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Saturn Drifting Bursts (SDBs)

by
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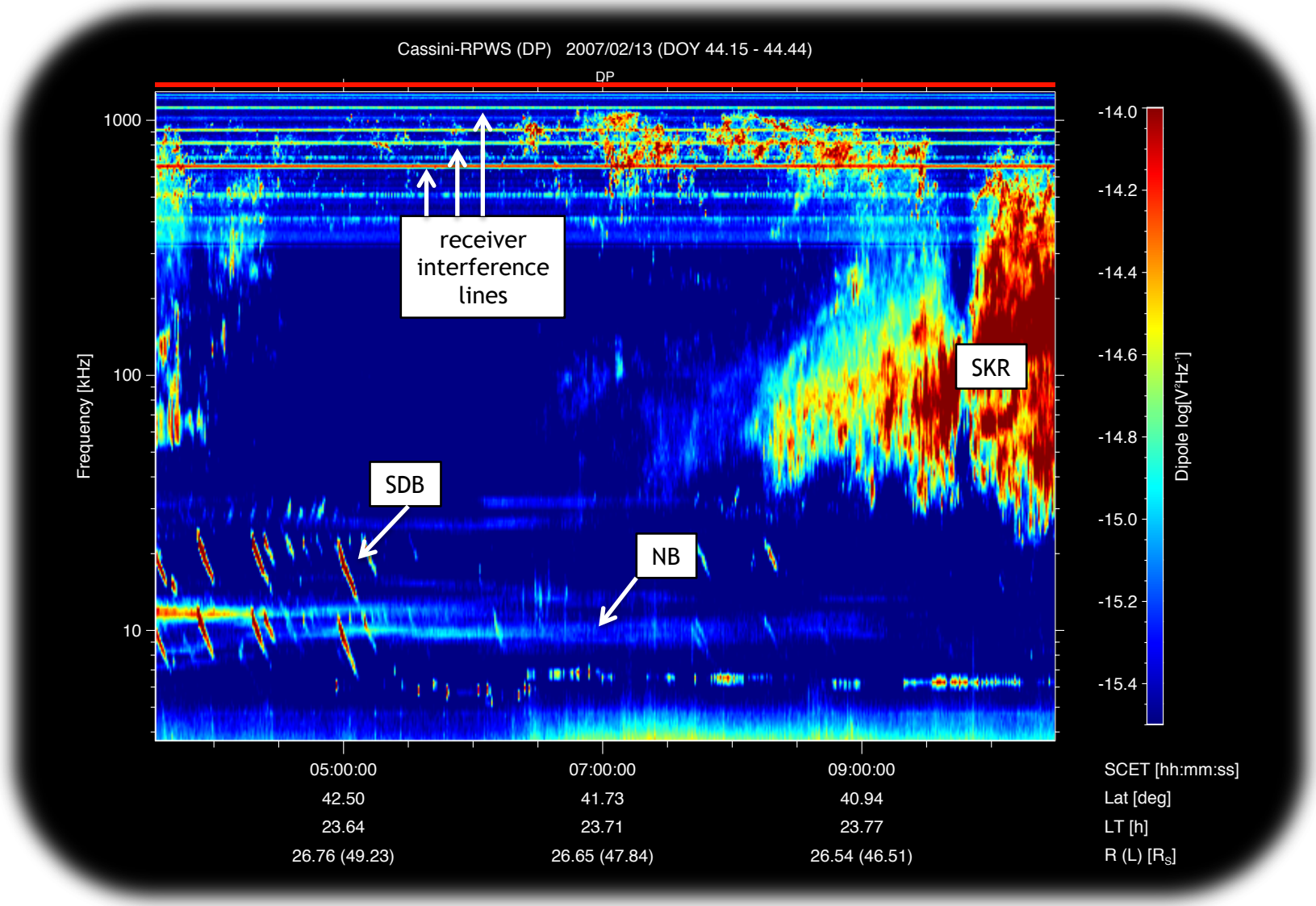
January 30, 2013, IRF-Uppsala



RPWS Spectrum

RPWS: Radio and Plasma Wave Science Experiment (3 electric monopoles, 3 magnetic search coils)

first SDB detection by Cassini on 2004/ DOY 184 (July 2) after SOI maneuver

named SDBs – "Saturn Drifting Bursts"

from 3 - 60 kHz (HFR)

negative/positive drift (negative: 88%)

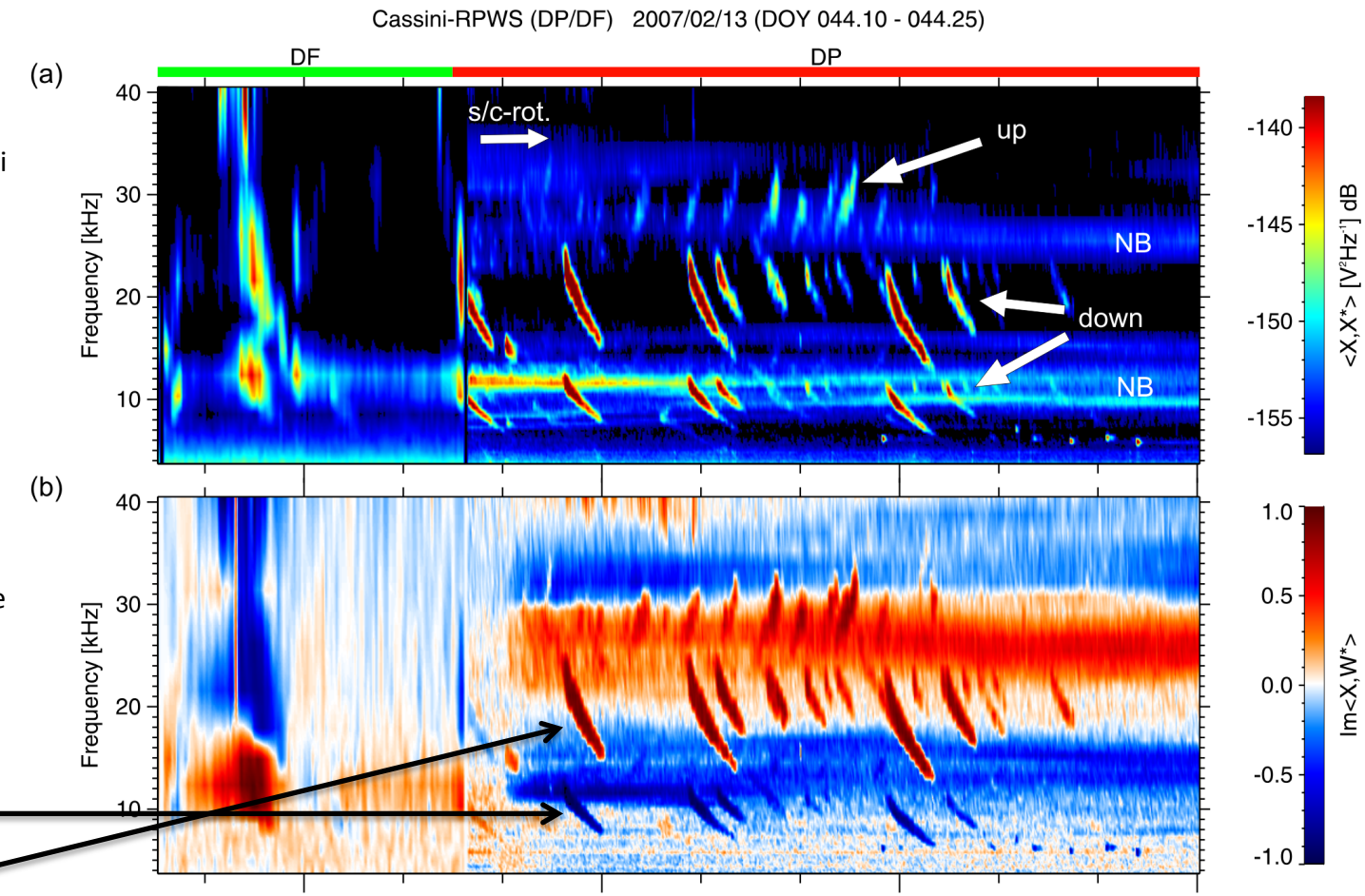
Sporadic spectral occurrence

SDB storm duration: 1 – 10 hours (max. 43 hours)

fundamental emission → LH O-mode

1st harmonic emission (n=2) → RH X-mode

fundamental & harmonic visible together in ~20% of cases



SCET [hh:mm:ss]	03:00:00	04:00:00	05:00:00	06:00:00
Lat [deg]	43.26	42.88	42.50	42.12
LT [h]	23.57	23.61	23.64	23.67
R [R_S]	26.86	26.81	26.76	26.70
SLS3 [deg]	129.17	161.90	194.64	227.38

