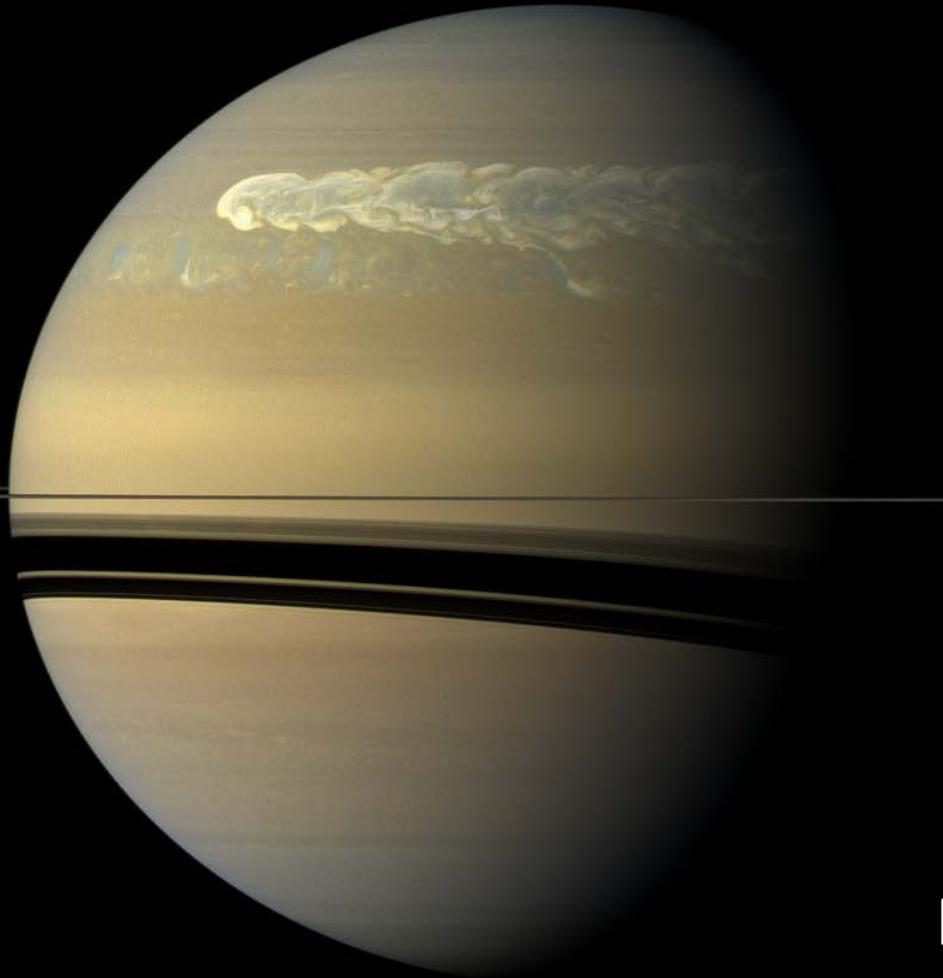


Les phénomènes orageux sur Saturne

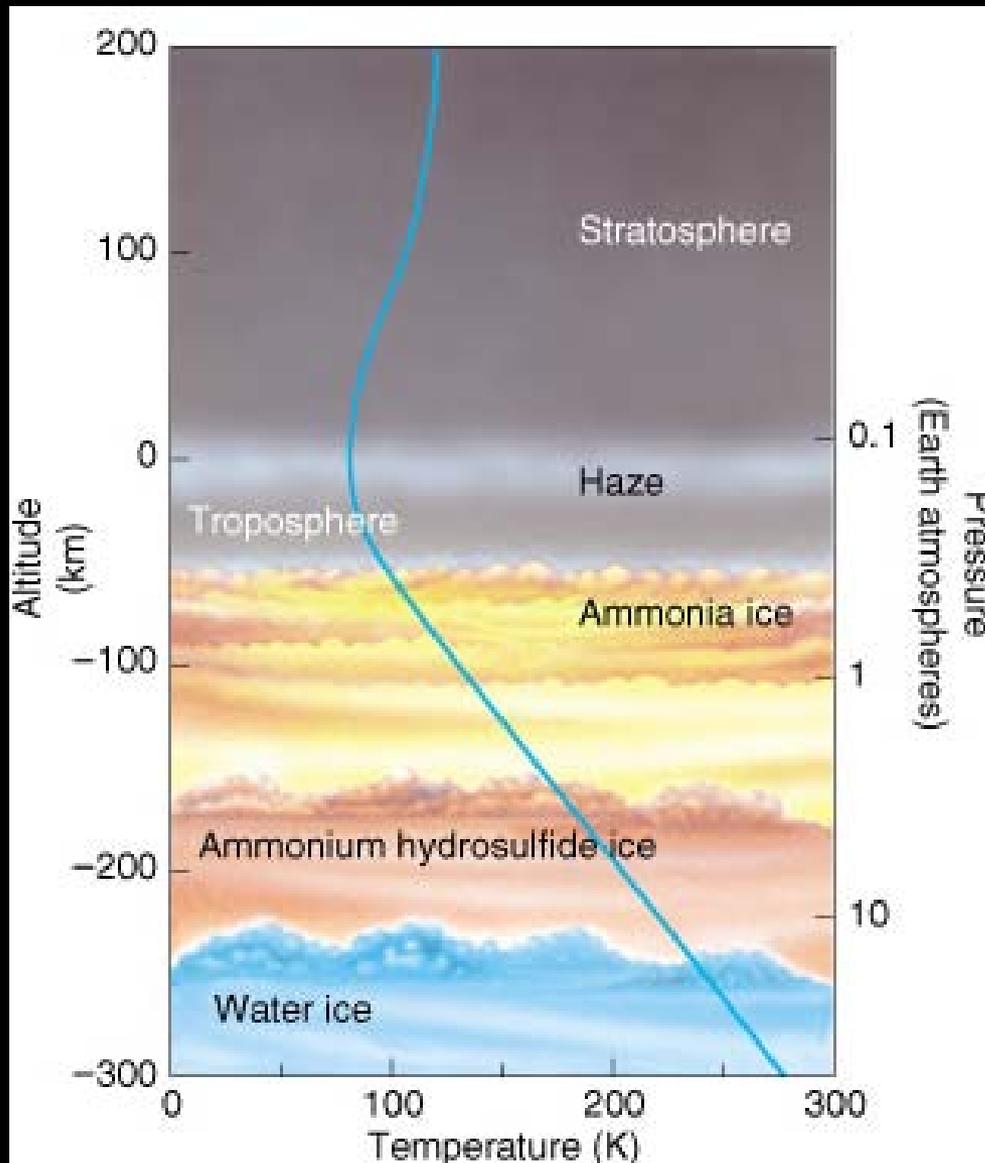
observés par la sonde *Cassini*



Régis Courtin

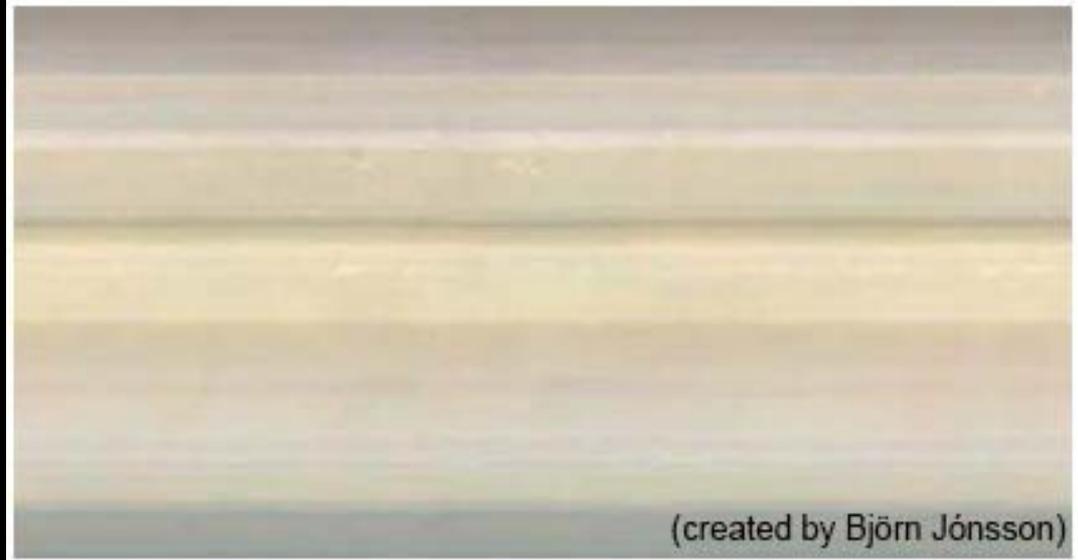
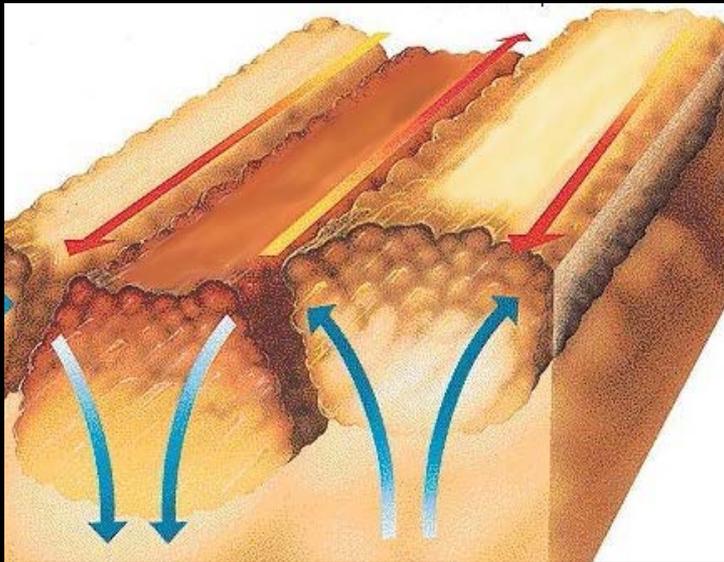
LESIA – Observatoire de Paris

La face visible de Saturne



Une différence marquée avec Jupiter

La face visible de Jupiter révèle une formidable activité météorologique alors que Saturne apparaît en général beaucoup plus calme. Est-ce seulement en apparence ?



(created by Björn Jónsson)

Un bref historique des phénomènes orageux sur Saturne

- durant la mission *Voyager* (1980-1981), les orages furent essentiellement observés dans l'hémisphère Nord
- en 1990, un puissant orage a été observé à l'équateur, notamment avec le Télescope Spatial Hubble
- durant la mission *Cassini* pré-équinoxiale (2004-2009), les orages étaient localisés et confinés à une zone baptisée "couloir des orages" (*storm alley*) vers 40°S
- un puissant orage s'est déclenché en décembre 2010 et ses conséquences à l'échelle planétaire sont encore visibles

**Six orages d'envergure planétaire ont été observés
à ce jour avec une périodicité voisine de 30 ans
(un par année saturnienne)**

