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DEVELOPMENT OF AN ANTENNA ARRAY SIMULATOR

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RESUMEN

El primer problema a resolver al diseñar un radiointerferómetro es la ubicación de sus antenas-elementos, la cual define la respuesta del interferómetro, cuya solución determina qué puntos del plano *uv* serán muestreados, junto con su densidad. Estos parámetros son de extrema importancia ya que la ubicación de las antenas define el haz sintetizado, o función de dispersión de puntos (PSF, por sus siglas en inglés), y una incorrecta distribución implica una degradación en la respuesta del haz. Ejemplos de las consecuencias de estos problemas pueden ser la eliminación de muestras sobre un rango de frecuencias espaciales debido a la baja relación señal-ruido, o, en la fase de reducción de datos, reducir la resolución espacial a fin de obtener una imagen más limpia. Con el objetivo de comprender mejor los parámetros involucrados en la respuesta del interferómetro, se va a presentar en este trabajo un simulador en desarrollo que provee la distribución de muestras en el plano de las líneas de base y el haz sintetizado correspondiente, al igual que otros programas ya desarrollados, pero con la diferencia de ser capaz de correr distintos métodos de optimización, como puede ser el conocido como "pressure forces" u otros personalizados, relacionados a las características del problema particular.

ABSTRACT

The first task to solve in designing a radio interferometer is the location of the antennas-elements, a problem which defines the interferometer response, whose solution determines which points of the *uv* plane will be sampled, together with their density. These two parameters are extremely important because the antenna's location, in turn, defines the synthesized beam or point spread function (PSF) of the whole instrument, and an inadequate array configuration implies an ill-constructed synthesized beam. Consequences in this case are for example the need to delete measures over a range of spatial frequencies due to low signal-to-noise ratio, or, at the data reduction stage, to degrade spatial resolution in order to get a cleaner image. In order to have a better understanding of the parameters involved in the interferometer response, in this presentation we will introduce an in-progress simulator that provides the distribution in the baselines plane and the corresponding synthetized beam, like other common softwares developed years before, but that it is also able to run various optimization tasks, like pressure forces or custom tasks more related with the particular characteristics of this problem.

Key Words: Instrumentation: Interferometers

1. INTRODUCTION

A radio interferometer is an array of antennas which, via correlation between pairs of them, samples components of the Fourier transform plane (or *uv* plane) of an astronomical source (Thompson et al. 2017). The more covered the *uv* plane is, the better the image quality. The aim is then, to cover as best the *uv* plane, in order to get as much information as possible to build the image.

On designing an interferometer array there are mainly three problems to face, namely: determining the antenna location, building of an appropriate correlator and the synchronization of the data acquisition and data transfer systems. This contribution focuses on the antenna location problem and, related to this particular problem, the aims to be achieved are:

- understand the effects of the antenna distribution,
- review of the simulators or software packages that mimics real situations,
- define the specifications of a new simulator to understand the involved variables.

The topics are distributed on different sections of this contribution. In section 2 the parameters involved on designing an interferometer array are described, how this information can be presented and also how this is shown after on the result, like *uv*

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coverage or PSF profile plots. Section 3 deals with three different simulators, their advantages and disadvantages on interferometer design. The more suitable simulators were configured for the specific case of an instrument whose design is being envisaged at IAR: the Multipurpose Interferometer Array (MIA), an array of up to 64 antennas that will be placed in Argentina. Finally, conclusions and perspectives are outlined.

2. THE ANTENNA LOCATION PROBLEM

To determine the optimal location of the antennas, it is useful to make assumptions on, or constraint characteristics of the instrument. Table 1 shows a list of the characteristics parameters and relations to those on the Fourier plane.

The aforementioned characteristics can be represented by means of plots of the *uv* coverage or the PSF. For example, in Fig. 1, the *uv* coverage of an example array is plotted: the curve with largest perimeter and the center wavelength define the angular resolution of the PSF. The curve with the smaller perimeter represents extended emission. Some larger sources, for instance, can be observed using a subarray of antennas whose *uv* coverage consists of the curves near the center in Fig. 1. In that case, the resolution changes (decreases).

