



Desde el Big Bang: Una historia del Universo

“De todo lo visible y lo invisible”

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S/C de Tenerife, 16 de Diciembre de 2016





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EXCELENCIA
SEVERO
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INDICE:

- I. El origen del Universo y el modelo de Big Bang
- II. Cosmología desde el Teide con el VSA

“De todo lo visible y lo invisible”

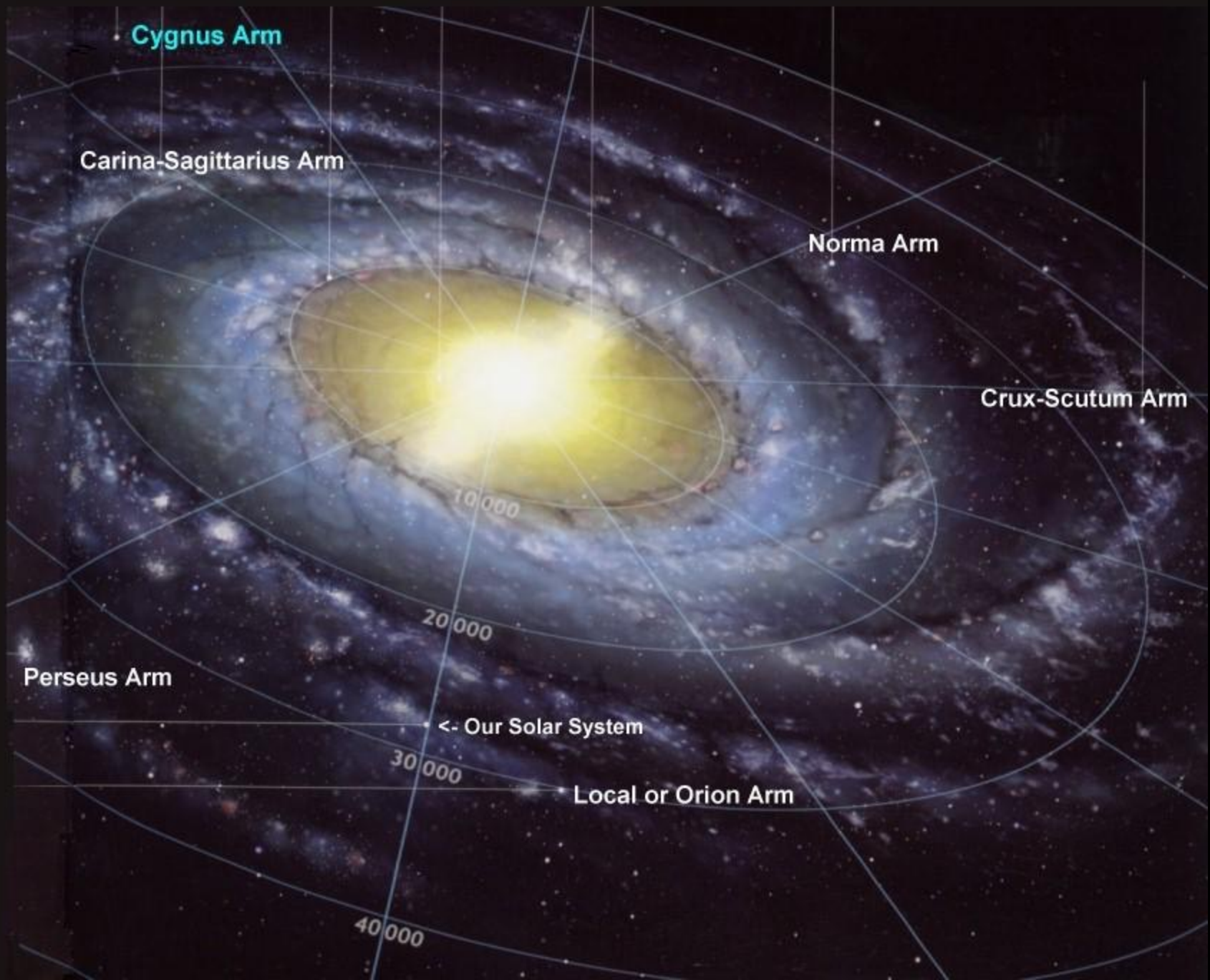


Marie Skłodowska-
Curie Actions
under Horizon2020



DANIEL LÓPEZ
ELCIELODECANARIAS.com

Telescopio TNG. ORM / IAC. La Palma

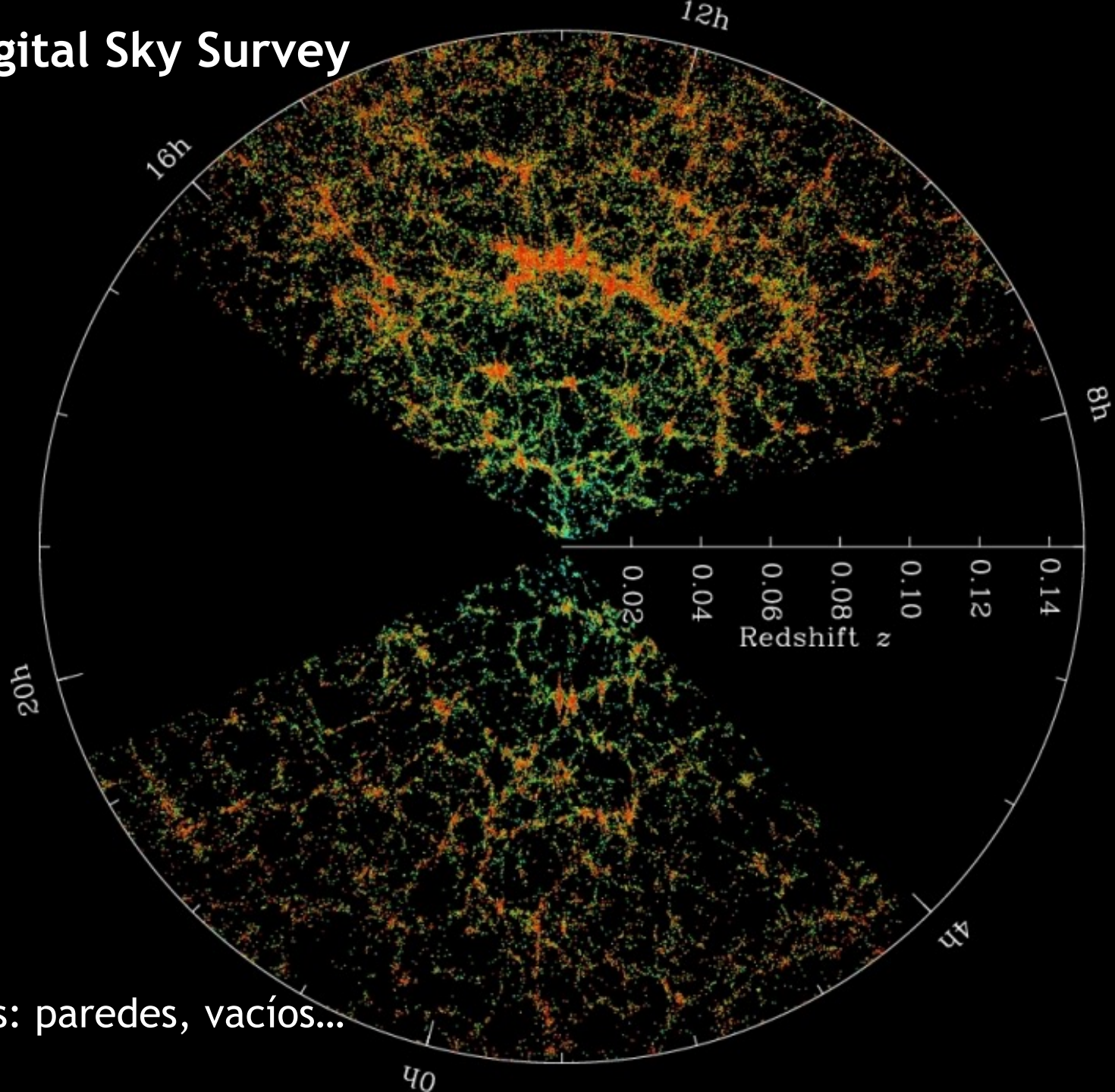






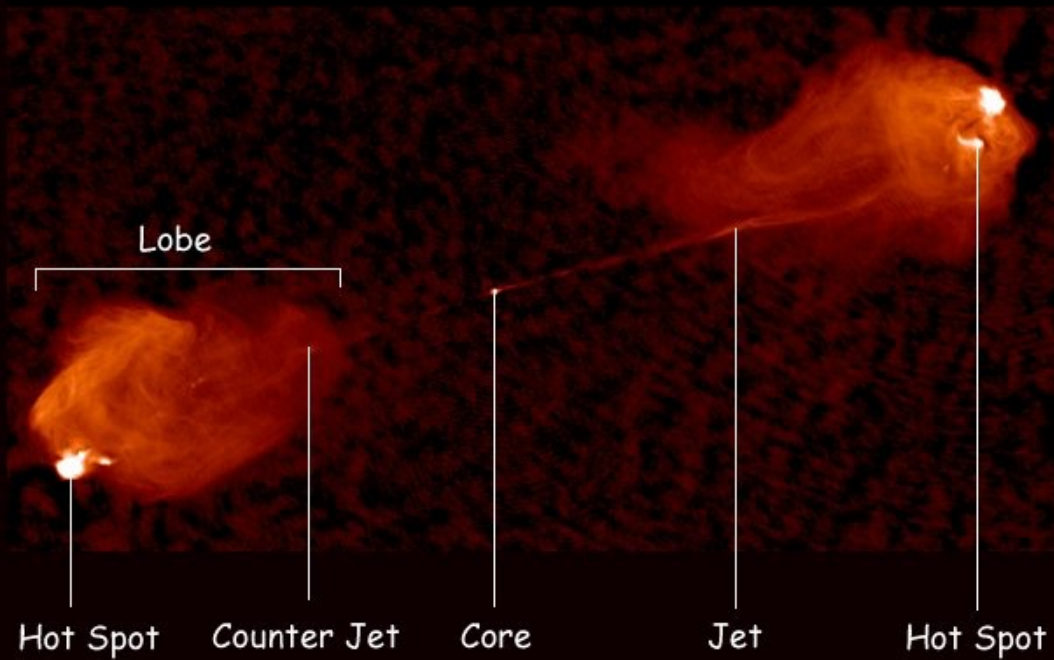
Galaxias a distancias de miles de millones de años luz

Sloan Digital Sky Survey

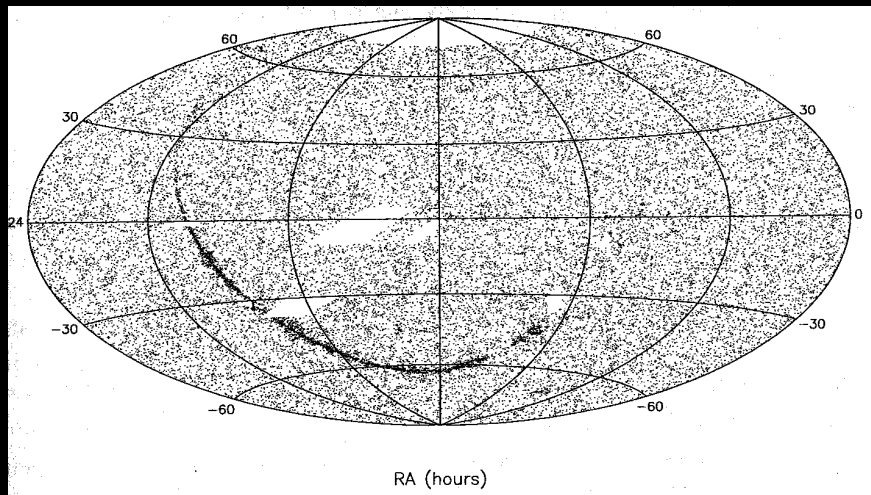


Estructuras: paredes, vacíos...

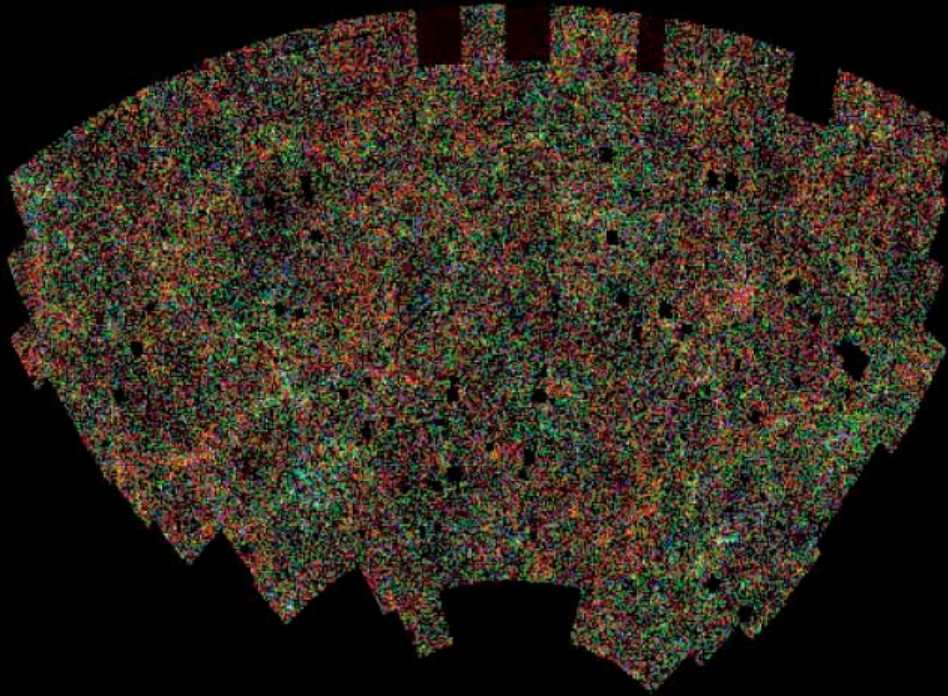
Radiogalaxies



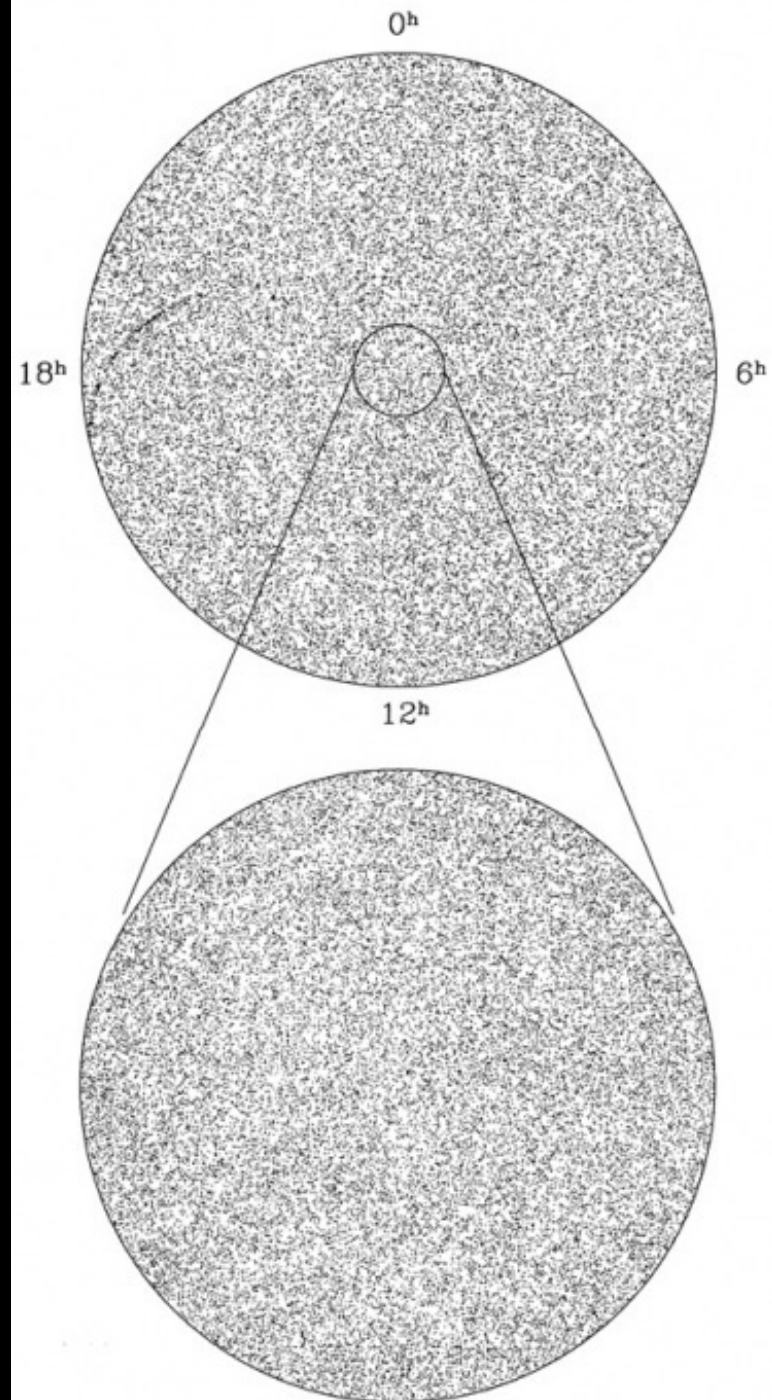
Parts of a DRAGN (Cygnus A)



El Universo a gran escala: homogeneidad e isotropía

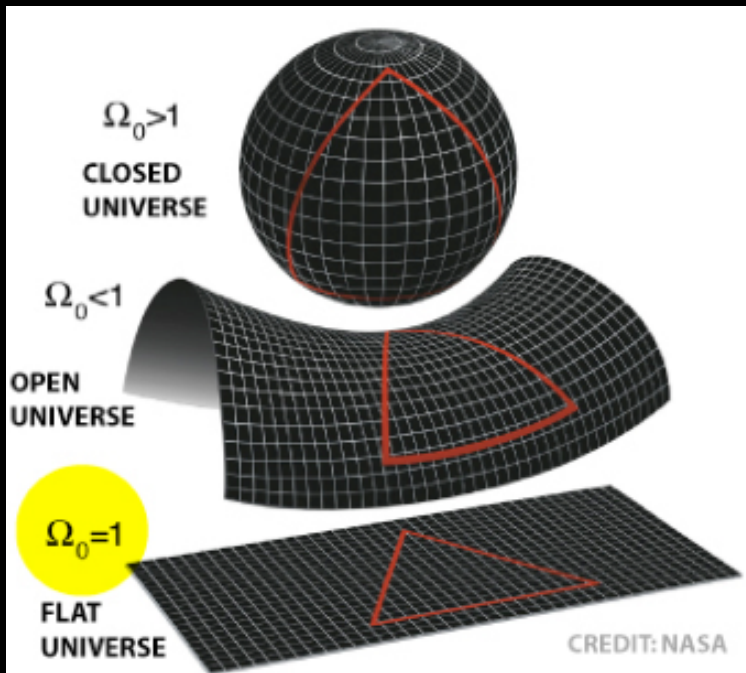
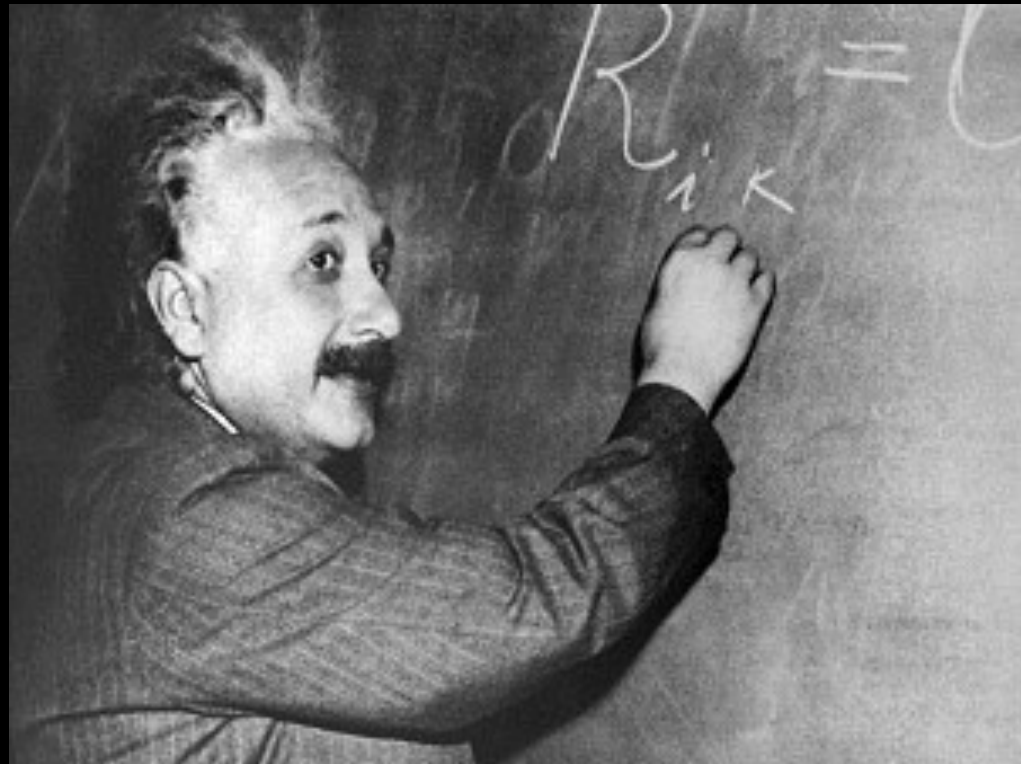


“Principio Cosmológico”



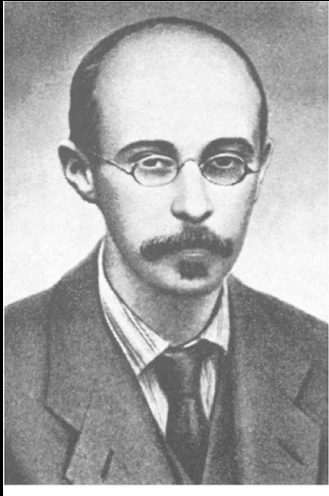
El Universo a gran escala:

