Introduction to the basic concepts and terminology of radio interferometry

ALMA
EUROPEAN ARC
ALMA Regional Centre || Germany

universitätbonn

Universität zu Köln

ALMA community days

German ARC node – March 2017

Outline

Part 1: by Á. Sánchez-Monge

- Introduction to aperture synthesis
- Interferometers: spatial filters

Part 2: by Á. Sánchez-Monge

- Interferometers: spectral setup
- An overview of receivers and correlator

Part 3: by Y. Pidopryhora

- The sensitivity of an interferometer

Part 1:

aperture synthesis, spatial filters

German ARC: ALMA community days (March 2017)

Telescopes … vs Radiotelescopes

Il “cannocchiale” di Galileo

Galileo Galilei

Telescopes … vs Radiotelesc

Where should I put the eye?

Il ***NUOVO*** “cannocchiale” di Galileo (a Sardinia)

Galileo Galilei

Atacama Large Millimeter/submillimeter Array

Image credit: Mélisse Bonfand

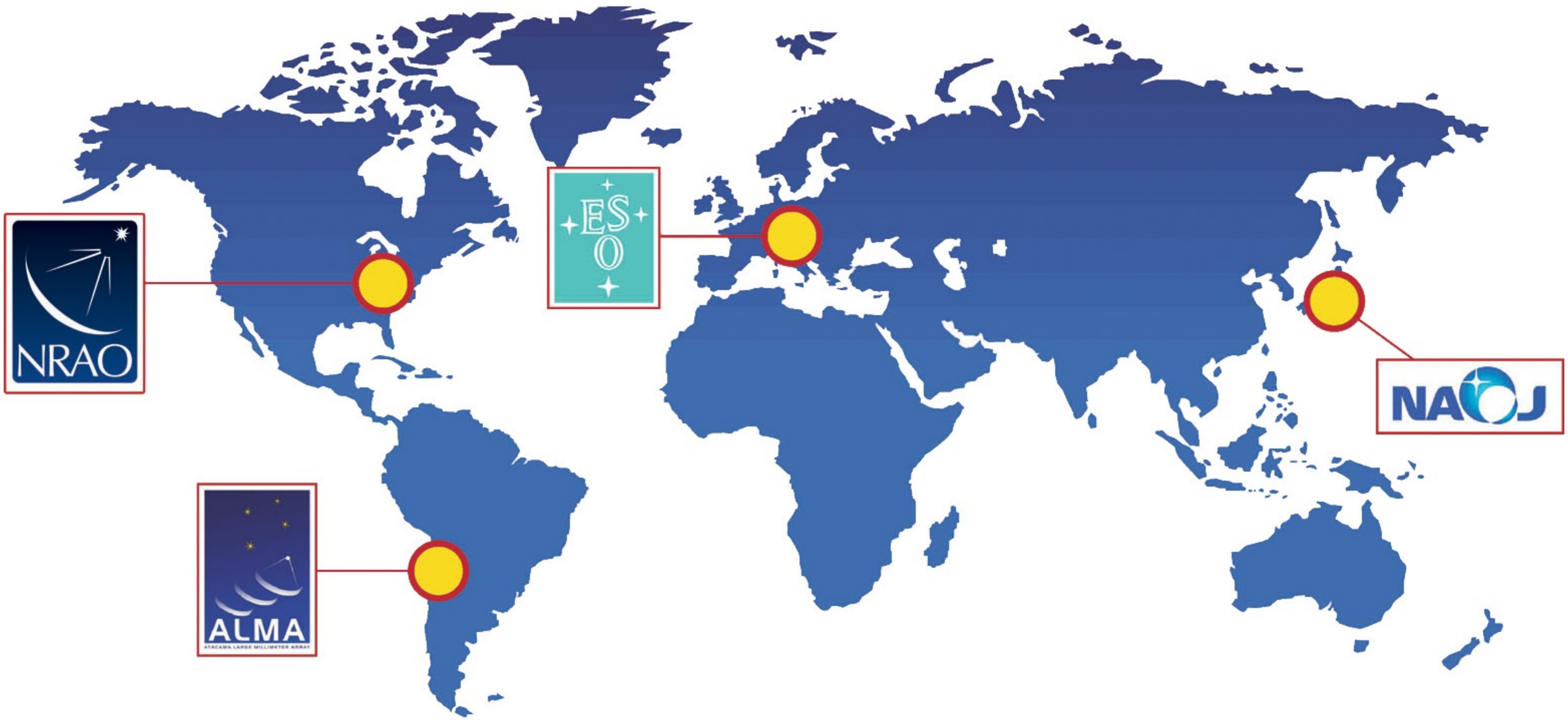
Where is ALMA?

Atacama desert (Chile)

… on the Chajnantor Plateau
at 5000 m height

… control center
at 2900 m height

What is ALMA?



International collaboration:

3 ARC (ALMA Regional Centers) + JAO (Joint ALMA Observatory)

What is ALMA?

ALMA in Cycle 5 is …

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43x	**12m antennas**
10x	7m antennas (ACA)
3x	12m antennas (TP)

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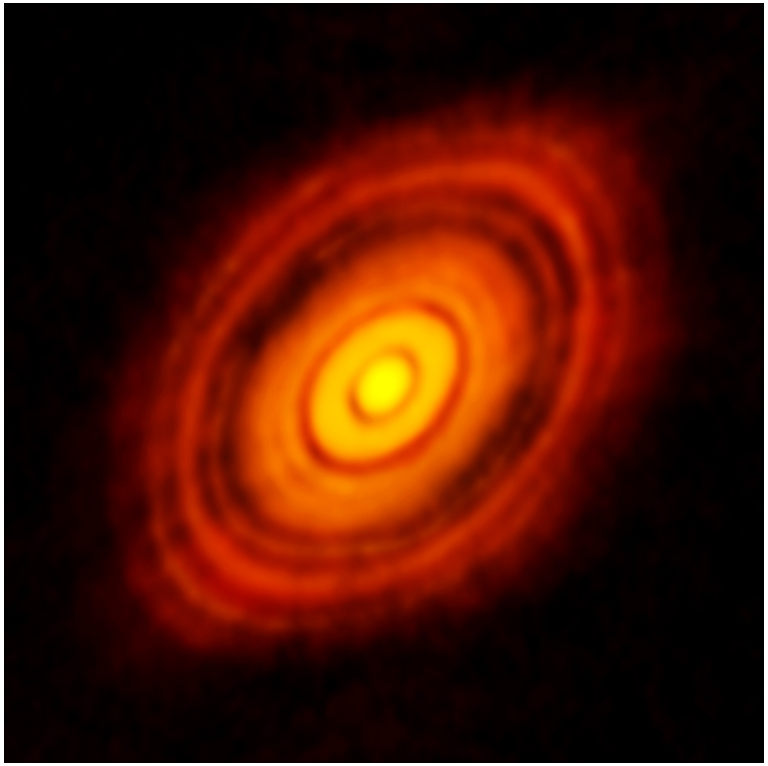
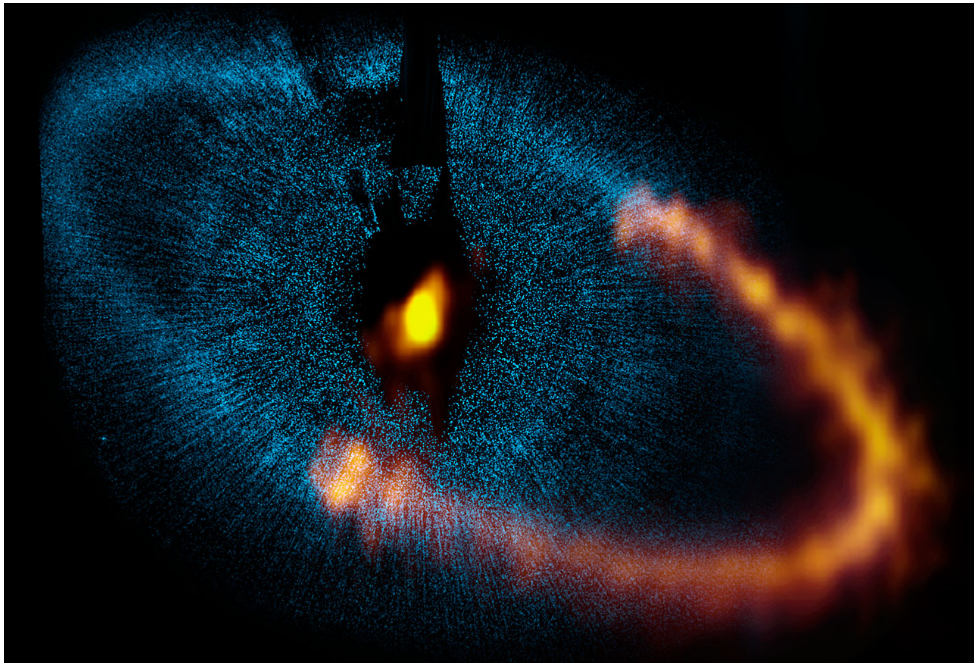
What can ALMA do?

HL Tau



protoplanetary disks

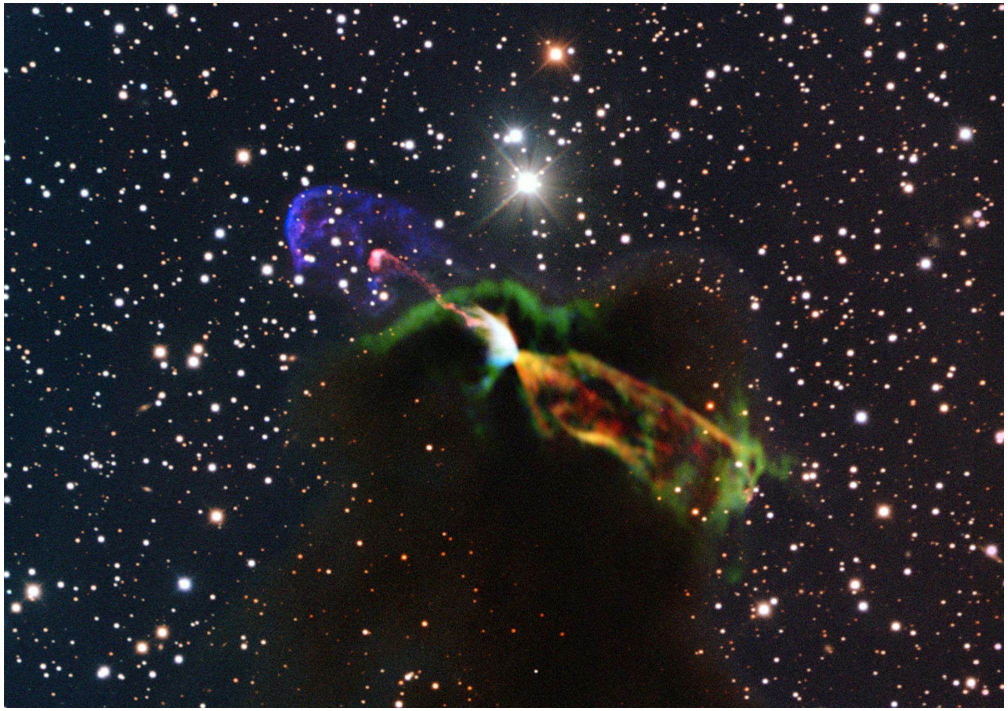
Formalhaut



debris disks

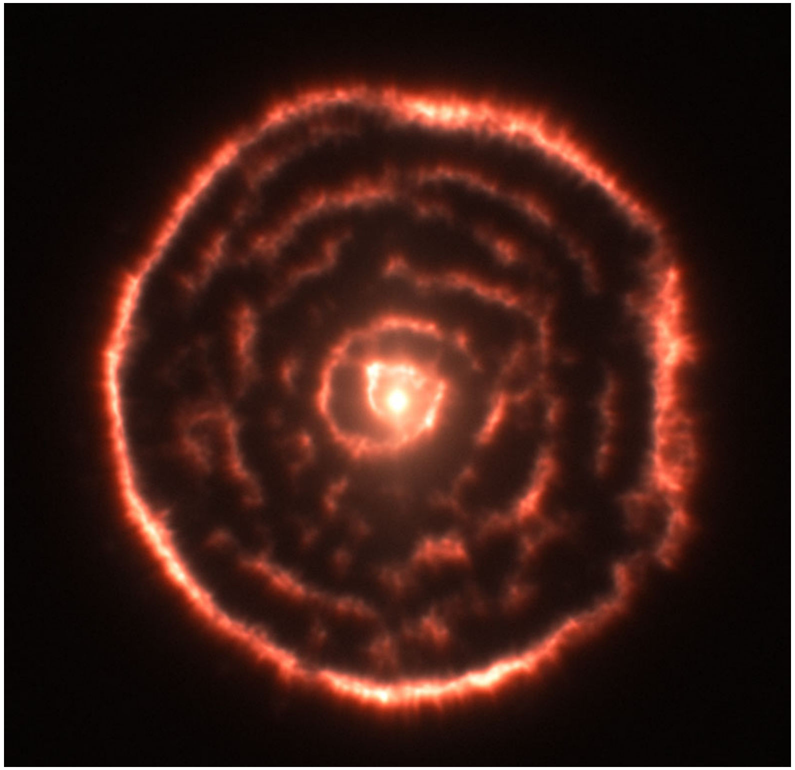
What can ALMA do?

Herbig-Haro 46/47



molecular outflows and jets

R Sculptoris



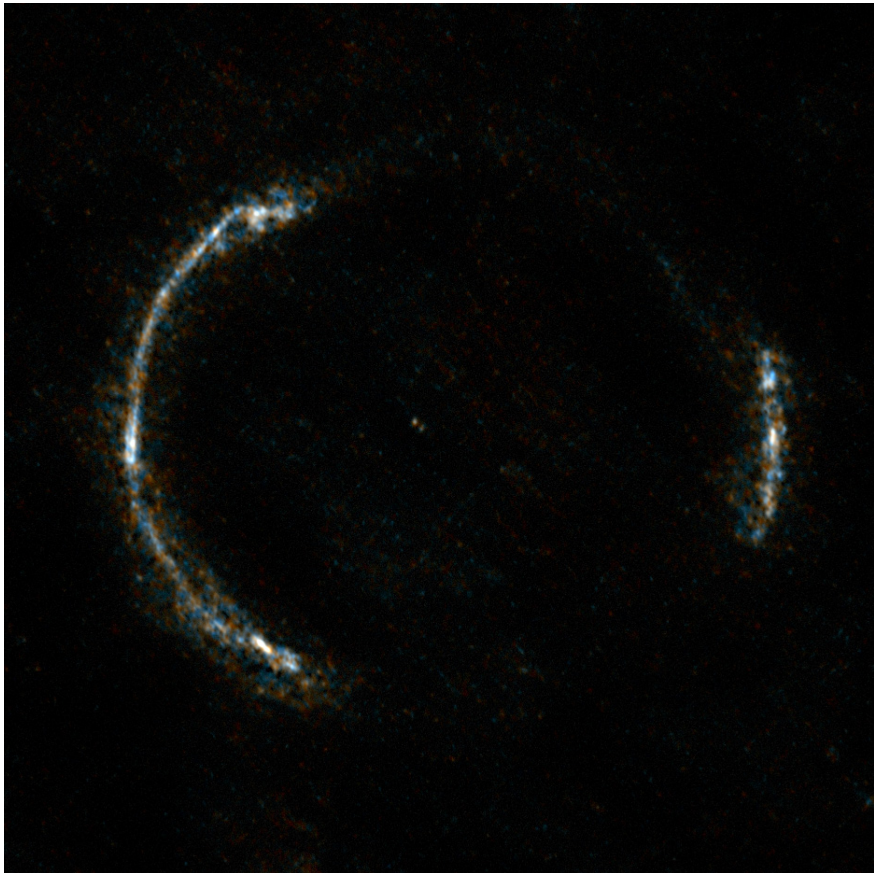
red giants and old stars

What can ALMA do?

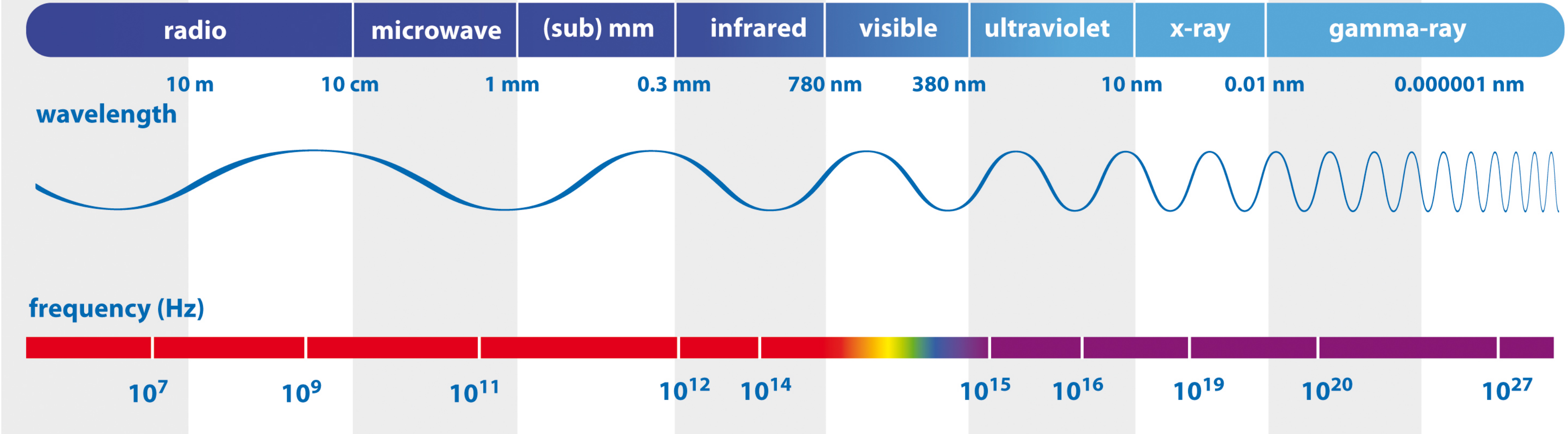
Antennae galaxies

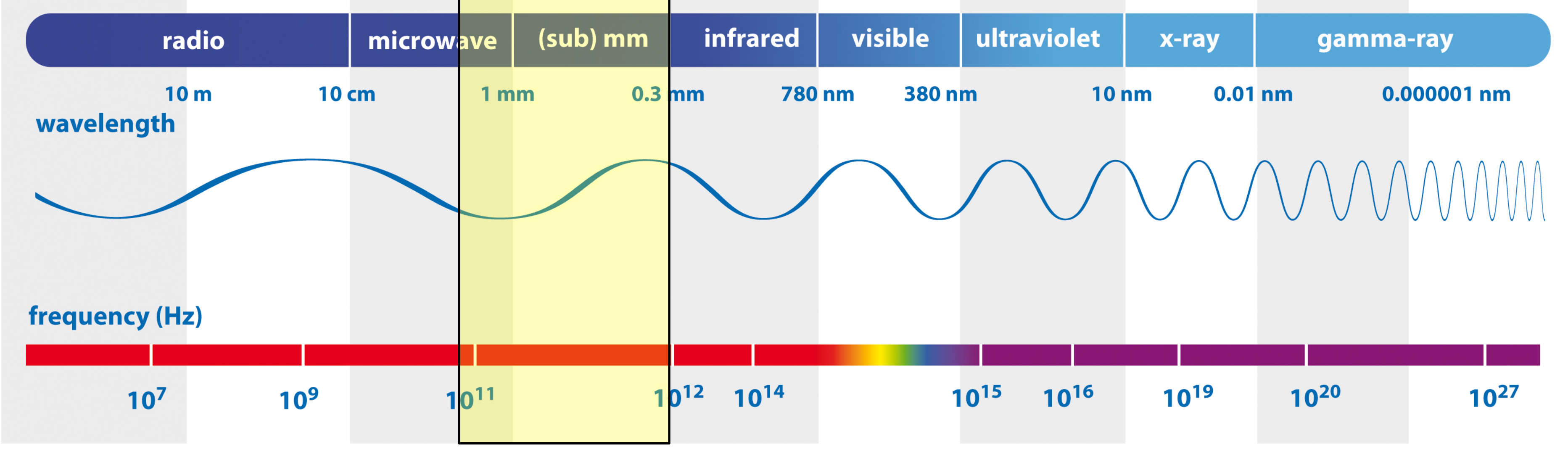
galaxy mergers

SPD.81



lensed galaxies


radio
microwave
(sub) mm
infrared
visible
ultraviolet
x-ray
gamma-ray
10 m
10 cm
1 mm
0.3 mm
780 nm
380 nm
10 nm
0.01 nm
0.000001 nm
wavelength
frequency (Hz)
10^{7}
10^{9}
10^{11}
10^{12}
10^{14}
10^{15}
10^{16}
10^{19}
10^{20}
10^{27}



ALMA observable range

“**Cold Universe**”

Why is ALMA on the Chajnantor plateau?

… at this altitude (5000 m) the water vapor in atmosphere is low

1 feet = 0.3 meters

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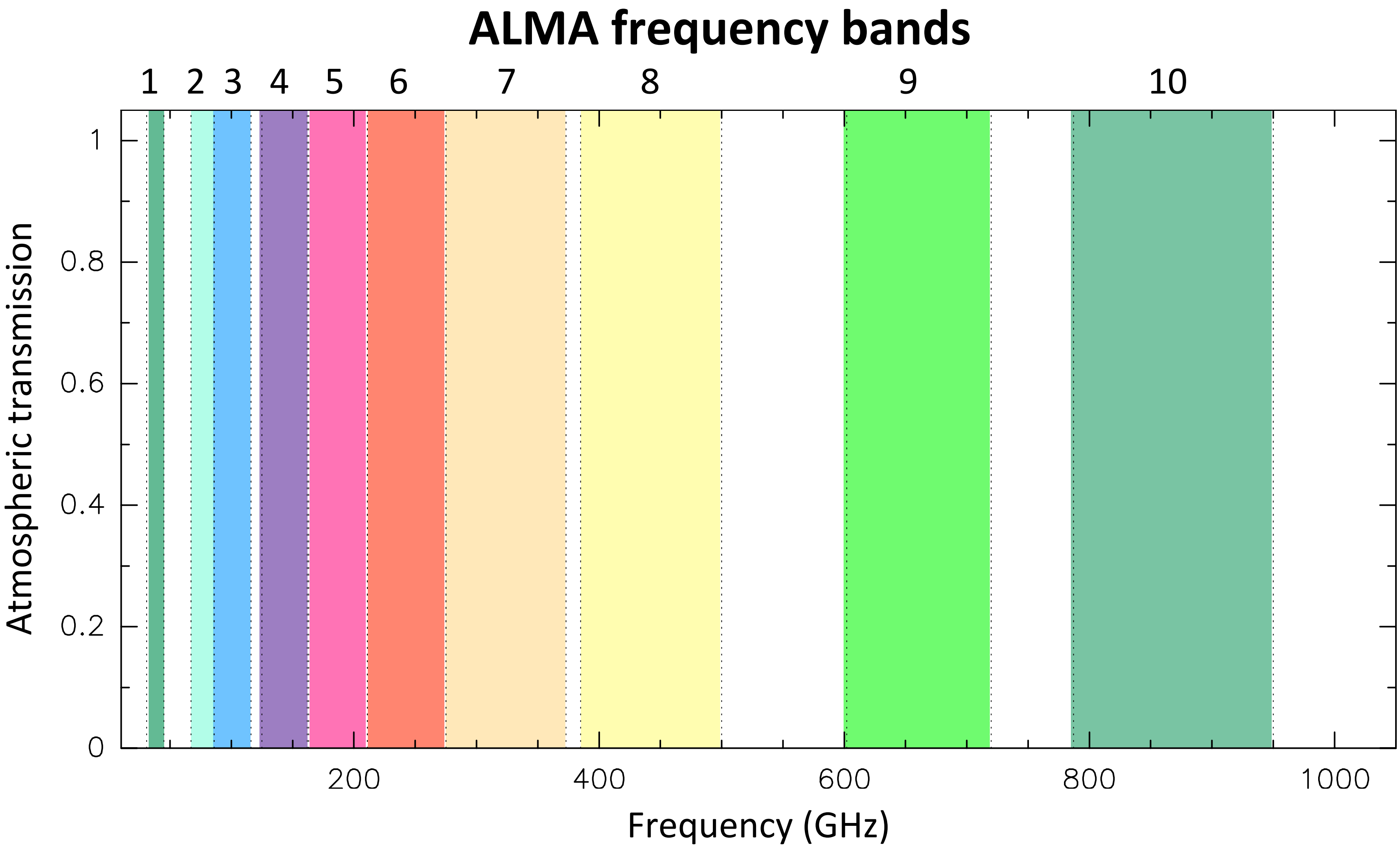

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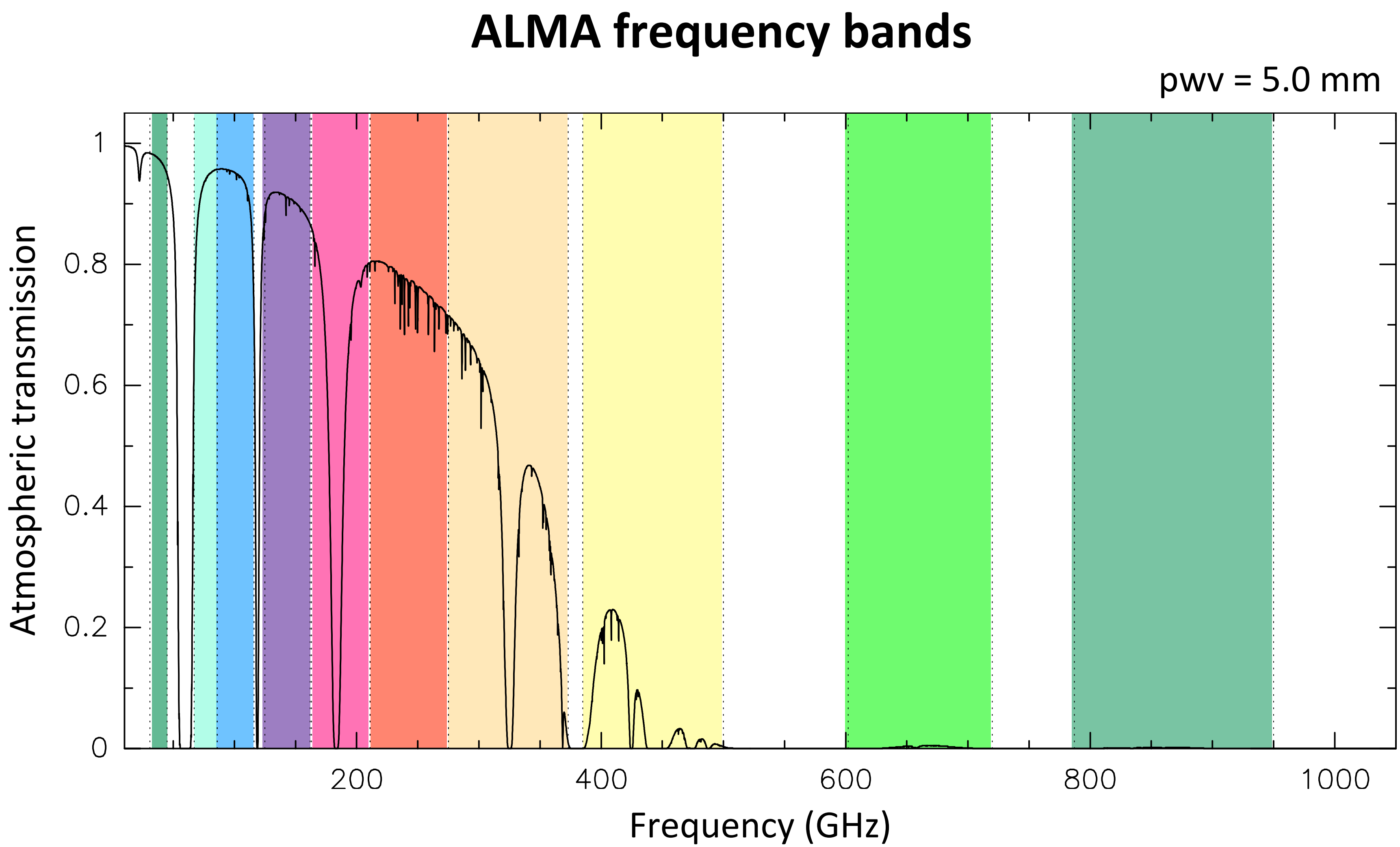

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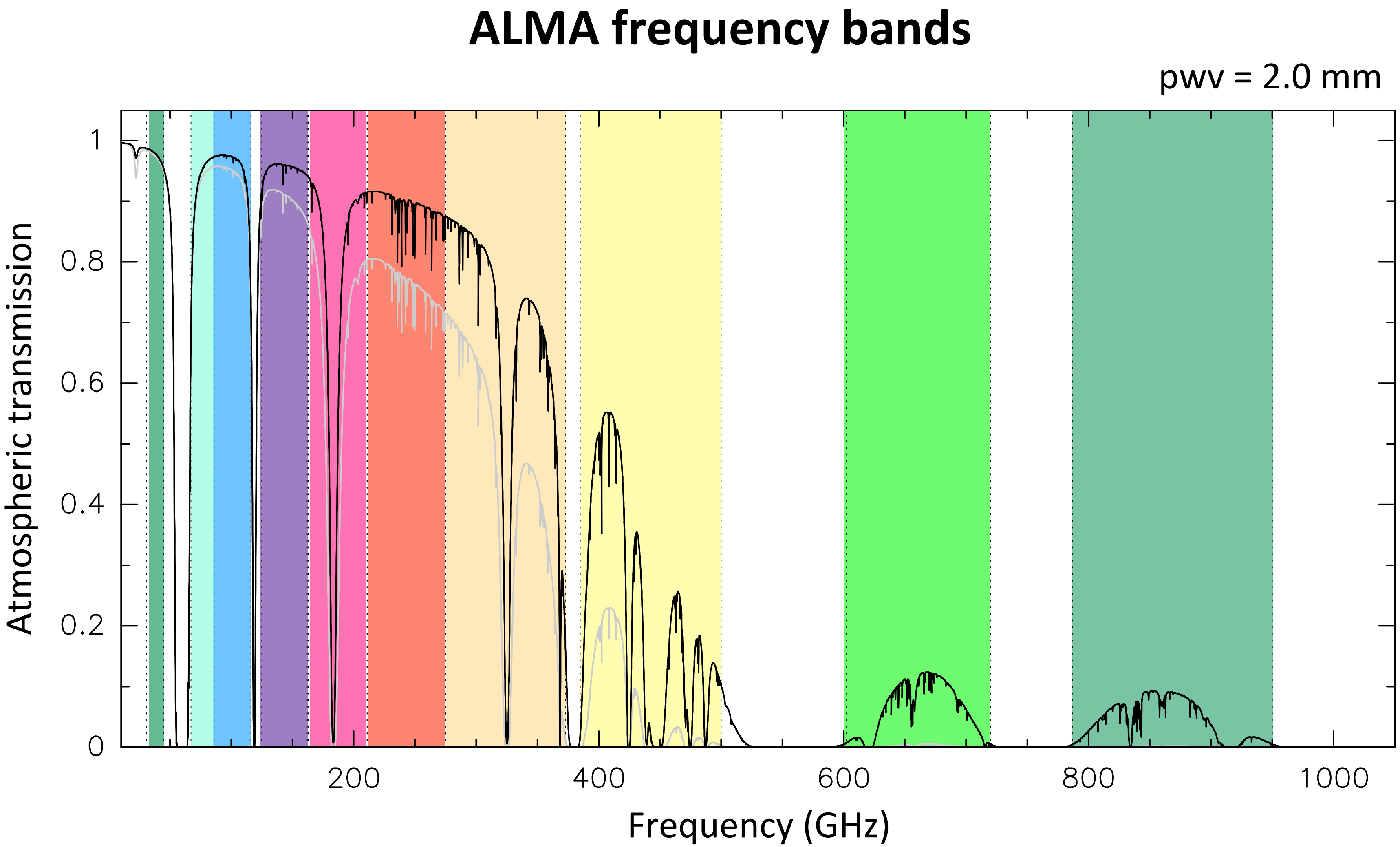

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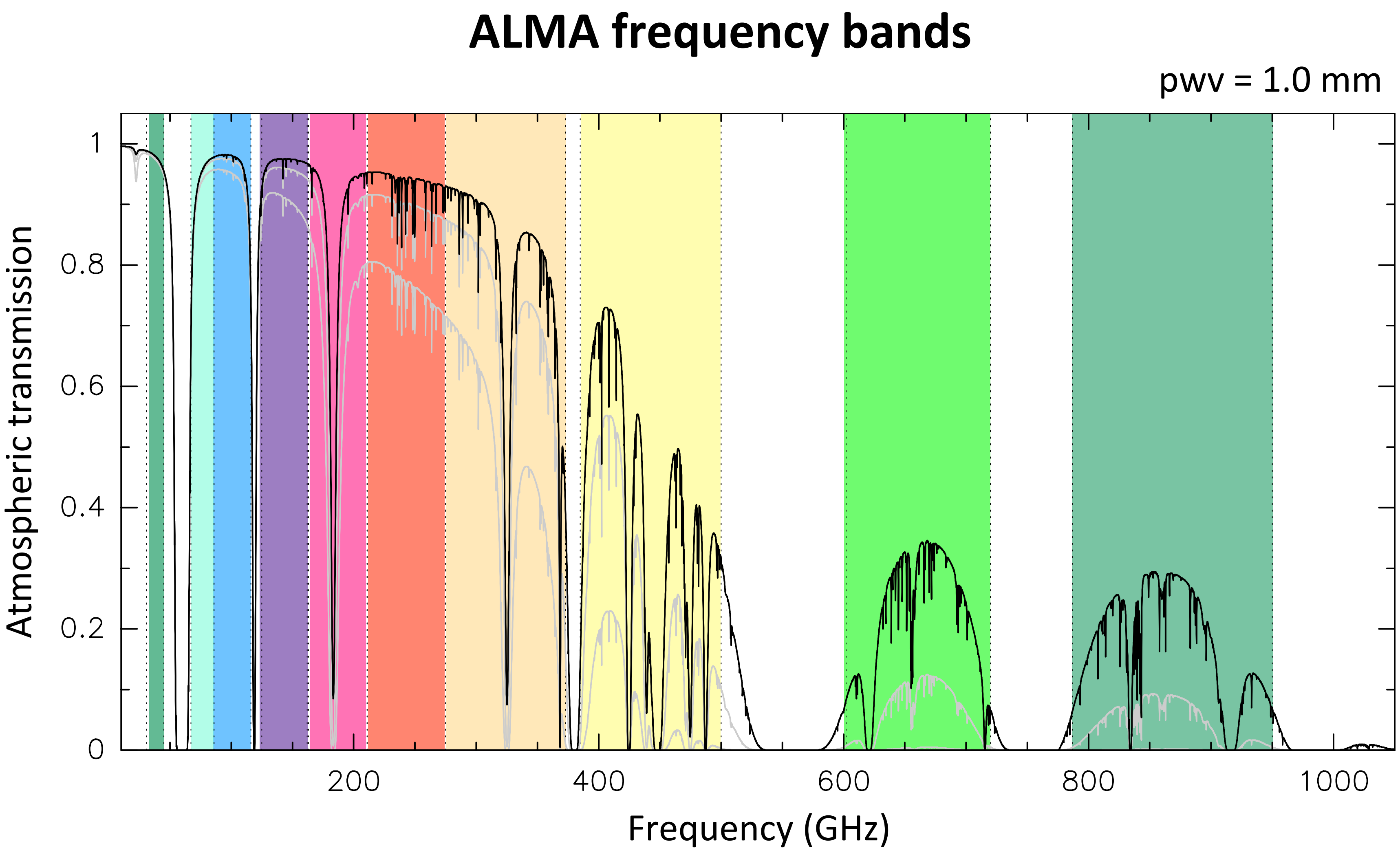

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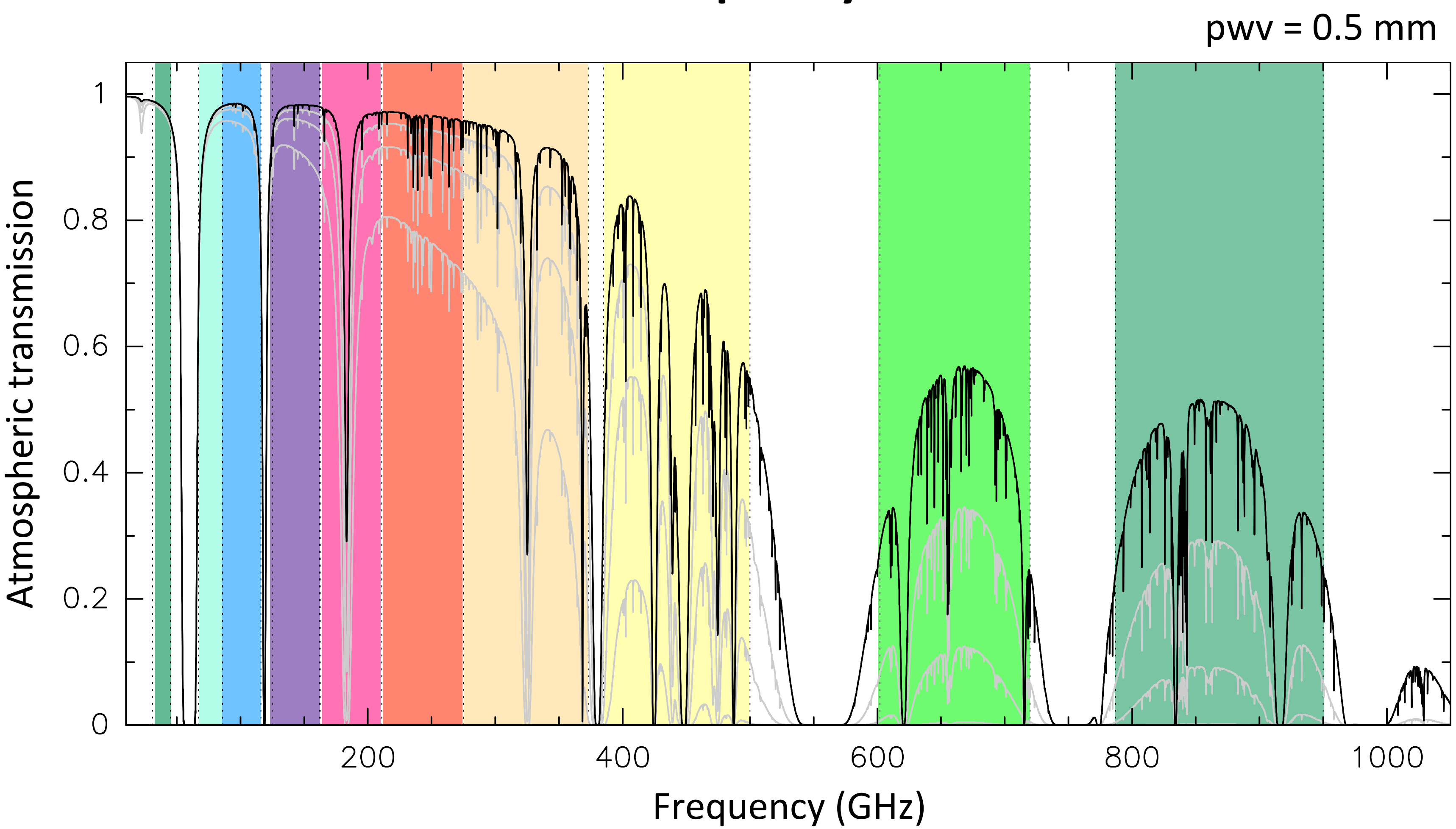
ALMA frequency bands



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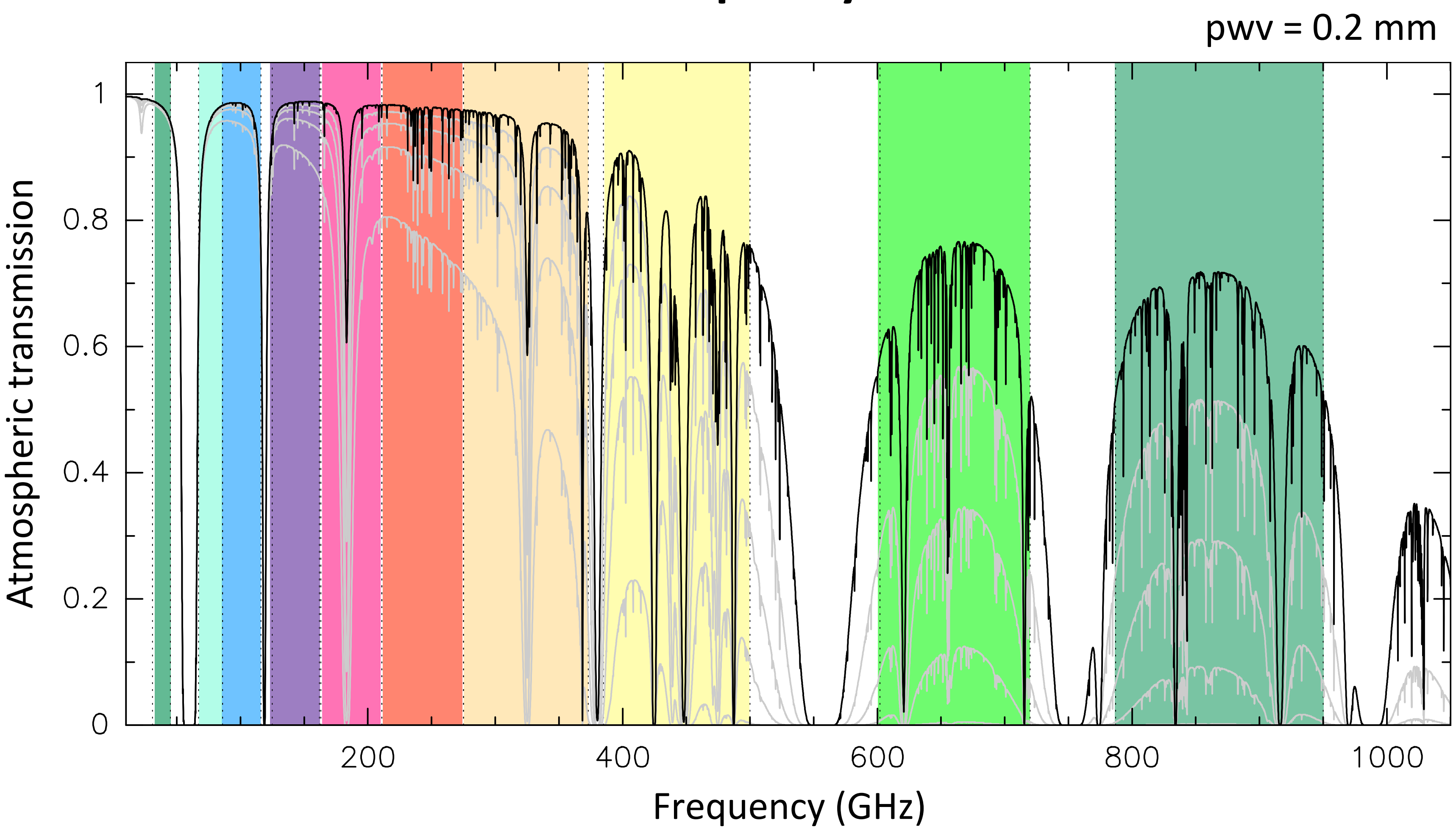
ALMA frequency bands

