



SOCIÉTÉ
ASTRONOMIQUE
DE FRANCE

La cosmologie à 21cm

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Paris , Juin 2022

- * Le modèle cosmologique: un état des lieux
 - ▶ les âges sombres, l'aube cosmique et la raie à 21cm
- * Les observations en radio
 - ▶ l'interférométrie numérique
- * La cartographie d'intensité à 21cm
 - ▶ Quelques instruments et projets
- * Epilogue: EHT





Gravure sur bois Flammarion
https://fr.wikipedia.org/wiki/Gravure_sur_bois_de_Flammarion

From ancient cosmography to modern Physical Cosmology

Ed. Gabel , the birth of the universe (1998)
<https://physicsdetective.com/the-edge-of-the-universe/>

THE BIG BANG THEORY

	Hydrogen nucleus	Hydrogen atom	Protogalaxy				
	Electron	Proton	Helium nucleus	Helium atom		Galaxy	
TIME BEGINS					ONE SECOND	PRESENT DAY	
Time	10^{-43} sec.	10^{-32} sec.	10^{-6} sec.	3 min.	300,000 yrs.	1 billion yrs.	
Temperature		10^{27} °C	10^{13} °C	10^8 °C	$10,000$ °C	-200°°C	
1	The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second	2	Post-inflation, the universe is a seething hot soup of electrons, quarks and other particles	3	A rapidly cooling cosmos permits quarks to clump into protons and neutrons	4	Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog
5	Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine	6	Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars	7	As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets		

Le modèle standard cosmologique (Big Bang)

Les grandes questions en physique

Les piliers observationnels du modèle de big bang

- Expansion de l'univers (Hubble)
- La nucléosynthèse primordial - l'abondance de H, He, Li
- Le fond diffus cosmologique (CMB)
- La formation des structures



13.8 Lookback time [Gyrs]

13.5

z=15

12.0

z=3.5

10.0

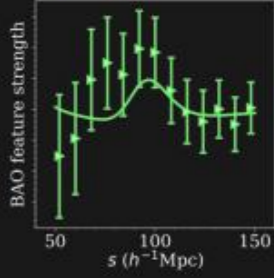
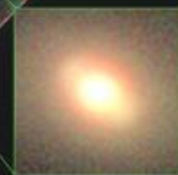
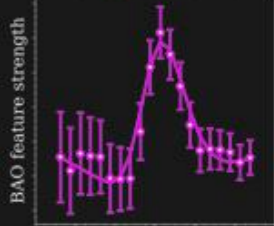
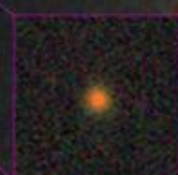
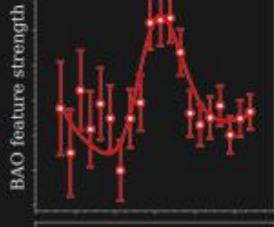
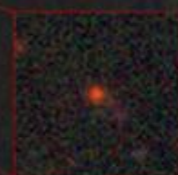
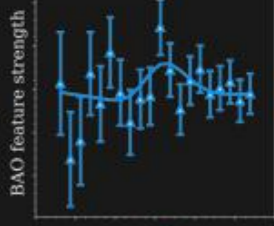
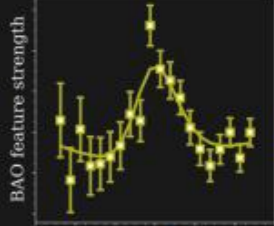
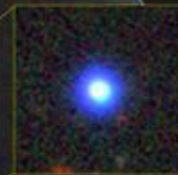
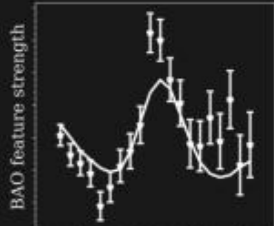
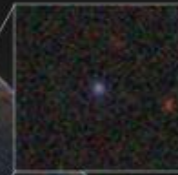
z=1.75

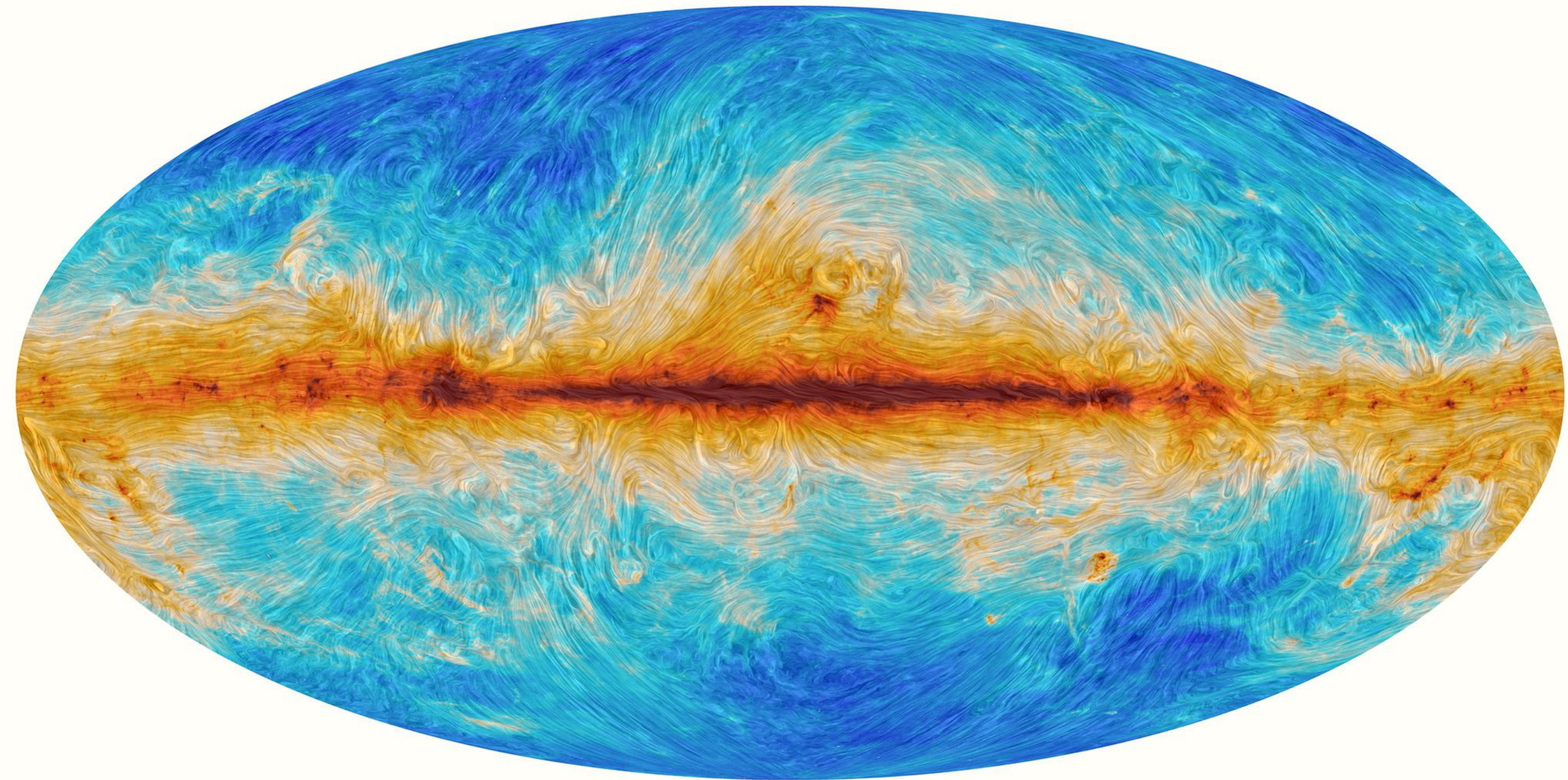
5.0

z=0.5

0.0

- eBOSS + BOSS Lyman- α (2008-2019)
- eBOSS + SDSS I-II Quasars (1998-2019)
- eBOSS Young Blue Galaxies (2014-2019)
- eBOSS Old Red Galaxies (2014-2019)
- BOSS Old Red Galaxies (2008-2014)
- SDSS I-II Nearby Galaxies (1998-2008)

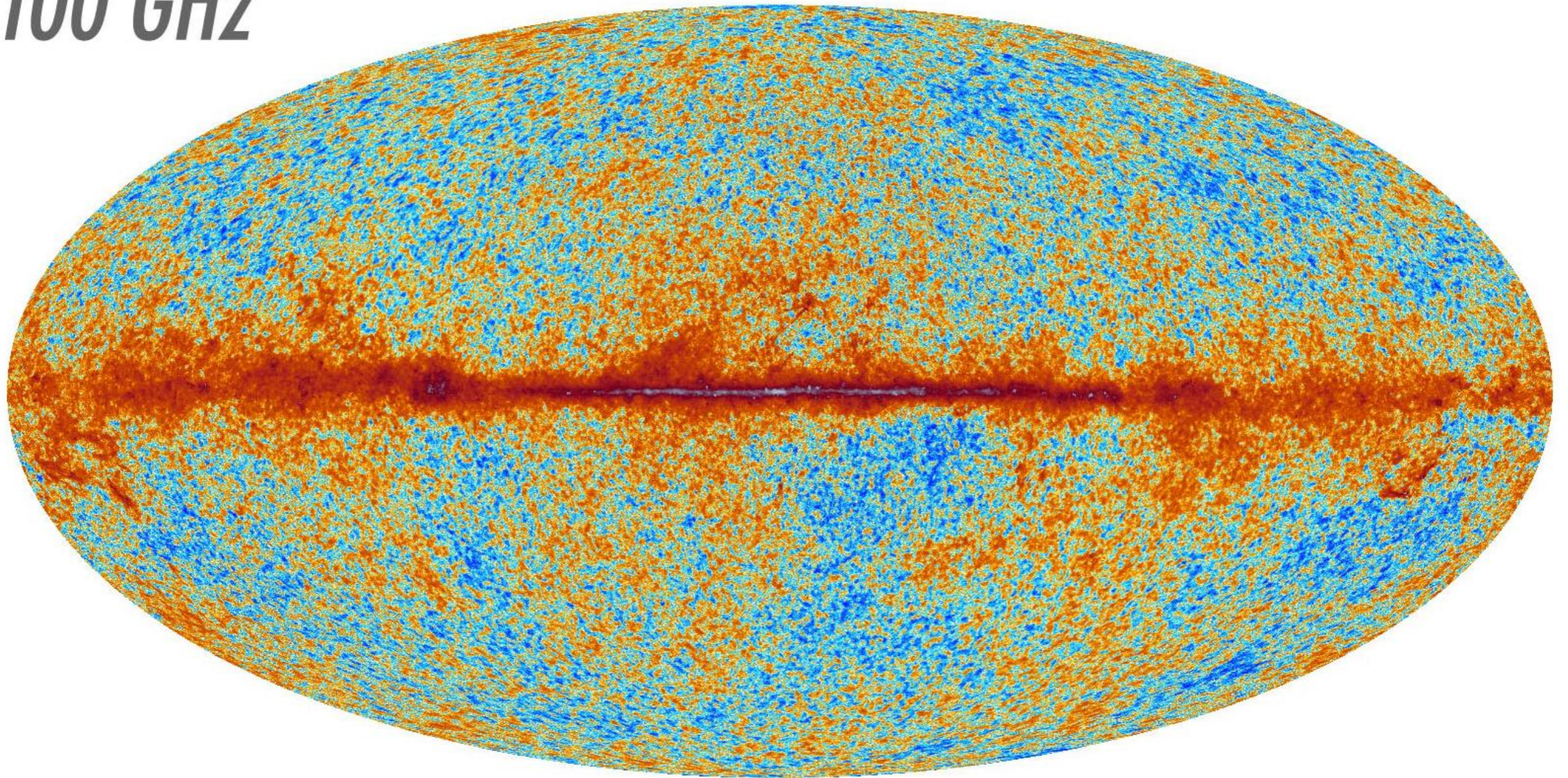




Structure du champ magnétique (dominée par celui de la voie lactée) ,
tracée par l'émission de poussière à 353 GHz
Observations de la mission Planck (ESA)
<https://www.cosmos.esa.int/web/planck/picture-gallery>

CMB , $z \sim 1100$

100 GHz



Observations de la mission Planck (ESA) - Carte à 100 GHz , dominée par
le fond diffus micro-ondes
<https://www.cosmos.esa.int/web/planck/picture-gallery>

Λ CDM model with 6 parameters

3 parameters to set (though General Relativity) the dynamics of the Universe,
 1 parameter to capture the effect of reionisation (end of the dark ages),
 2 parameters to describe the characteristics of primordial fluctuations.
 Flat spatial geometry assumed.

- $\Omega_b h^2$ Baryon density today - The amount of ordinary matter
- $\Omega_c h^2$ Cold dark matter density today - only weakly interacting
- Θ Sound horizon size when optical depth τ reaches unity
 (Distance traveled by a sound wave since inflation, when universe became transparent at recombination at $t \sim 380\,000$ years)
- τ Optical depth at reionisation (due to Thomson scattering of photons on e^-),
 fraction of the CMB photons re-scattered during that process
- A_s Amplitude of the curvature power spectrum
 (Overall contrast of primordial fluctuations)
- n_s Scalar power spectrum power law index
 ($n_s - 1$ measures departure from scale invariance)

Others are *derived* parameters within the model, in particular

- Ω "Dark Energy" fraction of the critical density (derived only if assumed flat)
- H_0 the expansion rate today (in km/s per Mpc of separation)
- t_0 the age of the universe (in Gy)

Planck 2015 , arXiv:
 Planck 2018, arXiv:1807.06209

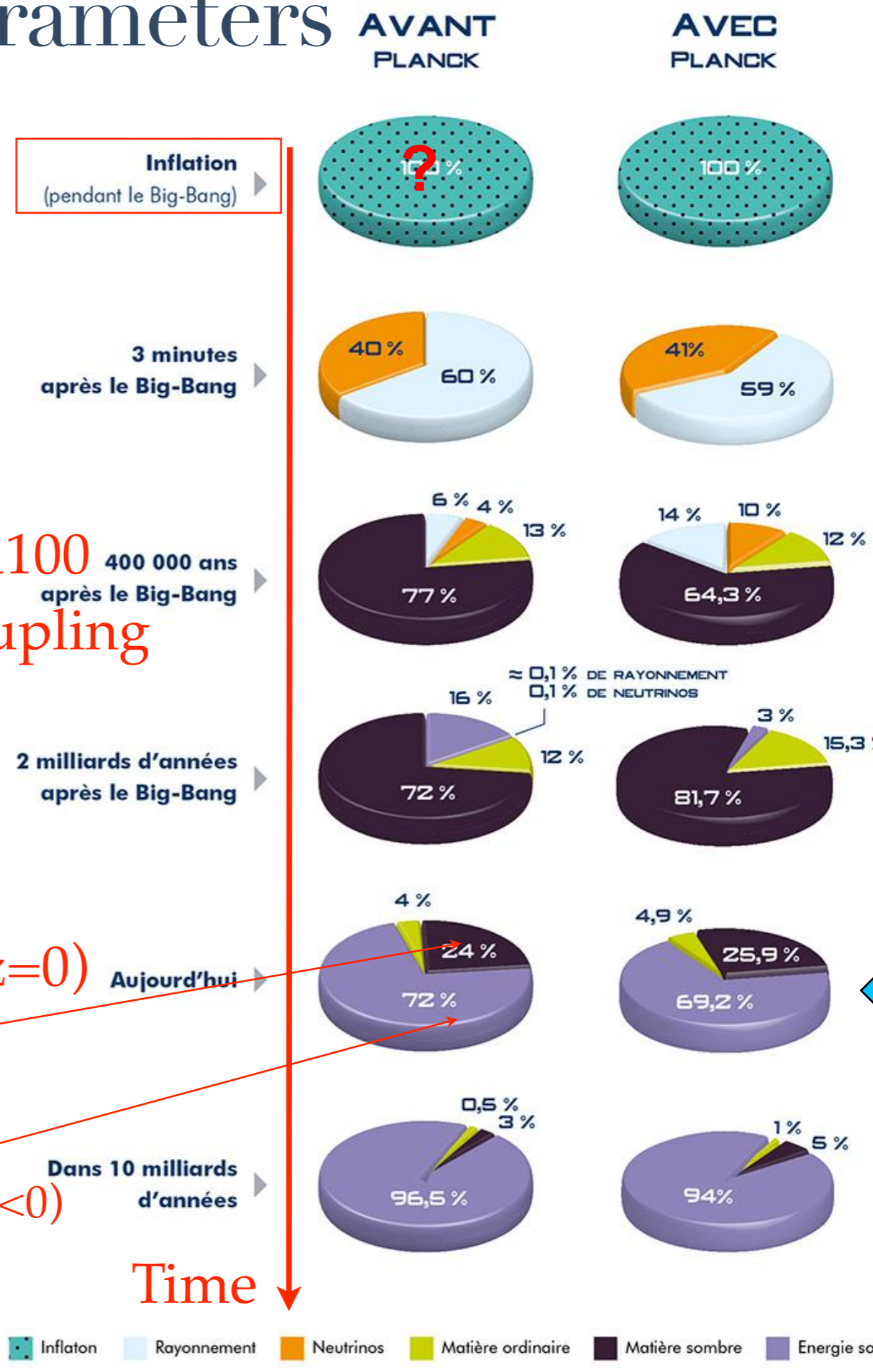
Dark Matter (25%)

Dark Energy / Λ (70%)

Today ($z=0$) Aujourd'hui

Future ($z < 0$)

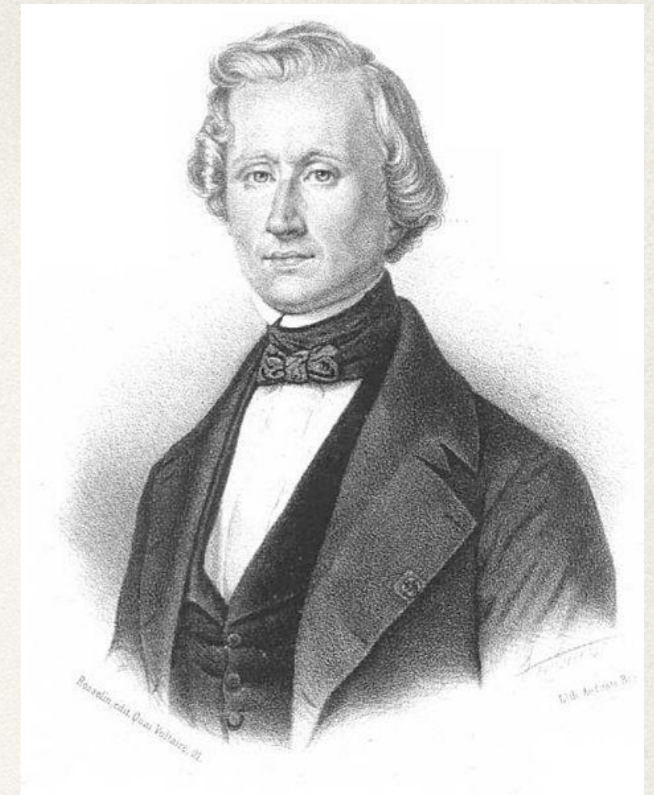
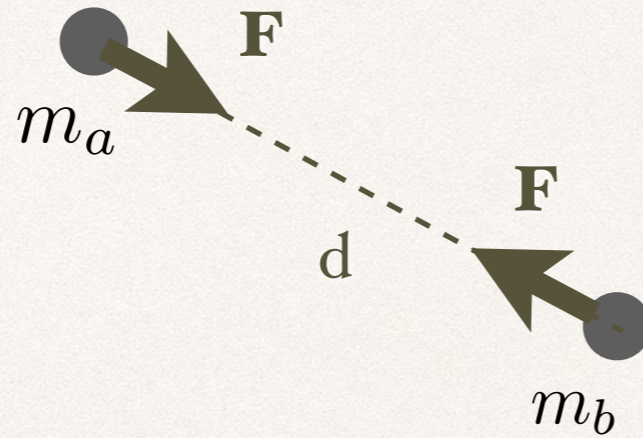
Time



Matière noire: matière *invisible* révélée par ses effets gravitationnels

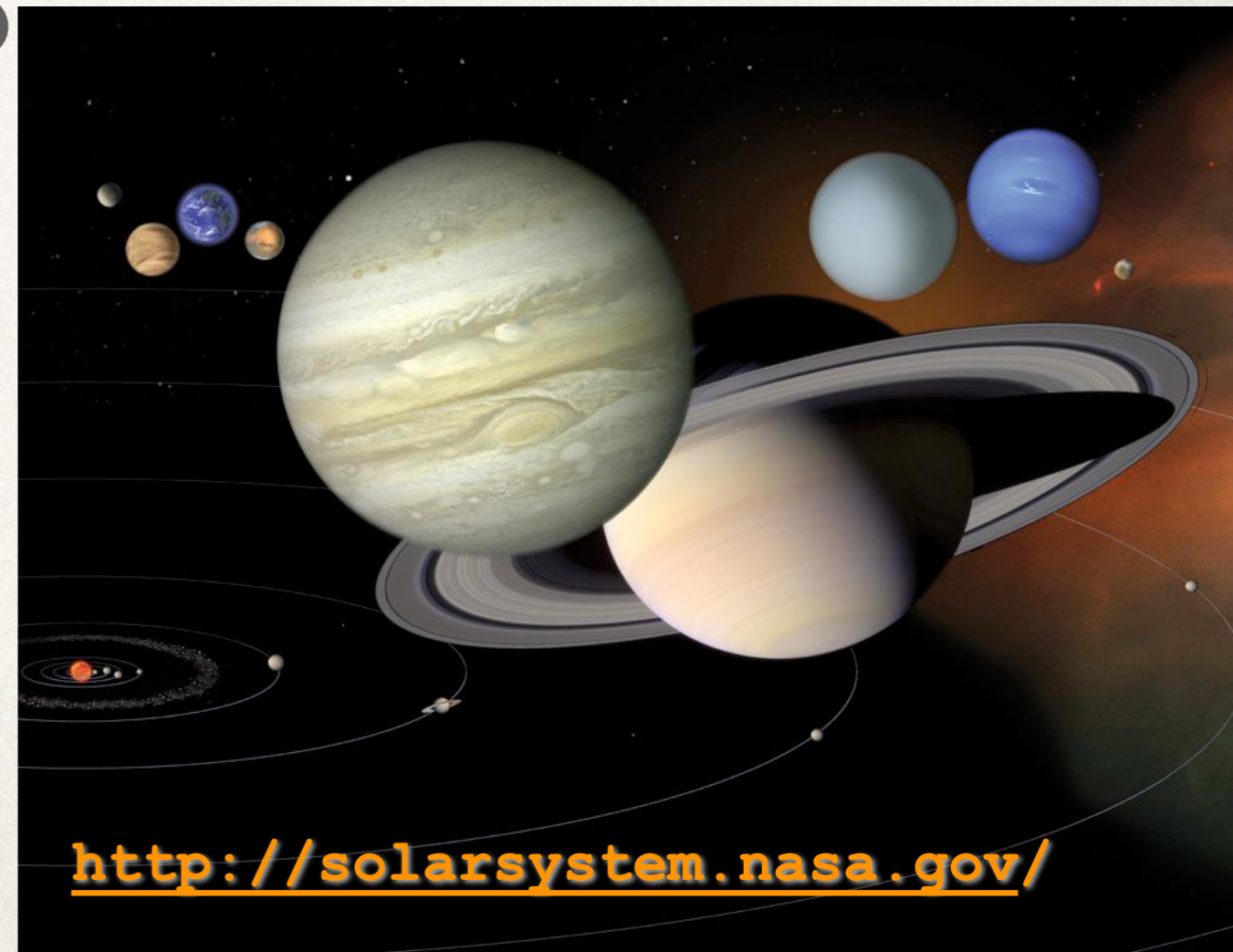
$$\mathbf{F} = G \frac{m_a m_b}{d^2} \mathbf{u}_{ab}$$

$$\Phi(r) = -G \frac{m}{r}$$



Urbain Le Verrier (1811-1877)

Le Verrier avait prédit
l'existence de Neptune à
partir des anomalies de
l'orbite d'Uranus



<http://solarsystem.nasa.gov/>

FRONTIERS OF KNOWLEDGE

New fundamental physics, chemistry, and biology can be revealed by astronomical measurements, experiments, or theory and hence push the frontiers of human knowledge.

