ALMA Proposal Preparation Tutorials

Argelander-Institut für Astronomie

EUROPEAN ARC
ALMA Regional Centre || Germany

Universität zu Köln

Introduction to the basic concepts and terminology of radio interferometry

Part I – spatial filters

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Key concepts to learn

Part 1

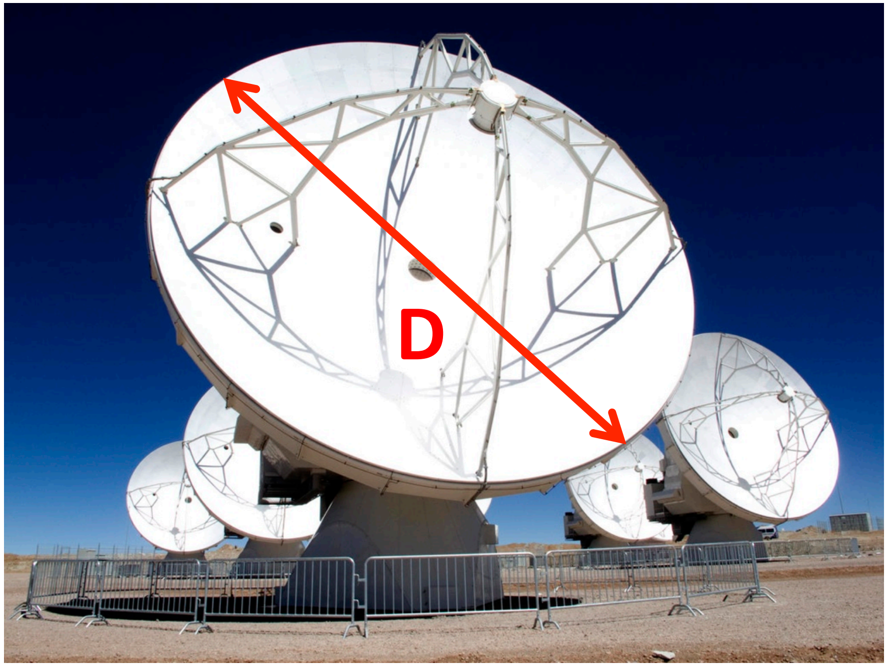
- Interferometer
- Baseline
- Primary beam
- Synthesized beam
- Largest angular scale

Atacama Large Millimeter/submillimeter Array

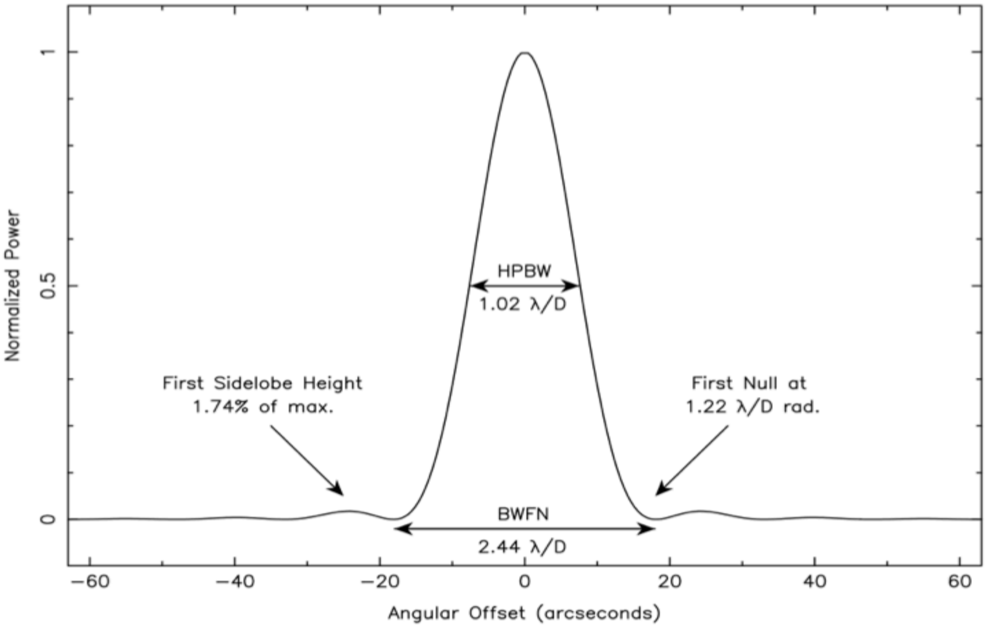
Why does ALMA need so many antennas?

… consider one single antenna (or single-dish)

Single-dish with diameter D



(1D) antenna power response



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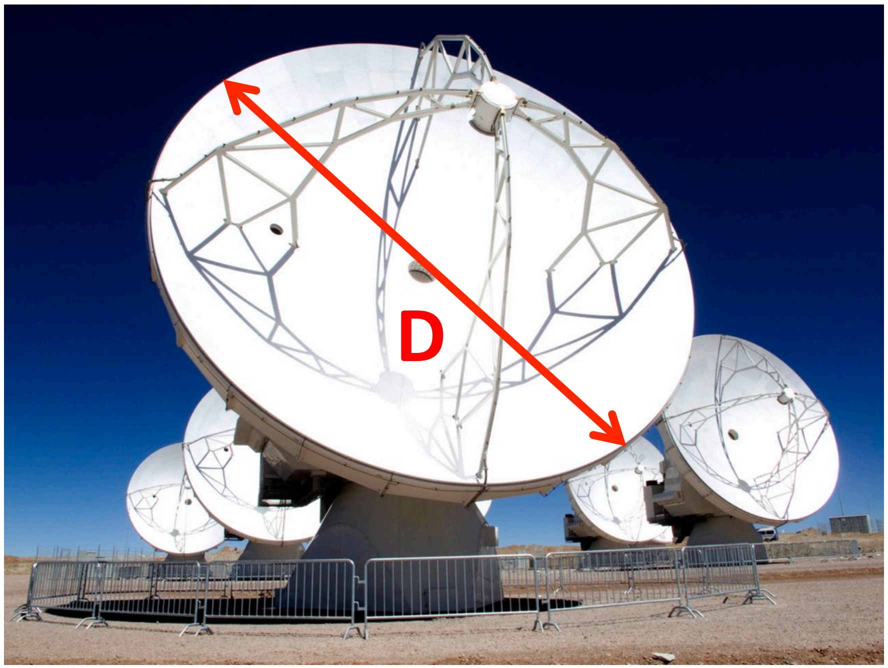
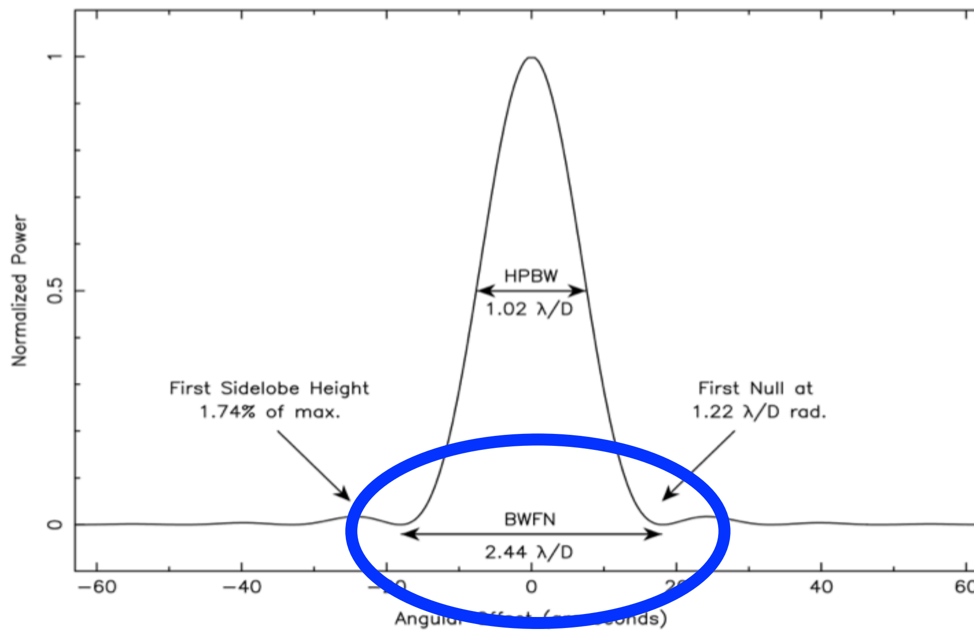
Single-dish with diameter D



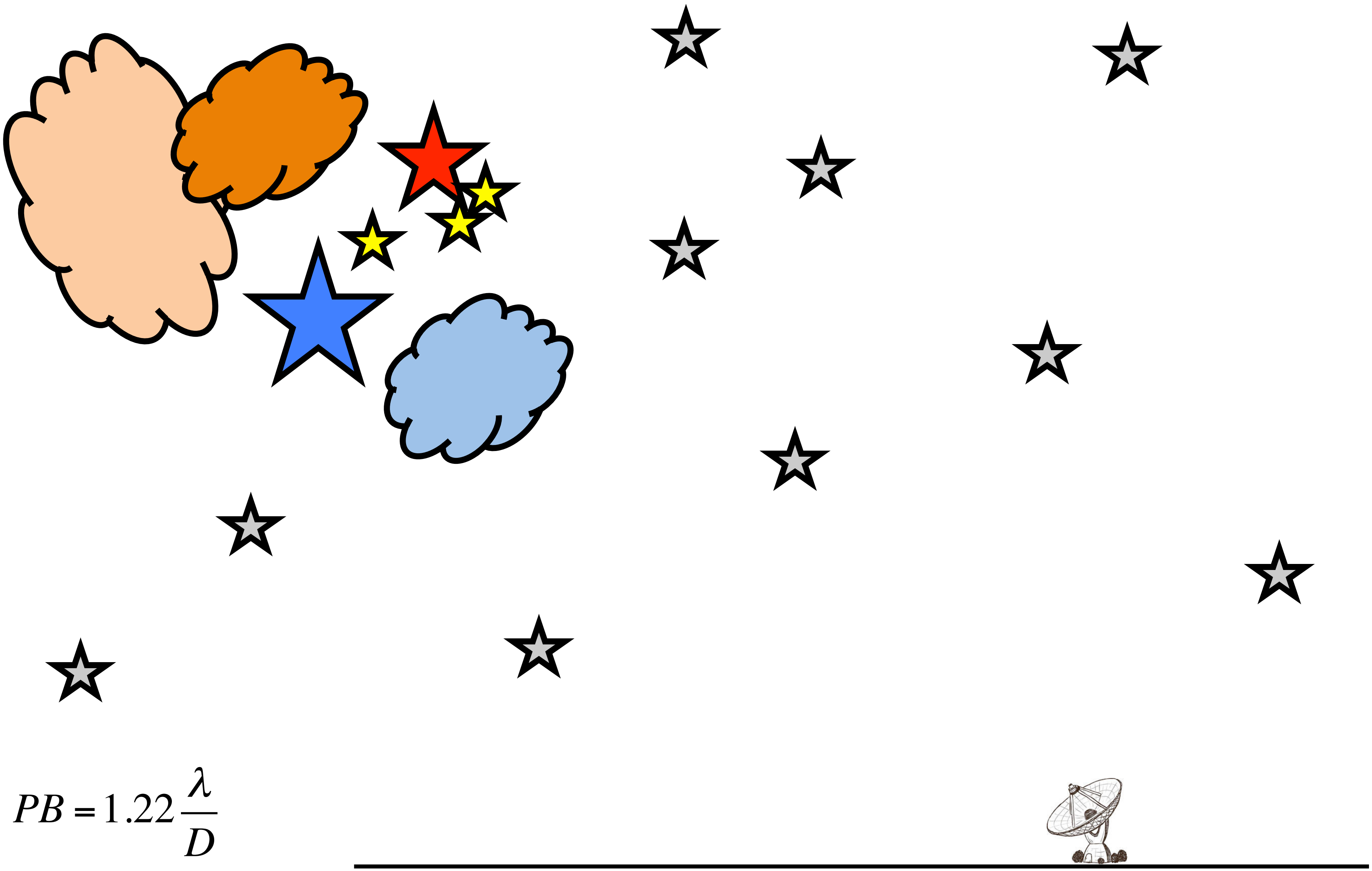
(1D) antenna power response



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

PRIMARY BEAM

Single-dish telescope



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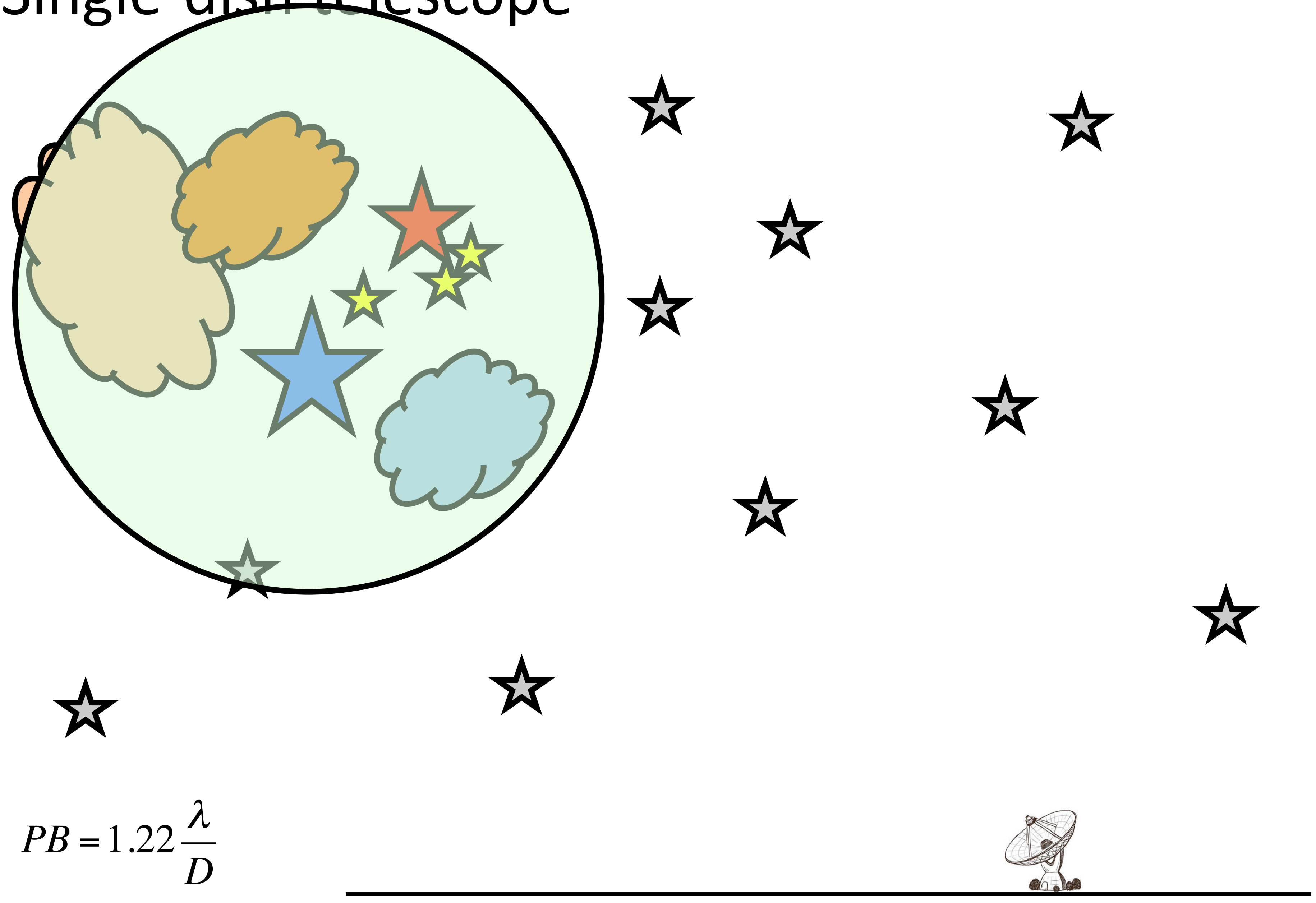

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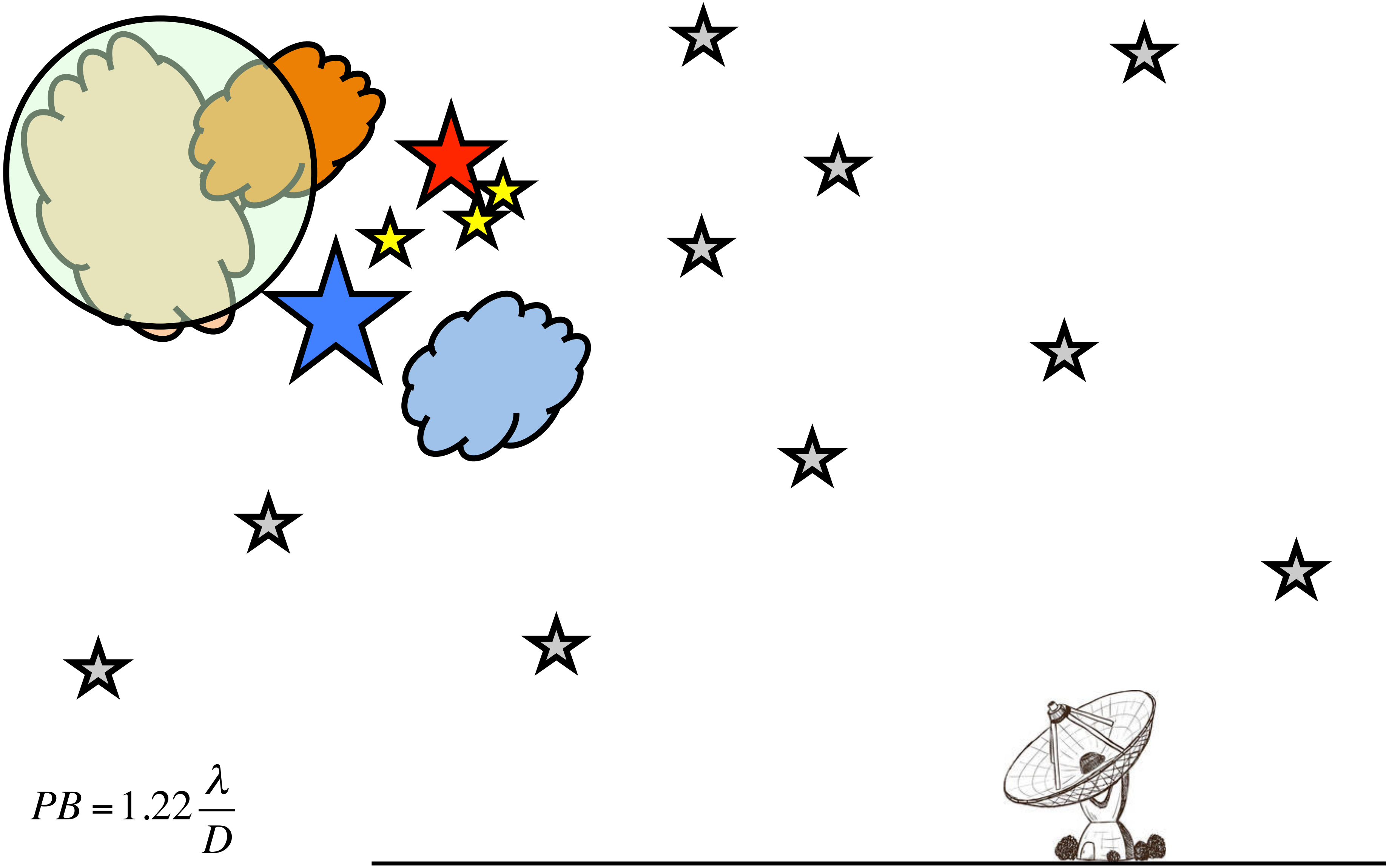

