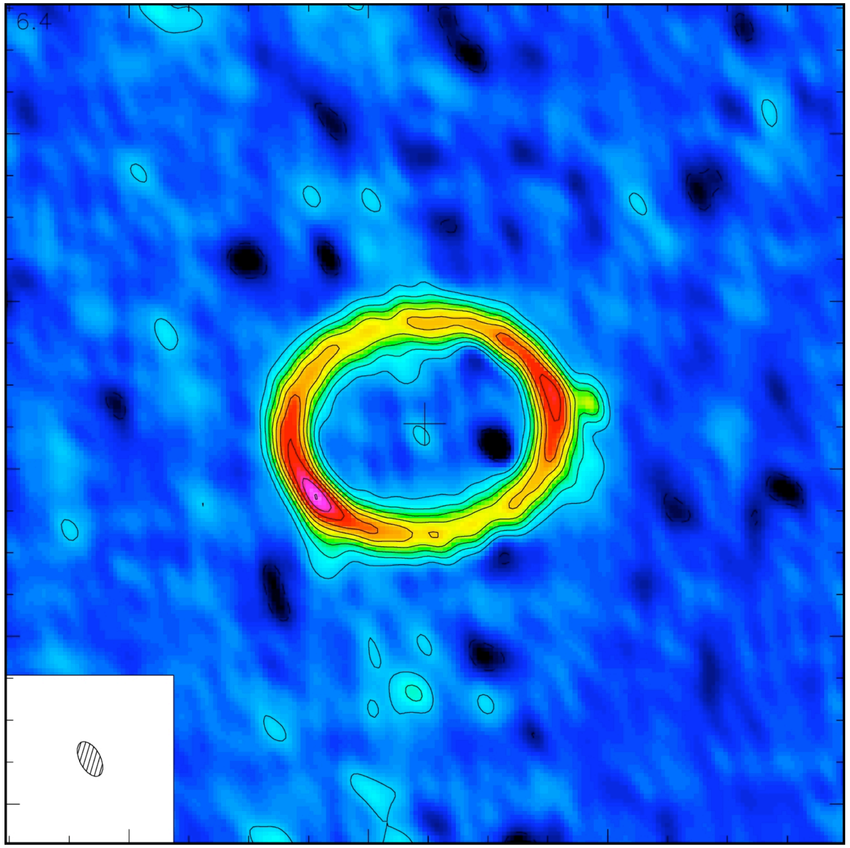
⇒ … belongs to mainstream science

IC 342 @ 146 GHz



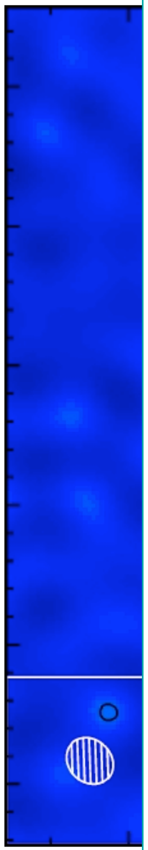
Rodriguez/Schinnerer et al. in prep.

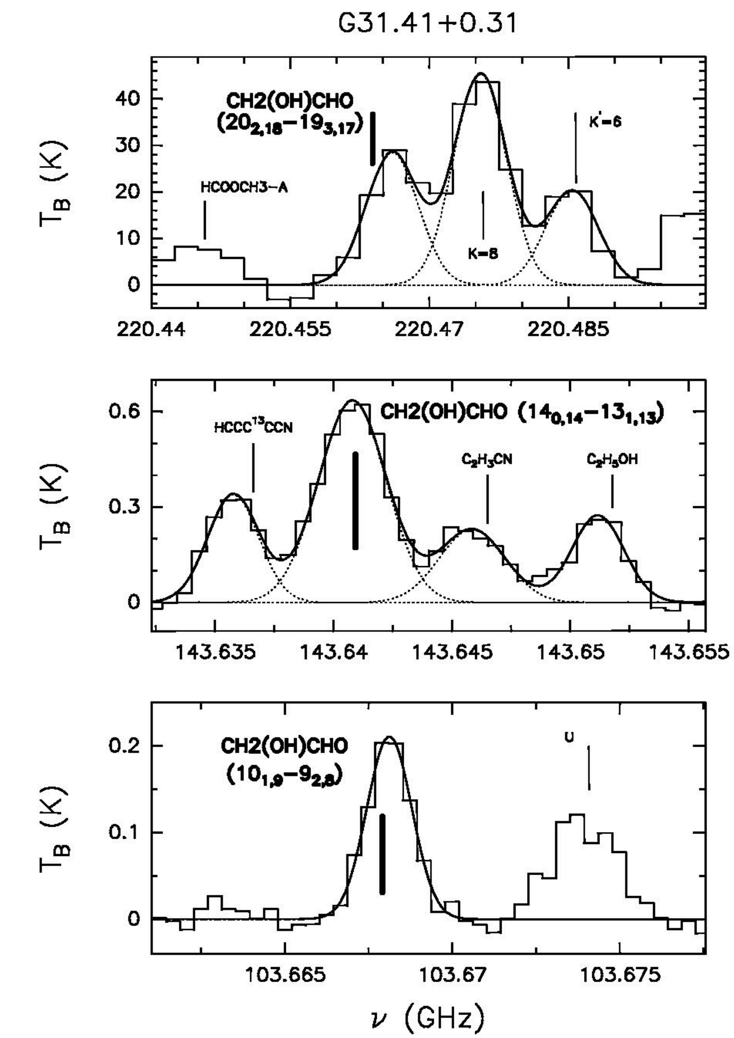
GG Tau @ 267 GHz

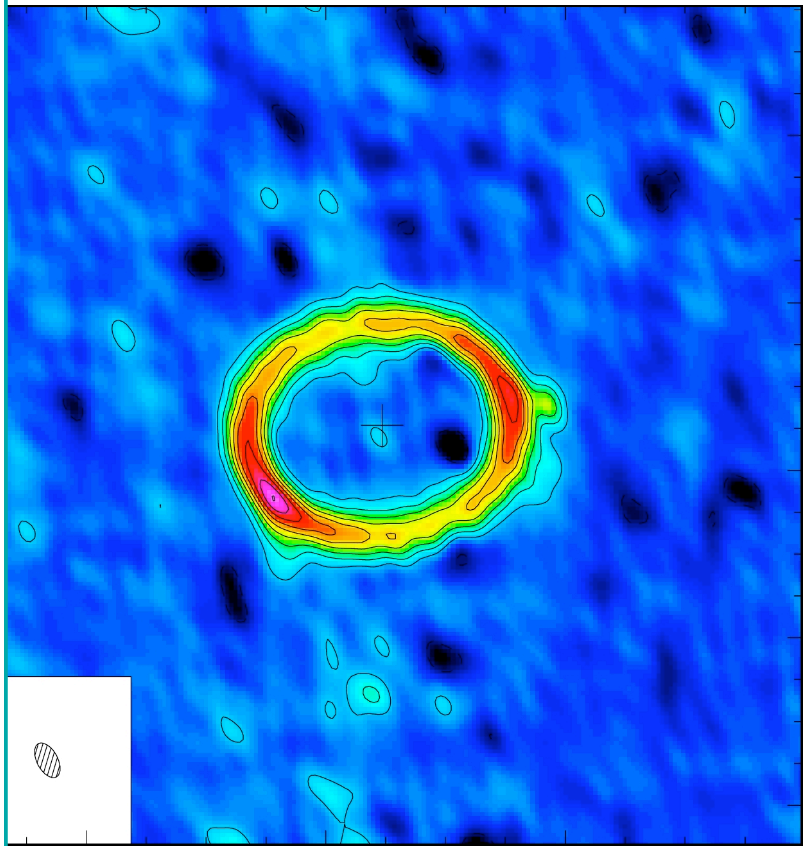


Piétu et al. in prep.

IC 3 G Tau @ 267 GHz



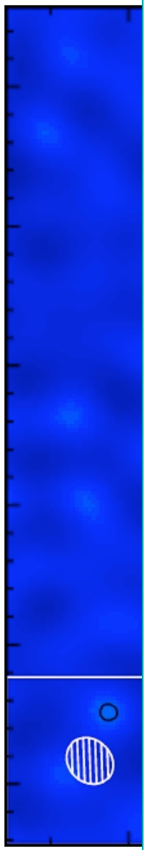


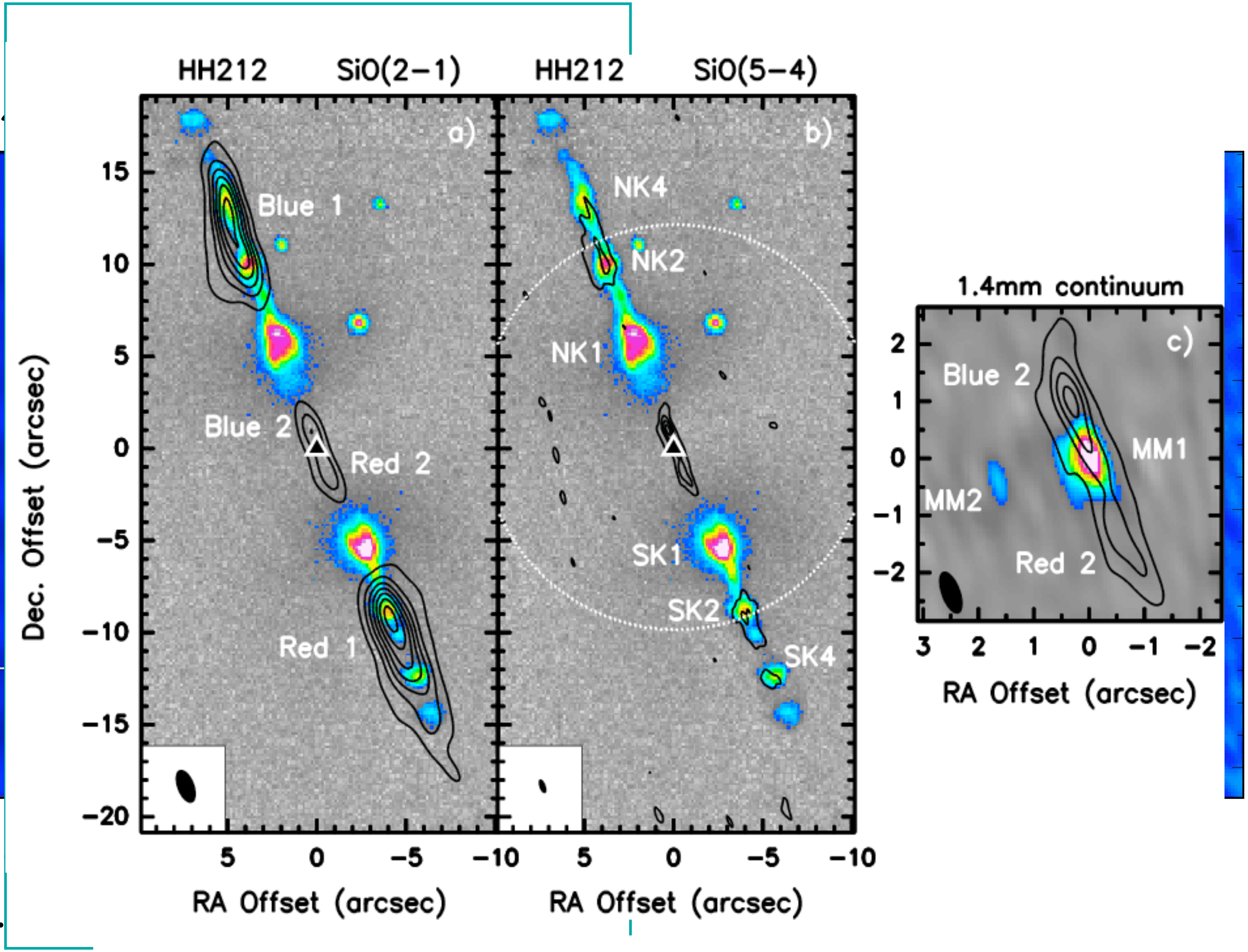


Rodr iétu et al. in prep.
prep.

Beltran et al. 2009

IC 3

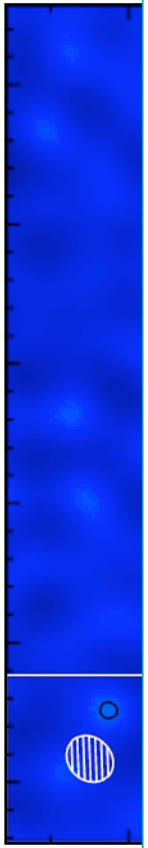




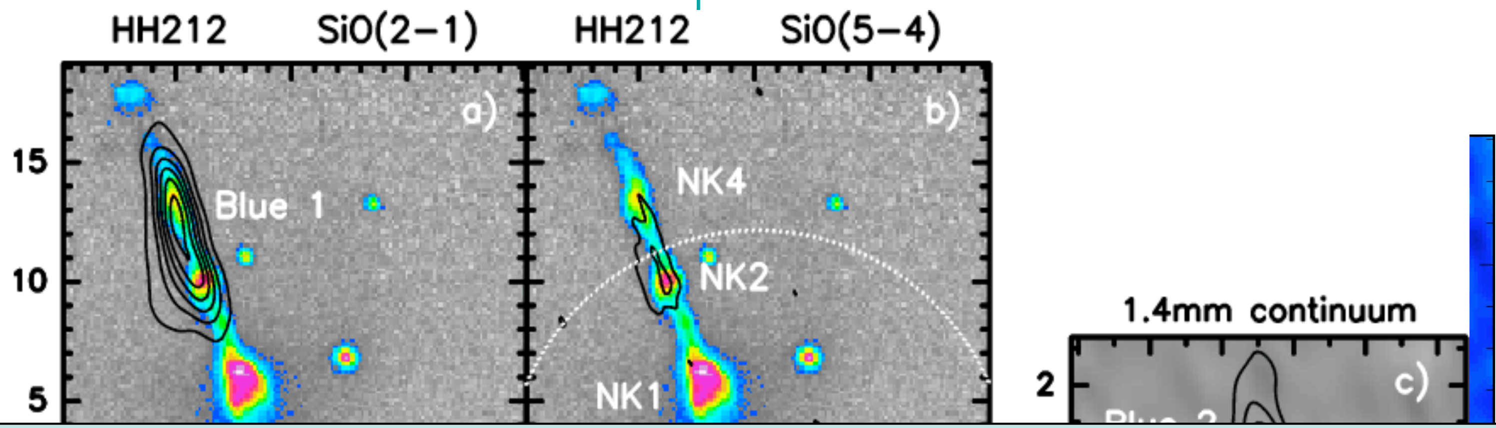
Rodr
prep.

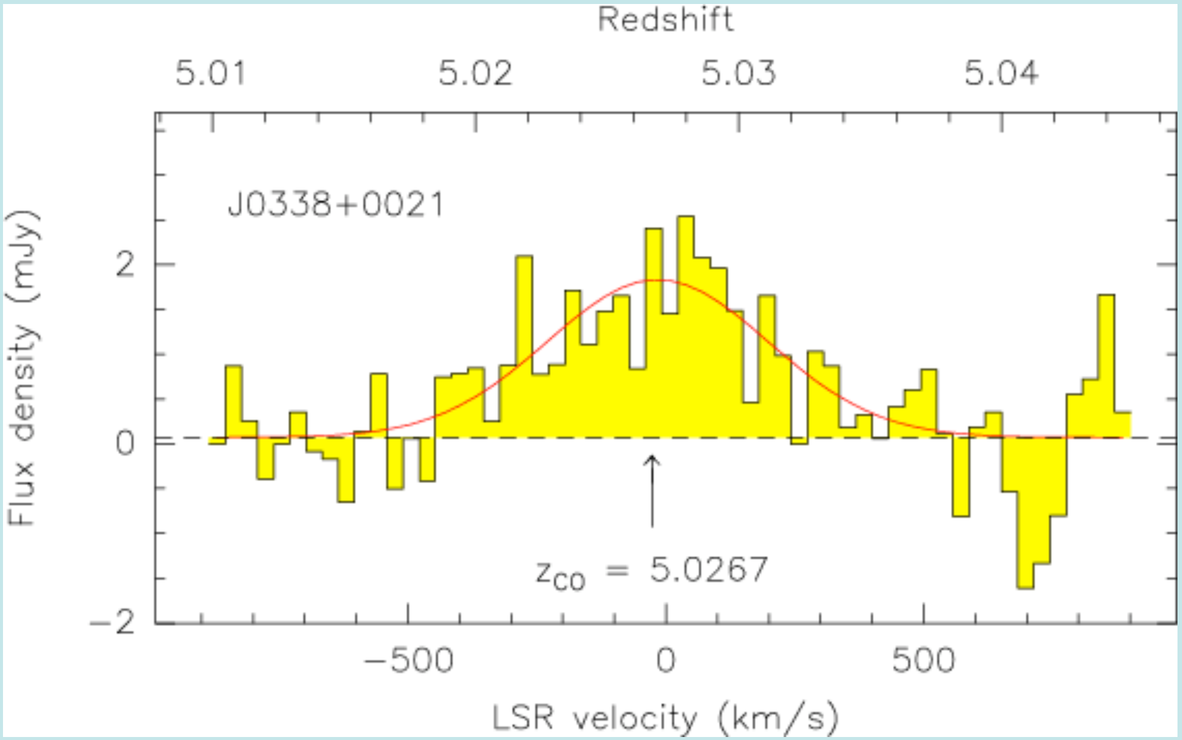
Codella et al. 2007

IC 3



Rodr
prep.





Maiolino et al. 2007

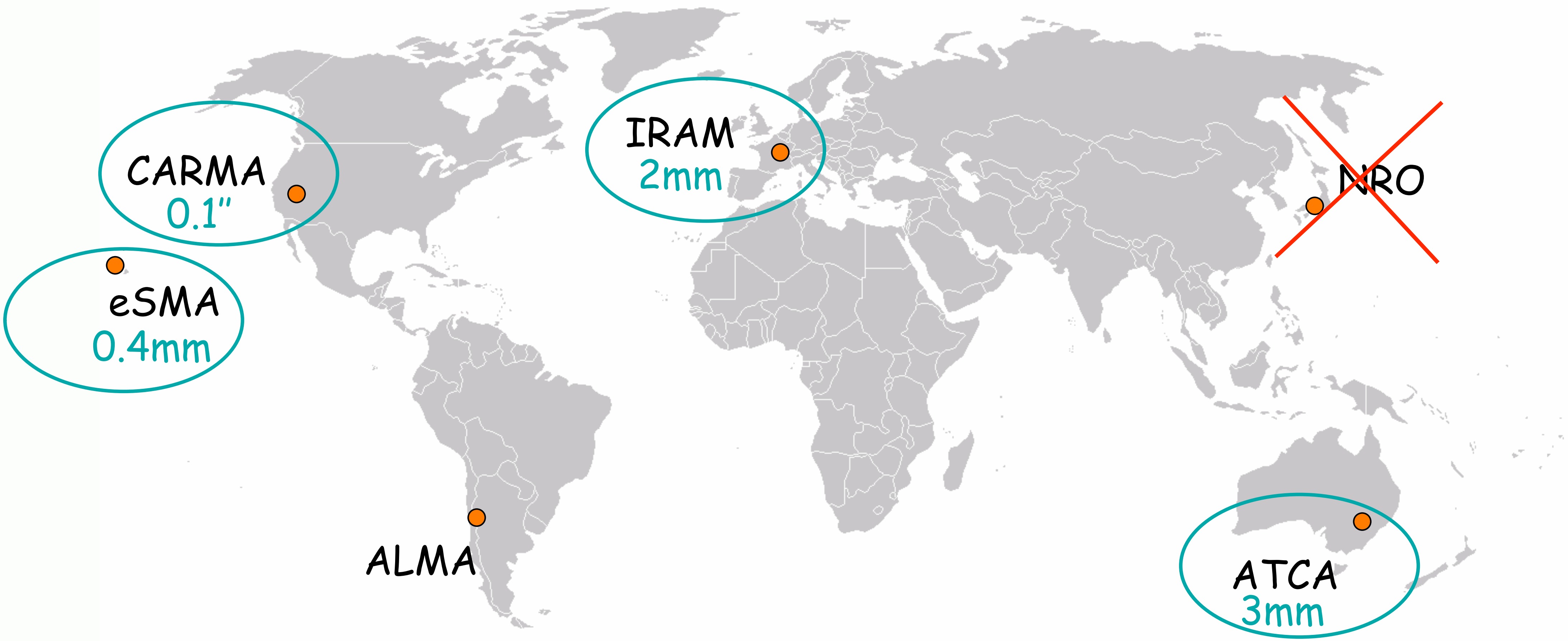
Interferometer Basics

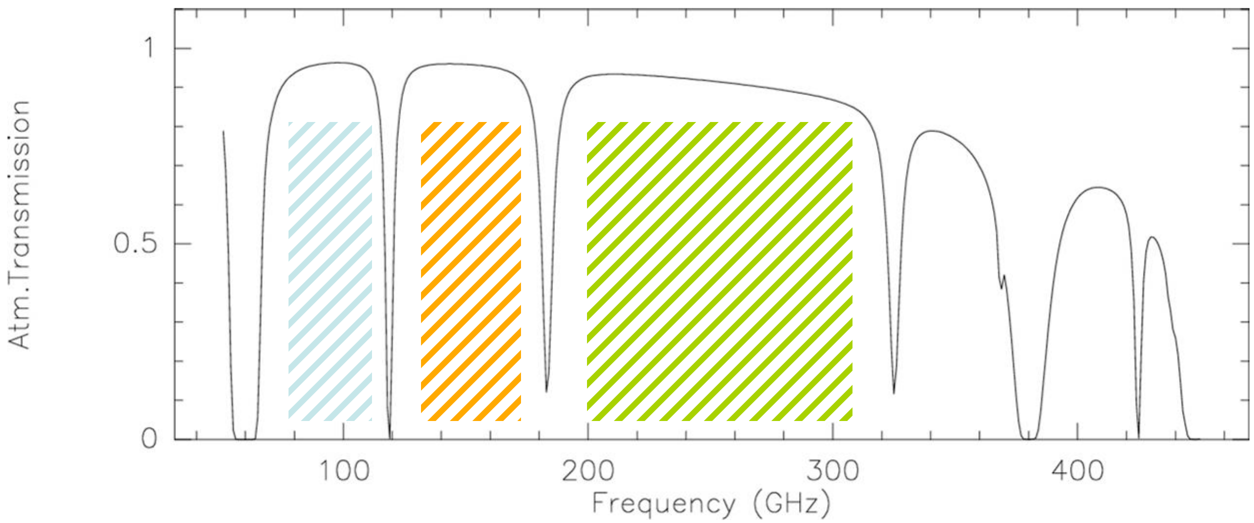
All you need as an observer:

