Saturn lightning storms and their implications on Saturn's atmosphere

G. Fischer[1], W.S. Kurth[2], D.A. Gurnett[2], P. Zarka[3], U.A. Dyudina[4], A.P. Ingersoll[4], S.P. Ewald[4], C.C. Porco[5], A. Wesley[6], C. Go[7], & M. Delcroix[8]

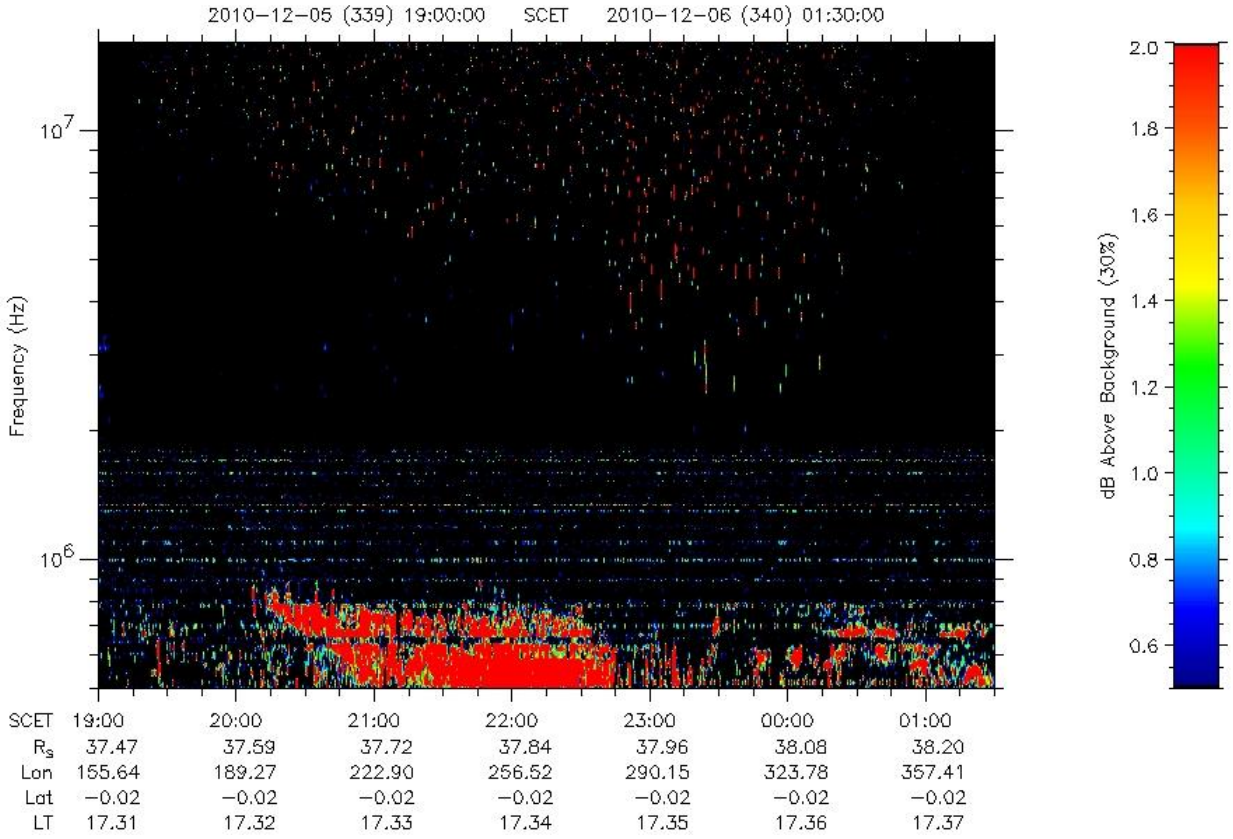
(1) Space Research Institute, Austrian Academy of Sciences, Graz, Austria
(2) Dept. of Physics and Astronomy, Univ. of Iowa, Iowa City, IA, USA
(3) LESIA, Observatoire de Paris-Meudon, Meudon Cedex, France
(4) California Institute of Technology, Pasadena, CA, USA
(5) Cassini Imaging Central Lab. For Operations, Boulder, CO, USA
(6) Murrumbateman, Australia
(7) University of San Carlos, Cebu City, Philippines
(8) Commission des observations planétaires, Société Astronomique de France

A Great White Spot on Saturn

- First lightning storm in Cassini era located in northern hemisphere (seasonal effect)
- Previous lightning storms observed by Cassini were 2000–3000 km in size and all located at 35° south
- Latitudinal diameter at storm's "head" ~10,000 km (distance from London to Cape Town)
- Main lightning activity in the "head" of the storm but extension into the tail with time
- "Tail" encircled whole planet (300,000 km) after 2 months (eastward winds)

