NGSPM-SOT

Topics III: Solar Cycles & Space Climate

for start of discussion

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Issues for Topic-III Solar Cycles & Space Climate

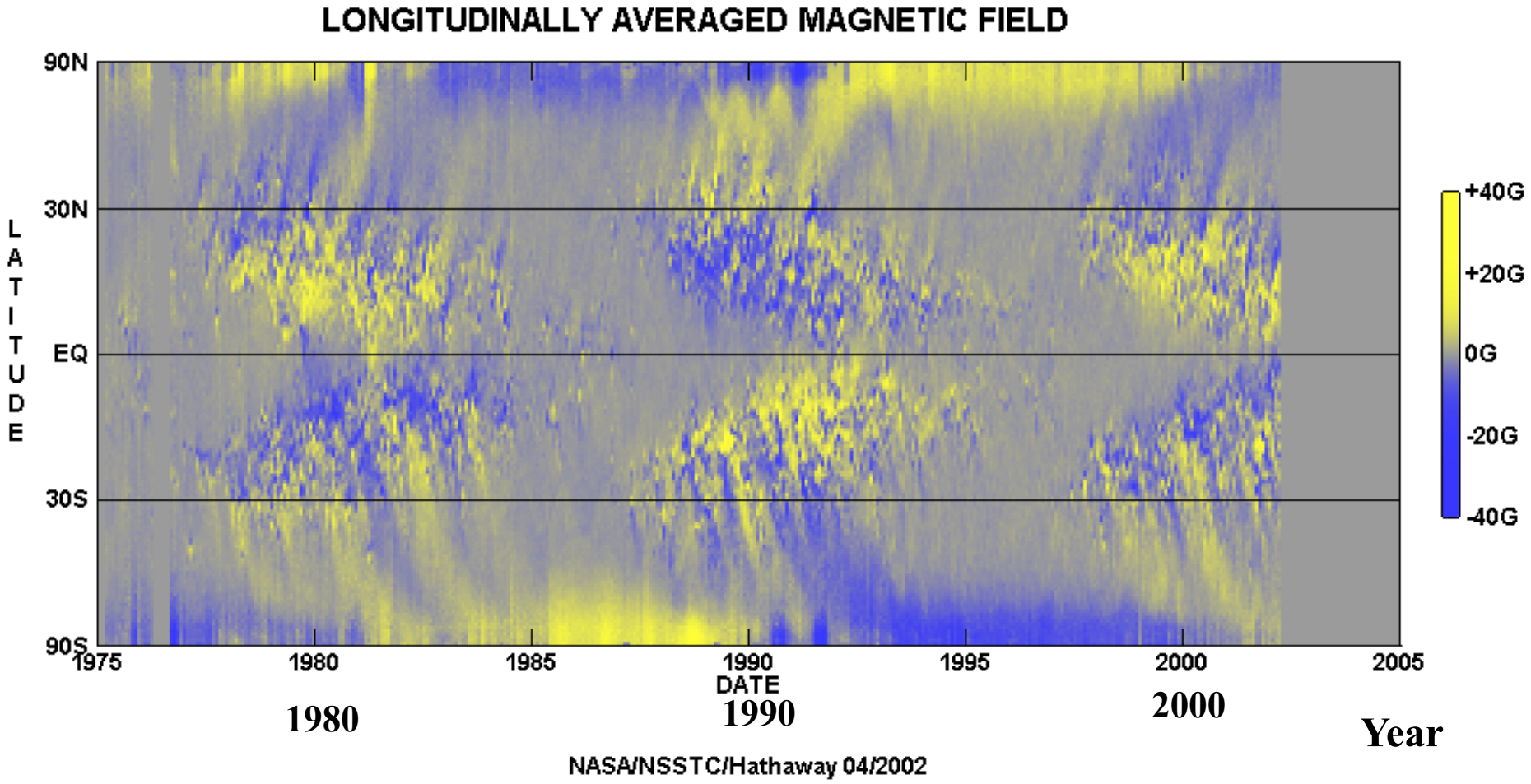
- It covers the science topics of the long-term magnetic cycle activity and its impact on the space climate.

- Tentative answers for the 'Homeworks' in NGSPM:
  - **Level1: Is the chromosphere the best and only target region for the Next Generation Solar Physics?**
    - Partially yes for the topics of total and spectral irradiance, but not the case for Topic-III in general.
    - Measuring the flows in the convection zone (CZ) may be more essential.
  - **Level2a: Has Solar-C science objective fully cover the most important ones?**
  - **Level2b: Regarding target regions other than the chromosphere, what are the science objectives?**
    - The flows in the convection zone and the coupling between the flow and magnetic field will be more essential for the Topic-III.