- the appropriate interferometer
- one or more configuration(s)
- the noise equation

(sub)mm-interferometers worldwide

(sub)mm-interferometers worldwide

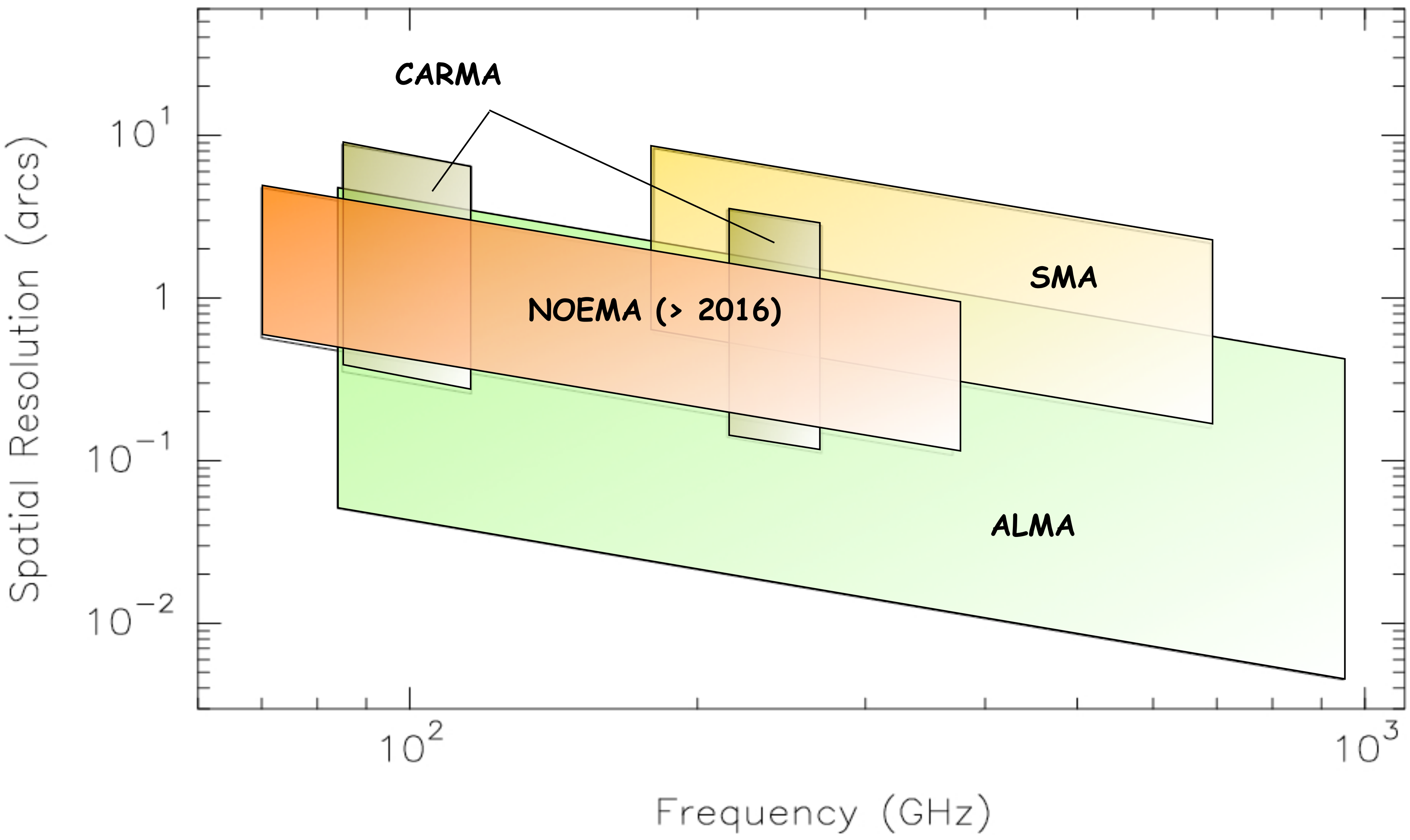




3mm = 100 GHz   2mm = 150 GHz   1mm = 300 GHz

Interferometer	Atmospheric window	Ang.Resolution
ATCA	3mm	1.6"
PdBI	3mm, 2mm, 1mm, 0.8mm	0.25"
eSMA	1mm, 0.8mm, 0.4mm	(0.15")
CARMA	3mm 1mm	(0.1")

Large differences !

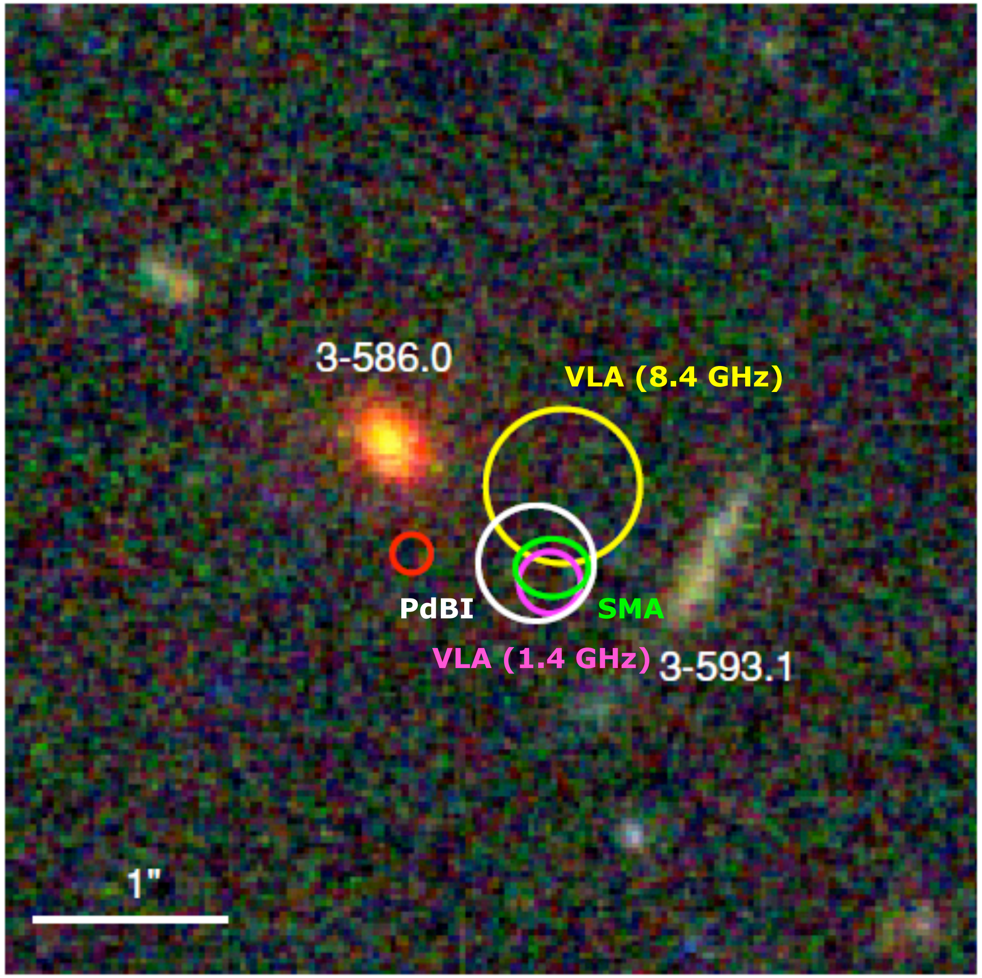

CARMA
SMA
NOEMA (> 2016)
ALMA
Spatial Resolution (arcs)
Frequency (GHz)
10^1
1
10^{-1}
10^{-2}
10^2
10^3

Interferometer Basics

All you need as an observer:

- the appropriate interferometer
- one or more configuration(s)
- the noise equation

HDF850.1 (Cowie et al. 2009)



⇨ mm-astronomy calls for positional accuracy

Single-Dish limitations

1. angular resolution : ~ 1/D

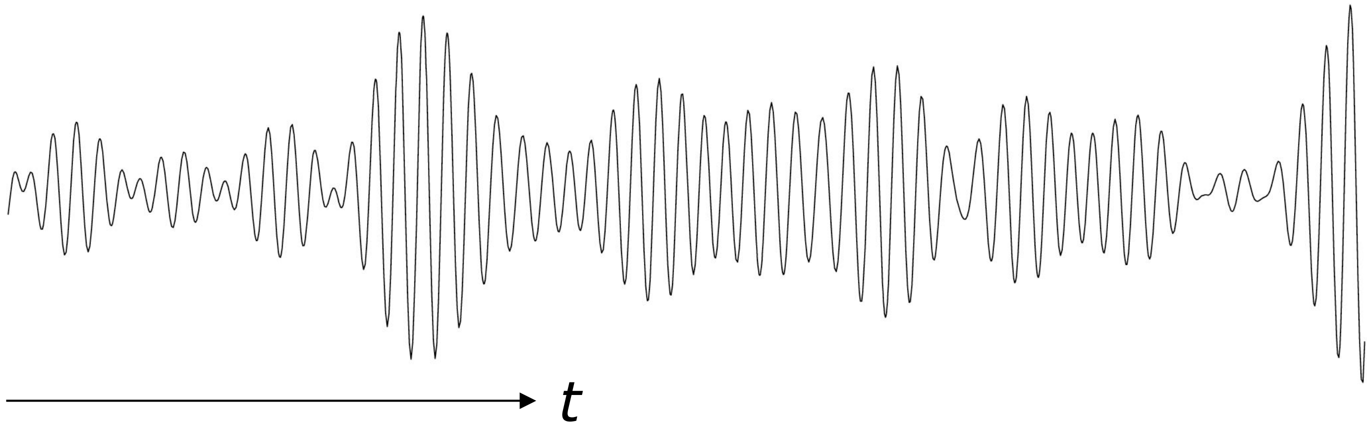
Need to

1. increase diameter
2. increase the pointing accuracy
3. keep a high surface quality

Single-Dish	Angular resolution @ 1mm
CSO 10m	24"
IRAM 30m	9"
LMT 50m	6"

the power of interferometers

Temporal coherence function

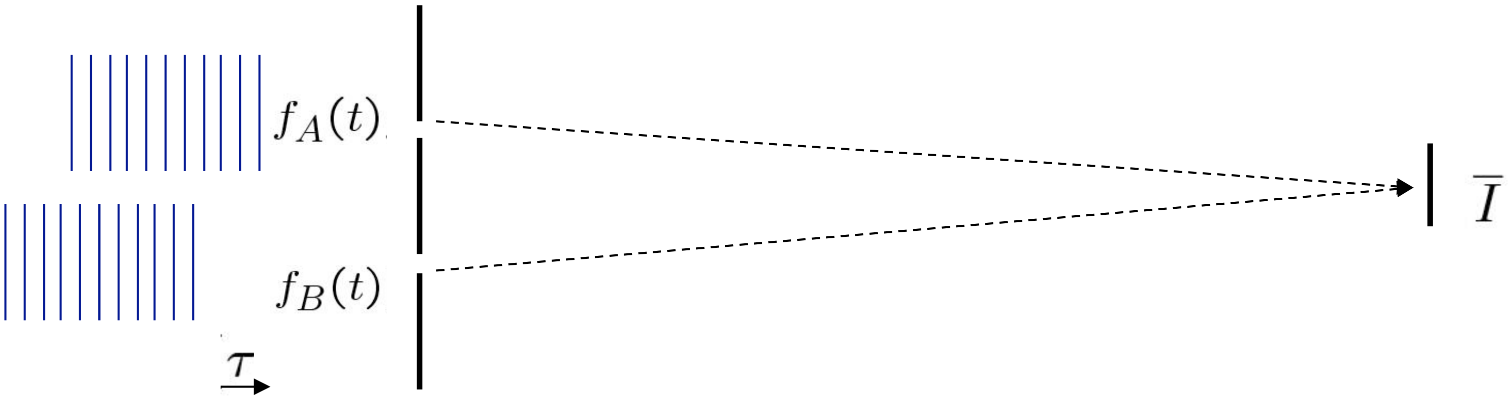


Correlation coefficient:

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

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

Temporal coherence



Correlation coefficient:

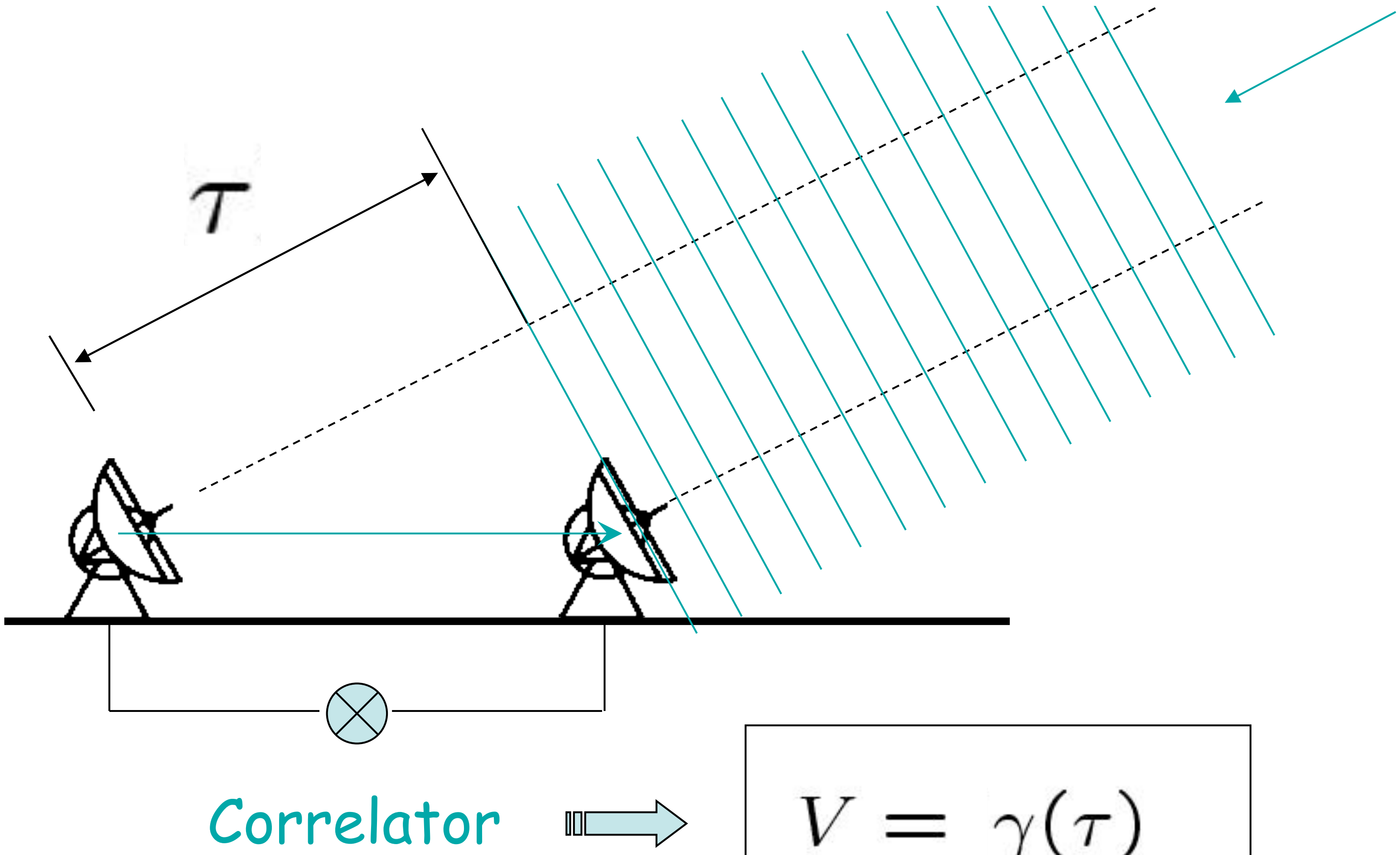
$$\gamma_{AB} = f_A(t) f_B^*(t+\tau) / (\overline{|f_A(t)|^2}\ \overline{|f_B(t)|^2})^{\frac{1}{2}}$$

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

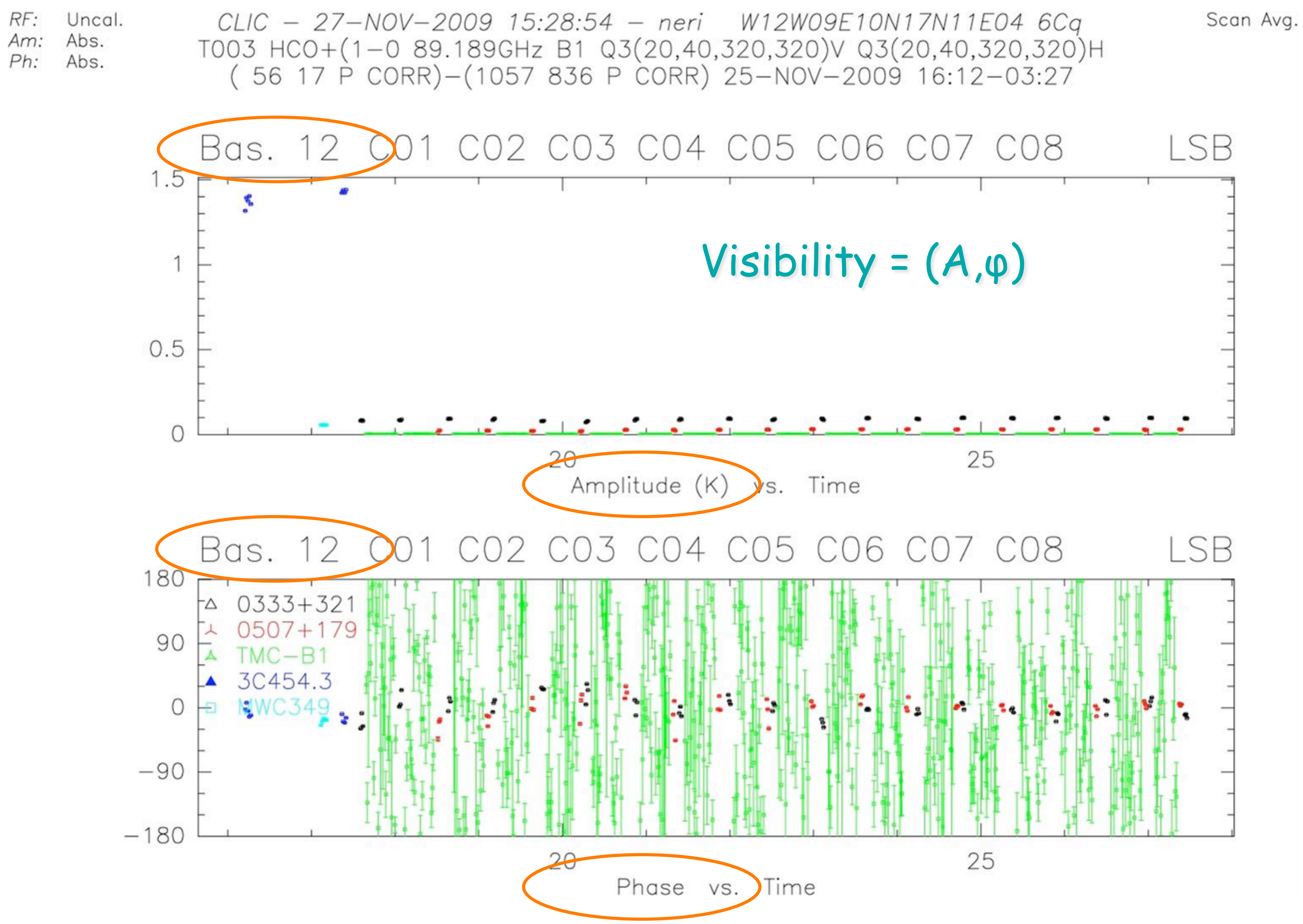
$$\bar{I}_A = \bar{I}_B \quad \Rightarrow \quad \boxed{V = |\gamma_{AB}|}$$