The start of the big storm

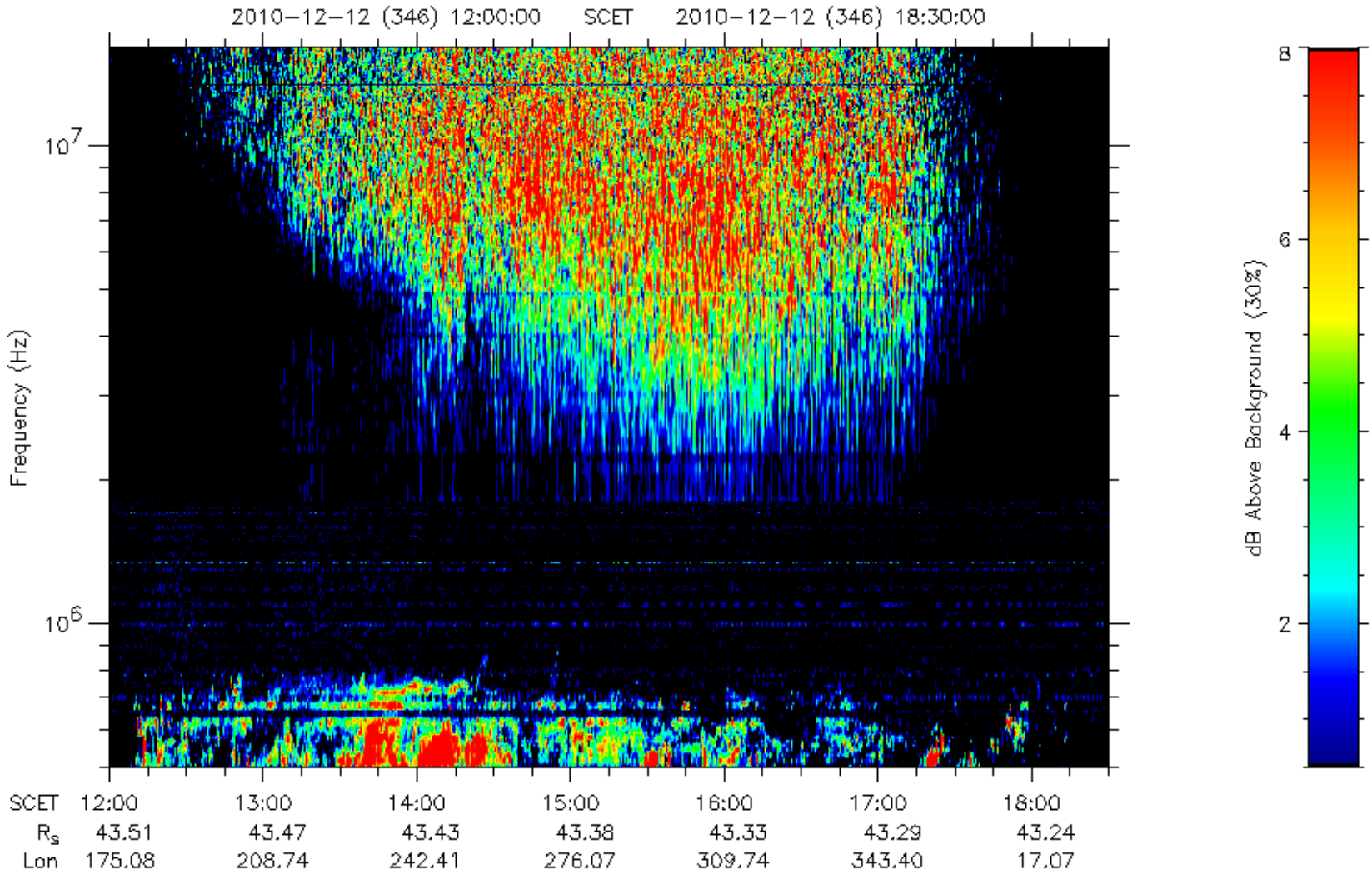
Cassini ISS image from 5 Dec. 2010



Lightning spherics called SEDs (Saturn Electrostatic Discharges) measured by Cassini RPWS (Radio and Plasma Wave Science) instrument on 5/6 Dec. 2010