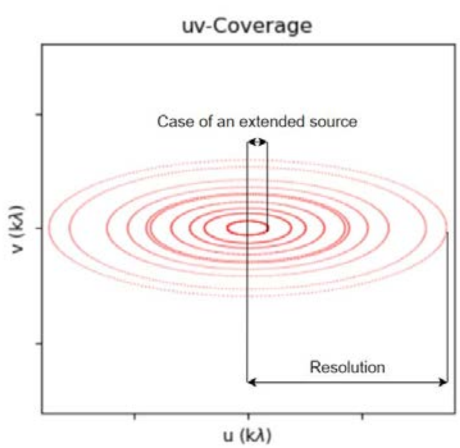

Fig. 1. Example of an *uv* plane coverage and how you can interprete features of the array by means of the plot.

Another important characteristic is the beam shape: depending on how the *uv* plane is covered, this will affect the shape of the main beam and also the strength of the sidelobes. An example is shown in Fig. 2, where a gaussian coverage of the *uv* plane corresponds to a gaussian beam shape.

There is a minimum baseline, related to the diameter of the antenna, for which the array can present the shadowing effect: it happens when one antenna eclipse another because of the short distance and also the inclination of both antennas. In order to avoid this problem and sample the *uv* components near the origin of the plane, it may be implemented a complementing single dish observation (Bajaja & van Albada 1979). How this works could be observed as a borderline case: when the separation between antennas decreases, this is seen as a displacement of the curves on the *uv* plane. In the limit case, this curve will be placed at the origin with only one antenna which measures the components from 0 up to approximately the diameter of the single dish antenna divided by the center wavelength. In terms of the responsivity (Emerson 2002), this is shown with an example in Fig. 3, using MIA parameters (5 m diameter antennas), complemented with a single dish of 30 m of diameter, as will be complementing MIA with the antennas of the IAR. In this example can be appreciated how the contribution of the single dish adds the lacking baselines towards the origin, to full fill this area an also to avoid shadowing.

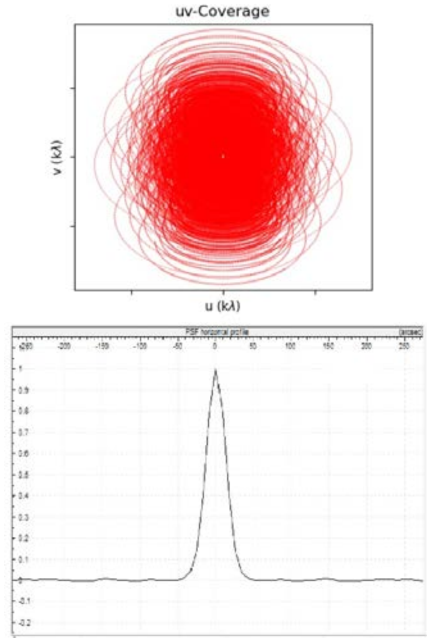

Fig. 2. Example of how the *uv* coverage defines the shape of the beam.

Because of this graphical interpretation of the parameters of the design, it is important to be aware of the available softwares for optimization and visualization of interferometers, to improve the design with a tool for both check the performance and make comparisons to find different ways of approaching the problem, and consequently, reach the optimal configuration.

TABLE 1

PARAMETERS AND RELATIONS

Ground plane	Fourier plane
Angular resolution	Max baseline
Detectability of extended sources	Min baseline
Desired uv coverage	Synthesized beam shape
Expected declination	uv coverage
Measurement time	...
Terrain constraints	...
Complementarity with single dish	...

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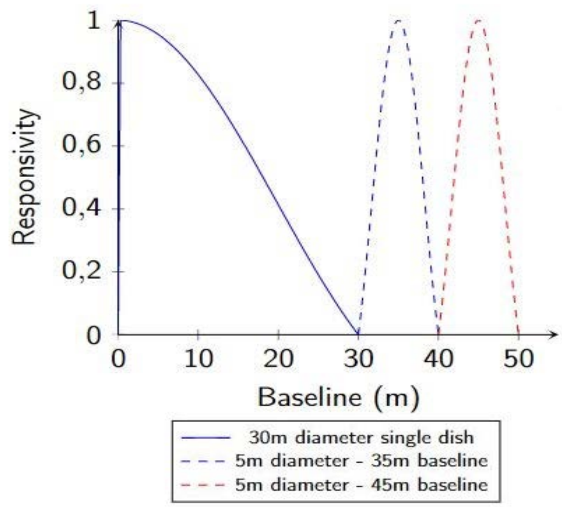

Fig. 3. Example of how the responsivity is related between single dish and interferometric observations.

