Panel D / Chapter 5
How do we fit in?

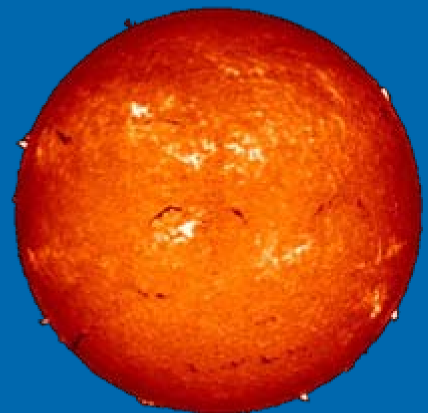
23 January 2007

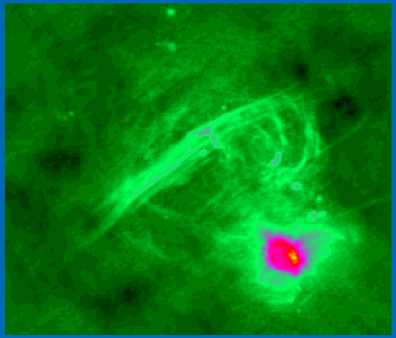
- Science Questions
- Recommendations
- Input from the Community

Science Questions

- What can the Sun tell us about fundamental astrophysical processes?
- What drives solar variability on all scales?
- What is the impact of solar activity on life on Earth?
- What is the dynamical history of the Solar system?
- What can we learn from Solar-system exploration?
- Where to look for life in the Solar system?