Storm size is 1300 x 2500 km at 32° north

Episode with high flash rate

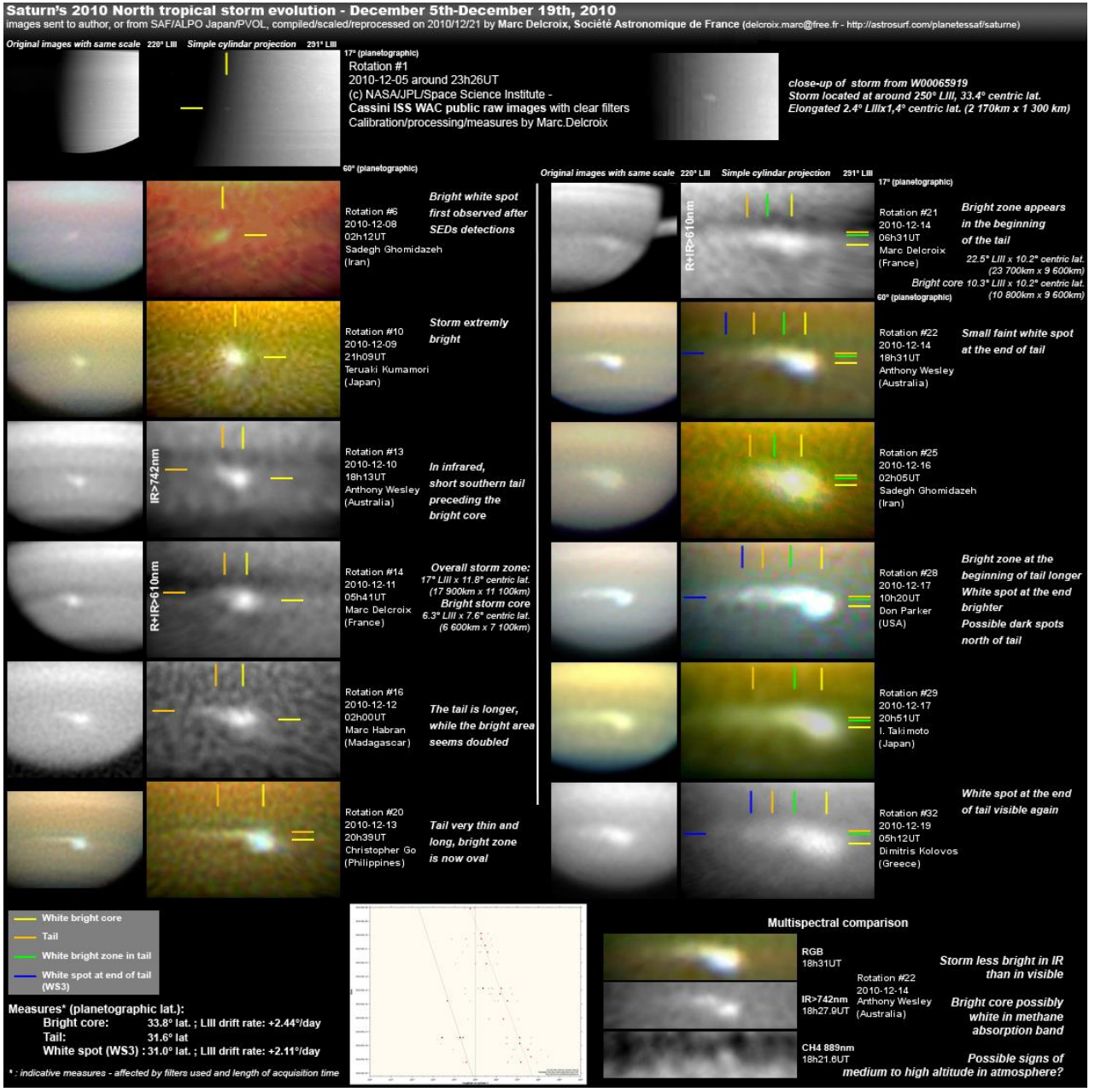


Cassini RPWS dynamic spectrum from 12 Dec. 2010 (Cassini LT ~18.6 hours) with high flash rate (sweeping receiver, $\Delta t = 35$ ms)

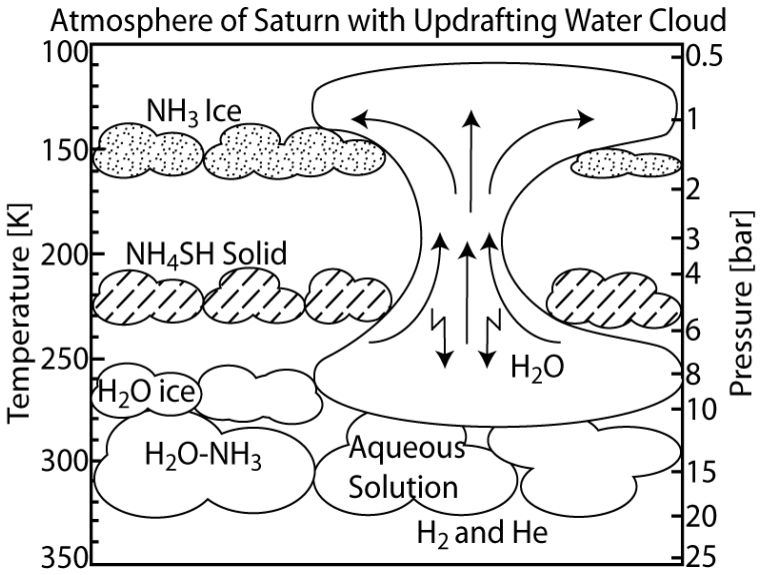
Storm observed from Earth

Images (5-19 Dec. 2010, here north downward) processed by M. Delcroix (poster 450 in session OA6)

Amateurs post their images at website of Planetary Virtual Observatory & Lab. http://www.pvol.ehu.es/pvol/ see Hueso et al. [2010]. Storm alert was posted there.

