



Large-field imaging

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Large-field imaging

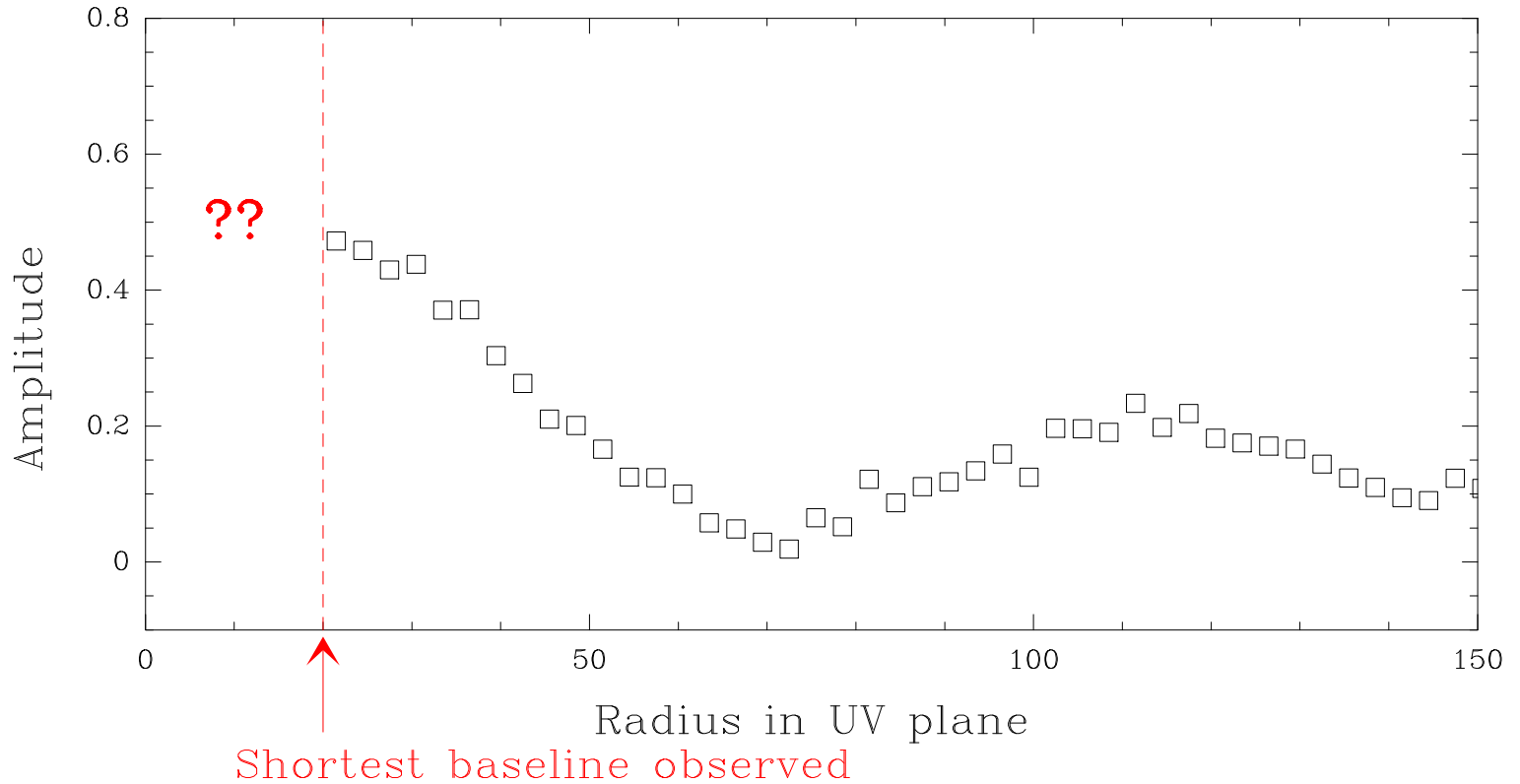
The problems

- The largest structures are filtered out due to the lack of the short spacings
Solution: add the **short spacing** information
- The field of view is limited by the antenna primary beam width
Solution: observe a **mosaic** = several adjacent overlapping fields
- Deconvolution algorithms are not very good at recovering small- *and* large-scale structures
Solution: try Multi-Scale CLEAN, Multi-Resolution CLEAN, ...
- Non-coplanar baselines
Solution: use appropriate algorithm if necessary