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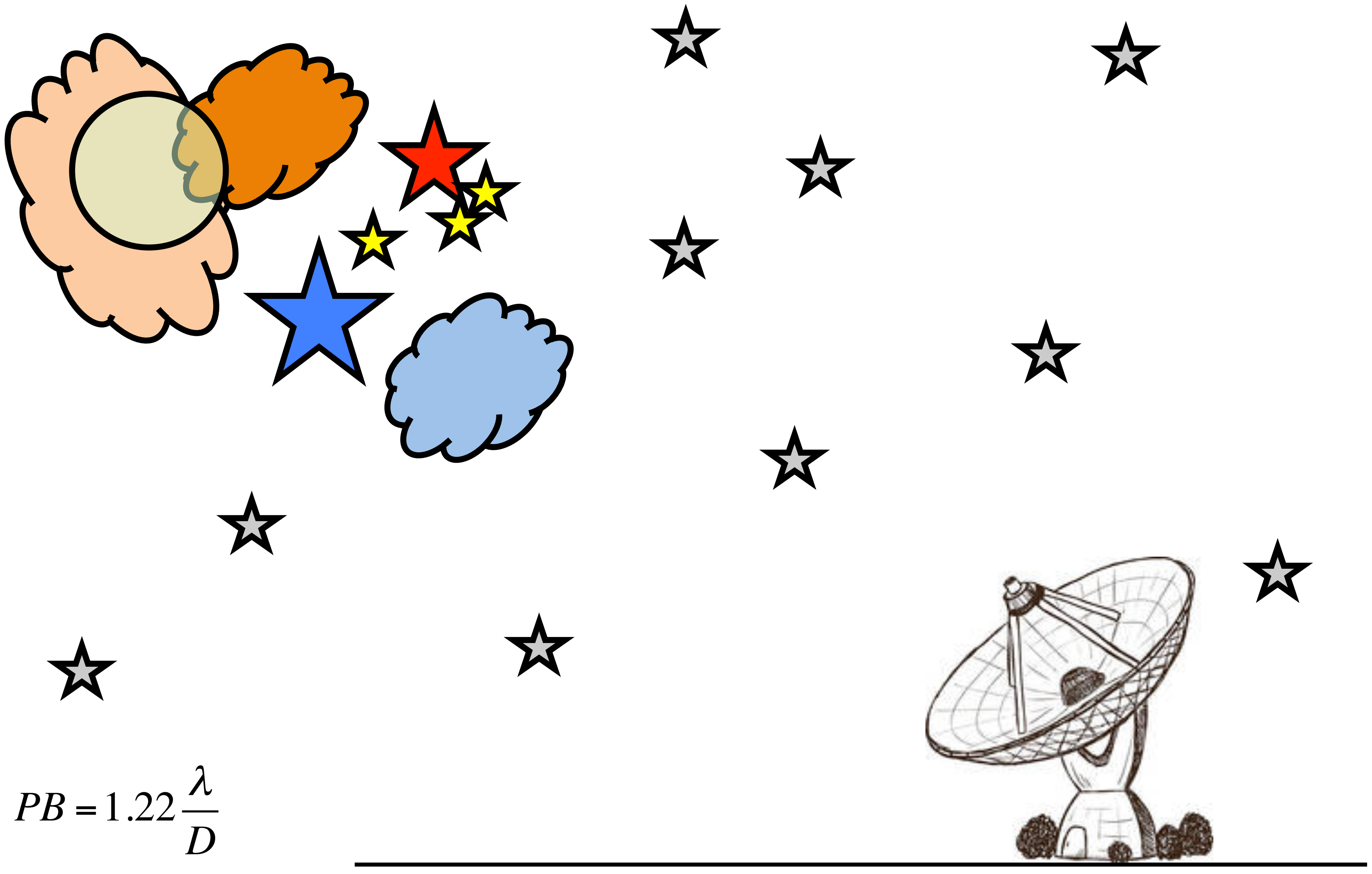

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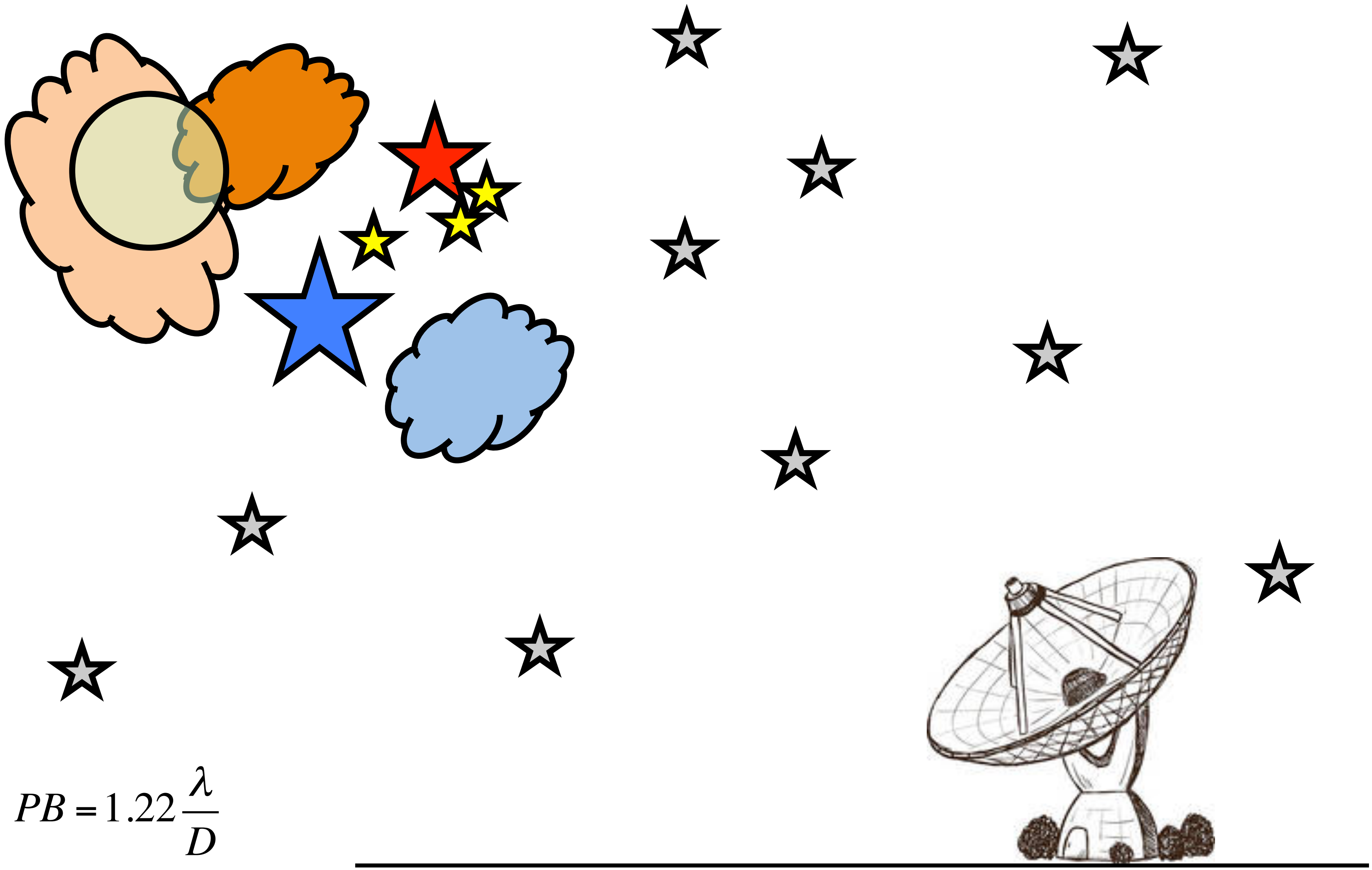
Single-dish telescope



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Single-dish telescope

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Interferometer – multiple dishes

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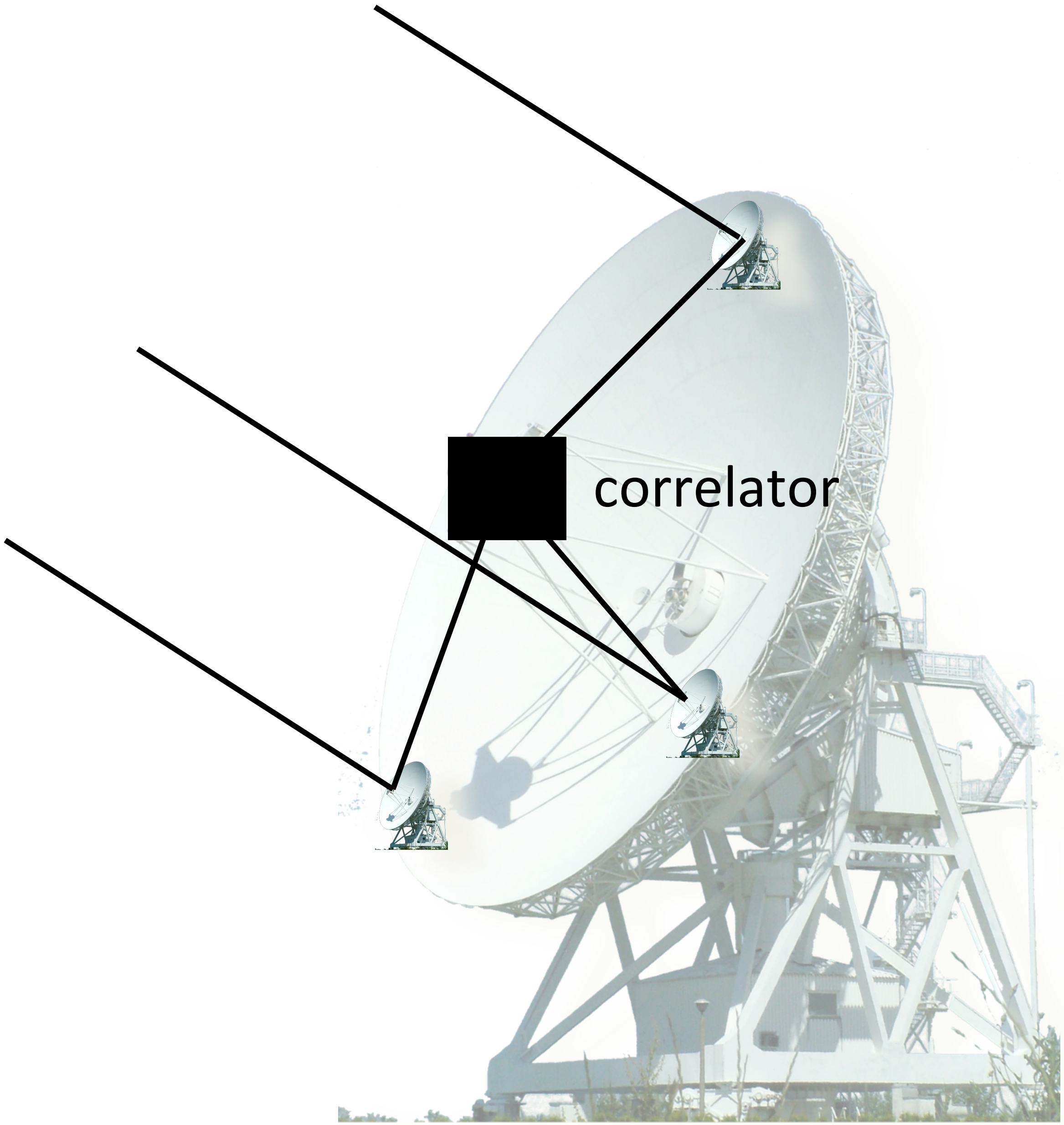
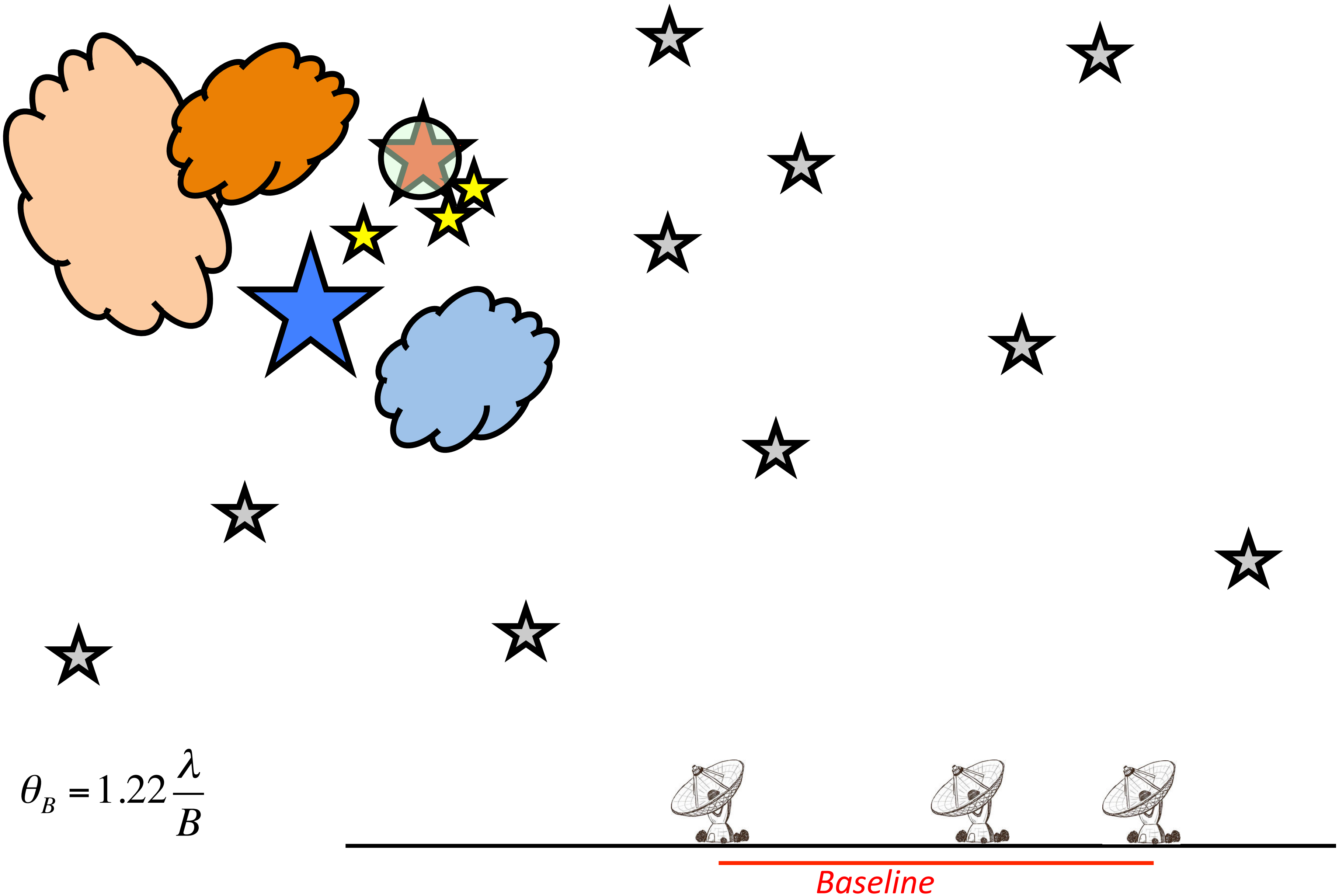


Interferometer – multiple dishes

$$\theta_B = 1.22\frac{\lambda}{B}$$

Interferometer – multiple dishes



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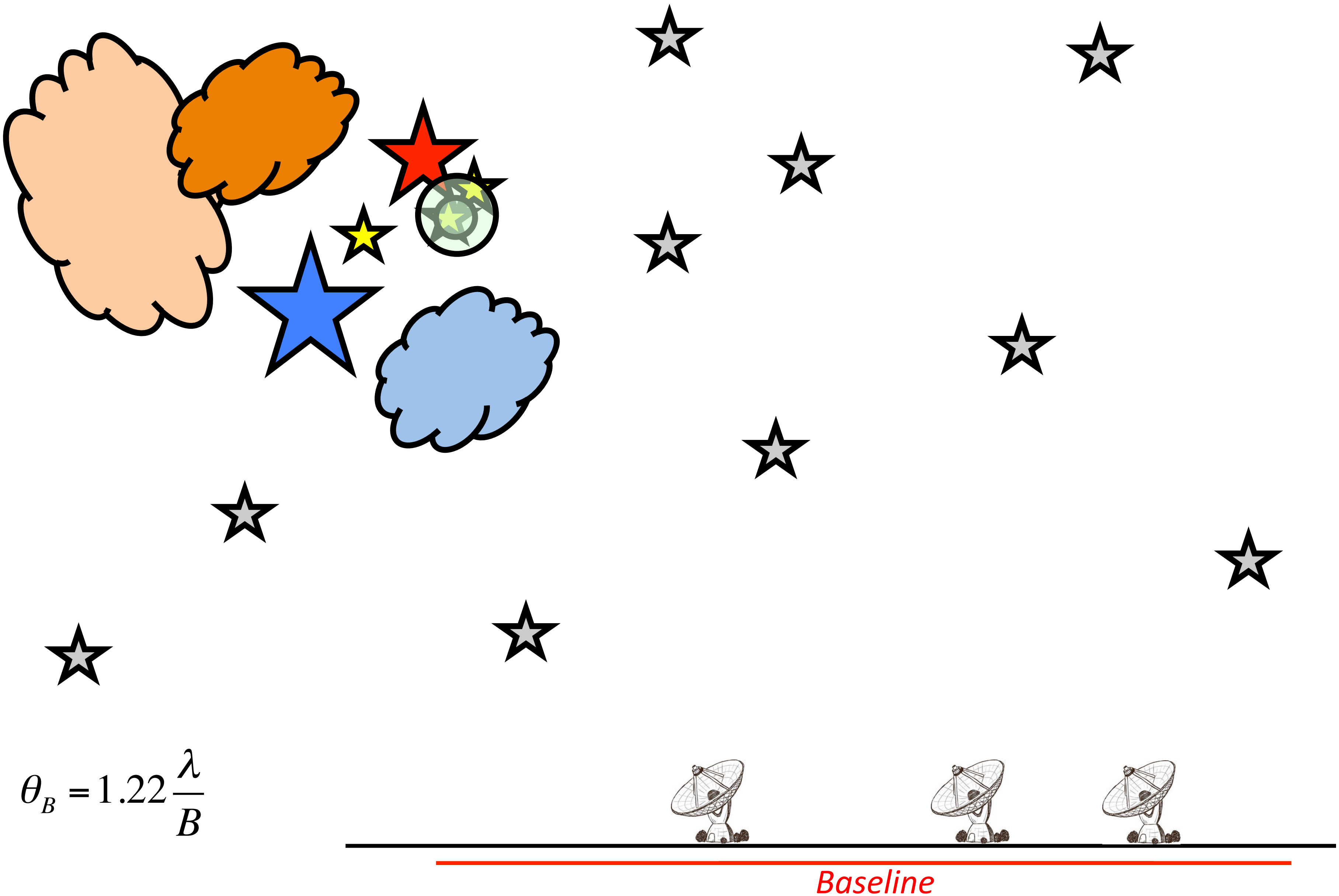

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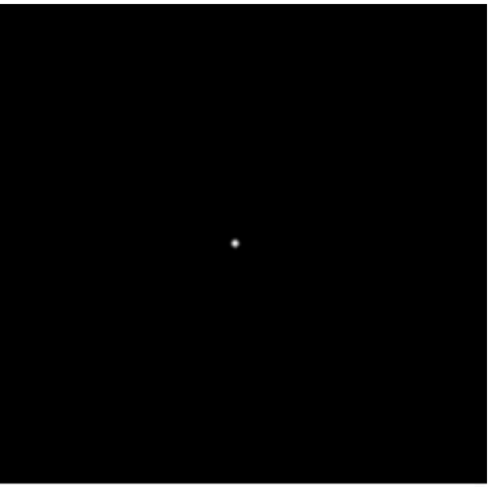
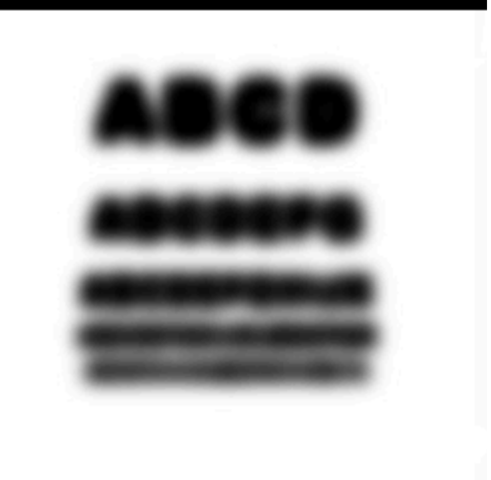
Interferometer – multiple dishes

