AN ISM GUY LOOKS AT THE SUN (AND OH/IR STARS)

Carl Heiles (UCB)

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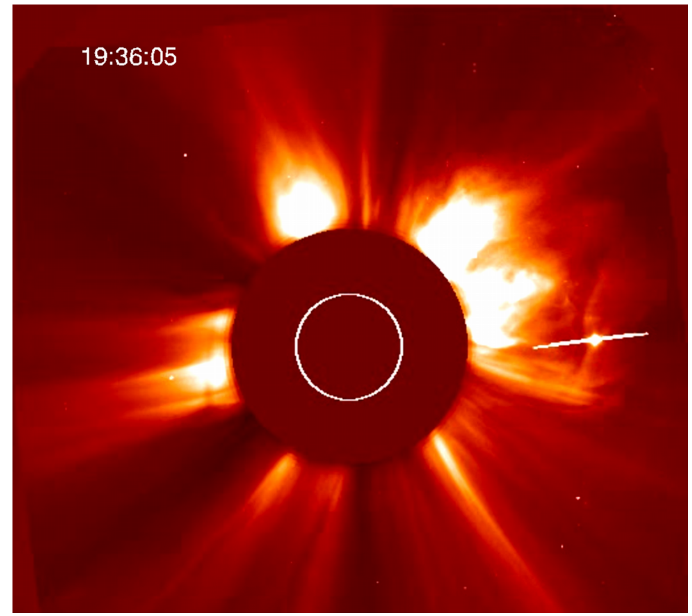
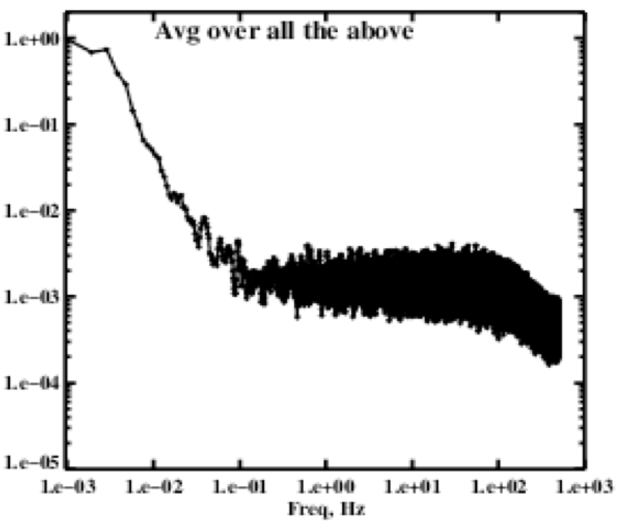
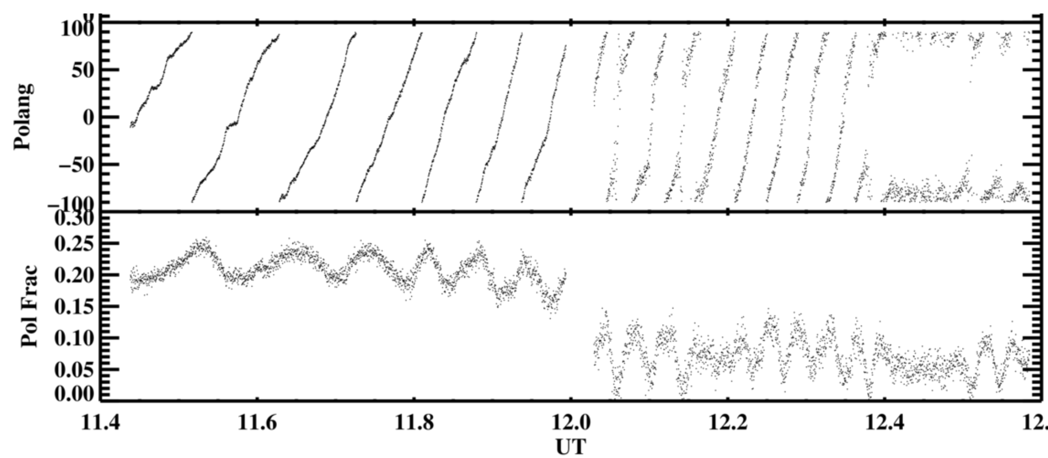
Others…







The MESSENGER satellite orbited Mercury (before it crashed). We used the GBT on its 8.4 GHz carrier as it went behind the Sun, getting data on 05 and 10-12 May 2013.

MESSENGER Web Site http://messenger.jhuapl.edu/

MESSENGER
MErcury Surface, Space ENvironment, GEochemistry, and Ranging

A NASA Discovery mission to conduct the first orbital study of the innermost planet

NASA CARNEGIE SCIENCE JOHNS HOPKINS APPLIED PHYSICS LABORATORY

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Mission Elapsed Time
August 3, 2004

DAYS	HRS	MINS	SECS
3552	12	14	24

Mercury Orbit Insertion
March 18, 2011
00:45 UTC

DAYS	HRS	MINS	SECS
1134	17	45	05

Time since Insertion Burn

Orbits Around Mercury

Orbits completed: 3014

Time until start of next orbit (hh:mm:ss): 03:59:35
Orbit start is at maximum altitude.

After 4,104 orbits of Mercury and billions of miles of space travel, NASA's Messenger orbiter ended its mission with a quiet bang on Thursday. Messenger crashed into the planet it has been orbiting for four years.

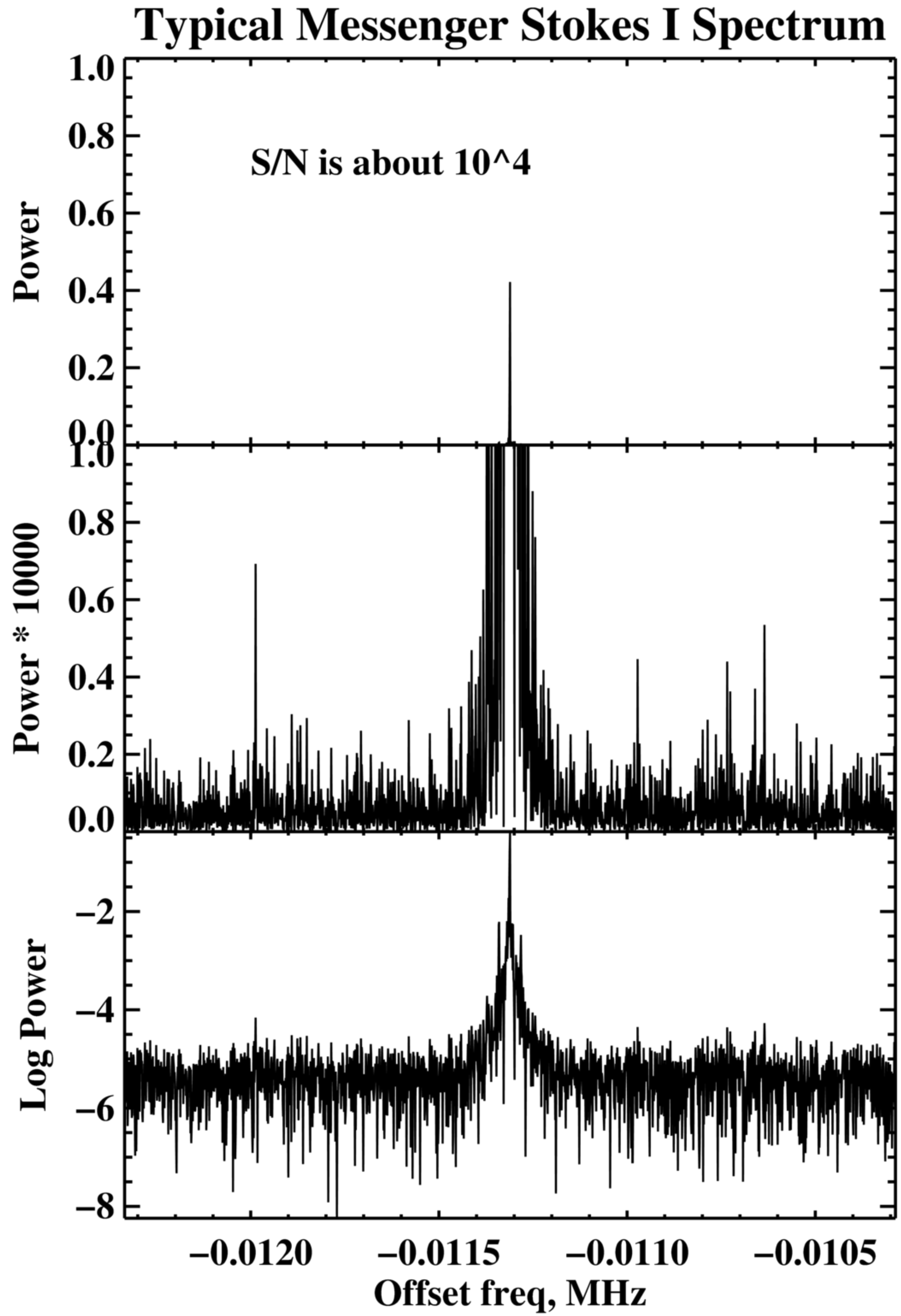
NASA says the orbiter began the process of lithobraking at 3:26 p.m. ET — meaning that Messenger essentially scraped to a stop after hitting the planet's surface traveling at thousands of miles an hour. The Oxford English Dictionary reminds us that *litho* is the combining form for the Greek word for "stone."

Messenger was launched from Earth in 2004. It took years just to get to Mercury and years more to reach orbit around Mercury in 2011. Now, after studying Mercury's craters, it will make a new one — NASA says its impact crater should be about 52 feet wide.

