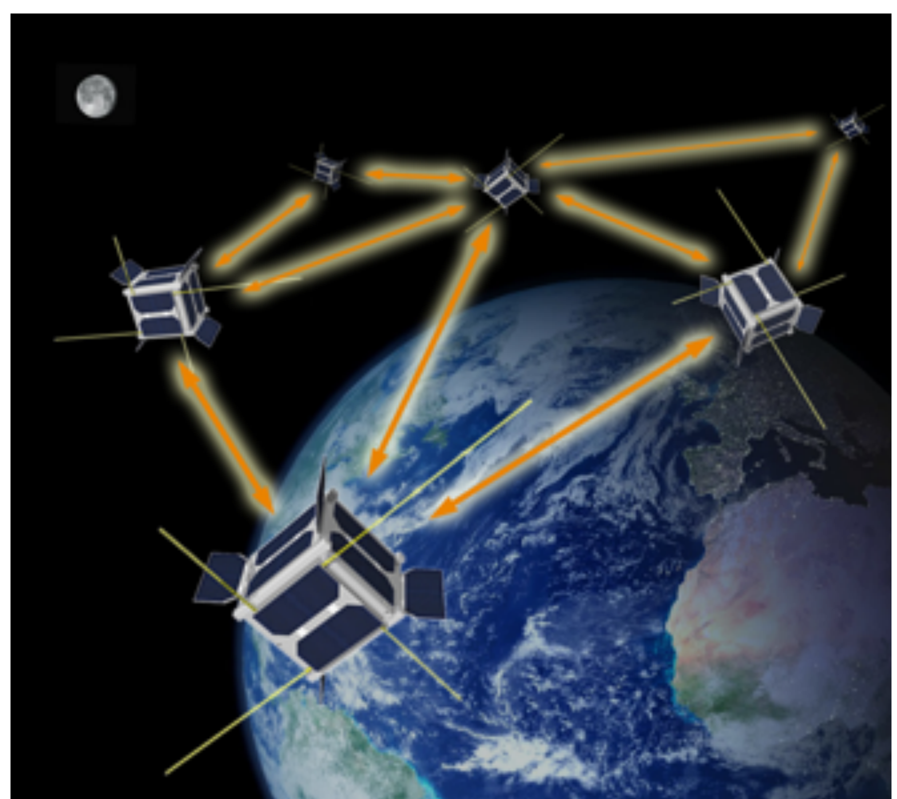
NOIRE: Nanosatellites pour un Observatoire Interférométrie Radio dans l'Espace

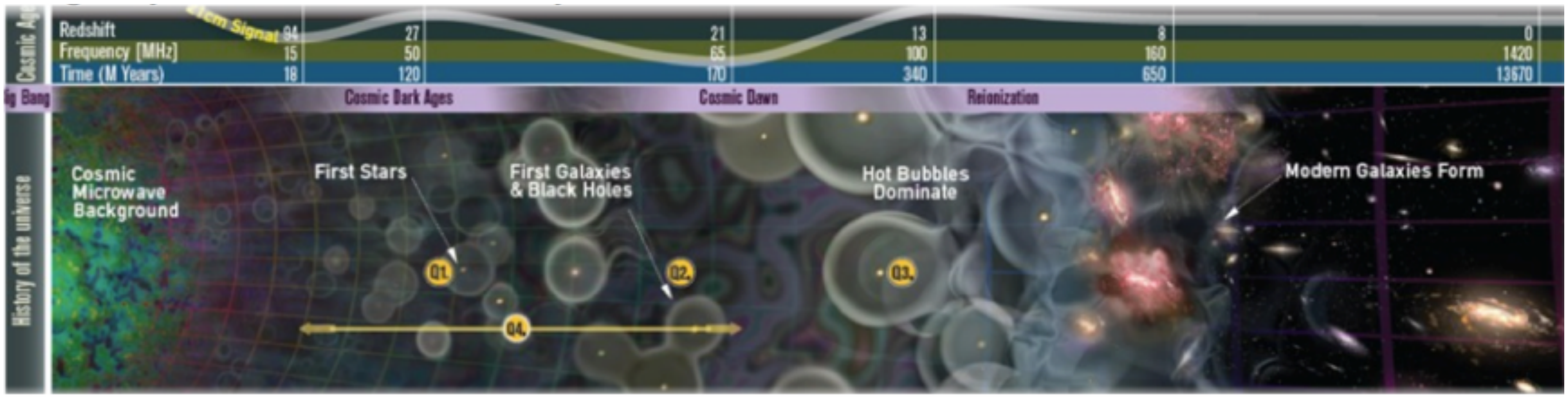
Etude menée par B. Cecconi

Labo impliqués:
LESIA, APC, LUPM, CEA/SAp/IRFU, ONERA/Toulouse,
IRAP, GEPI, LPC2E, C2S/TelecomParis
Campus Spatiaux:
CSU-Montpellier-Nîmes
Fondation Van Allen,
Campus Spatial Diderot, UnivEarthS
CERES, Obs Paris/PSL

