# STEREO/WAVES

## Interplanetary Radio Burst Tracker

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## SWG

Hamburg, Germany
2 May 2005

Observatoire de Paris
University of Minnesota
University of California - Berkeley
Goddard Space Flight Center

# Science Summary

The STEREO/WAVES (S/WAVES) experiment will:

- Track and probe CME-driven shocks from the corona to 1 AU
- Map the in situ structure of CME-driven shocks and flare electron beams
- Probe the density and IMF structure of the heliosphere before and after CMEs
- Understand the radio emission process and beam pattern of radio bursts
- Measure electron density and temperature of filament material in clouds

- A remote sensing instrument **and** an in-situ instrument in one
- Receivers in frequency domain **and** time domain

Sensitive receivers - require an electromagnetically clean spacecraft!

# Radio emissions from the inner heliosphere

- **Radio traces energetic electrons**
  - propagating along magnetic field lines (type III)
  - accelerated at shock fronts (type II)
  - trapped in magnetic traps (type I, type IV)

# Radio emissions from the inner heliosphere

- **Radio frequency is determined by the local electron density $N_e$ at the source location**
  - "plasma radiation" on local $f_p = 9\ N_e^{1/2}$ or $2\ f_p$

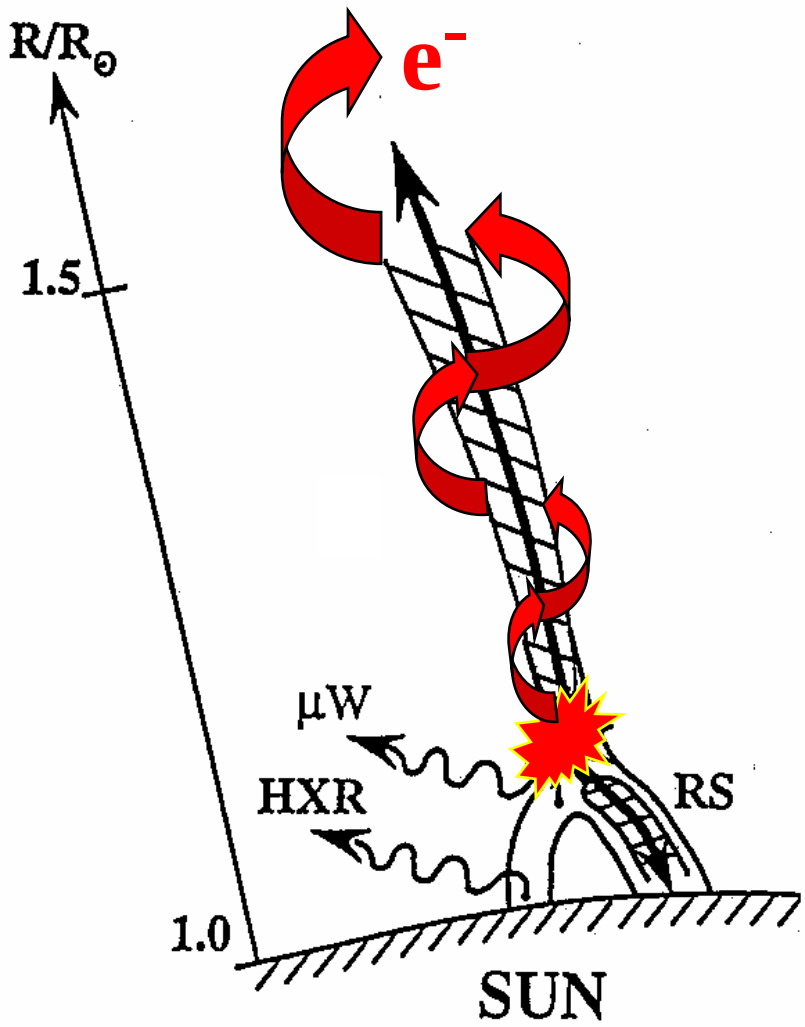
  → essentially long wavelength radio astronomy
  - $\lambda > 10$ m ; $f < 30$ MHz (angular resol. = $\lambda$ /D)

  → relation observing frequency - distance from Sun

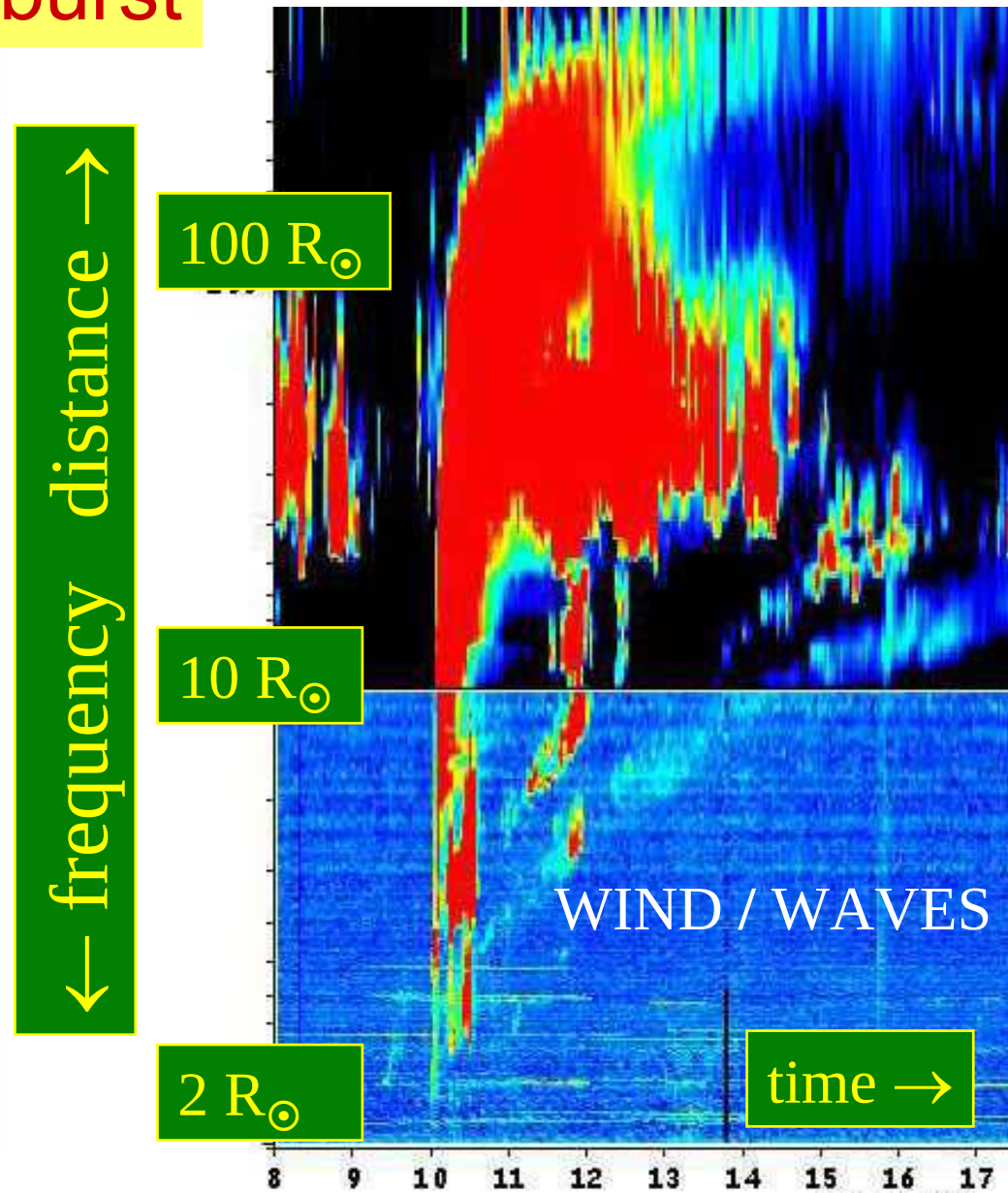
# Radio emissions from the inner heliosphere

| | $N_e$ ($cm^{-3}$) | $f_p$ |
|---|---|---|
| low corona | $\geq 10^8$ | $\geq$ 100 MHz |
| ~ 10 $R_\odot$ | ~ $10^4$ | ~ 1 MHz |
| ~ 30 $R_\odot$ | ~ 1.5 $10^3$ | ~ 350 kHz |
| ~ 1 AU | ~ 10 | ~ 30 kHz |

