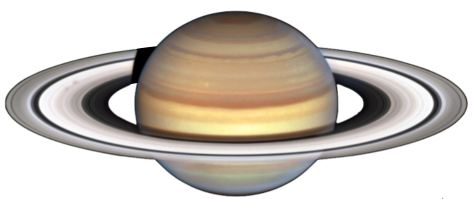
24-11046L I6710-N

Direction Finding for Saturn Drifting Burst Emissions

Ulrich Taubenschuss (1), David Píša (1), Georg Fischer (2), and Masafumi Imai (1)

(1) Institute of Atmospheric Physics, Czech Academy of Sciences, Prague, Czechia
(2) Institute of Physics, University of Graz, Graz, Austria

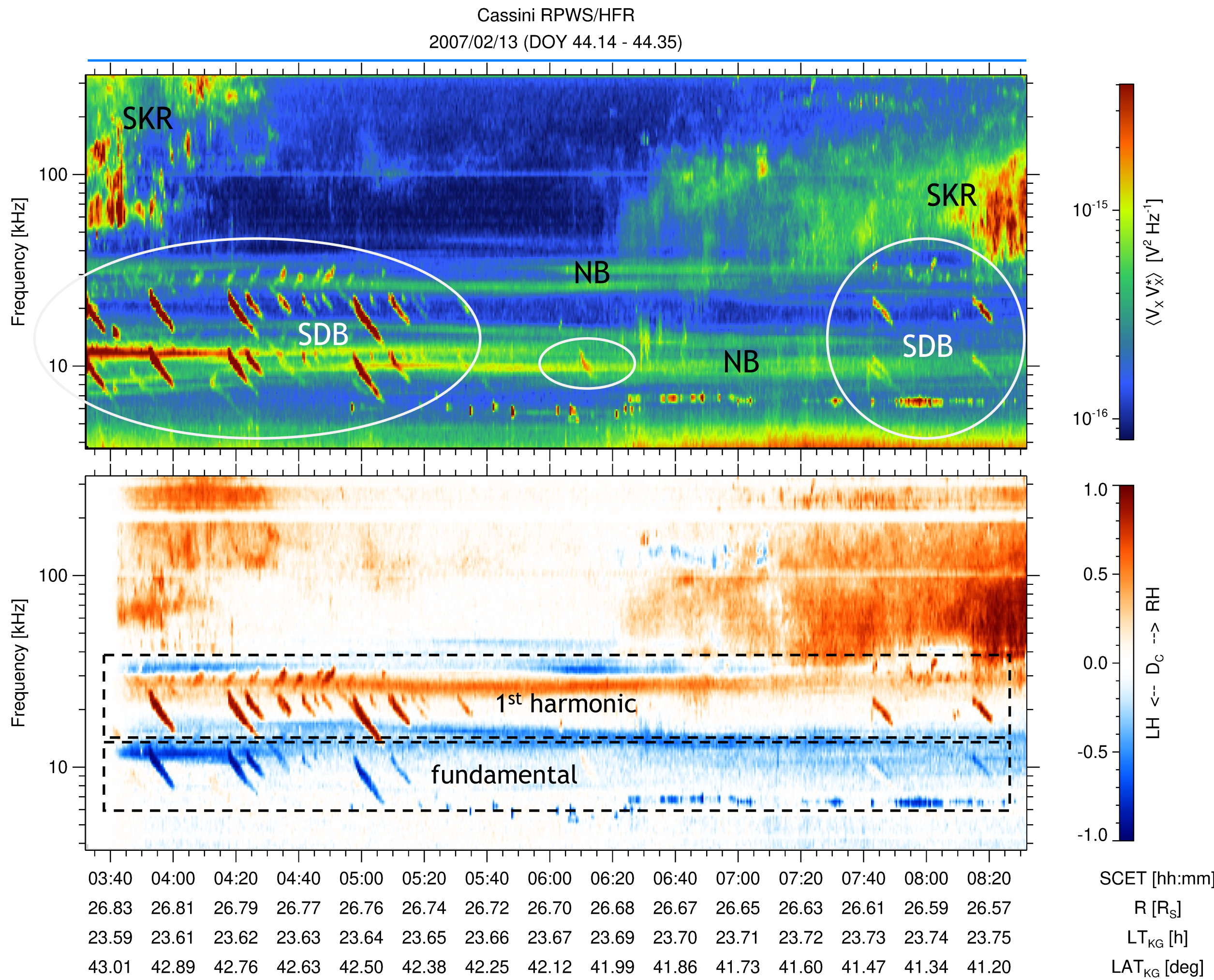


Saturn Drifting Bursts (SDBs)

- spectrum: bursty & drifting
  negative (90%) & positive (10%) drift
- drift rate .... 0.5 - 2 kHz/minute
- burst duration .... 1 – 10 minutes
- burst frequ.-extension ... 1 – 7 kHz
- frequ. range .... 3 - 50 kHz

- fundamental (at $f = f_0$) and 1st harmonic (at $f = 2^*f_0$) emissions
- fundamental .... O-mode (LH)
- 1st harmonic .... X-mode (RH)
- degree of polarization ... ~ 0.75
- ellipticity .... ~ ± 0.9

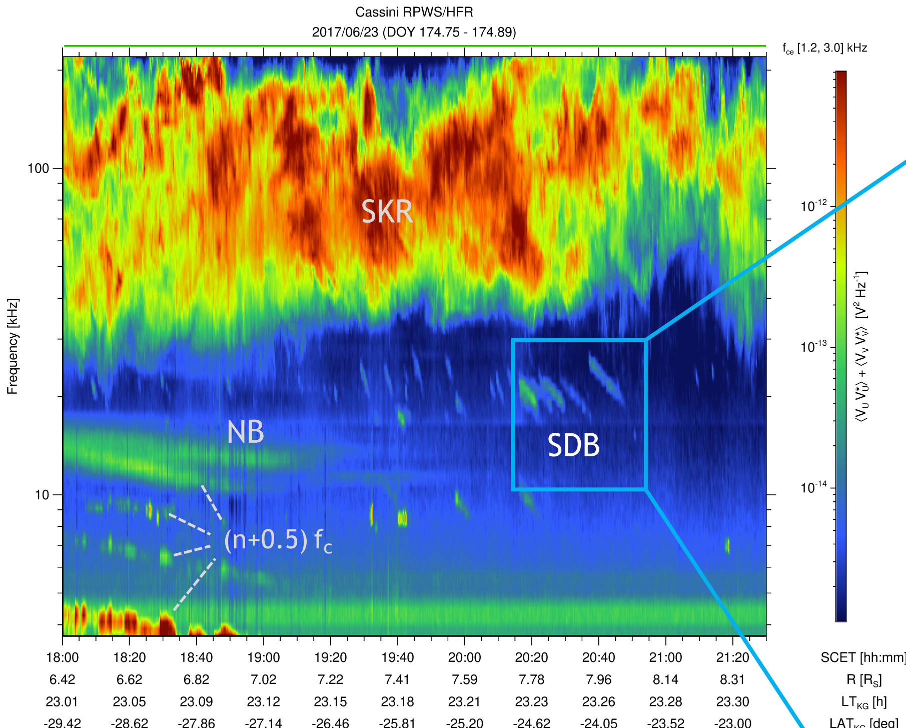
- generation by linear mode conversion of Z-mode → O-mode at $f \approx f_{pe}$
- harmonic X-mode from nonlinear conversion