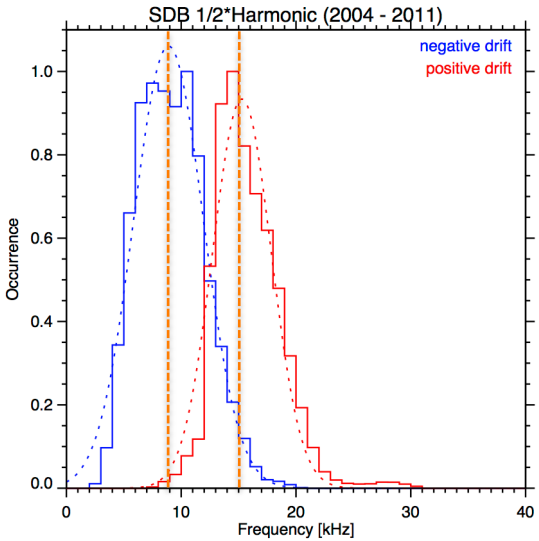
Time – Frequency Statistics

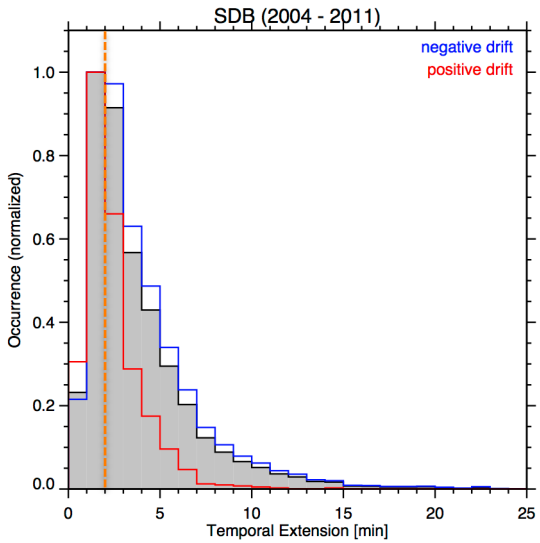
Analyzed period: 2004 (SOI) – end of 2011 ..... 4.5 years of data

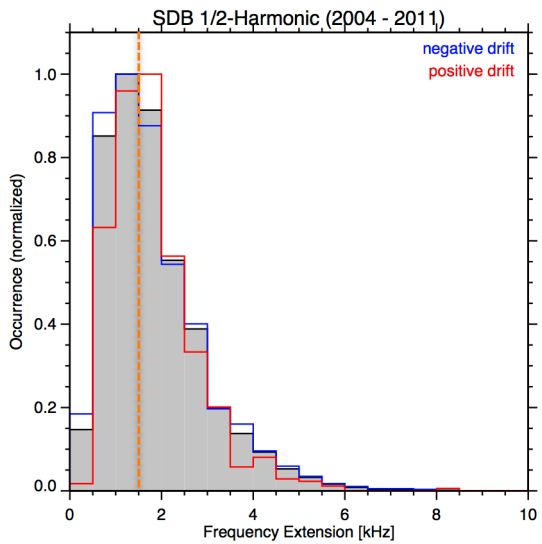
11252 SDBs identified (88% negative drift; 12% positive drift)

60153 spectral points scanned – various parameters derived for scanned points (time, frequency, intensity, Cassini-location)

Fundamental & harmonic distinguishable in 20% of cases (when visible together)







most probable fundamental frequency:
- negative drift ... 9 kHz
- positive drift ... 15 kHz

highest fundamental frequencies:
- negative drift ... 20 kHz
- positive drift .... 25 / 30 kHz

max. temporal extension:
15 – 20 minutes

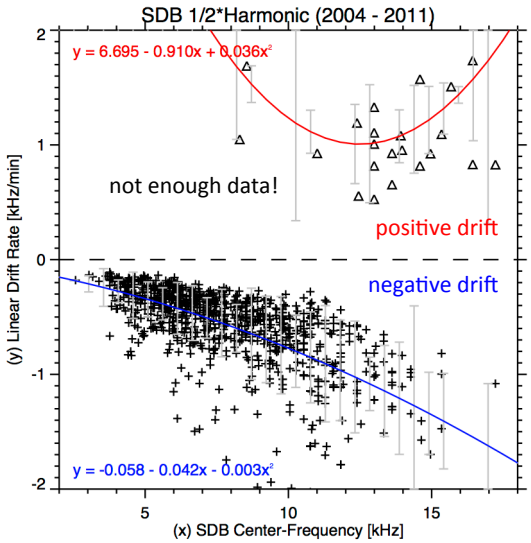
peak: 1 – 2 minutes

fundamental frequency extension:
< 1 – 7 kHz

peak: 1 – 2 kHz

Time – Frequency Statistics

Linear drift rate:



linear drift-rate (kHz/min) is a function of frequency!

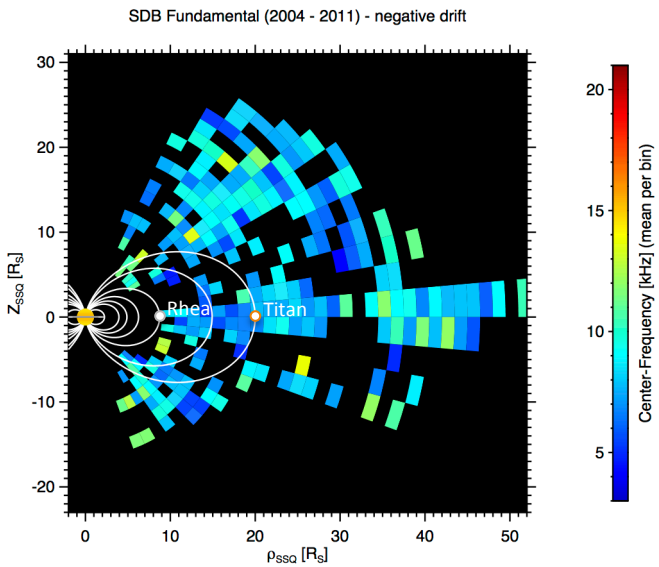
range: 0.1 – 2 kHz/min

there is a small residual quadratic drift (kHz/min^2) → curvature of SDB

quadratic drift too small to be analyzed (limited frequ. resolution of HFR receiver)

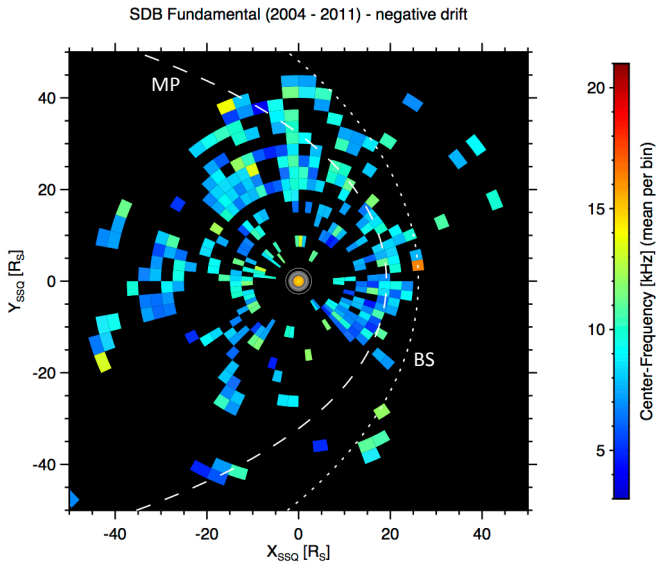
Meridional plane:

mean-frequency per bin has no special distribution with radius/latitude of Cassini



Equatorial plane:

mean-frequency per bin has no special distribution with radius/local-time of Cassini

