Helios „Näher an die Sonne ran“

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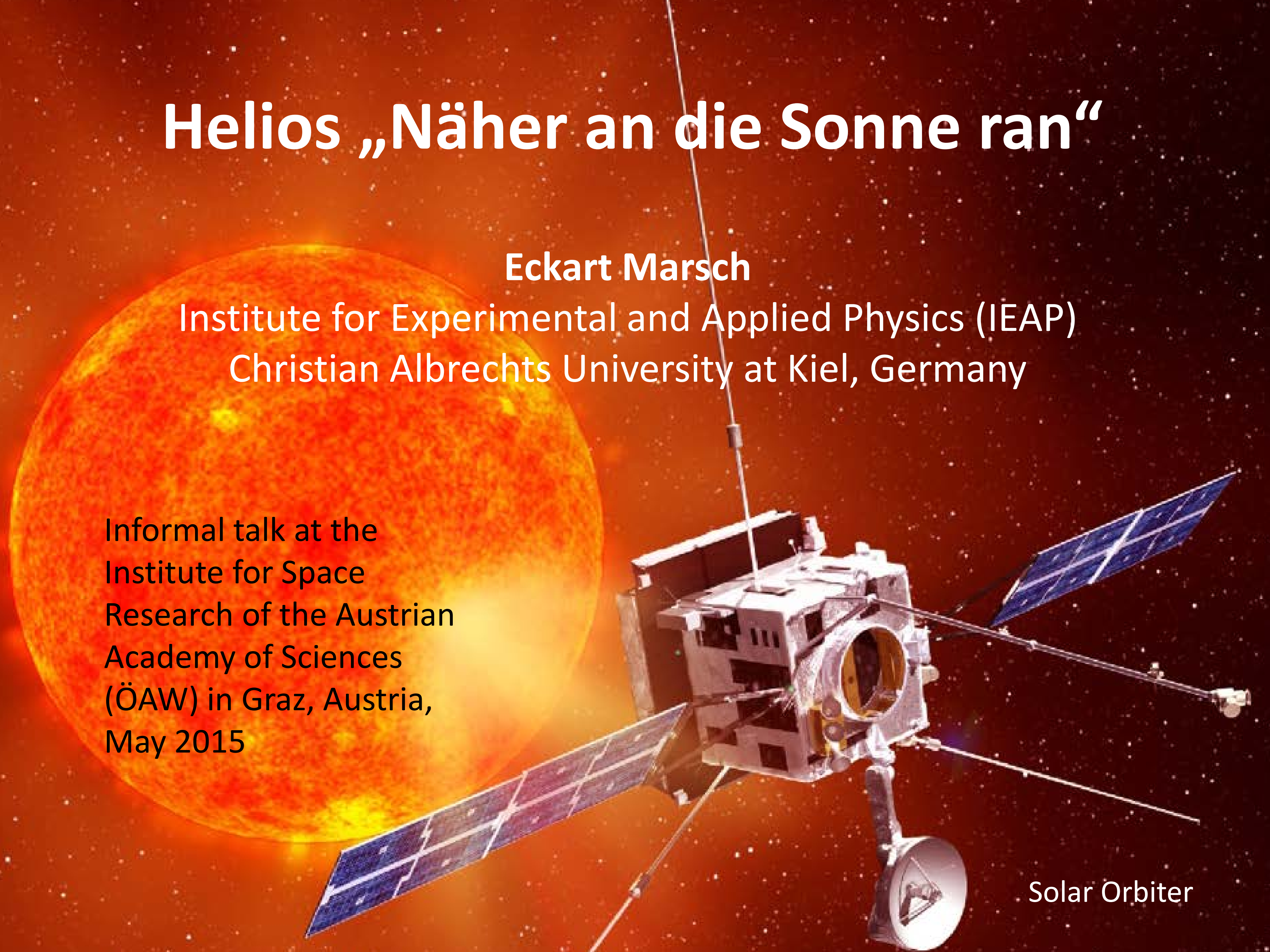
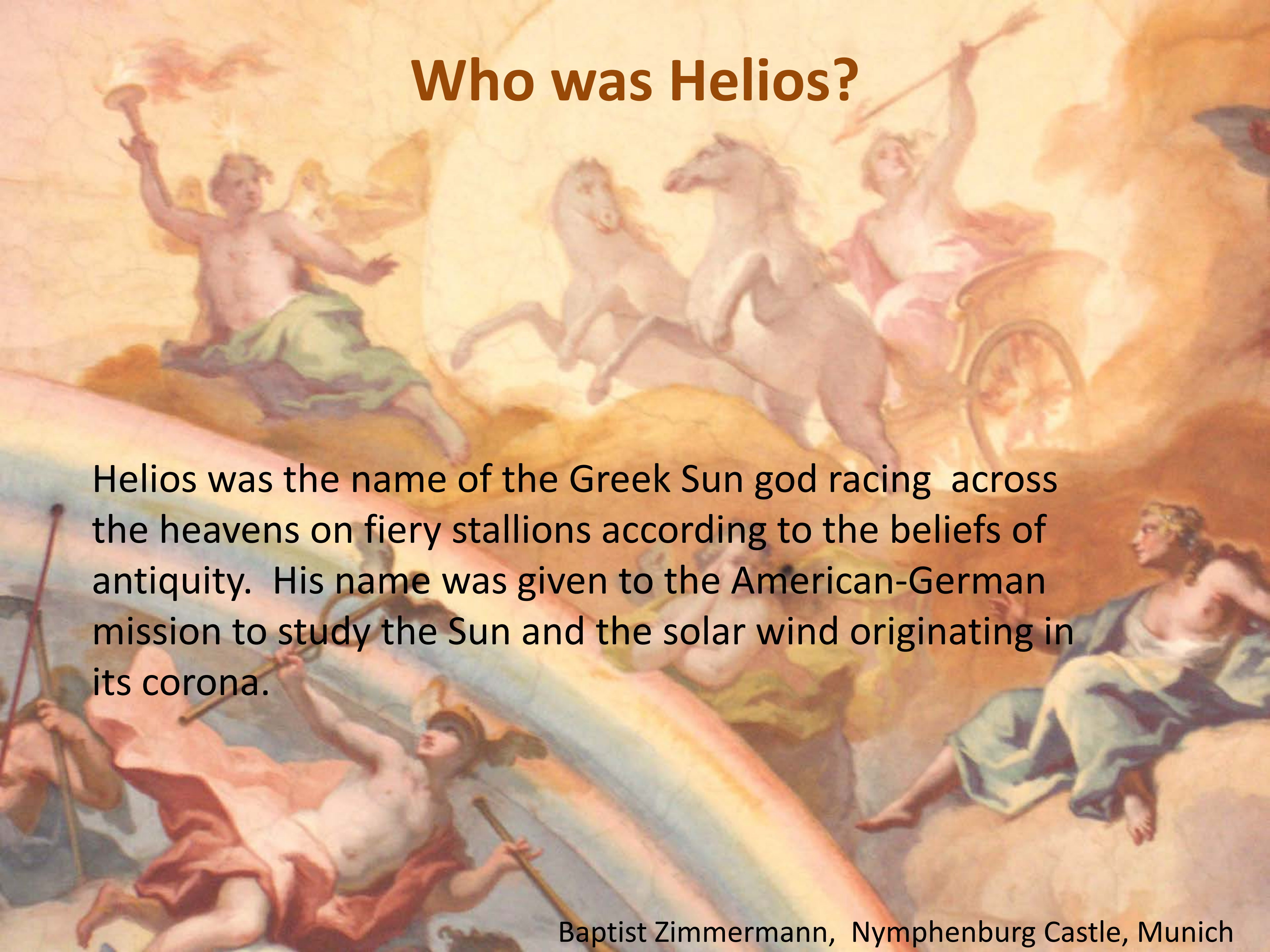
Informal talk at the Institute for Space Research of the Austrian Academy of Sciences (ÖAW) in Graz, Austria, May 2015



Solar Orbiter

Who was Helios?



Helios was the name of the Greek Sun god racing across the heavens on fiery stallions according to the beliefs of antiquity. His name was given to the American-German mission to study the Sun and the solar wind originating in its corona.

Baptist Zimmermann, Nymphenburg Castle, Munich

Key objectives of the Helios program

- To provide German and US scientists the opportunity of designing and flying an integrated set of experiments aimed at investigations of the properties and processes in interplanetary space by approaching the sun to 0.3 AU;
- To advance the managerial and technological expertise of Germany, thus progressing to more advanced equipment, better techniques and sophisticated experiments;
- To develop German capabilities for the solution of major problems in space science and technology

Space probe and launcher

A *Helios* probe being encapsulated for launch.

Helios-1 sitting atop the Titan IIIE/ Centaur launch vehicle.

