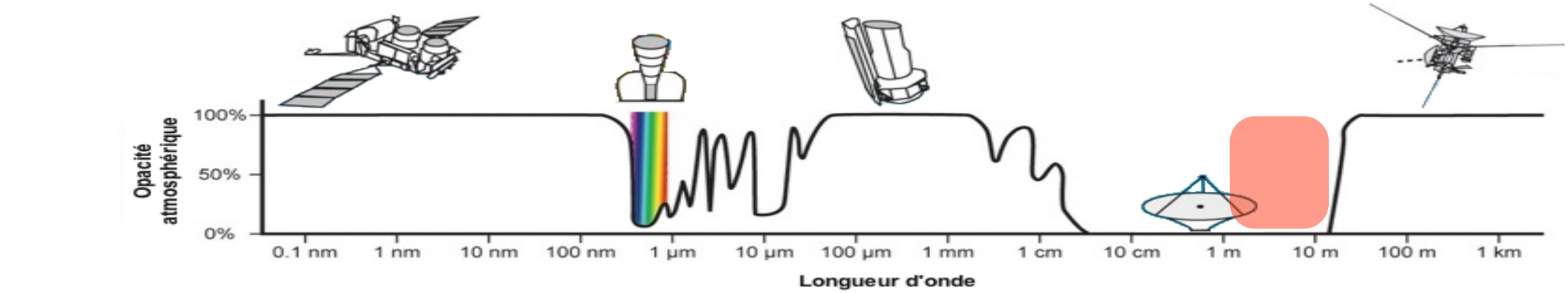
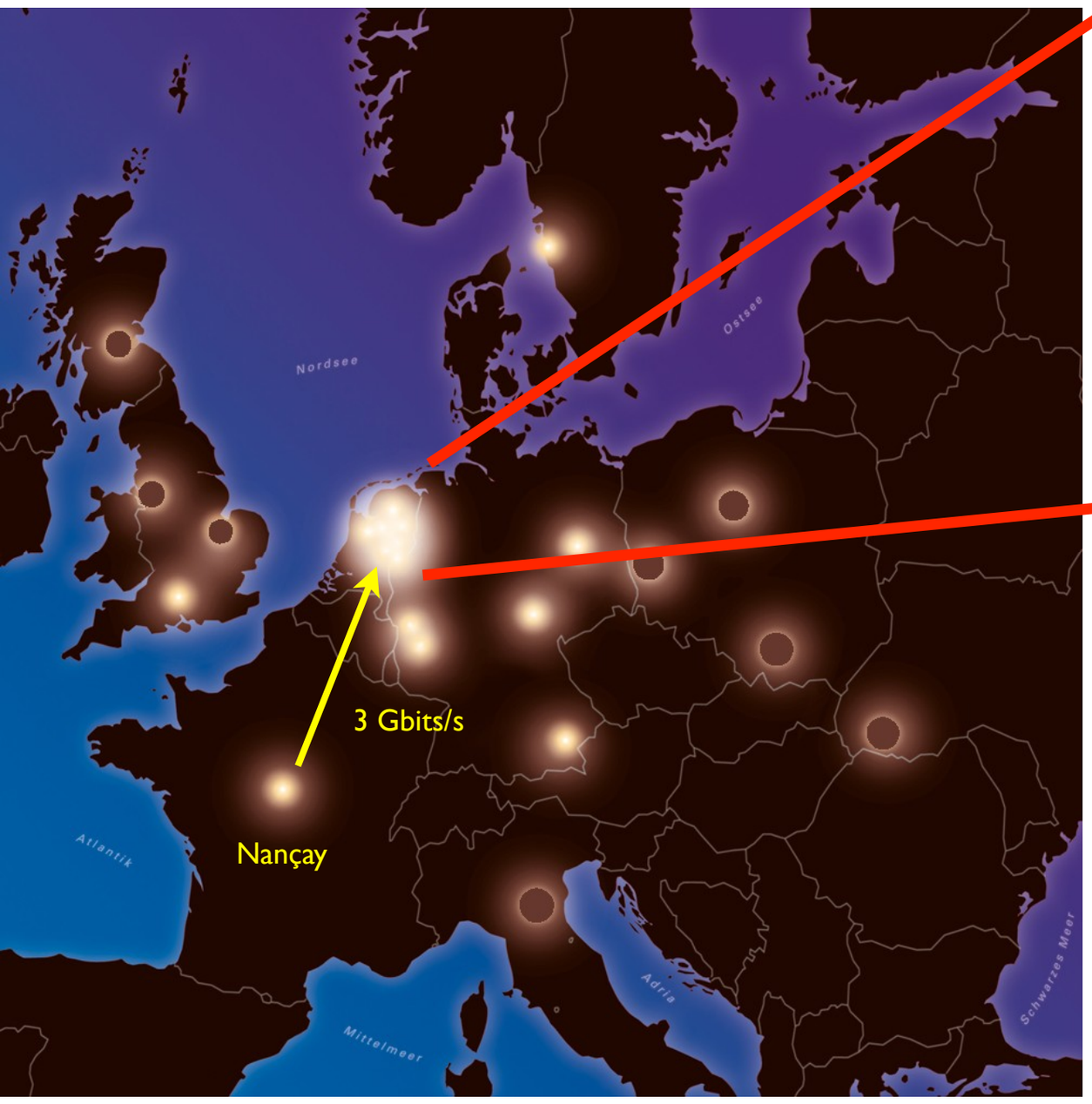
Observations planétaires avec LOFAR et projet NenuFAR

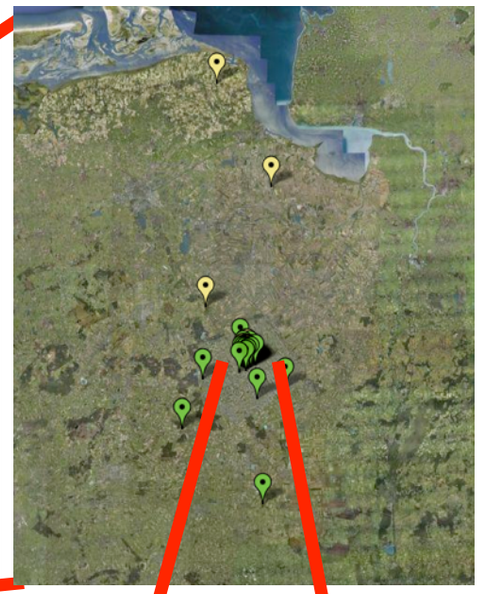
P. Zarka
le LOFAR-TKP-PWG & l'équipe LSS-France

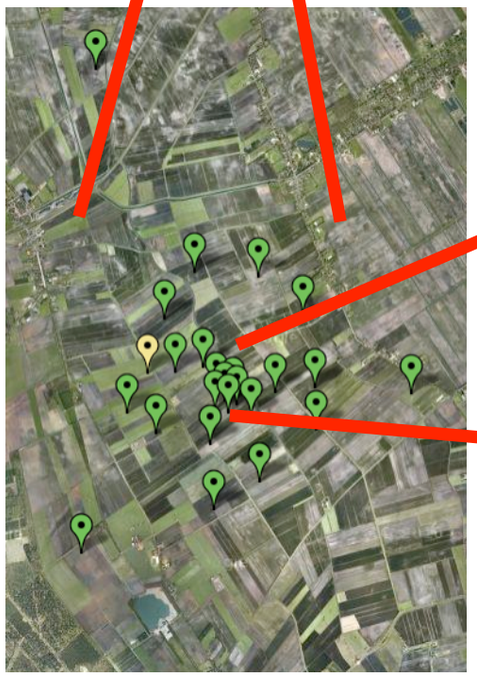
LESIA-CNRS-Observatoire de Paris

LOFAR : réseau phasé + interféromètre multi-échelles





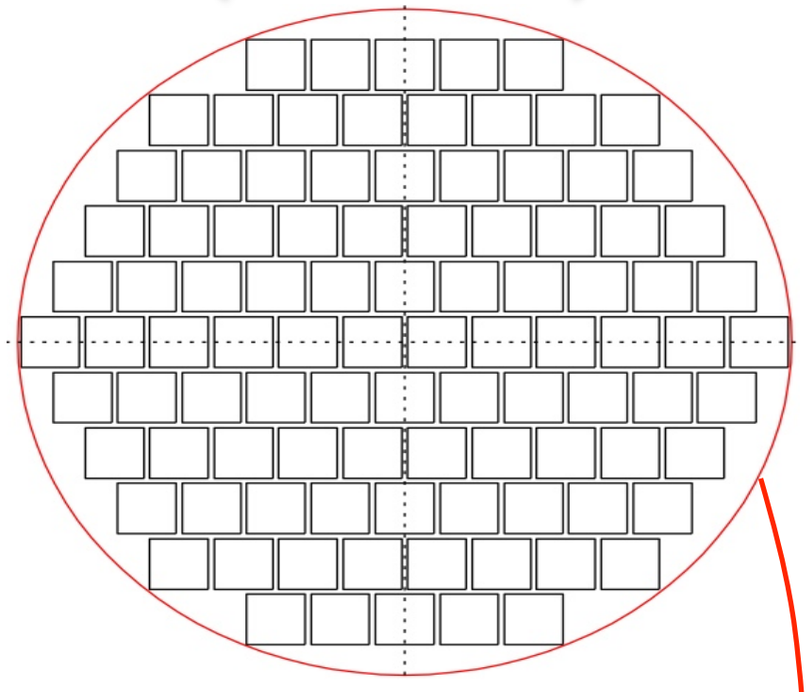


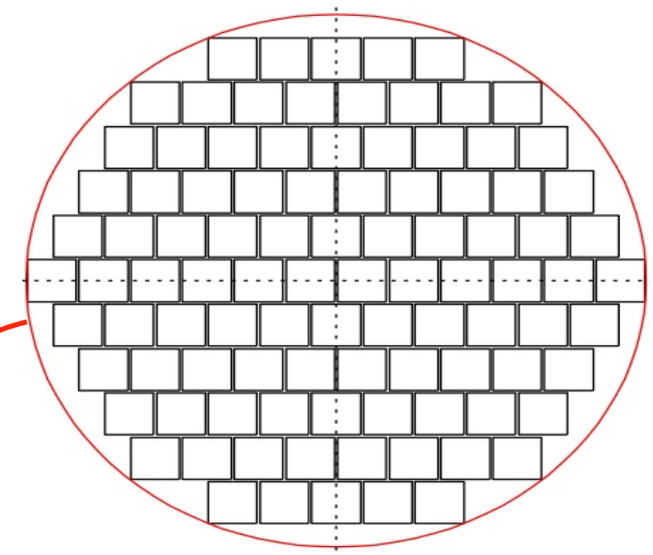


Station LOFAR

Basses fréquences
(30-80 MHz)

Hautes fréquences
(110-250 MHz)