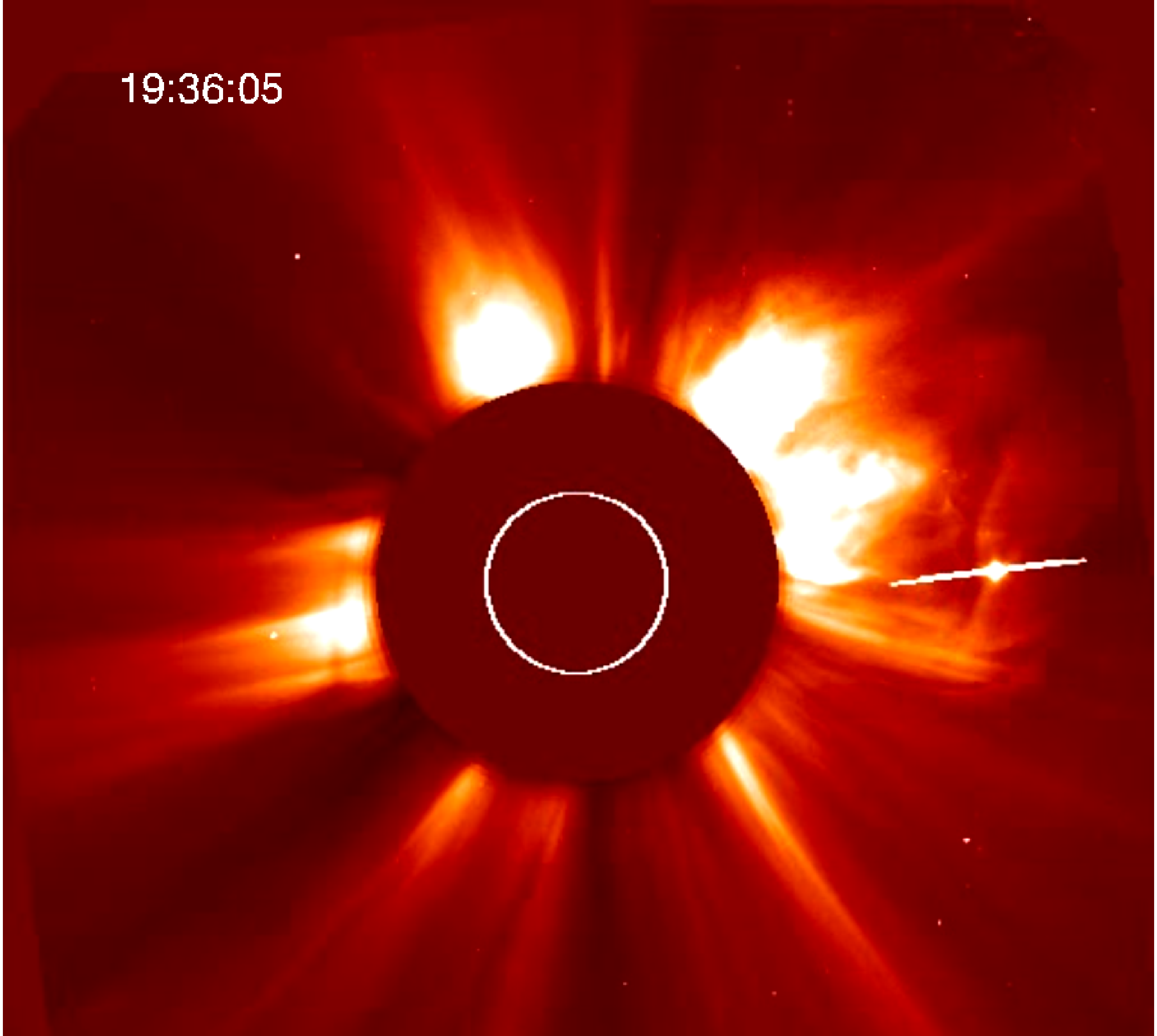
We voltage sample at 5 MHz and process the signal later. Mostly, 1-second chunks, providing a 5 million point spectrum every second for all four Stokes parameters.

S/N for Stokes I is huge—about 10^4!

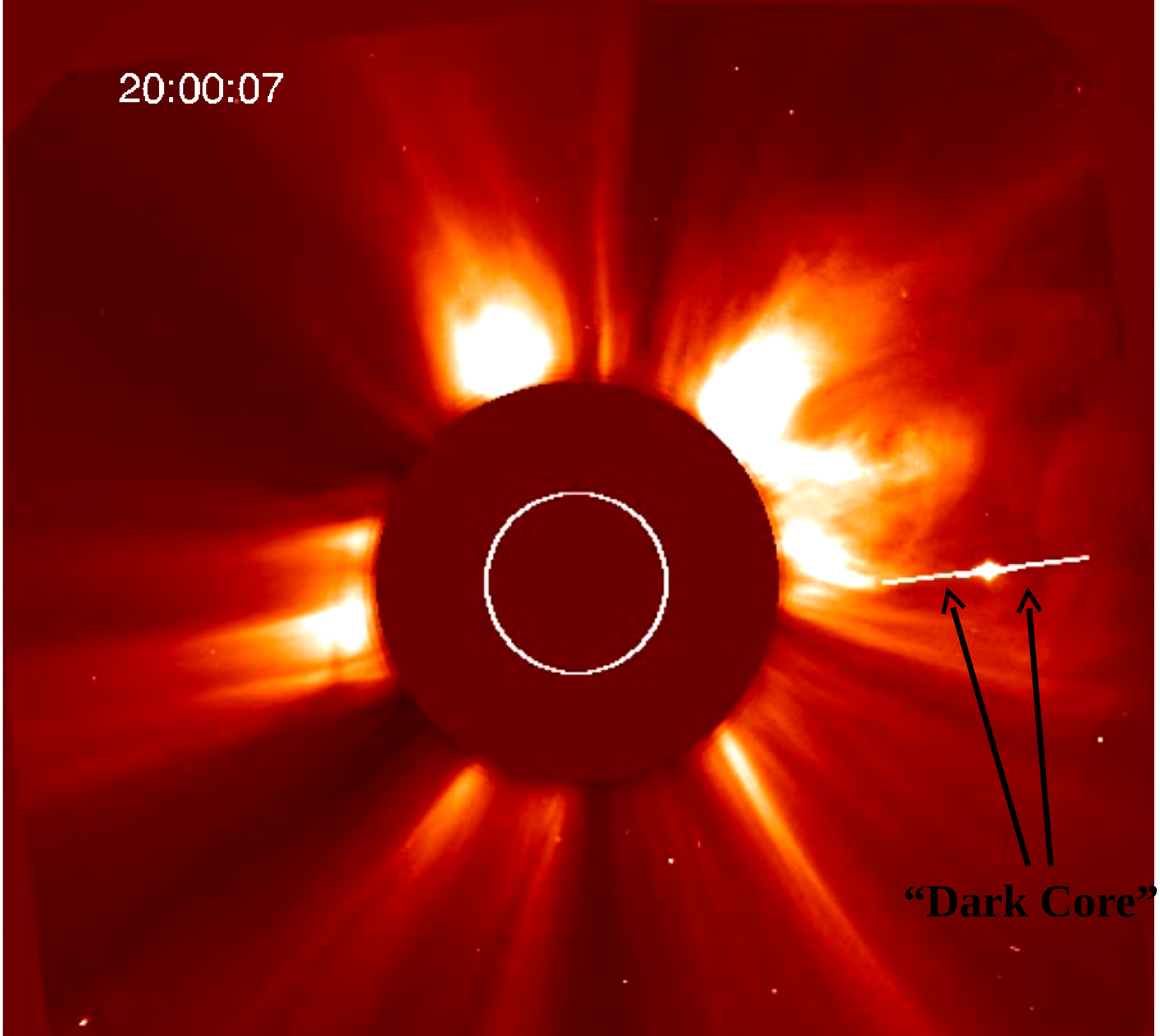
Messenger transmits RCP with a little leakage into LCP, which provides a stable ~10% linear polarized component. This lets us measure Faraday rotation (Sorry, folks: for this part, S/N is only 10^3!).