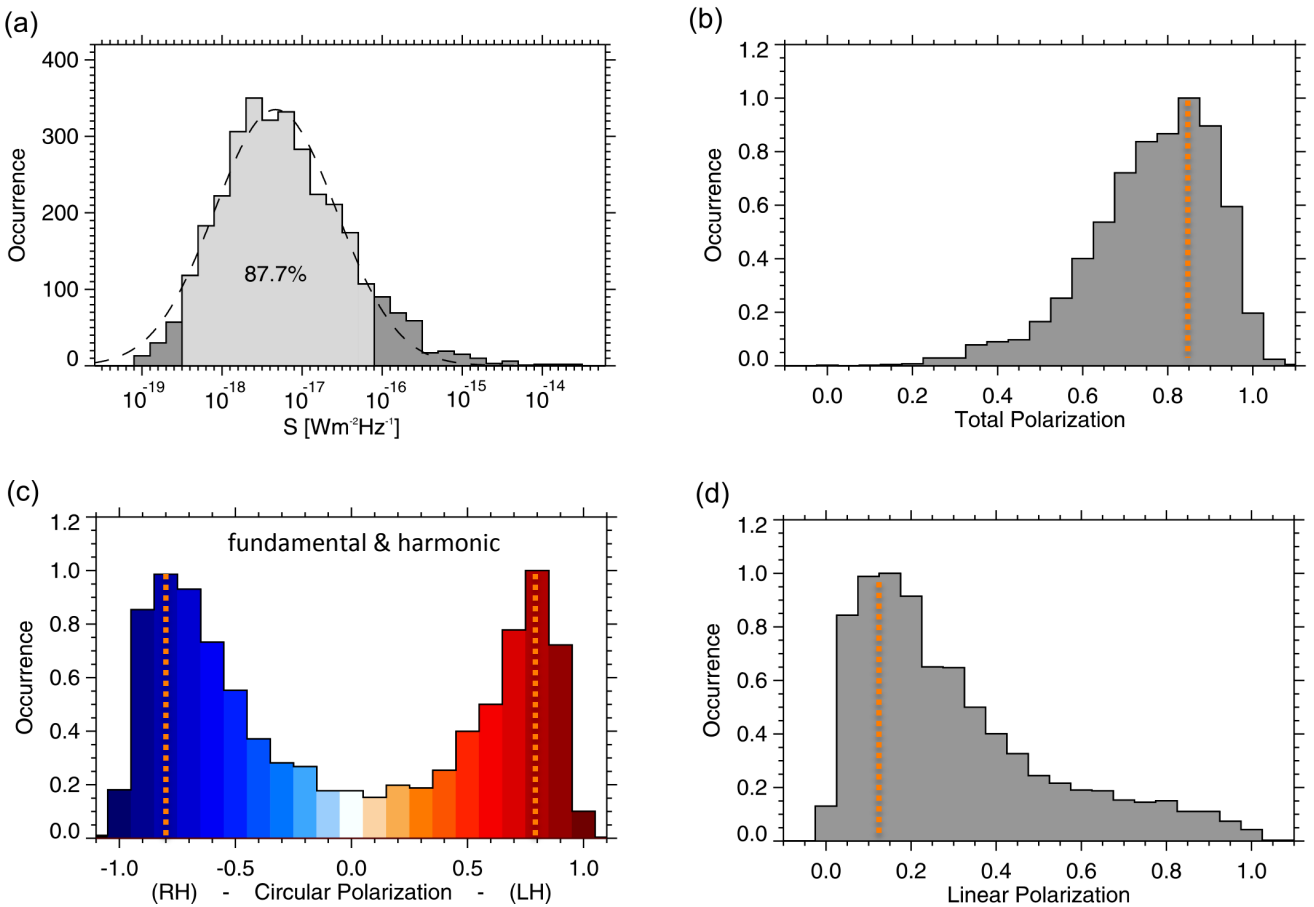


Polarization

Direction-Finding (DF) mode: all 3 electric antennas active (U-, V-, W-antenna) ..... ~ 17% of all data (rest = Dipole-mode data)

→ yields 3 auto-correlation signals: <UU*>, <VV*>, <WW*>
→ yields 2 real and 2 imaginary parts of cross-correlations: <Re{UW*}>, <Im{UW*}>, <Re{VW*}>, <Im{VW*}>

7 signals are enough to determine 6 unknown parameters: Stokes parameters (S, Q, U, V) and direction of incidence (θ, ϕ)
(works if **E** perp. **k** (f_wave >> f_cutoff); if signal at least 20 – 30 dB above background; if **k** out (> 10°) of antenna plane)



SDBs are strongly circularly polarized: d_c peaks at 0.8

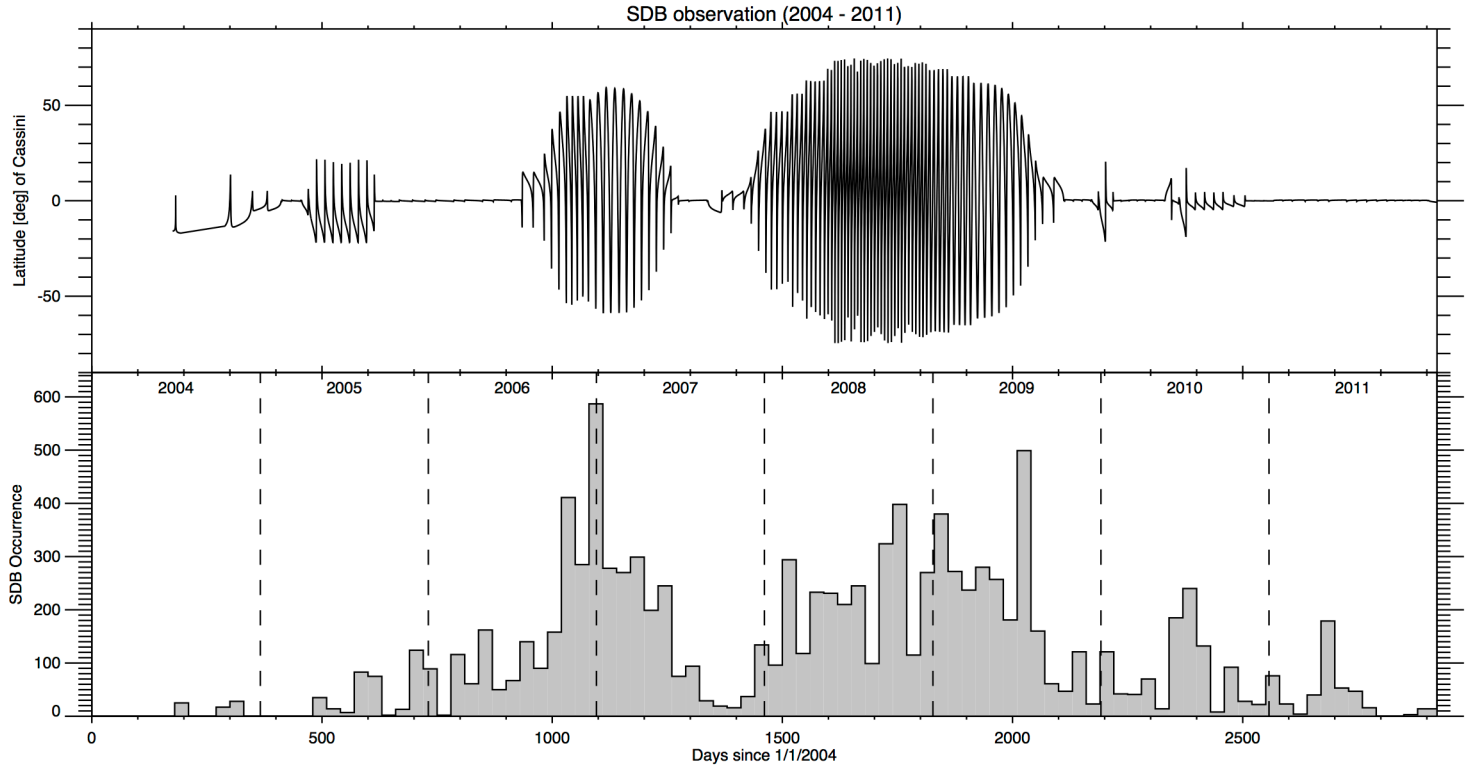
high total polarization:
d peaks at 0.85

Northern hemisphere:
- fundamental appears LH
- harmonic appears RH

Southern hemisphere:
- fundamental appears RH
- harmonic appears LH

Polarization with regard to magnetic field:
- fundamental ... LH O-mode
- harmonic ..... RH X-mode

Statistics: Position of Cassini



- SDB visibility is strongly varying during 4.5 years (mid of 2004 – end of 2011) .... SDB storms

- more SDBs seen by Cassini during high inclination orbits

SDB Visibility (2004 – 2011)

Latitude:

Visibility as a function of (krono-graphic) latitude of Cassini

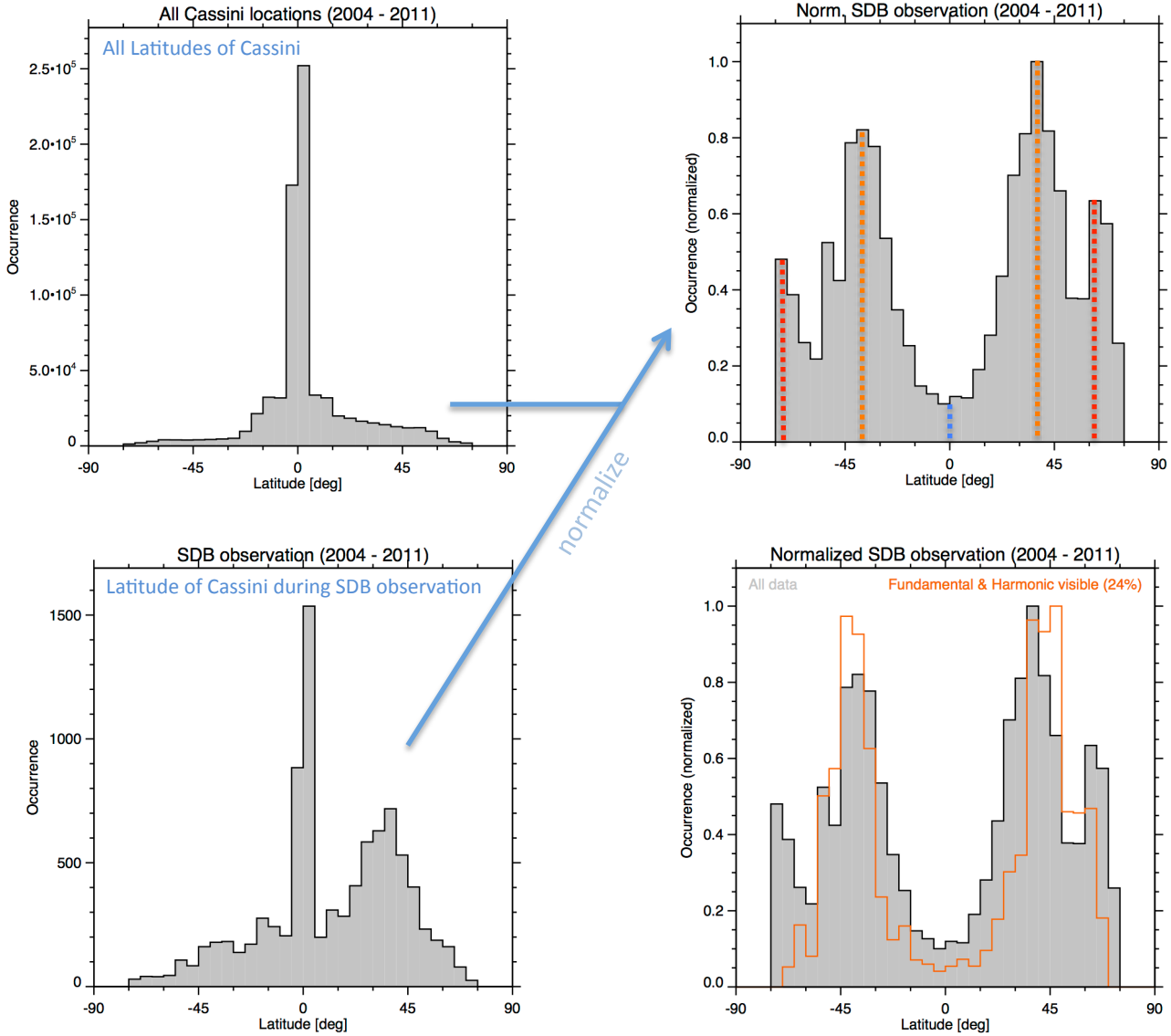
Count number of SDBs in spectra per LAT-bin

