

Introductory space physics and solar-planetary relationships - I

Lecture 2

W.K. Tobiska

Space Environment Technologies

Announcements

Miscellaneous

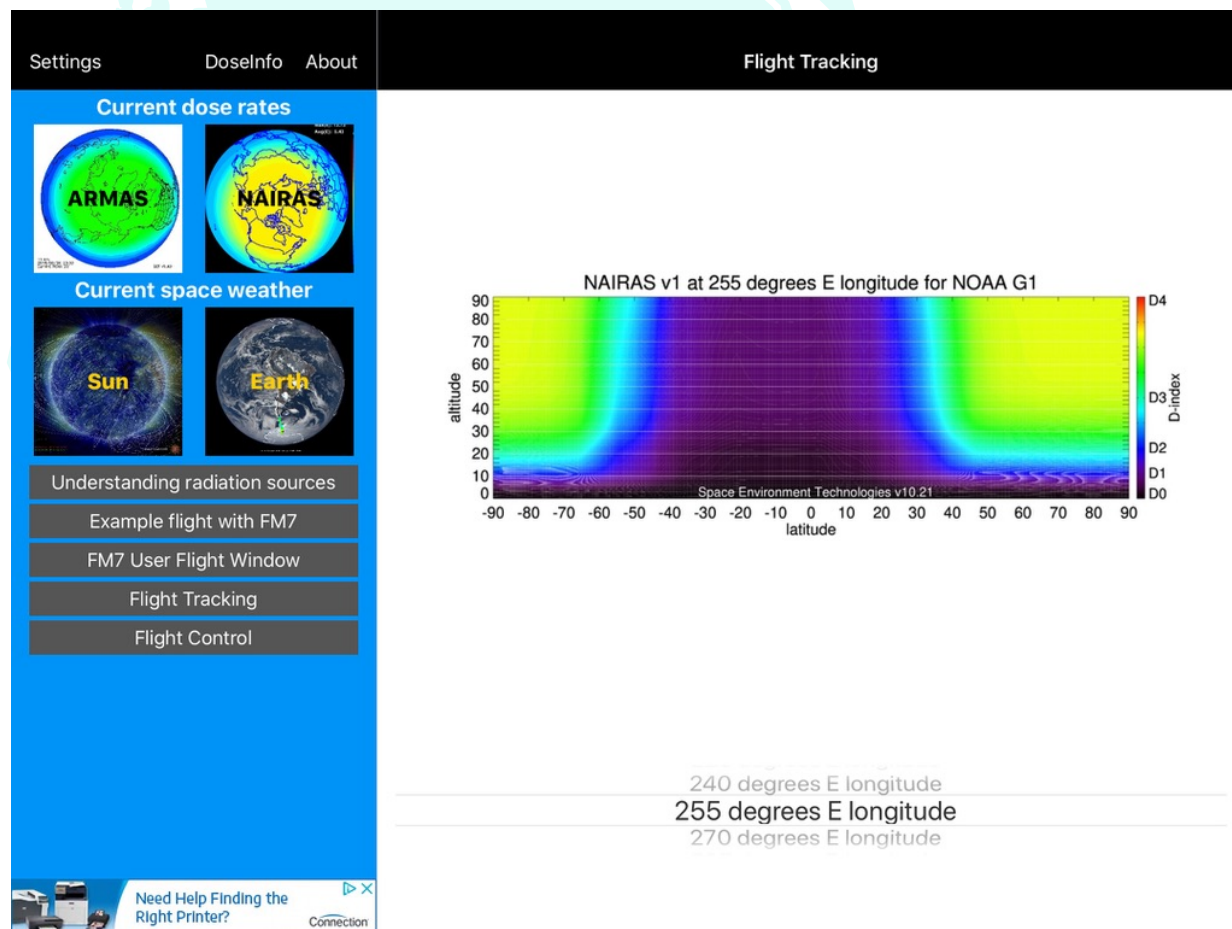
- Books - NSWP IP (2000), NSWP Assessment report, SWAS, and SWAP on DEN website under Supplemental Material folder
- SPENVIS - register at <http://www.spenvis.oma.be/spenvis/>
- Standards - ISO standards on SET <http://spacewx.com> website, Standards quicklink – **these are not official standards but for review purposes only; please go to ISO or AIAA websites to purchase the official standards**

Contributions

Daytime aurora at South Pole on YouTube

- ◆ <http://www.youtube.com/watch?v=A9UjRUWO308>
- ◆ Taken with a time-lapse camera from South Pole (24-hr sun, 24-hr sunset, 24-hr night)

ARMAS iPhone, iPad app at Apple iTunes



Class announcements

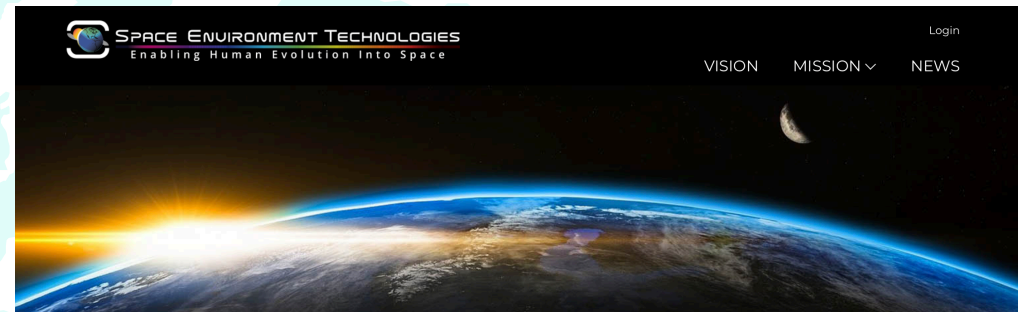
Partial list of WEB Space Environment and Space Weather locations

- ◆ Real-time solar, heliospheric, magnetospheric, thermospheric, ionospheric information: Apple iPhone app “SpaceWeather” update v2.1 in progress.
- ◆ Current global and CONUS TEC from GAIM and 15MHz global ray-traces for HF communications: <http://spaceweather.usu.edu/>
- ◆ Solar irradiances, flare alerts, current ionosphere and HF, GEO charging, and JB2006/JB2008 models: <http://www.SpaceWx.com/>
- ◆ Solar protons, electrons, wind, fields: <http://www.sec.noaa.gov/>
- ◆ NASA CCMC space weather: <http://iswa.gsfc.nasa.gov/iswa/iswa.html>
- ◆ LASP/CU space environment information: <http://lasp.colorado.edu/>
- ◆ Earth magnetosphere: <http://www.magnetosphere.ru/>
- ◆ Space Weather at Earth: <http://www.windows.ucar.edu/spaceweather/>
- ◆ NOAA data archive: <http://www.ngdc.noaa.gov/ngdc.html>
- ◆ GSFC data archive: <http://umbra.gsfc.nasa.gov/sdac.html>

Resources: data, models, standards

Public access data, models, standards products menu from

<http://spacewx.net>



Resources

Space Environment Technologies (SET) provides multiple resources for the space weather and space systems communities. We provide insight into standards in development, we make available team member publications, and we support K-14 educational activity. Standards provide common definitions, data, products, practices and transactions between diverse communities of users and producers to facilitate communication and commerce. Standards are developed at international, national, and organizational levels. Our Standards links identify ISO, AIAA, Corporate, ECSS, and SIF standards related to space weather and the space environment. Our Publications links provide a broad range of original scientific and engineering papers and documents from all areas of SET's team member activity. Our Service links present useful tools for individuals, for teachers, for students, and for the public.

Standards

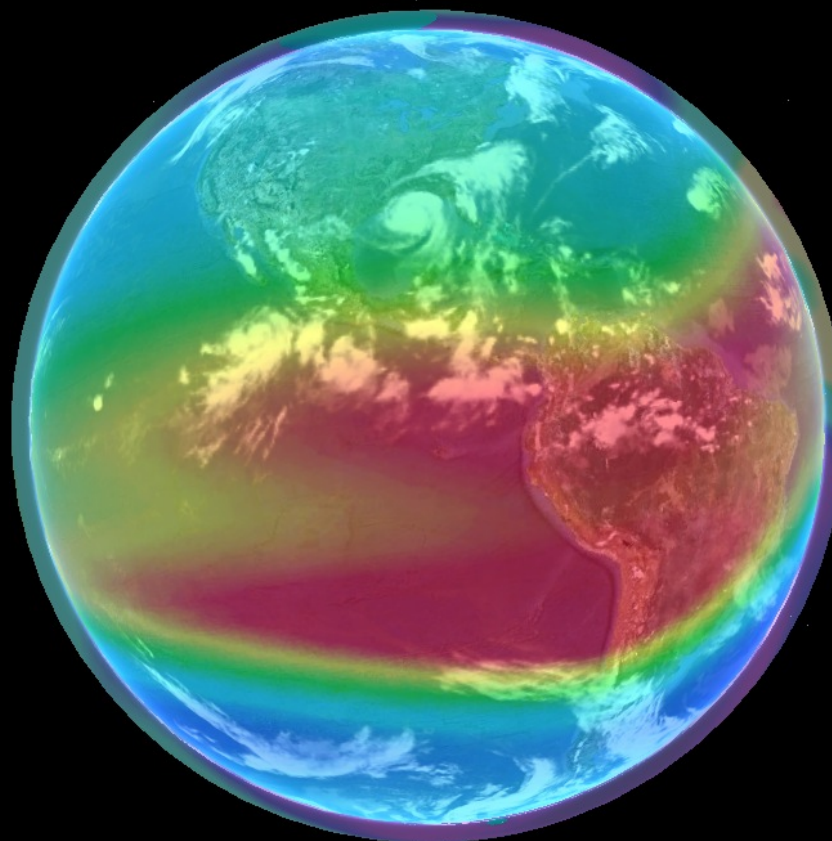
Publications

Service



Hurricane Isaac August 29, 2012 as it reached U.S. Gulf Coast and global ionosphere from Earth-Space 4D

(http://www.spacewx.com/Innovation_KML.html)



Data SIO, NOAA, U.S. Navy, NGA, GEBCO

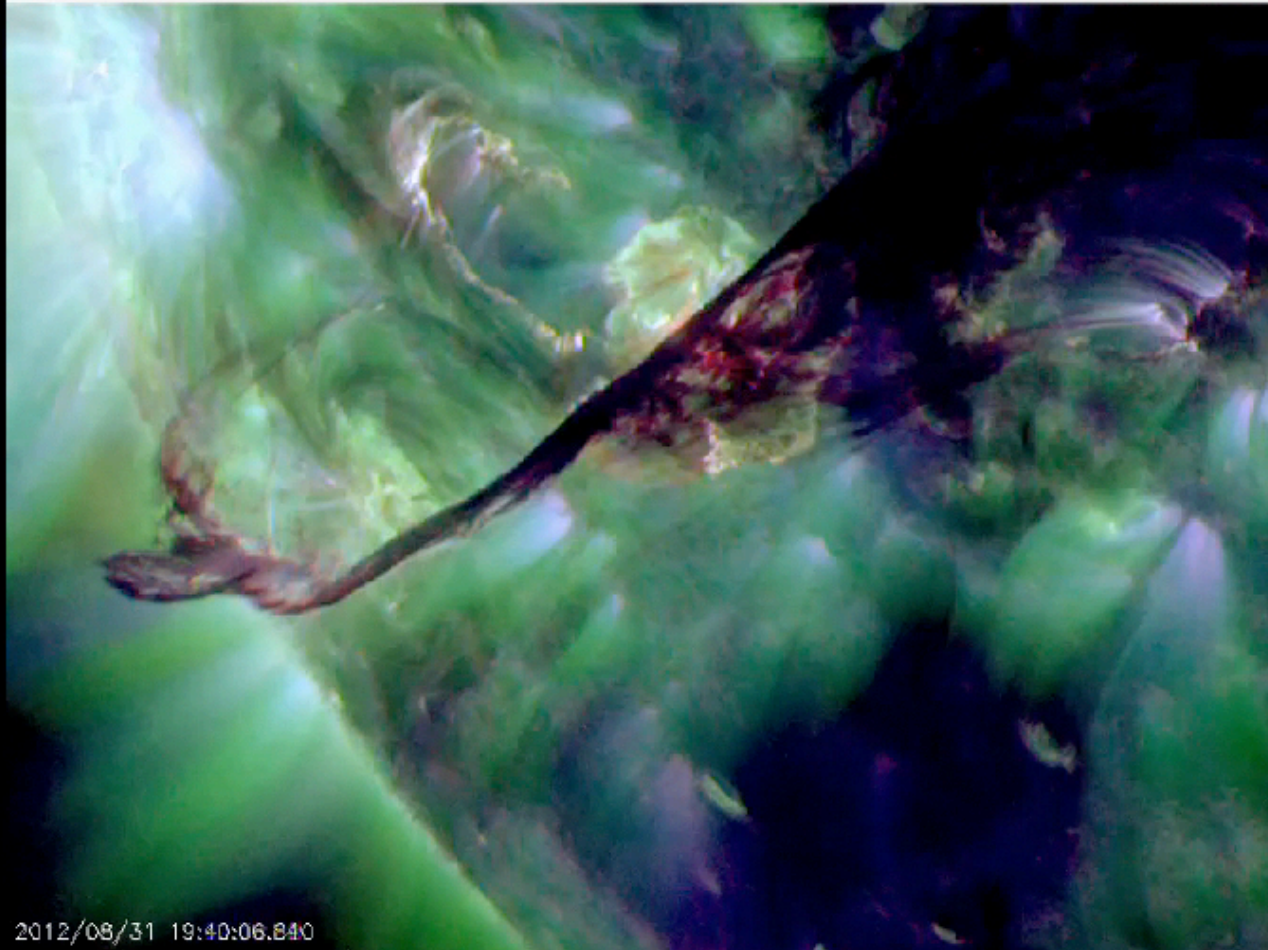
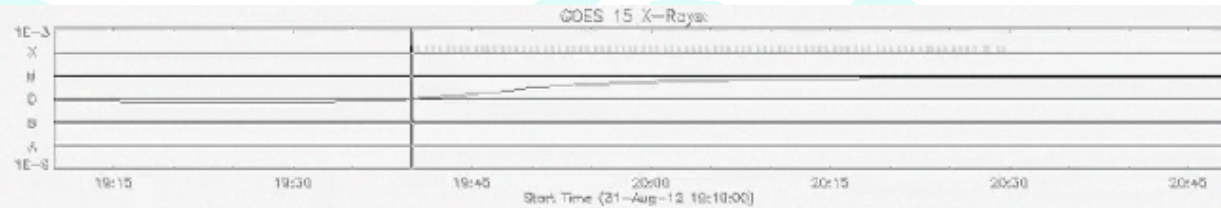
Google earth

2012-08-29 00:15 UTC

2°35'50.86" N 91°44'49.35" W elev -2164 m

Eye alt 23143.33 km

Aug 31, 2012 CME



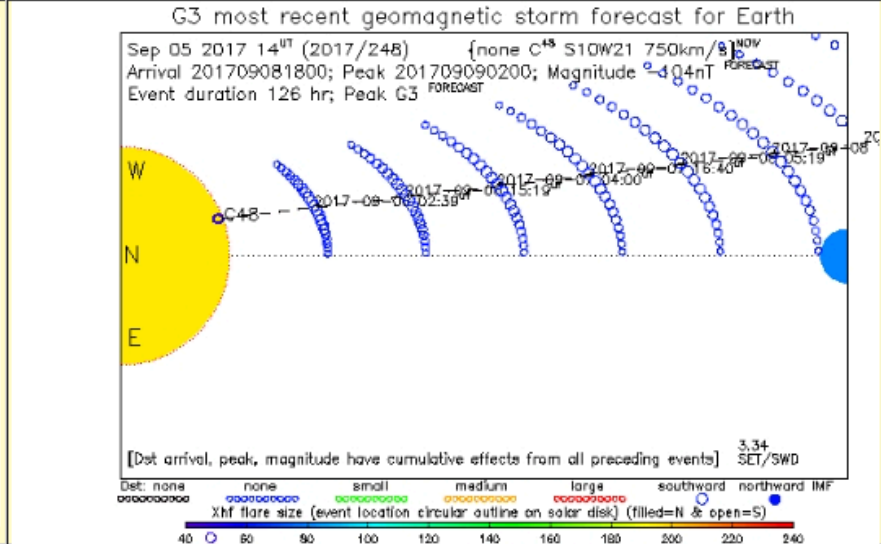
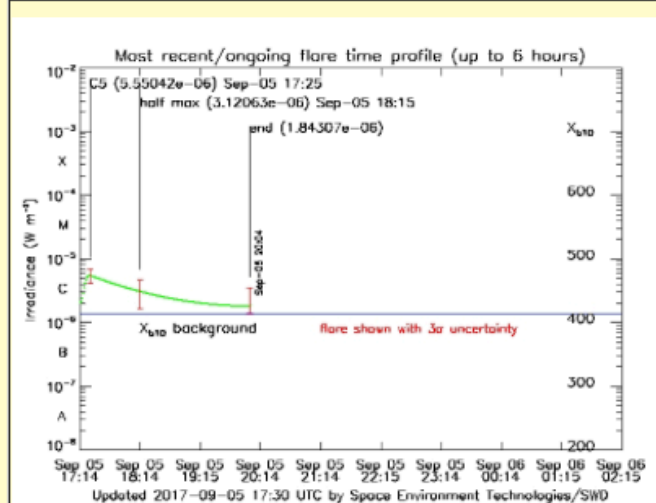
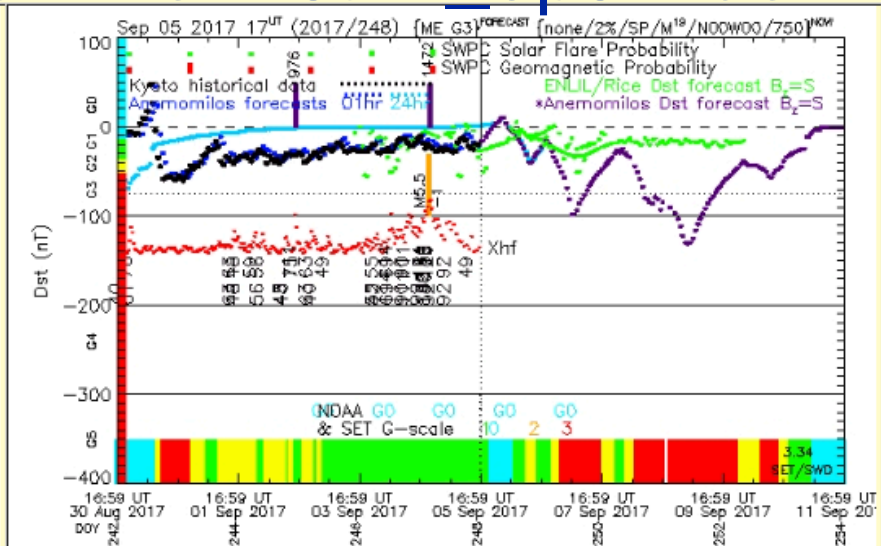
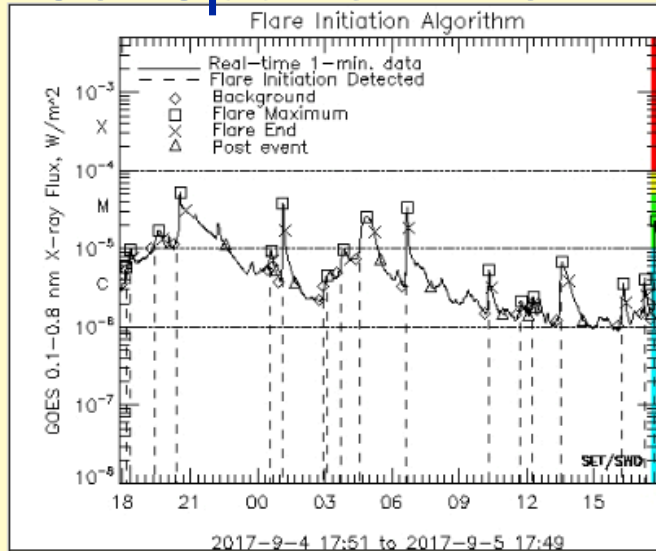


About the SpaceWx Alert Monitor

This website is for monitoring the SAM Twitter and Email alerts, watches, advisories, warnings. The short "tweets" are updated only when a significant event has occurred. The more detailed "messages" are updated every 5-minutes. The plots are refreshed about every 100 seconds so that real-time operations can be monitored.

Latest X-ray flare Tweet: X-ray W/Alert 09/05 17:52Z, Peak 09/05 17:44Z, minor impact M2.1, NOAA R1, #solarflare #spacewx http://bit.ly/P8bZX3
Current X-ray Flare Status Notice=ADVISORY Event_Status=EVN_X_Flare-T=2017-09-05_17:44 Mins_Elaps= class=M2.1, scale=R1, Xray_flux=2.26E-05, issued=2017-09-05_17:52
Latest Dst Tweet: Dst AD/ISOP, 09/05 17:52Z, Peak 09/08 23:02Z, moderate impact -80 nT, NOAA G3, 750 km, #spacewx http://bit.ly/P8bZX3
Current Dst Status Notice = ALERT , Alertissued = 2017-09-03_03:00, Mins_Elaps = 3772, PredictStart = 2017-09-03_03:00, PredictPeak = 2017-09-03_03:00, EL = 60, GX = G1, DST = -23, Pr = 2, Sr = SP, Velocity = 750, streamB_status = UN, issue_time_tag = 2017-09-05_17:52, CID = M021

http://sol.spacenvironment.net/~sam_ops/index.html?





About the SpaceWx Alert Monitor

This website is for monitoring the SAM website and email alerts, watches, advisories, warnings. The show "bulletins" are updated daily when a significant event has occurred. The more detailed "messages" are updated every 5-minutes. The plots are refreshed about every 100 seconds so that the current operations can be monitored.

Latest X-ray flare Tweet: Xray WATCH, 07/30 06:07Z, Peak 07/30 04:38Z, moderate impact M5.9, NOAA R2, #solarflare #spacewx <http://bit.ly/P8bZX3>

Current X-ray Flare Status Notice=MONITORING,Event_Status=POST_EVENT,UT=2018-08-25_12:09,Mins_Elaps=4804,Class=A0.0,R_scale=R0,Xray_flux=7.58E-08,Issued=2018-08-28_20:13

Latest Dist Tweet: Dist ADVISORY, 08/28 19:00Z, peak 08/29 09:00Z, moderate impact -65nT, NOAA G3, 750k/s, #spacewx <http://bit.ly/P8bZX3>

Current Dist Status Notice = ADVISORY, AlertIssued = 2018-08-28_19:00, Mins_Elaps = 73, PredictStart = 2018-08-29_08:00, PredictPeak = 2018-08-29_09:00, EL = 60, GX = G3, DST = -75, Pr = 2, Sr = SP, Velocity = 750, streamB_status = ME, issue_time_tag = 2018-08-28_20:13, CID = M037

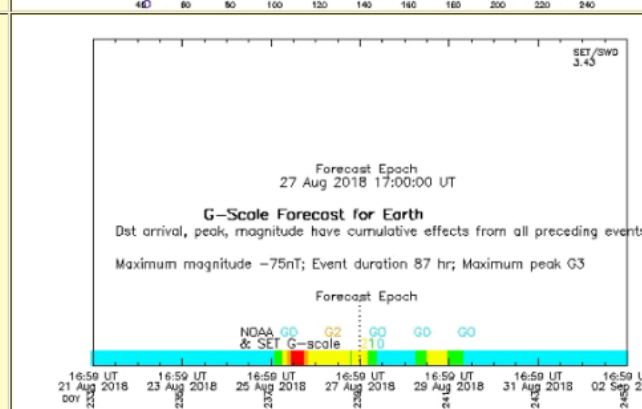
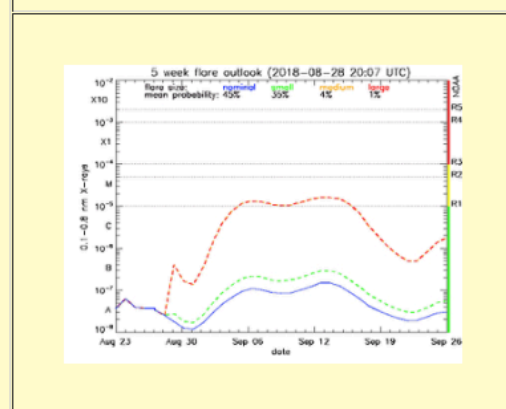
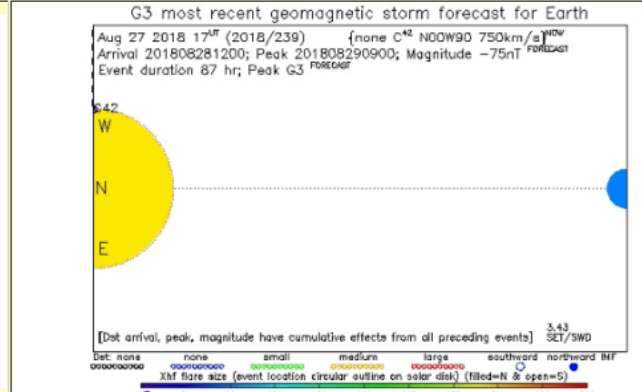
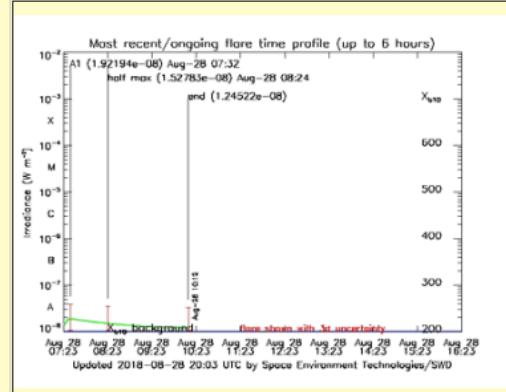
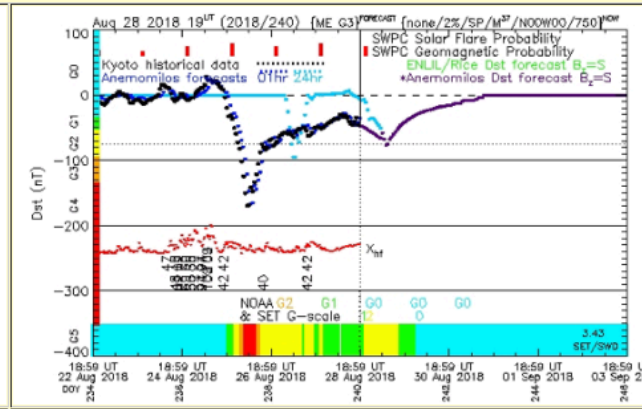
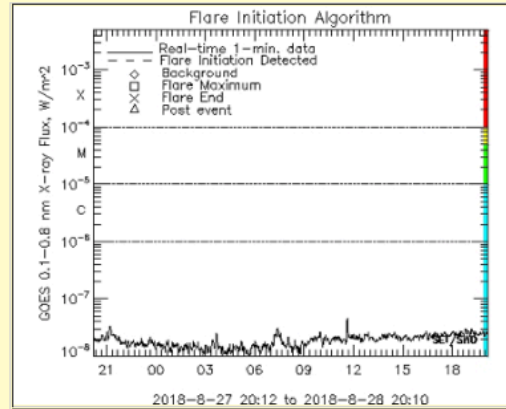


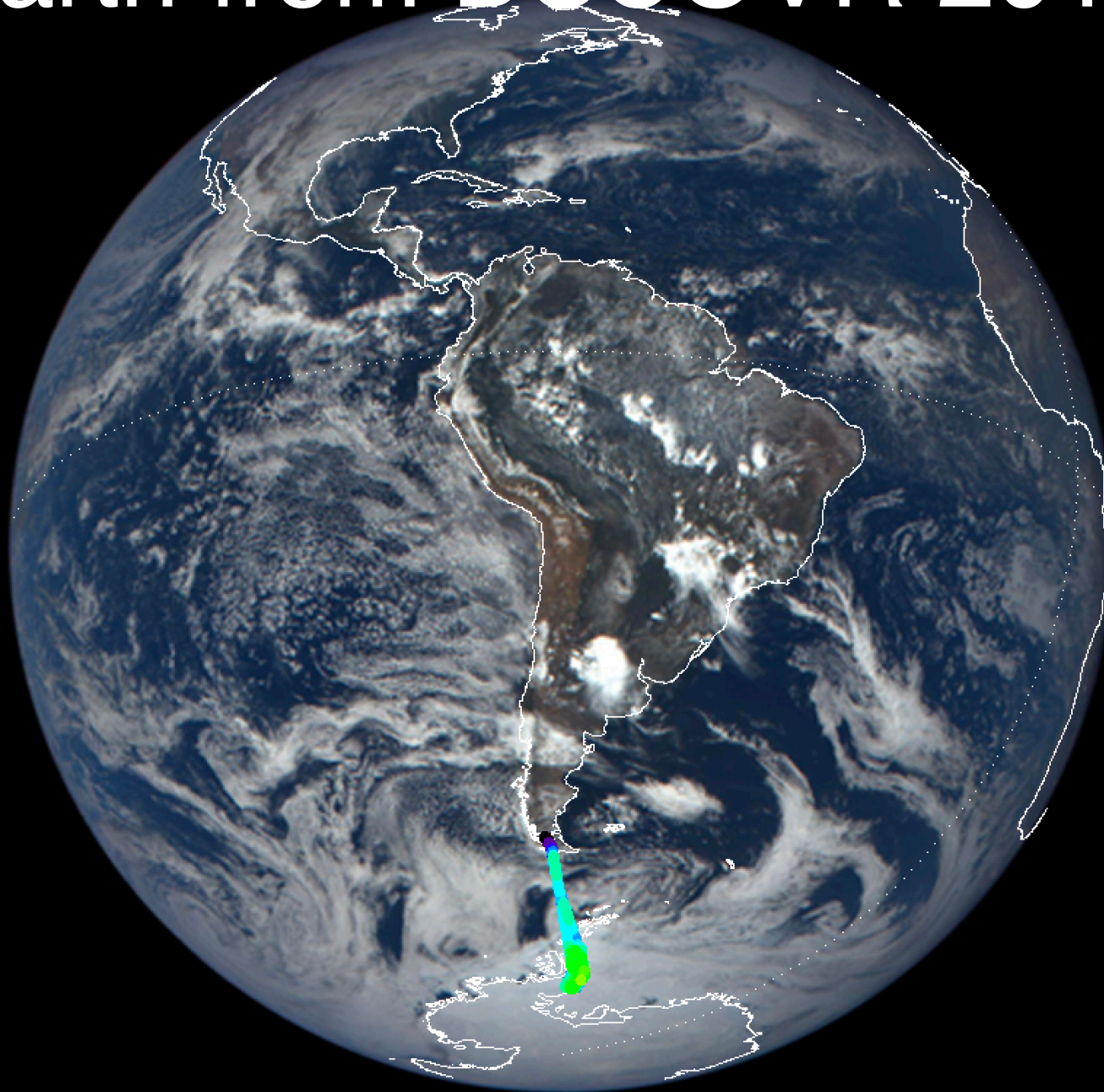
Figure 2

A large, dark rectangular image showing a view of Earth and the Moon from space. The Earth is a large, blue and white sphere on the right, and the Moon is a smaller, brownish sphere on the left. The background is black space.

Earth-Moon from Galileo 1994



Earth from DSCOVR 2015 re 2



[https](https://www.nasa.gov/content/dscovr/earth-from-dscovr-2015-re-2)

Lecture Overview

Operational drivers for mitigating space weather affects

Space environment standards activities

The interplanetary space environment

Atomic physics review and photon radiation

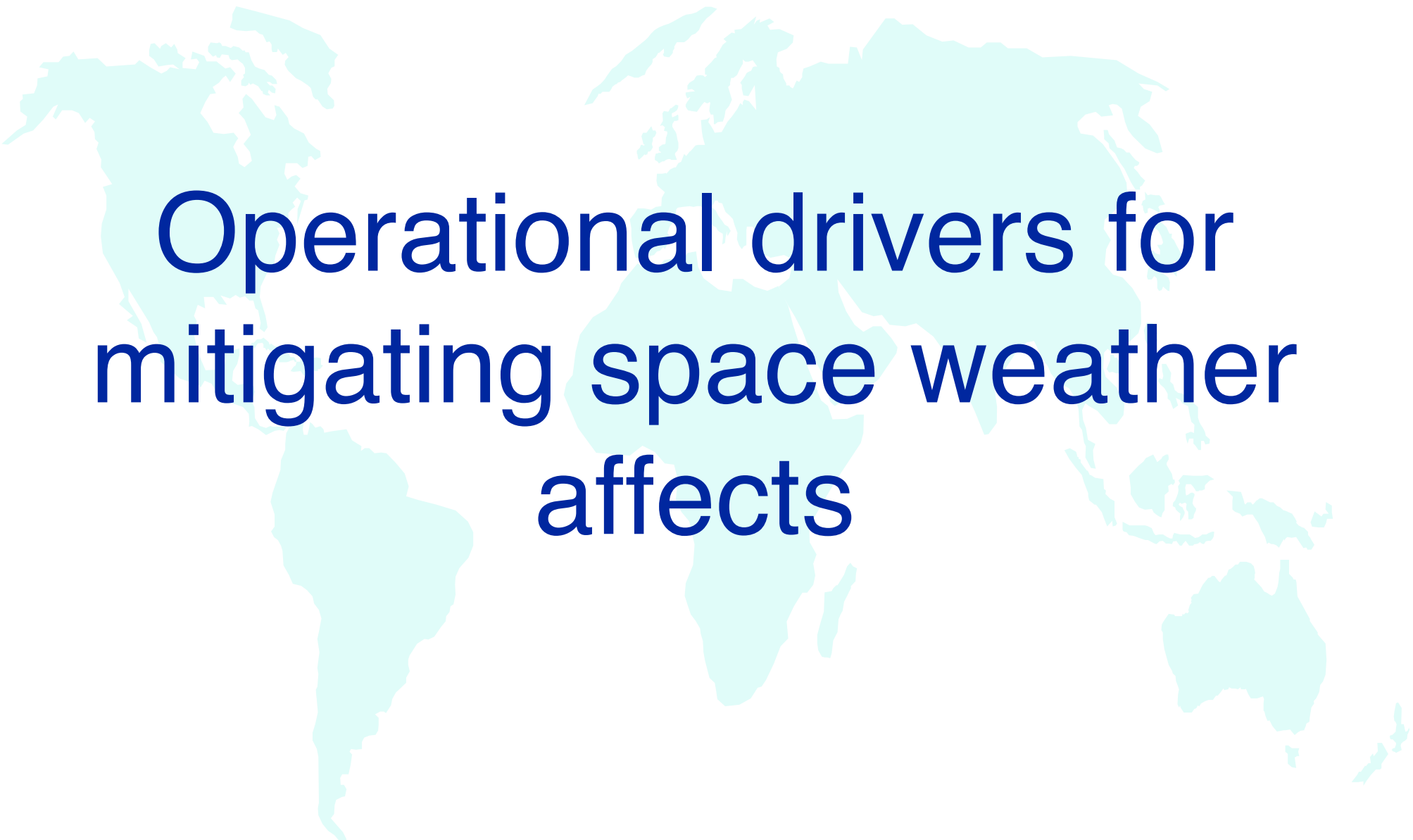
The Sun

Solar interior and atmosphere

Photons - solar irradiances

Resources

Homework

A light blue world map is centered in the background of the slide, showing the outlines of the continents.

