SOLAR-C Mission
Option-A (Plan-A)

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JAXA SOLAR-C WG

2010 Mar 9

2nd SOLAR-C Science Definition Meeting

SOLAR-C Concept

- Two options are under study:
  – Option-A (so-called Plan-A):

    Exploration of origin of the solar magnetic activity cycle
    from an out-of-ecliptic orbit
    by X-ray/magnetic field/helioseismic observations

    Toward understanding the solar magnetic activity cycle

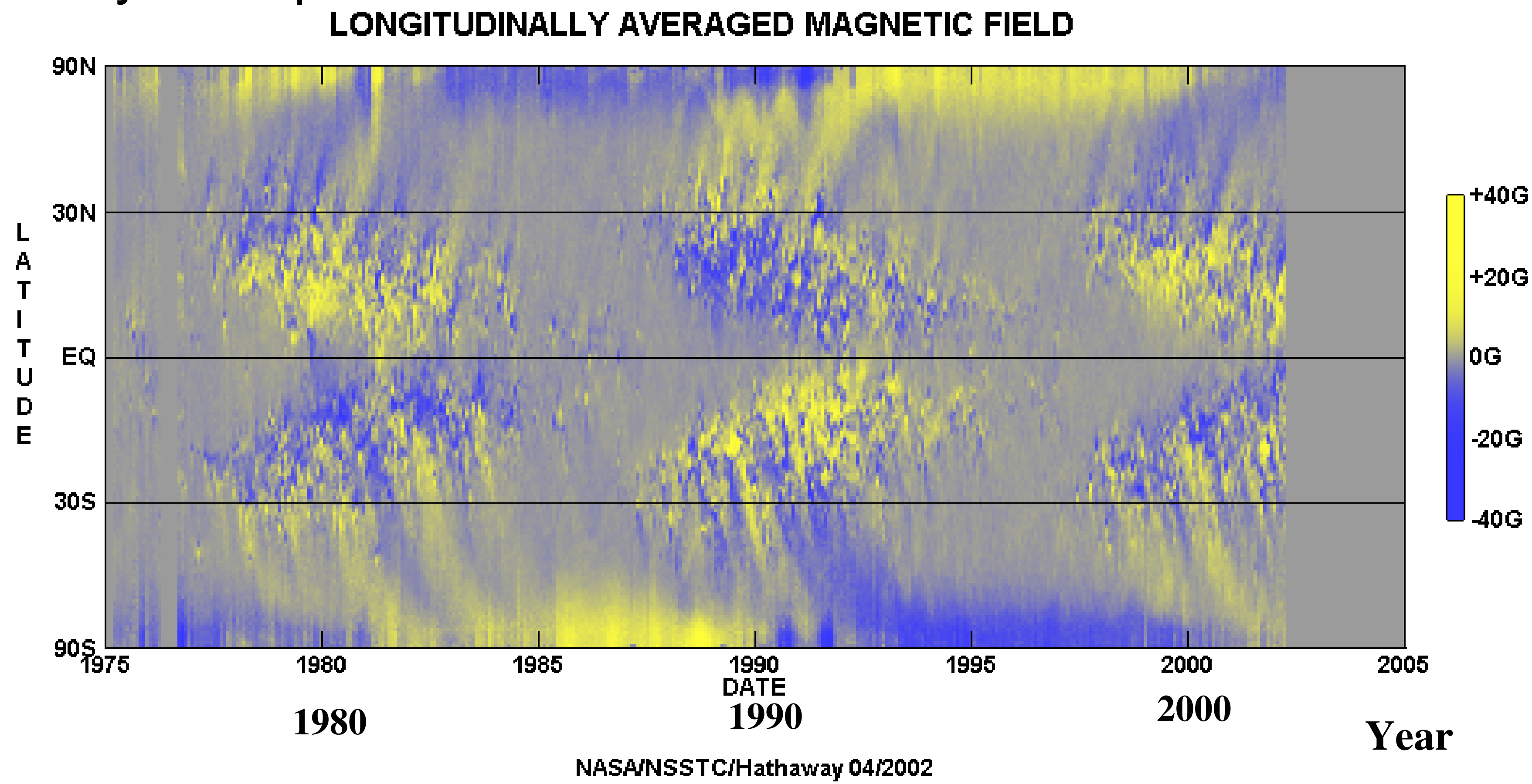
  – Option-B： high-spatial resolution observations of the dynamic Sun with enhanced spectroscopic and polarimetric capabilities

    Toward understanding the magnetic-field dissipation processes

- Launched by JAXA H2A rocket

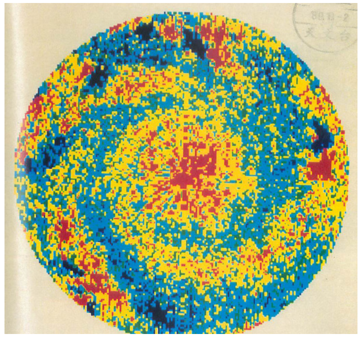
Solar Magnetic Activity Cycle

- How are magnetic fields created in the sun? (Dynamo)
- Internal flows, behavior of polar magnetic fields, and polarity reversal at poles from out-of-ecliptic observations may be important.



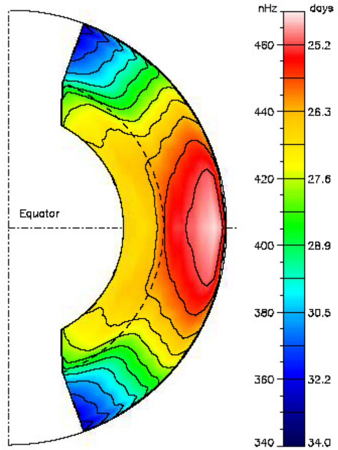
Option-A

Exploration from out-of-ecliptic orbit



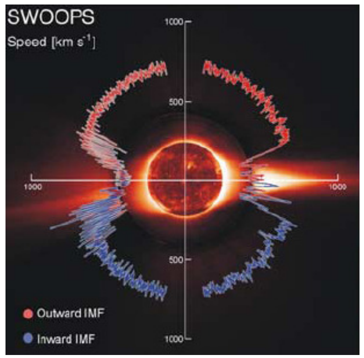
＜Toward understanding the solar dynamo＞

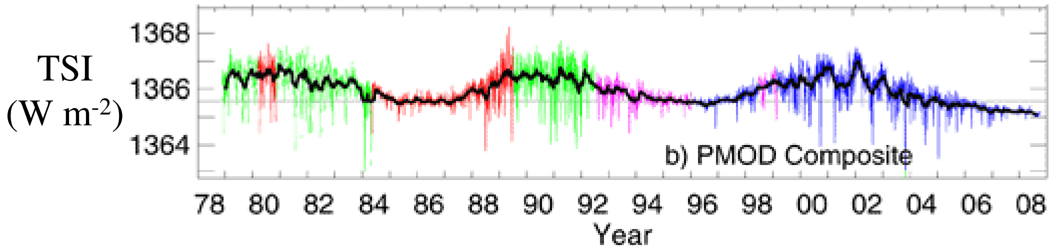
- Surface magnetic activity in polar regions
- Surface/internal flow fields in polar regions
- Search of tachocline regarded as a source region of strong magnetic fields



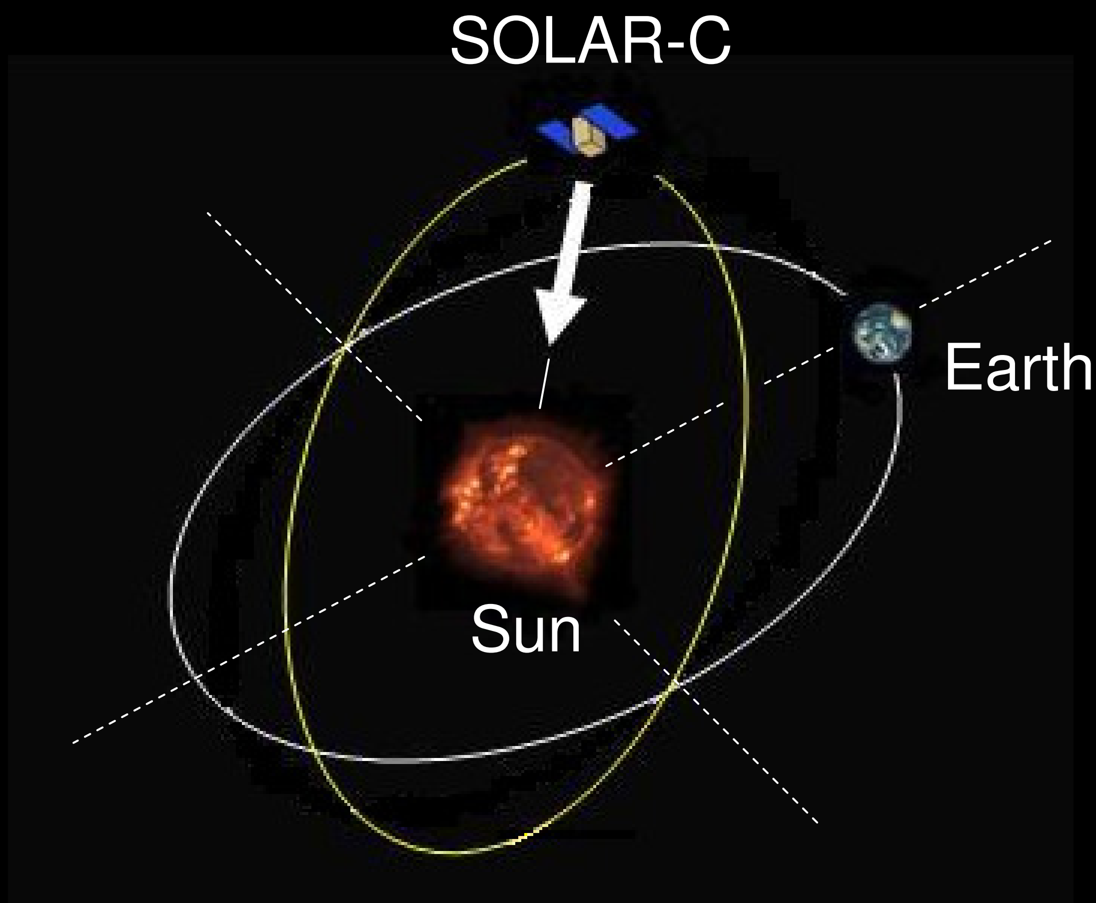
＜Exploration from Vantage Point＞

- Search of solar winds in polar coronal holes
- Total irradiance measurements from out-of-ecliptic orbit; The Sun as a star
- Imaging of CMEs and solar wind/CIR shock structures