The Coronal Mass Ejection on 11 May 2013…

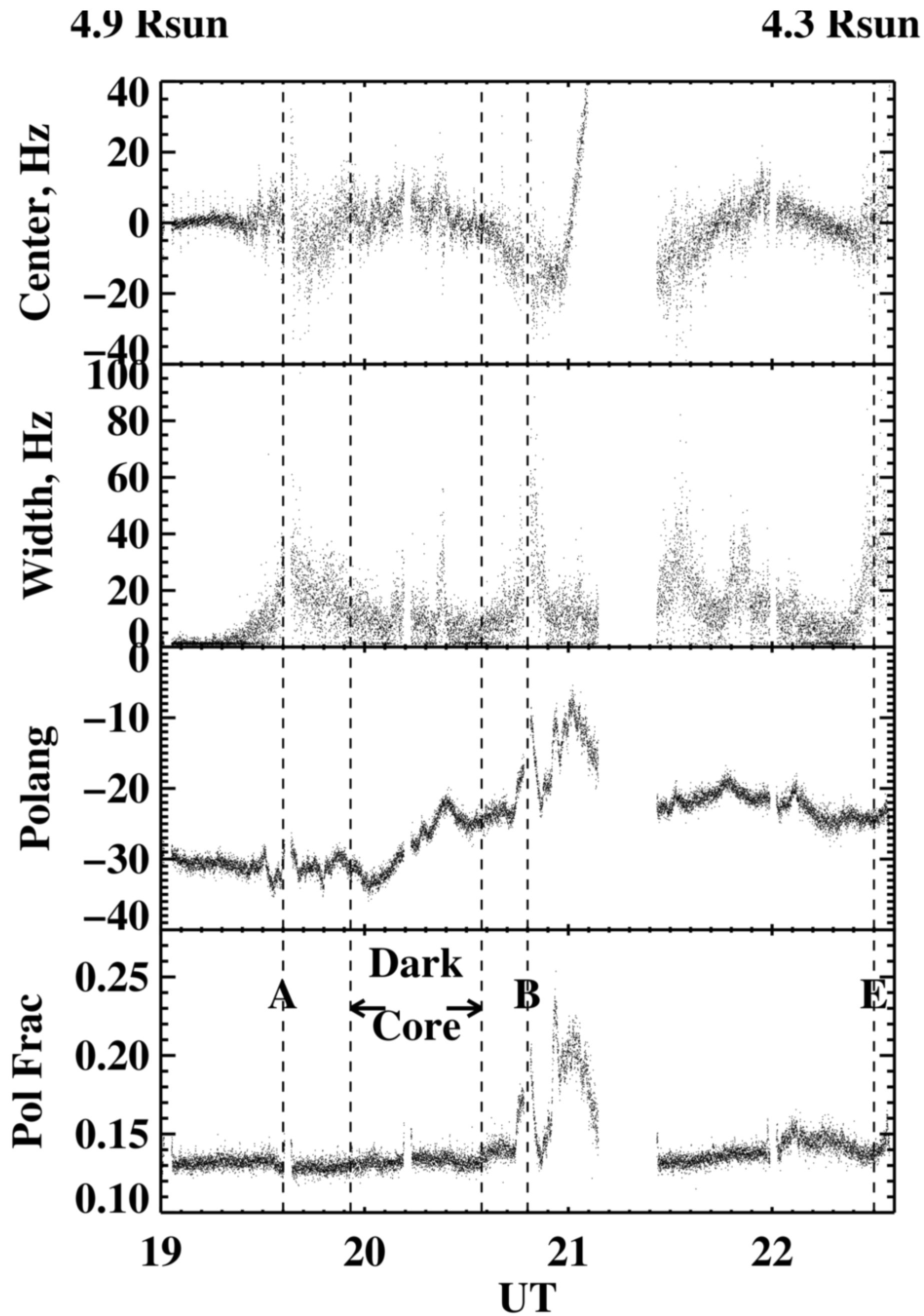


A


20:00:07
“Dark Core”

“A” marks where the leading edge overlies Messenger. This marks the beginning of large changes in:
--Line Width (turbulence)
--Line Center (N(e))
--Polang (Faraday Rotation)

These quantities don’t change suddenly; they begin slowly about 15 minutes before, showing that the CME perturbs the medium into which it flies—it doesn’t make a shock.



We see BOTH Faraday rotation AND frequency changes. We can combine them to get the field strength:

Faraday rotation:

$$\Delta\theta = 2.6 \times 10^{-17} N(e) B \lambda^2 \quad \text{radians}$$

$$\Delta\theta = 3.3 \times 10^{-16} B \, \Delta N(e)$$

Dispersion:

$$\Delta f_{Mess} = 1.34 \times 10^{-12} \; f_{Mess,GHz}^{-1} \frac{dN(e)}{dt}$$

Combine—eliminate N(e)

$$B = \frac{479 \; \Delta\theta}{\int \Delta f_{Mess} \; dt} \quad \text{G.}$$

For point A (the leading edge of the CME):

Faraday rotation: ~ 6 degrees

Frequency change ~ 5 Hz over 350 sec

Gives…

B ~ 30 milliG

$\Delta N(e) \sim 1.1$ e16 cm^{-2}

For the Dark Core:

Faraday Rotation ~ +/- 6 degrees

Frequency change ~ 5 Hz over 144 sec

Gives…

B ~ 70 milliG

$\Delta N(e) \sim 4.5$ e15 cm^{-2}, etc…

Turbulence…

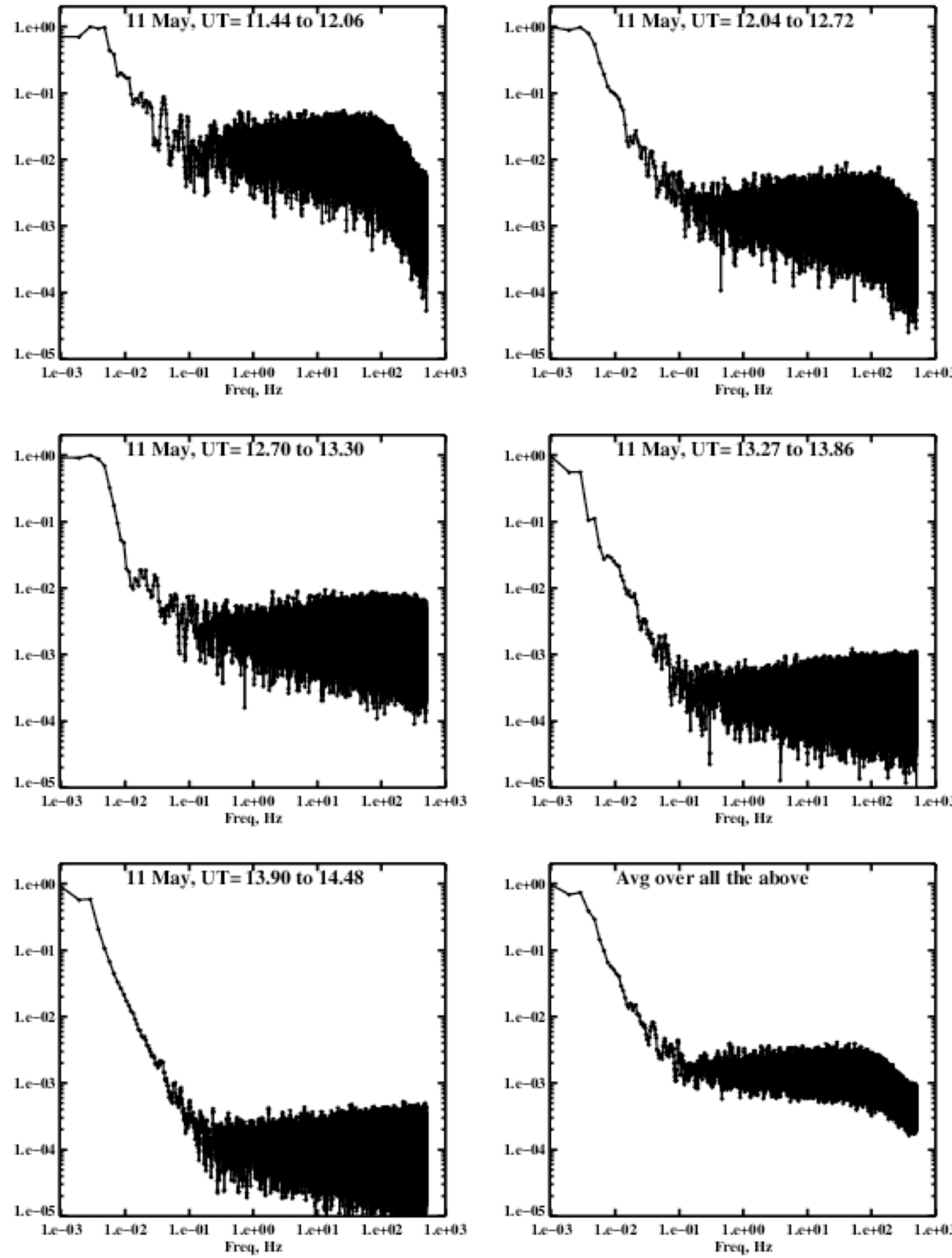
Turbulence elements produce refractive scintillation, so the signal amplitude changes with time. This leads to spectral broadening.

Here, we use 1 msec chunks and about 1 million points (about 1000 seconds). We Fourier transform the time series to obtain the spectral signature produced by turbulence.

I made a sample plot of one of these time series and it looks very boring…1 million random numbers.