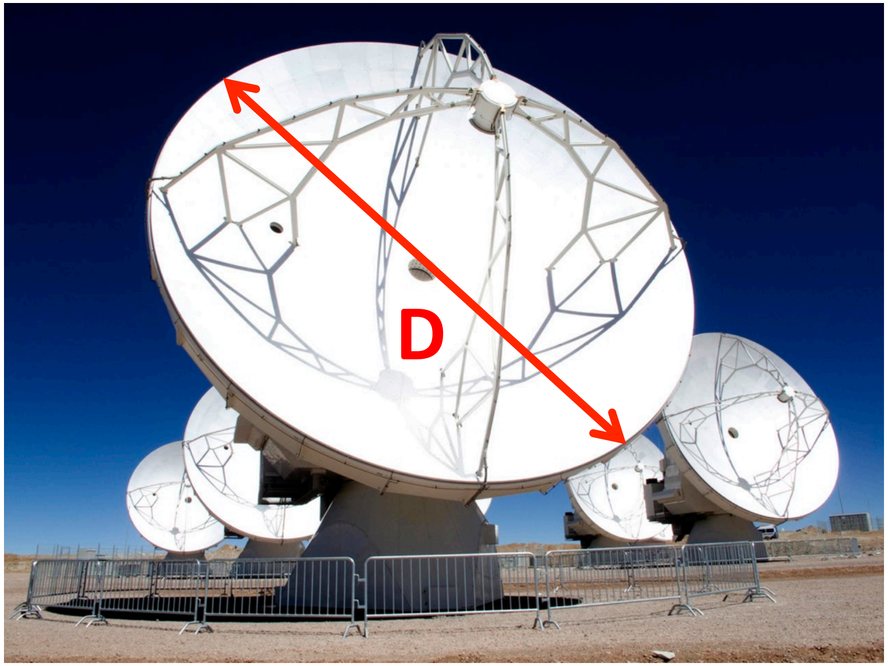


Why so many antennas? … instead of one

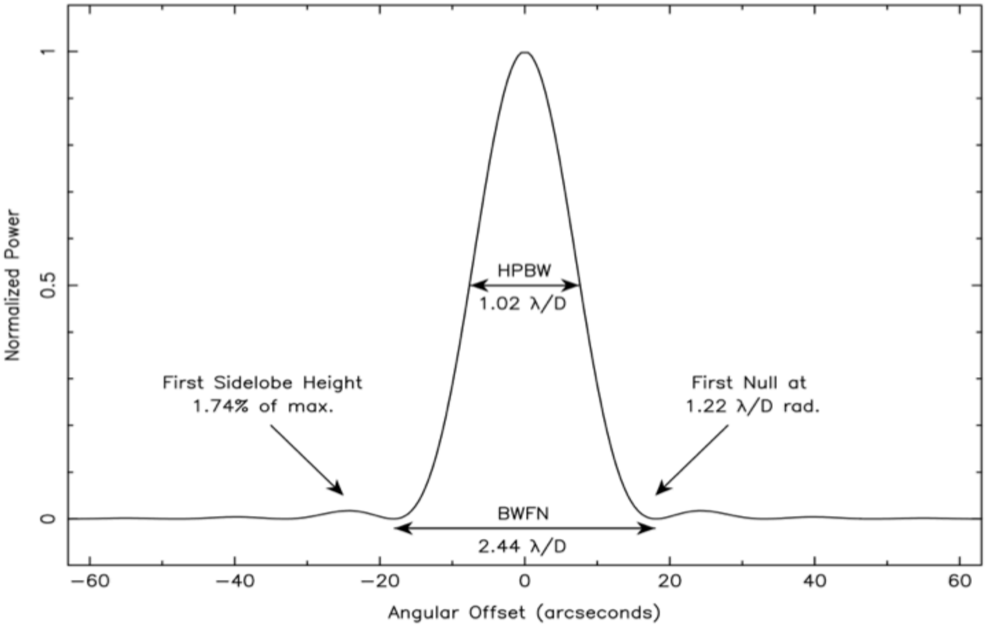
Image credit: Mélisse Bonfand

Single-dish response

Single-dish with diameter D



(1D) antenna power response



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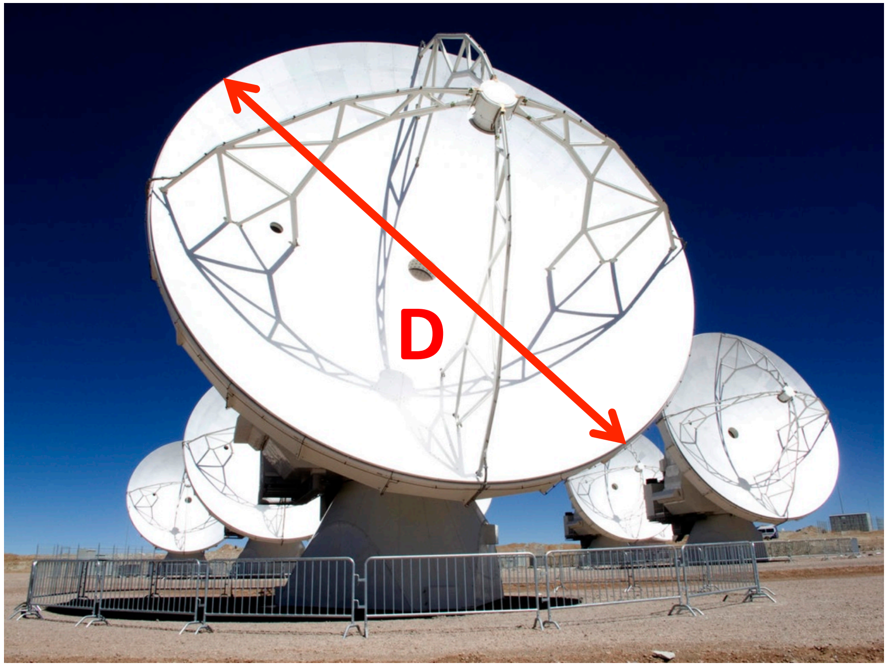

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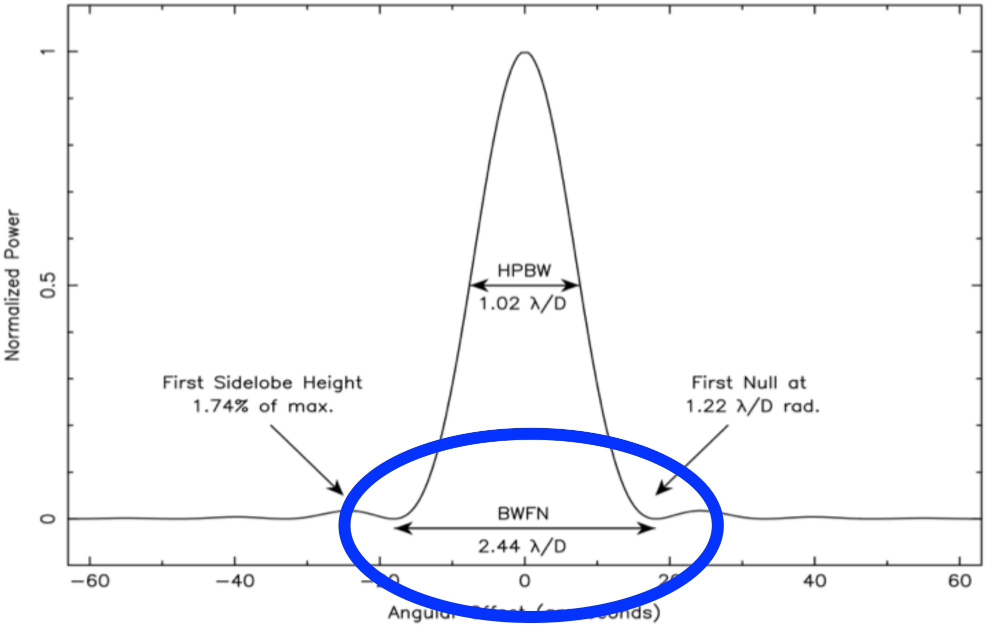
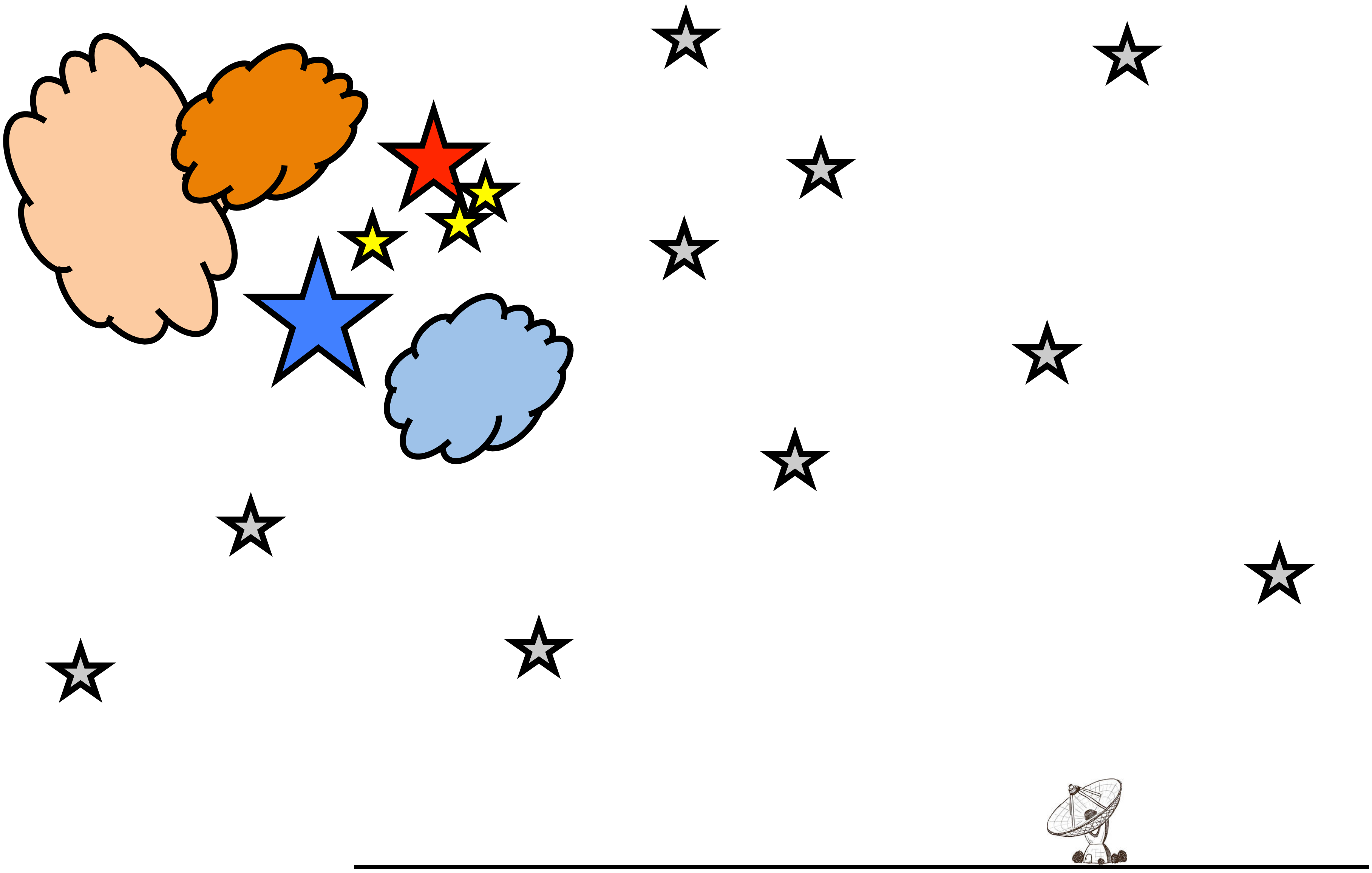


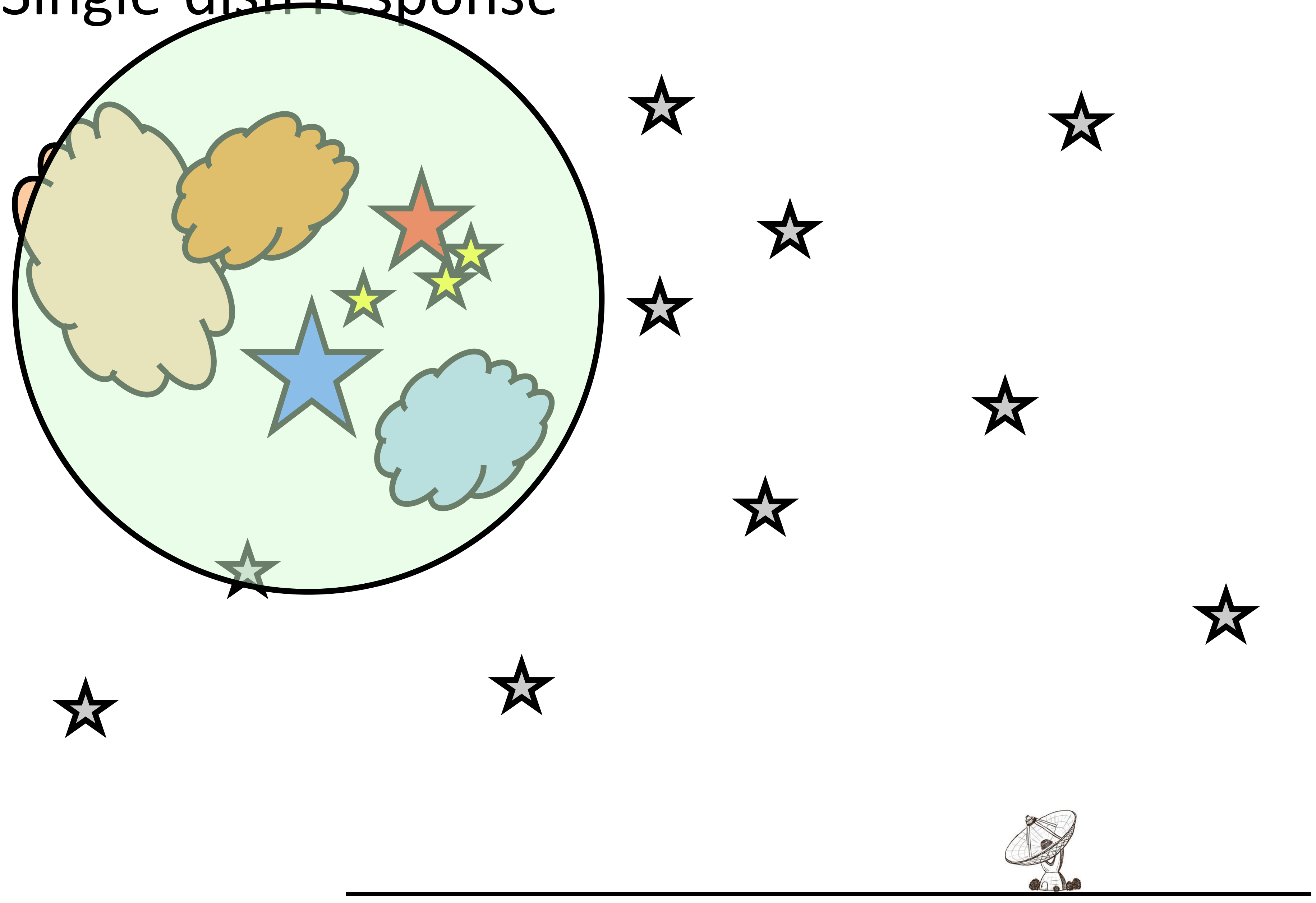
$$PB = 1.22\frac{\lambda}{D}$$

PRIMARY BEAM

Single-dish response



Single-dish response



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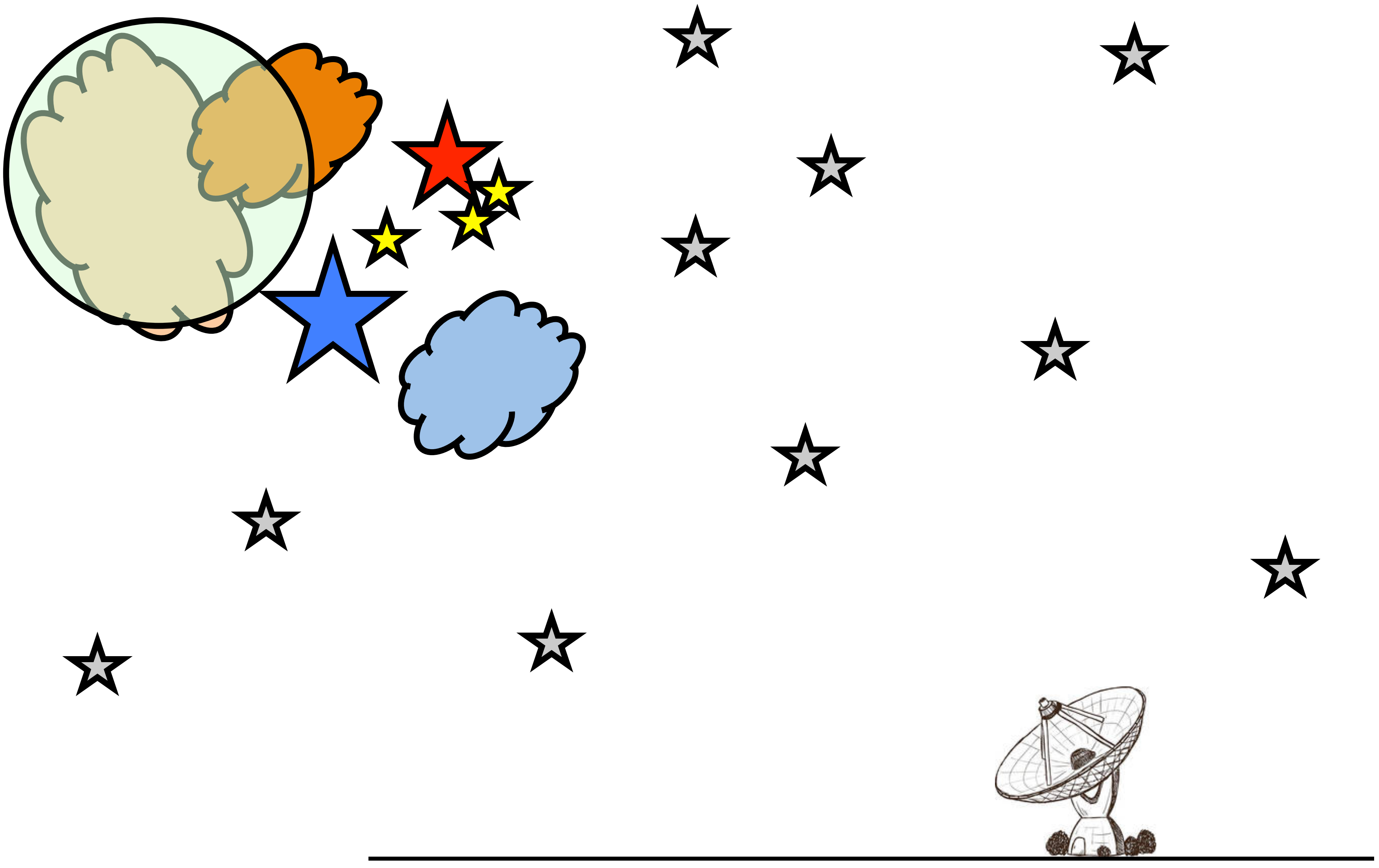

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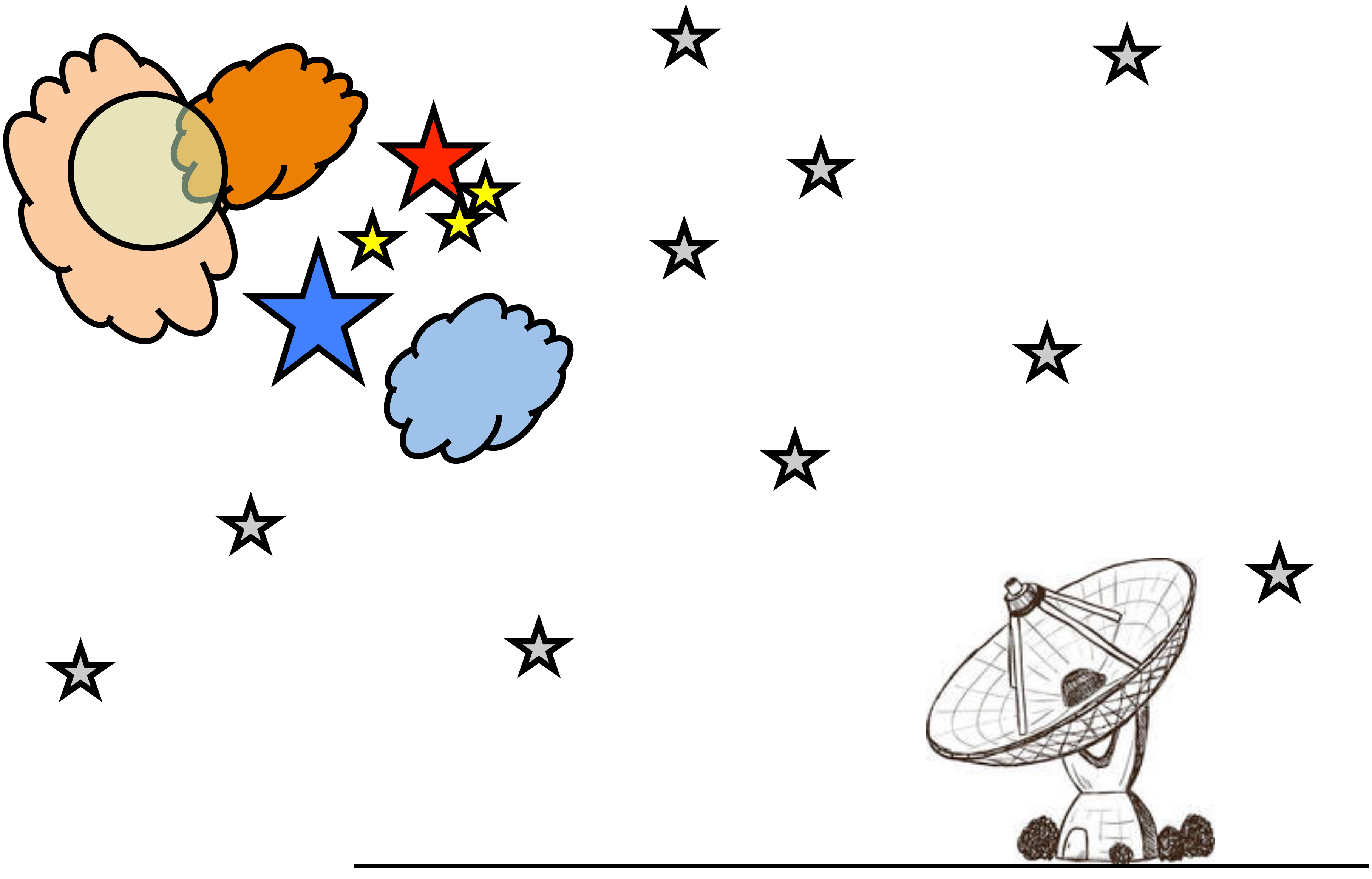

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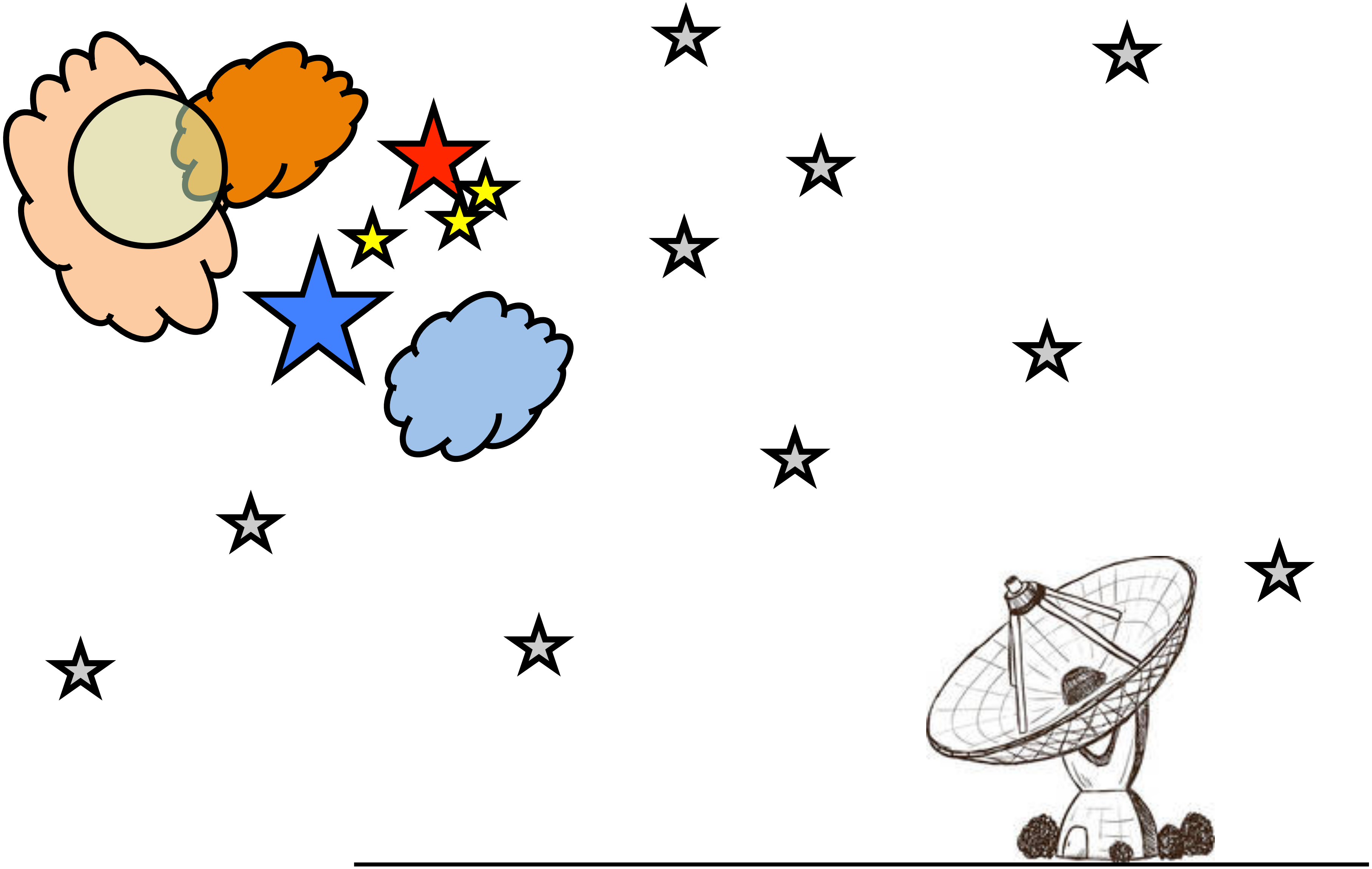

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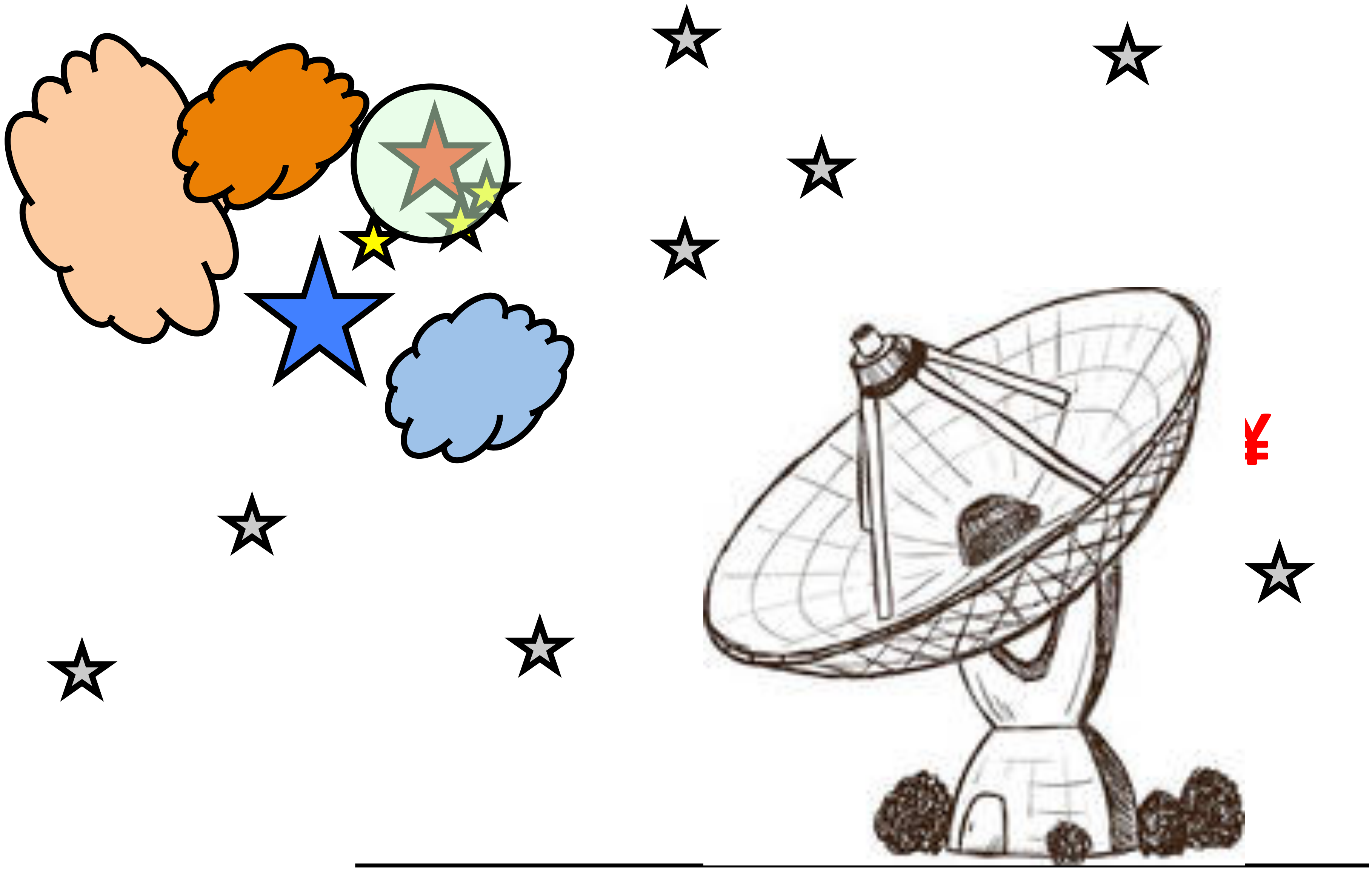

Interferometer – multiple dishes

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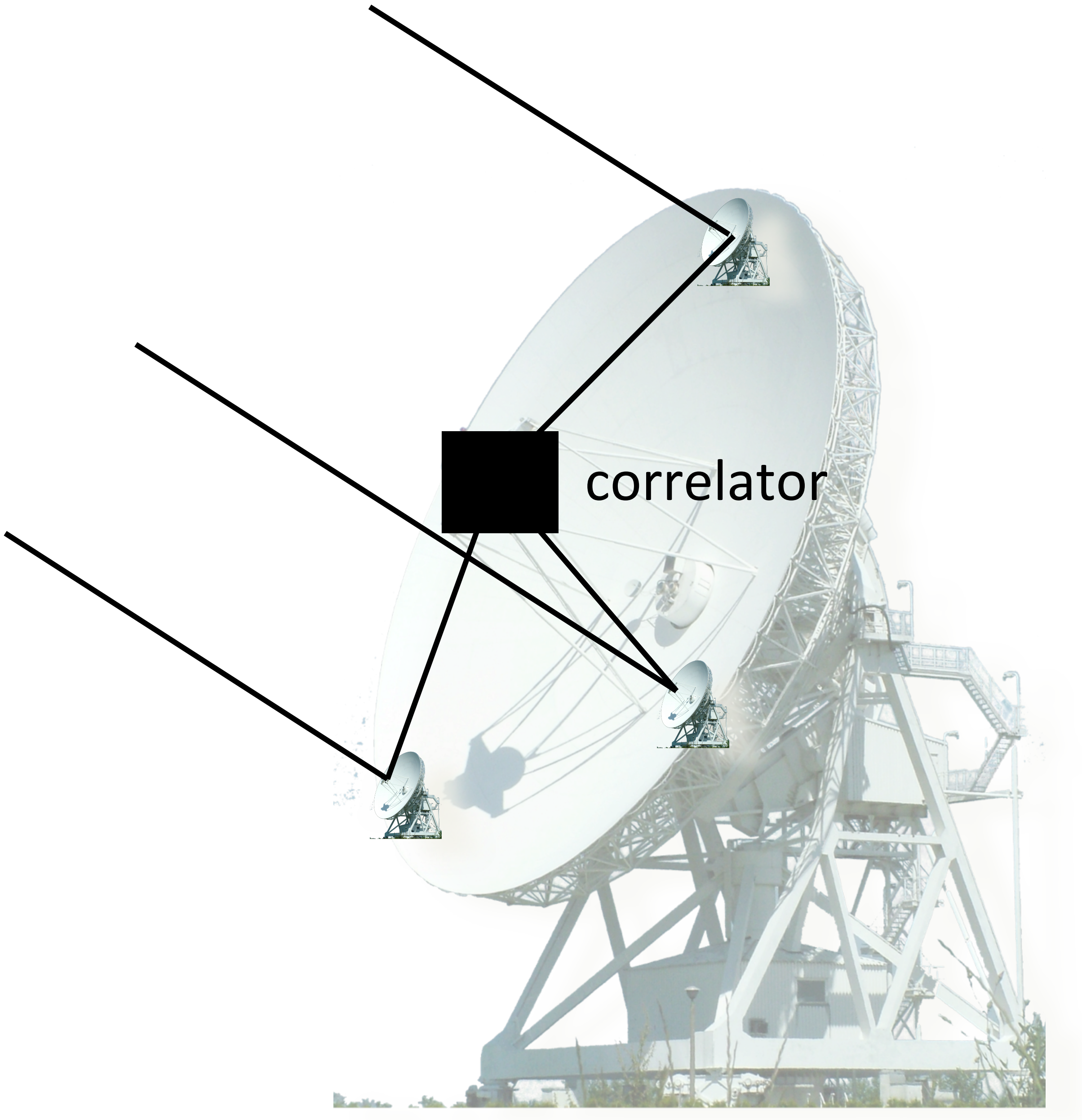

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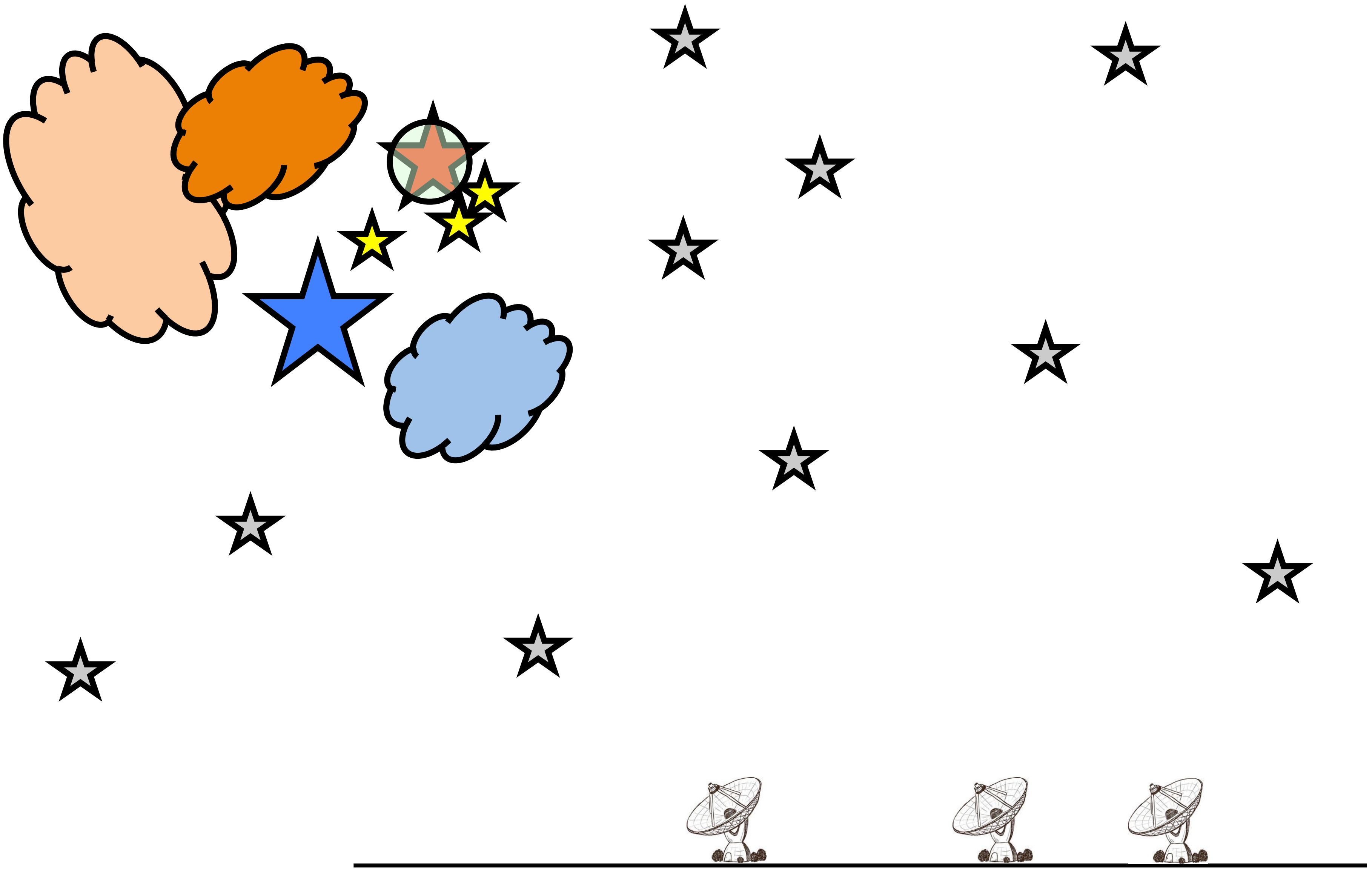

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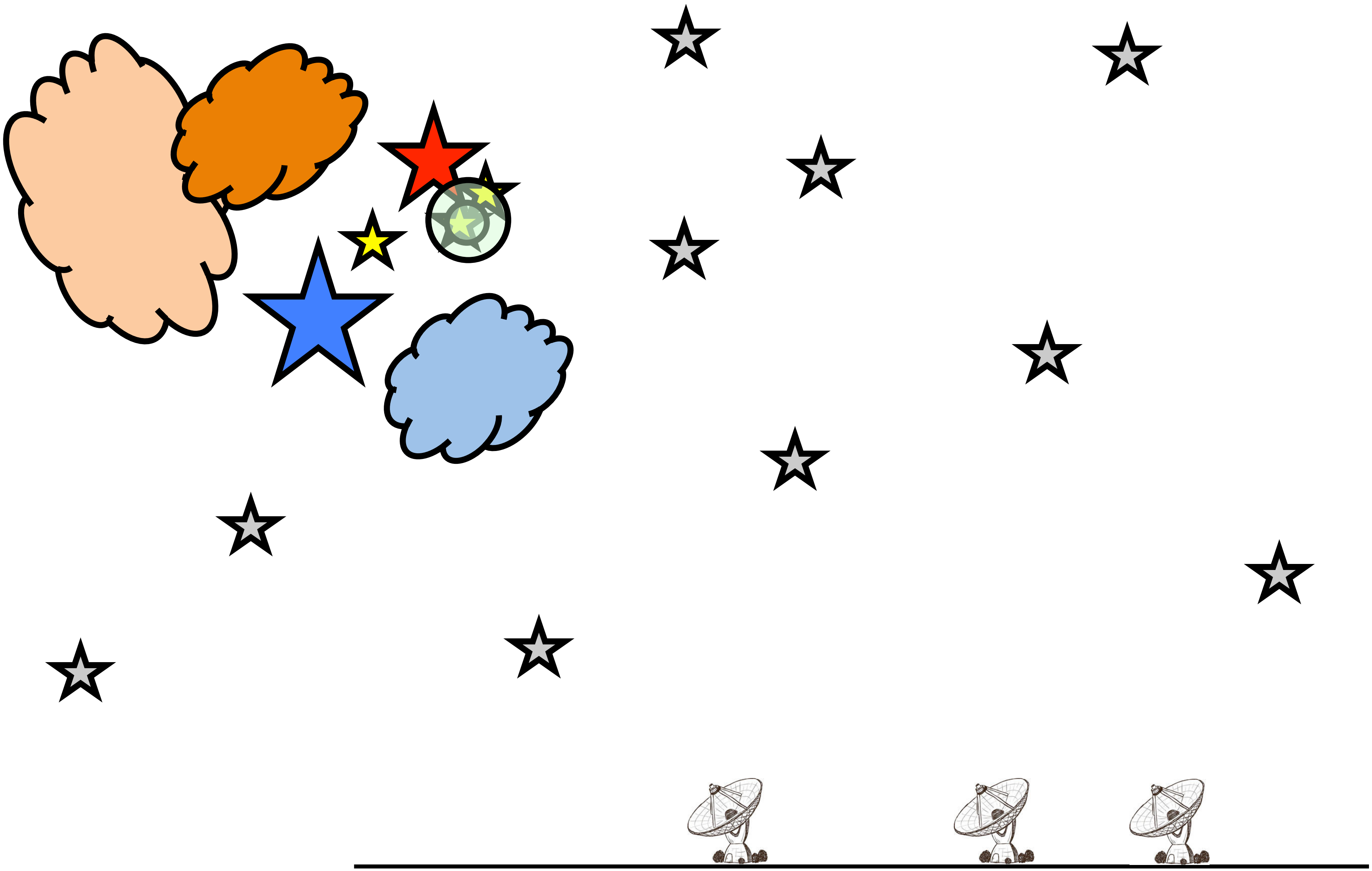
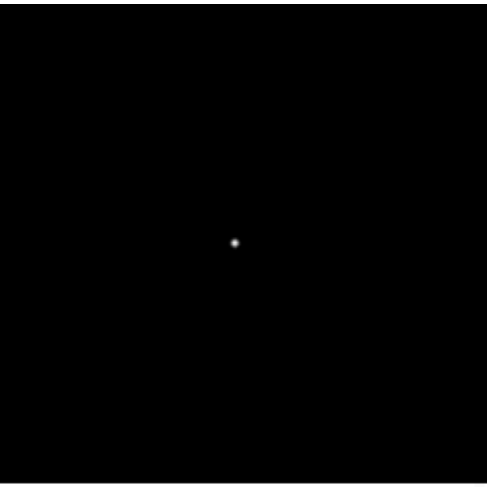