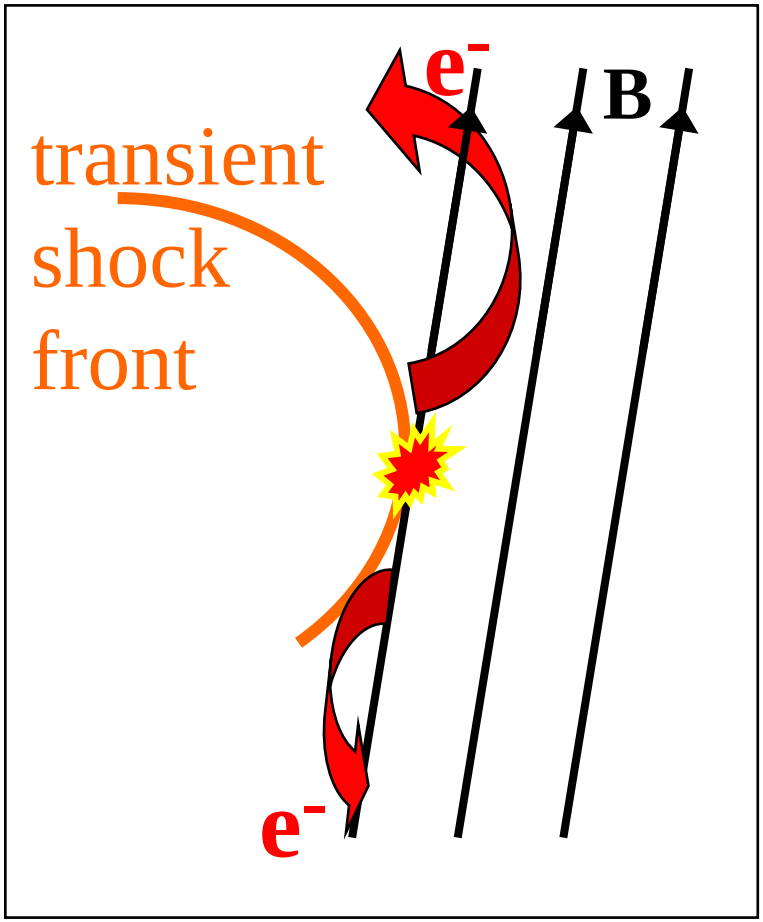
# Type III radio burst

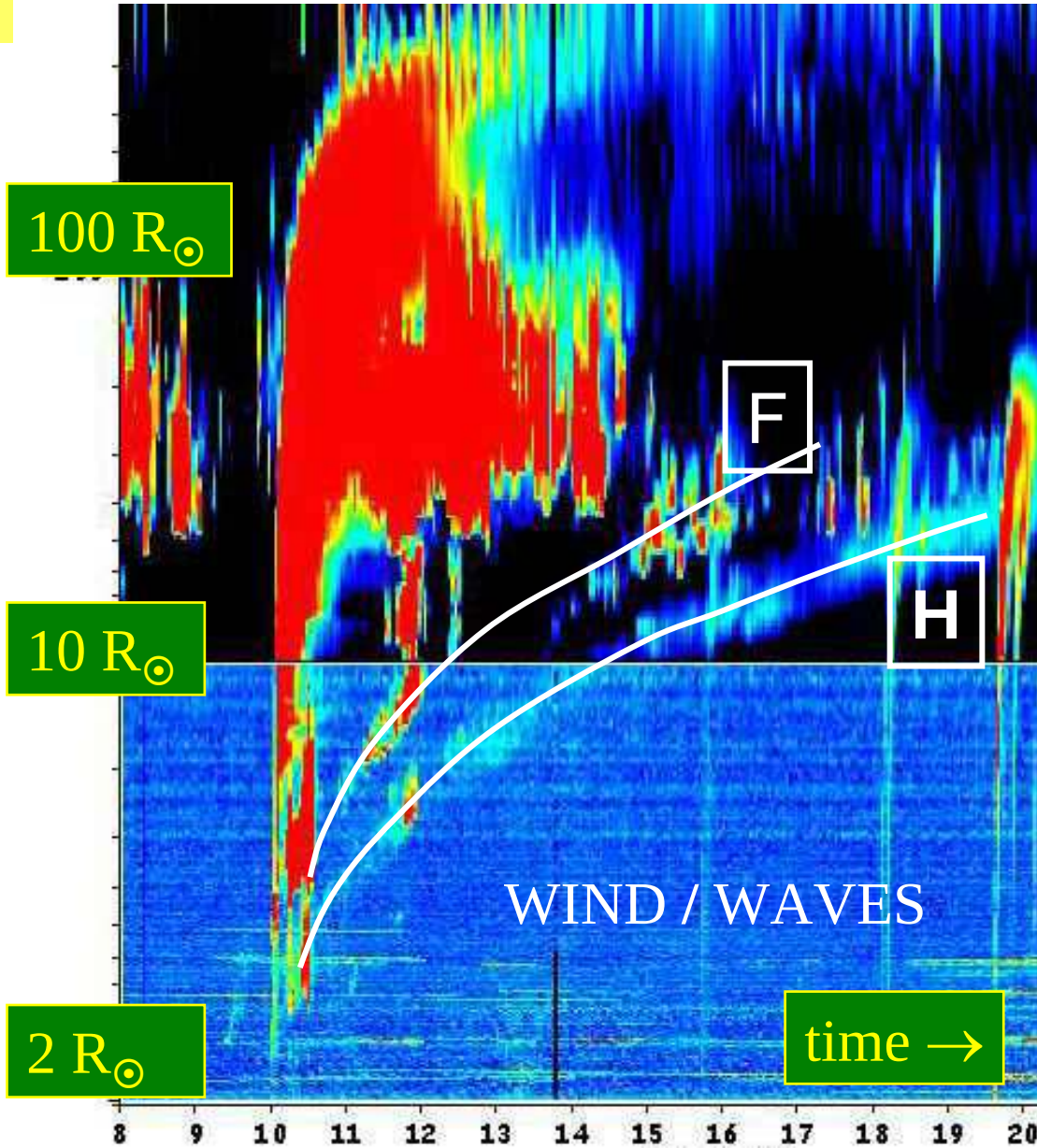



*(adapted from Marcus Aschwanden)*



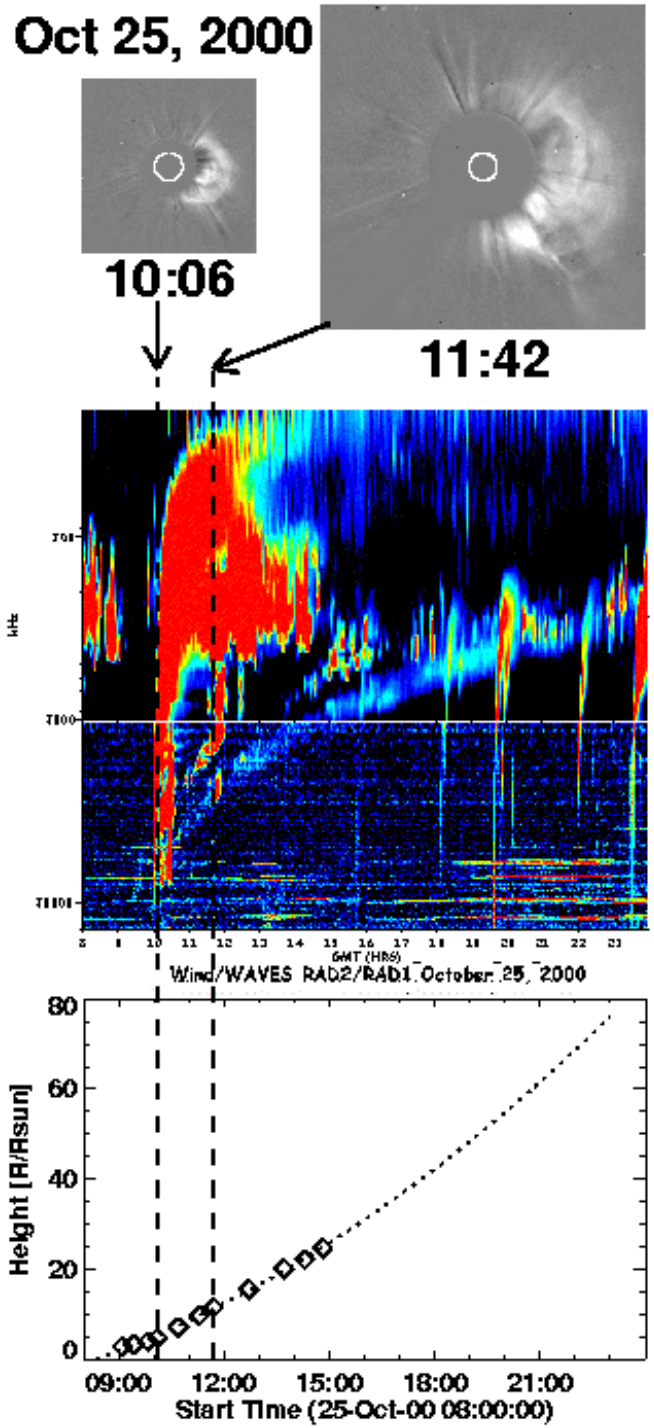
# Type II radio burst



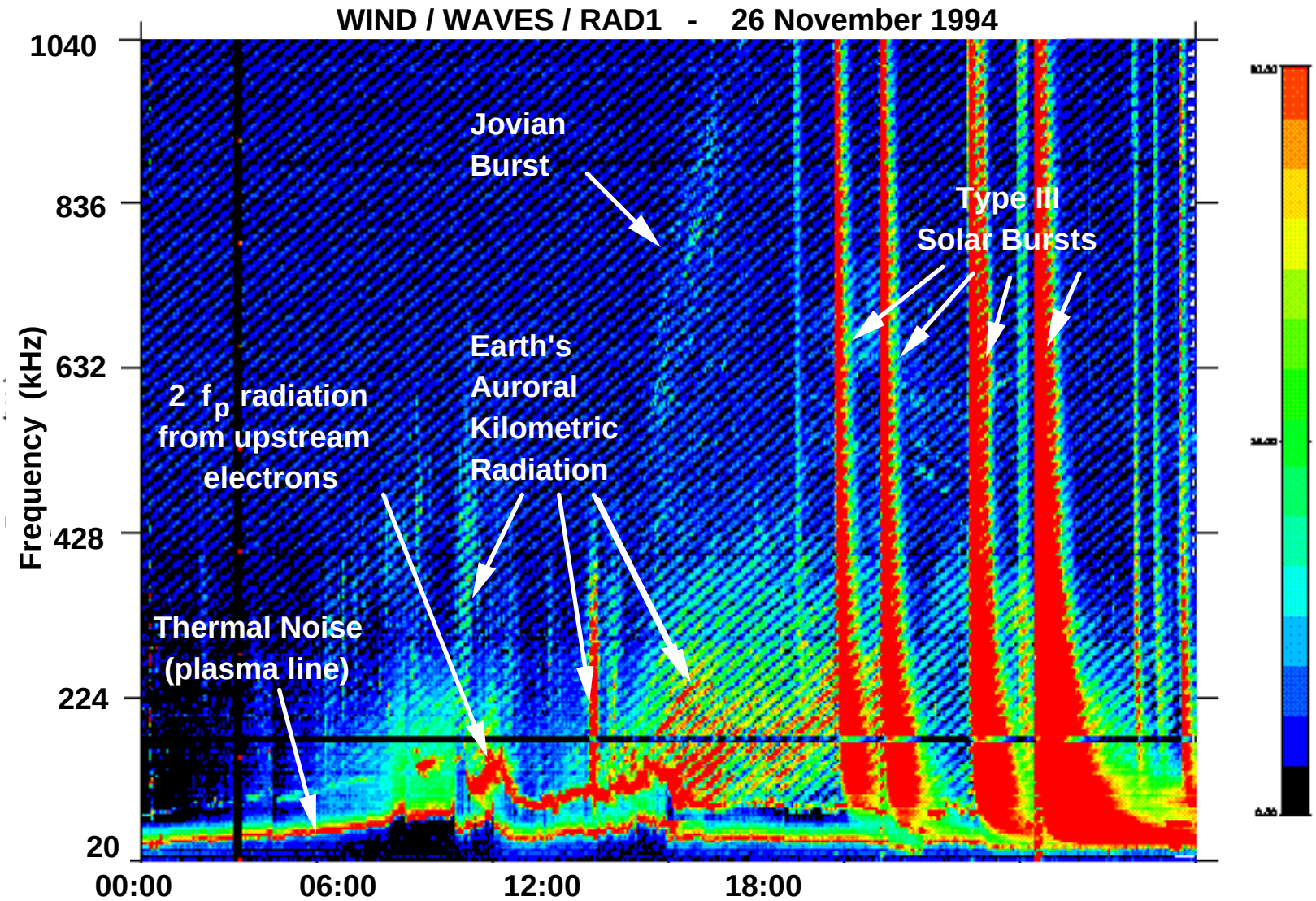



SOHO / LASCO

WIND / WAVES

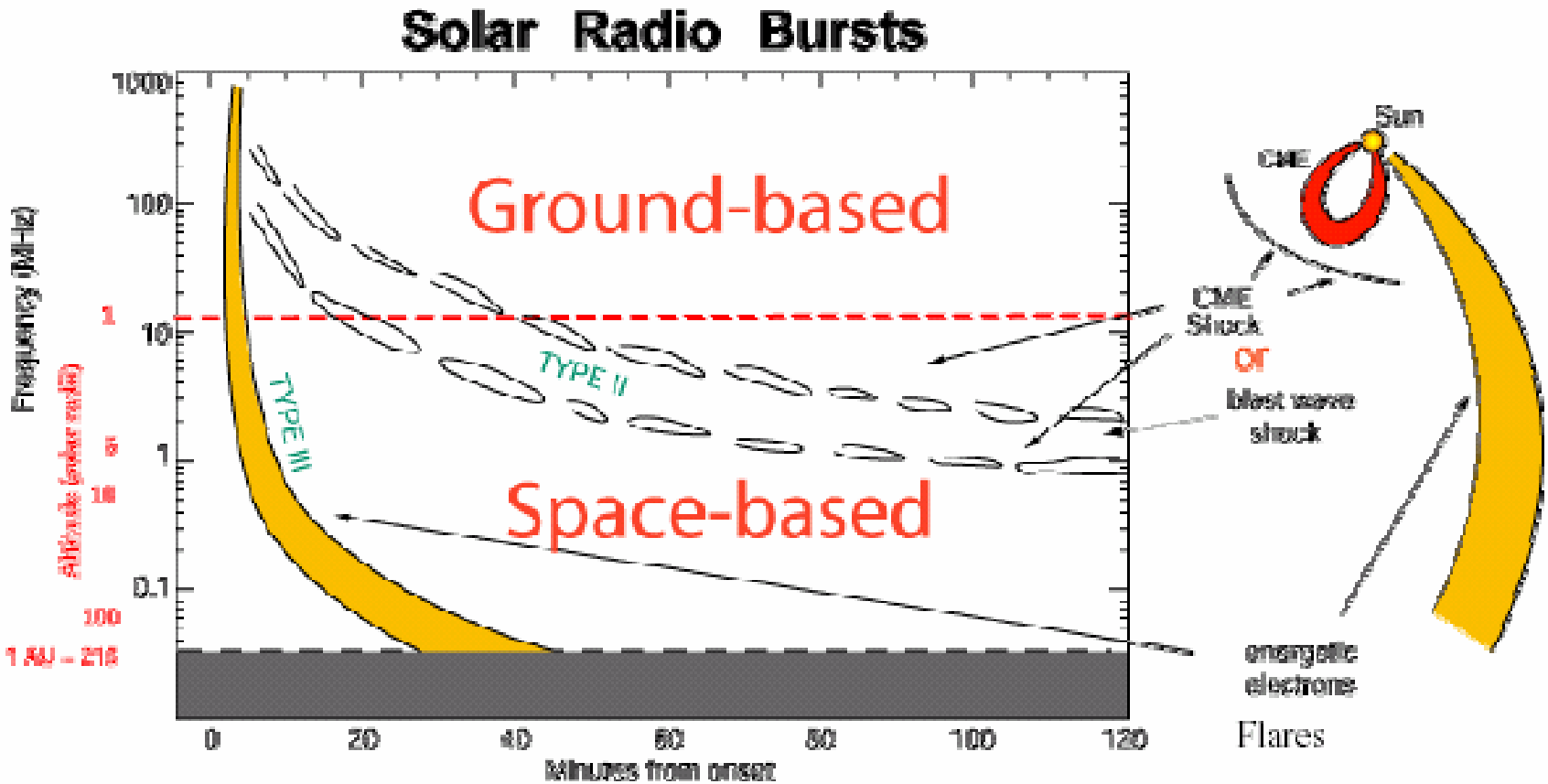



*(after Gopalswamy et al., 2001)*