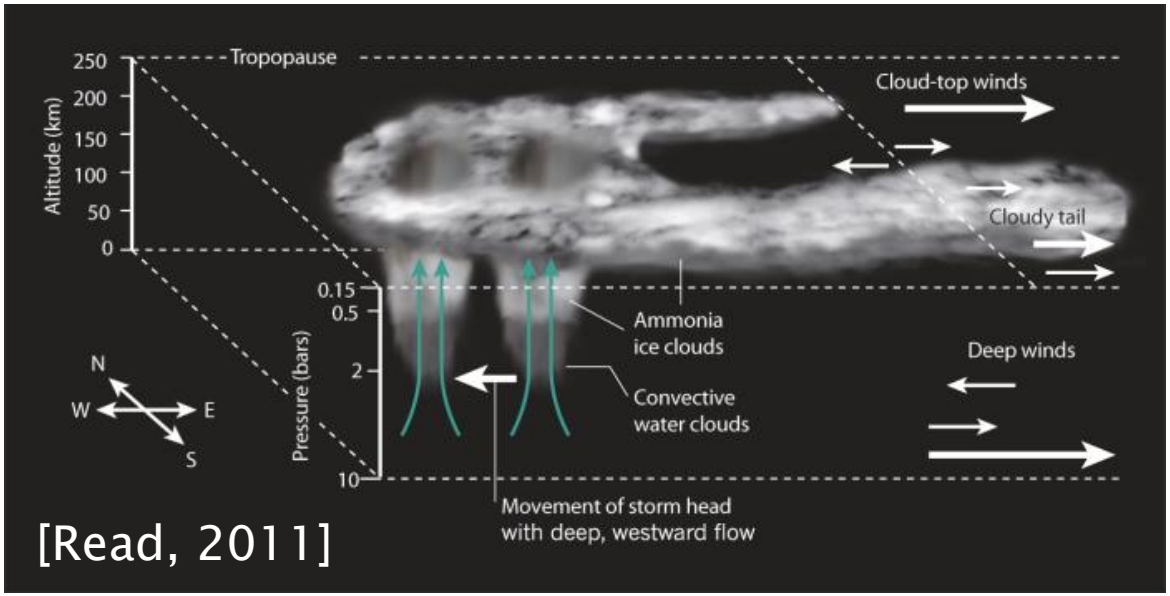


Saturn‘s atmosphere

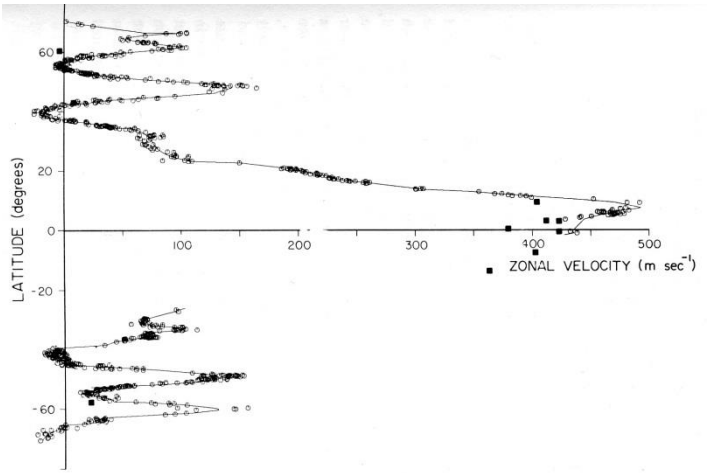


ECCM=Equilibrium cloud condensation model gives a three layered cloud structure of ammonia, ammonium hydrosulfide and water clouds [after model of Atreya et al., 2004]

SED source at 8–10 bar in water cloud (freezing level), flash observations give depth of 125–250 km below cloud tops



[Read, 2011]

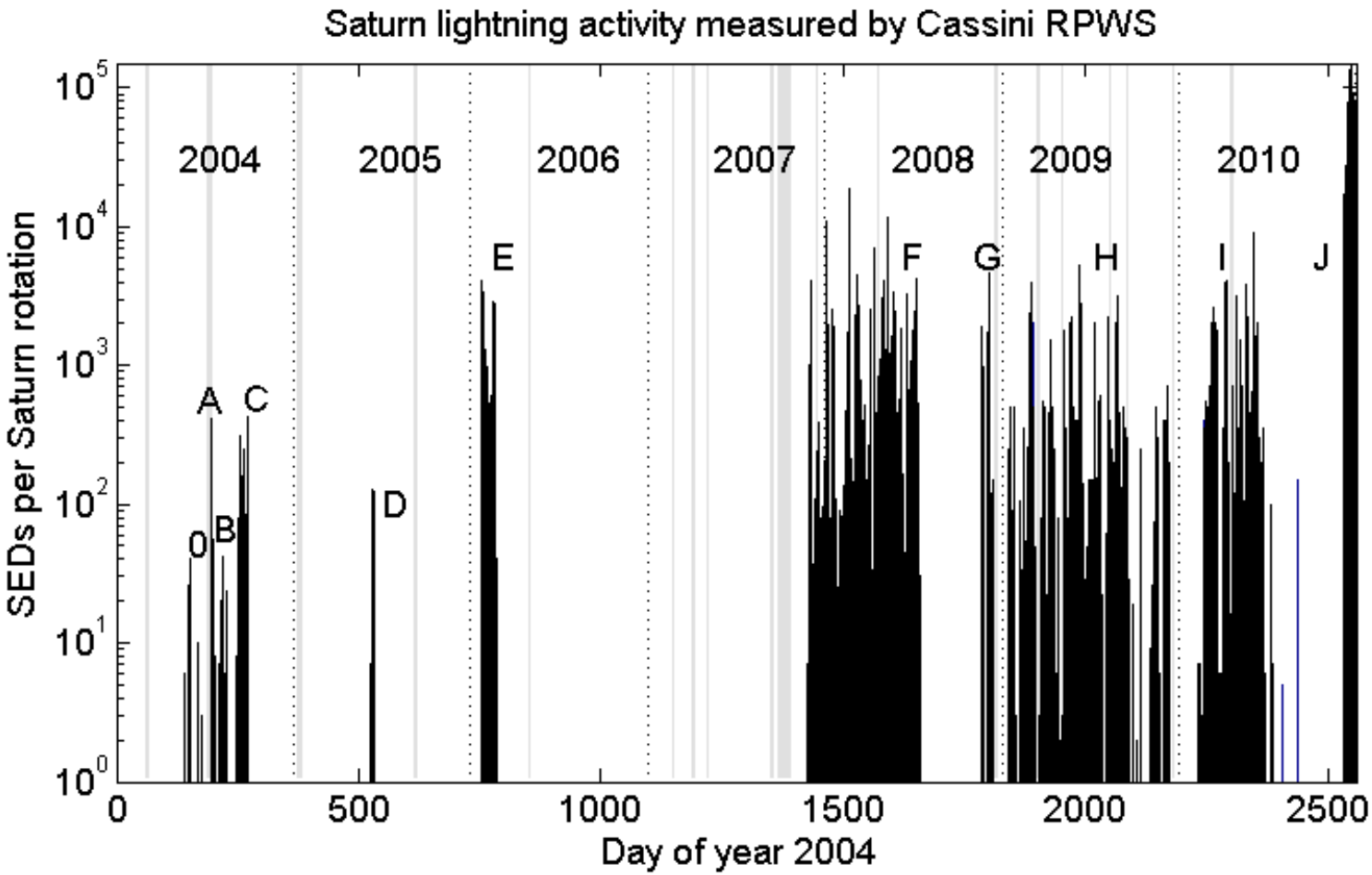


[Ingersoll et al., 1984]