Importance of normalization of visibility-histograms

Lowest visibility in the equatorial plane

2 main peaks:
-) around +40° north LAT
-) around -40° south LAT
➔ preferential beaming of SDBs into the mid-latitude sector

2 side peaks:
-) around +65° north LAT
-) around -70° south LAT
➔ propagation effect; SDBs at 55° - 60° (sinks) are blocked from the observer by high density plasma region?
➔ side peaks at high latitudes (65° - 70°) are due to enhanced O-mode count rate; O-mode (fundamental) can propagate across the poles from the other side; X-mode (harmonic) is blocked (high B over poles).



no harmonics (X-mode) in side peaks?

SDB Visibility (2004 – 2011)

Visibility with radial distance:
-) peak around 20 Rs
-) sporadic observations beyond 50 Rs (low SNR)
-) most distant obs. at 77 Rs

Visibility with Local Time (LT):
-) 2 peaks: midnight and noon
LT is strongly coupled with LAT – special orbit geometry

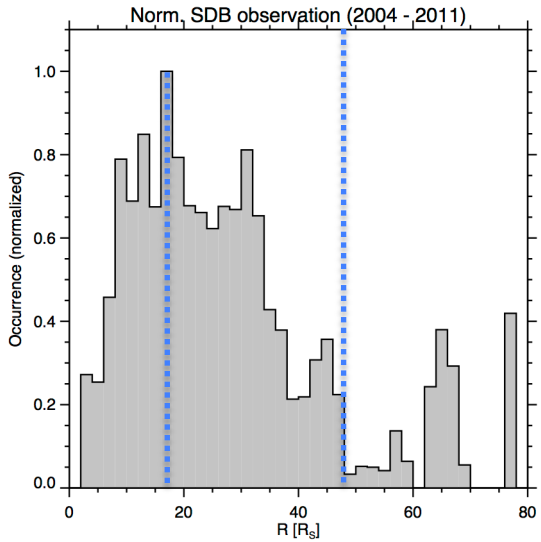
-) but, peaks with LT are also visible for observations in the equatorial plane only (|Lat| < 5°)
➔ variation with LT might be real

Visibility with SLS4:
-) separate observations into north and south; |Lat| > 15°
-) clear modulation with SLS4 in both hemispheres
-) north and south have approx. the same phase (100° – 113°)

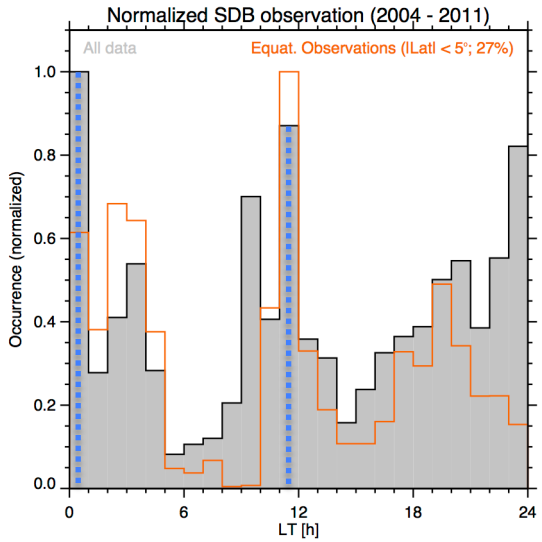
No modulation of SDB-visibility as a function of SLS4 at LT 12:00.

"clock-like" (flash-light) source?
➔ increased activity if a certain SLS4-longitude (-10°) is pointing at the observer
➔ + narrow beaming characteristic

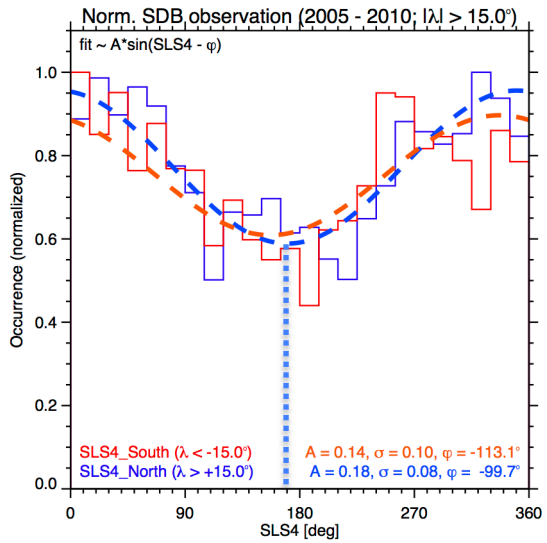
Radial dist. of Cassini during SDB obs.



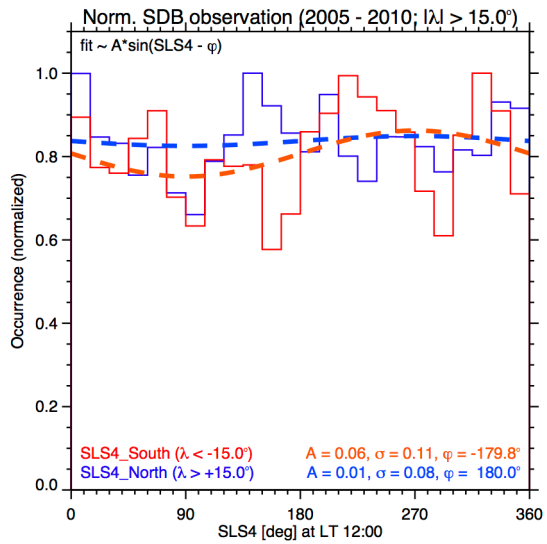
Local Time of Cassini during SDB obs.



SLS4 of Cassini during SDB obs.



SLS4 at LT 12:00 of Cassini during SDB obs.



SDB Visibility (2004 – 2011)

Visibility summary:

-) preferential beaming of radiation into mid latitudes (+/- 40°)

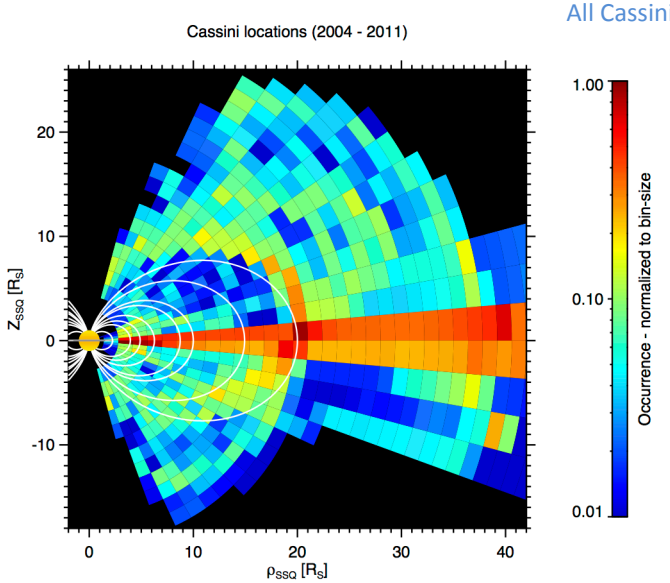
-) variation with Local Time; mostly observed around midnight and noon

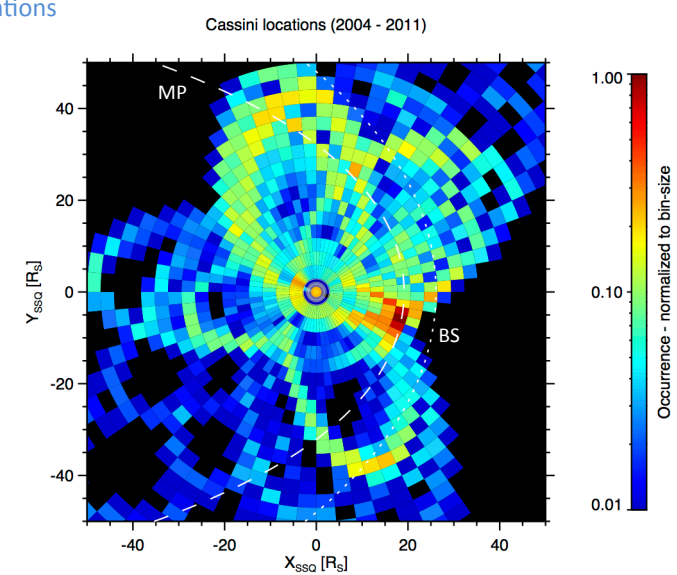
-) visibility out to large radial distances (80 Rs); visibility outside Saturn's magnetosphere ➔ evidence of electro-magnetic radiation

-) modulation with SLS4; higher SDB activity around SLS4 = -10°/-20° north/ south
➔ "clock-like" source?