1876

1903

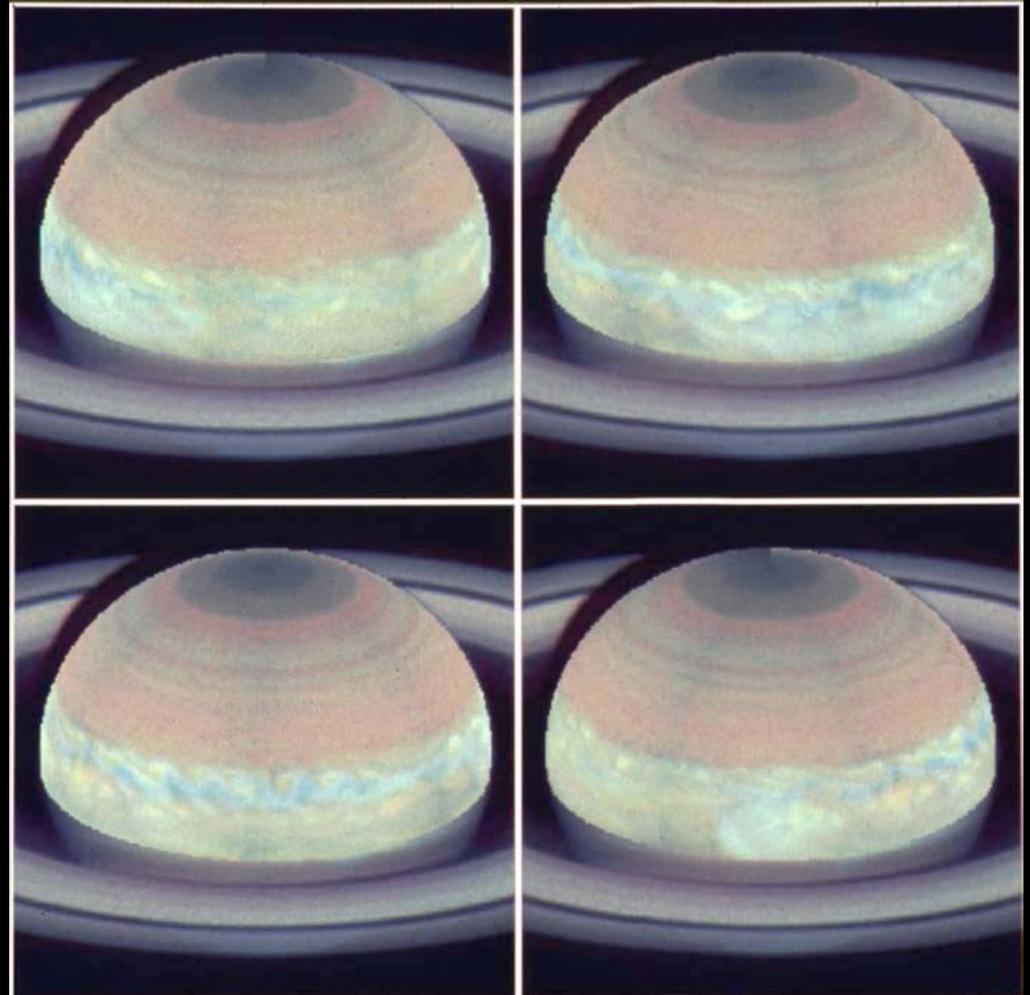
1933

1960

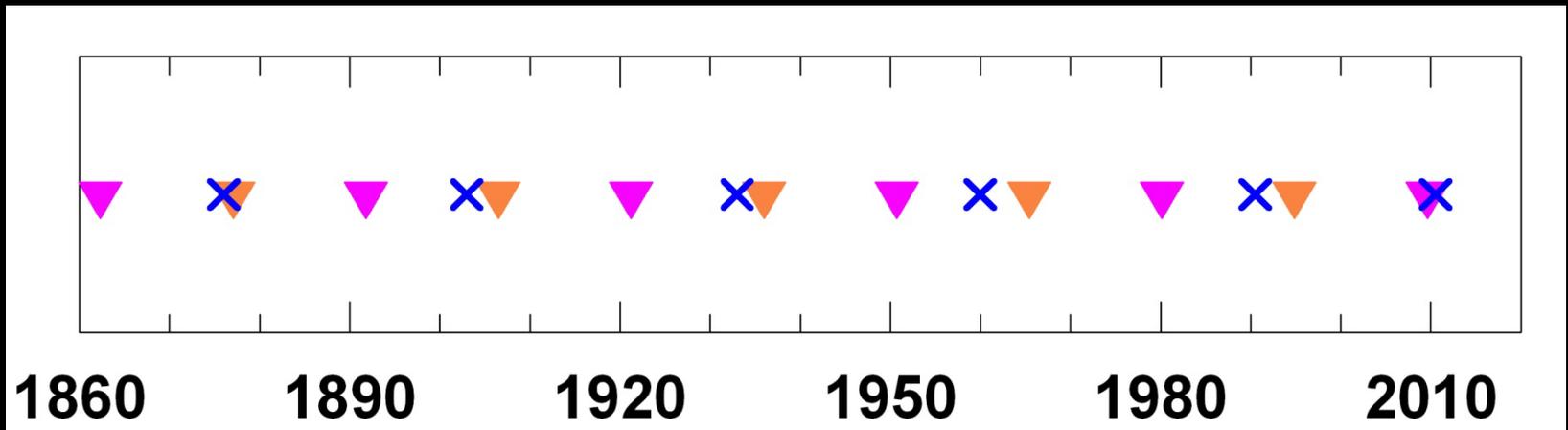
1990

2010

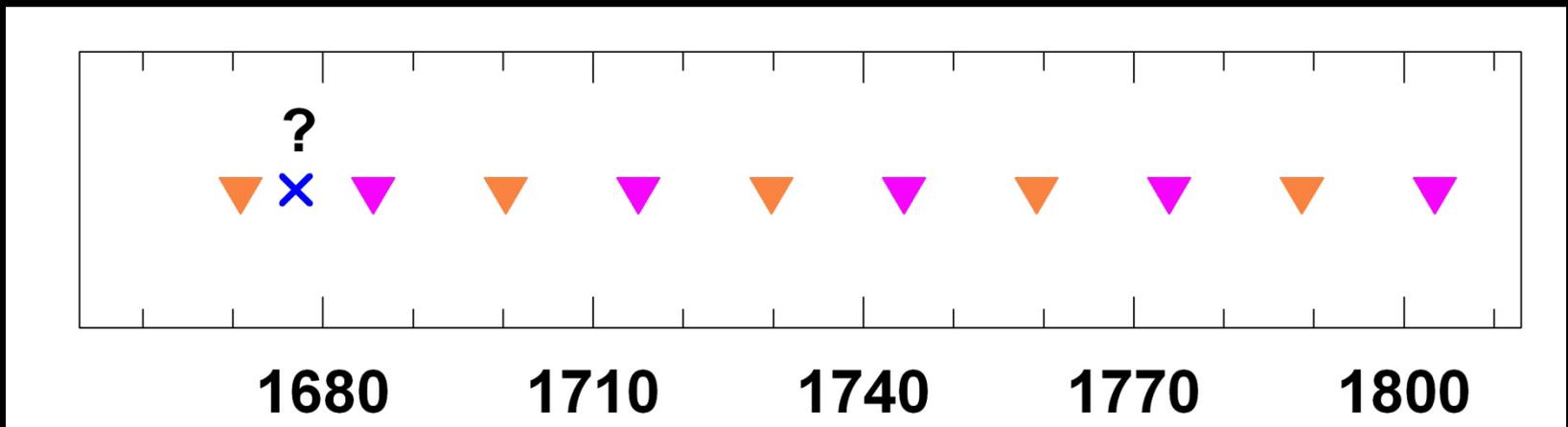
L'orage équatorial
de 1990 observé
par le Télescope
Spatial Hubble



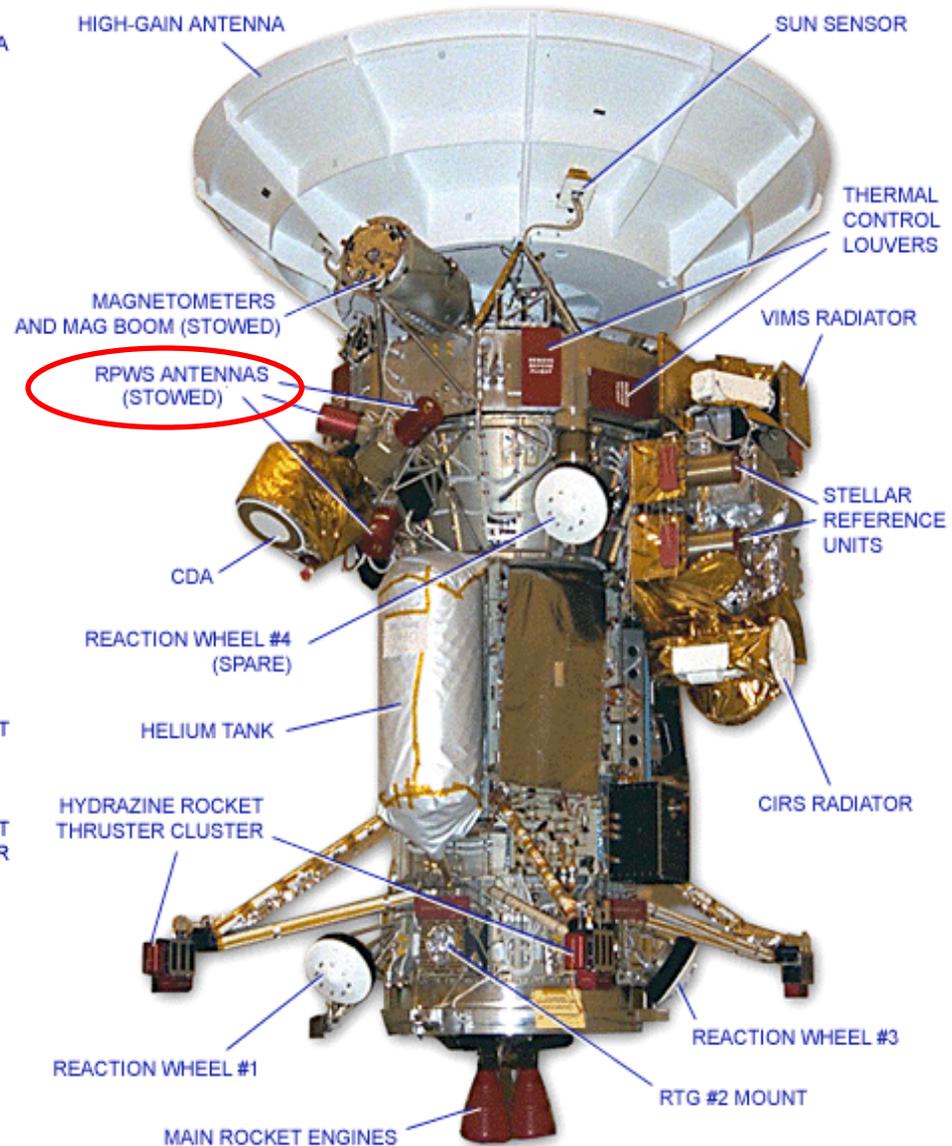
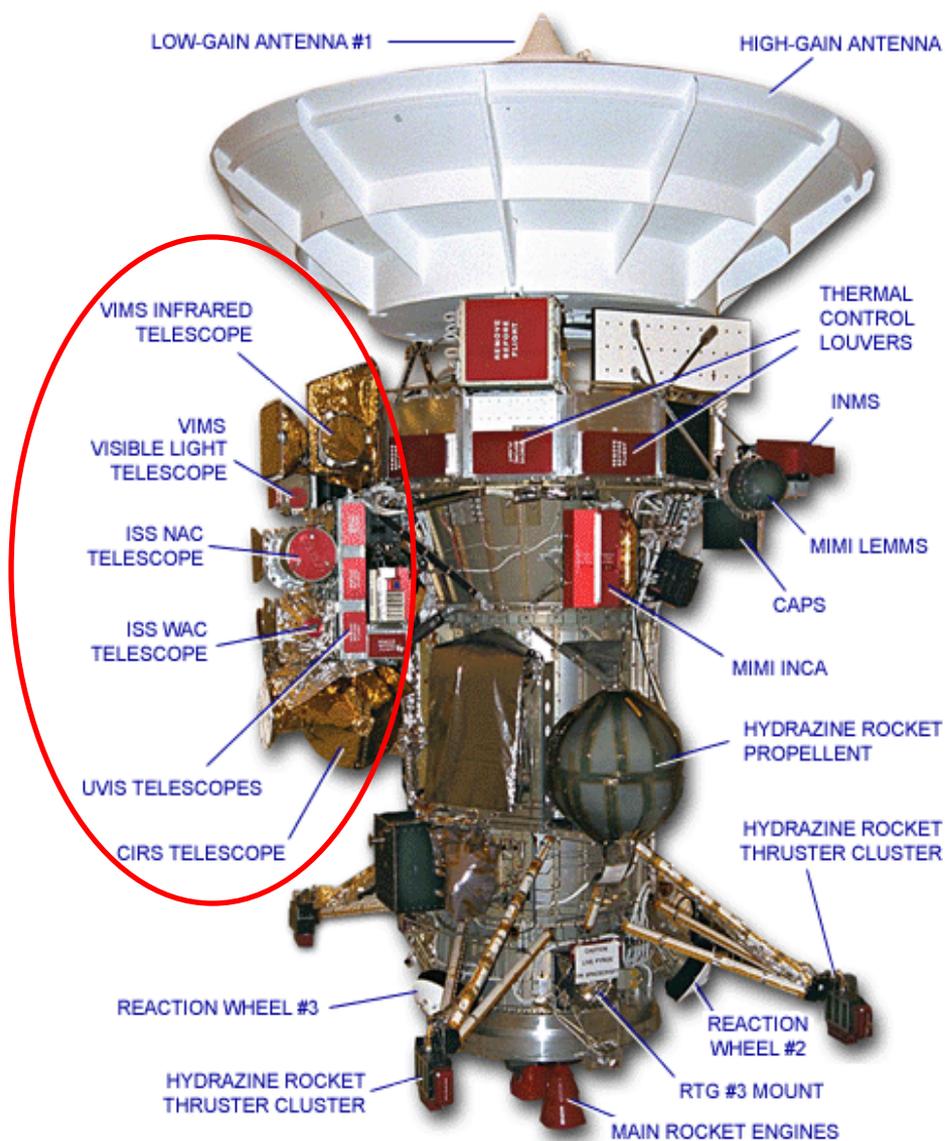
Les "orages planétaires" se produisent en moyenne tous les 30 ans et en général durant l'été boréal, à l'équateur (1876, 1933, 1990) ou dans les zones tempérées de l'hémisphère Nord (1903, 1960, 2010)

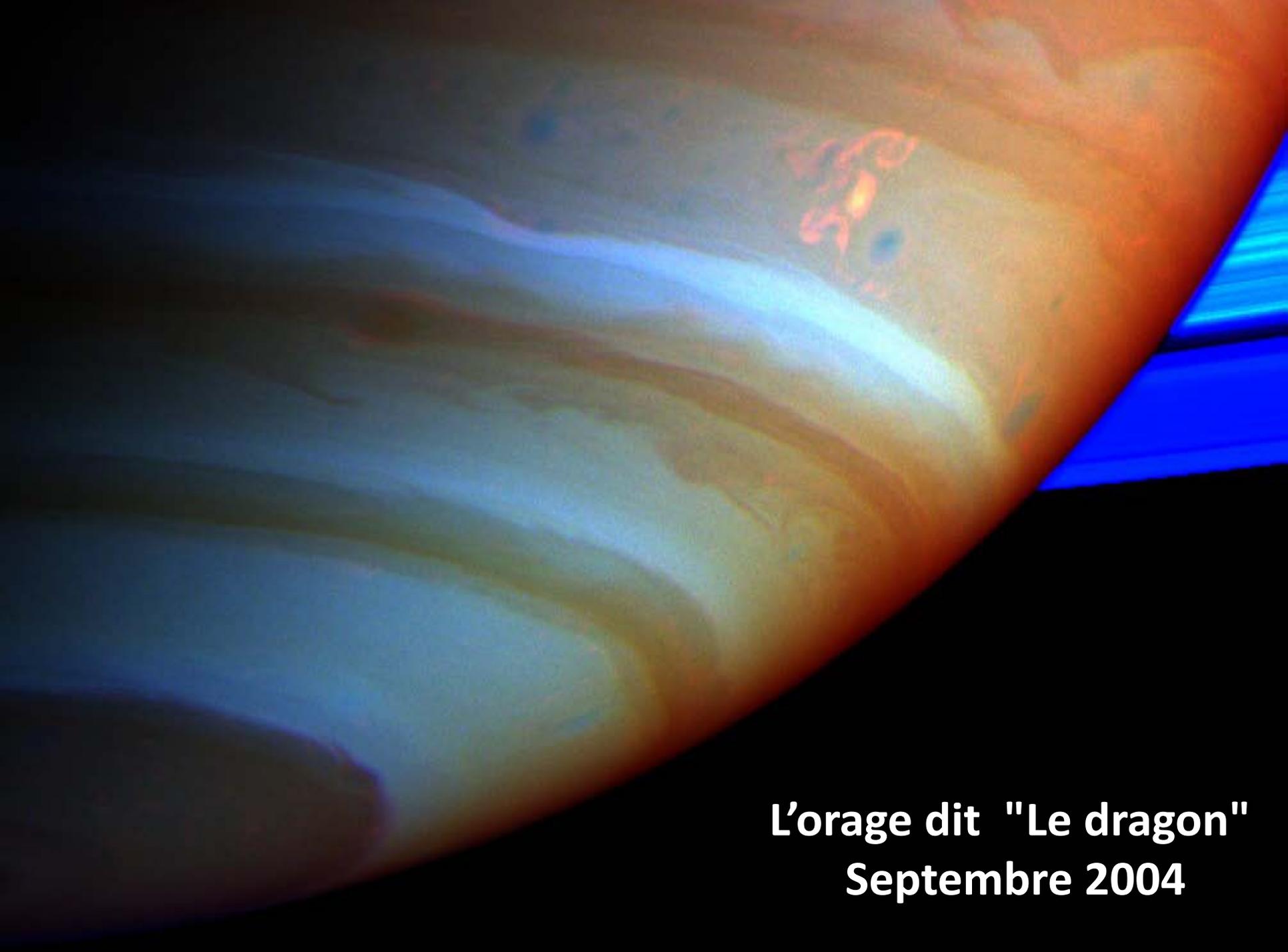


L'observation d'une bande nuageuse à l'équateur par J.-D. Cassini en 1677 est-elle compatible avec le déclenchement d'un tel orage ?