Position of Solar System Research





Fundamental Physics

Solar-Stellar Research

Solar-Terrestrial Research

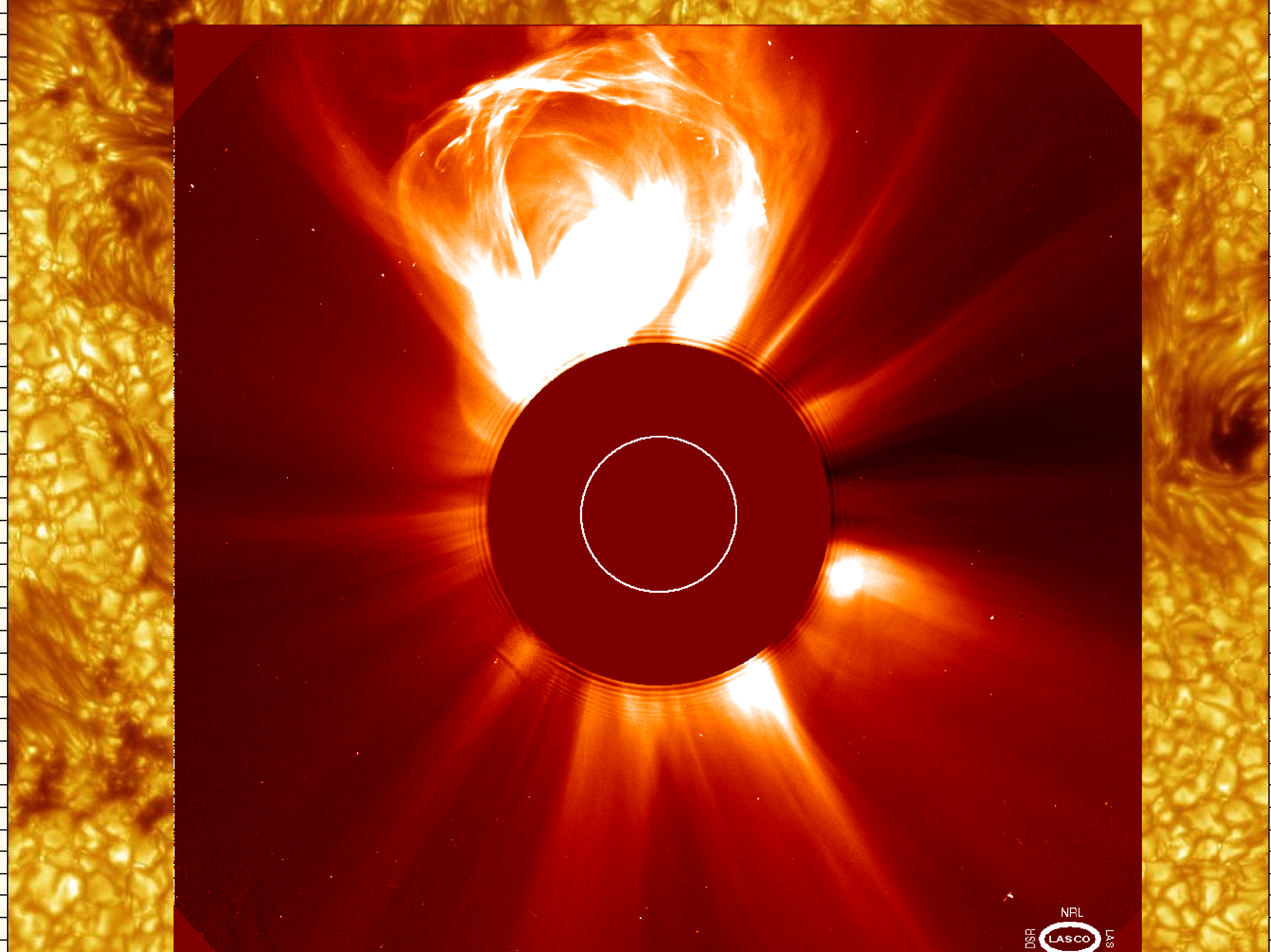
Comparative Planetology

History of the Solar System

Education and Public Outreach

What can the Sun tell us about fundamental astrophysical processes? (1)

- Background:
  - Solar research has contributed to many fundamental questions: atomic physics, nuclear fusion, particle properties, solar neutrino flux problem …
  - Today, solar physics contributes to MHD in a fundamental way
  - Spatial and temporal timescales cover many orders of magnitude
    - A few km to a fraction on a AU
    - Seconds to centuries
  - Stellar variability phenomena use the solar paradigm (“chromospheres”, “starspots”) to describe their likely nature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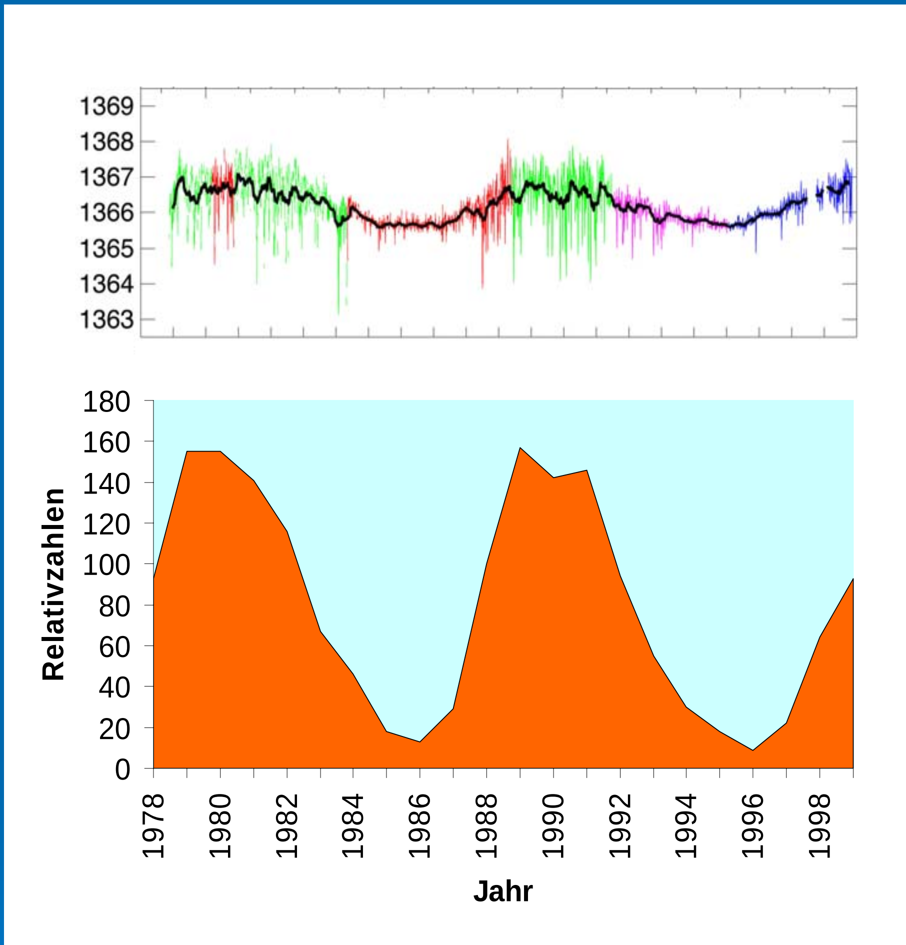
What can the Sun tell us about fundamental astrophysical processes? (2)