Teoría de la Relatividad General



Relatividad General
+
Principio Cosmológico
+
Postulado de Weyl

El Universo en expansión



A.
Friedmann



P. Lowell



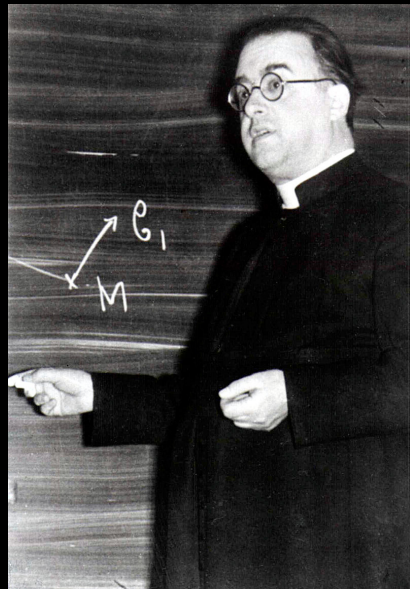
V. M. Slipher



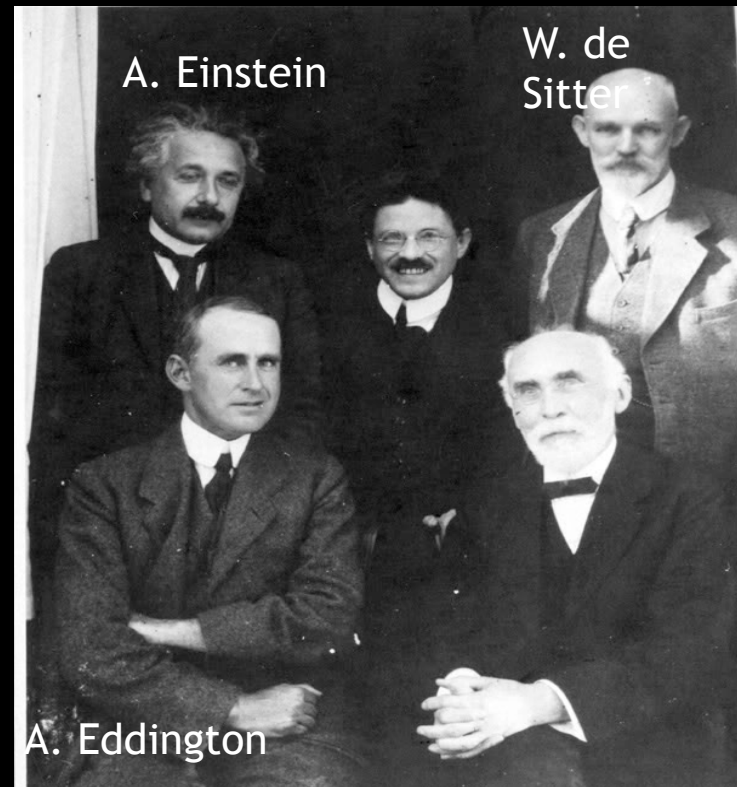
H. S. Leavitt



E. Hubble

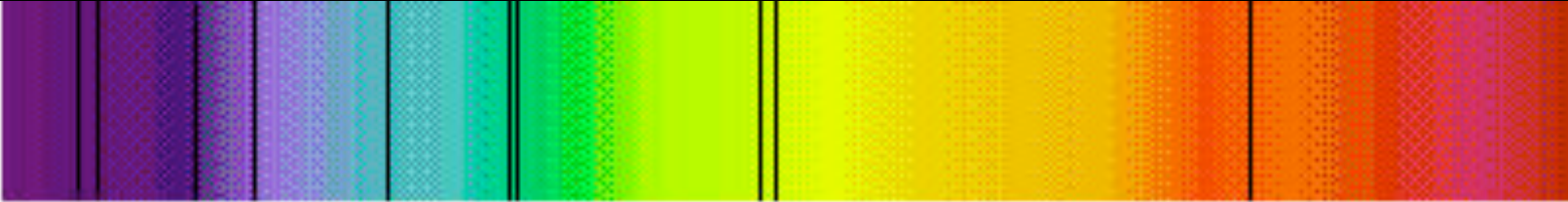


G. Lemaitre





V. M. Slipher



Acercándose a nosotros: desplazamiento al azul

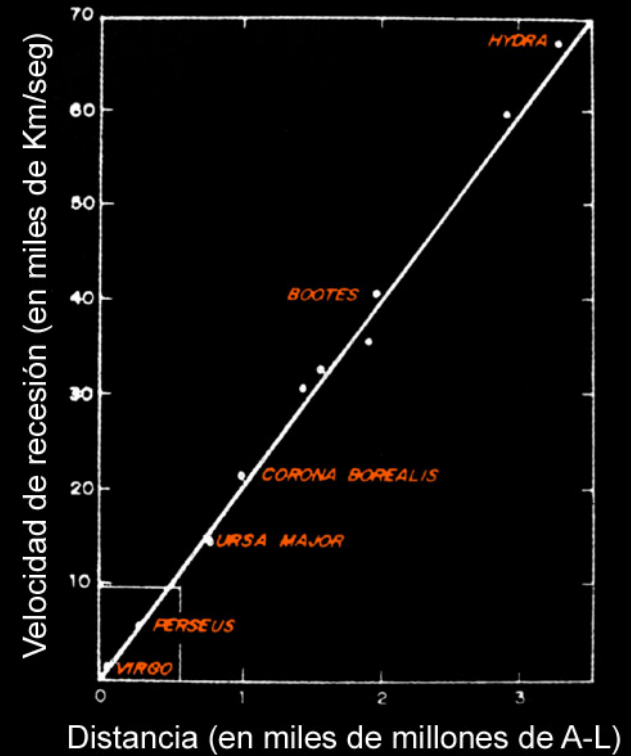
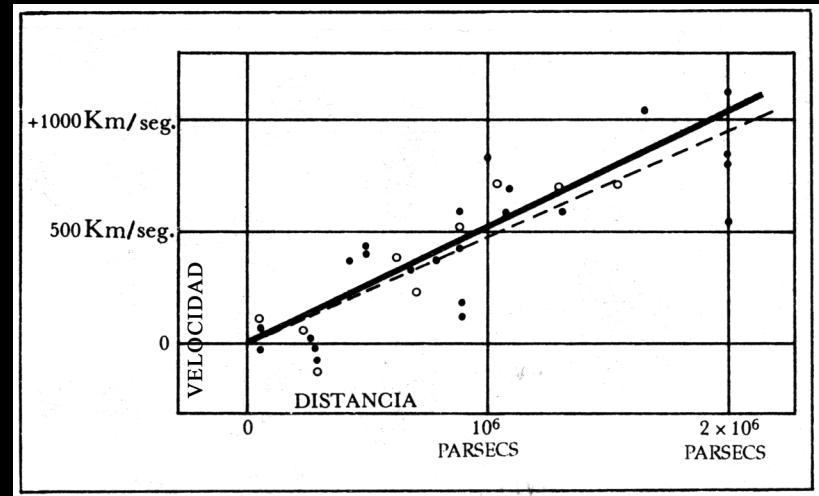
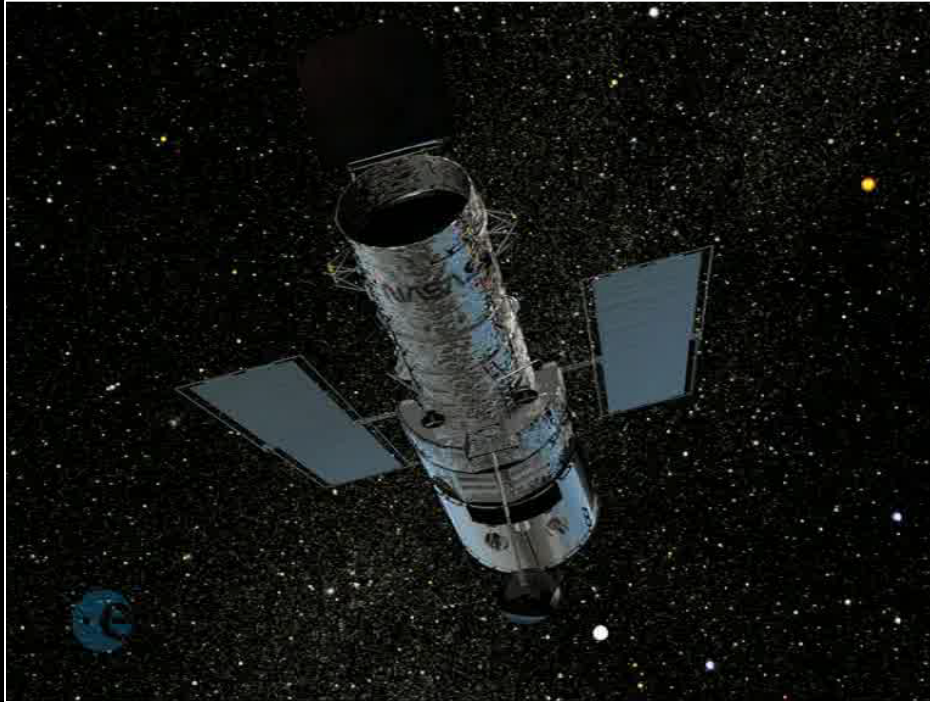


En reposo



Alejándose de nosotros: desplazamiento al rojo

El Universo está en Expansión

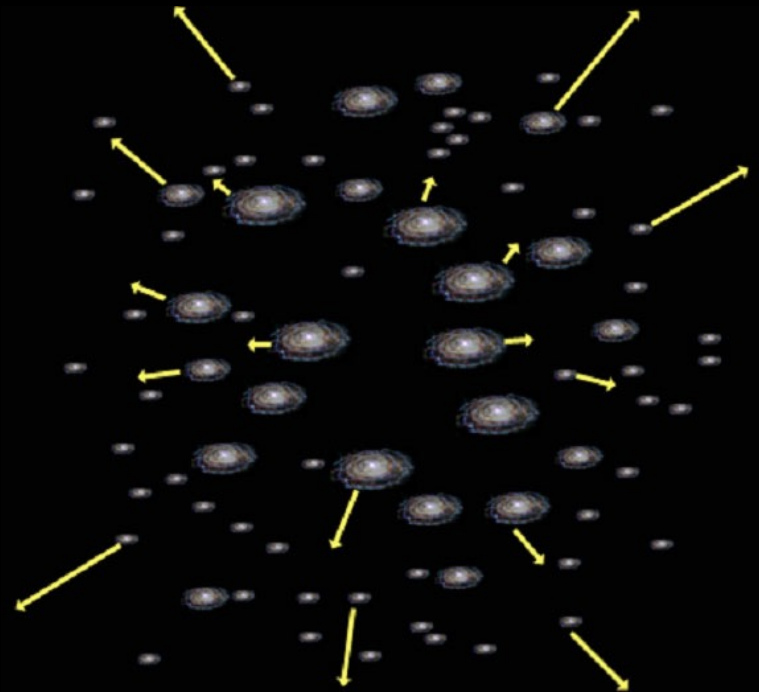


LA EXPANSIÓN DEL UNIVERSO

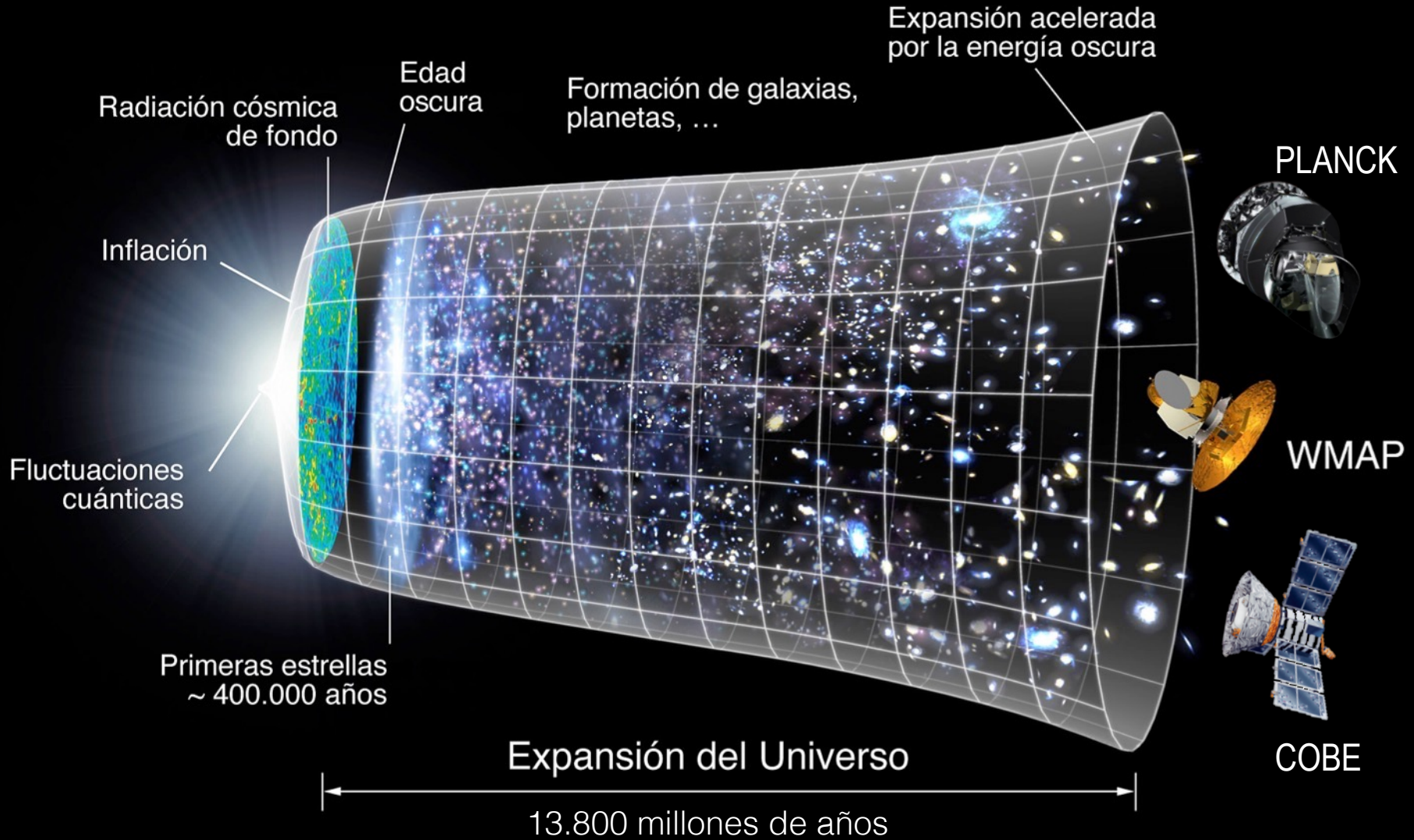


No existe un centro del Universo

Todos los observadores ven lo mismo:



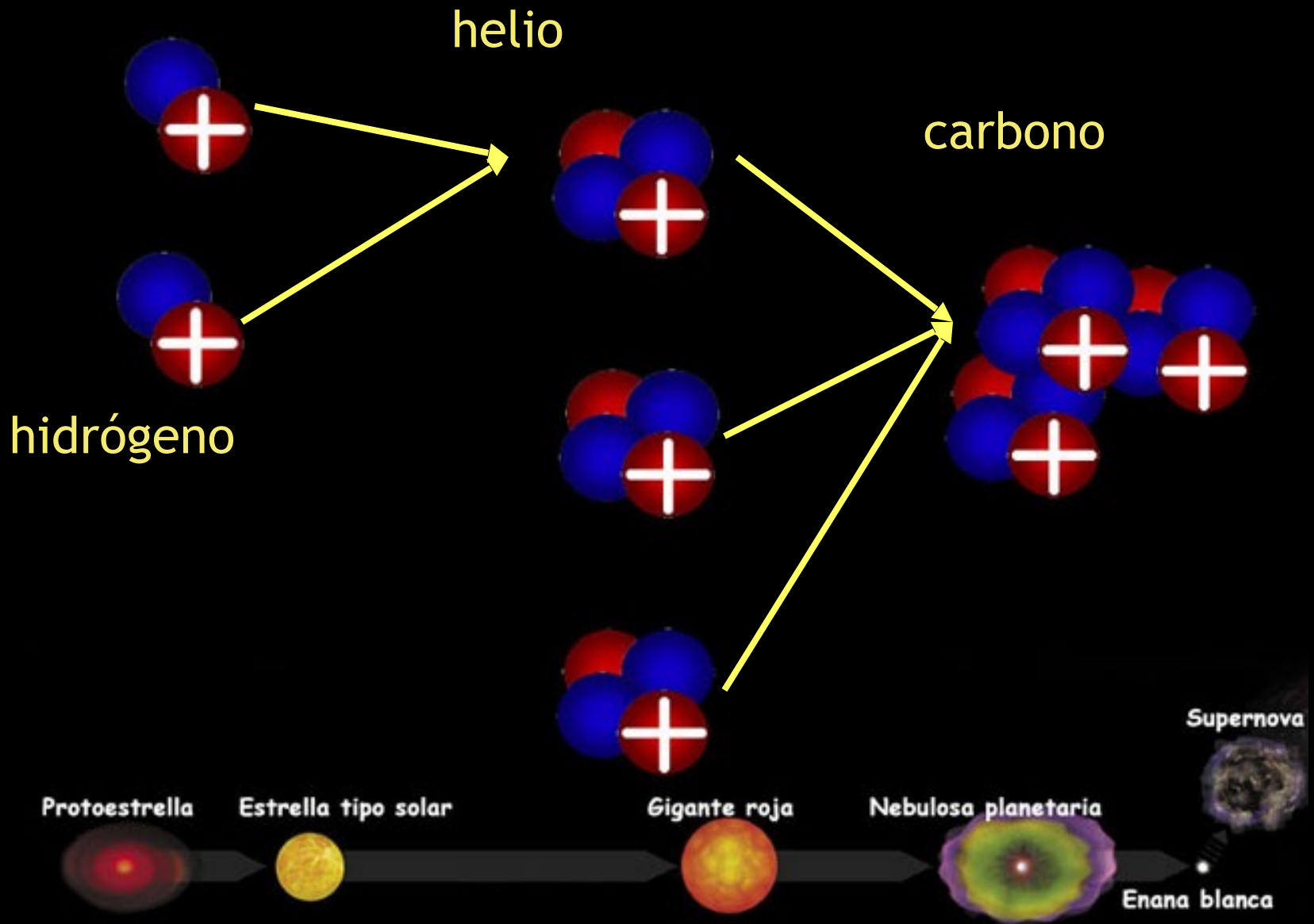
Nuestro modelo cosmológico



Nuestro modelo cosmológico

¿ Existen restos “fósiles” del Big Bang?

Elementos químicos y evolución estelar

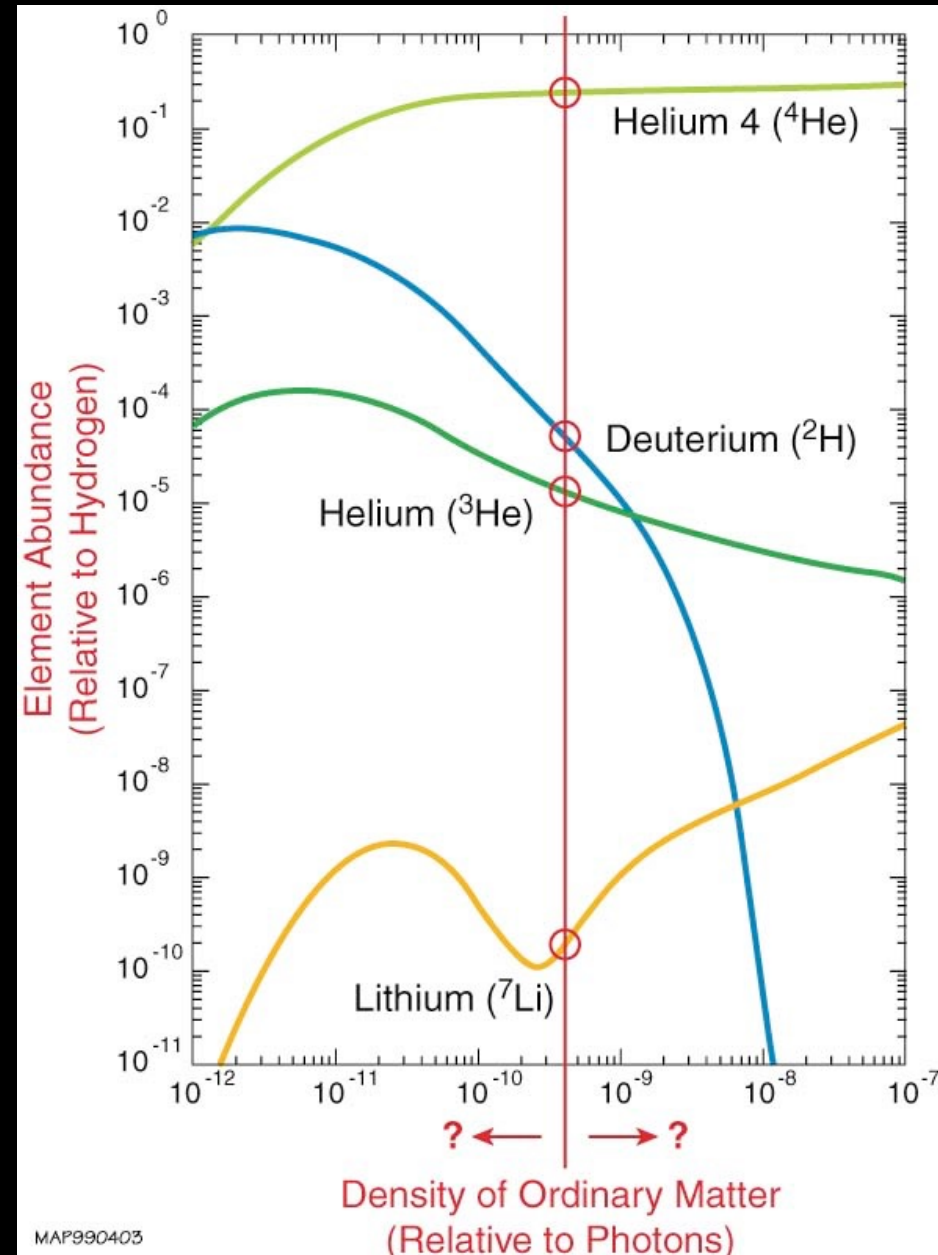


Abundancias de elementos ligeros. Nucleosíntesis en el Big Bang



Modelo de Big Bang propuesto por Gamow (1946) para explicar la generación de elementos ligeros en el Universo.

