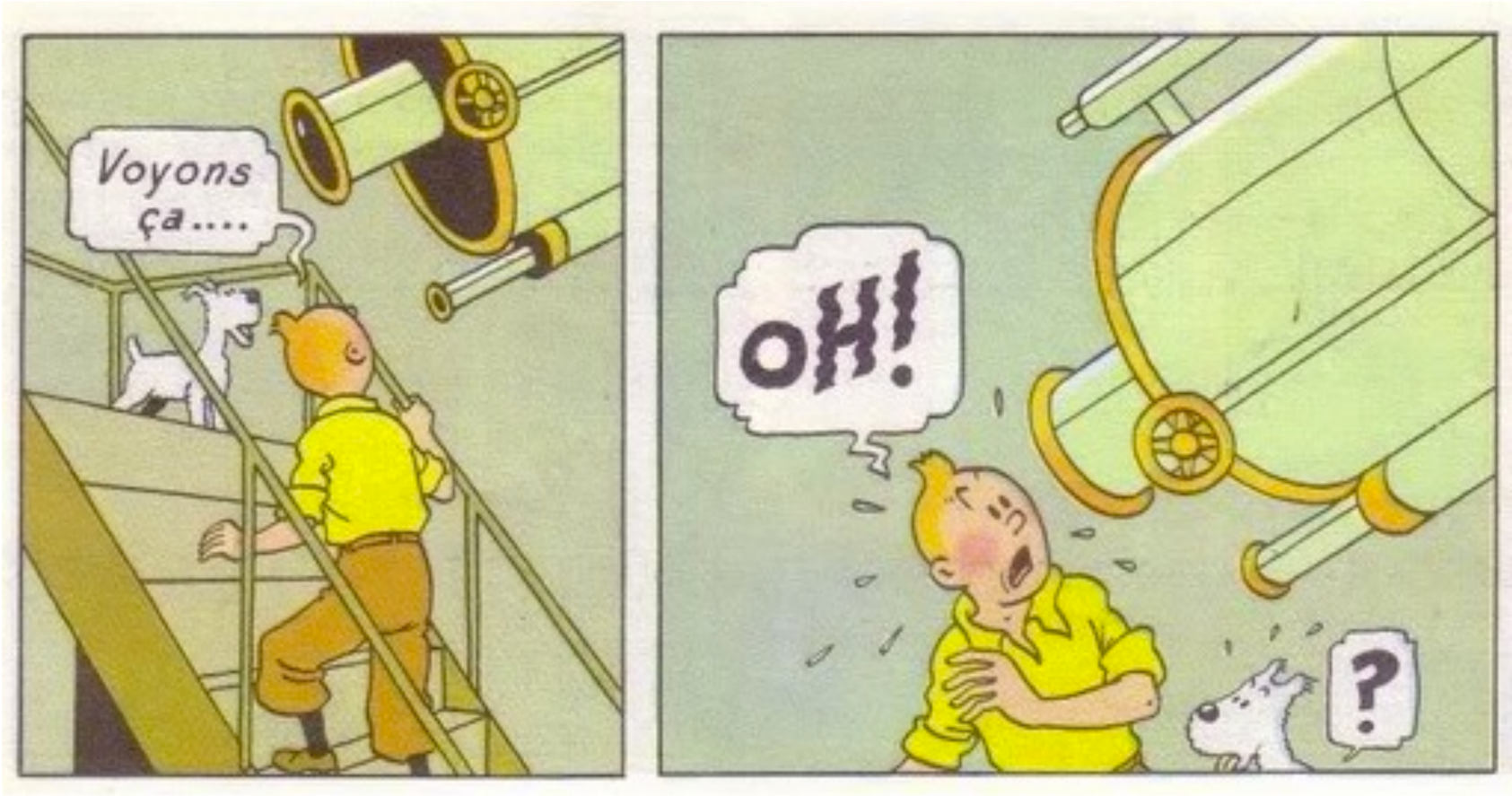
Earth-based characterization of Uranus' aurorae



L. Lamy (LESIA, Observatoire de Paris) and the HST team #12601 :

*R. Prangé, K.C. Hansen, J.T. Clarke, P. Zarka, **B. Cecconi**, J. Aboudarham, N. André, G. Branduardi, R. Gladstone, M. Barthélémy, N. Achilleos, P. Guio, M. Dougherty, H. Melin, S. Cowley, T. Stallard, J. Nichols, G. Ballester*

OPAG Meeting, Jan. 10th 2013, Atlanta

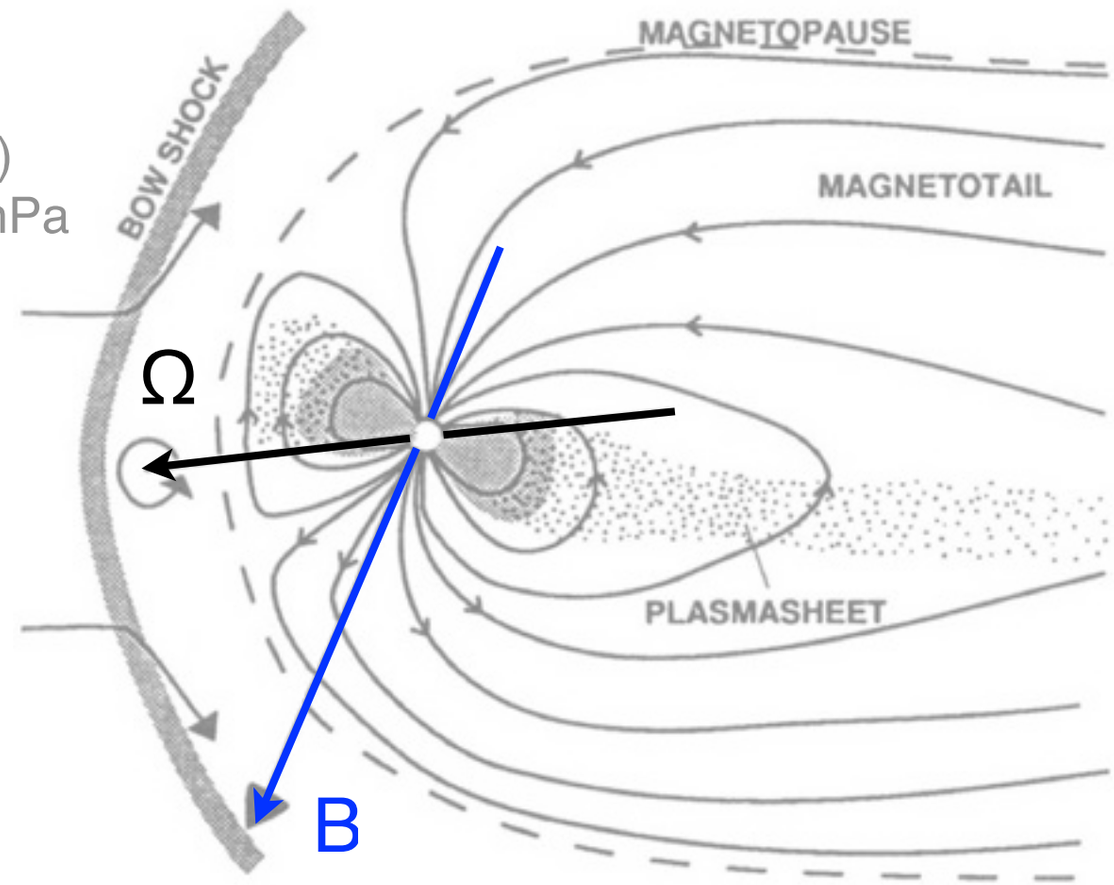
1986 : Voyager 2

$P_U \sim 17.24+/-0.01h$

P_{dyn} (SW)
~ 0.005 nPa

1986 : Solstice

SW →



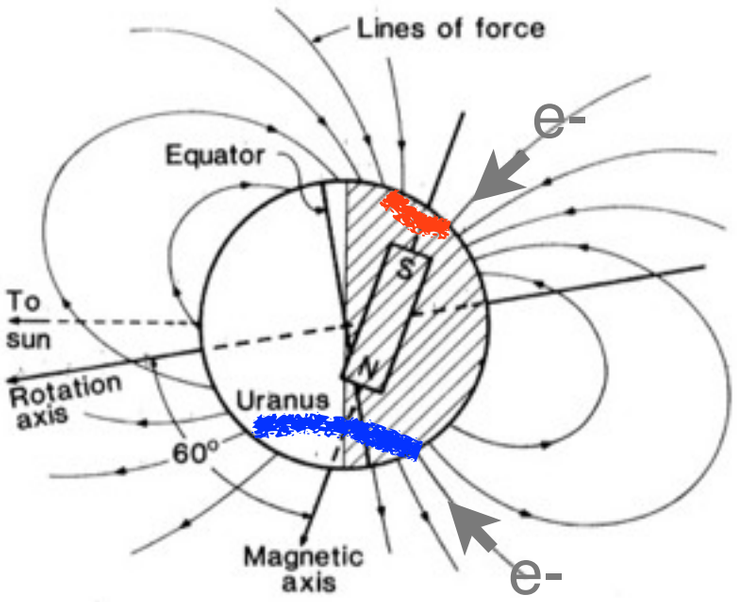
$B_{eq} \sim 20$ nT
(~ Earth, Saturn)

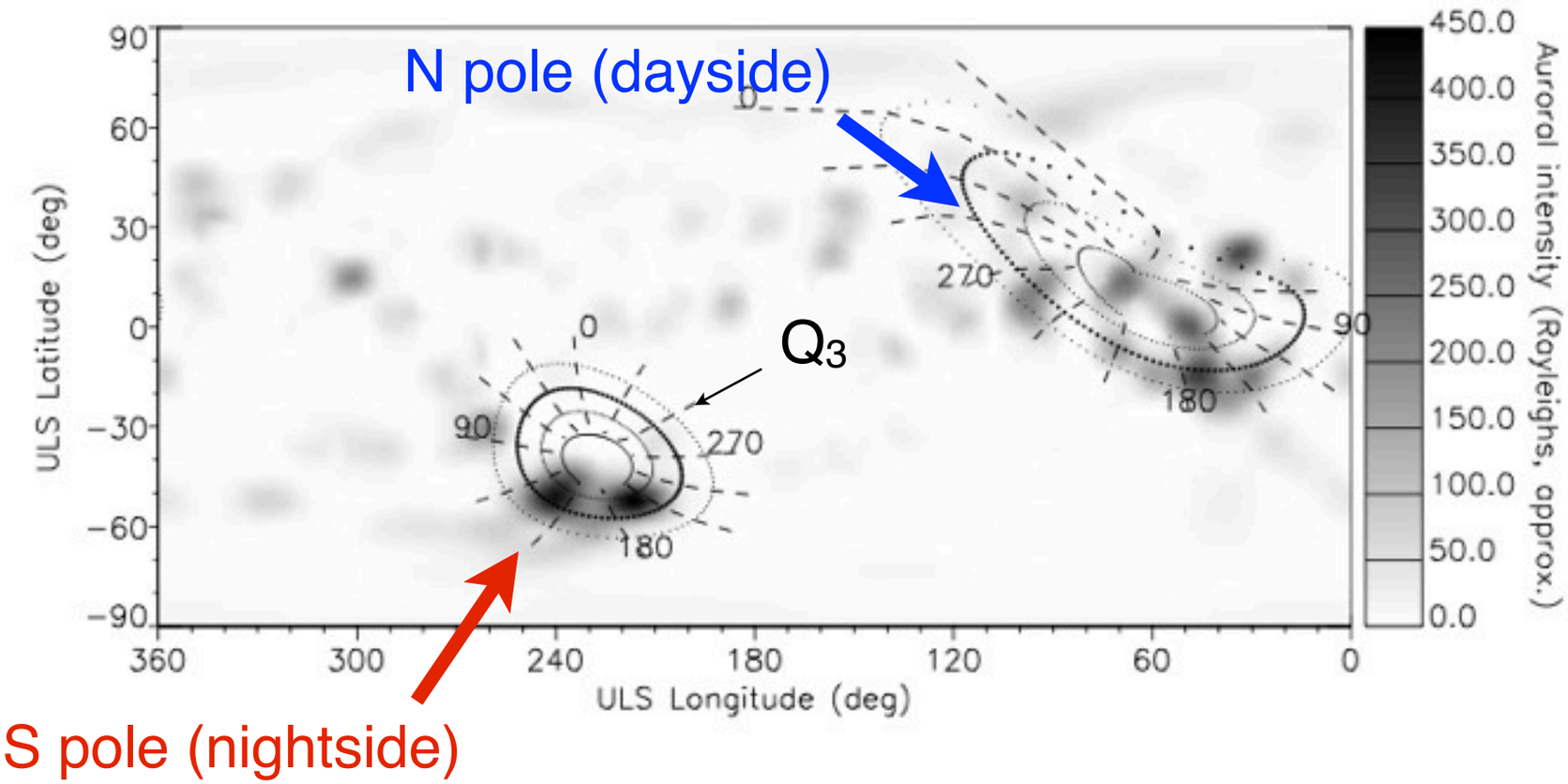
Internal plasma sources
(rings, moons, H corona)
$\beta \sim 0.1$

$R_{MP} \sim 20R_U$
(~ Saturn)

1986 : Voyager 2

(Herbert et al., 2009)





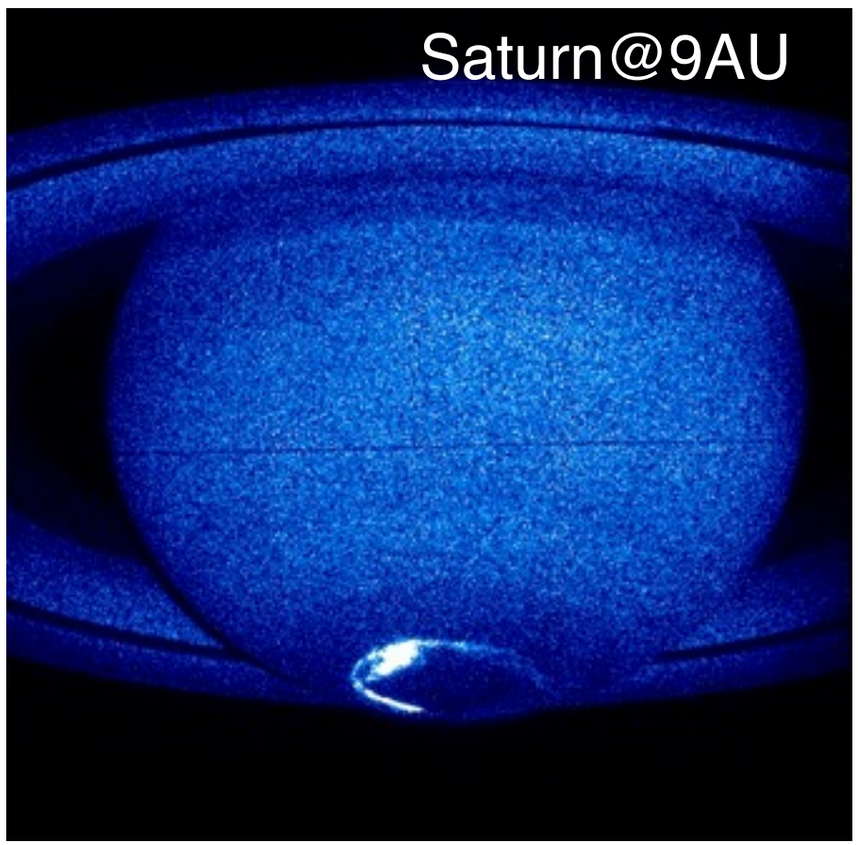
Auroral emissions detected at UV wavelengths (70-190nm) by the UVS spectrometer : a few kR of H and H_2 in average

Main properties :
- N and S aurora magnetically conjugate at ~60-65° latitude (L=5-10)
- enhanced along the magnetotail direction (~180° long.) => solar wind convection
- radiated power : N = 3.10^9 W / S = 7.10^9 W => input power ~ a few 10^{10} W
- modulated at the planetary rotation period : 17.24±0.01h