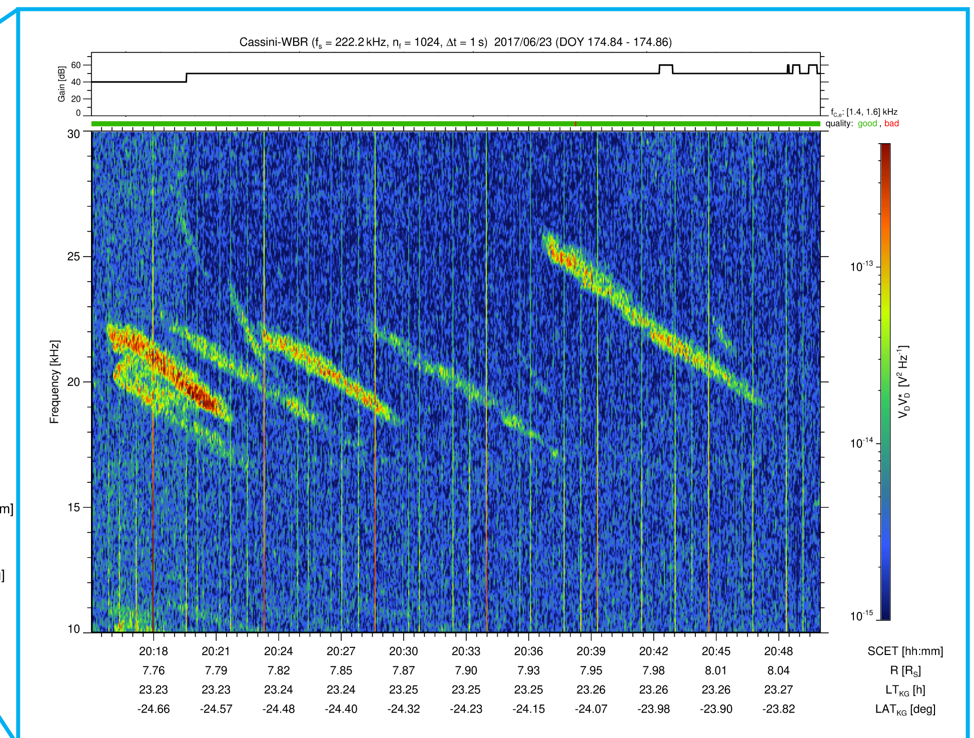
Saturn Drifting Bursts (SDBs)

- little spectral fine structure visible in RPWS/WBR

High Frequency Receiver (HFR)



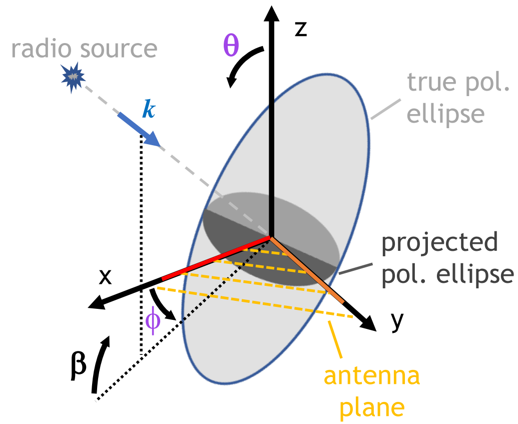
Wideband Receiver (WBR)

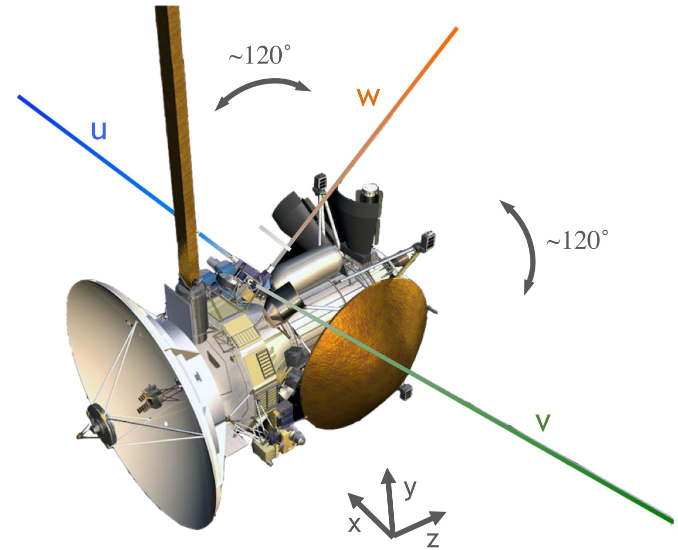


Cassini RPWS/HFR – Direction Finding

Unknown parameters:

- direction of wave incidence (wave vector $\boldsymbol{k}$)
  → 2 **direction angles** ... θ, ϕ
- 2D-**Stokes parameters** ... S, Q, U, V
  (size & shape of polariz. ellipse)





Cassini RPWS antennas:

- 3 electric monopoles ... u , v , w (10 m long)
- 1 (virtual) dipole .... D (= u - v)
- 2-antenna survey mode ... 3 signals $\langle V_D V_D^* \rangle$, $\langle V_w V_w^* \rangle$, $\langle V_D V_w^* \rangle$
- **3-antenna mode** ... 5 signals

$$J = \begin{pmatrix} \langle V_u V_u^* \rangle & \cdot & \langle V_u V_w^* \rangle \\ \cdot & \langle V_v V_v^* \rangle & \langle V_v V_w^* \rangle \\ \cdot & \cdot & \langle V_w V_w^* \rangle \end{pmatrix}$$

