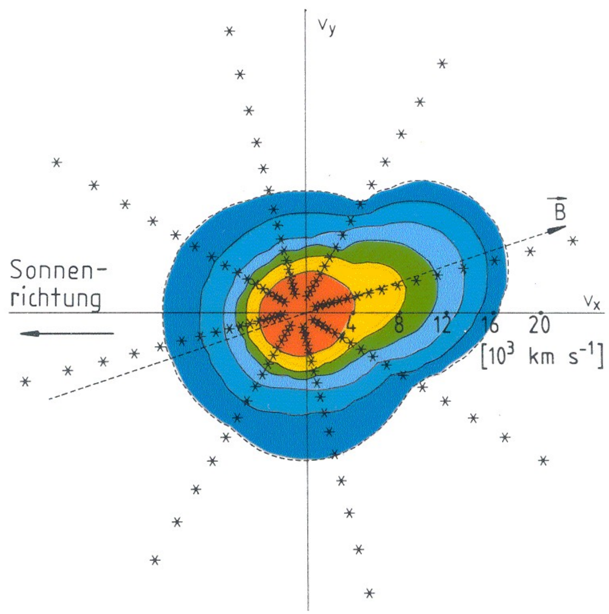
511TH WE-HERAEUS-SEMINAR

From the Heliosphere into the Sun

– Sailing against the Wind –

Collection of presentations

Edited by Hardi Peter (peter@mps.mpg.de)



Physikzentrum Bad Honnef, Germany
January 31 – February 3, 2012
http://www.mps.mpg.de/meetings/heliocorona/

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CORONAL RADIO SOUNDING EXPERIMENTS WITH THE ESA SPACECRAFT MEX, VEX, AND ROSETTA

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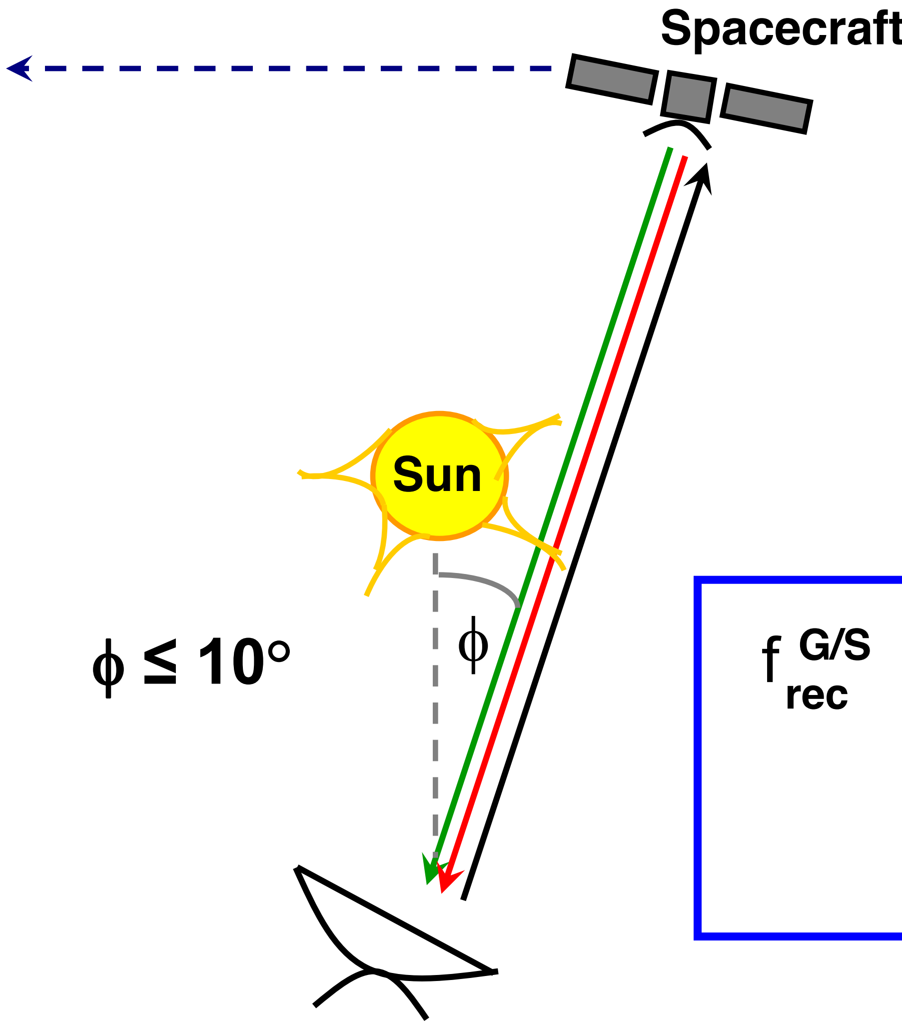
Solar Conjunction Measurements