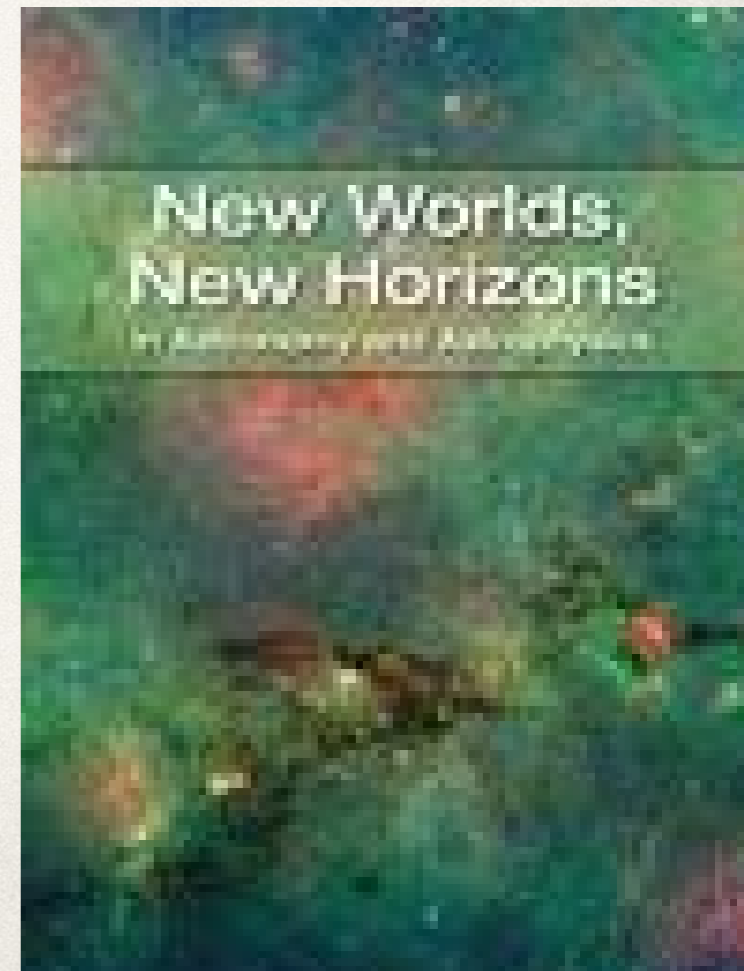
Science frontier questions in this category are:

- *Why is the universe accelerating?*
- *What is dark matter?*
- *What are the properties of the neutrinos?*
- *What controls the masses, spins and radii of compact stellar remnants?*

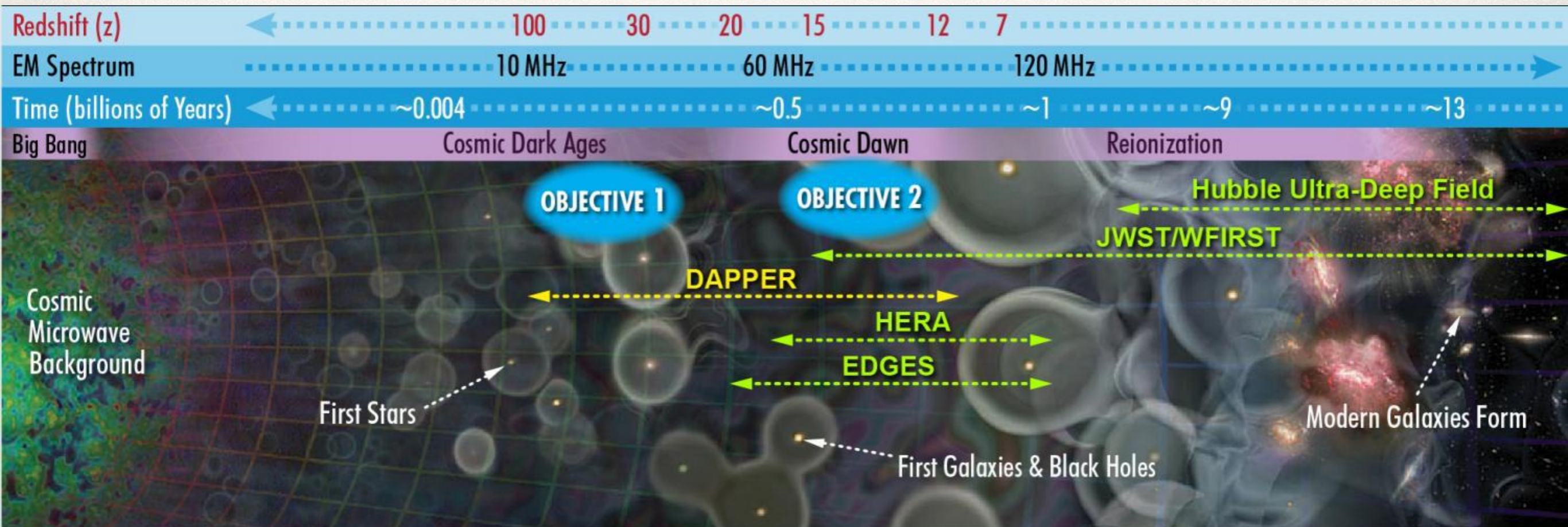
La nature de la matière noire, et la cause de l'expansion accélérée (l'énergie noire) sont les grandes questions au coeur de la physique et de la cosmologie

New Worlds, New Horizons
Astro 2010 decadal survey

<https://nap.nationalacademies.org/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics>



La cosmologie à 21cm





Inflation
Accelerated expansion of the Universe

Formation of light and matter

Light and matter are coupled
Dark matter evolves independently: it starts clumping and forming a web of structures

Light and matter separate
• Protons and electrons form atoms
• Light starts travelling freely: it will become the Cosmic Microwave Background (CMB)

Dark ages
Atoms start feeling the gravity of the cosmic web of dark matter

First stars
The first stars and galaxies form in the densest knots of the cosmic web

Galaxy evolution

The present Universe



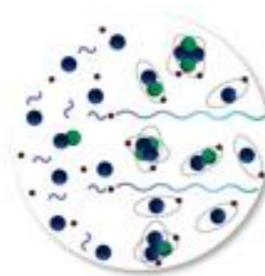
• Tiny fluctuations: the seeds of future structures
• Gravitational waves?



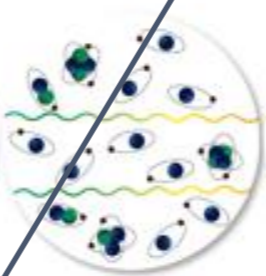
Frequent collisions between normal matter and light



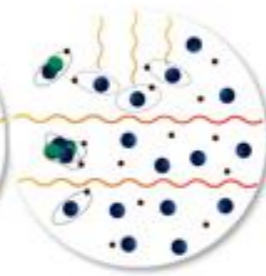
As the Universe expands, particles collide less frequently



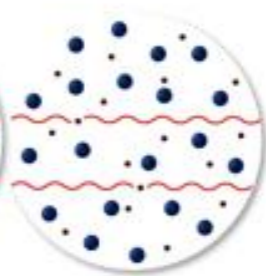
Last scattering of light off electrons
→ Polarisation



The Universe is dark as stars and galaxies are yet to form



Light from first stars and galaxies breaks atoms apart and "reionises" the Universe



Light can interact again with electrons
→ Polarisation

Today

21cm Cosmology

21cm IM cosmology

Dark ages

First stars / Galaxies ...

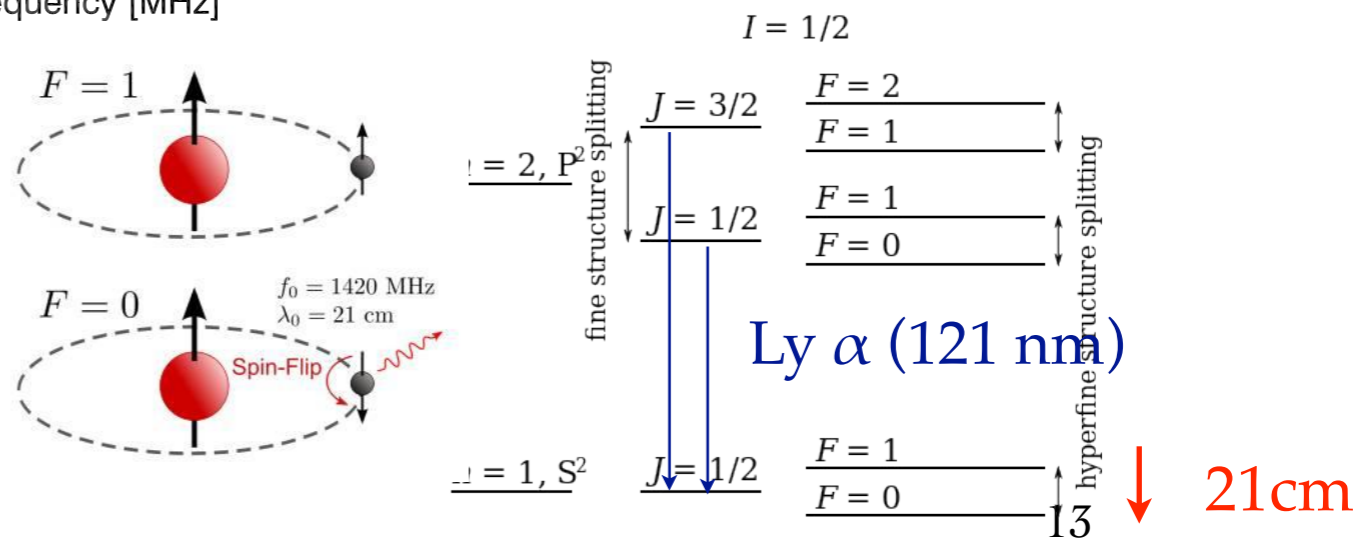
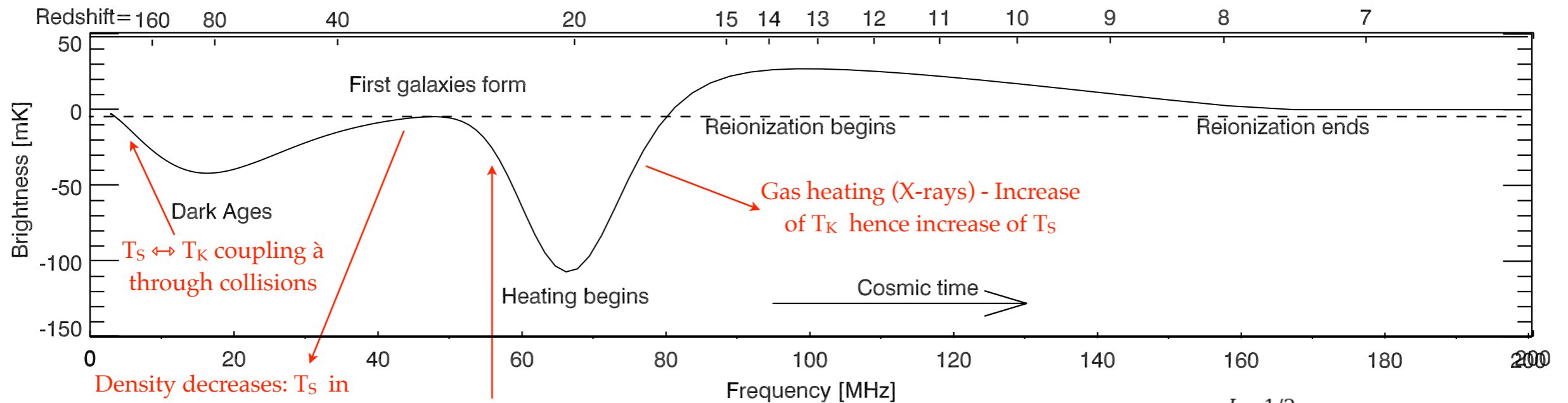
Quasars ...

Dark Energy

n_b (cm^{-3})	330	0.25	0.03	$3 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$2.5 \cdot 10^{-7}$
Age (MY)	0.38	15	50	500	1200	13800
T (K)	3000	300	150	30	15	2.725
Z	1100	100	50	10	5	0

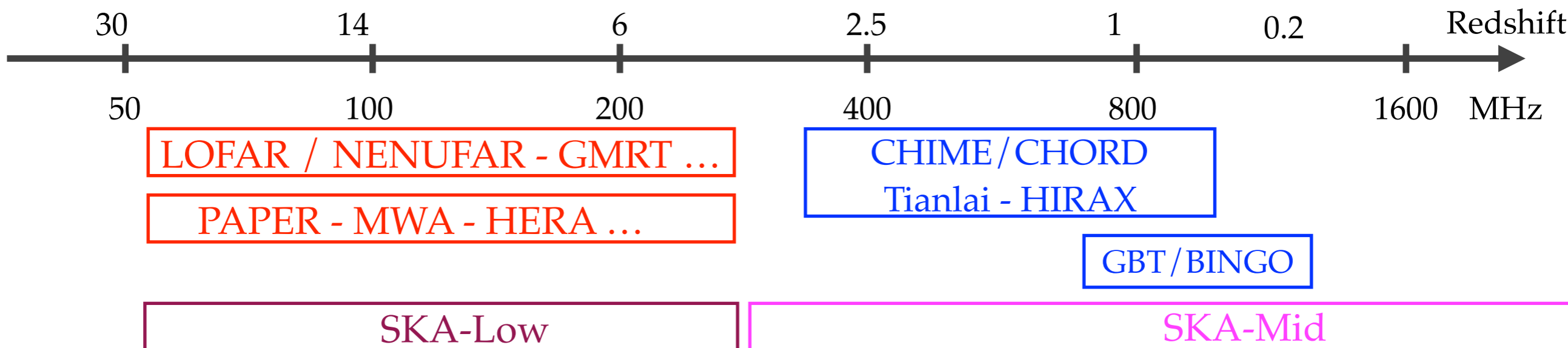
Reionisation

Histoire cosmique de la température de brillance à 21 cm



J. Pritchard, A. Loeb. (2012)

A. Liu, J.R. Pritchard, M. Tegmark,
B. A. Loeb. (2012), arXiv:1211.3743



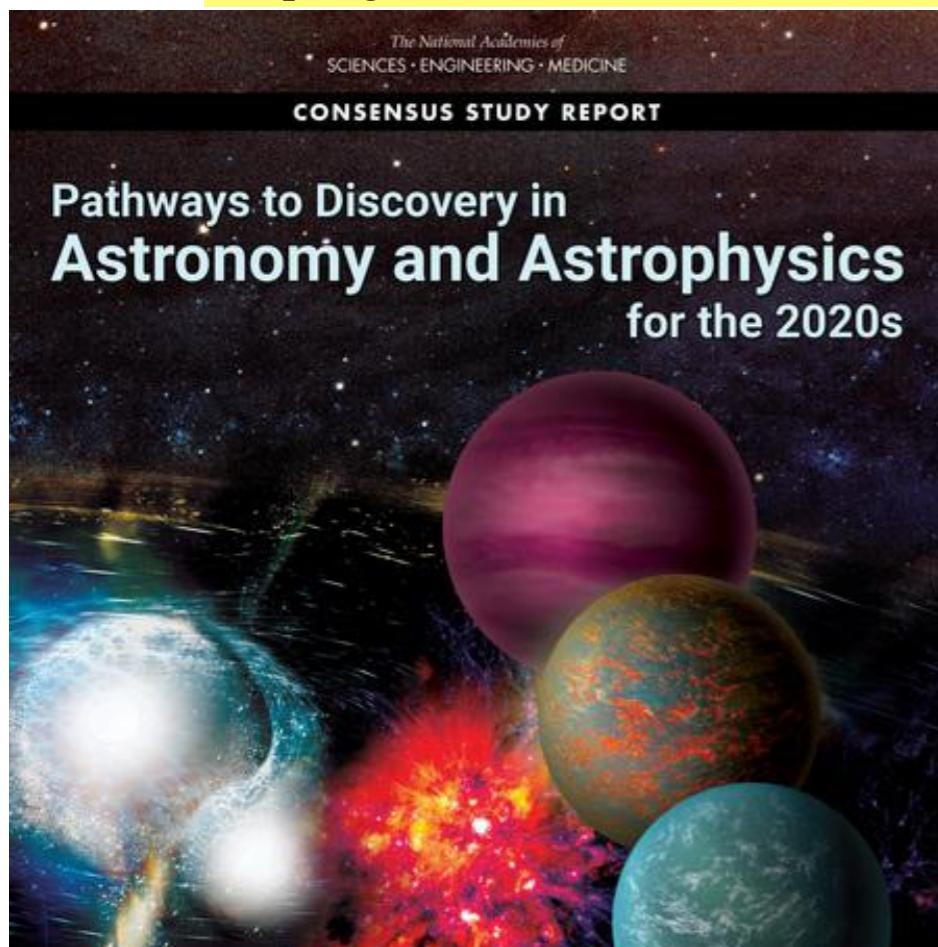
Extrait du rapport de panel cosmologie de Decadal survey 2020

In the coming decade, the panel anticipates that neutral hydrogen intensity mapping will mature to the point that it can make the first anisotropy measurements of reionization. This is a crucial milestone, and measuring the process of reionization and the CMB optical depth will improve the current understanding of cosmology. The panel also hopes to see the first measurements of the BAO scale using either the 21 cm or other atomic or molecular emission lines. As these techniques mature, the panel expects the precision, angular scale, and redshift of the measurements to steadily improve. A 30- to 40-year goal would be to map the density fluctuations in the pre-reionization universe with an unprecedented number of modes traceable to the primordial density fluctuations, using the power spectrum and non-Gaussianity to measure the statistical initial conditions of the universe.

Pathways to Discovery in AA 2020

Summary of Capabilities Needed for the Discovery Area

Needed capabilities include next-generation 21 cm interferometers targeting both the reionization epoch and lower redshifts, along with planning toward very high redshift mapping. Progress will require both higher sensitivity and a better understanding of instrumental systematics and astrophysical couplings.