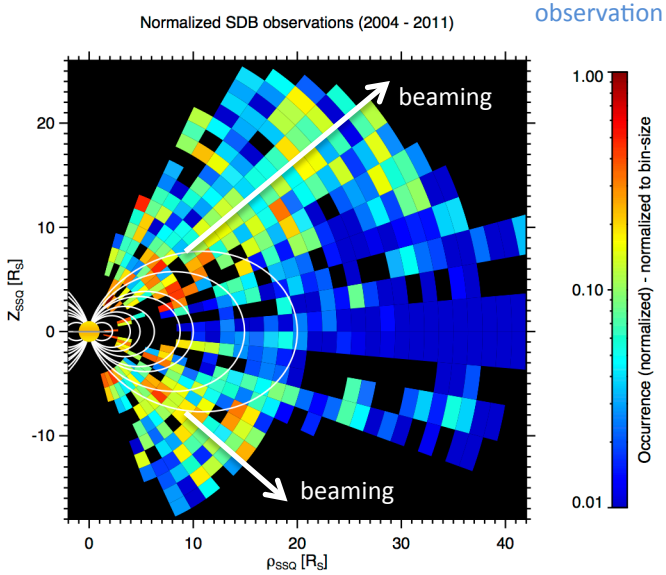
-) sporadic events; no permanent visibility; longest continuous observation ("SDB storm") lasting ~ 43 hours (with gaps < 3 h).

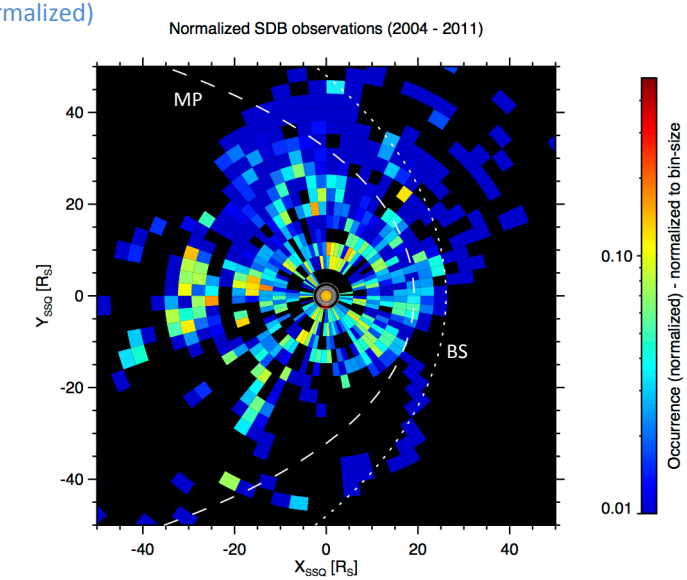
All Cassini locations



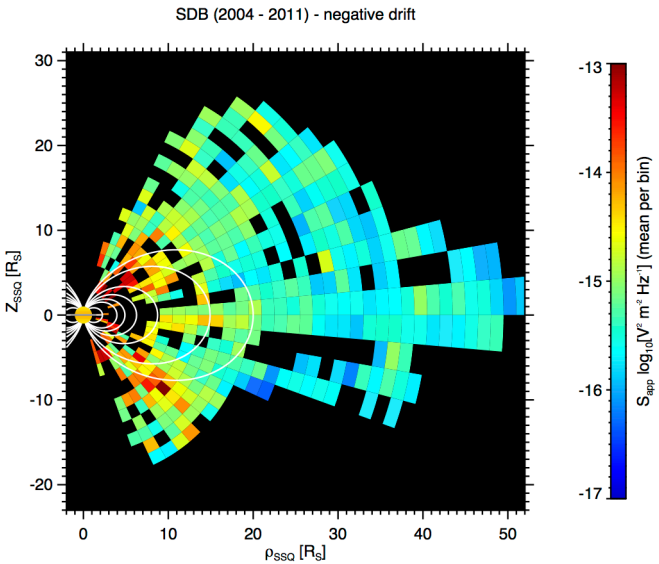


Cassini locations during SDB observation (normalized)





Statistics: Intensity

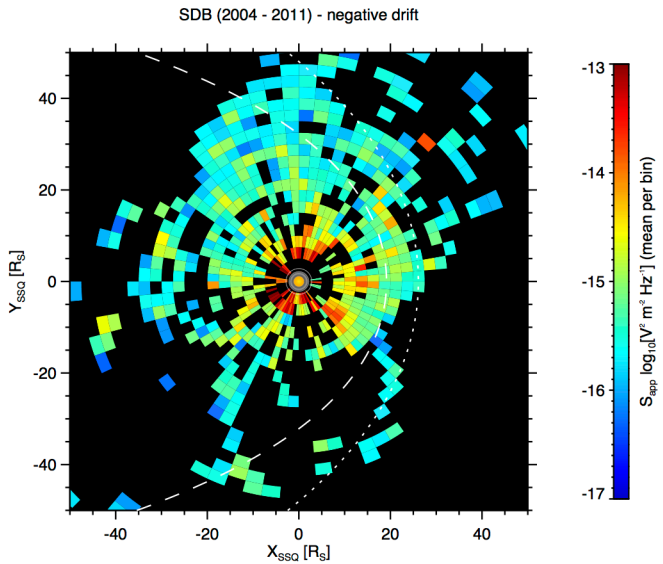


Meridional plane:

mean-intensity per bin has a clear distribution with radius/latitude of Cassini

- higher intensities at small radial distance (< 10 Rs)

- higher intensities at higher latitudes (> 30°)



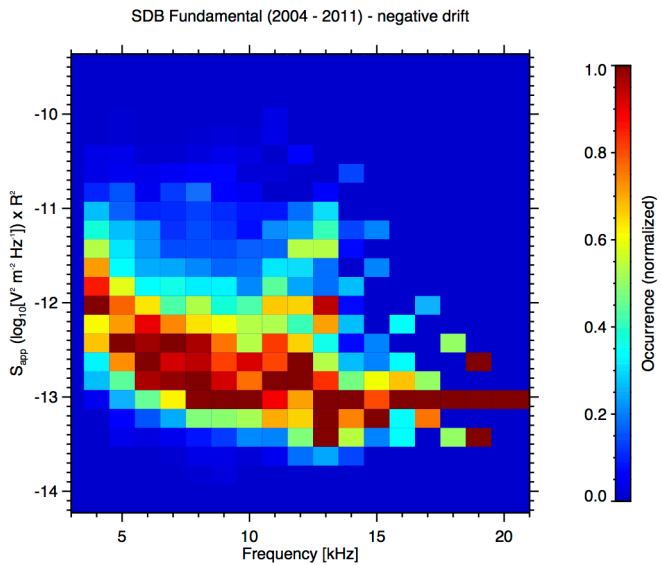
Equatorial plane:

mean-intensity per bin has no special distribution with LT of Cassini, but with radial distance → proximity to source region.

Intensity = apparent Stokes-S [V^2 m^{-2} Hz^{-1}]

DP-mode: S_{app} = $auto_D$/l_D^2 + $auto_w$/l_w^2

DF-mode: S_{app} = $auto_u$/l_u^2 + $auto_v$/l_v^2 + $auto_w$/l_w^2



S_{app} normalized by distance^2 is a function of frequency!