1998 and 2005 : HST

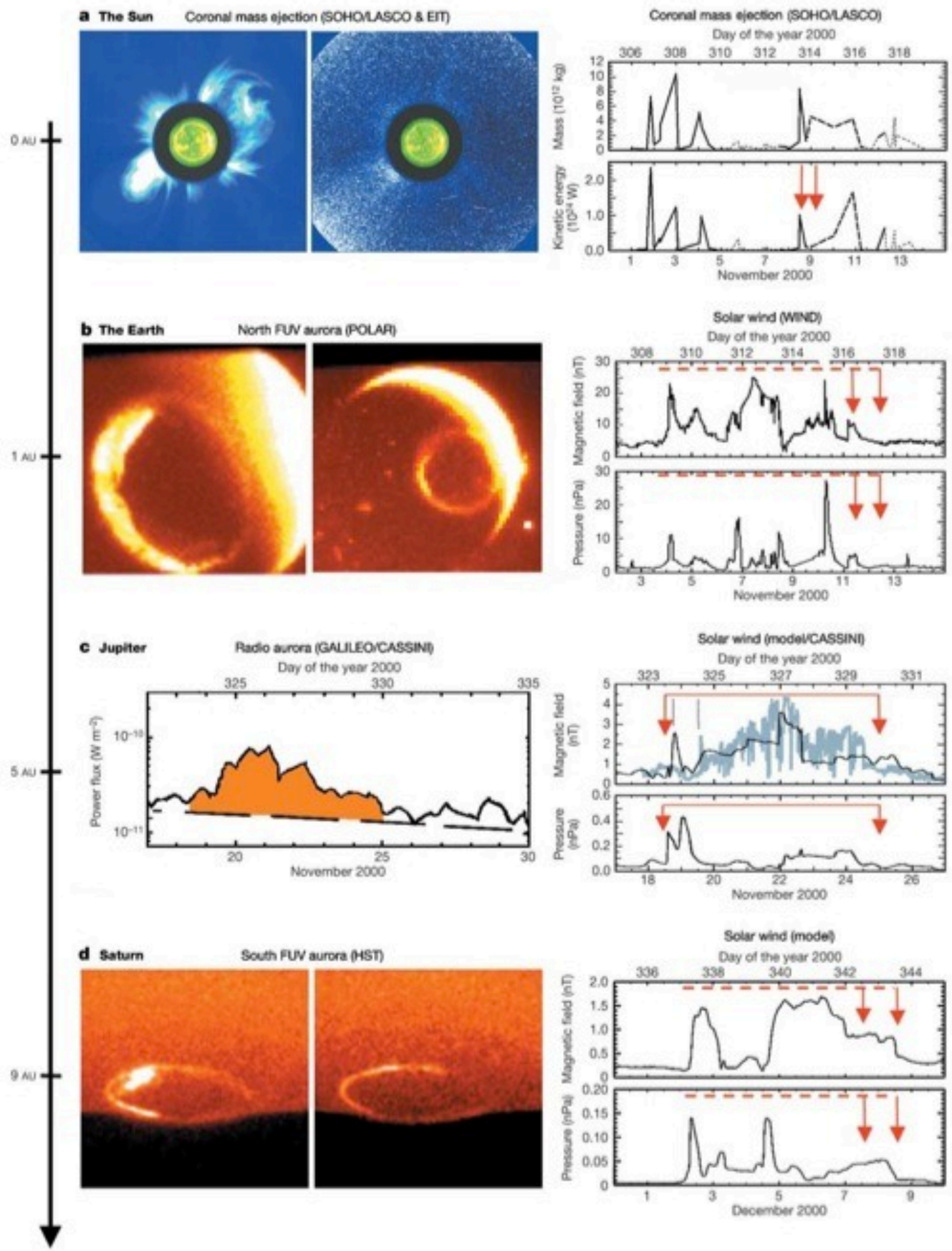
Post-Voyager attempts for redetecting Uranus aurorae with HST (sensitivity ~ 1kR) :

- 1998 : STIS (G. Ballester et al.) => unsuccessful
- 2005 : ACS (J. Clarke et al.) => unsuccessful



twice as far as Saturn
+ 2-3 less intense
=> attenuation by 1
order of magnitude

2011 : another HST attempt with a novel strategy

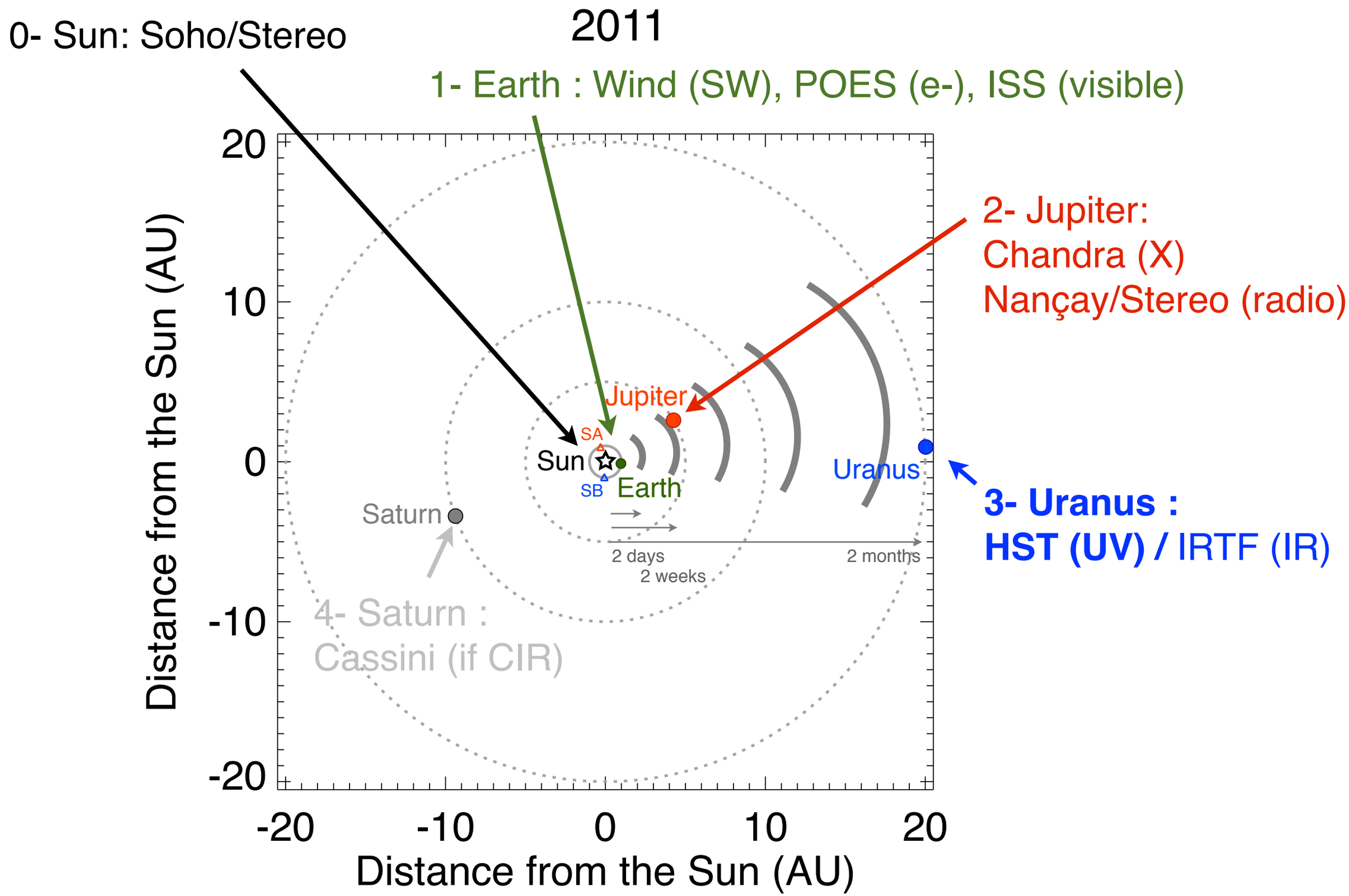


(Prangé et al., 2005)

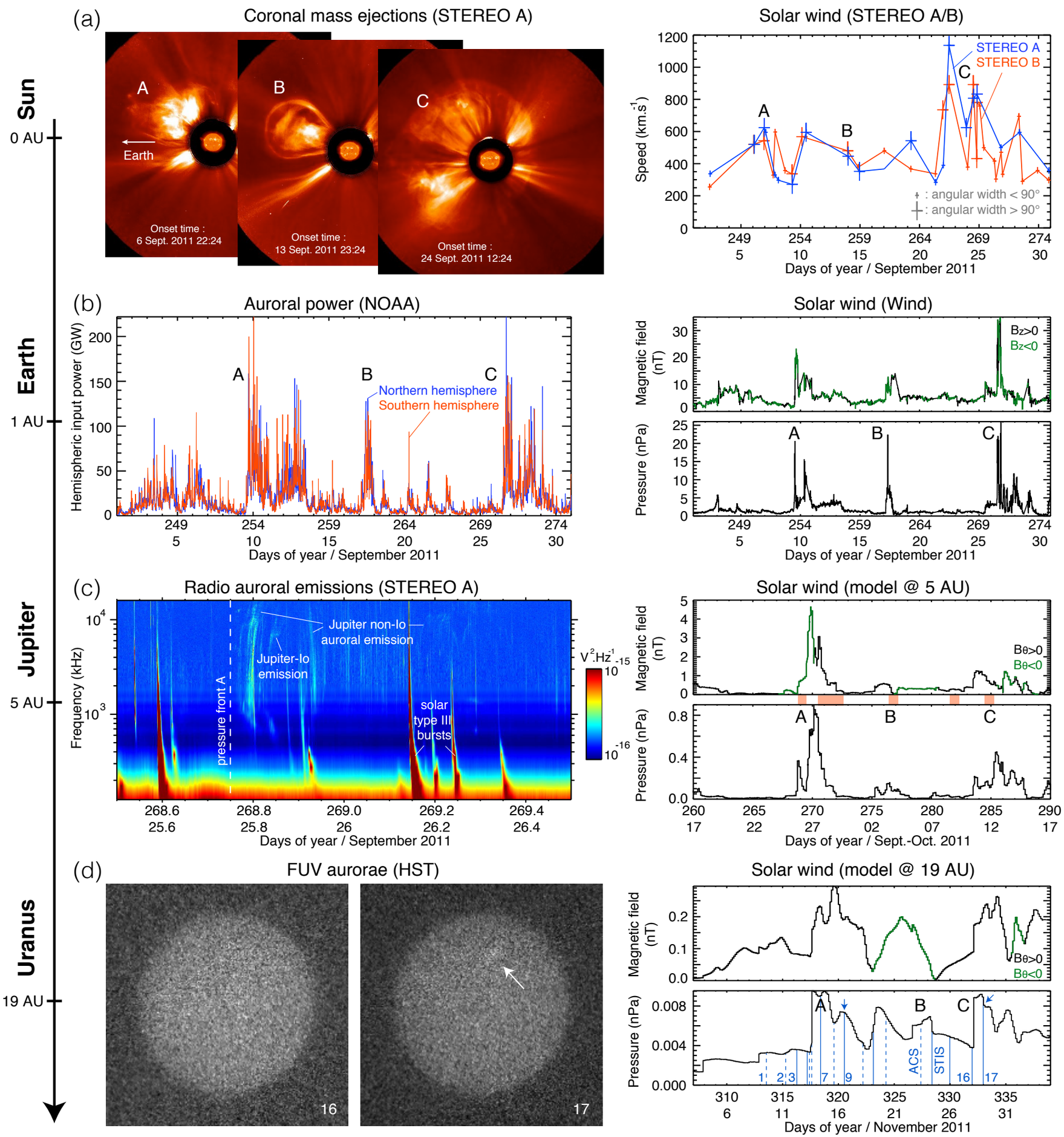
- Interplanetary shocks known to activate planetary aurorae

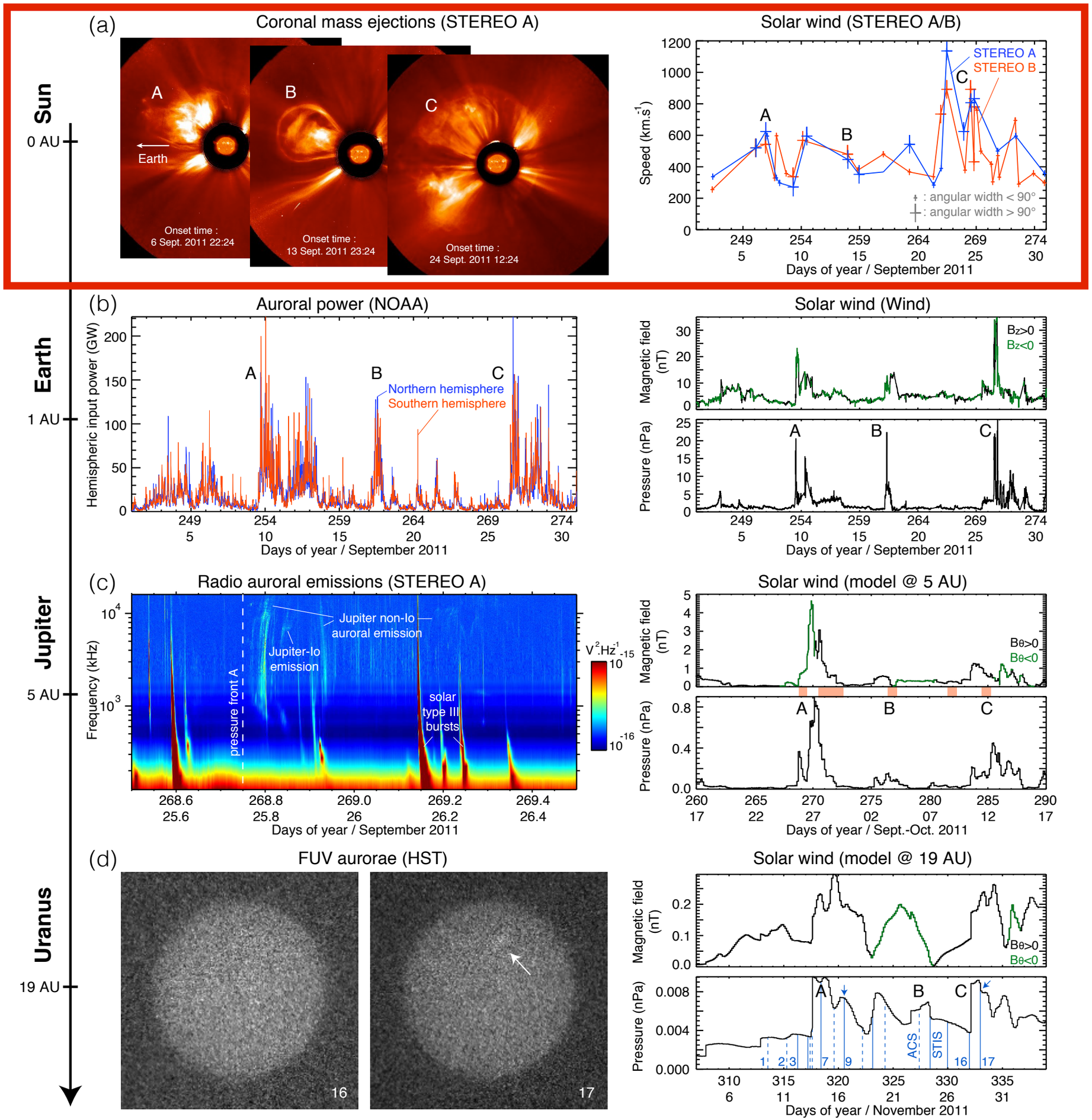
- Planetary alignment in Nov. 2000 => increase of auroral power along the same CME :
  - Earth : >10 (UV)
  - Jupiter : ~3 (radio)
  - Saturn : 3-5 (UV)

=> Uranus expected to be particularly sensitive to SW



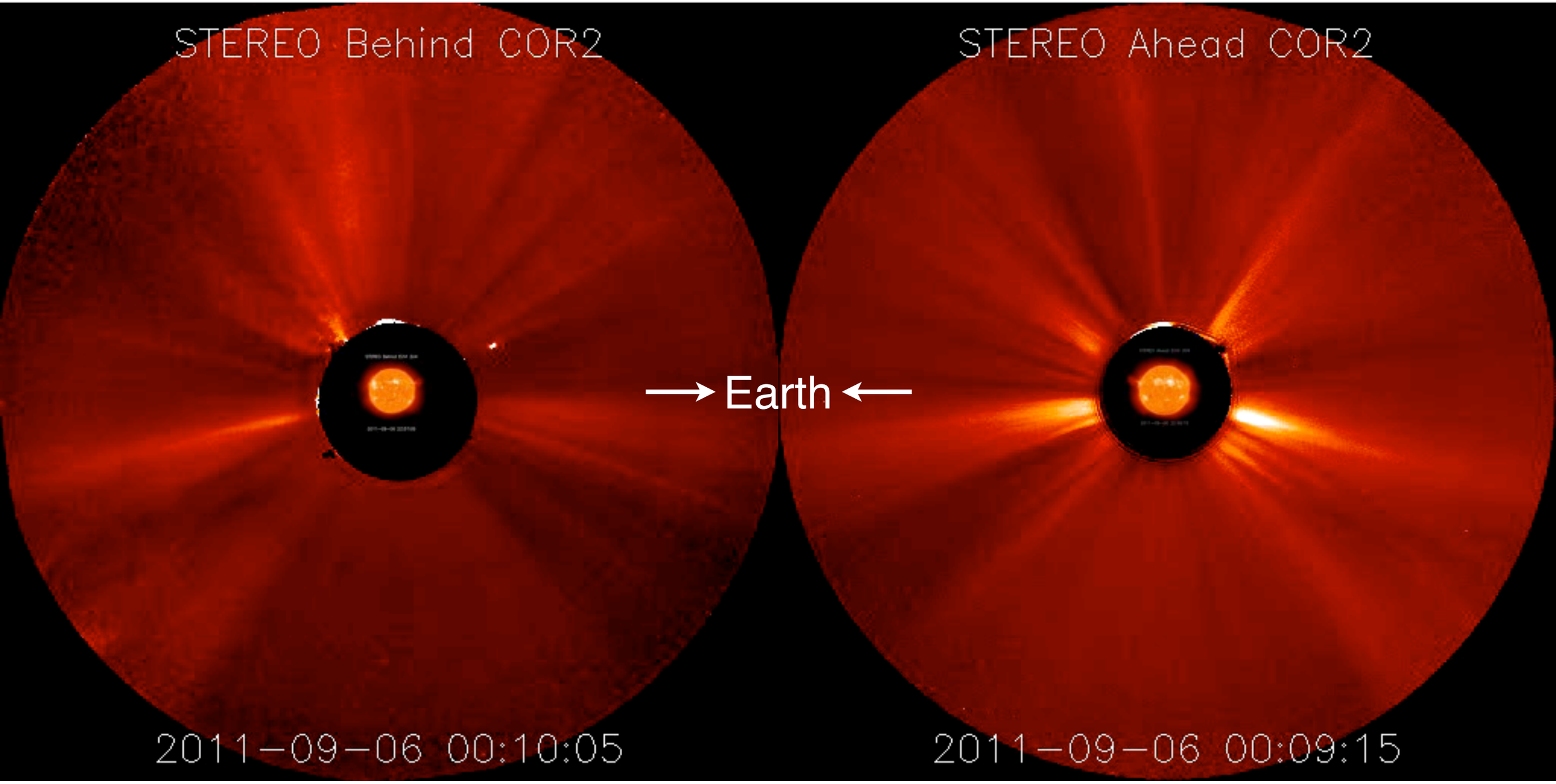
- HST accepted proposal for late 2011 :
(i) re-observing Uranus during active SW conditions (propagated from Earth)
(ii) multi-planet multi-spectral study of auroral planetary responses to the same shock