LIM experiments on LAMBDA:

Line Intensity Mapping (LIM)

LAMBDA - Data Products

Data Hosted Experiment Tables Space-Based Suborbital Astrophysical About Products

Line Intensity Mapping (LIM) Experiments

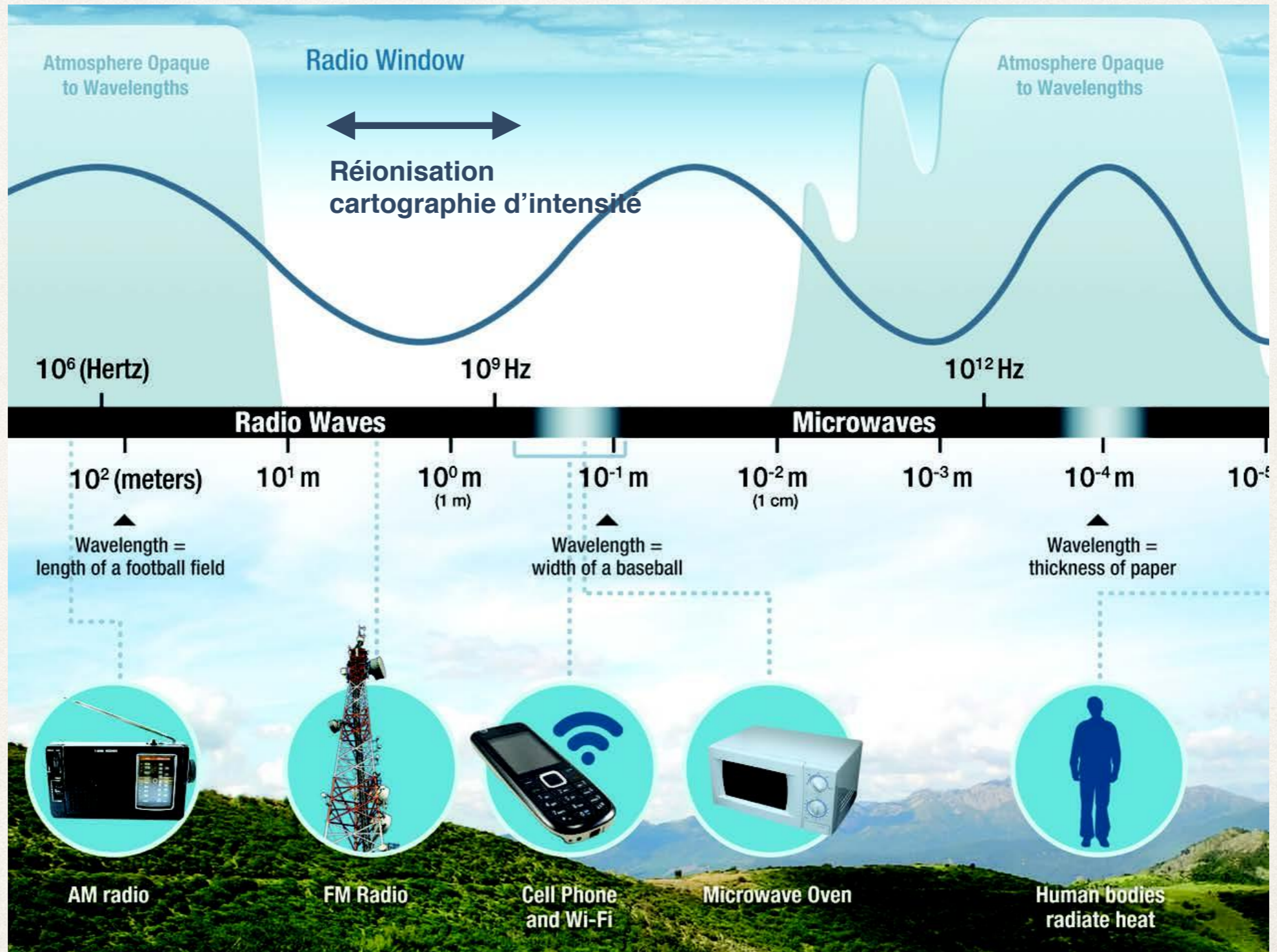
Below is a list of proposed or ongoing Line Intensity Mapping (LIM) experiments, with links to their home pages (if available), and a brief description. Experiments whose names are followed by a red asterisk (*) observe multiple spectral lines.

Publicly available data from these experiments are currently sparse, given that many of the listed projects are either pathfinders, recently underway, or in planning stages. If an experiment of interest to you is missing from the list, or there is experimental data you would like to provide, please contact us via the [suggestion form](#).

Click on any of the highlighted column headings to sort by that column.

LIM Experiments										
Project Name and Website	Full Name and Reference	Line(s)	Science	Dates of Operation	Technology	z-min	z-max	Frequency Min (GHz)	Frequency Max (GHz)	Type
BINGO	BAO from Integrated Neutral Gas Observations [ADS]	21 cm	HI, LSS	Future	Coherent, single dish	0.13	0.48	0.960	1.260	Ground
CCAT-p	Cerro Chajnantor Atacama Telescope	[CII]	reionization	Future	Fabry-Perot, TES	5	9	190	315	Ground

Observations en radio

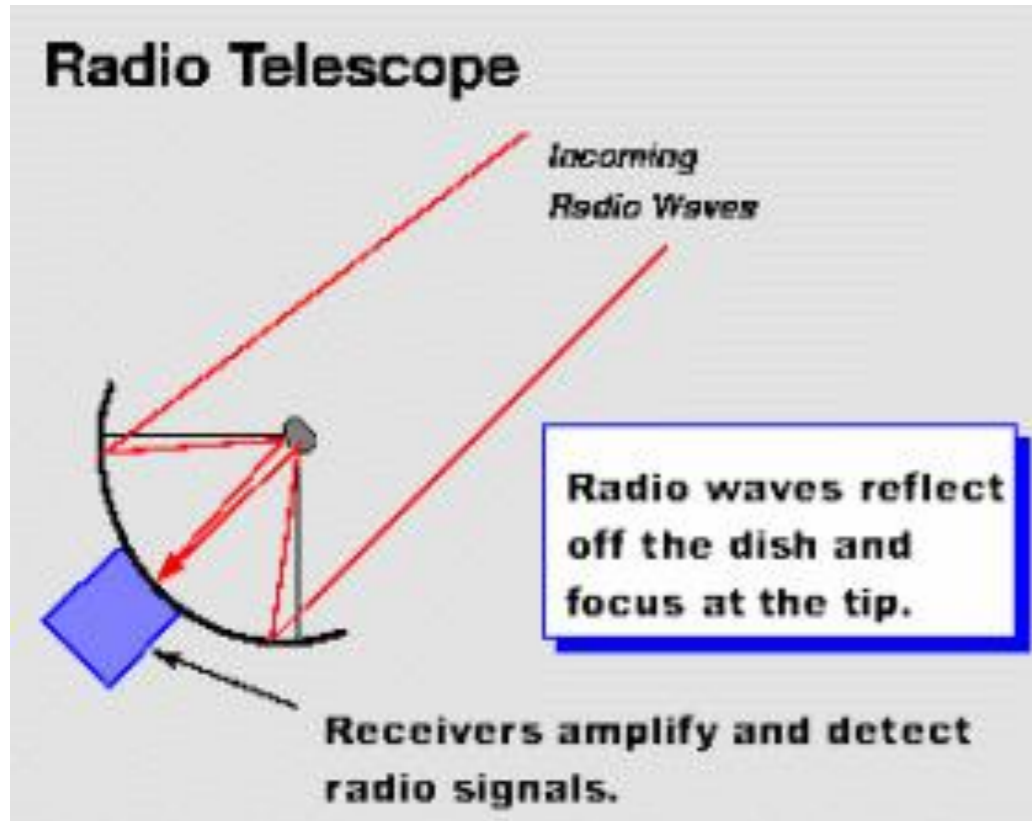


Spectre électromagnétique - domaine radio

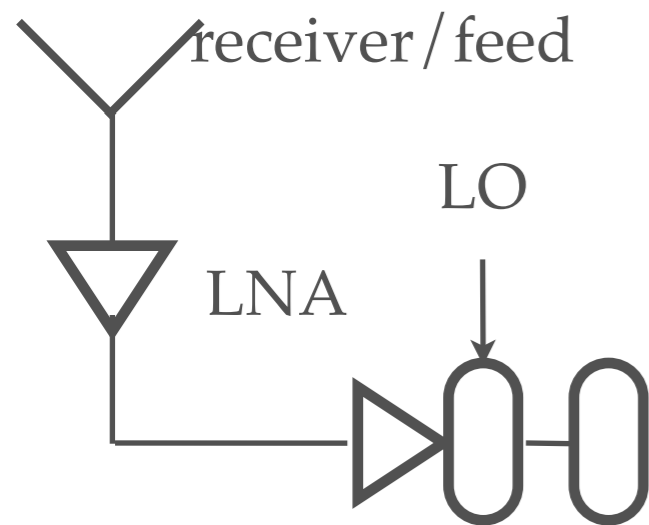
<https://science.nasa.gov/ems/>

Radio-telescopes

$$\lambda = 21 \text{ cm} ; \nu = 1420 \text{ MHz}$$



D	S	λ/D
10 m	78.5 m ²	1.2 deg
50 m	2000 m ²	15'
300 m	70 000 m ²	2.5'



- Single reflector - single receiver (feed)
- Single reflector - multiple receivers (feeds) in the focal plane (10 - 100)
- Single reflector and phased array in the focal plane
- **Several antenna : interferometry**
- Dense array of antenna (no reflector) : aperture synthesis

Une galaxie à $z=0.3$, $D_L = 1500$ Mpc

❖ Emission Radio à 21 cm

- $10^9 M_\odot$ de HI $\rightarrow 3 \cdot 10^{27}$ watts (puissance émise)
- Puissance reçue: $< 10^{-24}$ W / m² répartie sur ~ 1 MHz (qqques photons / m² / s)
- ce qui correspond à moins de 10^{-30} W / m² / Hz , $< 10^{-4}$ Jy (100 μ Jy)

❖ En optique

- $10^9 - 10^{10} L_\odot \rightarrow \gtrsim 10^{35}$ watts (puissance émise)
- Puissance reçue: $< 10^{-16}$ W / m² , $\sim 10^{-17}$ W / m² dans une bande photométrique (~ 10 photons / m² / s)

❖ Densité des galaxies:

- ≈ 0.05 Gal / Mpc³ avec $M_{\text{HI}} > 10^9 M_\odot$
- ≈ 0.01 Gal / Mpc³ avec $M_{\text{HI}} > 10^{10} M_\odot$



Grand radio-télescope
(single dish)
Résolution angulaire
déterminée par la taille
du réflecteur (~300 m
pour Arecibo, Puerto-
Rico, USA)

← En cours de démantèlement, suite à
des ruptures de câbles...

Interférométrie :
mesure de la phase et de
l'amplitude des ondes
radio incidentes.
Combinaison des
signaux électriques
provenant des
différentes antennes
(VLA aux Etats-Unis sur
l'image)



FAST (Chine)



Photo : © Jeff Dai - <https://apod.nasa.gov/apod/ap160929.html>

FAST (Five hundred meter Spherical Radio Telescope) <https://fast.bao.ac.cn>



Grand radio télescope de 100m
d'Effelsberg , Allemagne

<https://www.mpifr-bonn.mpg.de/en/effelsberg>

Grand radio télescope de
Nançay (France)

<https://www.obs-nancay.fr>



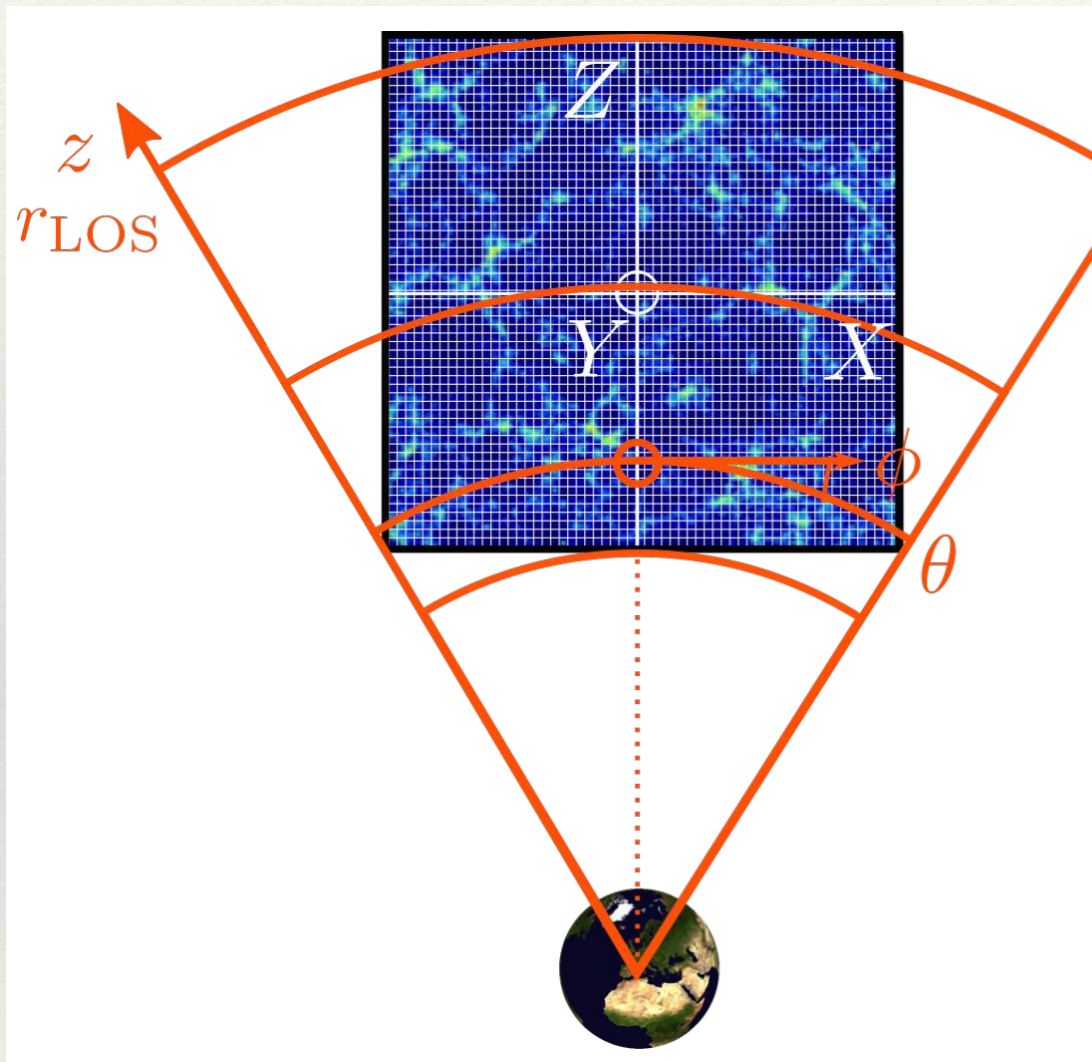
Copyright © Ronald Hijmans

Observations à 21 cm comparées à l'optique

- ❖ Possibilité d'observations spectro-photométrique à 21 cm - **seule signature spectrale en bande L (~GHz)**
- ❖ Bande: ~ 100 MHz ... 1500 MHz - $\nu = f(z)$, $z: 0 \dots 10$
1420 MHz @ $z=0$, 946 MHz @ $z=0.5$, 720 @ $z=1$, 284 @ $z=5$, 129 @ $z=10$
- ❖ La résolution des instruments radio limitée par la diffraction:
700 MHz: $D=100$ m \rightarrow $\sim 20'$, $D=1$ km \rightarrow $\sim 2'$, $D=100$ km \rightarrow $\sim 1''$ [$2' \rightarrow 1$ Mpc @ $z = 1$]
- ❖ Mesure d'intensité en optique, amplitude & phase en radio
- ❖ \rightarrow Interférométrie et spectroscopie en radio
- ❖ Bruit instrumental (détecteur / électronique) souvent négligeable en optique ($R_{\text{Onoise}} < 5$ e), mais dominant en radio ($T_{\text{sys}} \sim 20-100$ K)
- ❖ Pollution lumineuse, et diffusion atmosphérique en optique
Interférence électromagnétique (RFI), ionosphere (à basse fréquences) en radio

Observations à 21 cm

- redshift \leftrightarrow fréquence
- Position angulaire obtenue par imagerie



Single Dish

- Cartographie du ciel en mode drift-scan or ou en balayant le ciel : on obtient des cartes du ciel

Interféromètres

- On obtient des visibilités (signaux de corrélations) à partir desquels il faut reconstruire les cartes du ciel
- La décomposition en modes m dans le cas d'observation en drift-scan Est-Ouest complète
- Les visibilités correspondent aux modes de Fourier transverse k_{\perp}

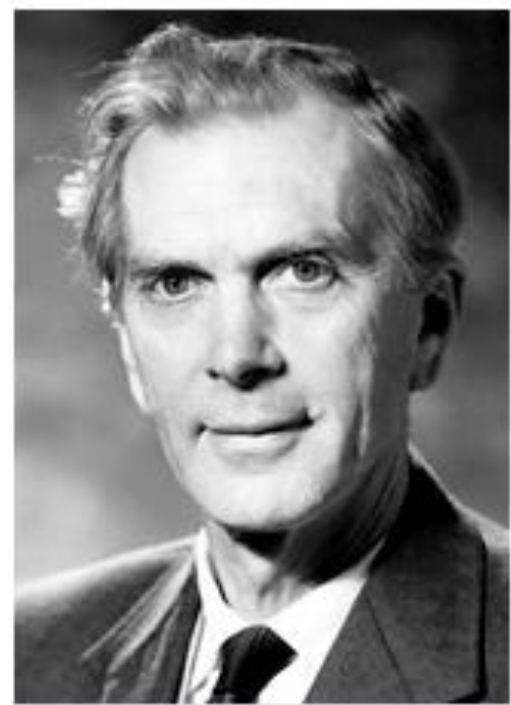


The Nobel Prize in Physics 1974

The Ryle Telescope

"for their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars"

- Interféromètre radio avec 8 éléments (réflecteurs)
- fonctionnant à 15 GHz
- Grand Bretagne (UK)
- Utilisé principalement pour le CMB



Sir Martin Ryle

🕒 1/2 of the prize



Antony Hewish

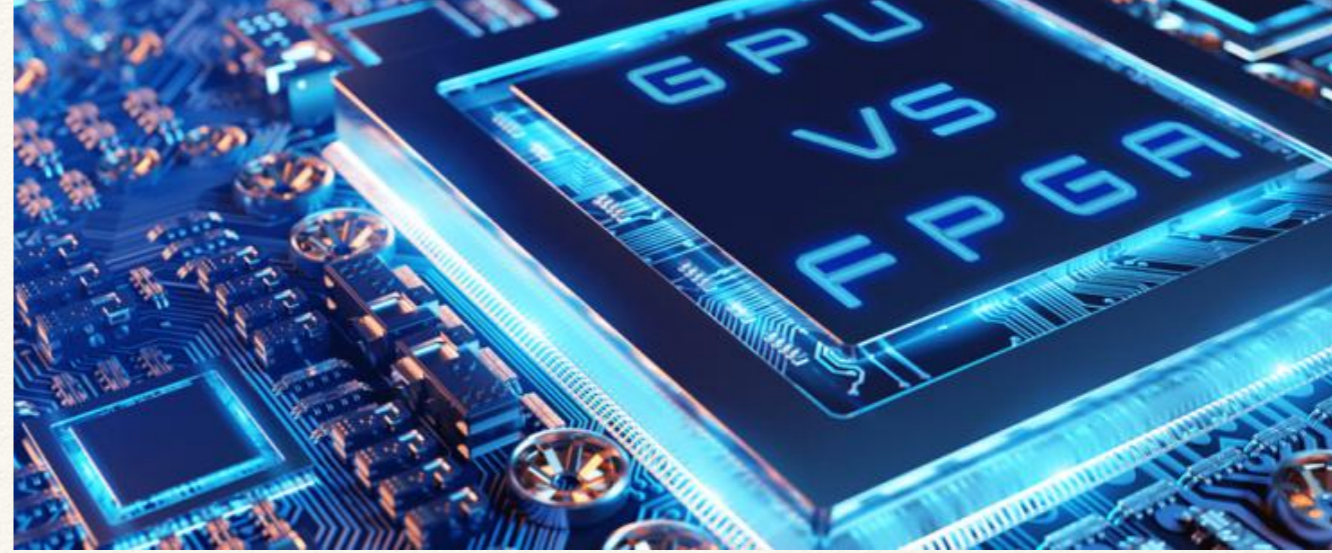
🕒 1/2 of the prize



Prix Nobel 1974

<https://www.nobelprize.org/prizes/physics/1974/summary/>

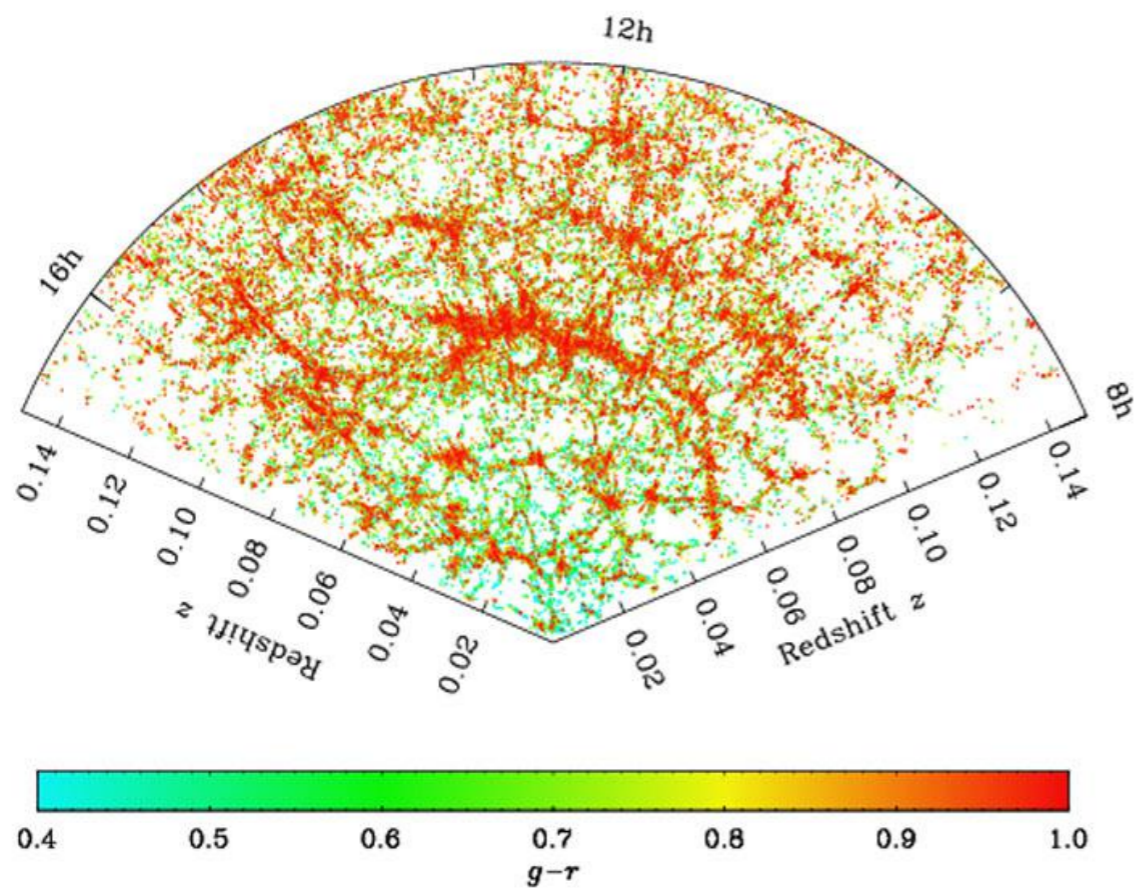
L'interférométrie numérique



- ❖ Les signaux RF issus des antennes sont numérisés, éventuellement après déclage en fréquence (forme d'onde)
- ❖ Pour le 21cm, signaux entre ~ 10 MHz et 1500 MHz
- ❖ l'interférométrie se fait sur des signaux "quasi" monochromatique
- ❖ Décomposition numérique en composantes de fréquences (FFT / filtres polyphases)
- ❖ Les visibilités, correspondent alors aux coefficients de corrélation entre les composantes en fréquence des différentes antennes, moyennés sur de courts intervalles de temps, calculés sur du matériel dédié ou des CPU/GPU
- ❖ Interféromètres avec des centaines ou des milliers d'antennes (N), de large bandes en fréquence (100 MHz ... 1 GHz) - calcul de N^2 corrélations.
- ❖ Très grand flux de données (\sim Tera Octets / s) à traiter au vol, implique une énorme puissance, puis des algorithmes complexes pour l'analyse des visibilités
- ❖ L'interférométrie permet d'atteindre de très hautes résolutions angulaires (VLBI)

La cartographie d'intensité à 21cm

Cartographie de la distribution cosmique de matière à l'aide de raie à 21cm, en utilisant l'hydrogène atomique comme traceur



L'univers est (quasi) homogène et isotrope à grand échelle ($>Gpc$), mais structuré à plus petites échelles, des quelques centaines de Mpc (BAO ~ 100 Mpc), puis les amas de galaxies (1-10 Mpc), jusqu'aux galaxies (10-100 kpc) et puis les étoiles.