Implications for the atmosphere

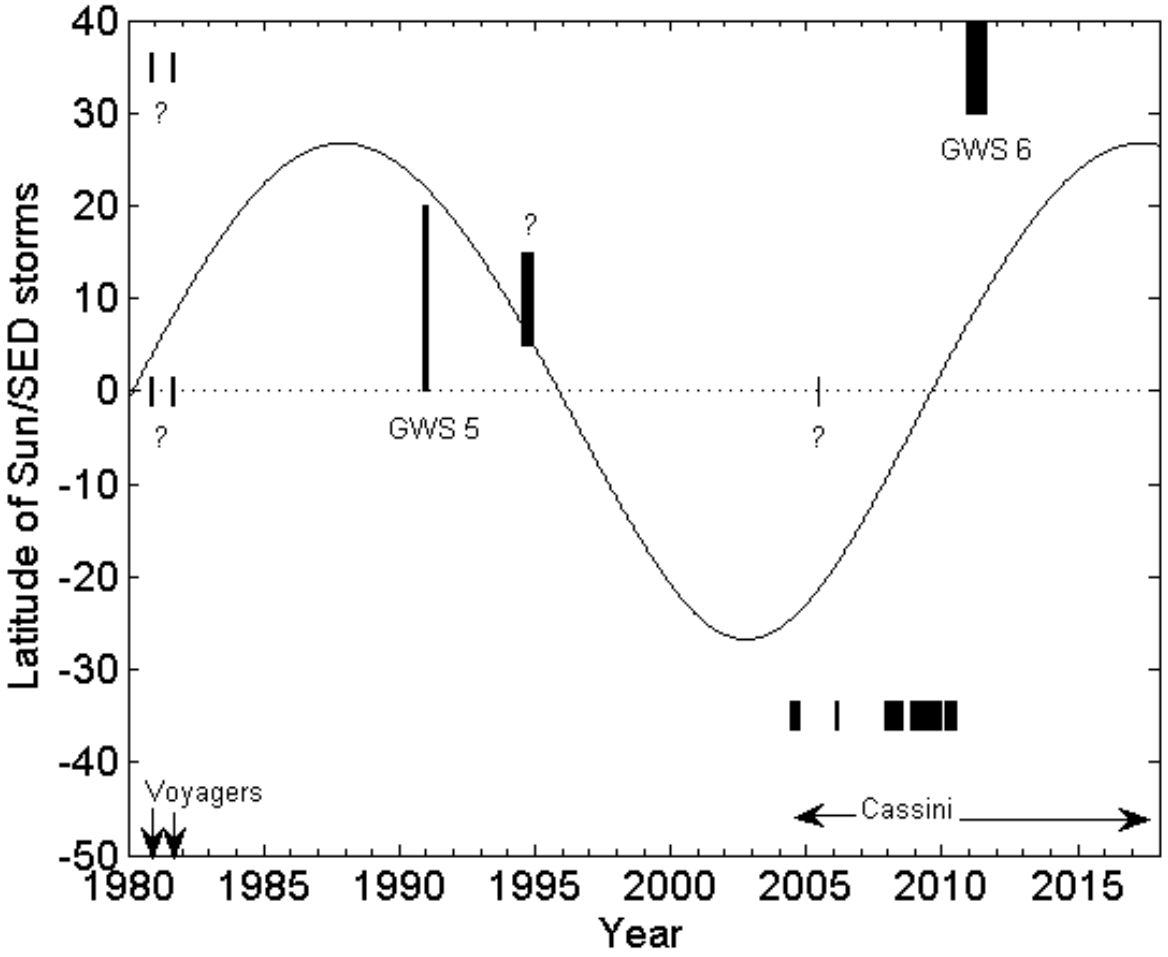
- Lightning is a good indicator of vertical convection: Dynamics of the atmosphere will be discussed by Sánchez-Lavega et al. and Sayanagi et al. based on optical observations and models
- Vertical convection (white clouds!) transports particles from ammonia and ammonia hydrosulphide clouds, and particles produced by lightning upwards to levels above 1 bar
- Dark spots (at higher levels) might be dark due to soot particles produced by dissociation of CH_4 by lightning [Baines et al., 2009], and they show no more lightning activity
- Effect of the disturbance on stratospheric temperatures will be discussed by Fletcher et al.
- Bjoraker et al. and Hesman et al. will discuss the detection of further trace species like ethylene in the storm region
- The storm has significant implications for the dynamics and chemistry of Saturn‘s atmosphere

SEDs observed by Cassini



SED storms can last for days to several months and there are long times with no lightning storms at all; RPWS has nearly continuous data coverage (gray background = no data)