Option-A Target Final Orbit

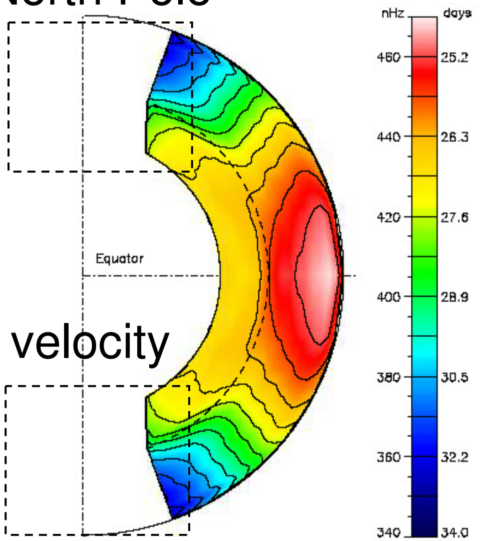


The target orbital period of 1 yr, synchronized with Earth

Rotation and Meridional Flows

- Basic quantities to understand the solar dynamo
- cannot be determined from observations in ecliptic plane for high-latitude and polar regions
- Need out-of-ecliptic helioseismic observations to fill up for all latitude regions

North Pole

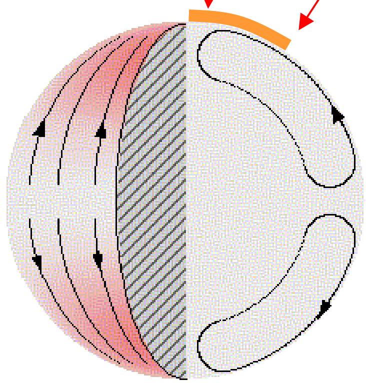


Angular velocity

South Pole

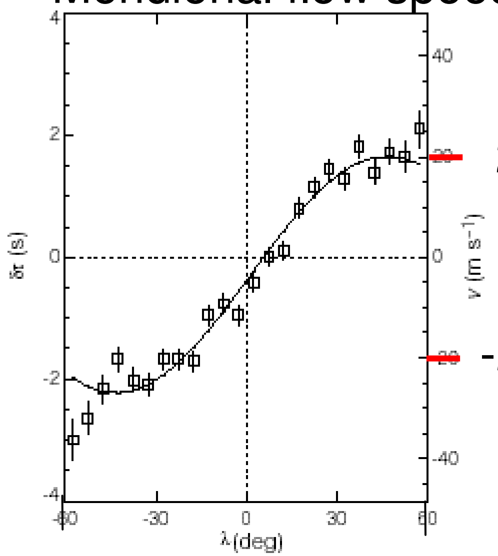
Submergence of magnetic field？

Surface magnetic field transport



Meridional flow

Meridional flow speed

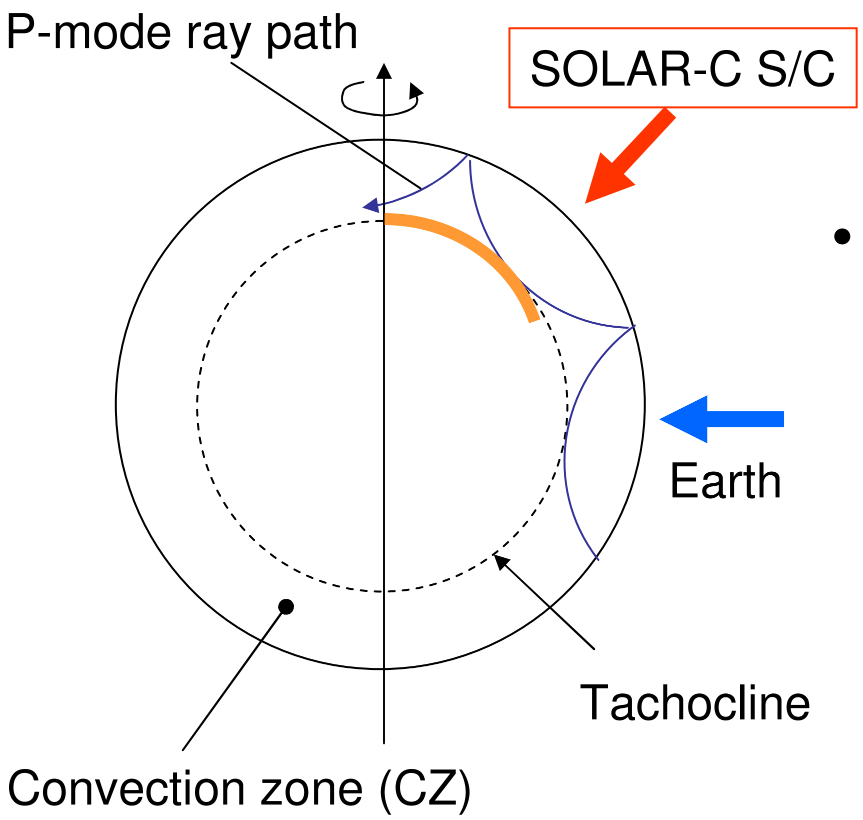


20m/s

-20m/s

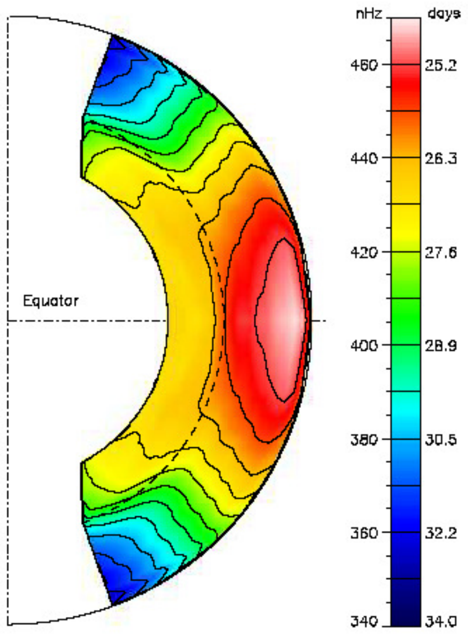
-60 deg Latitude 60 deg

Exploration of B at the base of CZ

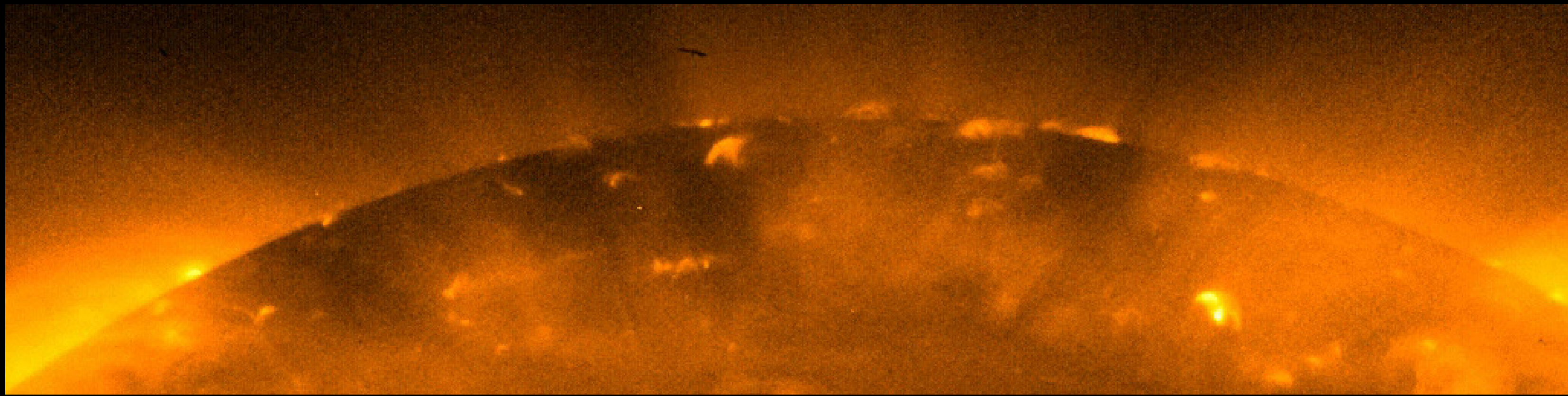


- Many solar physicists believe that magnetic flux tubes are produced at tachocline.
- Exploration of magnetic flux tube at tachocline by helioseismic observations