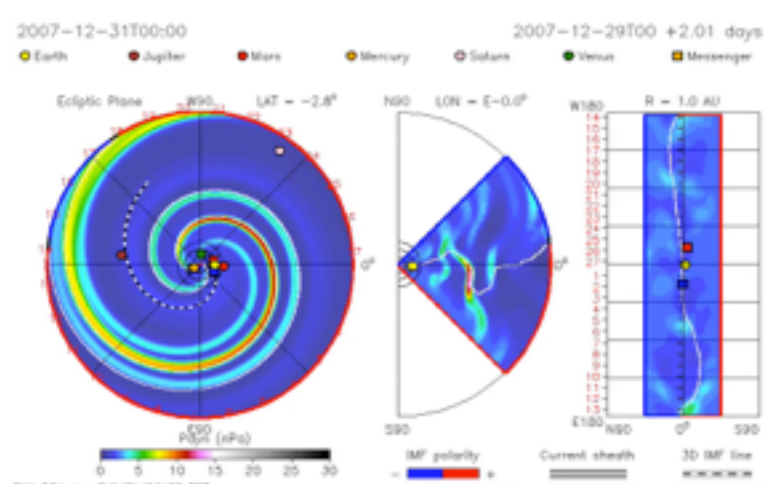


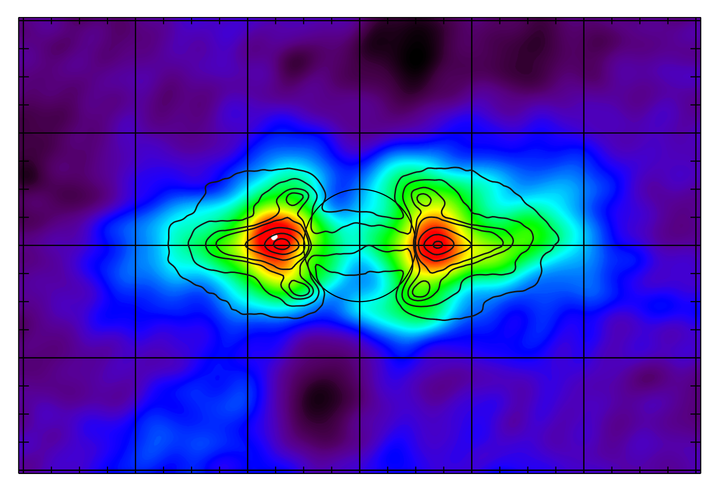
OLFAR, NL

Objectifs Scientifiques



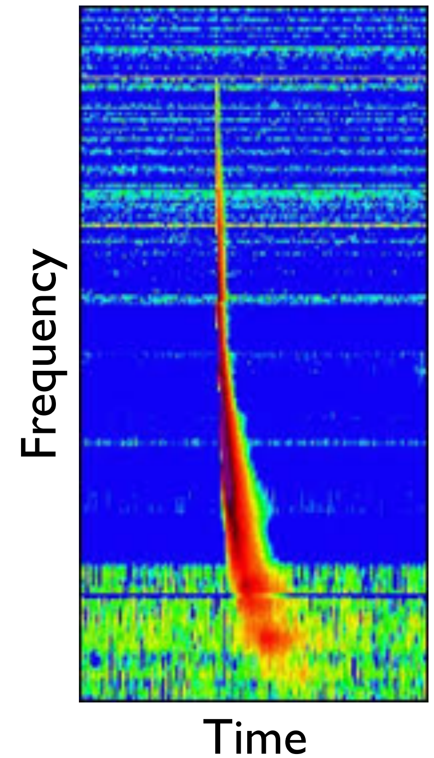
- Cosmologie (Dark Ages), Galaxie, Pulsars…
- Planétologie (magnétosphères, éclairs d'orages), Exoplanètes ?
- **SSA**:
  - Imagerie de l'hémisphère interne
  - Imagerie des ceintures de radiations terrestres

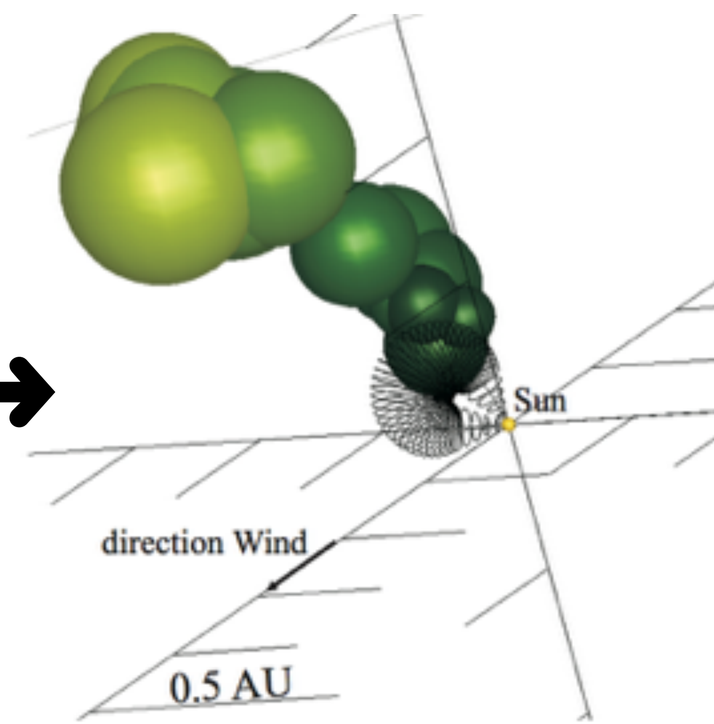




Imagerie des émissions radio solaires

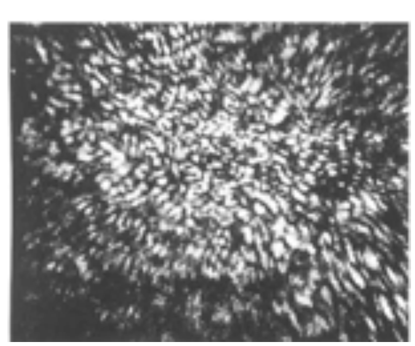
- **What we can do now**:
  using simple a model
  for extended source
  (*on left figure, each «bubble» is a frequency step)*
  STEREO, Solar Orbiter…





Magdalenic et al, 2014

- **What to expect**:
  each record = 1 image (= flux map)

Will we see  or  ?

Interférométrie radio

- **Nécessairement multi-point** (>10 voire, jusqu'à ~50?)
- Mesures en forme d'onde **simultanées et synchronisées**
- Calcul des visibilité interférométriques (=TF du ciel)

Dans l'espace:

- Antennes = **dipoles courts** électriques
- Volume de données énormes => **réduction en vol**
- Vision "3D" (pas de sol) => **algorithmes différents** que radio sol (LOFAR, SKA)
- Grandes lignes de bases => **communications inter-nœuds** ?

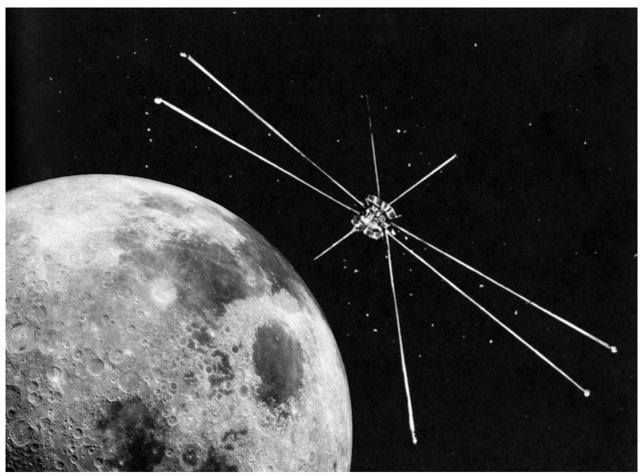
Points durs si nanosats:

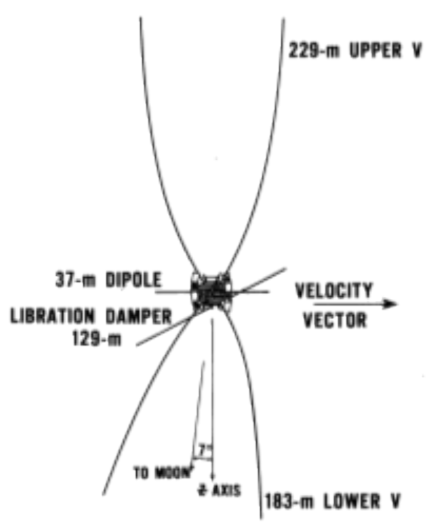
- Consommation des récepteurs radio "du commerce" (solution: R&D STAR?)
- Positions relatives (**distances, vitesses**) instantanées, datation
- **Communication** inter-nœuds et bord-sol
- Plateforme nanosat "**RFI-friendly**"
- **Calculs** des "visibilités" à bord

➡ **Phase(s) 0 CNES à définir**

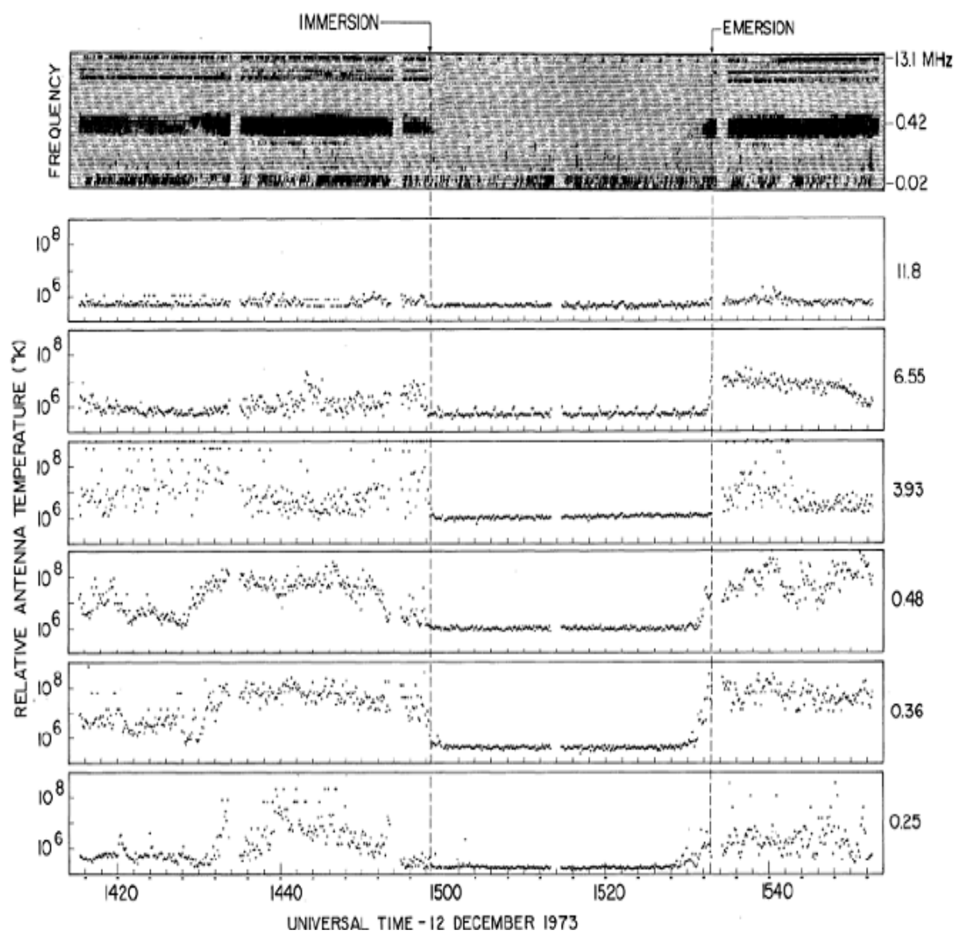
Behind the moon: no terrestrial RFI

RAE-2 : 1100 km circular orbit
inclined by 59° / lunar equator

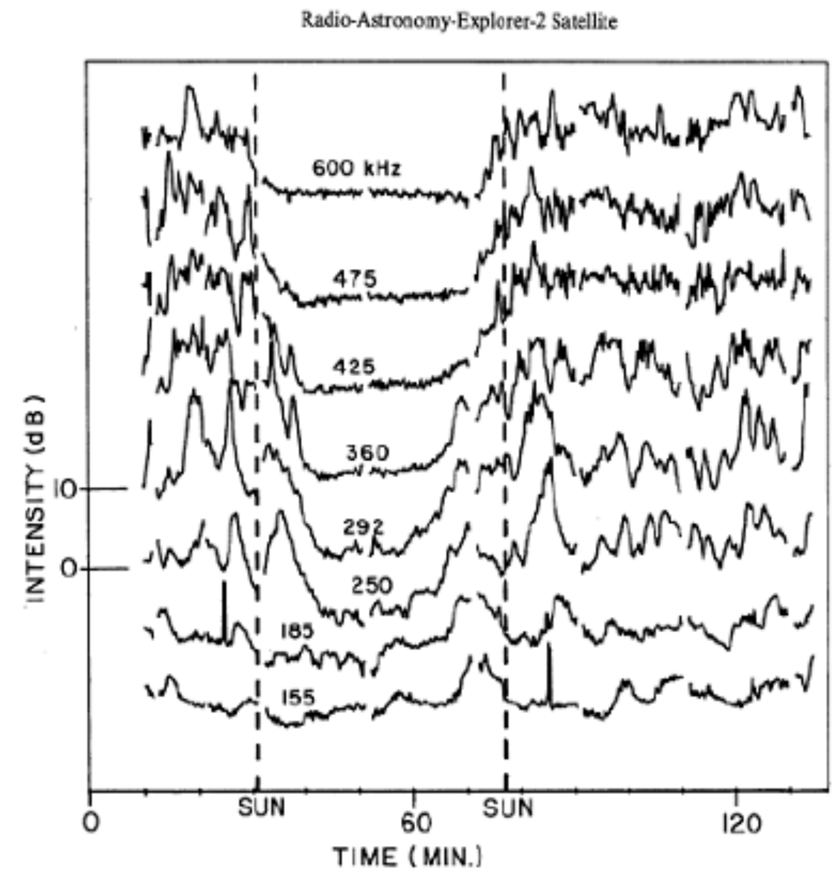




RAE-2 occultation of Earth (1973)



RAE-2 occultation of a solar storm



Contexte international

Europe

- Surtout les **Pays-Bas**: Univ. de **Twente**, **Delft** et Nijmegen; et institut ASTRON
- Projet ESA-S2 DSL: NL+PL+FR et Chine