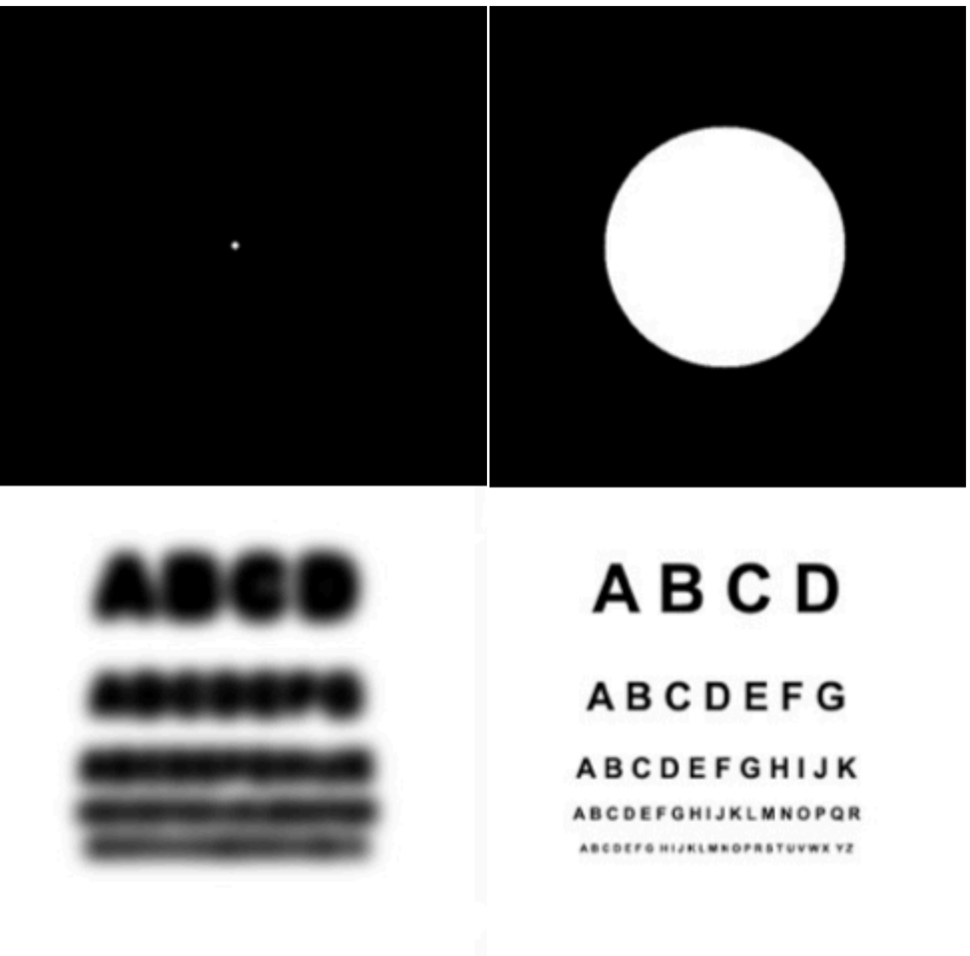
Interferometer – multiple dishes

Small Single-Dish



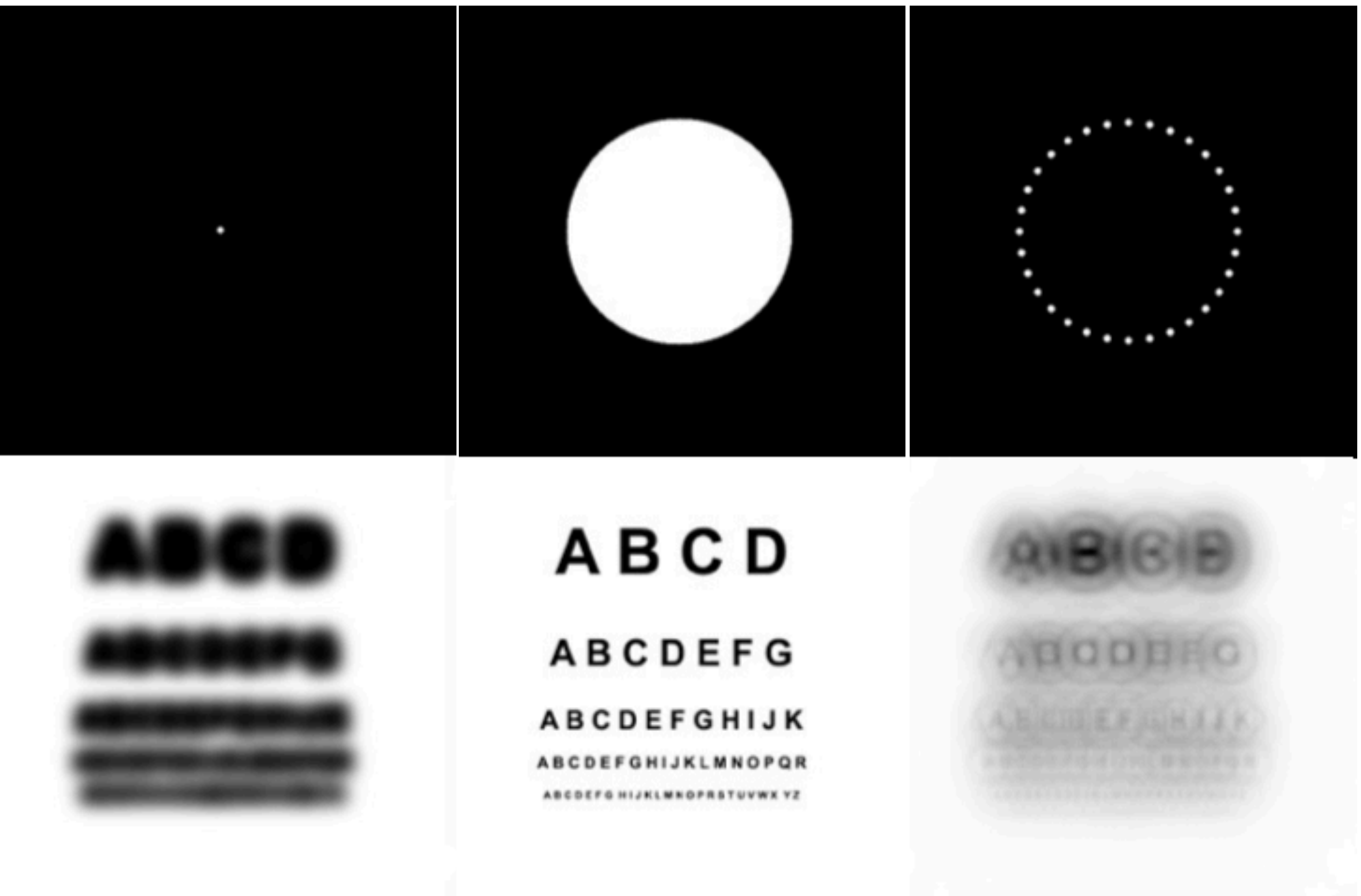
Interferometer – multiple dishes

Large Single-Dish



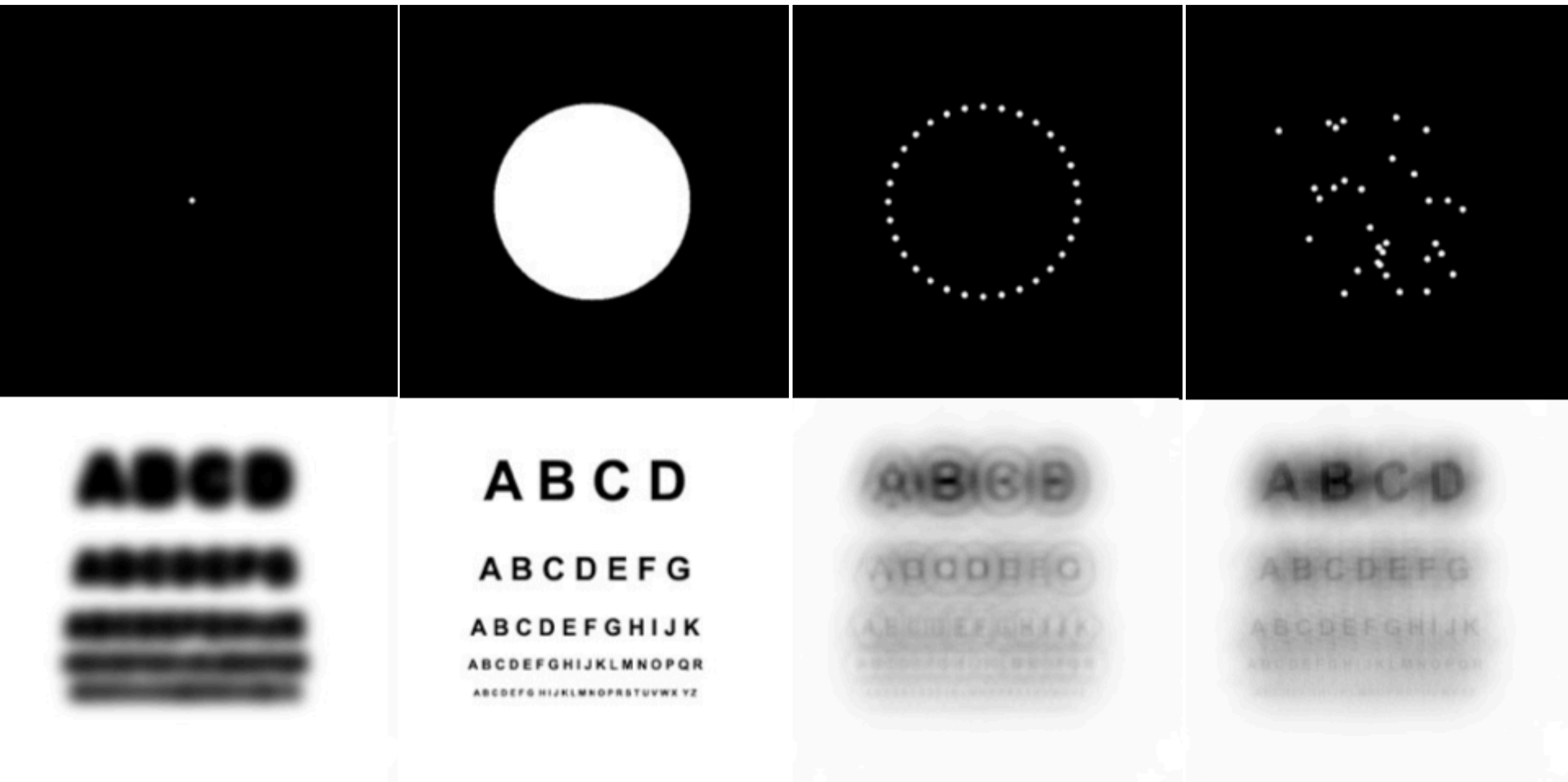
Interferometer – multiple dishes

“Circular” dishes



Interferometer – multiple dishes

"Random" dishes



Interferometry – visibilities

… a bit of equations (Fourier Transform)

$$V(u,v) = \int\int I(l,m)\, e^{2\pi i(ul+vm)}\, dl\, dm$$

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$$V(u,v) = \int\int I(l,m)\, e^{2\pi i(ul+vm)}\, dl\, dm$$

I (l,m)

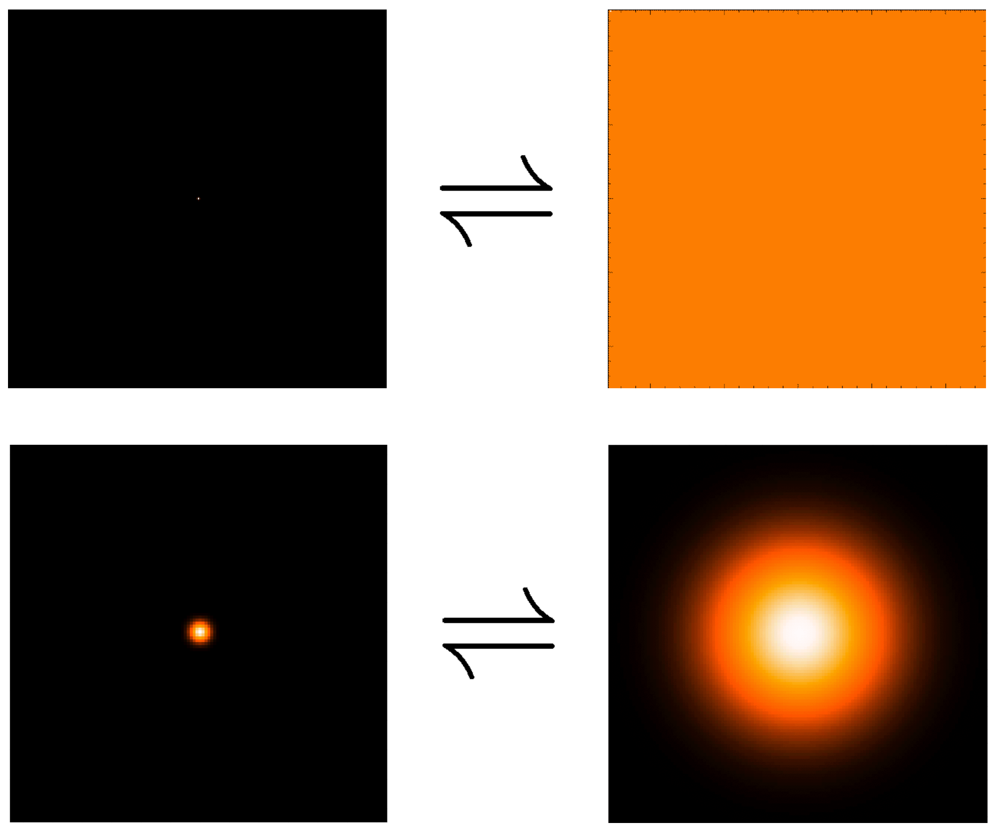
V (u,v)

δ Function

Constant

Gaussian

Gaussian



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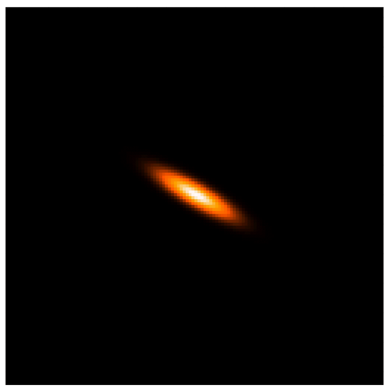
$$V(u,v) = \int\int I(l,m)\, e^{2\pi i(ul+vm)}\, dl\, dm$$

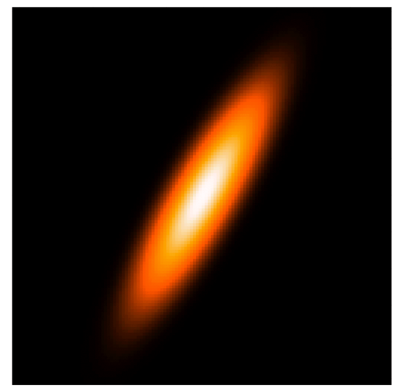
I (l,m)

V (u,v)

elliptical Gaussian

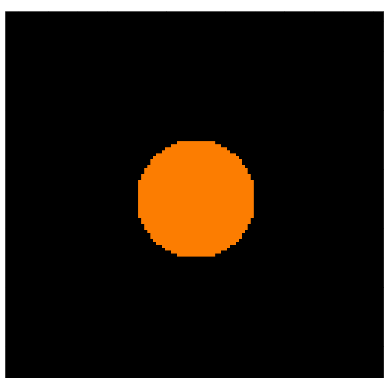


⇌



elliptical Gaussian

Disk



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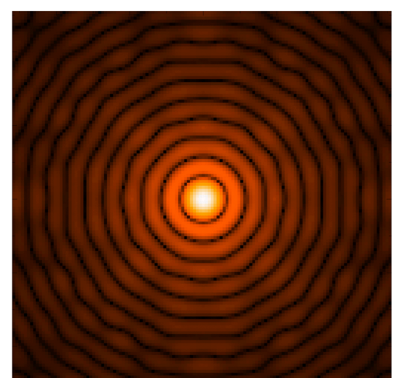
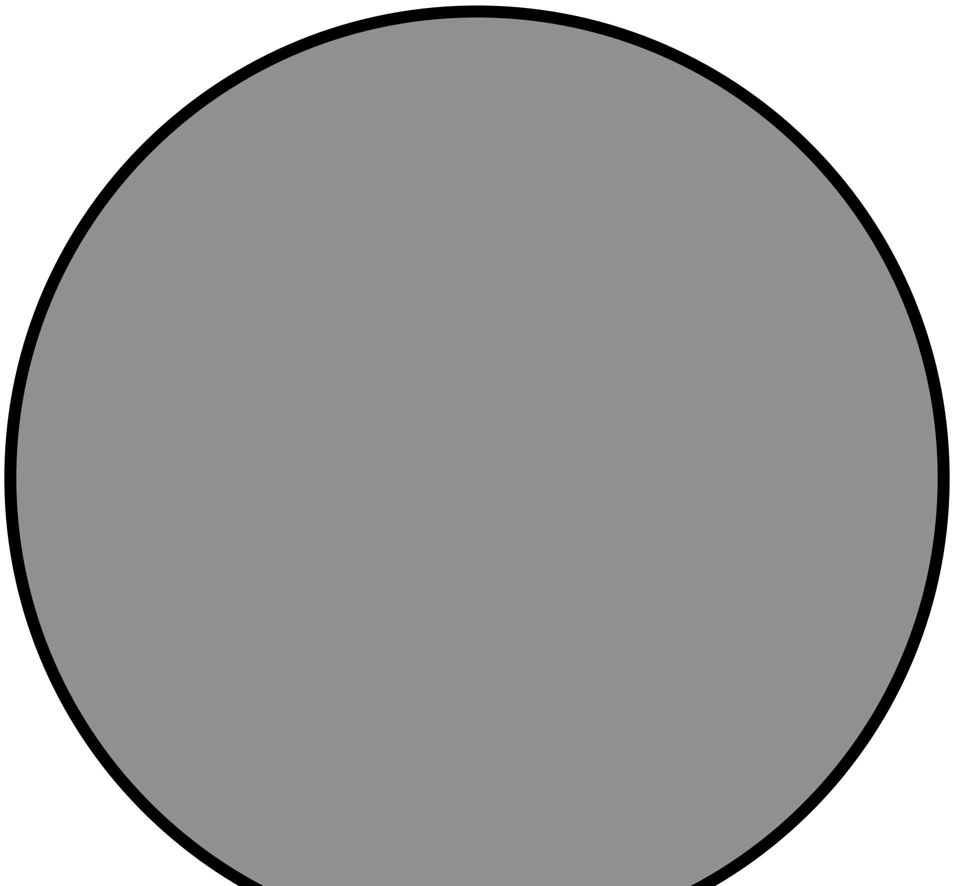
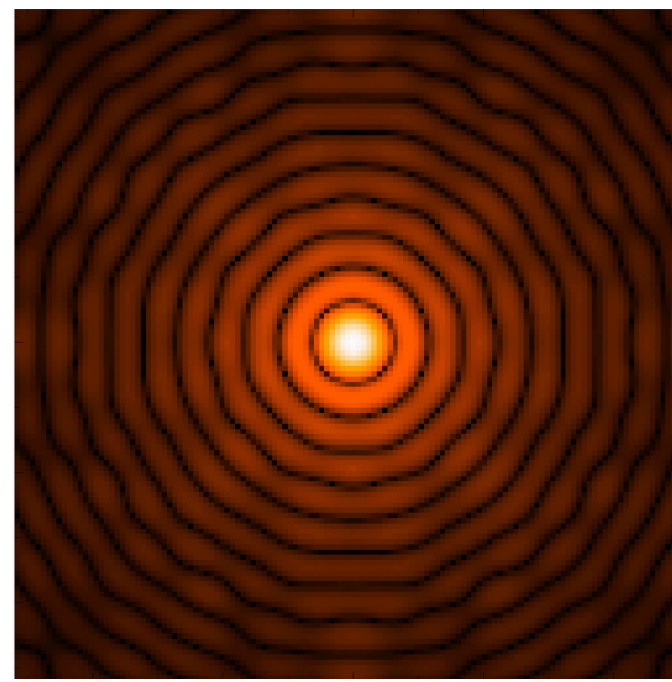


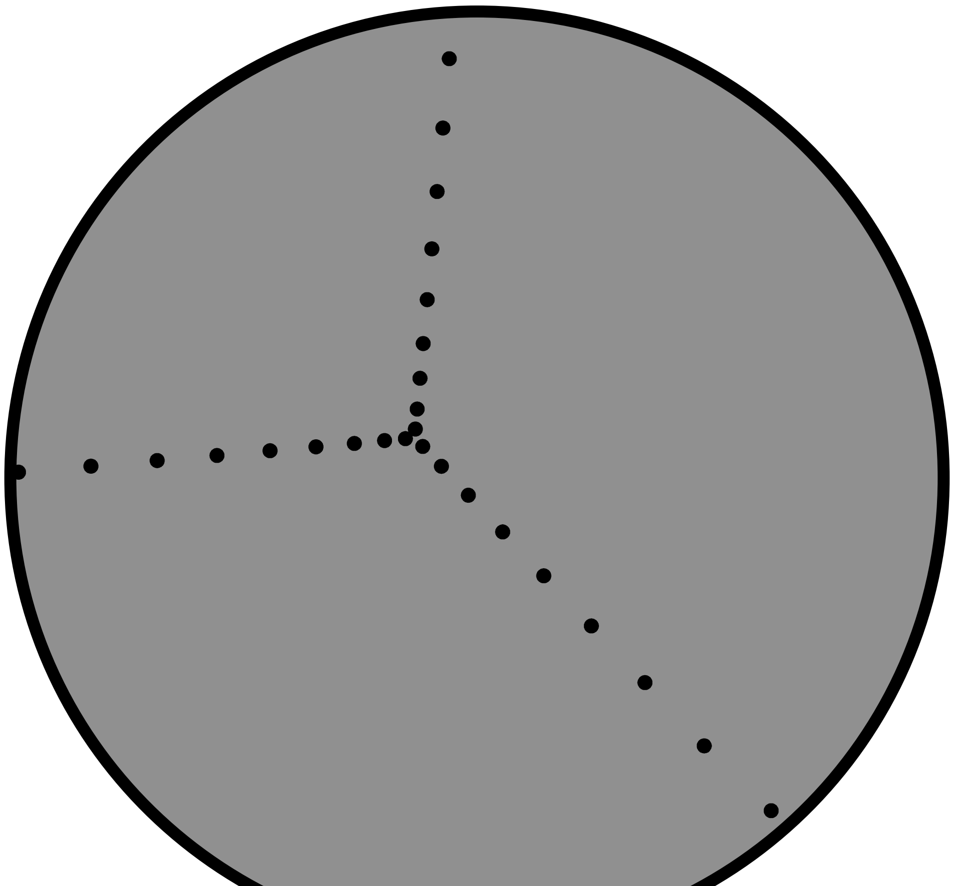
Bessel

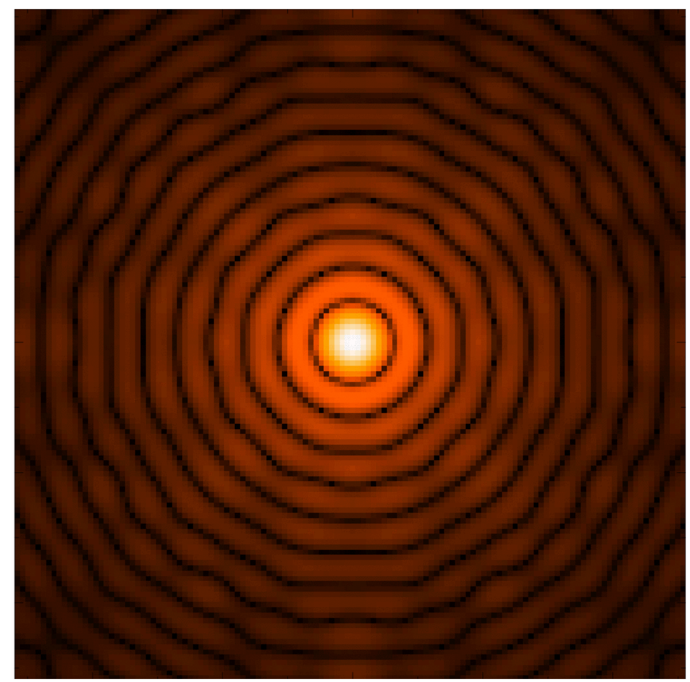
Interferometry – spatial filters



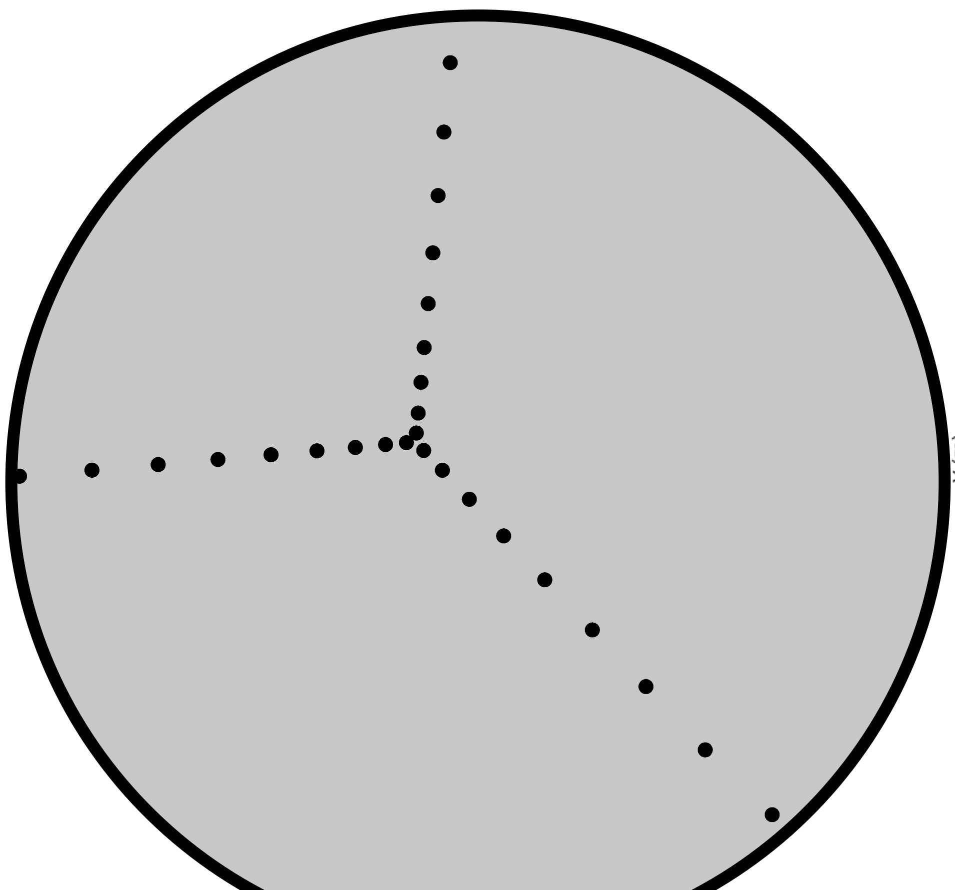


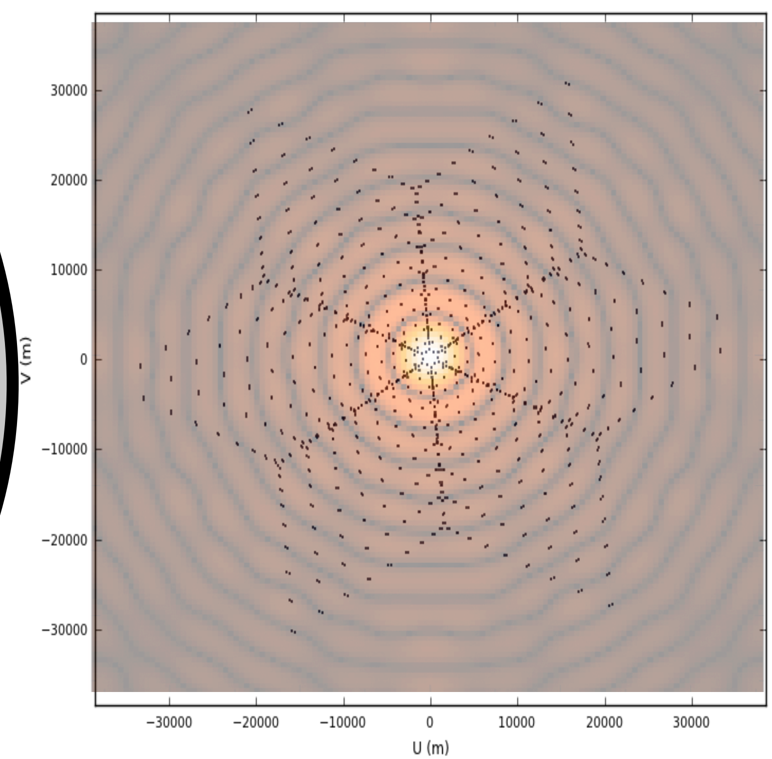
Interferometry – spatial filters





Interferometry – spatial filters

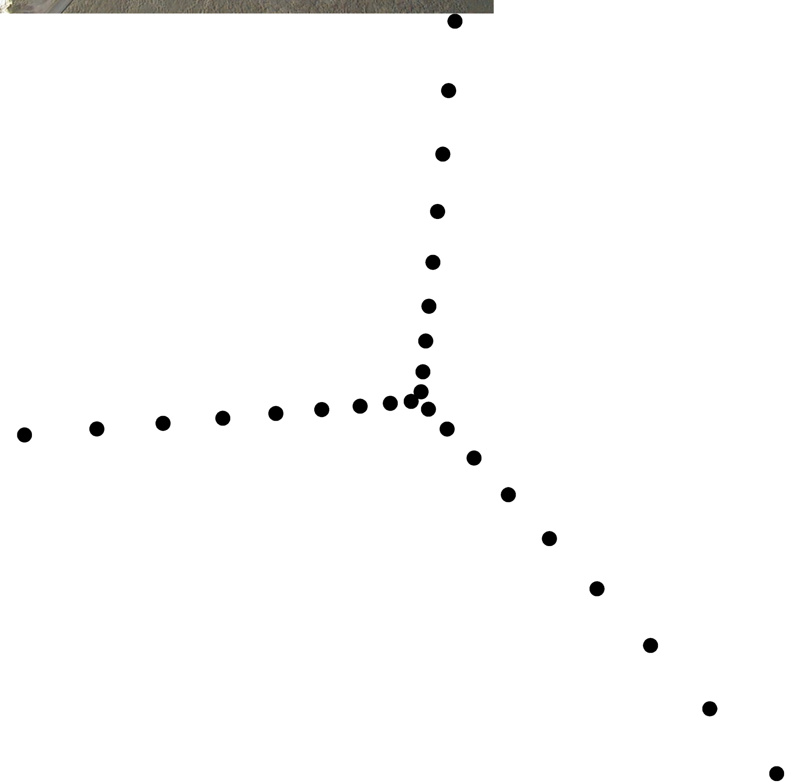


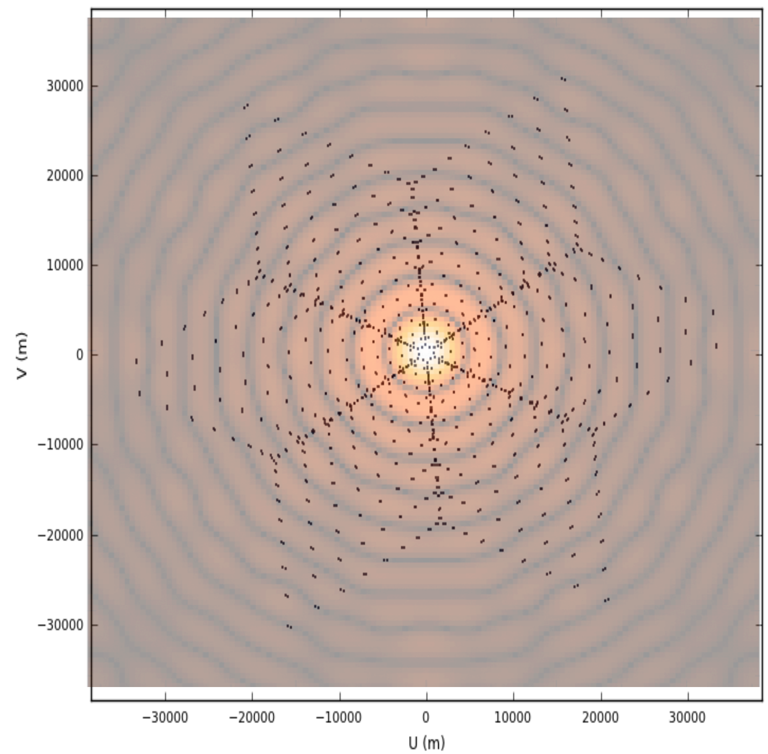


Example: VLA

Very Large Array (VLA)

- 27 antennas of 25 meters (diameter)
- observing from cm to mm wavelengths
- in New Mexico (USA)

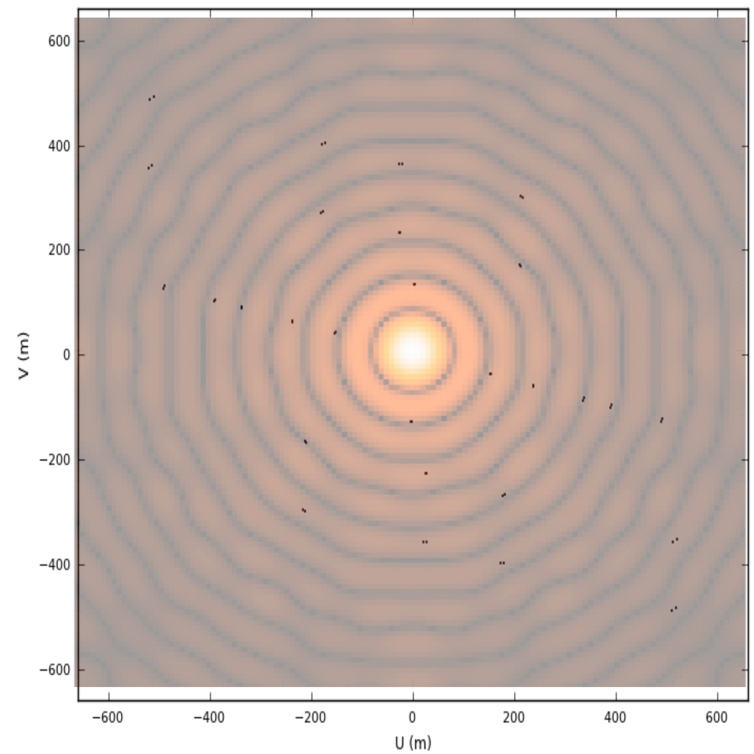




Example: PdBI

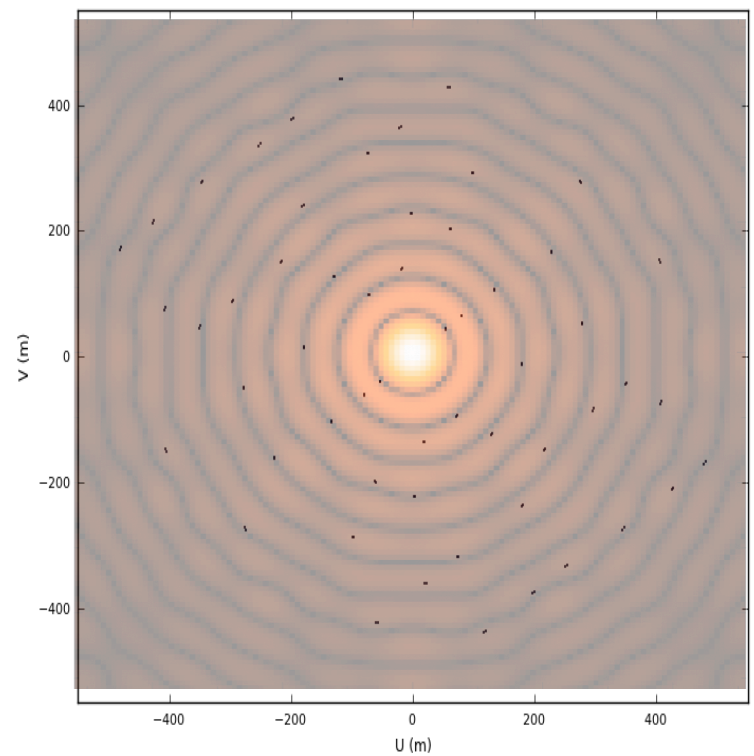
Plateau de Bure Interferometer (PdBI)

- 6 antennas of 15 meters (diameter)
- observing from mm to submm
- in Grenoble (France)



Example: SMA

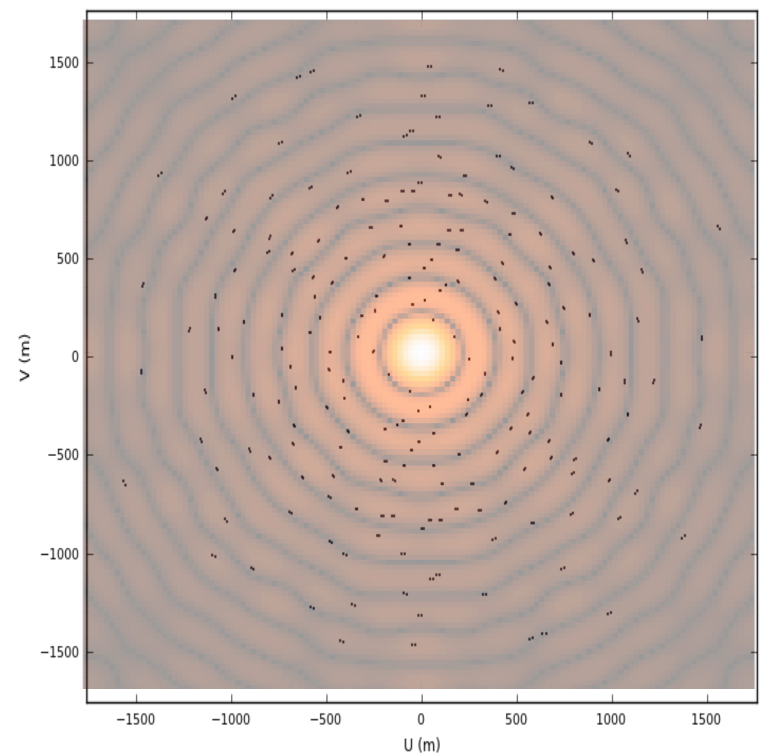
SubMillimeter Array (SMA)
- 8 antennas of 6 meters (diameter)
- observing from mm to submm
- in Hawaii (USA)



Example: CARMA

Combined Array for Research in mm Astro (CARMA)

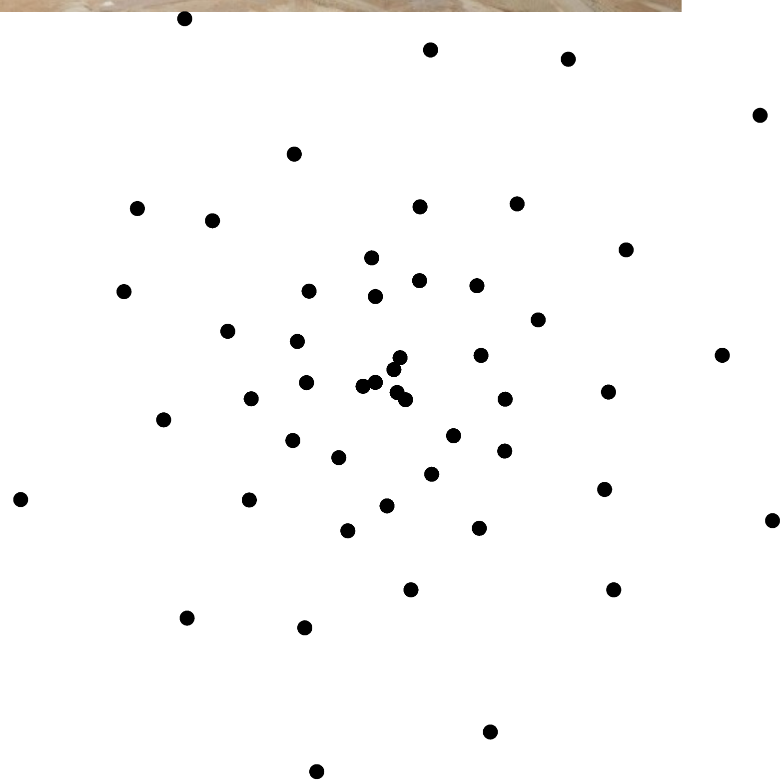
- 23 antennas of 10.4/6.1/3.5 meters
- observing from cm to mm wavelengths
- in California (USA)

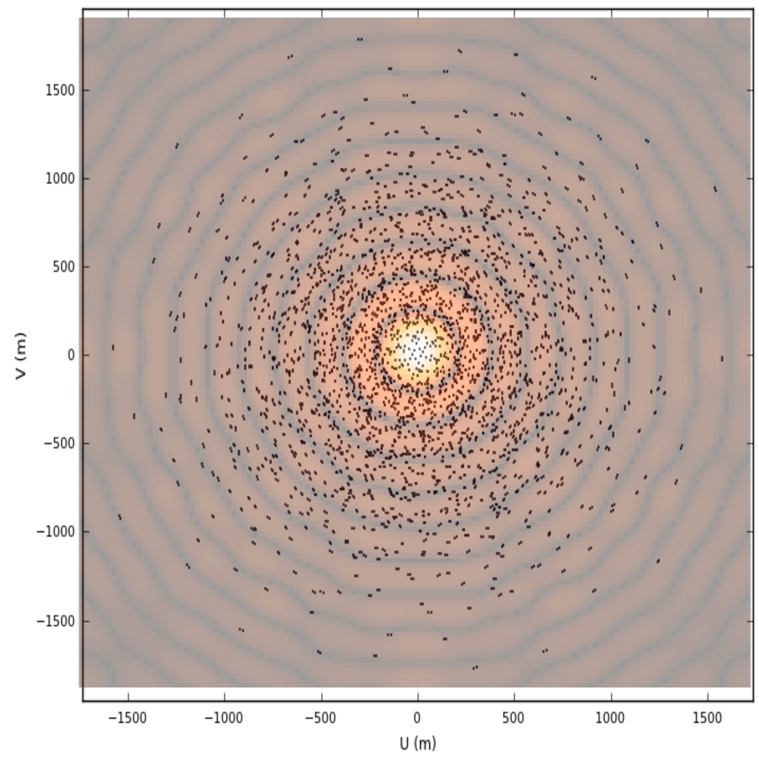


Example: ALMA

Atacama Large mm/submm Array (ALMA)

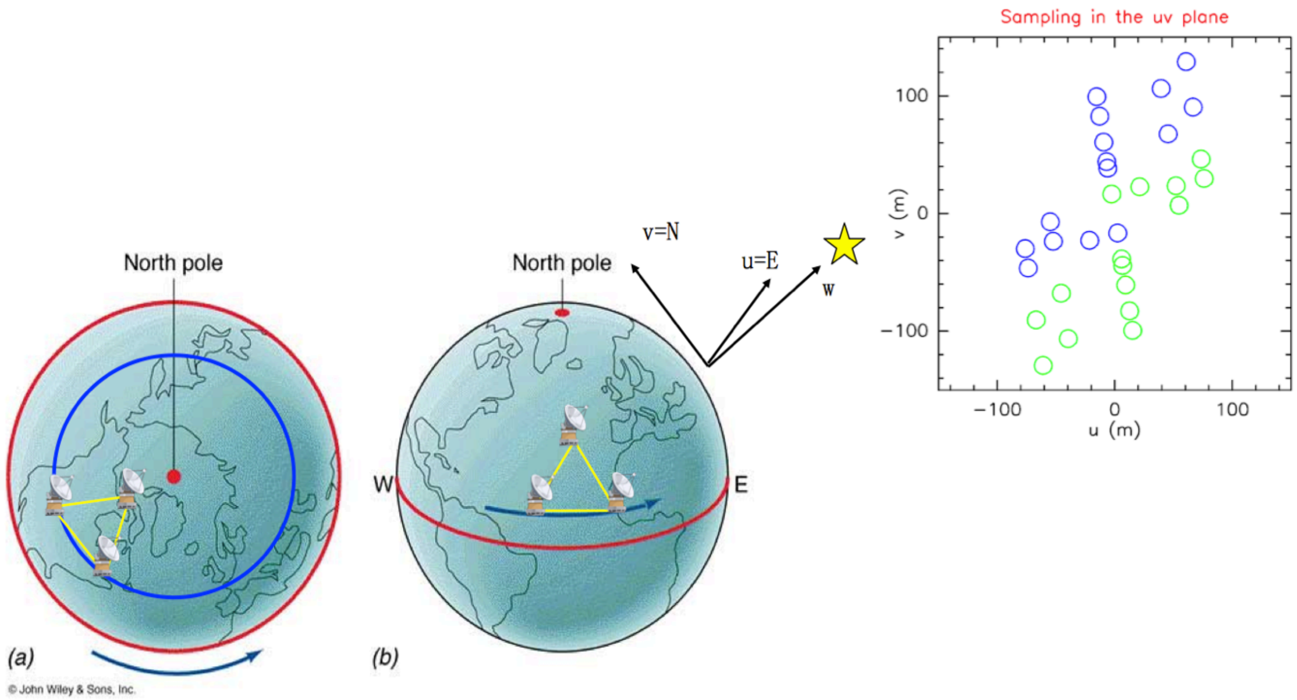
- 50 antennas of 12/7 meters
- observing from mm to submm
- in Llano Chajnantor (Chile)