SOLAR-C PLAN-A

Solar Magnetic Activity Cycle

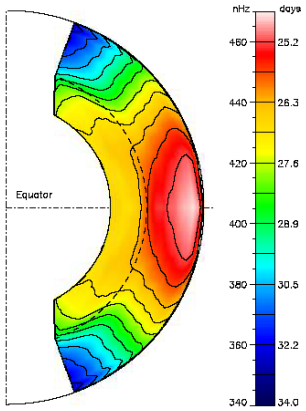
- How are magnetic fields created in the sun? (Dynamo)
- Internal flows, behavior of polar magnetic fields, and polarity reversal at poles from out-of-ecliptic observations may be important.



Topics: Solar Cycle & Space Climate

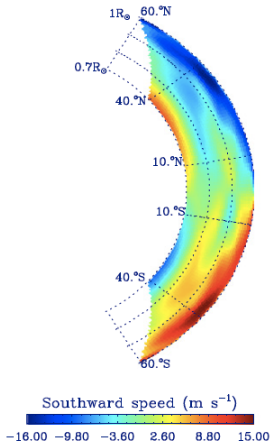
- Candidates:
  - Understanding the flow structures in CZ
    - ✓Differential rotation: average over longitudes well known from helioseismology: latitude θ = 0–60 deg
    - ✓Meridional flows: θ = 0–60 deg, 0.95–1.00 $R_\odot$ well known from helioseismology.
    - ✓Other convective thermal flows? (LS global convection was found?)

Diff. Rotation



Thompson+ 1996

Meridional Flow (MF)



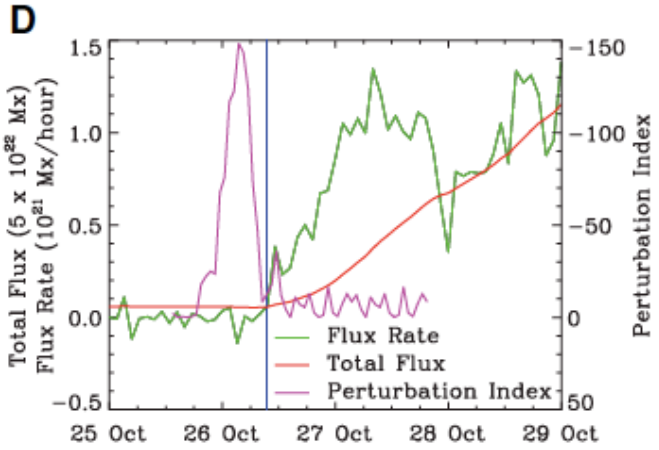
There is consensus in MF in the shallow part of CZ.

MF in the deep part may be estimated from HMI data in the near future.

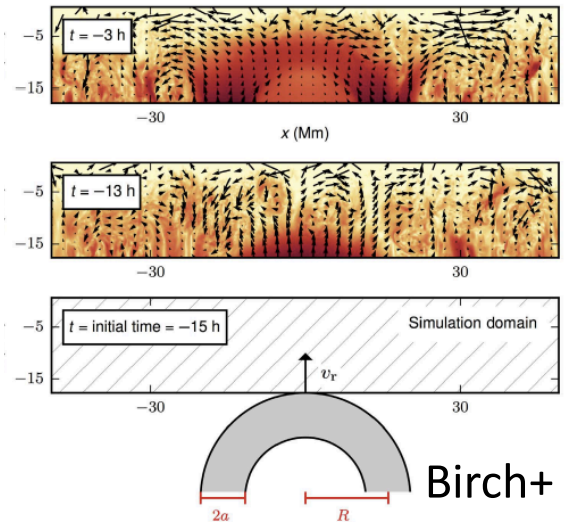
Rajaguru & Anita 2015

Topics: Solar Cycle & Space Climate

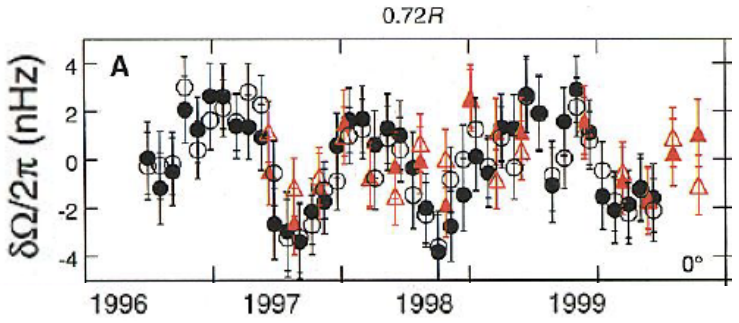
- Candidates:
  - Detection of global magnetic flux in deep CZ
    - ✓Acoustic anomaly only found at most upper part of CZ.
    - ✓Detection of a flow in flux tube near tachocline: was one of the targets for Solar-C Plan-A (out-of-ecliptic mission)