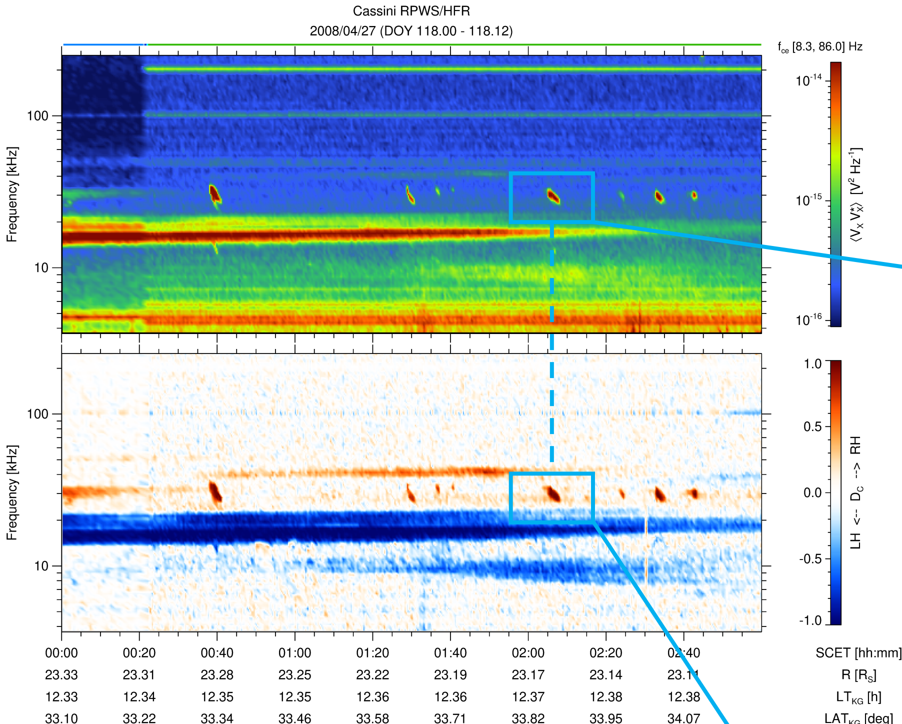
→ product $\langle V_u V_v^* \rangle$ is missing for a complete spectral matrix $\boldsymbol{J}$

→ no *Singular Value Decomposition* (SVD) analysis possible

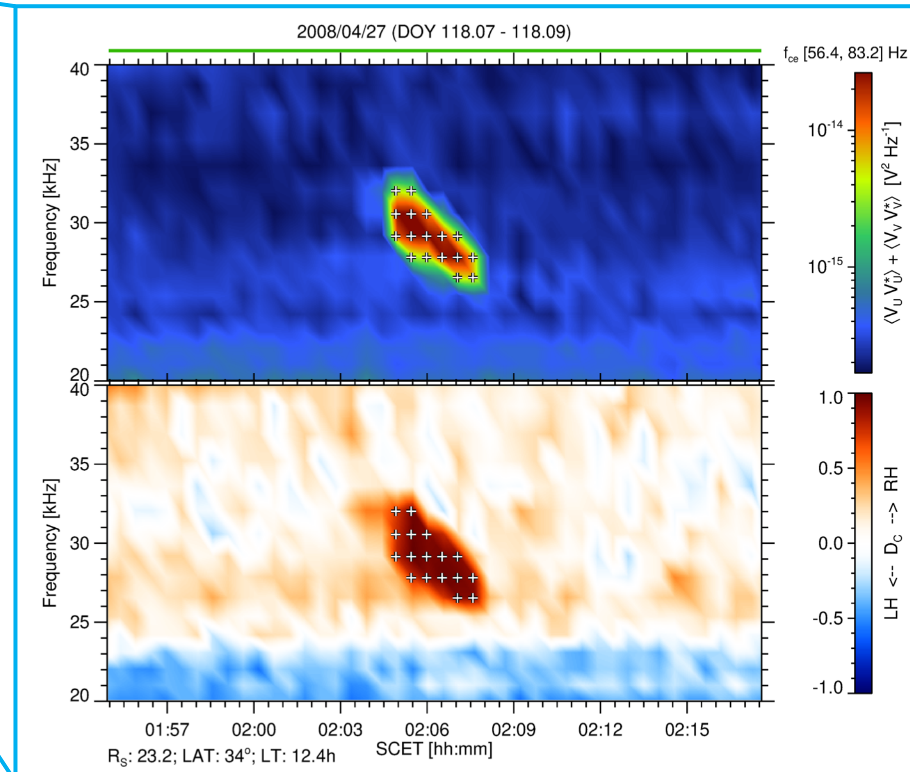
Direction Finding (Goniopolarimetry) [*Cecconi and Zarka, 2005*]

- assumptions:
  - plane wave
  - $\boldsymbol{E} \perp \boldsymbol{k}$
- **solution by analytical inversion**
- data selection:
  - high signal-to-noise ratio (SNR)
  - stable radio source during switching of antennas from $\langle V_u V_w^* \rangle$ to $\langle V_v V_w^* \rangle$ (45 – 2000 ms)
  - $\boldsymbol{k}$-vector far above antenna plane ($\beta \geq 20°$)

SDB Direction Finding - Example

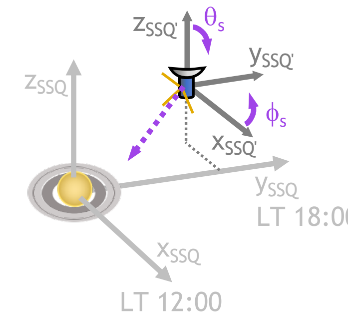


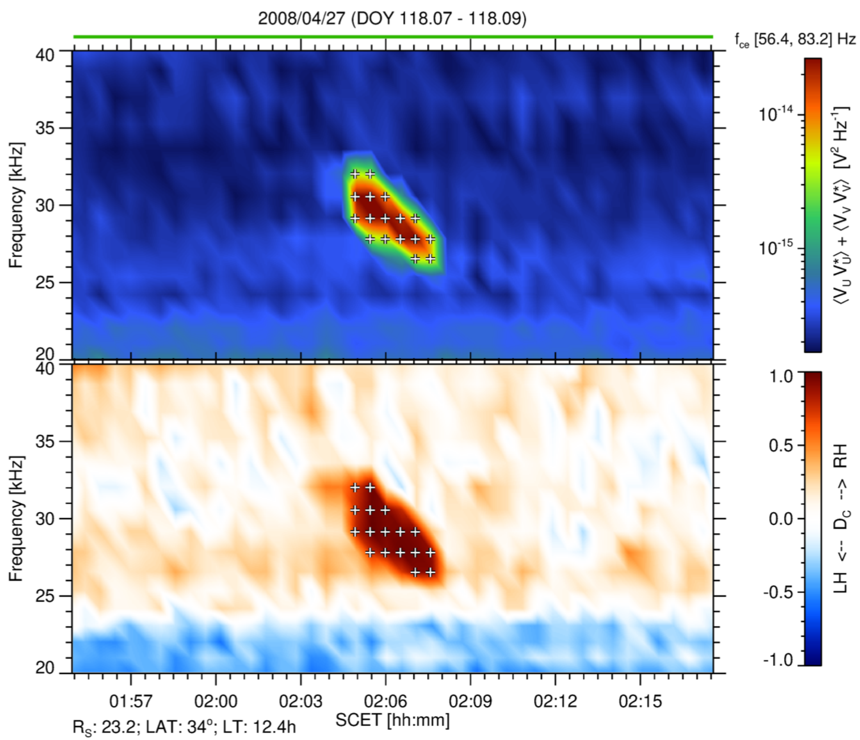
- Spectral scanning of single SDBs
- DF-analysis with selected spectral points