60 m

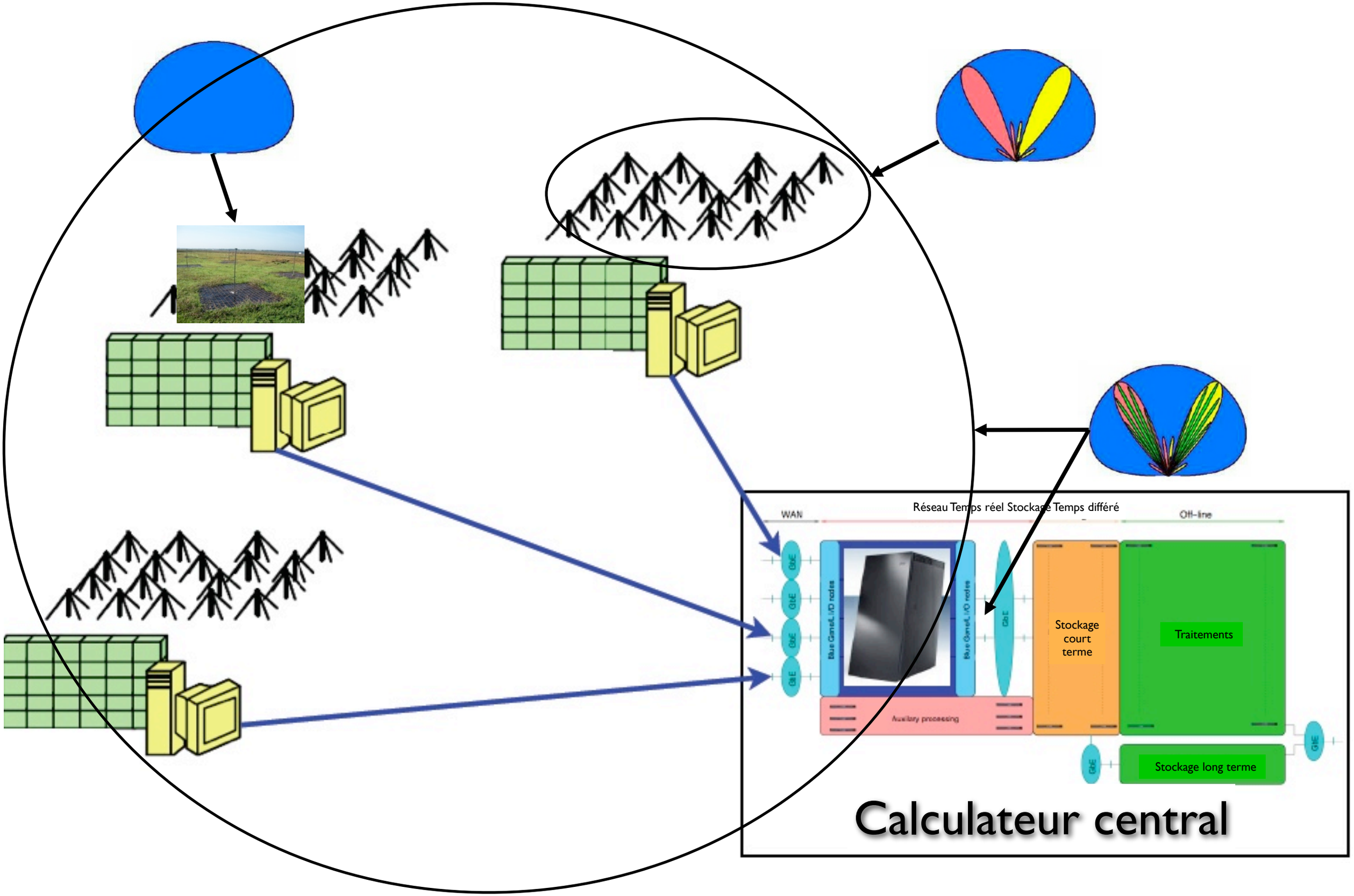
50 m

Lien à 3+ Gbit/sec

Superordinateur Blue Gene

La station LOFAR de Nançay : FR606

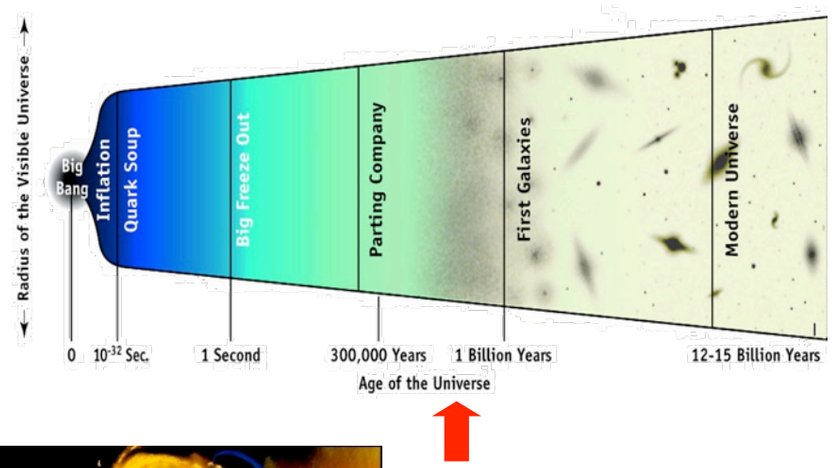
Réseau phasé & Imageur

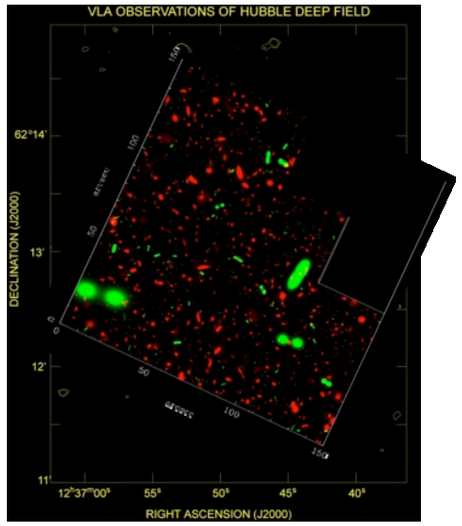


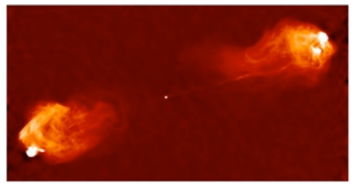
Caractéristiques techniques

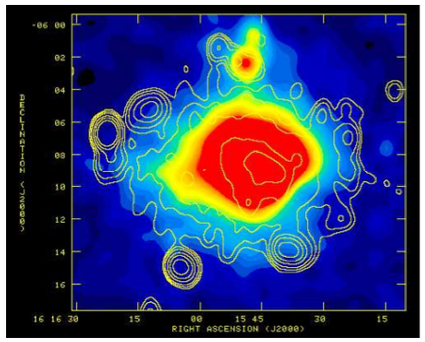
- « Interféromètre » de « Réseaux phasés » Européen
- 24 stations «coeur» + 16 distantes + 8 internationales
- Diamètre ~100 km (NL) → 1000 km (Europe)
- Aire collectrice ~ 100 000 m^2 ($\propto \lambda^2$)
- Gamme de fréquences = 30-80 & 110-250 MHz (λ=1.2-10m)
- Modes imagerie + Faisceaux cohérents + Mesures ultrarapides
- Résolution ~ 0.1 " - 10 ", grand champs (~10°)
- Sensibilité < mJy (10^{-29} $Wm^{-2}Hz^{-1}$)
- Résolutions → 1 msec × 1 kHz, Polarisation complète
- Élimination des parasites, « optique adaptative » ionosphérique
- Premier spectro-imageur Basses Fréquences « généraliste »
- 1er précurseur de SKA

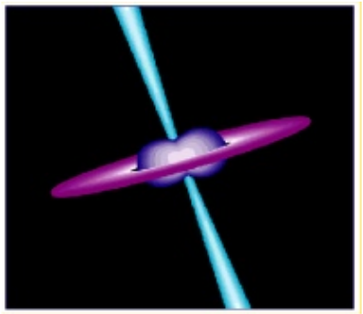
La Science avec LOFAR







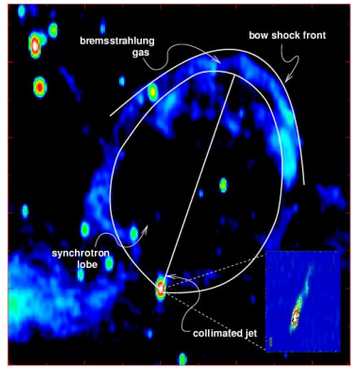


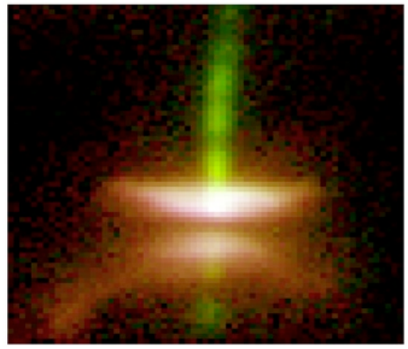


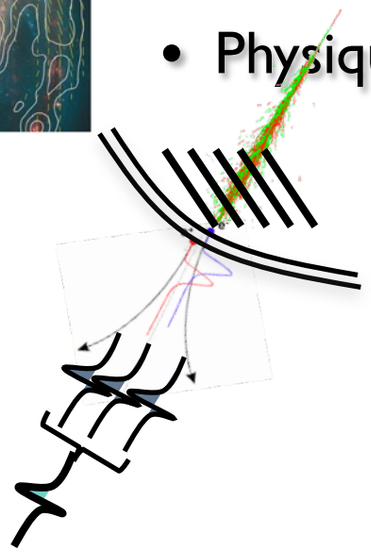
- Cosmologie, Réionisation *(Groningen)*
- Cartographie, Formation stellaire, NAG, amas… *(Leiden)*

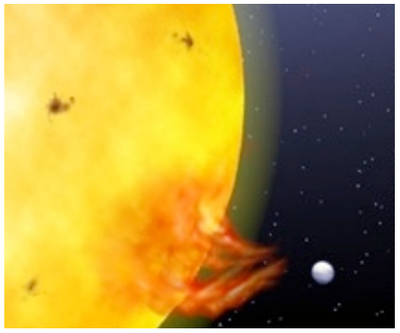
Planets WG

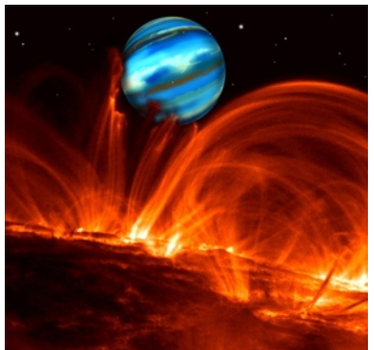
- Transitoires *(Amsterdam / Manchester / NRAO / Obs. Paris)*
- Rayons Cosmiques, Neutrinos sur la Lune *(Nijmegen)*
- Magnétisme Galactique *(Bonn)*
- Physique Solaire et Spatiale *(Potsdam)*

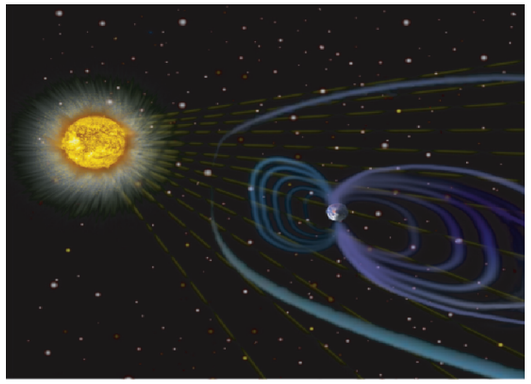


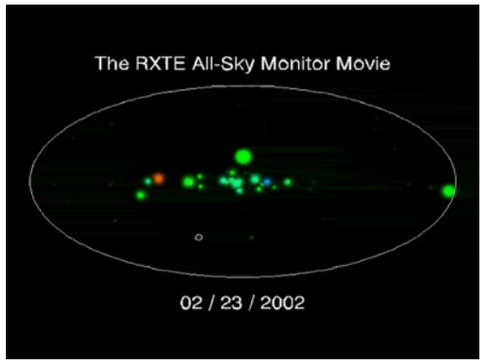




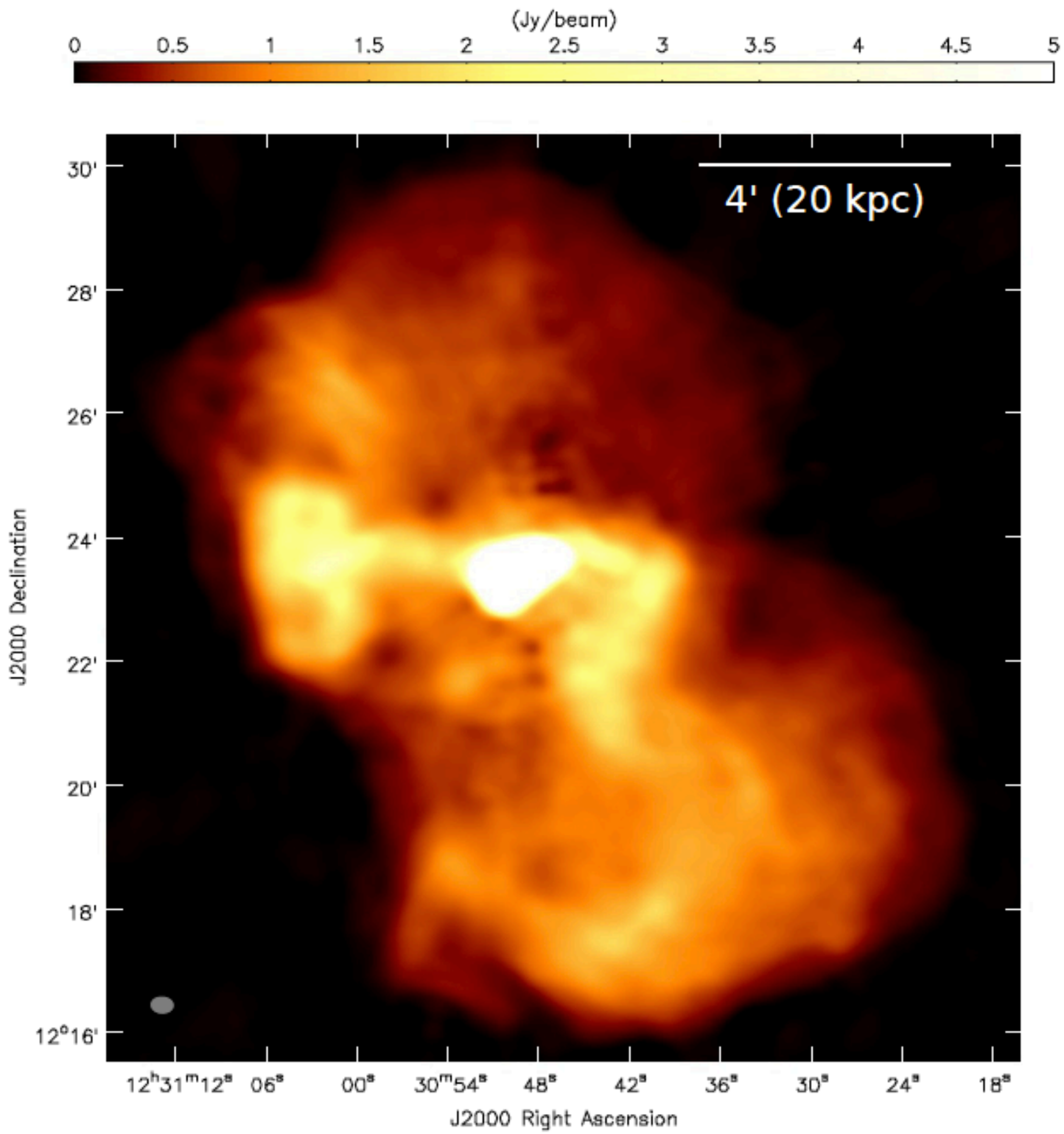








La recette (commissioning) de LOFAR : M87



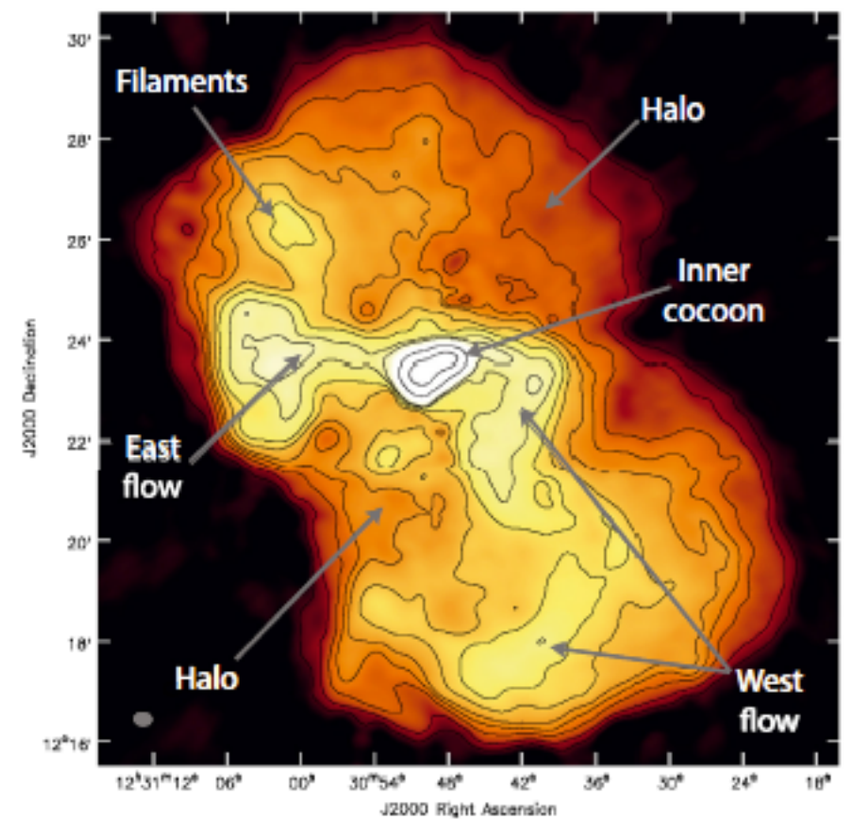
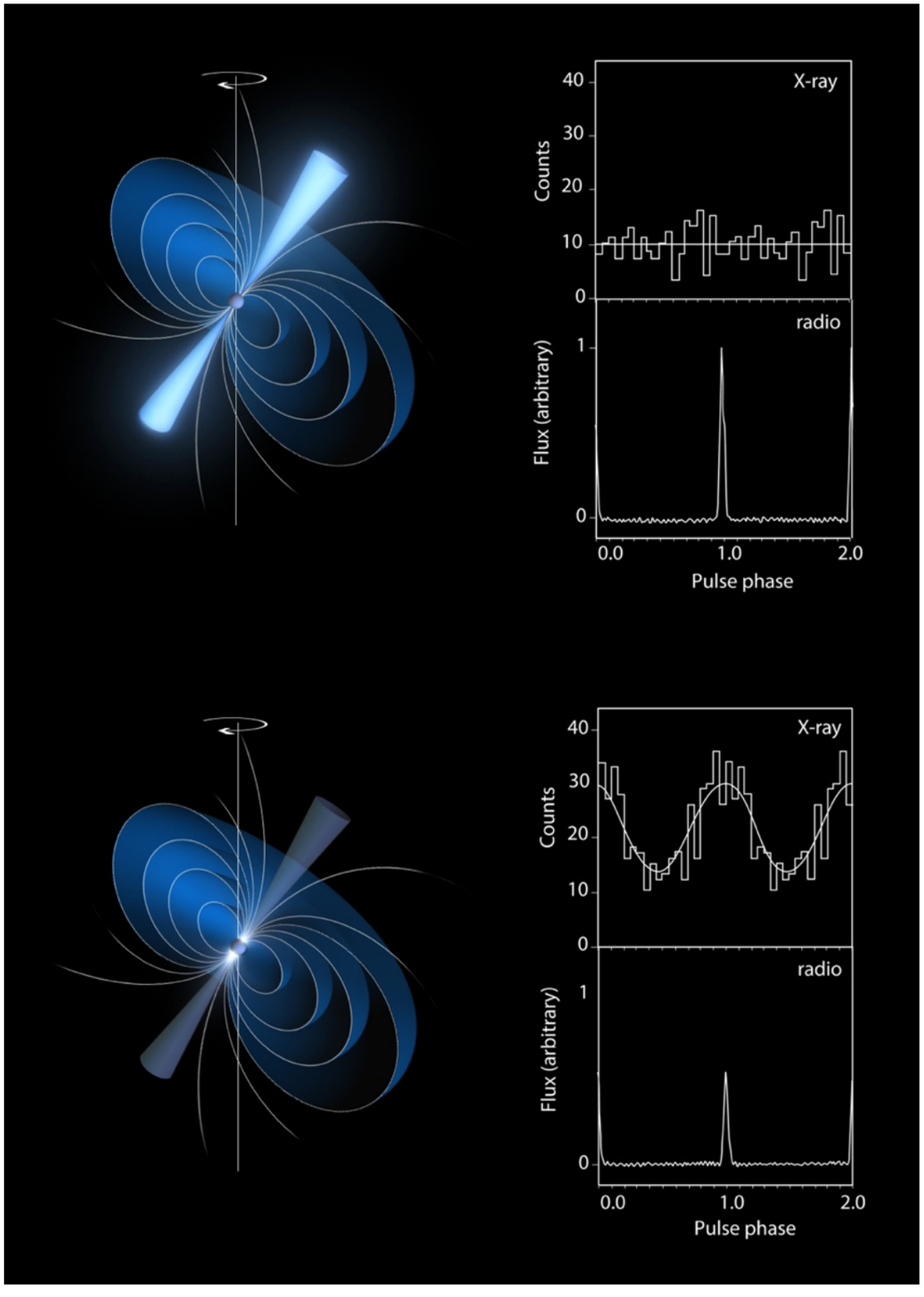


Fig. 8. Same as Fig. 5 with most prominent features described in the text labelled. Contour lines are at (1, 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, 45, 250, 1000) × 3σ.