Short Spacings

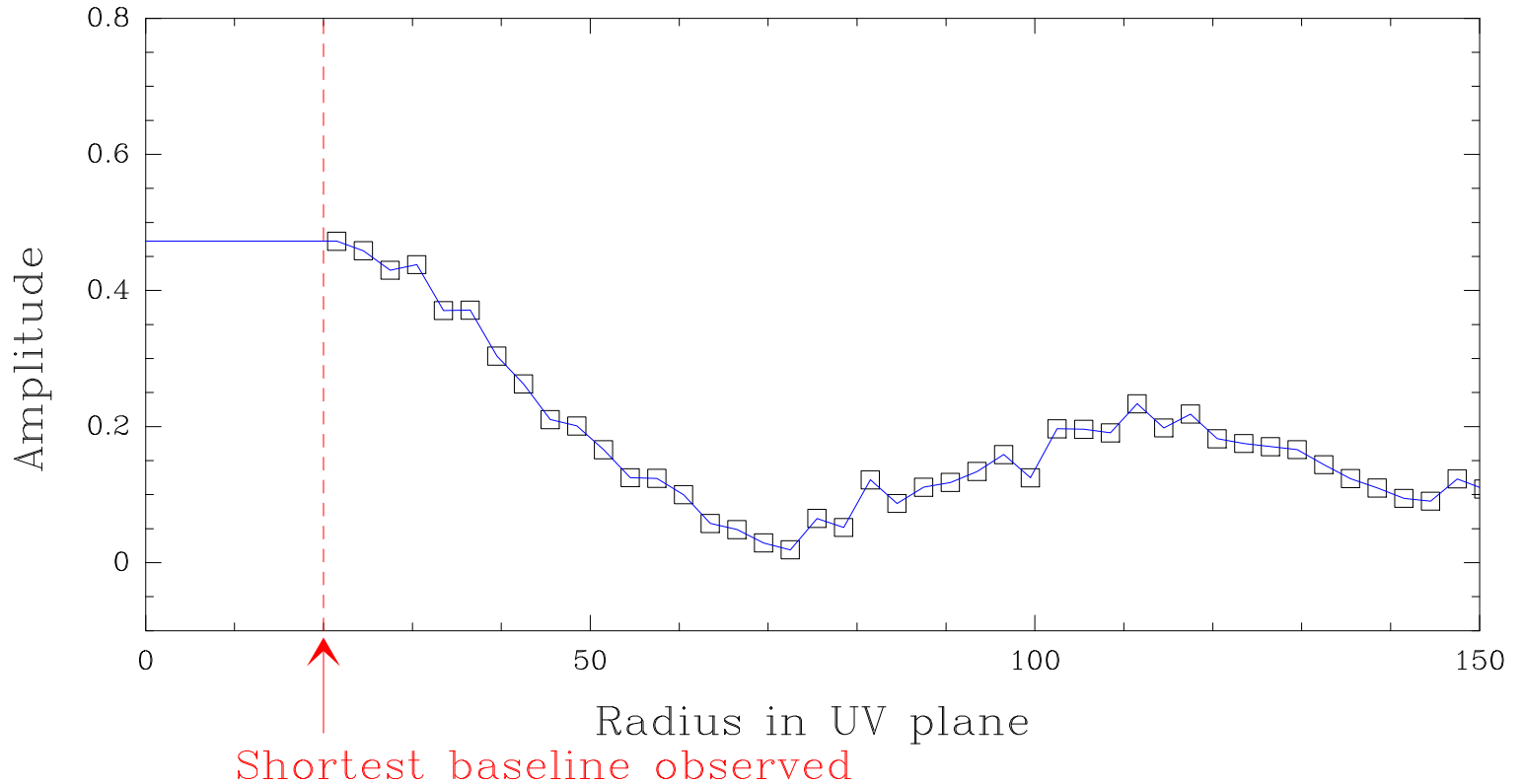
Lack of the short spacings





Short Spacings

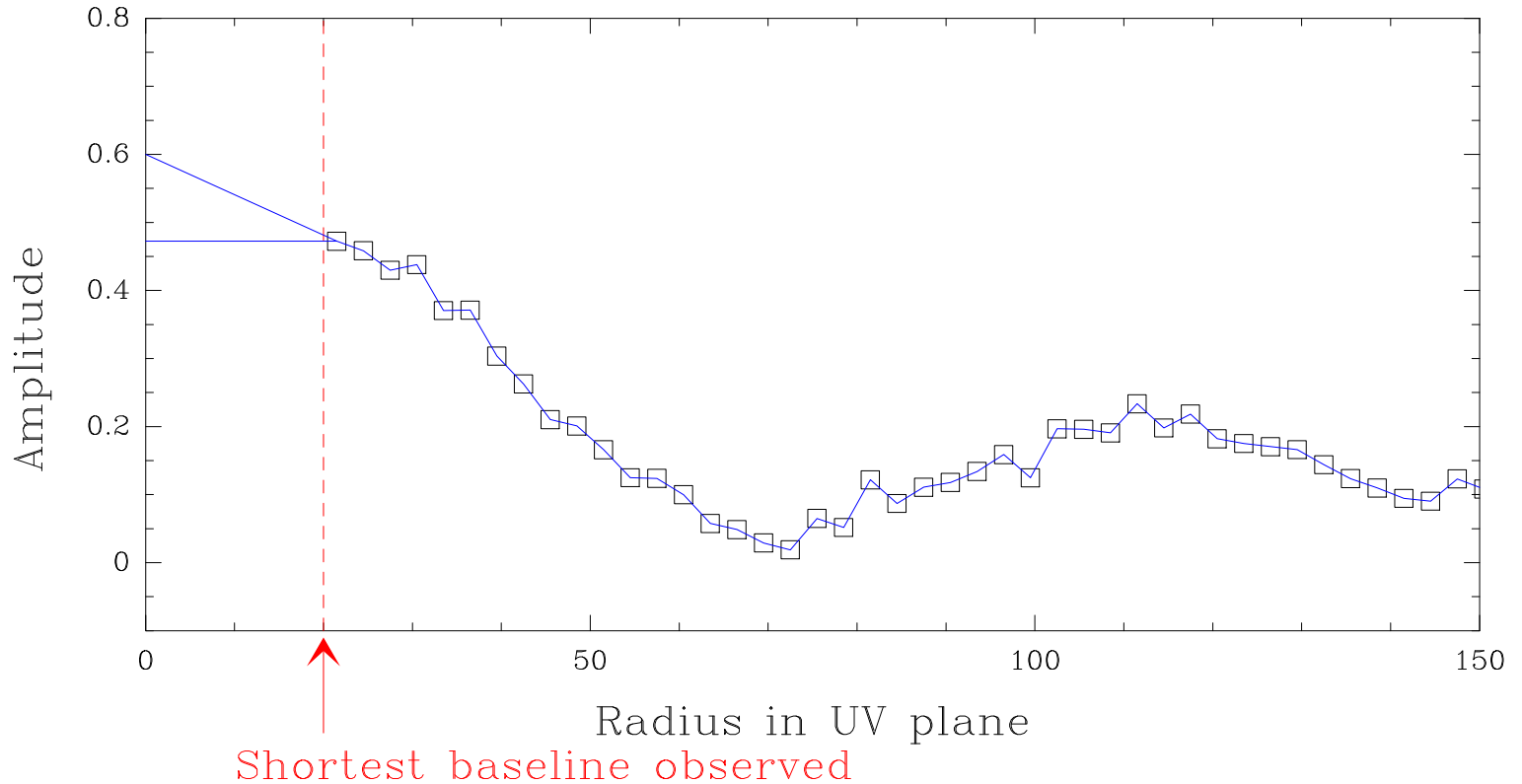
Lack of the short spacings





Short Spacings

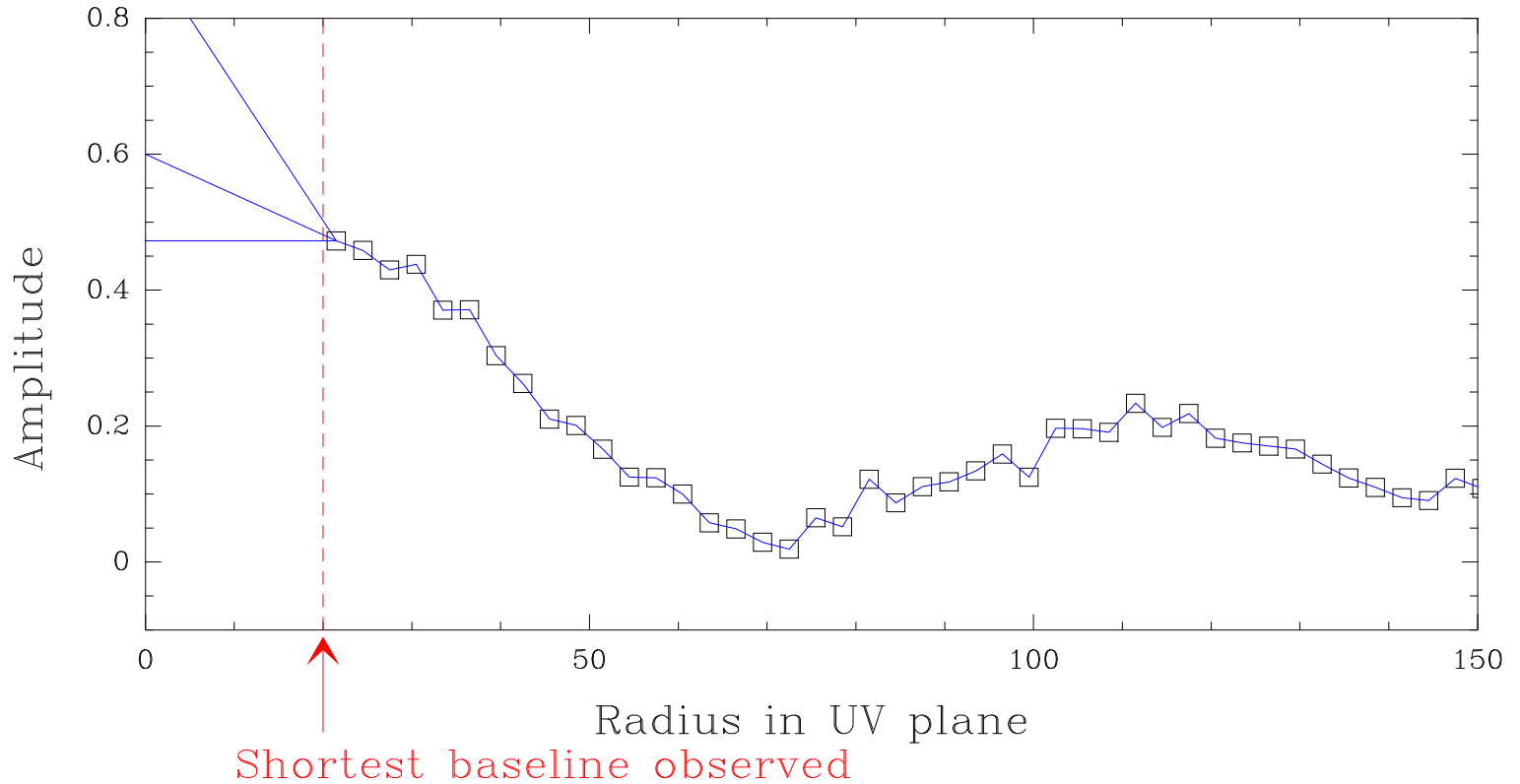
Lack of the short spacings





Short Spacings

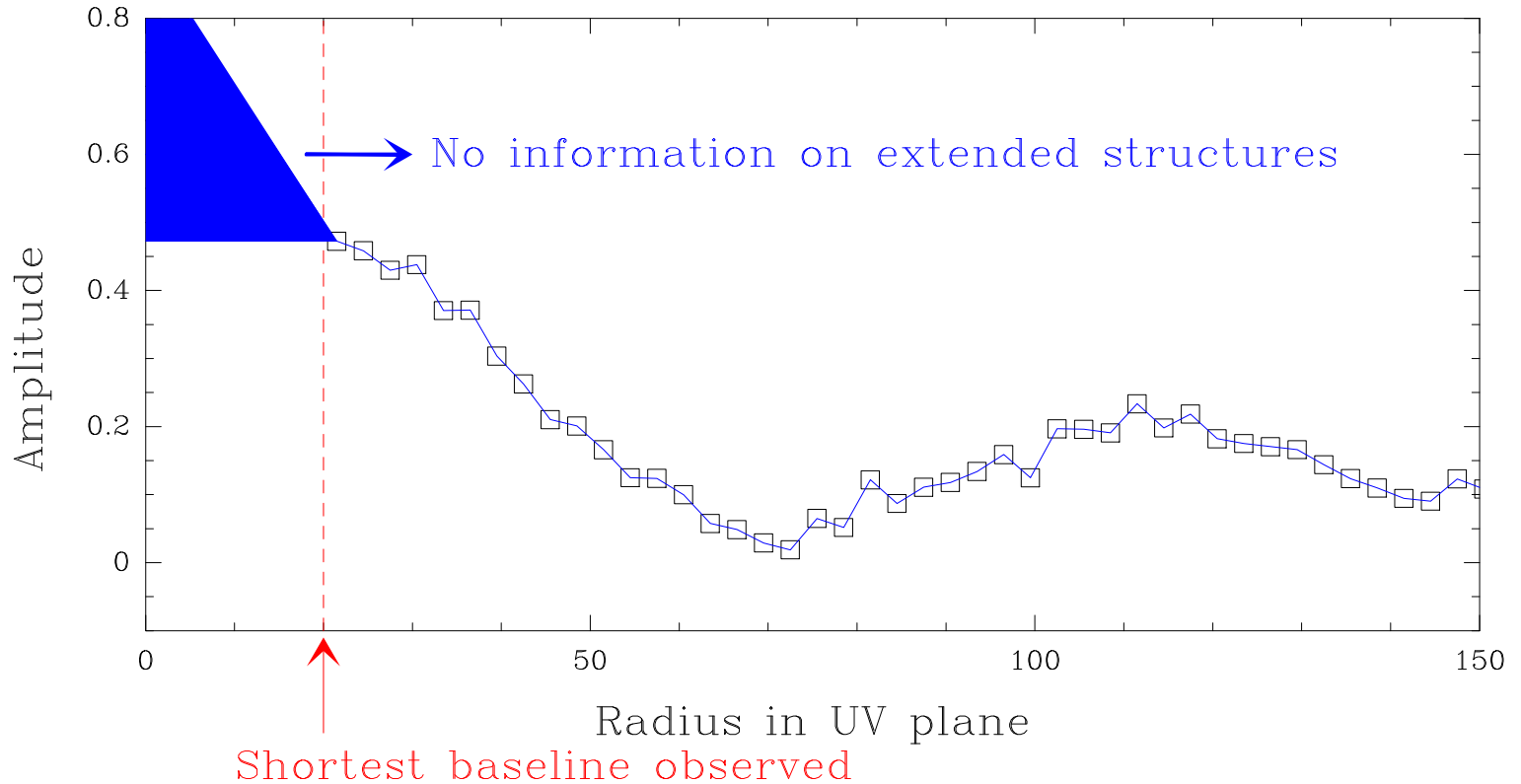
Lack of the short spacings





Short Spacings

Lack of the short spacings





Short Spacings

The problem

Missing short spacings :

- Shortest baseline $B_{\min} = 24$ m at Plateau de Bure
- Projection effects can reduce the minimal baseline – but baselines smaller than antenna diameter D can never be measured
- In any case: **lack of the short spacings information**

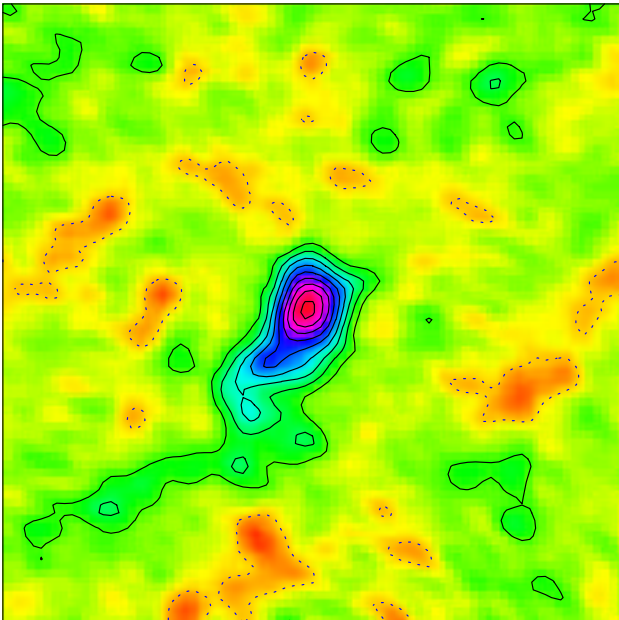
Consequence :

- **The most extended structures are filtered out**
- The largest structures that can be mapped are $\sim 2/3$ of the primary beam (field of view)
- Structures larger than $\sim 1/3$ of the primary beam may already be affected

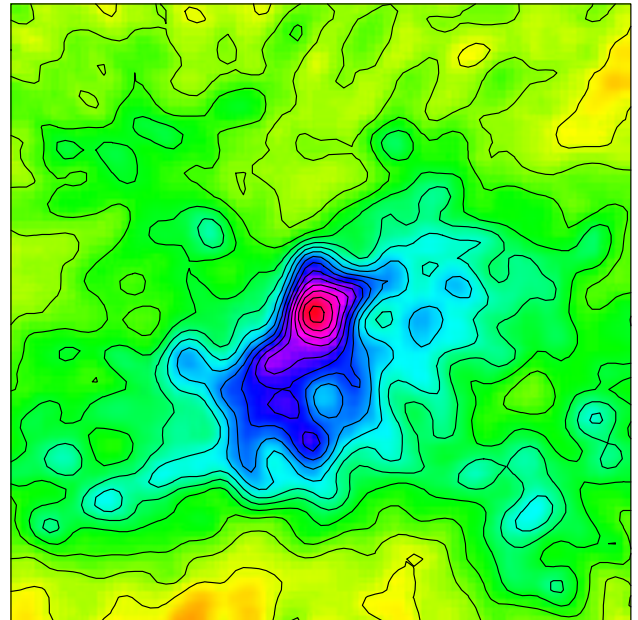


Short Spacings Example

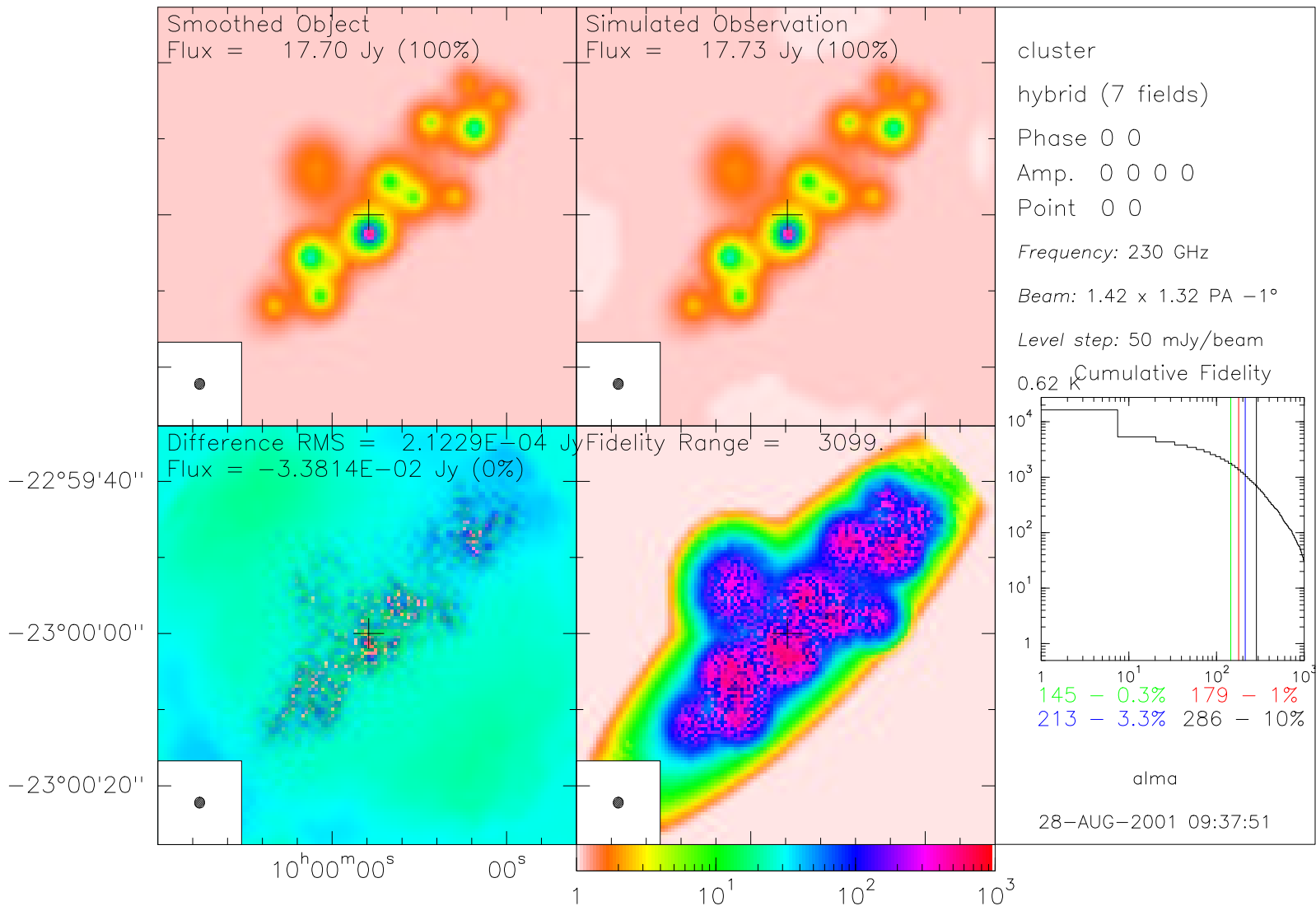
Without short spacings



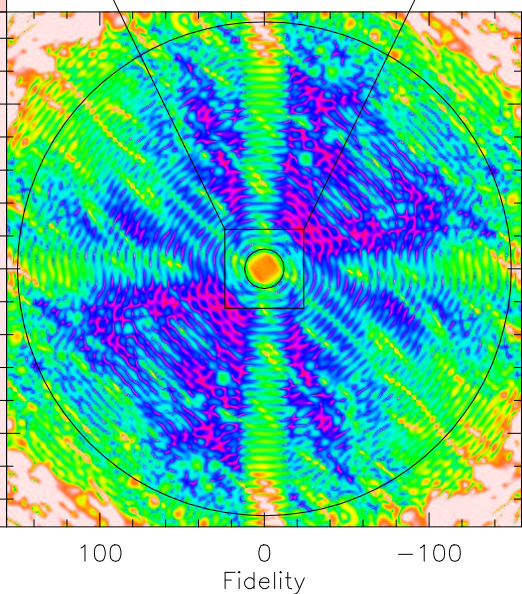
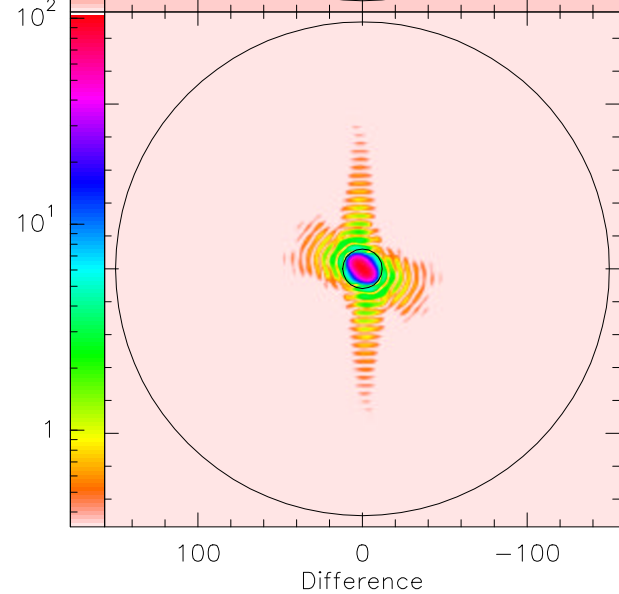
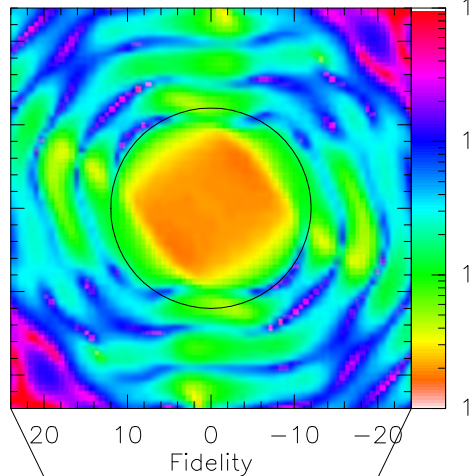
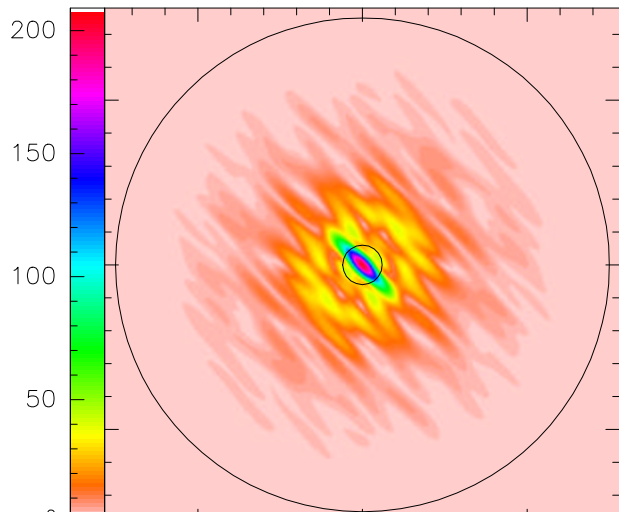
With short spacings



^{13}CO (1-0) in the L 1157 protostar (Gueth et al. 1997)



Model



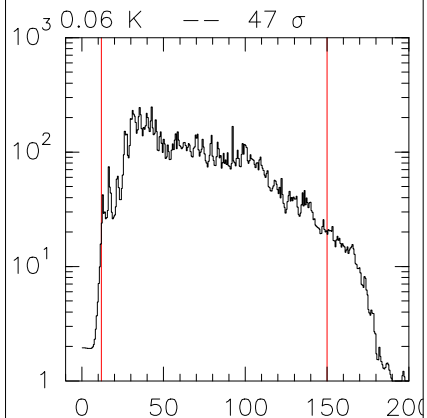
cluster
alma-only (7 fields)

Phase 0 0
Amp. 0 0 0 0
Point 0 0

Frequency: 230 GHz

Beam: 1.42 x 1.35 PA -1°

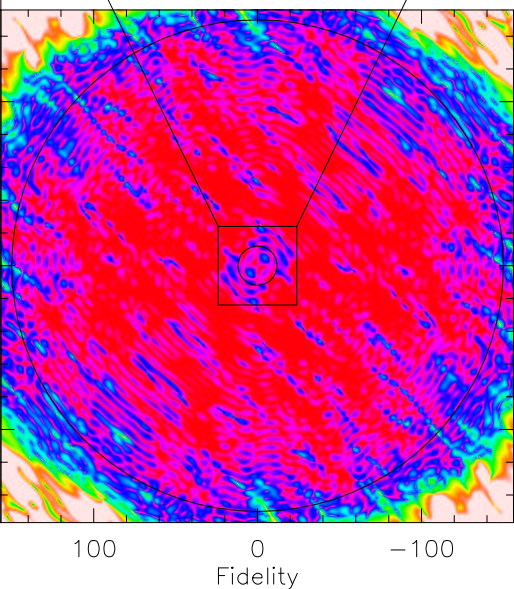
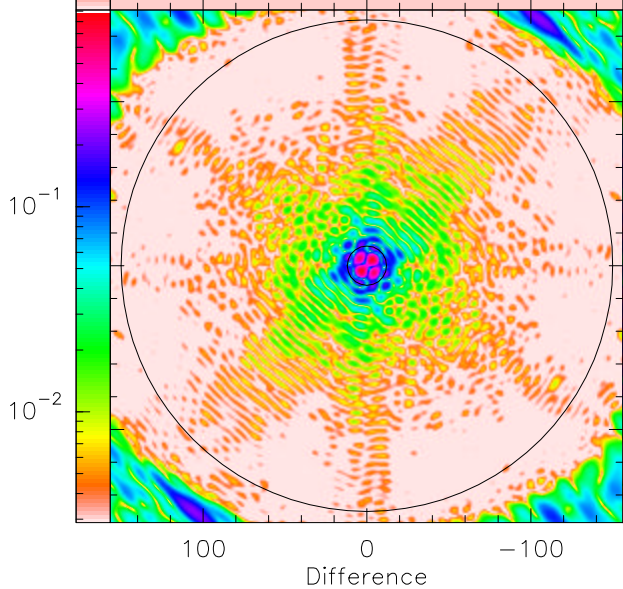
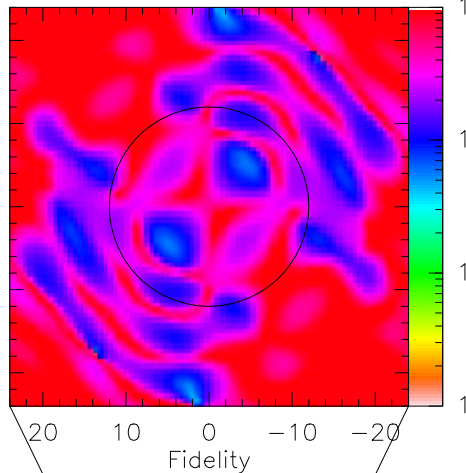
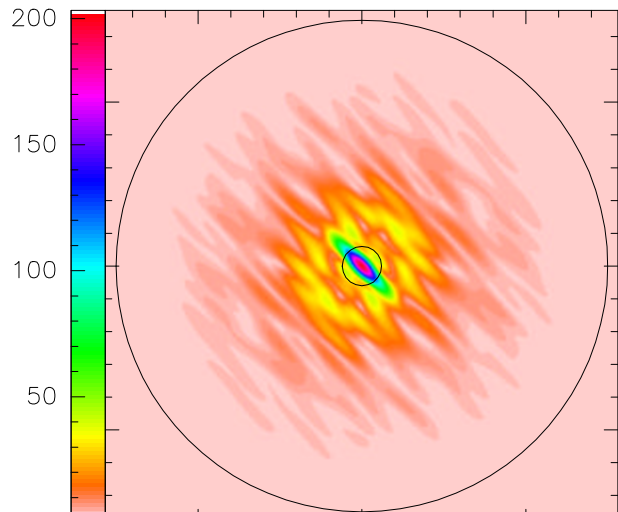
Level step: 5 mJy/beam



alma

28-AUG-2001 09:37:46

Model



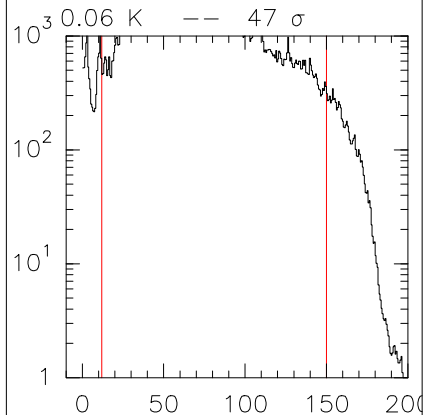
cluster
hybrid (7 fields)