3. SIMULATORS

Here, three different simulators are described. They are FriendlyVRI (Purcell & Truelove 2017), APSYNSIM (Marti-Vidal 2017) and AntConfg (de Villiers 2007), each one detailed in the following subsections with their advantages and disadvantages.

3.1. *FriendlyVRI*

FriendlyVRI is a practical simulator coded on Python for understanding all the steps of an observation. This program provides a Control Window (Fig. 4) and a Plot Window (Fig. 5). In the Control Window the array and observation parameters like the Hour Angle (HA), the sampling cadence and the declination are introduced. To account for model source, any image can be load and, to load a new array, there is a particular type of file that not only contains the offset position (North and East) of each array antenna with respect to a reference, but also the geographical location of the antennas, the name of the array and the diameter of each antenna. Finally, there are checkboxes to check if the array and model are loaded, and for selections to display the different plots of the observation.

In the Plot Window (Fig. 5) all the steps of the observation are displayed. Relationships are marked between the subplots that show, besides the final image (observed image), the intermediate steps like the observed FFT and the uv coverage, from the point of view of a linear system.

Briefly, the advantages of FriendlyVRI are:

- all the steps of the process to obtain a final image are plotted,
- several types of images can be uploaded,
- all the parameters that characterize an observation can be settled.

As disadvantages we can mention:

- it becomes hard to load a new configuration array, because this includes to create a new script with the new locations, names and diameters. When an array is created, it remains fixed along with its characteristics,
- any change on the measurement needs a rerun of the simulation.

Taking into consideration the above features, FriendlyVRI is a good simulator to perfom simulation of observations, since all the steps can be viewed at once.

3.2. *APSYNSIM*

The APerture SYNthesis SIMulator (APSYNSIM) is a FriendlyVRI kind of simulator, with the main difference of being able to change the parameters of the observation dinamically on its window (Fig. 6).

Because of the similarities, APSYNSIM skills on understanding the perfomance of an array are alike. Its advantages are:

- all the steps of the observation are plotted, like FriendlyVRI,

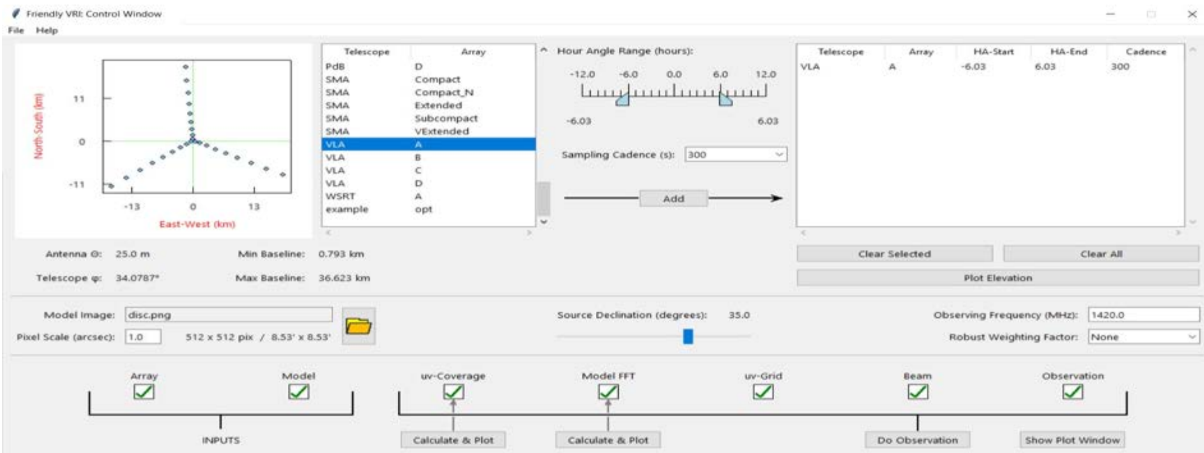

Fig. 4. FriendlyVRI - Control Window.

