An analysis of the Solar Coronal dynamics using S band signals from Mars Orbiter Mission

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Today's Agenda

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Solar Wind ?

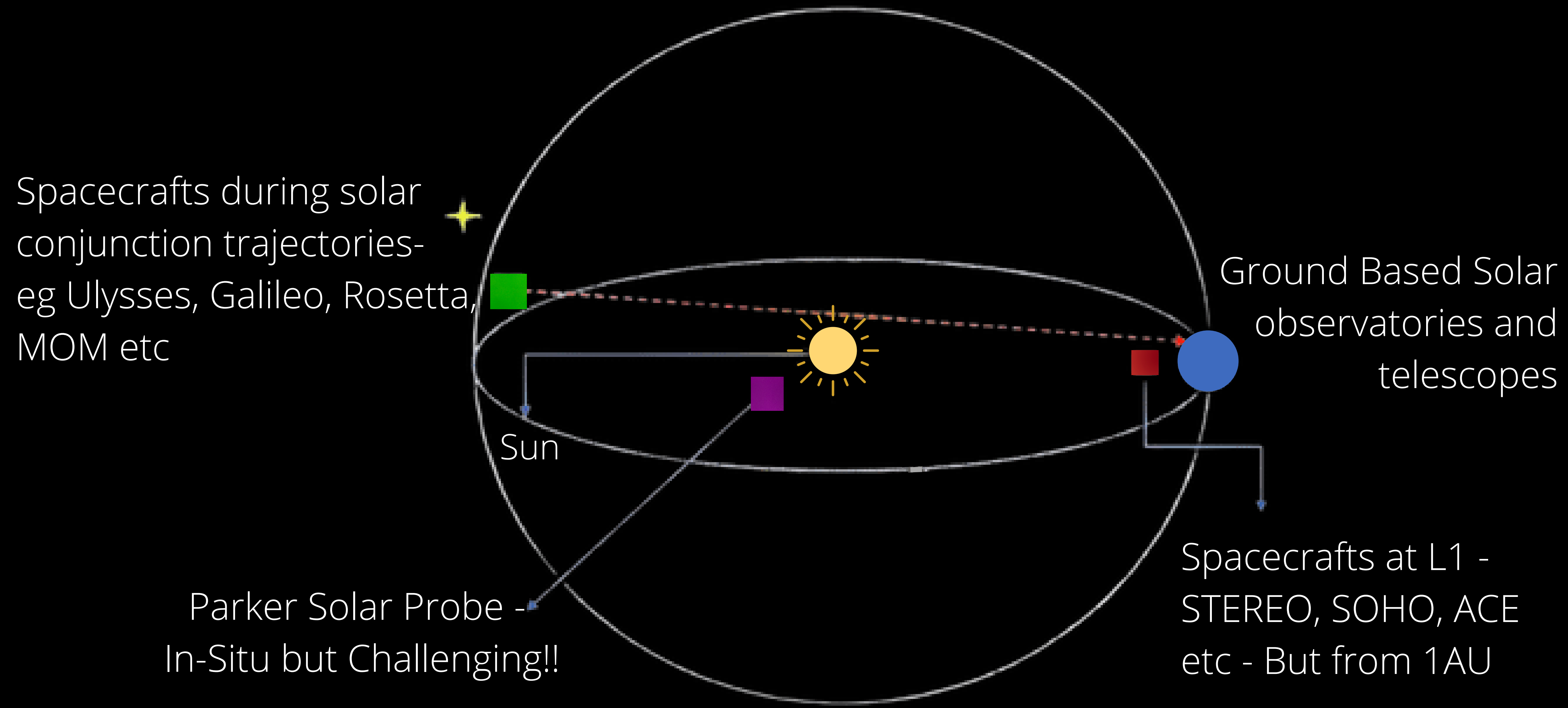
- The solar wind magnetically blankets the solar system, protecting life on Earth from even higher-energy particles coming from elsewhere in the galaxy.

- Affects the sophisticated satellite communications we have today.

Measurements of solar corona and wind

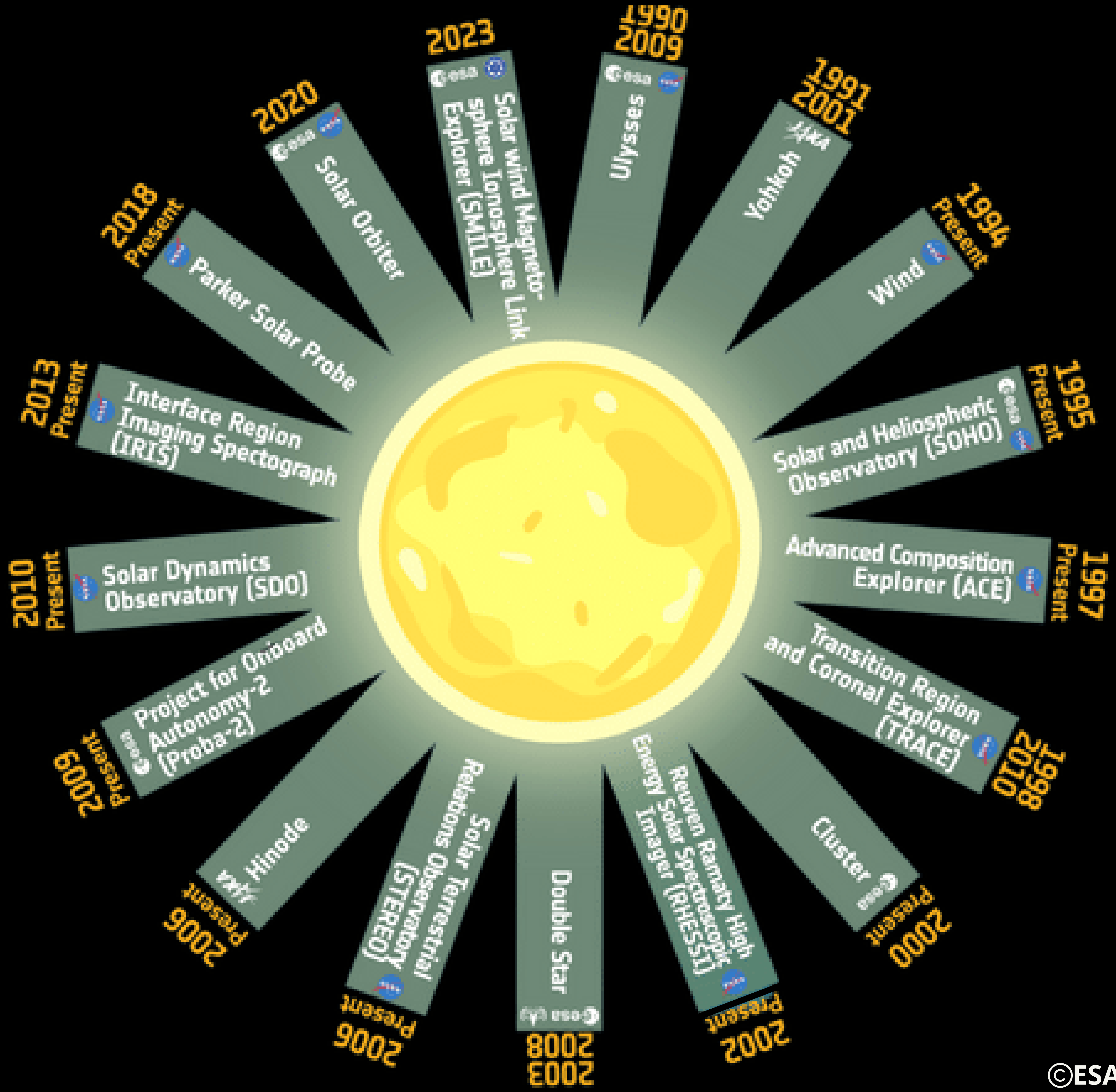
Observation of corona and solar wind :

1. In-situ
2. Remote sensing
   a. Signals which generate naturally within the coronal region
   b. Probe signals from natural/ man-made radio source