Phase 0 0
Amp. 0 0 0 0
Point 0 0

Frequency: 230 GHz

Beam: 1.42 x 1.32 PA -1°

Level step: 5 mJy/beam



alma

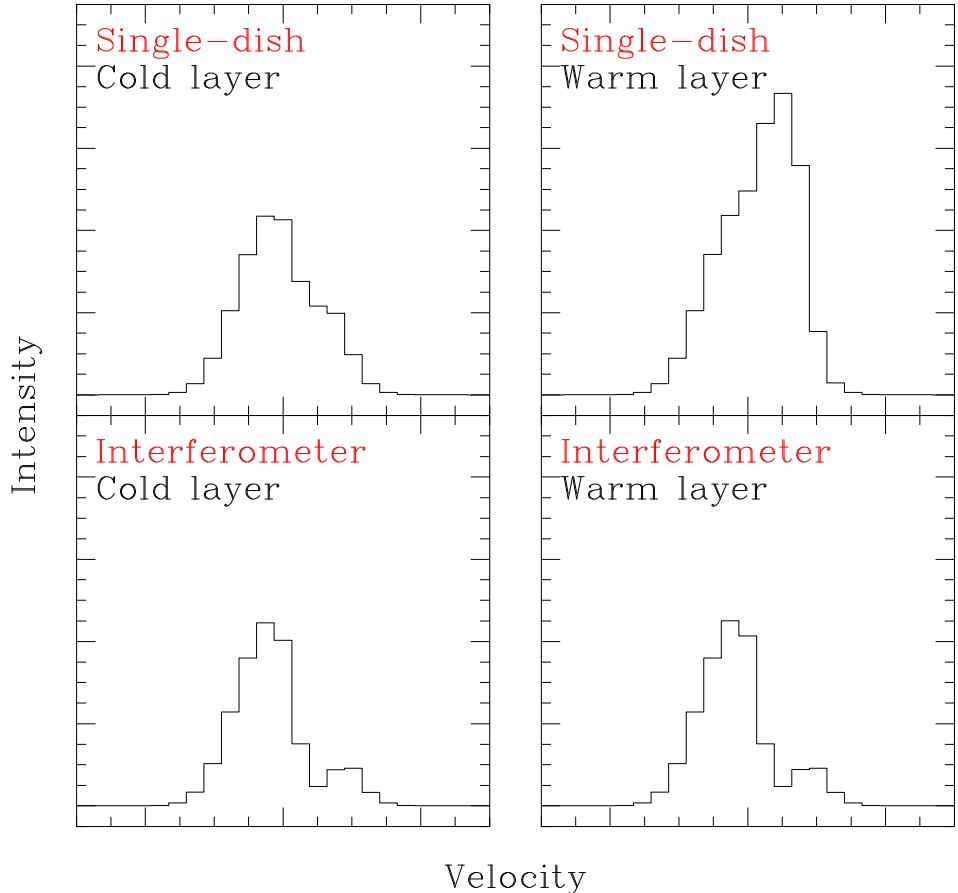
28-AUG-2001 09:37:52



Short Spacings Simulations

Simulations of small source
+ extended cold/warm
layer

Lack of short spacings can
introduce complex arti-
facts **leading to wrong
scientific interpreta-
tion**

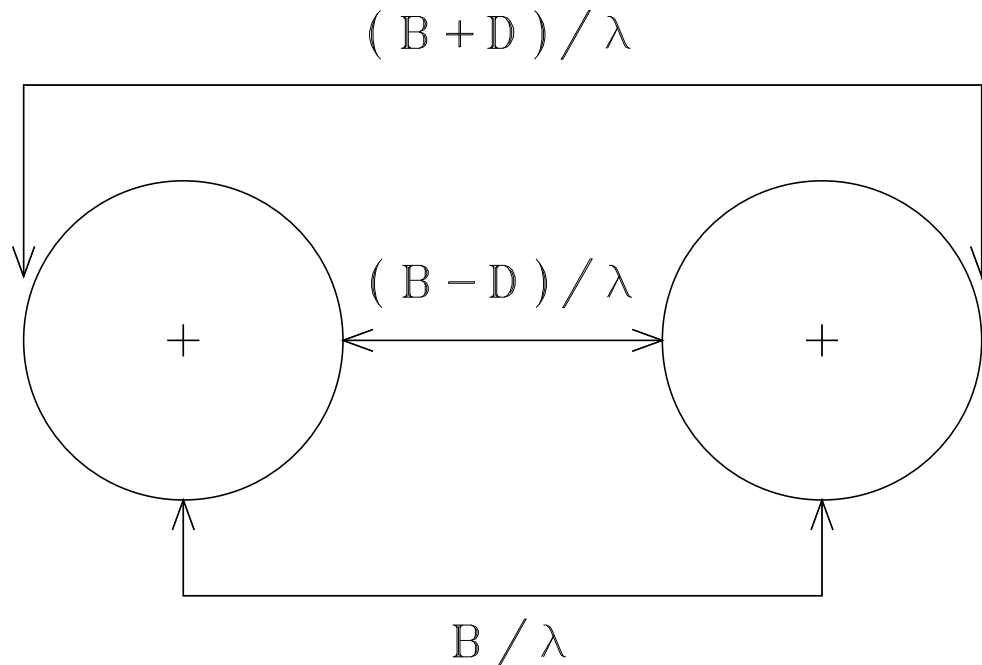




Short Spacings

Spatial frequencies

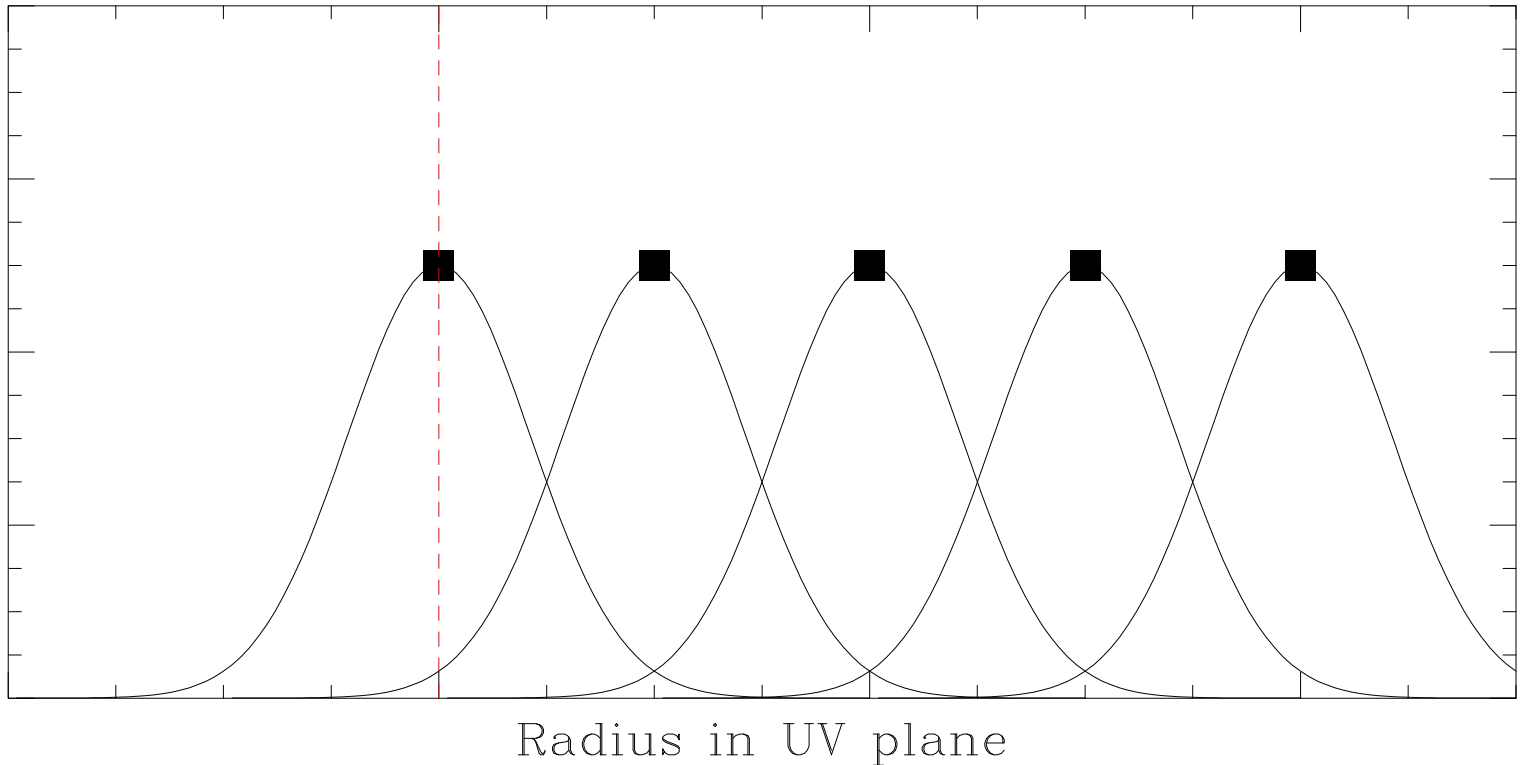
- A single-dish of diameter D is sensitive to spatial frequencies from **0 to D**
- An interferometer baseline B is sensitive to spatial frequencies from **$B - D$ to $B + D$**





Short Spacings Measurements

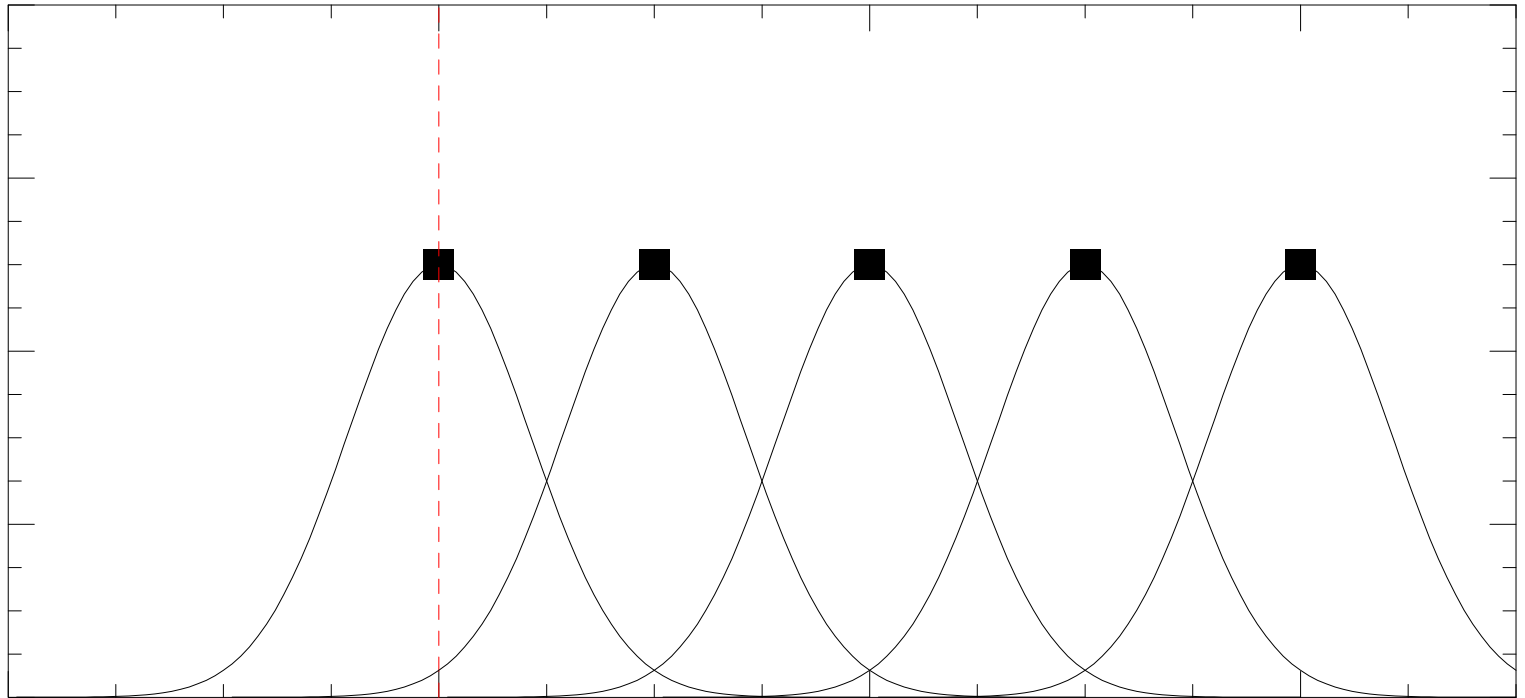
An interferometer measures the **convolution** of the “true” visibility with the **antenna transfer function**