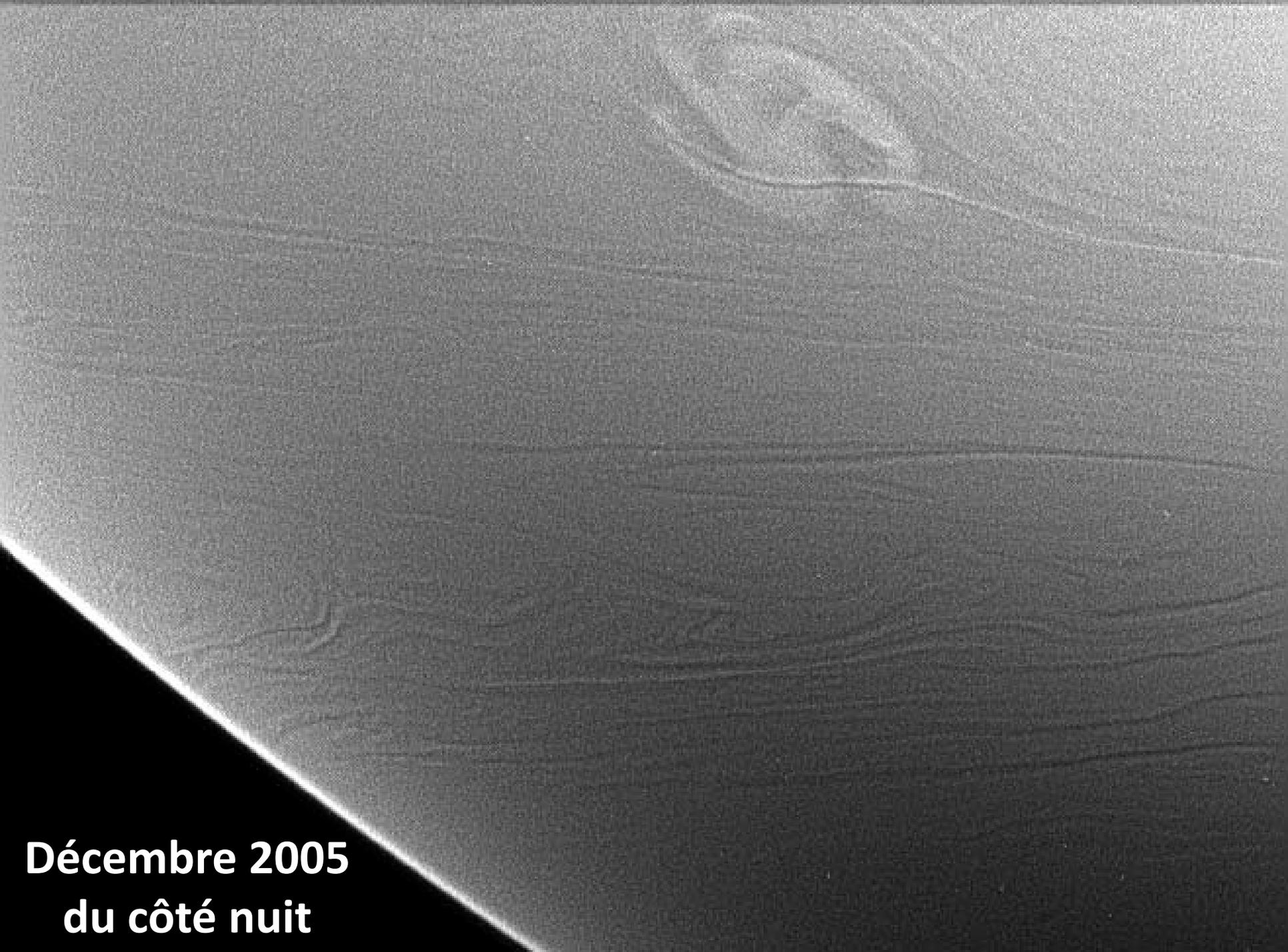


Une panoplie d'instruments de la sonde *Cassini* au service de l'observation des phénomènes orageux

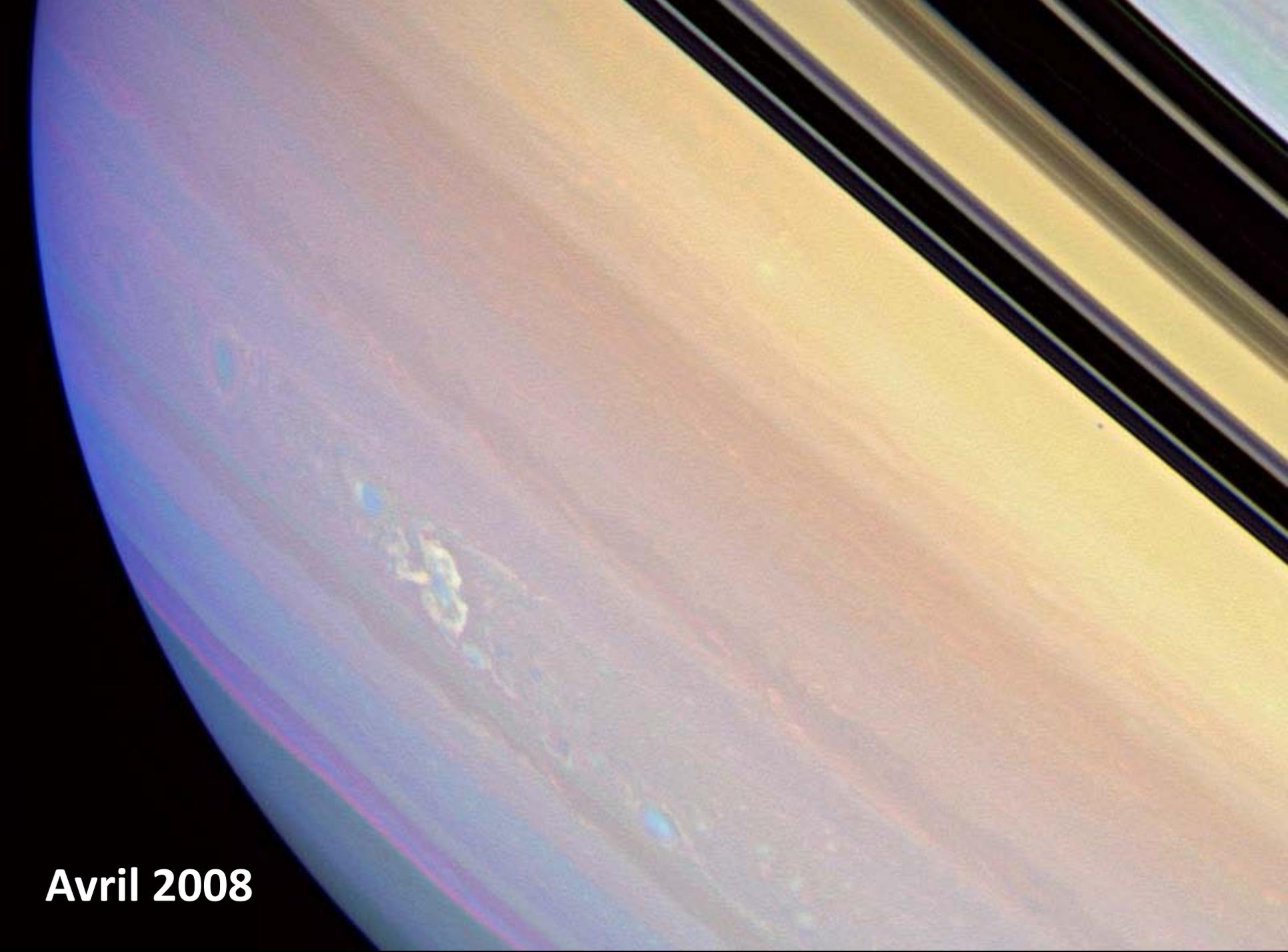




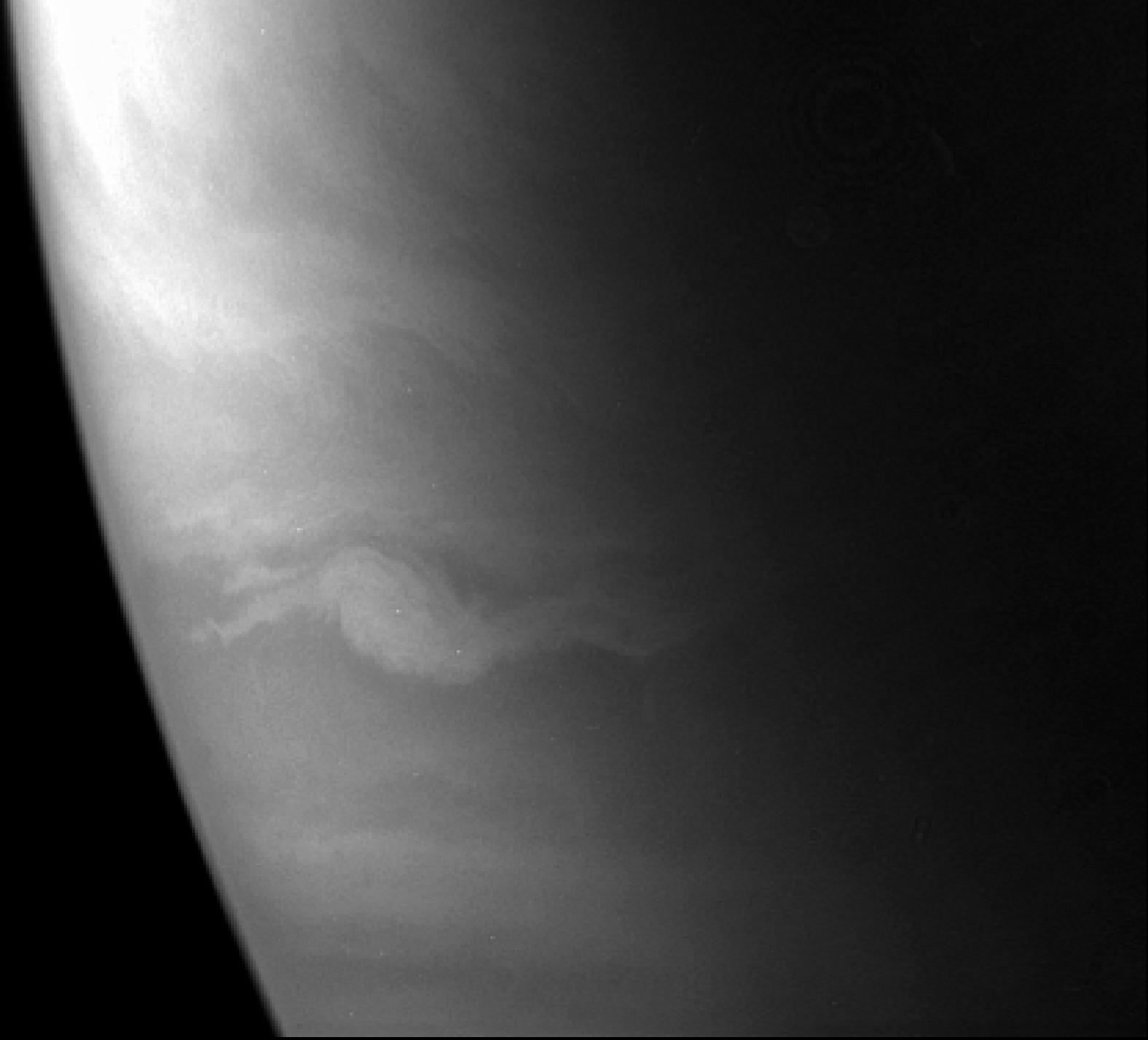
**L'orage dit "Le dragon"
Septembre 2004**