Ilonidas+ 2011



Birch+ 2016

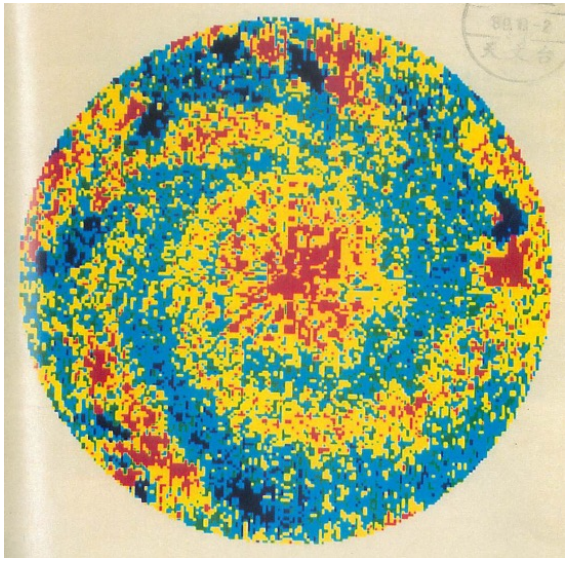


Howe+ 2000

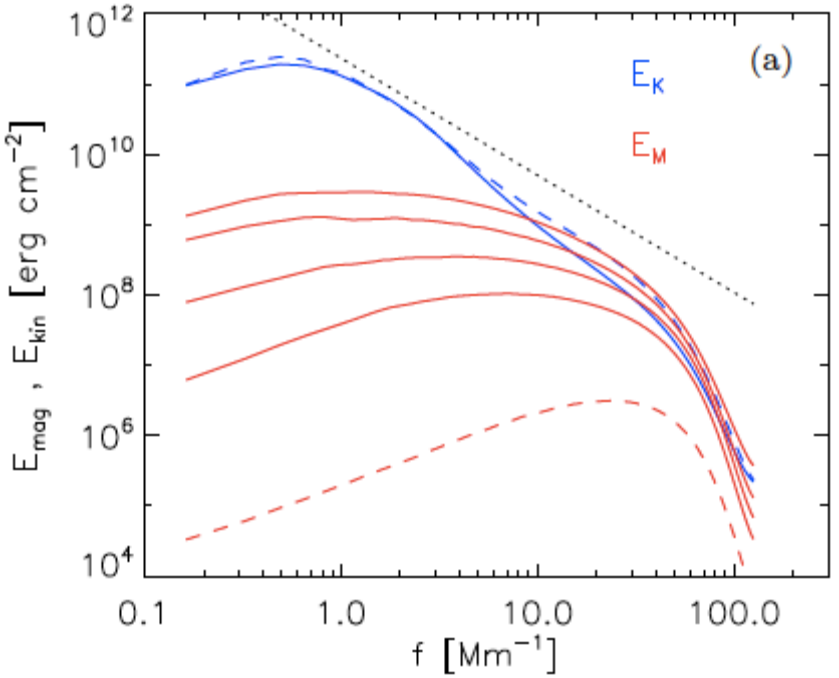
  - Location and mechanism of the alpha effect
    - Is the possible access to this problem is to measure the current helicity in an improved condition?
      (e.g. stereoscopic magnetic field measurements to reduce the 180 deg uncertainty)

Topics: Solar Cycle & Space Climate

- Candidates: (continues)
  - Observation of surface convective features in high latitudes
  - Local dynamo near the surface and its impact on the global dynamo