Internal angular rotation rate



Polar Coronal Activity



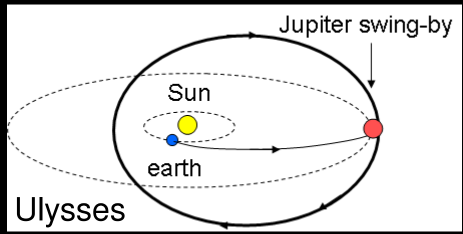
2006/11/23 00:47:25

XRT Al_poly filter exp. 16385msec

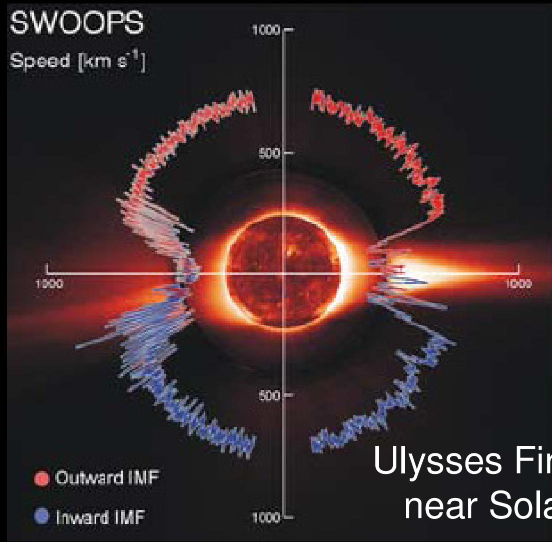
Hinode XRT

- Dynamic polar regions of the sun
- Highly transient jets
- More stable plumes in EUV images
- Source of high-speed solar wind

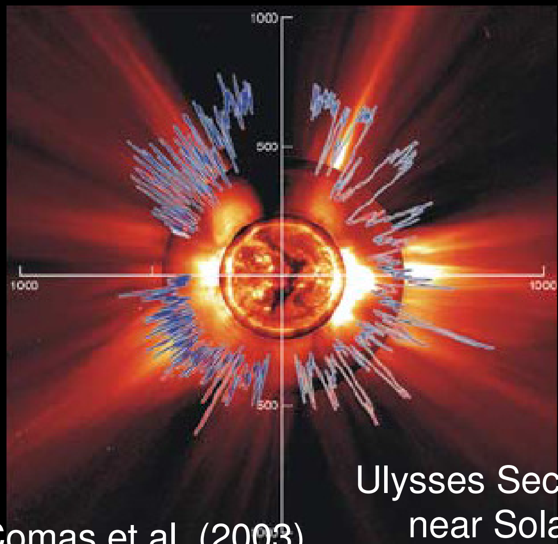
Solar Wind



- How is the high-speed solar wind from polar coronal holes accelerated?
- Measurement of global magnetic fields in polar coronal holes, flows in transition region and low corona, and the wind speed may provide the linkage between sun and inner heliosphere.
- We may be able to see the Parker spiral of solar winds by a heliospheric imaging.



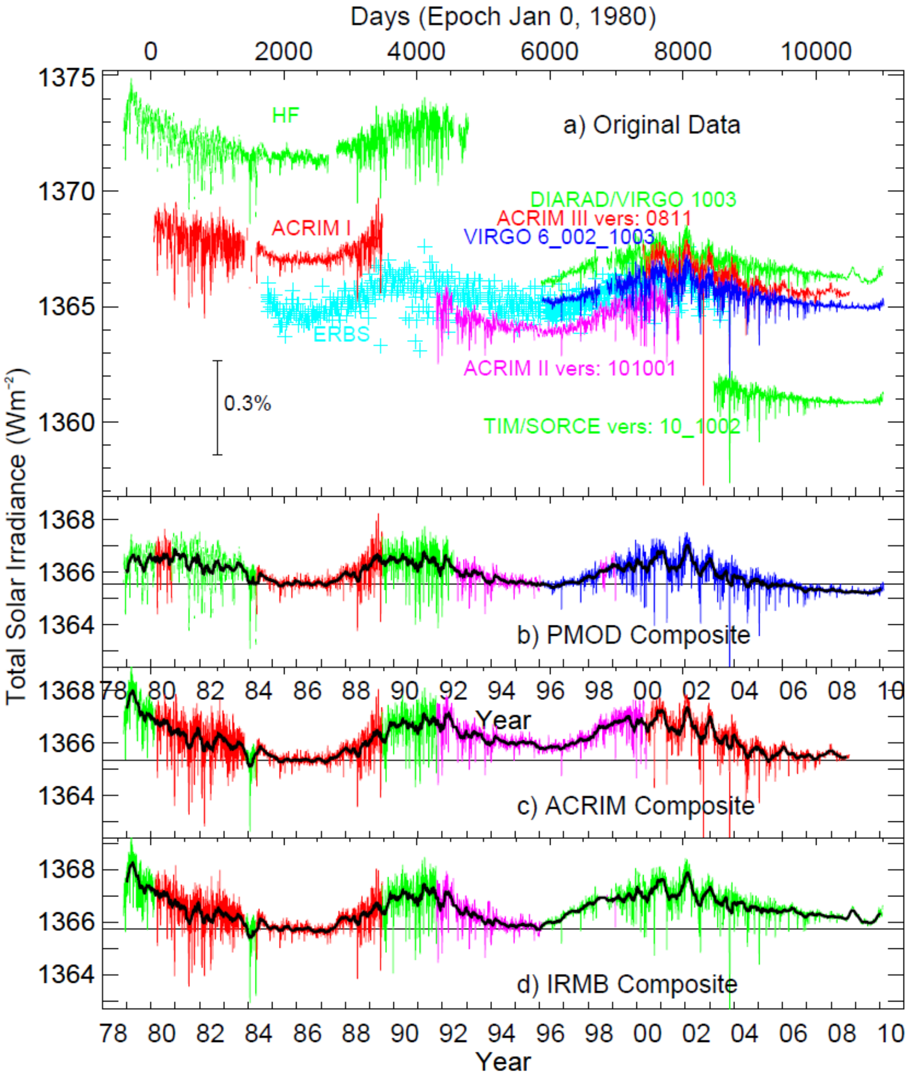
Ulysses First Orbit near Solar Min



McComas et al. (2003)

Ulysses Second Orbit near Solar Max

Total Solar Irradiance (TSI) from out-of-ecliptic plane

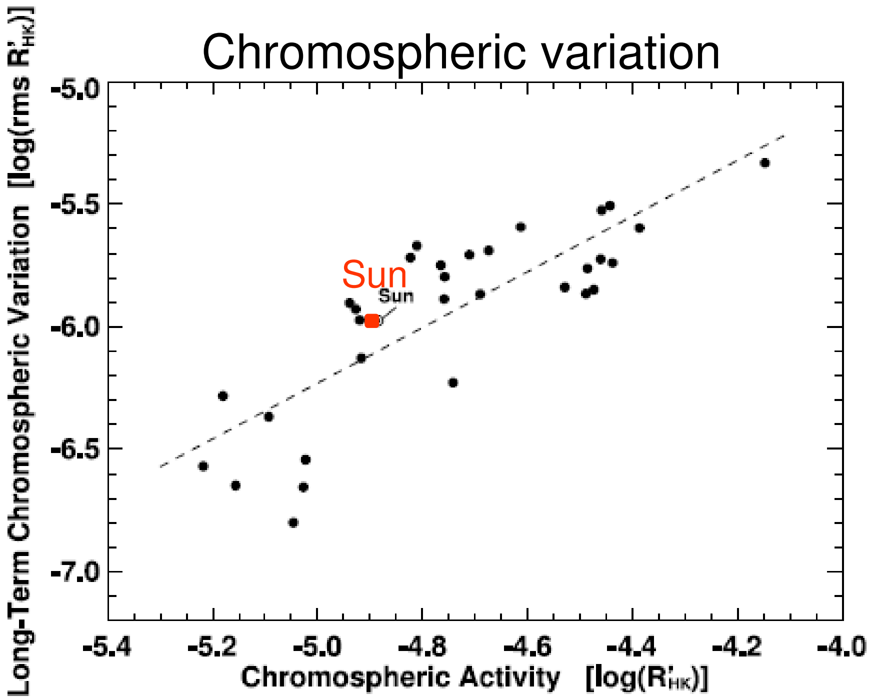


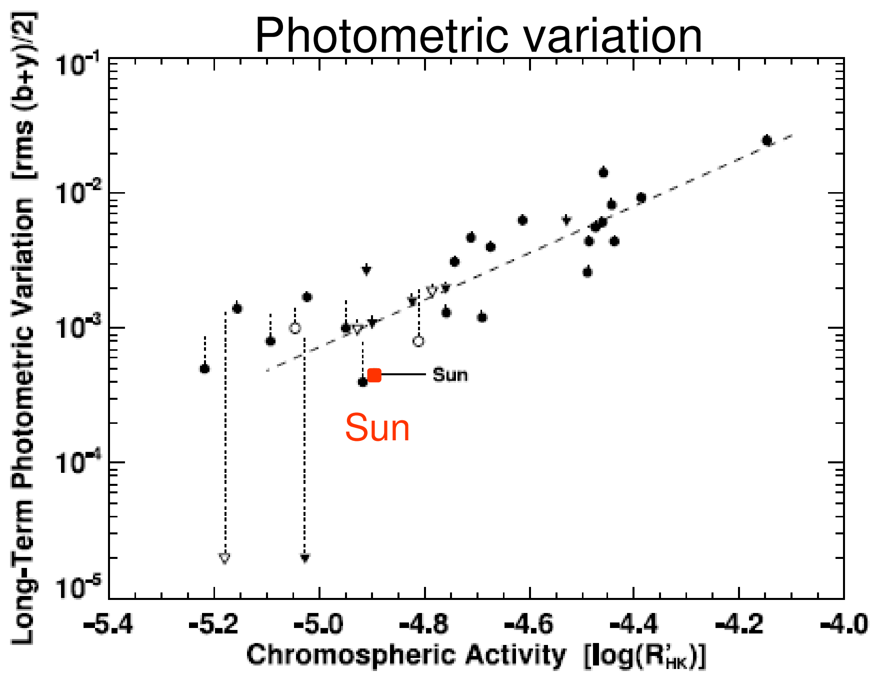
- Understand the sun as a star
- Solar irradiance TSI cycle variation ~0.1% p-p

