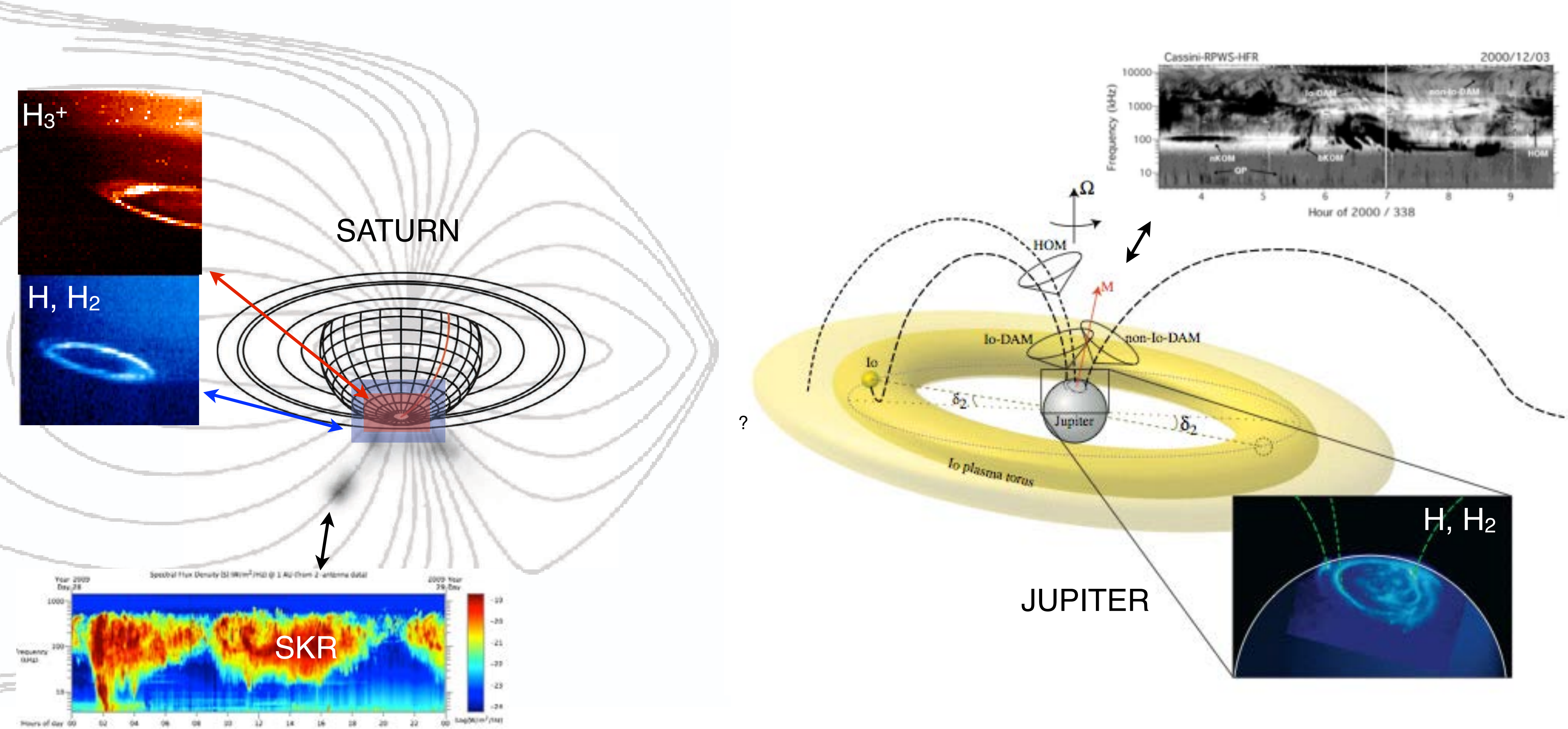
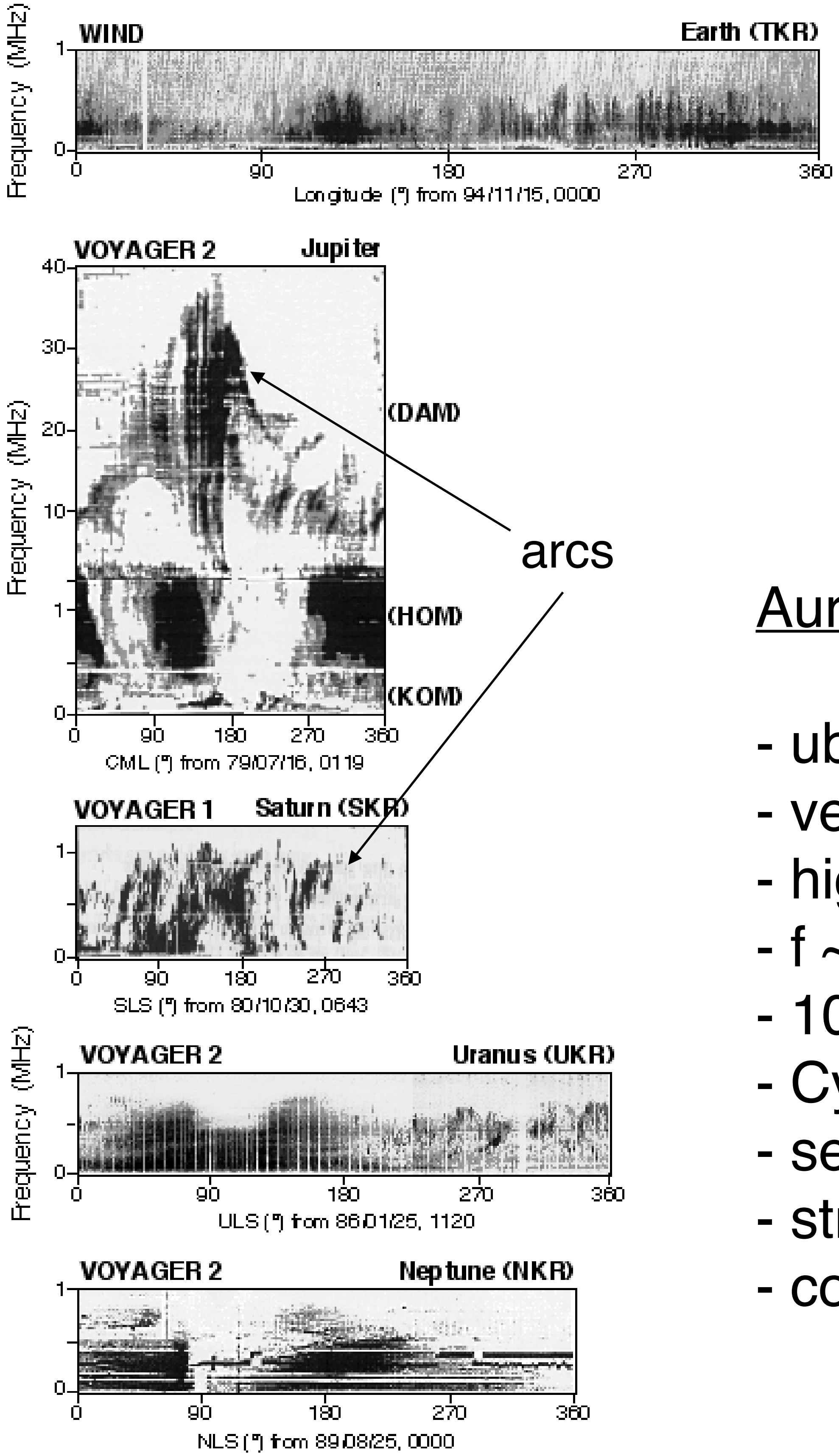
Multi-wavelength view of planetary aurorae and implications on our understanding of radio emissions

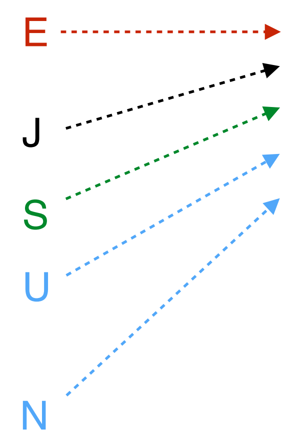


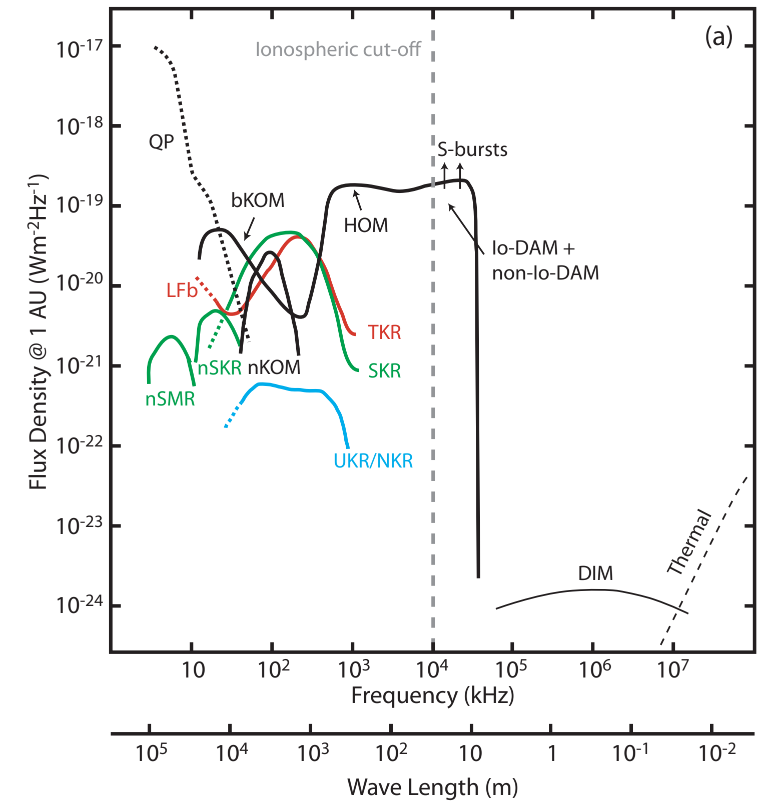
L. Lamy (LESIA, Obs. Paris)
kindly given by S. Hess (ONERA, Toulouse)

AOGS, Sapporo, 31 July 2014

Preamble



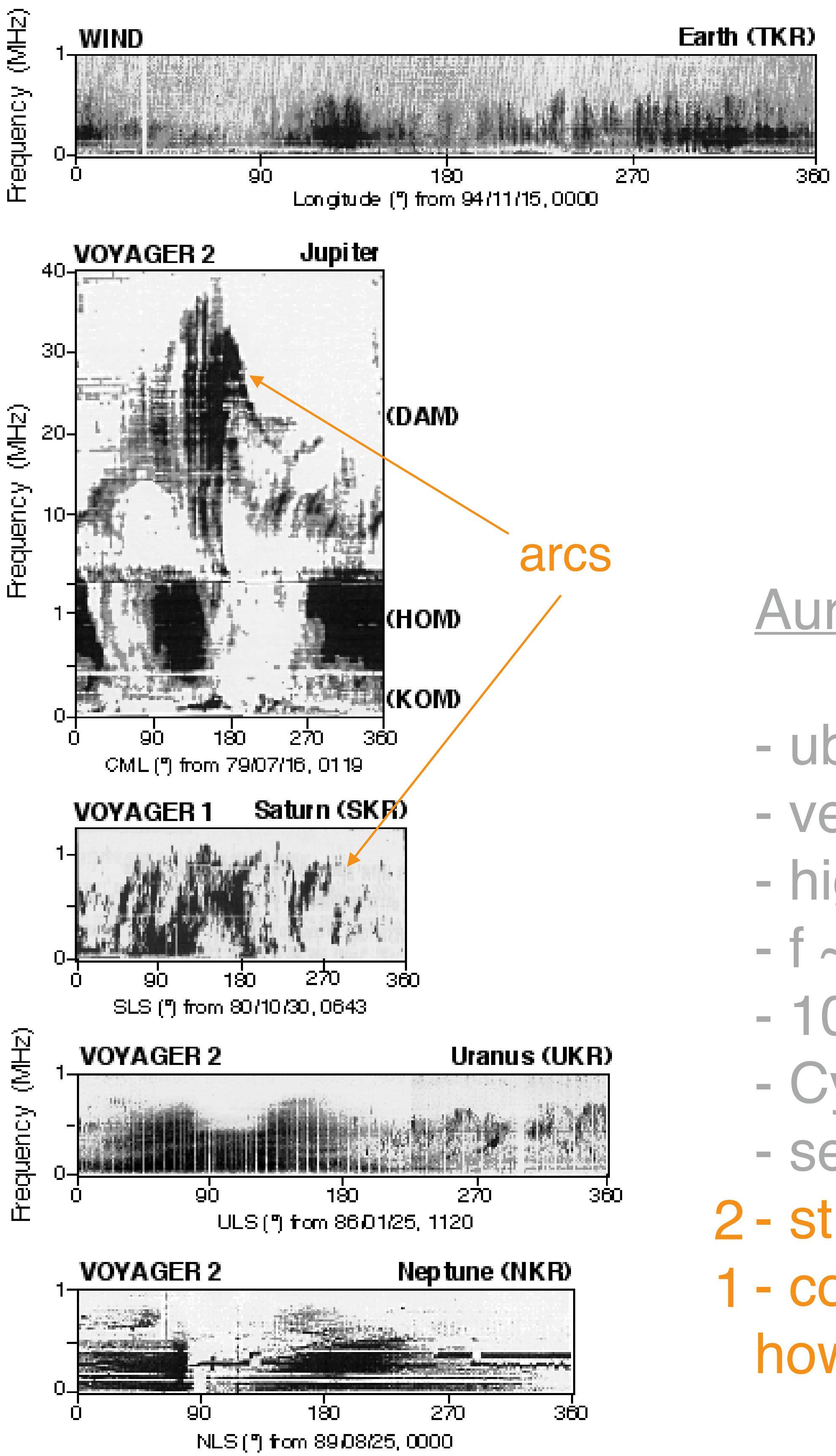


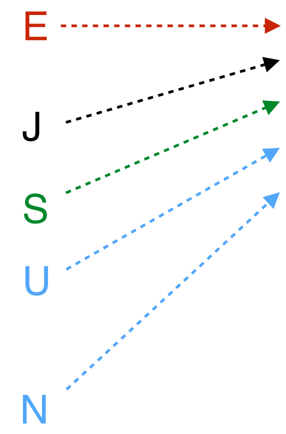


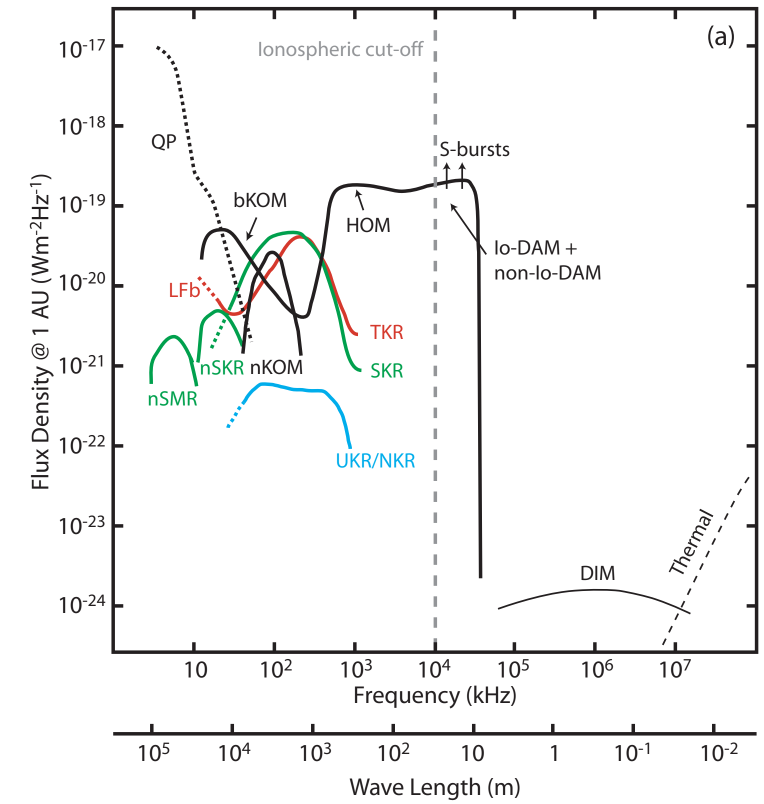
<u>Auroral Radio Emissions (AREs) :</u>

- ubiquitous in the solar system within [1kHz-40MHz]
- very intense
- high latitude (auroral) sources where $f_{pe} << f_{ce}$
- $f \sim f_{ce}$ on X,O free-space modes
- 100% elliptically polarized
- Cyclotron Maser Instability (CMI) driven by electrons
- sensitive to MS dynamics (rotation, solar wind etc.)
- strongly anisotropic emission (complex morphology, arcs)
- correlation with other aurorae