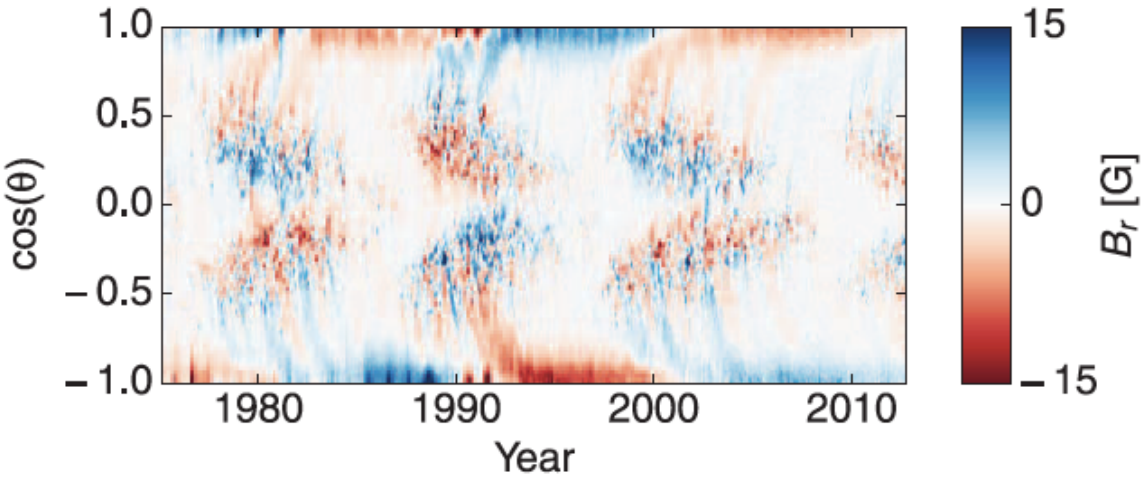
Wang, Sheeley, Nash 1990



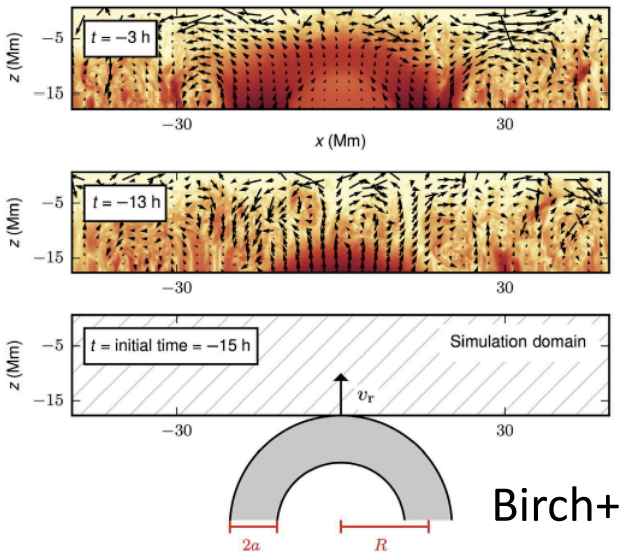
Rempel 2014

Topics: Solar Cycle & Space Climate

- Candidates: (continues)
  - Magnetic flux transport and flux cancellation
    - ✓Horizontal flux transport
    - ✓Vertical flux transport:
      - Speed of rising flux tube in CZ
      - Transport from photosphere to upper layers
  - Formation of large-scale unipolar regions



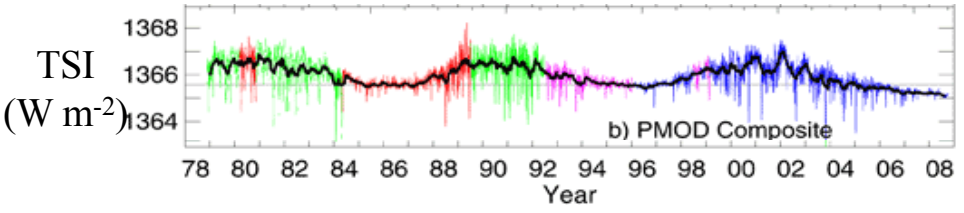
Cameron+ 2015

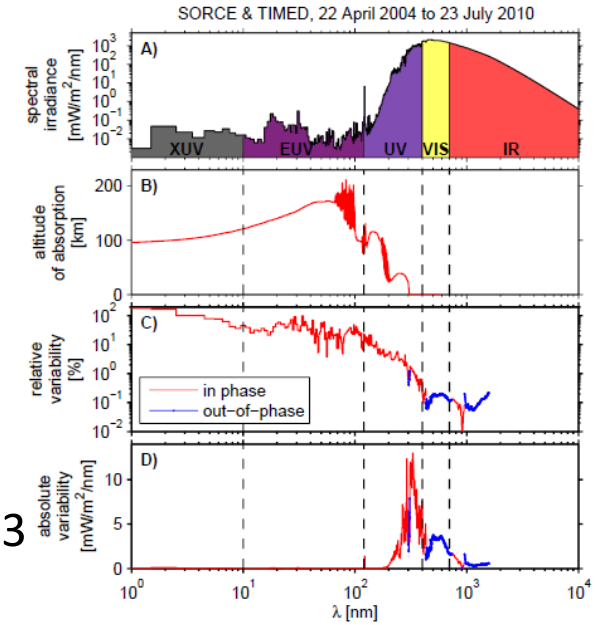


Birch+ 2016

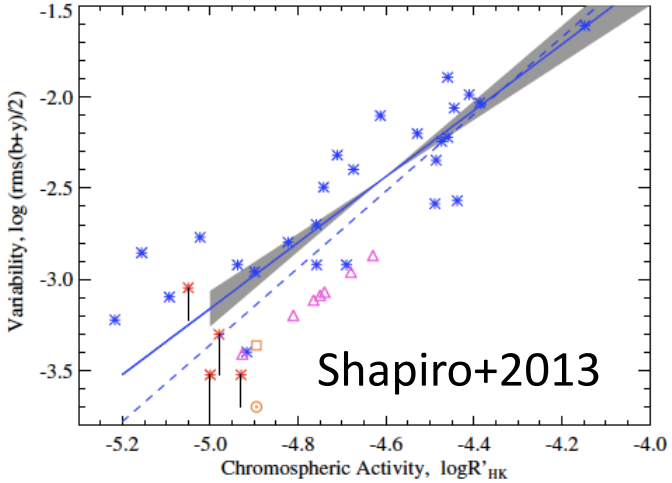
Topics: Solar Cycle & Space Climate

- Candidates: (continues)
  - Understanding the mechanism of UV irradiance (in EPIC)
  - Model construction of TSI and SSI (in EPIC)
  - Understanding photometric low variability of the Sun to other solar-like stars





