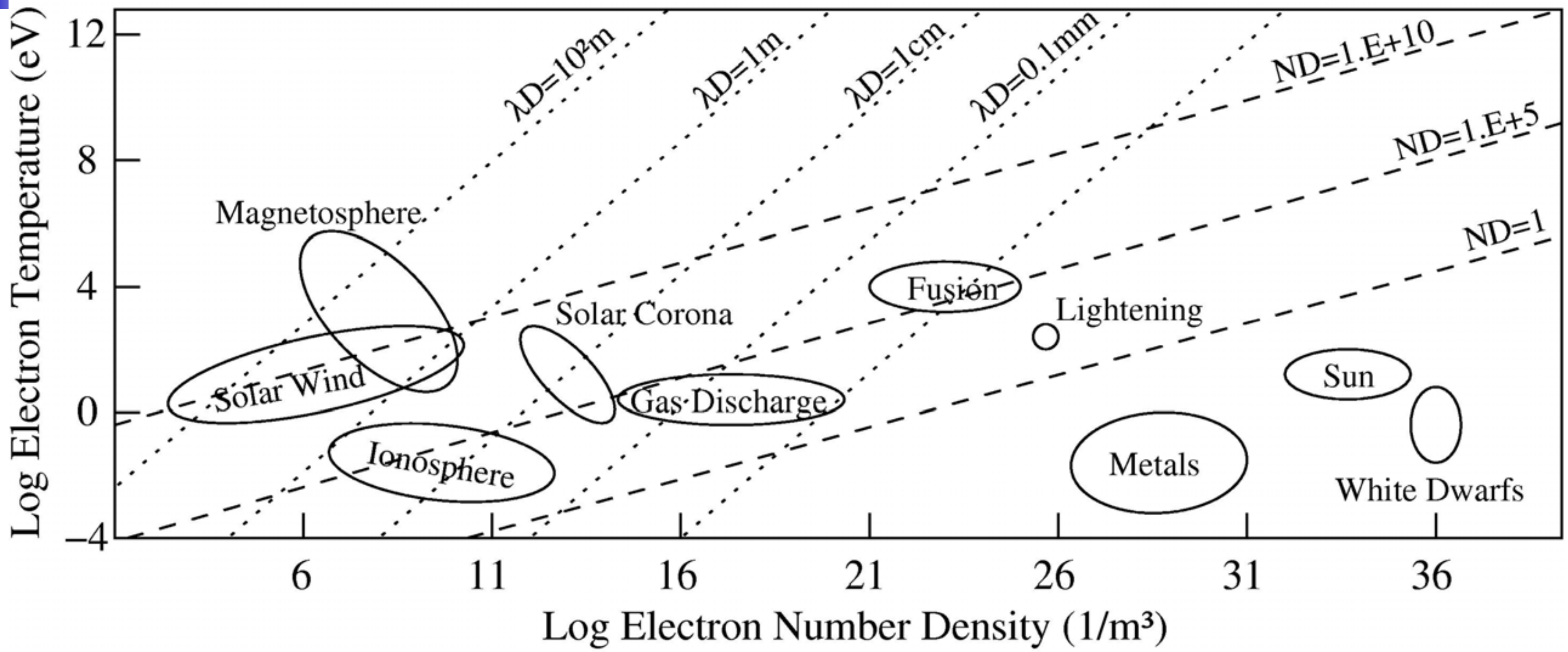
Plasma: The Basics

- Definition: a plasma is a gas with following properties:
  - It contains charged particles,
  - Electromagnetic interactions between the particles are possible,
  - A plasma is quasi-neutral.
- Characteristic parameters:
  - Electron density n,
  - Electron temperature T.
- Secondary parameters:
  - Debye-length,
  - Number of particles inside a sphere with Debye-radius.