Preamble







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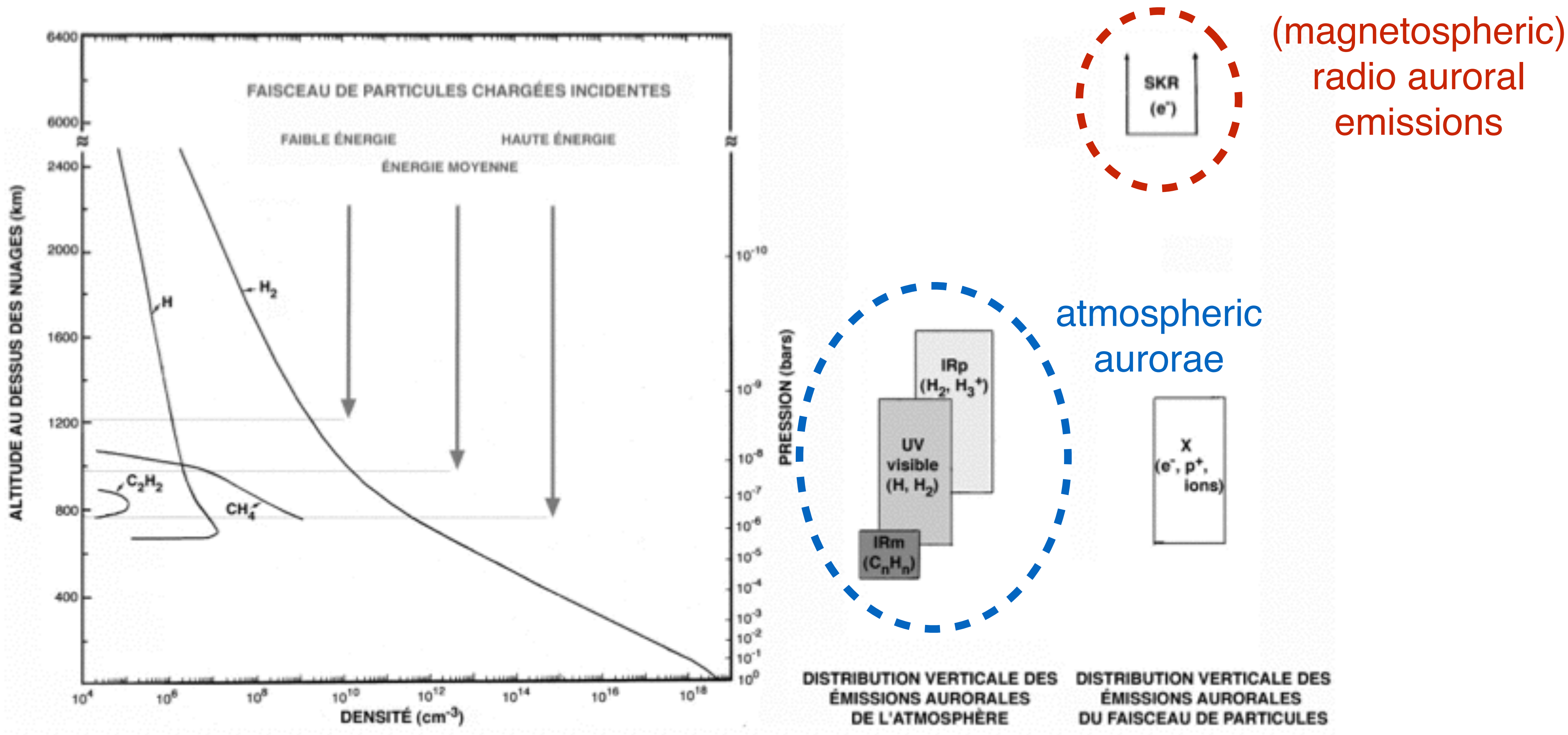
- Cyclotron Maser Instability (CMI) driven by electrons
- sensitive to MS dynamics (rotation, solar wind etc.)

2 - strongly anisotropic emission (complex morphology, arcs)

1 - correlation with other aurorae :

how/why ? useful to better understand AREs ?

Link between atmospheric and radio aurorae ?



Reasons <u>to expect</u> a close relationship :

- both types of emissions produced in auroral regions from …
- energetic source particles = 1-100 keV electrons

Link between atmospheric and radio aurorae ?

CMI

Resonance condition: $\omega = \omega_{ce}/\Gamma + k_{\parallel} v_{\parallel}$

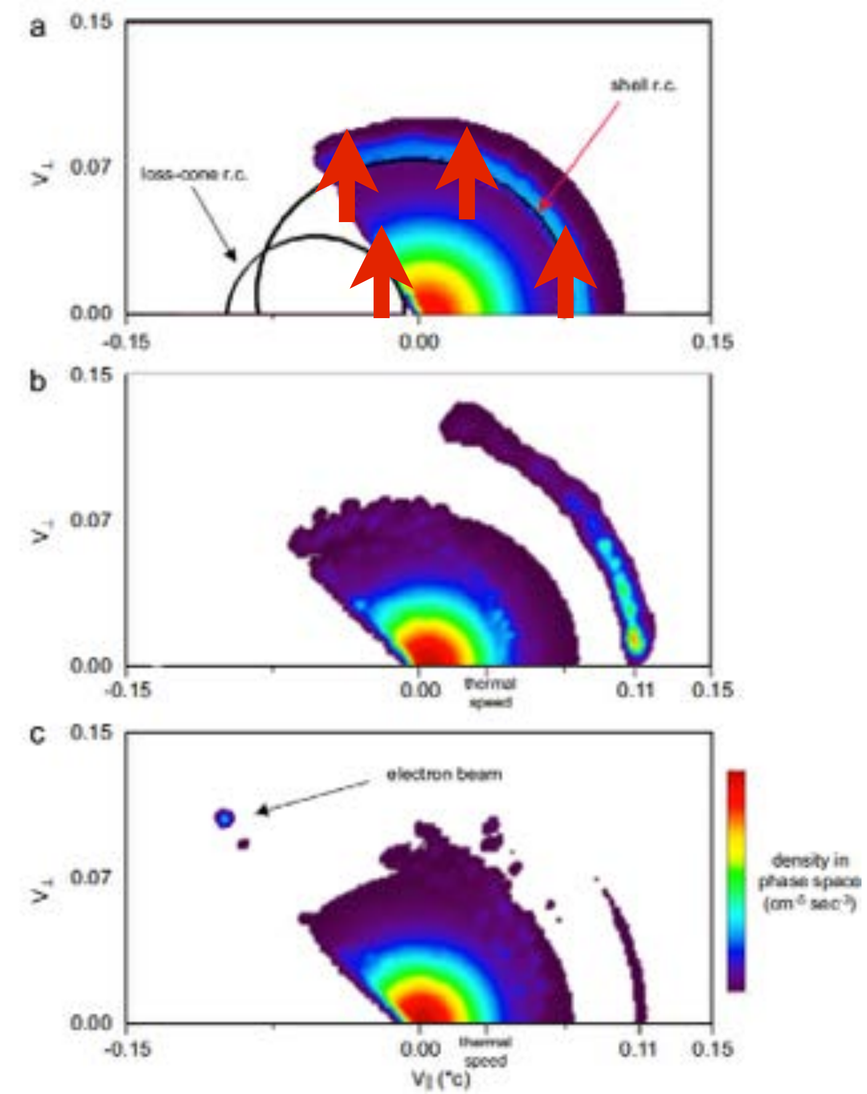
Wave growth rate :

$$\gamma \;\alpha\; \omega_{pe}^2/\omega^2 \int p_\perp^2 \, \partial f/\partial p_\perp \, (\omega - k_{//}v_{//} - \omega_{ce}/\Gamma)^{-1} \, d^3p$$

$$\alpha \iint_{v_{//},v_\perp} v_\perp^2 \, \partial f/\partial v_\perp \, \delta(\omega - k_{//}v_{//} - \omega_{ce}/\Gamma) \, dv_{//} \, dv_\perp$$

=> requires unstable (non-maxwellian) e-
=> max growth reached for perp. motion

(Wu and Lee, 1979 ; Wu, 1985 ; Treumann, 2000 ; Le Quéau, 1984)

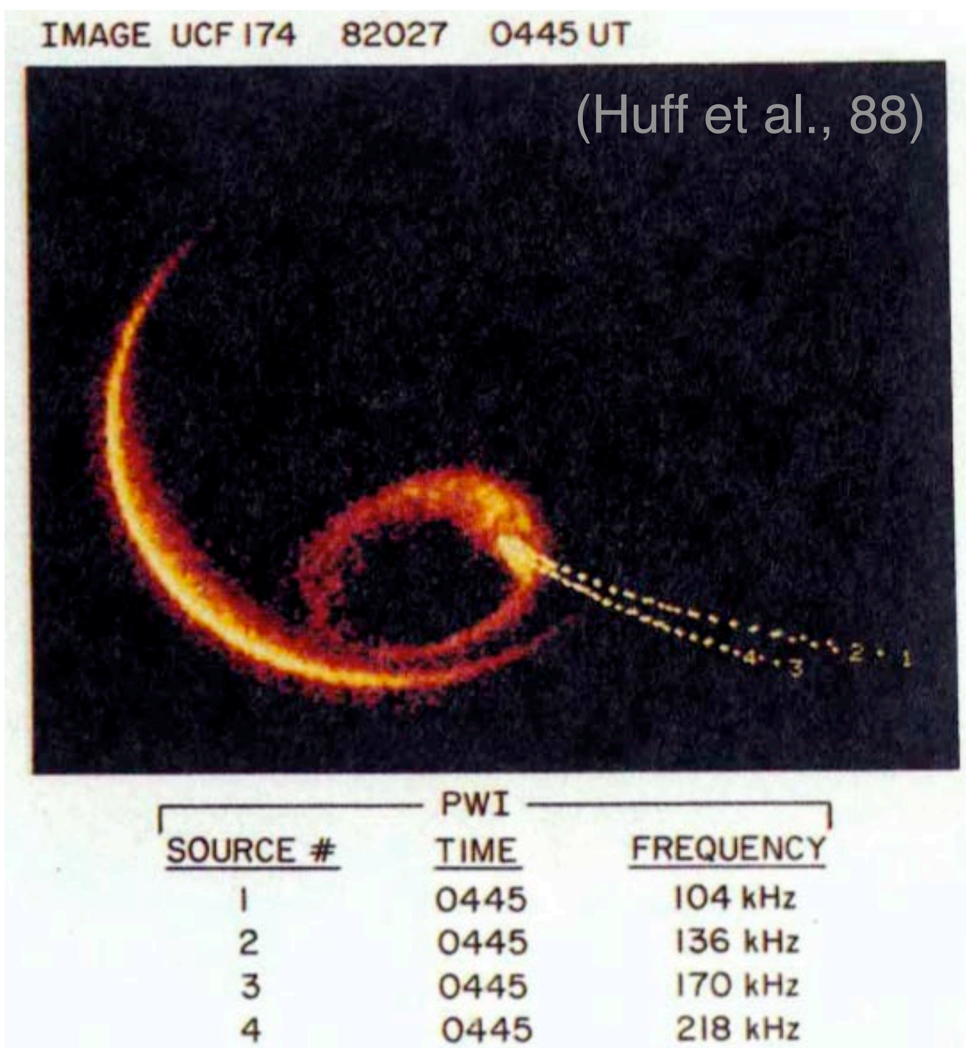


courtesy to S. Hess

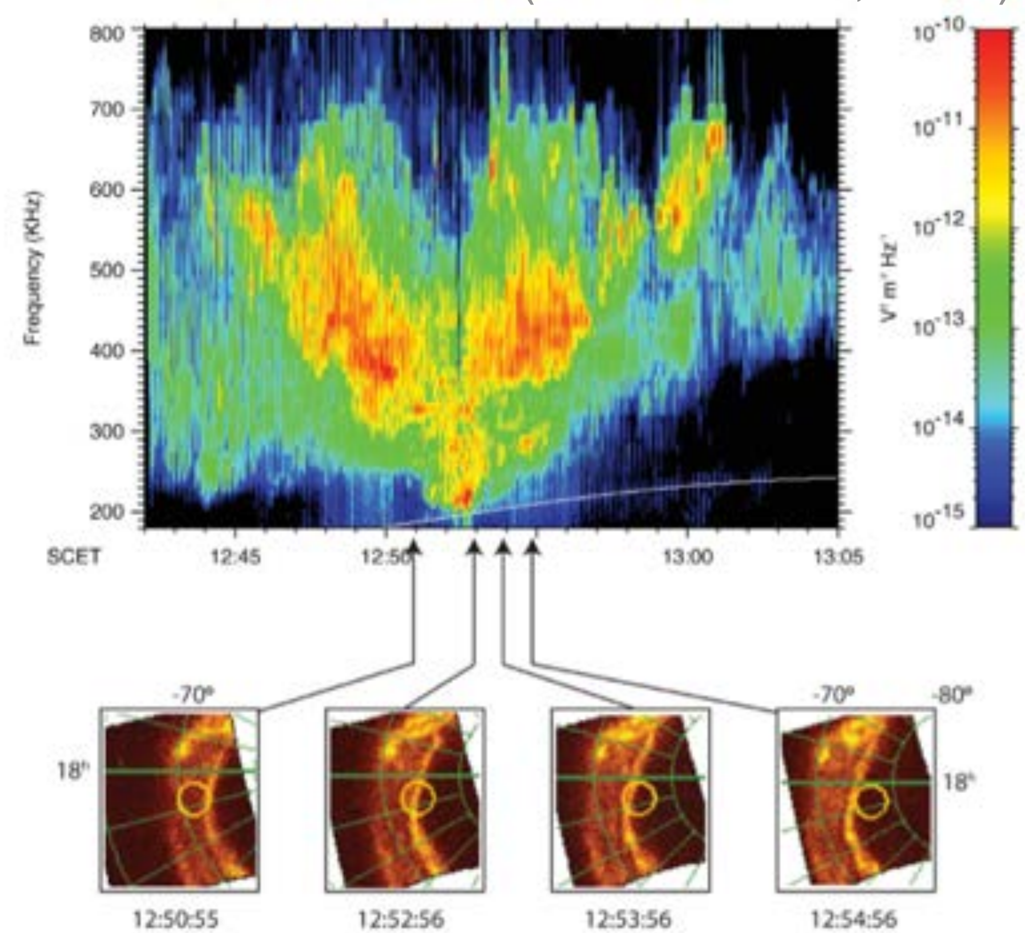
Reasons <u>to question</u> a close relationship :
- atmospheric aurorae can be produced by precipitating ions as well
- CMI displays a maximal wave amplification for perp. electron motion
(= electrons reaching their mirror point)

Link between atmospheric and radio aurorae ?