Figure from PMOD WRC homepage

Photometric variation of solar type stars

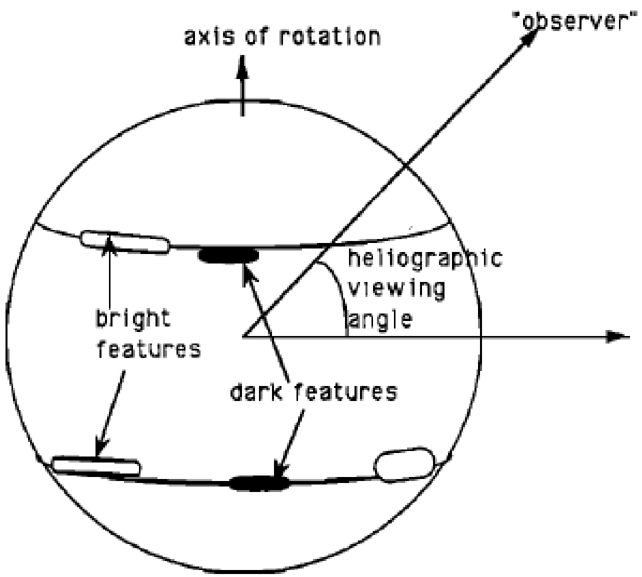
- Solar type stars show larger amplitude photometric variations, (though the number of sample is small…)
- Is it due to a difference in viewing angle to activity belts?





Lockwood et al. 2007, ApJS,171, 260

Total Solar Irradiance (TSI) from out-of-ecliptic plane



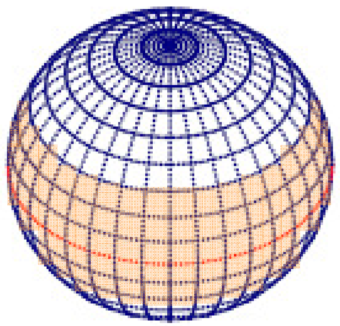
from Schatten 1993, JGR, 98, 18907

- Interesting to measure TSI from an orbit with inclination >40 deg

  Latitudinal variation of TSI

- Overall effects of sunspot blocking, facular brightening near the limb, and change of activity-band location when viewing from an out-of-ecliptic plane

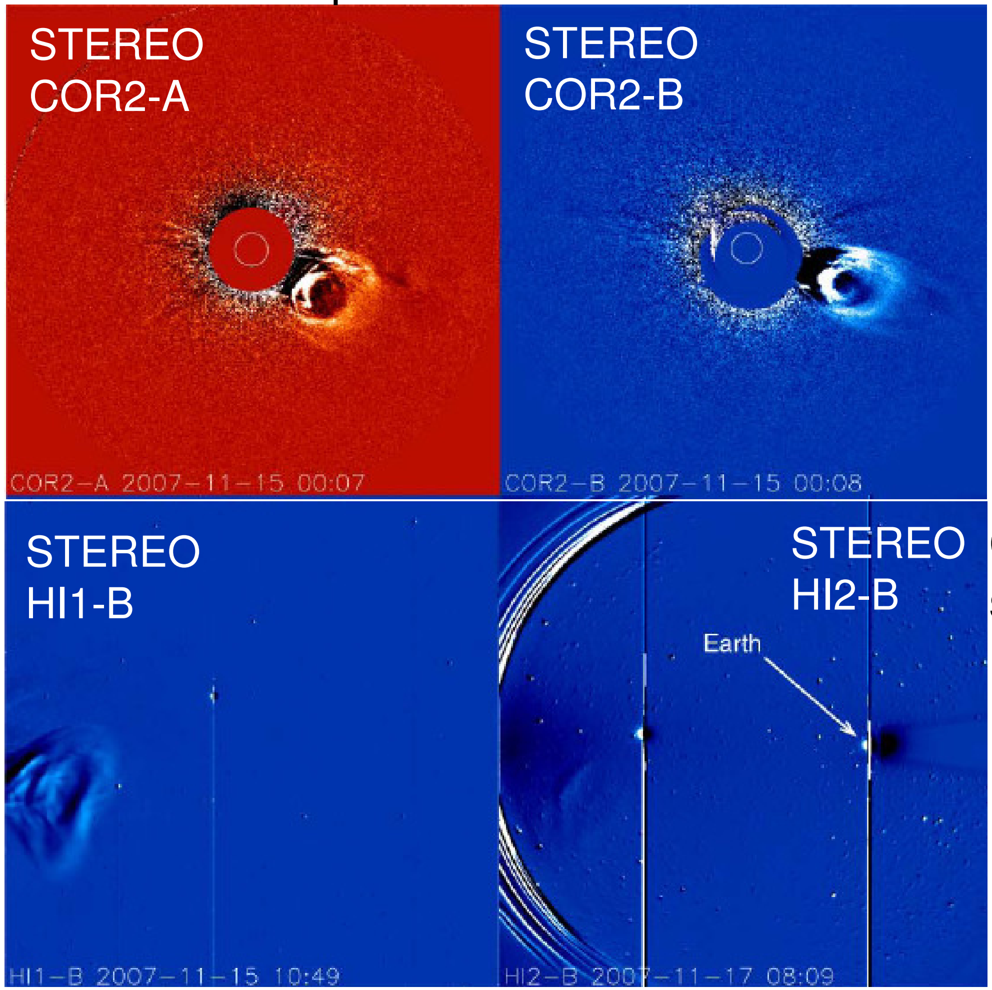
- Amplitude over the solar cycle will increase at the max viewing angle from Plan-A S/C. How large? The Sun is a special mild star for life to adjust its irradiance change?



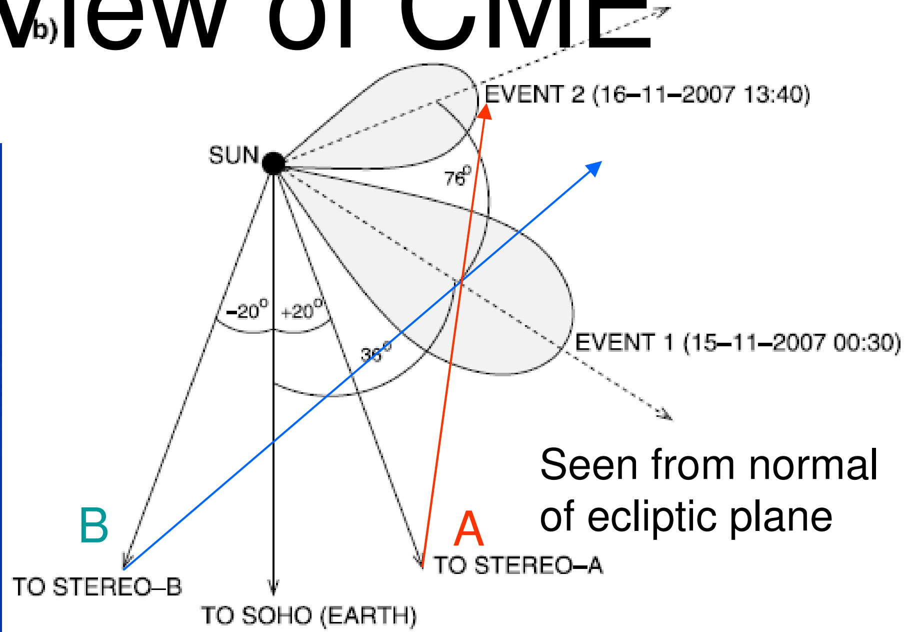
A view at latitude 40 deg from solar equatorial plane and location of the activity belt ($-30 < \theta < 30$ deg)

Stereoscopic View of CME

Stereoscopic view from STEREO

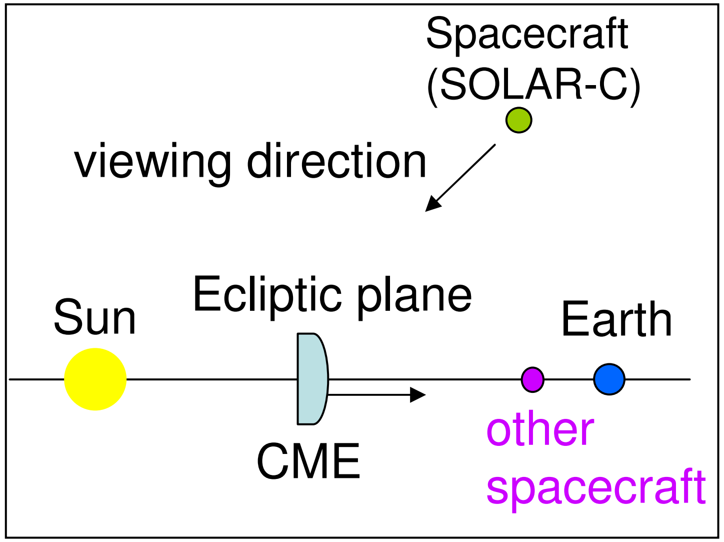


Howard & Tappin (2008)