- Key questions and opportunities:
  - Understanding solar magnetic field generation at all scales is essential for understanding stellar magnetic cycles and the origin of solar variability
    - Large aperture (3-5m) telescopes to resolve 20km in the solar atmosphere with sufficient sensitivity
    - Detailed magnetic field measurements outside the ecliptic – Solar Orbiter
  - Understanding which global dynamo processes are at work
    - Very detailed MHD models of entire stars
    - Continuous, synoptic measurements of full Sun surface magnetic field – Synoptic telescope network
    - High precision velocity field measurements throughout the solar convection zone - helioseismology
  - Understanding Stars from the Sun and vice versa
    - Stellar rotation – high spectral resolution surveys and interferometry
    - Stellar structure - asteroseismology

What drives solar variability on all scales? (1)

- Background:
  - Solar variability is due to the interaction of the solar magnetic field with the solar atmosphere
    - Small effect for integrated radiative output
    - Huge effect – orders of magnitude – in UV, EUV and X ray regimes
  - The extended solar atmosphere is a system of extremes (in densities and temperatures), with extreme variability at short wavelengths
  - Variability affects all spectral regimes and is monitored with
    - UV and X-rays space facilities
    - Optical ground and space facilities
    - Ground-based Radio facilites
    - In-situ measurements in space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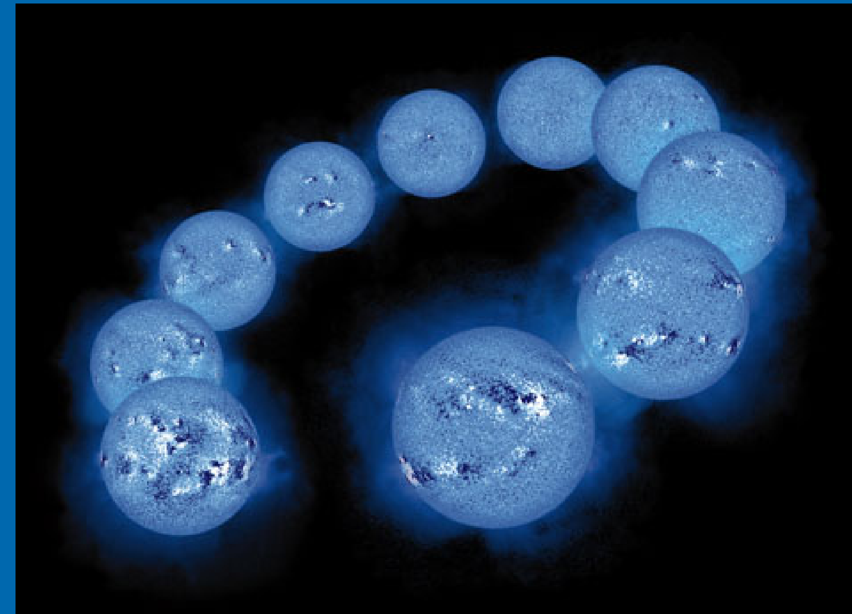
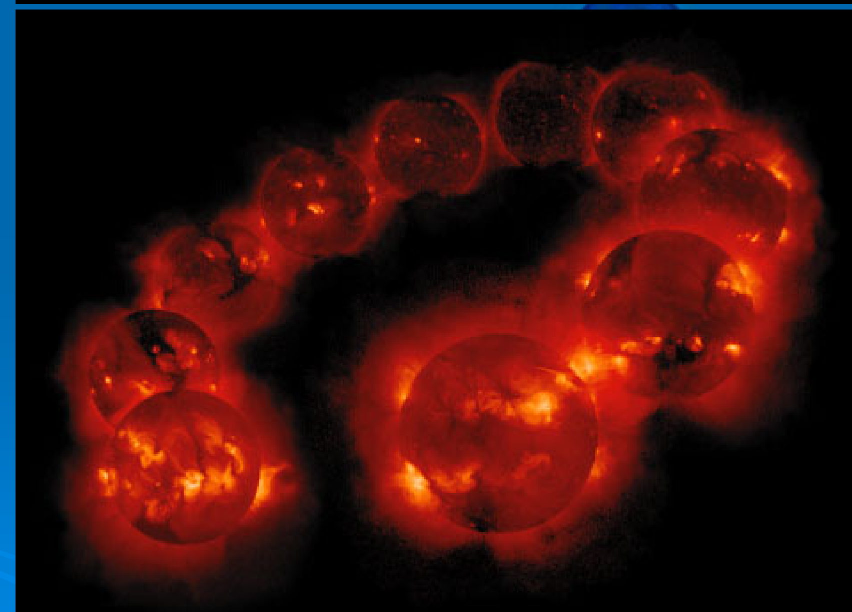