USA

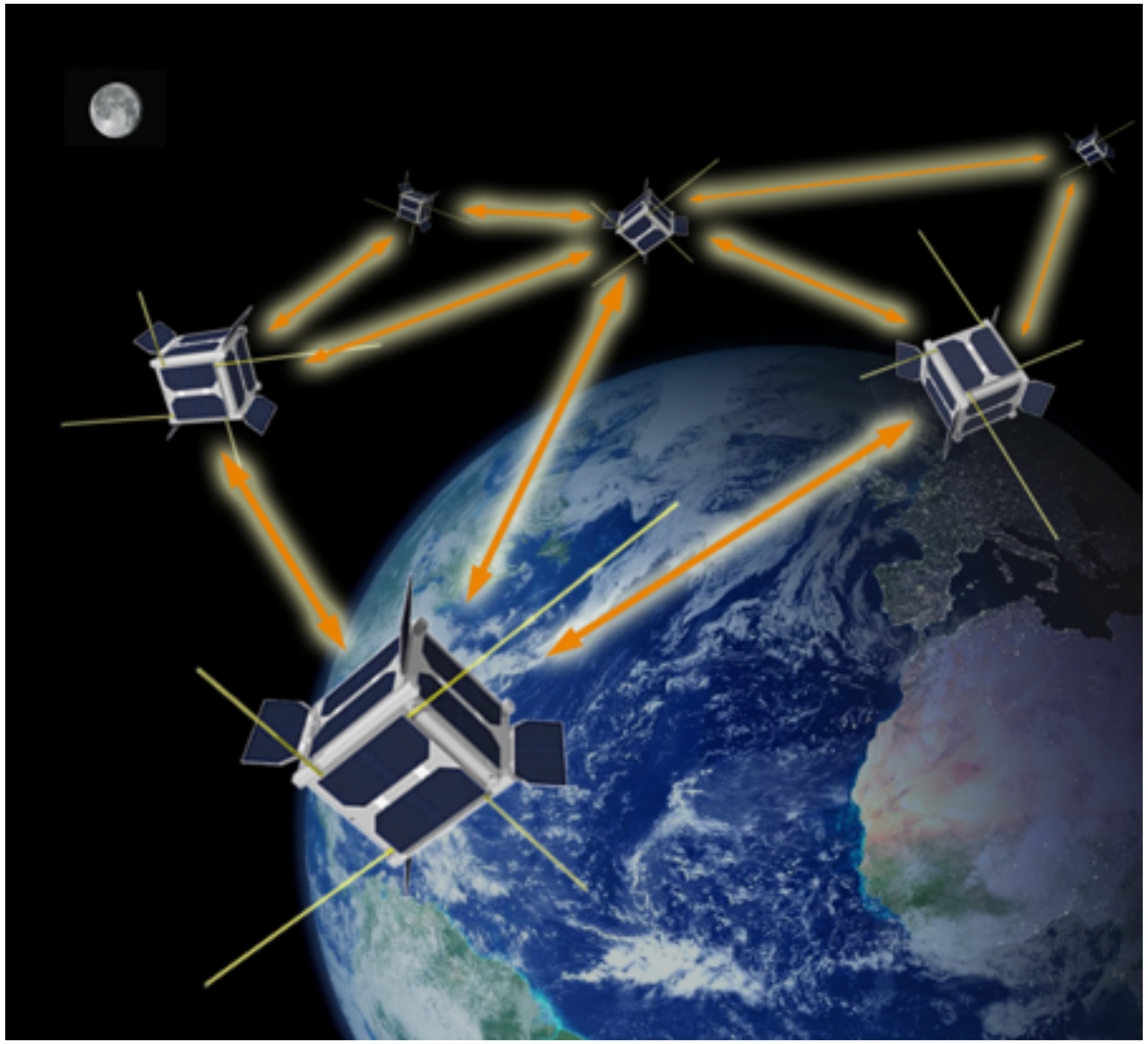
- NASA/GSFC et MIT s'y sont intéressés aussi

Chine *intéressée (Shanghai, NCAO…)*

Name	Freq. range	baseline	S/C nb	Location	Teams
SIRA	30 kHz – 15 MHz	>10 km	12 – 16	Sun-Earth L1 halo	NASA/GSFC [2004]
SOLARA/ SARA	100 kHz – 10 MHz	<10,000 km	20	Earth-Moon L1	NASA/JPL - MIT [2012]
OLFAR	30 kHz – 30 MHz	~100 km	50	Lunar orbit or Sun-Earth L4-L5	ASTRON/Delft (NL) [2009]
SULFRO	1 MHz – 100 MHz	< 30 km	12	Sun-Earth L2	NL-FR-Shanghai [2012]
DSL	100 Khz – 50 MHz	<100 km	8	Lunar Orbit (linear array)	ESA-S2 [2015]