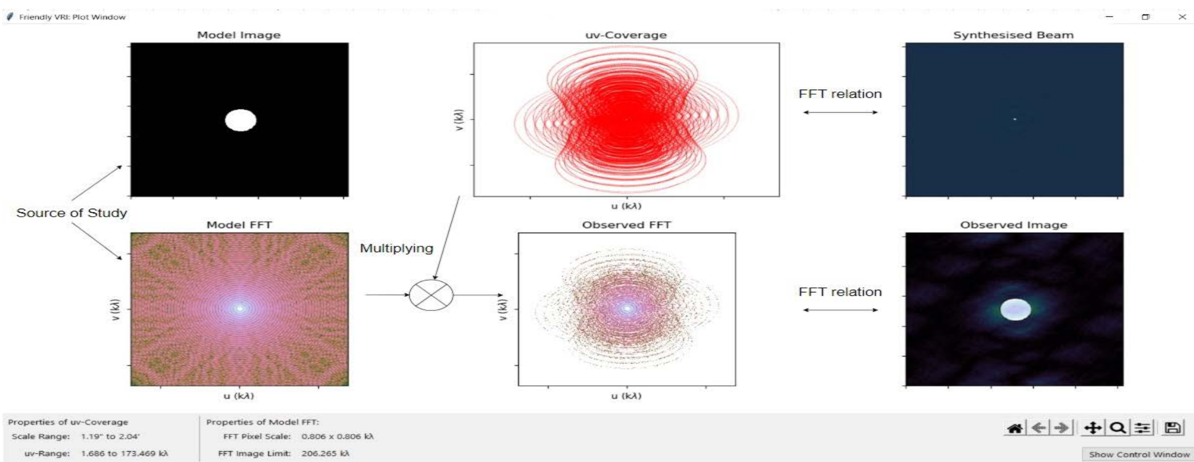

Fig. 5. FriendlyVRI - Plot Window.

- it is possible to dinamically change parameters during the simulation.

Regarding the disadvantages:

- it is hard to load a new array, like FriendlyVRI. In this case, a new script needs to be created with the geographical location of the antennas, and also the range of wavelengths the array can observe,
- in the same way as loading an array, loading a new source model requires creating a new script where an image can be load, or via describing it with a few parameters besides its location on the sky.

Considering their perfomance, APSYNSIM and FriendlyVRI are both good simulators for understanding and simulating results for several arrays in different kind of observations.

3.3. *AntConfig*

The mainly difference between AntConfig with the two simulators previously described is that AntConfig was made for optimize the locations of the antennas of an array. This optimization is an implementation of the pressure forces method (Boone 2001), which works defining a desired uv density described by an exponential with changable parameters, like the Full Width at Half Maximum (FWHM), parameter related with the angular resolution on the PSF. Then, by taking the gradient of the difference of the desired density and the actual density of the array, the antennas are displaced until to reach the desire density.

The AntConfig plot section (Fig. 7) displays the antenna's distribution, the PSF, the uv coverage and also the uv density histogram. It can be appreciated that, unlike the previous simulators, there are different plots, more directly related with the perfomance