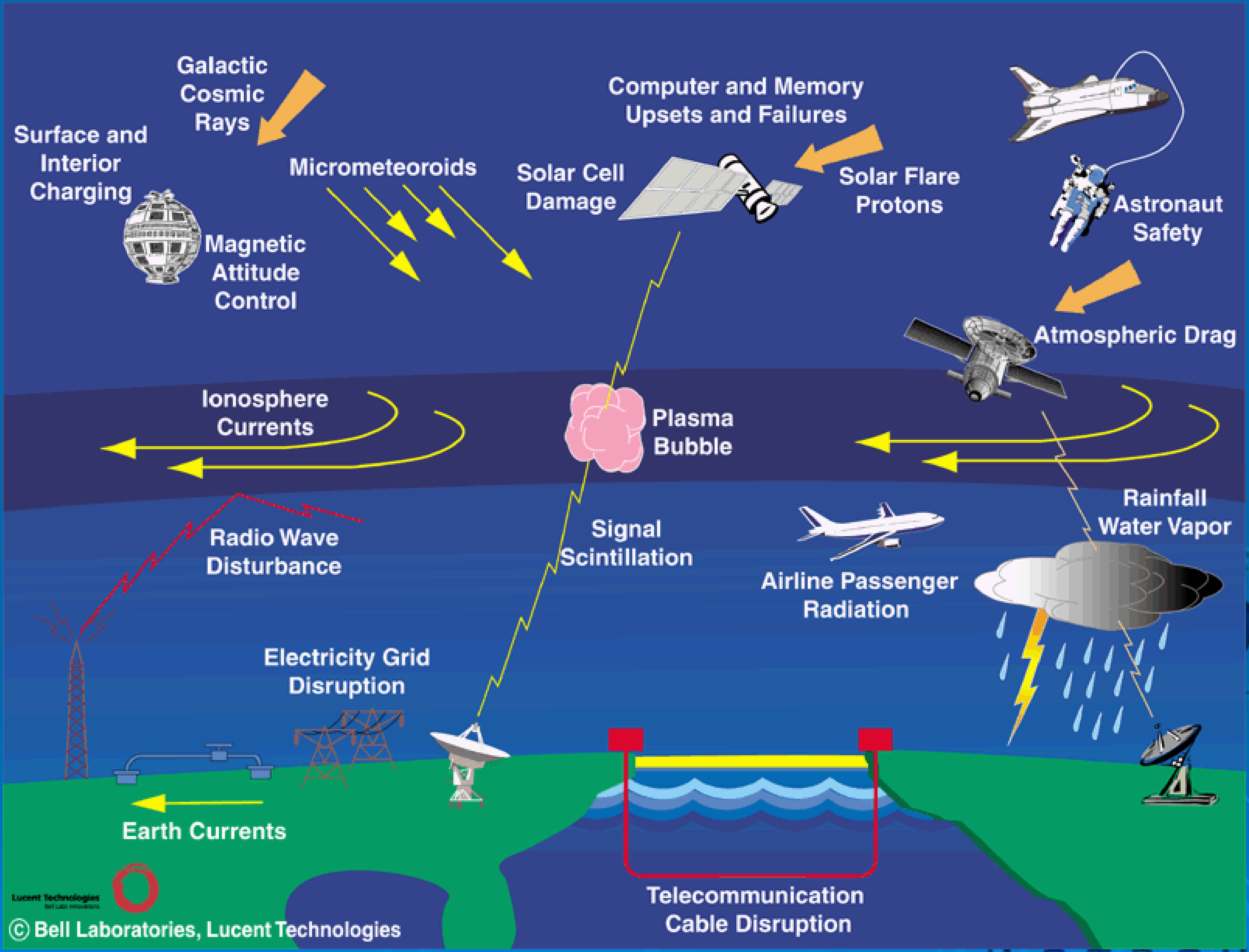


What drives solar variability on all scales? (2)