Jain et al. 2022

Observing the Sun



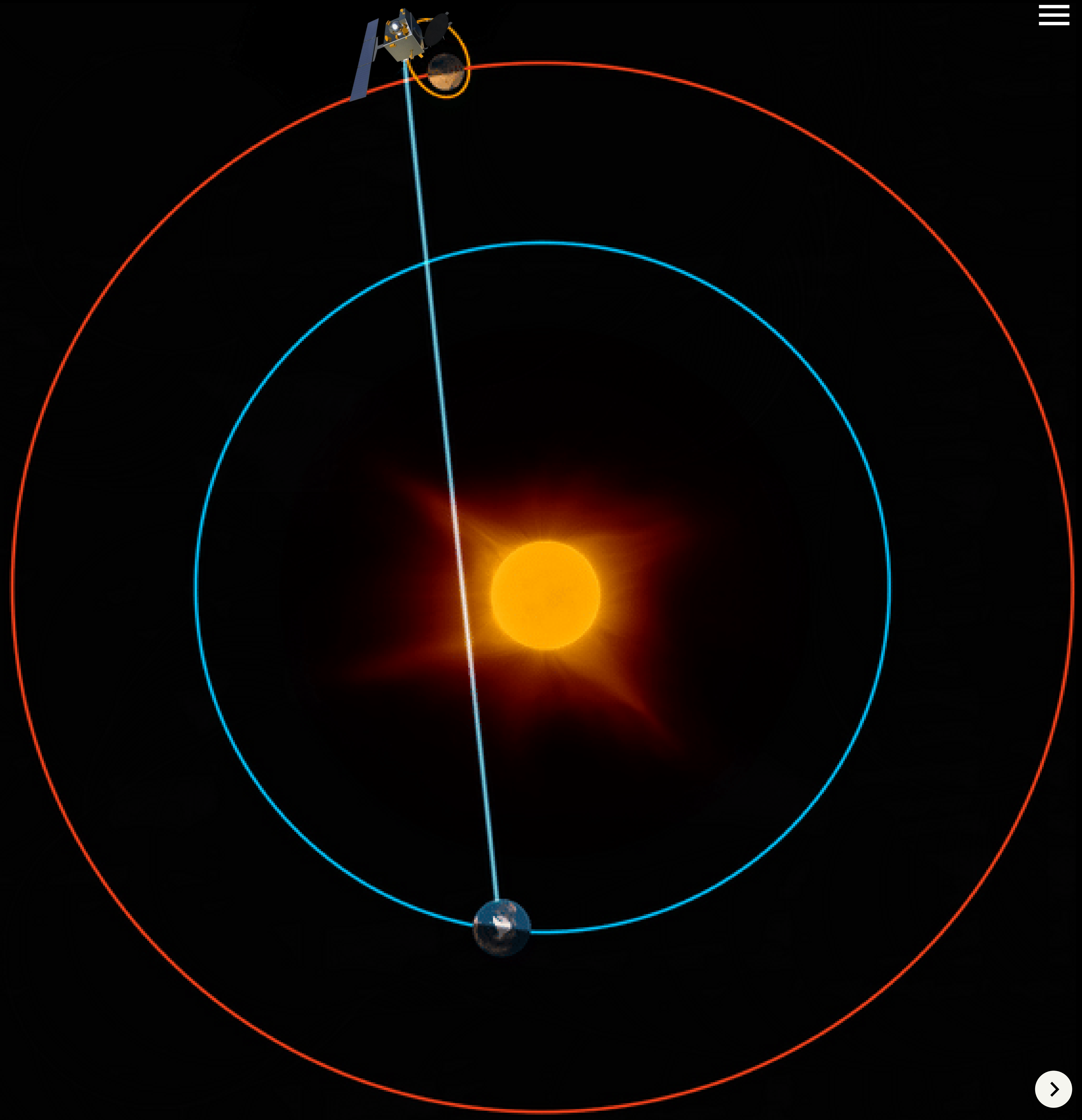
Solar Conjunction

Solar wind acceleration and the coronal heating take place very cclose to the Sun where in situ observations are not possible.

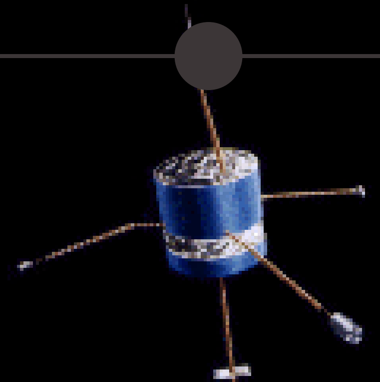
This approach enables us to observe this specific region around the Sun, while posing no risk to the spacecraft.

No extra instruments needed for conducting the experiment.

Cost effective - Two for the cost of one.



Past studies



1968

Pioneer 6

(Goldstein et al.)

1975-76

HELIOS

(Wexler et al.)

1978

Pioneer 10/11

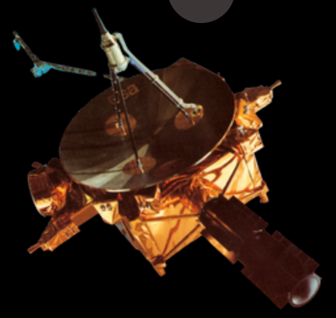
(Woo et al.)

1979

Viking

(Armstrong et al.)

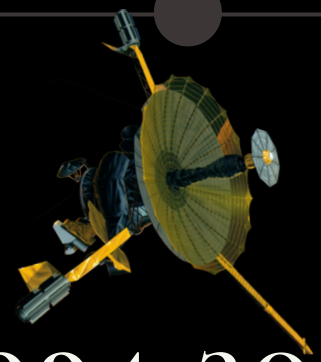
Past studies



1991

Ulysses

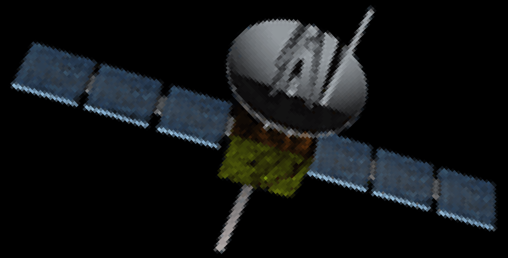
(Efimov et al.)



1994-2000

Galileo

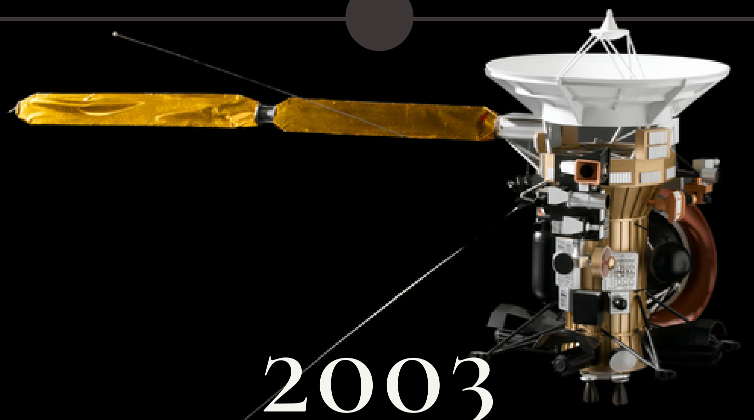
(Plettemeir et al.)



2000-2001

Nozomi

(Imamura et al.)

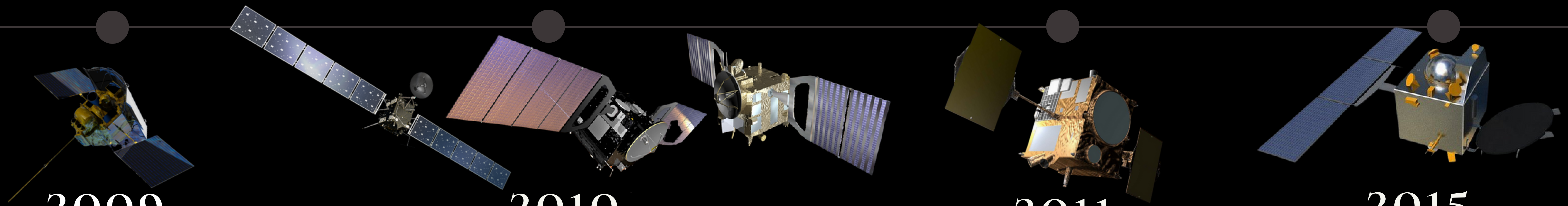


2003

Cassini

(Morabito et al.)