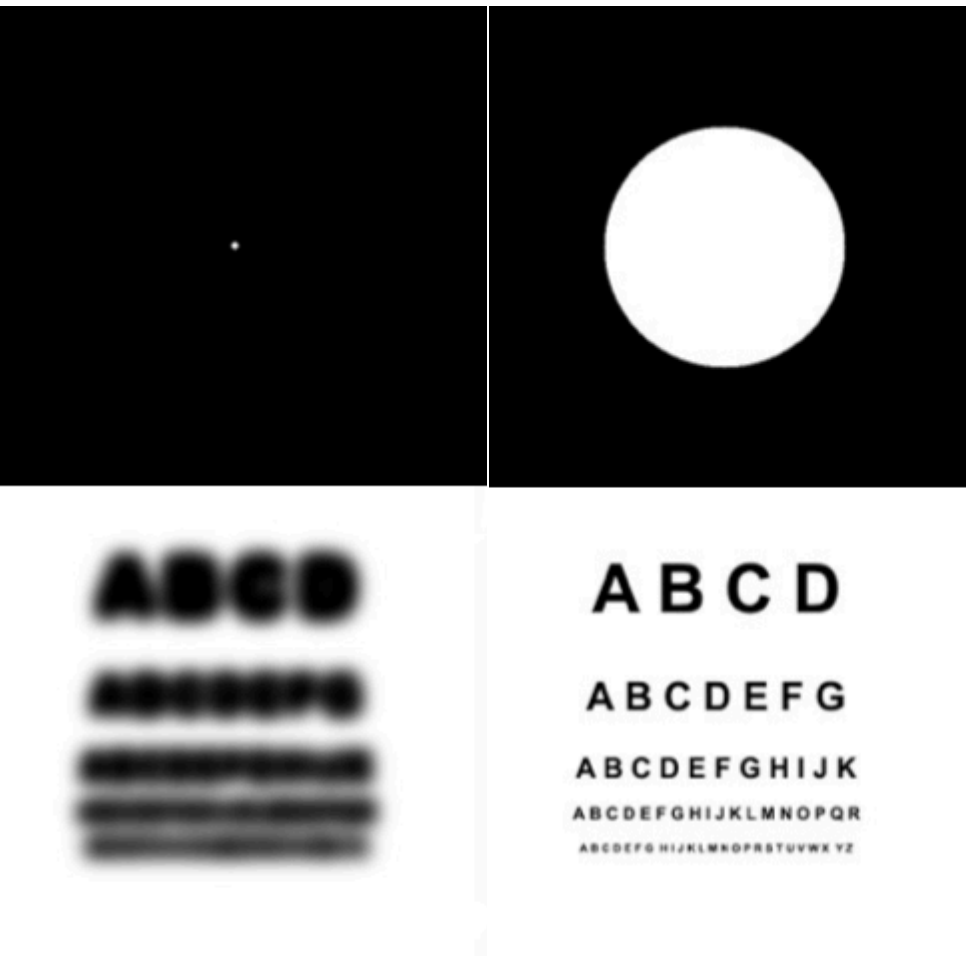
Small Single-Dish





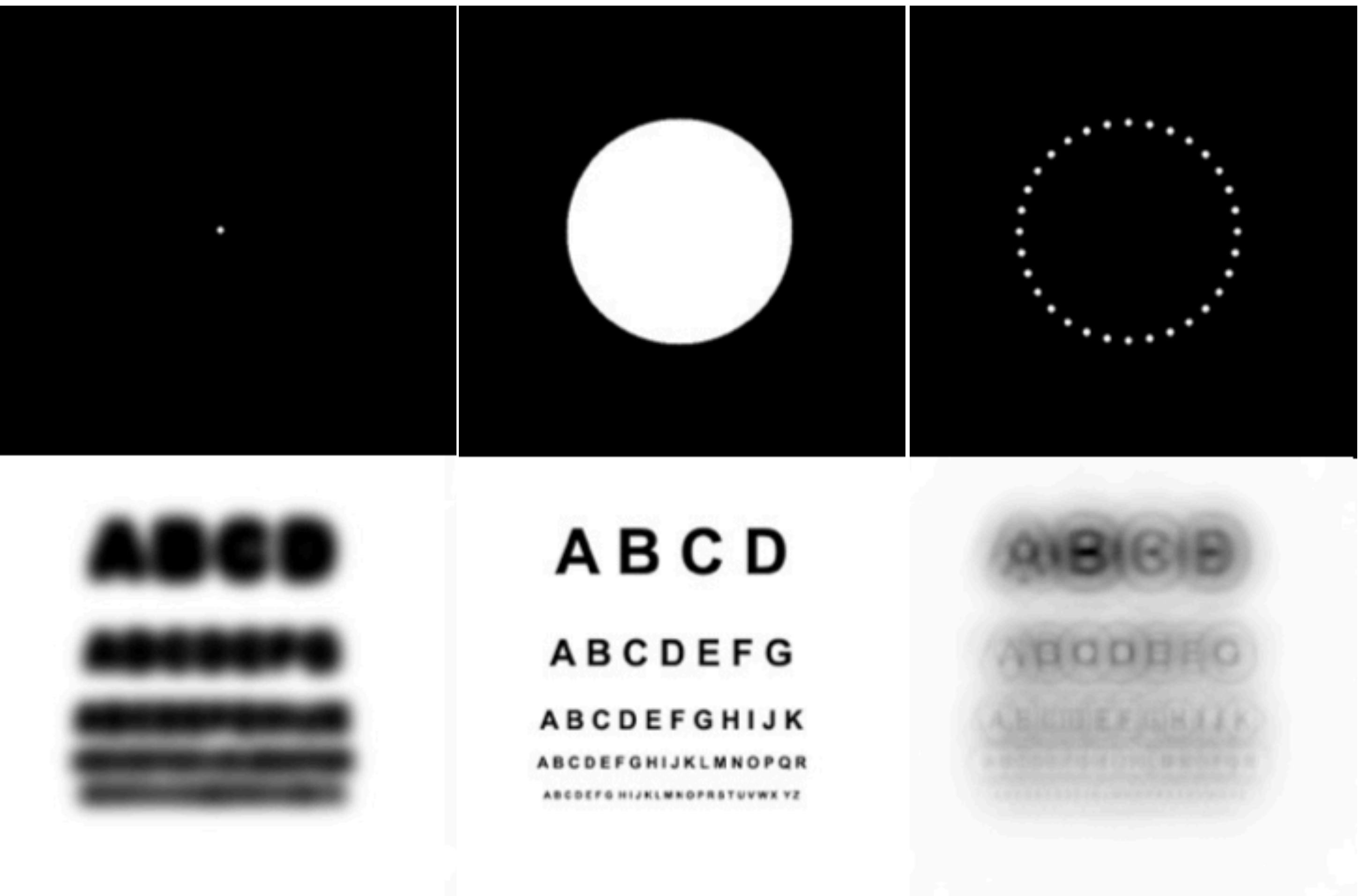
Interferometer – multiple dishes

Large Single-Dish



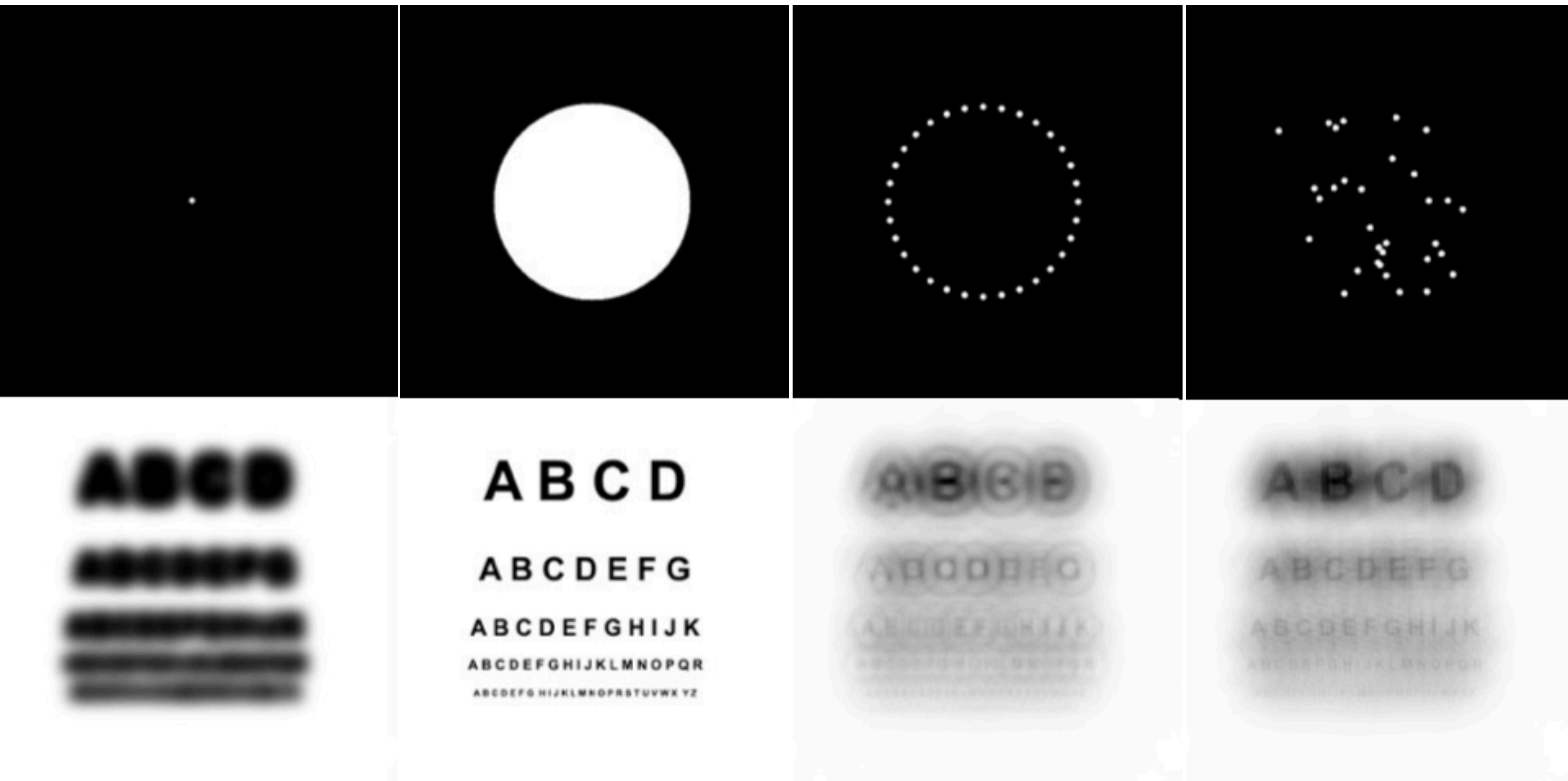
Interferometer – multiple dishes

“Circular” dishes



Interferometer – multiple dishes

"Random" dishes



Interferometers as spatial filters

… a bit of equations (Fourier Transform)

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

Interferometers as spatial filters

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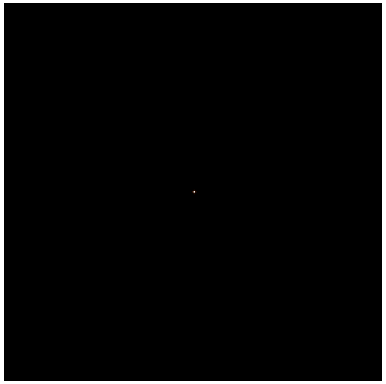
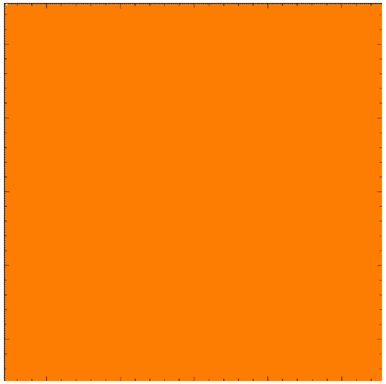
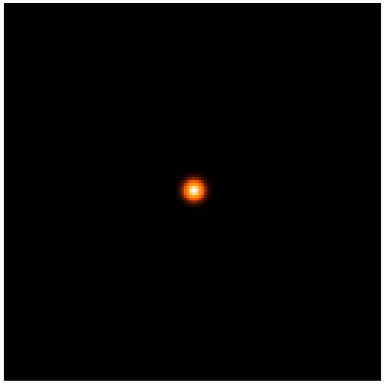
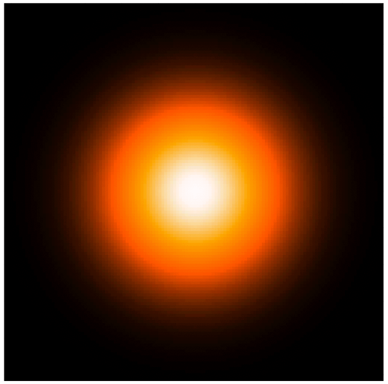
I (l,m) V (u,v)

δ Function  $\rightleftharpoons$  Constant

Gaussian  $\rightleftharpoons$  Gaussian

Interferometers as spatial filters

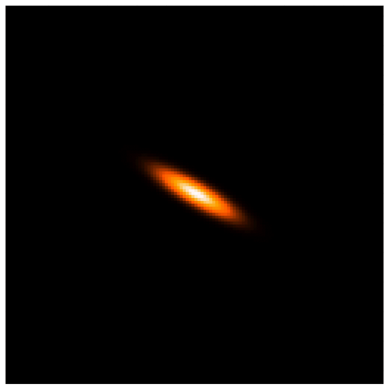
… a bit of equations (Fourier Transform)

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

I (l,m)

V (u,v)

elliptical Gaussian



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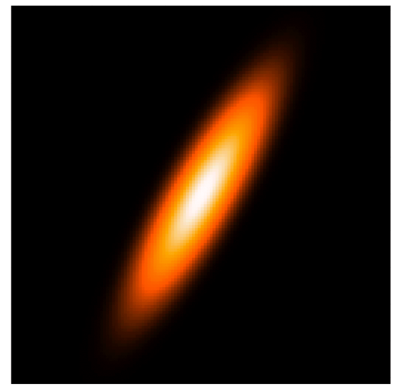
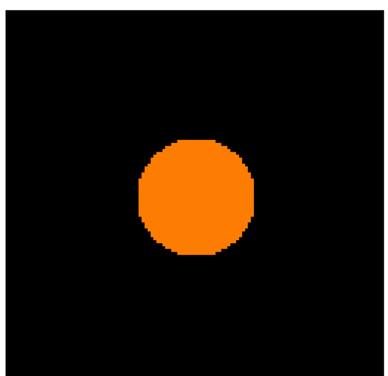


elliptical Gaussian

Disk



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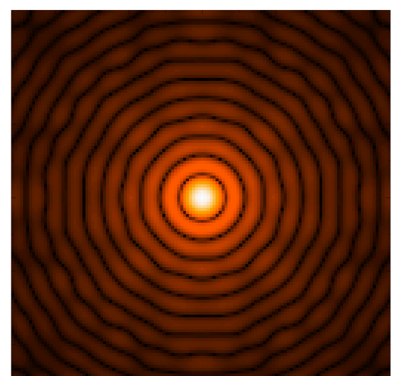
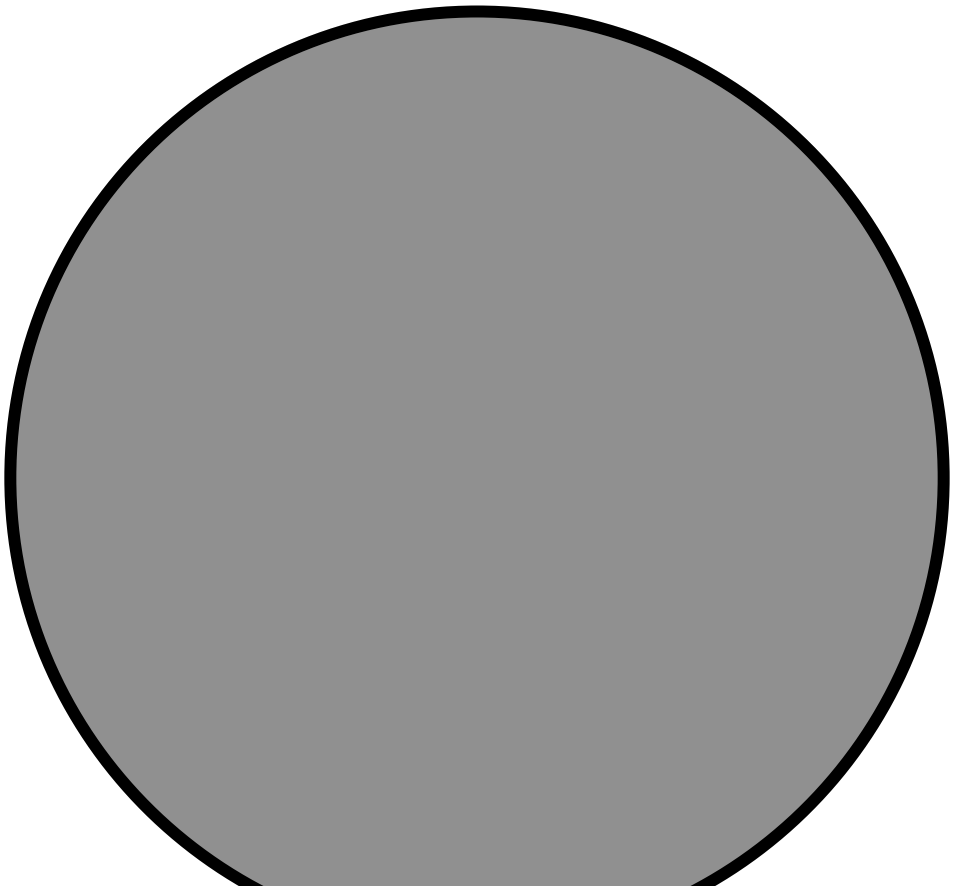
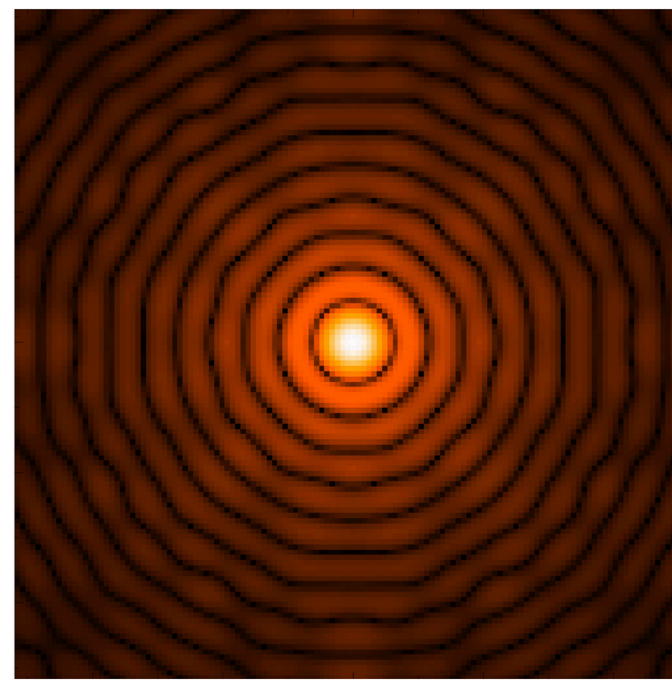