- Key questions and opportunities:
  - How is energy transferred from the photosphere to the chromosphere and corona?
    - Numerical MHD and plasma physics modeling
    - High spatial and temporal resolution observations of chromosphere and corona with the capability to measure its magnetic field – dedicated meter-class space facility
    - Large aperture Solar telescope with adaptive optics
    - Network of medium-size synoptic telescopes to monitor the evolution of the magnetic flux distribution
  - How can we unravel the magnetic field structure in the chromosphere and corona?
    - Develop new, sophisticated diagnostics, e.g., Hanle effect
  - What determines chemical abundances in the corona?

What is the impact of solar activity on life on Earth? (1)

- Background:
  - – Objective of “space weather”: ability to characterize solar energetic events to allow reaction (nowcasting and forecasting)
  - – The connection between solar variability and Earth climate is complex
  - – Need for deriving proxies for the climate and the solar output from historical records
  - – A detailed understanding of the solar dynamo is needed to predict the solar activity for long periods (Maunder minimum and “little ice age”)



Galactic Cosmic Rays
Surface and Interior Charging
Micrometeoroids
Magnetic Attitude Control
Solar Cell Damage
Computer and Memory Upsets and Failures
Solar Flare Protons
Astronaut Safety
Atmospheric Drag
Ionosphere Currents
Plasma Bubble
Radio Wave Disturbance
Signal Scintillation
Airline Passenger Radiation
Rainfall Water Vapor
Electricity Grid Disruption
Earth Currents
Telecommunication Cable Disruption
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What is the impact of solar activity on life on Earth? (2)

- Key questions and opportunities:
  - How can the evolution of the solar magnetic field configuration and abrupt reconfiguration (flares, CMEs) be predicted?
    - Full disk monitoring deliver boundary conditions, proxies for chromosphere and corona magnetic fields
    - Solar Dynamics Observatory and successors complemented by ground-based network of medium-size synoptic telescopes to monitor the evolution of the magnetic flux distribution (SOLIS)
    - Detailed study of coronal events: Hinode, STEREO and successors
  - How can we monitor the Sun's far side?
    - Solar Orbiter
    - Helioseismology far side imaging

What is the dynamical history of the Solar system? (1)

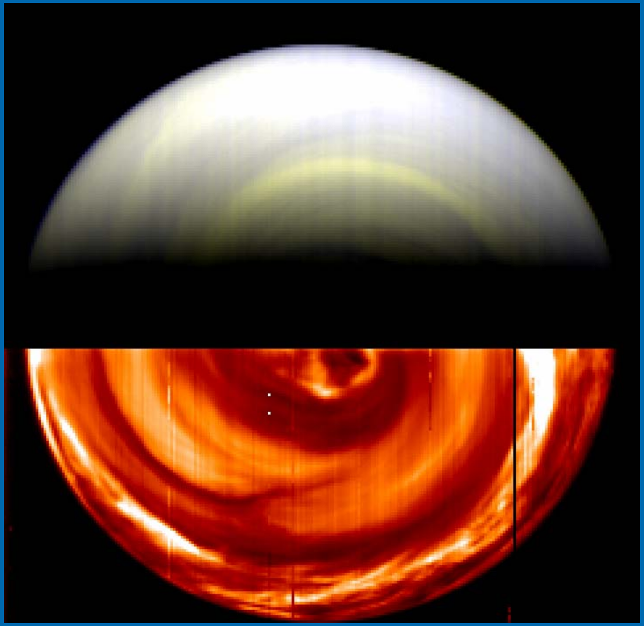
- Background:
  - It is generally accepted that planets formed within the protosolar disk from the accretion of solid particles
  - Planetesimals first grew through multiple collisions, then by gravity
  - Giant planets probably formed through the core-accretion scenario, rather than the direct-collapse model
  - There is still a problem with the formation time scale of the giant planets (over 10 My in models)