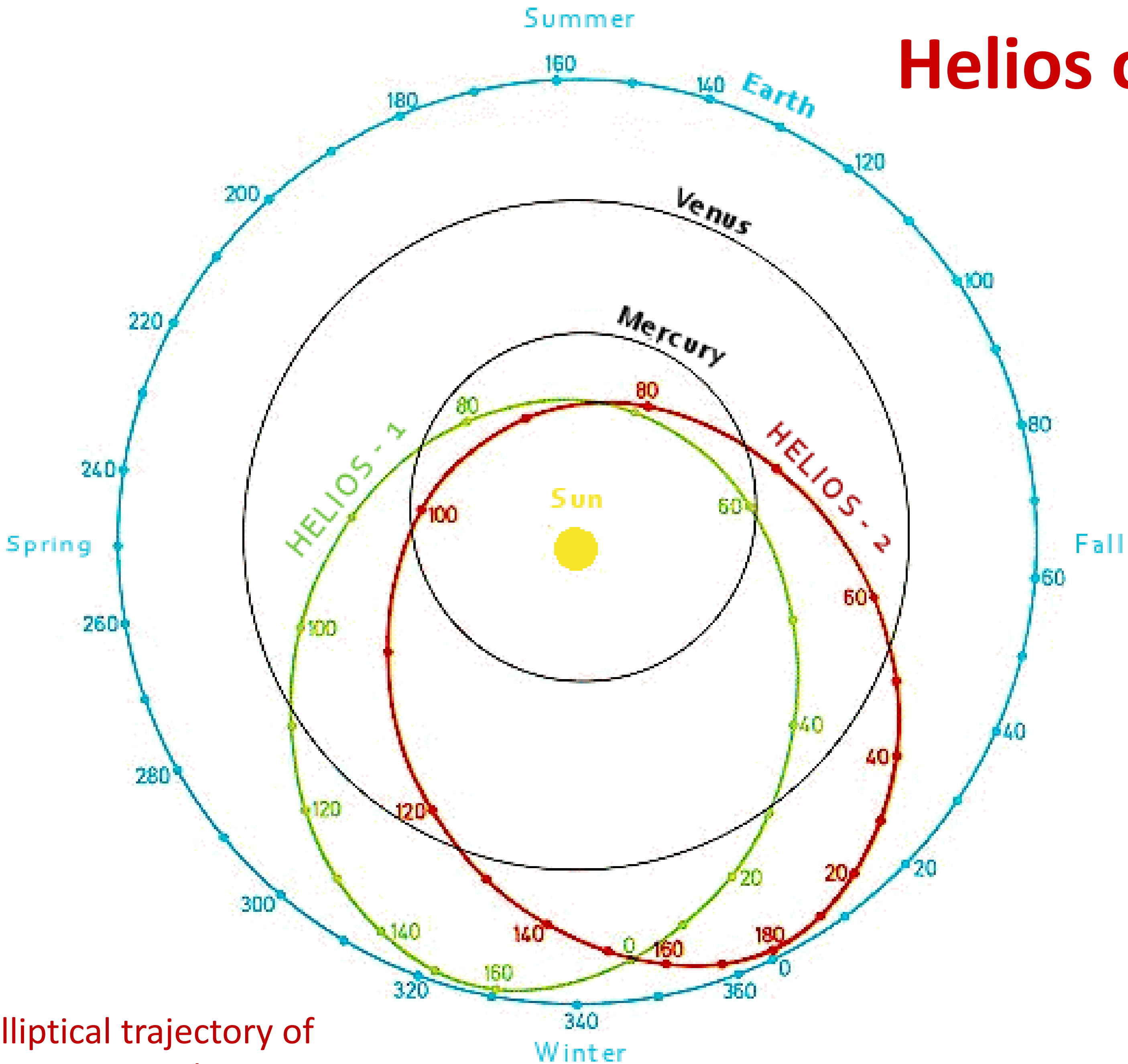
General aspects of the Helios mission

- Helios was an American-German twin-space-probe mission to investigate the innermost part of interplanetary space (inner heliosphere) and the solar influences (space weather) on the interplanetary medium.
- Two nearly indentical, but oppositely spinning (spin of Helios 1 pointing north and Helios 2 south), spacecraft were launched into highly elliptical orbits with low perihelia, for Helios 1 at 0.31 AU and Helios 2 at 0.29 AU.
- These orbits were designed to provide the opportunity to separate spatial and temporal effects, to cover ± 7.5 degree of solar latitude, and to study radial gradients (0.3--1 AU) and phenomena (particles and fields) travelling outward from the Sun.

Mission characteristics

Operator	NASA/ FRG
Major contractor	MBB (now part of EADS)
Mission type	Orbiters
Launch date	**Helios-1 :** 1974-12-10 07:11:02 UTC (about 41 years ago) **Helios-2 :** 1976-01-15 05:34:00 UTC (about 39 years ago)
Launch vehicle	Titan IIIE / Centaur
Launch site	Space Launch Complex 41 Cape Canaveral Air Force Station
Mission duration	**Helios-1 :** January 16, 1975 --- February 18, 1985 **Helios-2 :** July 21, 1976 --- December 23, 1979