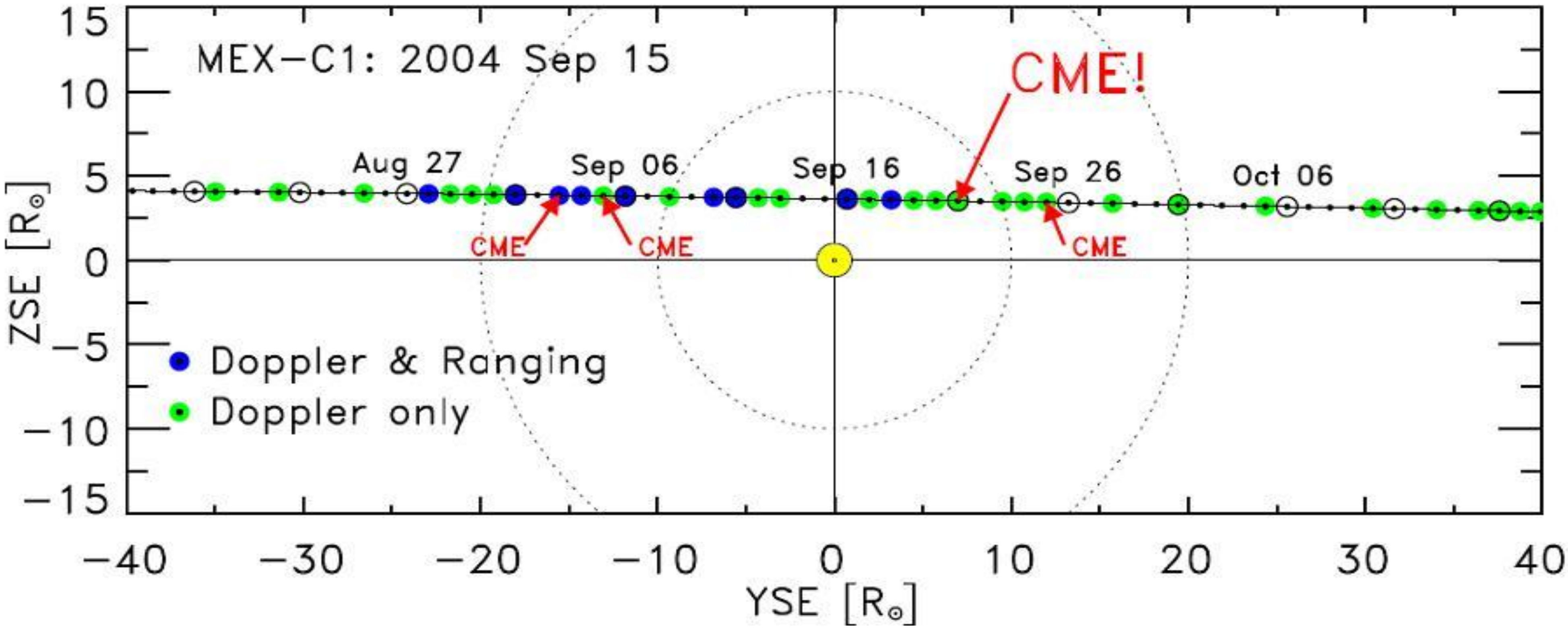
Uplink: (x-band) $f_{ul} = 7.1$ GHz

Downlinks: (s/x-bands) $f_{dl\text{-}x} = 8.4$ GHz, $f_{dl\text{-}s} = 2.3$ GHz

$$\frac{f_x}{f_s} = \frac{11}{3}$$

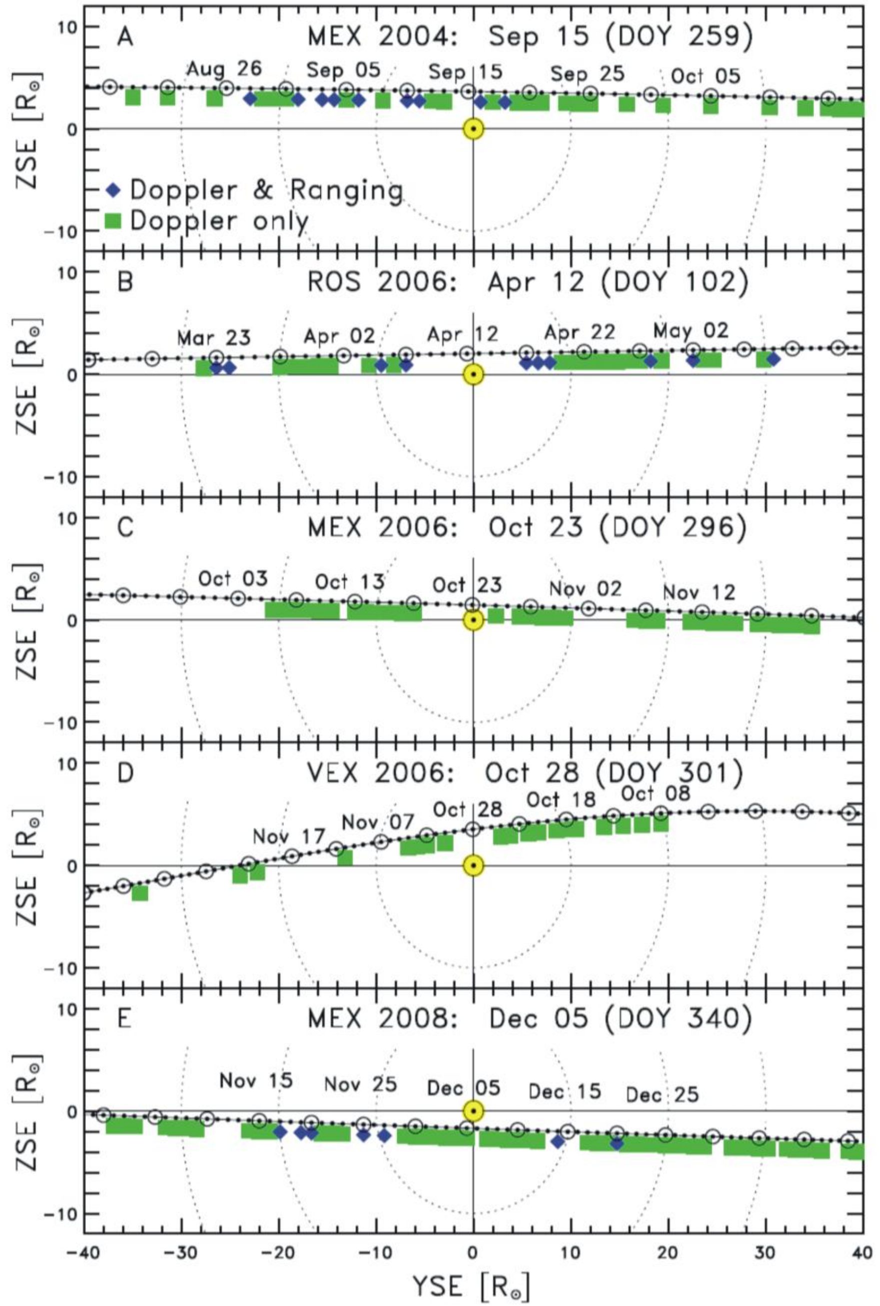
$$f_{rec}^{G/S} = k_{x,s} \cdot [f_{ul} + \Delta f_{ul\text{-}plasma}] + \Delta f_{dl\text{-}plasma}$$

