

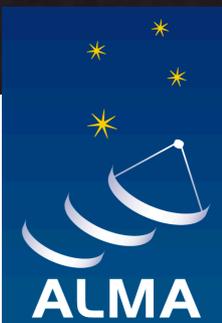
INTRODUCTION TO RADIO ASTRONOMY AND ALMA

Elizabeth Artur de la Villarmois
ESO/ALMA Fellow



LA SILLA OBSERVING SCHOOL 2026

February the 12th, 2026



OUTLINE

RADIO ASTRONOMY

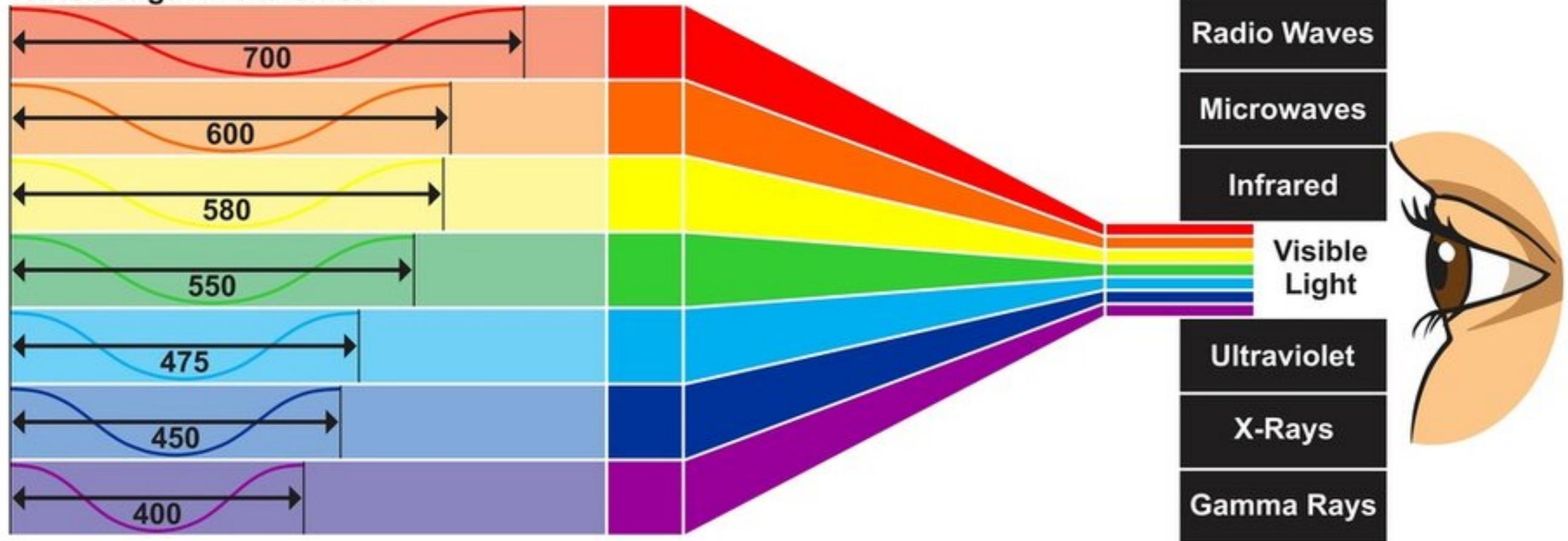
- WHY RADIO WAVELENGTHS?
- HISTORY
- THE PHYSICS BEHIND 1 ANTENNA
- THE BASICS OF RADIO INTERFEROMETRY

SINGLE DISH VS. INTERFEROMETRY

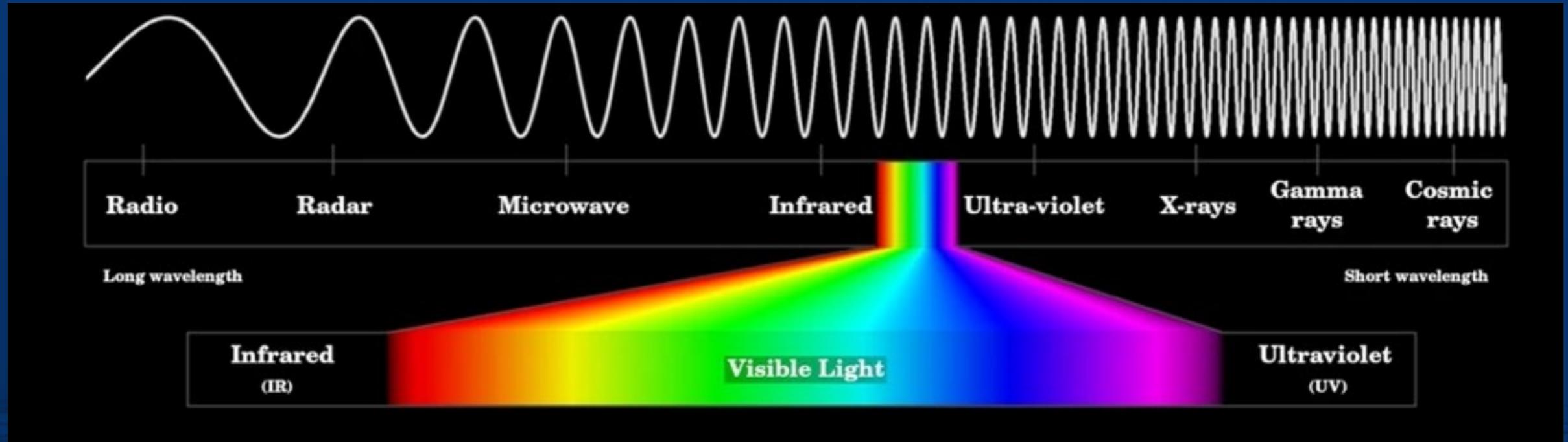
ALMA

THE ELECTROMAGNETIC SPECTRUM

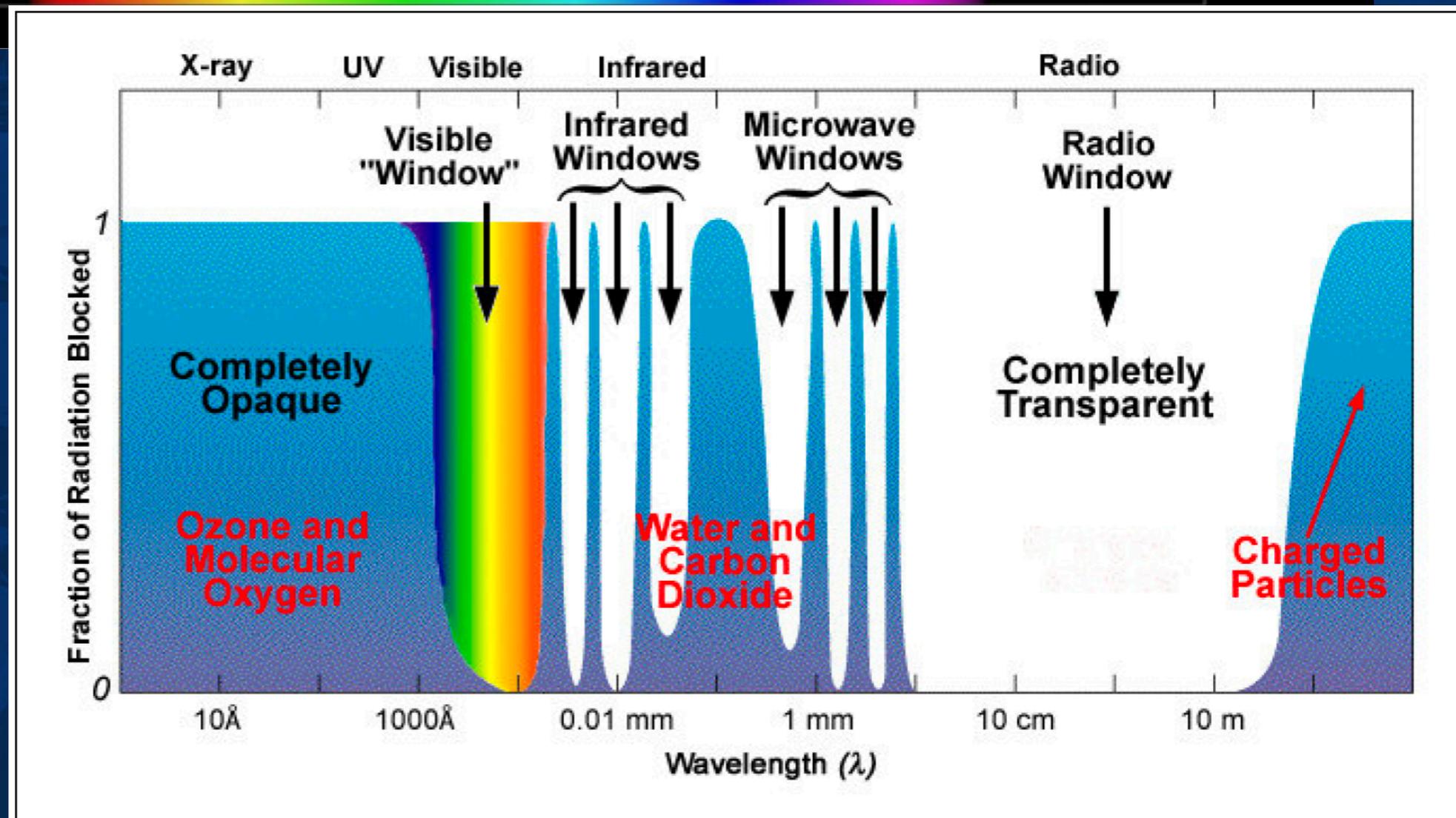
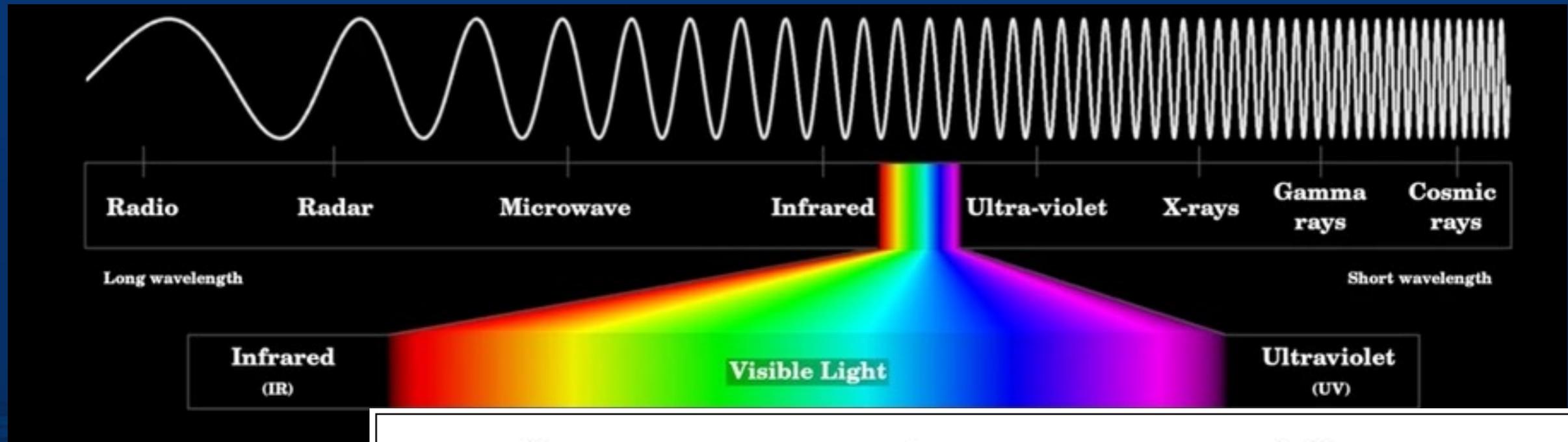
Wave Length in Nanometer



THE MILKY WAY AT DIFFERENT WAVELENGTHS

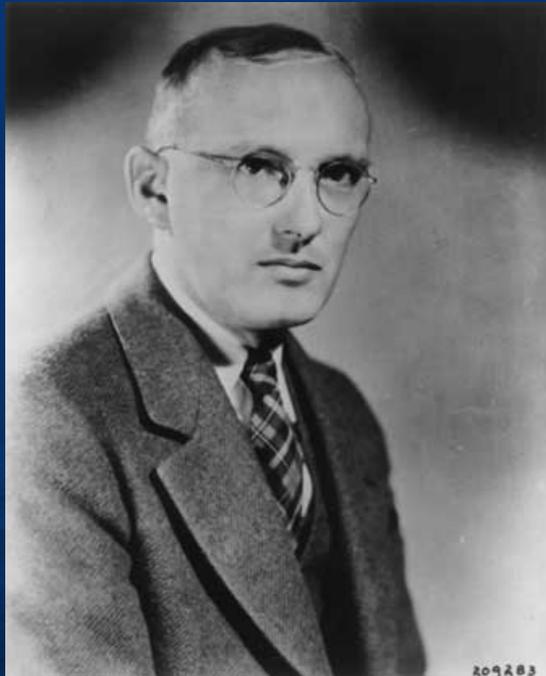


THE MILKY WAY AT DIFFERENT WAVELENGTHS



HISTORY

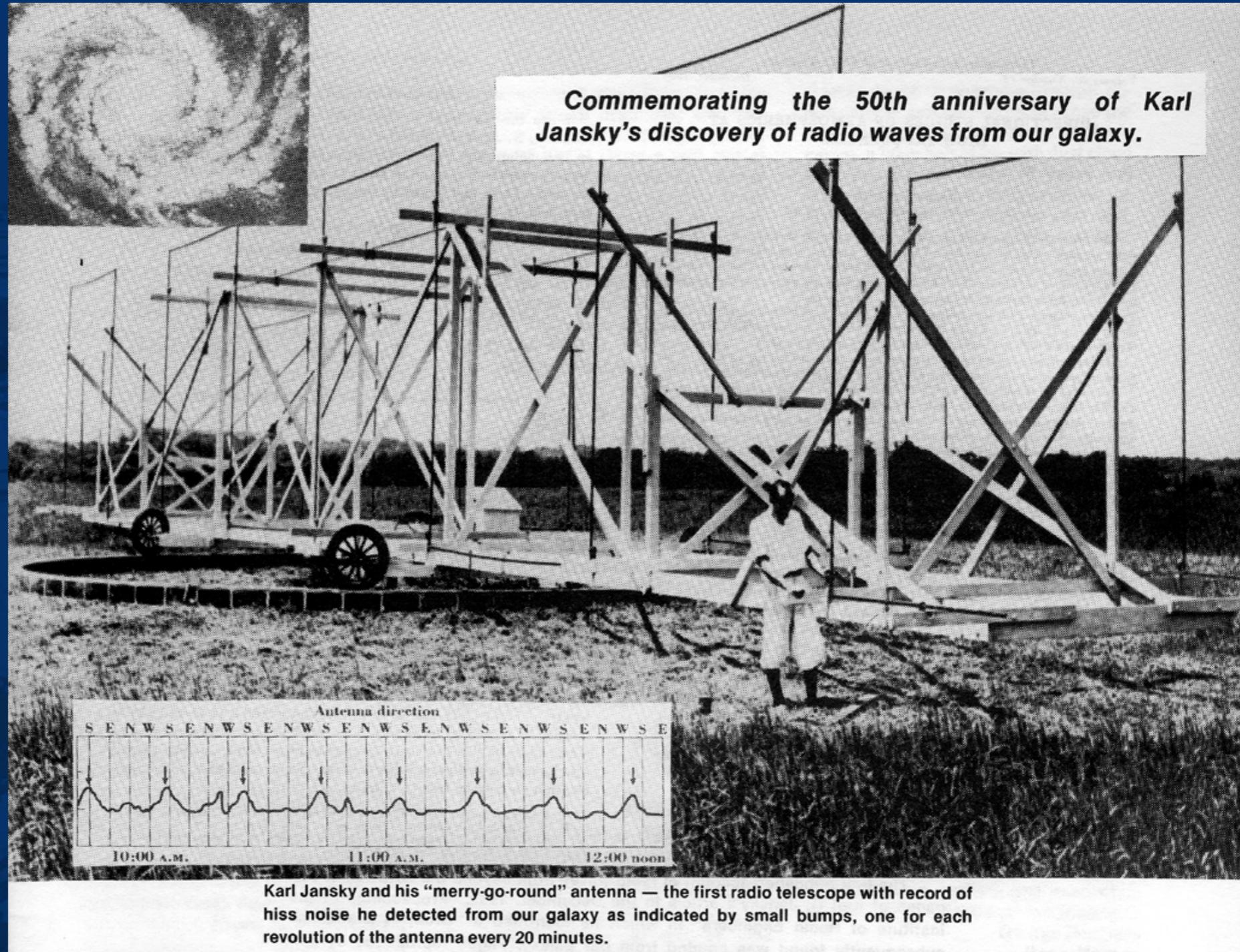
Radio Astronomy



Karl Guthe Jansky
Bell Telephone Laboratories

First Radio signals, coming from the Galactic Center (Sagittarius Constelation)

1933



HISTORY

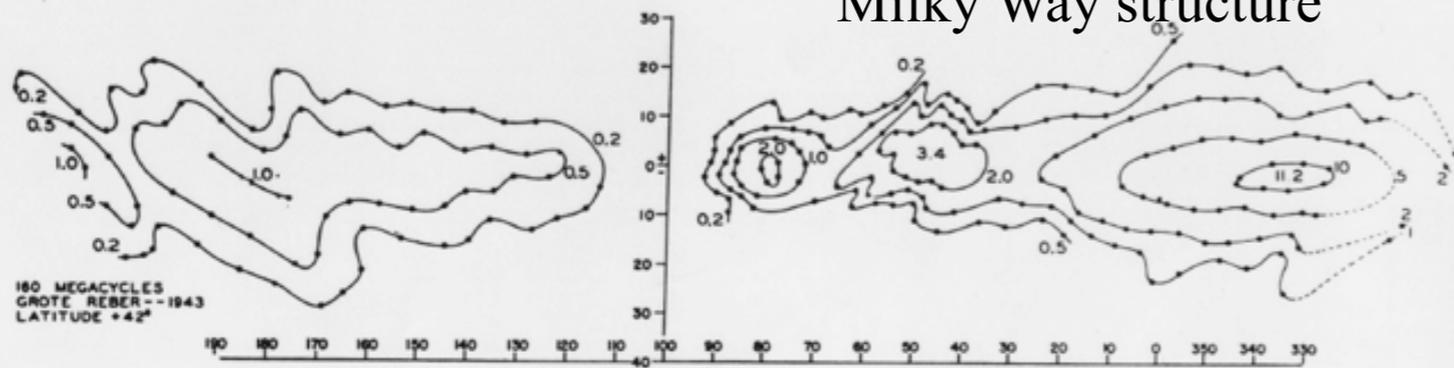
Radio Astronomy



In 1937: Grote Reber built a 10m-antenna, to investigate cosmic radio waves. He made the 1st Radio map of the Milky Way and discovered Radio emission from the Sun.



Milky Way structure



Cygnus A

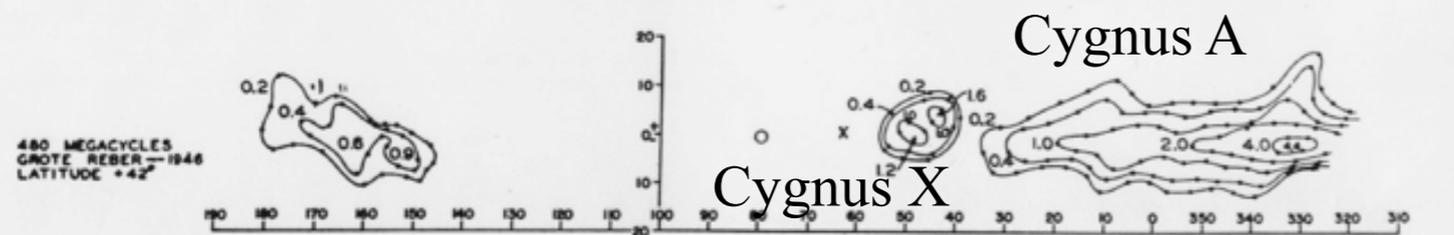
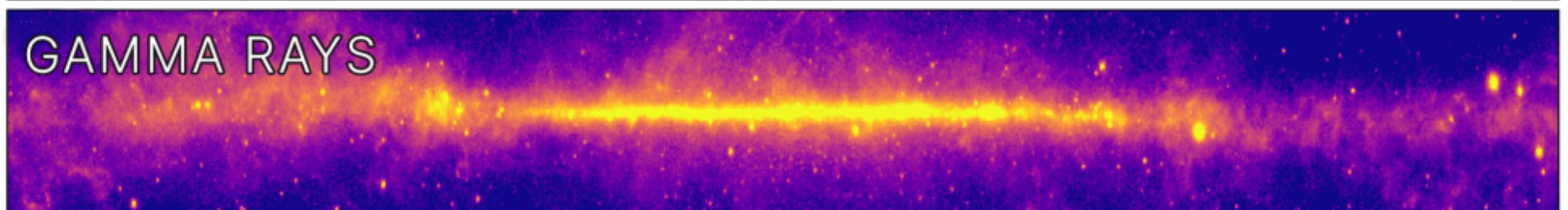
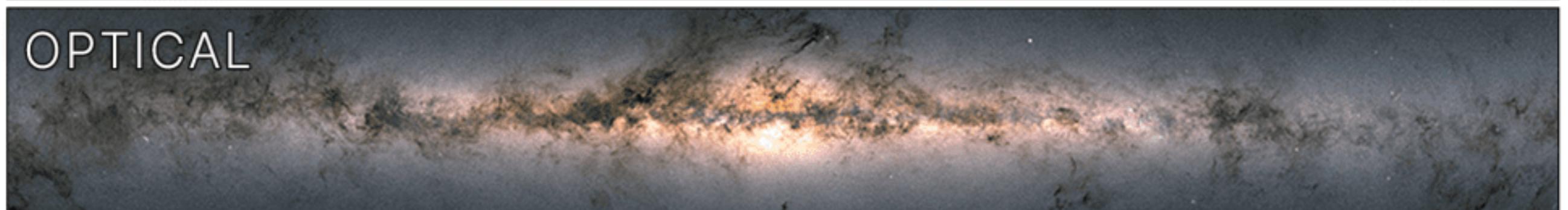
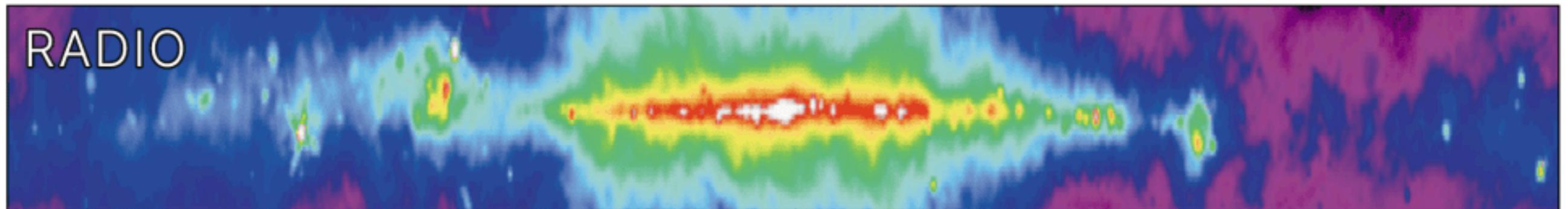
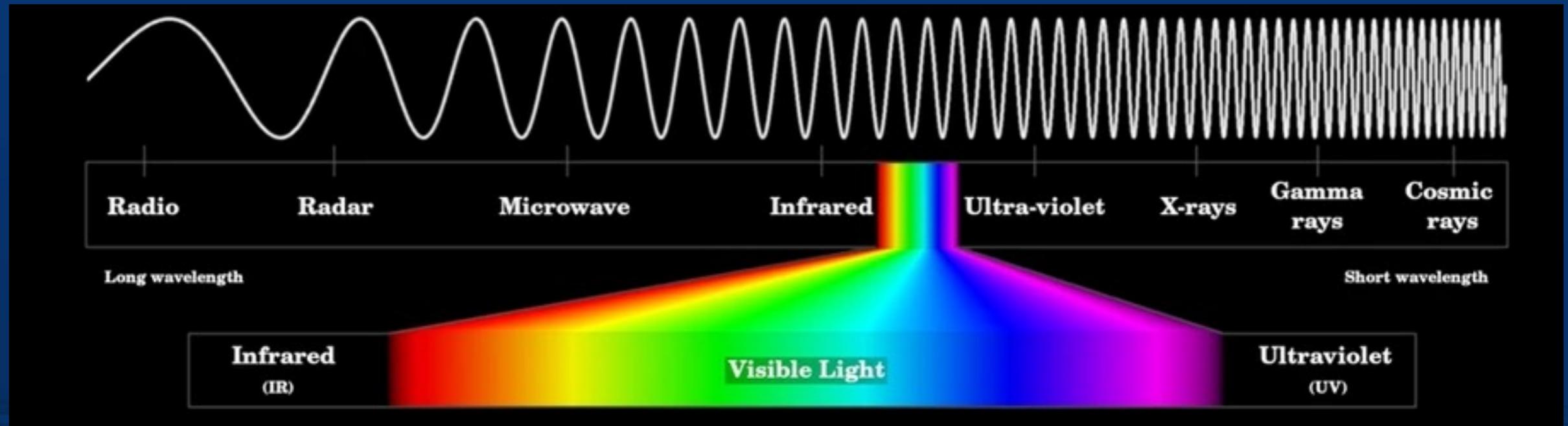


FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

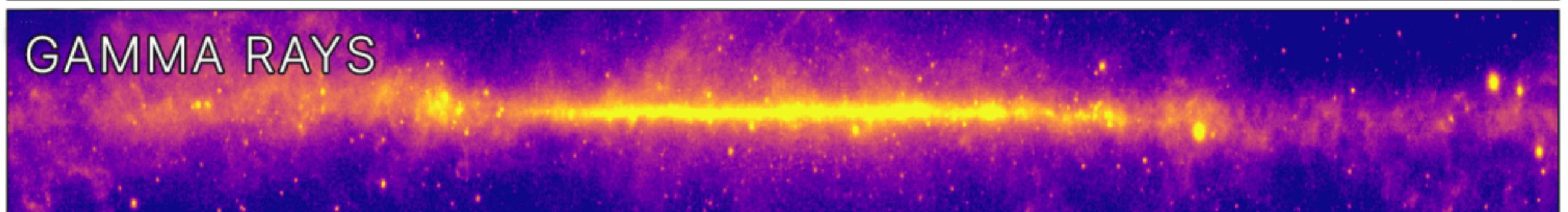
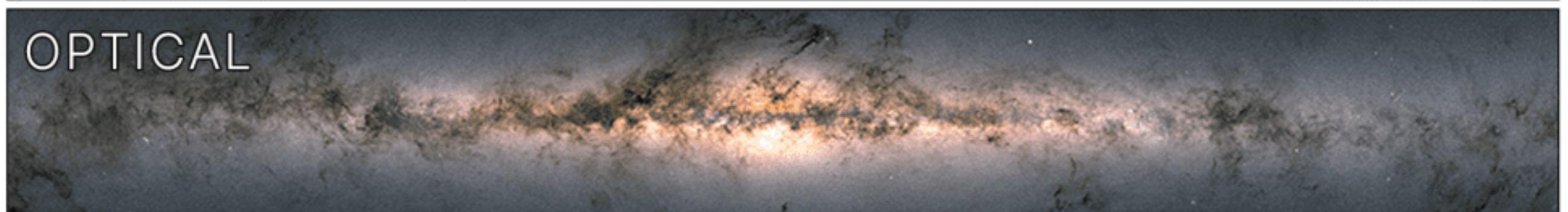
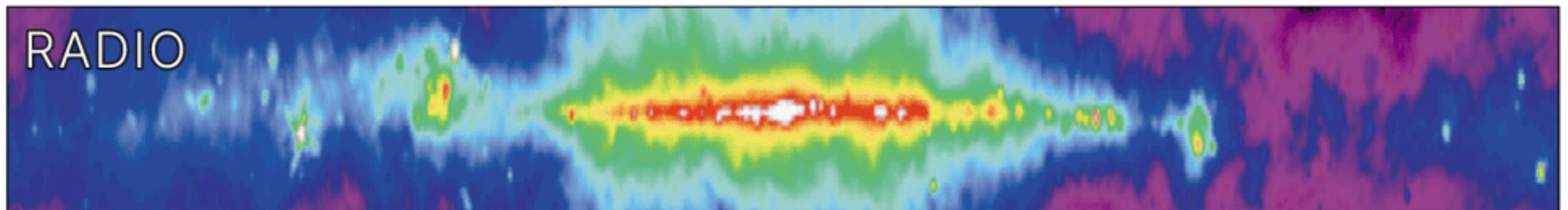
Reber 1948