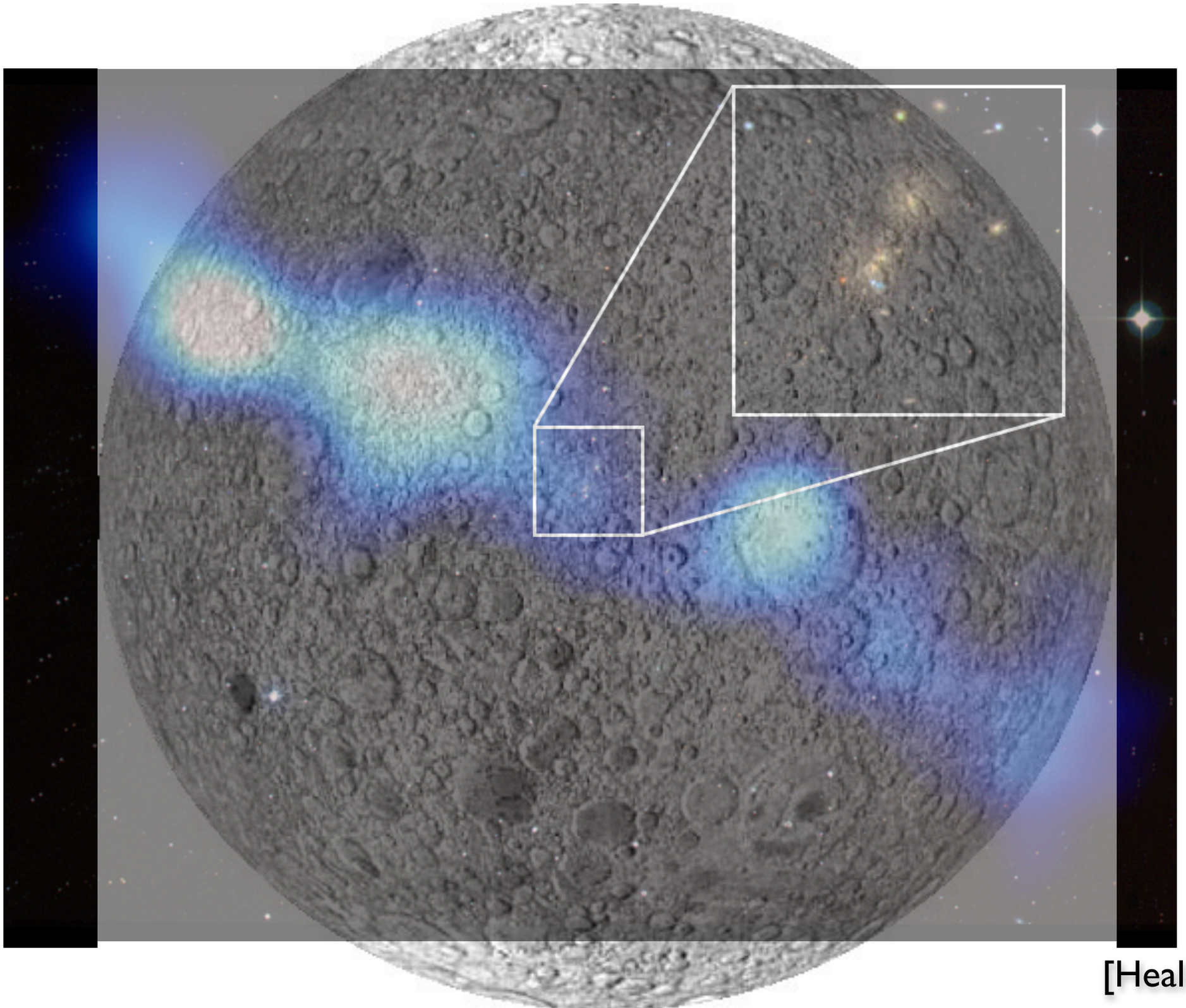
[de Gasperin et al., 2012]

La recette (commissioning) de LOFAR : alternance synchrone radio/X du pulsar 0943+10



[Hermsen et al., 2013]

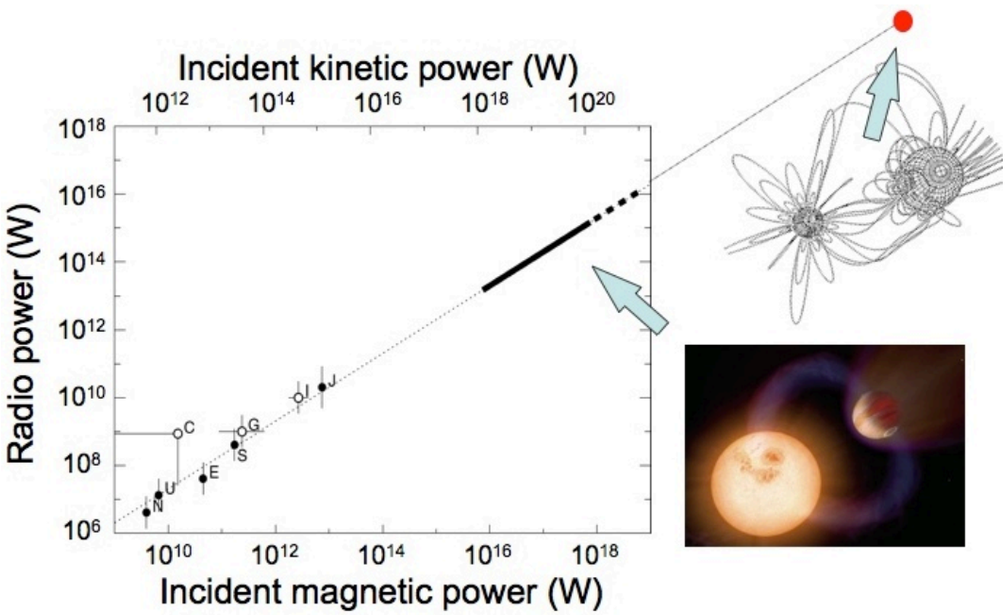
La recette (commissioning) de LOFAR : Radio galaxie géante autour du triplet UGC 09555

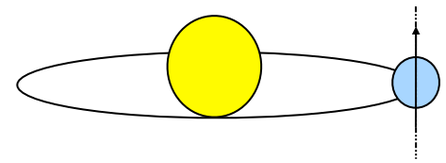


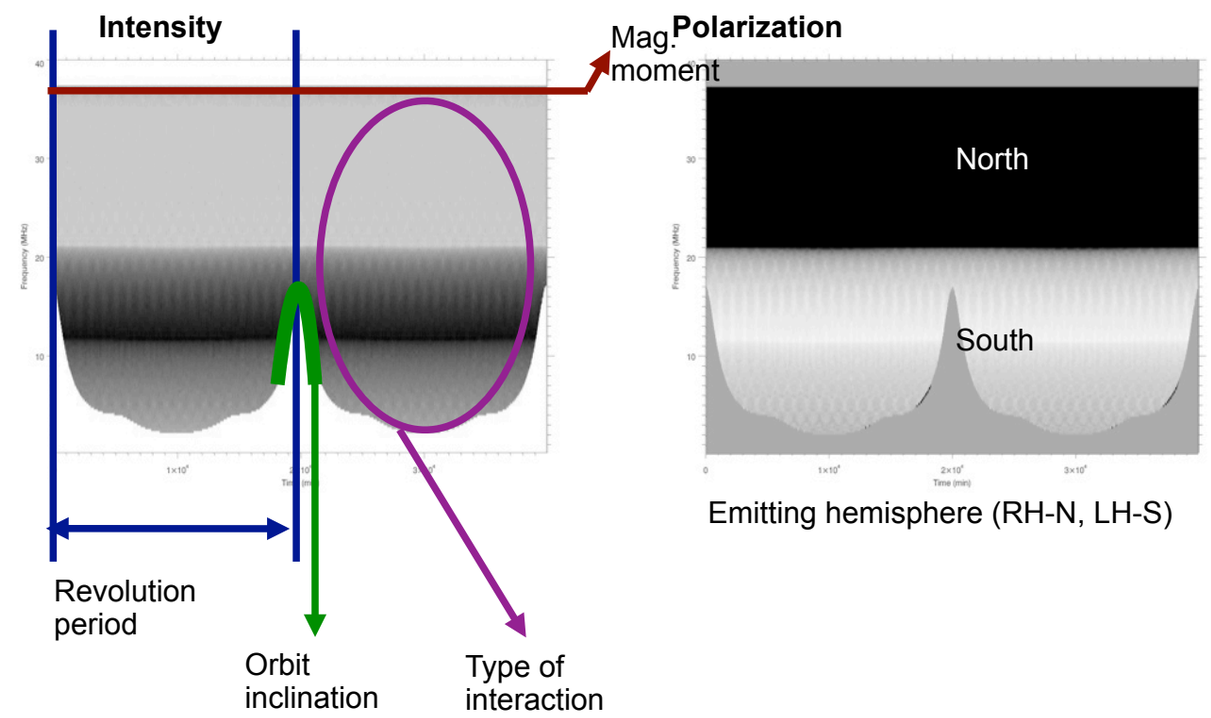
[Heald et al., 2013]

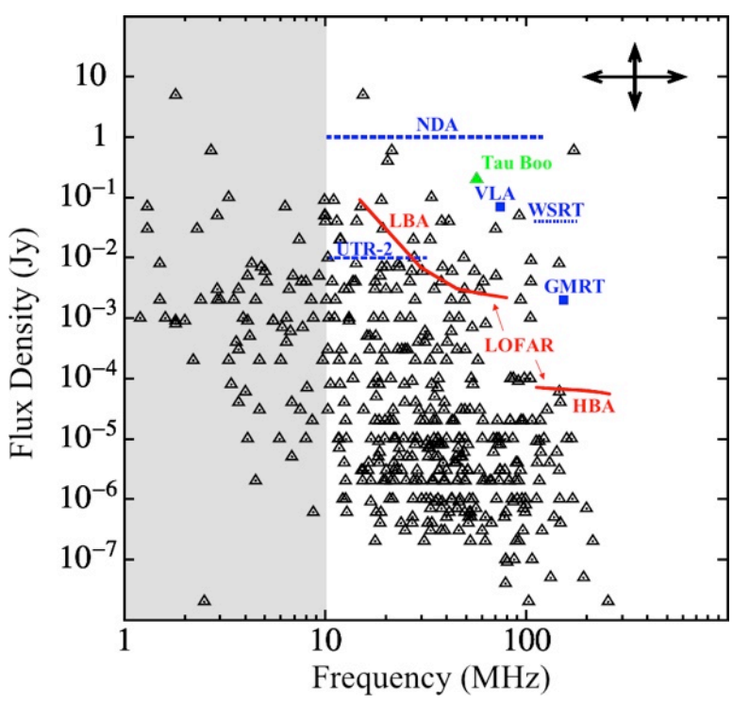
LOFAR cycle 0 (12/2012 - ~9/2013)

- LC0_007 (Zarka et al.) - Exoplanets - 30h [70%]





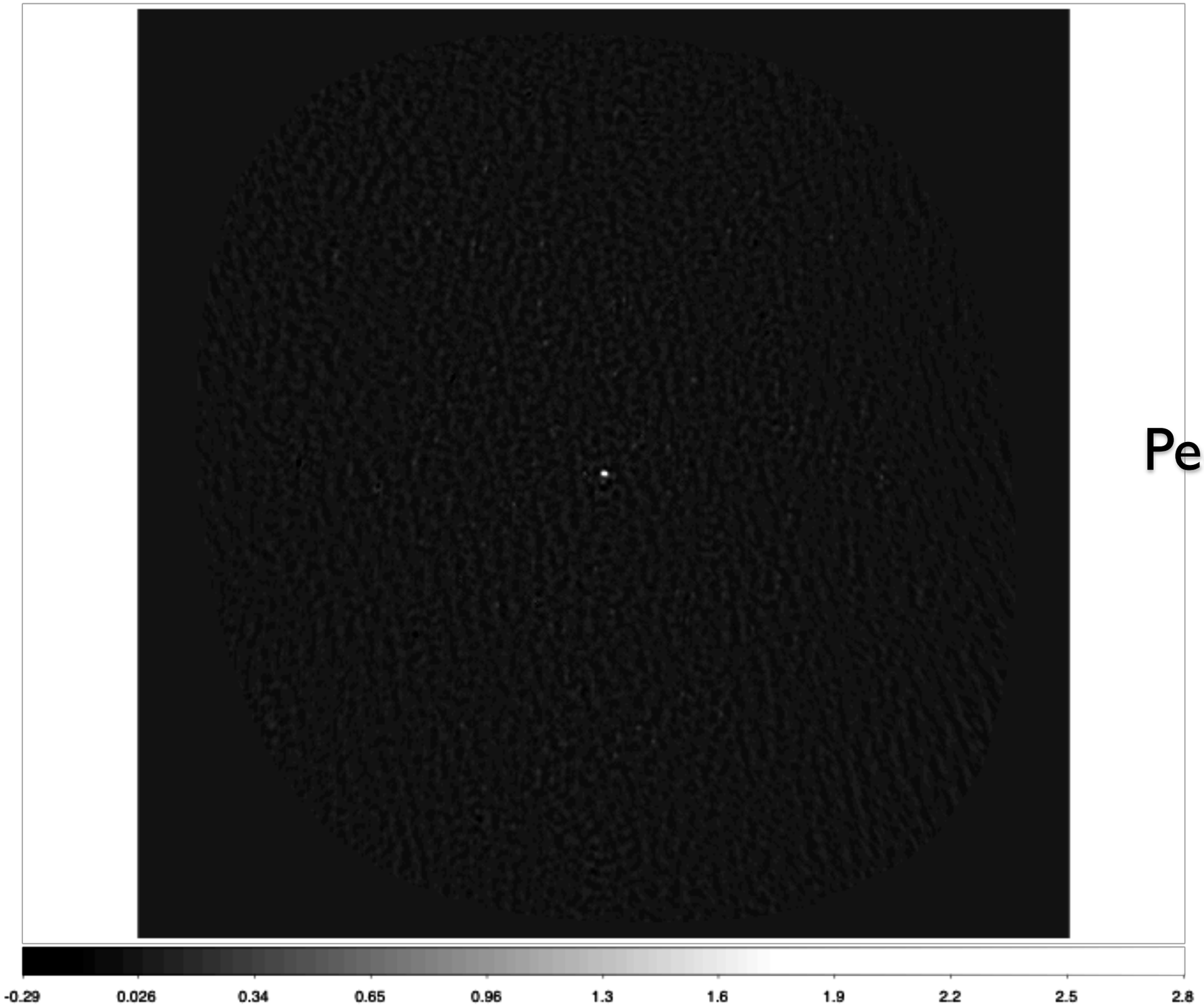




Tau Boo, Ups And, ...