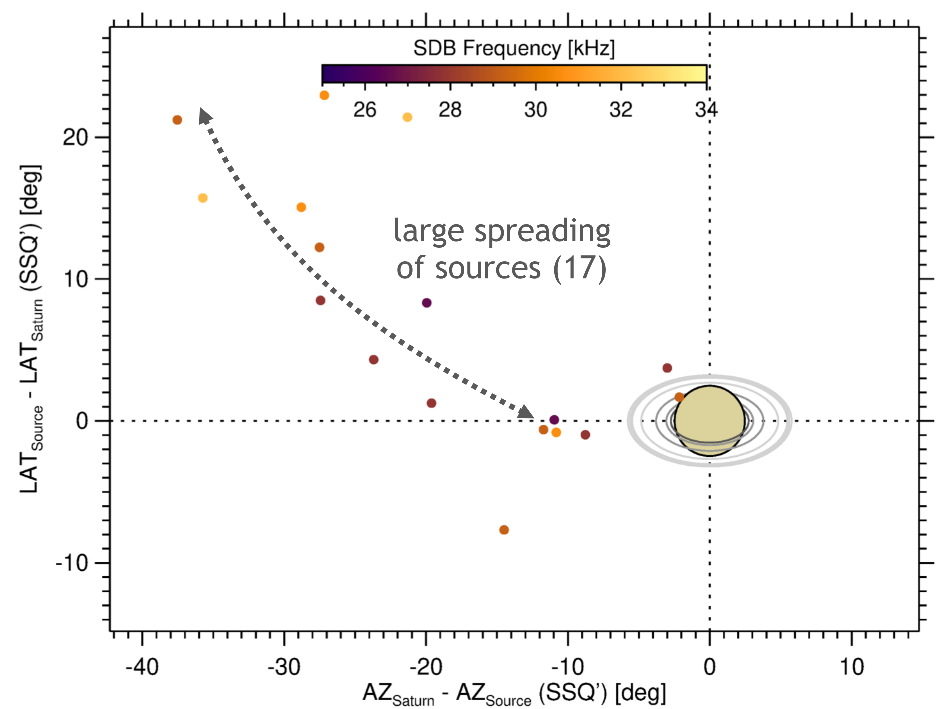


SDB Direction Finding - Example

- Spectral scanning of single SDBs
- DF-analysis with selected spectral points
- direction angles toward source → ϕ_s, θ_s