Short Spacings Measurements

No short-spacings

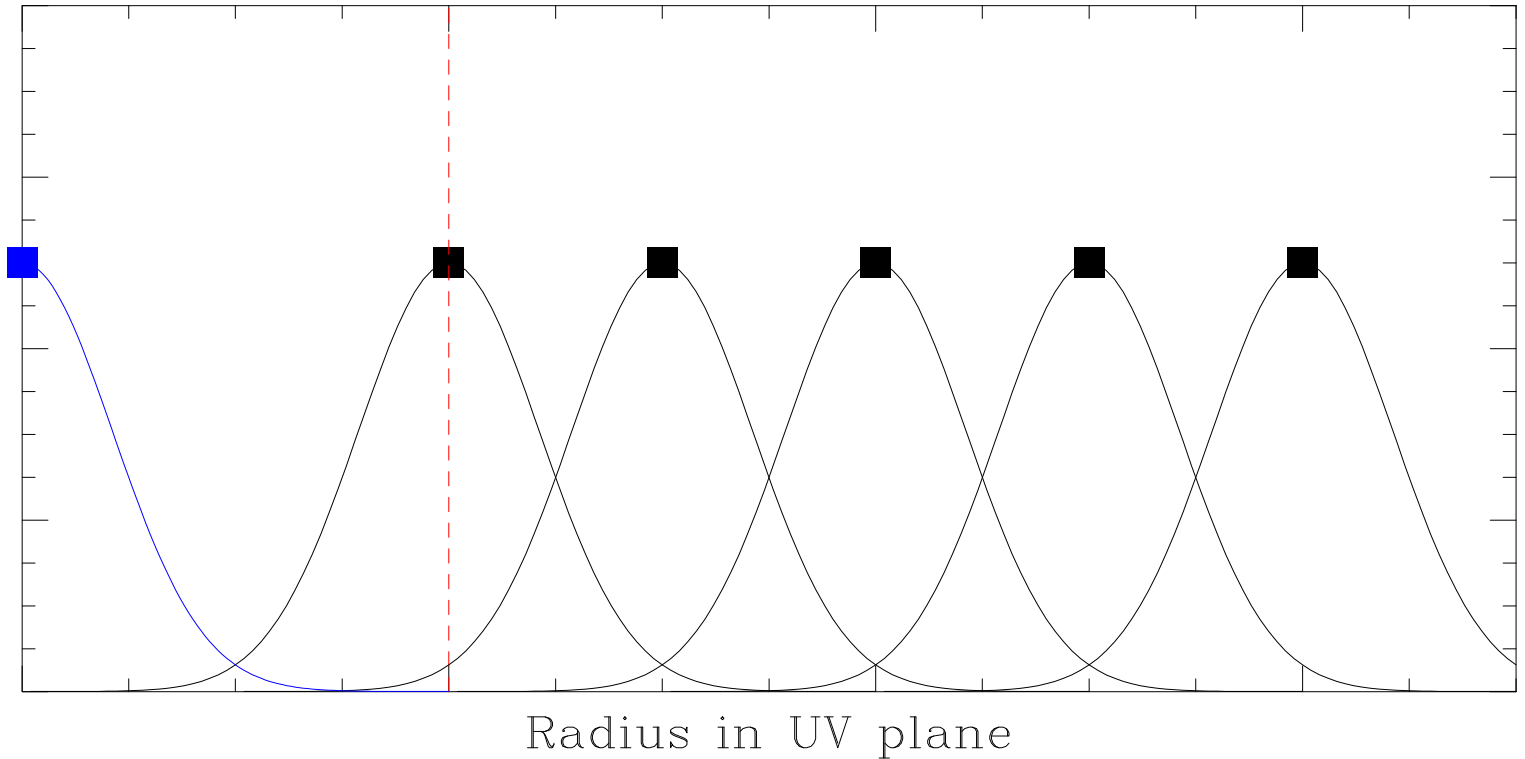


Radius in UV plane



Short Spacings Measurements

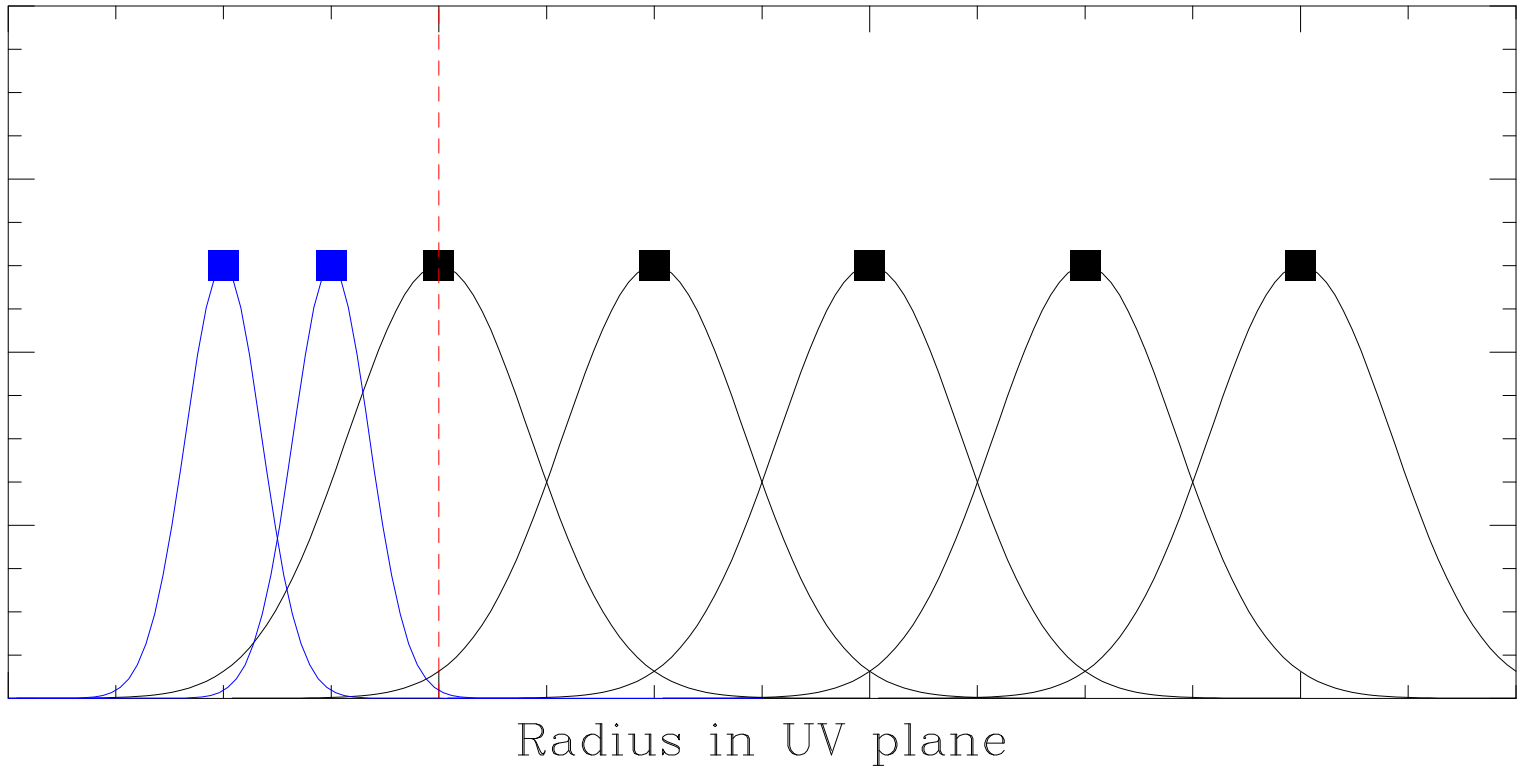
Single-dish measurement (same antenna diameter)





Short Spacings Measurements

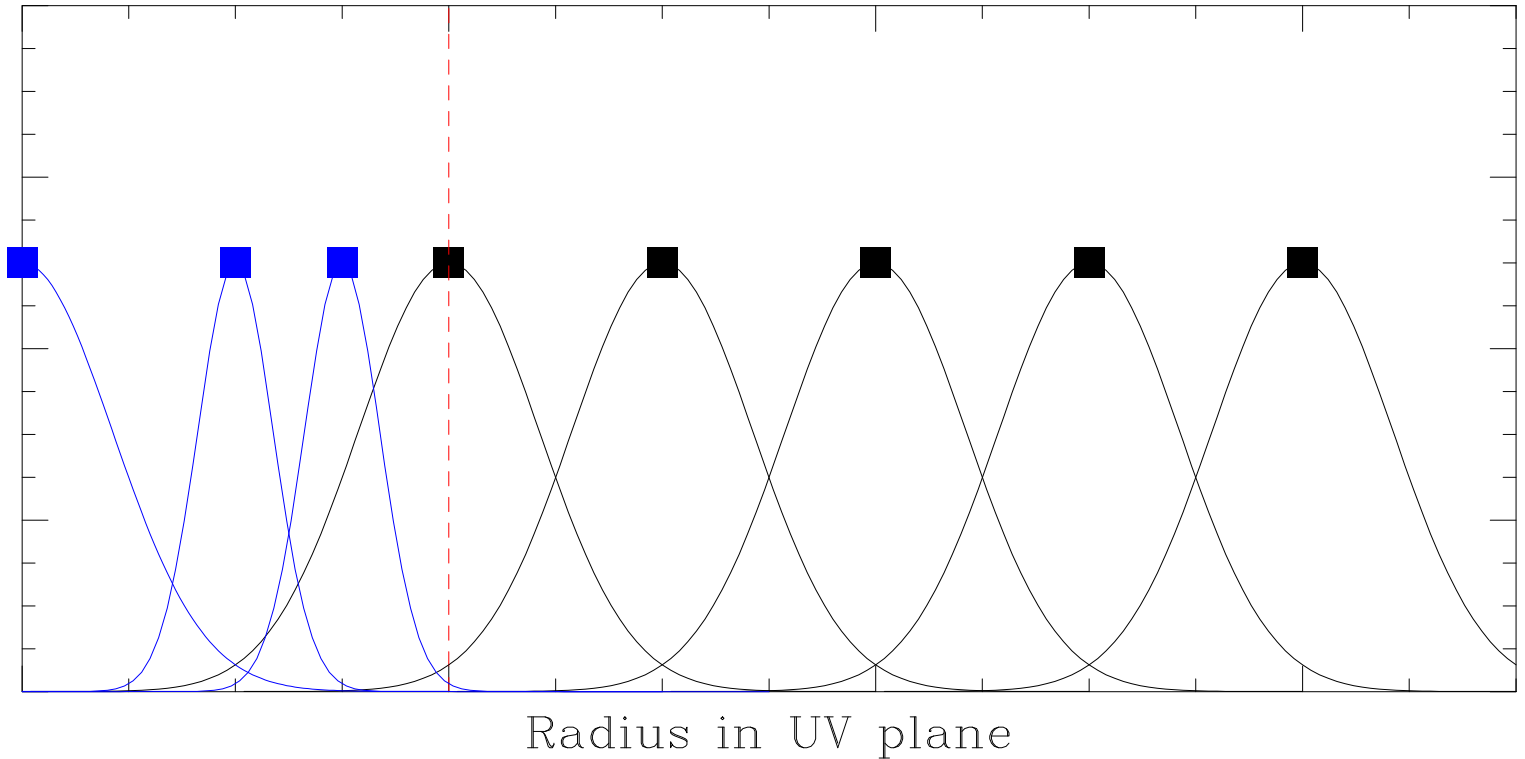
Interferometer with smaller antennas

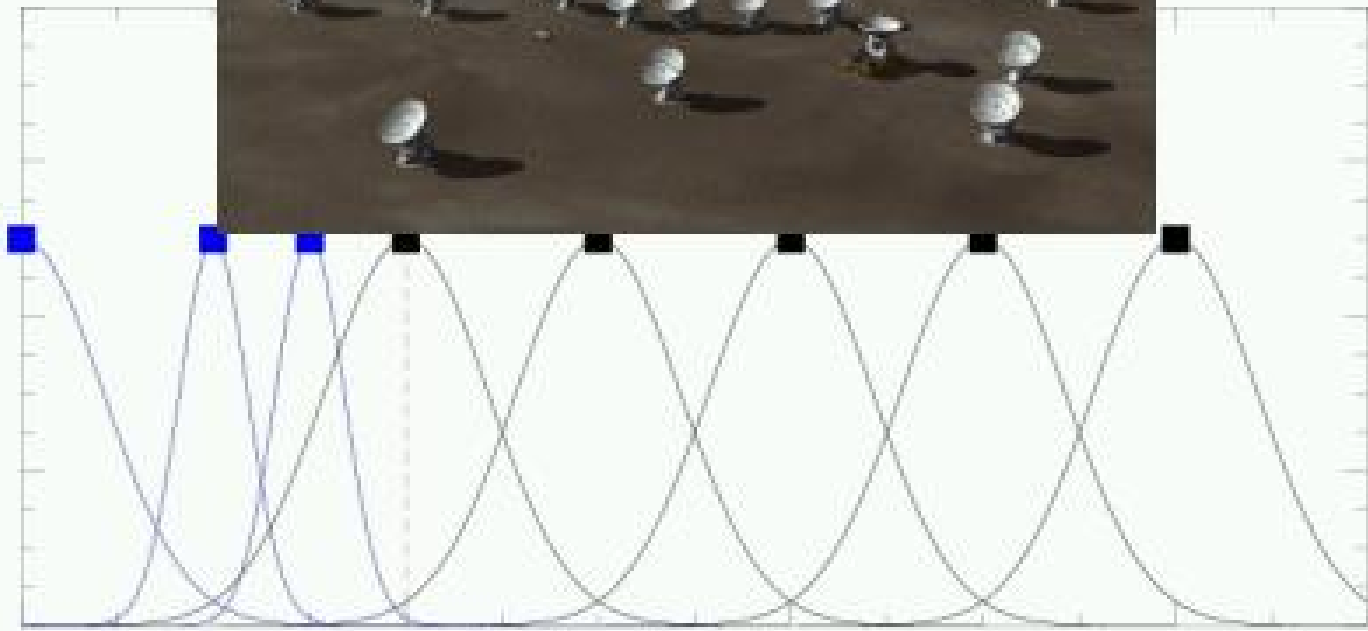
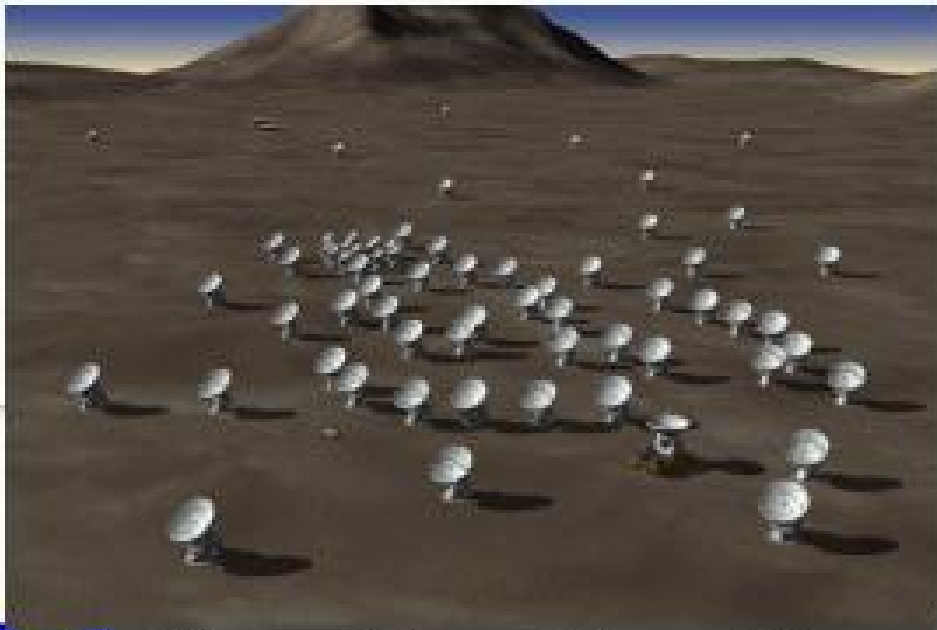