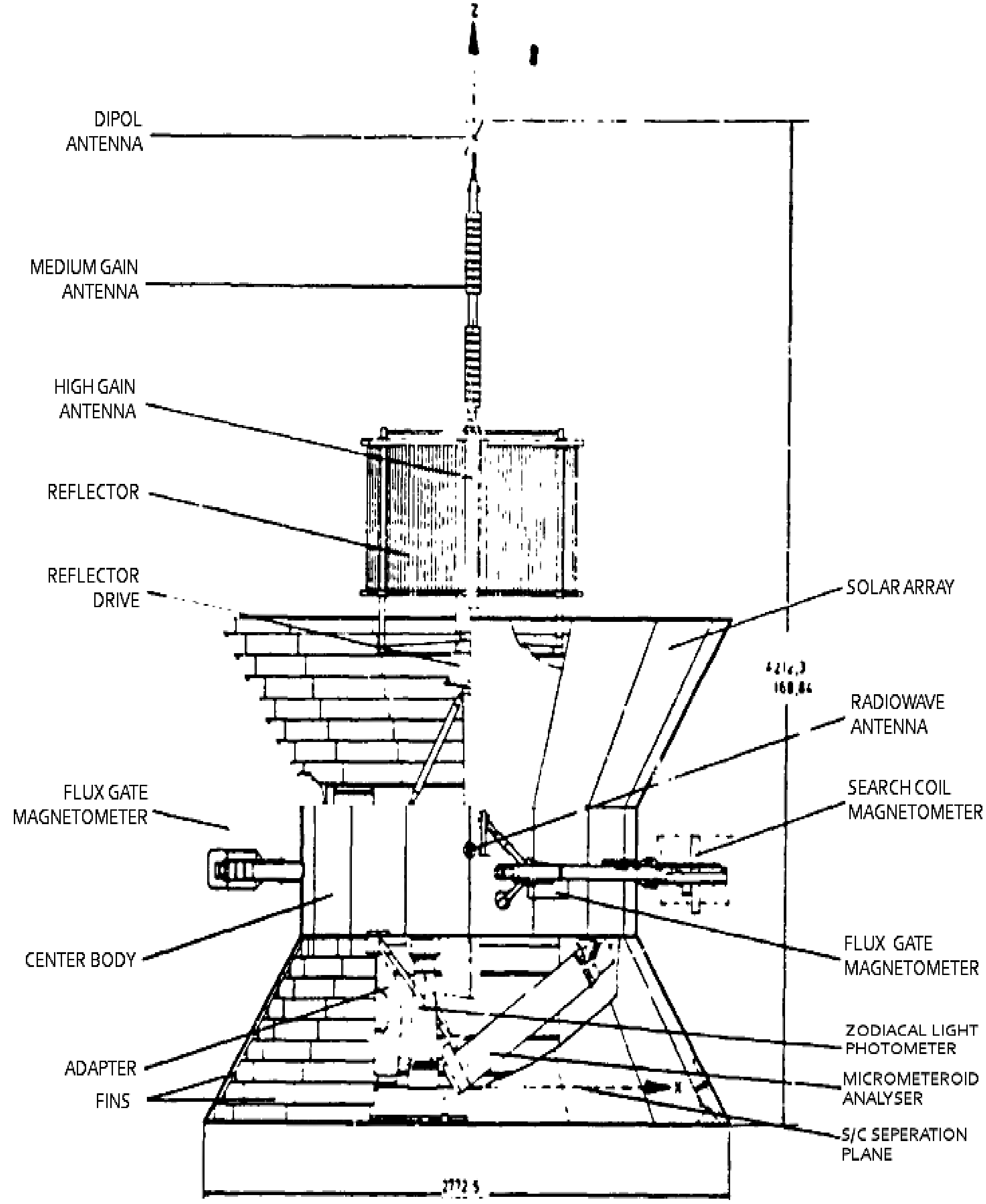
Helios orbits



Highly elliptical trajectory of the Helios space probes

Helios spacecraft

Helios launch configuration



Instruments and measurements

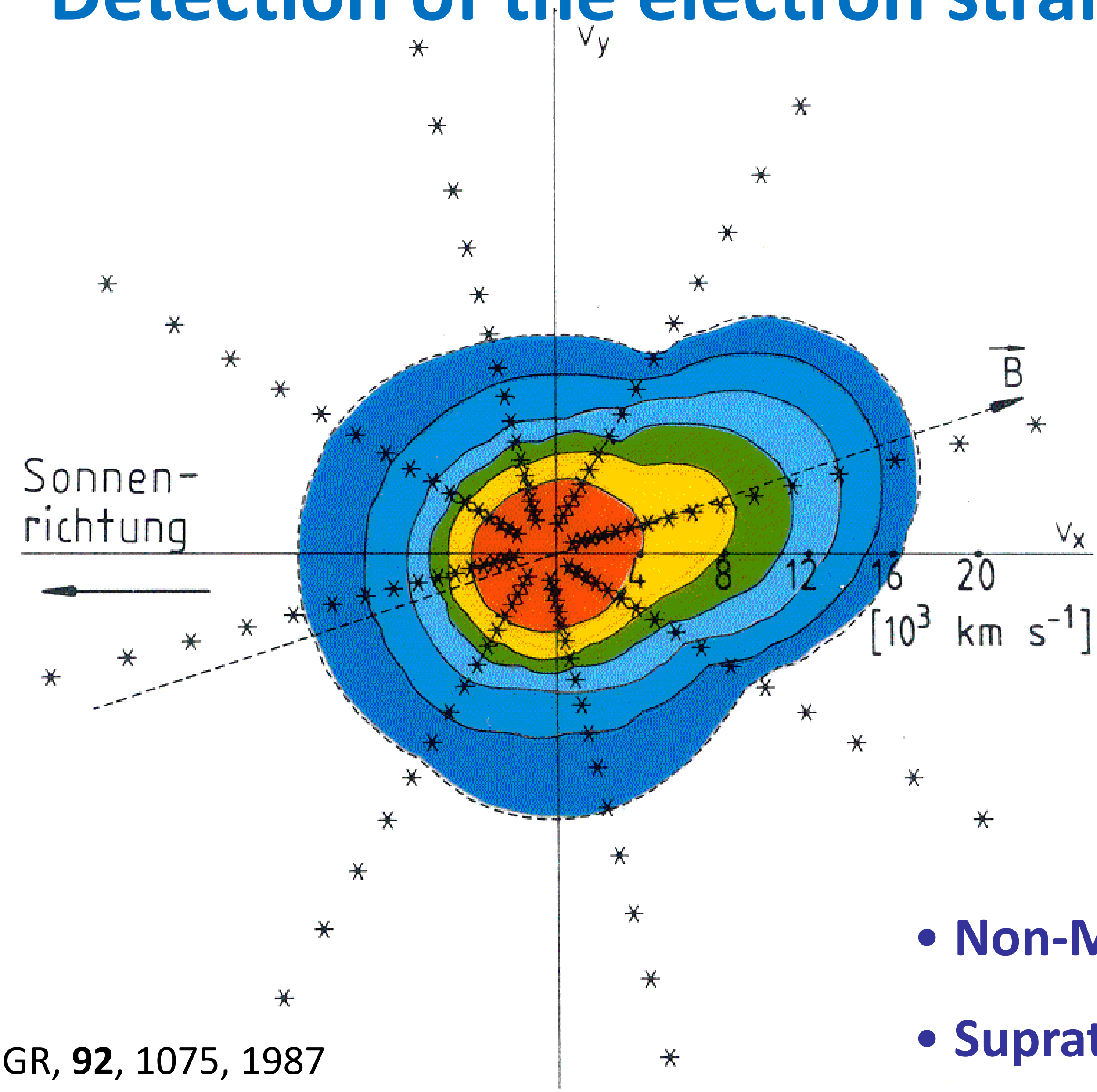
Investigation	Principal Investigator	Measurements
Flux-Gate Magnetometer	(1) Musmann, Neubauer, (2) Mariani, Ness	Magnetic field strength and direction of low-frequency magnetic fields in the inner heliosphere
Search-Coil Magnetometer	Dehmel, Neubauer	Complement of the Flux-Gate Magnetometer by measuring the magnetic field fluctuations up to 3 kHz
Plasma Particles	Rosenbauer, Schwenn	Velocity distribution functions of solar wind protons, alpha-particles and electrons
Plasma Waves	(1) Gurnett, (2) Kellogg	Electric field of plasma waves in the solar wind from 10 Hz to 3 MHz
Cosmic Rays	Kunow, Trainor	Energetic protons, electrons and x-rays to determine the distribution of cosmic rays
Low-Energy Cosmic Rays	Keppler	Higher energy portion of the crossover region between solar wind particles and cosmic rays.
Zodiacal Light Photometer	Leinert	Scattering of sunlight by interplanetary dust particles
Micrometeoroid Analyser	Grün	Composition, charge, mass, velocity and direction of interplanetary dust particles

Selected scientific highlights (plasma)

- Detection of narrow electron strahl
- Rare He^{3+} in ejecta associated with a CME
- Increasing anisotropy of proton temperature
- Evidence for proton pich-angle scattering
- Nonadiabatic radial temperature profiles
- Radial evolution of MHD turbulence
- Intense but intermittent ion acoustic waves
- Preferential heating and acceleration of alphas
- Surfing of alphas on Alfvén waves