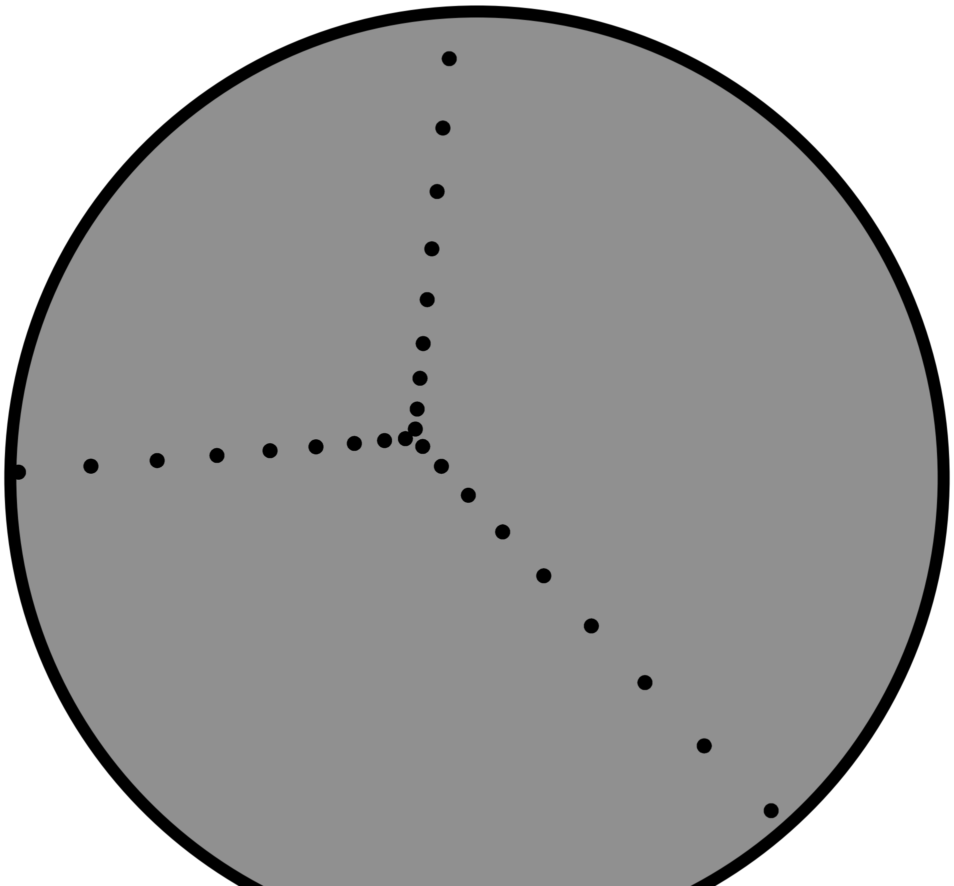
Bessel

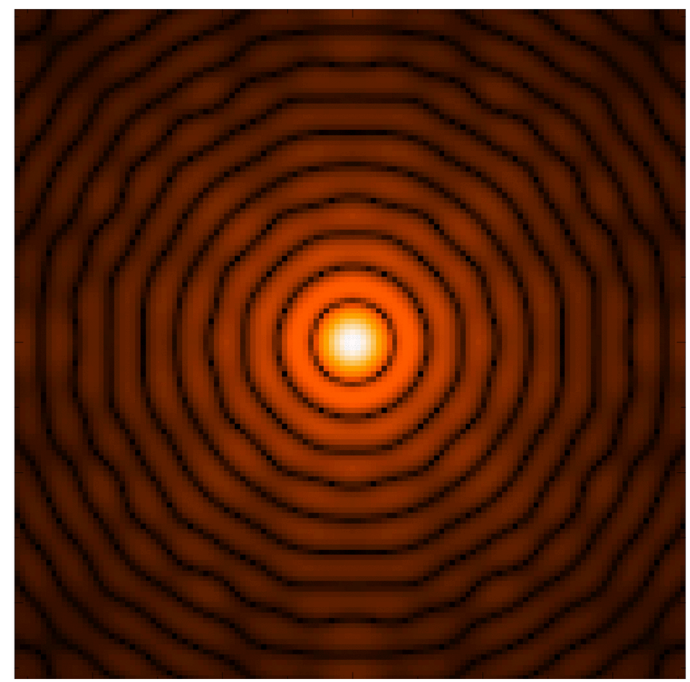
Interferometers as spatial filters



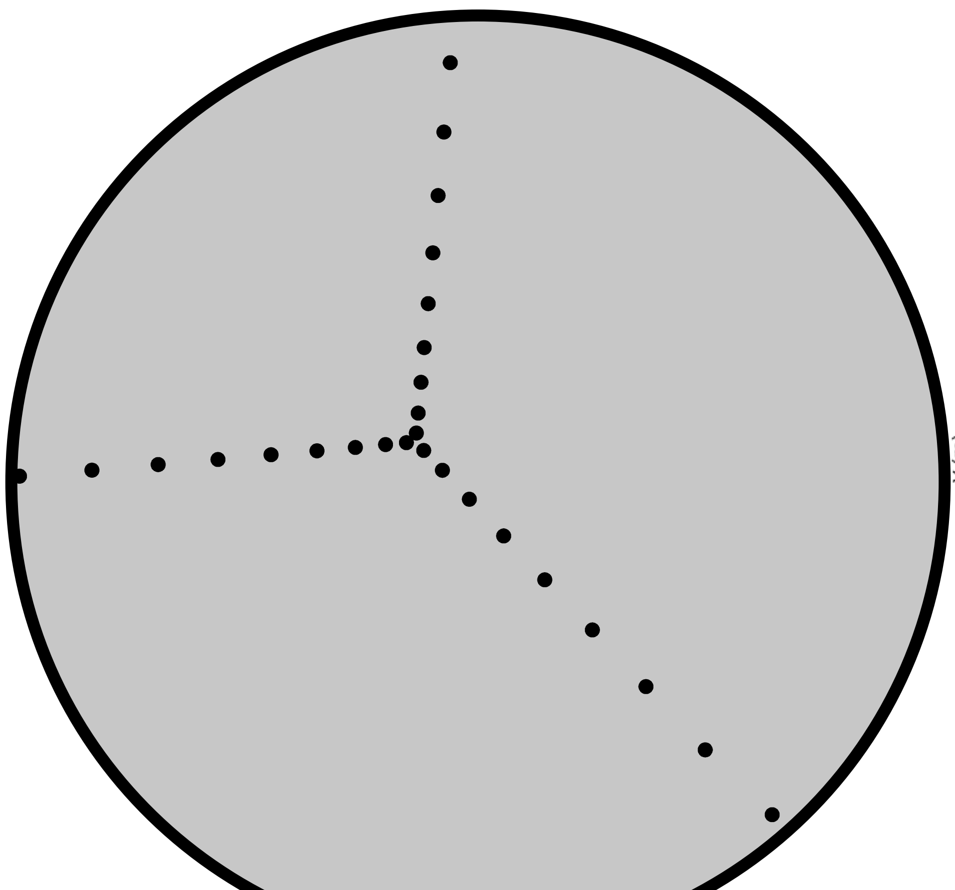


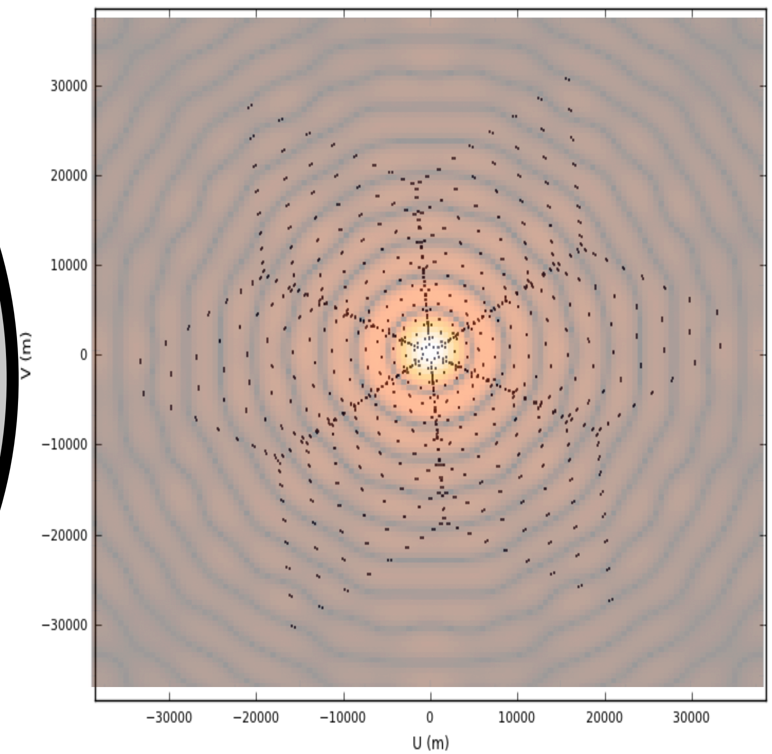
Interferometers as spatial filters





Interferometers as spatial filters

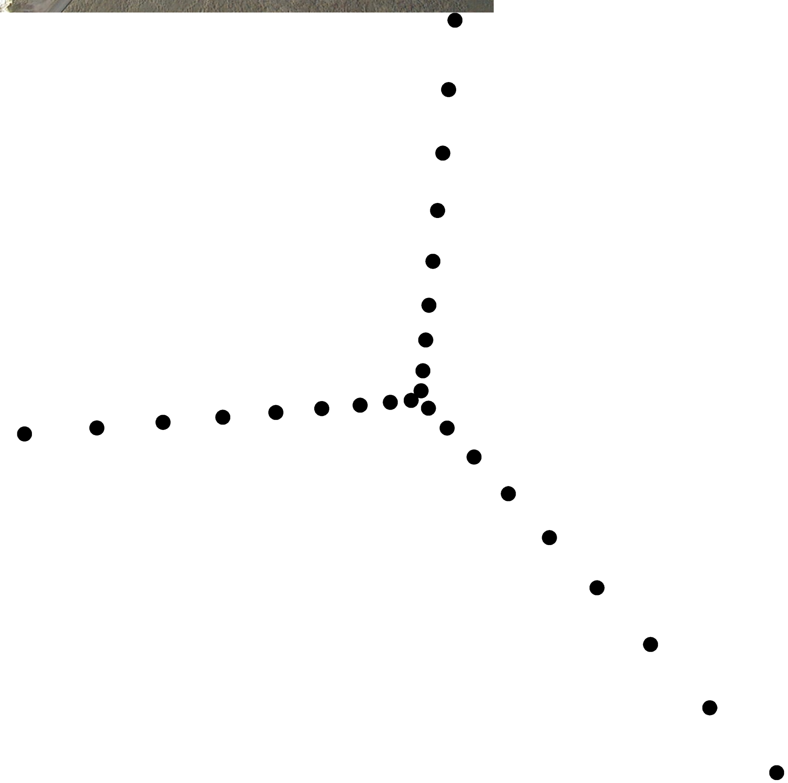


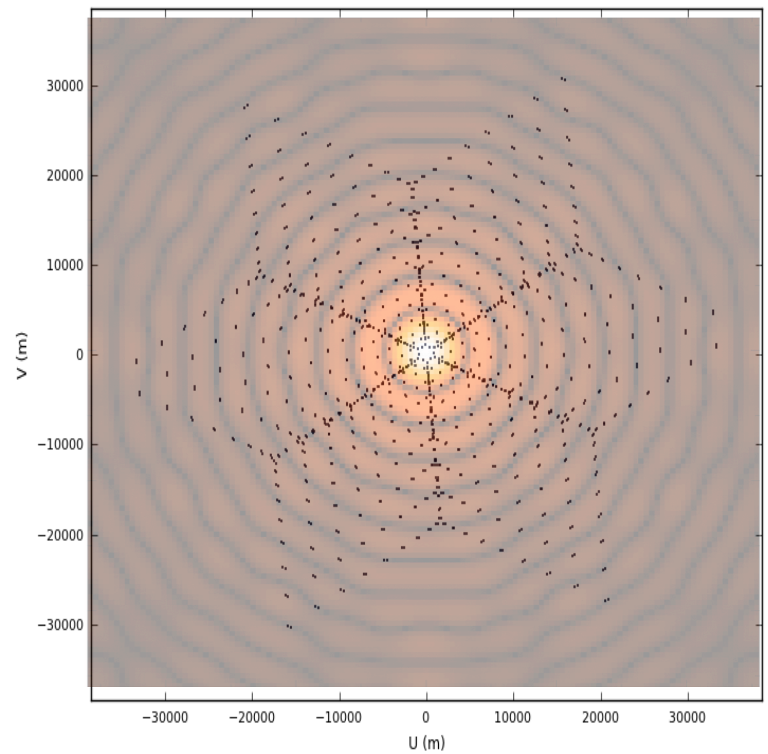


Example: VLA

Very Large Array (VLA)

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

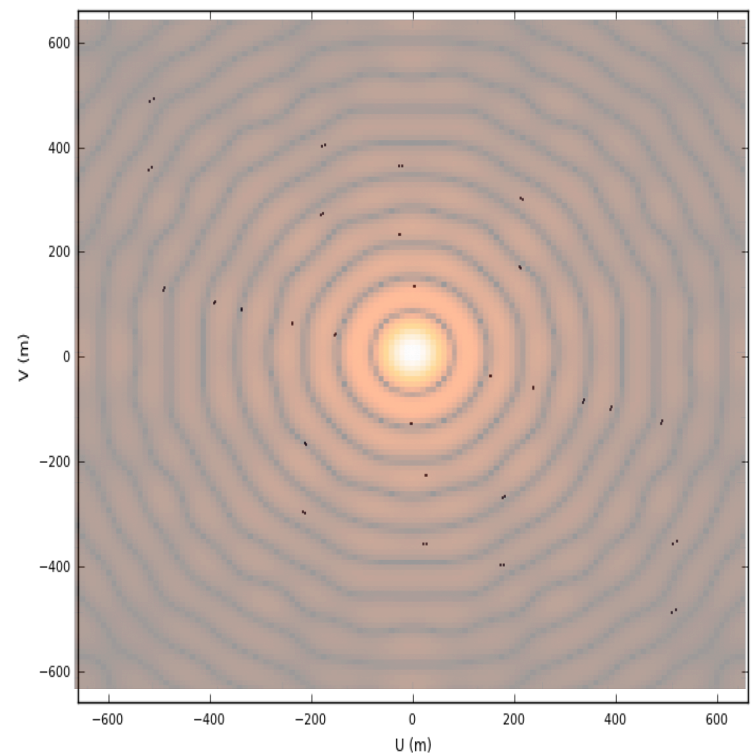




Example: PdBI

Plateau de Bure Interferometer (PdBI)

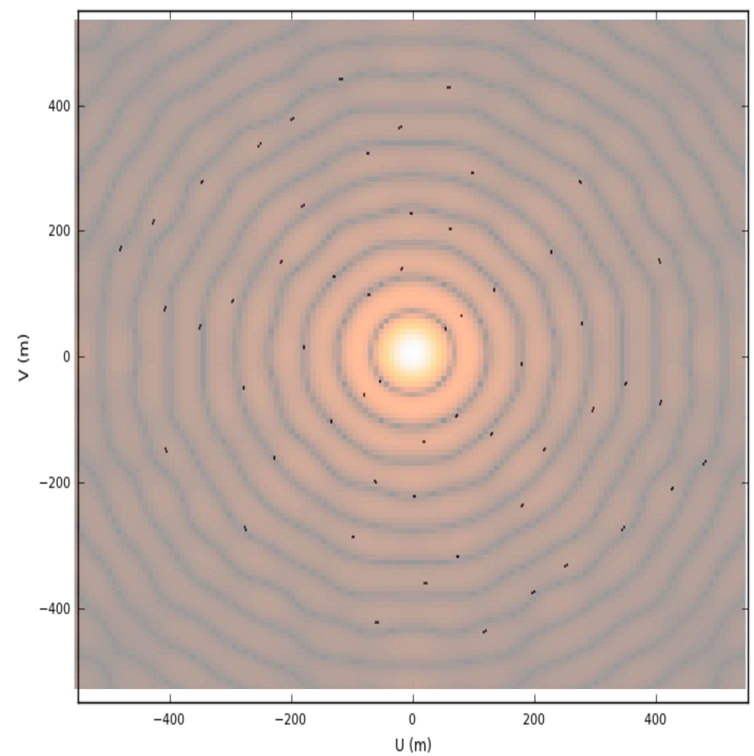
- 6 antennas of 15 meters (diameter)
- observing from mm to submm
- in Grenoble (France)



Example: SMA

SubMillimeter Array (SMA)

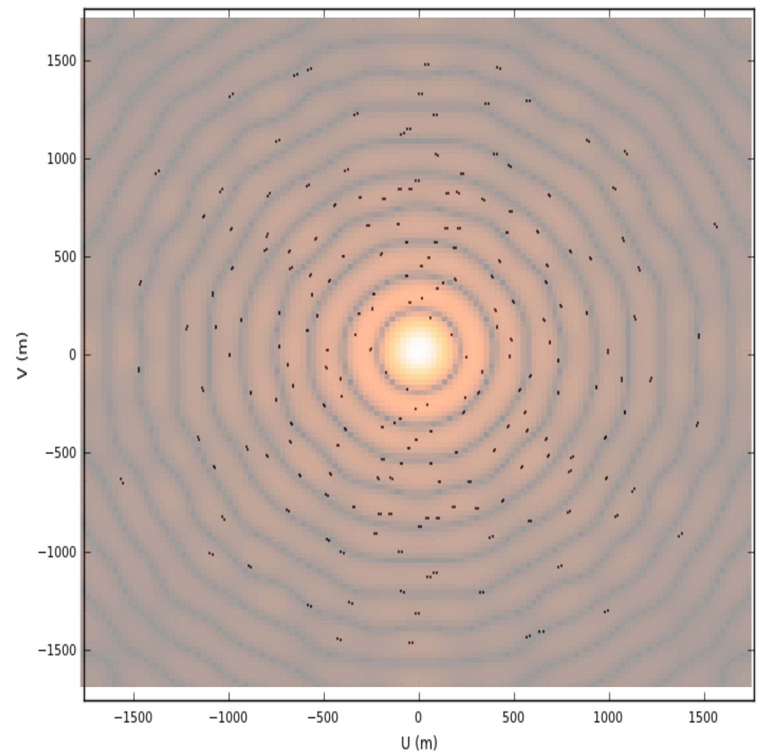
- 8 antennas of 6 meters (diameter)
- observing from mm to submm
- in Hawaii (USA)



Example: CARMA

Combined Array for Research in mm Astro (CARMA)

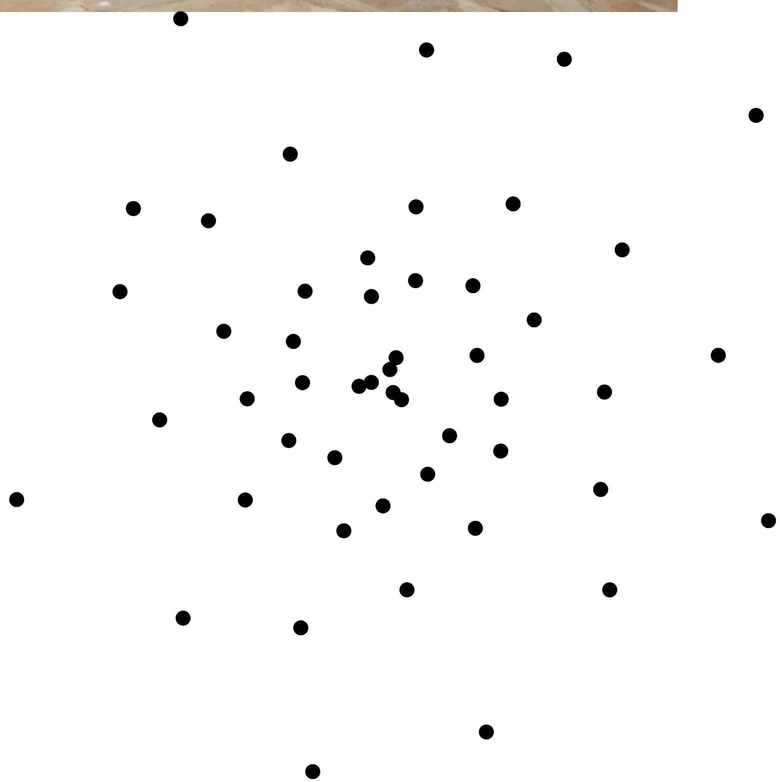
- 23 antennas of 10.4/6.1/3.5 meters
- observing from cm to mm wavelengths
- in California (USA)

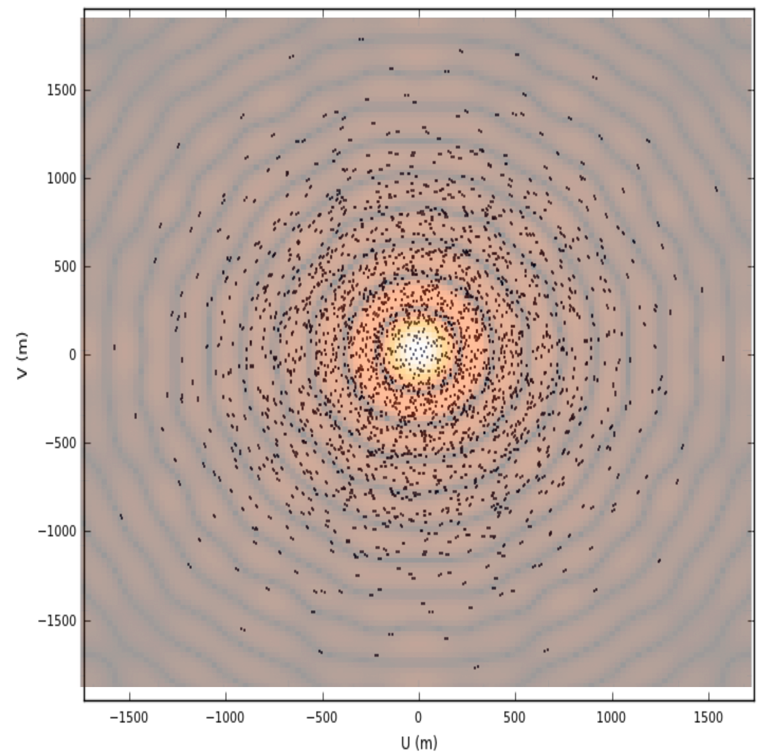


Example: ALMA

Atacama Large mm/submm Array (ALMA)

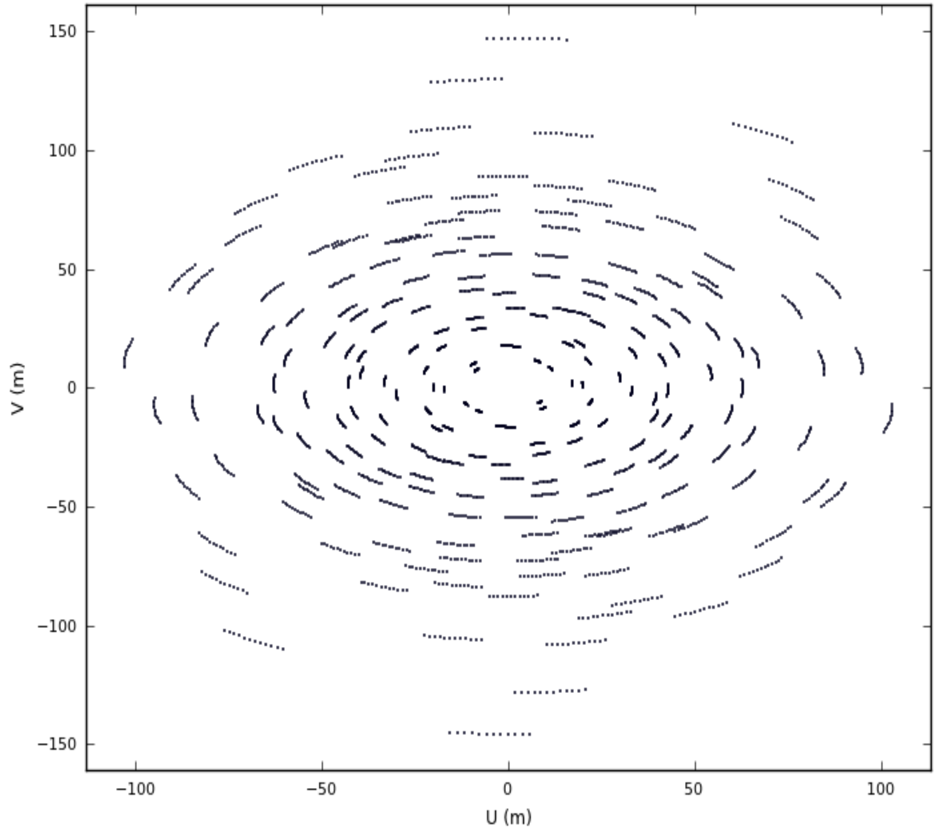
- 50 antennas of 12/7 meters
- observing from mm to submm
- in Llano Chajnantor (Chile)





Interferometers as spatial filters

- samples of V(u,v) are limited by the number of telescopes, and the Earth-sky geometry