LOFAR cycle 0 (12/2012 - ~9/2013)

- LC0_007 (Zarka et al.) - Exoplanets - 30h [70%]



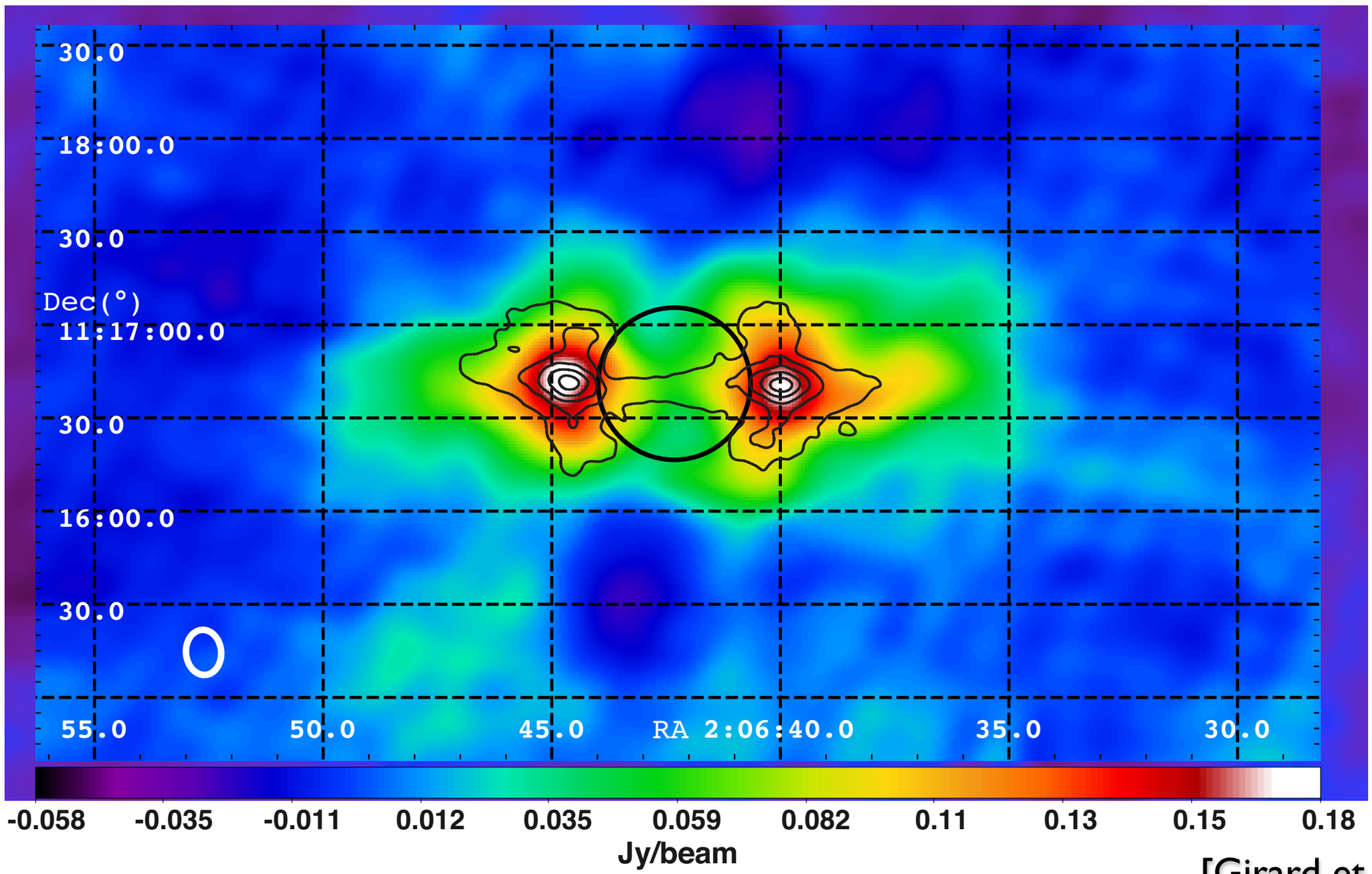
Peeling ...

LOFAR cycle 0 (12/2012 - ~9/2013)

- LC0_ 006 (de Pater) - Jovian radiation belts - 11.5h [50%]

Δf = 127-172 MHz), Δt = 7h, Beam = 17.8”x15.5”, Pixel = 1", Jupiter disk = 49”

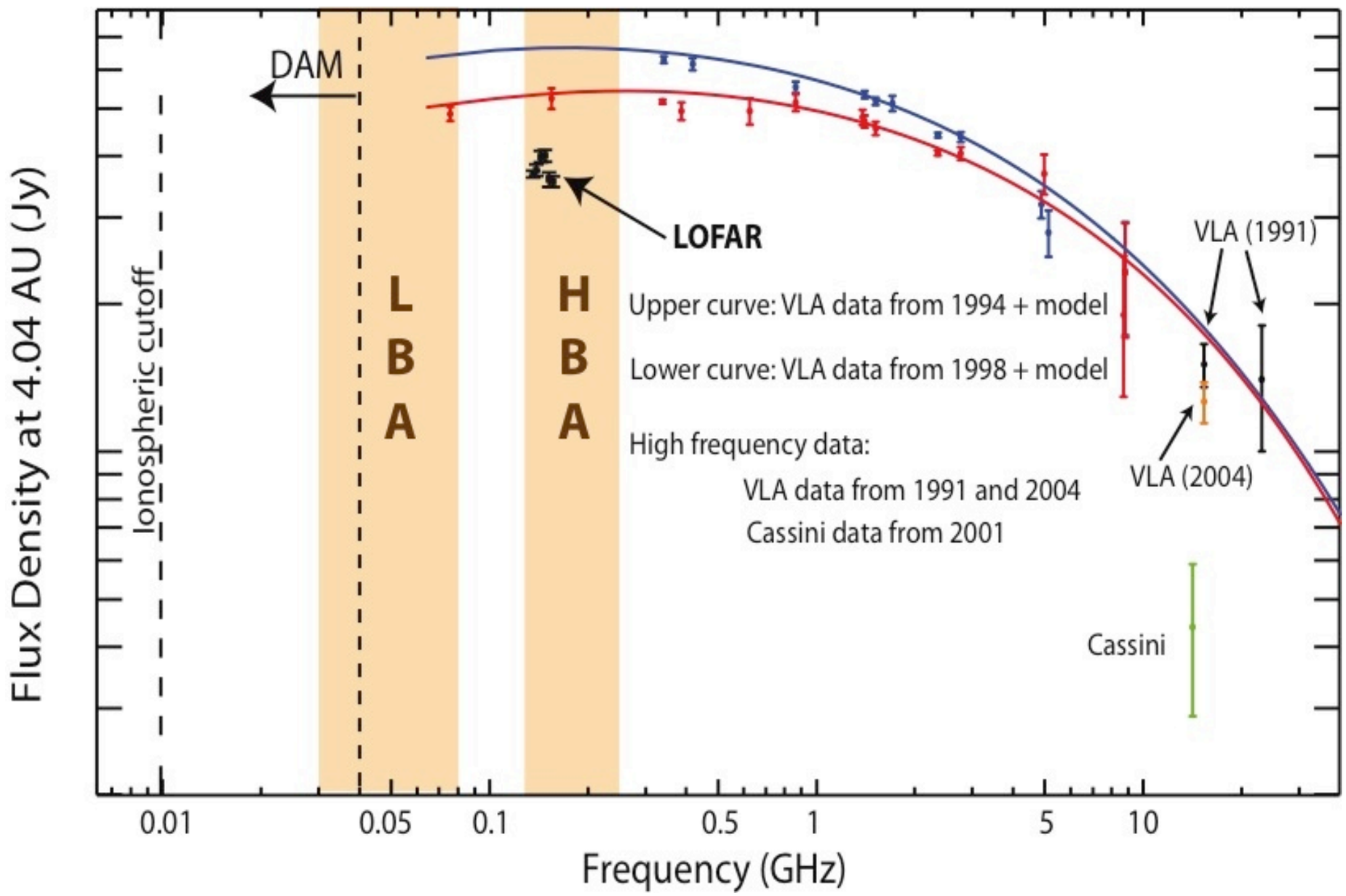
Contours @ 15 GHz [de Pater & Dunn, 2003]



[Girard et al., 2013]

LOFAR cycle 0 (12/2012 - ~9/2013)

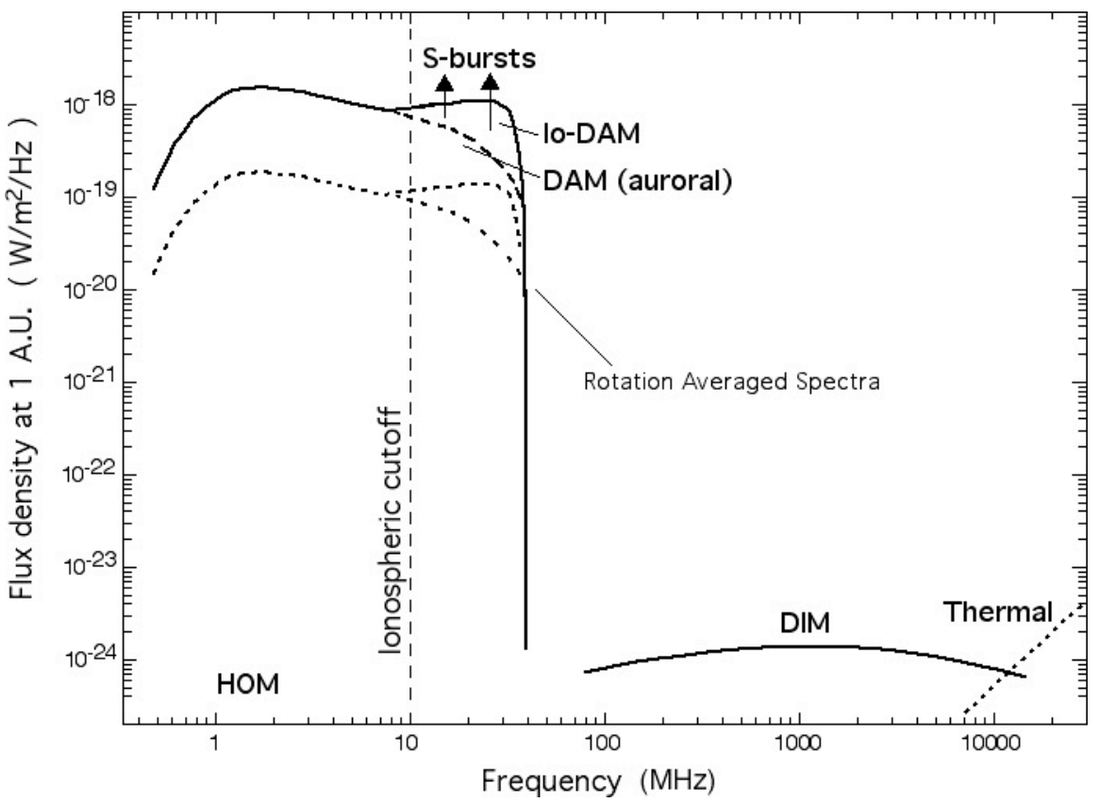
- LC0_ 006 (de Pater) - Jovian radiation belts - 11.5h [50%]

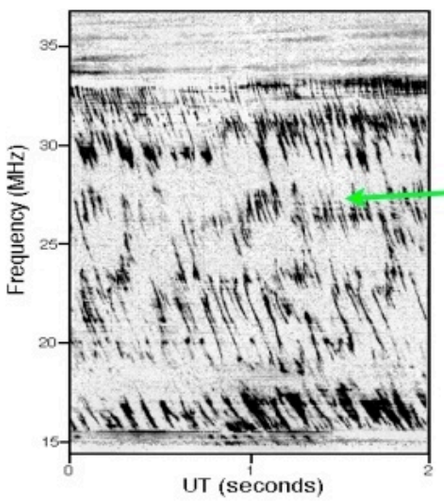


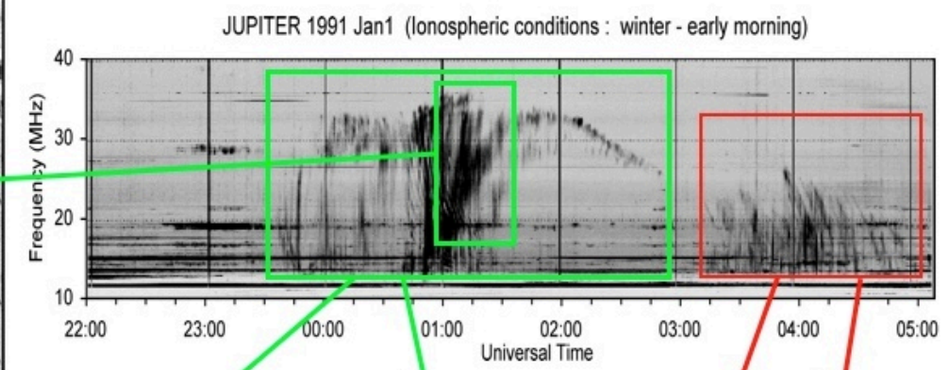
[Girard et al., 2013]

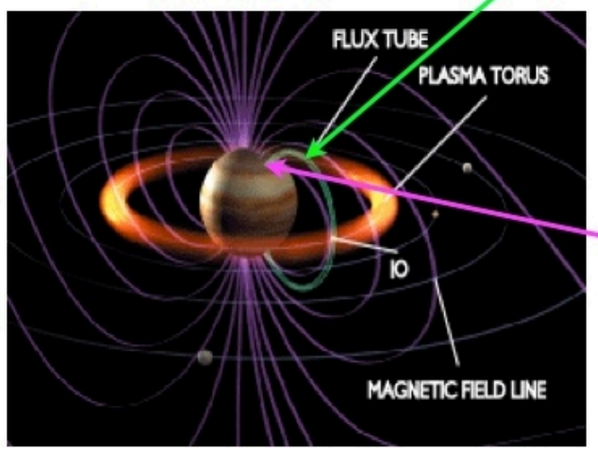
LOFAR cycle 0 (12/2012 - ~9/2013)

