



EL UNIVERSO EN RADIO

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Universidad de Valencia

Arquitectura Cósmica II
Materia y Energía en el Universo

FUNDACIÓN VALENCIANA DE
ESTUDIOS AVANZADOS

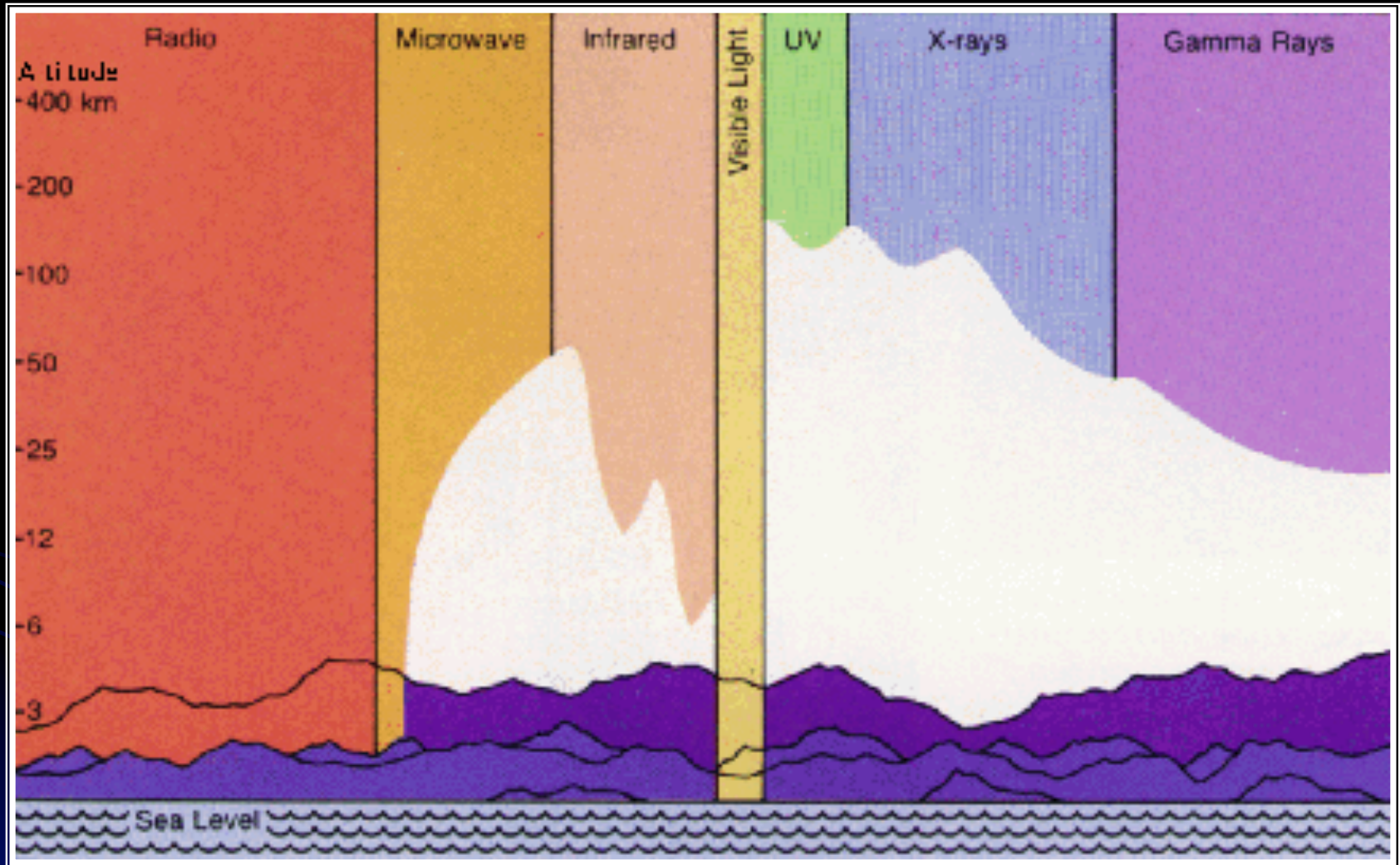


Foto: Roger Smith, CTIO (APOD 13.02.04)

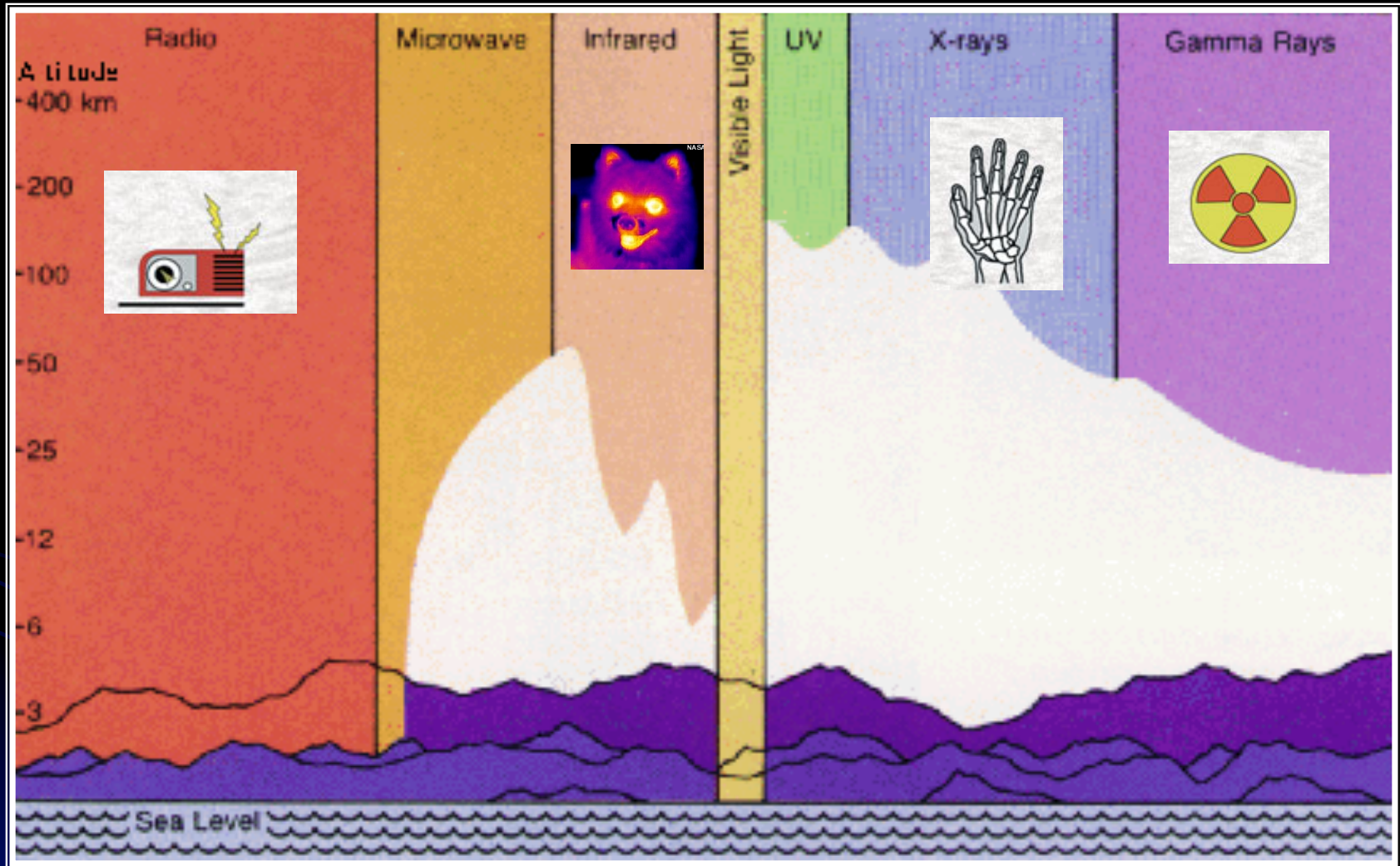


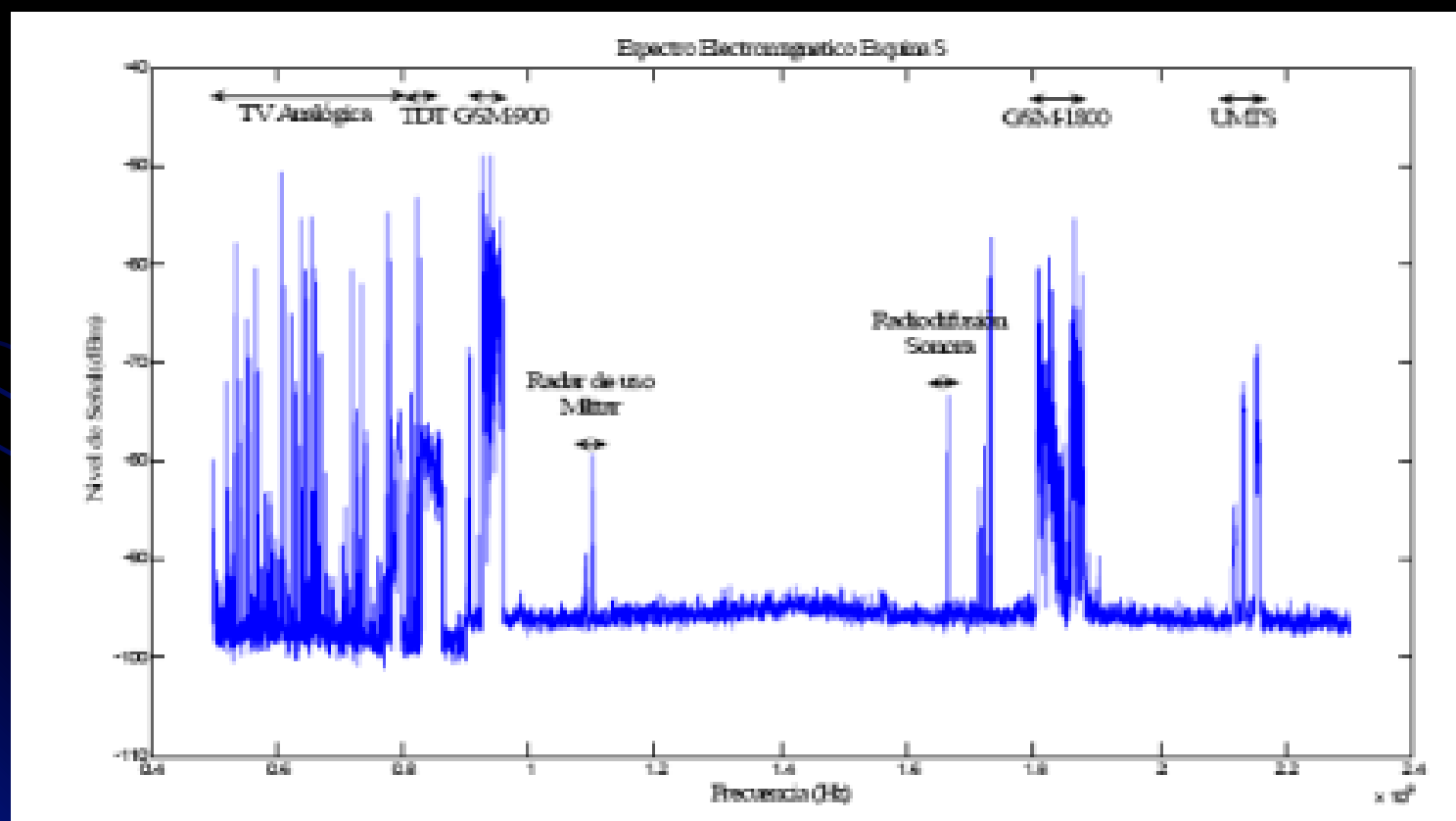
Foto: National Radio Astronomy Observatory

Transparencia de la atmósfera



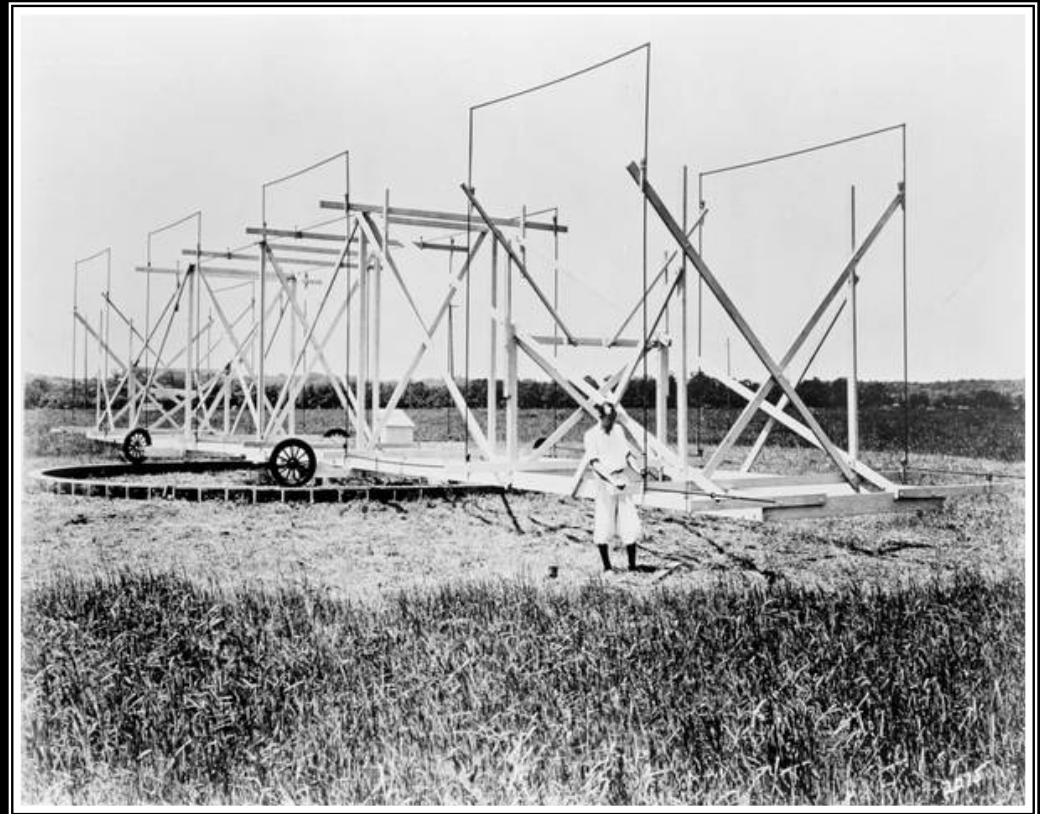
Transparencia de la atmósfera



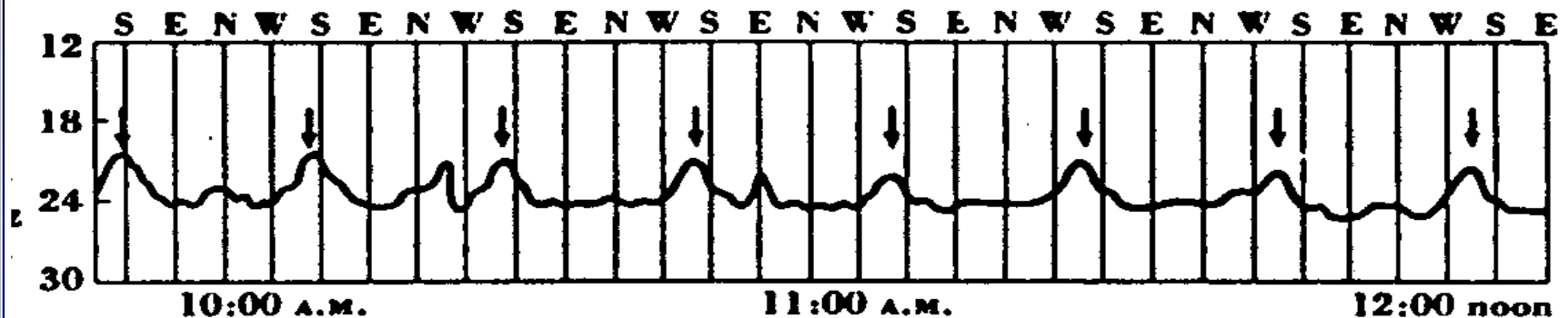


Antenas y Casualidad

En 1931 Karl Jansky detecta emisión en radio (interferencias) de origen cósmico

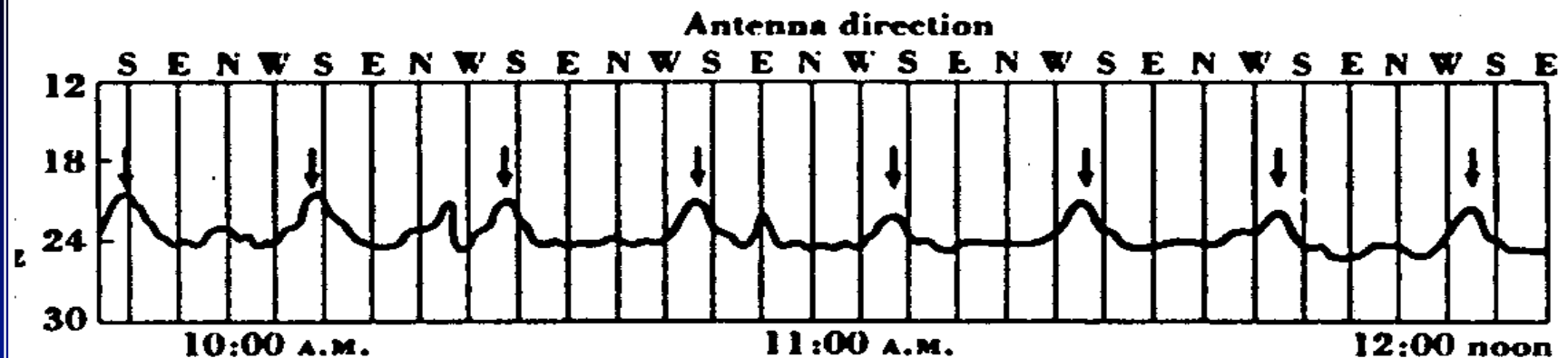


Antenna direction



Antenas y Casualidad

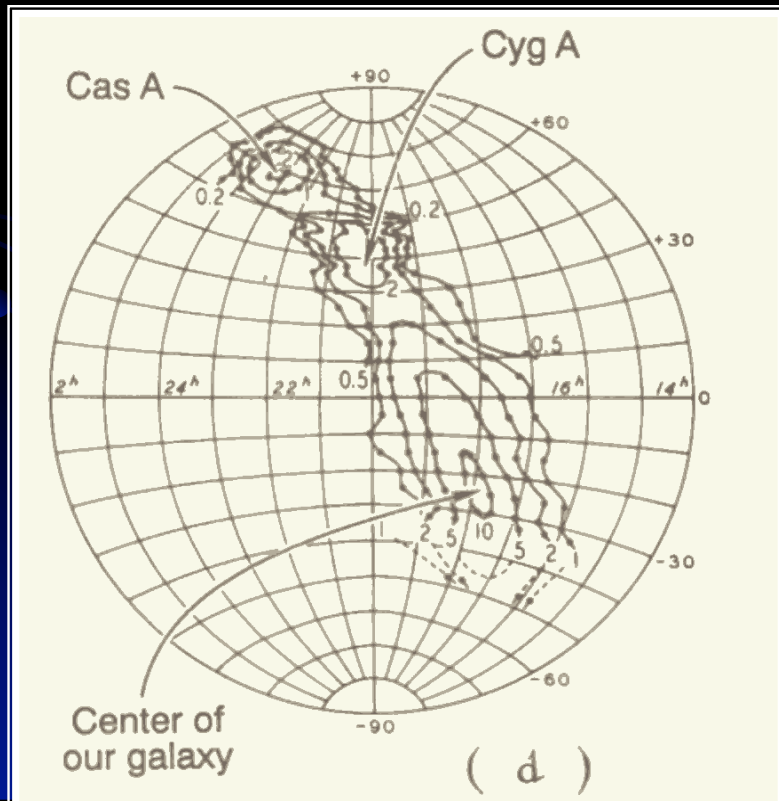
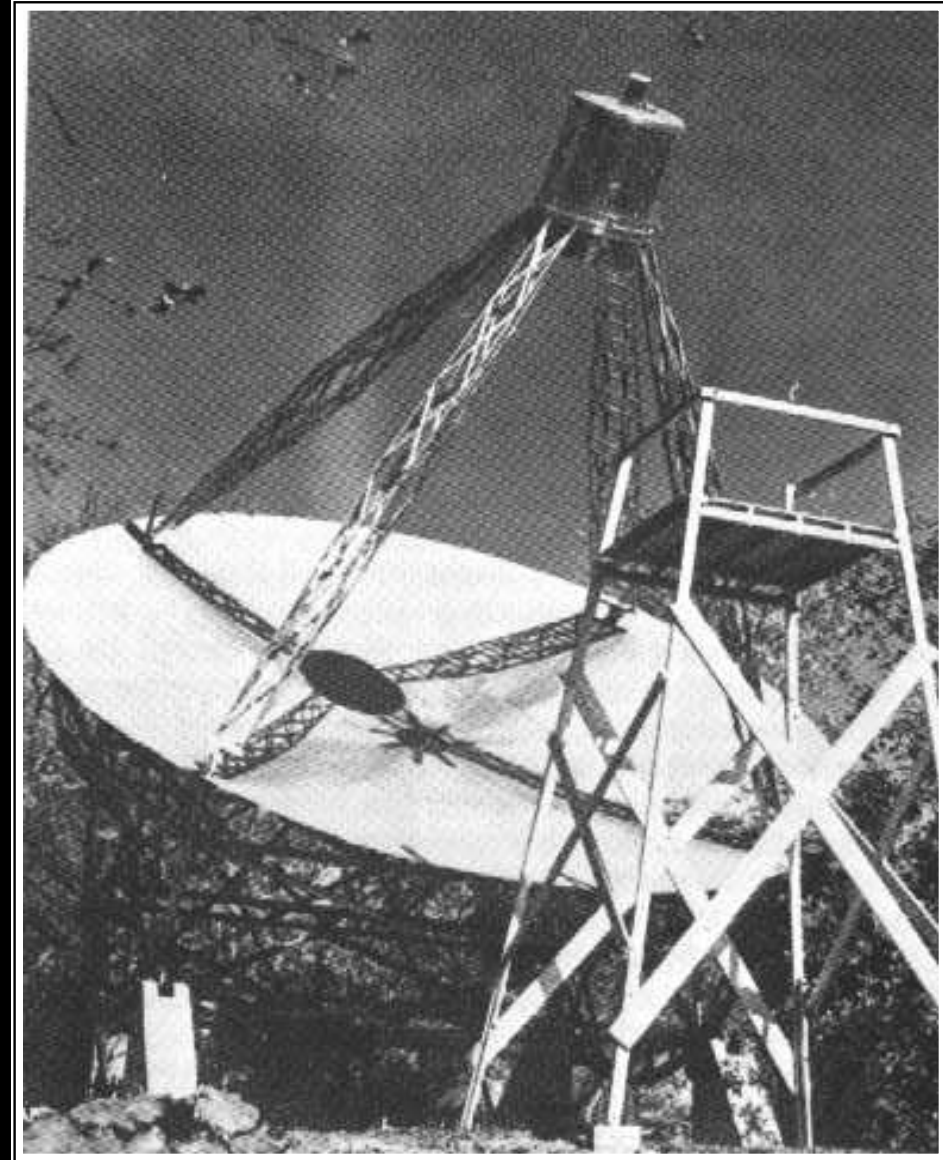
En 1931 Karl Jansky detecta emisión en radio (interferencias) de origen cósmico.
Frecuencia: 20 MHz

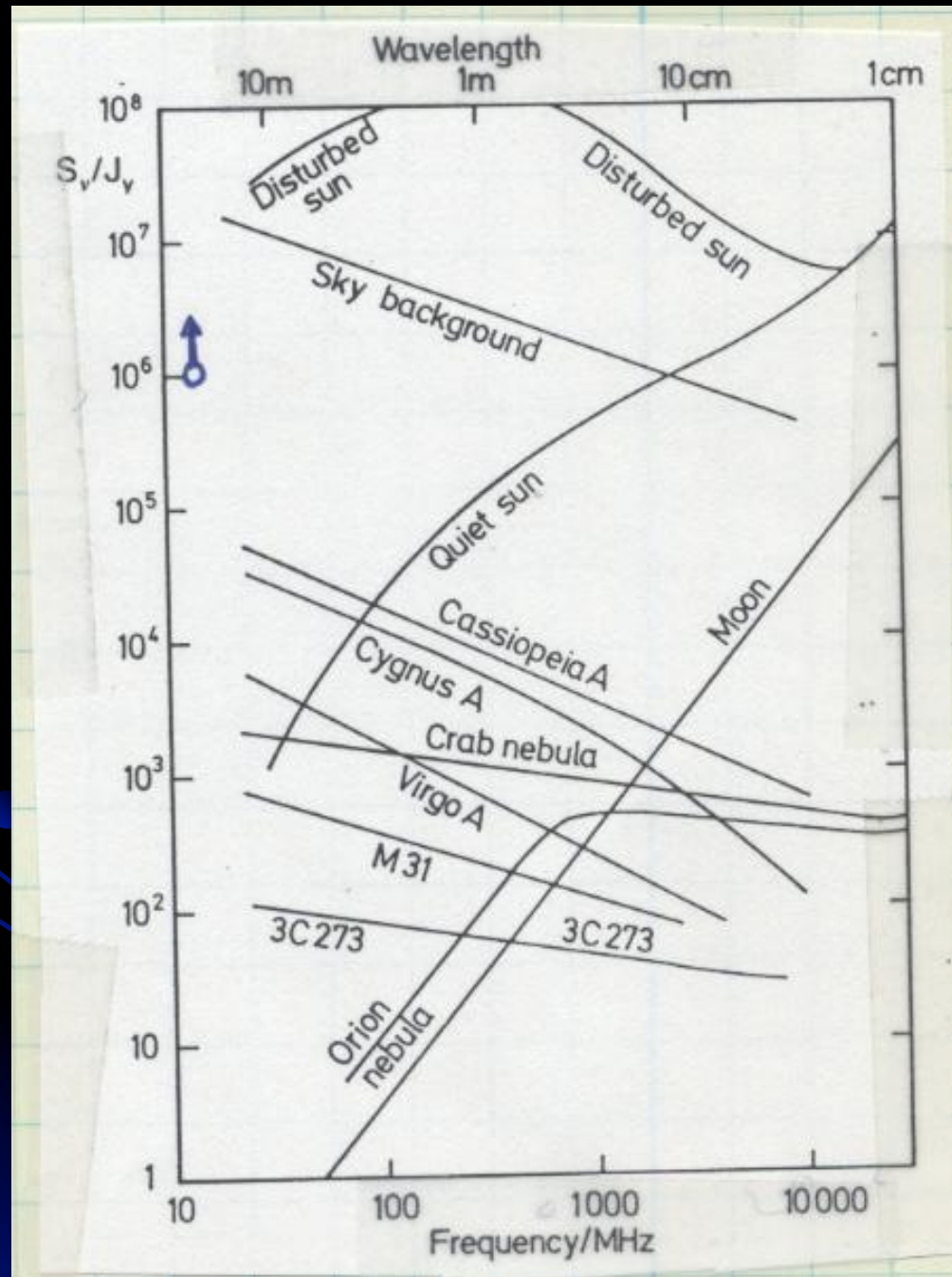


Antenas y Casualidad

En torno a 1940, Grote Reber construye la primera antena parabólica y el primer mapa en radio del cielo.