a range of diagnostics obtained with the same instrument and well discriminated on the dynamic spectrum

$$F_p(\mathrm{kHz}) = 9\sqrt{N_e(\mathrm{cm}^{-3})} \rightarrow F_p \propto 1/\mathrm{R}$$



# Radio emissions from the inner heliosphere

## direction finding

- presently (one spacecraft):

  radio yields full direction + frequency-distance ranging

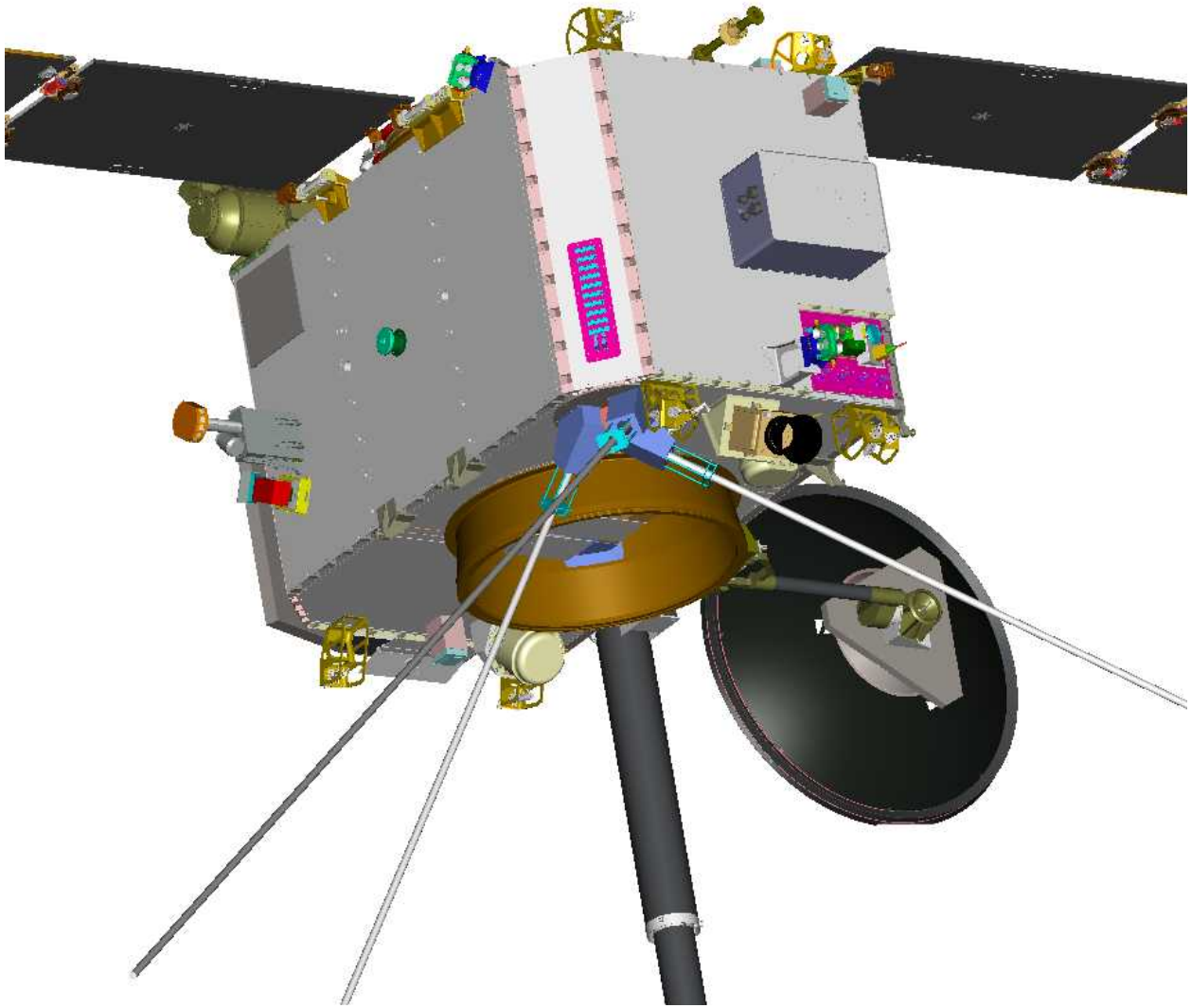
  → full 3-D localization in space with one instrument