An interferometer

measures the temporal coherence of the incoming wavefront



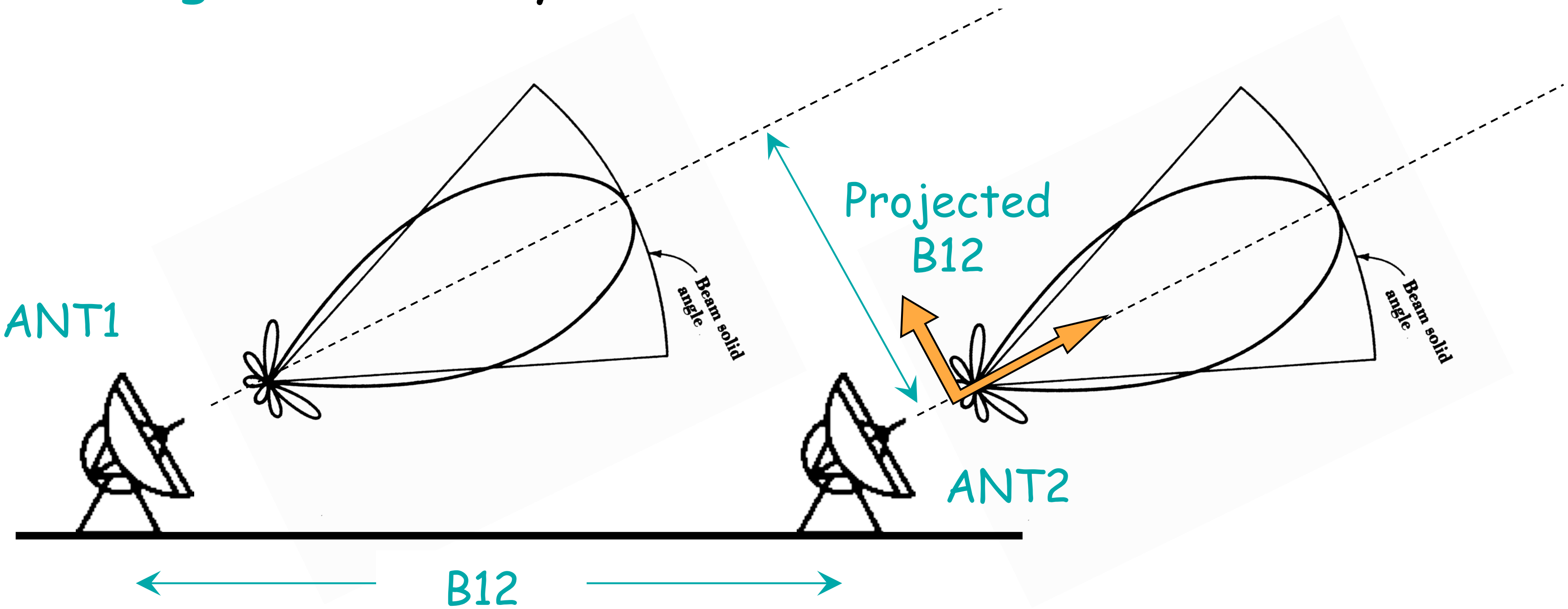
$$V = \gamma(\tau)$$

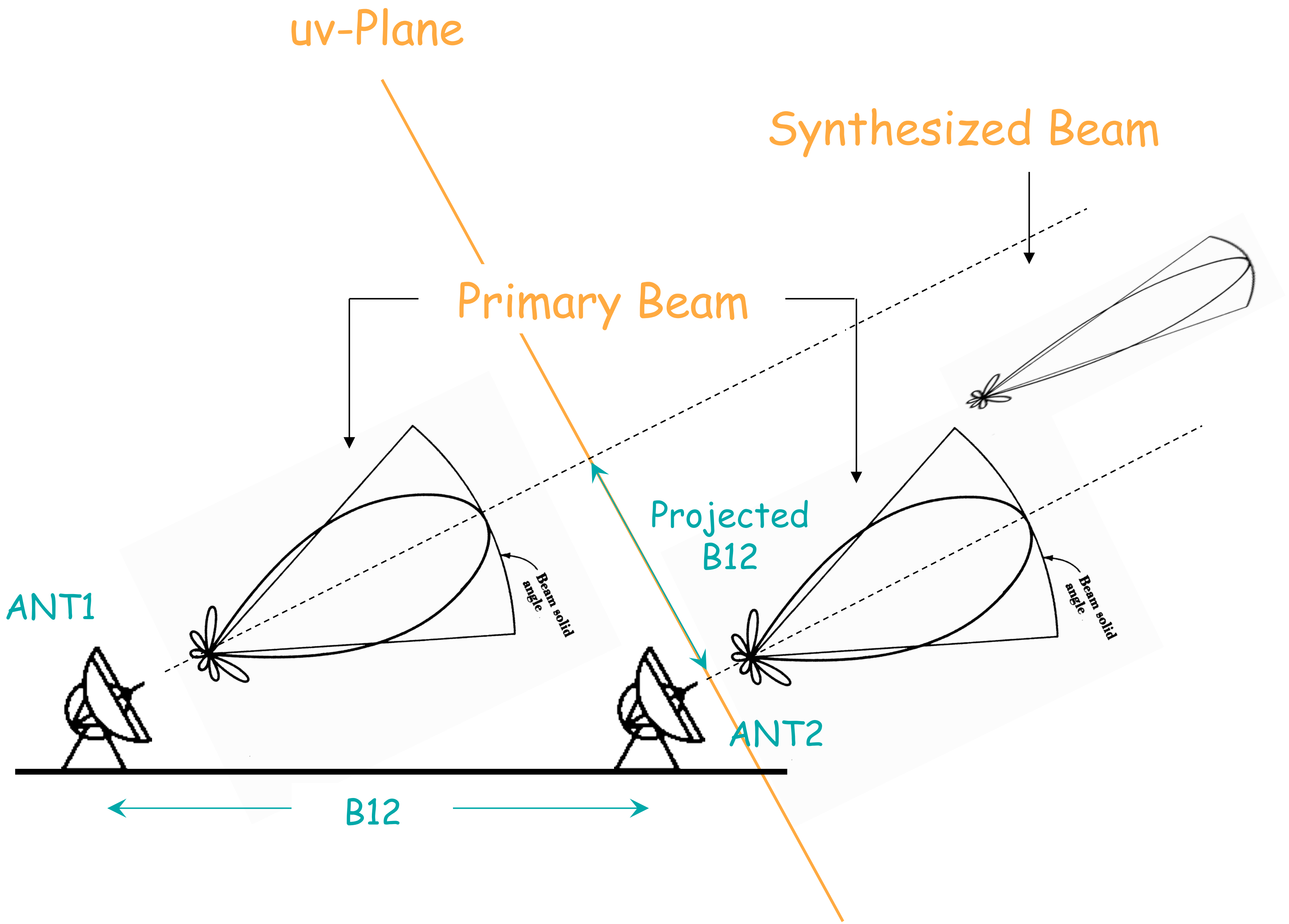

RF: Uncal.
Am: Abs.
Ph: Abs.
CLIC – 27-NOV-2009 15:28:54 – neri W12W09E10N17N11E04 6Cq
Scan Avg.
T003 HCO+(1-0 89.189GHz B1 Q3(20,40,320,320)V Q3(20,40,320,320)H
(56 17 P CORR)-(1057 836 P CORR) 25-NOV-2009 16:12-03:27
Bas. 12 C01 C02 C03 C04 C05 C06 C07 C08 LSB
Visibility = (A,φ)
Amplitude (K) vs. Time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

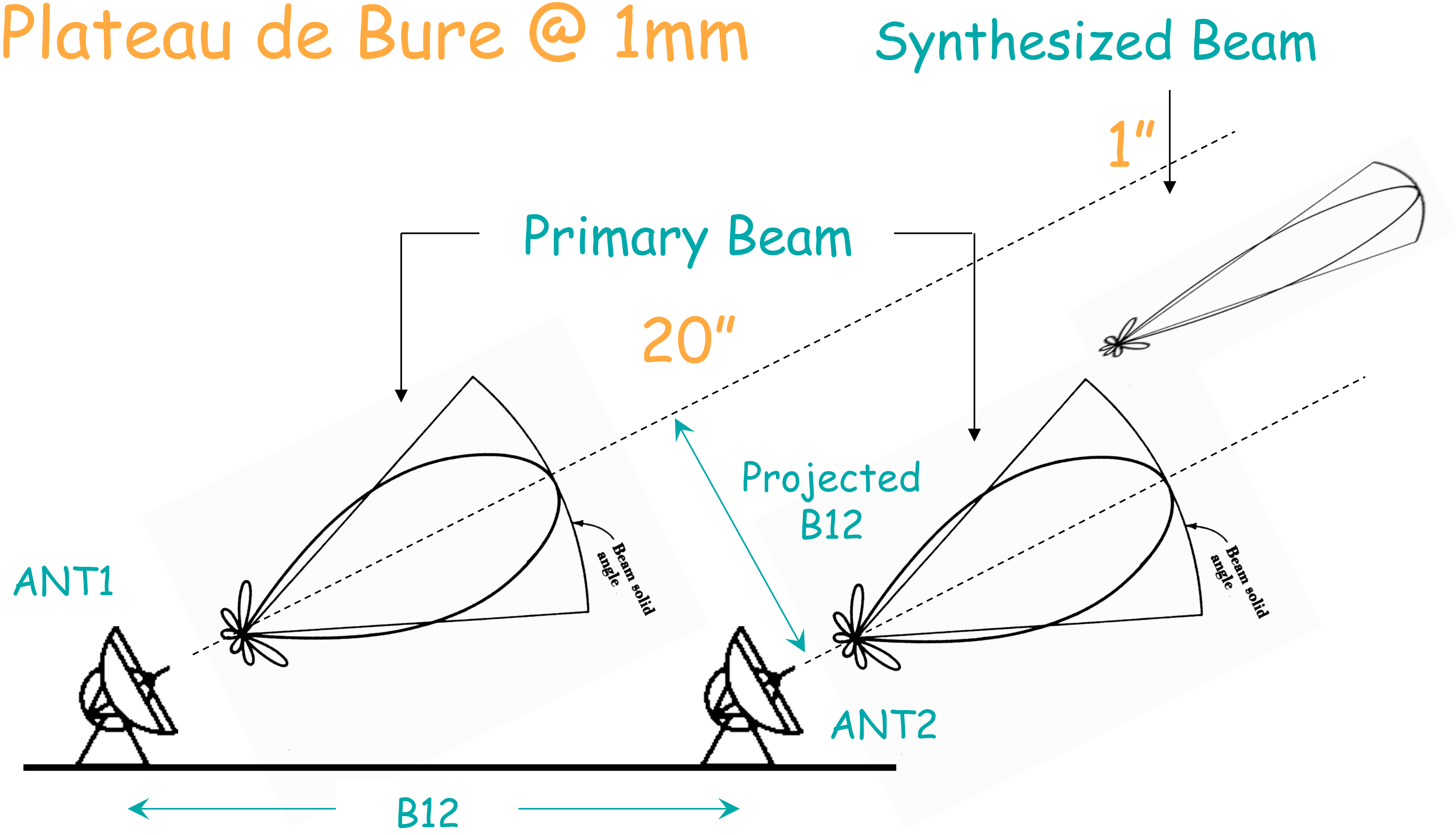
Projected Baseline Bij : distance between two antennas as seen from the sky

Configuration : layout of the antenna stations




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

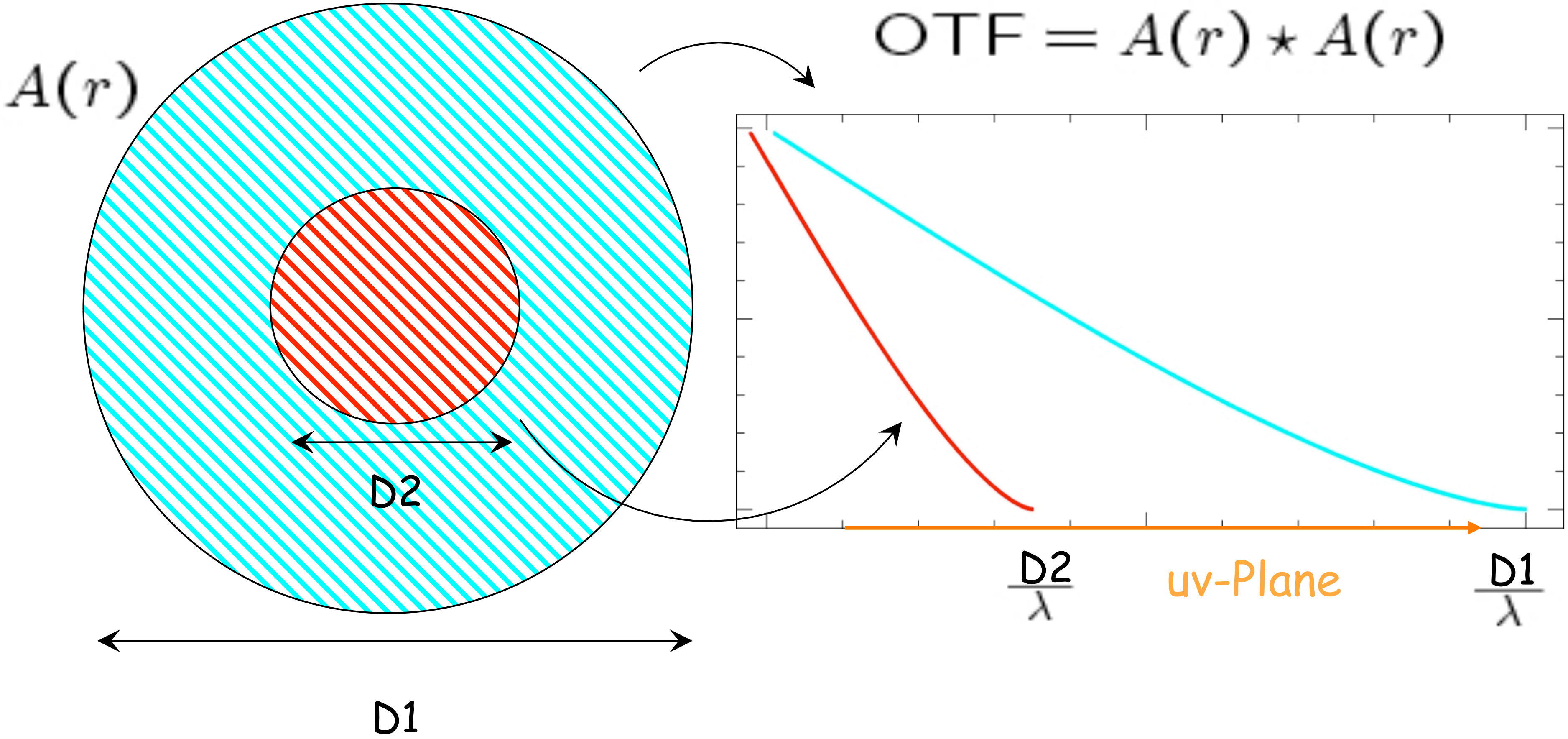
Plateau de Bure @ 1mm

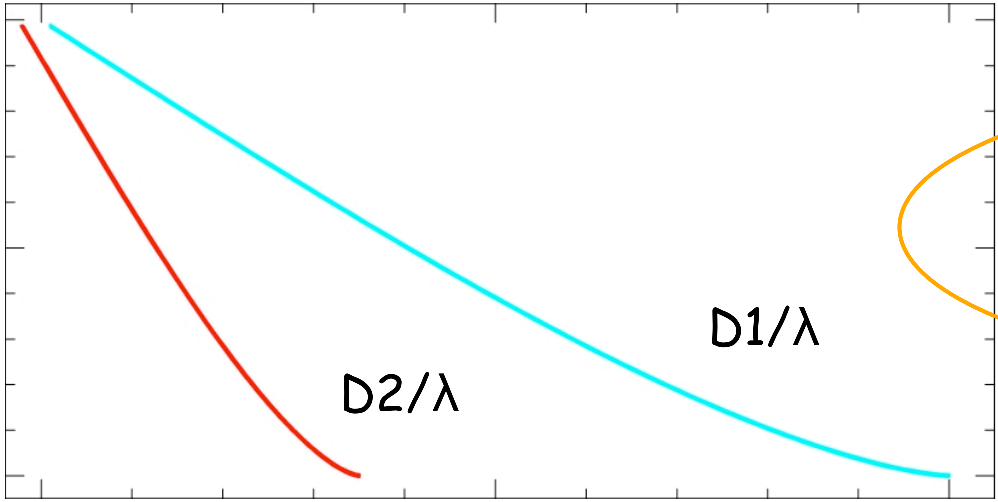


C configuration = 200m

The ideal lens (or antenna)

samples all spatial frequencies up to D/λ – the lower frequencies are favored

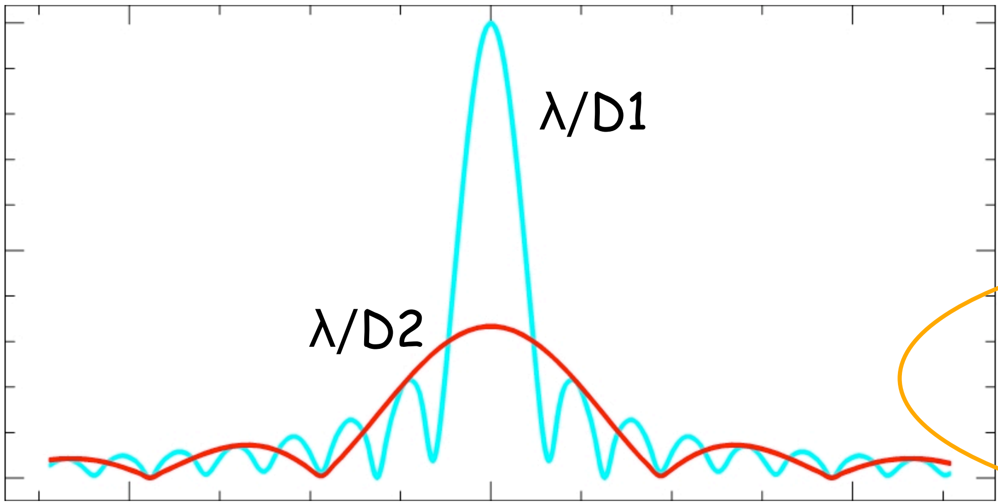




Spatial Frequency (= uv-plane)