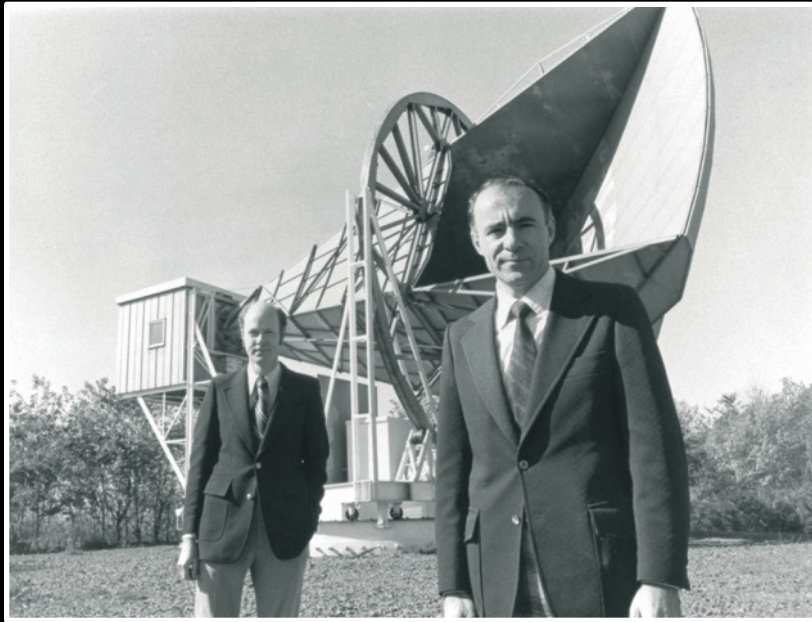
- Hoy día, las abundancias de elementos ligeros se usan como herramienta para determinar la densidad de materia ordinaria (bariónica) en el Universo.
- Consistente con 4% de materia ordinaria (Burles et al. 2001).
- Además, hay 10^{10} fotones por cada barión.



El Fondo Cósmico de Microondas

Radiación fósil que se generó cuando el Universo tenía 380.000 años.

- Predicha por Gamow, Alpher y Herman (1946). Doroshkevich & Novikov (1964)
- Descubierta por Penzias & Wilson (1964).
- Propiedades:
 - Espectro Planckiano
 - Muy isótropa.



Nobel de Física en 1978.
Por su descubrimiento.



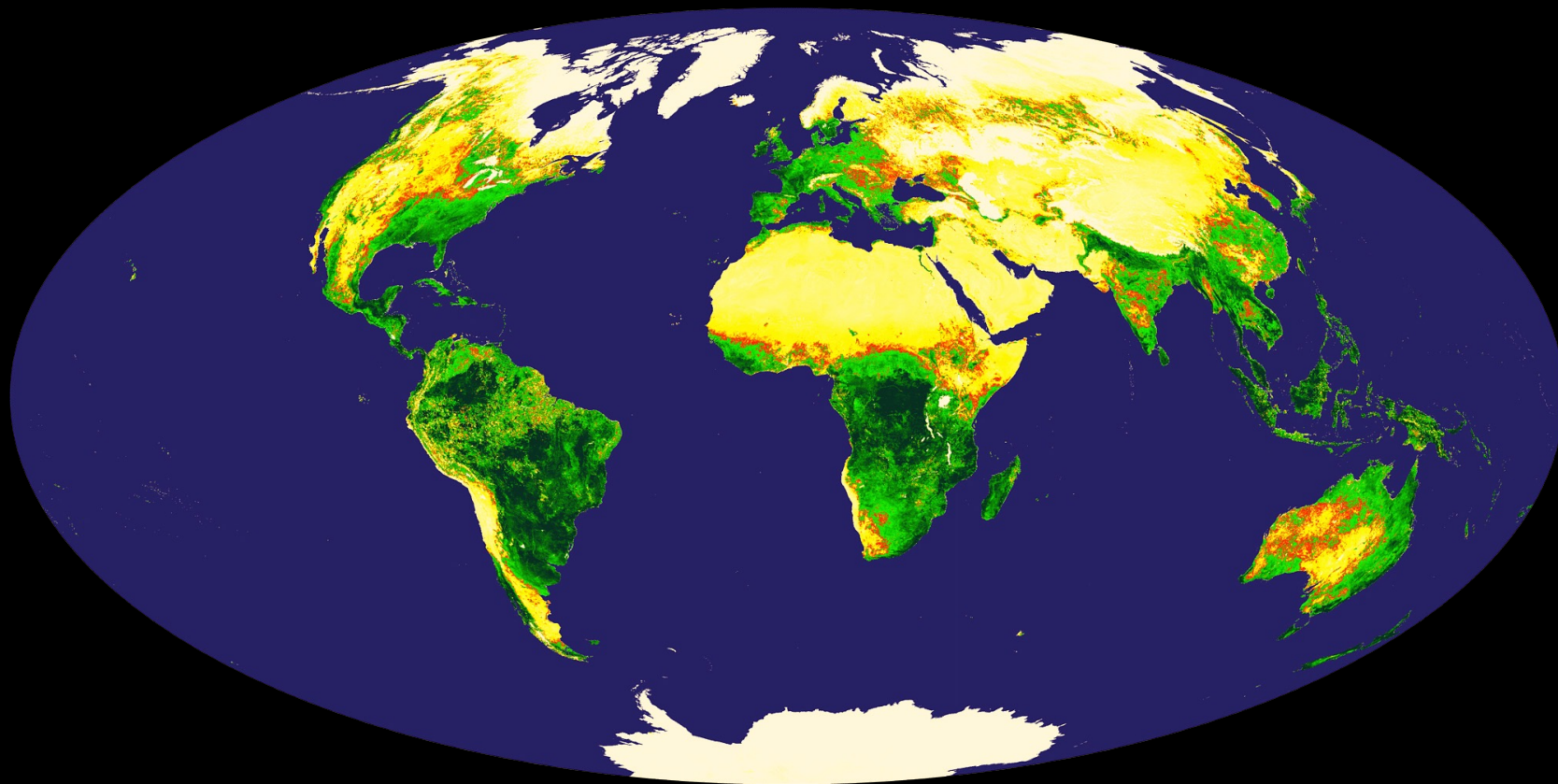
Nobel de Física en 2006. Por la medida del espectro y el nivel de anisotropía.

El Fondo Cósmico de Microondas

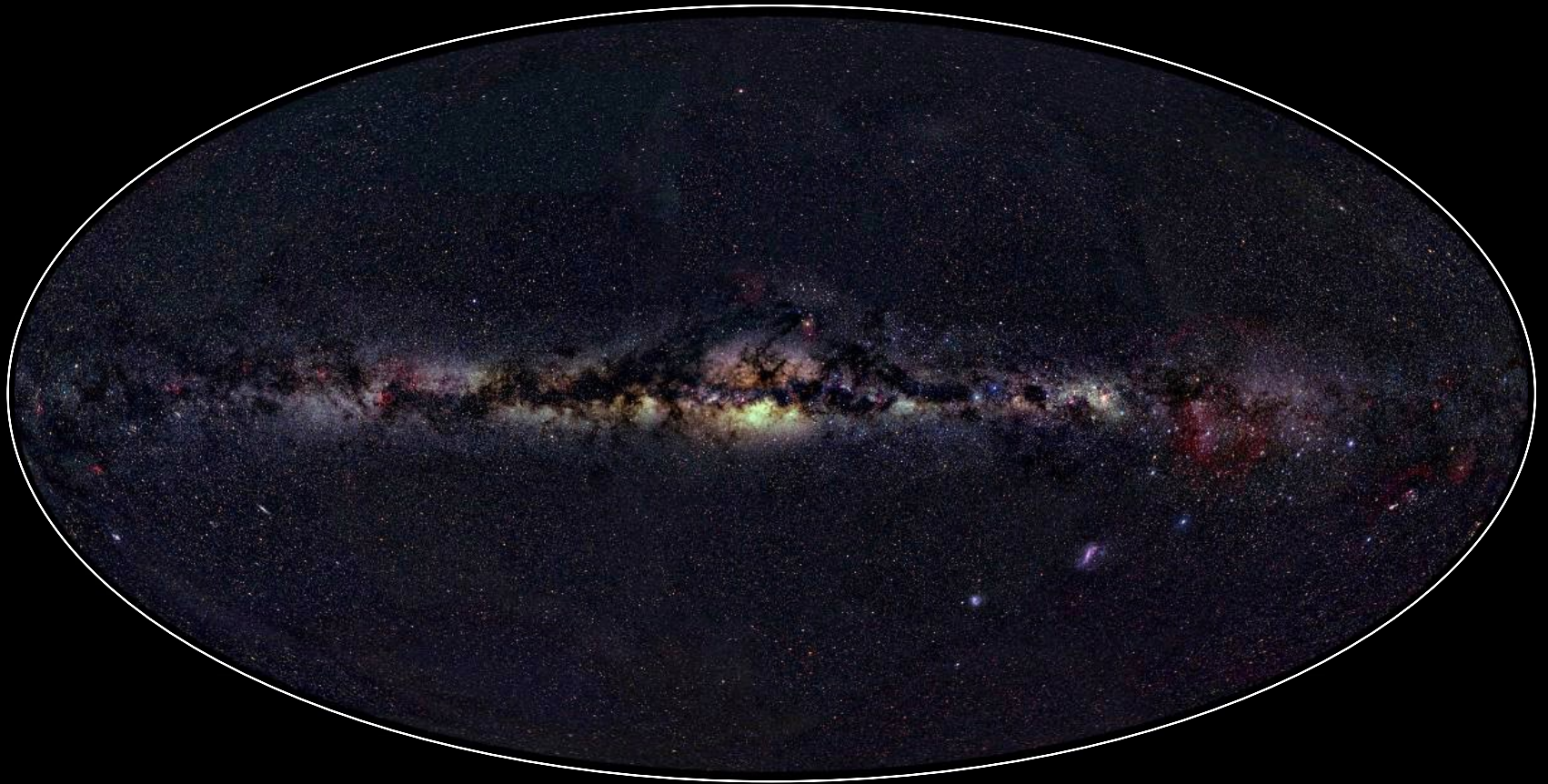
Radiación fósil que se generó cuando el Universo tenía 380.000 años.

- Antes de ese momento, el Universo estaba en forma de plasma.
- En ese momento (recombinación) el Universo se vuelve globalmente neutro y transparente a la luz.
- La temperatura era de unos 3000K.
- Con la expansión, esa radiación se enfría.
- Hoy la observamos a unos 3K, en las microondas.

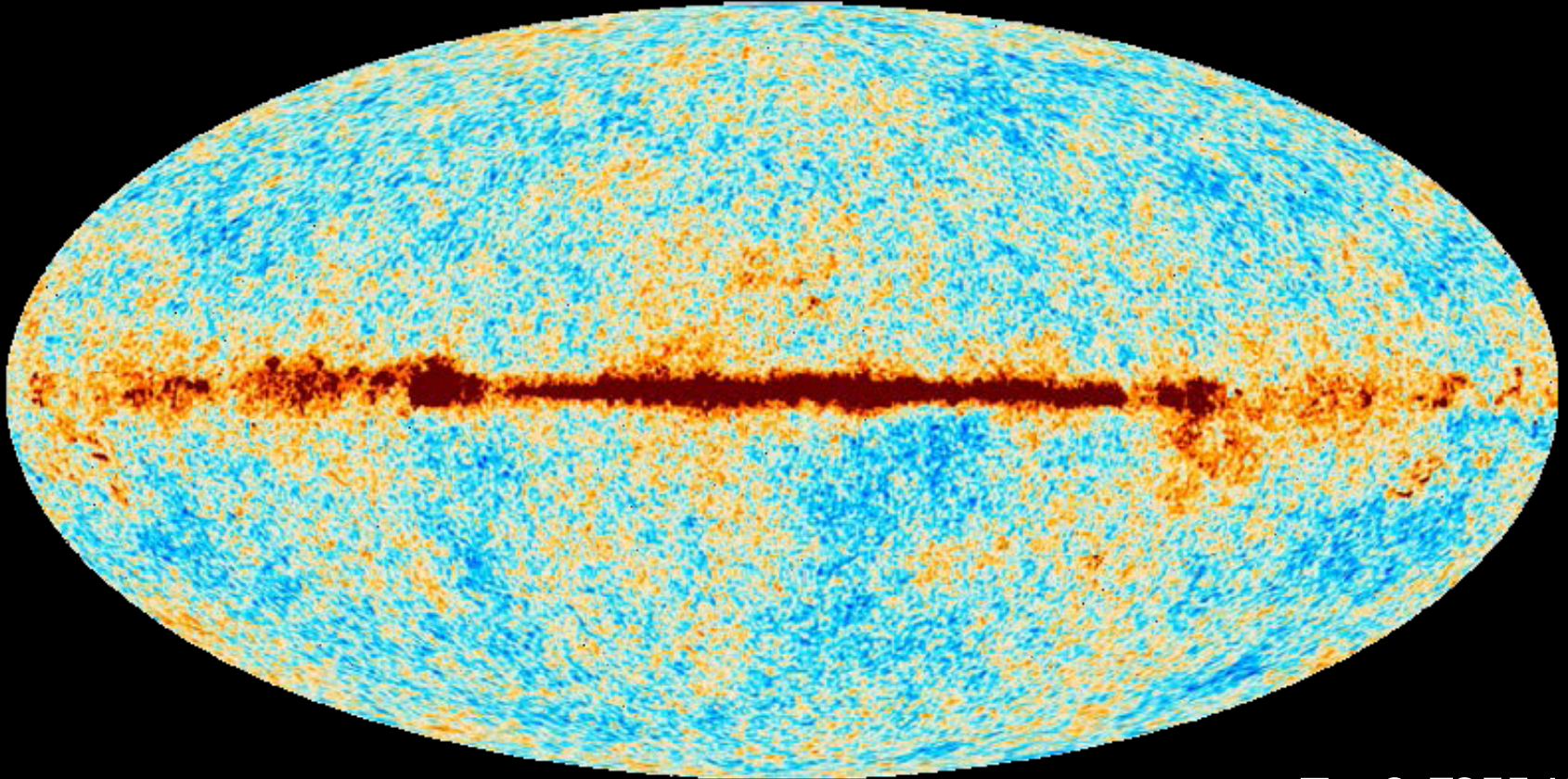
Planisferio Terrestre



El Cielo visto con Telescopios Ópticos



El Fondo Cósmico de Microondas

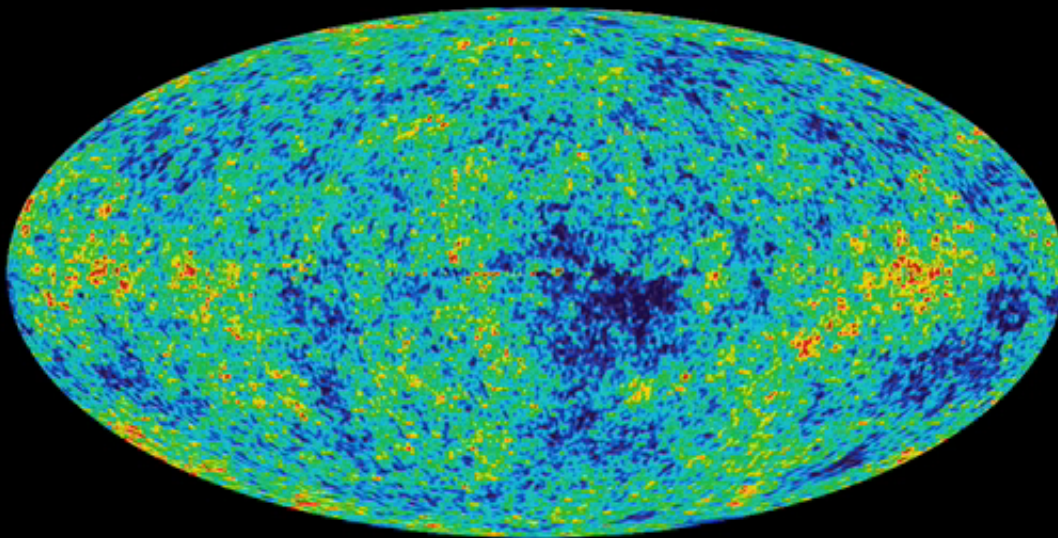


$T = 2.7255 \text{ K}$

Pero la Radiación del Big Bang no puede ser perfectamente uniforme...

¿Porqué esperamos ver anisotropías en el Fondo Cósmico de Microondas?

❖ Todas las estructuras en el Universo actual (galaxias, cúmulos de galaxias, etc) crecen por efecto de la atracción gravitatoria a partir de las semillas originales que observamos en el fondo cósmico de microondas: las *anisotropías*.



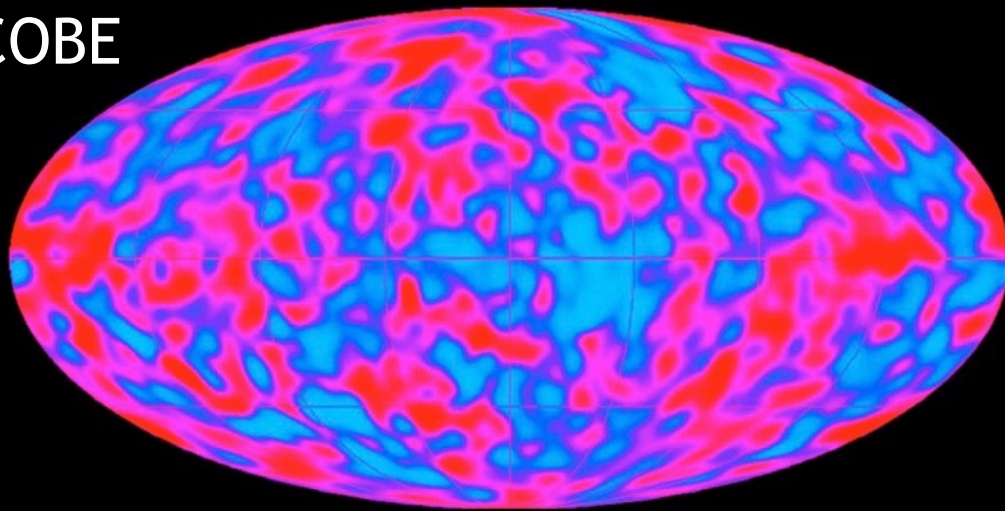
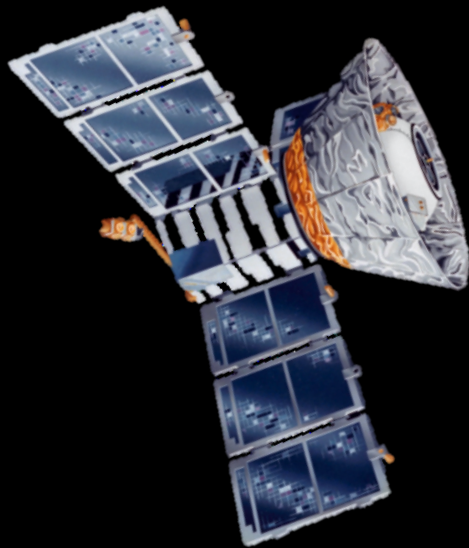
Credit: NASA



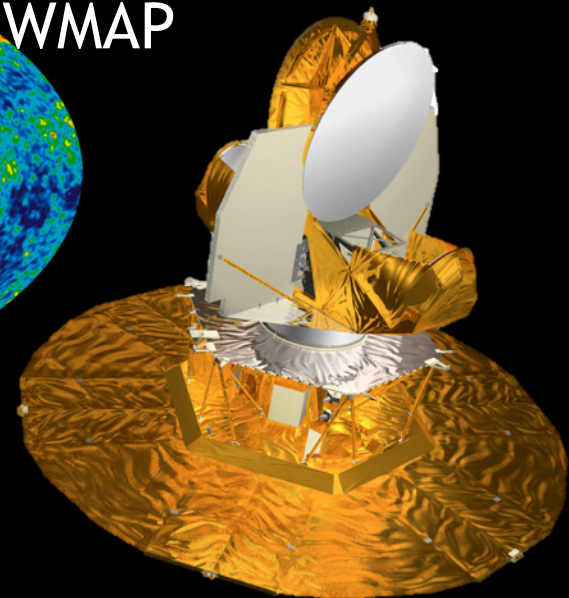
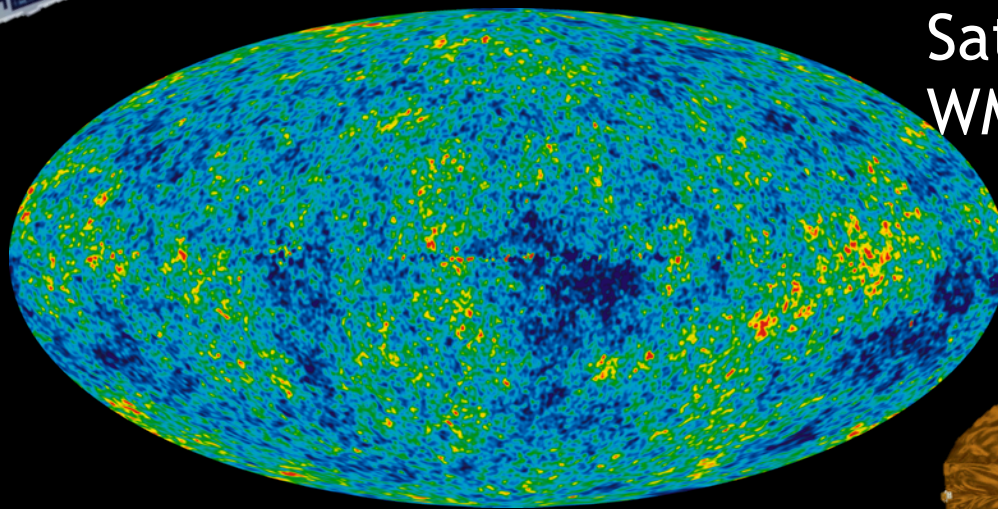
El Fondo Cósmico de Microondas. La luz más antigua del Universo