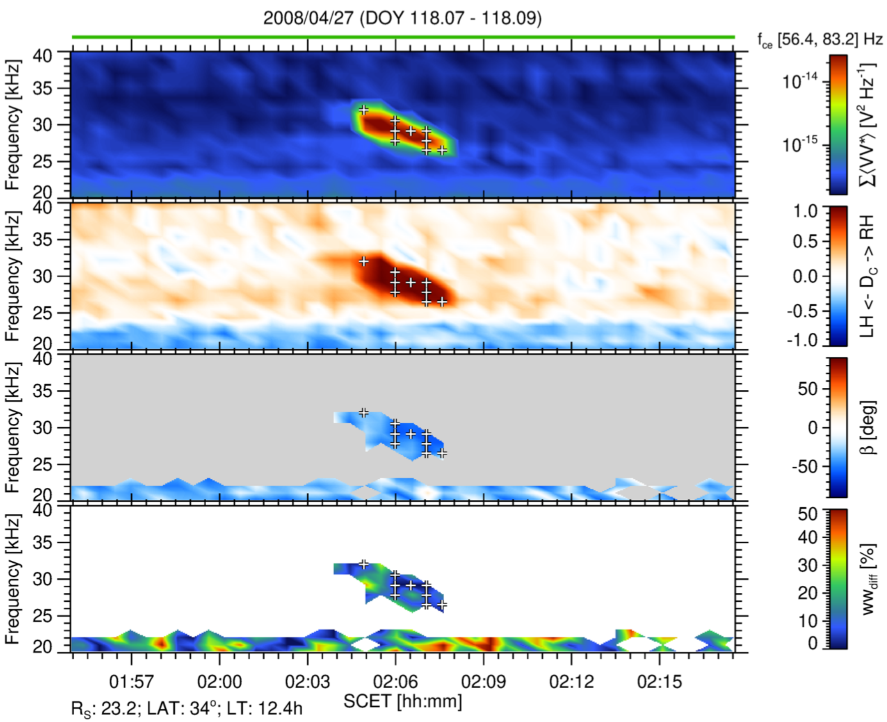


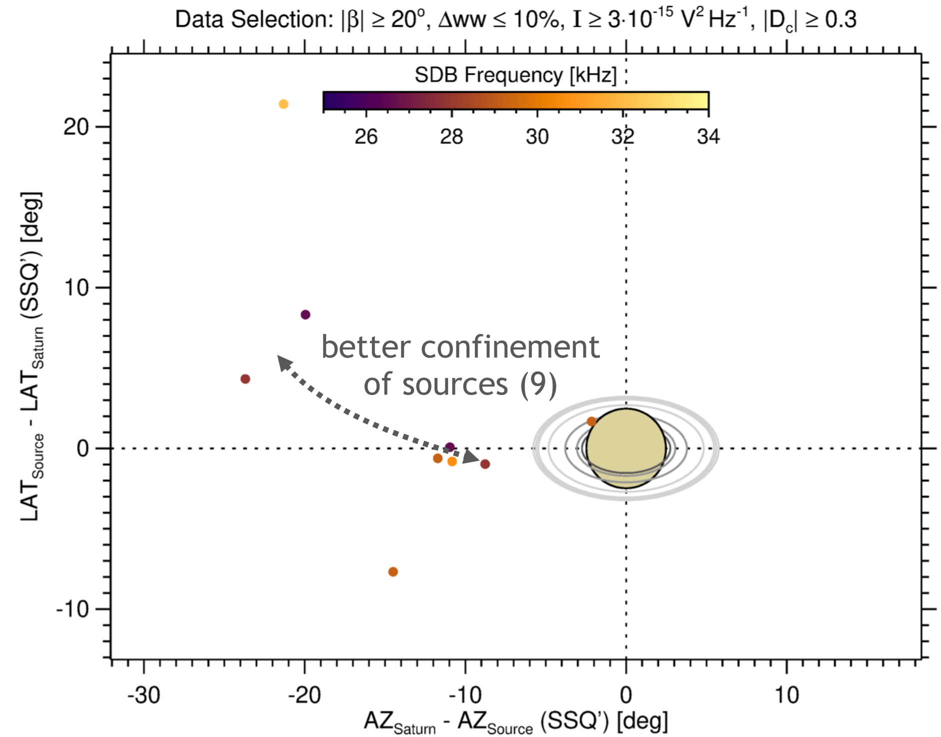




SDB Direction Finding - Example

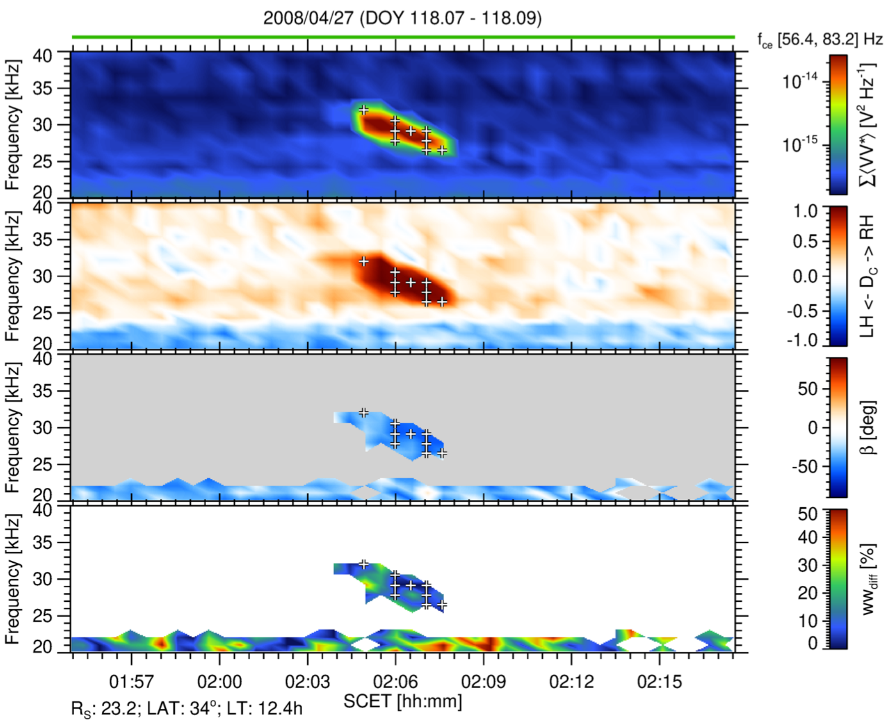
- Spectral scanning of single SDBs
- DF-analysis with selected spectral points
- direction angles toward source $\rightarrow \phi_s, \theta_s$
- selection of sources by data quality (β, ww_{diff}, intensity)

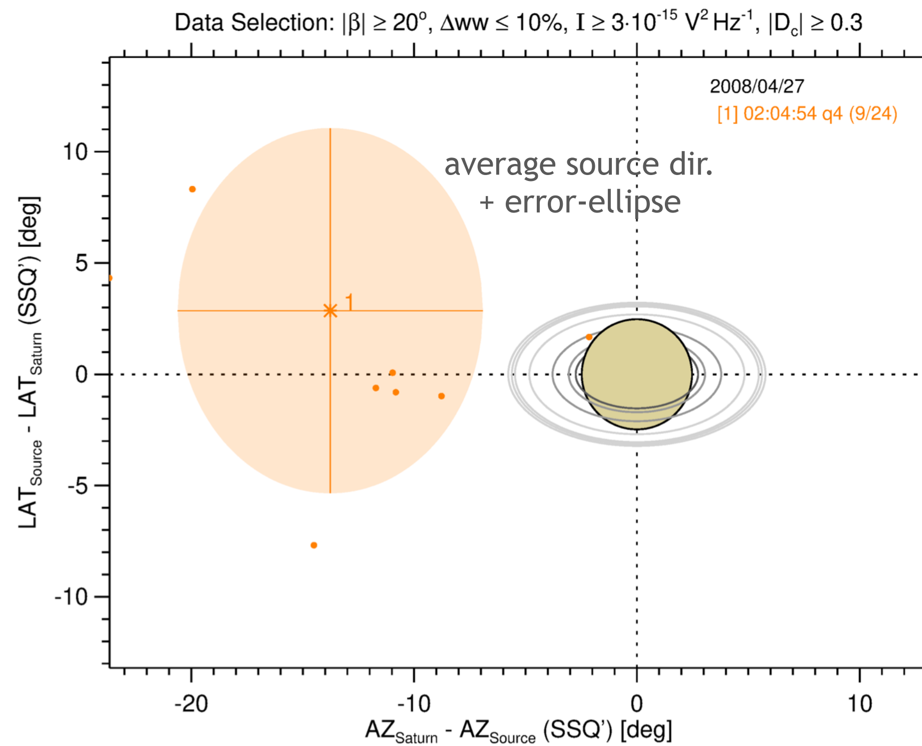




SDB Direction Finding - Example

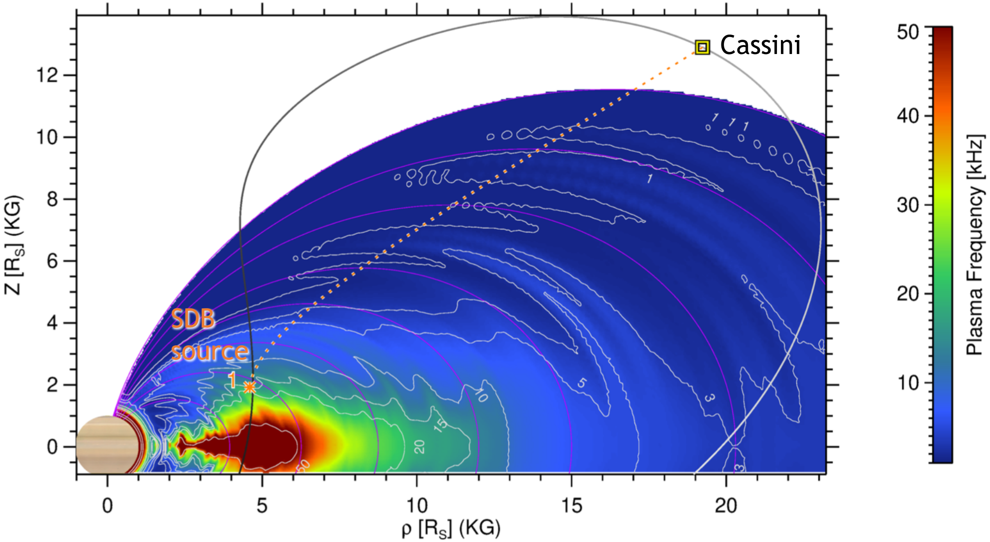
- Spectral scanning of single SDBs
- DF-analysis with selected spectral points
- direction angles toward source → ϕ_s, θ_s
- selection of sources by data quality (β, ww_{diff}, intensity)
- **average source direction and standard deviation (error-ellipse)**