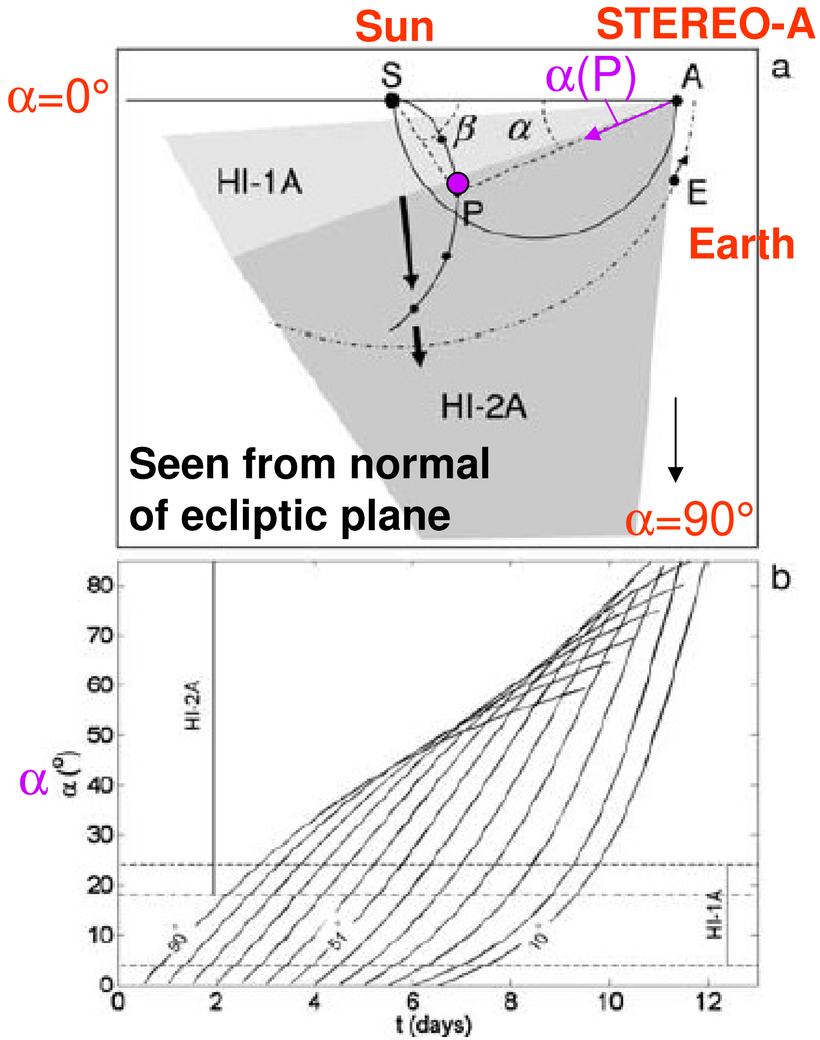


Seen from normal of ecliptic plane

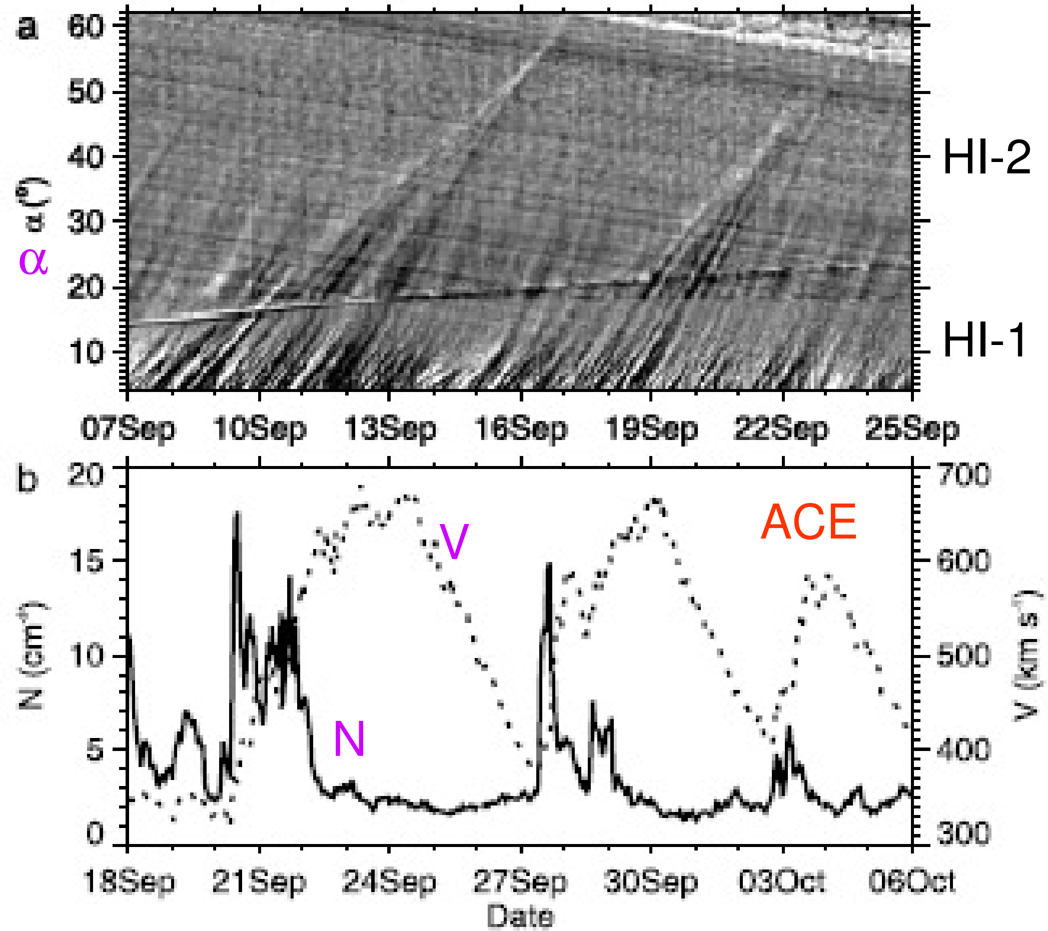
Can we see a signature of Parker-spiral structures by an imaging observation?



Direct Imaging of Density Pattern in Solar Wind Structures



CIR structures detected by STEREO HI

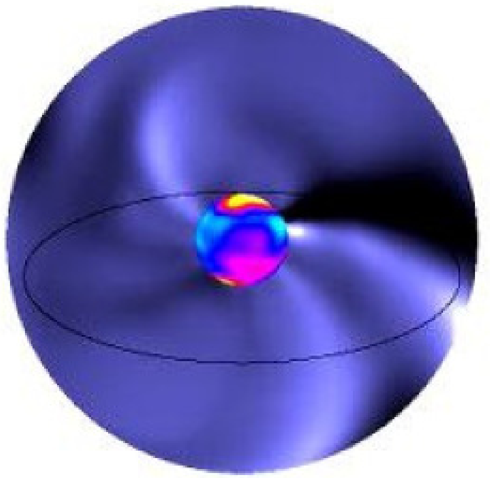


Rouillard et al. 2008, GRL, 35, L10110

Direct Imaging of Density Pattern in Solar Wind Structures

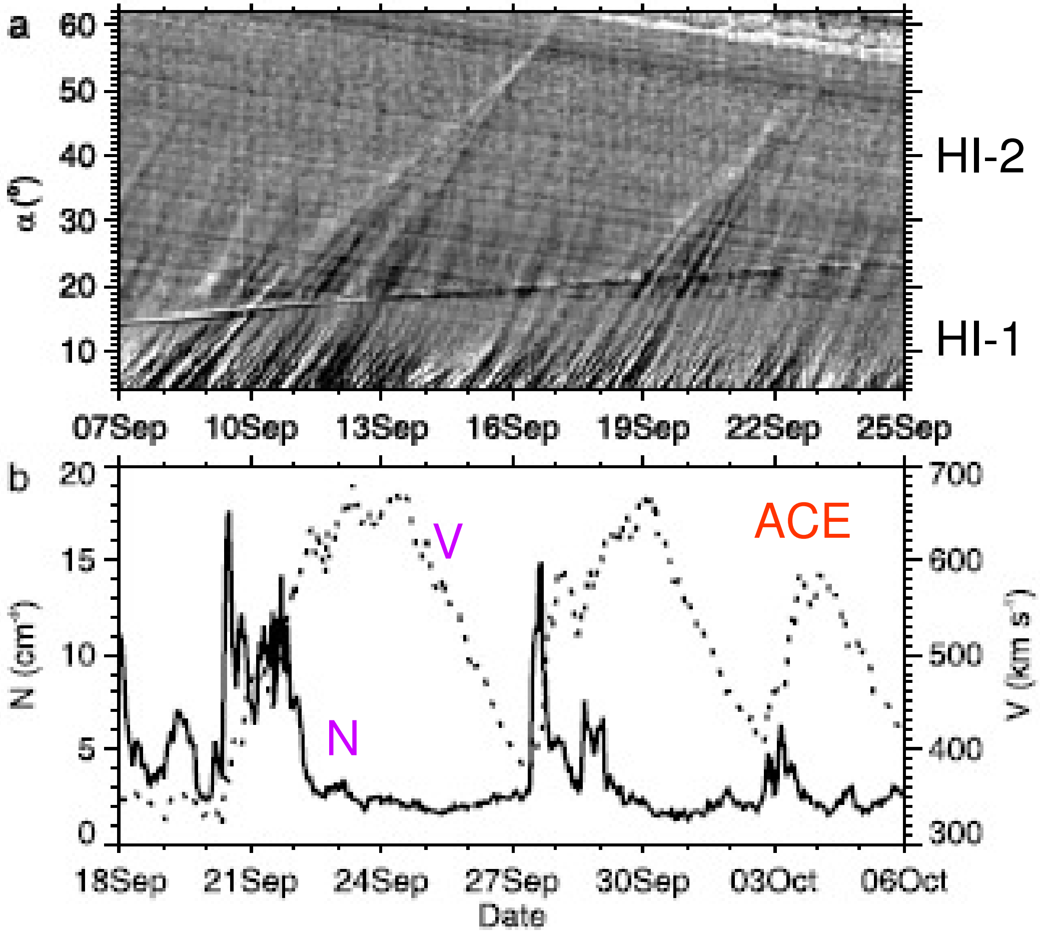
Density difference in SW structures detectable by a slightly-modified STEREO HI from the Plan-A orbit

in ~4 σ significance level to the zodiacal-light background by 6 hours exposure (Preliminary)