More studies



2009
MESSENGER
(Wexler et al.)

Rosetta

2010
Mars Express
(Patzold et al.)

Venus Express

2011
Akatsuki
(Ando et al.)

2015
Mars Orbiter Mission
(Jain et al.)

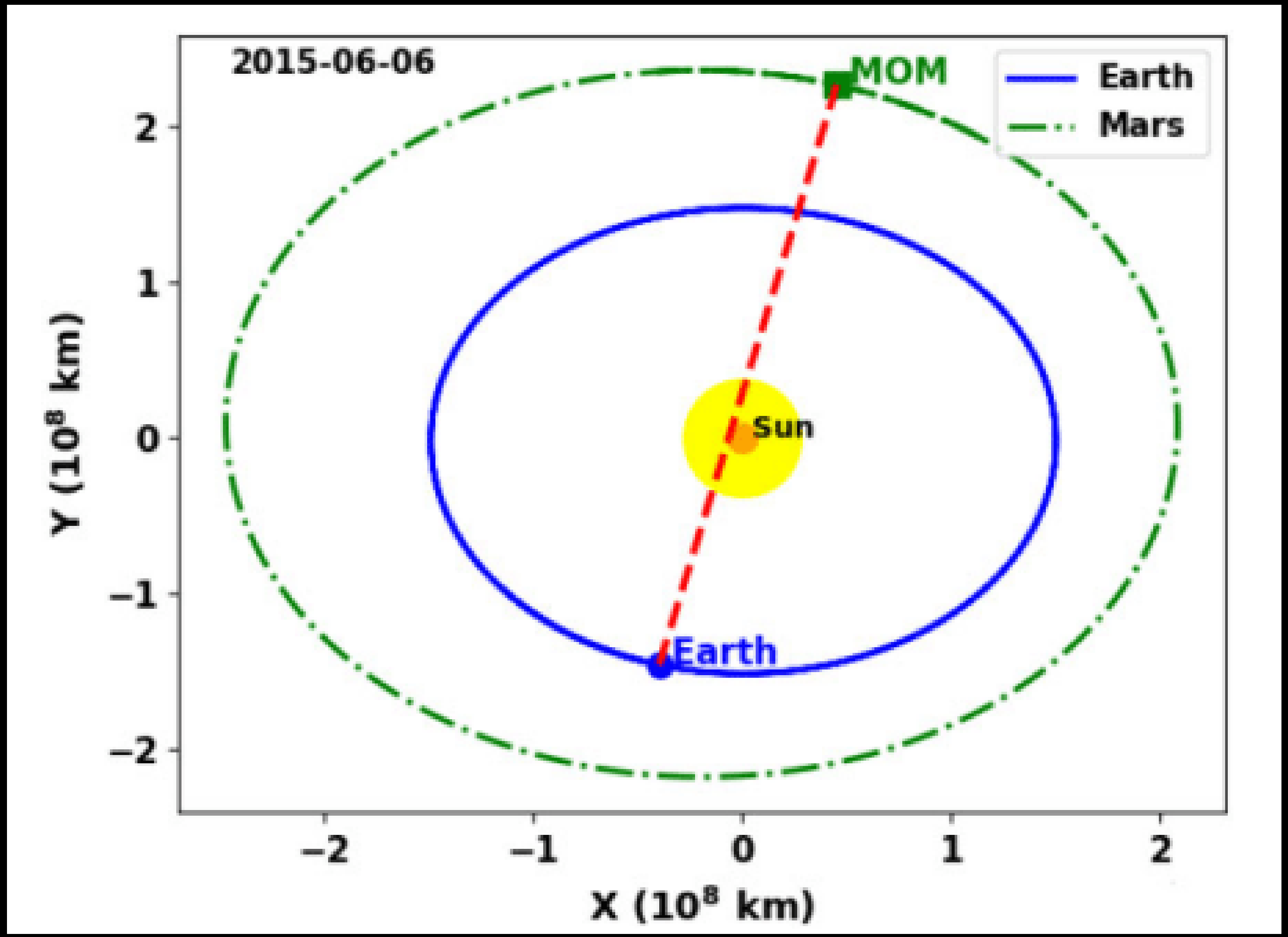
Radio occultation experiment conducted in 2015

MOM spacecraft RO experiment specification :

- Signal Frequency - Downlink S band
- Receiver - IDSN 32m Bangalore
- Experiment in closed loop - 1 way
- High gain antenna - 2.2 m Diameter
- Conducted between - 2015 May 28 and June 26
- Avg. Received Signal power - 134 dBm

Solar conditions in May-June 2015 :

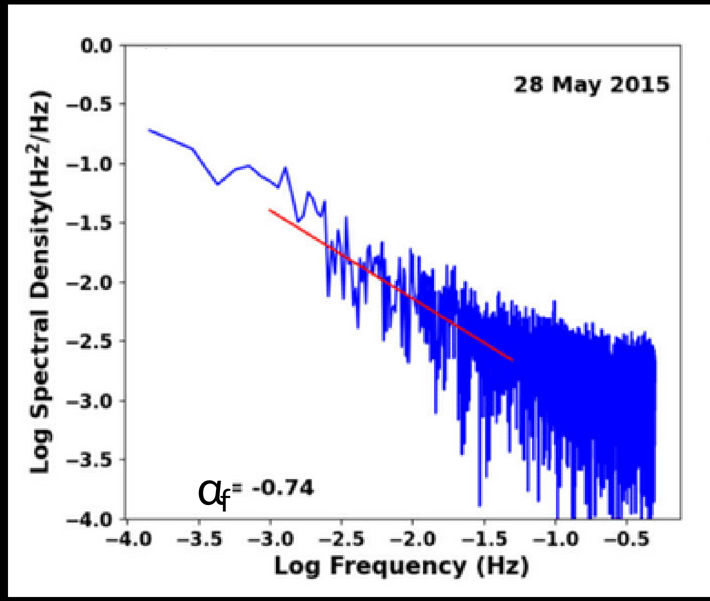
- Descending phase of Solar Cycle 24
- Overall low activity solar cycle



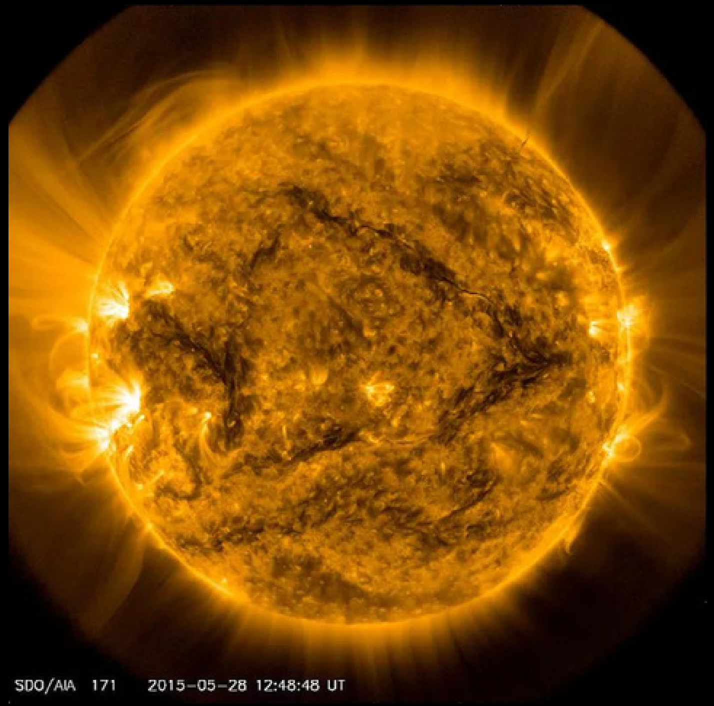
Schematic of the positions of the Earth and MOM spacecraft relative to the Sun on 2015 June 6, on the ecliptic (XY) plane as seen from north in the ECLIPJ2000 reference frame.