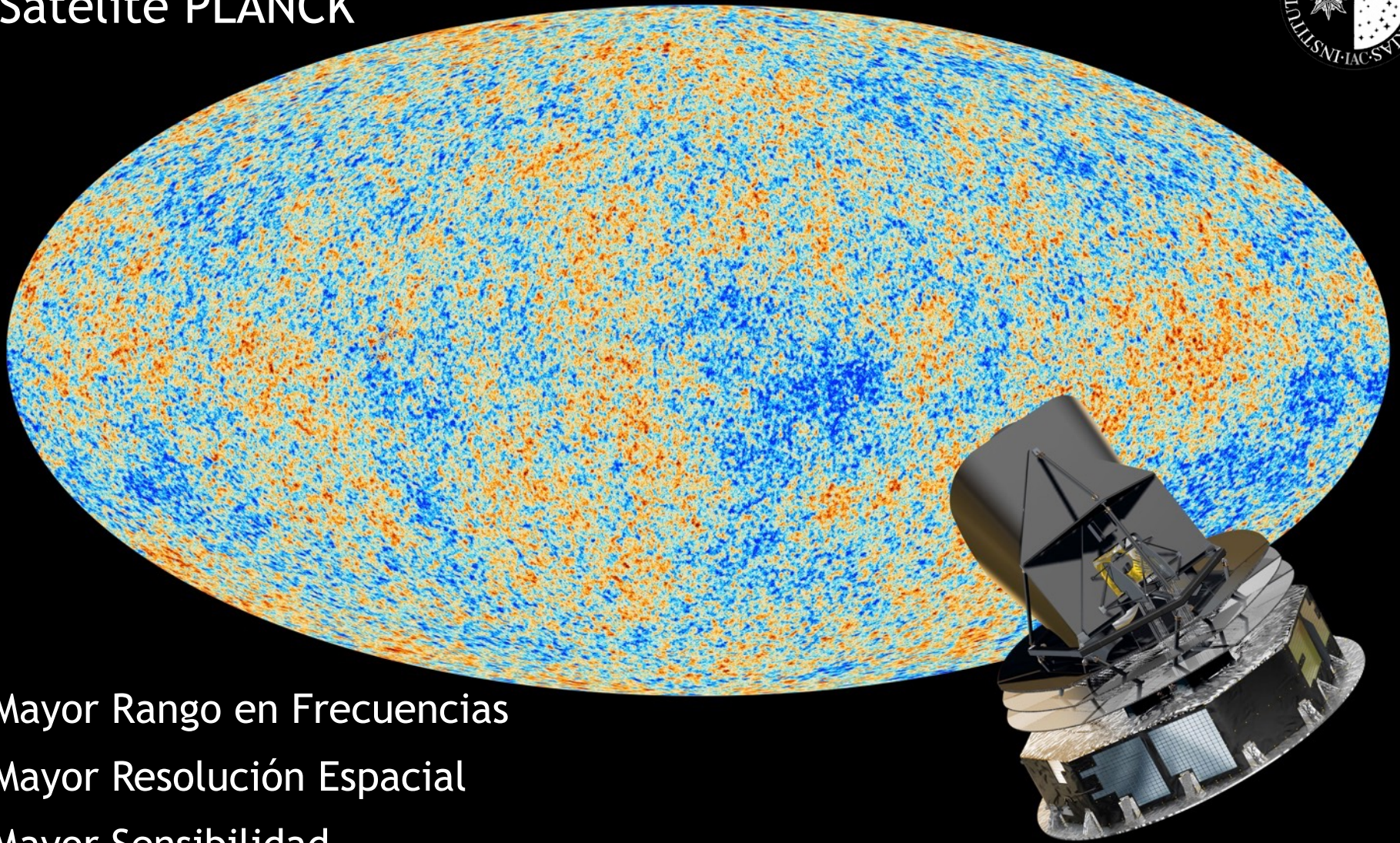
Satélite COBE



Satélite
WMAP



Satélite PLANCK



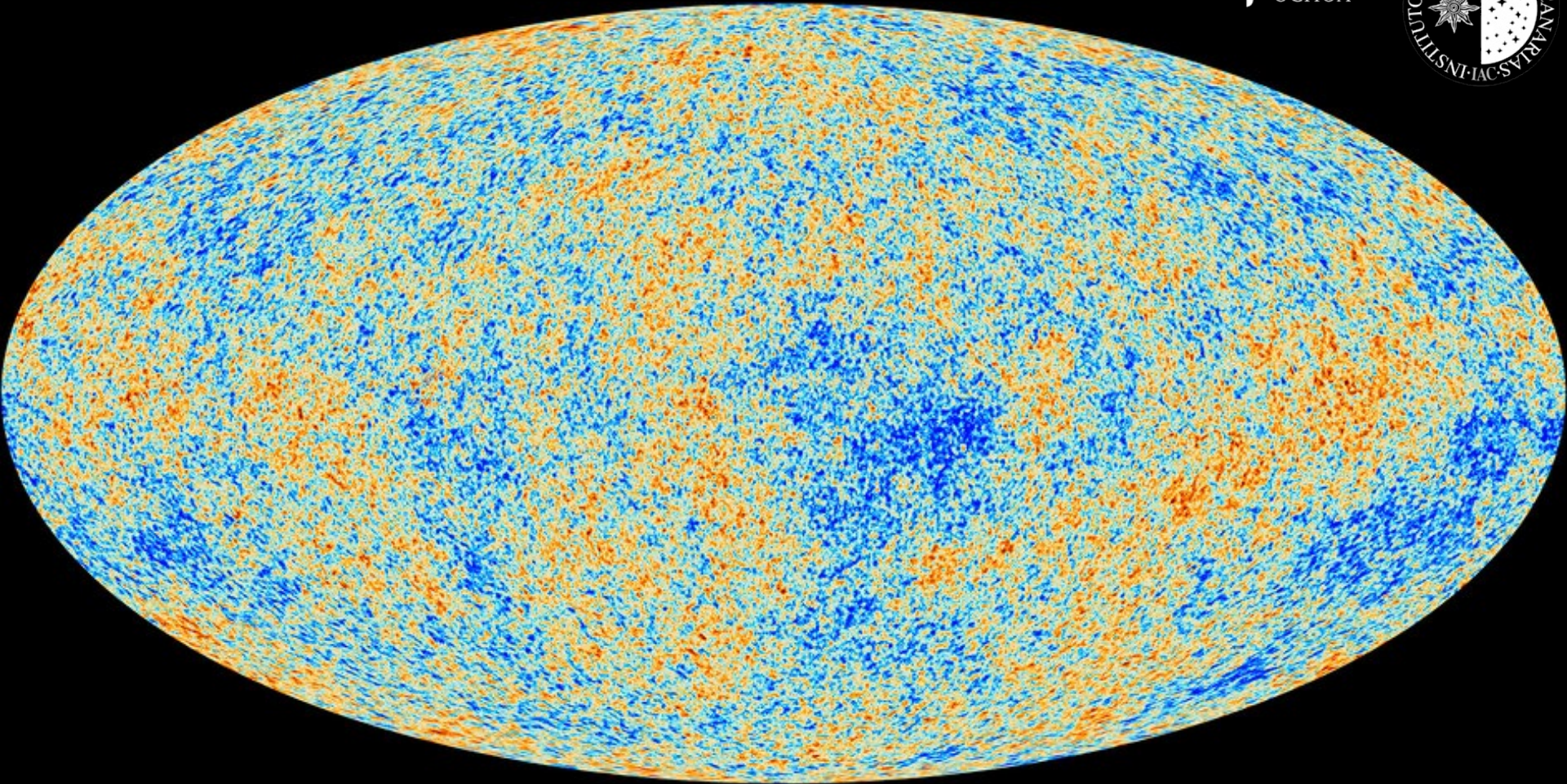
Mayor Rango en Frecuencias

Mayor Resolución Espacial

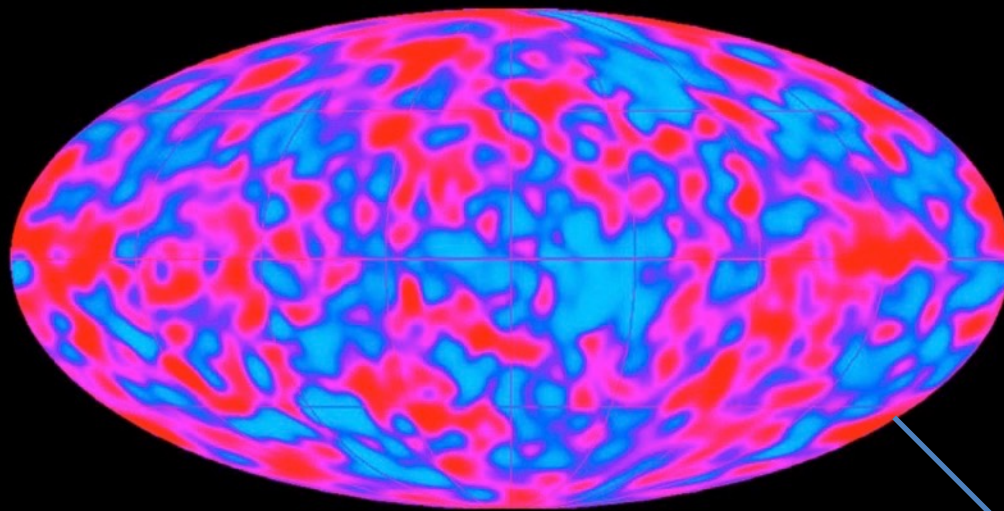
Mayor Sensibilidad

Posibilidad de estudiar nuevos fenómenos en los primeros instantes del Universo

EL FONDO CÓSMICO DE MICROONDAS visto por PLANCK



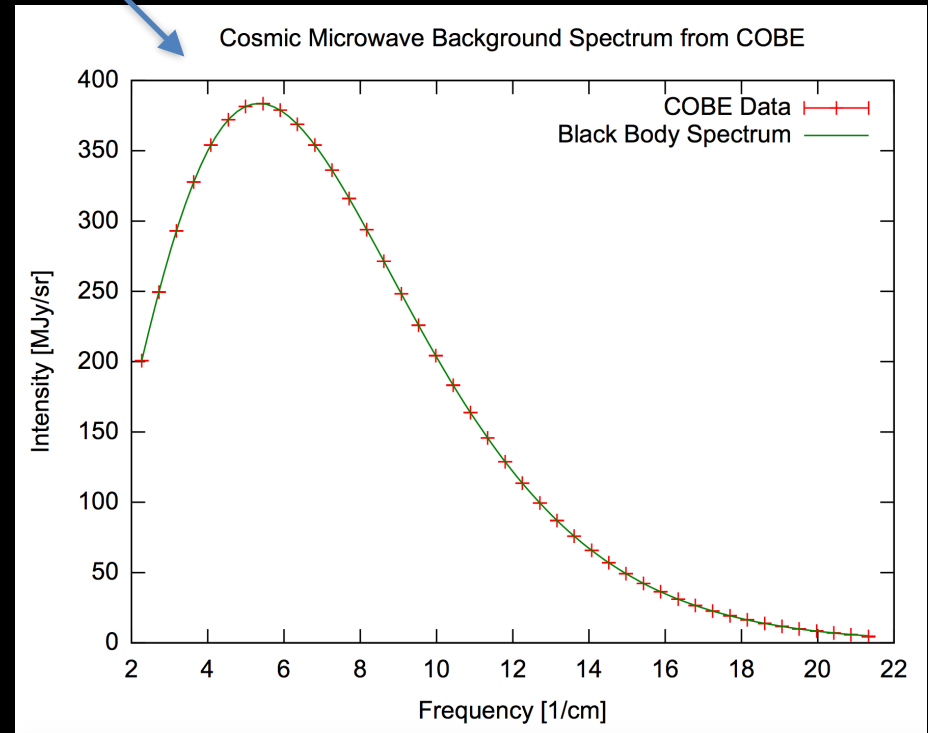
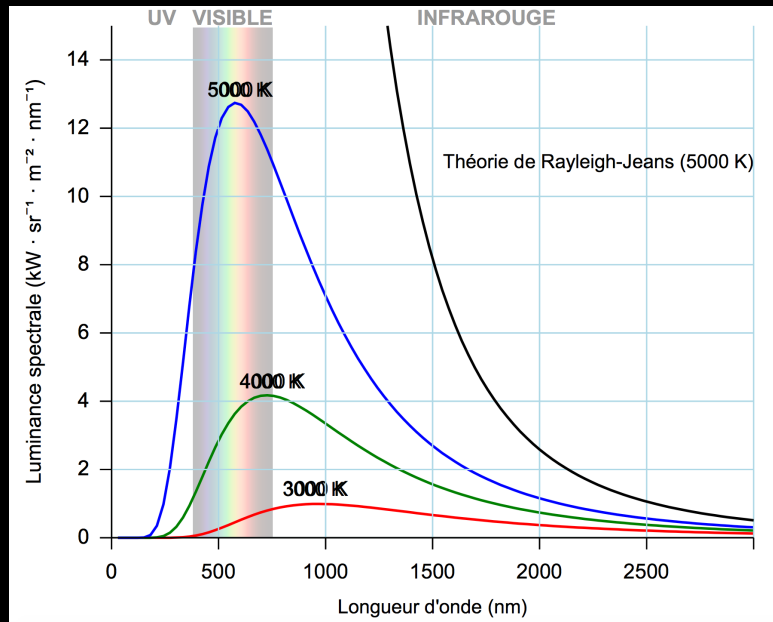
El Universo con 380.000 años de edad



El espectro de la radiación de fondo de microondas medido por el instrumento FIRAS en el satélite COBE es el espectro de cuerpo negro medido con más precisión en la naturaleza.

Ultimas medidas por el Satellite *Planck* dan una temperatura de 2.7255 K.

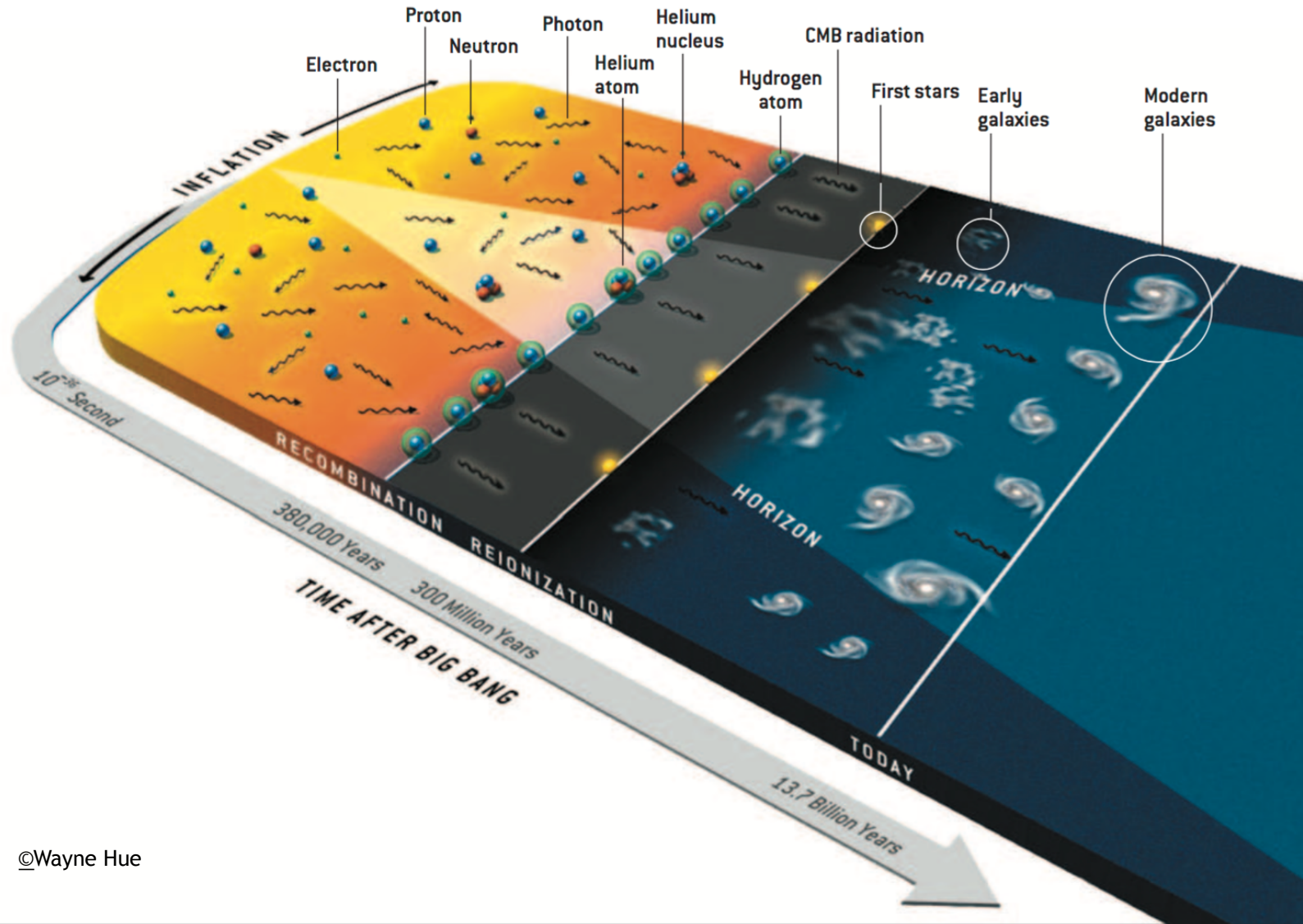
Espectro de cuerpo negro

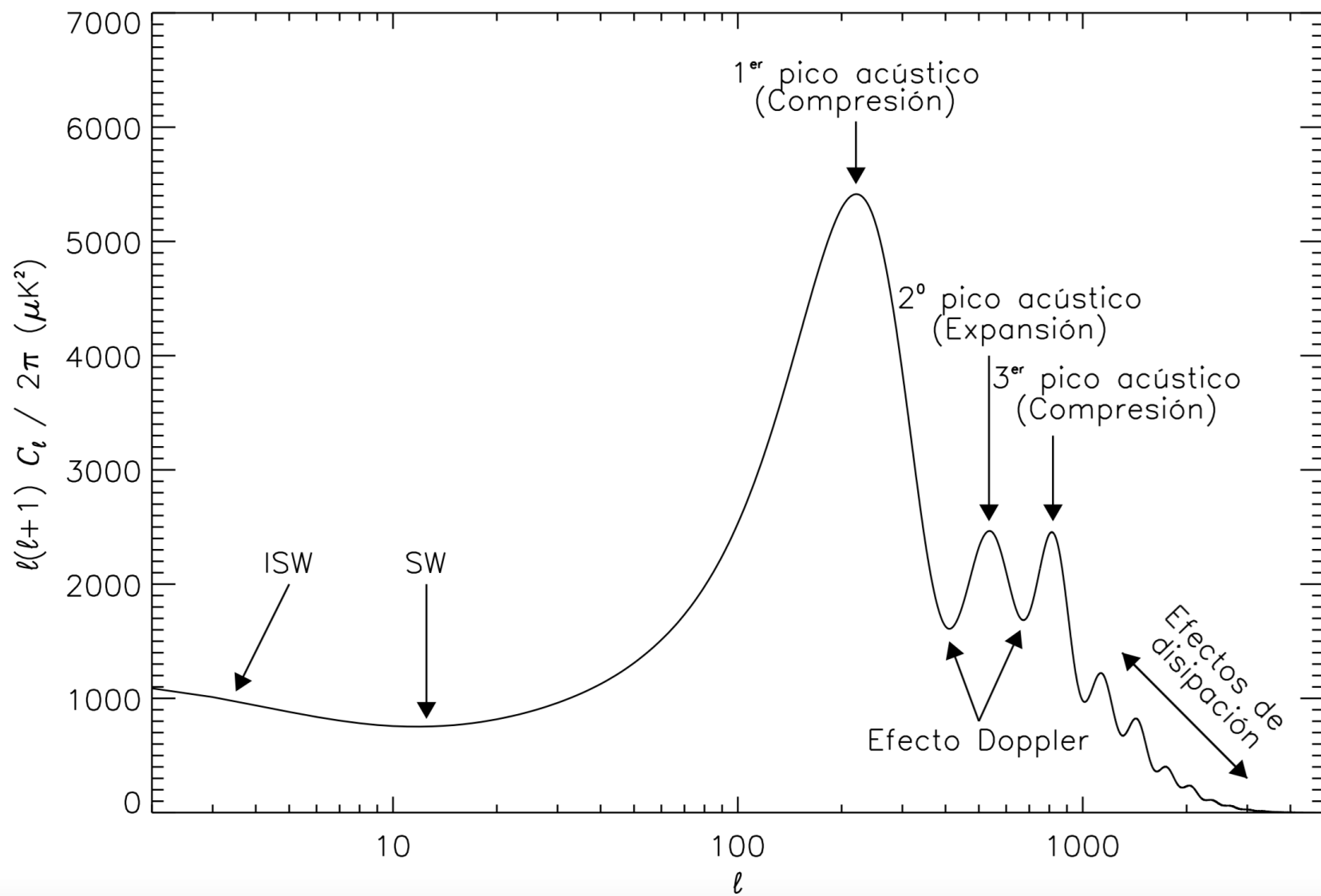


TIMELINE OF THE UNIVERSE

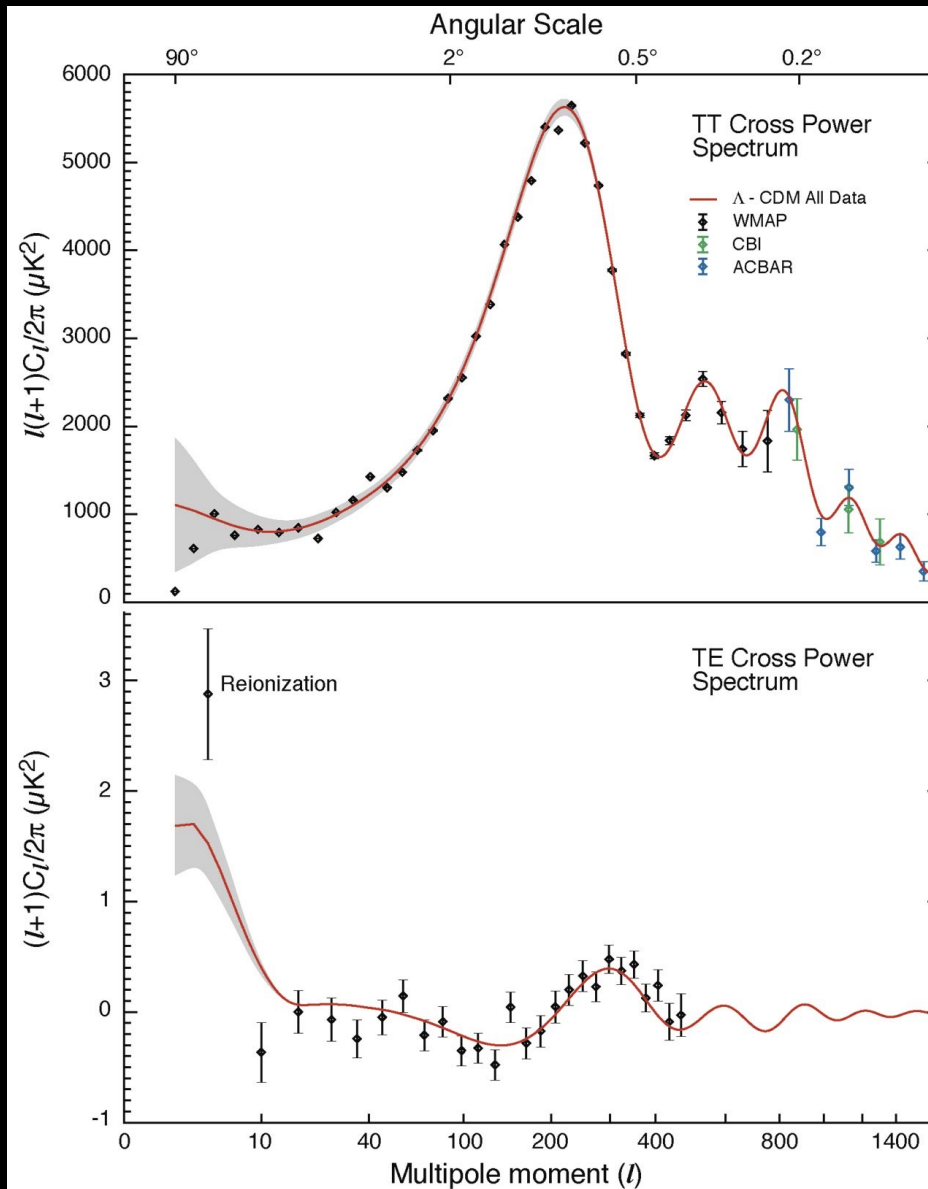
AS INFLATION EXPANDED the universe, the plasma of photons and charged particles grew far beyond the horizon (the edge of the region that a hypothetical viewer after inflation would see as the universe expands). During the recombination period

about 380,000 years later, the first atoms formed and the cosmic microwave background (CMB) radiation was emitted. After another 300 million years, radiation from the first stars reionized most of the hydrogen and helium.