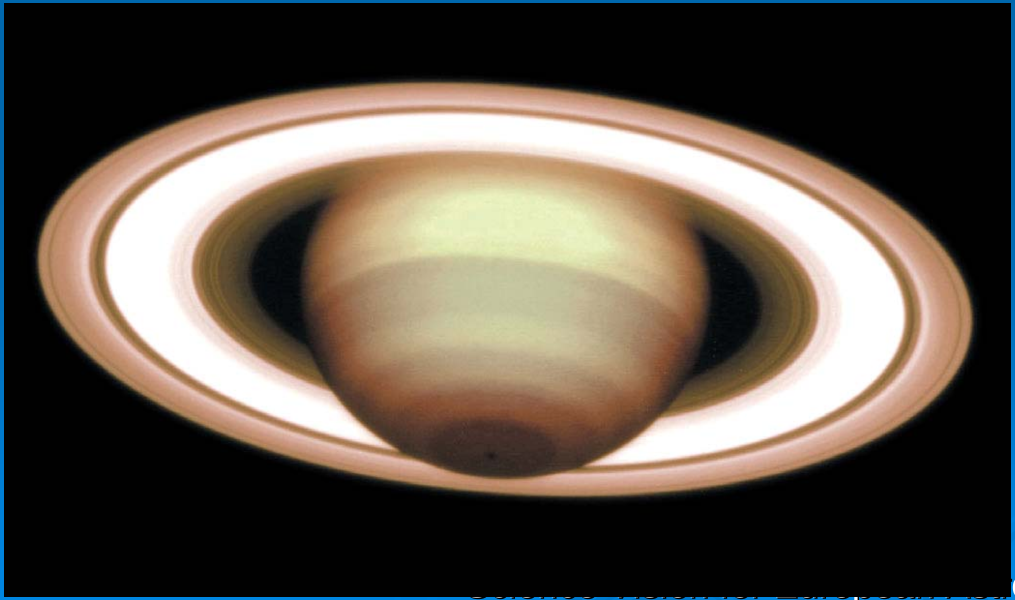
What is the dynamical history of the Solar system? (2)

- Key questions :
  - How did the first km-sized particles form?
  - How did the solar nebula evolve? (vortices, solar waves?)
  - What are the interactions of planets and disks (migration)?
  - Origin and evolution of Mercury and the Moon (role of giant impacts)?
- Opportunities:
  - Theory and numerical simulations are essential!
  - Comparison with other planetary systems is essential
  - Mercury: Messenger and BepiColombo (chemical data)

What can we learn from Solar-system exploration? (1)

- Background: Terrestrial planets
  - Differentiated objects, with iron-rich cores and silicate mantles
  - A large variety of atmospheric conditions (diverging evolutions)
  - An extensive exploration with space missions
- Background: Giant planets and their satellites
  - Enrichments in heavy elements suggest a core-formation model
  - Spectacular diversity among outer satellites
  - Space exploration by Voyager, Galileo and Cassini
- Background: Small bodies and extraterrestrial matter
  - Cometary exploration: Halley, Hale-Bopp, Tempel-1 (DI)
  - TNOs: Ground-based exploration since 1992
  - Analysis of extraterrestrial matter: Moon, meteorites, Stardust, Genesis





What can we learn from Solar-system exploration? (2)

- Key questions: Terrestrial planets
  - What are the internal structures, and how big are the cores?
  - How does the dynamo and the planetary heat engine work?
  - What is the history of the atmospheres and the water inventory?
  - Did liquid water stay on Mars in the past and for how long?
- Key questions: Giant planets and their satellites
  - What was the nature of their planetesimals?
  - Why are Uranus and Neptune so different?
  - What is the origin of Uranus' high obliquity?
  - What is the origin of Titan's atmosphere? (CH4 cycle?)
- Key questions: Small bodies and extraterrestrial matter
  - What is the rate of potential Near-Earth Asteroid encounters?
  - What is the origin and processing of cometary constituents?