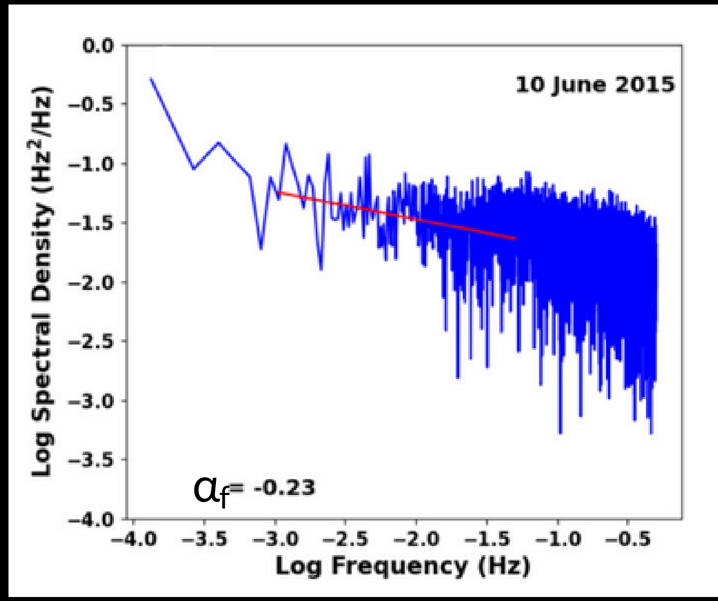
Jain et al. 2022

OBSERVATIONS

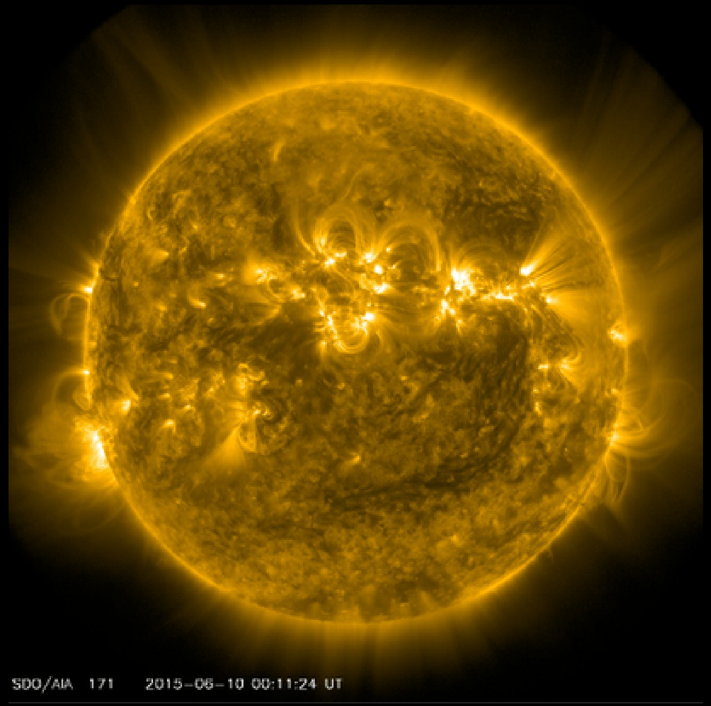


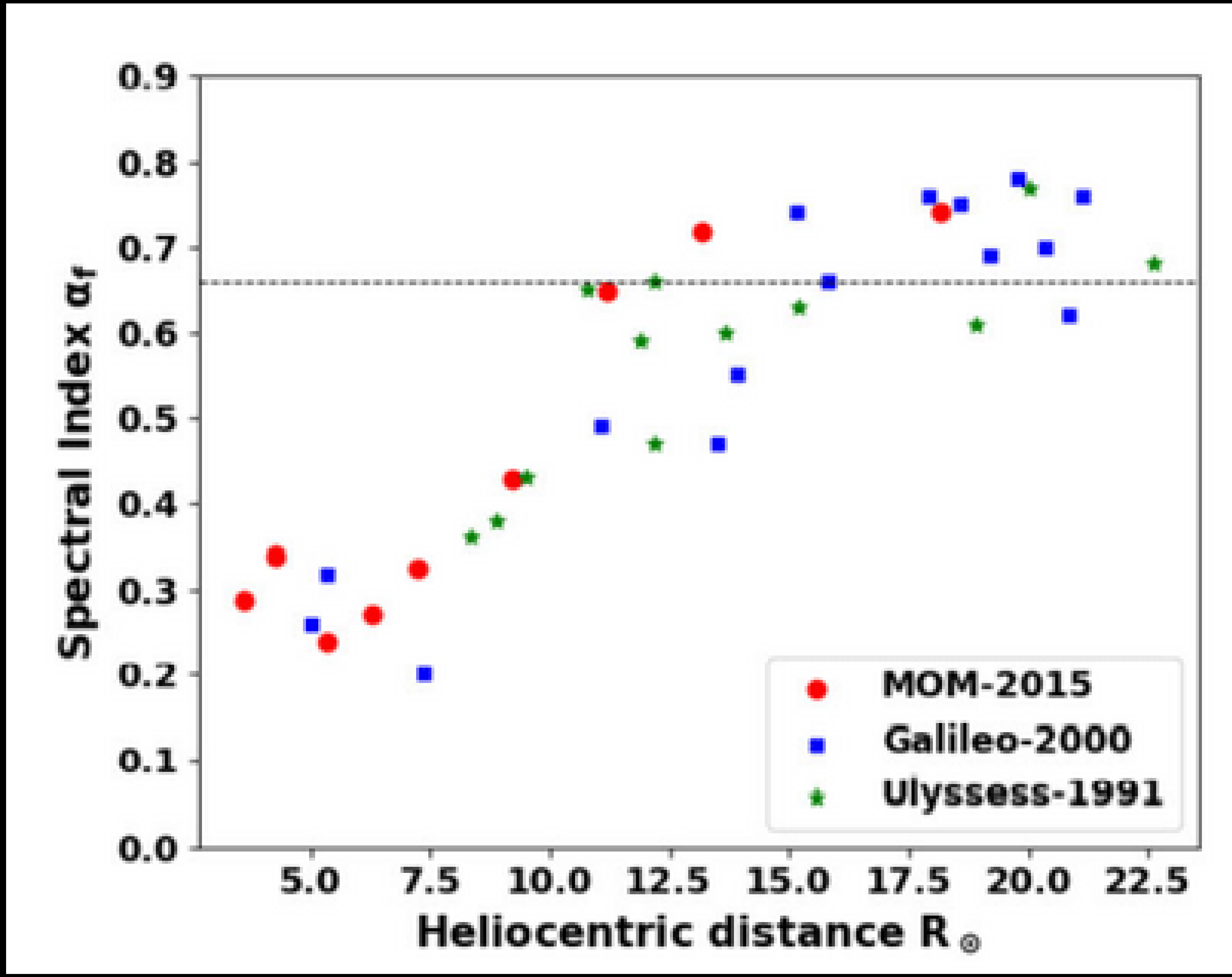
Frequency fluctuation spectrum of the MOM downlink signal on 2015 May 28 when the heliocentric distance of the proximate ray path was r= 18.17 $R_\odot$ and the spectral index = slope = α_f = −0.74.





Frequency fluctuation spectrum of the MOM downlink signal on 2015 June 10 when the heliocentric distance of the proximate ray path was r= 5.33 $R_\odot$, and the spectral index = slope = α_f = −0.23.