Les structures se forment essentiellement sous l'effet de la gravitation effondrement gravitationnel

Relevé SDSS, cartes des galaxies:

[Zehavi et al. ApJ 2011, arXiv:1005.2413](#)

Observer les galaxies à 21cm à des distances cosmologiques

$$S_{21}^{Jy} \simeq 0.021 \cdot 10^{-6} \text{ Jy} \frac{M_{HI}}{M_{\odot}} \times \left(\frac{1 \text{ Mpc}}{D_L} \right)^2 \times \frac{200 \text{ km/s}}{\sigma_v} (1+z)$$

$$S_{lim} = \frac{2 k T_{sys}}{A \sqrt{2 t_{integ} \Delta \nu}}$$

Jansky : $1 \text{ Jy} = 10^{-26} \text{ W/Hz/m}^2$

S_{lim} en μJy pour
 $t_{integ} = 86400 \text{ s}$, $\Delta \nu = 1 \text{ MHz}$

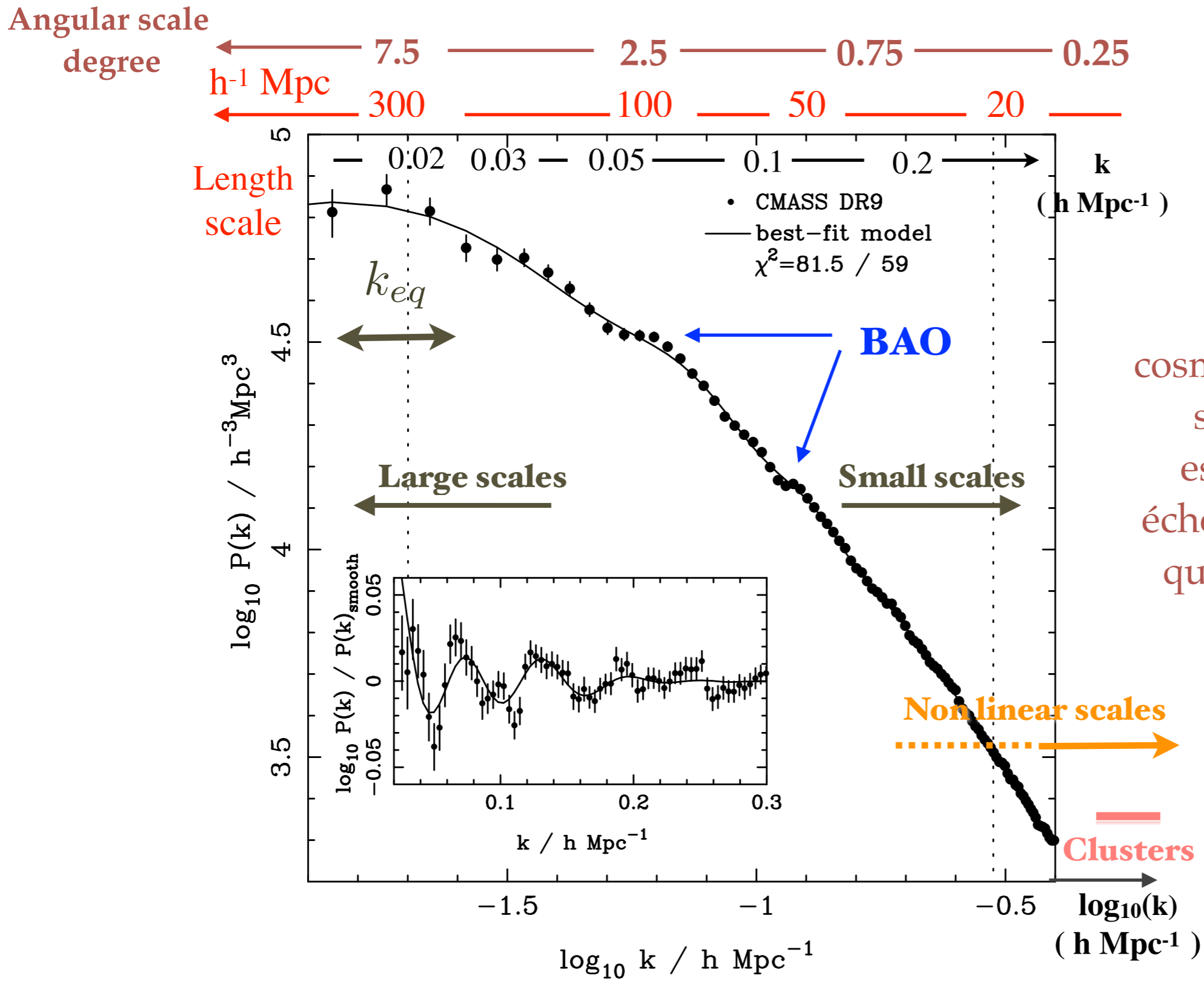
S_{21} en μJy pour $M_{HI} = 10^{10} M_{\odot}$

A (m ²)	Tsys (K)	Slim
5000	50	66
5000	25	33
100000	50	3,5
100000	25	1,7

z	S21 (μJy)
0,25	175
0,5	40
1	9,6
1,5	3,5
2	2,5

$> 100\,000 \text{ m}^2 \rightarrow \text{SKA!}$

LSS: spectre de puissance et échelles pertinentes



L'information cosmologique des grandes structures se trouve essentiellement à des échelles plus grandes que quelques minutes d'arc
BAO: ~ 0.5 degré

Cartographie 3D à 21 cm : $T_{21}(\alpha, \delta, z)$

- ❖ Cartographie 3D mapping de la distribution de l'hydrogène atomique et son évolution avec le redshift: mesure de la carte d'émission à 21 cm, **sans détection des sources ponctuelles**
- ❖ Instrument avec un grand champ de vue instantané et une grande largeur de bande, pour observer de grands volumes d'univers
- ❖ **Interférométrie numérique**
 - Implique de traiter au vol un très grand flot de données, plusieurs *TeraOctets/seconde*
- ❖ Ou Grand réflecteurs équipés de récepteurs multi-lobes
 - **Bruit instrumental (électronique) (T_{sys})**
 - **Avant-plans: Emissions diffuses (Galactique) et sources radio → séparation des composantes**
 - **Calibration, stabilité de l'instrument, RFI ...**

Furlanetto et al. Phys.Rep 2006, arXiv:0608032

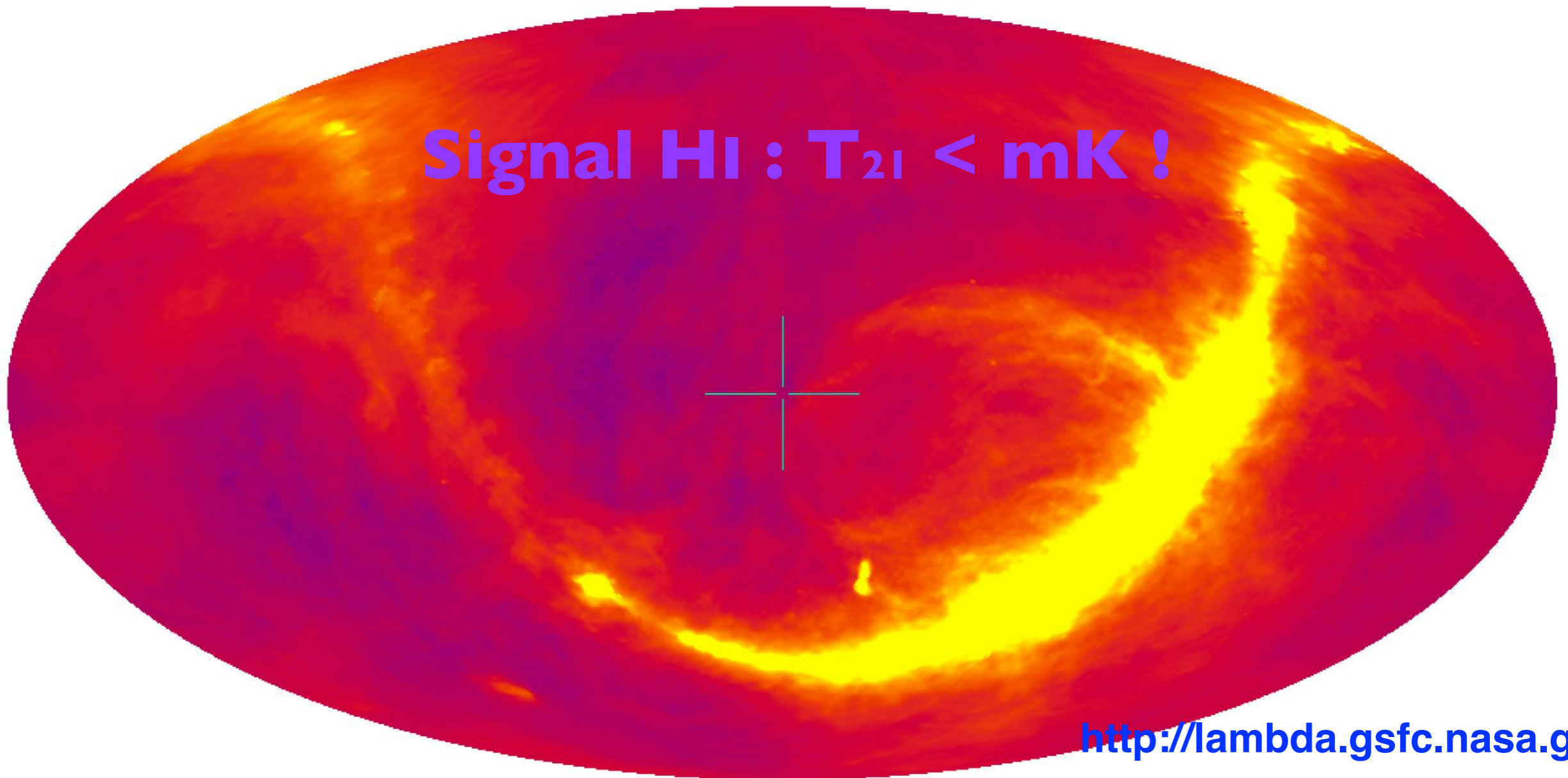
Wyithe et al. MNRAS 2008, arXiv:0709.2955

Chang et al. PRL 2008, arXiv:0709.3672

Ansari et al. A&A 2012, arXiv:0709.3672

Les avant-plans

Signal HI : $T_{21} < \text{mK}$!



<http://lambda.gsfc.nasa.gov/>

10 K
5

Temp. T (Ech. Log)

80 K
80

Carte Haslam à 408 MHz (synchrotron Galactic)

La température de brillance, en loi de puissance: $\nu^{-\beta}$ ($\beta \sim 2.5$)

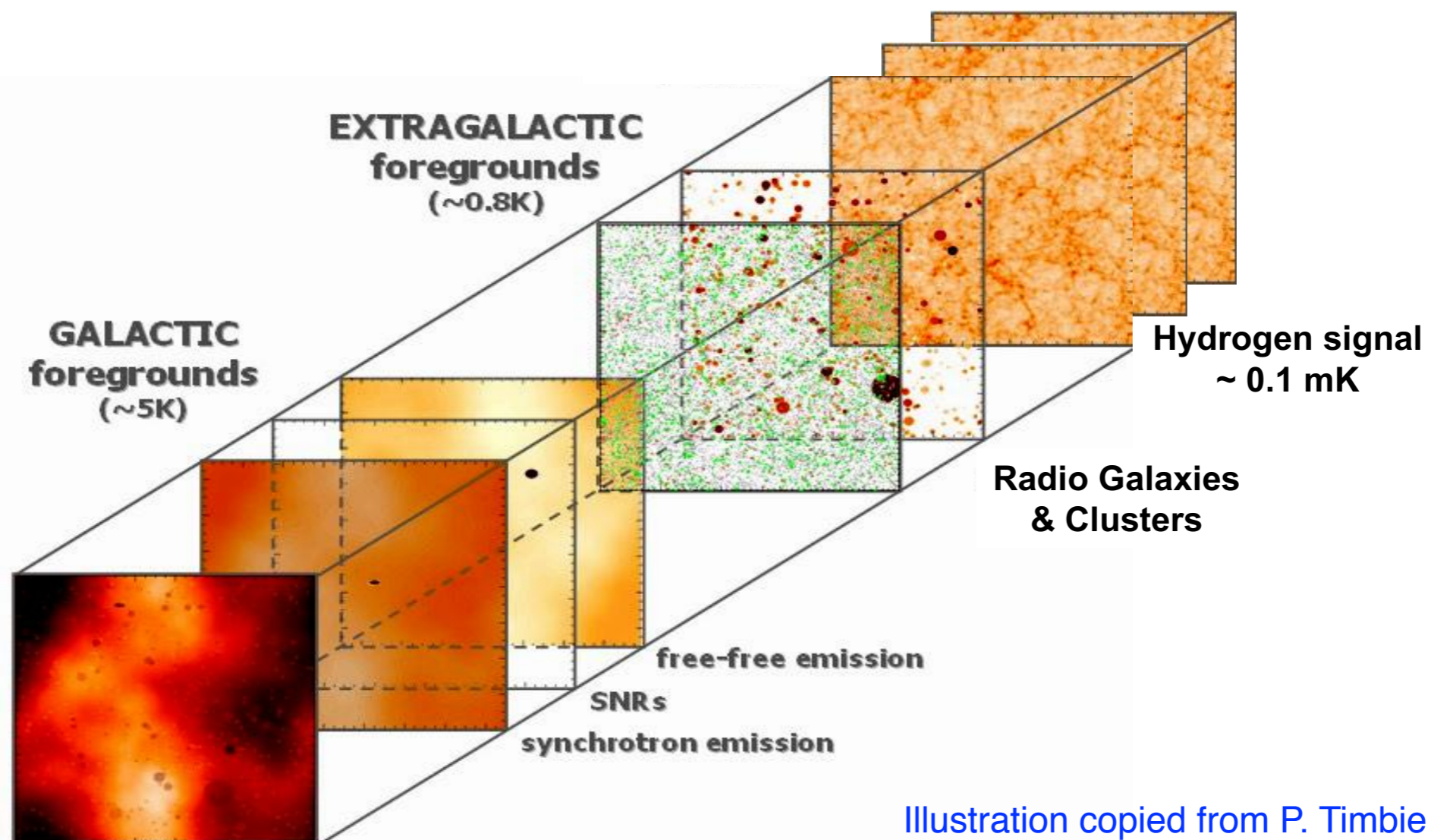
400 MHz ($z \sim 2.5$) \rightarrow 710 MHz ($z \sim 1$) \rightarrow 950 MHz ($z \sim 0.5$)

T_{sync} : 10 K \rightarrow ~ 4 K \rightarrow ~ 1.5 K

Les avant-plans

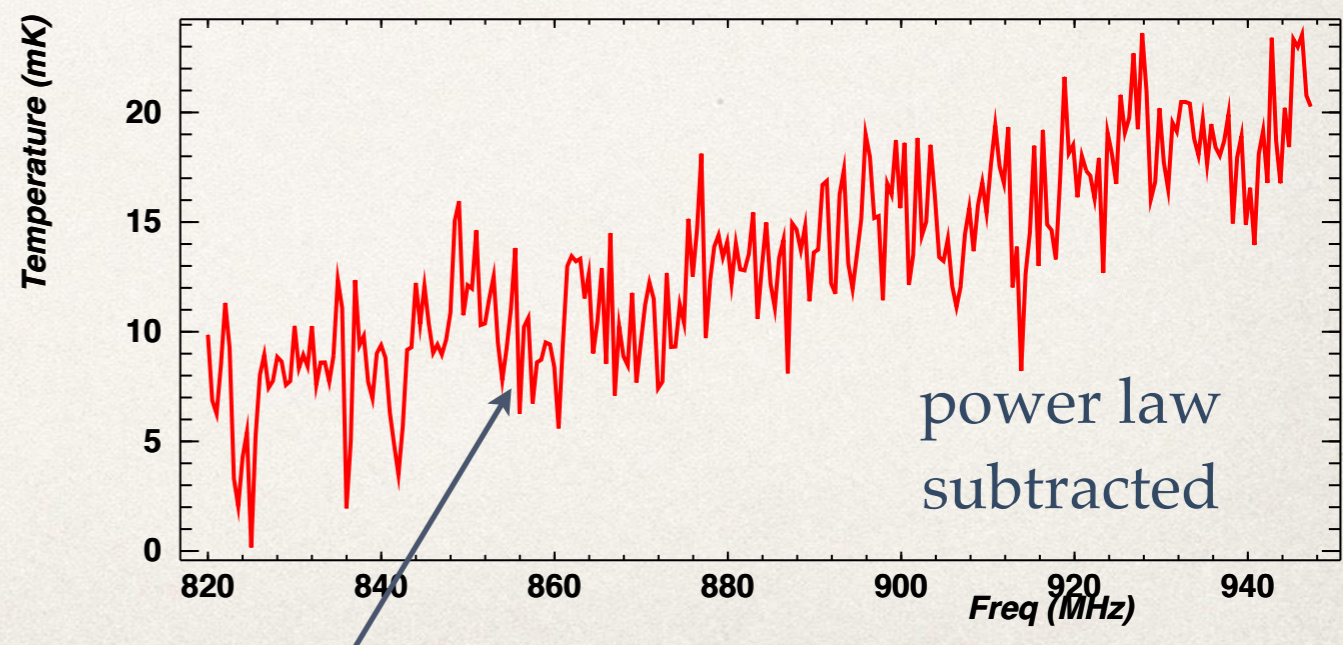
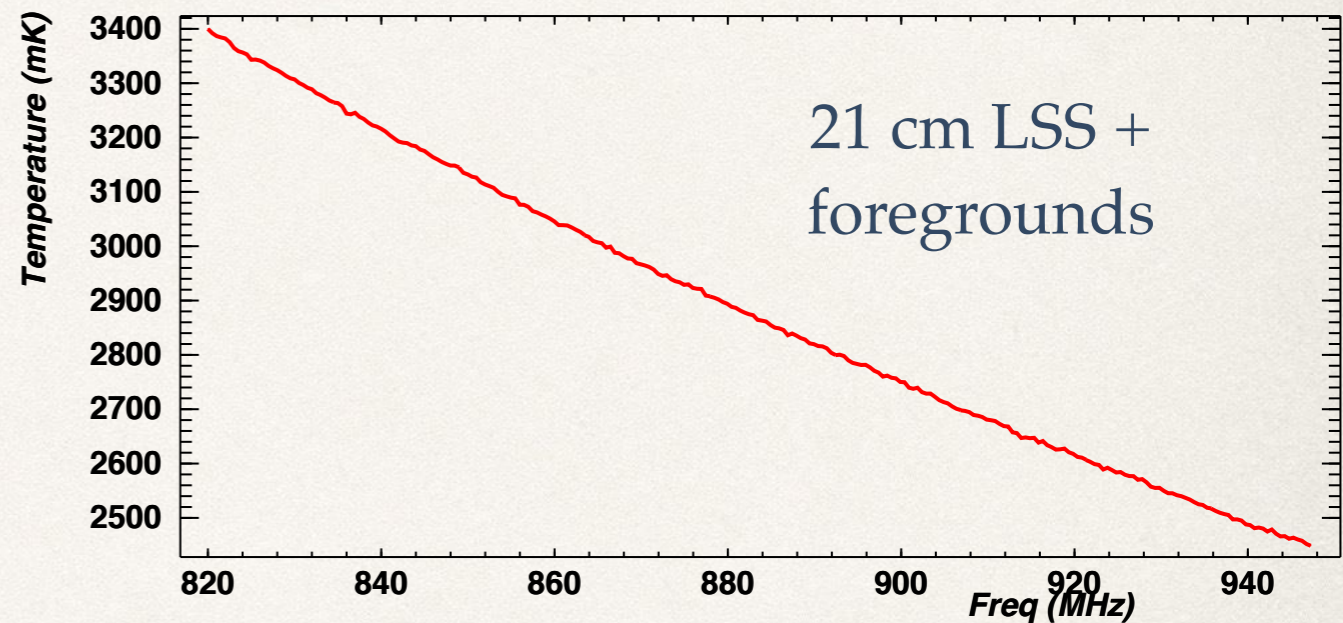
Extraction du signal cosmologique

- ❖ Les avant-plans, dominés par le rayonnement synchrotron de la Voie Lactée et des sources radio est 1000-10000 plus intense que le signal cosmologique (1-10 K dans les zones les plus froides du ciel, comparés à <0.1 mK pour le signal cosmologique à 21cm)



Synchrotron et signal 21cm, évolution en fréquence ...