Short Spacings Measurements

Small interferometer + Single-dish measurement



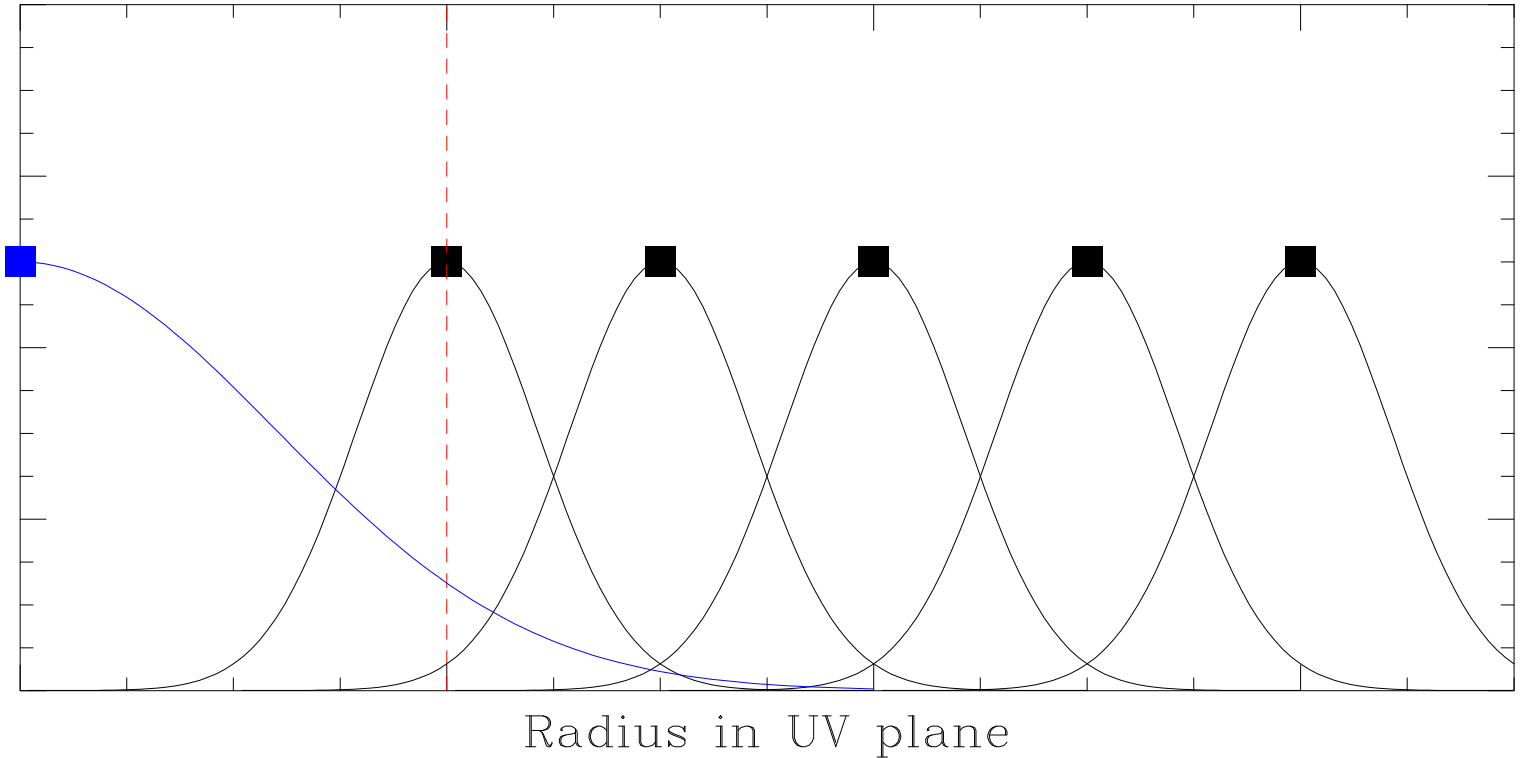


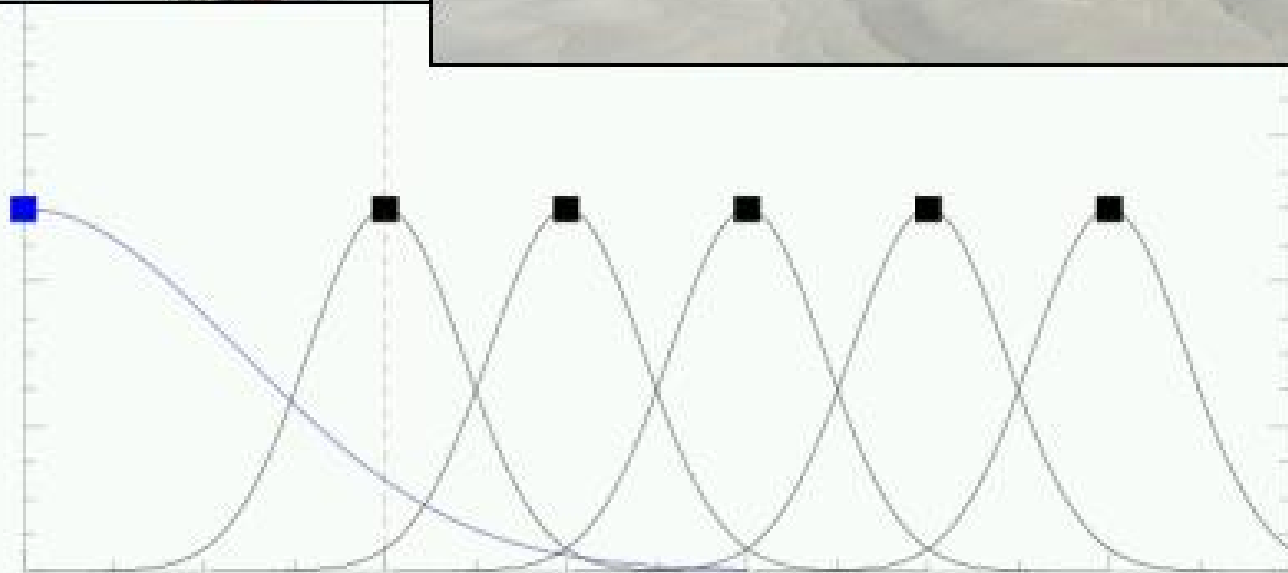
ALMA = 4 12m + 12 7 m + 50 12 m



Short Spacings Measurements

Single-dish measurement (larger antenna diameter)





Radius in UV plane



Short Spacings

Short spacings from SD data

- Combine SD and Interferometric maps in the image plane
- Joint deconvolution (MEM or CLEAN)
- **Hybridization**: fill inner hole in uv plane with FT of single-dish image
- **Combine data in the uv plane before deconvolution**
 1. Use the 30-m map to simulate what would have observed the PdBI, i.e. extract “pseudo-visibilitys”
 2. Merge with the interferometer visibilitys
 3. Process (gridding, FT, deconvolution) all data together

This **drastically improves the deconvolution**



Short Spacings

Extracting visibilities

$$\text{SD map} = \text{SD beam} * \text{Sky}$$

$$\text{Int. map} = \text{Dirty beam} * (\text{Int beam} \times \text{Sky})$$

- Image plane Gridding of the single-dish data
- uv plane Correction for single-dish beam
- Image plane Multiplication by interferometer primary beam
- uv plane Extract visibilities up to $\mathbf{D}_{\text{SD}} - \mathbf{D}_{\text{Int}}$
- uv plane Apply a **weighting factor** before merging with the interferometer data



Short Spacings

Extracting visibilities

Weighting factor to SD data :

- Produce different images and dirty beams
- Methods are not perfect, noise \longrightarrow weight to be optimized
- Usually, it is better to **downweight the SD data** (as compared to natural weight)

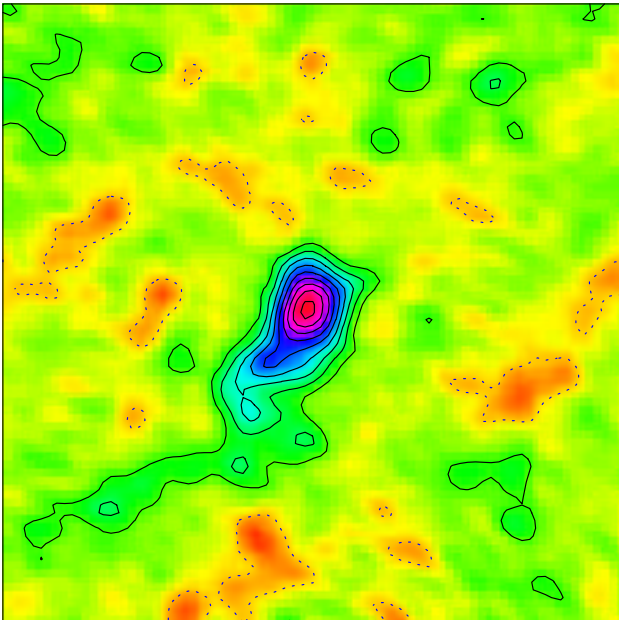
Optimization :

- Adjust the weights so that there is almost **no negative sidelobes** while keeping the highest angular resolution possible
- Adjust the weights so that the **weight densities in 0-D and D-2D** areas are equal \longrightarrow mathematical criteria

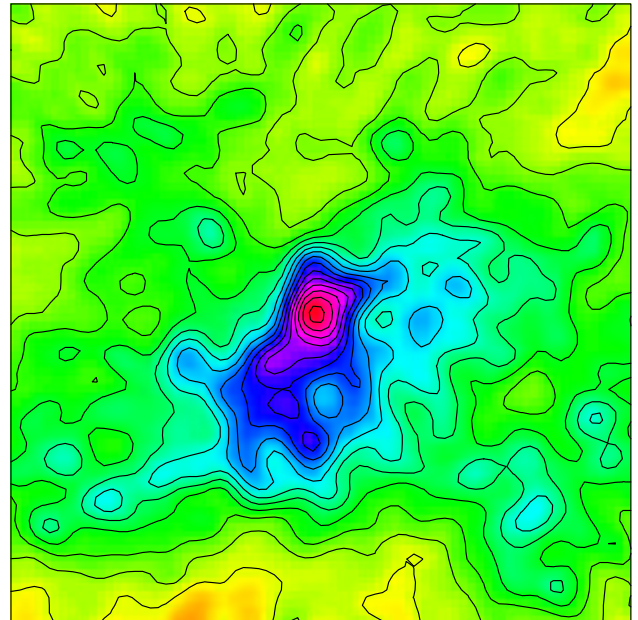


Short spacings Example

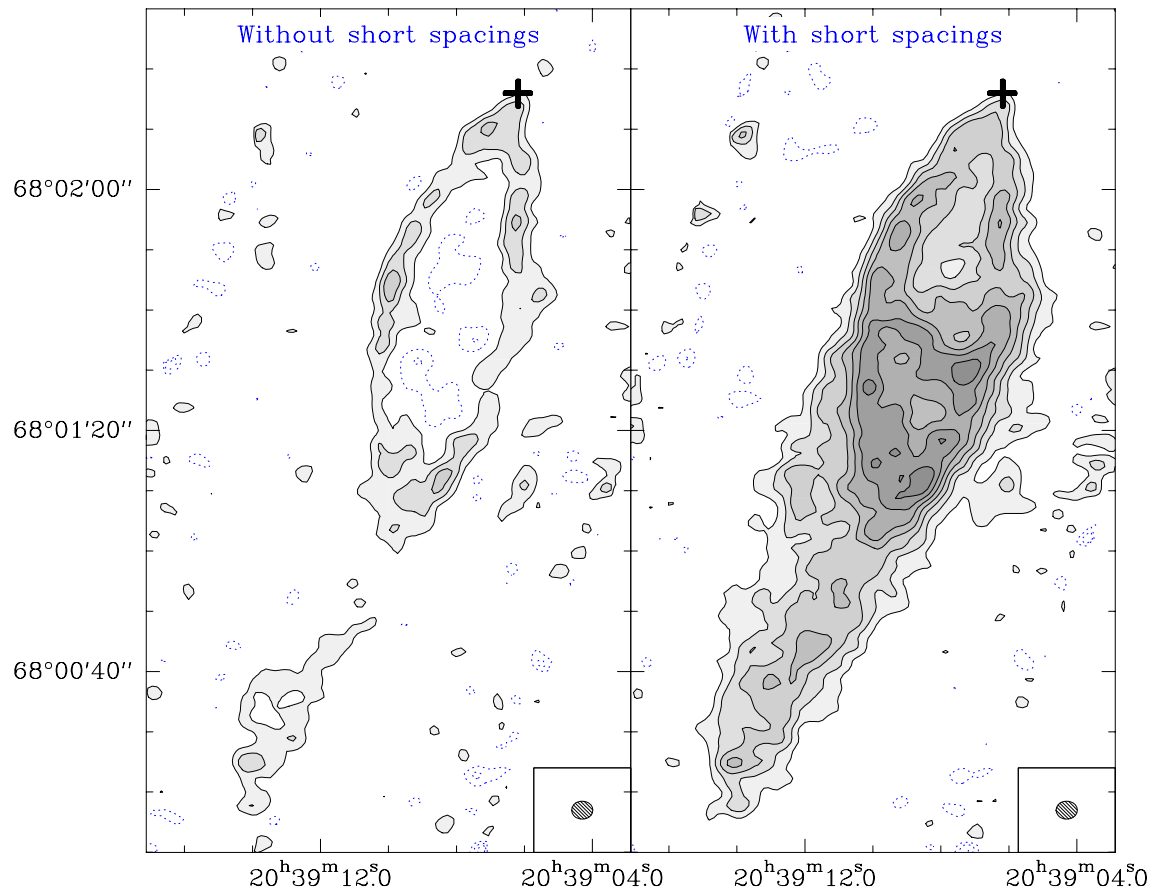
Without short spacings



With short spacings

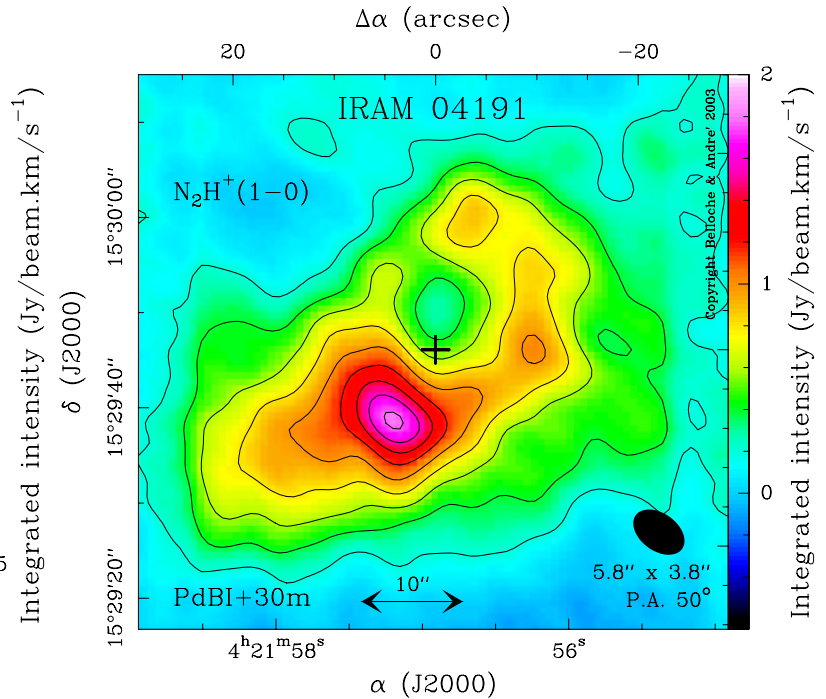
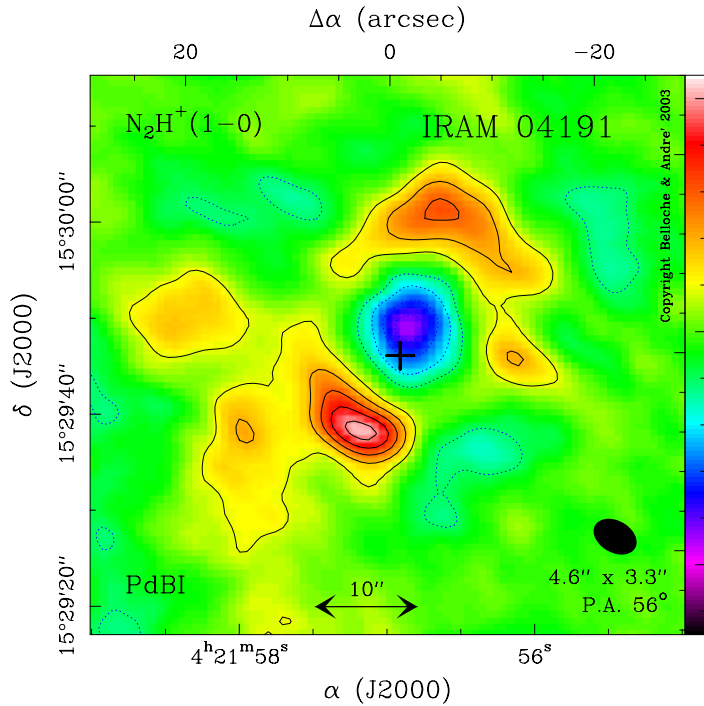


^{13}CO (1-0) in the L 1157 protostar (Gueth et al. 1997)





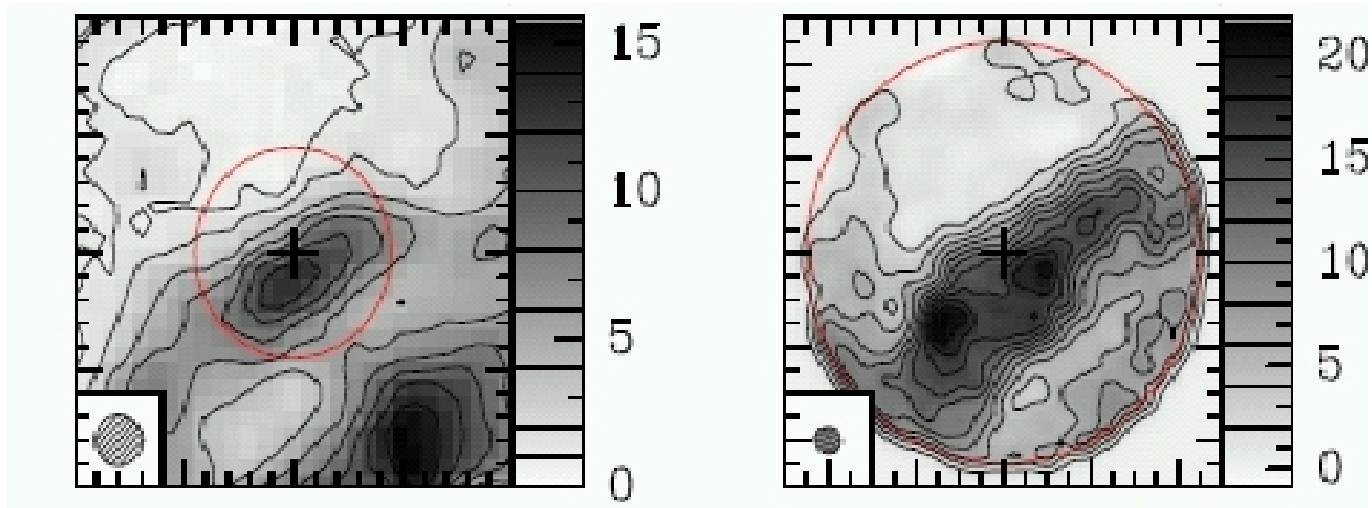
Short spacing Example



N_2H^+ in the IRAM 04191 protostar (Belloche et al. 2004)