Décembre 2005
du côté nuit

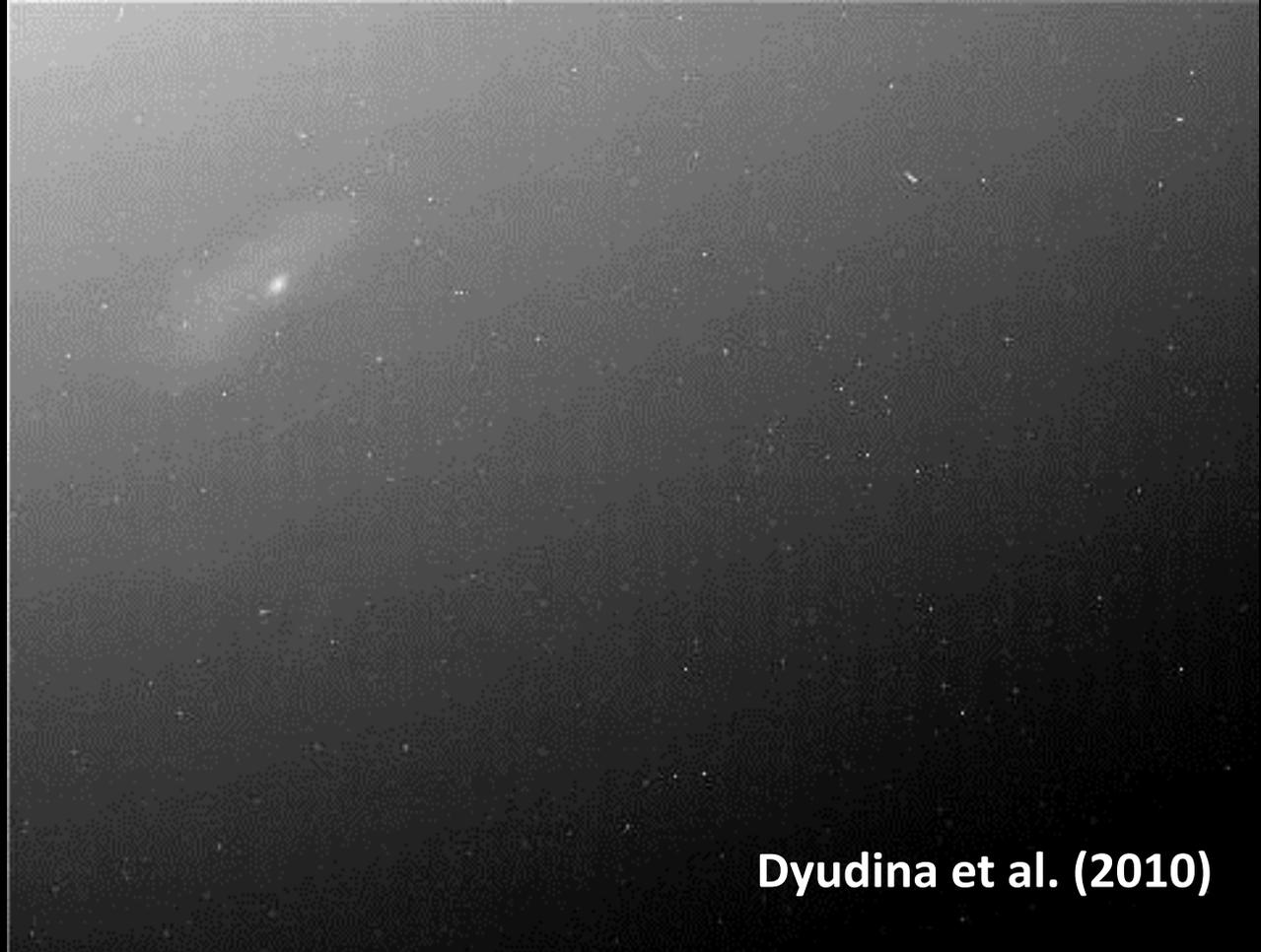


Avril 2008

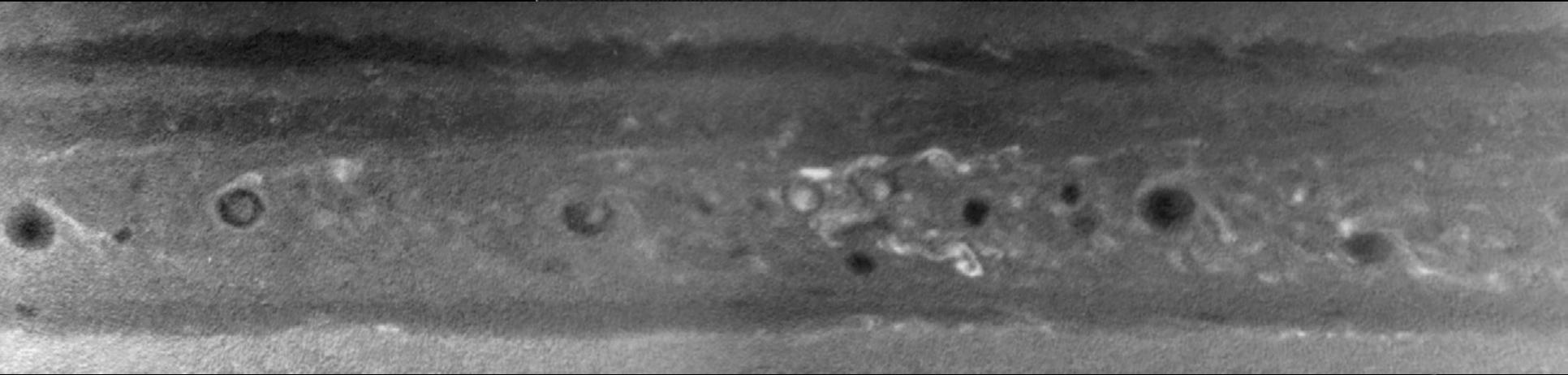


Détection d'éclairs du côté nuit par *Cassini/ISS* en août 2009 (équinoxe) vers 40°S. L'observation a été possible du fait que le soleil était dans le plan des anneaux ("clair d'anneaux" minimum)

Forte activité observée dans le "couloir des orages" (*storm alley*) à 35°-40°S en 2008

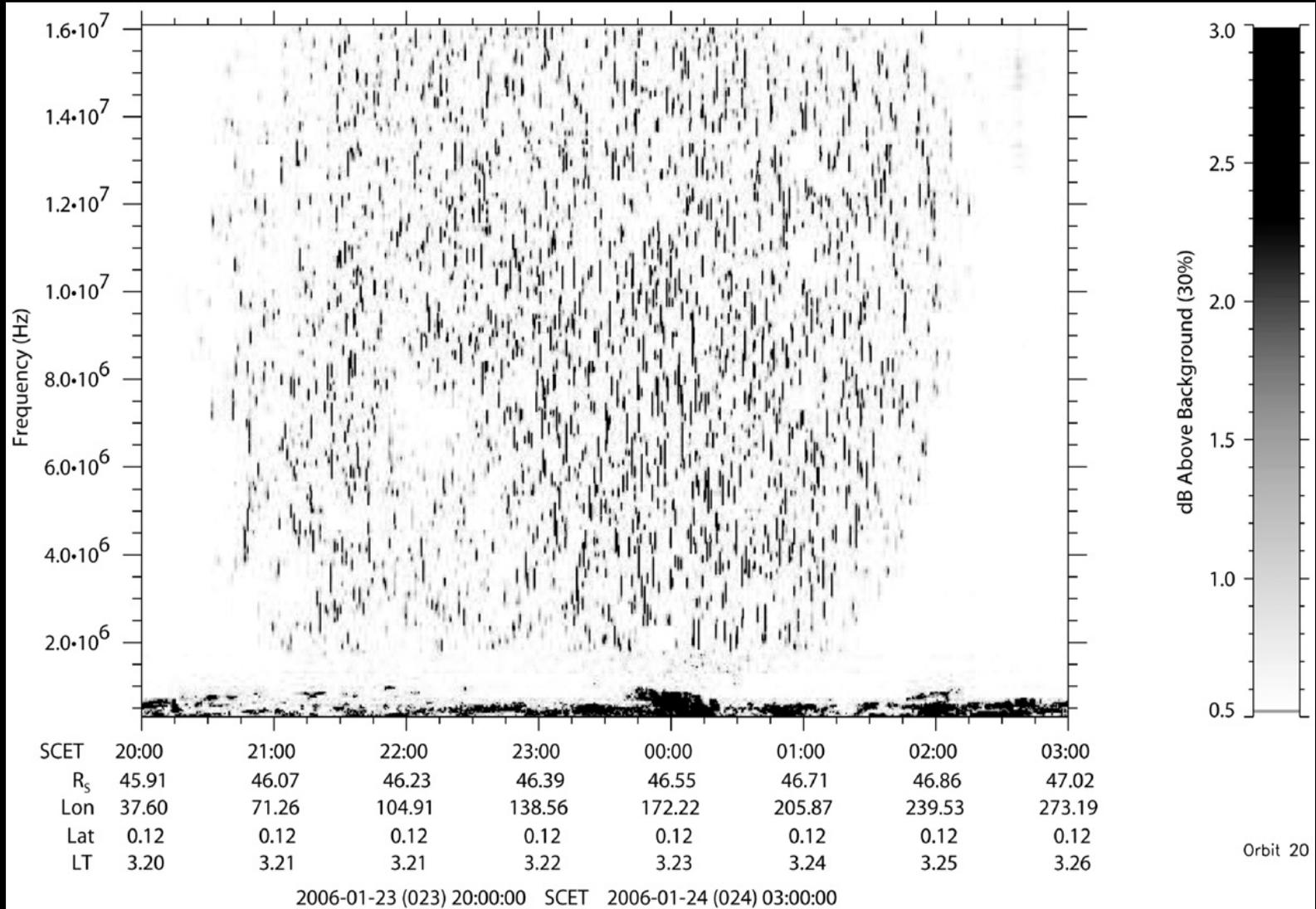


Dyudina et al. (2010)



Détection de SED par *Cassini*/RPWS le 23-24 janvier 2006

Fischer et al. (2007) *Icarus* 190, 528–544



Message de Michael Kaiser du 25 janvier 2006

I contact you to see if any of your people have reported any unusual cloud activity on Saturn the past couple of nights (Jan 23-24). The Cassini Radio Astronomy team, of which I am a member, has detected a very sudden appearance of what we call (for historical reasons) SED for Saturn Electrostatic Discharges. These are actually the radio signatures of lightning flashes and have been studied by Cassini and Voyager. Last year, we successfully correlated some of these episodes with a peculiar atmospheric feature detected by the Cassini imaging team. However, this current series of SED episodes, which in the radio, are the most intense ever observed, occur when Cassini is on the backside (~3 hr Saturn local time), so the imaging folks aren't observing the cloud tops. The dragon feature from last year was certainly observable from the ground, so we suspect whatever storm these current SED are associated with might be, too, so we'd be most interested in any reports of unusual activity.

Cheers,

Michael L. Kaiser
STEREO Project Scientist and Cassini co-investigator
NASA/GSFC/Code 695 Greenbelt, MD 20771

**Observation faite le 25 janvier 2006 avec un T300
par E. Bondoux et J.-L. Dauvergne (France)**



**Observation faite le 22 mars 2010
avec un T400 par A. Wesley (Australie)**





A GIANT STORM ON SATURN

Thunderclouds ring the planet **PAGES 44, 71 & 75**

NUTRITION
PILL POPPING
The big debate about vitamins – Deficiency **PAGE 25**

REVIEWS
SUMMER BOOKS
From 'God particle' to capitalism **PAGE 32**



NEUROSCIENCE
MODELLING THE MIND
Recreating mental disorders in animals **PAGE 123**

NATURE.COM/NATURE
7 July 2011



LETTER

doi:10.1038/nature10205

A giant thunderstorm on Saturn

G. Fischer¹, W. S. Kunkh², D. A. Garment³, P. Zaika², U. A. Dyduna⁴, A. P. Ingermiti⁵, S. P. Ewald⁶, C. C. Porco⁷, A. Wesley⁸, C. Go⁹ & M. Delcroix⁹

Lightning discharges in Saturn's atmosphere emit radio waves¹ with intensities about 10,000 times stronger than those of their terrestrial counterparts². These radio waves are the characteristic features of lightning from thunderstorms on Saturn, which last for days to months³. Convective storms about 2,000 kilometres in size have been observed in recent years at planetocentric latitude 35° south^{4,5} (corresponding to a planetocentric latitude of 41° north). Here we report observations of a giant thunderstorm at planetocentric latitude 35° north that reached a latitudinal extension of 10,000 kilometres—comparable in size to a 'Great White Storm'^{6,7}—about three weeks after it started in early December 2010. The visible plume consists of high-altitude clouds that overlie the outermost ammonia cloud layer owing to strong vertical convection, as is typical for thunderstorms. The flash rates of this storm are about an order of magnitude higher than previous ones, and peak rates larger than ten per second were recorded. The main storm developed an elongated eastward tail with additional but weaker storm cells that wrapped around the whole planet by February 2011. Unlike storms on Earth, the total power of this storm is comparable to Saturn's total emitted power. The appearance of such storms in the northern hemisphere could be related to the change of seasons⁸, given that Saturn experienced vernal equinox in August 2009.

On 5 December 2010, the Radio and Plasma Wave Science (RPWS) instrument⁹ onboard the Saturn-orbiting Cassini spacecraft detected radio emissions associated with a new lightning storm. On the same day, the Cassini Imaging Science Subsystem (ISS) observed a bright cloud, 1,500 km × 2,500 km in size, at planetocentric latitude 32° N and longitude 245° W (here we use the Voyager Saturn Longitude System, SLS, corresponding to a rotation period of 10 h 39 min 22 s). The storm might have started somewhat earlier, as there is a gap in observations of about 2 days before the detection in the RPWS data.

The radio waves emitted by lightning discharges in Saturn's atmosphere are known as Saturn electrostatic discharges¹, SEDs, and are usually observed as short individual radio bursts, but in this event (see the time–frequency spectrogram of Fig. 1) they cluster to an almost continuous emission owing to the high flash rate. On their way to Cassini's radio receiver the SEDs must pass through Saturn's ionosphere, and therefore the low-frequency content of the emission can be used as a measure of the peak electron plasma frequency of the intervening plasma¹⁰. The decreasing low-frequency cut-off in Fig. 1 is consistent with a storm rotating with the planet from the dayside to the nightside, where electron density of the ionosphere are lower. Such measurements by the Voyager and Cassini spacecraft have yielded typical peak electron density somewhat larger than 10¹⁷ cm⁻³ around noon, but nighttime densities as large as 10¹⁸–10¹⁹ cm⁻³ (derived from the Voyager SEDs⁹) have not so far been observed by Cassini¹¹. Averaged day/night variations in electron density observed by Cassini were less than two orders of magnitude¹². Models taking into account an influx of water from Saturn's rings

can reproduce the electron densities at dusk and dawn, but most models cannot reproduce the large day/night variation; this is because of the long-lived H⁺ ion in Saturn's ionosphere^{13–15}.