- ❖ Exploiter la dépendance spectrale des avants-plans (spectre en loi de puissance $\propto \nu^\beta$) du rayt. synchrotron et des radio sources
- ❖ Effets instrumentaux (mode mixing) propagation des erreurs de soustraction ...



21 cm LSS signal

Mode Mixing

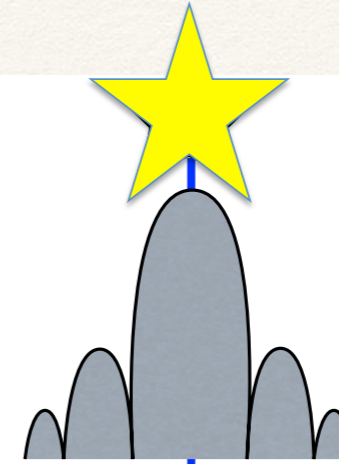
Illustration par
Kris Sigurdson
UBC

En radio, la forme de la réponse (lobe) d'antenne est dominée par le phénomène de diffraction ($\delta\theta \sim \lambda/D = c/(v D)$)

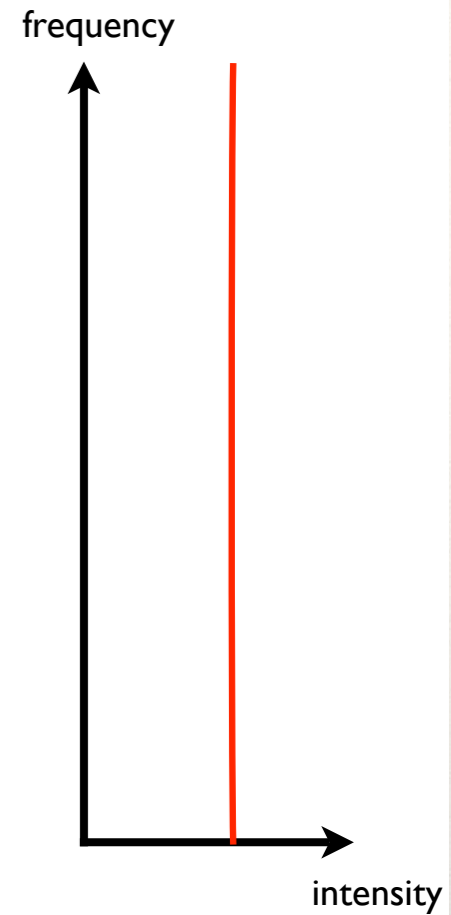
La réponse instrumentale a donc une forte dépendance avec la longueur d'onde (ou la fréquence) $L(v)$

Cette réponse $L(v)$ est donc à l'origine d'un Couplage des modes de variation transverse k_{\perp} et longitudinal k_{\parallel}

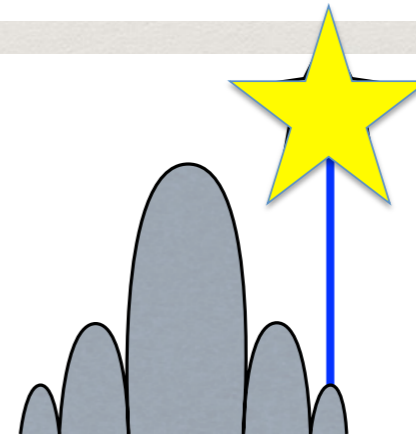
High frequency



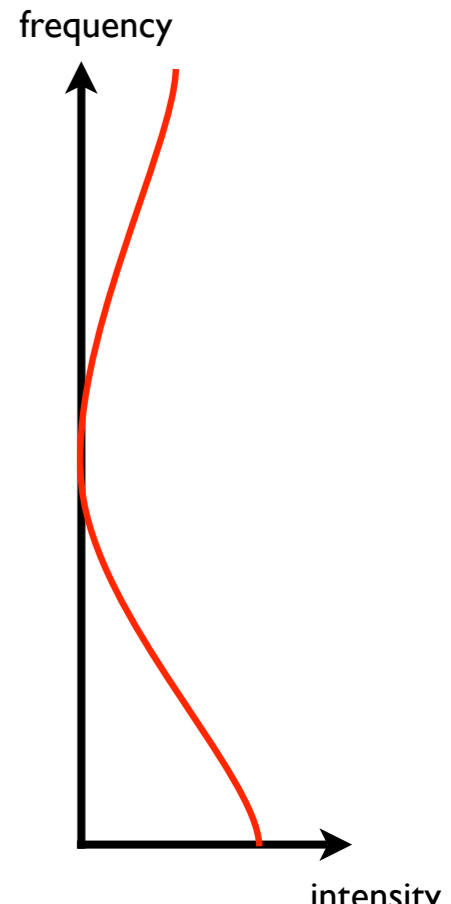
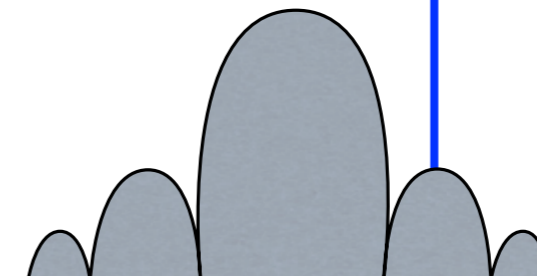
Low frequency



High frequency



Low frequency

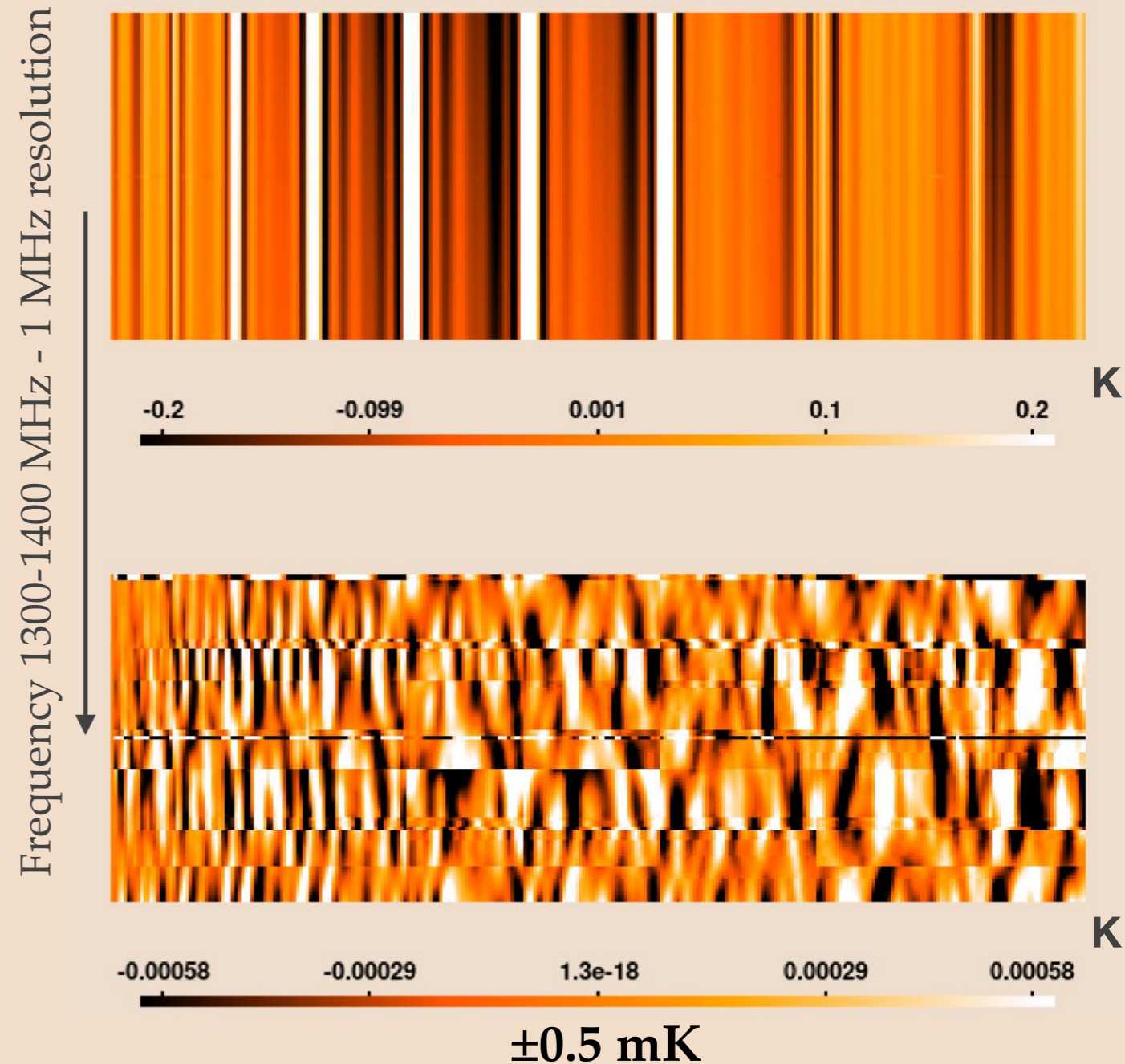
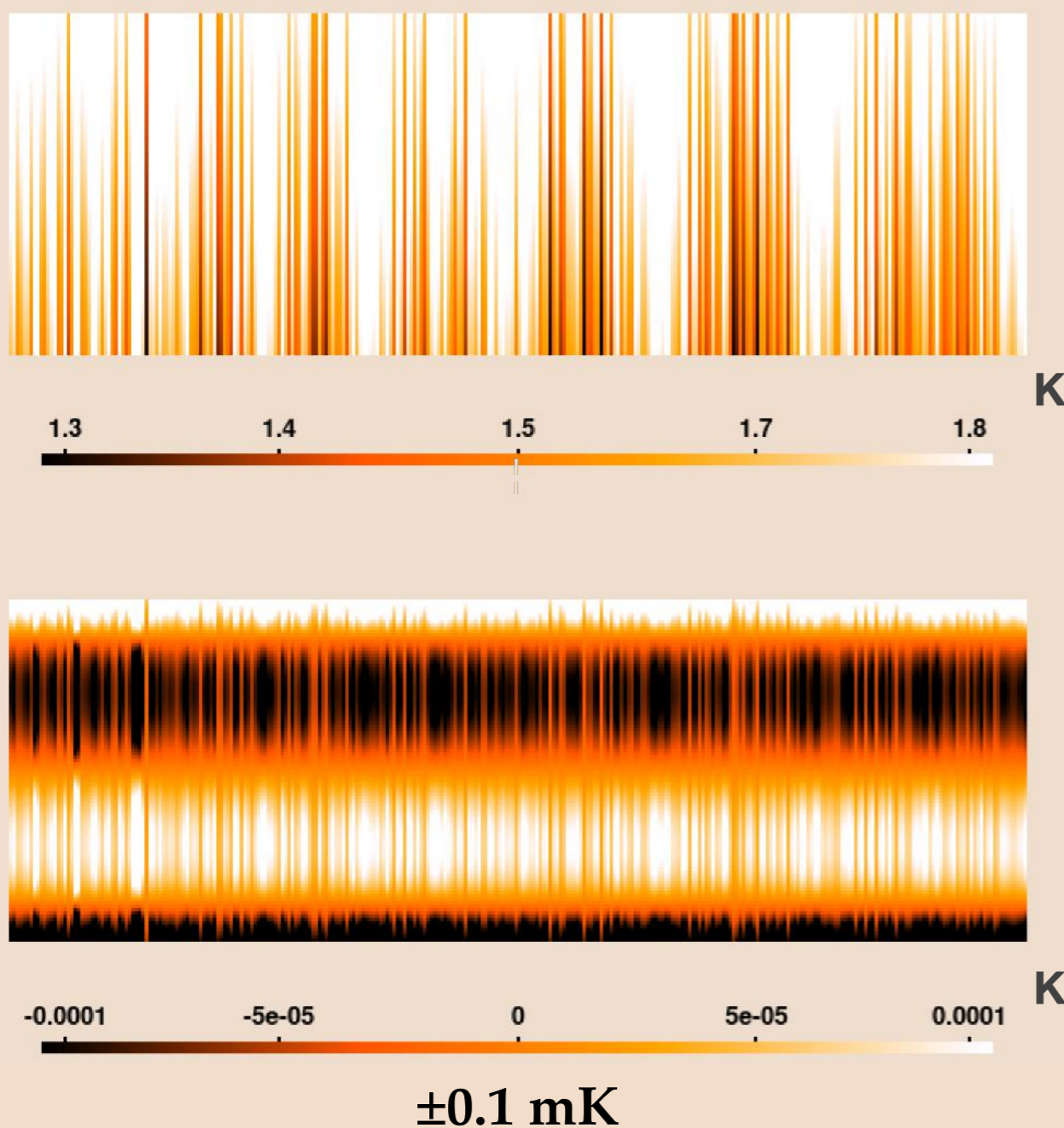


Mode mixing - A realistic illustration

Top: reconstructed 3D maps - bottom After simple 2nd order polynomial subtraction

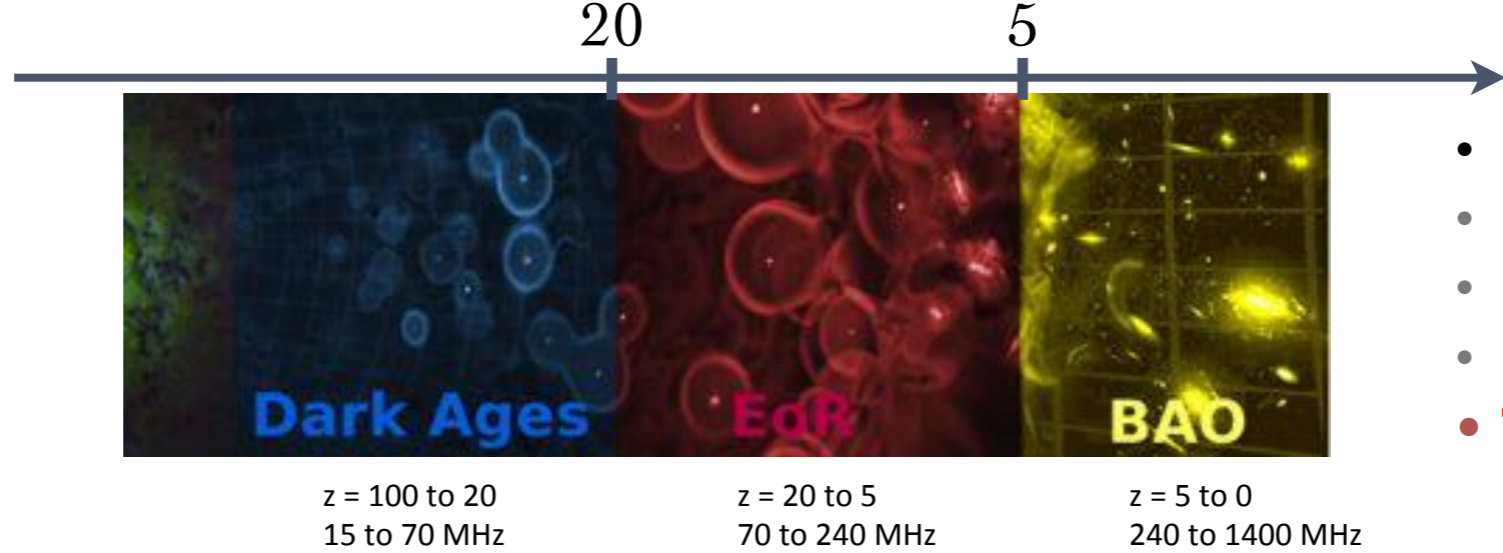
Perfect instrument - frequency independent gaussian beam
Imperfect foreground model

Tianlai T16D - NCP survey
Residual mode mixing



map pixels (ra,dec) - 5' pixels

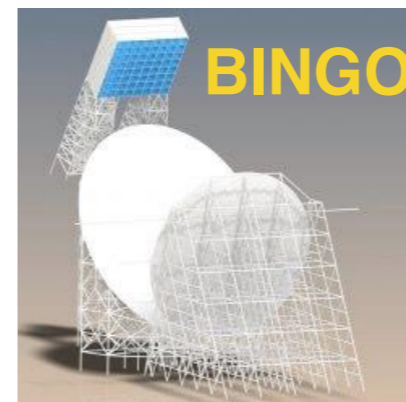
- LOFAR
- GMRT
- MWA
- HERA
- PAPER



- CHIME
- HIRAX
- CHORD
- BINGO
- Tianlai / PAON4

SKA

La cartographie d'intensité à 21cm Expériences en cours (et futures)

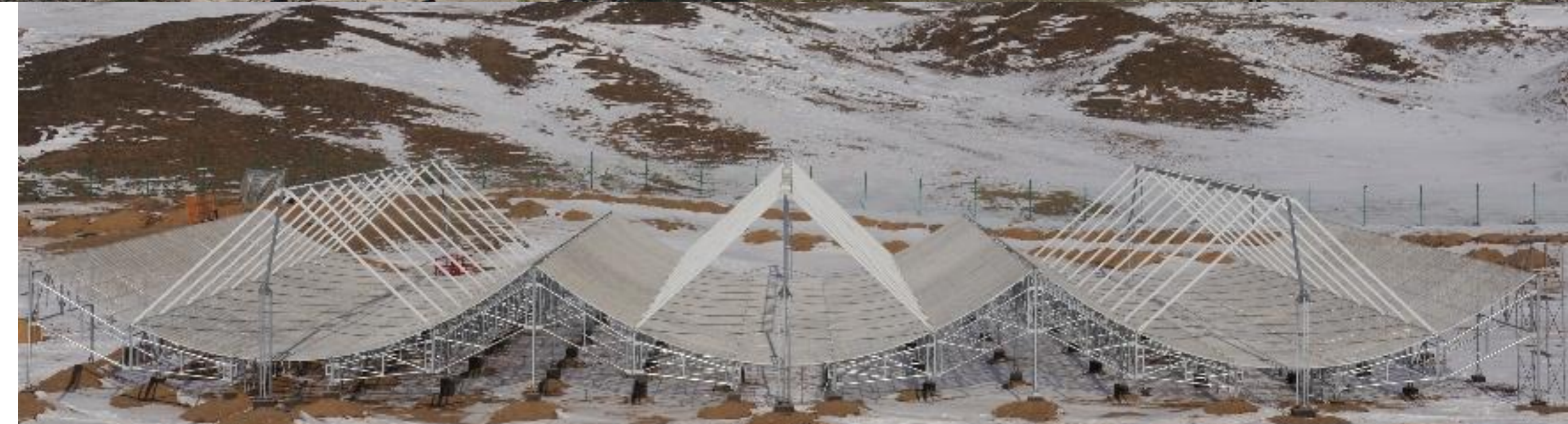




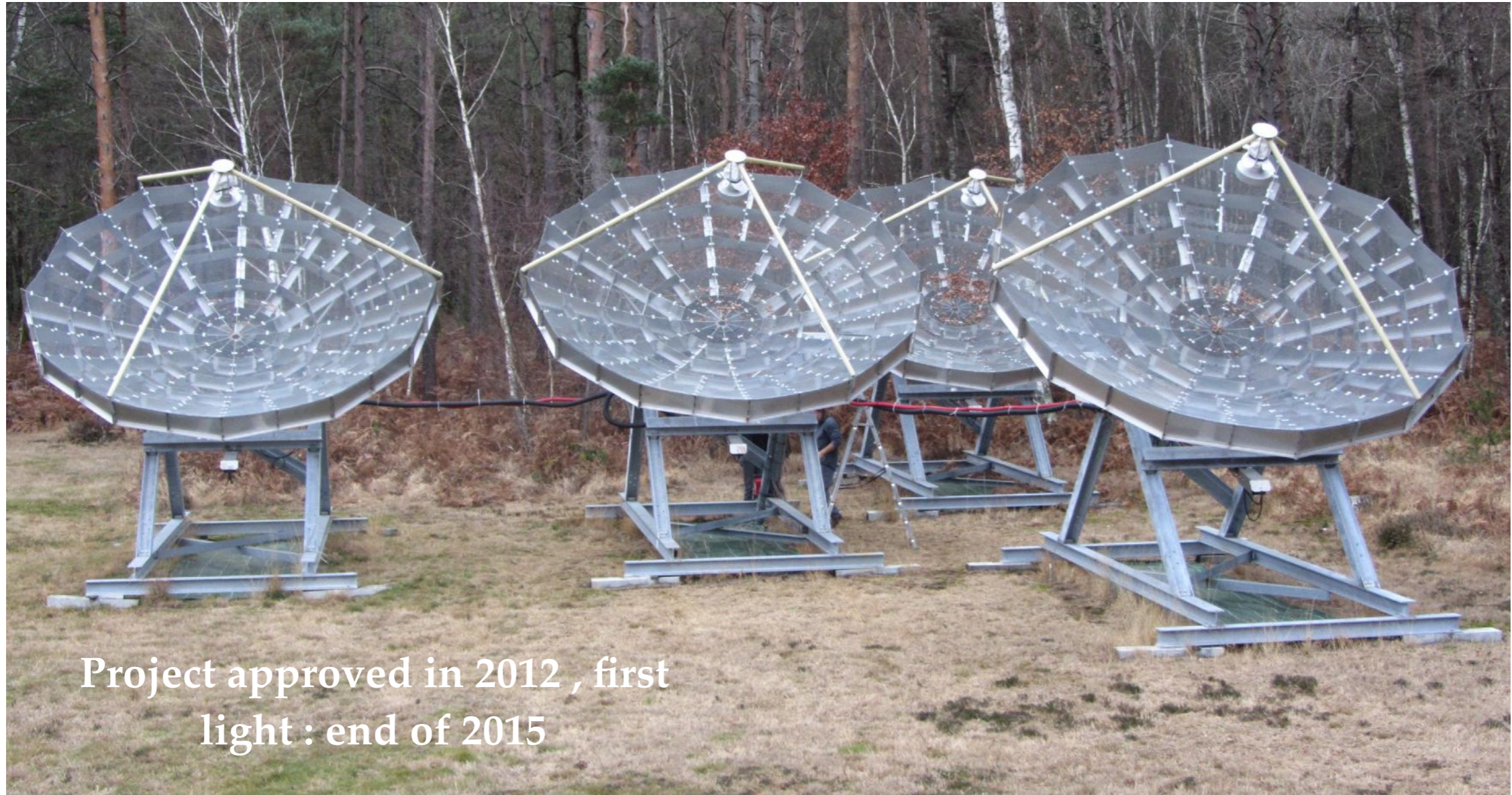
TIANLAI

3 Cylinders , 15mx40m

16 x D=6m dish array



PAON4 @Nançay, (France)