THE MILKY WAY AT DIFFERENT WAVELENGTHS



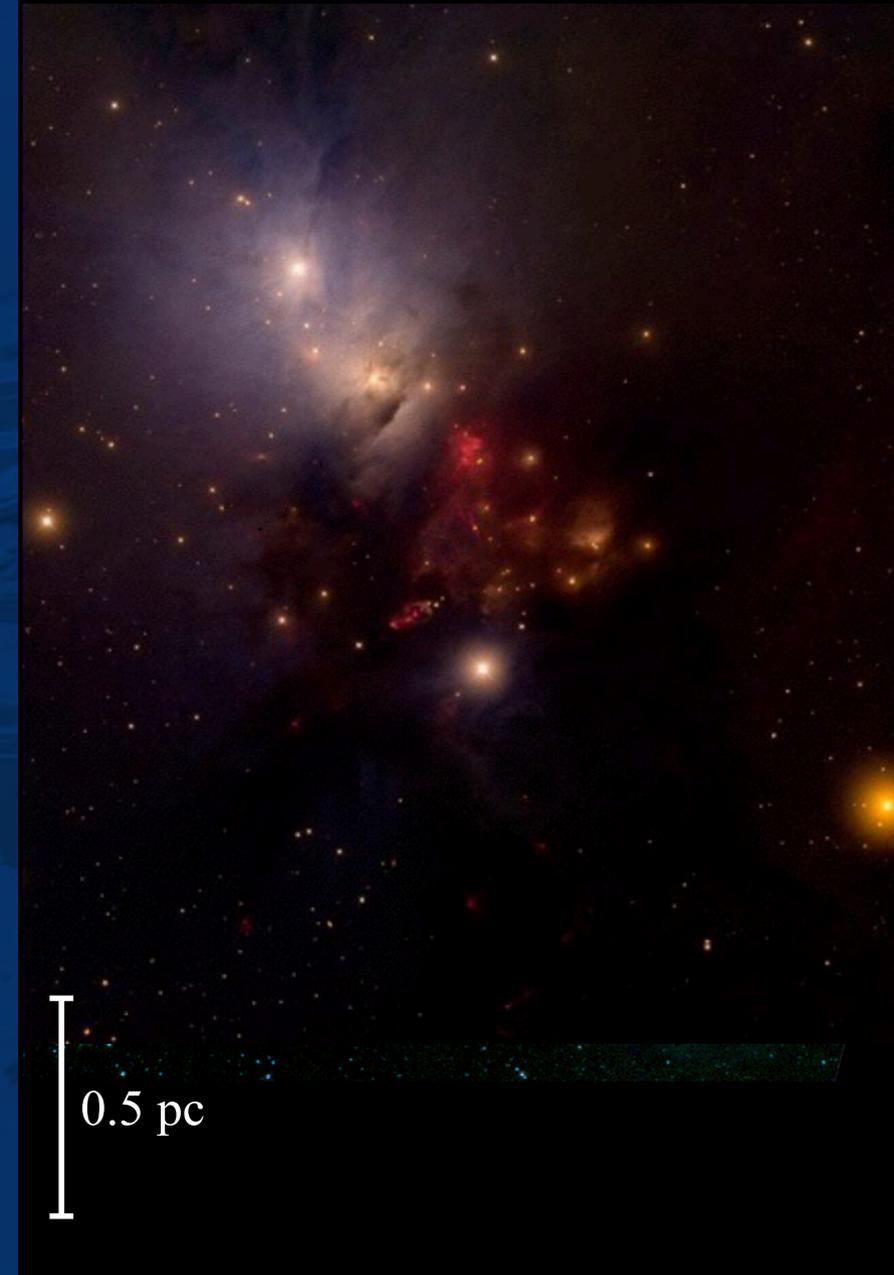
THE MILKY WAY AT DIFFERENT WAVELENGTHS

Radio wavelengths are tracing colder material and less energetic physical processes.

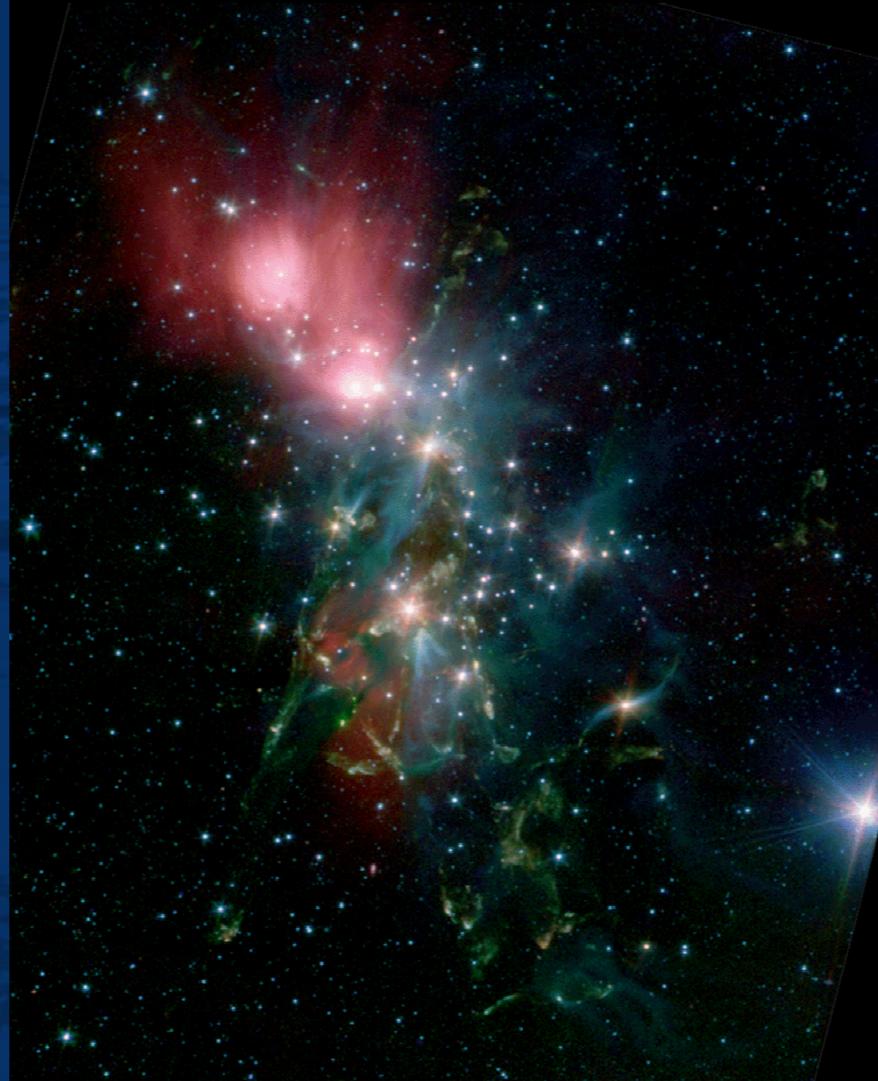


STAR FORMATION AT DIFFERENT WAVELENGTHS

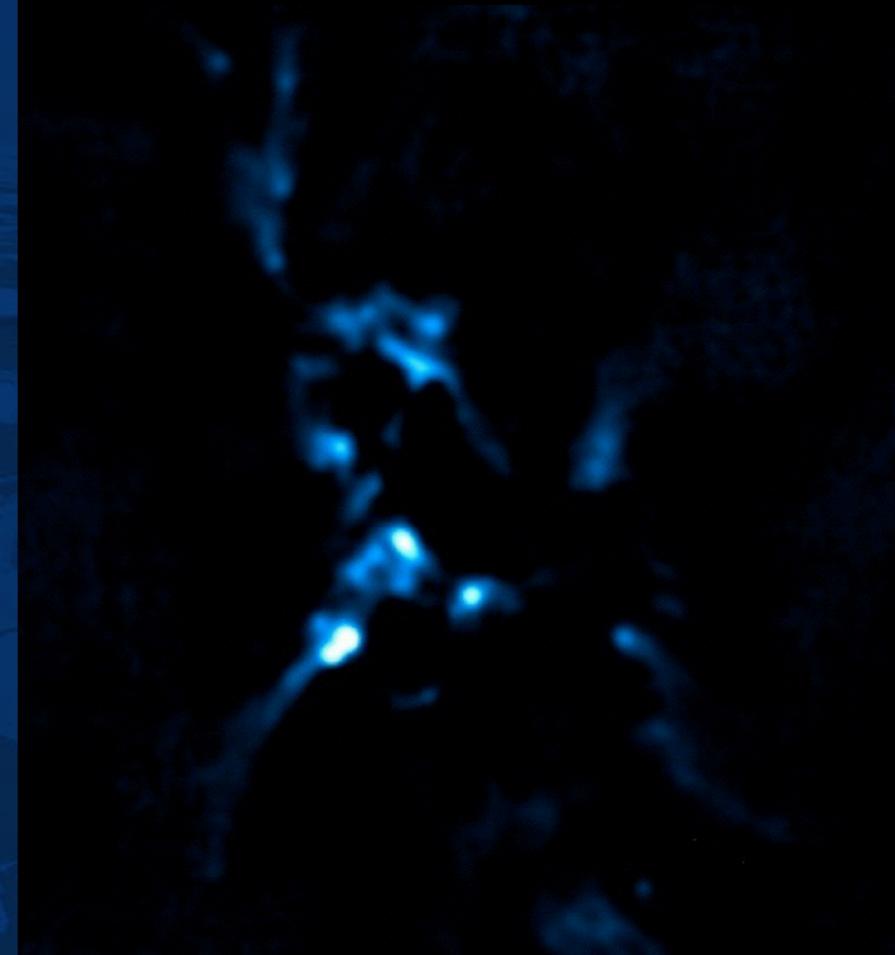
Optical



Infrared



Sub-mm (850 μm)



HISTORY

Radio Astronomy

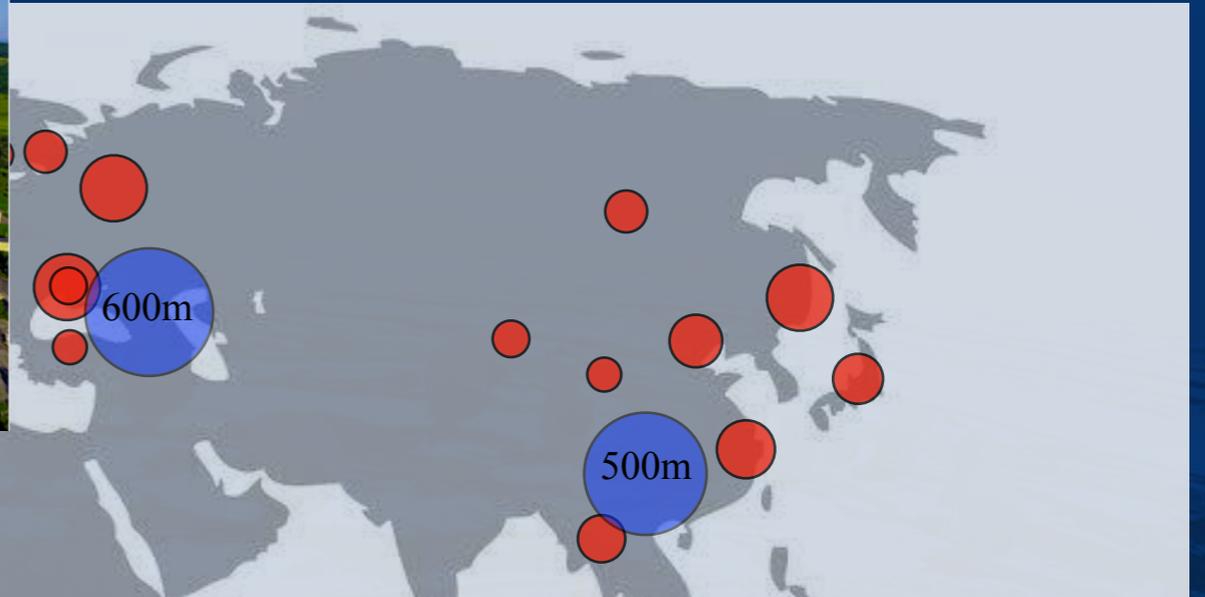
After 1937 - Several single-dish antennas of different diameters around the World



HISTORY

Radio Astronomy

RATAN-600



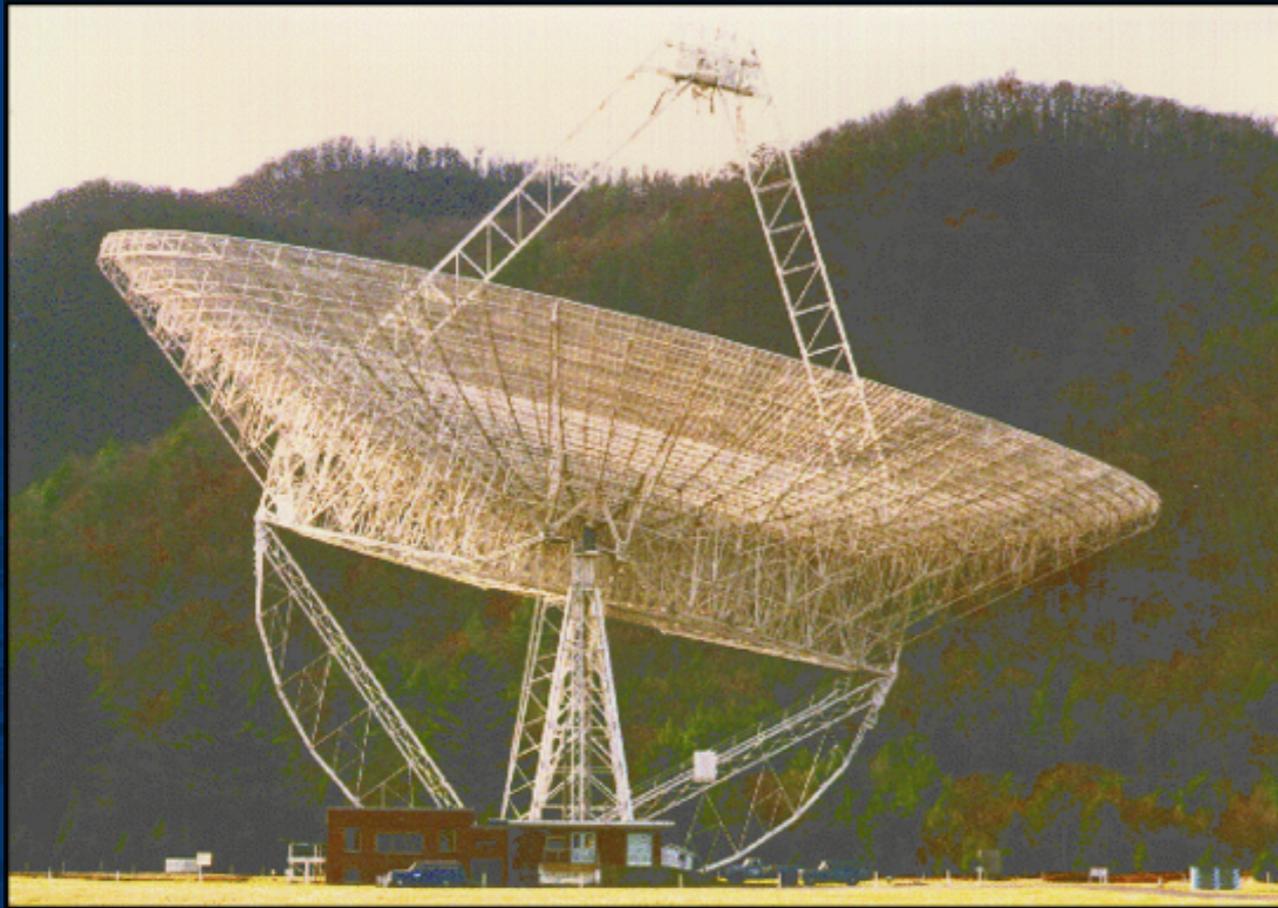
Arecibo



FAST



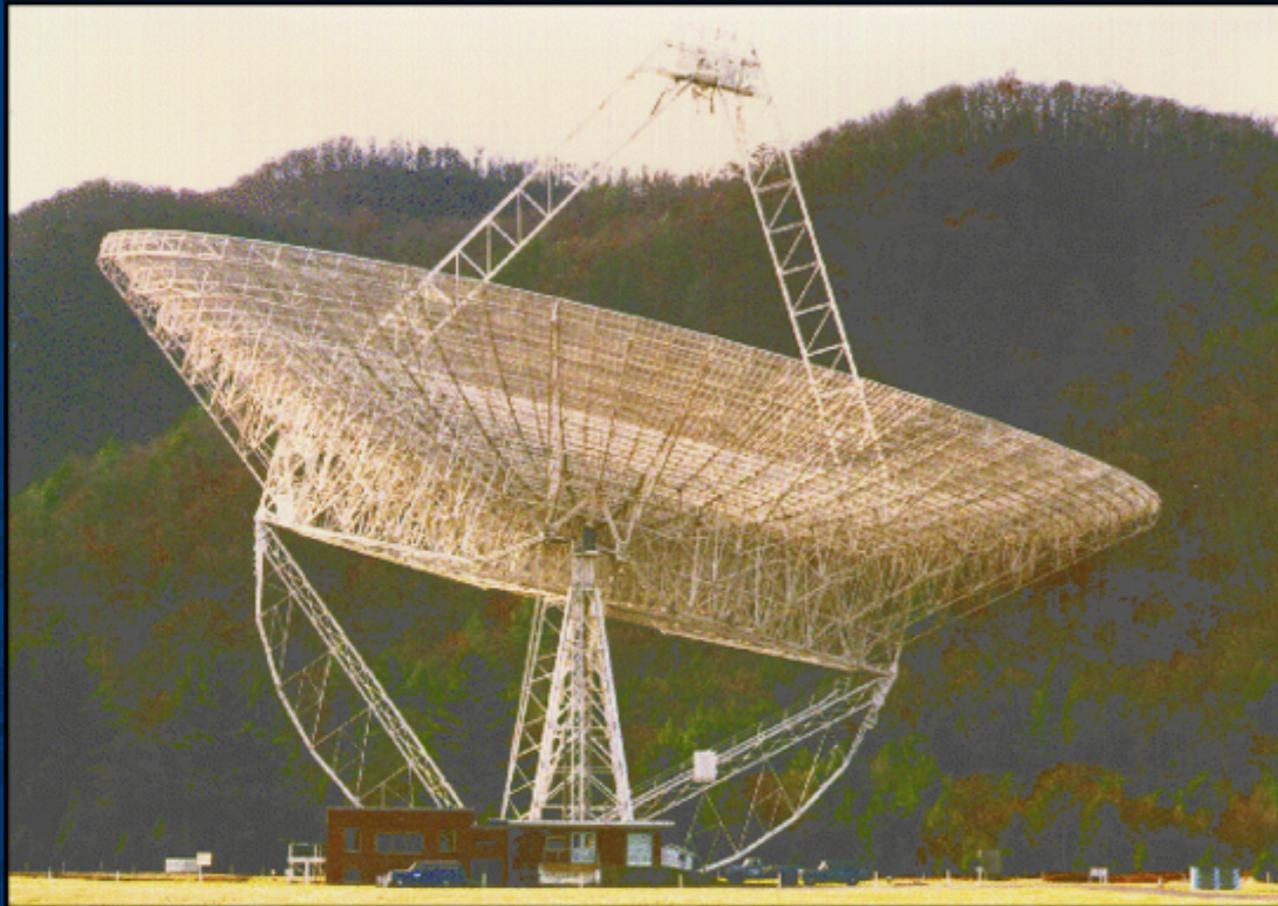
How big can an antenna be?



100 m - Green Bank
NRAO - USA

Angular resolution: $\theta \sim \lambda/D$

How big can an antenna be?



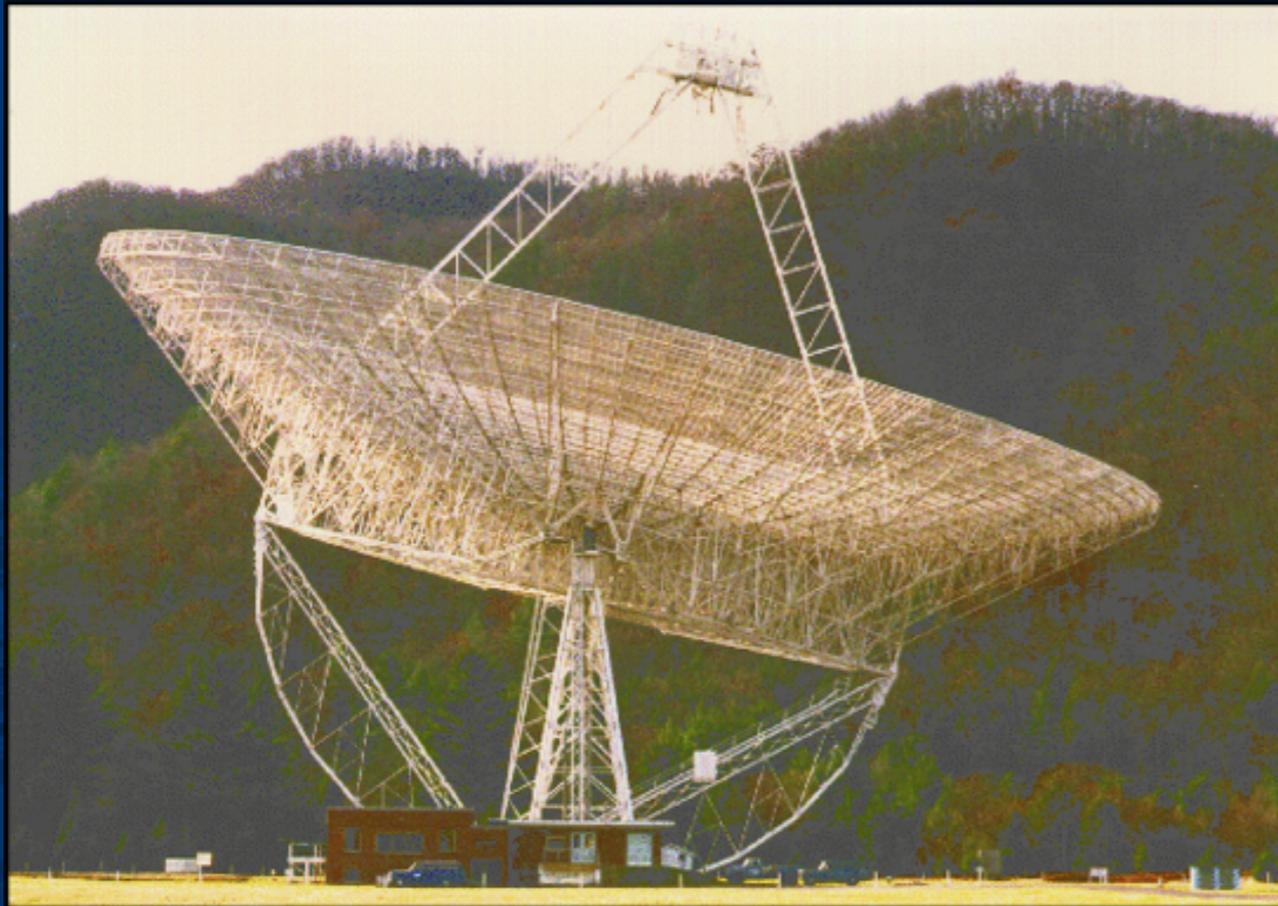
100 m - Green Bank
NRAO - USA

Angular resolution: $\theta \sim \lambda/D$



Gravity...

How big can an antenna be?



100 m - Green Bank
NRAO - USA

Angular resolution: $\theta \sim \lambda/D$



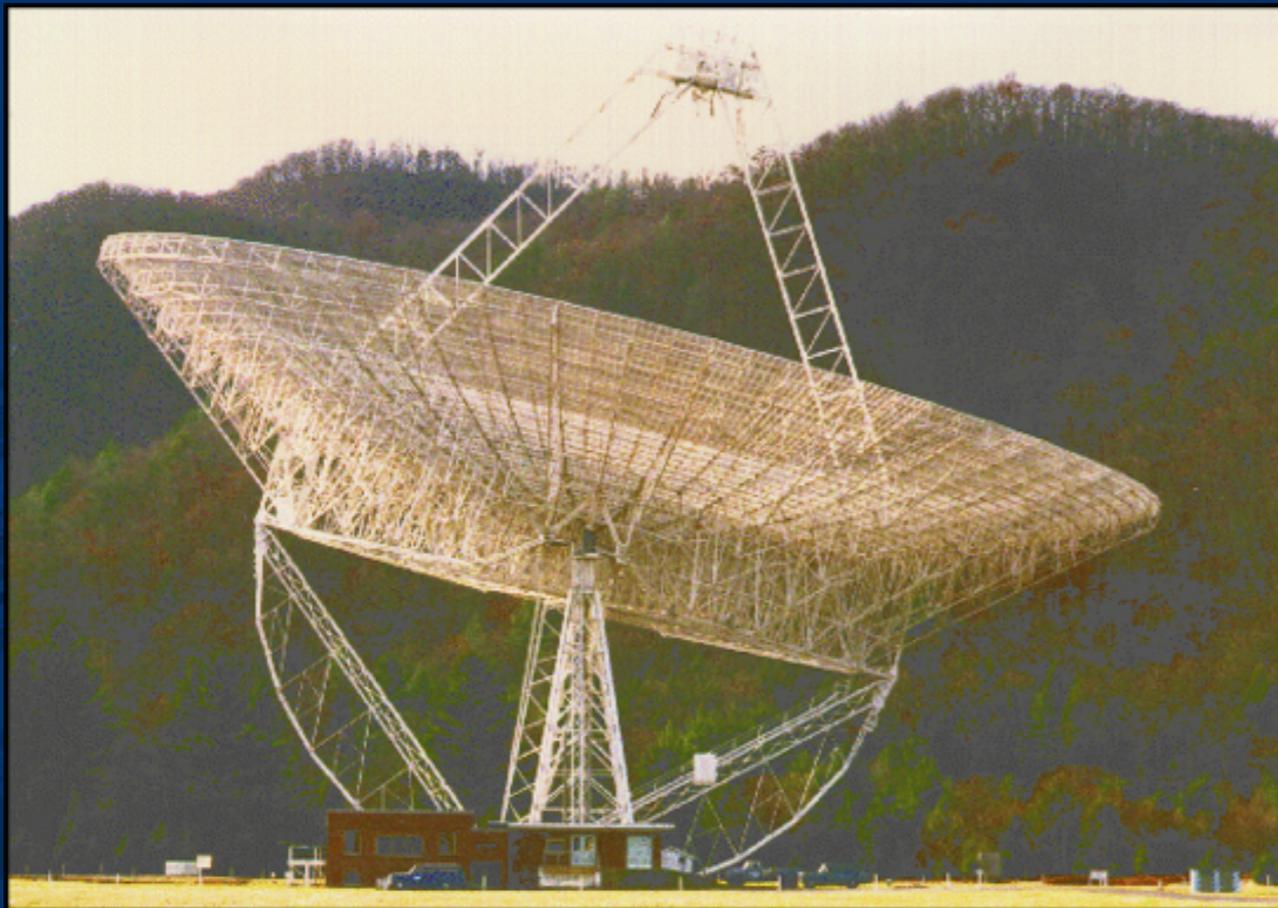
Gravity...