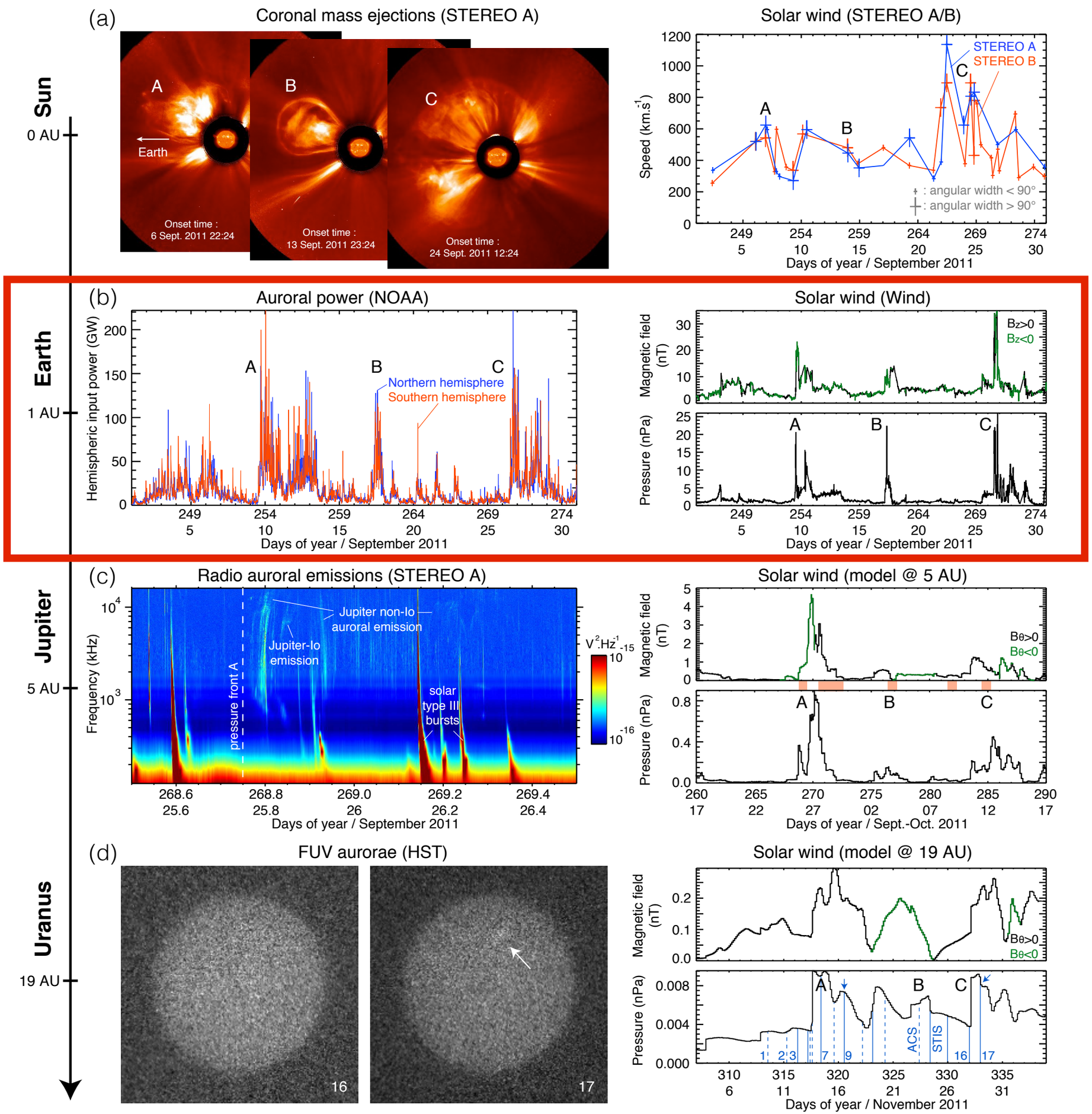

(a)
Coronal mass ejections (STEREO A)
A
B
C
Earth
Onset time : 6 Sept. 2011 22:24
Onset time : 13 Sept. 2011 23:24
Onset time : 24 Sept. 2011 12:24
Solar wind (STEREO A/B)
STEREO A
STEREO B
Speed (km.s-1)
: angular width < 90°
: angular width > 90°
Days of year / September 2011
(b)
Auroral power (NOAA)
Hemispheric input power (GW)
Northern hemisphere
Southern hemisphere
Days of year / September 2011
Solar wind (Wind)
Magnetic field (nT)
Bz>0
Bz<0
Pressure (nPa)
Days of year / September 2011
(c)
Radio auroral emissions (STEREO A)
Jupiter non-Io auroral emission
Jupiter-Io emission
pressure front A
solar type III bursts
Frequency (kHz)
V2.Hz-1
Days of year / September 2011
Solar wind (model @ 5 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
Days of year / Sept.-Oct. 2011
(d)
FUV aurorae (HST)
16
17
Solar wind (model @ 19 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
ACS
STIS
Days of year / November 2011
Sun
0 AU
Earth
1 AU
Jupiter
5 AU
Uranus
19 AU


(a)
Coronal mass ejections (STEREO A)
Solar wind (STEREO A/B)
Sun
0 AU
Earth
Onset time : 6 Sept. 2011 22:24
Onset time : 13 Sept. 2011 23:24
Onset time : 24 Sept. 2011 12:24
STEREO A
STEREO B
Speed (km.s-1)
: angular width < 90°
: angular width > 90°
Days of year / September 2011
(b)
Auroral power (NOAA)
Solar wind (Wind)
Earth
1 AU
Hemispheric input power (GW)
Northern hemisphere
Southern hemisphere
Magnetic field (nT)
Bz>0
Bz<0
Pressure (nPa)
Days of year / September 2011
(c)
Radio auroral emissions (STEREO A)
Solar wind (model @ 5 AU)
Jupiter
5 AU
Frequency (kHz)
Jupiter non-Io auroral emission
Jupiter-Io emission
pressure front A
solar type III bursts
V2.Hz-1
Bθ>0
Bθ<0
Days of year / September 2011
Days of year / Sept.-Oct. 2011
(d)
FUV aurorae (HST)
Solar wind (model @ 19 AU)
Uranus
19 AU
16
17
ACS
STIS
Days of year / November 2011

Sun

event A


STEREO Behind COR2
STEREO Ahead COR2
→ Earth ←
2011-09-06 00:10:05
2011-09-06 00:09:15


(a)
Coronal mass ejections (STEREO A)
Sun
0 AU
A
B
C
Earth
Onset time : 6 Sept. 2011 22:24
Onset time : 13 Sept. 2011 23:24
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Solar wind (STEREO A/B)
STEREO A
STEREO B
Speed (km.s-1)
: angular width < 90°
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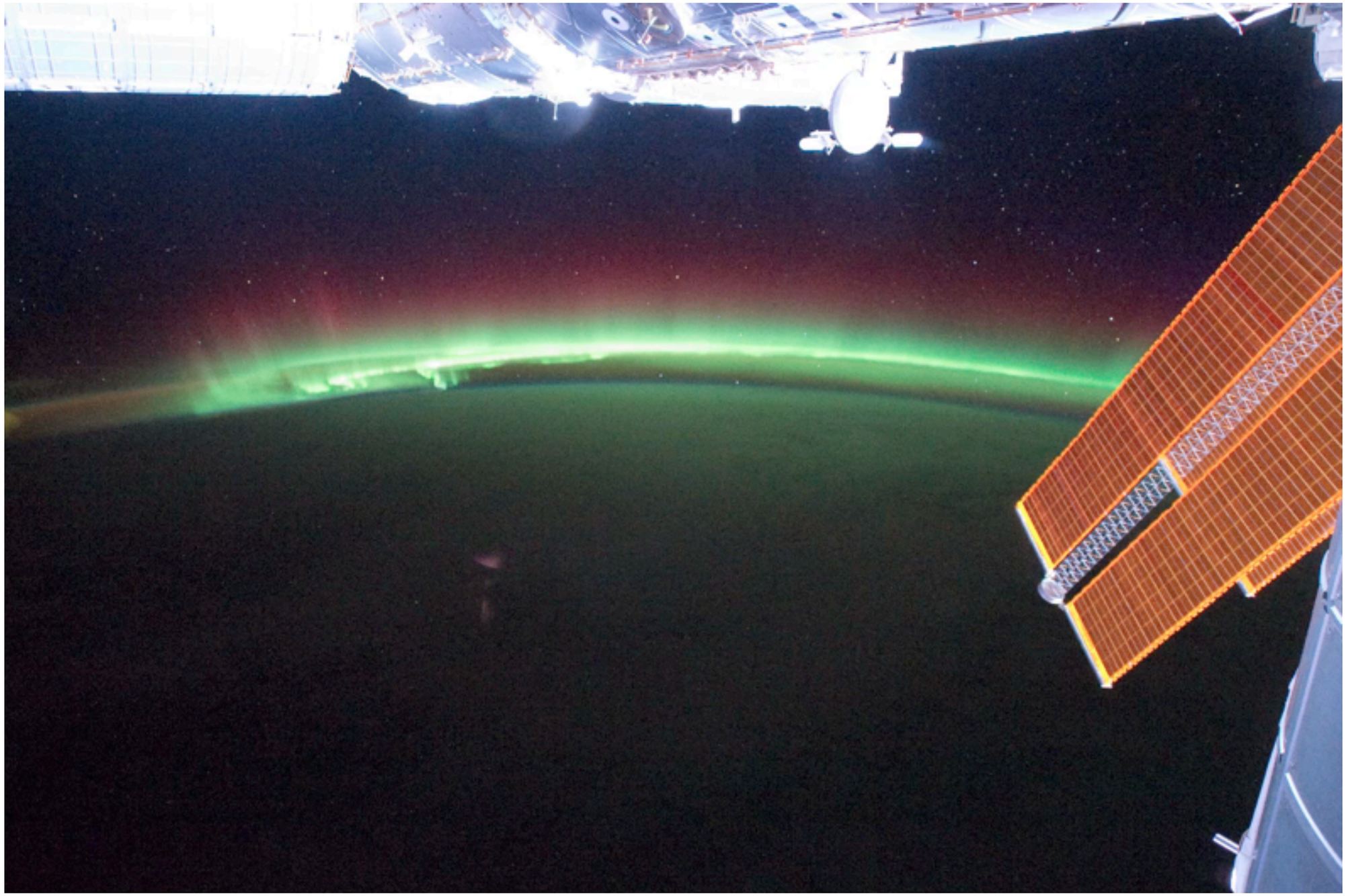
Days of year / September 2011
(b)
Auroral power (NOAA)
Earth
1 AU
Hemispheric input power (GW)
Northern hemisphere
Southern hemisphere
Solar wind (Wind)
Magnetic field (nT)
Bz>0
Bz<0
Pressure (nPa)
Days of year / September 2011
(c)
Radio auroral emissions (STEREO A)
Jupiter
5 AU
Frequency (kHz)
Jupiter non-Io auroral emission
Jupiter-Io emission
pressure front A
solar type III bursts
V2.Hz-1
Days of year / September 2011
Solar wind (model @ 5 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
Days of year / Sept.-Oct. 2011
(d)
FUV aurorae (HST)
Uranus
19 AU
16
17
Solar wind (model @ 19 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
ACS
STIS
Days of year / November 2011

Earth

event B

17/09/2011



- Magnetospheric compressions => magnetotail reconnection over extended longitudes
- global intensification of the auroral activity (0.59), favored for Bz<0 (0.64)
- hemispheric radiated power : 5-230GW (intensification by 30-60)

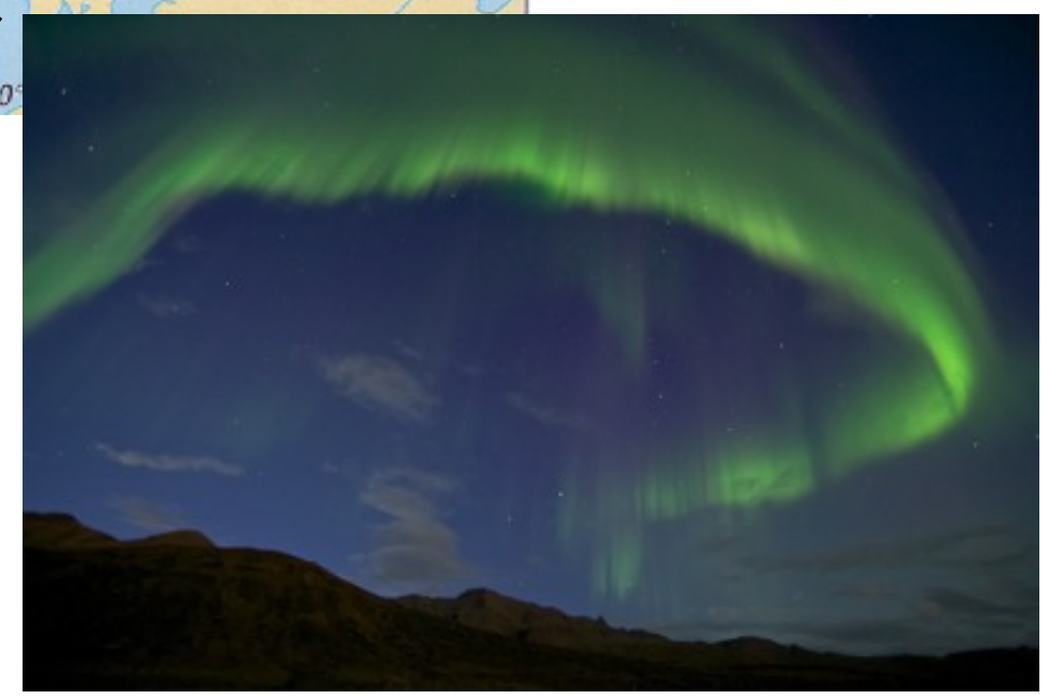
Earth

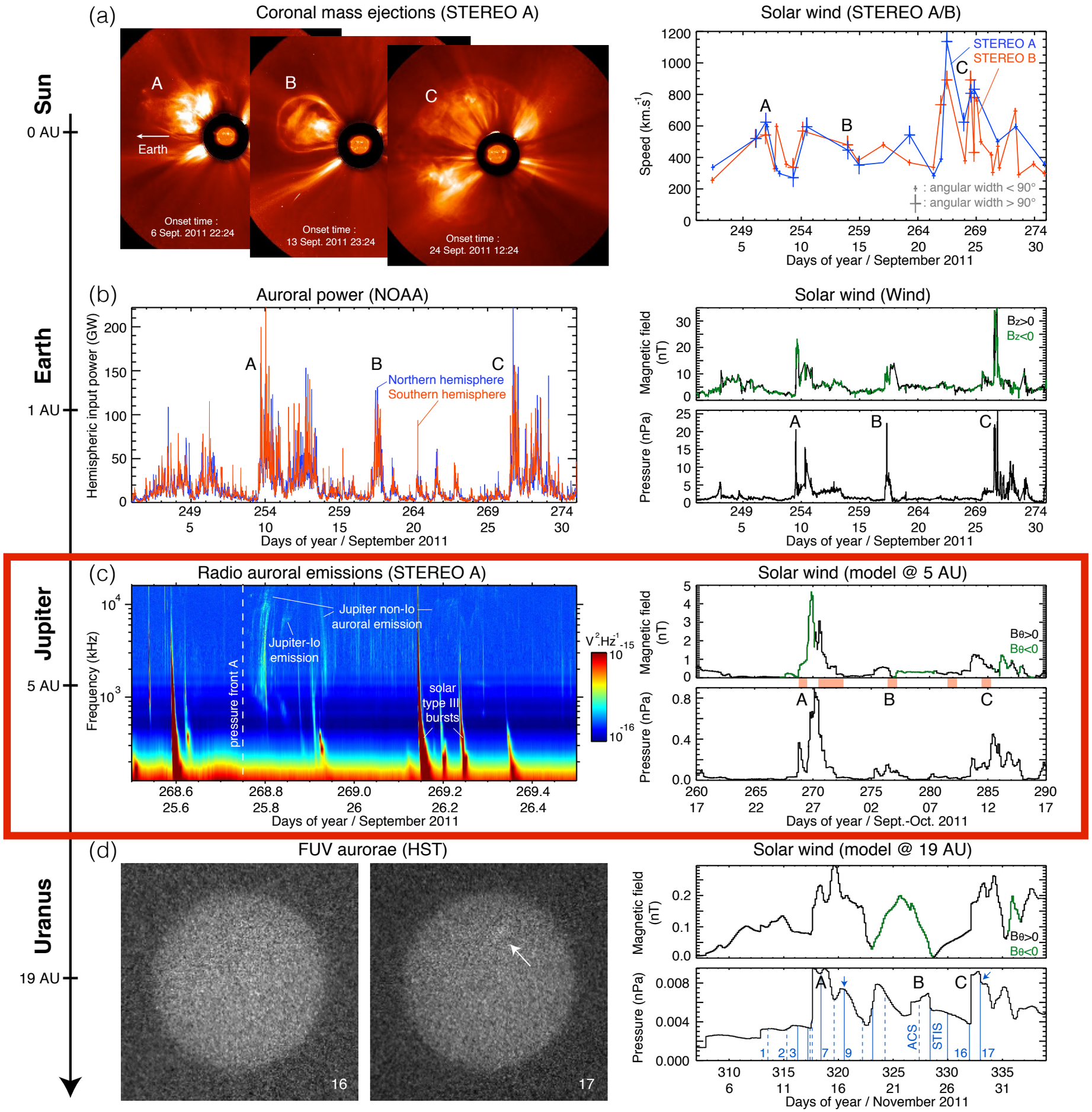
event A

09/09/2011

Sept : A coronal mass ejection (CME) hit Earth's magnetic field on Sept. 9th, sparking a (Kp=7) geomagnetic storm. Northern Lights were sighted in the United States as far south as Maine, Michigan, Vermont and Washington. Another CME struck on Sept. 17th, sparking a Kp=6 storm. The biggest CME strike of the month occured on Sept. 26th. A severe (Kp=8) geomagnetic storm ignited auroras over both hemispheres.