  **BUT**

  - only position of source centroid and equivalent width
  - need to use average or assumed density model

- **STEREO ≡ major step** :
  - will allow us to refine the density model,
  - will give us access to propagation effects (IPS-like),
  - will provide new information on radiation mechanisms, source structure, etc

# S/WAVES Investigation



# S/WAVES Measurements

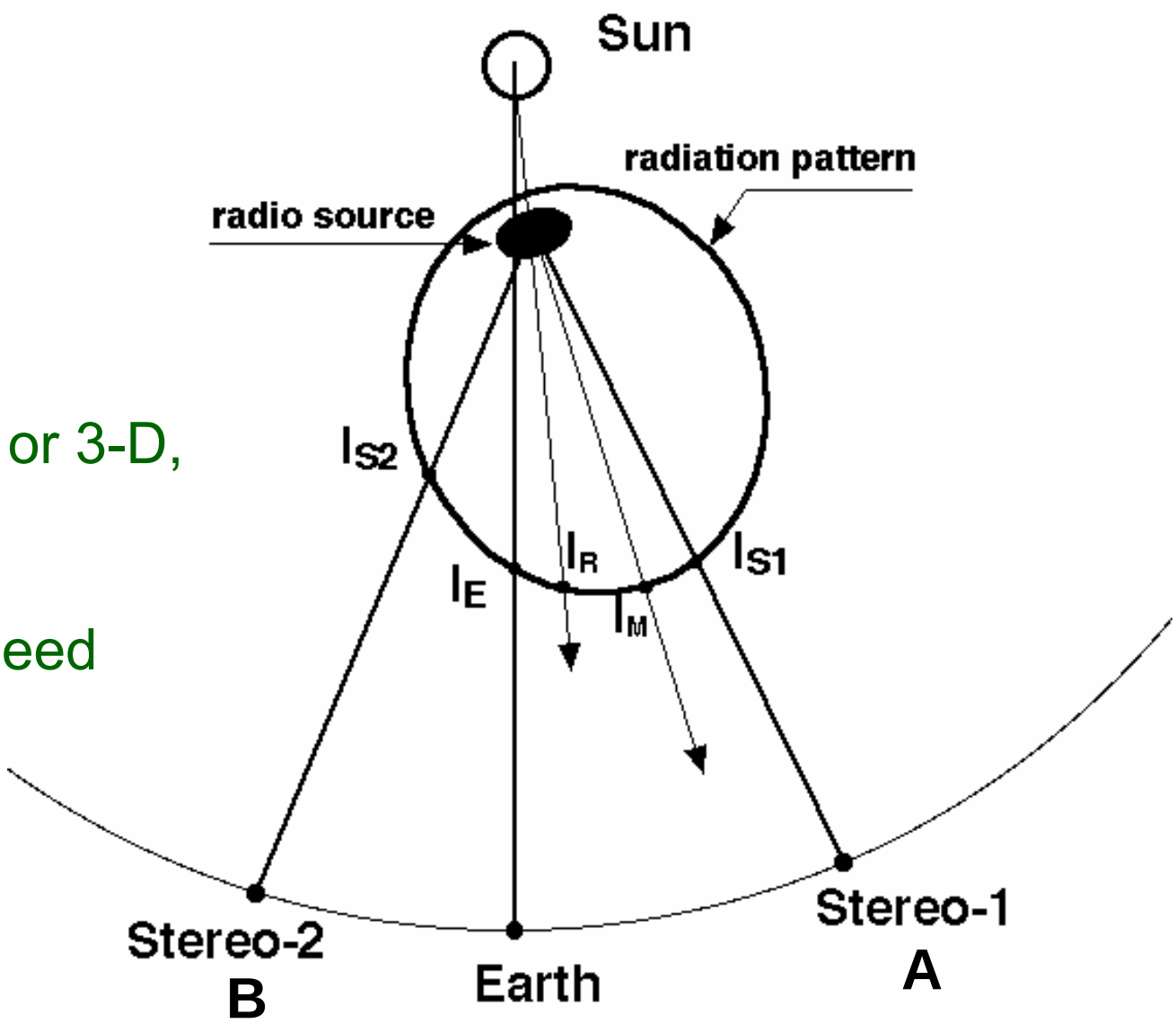
- Frequency Domain - 2.5kHz to 16MHz
  - Low Frequency Receiver (LFR)
    - 1 channel, 3 bands (160kHz-40kHz), (40kHz-10kHz), (10kHz-2.5kHz)
    - 1 channel, 2 bands (160kHz-40kHz), (40kHz-10kHz)
  - High Frequency Receiver (HFR)
    - 2 channels, 125kHz to 16.025MHz in 319 steps of 50kHz (picket fence)
- Fixed Frequency Receiver (FFR)
  - 1 channel, 30MHz or 32MHz
- Time Domain - 30mHz to 125kHz
  - Time Domain Sampler (TDS) has 4 wideband burst channels
    - Snapshots sampled at up to 250,000 samples/second/channel
    - 16Mbits/second acquired (24by7), **much** less sent to the ground
  - Interval Max - 4 channels
  - LWS histogram
  - Low rate science (64S/s)
- Sensors
  - 3 orthogonal electric antennas

- S/WAVES package is **identical** on both spacecraft

# Radio stereoscopy

For radio waves,
"STEREO"
means a lot more
than triangulation or 3-D,

but triangulation
remains a basic need



# Radio stereoscopy : Parameters and methods

- **basic physical parameters :**
  - Detailed radiation pattern
  - 3-D localization of radio sources + propagating effects
  - group delays
- **measured parameters:**
  - radio intensity ----> directivity
  - polarization ----> directivity of modes, propagation
  - time-of-flight ----> localization, group delays
  - dynamic spectrum ----> radiation mecanism / propagation
  - source direction ----> triangulation, propagation
  - source diameter ----> source structure, propagation
- **methods :**
  - dispersive diagrams of intensities
  - statistical analyses as a function of the stereo angle
  - triangulation
  - Study of time-of-flights
  - Correlation studies (in situ plasma, coronagraphs, imagers, ground data)

# Radio stereoscopy

- Results have been sometimes surprising :
  - strong directivity (beaming ≈ 15° at HF, 50° at LF)
  - Non radial orientation of the beam patterns
  - Evaluation of time-of-flight and group delays

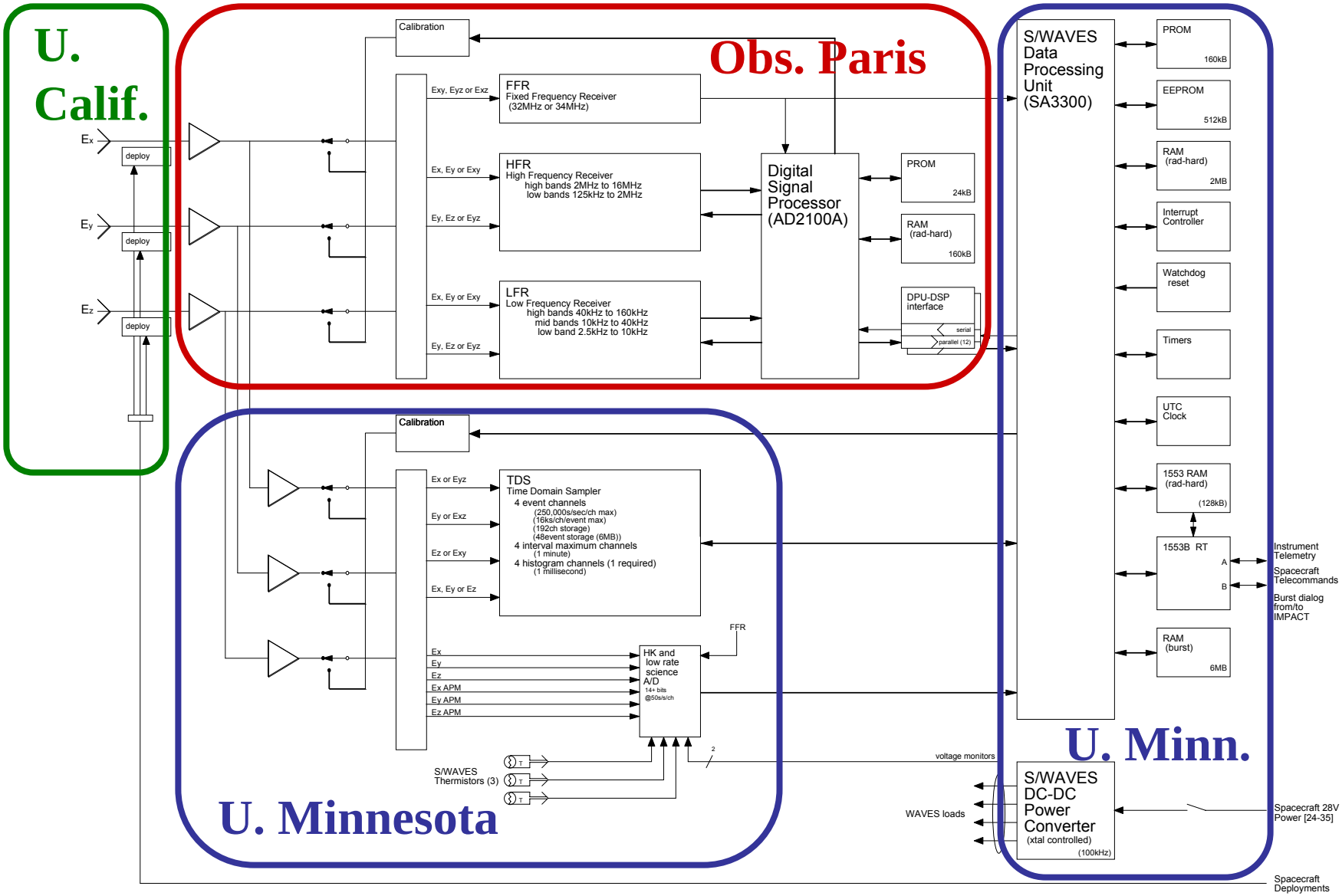
    (often 'anomalous')
  - Radio bursts seen behind the Sun