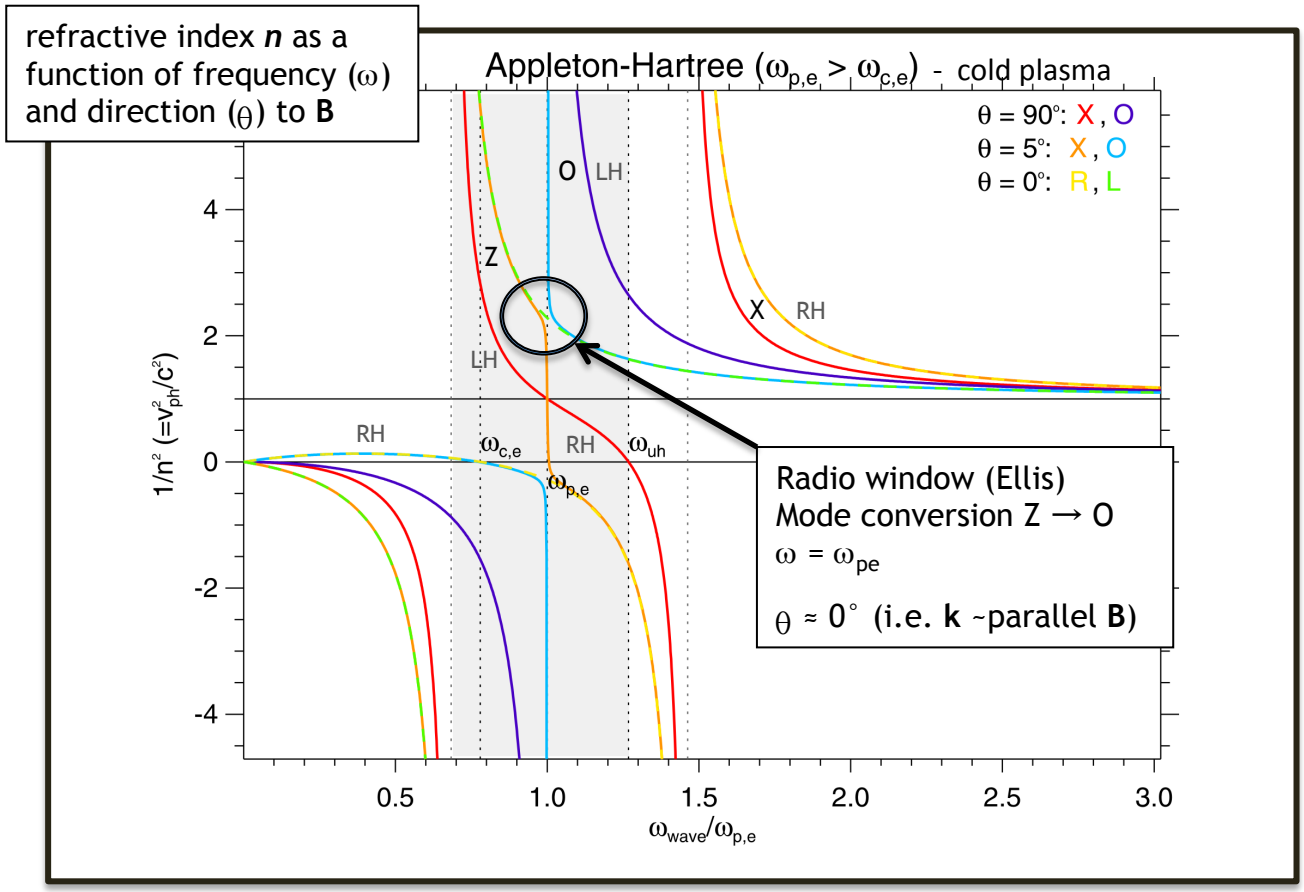
→ efficiency of the generation mechanism for SDBs is a function of frequency?

Mode Conversion

Focus on electrostatic upper hybrid oscillations → thermally excited at $f^2_{UH} = f^2_c + f^2_p$

Upper hybrid oscillations can be converted to electromagnetic modes (Z-mode, O-mode) by linear (Oya, 1971; Jones, 1976) or nonlinear mechanisms (Melrose, 1981).

Focus on linear mode conversion: UHR → Z-mode → O-mode



Beam/anisotropy in velocity distribution/MHD wave shifts UH oscillation onto the Z-mode branch at $f \leq f_{uh}$.

Z-mode propagates into a region where $f_z = f_p$.

Z-mode converts to O-mode at $f \approx f_p$ (1st Ellis- window).

A gradient in the plasma density is required for this scenario.

$\nabla n / \lambda$ must be in the right range for an efficient conversion.

Mode Conversion

Linear mode conversion

1) UHR → Z-mode

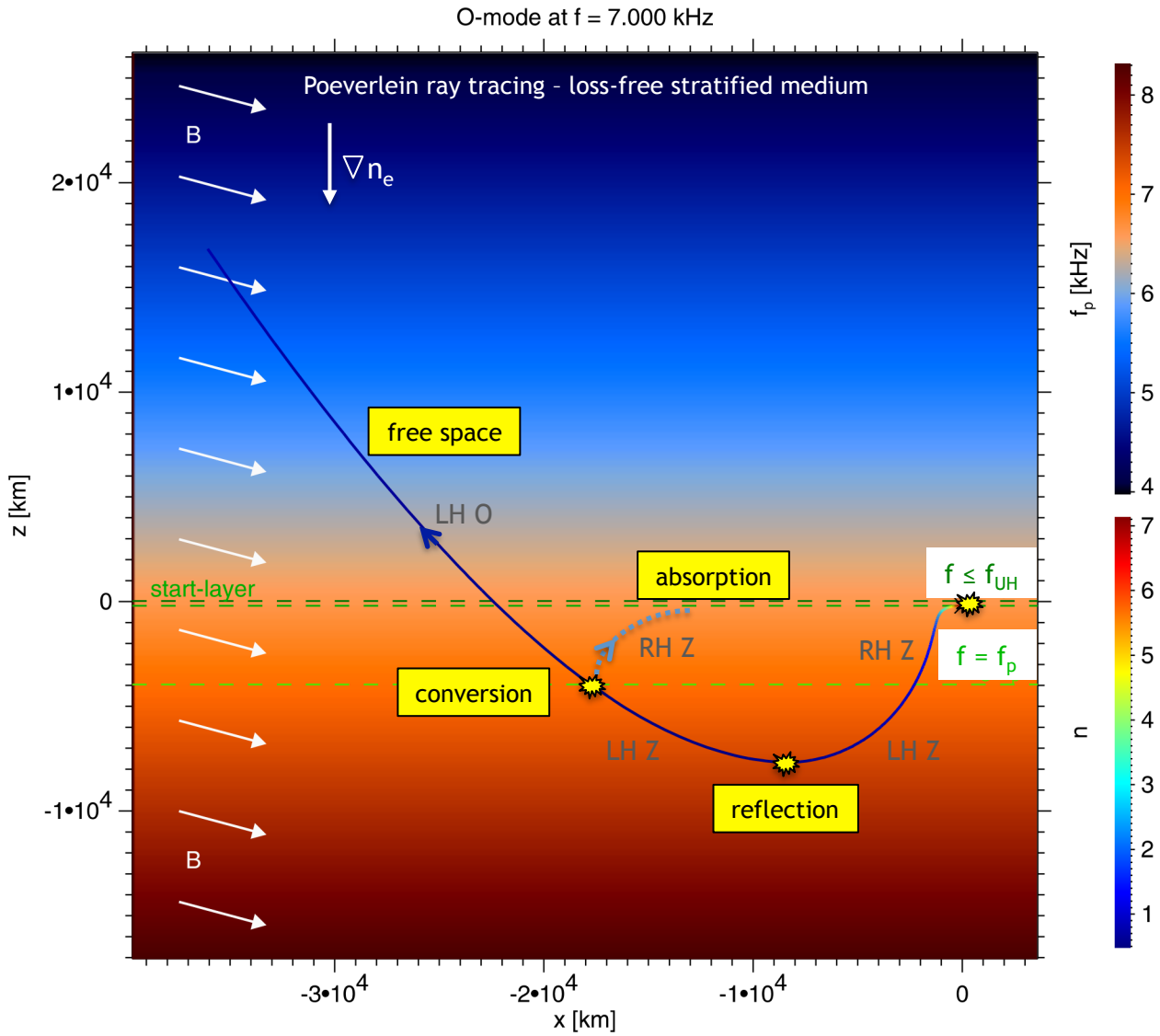
2) Z-mode propagates towards increasing plasma density

3) Z-mode is reflected at cutoff and propagates back towards decreasing plasma density

4) In the layer where $f_p \approx f_Z$, it can convert to O-mode ($f_O \approx f_p \approx f_Z$)

5) O-mode escapes towards decreasing plasma density into "free space"; detected remotely by spacecraft.

6) Z-mode which didn't convert gets absorbed again (Z-mode → UHR)



Mode Conversion

Sporadic conversion event 2009/DOY 207

Cassini is at medium northern latitudes: 20° – 35°

SKR is dominantly RH X-mode
→ red shades .... RH
→ blue shades ... LH
Sign of Im (+ vs. -) depends on direction of incidence: source below or above antenna plane.