Solar-wind density structures
from MHD simulation
as observed at an out-of-ecliptic plane

CIR detected by STEREO HI



Rouillard et al. 2008, GRL, 35, L10110

Other non-solar observations

- Zodiacal light or interplanetary dusts
  - Photometric measurements have only been done from Earth, near-Earth orbits, and inner-heliospheric orbits (by Helios) in the ecliptic plane.
  - Photometric measurements in near-infrared wavelength may access the age of re-ionization of Universe
  - An in-situ measurement of colliding dusts particles as infrequent plasma detection (Ulysses, Japanese “Nozomi” mission, …)
- Anomalous cosmic rays in Heliosphere
  - See Isobe-san’s presentation

Option-A : Model Payload

Each has a space heritage/a slightly modified version in missions that have been flown.

- Visible-light Magnetic-field and Doppler imager
  - full-disk observations
  - Internal flow structures, mag. fields, convection, .. in polar regions
- X-ray/EUV telescope
  - Coronal dynamics in polar regions, synergy with coronal imagers, observing the sun around the earth, in stereo-scopic views
- EUV imaging spectrometer
  - Flow/wave structures in polar regions (plume, solar wind)
- Total irradiance monitor
  - Latitudinal distribution of surface irradiance
- Others (Options at present)
  - Heliospheric imager: CME imaging, solar wind/CIR shock structures
  - Zodiacal-light photometer: distribution of interplanetary dust
  - In-situ instruments (magnetometer, dust counter, …., etc.)
- Total mass 130 kg (tentative allocation for design activity)

Requirements for S/C System Design

- Sojourn time >40 days (TBD) for a solar latitude of >30 deg (TBD)
  - Target of max. latitude : ~40 deg (higher is better, of course)
  - Need to define these numbers clearly from evaluation through helioseismic model calculations
- Distance to the Sun in the final orbit: 1.0 AU
  - Minimum distance to the sun is 0.7 AU from the thermal-design point of view
  - Maximum distance to the sun is not defined because of a possibility of ballistic orbits by Jupiter swing-by
- Use 7 deg tilt angle of the solar rotation axis to the ecliptic plane

- Duration of cruise phase to the final orbit: ~5 years
  - Need 40-days (TBD) observations near perihelion/aphelion points in the cruise phase
- Payload weight: 130 kg
- Data recording rate: >100 kbps ave.
- Mission life:

  cruise phase N_0~5 yr + N_1 yr + extended duration N_2 yr (total ~N_3 yr)

Orbit Design & Option-A Spacecraft

- Dr. Kawakatsu explains candidate orbits and spacecraft system for the Option-A mission.

Option-A orbit

- Near-Earth orbit using ion engine & Earth swing-by
  - Higher-priority orbit for Solar Physics
  - High-data rate observations required for magnetic and helioseismic research
  - Limited imaging observations of the Sun during the use of ion engine if there is no active pointing mechanism on the payload
  - Launch opportunity: every 0.5 year
  - 40° inclination from solar equatorial plane,1AU distance, synchronized with Earth
  - It takes ~5 yr to achieve the target orbit.
- Jupiter swing-by + Earth swing-by (ballistic orbit)
  - Lower-data rate observations and lower spatial resolution before achieving target orbit
  - Observations are always possible except for swing-by operation
  - Launch opportunity: every ~1.1 yr
  - 36-40° inclination from solar equatorial plane,1AU distance, synchronized with Earth
  - Shorten the orbital period by Earth swing-by. It takes ~7 yr to achieve the orbital period of 1 yr.

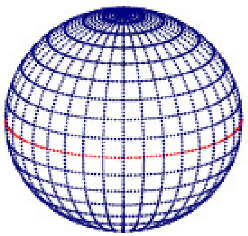
How is the solar poles seen as a function of inclination angle?

i : inclination angle from solar equatorial plane

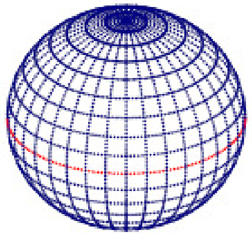
Rocket: H-II A-202

Cruise by Ion engine
in a shorter duration
compared with SO
~**5 years** for final orbit
of a=1.0AU, 1yr period

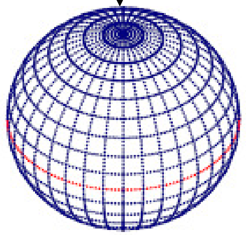
Possible by
Earth swing-by
only



i = **20 deg**

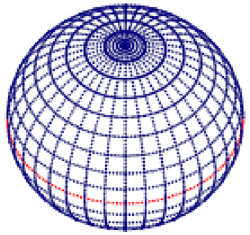


i = **30 deg**

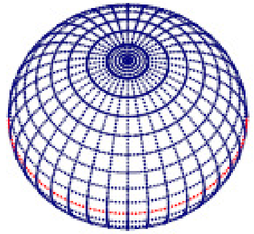


i = **40 deg**

Ballistic orbit
by **Jupiter & Earth Swing-by**
H-II A-202
~**7 years** for final orbit of
a=1.0AU, 1yr period