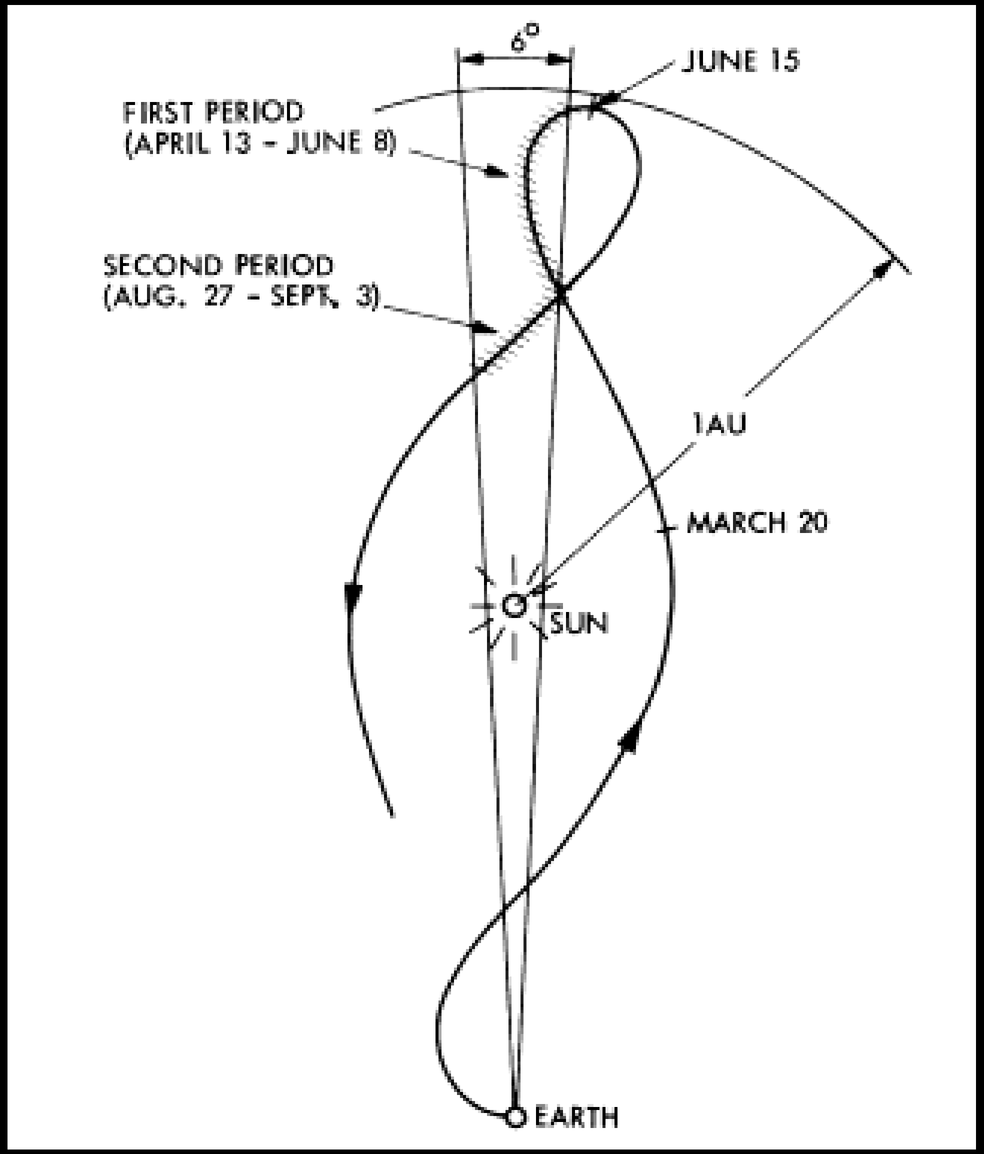




Critical spectral index of α_f~ 0.6–0.7, which indicates the transition from the source regime to the Kolmogorov regime

Jain et al. 2022

Radial dependence of solar wind properties



Helios 1 - 1975

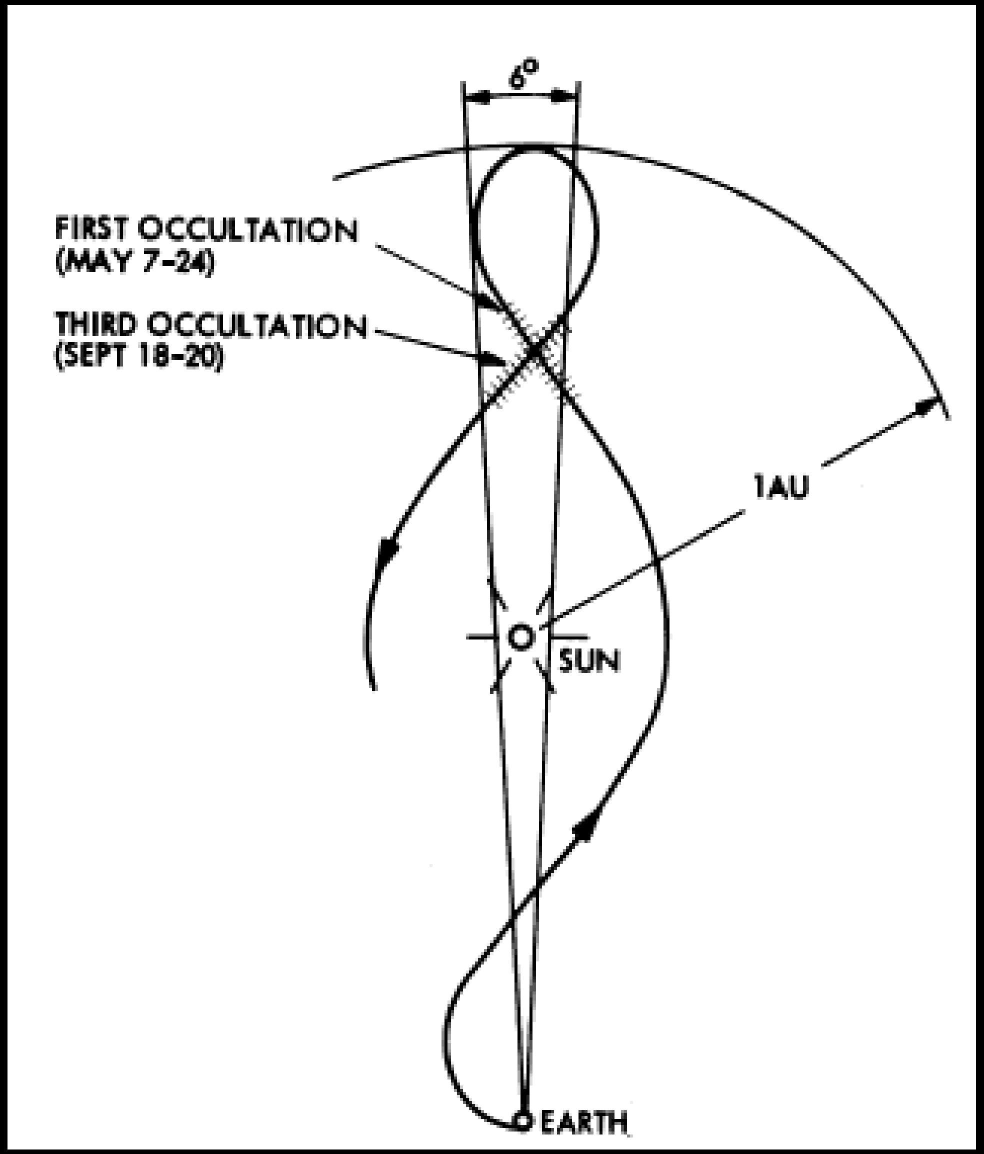
Primary Data - Power spectrums of S band carrier signals sampled digitally
Converted into power spectrum by FFT
Frequency resolution - 0.2Hz for 100Hz
10Hz for 500Hz Bandwidth.

Although there were 3 solar occultations of Helios 2 in 1976, data were obtained only during the first (May 7-24) and the third (September 18-20).

HELIOS Operation Modes -

- One Way mode - 2.3GHz (13 cm), linearly polarized signal transmitted from the spacecraft to the ground receiver.
- Two Way mode - Signal transmitted from Earth to the spacecraft and then back to Earth.

One way measurements preferred.