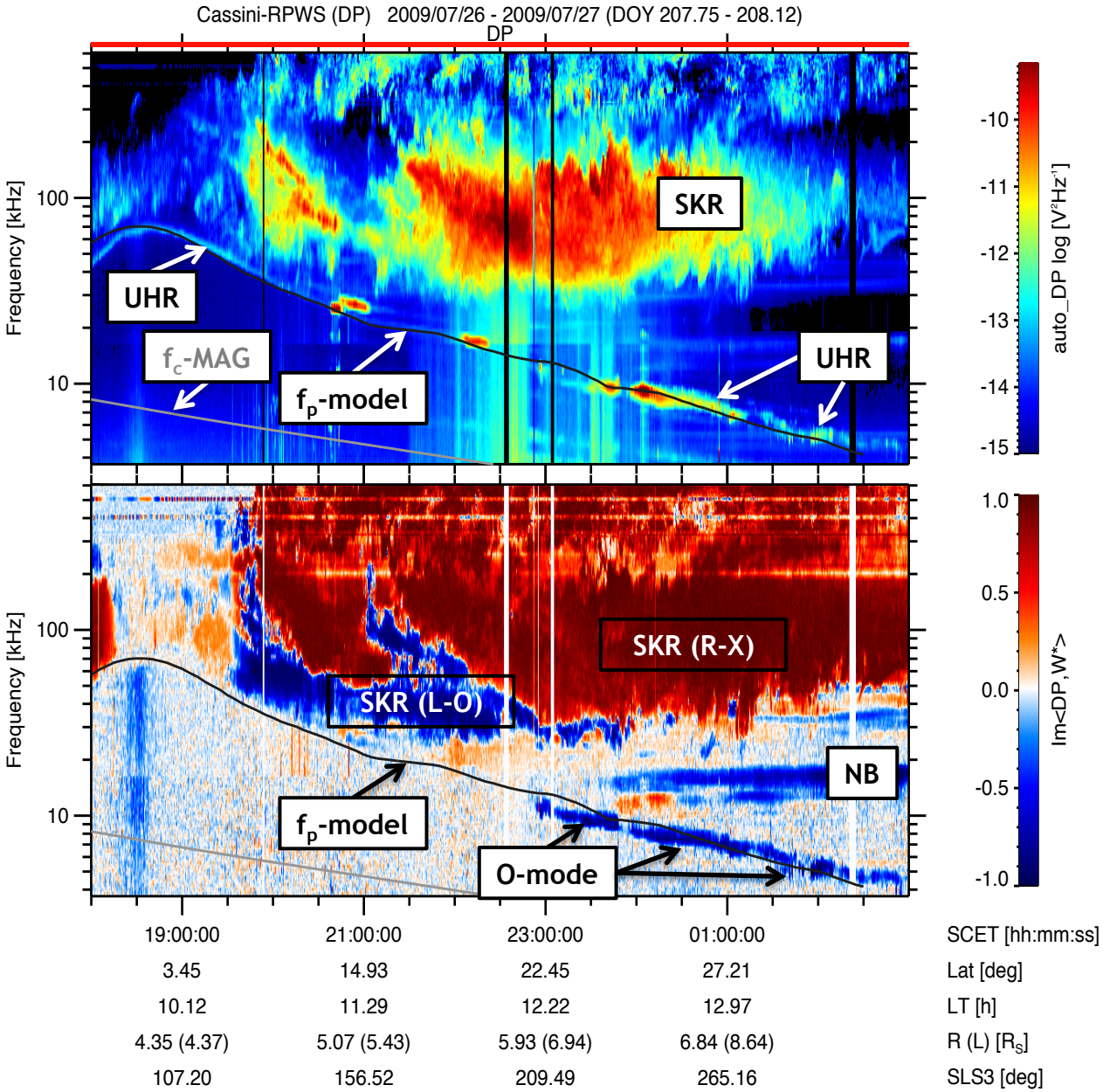
unpolarized UHR (white imaginary-part) at f < 11 kHz becomes intense, bursty and circularly polarized

the sense of apparent circular polarization stays constant → systematic behavior

Interpretation:
mode conversion
UHR → Z-mode
Z-mode → O-mode

Mode conversion is active along a broad range of latitudes

Cassini is crossing source regions for SDBs?



Mode Conversion

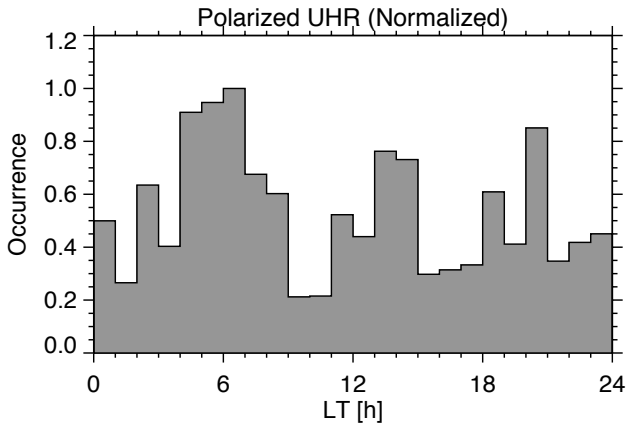
Where does mode conversion occur?

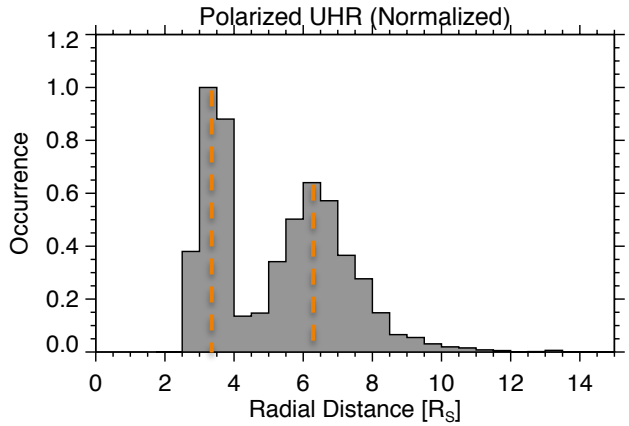
scan spectral points where UHR becomes polarized (2004 – 2012)

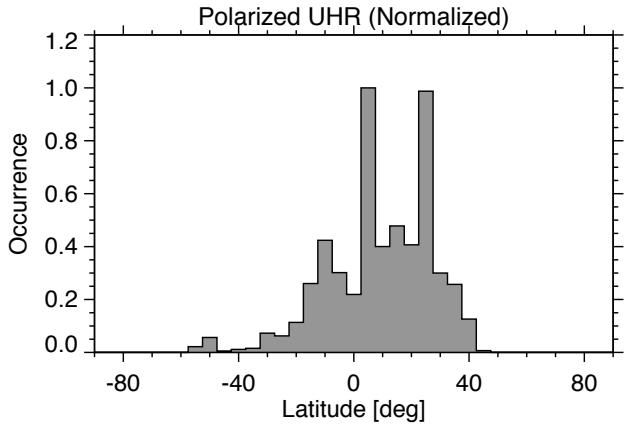
data selection:
-) $S_{app} > 10^{-14}\ V^2m^{-2}Hz^{-1}$
-) $d_{app} > 0.5$

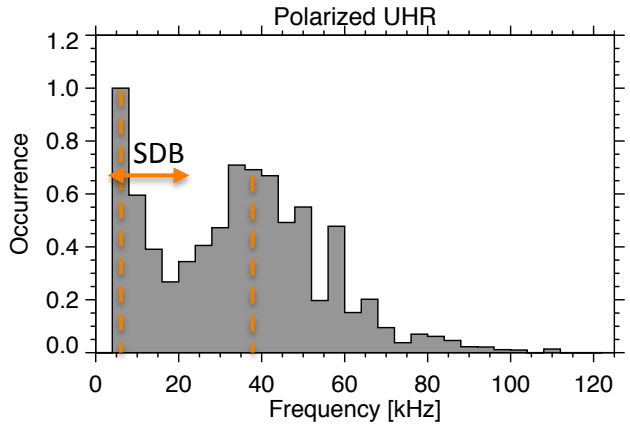
histograms for location of conversion (= location of Cassini)

histograms are normalized to the time Cassini spends in a certain bin; exclude positions at r > 15 R_S; UHR becomes invisible; $L_{Debye} >> L_{antenna}$









Results

- Polarized UHR seen at all LT and along a broad range of latitudes (up to 50°)

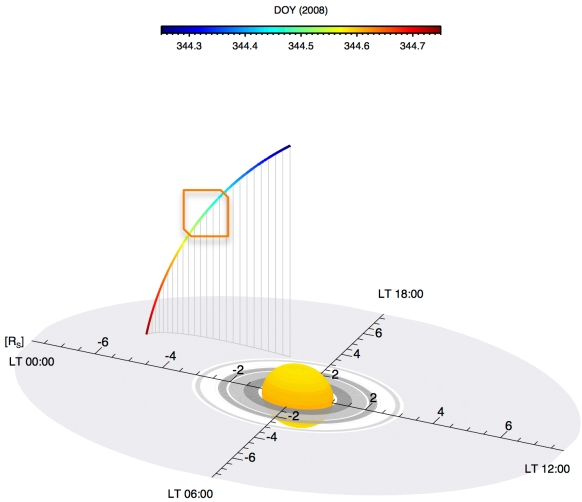
- 4 groups:
  1) sporadic conversion
  2) conv. in injection events
  3) conv. close to Enceladus
  4) conv. when UHR meets ECH