weighting function

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



Spatial resolution

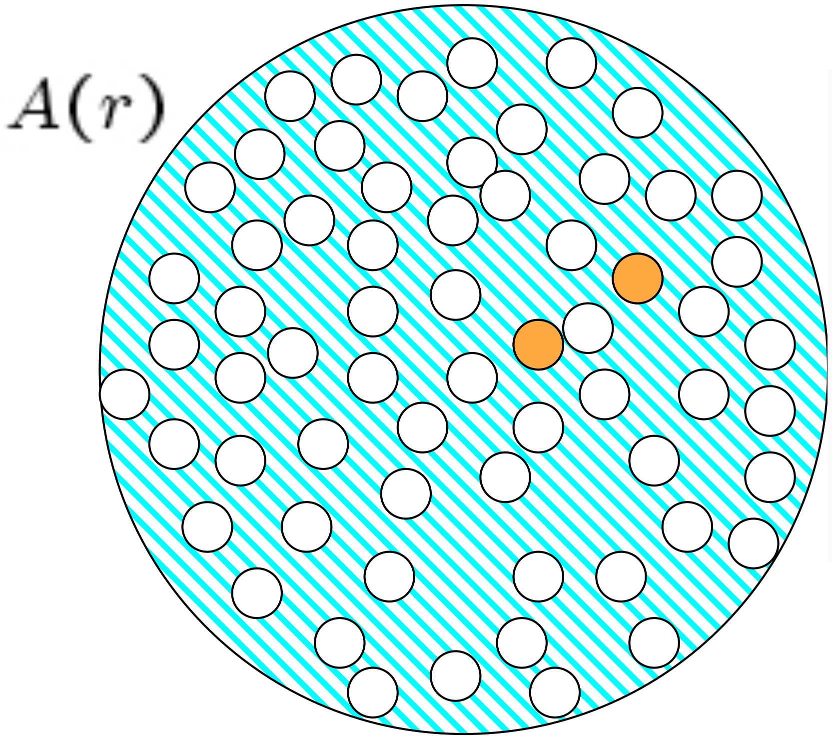
$$\mathrm{PSF} = FFT(\mathrm{OTF})$$

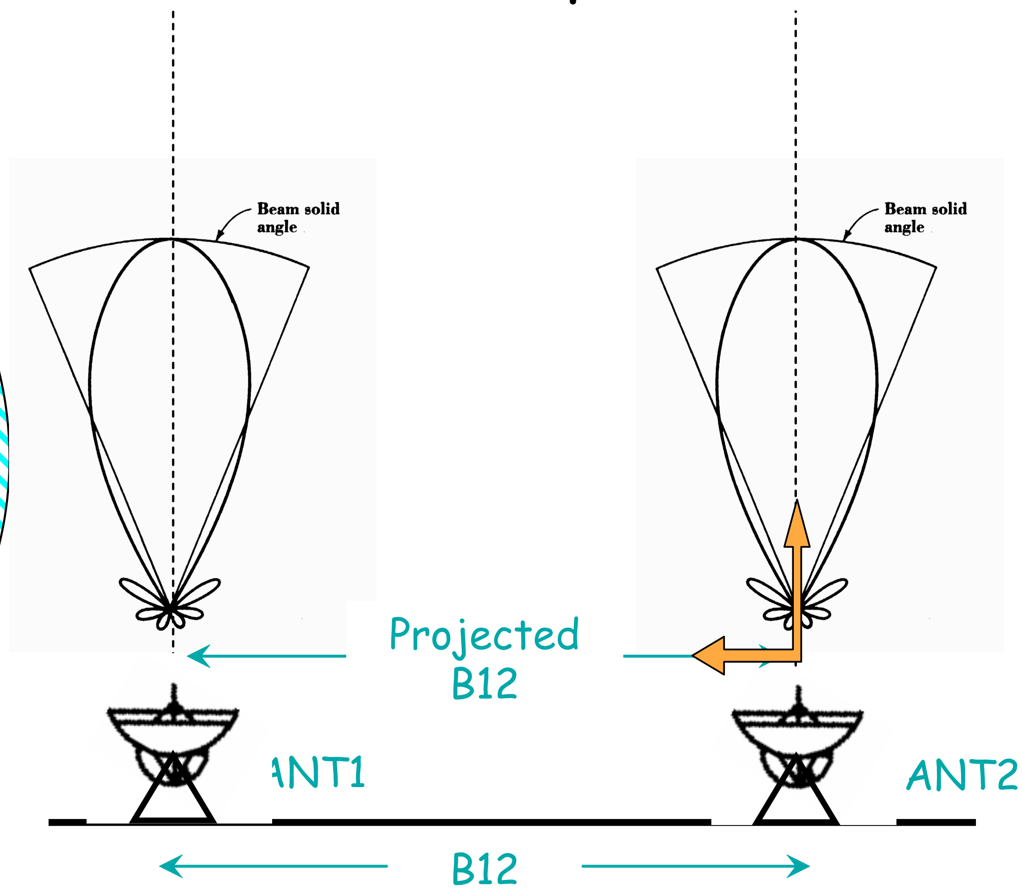
$$= |FFT(A(r))|^2$$

primary beam

Interferometry or Aperture Synthesis

is the technique by which a large telescope is replaced by a number of smaller telescopes

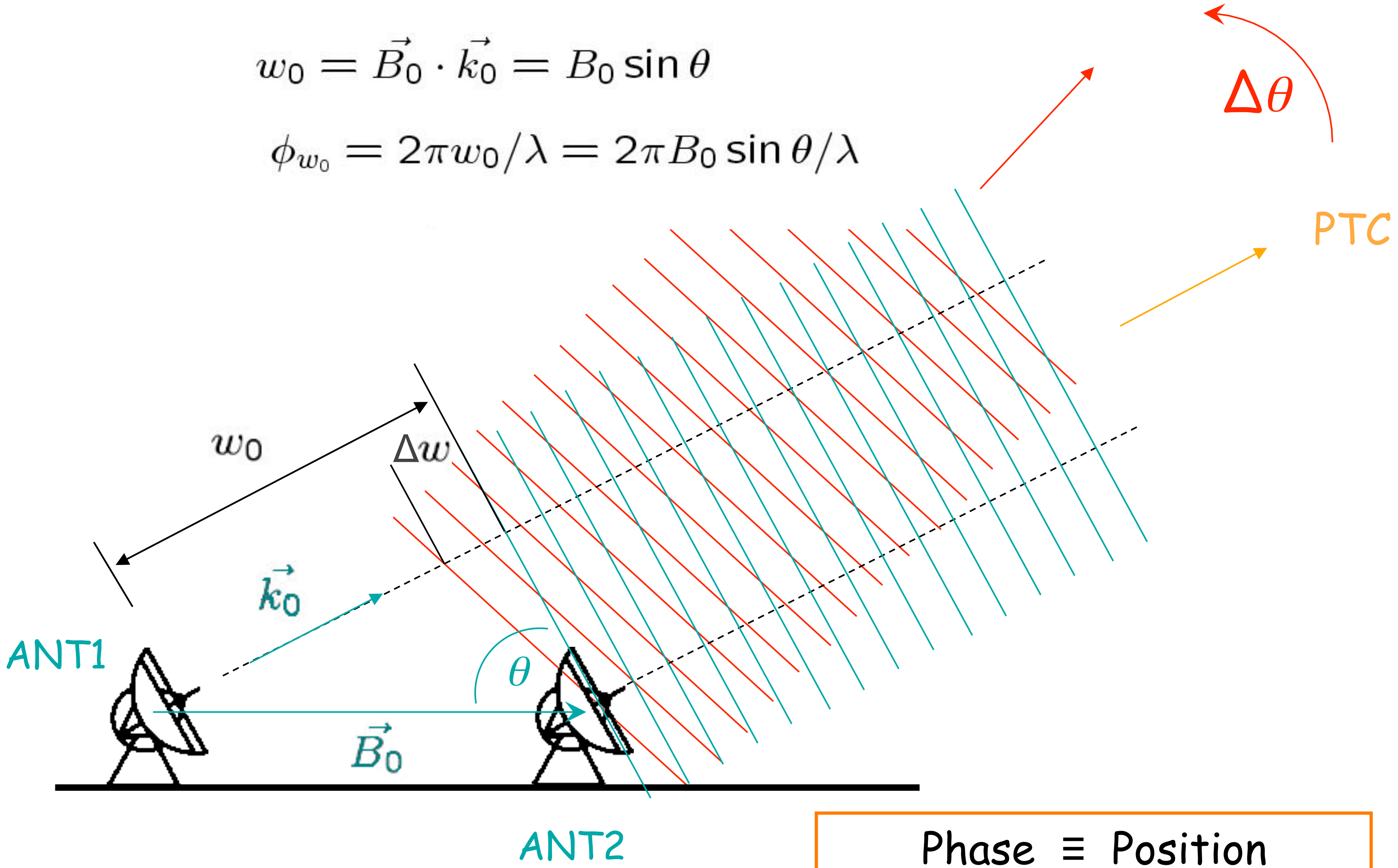




The phase equation

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

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

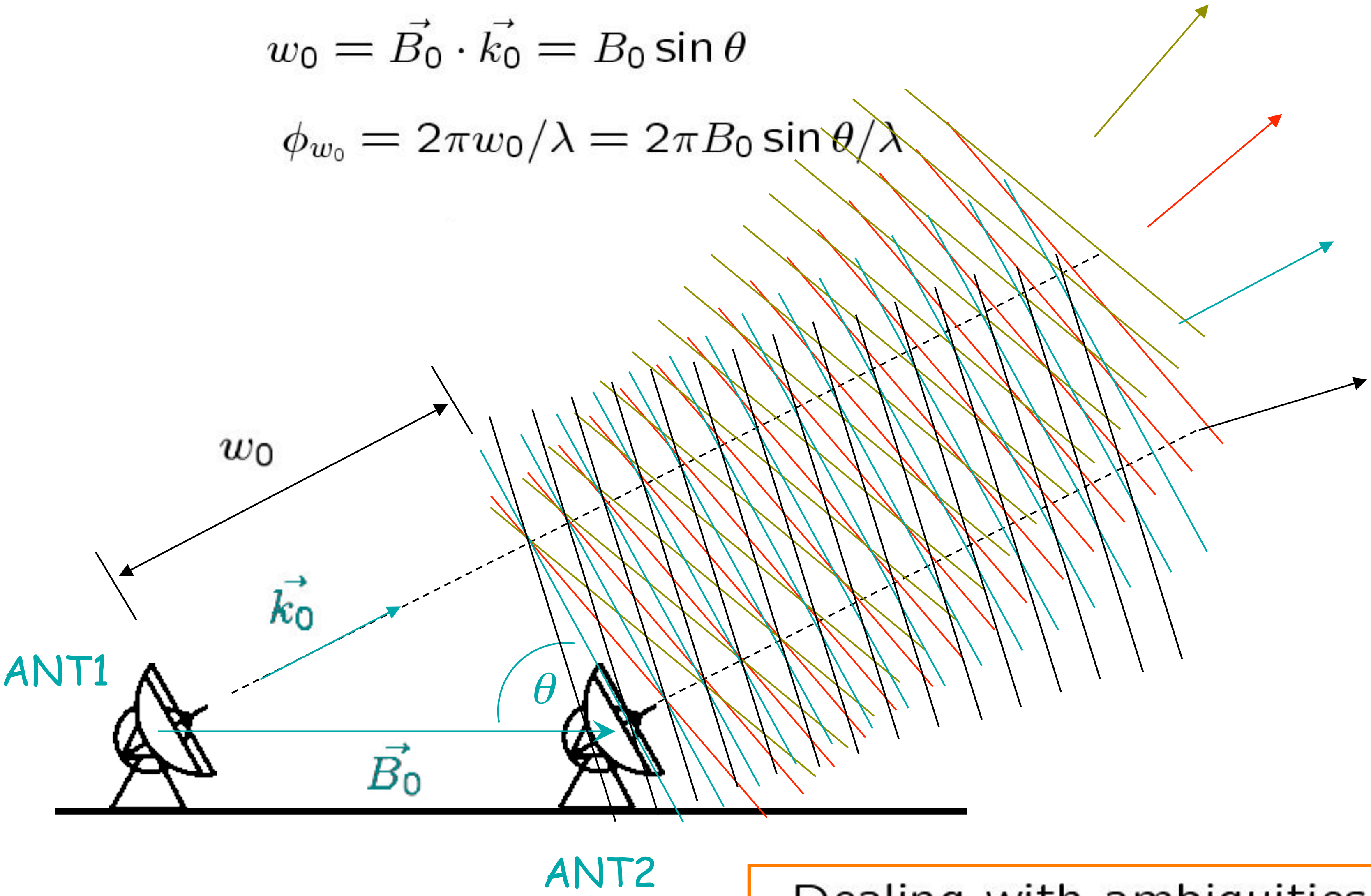


Phase ≡ Position

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 . . .

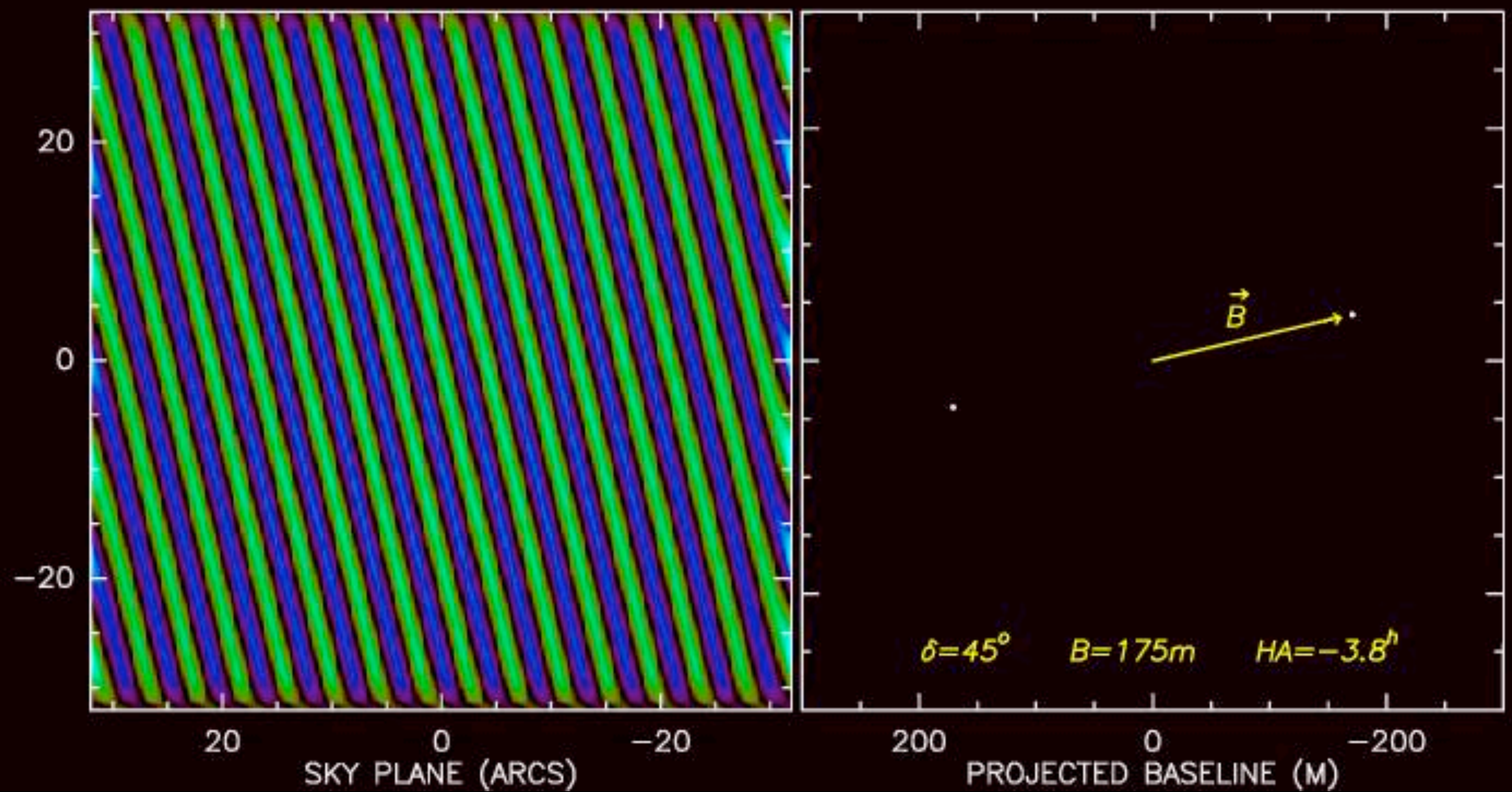
Dealing with $\quad \omega_0 = \vec{k_0} \cdot \vec{B_0}$

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

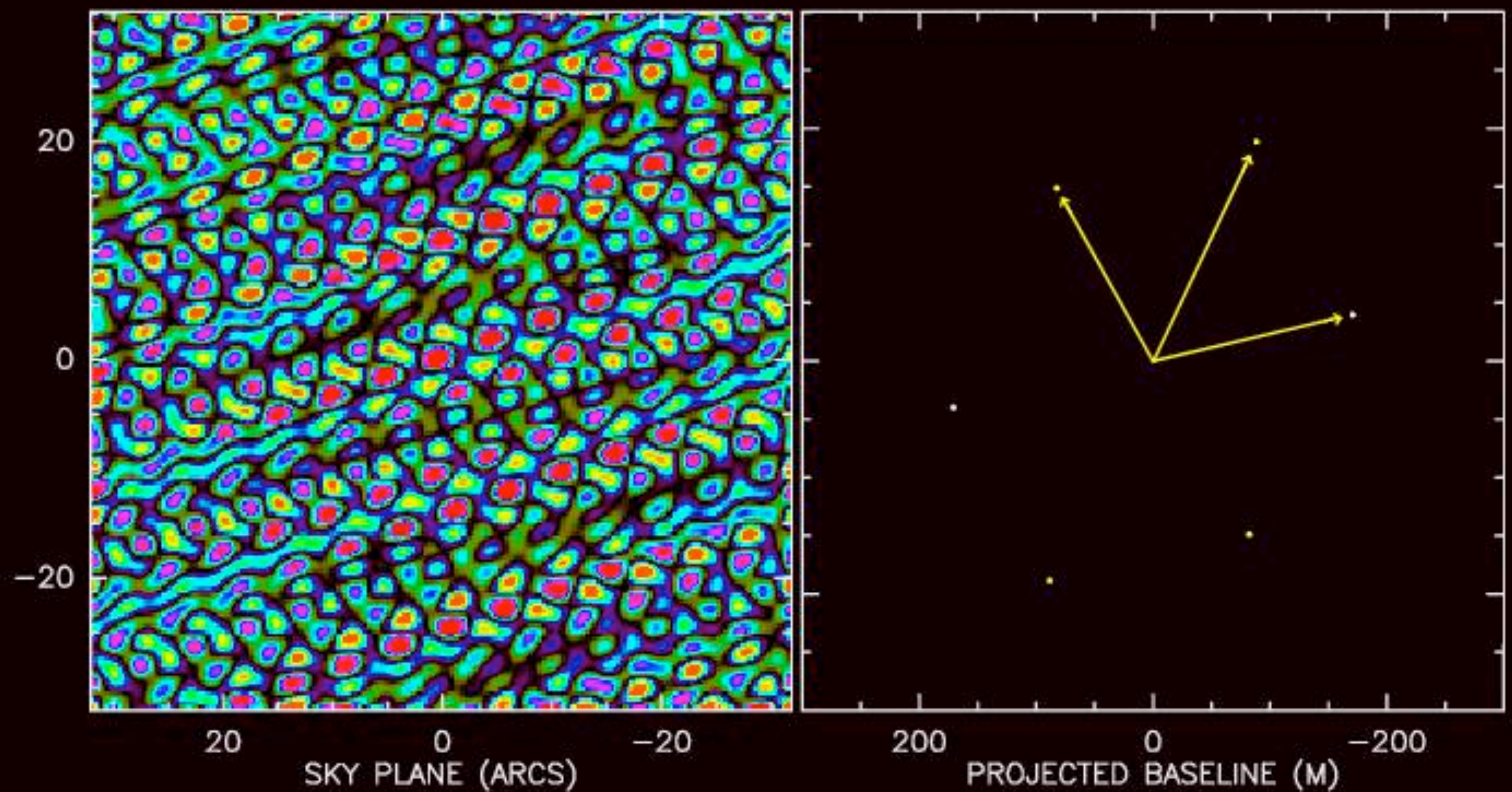
Ex: with $B_0 = 300\,\mathrm{m}$ and $\lambda = 3\,\mathrm{mm}$, the positional ambiguity on the skyplane becomes:

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

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

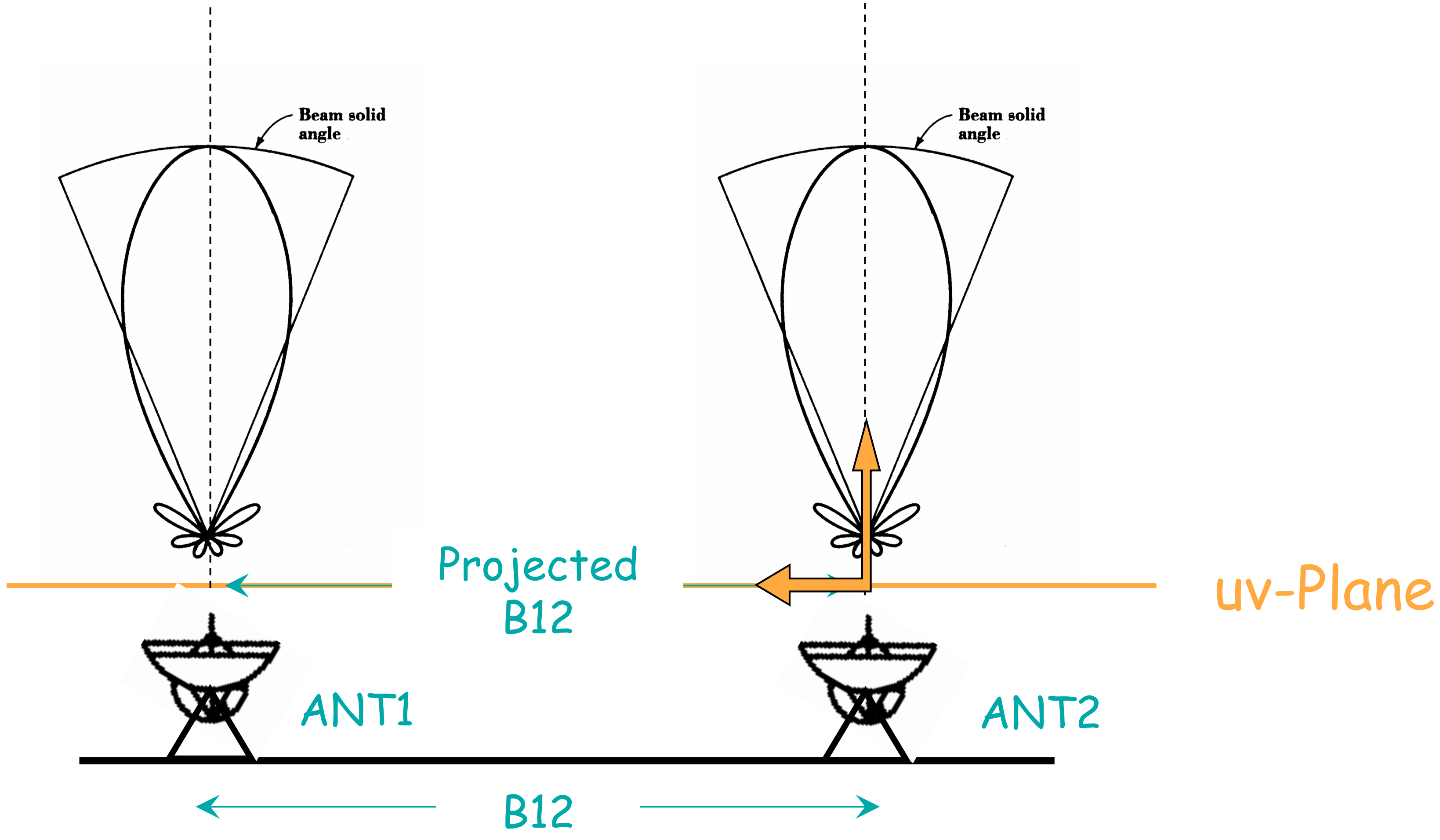


20
0
−20
20
0
−20
SKY PLANE (ARCS)
B
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)