Seasonality of lightning storms

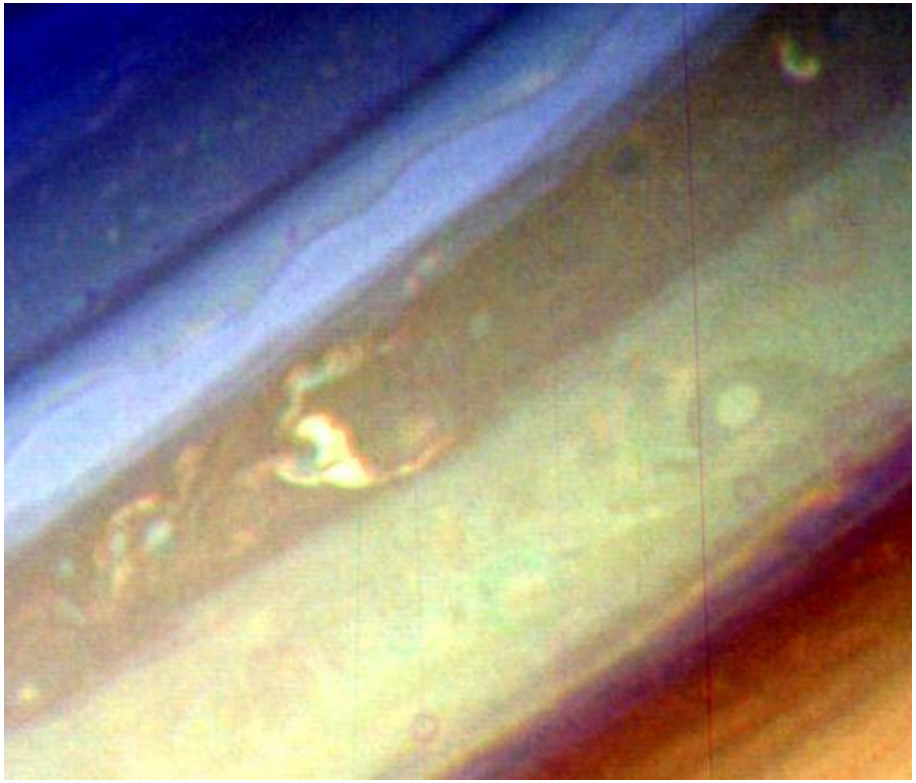


Latitude of sun (sinusoidal curve) and SED storms as a function of time since 1980

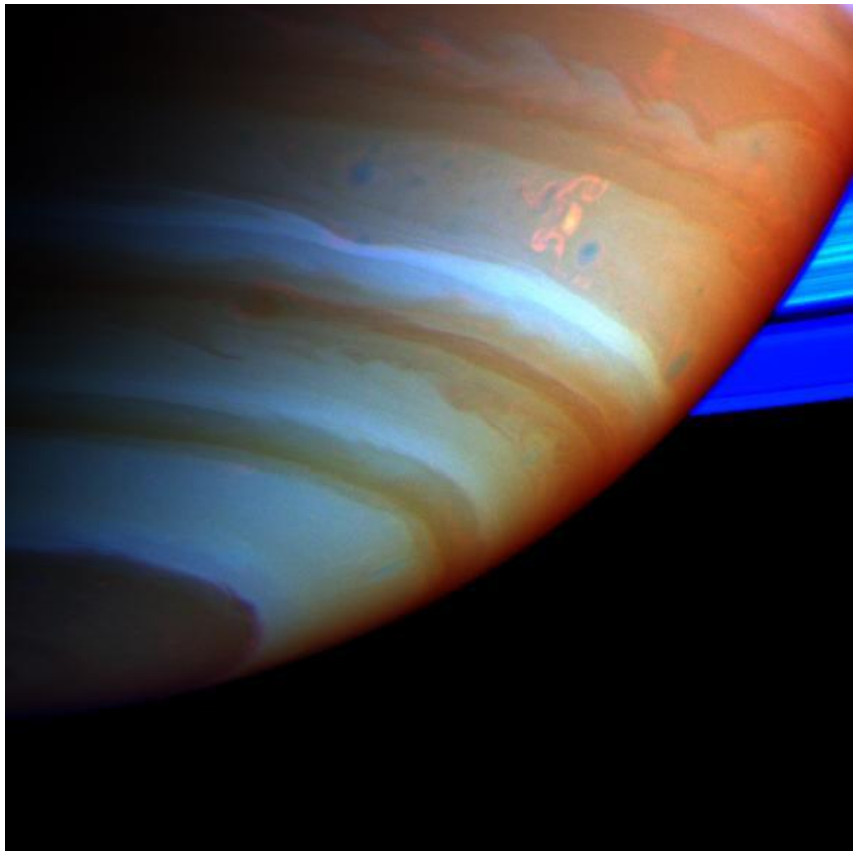
Equinoxes: March 1980, Nov. 1995, August 2009

Question marks: Voyager SEDs at equator or 35° north? Equatorial storm from 1994 an SED storm? Location of weak June 2005 storm uncertain.