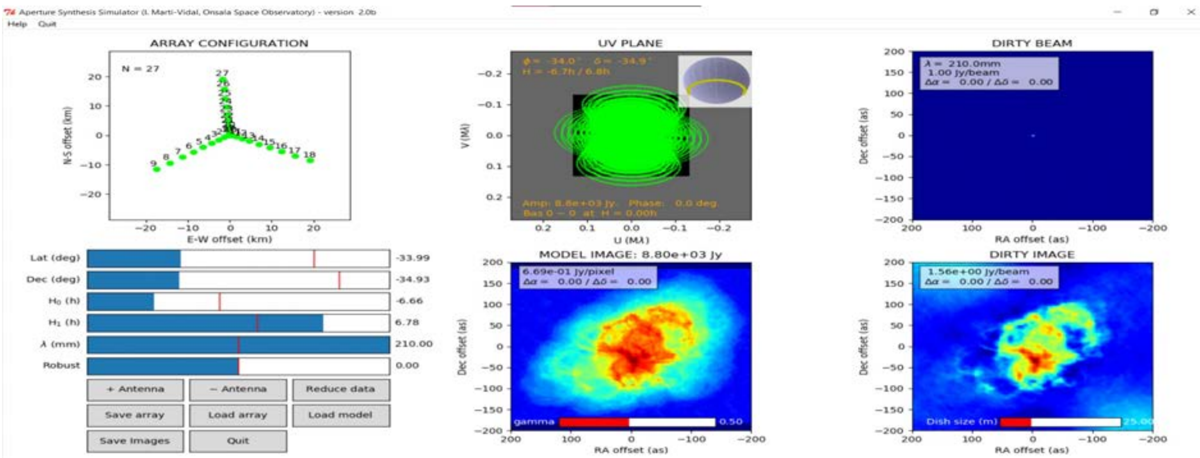

Fig. 6. APSYNSIM window.

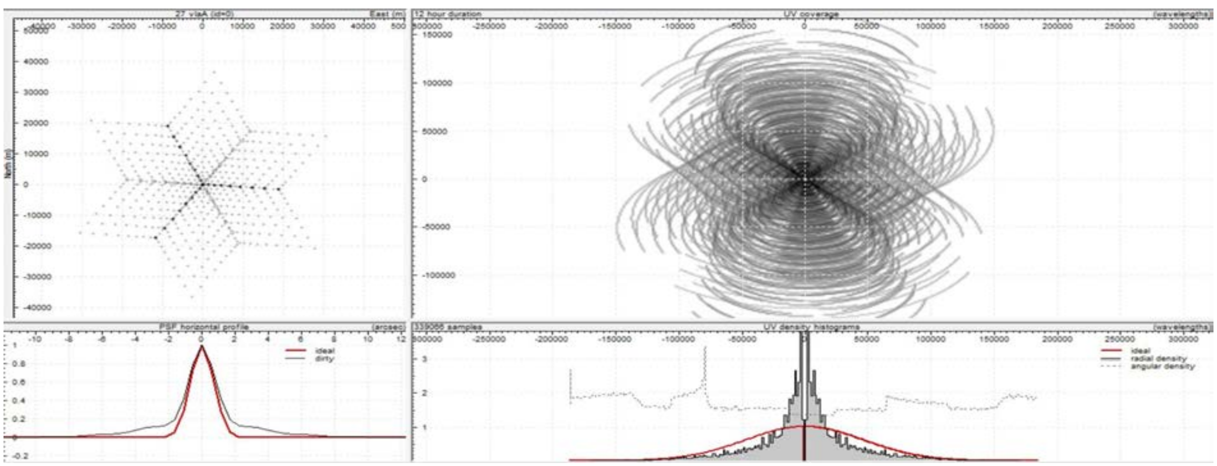

Fig. 7. AntConfig plot section.

of the array.

Because this is a different kind of simulator, it has different advantages, such as:

- it is easy to load a new array, what is accomplished by typing the different locations on a .txt file,
- the simulator is able to carry out optimizations,
- able to dinamically change parameters on the simulation,
- able to open .fits files.

As disadvantages,

- it is only able to do one method of optimization,
- it is unable to display at the same time all the steps in the sense of a linear system, like FriendlyVRI or APSYNSIM.

In summary, AntConfig is able to run optimizations with the most important parameters of an array, which turns it a remarkable tool in the topic of interferometer design.

4. MIA SIMULATIONS

AntConfig was used to run simulations for future MIA observations. The parameters used in the opimtization were:

- equatorial declination and geographical latitude of -34 deg (it is the value of IAR's latitude),
- maximum baseline of 55 km, in order to achieve an agular resolution of 1 arcsec with a 21 cm wavelength receiver.
- Minimum baseline of 150 m, for good complementation with single dish observations.
- Total observing time of 12 hr.