WMAP 1st year resultados (Feb.2003)



- Confirmación del modelo estándar

$$\Omega_b h^2 = 0.0224 \pm 0.0009$$

$$\Omega_{tot} = 1.02 \pm 0.02$$

$$n = 0.93 \pm 0.03$$

$$\Omega_{cdm} h^2 = 0.113 \pm 0.008$$

$$h = 0.71 \pm 0.03$$

$$\Omega_m = 0.27 \pm 0.04$$

$$\Omega_\Lambda = 0.73 \pm 0.04$$

$$\text{Age} = 13.7 \pm 0.2 \text{ Gyr}$$

$$\sigma_8 = 0.84 \pm 0.04$$

- Polarization-Intensity cross power spectrum.

- Detección de la reionización precoza:

$$\tau = 0.17 \pm 0.04 \quad (z_{re} = 20^{+10}_{-9})$$

- Mapas de la radiación de nuestra galaxy



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Curie Actions
under Horizon2020

The Izaña Site



Observatorio del Teide

Altitude: 2400 m

Longitude: 16° 30' W

Latitude: 28° 17' N

Typical PWV: 3 mm

Transmissivity: 98%
 $\equiv T_{\text{sky}} \approx 5 \text{ K}$

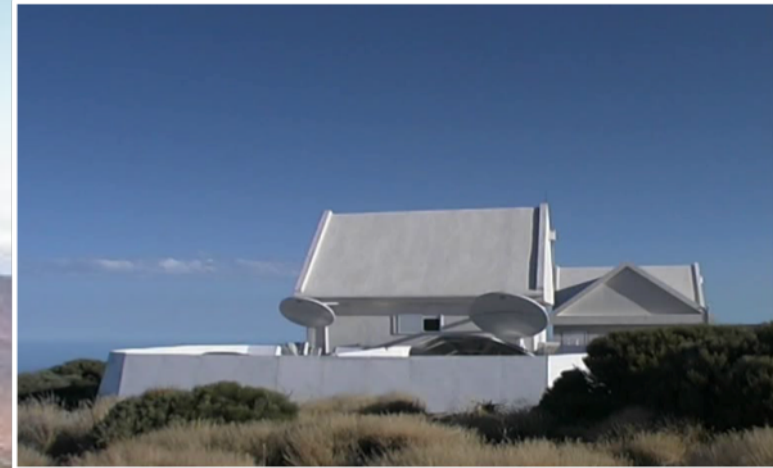
Good weather: 90%

Easy access: 40 km
road journey from IAC

The Teide Observatory site run by the Instituto de Astrofísica de Canarias (IAC) and is above much of the atmospheric water vapour with a stable dry climate.

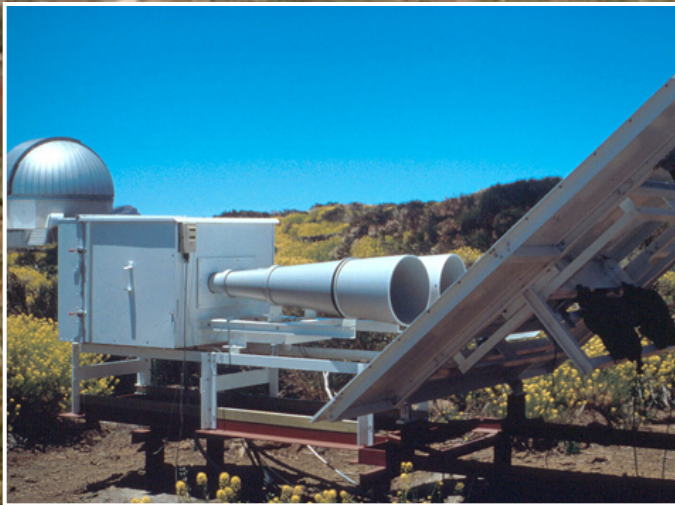
It is accessible by just a 60 minute car drive from the IAC in La Laguna. There are cheap direct charter flights to Tenerife

90% of the time the data is just system noise limited!



COSMOSOMAS (1998-2007)

Frecuencias: 11, 13, 15 y 17 GHz



Experimento Tenerife (1984-2000)

Frecuencias: 10, 15 y 33 GHz



The Very Small Array (2000 - 2008)

Frecuencias: 30 GHz

Desde 2012: El Experimento QUIJOTE





Cosmologia al IAC

- > Principal Investigator
Prof Rafael Rebolo
- > Investigators
Dr. Ricardo T. Génova Santos
Dr. Carlos M. Gutiérrez de la Cruz
Dr. José Alberto Rubiño Martín
Dr. Frederick Poidevin
- > PhD Students
Denis Tramonte
Alba E. Peláez Santos
Riccardo Vignaga
- > Engineers
Marta Aguiar
M.F. Gómez Reñasco
Dr Roger J. Hoyland
Angeles Pérez de Taoro
Vicente Sánchez de la Rosa
Teodora Viera Curbelo

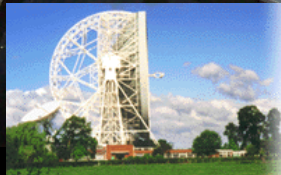
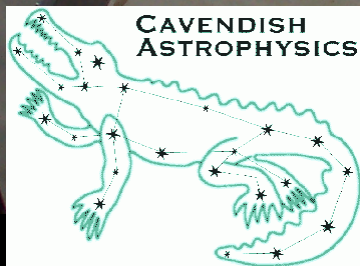
- > Former members of the group
Dr. Robert A. Watson (Jodrell Bank)
Dr. Clive Dickinson
Dr. Elia S. Battistelli (University British Columbia)
Dr. Bruno Femenía (IAC)
Dr. Inés Flores-Cacho (IRAP, Toulouse)
Dr. Silvia Fernández Cerezo
Julio E. Gallegos
Dr. Sergi Hildebrandt (Caltech)
Dr. Juan F. Macías-Pérez (LPSC, Grenoble)
Dr. Carmen P. Padilla Torres (TNG)
Dr. Marco Tucci (LAL, IN2P3, Paris)
Dr. Angela Hempel
Dr. Claudia G. Scoccola
Dr. Carlos H. López Caraballo

> External collaborators

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Dr. Keith Grainge (Cavendish)
Dr. Mike Hobson (Cavendish)
Dr. Mike Jones (Cavendish)

Dr. Richard Saunders (Cavendish)
Dr. Paul Scott (Cavendish)
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Dr. Juan E. Betancort Rijo (IAC)
Dr. Nelson Falcón (Universidad de Carabobo)
Dr. Carlos Hernández Monteagudo (CEFCA, Teruel)
Dr. Enrique Martínez González (Instituto de Física de Cantabria)
Prof. Eduardo Battaner (Universidad de Granada)

The Very Small Array



Jodrell Bank
Observatory



VSA specifications



Type: 14-element:
Scanning: Tracking by antennas co-mounted on tip-tilt table. Horns rotate E-W.
Pointing range Hour Angle: ± 3 hrs Declination: -6 to +63
Antennas: Corrugated horn feeding 90 degree-offset paraboloidal mirror
Receivers: NRAO design pseudomorphic HEMTs cooled to 15K with Noise temp 25K
Frequency: 31 GHz $\pm$ 5 GHz (Compact 34.1 GHz, Extended mostly 33.0 GHz)
Bandwidth: 1.5 GHz
1st LO: 20-30 GHz
2nd LO: 9.0 GHz (fixed)
Baselines: 91
Correlator: 182 analogue phase-switched channels

Compact Array

Primary beam: 4.5° (143mm aperture)
Resolution: 30 arcminutes
 ℓ range: 100 – 800
Sensitivity: 30 mJy in 300 hrs

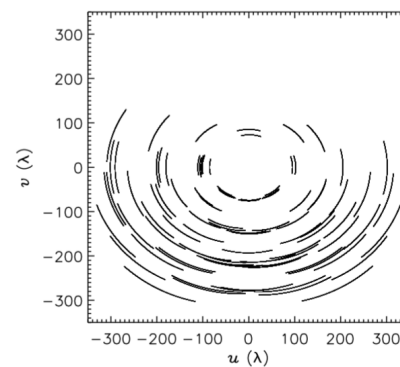
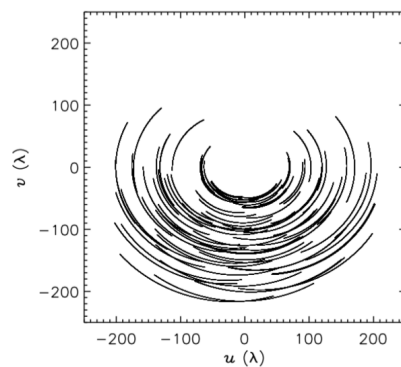
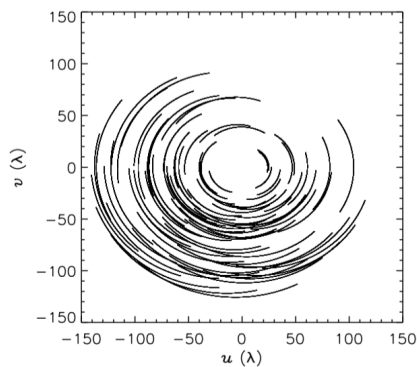
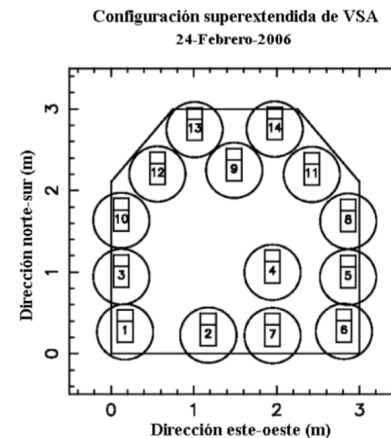
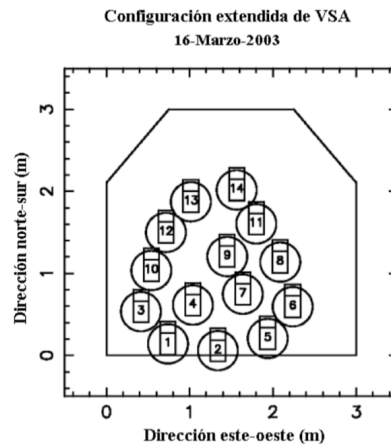
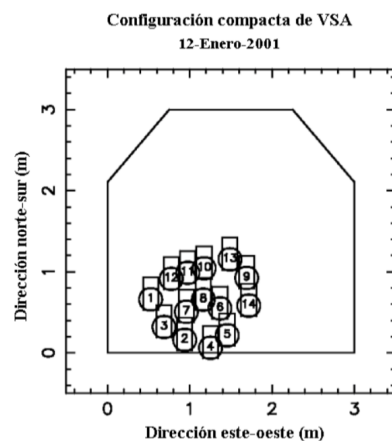
Extended Array

Primary beam: 2.0° (322 mm aperture)
Resolution: 12 arcminutes
 ℓ range: 250 – 1500
Sensitivity: 6 mJy in 300 hrs

Source Subtraction system

Type: 2-element (double side-band) 3.7 m Cassegrain parabolic dishes
Baseline: 9 m separation N-S
Primary beam: 12' Resolution: 3'
Correlator: 4 analogue phase-switched channels
Sensitivity: 5 mJy in 1 hour

	Compacta	Extendida	Superextendida
Tamaño de los espejos, d (mm)	143	322	600×950
FWHM del haz primario (grad)	4.6	2.1	1.2
FWHM del haz sintetizado (minarc)	~ 20	≈ 11	≈ 7
Cobertura de multipolos, ℓ	$\sim 150 - 900$	$\sim 300 - 1500$	$\sim 500 - 2400$
Temperatura de sistema ^a , T_{sis} (K)	30	35	25
Sensibilidad en $28 \times 7^{\text{h}}$, ΔS_{RMS} (mJy/haz)	29	7	4
Sensibilidad en $28 \times 7^{\text{h}}$, $[\Delta T_{\text{RMS}}]_{\text{RJ}}$ (μK)	23	18	26

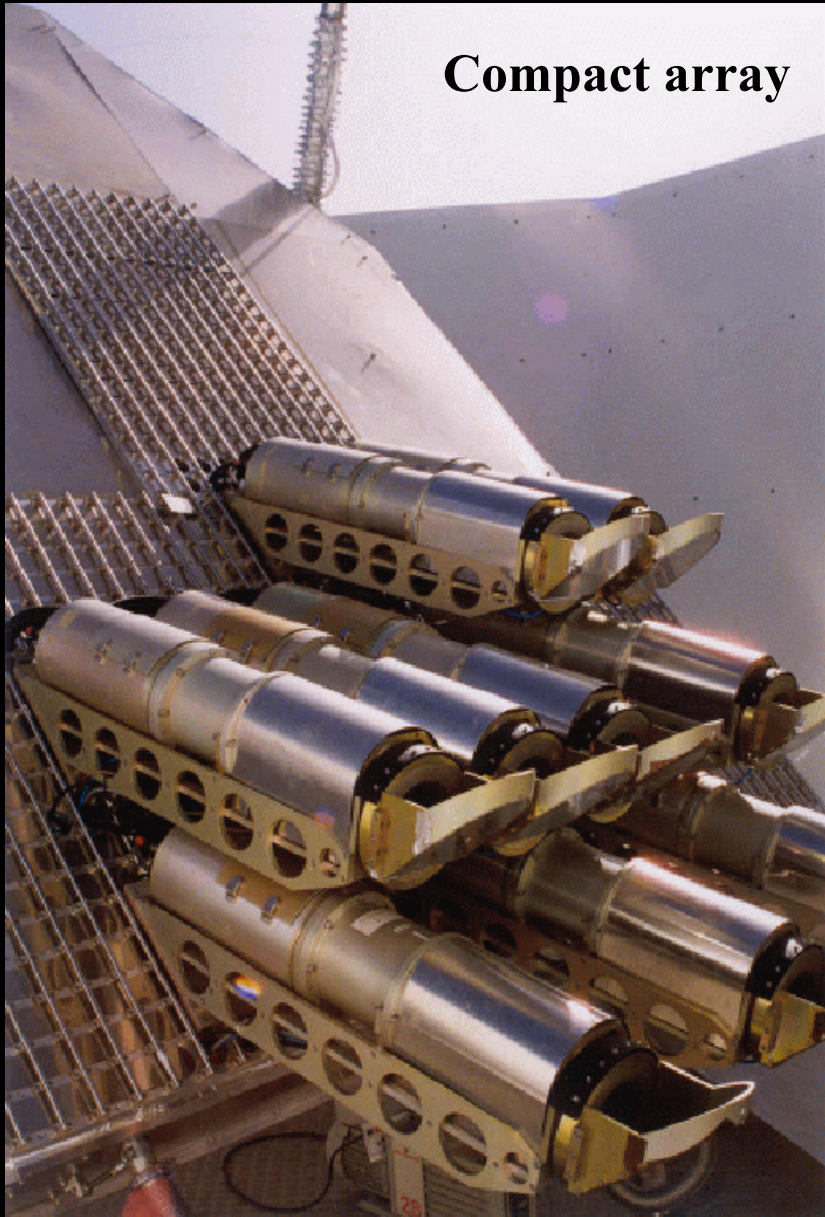


Very Small Array (VSA)



The VSA antennas

Compact array



Extended array



- Efficient, unblocked with a clean aperture
- Compact for close packing (small aperture)
- Low cross-coupling
- Can track independently (fringe rate tracking)

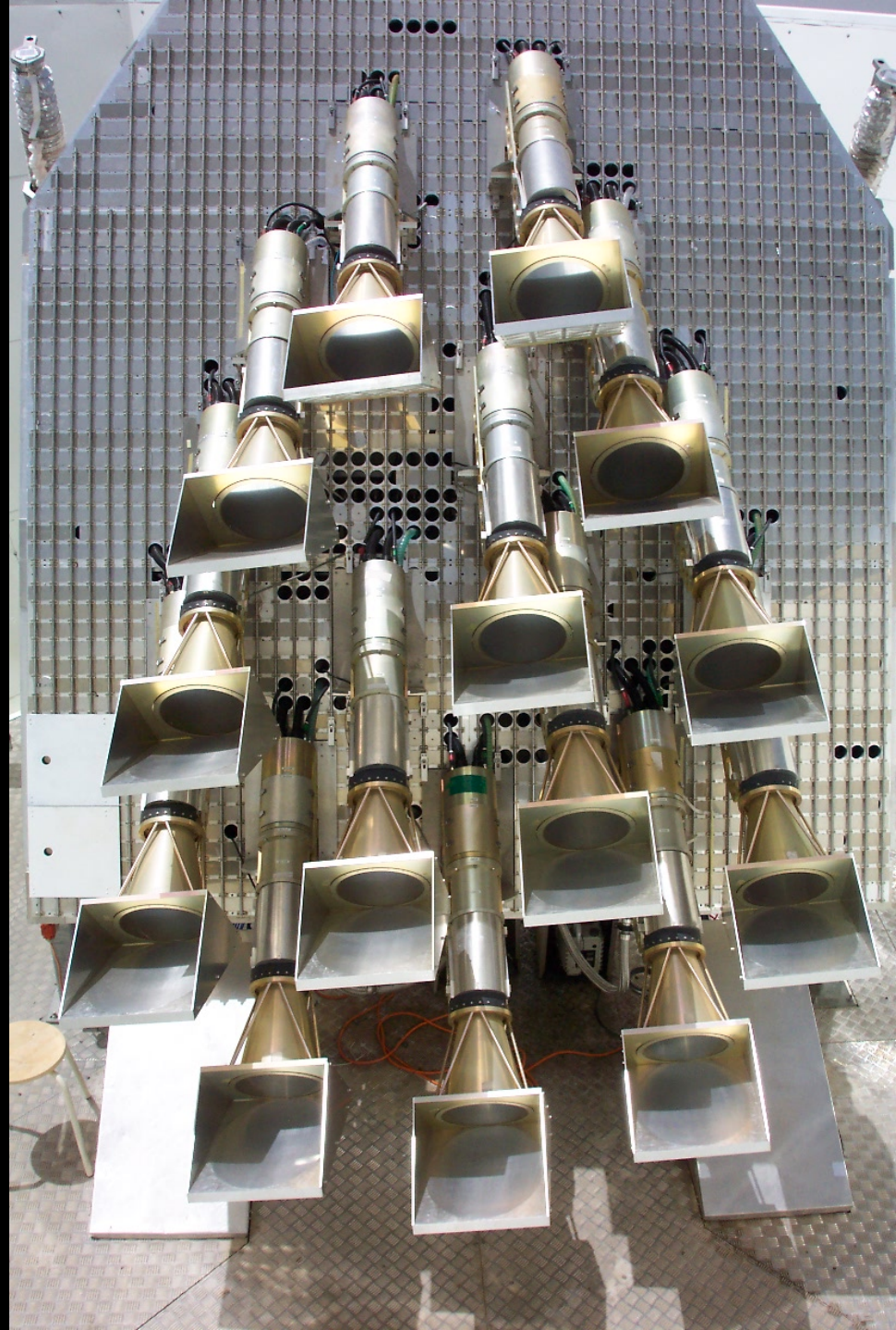
These conditions are met by conical horn reflector antennas (CHRA).

The 90° reflector gives the antennas a periscope-like property so they can be close packed like organ pipes.

This can be rotated to give one dimension of independent tracking.