Project approved in 2012 , first
light : end of 2015

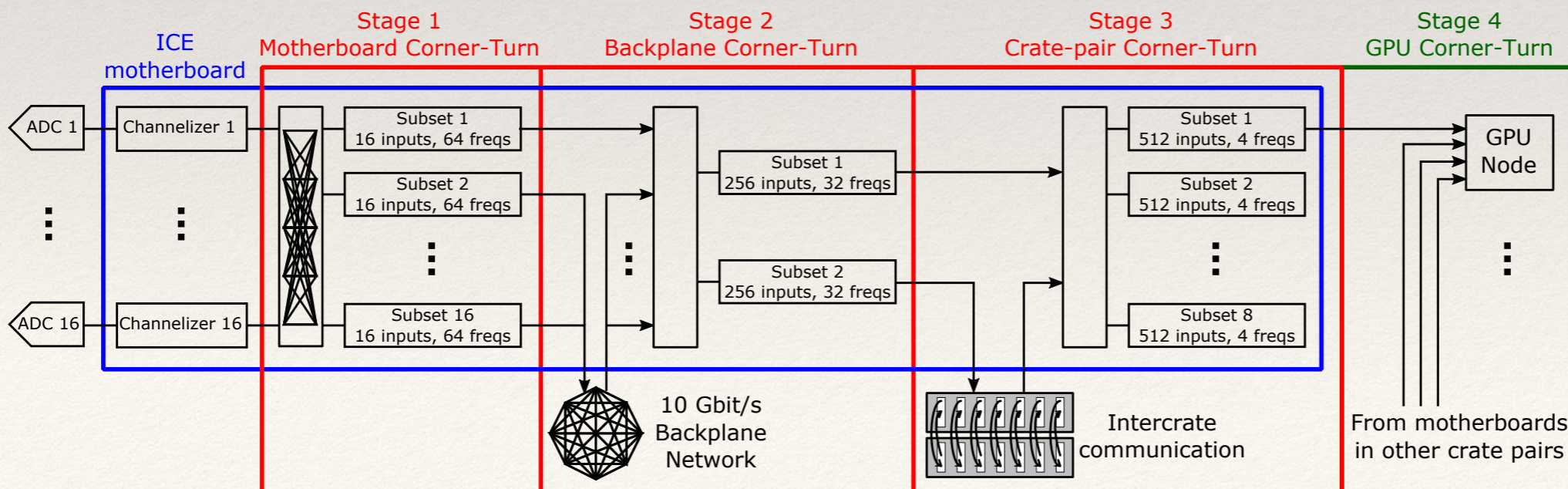
4 x 5m dishes, réseau interférométrique dense en mode transit
bande ($\sim 1250-1500$ MHz)

Banc de qualification pour la nouvelle chaîne électronique -
IDROGEN (numérisation+ F-engine) - utilise la technologie
WhiteRabbit pour la synchronisation des horloges
en cours de déploiement sur PAON4

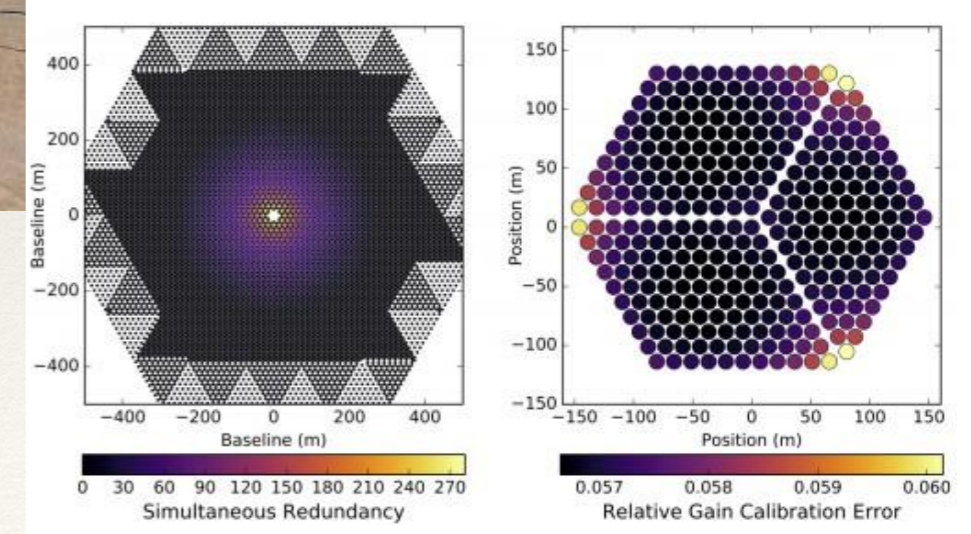
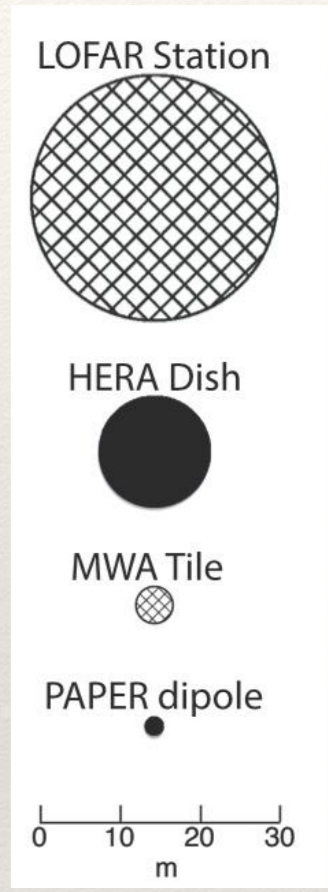
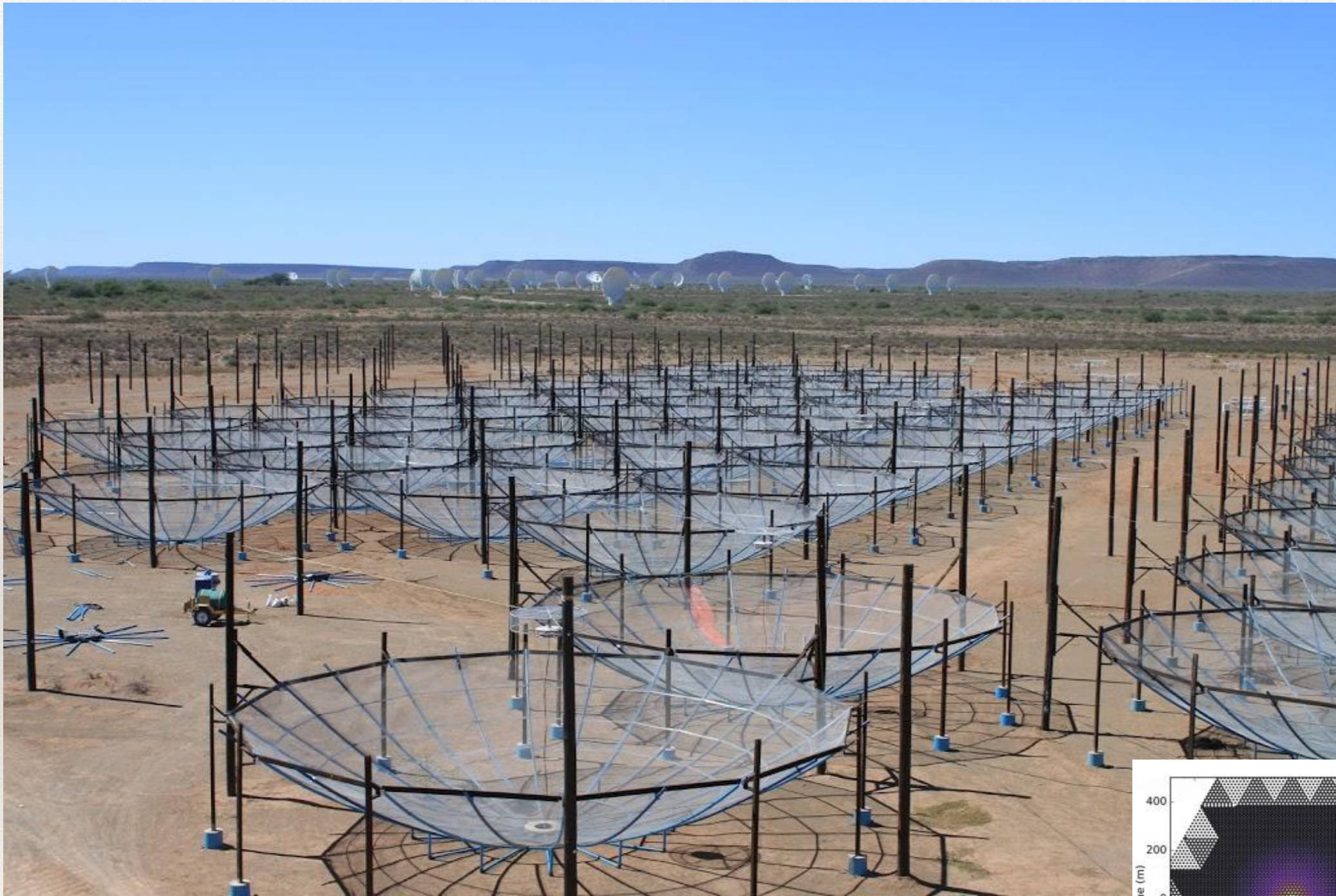
CHIME



- ❖ Canadian Hydrogen Intensity Mapping Experiment
- ❖ 4 cylinders, 100m x 20 m , each equipped with 256 dual polarisation feeds
- ❖ 400-800 MHz - 1024 frequency channel $0.8 < z < 2.5$
- ❖ N^2 correlations, FPGA + GPU FX correlator



HERA : Hydrogen Epoch of Reionisation Array



Pober et al. ApJ 2014, arXiv:1310.7031



NenuFAR (/ LOFAR) @Nançay, (France)



Image : © Radio France bleu, Berry


<https://www.francebleu.fr/infos/sante-sciences/un-nouveau-radiotelescope-operationnel-a-nancay-1571935931>


SKA Science Working Groups & Focus groups

The Science Working Groups (SWGs) and Focus Groups (FGs) are scientific advisory bodies that provide input to the SKA Organisation on issues related to the design, construction, and future operations of the SKA that are likely to affect the Observatory's scientific capability, productivity and user relations. In addition, the FGs have a more specific, technical focus.


If you are interested in participating in any of the groups, please contact the current chairs or corresponding project scientists via the website link below.

- **Cosmology**
- **Cradle of Life**
- **Epoch of Reionization**
- **Extragalactic Continuum (galaxies/AGN, galaxy clusters)**
- **Extragalactic Spectral Line**
- **HI galaxy science**
- **High Energy Cosmic Particles (FG)**
- **Magnetism**
- **Our Galaxy**
- **Pulsars**
- **Solar, Heliospheric & Ionospheric Physics**
- **Transients**
- **VLBI (FG)**

 @ska_telescope

 @SKA_telescope

 Square Kilometre Array

 YouTube The Square Kilometre Array

For more, visit



[astronomers.skatelescope.org/science-working-groups](https://www.skatelescope.org/astronomers)

SKA1-mid

the SKA's mid-frequency instrument



Location:
South Africa



Frequency range:
350 MHz
to
15.3 GHz
with a goal of 24 GHz



197 dishes
(including 64 MeerKAT dishes)



Maximum baseline:
150km

SKA1-low

the SKA's low-frequency instrument



Location: Australia



Frequency range:
50 MHz
to
350 MHz

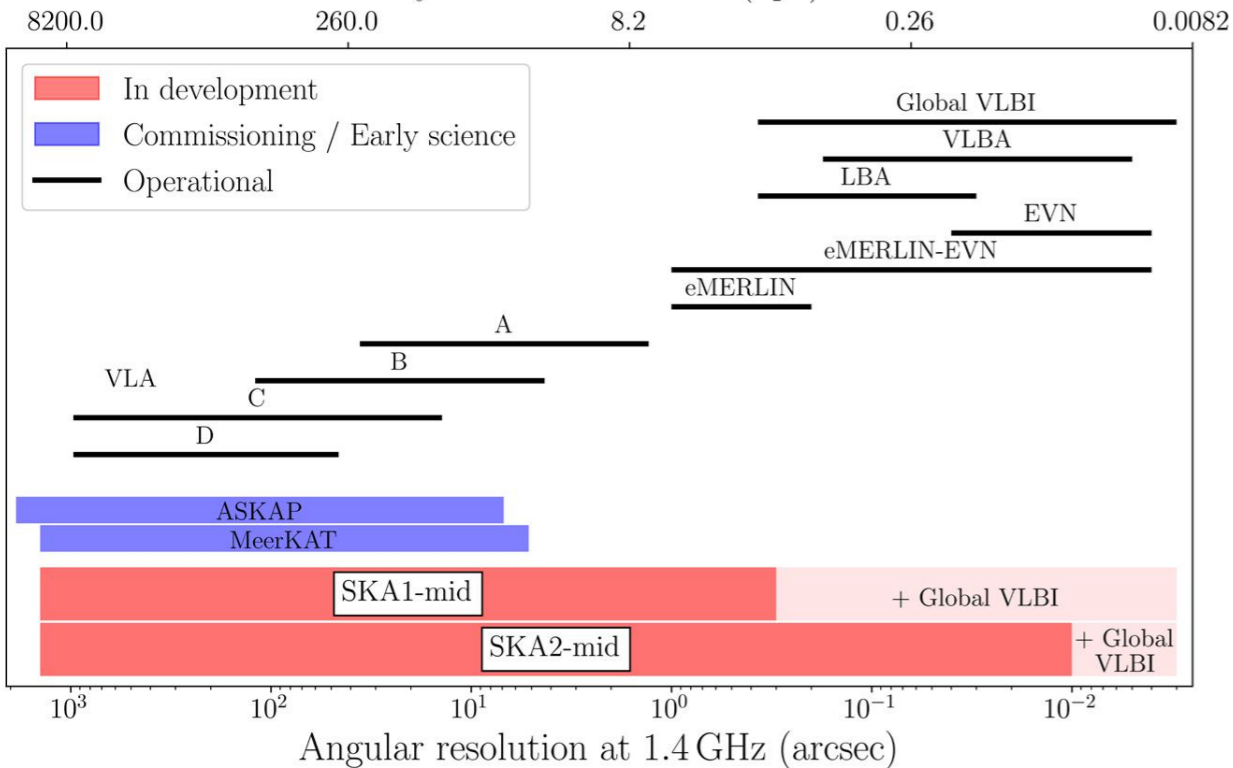


~131,000
antennas spread between
512 stations

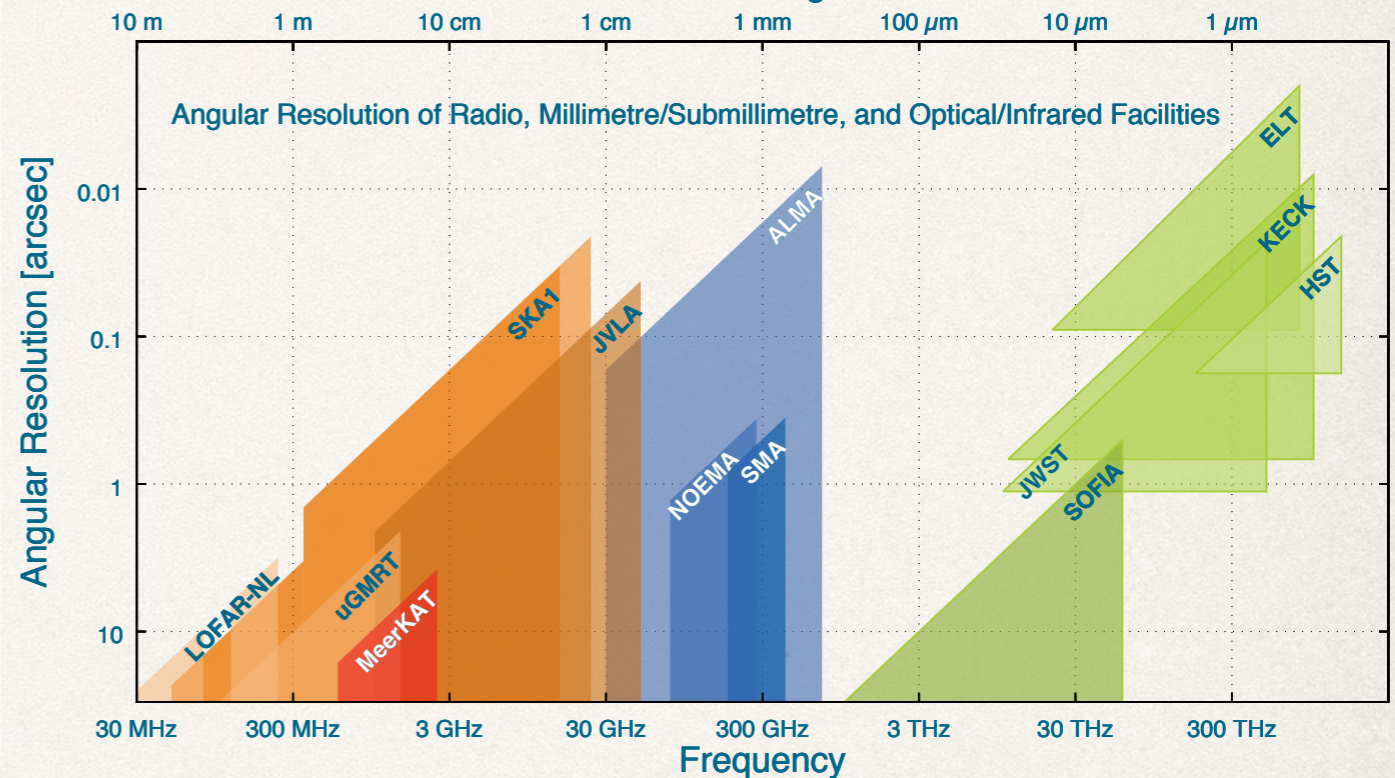


Maximum baseline:
~65km

Physical scale at $z = 1$ (kpc)



Wavelength



Major dates



2017–2018

Prototypes deployed at the telescope sites

2020

Start of construction activities

2022

Start of Observatory & Science commissioning

2024–2027

Key Science Project (KSP) planning & proposals

late 2026

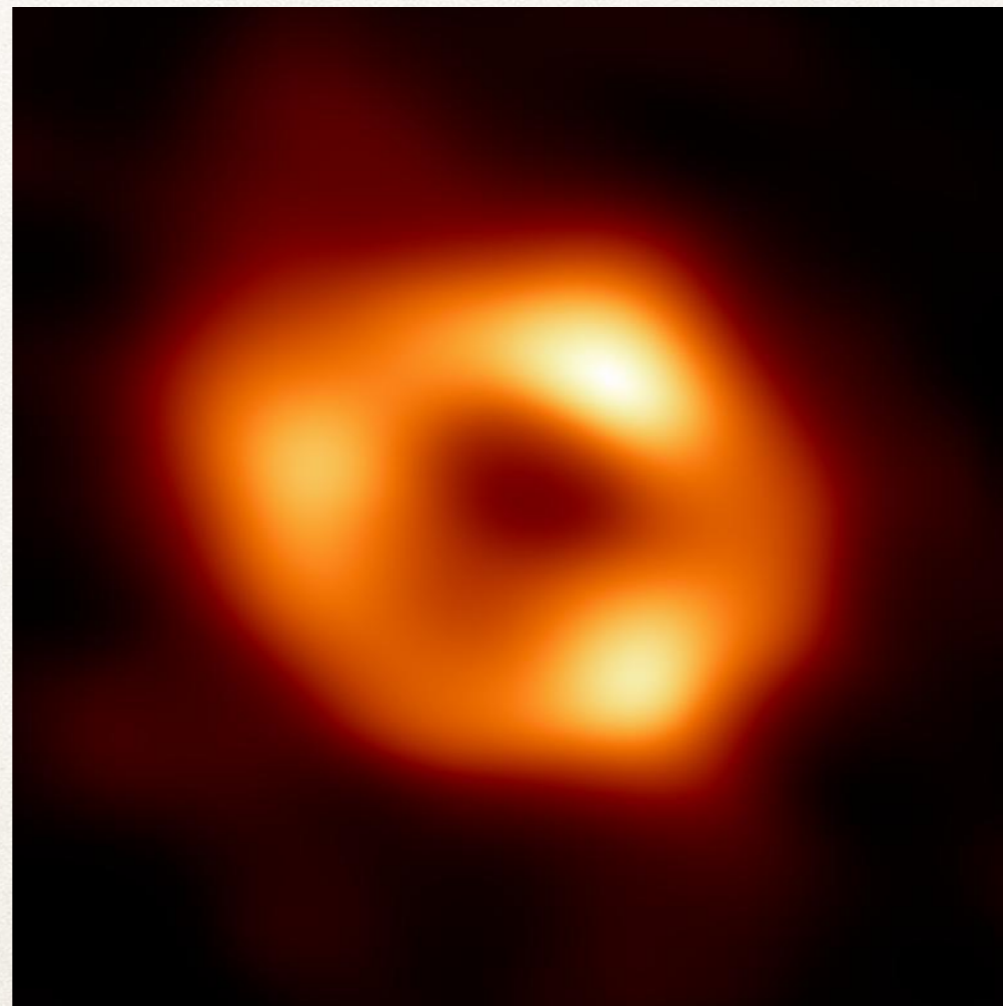
Commencement of PI-led programmes

late 2027

Commencement of KSPs



Event Horizon Telescope





First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole

The Event Horizon Telescope Collaboration
(See the end matter for the full list of authors.)