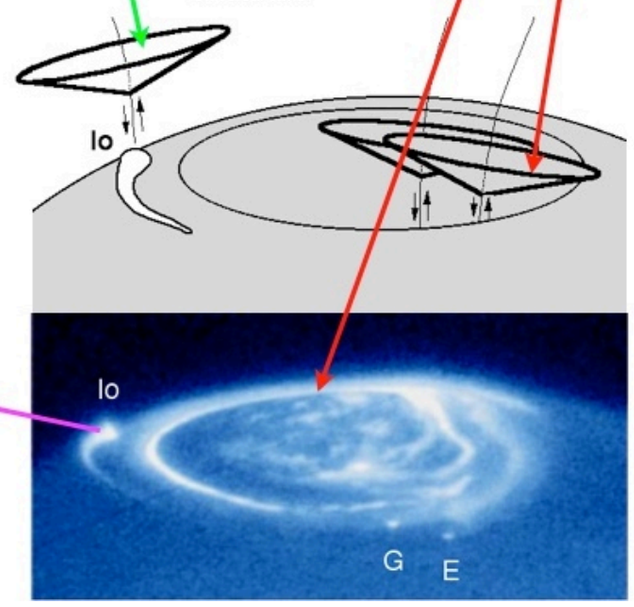
- LC0_002 (Wucknitz) - Long baselines measurements of Jovian DAM - 9h [100%]





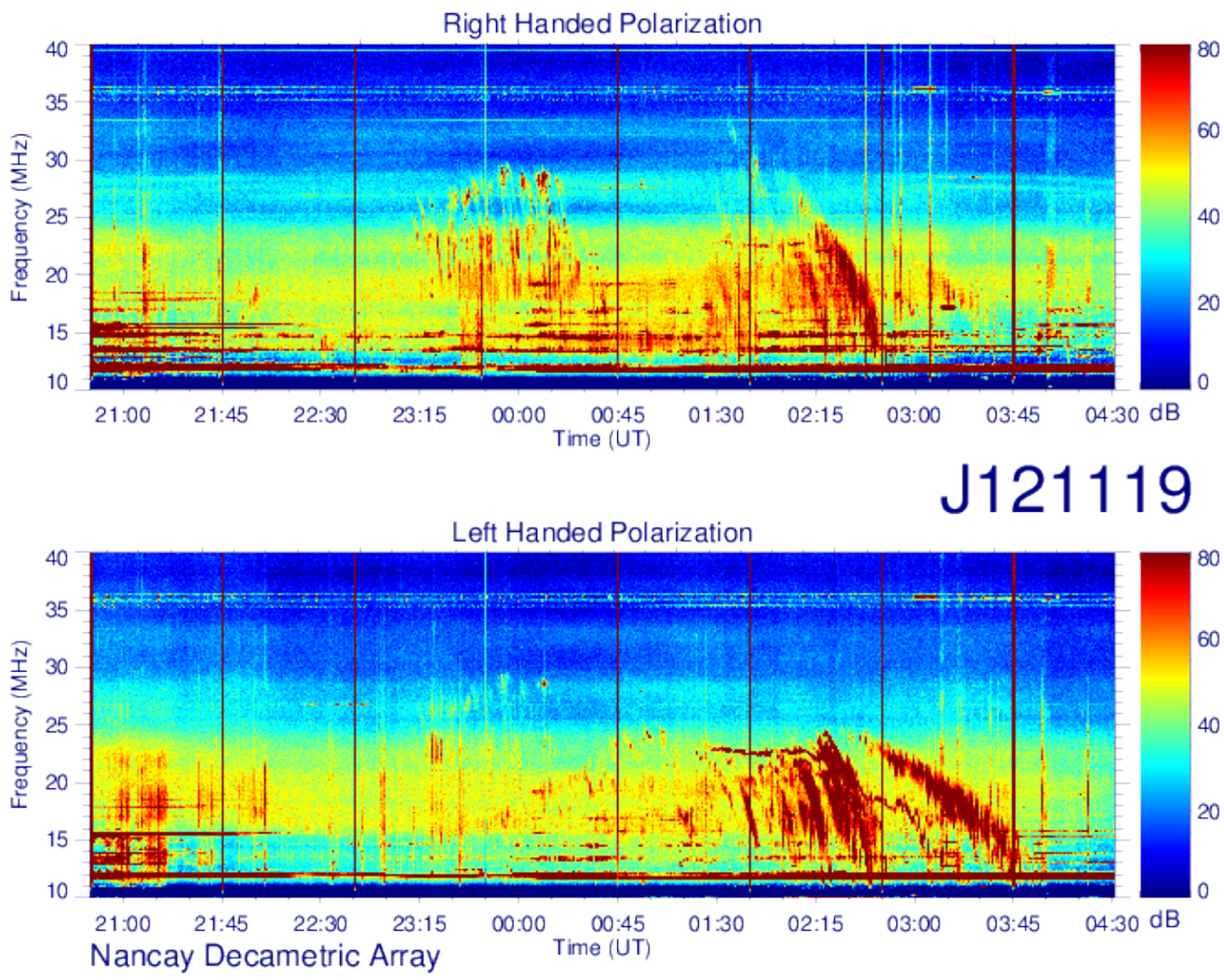


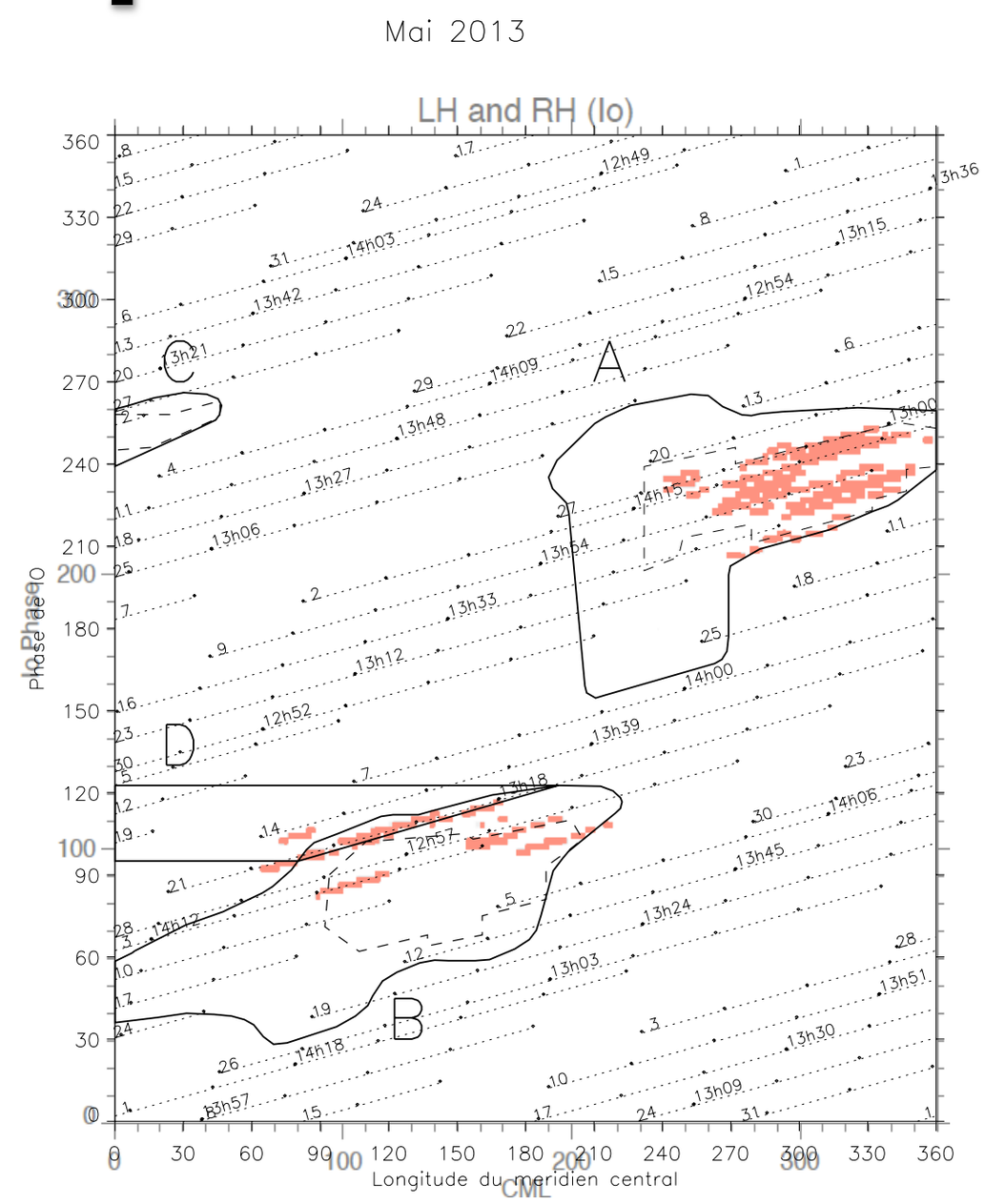




LOFAR cycle 0 (12/2012 - ~9/2013)

- LC0_002 (Wucknitz) - Long baselines measurements of Jovian DAM - 9h [100%]

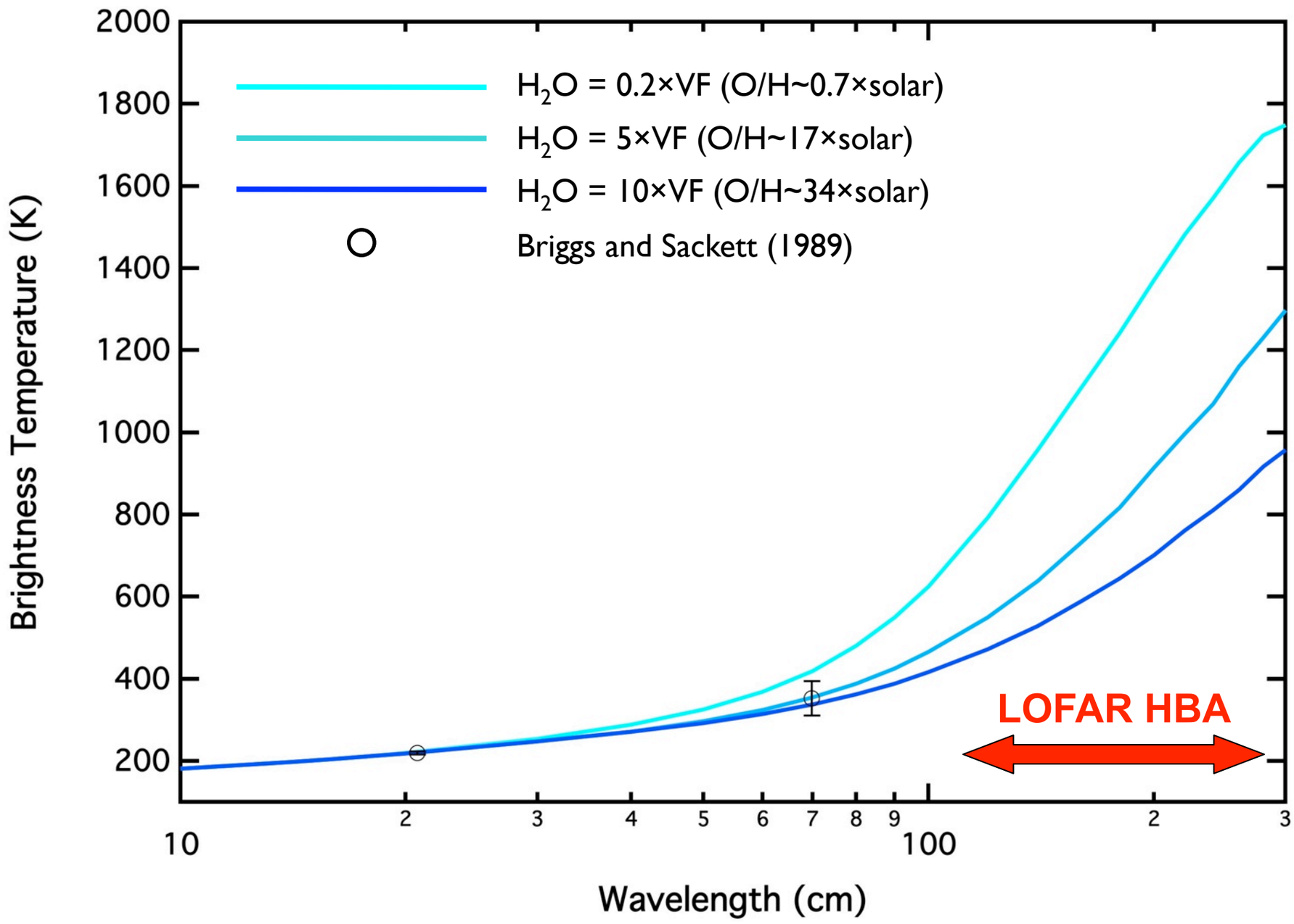




Ground-based support of JUNO & JUICE

LOFAR cycle 0 (12/2012 - ~9/2013)

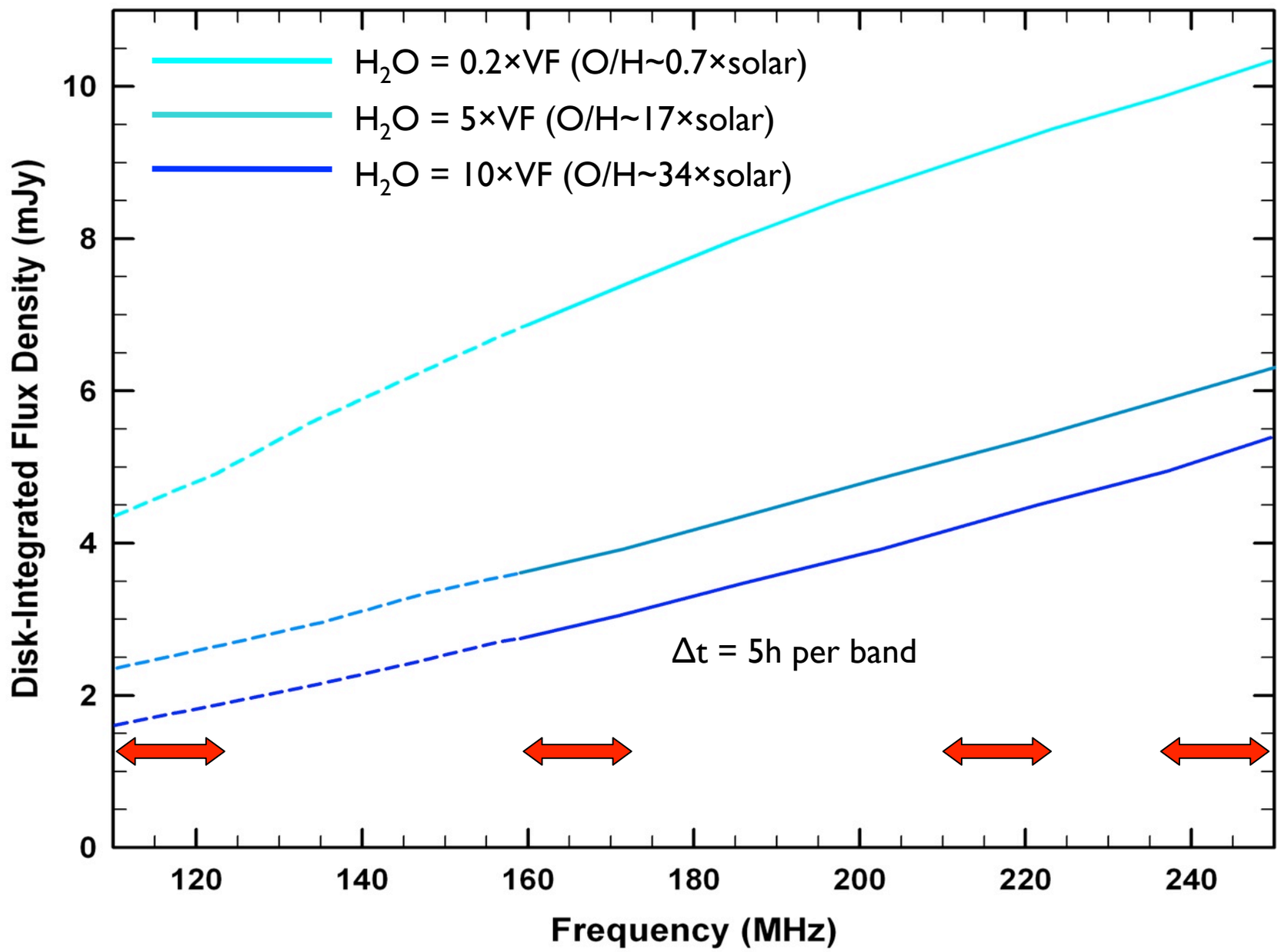
- LC0_ 005 (Courtin) - Thermal spectrum of Saturn's atmosphere - 10h [50%]