Side blinders are required to block cross Coupling

Primary beam 2 degrees FWHM ,
Synthetized beam approx. 11 arcmin

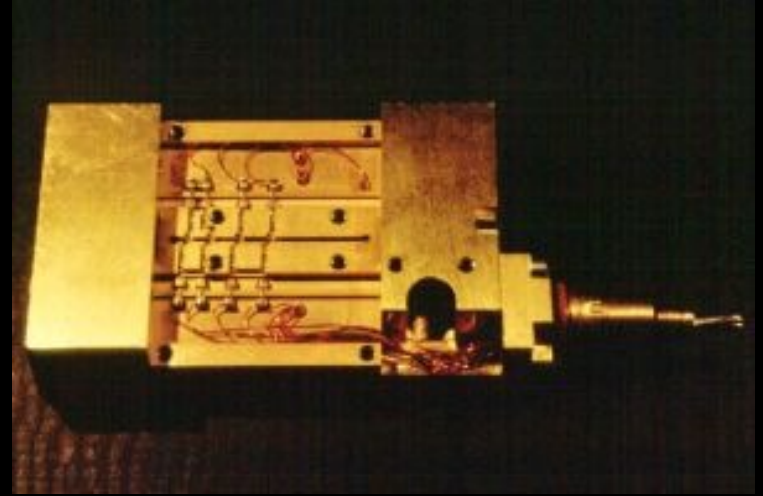
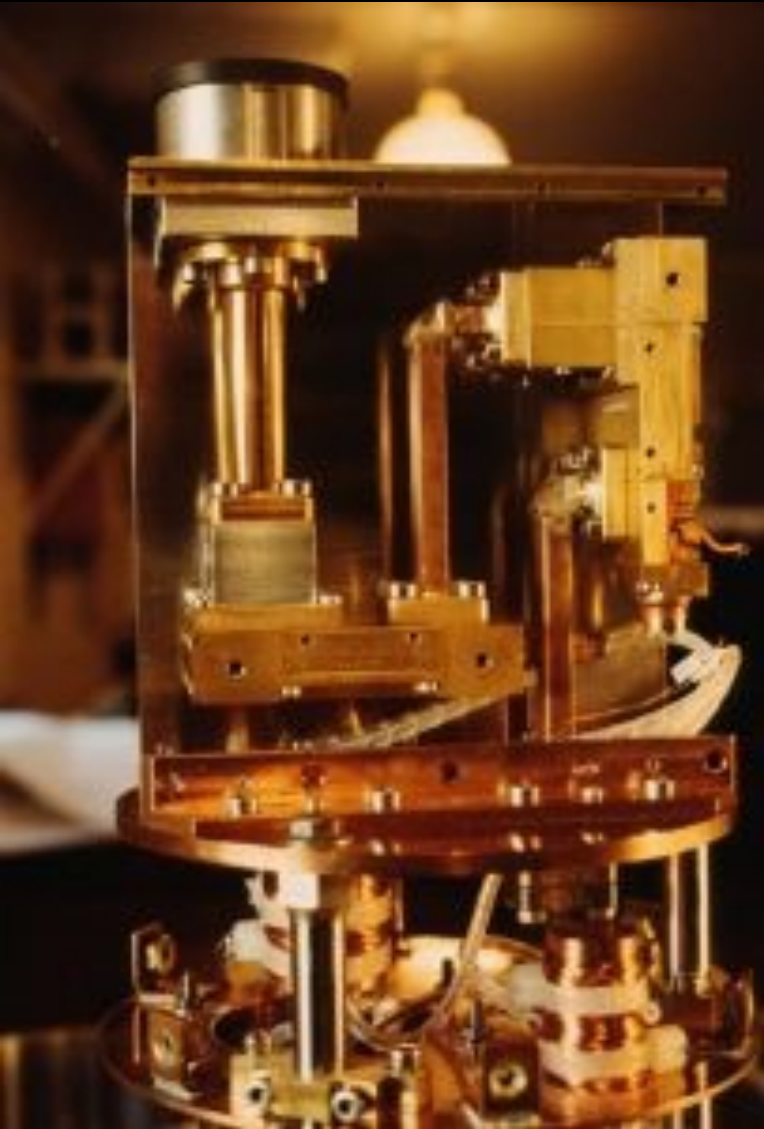


VSA en configuracion superextendida



10 desas antenas están aqui !!!

Los receptores



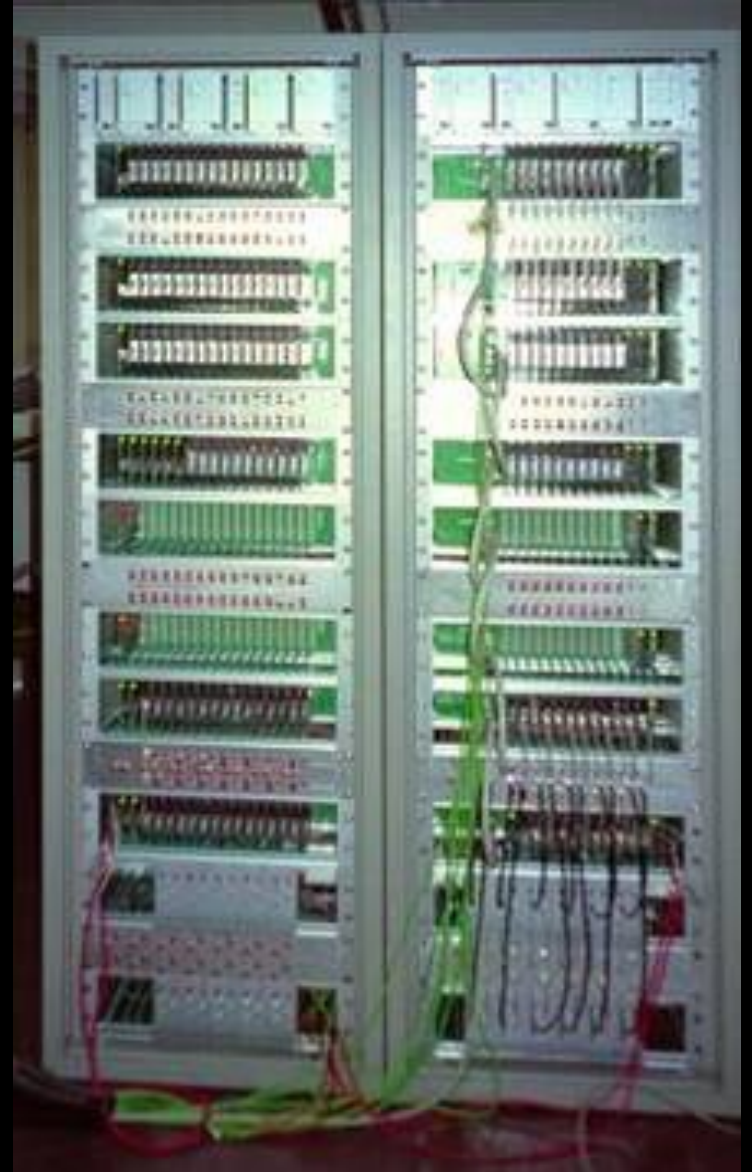
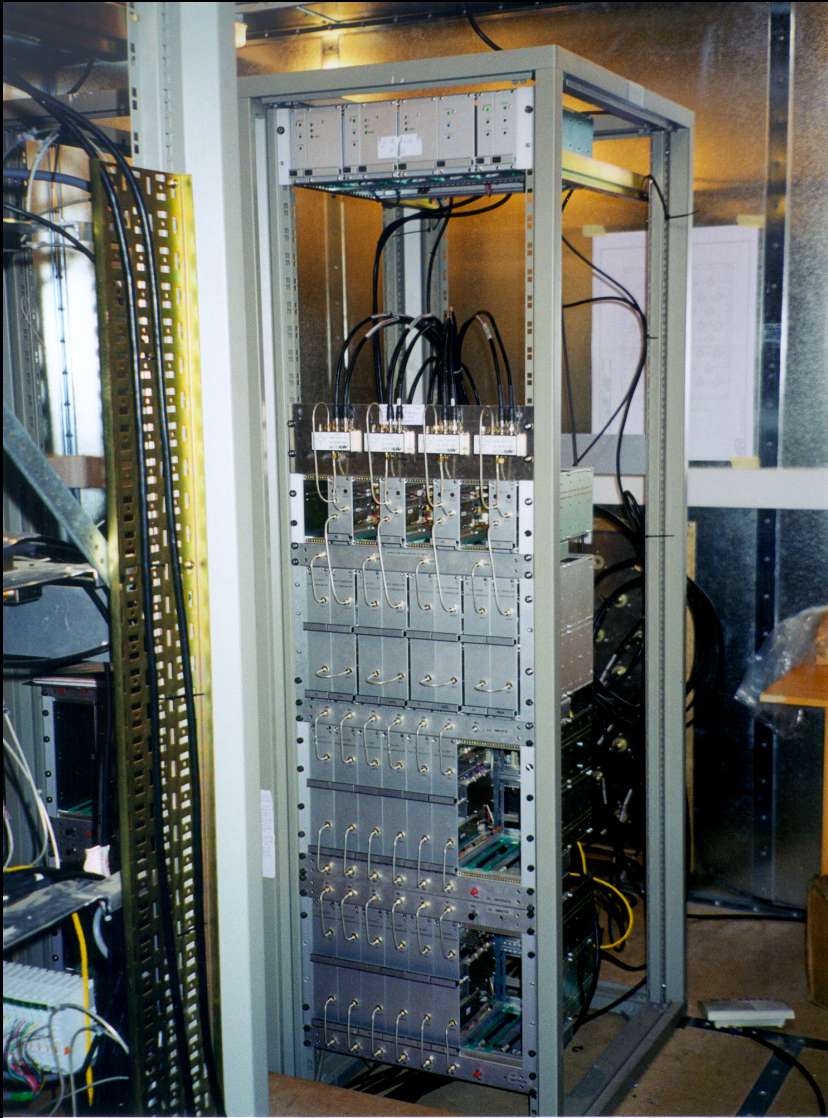
The amplifiers are based on the 26-36 GHz Pospieszalski NRAO design. Built and modified by Eddie Blackhurst at the Jodrell Bank Observatory, using unpassivated InP HEMTs from Hughes and Fujitsu.

The bias supplies are fed from a battery pack to give a low noise protected voltage free from switch transients which can cause damage to the HEMTs.

Each antenna has a 4-stage (Hughes) and a 2-stage (Fujitsu) amps. Bias conditions can be set individually for each transistor to optimize sensitivity.

Noise temperatures of 25 K (including horn) are achieved across the band which is flat to 1dB.

The Very Small Array



VSA: Source subtractor baseline

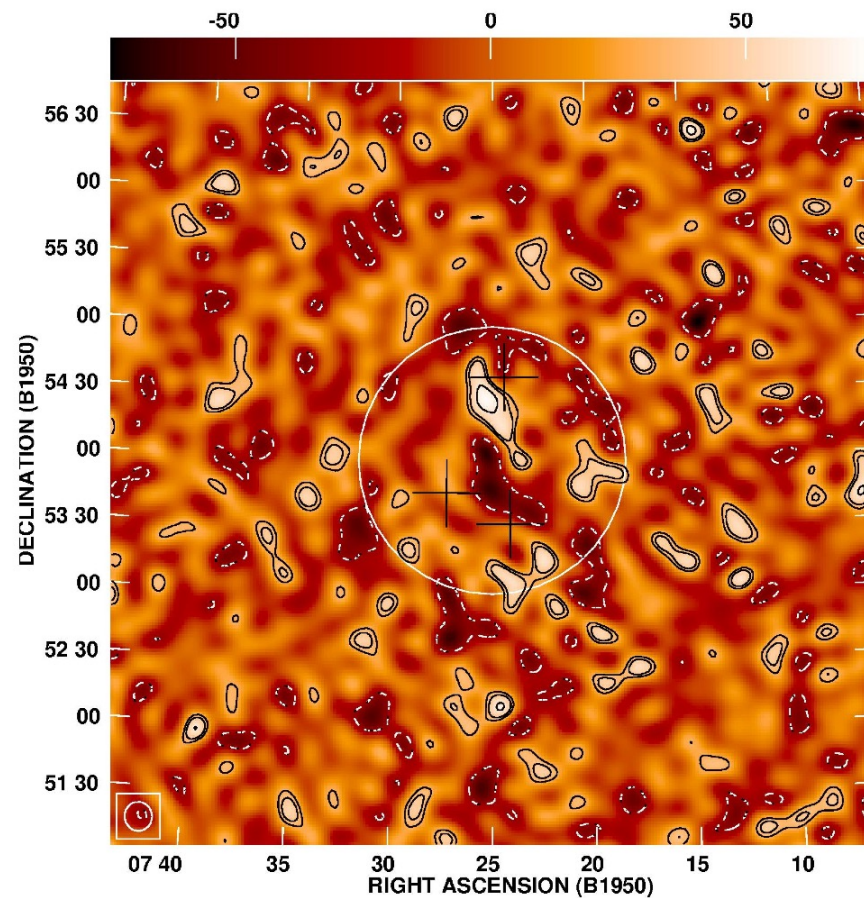
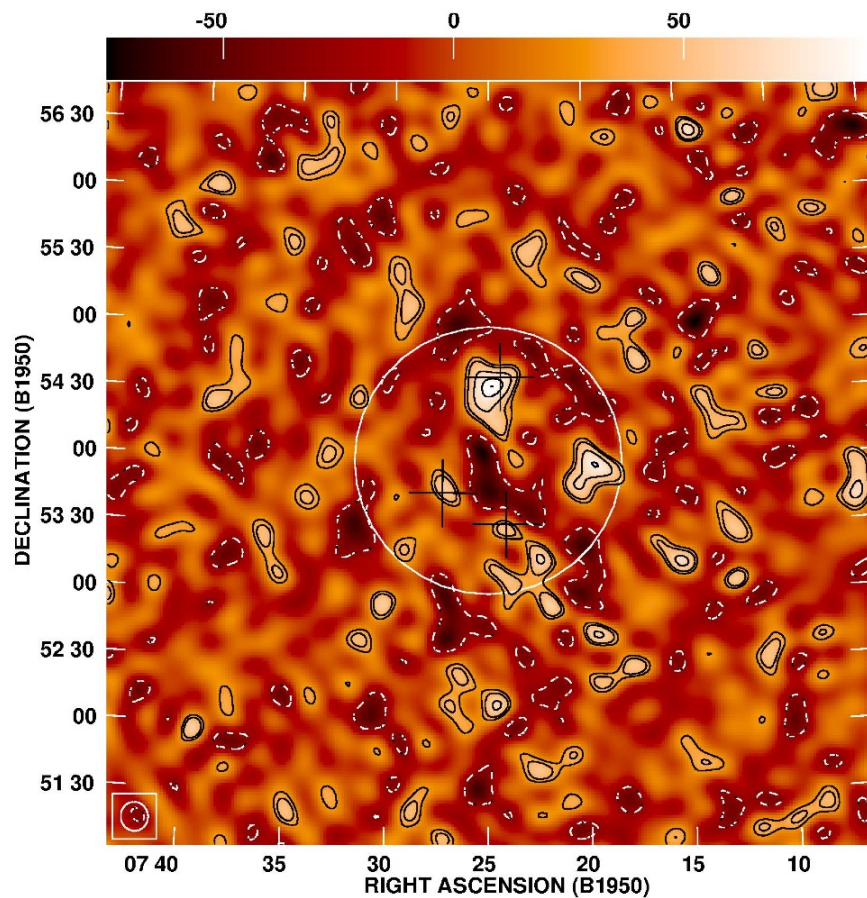


- ❑ Two elements,
 $D = 9\text{m}, 3.6\text{m}$
each dish.

- ❑ Simultaneous
observations



Source subtraction strategy: we use the Ryle Telescope at 15GHz (5 ant., 13m, $\sigma \sim 4$ mJy) to identify sources.

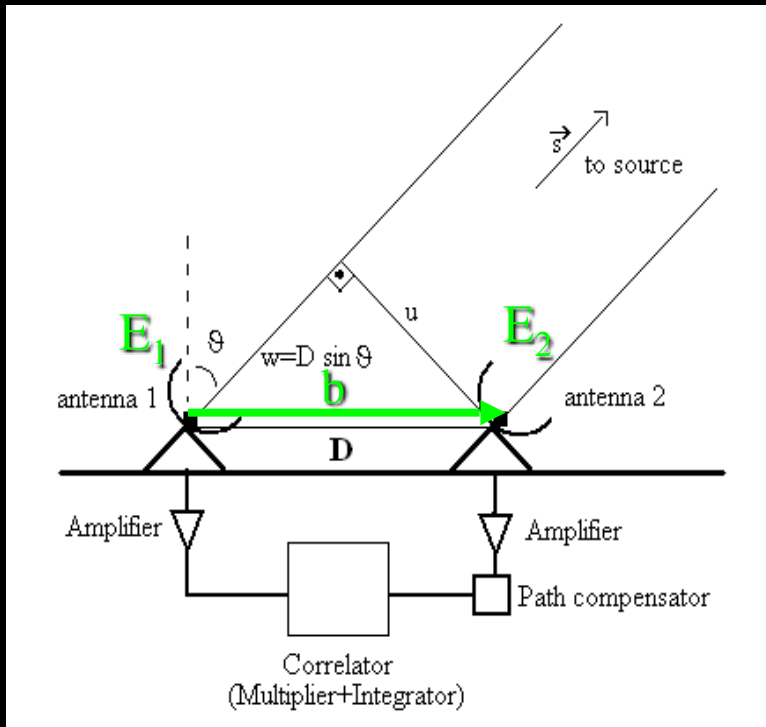


Antes

Después

subtraction de radio fuentes

How do interferometers work?



- Interferometer response: $r = \langle E_1 E_2^* \rangle$
- Signal from point source $\sim |E_2|^2 \exp(i2\pi w/\lambda)$
- Signal is attenuated by primary beam $P(x)$
 $r \sim P(s) |E_2|^2 \exp(i 2 \pi w/\lambda)$
- For extended source, we integrate over solid angle.

$$\tau = \Delta\nu \int_S P(\vec{s}) B(\vec{s}) \exp(i \frac{2\pi\nu}{c} \vec{b} \cdot \vec{s}) d\Omega$$

where the **baseline vector** is $|\vec{b}| = D$.

- Flat sky approximation is very accurate, so the integral is approximated by the
Fourier transform of sky brightness

How do interferometers work? (II)

- An interferometer samples the Fourier transform of the sky brightness $B(\vec{x})$ (or sky temperature), multiplied by primary beam profile $P(\vec{x})$.
- The measurement is called **complex visibility** (units of flux, Jy)

$$V(\vec{u}) = \int P(\vec{x}) B(\vec{x}) \exp(i2\pi\vec{u} \cdot \vec{x}) d^2\vec{x}$$

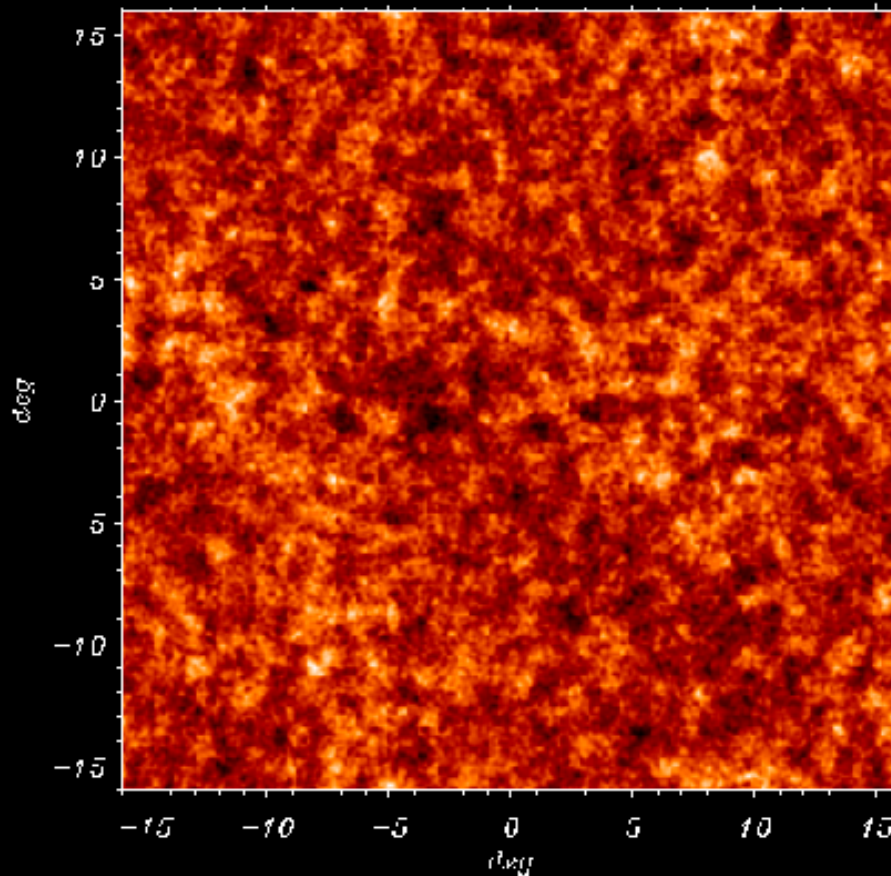
$$\vec{u} = \vec{b}/\lambda, \quad = (u, v) \quad \Rightarrow \quad \text{Fourier space} = \text{UV-plane}$$

- Fourier space is sampled at the points that correspond to the **projected baselines** onto a plane normal to the source

$$\vec{k} = 2\pi\vec{u}, \quad \theta \sim \lambda/D$$

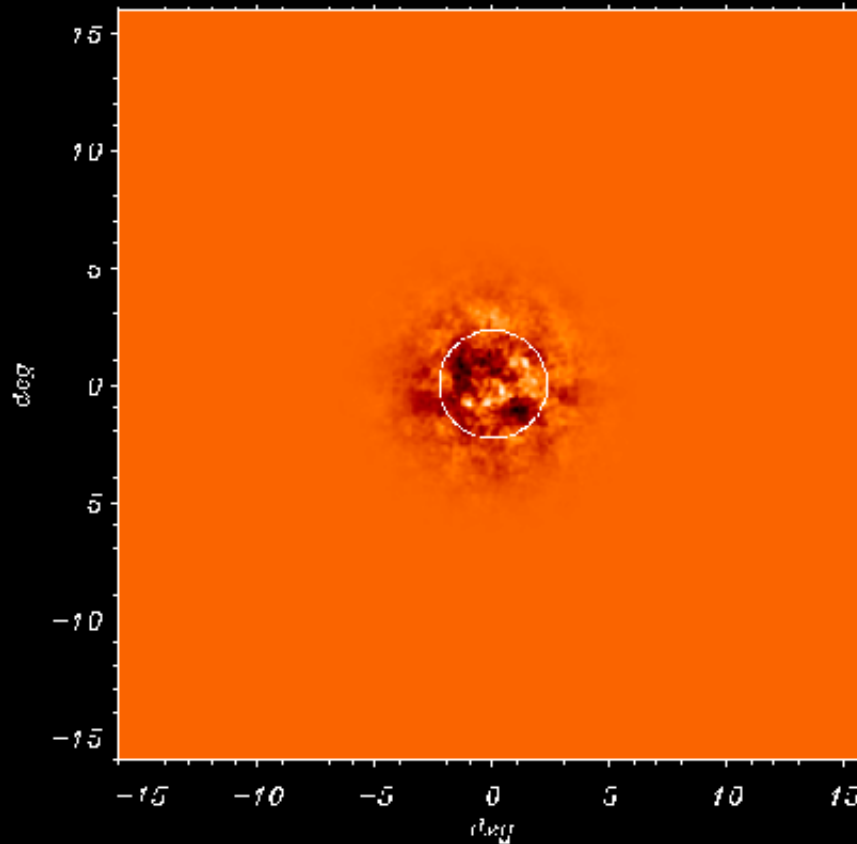
What a CMB interferometer measures

- We make a CMB realisation of the sky ...