Frecuencia: 3300-900 MHz

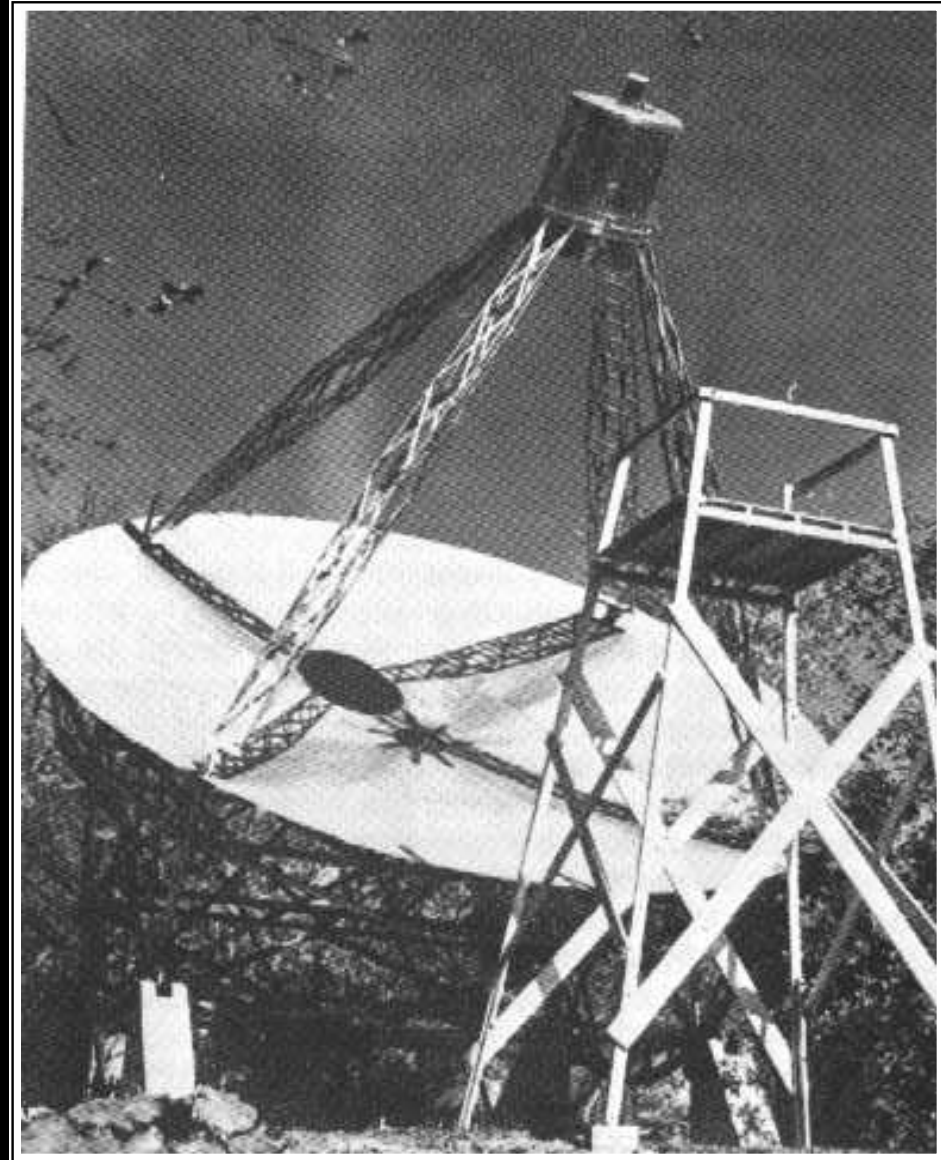


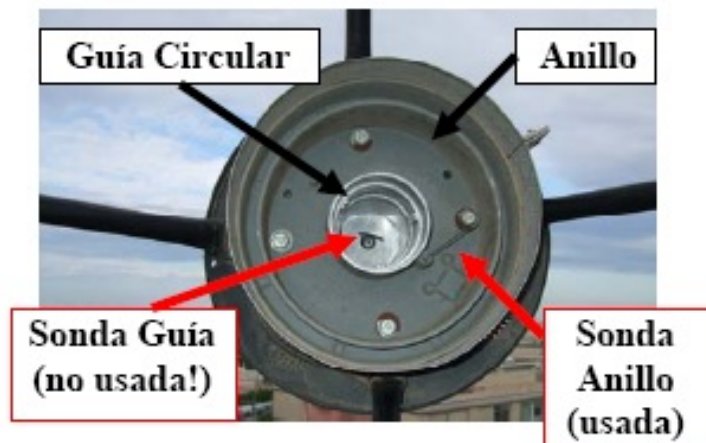
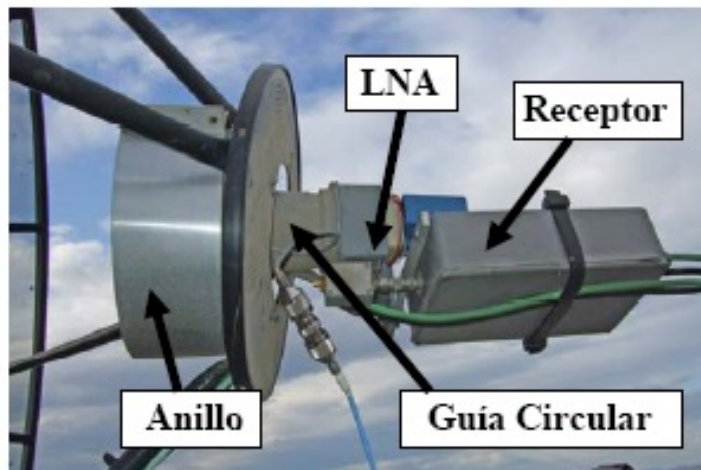


$S \propto \nu^{**2}$ –cuerpo negro

$S \propto \nu^{**(-0.7)}$ -sincrotron

Antenas y Casualidad

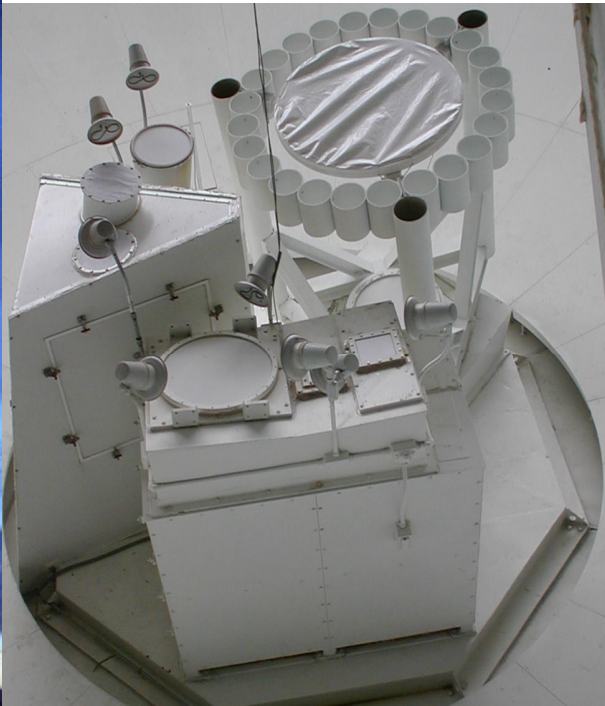






VLBA Antenna located at Fort Davis, TX

The colored beam illustrates how the radio signal from the source is reflected from the dish to the subreflector and into the feed horn of the receiver.



El mapa del cielo de G. Reber

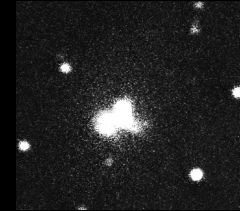
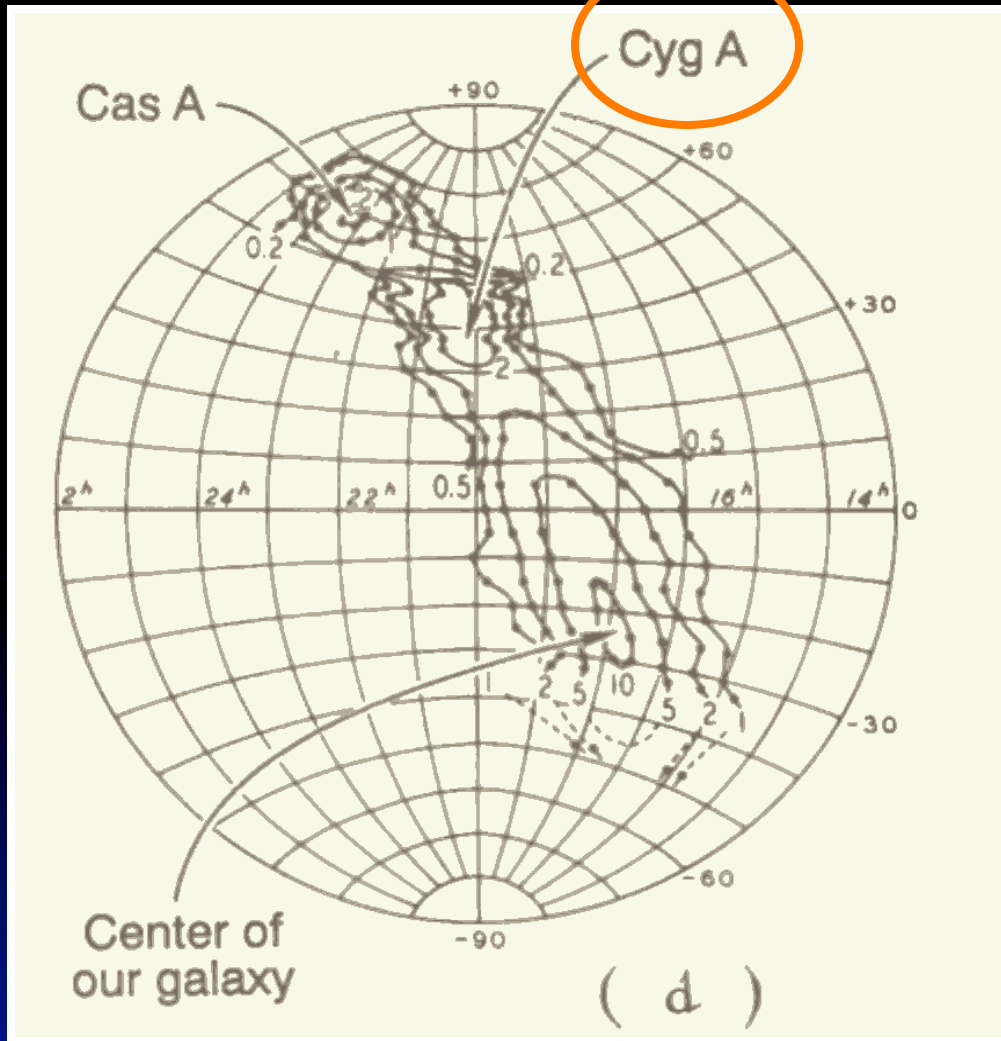


Imagen de Cygnus A tomada con un telescopio óptico

El mapa del cielo de G. Reber

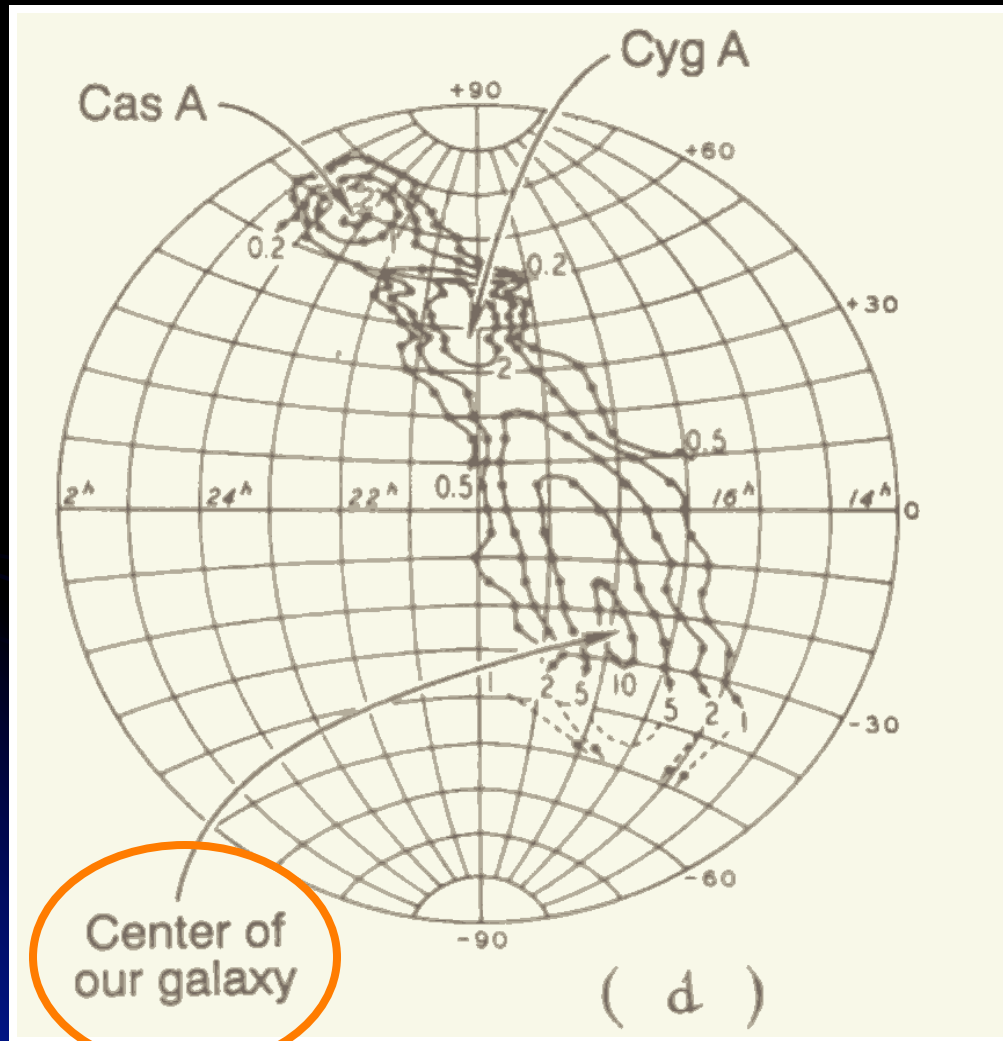
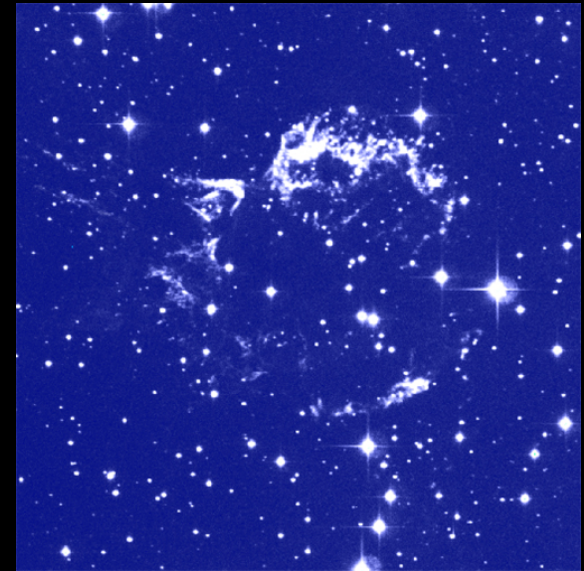
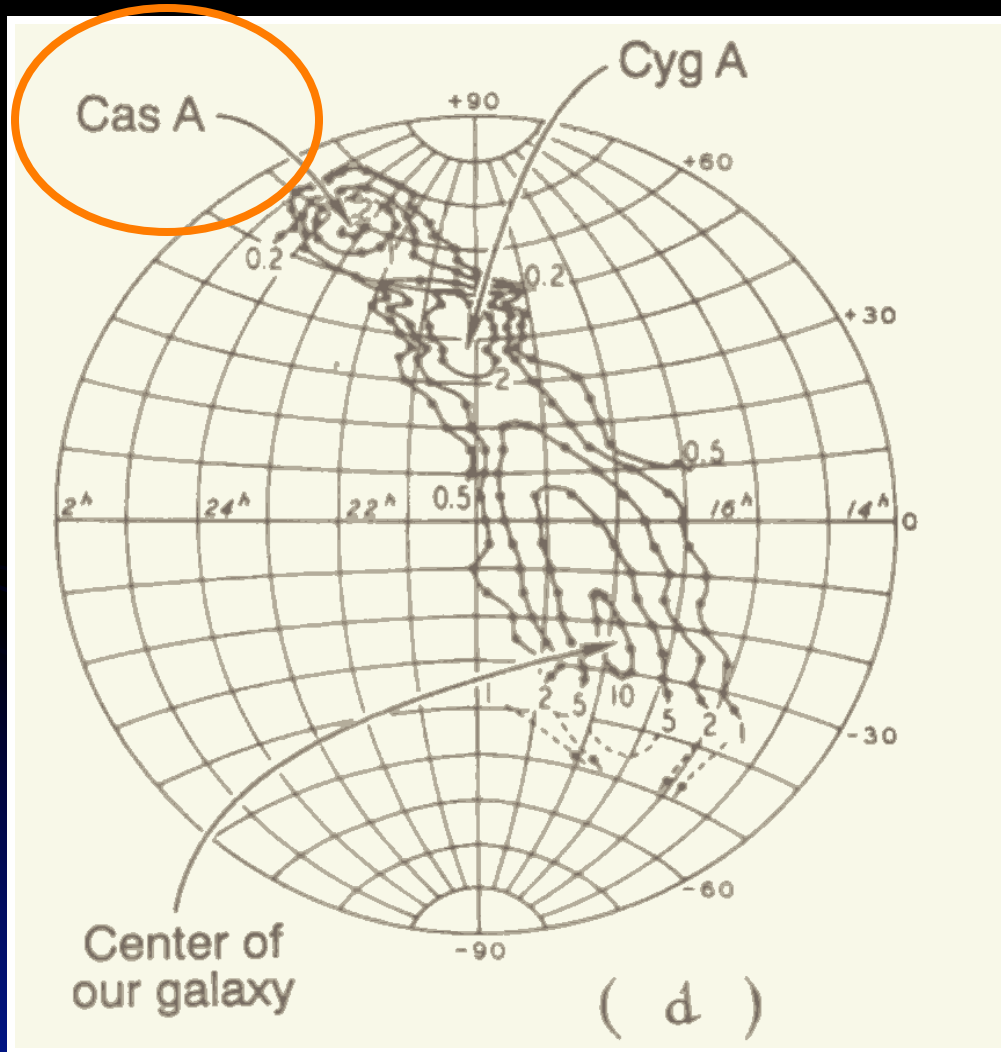


Imagen del centro de la Galaxia
tomada con un telescopio óptico

El mapa del cielo de G. Reber



óptico

Resolución / Difracción

Los astrónomos ópticos no dieron importancia a los descubrimientos de Reber. La resolución era muy baja.

$$\text{Resolución} = \frac{\lambda}{D}$$

$$\lambda = 10 \text{ cm}$$

$$D = 5 \text{ m}$$

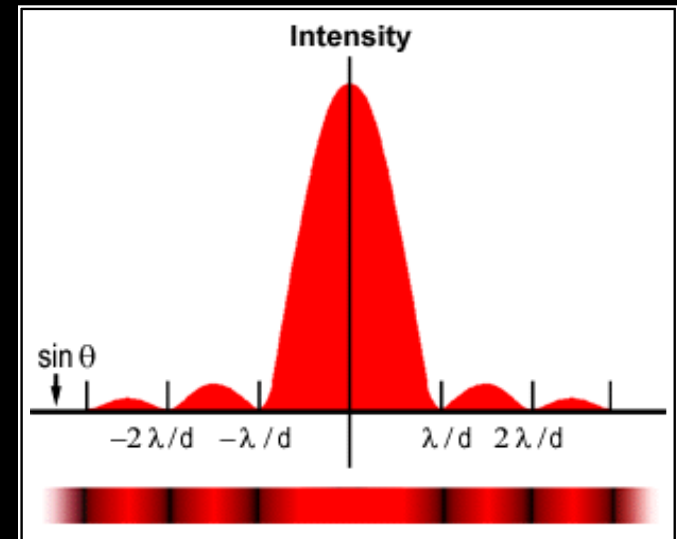
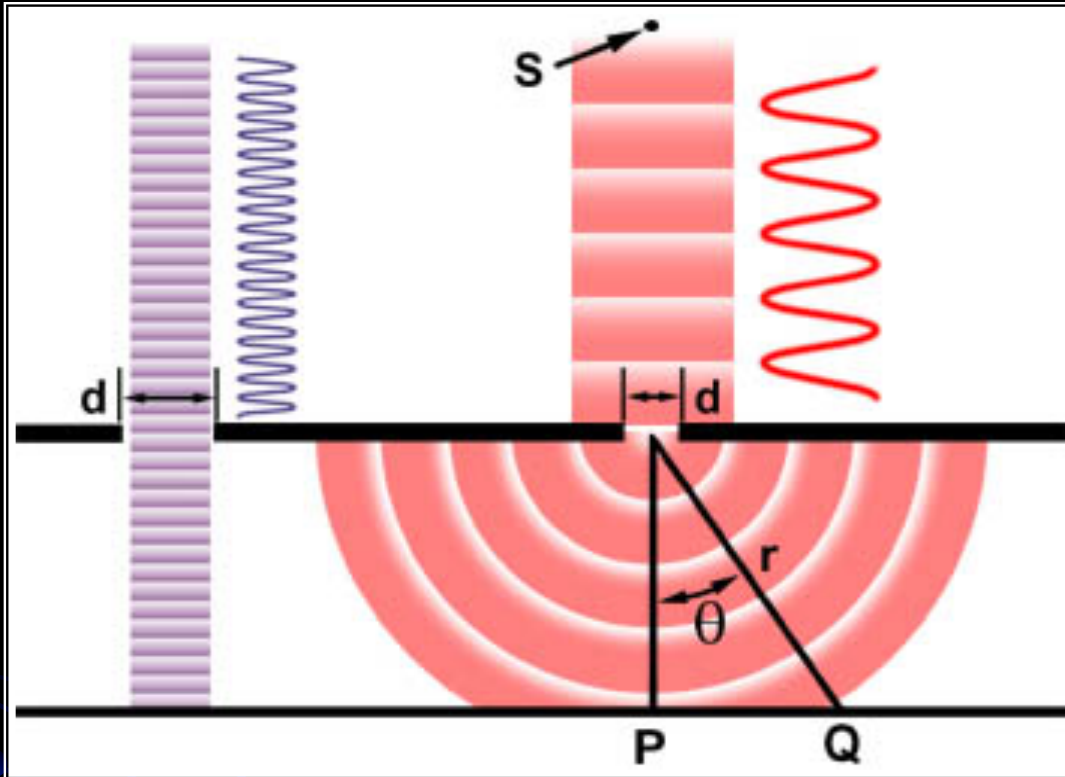
$$R = 1^\circ \quad (\text{radio})$$

$$\lambda = 500 \text{ nm}$$

$$D = 2.4 \text{ m}$$

$$R = 0.04'' \quad (\text{óptico})$$

Resolución / Difracción



*En el rango de radio, la resolución viene limitada por el fenómeno de difracción (**límite de difracción**)*

*En el rango óptico, la resolución viene limitada por **irregularidades de la atmósfera***

Resolución / Difracción

Los astrónomos ópticos no dieron importancia a los descubrimientos de Reber. La resolución era muy baja.

$$\text{Resolución} = \frac{\lambda}{D}$$

$$\lambda = 10 \text{ cm}$$

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$$R = 1^\circ \quad (\text{radio})$$

$$\lambda = 500 \text{ nm}$$

$$D = 2.4 \text{ m}$$

$$R = 1'' \quad (\text{óptico})$$

Radiotelescopios del mundo...

A
C

H
M

SE
Parkes

Onsala

Nobeyama

TIGO

Lovell

K

A
APE



How to improve your resolution?

$$\text{Resolution} = \frac{\lambda}{D}$$

Pico Veleta, 30 m

sub-mm
wavelengths



increasing D: the size matters (?)

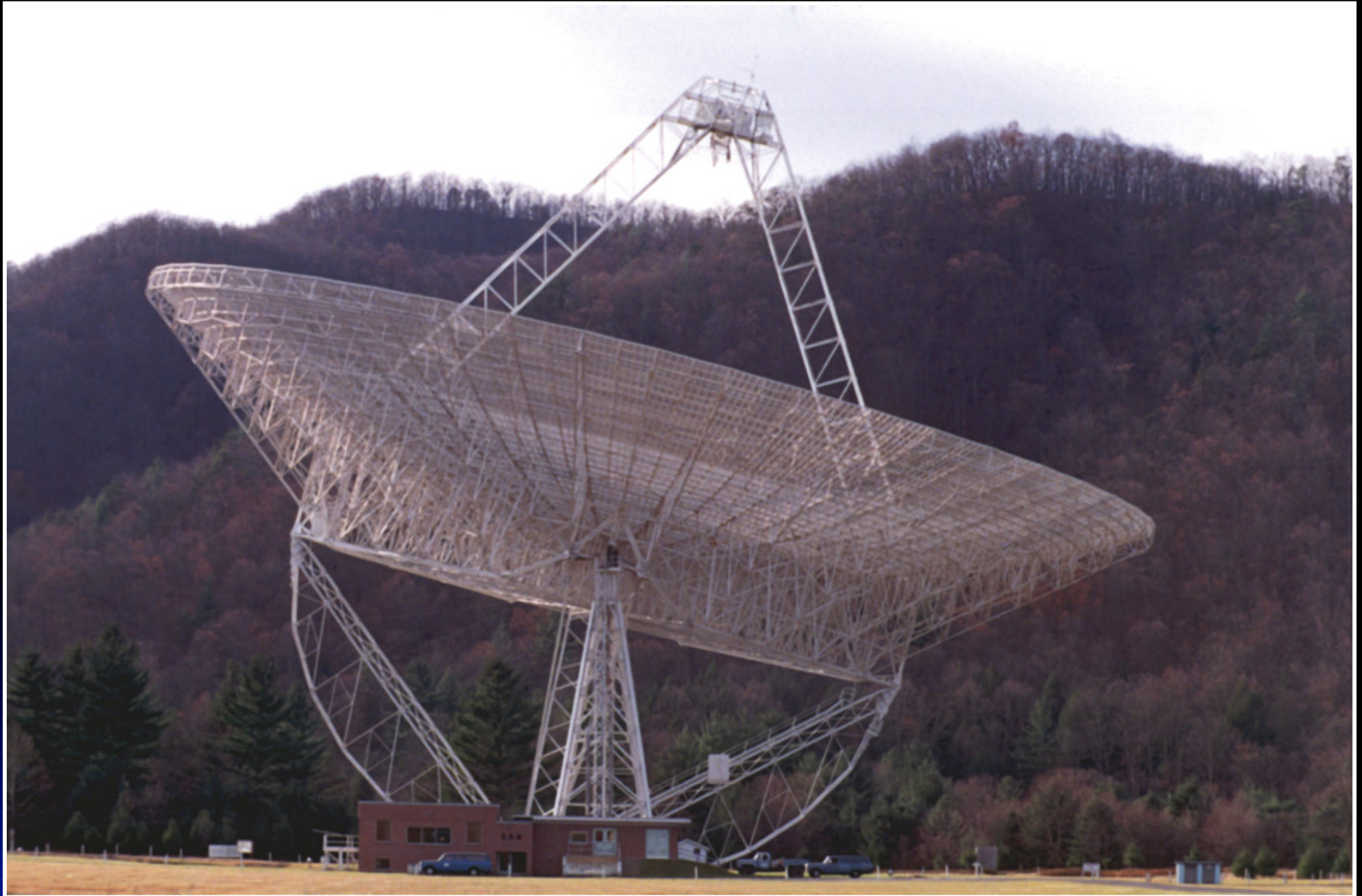
Green Bank (USA) --100x110m--



Effelsberg (Germany) --100m--



increasing D: the size matters (?)



increasing D: the size matters (?)