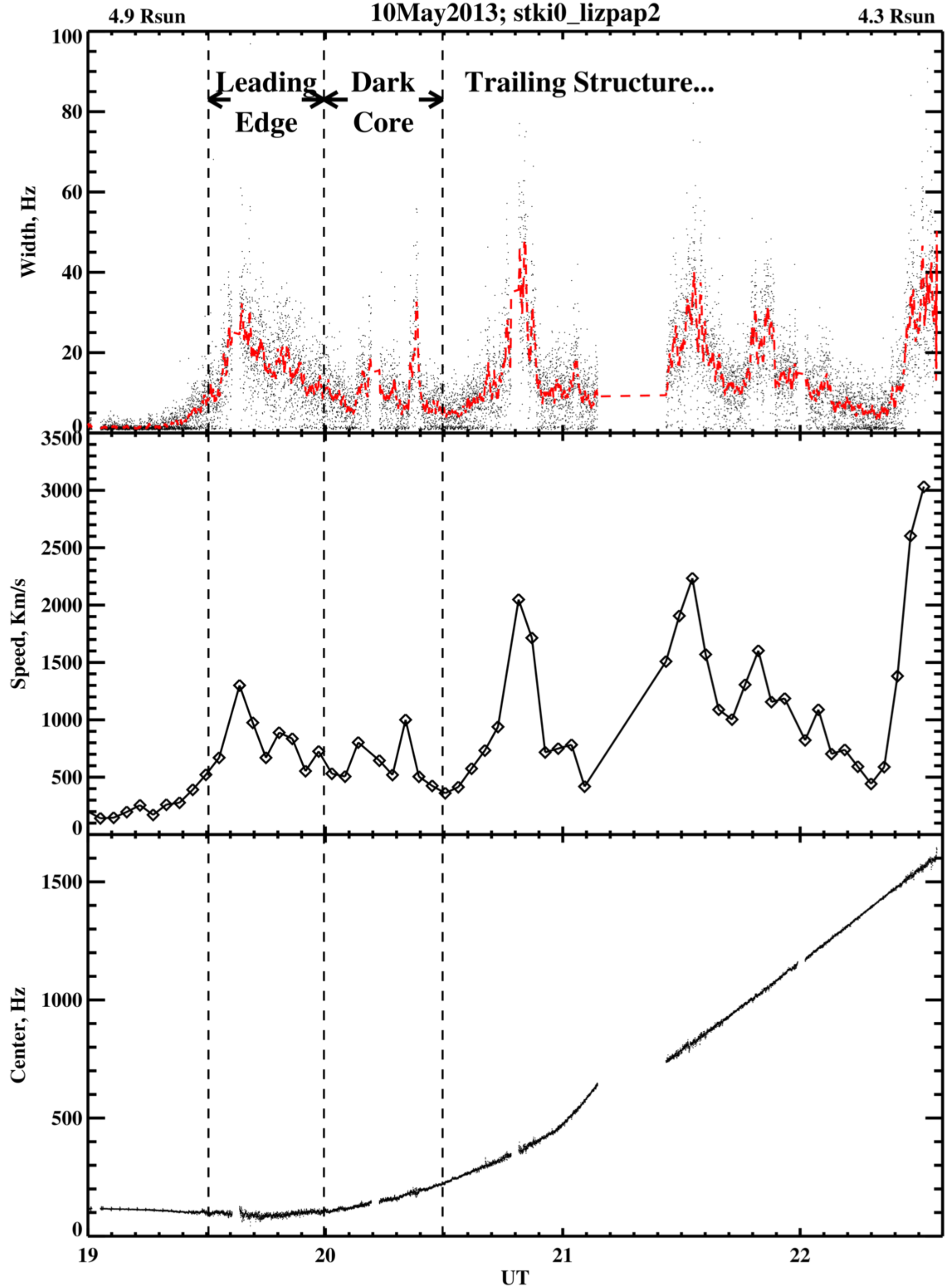
But…not REALLY random, because their Fourier transforms reveal interesting power-law spectra with one (or sometimes two?) breaks.

During the CME, the intensity spectrum has a pronounced knee and a Kolmogoroff slope of -11/3.



The "speed" (transverse velocity of the CME) is calculated from the spectral knee (see next slides). It tracks the line width. The line width and the speed are both are good turbulence indicators.

The center frequency increases steadily with time. Is this refraction, dispersion as Messenger probes deeper into the Sun, or GR?



V is the transverse speed
F_{char} =8.2 Hz, the turnover frequency
K_{char}=6.9e-5 rad/m, the associated spatial wavenumber (from theory)

$$V = \frac{2\pi f_{\text{char}}}{k_{\text{char}}}.$$

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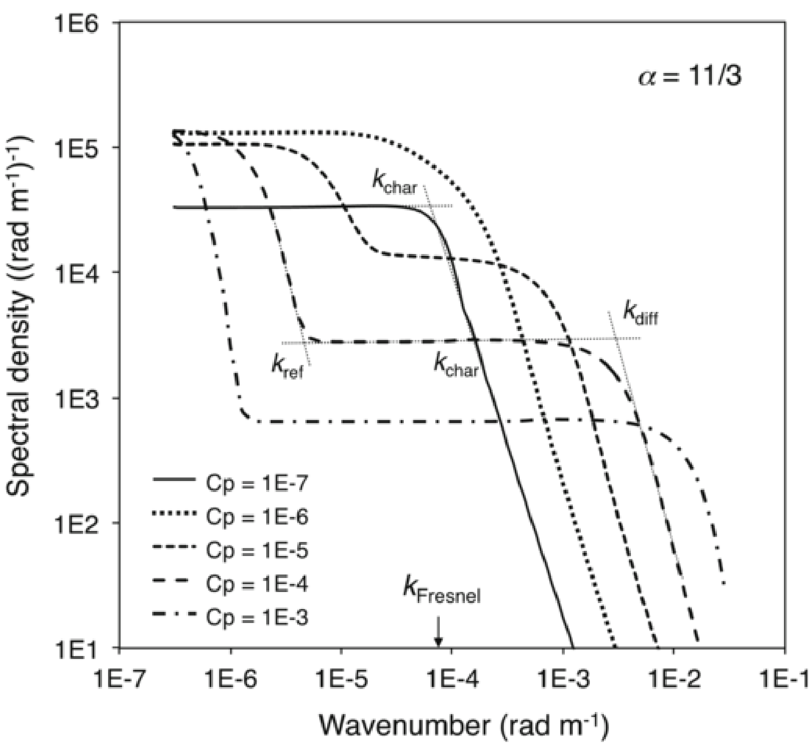
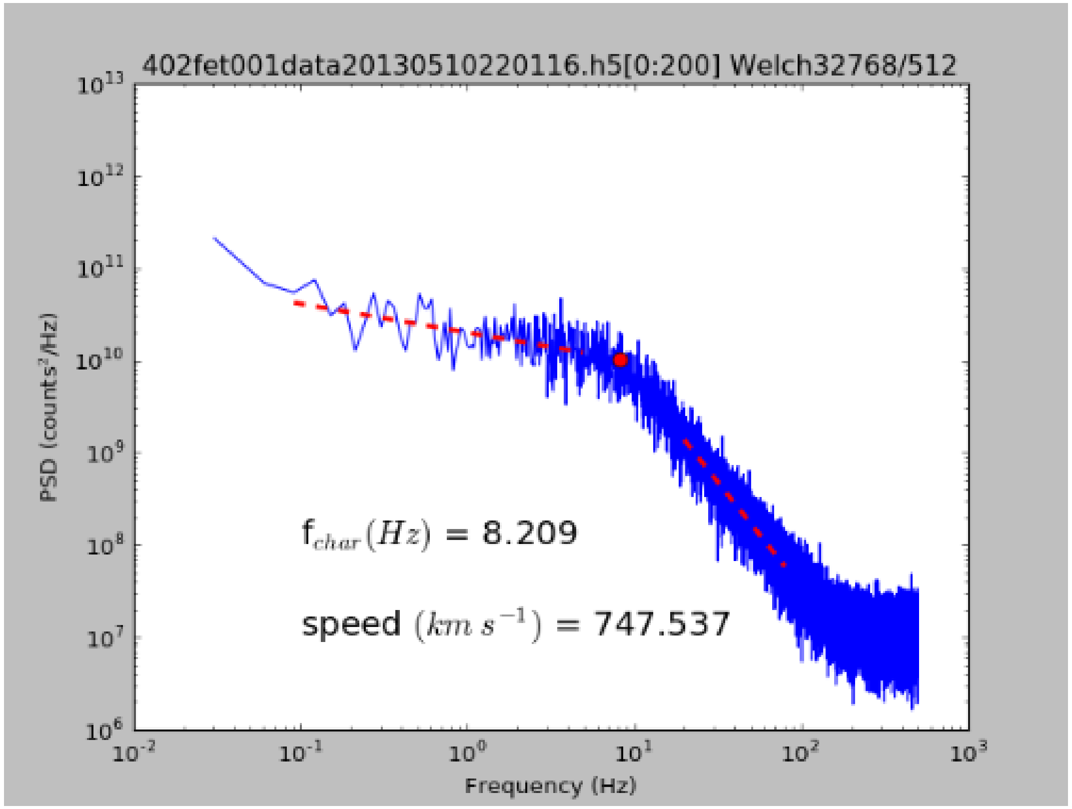