Ermolli+ 2013



  - Detection of g-mode for understanding its excitation and travel in the Sun (and for investigating the solar core)

ID	Science topics	Tasks	Key Observations	Requirements	Instruments	Conflict with other missions	Questions
1	Understanding the flow structures in convection zone (CZ)	Measure meridional flows in high latitudes & in deep CZ	・Doppler velocity for helioseismology	Full-disk obs.	One as HMI	SDO HMI SO PHI	Are the data set of HMI good enough?
2		Search for global convection features	・Doppler velocity ・Magnetic field	Full-disk obs.	One as HMI	HMI	Are the data set of HMI good enough?
3		Observe surface convective features in high latitudes	・Doppler velocity ・Magnetic field	FOV≳200” (SG size x n)	One as HMI	Hiniode SO PHI	Is high-resol. Doppler obs. attractive?
4	Detection of global magnetic flux in deep CZ	Acoustic anomaly in convection zone	・Doppler velocity for helioseismology	Full-disk obs.	One as HMI	SOHO &SDO	Only found at most upper part of CZ
5		Detection of a flow in flux tube near tachocline	・Doppler velocity for helioseismology	Full-disk obs.	One as HMI at L5 point for large-angle helioseismology	SOHO & SDO from Earth side obs.	Was a target for Solar-C Plan-A. Is 1.3yr modulation at deep CZ real?
6	Location and mechanism of the alpha effect	Observe small-scale kinetic and current helicities in the photosphere	・Photospheric vector magnetic fields	FOV≳ 300” (AR size)	One as GBO telescope or HMI	Has been done by GBO HMI will do it.	Hinode were used for current helicity. Need further upgrade?
7	Understand local dynamo near the surface and its impact on the global dynamo	Measure kinetic and magnetic energy in small-scale turbulent convection	・Doppler velocity ・Photospheric vector magnetic fields	$\Delta x \leq 0.1$”	One as Hinode NBF & SP	DKIST Solar-C SUVIT SO PHI?	Can knowledge at the surface be applied to the local dynamo in deep CZ?

GBO: Ground-Based Observatories

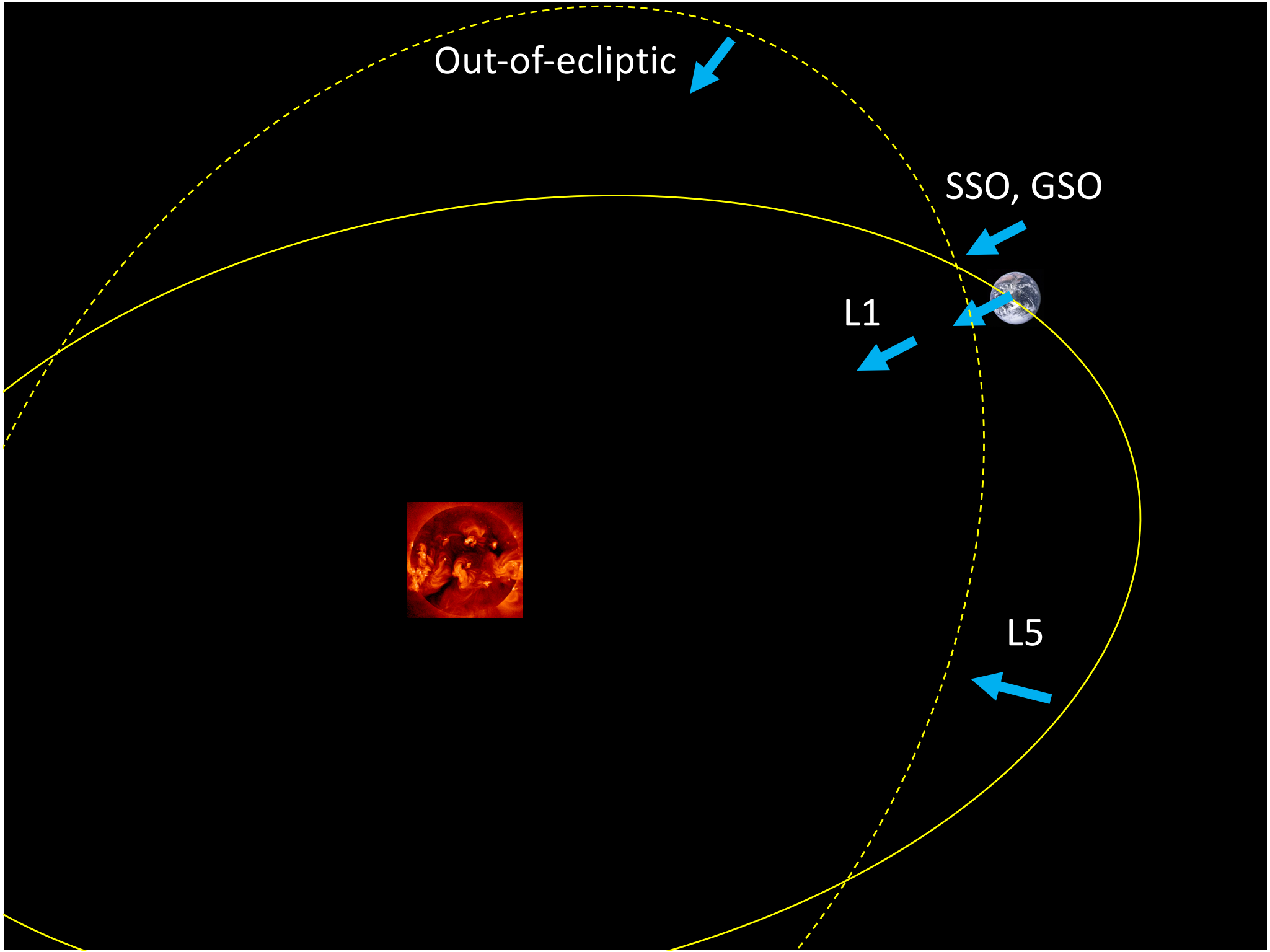
ID	Science topics	Tasks	Key Observations	Requirements	Instruments	Conflict with other missions	Questions
8	Magnetic flux transport and flux cancellation	Evaluate horizontal flux transport	・Doppler velocity ・Magnetic field	$\Delta x \leq 0.1''$ for observing small-scale processes	One as Hinode NFI	DKIST Solar-C SUVIT SO PHI?	Clarify the formation & fragmentation of magnetic patches
9		Evaluate vertical flux transport	・Doppler velocity for helioseismology to detect rising flux tube in CZ ・Magnetic fields	$\Delta x \leq 1''$	One as HMI	HMI	Cannot be detected by GONG?
10			・Transport of magnetic flux from photosphere to upper layers	Photospheric and chromospheric magnetic fields in spectro-polarimetry $\Delta x \lesssim 0.5''$	Spectro-polarimeter	DKIST Solar-C SUVIT	Need wide FOV instrument for AR loops?
11	Formation of large-scale unipolar regions	What gives the size and lifetime of the unipolar regions?	・Doppler velocity ・Magnetic field	Full-disk obs. $\Delta x \sim 1''$	One as HMI	MDI, HMI, …	Due to a mere diffusion? No contribution of global convection?