We have physical and mechanical limitations

How do we solve this issue?

Interferometry

Angular resolution: $\theta \sim \lambda/D$



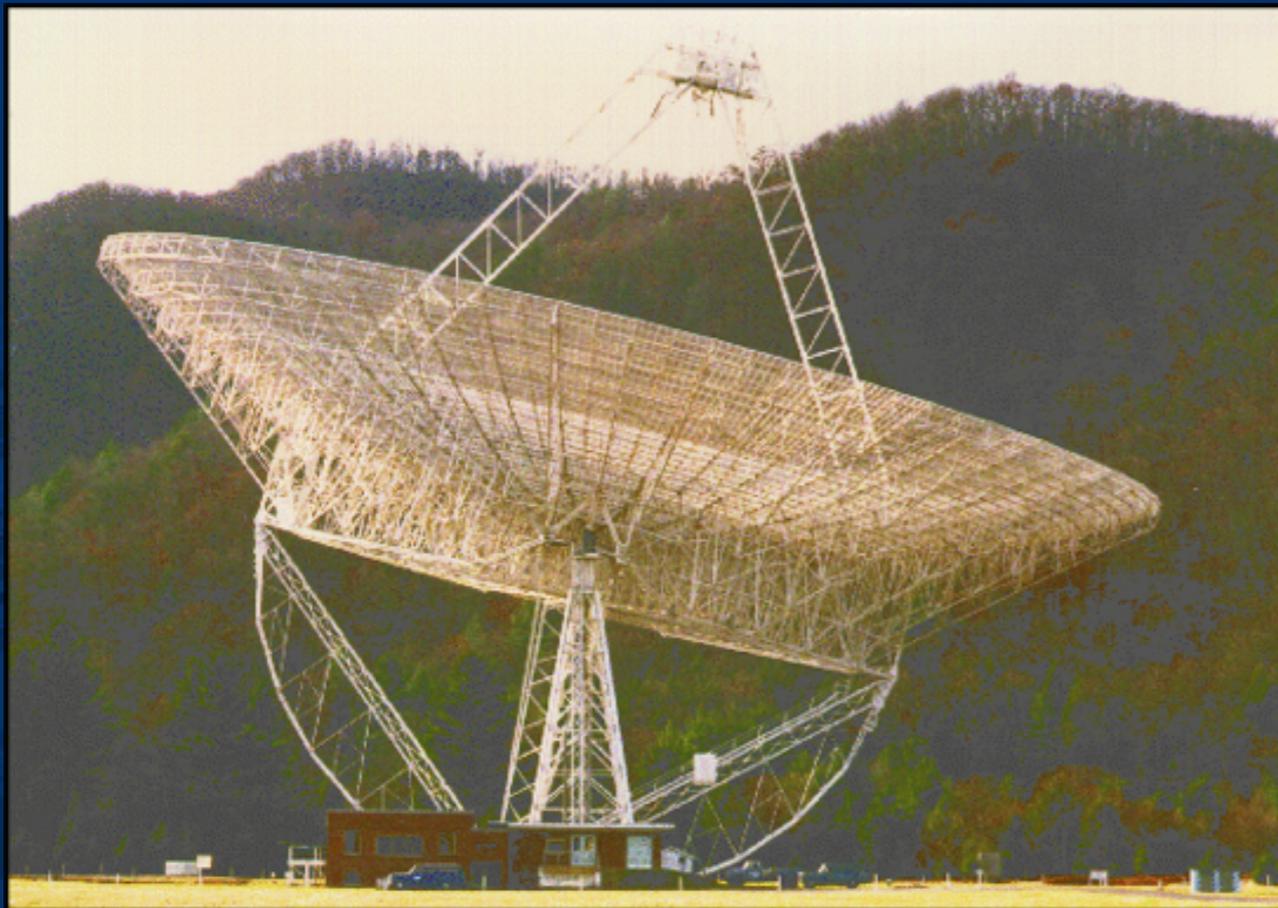
$D = 100 \text{ m}$



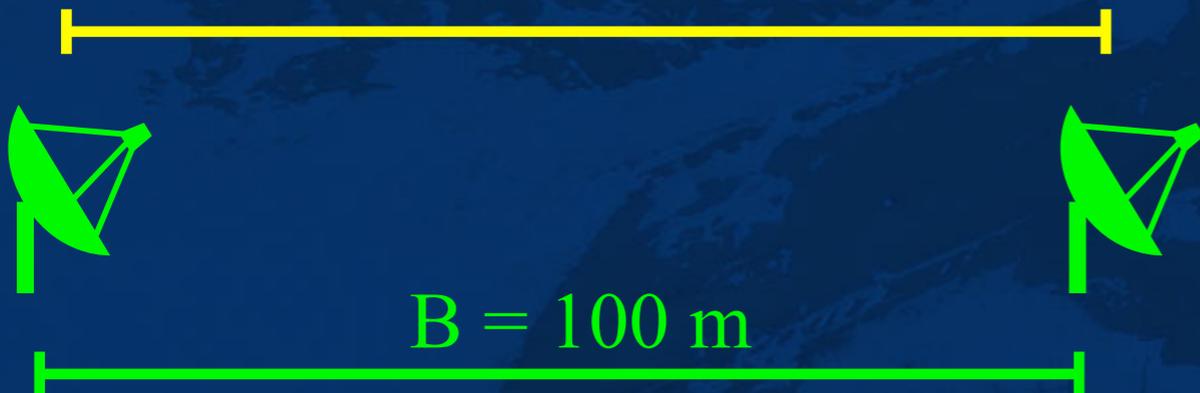
How do we solve this issue?

Interferometry

Angular resolution: $\theta \sim \lambda/D$



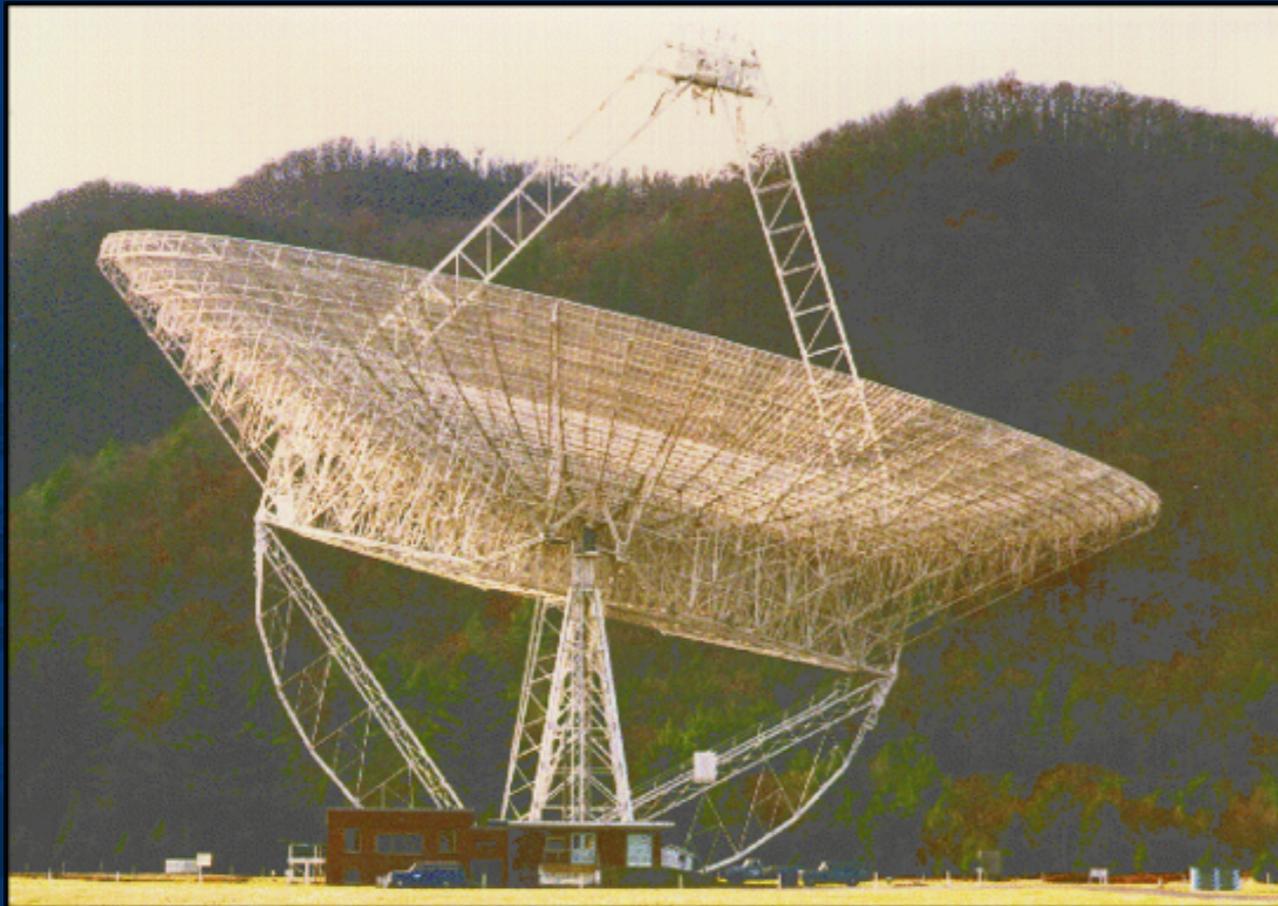
$D = 100 \text{ m}$



$B = 100 \text{ m}$

How do we solve this issue?

Interferometry



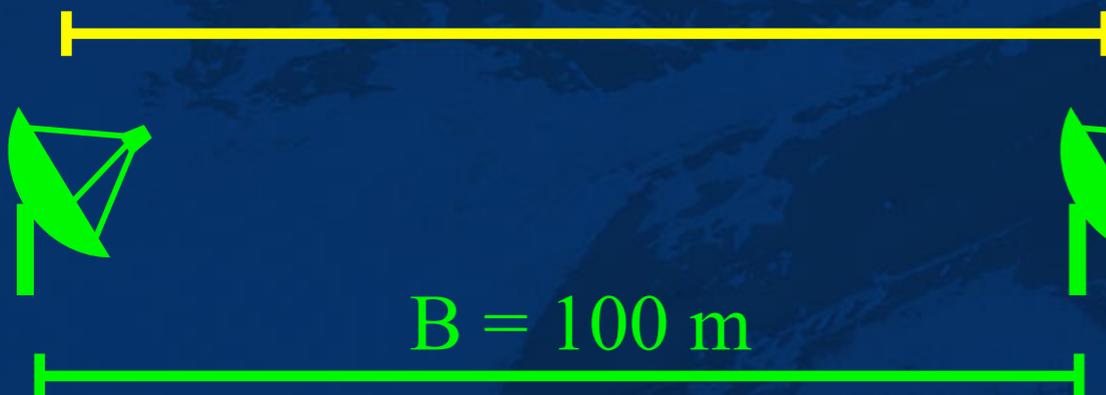
Angular resolution: $\theta \sim \lambda/D$



Angular resolution: $\theta \sim \lambda/B$

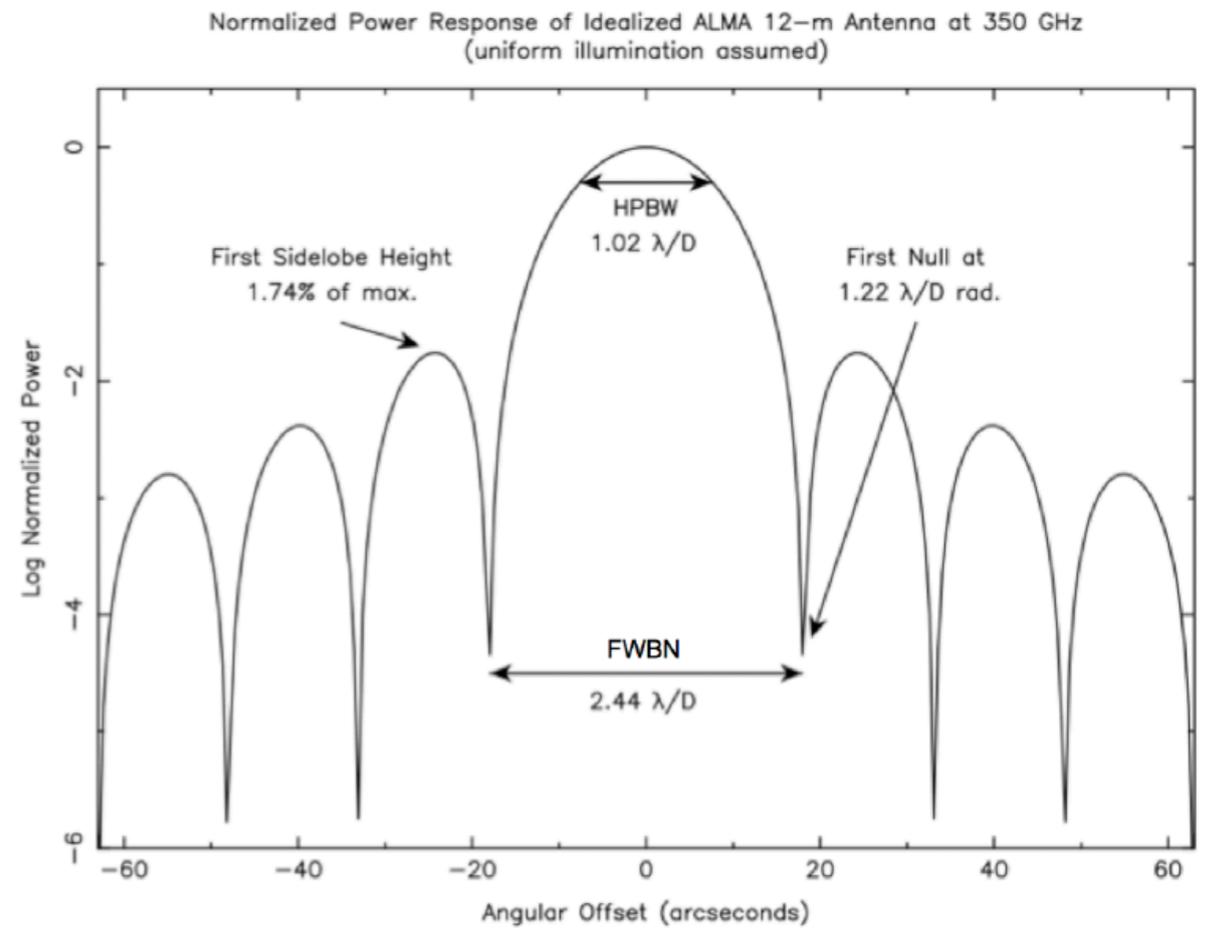
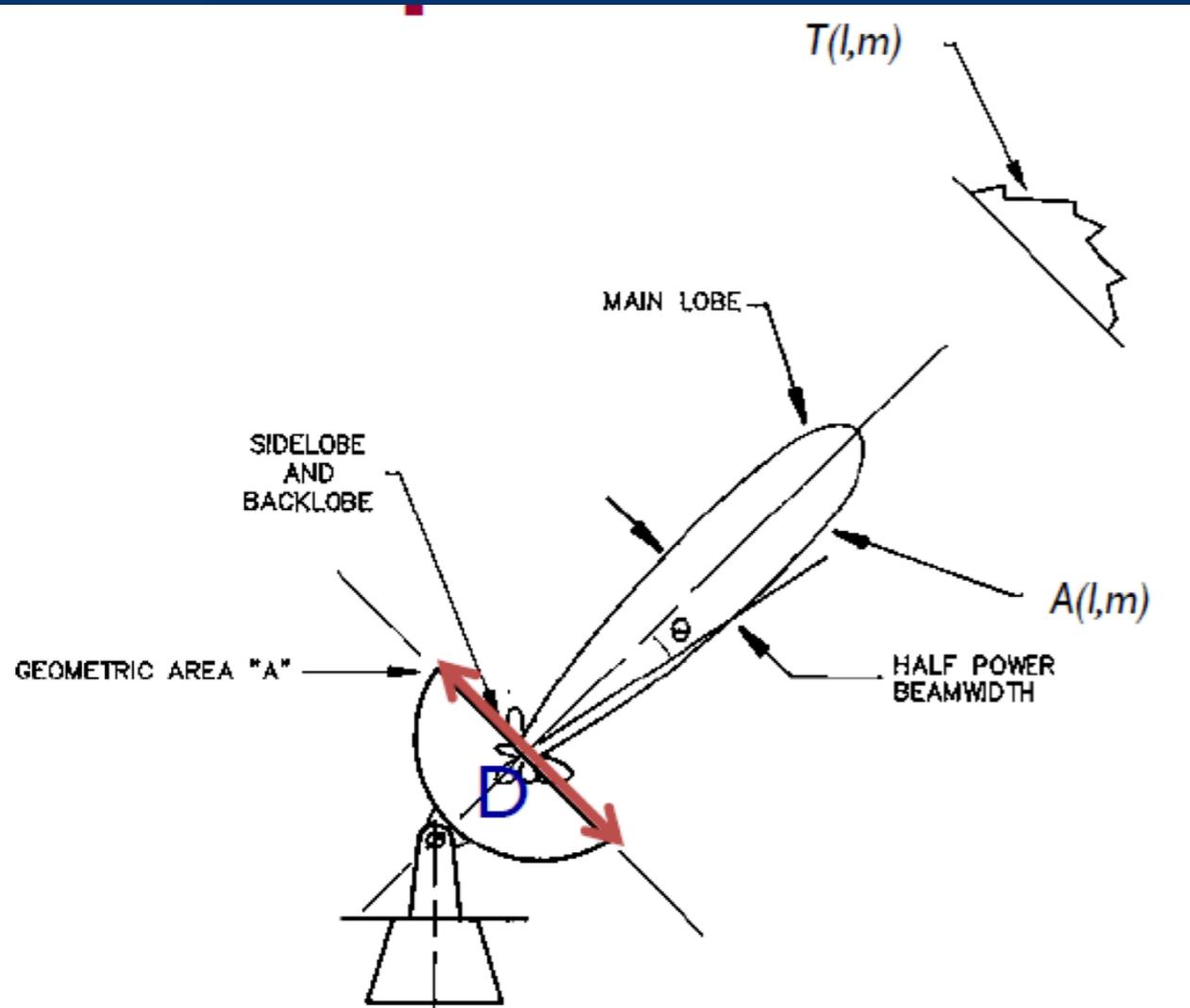
BASELINE