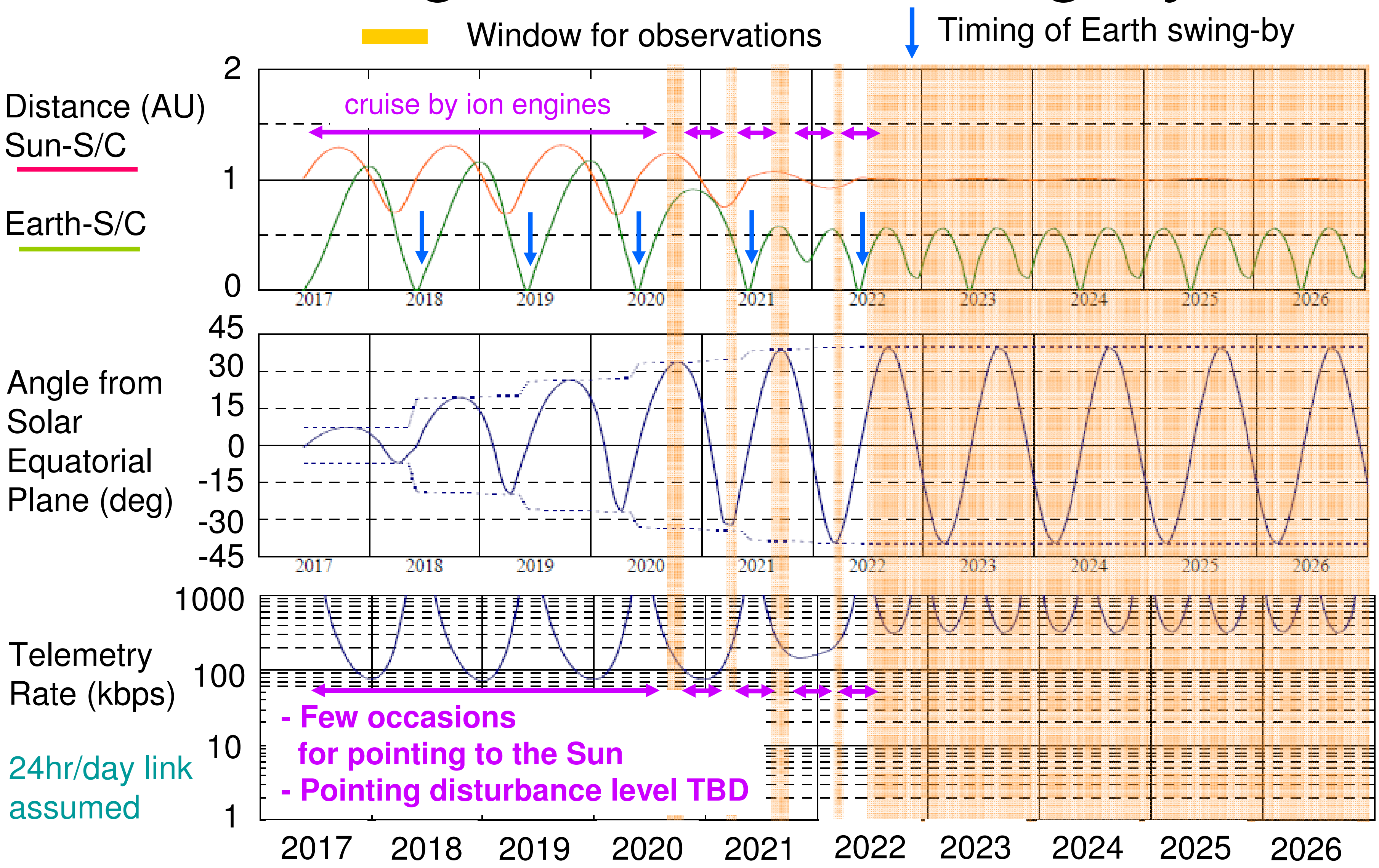
i = **50 deg**



i = **60 deg**

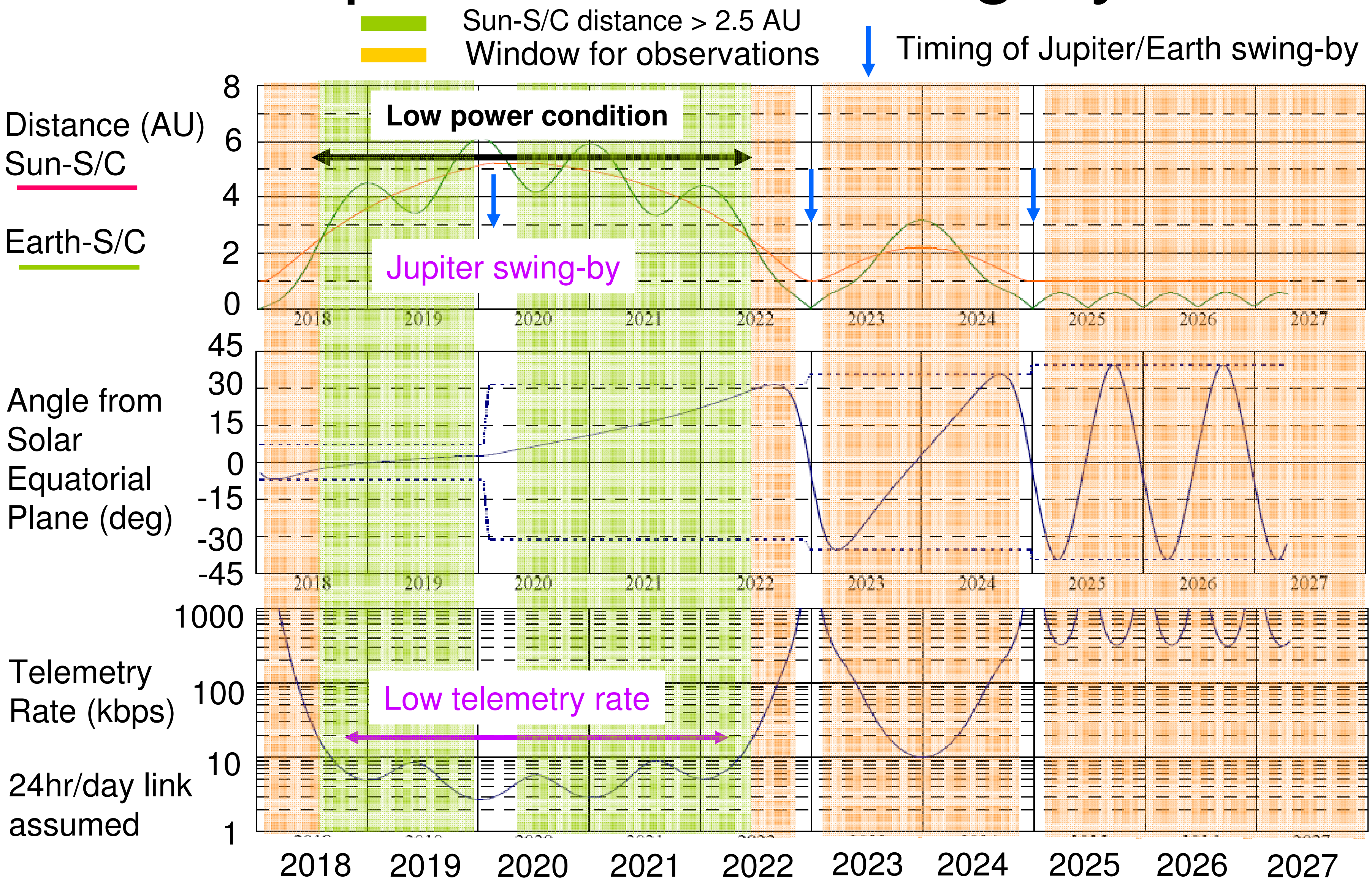
Ballistic orbit
Jupiter & Earth
swing-by
of long-duration
cruise (>7 yr)
Final period ~ 2 yr
H-II A-204

Ion engine + Earth swing-by



Priority in this case: reach max inclination as soon as possible

Jupiter + Earth swing-by



Priority in this case: reach max inclination as soon as possible

Technical Issues in spacecraft system for SEP Option

- Option-A - escaping from ecliptic plane
  - Kick-motor: no suitable kick motor for H II-A interplanetary mission
  - High power systems (~7 kW)
    - need high-efficiency power supply for operating ion engines toward further reduction of the S/C weight
    - need light weight solar array paddle (being developed in JAXA)
  - High telemetry rate in interplanetary space (~100 kbps data recording rate @0.5AU set as minimal required level)
    - not a high rate for NASA's S/C missions (slightly better in STEREO)
    - a key issue to enhance scientific return from helioseismology
    - needs downlink stations for deep space at both northern and southern hemispheres
  - High thrust ion engines (120 mN max)
    - endurance test of ENG model being performed at JAXA/ISAS
  - Heat exhaust from high-heat-generating components
    - found to be little problems after a thermal design for a model orbit

Technical Issues in spacecraft system for Jupiter Option

- Option-A - escaping from ecliptic plane
  - Kick-motor: no suitable kick motor for H II-A interplanetary mission
  - High power systems (TBD kW) for operating at far Sun-S/C distance
    - needs high-efficiency power supply for operating ion engines toward further reduction of the S/C weight
    - needs light weight solar array paddle (being developed in JAXA)
  - High telemetry rate in interplanetary space (~100 kbps data recording rate @0.5AU set as minimal required level)
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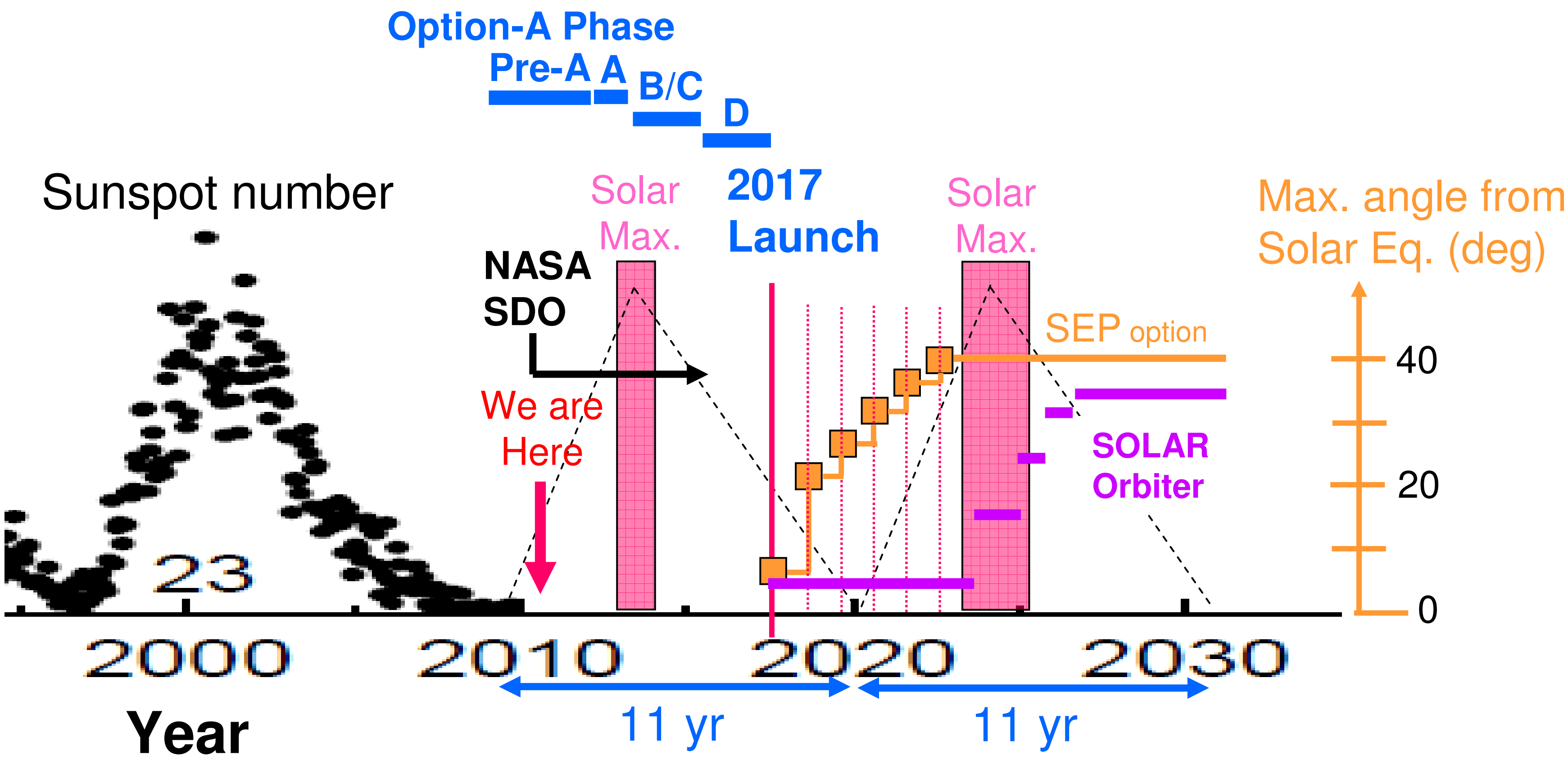
Provisional Schedule

- If Option-A needs to look at the polar polarity reversal in 2020's in a good observing condition, the launch of 2017/2018 is required in SEP option.
- In the baseline Jupiter option, the polar reversal may occur before S/C reaches the maximum inclination.