OLFAR
Teams involved: NL, FR, SE
+ many other interested

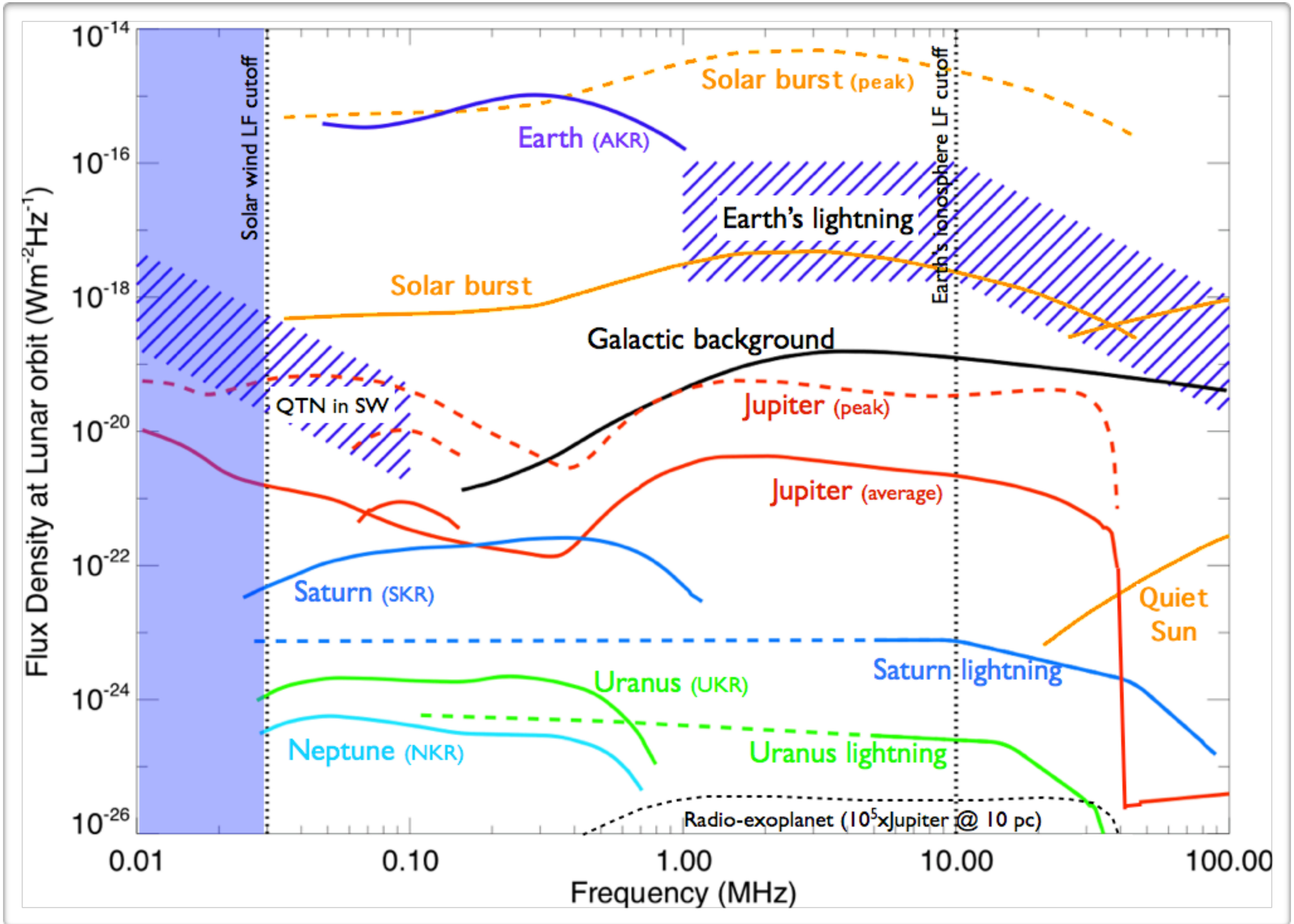
- **OLFAR: Orbiting low Frequency Antennas for Radio Astronomy**
- **Science objectives**:
  - «Dark Ages» (cosmology < 10MHz, redshift ~100, EoR [*Epoch of Recombination*])
  - Sun-Earth (space weather), Planets (outer planets: Uranus...)
  - In situ measurements (Thermal Noise).
- **Technology objectives**:
  - Passive formation flying (swarm configuration); inter-satellite distance < 100 km
  - Inter-satellite communication with GSM, shared computing power (distributed computing)
  - Radio antennas: 3 electric dipoles axes (6 x 5 m); frequency range: 30 kHz-30 MHz
- **Schedule**: 2020 ?
  Orbitography: lunar orbit (or L4-L5 Earth Lagrange Points)



Projects [50 cubesats]
OLFAR (NL, et al.)

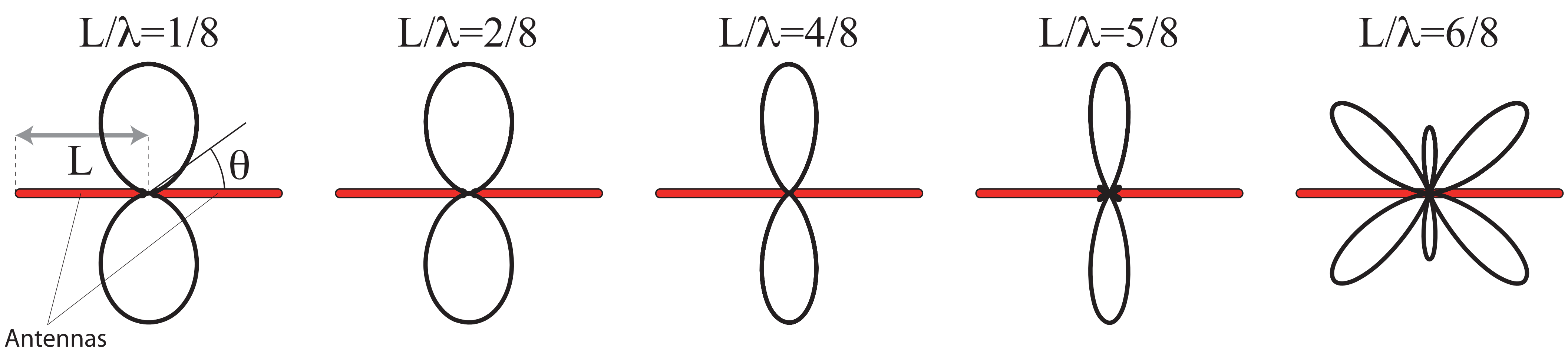
- Example of developments in the roadmap of Univ. Delft (Delfi)
  - Delfi-C^3 :
    - launched in april 2008, still operating
    - attitude control
    - wireless communication with «solar sensor» module
  - Delfi-n3Xt
    - launched in november 2013
    - solar sensor coupled with attitude control
    - successful tests of micropropulsion (solid state)
  - DelFFI
    - launch planned for 2015
    - formation flying test
- more info: http://www.delfispace.nl

Natural radio environment around Earth



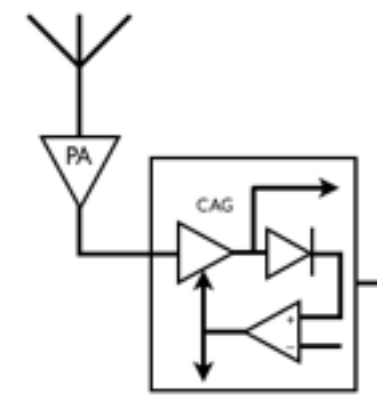
Space borne Radio Astronomy Goniopolarimetry

- Space based radio antennas: simple dipoles or monopoles with length L of a few meters
  (impossible to have a reflector large enough to have $\lambda/D << 1$)
- Short antenna range ($L << \lambda$) : monopole antenna + S/C body ~ effective dipole
- Antenna gain ~ $L^2 \sin^2\theta$ → null // antenna, max ⊥ to antenna
- Resonance at $L \sim \lambda/2$ (*multi-lobed, complex gain depending on direction*)



Today Space radio instrument characteristics

- Performances: receiver sensitivity 3-5 nV/Hz$^{1/2}$, need separate LF & HF due to 1/f spectrum, dynamic range 80-100 dB (without/with Automatic Gain Control (AGC) circuit)
  - → ≤a few MHz : local conditions, Sun & Planets
  - → a few to 100 MHz : all other science measurements