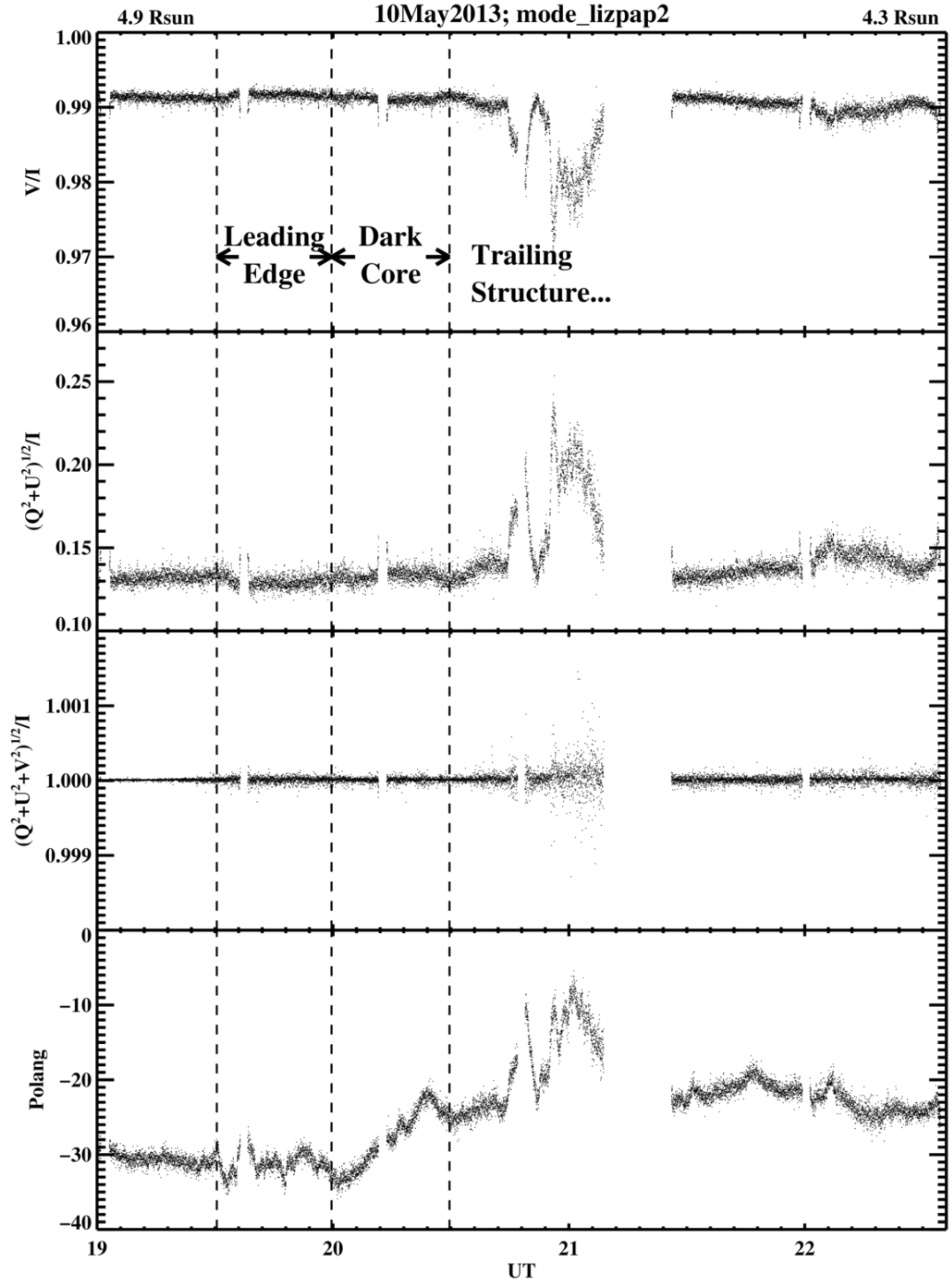


Polarization mode changing: conversion of Stokes V to (Q, U). For no turbulent scattering, total polarized power is conserved:

$$(Q^2 + U^2 + V^2)^{1/2} = \text{const.}$$

as happens here (with modest line broadening.

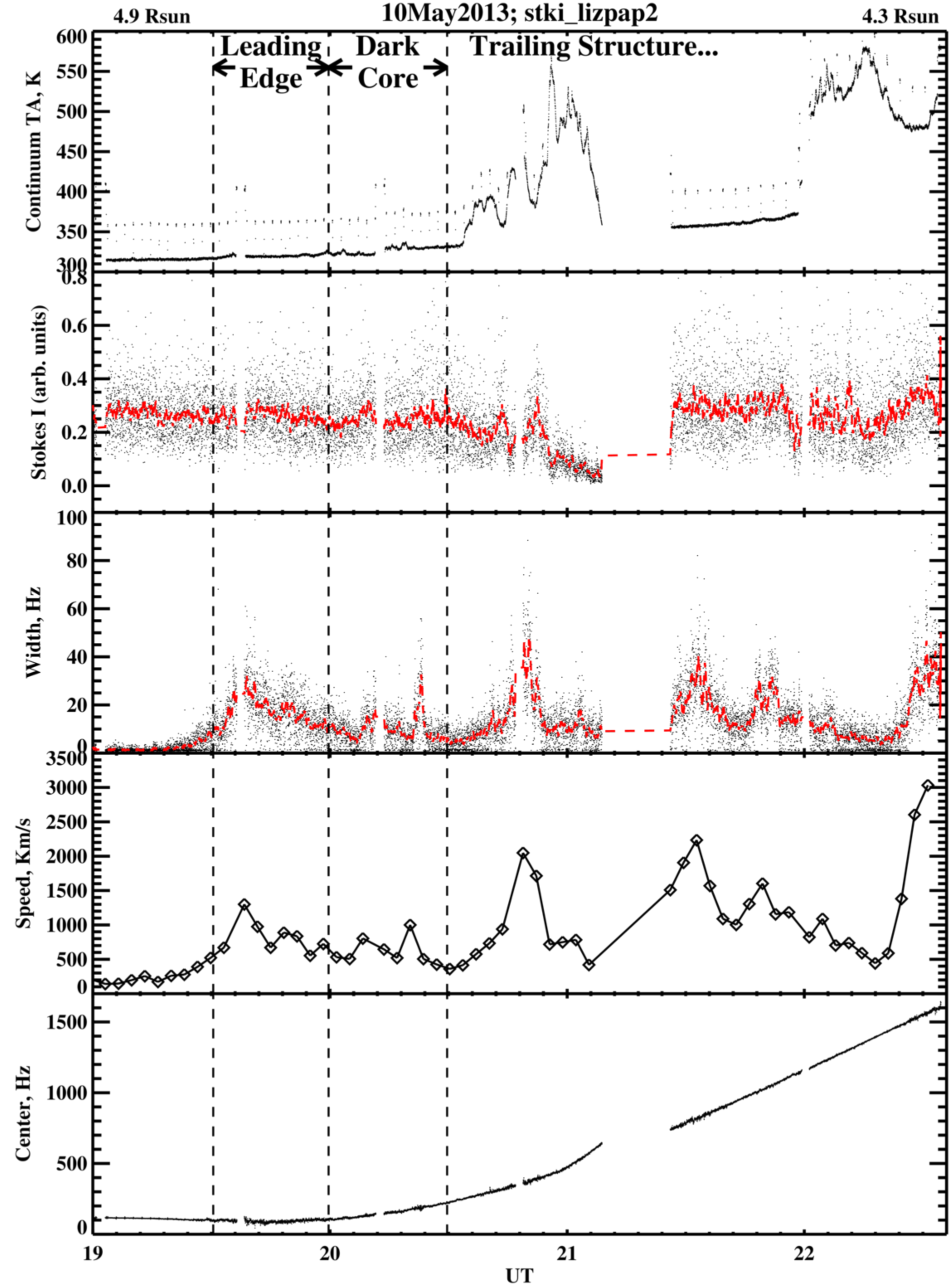
With increased line width from turbulent scattering (as on May 12), some polarized power is lost to Stokes I.



A surprise:

The top panel shows the system temperature, which increases by a factor of 2 for two periods.

Take a closer look: the polarization…



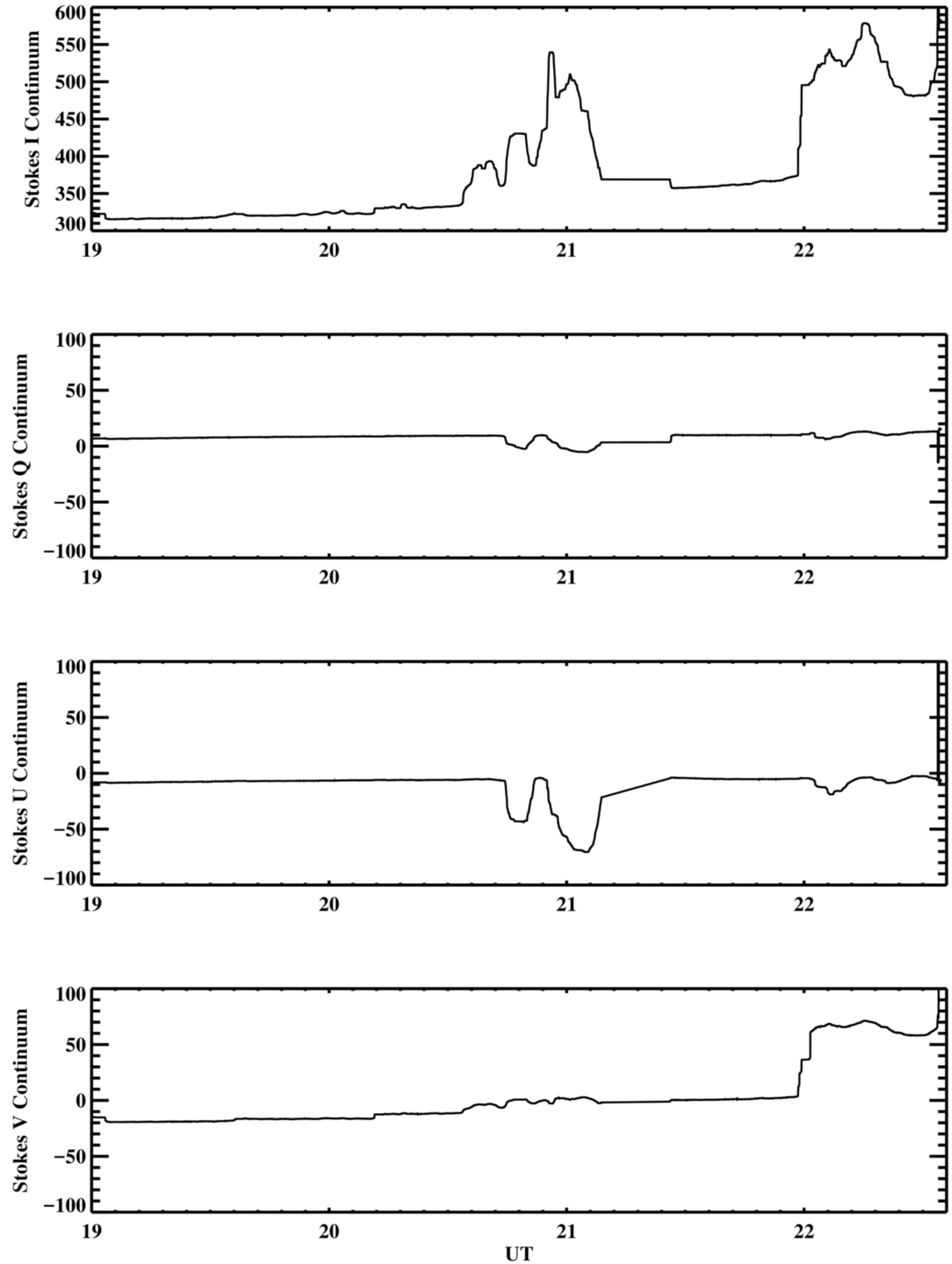
The first rise is highly LINEARLY polarized.