Viewed from Cassini, SEDs occur in episodes, and start or stop at the time when the visible storm enters or leaves the radio horizon. This consistency in longitude enables an association of SEDs with storm clouds. Further confirmation of such a link comes from a drift rate of the storm cloud consistent with the SED episode duration or period, and a correlation between cloud brightness and SED rate¹⁶. Figure 2 shows the episodic SED activity, which was comparable to previous SED storms in the first days of the storm and reached unprecedented levels on 12 December. The real flash rate is unknown, as we do not know how many SEDs would appear very close to the source. The lower limit of the peak flash rate is ~10 SEDs per second.

The polarization of SEDs for this storm at frequencies below 2 MHz is strongly left-hand circularly polarized, which is opposite to the SED polarization from southern hemisphere storms¹⁷. This difference is related to the opposite direction of the magnetic field in the two hemispheres relative to the radio wave propagation vector, as the field is

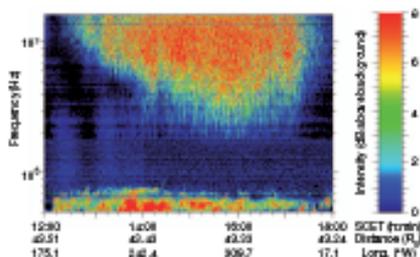
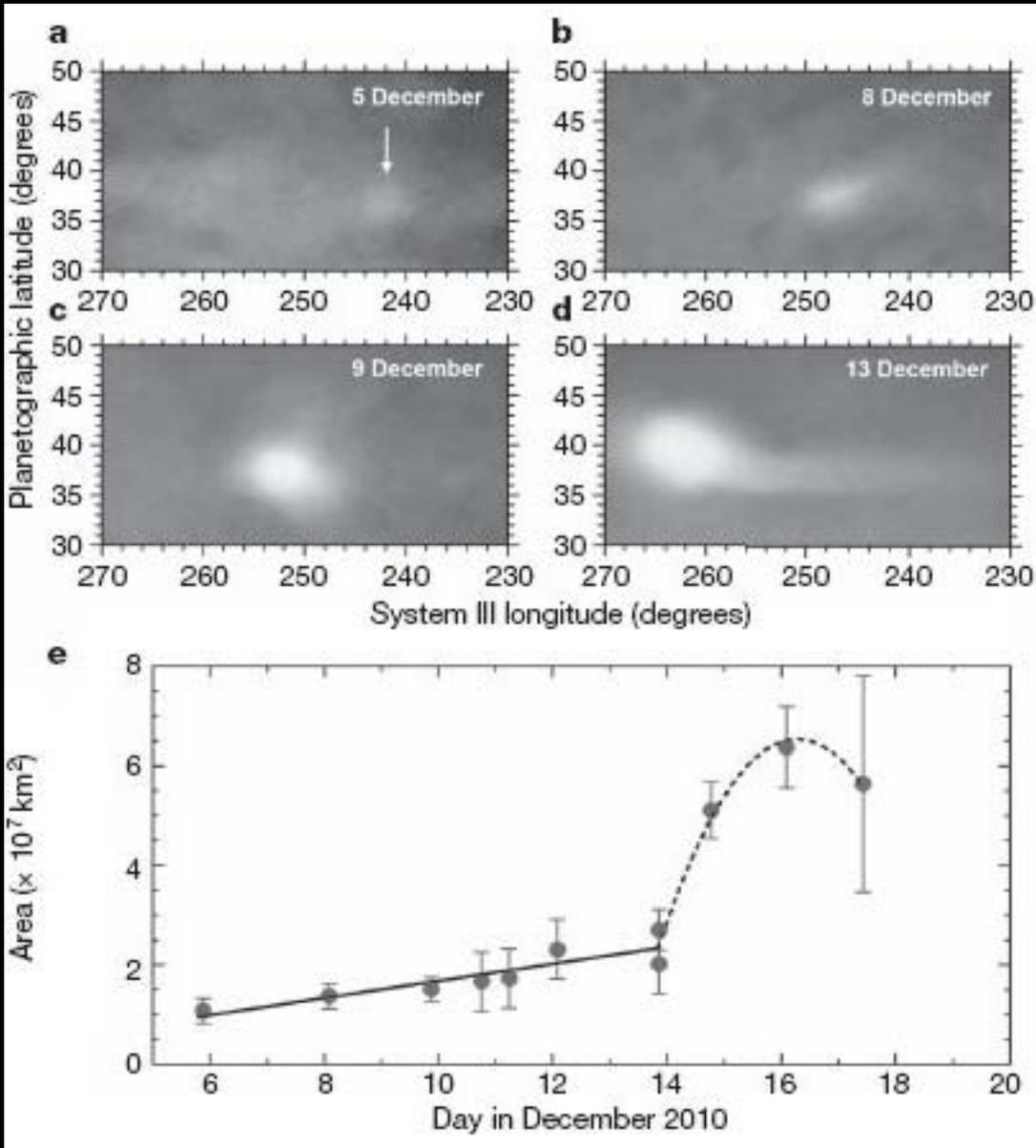


Figure 1 | Time–frequency spectrogram of the SED episode on 12 December 2010. The colour-coded intensity (with 10% background division) of the radio emissions is plotted as a function of spacecraft event time (SGT) over 6 h and frequency from 500 kHz to 16 MHz on a logarithmic scale. Cassini coordinates (of distance to Saturn's centre in units of Saturn's radius, R_S , and SLS west longitude in degrees, Long^W) are indicated on the abscissa. Cassini was in the equatorial plane at local time of ~18.0 h. The RPWS instrument sweeps in frequency and it detects the broadband SEDs at whatever frequency is above the ionospheric cut-off. It happens to be tuned to a time off the flash. This SED episode shows such a high flash rate that the receiver sweep rate of ~38 frequency channels per second (35.3 ms per channel) can no longer resolve the single SEDs. Flash rates of 5–10 SEDs per second can lead to a temporal superposition of SEDs that normally are above several frequency channels. At the edges of the episode, where the rate is lower, one can see the individual SED bursts. The continuous emission below 100 kHz is Saturn's thermal radiation.

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Les premiers signes de l'orage sont apparus aux observateurs du réseau IOPW* le 5 décembre 2010 (21h05 UT) sous la forme d'un point brillant à 37.7°N , précurseur d'une classique GWS (*Great White Spot*).

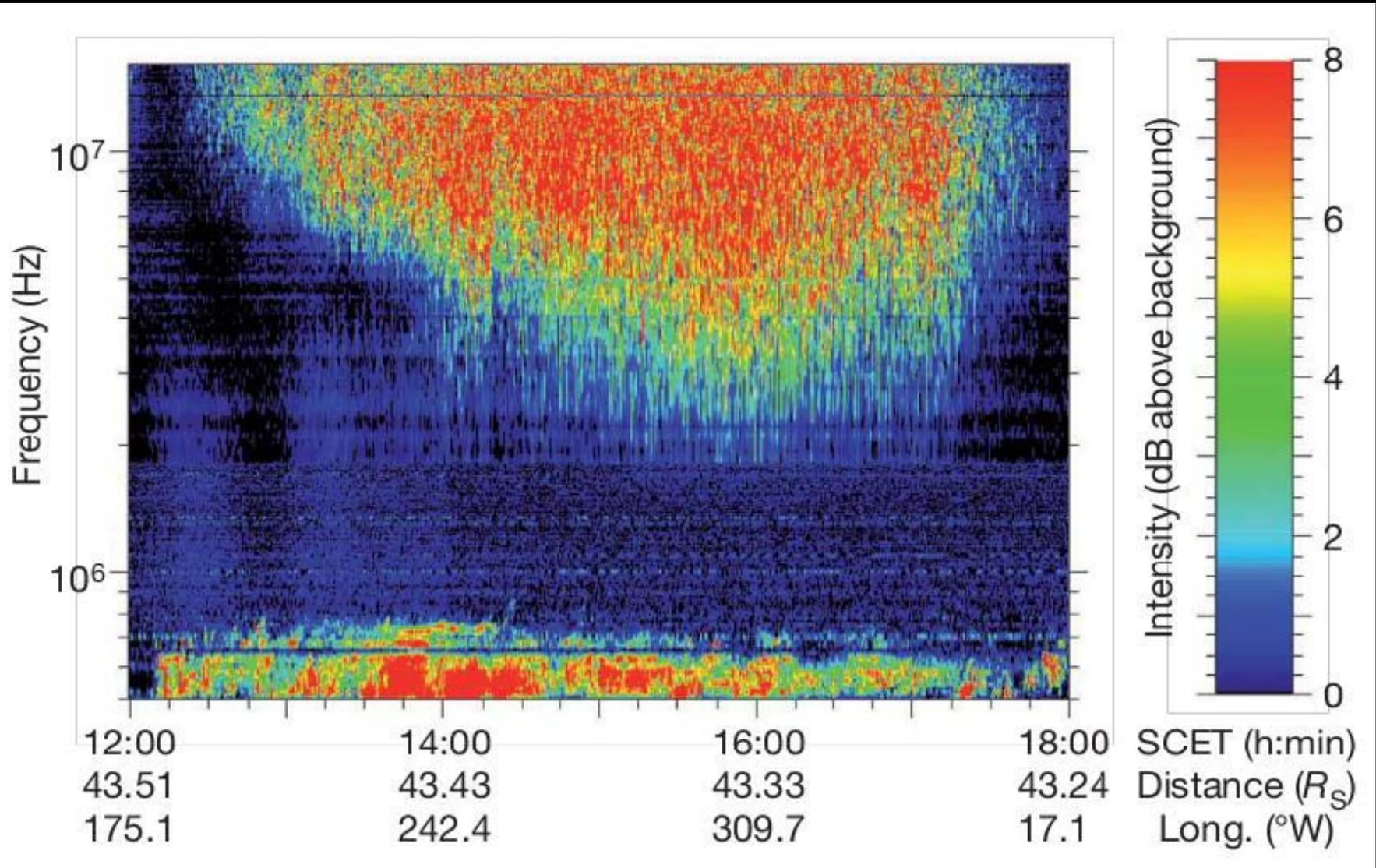
Durant les deux premières semaines, le taux de croissance de la GWS s'est maintenu à $20 \text{ km}^2 \cdot \text{s}^{-1}$. Les deux jours suivants (15-16), il est passé à $212 \text{ km}^2 \cdot \text{s}^{-1}$.

L'aire de la GWS a plafonné à 65 millions de km^2 (120 fois la France) avant son interaction avec les vents zonaux.

* *International Outer Planet Watch*

Détection de SED par *Cassini*/RPWS le 12 décembre 2010

Fischer et al. (2011) Nature 475, 75-77



**Observation faite le 13 décembre 2010 avec un T280
par C. Go (Philippines)**





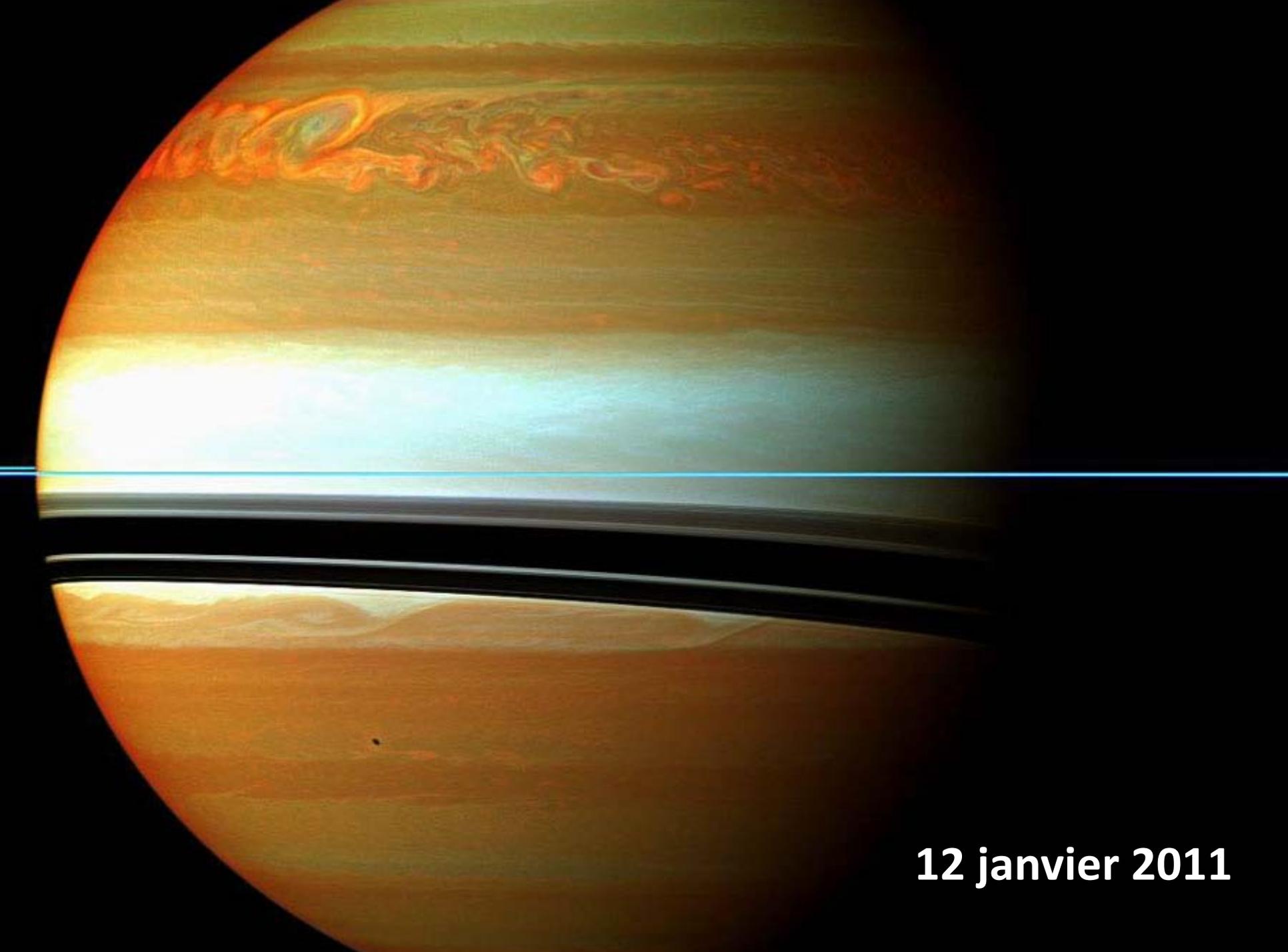
**Image *Cassini*/WAC
24 décembre 2010**