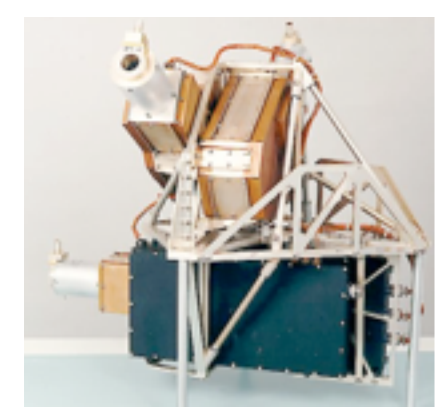


A channel of Cassini/RPWS/HFR

- Resources: ~1 W, a few 100's g, A5 board


BepiColombo/MMO/RPW/Sorbet

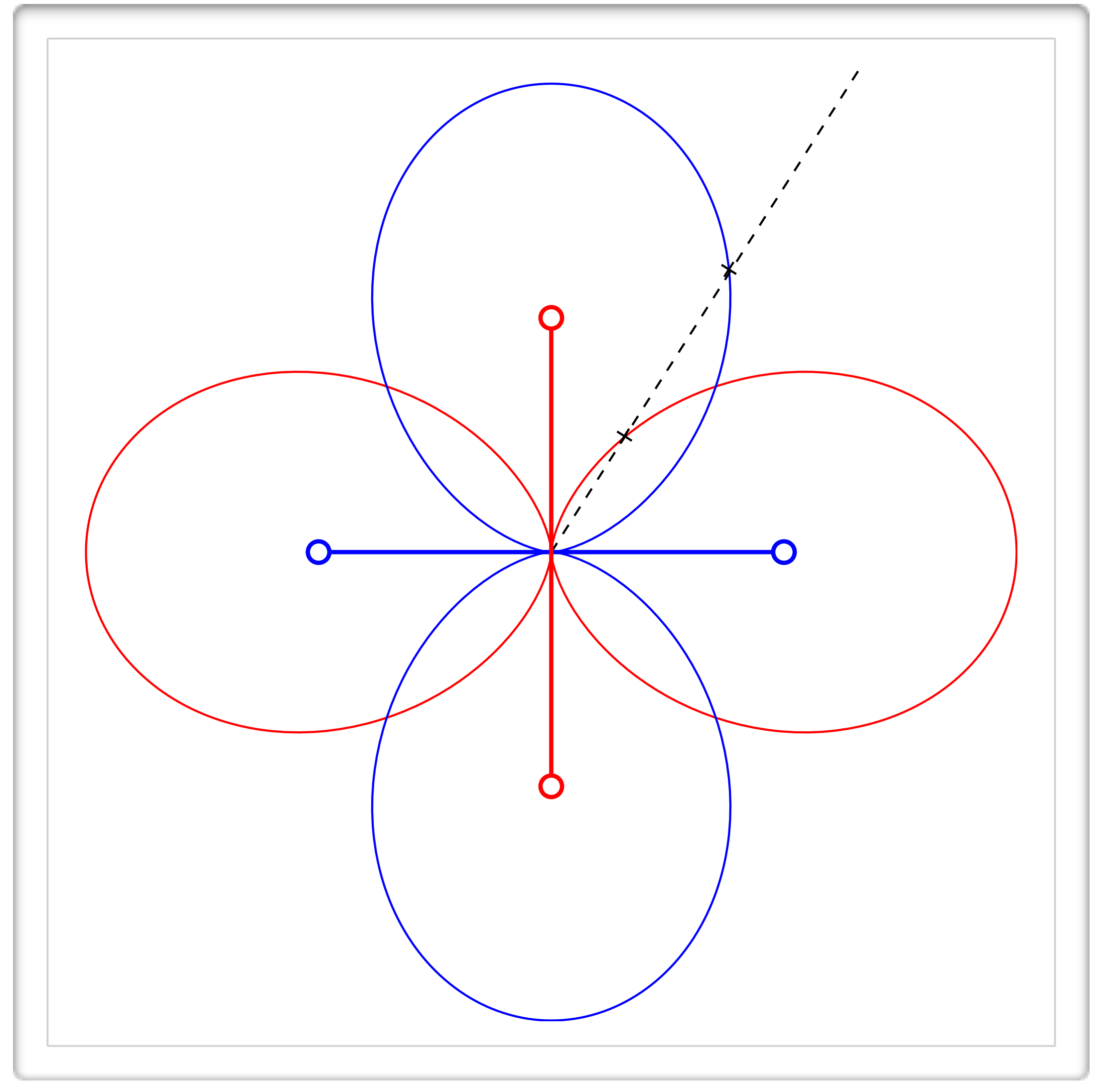
- Interfaces: booms, antennas, deployment, EMC (crucial for exploiting the quiet site)