[Briggs & Sackett, 1989]

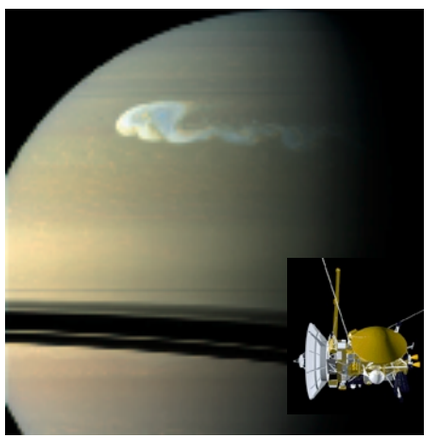
LOFAR cycle 0 (12/2012 - ~9/2013)

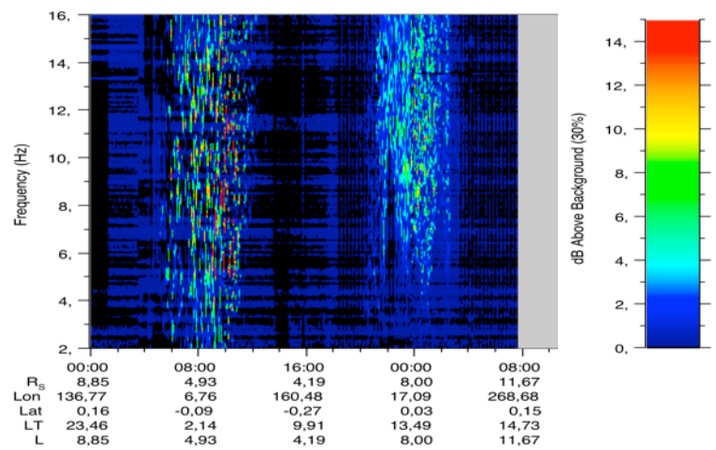
- LC0_ 005 (Courtin) - Thermal spectrum of Saturn's atmosphere - 10h [50%]

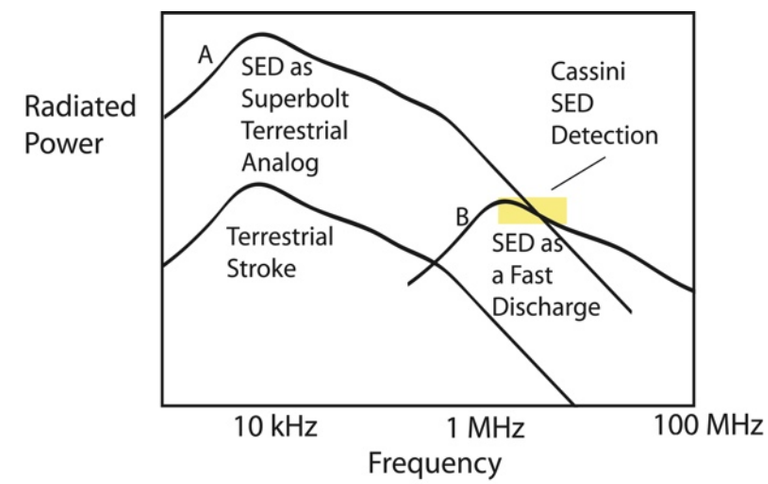


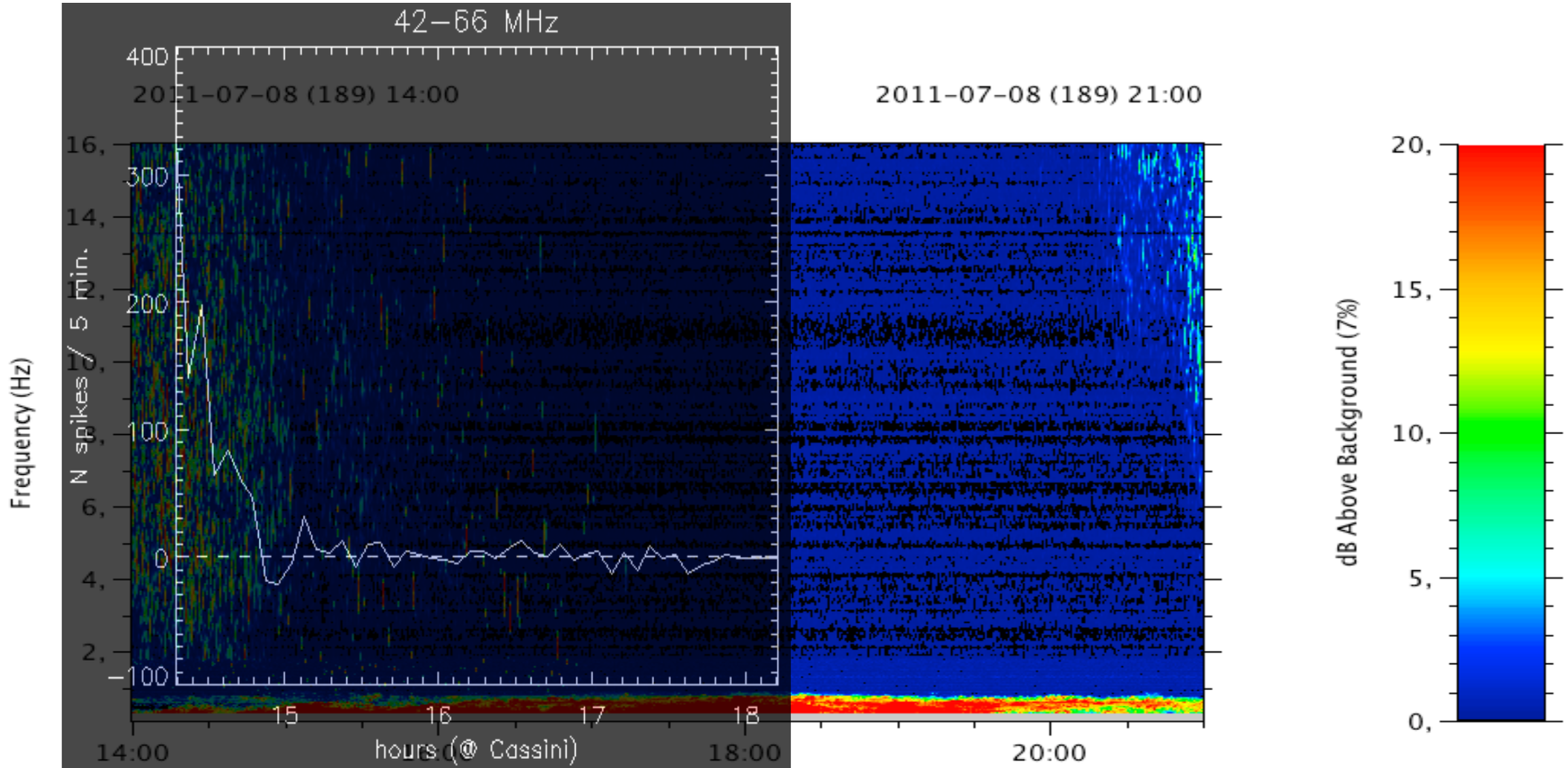
LOFAR cycle 0 (12/2012 - ~9/2013)

- LC0_023 (Griessmeier) - Saturn's lightning - 0h [0%] (ToO ?)

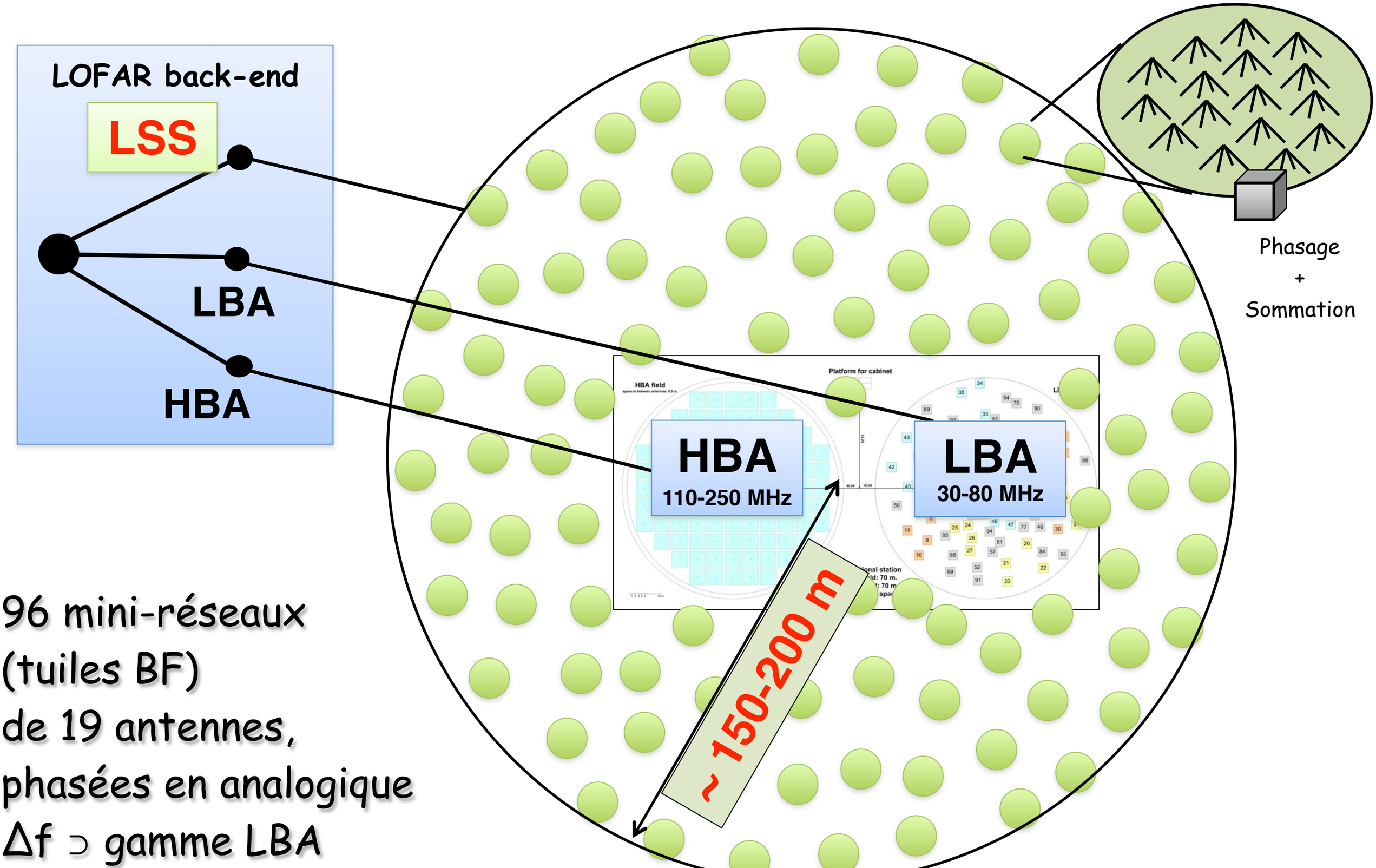






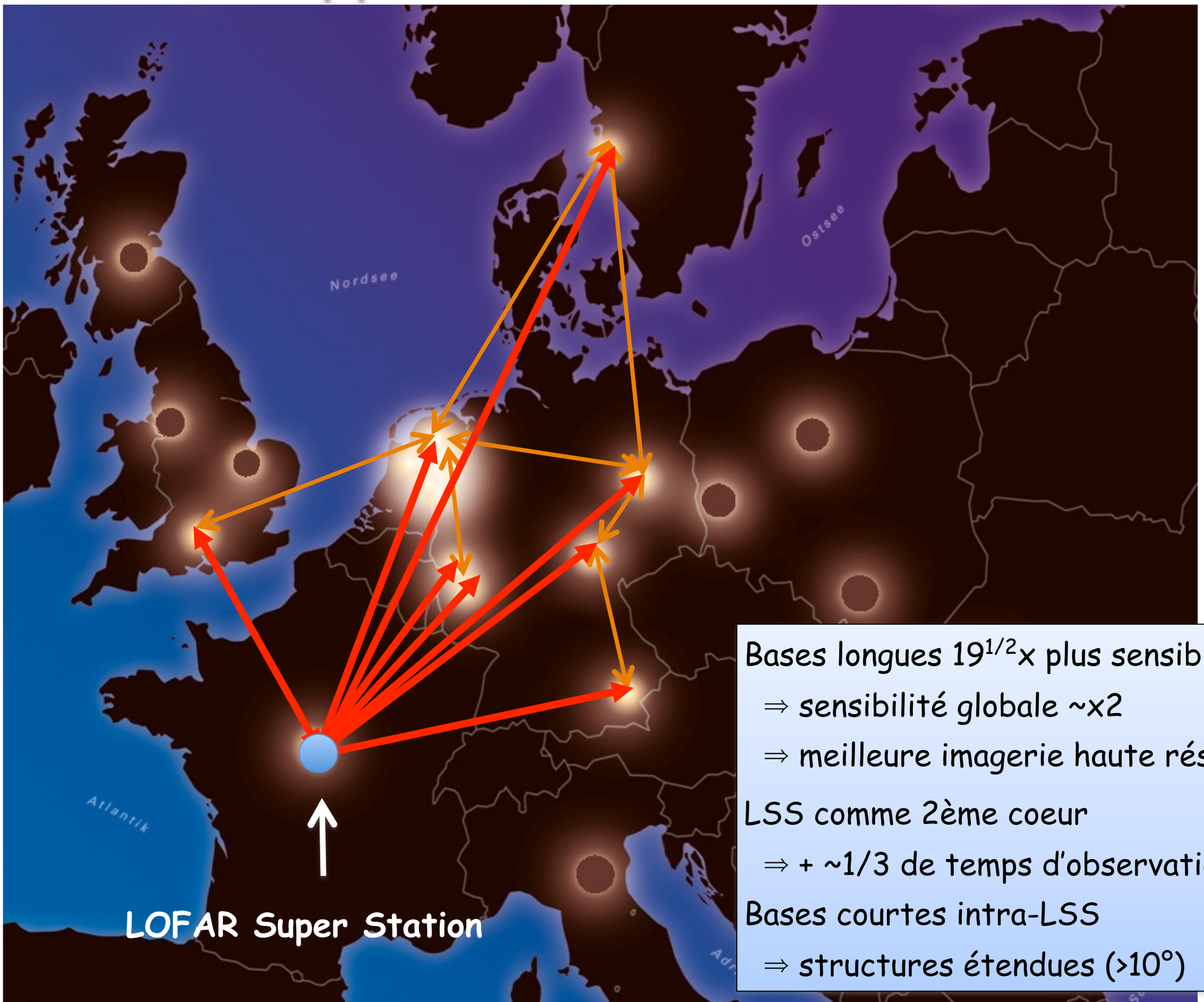


Le concept de Super Station LOFAR : réseau phasé + interféromètre géant à Nançay



96 mini-réseaux
(tuiles BF)
de 19 antennes,
phasées en analogique
$\Delta f \supset$ gamme LBA