Resolución / Difracción

Los astrónomos ópticos no dieron importancia a los descubrimientos de Reber. La resolución era muy baja.

$$\text{Resolución} = \frac{\lambda}{D}$$

$$\lambda = 3.6\text{cm}$$

$$D = 100\text{ m}$$

$$R = 74'' \quad (\text{radio})$$

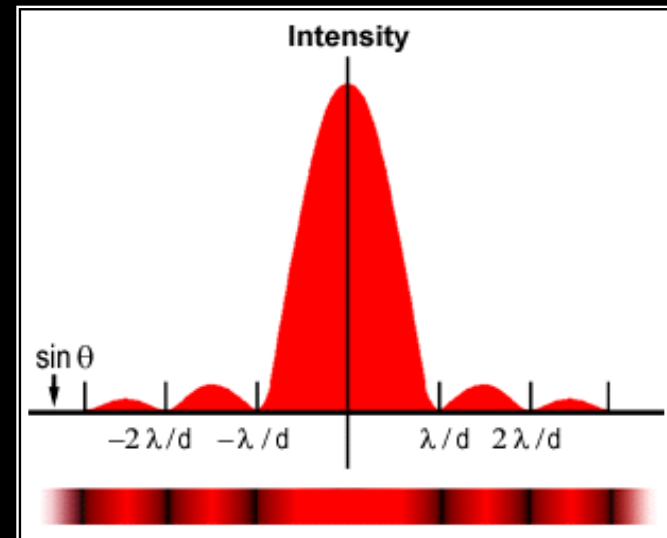
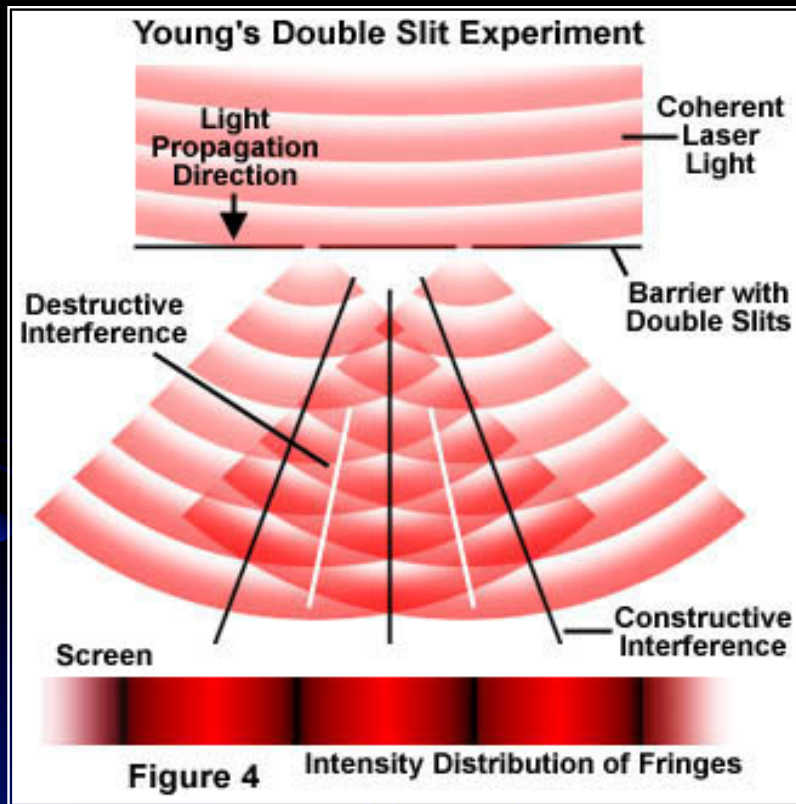
$$\lambda = 500\text{nm}$$

$$D = 2.4\text{m}$$

$$R = 0.04'' \quad (\text{óptico})$$

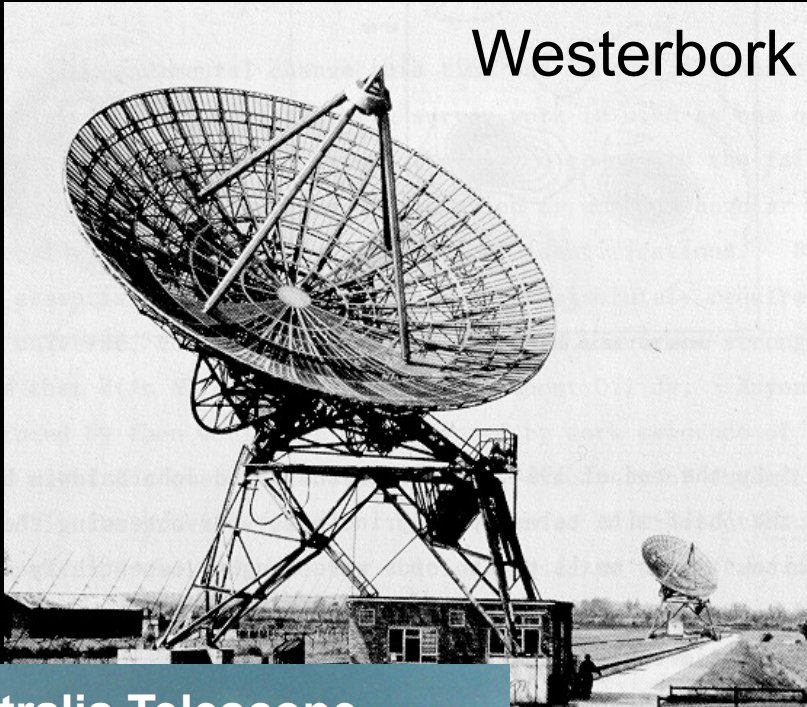
INTERFEROMETRÍA

en busca de un aumento en resolución

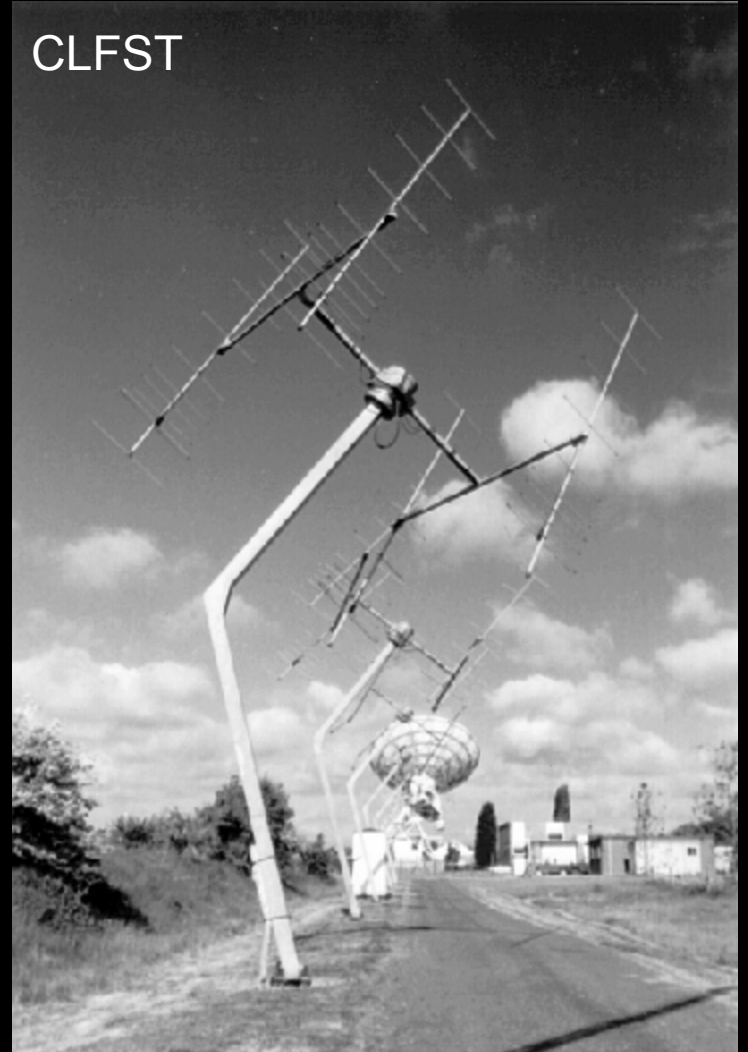


Radiotelescopios del mundo...

Westerbork



CLFST



ATCA: Australia Telescope Compact Array





VLA (Very Large Array):
Conjunto de 27 antenas
individuales con 25m de
diámetro cada una.

**Situación: Socorro, Nuevo
México, EE.UU., a una
altitud de 2100m.**



Esta red de telescopios
puede alcanzar una
resolución angular
equivalente a la de un
único radiotelescopio de
36km de diámetro.

Imágenes: NRAO (Socorro)

VLA, Socorro, EE.UU.



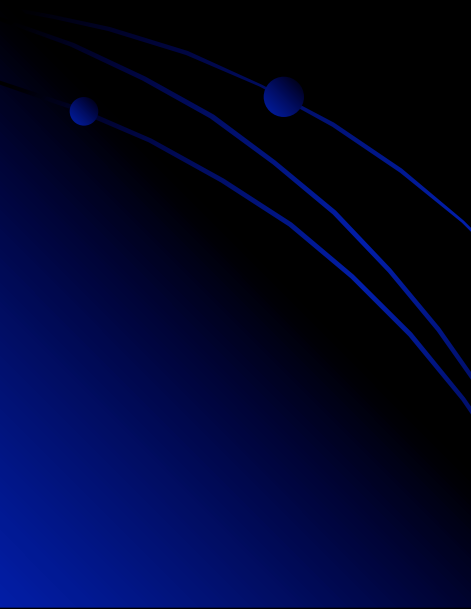
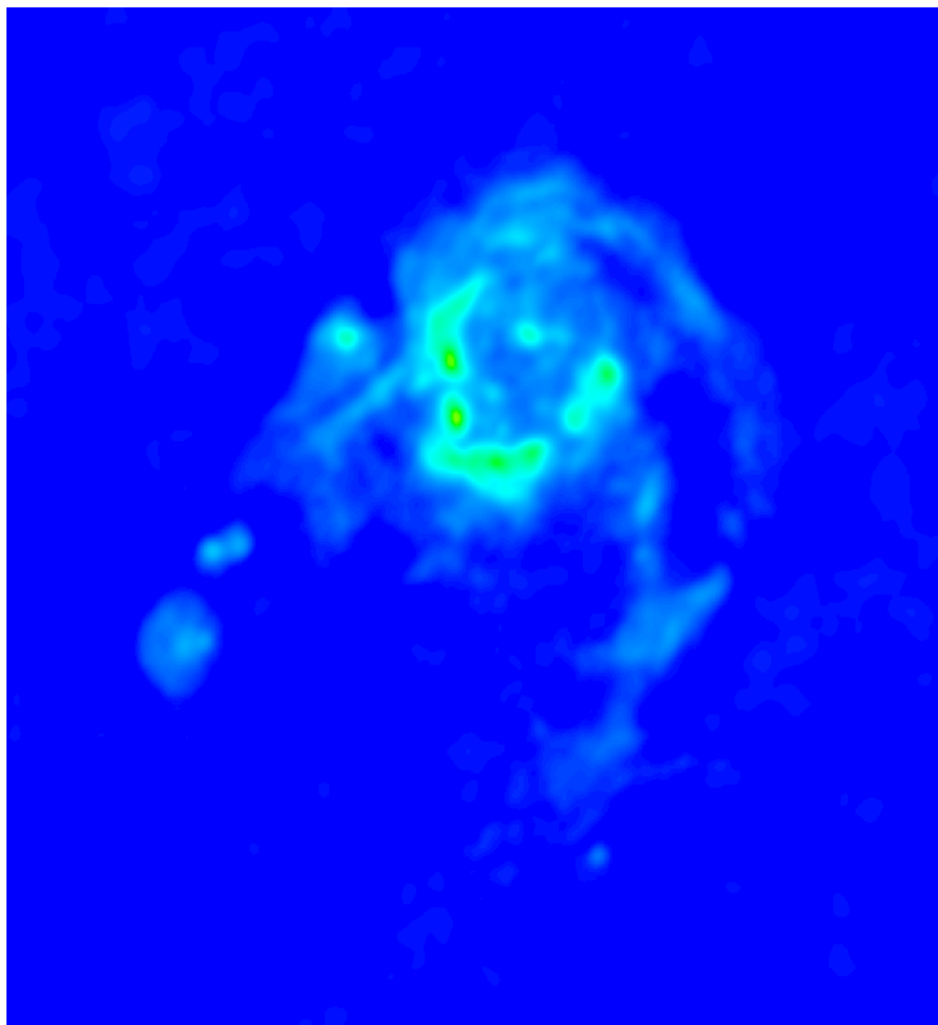
Contact



Director: Robert Zemeckis
Protagonista: Jodie Foster
Guión según la novela homónima de Carl Sagan

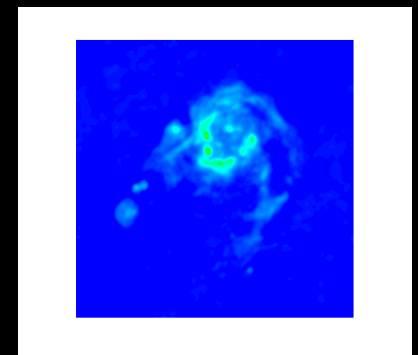
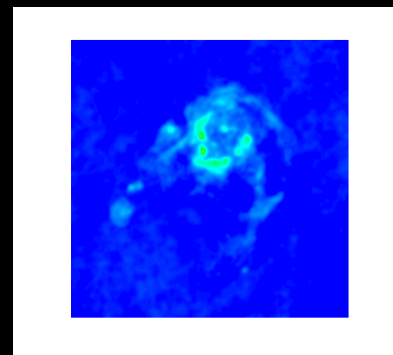
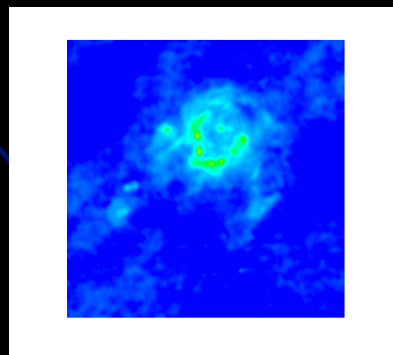
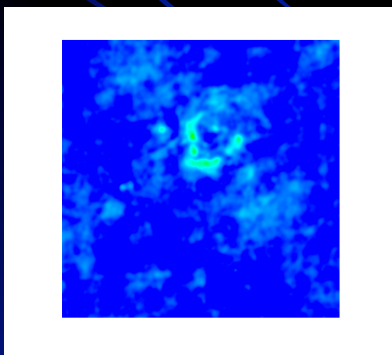
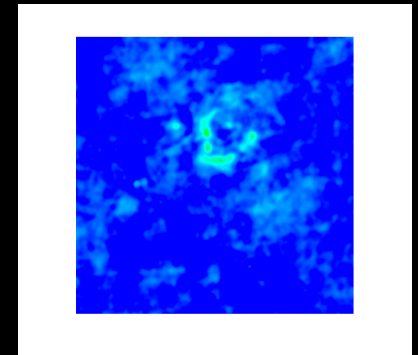
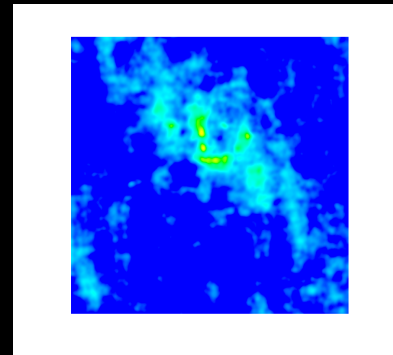
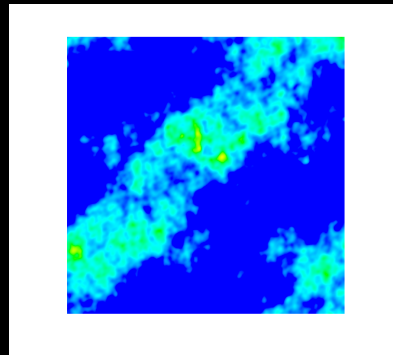
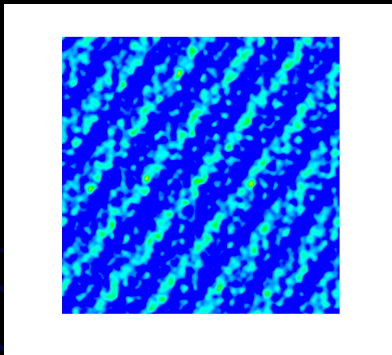
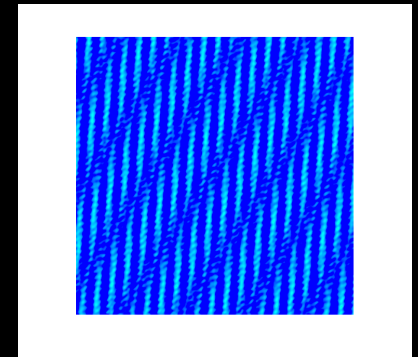
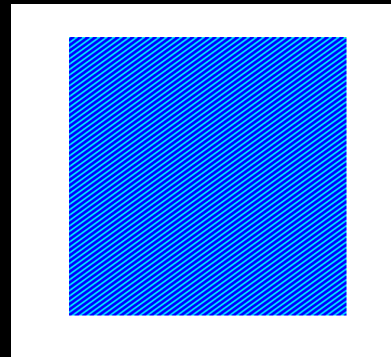
Interferometría: símil óptico

- Tenemos un telescopio: ¿es posible tener una buena imagen incluso con una máscara que cubra el objetivo?
- ¿Cómo cambia la calidad con el número de agujeros?
- Prueba
 - Elegir una imagen representativa
 - Añadir agujeros a una máscara
 - Empezar con dos agujeros y duplicar en cada paso



Símil óptico

Duplicamos en nº de agujeros en cada paso
• 2, 4, 8, 16, 32, 64, 128, 256, 512,
1024



INTERFEROMETRÍA CONEXA

Very Large Array (VLA)



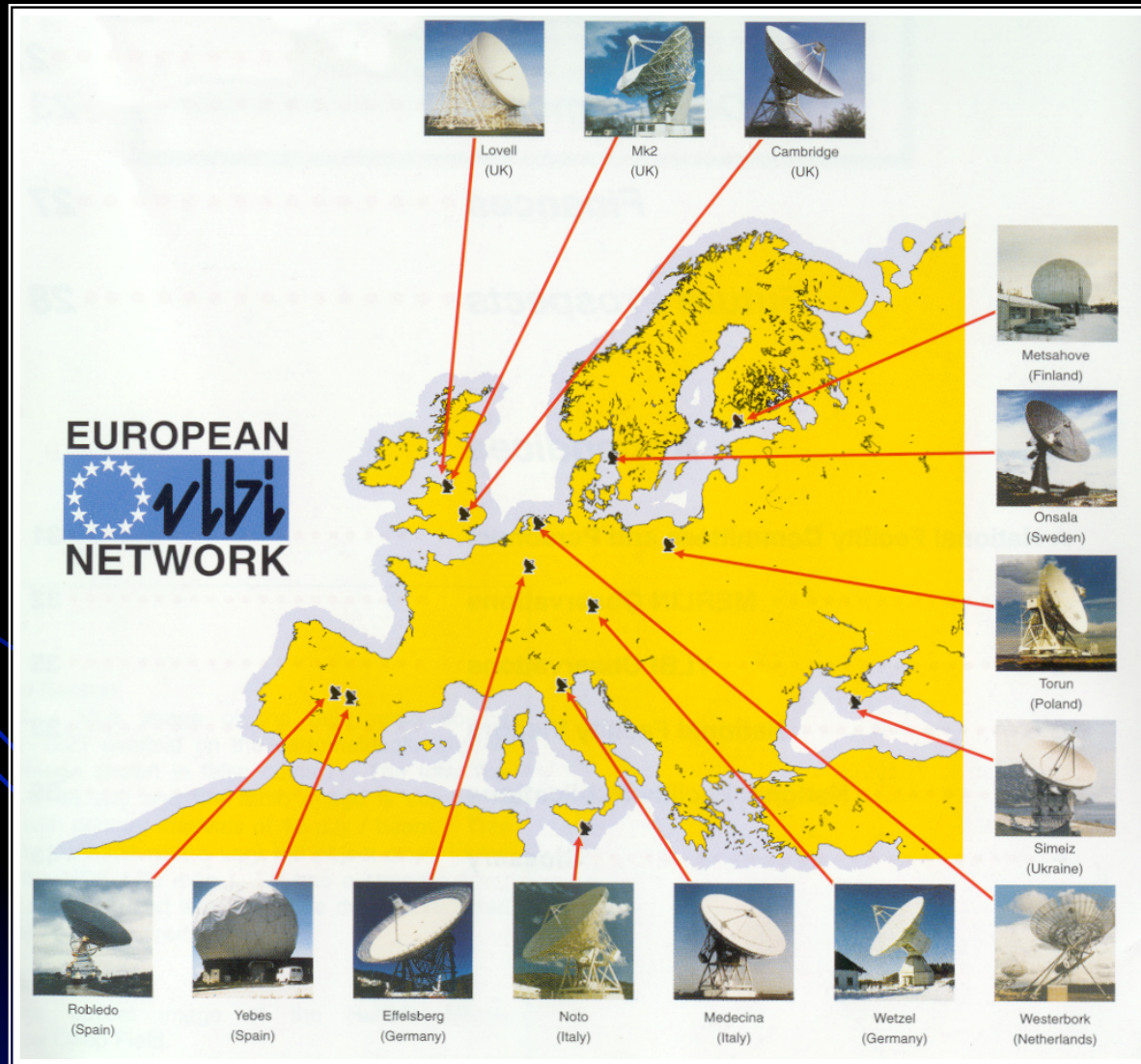
Interferometría intercontinental



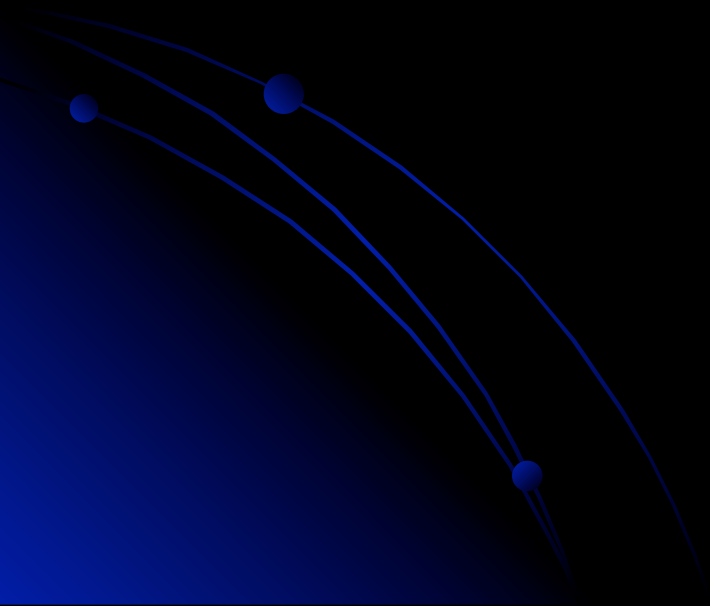
- Very-Long-Baseline Interferometry (VLBI)
- Resolución $100\times$ HST

INTERFEROMETRÍA

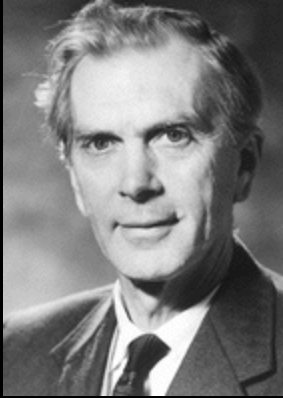
Formación de Imágenes



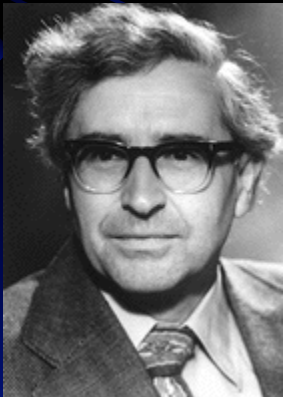
**¡Ya podemos realizar imágenes en radio y
comparar con el óptico!**



Nobel 1974: radioastronomía (síntesis de apertura y púlsares)



Sir Martin Ryle
(1918-1984)
Univ. Cambridge, R.U.



Antony Hewish
(n. 1924)
Univ. Cambridge, R.U.