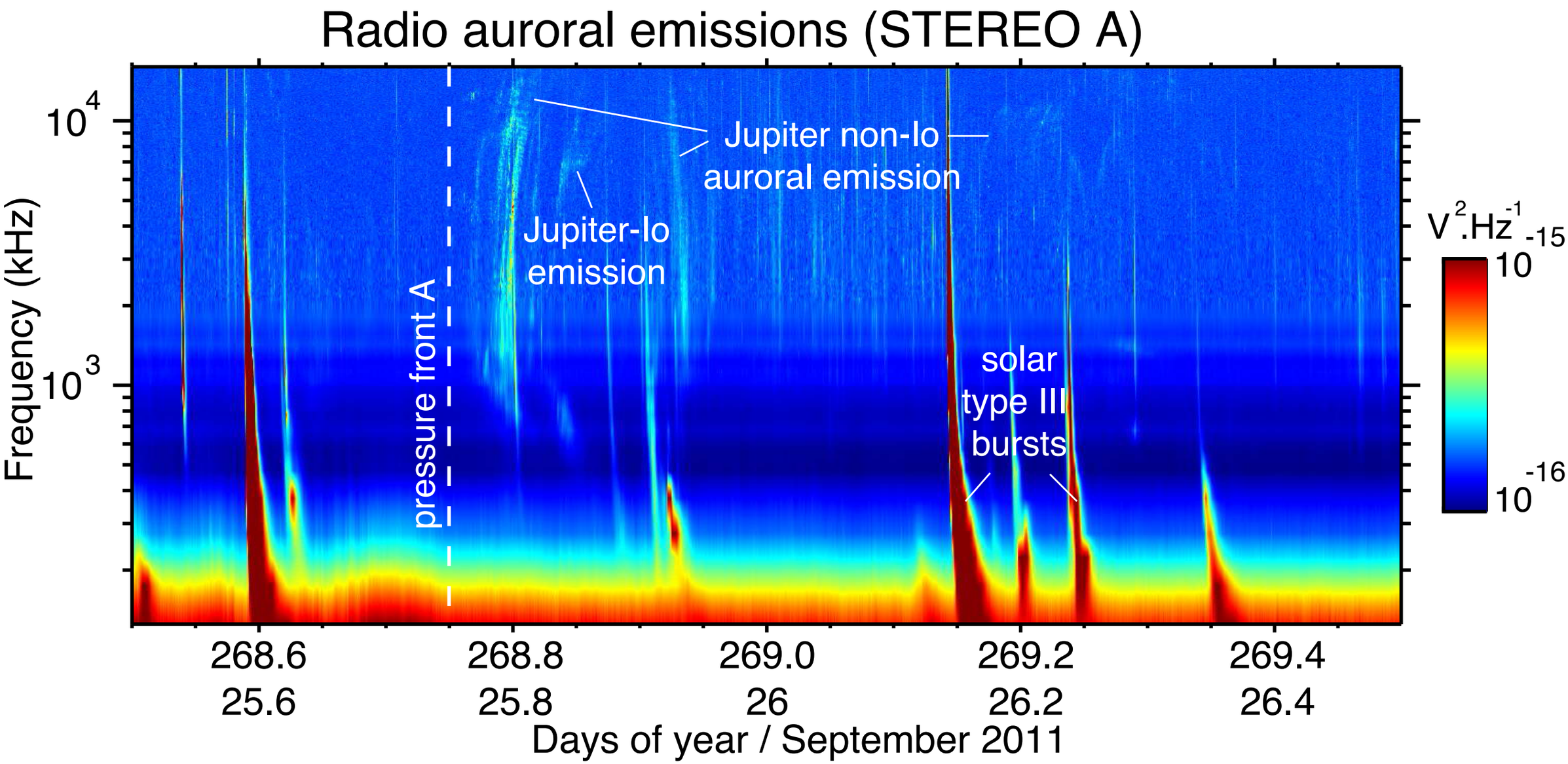
Washington



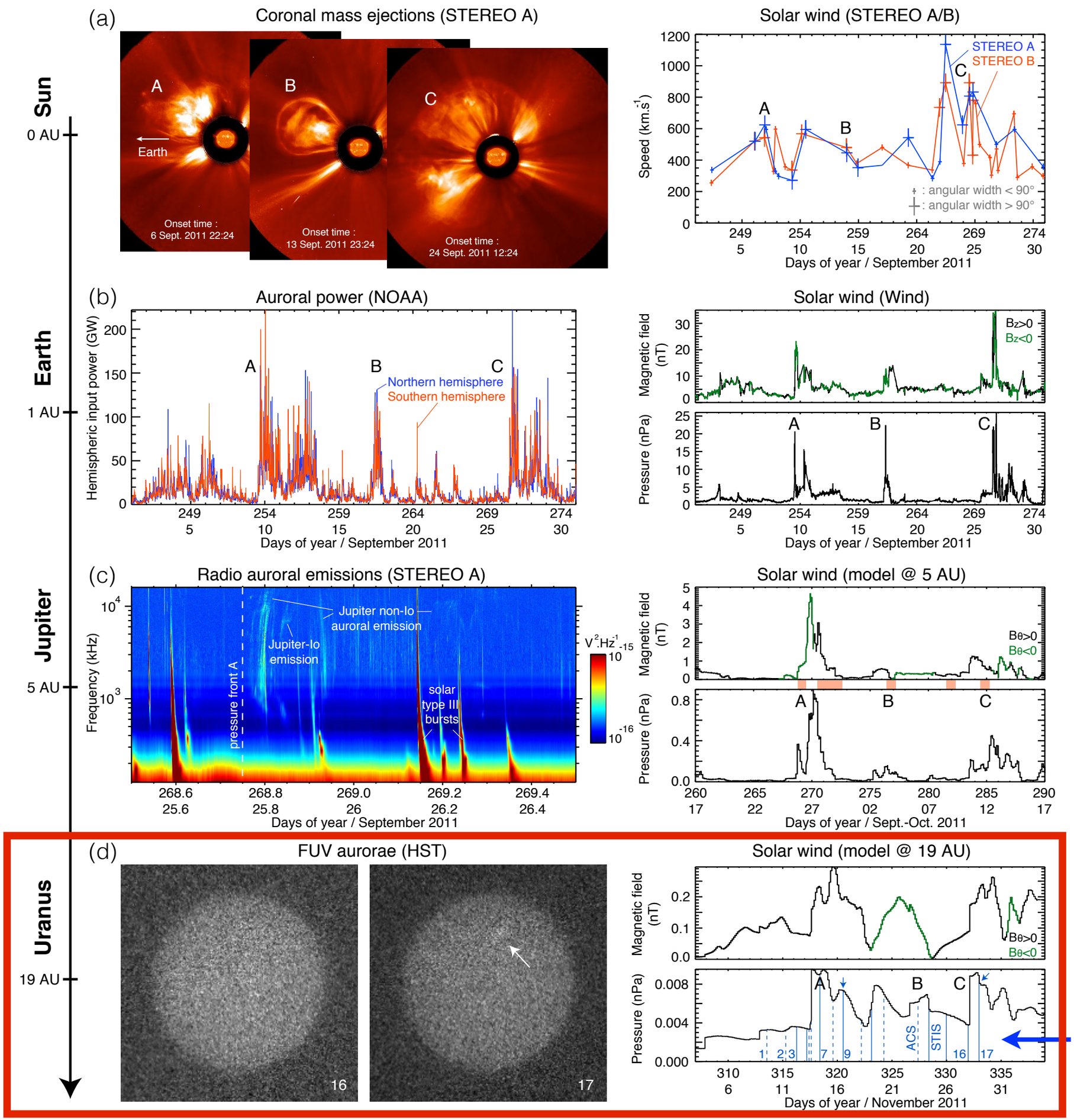

(a)
Coronal mass ejections (STEREO A)
Sun
0 AU
Earth
A
B
C
Earth
Onset time :
6 Sept. 2011 22:24
Onset time :
13 Sept. 2011 23:24
Onset time :
24 Sept. 2011 12:24
Solar wind (STEREO A/B)
STEREO A
STEREO B
Speed (km.s-1)
: angular width < 90°
: angular width > 90°
Days of year / September 2011
(b)
Auroral power (NOAA)
1 AU
Hemispheric input power (GW)
Northern hemisphere
Southern hemisphere
Days of year / September 2011
Solar wind (Wind)
Magnetic field (nT)
Bz>0
Bz<0
Pressure (nPa)
Days of year / September 2011
Jupiter
5 AU
(c)
Radio auroral emissions (STEREO A)
Frequency (kHz)
Jupiter non-Io auroral emission
Jupiter-Io emission
pressure front A
solar type III bursts
V2.Hz-1
Days of year / September 2011
Solar wind (model @ 5 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
Days of year / Sept.-Oct. 2011
Uranus
19 AU
(d)
FUV aurorae (HST)
16
17
Solar wind (model @ 19 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
ACS
STIS
Days of year / November 2011

Jupiter

event A



- occurrence close to each predicted arrival within 12h
- brightening from DAM to KOM : common origin
- calibration with Nançay => intensity : 1% occurrence level (50GW/sr)
- intensification by a factor of >2 (<< Earth)


(a)
Coronal mass ejections (STEREO A)
Sun
0 AU
Earth
A
B
C
Earth
Onset time :
6 Sept. 2011 22:24
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STEREO A
STEREO B
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Days of year / September 2011
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Auroral power (NOAA)
1 AU
Hemispheric input power (GW)
Northern hemisphere
Southern hemisphere
Days of year / September 2011
Solar wind (Wind)
Magnetic field (nT)
Bz>0
Bz<0
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Days of year / September 2011
(c)
Radio auroral emissions (STEREO A)
Jupiter
5 AU
Frequency (kHz)
Jupiter non-Io auroral emission
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pressure front A
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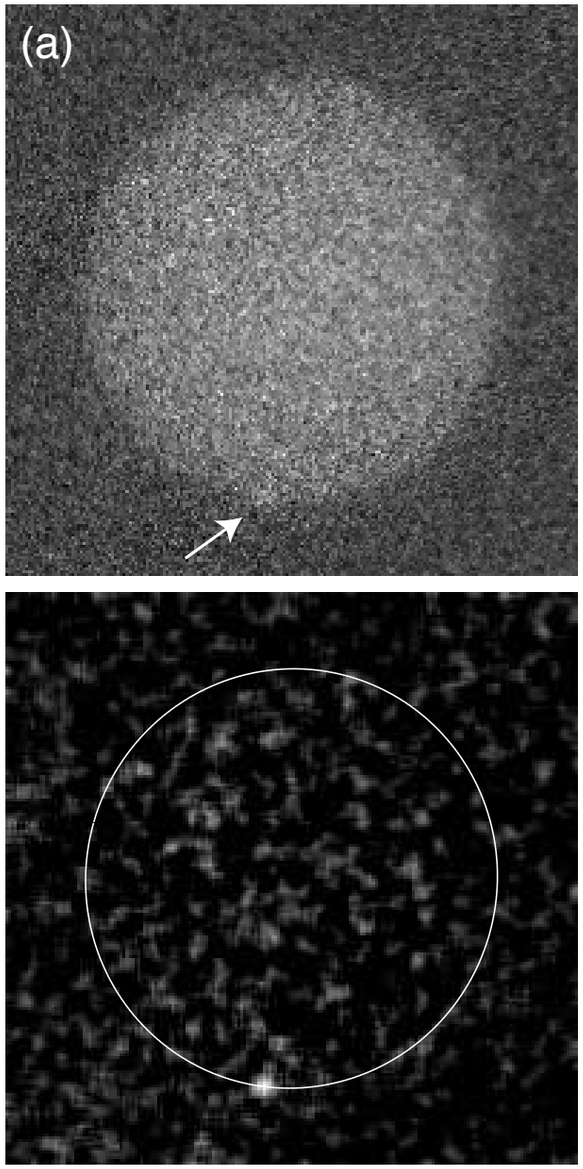
V2.Hz-1
Days of year / September 2011
Solar wind (model @ 5 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
Days of year / Sept.-Oct. 2011
(d)
FUV aurorae (HST)
Uranus
19 AU
16
17
Solar wind (model @ 19 AU)
Magnetic field (nT)
Bθ>0
Bθ<0
Pressure (nPa)
ACS
STIS
Days of year / November 2011
17 HST orbits (images and spectra)