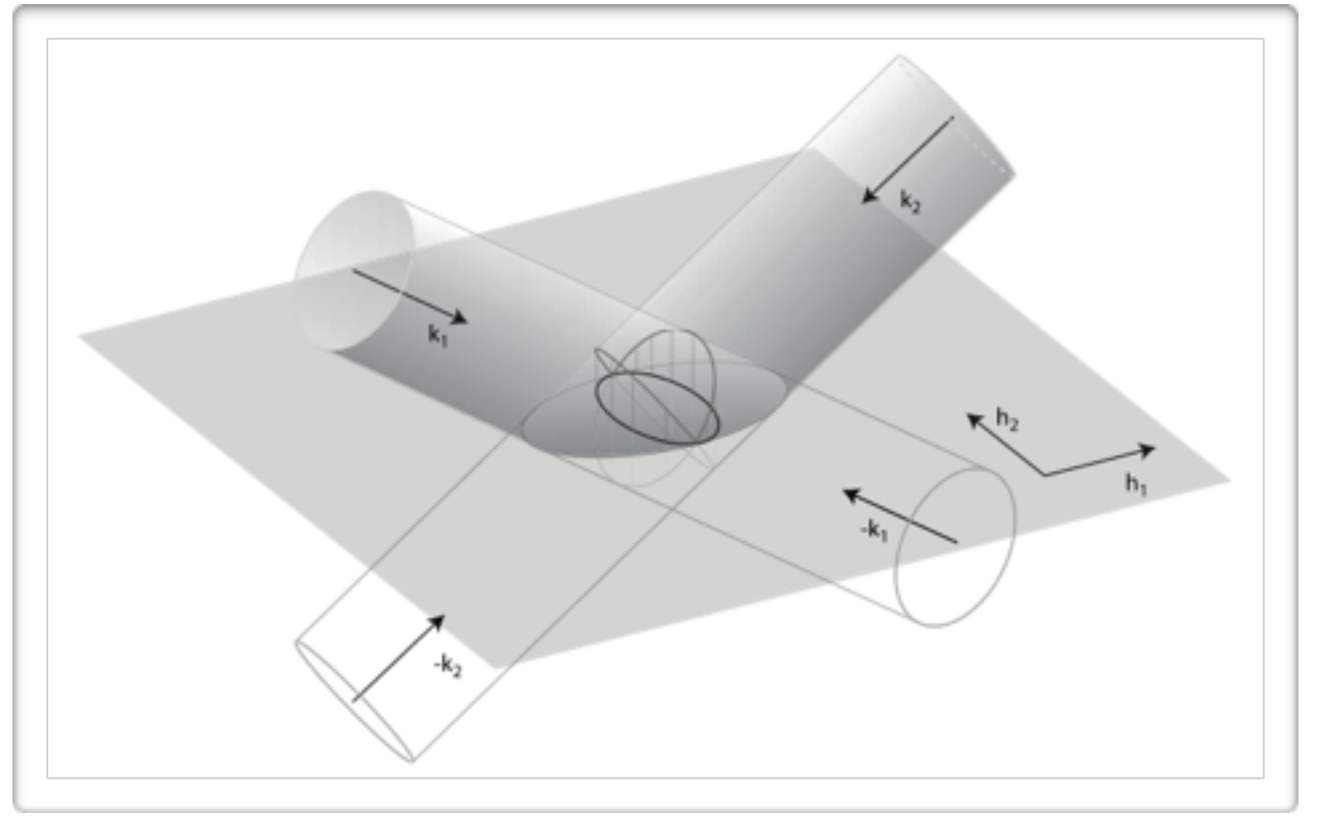

Cassini/RPWS antennas (stowed)

- **New R&D action is starting in France between Radioastronomy and Telecom labs for a new generation of digital radio receiver with high dynamic, low power and sampling up to 100 MHz.**

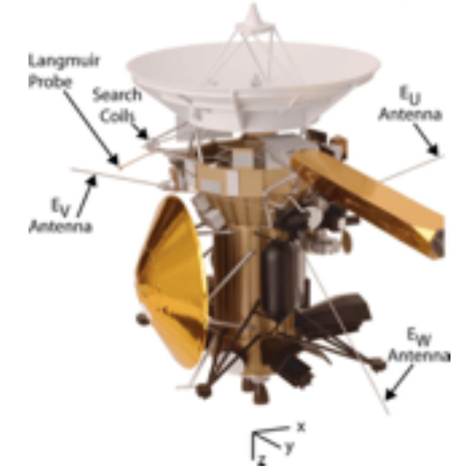
GonioPolarimetry

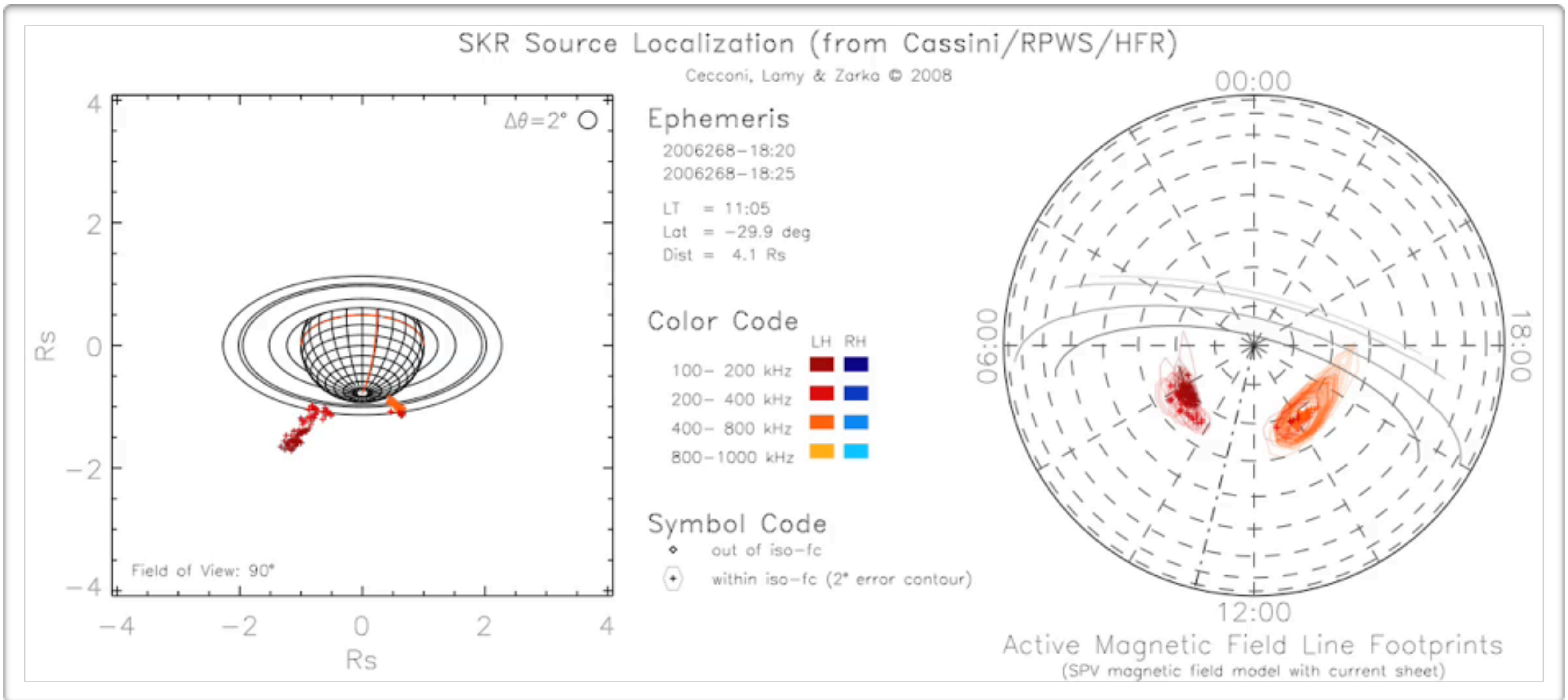
- Dipole has no angular resolution:
  ∫ antenna pattern = 8π/3 sr
- Solution : Use 2 crossed dipoles connected to a dual-input receiver and correlate measurements on both antenna
- With 3 antennas + crosscorrelations : full wave parameters (flux S, polarization Q,U,V, and wave vector θ, φ)
- Angular resolution depends on phase calibration of receiver + effective antenna calibration (typically ~ 1°, instead of ~90°)





Goniopolarimetry illustrated (Cassini/RPWS @ Saturn)