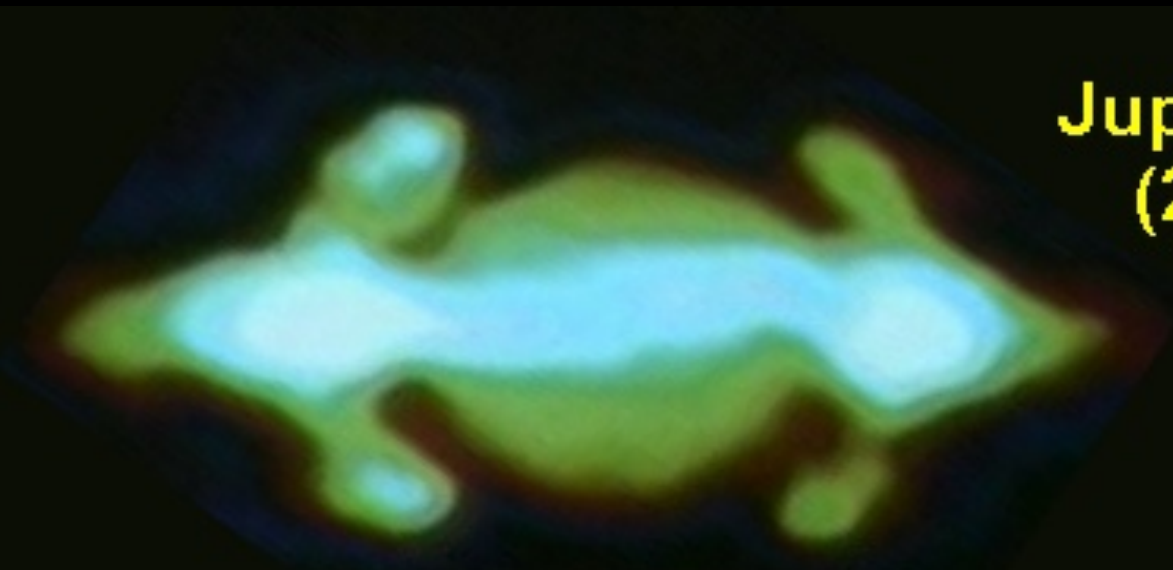
- Ryle por sus descubrimientos en radioastronomía, en particular, el principio de síntesis de apertura utilizado en interferometría
- Hewish por su papel en el descubrimiento de los púlsares (su estudiante de doctorado Jocelyn Bell, fue la verdadera descubridora)

Nobel 1974: radioastronomía (síntesis de apertura y púlsares)

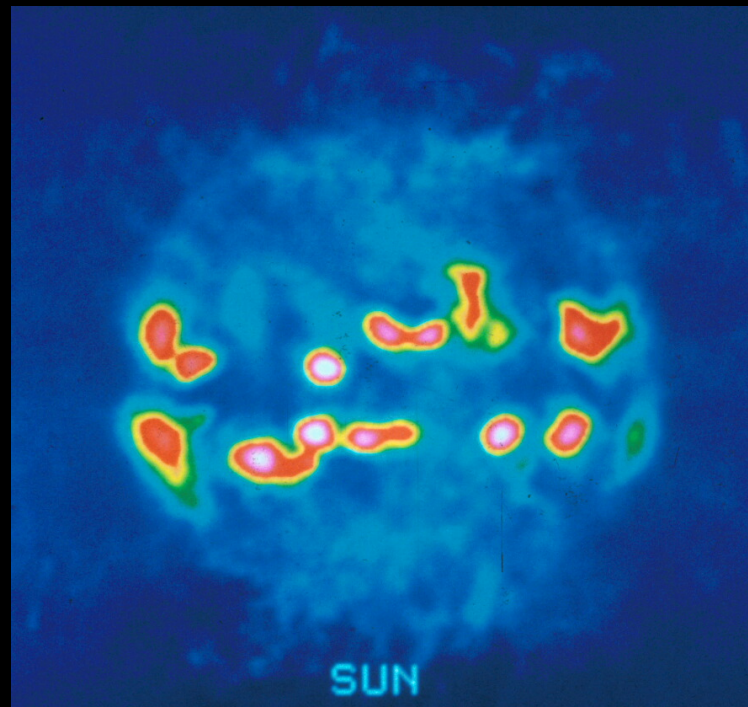


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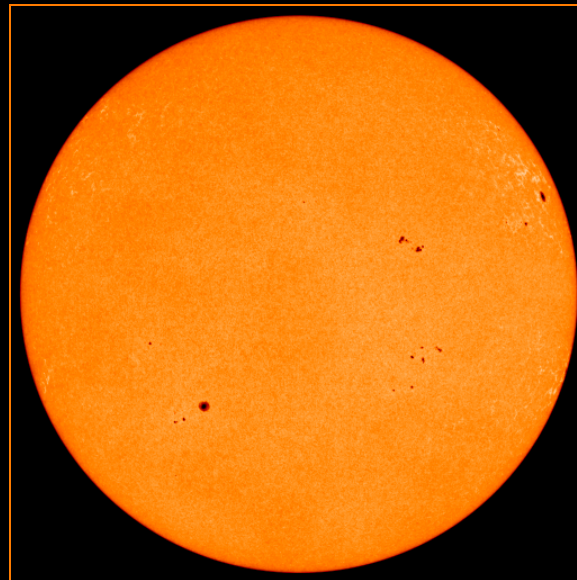
**Jupiter: radio
(21 cm)**



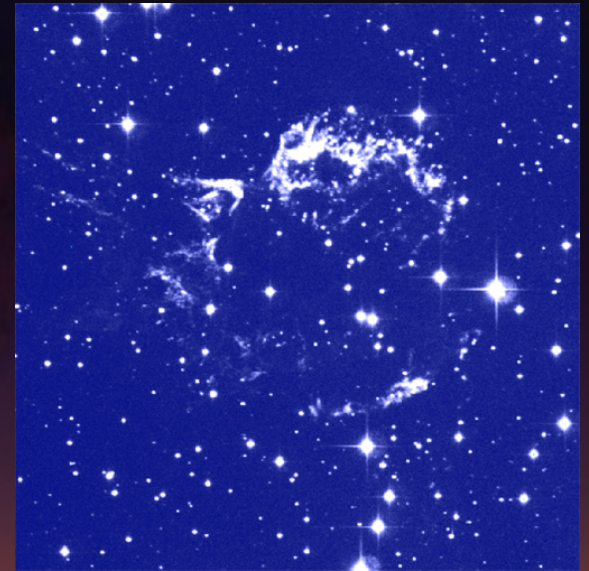
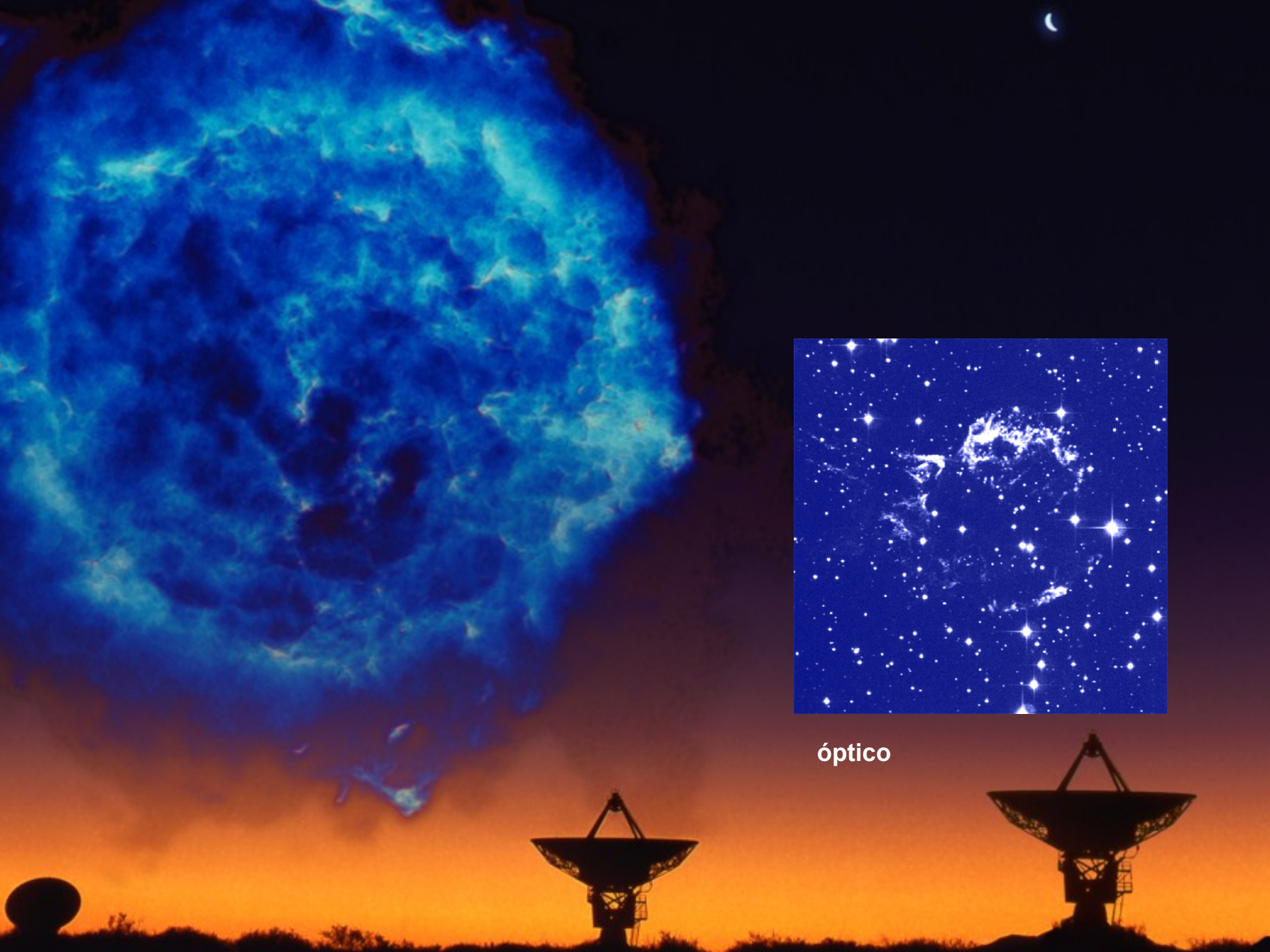
Jupiter: visible



Radio



Visible

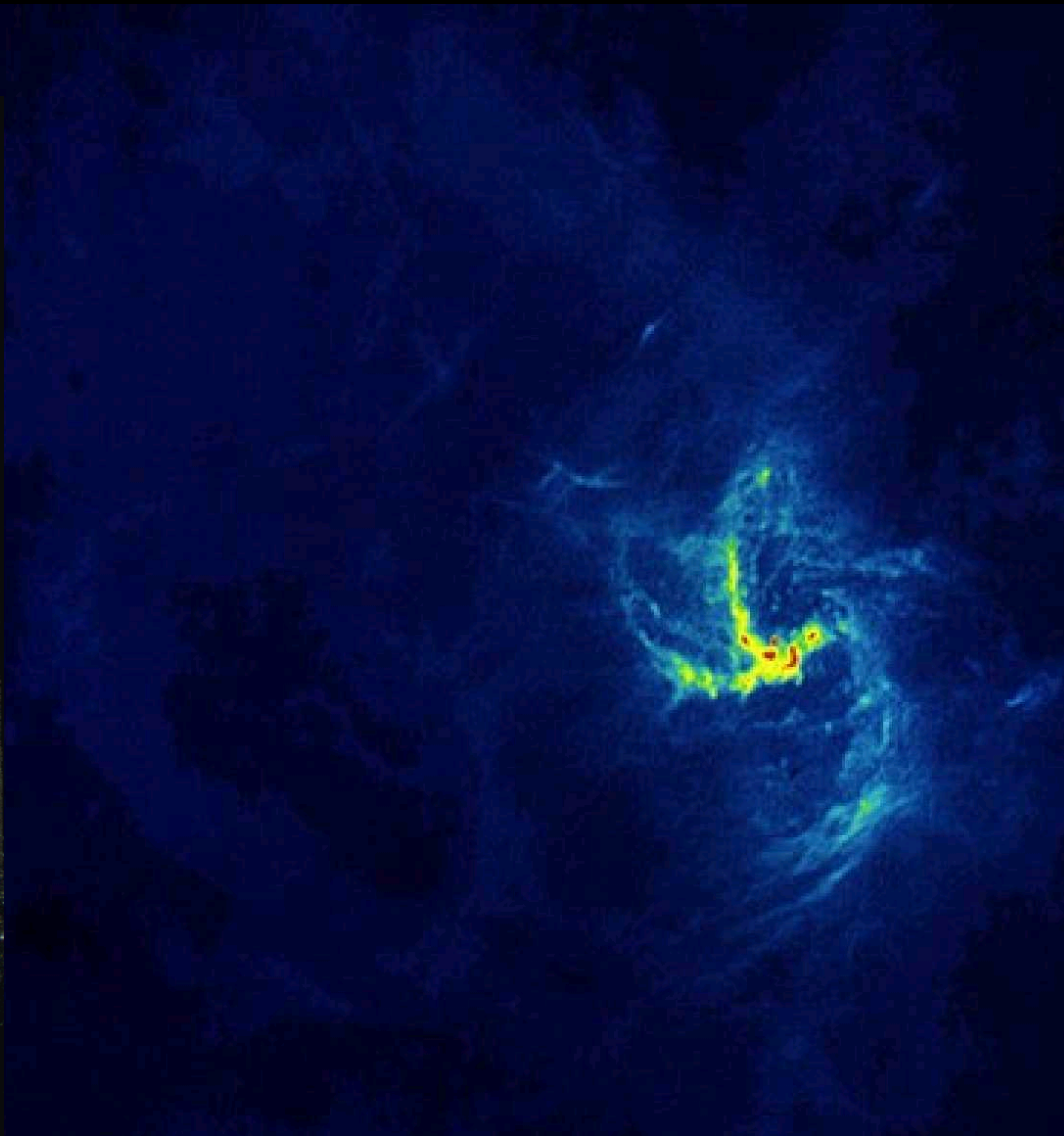


óptico

El Centro Galáctico

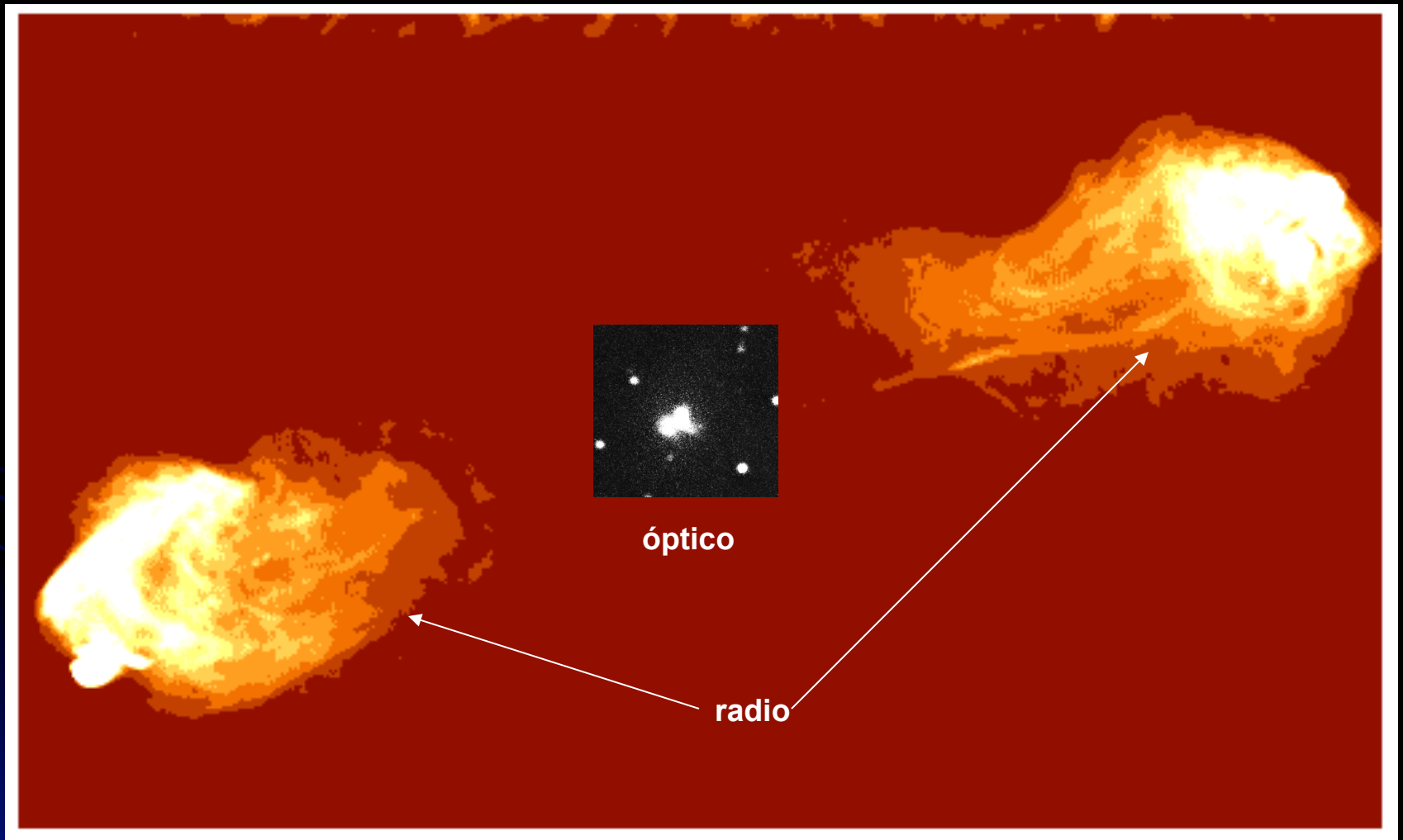


óptico



radio

Cygnus A



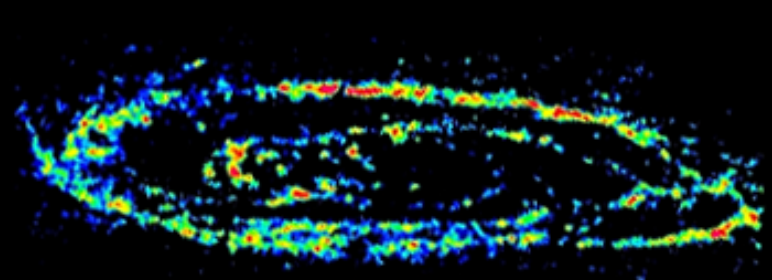
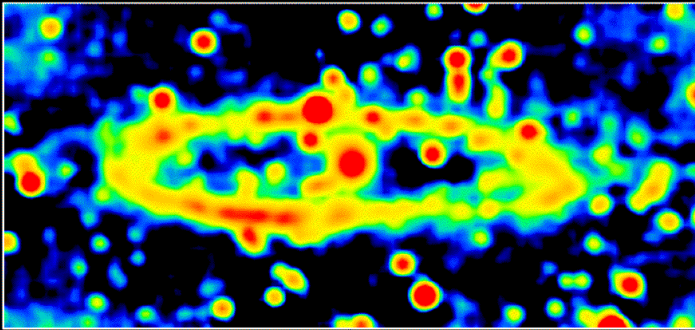
Radioemisión – CO, 5GHz

a) M31: Luz visible

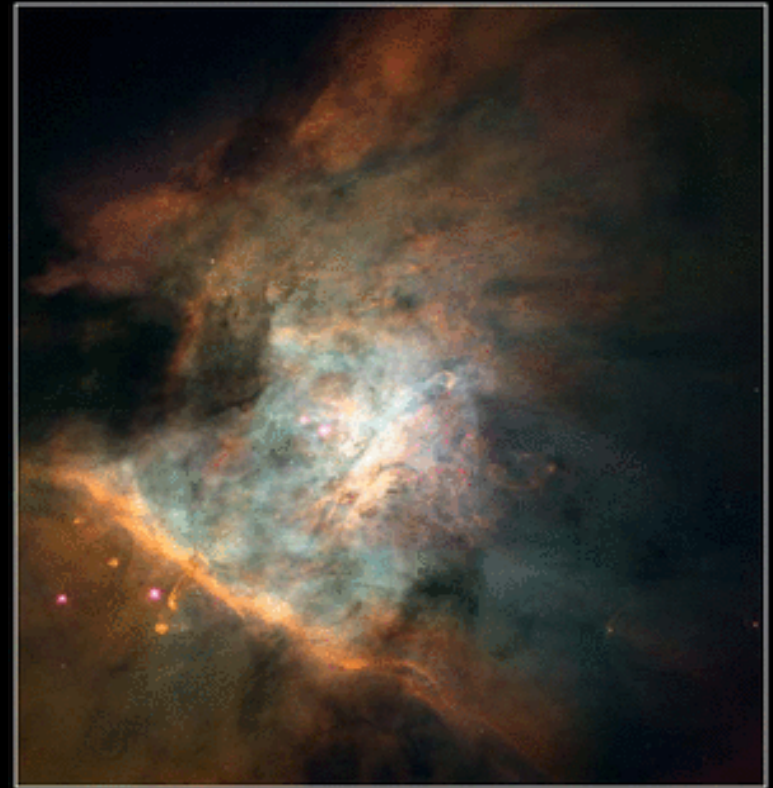
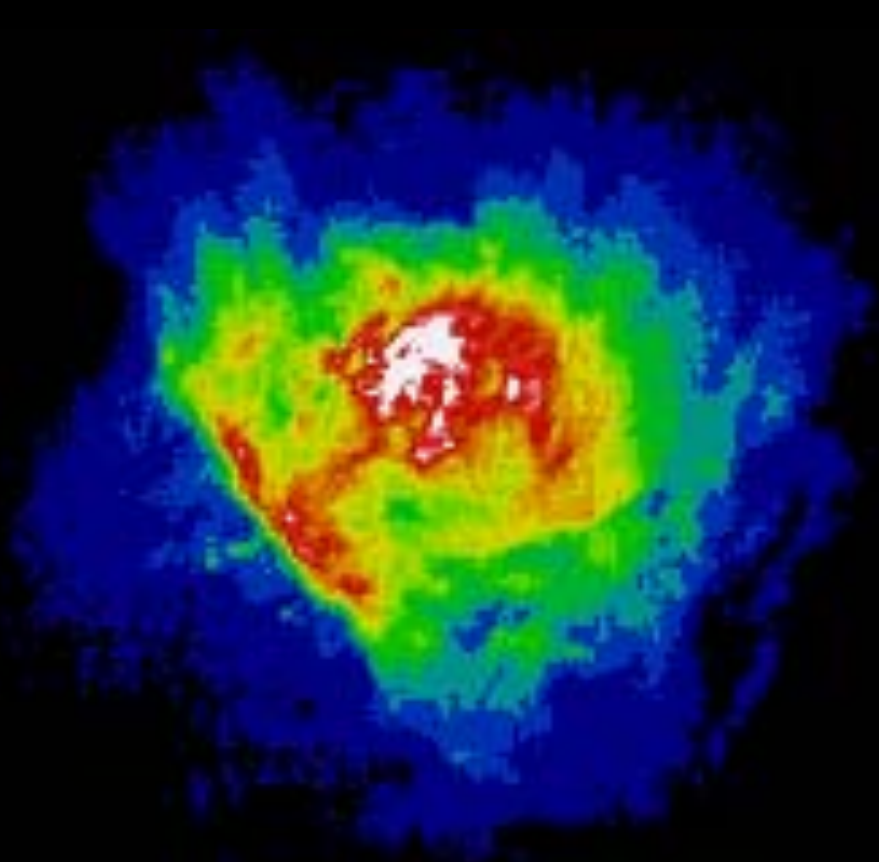


b) M31: Emisión en radiofrecuencia (6cm, CO)

Die Andromeda-Galaxie bei 6cm (100-m-Teleskop Effelsberg)



Emisión de gas ionizado



Orion Nebula Mosaic

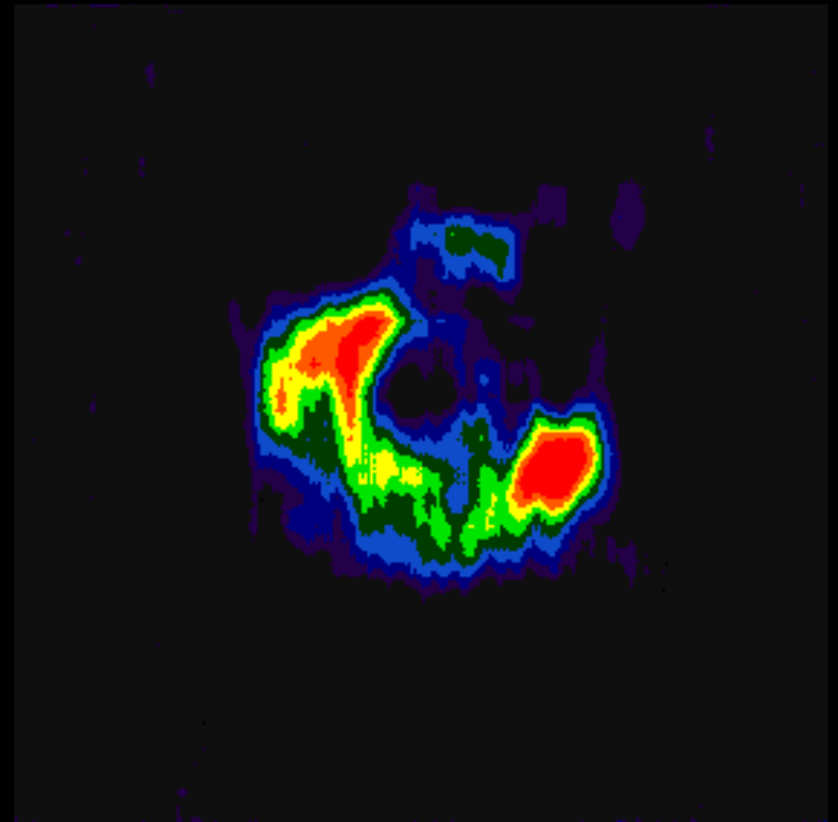
HST · WFPC2

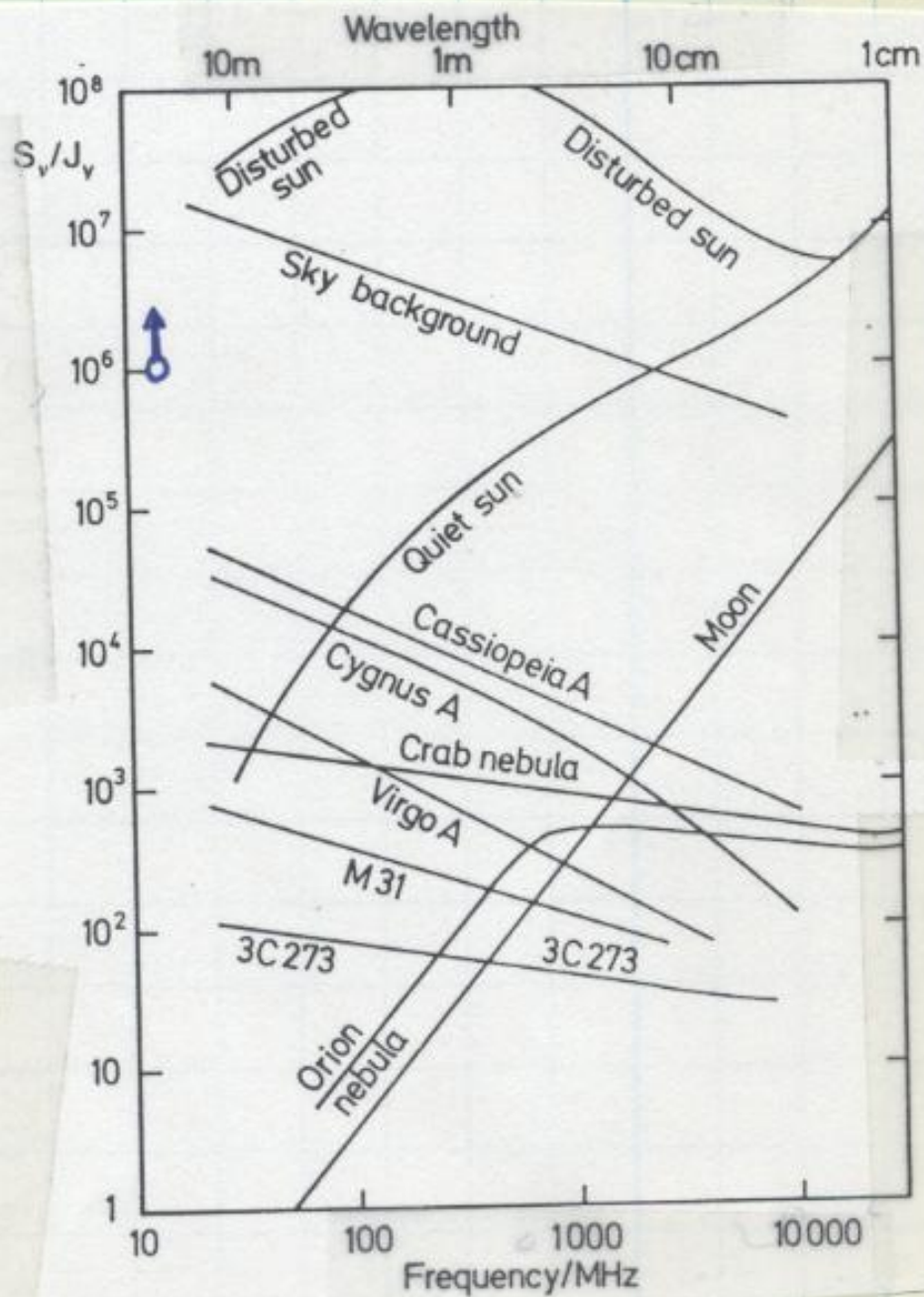
PRC95-45a · ST ScI OPO · November 20, 1995