Operational drivers for mitigating space weather affects

Space weather drives operations

◆ The short-term variable impact of the Sun's

- Photons, solar wind particles, and interplanetary magnetic field upon the Earth's environment
- Can adversely affect technological systems
- Effects come from
 - solar coronal mass ejections
 - solar and galactic energetic particles
 - solar flares and irradiances
- and they affect Earth's
 - magnetospheric particles and fields
 - geomagnetic and electrodynamical conditions
 - radiation belts
 - ionosphere
 - neutral thermosphere

Credit: Tobiska

Space Weather Operations Impacts

◆ Earth-orbiting (EO)

- Atmospheric drag affects location knowledge
- Attitude perturbations affect pointing precision and gas supply

◆ Deep space (DS)

- Attitude perturbations affect pointing precision and gas supply

◆ End-of-life (EL)

- Atmospheric drag affects end-of-life timing, location

Space Systems Impacts

◆ Mission planning (MP)

- Atmospheric drag affects location knowledge
- Attitude perturbations affect pointing precision and gas supply

◆ Telemetry transmission (TT)

- Ionospheric scintillation can impact radio link

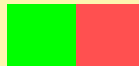
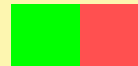
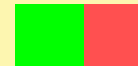
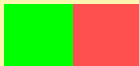
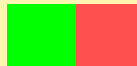
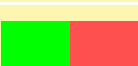
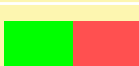
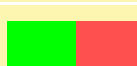
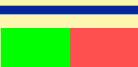
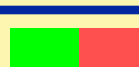
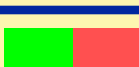
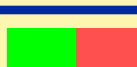
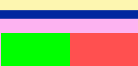
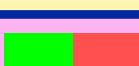
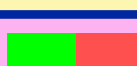
◆ Command and control (CC)

- Atmospheric drag error, ionospheric variability (scintillation and GPS location error), memory upsets from charged particle impacts

◆ Analysis capability (AC)

Credit: Tobiska

SPACE SYSTEMS USER ACTIVITIES

	EO	DS	EL	MP	TT	CC	AC
I_s							
I_{EUV}							
T_{heat}							
T_{wind}							
I_{ono}							
Q_J							
Q_P							
E							
B							
S_{wind}							

A light blue world map is centered in the background of the slide.

Space environment standards activities

A faint, light blue world map is visible in the background of the slide, centered behind the main text.

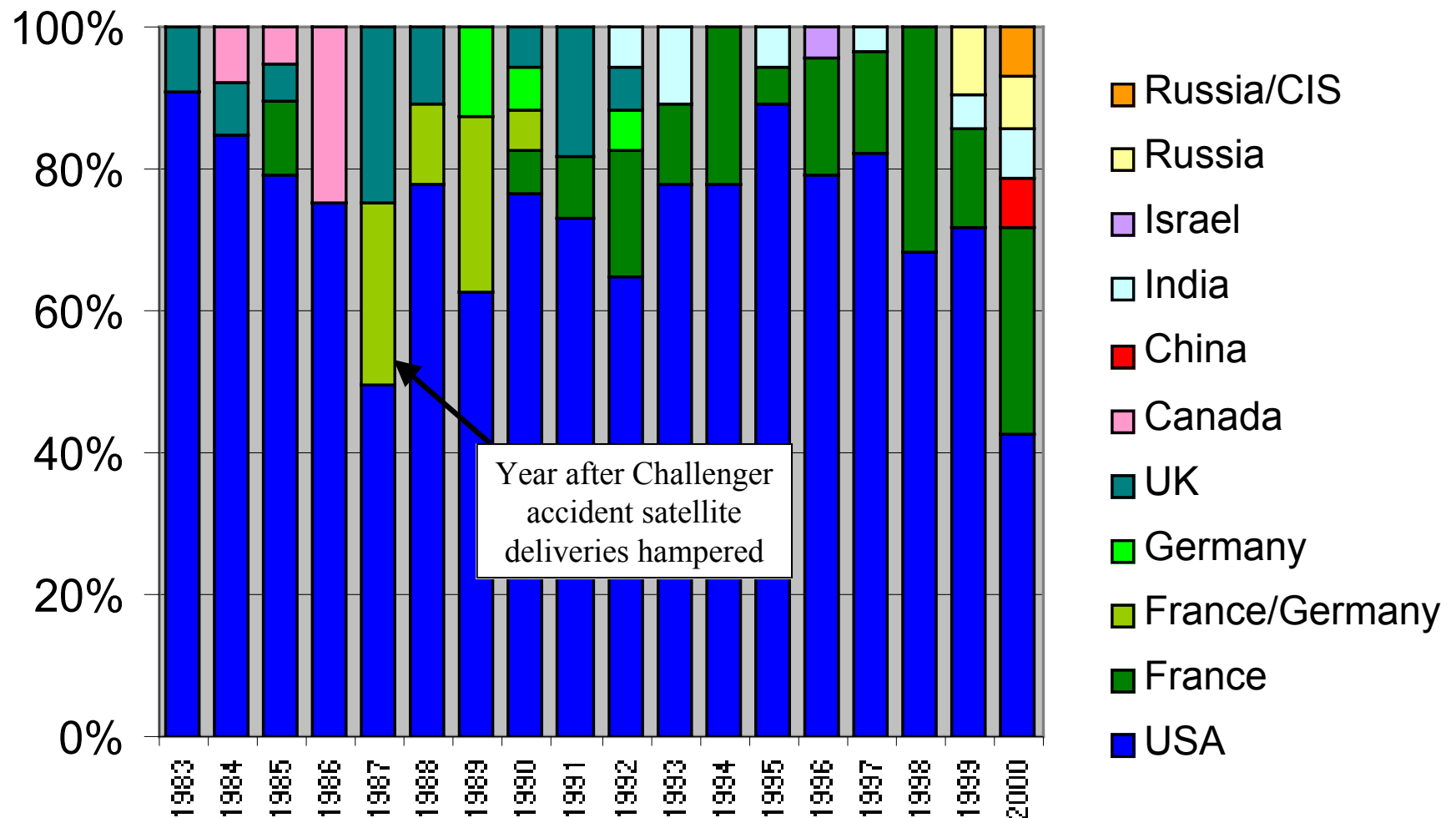
Space Environment Standards – ISO TC20/SC14 WG4

Why space environment standards?

- ◆ Standards provide common definitions, data, products, practices and transactions between diverse communities of users and producers to facilitate communication and commerce.
- ◆ Standards are developed at international, national, and organizational levels

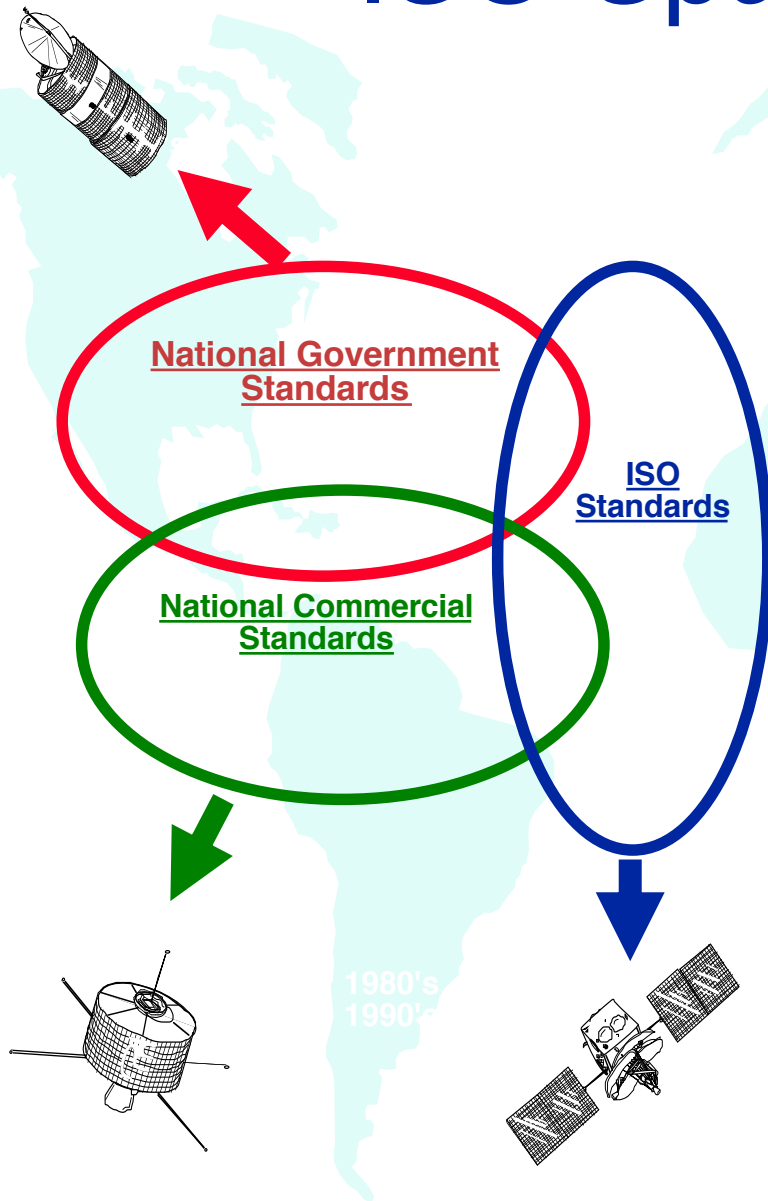
Market share of commercial space

Market Share of All Commercial GEO Satellites (by country of mfg)



Credit: L. Andrews

ISO Space Standards



They are voluntary

They enhance Scientific Cooperation and promote Trade

They provide for:

- International Definition of Space Environment
- Spacecraft to Launch Vehicle Interchangeability
- Equipment and Component exchange and/or utilization capability
- Experiment Spacecraft Integration and Interchangeability
- Common Launch Site Safety requirements and Support capability
- Control Center International Usability

ISO Standards do not require individual countries to change or discard their existing specifications

Rather, ISO Standards encourage individual countries to exchange information to create common definition of existing and agreed upon interfaces

Standards and guidelines

International standards

ISO TC20 Aircraft and space vehicles

- SC13 - CCSDS (Consultative Committee on Space Data Systems)
- SC14 - Space systems and operations includes Working Group 4 (Space environment (natural and artificial))

National standards

ANSI/ASTM, IEEE, MIL, GOST, ECSS

National and international guidelines (AIAA, ASTM, IADC)

Credit: Tobiska

Who participates in SC14?

<u>Delegation</u>	<u>Active Participation?</u>	<u>Industry</u>	<u>Organization Represented</u>	
			<u>Gov't./Academia/Association</u>	
France	yes	Aerospatiale Matra-Marconi Thomson-CSF	BNAE CNES	
Germany	yes	Deutsche Aerospace	DARA DLR	
Japan	yes	Mitsubishi Elect. Co. Hitachi M.H.I. Rocket Systems Co. NEC Kowasaki H.I. Toshiba Harina H.I.	NASDA CSP JICST Soc. Japan Aerospace Co.s	
Russia	yes	NPO-Energia NPO-Mashinostroenya SRC "KOSMOS"	TsAGI TsNI I Mash NIICIM Mash Kazpov Institute Institute of Standardization	Committe of Defense Branches Moscow State University Gosstendatt of Russia
U.S.A.	yes	Boeing Aerospace Corporation Lockheed Martin Space Environment Technologies	AIAA NASA JPL	
Italy	yes	Alenia Spazio		
China	yes		CASI	
Brazil	yes		INPE -Inst. of Space Research	
U.K.	yes	Astrium	BSI BNSC	

ISO TC20/SC14

Membership

P-Members

China
France
Germany
Italy
Japan
Russia
USA
Brazil
Canada
United Kingdom
Israel
Ukraine

VOTING MEMBERS

O-Members

Poland
Slovakia
Argentina
India
Spain
Sweden

Work Program

Spacecraft to launch vehicle interfaces
Electromagnetic compatibility
Pyrotechnic devices
EEE parts requirements
Structural design
Pressure vessels
Safety & Material compatibility testing
Fluid characteristics - Surface cleanliness
Mission operations - Concepts
Space solar cell - measurement & calibration
Ground support equipment - Requirements
Flight to ground umbilical
Launch site operations - Safety requirements
Program management - Risk mgmt.
Unmanned spacecraft transportation
Space environment and debris

Organization

Working Group 1

Design, Engineering, and Production

Working Group 2

Interfaces, Integration, and Test

Working Group 3

Operations and Ground Support

Working Group 4

Space Environment

Working Group 5

Program Management

Working Group 6

Materials

ODCWG

Debris

ISO standards development

- ◆ **Working Group 4 (Space environment)**
 - Sub-stage 10.00 – New Work Item (NWI)
 - Sub-stage 20.00 – Working Draft (WD), Technical Specification (TS), or Technical Report (TR)
- ◆ **Sub-Committee 14**
 - Sub-stage 30.00 – Committee Draft (CD)
 - Sub-stage 40.00 – Draft International Standard (DIS)
- ◆ **ISO (Geneva)**
 - Sub-stage 50.00 – Final Draft International Standard (FDIS)
 - Sub-stage 60.00 – International Standard

Credit: Tobiska

WG4 ACTIVITY OVERVIEW

◆ Active Projects (13 published documents)

- 1) **IS 10788** Lunar simulants
- 2) **TR 11225** Guideline to reference and standard atmosphere models
- 3) **TS 12208** Observed proton fluences over long duration at GEO and guideline for selection of confidence level in statistical model of solar proton fluences
- 4) **IS 14200** Guide to process-based implementation of meteoroid and debris environmental models (orbital altitudes below GEO+2000km)
- 5) **IS 14222** Earth upper atmosphere
- 6) **IS 15390** Models of galactic cosmic rays
- 7) **IS 15856** Simulation guidelines for radiation exposure of non-metallic materials
- 8) **IS 16457** The Earth's ionosphere model — International reference ionosphere (IRI) model and extensions to the plasmasphere
- 9) **IS 16695** Earth's internal magnetic reference field models
- 10) **IS 16698** Methods for estimation of future geomagnetic activity
- 11) **TR 18147** The method of the solar energetic protons fluences and peak fluxes determination
- 12) **IS 21348** Solar irradiance determinations
- 13) **IS 22009** Model of Earth's magnetospheric magnetic field

WG4 ACTIVITY OVERVIEW

◆ 5 active documents

1. **DIS 17520** Cosmic ray and solar energetic particle penetration inside the magnetosphere: Method of the effective vertical cut-off determination
2. **FDIS 17761** Model of high energy radiation at low altitudes (300-600 km)
3. **FDIS 17851** Space environment simulation for material tests. General principles and criteria
4. **CD 19923** Spacecraft potential estimation in worst case environment
5. **WD 20854** Spacecraft charging — Earth orbit

◆ 1 NWI document

1. **N0764** Cosmic ray and solar energetic particle penetration inside the magnetosphere: Method of the effective vertical cut-off determination

WG4 ACTIVITY OVERVIEW

13 new proposal concepts

1. space environment effects on nano-materials
2. electrostatics and dust (lunar)
3. worst case solar events
4. protection of materials from MMOD impact
5. solar wind data in the OMNI database
6. space weather information for use in space systems operations
7. compilation of radiation environments and transport codes
8. AE9/AP9 radiation belt model
9. Terrestrial environment guideline
10. Solar wind
11. Low-cost satellite radiation mitigation
12. Satellite drag
13. Atomic oxygen

Space Environment Domains	Terrestrial and Lunar Space Environment LEO PEO MEO GEO >GEO Space Systems and Operations Orbital Domains				
	Published, In process, To be initiated				
	Testing/Analysis/ Framework	15856, 17851, 21980, 22295, AUL	15856, 17851, 21980, 22295, AUL	15856, 17851, 22295, AUL	15856, 17851, 22295, AUL
	Cosmic Rays	15390, 17520, (space weather)	15390, 17520, (space weather)	15390, 17520, (space weather)	15390, 17520, (space weather)
	Solar photons	21348, (space weather)	21348, (space weather)	21348, (space weather)	21348, (space weather)
	Solar particles	16698, 17520, 18147, (solar wind) , (space weather)	16698, 17520, 18147, (solar wind) , (space weather)	16698, 17520, 18147, (solar wind) , (space weather)	16698, 17520, 18147, (solar wind) , (space weather)
	Solar fields	16698 (solar wind), (space weather)	16698 (solar wind), (space weather)	16698 (solar wind), (space weather)	16698 (solar wind), (space weather)
	Main magnetic field	16695, 16698, (space weather)	16695, 16698, (space weather)	16695, 16698, (space weather)	16695, 16698, (space weather)
	Magnetosphere	16695, 16698, 19923, 20584, (space weather, PC-index)	16695, 16698, 19923, 20584, (space weather)	16695, 16698, 22009, 19923, 20584, (space weather)	16695, 16698, 22009, 19923, 20584, (space weather)
	Radiation Belts	17761, 20584, 17520, 21979, (IRENE, internal chrg), (space weather)	17761, 20584, 17520, 21979, (IRENE, internal chrg), (space weather)	20584, 17520, 21979, (IRENE, internal chrg), (space weather)	20584, 17520, 21979, (IRENE, internal chrg), (space weather)
	Plasmasphere	16457, 20584, (space weather)	16457, 19923, 20584, (space weather)	16457, 19923, 20584, (space weather)	16457, 19923, 20584, (space weather)
	Ionosphere	16457, 16698, 20584, (space weather)	16457, 16698, 20584, (space weather)	June 12, 2018	
	Neutral atmosphere	14222, 11225, 16698, (AO, sat drag), (space weather)	14222, 11225, 16698, (AO, sat drag), (space weather)		
	Micrometeoroids	14200	14200	14200	14200
	Debris	14200, (rad debris)	14200, (rad debris)	14200	14200
	Lunar				10788

Galactic Cosmic Rays

- ◆ **IS 15390:2004 – Models of galactic cosmic rays**
 - This standard is a model describing the variations of the GCR fluxes due to variation in solar activity and in the large-scale heliospheric magnetic field throughout 22-year cycles
 - Sub-stage 60
 - Publication (2004)
 - Project lead: Russia (Nymmik)
 - Recommendations: review

Credit: Tobiska

Solar Irradiance Determination

- ◆ **IS 21348:2007 – Process for determining solar irradiance**
 - This process-based draft standard specifies representations of solar irradiances and is applicable to measurements, reference spectra, empirical models, and first-principles models
 - Sub-stage 60
 - Publication (2007)
 - Project Leads: USA and Russia (Tobiska & Nusinov)
 - Recommendations: review

Earth's Ionosphere

- ◆ **TS 16457:2009 – Earth's ionosphere and plasmasphere model – density, temperature, and electron effective collision frequency**
 - This TS describes the IRI model that defines the critical parameters for the Earth's ionosphere
 - Sub-stage 60
 - Publication (2009)
 - Project Leads: Russia and USA (Gulyaeva & Bilitza)
 - Recommendations: review

Earth's Magnetic Field

- ◆ **IS 22009:2010 – Model of Earth's magnetospheric magnetic field**
 - The standard describes the magnetic field in the Earth's magnetosphere and the parameters of magnetospheric large-scale current systems in accord with conditions in the space environment
 - Sub-stage 60
 - Publication (2010)
 - Project Lead: Russia (Alexeev)
 - Recommendations: review

Earth Atmosphere Density

- ◆ **IS 14222 –Earth atmosphere density**
 - This TS will provide empirically based model(s) of the Earth's atmosphere based on the NRLMSIS and JB2008, including density, pressure, & chemical species
 - Sub-stage 20+
 - FDIS status (Sep-12)
 - Project Leads: UK and USA (Rees & Tobiska)
 - Recommendations: proceed to draft document

Credit: Tobiska

Space Weather NWI

Overview – 1

- ◆ Space systems operations require accurate knowledge of recent, current, and forecast space environment conditions
- ◆ These conditions change dynamically (seconds to years) and are driven by the Sun's photon and particle interactions with the near Earth environment
- ◆ This short-term variability is called space weather

Space Weather NWI

Overview – 2

- ◆ ISO TC20/SC14/WG4 is developing an International Standard (IS) document (Technical Report – TR) on space weather information for use in space systems operations
- ◆ Objective is to describe the main space weather factors affecting space systems operations and to identify tools and parameters needed for effective space weather risk management

Space Weather NWI

Overview – 3

- ◆ This TR will establish definitions for space weather information and aid in harmonizing key space weather tools provided by international organizations, national government agencies, and industries
- ◆ Includes space weather time frames as well as galactic cosmic ray, solar, and near-Earth environments

Space Weather NWI

Overview – 4

- ◆ Effects include ionospheric, magnetic, and radiation storms
- ◆ Annex A includes space weather indices listing with: 1) derivation, assumptions, uncertainties and limitations; 2) application to system operation and maintenance; 3) contributors with dates of development, authors/sponsors, collection frequency, locations or instruments; and 4) publication references and URL access

Space Weather NWI

Overview – 5

- ◆ Annex B includes space weather effects to systems by environmental region including:
 - Ground Systems
 - Lower and Upper Atmosphere
 - Suborbital
 - Low Earth orbit, Mid-Earth orbit, Geostationary Earth orbit, High Earth orbit, and
 - Interplanetary orbits



Outline of Space Weather TR

Table of Contents

Forward	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Time frames for space weather information	2
4.1 Historical	2
4.2 Current epoch (Nowcast)	2
4.3 Forecast	2
5 Galactic cosmic rays	2
6 Solar environment within the heliosphere	2
6.1 Solar dynamo	2
6.2 Sunspots	3
6.3 Solar energetic electromagnetic radiation	3
6.4 Long wavelength electromagnetic radiation	4
6.5 Solar energetic particles	4
7 Solar event effects on the near-Earth environment	5
7.1 Magnetosphere	5
7.2 Plasmasphere	6
7.3 Van Allen radiation belts	6
8 Terrestrial environment	7
8.1 Neutral atmosphere	7
8.2 Ionosphere	7
9 Micrometeoroid and Debris environment	8
9.1 Natural	8
9.2 Artificial	8
Annex A Space Weather Indices	9
A.0 Example index (Full index title)	9
A.1 Kp Index (Planetary K index)	9
A.2 Ap Index	9
A.3 Dst index (Storm time disturbance index)	9
A.4 Sunspot number (R)	10
A.5 F10.7	11
A.6 S10.7	12
A.7 M10.7	13
A.8 Y10.7	13

A.10 National Oceanic and Atmospheric Administration (NOAA) scales	14
A.11 SBUV MgII c/w ratio	16
Annex B Space weather effects to systems by environmental region	17
B.1 Ground	17
B.2 Lower Atmosphere (0–15 km)	18
B.3 Middle Atmosphere (15–85 km)	18
B.4 Suborbital	18
B.5 Low Earth orbit	18
B.6 Mid-Earth orbit	20
B.6.1 Single event effects	20
B.6.2 Total dose effects	20
B.6.3 Space vehicle surface and internal charging	20
B.6.4 Micrometeoroid/orbital debris	20
B.6.5 Resources	20
B.7 Geostationary Earth orbit	20
B.7.1 Single event effects	20
B.7.2 Total dose effects	20
B.7.3 Space vehicle surface and internal charging	20
B.7.4 Micrometeoroid/orbital debris	20
B.7.5 Resources	20
B.8 High Earth orbit	20
B.8.1 Single event effects	20
B.8.2 Total dose effects	20
B.8.3 Space vehicle surface and internal charging	20
B.8.4 Micrometeoroid/orbital debris	21
B.8.5 Resources	21
B.9 Interplanetary orbits	21
B.9.1 Single event effects	21
B.9.2 Total dose effects	22
B.9.3 Resources	22
Bibliography	23

Example of entries in TR

increased flux of energetic particles exposes low Earth orbiting (LEO) systems higher levels of radiation. The heart of the region is in the southern hemisphere of the Atlantic Ocean but the end regions are dependent on the altitude of the spacecraft.

7.3.1.5 Polar region field aligned currents

7.3.2 Effects

8 Terrestrial environment

8.1 Neutral atmosphere

8.1.1 Phenomenology

8.1.1.1 Atmospheric layers

8.1.2 Effects

8.1.2.1 Atmospheric drag

8.1.2.2 Atomic oxygen

8.1.2.3 Vehicle glow

8.2 Ionosphere

Region of the Earth's atmosphere in the height interval from 50 km to 1 500 km containing weakly ionized cold plasma, both electrons and ions.

[ISO/DIS 16457(E), 2.1]

8.2.1 Phenomenology

8.2.1.1 Ionospheric layers

8.2.2 Effects

8.2.2.1 Scintillation

Gradients in the total electron content (TEC) can be caused by traveling ionospheric disturbances, bubbles, plumes, streams, or sharp borders. Small structures within the ionosphere are frequently associated with large-gradient regions and can cause scintillation. For GPS users, scintillation is observed as amplitude and phase fluctuations in the received signal. Severe scintillation effects in either amplitude or phase can cause a GPS receiver to lose lock.

Large gradients in TEC and scintillation are primarily associated with the equatorial and polar regions. However, large gradients in TEC and scintillation can be observed at mid-latitudes during moderate to severe geomagnetic disturbances. Because the majority of GPS users are located at mid-latitudes, the disturbances caused by large geomagnetic storms can potentially affect the average GPS user.

Knowledge of these TEC gradients is important to various GPS users. When a GPS signal encounters large gradients in TEC, the ionospheric error in the range measurement is difficult to model and remove (required for single-frequency GPS

users), or in the case of differential GPS, it cannot be canceled out. For DGPS or RTK users, differences as small as two TEC units over the baseline (one TEC unit is 1×10^{16} electrons m^{-2}) can make resolution of ambiguities difficult. (A TEC unit is approximately equivalent to 0.162 meters of range delay at L1, or 1 meter of delay at L1 is equivalent to 6.159 TEC units).

8.2.2.2 Surface charging

9 Micrometeoroid and Debris environment

9.1 Natural

Particles of natural origin that result from the disintegration and fragmentation of comets and asteroids, which orbit around the Sun. [ISO 14200:2012(E), 3.11]

9.2 Artificial

Human-made objects, including fragments and elements thereof, in Earth's orbit or re-entering the atmosphere that are often non-functional components of spacecraft. There are currently more than half a million pieces of space debris orbiting the earth. Forty percent of these objects are larger than a softball ball while the rest are about the size of a marble. They all travel at speeds faster than 7,5 km/s and can severely damage a satellite. There have been several incidents that have caused the creation of increased debris fields and, if left unmonitored, will become a larger problem. [ISO 24113:2011, 3.17]

Orbit debris

- ◆ **IS 14200 – micrometeoroids & orbit debris**
 - This draft standard defines the parameters affecting the Earth's orbit debris environment
 - Sub-stage 20
 - IS status (Sep-12)
 - Project Leads: Japan (Kitazawa)
 - Recommendations: consider input from ODCG; strong support for Earth atmosphere density, solar irradiance, and solar/geomagnetic proxy standardization that is already in progress

Guide to Atm Density Models

- ◆ **TR 11225 – Guide to reference and standard atmosphere models**
 - This TR provides a listing of all atmosphere density models, along with a description of their source, utility, derivation, and relevance
 - Sub-stage: 20
 - In publication (Sep-12)
 - Project Leads: US (Vaughan)
 - Recommendations: document nearly complete, prepare in ISO format for publication as TR

Credit: Tobiska



Lecture 2

ANSI/AIAA
G-003B-2004

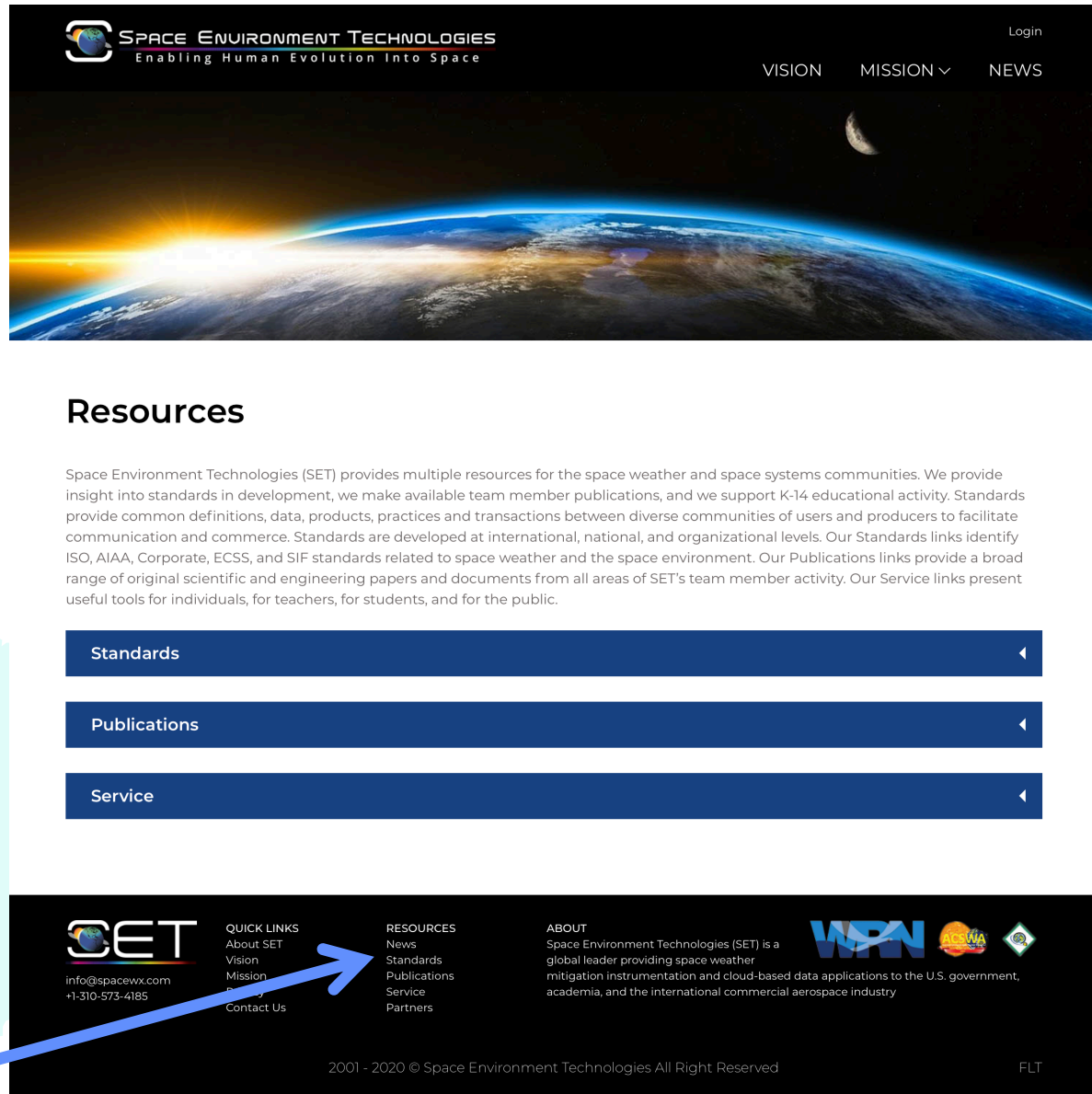
Guide

Guide to Reference and Standard Atmosphere Models

AIAA standards are copyrighted by the American Institute of Aeronautics and Astronautics (AIAA), 1801 Alexander Bell Drive, Reston, VA 20191-4344 USA. All rights reserved.

AIAA grants you a license as follows: The right to download an electronic file of this AIAA standard for temporary storage on one computer for purposes of viewing, and/or printing one copy of the AIAA standard for individual use. Neither the electronic file nor the hard copy print may be reproduced in any way. In addition, the electronic file may not be distributed elsewhere over computer networks or otherwise. The hard copy print may only be distributed to other employees for their internal use within your organization.





Resources

Space Environment Technologies (SET) provides multiple resources for the space weather and space systems communities. We provide insight into standards in development, we make available team member publications, and we support K-14 educational activity. Standards provide common definitions, data, products, practices and transactions between diverse communities of users and producers to facilitate communication and commerce. Standards are developed at international, national, and organizational levels. Our Standards links identify ISO, AIAA, Corporate, ECSS, and SIF standards related to space weather and the space environment. Our Publications links provide a broad range of original scientific and engineering papers and documents from all areas of SET's team member activity. Our Service links present useful tools for individuals, for teachers, for students, and for the public.