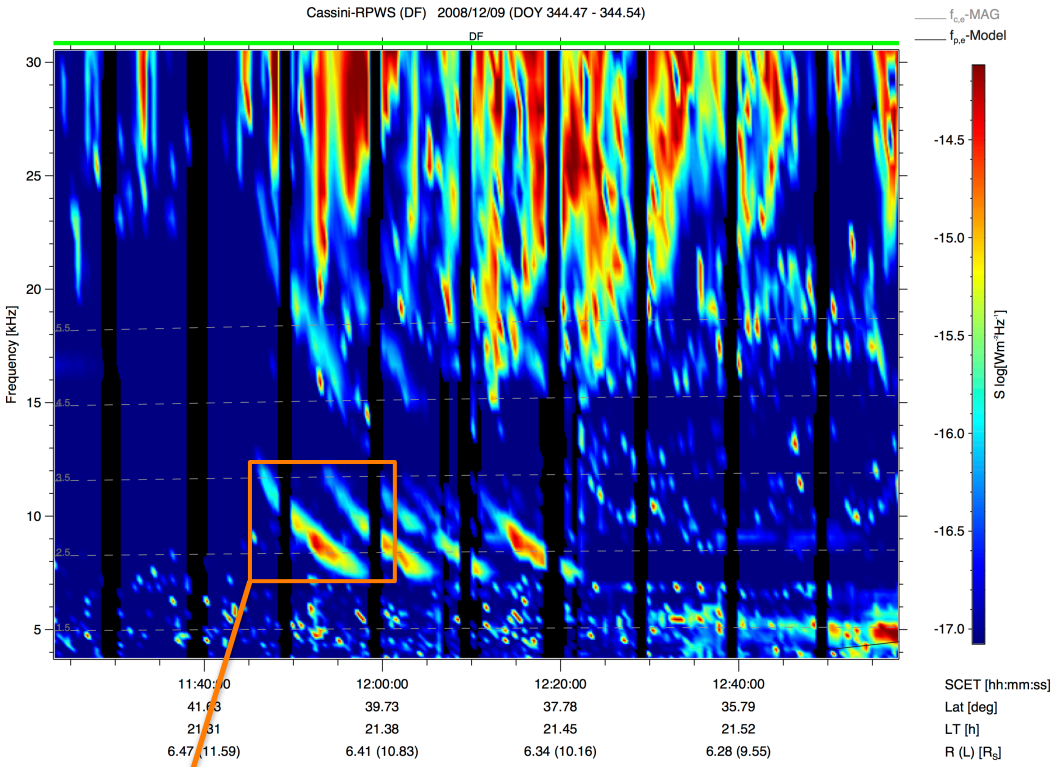
- 2 peaks in occurrence of radial distances:
  r = 2.5 – 4.0 R_S: Enceladus flybys, UHR between ECH
  r = 5.0 – 9.0 R_S: sporadic events, injection events

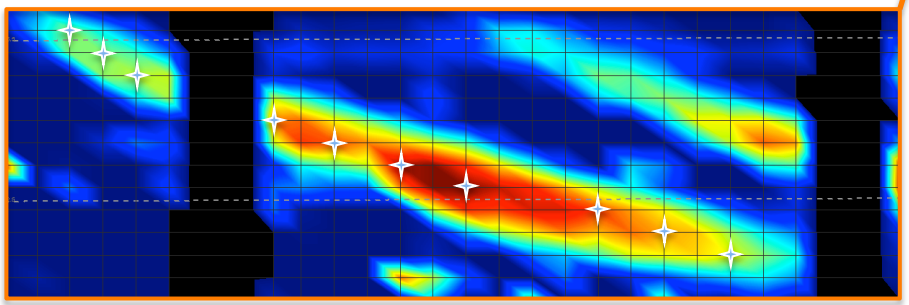
- 2 peaks in occurrence of frequencies:
  → 10 kHz vs. 40 kHz
  (strongly correlated with radial dist. and lat.)

Direction Finding – Case Study

2008/344 12:00:
Cassini at high northern latitudes (40°); close to Saturn (6.4 Rs)







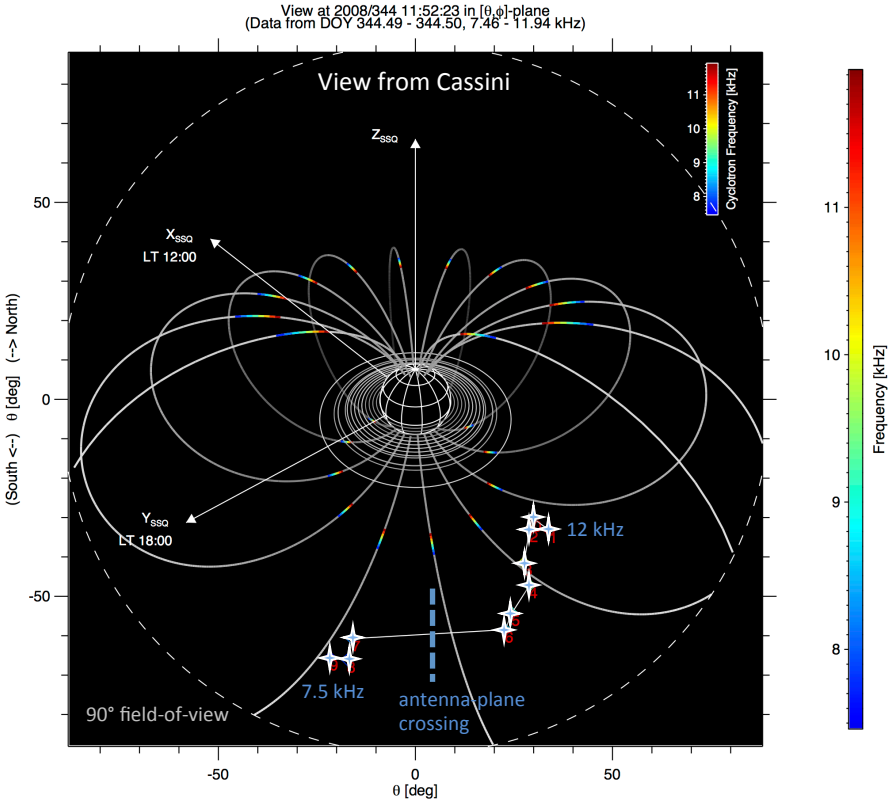
SDBs are poorly resolved in DF-mode
(Δt = 32sec, $\Delta f/f \approx 5\%$)

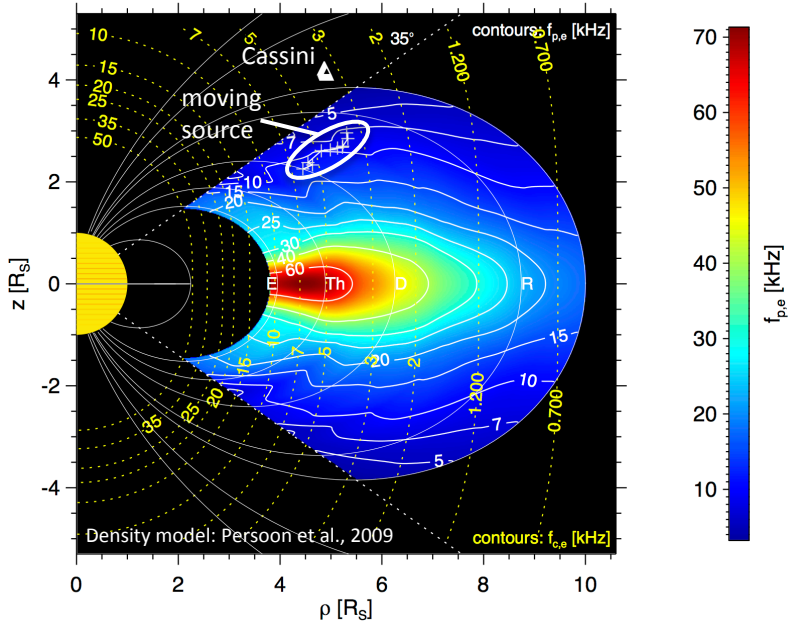
Scan 1 point/frequency-channel along the spectral middle line

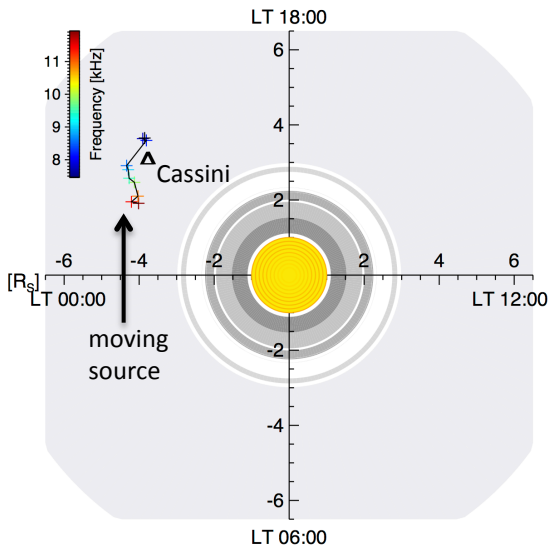
SNR of scanned points should be > 10^3

Scanned points → direction-finding (S, Q, U, V, θ, ϕ)

Direction Finding – Case Study







- SDB spectral drift is generated by a moving source as a function of frequency
- mode conversion scenario: SDB-frequency = f_p in crossed layer

- source is moving along ~ const. latitude towards greater radial distance → f_p decreasing → negative drifting SDB

- source is moving at a high inclination to dipol field lines

- source is drifting in LT, against rotation direction of MS (= drift-direction of electrons)

Conclusions

Summary:

- Saturn Drifting Bursts (SDB) detected by Cassini/RPWS below 60 kHz

- Sporadic events (storms of several hours)

- Drift rates 0.1 - 2 kHz/min (positive, negative)

- 20% of cases: fundamental & 1st harmonic visible (harmonic at twice the fundamental frequency)

- fundamental = LH O-mode; harmonic = RH X-mode (circularly polarized)

- best visibility at mid latitudes (40° north & south) around noon and midnight

- generation mechanism: linear or non-linear mode conversion ($f_{UHR} \rightarrow f_Z = f_p = f_O$); explains polarization and harmonics

- spectral drift is the consequence of a source moving through layers of decreasing/increasing plasma frequency

Open questions:

- is mode conversion working efficiently enough in Saturn's plasma torus (linear or non-linear mechanism)?

- what kind of particles are providing free energy: electrons, protons or water group ions (H^+, OH^+)?

- what kind of particle distribution function is initiating the conversion process (direct source-crossing needed)?

- what is the particle energy range needed for explaining drift durations of minutes?