<u>Earth :</u>
- AKR and auroral power correlated (+ triggered by substorms) (Morioka et al., 2010)
- direct evidence for spatial conjugacy with radiogoniopolarimetry (Huff et al., 1988)
- many *in situ* analysis of AKR sources = upward field-aligned currents (Roux et al., 1993)



(Menietti et al., 2011)



+ (Panchenko et al., 2003 ; Mutel et al., 2004)

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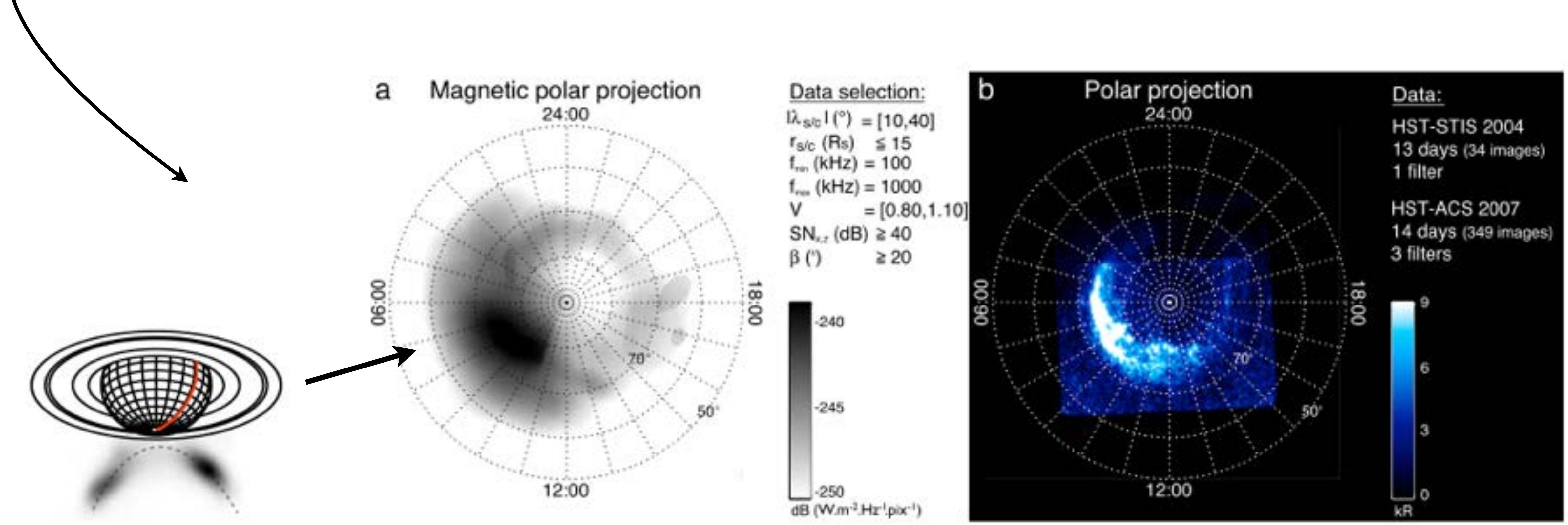
<u>Jupiter :</u>

- DAM activity correlated with UV aurorae for Io / non-Io emissions (Prangé et al., 1993)

<u>Saturn :</u>

- SKR and auroral power correlated (+ triggered by SW compressions) (Clarke et al., 2009)
- direct evidence for spatial conjugacy with radiogoniopolarimetry (Lamy et al., 2009)
- only 2 *in situ* analysis of SKR sources = upward field-aligned currents (Lamy et al., 2010)



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In summary :

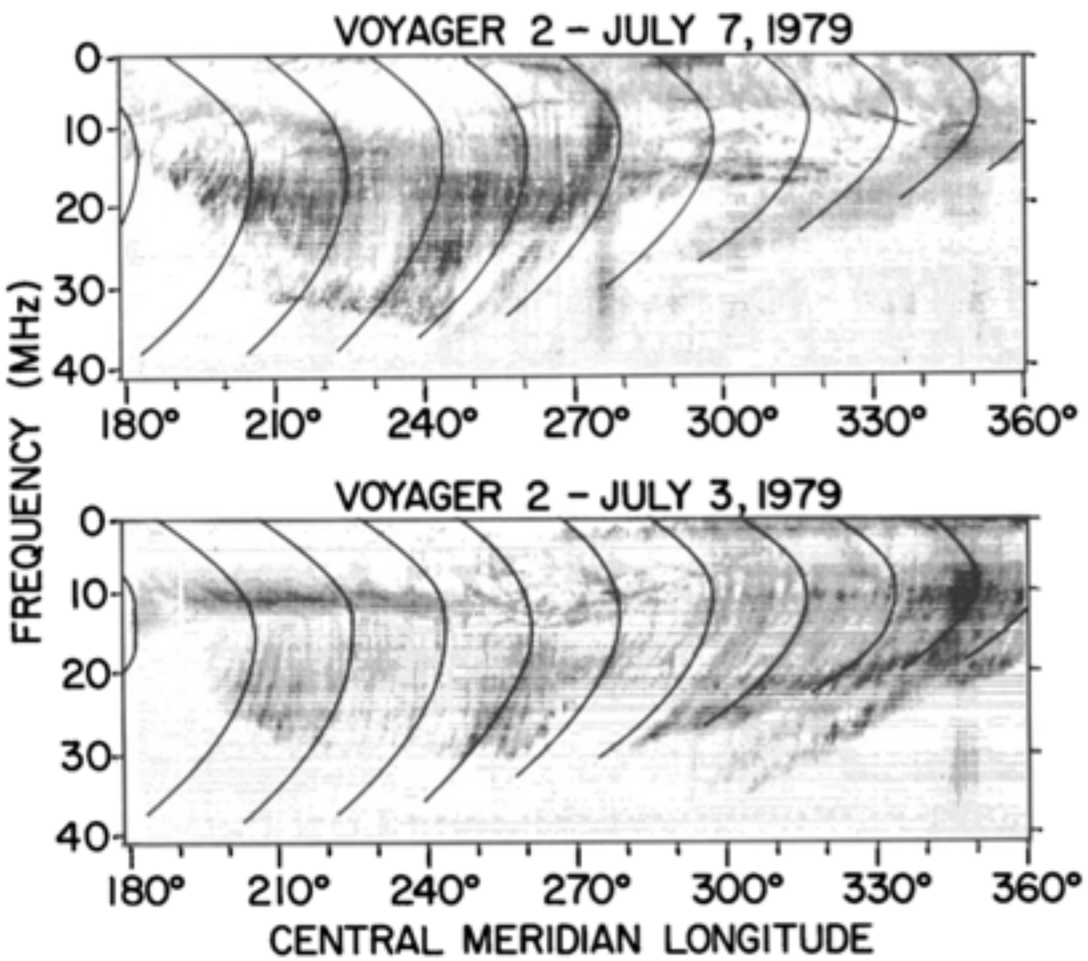
- common properties shared by the investigated planets
- radio sources lie along field lines mapping to (bright) atmospheric aurorae
- both emissions are believed to be triggered by a common population of electrons (not directly the same electrons)

=> atmospheric aurorae helpful to simulate radio emissions and better understand their anisotropy

Modeling of planetary radio emissions

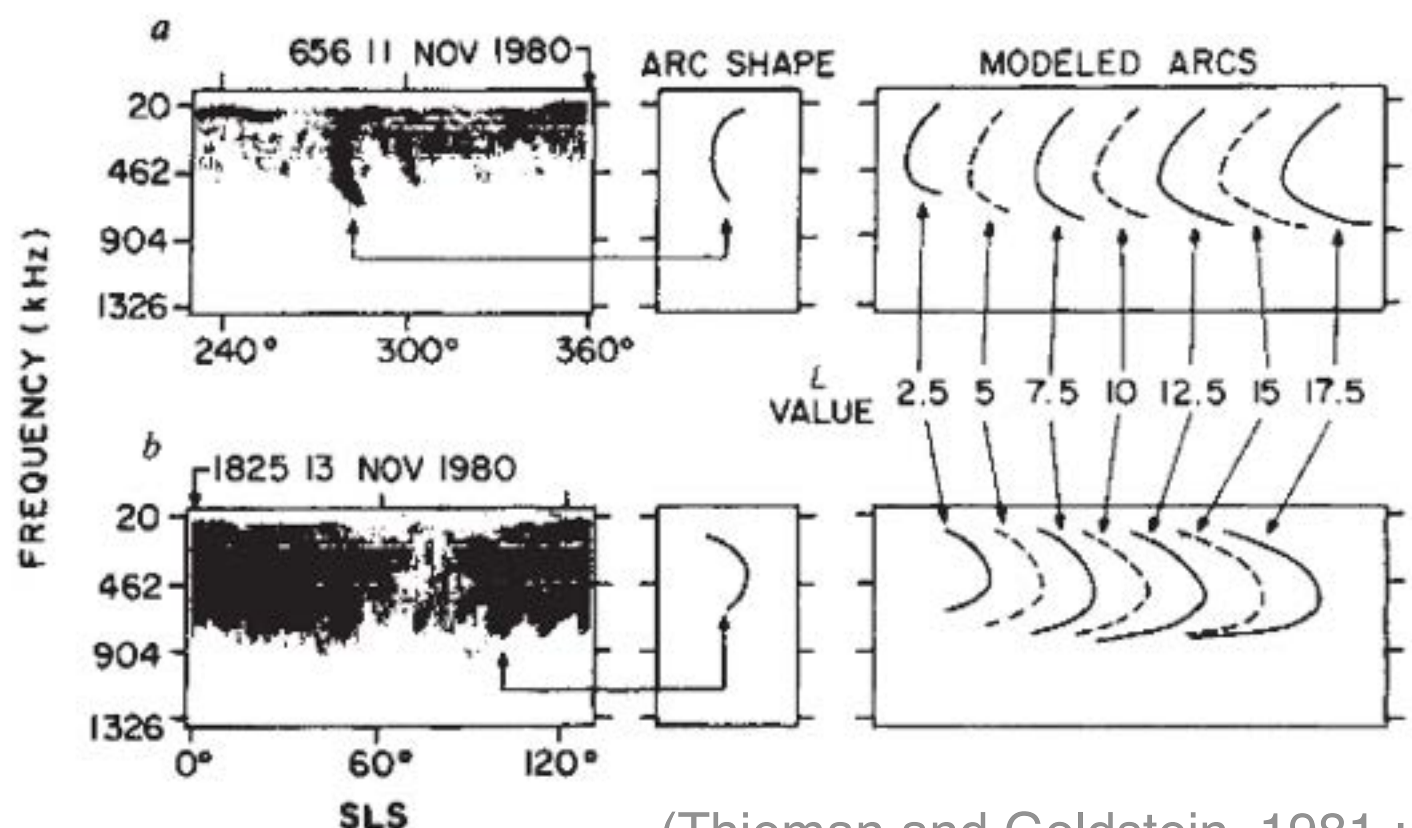
- 1980s : early early attempts to model arcs with empirical beaming + fixed sources

JUPITER



(Goldstein and Thieman, 1981)

SATURN



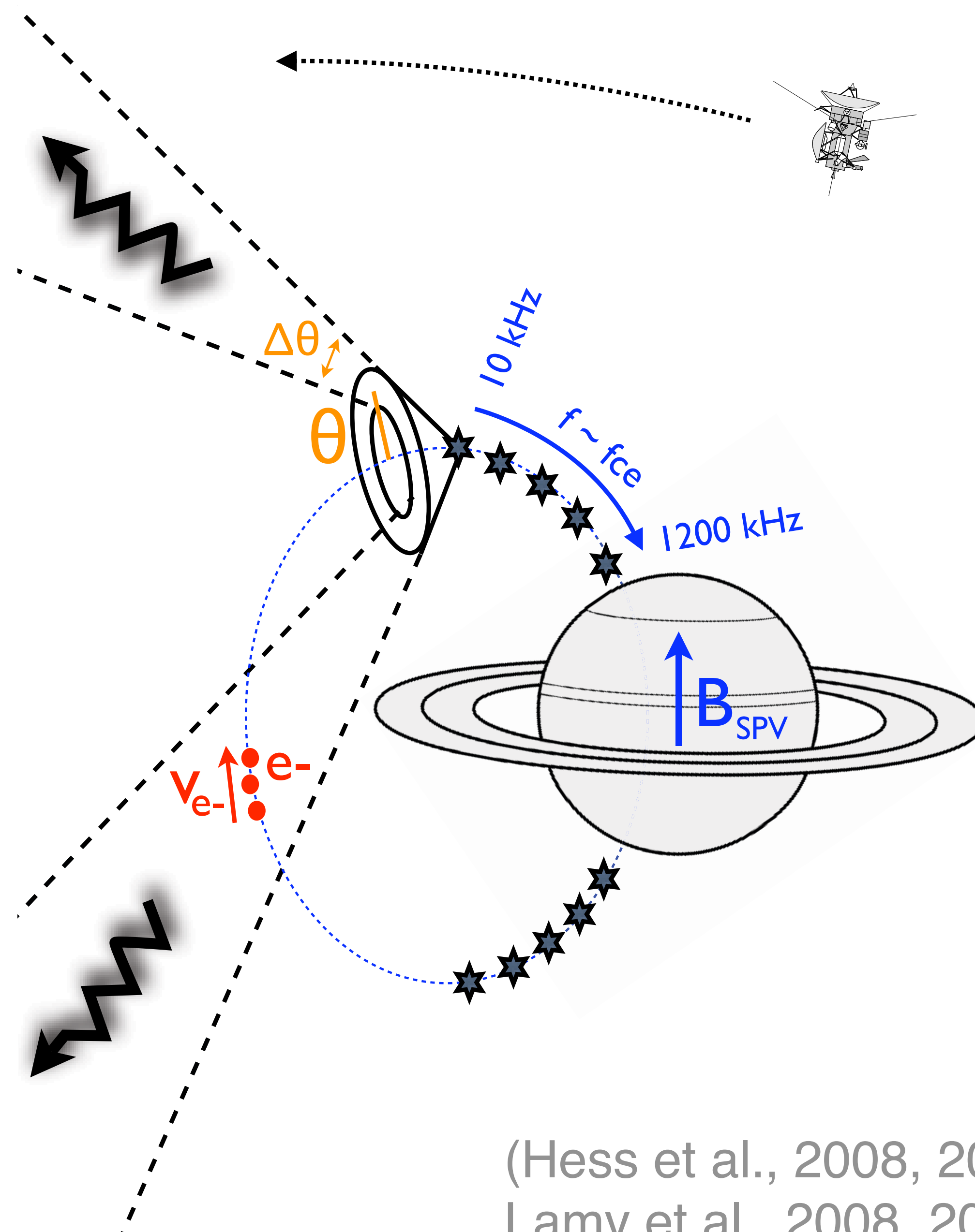
(Thieman and Goldstein, 1981 ; Boischot et al., 1981)

Modeling of planetary radio emissions

- 1980s : early early attempts to model arcs with empirical beaming + fixed sources
- 2010s : accurate modeling with the ExPRES code using realistic inputs

Principle of the ExPRES code :

- up-to-date magnetic field models
- assume $f \sim f_{ce}$ + straight-line propag.
- realistic beaming angles (observed or theoretically calculated)
- realistic source position



(Hess et al., 2008, 2010, in prep. ; Lamy et al., 2008, 2013)