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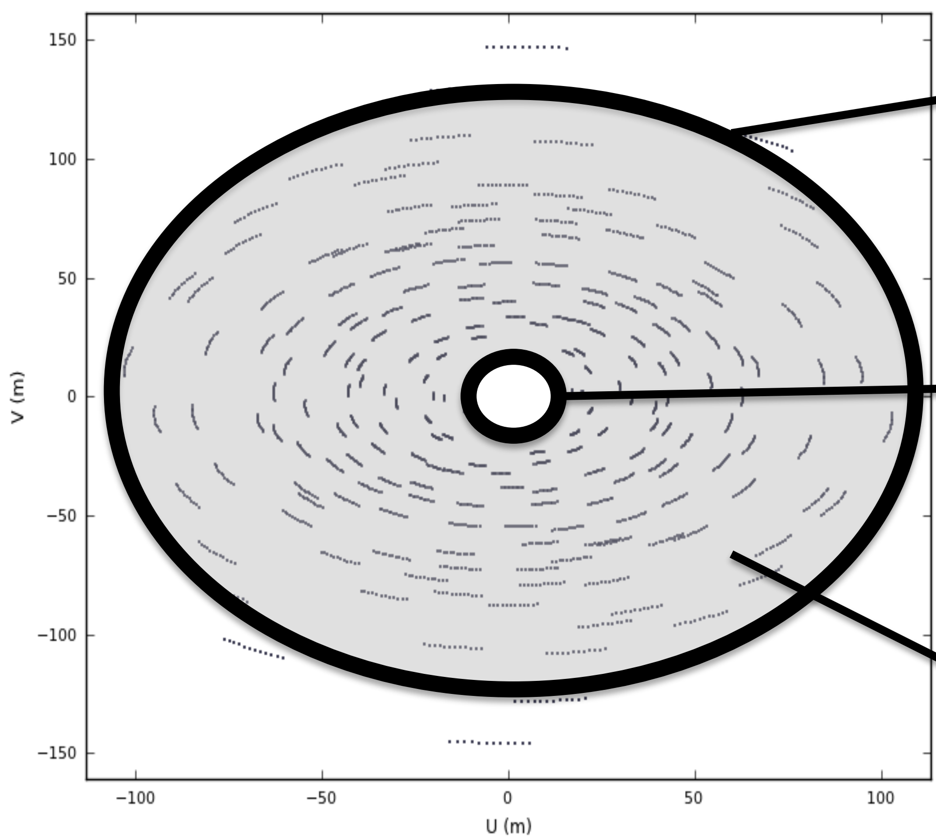
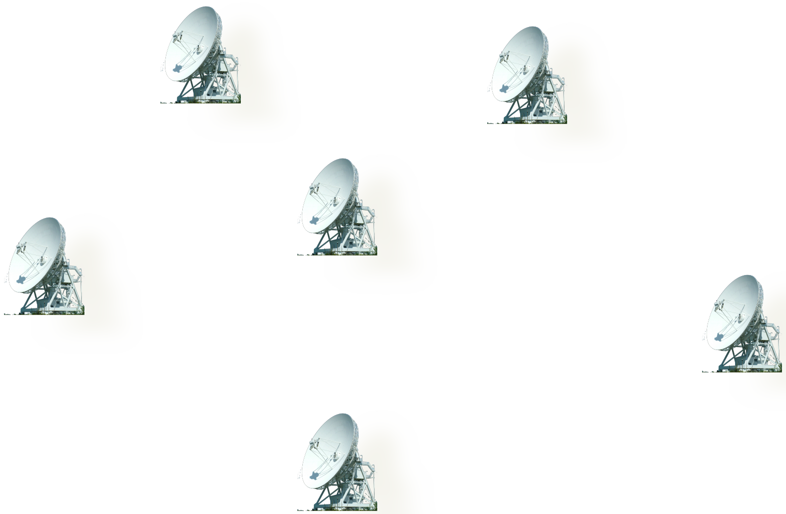


outer boundary:
- no small scales
- resolution limit

inner hole:
- no large scales
- extended structures

irregular coverage:
- information missing

Primary beam, synthesized beam, and LAS

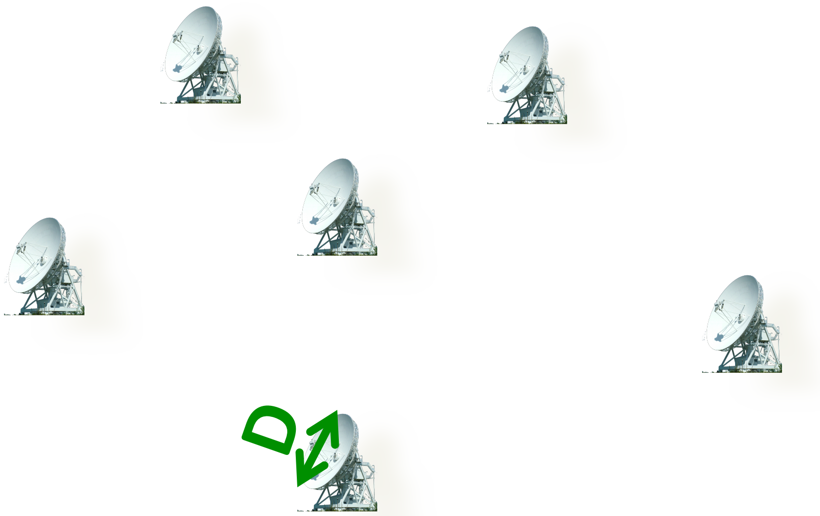


PRIMARY BEAM

SYNTHESIZED BEAM

LARGEST ANGULAR SCALE

Primary beam, synthesized beam, and LAS



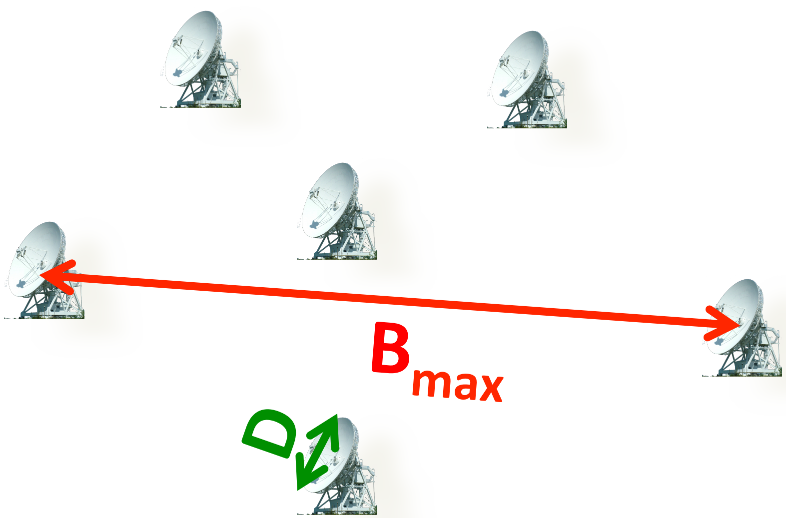
PRIMARY BEAM

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

SYNTHESIZED BEAM

LARGEST ANGULAR SCALE

Primary beam, synthesized beam, and LAS



PRIMARY BEAM

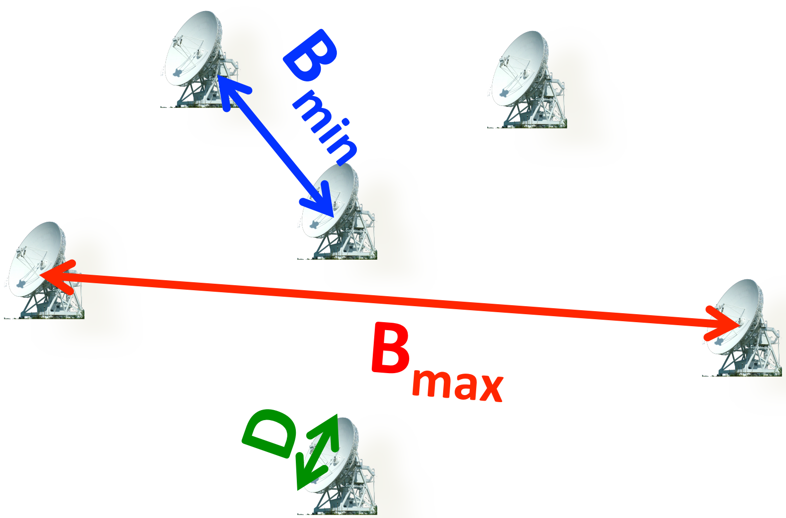
$$PB = 1.22\frac{\lambda}{D}$$

SYNTHESIZED BEAM

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

LARGEST ANGULAR SCALE

Primary beam, synthesized beam, and LAS



PRIMARY BEAM

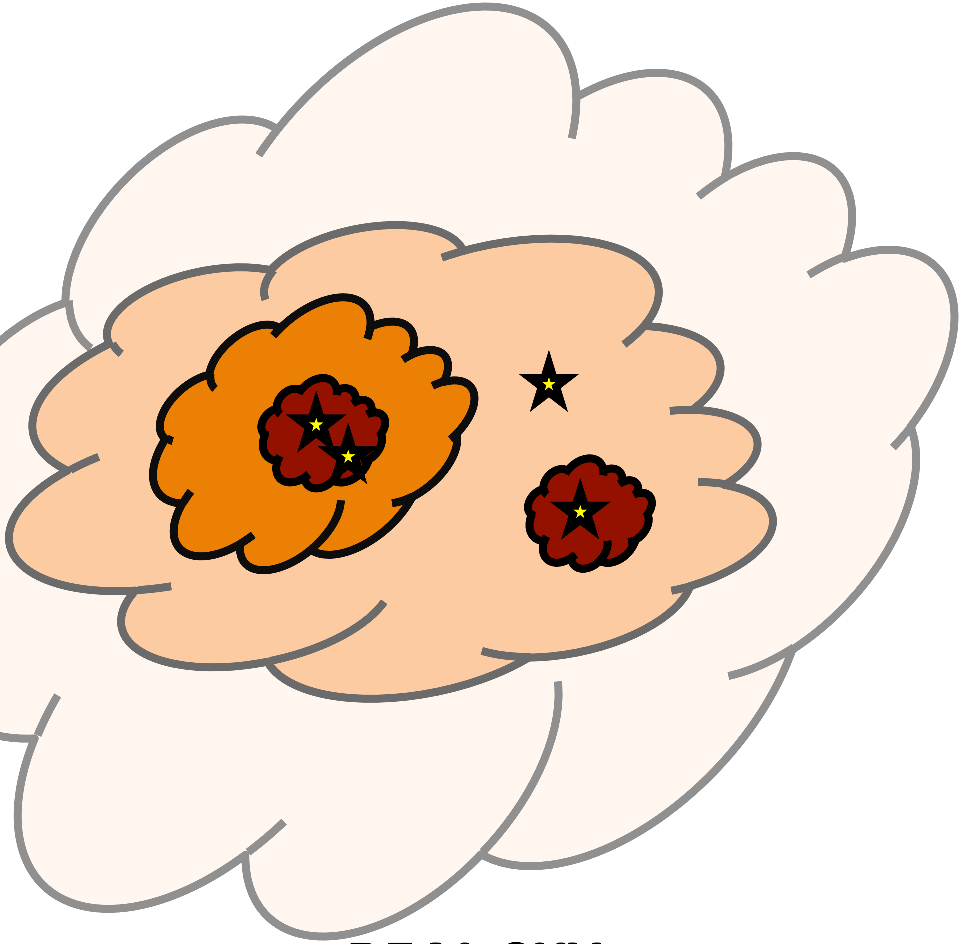
$$PB = 1.22\frac{\lambda}{D}$$

SYNTHESIZED BEAM

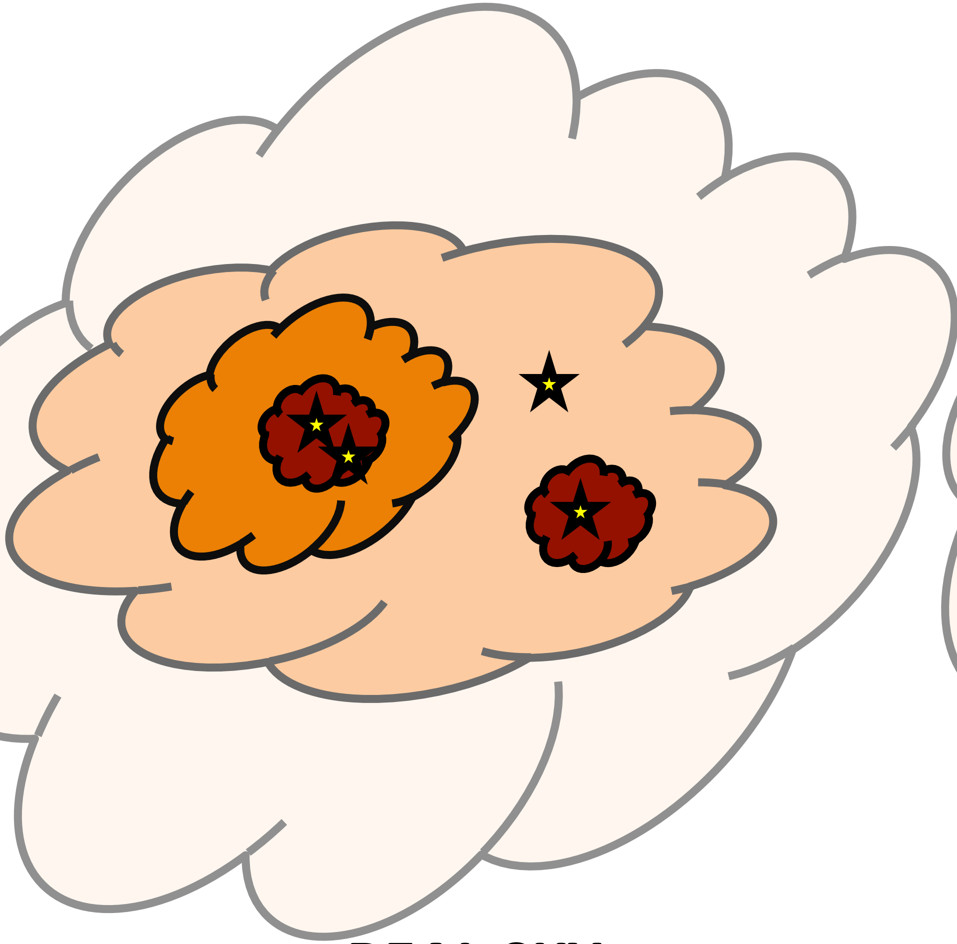
$$\theta_{beam} = 1.22\frac{\lambda}{B_{\max}}$$

LARGEST ANGULAR SCALE

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



REAL SKY



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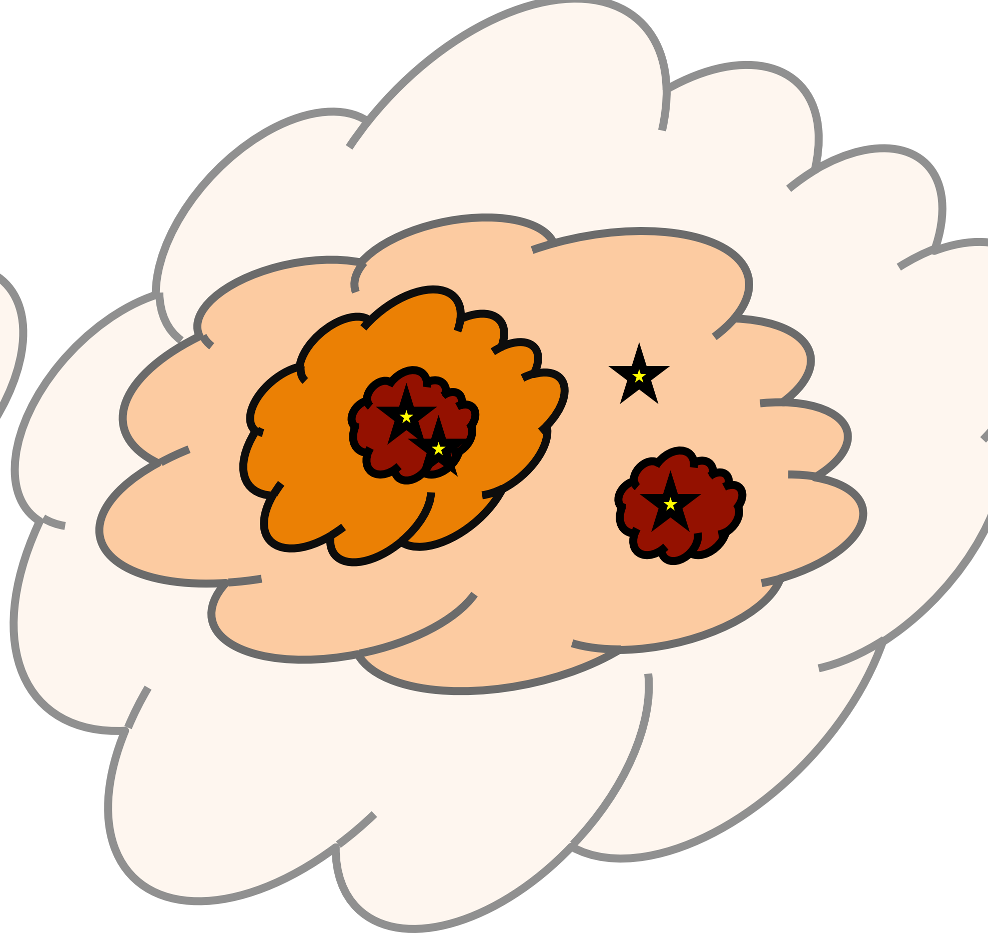
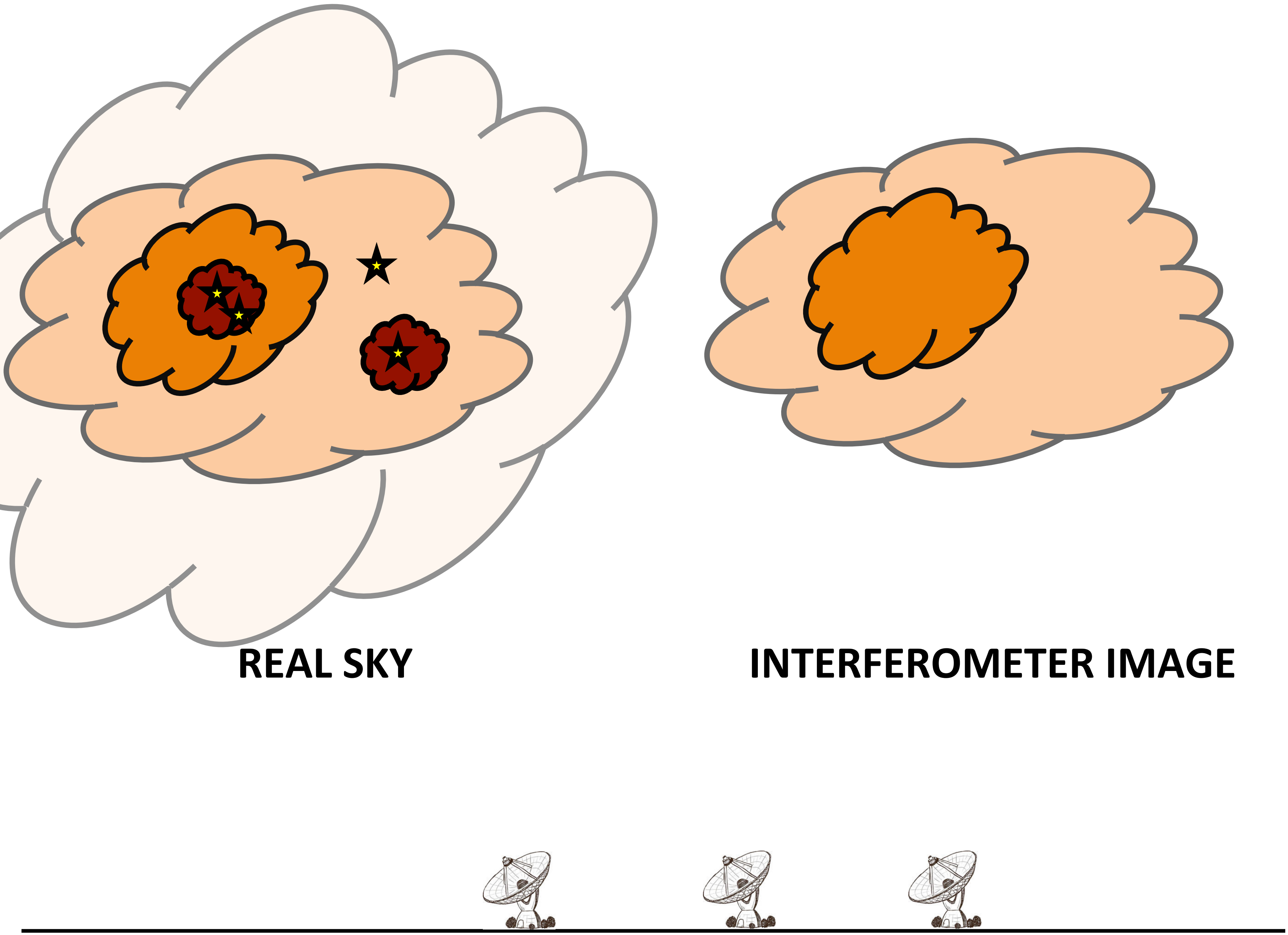
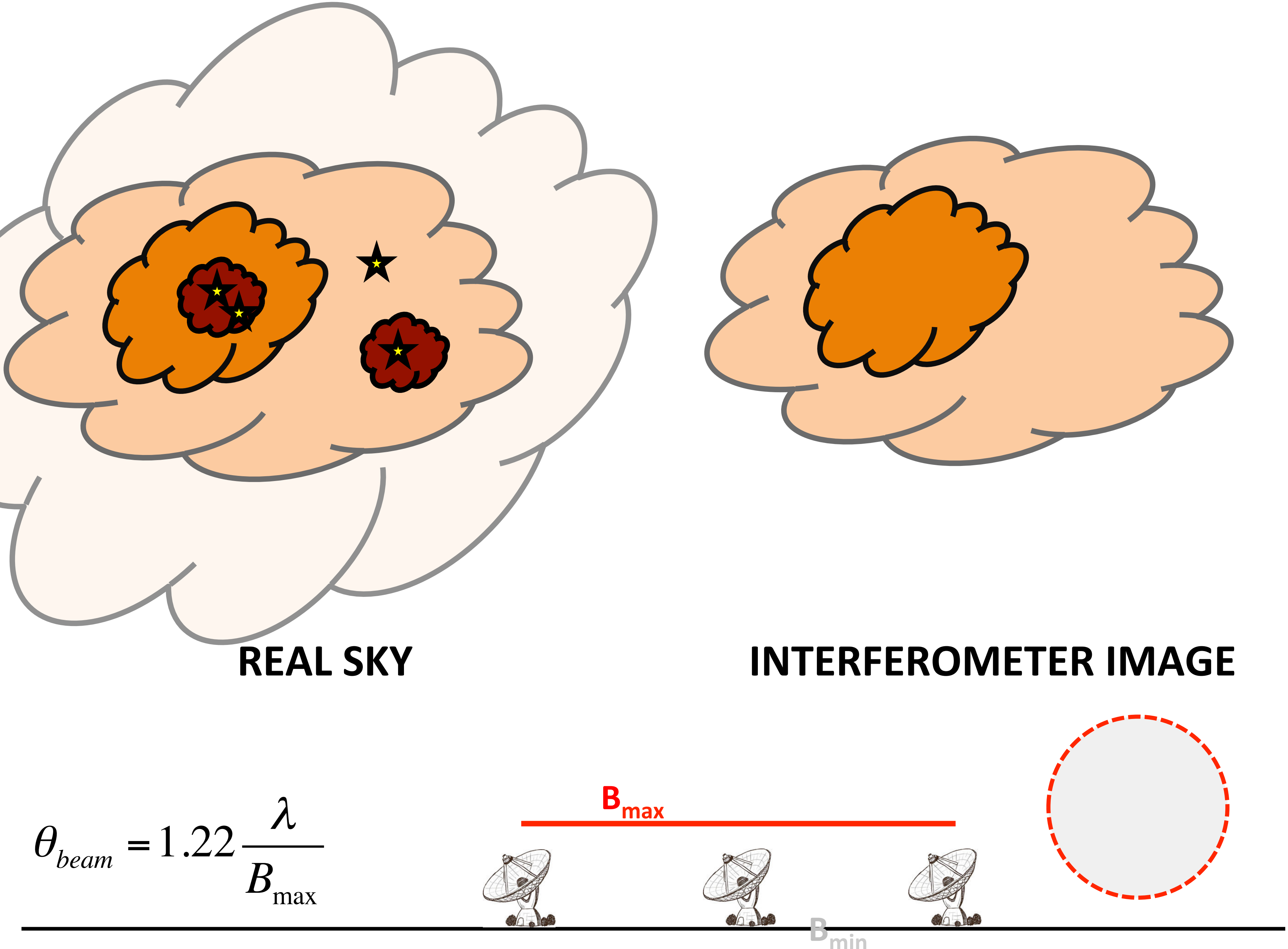
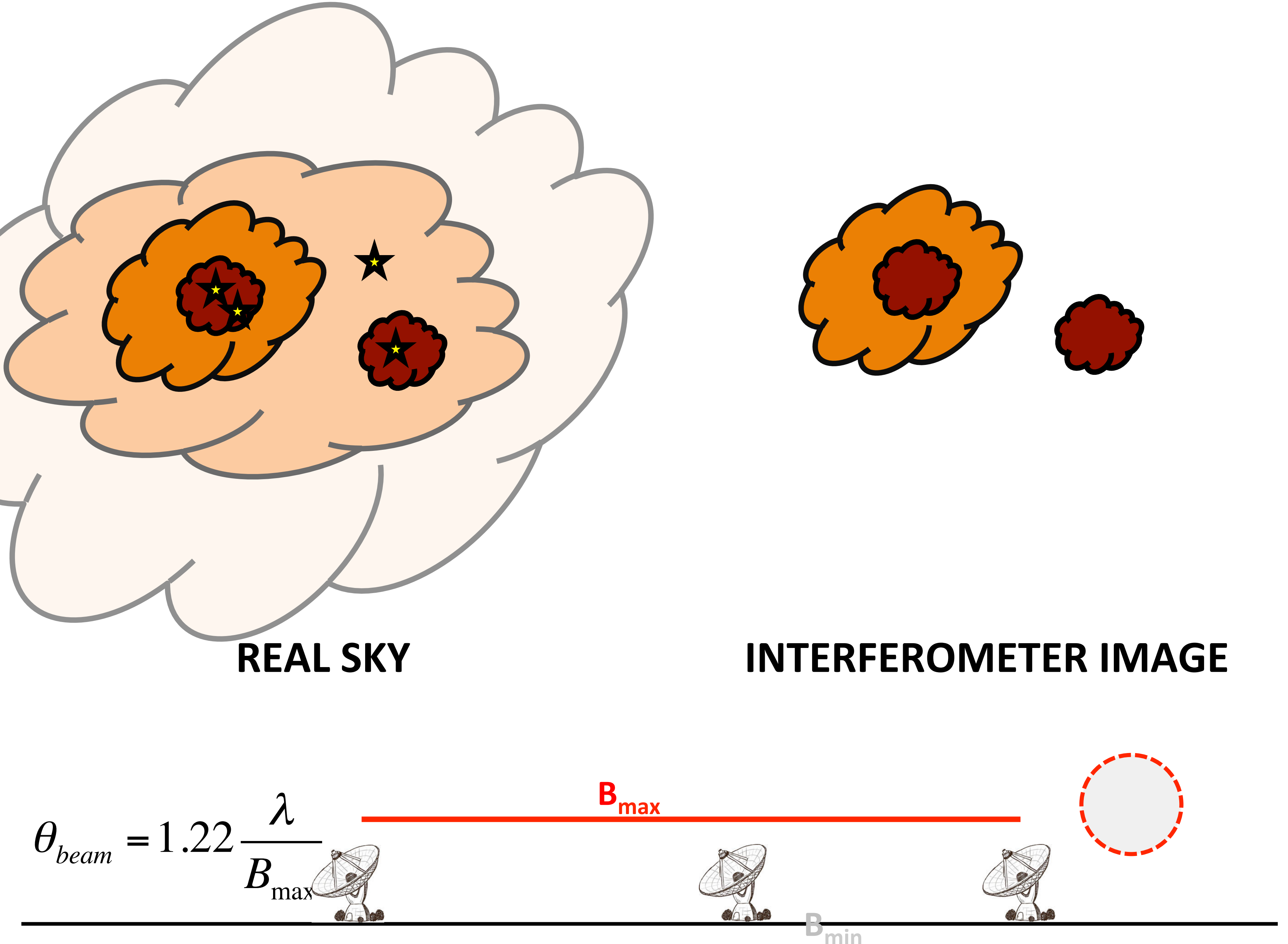