Images of smaller storms



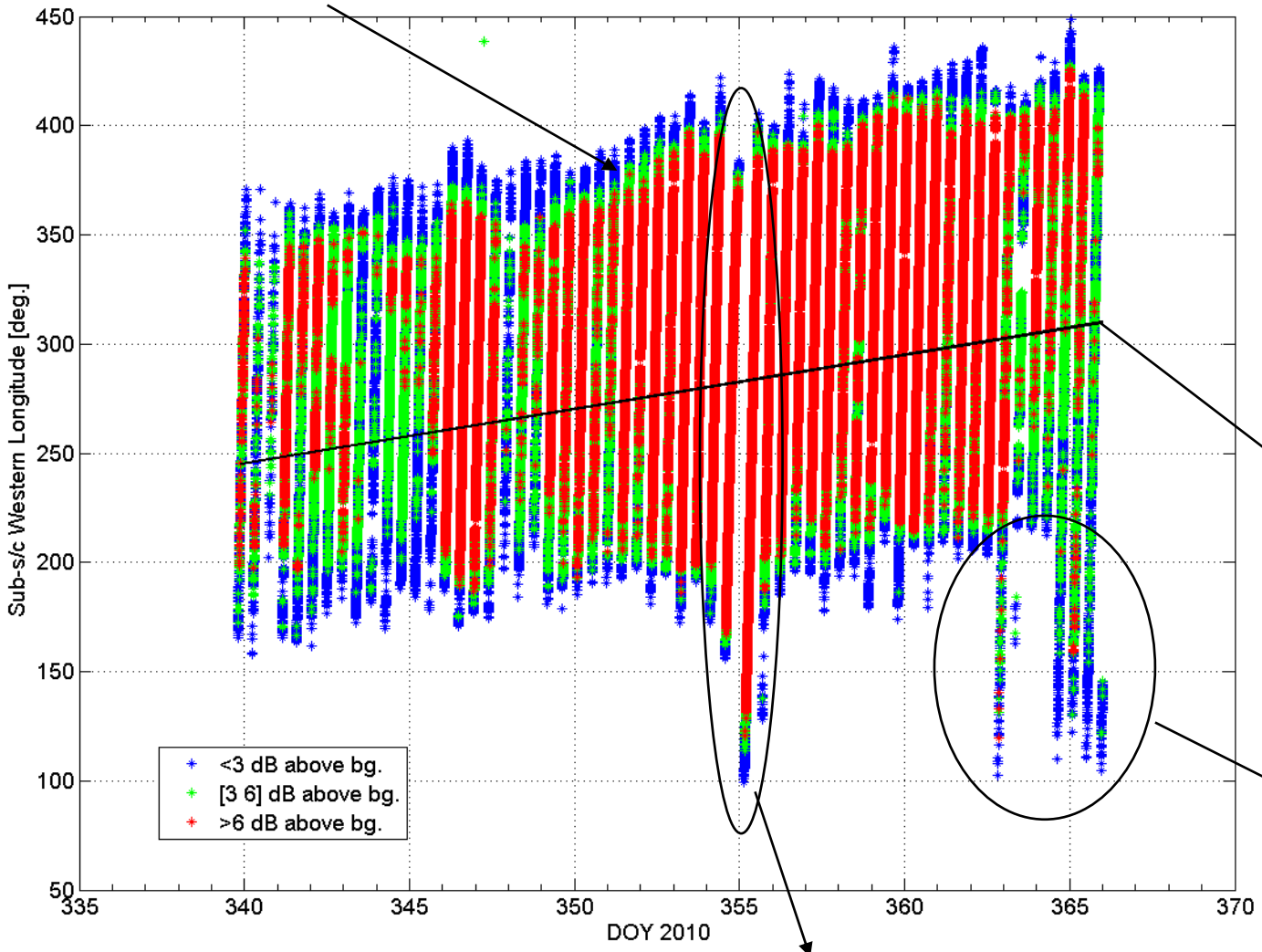
False-color image of convective cloud taken on 5 November 1980 by Voyager 1 around 35° north [see Hunt et al., 1982; Sromovsky et al. ,1983]



False-color image of „dragon storm“ taken by Cassini ISS on 13 September 2004 around 35° south („storm alley“).

Drift of the big SED storm

Asymmetry due to "over-horizon effect" (~30°, radio wave propagation effect, SED waves trapped below ionosphere, s/c mainly in local afternoon)



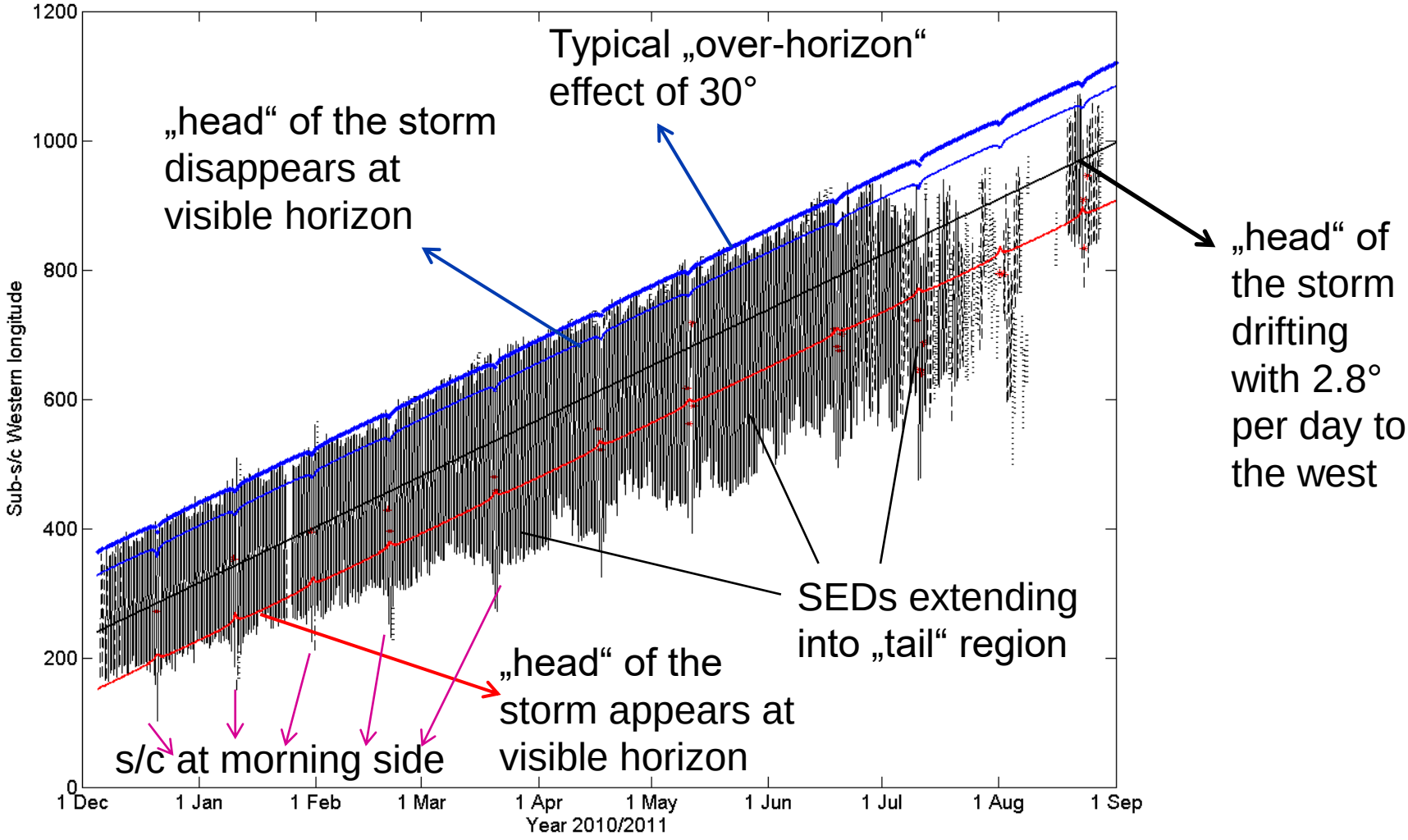
Location of storm core from images, westward drift of 2.8° per day