Detection of the electron strahl

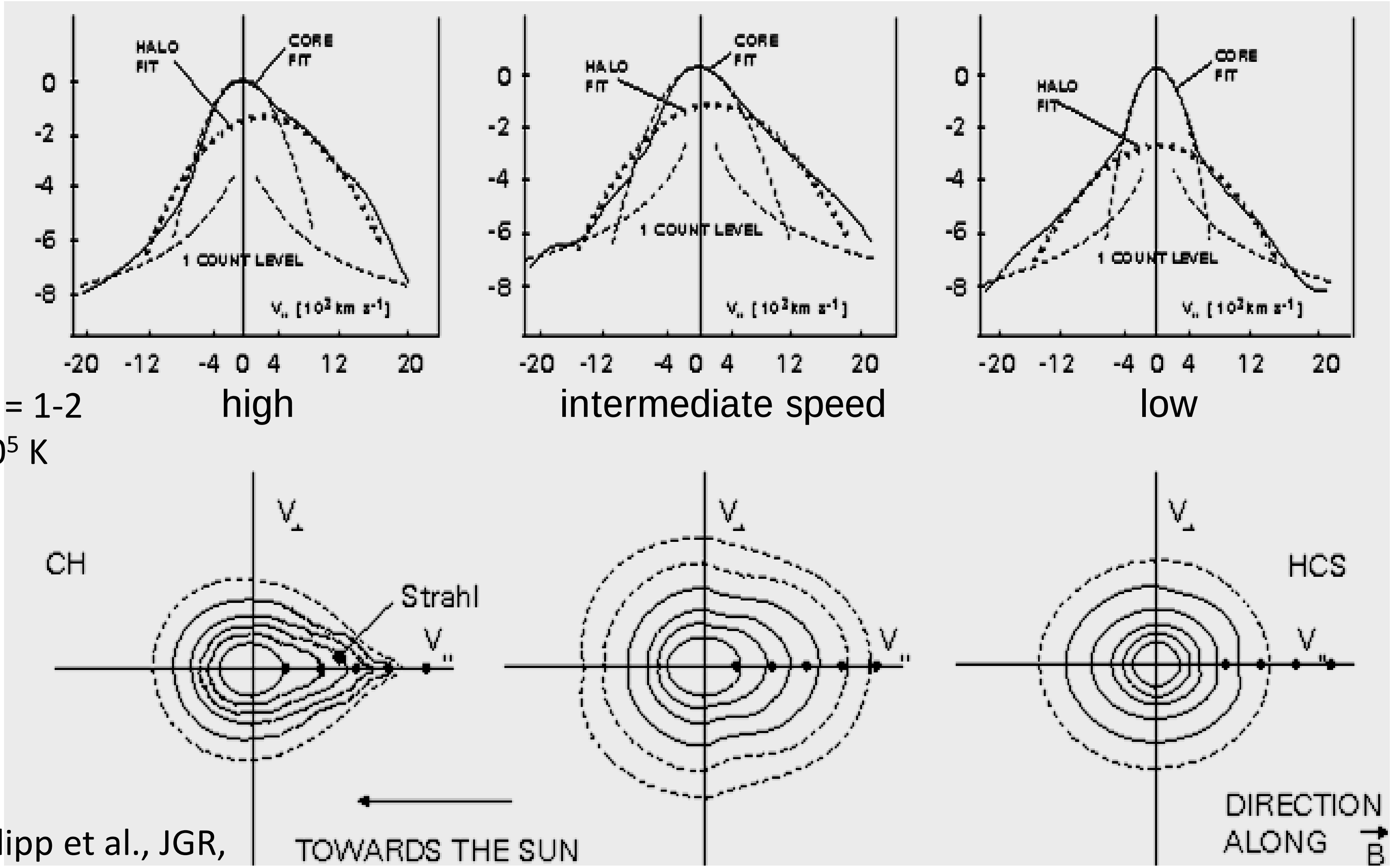
Sun



Pilipp et al., JGR, **92**, 1075, 1987

- **Non-Maxwellian**
- **Suprathermal tail**

Electron velocity distributions



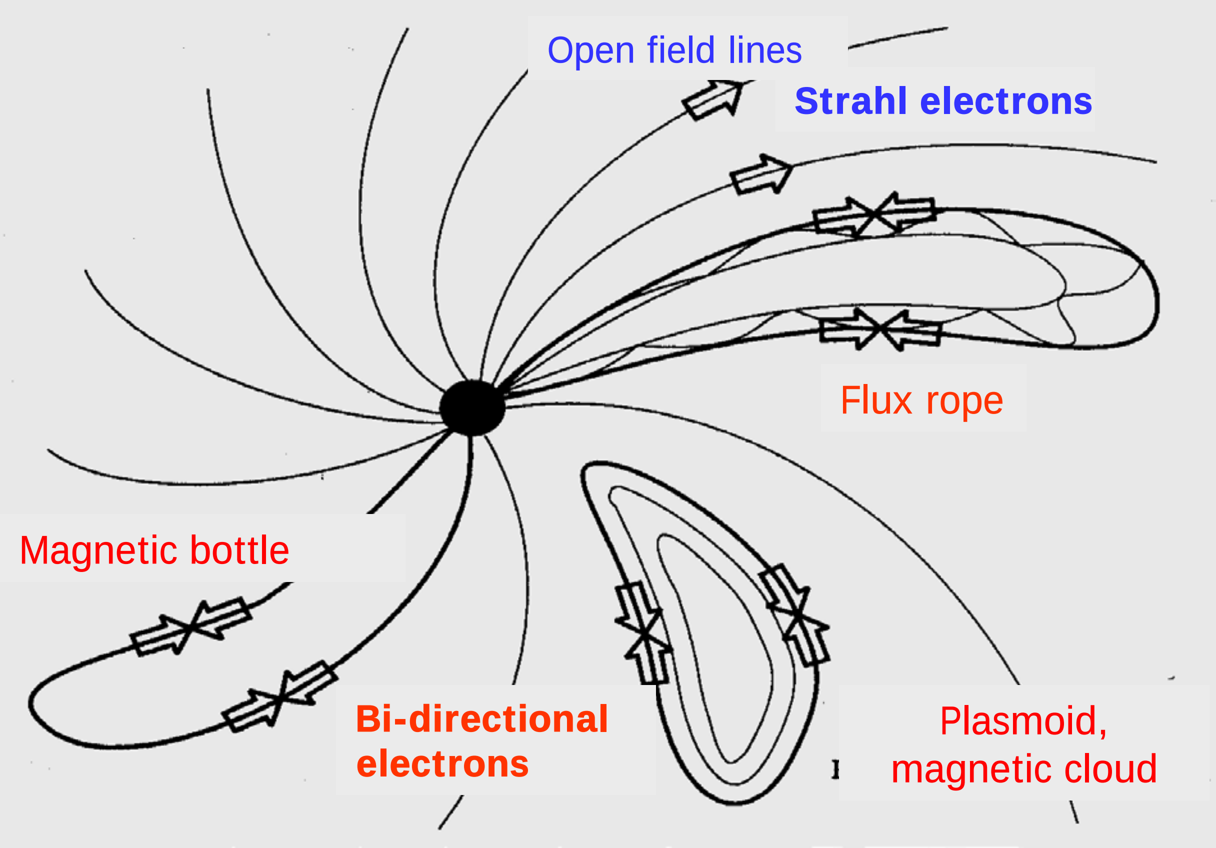
T_e = 1-2 10^5 K

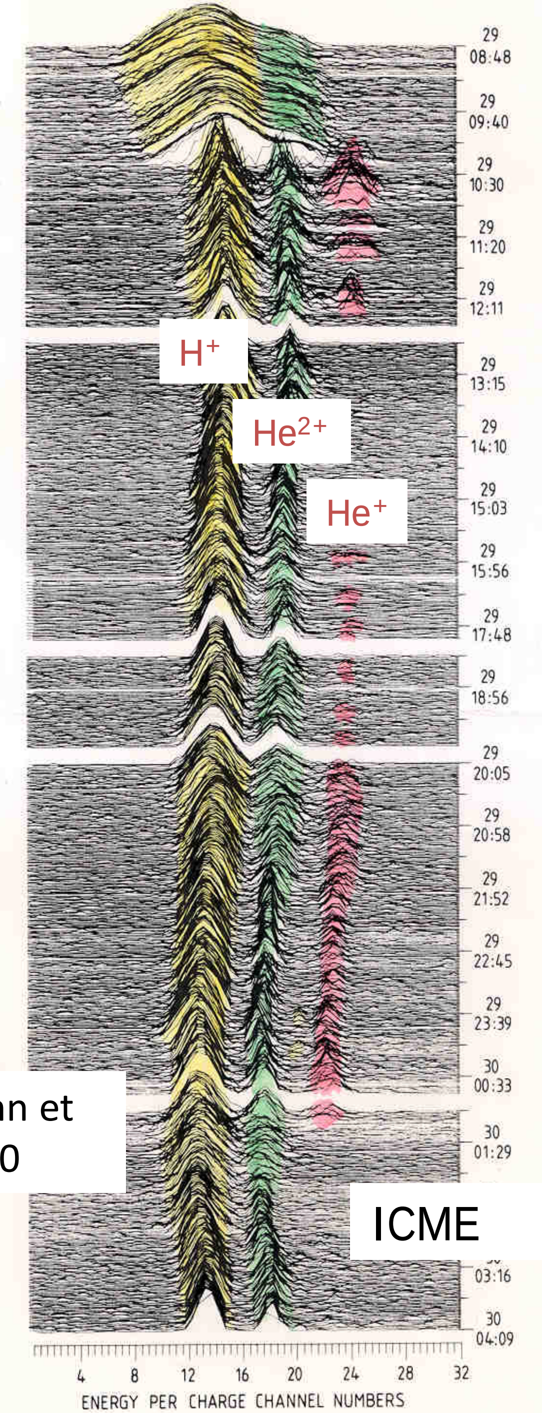
Pilipp et al., JGR, **92**, 1075, 1987

Core (96%), halo (4%) electrons, and the „strahl“

Bi-directional electron heatflux and rare He^+

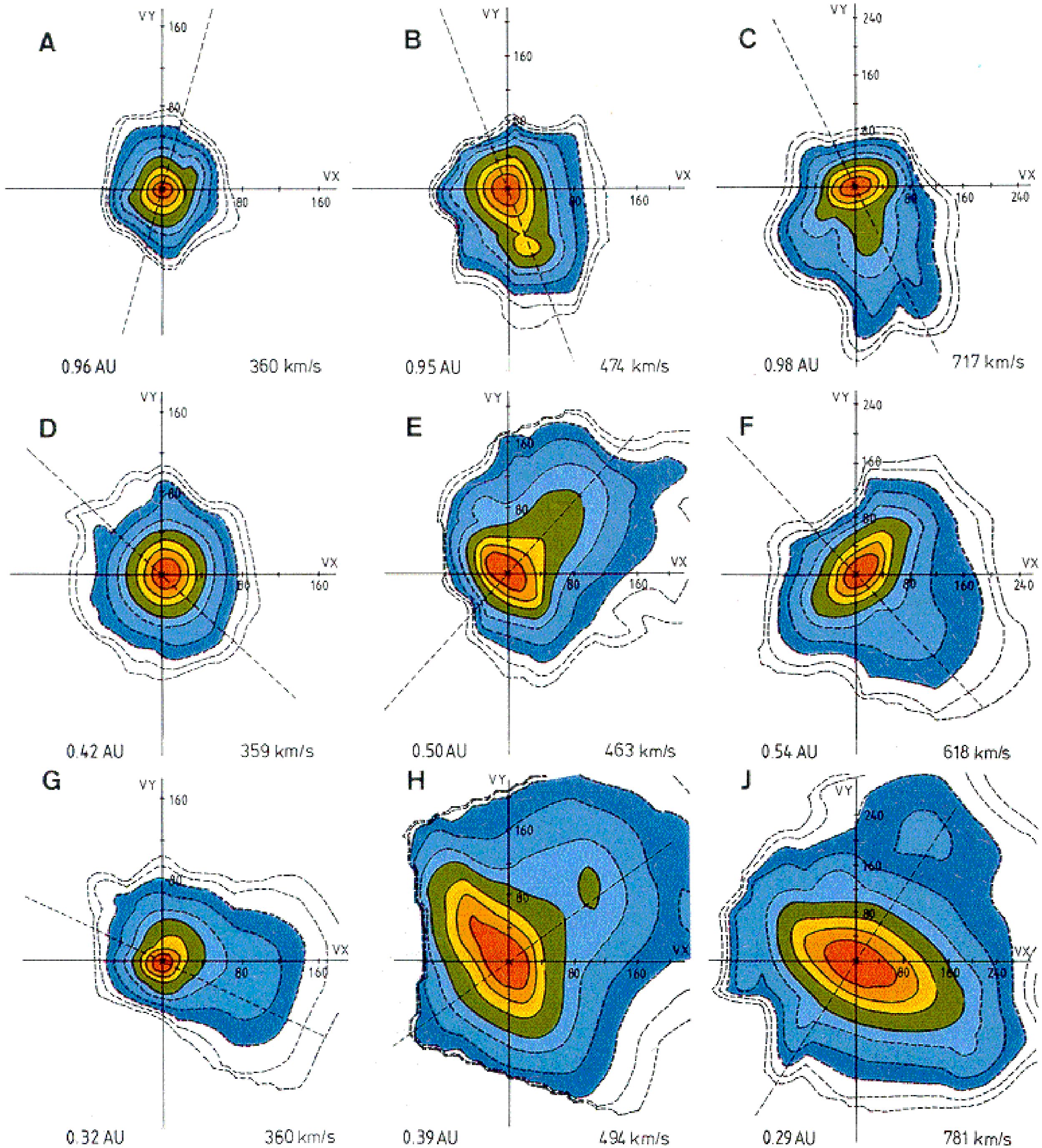
- Palmer et al., 1978, Solar energetic electrons indicate bottle
- Kutchko et al., 1982, Bi-dir. ions and trapped electrons in loop
- Pillipp et al., 1987, Double-strahl solar-wind electrons in loop
- Gosling et al., 1987, Bi-dir. suprathermal electrons in cloud