Uranus

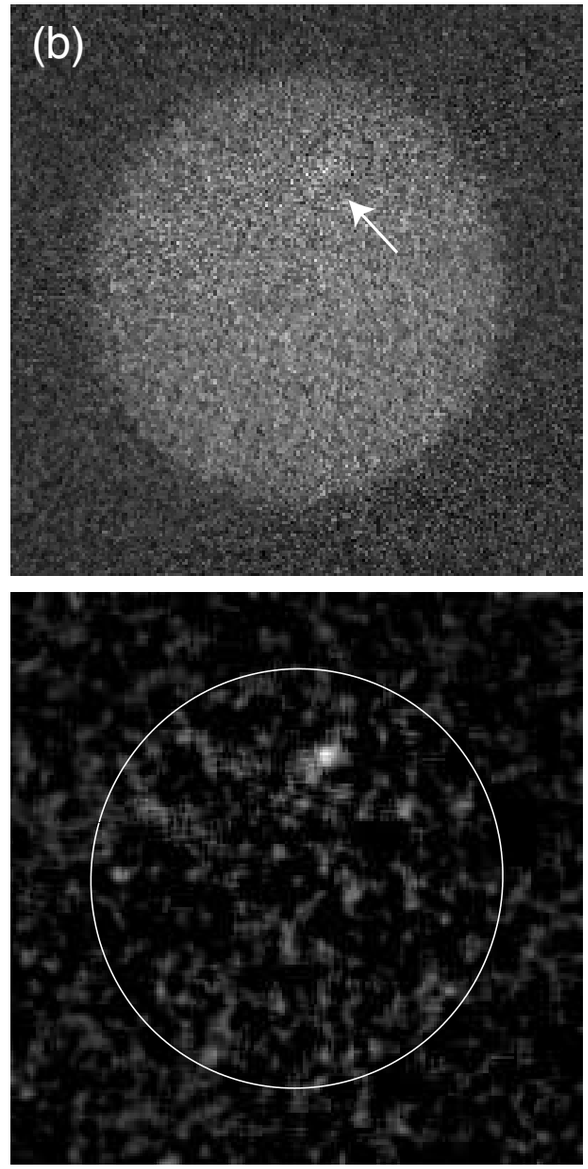
event C

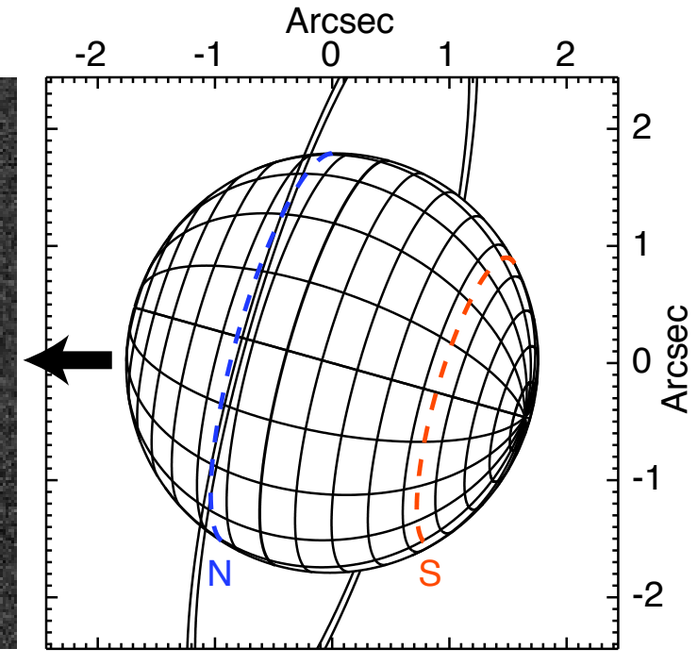
16 Nov. 2011



event A

29 Nov. 2011



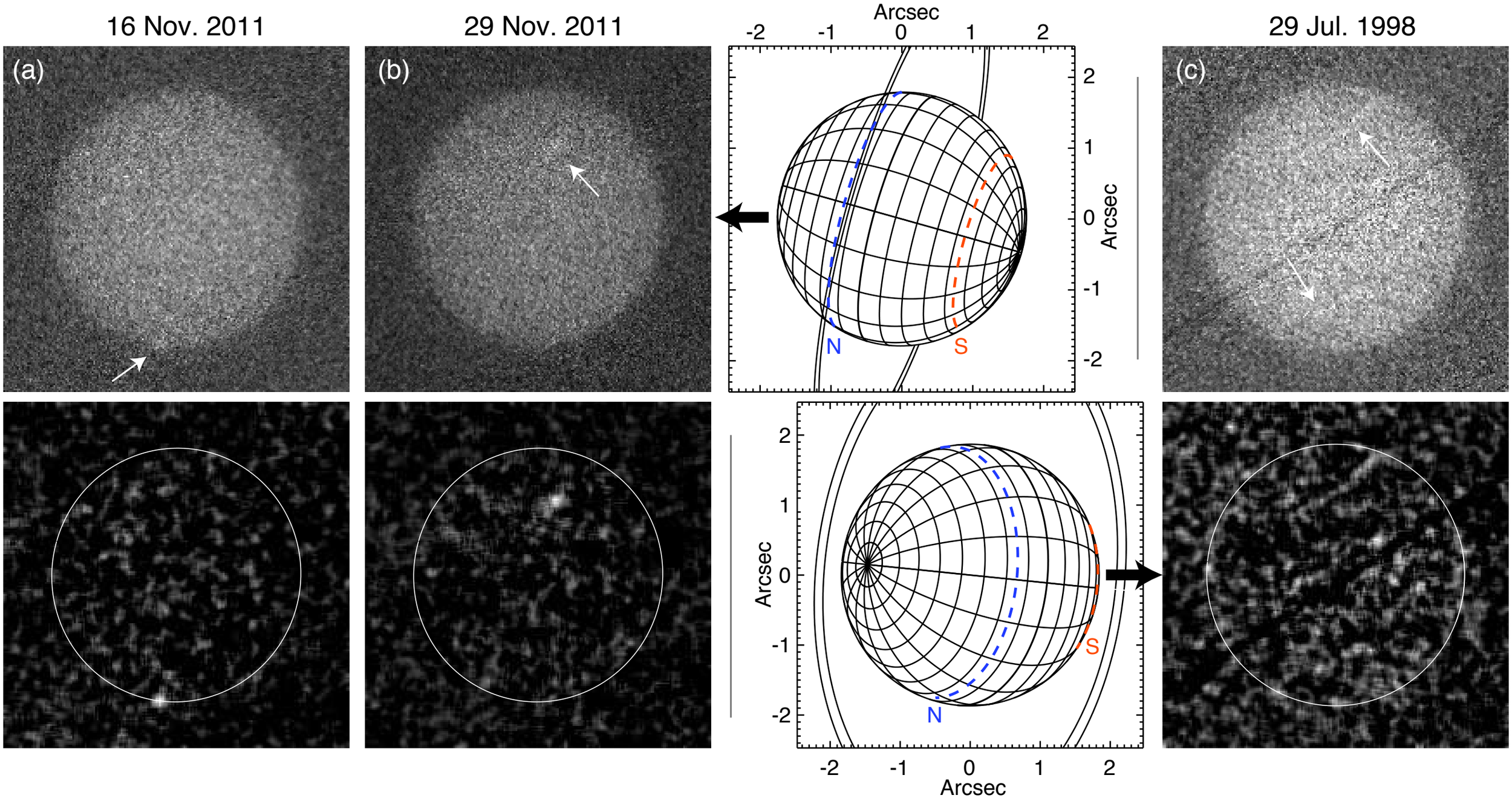


~ 3-5σ

Uranus

event C | *event A* | *1998 Campaign*

16 Nov. 2011 | 29 Nov. 2011 | 29 Jul. 1998

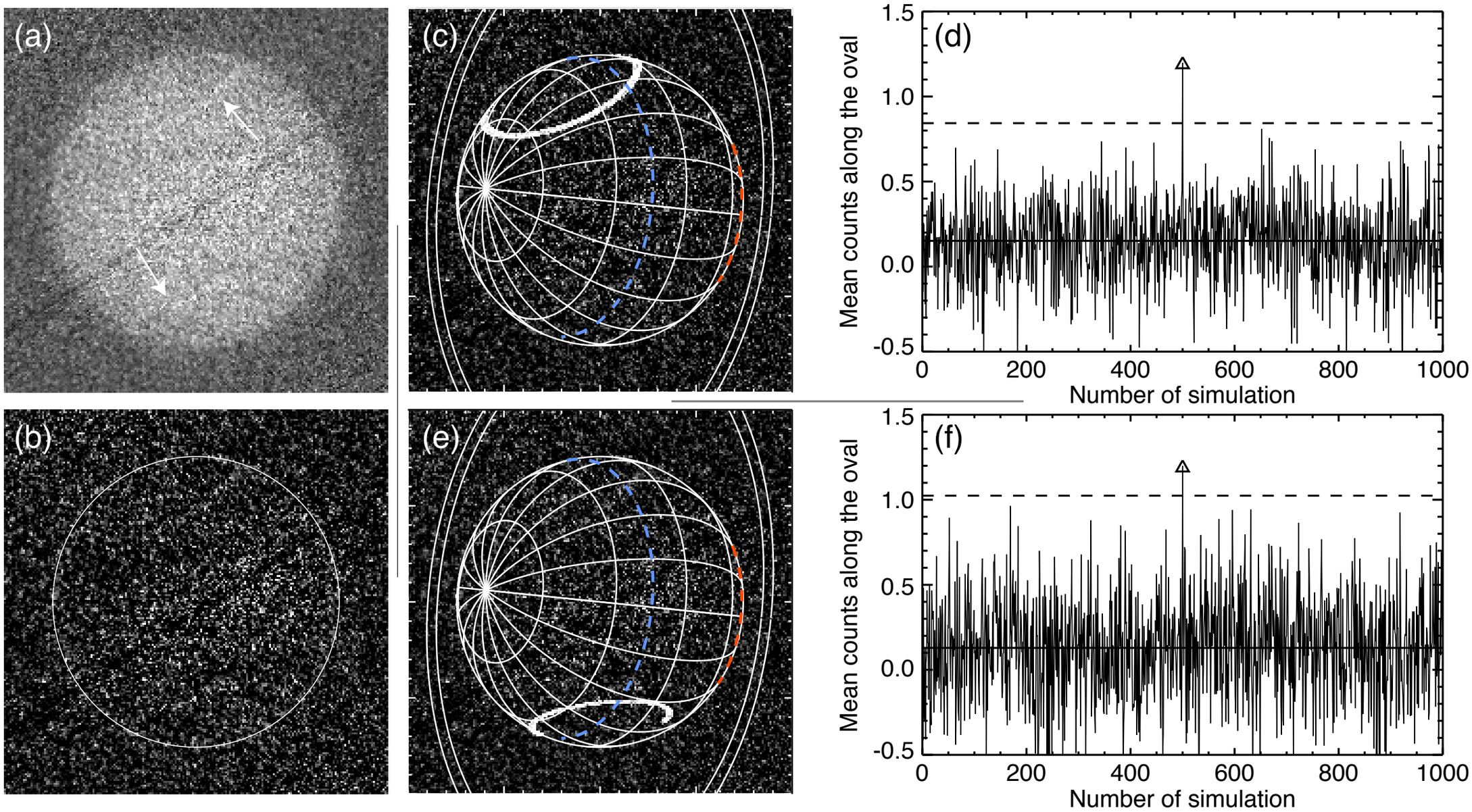


~ 3-5σ

~ 1-3σ

Uranus

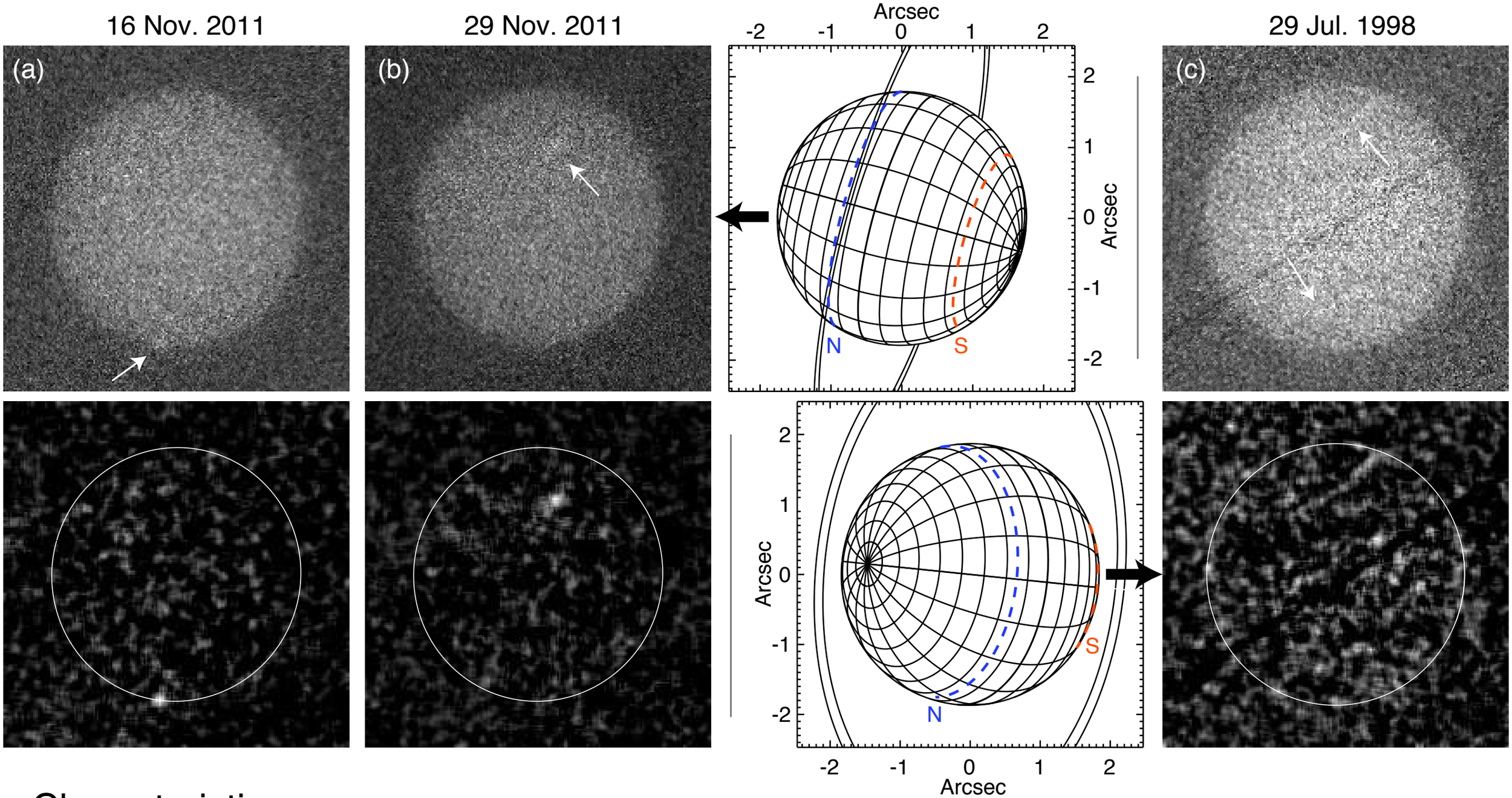
1998 Campaign



- ovals (assumption = circular) fitted by two partial ellipses
- integrated signal along the oval ~ 4-5σ

Uranus

event C | *event A* | *1998 Campaign*

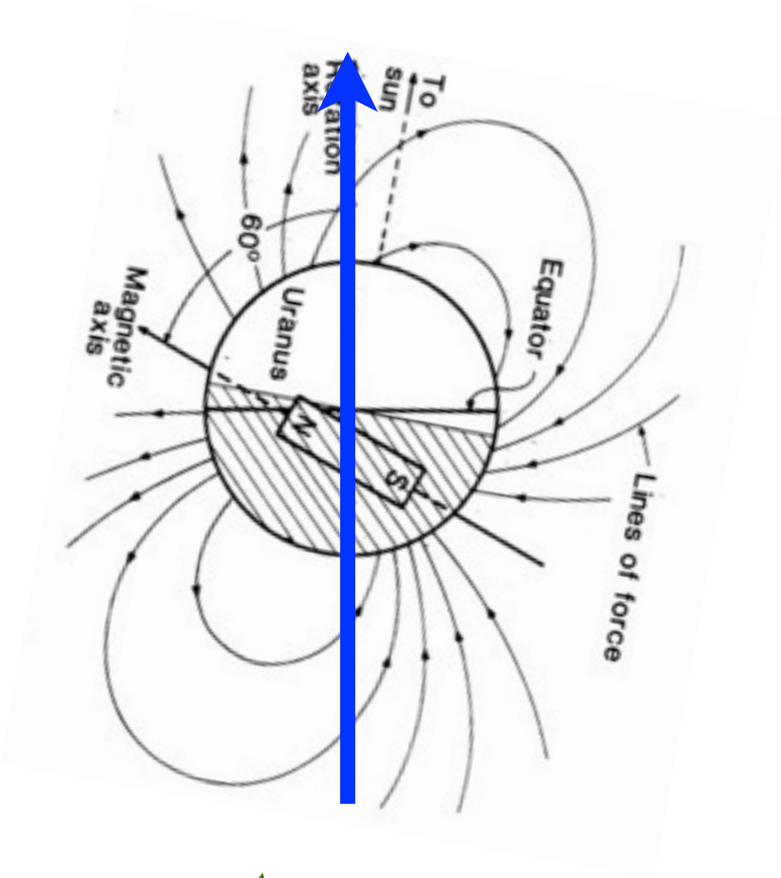


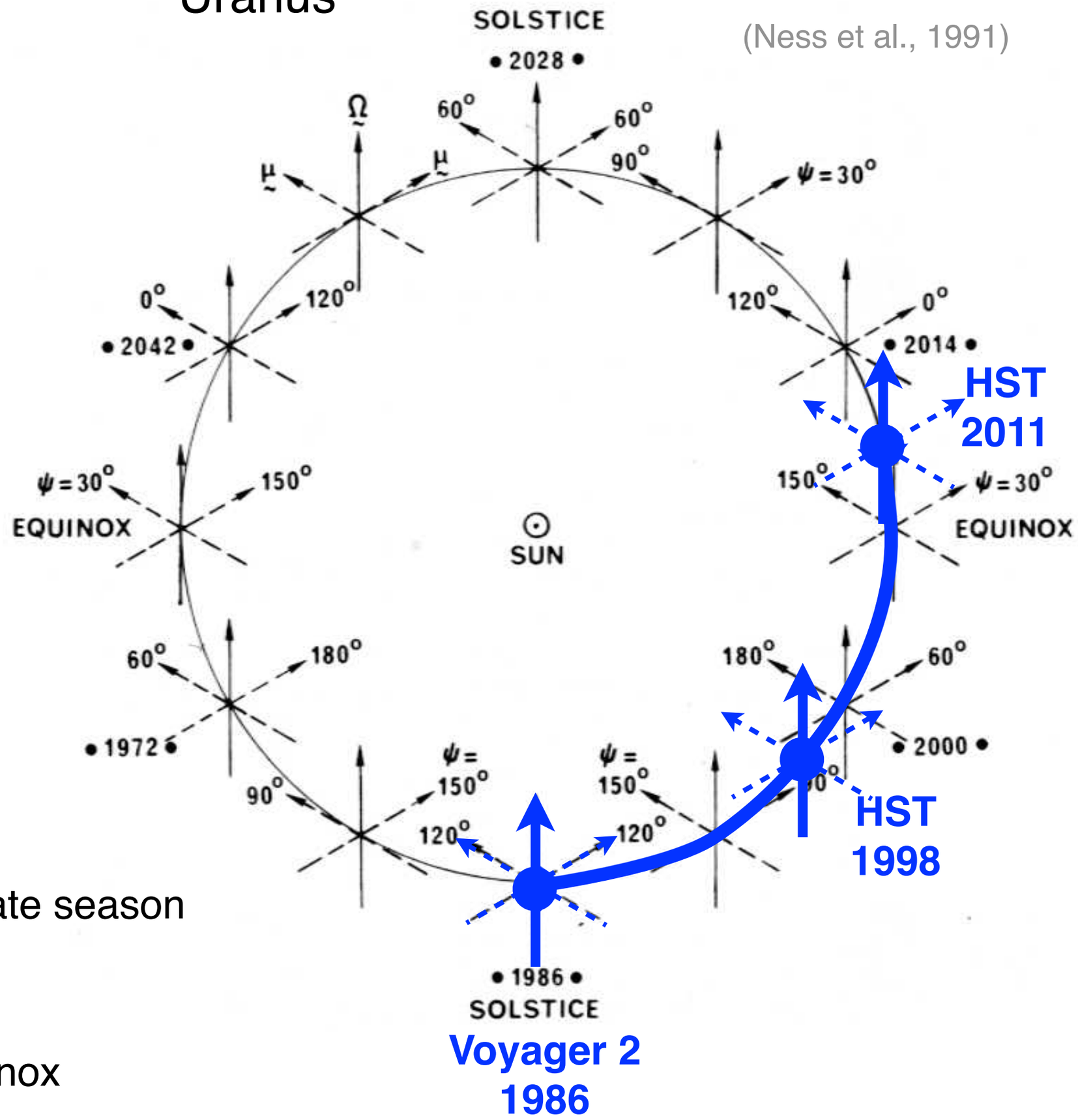
Characteristics :

- transient emissions (down to min) differing from other well-known planetary aurorae
- 2011 : bright (N?) spots in 2011 of 1-2kR, occurrence close to SW shocks
- 1998 : quasi-continuous ovals, centers do not match magn. poles, quiet SW, polar em.