Short spacing Example



CO 1-0 in the direction of NRAO 530, Pety et al. 2008



Mosaics

Interferometer field of view

Measurement equation of an interferometric observation:

$$\mathbf{F} = \mathbf{D} * (\mathbf{B} \times \mathbf{I}) + \mathbf{N}$$

F = dirty map = FT of observed visibilities

D = dirty beam (\longrightarrow deconvolution)

B = primary beam = FT of transfer function

I = sky brightness distribution = FT of “true” visibilities

N = noise distribution

- **An interferometer measures the product $\mathbf{B} \times \mathbf{I}$**
- **$B \sim \text{Gaussian}$** \longrightarrow primary beam correction possible (proper estimate of the fluxes) but strong increase of the noise



Mosaics

Primary beam width

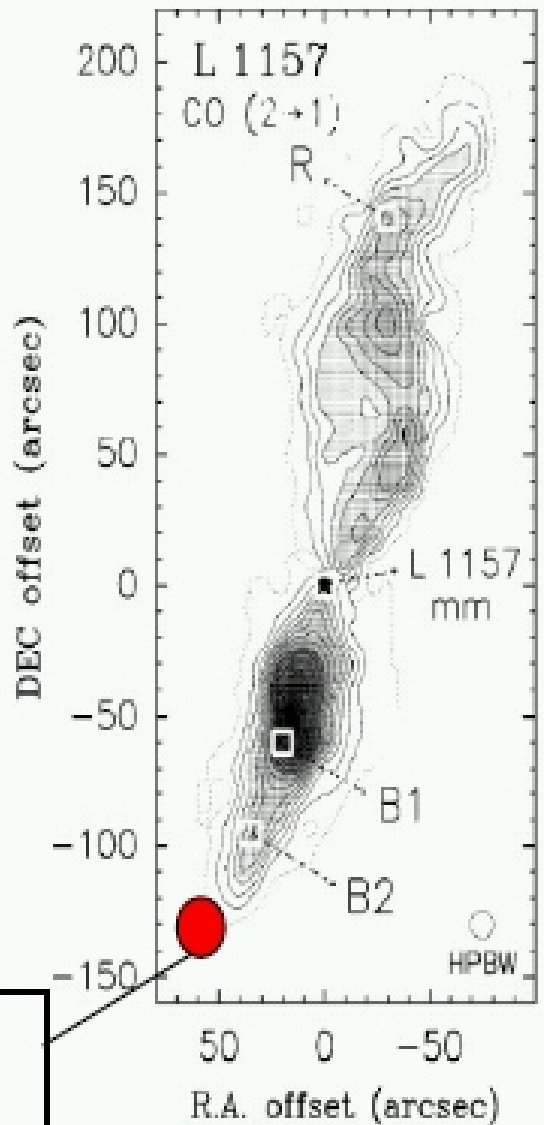
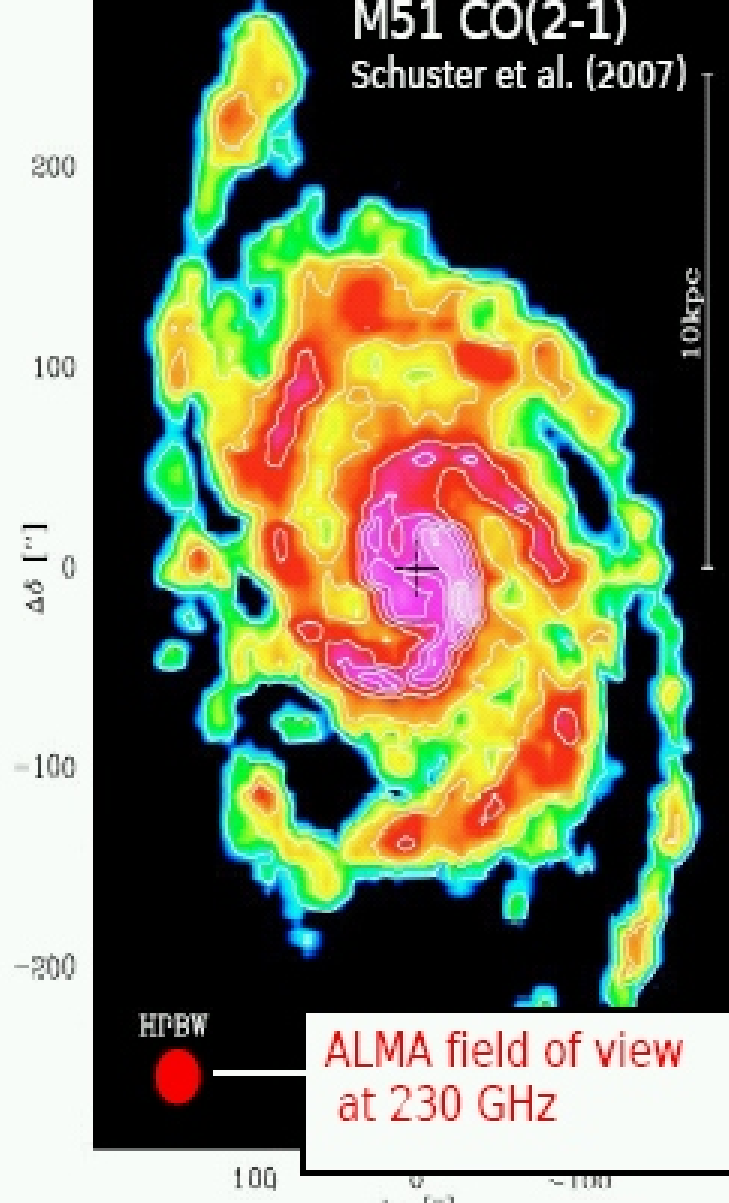
$$\begin{array}{ccc}
 \text{Aperture function} & \rightleftharpoons & \text{Voltage pattern} \\
 \star \downarrow & & \downarrow |\cdot|^2 \\
 \text{Transfer function } T(u, v) & \rightleftharpoons & \text{Power pattern } B(\ell, m) \\
 & & = \text{Primary beam}
 \end{array}$$

Gaussian illumination $\implies B \sim$ Gaussian of $1.2 \lambda/D$ FWHM

Plateau de Bure
 $D = 15$ m

Frequency	Wavelength	Field of View
85 GHz	3.5 mm	58''
100 GHz	3.0 mm	50''
115 GHz	2.6 mm	43''
215 GHz	1.4 mm	23''
230 GHz	1.3 mm	22''
245 GHz	1.2 mm	20''

M51 CO(2-1) Schuster et al. (2007)





Mosaics

Mosaicing with the PdBI

Mosaic :

- **Field spacing = half the primary beam FWHM** i.e. one field each $11''$ at 230 GHz
- Observations with two receivers: choice of the spacing for one frequency \longrightarrow under- or oversampling for the other frequency **NO LONGER VALID**
- Mosaic at 3 mm \longrightarrow no mosaic at 1 mm **WITH NEW RECEIVERS**

Observations :

- **Fields are observed in a loop**, each one during a few minutes \longrightarrow similar atmospheric conditions (noise) and similar uv coverages (dirty beam, resolution) for all fields



Mosaics

Mosaicing with the PdBI

Size of the mosaic :

- Observing time to be minimized, uv coverage to be maximized \longrightarrow maximal number of fields ~ 20

Calibration :

- Procedure identical with any other Plateau de Bure observations (only the calibrators are used)
- Produce one dirty map per field

Short spacings :

- Visibilities from 30-m data are computed and merged with Plateau de Bure data **for each field \longrightarrow process as a normal mosaic**



Mosaics

Mosaic reconstruction

- Forgetting the effects of the dirty beam:

$$F_i = B_i \times I + N_i$$

- This is similar to several measurements of I , each one with a “weight” B_i
- Best estimate of I in least-square formalism (assuming same noise):

$$\mathbf{J} = \frac{\sum_i \mathbf{B}_i \mathbf{F}_i}{\sum_i \mathbf{B}_i^2}$$

- J is homogeneous to I , i.e. the mosaic is **corrected for the primary beam attenuation**



Mosaics

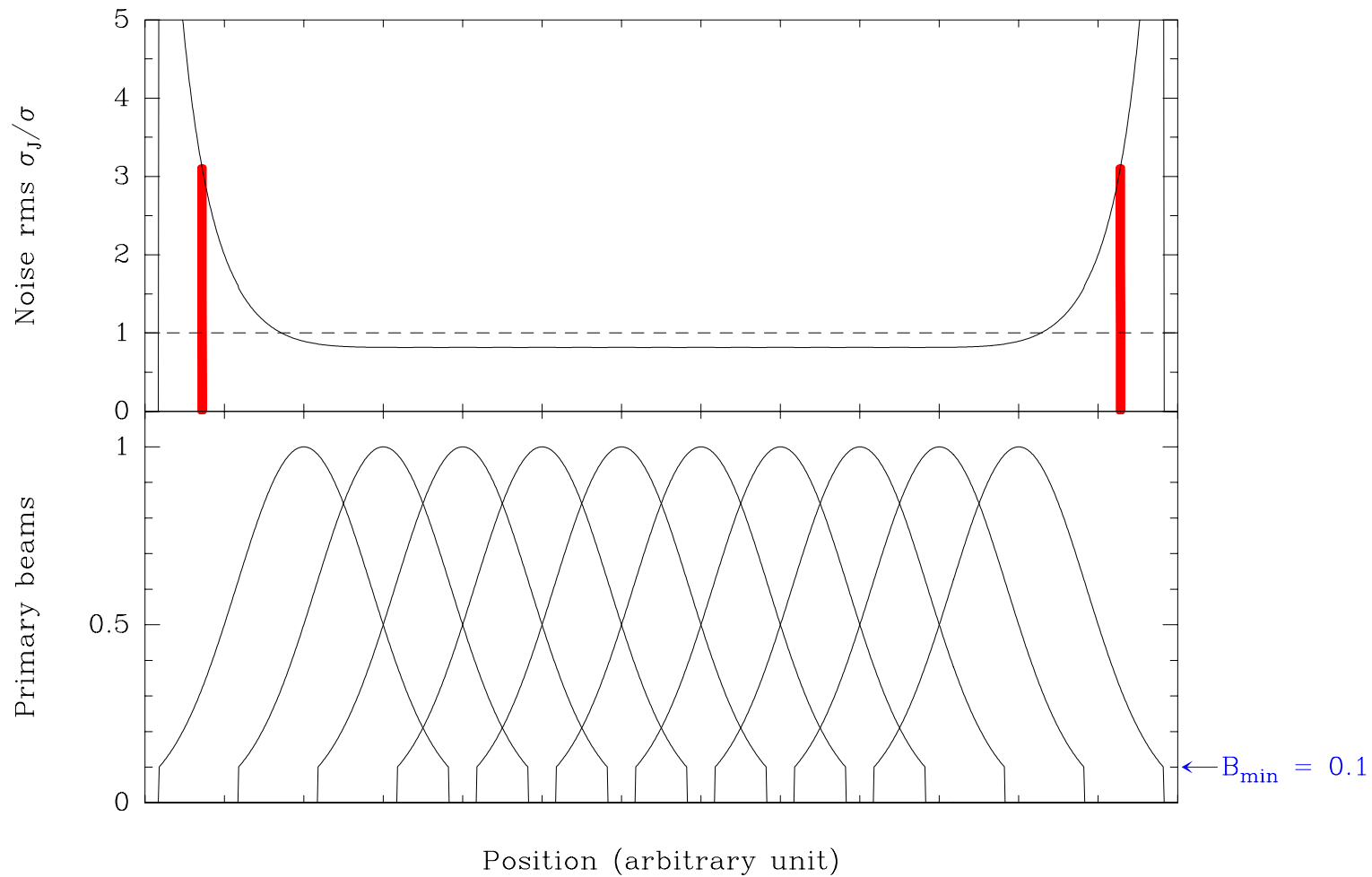
Noise distribution

$$J = \frac{\sum_i B_i F_i}{\sum_i B_i^2} \quad \Rightarrow \quad \sigma_J = \sigma \frac{1}{\sqrt{\sum_i B_i^2}}$$

The noise depends on the position and strongly increases at the edges of the field of view

In practice :

- Use **truncated primary beams** ($B_{\min} = 0.1 - 0.3$) to avoid noise propagation between adjacent fields
- **Truncate the mosaic**





Mosaics

Mosaic deconvolution

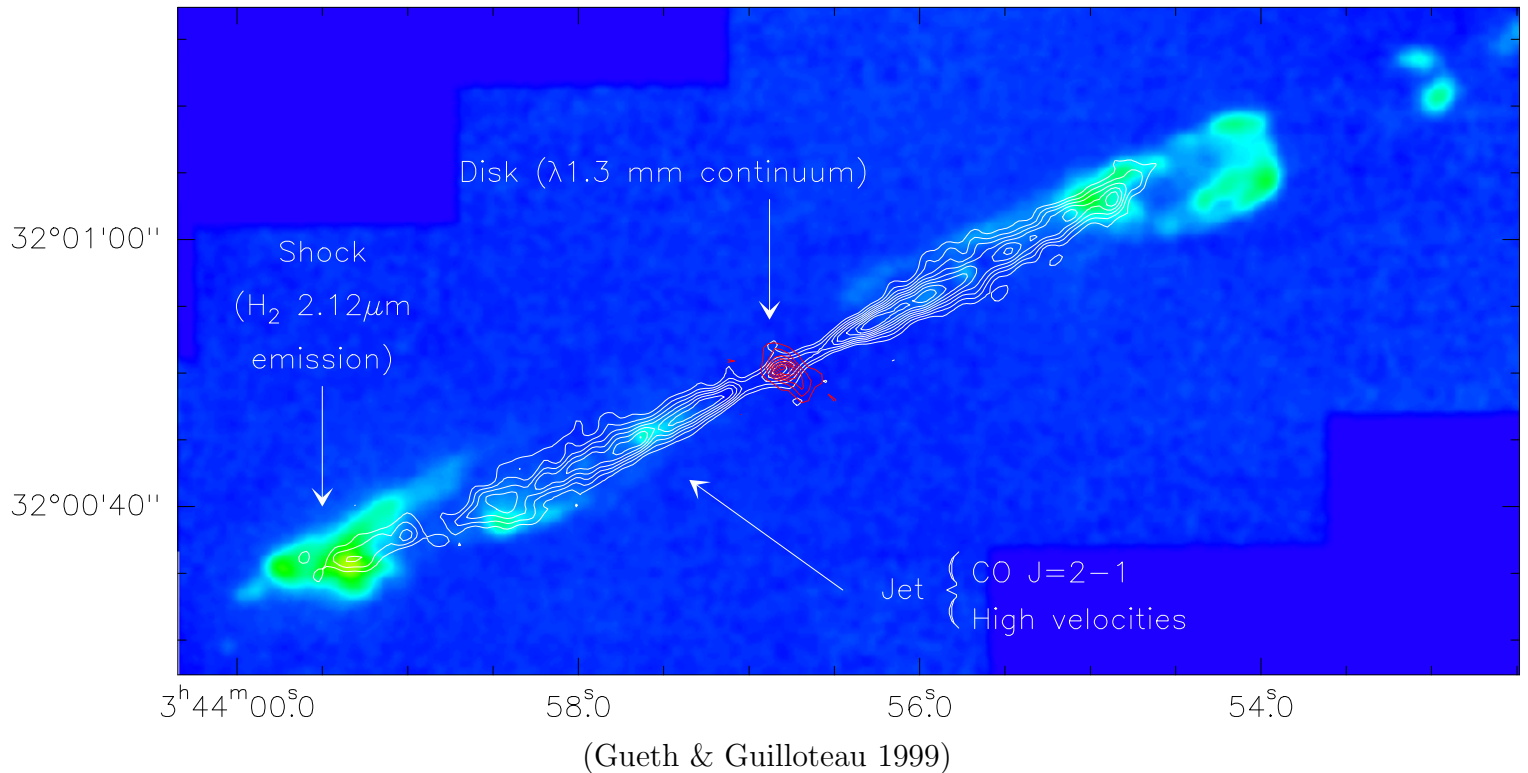
- **Linear mosaicing:** deconvolution of each field, then mosaic reconstruction
- **Non-linear mosaicing:** mosaic reconstruction, then global deconvolution
- The two methods are not equivalent, because the deconvolution algorithms are (highly) non-linear
- **Non-linear mosaicing gives better results**
 - sidelobes removed in the whole map
 - better sensitivity
- Plateau de Bure mosaics: **non-linear joint deconvolution based on CLEAN**