Interferometry – snapshots vs Earth rotation

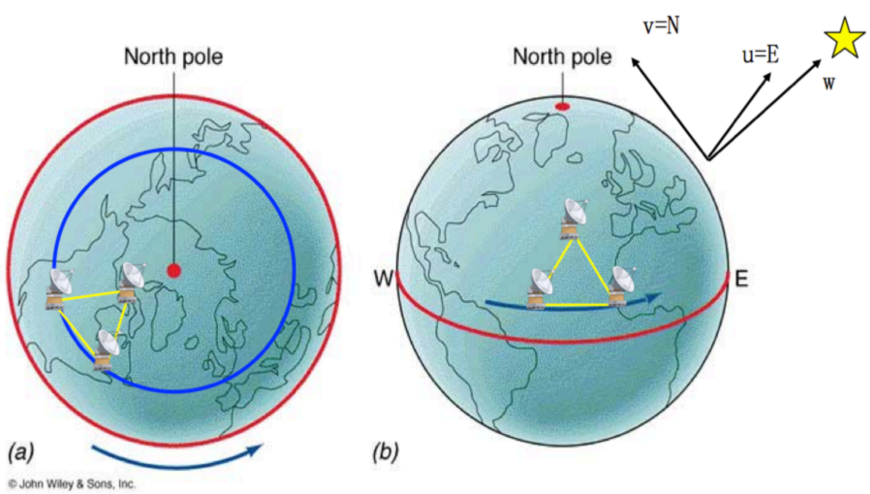
physical distance between antennas is **constant**

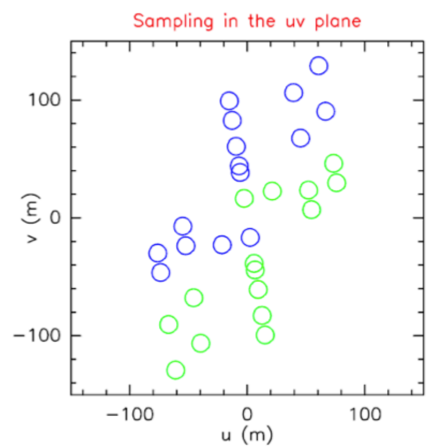


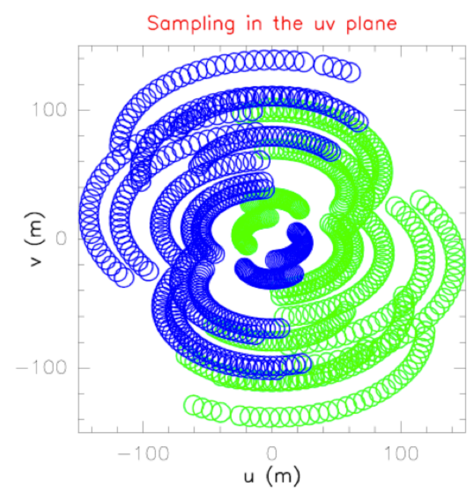
Interferometry – snapshots vs Earth rotation

physical distance between antennas is **constant**

with Earth rotation, projected distances [altitude, azimuth] are **NOT constant**







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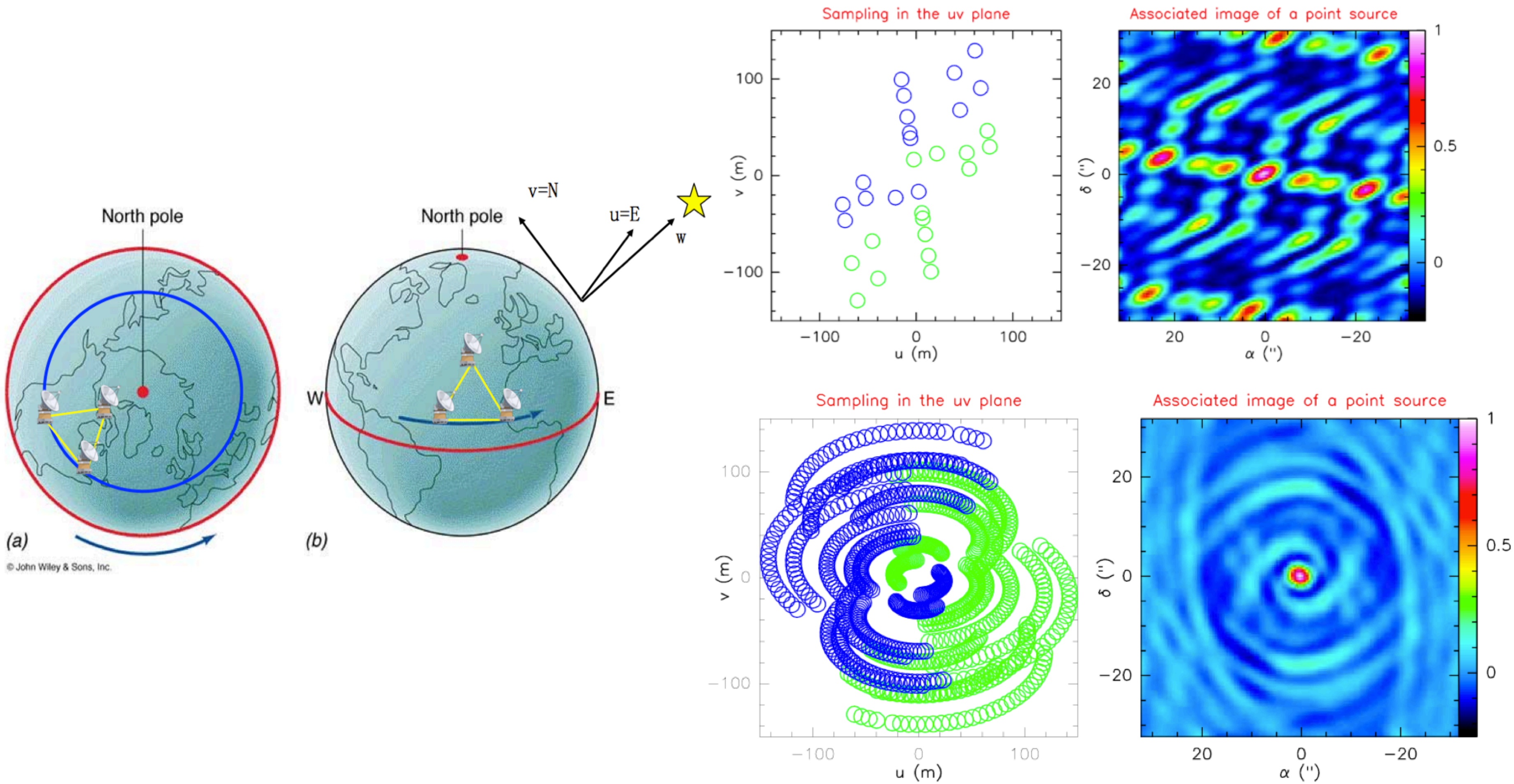

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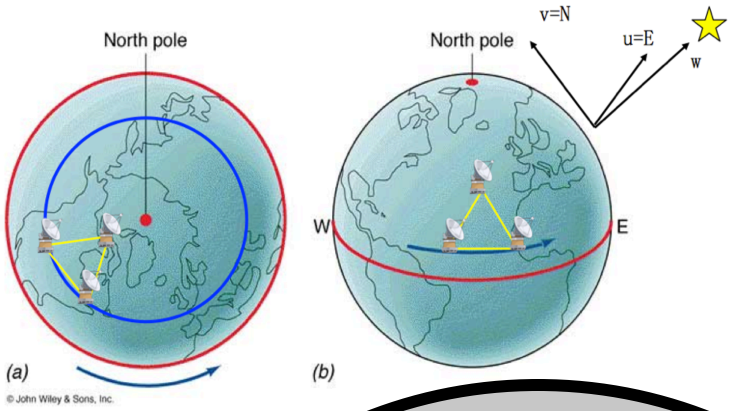

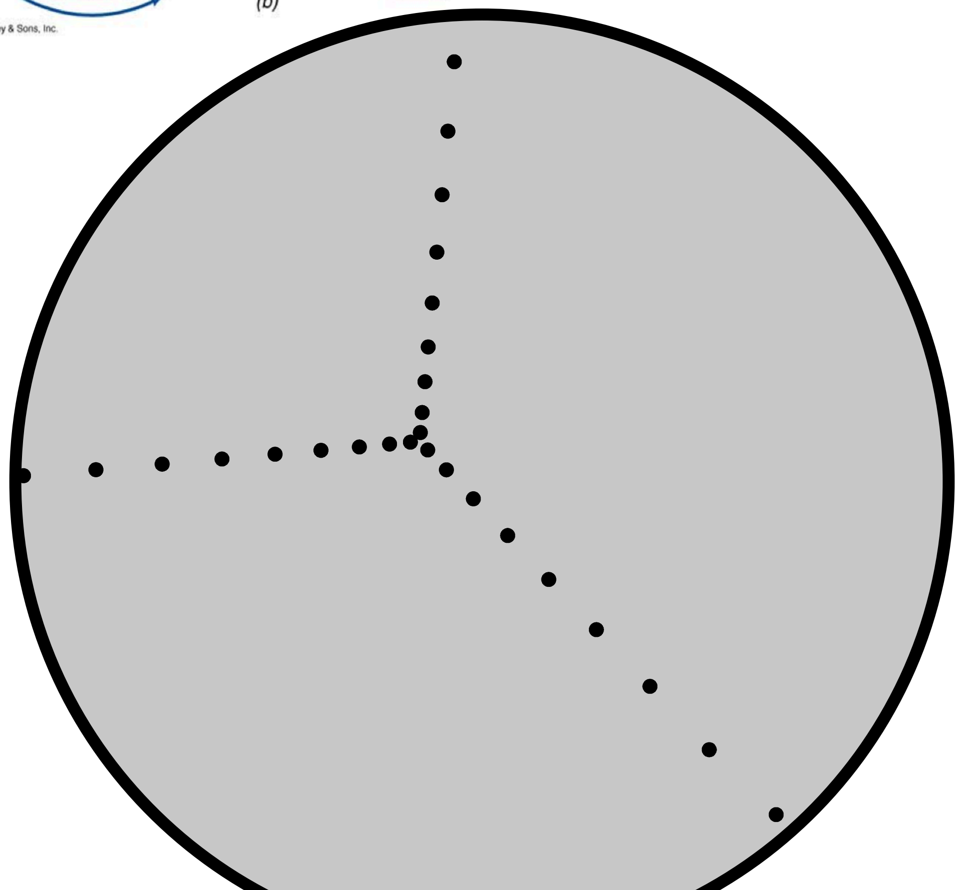

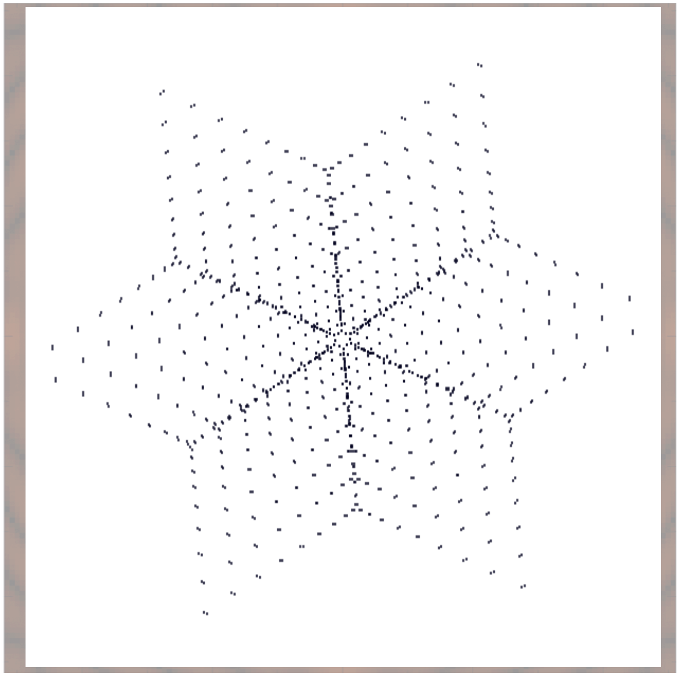

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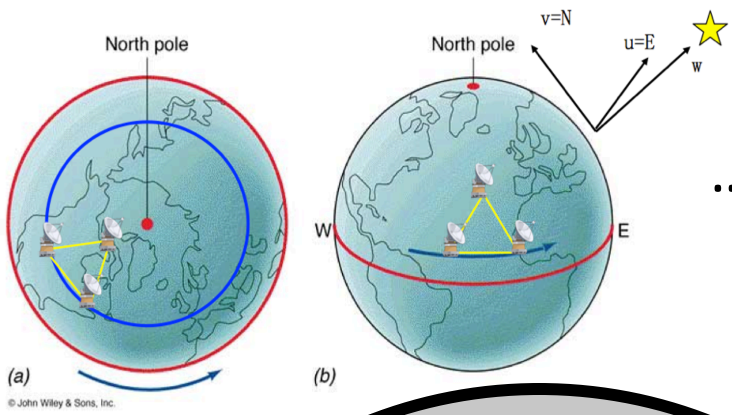
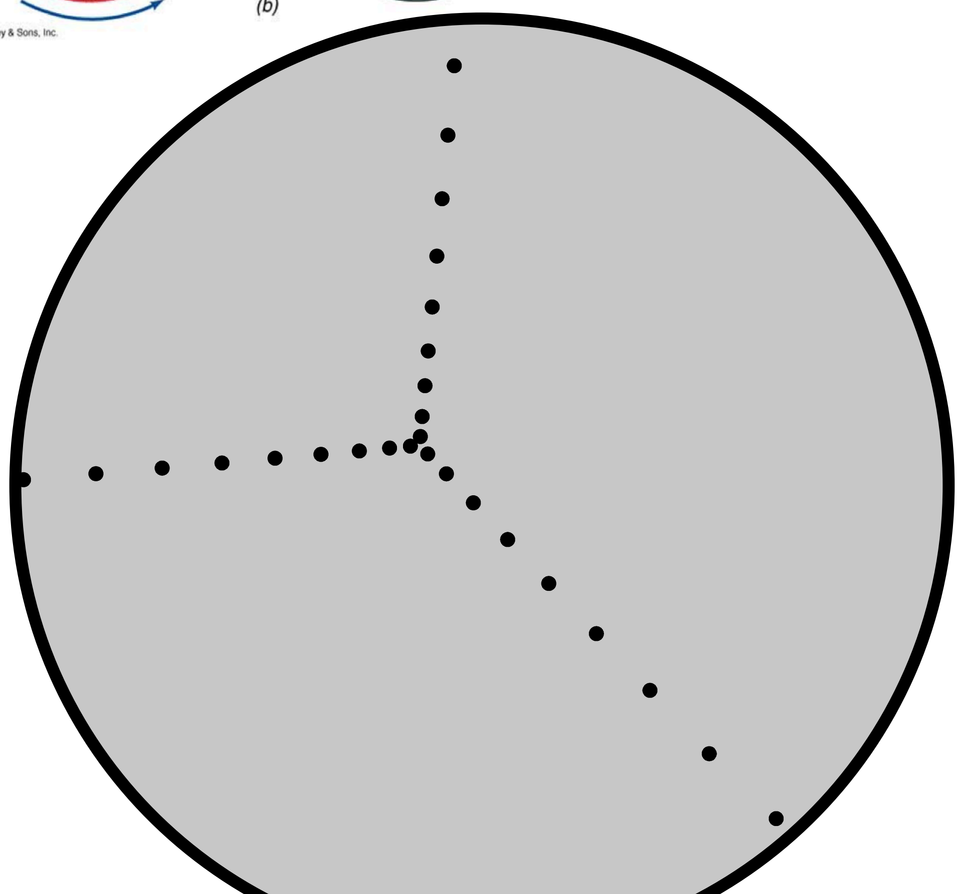
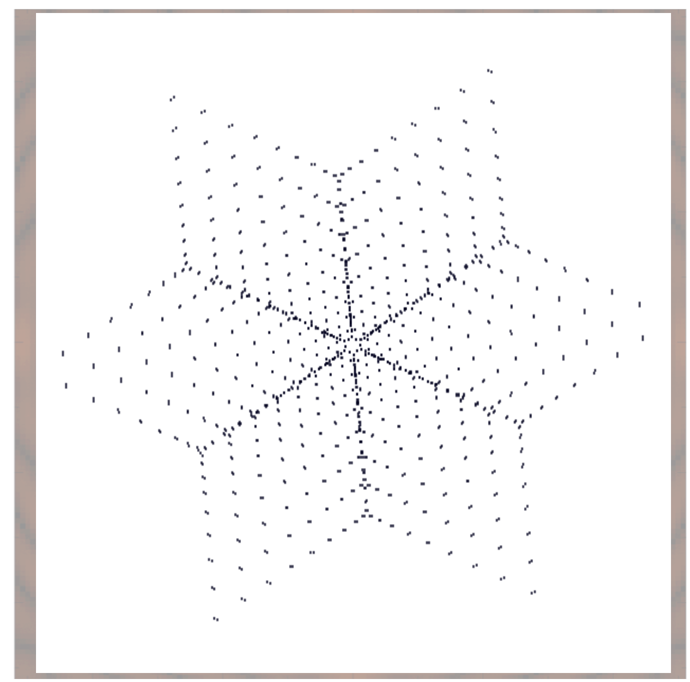
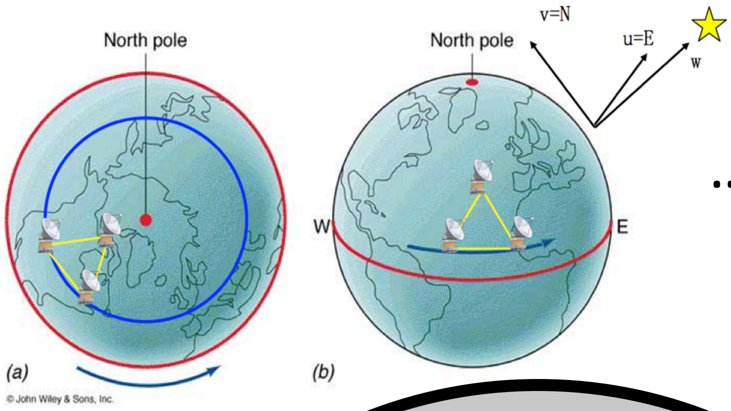


… we can just wait for the Earth to rotate

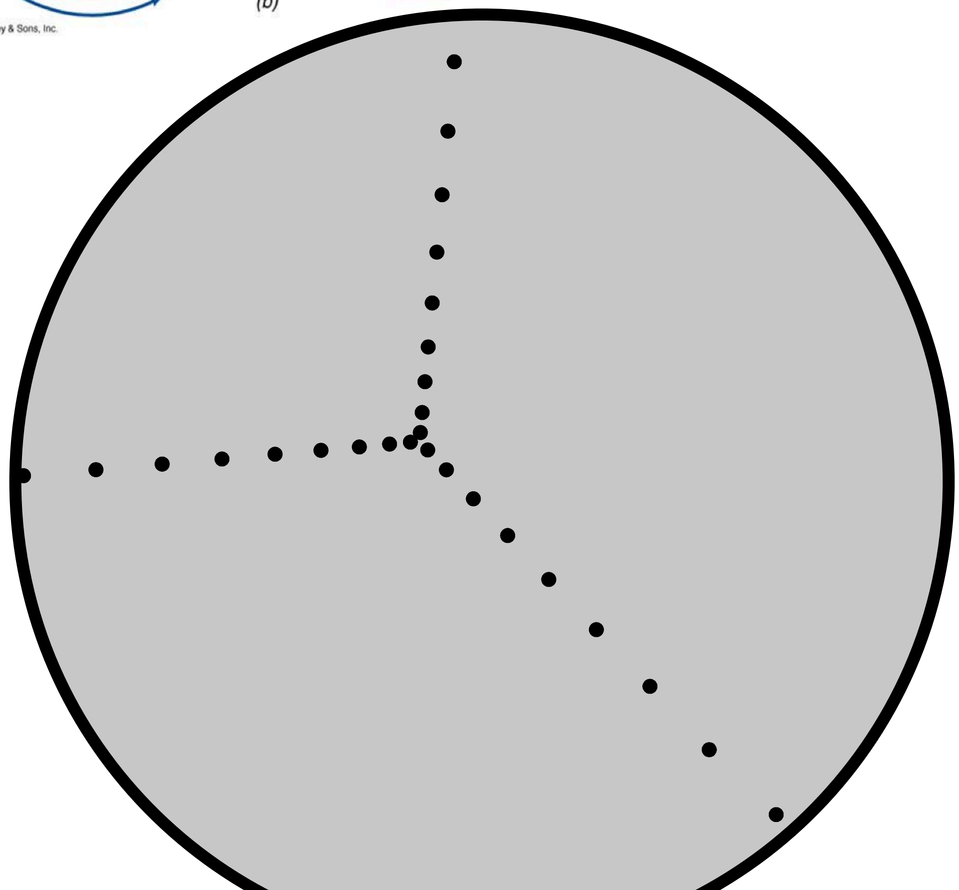


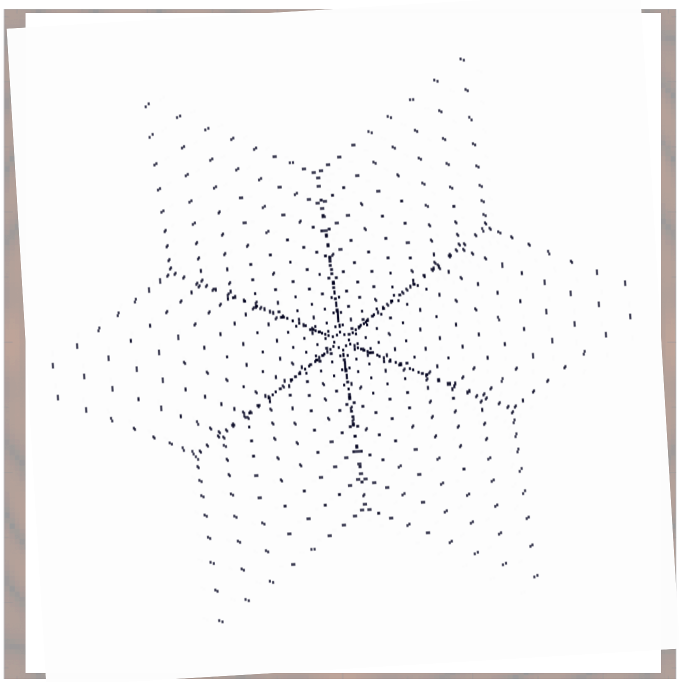


Interferometry – snapshots vs Earth rotation

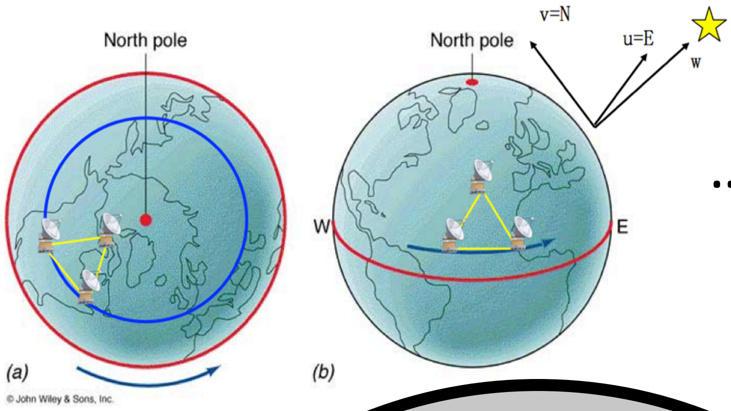


… we can just wait for the Earth to rotate





Interferometry – snapshots vs Earth rotation



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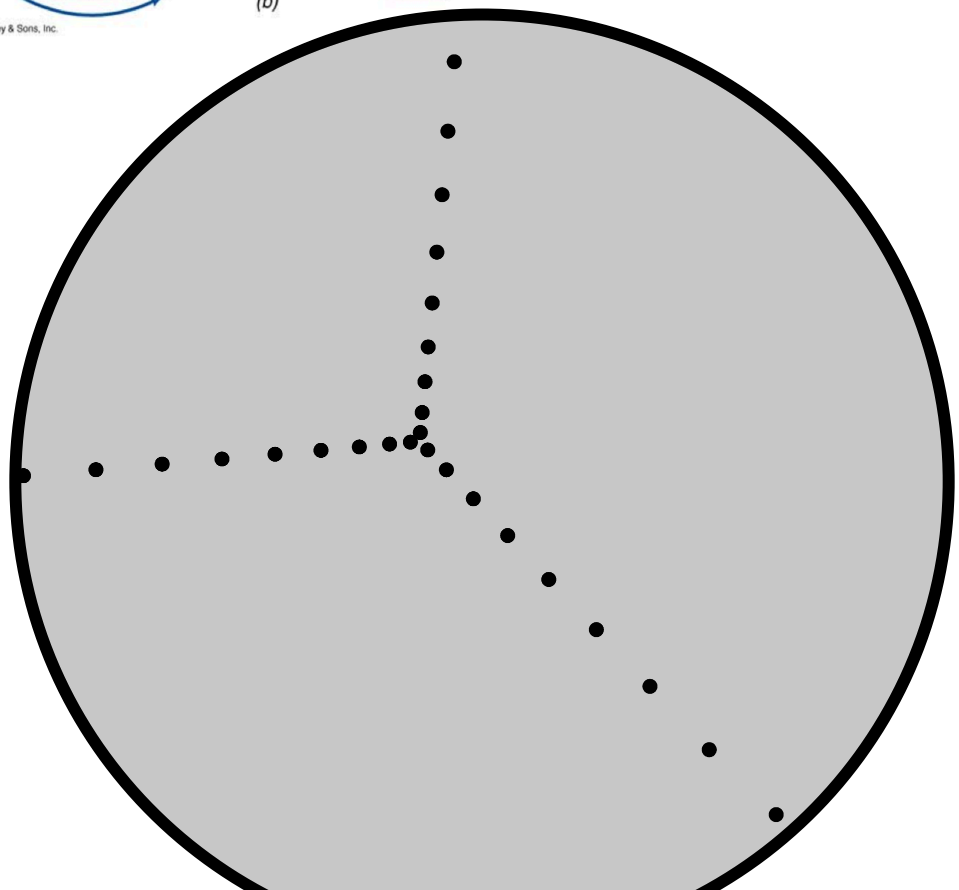
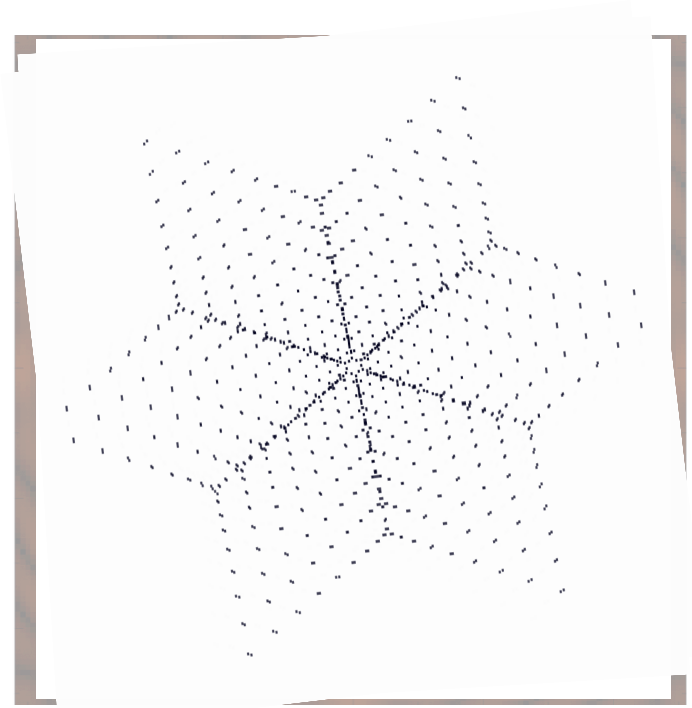
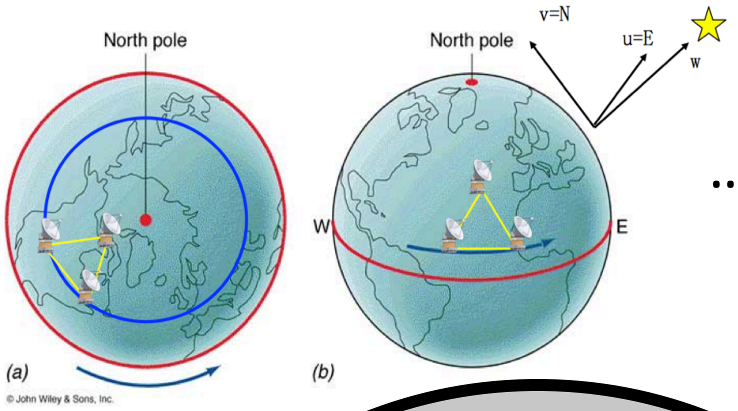




Interferometry – snapshots vs Earth rotation



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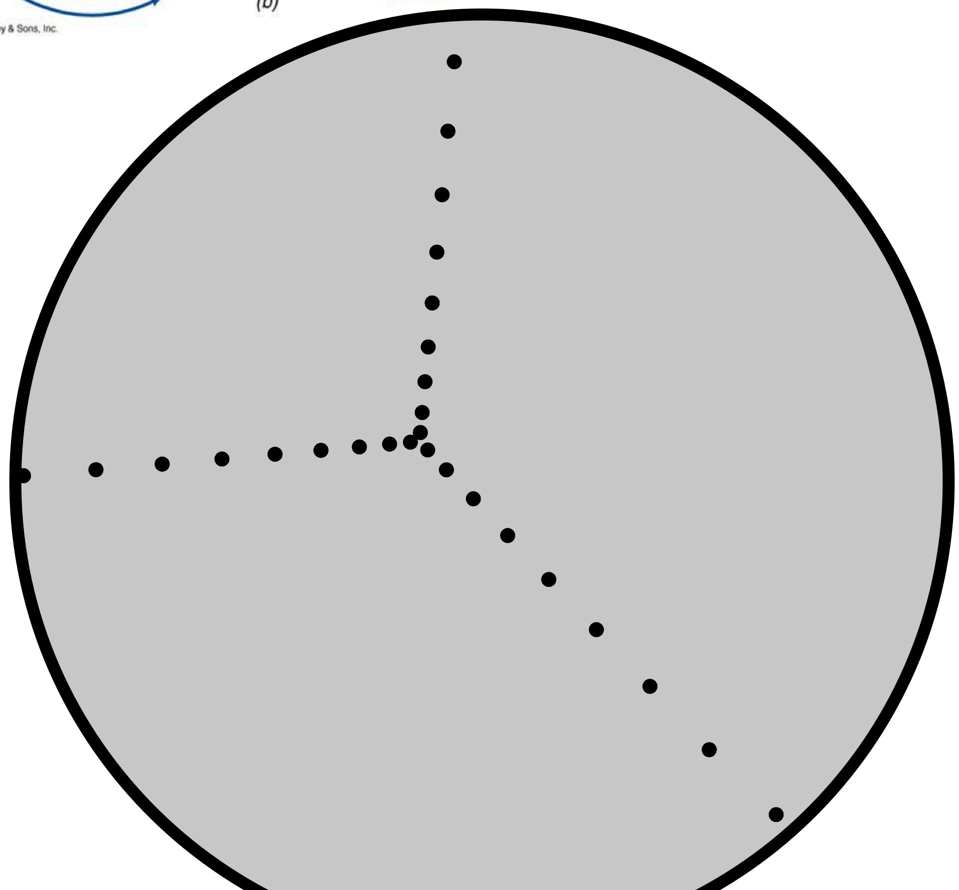
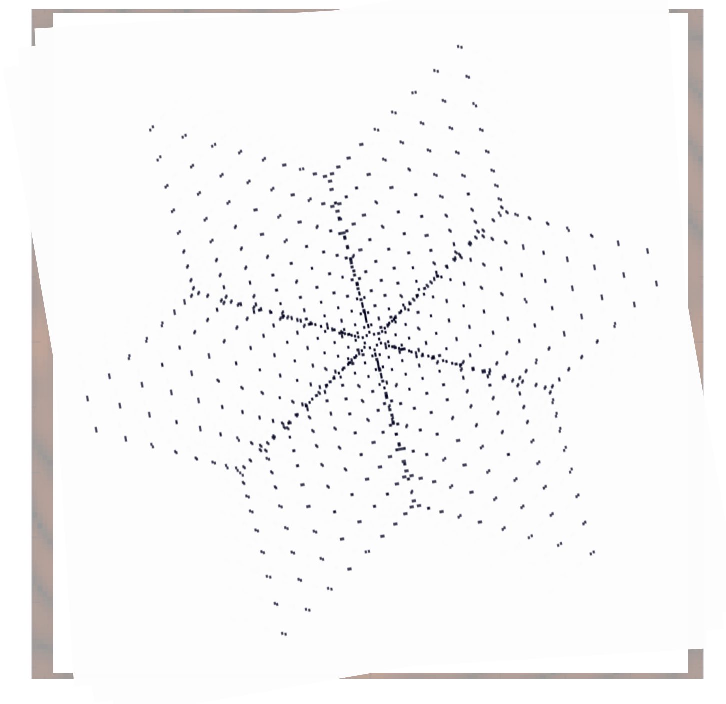
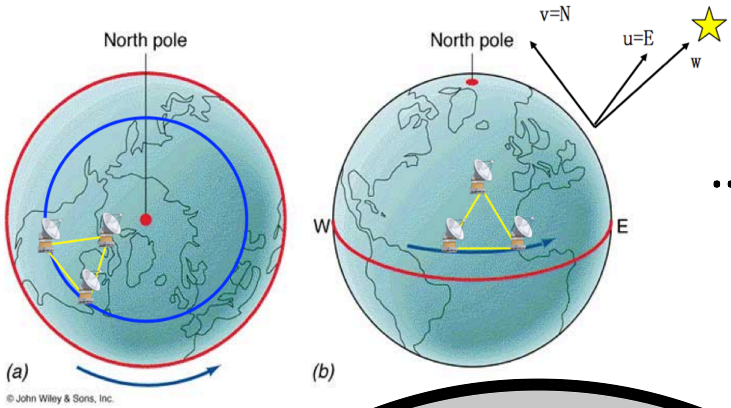




Interferometry – snapshots vs Earth rotation



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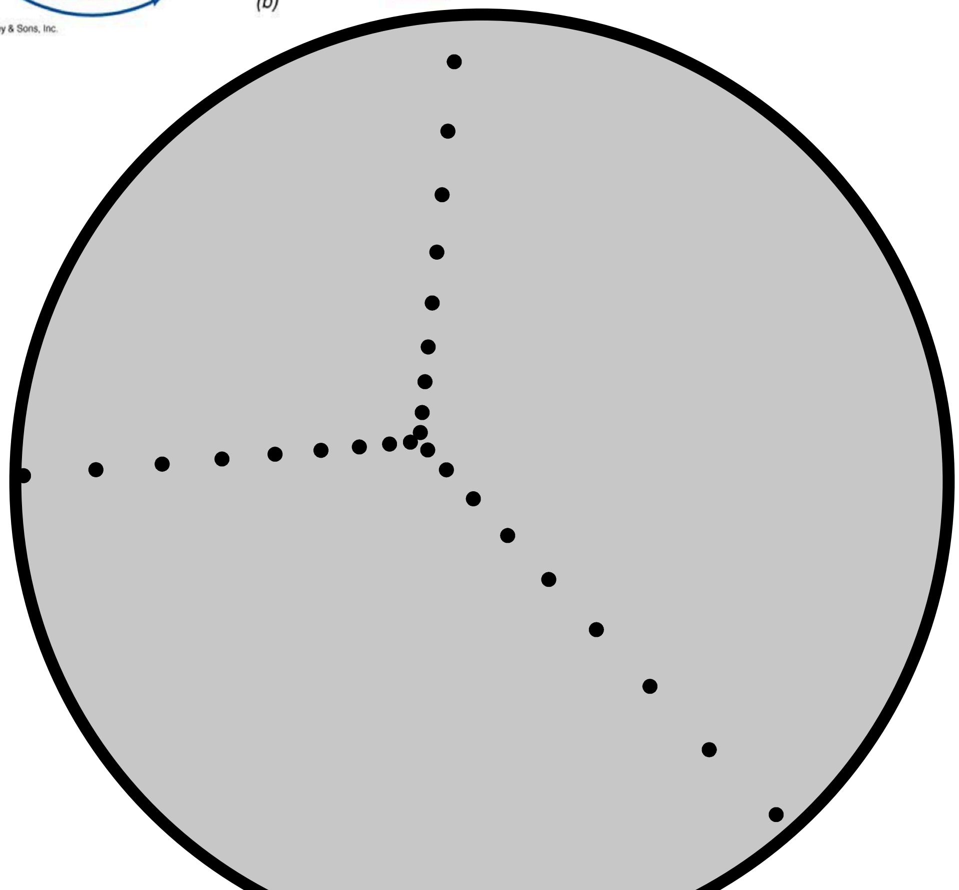

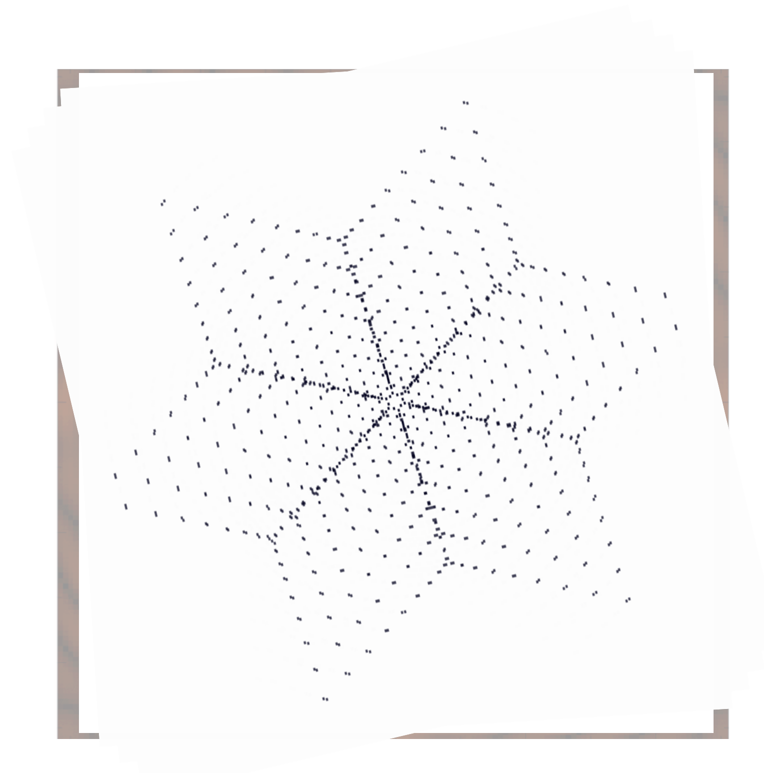

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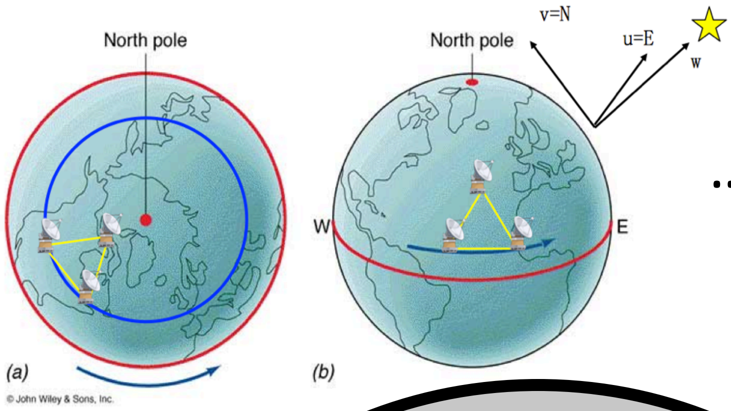

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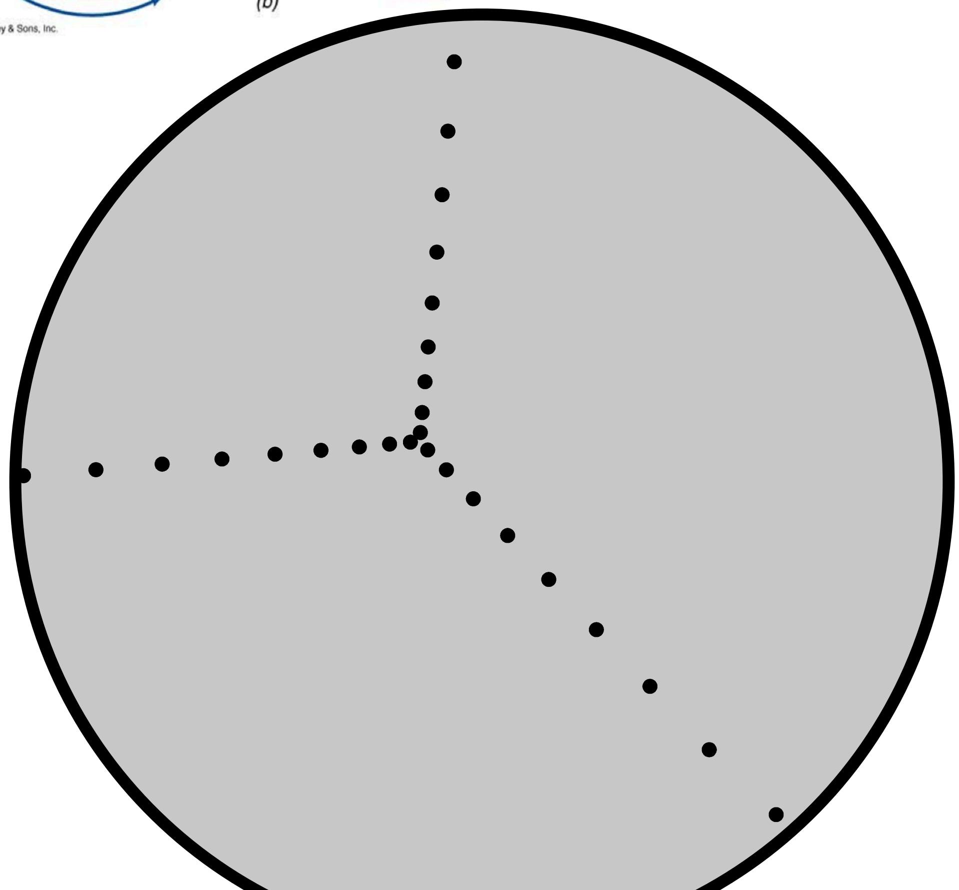
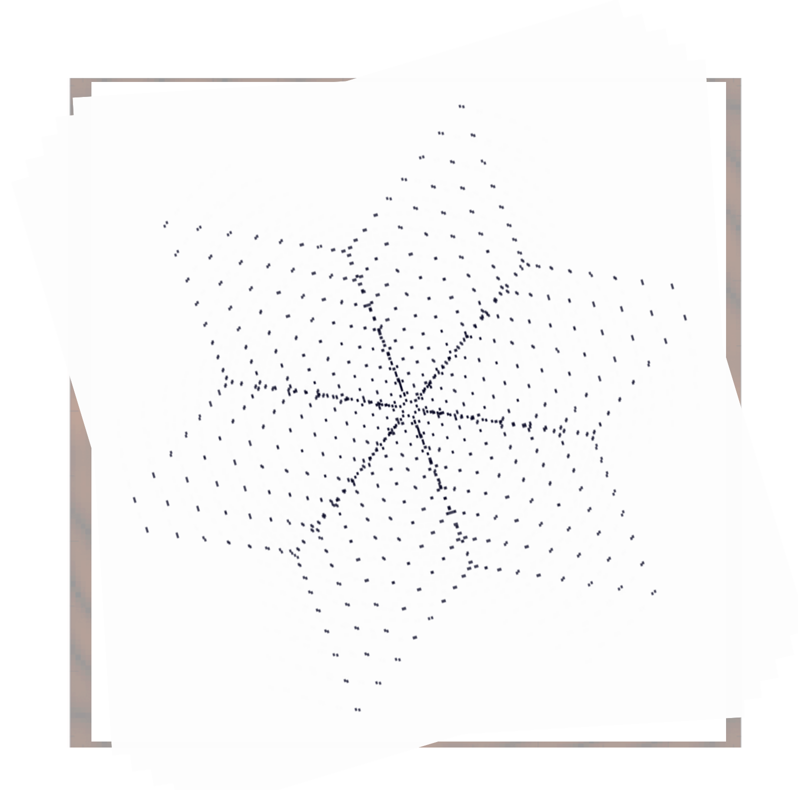
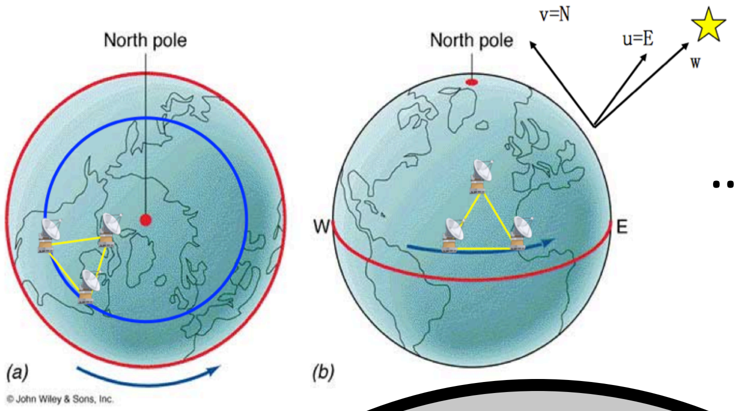