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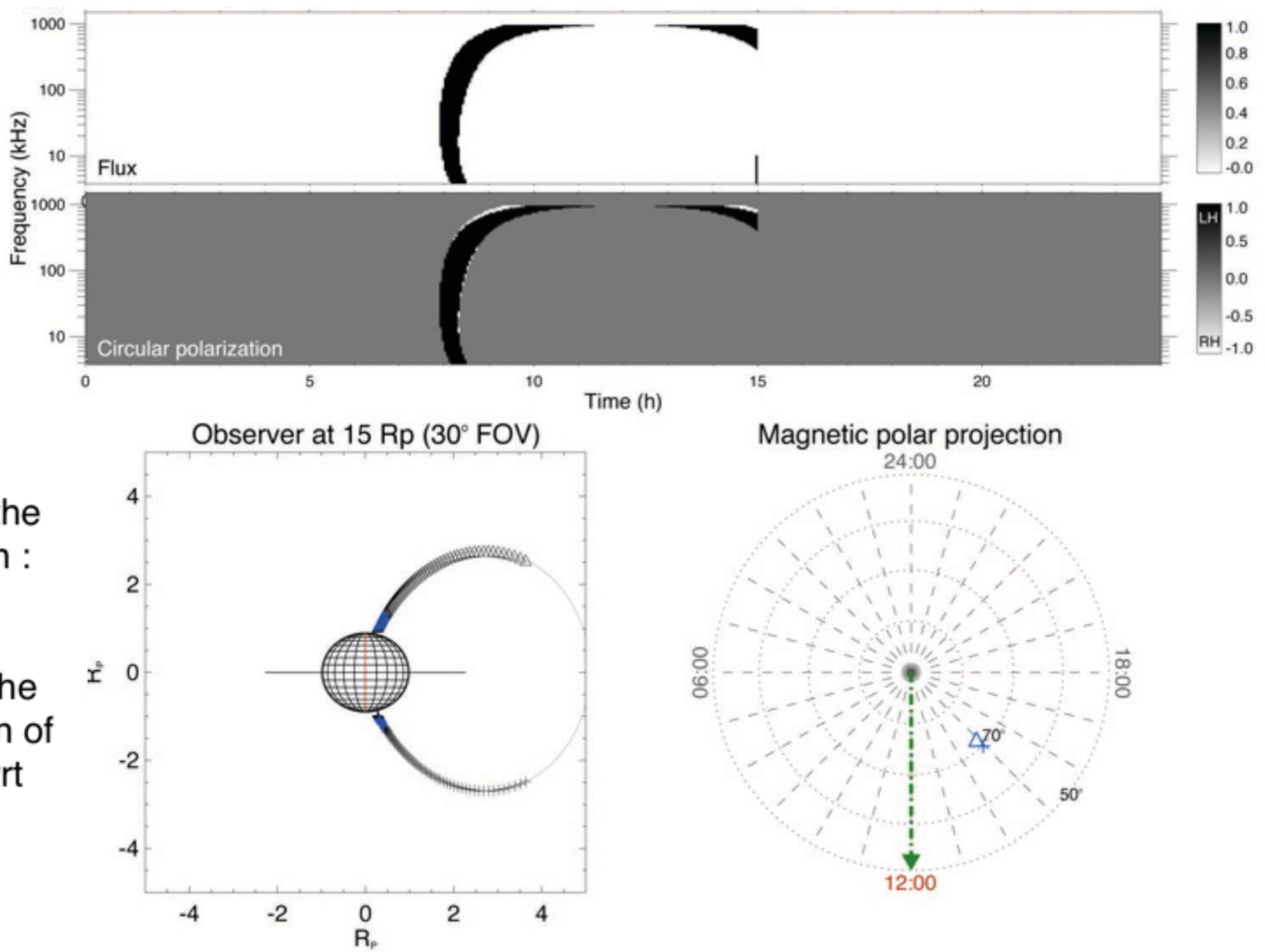
Illustration in the case of Saturn :

arc-shape = produced by the relative motion of the sources wrt the observer



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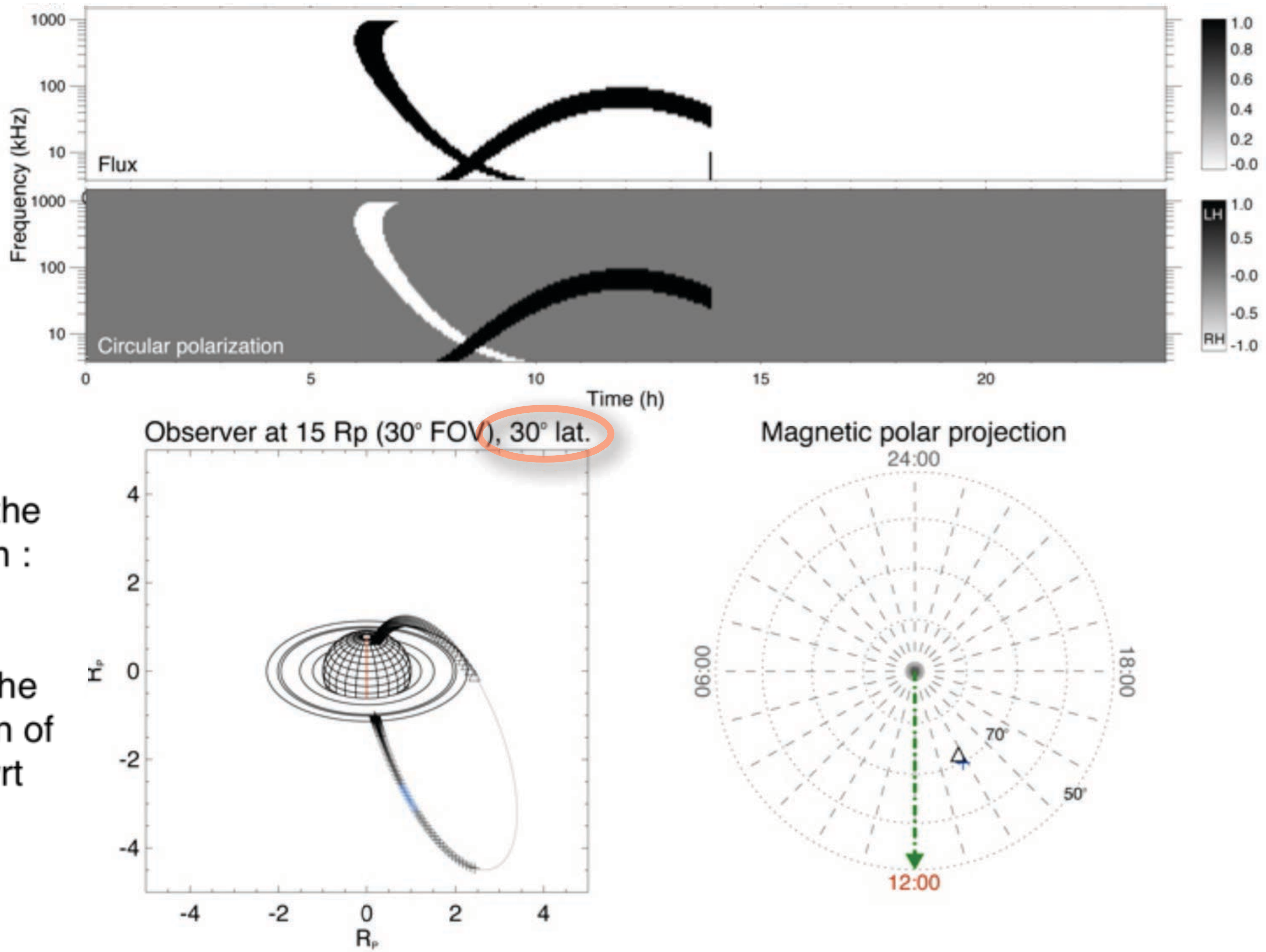

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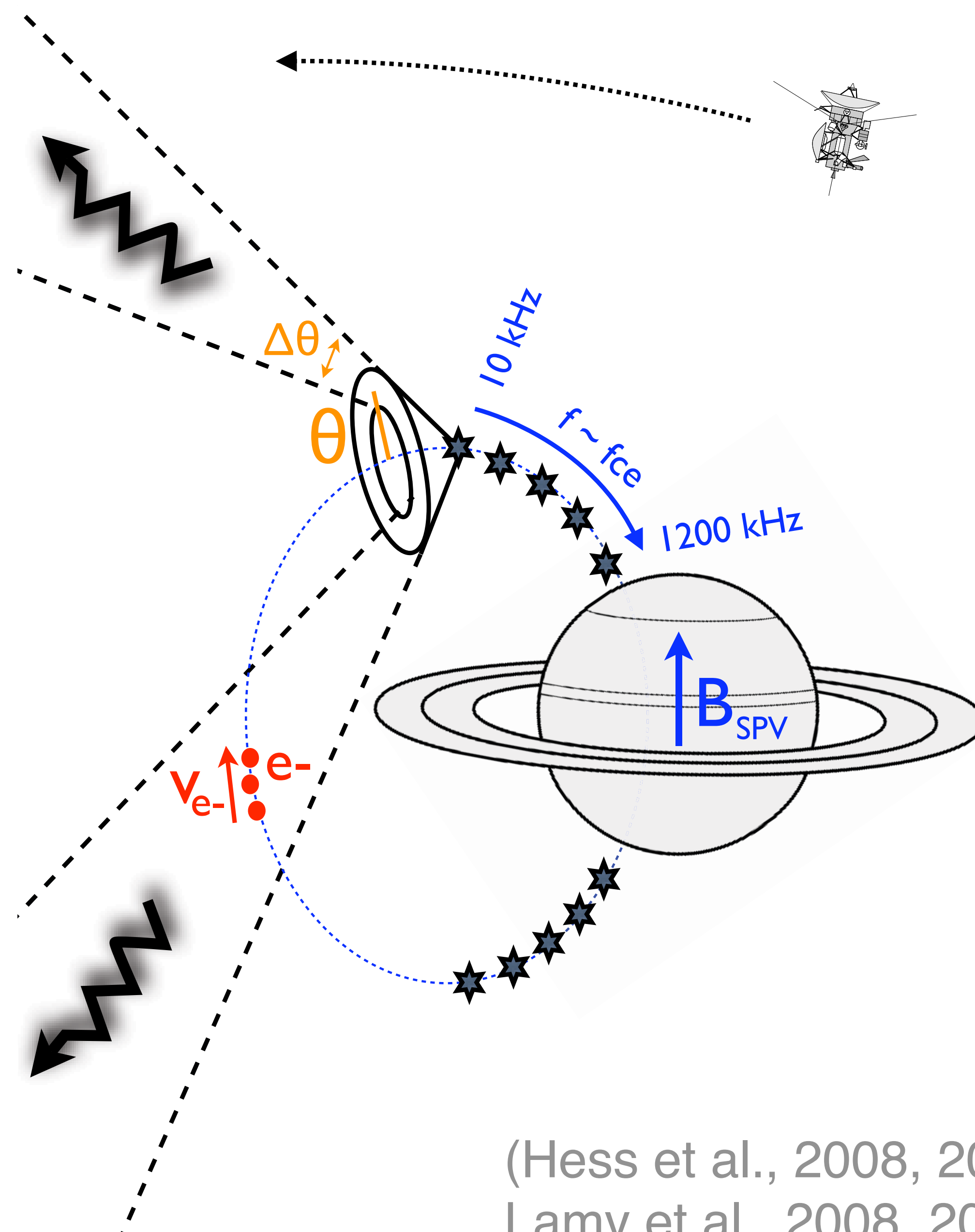
↑

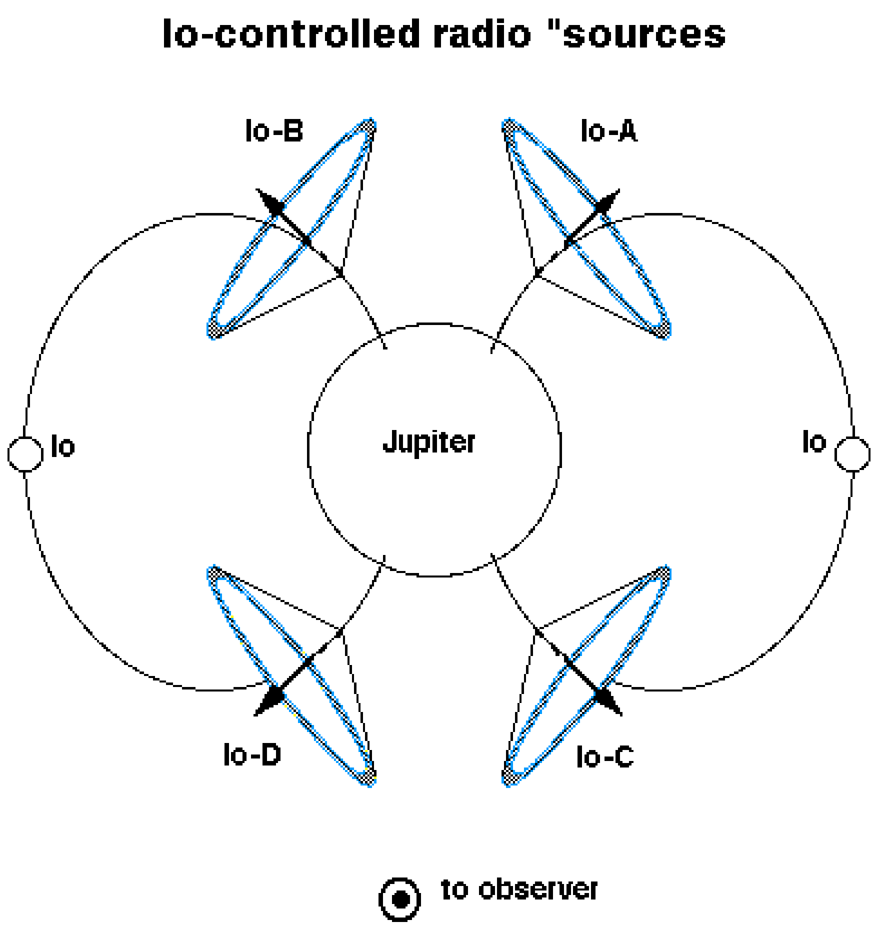
using atmospheric aurorae to fix « radio-active » field lines => reduces free parameters to the beaming angle only