Received 2019 March 1; revised 2019 March 12; accepted 2019 March 12; published 2019 April 10

The EHT Collaboration et al.

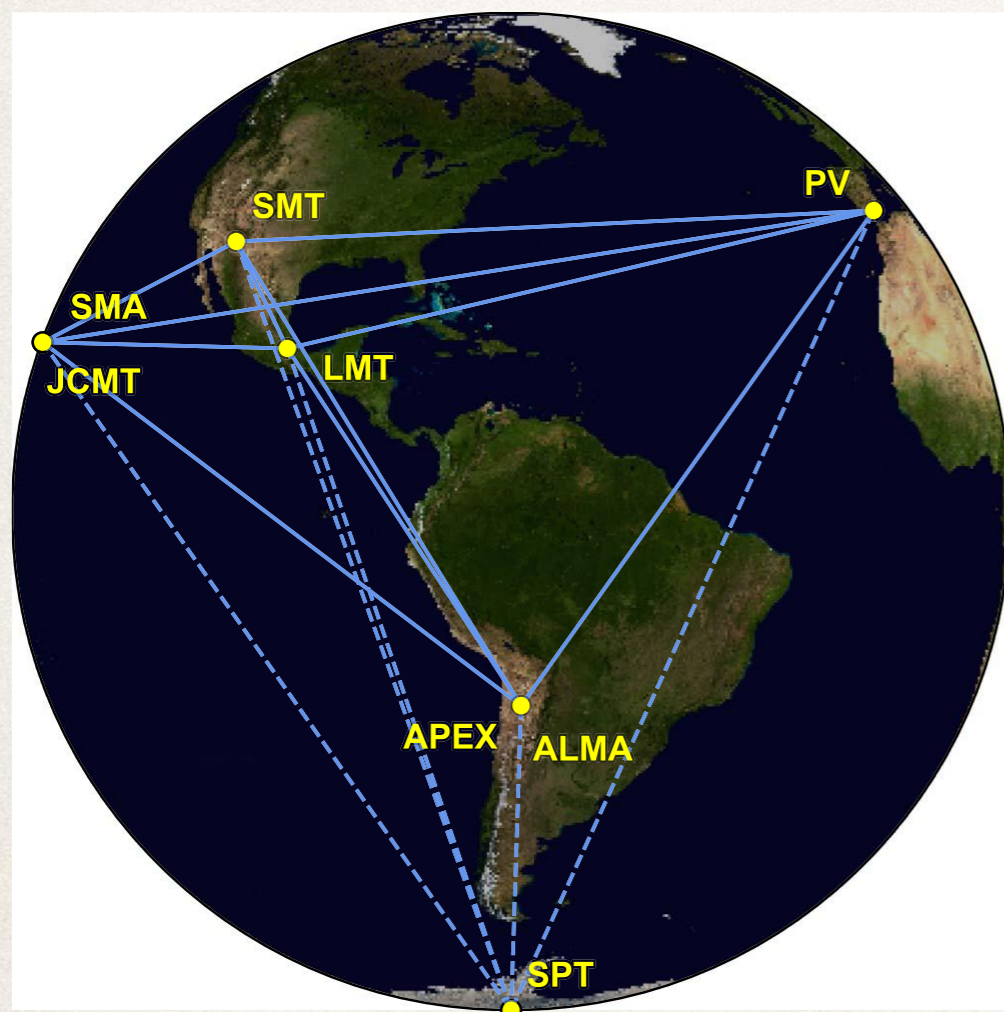
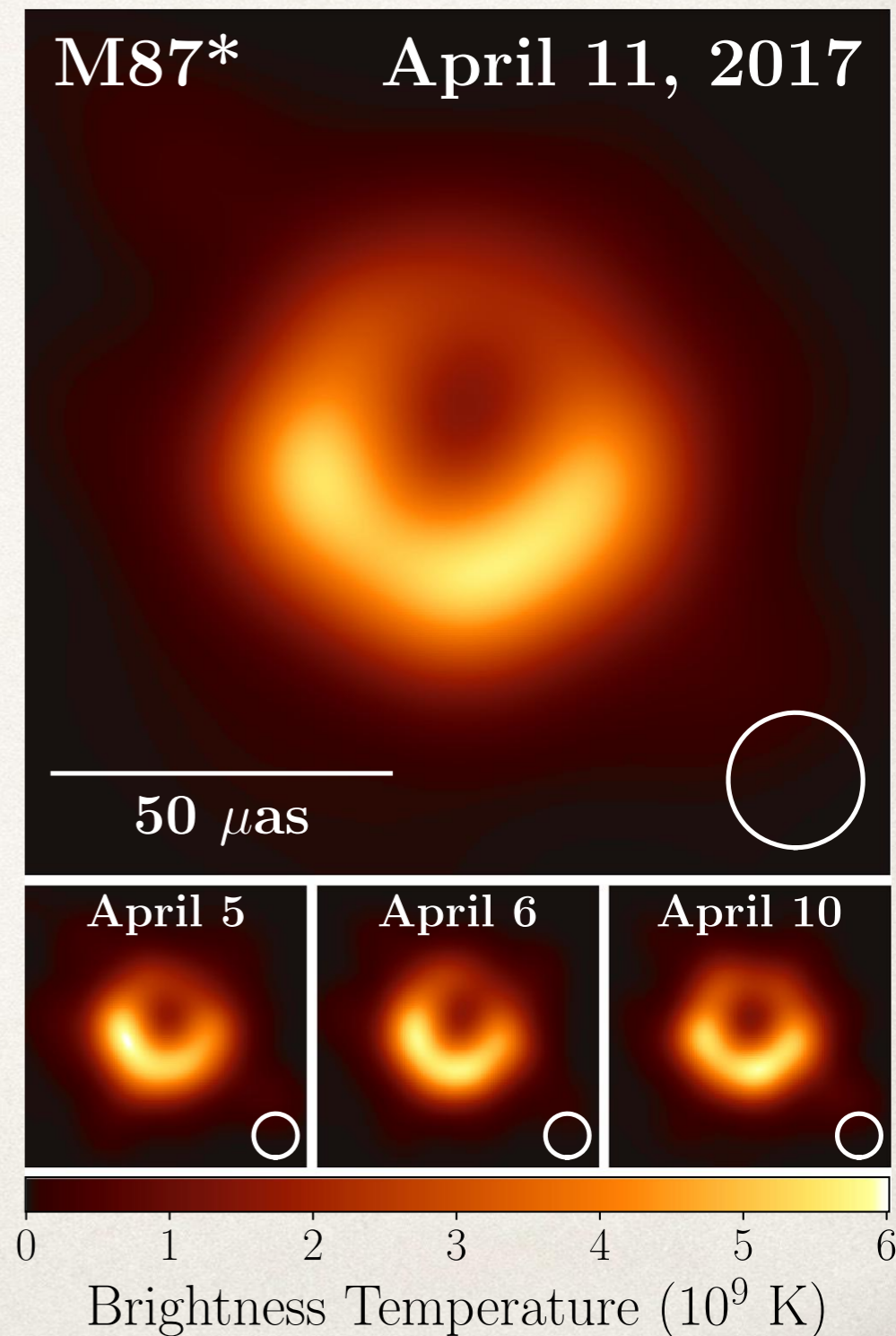
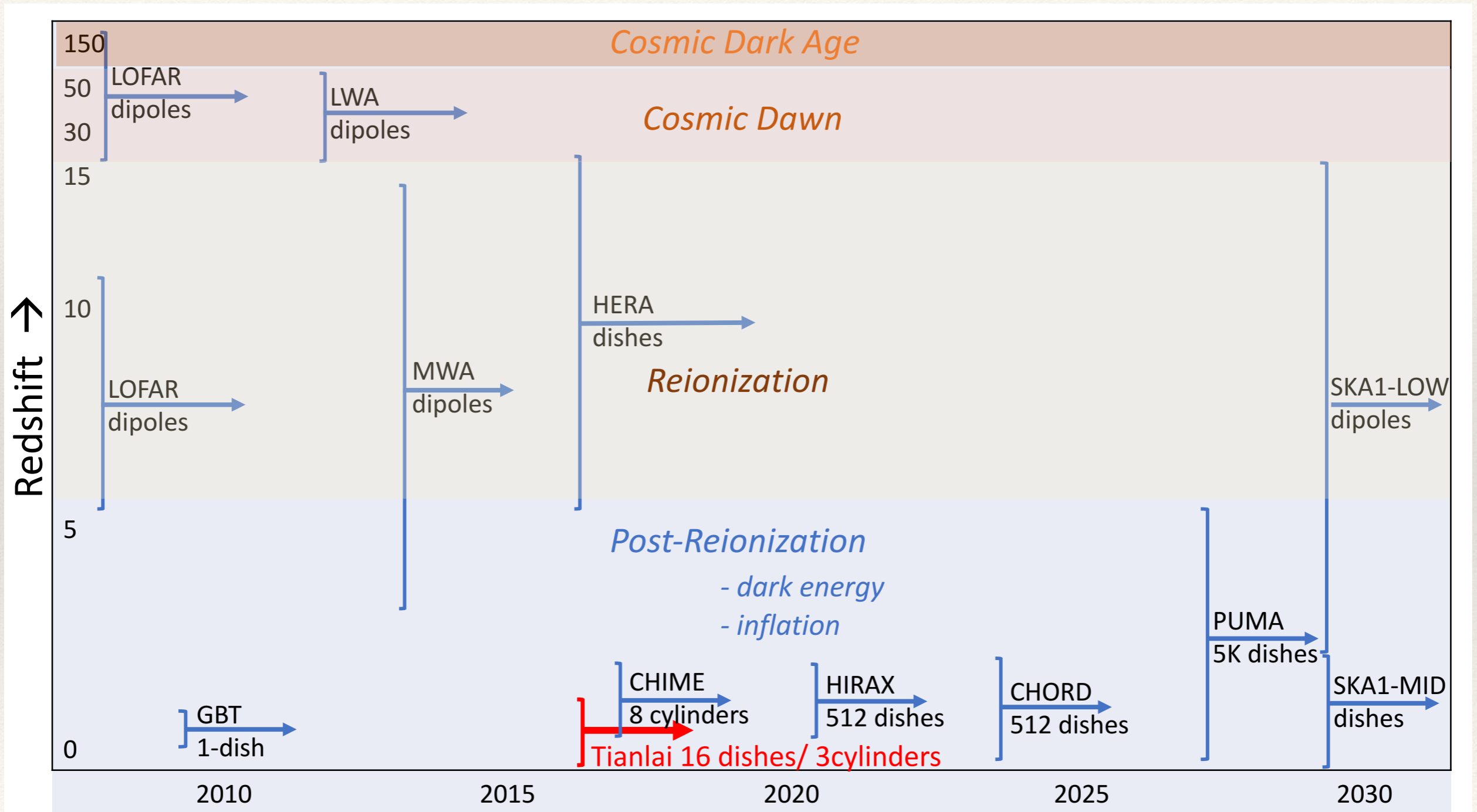


Figure 1. Eight stations of the EHT 2017 campaign over six geographic locations as viewed from the equatorial plane. Solid baselines represent mutual visibility on M87* (+12° declination). The dashed baselines were used for the calibration source 3C279 (see Papers III and IV).



Futur de la cosmologie à 21 cm



Cosmology

cosmology |kɒz'mɒlədʒi|

noun (pl. **cosmologies**) [mass noun]

the science of the origin and development of the universe. Modern cosmology is dominated by the Big Bang theory, which brings together observational astronomy and particle physics.

• [count noun] an account or theory of the origin of the universe.

DERIVATIVES

cosmological |-mə'lɒdʒɪk(ə)| adjective,

cosmologist noun

ORIGIN mid 17th cent.: from French *cosmologie* or modern Latin *cosmologia*, from Greek *kosmos* 'order or world' + *-logia* 'discourse'.

COSMOLOGY MARCHES ON

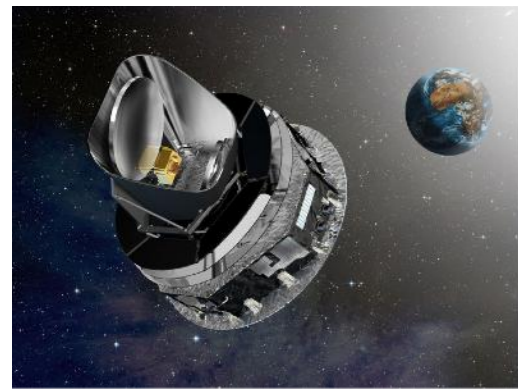
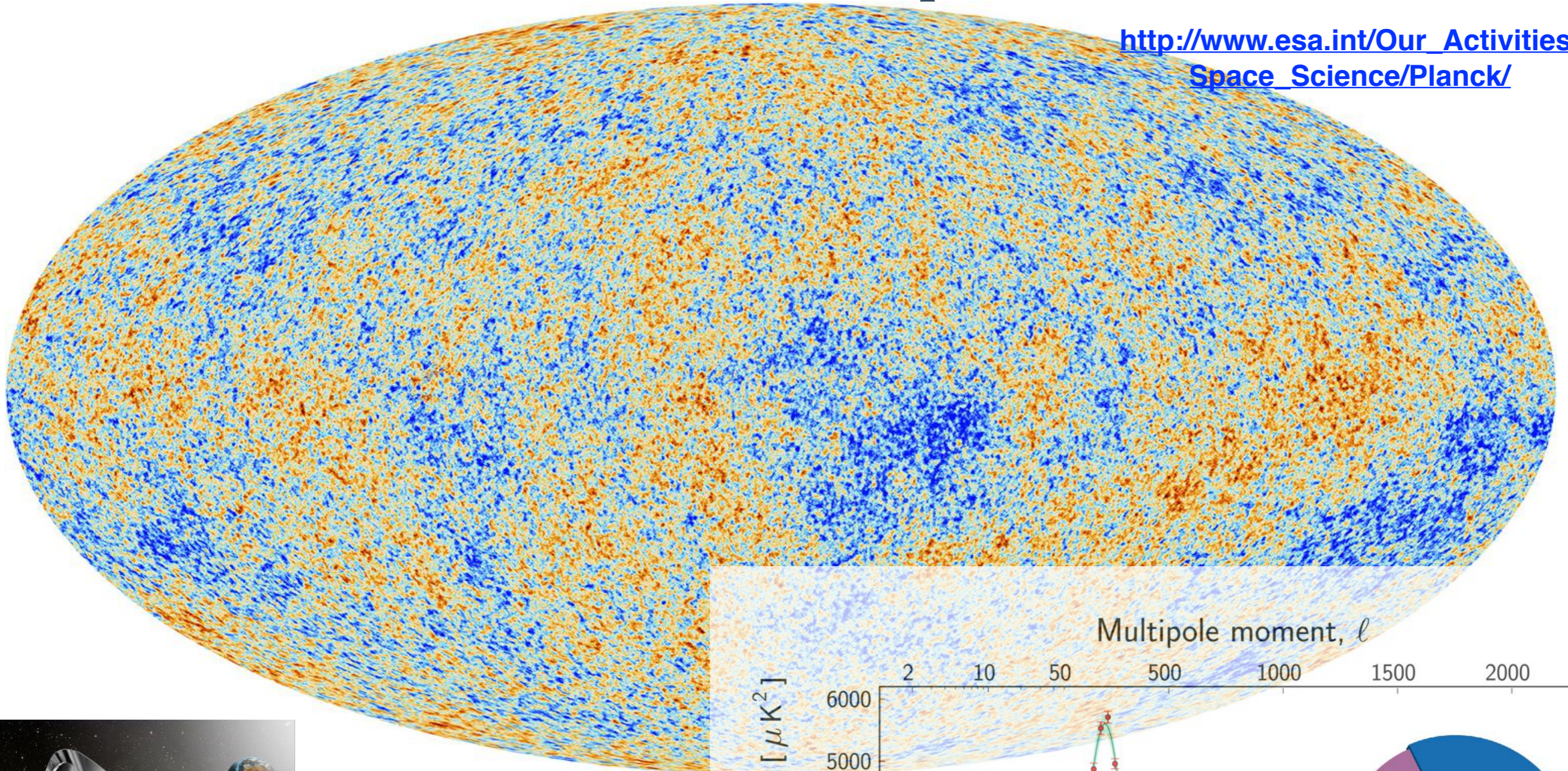
(Cosmology seen by S. Harris)



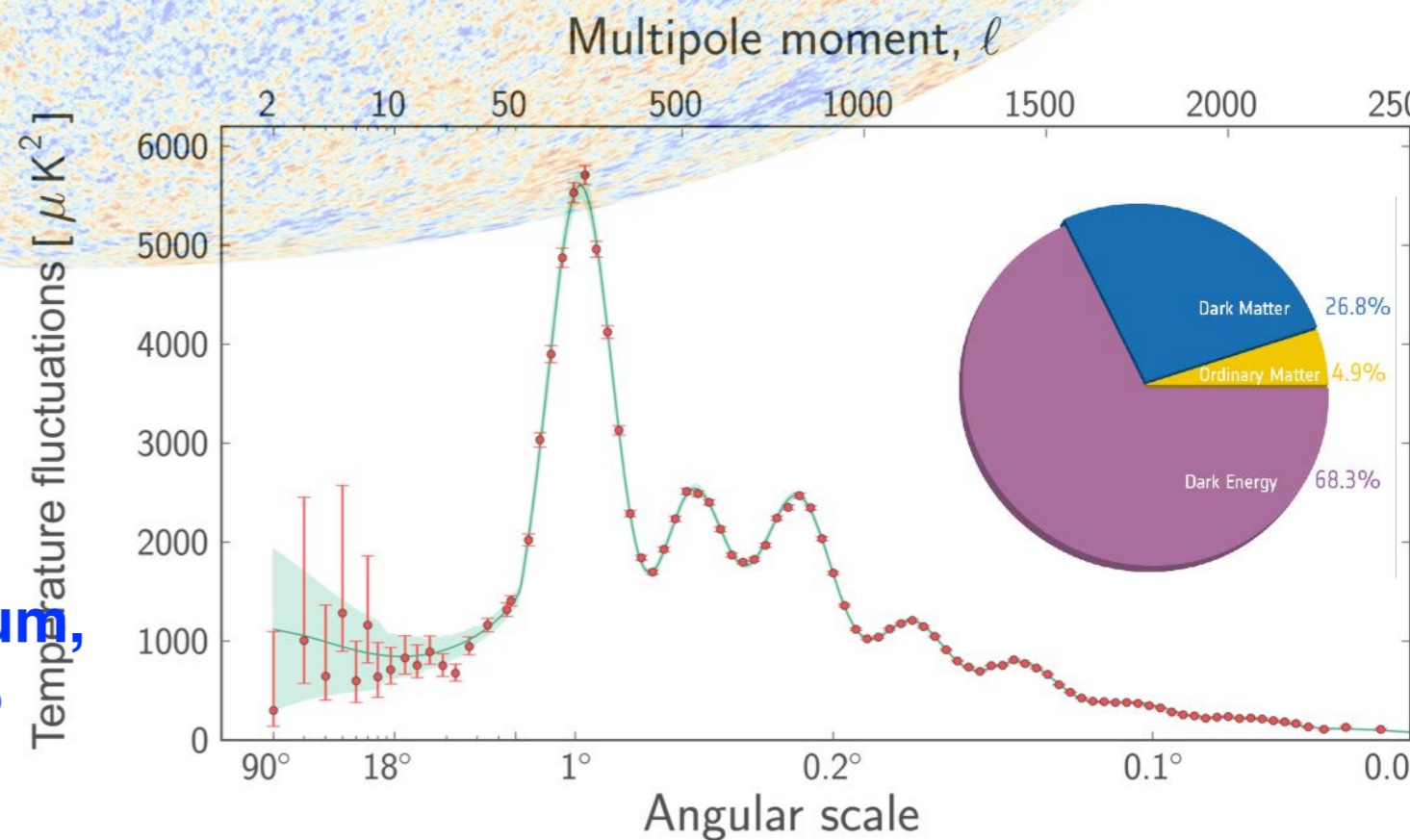
The End

Planck CMB map (2013)