$D = 100 \text{ m}$



$B = 100 \text{ m}$

THE PHYSICS BEHIND AN ANTENNA



SINGLE DISH VS. ARRAY

Single dish



$D = 30 \text{ m}$

Array



$B_{\text{max}} = 16 \text{ km}$



SINGLE DISH VS. ARRAY

Single dish

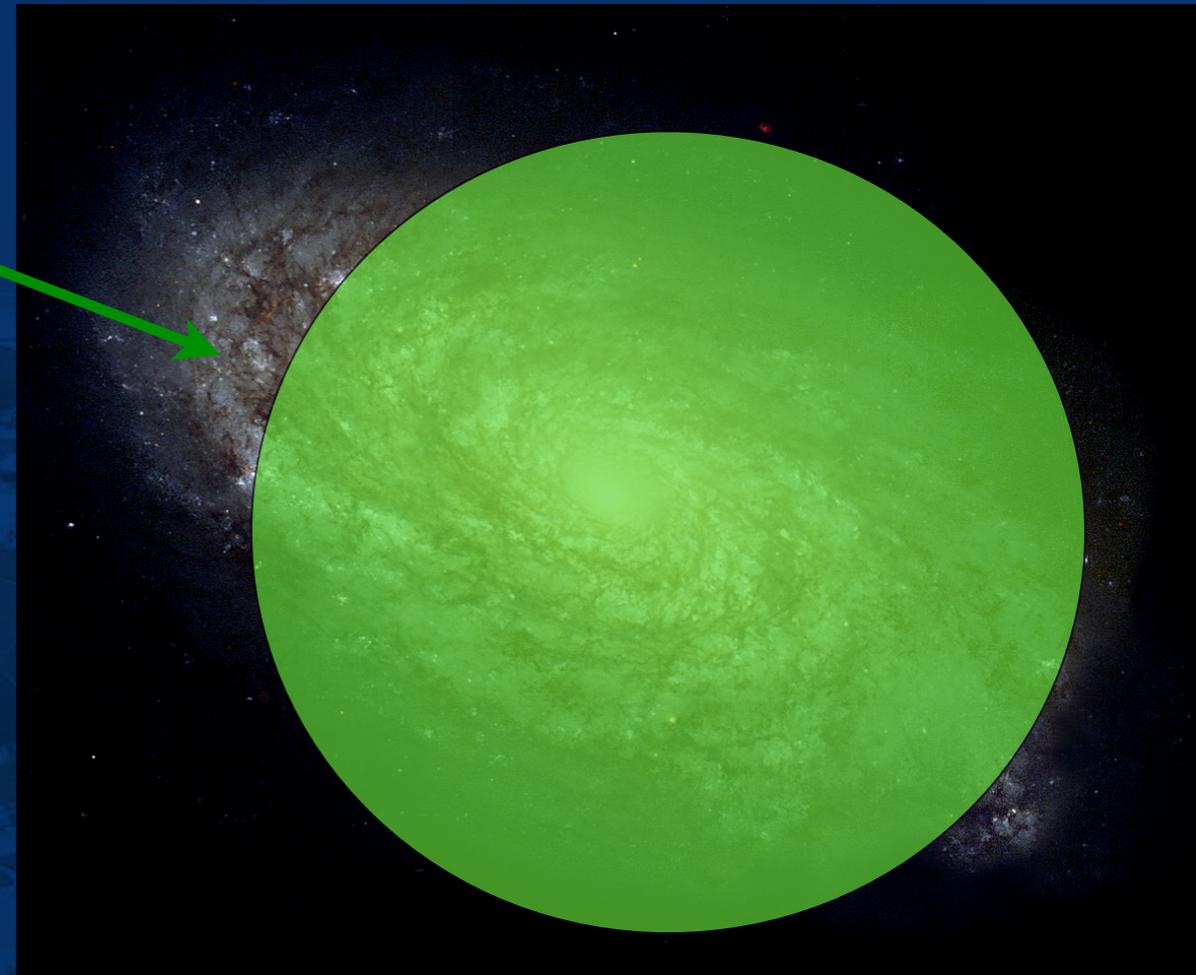


$D = 30 \text{ m}$

Array



$B_{\text{max}} = 16 \text{ km}$



Angular Resolution: $\theta \sim \lambda/D$

SINGLE DISH VS. ARRAY

Single dish

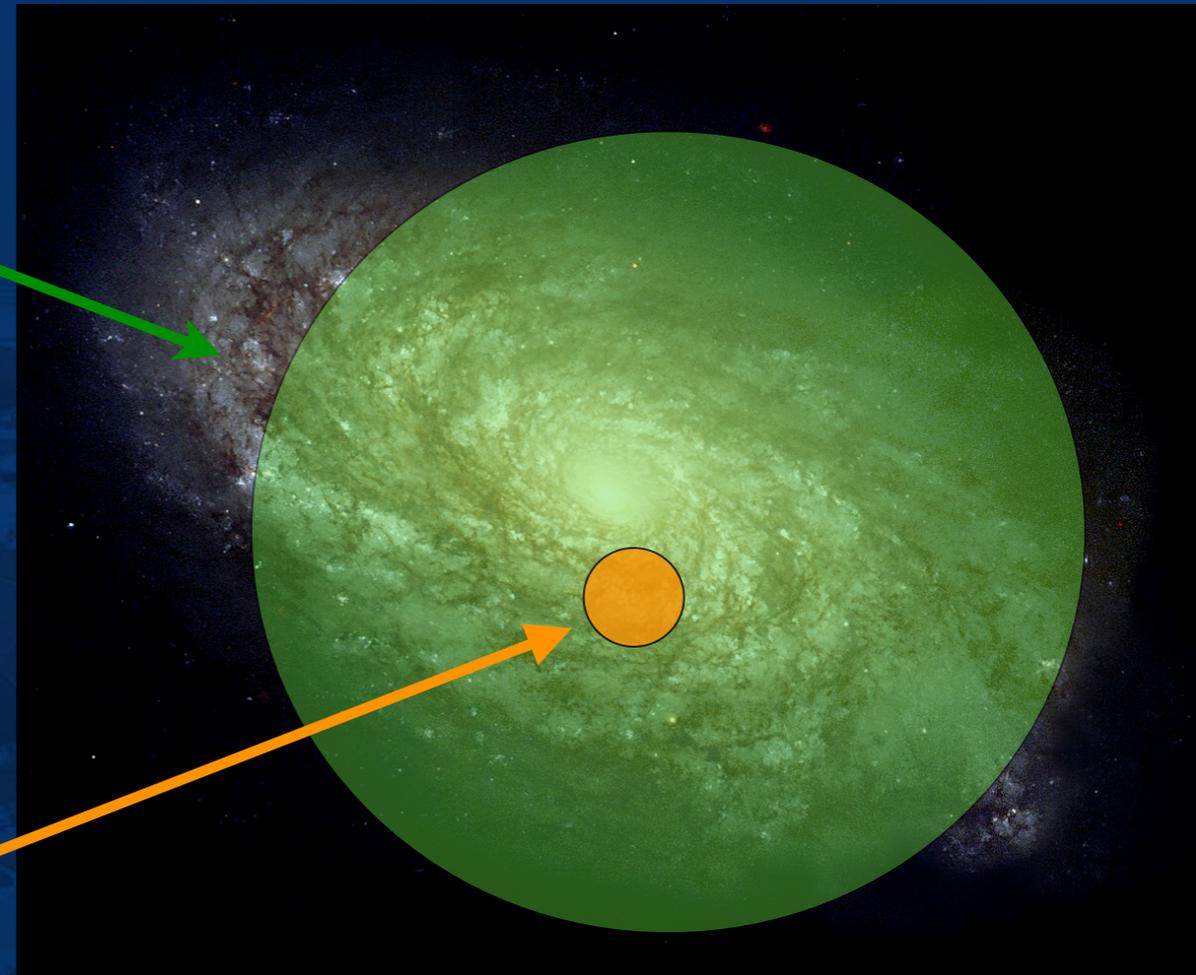


$D = 30 \text{ m}$

Array



$B_{\text{max}} = 16 \text{ km}$

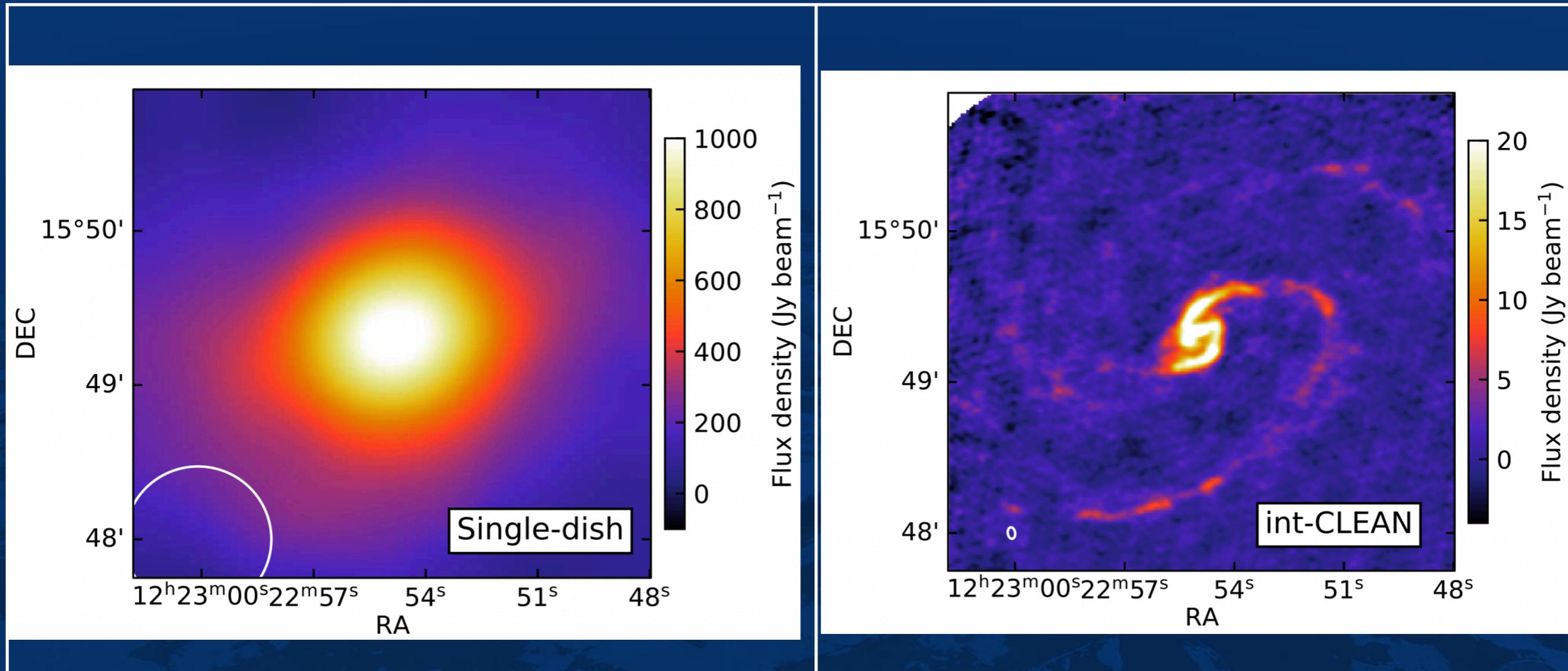


Angular Resolution: $\theta \sim \lambda/D$

Angular Resolution: $\theta \sim \lambda/B$

SINGLE DISH VS. ARRAY

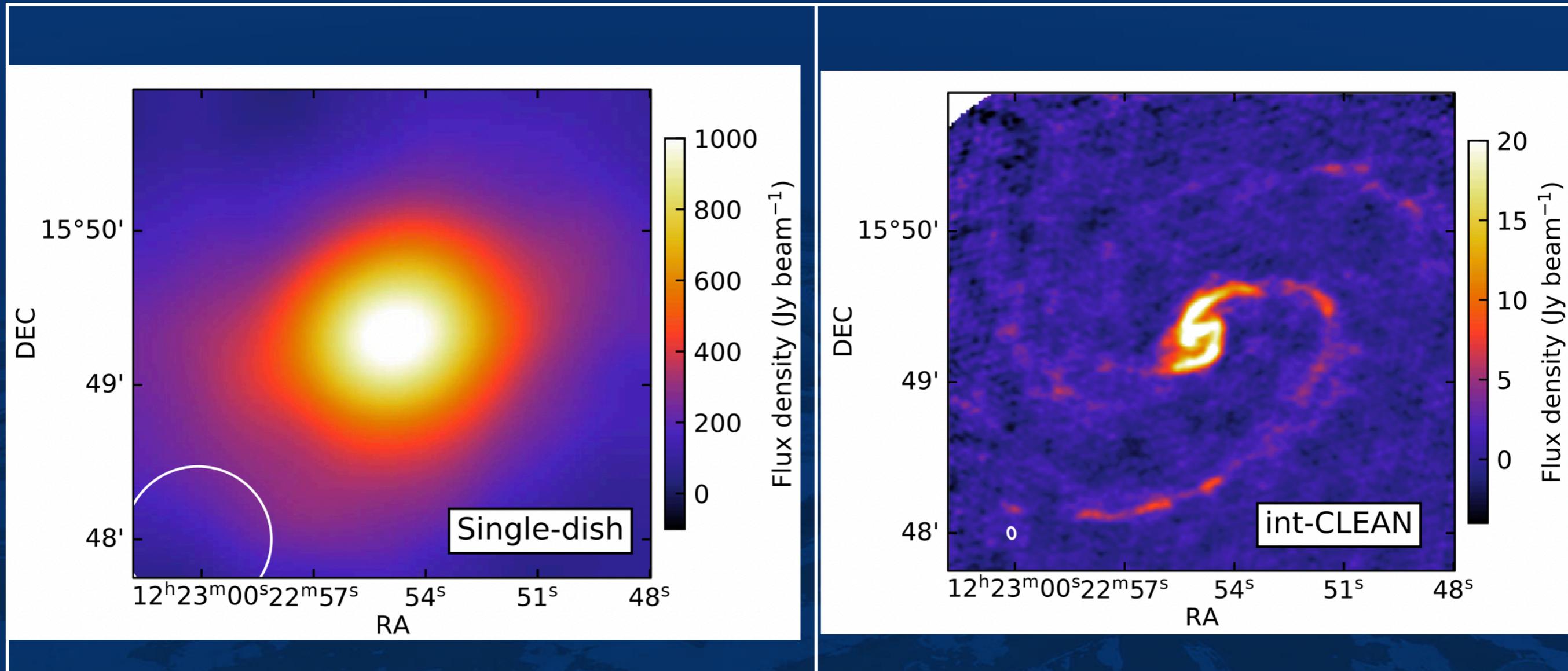
Galaxy M100



Plunkett et al. (2023)

SINGLE DISH VS. ARRAY

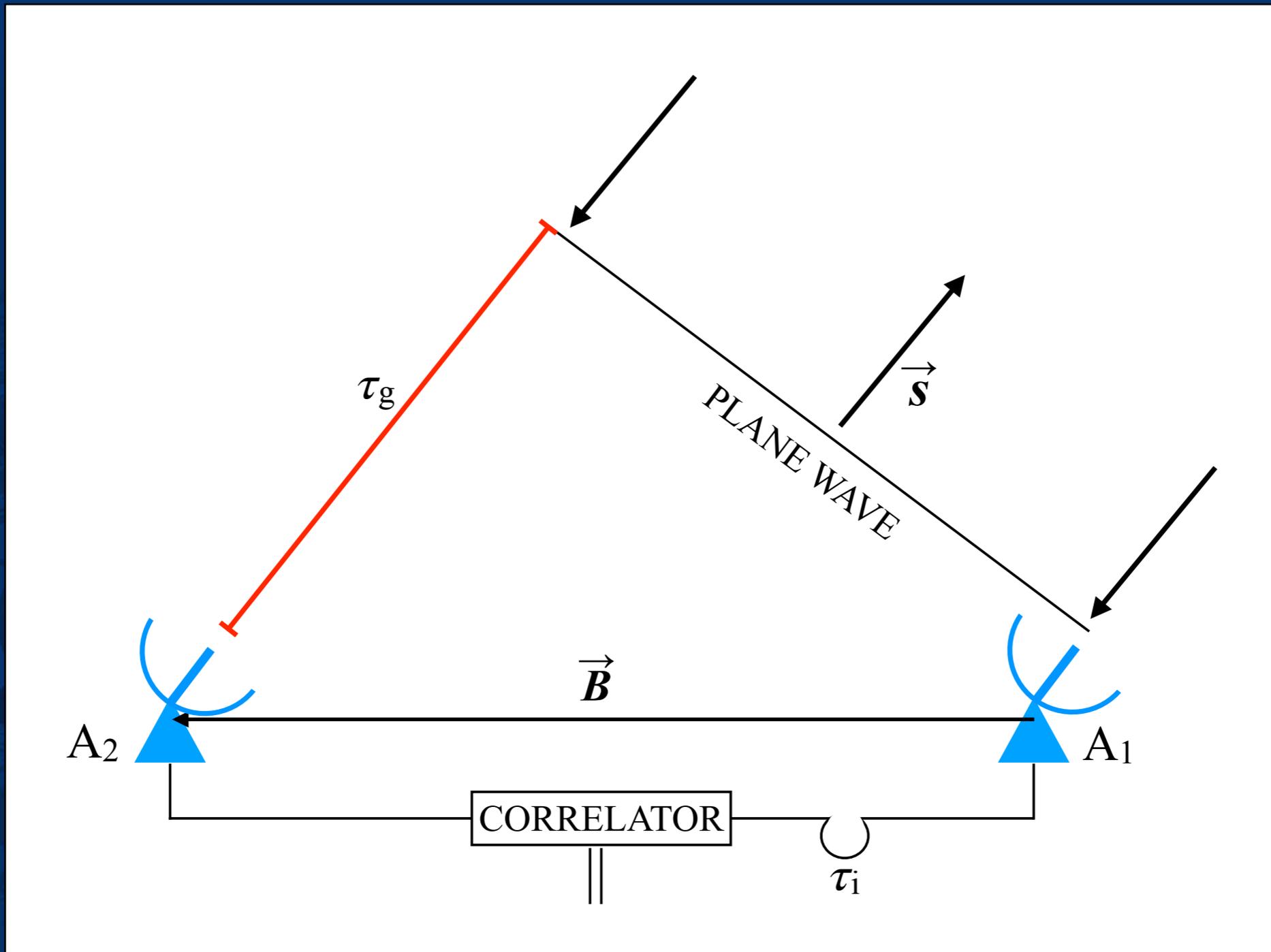
Galaxy M100



Plunkett et al. (2023)

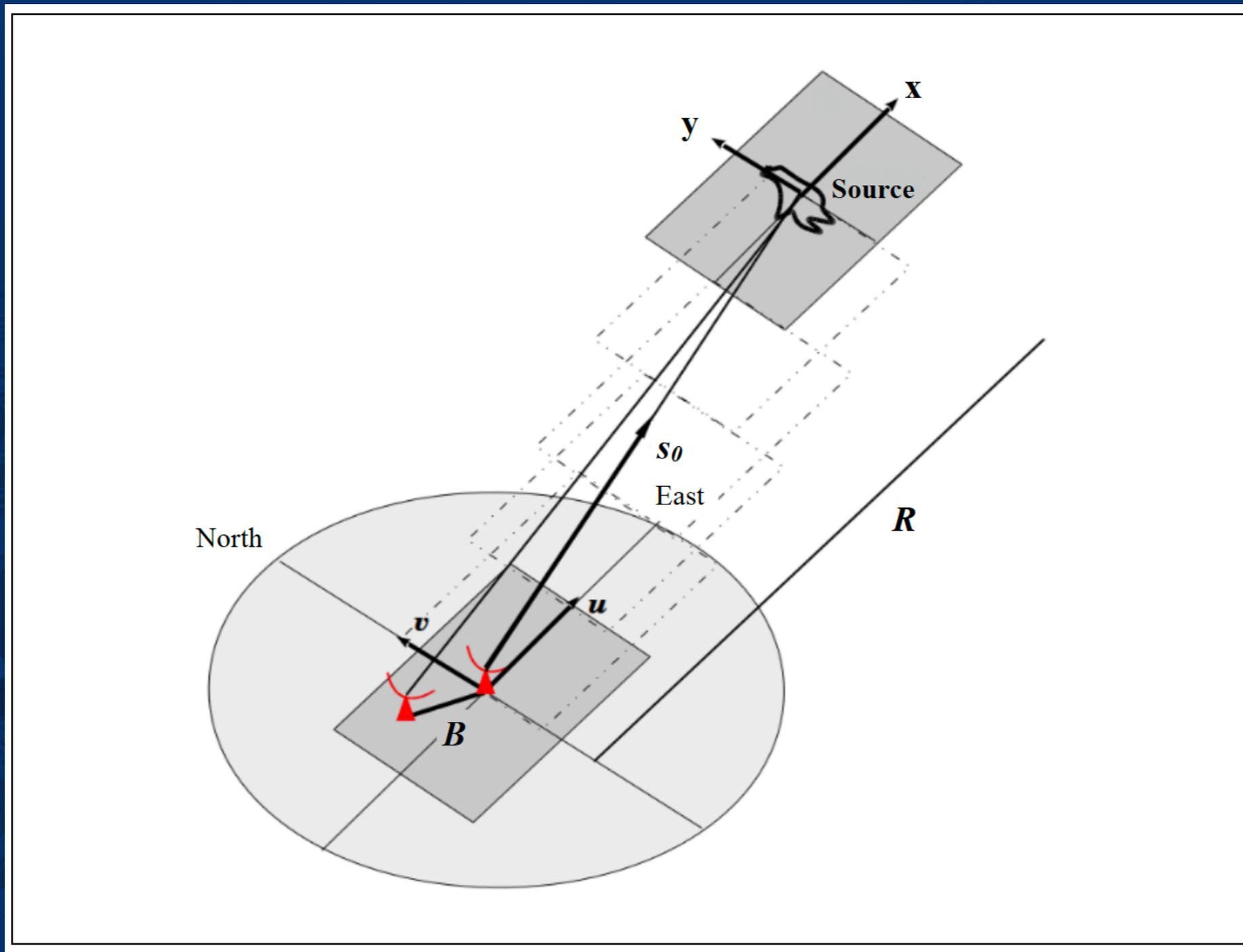
The best is to combine both techniques:
Single dish + Interferometry

INTERFEROMETRY



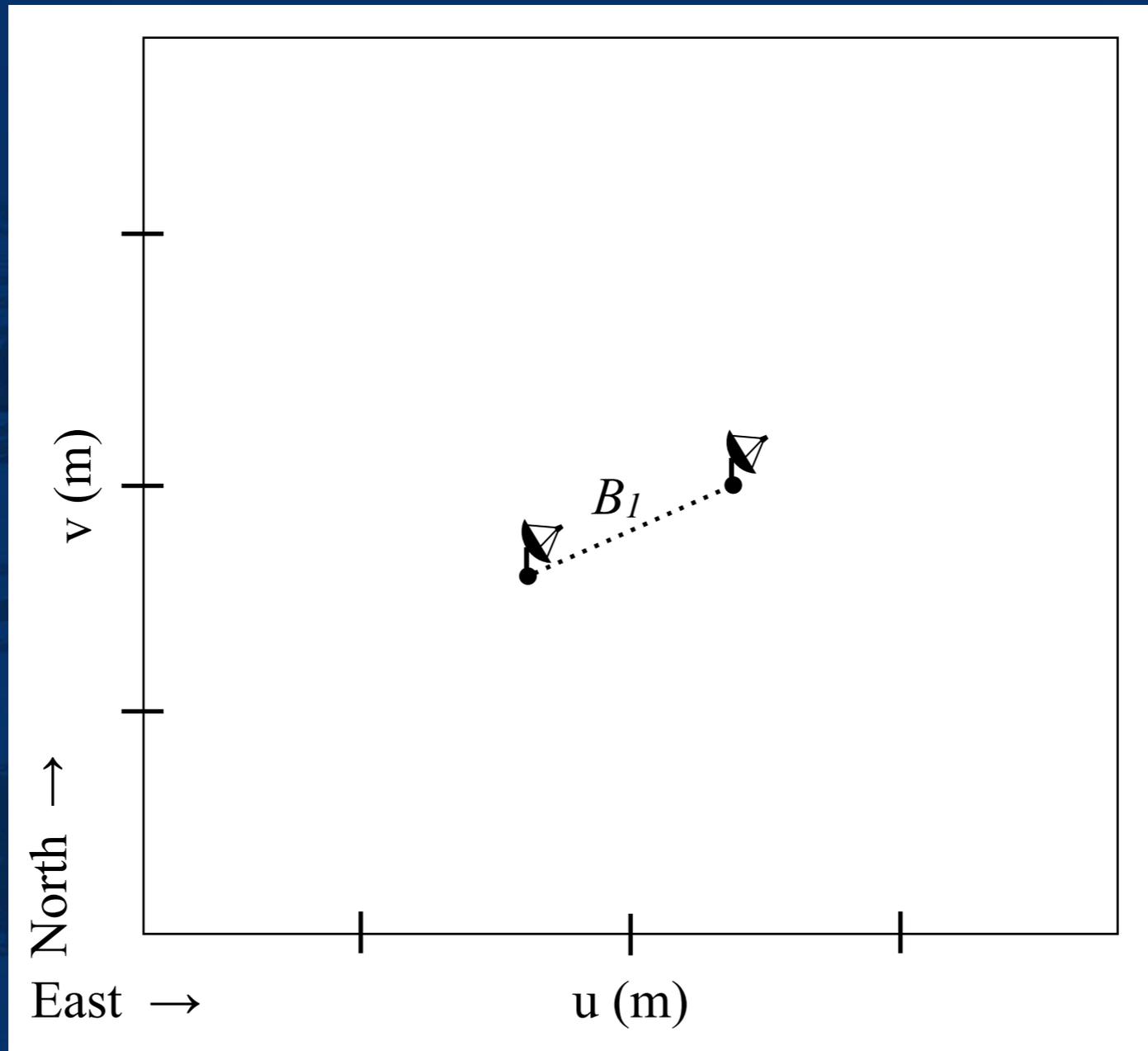
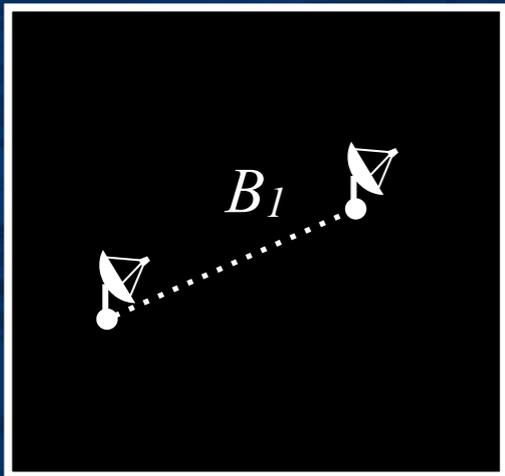
$$\tau_g = \frac{\vec{B} \cdot \vec{s}}{c}$$

INTERFEROMETRY



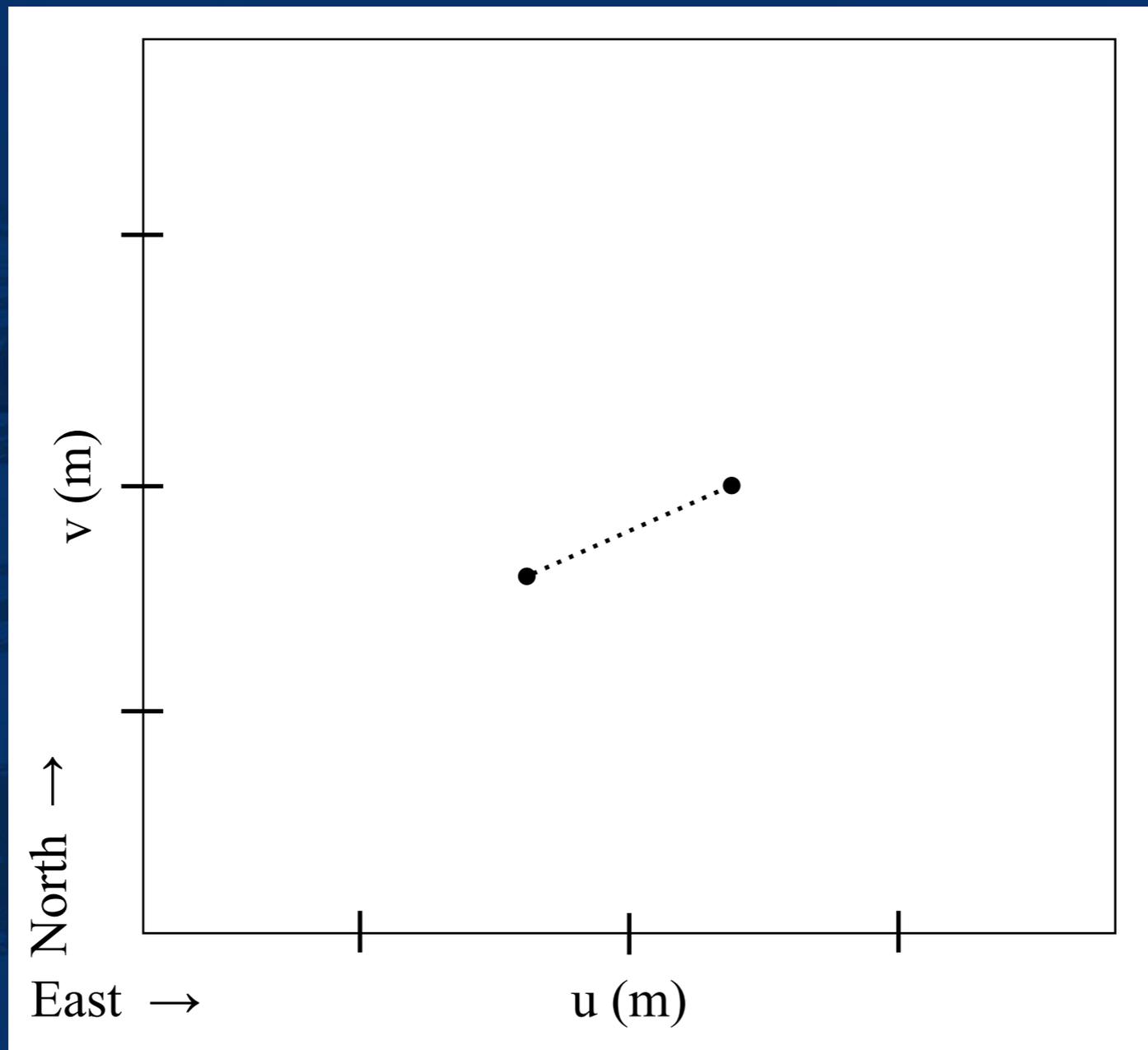
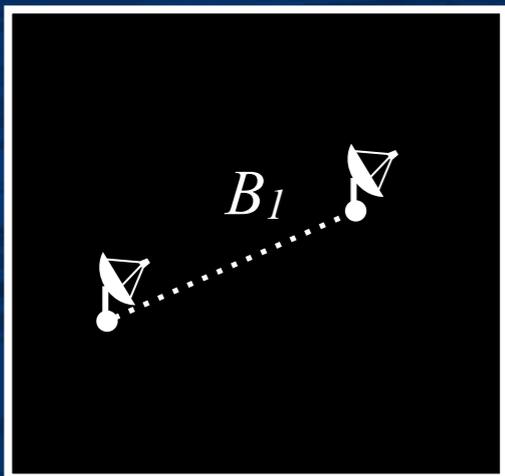
INTERFEROMETRY

The (u,v) plane



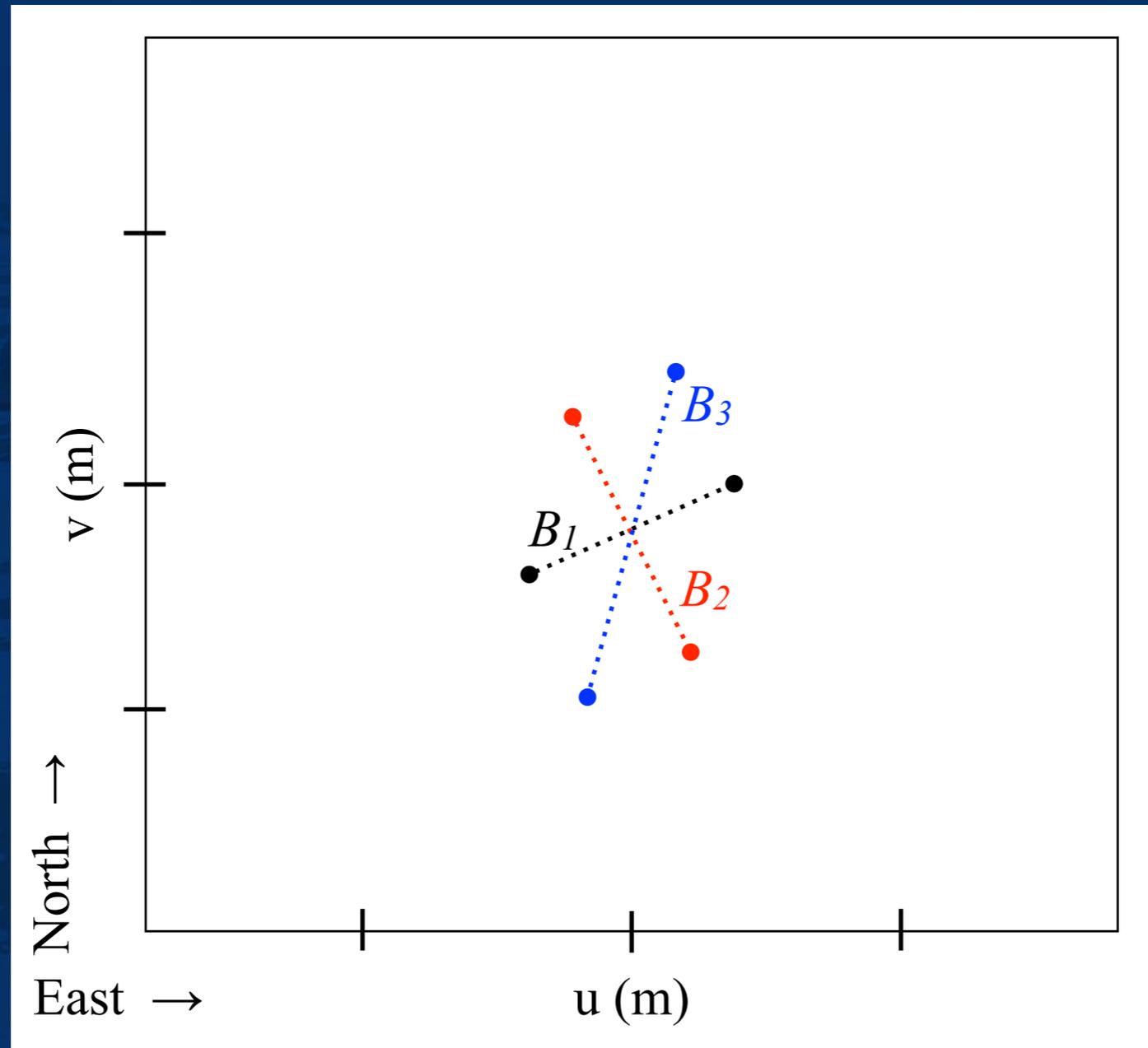
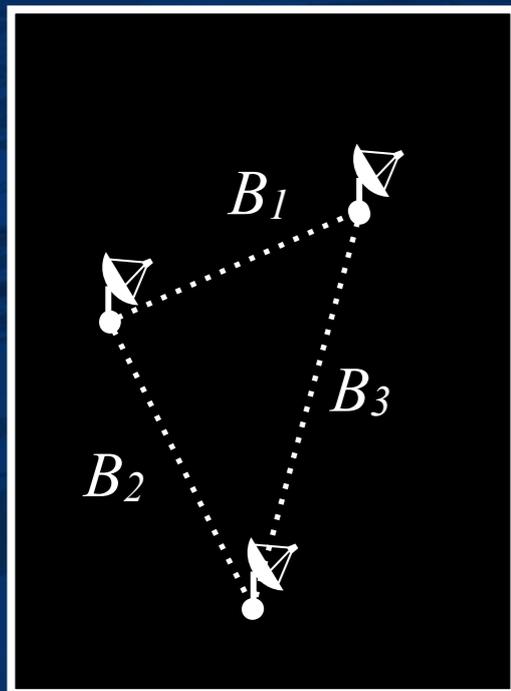
INTERFEROMETRY