nT-Diagram

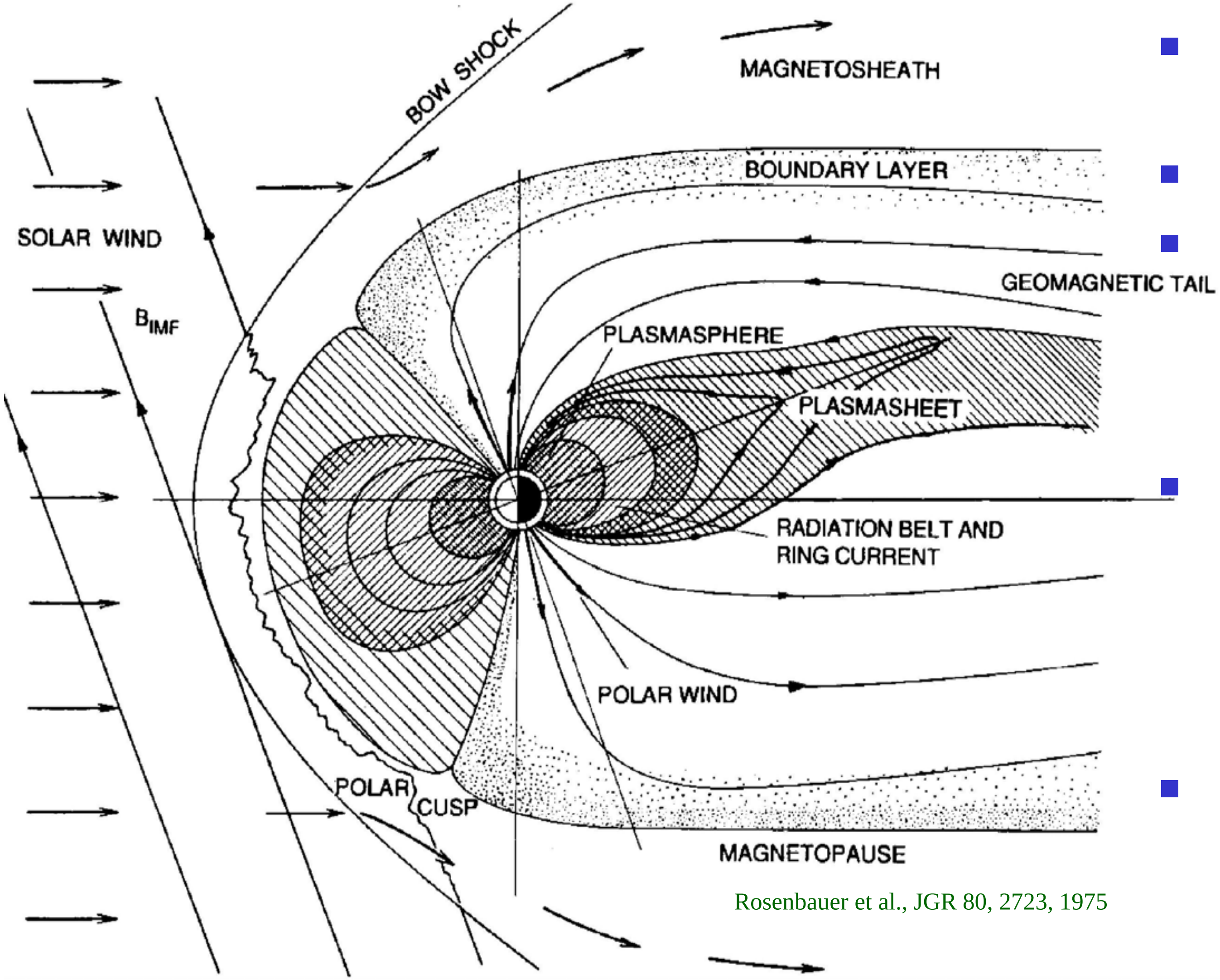


- Densities/temperatures vary over many orders of magnitude.
- Space plasmas can be found in different regions of the nT-diagram.
- Possible method for ordering: Debye length λD und number of particles ND inside a sphere with radius λD.

Space Plasmas

- **Solar wind**: a few particles per cm^3, about 1 Mio K, energy density of the particles larger than that of the field → frozen-in magnetic field
- **Magnetosphere**: larger densities but lower temperatures, energy density of the particles smaller than that of the field → particle motion is determined by the magnetic field (guiding center, adiabatic invariants)
- **Sun**: extremely high densities (26 orders of magnitude larger than the solar wind), about 15 Mio K → frequent collisions
- **Interstellar medium**: lower densities than the solar wind, many open questions (not directly accessible for observation)