Small storm system in the tail

s/c periapsis with local time change

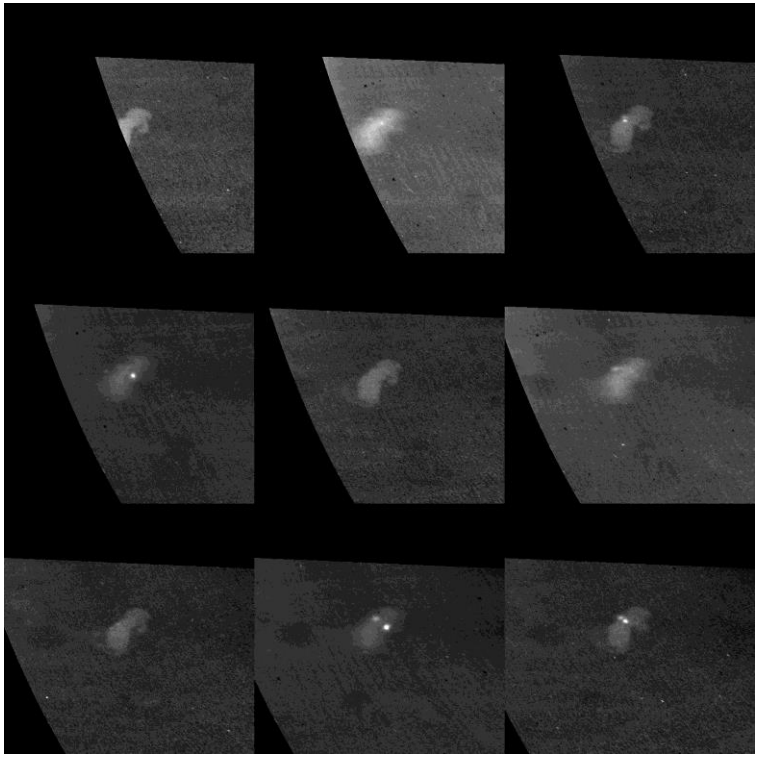
Drift of the big SED storm

561 SED episodes in total (26 of them extended over 1 Saturn rotation);
Cassini made 11 equatorial orbits during storm duration of 8–9 months



Energies and flash rates

- SED optical energy measured as ~10^9 J (0.1% of total energy; Borucki and McKay [1987])
- SED total energy ~10^{12} J
- 2010/2011 storm: from volume of thundercloud and latent heat release during condensation estimated storm energy is 10^{24} J (within 3 months ~10^7 s)
- If 10^{-4} of storm energy goes into lightning (10^{20} J) the average SED rate is 10 s^{-1} (peak rates larger), smaller storms have rates 1 s^{-1}
- Earth: an hour-long thunderstorm has 10^{15} J and several hundreds of flashes with 10^{8-9} J



Observation of optical flashes at Saturn's nightside [Dyudina et al., 2010] in Nov. 2009 in a storm cloud at 35° south

Summary

- First lightning storm in northern hemisphere observed by Cassini started on 5 December 2010 and ended on 28 August 2011
- Cassini/RPWS instrument measured very high flash rates (~10 times more SEDs than smaller southern storms of ~2000 km size). Peak flash rates >10 s^{-1}, average SED rate ~10 s^{-1}
- Latitudinal diameter of storm grew to 10,000 km within ~2-3 weeks, "tail" encircled whole planet after 2 months. Lightning activity always in the "head" of the storm, but extension into the "tail" with time (almost half way around the planet, 180°)
- SED storms observed by the Voyagers at same season might be located at 35° north and not at the equator
- Thunderstorms on Saturn might follow the summer hemisphere and the total power of the storm is comparable to Saturn's total emitted power (~10^{24} J within a few months)
- Storm had significant effects on dynamics and chemistry (e.g. dark spots) of Saturn's atmosphere due to vertical convection