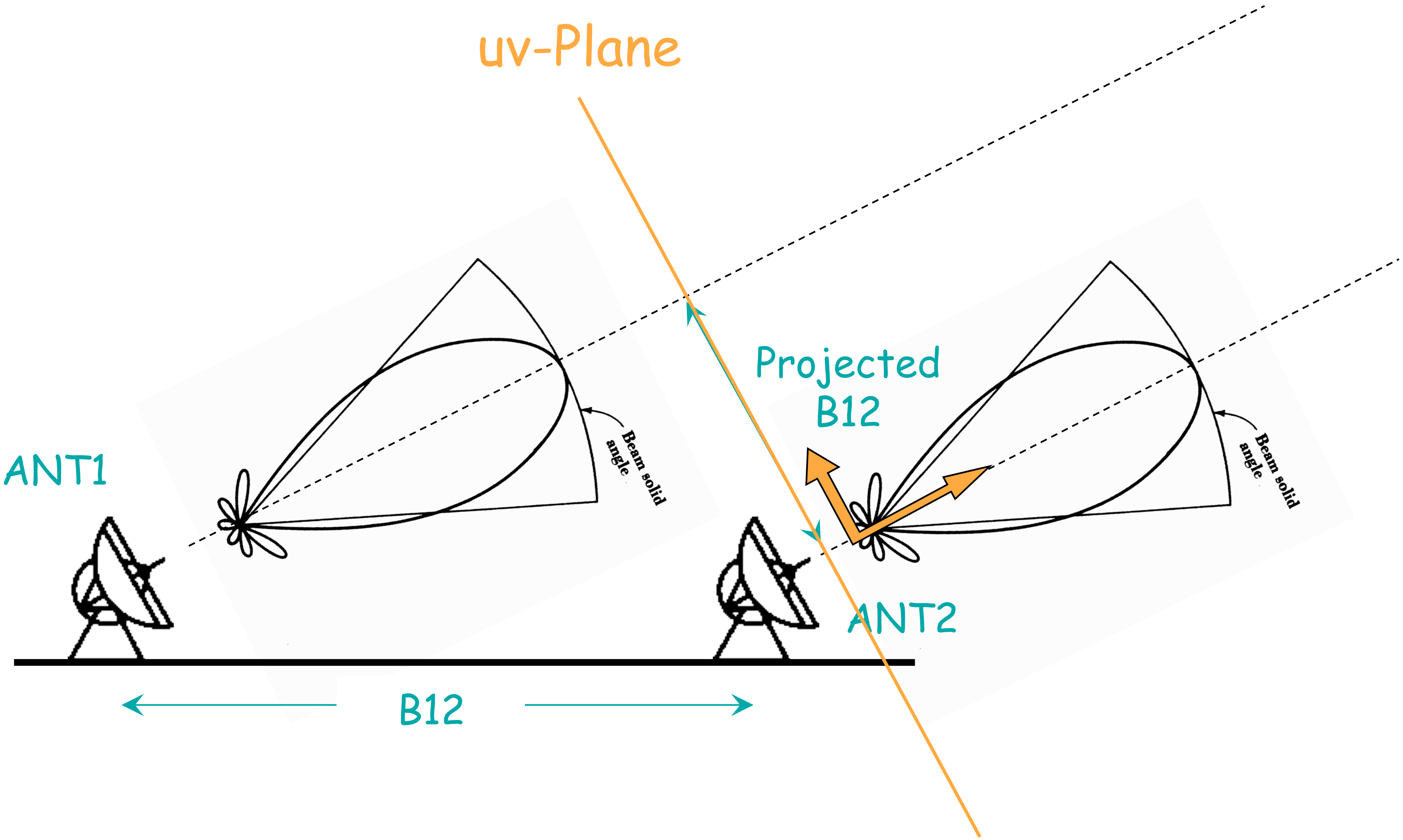


20
0
−20
20
0
−20
SKY PLANE (ARCS)
200
0
−200
PROJECTED BASELINE (M)

The projected baseline changes with elevation i.e. with source declination and hour-angle

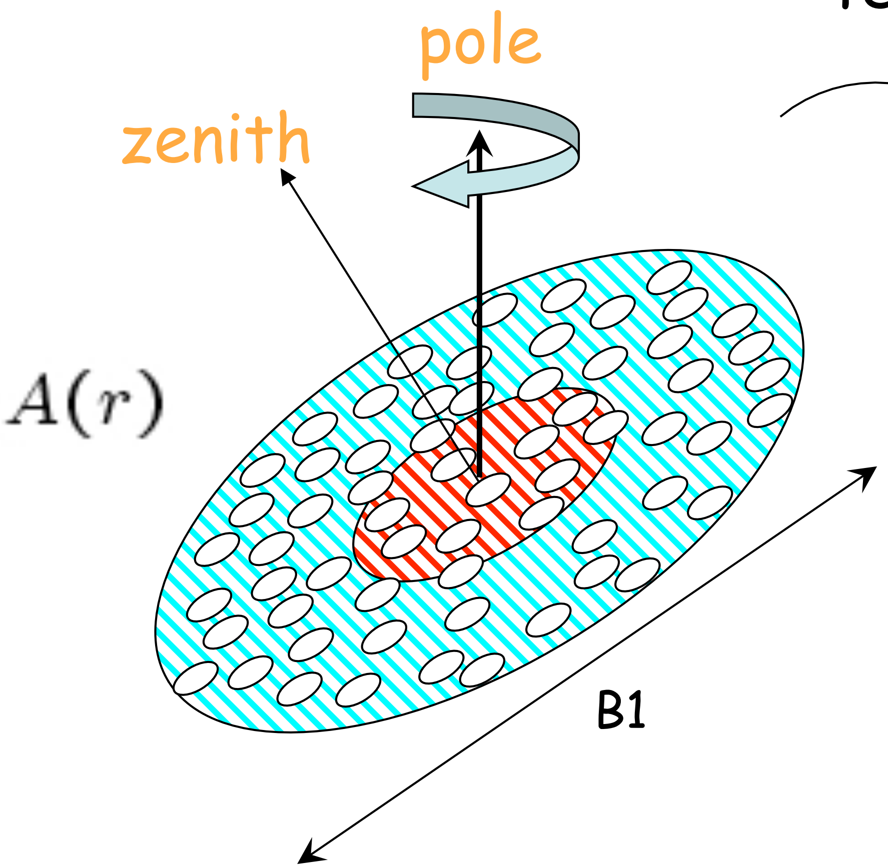


The projected baseline changes with elevation i.e. with source declination and hour-angle

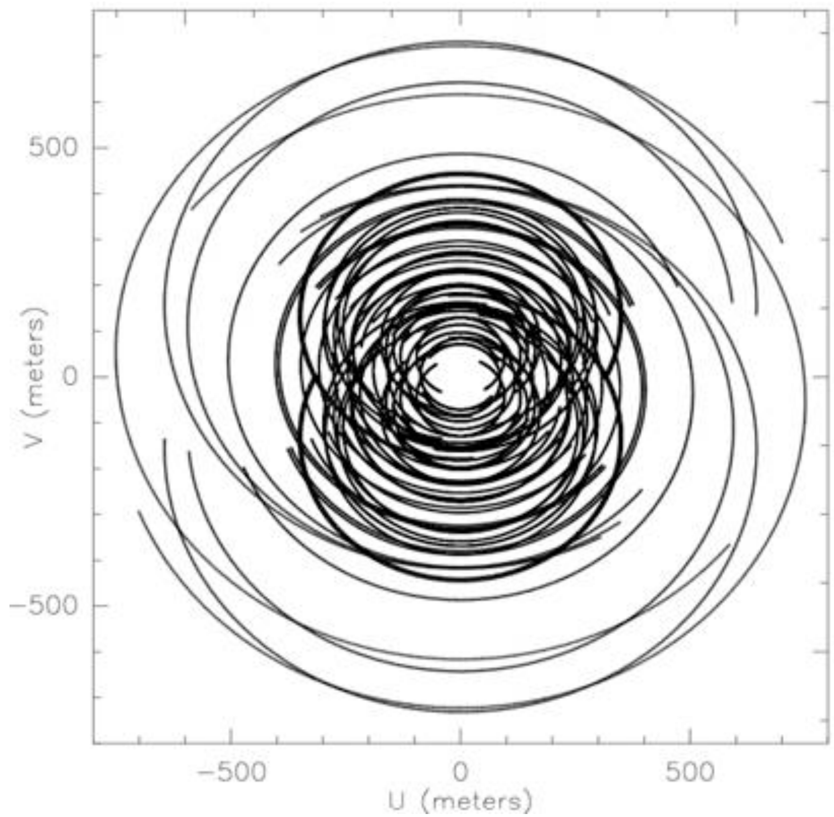


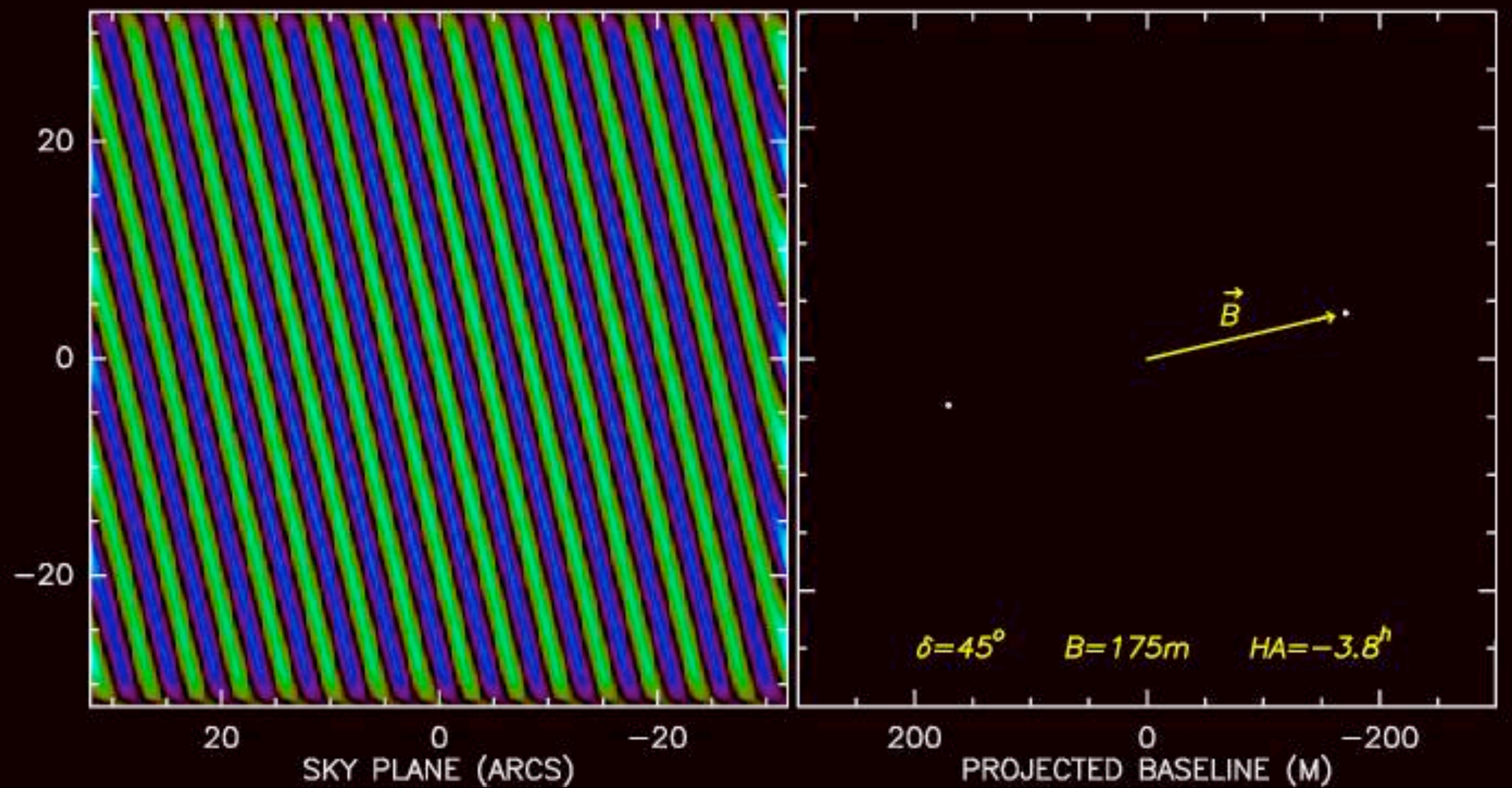
Super-Synthesis or Earth Rotation Synthesis

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

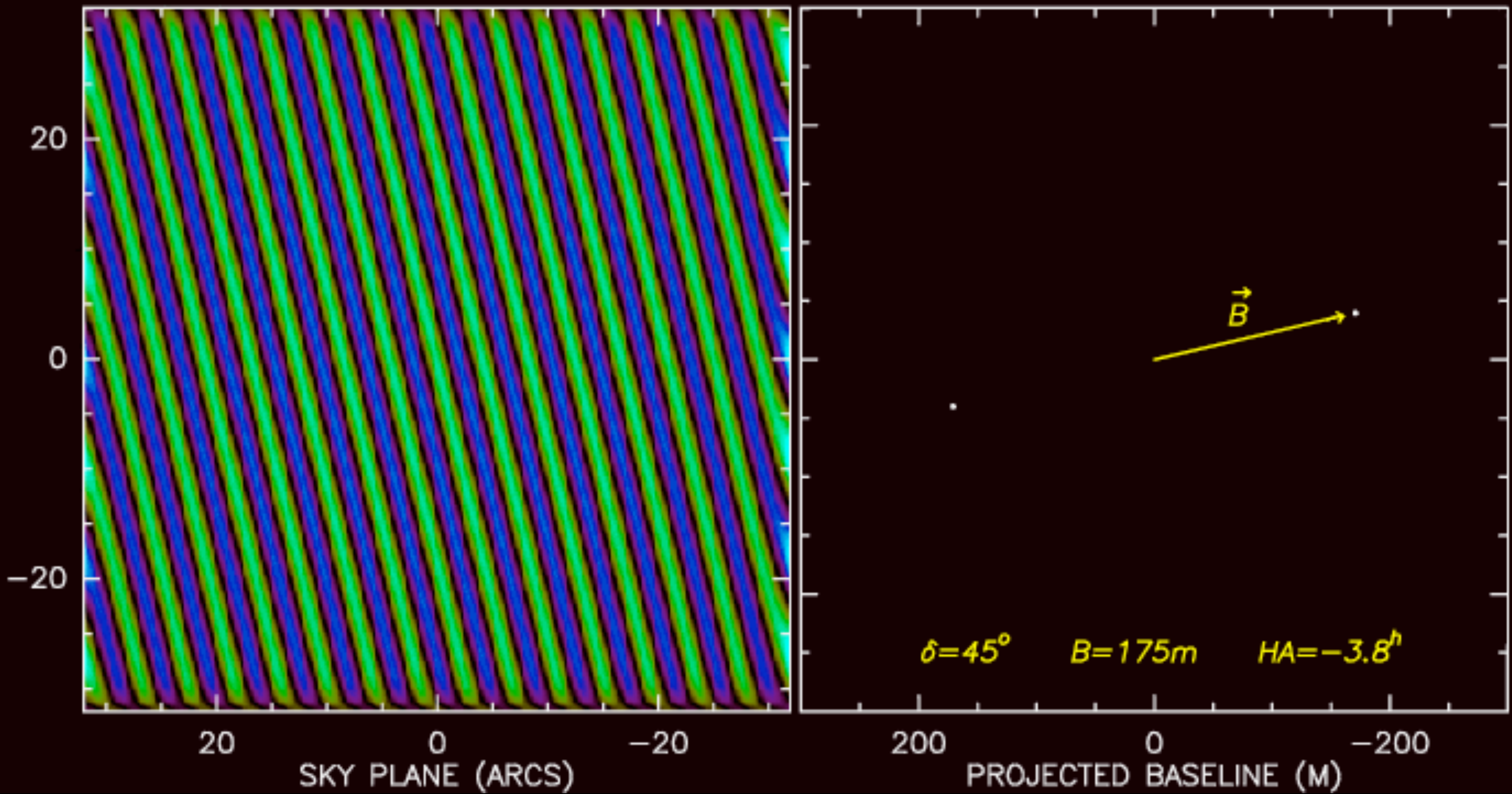


$$\mathrm{OTF} = A(r) \star A(r)$$

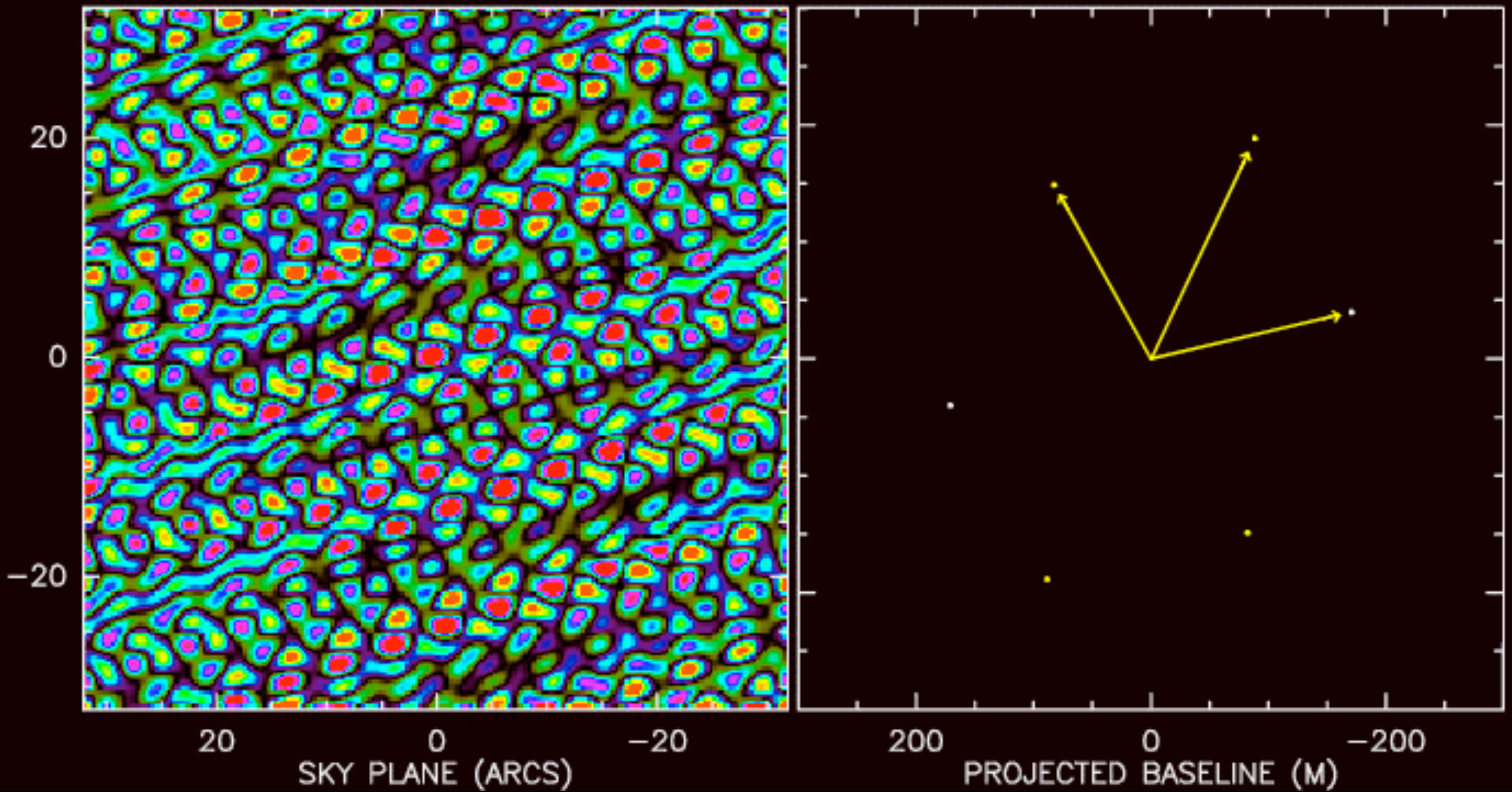




20
0
−20
20
0
−20
SKY PLANE (ARCS)
B
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)