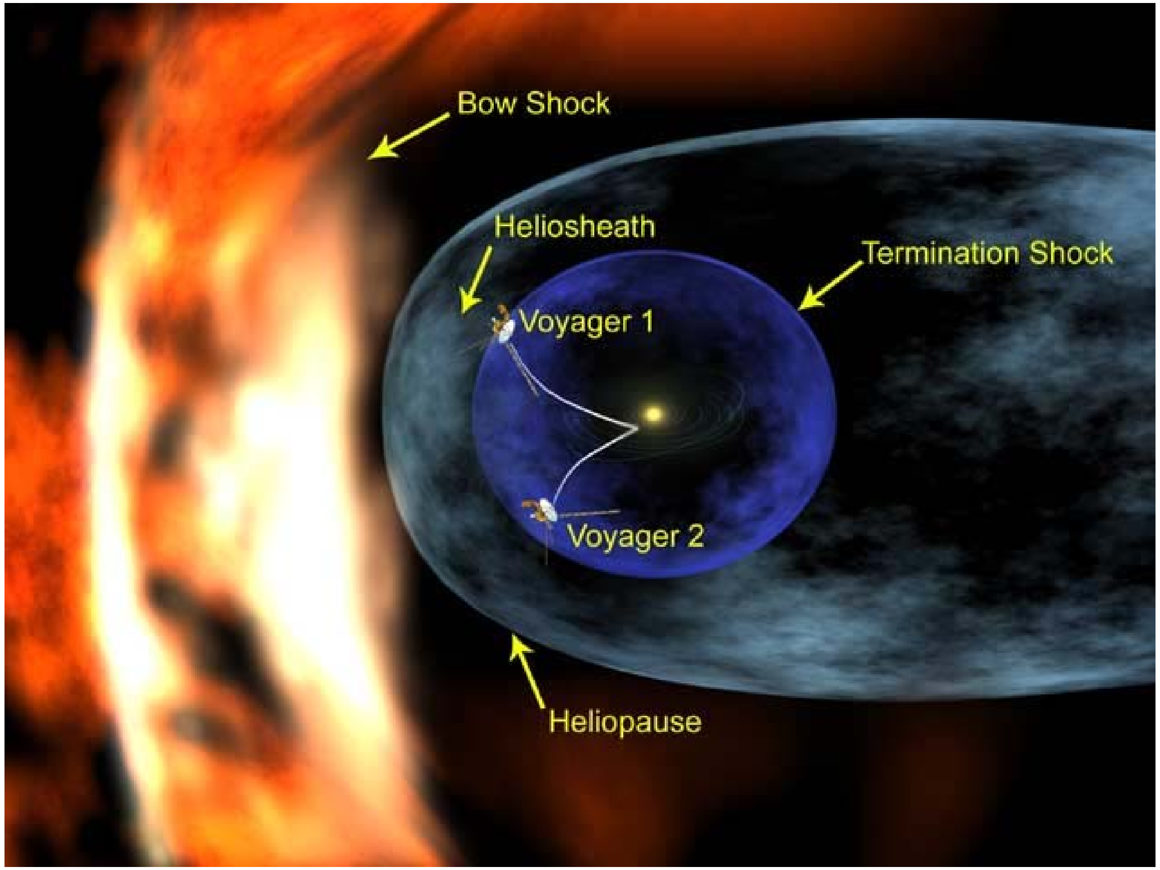
WeWi von Weltraumplasmen



Rosenbauer et al., JGR 80, 2723, 1975

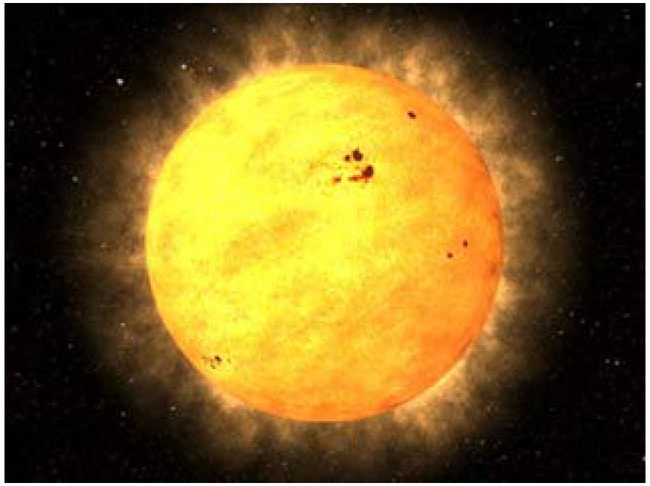
- Interplanetarer Raum: Sonnenwind
- Planet: Magnetfeld
- WeWi: Sonnenwind aus der Magnetosphäre „ausgefroren“
- Aber: interplanetares Magnetfeld im Sonnenwind eingefroren (Energiedichten!)
- Ausbildung Bugstoßwelle