- Standards
- Publications
- Service

Standards Link

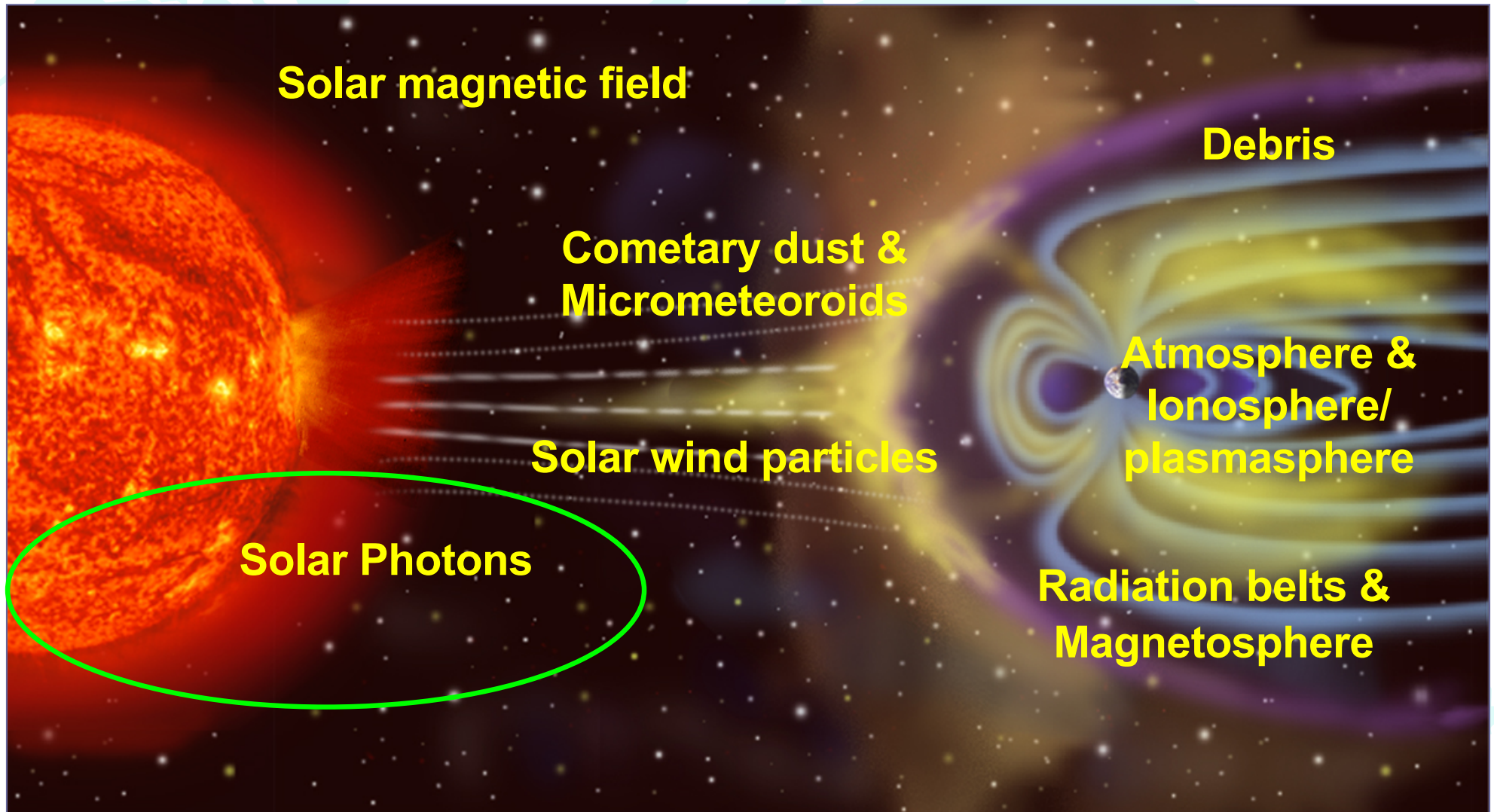
2001 - 2020 © Space Environment Technologies All Right Reserved

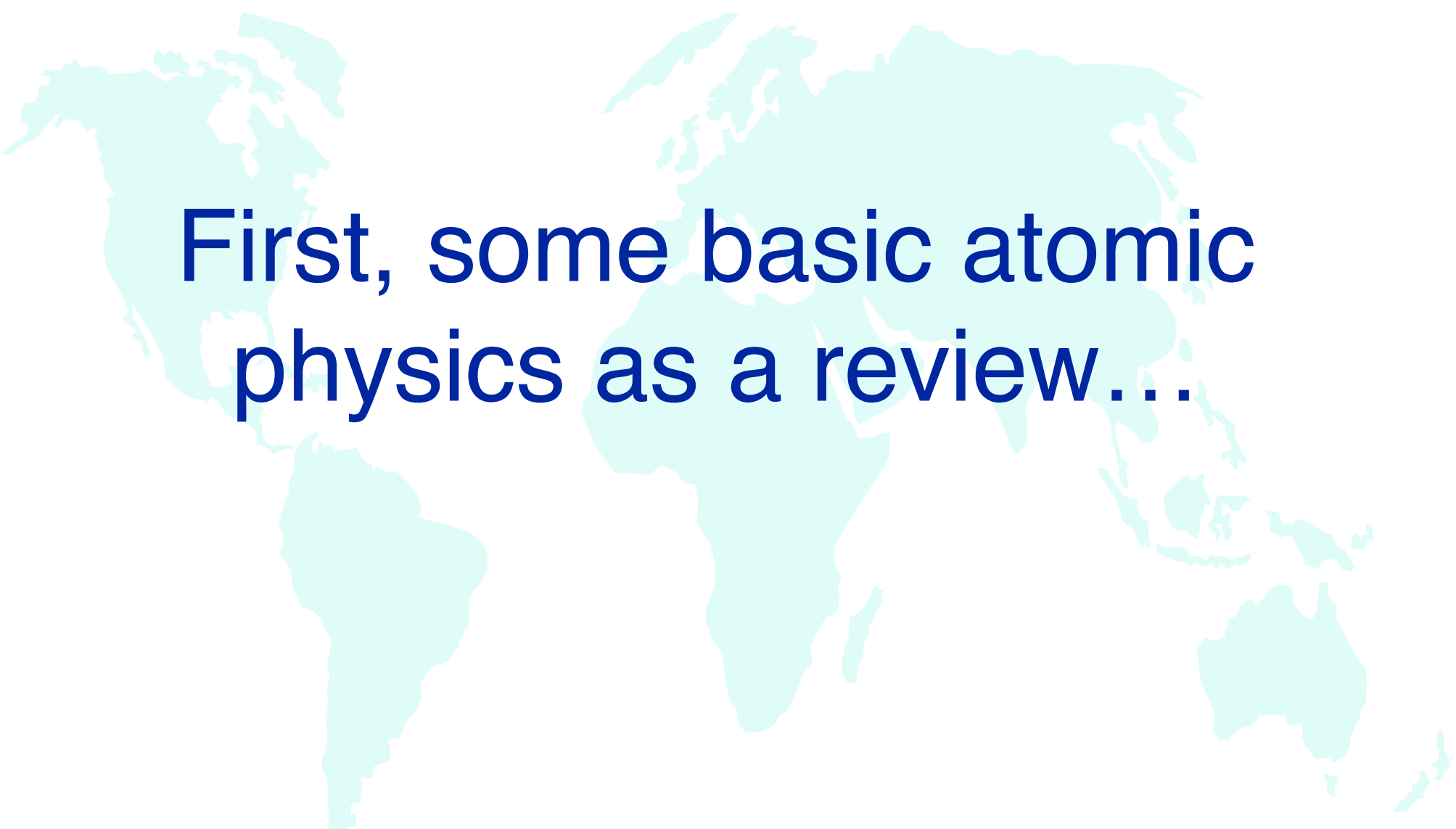
Standards Link

A light blue world map is centered in the background of the slide.

The interplanetary space environment

The space environment



A light blue world map is centered in the background of the slide, showing the continents of North America, South America, Europe, Africa, Asia, and Australia.

First, some basic atomic
physics as a review....

Atomic physics - 1

Electronic configuration

- **The energy state of an atom's electrons are identified by spectroscopic notation**
- A hydrogen-like atom (i.e. any atom with all but one electron removed, for example He^+ or O^{7+}) consists of a light, very mobile electron of mass m_e , and a heavy, immobile atomic nucleus
- Atoms of this nature can be described by an electron moving in a spherically-symmetric electric field of the nucleus
- The electric force between the two charges is the Coulomb force

Atomic physics - 2

The potential energy of the electron-nucleus interaction is given by the **Coulomb potential** as

$$U(r) = -k \frac{Ze^2}{r} \quad (2-1)$$

where Z is the charge number of the nucleus ($Z = 1$ for the hydrogen atom), e is the elementary charge and r is the distance between the electron and the nuclear center. k is the Coulomb constant of $1/(4\pi\epsilon_0)$

Atomic physics - 3

- The negative sign indicates that the interaction between the electron and the nucleus is attractive. Therefore, as long as the electron's total energy [kinetic ($mv^2/2$) + potential ($-Ze^2/r$)] is *negative*, the electron will be bound to the nucleus.
- If the atom is excited by supplying energy to the electron, then the kinetic energy of the electron may become large enough that the total electron energy becomes *positive*.
- When this occurs, the electron leaves the nucleus to become a free electron in a process known as **ionization**.
- Table 1 shows the ionization potentials for several atoms.

Atomic physics - 4

Table 1. Ionization potentials

Atom	H	He	C	N	O	Ar	Ne
Ionization Potential (eV)	13.60	24.59	11.26	14.53	13.62	15.76	21.56
Max wavelength (nm)	91.2	50.4	110.1	85.3	91.0	78.7	57.5

Atomic physics - 5

Energy can be transferred to an electron during **atomic collisions** with other electrons or atoms (taking the kinetic energy of the collision partner and transferring it to the electron) or by the **absorption of photon** energy. These processes are fundamentally different (although they may lead to the same end result).

Atomic physics - 6

In order to obtain complete specificity of the electron behavior in a Coulomb potential, the Schrödinger equation in spherical coordinates is solved using the potential in equation (2-1). When solved for multi-electron atoms, four quantum numbers are required to describe the electrons. The four quantum numbers for specifying individual electrons are:

1. **Principle quantum number:** $n = 1, 2, 3, \dots$
2. **Orbital or azimuthal quantum number:** $l = 0, 1, 2, \dots, (n-1)$
3. **Magnetic quantum number:** $m_l = 0, \pm 1, \pm 2, \dots, \pm l$
4. **Spin quantum number:** $s = 1/2$

Atomic physics - 7

The electron **orbital angular momentum** quantum numbers (l) are designated by various letters

l = 0, 1, 2, 3, 4, 5, 6
s p d f g h i

(2-2)

To completely describe multi-electron atoms, additional quantum numbers are required which act as total or vector-summed values over all the atomic electrons. The capital L quantum number is the sum of the individual electron numbers ($L = \sum l$).

Atomic physics - 8

In multi-electron atoms, the electron spins sum as vectors to a total **spin quantum number** S . The total **orbital angular momentum** quantum number, L , also adds individual electron orbital angular momentum quantum numbers as vectors. The total electron spin and orbital motion are coupled quantities in atomic systems and the total **resultant** quantum number is J . Therefore, for two electrons the *total orbital number* is (2-3)

$$L = (l_1 + l_2), (l_1 + l_2 - 1), (l_1 + l_2 - 2), \dots, |l_1 - l_2|$$

and the *total quantum number* is (2-4)

$$J = (L + S), (L + S - 1), (L + S - 2), \dots, |L - S|$$

Atomic physics - 9

The total orbital angular momentum quantum number is also designated by various letters

$$L = 0, 1, 2, 3, 4, 5, 6 \quad (2-5)$$

S P D F G H I

Total degeneracy (statistical weight) resulting from the quantization of both orbital (L) and spin (S) angular momentum is

$$d_g = (2L + 1) (2S + 1) \quad (2-6)$$

Atomic physics - 10

The statistical weight is equal to the total number of atomic quantum states that have the same values of the quantum numbers L and S but different sets of the quantum numbers m_l and s .

A general scheme for designating electronic configurations of multi-electron atoms is the spectroscopic notation of

$$(n_i l_i)^{r_i} \cdot (n_k l_k)^{r_k} \cdot (n_m l_m)^{r_m} {}^a Y_{J_1, J_2} \dots \quad (2-7)$$

where the parentheses (often omitted) contain the **principle** (n) and **orbital** (l) quantum numbers of each group of equivalent electrons

Atomic physics - 11

- Electrons having the same principle quantum number form an atomic shell, and the shells with $n = 1, 2, 3, 4, 5, 6$ are called the K, L, M, N, O, P shells, respectively
- An atomic shell can have several groups (called subshells) of equivalent electrons
- The number of equivalent electrons in the k^{th} subshell is given by the superscript r_k
- The letter Y in equation (2-7) indicates the value of the quantum number L for the total electronic orbital momentum of the atom
- $Y = S, P, D, F, \dots$ for $L = 0, 1, 2, 3, \dots$ respectively

Atomic physics - 12

- For example, an atomic state with total orbital angular momentum $L = 1$ is called the P state. The Eq. 2-7 superscript $a = 2S + 1$ is called the multiplicity of the term. If the multiplicity a equals 1, the term is called singlet, 2 = doublet, 3 = triplet, 4 = quartet, etc.
- The values of the possible quantum number J of the term's levels are sometimes shown as the subscript $J_1, J_2, \dots$, in the designation configuration of Eq. (2-7)
- The interaction of the spin and orbital angular momenta leads to a splitting or fine structure in the atomic levels

Atomic physics - 13

Electronic transitions

For a hydrogen-like atom, the energy of the atomic state can be reasonably approximated by

$$E_n = \frac{2\pi^2 \mu e^4}{ch^3} Z^2 \left(\frac{1}{n^2} \right) \quad (2-8)$$

where μ is the electron-proton reduced mass, c is the speed of light, h is Planck's constant, n is the principle quantum number of the particular energy state in which the electron resides, Z is the atomic number, e is charge

Atomic physics - 14

The electron in an excited state (i.e., $n = 2$) will make a transition to a lower state and energy conservation is observed by the emission of a photon (for H it is the Lyman-alpha photon at 121.6 nm). The energy of the photon emitted is

$$E_{\text{photon}} = E_2 - E_1 = h\nu \quad (2-9)$$

where E_2 and E_1 are the energy of the upper and lower electronic state respectively and ν is the photon frequency. The wavelength of the emitted photon is

$$\lambda = \frac{c}{\nu} \quad (2-10)$$

Atomic physics - 15

- Transitions between quantum states can cross any number of principle quantum numbers, n
- However, there are specific transition rules for allowed dipole transitions for the other quantum numbers
- For example, for the orbital angular momentum quantum number, l , only transitions between levels with $l = \pm 1$ are allowed. No other upward or downward transitions are dipole allowed transitions
- This rule is not absolute. So-called “forbidden” transitions do occur particularly when there is no alternative branch for an excited state to decay.

Atomic physics - 16

Forbidden transition emissions are observed in the Earth's aurora, dayglow and nightglow from altitudes above 80 km. The forbidden transitions occur on time scales of a few seconds to many hours; this is because the downward transitions occur only with a low probability. Atoms in excited states with no allowed downward transitions are called **metastable** atoms. The following is a list of transition rules for dipole allowed transitions

$$l = \pm 1$$

$$L = 0, \pm 1$$

$$S = 0$$

$$J = 0, \pm 1 \text{ (except } J=0 \text{ does not transition to } J=0\text{)}$$

A light blue silhouette of a world map is centered in the background of the slide.

BREAK

A light blue silhouette of a world map is centered in the background of the slide.

Photon radiation

Black Body Radiation

- Every substance emits electromagnetic radiation and the wavelength depends on the nature (composition) and temperature (energy) of the substance
- Discrete spectra of excited gases originate from electronic, vibrational, and/or rotational transitions within atoms and molecules
- Condensed matter, however, radiates continuous spectra in which all frequencies are present
- Atoms in a solid or dense body (for example, the Sun) are so close together that their mutual interactions result in a multitude of adjacent quantum states indistinguishable from a continuous band of permitted energies

Black Body Radiation

- The ability of a body to radiate is closely related to its ability to absorb radiation
- When considering a body at constant temperature
 - the body is in thermal equilibrium with its surroundings and must absorb the energy at the same rate as it emits or radiates energy
 - a **blackbody** is an ideal body that absorbs all the radiation incident upon it
- Since a substance's ability to emit radiation is proportional to its ability to absorb energy, the blackbody is also the ideal radiator
- The blackbody approximation is good for the Sun since the Sun is condensed matter

Planck's Law

The intensity per unit frequency, f , as a function of the wavelength of blackbody radiation, λ (see eq. 2-10), is defined by the Planck function as

$$f_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{\left(e^{\frac{hc}{\lambda kT}} - 1\right)} \quad (2-11)$$

where h is Planck constant, c is the speed of light and T is the body temperature, λ is the wavelength, k = Boltzmann constant

Wien's Law

Wien's law gives the **wavelength of peak spectral intensity** by

$$\lambda_{\text{max}} = \frac{hc}{4.965kT} \quad (2-12)$$

which expresses the fact that the peak in the blackbody spectrum shifts to progressively shorter wavelengths (higher frequencies) as the temperature is increased

Heat absorption

An object will absorb energy (heat), Q_{absorb} , from its surroundings according to the integral of Planck's function over all frequencies by

$$Q_{\text{absorb}} = \int_0^{\infty} f_{\nu} d\nu \quad (2-13a)$$

$$Q_{\text{absorb}} = aT^4 \quad (2-13b)$$

where a is a universal constant dependent on various powers of c , k and h . This result is valid for a perfect blackbody absorber only. In general, the same equation can be used with the value of a as a coefficient which is material dependent.

Stefan-Boltzmann's Law

The total energy absorbed is proportional to the fourth power of the temperature of the body. Therefore, it is expected that the energy radiated by the body, Q_{radiated} , per unit area per second will also be proportional to T^4 . This is shown by the **Stefan-Boltzmann law** as

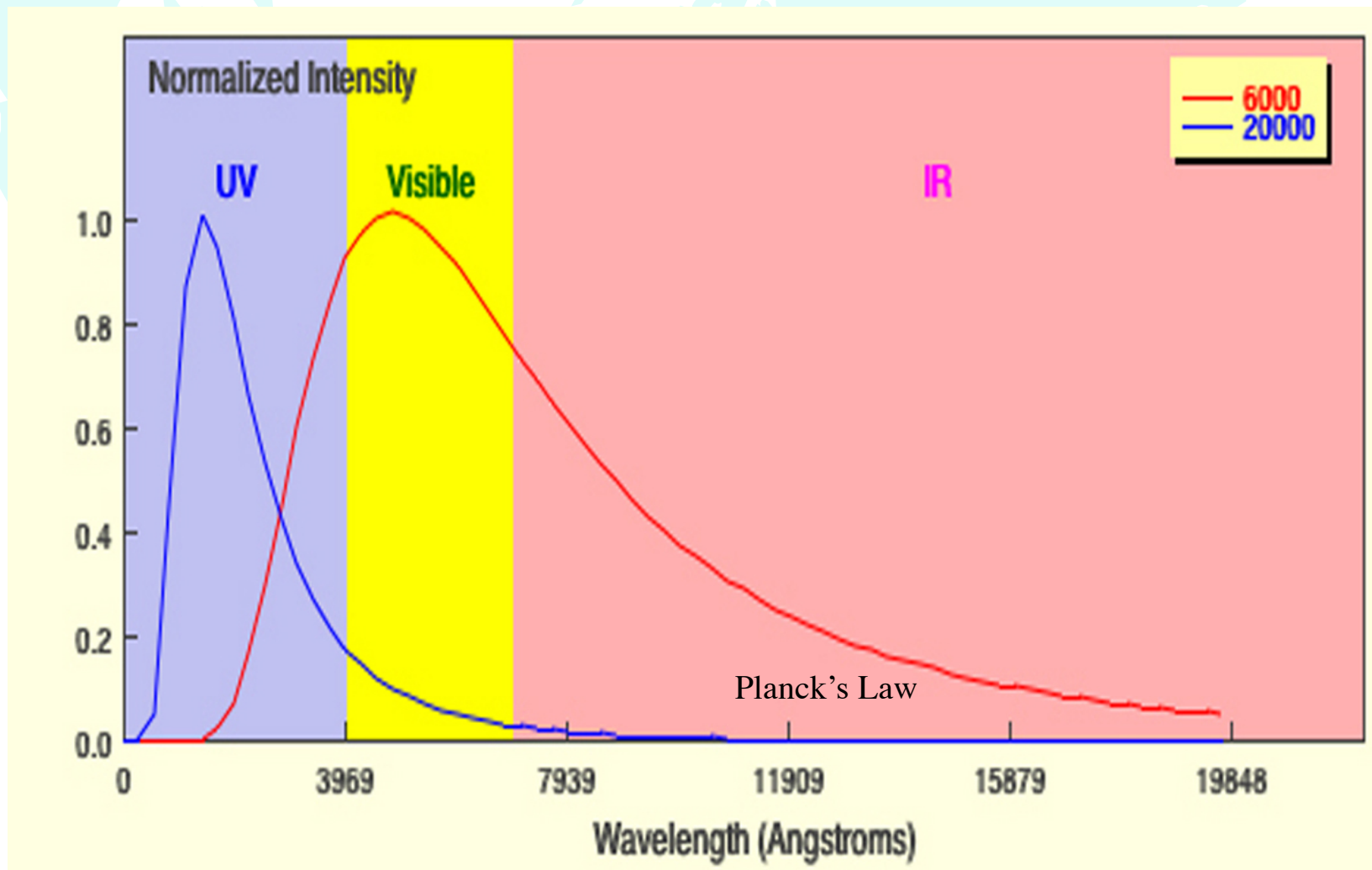
$$Q_{\text{radiated}} = e\sigma T^4 \quad (2-14)$$

where e is the emissivity of the radiating surface (nature dependent) and σ is the Stefan-Boltzmann constant ($\sigma = 5.67 \times 10^{-5} \text{ erg cm}^{-2} (\text{deg K})^4 \text{ sec}$). The emissivity = 0 for a perfectly reflecting surface and = 1 for a blackbody; all real objects have an emissivity between 0 and 1.

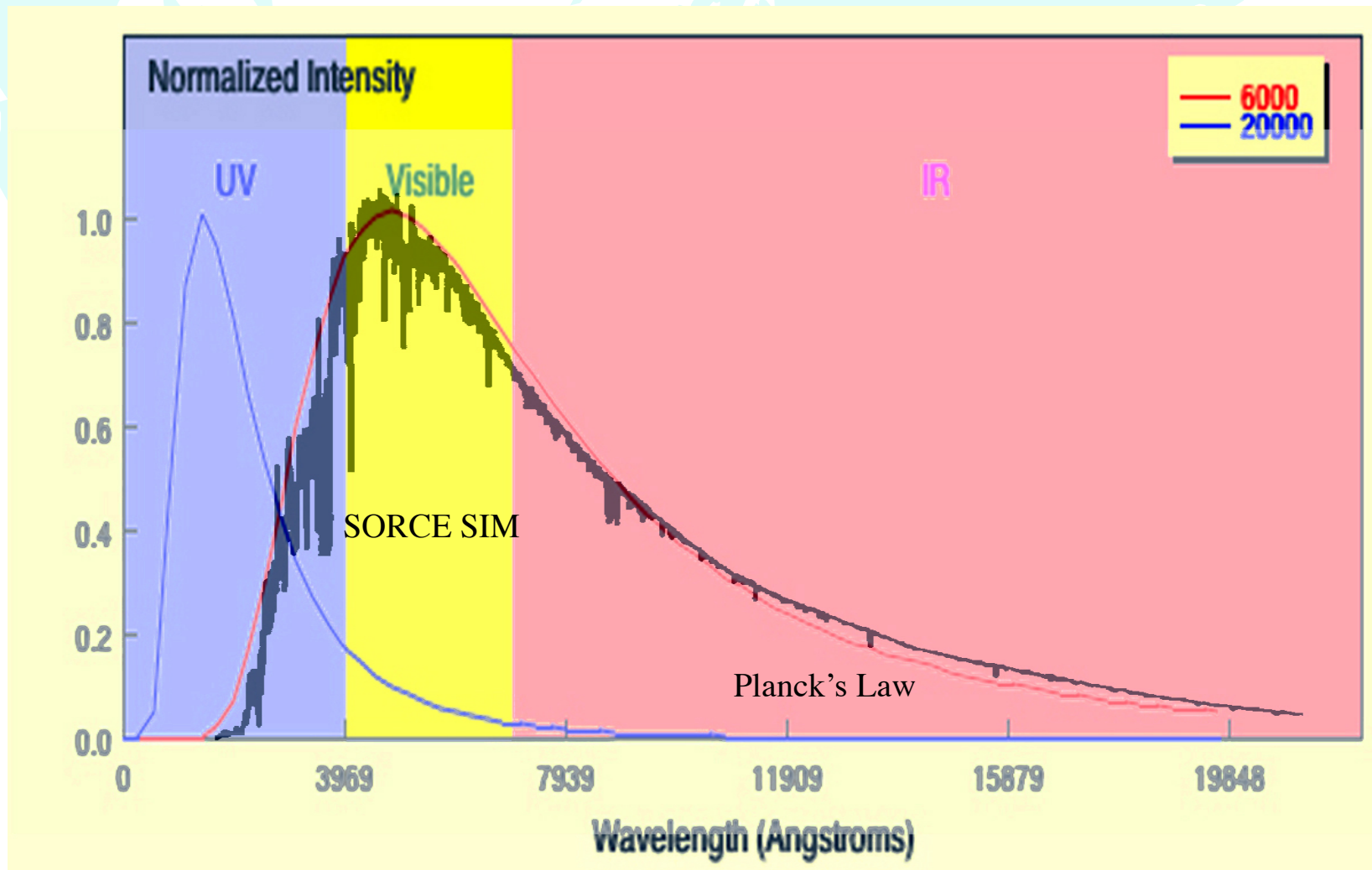
Applications

- Equation (2-14) can be used in several applications where the blackbody assumption may not be completely valid
- Equations (2-13b) and (2-14) are of particular importance in spacecraft design for the space environment
- It is necessary to evaluate these equations in order to determine the energy balance or heat load to a particular spacecraft surface
- The spacecraft surface absorbs solar energy according to equation (2-13b) per unit area per second, and radiates energy away according to equation (2-14)

Blackbody (Planck) spectrum



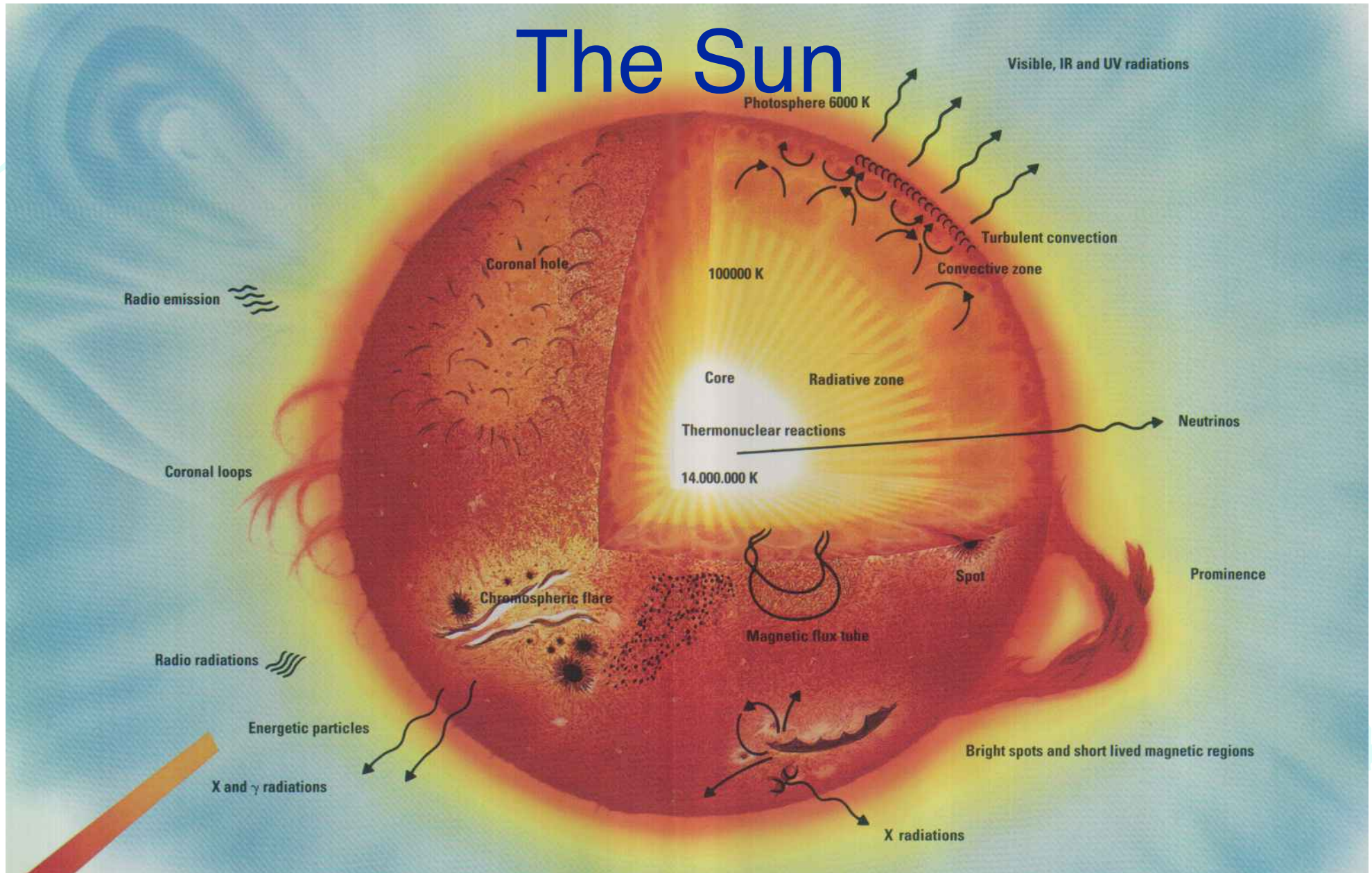
Solar spectrum

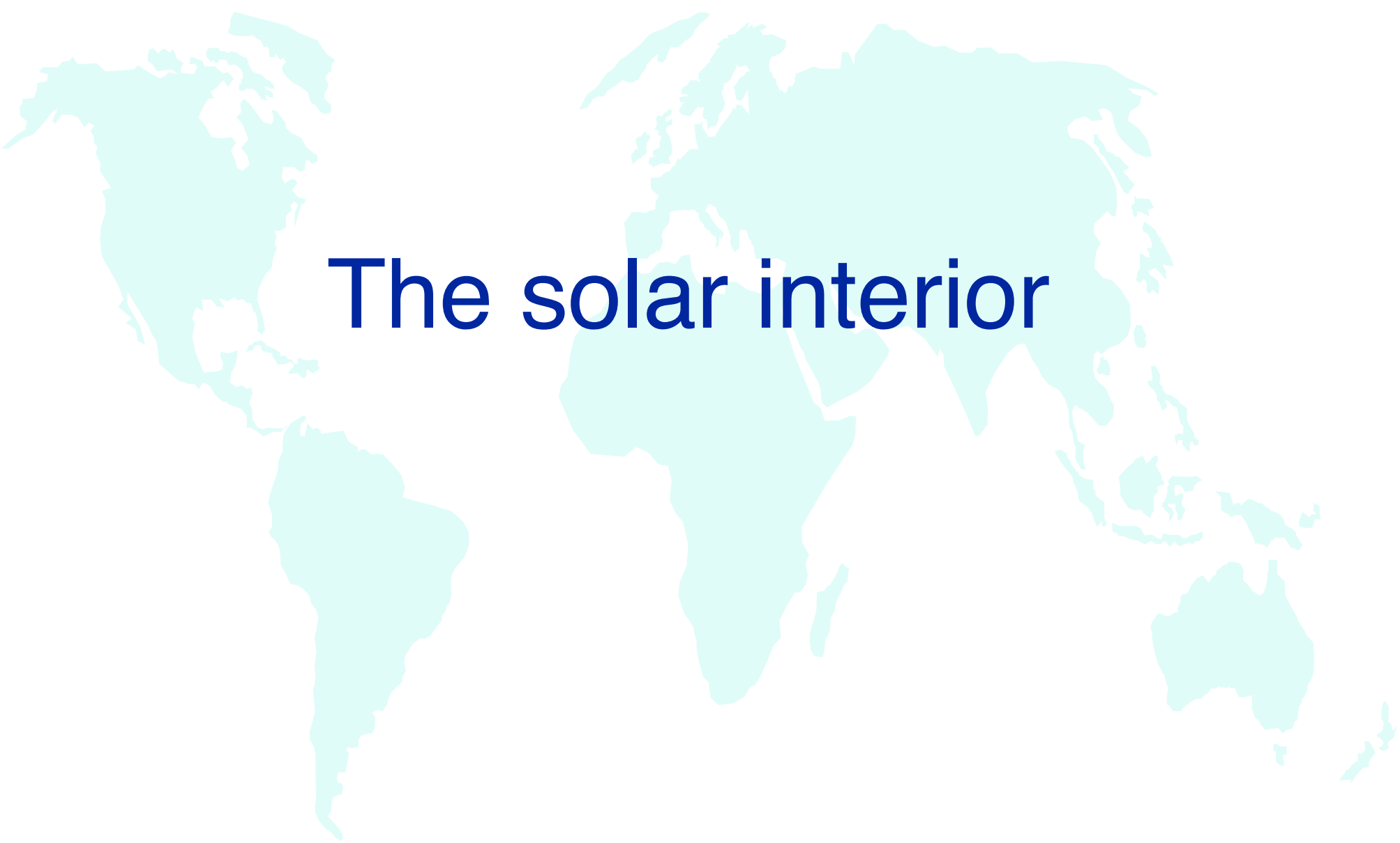


A light blue silhouette of a world map is centered in the background of the slide.

The Sun

The Sun



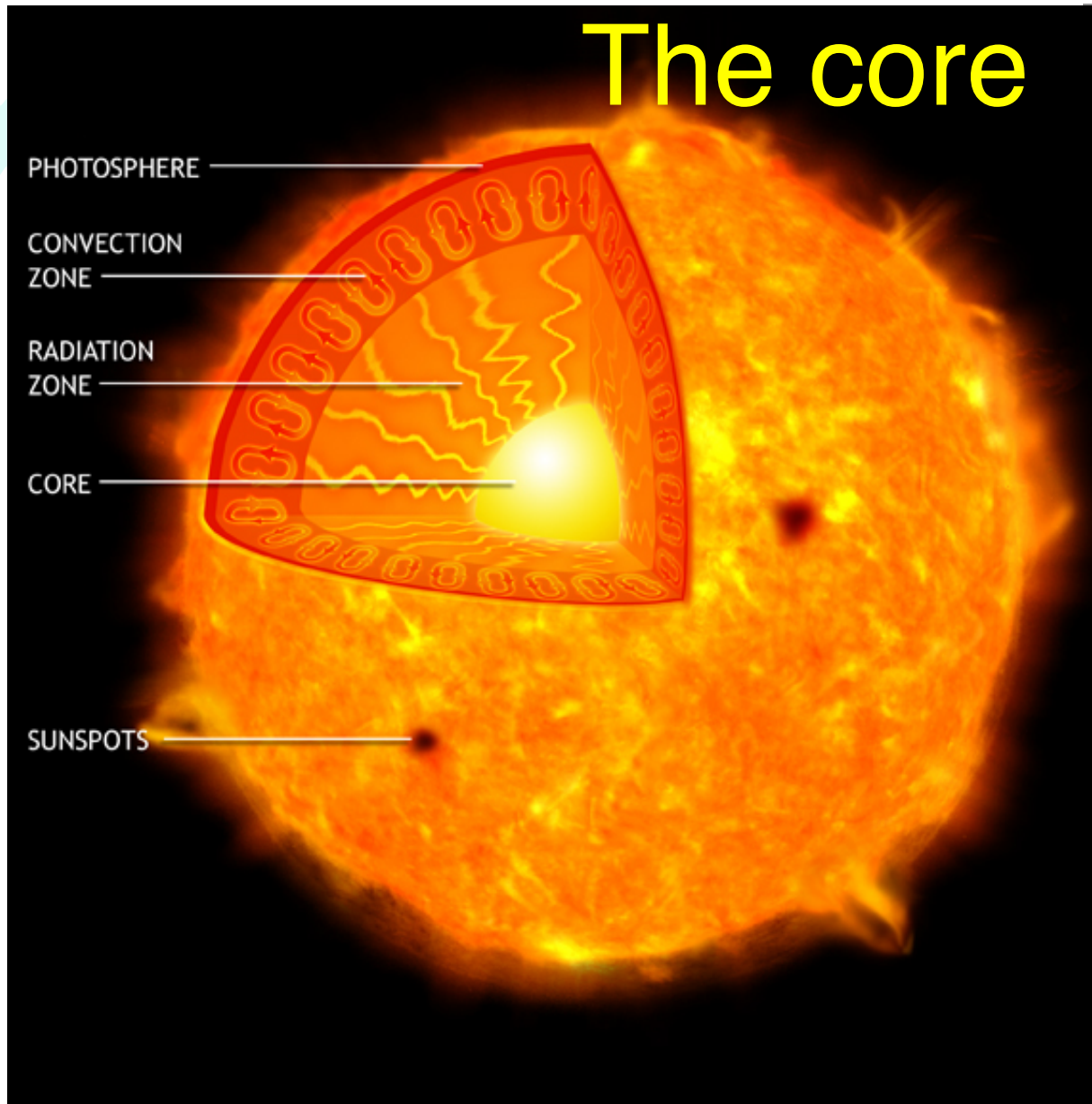
A light blue silhouette of a world map is centered in the background of the slide.