Mosaics

Example

H_2 + $\text{CO}(2-1)$ EHV + continuum 1.3 mm in HH211

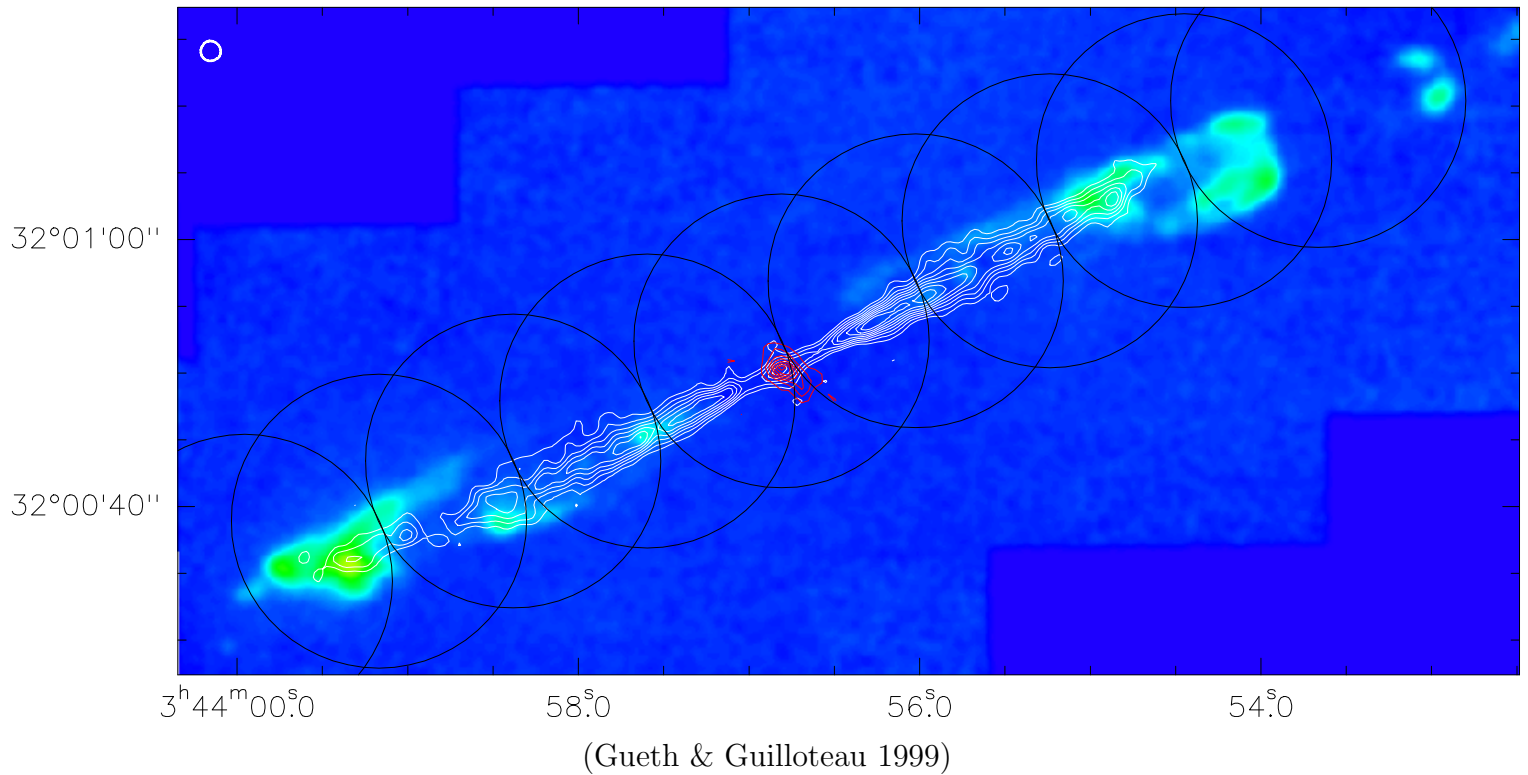




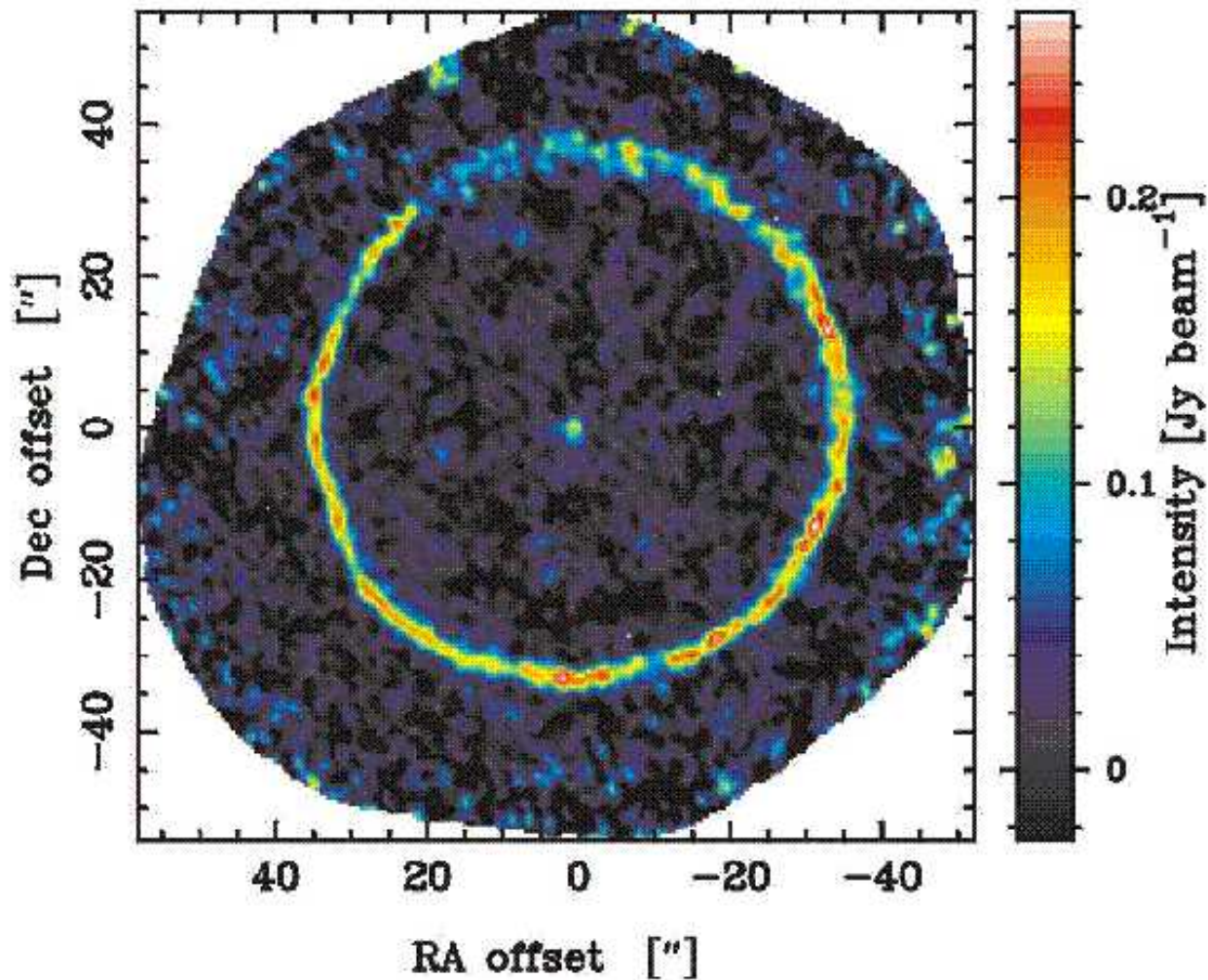
Mosaics

Example

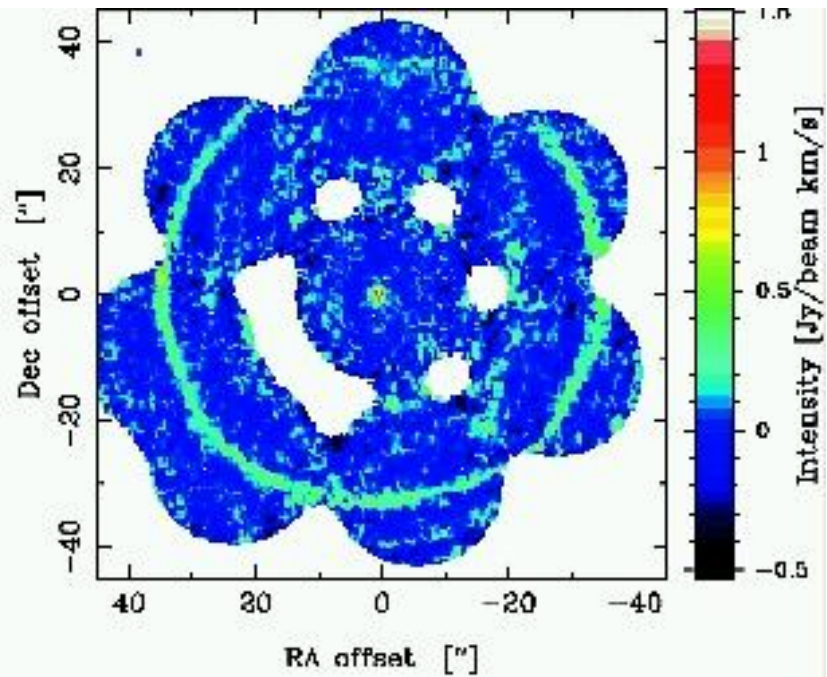
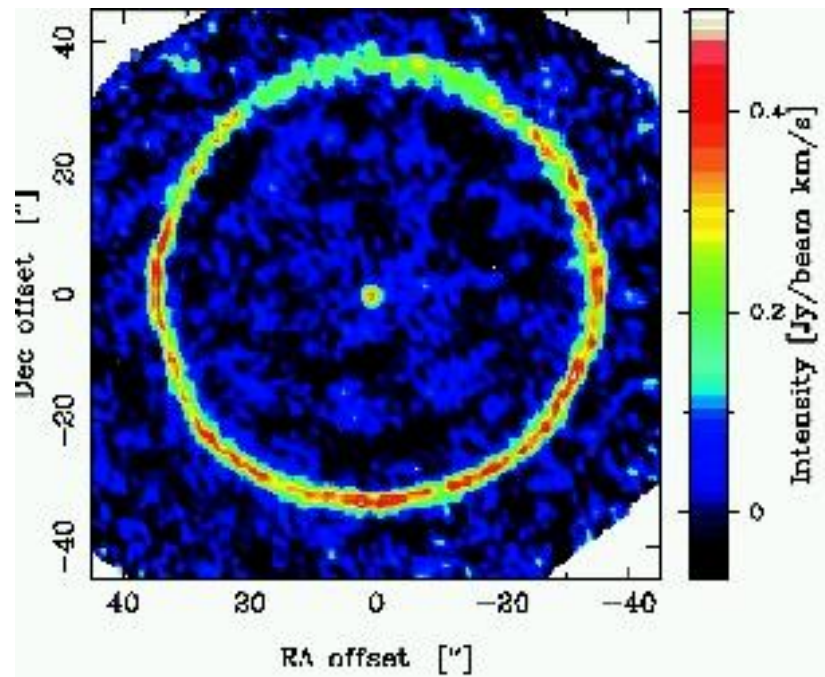
H_2 + $\text{CO}(2-1)$ EHV + continuum 1.3 mm in HH211



TT Cyg CO(1-0) $v = -28.5$ to -26.5 km s⁻¹

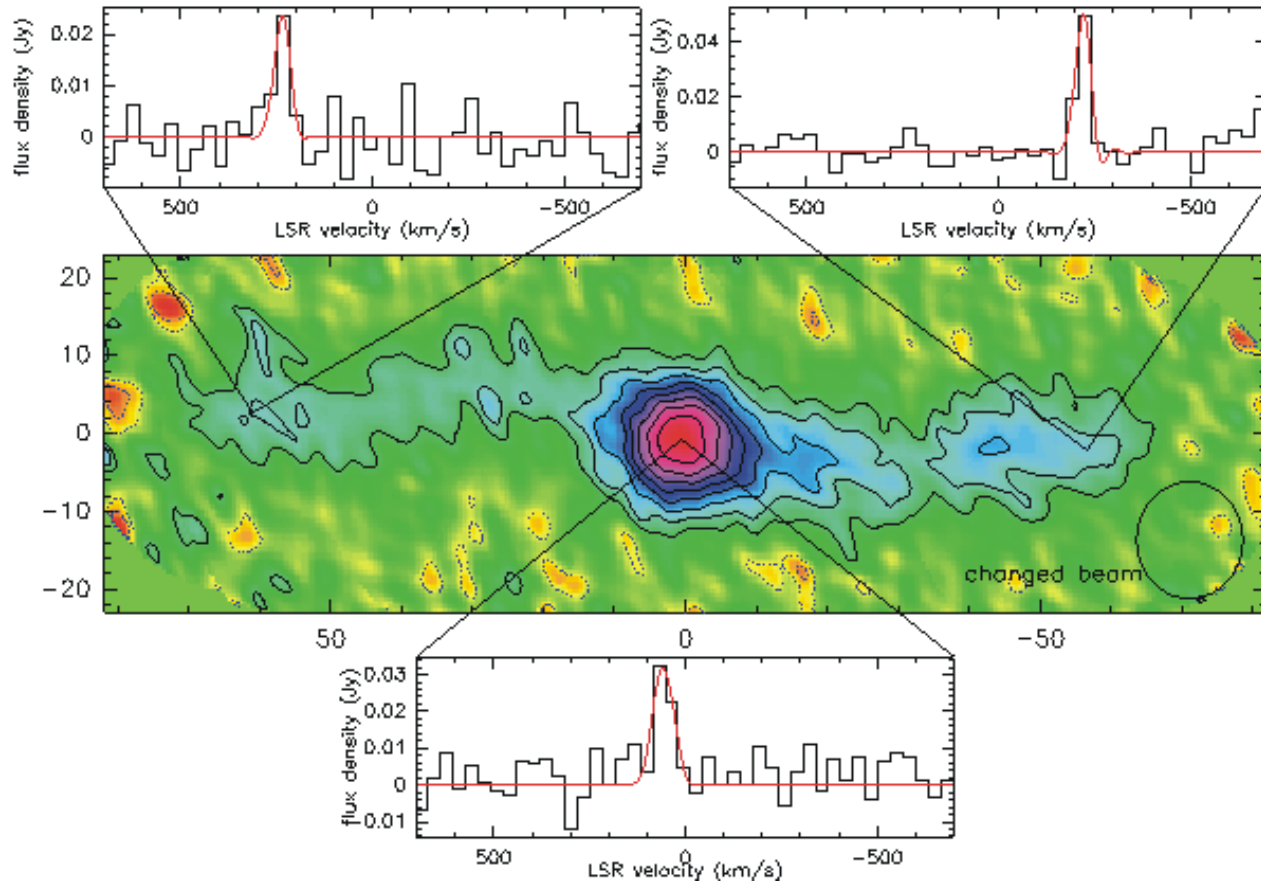


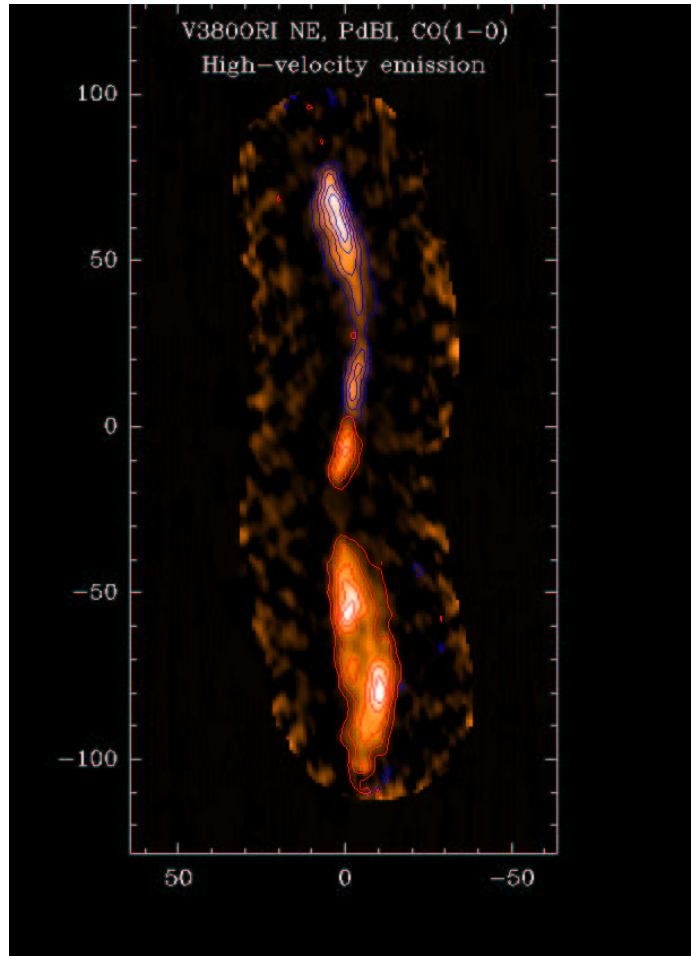
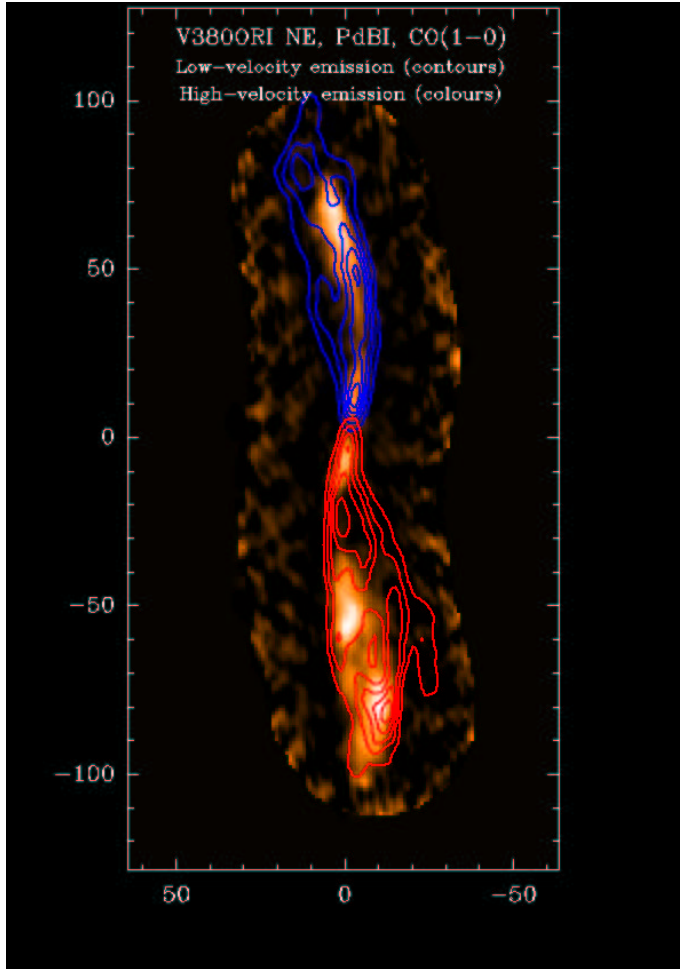
CO 1-0 in TT Cygni, Olofsson et al. 2000