The (u,v) plane



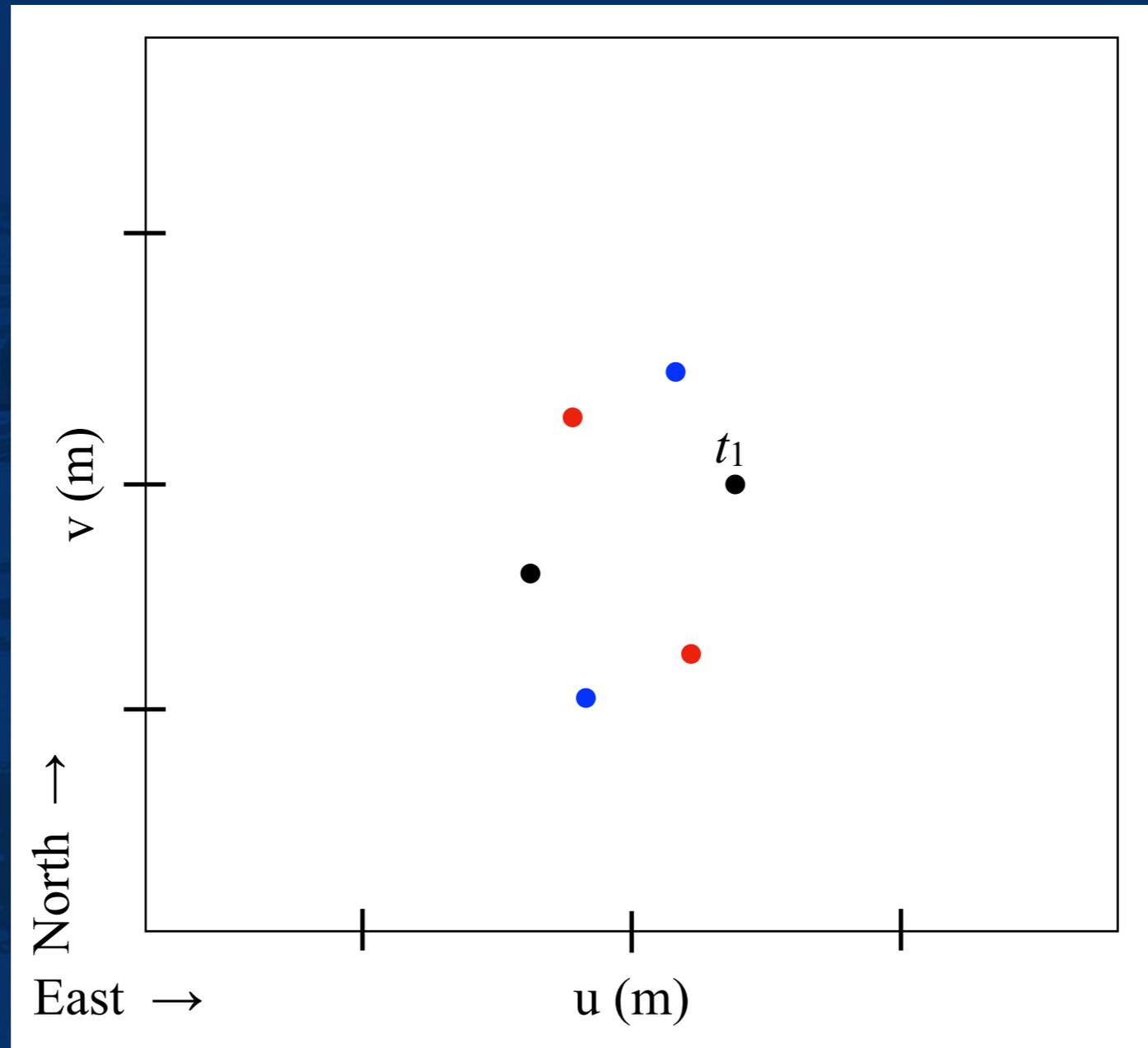
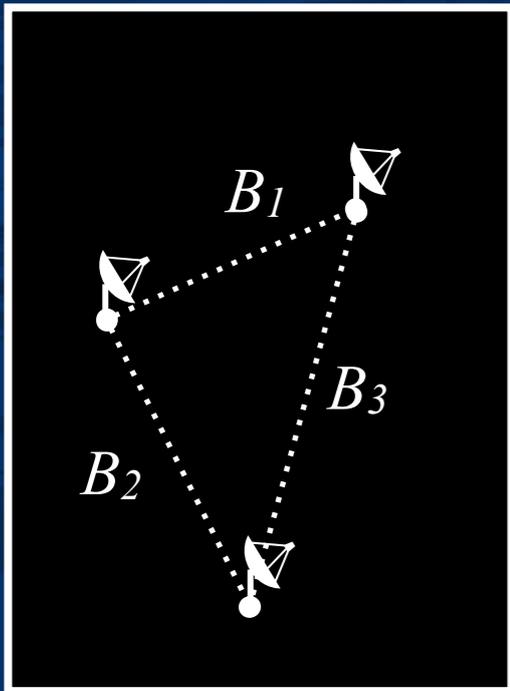
INTERFEROMETRY

The (u,v) plane



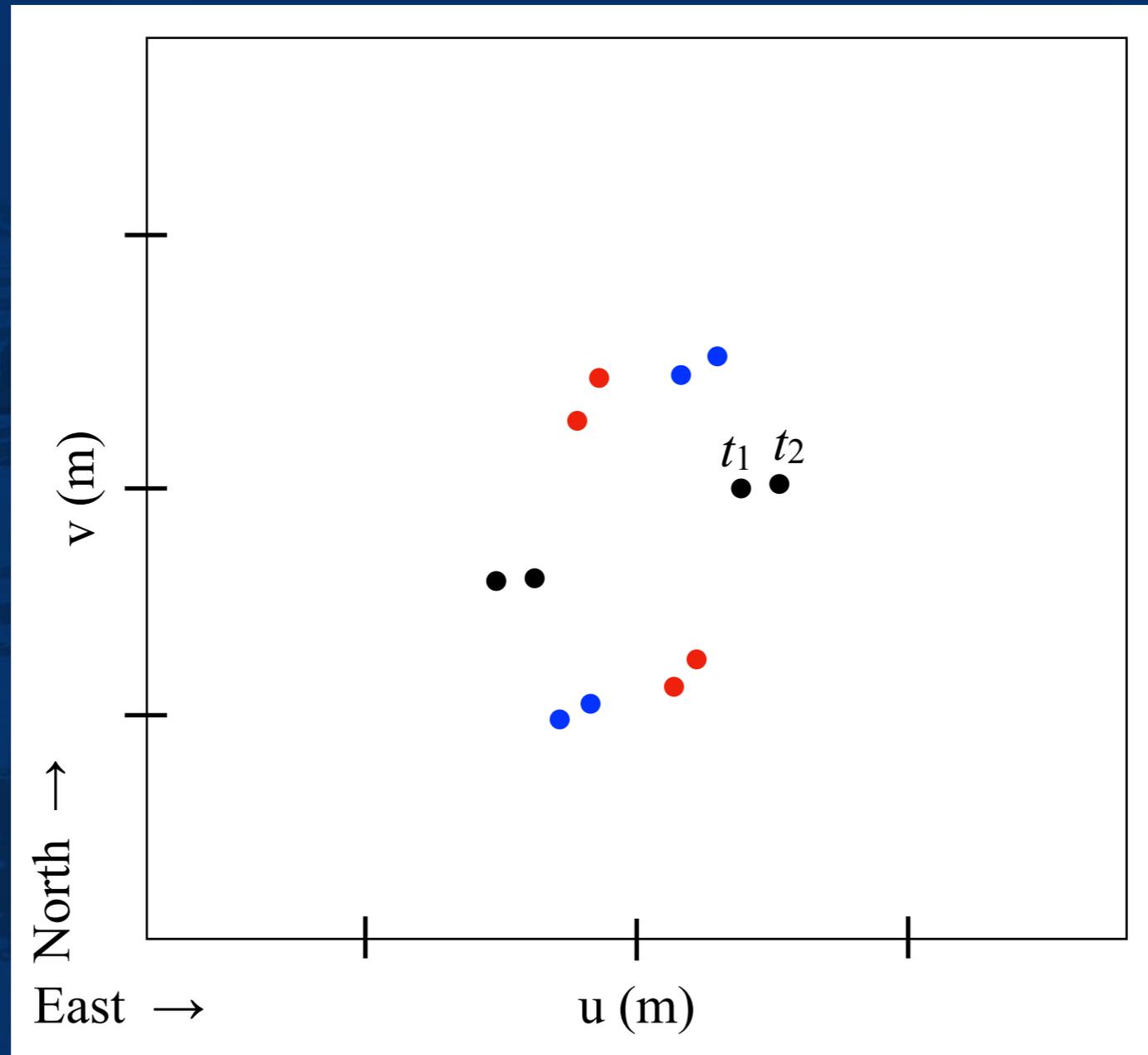
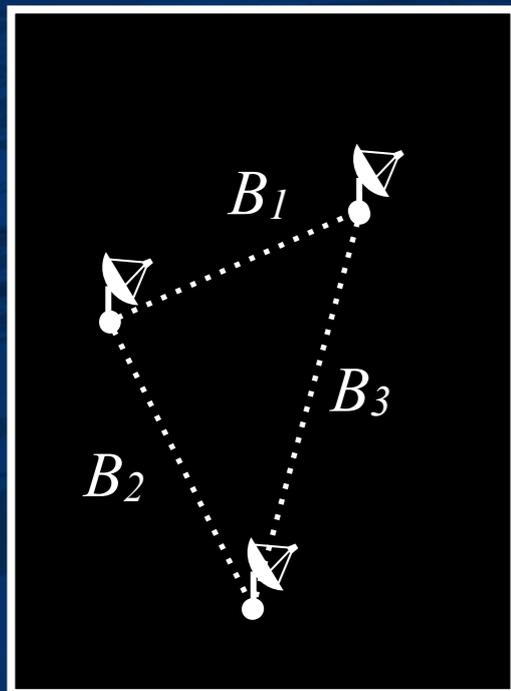
INTERFEROMETRY

The (u,v) plane



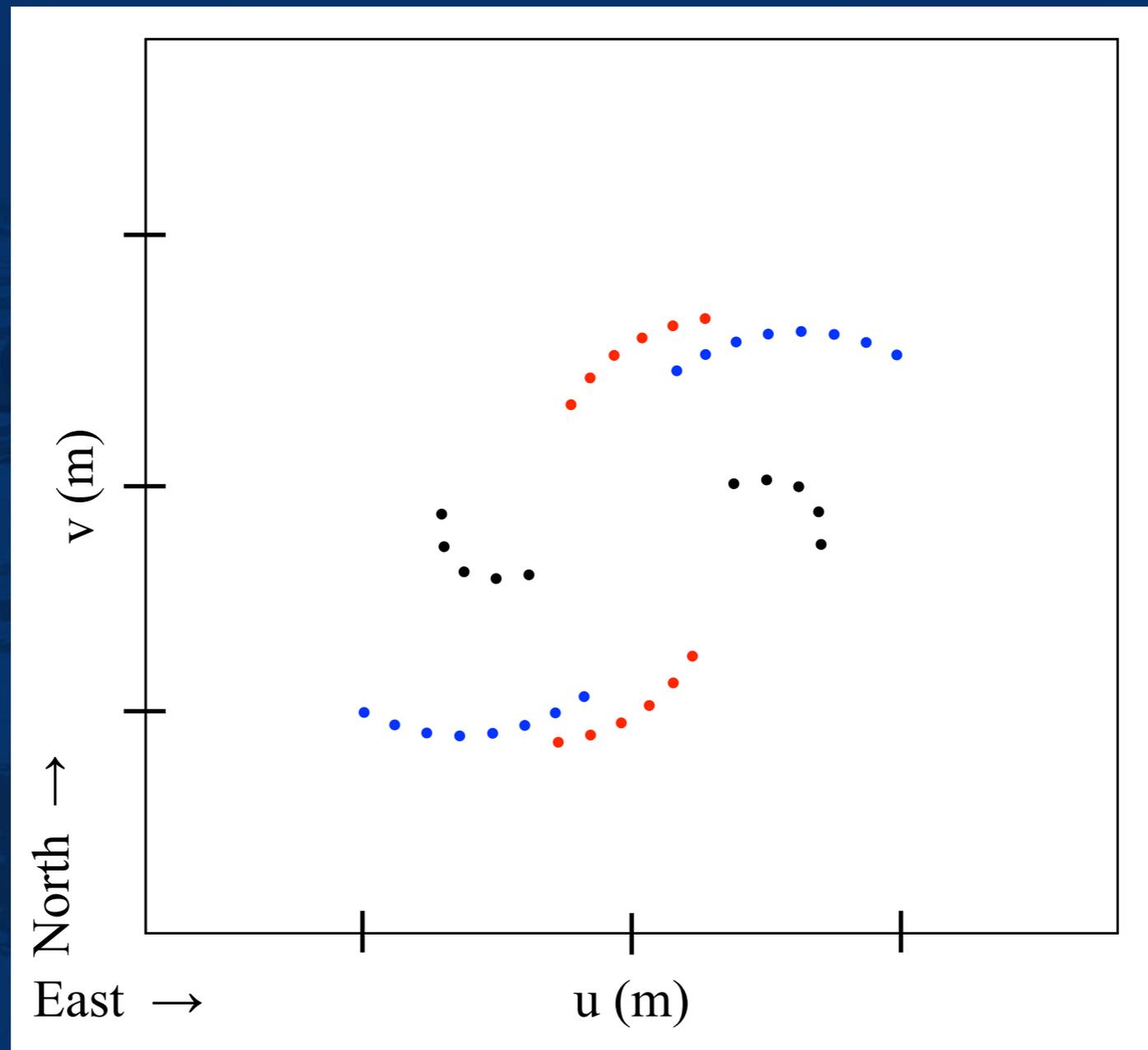
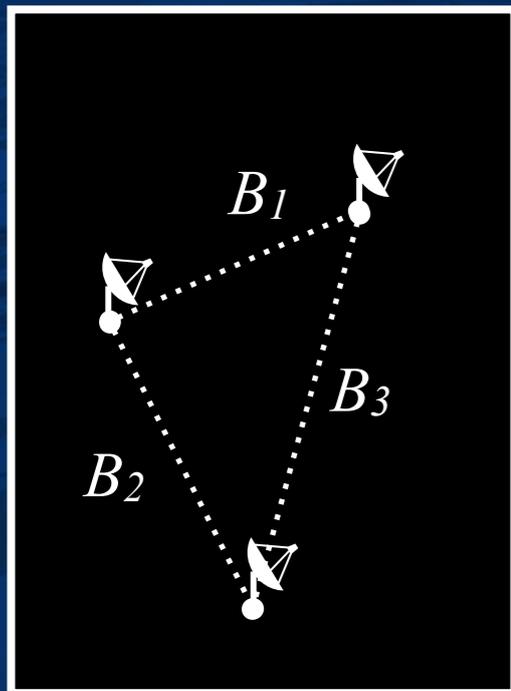
INTERFEROMETRY

The (u,v) plane



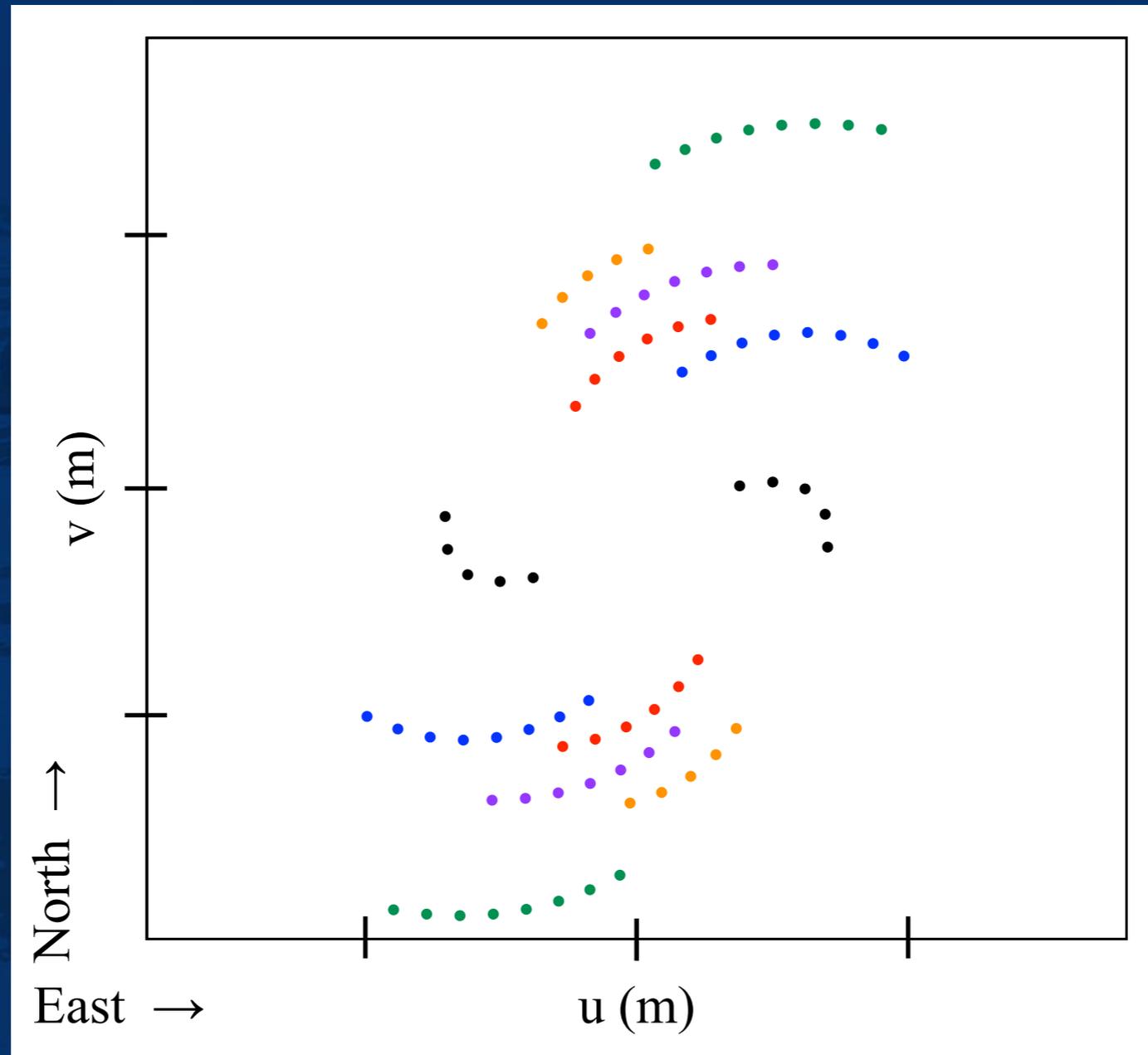
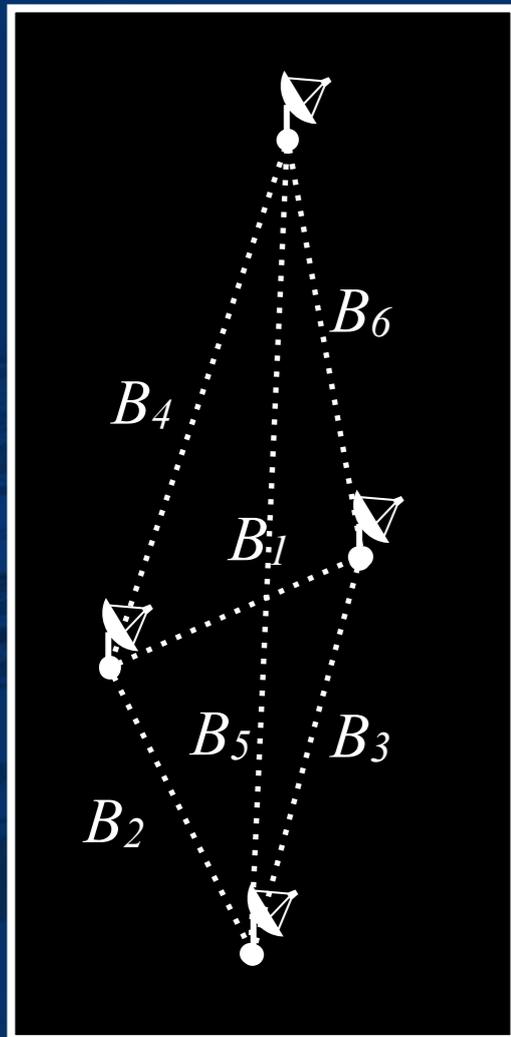
INTERFEROMETRY