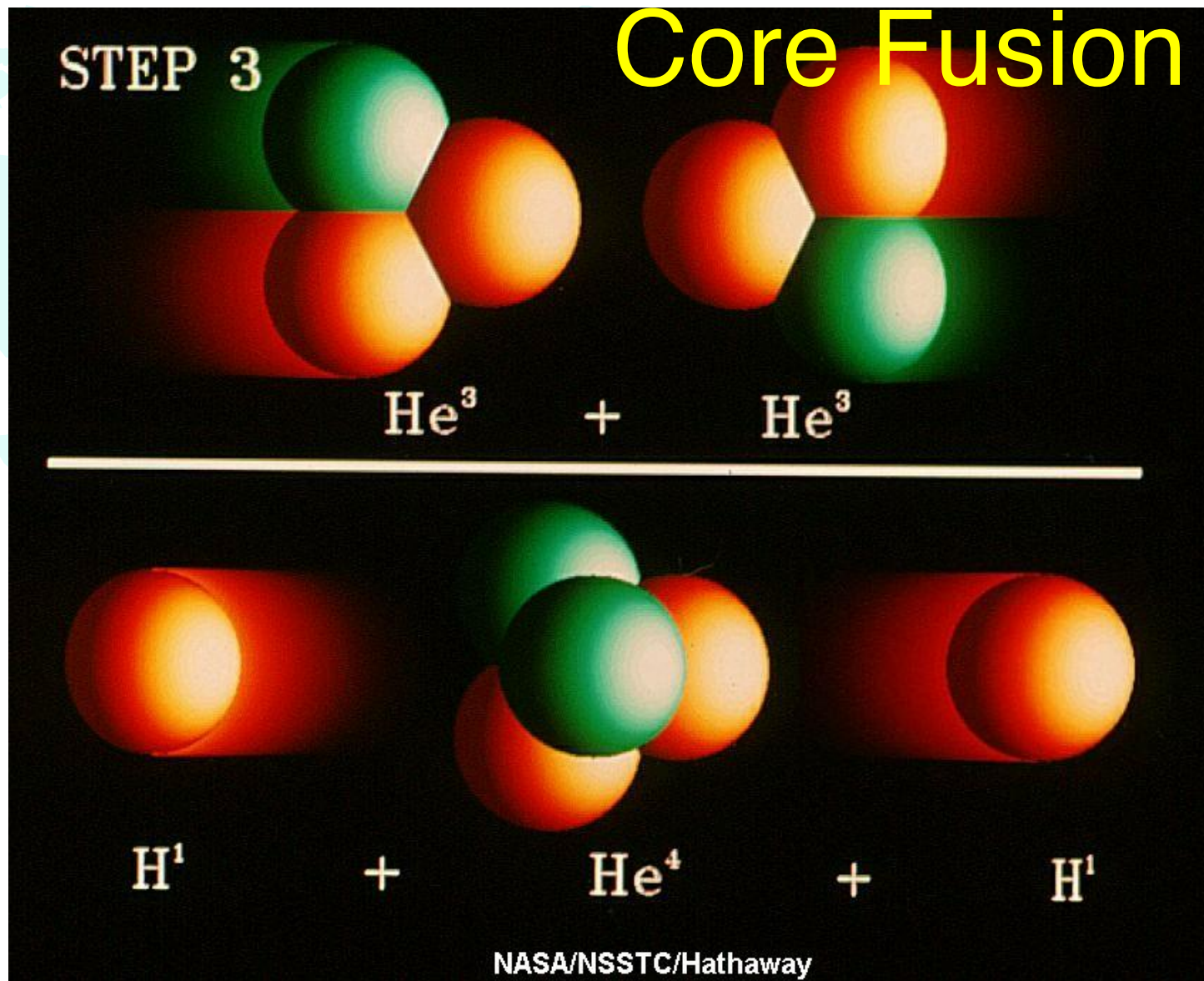
The solar interior

The core

The solar interior has four energy processing regions:

- energy **generated** in the core (~25% $\odot$ radius)
- outward **diffusion** by radiation (mostly gamma-rays and X-rays) through radiative zone (~45%)
- thin **interface** layer (the tachocline) between the radiative zone and the convection zone (where Sun's magnetic field is thought to be generated) (~1%)
- **convection** where magnetized fluid recirculates through convection zone (~30%)





The solar interior - 2

The Radiative Zone (25-70% distance)

- from outer edge of the core (150 g cm^{-3}) radiation is the method of energy transport
- core energy is carried by photons
 - bounce from particle to particle through the radiative zone
 - individual photon takes $\sim 1\text{My}$ to reach interface layer
- density drops from 20 g cm^{-3} (Au) down to only 0.2 g cm^{-3} ($< \text{H}_2\text{O}$)
- temperature falls from $7,000,000 \text{ K}$ (7MK) to $2,000,000 \text{ K}$ (2MK)

The solar interior - 3

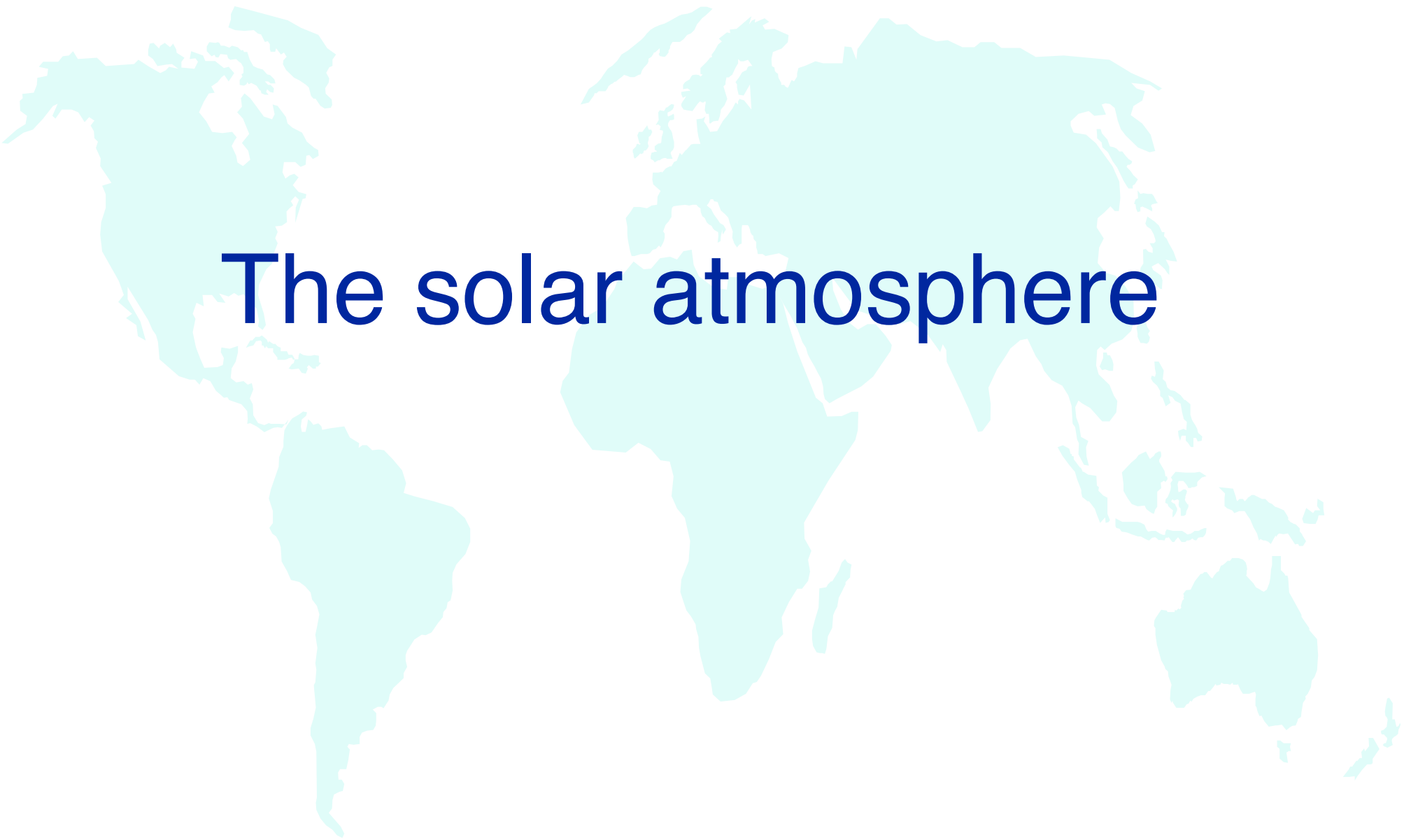
The Interface Layer (tachocline)

- lies between radiative and convective zones with sudden chemical composition changes (ions)
- convection zone fluid motions slowly disappear from the layer top to bottom where the conditions match those of calmer radiative zone
- Sun's magnetic field is likely generated by a magnetic dynamo in the tachocline
- changes in fluid flow velocities (shear flows) across the layer can stretch magnetic field lines and make them stronger

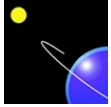
The solar interior - 4

The Convection Zone

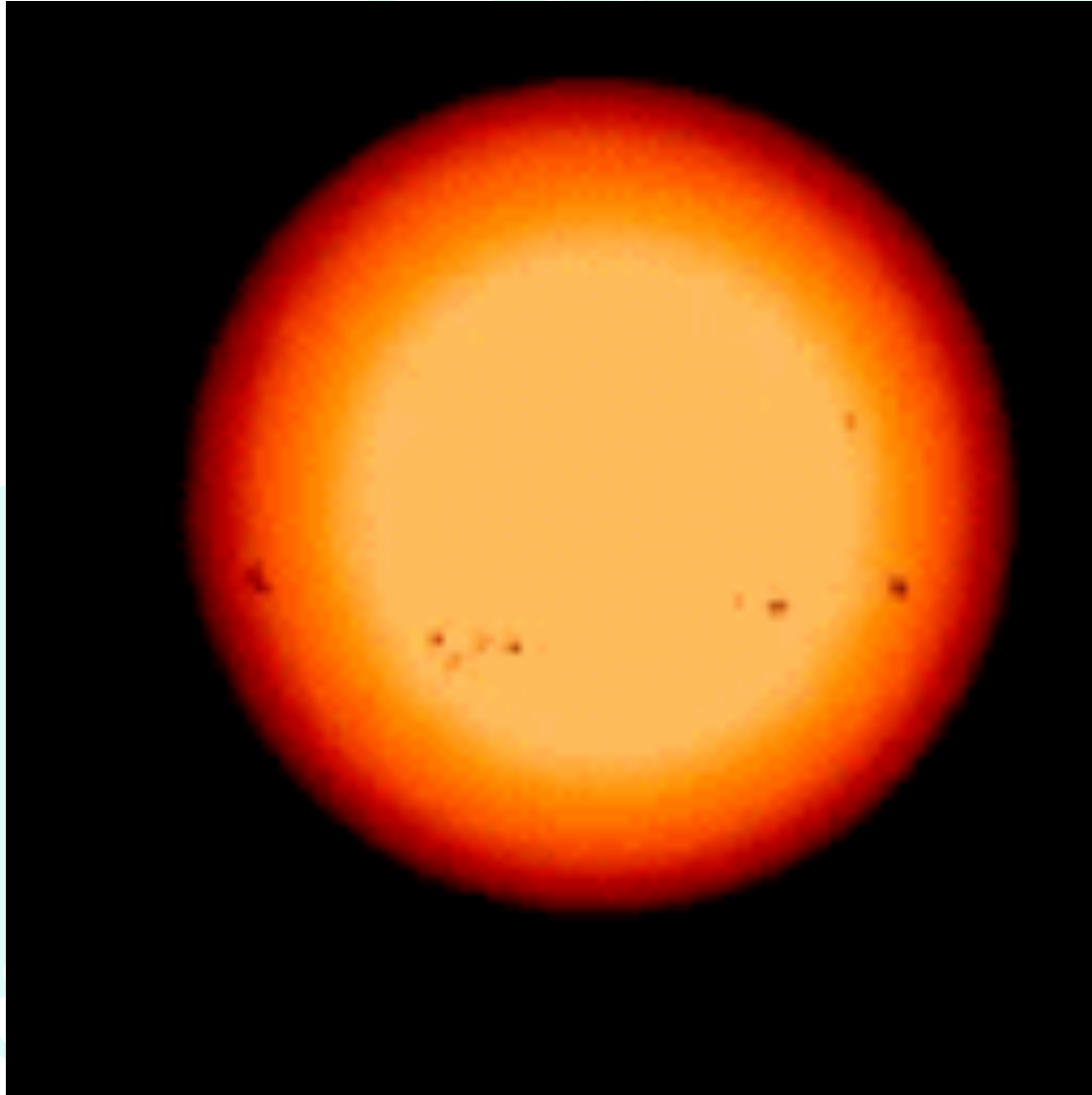
- outer-most layer of the solar interior
- extends from a 200,000 km up to the visible surface
- base zone temperature is 2,000,000 K
 - "cool" enough for the heavier ions (such as carbon, nitrogen, oxygen, calcium, and iron) to hold onto some of their electrons
 - makes the material more opaque (harder for radiation to get through) and traps heat
 - ultimately makes fluid unstable and it recirculates, "boils" or convects

A light blue silhouette of a world map is centered in the background of the slide.

The solar atmosphere



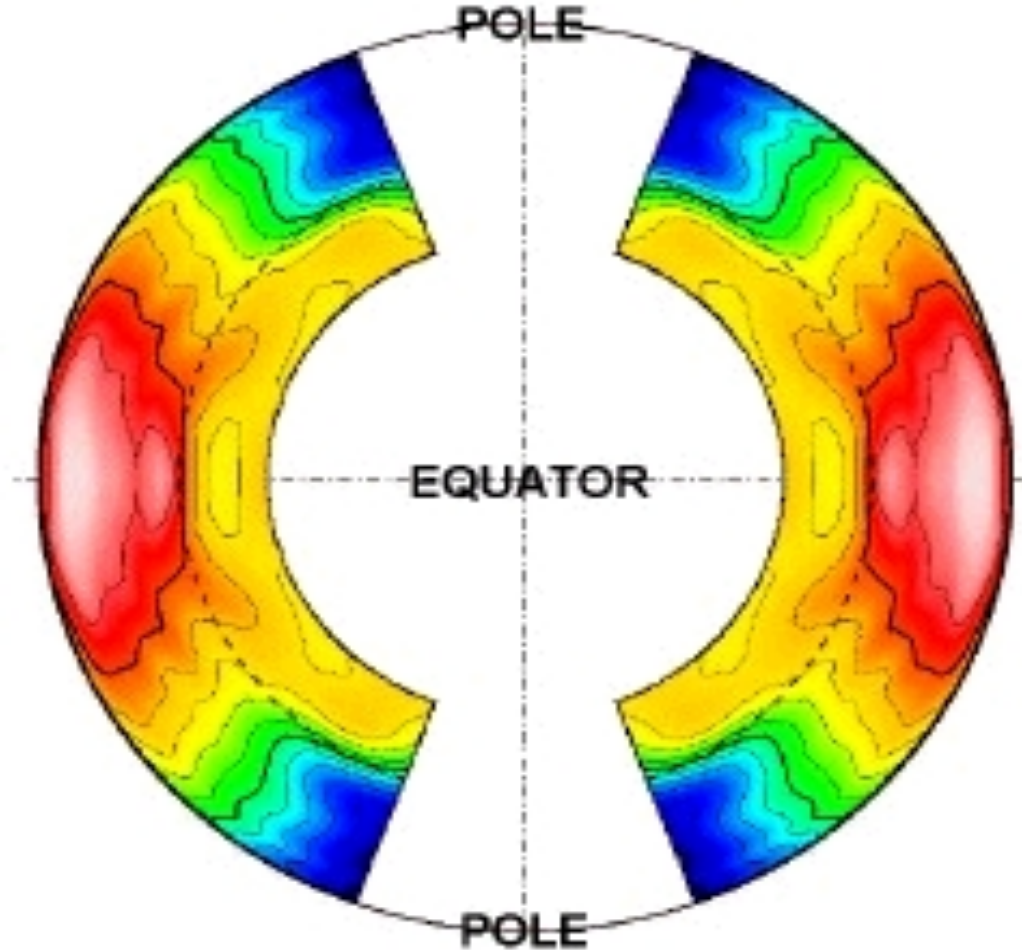
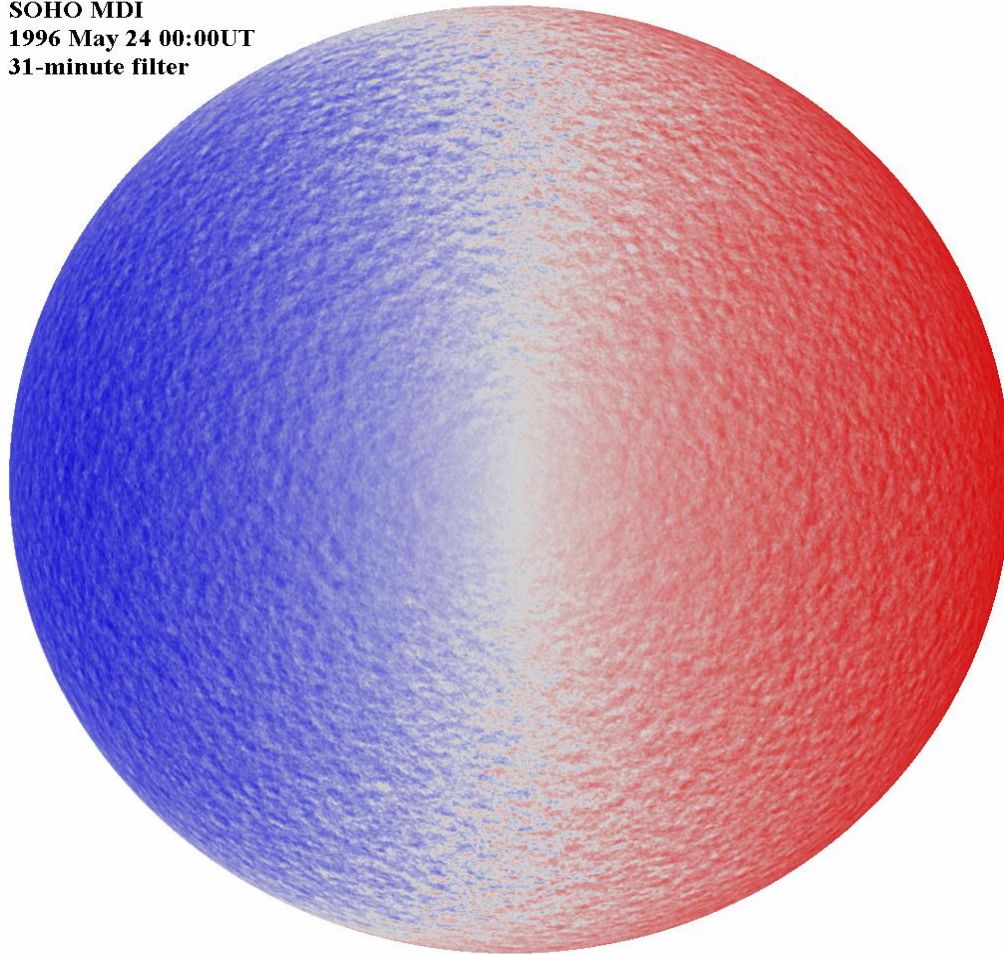
Solar atmosphere



The solar atmosphere - 1a

Surface and internal rotation

SOHO MDI
1996 May 24 00:00UT
31-minute filter



The solar atmosphere - 1b

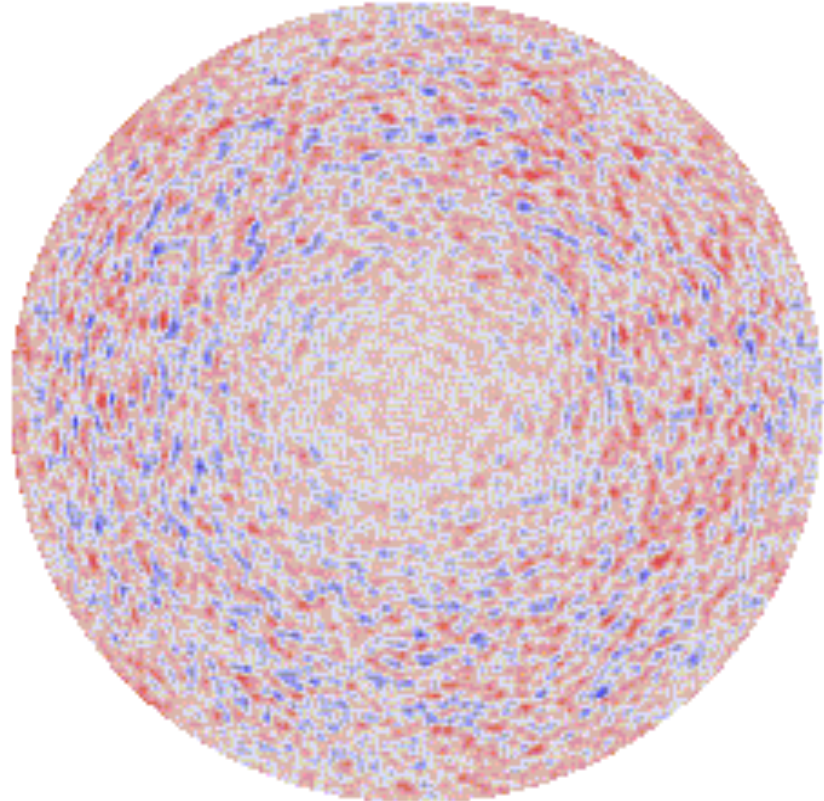
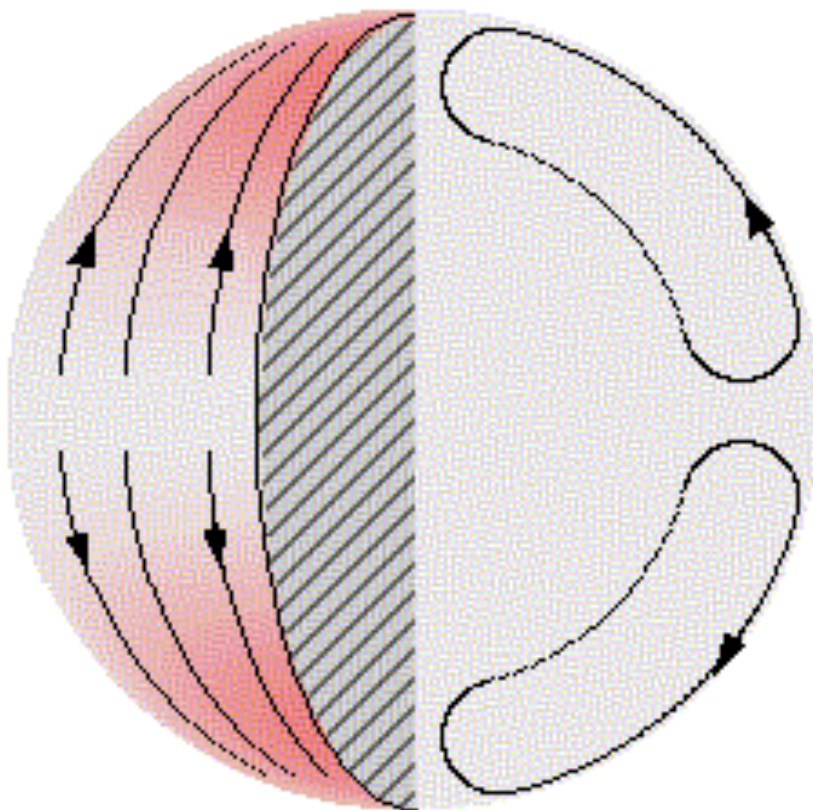
Sidereal differential rotation (deg/day)

Tracers	A	B	C
Individual sunspots	14.522	-2.84	
 Sunspot groups	14.39	-2.95	
plages	14.06	-1.83	
Magnetic field pattern	14.37	-2.30	-1.62
Supergranular pattern	14.71	-2.39	-1.78
Filaments and prominences	14.48	-2.16	
Coronal features	13.46	-2.99	
Small magnetic features	14.42	-2.00	-2.09

$$w = A + B \sin^2 \phi + C \sin^4 \phi \quad (2-15)$$

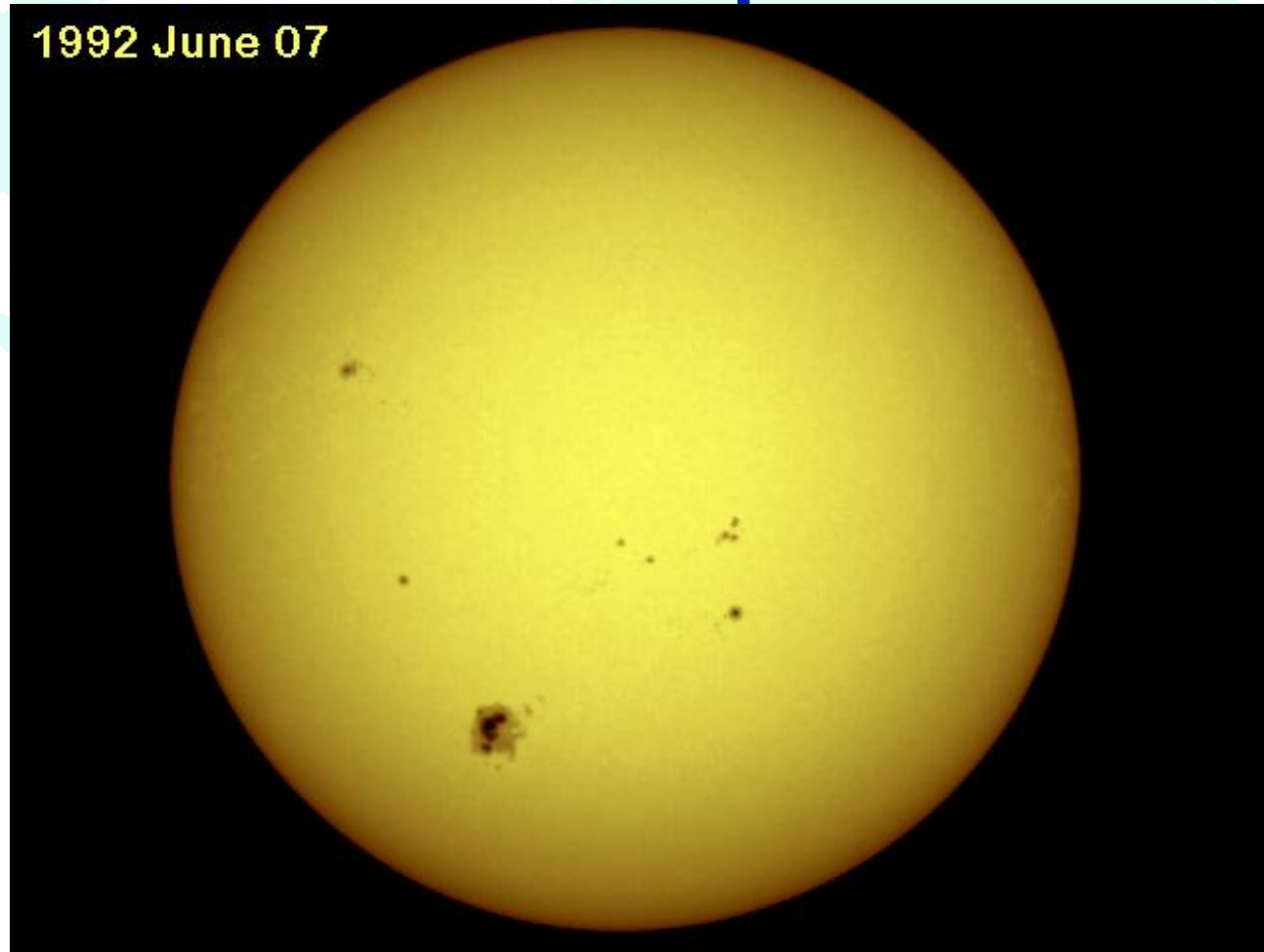
The solar atmosphere - 1c

Meridional flows and granulation



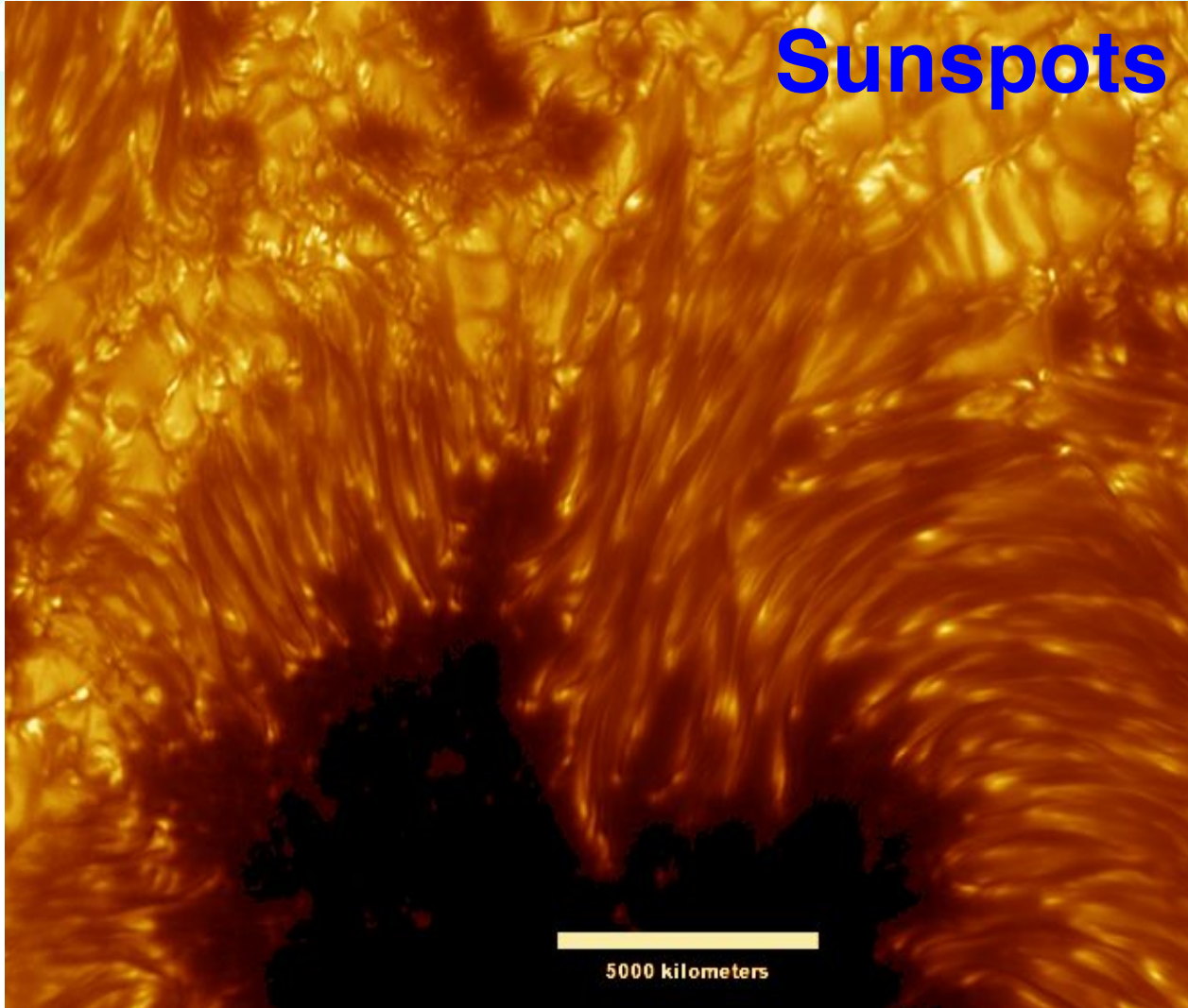
The solar atmosphere - 2

The Photosphere

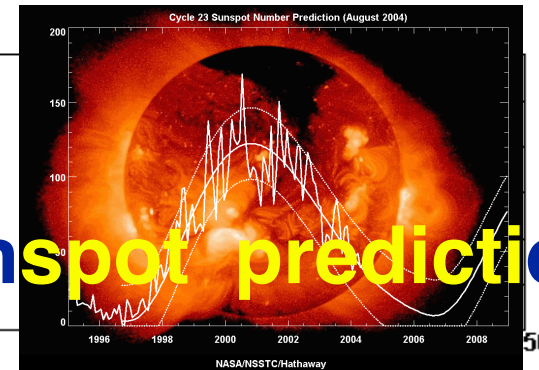
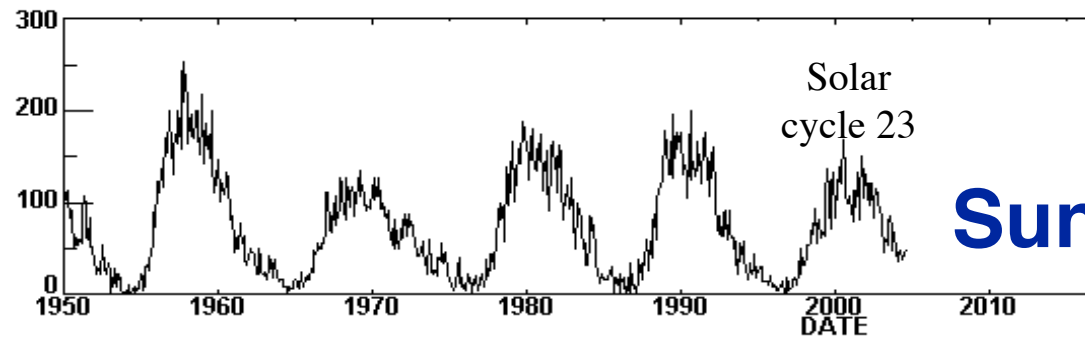
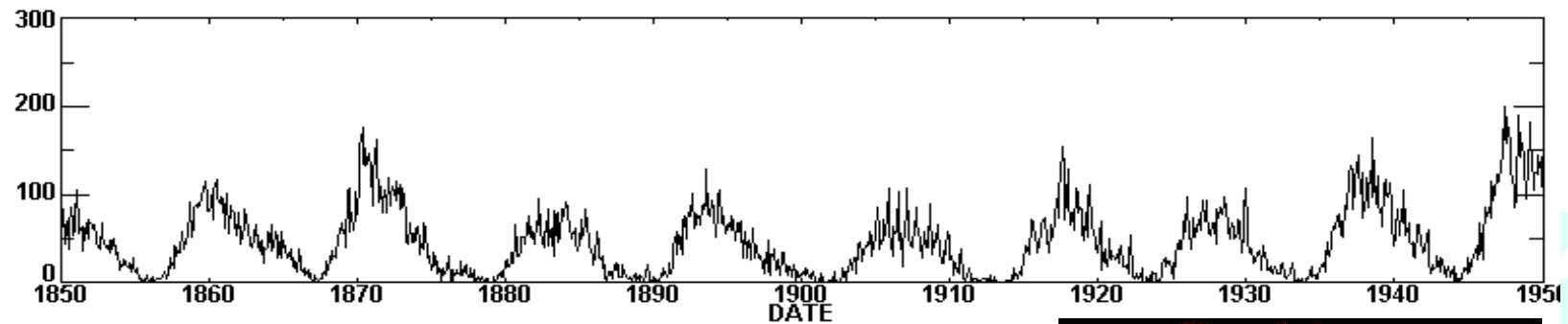
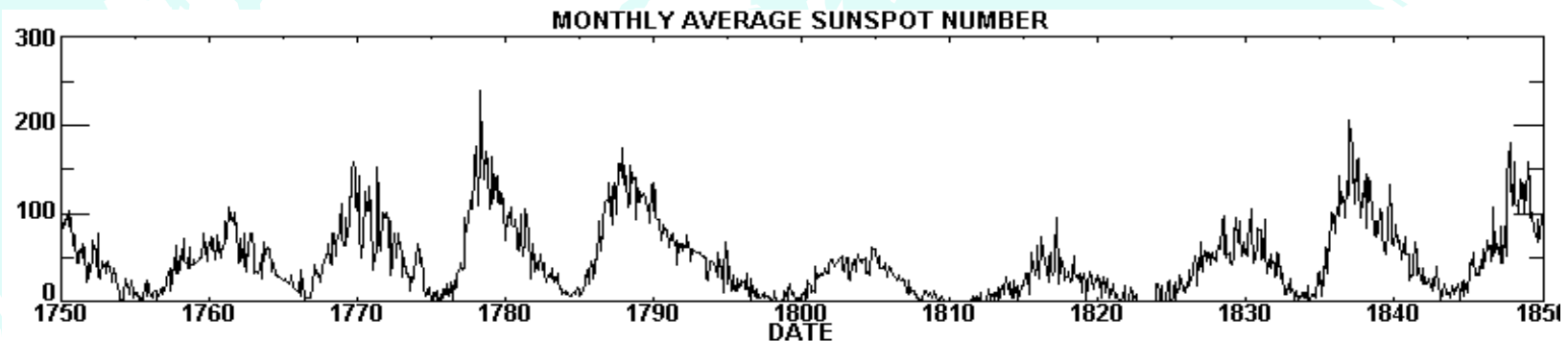