What can we learn from Solar-system exploration? (3)

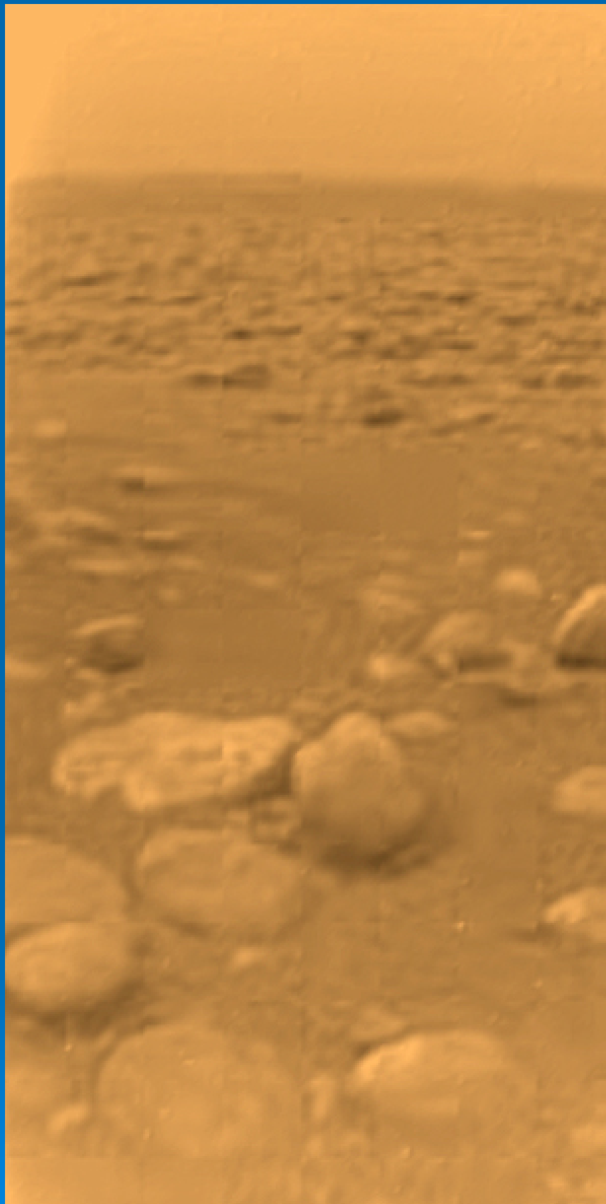
- Opportunities: Terrestrial planets
  - Future missions: NASA Mars missions, ExoMars, Messenger, and BepiColombo
  - Mars next step: Station network (geophysics, meteorology)
  - Later on: Sample return
- Opportunities: Giant planets and their satellites
  - Follow-up of Galileo/Cassini: Science Vision (Jupiter, Saturn)
  - Outer satellites: special emphasis on Europa, Titan, Enceladus
  - Use of astronomical facilities: Herschel, ALMA, JWST, ELT
- Opportunities: Small bodies and extraterrestrial matter
  - Space exploration: Rosetta (comet CG), Gaia (NEA)
  - Use of astronomical facilities: Herschel, Alma, JWST, ELT
  - To be studied: Space exploration of a Near-Earth Asteroid

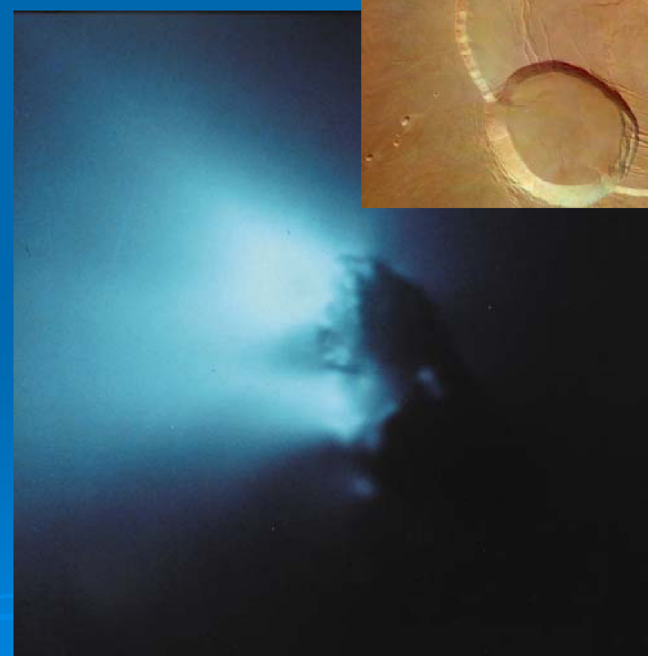
Where should we look for life in the Solar system? (1)