Étendue estimée de la GWS :
- 10 000 km en latitude
- 17 000 km en longitude

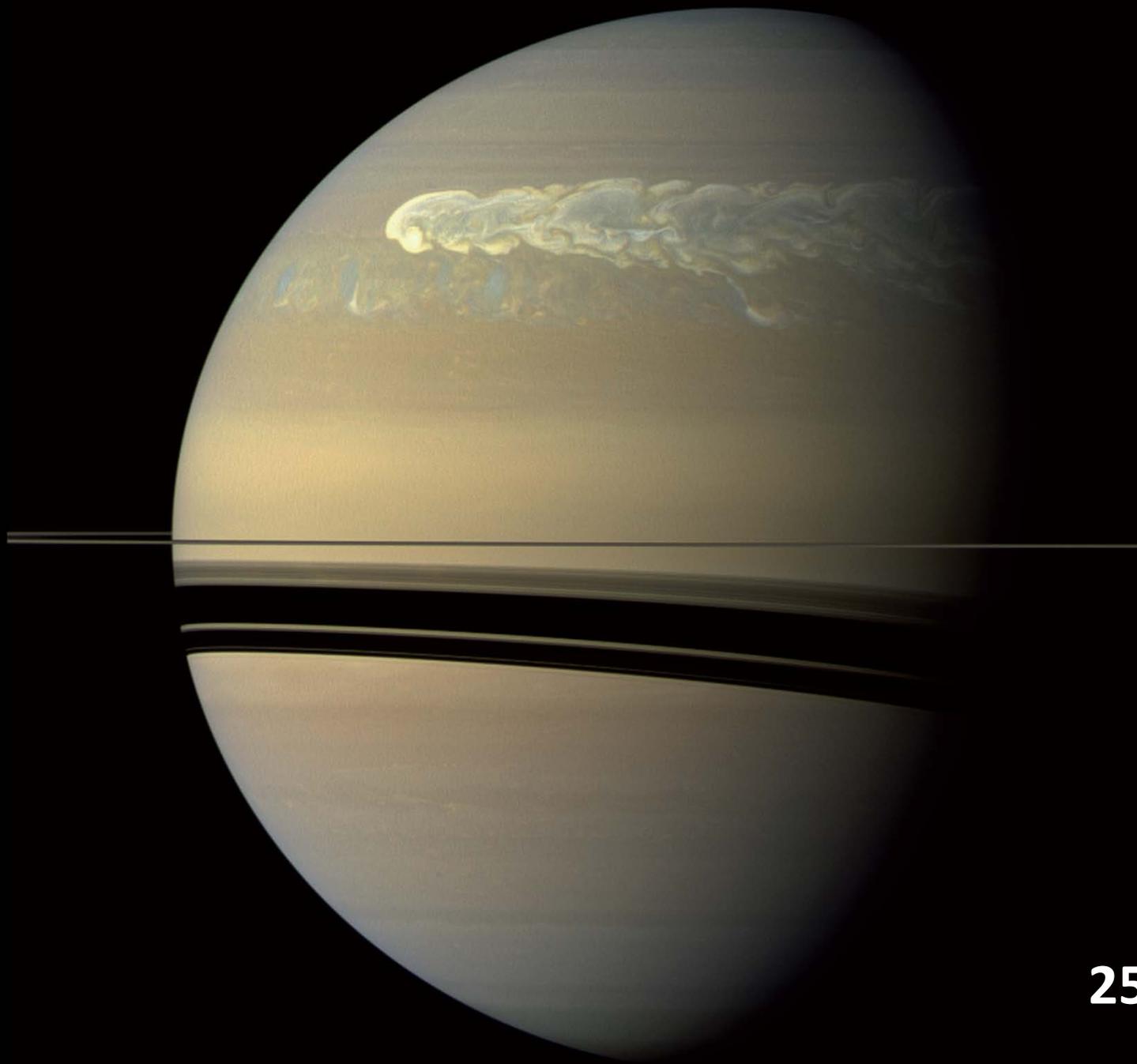
**Elle est devenue
comparable à la**



!



12 janvier 2011



25 février 2011

**Observation faite le 2 mars 2011 avec un T280
par C. Go (Philippines)**



**Observation faite le 21 avril 2011 à la lunette Arago
par F. Colas et collègues (Observatoire de Paris)**

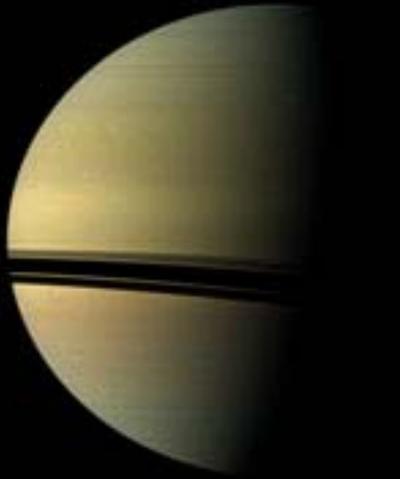


24 mai 2011



Plus de 8 mois après son déclenchement, la perturbation est encore visible

Dec 5, 2010



Jan 2, 2011



Feb 25, 2011



Apr 22, 2011



May 18, 2011

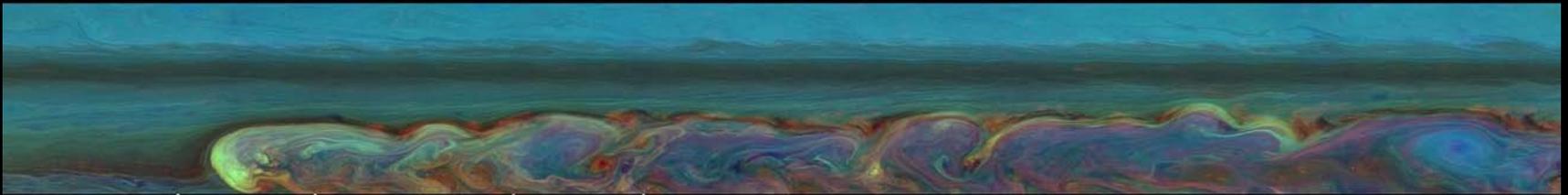
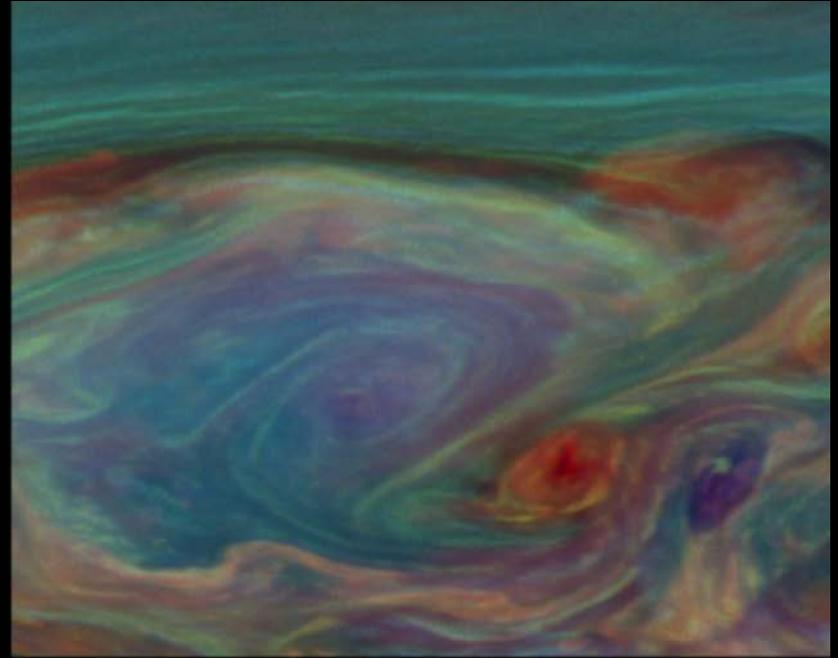


Aug 12, 2011

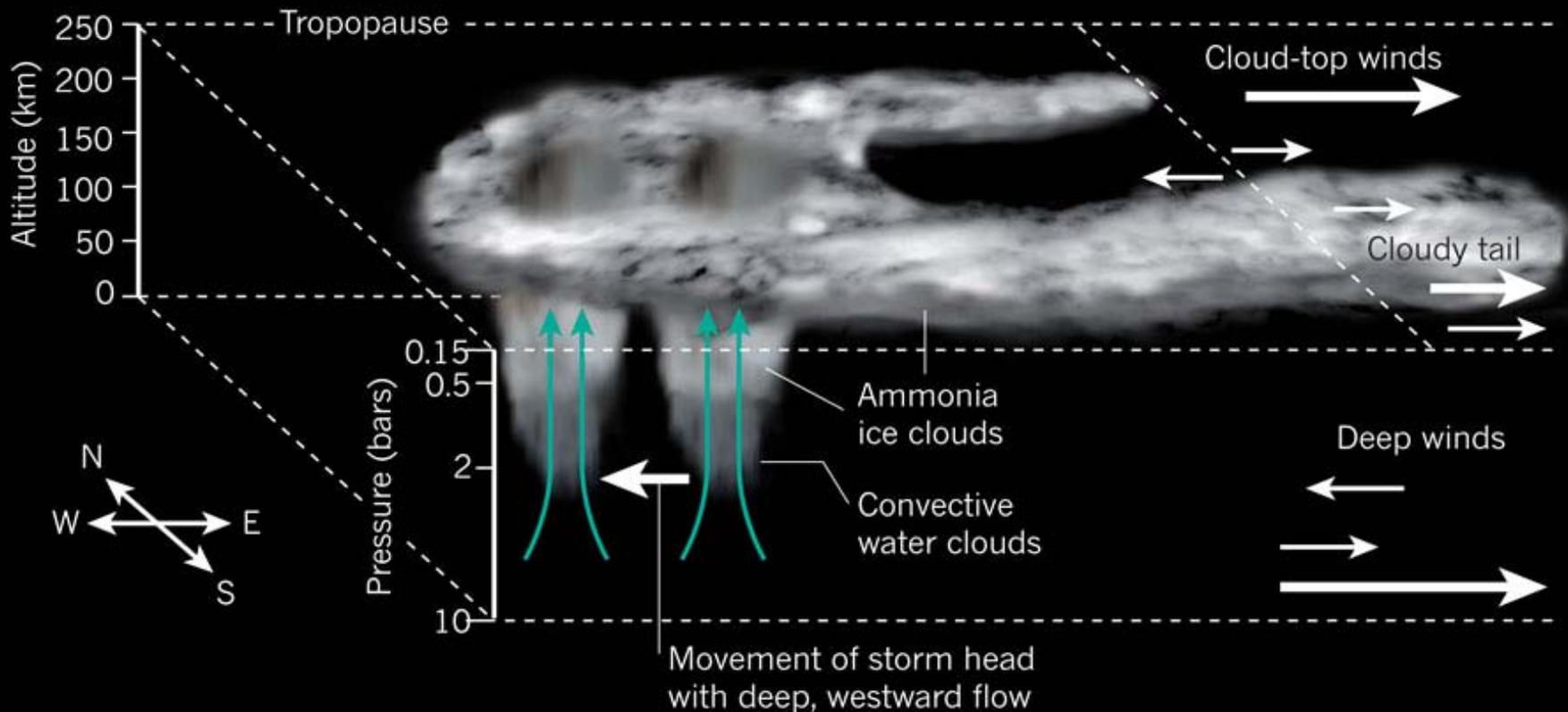


Images *Cassini*/NAC du 26 février 2011

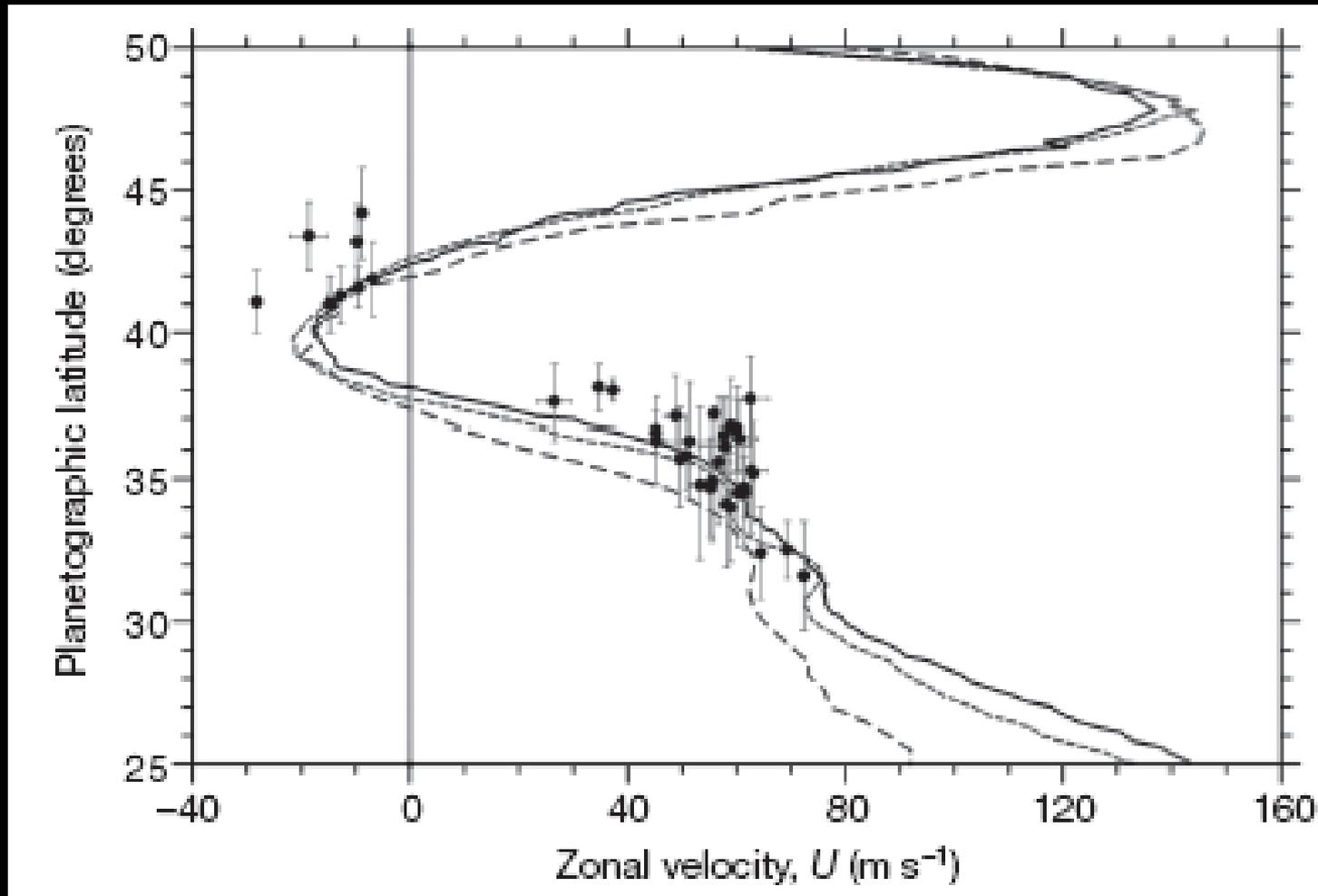
rouge=750 nm (continu) / vert=727 nm (CH_4) / bleu=889 nm (CH_4 saturé)