ID	Science topics	Tasks	Key Observations	Requirements	Instruments	Conflict with other missions	Questions
12	Understanding the mechanism of UV irradiance (a topic in EPIC)	Measure brightness of fine scale structures in multiple UV (200–400 nm) and visual wavelengths in magnetized and non-magnetized regions	・High-res. UV images ・Photospheric vector magnetic fields ・chromo. images	$\Delta x \leq 0.1''$ UV: 200-400 nm	High-res. UV imager One as Hinode fast NFI and slow SP	(Suunrise)	Partially possible, but difficult for stable observations in Sunrise balloon
13	Model construction of TSI and SSI (a topic in EPIC)	Construct solar irradiance model against full disk magnetic fields based on understanding the mechanism of UV irradiance	・TSI & SSI obs. ・Magnetic field	$\Delta t \gtrsim 3$ yr ? Full-disk obs. Δx=NA (TSI & SSI) $\Delta x \sim 1''$ (magnetogram)	・TSI & SSI monitors ・One as HMI	(SOHO) (SORCE)	Not done without any new information
14	Understanding photometric low variability of the Sun to other solar-like stars	Measure the variability of photometric band intensity	・Long-term photometory at photometric bands ・Magnetic field	$\Delta t \gtrsim 3$ yr ? Full-disk obs.	photometric band obs.	Some with SO PHI Solar-C PlanA	Can we confirm the STARE model prediction in the recent study correct?
15	Detection of g-mode for understanding its excitation and travel of waves in the Sun (and for investigating the solar core)	Detect g-mode signals near 100micro Hz and specify the modes for further study	Low-noise photometric or Doppler observations of low l g-mode	$\Delta t \gtrsim 3$ yr ? Full-disk obs. Δx=NA	*Noise reduction methodology not yet understood	*Some mission in Europe (such as ASTROD)	g-mode has not been detected by $\gtrsim$10yr SOHO observations.

Supplemental Slides

Installation Site of Science Instruments

- Earth
  - At the best seeing site for topics of high-resolution surface magnetic and velocity fields
  - Multiple points like GONG for a level of helioseismology
- Space
  - LEO sun synchronous orbit like TRACE, Hinode, IRIS
  - GEO like SDO for high-speed data link to ground; Solar-C
  - L1 like SOHO for full-time day condition
  - L5 for a large angle helioseismology; also a vantage point for stable imaging of ICME impact to Earth, active region watch before appearing the view from Earth, etc.
  - Out-of-ecliptic orbit like SO for access to high-latitude regions; also a view of Sun as a star; (some except for Doppler helioseismology are possible by high-res. telescopes from the Earth direction.)