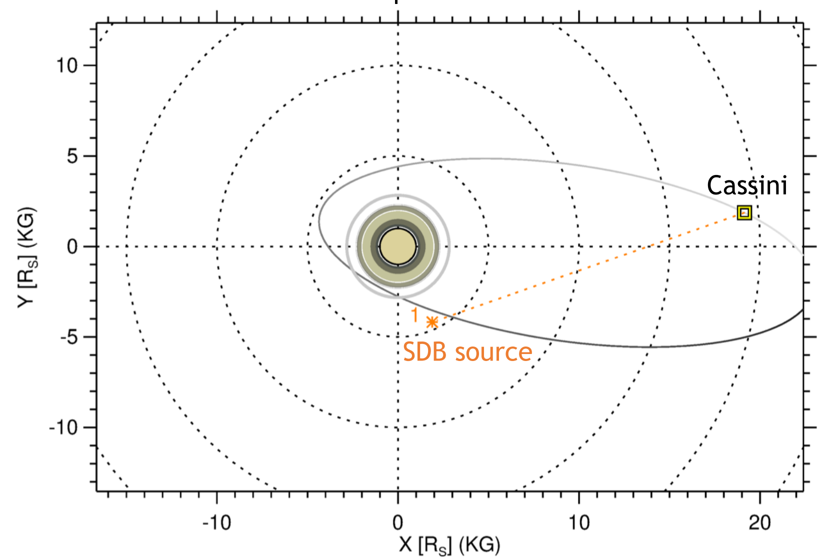


SDB Direction Finding - Example

- Spectral scanning of single SDBs
- DF-analysis with selected spectral points
- direction angles toward source → ϕ_s, θ_s
- selection of sources by data quality (β, ww_{diff}, intensity)
- average source direction and standard deviation (error-ellipse)
- follow straight ray until $f \approx f_{pe}$ (O-mode fund.) or $f \approx 2 f_{pe}$ (X-mode harm.)
  - yields average source location for SDB
  - source = region of mode conversion Z → O/X

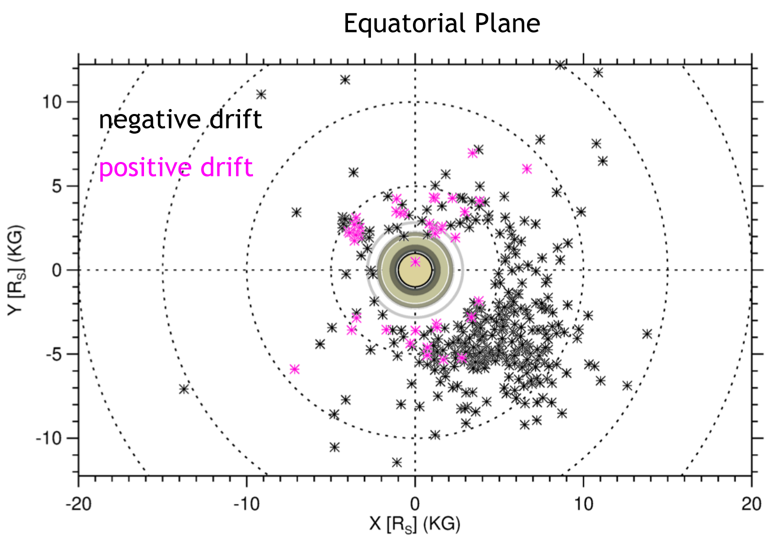


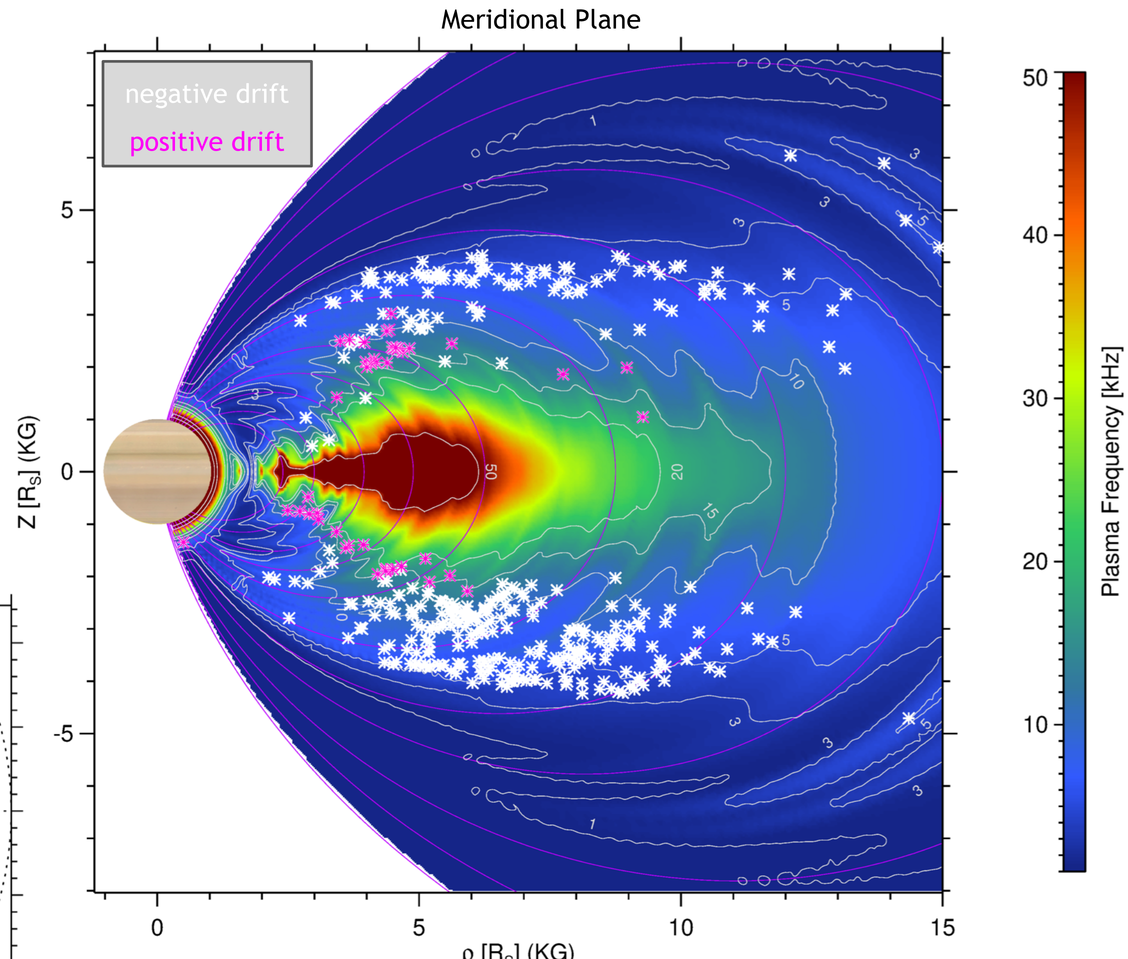
f_{pe} from density model [*Taubenschuss et al.*, *JGR*, submitted]