MEX 2004 Conjunction Geometry



View from Earth: Solar Ecliptic Coordinates

Solar Conjunction Geometries: ESA Spacecraft 2004-2008



Electron Column Density (Electron Content)

Ranging measurements:

$$\tau = \frac{s}{c} + \frac{40.31}{c} \cdot \frac{1}{f^2} \int_{S/C}^{Earth} N_e ds$$

τ = range delay (round-trip light time)

$$\int_{S/C}^{Earth} N_e ds = I$$ **= electron content (up + down-link)**

Differential ranging (uplink contribution drops out):

$$\Delta\tau = \tau_S - \tau_X = \frac{40.31}{c}\left\{\frac{1}{f_S^2} - \frac{1}{f_X^2}\right\} \cdot I_{down}$$

Observable

Temporal Change in Electron Content

$$\Delta f_{Plasma} = \frac{40.31}{c} \cdot \frac{1}{f} \cdot \frac{dI}{dt}$$

$\frac{dI}{dt}$ = Change in electron content along uplink or downlink

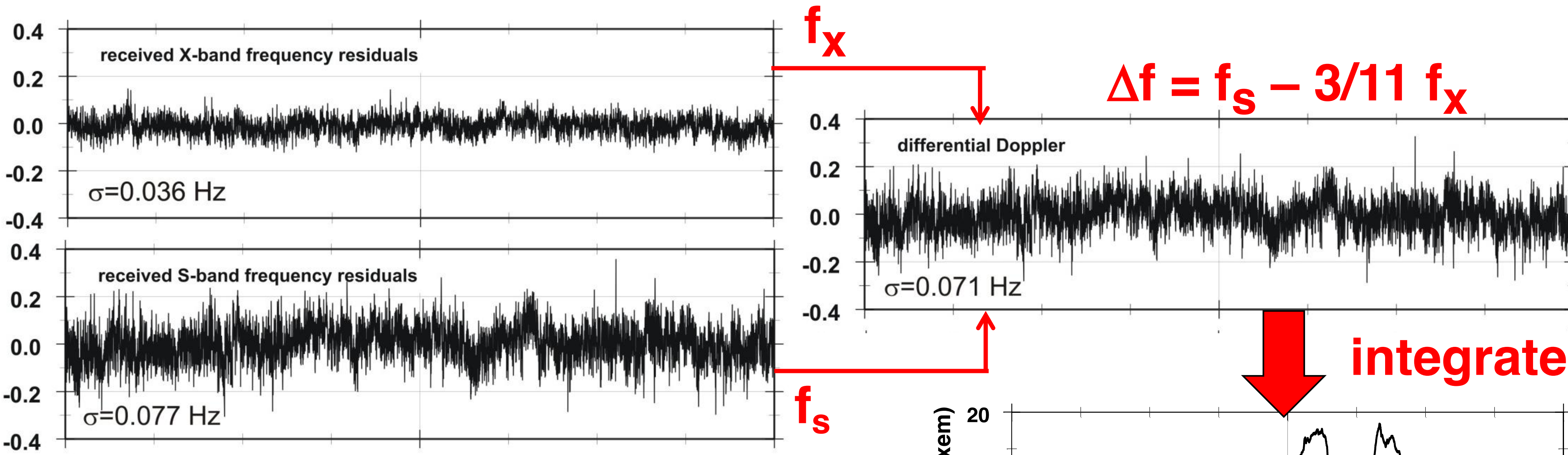
Differential Doppler (uplink contribution drops out):