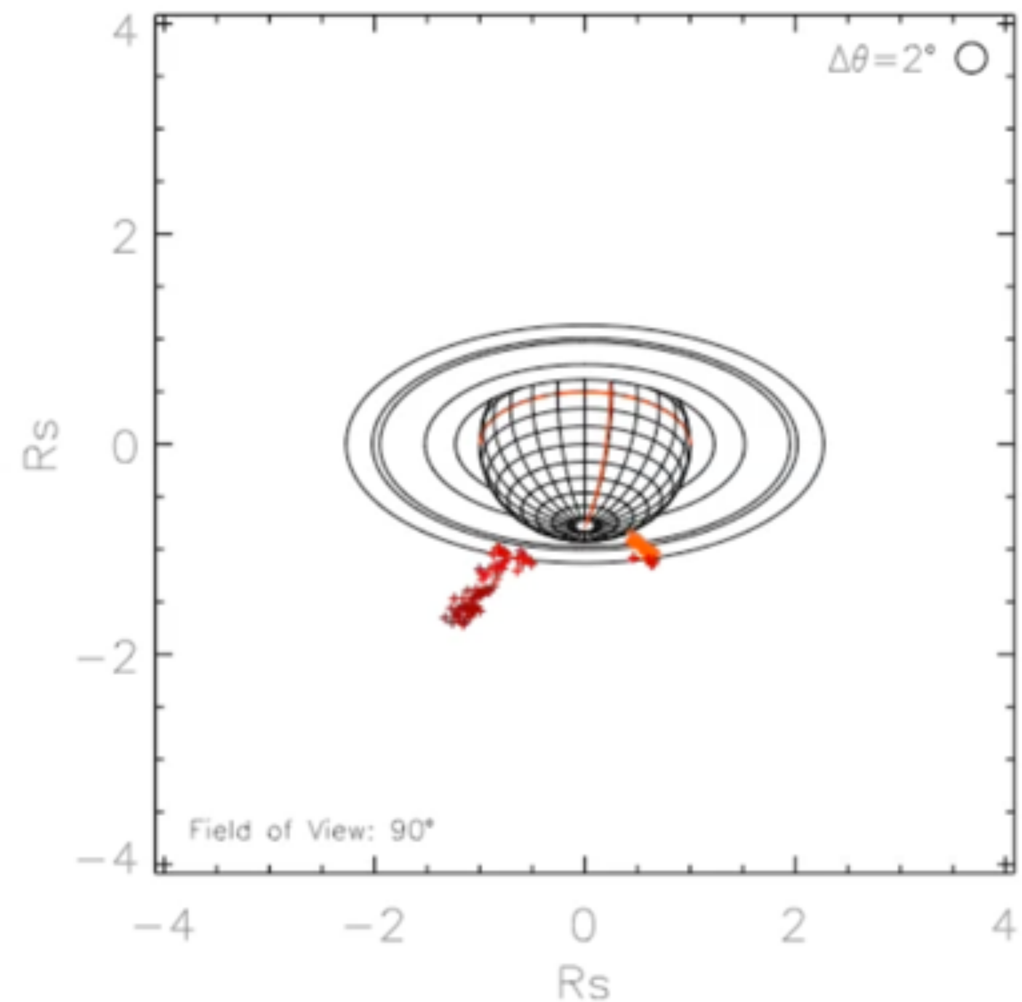




Saturn auroral kilometric radio source location from Cassini/RPWS data

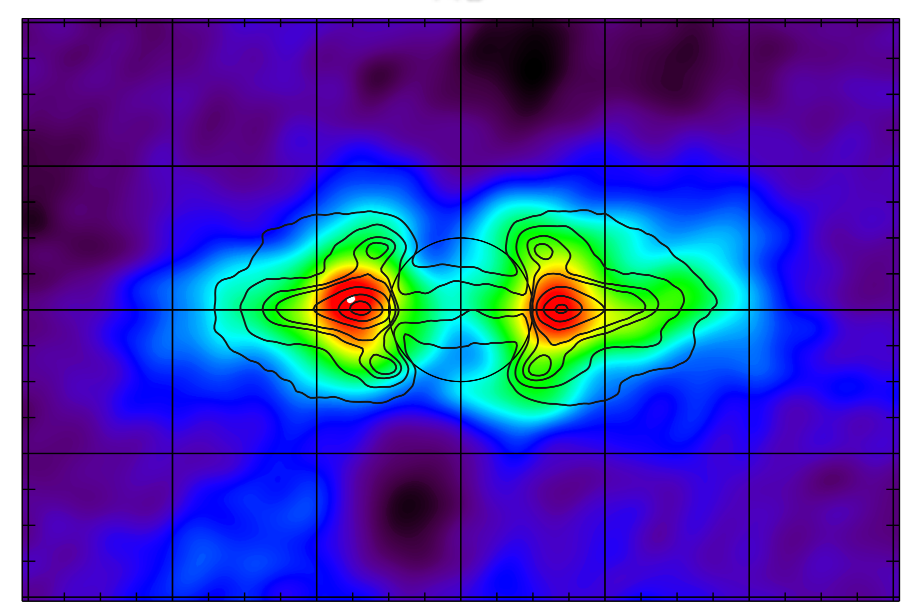
Planetary Radio Emissions

- **What do we see now**:
  for each time-frequency step:
  1 location, 1 flux,
  1 polarization
  (a posteriori reconstruction with a lot a records, i.e., time/freq averaging)



Cecconi et al, 2009
Cassini/RPWS

- **What to expect**:
  each time-frequency:
  1 flux map,
  1 polarization map



Girard et al, 2014
LOFAR

Past and present projects

- **Low Frequency radio interferometer** has already been proposed several times, here **in the USA**:
  - SIRA project (MacDowall et al, GSFC)
  - SOLARA/SARA project (Knapp et al, MIT)

- **in Europe**, with the LOFAR team:
  - OLFAR project (Bentum et al., NL)
  + other emerging projects in NL, Sweden and France (DEX, SURO, DARIS, FOAM...)

- **ESA-CAS** proposal:
  - SULFRO (Astron NL + SHAO China, et al)

Other projects
SULFRO (presented at ESA-CAS meeting)

- SULFRO (*Space Ultra Low Frequency Radio Observatory*)
  - 12+ nanosats
  - coupled with a larger mothership spacecraft
  - low frequency interferometry
  - Frequency Range = ~1kHz - 100MHz
  - Science = «Dark Ages» (but could do many thing else)
  - Candidate for S2 ESA/China mission

Other projects
DSL (submitted for ESA-CAS S2)

- DSL (*Discovering the Sky at the Longest wavelengths)*
  - 8 nanosats (~27 U)
  - coupled with a larger mothership spacecraft
  - low frequency interferometry
  - Frequency Range = ~30kHz - 30MHz
  - Science = «Dark Ages»
  - Submitted for S2 ESA/China S2