Synergy among multiple spacecrafts

3D Scanning of Heliosphere by Multiple Spacecrafts

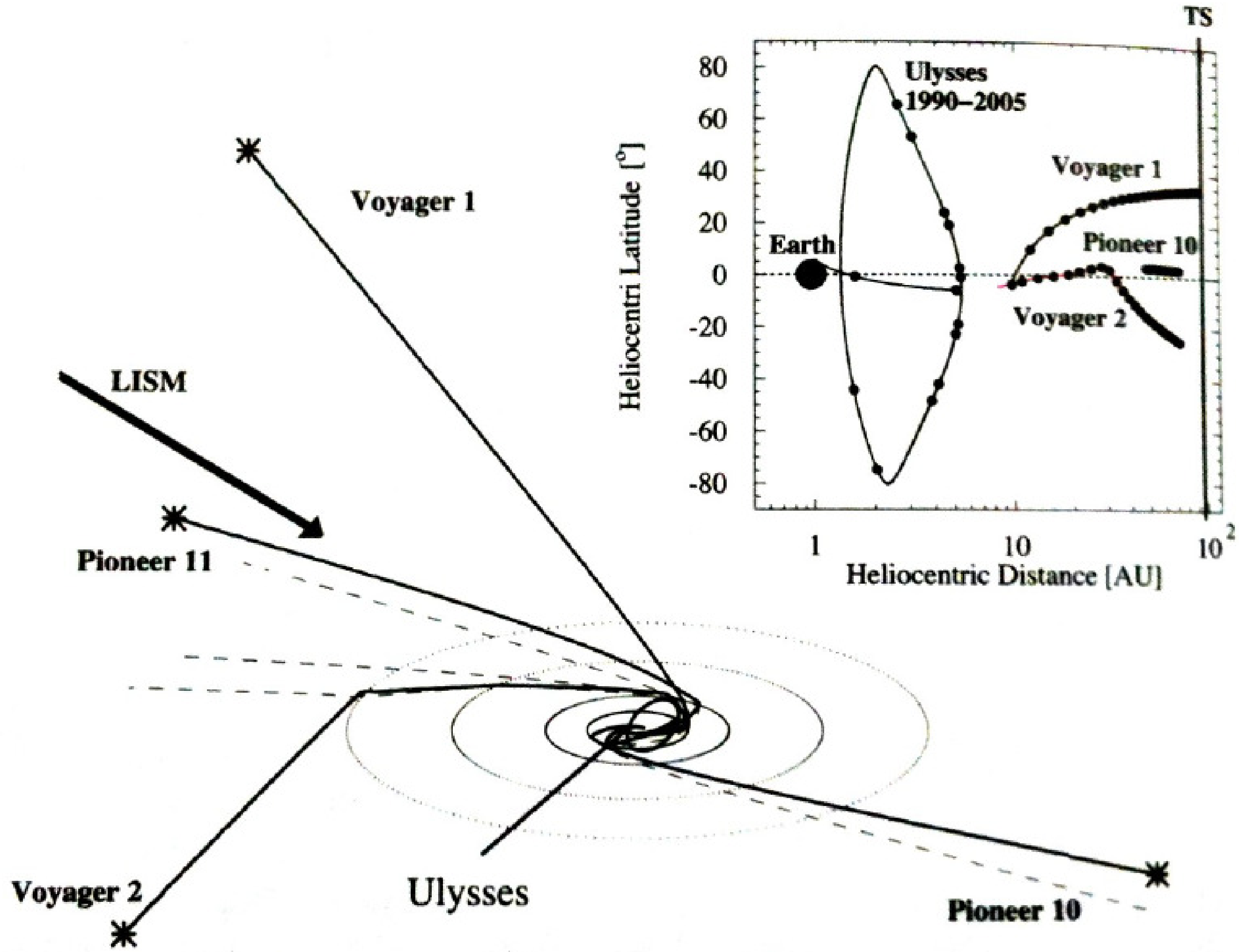
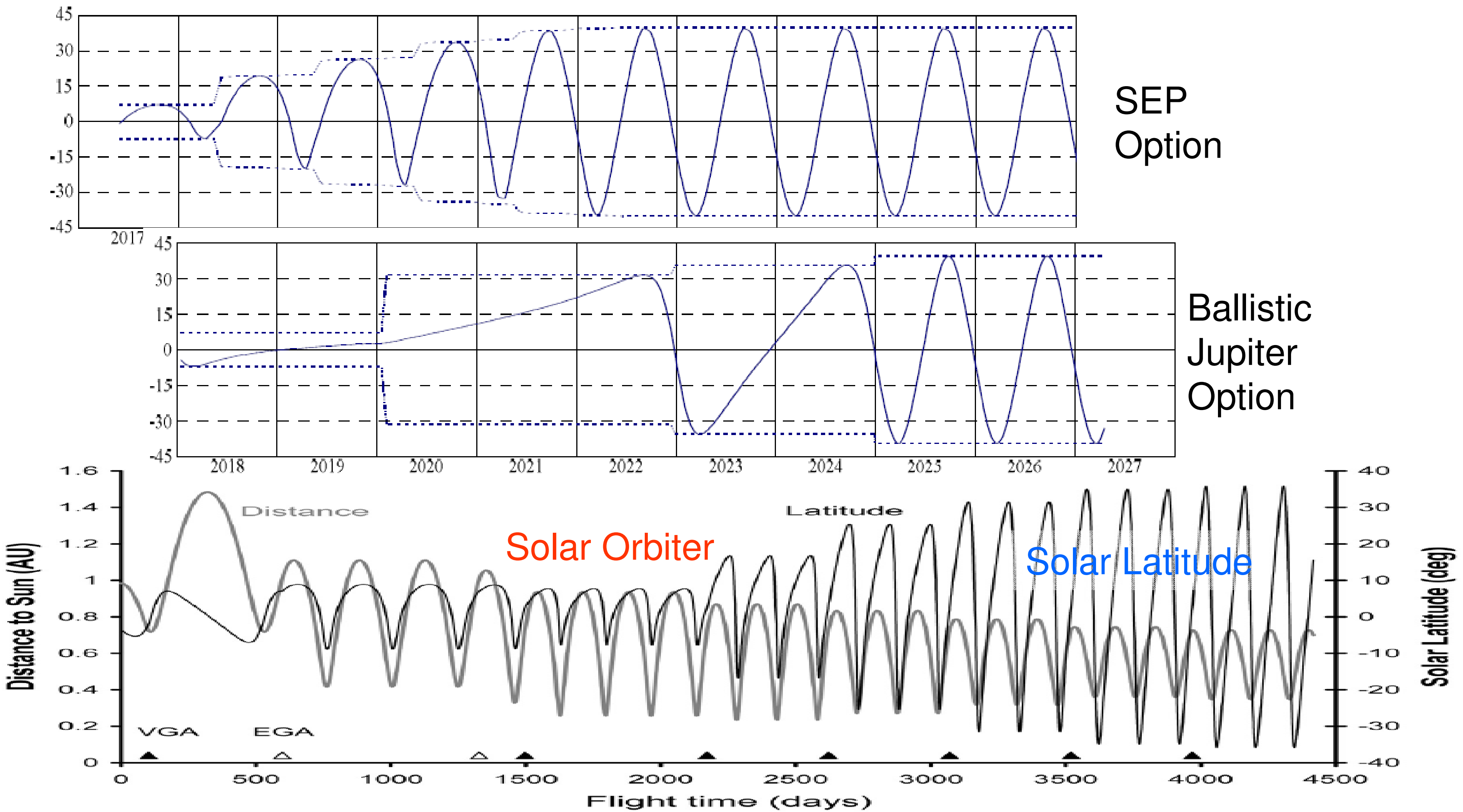


Figure from Heber & Cummings (2001)

Synergy between Option-A and SO

3D Scanning of the Sun by Multiple Spacecrafts

One spacecraft cannot cover both polar regions at one time.



Summary

- SOLAR-C Option-A is a mission to look at the Sun from a high-inclination out-of-ecliptic orbit.
- We will observe features all over the latitudes on the sun and a wide rage of heliospheric latitudes at ~1AU:

  Magnetic fields, convection, internal rotation, meridional flows from polarimetric and helioseismic observations, activity of upper atmosphere, source region of solar wind, and interplanetary in-situ measurements.
- Science in Heliospheric Physics has not been well discussed with heliophysics group.
- There are practical solutions for a spacecraft to enter a 40-deg inclination orbit with1-yr orbital period.
- The orbit with ion engines may be better at a glance, but there need many technical challenges.