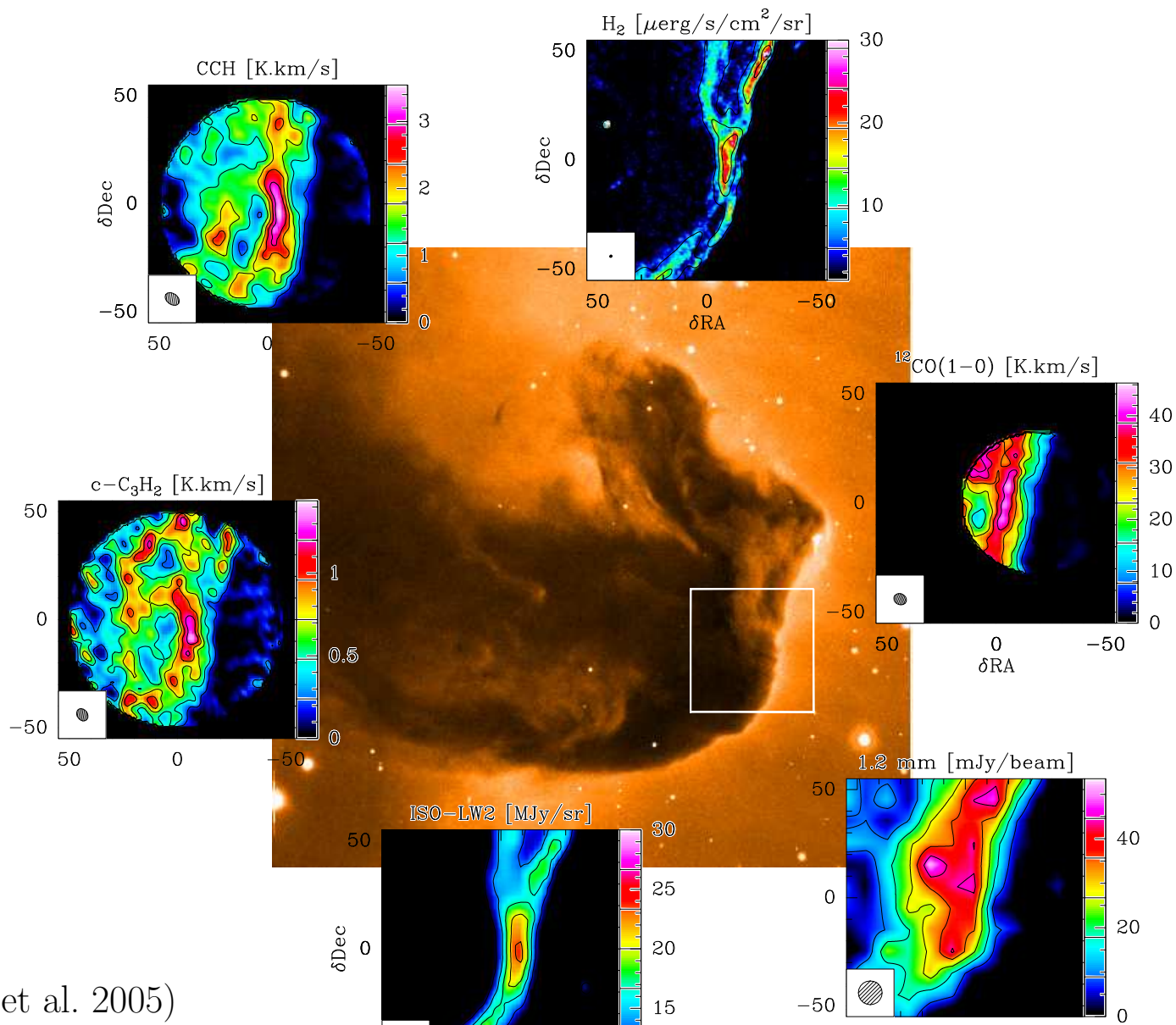
CO 1-0 in TT Cygni, Olofsson et al. 2000

CO in the warped galaxy NGC 3718 (Krips et al. 2005)





(Stanke et al. 2004)



(Pety et al. 2005)



Mosaics and short spacings

The problem

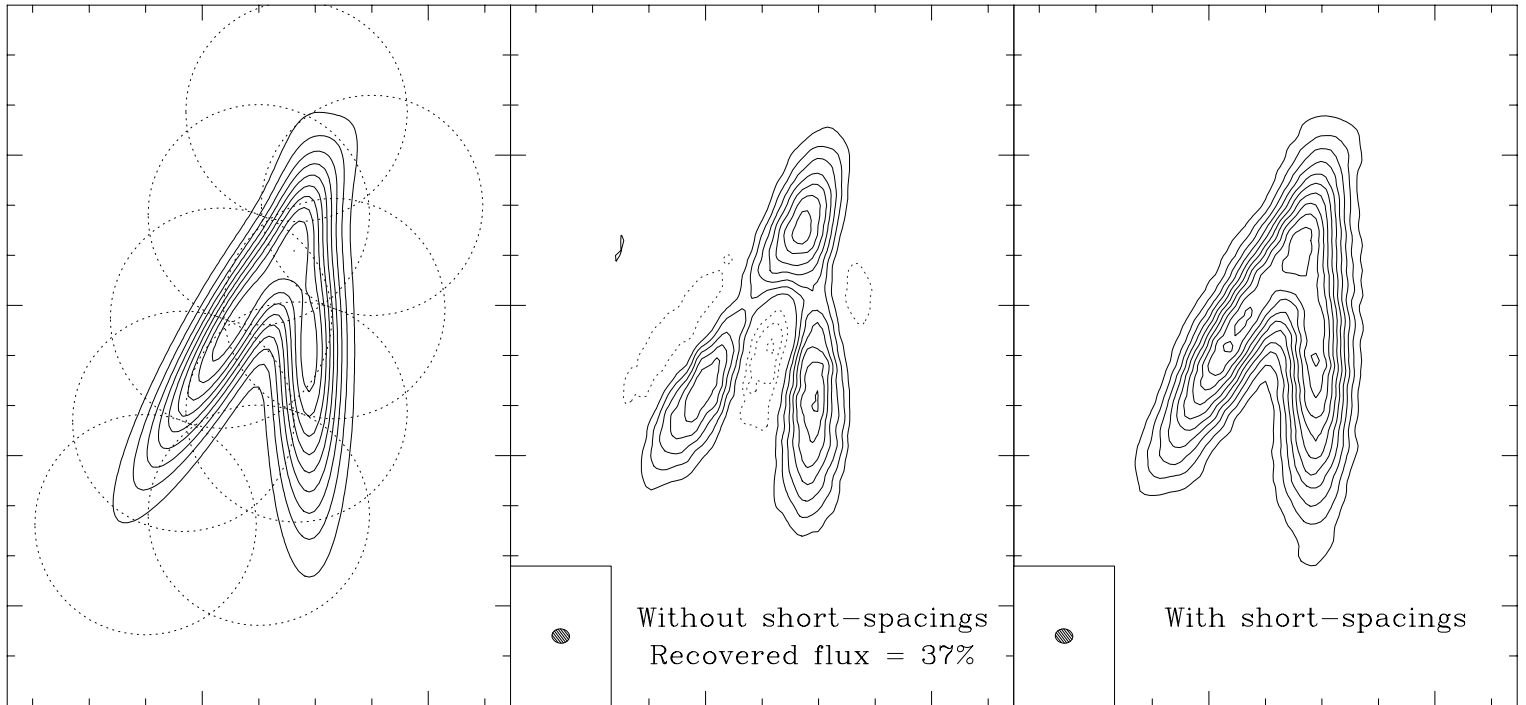
Effect of missing short spacings more severe on mosaics than on single-field images:

- Extended structures are filtered out **in each field**
- Lack of information on an **intermediate scale** as compared to the mosaic size
- Possible artefact: extended structures split in several parts
- **In most cases cases, adding the short spacings is required**



Mosaics and short spacings

Simulations





Mosaics and short spacings

The problem

Effect of missing short spacings more severe on mosaics than on single-field images:

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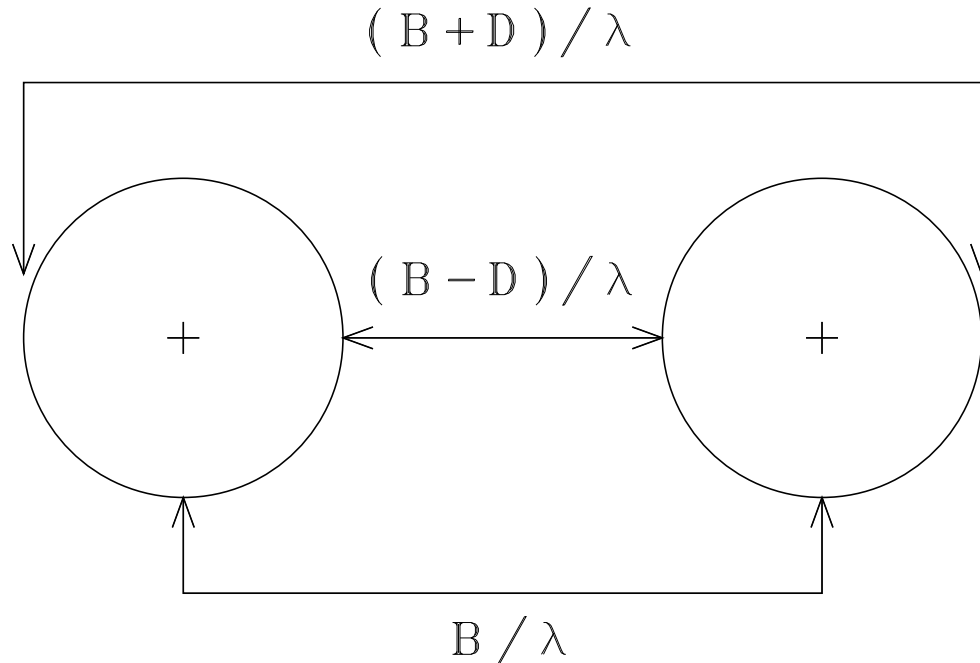
However, **mosaics are able to recover part of the short spacings information**



Mosaics and short spacings

Image formation

- An interferometer is sensitive to all spatial frequencies from $\mathbf{B-D}$ to $\mathbf{B+D}$ \implies it measures a **local average** of the “true” visibilities





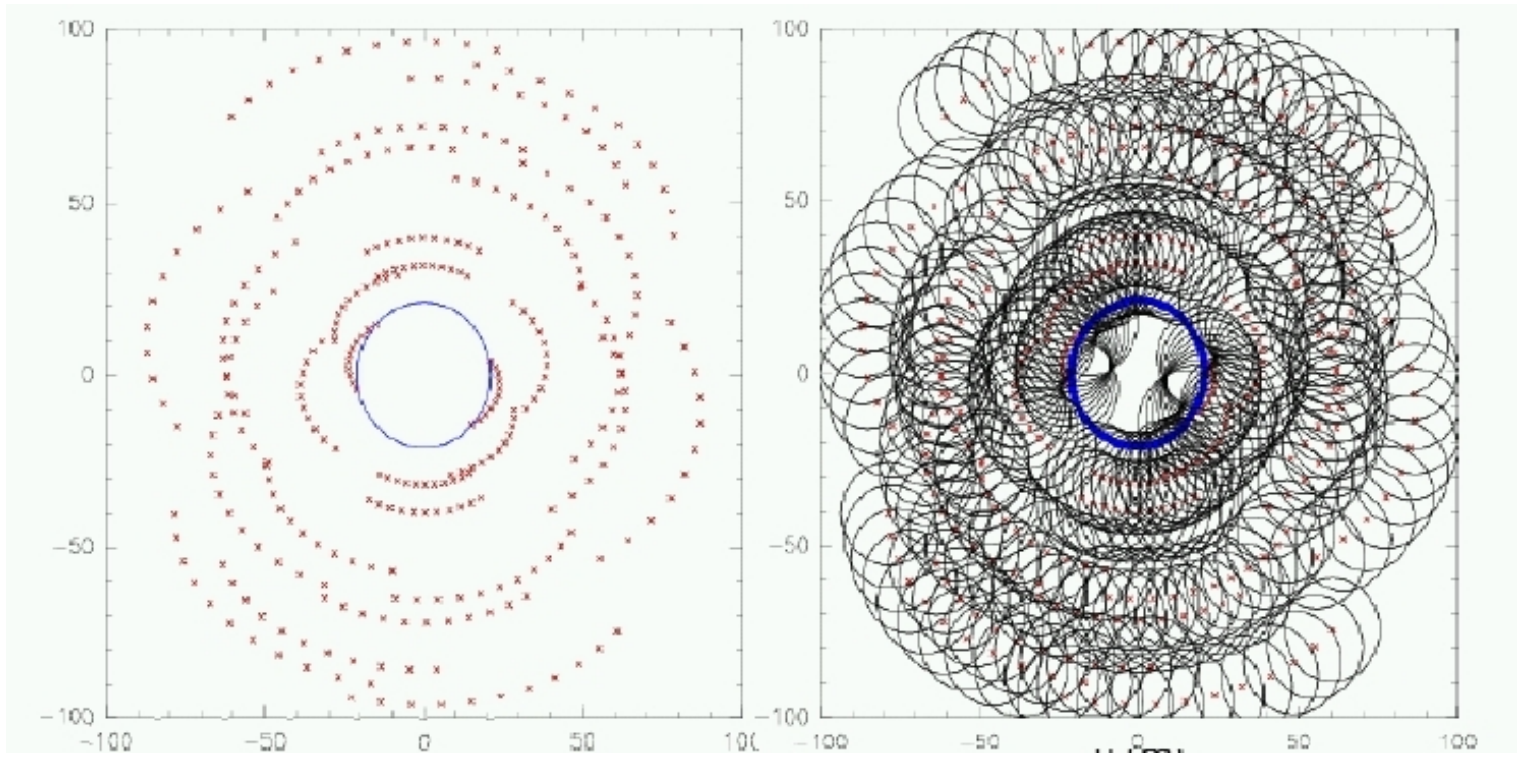
Mosaics and short spacings

Image formation

- An interferometer is sensitive to all spatial frequencies from $\mathbf{B}-\mathbf{D}$ to $\mathbf{B}+\mathbf{D} \implies$ it measures a **local average** of the “true” visibilities
- Measured visibilities: $V_{\text{mes}} = \text{FT}(B \times I) = \mathbf{T} * \mathbf{V}$ where T is the transfer function of the antenna
- Pointing center $(\ell_p, m_p) \neq$ Phase center: phase gradient across the antenna aperture

$$V_{\text{mes}}(u, v) = [T(u, v) e^{-2i\pi(u\ell_p + vm_p)}] * V(u, v)$$

- **Combination of measurements at different (ℓ_p, m_p) should allow to derive V**
- The recovery algorithm is a simple Fourier Transform (Ekers & Rots)





Conclusions

- Mosaicing is a **standard observing mode** at Plateau de Bure
- Adding short spacings from the IRAM 30-m is an **standard procedure** (box in proposal form)
- ALMA designed from the beginning to include the short-spacings (ACA, SD antennas) – but not for all projects
- New developments to come: on-the-fly interferometry