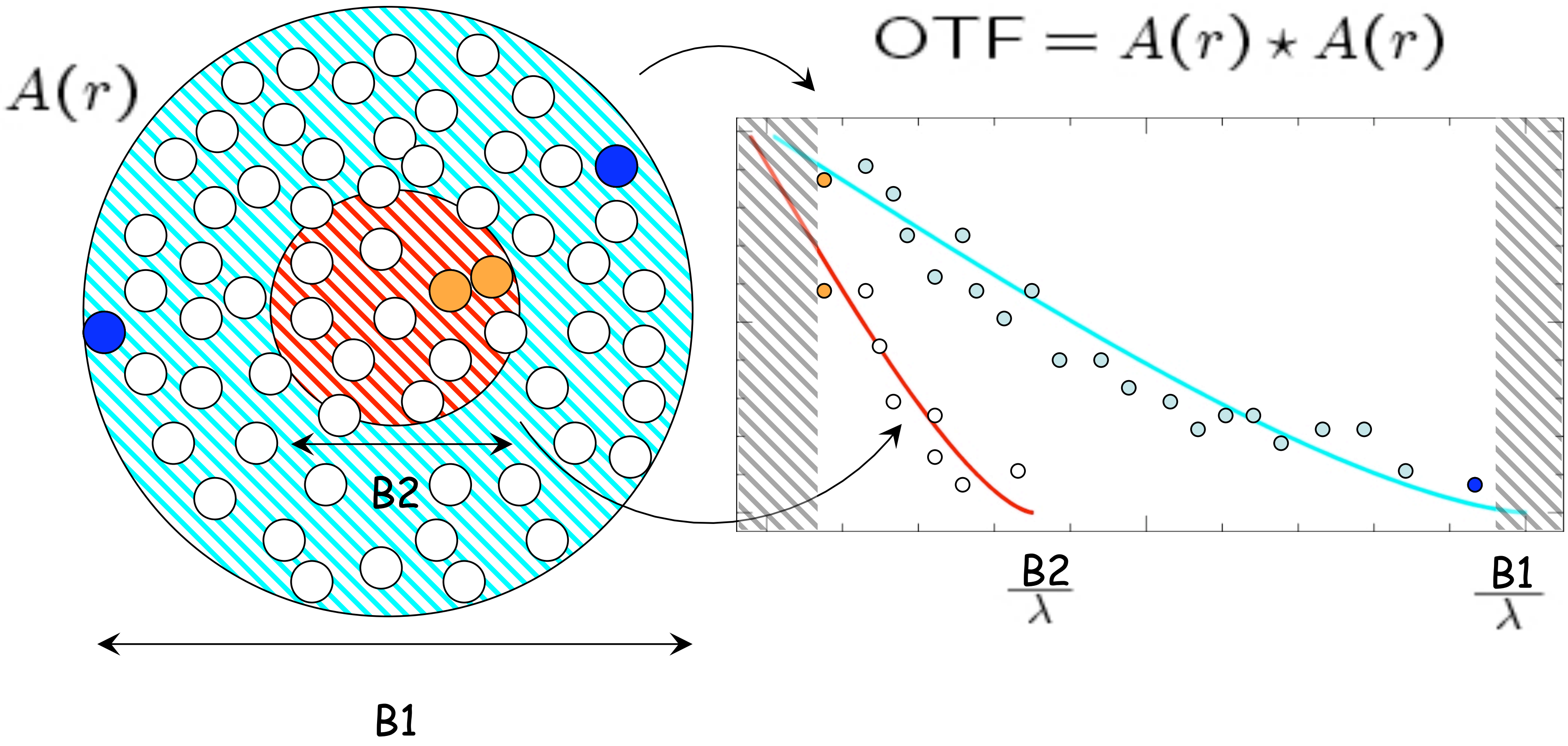


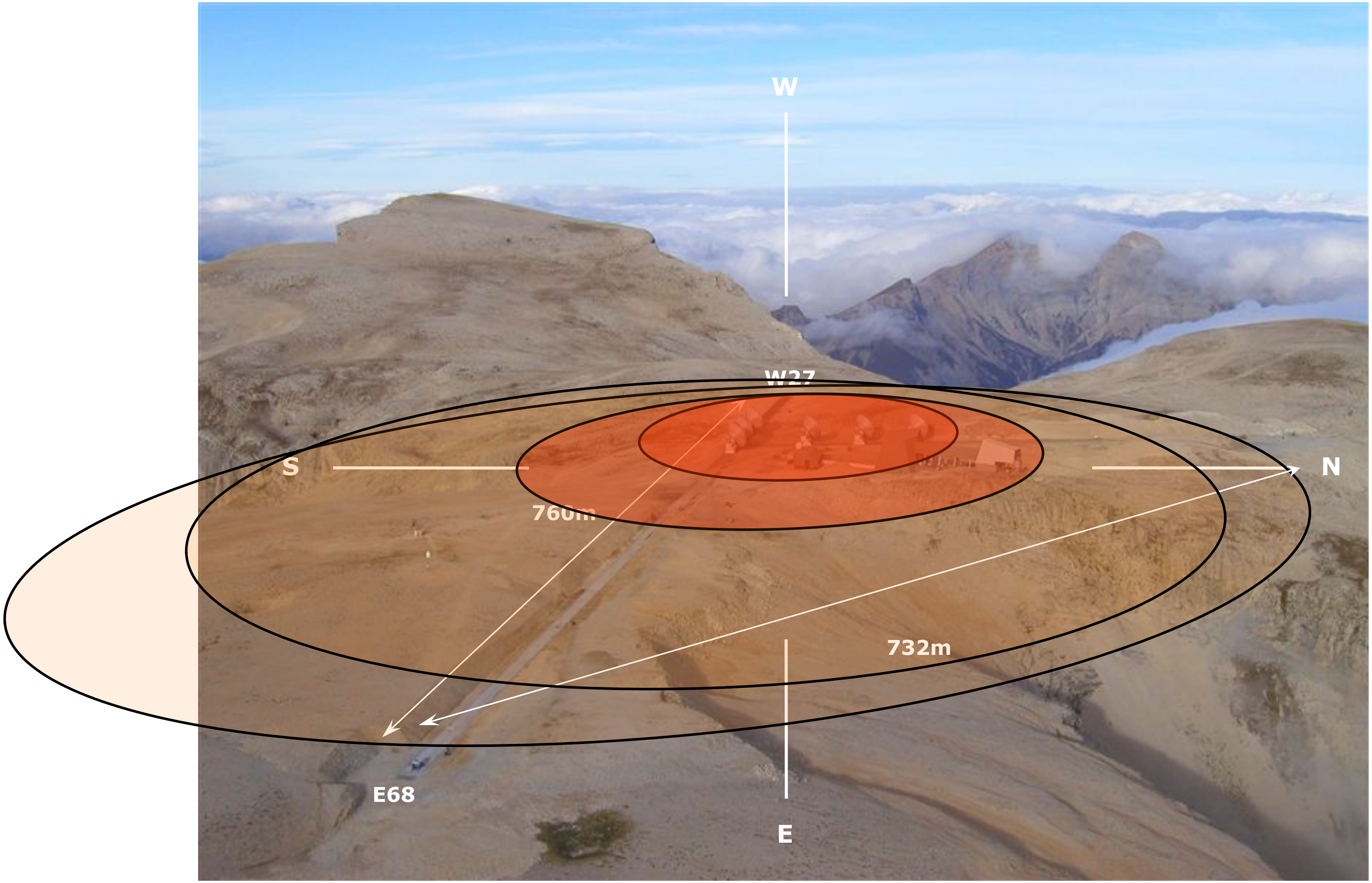
20
0
−20
20
0
−20
SKY PLANE (ARCS)
B⃗
δ=45°
B=175m
HA=−3.8h
200
0
−200
PROJECTED BASELINE (M)


20
0
−20
20
0
−20
SKY PLANE (ARCS)
200
0
−200
PROJECTED BASELINE (M)

Interferometry or Aperture Synthesis

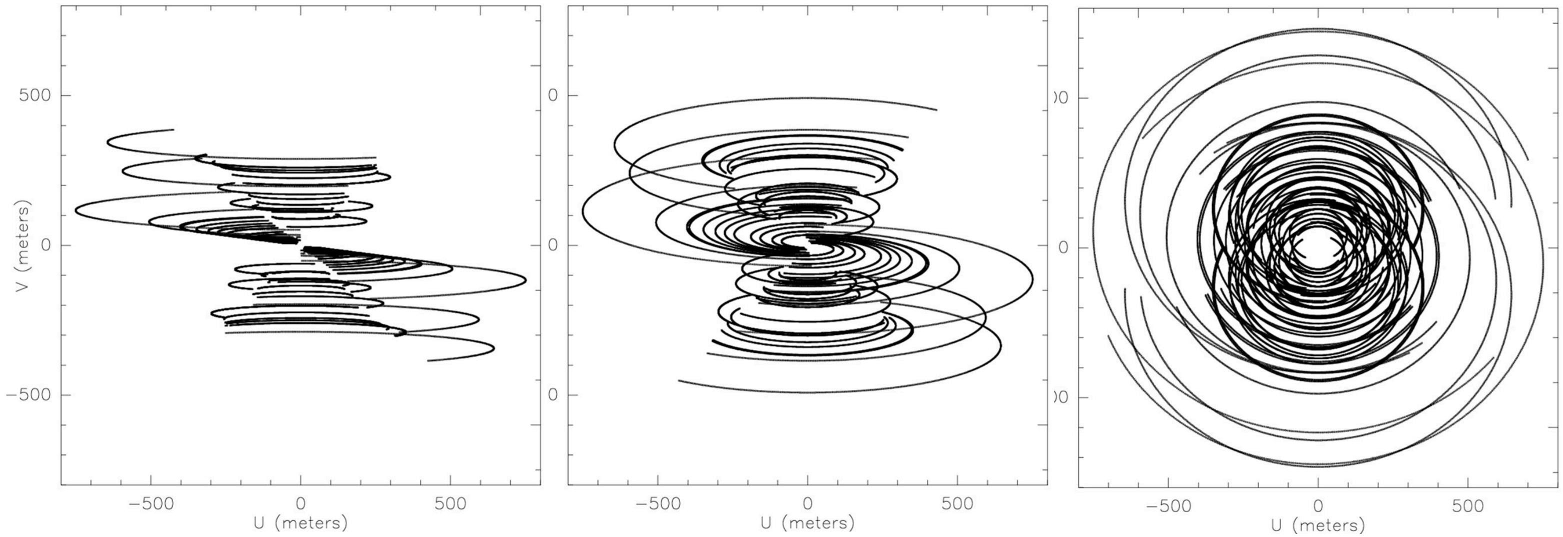
is the technique by which a large telescope is replaced by a number of smaller telescopes





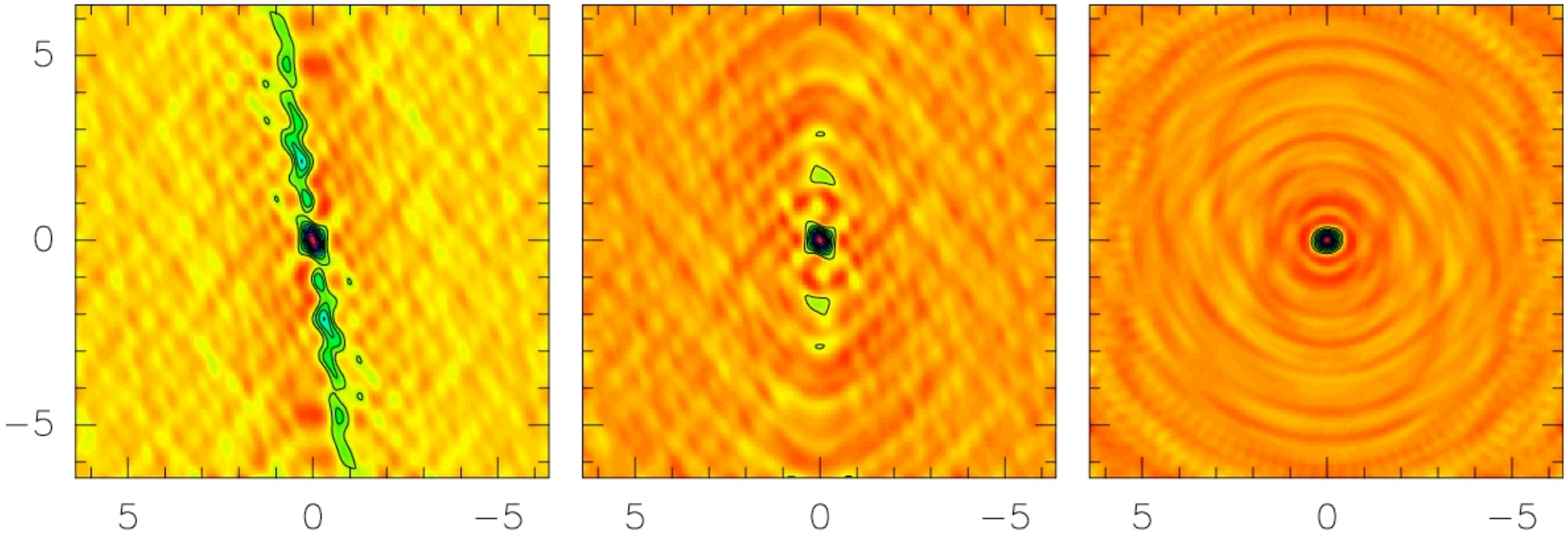
W
W27
S
N
760m
732m
E68
E

PdBI's AB configurations @ 230 GHz
Three Examples



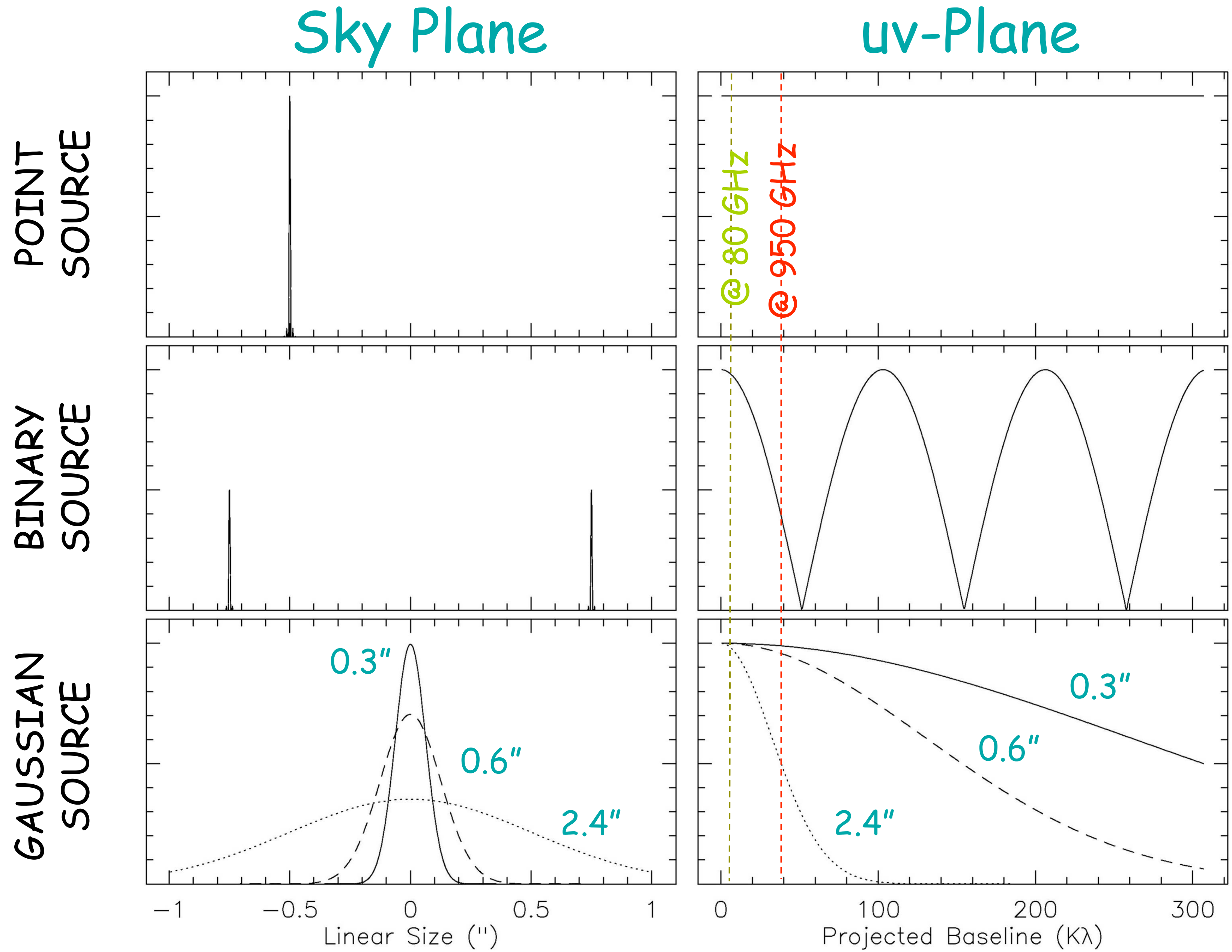
	Orion @ -5°	W51N @ 14°	S140 @ 63°
Δt	8 hrs	9 hrs	10 hrs

PdBI's AB configurations @ 230 GHz
Three Examples



	Orion @ -5°	W51N @ 14°	S140 @ 63°
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″

⇒ select the appropriate observatory!