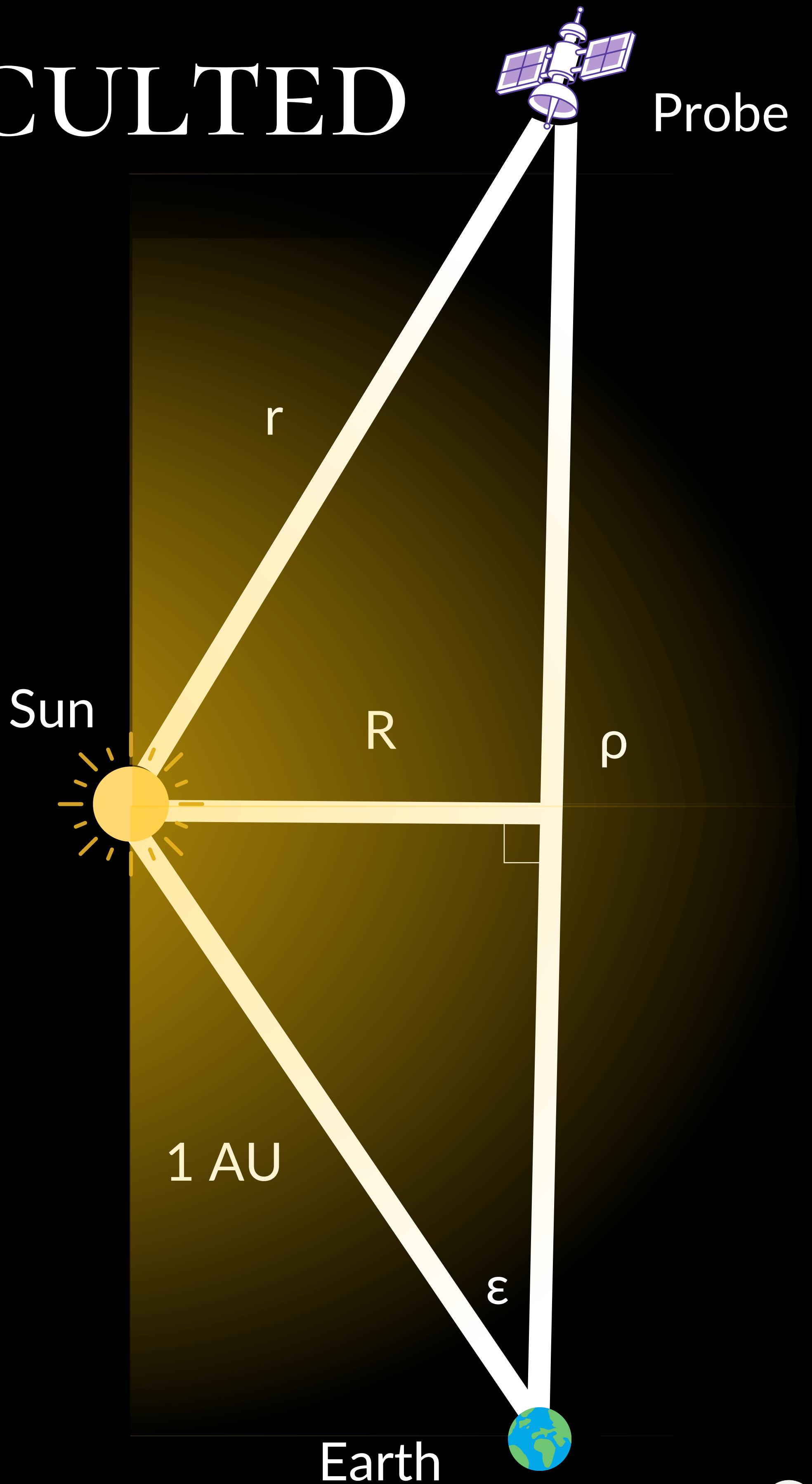


Helios 2 - 1976

Woo et al 1977

Coronal investigations with occulted spacecraft signals

SIGNAL PARAMETER MEASURED	PHYSICAL QUANTITY INFERRED
Group/Phase Velocity (ranging/Doppler)	Electron density N
Spectral/Angular Broadening	Plasma flow velocity $V_\perp$



Bird et al. 1982

Scintillation effects on radio wave propagation through Solar Corona

There are mainly three types of degradation effects on RF signals:
(1) Intensity scintillation
(2) Phase scintillation
(3) Spectral broadening

$$\alpha\, f^{\beta}\, RTEC^{\gamma}$$

Ho et al. 2002

Intensity Scintillation -

RMS signal intensity fluctuation relative to the mean intensity

$$m = a_0 f^{-1.42} RTEC$$

where, $a_0 = 2.07 \times 10^{-20}$

Phase Scintillation -

- The Doppler noise (or phase scintillation) is defined as

$$\sigma_D(Hz), = b_0 f^{-1} RTEC$$

where, $b_0 = 1.64 \times 10^{-21}$

Spectral Broadening -

Spectral broadening arises because of Doppler shifting of the radio signal as it is scattered by moving plasma irregularities and is defined as

$$B = c_0 f^{-1.2} RTEC^{1.2}$$

where, $c_0 = 1.14 \times 10^{-24}$

Table 1. Solar Corona Effect Dependence on Signal Frequency

Effects	Typical Value (at 2.3 GHz, 4 R_o)	Frequency Dependence (f)
Group Delay	17 µsec (250 nsec in ionosphere)	$1/f^2$
Dispersion	10 nsec/MHz	$1/f^3$
Absorption	negligible	$1/f^2$
Faraday Rotation	20°-200° (3°-7° in ionosphere)	$1/f^2$
Phase Advance	1.07×10^5 rad	$1/f^1$
Intensity Scintillation	Saturates at $m = 1$	$1/f^{1.42}$ to $1/f^{1.2}$
Phase Scintillation	< 1 Hz	$1/f^1$
Spectral Broadening	~ 10 Hz	$1/f^{1.2}$ to $1/f^2$
Angular Broadening	0.02 – 2 min arc	$1/f^{2.2}$ to $1/f^3$

Ho et al. 2002

Plasma Frequency

Yan et al. 2002, Solar Radio Spectro-Interferometry at Low Frequency,COSPAR Colloquia Series,Pergamon,Volume 14,2002,Pages 349-352,https://doi.org/10.1016/S0964-2749(02)80180-9.