WHAT WE WANT TO OBTAIN


REAL SKY
INTERFEROMETER IMAGE


REAL SKY
INTERFEROMETER IMAGE
$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$
B_{max}
B_{min}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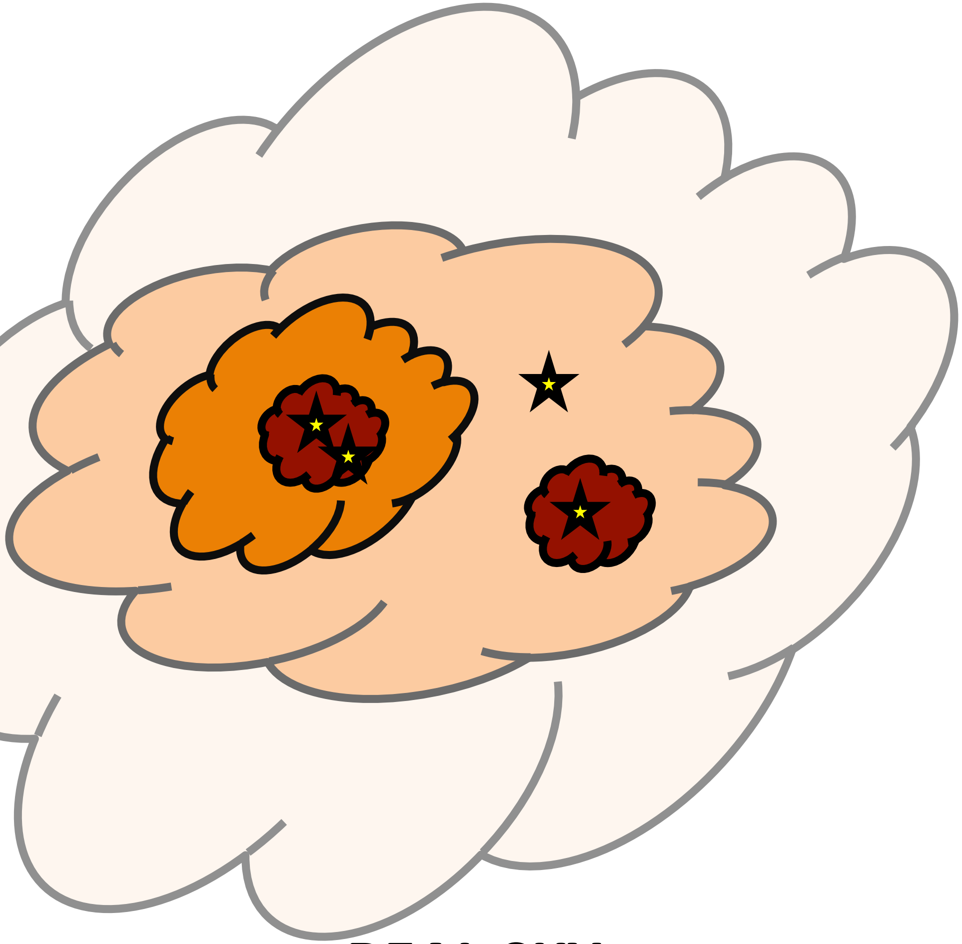

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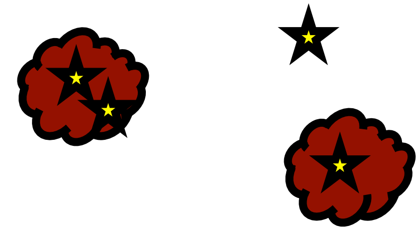
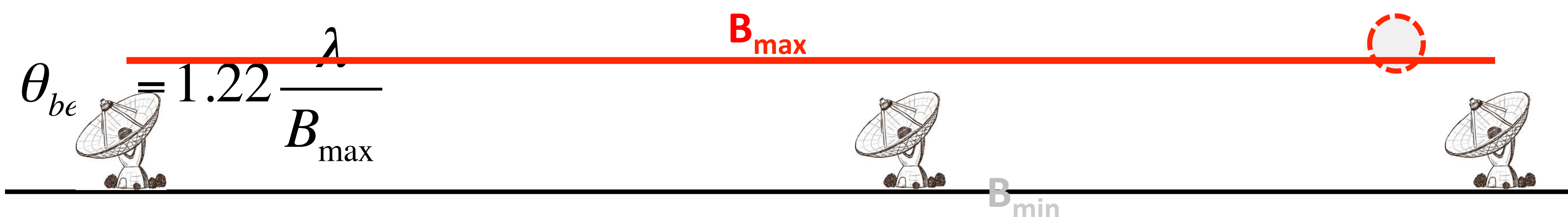


INTERFEROMETER IMAGE



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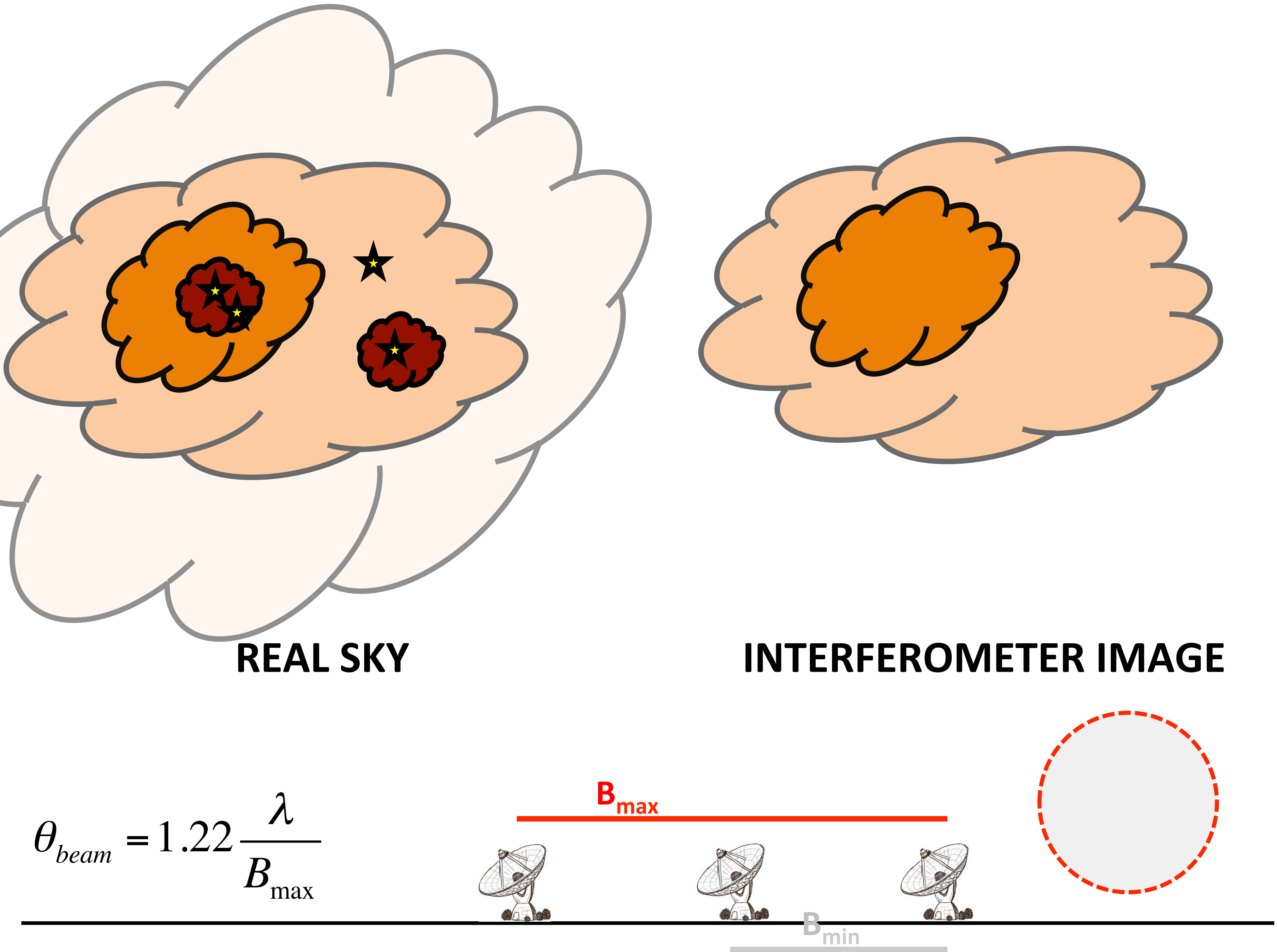
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INTERFEROMETER IMAGE
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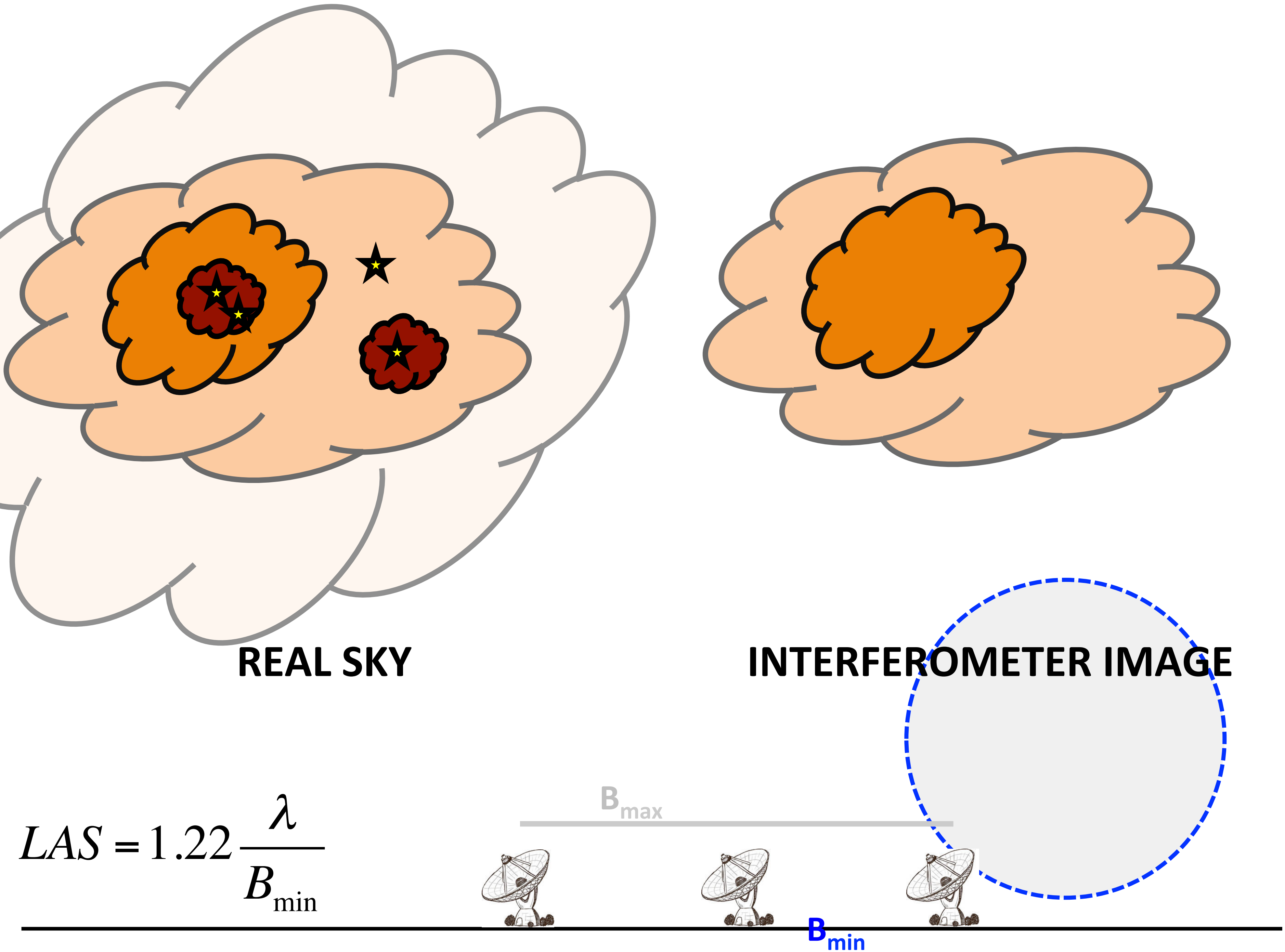
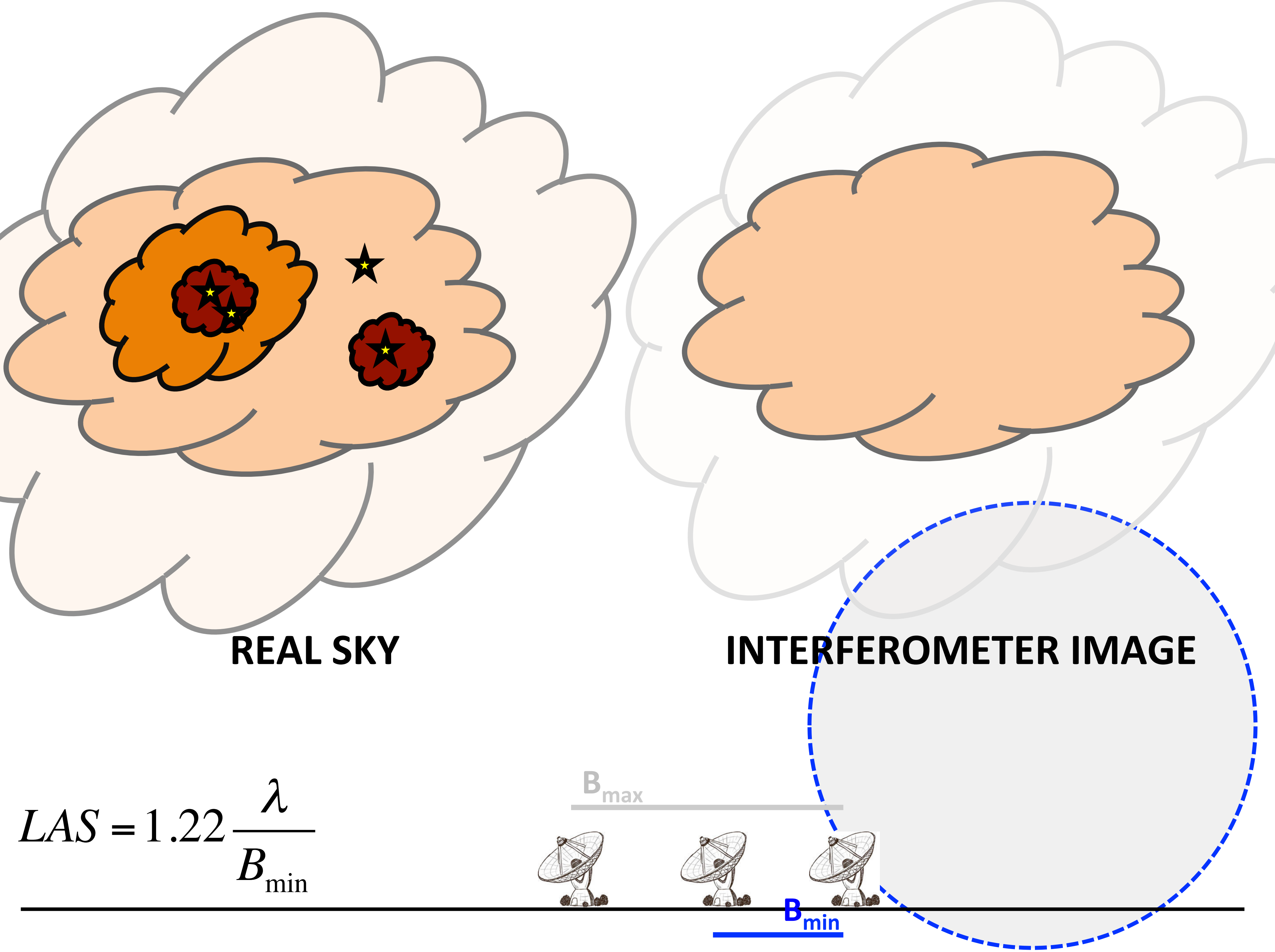
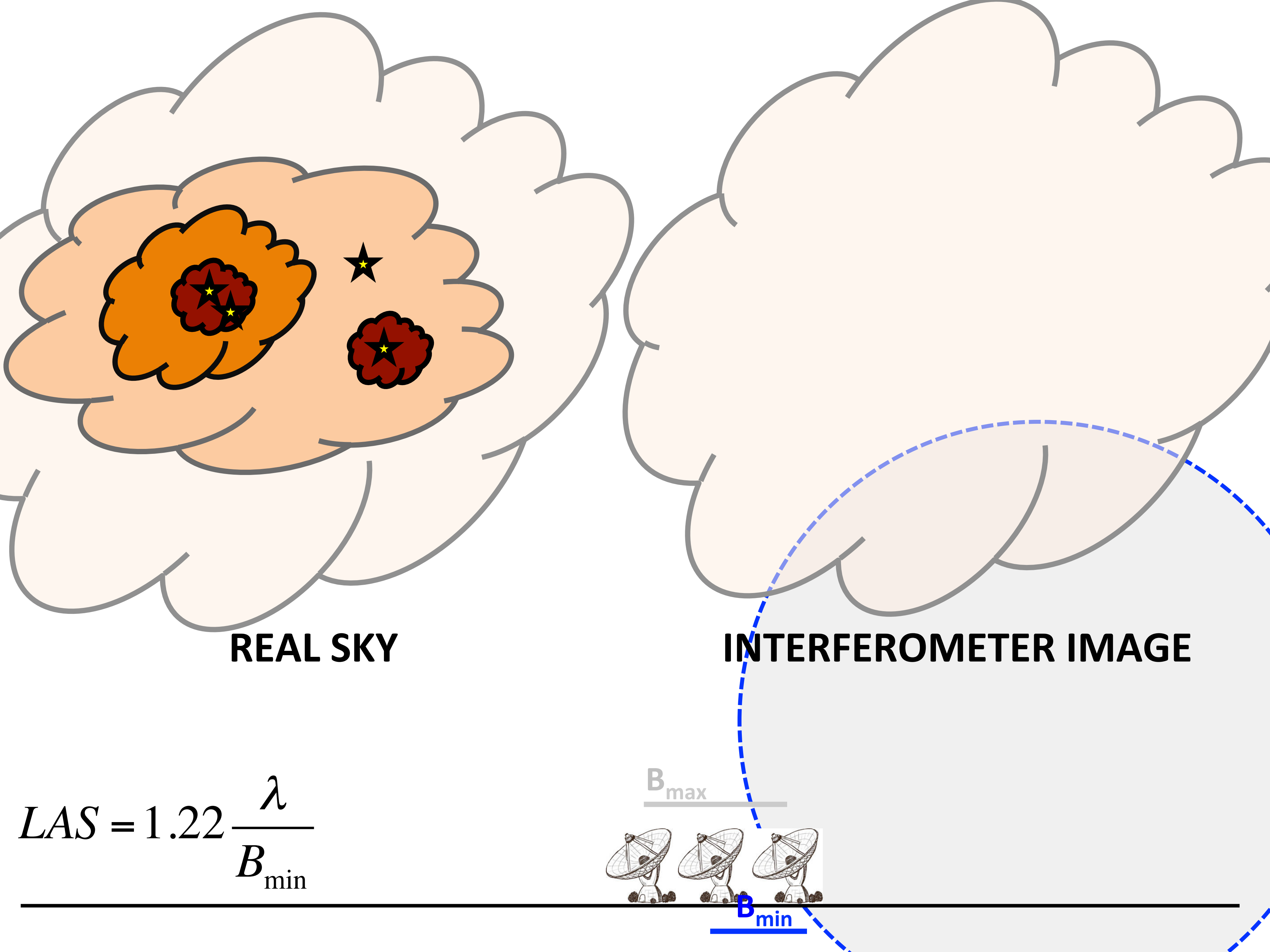