The second is highly CIRCULARLY polarized.

The emission is almost certainly coherent plasma emission. This means the plasma freq is half the observed freq, or about 4 GHz.

n(e) ~ 2 e11 cm^{-3} at

4.5 Solar Radii



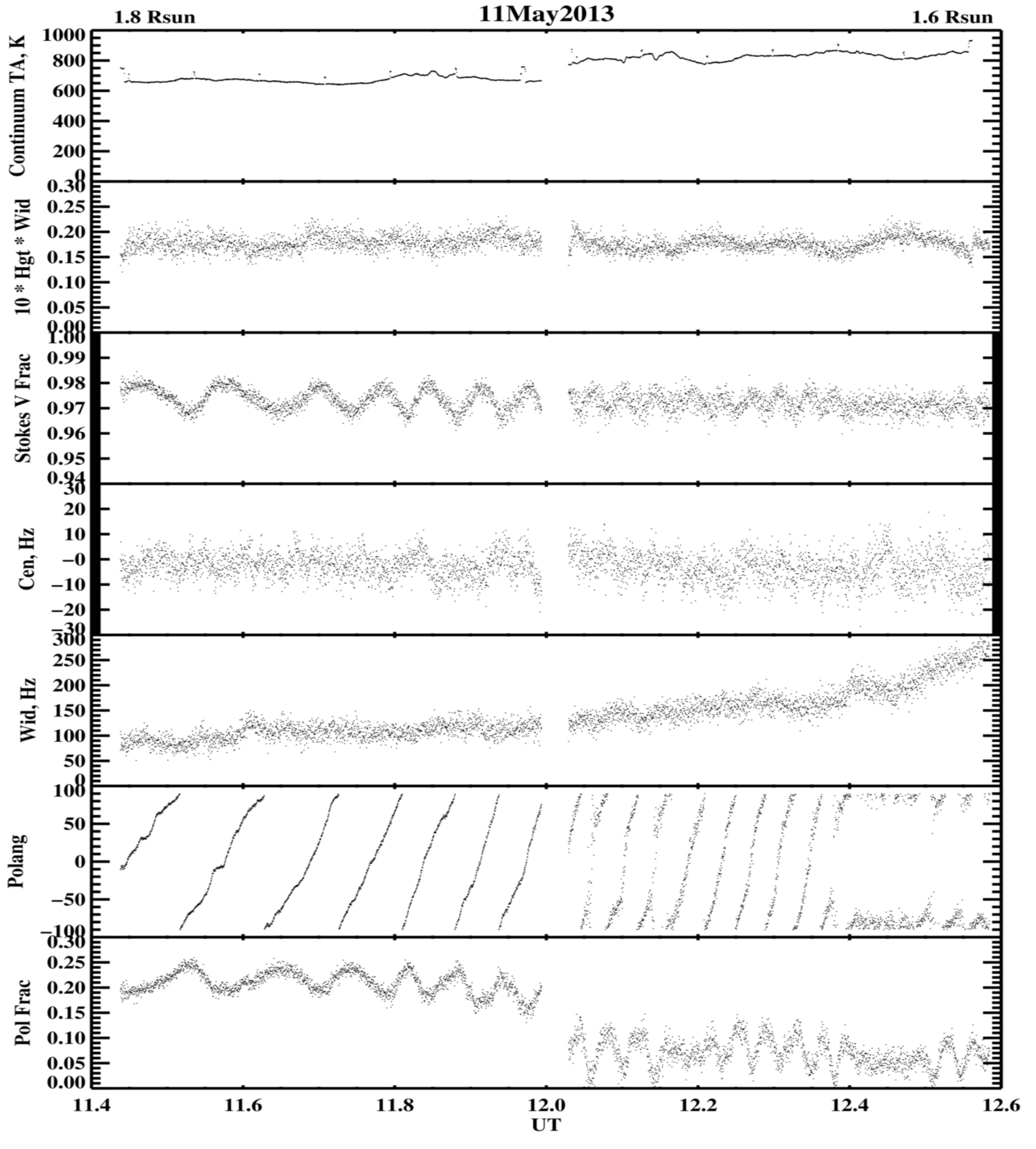
The next day, 12 May, Messenger was “dove into the Sun”, showing huge RM increases

12 May: the line-of-sight enters the chromosphere.

N(e) increases;

RM increases: 8.5 full turns!

Accompanied by increasing line width and mode conversion.



For each half-turn of the position angle:

Faraday rotation: ~ 180 degrees

Frequency change ~ 5 Hz over 180 sec

Gives…

B ~ 1.7 Gauss

ΔN(e) ~ 6 e15 cm^{-2}

We have 17 half-turns, so the total change in N(e) is

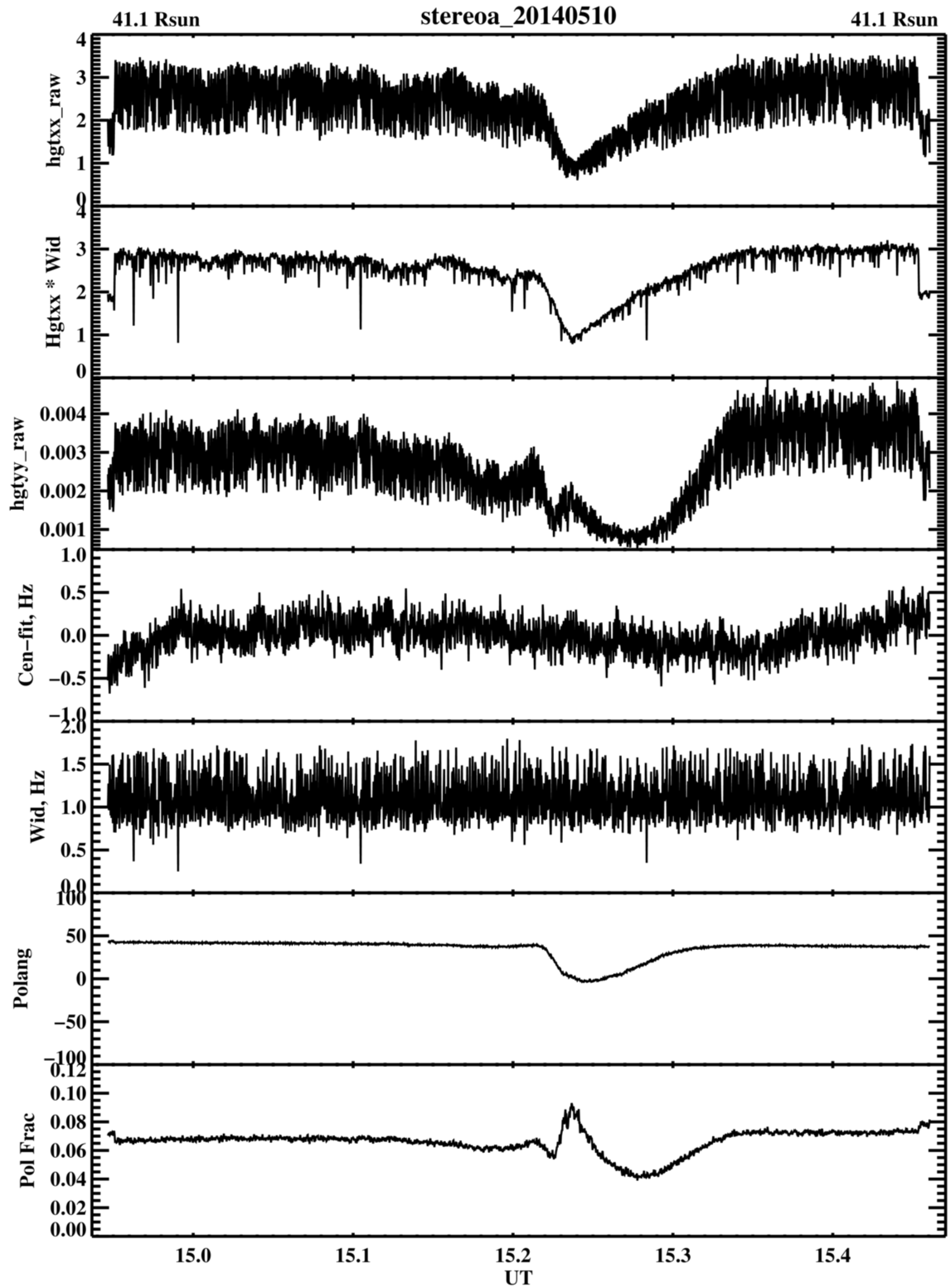
ΔN(e) ~ 1 e17 cm^{-2}.