$$\mu_{pe} = (\frac{N_e e^2}{\pi m_e})^{1/2}$$

Chen F. F., 1974, Introduction to Plasma Physics. Plenum Press, New York,p. 8

$$\mu_{pe} = (\frac{4\pi N_e e^2}{m_e})^{1/2}$$

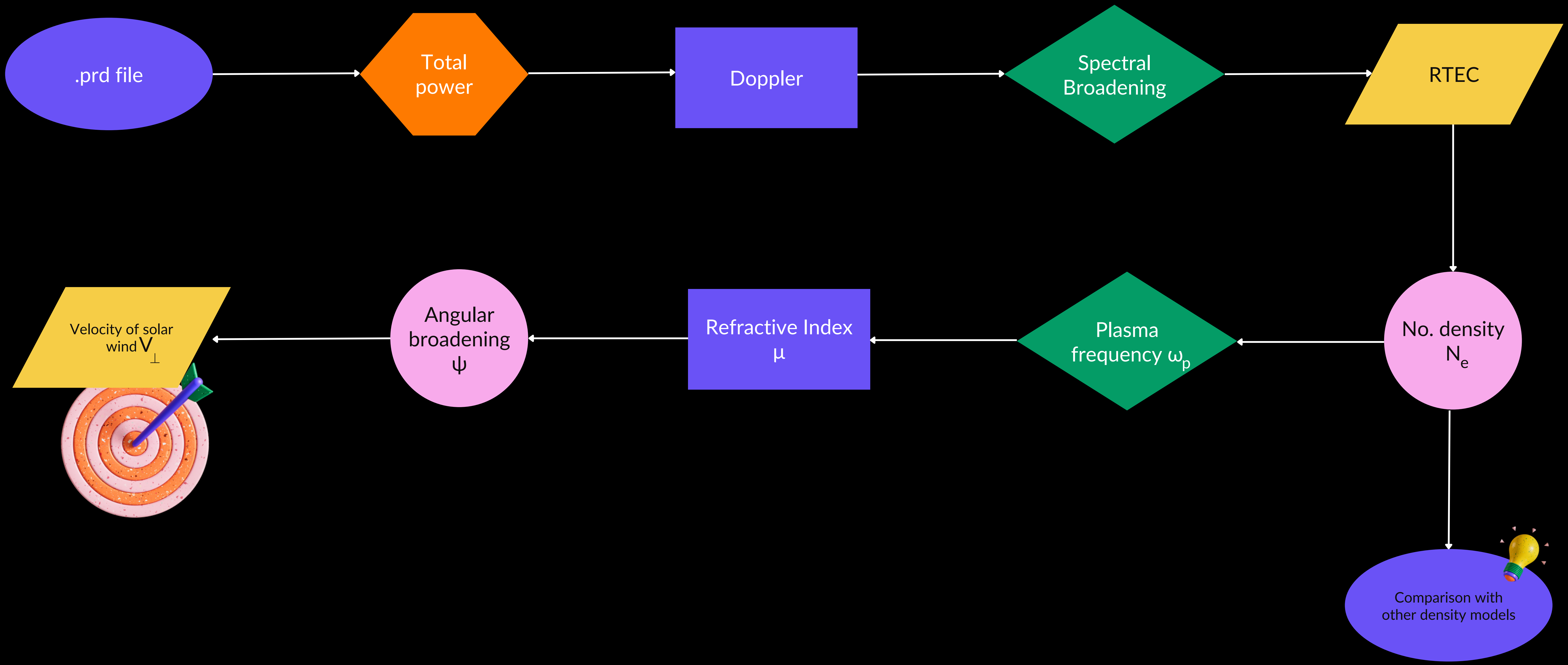
Angular Broadening of radio sources by Solar Wind Turbulence

$$\mu^2 = 1 - \omega_p^2/\omega^2$$

$$\delta\psi(s) = \int_0^s \frac{\partial\delta\mu}{\partial y} ds$$

Hollweg et al. 1970

Workflow


.prd file
Total power
Doppler
Spectral Broadening
RTEC
No. density N_e
Plasma frequency ω_p
Refractive Index μ
Angular broadening ψ
Velocity of solar wind $V_\perp$
Comparison with other density models

Moments of the spectra

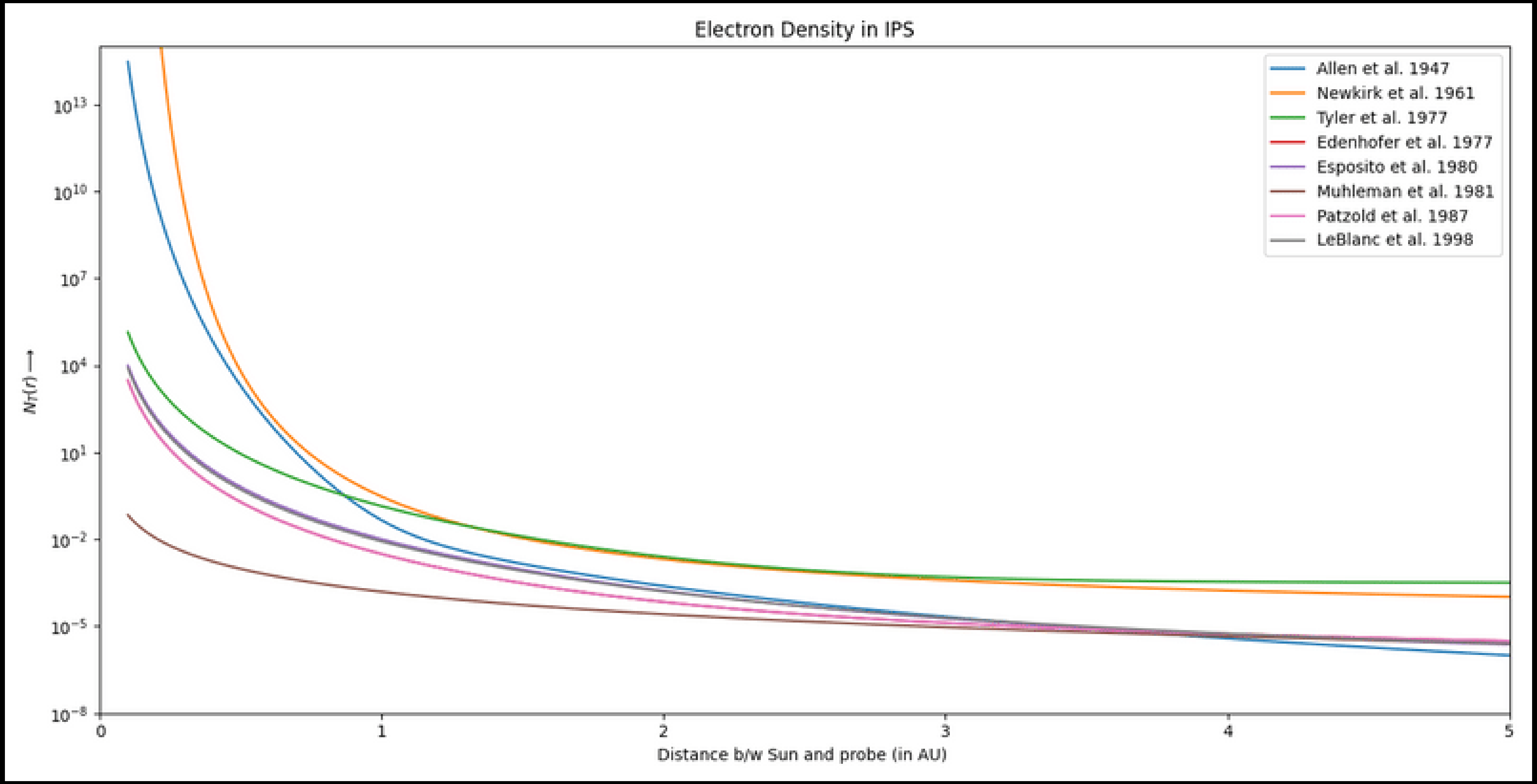
$$S(\omega) = \frac{P}{(2\pi W)^{1/2}} exp(\frac{-(\omega - \Omega)^2}{2W^2})$$

$$P = \int S(\omega) d\omega$$

$$\Omega = \frac{1}{P} \int \omega S(\omega) d\omega \qquad W^2 = \frac{1}{P} \int (\omega - \Omega)^2 S(\omega) d\omega$$