REAL SKY
INTERFEROMETER IMAGE
$LAS = 1.22 \frac{\lambda}{B_{min}}$
B_{max}
B_{min}



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



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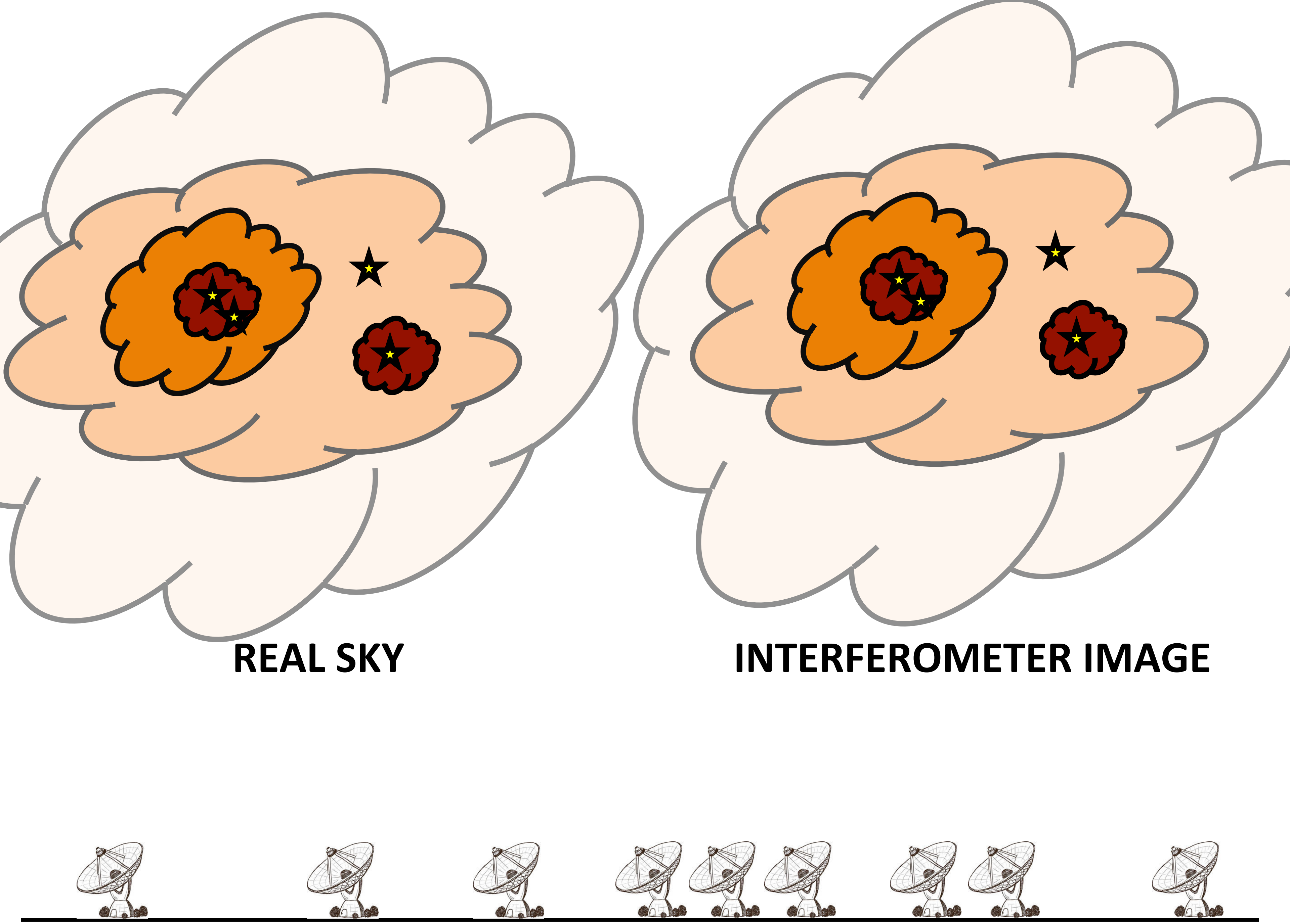
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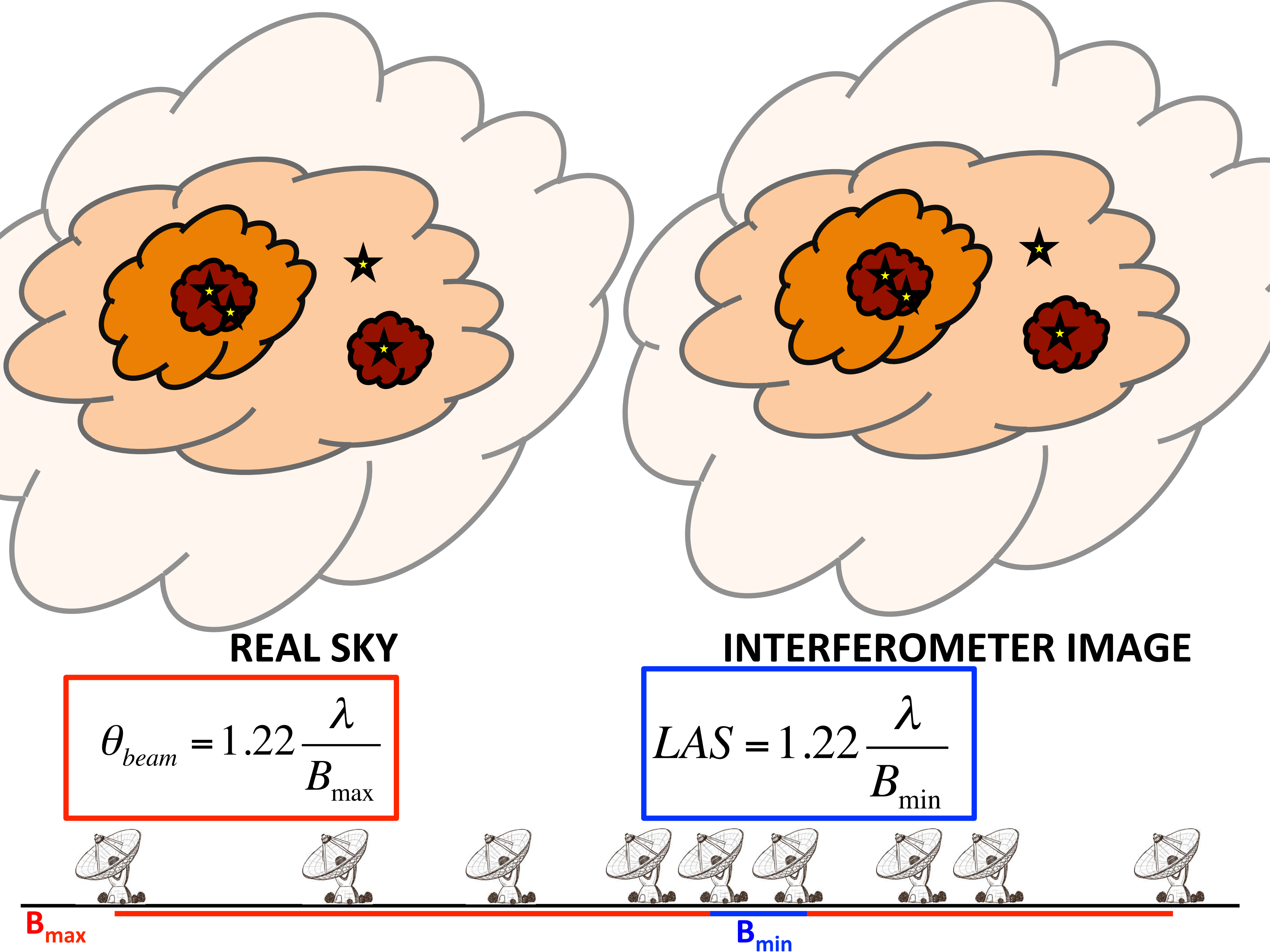
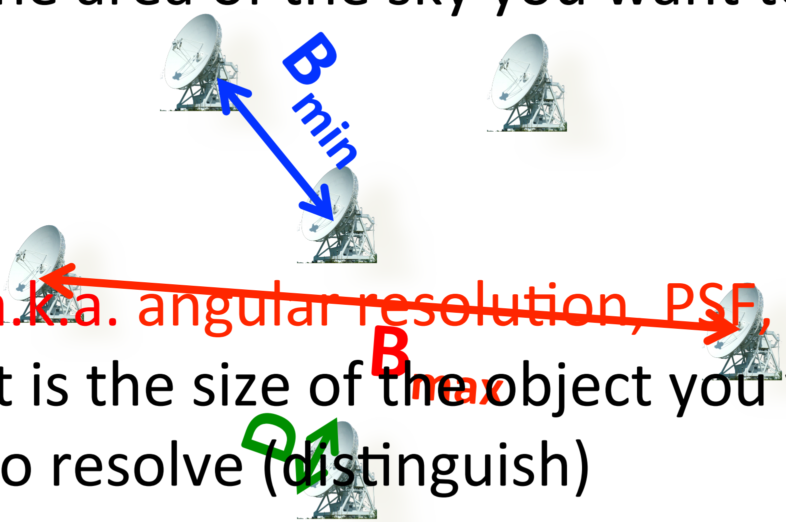

REAL SKY
INTERFEROMETER IMAGE
$\theta_{beam} = 1.22 \frac{\lambda}{B_{\max}}$
$LAS = 1.22 \frac{\lambda}{B_{\min}}$
B_{max}
B_{min}

Primary beam, synthesized beam, and LAS

PRIMARY BEAM

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

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



SYNTHESIZED BEAM

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

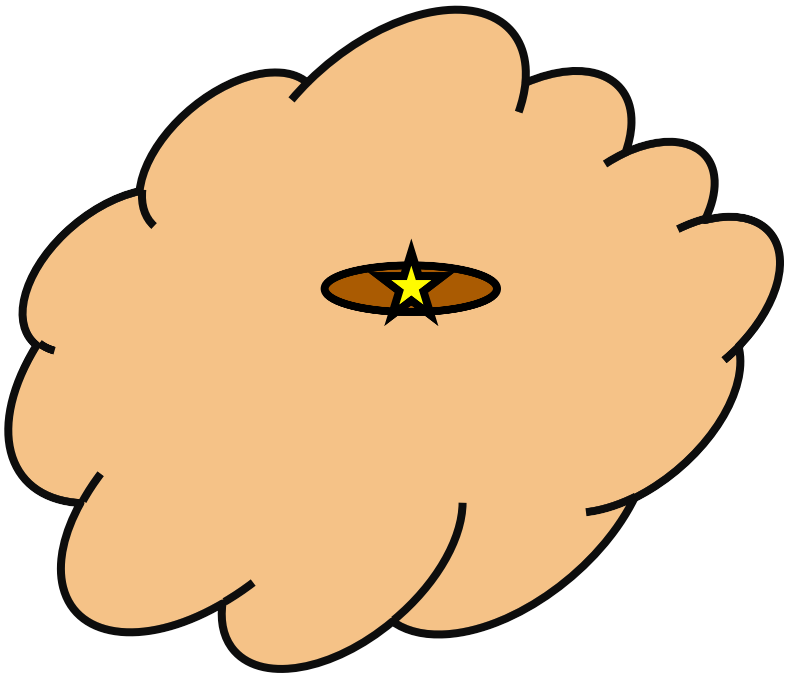
$$\theta_{beam} = 1.22\frac{\lambda}{B_{\max}}$$

LARGEST ANGULAR SCALE

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

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

Example I: compact protoplanetary disk



PRIMARY BEAM

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

SYNTHESIZED BEAM

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

LARGEST ANGULAR SCALE

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

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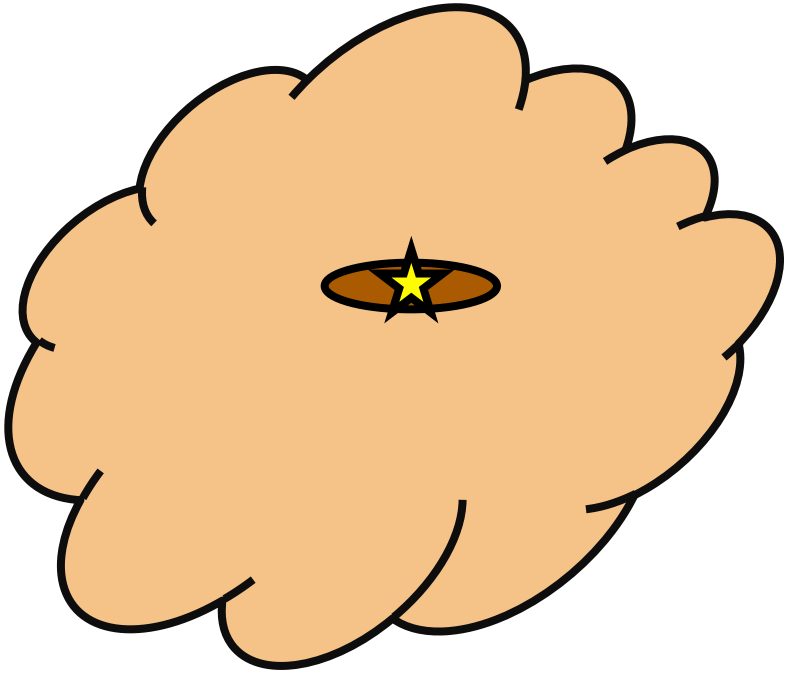

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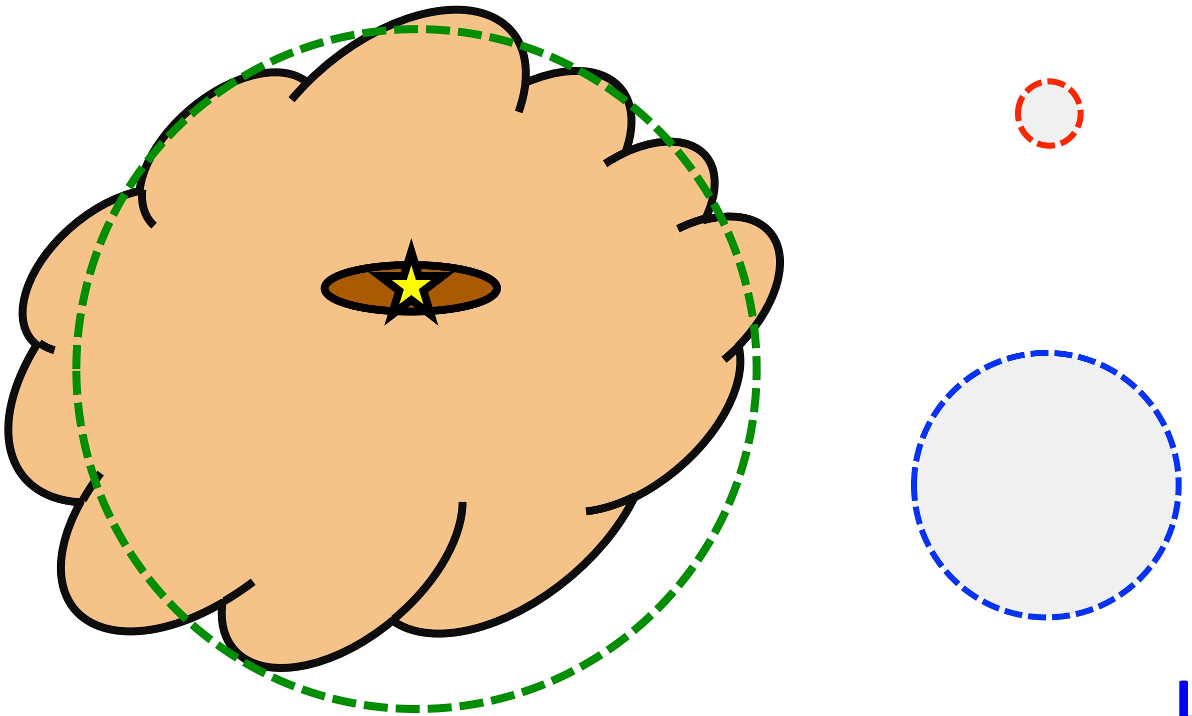

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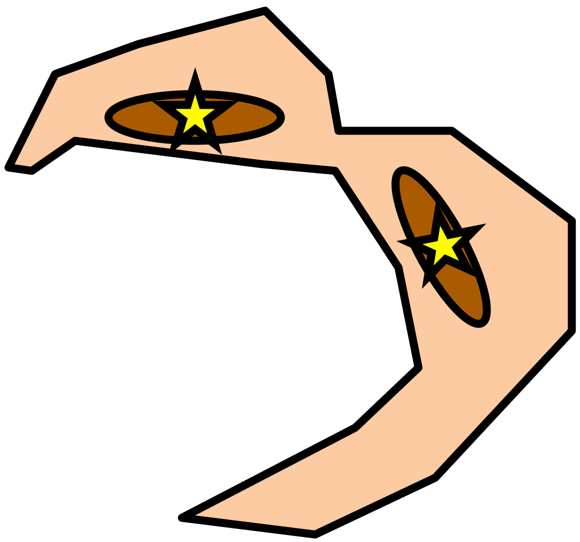
Example II: disks and filament