Schwenn et al., 1970

Proton velocity distributions



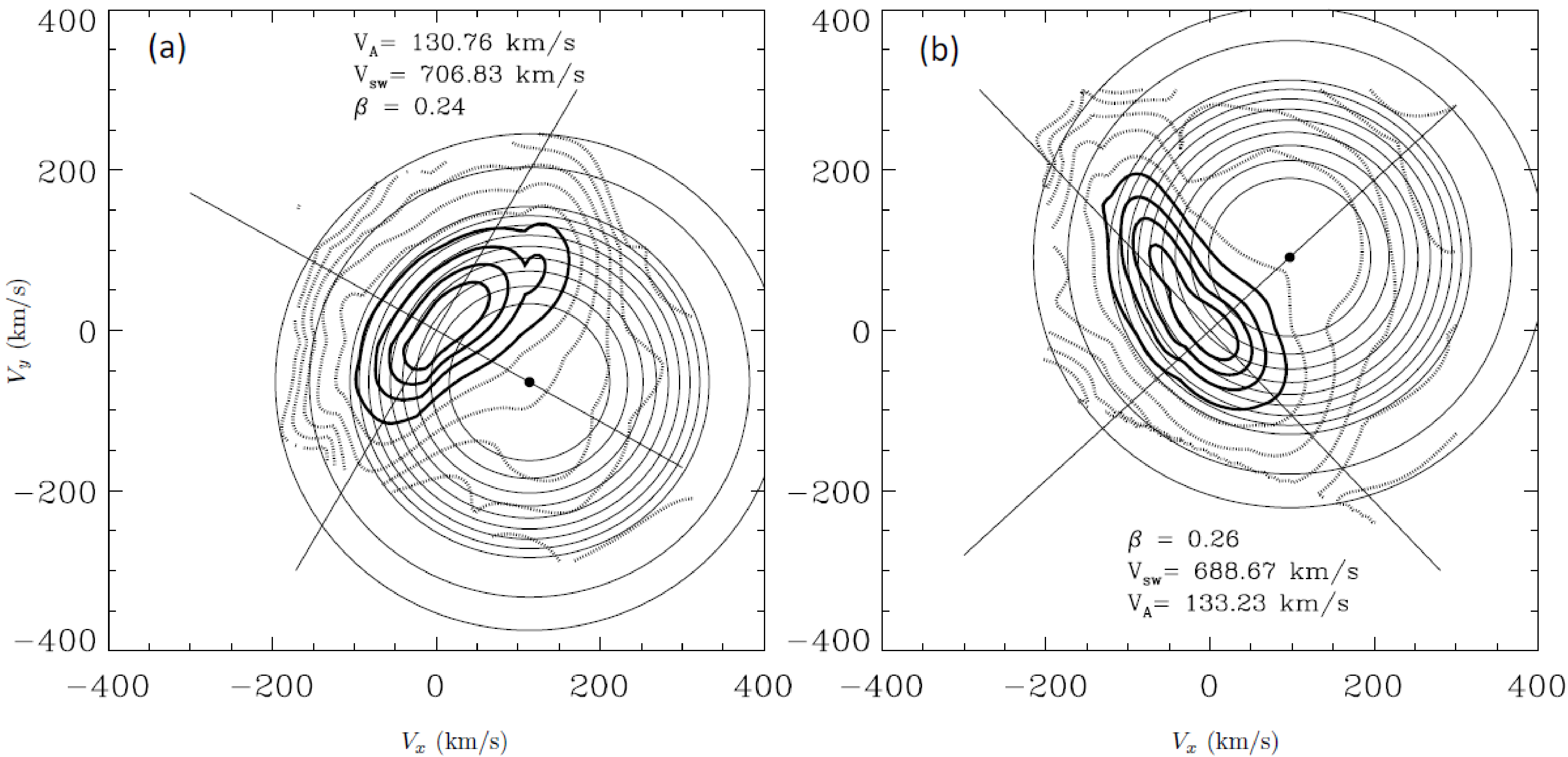
- **Temperature anisotropies**
- **Ion beams**
- **Heat flux tails**
- **Interplanetary heating**

Plasma measurements made at 10 s resolution

(> 0.29 AU from the Sun)

Marsch et al., JGR, **87**, 52, 1982

Proton pitch-angle scattering by waves



$$E(V_\parallel, V_\perp) = \frac{1}{2}\left(V_\perp^2 + V_\parallel^2\right) - \int_0^{V_\parallel} dV_\parallel' C(V_\parallel')$$

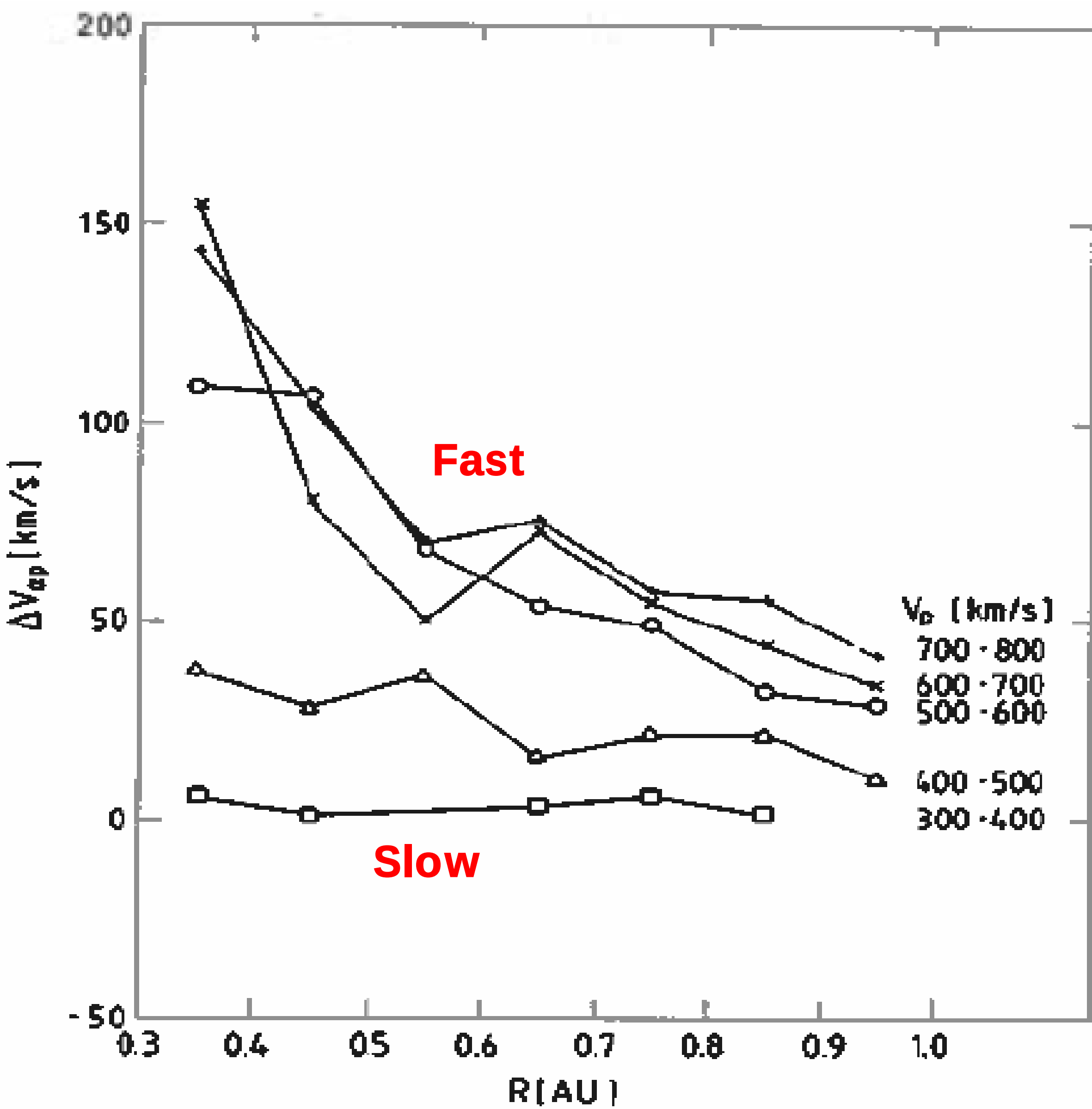
$$\boxed{C(\mathbf{k}) = \omega(\mathbf{k})/k_\parallel}$$

Marsch and Bourouaine, 2011

Wave-ion kinetic interactions

- Beams and temperature anisotropies usually occur in solar wind proton velocity distributions.
- They are manifestations of ubiquitous kinetic wave-ion interactions, which involve cyclotron and Landau resonances with plasma waves.
- Kinetic instabilities and resonant ion diffusion play key roles in the dissipation of MHD turbulence and interplanetary ion heating and differential acceleration.

Ion differential streaming



- **Helios:**

Alpha particles are faster than the protons!

- **In fast streams the differential velocity**

$$\underline{\Delta V} \leq \underline{V_A}$$

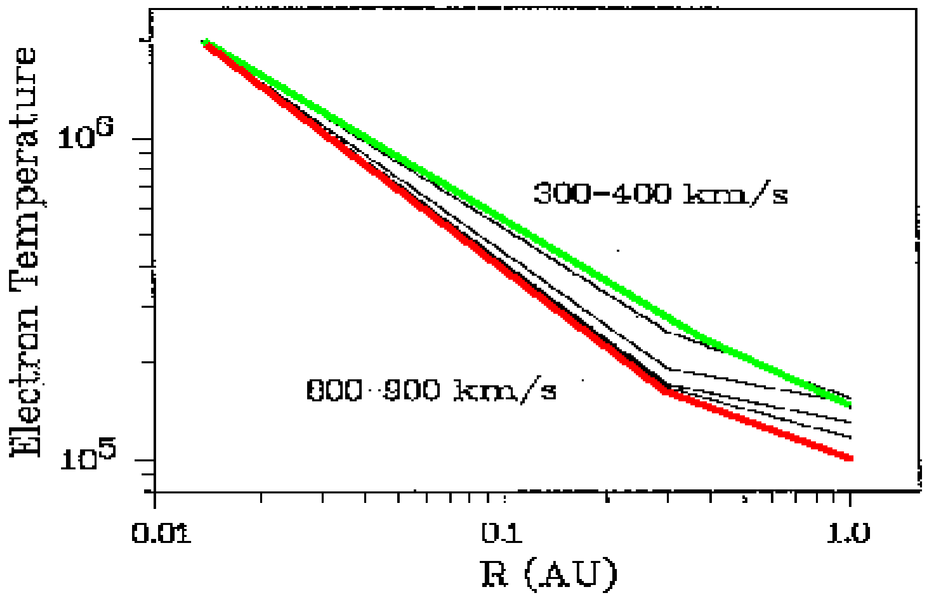
- **Ulysses:**

Heavy ions travel at alpha-particle speed!