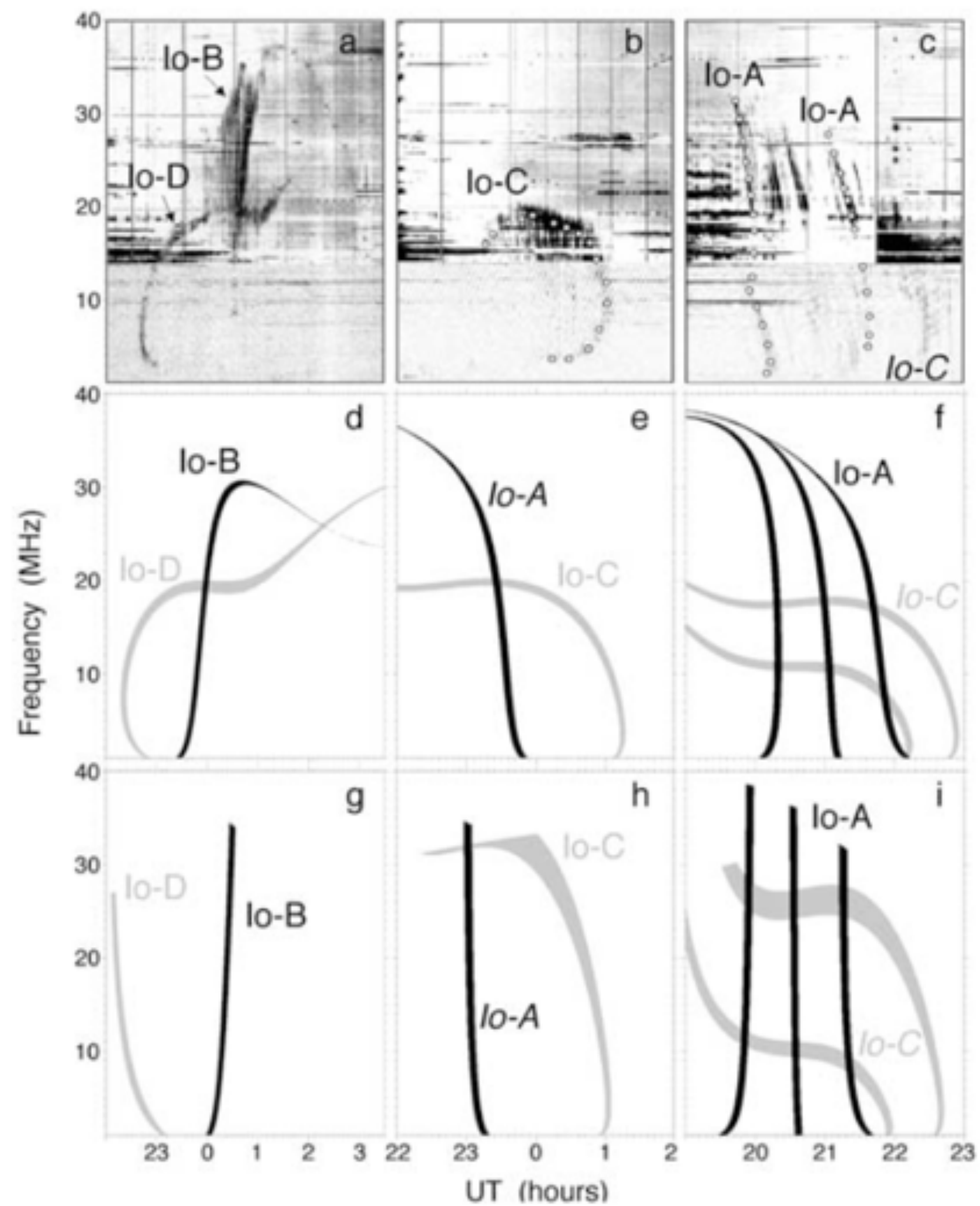


(Hess et al., 2008, 2010, in prep. ; Lamy et al., 2008, 2013)

Modeling of planetary radio emissions

Jupiter : successful modeling of Io arcs



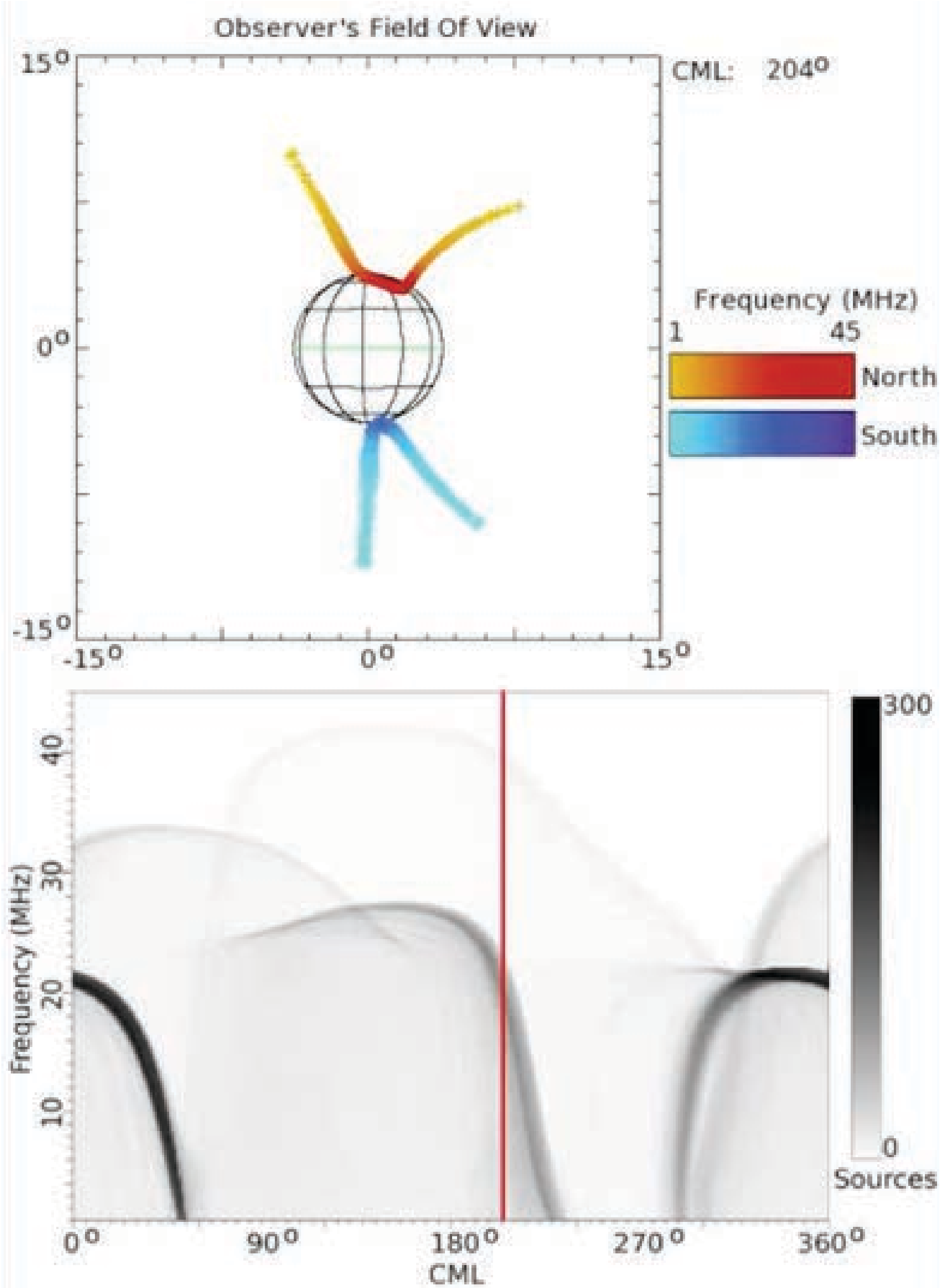


(Hess et al., 2008)

Best-fit :
loss-cone electron distribution
E(e-) ~ 1-3 keV & Lead angle ~ 1-40°

Modeling of planetary radio emissions

<u>Jupiter :</u> successful modeling of Io and non-Io DAM as seen from JUICE and Voyager



(Cecconi et al., 2012)

non-Io DAM as seen from Ganymede

<u>NB :</u> realistic observed and modeled beaming angles

=> good matching which helps to predict periods of observations along JUICE's orbit

Modeling of planetary radio emissions

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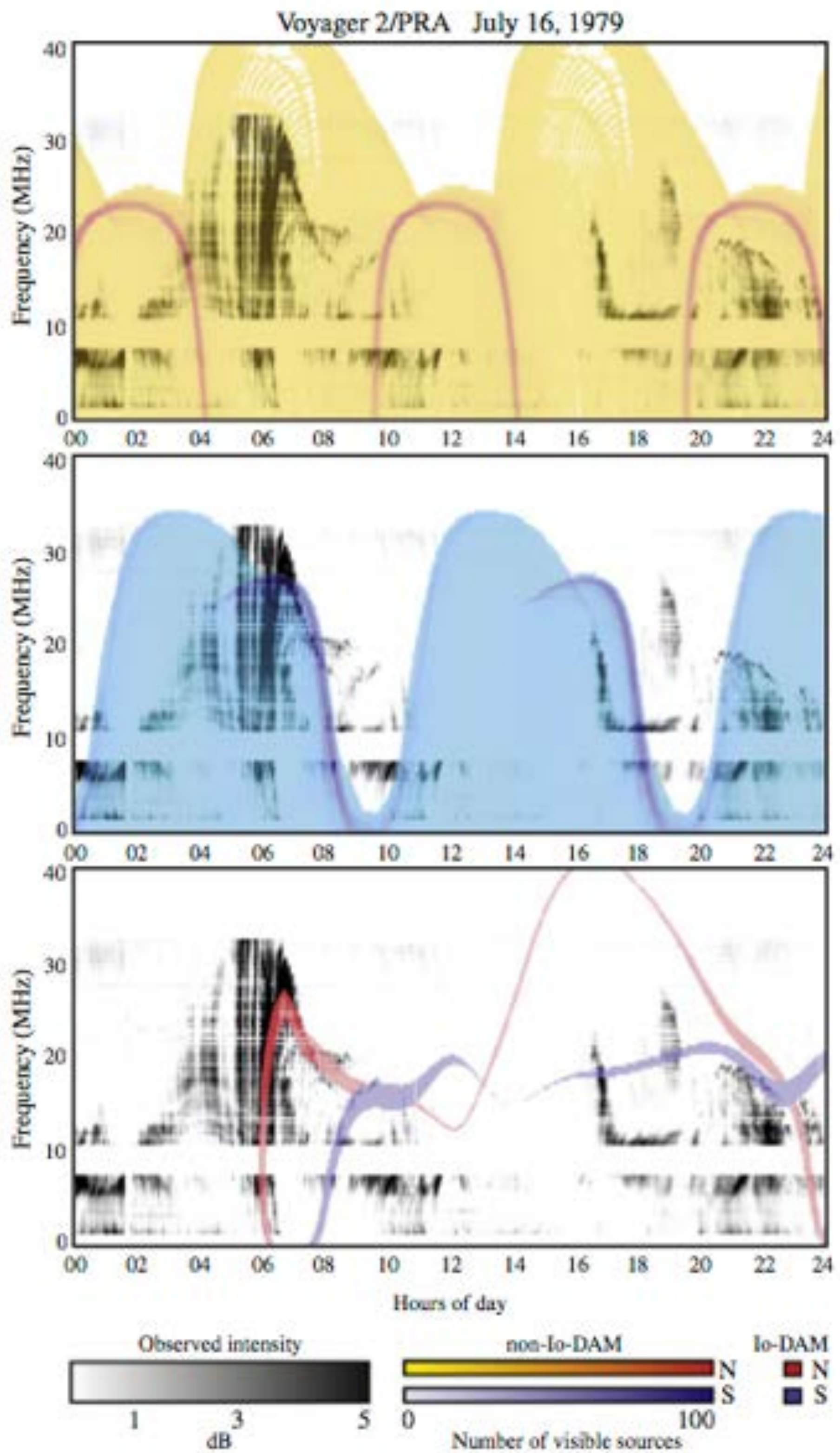

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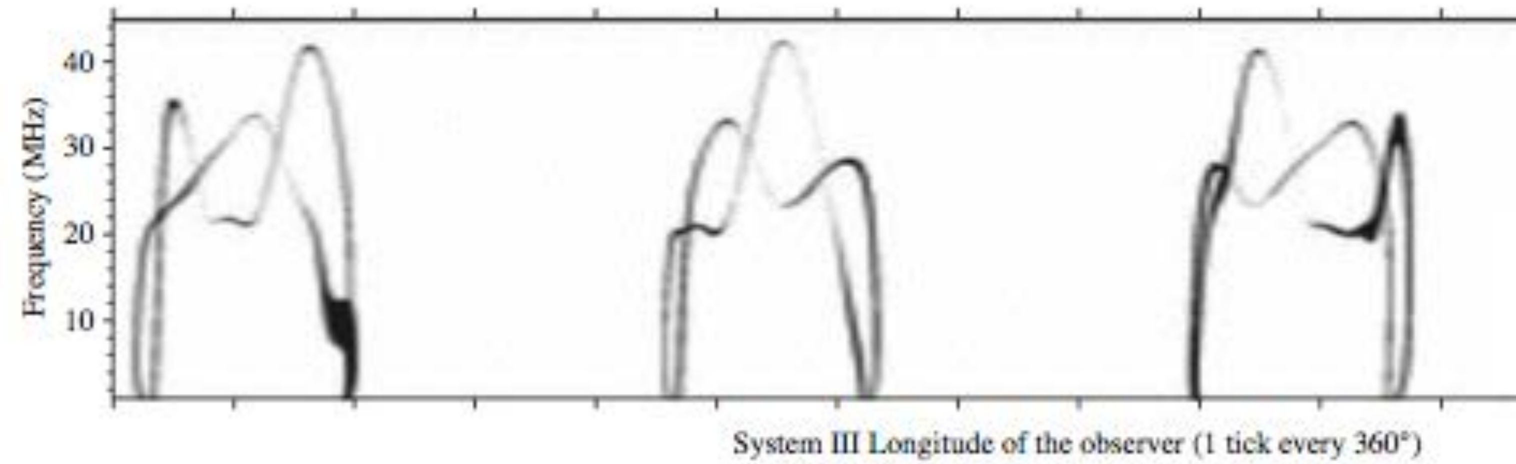
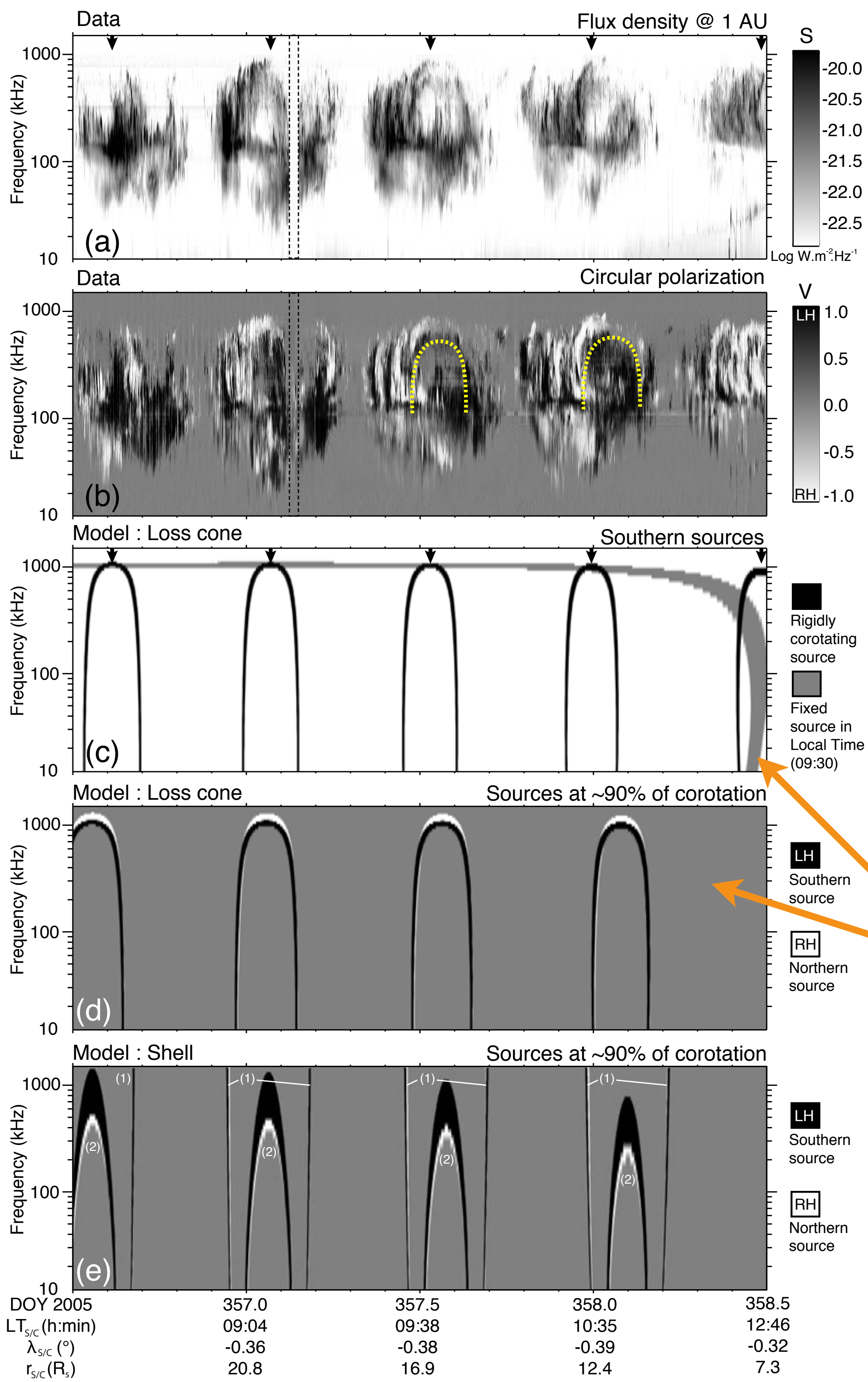