    (quasi-isotropic halo at low level)
- Very rich diagnostic with many tools

# What can we learn from radio stereoscopy?

- **radio radiation mechanisms** *(S/WAVES / IMPACT)*
  - radiation modes (fundamental and/or harmonic : ambiguity is raised)
  - Wave-particle correlations (micro-physics)
    - constraints on theories
    - local structure and topology of the source
- **type III bursts (energetic electrons)** *(S/WAVES / IMPACT / SECCHI)*
  - Radiation mechanism, association with electron events
  - structure and topology of large scale magnetic fields (mapping)
  - understanding propagation phenomena (weak/strong scattering)
- **type II bursts (shock waves)** *(S/WAVES / IMPACT / SECCHI)*
  - association with Coronal Mass Ejections (3-D localization of the source)
  - formation and evolution of the shock (study of multiple sources)
  - acceleration of energetic particules from the shock
- **interplanetary type III storms (long lasting electr. streams)** *(S/WAVES/SECCHI)*
  - association with Active Regions and Heliospheric Current Sheet (study in 3-D)
  - relaxation of magnetic energy in active regions associated with CMEs

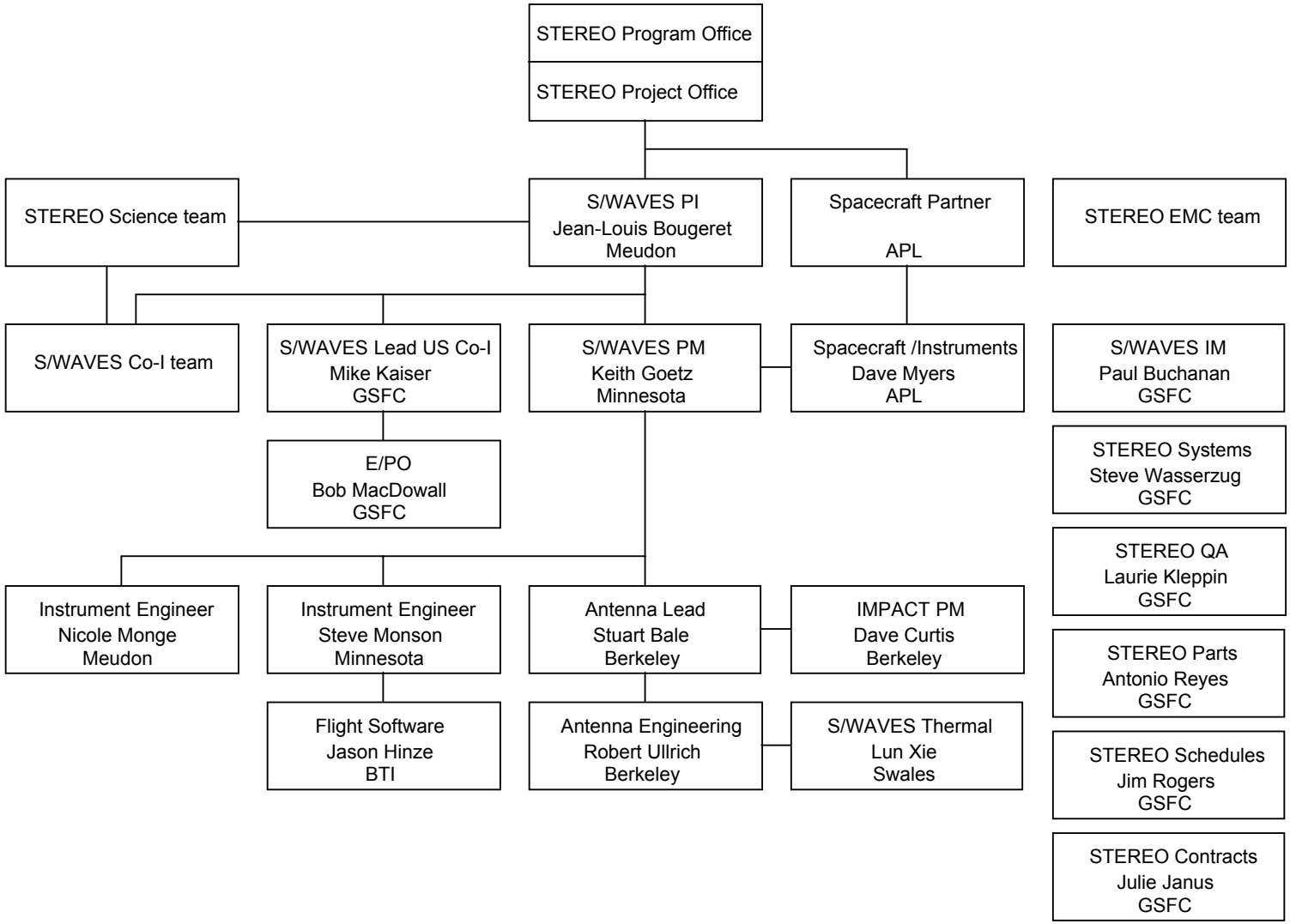
# The S/WAVES instrument



# S/WAVES hardware

- Main electronics package
  - Meudon
    - High Frequency Receiver (FFR, HFR, LFR)
    - Digital Signal Processor
  - Minnesota
    - Time Domain Sampler
    - Data Processing Unit (HK, LRS, FFR)
    - Power Supply
- Antenna Assembly
  - Berkeley
    - Antenna deployment units
    - Antenna mounting plate
  - Meudon
    - Preamplifier electronics
  - Minnesota
    - Preamplifier enclosure
    - Deployment filters
- Ground Support Equipment
  - Minnesota
    - Data acquisition/access/analysis hardware and software
    - Test, analysis and display software
  - Meudon
    - Stimuli hardware
    - Test, analysis and display software
  - Berkeley
    - RF test caps

# S/WAVES team


STEREO Program Office
STEREO Project Office
STEREO Science team
S/WAVES PI
Jean-Louis Bougeret
Meudon
Spacecraft Partner
APL
STEREO EMC team
S/WAVES Co-I team
S/WAVES Lead US Co-I
Mike Kaiser
GSFC
S/WAVES PM
Keith Goetz
Minnesota
Spacecraft /Instruments
Dave Myers
APL
S/WAVES IM
Paul Buchanan
GSFC
E/PO
Bob MacDowall
GSFC
STEREO Systems
Steve Wasserzug
GSFC
STEREO QA
Laurie Kleppin
GSFC
Instrument Engineer
Nicole Monge
Meudon
Instrument Engineer
Steve Monson
Minnesota
Antenna Lead
Stuart Bale
Berkeley
IMPACT PM
Dave Curtis
Berkeley
STEREO Parts
Antonio Reyes
GSFC
Flight Software
Jason Hinze
BTI
Antenna Engineering
Robert Ullrich
Berkeley
S/WAVES Thermal
Lun Xie
Swales
STEREO Schedules
Jim Rogers
GSFC
STEREO Contracts
Julie Janus
GSFC