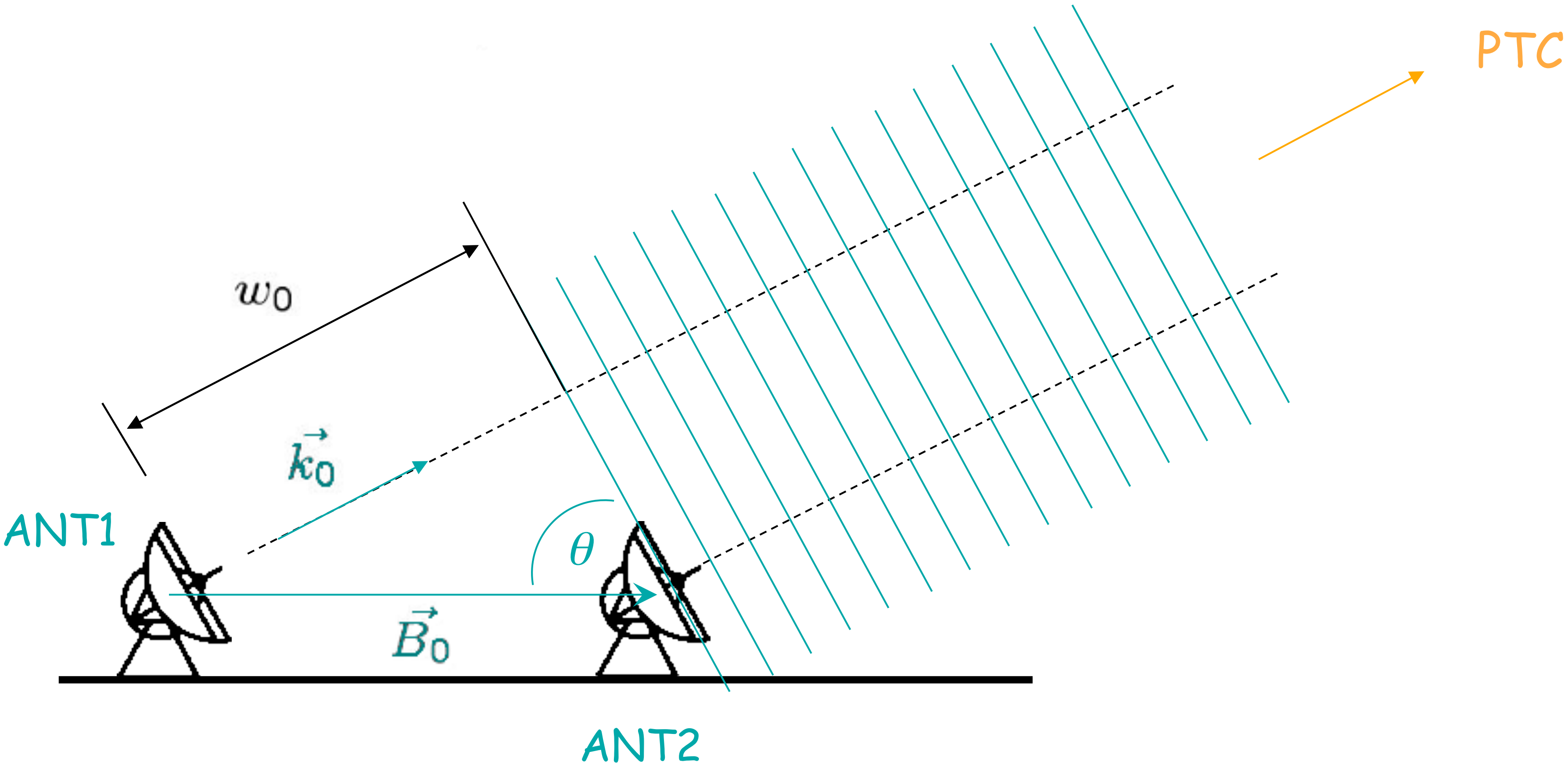


Sky Plane
uv-Plane
POINT SOURCE
BINARY SOURCE
GAUSSIAN SOURCE
@ 80 GHz
@ 950 GHz
0.3″
0.6″
2.4″
0.3″
0.6″
2.4″
−1
−0.5
0
0.5
1
Linear Size (")
0
100
200
300
Projected Baseline (Kλ)

The phase equation

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

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

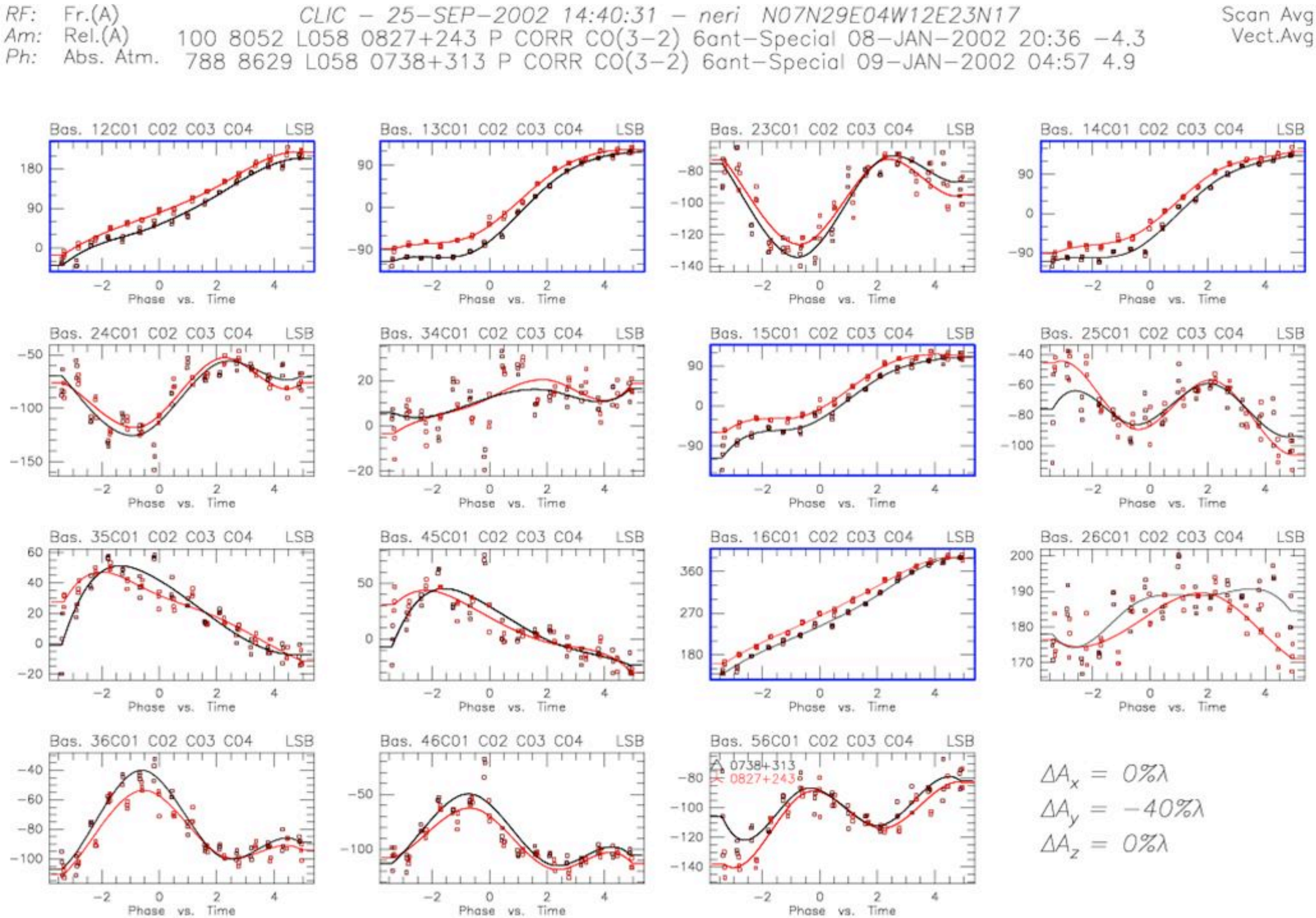


$$\rightarrow \phi_{w_0} = 2\pi\,(B_x \cos H \cos\delta - B_y \sin H \cos\delta + B_z \sin\delta)/\lambda$$

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

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.

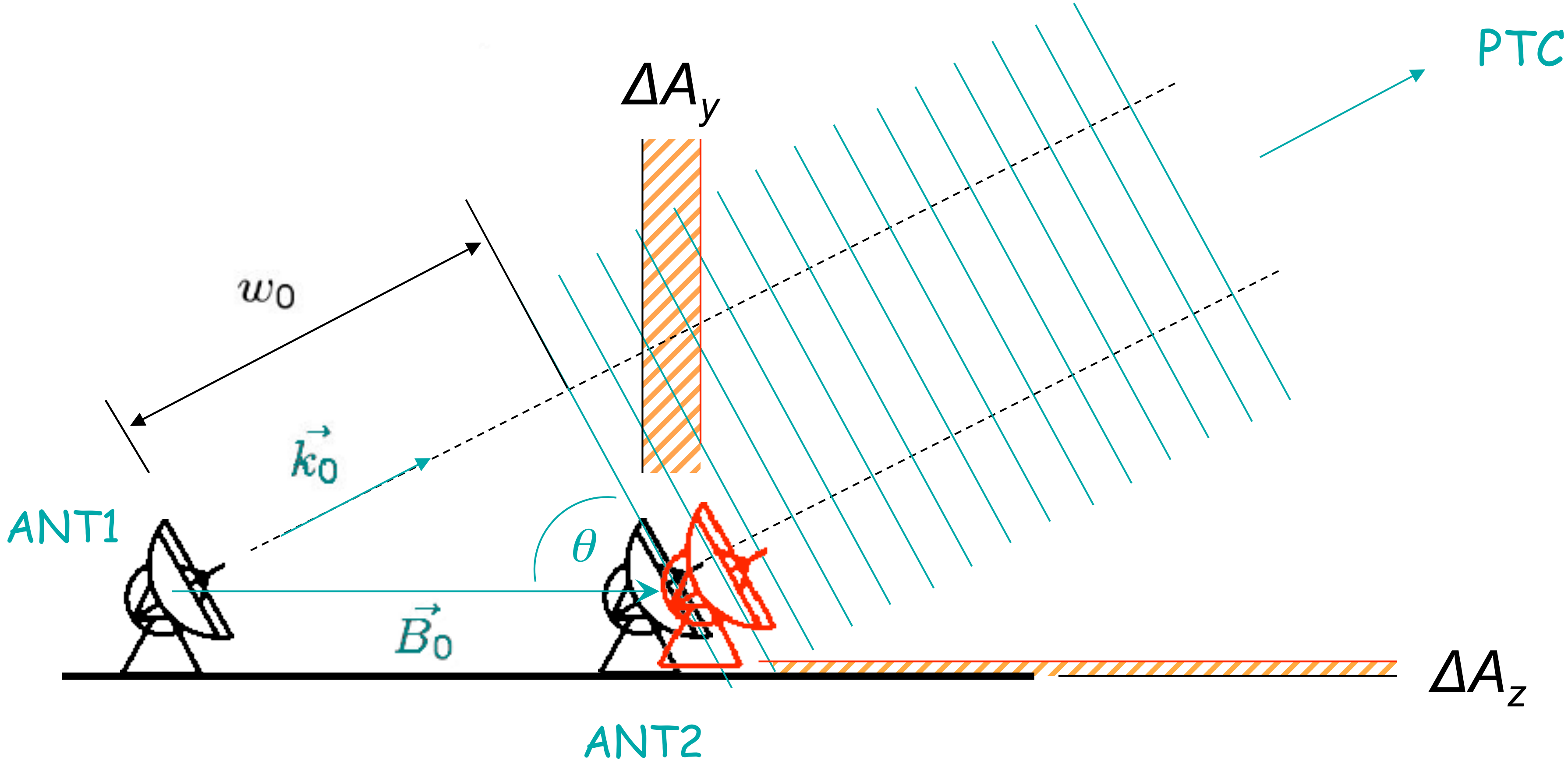


RF: Fr.(A)
Am: Rel.(A)
Ph: Abs. Atm.
CLIC – 25-SEP-2002 14:40:31 – neri N07N29E04W12E23N17
100 8052 L058 0827+243 P CORR CO(3–2) 6ant–Special 08–JAN–2002 20:36 –4.3
788 8629 L058 0738+313 P CORR CO(3–2) 6ant–Special 09–JAN–2002 04:57 4.9
Scan Avg
Vect.Avg
Bas. 12C01 C02 C03 C04 LSB
Bas. 13C01 C02 C03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

The phase equation

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

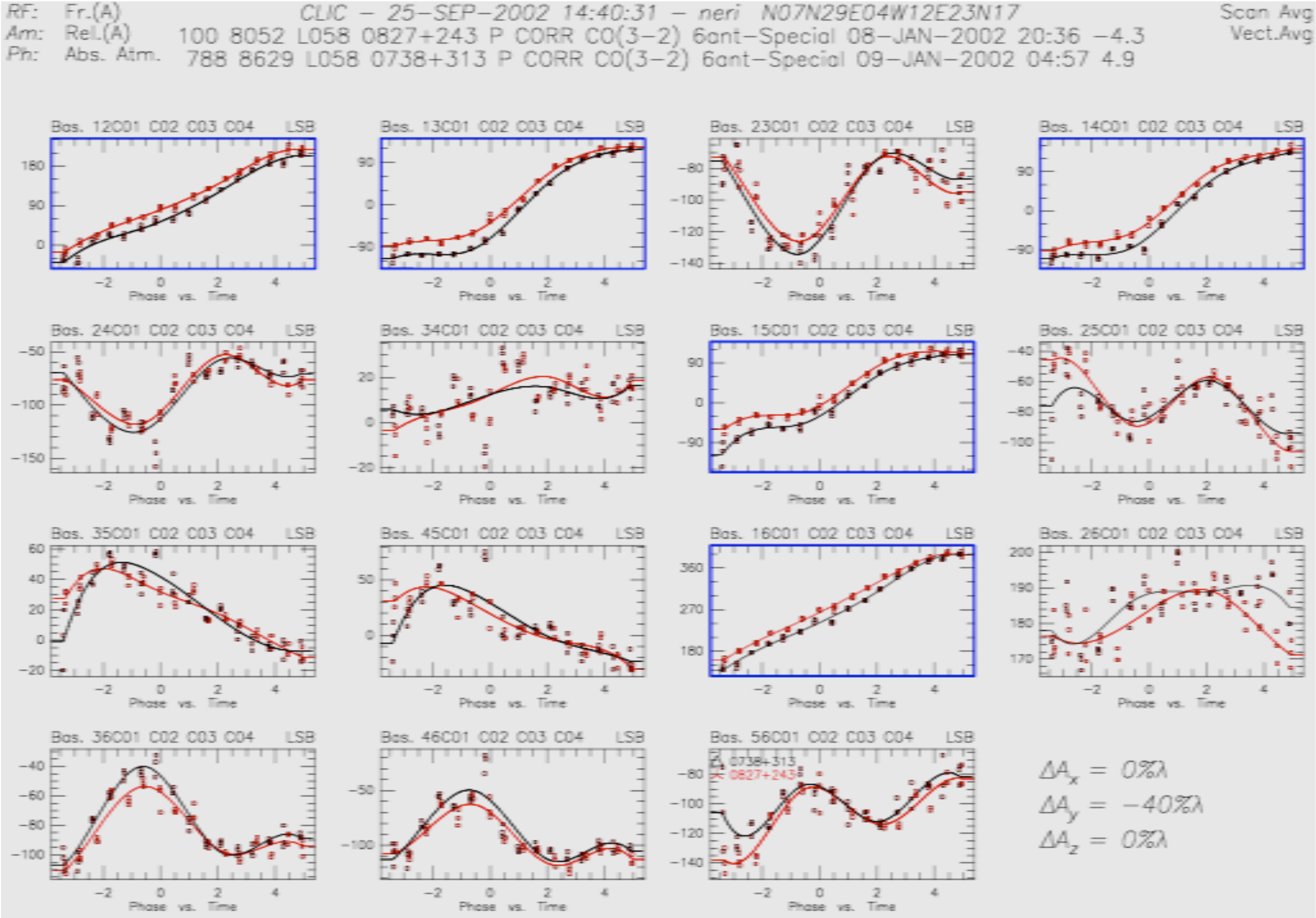
$$\phi_{w_0} = 2\pi w_0/\lambda = 2\pi B_0 \sin\theta/\lambda$$



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

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.

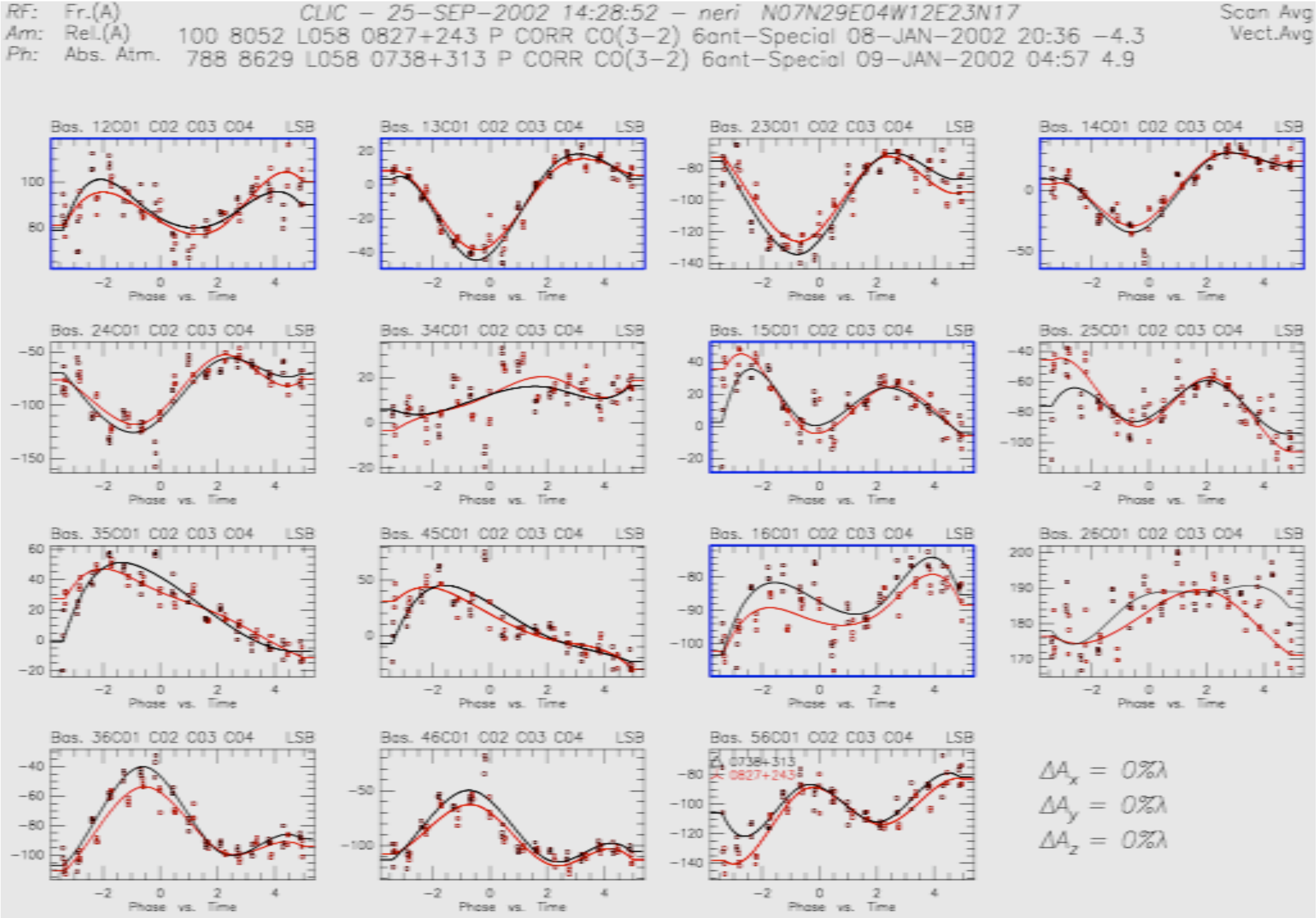


RF: Fr.(A)
Am: Rel.(A)
Ph: Abs. Atm.
CLIC - 25-SEP-2002 14:40:31 - neri N07N29E04W12E23N17
100 8052 L058 0827+243 P CORR CO(3-2) 6ant-Special 08-JAN-2002 20:36 -4.3
788 8629 L058 0738+313 P CORR CO(3-2) 6ant-Special 09-JAN-2002 04:57 4.9
Scan Avg
Vect.Avg
Bas. 12C01 C02 C03 C04 LSB
Bas. 13C01 C02 C03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

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

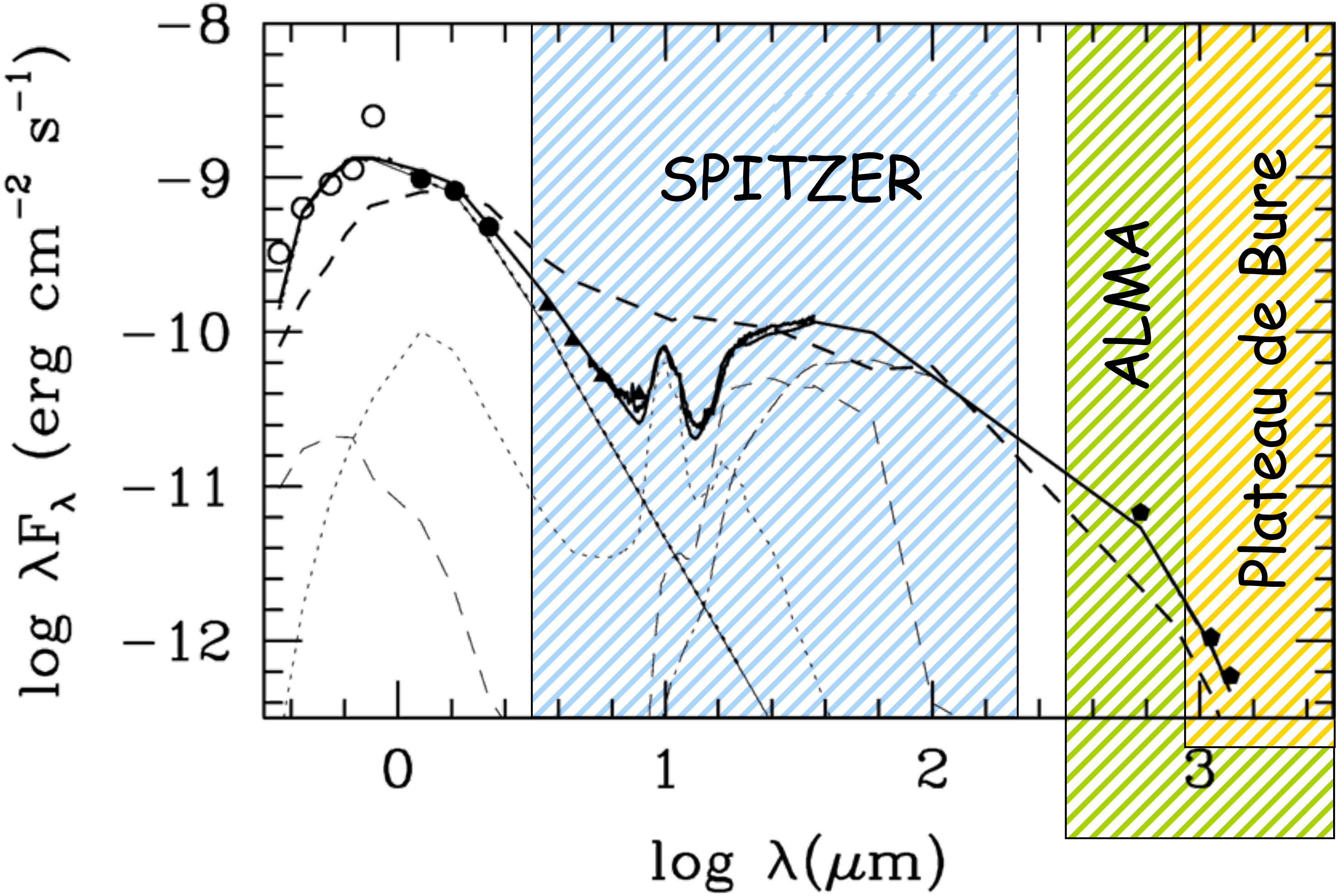
OBJECT	$\Delta\theta$	Calibration
Source Intensity	$\leq 10^{-1}\,\theta_B$	No
Calibrator Position	$\leq 0.02''$	No
MISCELLANEOUS		
Bandwidth smearing	$\leq 0.08''$	No
Visibility averaging	$\leq 0.06''$	No
Gravitational lensing	$\leq 0.02''$	No
Primary beam correction	$\leq 0.02''$	No