- Background:
  - A complex prebiotic chemistry, based on carbon, exists in the interstellar medium
  - Amino-acids have been found in meteorites
  - Liquid water was most likely essential in the apparition of life on Earth
  - Carbon and liquid water seem to be the best conditions for extraterrestrial life
  - In the Solar system, the best potential sites are Mars (in the past), Europa, possibly Enceladus
  - Titan and comets are best potential sites for prebiotic chemistry

Where should we look for life in the Solar system? (2)

- Key questions:
  - Are amino-acids present in comets?
  - How did life appear on Earth? (external/internal origin)
  - Could Mars host life in its past history? Could we find fossil traces of it and how?
  - How deep is Europa's icy crust? Could life have appeared and developed under the crust? If so, could we detect it?
  - Are there other outer satellites which host a water ocean under their surface, and at what depth?





Where should we look for life in the Solar system? (3)

- Opportunities:
  - Cometary exploration: Rosetta, Herschel, ALMA
  - Mars exploration: Mars Sample Laboratory, ExoMars
  - Future exploration of Mars : Mars sample return
  - In the Cosmic Vision frame: Future space exploration of Europa, Titan, Enceladus

Recommendations
General

- Essential role of theoretical work
  - Comprehensive physical (HD, MHD, plasma physics) simulations of
    - Entire stars
    - Extended stellar atmospheres
    - Heliosphere and stellar environment
  - Dynamical simulation of the solar system: formation of planets and small bodies, evolution of orbits, migration…
  - Models of the internal structures of solar-system bodies (not accessible through observation)
- Importance of laboratory work
  - Equations of state at high pressure and temperature
  - Phase diagrams at high P and T
  - Need for laboratory data for photochemical models (chemical reactions)
  - Analysis of extraterrestrial matter

Recommendations
Requirements for principal facilities (1)

- European large-aperture (3-5m) solar telescope with adaptive optics
  - Interaction magnetic fields/plasma motions in the solar atmosphere
- Solar Orbiter *(not exactly in Tim's spirit …)*
  - In situ measurements close to the Sun
  - Remote sensing of polar regions
- Meter class UV space mission with X-ray capabilities
  - Magnetic field dynamics in the chromosphere and inner corona

Recommendations
Requirements for principal facilities (2)

- Mars sample return mission
  – Origin and evolution of Mars, search for past traces of life
- Space missions toward Jupiter's and Saturn's systems, with special emphasis to Europa, Titan, and Enceladus
  – Depth of Europa's ocean, origin of Titan's atmosphere, internal structure of Enceladus)
- Space mission toward a Near-Earth asteroid, with lander and (possibly) sample return
  – In-situ analysis of a NEA
- Saturn probe mission
  – Origin of the planetesimals that formed Saturn
- Mission to Venus
  – Atmospheric escape and surface-atmosphere interactions

Recommendations

Requirements for secondary facilities(1)

- Network of ground-based, synoptic solar instruments
  - > Monitoring of full-disk solar magnetic field and velocity fields
  - > Space weather forecast, magnetic field generation and destruction
- Radio-telescopes arrays, from the sub-mm to meter (ALMA, LOFAR)
  - > Imaging of the Sun at very high resolution
- High-resolution multi-objects spectrographs at 4-8m class telescopes
  - > Monitoring a large number of solar-type stars
  - > Tests theories of stellar magnetic fields
- Numerical simulations:
  - > Large scale numerical MHD models of stellar atmospheres
  - > Climate evolution on short and long time scales

Recommendations

Requirements for secondary facilities (2)

- Space missions in operation: Mex, MO, MRO, Mars rovers, VEx, Cassini, Rosetta, Stardust, Genesis
  - Exploration of planets and satellites
- In the future: Messenger, BepiColombo
  - Exploration of Mercury
- Access to optical facilities: ELT, JWST
  - All solar-system objects
- Access to sub-millimeter facilities: ALMA, Herschel
  - outer solar-system objects
- Laboratory studies
  - Equations of state, phase diagrams at low T, extraterrestrial matter
- Numerical simulations:
  - dynamical evolution of solar-system-bodies

Thanks to the Panel D members

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