# Resources

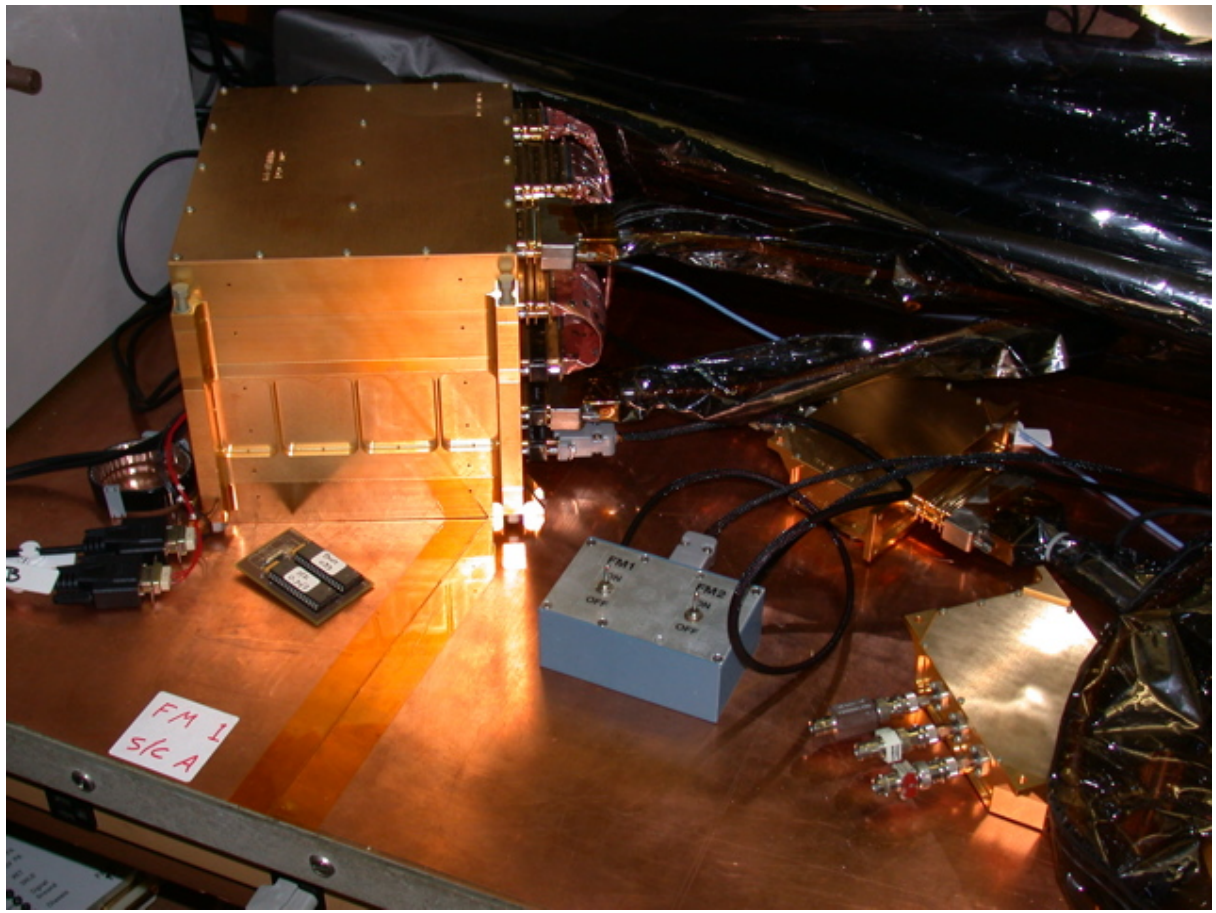
- All resources are probably in acceptable shape

- Mass 13.23kg against 14.1kg delivery NTE
- Power 15.4W against 14.0W delivery NTE - 1.4W
- Bit rate 1,916b/s against 2,037b/s minimum allocation

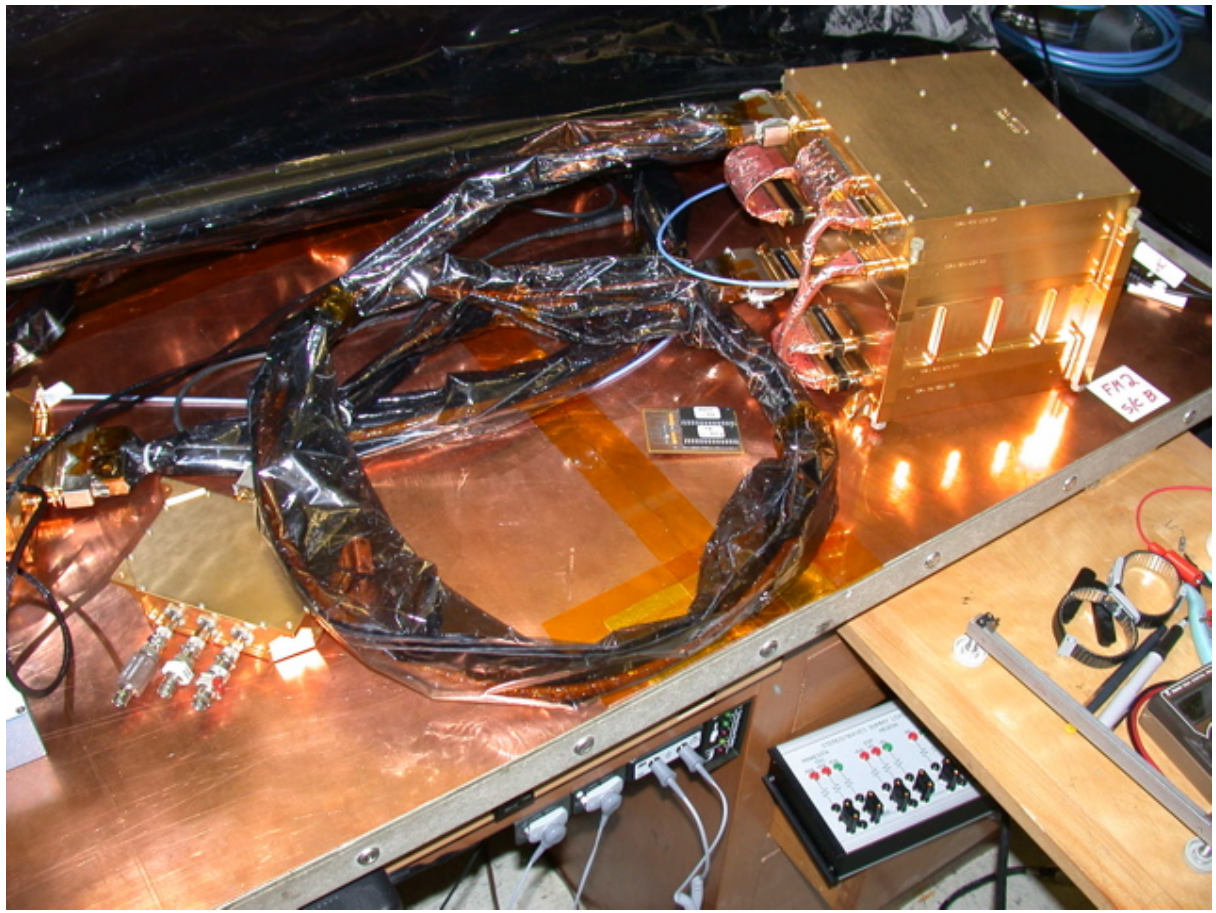
- Schedule no slack - APL is waiting
- Dollars Program is fully funded, slightly under budget
- Euros French program is fully funded

- Power has crept up
  - A request for a power increase is in process - no problem
  - Current value has been reported to our S/C partners at APL