Marsch et al., JGR, **87**, 52, 1982

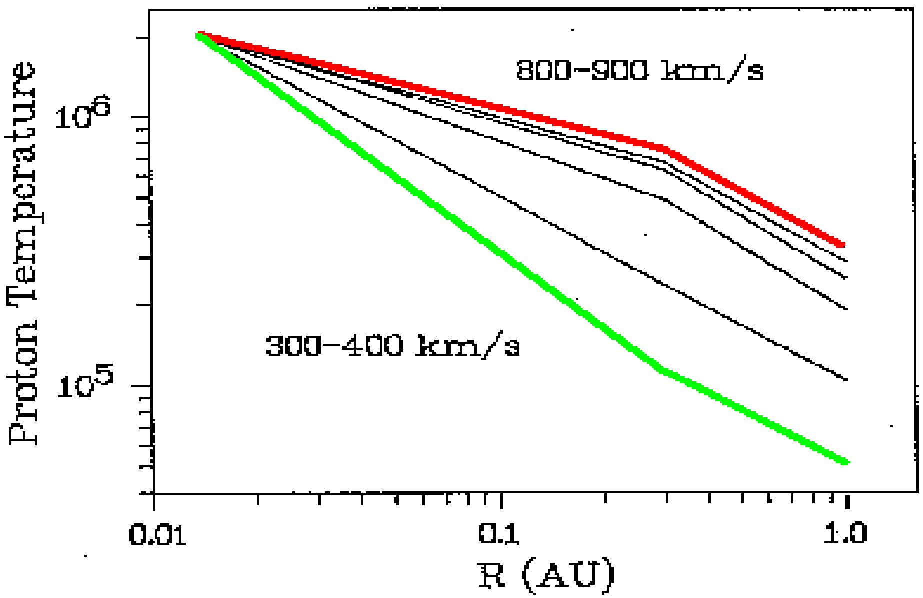
Proton and electron temperatures

Electrons
are cool!



slow wind
↓
fast wind

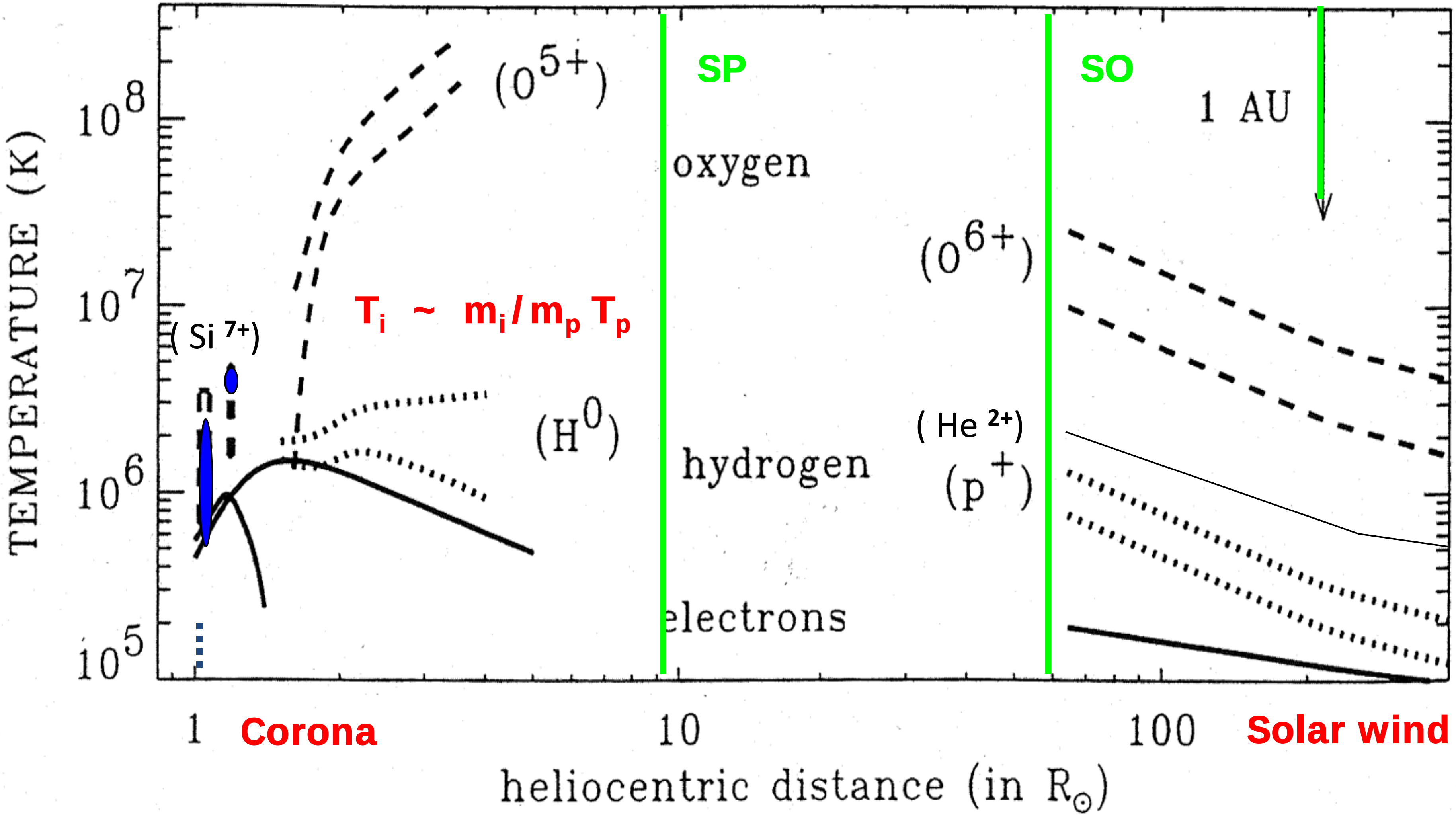
Protons
are hot!



fast wind
↓
slow wind

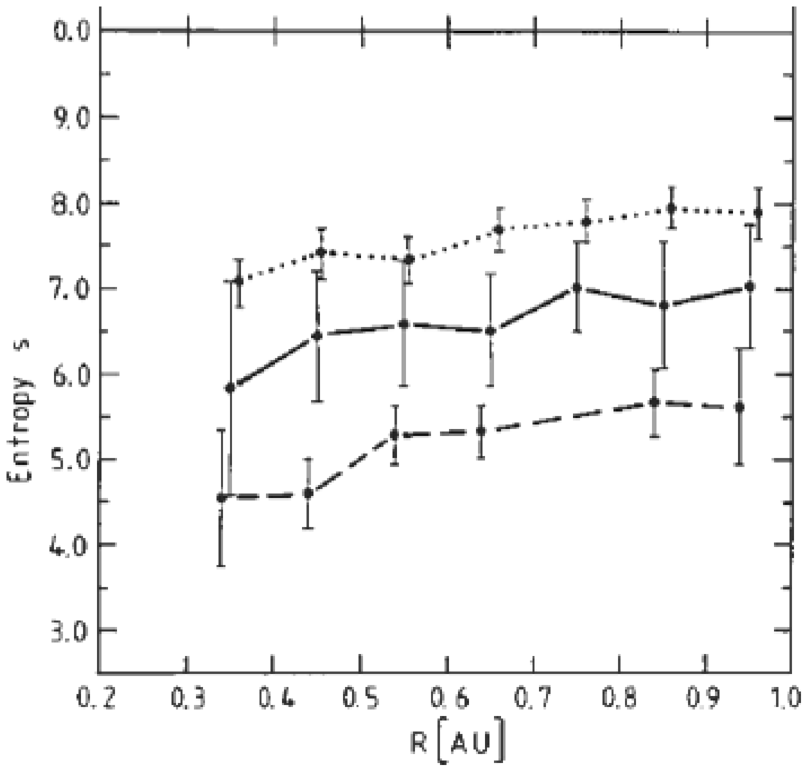
Marsch, 1991

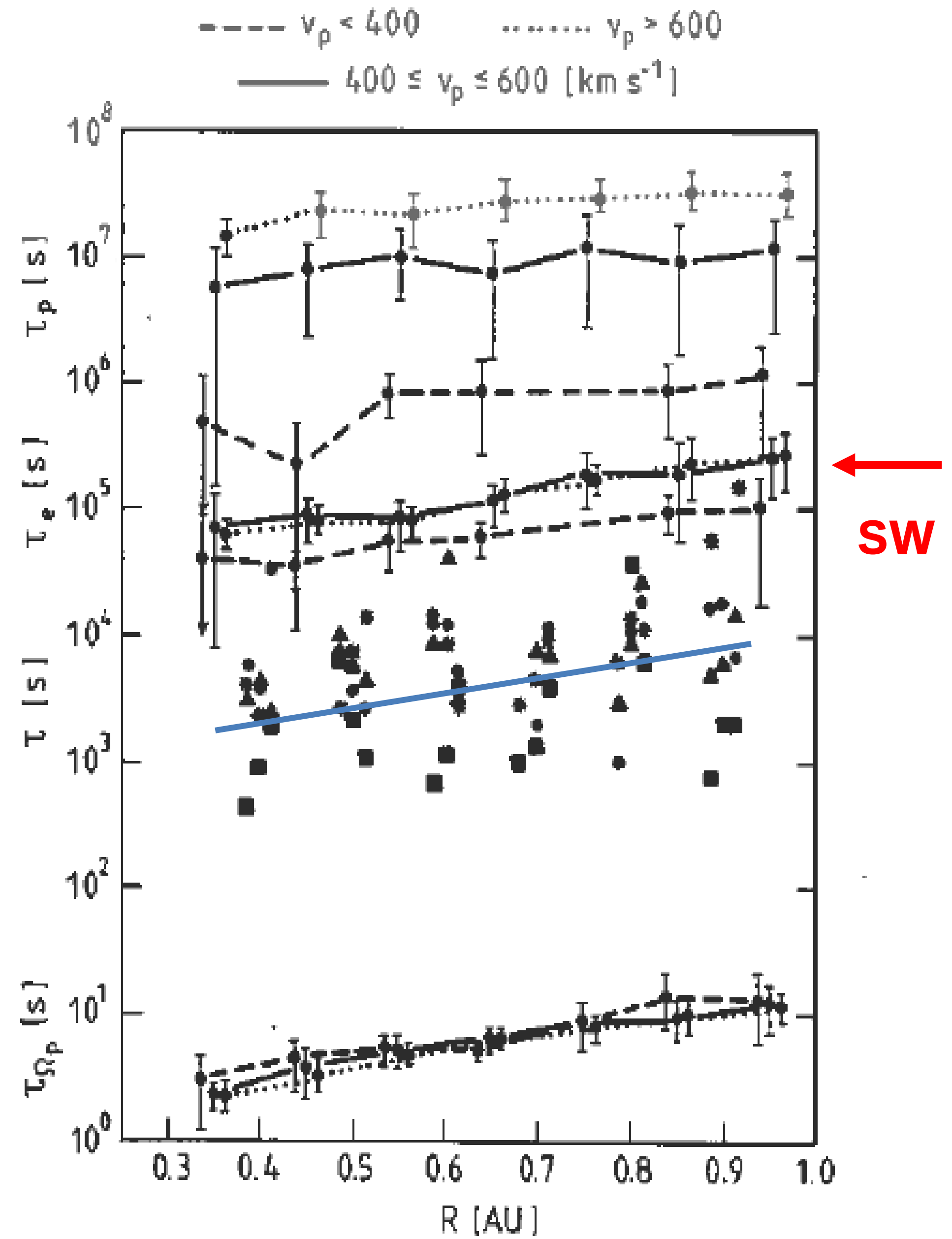
Temperatures in corona and fast solar wind