Les apports de la LSS/NenuFAR



Bases longues $19^{1/2}$x plus sensibles

⇒ sensibilité globale ~x2

⇒ meilleure imagerie haute résolution

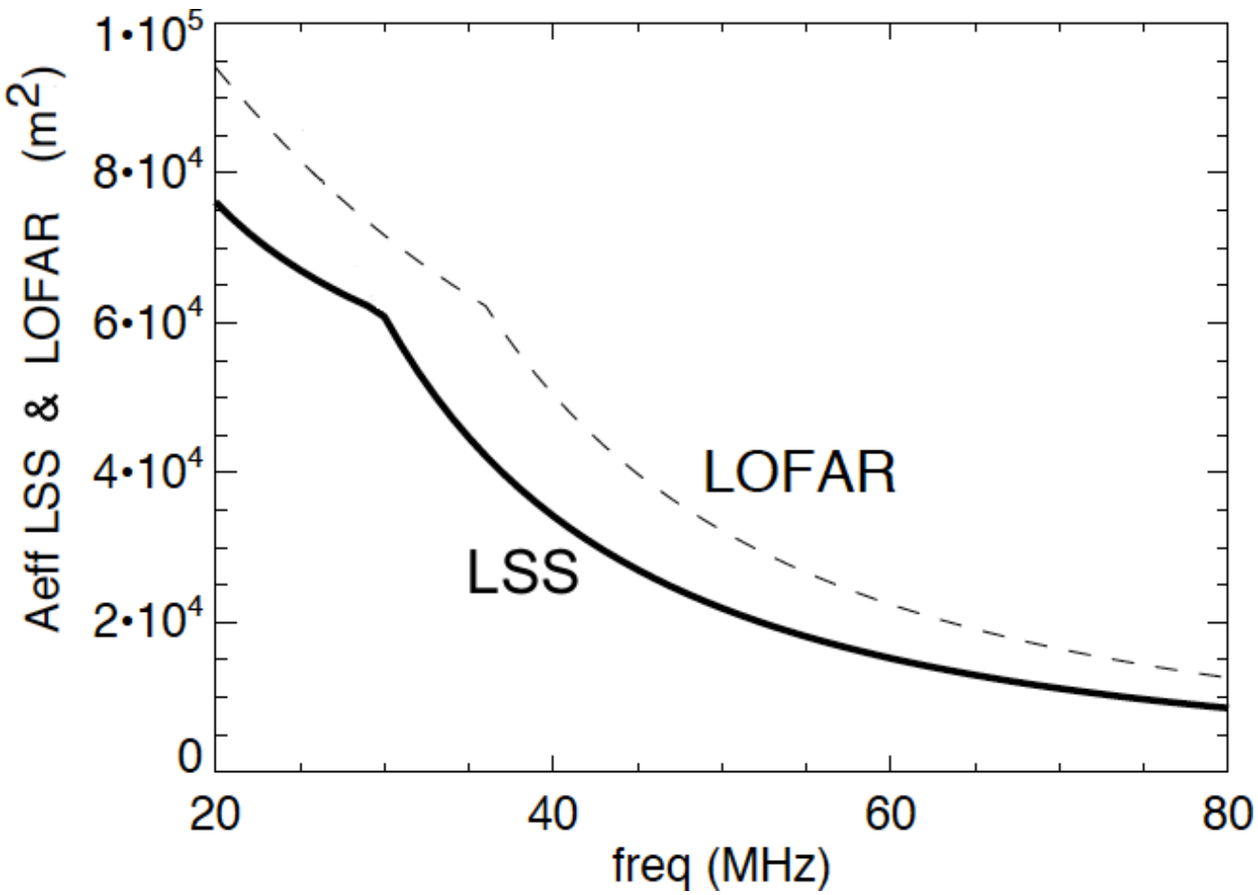
LSS comme 2ème coeur

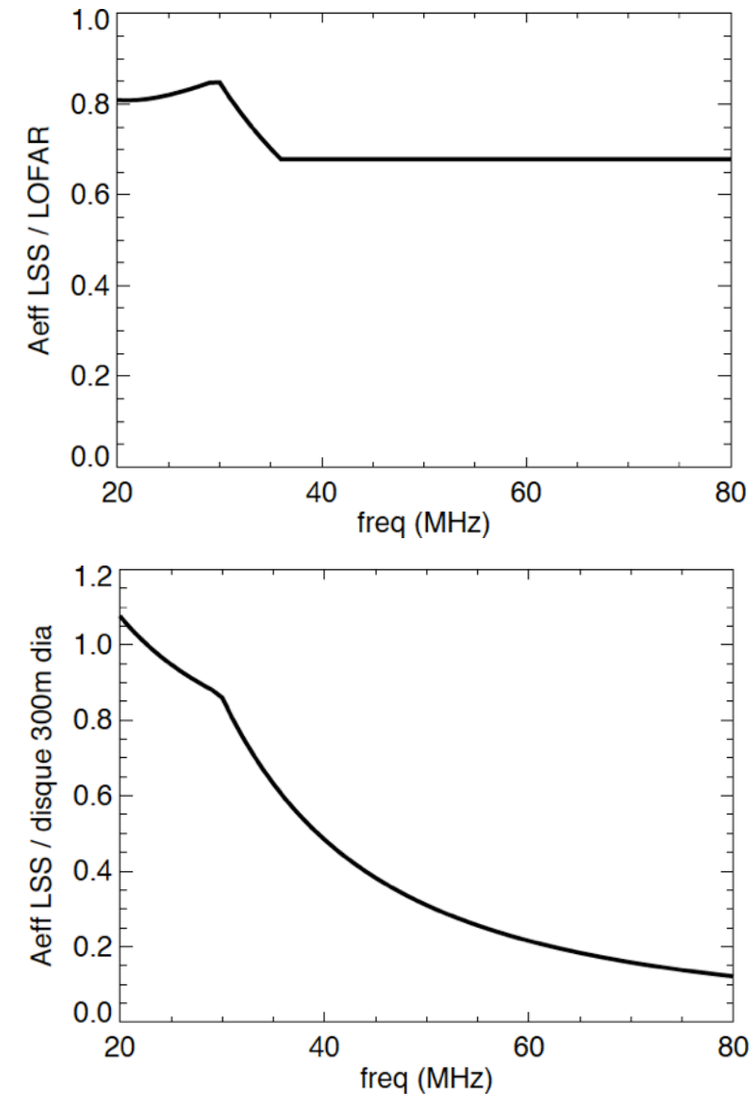
⇒ + ~1/3 de temps d'observation

Bases courtes intra-LSS

⇒ structures étendues (>10°)

Les apports de la LSS/NenuFAR





Grand instrument autonome : « Arecibo à Nançay »

⇒ ~19x la sensibilité d'une station internationale en LBA

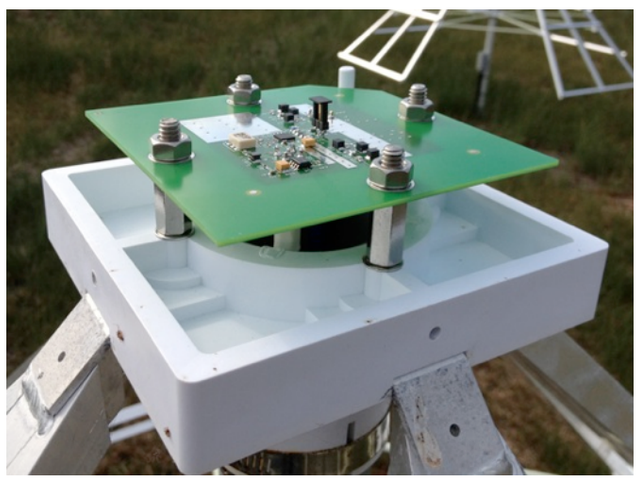
⇒ A_{eff} = 70-80% x A_{eff} LOFAR LBA = 190% x A_{eff} Coeur LOFAR LBA

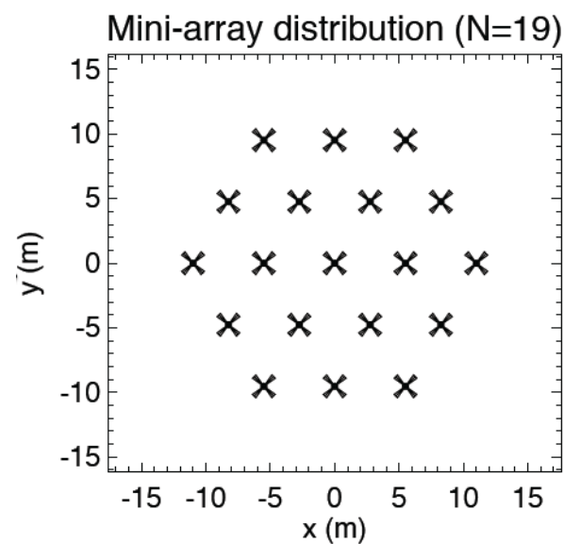
(mode faisceau cohérent > 2x+ efficace que LOFAR)

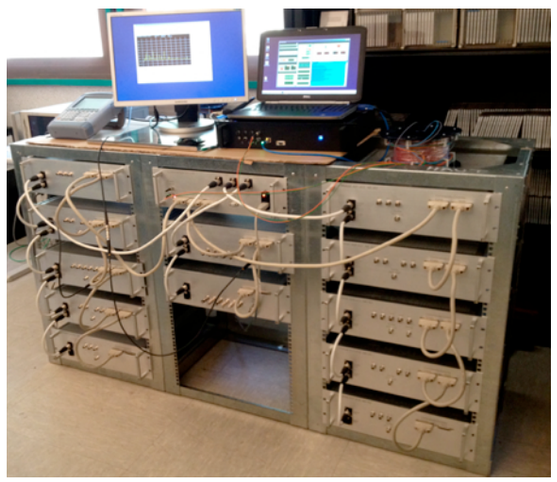
Accès aux TBF (15-80 MHz)

Design + Prototype de la LSS/NenuFAR

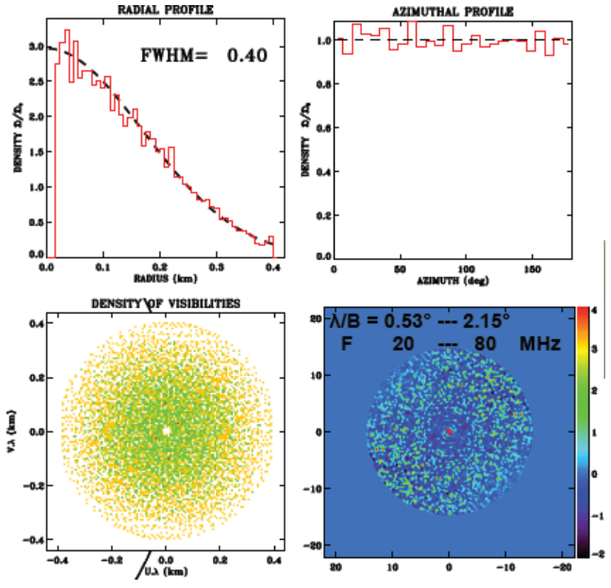
programme ANR 9/2009 - 2/2013 - 500 k€
http://www.obs-nancay.fr/lss/

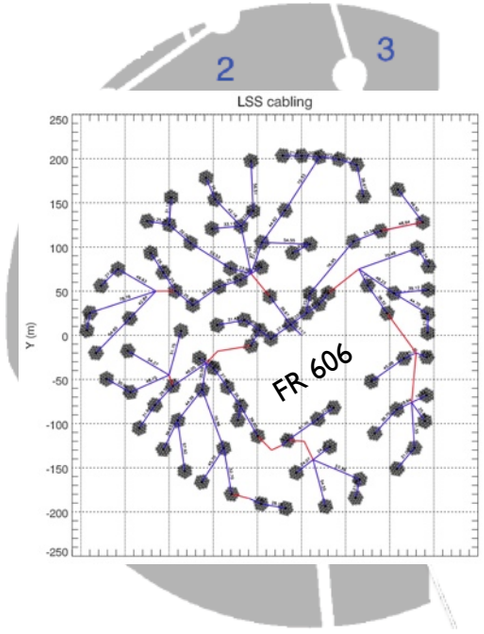


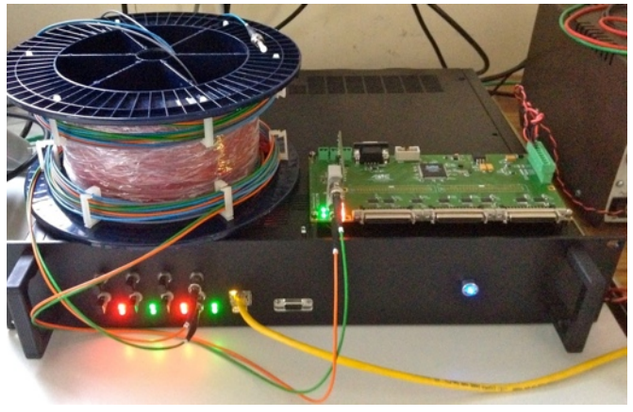




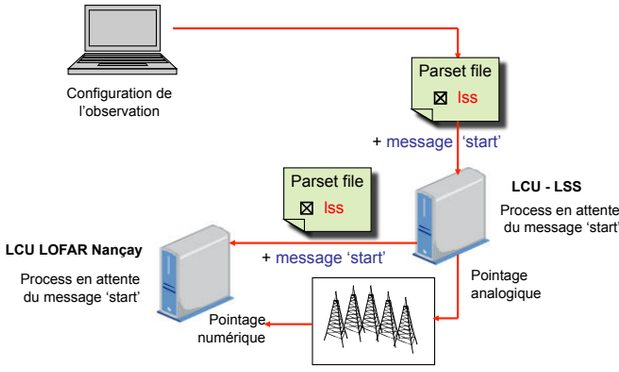
- Etude de tous les aspects du projet : antenne, préampli, distribution mini-réseau & globale, phasage, câblage/tranchées, contrôle/commande silencieux, dialogue/LOFAR