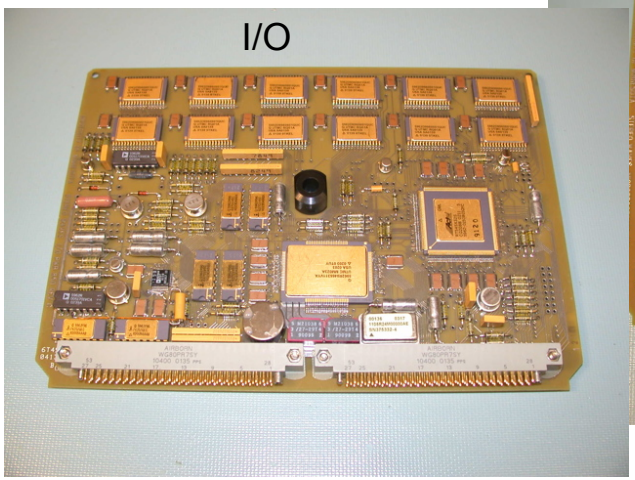
# Receiver - FM1

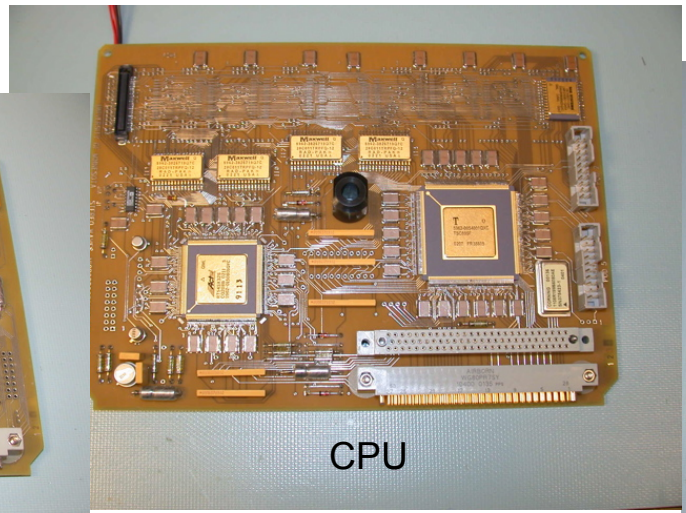


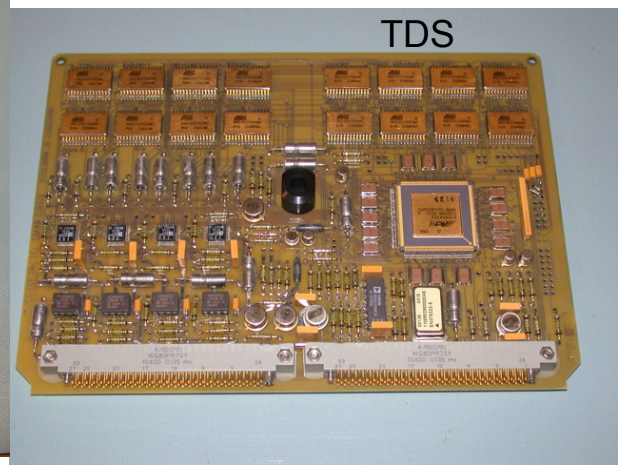
# Receiver - FM2

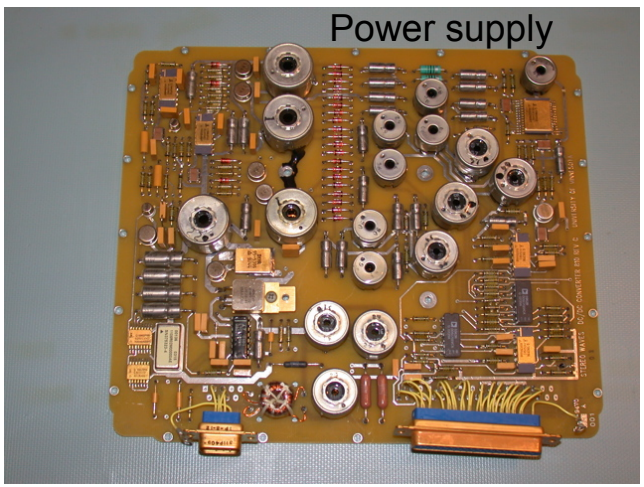


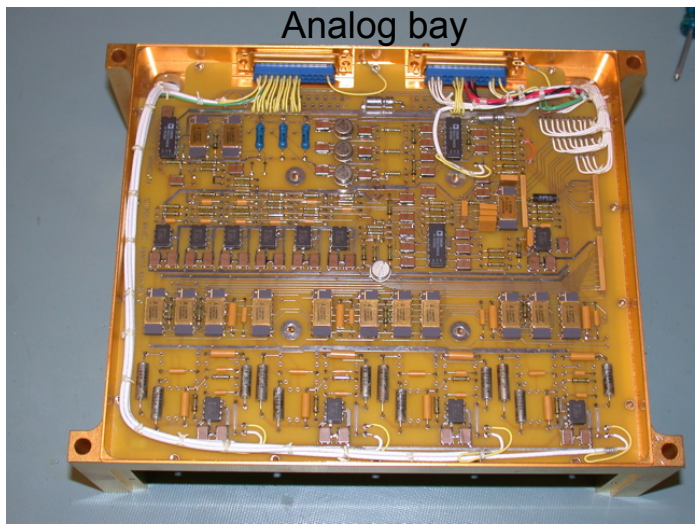
# Insides


I/O

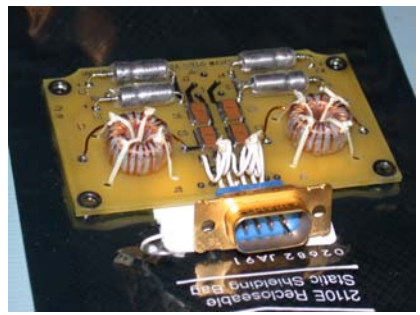

CPU


TDS

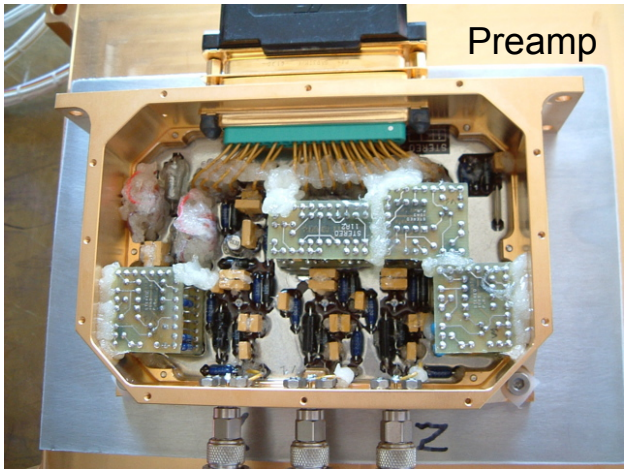

Power supply

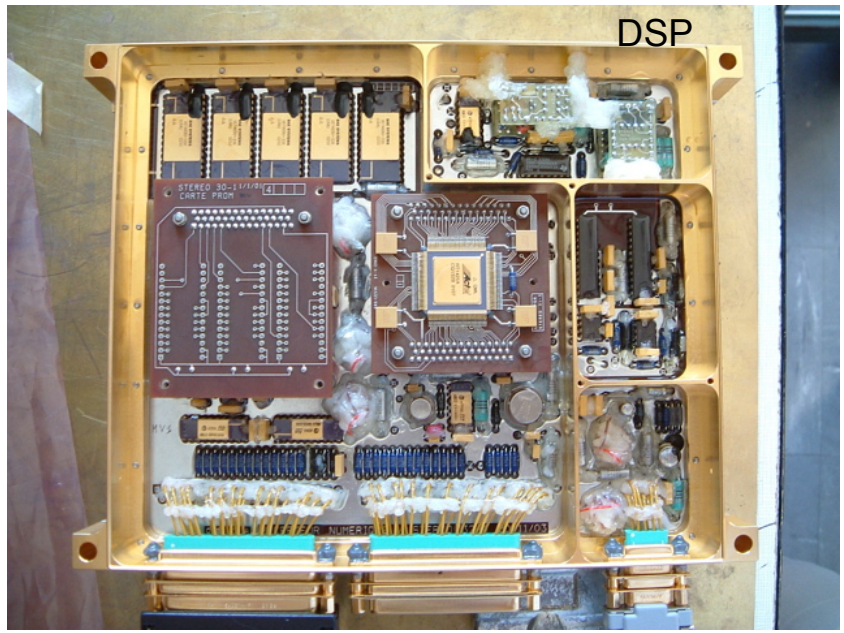

Analog bay

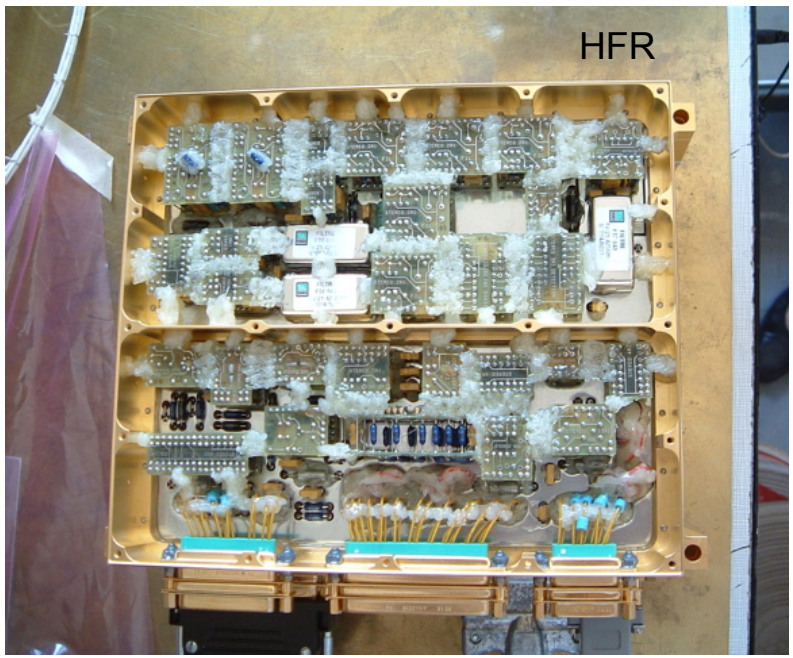
Antenna filter

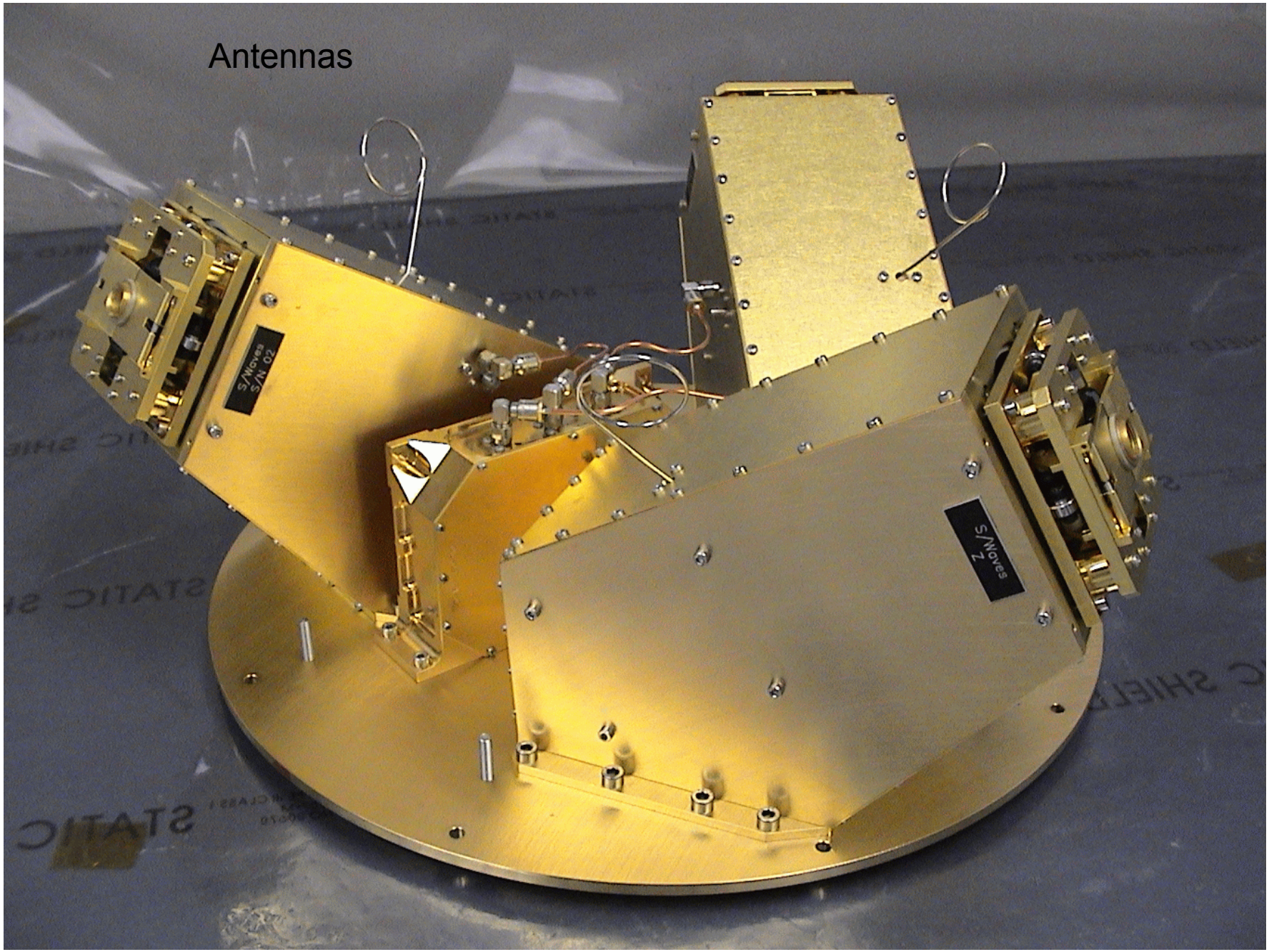


# And more

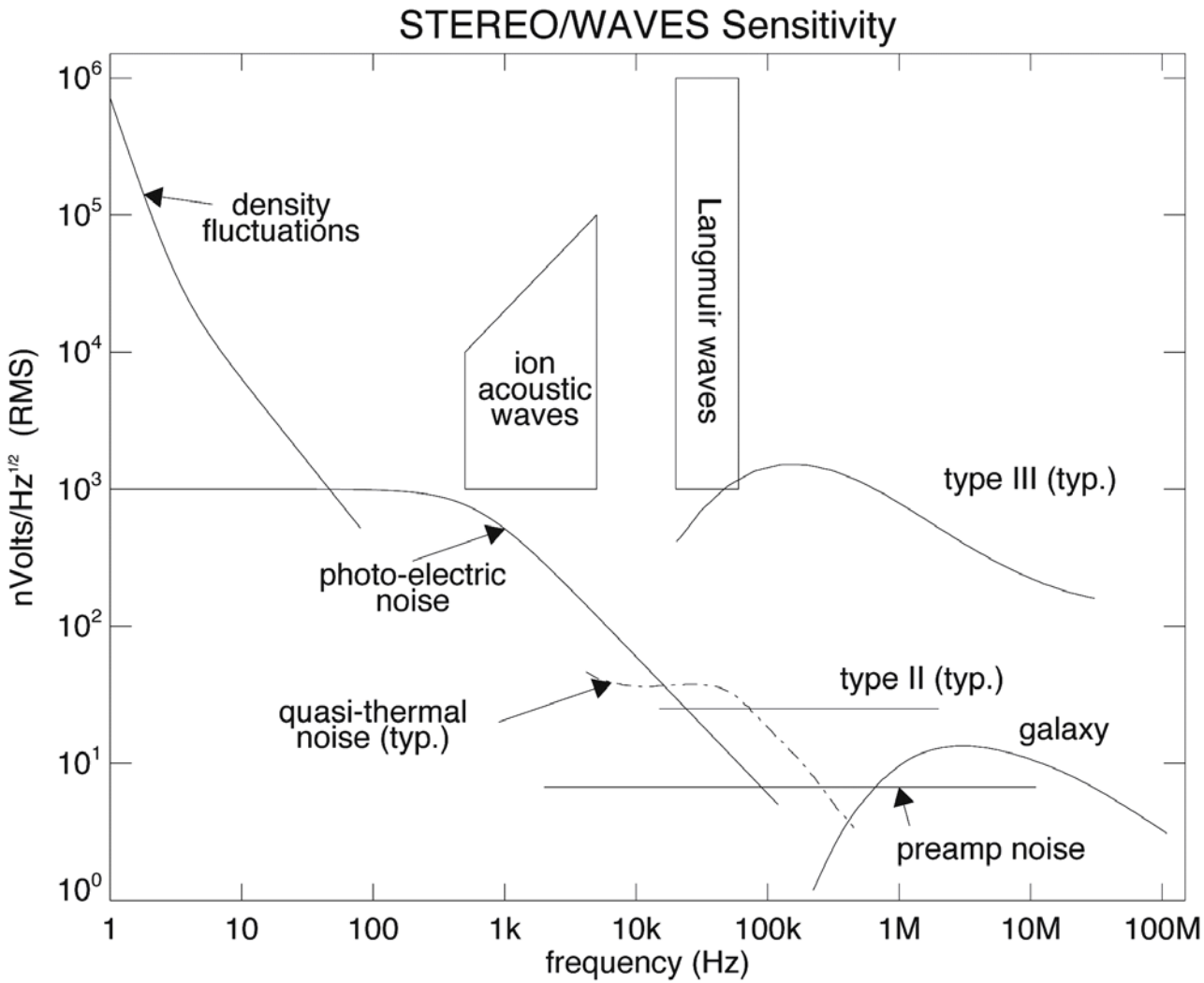


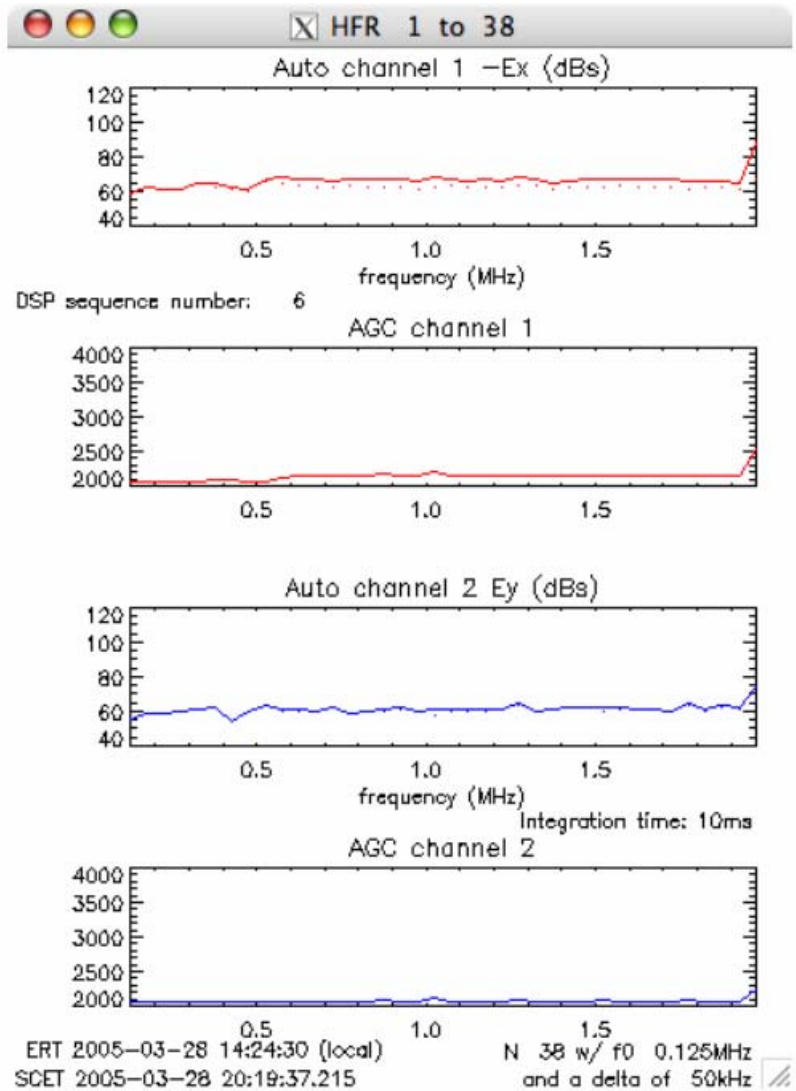




Antennas
S/Waves
S/N 02
S/Waves
Z

# Sensitivity



# HFR1


HFR 1 to 38
Auto channel 1 −Ex (dBs)
120
100
80
60
40
0.5
1.0
1.5
frequency (MHz)
DSP sequence number: 6
AGC channel 1
4000
3500
3000
2500
2000
0.5
1.0
1.5
Auto channel 2 Ey (dBs)
120
100
80
60
40
0.5
1.0
1.5
frequency (MHz)
Integration time: 10ms
AGC channel 2
4000
3500
3000
2500
2000
0.5
1.0
1.5
ERT 2005-03-28 14:24:30 (local)
SCET 2005-03-28 20:19:37.215
N 38 w/ f0 0.125MHz
and a delta of 50kHz