Interferometry – snapshots vs Earth rotation



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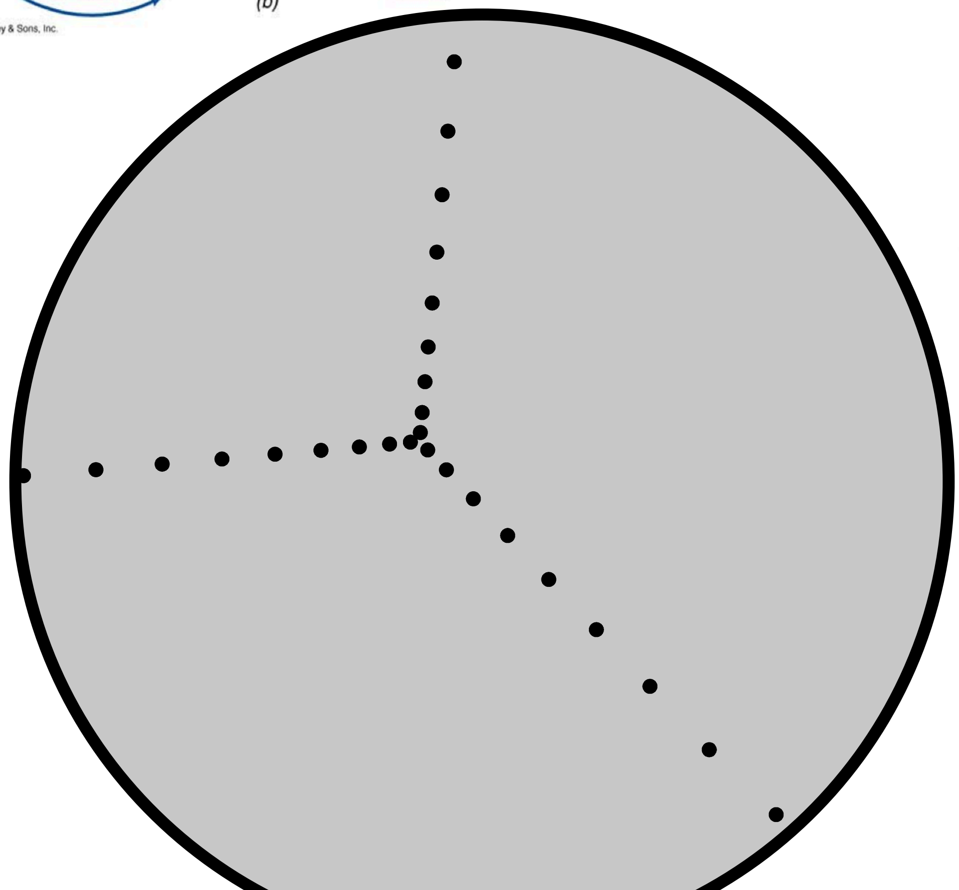
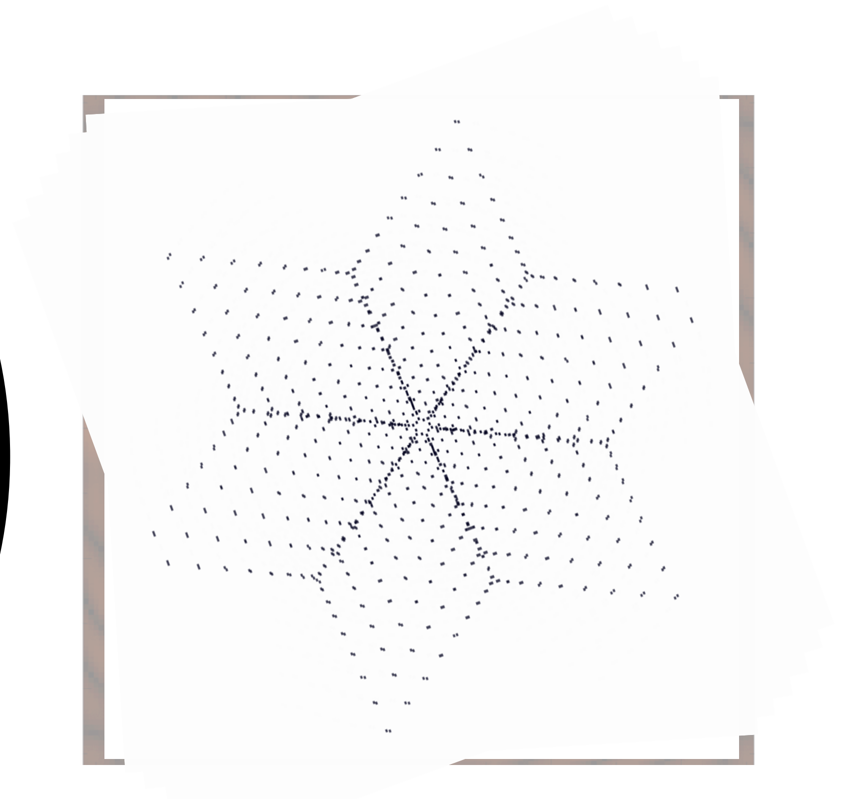
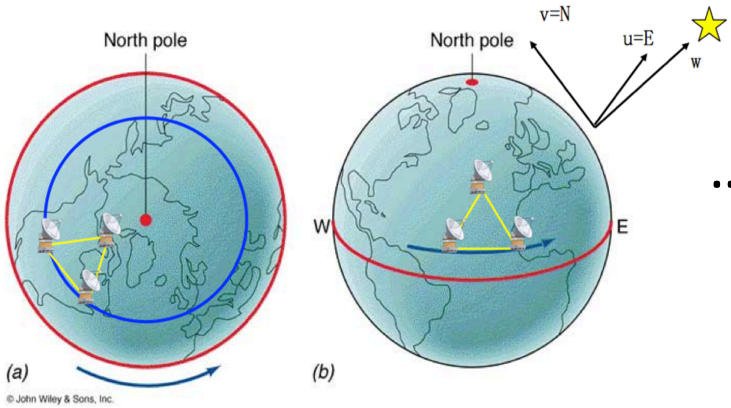




Interferometry – snapshots vs Earth rotation



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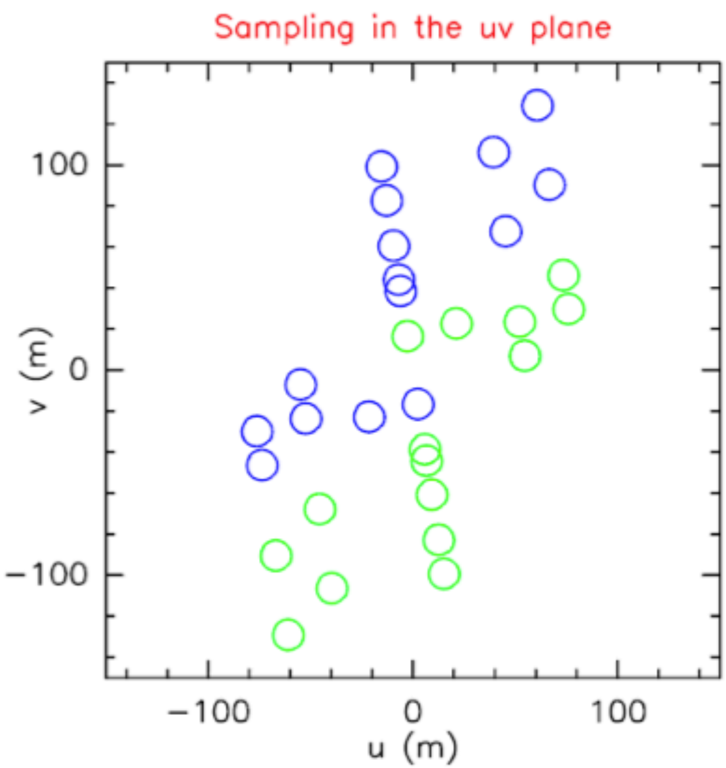
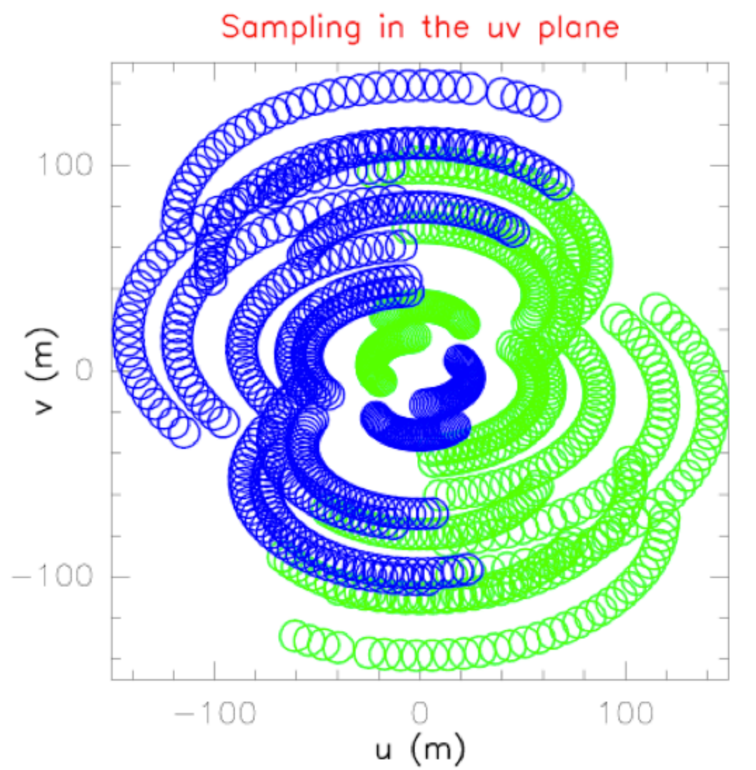
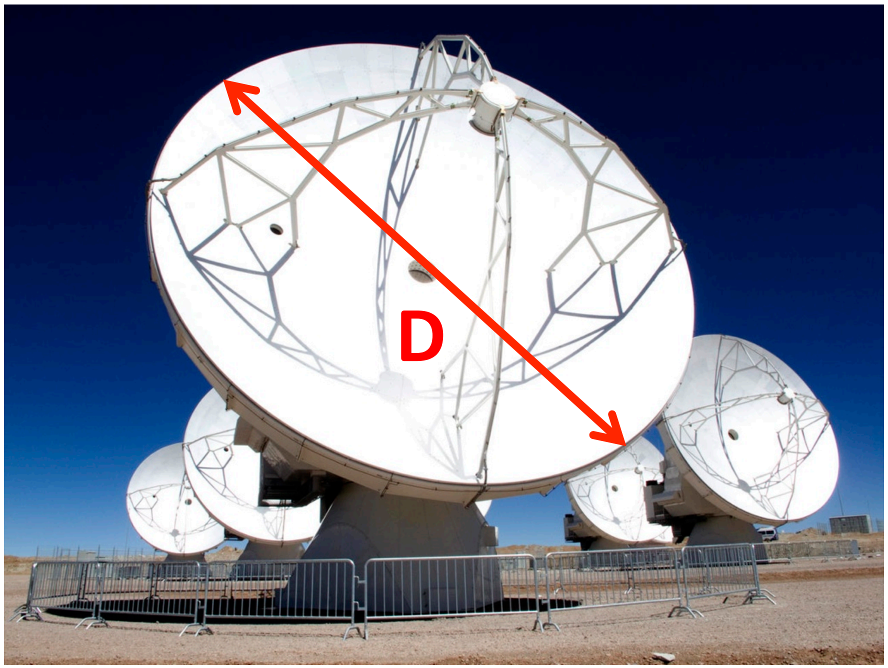


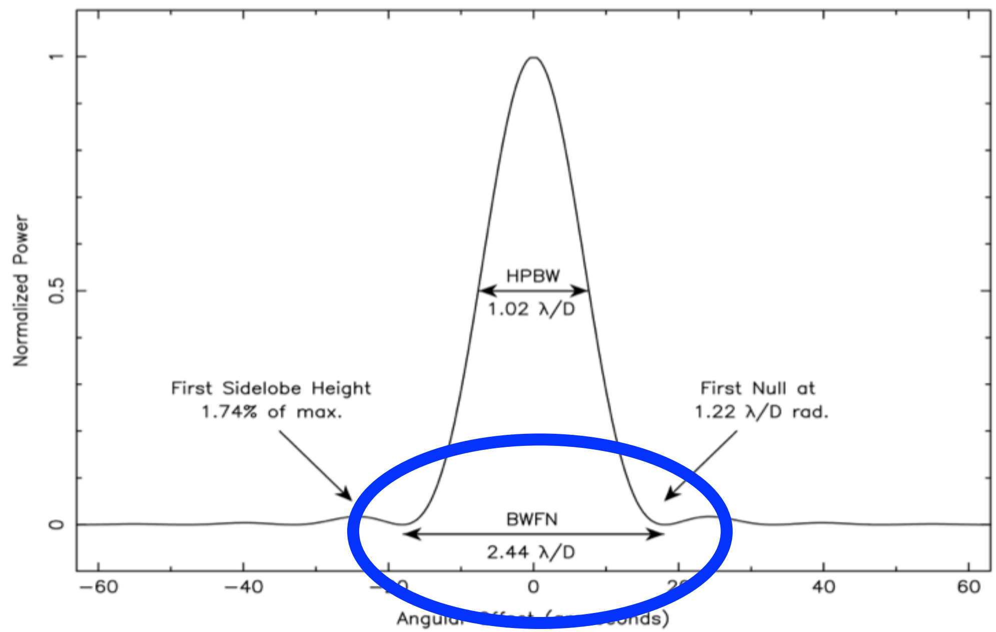


REMEMBER … Single-dish response

Single-dish with diameter D



(1D) antenna power response

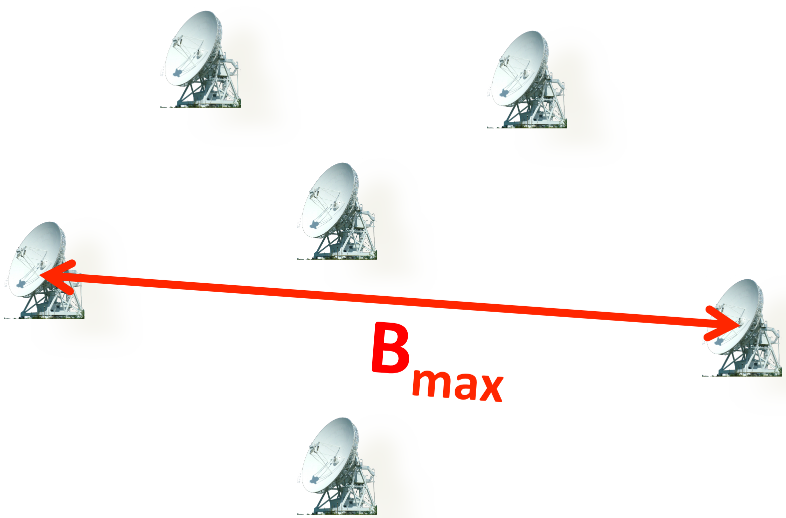


$$PB = 1.22\frac{\lambda}{D}$$

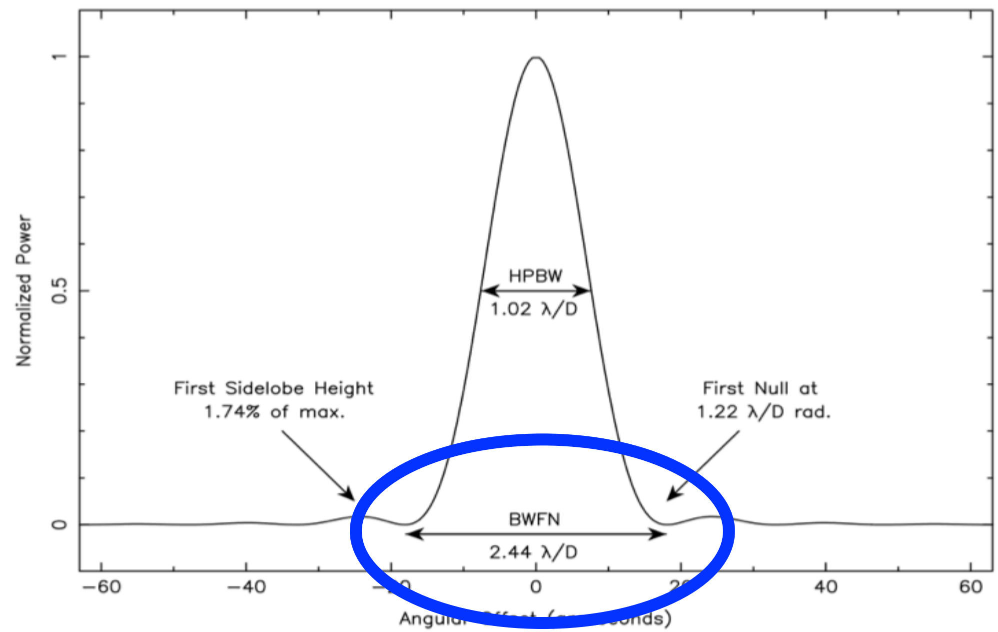
PRIMARY BEAM

Interferometer "response"

Interferometer with baseline B



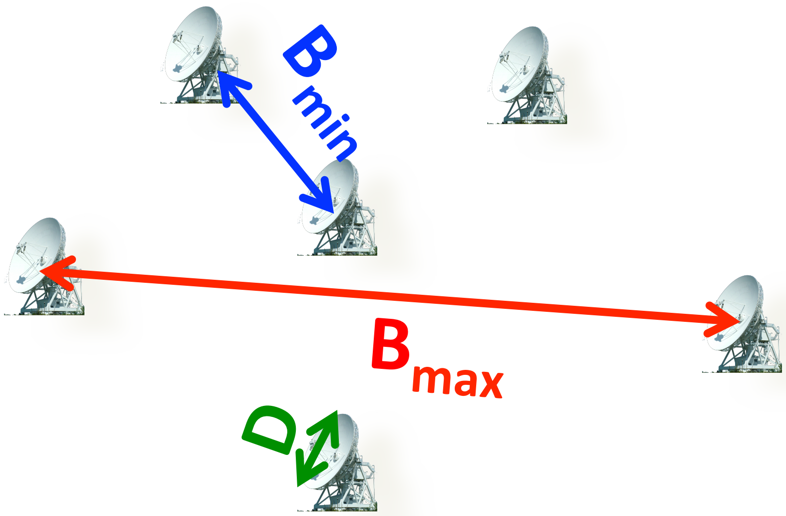
interferometer power response



$$\theta_{beam} = 1.22\frac{\lambda}{B_{\max}}$$

SYNTHESIZED BEAM

Synthesized beam, primary beam and LAS



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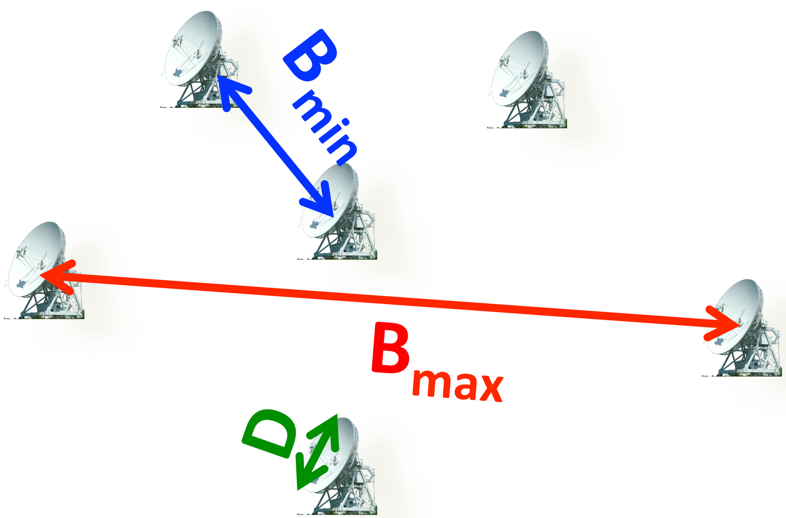
$$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$$

Synthesized beam, primary beam and LAS



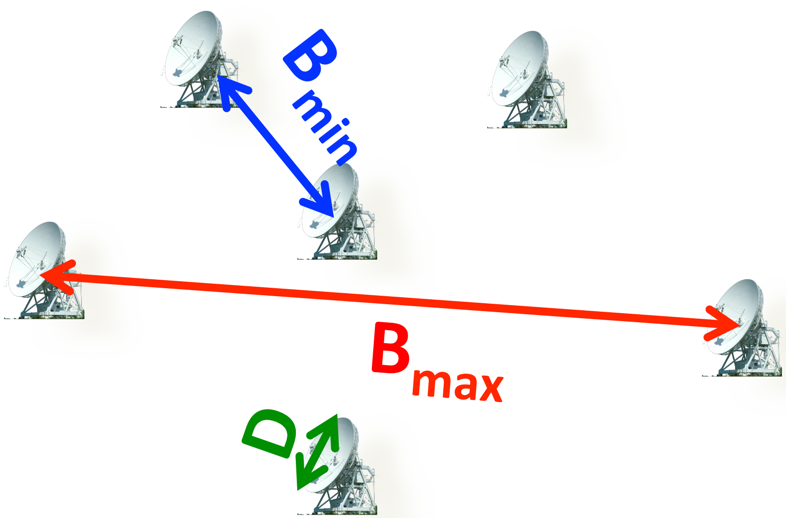
SYNTHESIZED BEAM

$$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$$

LARGEST ANGULAR SCALE

$$LAS = 1.22 \frac{\lambda}{B_{\min}}$$

Synthesized beam, primary beam and LAS



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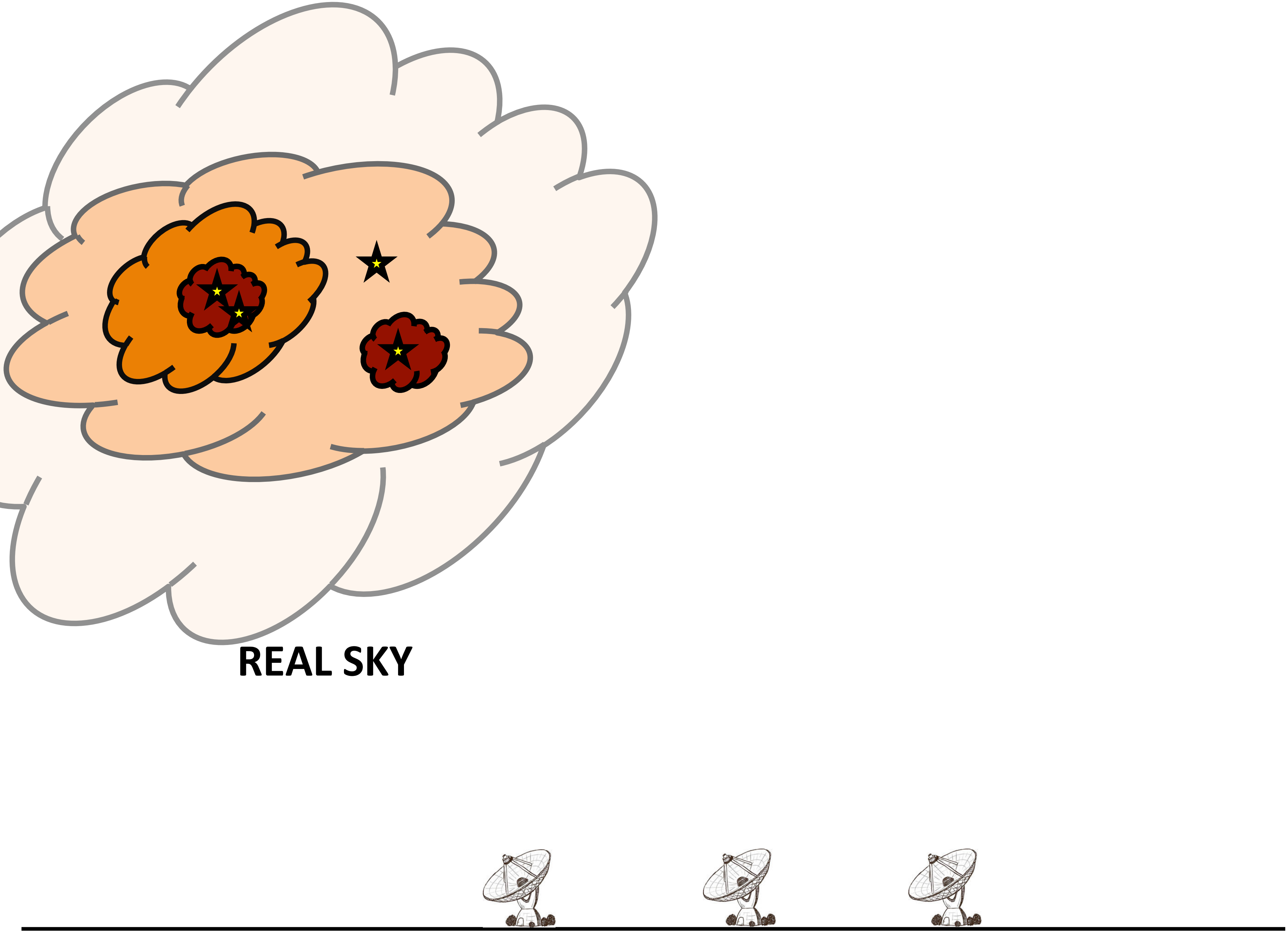
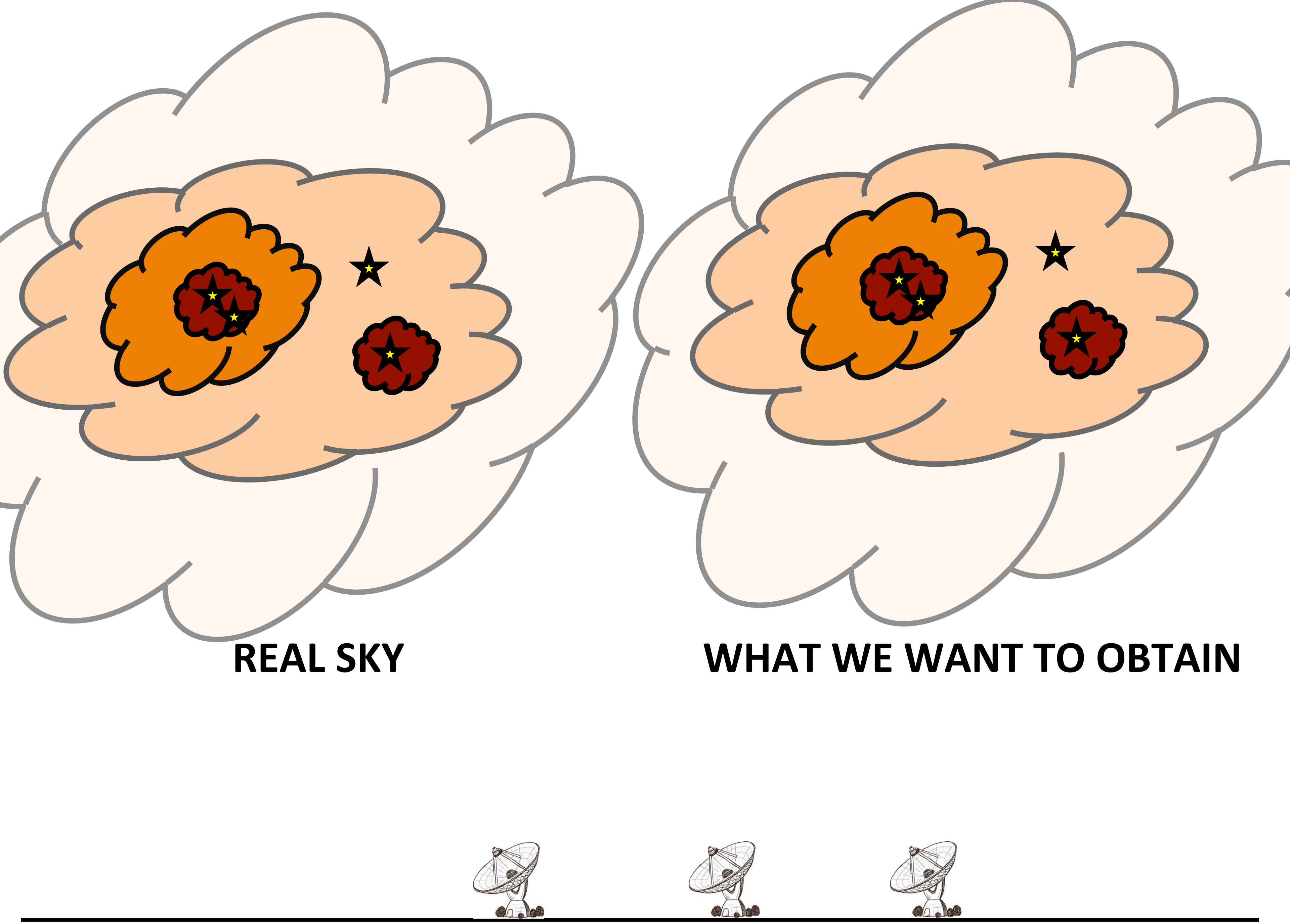
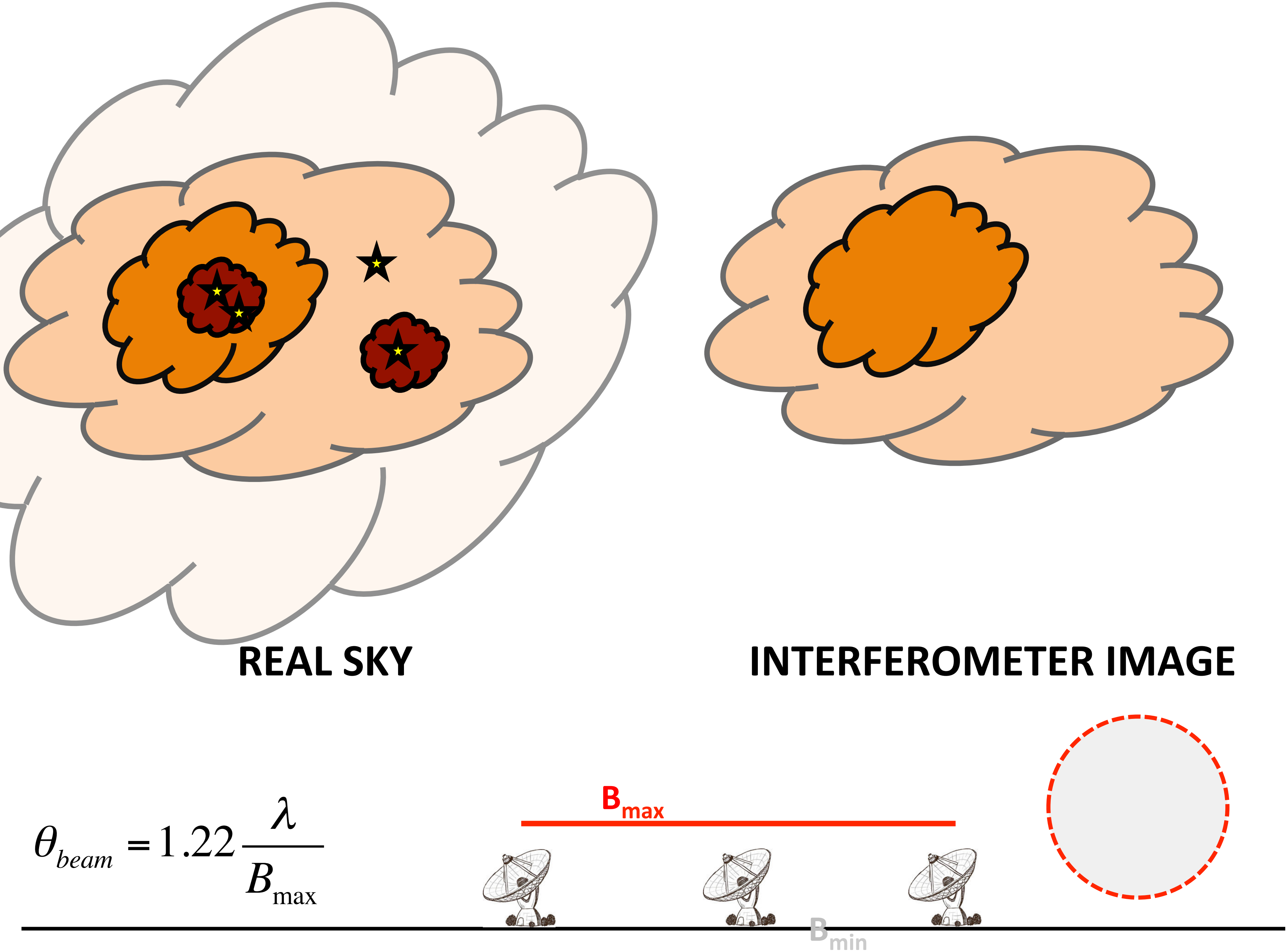
$$PB = 1.22 \frac{\lambda}{D}$$


REAL SKY


REAL SKY
WHAT WE WANT TO OBTAIN



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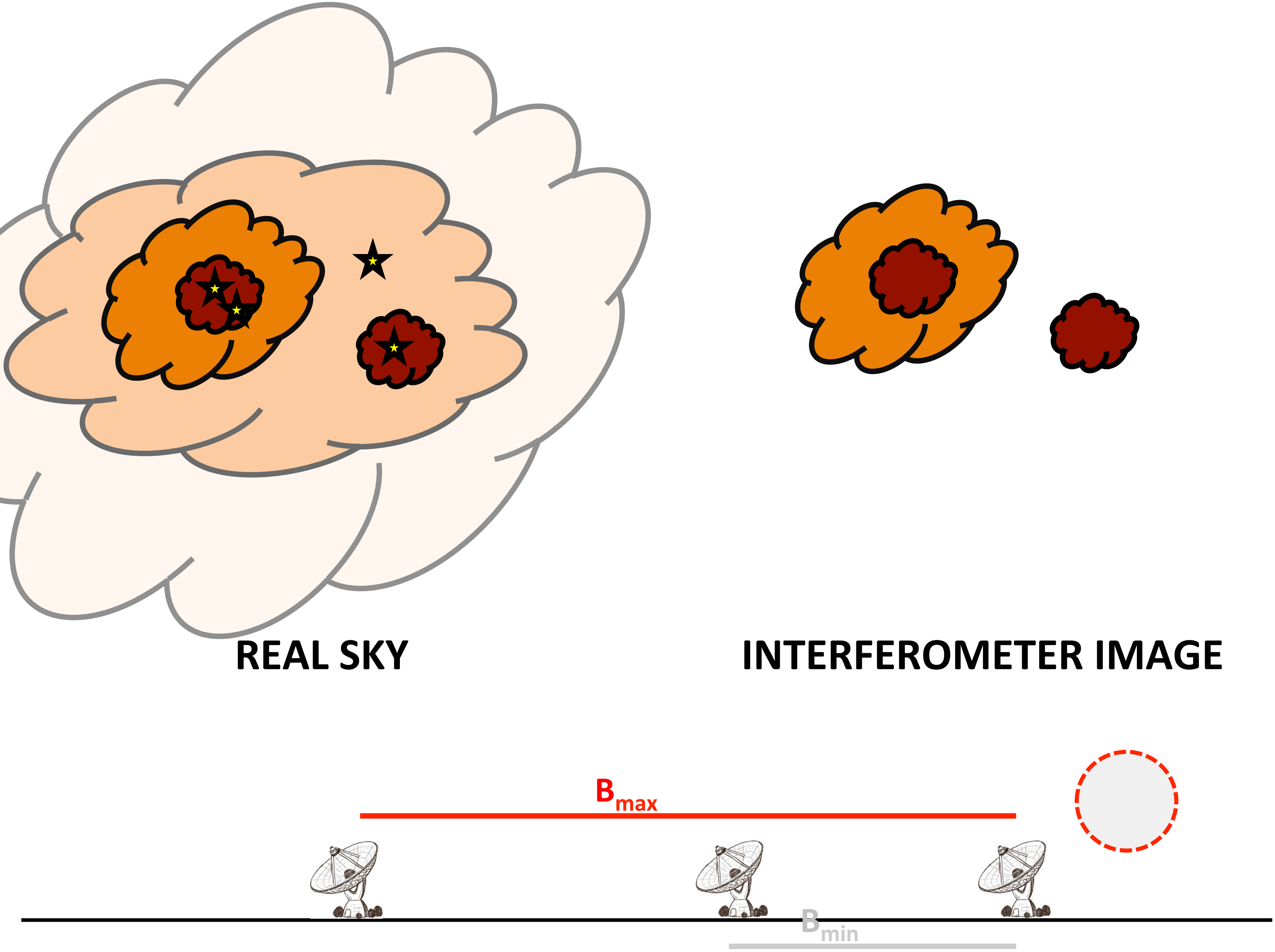
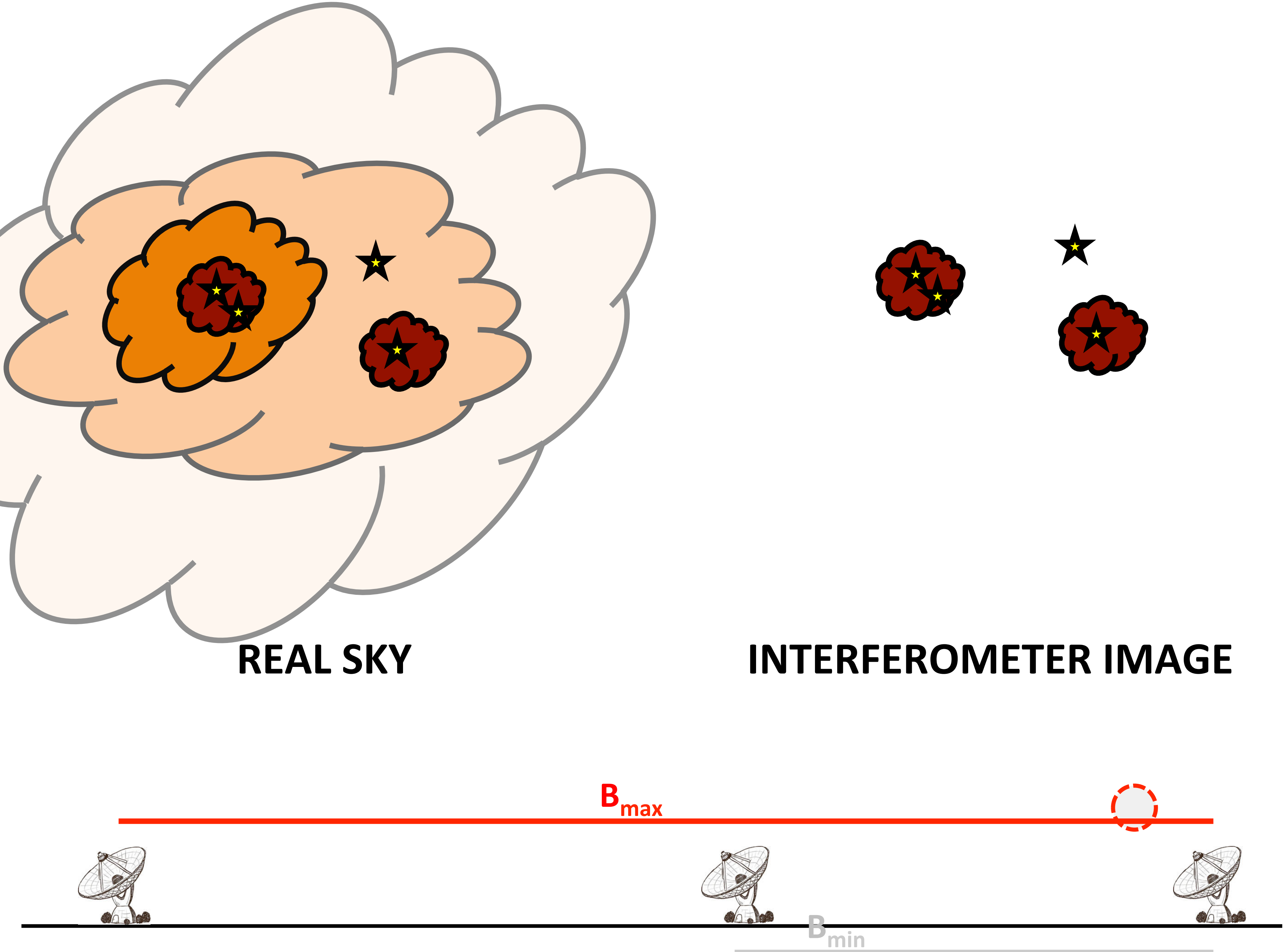
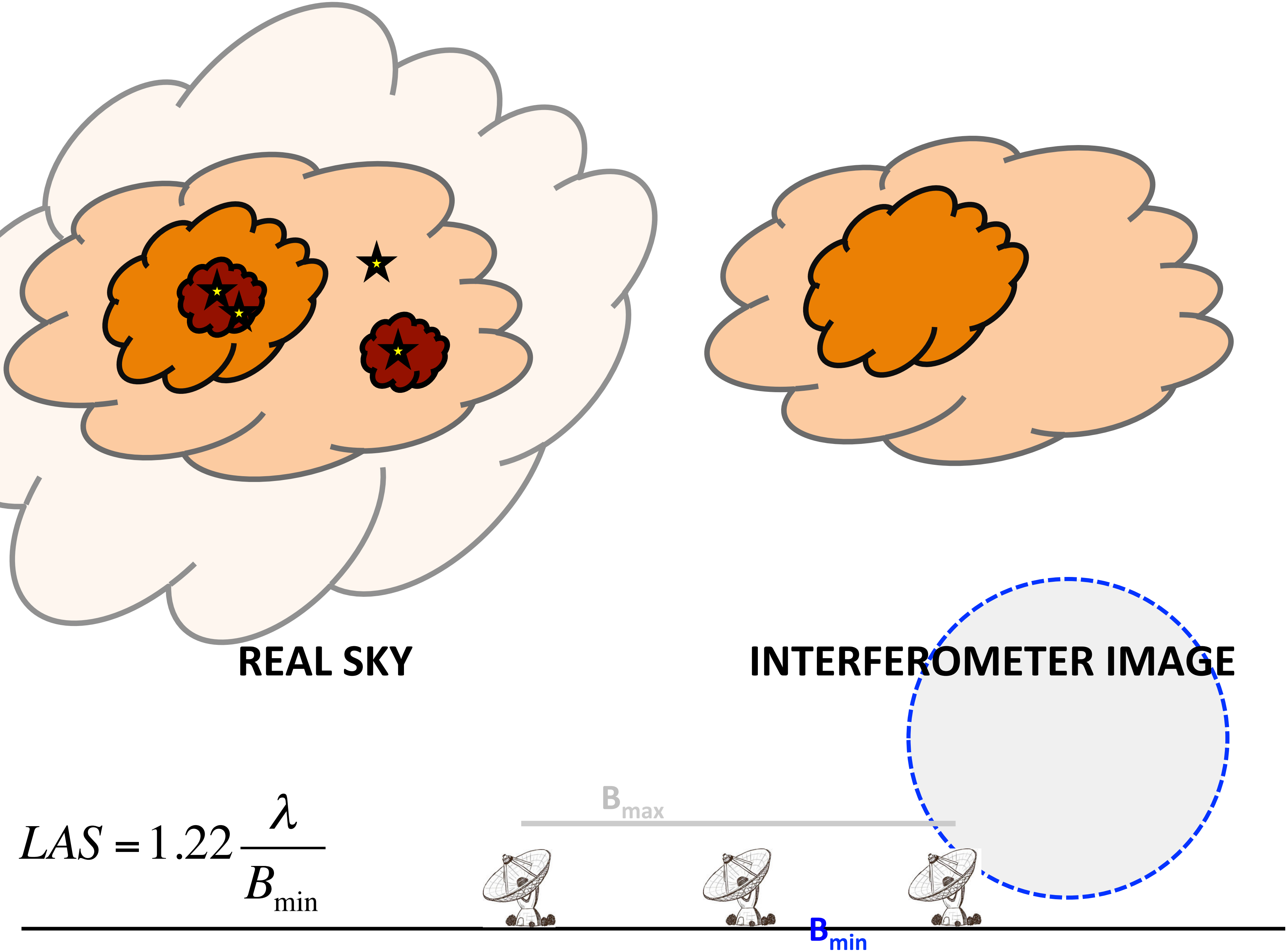
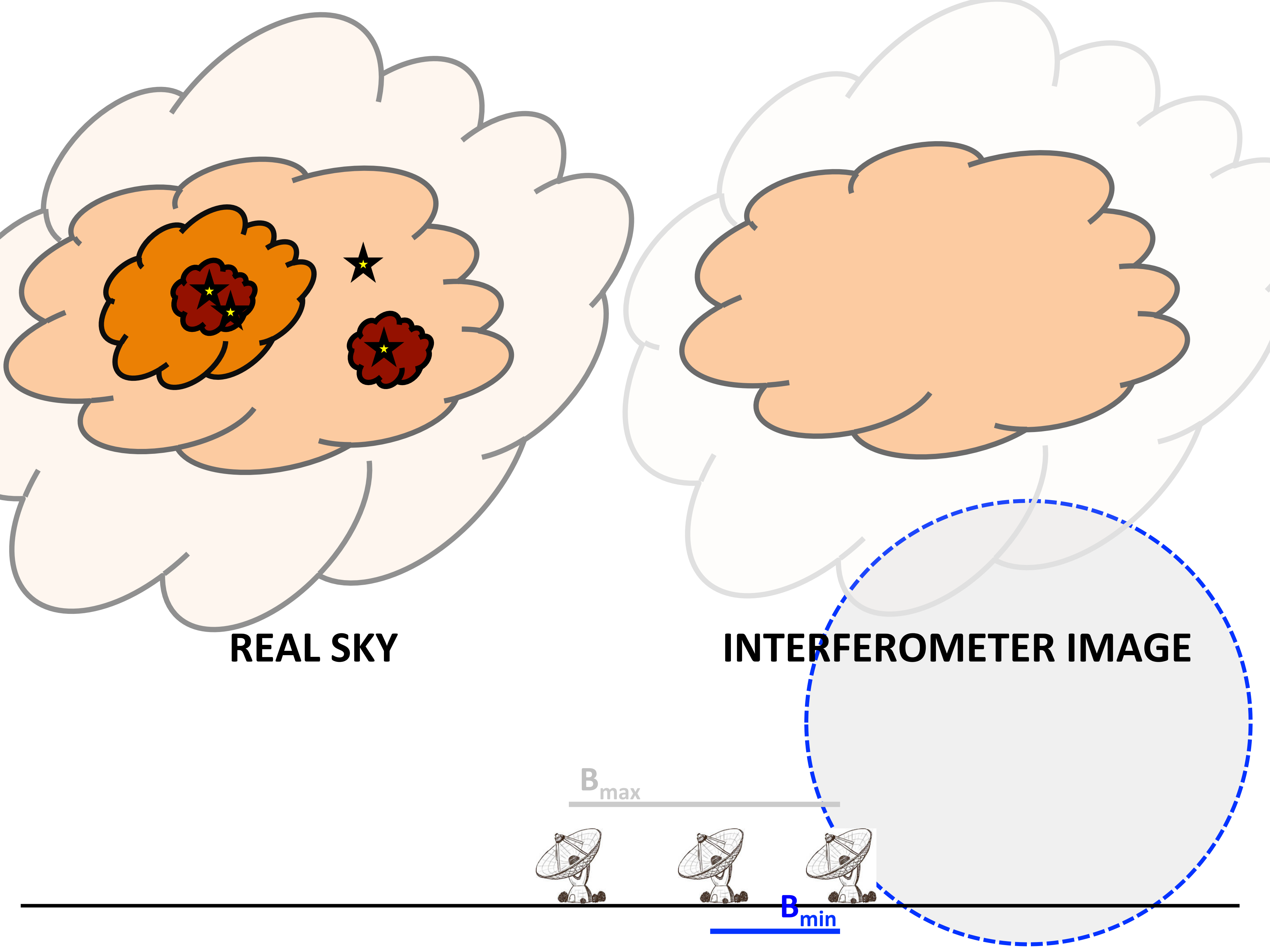