Déplacements en longitude : la base de la colonne se déplace vers l'ouest tandis que le sommet est entraîné vers l'est par les vents zonaux troposphériques



Les mouvements de la perturbation orageuse sont compatibles avec les vitesses de vent zonaux mesurées par *Voyager* en 1980-81 ou par *Cassini* en 2004-2009



Sanchez-Lavega et al. (2011) Nature 475, 71-74

Observations en lumière réfléchie par *Cassini/VIMS* le 24 février 2011



Yellow storm = large red/green signal. Combination of (1) ammonia ice comprised of (2) large particles indicates extremely powerful convective storm.

R = 4.08 μm **G** = 0.90 μm **B** = 2.73 μm

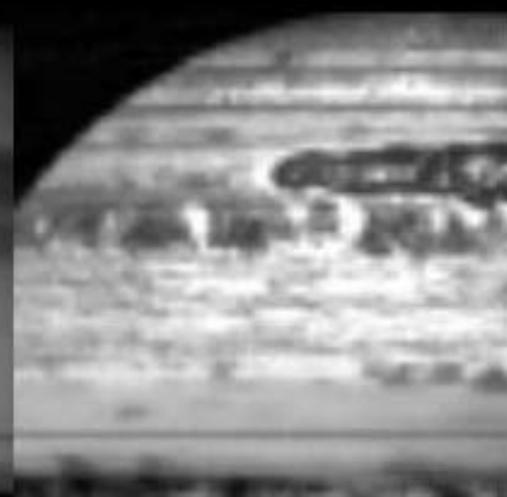
(aérosols)

(CH_4)

(NH_3)



G = 3.00 μm
(composés N-H)

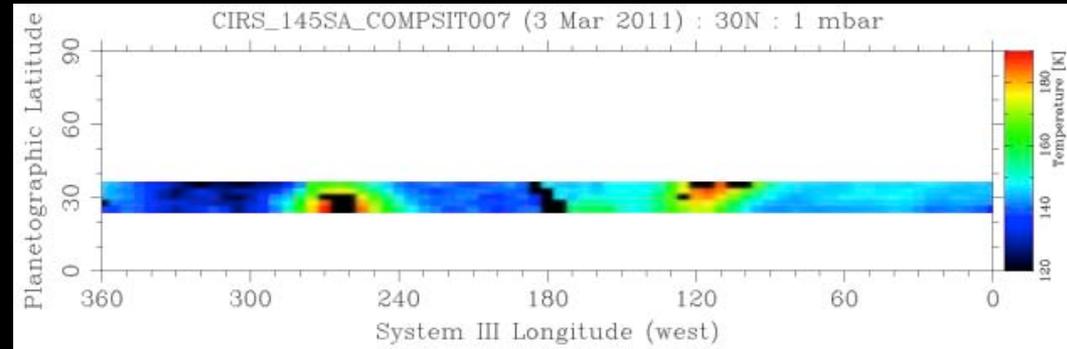


B = 5.12 μm
(nuages)

Evolution thermique mesurée avec Cassini/CIRS

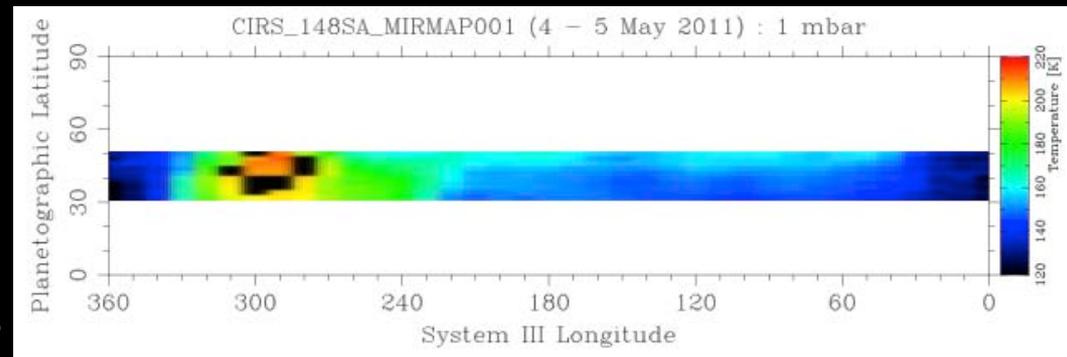
Phase 1:

- deux points chauds
- augmentation des températures de janvier à mai
- renforcement des émissions par les hydrocarbures
- accélération des vents stratosphériques



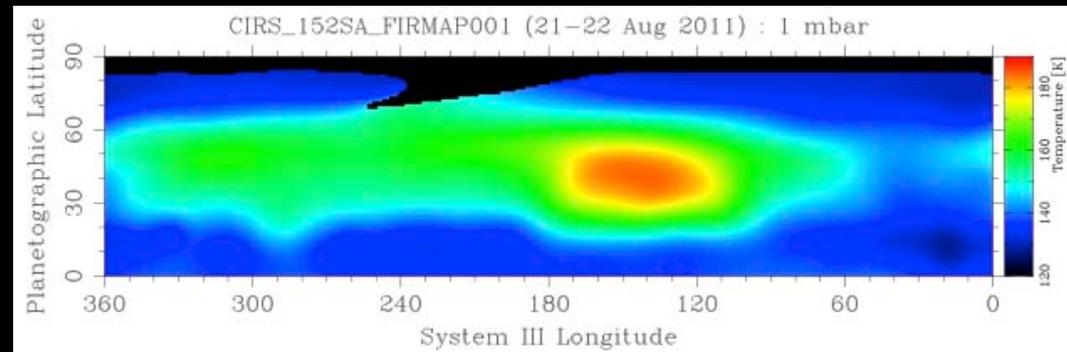
Phase 2:

- points chauds fondus en un seul
- températures stratosphériques dépassant 220 K
- vents stratosphériques semblables aux vents troposphériques



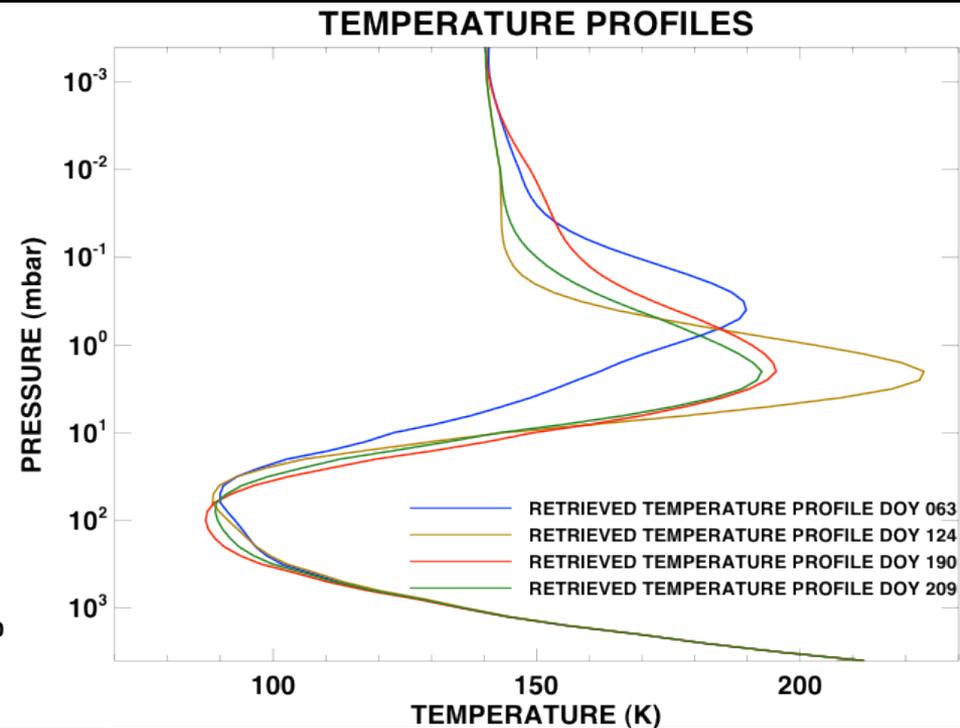
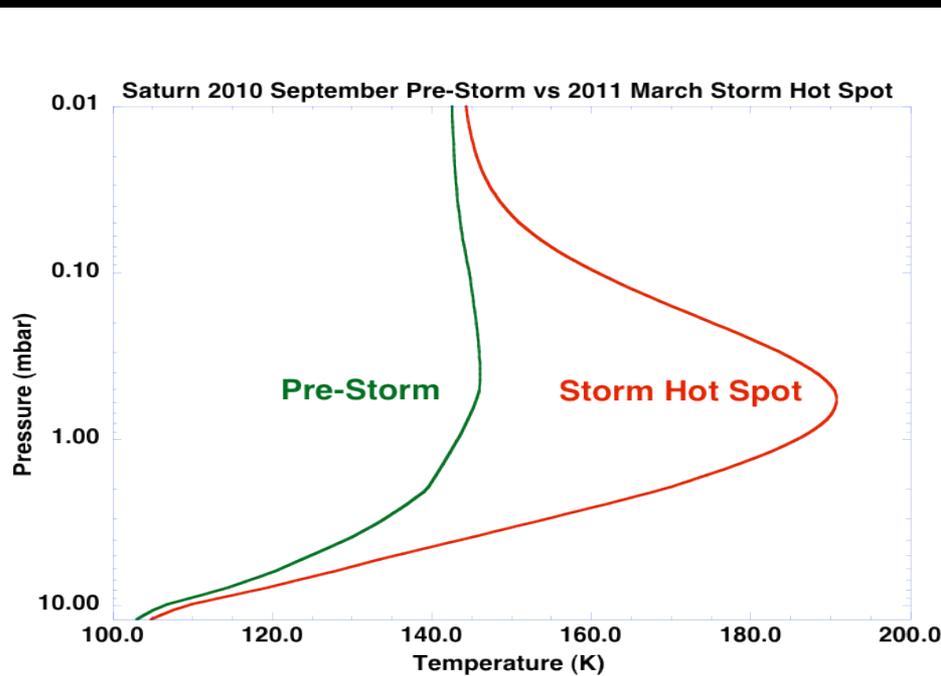
Phase 3:

- toujours un seul point chaud
- températures stratosphériques relaxées
- nouvelle accélération des vents stratosphériques

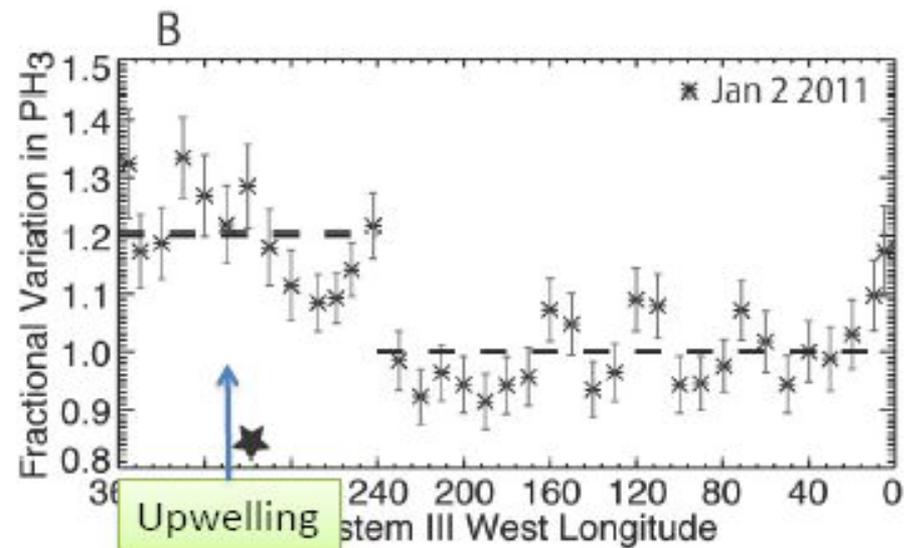
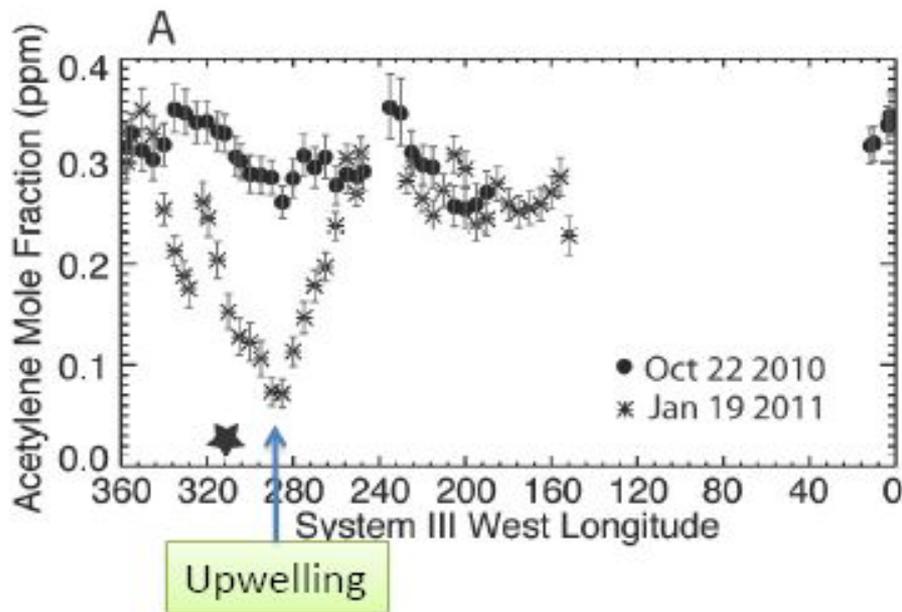


Point chaud (*beacon*) : la stratosphère s'est réchauffée localement de 40° à 80°.