Матрешки в космосе

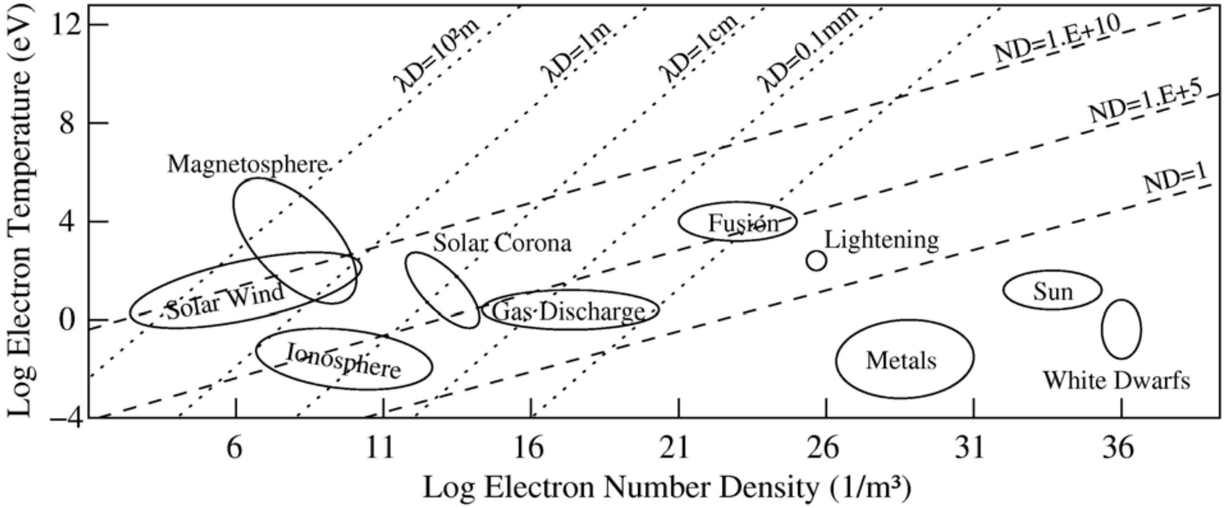


http://www.nasa.gov/mov/52704main_heliopause.mov

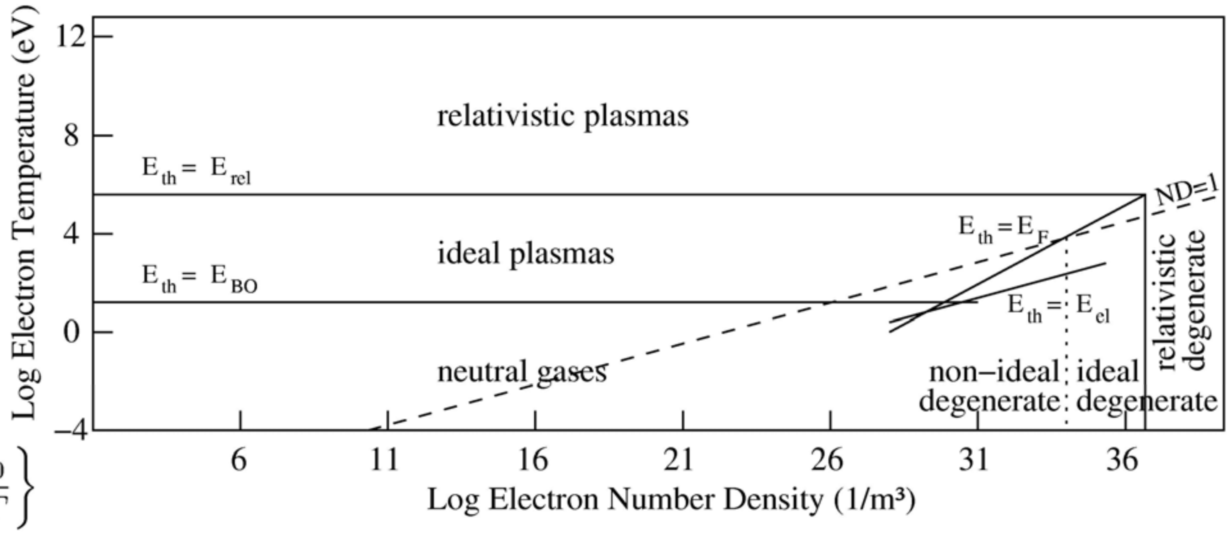
- Open Questions:
  - Boundary of the heliosphere
  - Termination shock as the solar wind slows down to sub-sonic speed
  - Properties of the interstellar medium?