What a CMB interferometer measures

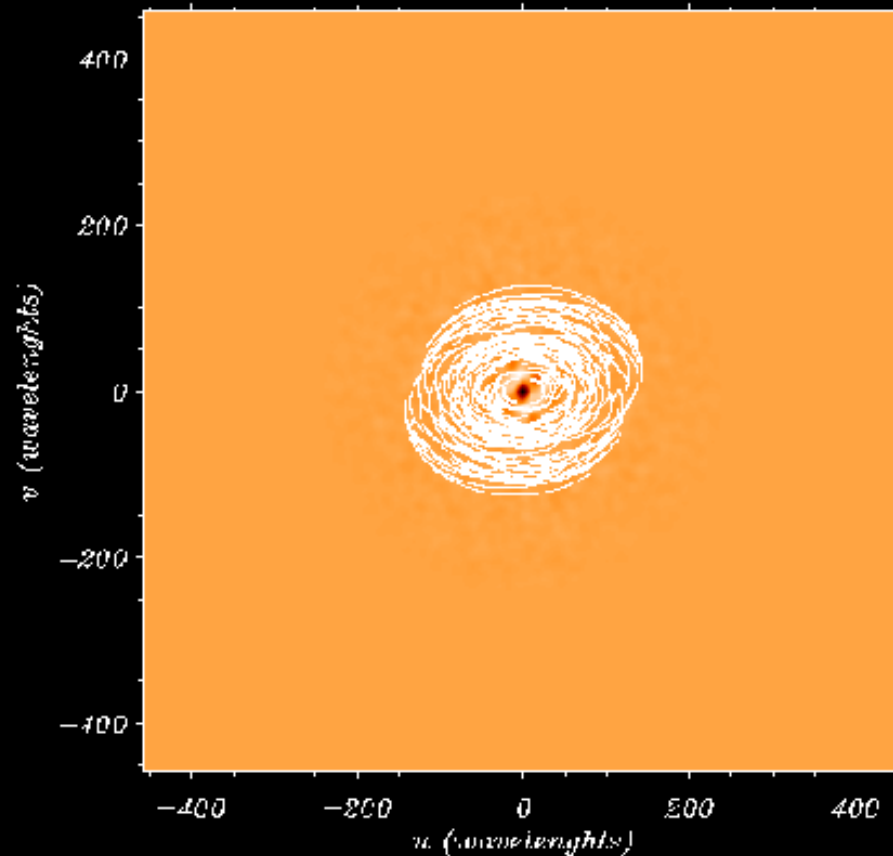
- the primary beam gives field of view...



FWHM=4.6°

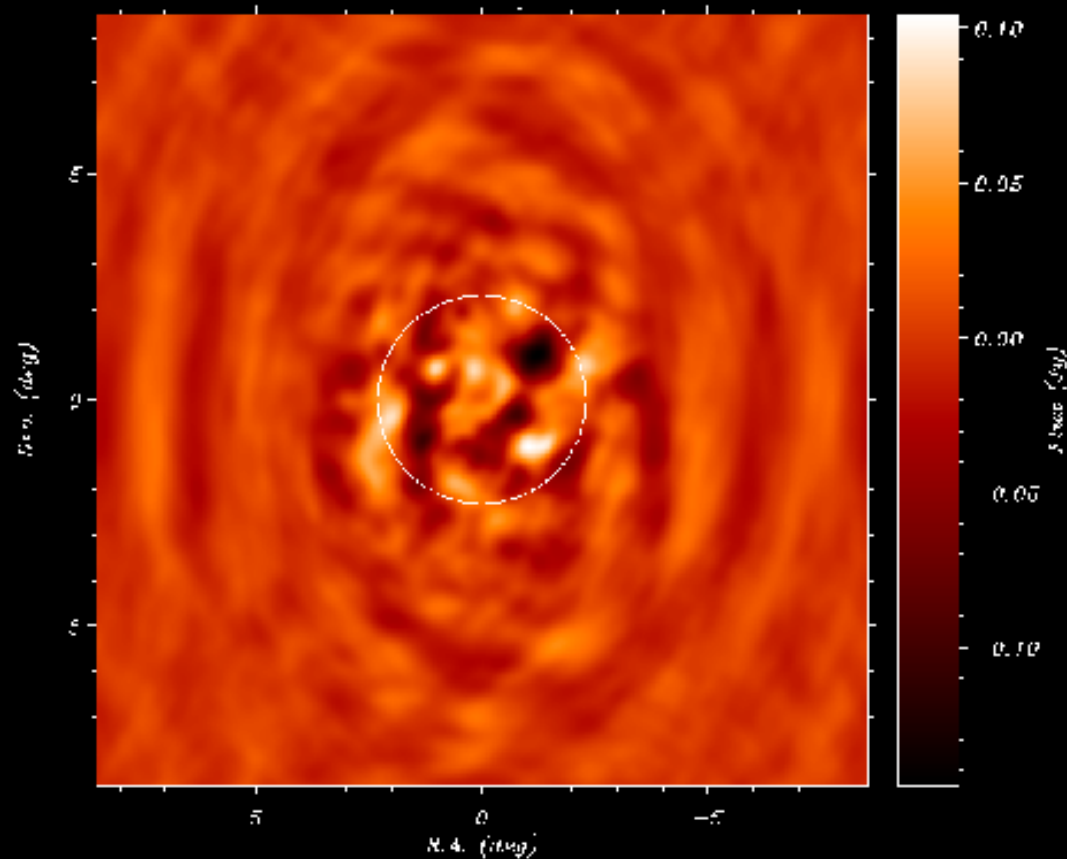
What a CMB interferometer measures

□ and we observe Fourier space...

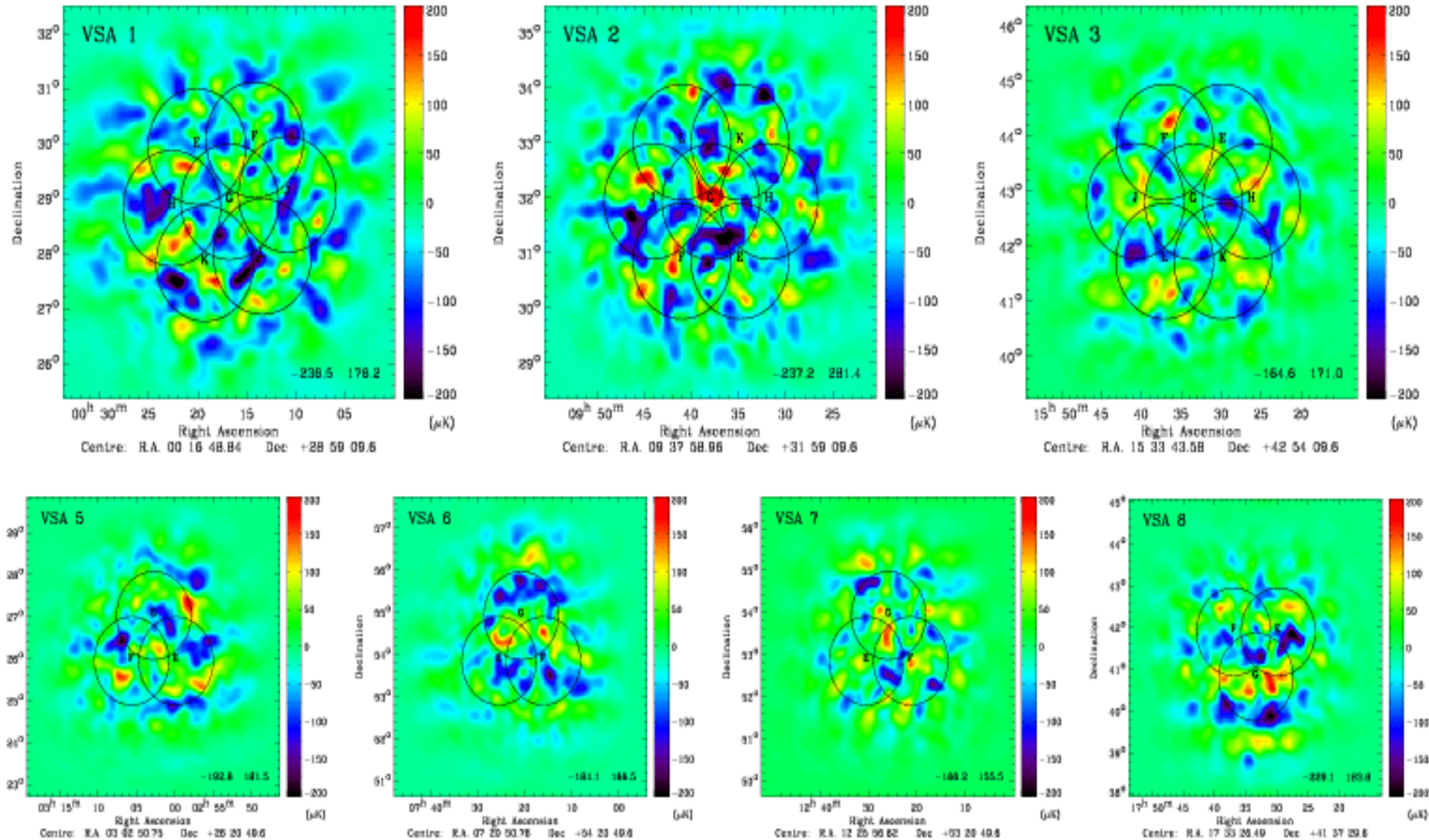


What a CMB interferometer measures

□ ... so the observed sky by an interferometer is



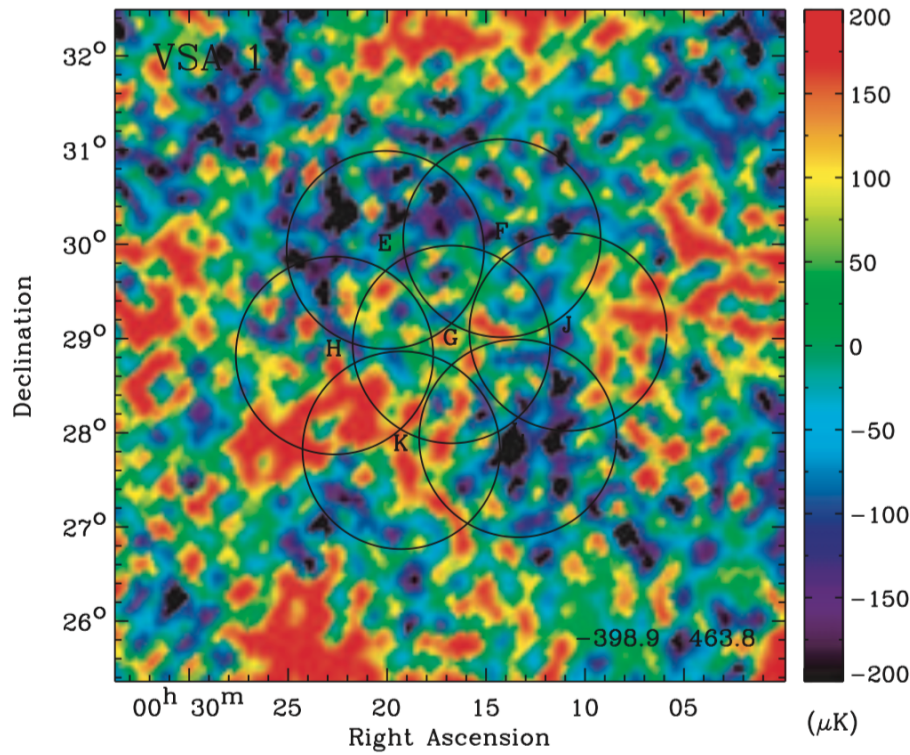
VSA extended configuration (Feb 2004)



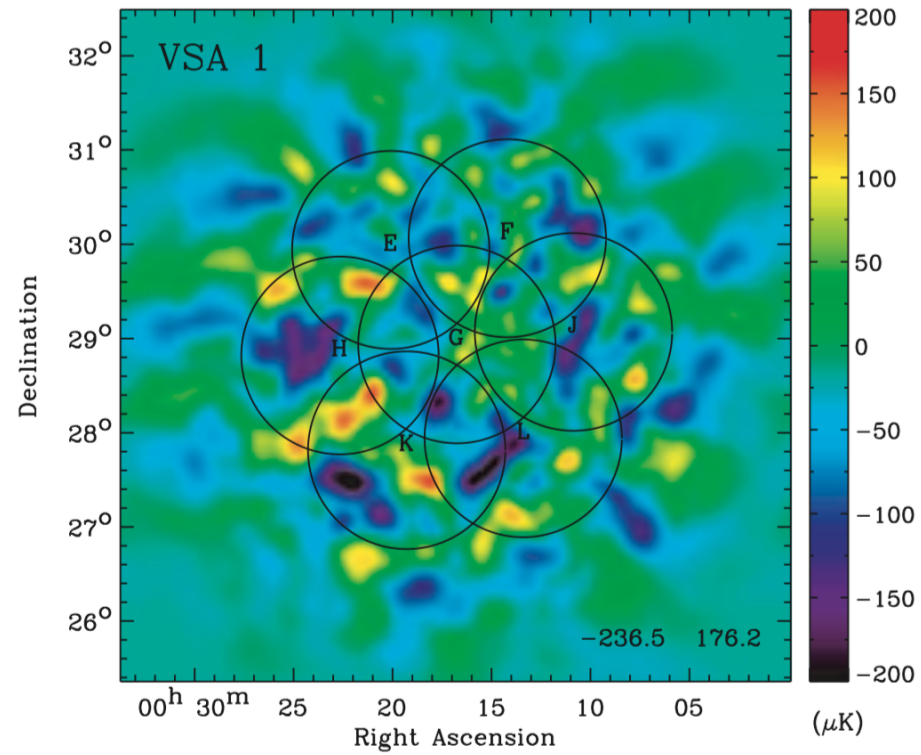
(Dickinson et al.2004)

FCM visto por el satélite WMAP y por el VSA

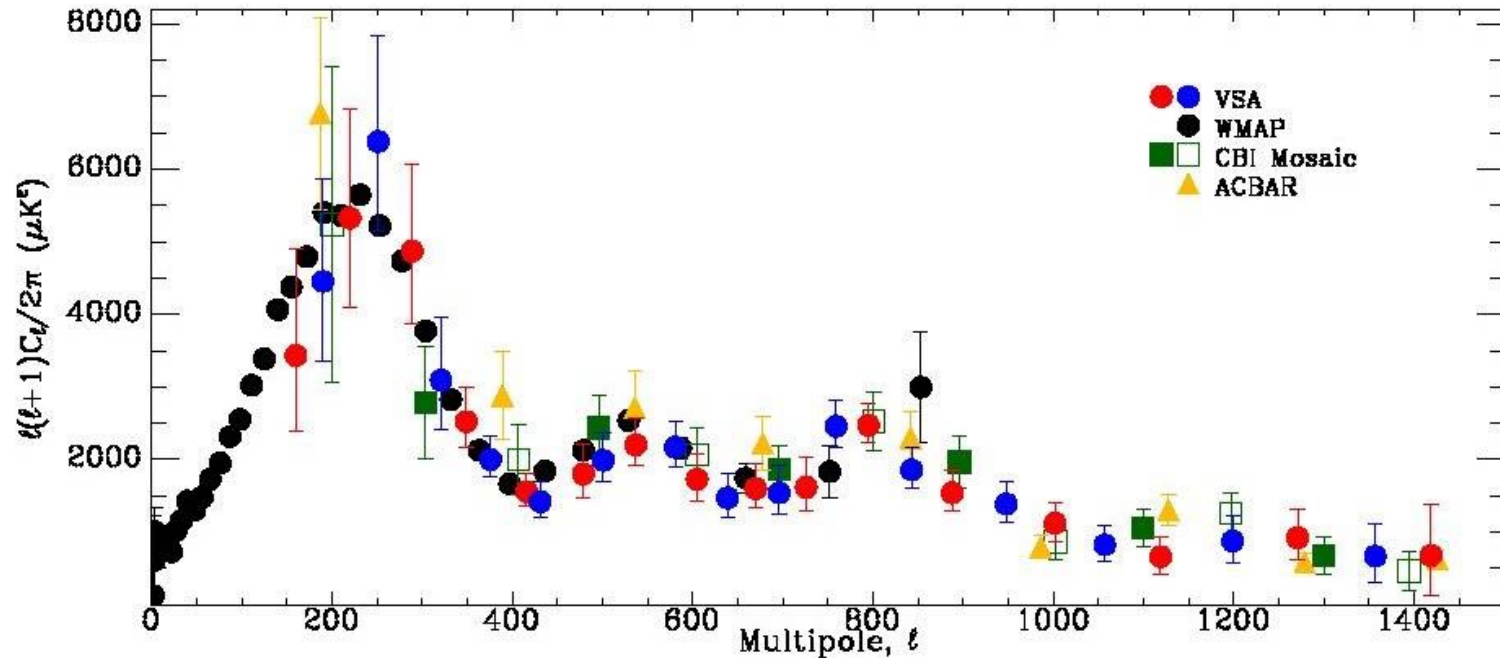
WMAP 1st-year



VSA



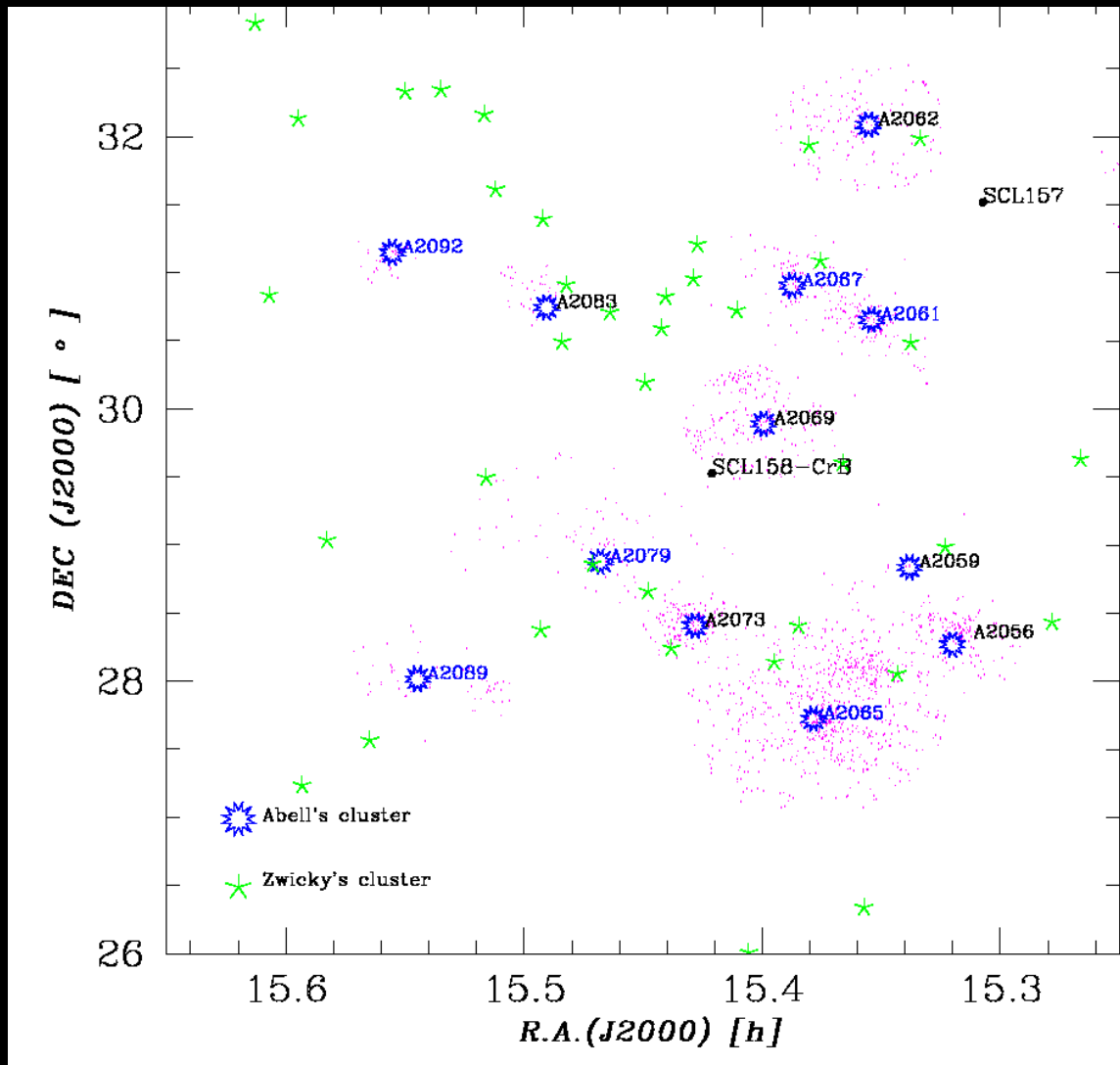
VSA extended configuration (Feb 2004)



$\Omega_b h^2$	0.023 ± 0.0012	Ω_{tot}	1.01 ± 0.03
n	0.97 ± 0.03	$\Omega_{cdm} h^2$	0.113 ± 0.013
h	0.73 ± 0.05	Ω_m	0.32 ± 0.06
Ω_{λ}	0.66 ± 0.05	Age	$13.8 \pm 0.4 \text{ Gyr}$

(Rebolo et al.2004)

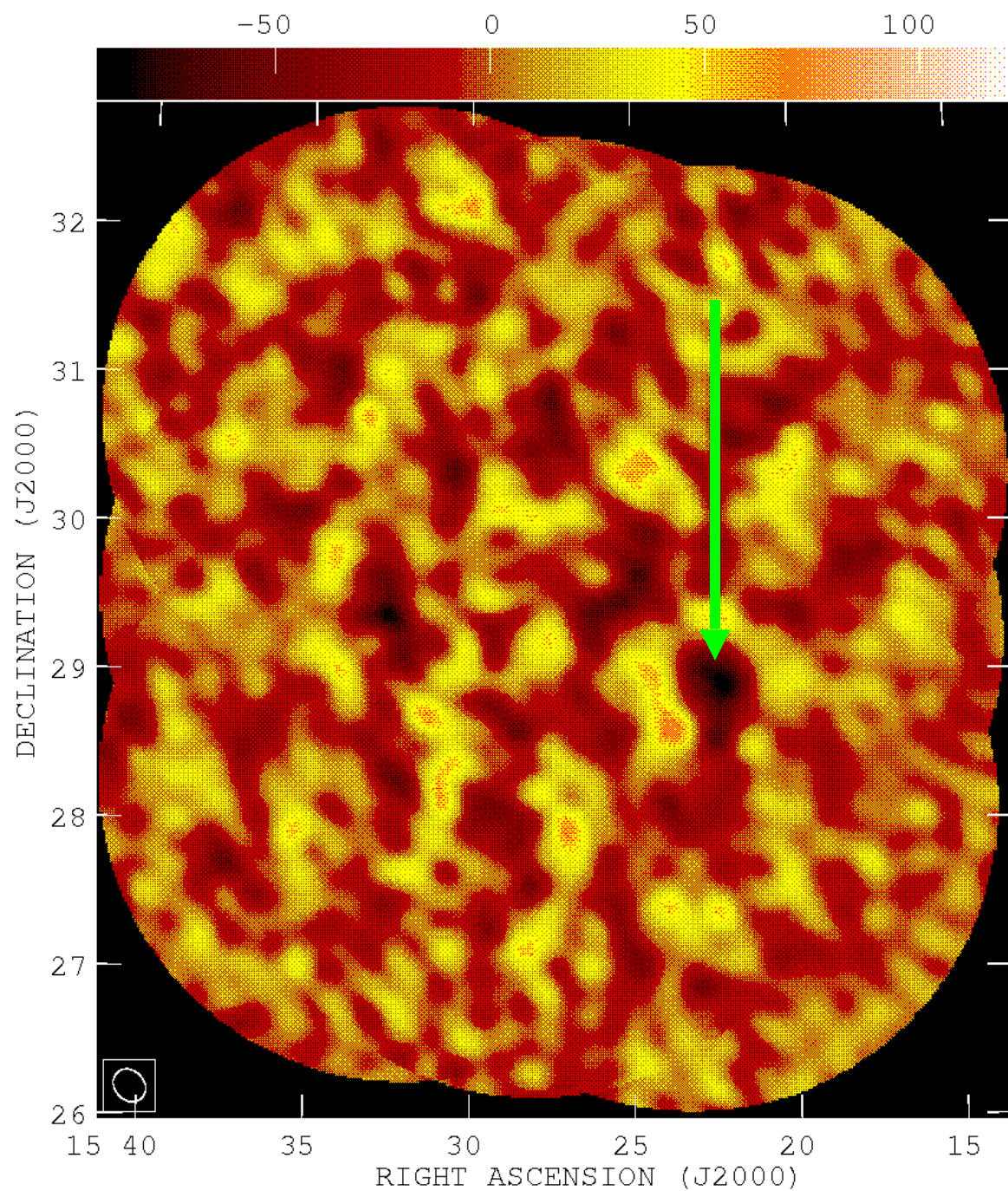
A Survey with the VSA in the Corona Borealis Supercluster