Mode standalone



Design + Prototype de la LSS/NenuFAR

programme ANR 9/2009 - 2/2013 - 500 k€
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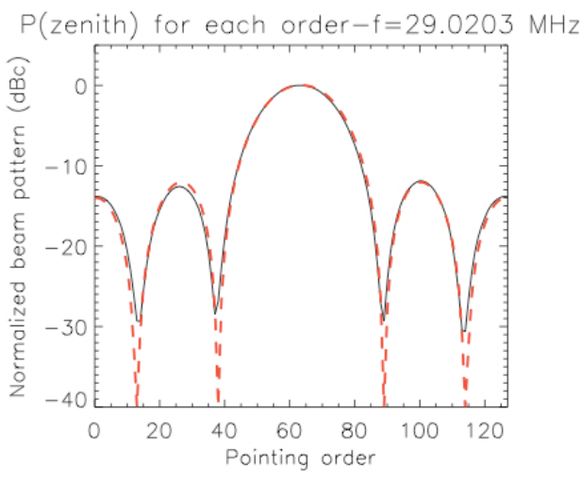
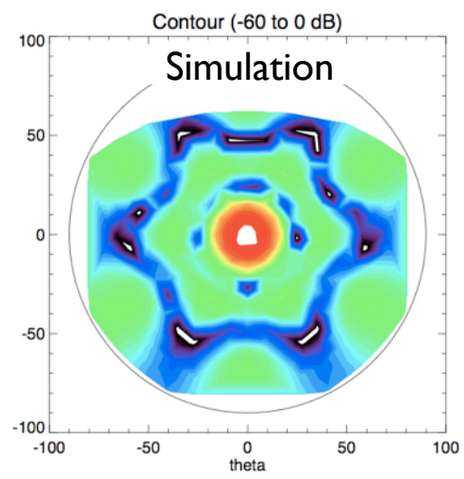
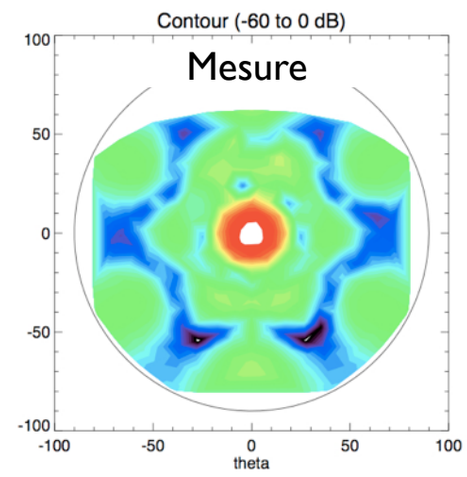
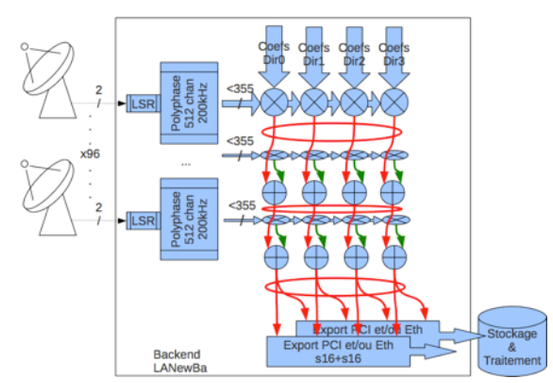


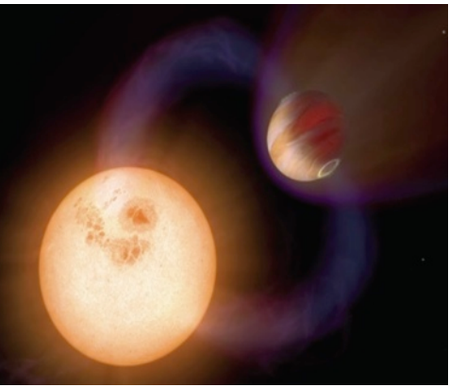


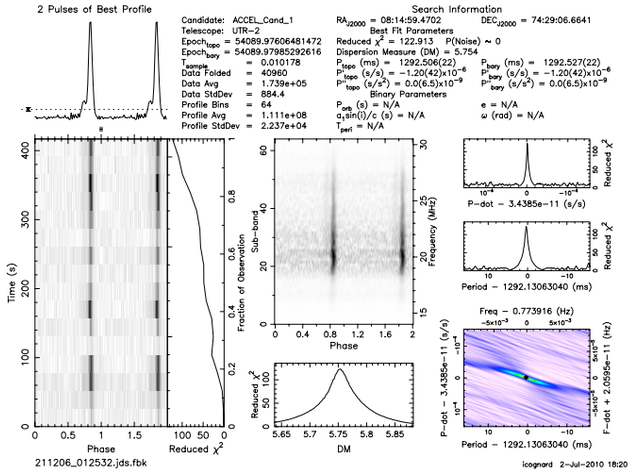


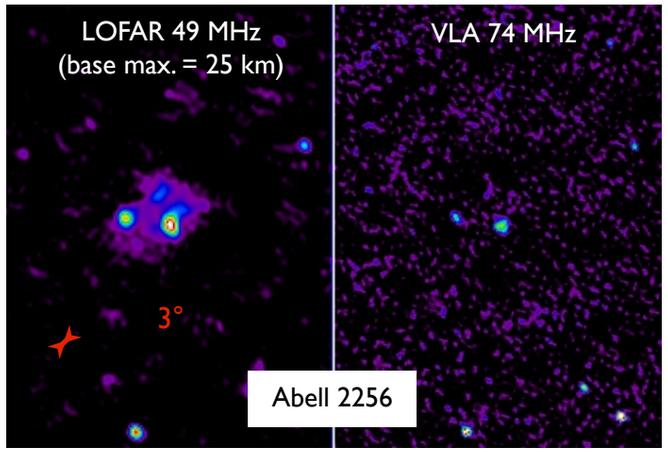


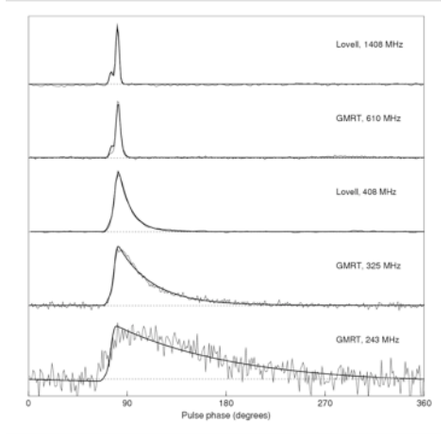
- Construction de 3 mini-réseaux (x 2 polarisations) + récepteur de test dédié
- Définition d'un récepteur autonome dédié (Nançay/ALSE)
  ⇒ "duty-cycle" ~100% dans le faisceau analogique mini-réseau (~30° @ 30 MHz)
- Études industrialisation, site (ONF), chiffrage, sous-traitance, calendrier

Les apports scientifiques de la LSS/NenuFAR



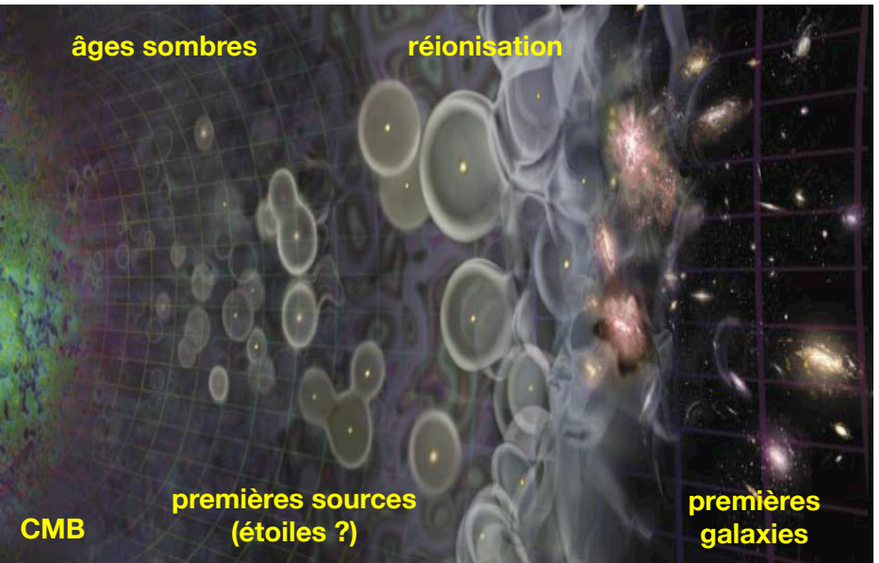






- Étoiles Binaires/Éruptives & Exoplanètes
- Pulsars & Rotating radio transients (RRATs)
- Structure du Milieu InterStellaire Galactique
- Cosmologie et Formation des galaxies
- L'Univers impulsionnel
- Les flashes lumineux dans les atmosphères Terrestre et planétaires

⇒ LSS autonome, LSS+LOFAR, LSS//LOFAR



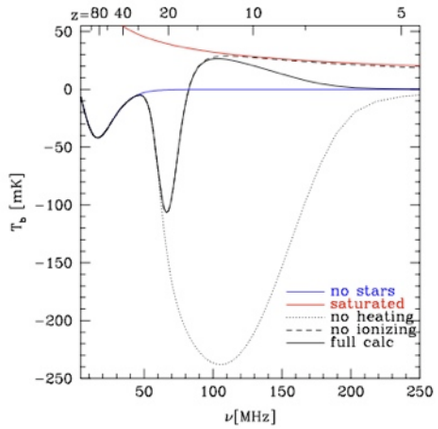
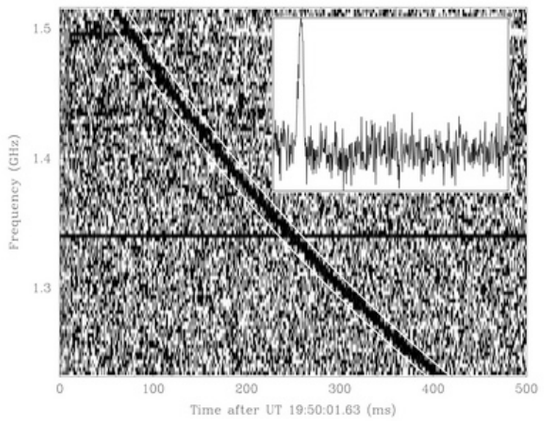
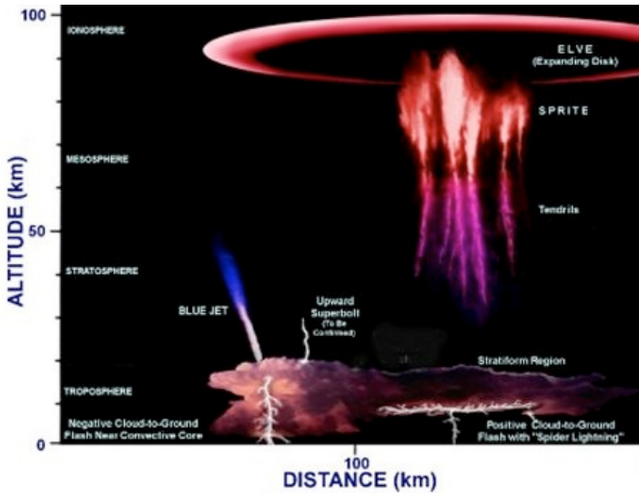


FIG. 1 (color online). Evolution of the 21 cm global signal for different scenarios. *Solid blue curve:* no stars; *solid red curve:* $T_S \gg T_\gamma$ and $x_H = 1$; *black dotted curve:* no heating; *black dashed curve:* no ionization; *black solid curve:* full calculation.





LSS dans le contexte national & international

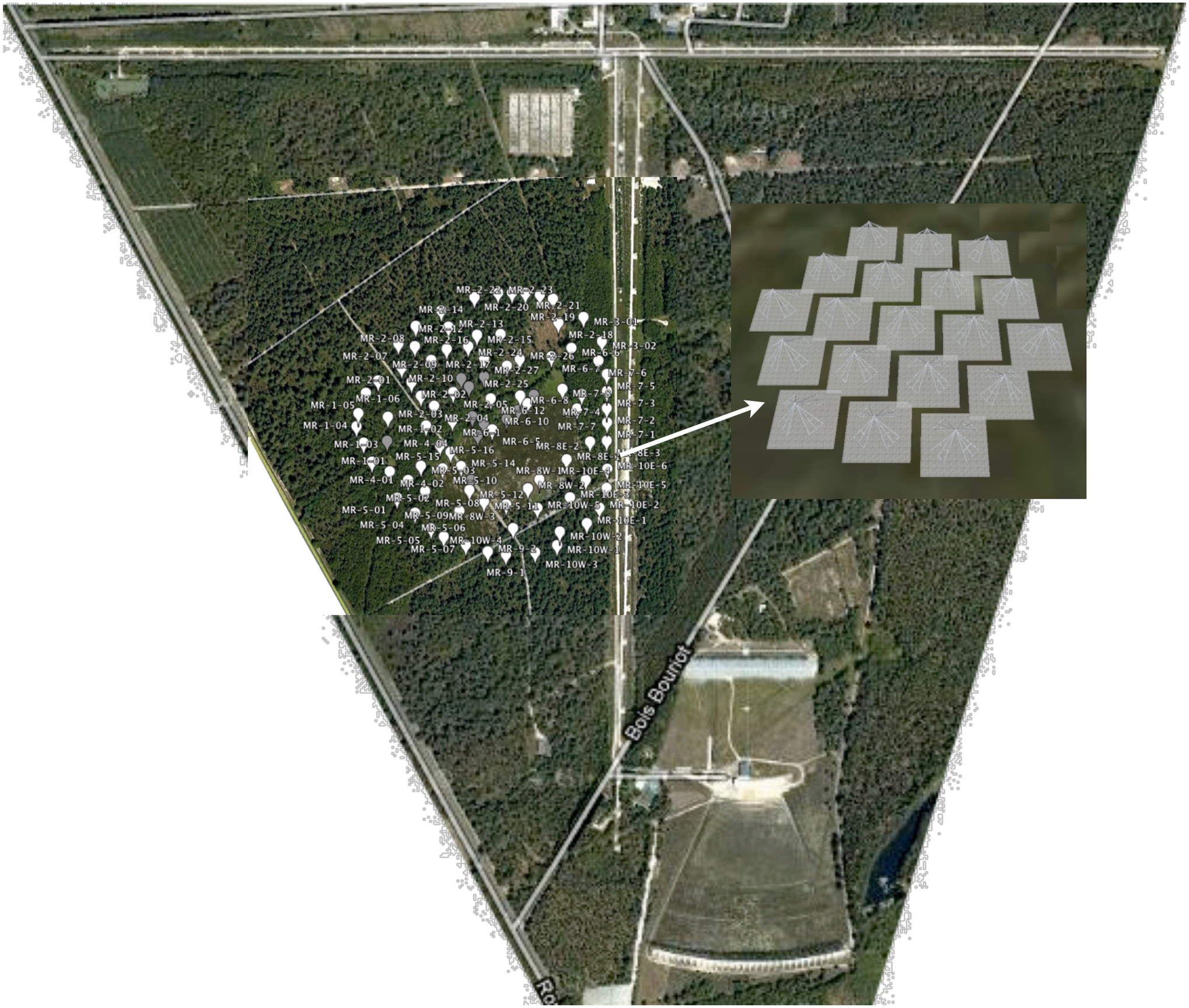
<u>Equipe LSS-France</u> : ~ 25 chercheurs + 15-20 ITA
<u>Laboratoires impliqués dans la réalisation</u> : Nançay, LESIA, GEPI, LERMA, LPC2E, Prisme, Subatech, IRA Kharkov, SRI Graz (soutien OP, ESEP) ⇒ Axe Paris(Meudon)-Orléans-Nançay, en vue de SKA

(LSS = précurseur scientifique et technique de SKA)

<u>Laboratoires utilisateurs</u> : OP (LESIA, GEPI, LERMA, LUTh), CEA/Sap-DASE-AIM, IAS, IAP, E. Polytechnique, ENS/LRA, APC, IN2P3, LPC2E, Nançay, OCA, IRAP ...

UTR-2	2040 dipoles	143000 m^2	8-32 MHz	0.5°	5 faisceaux	1 polar. lin.
VLA	27 paraboles x 25 m	~2000 m^2	73-74.5 MHz	0.5'	1 faisceau	4 Stokes
LWA	256 Xdipoles	8000 m^2 @ 20 MHz	10-88 MHz	9° 20 MHz	4 faisceaux x 20 MHz	4 Stokes
LOFAR (LBA)	2688 Xdipoles	72000 m^2 @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
LSS autonome	1824 Xdipoles	62000 m^2 @ 30 MHz	15-80 MHz	3° @ 30 MHz	4 faisceaux x 65 MHz	4 Stokes
LSS+LOFAR	4512 Xdipoles	134000 m^2 @ 30 MHz	30-80 MHz	2" @ 30 MHz	8+ faisceaux x 4- MHz	4 Stokes
SKA	??	1 000 000 m^2	100+ MHz	0.2" @ 100 MHz	nombreux faisceaux	4 Stokes

Demain la LSS/NenuFAR ?



NENUFAR
Le projet dans les temps