Cranmer et al., Ap.J., 2000; Marsch, 1991

Entropy production





Entropy of a bi-Maxwellian

$$s = \frac{1}{2} \ln \left(v_\parallel^2 \, v_\perp^4 / \rho^2 \right) + s_0$$

Marsch and Richter, Annales Geophysicae, 5A, 71, 1986

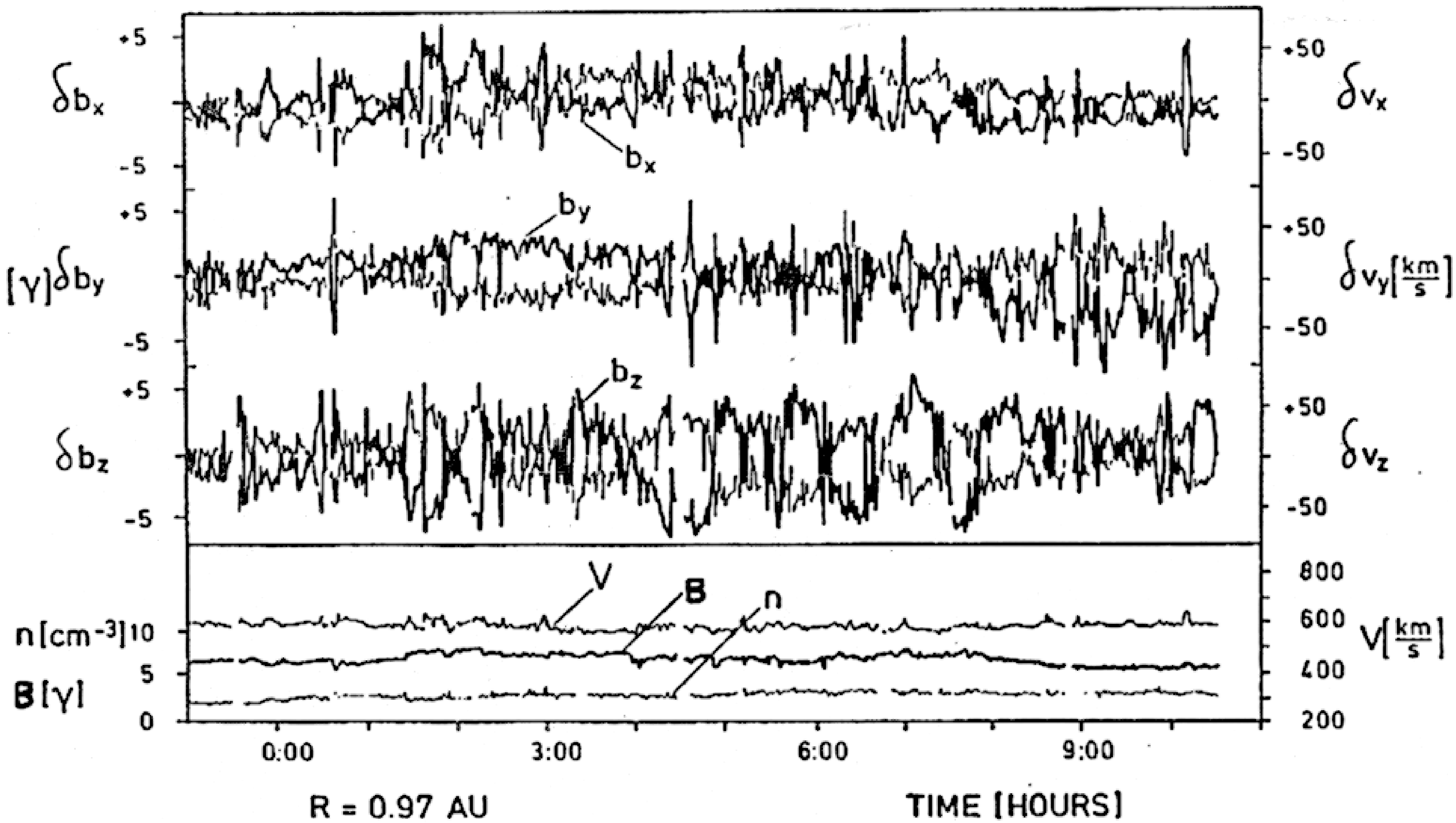
Spatial and temporal scales

Phenomenon	Frequency (s^{-1})	Period (day)	Speed (km/s)
Solar rotation:	$4.6\ 10^{-7}$	25	2
Solar wind expansion:	$5 - 2\ 10^{-6}$	2 - 6	800 - 250
Alfvén waves:	$3\ 10^{-4}$	1/24	50 (1AU)
Ion-cyclotron waves:	1 - 0.1	1 (s)	(V_A) 50