(Génova-Santos et al. 2005)

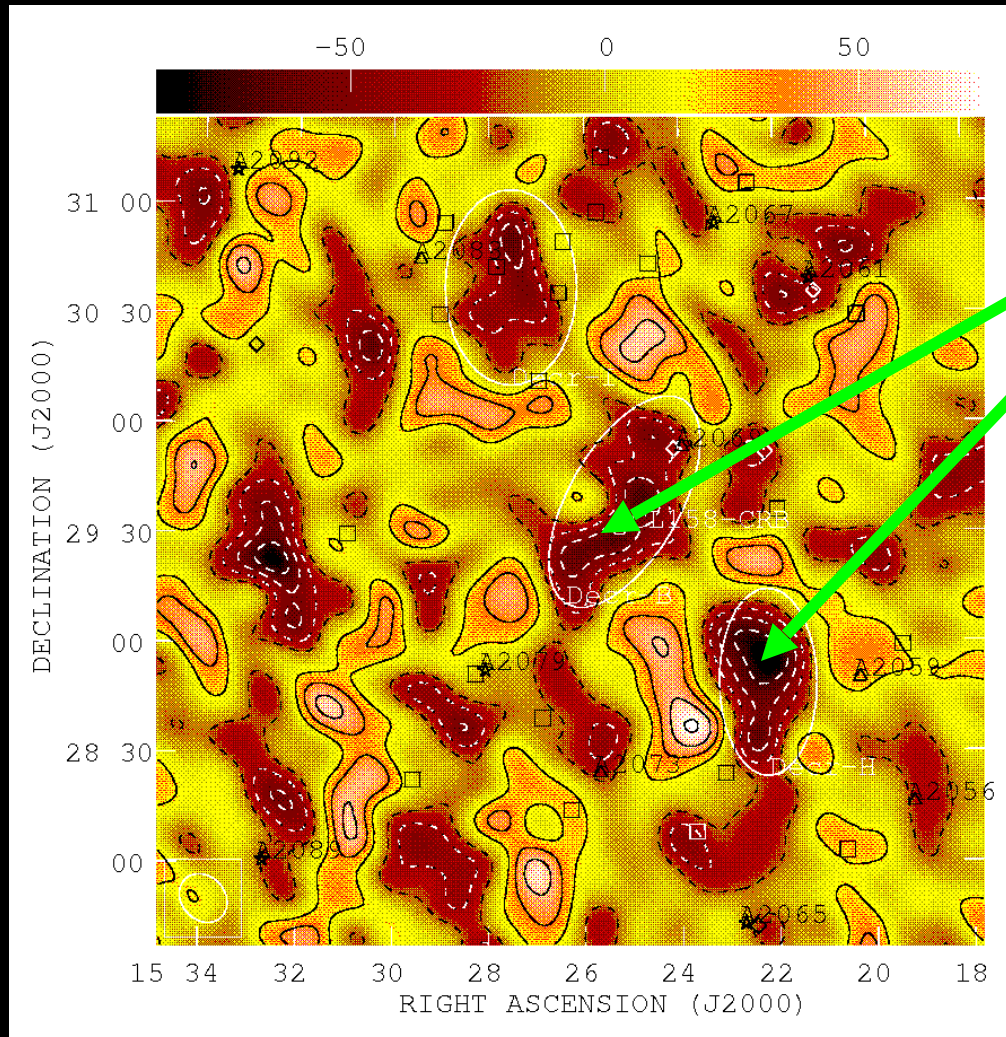
Summary of Observations (33 GHz)

Pointing	RA (J2000)	DEC (J2000)	T _{obs} (hrs)	T _{int} (hrs)	Thermal noise (mJy/beam)
CrB-A	15 23 12.00	+28 06 00.0	54	50	12.4
CrB-B	15 27 48.00	+29 24 00.0	70	70	10.8
CrB-C	15 22 48.00	+30 21 00.0	33	33	18.9
CrB-D	15 32 00.00	+30 45 00.0	19	19	20.5
CrB-E	15 32 00.00	+28 18 00.0	22	22	19.7
CrB-F	15 02 57.20	+27 11 17.3	47	43	14.4
CrB-G	15 45 00.00	+36 03 57.6	19	19	21.4
CrB-H	15 23 00.00	+29 13 30.0	167	130	10.2
CrB-I	15 27 24.00	+30 33 00.0	56	41	18.6
CrB-J	15 32 00.00	+29 31 30.0	55	39	18.9
CrB-K	15 28 00.00	+28 12 00.0	41	33	20.3



CrB SC
seen by
VSA

CrB SC seen by VSA



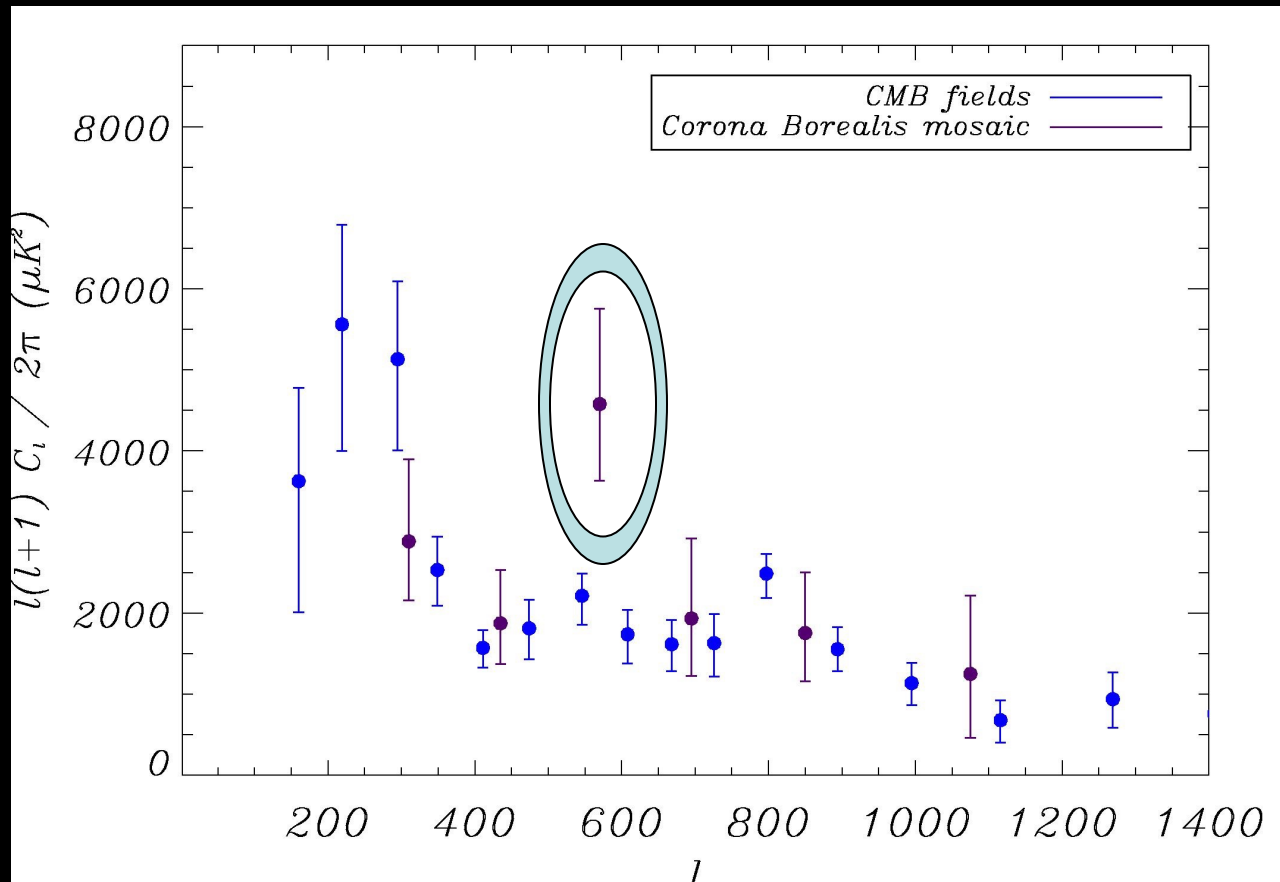
	ΔS_ν (mJy/beam)	ΔT_{RJ} (μ K)
Decrement B	-70 ± 11	-158 ± 24
Decrement H	-103 ± 10	-231 ± 23

The H spot is detected with a significance greater than 4-sigma with respect to the CMB+noise.

No known cluster of galaxies is associated to these spots.

What is the origin of these two negative spots?

Origin of the spots (I): primordial CMB?



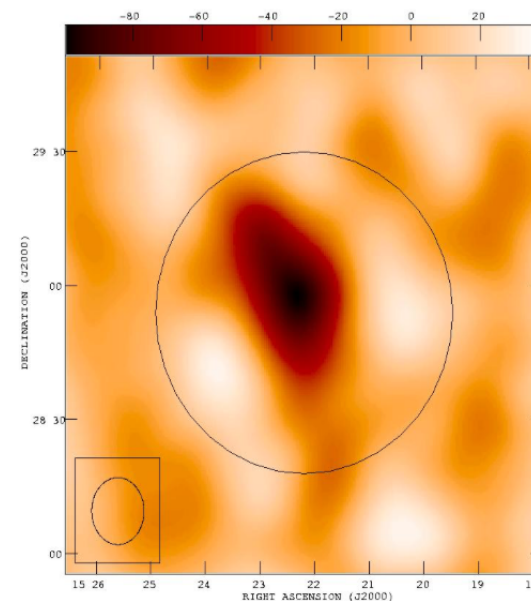
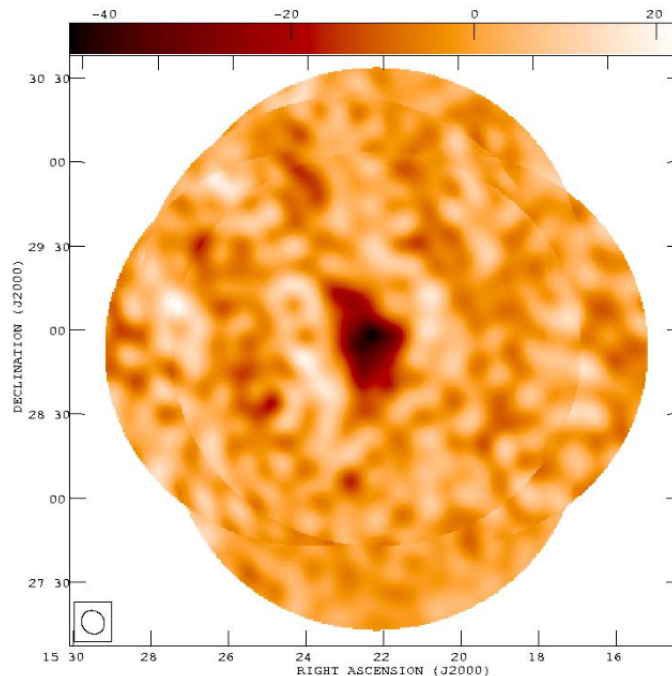
The deviation in the power spectrum at $l=550$ is due to the presence of decrement H. Using MC simulations (CMB+noise), we find that the probability for H spot is 0.16% (for spot B is 32%).

VSA RESULTS. A NEW SURVEY IN THE CORONA BOREALIS SUPERCLUSTER

Using the new **superextended configuration** of the VSA, we have performed observations on the very deep decrement in the **Corona Borealis supercluster discovered with the previous extended configuration (Genova-Santos et al. 2005)**. A total area of 3 square degrees has now been imaged, with an angular resolution of 7 arcmin. The new maps have a finer angular resolution, and confirm the presence of this non-Gaussian spot, at a signal-to-noise level of 7.

Our statistical analyses bear out that **this structure deviates significantly (4.4-sigma) from the primordial CMB**. As a result, these observations reinforces the hypothesis of a different component in this decrement, probably generated via the extended SZ effect from a WHIM structure located within this supercluster. This hypothesis is especially relevant, as the presence of such structures, if confirmed, could provide the location for a significant fraction of the missing baryons in the Local Universe.

For further details, see **Génova-Santos et al. (2008)**.



En resumen: El VSA fue un experimento fructuoso!

resultados científicos publicados con el experimento VSA

THE VERY SMALL ARRAY. PUBLICATIONS

2008

- **"Observations of the Corona Borealis supercluster with the superextended Very Small Array: further constraints on the nature of the non-Gaussian CMB cold spot"**
 - R. Génova-Santos et al. 2008, MNRAS, 391, 1127.
- **"Radio source calibration for the Very Small Array and other cosmic microwave background instruments at around 30 GHz"**
 - Y. Hafez et al. 2008, MNRAS, 388, 1775.
- **"Multifrequency spectral analysis of extragalactic radio sources in the 33-GHz VSA catalogue: sources with flattening and upturn spectrum"**
 - M. Tucci et al. 2008, MNRAS, 386, 1729.

2007

- **"Constraints on spinning dust towards Galactic targets with the Very Small Array: a tentative detection of excess microwave emission towards 3C396"**
 - A. Scaife et al. 2007, MNRAS, 377, L69.

2006

- **"Non-Gaussianity in the Very Small Array CMB maps with Smooth-Goodness-of-fit tests"**
 - J.A. Rubiño-Martín et al. 2006, MNRAS 369, 909.

2005

- **"Cosmic microwave background observations from the Cosmic Background Imager and Very Small Array: a comparison of coincident maps and parameter estimation methods"**
 - Nutan Rajguru et al. 2005, MNRAS, 363, 1125.
- **"A VSA search for extended Sunyaev-Zel'dovich Effect in the Corona Borealis Supercluster"**
 - R. Génova-Santos and the VSA Collaboration, 2005, MNRAS, 363, 79.
- **"Source subtraction for the extended Very Small Array and 33-GHz source count estimates"**
 - Kieran A. Cleary and the VSA collaboration, 2005, MNRAS, 360, 340.
- **"Very Small Array observations of the Sunyaev-Zel'dovich effect in nearby galaxy clusters"**
 - K. Lancaster and the VSA collaboration, 2005, MNRAS 359, 16.

2004

- **"Cosmological parameter estimation using Very Small Array data out to $l = 1500$ "**
 - R. Rebolo and the VSA collaboration, 2004, MNRAS 353, 747.
- **"High-sensitivity measurements of the cosmic microwave background power spectrum with the extended Very Small Array"**
 - C. Dickinson and the VSA collaboration, 2004, MNRAS 353, 732.
- **"Estimating the bispectrum of the Very Small Array data"**
 - S. Smith and the VSA collaboration, 2004, MNRAS 352, 887.
- **"Searching for non-Gaussianity in the Very Small Array data"**
 - R. Savage and the VSA collaboration, 2004, MNRAS 349, 973.

2003

- **"Cosmological parameter estimation and Bayesian model comparison using Very Small Array data"**
 - A. Slosar and the VSA collaboration, 2003, MNRAS 341, L29.
- **"The cosmic microwave background power spectrum out to $l = 1400$ measured by the Very Small Array"**
 - K. Grainge and the VSA collaboration, 2003, MNRAS 341, L23.
- **"First results from the Very Small Array - IV. Cosmological parameter estimation"**
 - J.A. Rubiño-Martín and the VSA collaboration, 2003, MNRAS, 341, 1084.
- **"First results from the Very Small Array - III. The cosmic microwave background power spectrum"**
 - P.F. Scott and the VSA collaboration, 2003, MNRAS 341, 1076.
- **"First results from the Very Small Array - II. Observations of the cosmic microwave background"**
 - A.C. Taylor and the VSA collaboration, 2003, MNRAS 341, 1066.
- **"First results from the Very Small Array - I. Observational methods"**
 - R.A. Watson and the VSA collaboration, 2003, MNRAS 341, 1057.

Algunas conclusiones sobre el Universo

- Existe otras teorías que la de la Gran Explosión pero esta teoría es todavía la mas potente para explicar el FDM y otros fenómenos físicos.

- El Universo es eviterno. Tiene 13.800 millones de años.

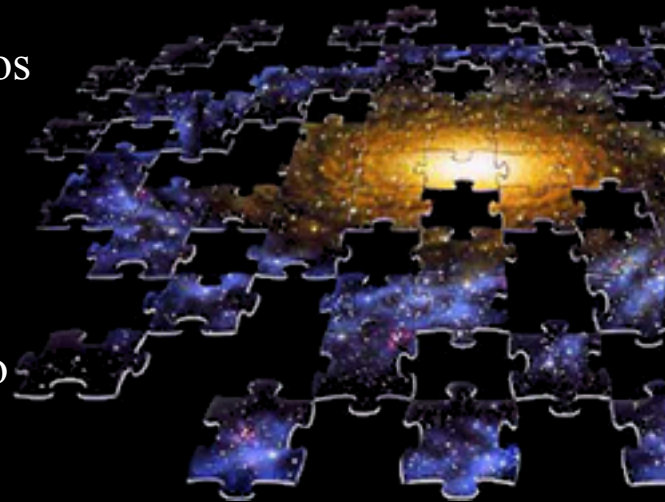
- Como la velocidad de la luz es finita, existe un “Universo observable”.

- El Universo es más grande que el “Universo observable”.

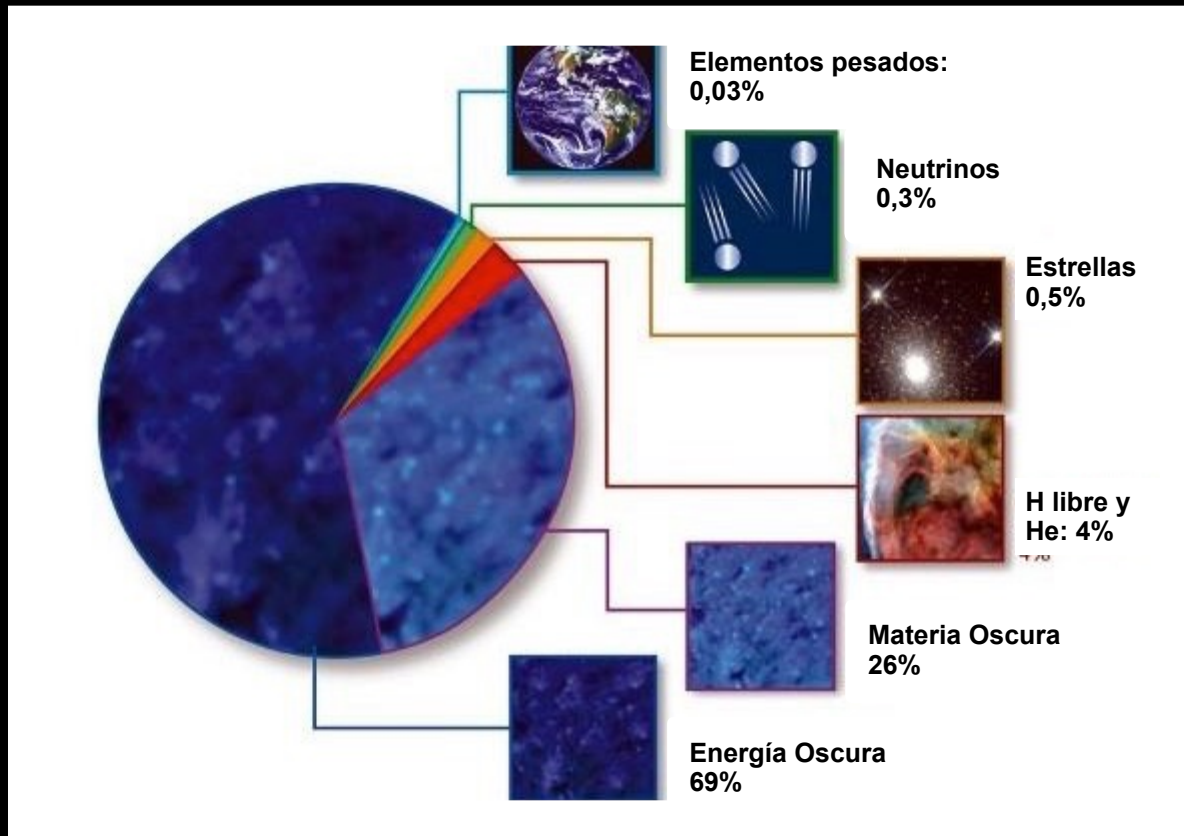
- Si la distancia media entre galaxias es de 3 millones de años luz ($=1 \text{ Mpc}$), en el Universo observable habrá unos 100 mil millones de galaxias.

- Lo más lejos que podemos observar está a 13.800 millones de años-luz. ($=1.3 \times 10^{23} \text{ km} = 4200 \text{ Mpc}$).

- Los mapas producidos por el Experimento COBE y los experimentos que siguieron hicieron entrar la cosmología en una era observacional de alta precisión cuyo el Modelo estándar es la teoría la mas favorecida.



¿Qué hay en el Universo?



Nuestra comprensión y la representación actual que tenemos del Universo con el modelo estándar



Hemos hablado mucho del trabajo de los astrofísicos pero ¿qué sabemos de lo que hacen cracks conocidos por los keroxenitas con antenas?