nT-Diagram expanded



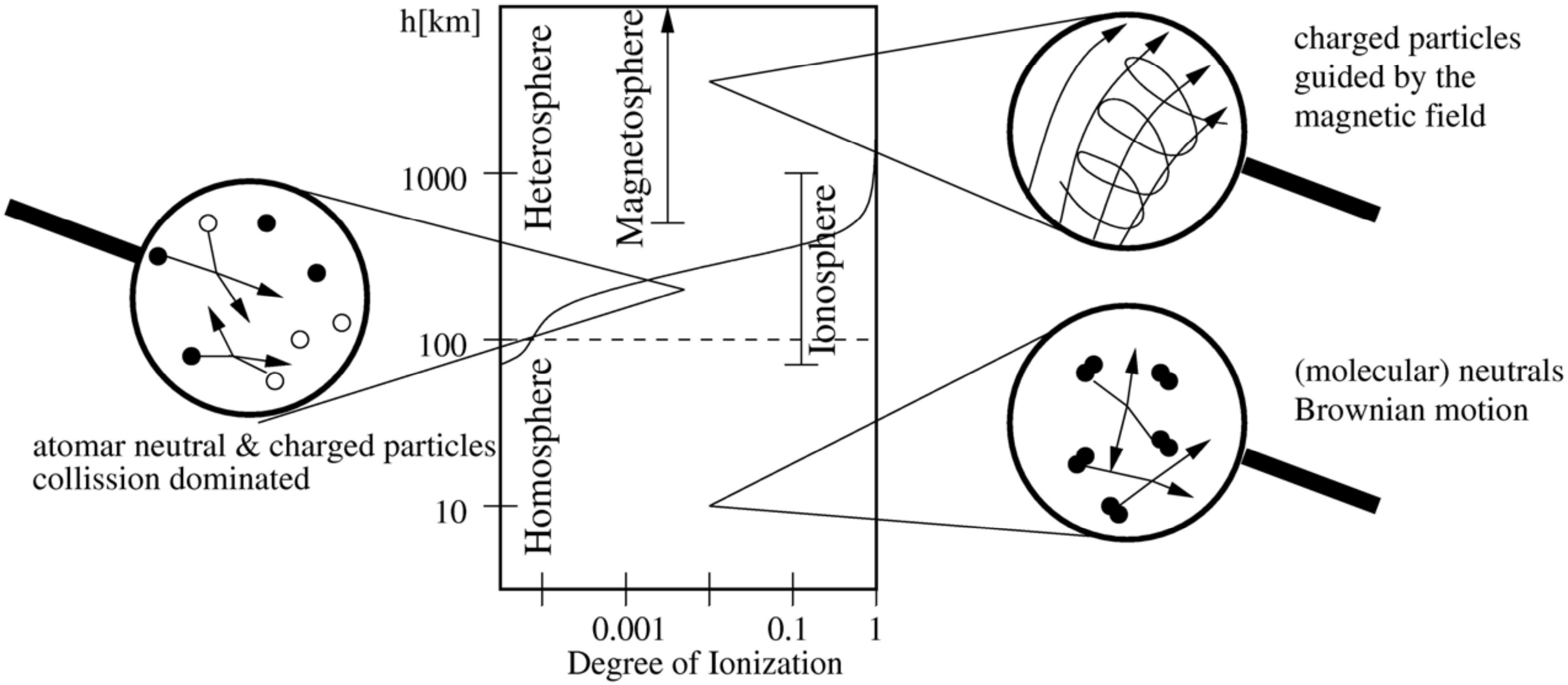
$E_{\rm th}$ Thermal energy
$E_{\rm F}$ Fermi energy
$E_{\rm el}$ Electrostatic energy
$E_{\rm B0}$ Energy of the ground state
$E_{\rm rel}$ Relativistic electron energy



Saha equation (degree of ionization χ)

$$\frac{\chi^2}{\chi - 1} = \frac{(2\pi m_{\rm e})^{3/2}}{h^3} \frac{(k_{\rm B}T)^{5/2}}{p_{\rm gas}} \exp\left\{-\frac{E_{\rm B0}}{k_{\rm B}T}\right\}$$

Example: degree of ionization in the atmosphere



Degree of ionization depends on

- intensity of the ionizing radiation,
- number of particles available for ionization, and
- recombination.

Debye-Length λD

- local deviation from quasi-neutrality due to thermal motion
- Characteristic length scale for a test particle to sense the electrostatic forces exerted on it by the other charges

$$\lambda_\mathrm{D} = \sqrt{\frac{3\varepsilon_\mathrm{o} k_\mathrm{B} T_\mathrm{e}}{e^2 n_\mathrm{e}}} = \sqrt{\frac{k_\mathrm{B} T}{m_e}} \frac{1}{\omega_\mathrm{pe}}$$

λ_D	Debye length
T_e	Electron temperature
n_e	Electron density
ε_o	Absolute permittivity
k_B	Boltzmann constant
e	Elementary charge
m_e	Electron mass
ω_pe	Electron plasma frequency