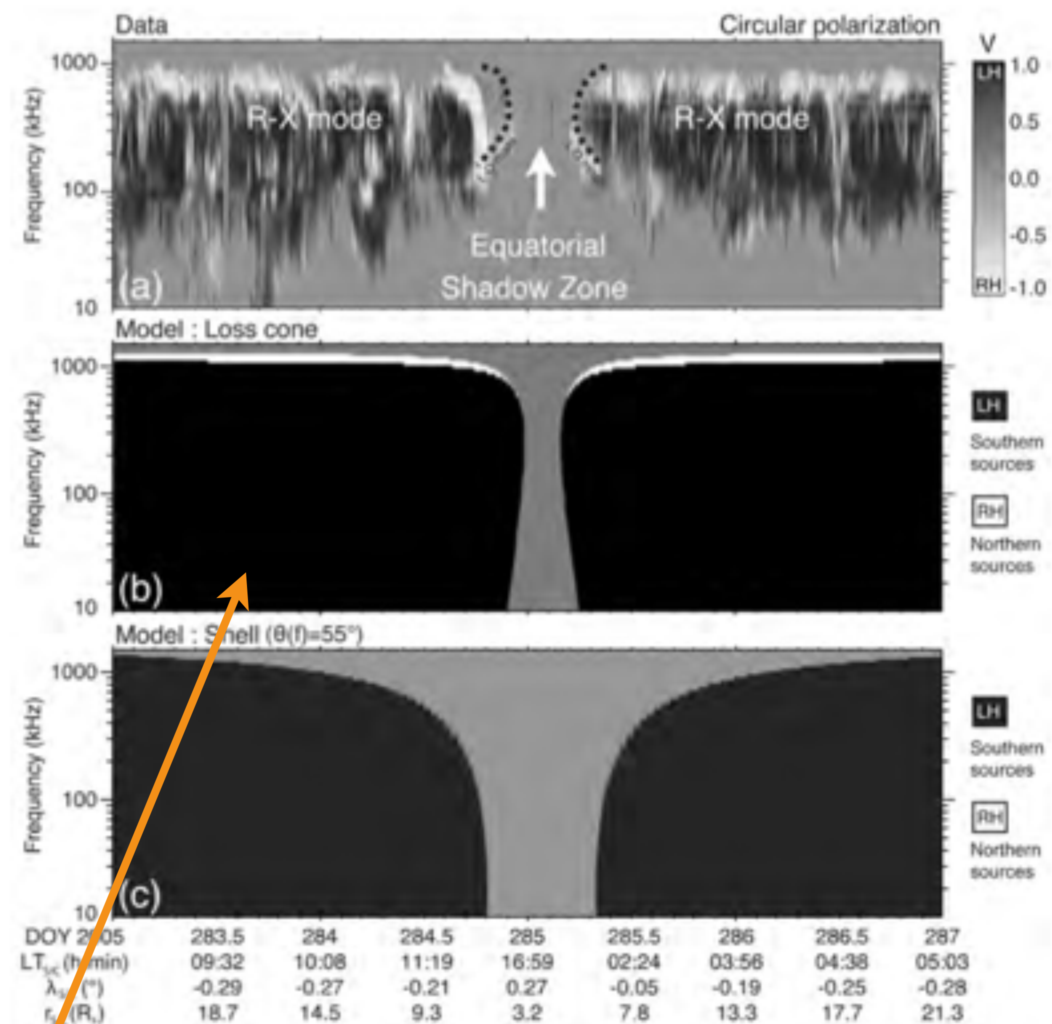
Io-DAM as seen from Ganymede

non Io-DAM as seen from Voyager 2

Modeling of planetary radio emissions

Saturn : successful modeling of SKR arcs and signal extinction





(Lamy et al., 2008)

NB : circular auroral oval

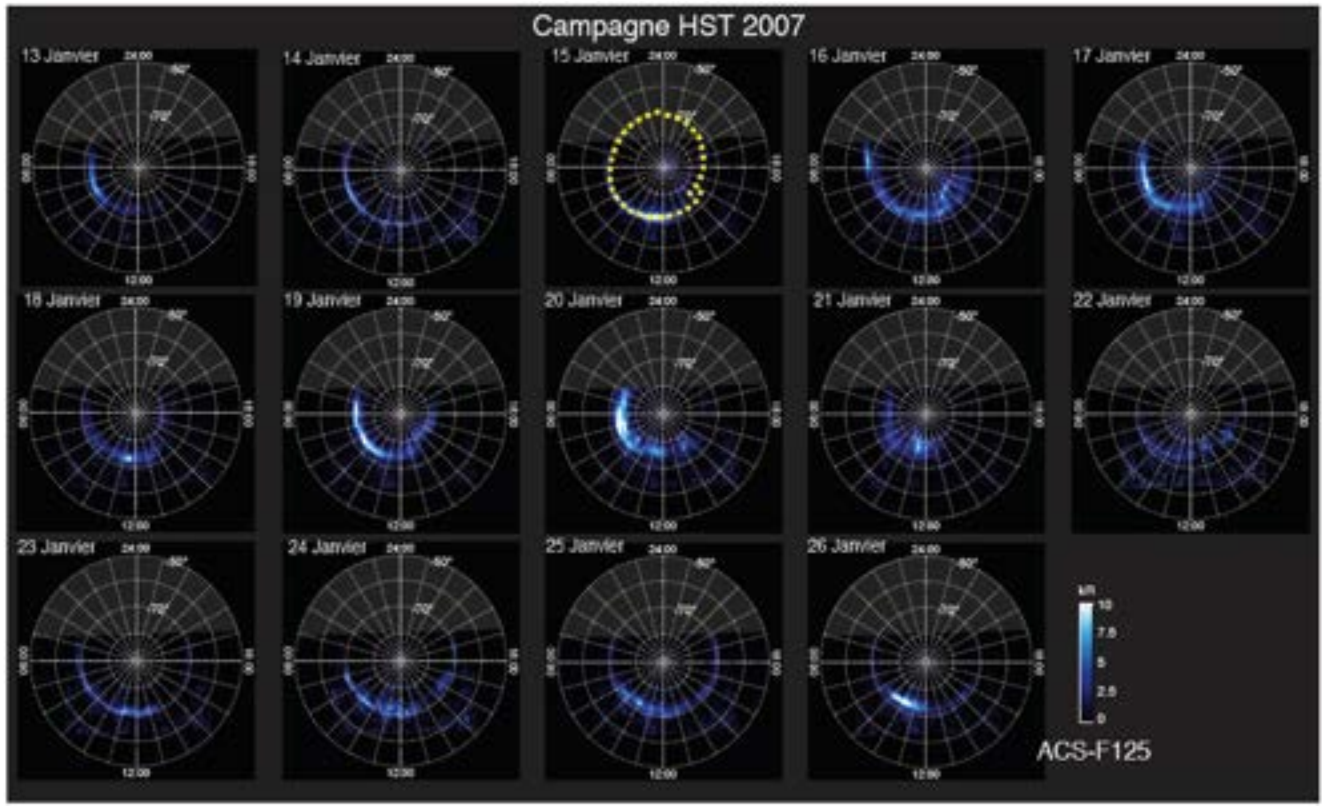
Best-fit :

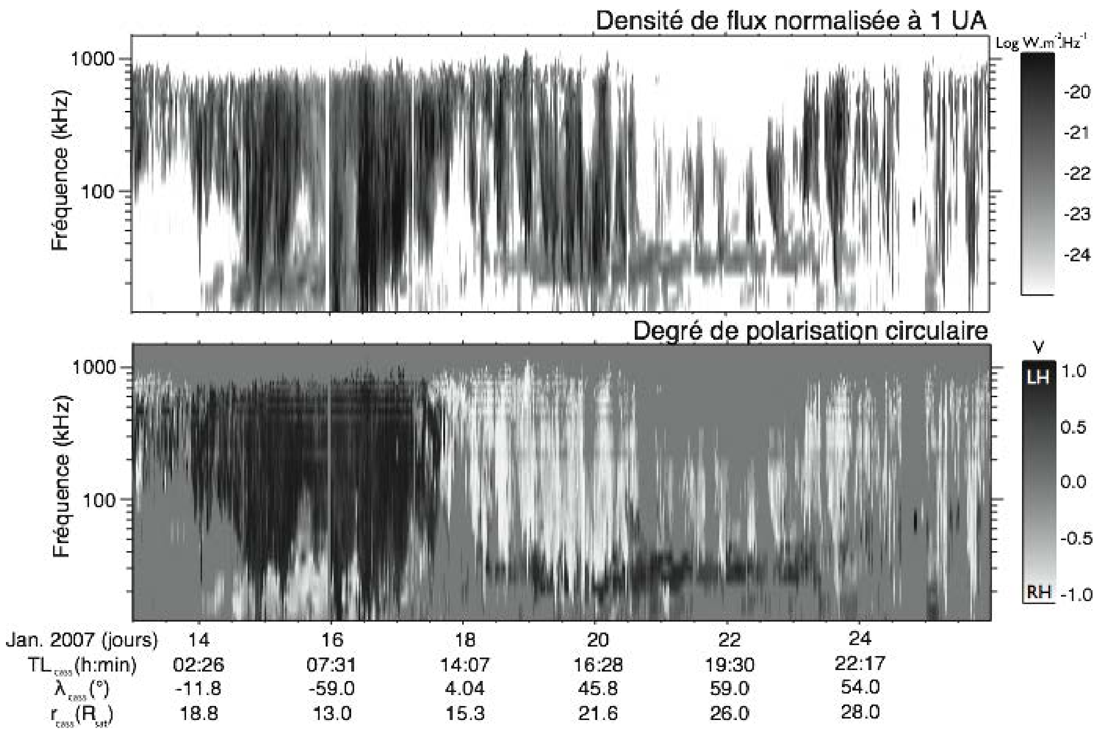
- loss-cone distribution with E(e-) = 20keV e-
- repeated arc = (sub-) corotating source

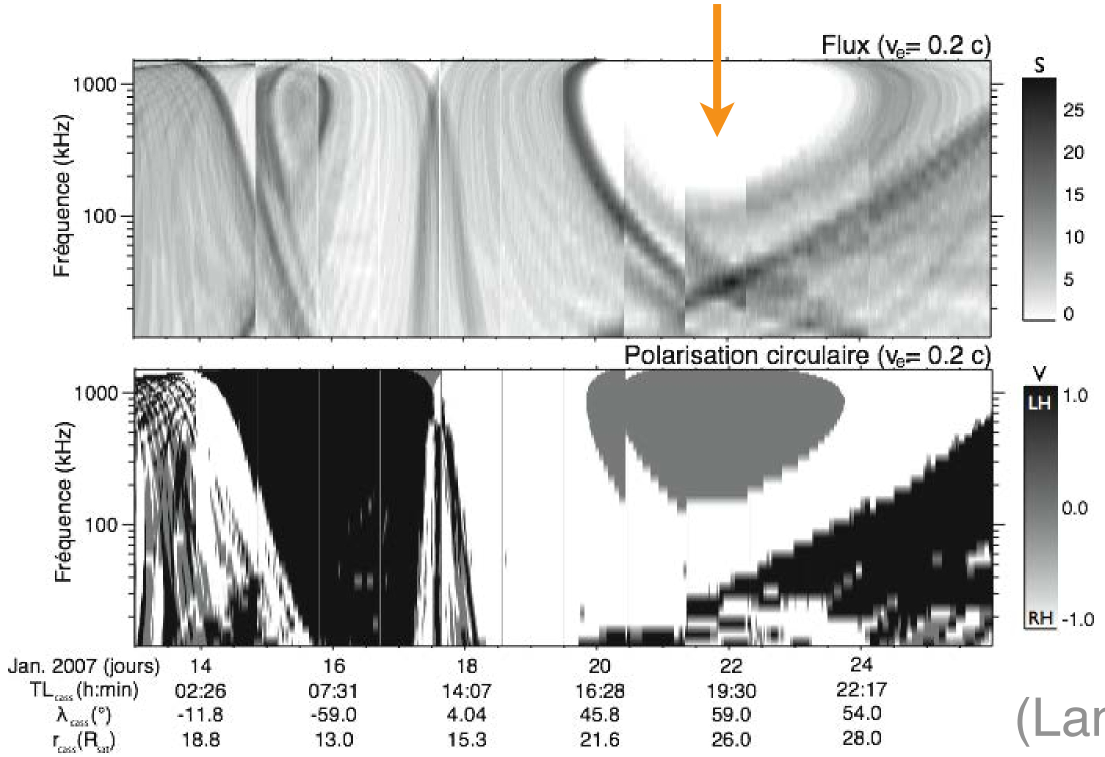
Modeling of planetary radio emissions

<u>Saturn :</u> successful modeling of high latitude SKR extinctions

<u>NB :</u> real-time auroral oval







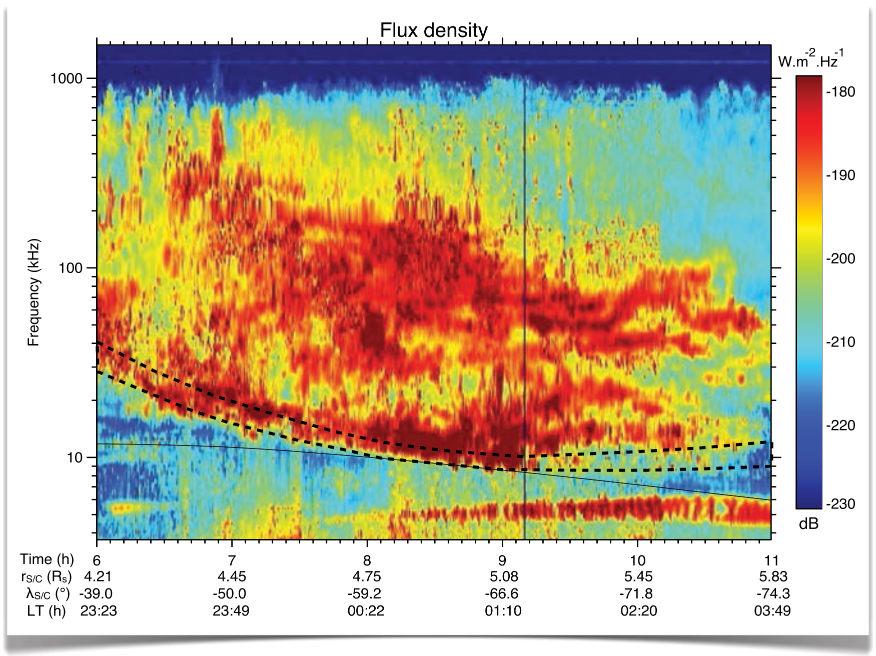
(Lamy, 08)