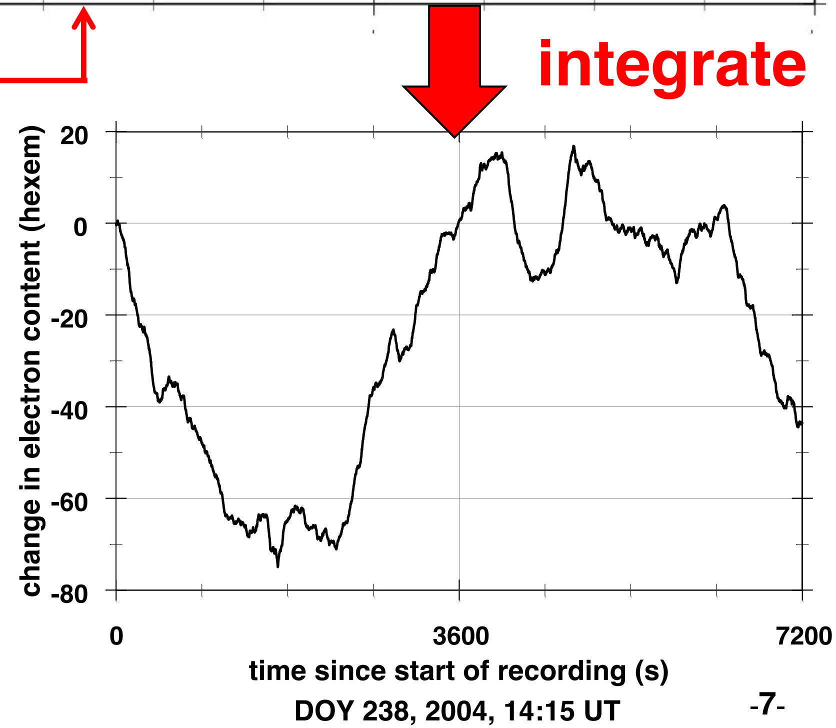
$$\Delta f = f_{rec,S} - \frac{3}{11} f_{rec,X} = -\frac{40.31}{c} \left\{ \frac{1}{f_S^2} - \frac{1}{f_X^2} \right\} f_S \frac{dI_{down}}{dt}$$

Observable

Data Processing: Typical Example

MEX 2004 Aug 25 (DOY 238); R = 26.5 Rs

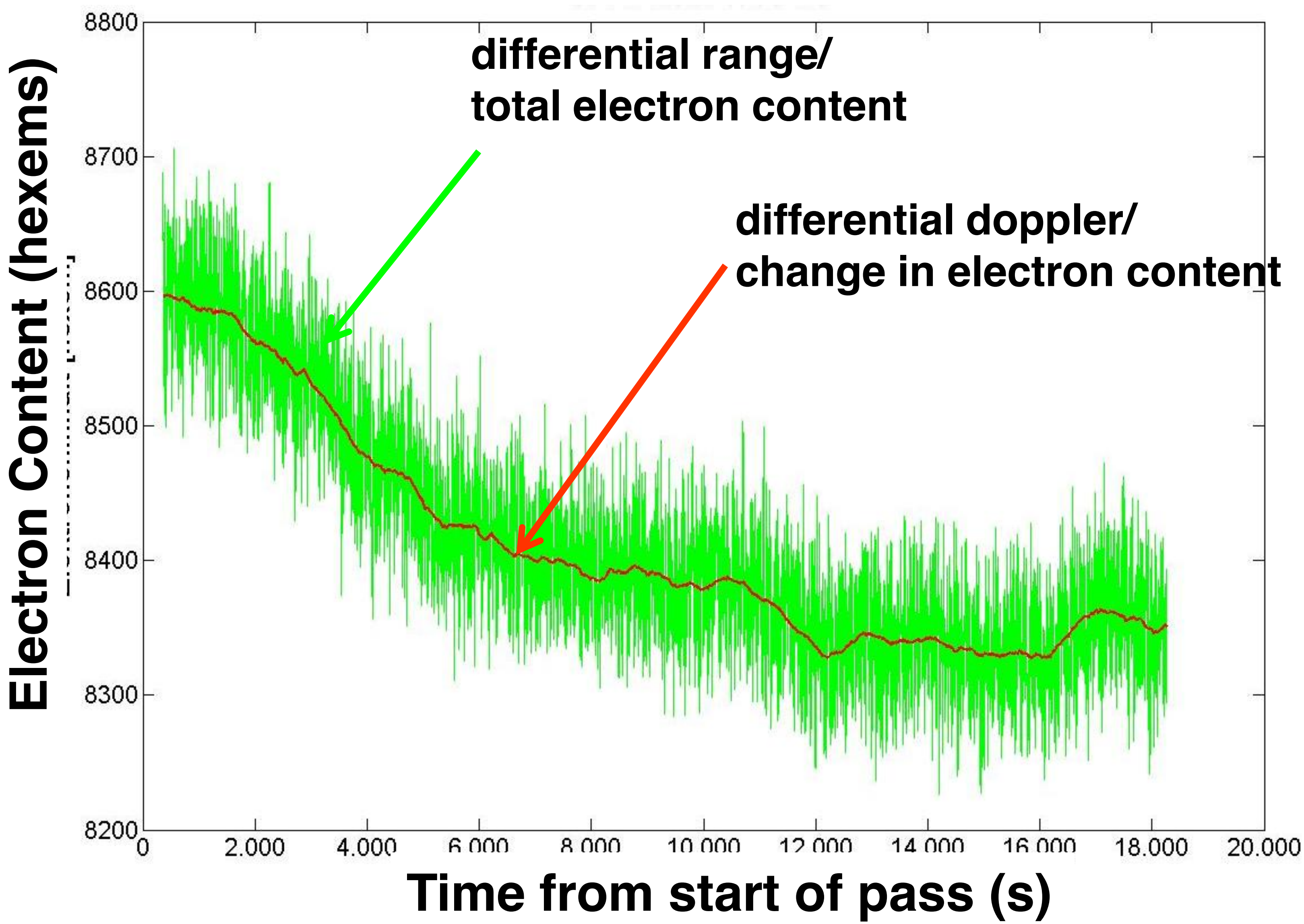




Frequency Residuals:
- X-band and S-band (above)
- Differential Frequency (upper right)
- Change in Electron Content (right)