Uranus

(Ness et al., 1991)





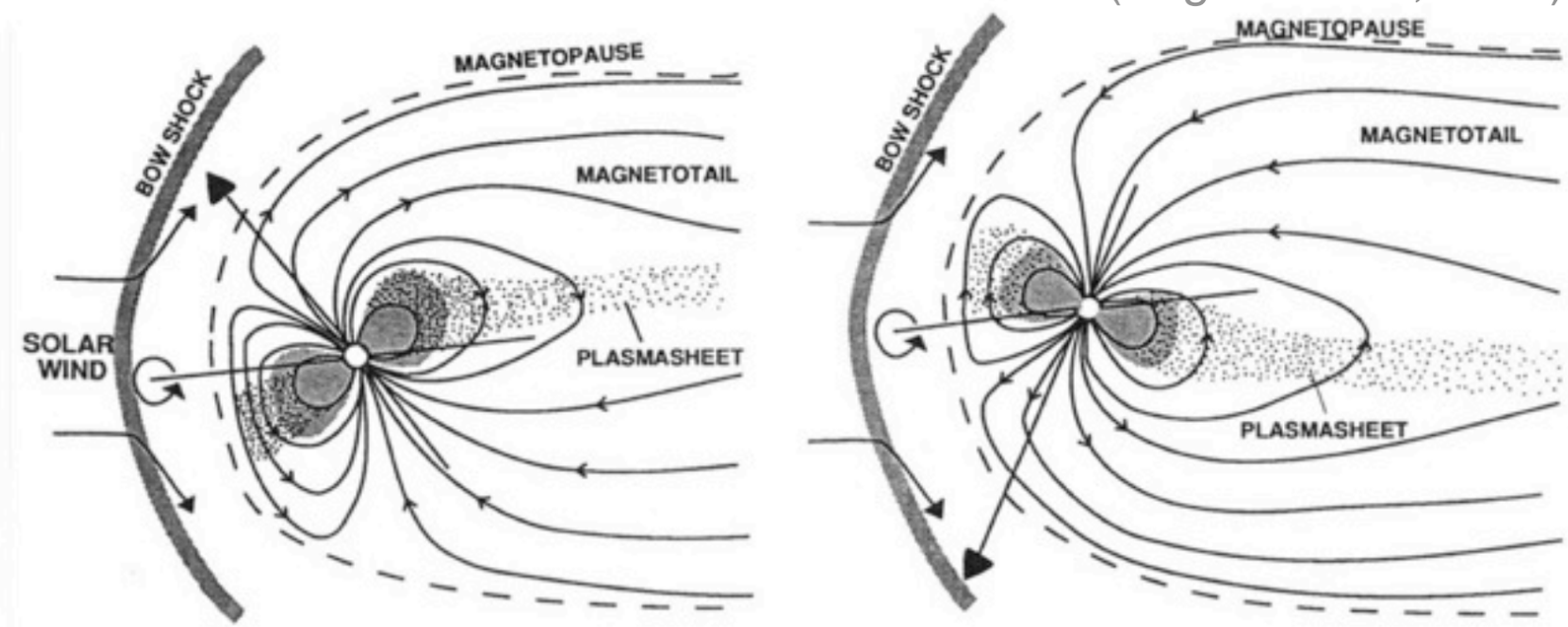
Sun ↑ 1986 : Solstice

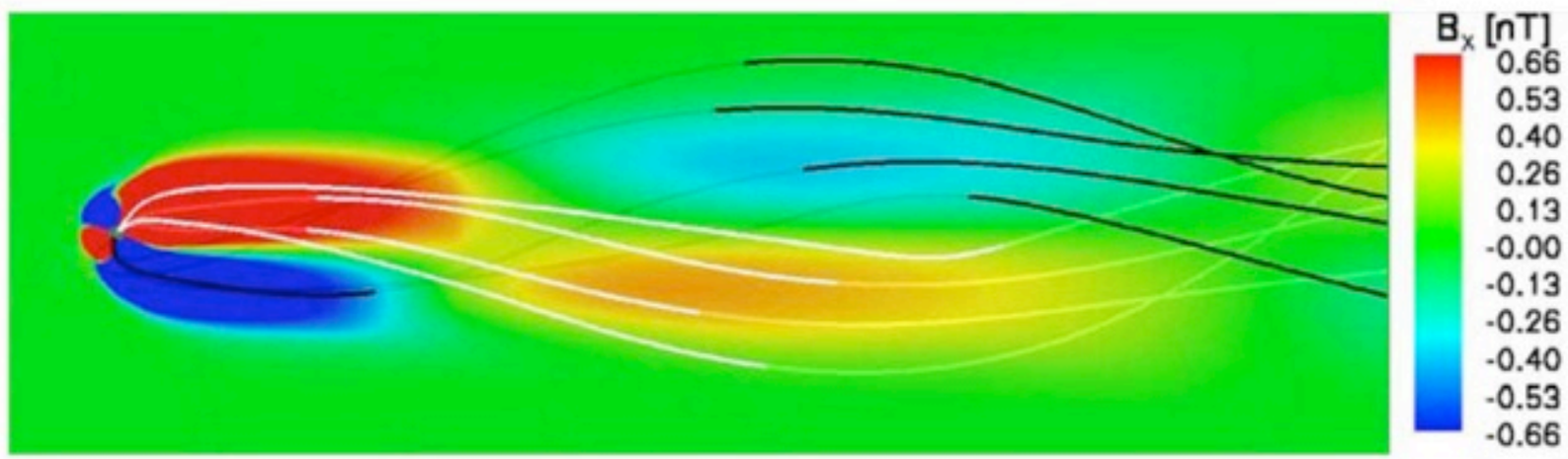
Sun ↖ 1998 : Intermediate season

Sun ← 2011 : Near-equinox

Uranus

(Bagenal et al, 1992)





(Toth et al., 2004)

<u>1986 :</u> N (S) magnetic pole rotates on the dayside (nightside)

=> SW convection and planetary rotation act in orthogonal planes

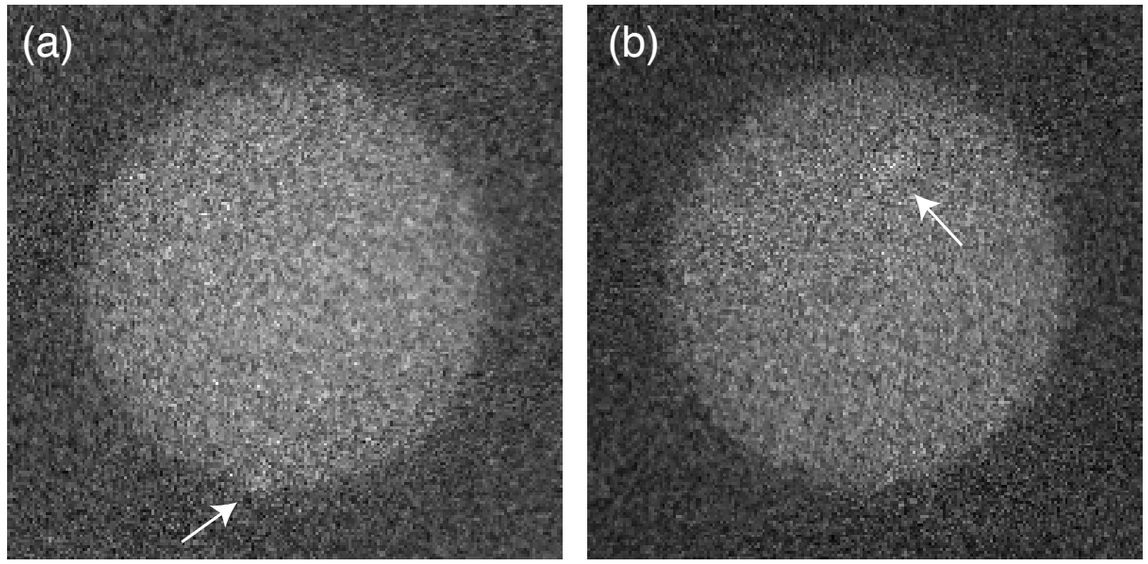
=> stable helical plasma sheet

=> Earth-type situation (nightside auroral precipitations)

NB : Voyager 2 UV data acquired <u>during</u> a SW shock

Voyager 1986 Solstice

16 Nov. 2011 29 Nov. 2011



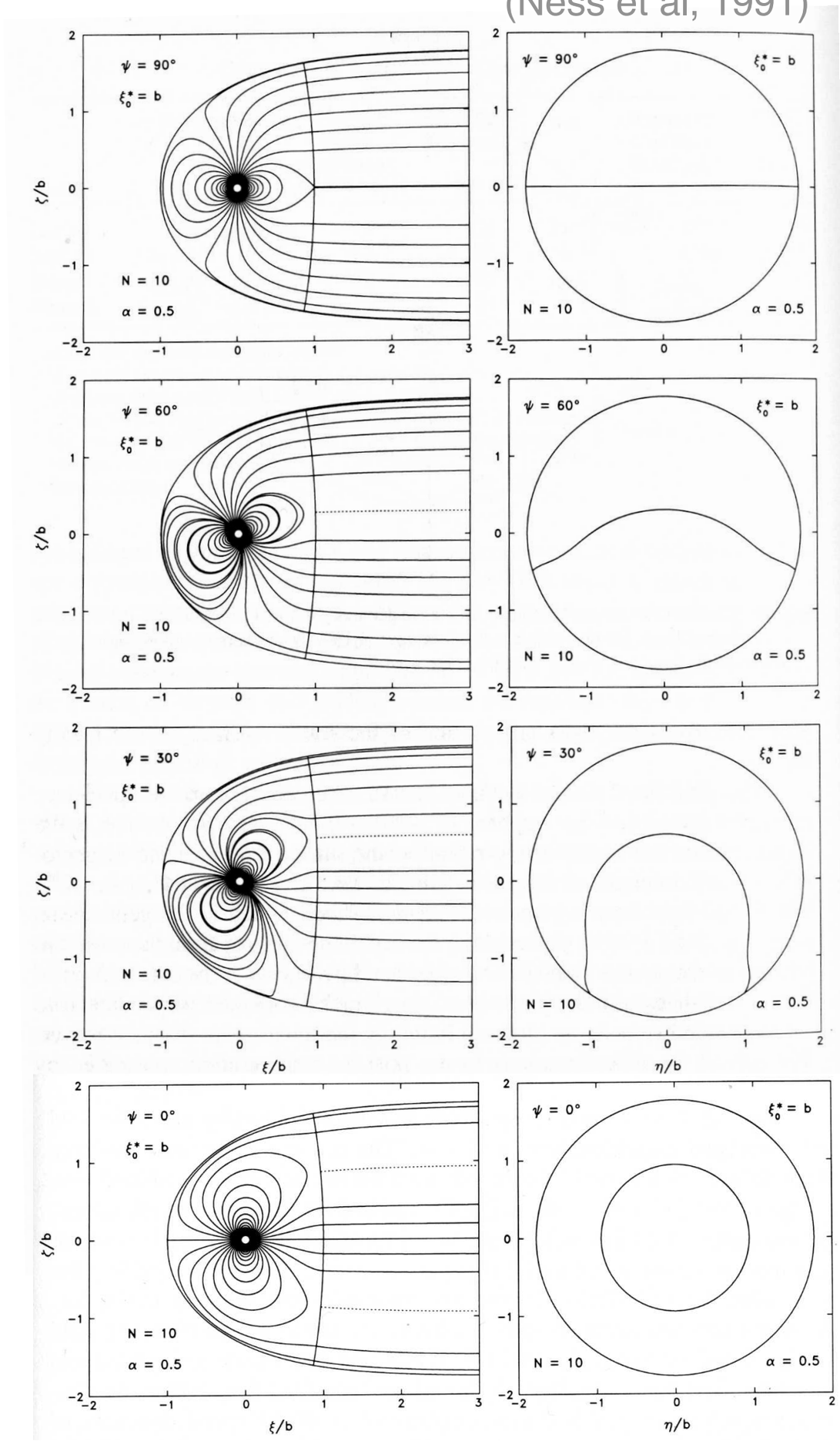
<u>2011 :</u> extreme SW/MS configurations during each rotation from Earth-like to 'pole-on'

(i) unlikely that a significant plasma sheet survives more than half a rotation
=> occurrence close to SW shocks but short lifetime, MS compressions have a different effect - if any - than at other planets

(ii) dayside reconnexion with interplanetary magnetic field favored once per rotation
=> may cause observed brights spots

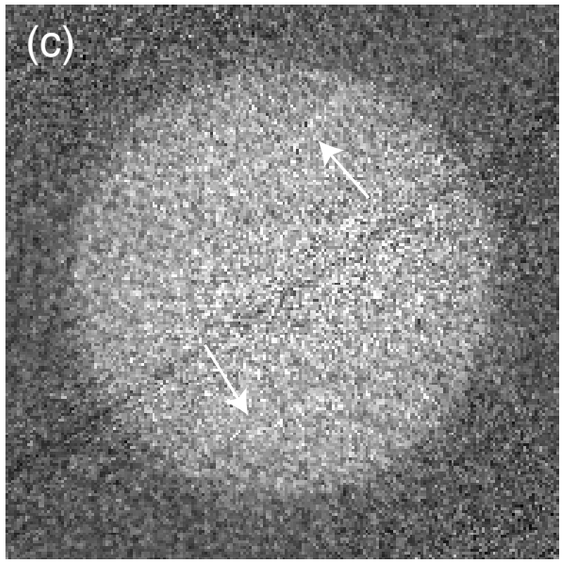
HST-2011
Near Equinox

(Ness et al, 1991)



Uranus

29 Jul. 1998



<u>1998 :</u> intermediate situation, transient continuous emissions
=> possible short-live twisted magnetotail
=> acceleration mechanism(s) and plasma source(s) at work to be determined

- quiet SW => «usual» aurorae

- ovals not centered on the magnetic poles : bias (incomplete view)? dynamical morphology (spiral)? secular change of the magnetic field?

- single position of the N oval gives a new constraint on the rotation period :
8 putative periods coincident with the 17.24±0.01h with an uncertainty of ±0.003h
=> more definite conclusions require the detection of (at least) one other oval

HST-1998
intermediate

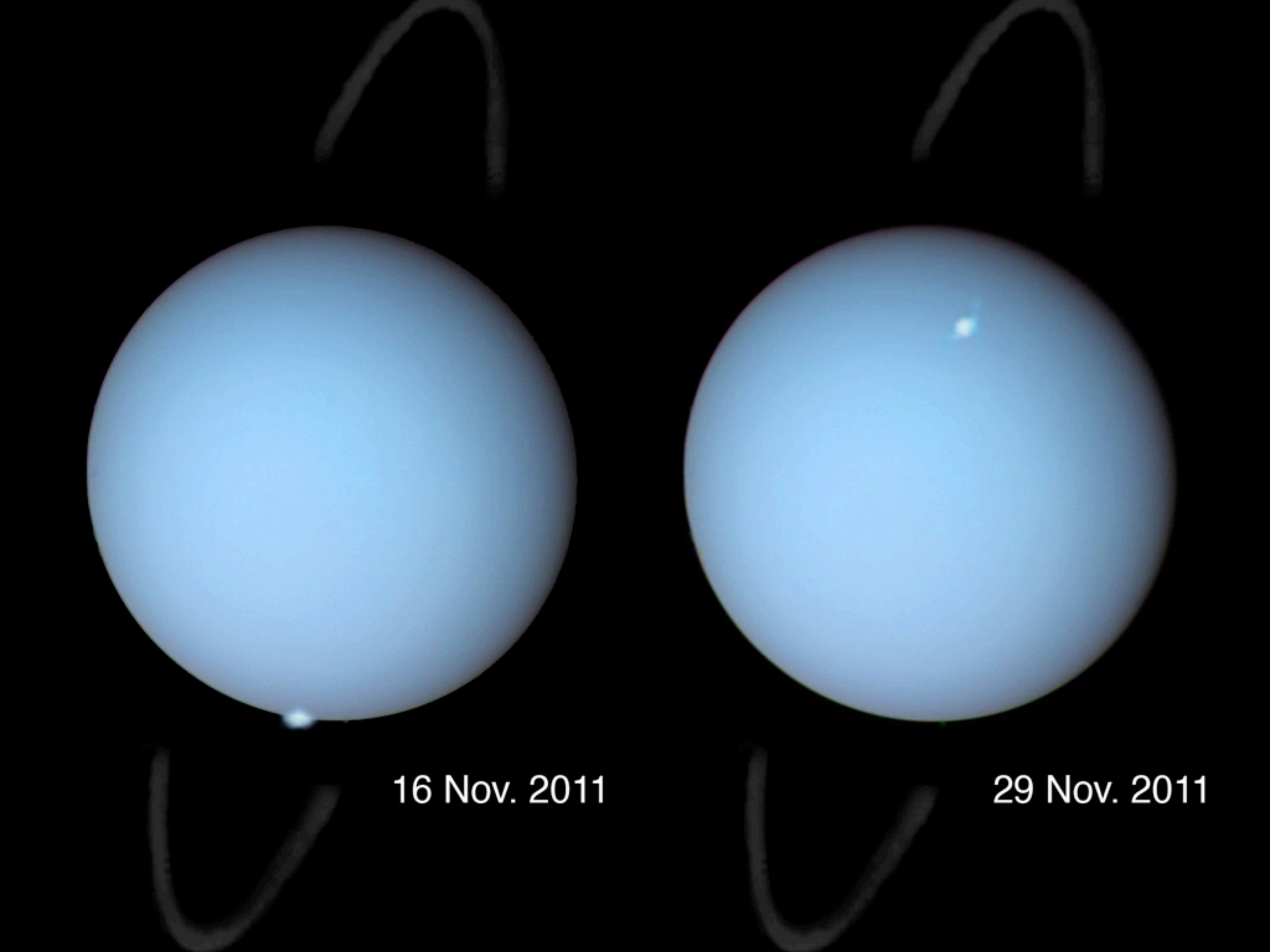
Summary

Results : (Lamy et al., GRL, 2012)
- Re-detection of Uranus aurorae for the first time since their discovery (26 years ago !)
- First images : accurate constraints on active MS regions
- Near-equinox : unique configuration of an asymmetric MS, never investigated before
- Solstice to equinox : different auroral characteristics assigned to changes in the SW/ MS configuration