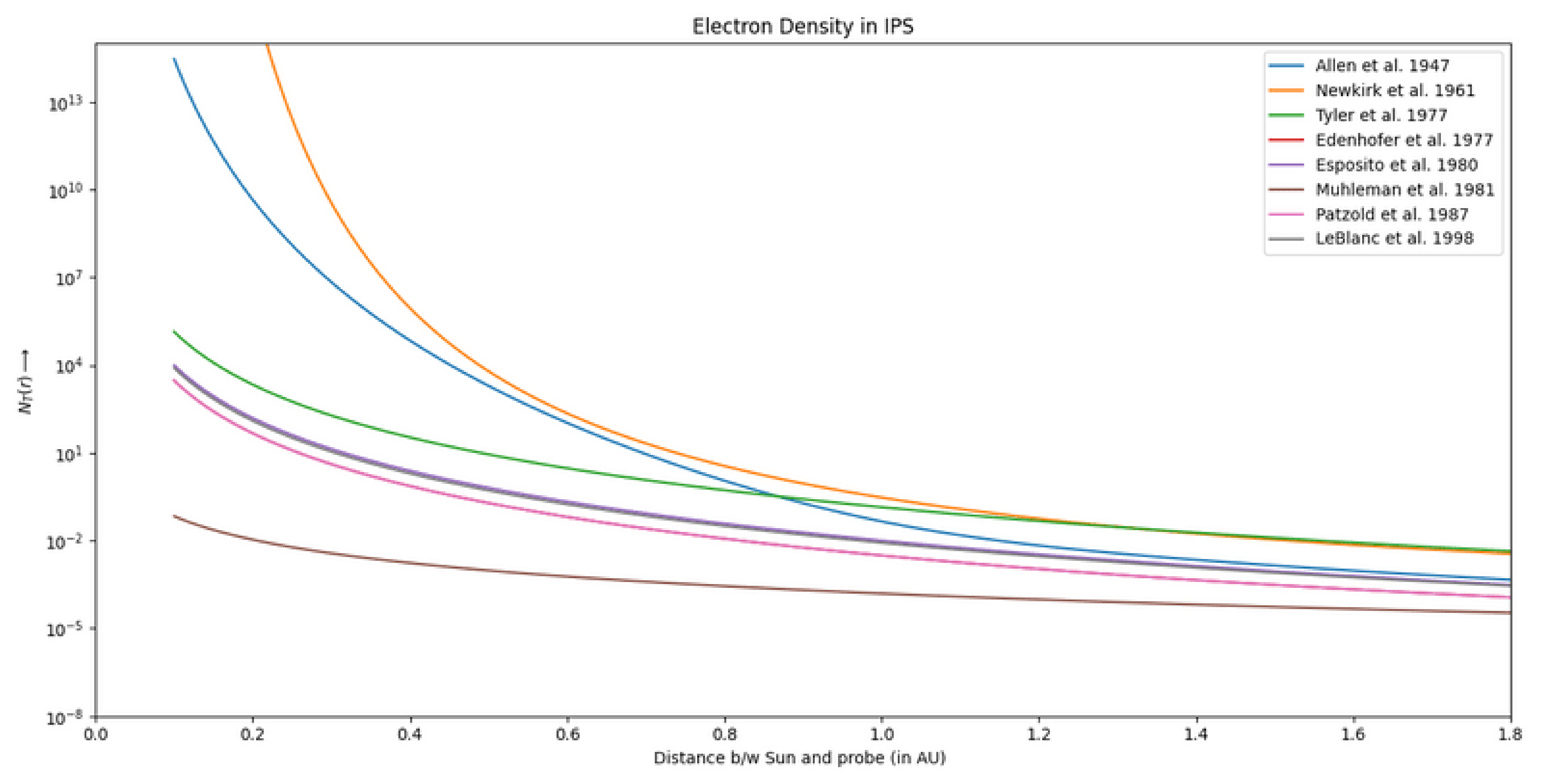
Hollweg et al. 1970

Models for number density in the IPS



Hollweg et al. 1970

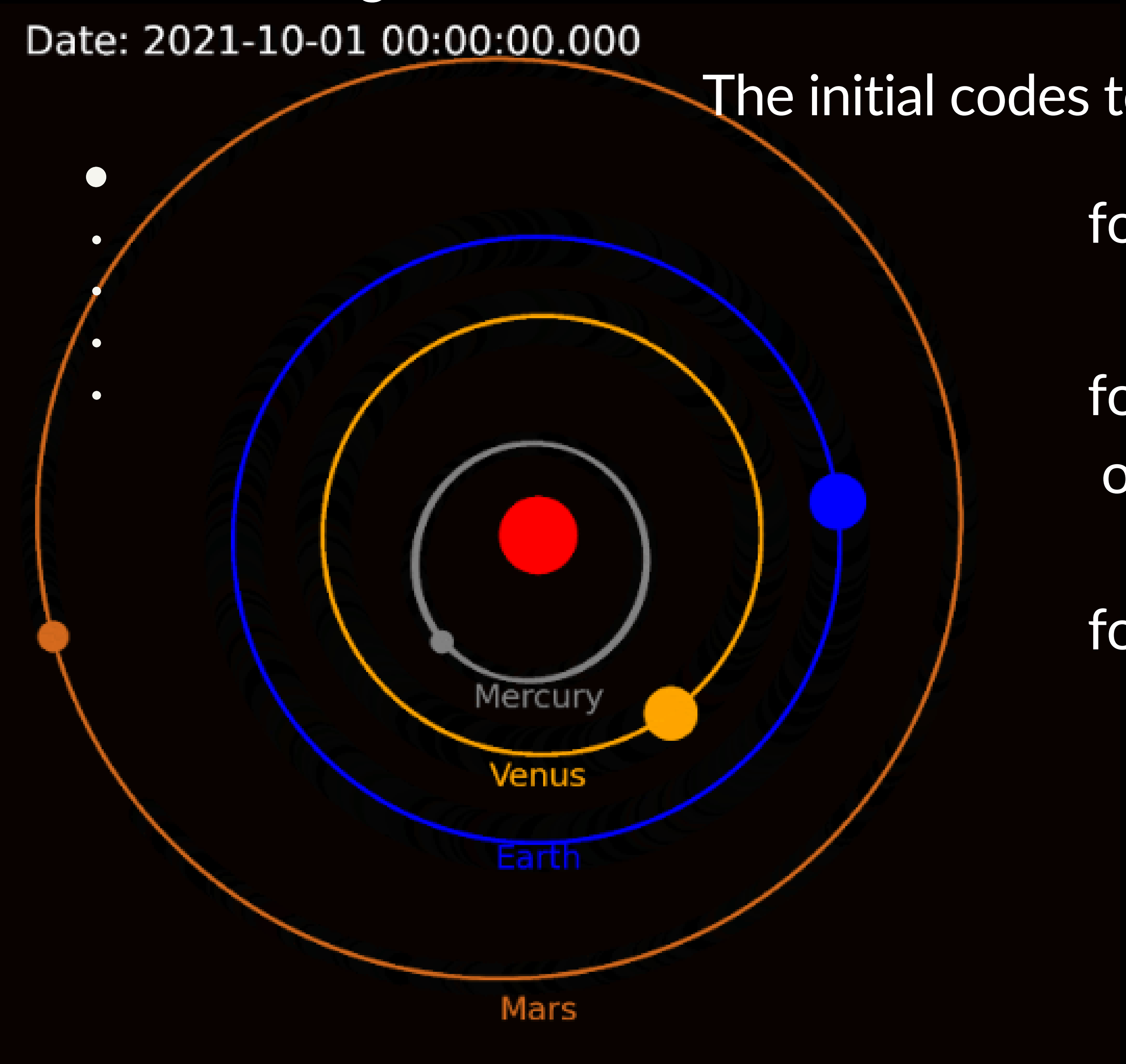
Models for number density in the IPS



Hollweg et al. 1970

Initial Results

We have managed to establish relations between different parameters that will be needed for obtaining the desired results



- The initial codes to read the .prd data file for the MOM mission
- for generating dataframes for required calculations and plotting them
- for plotting the positions of the planets and the Sun during the period of the conjunction
- for comparison of different density models have been developed.

Expected Outcome

- An insight into the solar coronal dynamics during the period of October 2021.
- An estimate of the total electron content (TEC) of the region through which the signal passes.
- Further, estimation of electron density in the IPS from the Sun to the Earth, and comparison with other models in literature.
- Calculation of the velocity of the Solar Wind.

References

A study on the solar coronal dynamics during the post-maxima phase of solar cycle 24 using S-band radio signals from Mars Orbiter Mission | Jain et al. |doi: 10.1093/mnras/stac056

Design and Development of HGA for MOM| Sriharsha et al. | https://www.researchgate.net/publication/268686105_Design_and_Development_of_High_Gain_Antenna_for_Mars_Orbiter_Mission

Coronal investigations with occulted spacecraft signals| Bird et al. | doi: https://link.springer.com/article/10.1007/BF00213250

Scintillation Effects on Radio Wave Propagation Through Solar Corona| Ho et al. | https://ntrs.nasa.gov/citations/20060029492

RADIAL DEPENDENCE OF SOLAR WIND PROPERTIES DEDUCED FROM HELIOS 1/2 AND PIONEER 10/11 RADIO SCATTERING OBSERVATIONS| Woo et al. 1978 |doi:1978ApJ. . .219. .7 2 7W

Angular Broadening of radio sources by Solar Wind Turbulence | Hollweg et al. | https://doi.org/10.1029/JA075i019p03715