Turbulent cascade: generation + transport

→ inertial range → kinetic range + dissipation

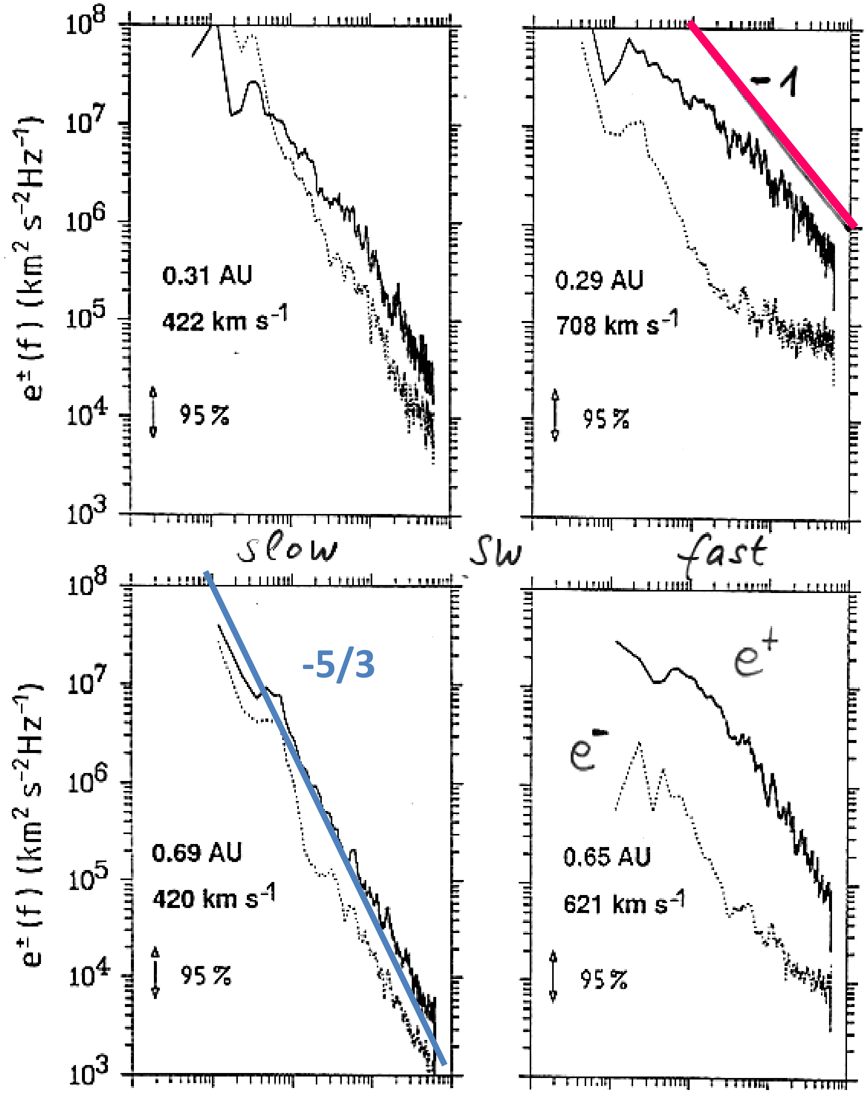
Alfvénic fluctuations

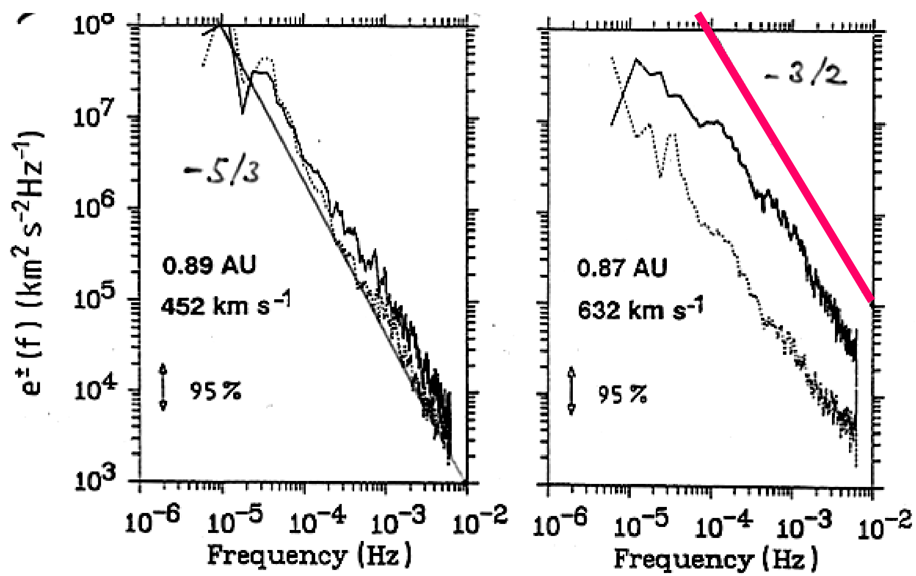


Neubauer et al., 1977

$\delta V = \pm \delta V_A$

Spectral and spatial evolution of turbulence



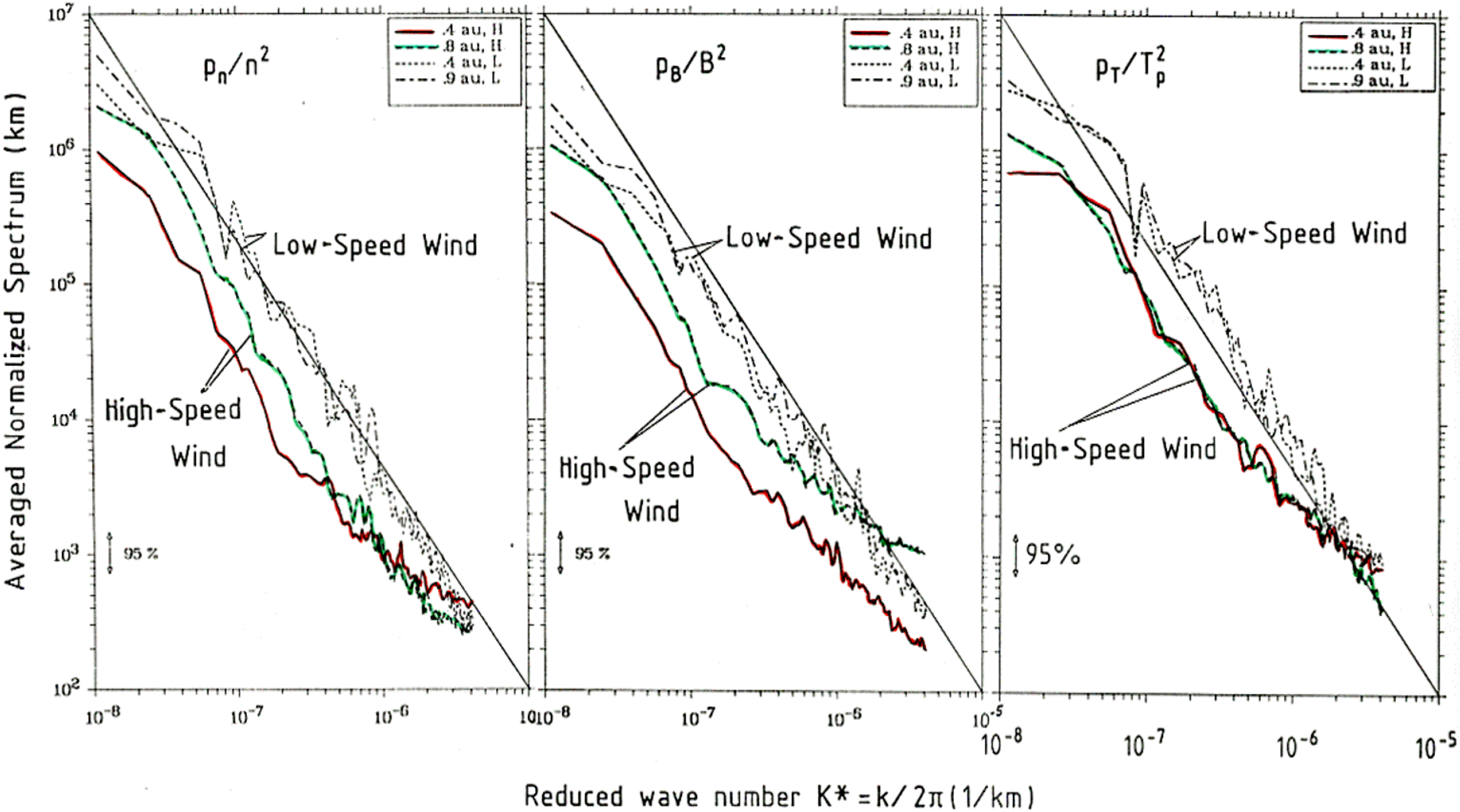


- Spectra steepen!
- $e^+ >> e^-$, Alfvén waves dominate!

slow <-> fast wind

Marsch and Tu, JGR, 95, 8211, 1990

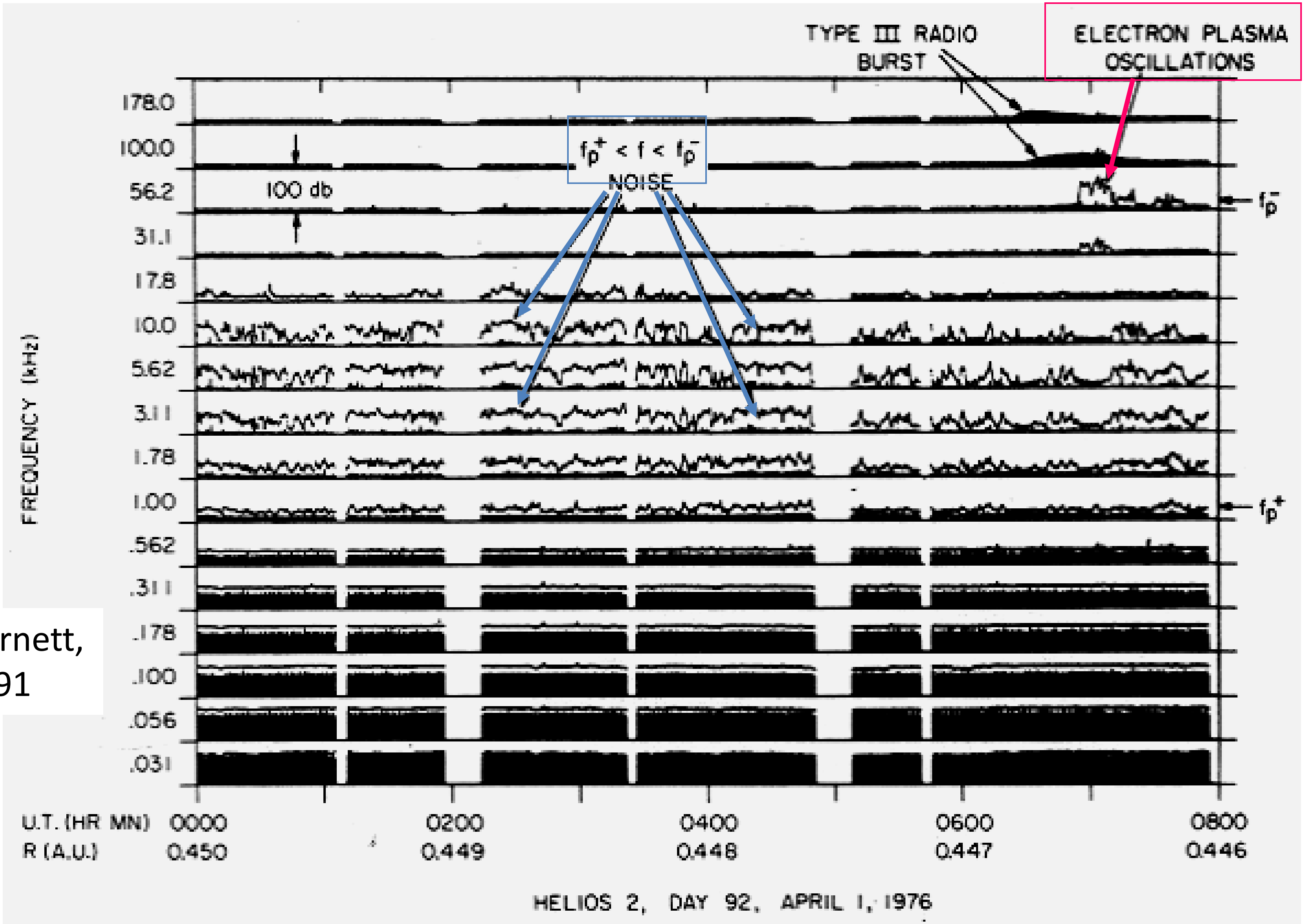
Compressive fluctuations in the solar wind



Kolmogorov-type turbulence

Marsch and Tu, JGR, 95, 8211, 1990

Ion acoustic and Langmuir waves



Gurnett, 1991

Kinetic and fluid processes in solar wind

- **Plasma is multi-component, anisotropic and nonuniform**

$\rightarrow$ MHD, multi-fluid or kinetic physics is required

- **Plasma is weakly collisional and strongly turbulent**

$\rightarrow$ ample free energy driving micro-instabilities

$\rightarrow$ resonant kinetic wave-particle interactions

$\rightarrow$ turbulent energy cascade (intermittency)

$\rightarrow$ weak collisions described by Fokker-Planck operator

Problem: Transport properties of space plasma, which is turbulent and involves multiple species and many spatio-temporal scales......