Modeling of planetary radio emissions

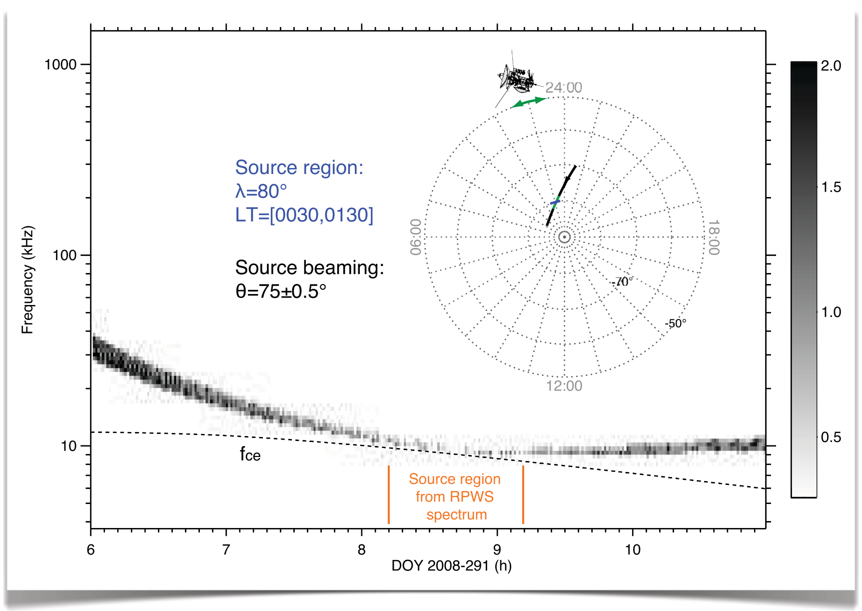
Saturn / Earth : successful modeling of source crossings

SKR visibility modeling

SATURN



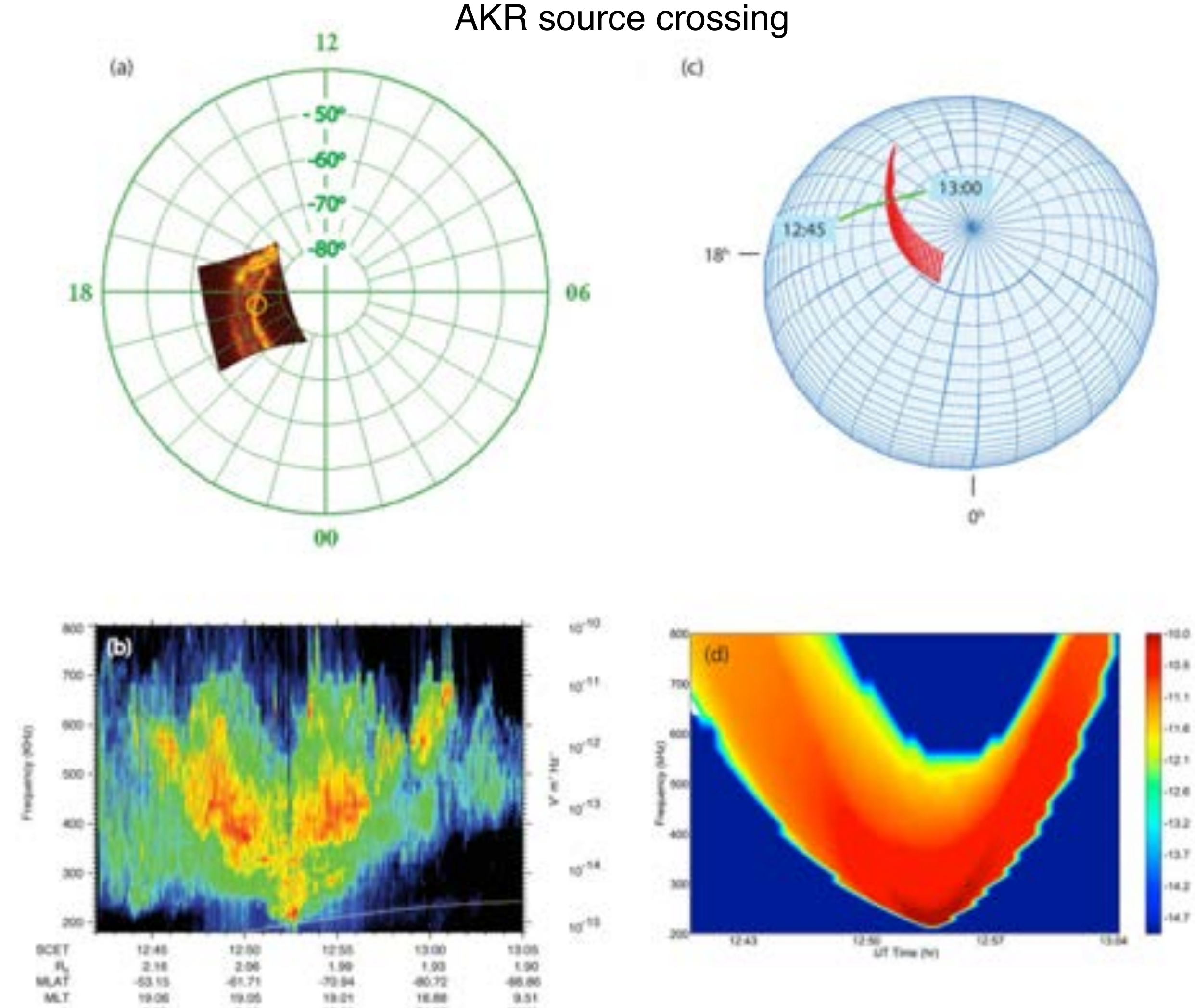
SKR visibility modeling



(Lamy et al. 2010)

EARTH

AKR source crossing

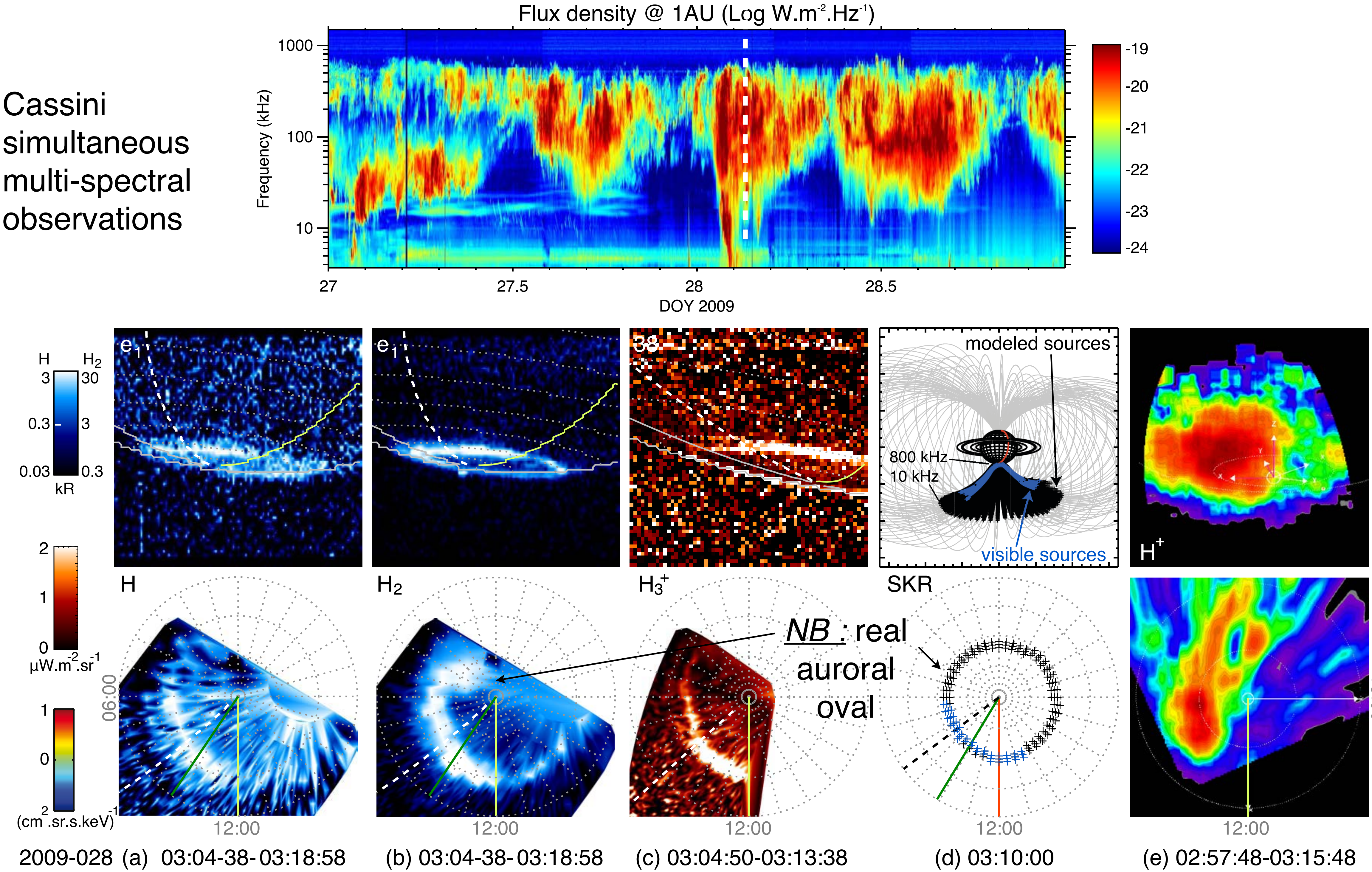


(Menietti et al. 2011)

Modeling of planetary radio emissions

<u>Saturn :</u> simulations can then be used to refine our understanding of dynamic spectra

Cassini simultaneous multi-spectral observations



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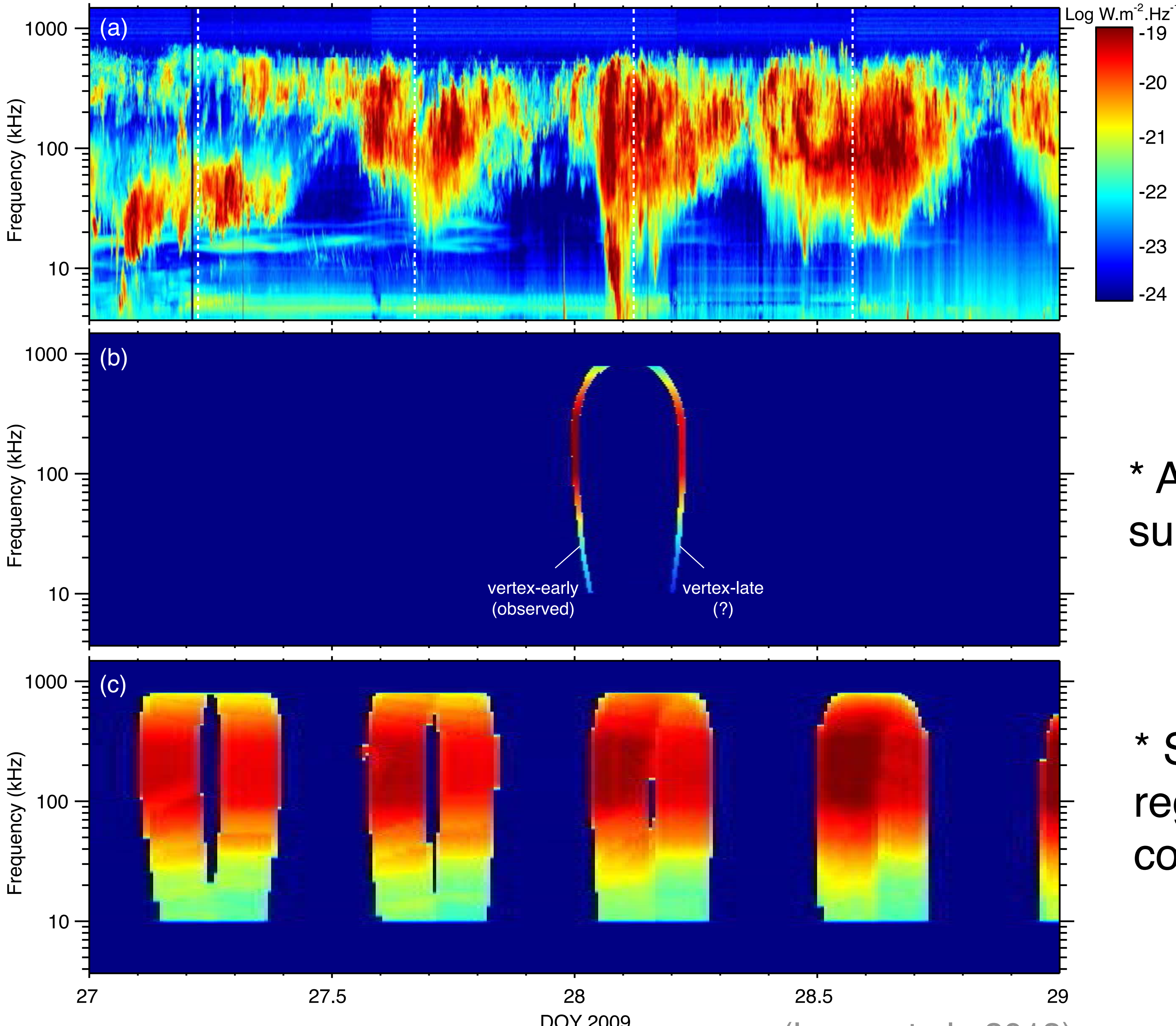


(Lamy et al., 2013)

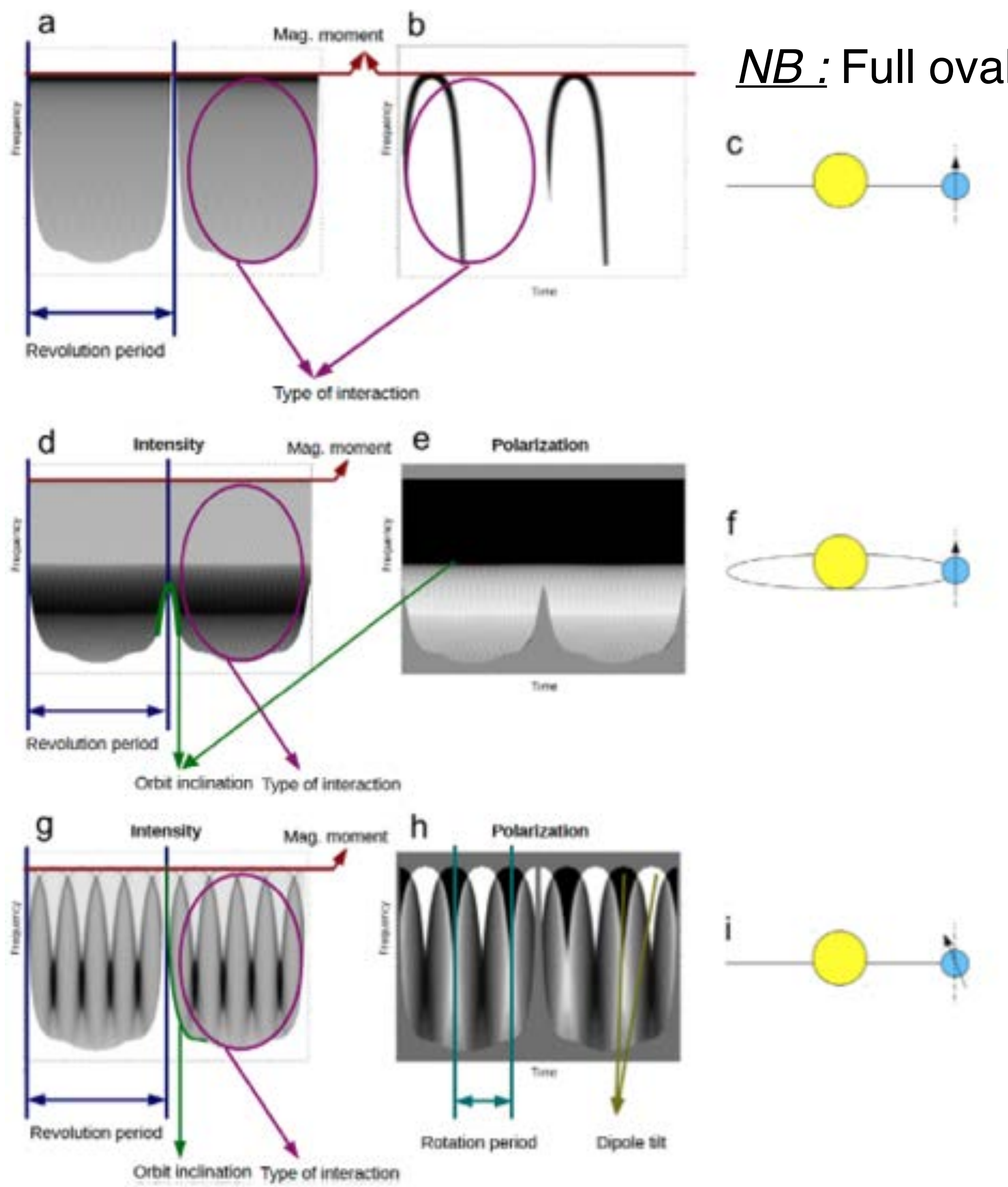
* Total visible power ~ a few % of the total radiated power