The (u,v) plane



INTERFEROMETRY

The (u,v) plane



$$B_{i,j} = \frac{N(N-1)}{2}$$

$N = \#$ of antennas

NUMBER OF ANTENNAS

INTEGRATION TIME

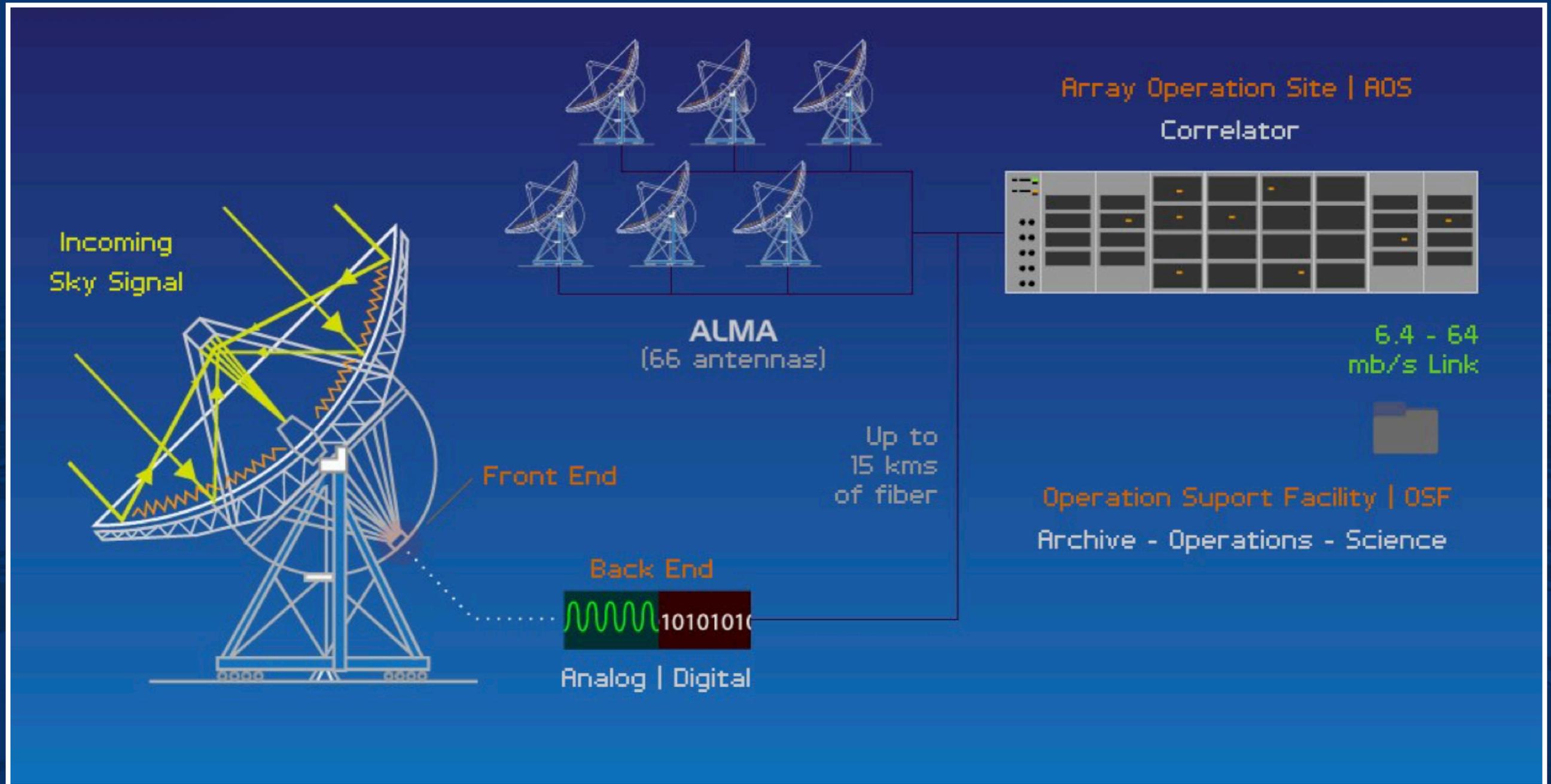
EARTH'S ROTATION

t_1

Δt



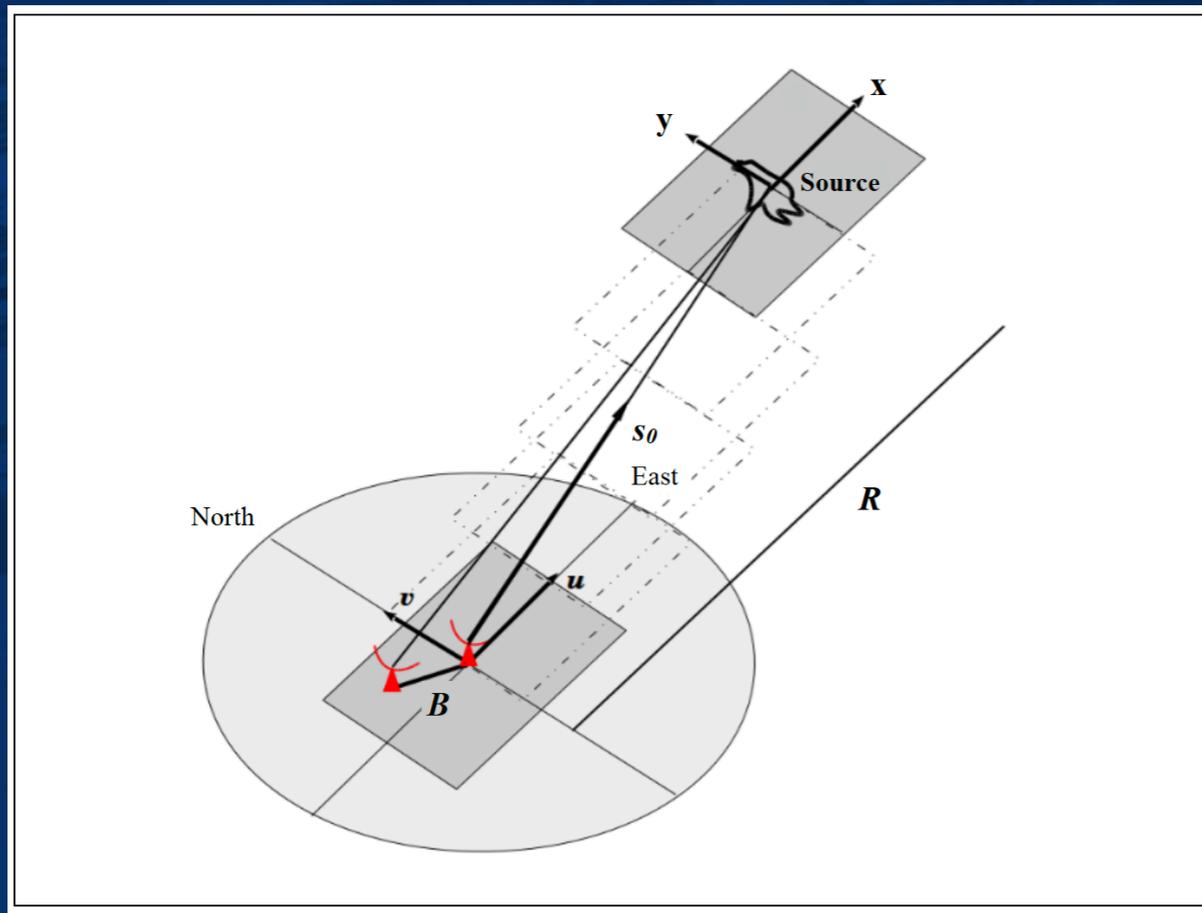
INTERFEROMETRY



INTERFEROMETRY

uv plane
 $V(u,v)$

Fourier transform
 $I_D(x,y)$



INTERFEROMETRY

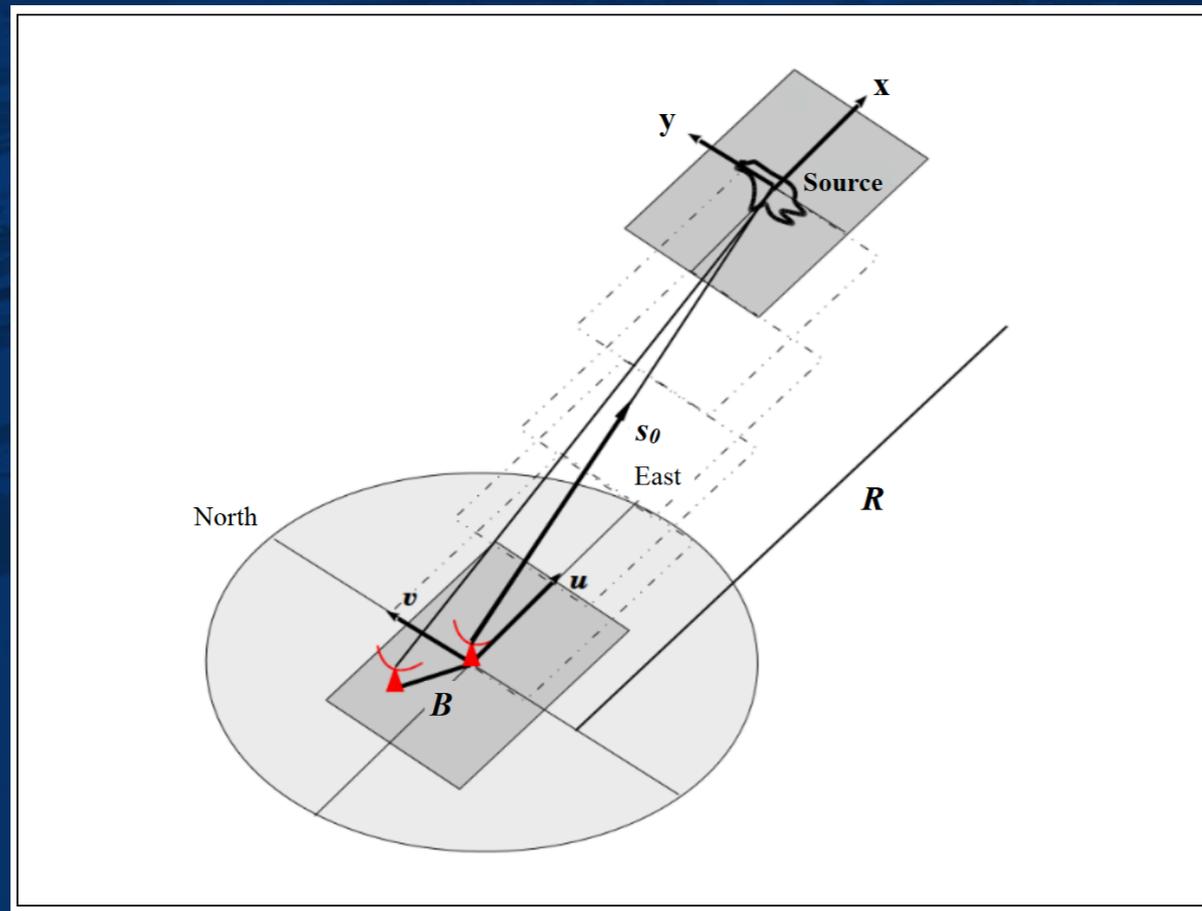
uv plane
 $V(u,v)$

Fourier transform
 $I_D(x,y)$

deconvolution

CLEAN
algorithm

$I(x,y)$



INTERFEROMETRY

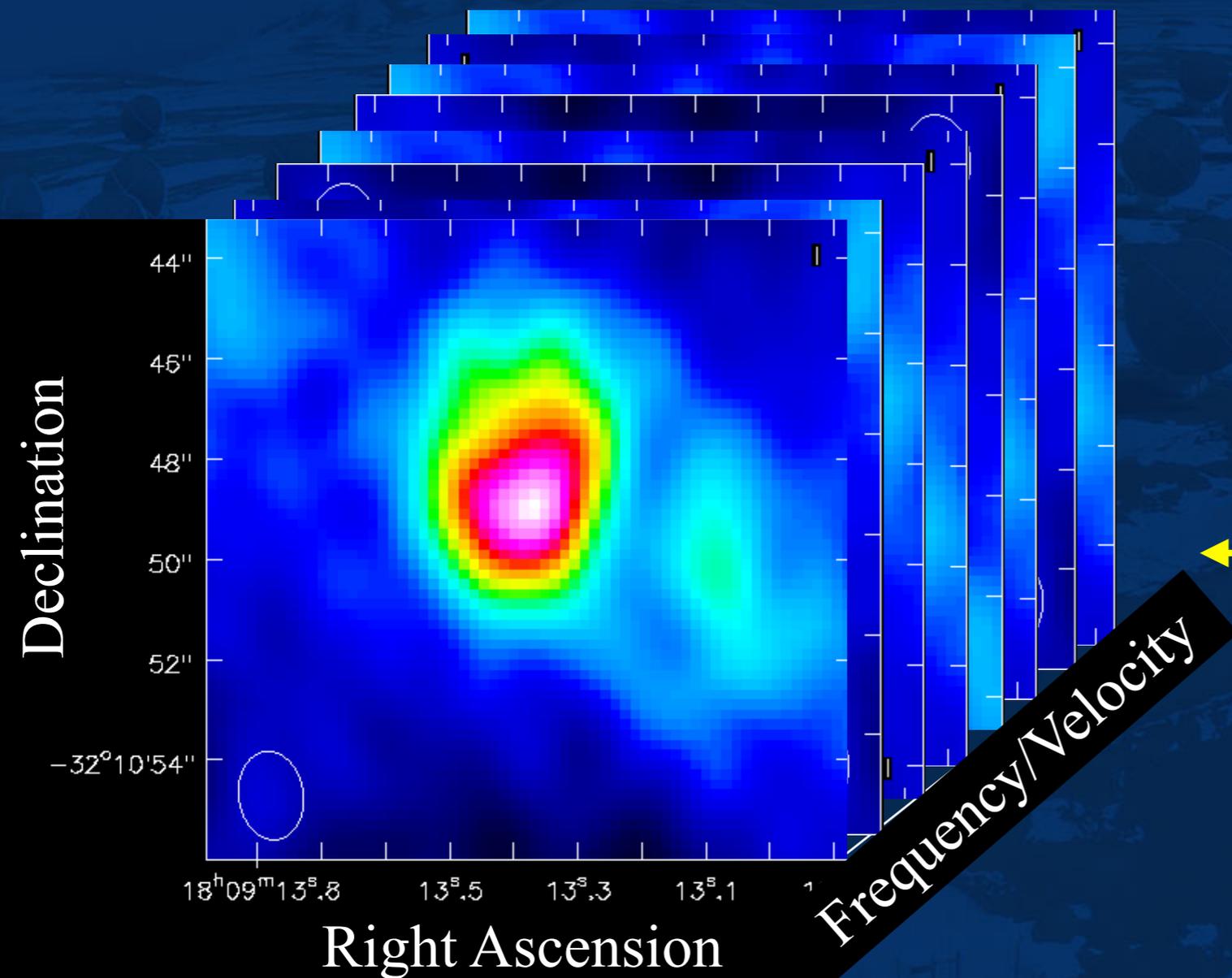
uv plane
 $V(u,v)$

Fourier transform
 $I_D(x,y)$

deconvolution

CLEAN
algorithm

$I(x,y)$



Frequency/Velocity

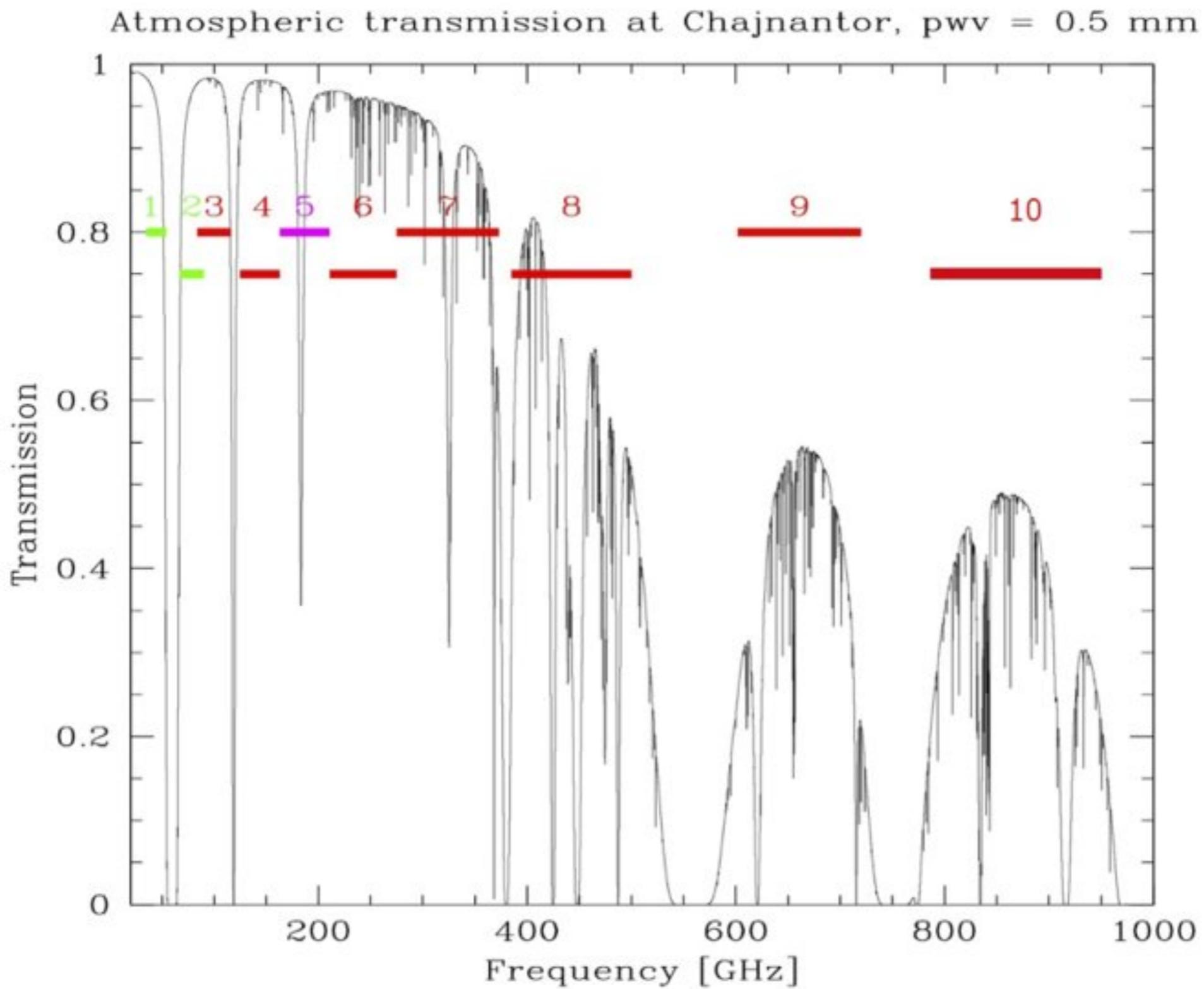
ALMA

ATACAMA LARGE MILLIMETER/SUB-MILLIMETER ARRAY



The Atacama desert
Chajnantor Plateau (5.000 mts)

WEATHER CONDITIONS



OPERATIONS

Operation Support Facility (3.000 mts)



OSF Technical Building

Array Operation Site (5.000 mts)



- AOS
- Antenas
- Power
- Fiber Optic Network
- Local Oscillator (Timing)
- Correlator



AOS Technical Building



- OSF
- Hotel
- Archive
- Laboratorio
- Maintenance
- Array Control Center
- Integration Center

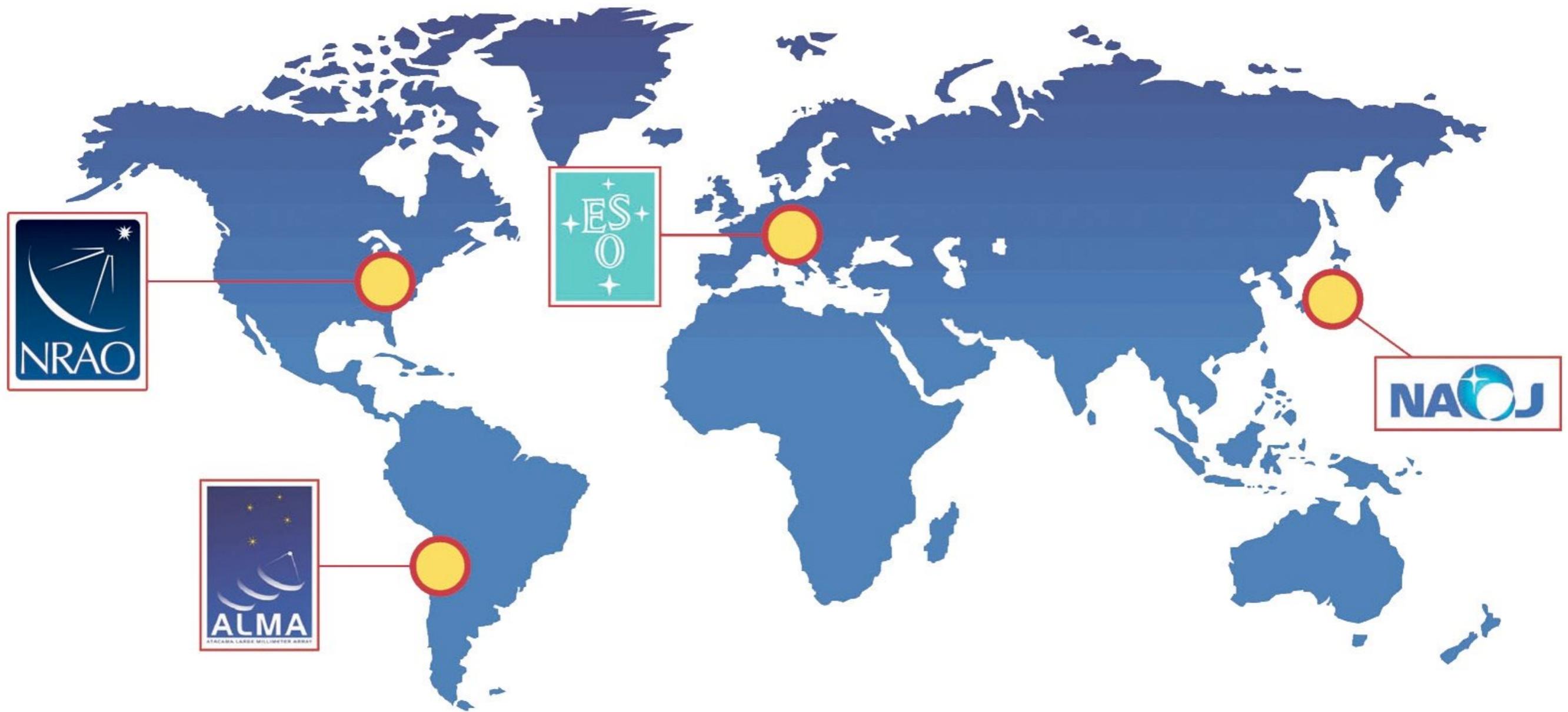


- SCO
- Main Archive
- Data Transmission to the ALMA
- Regional Center
- Offices:
- Science
- Computing
- Administration
- Management

Santiago Central Offices



ALMA OPERATIONS



ALMA



Credit: ESO/C. Malin

ALMA



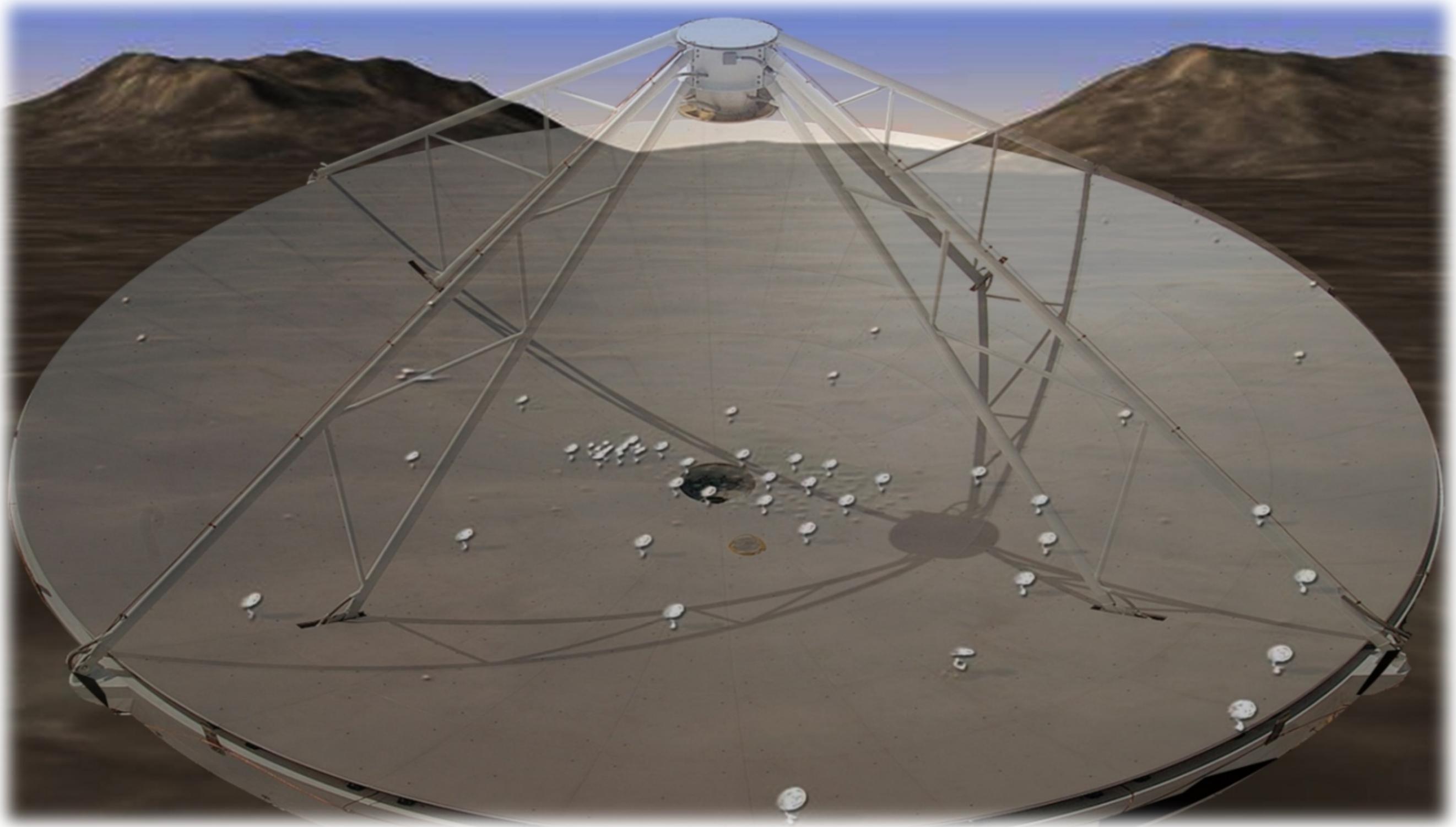
Visualisation of ALMA as an interferometer.ogv



0:04 / 0:36



ALMA



$B = 16 \text{ km}$



OPERATIONS

Configurations at ALMA

50 antennas of 12-m Extended Array

12 antennas of 7-m Compact Array

Complete Tentative Cycle 11 Configuration Schedule¹

Start date	Configuration	Longest baseline
1-Oct-2024	C-3	0.50 km
25-Oct-2024	C-2	0.31 km
10-Nov-2024	C-1	0.16 km
25-Nov-2024	C-2	0.31 km
15-Dec-2024	C-3	0.50 km
10-Jan-2025	C-4	0.78 km
1-Feb-2025	No observations due to maintenance	
1-Mar-2025	C-4	0.78 km
20-Mar-2025	C-5	1.4 km
25-Apr-2025	C-6	2.5 km
30-May-2025	C-7	3.6 km
20-Jun-2025	C-8	8.5 km
11-Jul-2025	C-9	13.9 km
30-Jul-2025	C-10	16.2 km
20-Aug-2025	C-9	13.9 km
10-Sep-2025	C-8	8.5 km

¹NOTE: The Configuration Schedule is SUBJECT TO CHANGE.



4 antennas of 12-m

They work as “single-dish”

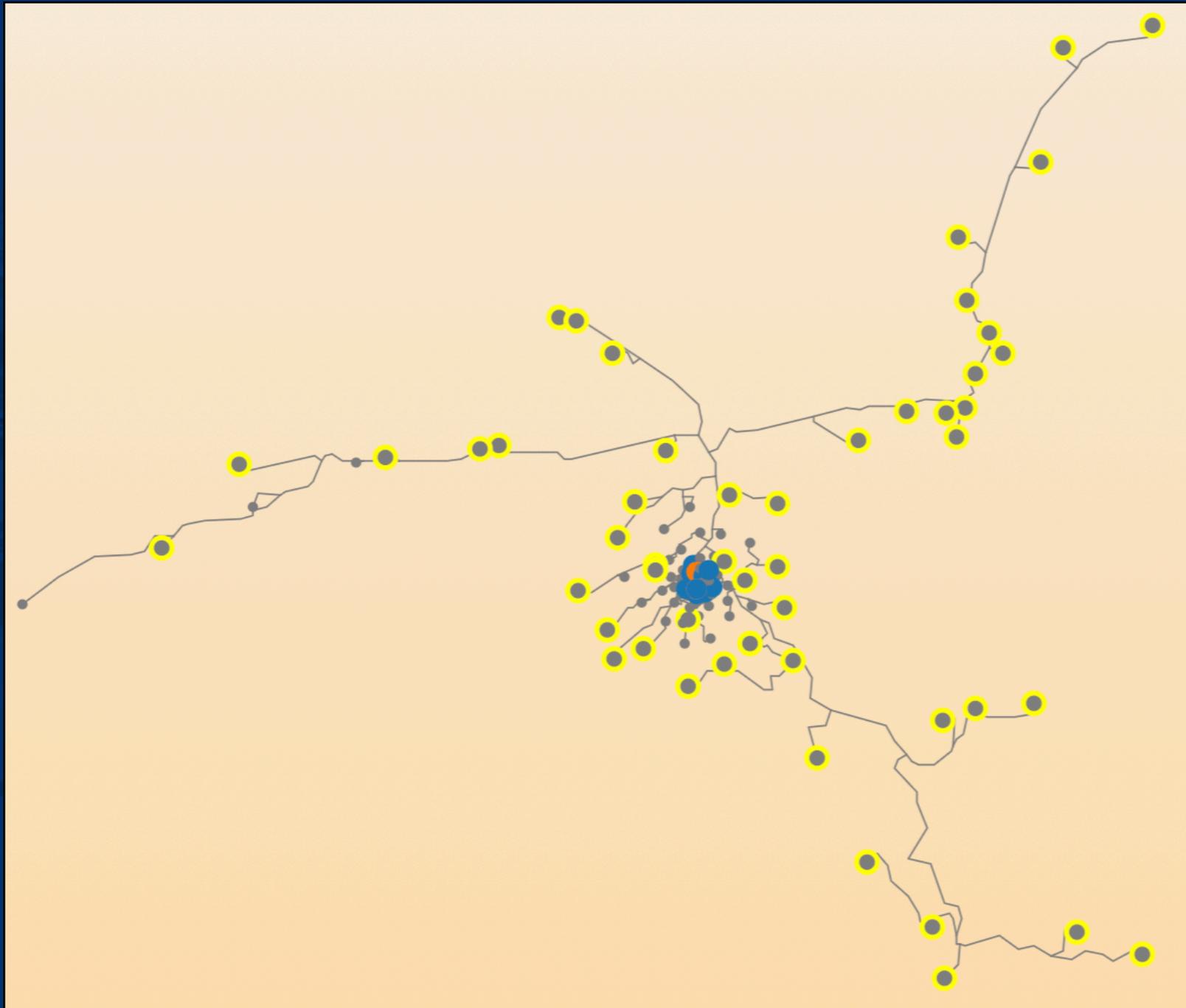
OPERATIONS

Configurations at ALMA

50 antennas of 12-m

Extended Array

C-10



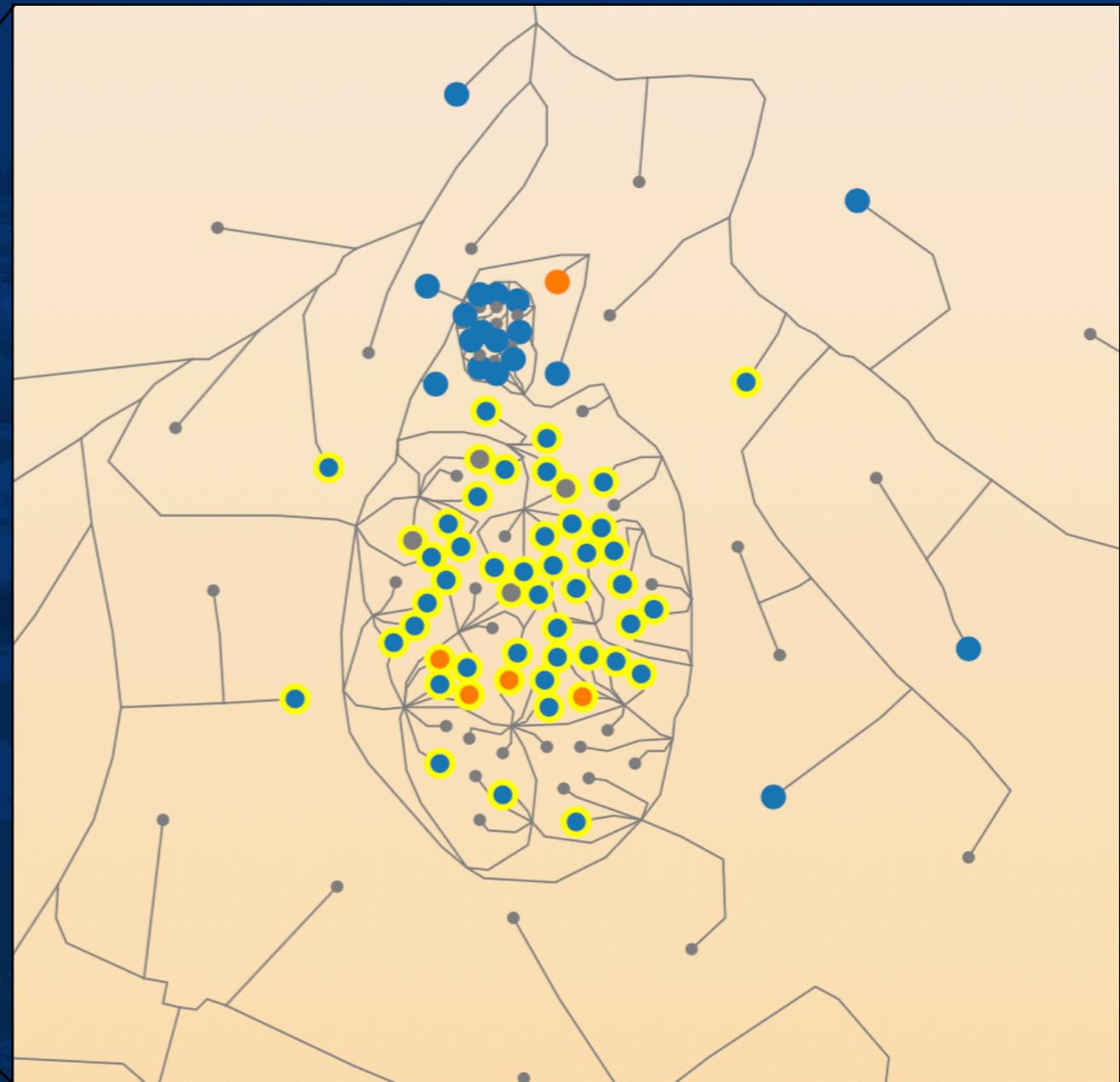
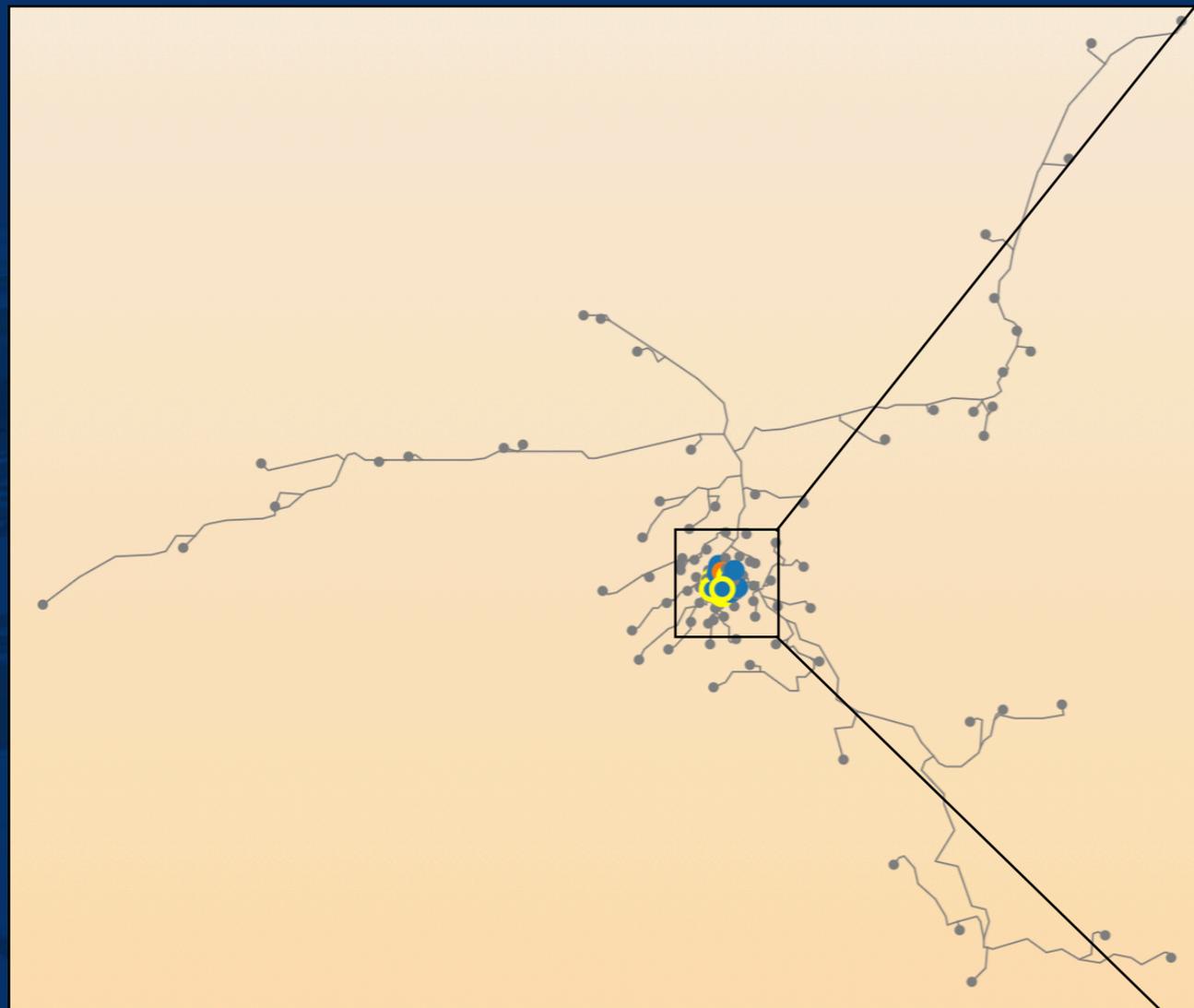
OPERATIONS