Interferometer Basics

All you need as an observer:

- the appropriate interferometer
- one or more configuration(s)
- the noise equation

GM Aur (Hughes et al. 2009)

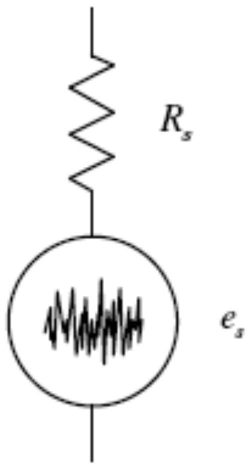


⇨ mm-astronomy calls for sensitivity

Noise Power

The output power of a …

… Resistor :



$$P_N = kT\Delta\nu$$

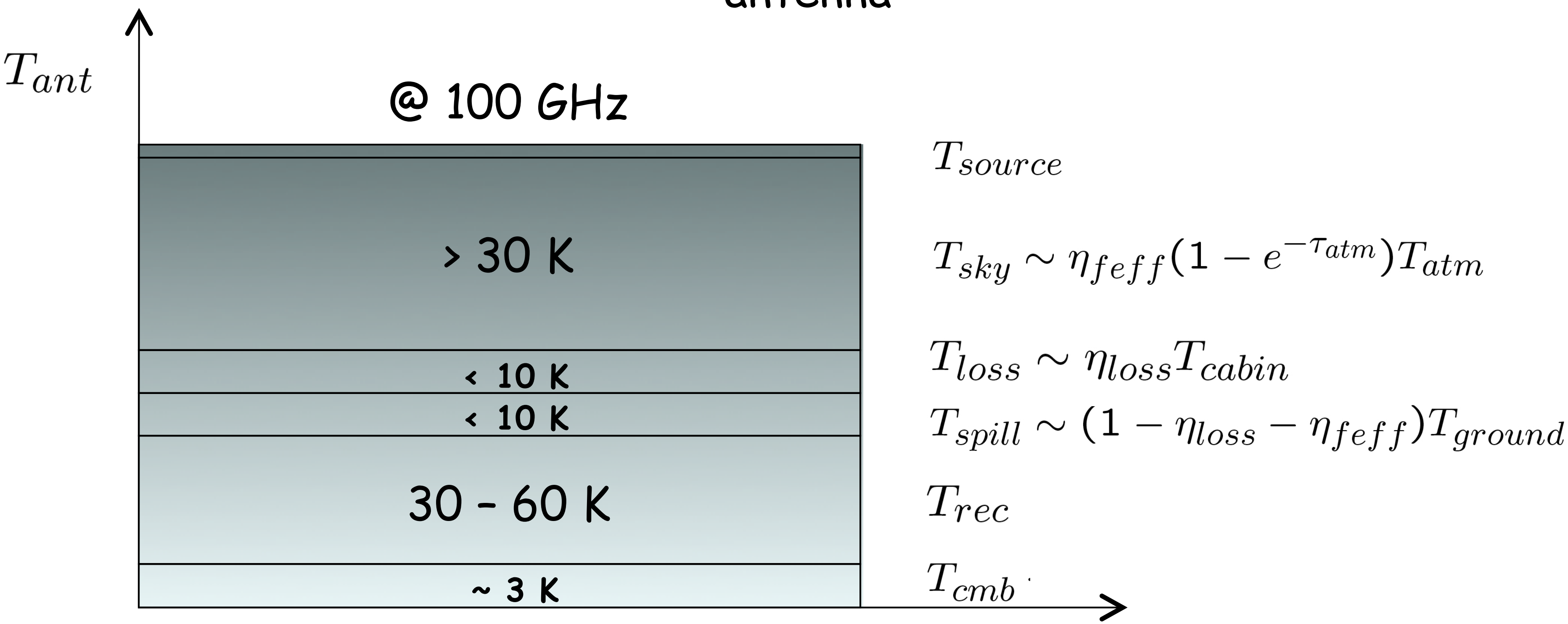
… Receiving System :

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

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.

The Noise Equations

Sensitivity of a single-dish antenna:

$$\sigma_S = \frac{2k}{\eta_A A} \frac{T_{\mathrm{SYS}}}{\sqrt{\Delta\nu \Delta t}}$$

Sensitivity on a single baseline:

$$\sigma_S = \frac{2k}{\eta_A A} \frac{T_{\mathrm{SYS}}}{\sqrt{2\Delta\nu \Delta t}}$$

$\sqrt{2}$ better than a single antenna in total power

$\sqrt{2}$ worse than a single antenna with the same collecting area

Single-Dish limitations:

2. sensitivity : $\sim 1/D^2$

Need to

1. increase collecting area
2. increase the pointing accuracy
3. keep a high surface quality

Single-Dish	Collecting area
CSO 10m	80 m2
IRAM 30m	710 m2
LMT 50m	1960 m2
SRT 64m	3200 m2

Telescope	Collecting area
SMA	150 m2
IRAM Array	1060 m2
LMT	1960 m2
NOEMA	2100 m2
ALMA 50	5700 m2

The Interferometer Noise Equation

The reality is often a bit more complex ...

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

Single Dish Efficiency (Jy/K)

ATMOSPHERE (SITE)

Seeing

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

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

Antenna

Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE

Interferometric Efficiency (Jy/K)

ATMOSPHERE (SITE)

Seeing

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

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

Antenna

Local Oscillators

Correlator

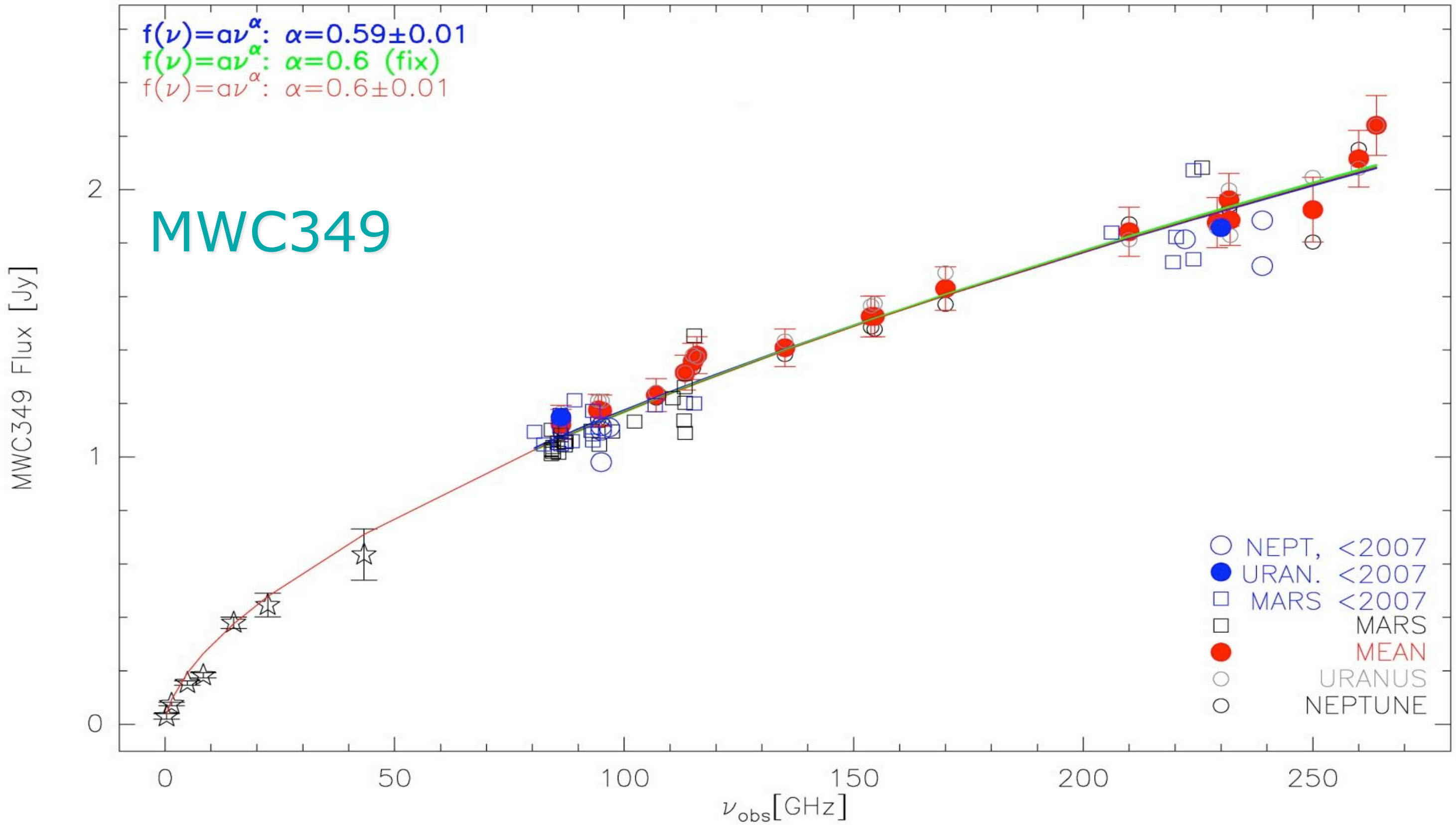
INSTRUMENTAL PERFORMANCE

Interferometric efficiencies for the PdBI

$\rightarrow 22 \times \sigma_T$	[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 $\leq 20\%$

Calibration precision is limited by knowledge on reference calibrators (planets, source polarization, variability, etc.), instrumental drifts, atmospheric variability, etc.

Best calibrator available in the Northern Sky



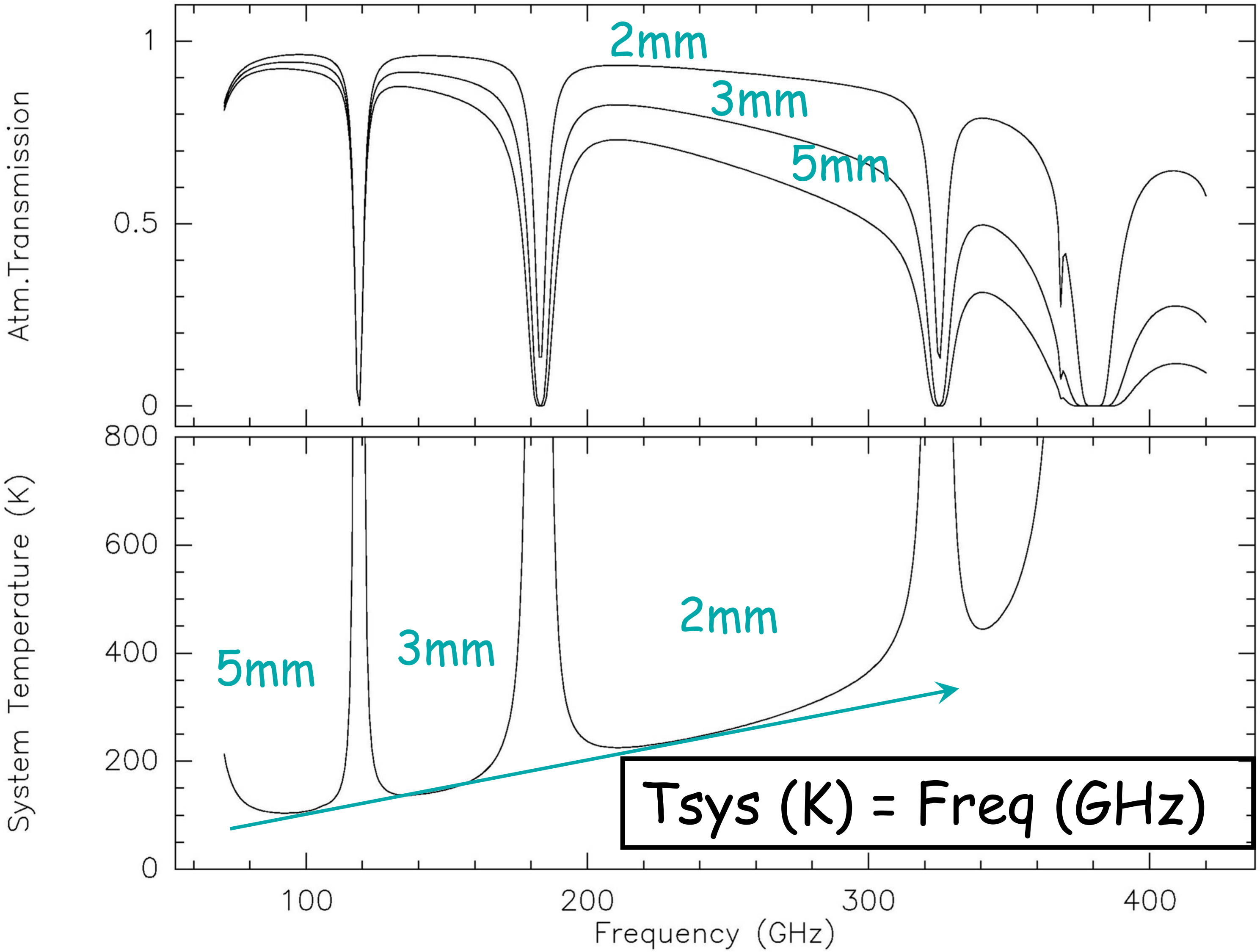
Calibration Precision ~ 5%!

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)

Pardo et al. 2007



Point Source Sensitivity

One baseline, two antennas:

$$\sigma_S \simeq \frac{2k}{\eta_a A} \times \frac{< T_{\mathrm{SYS}} >}{\sqrt{2 \Delta\nu \Delta t}} \times \frac{1}{\sqrt{N_P}}$$

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

The PdBI array:

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

Extended Source Sensitivity

Brightness noise equation:

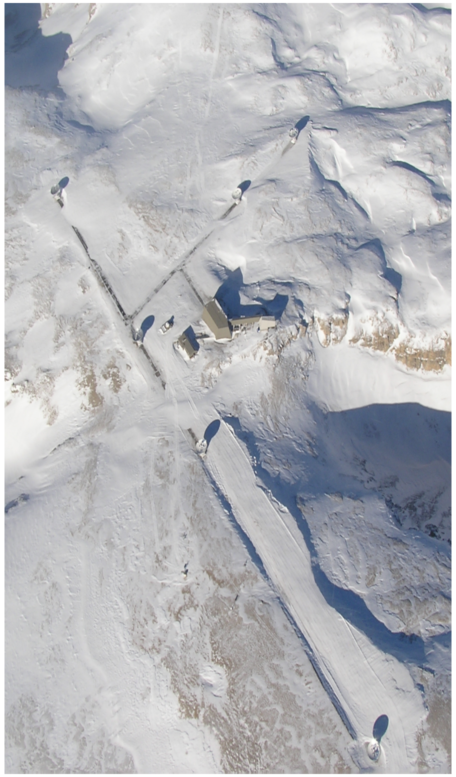
$$\sigma_{T_b} = (\frac{\theta_p}{\theta_s})^2 \frac{T_{\mathrm{SYS}}}{\eta\sqrt{N(N-1)\Delta\nu\Delta t}} \qquad \eta = 0.5$$

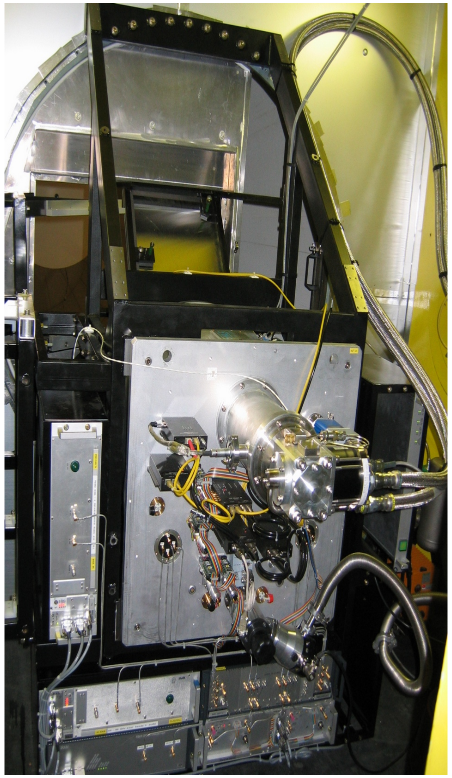
Uses the flux density to brightness conversion factor

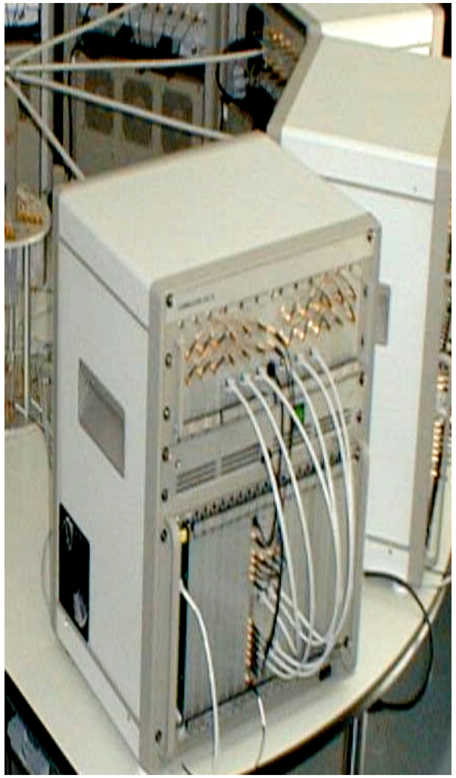
Only for sources just filling the synthesized beam i.e. the sensitivity estimate is based on the 'beam dilution' approximation

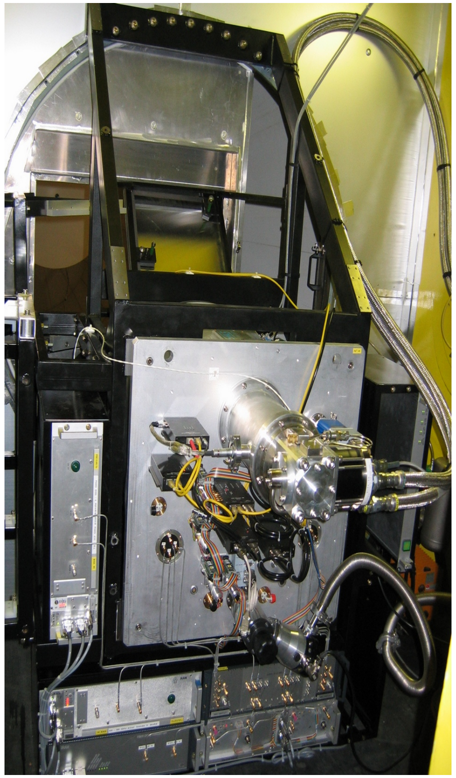
Cannot be extrapolated easily to more extended targets e.g. missing flux problem

PdBI : recent and future milestones









Track Extensions
W05/06

New 3mm and 1mm
bands W06/07

2mm band W07/08

WideX 2 x 4 GHz
W09/10

0.8mm band
W10/11

NOEMA 2011 > 2016

- is well-matched to science interests and pressure
- French ALMA time = <6%, <1% for the 3-1mm windows
- need to complement ALMA @ 3-1mm ⇒ within a sensitivity of 2-3
- doubles ALMA time for the IRAM community
- covers the northern sky (1/3 of the full sky)
- ensures expertise within IRAM partner organizations