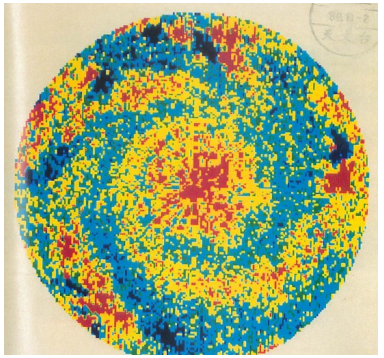

Out-of-ecliptic
SSO, GSO
L1
L5

SOLAR-C PLAN-A

Exploration from out-of-ecliptic orbit

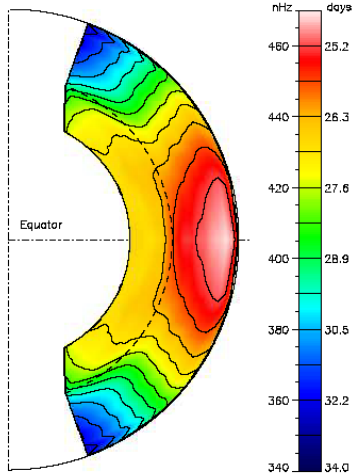
＜Toward understanding the solar dynamo＞

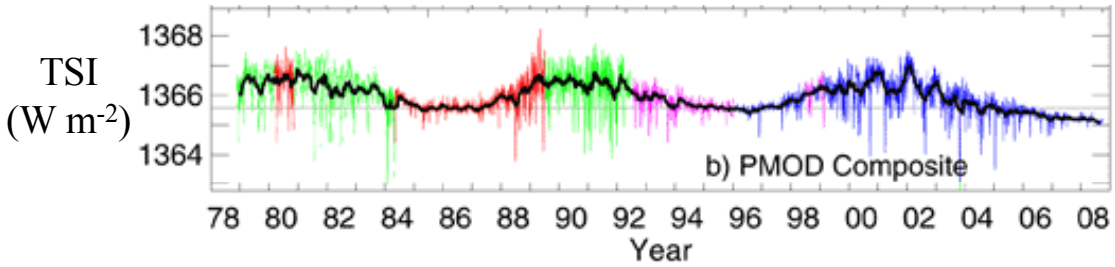
- Surface magnetic activity in polar regions
- Surface/internal flow fields in polar regions
- Convection in polar regions
- Search of tachocline regarded as a source region of strong magnetic fields

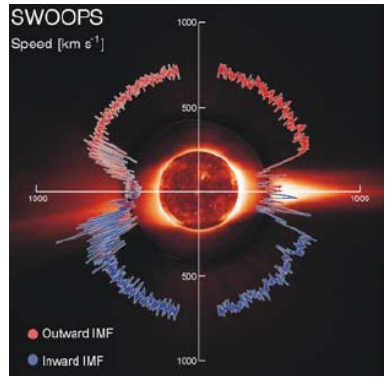


＜Exploration from Vantage Point＞

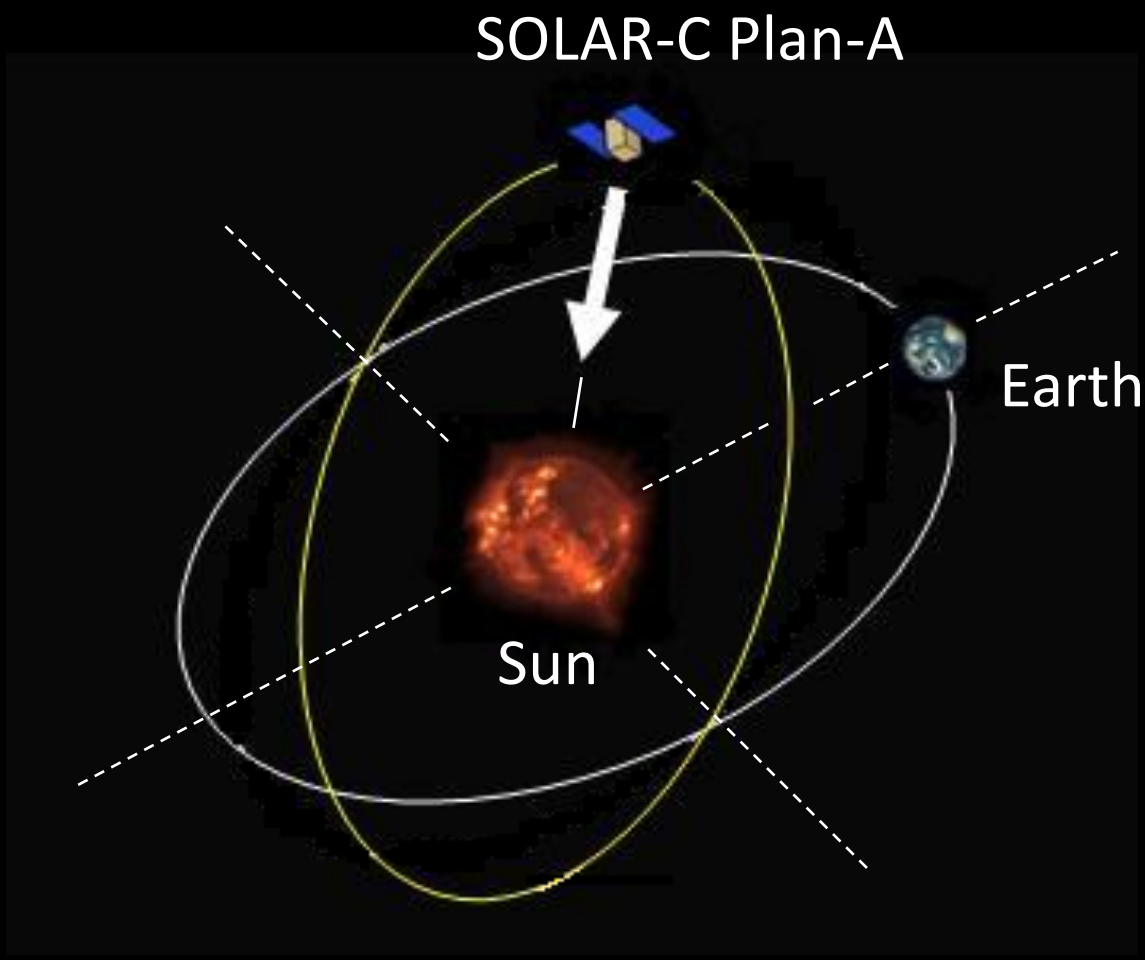
- Global and local evolution of polar upper atmosphere from new viewpoints
- Total irradiance measurements from out-of-ecliptic orbit
- Solar wind measurement in polar CH and Alfven wave detection from inclined views
- Imaging of CMEs and solar wind/CIR shock structures
- Others