Configurations at ALMA

50 antennas of 12-m

Extended Array

C-1



ALMA ANTENNAS



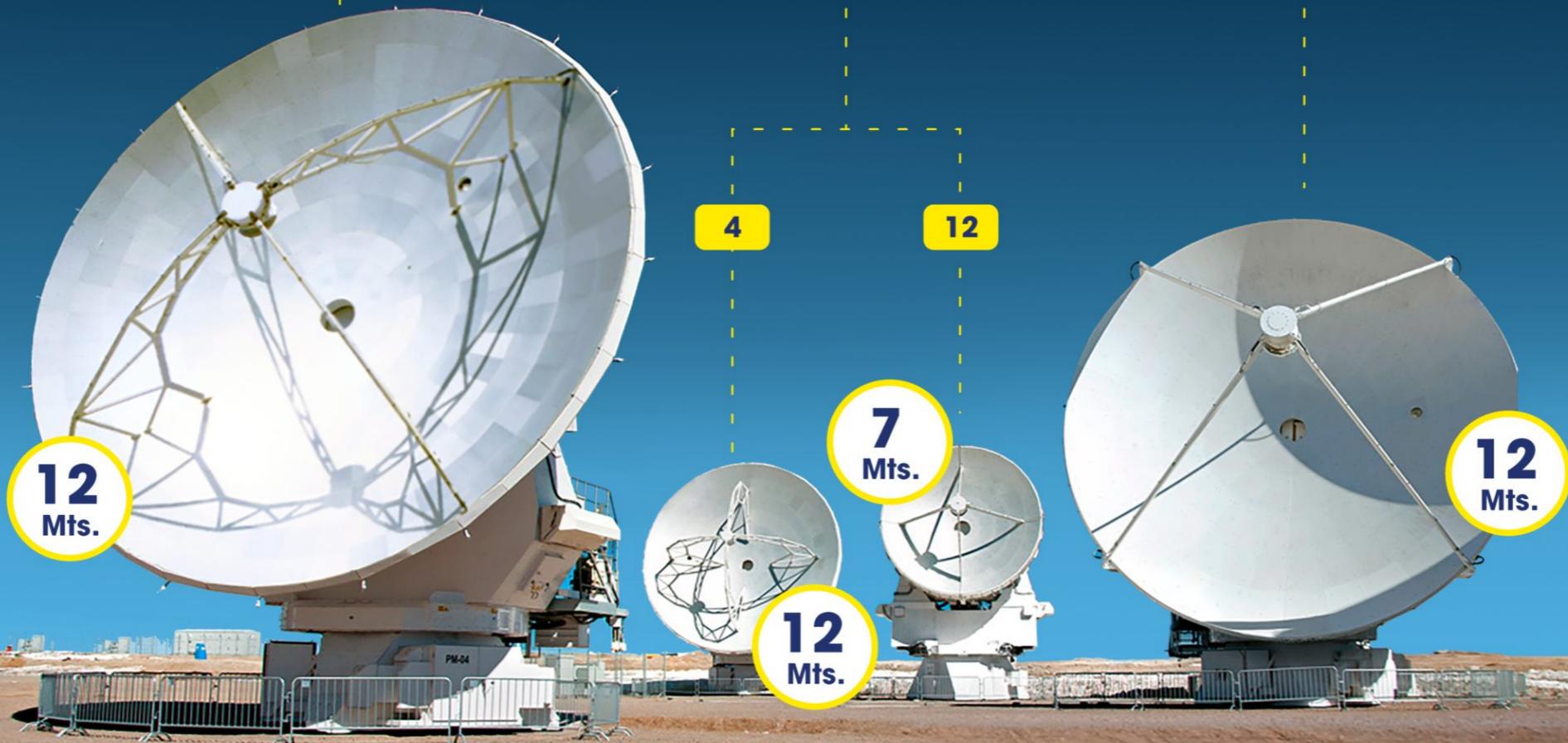
25 antennas



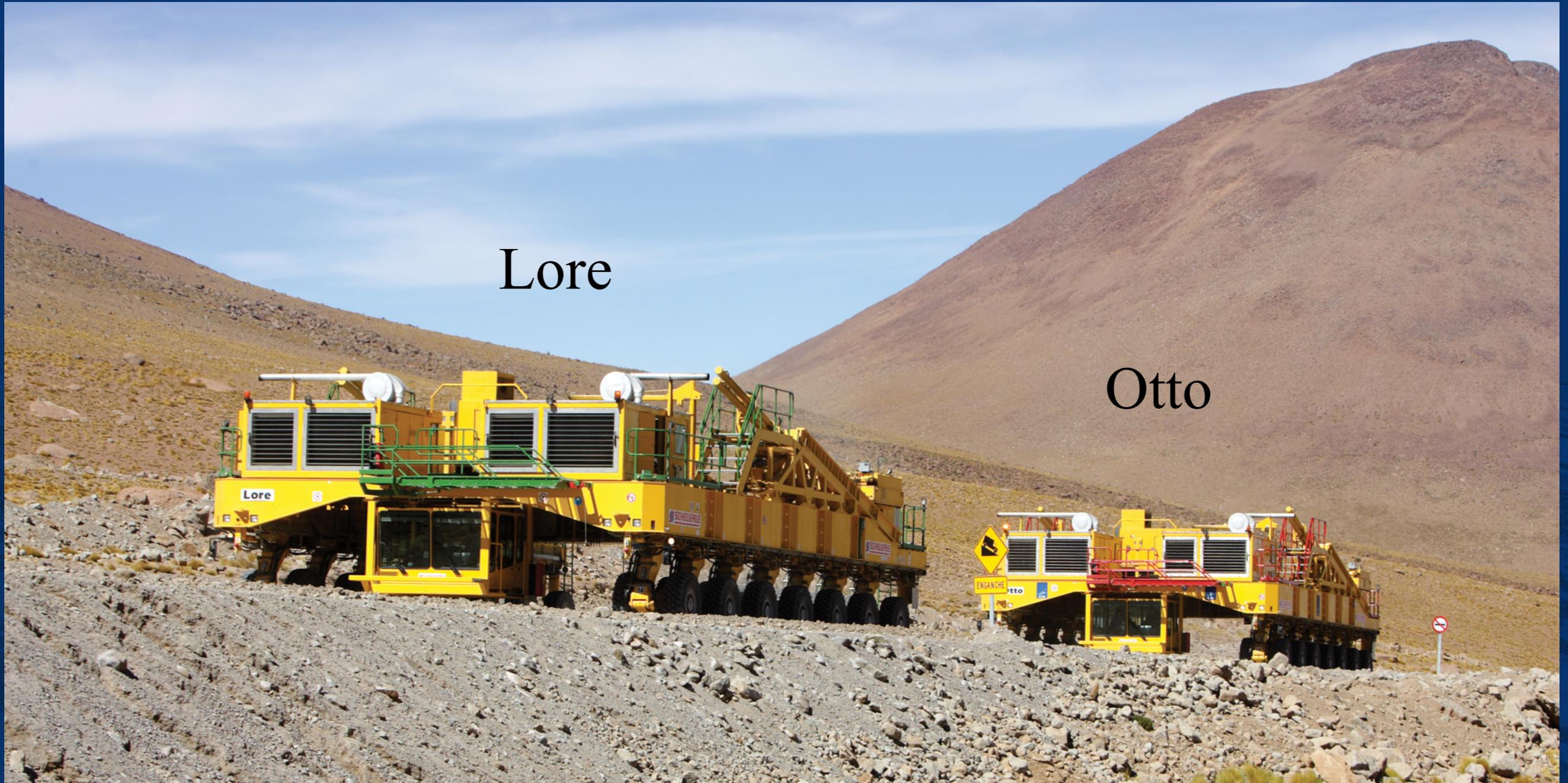
16 antennas



25 antennas



ALMA TRANSPORTERS



Lore

Otto

Otto Rettermaier: president of the German company, Scheuerle, who built the transporters, and his wife Lore

ALMA TRANSPORTERS



ALMA TRANSPORTERS



www.eso.org

SCIENCE

Main Objectives



Detect the CO and C+ transitions in galaxies like the Milky Way, at a red-shift $z=3$, in less than 24 hours.



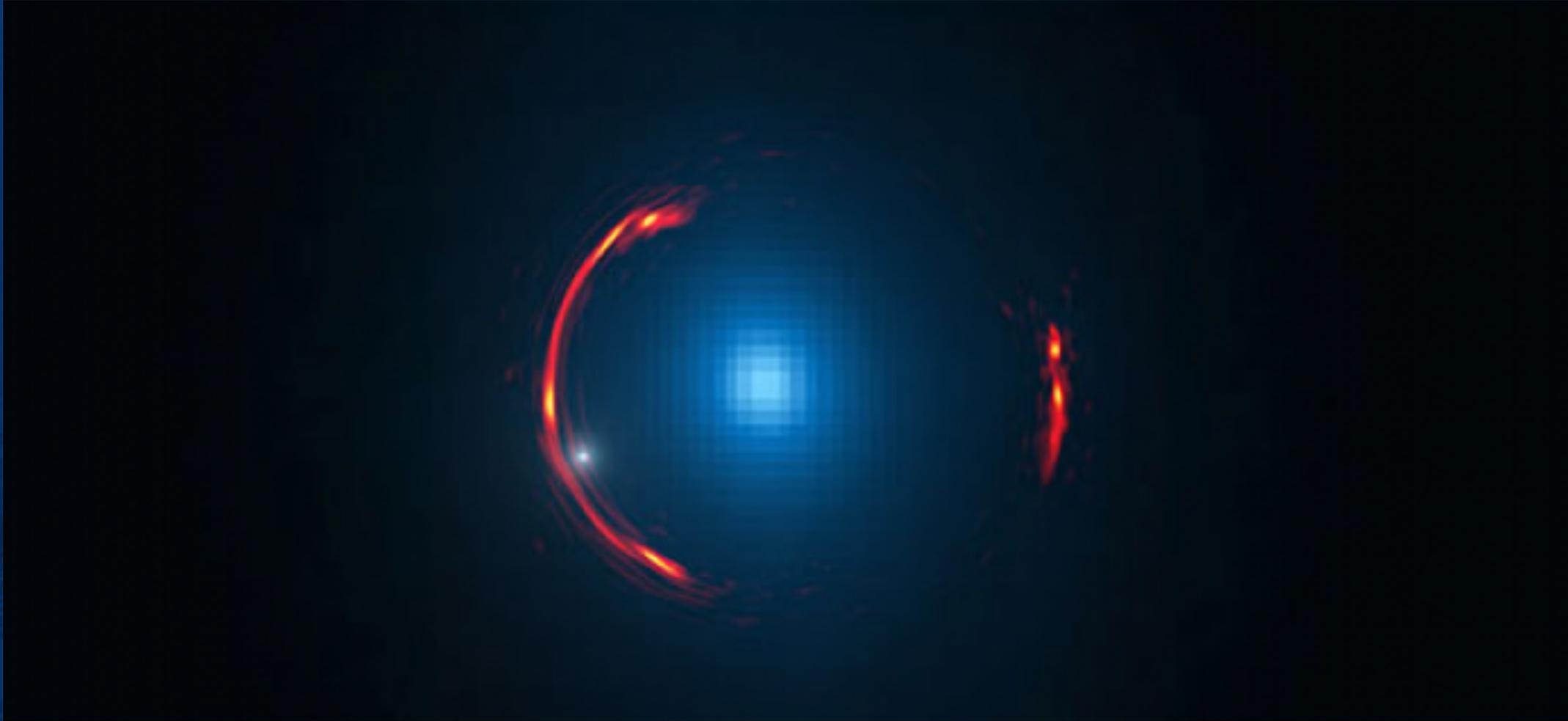
Trace the gas kinematics in a protoplanetary disk (solar type) and detect evidence of planet formation.



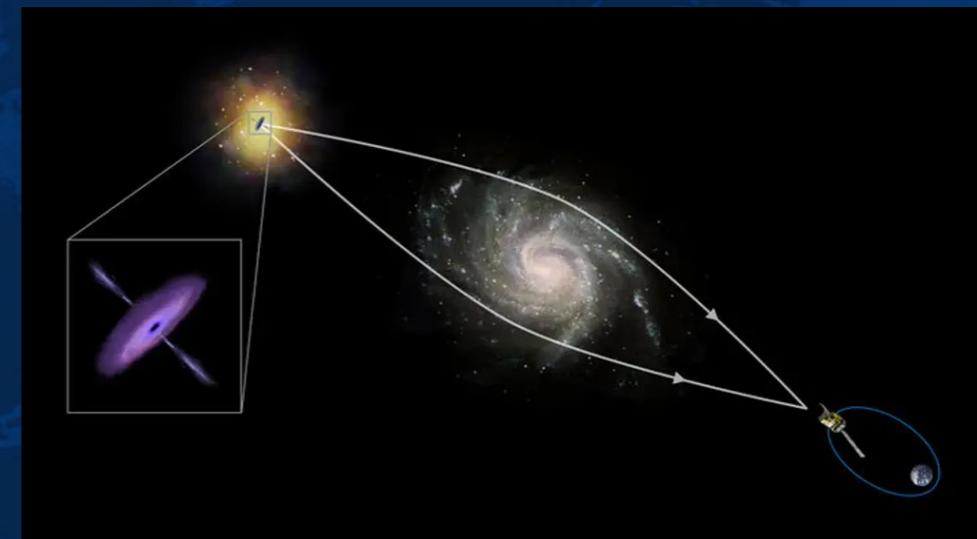
Obtain good quality images at an angular resolution of 0.1 arcsec.

SCIENCE

Gravitational Lenses



Credit: Y. Hezaveh, Stanford Univ.; ALMA (NRAO/ESO/NAOJ); NASA/ESA Hubble Space Telescope

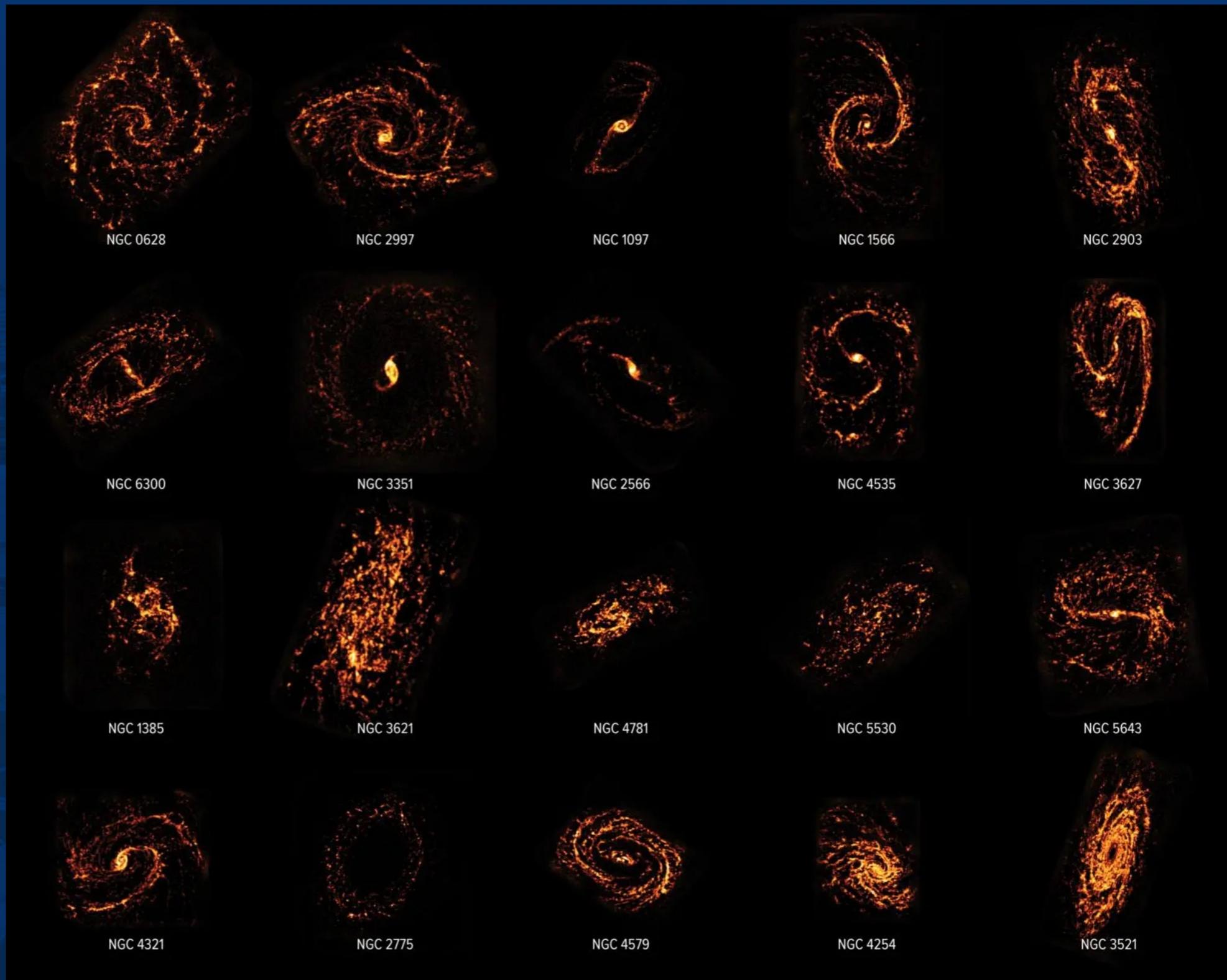


SCIENCE

Galaxies

PHANGS

Physics at High
Angular
Resolution
in Nearby
Galaxies

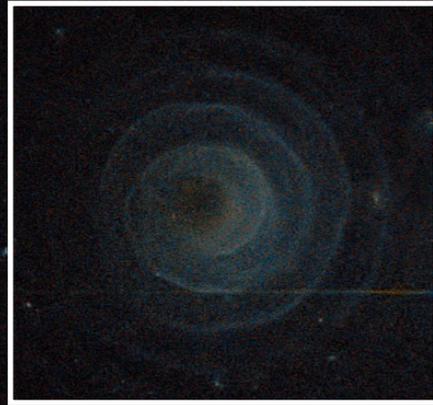


Credit: ALMA (ESO/NAOJ/NRAO)/PHANGS, S. Dagnello (NRAO)

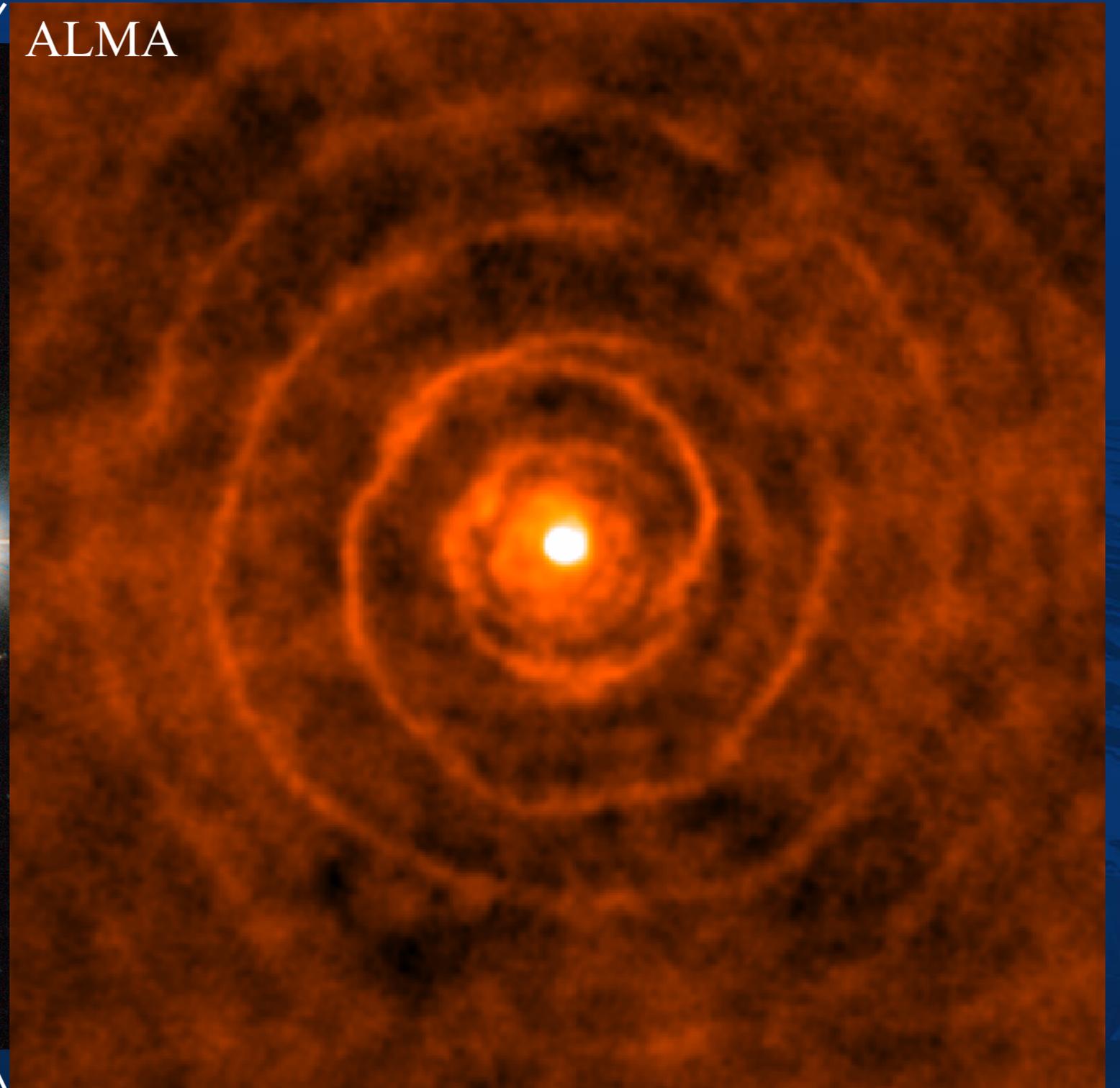
SCIENCE

Evolved Stars

Hubble



ALMA



Credit: ESA/NASA & R. Sahai

Credit: ALMA (ESO/NAOJ/NRAO)/H. Kim et al.