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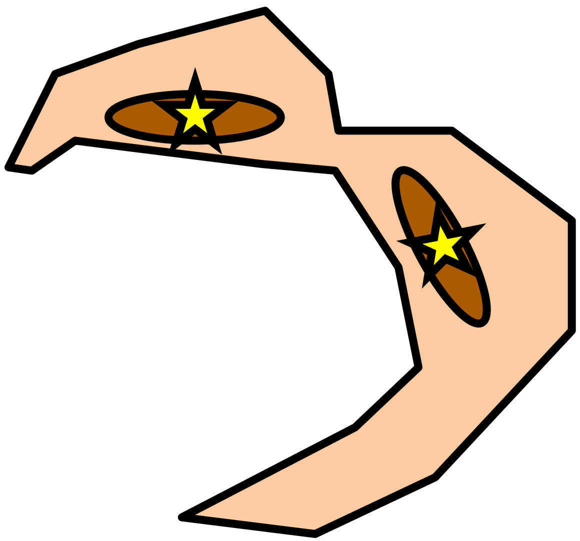

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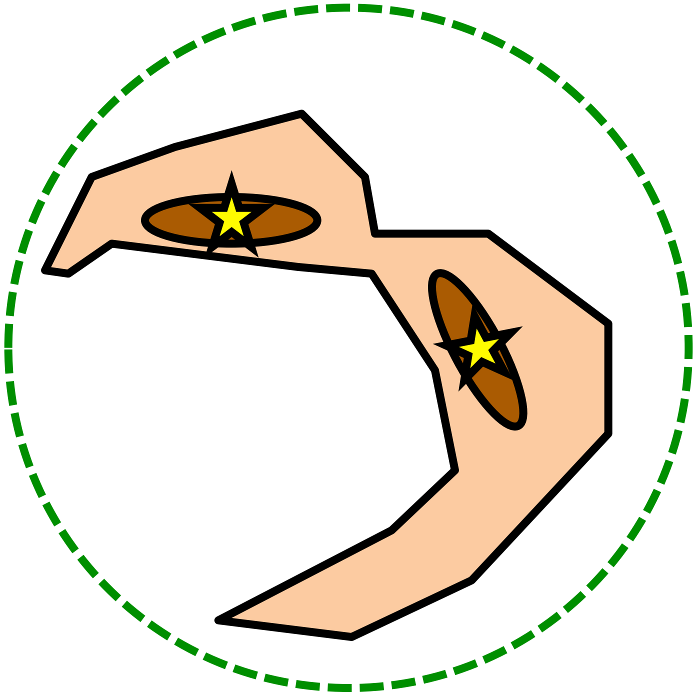

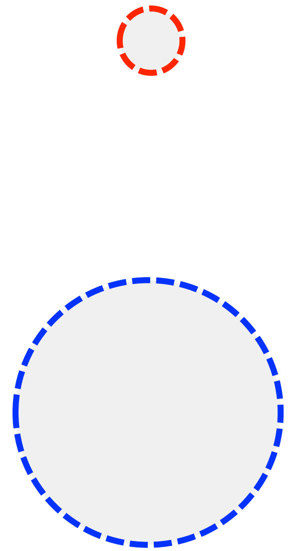

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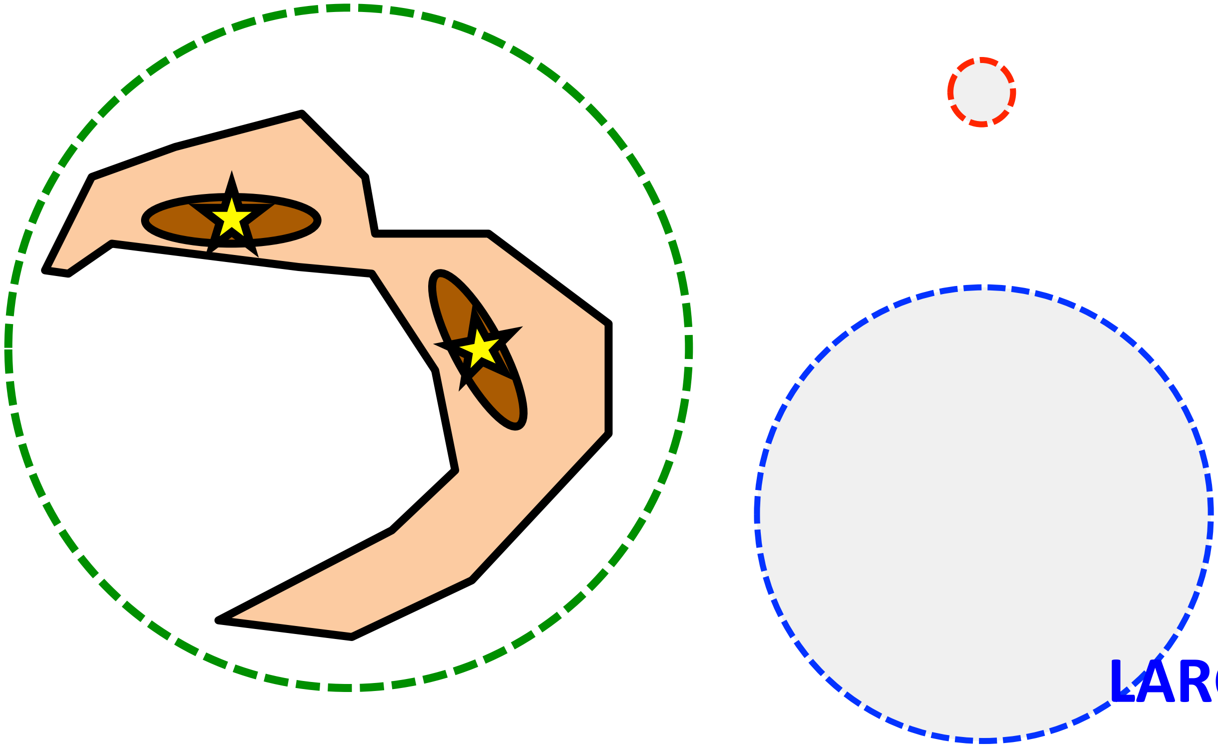

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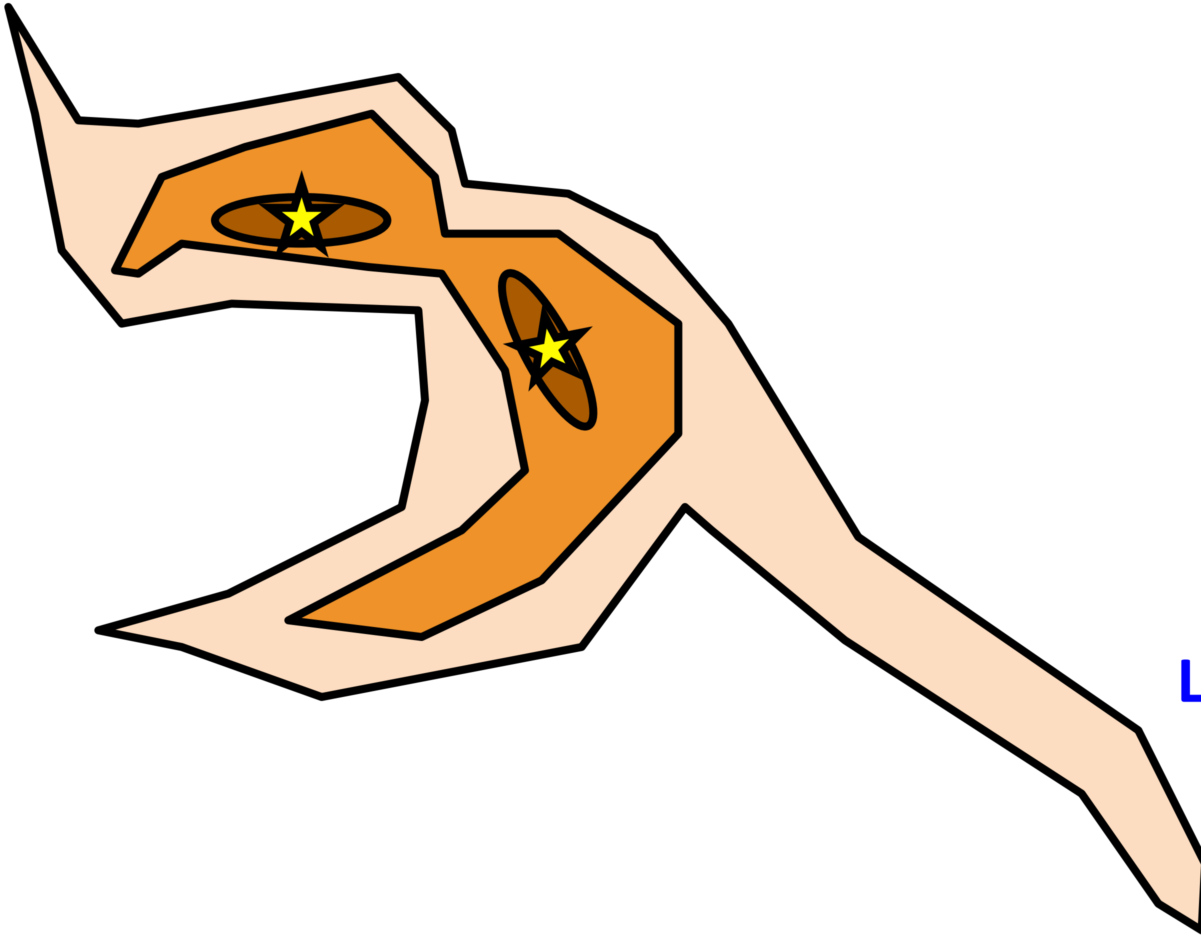
Example III: disks and extended filament



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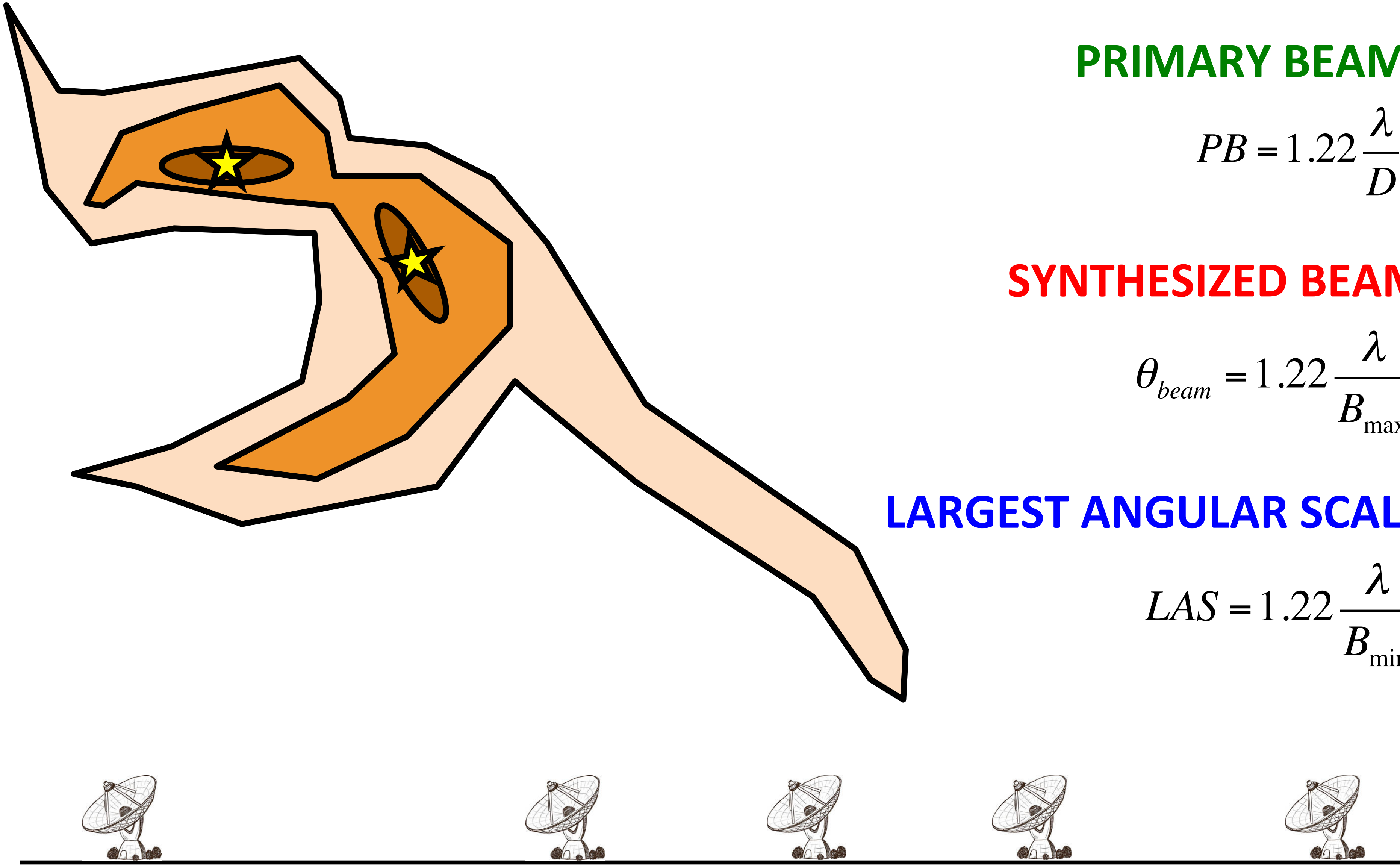

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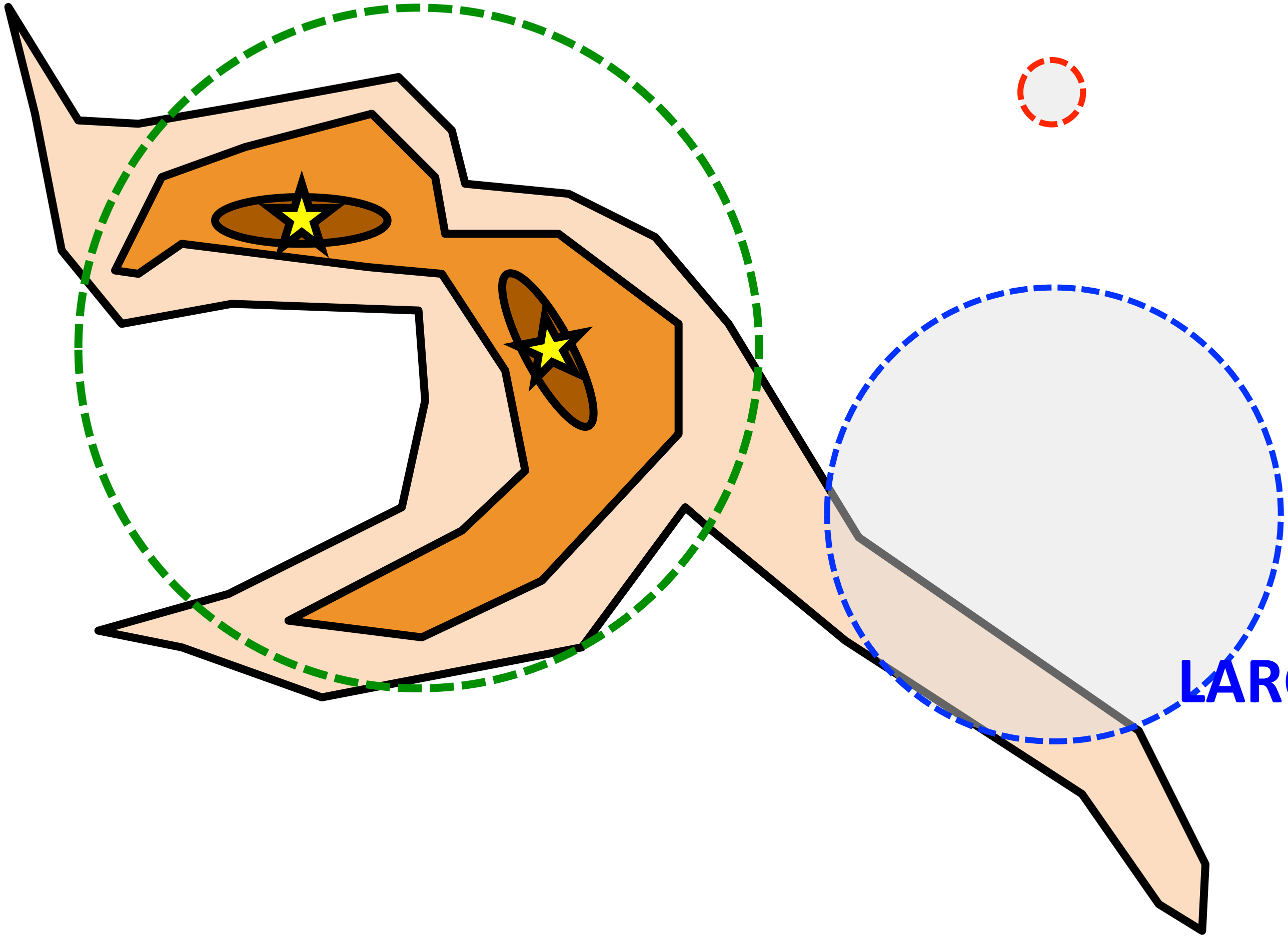

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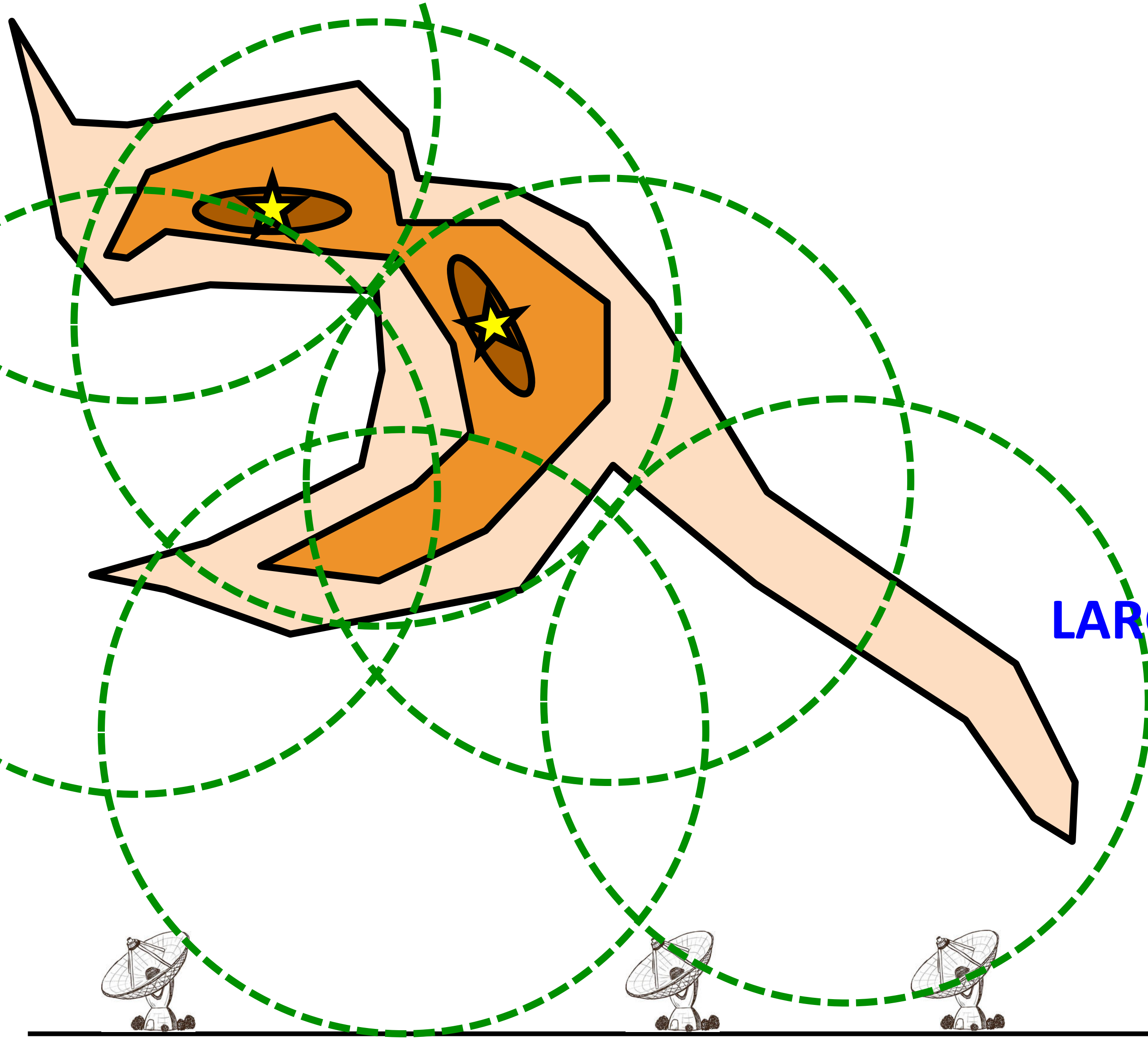

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Key concepts that we have learned

Part 1

- Interferometer
- Baseline
- Primary beam
- Synthesized beam
- Largest angular scale

Questions?

Contact us at arc@astro.uni-bonn.de

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