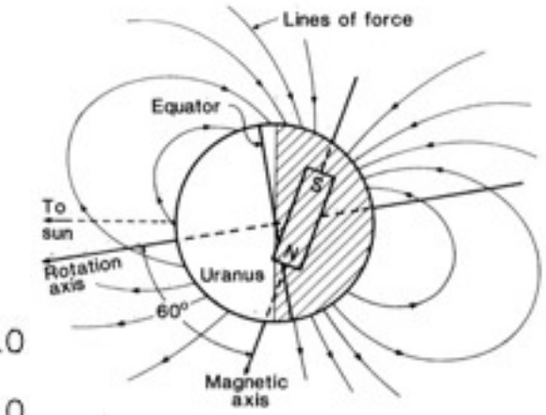
In progress :
- exhaustive analysis of fainter candidates for auroral signals in other images
- analysis of spectra : radiated power (+ energy of incident e-?)
- analysis of simultaneous observations (UV/IR @Uranus, radio/X @Jupiter)

Perspectives :
- Renewed interest for Uranus (ice giants) : 4 mission proposals @ESA/NASA
- No orbited planned yet + long cruise phase (12-15 years)
- Earth-based UV observations (HST) = the only tool to remotely study Uranus MS

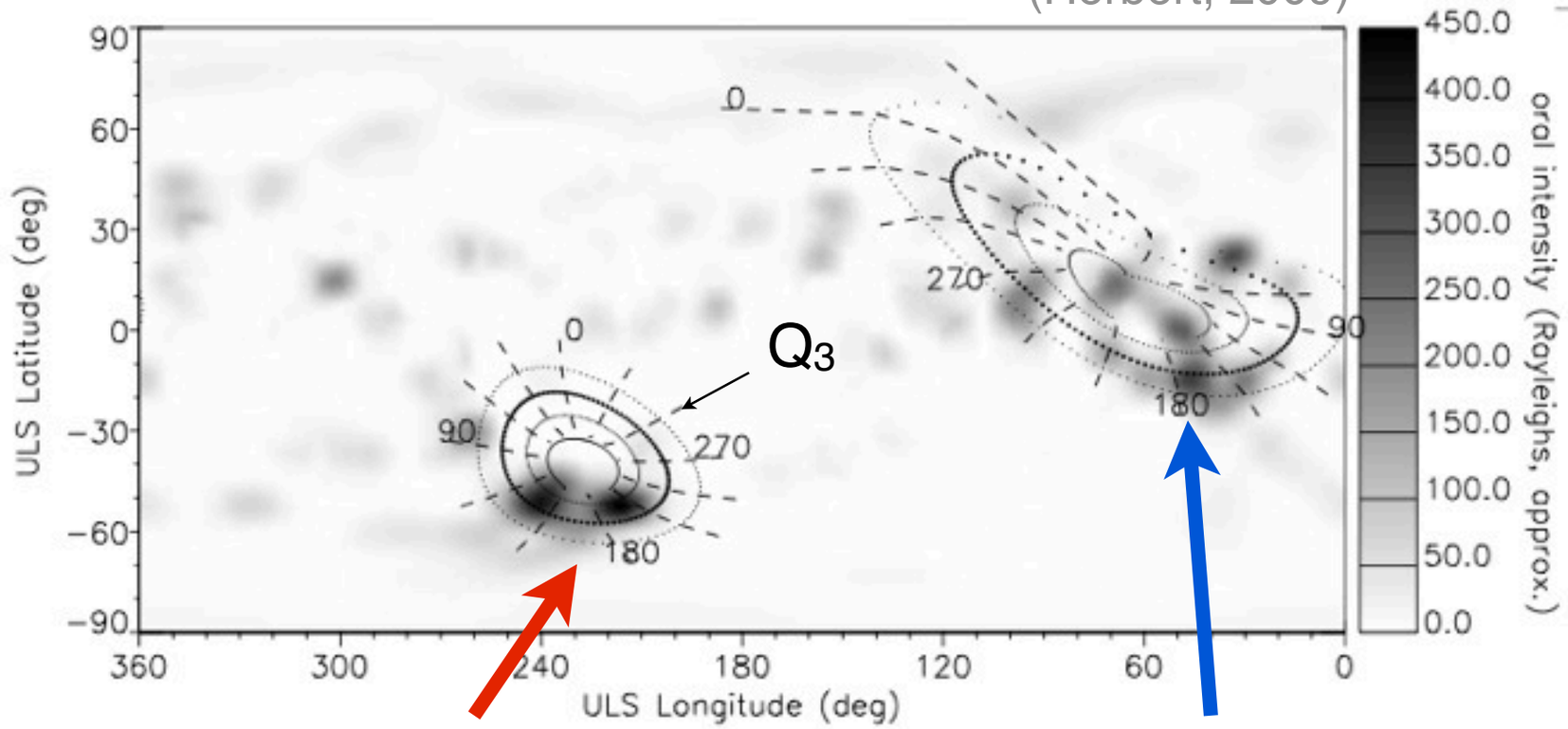
=> new HST observation campaign occurred in september 2012
- Results under active study


16 Nov. 2011
29 Nov. 2011

1986 : Voyager 2



(Herbert, 2009)



S pole (strong-field, nightside) :
~10° colatitude

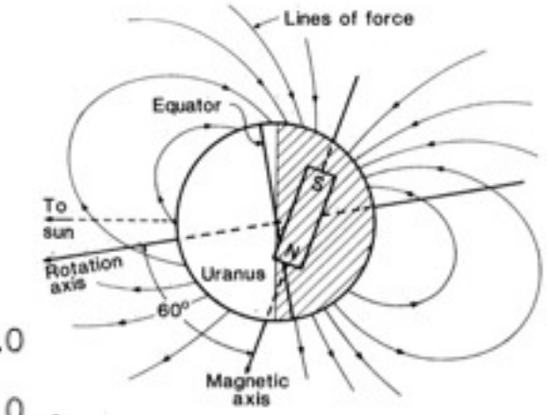
N pole (weak-field, dayside) :
~35-40° colatitude

Main properties :

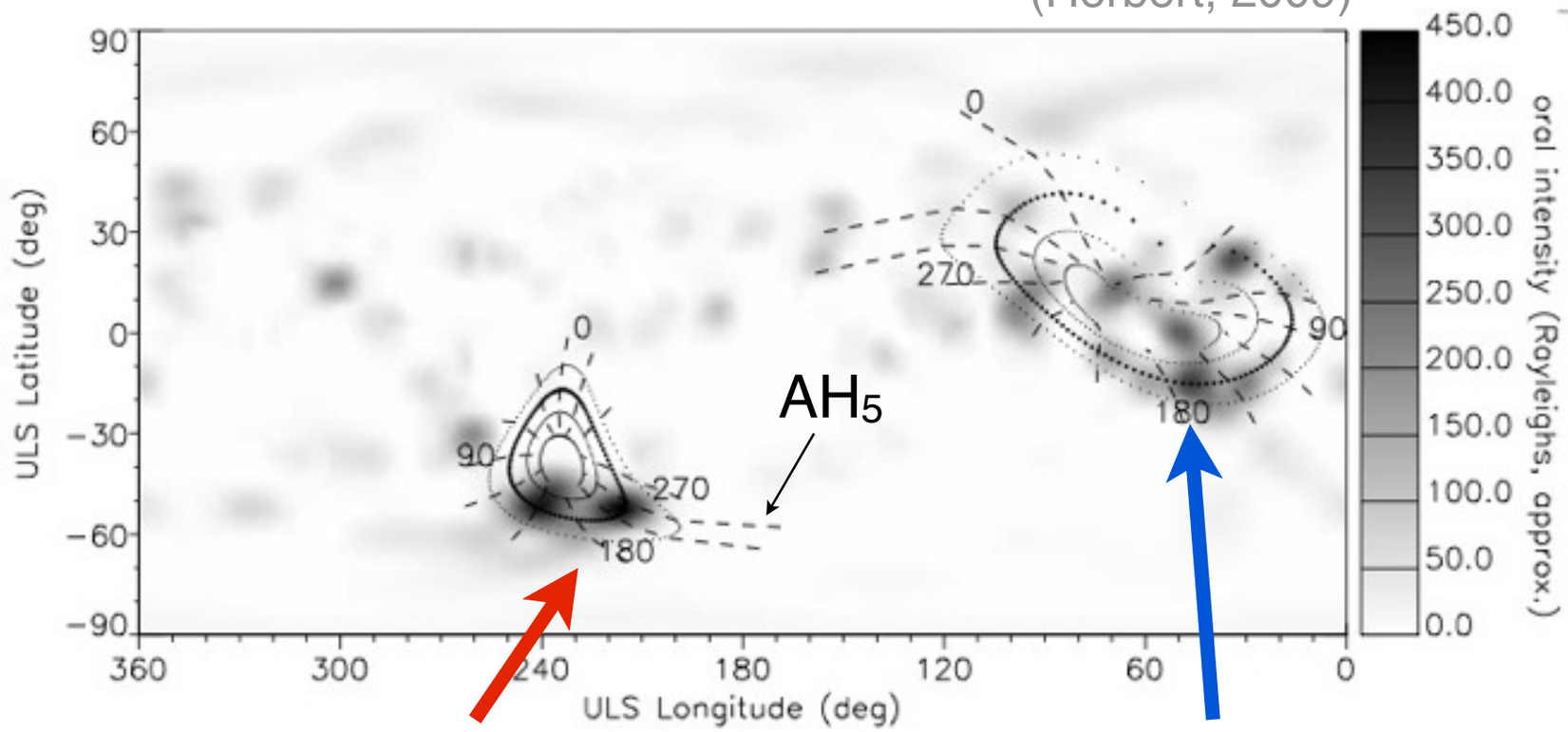
- N and S aurora magnetically conjugate at ~60-65° latitude (L=5-10)
- enhanced along the magnetotail direction (~180° long.) => solar wind convection
- radiated power : N = 3.10^9 W / S = 7.10^9 W => input power ~ a few 10^{10} W
- modulated at the planetary rotation period : 17.24±0.01h
- strongly conjugate with whistler mode activity and UKR nightside emissions

=> N/S magnetic conjugacy used to build an improved magnetic field model AH_5 (n=4)

1986 : Voyager 2



(Herbert, 2009)



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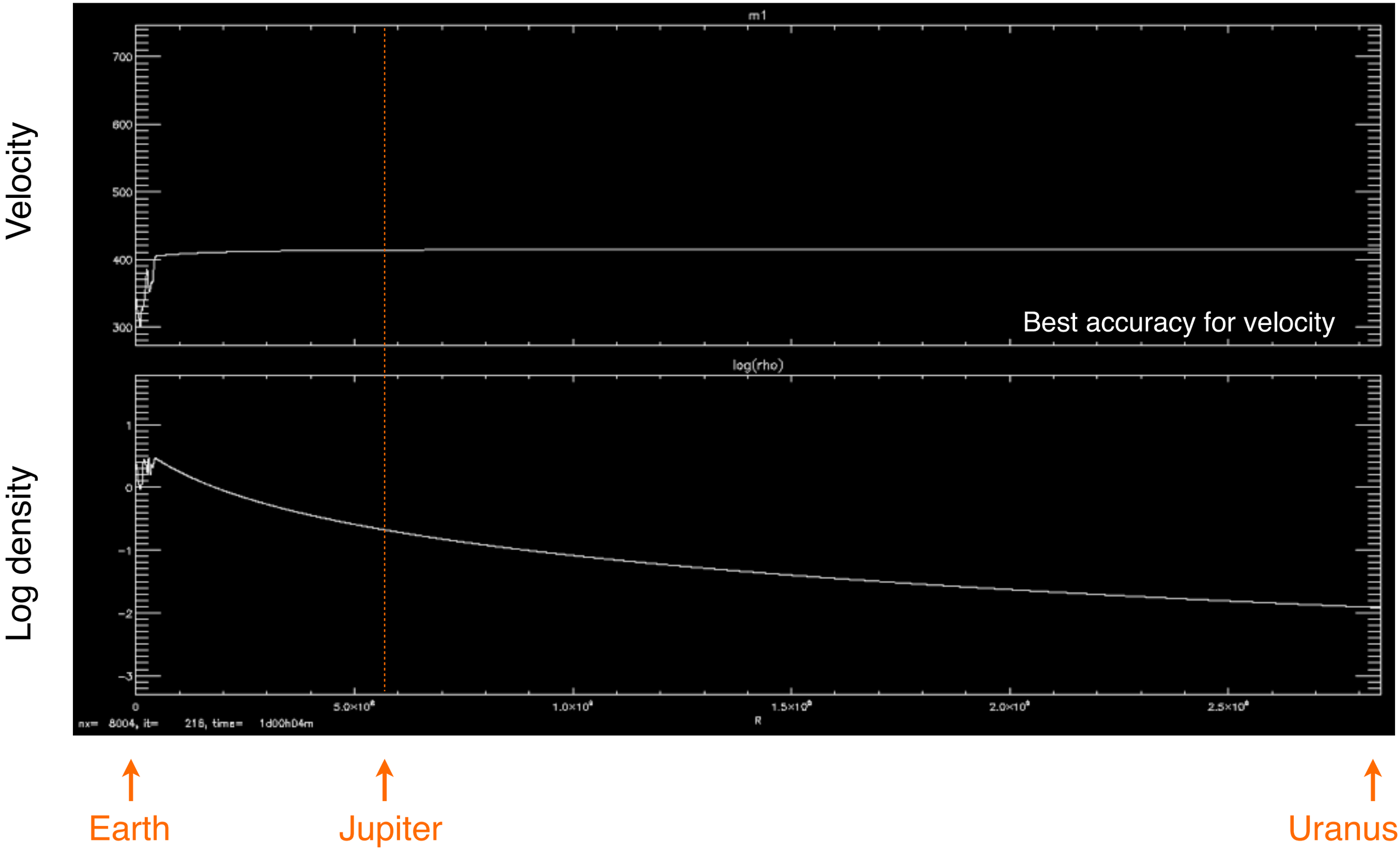
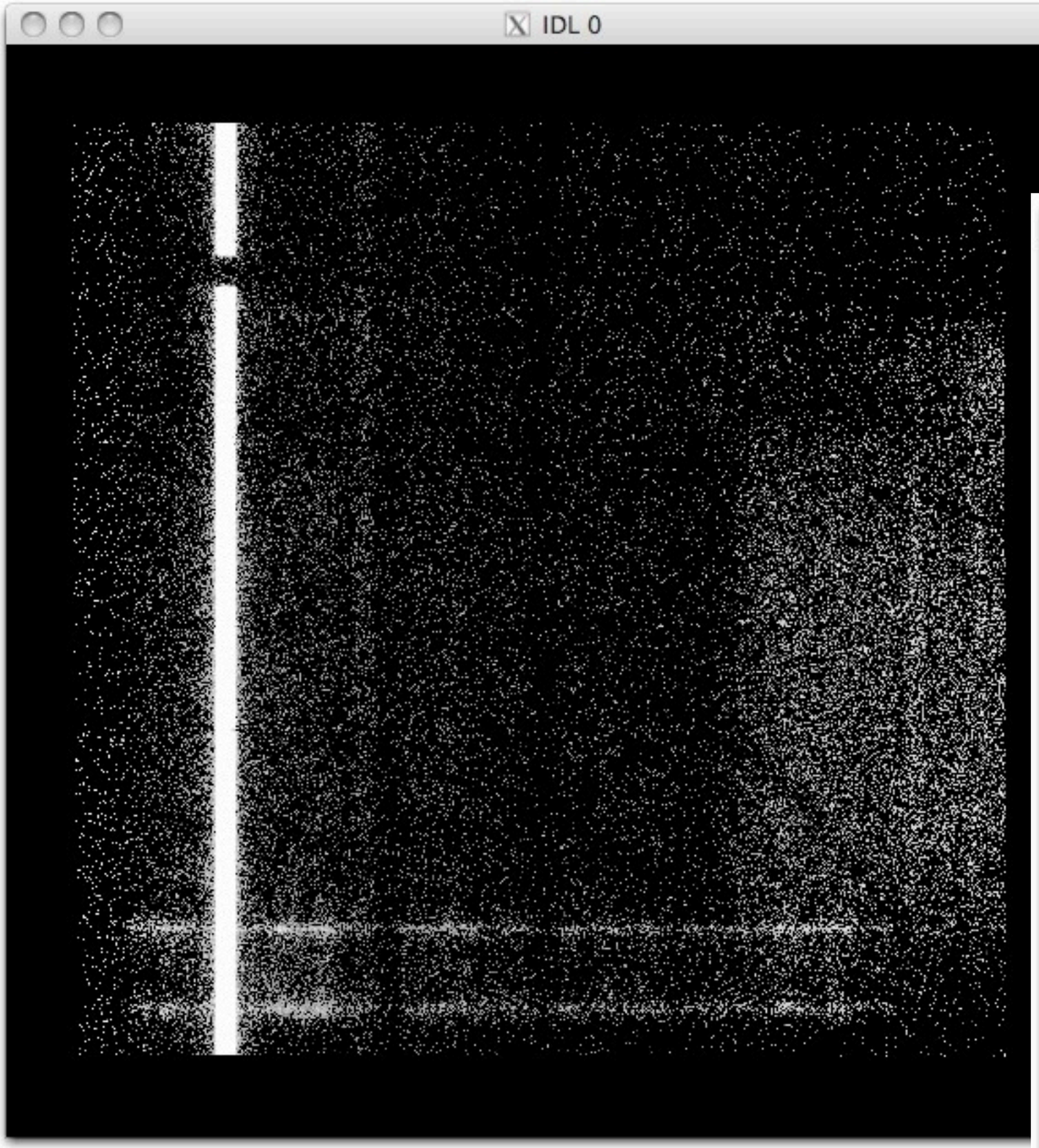
SW propagation results