(The elongation was 1.8 Solar radii)

At the other extreme, far from the Sun:
In May 2014 we had some short test time for observing STEREO. We began on 10 May.

Within the first half-hour, we saw remnants of a CME!

At 41 R_{sun}!!!



CAN WE SEE CMEs ON OTHER STARS?

To do so, we need a strong, narrow-band signal whose path just grazes the star.

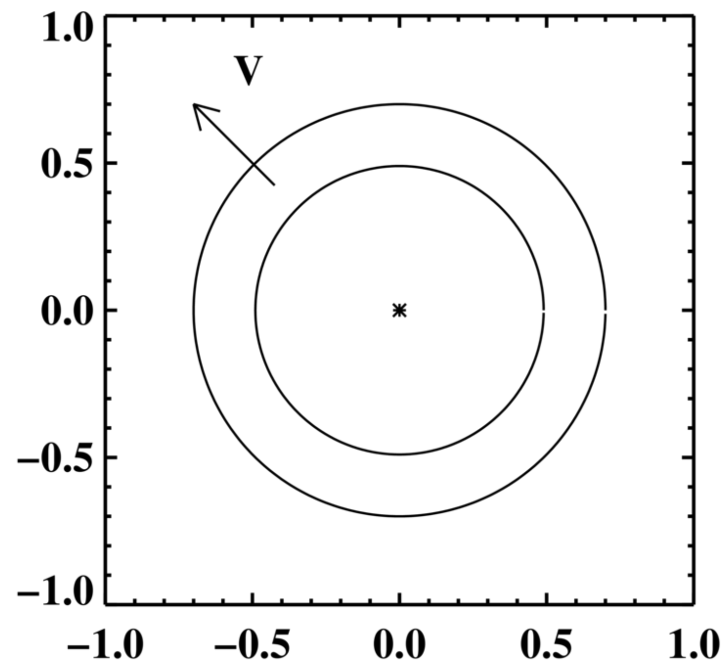
SETI???????????

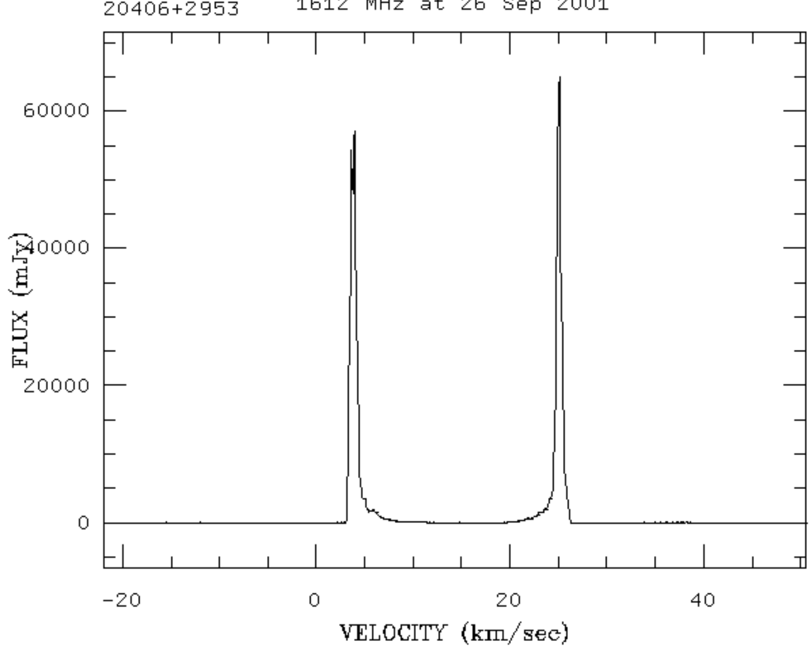
CAN WE SEE CMEs ON OTHER STARS?

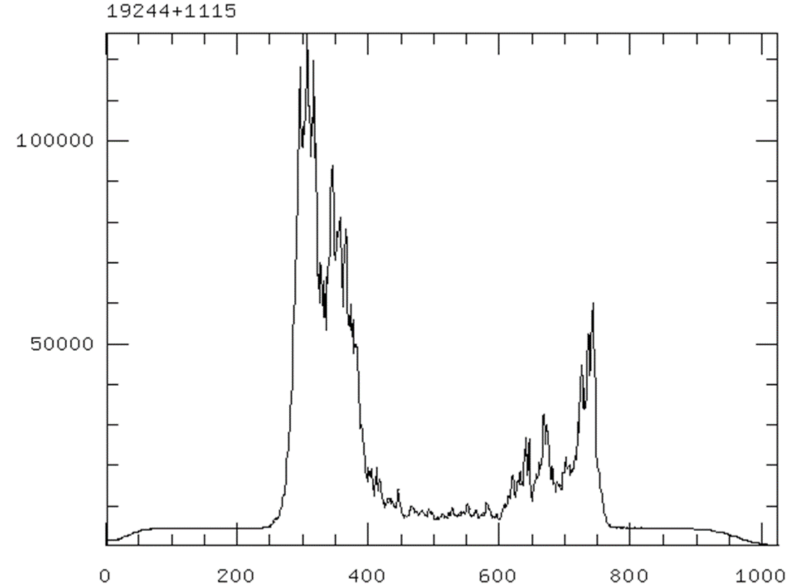
To do so, we need a strong, narrow-band signal whose path just grazes the star.

OH/IR STARS FILL THE BILL!

OH/IR stars are Asymptotic Branch Stars, the longest period Mira Variables, with large magnetically convective motions that throw off atmospheric debris. The debris are dusty and molecular, forming a patchy shell that is accelerated by radiation pressure. The dust converts all of the visible light to IR. The IR pumps the OH molecules, making masers.





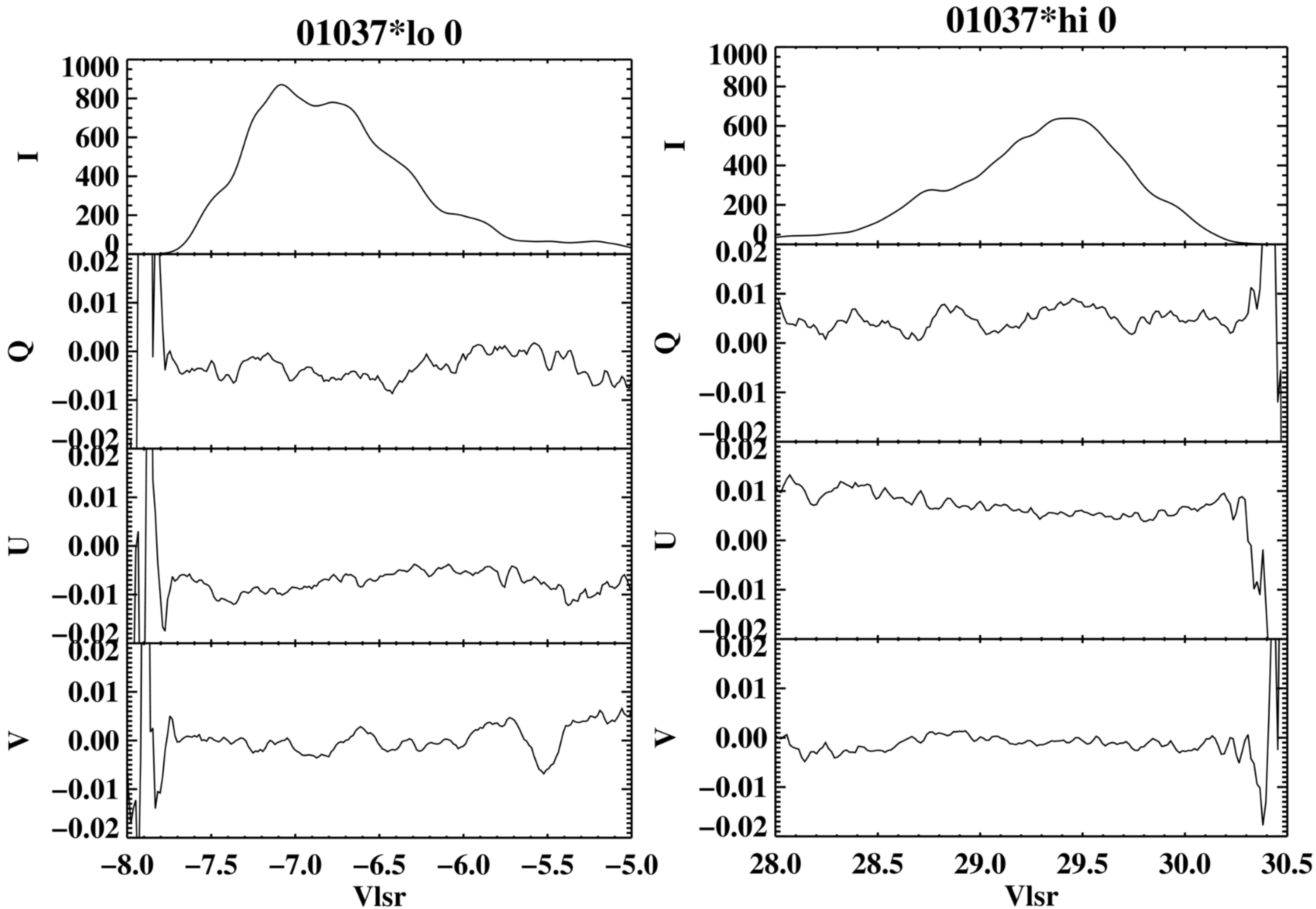


OH Masers occur at the front/back along the line of sight to the star. Masers in some stars come from larger areas and have more complex velocity structure. Some OH/IR masers exhibit linear polarization, so we can measure not only frequency changes (changes in N(e)) but also angle changes (changes in Faraday rotation).