The solar atmosphere - 3

Sunspots



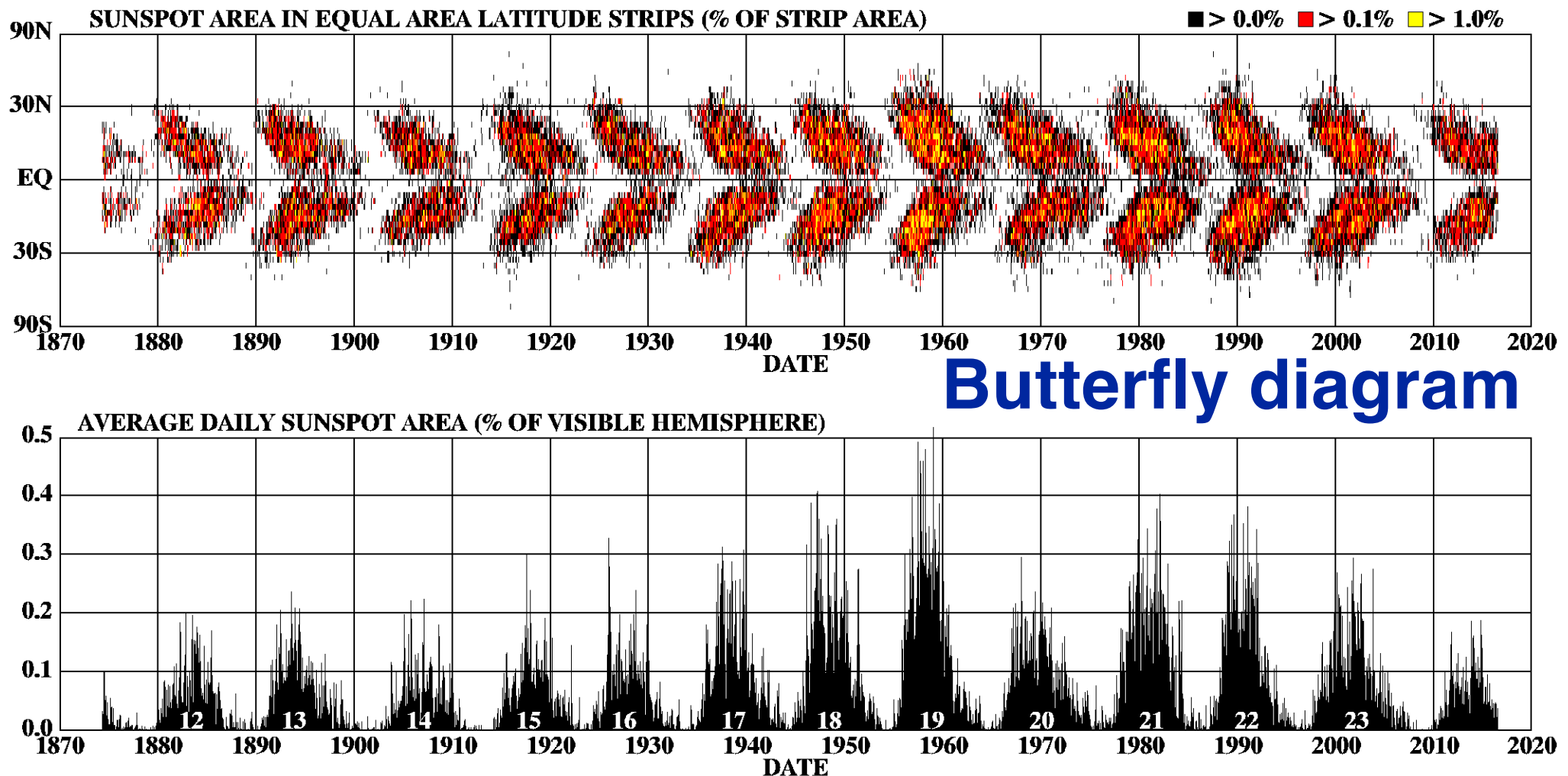
The solar atmosphere - 4



Sunspot predictions

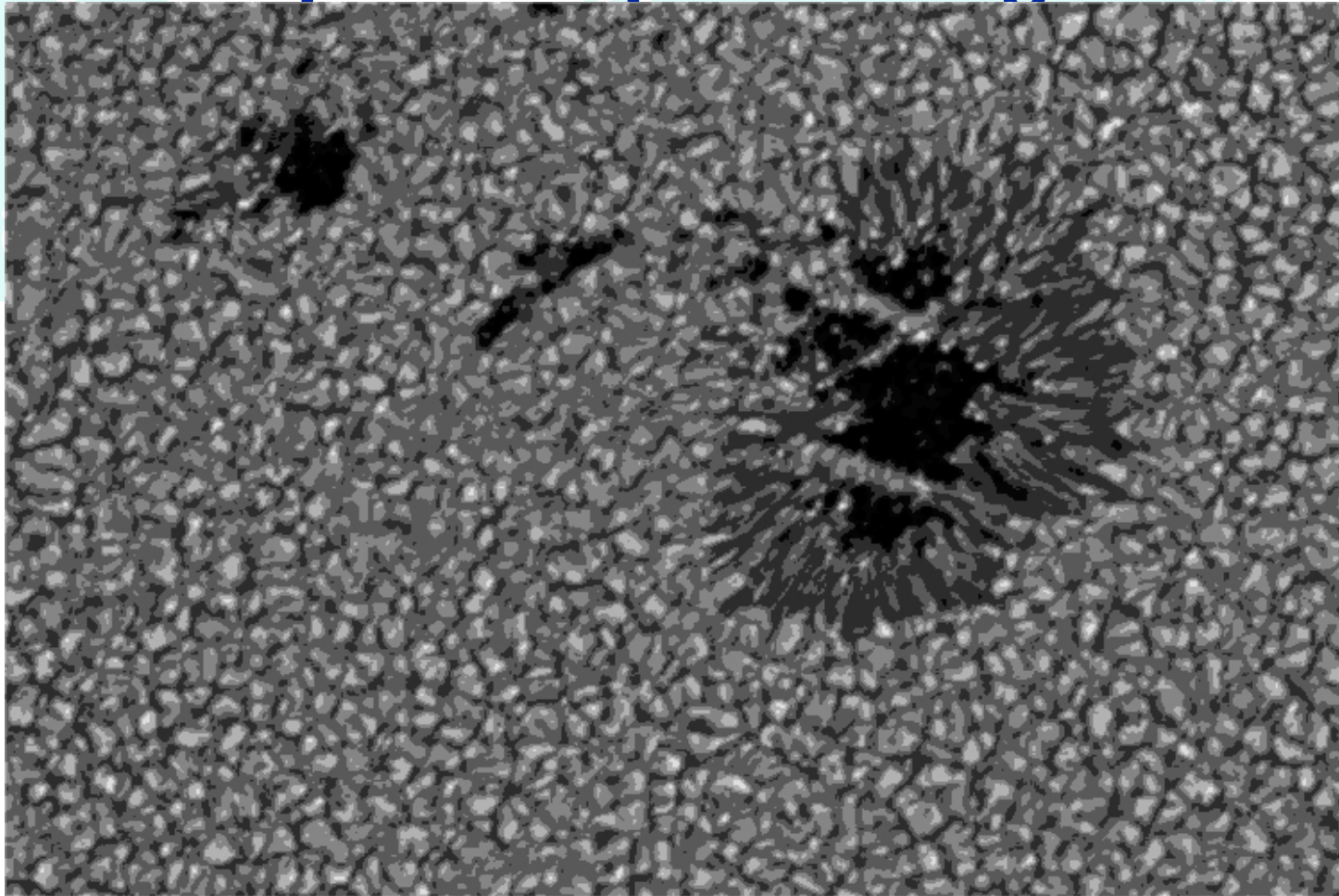
The solar atmosphere - 5

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

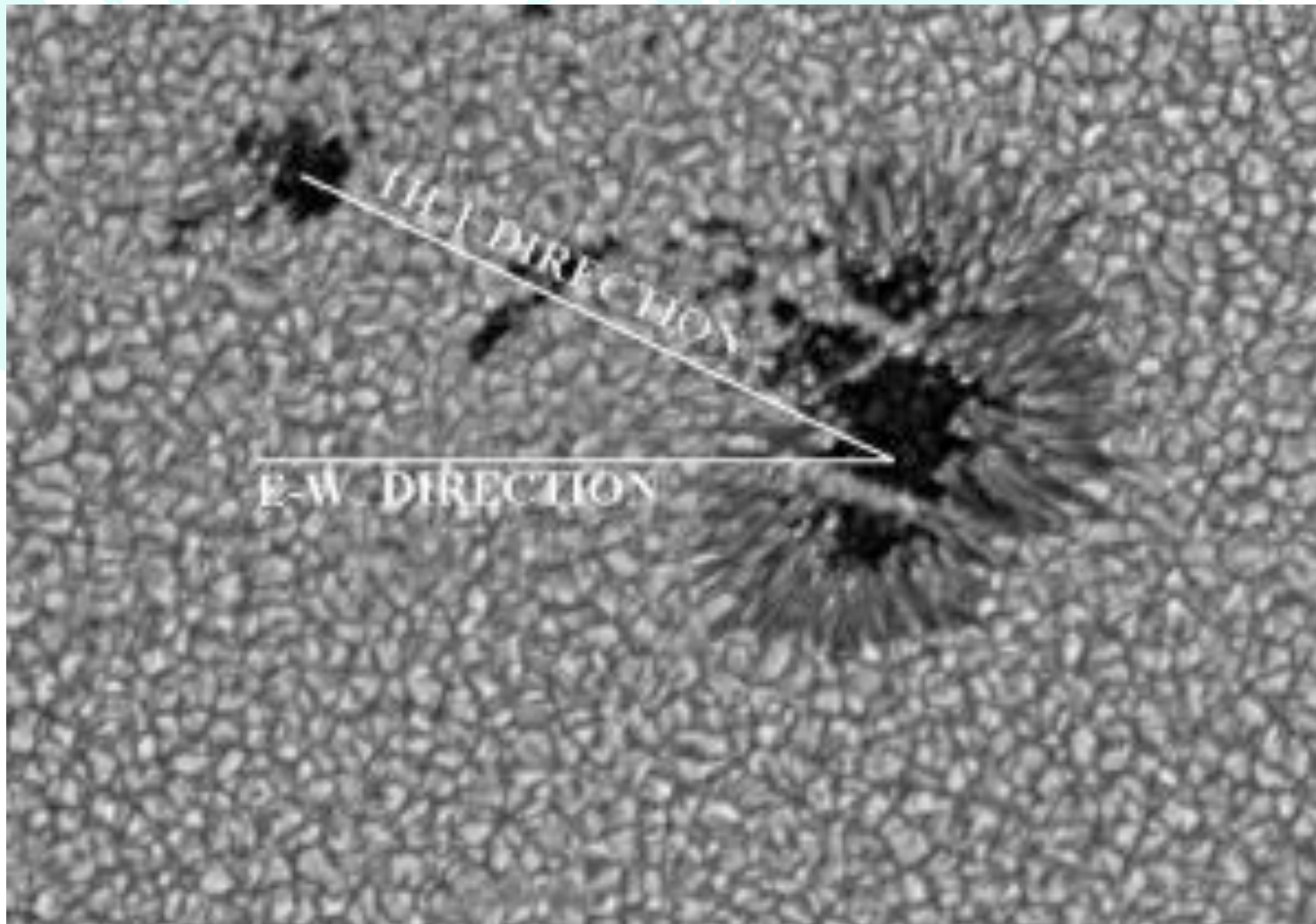


The solar atmosphere - 6

Photospheric spots and granules

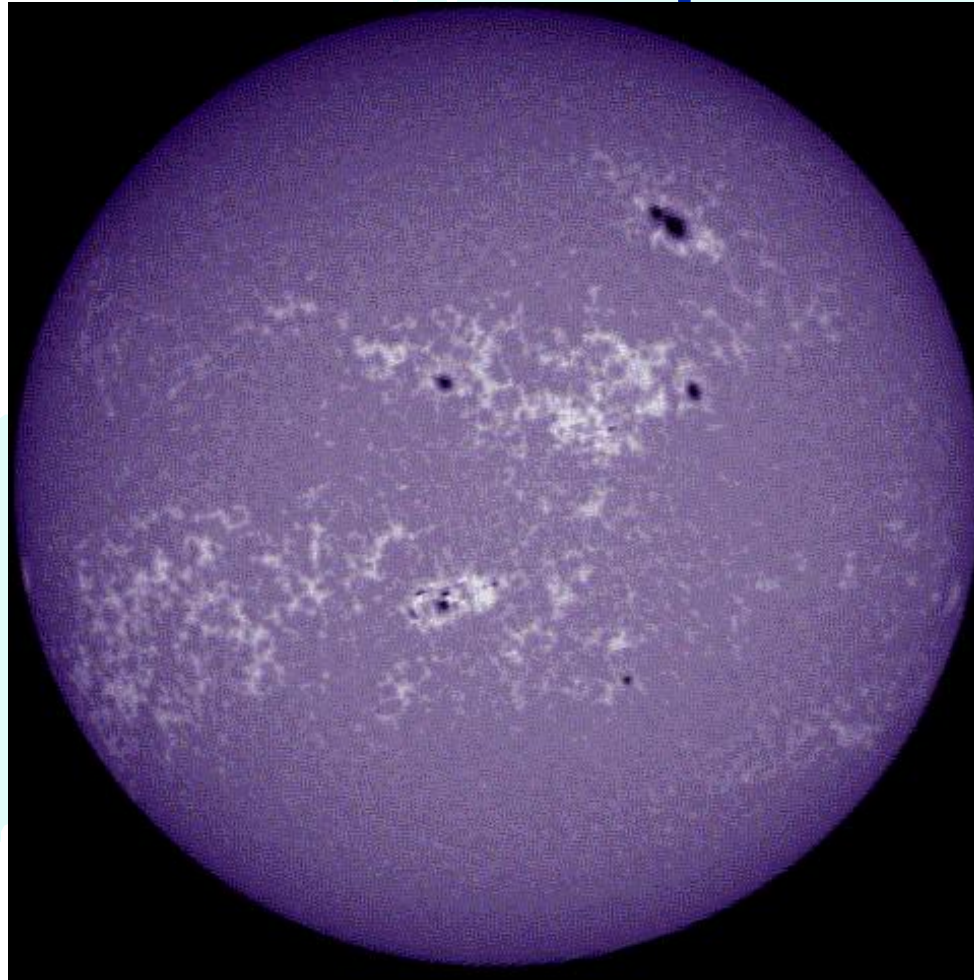


Joy's Law



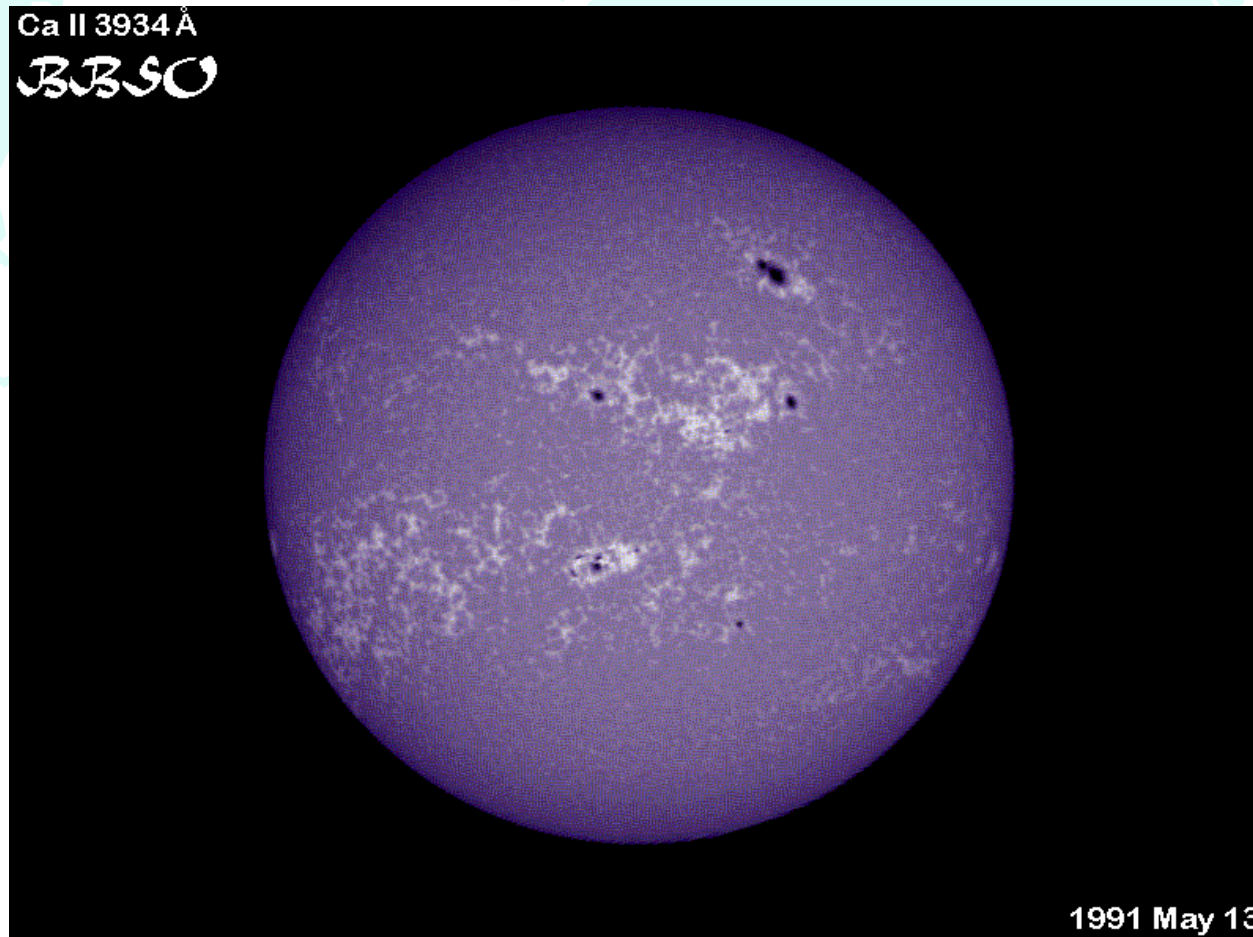
The solar atmosphere - 7

The Chromosphere



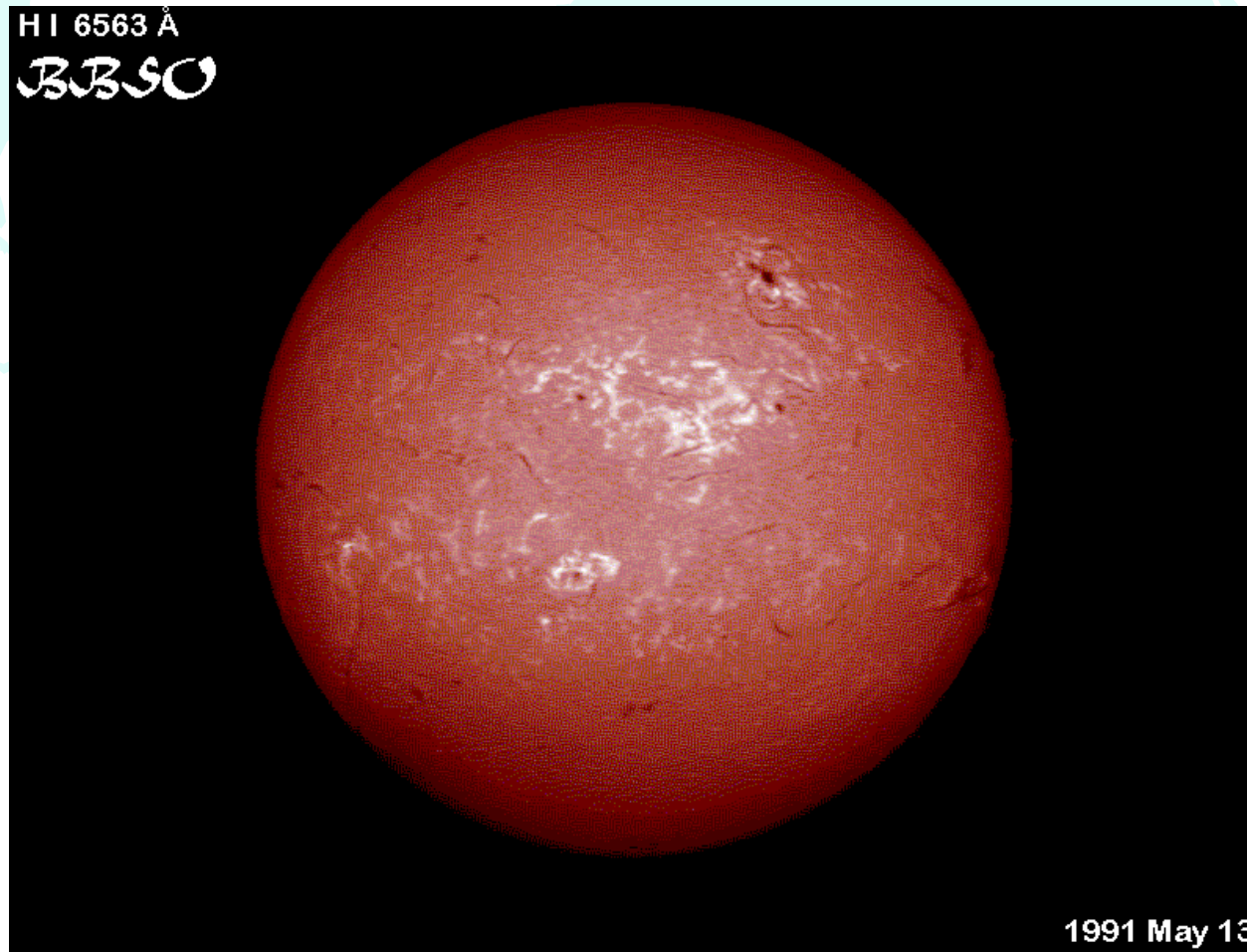
The solar atmosphere - 8

Chromospheric network



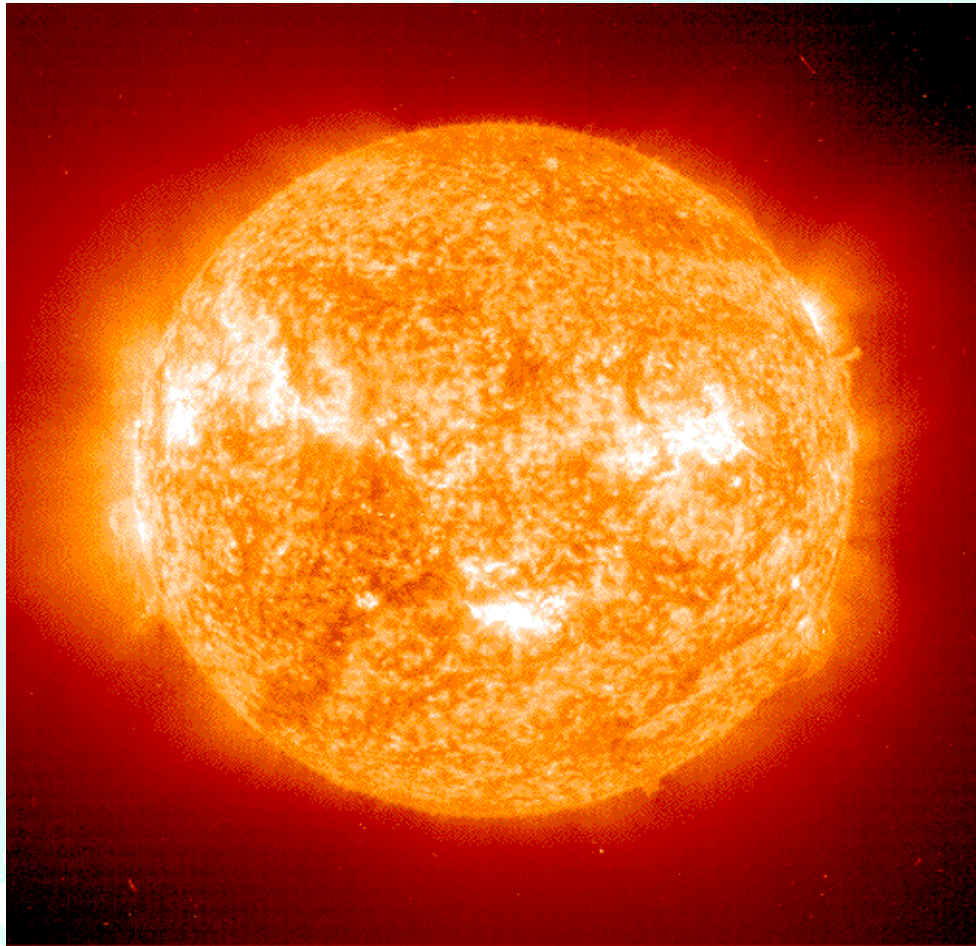
The solar atmosphere - 9

Chromospheric filaments and plage



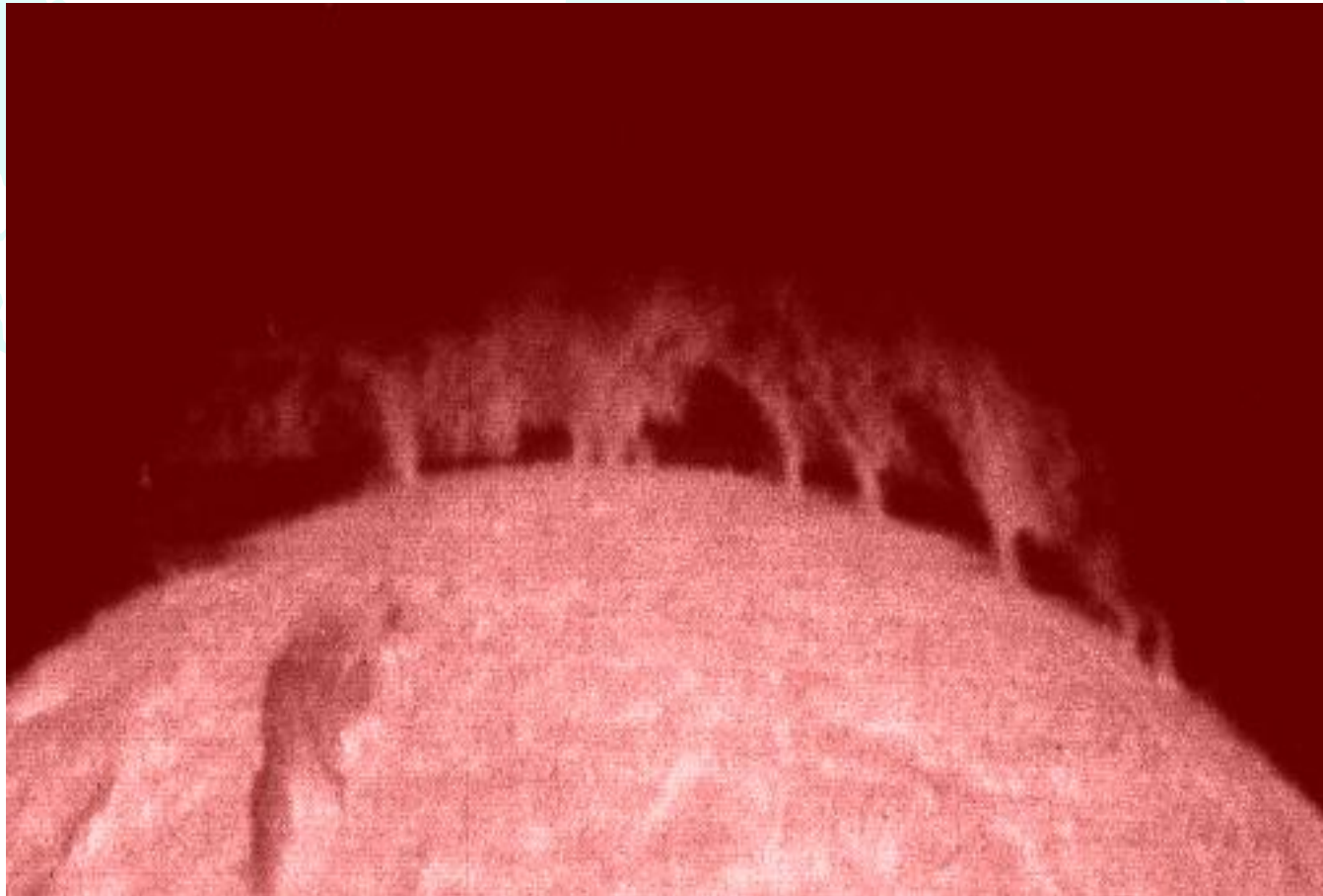
The solar atmosphere - 10

Chromospheric active regions