# S/WAVES Sensitivity

| Subsystem | Sensitivity/dB Requirement | Sensitivity Goal | Sensitivity Obtained |
|---|---|---|---|
| FFR | 5μV/56dB | 500nV | 4μV/40dB |
| HFR1/2 | 1.6μV/70dB | <1μV | .7μV/80dB |
| LFR C | 1.6μV/80dB | 1μV | .4μV/90dB |
| LFR B | 1.6μV/80dB | 1μV | .4μV/104dB |
| LFR A | 1.6μV/80dB | 1μV | .4μV/106dB |
| TDS | NA/72dB | NA/96dB | 30μV/72+dB |
| LRS | 100μV/72dB | 6μV/96dB | 22μV/75+dB |

# SWAVES Current Status

- Both receivers are complete and work very well
- SWAVES PER held April 4, 2005 - minor RFAs
- Vibration/EMC/Mag testing completed with no problems
  - Bake-outs were all very clean
  - Magnetics were clean too
- Thermal vacuum exposed some problems
  - VCOs in radio receivers (both units) failed at high temperature (qualification temp lowered)
  - Flight unit 2 seems to have an FPGA problem
  - Flight unit 1 needs circuit breaker tuning
- Both units back to U of Minnesota for rework
  - FM1 back to GSFC in about a week and then APL
  - FM2 a couple of weeks later

3D

HAMBURG


Ed. "Les Editions en Anaglyphes", Imprimerie Aulard, Paris 1937