REAL SKY
INTERFEROMETER IMAGE
B_{max}
B_{min}

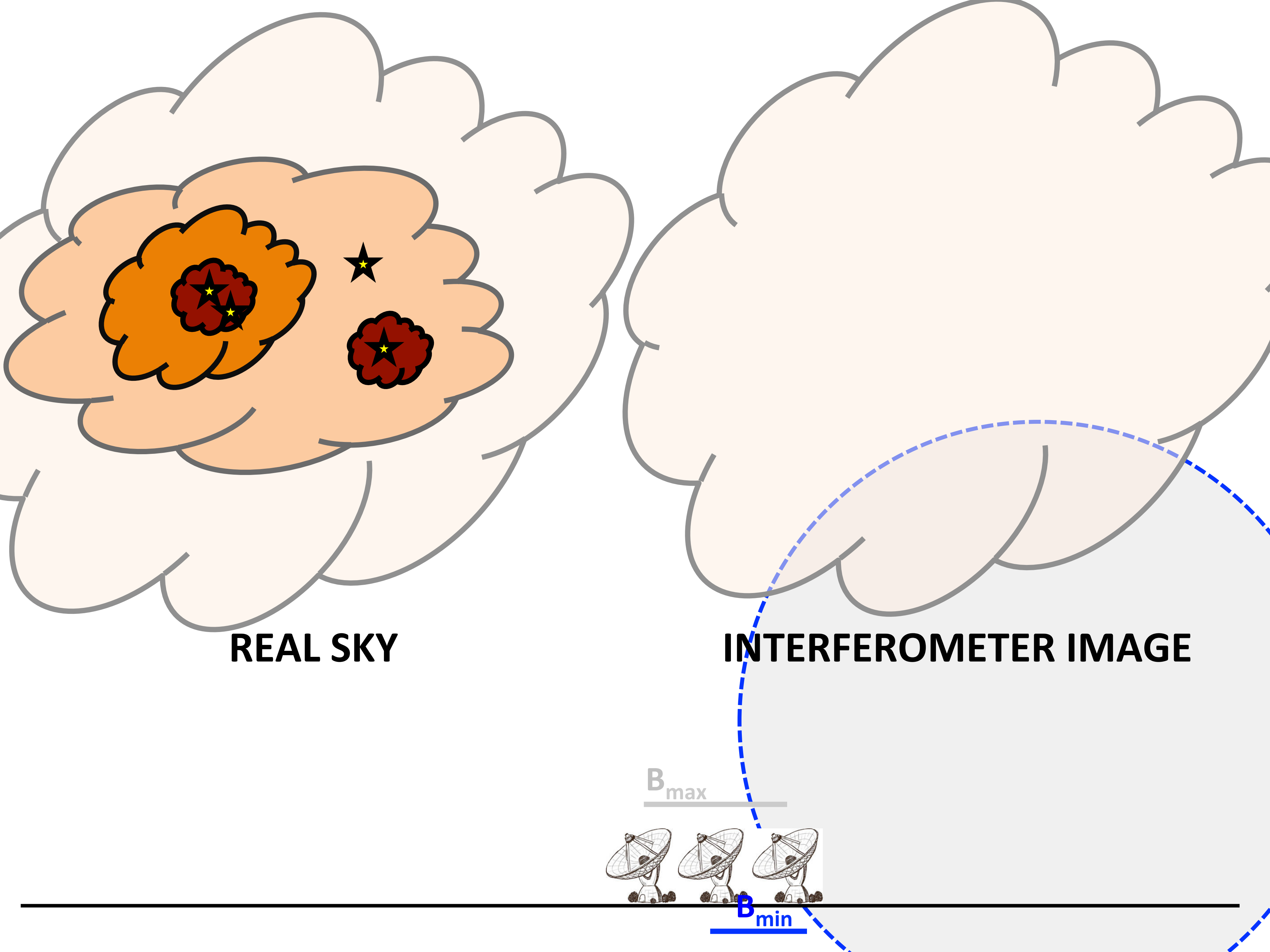


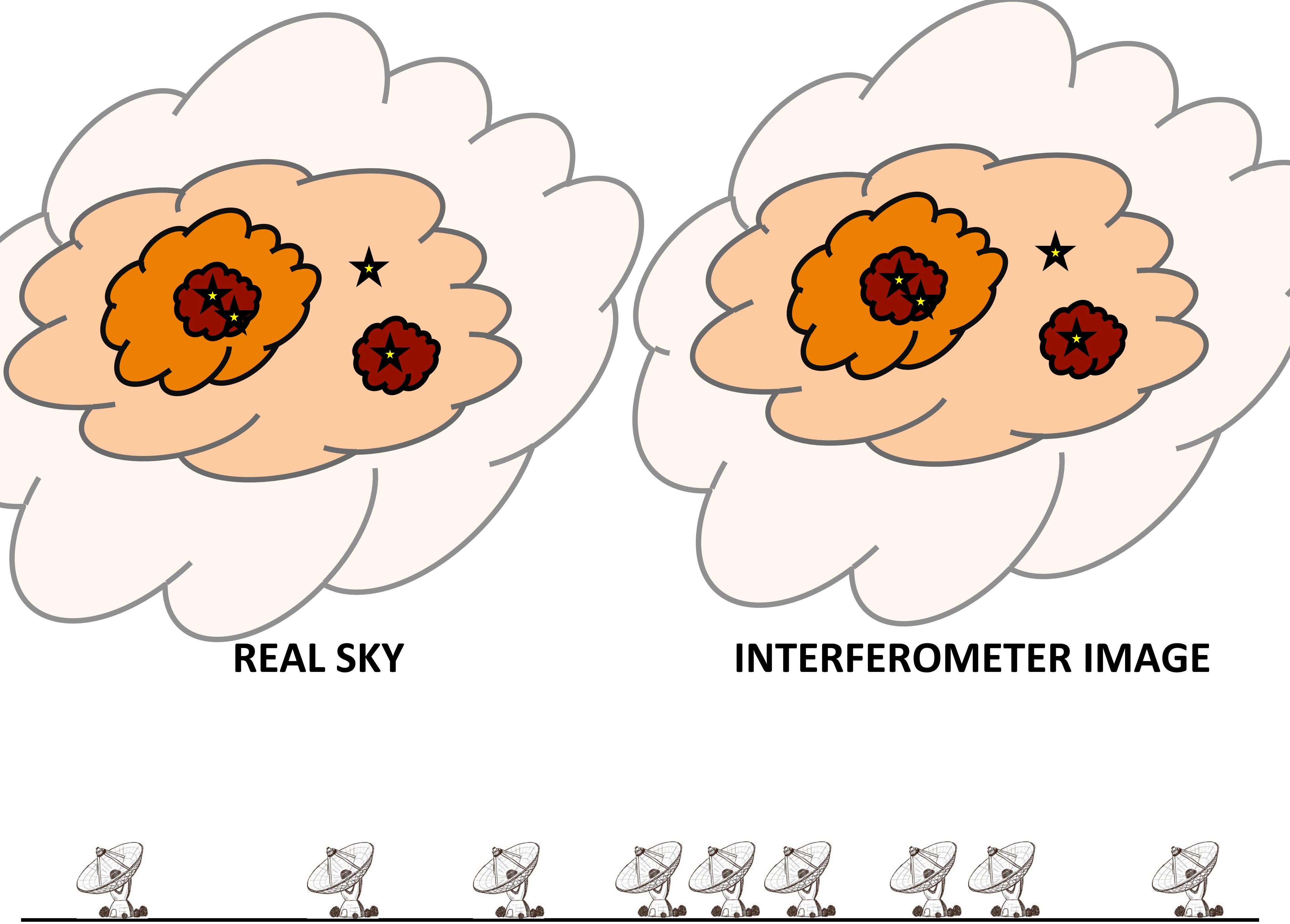
REAL SKY
INTERFEROMETER IMAGE
B max
B min



$$LAS = 1.22\frac{\lambda}{B_{\min}}$$


REAL SKY
INTERFEROMETER IMAGE
B$_{max}$
B$_{min}$


REAL SKY
INTERFEROMETER IMAGE
B_{max}
B_{min}

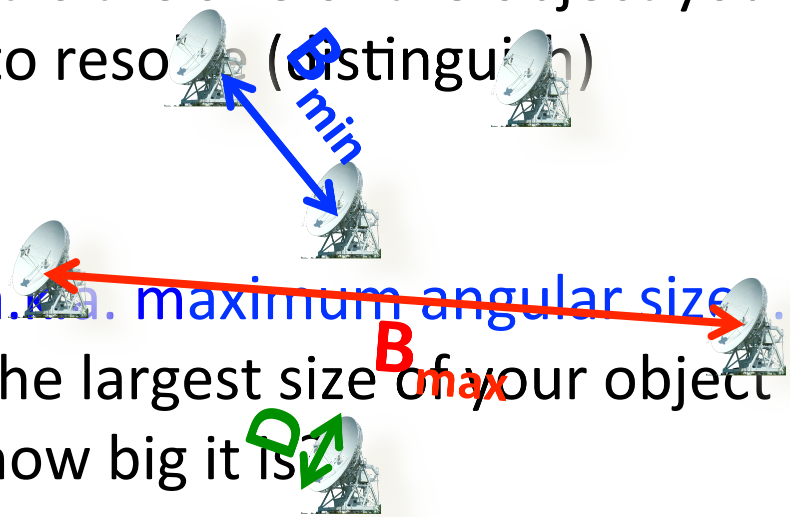

REAL SKY
INTERFEROMETER IMAGE

Synthesized beam, primary beam and LAS

a.k.a. angular resolution, PSF, ...
it is the size of the object you want to resolve (distinguish)

SYNTHESIZED BEAM

$$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$$



a.k.a. maximum angular size, ...
the largest size of your object
how big it is?

LARGEST ANGULAR SCALE

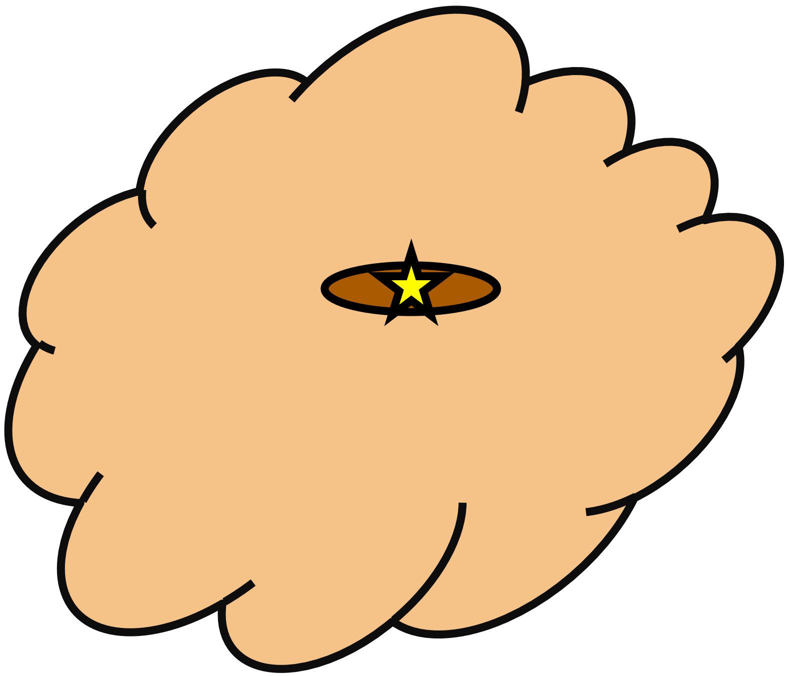
$$LAS = 1.22 \frac{\lambda}{B_{\min}}$$

a.k.a. field of view (FOV), ...
the area of the sky you want to observe

PRIMARY BEAM

$$PB = 1.22 \frac{\lambda}{D}$$

Example I: compact protoplanetary disk



SYNTHESIZED BEAM

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LARGEST ANGULAR SCALE

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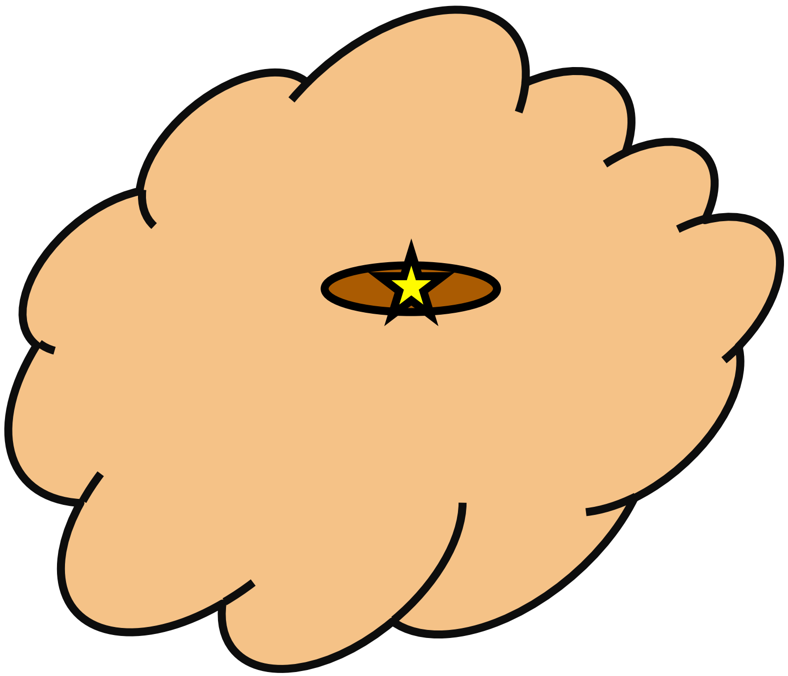
Example I: compact protoplanetary disk



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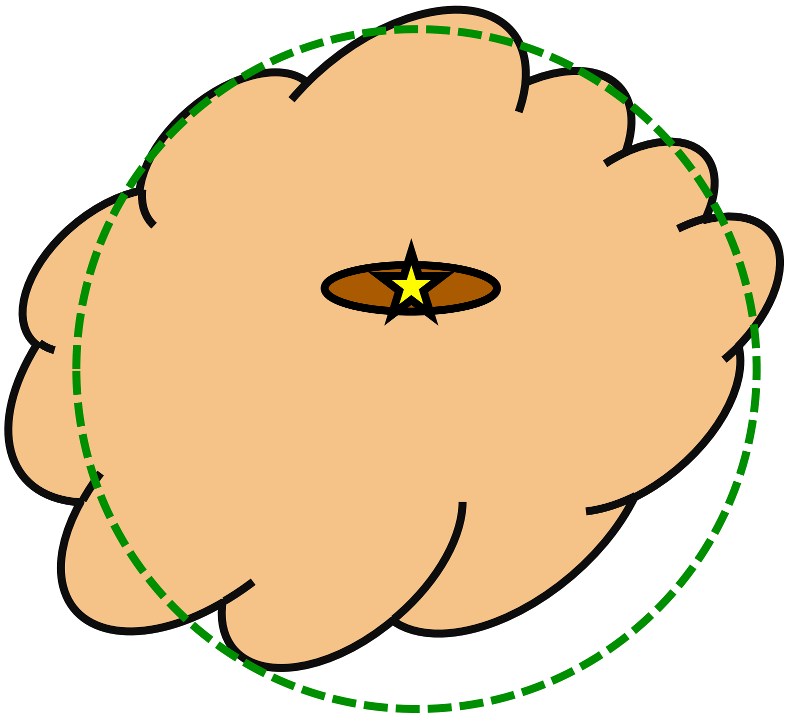

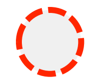

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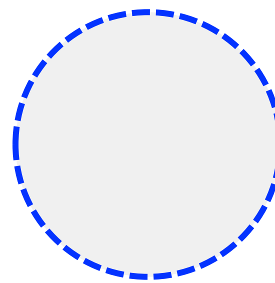


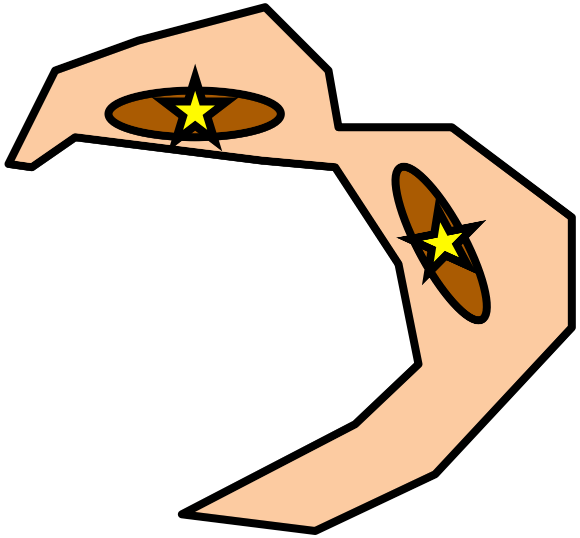
LARGEST ANGULAR SCALE

$$LAS = 1.22 \frac{\lambda}{B_{\min}}$$

PRIMARY BEAM

$$PB = 1.22 \frac{\lambda}{D}$$

Example II: disks and filament



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LARGEST ANGULAR SCALE

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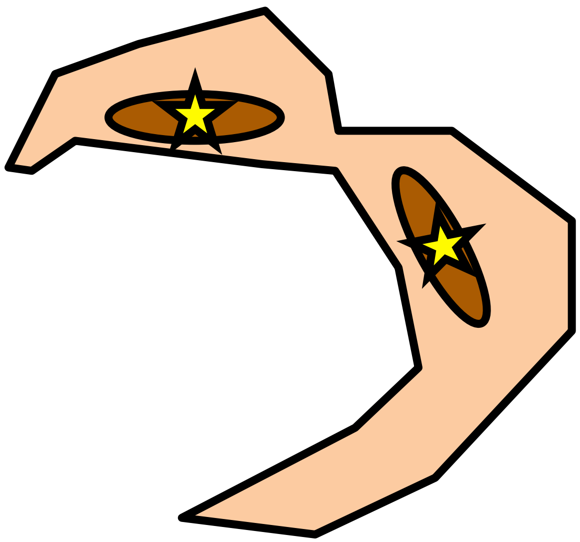

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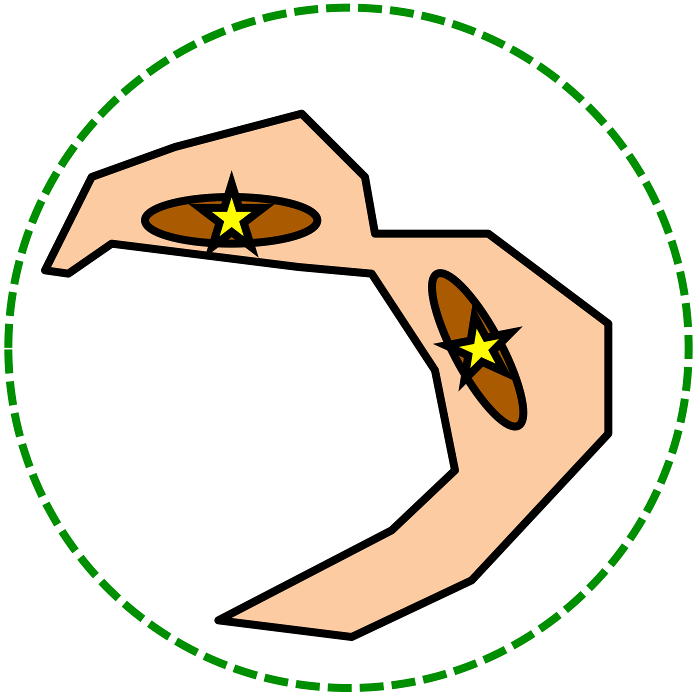

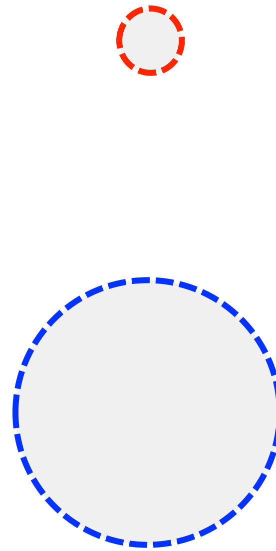

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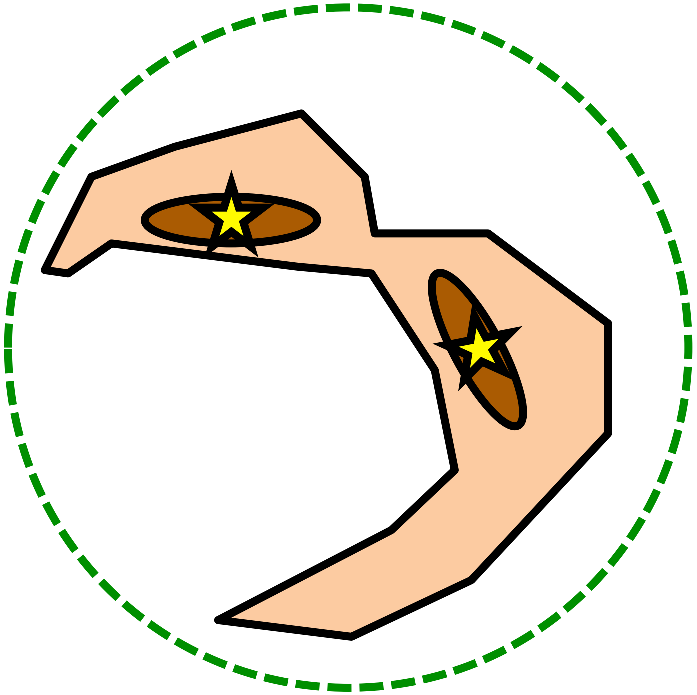

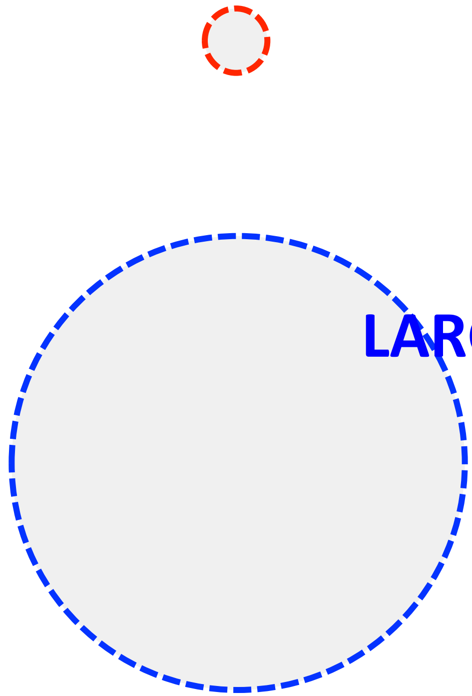

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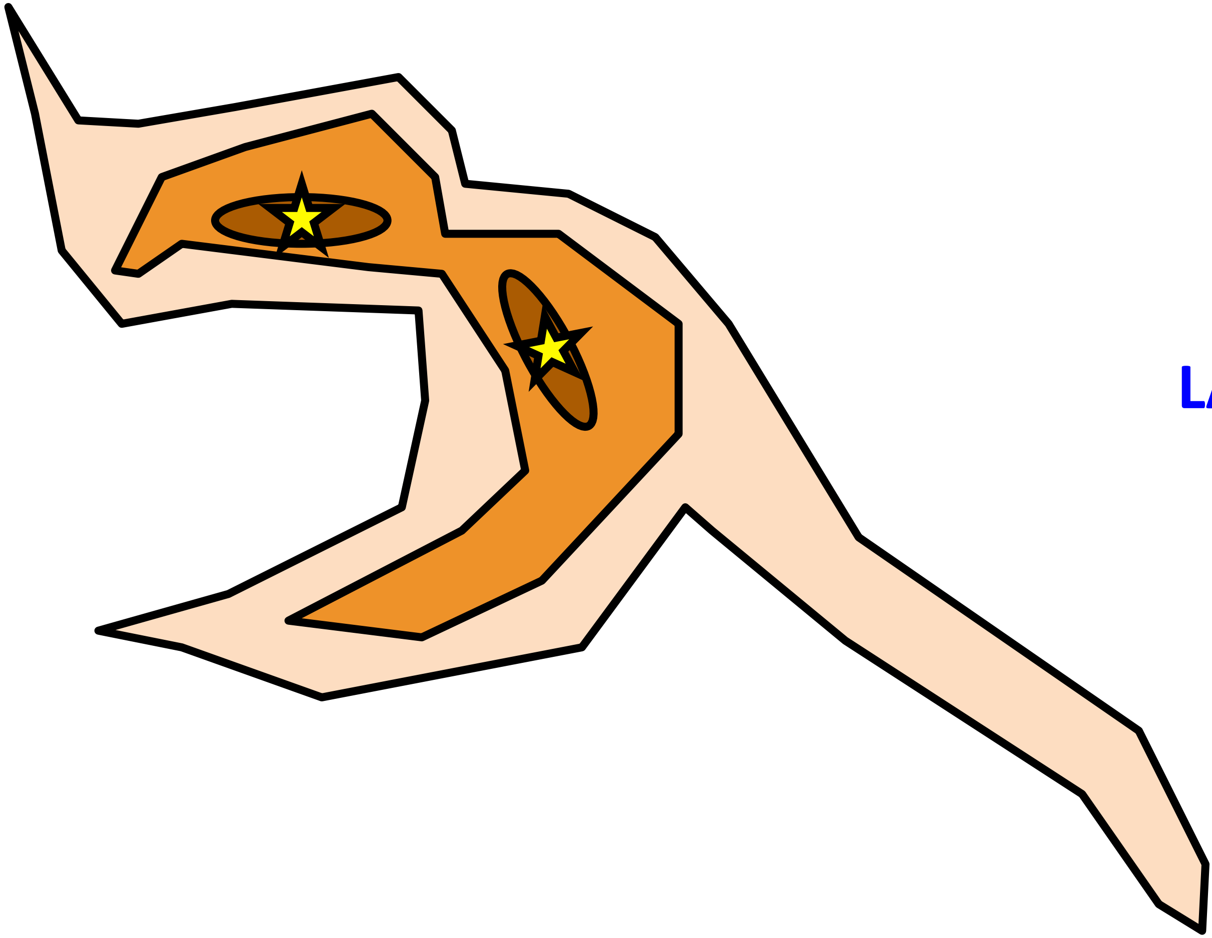
Example III: disks and extended filament



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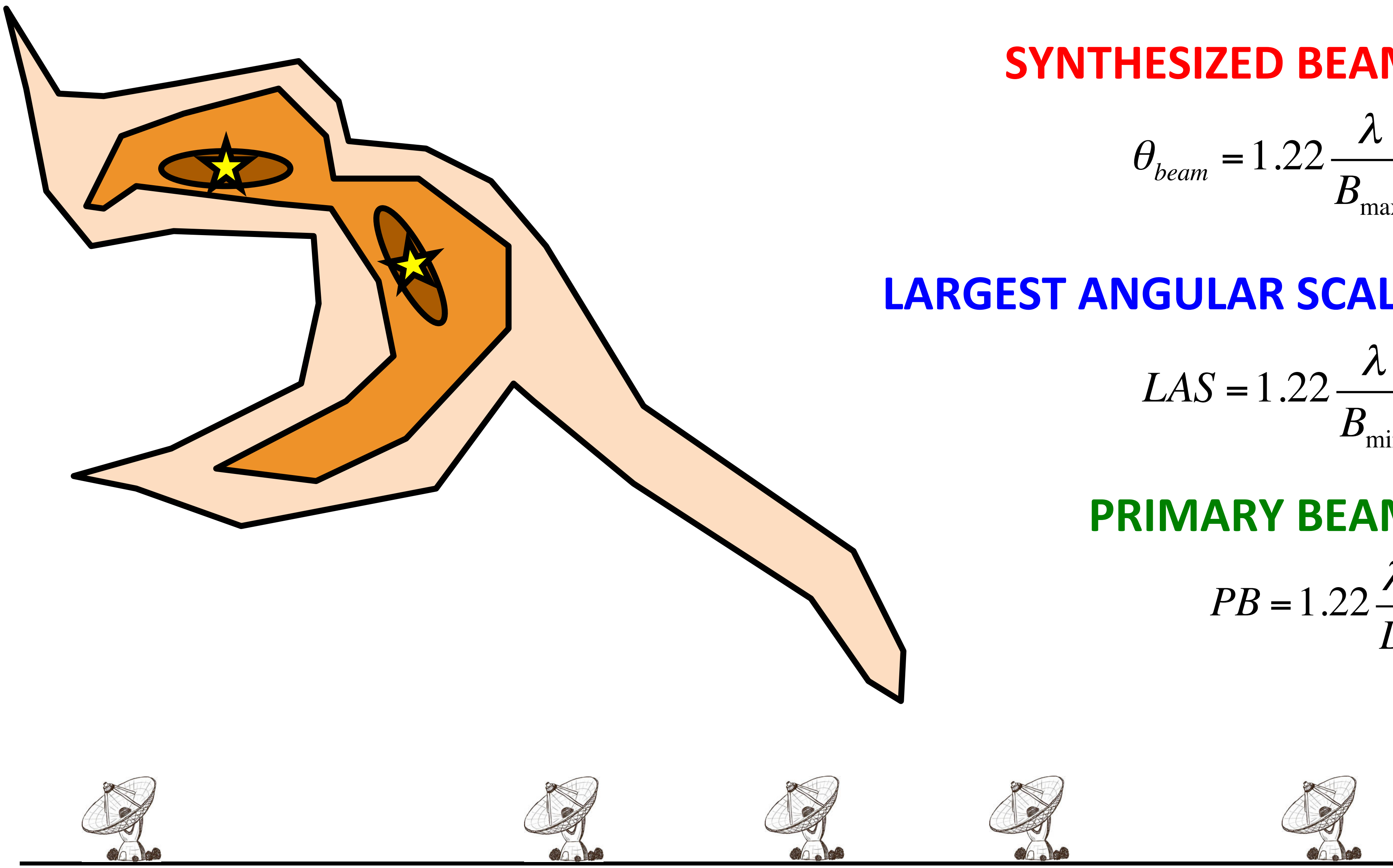

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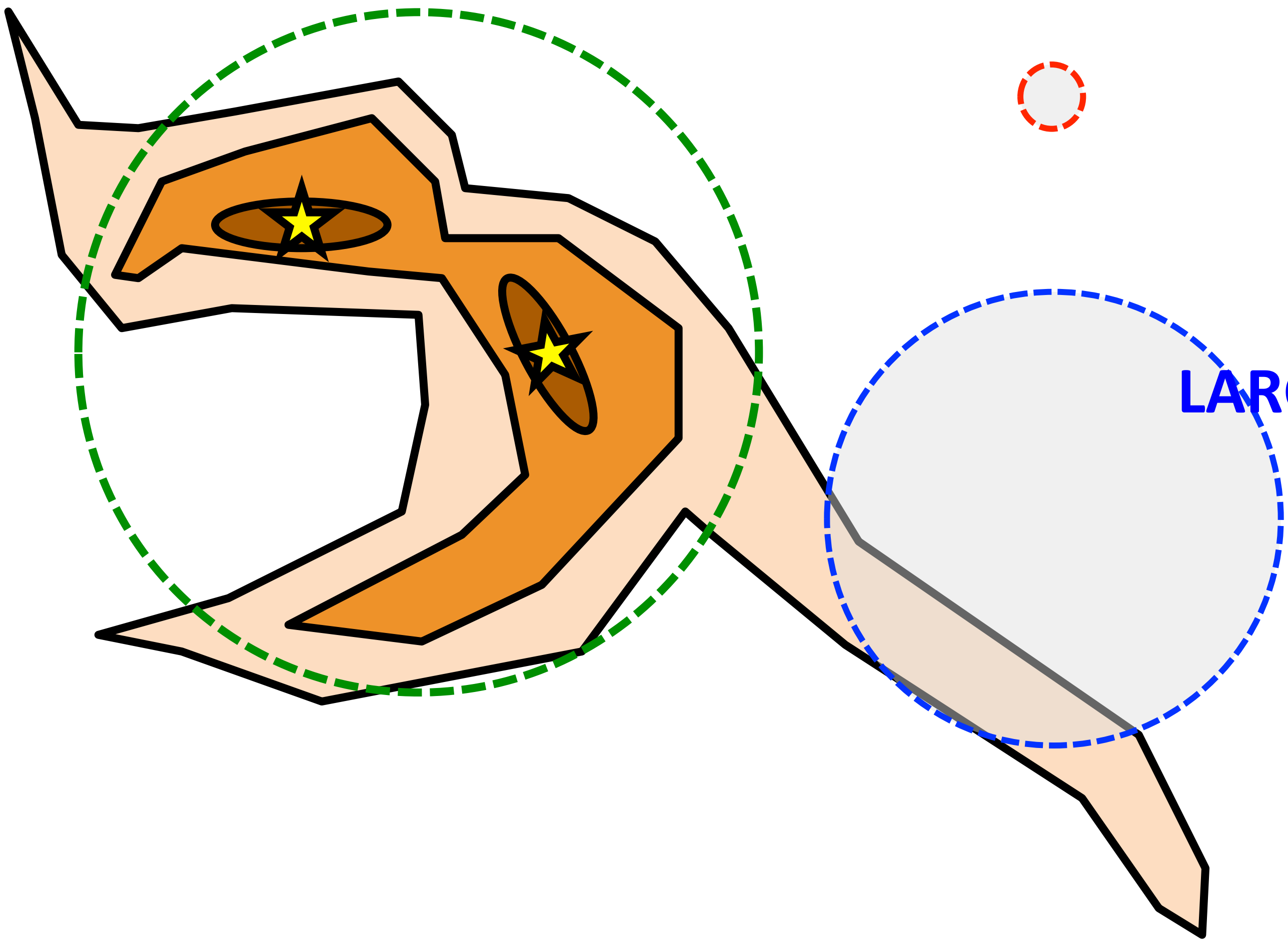

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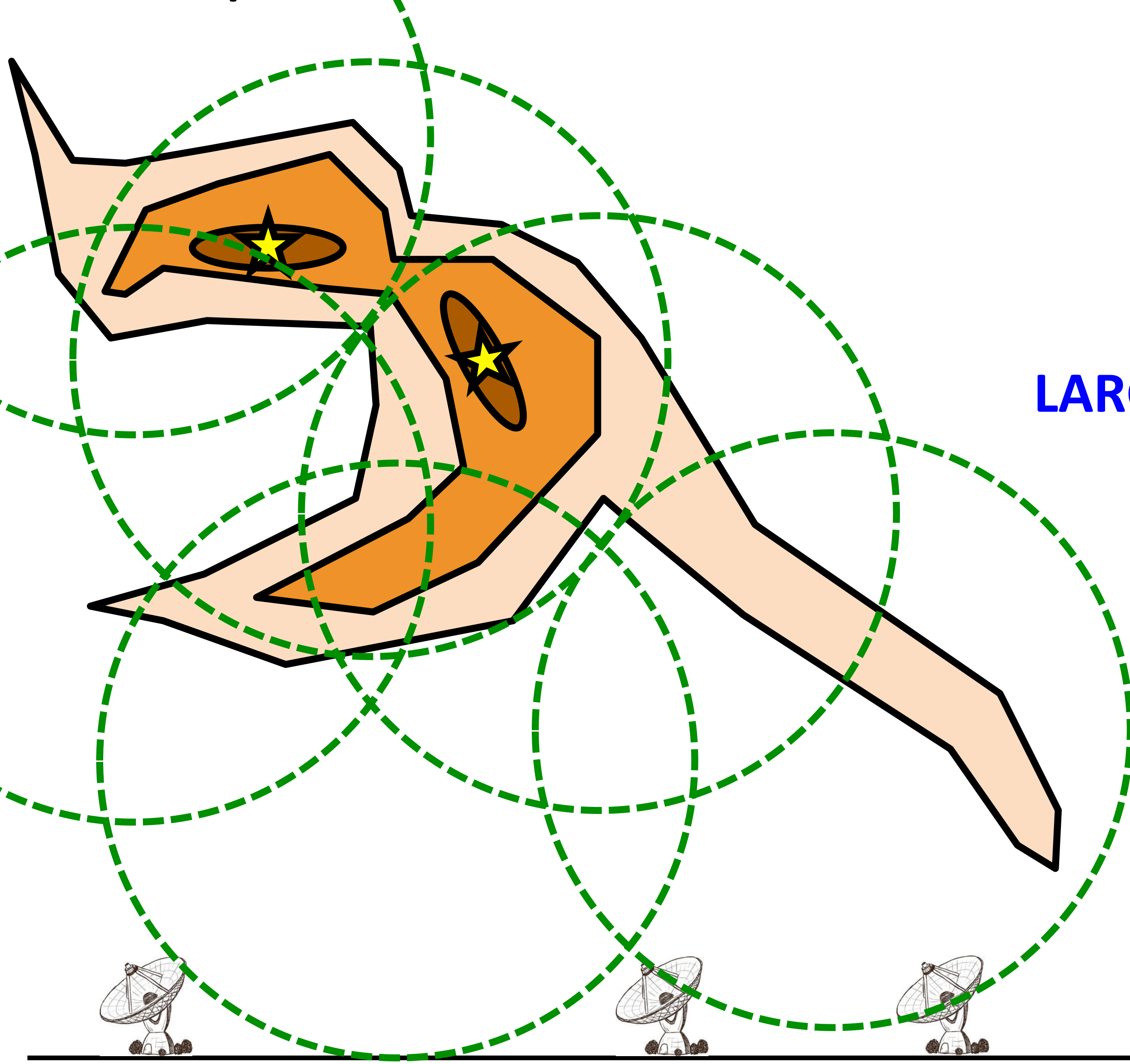