C. R. O'Dell and S. K. Wong (Rice University), NASA

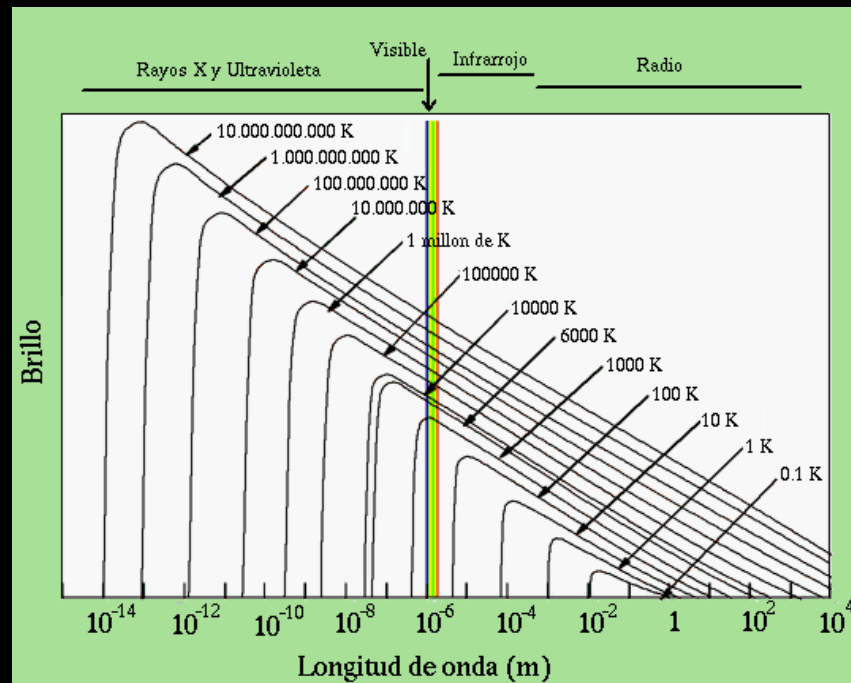
Nebulosa de Orión

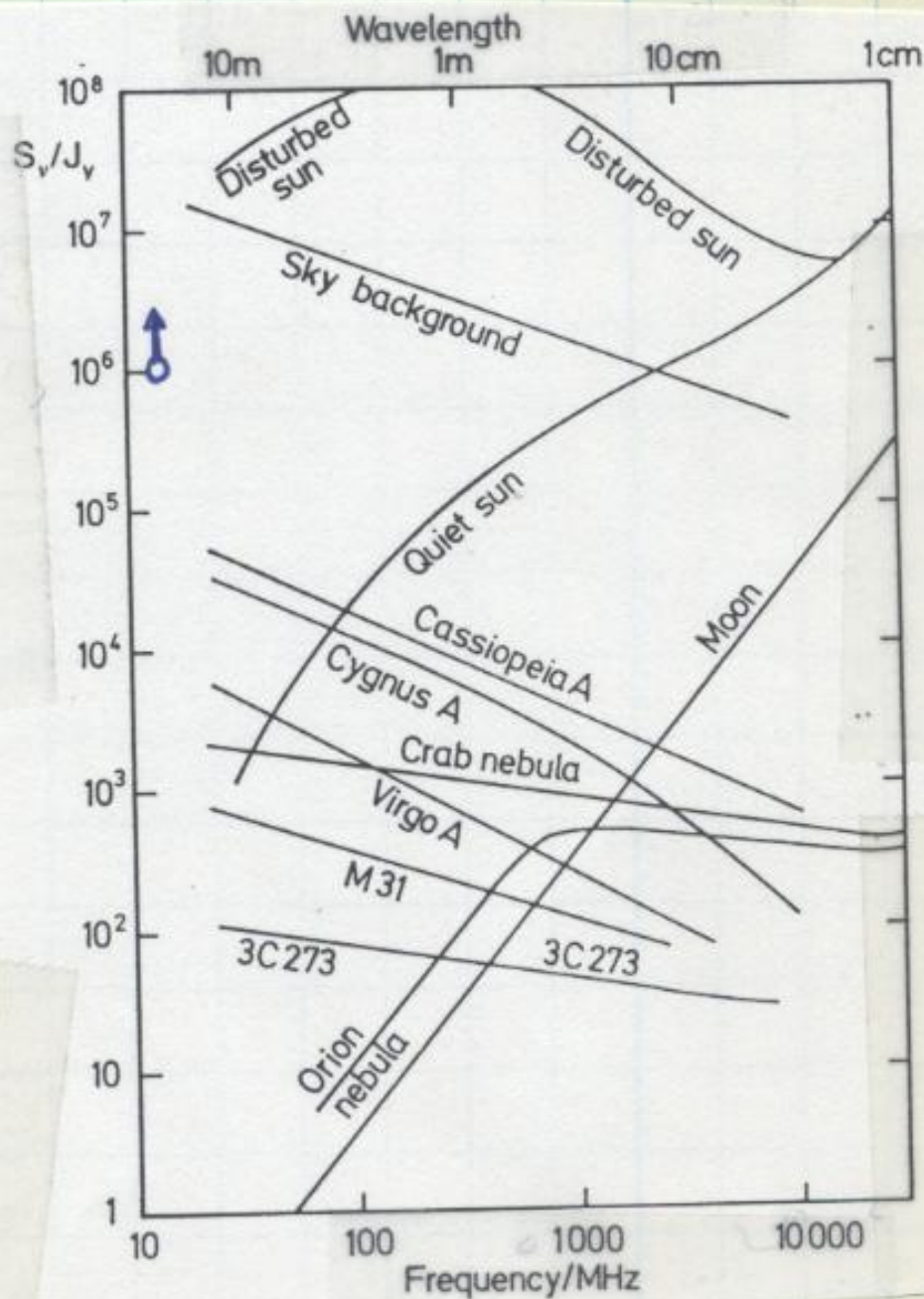
Bremsstrahlung (radiación libre-libre)





$$S \propto \nu^{**2} \text{ —cuerpo negro}$$





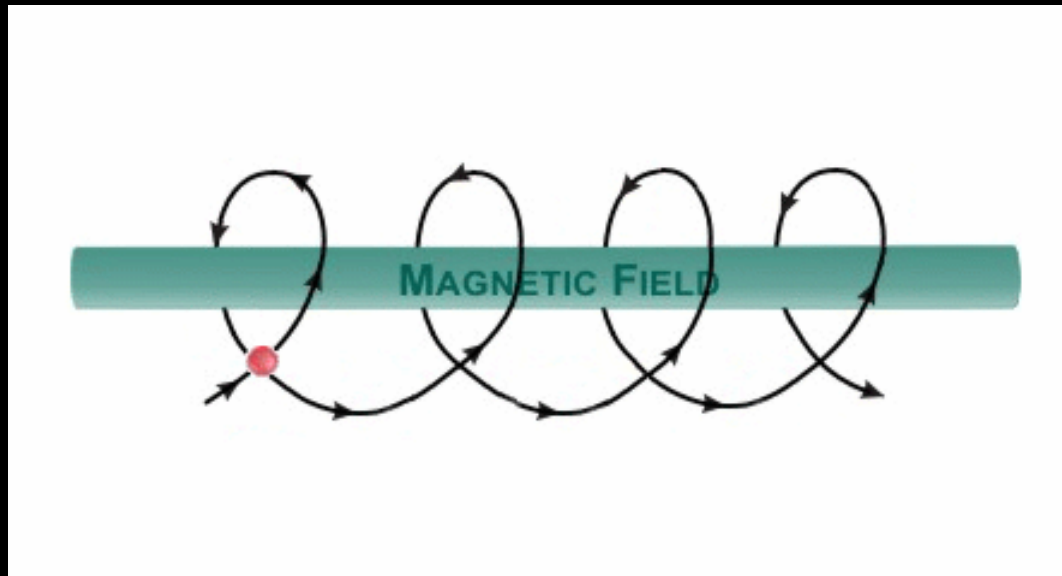
$S \propto \nu^{**2}$ –cuerpo negro

$S \propto \nu^{*(-0.7)}$ -sincrotron

*Cas A, SgrA y Cyg A, tienen el mismo tipo de emisión: **radiación sincrotrón***

Radiación sincrotrón: ocurre en presencia de electrones y campos magnéticos.

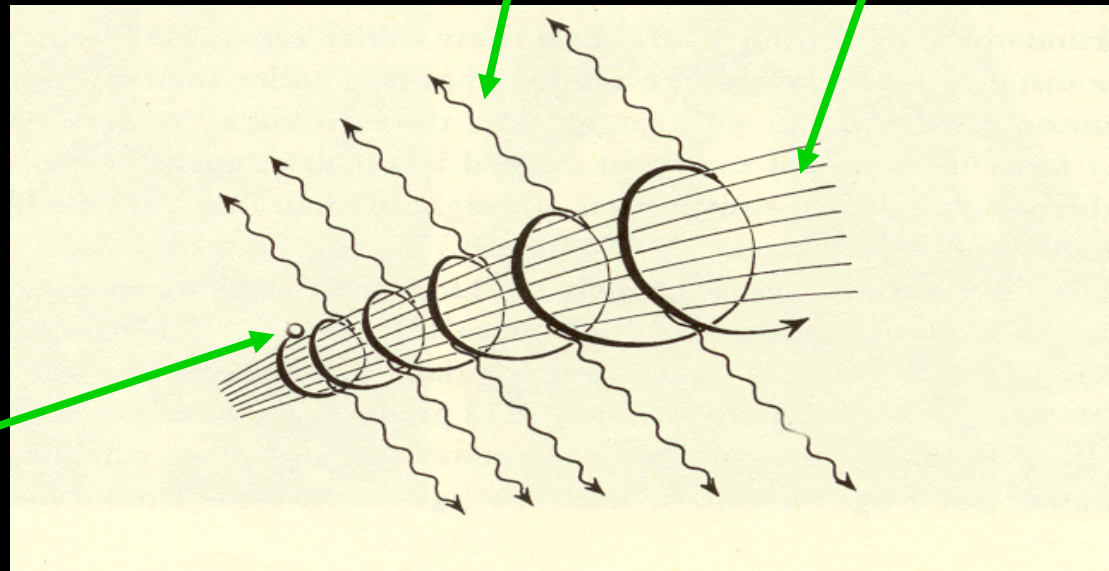
Radiación sincrotrón



Radiación
sincrotrón

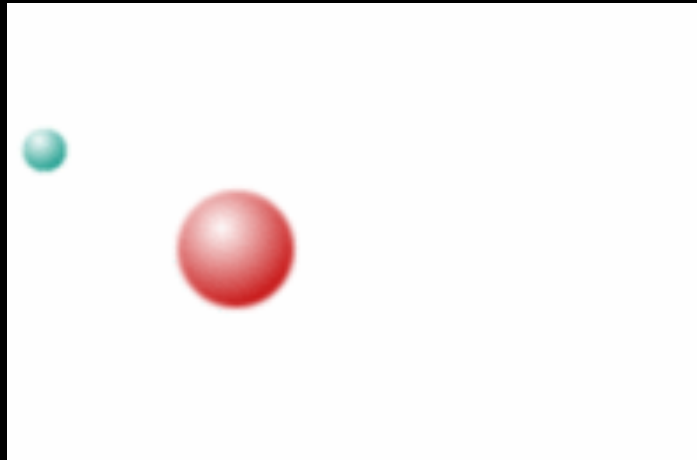
Campo
magnético

electrón



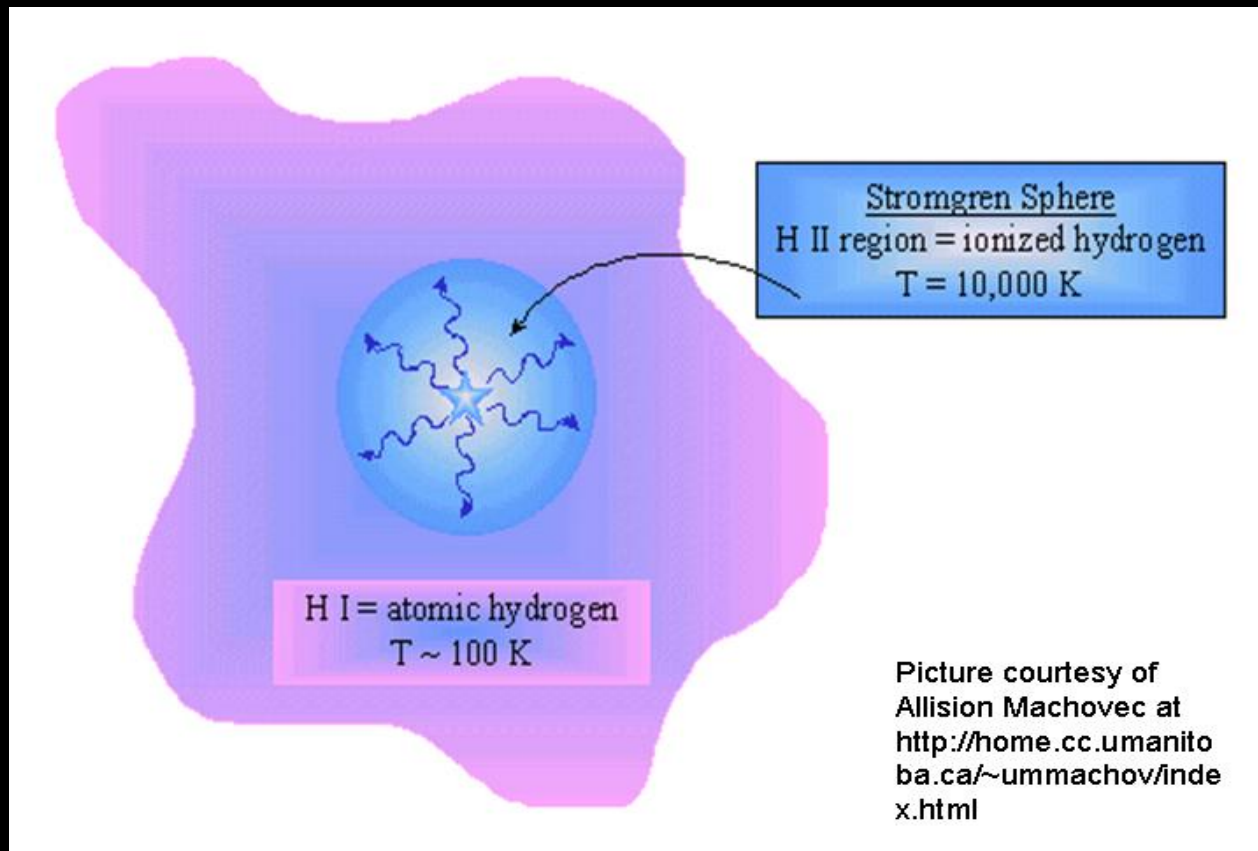
Radiación de frenado

Se emiten ondas EM

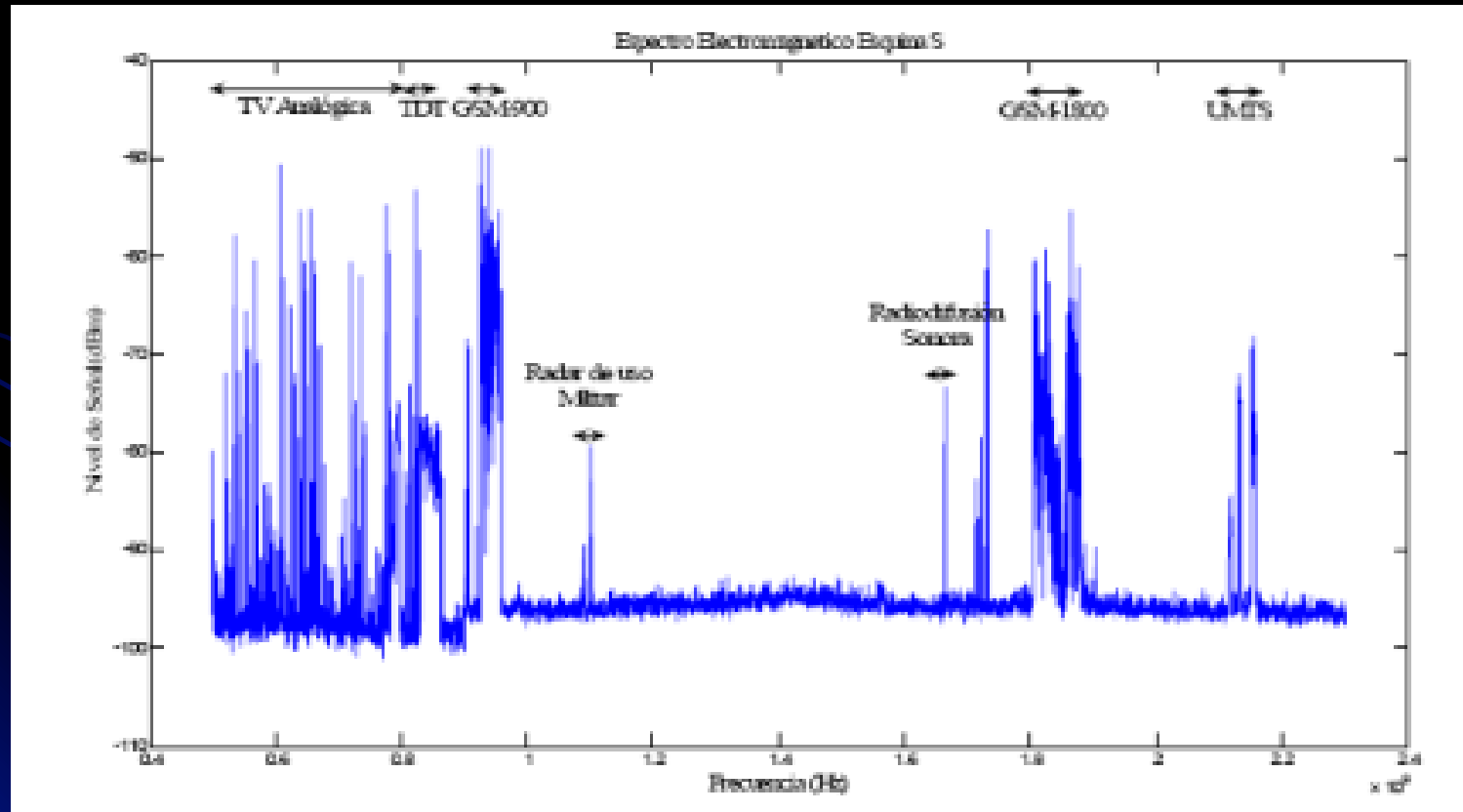


El electron “se frena” cuando pasa cerca de un protón.

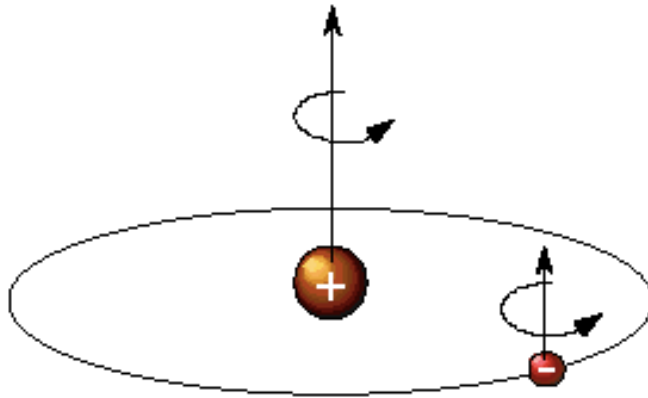
Emisión de gas ionizado



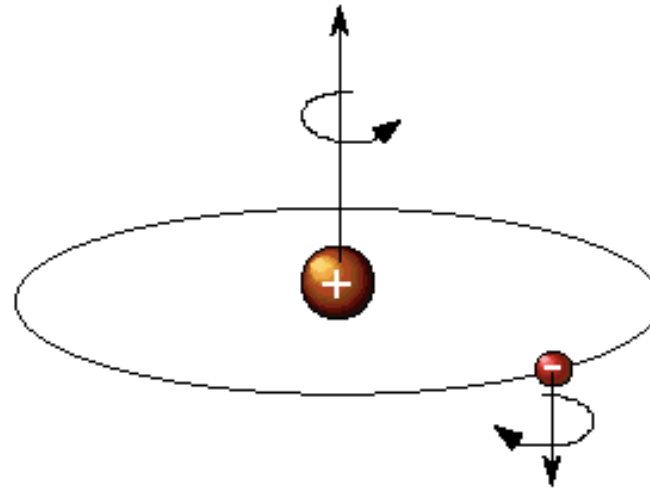
Algunas frecuencias importantes...



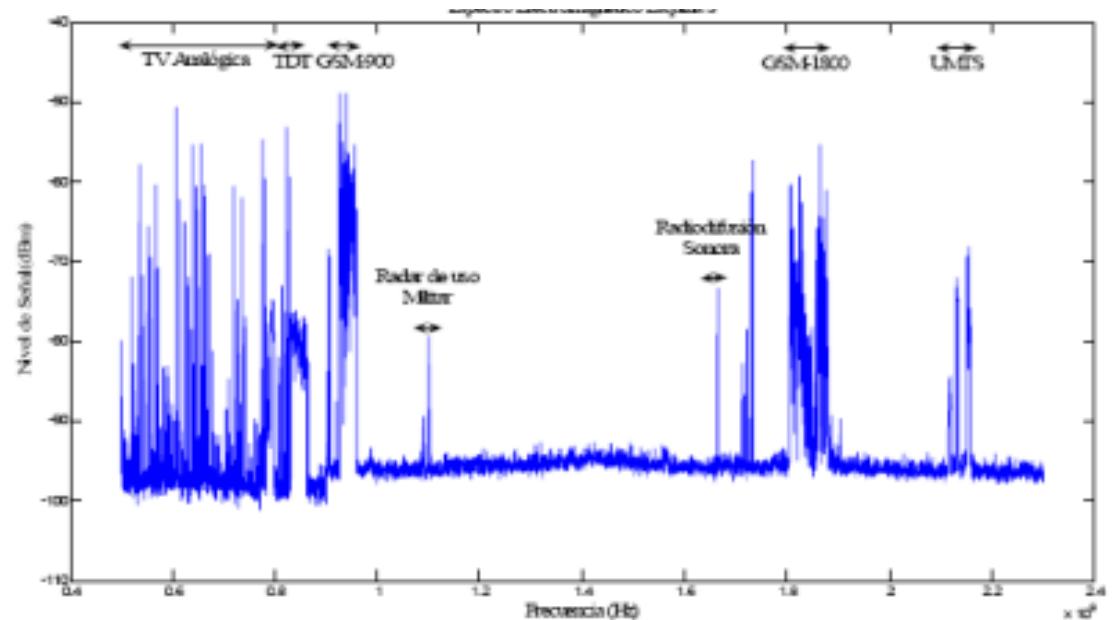
Línea de 21cm (1.4 GHz)



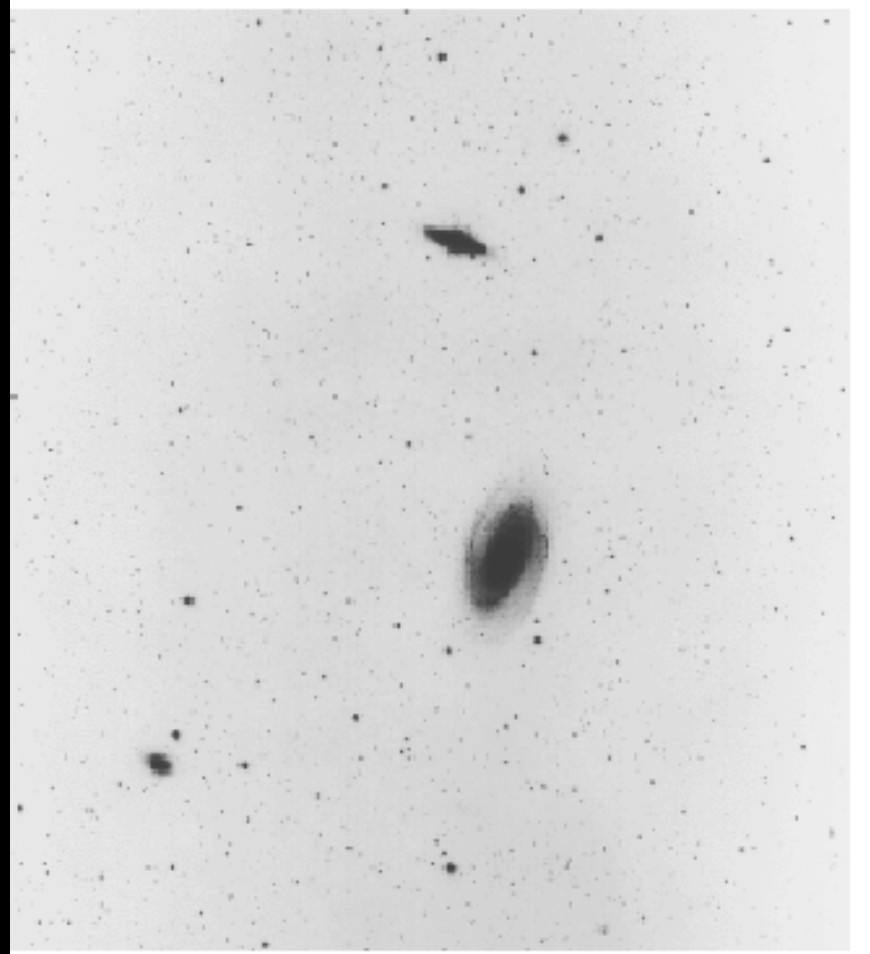
Estado superior: espín del
protón y el electrón alineados