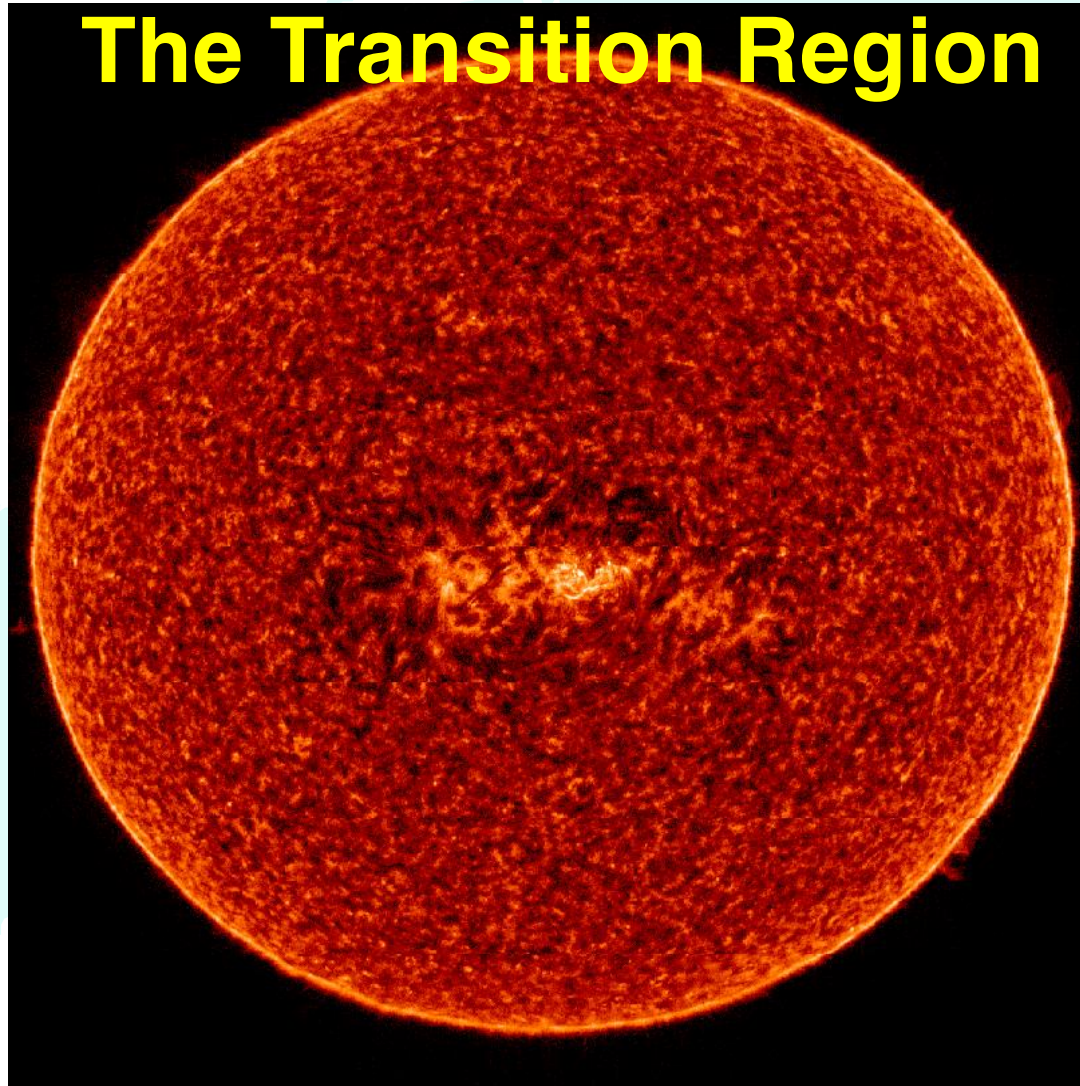
The solar atmosphere - 11

Chromospheric prominences

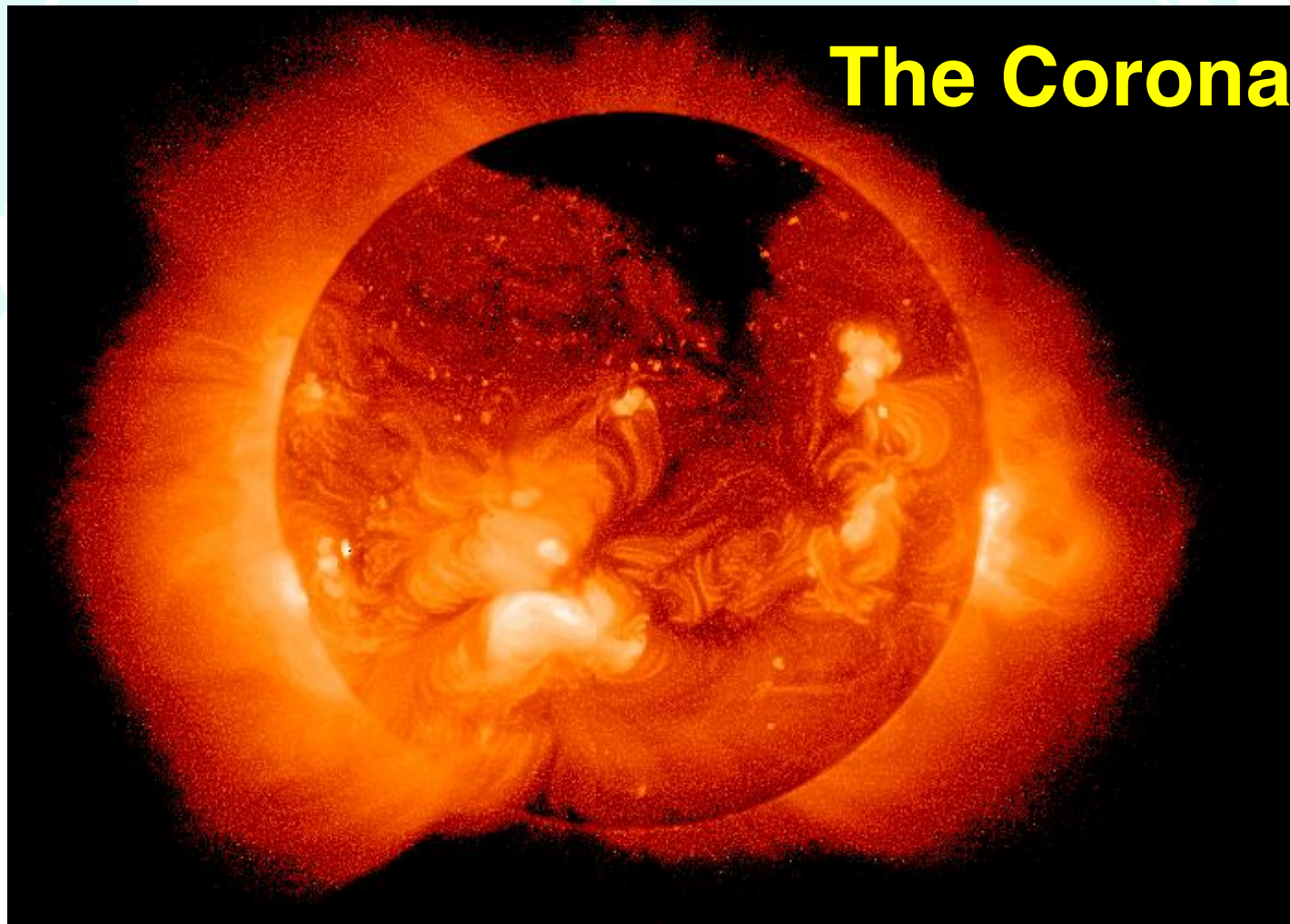


The solar atmosphere - 12

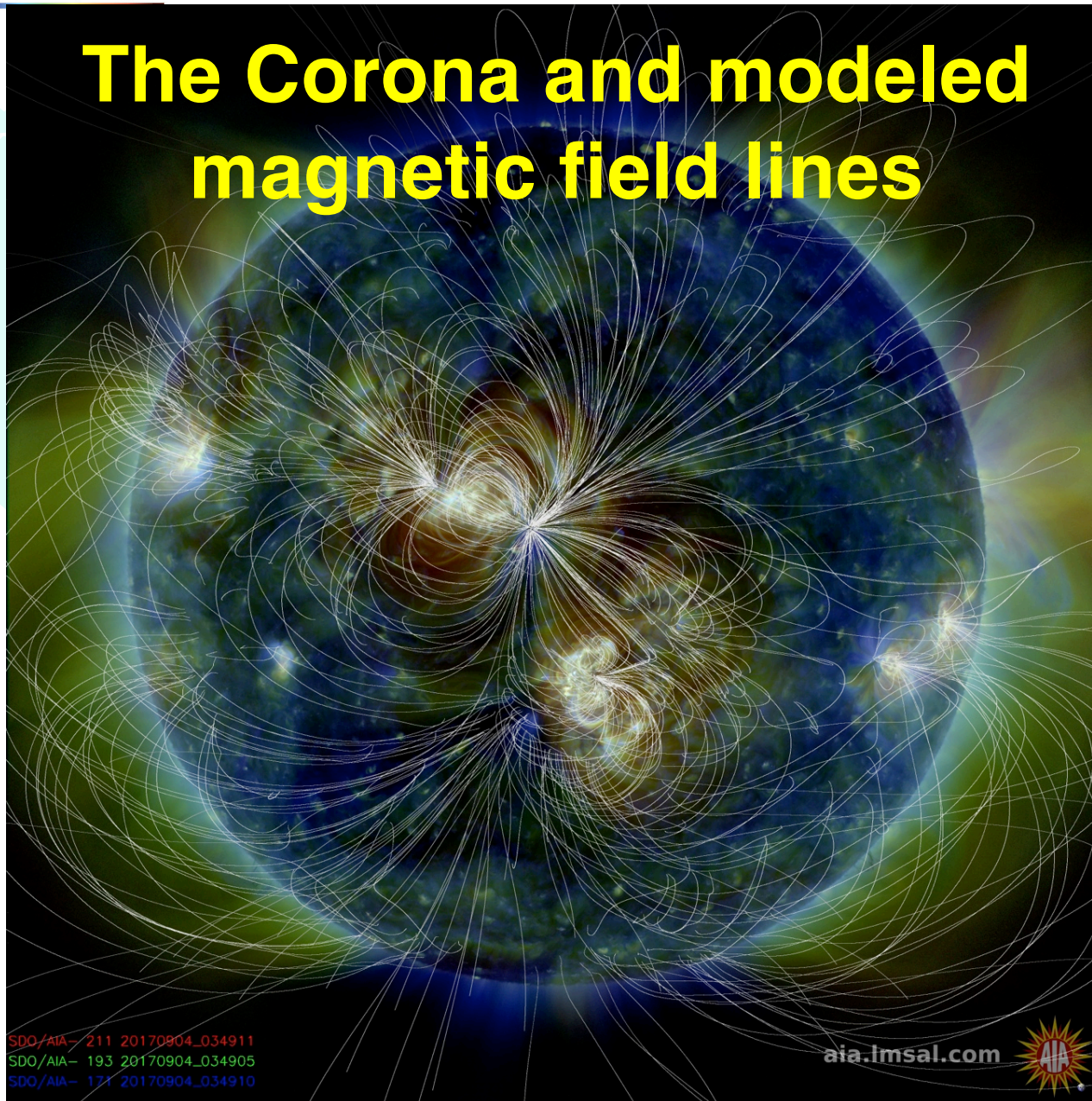
The Transition Region



The solar atmosphere - 13

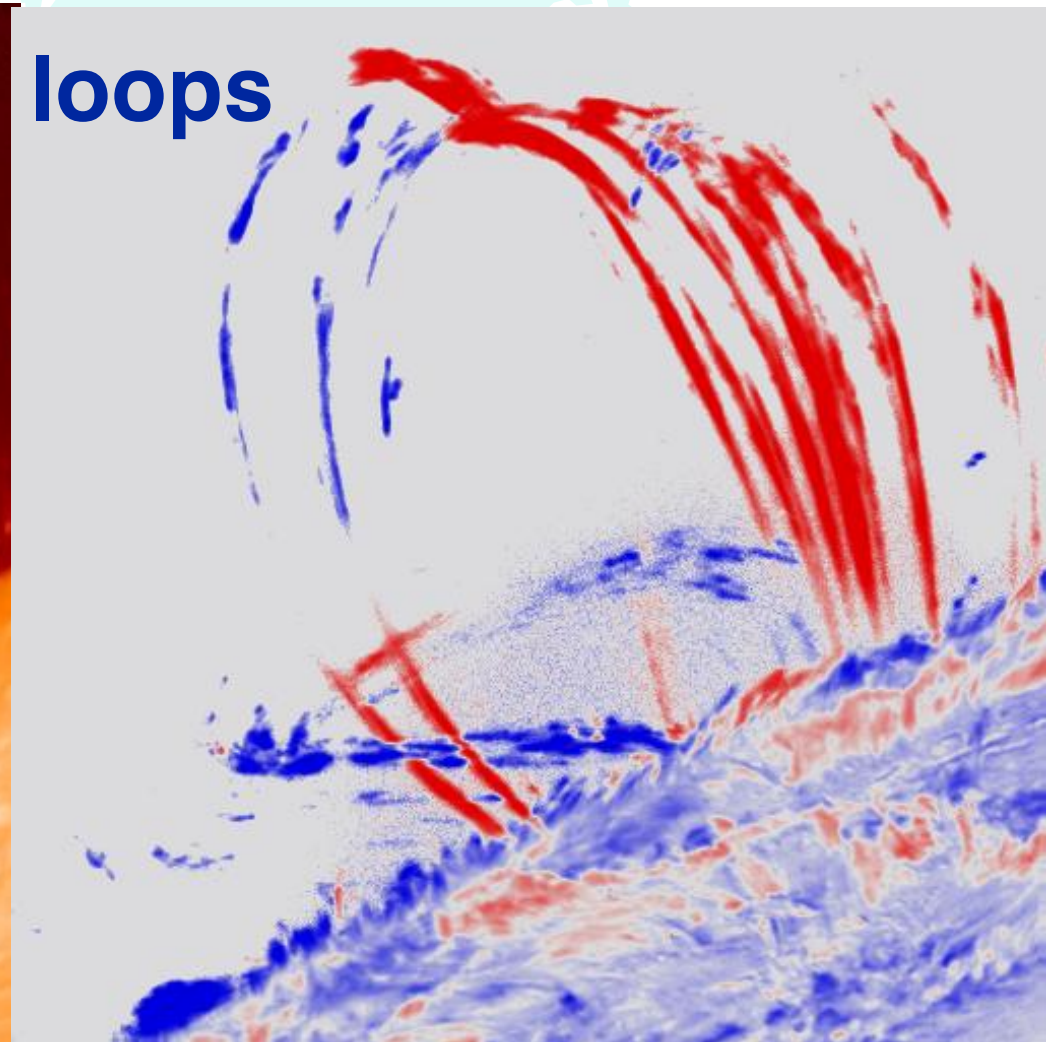
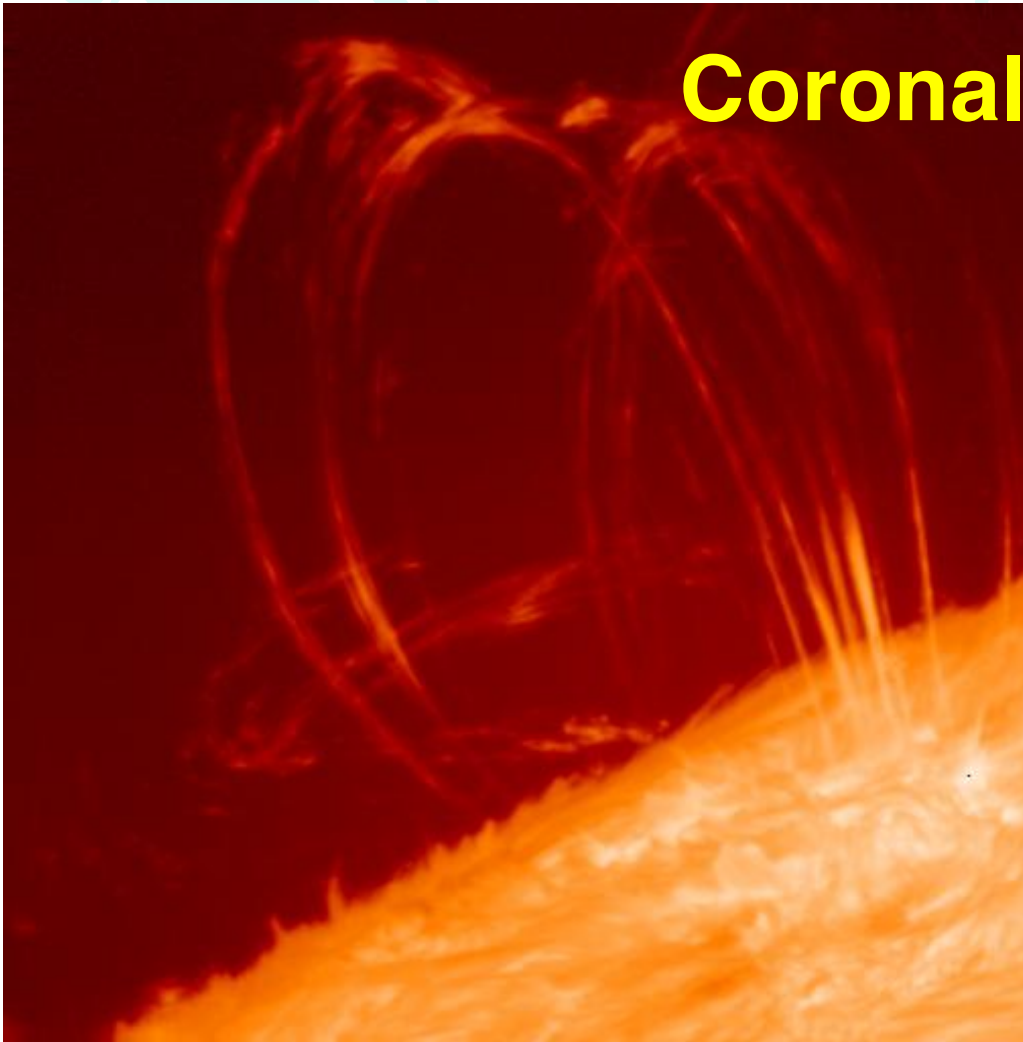


The Corona and modeled magnetic field lines



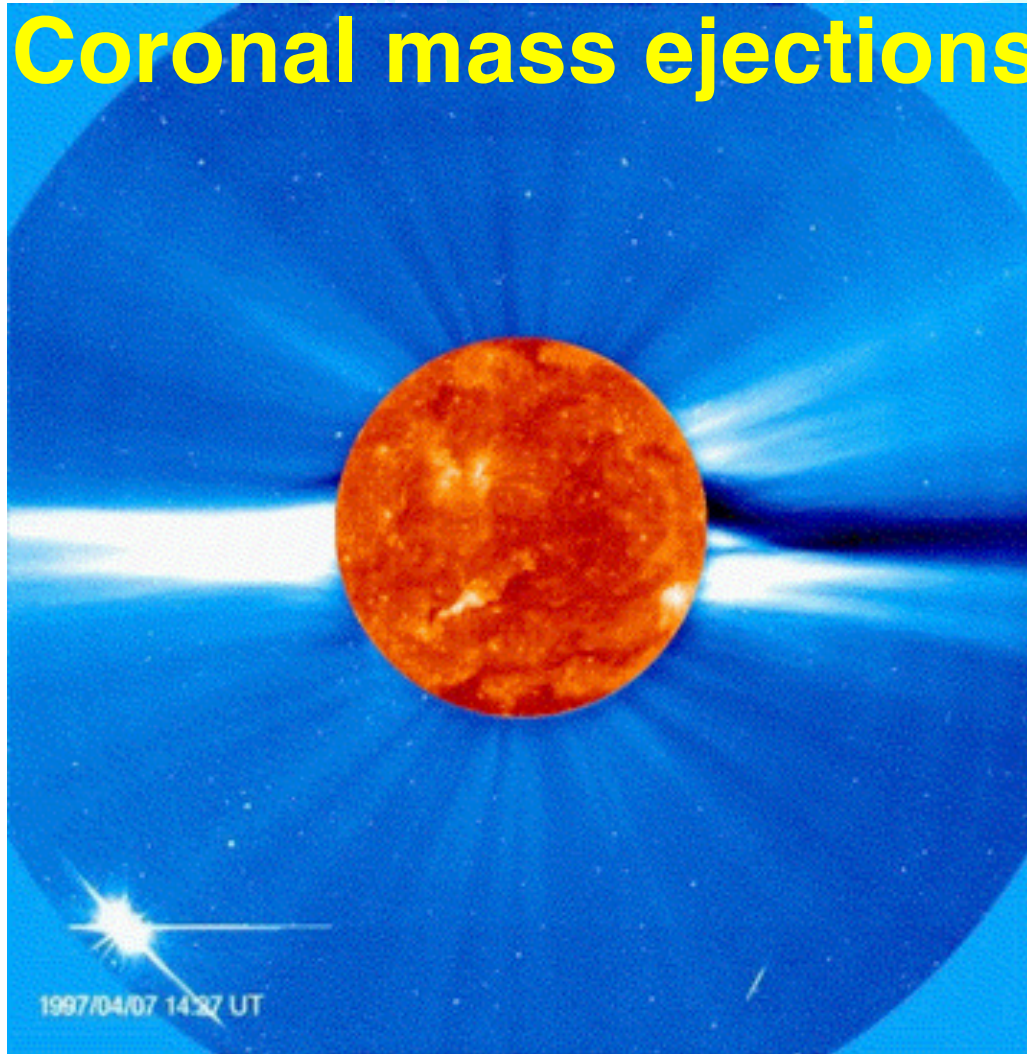
The solar atmosphere - 14

Coronal loops



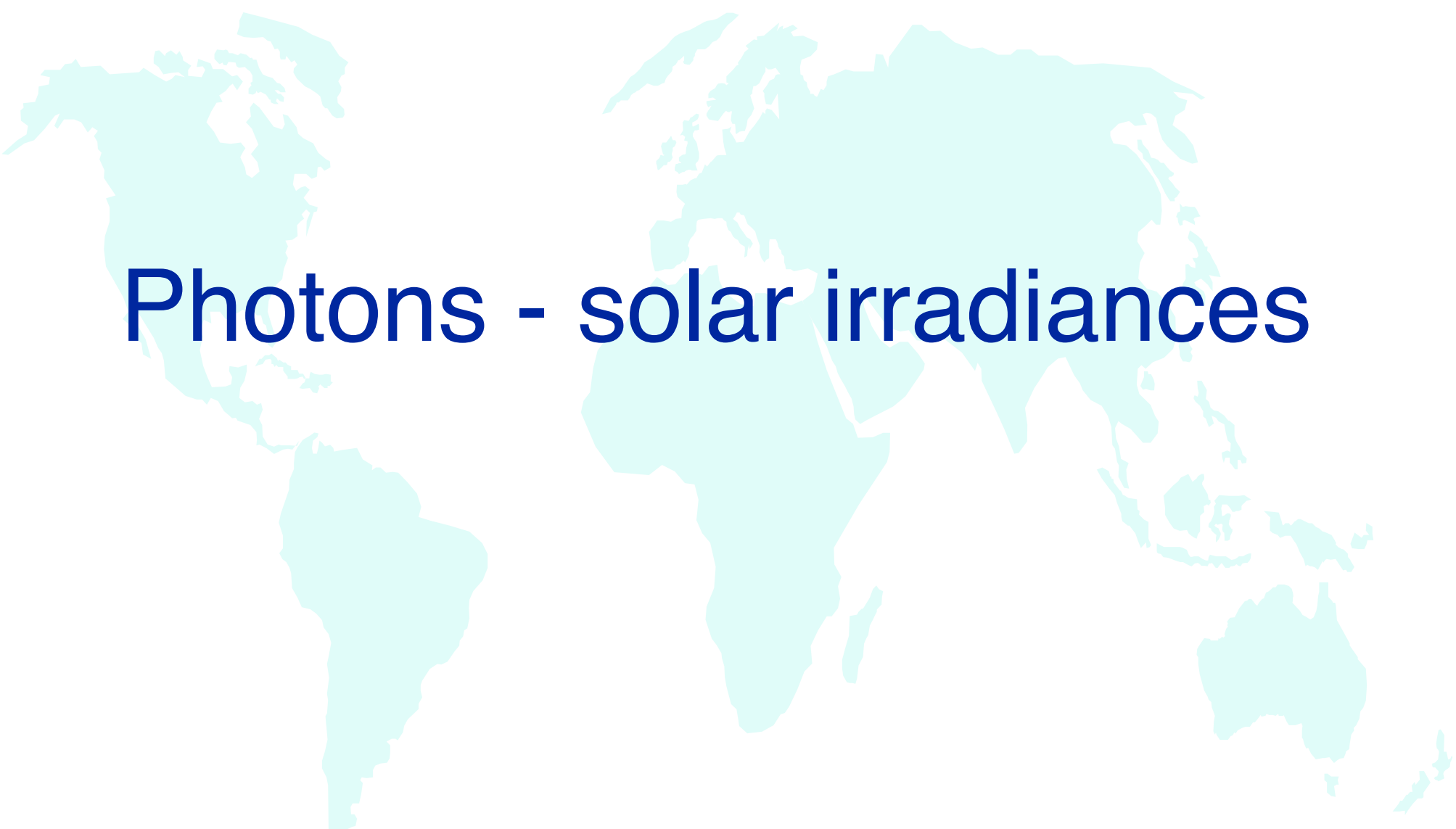
The solar atmosphere - 15

Coronal mass ejections



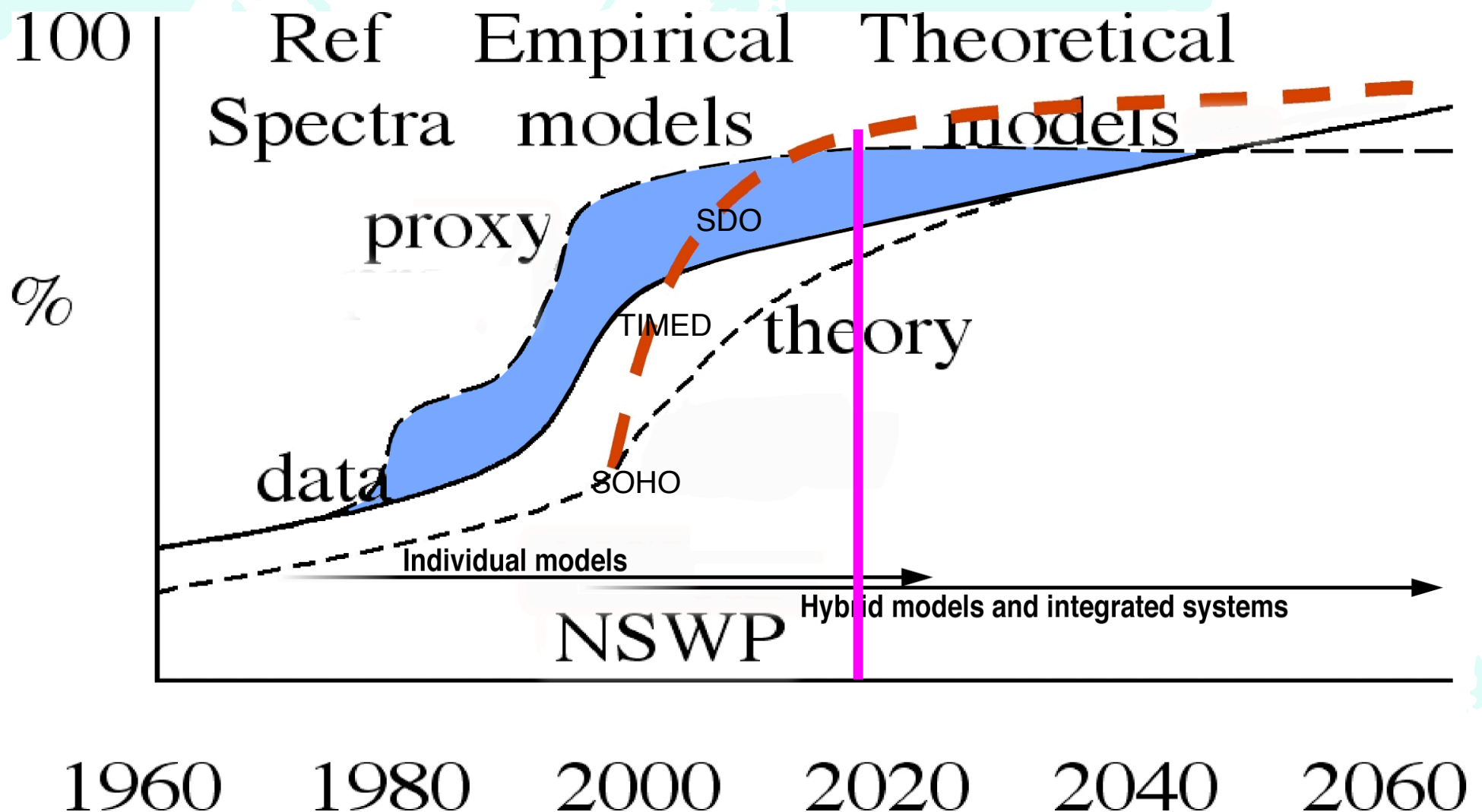
Helmet streamers

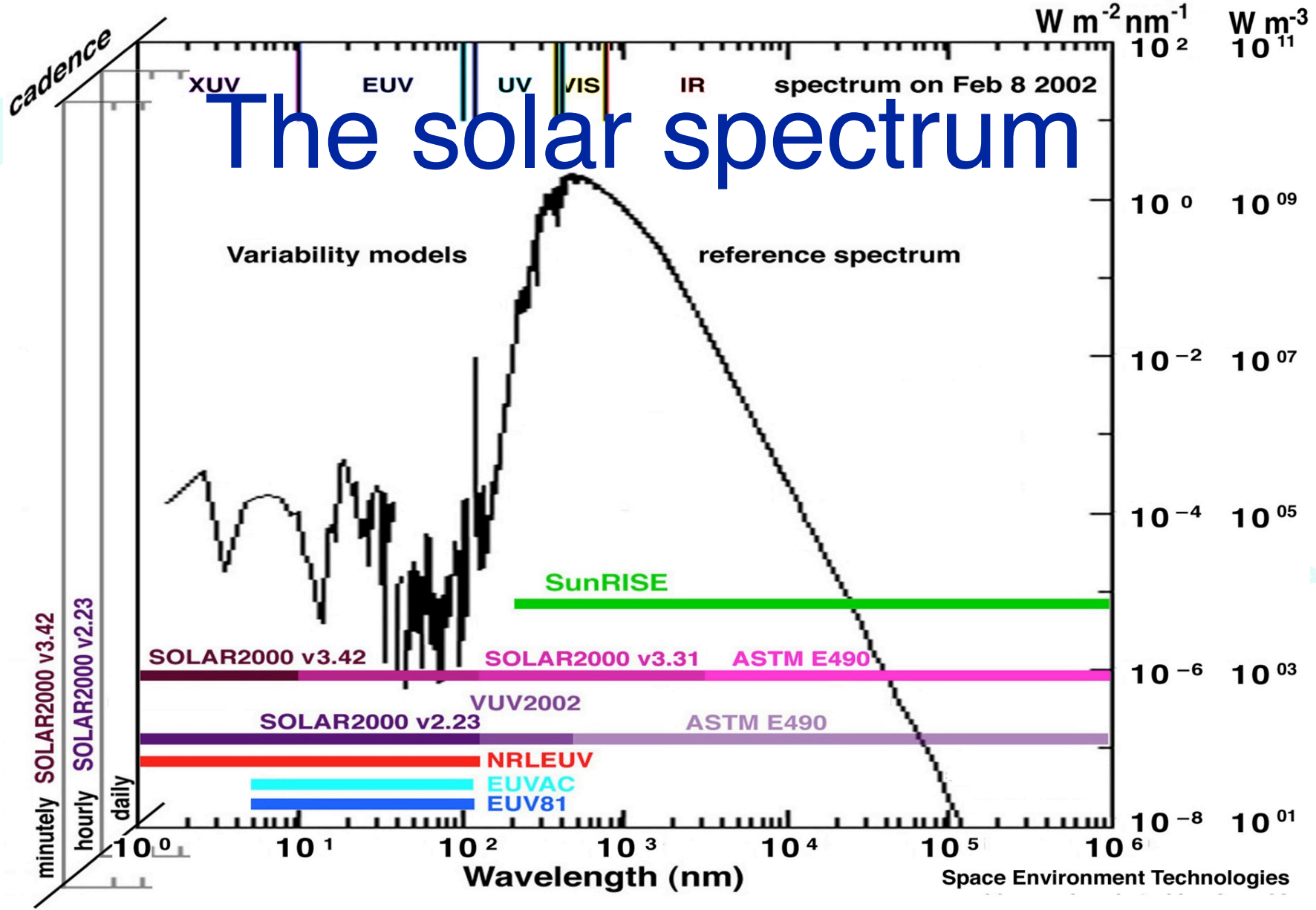


A faint, light blue world map is visible in the background of the slide, centered behind the title text.