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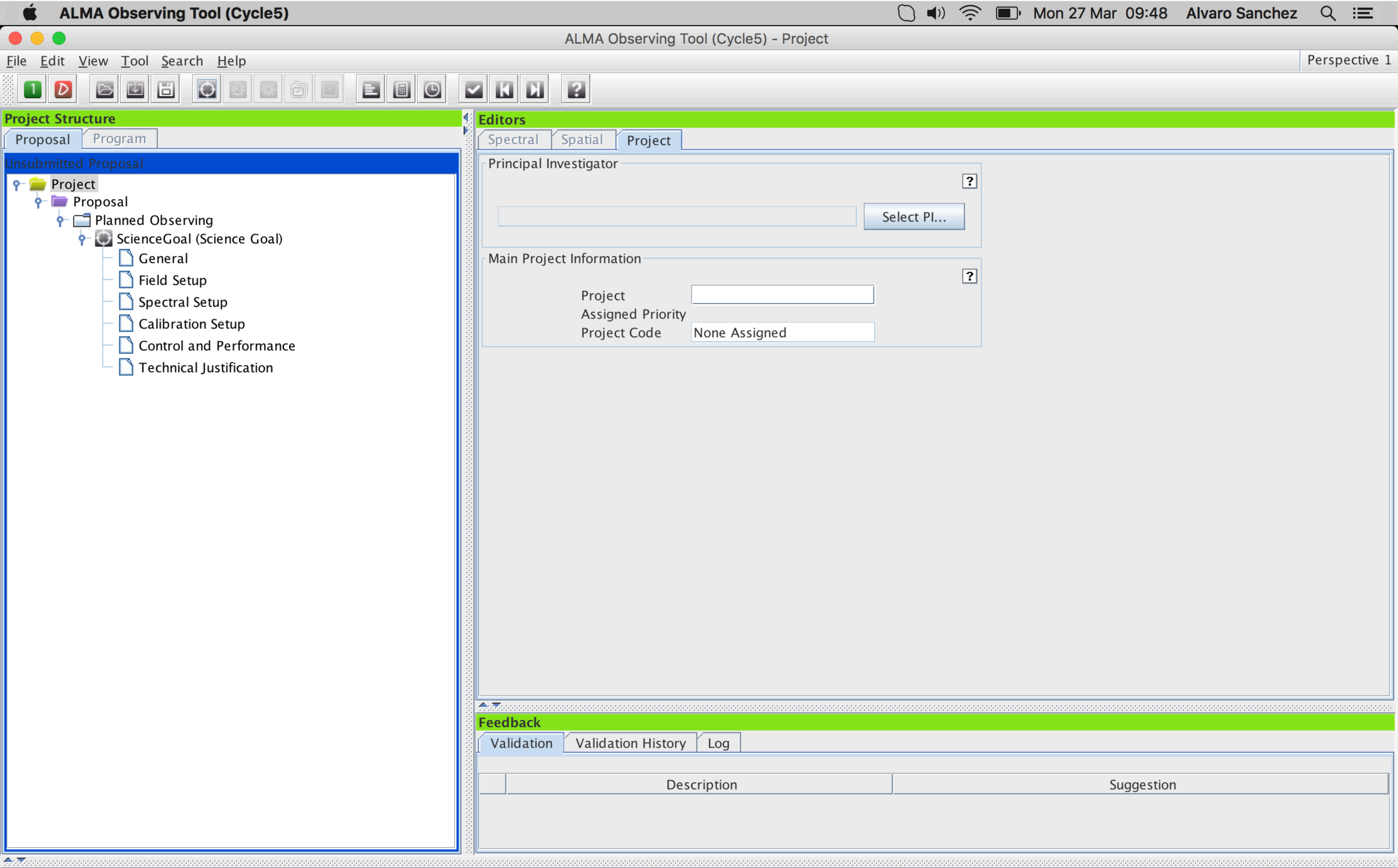
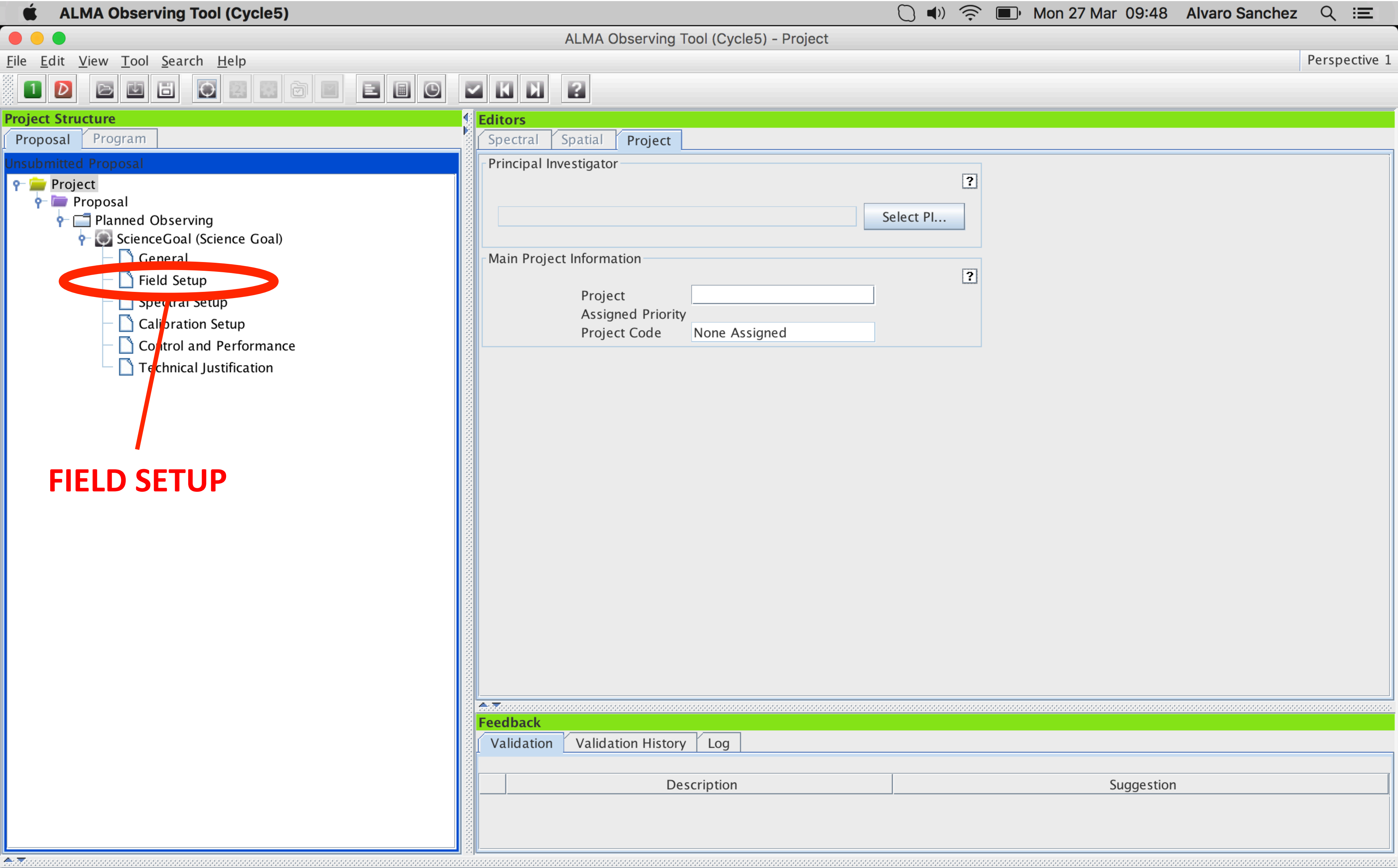
Practical work with the almaOT

Starting the almaOT



Field setup in the almaOT



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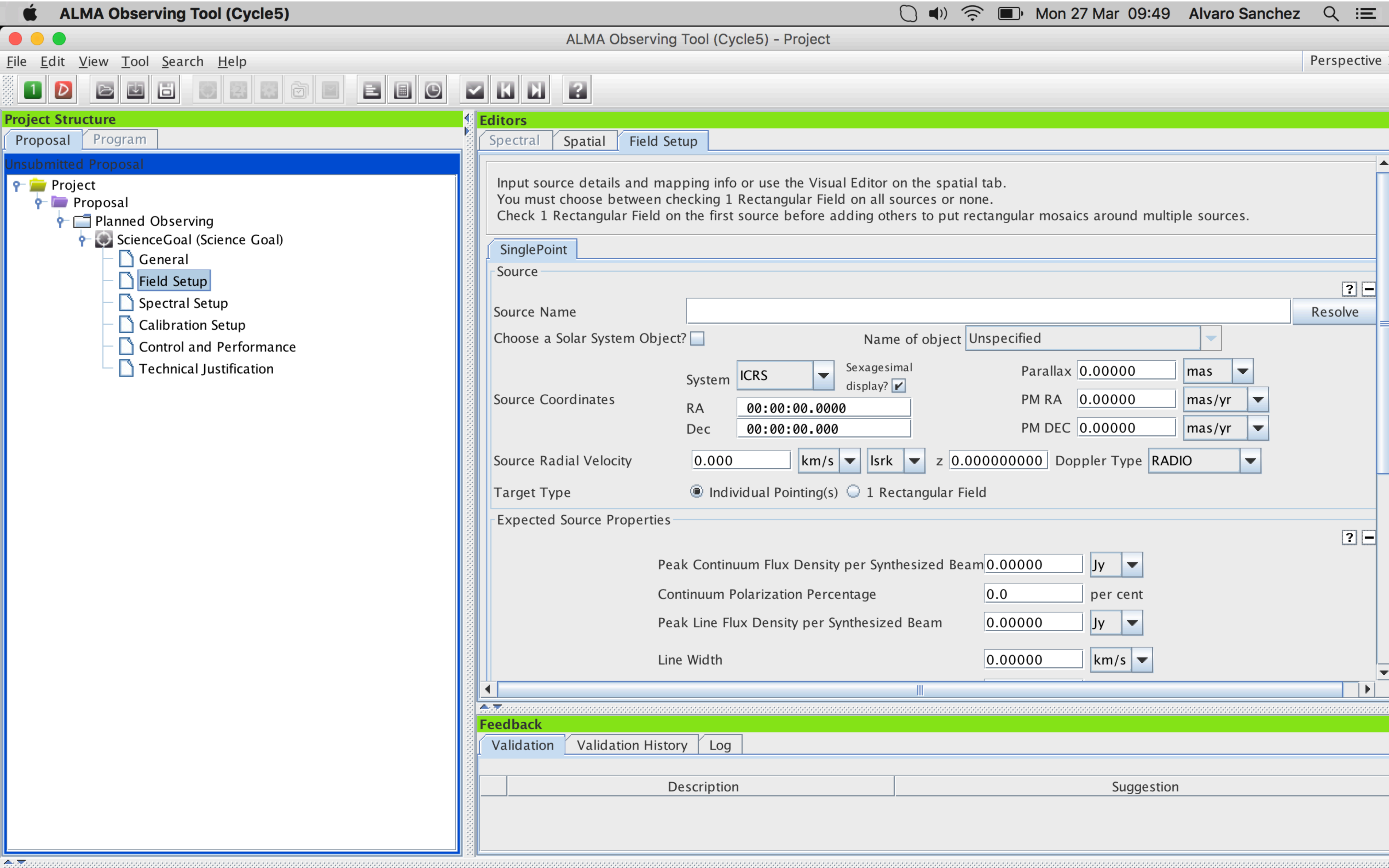
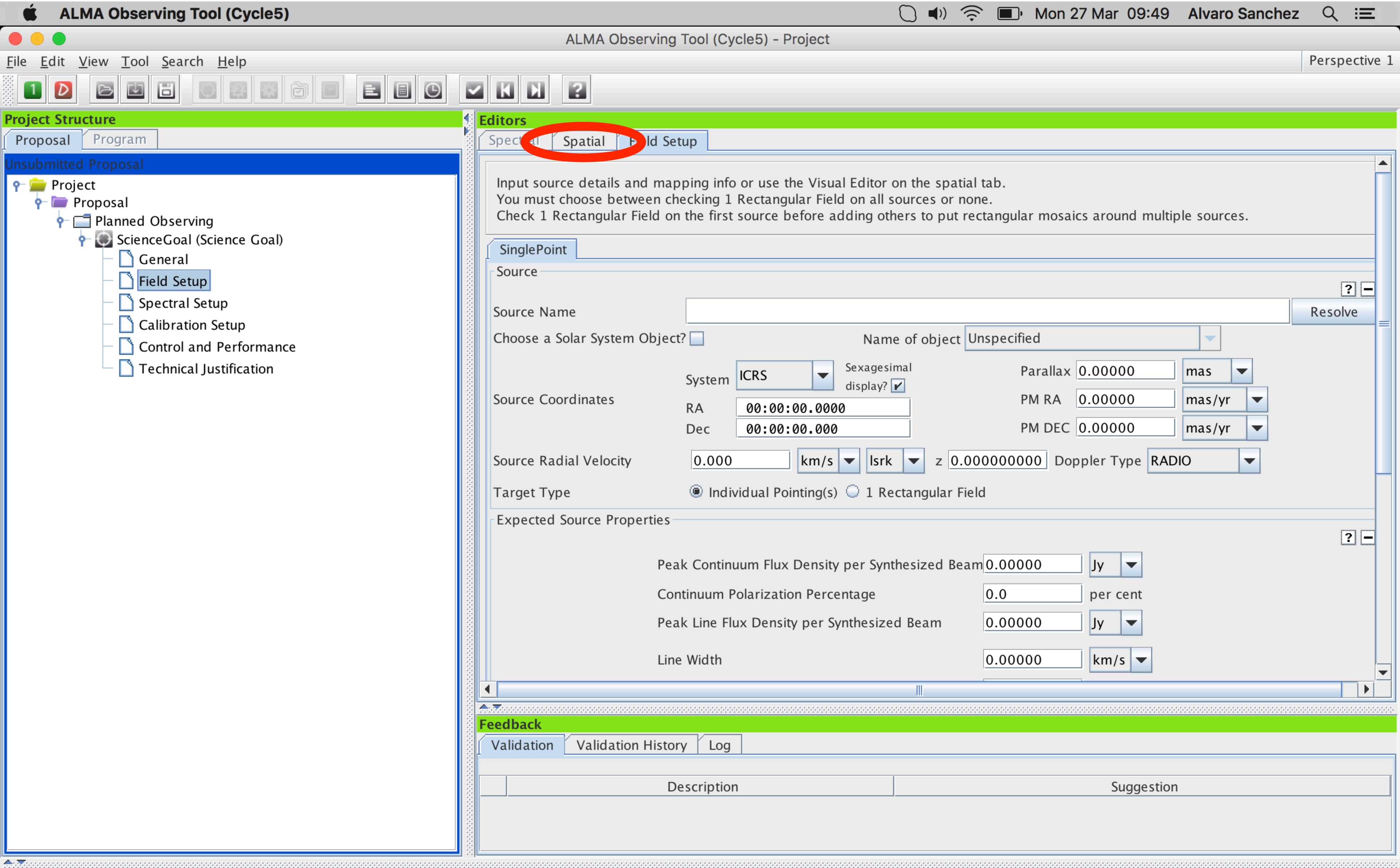
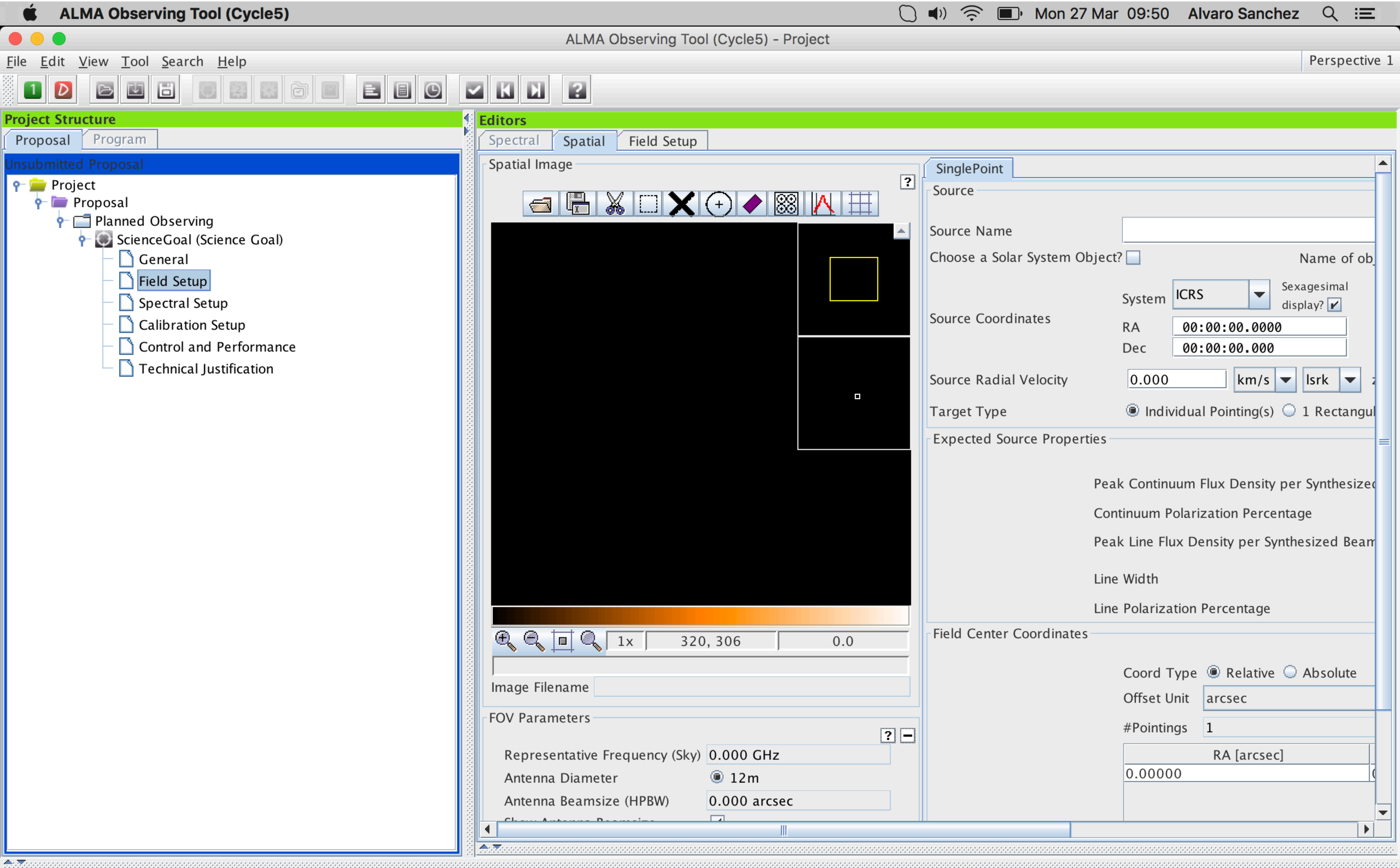


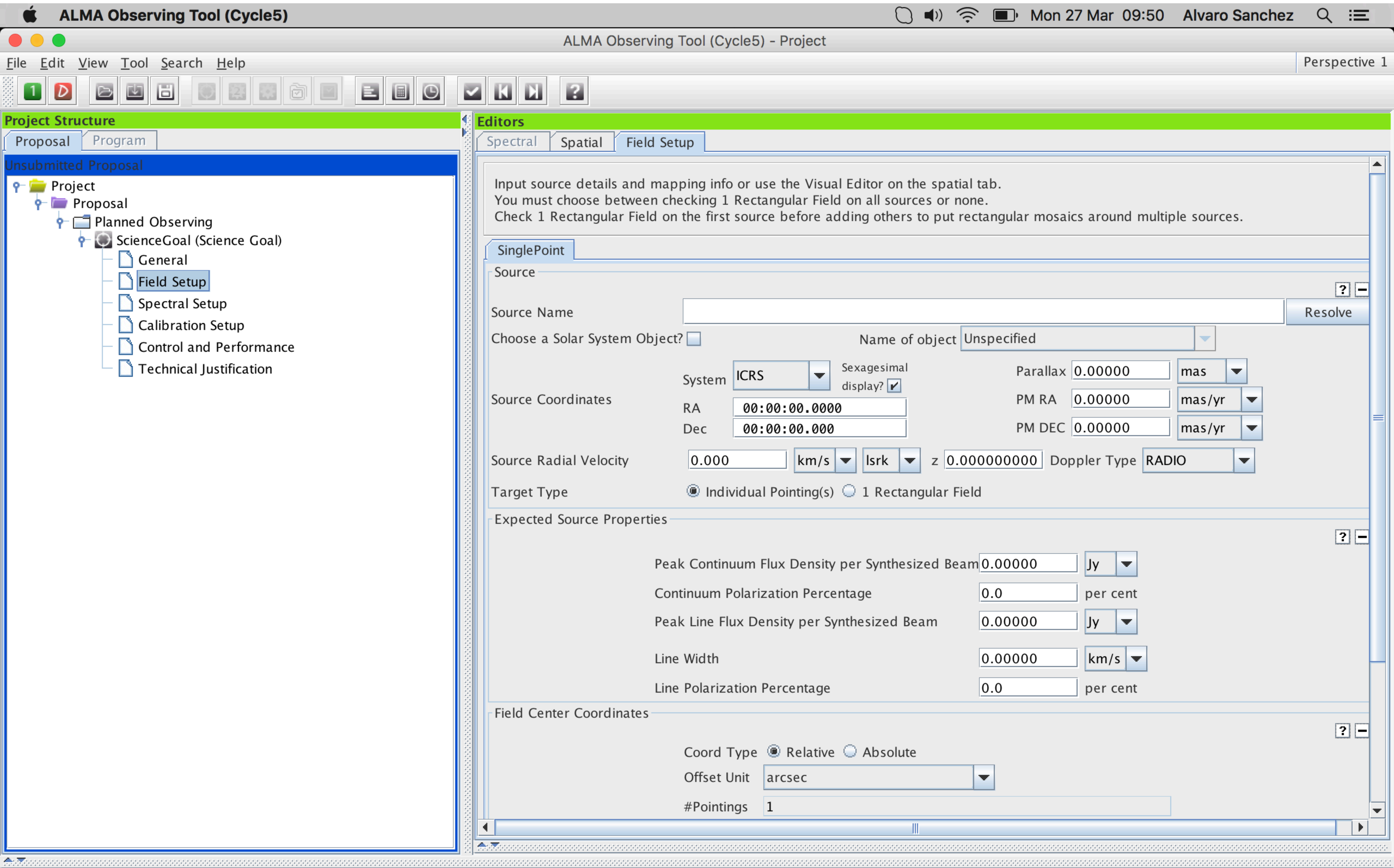
Field setup in the almaOT



Field setup in the almaOT



Field setup in the almaOT



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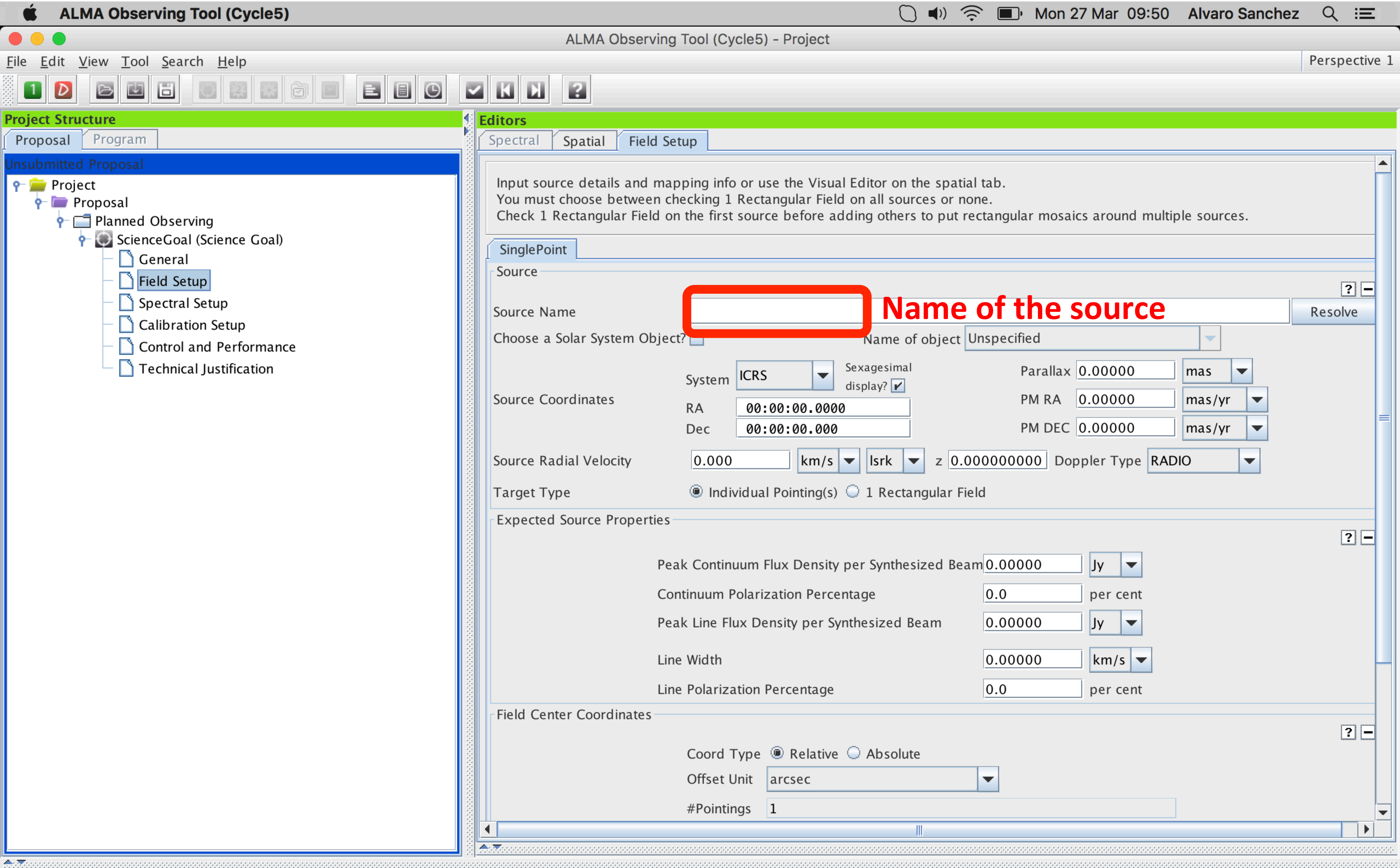
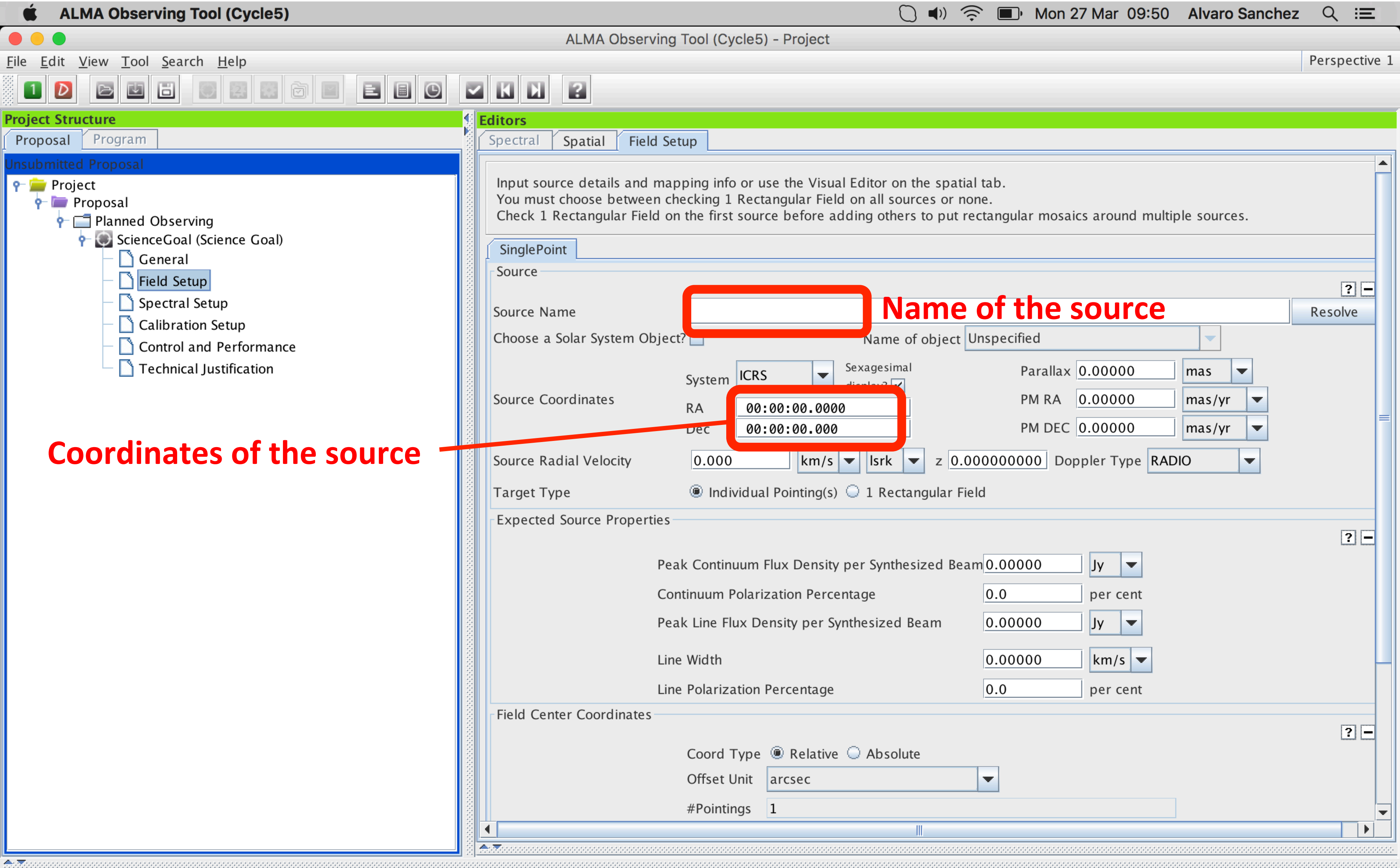


Field setup in the almaOT



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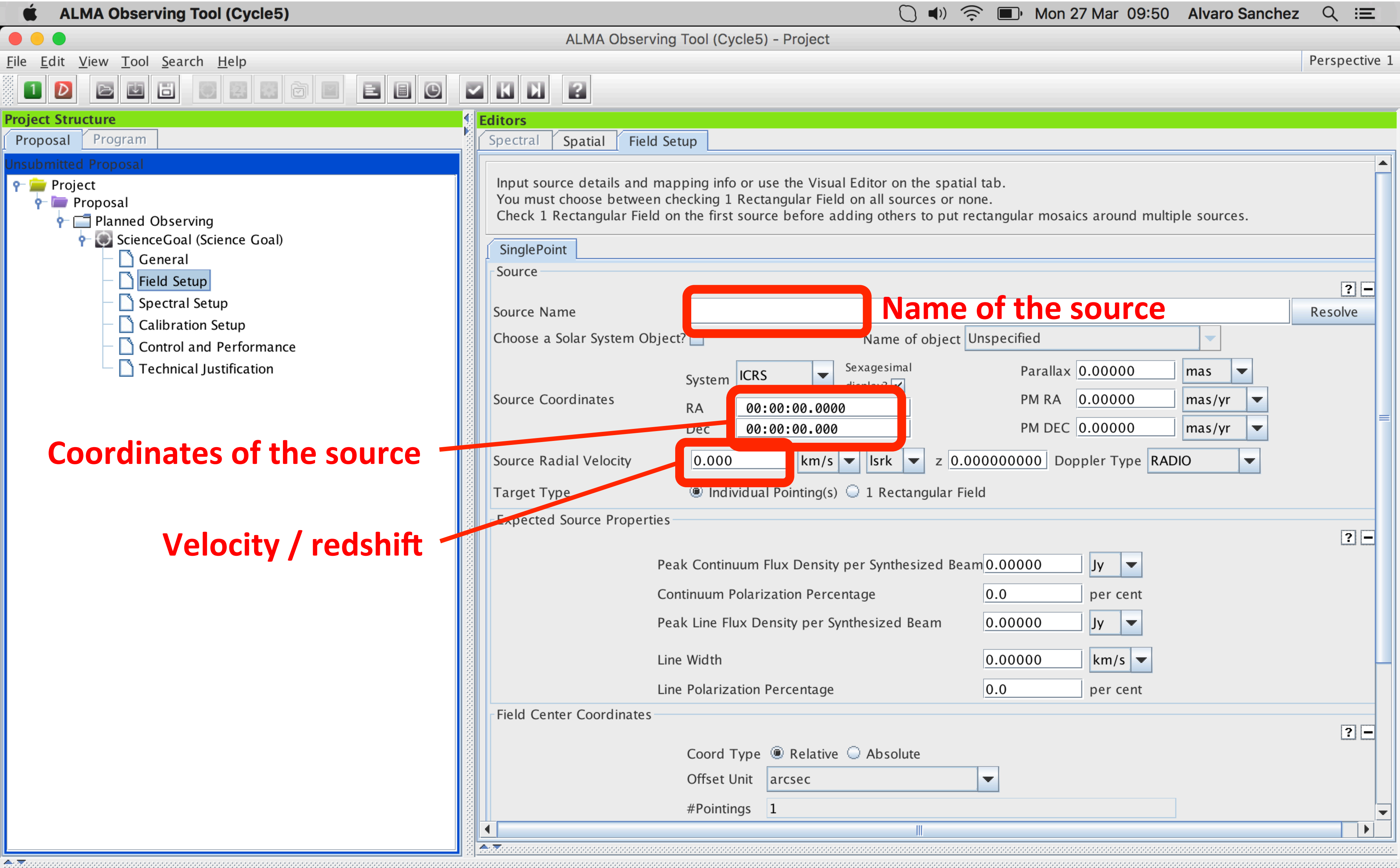

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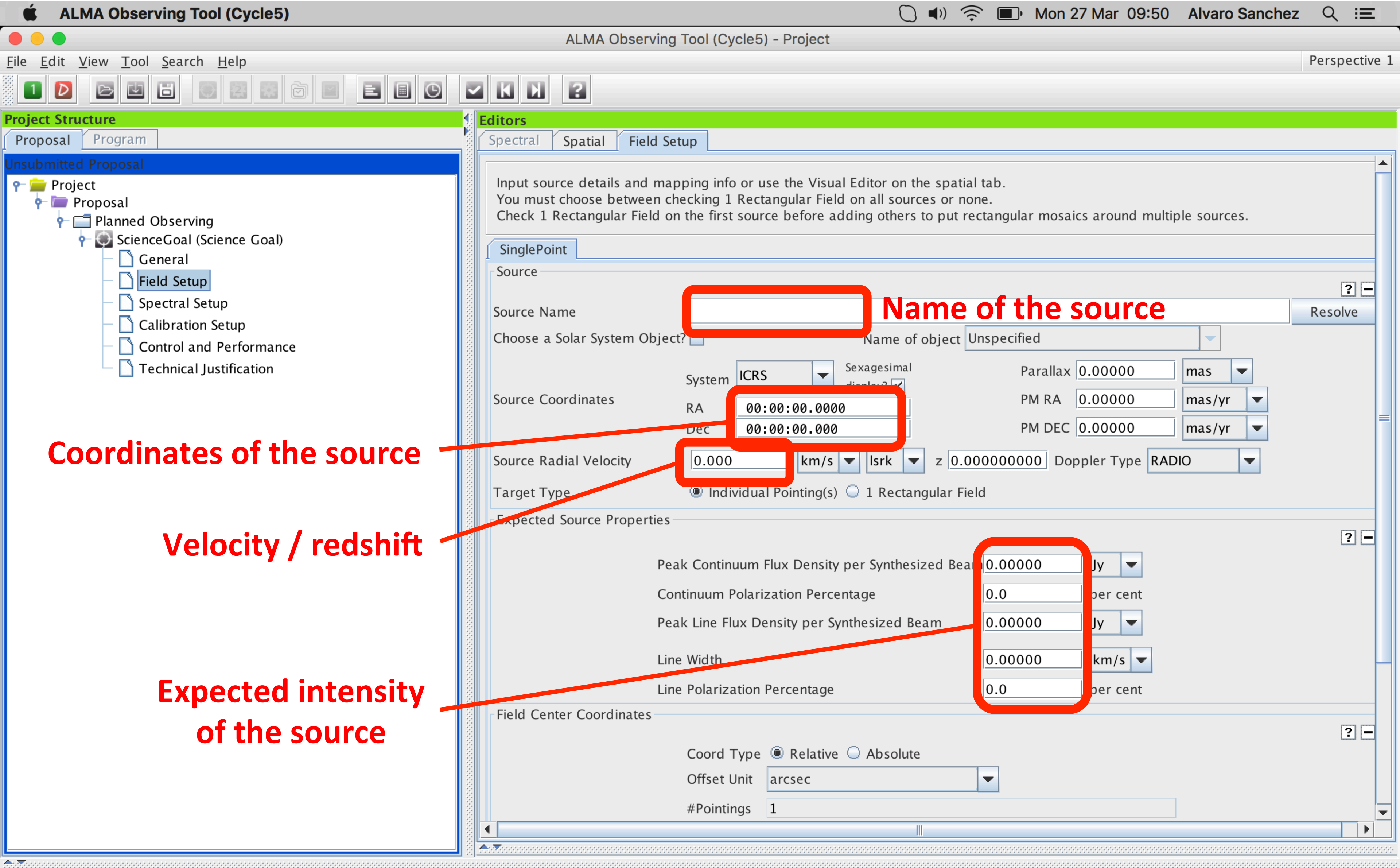