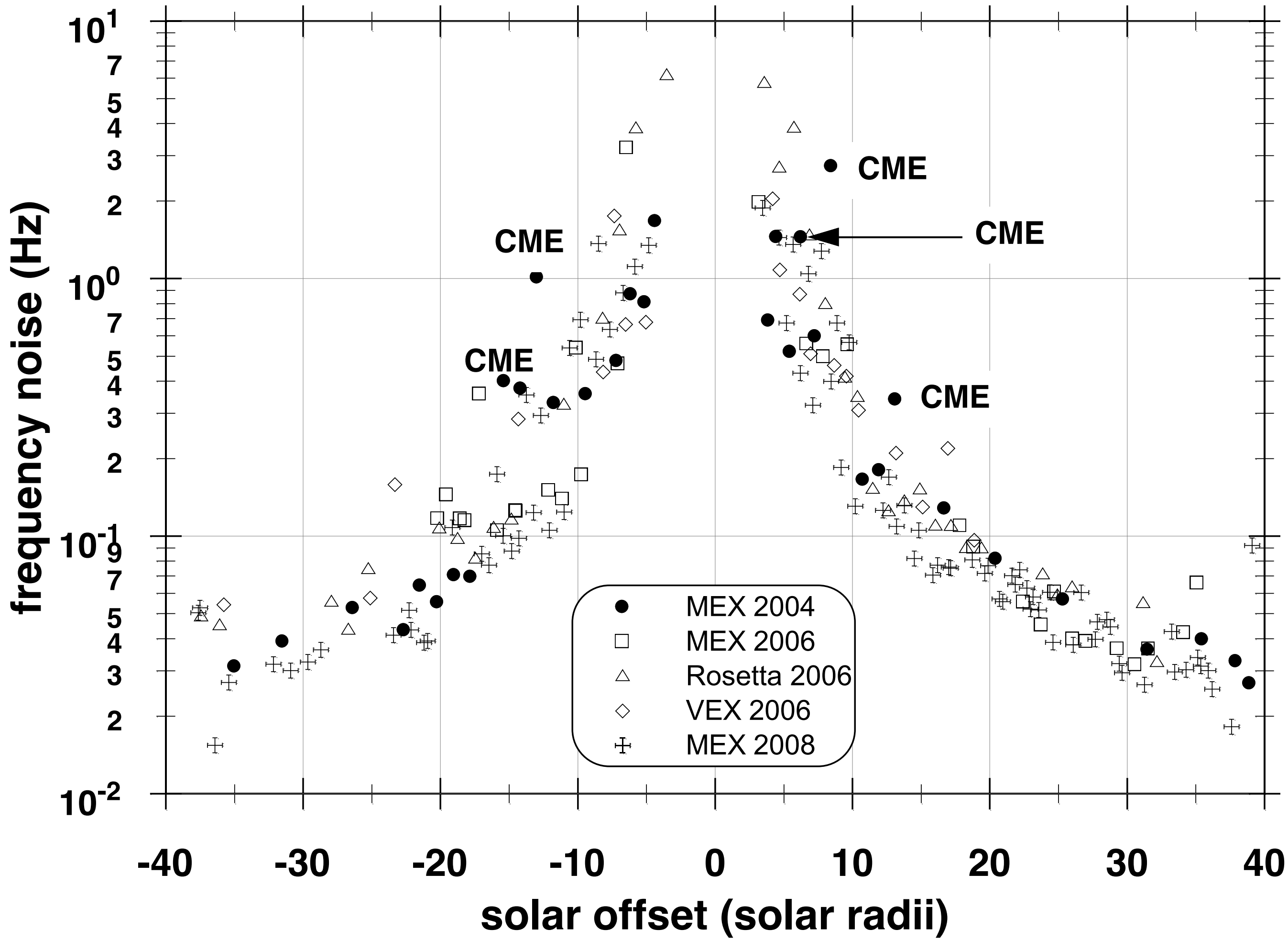
Comparison: Ranging vs Doppler

Example: ROS, 22 Mar 2006 (R = 28 R_S)