SDB Direction Finding - Summary

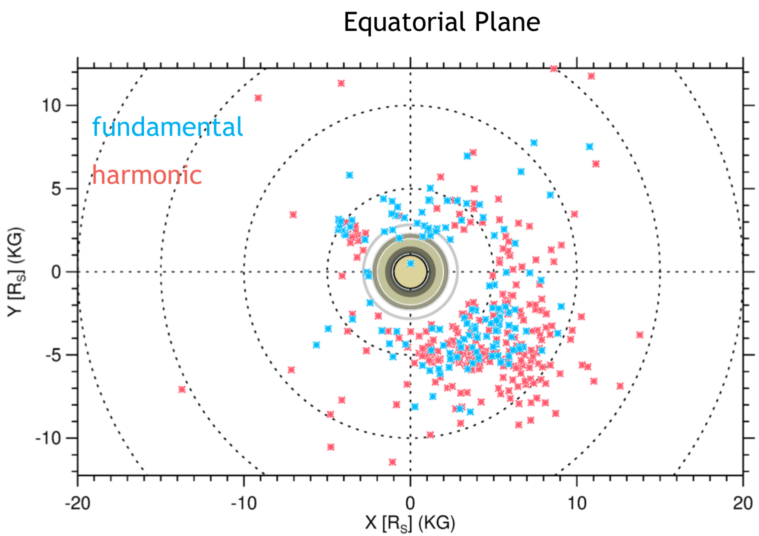
- 386 analyzed SDBs from year 2008
  (in 3-antenna mode, "good" quality for DF)
- source regions along northern/southern edge of Enceladus plasma torus
- 343 with negative drift / 43 with positive drift
- positive drifting SDBs are at higher frequencies
  → sources are located deeper inside the torus

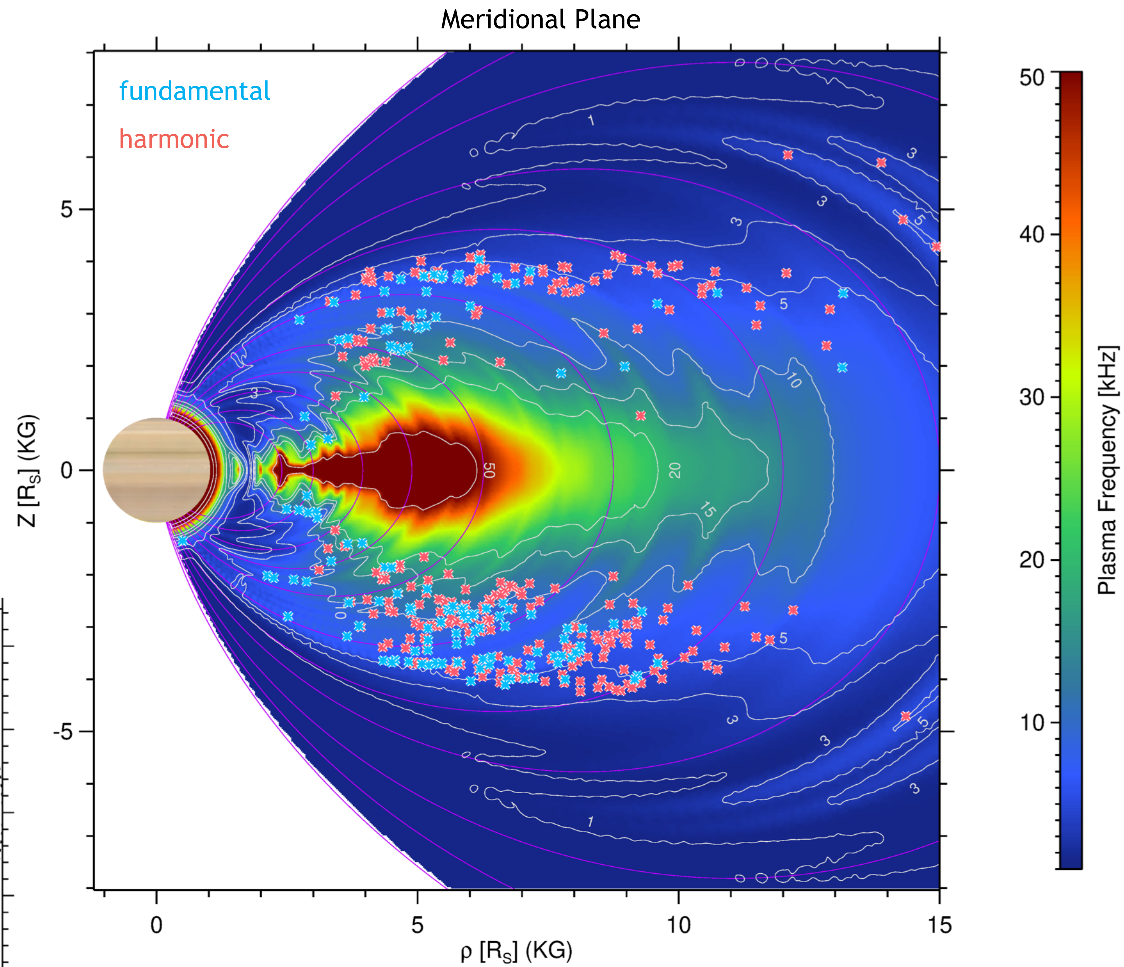




SDB Direction Finding - Summary

- 386 analyzed SDBs from year 2008
- 136 fundamental / 250 harmonic SDBs
- harmonic emission can escape more easily from source region?
- harmonic emission is produced along the entire edge of the plasma torus