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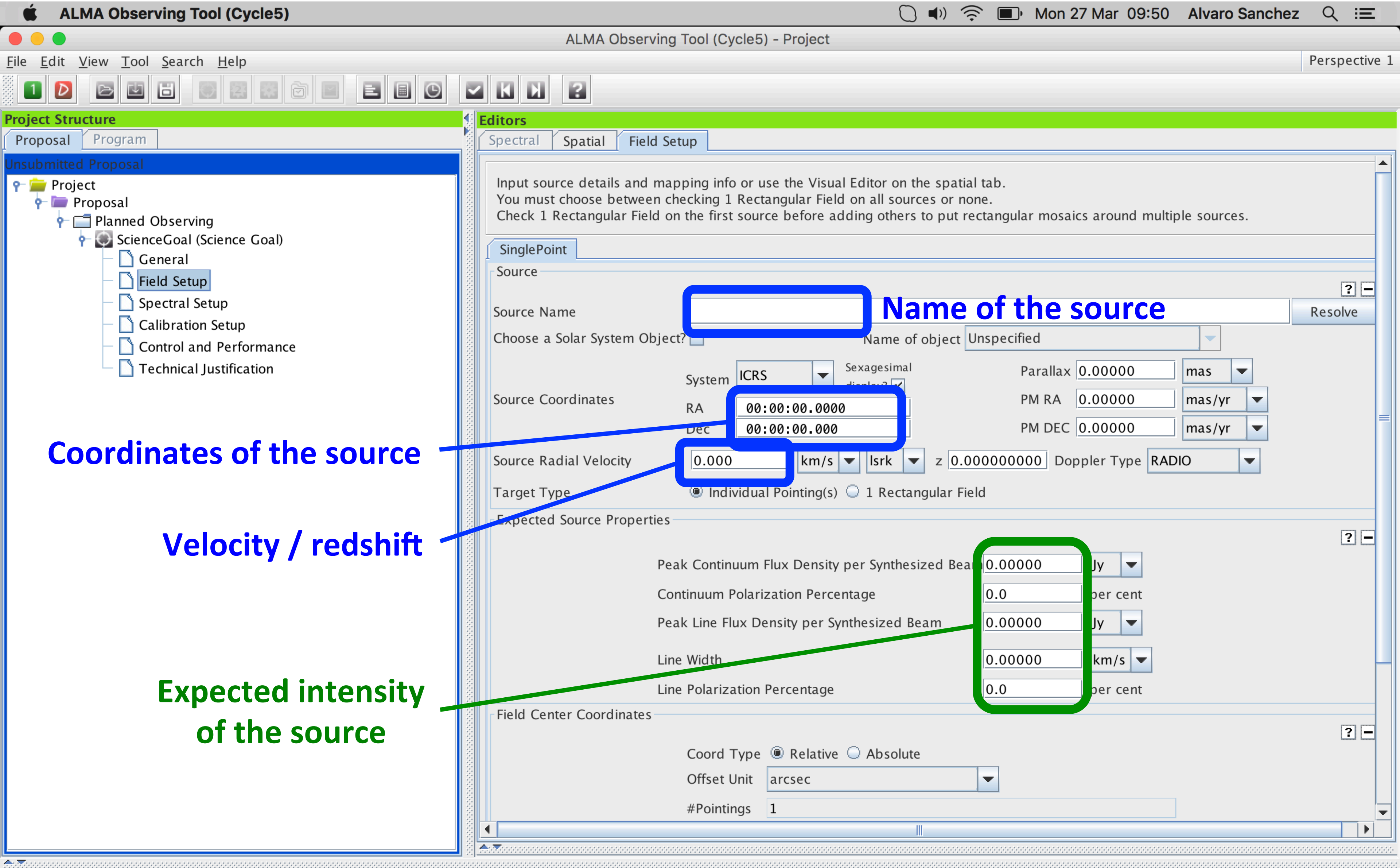
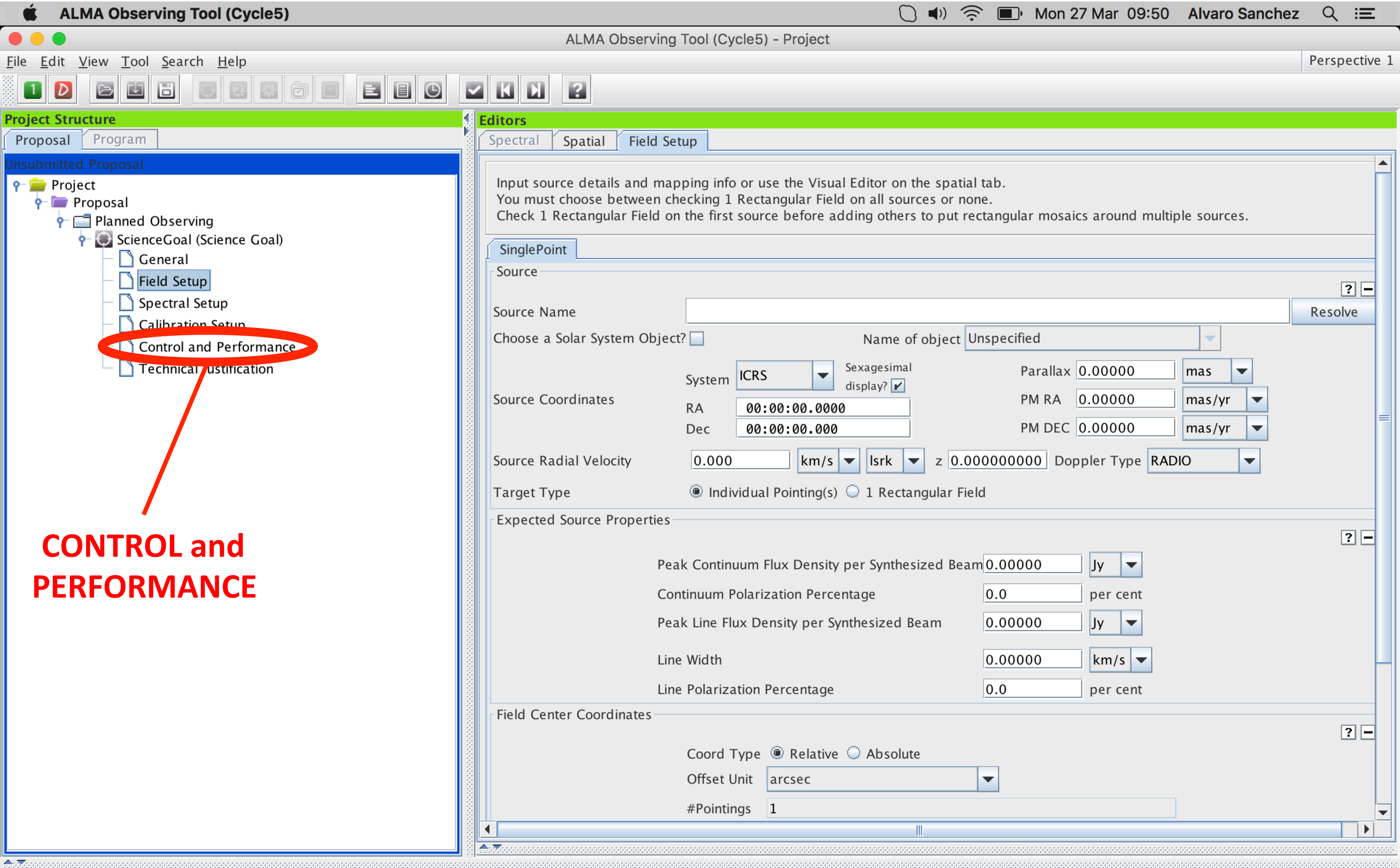
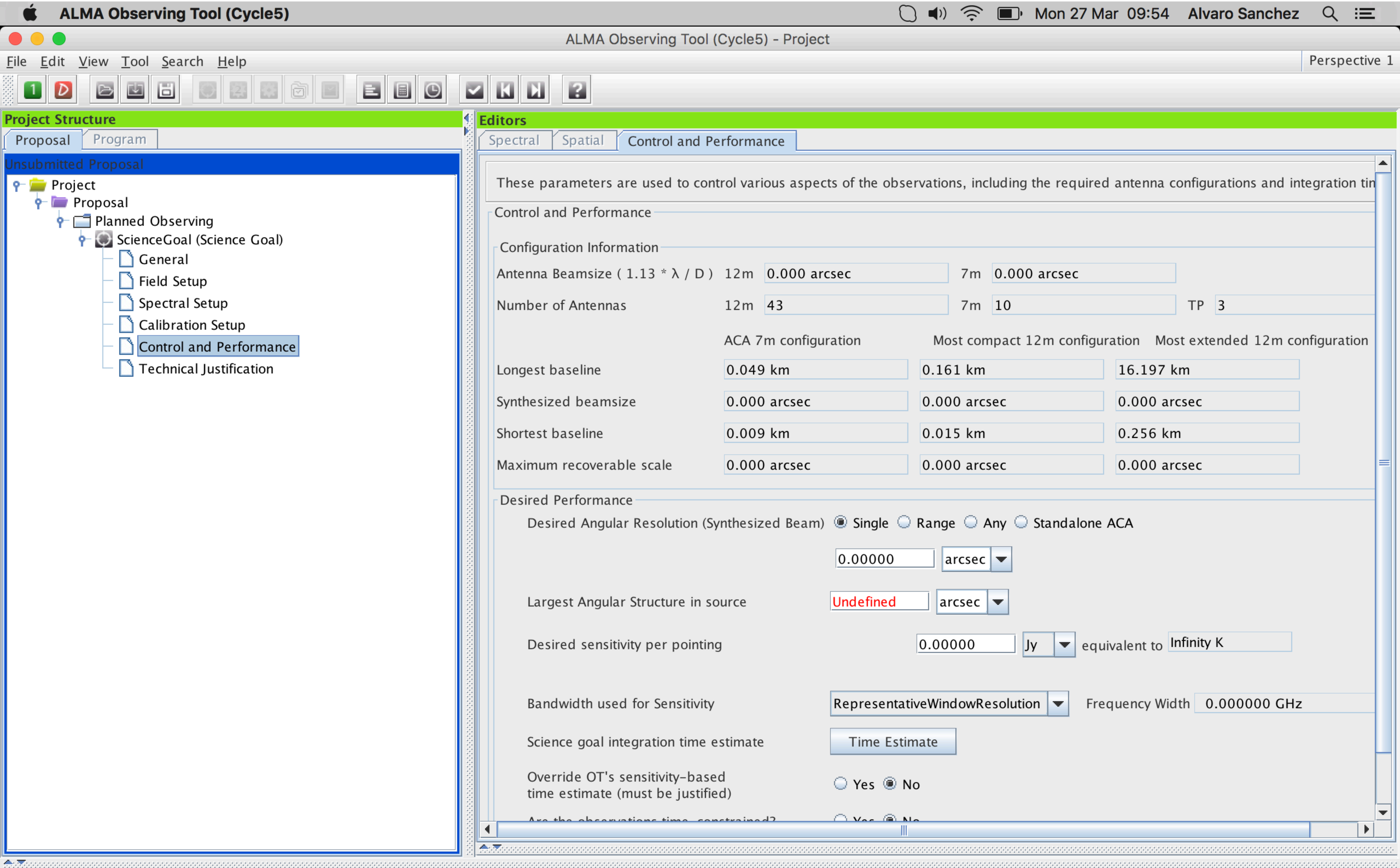


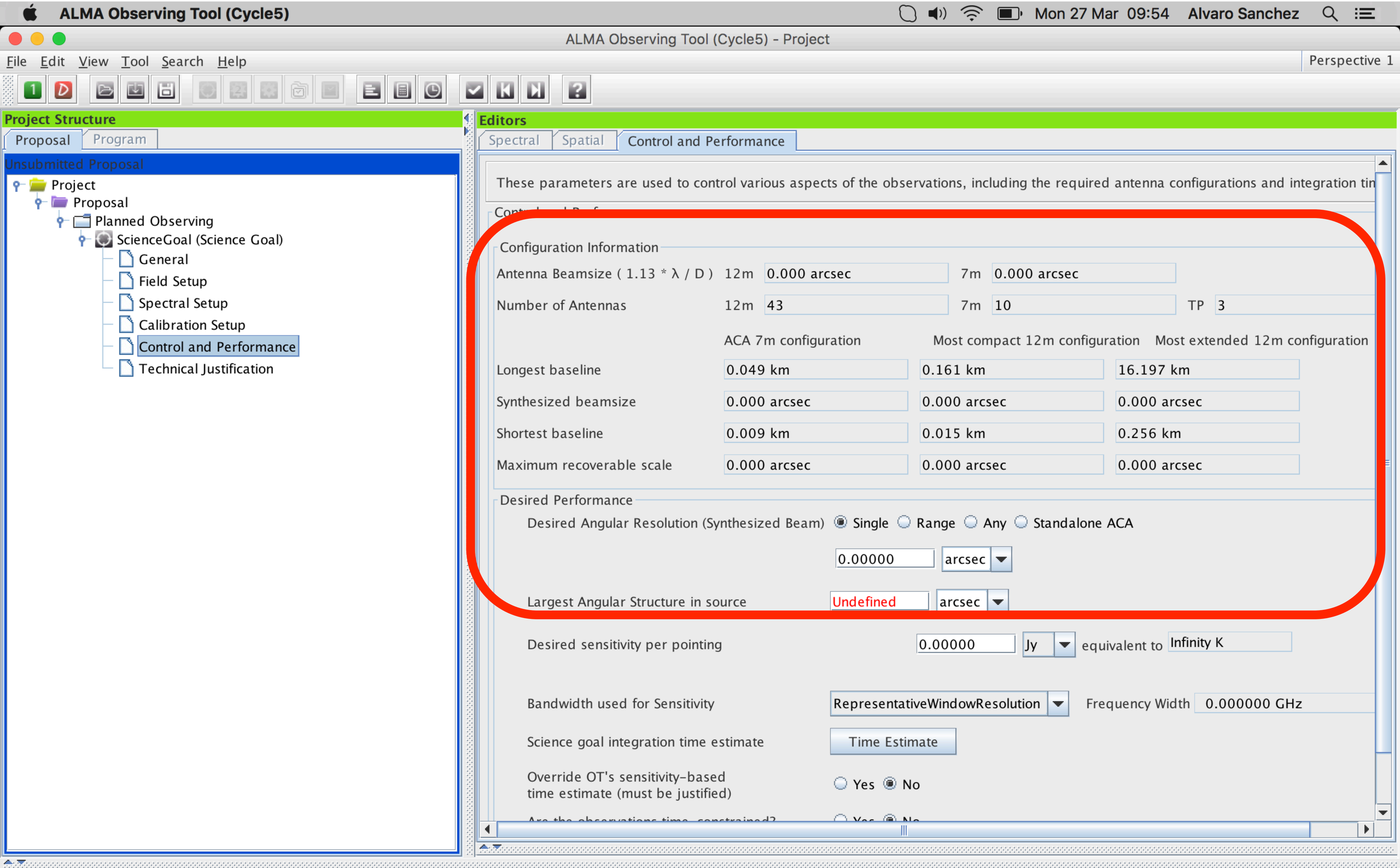
Field setup in the almaOT



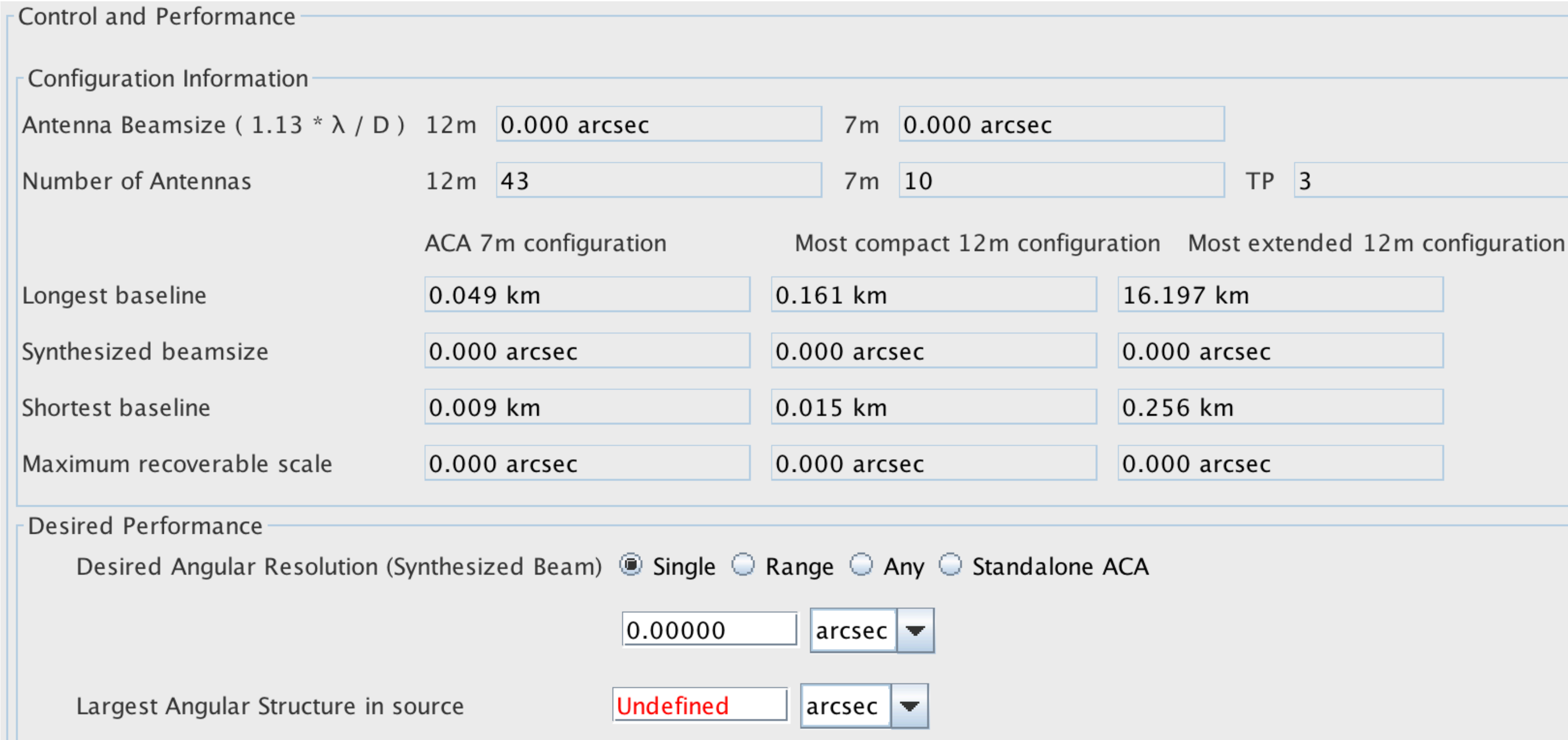
Control and Performance in the almaOT



Control and Performance in the almaOT



Control and Performance in the almaOT



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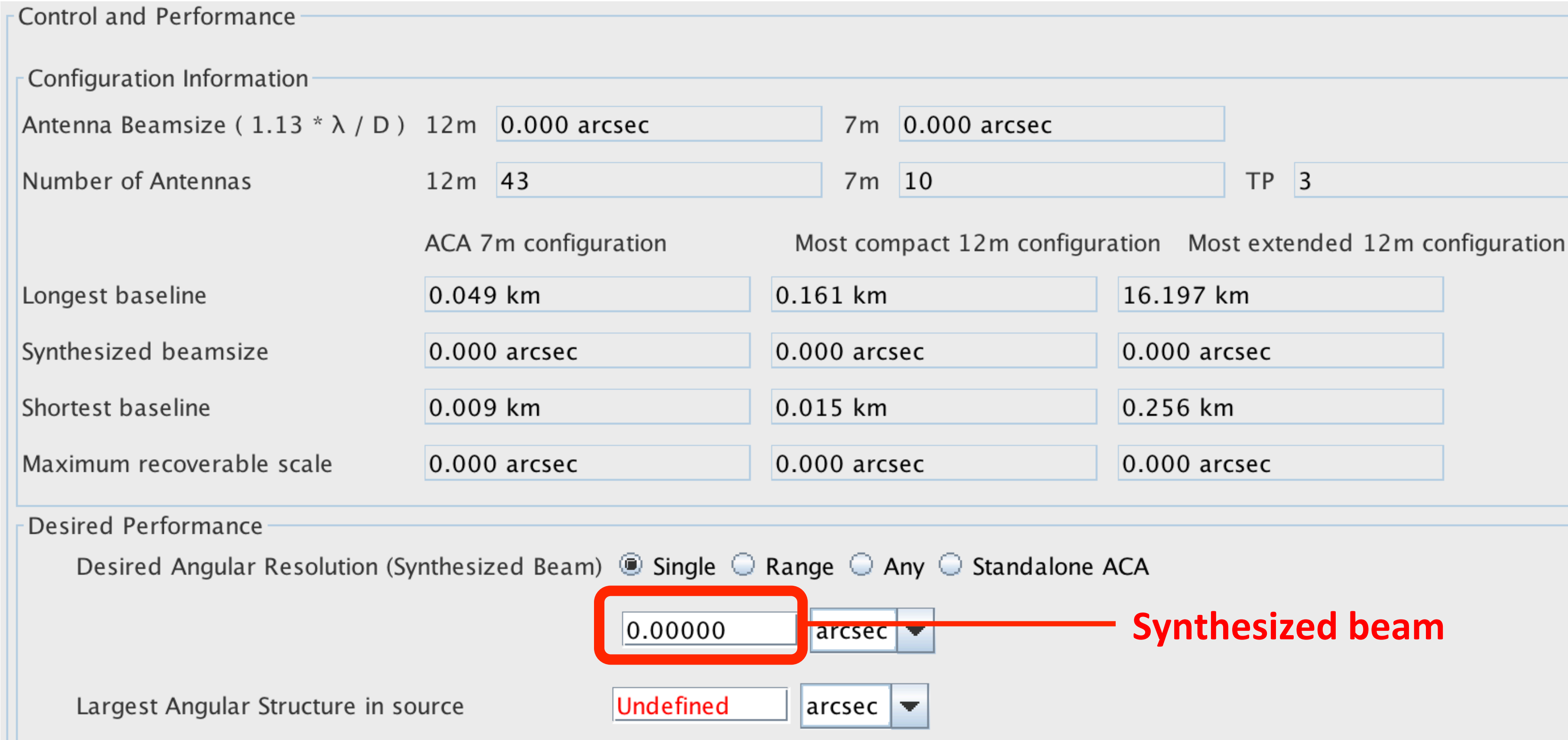
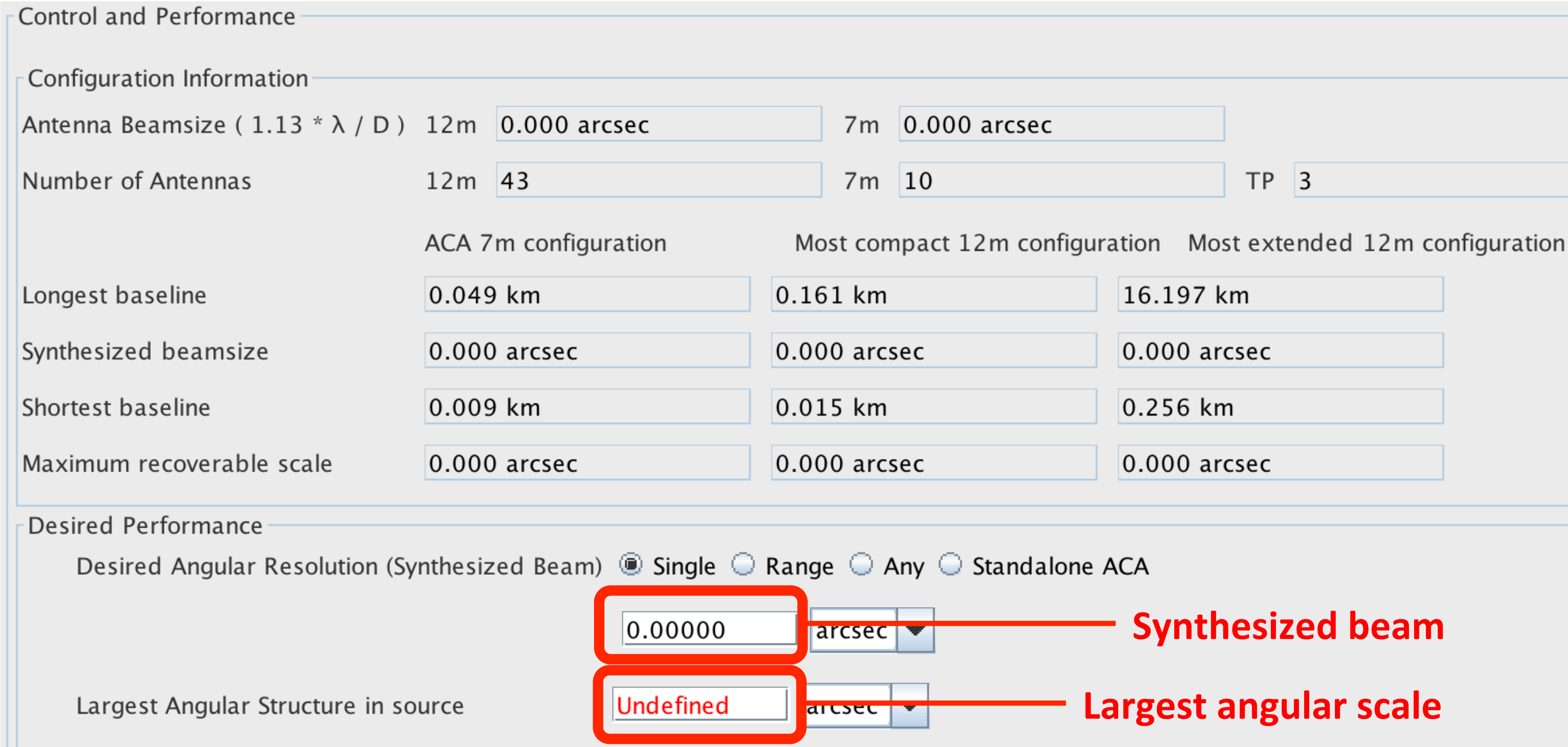
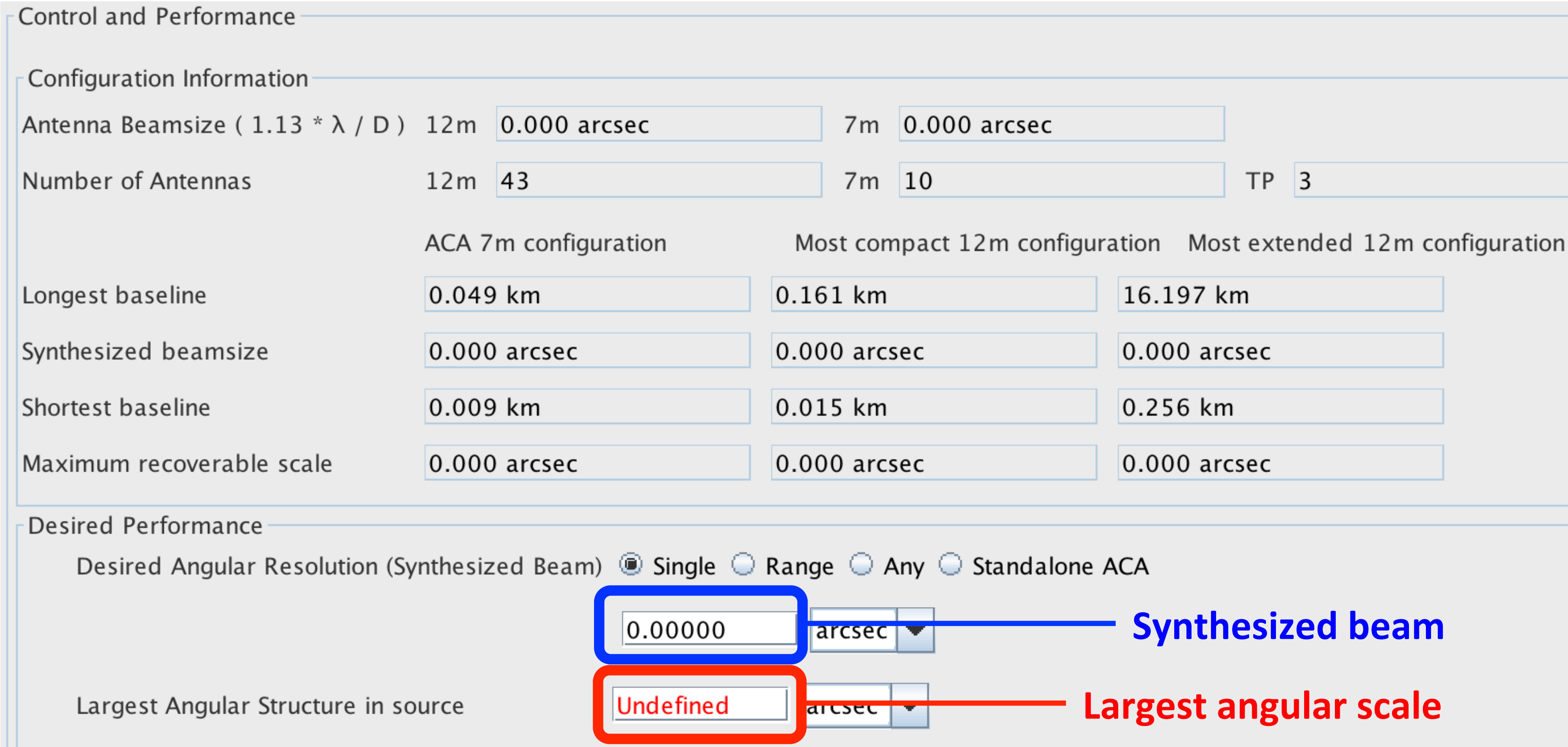


Control and Performance in the almaOT



Control and Performance in the almaOT



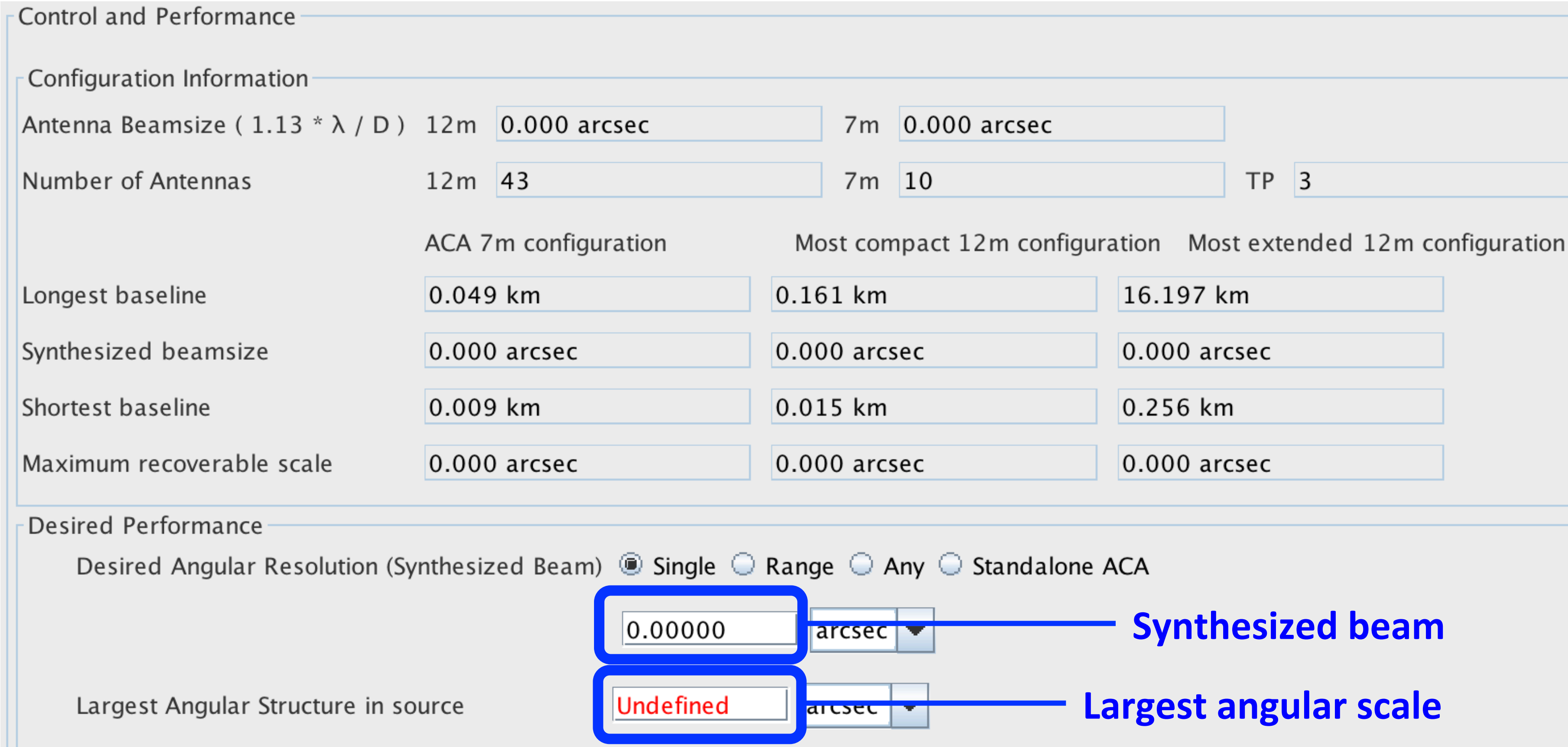
SYNTHESIZED BEAM

a.k.a. angular resolution, PSF, ...

it is the size of the object you want to resolve (distinguish)

$$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$$

Control and Performance in the almaOT

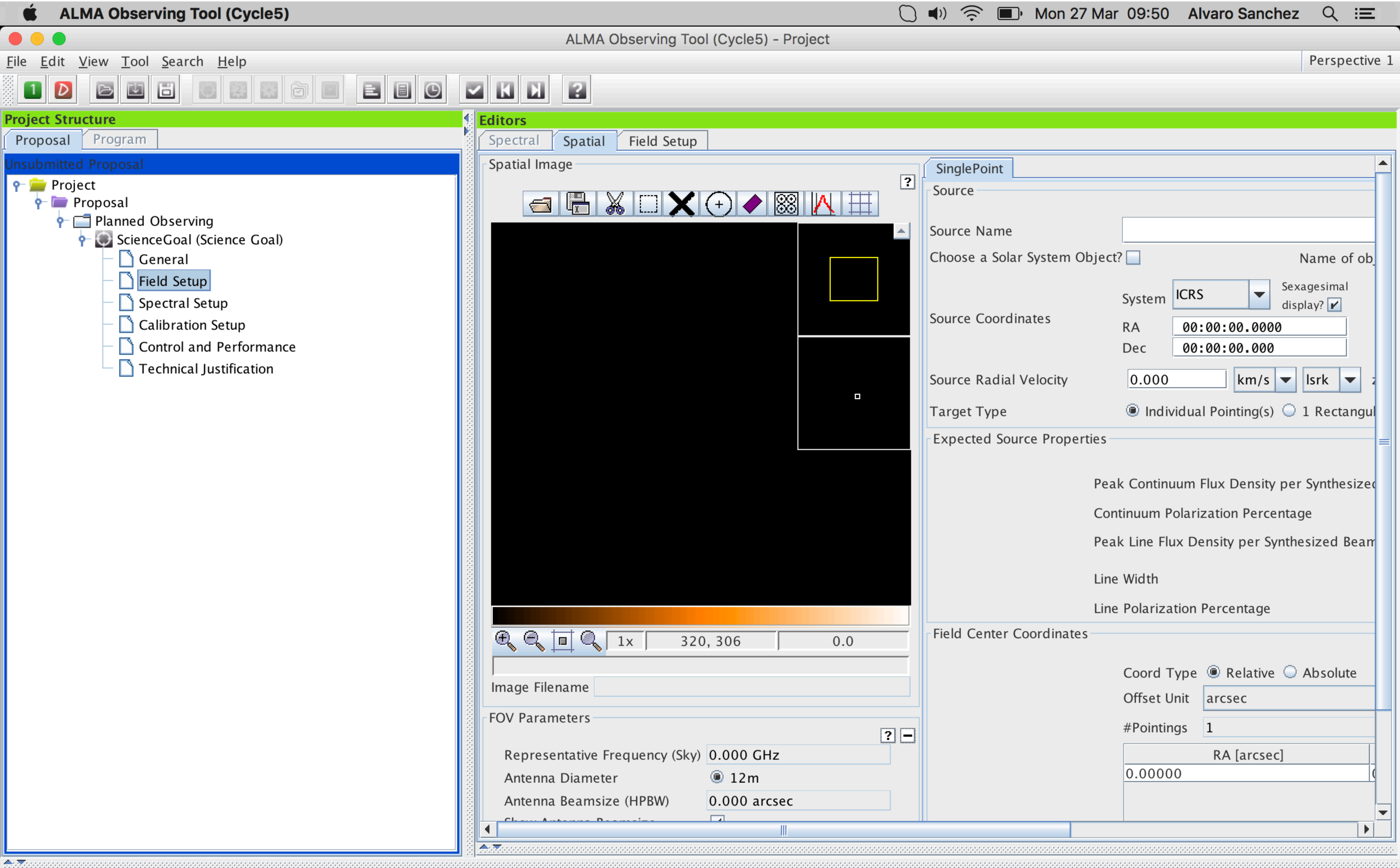


LARGEST ANGULAR SCALE

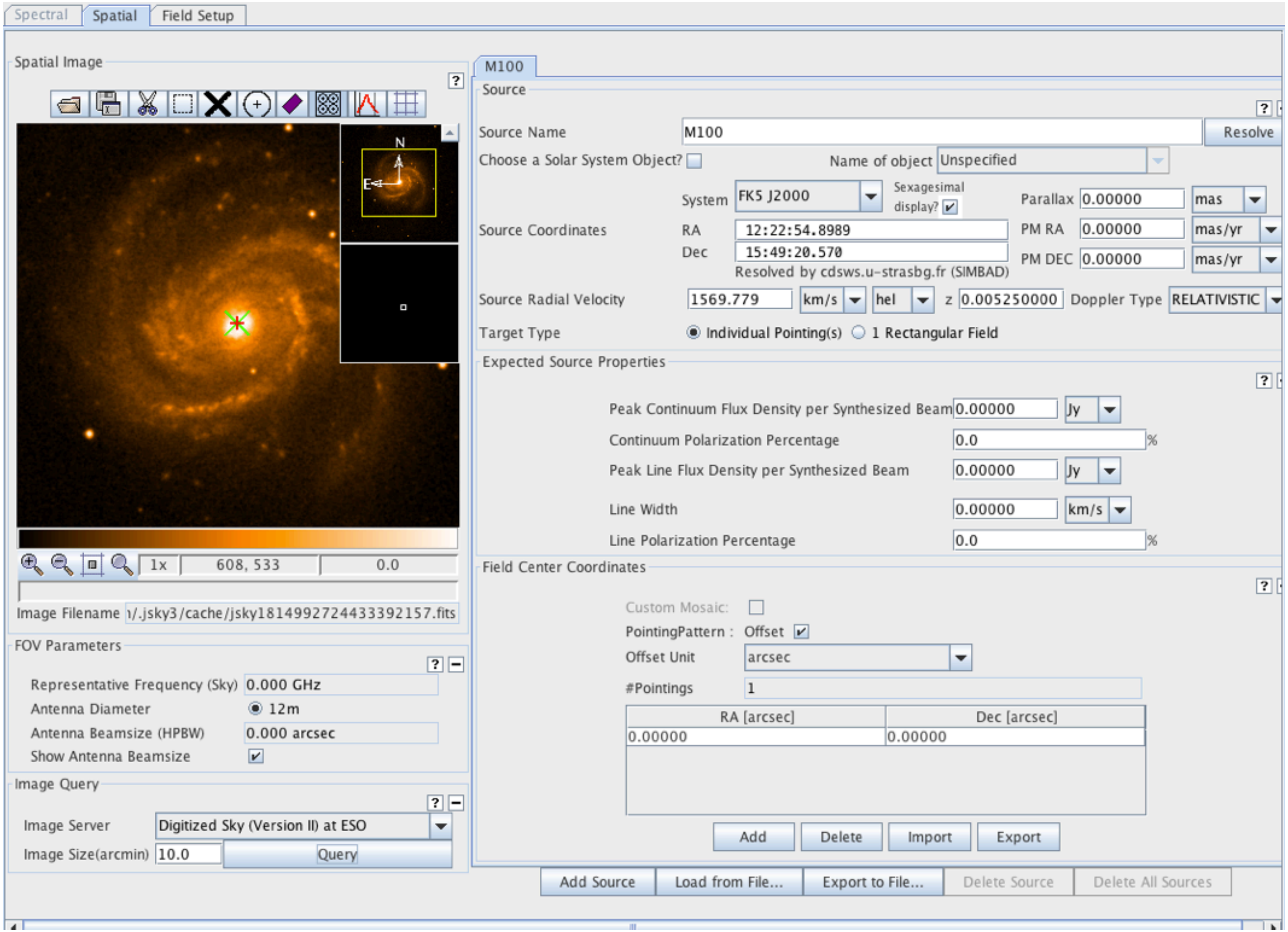
a.k.a. maximum angular size, …
the largest size of your object
how big it is?

$$LAS = 1.22\frac{\lambda}{B_{\min}}$$

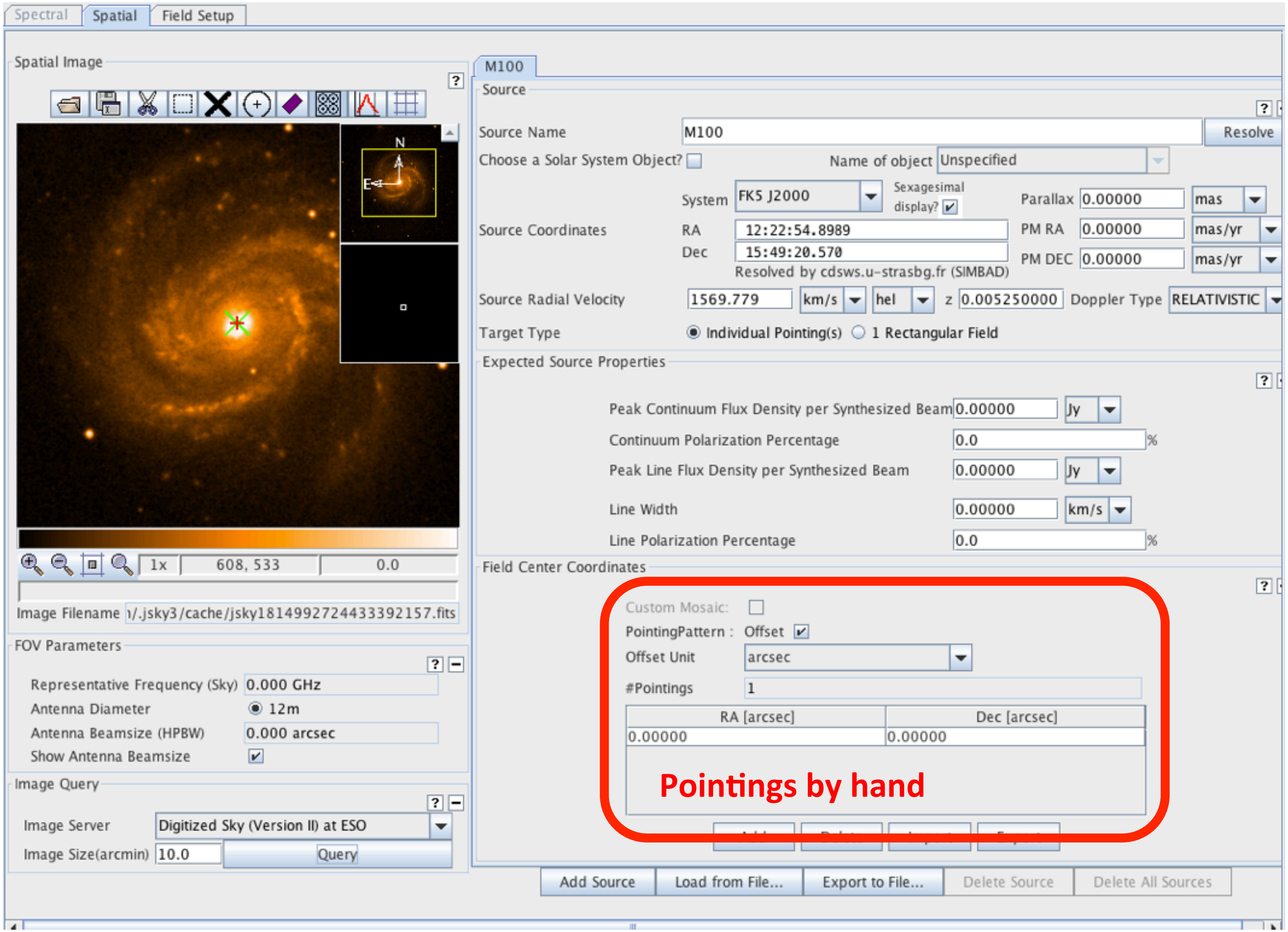
Mosaics in the almaOT



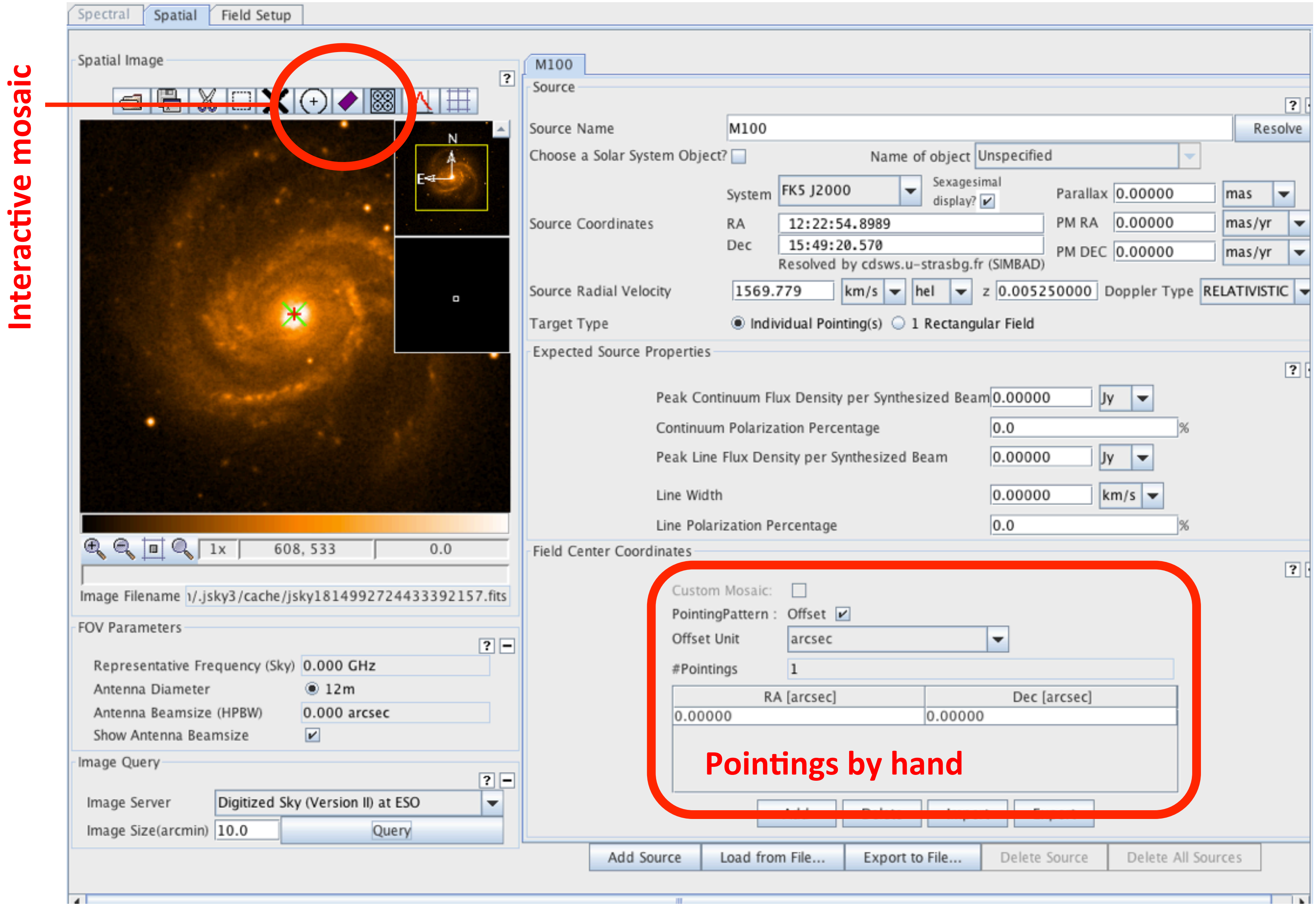
Mosaics in the almaOT



Mosaics in the almaOT



Mosaics in the almaOT



Break #1