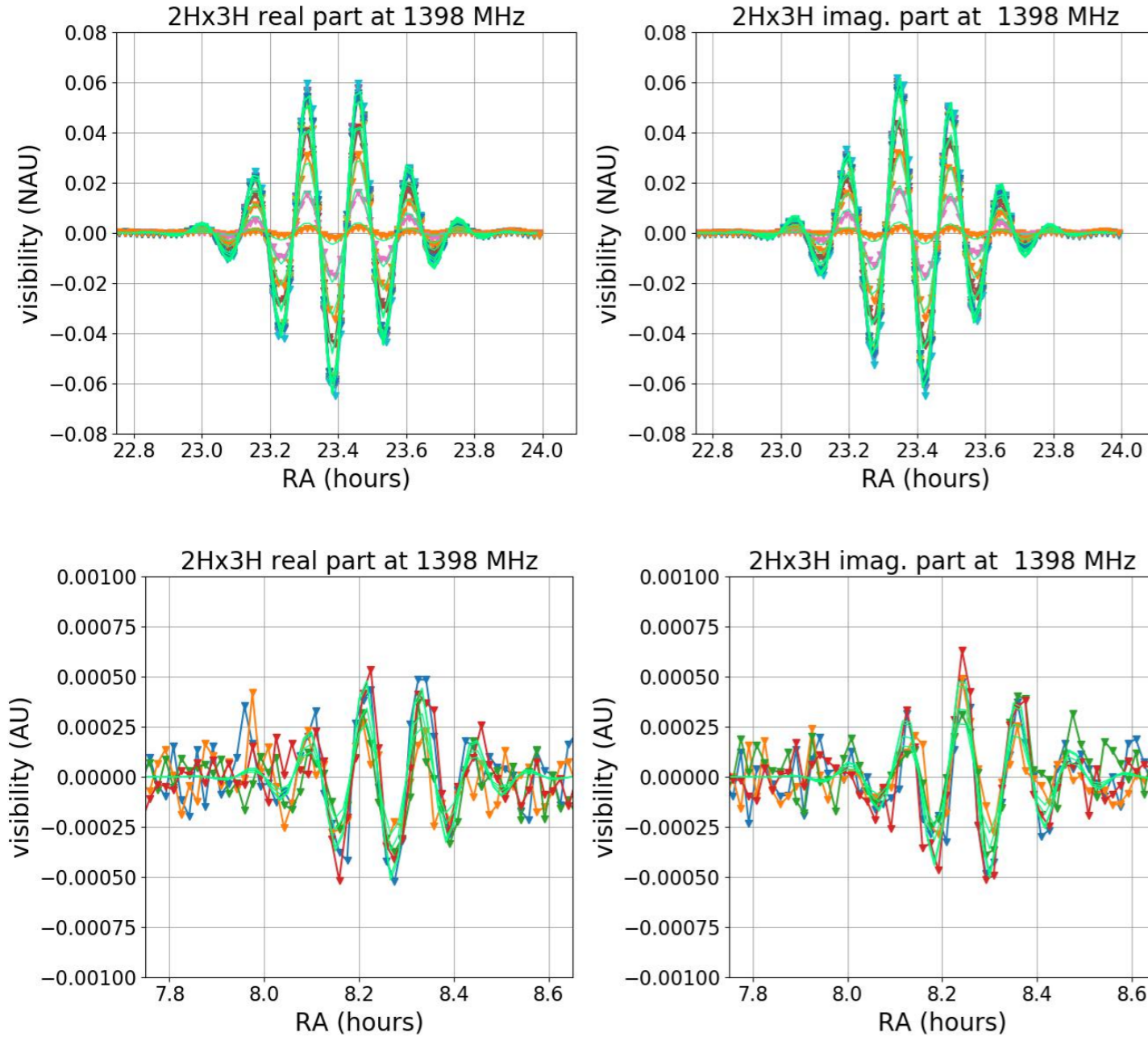
http://www.esa.int/Our_Activities/Space_Science/Planck/



**Planck CMB map, and TT power spectrum,
Planck collaboration arXiv 1303.5075**

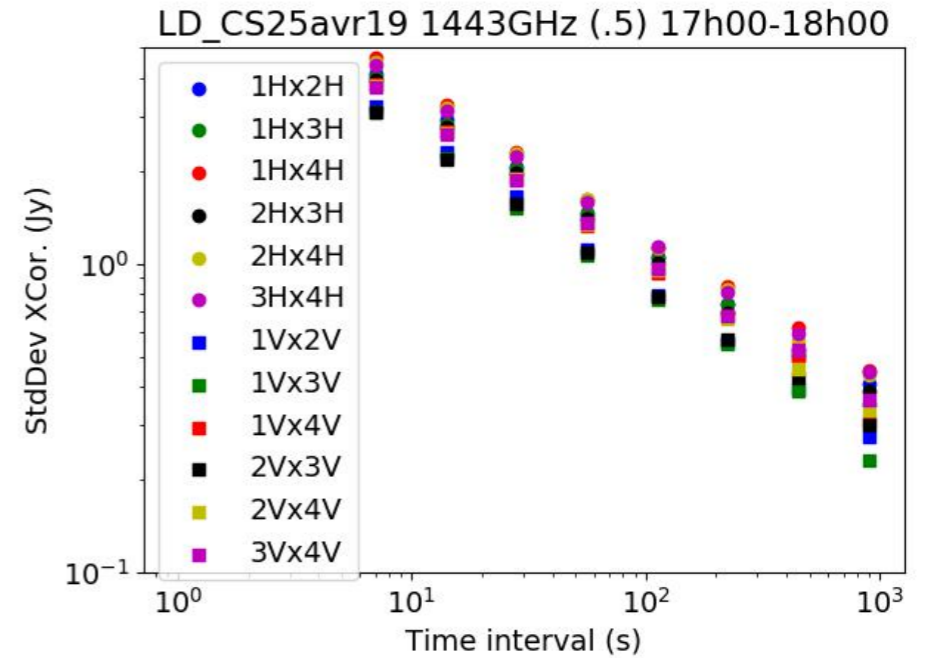


PAON4 : some results from 2018-2019 observations/analysis



CasA transits (top) , 3C196 (bottom) - PAON4 observations (different declinations) - compared with expected signals

Geometry & Phase calibration using GPS, Galileo & Beidou satellite



Noise level evolution with integration time (cross-correlations)

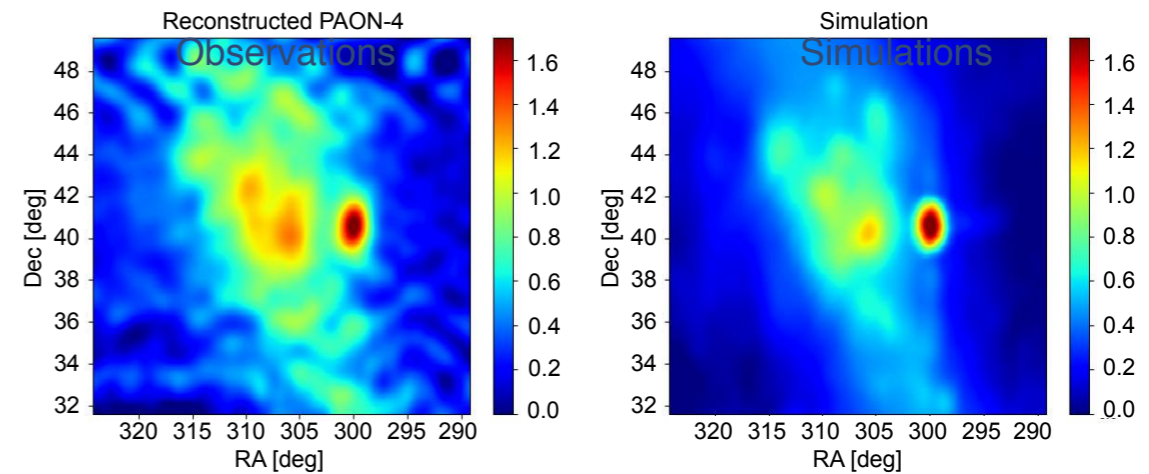
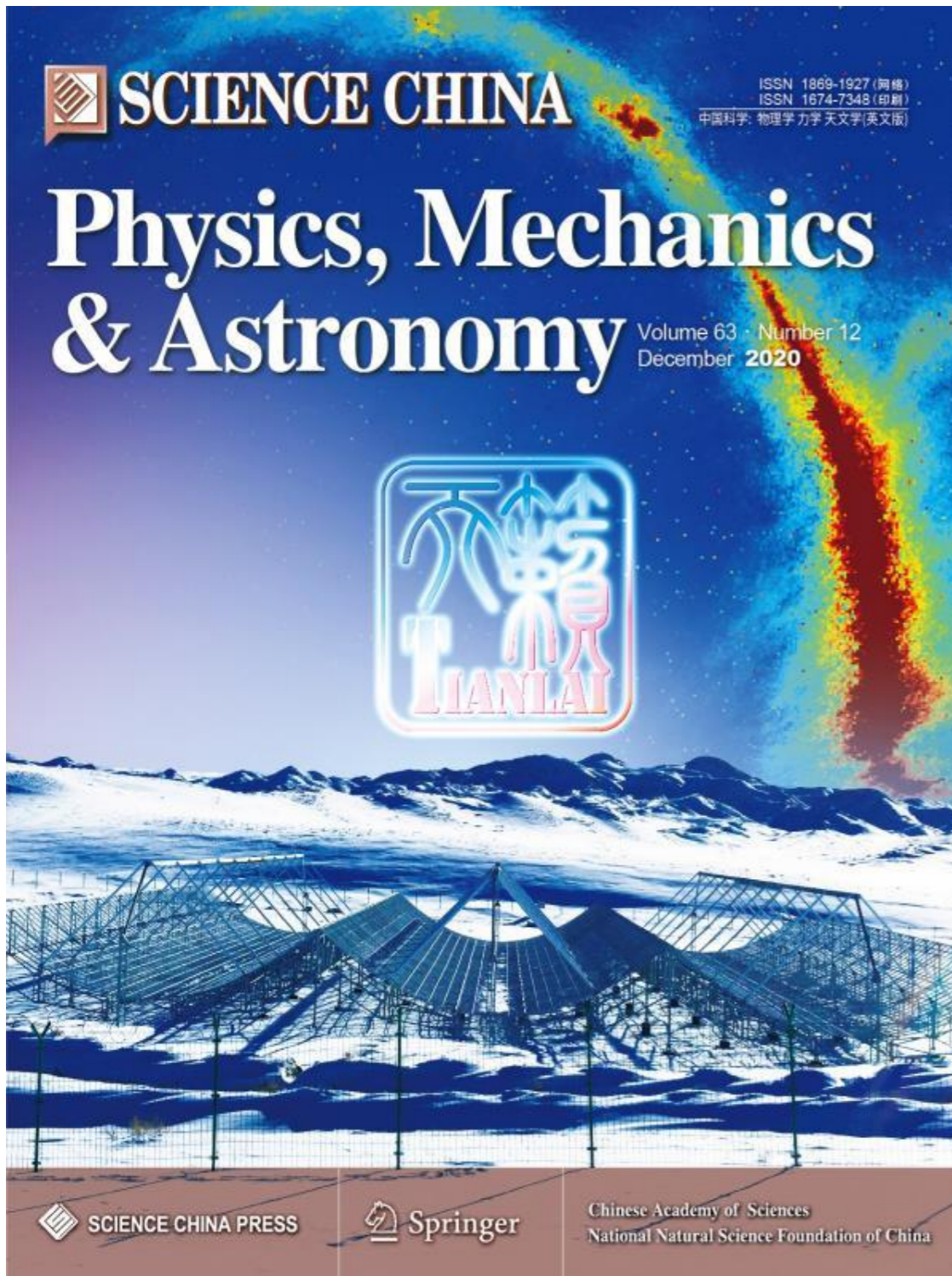


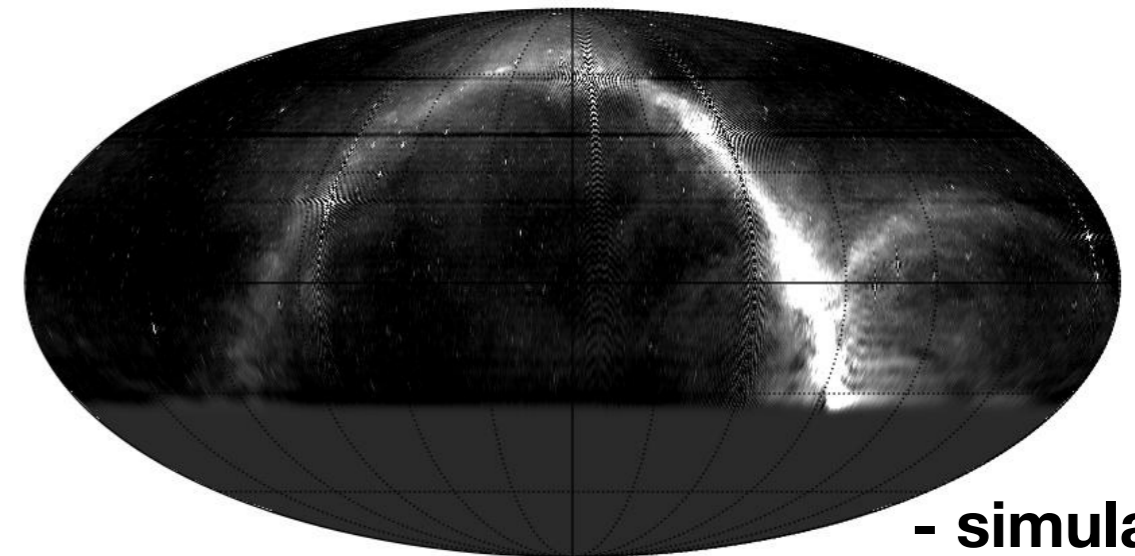
Figure 16. Example of a reconstructed map in a $\sim 35^\circ \times 18^\circ$ region around Cyg A, covering the area ($32^\circ < \delta < 50^\circ$) in declination and ($290^\circ < \alpha < 325^\circ$) in right ascension, from November 2016 data (left). Right panel shows the simulated map. (Huang 2019)

Reconstructed and simulated PAON4 maps

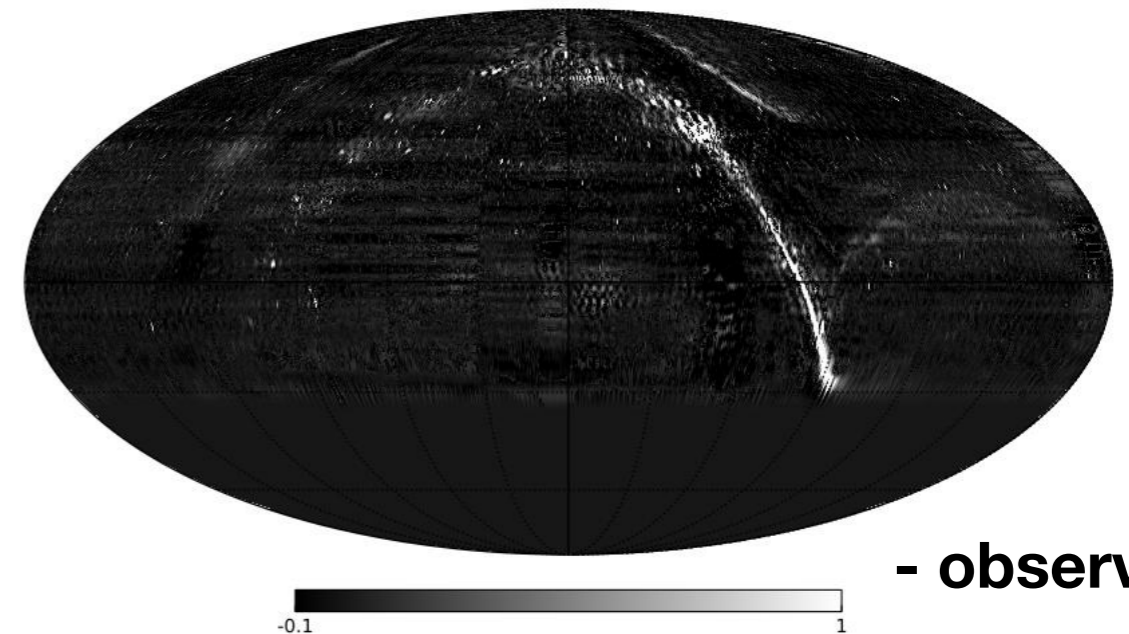
Tianlai cylinder array



Cylinder array



- simulated



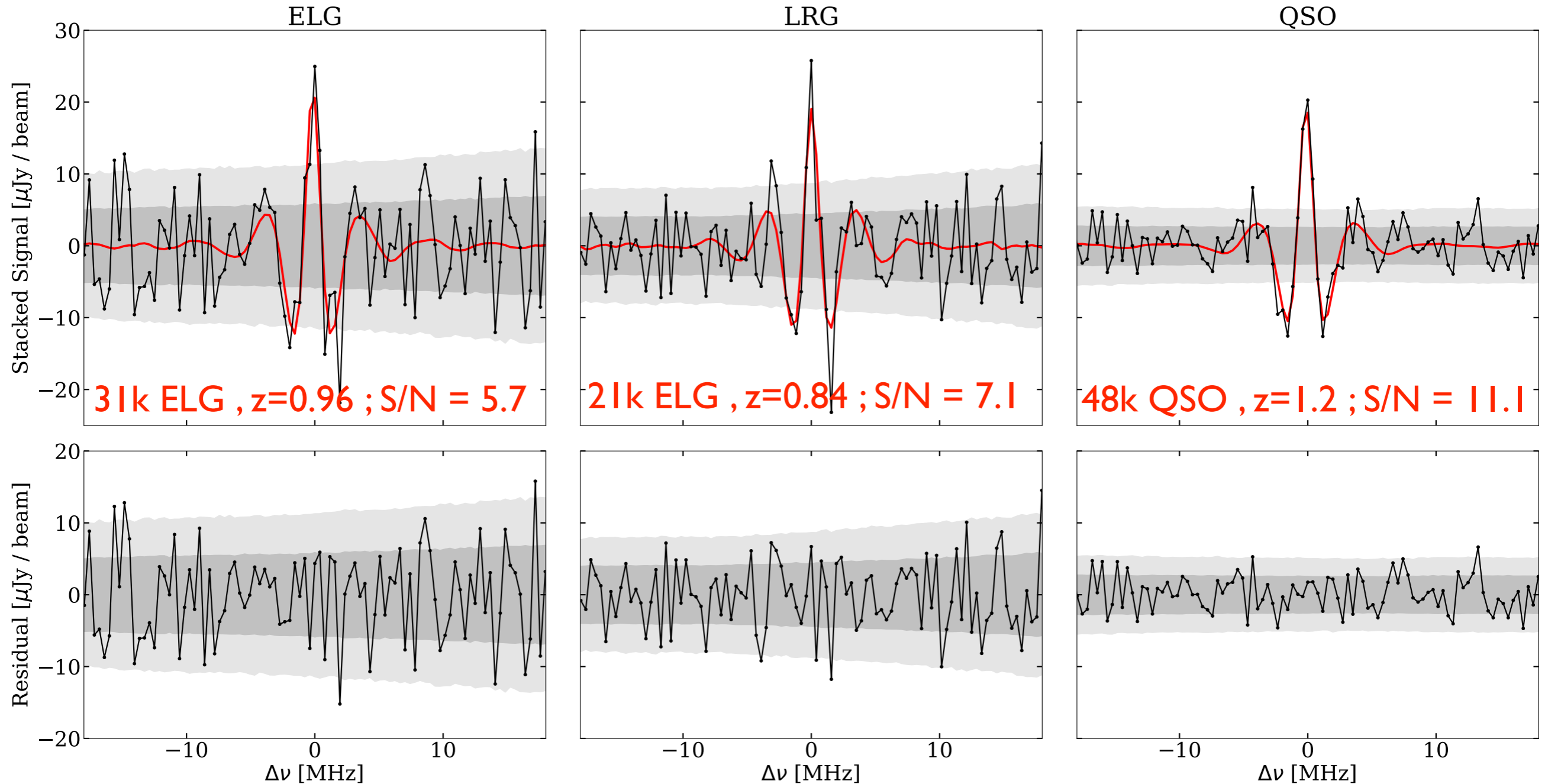
- observed

Jixia Li et al, 2020 , arXiv:2006.05605

Avoiding grating lobes / spurious images
using different feed spacing along different cylinders :

J. Zhang et al, 2016 , arXiv:1606.03830

CHIME x eBOSS



Courtesy of Richard Shaw, with CHIME permission

Cross-correlation detection through stacking using eBOSS ELG, LRG and QSO

H I fraction measurement around $z \sim 1$, $\Omega_{\text{HI}} \sim 1-2 \times 10^{-3}$

Publication should be on arXiv end of January / early Feb 2022 ...