Photons - solar irradiances

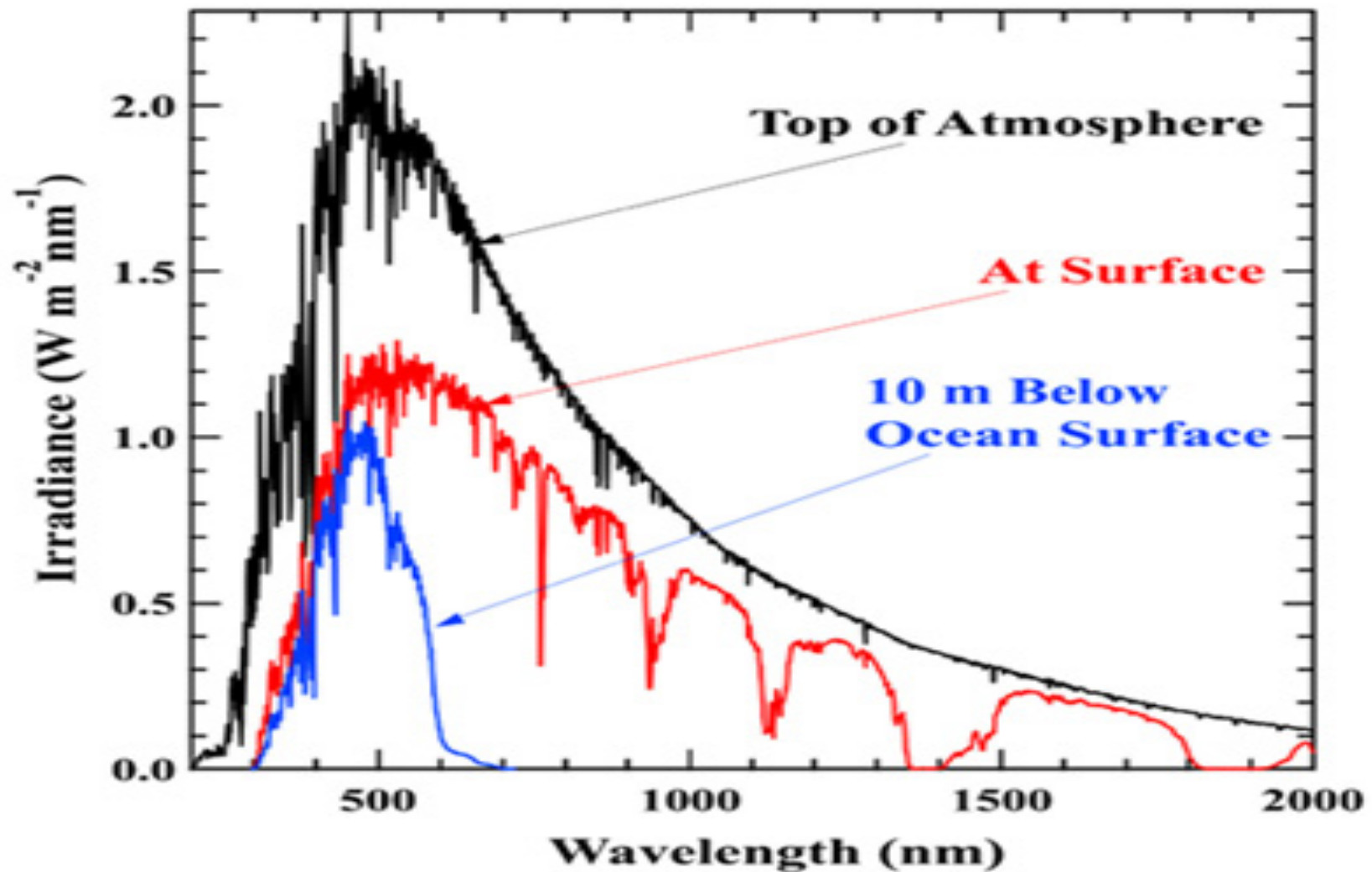
Improving irradiance specification



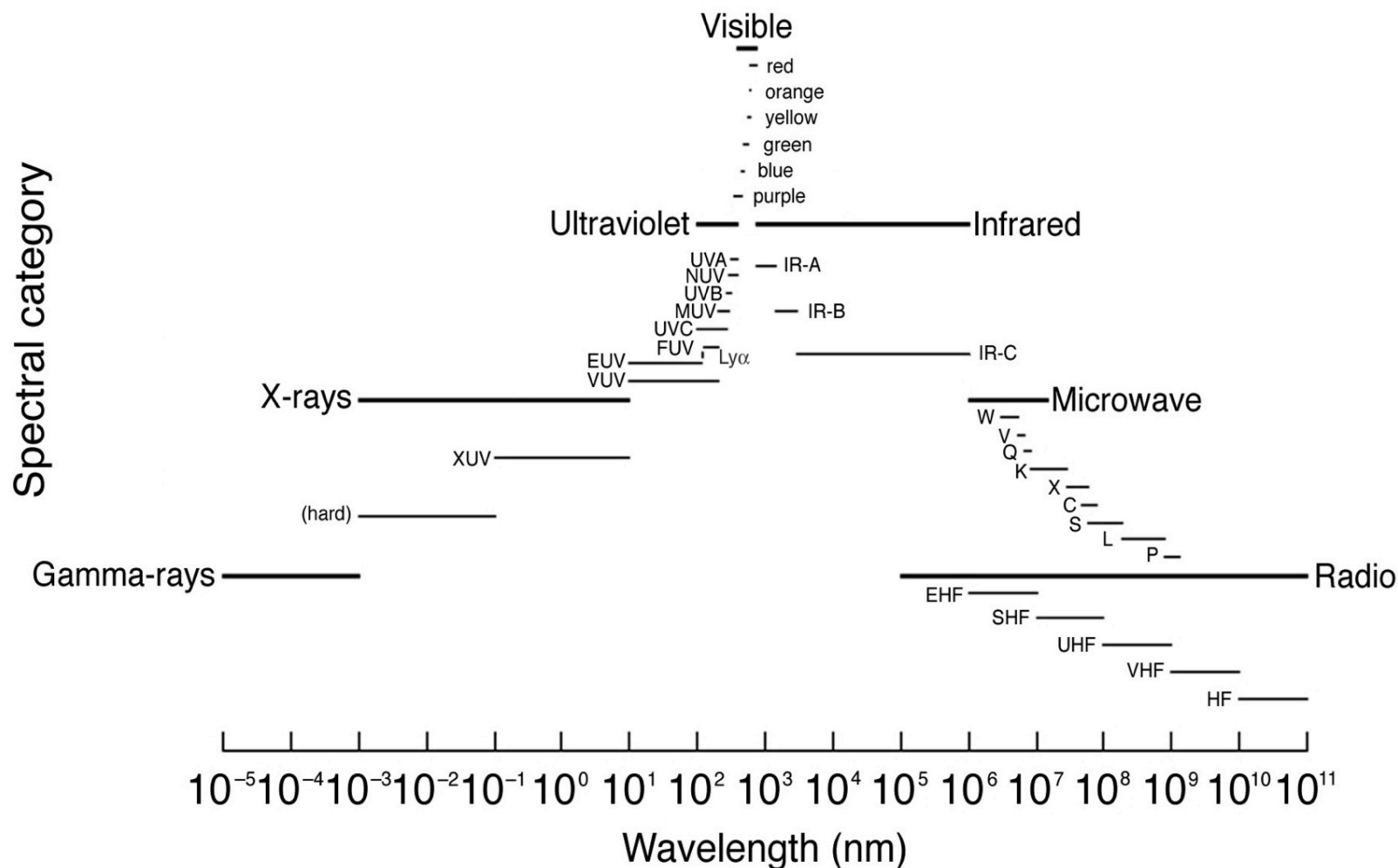


Credit: Tobiska

SORCE measurements

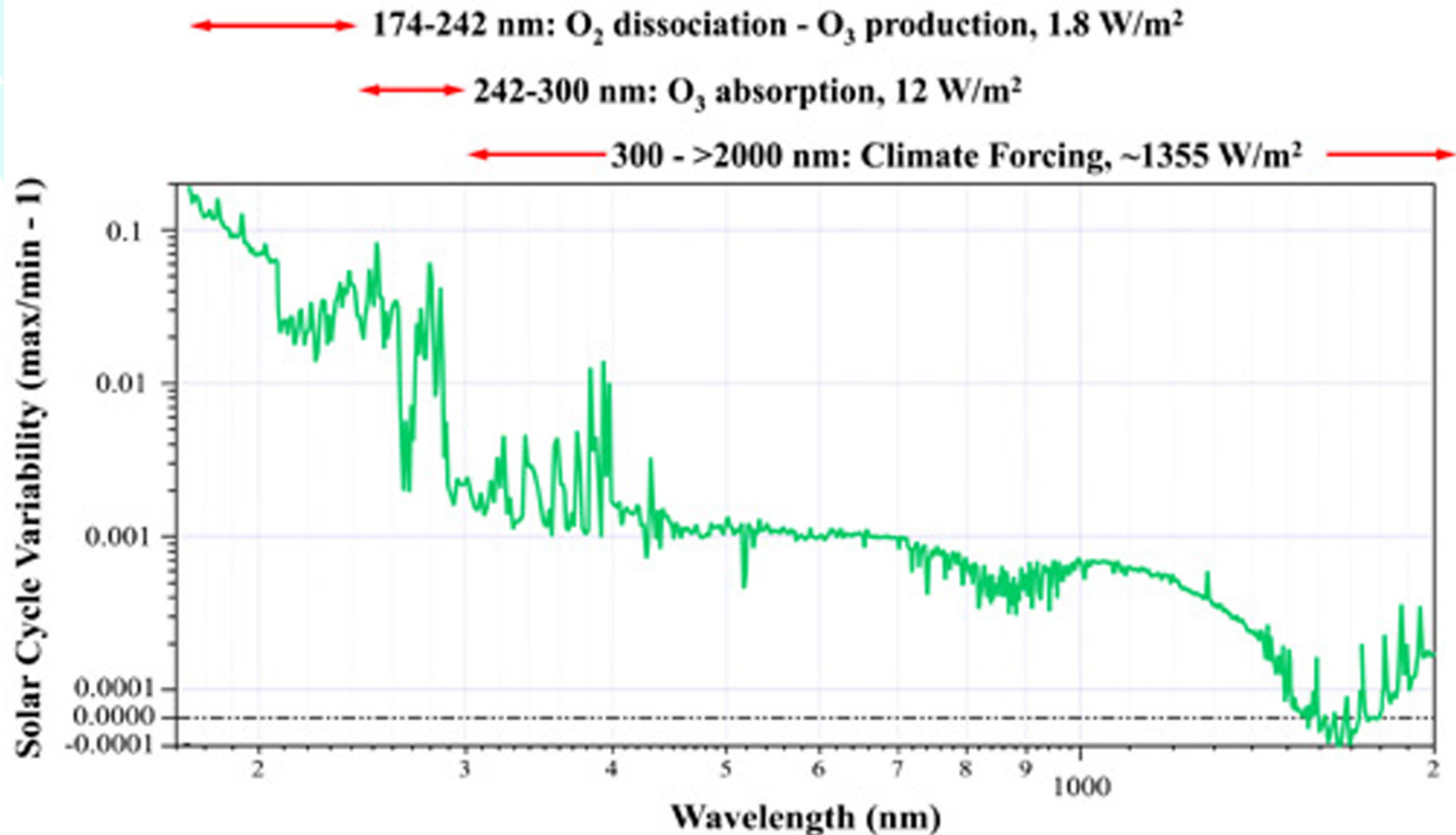


ISO 21348 wavelength ranges

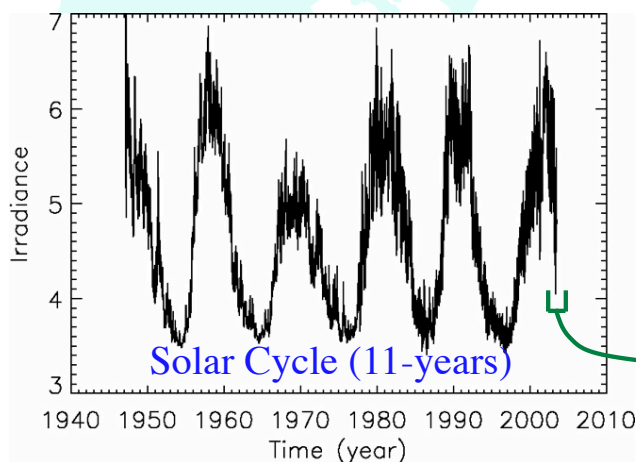


Credit: Tobiska

Solar spectral variability

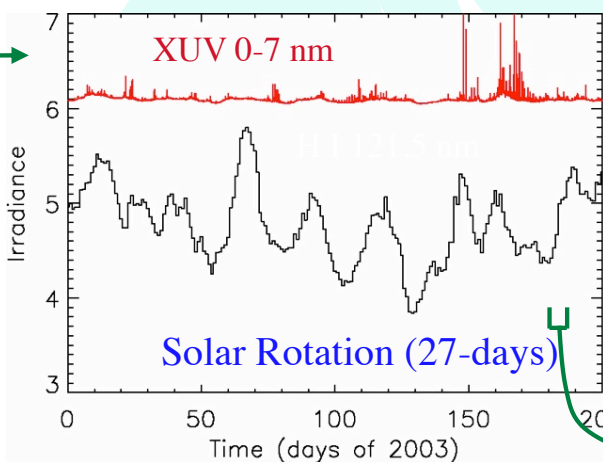


TIMED SEE measurements



◆ Solar Cycle - months to years

- Evolution of solar dynamo with 22-year magnetic cycle, 11-year intensity (sunspot) cycle
- Long-term H I Lyman- α time series has been extended with TIMED SEE measurements

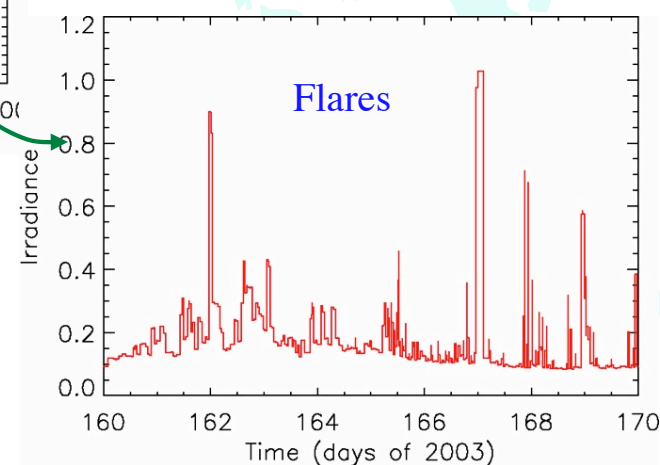


◆ Solar Rotation - days to months

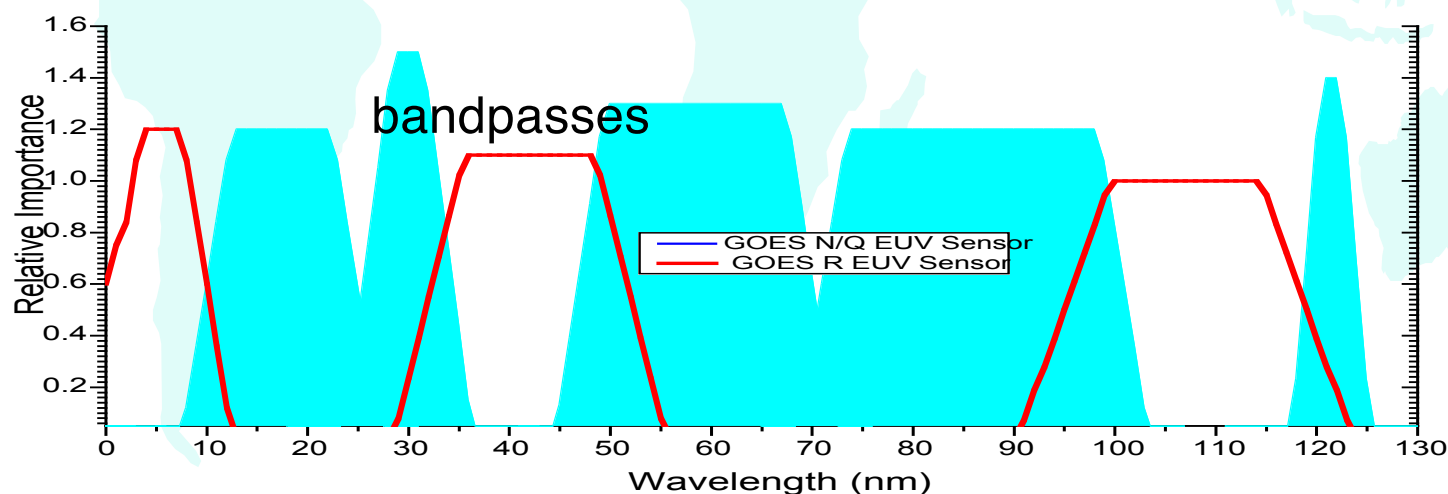
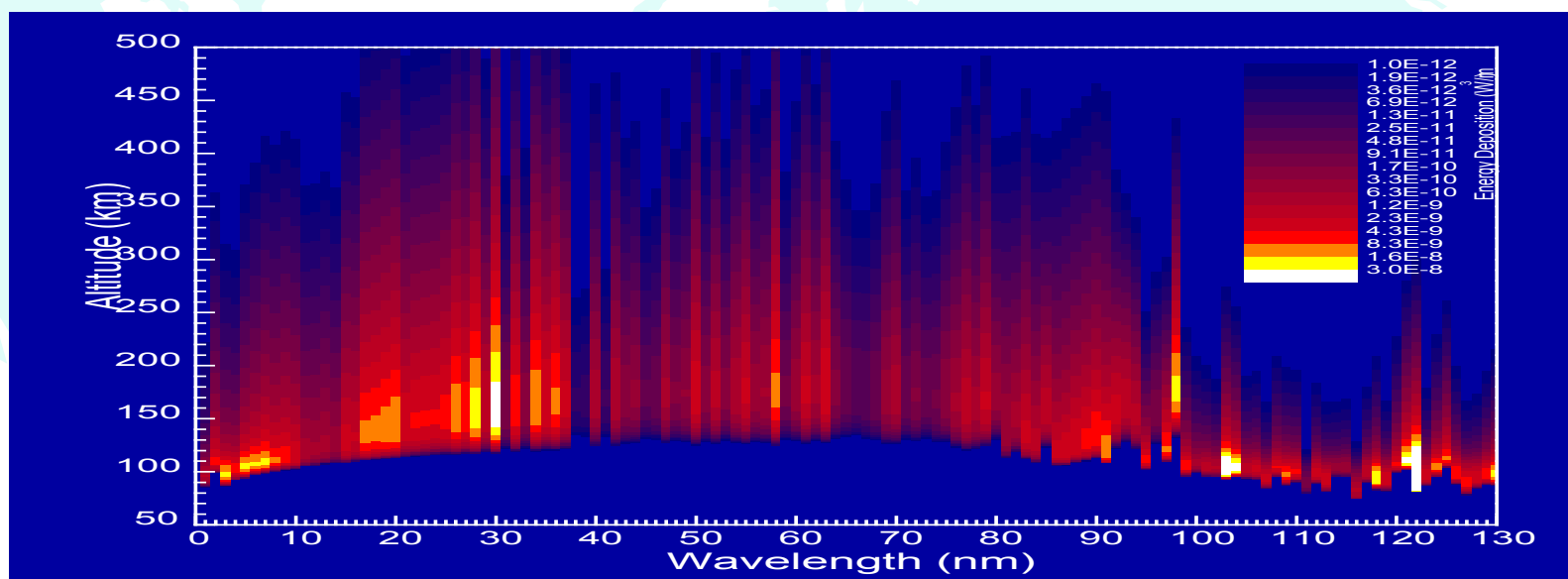
- Beacon effect of active regions rotating with the Sun (27-days)

◆ Flares - seconds to hours

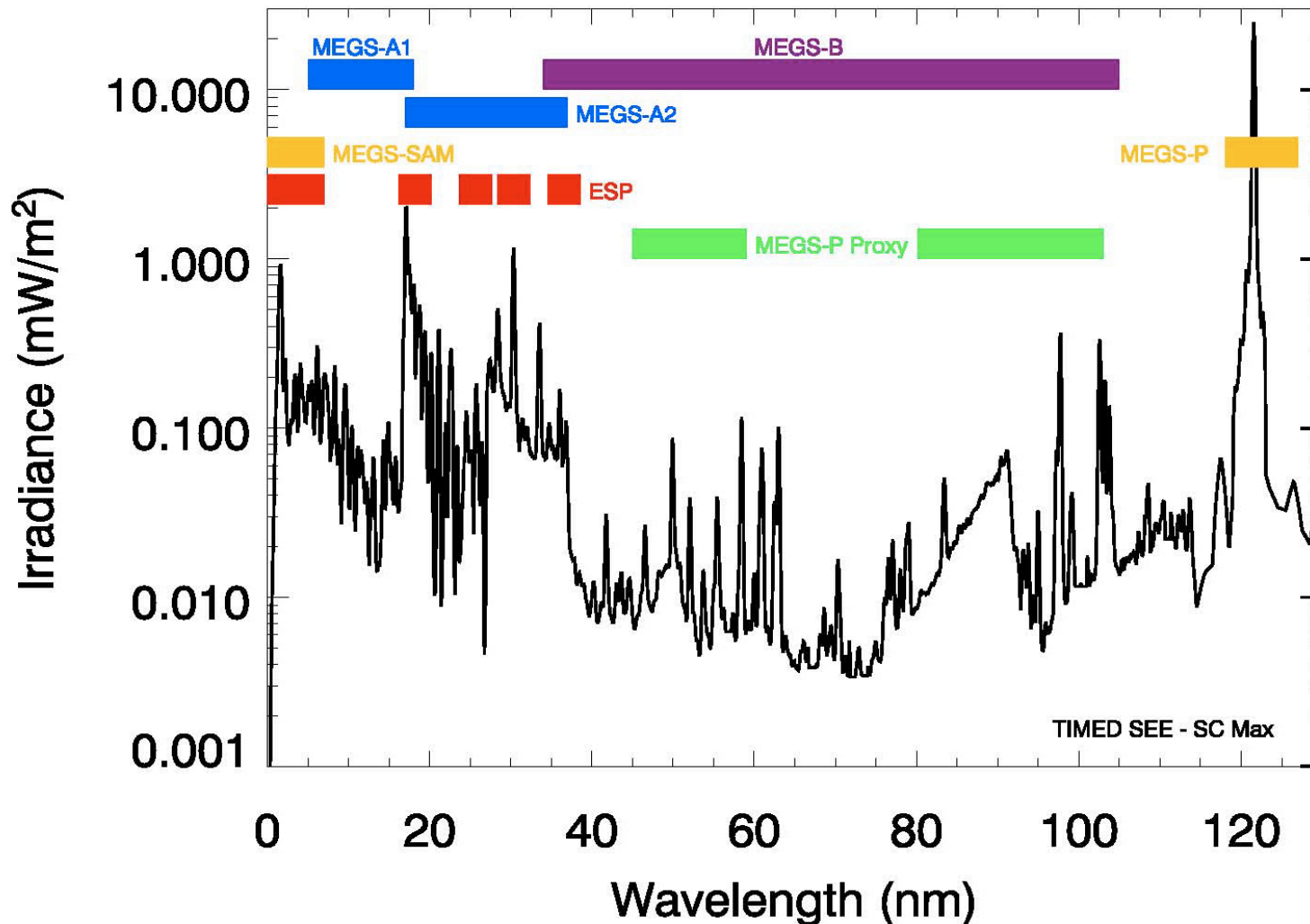
- Related to solar storms (such as CMEs)



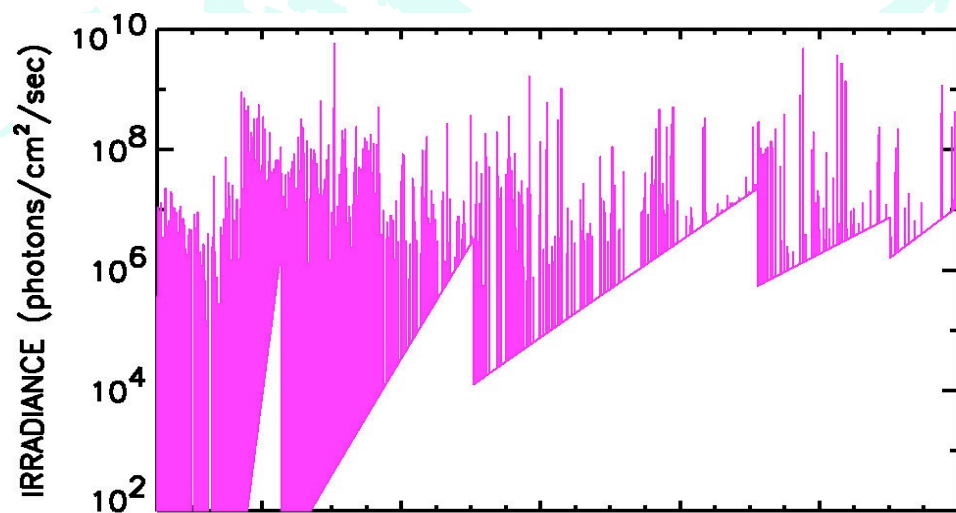
GOES 13 EUVS



Current state of art: SDO EVE



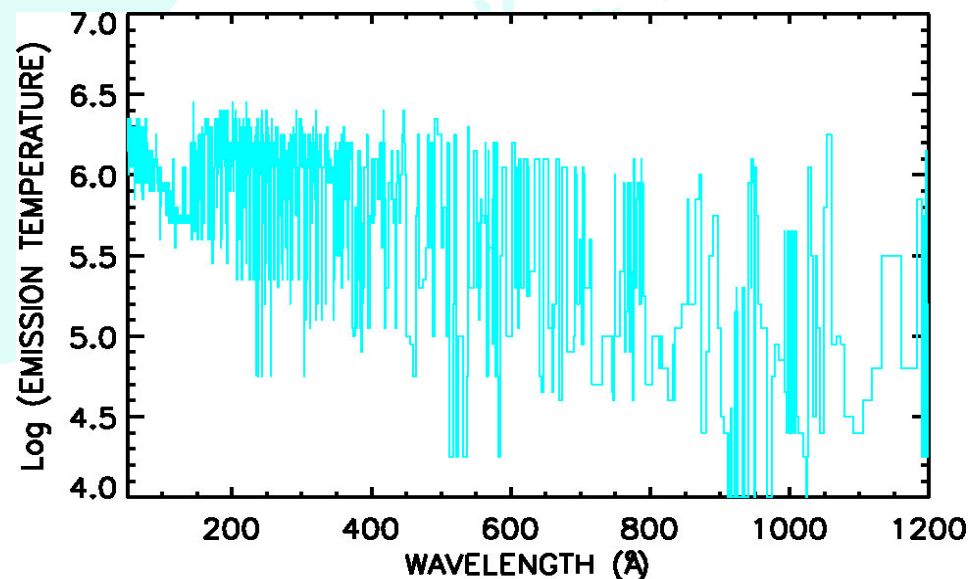
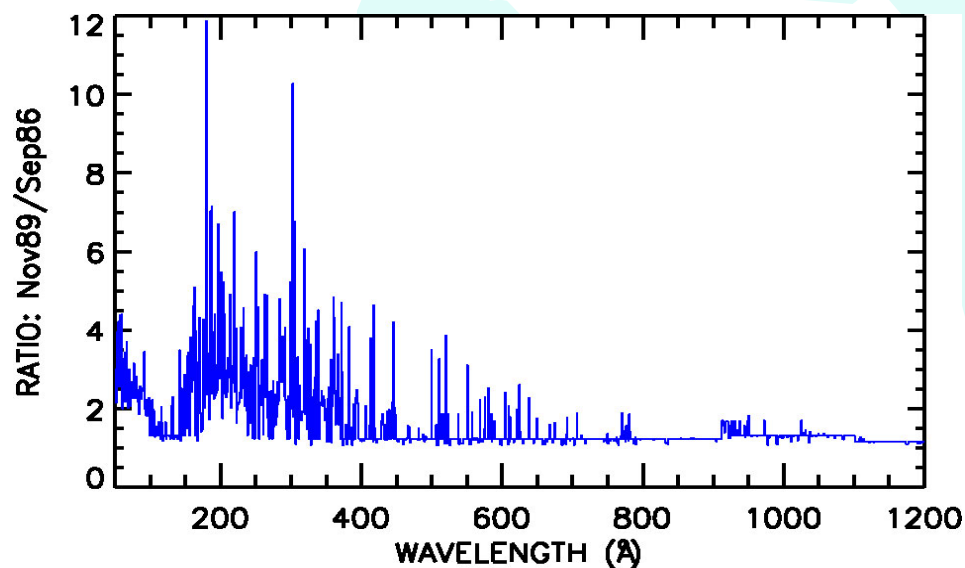
Models: NRLEUV



NRLEUV
spectrum:
>1500 lines
5 continua

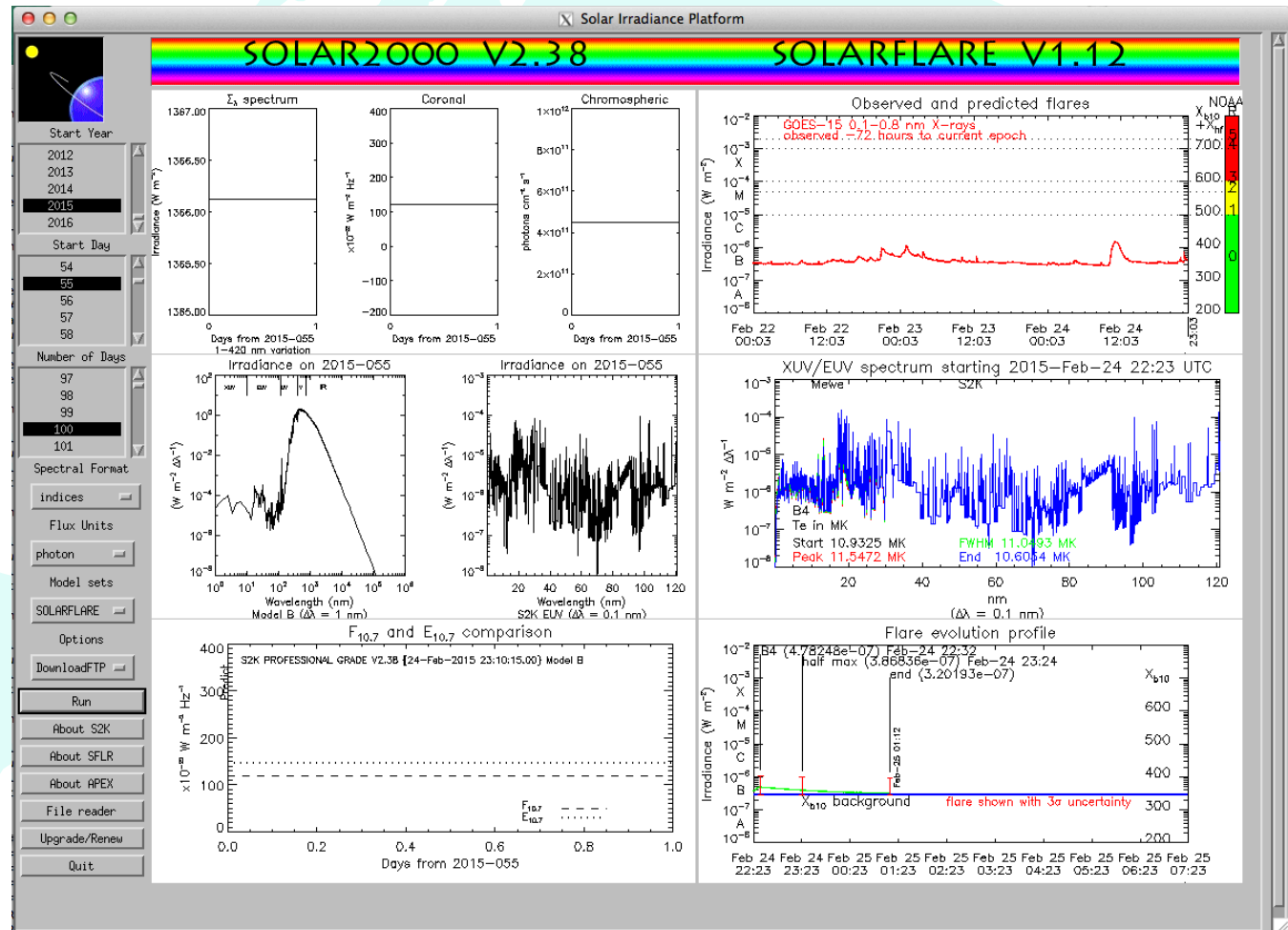
emission line
temperatures at
solar minimum

NRLEUV: Warren et al., JGR, 2001



Models: Solar Irradiance Platform

SIP provides historical, nowcast, and operational forecast XUV-UV variability in several spectral and proxy formats using the IDL Virtual Machine that runs on any platform



Credit: Tobiska

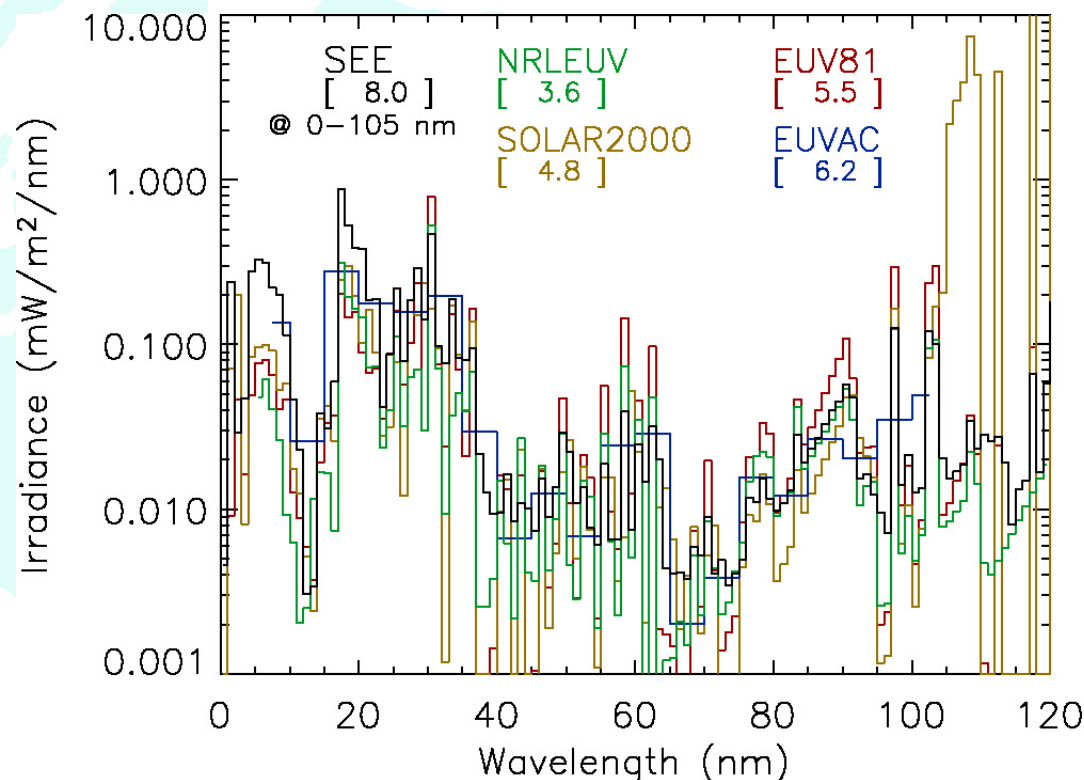
Comparisons of models & SEE

◆ Short wavelength issue for models

- EUV81 > 1.8 nm
- EUVAC > 5 nm
- NRLEUV > 5 nm

◆ Model comparisons to SEE V7 are shown for day 2002/039

- EUV81 (Hinteregger) is
 - low in the XUV
 - high in the EUV
 - low in the FUV
- EUVAC (Richards) is
 - best comparison, but in 5 nm bins
- NRLEUV (Warren) is
 - low in the XUV
- SOLAR2000 v2.23 [S2K] (Tobiska) is
 - low in the XUV
 - high in 102-121 nm range



In mW/m ² units	Q_{EUV} (0-40 nm)	EUV (30-105 nm)	Lyman- α (120-123 nm)	FUV (130-190 nm)
SEE	6.7	2.4	8.9	49
EUV81	3.3	3.5	12.0	31
EUVAC	5.0	2.3	-	-
NRLEUV	2.4	2.0	-	-
S2K V2.23	3.4	2.1	35	46