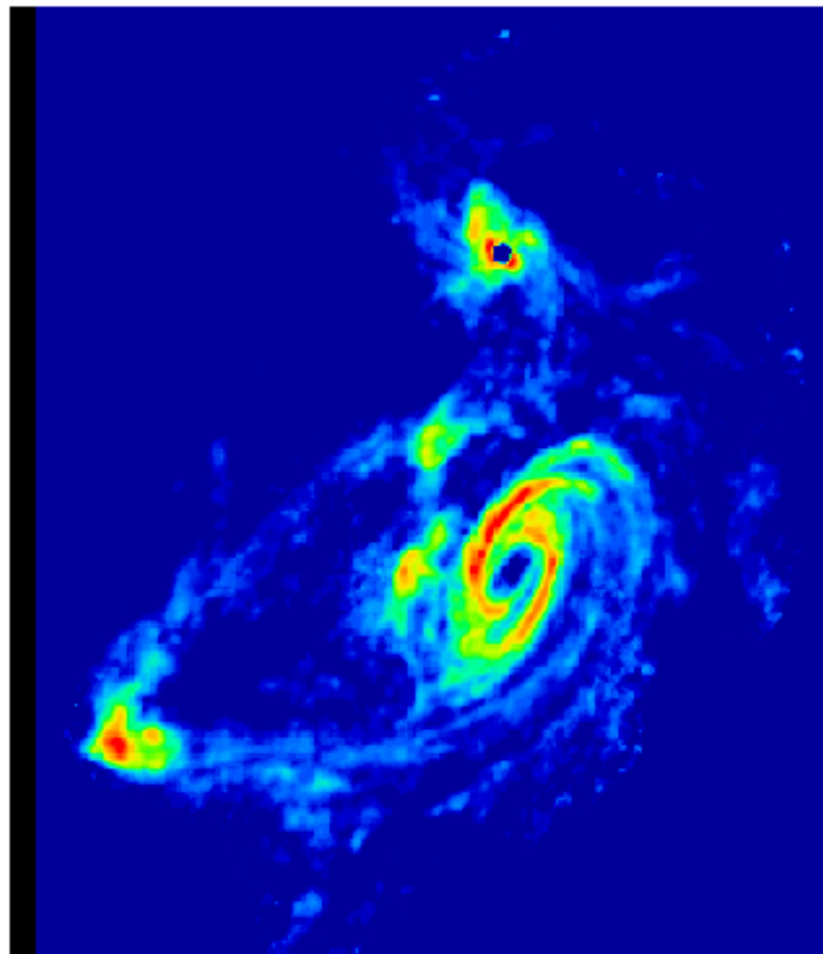
Estado inferior: espín del protón y el
electrón de signo opuesto



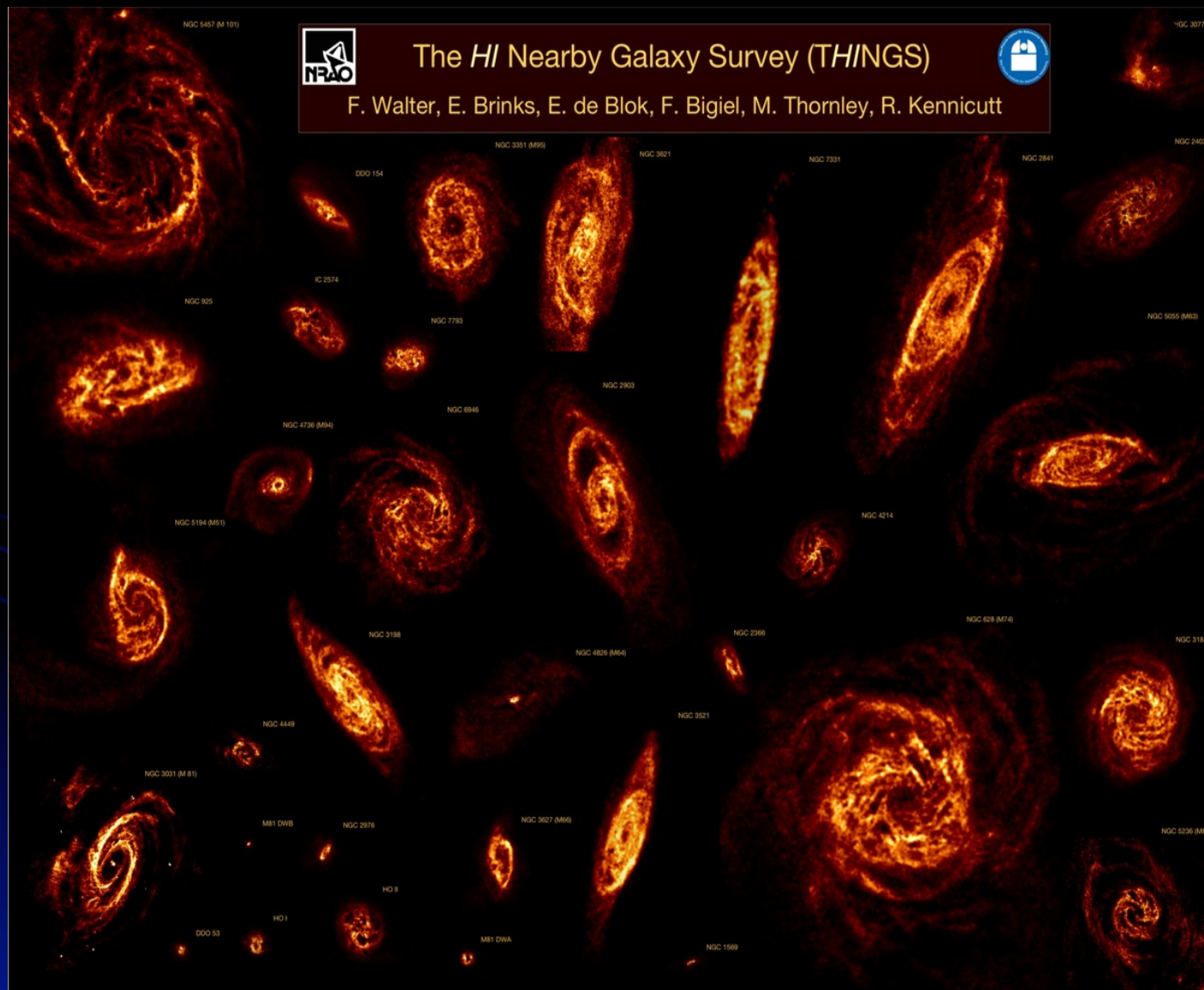
Stellar Light Distribution



21cm HI Distribution



Línea de 21cm – otras galaxias



Science with new radio interferometers

ALMA, SKA



“Prediction is very difficult, especially about the future”.
– Niels Bohr

ALMA: Llano de Chajnantor, Chile



Atacama Large Millimetre Array

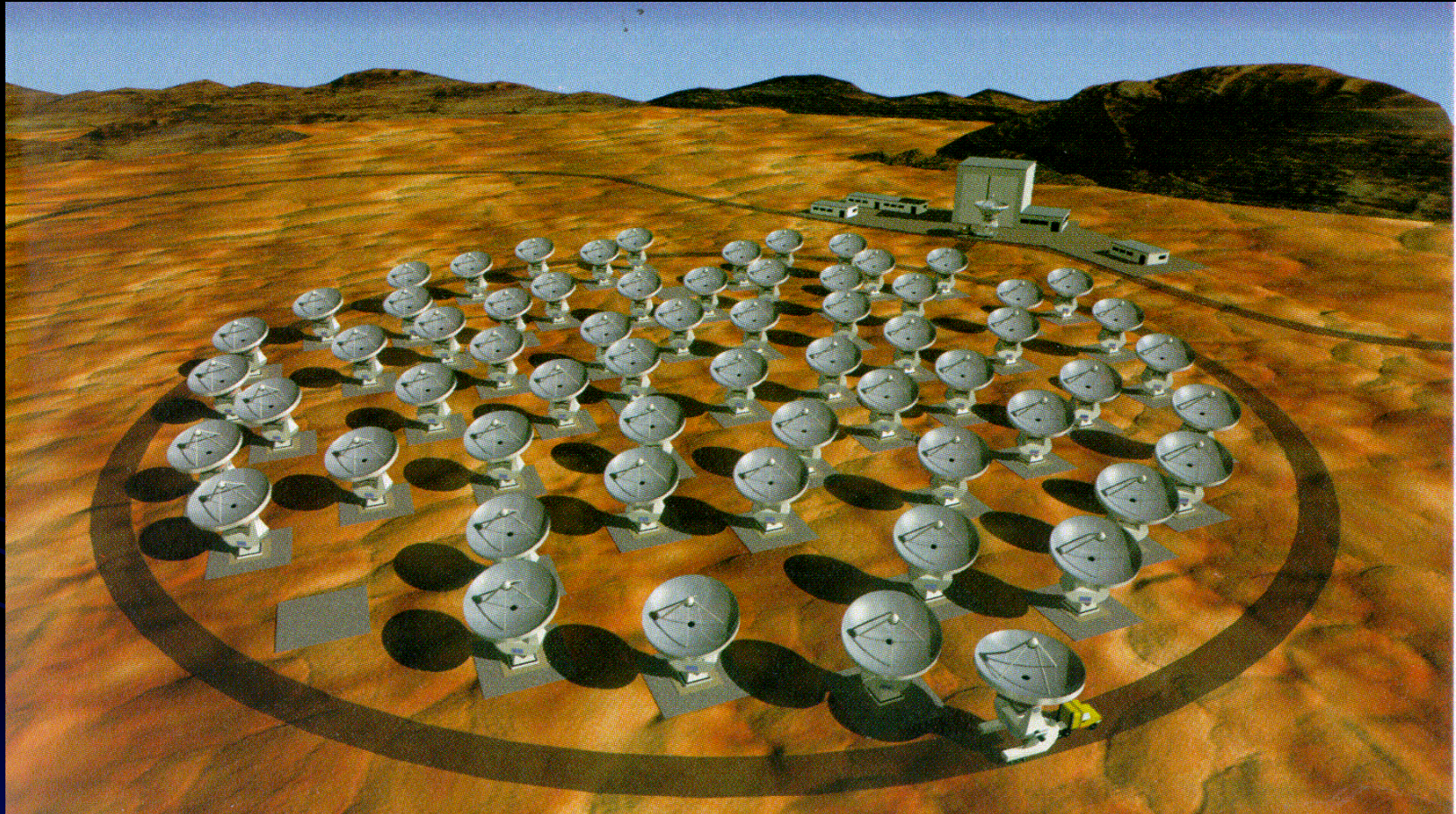
Atacama Large Millimeter Array



- ◆ At least 50x12m Antennas
- ◆ Frequency range 30-1000 GHz (0.3-10mm)
- ◆ 16km max baseline (<10mas)
- ◆ ALMA Compact Array (4x12m and 12x7m)

1. Detect and map CO and [C II] in a Milky Way galaxy at $z=3$ in less than 24 hours of observation
2. Map dust emission and gas kinematics in protoplanetary disks
3. Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution

ALMA: Llano de Chajnantor, Chile



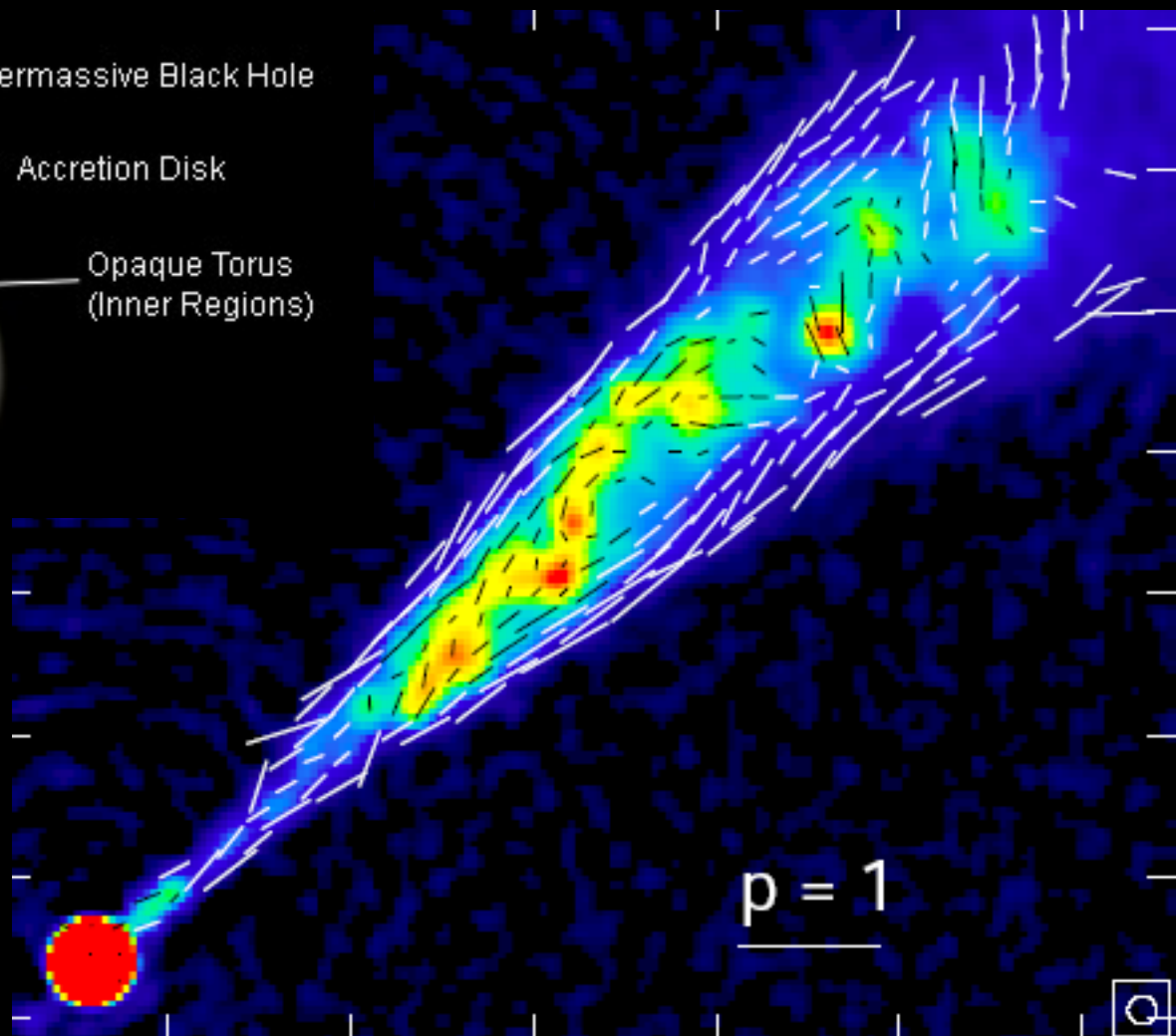
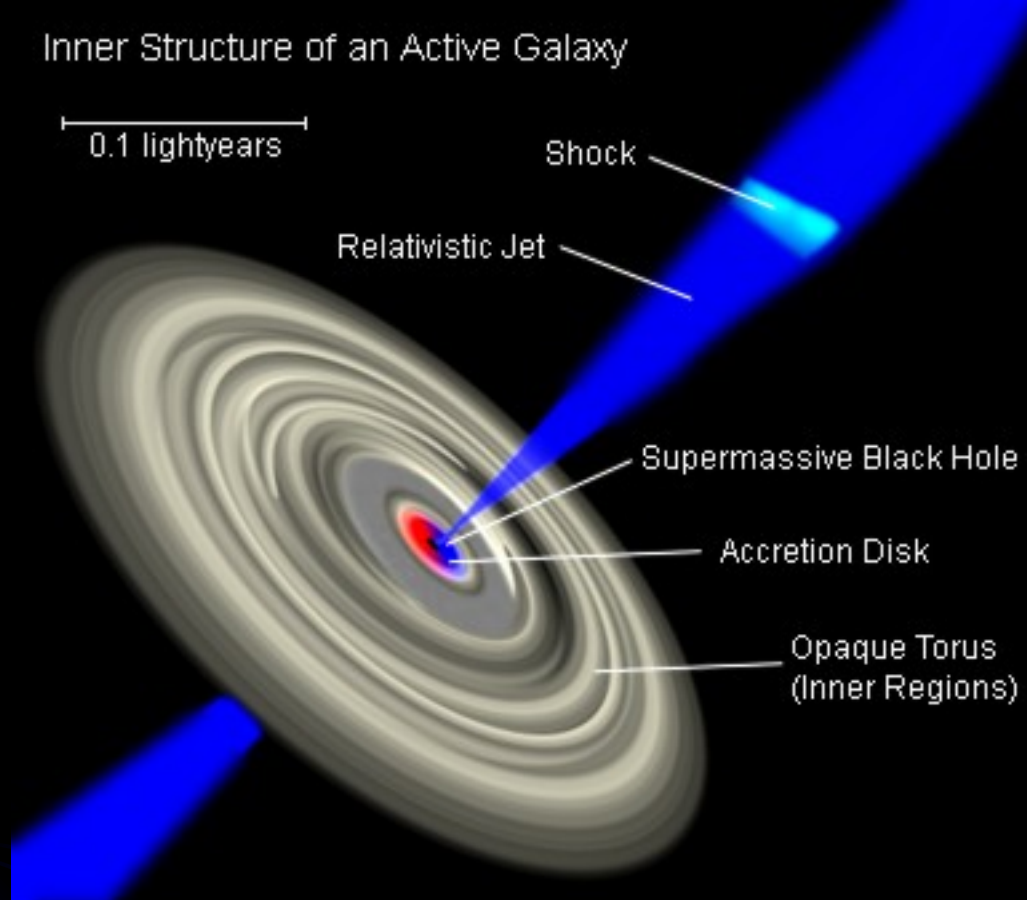
Atacama Large Millimetre Array

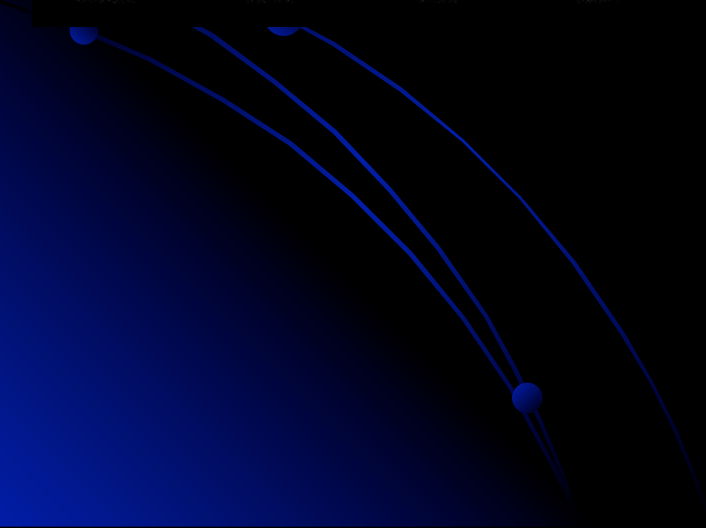
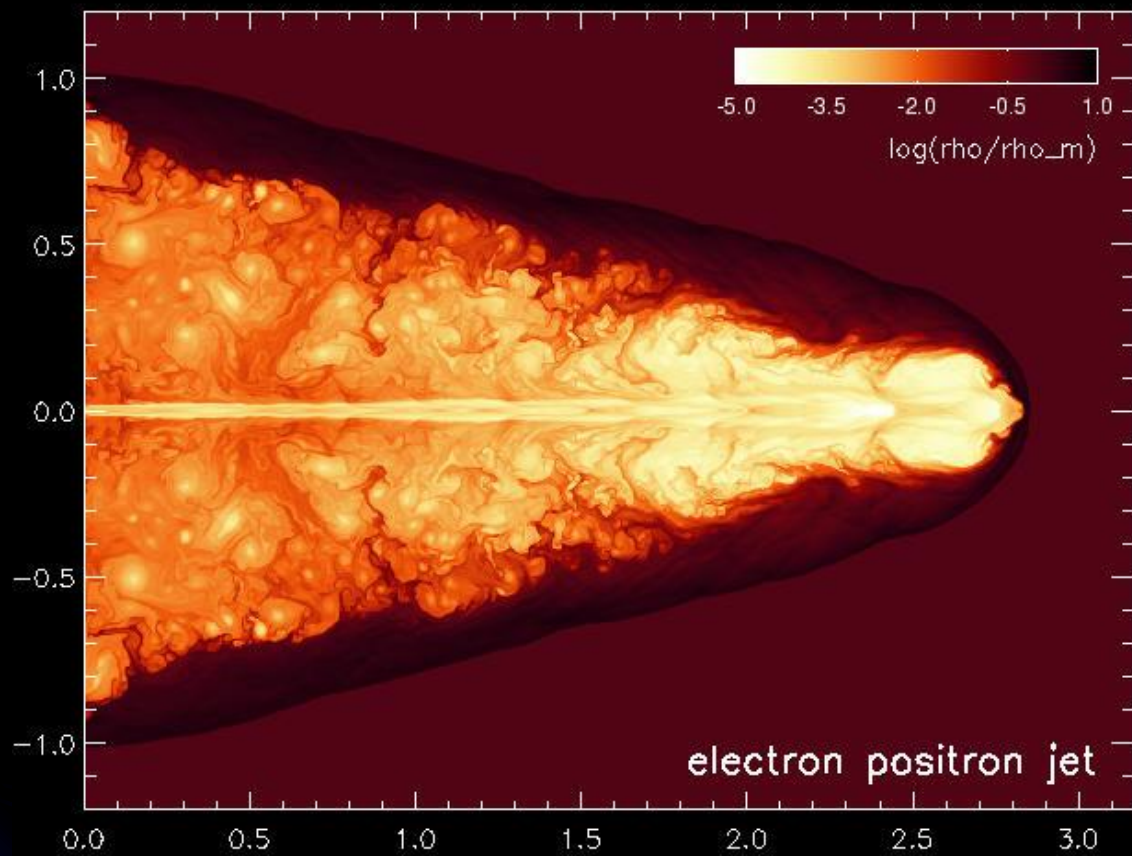


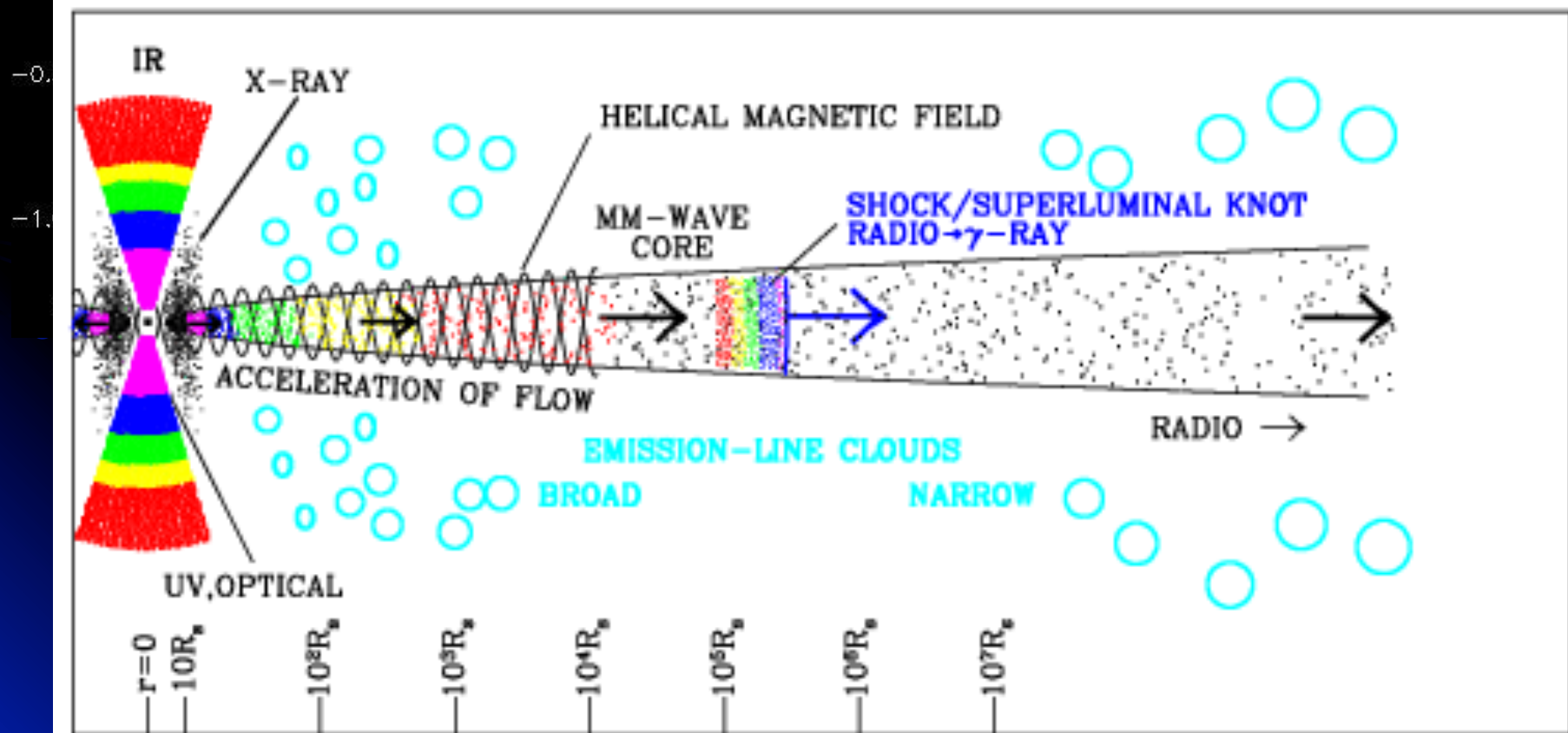
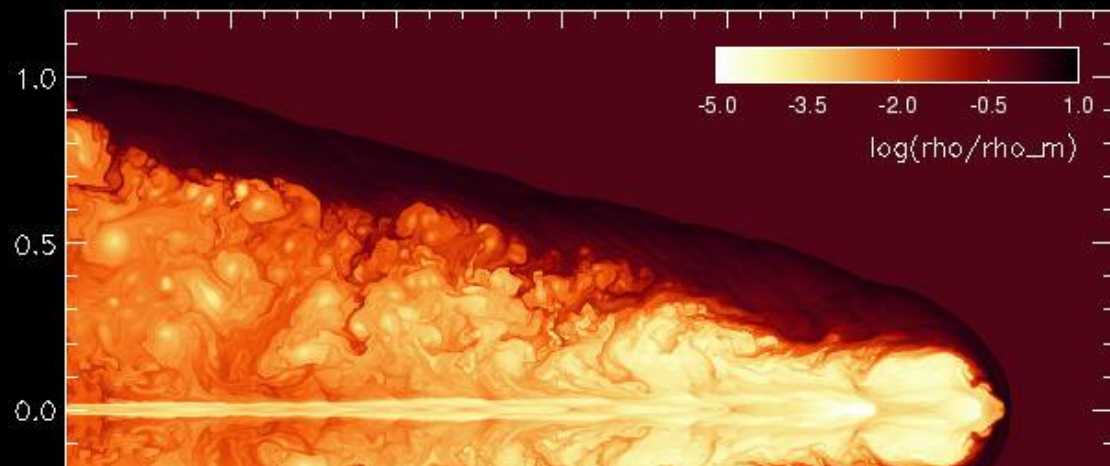
ALMA: Llano de Chajnantor, Chile