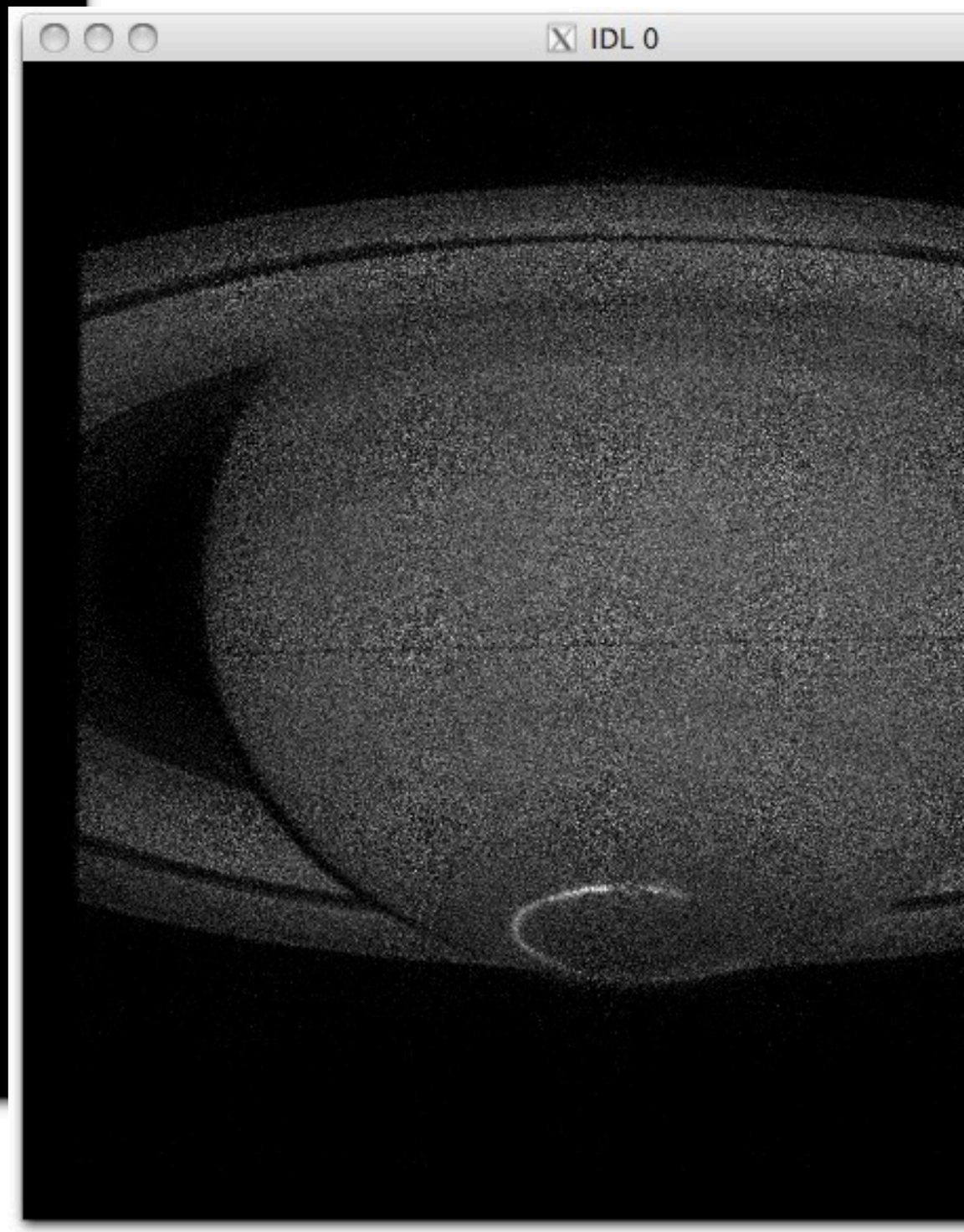
SW propagation :



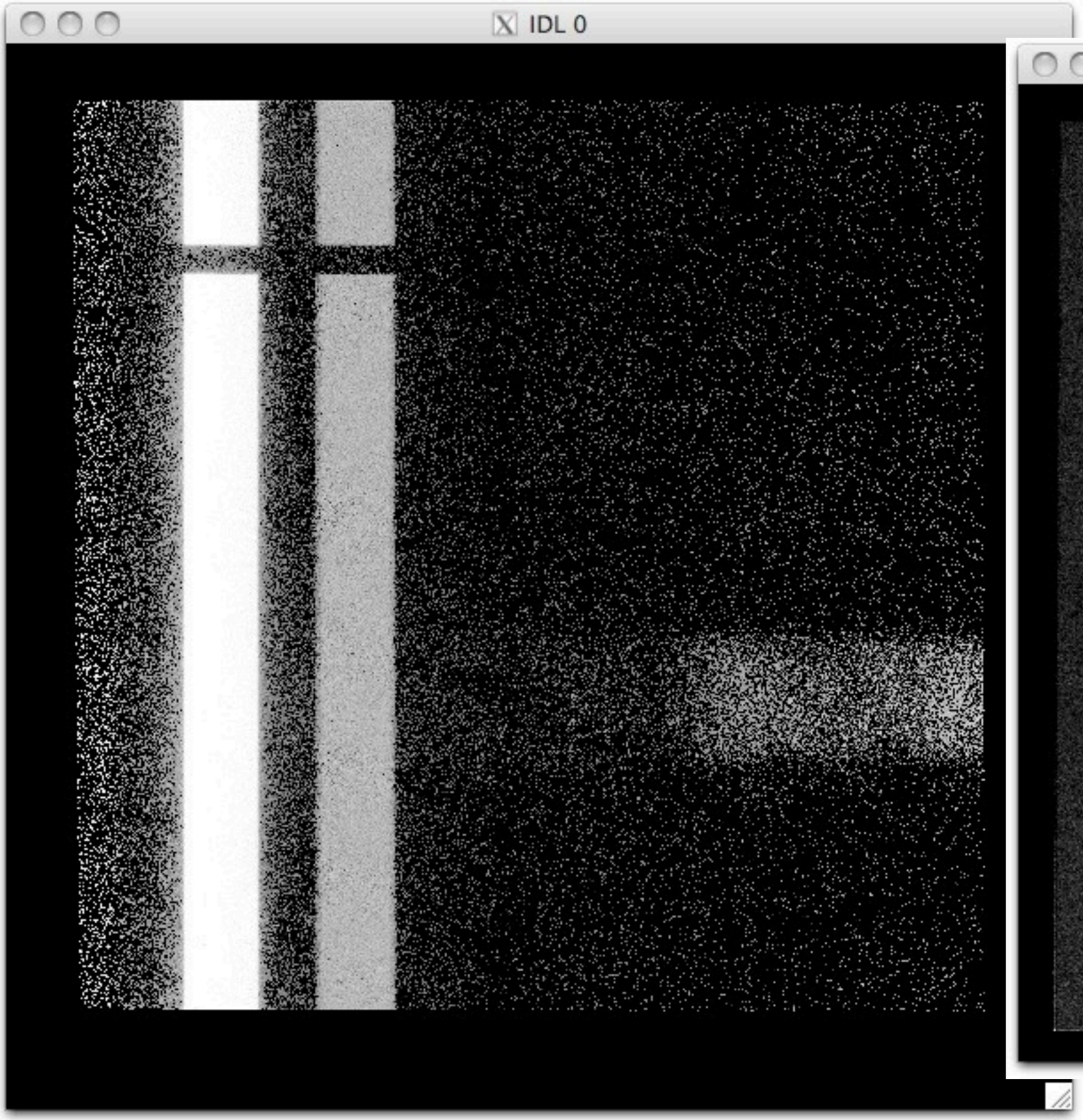
Saturn, Dec. 2000

for comparison





Visit 14



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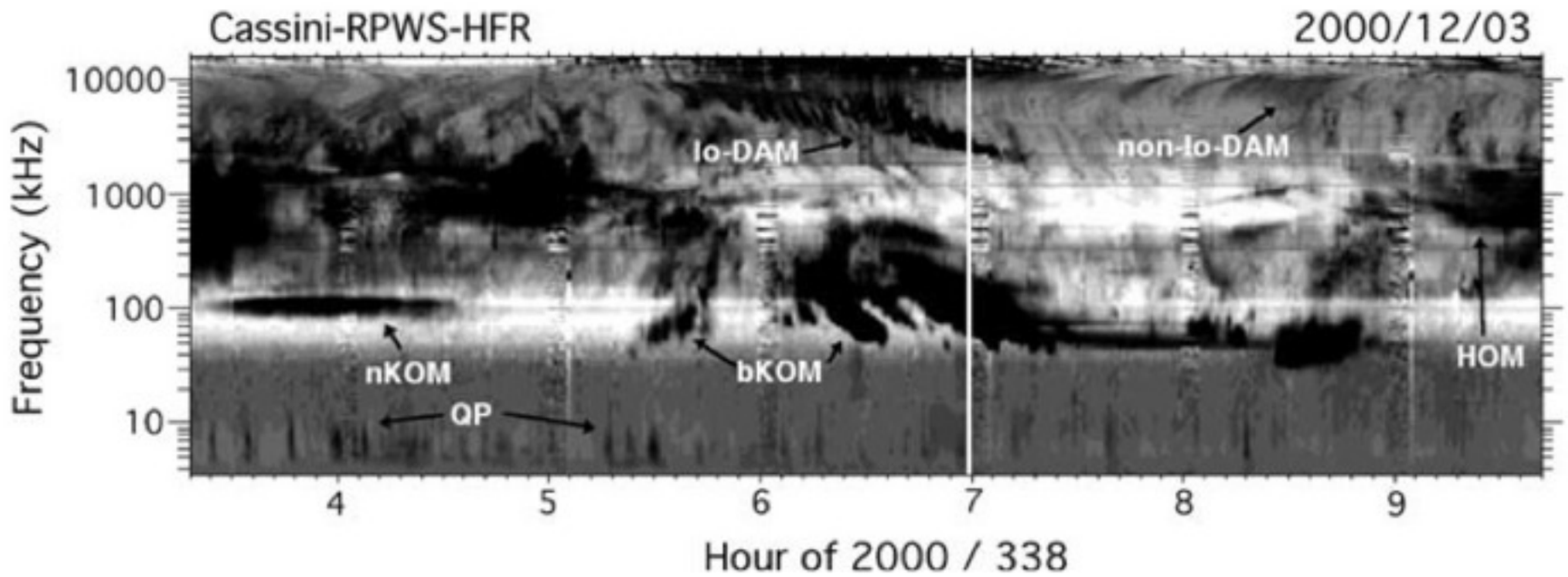
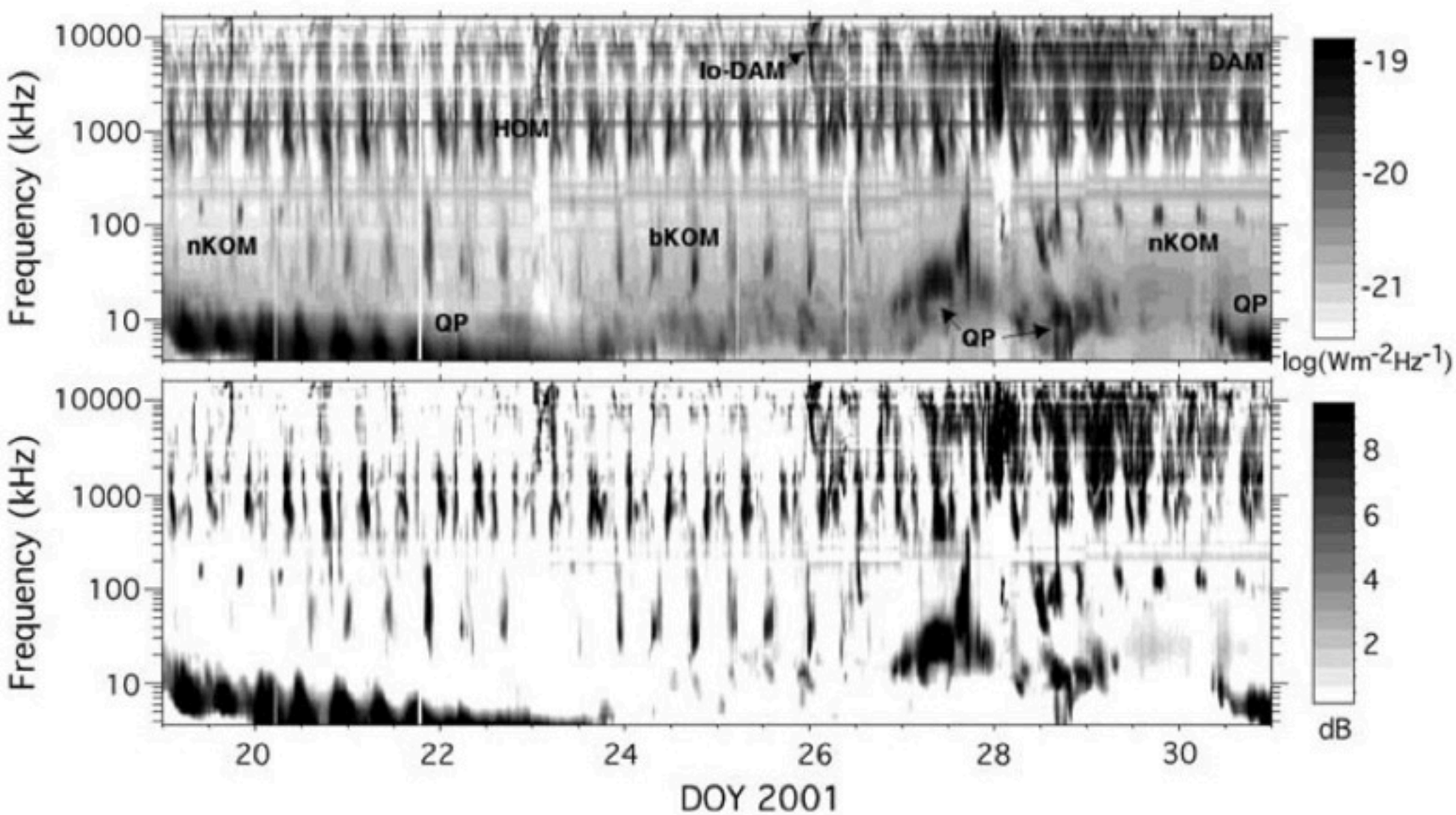
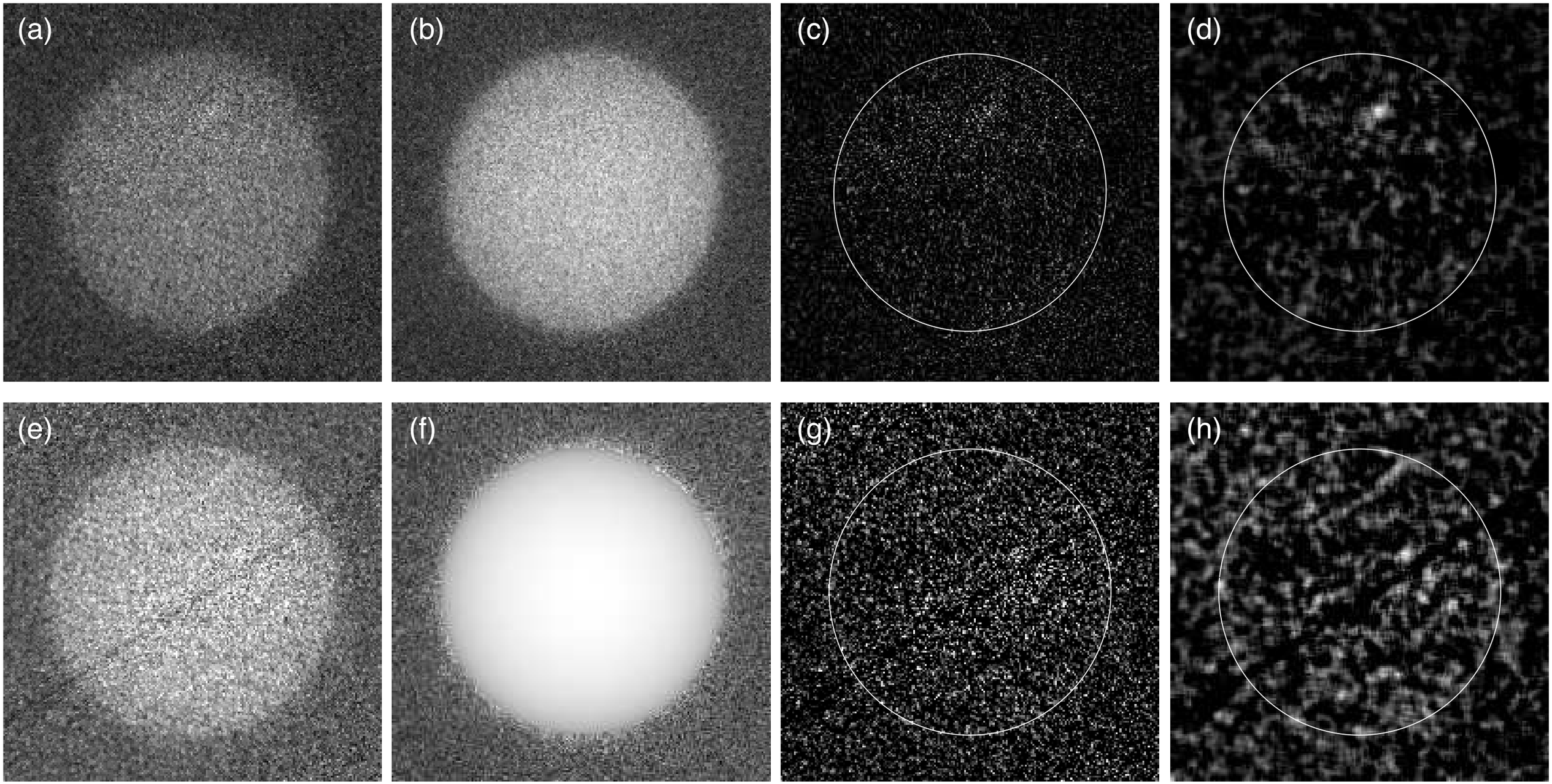
Exposure = 1100s

2011-11-24 11:59:05
Exposure = 1000s



(Zarka et al, 2004)




(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)