L'origine du chauffage est probablement la compression adiabatique des masses d'air du sommet de la colonne qui retombent après culmination à quelques dixièmes de millibar

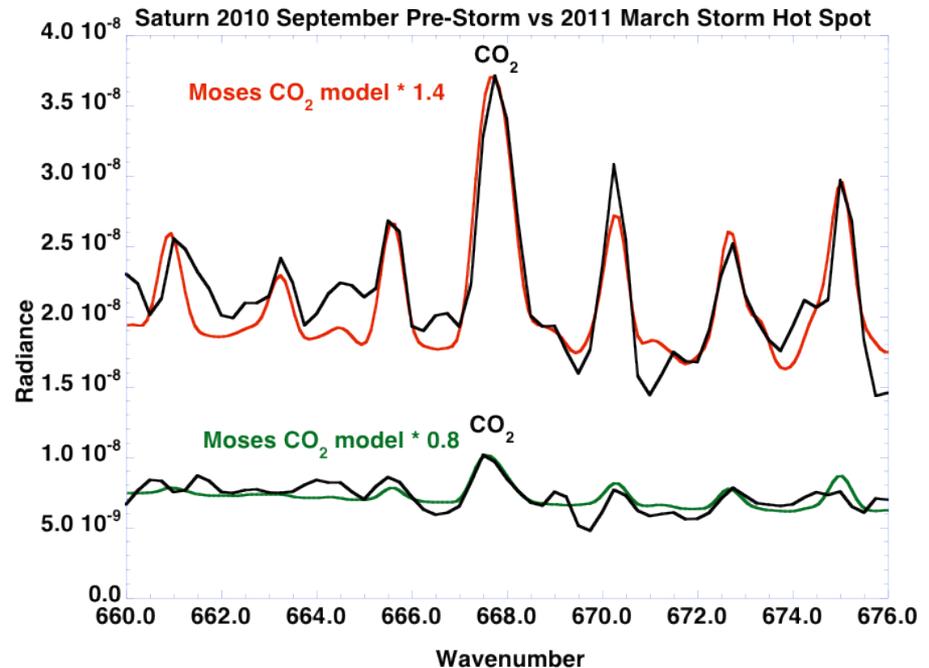
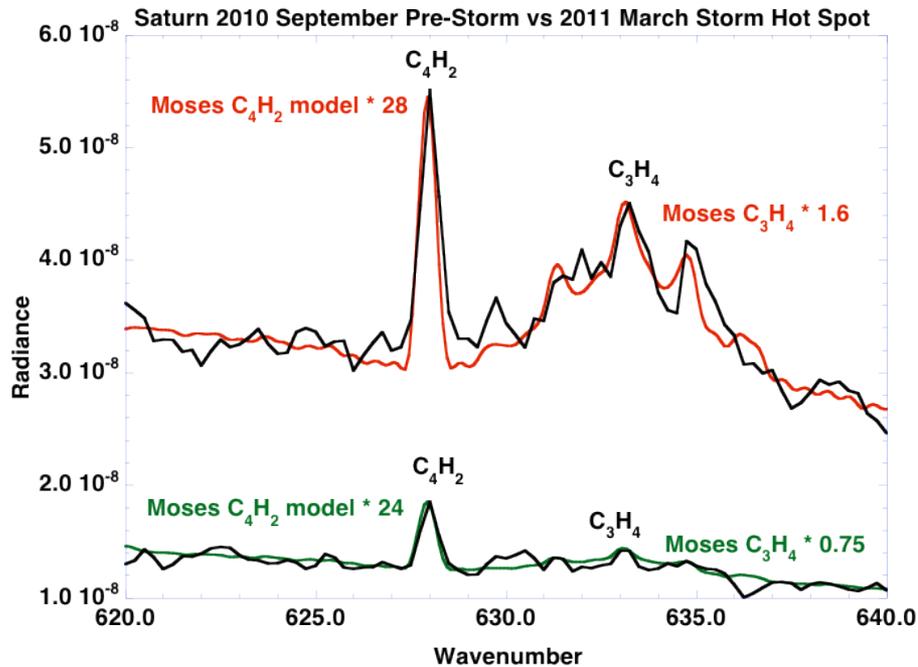


Certains constituants atmosphériques,
en particulier C_2H_2 et PH_3 observés avec *Cassini/CIRS*,
permettent de caractériser le mouvement vertical
des masses d'air liées à la perturbation orageuse



Fletcher (2011)

D'autres composants atmosphériques qui sont de bons émetteurs en infra-rouge (C_4H_2 , C_3H_4 et CO_2) permettent de suivre l'évolution thermique de la stratosphère

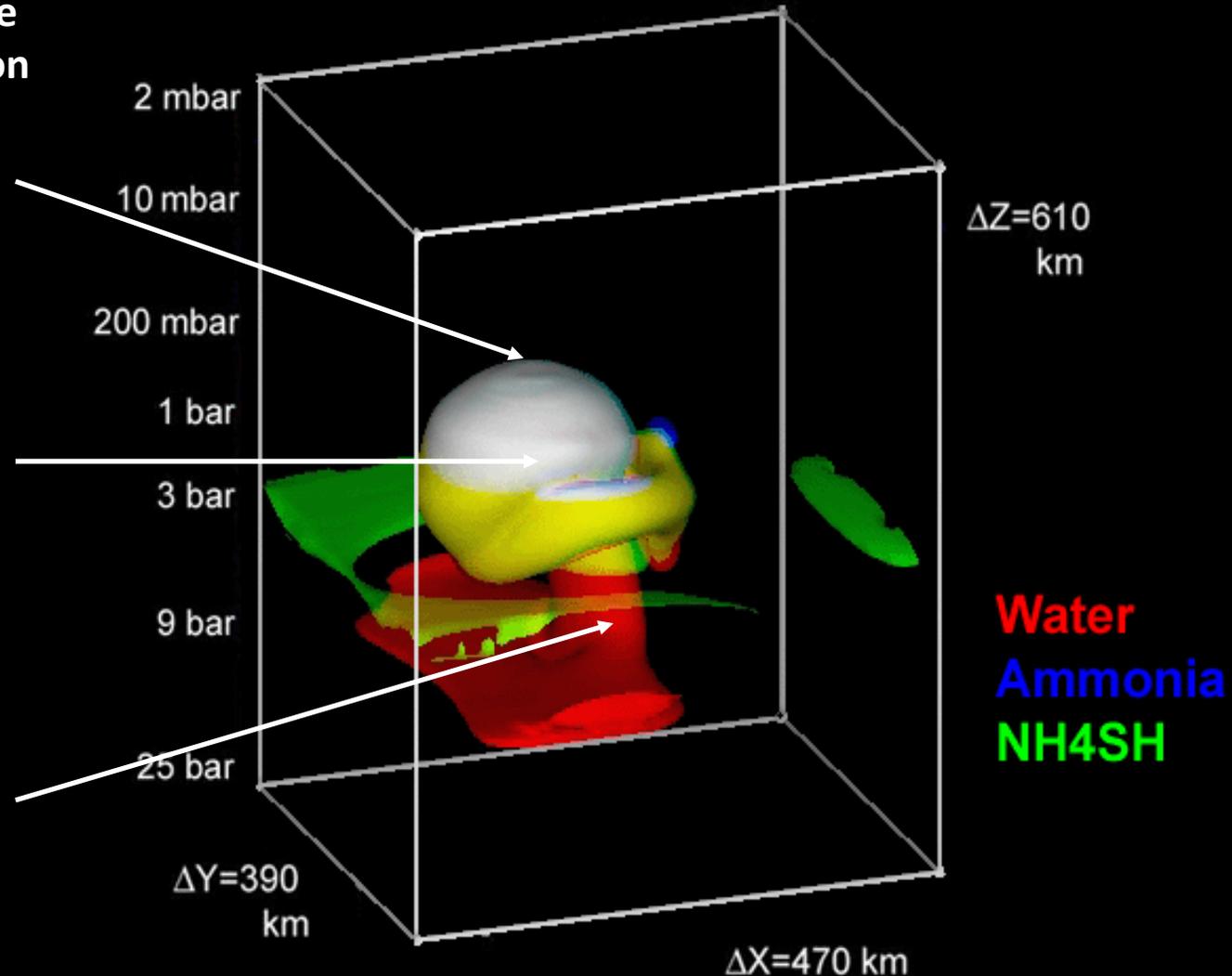


Modèle de la structure verticale de l'orage

Le sommet de la colonne se refroidit par expansion adiabatique alors qu'au pourtour, les masses d'air descendantes se réchauffent créant les points chauds observés

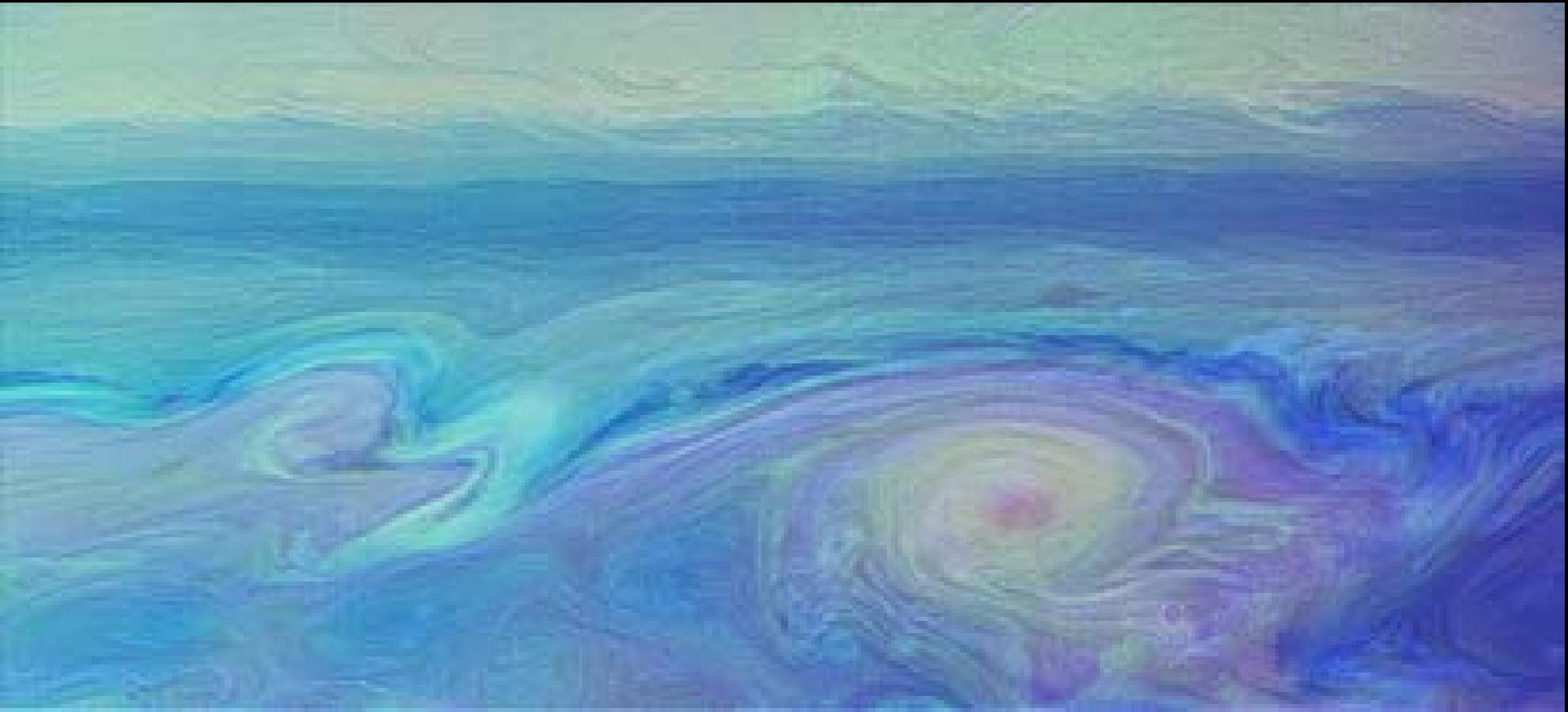
La colonne entraîne des composés N-H qui condensent sous forme de glace dans la haute troposphère

Colonne ascendante issue du nuage de vapeur d'eau situé vers 12 bar, soit 200 à 300 km sous la couche nuageuse visible



L'énergie dégagée est colossale

On estime que l'énergie totale dégagée par l'orage est comparable à la chaleur émise par l'intérieur de Saturne en une année, soit 45% de son bilan annuel



Merci de votre attention !

**Rendez-vous dans 30 ans
pour le prochain orage planétaire de Saturne...**