Inner Structure of an Active Galaxy

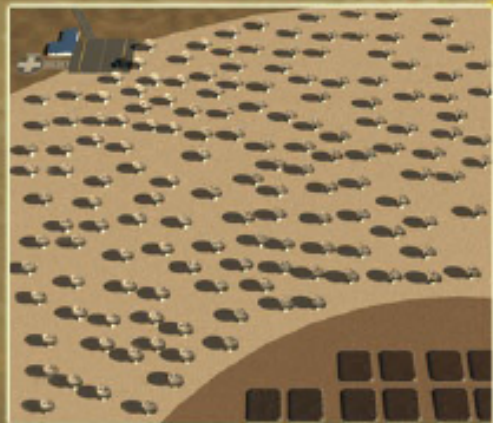
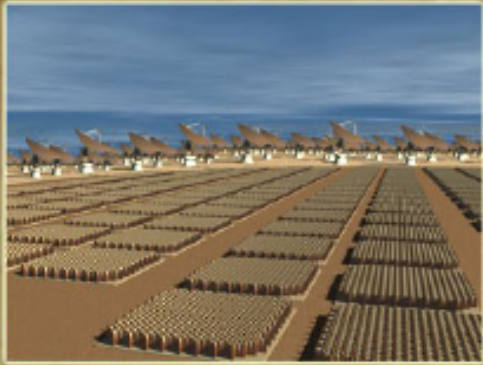








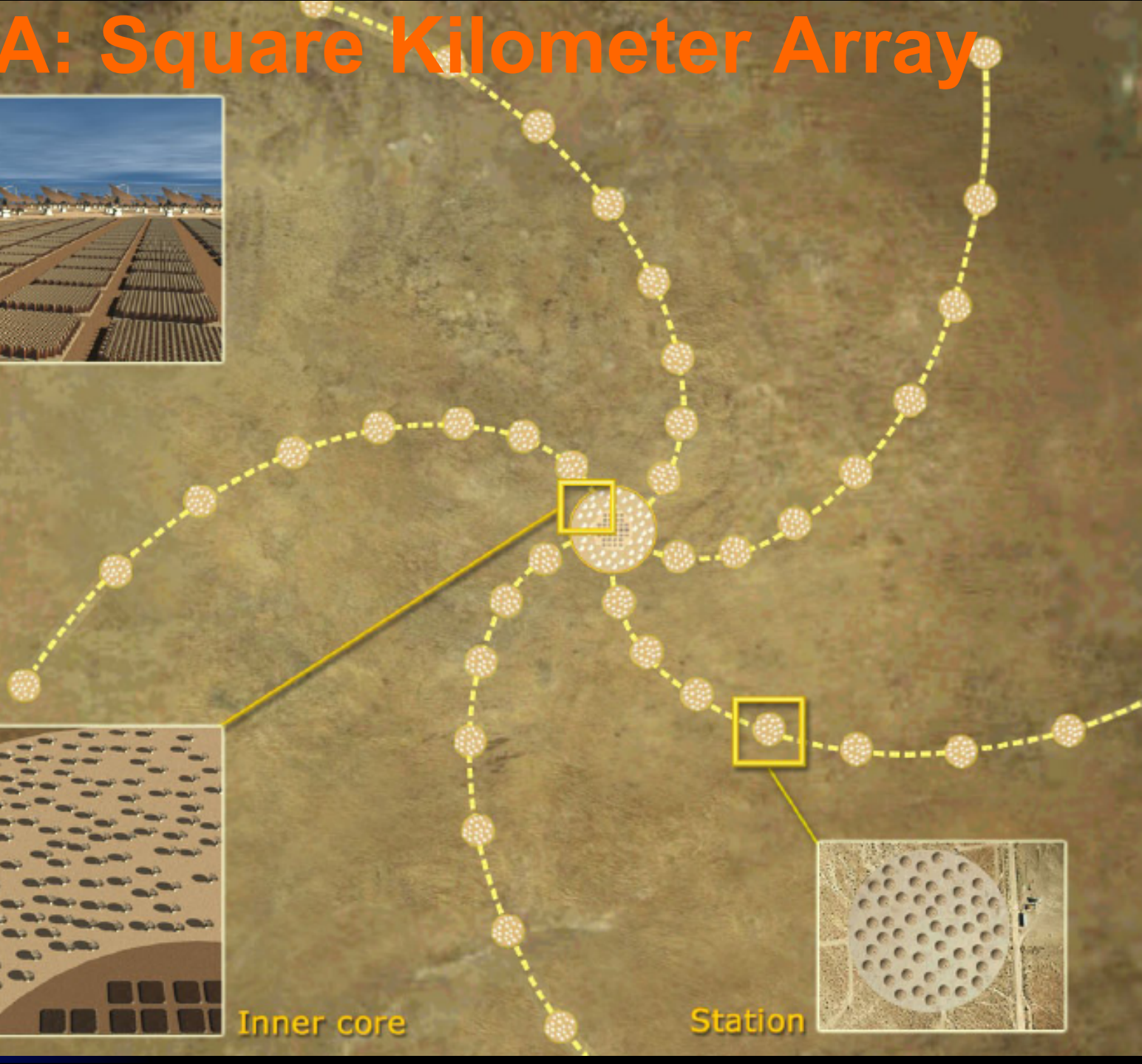
SKA: Square Kilometer Array



Inner core



Station



QUICK OVERVIEW OF SKA

- 1000 -1500 antennas x15m in 5km
- 1000 -1500 antennas x15m up to 3000 km

70 MHz - ≥ 25 GHz
4-3m - 1.2 cm

200 - 1 SQ² FOV
0.1" - 0.001" resolution

interferometers can be incrementally built

- **SKA1** = 10% collecting area, 70 Mhz - 3 GHz , 350 M€, 2016 -2019
- **SKA2** = 100% collecting area, 70MHz - 10 GHz, ~1100 M€, 2018 -2023
- **SKA3** High frequencies: ≥ 25 GHz. No defined dates
- \$2 billion total cost

ANTENNAS

Frequency range > two decades:

Combination of different types of antennas

Can observe towards **several directions simultaneously**

Aperture Array

70 - 450 MHz

Baselines 100 km



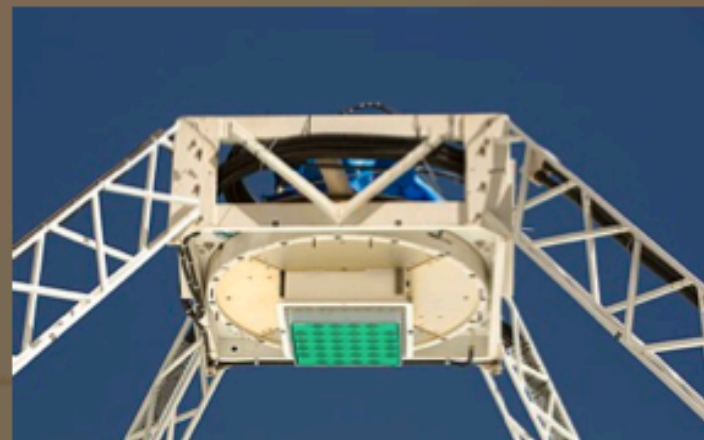
SKA1

2016 -2019

single pixel feed
450 MHz - 3GHz
baselines 100 km



Enhancing FOV



+ focal
plane array



dense
aperture
array

200 - 500 MHz
200 deg²

SKA2

2018 - 2023

QUICK OVERVIEW OF SKA

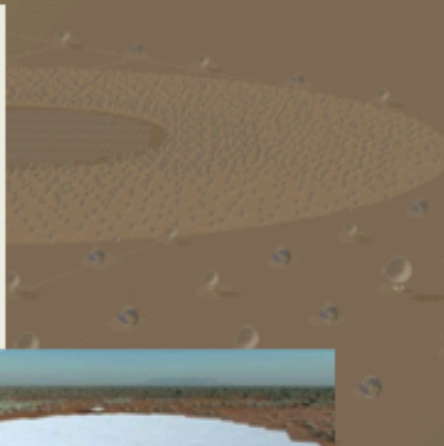
Preparatory Phase:

- Establishment of a **legal entity** for the SKA Organisation
- **Selection of the SKA site: Australia vs South Africa**



SITE DECISION

Square Kilometre Array Board has decided joint operation between Australia, South Africa



SKA1&2 mid



SKA2 AIP_AA



SKA1&2 low



SKA1
survey_AIP



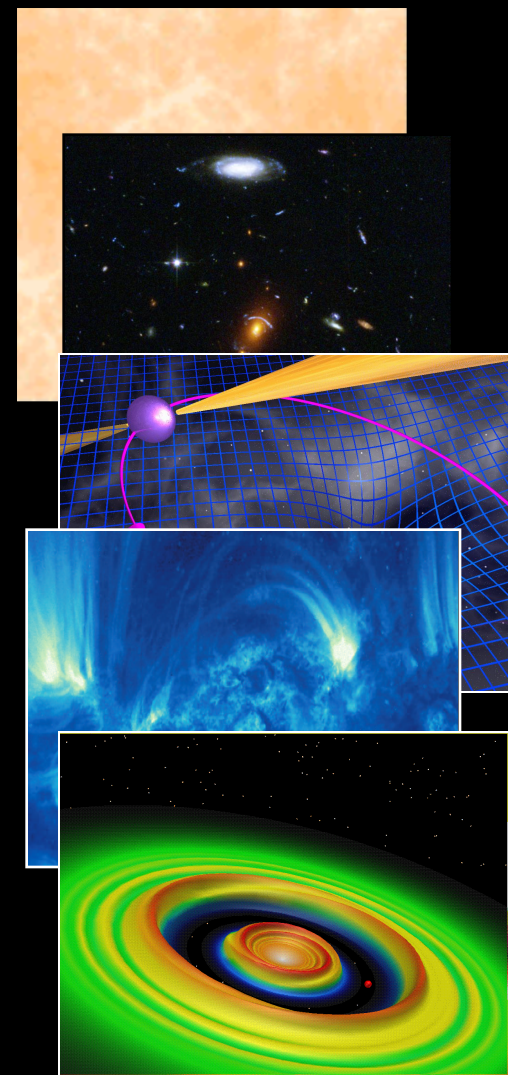
SKA1		SKA2	
SKA1_LOW	ANZ	SKA2_LOW	ANZ
SKA1_MID	RSA	SKA2_MID	RSA
SKA1_SURVEY	ANZ	SKA2_AA	RSA

ALMA / SKA

1. SKA is a survey instrument. ALMA is more adequate to detailed follow-up (limited FoV).
2. Complementary frequency range:
SKA: 0.1 - 25 GHz
ALMA: 30-950
3. Similar resolution:
SKA: 1 mas (25GHz, 3000km baseline)
ALMA: 5mas (950GHz)
4. Both are sensitive different emission processes.
ALMA (in essence) : elements heavier than H
SKA (in essence too): HI -- 21cm
5. Both far in the South...

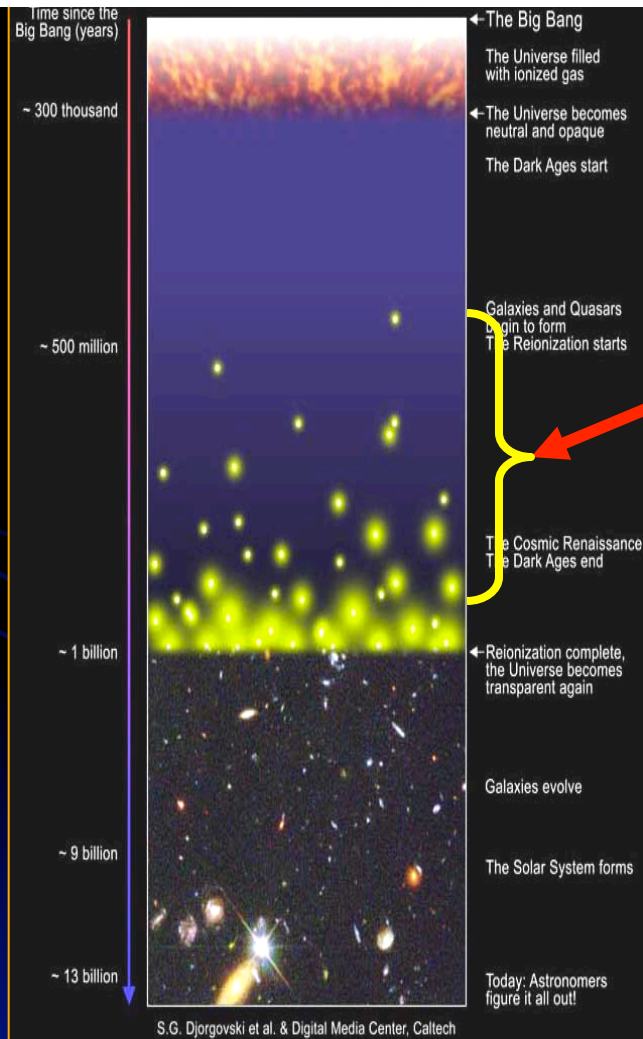
SKA KSP (Proyectos clave)

- Detectar el hidrógeno neutro HI en las fases iniciales del Universo, cuando las primeras estrellas y galaxias aparecieron – **“época de reionización”**
- Localizar 1000 millones de galaxias via su emisión HI y medir su distribución en el espacio – **“energía oscura”**
- Origen y evolución de los campos magnéticos cósmicos – **“El universo magnético”**
- Medidas del timing de púlsares. Detección de **ondas gravitatorias**
- **Formación de planetas** – imágenes de huecos en los discos protoplanetarios del tamaño de la Tierra. SETI



1- Probing the Dark Ages

COSMIC HISTORY OF THE UNIVERSE

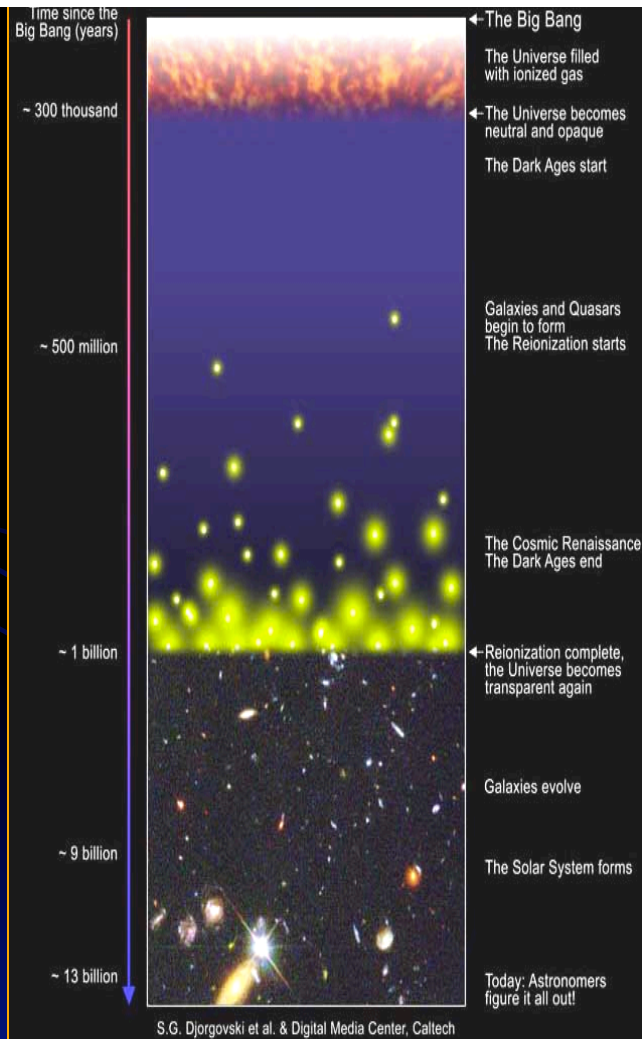


La Edad Oscura:

Era del Universo entre
300 000 - 1 000 000 000 yr
tras el Big Bang durante el cual
se formaron las primeras
estrellas y galaxias

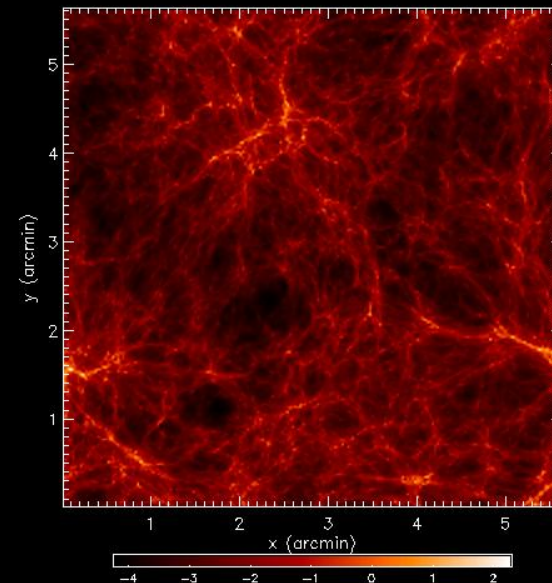
1- Probing the Dark Ages (neutral medium)

COSMIC HISTORY OF THE UNIVERSE



SKA (< 200MHz)

Detecta y cartografía H en la Edad Oscura -física de la formación de los primeros objetos del Universo



7.2

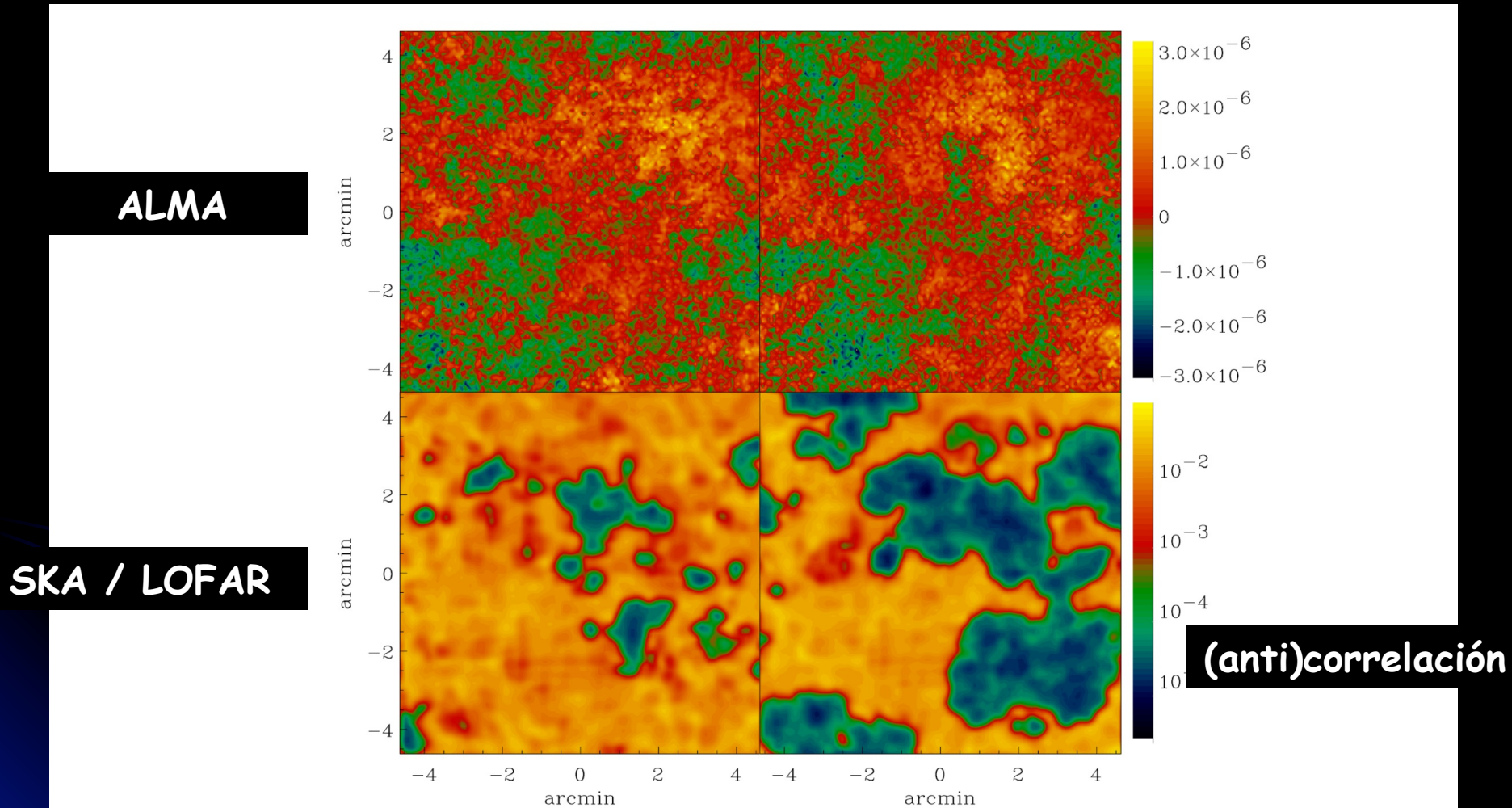


Figure 2. Top panels: maps of CMB temperature fluctuations, $(\delta T/T)_{\text{CMB}}$, due to patchy reionization for the S5 (left panel) and L20 (right panel) models. The maps measure ≈ 9.25 arcmin on a side. Lower panels: maps of differential antenna temperature, $(\delta T/T)_{21\text{cm}}$, from 21-cm line emission for the S5 (left panel) and L20 (right panel) models, at observed frequencies (redshift) $\nu \approx 115$ MHz ($z \approx 11$) and $\nu \approx 90$ MHz ($z \approx 14.5$), respectively. The maps have been derived assuming a bandwidth $\Delta\nu = 1$ MHz, and measure ≈ 9.25 arcmin on a side.

2- Galaxy Evolution, Cosmology and Dark Energy

- Localizar 1000 millones de galaxias via su emision HI y medir su distribución en el espacio -"energía oscura"
- La formación estelar parece alcanzar un pico a $z=2$



2- Galaxy Evolution, Cosmology and Dark Energy

- Galaxy assembly, steadily, from smaller to larger systems.
- Star formation seems to reach a peak at $z \sim 2$

Relation between these two processes?

- SKA role:
 - measurement of HI (basic ingredient)
 - estimate of star formation rate

- ALMA:
 - measurement of the mass of molecular gas; CO trans.
 - powerful tracer of star forming galaxies out to $z \sim 3$ (and starbusts to $z \sim 10$)

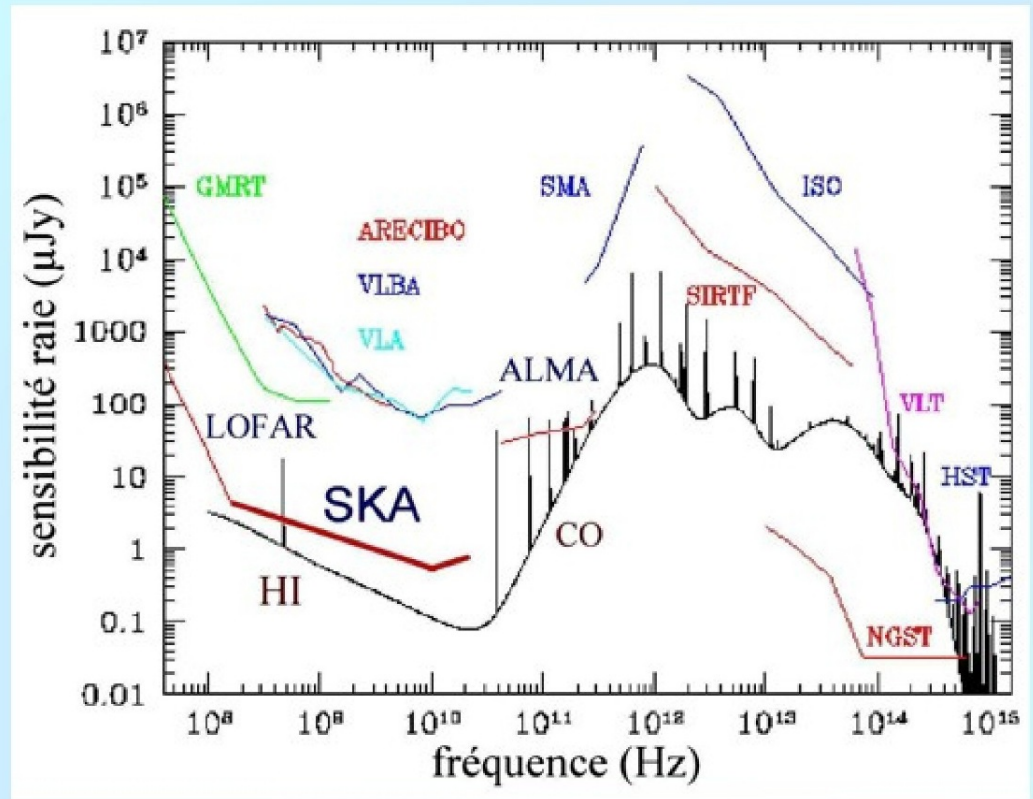
2- Galaxy Evolution, Cosmology and Dark Energy

- Galaxy assembly, steadily, from smaller to larger systems.
- Star formation seems to reach a peak at $z \sim 2$

Relation

- SKA role:
 - measurement of H₂
 - estimate of star formation rate

- ALMA:
 - measurement of the dust emission
 - powerful tracer of star formation (from $z \sim 10$)



Detection of spectral lines of a 'standard' spiral galaxy at $z = 2$

5σ in 1 hour

3- Tests sobre la Relatividad General

Púlsares

Estrellas colapsadas
con propiedades
físicas extremas

Fuerte campo
gravitatorio
 $200000 \times \text{Sol}$

Relojes muy
precisos
 10^{-9}sec

3- Tests sobre la Relatividad General

SKA:

Identificar y medir el periodo de púlsares con precisiones de nanosegundos



Gravedad

Test GR
alrededor de
agujeros
negros

Supera cualquier
test anterior



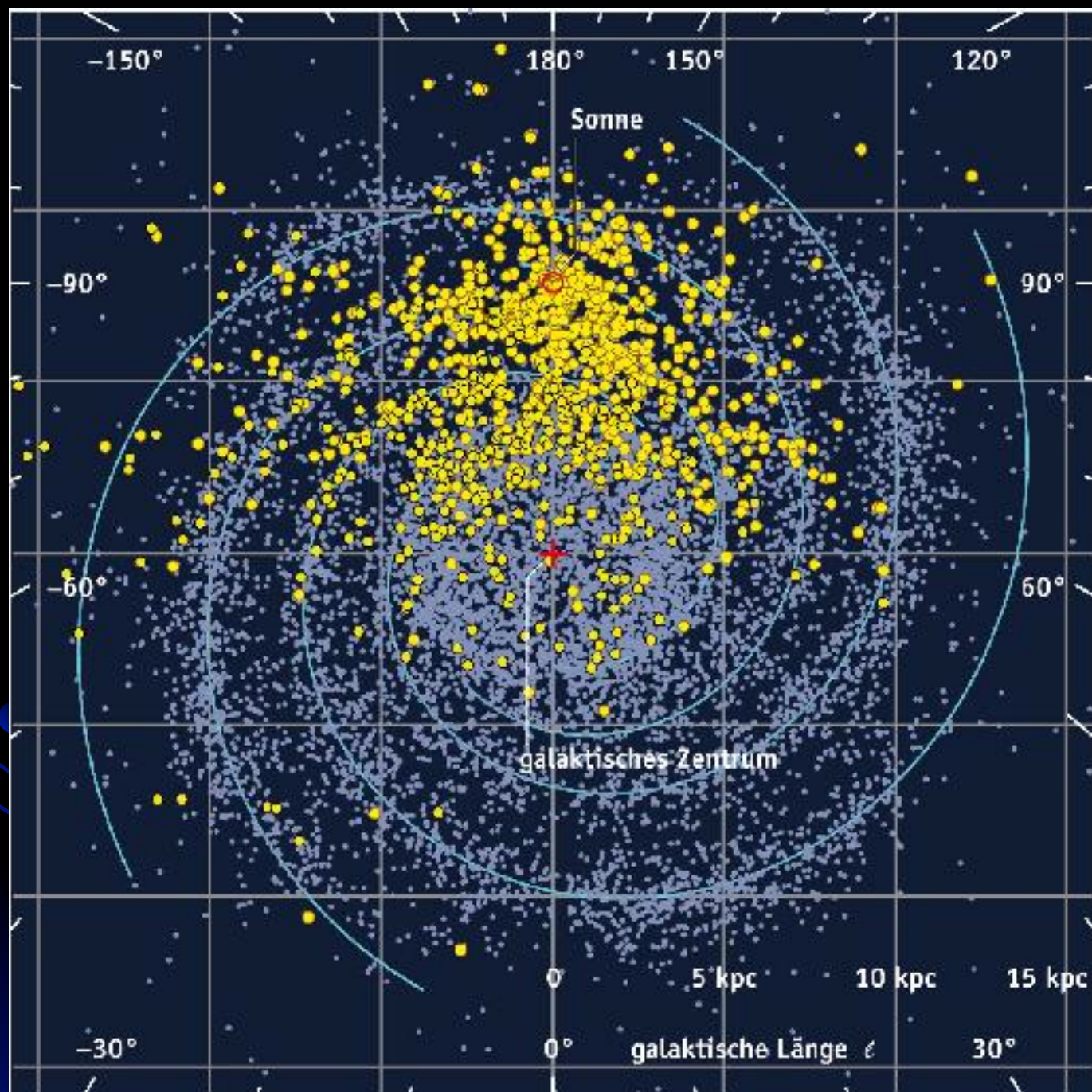
Relojes

Detector de
ondas
gravitatorias

Complementa a
LIGO/LISA

SKA encontrará 20 000
púlsars en la Galaxia

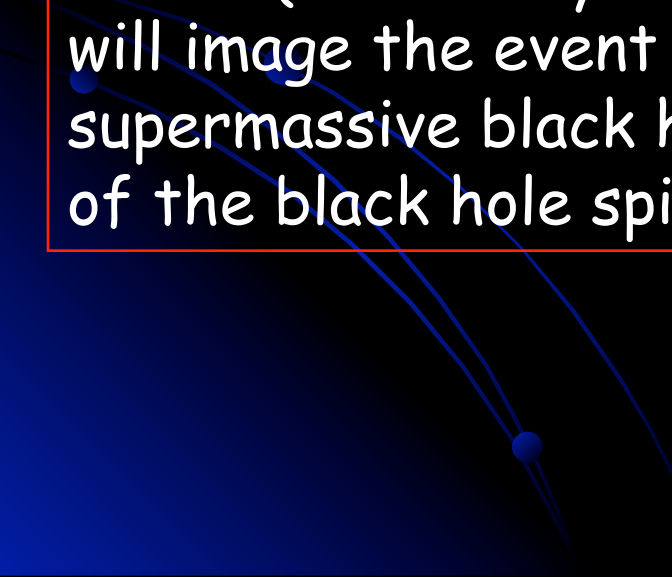
Click here to download a
Gimpak de compresor
and need to see this picture.