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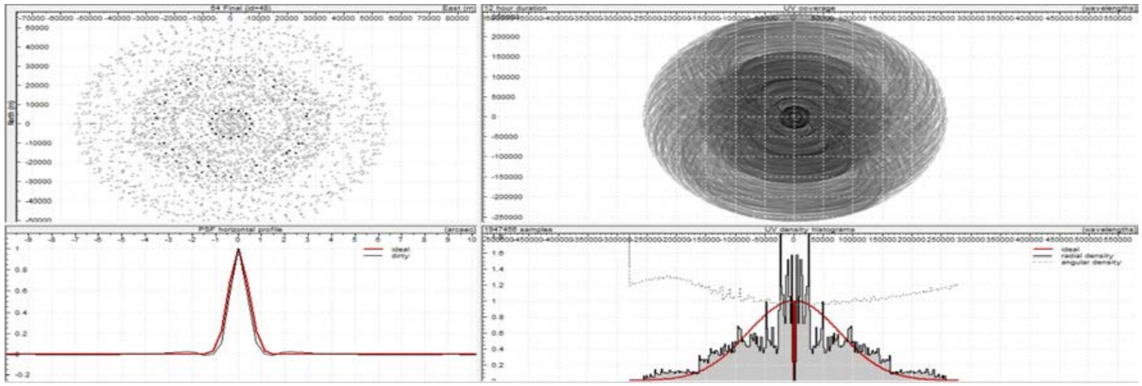

Fig. 8. Result of the optimization for MIA.

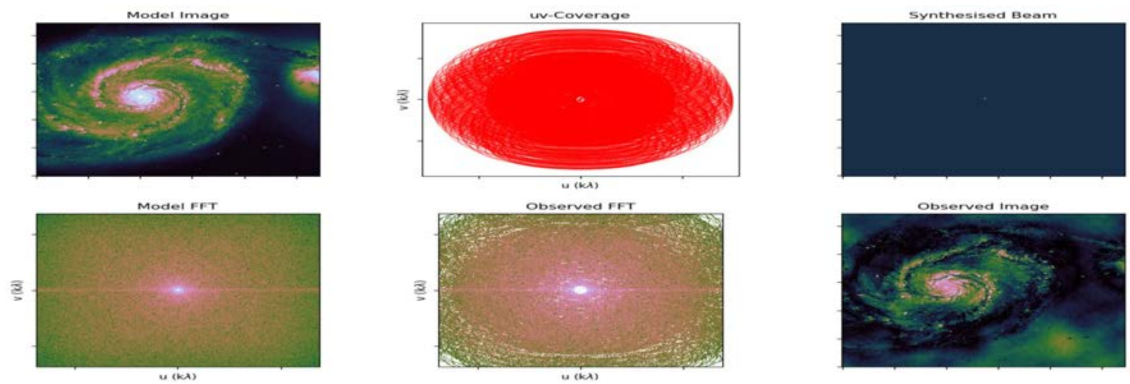

Fig. 9. Simulation of an observation with the optimized array.

- Gaussian beam shape.

The results are shown in Figs. 8, 9 and 10 , where it can be seen how the requirements are reached and how the array can reconstruct an image similar to the original one.

5. CONCLUSIONS AND FUTURE WORK

After reading about the theory and state of the art of radio intererometry and radio interferometers, study and comparison of existing simulators applied to different virtual radio interferometers, could be achieved. At last, by this simulators and the very first parameters to optimize the case of MIA, a case of optimization could be achieved. For future work, the development of a software to optimize an array with a different method or implementation like AntConfig is under way; a software who also involve plots like the described simulators, in order to permit to make an extensive study of different results, and at the end, reach the optimal configuration for MIA.

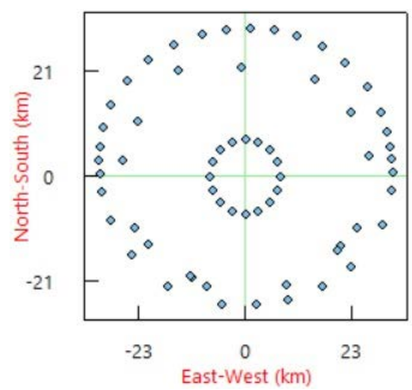

Fig. 10. Optimized location of the antennas.

REFERENCES

Bajaja, E. & van Albada, G. D. 1979, A&A, 75, 251
Boone, F. 2001, A&A, 377, 368
de Villiers, M. 2007, A&A, 469, 793
Emerson, D. 2002, Single-Dish Radio Astronomy: Techniques and Applications, 278, 27
Marti-Vidal, I. 2017, arXiv:1706.00936
Purcell, C., & Truelove, R. 2017, Macquarie University, Sydney, USA.
Thompson, A. R., Moran, J. M., & Swenson, G. W. 2017, Interferometry and Synthesis in Radio Astronomy, 3rd ed. Springer

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