* Arc = auroral hot spot in sub-corotation

* SKR modulation = bright region of the auroral oval in corotation

Modeling of planetary radio emissions

Exoplanets : simulations of exoplanetary emissions (to be detected) provide a wealth of informations of exoplanetary characteristics



NB : Full oval

Parametric simulations of different types of emissions (interactions)

Shape of dynamic spectra provide :
- the magnetic field strength
- the dipole tilt and offset
- the rotation period
- the orbital revolution period and inclination

(Hess et al., 2011)

Conclusions

1- Close relationship atmospheric aurorae and auroral radio emissions :
- same dynamics : controlled by the same large-scale drivers
- spatial conjugacy : radio sources lie in upFAC regions, along field lines mapping to bright atmospheric aurorae
=> the study of AREs benefits from the knowledge of the position and variability of atmospheric aurorae

2- Modern realistic simulations (eg with ExPRES) are quite successful :
- better understanding of the physics of radio emission and propagation (beaming angle, frequency cutoff, polarization)
- provide a powerful diagnostic tool once extrapolated to exoplanets

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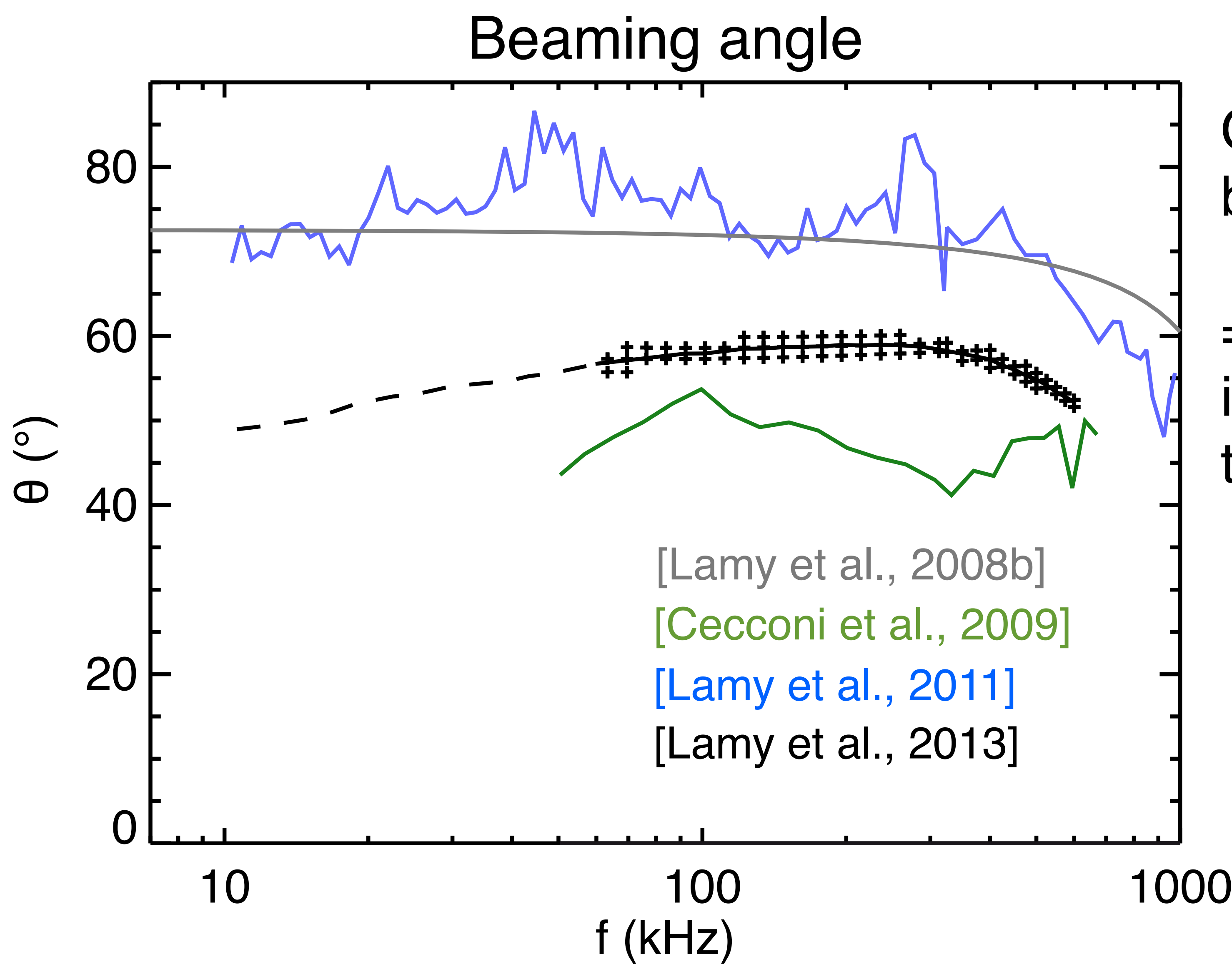
3- Thanks to Sébastien for giving this talk of 24 slides in 12min + addressing questions

SKR beaming angle

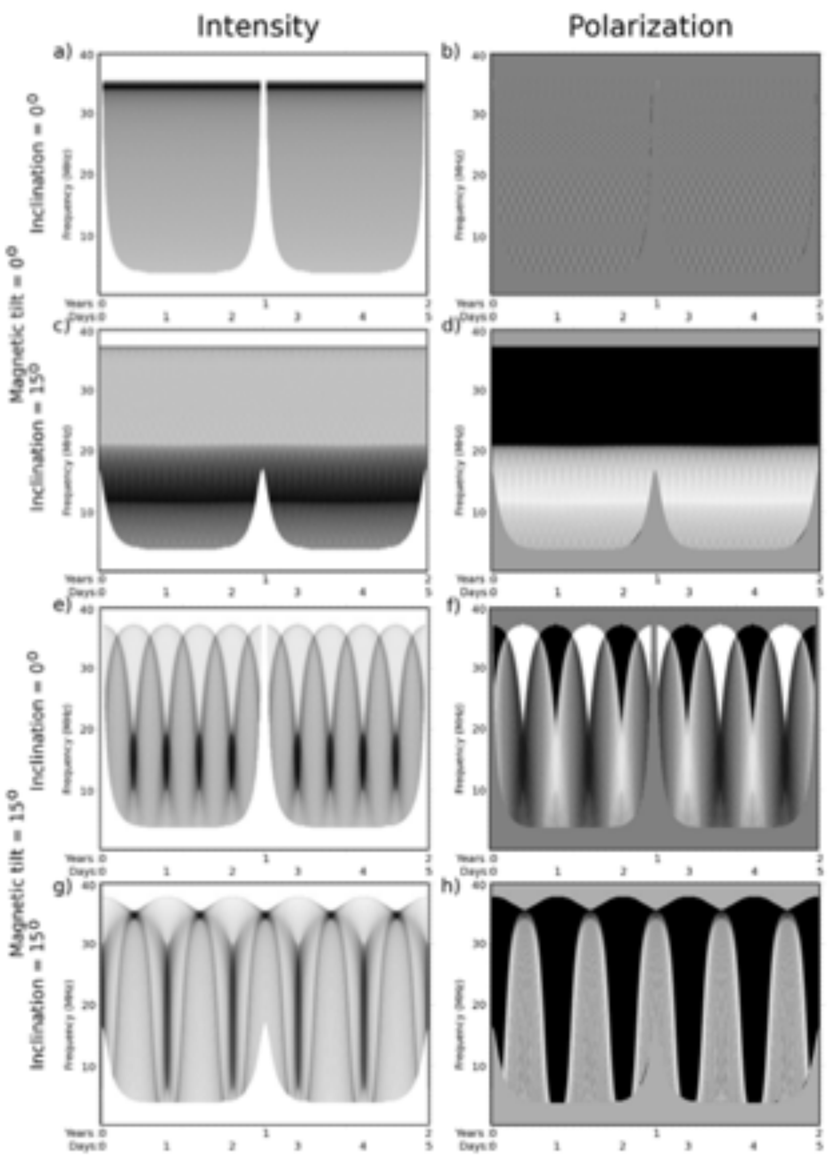


Observations yield very different beaming angles !

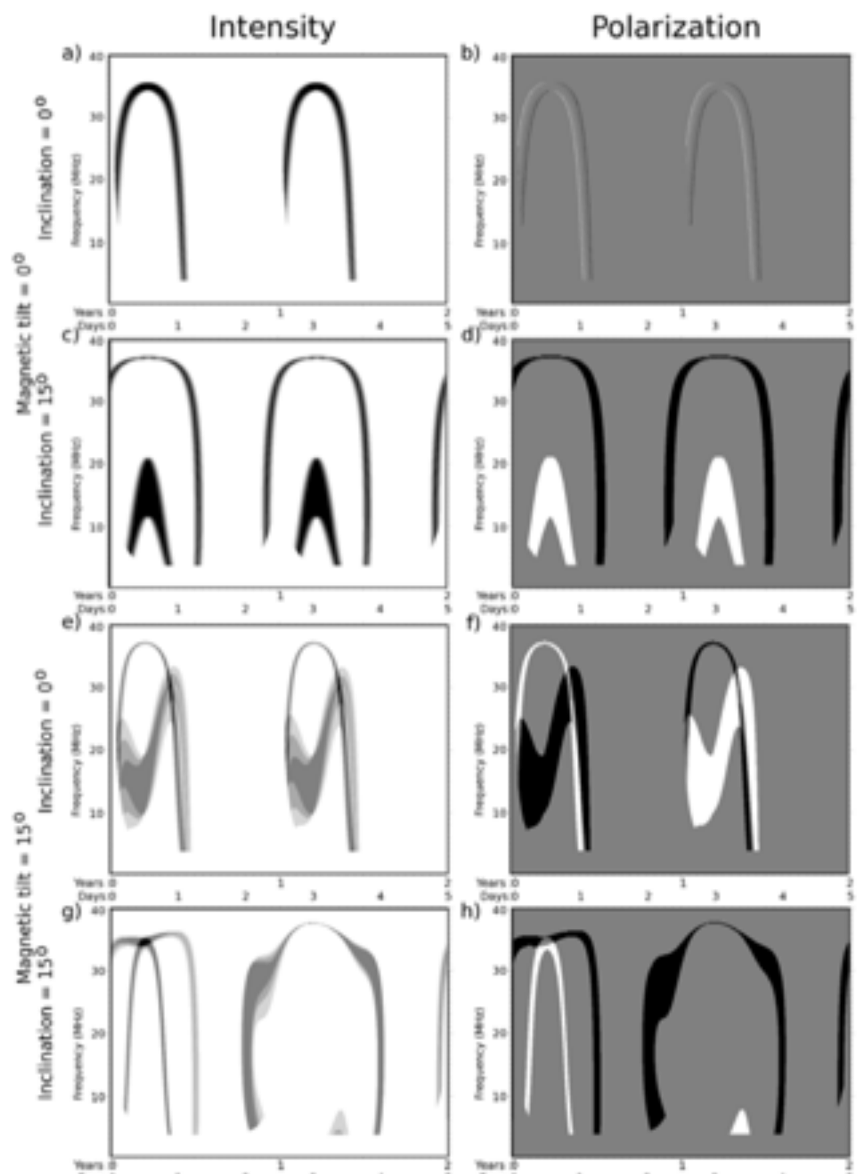
=> crucial to understand the origin of its variability (refraction/geometry, temporal variation...)

Exoplanets

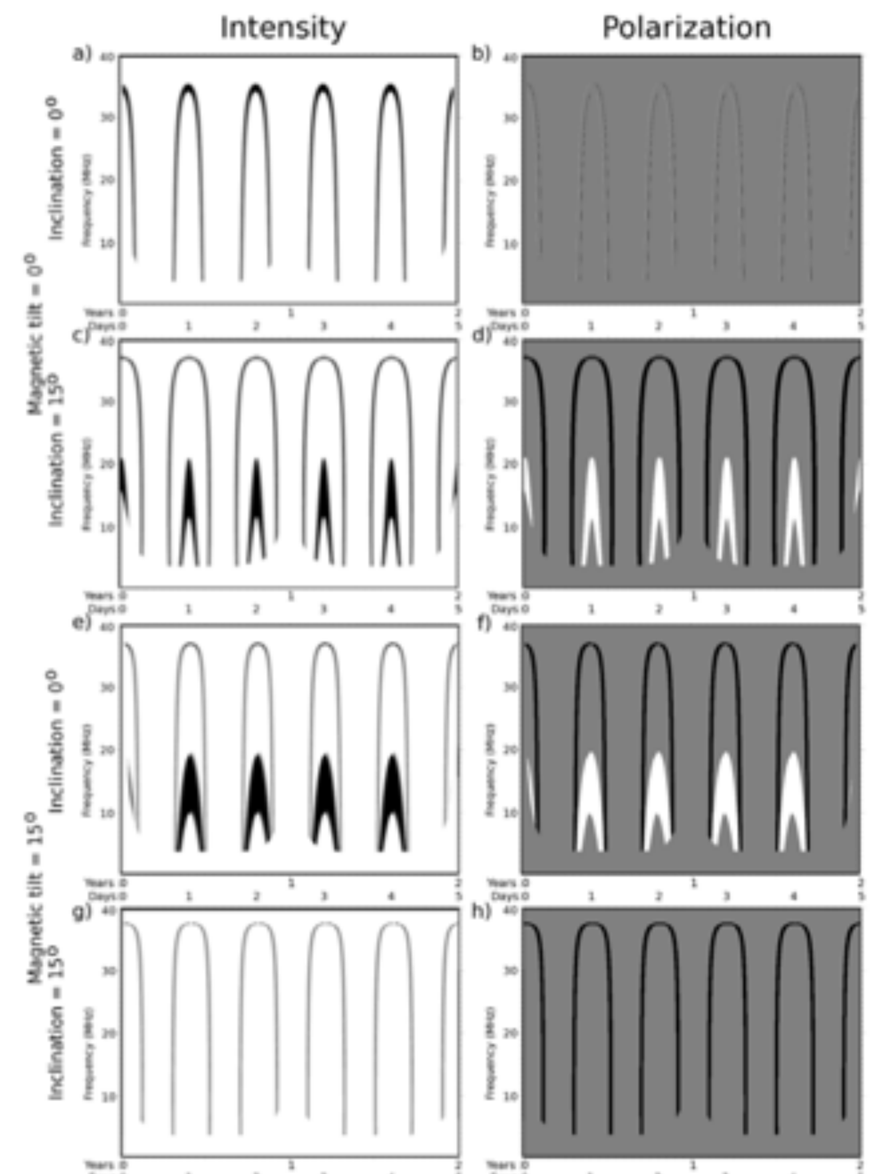
(Hess et al., 2011)



NB : Full oval
(Jupiter-like)



NB : Hot spot fixed in
longitude (Jupiter-like)



NB : Hot spot fixed in LT
(Earth or Saturn-like)