3- Strong-field tests of General Relativity

SKA will observe pulsars - black hole binaries, allowing precise tests of strong-field general relativity and measurement of black hole spin

ALMA (as the key element of a sensitive mm-VLBI array) will image the event horizon around the nearest supermassive black holes (Sgr A* and M87). Measurement of the black hole spin.



5- The Cradle of Life

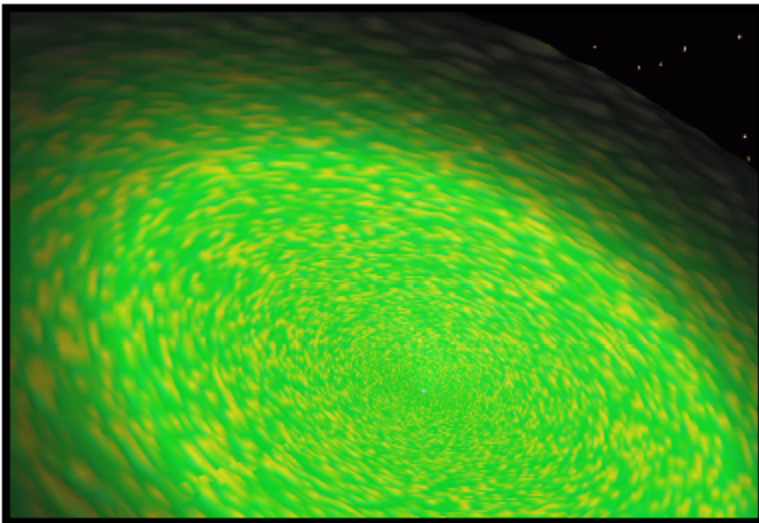
- Test para encontrar condiciones de vida en otras partes del universo
 - Discos protoplanetarios
 - Búsqueda de inteligencia extraterrestre



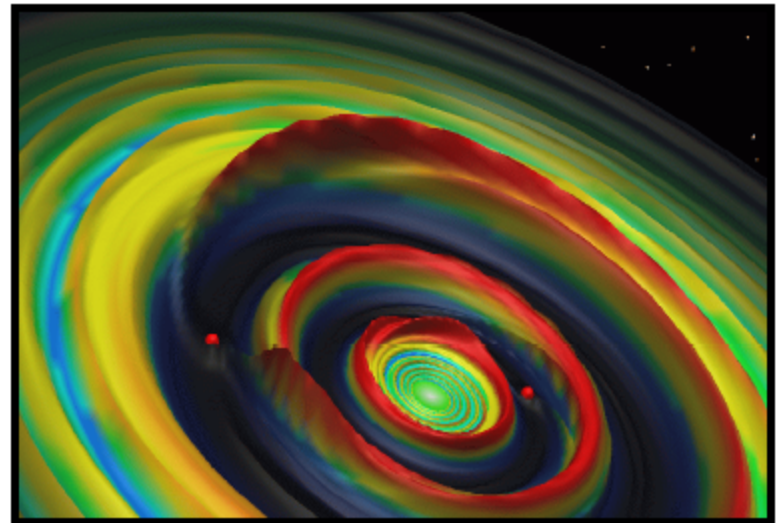
5. The cradle of life

- Formación de planetas – imágenes de huecos en los discos protoplanetarios del tamaño de la Tierra. SETI

I. Initial Disk



II. Gap Formation



5- The Cradle of Life

SKA Role

Movies of proto-planetary
disks in formation

Theoretical Simulation

cm λ



Composition of
'building blocks' of
disks

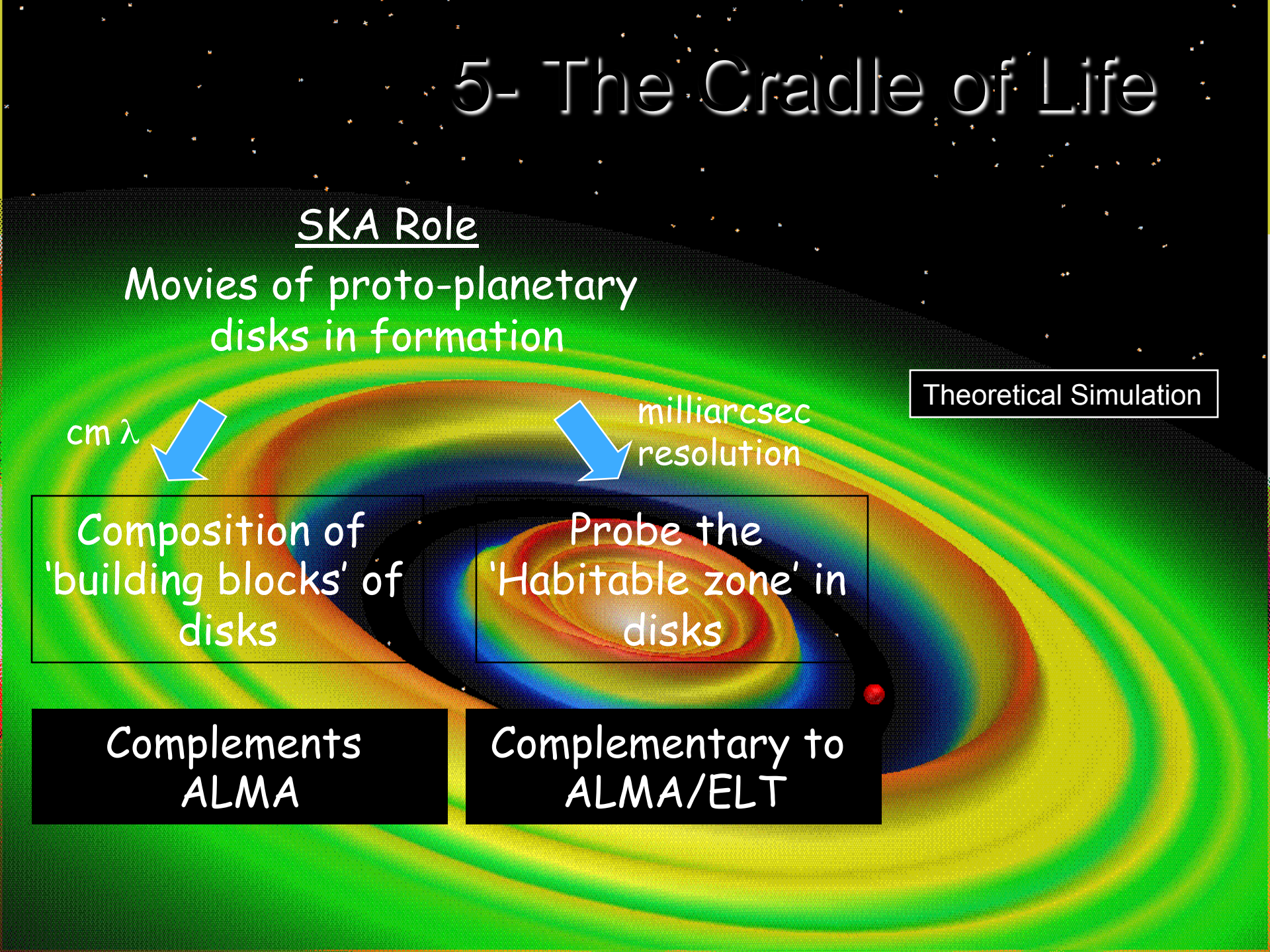
milliarcsec
resolution



Probe the
'Habitable zone' in
disks

Complements
ALMA

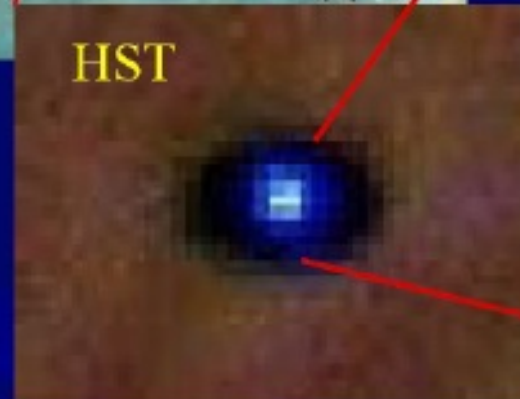
Complementary to
ALMA/ELT



Protoplanetary disks with ALMA

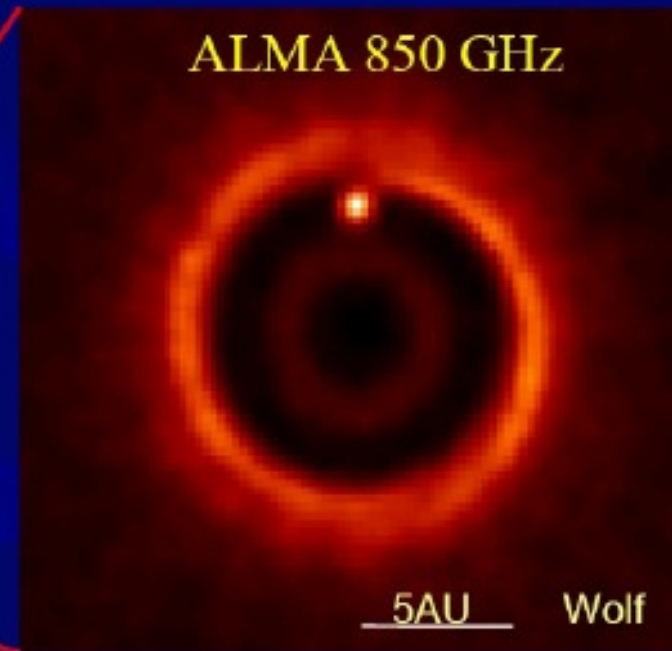


Williams +

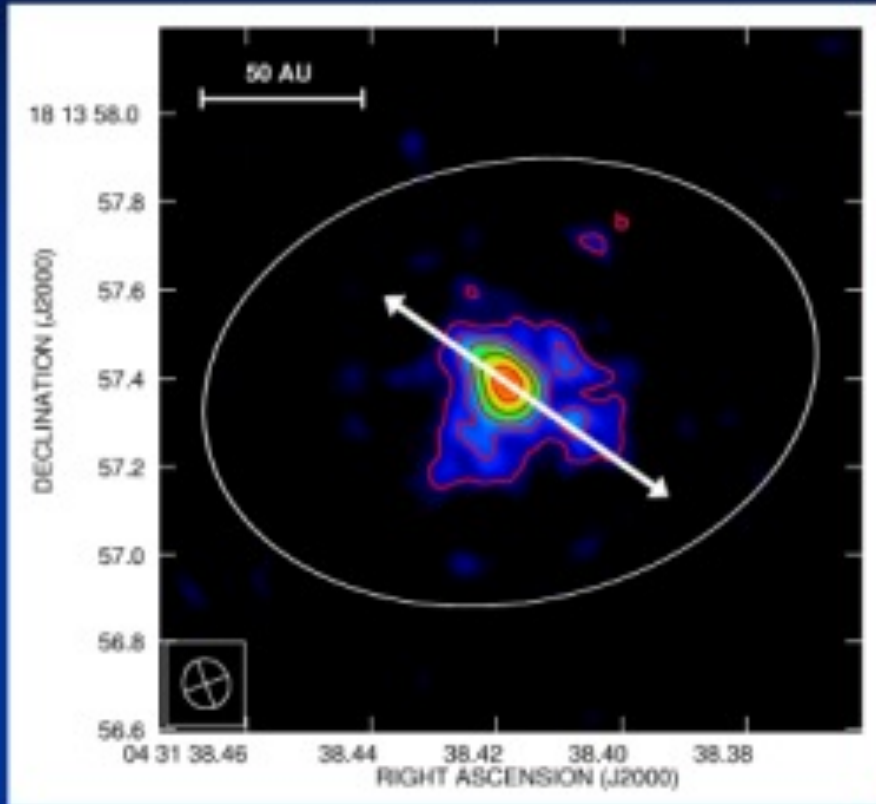


Birth of planets

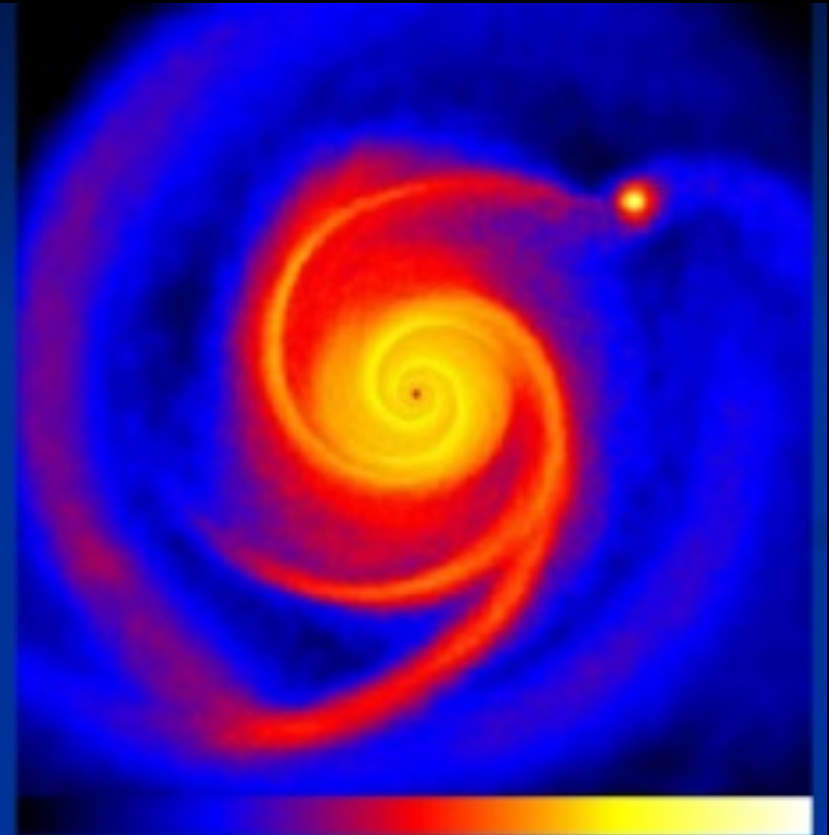
- $M_{\text{planet}} / M_{\text{star}} = 1.0 M_{\text{Jup}} / .5 M_{\text{sun}}$
- Orbital radius: 5AU at 50pc distance
- Disk mass = circumstellar disk around the Butterfly Star in Taurus



Discos protoplanetarios

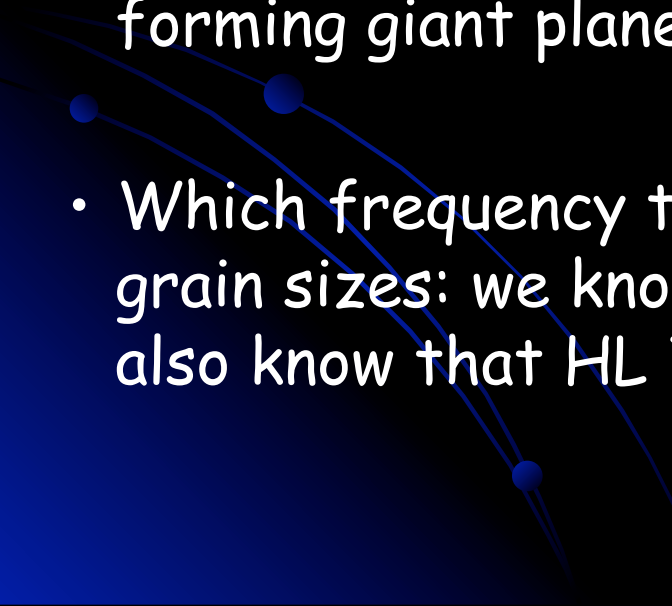


VLA + Pie Town 43GHz
HL Tau b: a very young planet? (Greaves, Richards et al. 2008)



Simulation

Protoplanetary disks ALMA / SKA

- Both arrays can resolve protoplanetary discs around the nearest stars
 - Expect to detect gaps caused by Jupiter-mass planets
 - May also be able to see heated dust associated with forming giant planets
 - Which frequency to use depends on the distribution of grain sizes: we know that debris discs radiate at 1mm; we also know that HL Tau b is clearly visible at 1cm.
- 

Astrobiology / prebiotic molecules

ALMA:

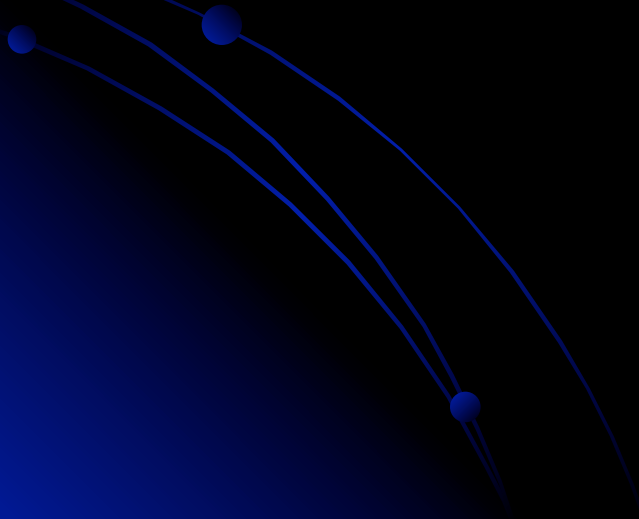
- Prime instrument to probe of molecules in interstellar clouds (high spatial resolution, short-wavelengths).

SKA:

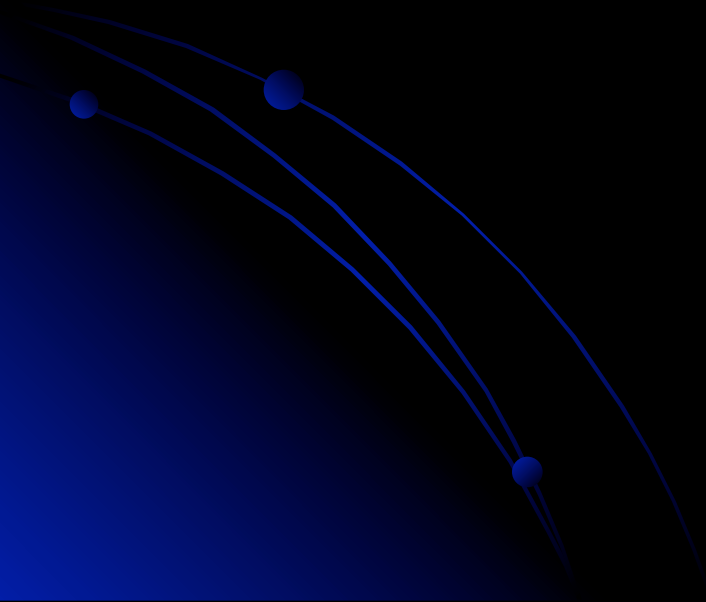
- These (or other) molecules have been already detected by their low-energy transitions (longer wavelengths).
- Example: glycolaldehyde (CH_2OHCHO), detected by the GBT from observations of transitions frequencies from 13 to 22 GHz).

Conclusions

- ALMA is coming shortly and it will be a huge improvement in sensitivity, resolution, and frequency coverage.
- SKA and ALMA are complementary (although SKA will need high frequency and high resolution)
- Importance of SKA Pathfinders (ASKAP / MeerKAT). They will be running well before the complete SKA.

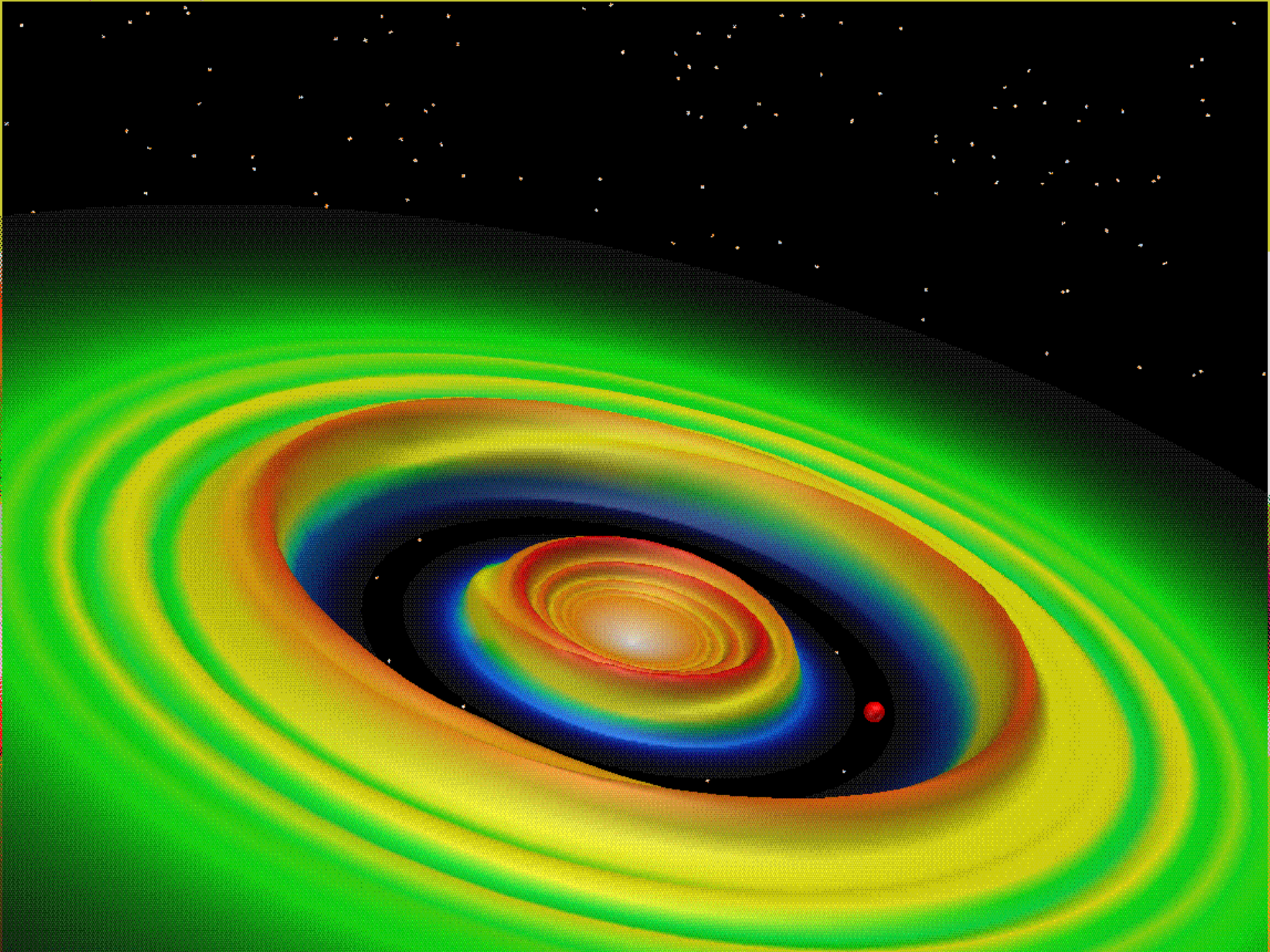


*SKA dedicará tiempo a búsquedas tipo SETI,
pero...*



...no, no haremos esto:





EL UNIVERSO EN RADIO

José Carlos Guirado
Universidad de Valencia

(Some) slides taken from other talks by Eduardo Ros, Michael Kramer, Lourdes Verdes, Leonardo Testi, John Monnier, SKA and ALMA web pages.