Dual-Frequency Doppler Noise vs Solar Offset

Mean values <Δf> over each tracking pass

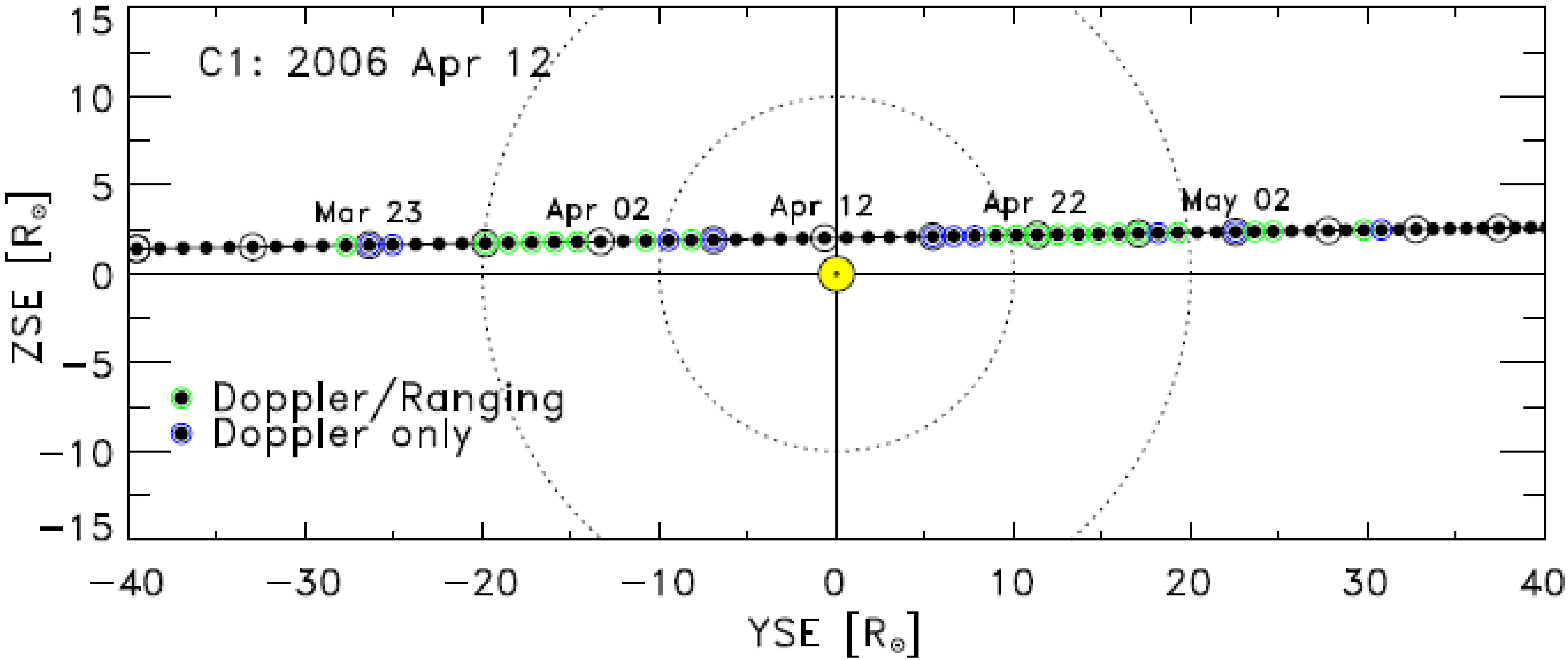


$\Delta f \propto R^{-\beta}$

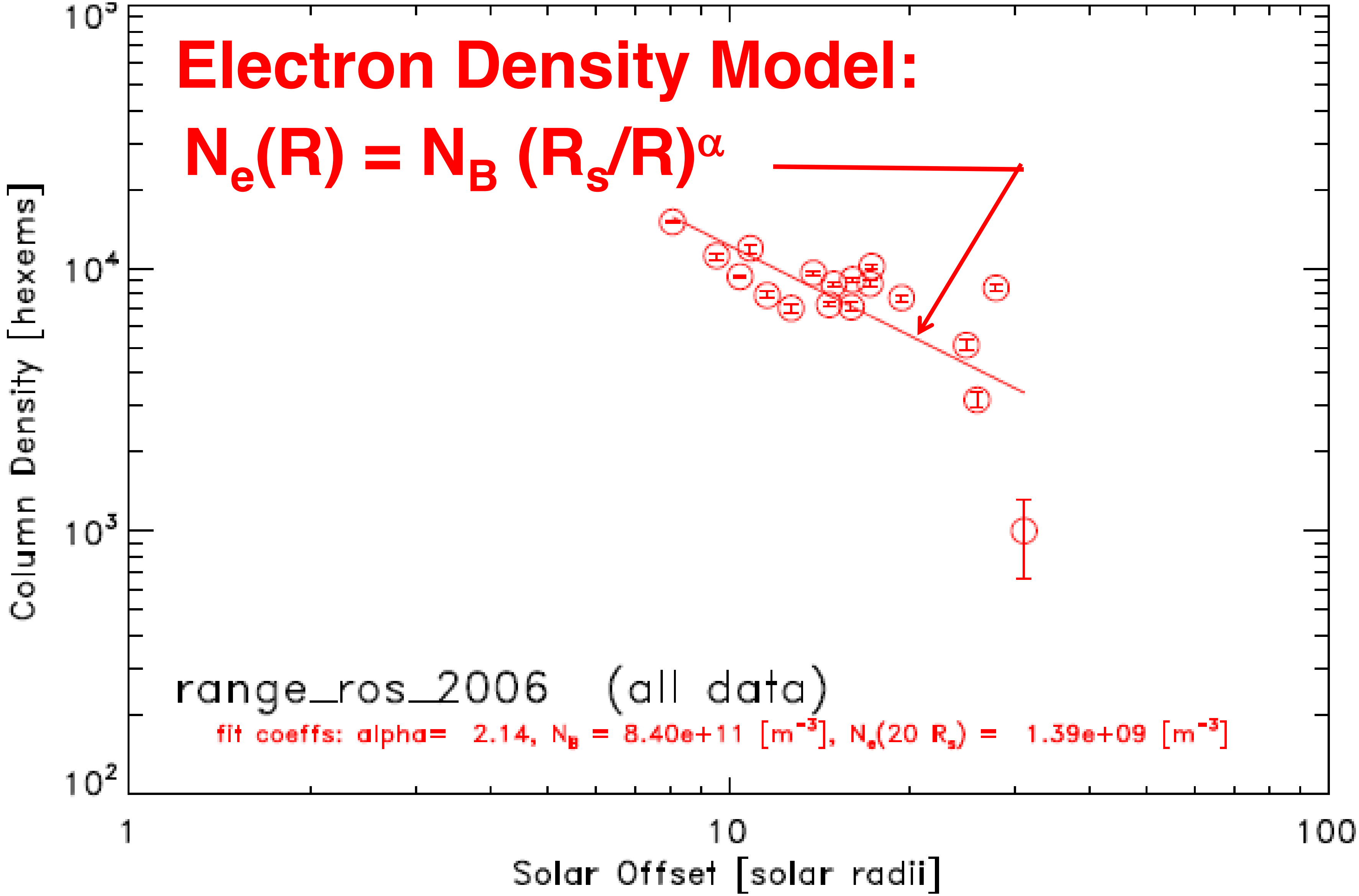
$1.2 < \beta < 2.5$

Dual-Frequency Ranging:
Electron Density in the Corona (R < 40 Rs)