SCIENCE

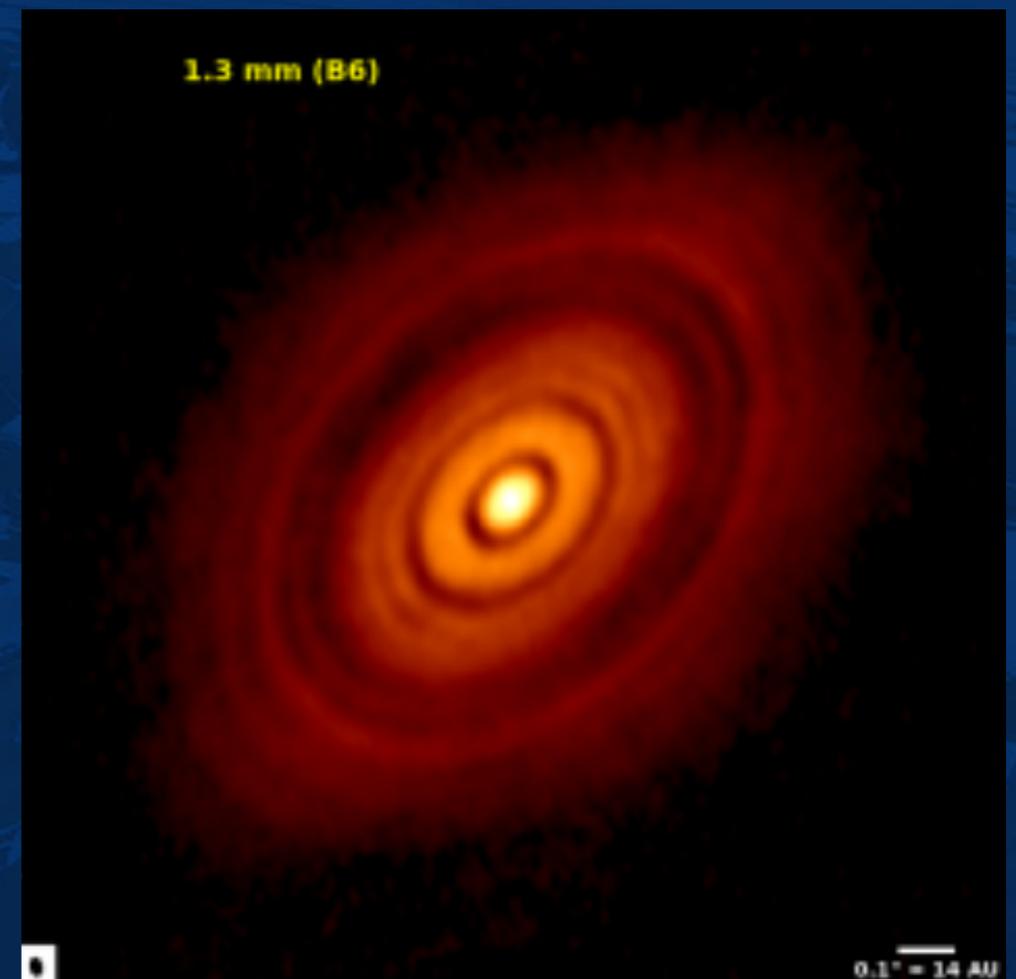
HL Tau: Proto-planetary disk

Proto stars, where planets are forming within a disk of gas and dust

Before ALMA



ALMA

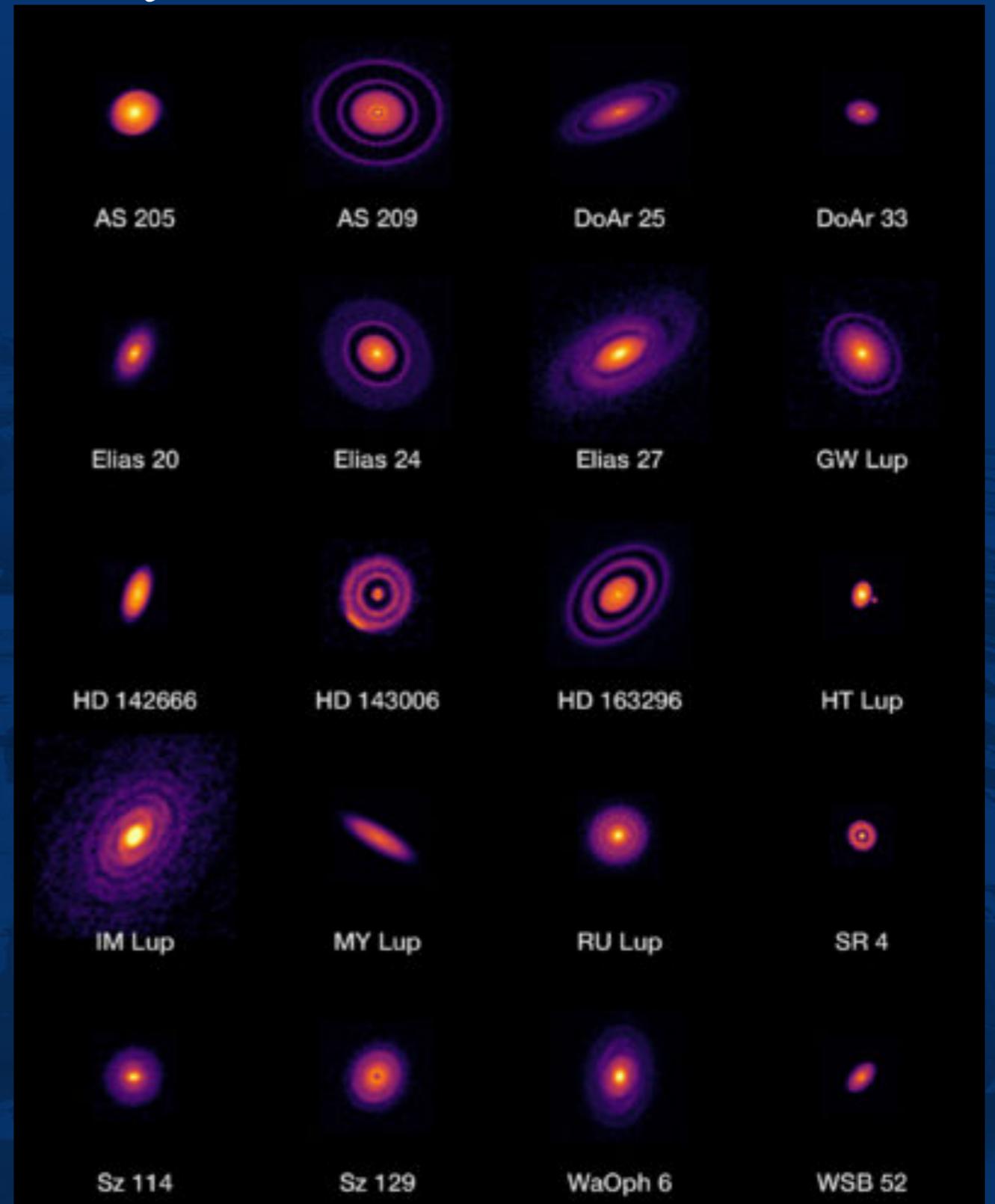


Credit: ALMA (ESO/NAOJ/NRAO)

Proto-planetary disks

DSHARP

Disk Substructures at
High Angular
Resolution Project



SCIENCE

Formation of multiple systems



Credit: Bill Saxton, ALMA (ESO/NAOJ/NRAO), NRAO/AUI/NSF.

SCIENCE

Planet formation

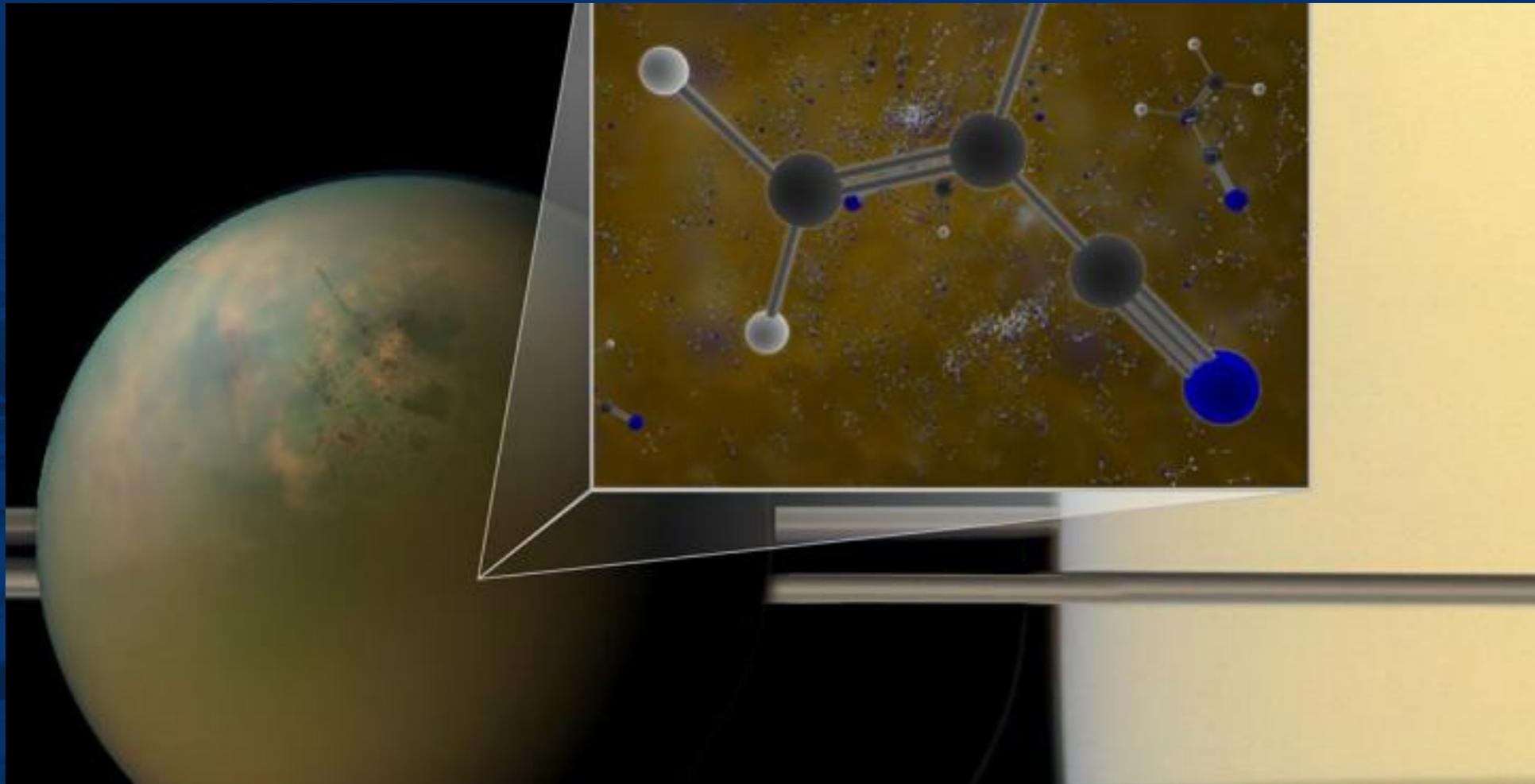
PDS 70



Credit: ALMA (ESO/NAOJ/NRAO)/Benisty et al.

SCIENCE

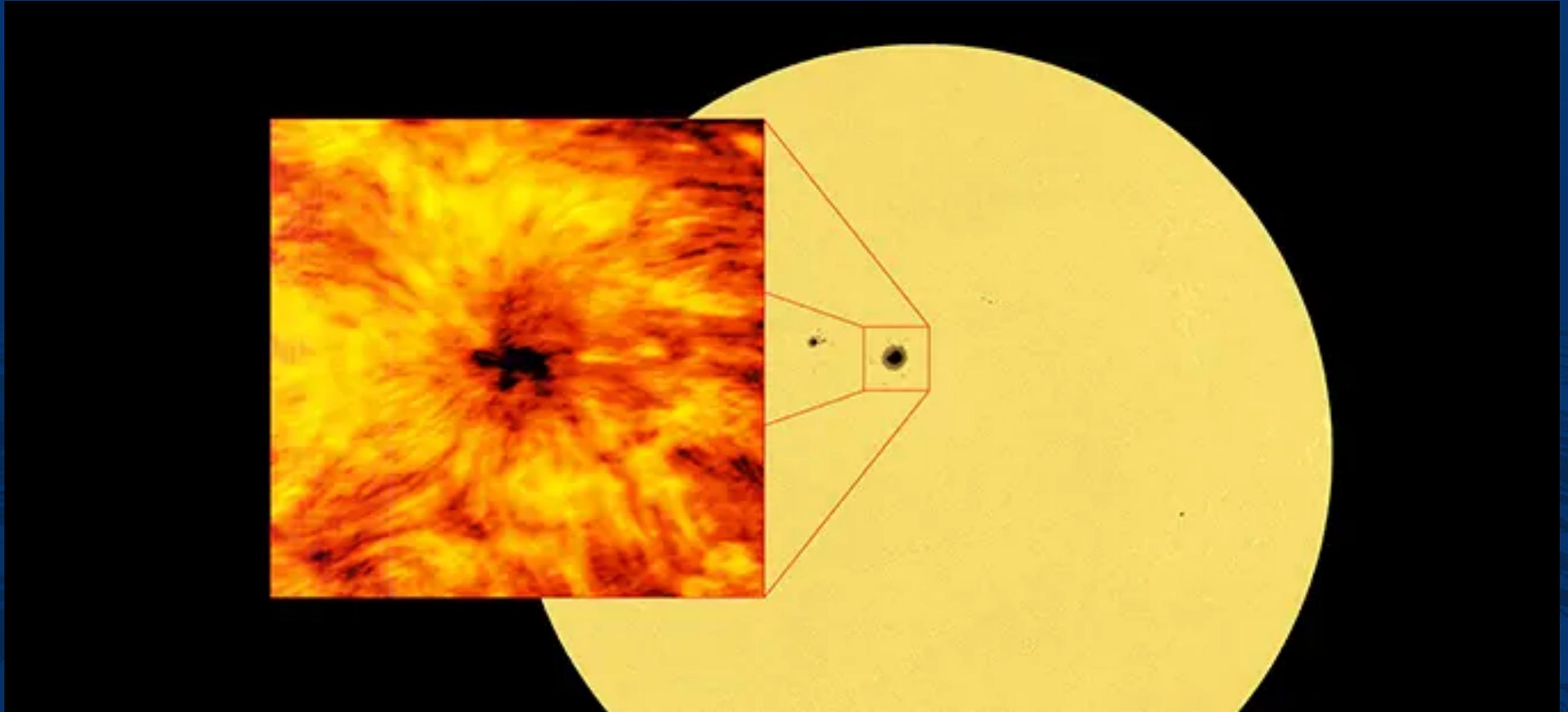
Detection of Vinyl Cyanide (complex molecule) in Titan's atmosphere



Palmer et al. (2018)

SCIENCE

Solar observations

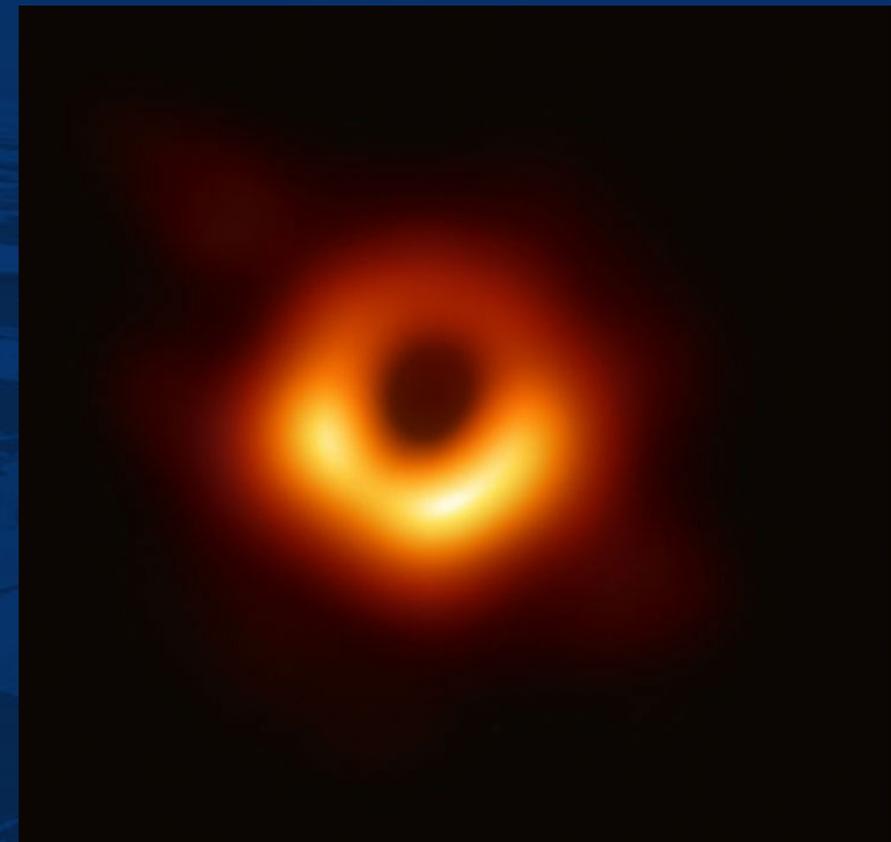


Credit: ALMA (ESO/NAOJ/NRAO)

SCIENCE

Black Holes

EHT: Event Horizon Telescope



$D \sim 12.700 \text{ km}$

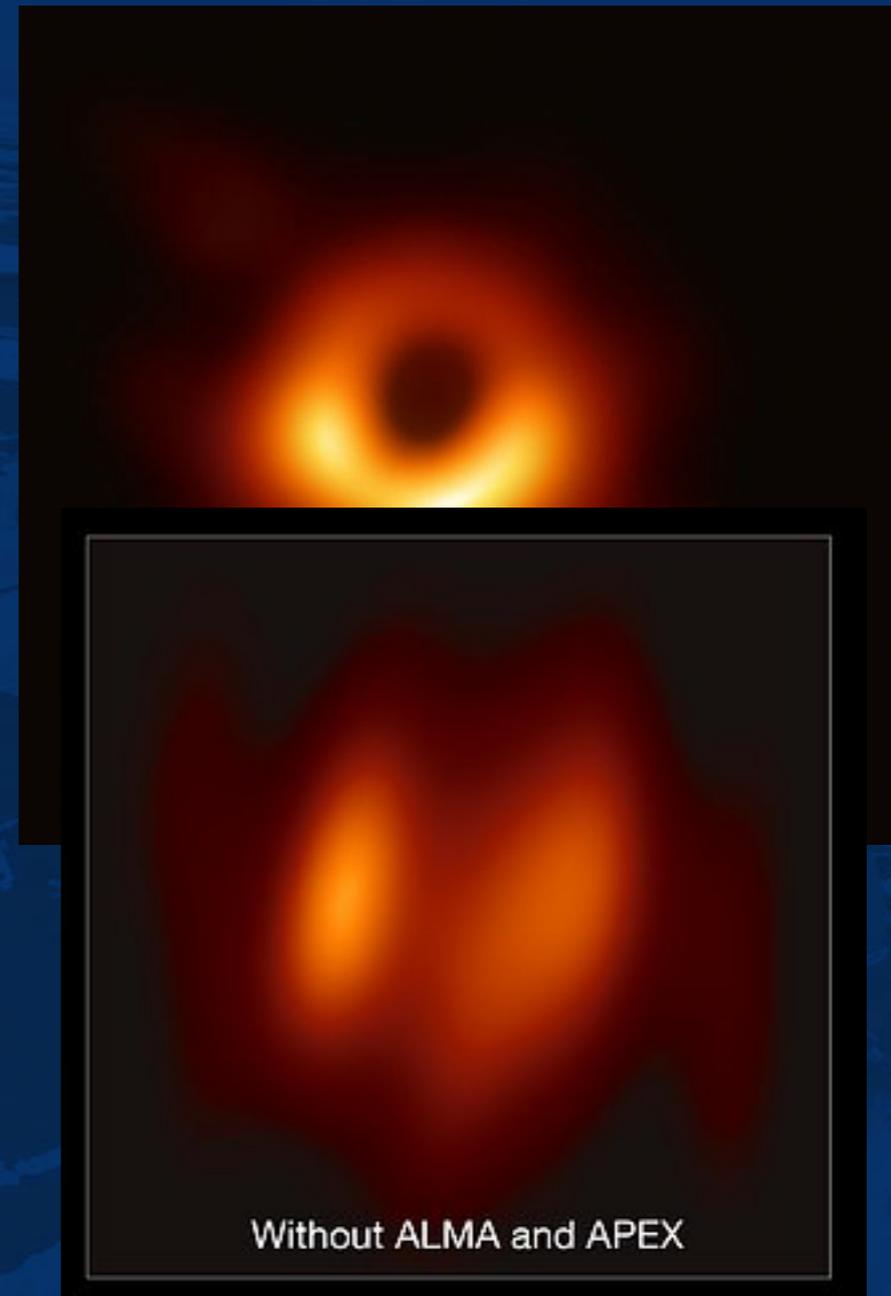
SCIENCE

Black Holes

EHT: Event Horizon Telescope



$D \sim 12.700 \text{ km}$



Without ALMA and APEX

ALMA: THE FUTURE

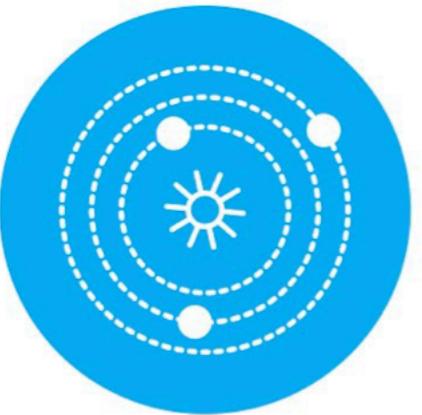
Wideband Sensitivity Upgrade (WSU) - 2030



Origin of Galaxies. Trace the evolution of the first galaxies ($z > 10$) with CO, [CII], and [OIII].



Origin of chemical complexity. Trace the evolution of complex molecules in the process of star and planet formation through spectral studies.



Origin of planets. Resolve regions where Earth-like planets are forming (~ 1 au) and trace their physics.

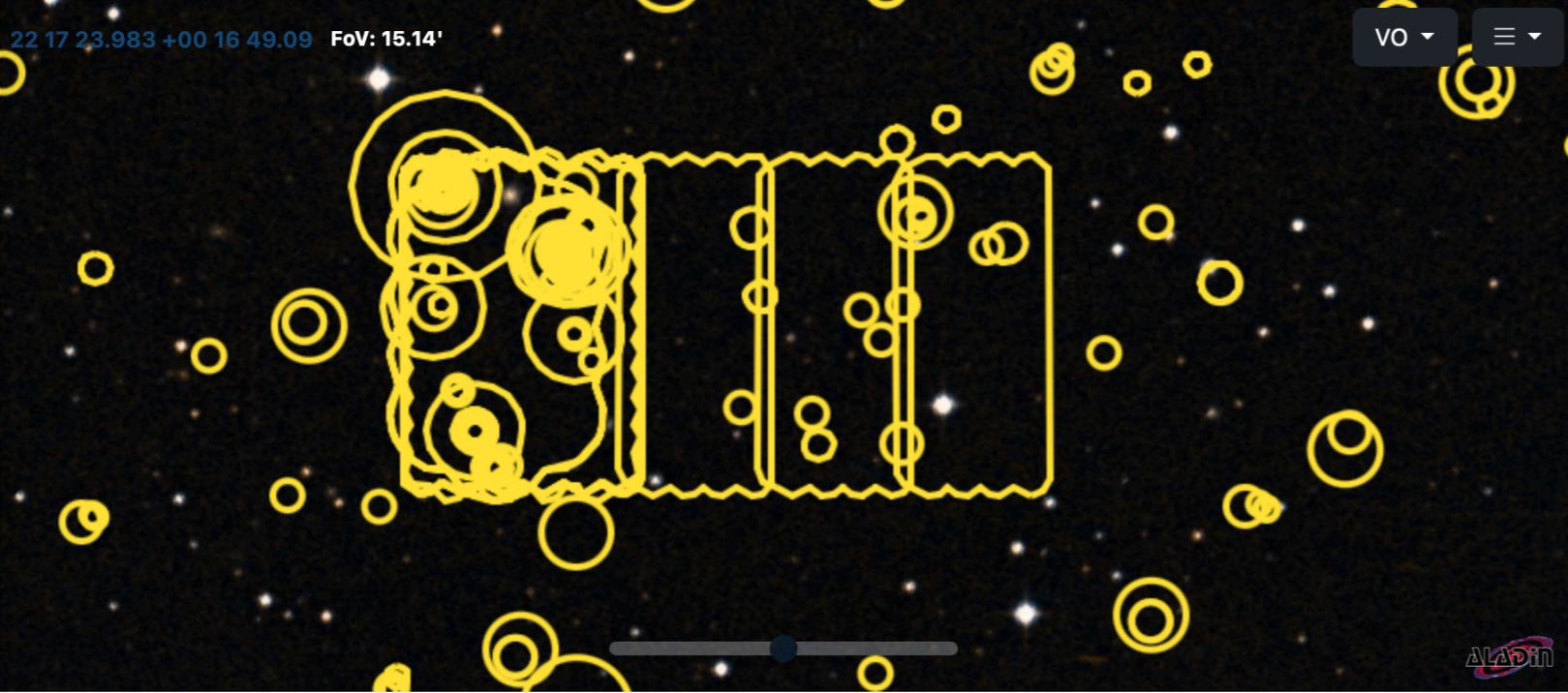
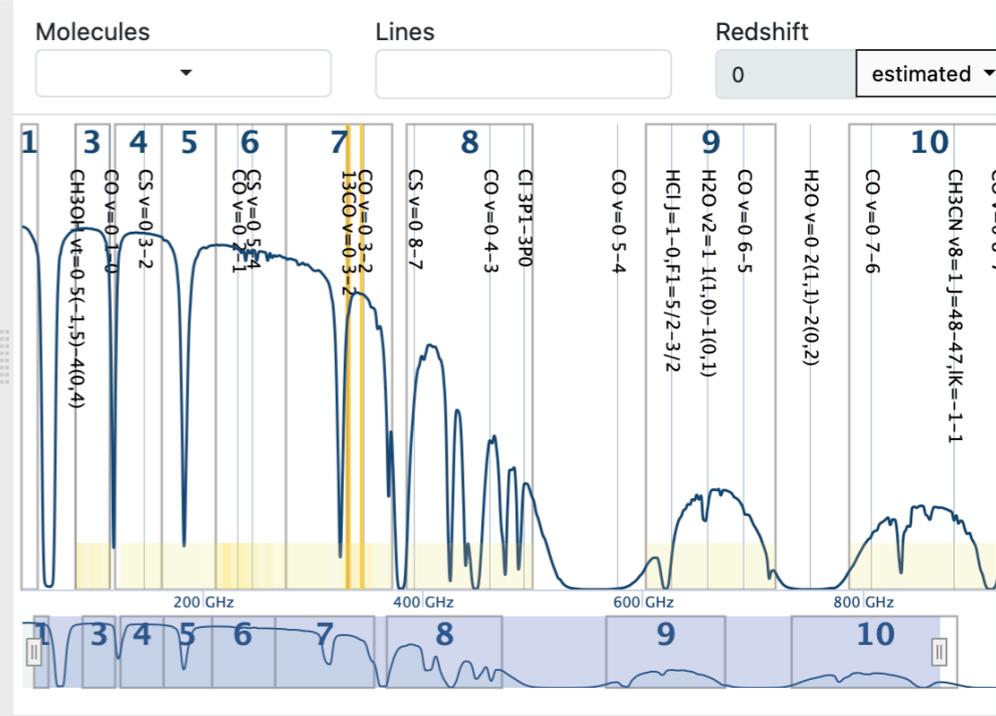
Improvement in the receivers, the digital system (data transmission) and the correlator (supercomputer for data processing).

THE ALMA ARCHIVE

<https://almascience.eso.org/aq/>

Search

22 17 23.983 +00 16 49.09 FoV: 15.14' VO ☰

Molecules Lines Redshift

1 CH3OH v=0-5(-1,5)-4(0,4)
3 CO v=0-1-0
4 CS v=0-3-2
5 CS v=0-3-2
6 CS v=0-5-4
7 CO v=0-3-2
13CO v=0-3-2
8 CS v=0-8-7
9 H2O v=2=1-1(1,0)-1(0,1)
HCl J=1-0, F=1=5/2-3/2
CO v=0-5-4
10 CH3CN v=8=1j=48-47, k=-1-1

200 GHz 400 GHz 600 GHz 800 GHz

☉ Observations (91446) Projects (5460) Publications (4713)

	Project code	ALMA source name	RA	h:m:s	Dec	d:m:s	Band	Cont.sens. mJy/beam	Frequency support	Release date	Publicator	Ang.res. arcsec	Min.vel.res. km/s	Array	Mosaic	Max.reco.scale arcsec	FO
<input type="checkbox"/>	2011.0.00191.S	Fomalhaut b	22:57:38.685	-29:37:12.616	7			0.1181	343.077..358.839 GHz	2012-12-06	2	1.047	0.816	12m		10.640	16
<input type="checkbox"/>	2011.0.00101.S	GRB021004	00:26:54.680	+18:55:41.60	(7)			0.1136	337.009..353.001 GHz	2012-12-06	2	1.107	26.541	12m		9.257	16
<input checked="" type="checkbox"/>	2011.0.00131.S	R Scl	01:26:58.079	-32:32:36.42	7			0.9115	330.246..346.109 GHz	2012-12-06	5	1.043	0.846	12m	mosaic	11.517	6:
<input type="checkbox"/>	2011.0.00397.S	J041754.10-281655.9	04:17:54.100	-28:16:55.90	(7)			0.4848	337.023..353.008 GHz	2012-12-20	3	1.118	26.541	12m		7.842	16
<input type="checkbox"/>	2011.0.00397.S	J035448.24-330827.2	03:54:48.240	-33:08:27.20	(7)			0.4848	337.026..353.011 GHz	2012-12-20	3	1.128	26.541	12m		7.950	16
<input type="checkbox"/>	2011.0.00397.S	J061200.23-062209.6	06:12:00.230	-06:22:09.60	7			0.5346	337.005..352.989 GHz	2012-12-20	3	1.183	26.541	12m		7.819	16

After 1 year of proprietary time, the data are released