Target Final Orbit



The target orbital period of 1 yr, synchronized with Earth

SOLAR-C PLAN-A: Science Questions

Table 1: Summary of scientific questions, targets and the required observations.

Key Questions	Section	Observation Targets; overview	Observation Targets in detail	Instruments / Measurements	Scientific objectives/Background in brief	Importance / Difficulty
Q1: How is the global cyclic, solar magnetic field generated ?	1.2.1	T1) Dynamical coupling between magenetic fields and flows	* Surface meridional circulation beyond latitudes of 60 degrees * Surface magnetism * Polar magnetic field reversal * Cyclic variation of above variables	* Doppler for Local HS * Magnetic (longitudinal)	* Possible correlations between the hihg-latitude meridional flow speed and magnetic activity patterns are necessary to distinguish between different dynamo paradigms. * Determining the differential rotation profile close to the poles will provide	important / definite
Q2: What is the nature of flows in the polar regions of the Sun, and how they vary with magnetic field?	1.2.2	T2) Photospheric magnetic flux distribution and evolution in the polar regions	* Transport of magnetic flux by super-granular flows in the polar region * Differential rotaion in the polar regions	* Magnetic (vector) * Granular patterns	* Constrain the amplitude of turbulent flux dispersal from models that describe the surface evolution of magnetic field, that limit the processes rebuilding the poloidal field from troidal field. * Small versus large scale dynamo	moderate / definite
			* non-axisymmetric flows	* Doppler for Local HS	* Limit the efficiency of poloidal field generation	important / definite
			* Jet-like flow associated with the flux tubes in the tachocline * Flows associated with flux emergence	* Doppler for Global HS from additional vantage points	* Possible limitation for the field structure and amplitude in the solar convection zone	very important / very difficult
			* Near-surface super-granular-scale convection in the polar regions * Global convection, giant cell	* Doppler for Local HS * Magnetic (longitudinal)	* Progress into understanding convective transport and the establishment of mean flows in the deep convection zone.	important / difficult
			* Meridional counter flow * Thermal structure in the convection zone	* Doppler for Global HS from additional vantage points	* Unprecedented insights into the dynamics of the deep convection zone.	very important / very difficult
Q3: How does the radiative energy output of the Sun depends on latitude?	1.2.3	T3) High-precision measurement of total solar irradiance	* Continuous measurement of the total solar irradiance from various solar latitues	*Total irradiance	*Understand the irradiance variation against latitude *Understand the irradiance variation in stellar activity cycles	very important / definite
Q4: How does magnetic activity shape the structure and evolution of the polar solar corona and how does it affect the Earth ?	1.2.4	T4) Structure and dynamics of the high-latitude solar corona and solar wind	* Imaging and spectroscopy in EUV emission lines for outer solar atmosphere * White-light imaging of heliospheric structures between the Sun and Earth * In-situ measurements of the solar wind and particles (including cosmic rays)	*EUV Imager *EUV Imaging Spectrograph *Heliospheric Imager (optional) *In-situ instruments (optional; not clearly defined yet)	*Progress of understanding the variation of polar coronal structures in a solar cycle *Progress of understanding polar region dynamics in outer solar atmosphere *New view by direct imaging of innter heliosphere from a vantage point *Progress in understanding the	important/ definite