Values with larger than 30% difference are shown in red

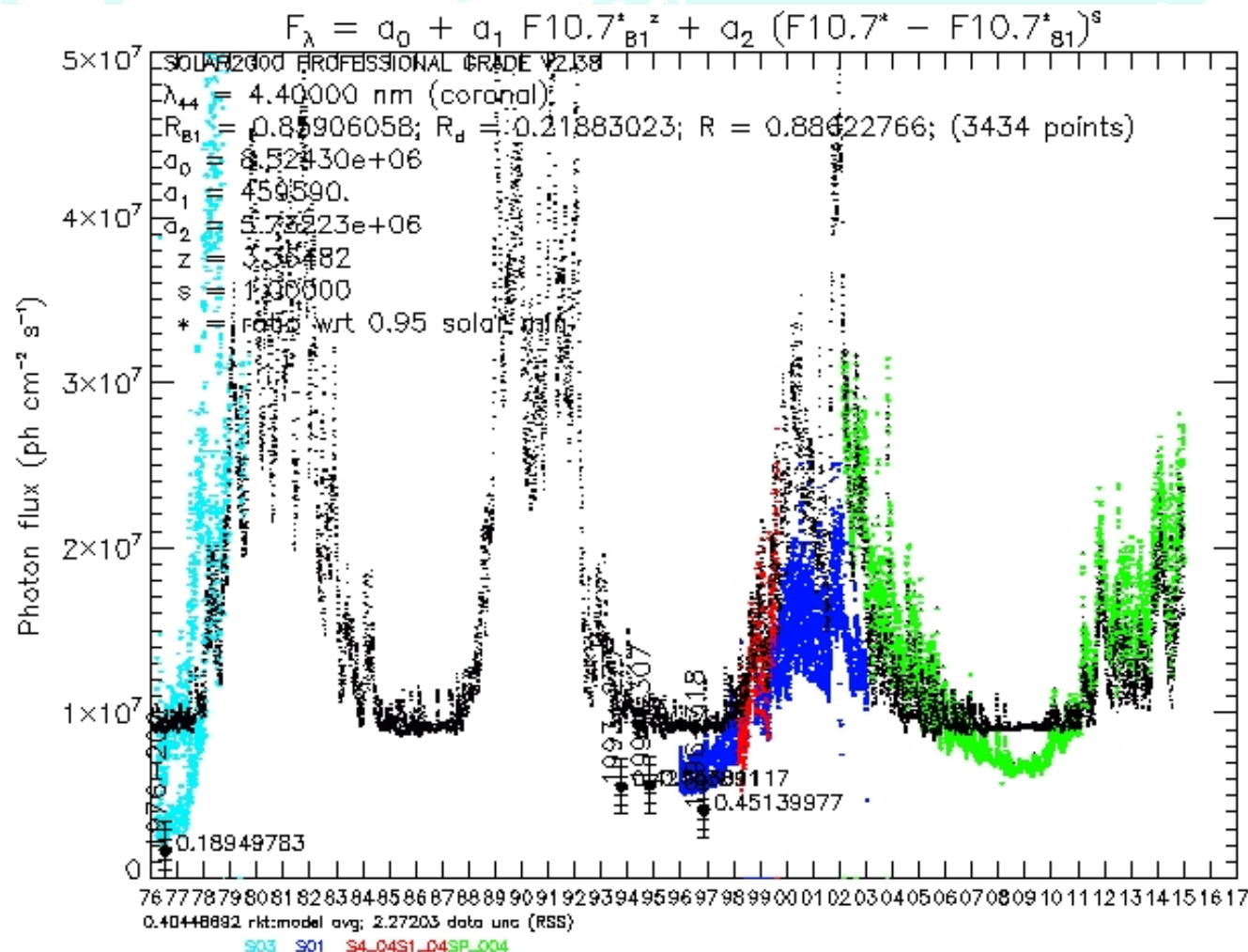
<https://SpaceWx.com>

W. Kent Tobiska <ktobiska@spacewx.com>

Credit: T. Woods

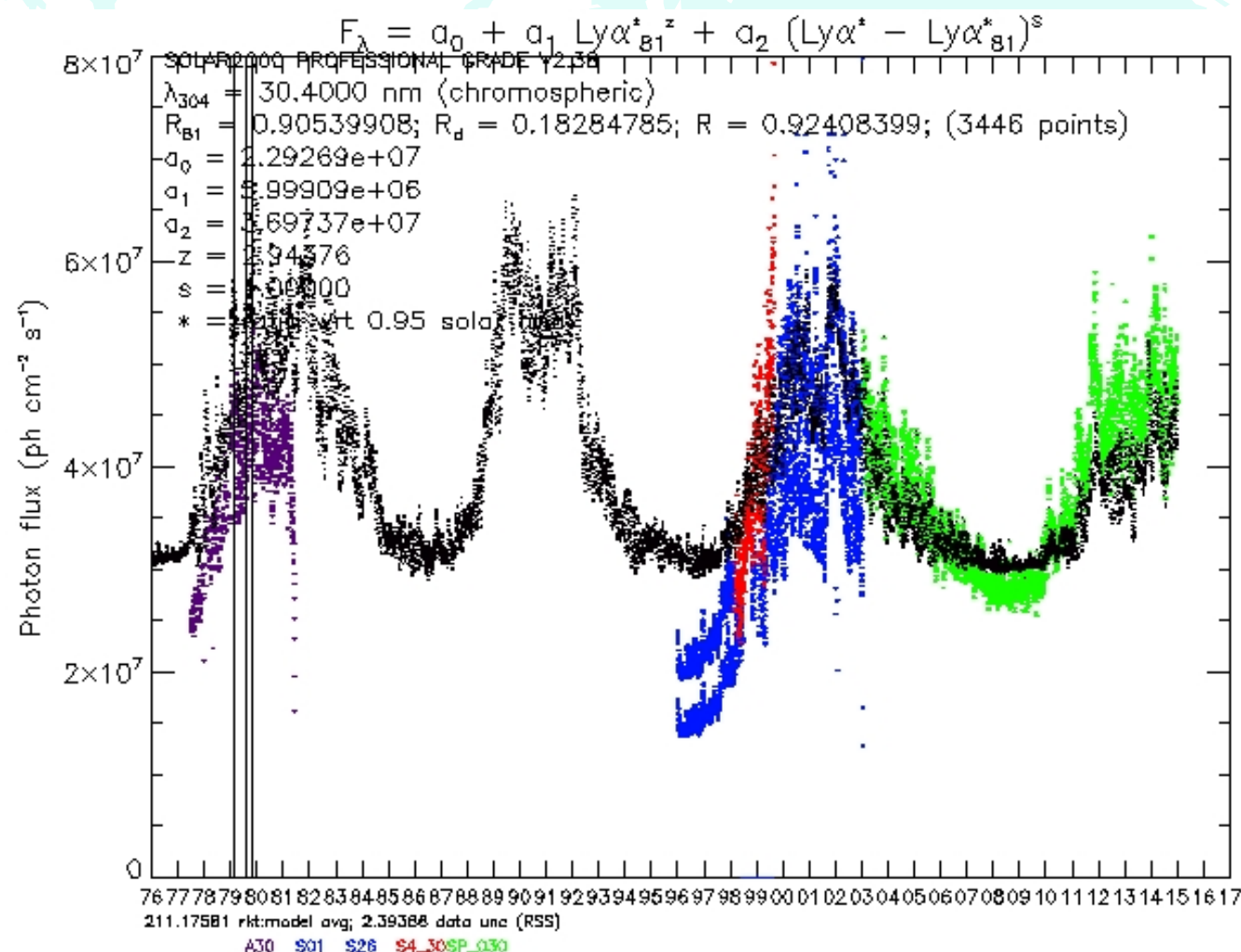
11 /

S2K v2.38 soft X-rays & SEE v11



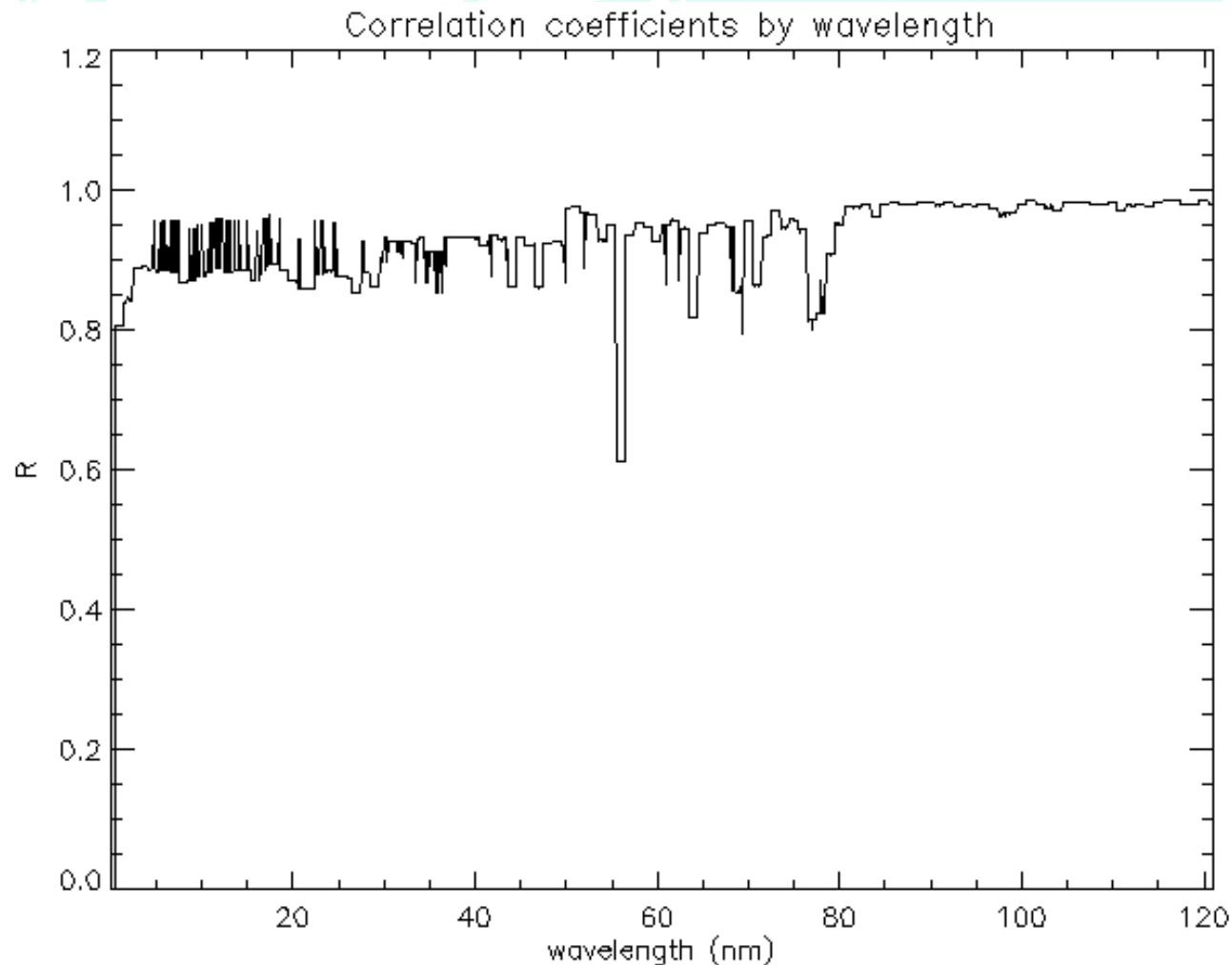
Credit: Tobiska

S2K v2.38 EUV & SEE v11



Credit: Tobiska

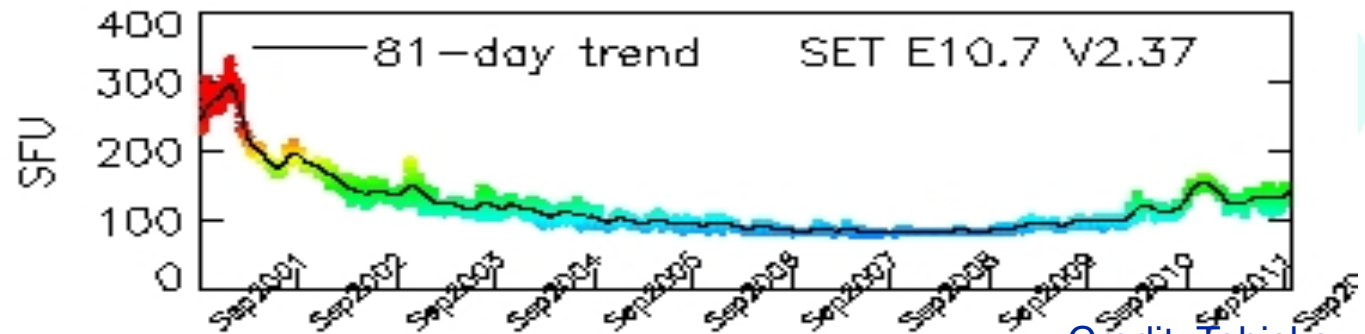
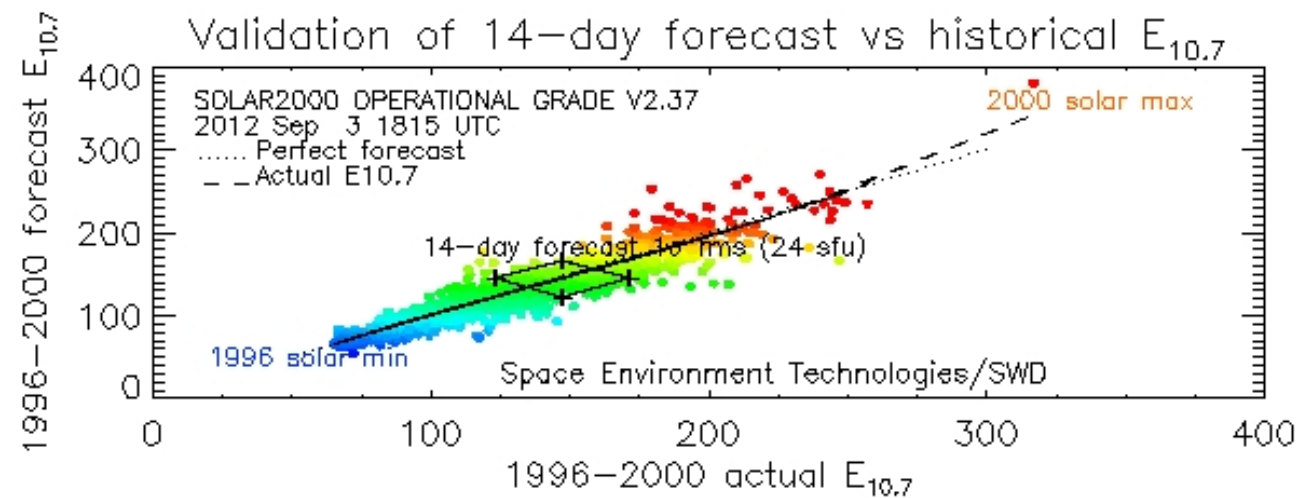
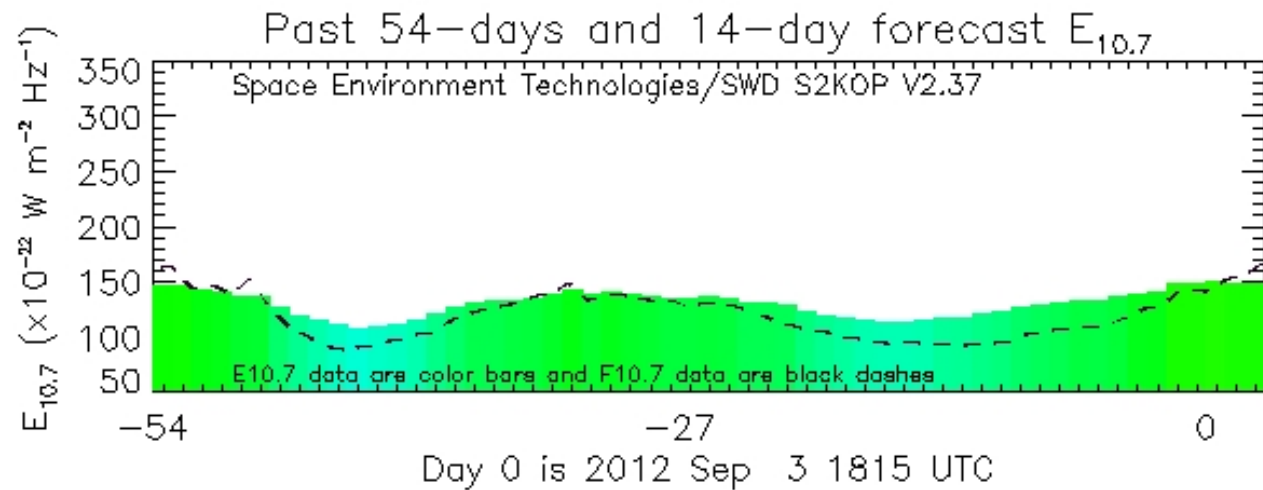
S2K v2.38 correlations vs SEE v11



Credit: Tobiska

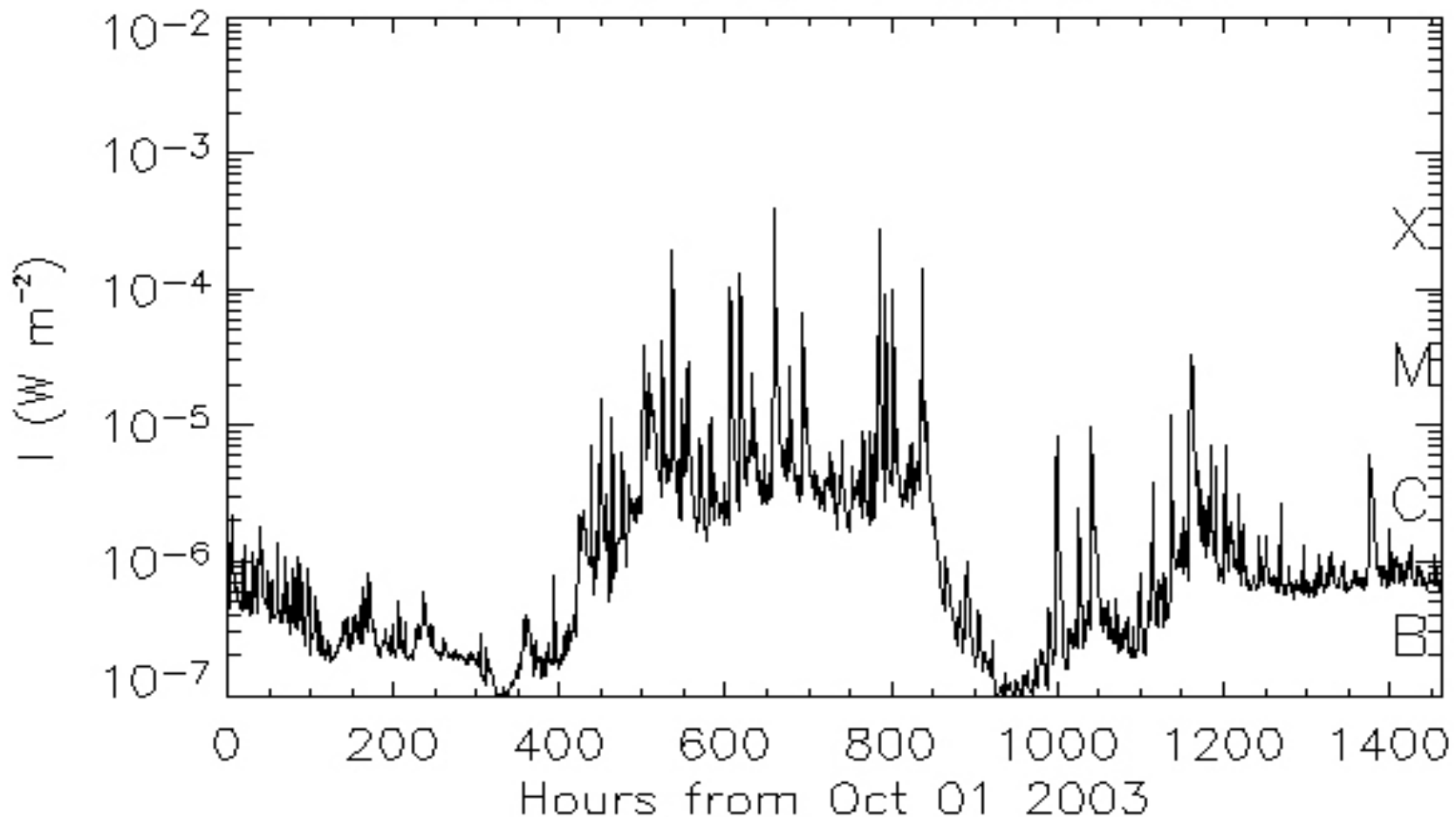


Integrated irradiances and E10.7



X_{b10} , X_{hf} , and $X_{10.7}$

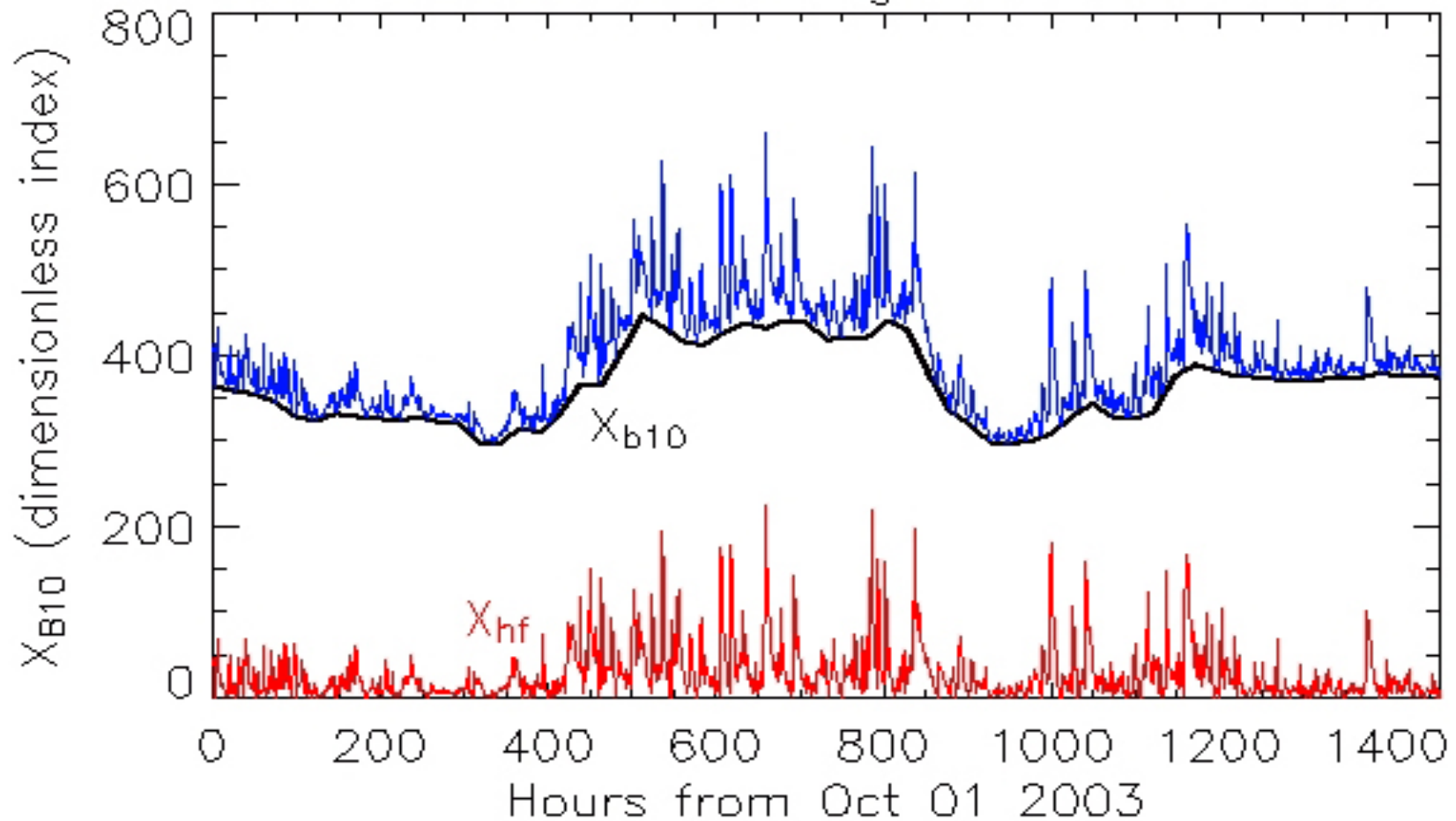
Oct–Nov 2003 GOES–12



Credit: Tobiska

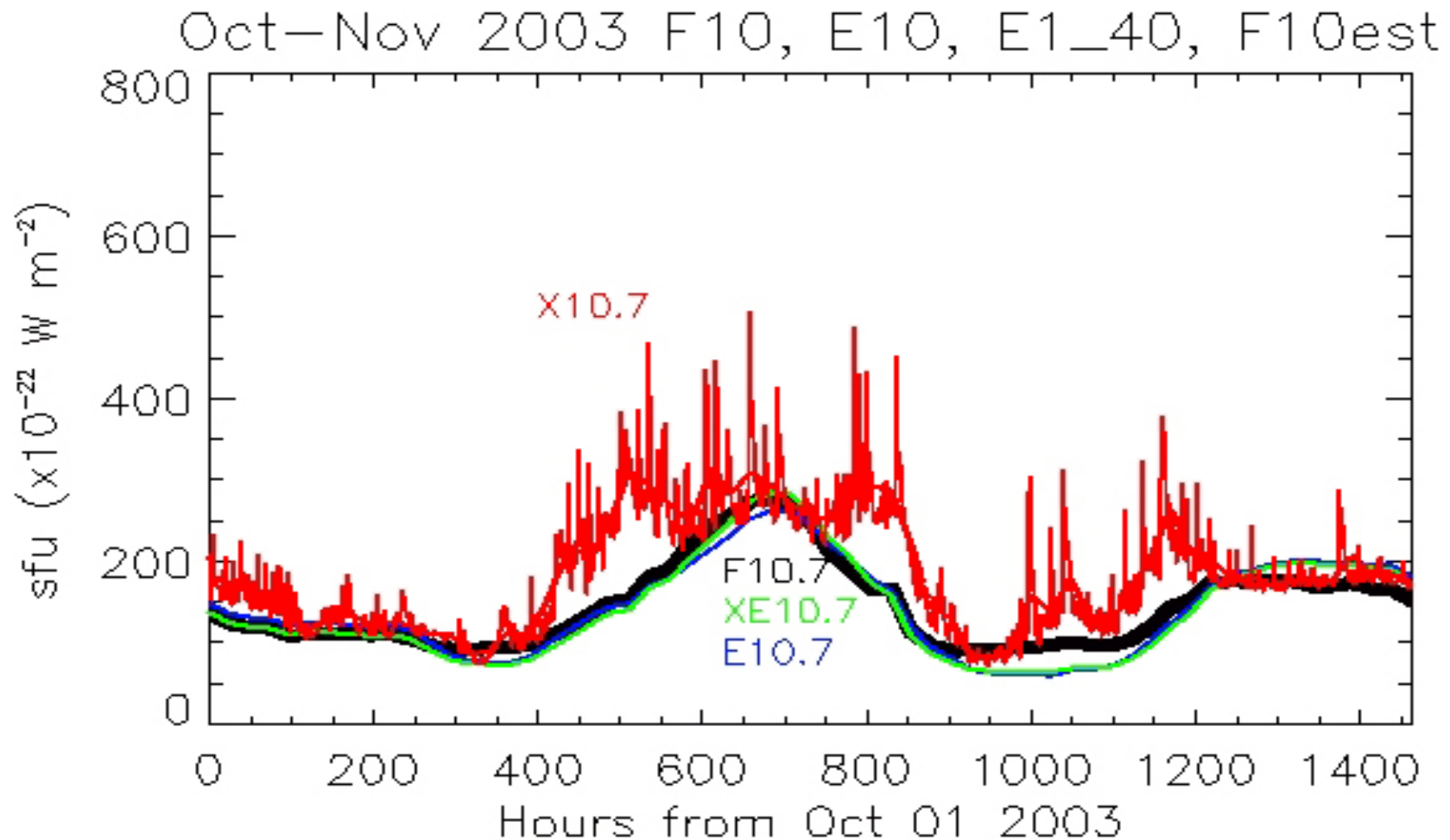
X_{b10} , X_{hf} , and $X_{10.7}$

Oct–Nov 2003 background and flares



Credit: Tobiska

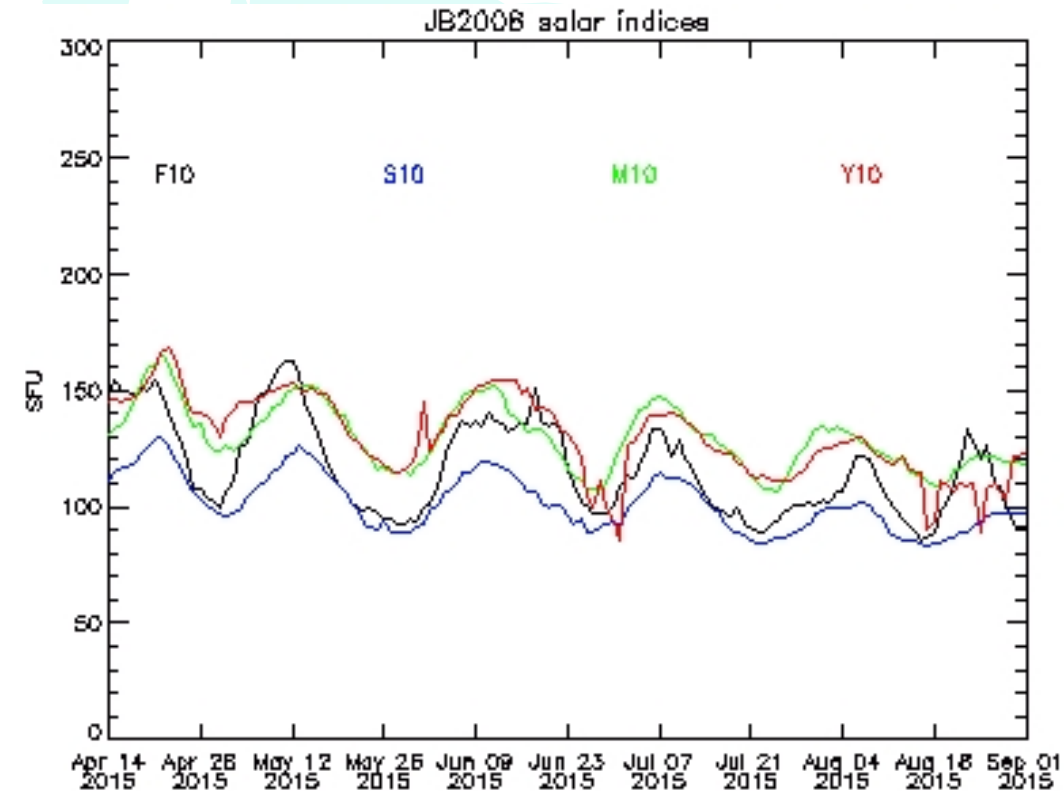
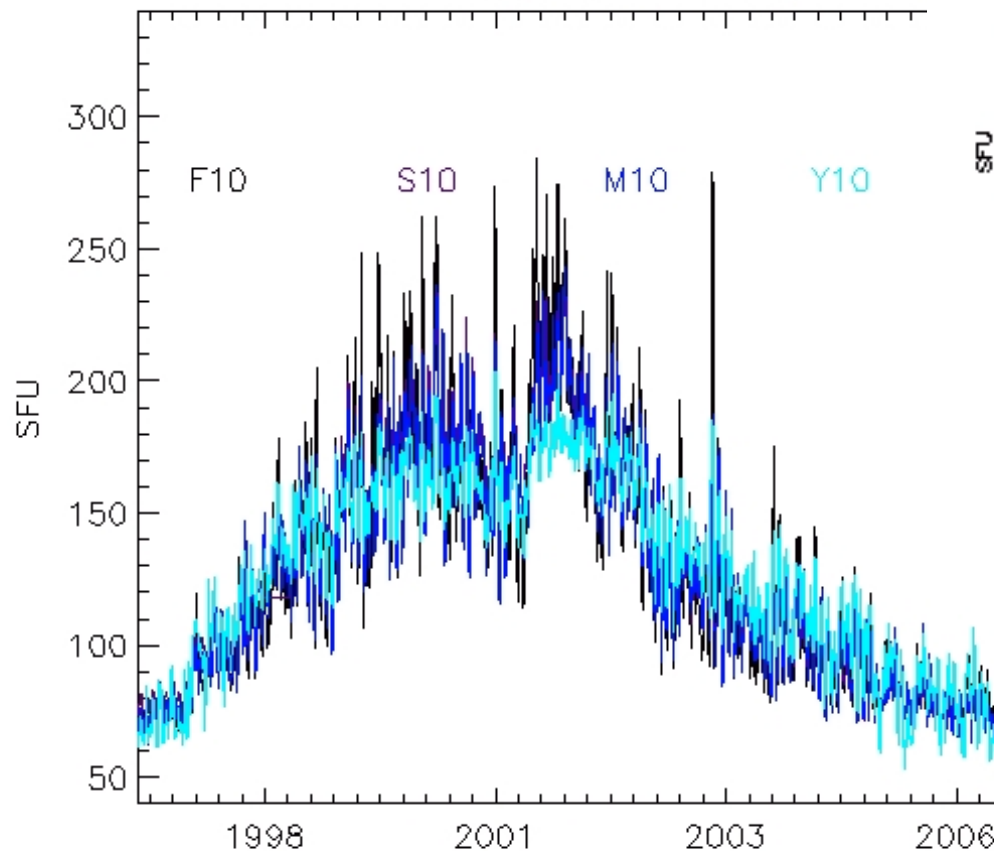
X_{b10} , X_{hf} , and $X_{10.7}$



Credit: Tobiska

JB2008 solar indices

SOLFSMY4MON.txt



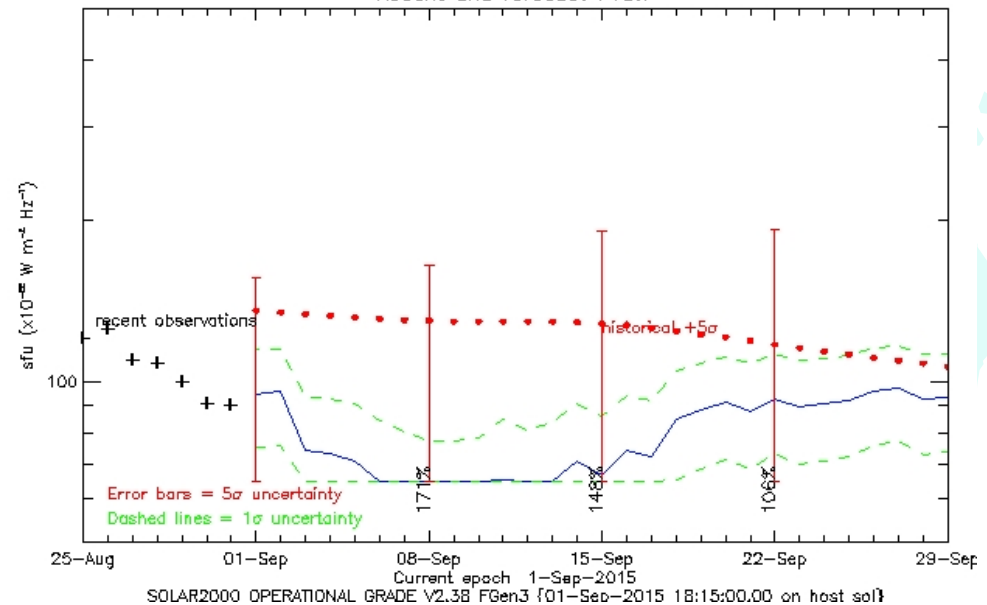
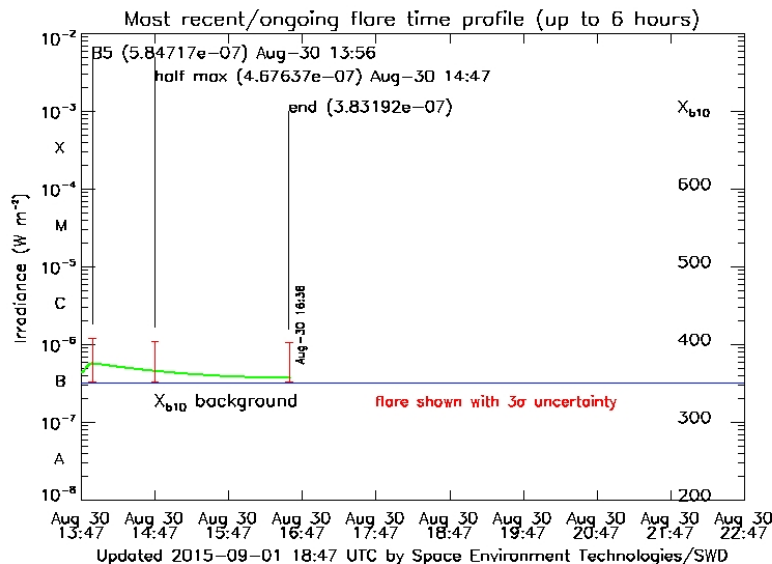
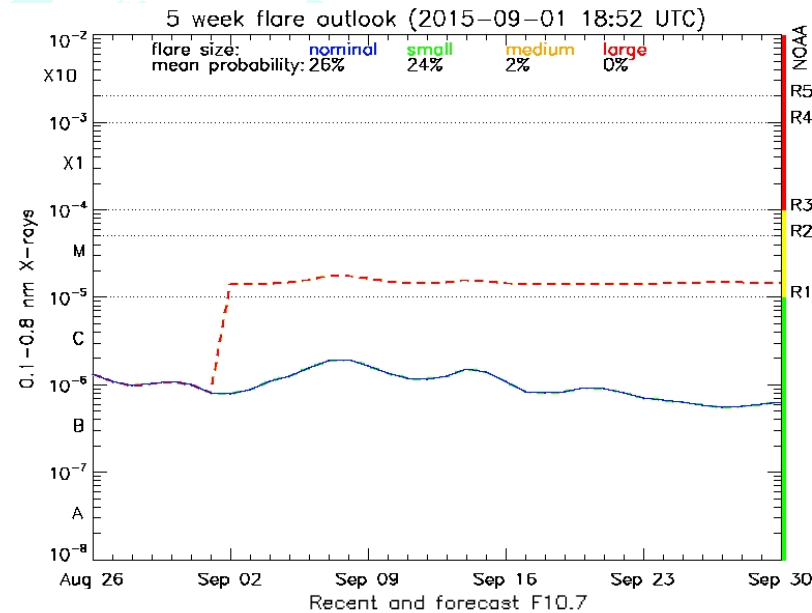
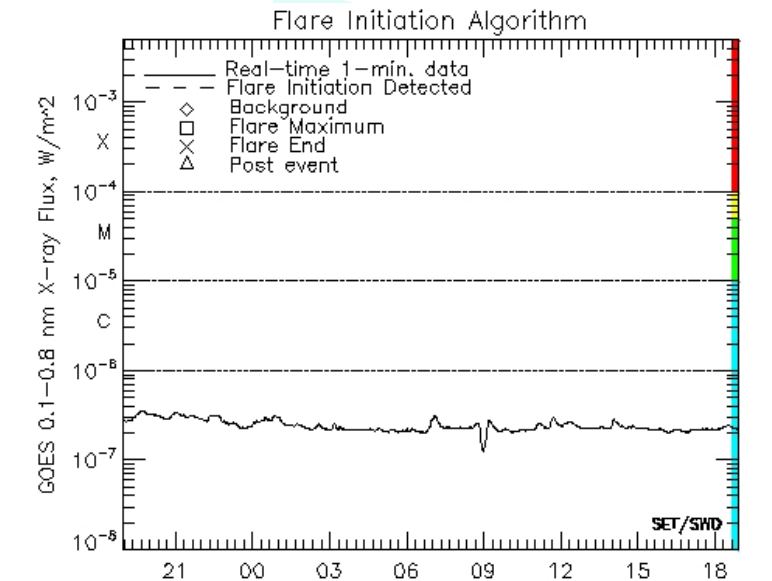
Credit: Tobiska



X-ray flare monitoring

Lecture 2

http://sol.spacenvironment.net/set_ops/index.html



<https://SpaceWx.com>

W. Kent Tobiska <ktobiska@spacewx.com>

126

Credit: Tobiska

Summary

- ✓ **Operational drivers for mitigating space weather affects**
- ✓ **Space environment standards activities**
- ✓ **The interplanetary space environment**
 - ✓ Atomic physics review and photon radiation
 - ✓ The Sun
 - ✓ Solar interior and atmosphere
 - ✓ Photons - solar irradiances
- ✓ **Resources**