Example: Tracking Data for Rosetta 2006

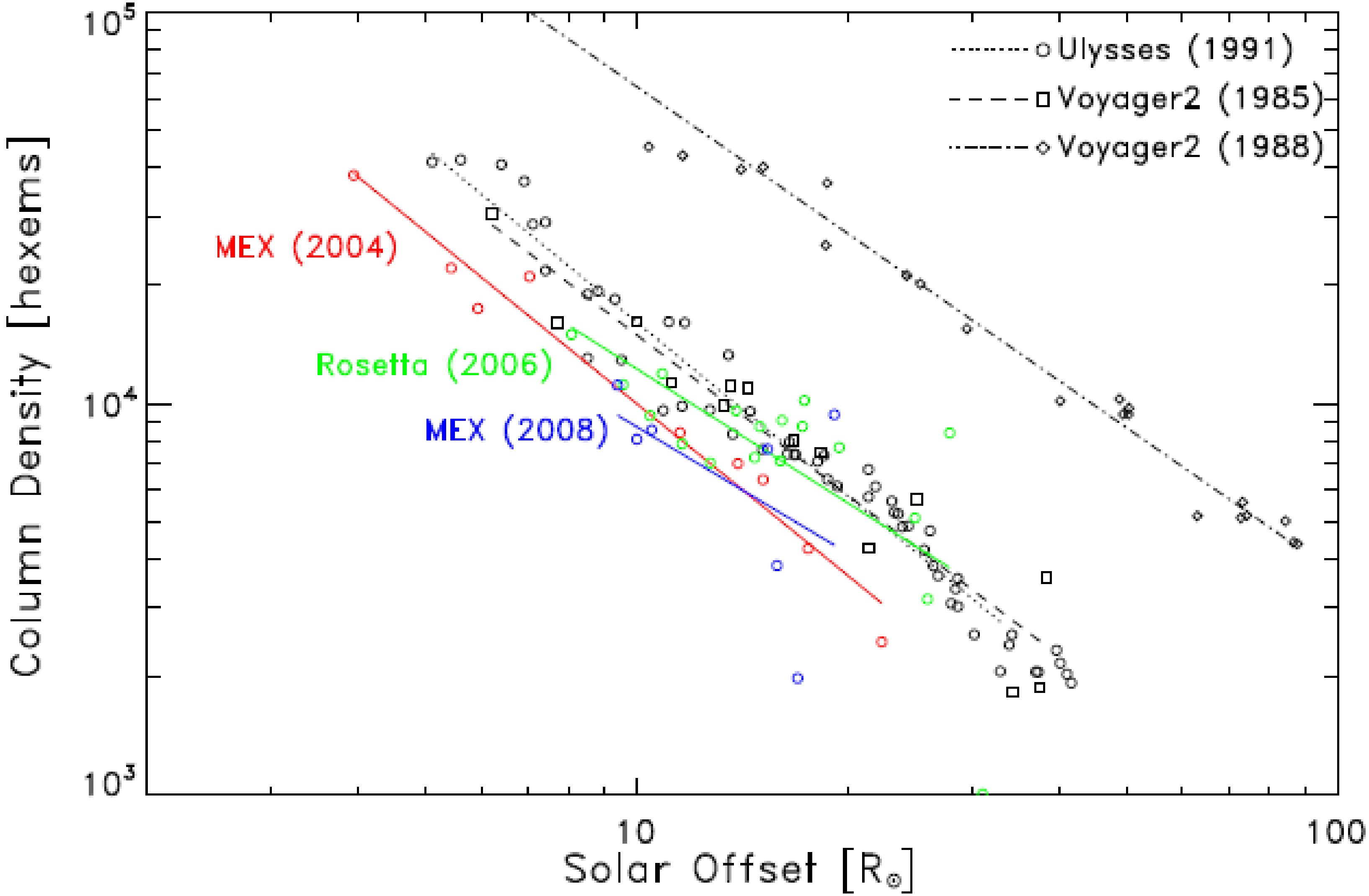


Dual-Frequency Ranging: Rosetta 2006

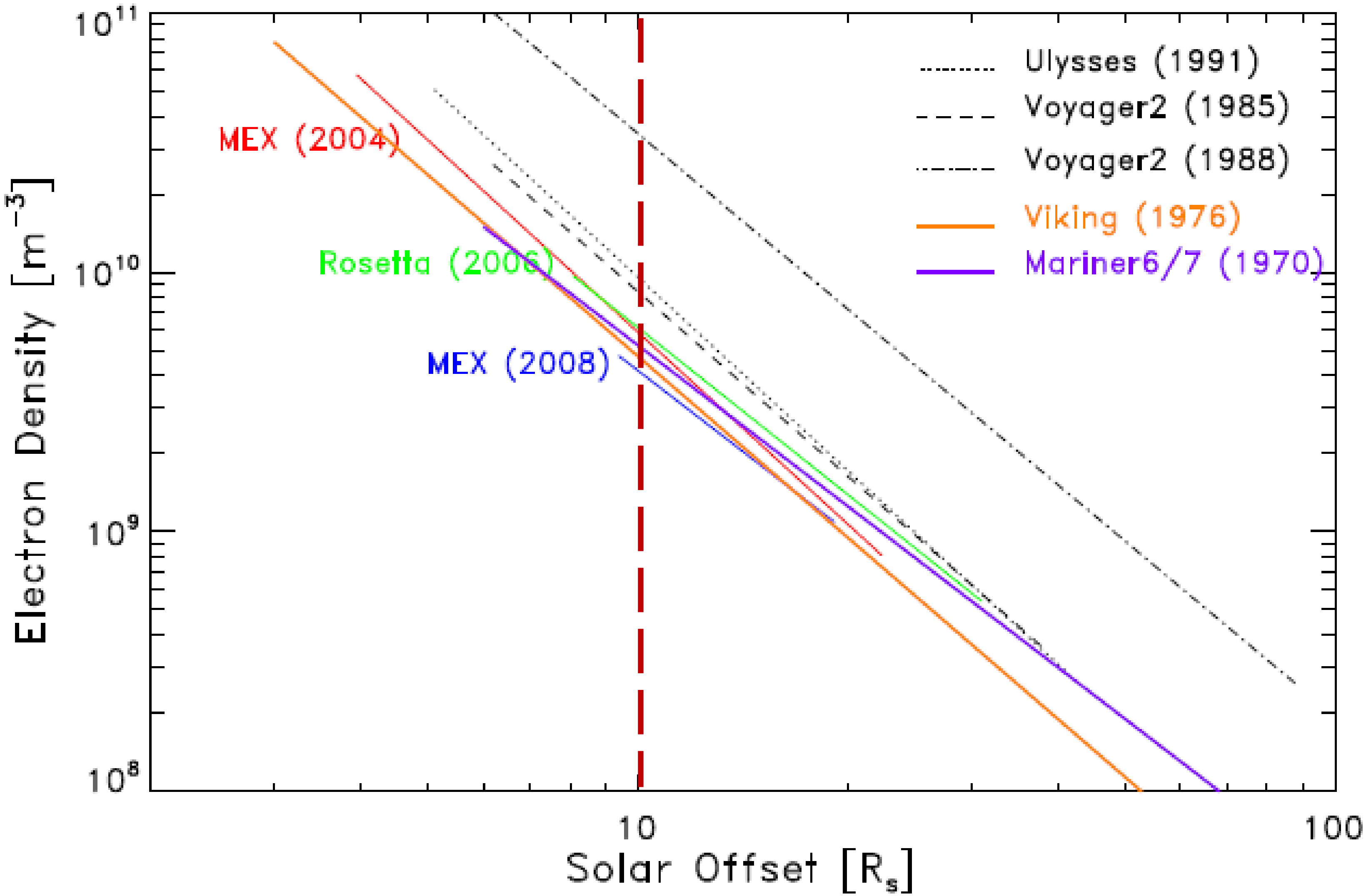


Electron Column Density [m^{-2}]

All Dual-Frequency Ranging Data



Coronal Electron Density [m^{-3}]



Coronal Electron Density:
All Radio-sounding Data

Data set	Mission	year	points	α	N_B (10^{12} m^{-3})	N(10 Rs) (10^{10} m^{-3})	R_min (Rs)	R_max (Rs)
1	MAN 6/7	1970	n.a.	2.06	0.60	0.52	6.0	100.0
2	VIK 1/2	1976	n.a.	2.32	0.99	0.46	3.0	214
3	VOY 2	1985	14	2.36	1.92	0.84	6.2	38.4
4	VOY 2	1988	23	2.25	6.04	3.42	5.1	87.6
5	ULS	1991	56	2.47	2.85	0.96	5.1	41.7
6	MEX	2004	9	2.46	1.68	0.59	3.9	22.4
7	ROS	2006	18	2.14	0.84	0.61	8.1	31.1
8	MEX	2008	7	2.07	0.49	0.42	9.4	19.1

Summary (1)

Dual-Frequency Ranging Experiments:

- **Radial Profiles of the coronal large-scale structure in the acceleration region of the solar wind out to 40 R_s**
- **Radial density falloff exponent α > 2.0 for all data sets**
- **α tends to be proportional to solar activity**
  - **Minimum in 2008 with MEX (α = 2.07)**
  - **Maximum in 1991 with Ulysses (α = 2.47)**
- **Anomalously high electron density N(R) in 1988 (VOY 2)**

Summary (2)

Coronal Radio-Sounding Experiments With MEX, VEX and ROS Provide:

- Radial profiles of radio frequency fluctuations and their spectra in the solar wind acceleration region ($R < 40$ Rs)
- A diagnostic tool for investigation of CMEs
- Proof of evolution of solar wind spatial turbulence regime with solar distance
- Consistency with previous Ulysses and Galileo results

References:

1. Pätzold et al., *Solar Phys.,* in press, 2012.
2. Efimov et al., in *Solar Wind 12*, AIP-CP1216, 94, 2010.
3. Hahn et al., paper presented at this meeting, 2012.