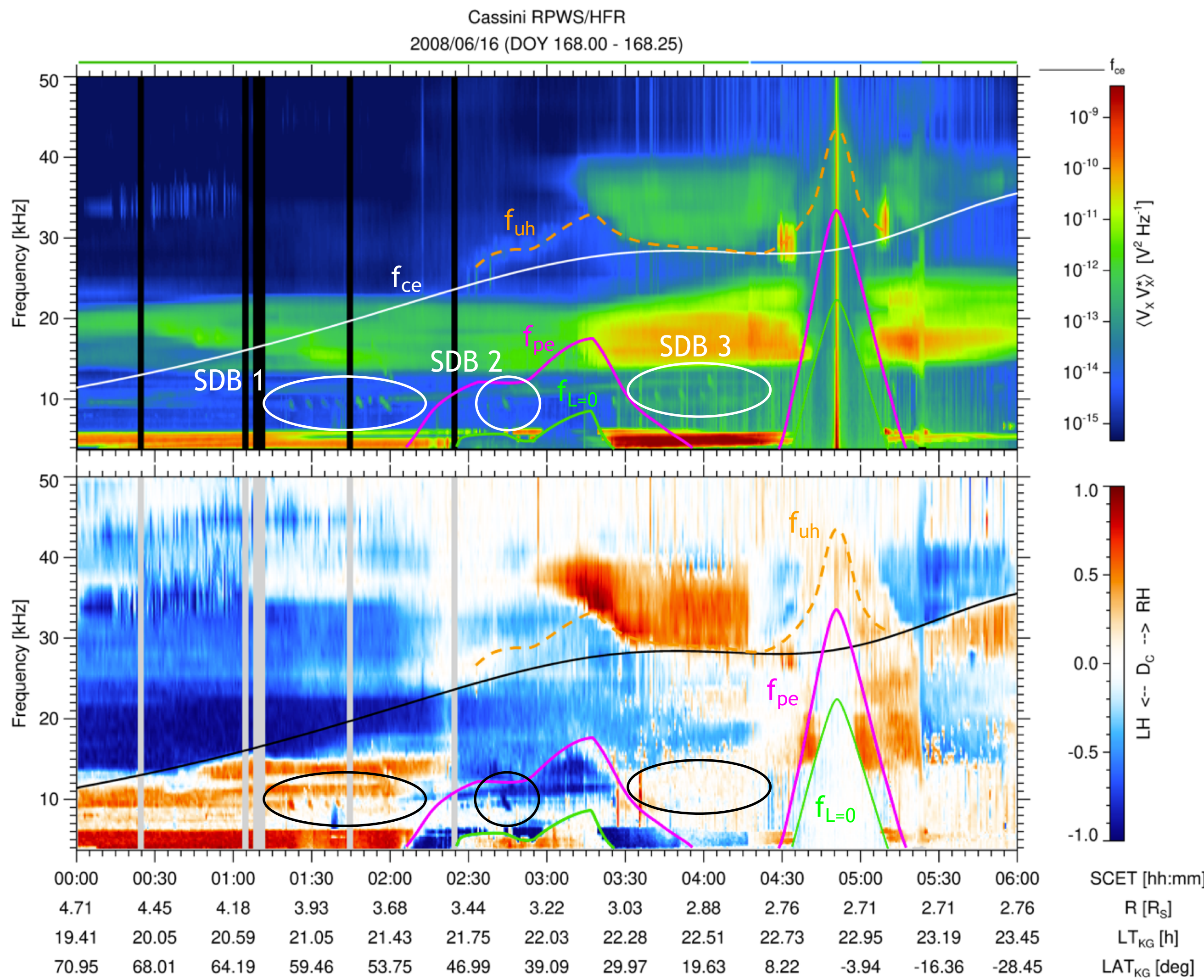


SDB Source Crossing Event

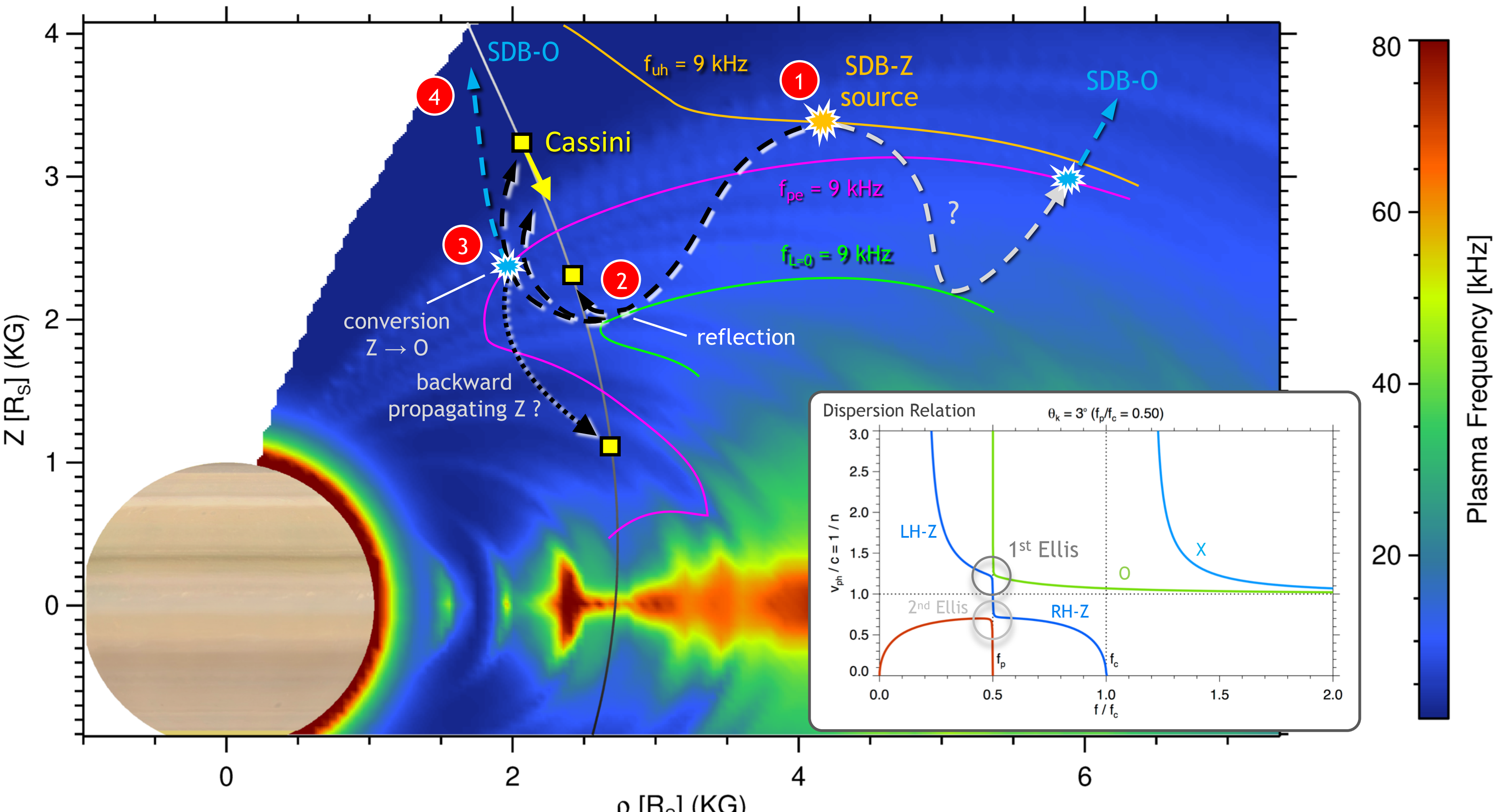
- SDB #1 ... RH Z-mode at
  $f_{pe} < f < f_{uh}$
- SDB #2 ... LH Z-mode at
  $f_{L=0} < f < f_{pe}$
- SDB #3 ... RH Z-mode or LH O-mode at
  $f_{pe} < f < f_{uh}$

→ observational evidence for SDBs propagating in the Z-mode

→ for escaping the plasma torus, they must first mode-convert into O or X mode



SDB Source Crossing Event – The linear mode conversion Scenario



Conclusions

- Direction Finding with Cassini RPWS/HFR confirms that Saturn Drifting Bursts (SDBs) are generated by linear (O-mode fundamental) and nonlinear (X-mode harmonic) mode conversion mechanisms

- SDB source regions are found along the northern and southern edges of the Enceladus plasma torus, between $3 < L\text{-}shell < 15$

- The emissions are usually beamed at an oblique angle to the local magnetic field, out of the meridional plane

- 3D ray tracing is needed for reconstructing the exact ray path and for a refinement of source locations

- Which mechanism is responsible for initiating the drifting Z-mode SDB in the first place?