In any one star, the masers behind, at positive velocity, should suffer stellar-atmosphere propagation effects; the ones in front should not. We get a free control sample!

Here's the most intense OH/IR maser in our sample. Each "polar cap" has several narrow (few hundred Hz) components. Polarizations are not impressively large—damn! Masers are saturated, hence Stokes I depends linearly on star's luminosity.

Maser line shapes remain <u>strictly constant</u> during the star's cycle!



Do we see CMEs in OH/IR stars?

Don’t know yet! Data reduction still underway.

We saw enough to convince the TAC to allot time. But the changes were subtle and need verification using the very best calibration techniques (a sort of “self-cal”).

FIN

Quasi-periodic frequency fluctuations observed during coronal radio sounding experiments 1991–2009

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Received 9 February 2011; received in revised form 10 October 2011; accepted 15 October 2011
Available online 21 October 2011

6. Conclusion

Large-scale coronal sounding experiments carried out over during the years from 1991 to 2009 with the spacecraft ULYSSES, GALILEO, MARS-EXPRESS, VENUS-EXPRESS and ROSETTA have provided evidence for quasi-periodic oscillations of the electron density in the 5-min band in the outer solar corona at heliocentric distances between 3 and 40 R_S. It is suggested that the origin of these quasi-periodic fluctuations is associated with propagating magnetosonic waves, generated locally via nonlinear interactions with Alfvén waves propagating from the corona base.

Table 2
Characteristics of the QPC (2004–2008).

No in Fig. 5	Spacecraft	Date	E/W	R/R_S	θ	ν_{max}, mHz	g
1	MEX	10 September 2004	E	7.22	30°	3.72	2.42
2	ROS	17 April 2006	W	5.86	25.7°	3.92	2.58
3	VEX	19 October 2006	W	8.63	23°	4.22	2.43
4	MEX	18 October 2006	E	6.45	19.5°	4.77	2.33
5	MEX	13 December 2008	W	7.73	−22°	3.51	2.96

Table 3
Characteristics of RFF spectra, ULYSSES 1995.

Spectrum number	1	2	3	4	5	6
DOY 1995	56	55	57	59	71	71
R/R_S	28.2	29.4	26.5	23.6	28.5	28.6
θ, degree	−88.9	−88.1	−84.5	−73.0	−6.0	−5.7
ν_{max}, mHz	6.00	6.22	5.36	4.95	4.36	4.52
$\Delta\nu$, mHz	2.93	2.88	2.62	3.43	2.58	2.90
$\Delta\nu/\nu_{max}$	0.49	0.46	0.49	0.69	0.59	0.64
g	3.38	3.11	2.80	4.23	2.36	2.80

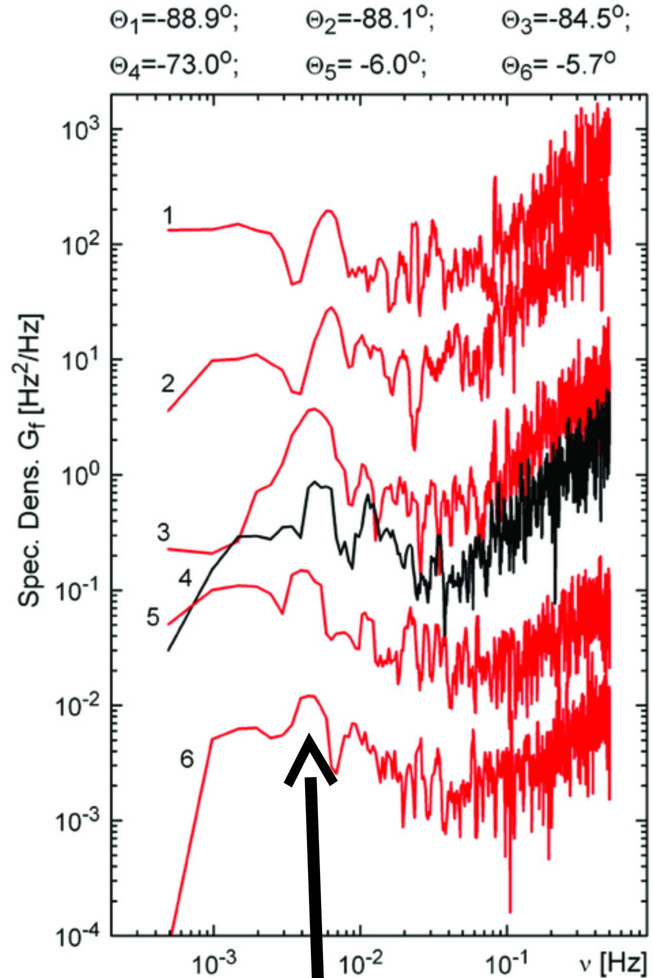
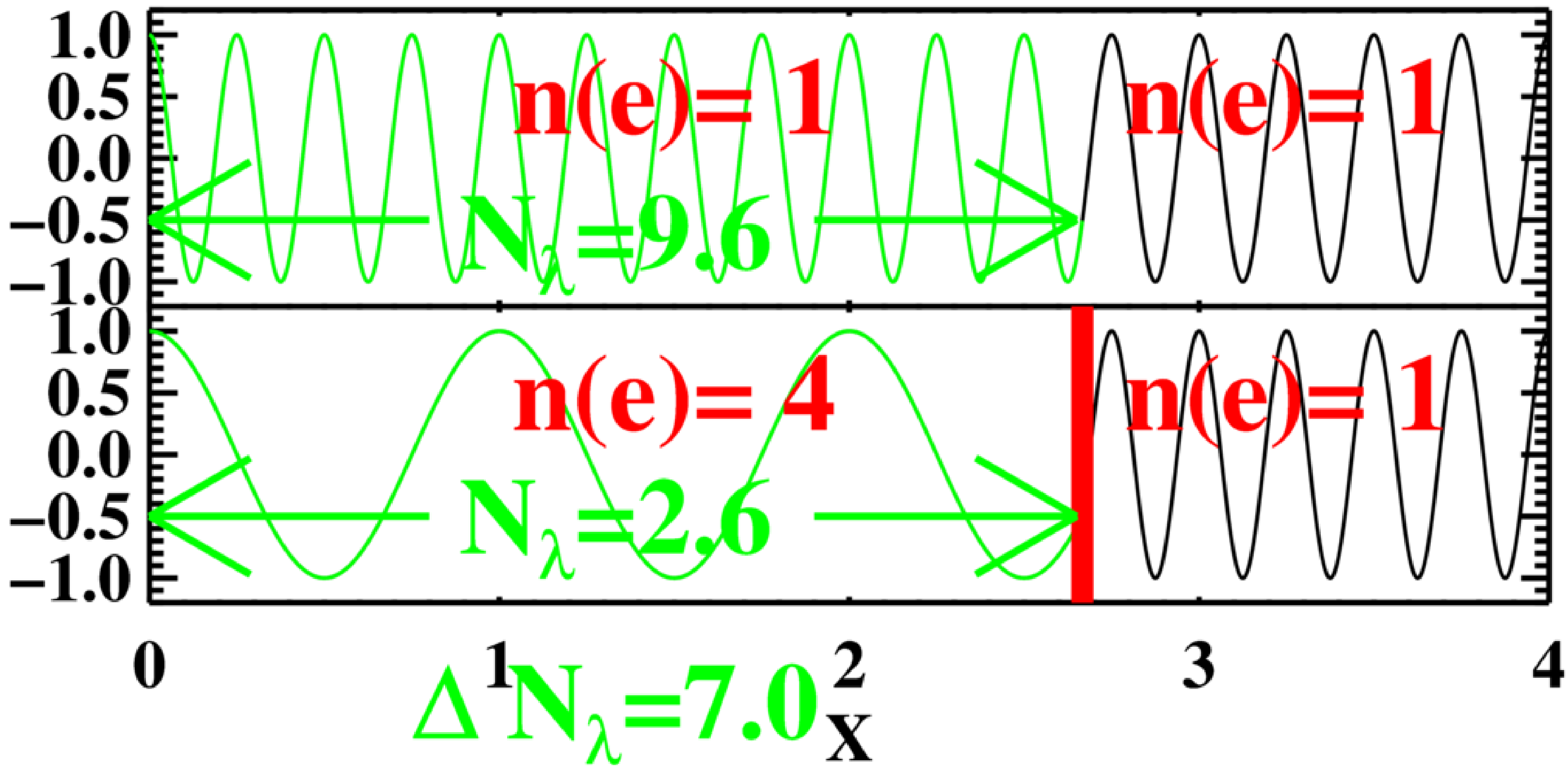


Fig. 6. Temporal RFF spectra (differential frequency fluctuatio observed with ULYSSES at high latitude regions of the solar coro (spectra 1–4) and low-latitude regions (spectra 5 and 6) during the peri between 24 February and 12 March 1995. The heliographic latitude of t solar proximate point for each spectrum is denoted at the top.

"QPO"

It's NOT Doppler. What can it be? Suppose N(e) increases with time. The phase velocity increases with n(e)…



$$\frac{v_{ph}}{c} = 1 + \frac{1}{2}\left(\frac{f_p}{f_{Mess}}\right)^2$$

$$\Delta f_{Mess} = \frac{\Delta N_\lambda}{\Delta t}$$

$$\Delta f_{Mess} = 1.34 \times 10^{-12}\ f_{Mess,GHz}^{-1}\frac{dN(e)}{dt}$$