Solar Databases

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Overview

- <u>Setting the stage, terminology</u>
- <u>Data collection</u>: overview of grounbased and space observations and observatories relevant to Space Climate research. What is observed, how and why. Best practices, or what do we need to know about the data to ensure their proper interpretation?
- <u>Calibration and data reduction:</u> data preservation, calibration etc.
- <u>Data access</u> (e.g., VSO, Helioviewer etc).
- <u>Future planning</u>: how solar databases change with time (e.g., need for new observables, requirements from modelers and forecasters. (also, a "typical" lifecycle of modern data archives), continuity of solar data sets and future networks.

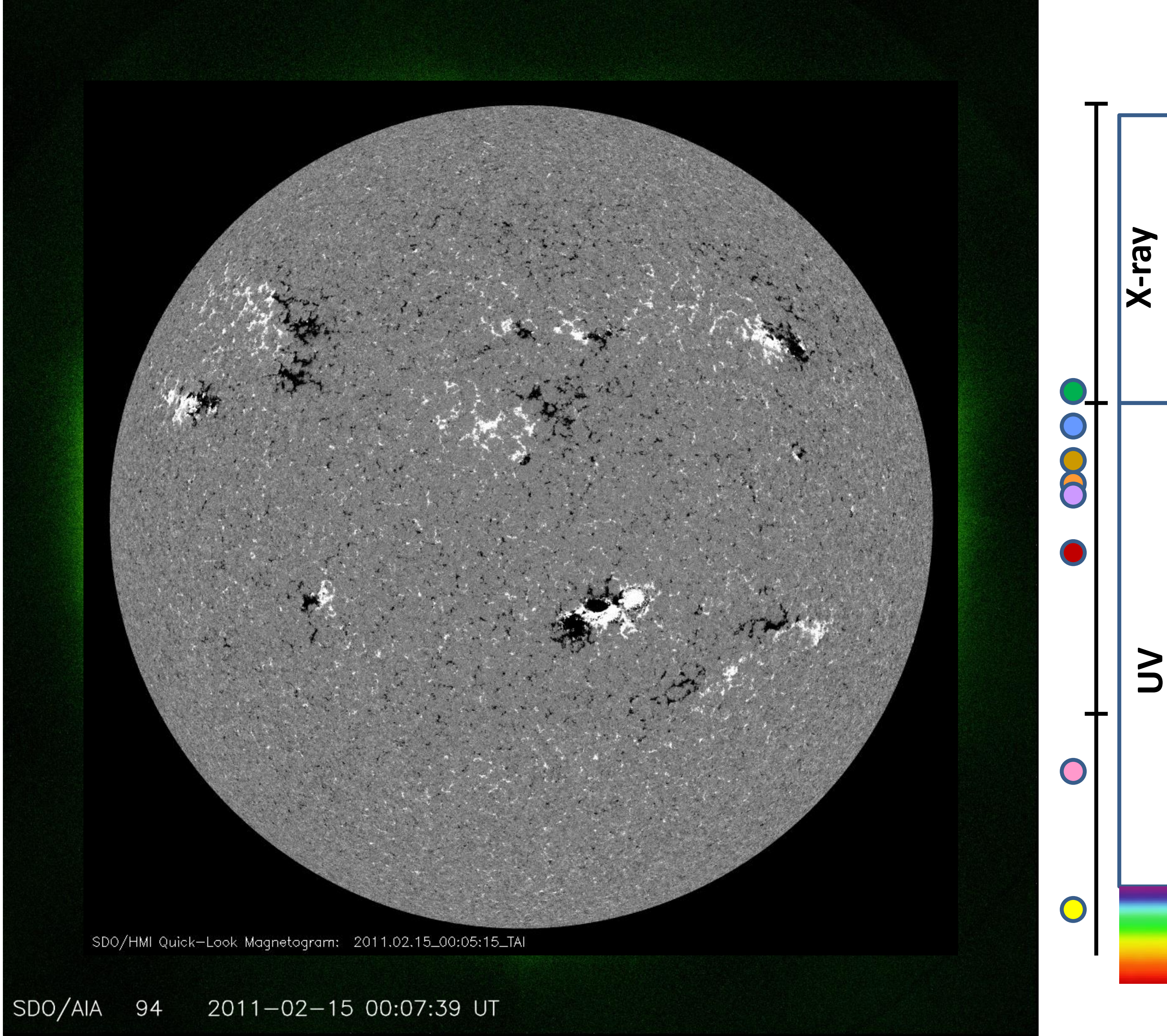
corona

6-10MK

Temperature

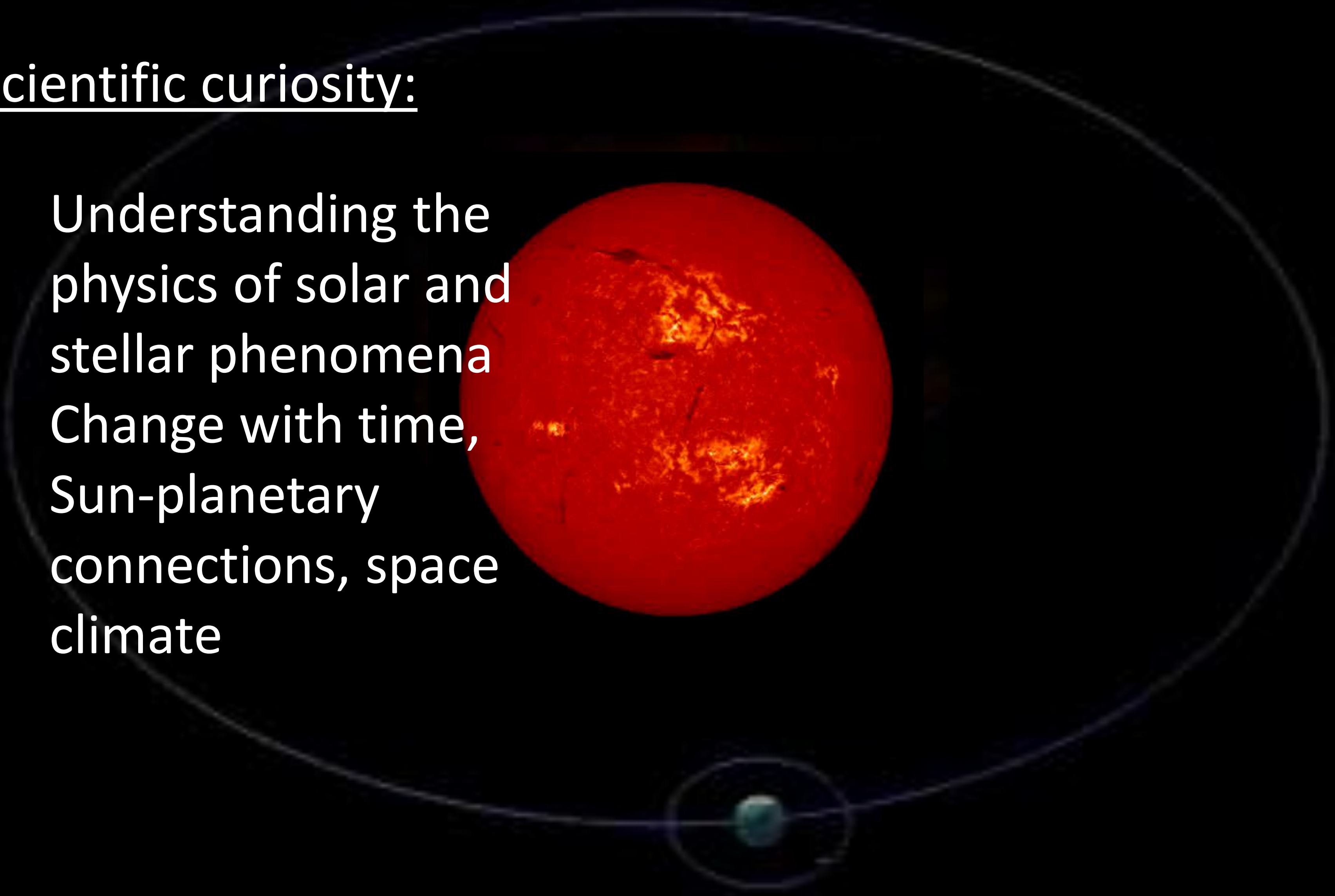
5000K

Photo-
sphere



<u>Scientific curiosity:</u>

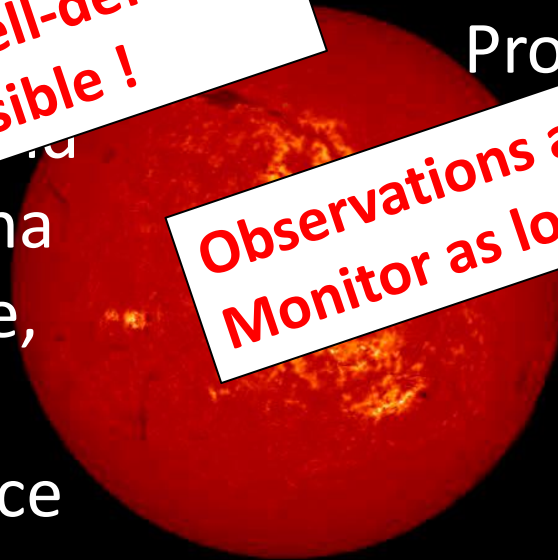
- Understanding the physics of solar and stellar phenomena
- Change with time, Sun-planetary connections, space climate



Scientific curiosity:

- Understan[...] ph[...] [...]d [...]enomena change with time, Sun-planetary connections, space climate

Observations are not well-defined.
Monitor as long as possible !

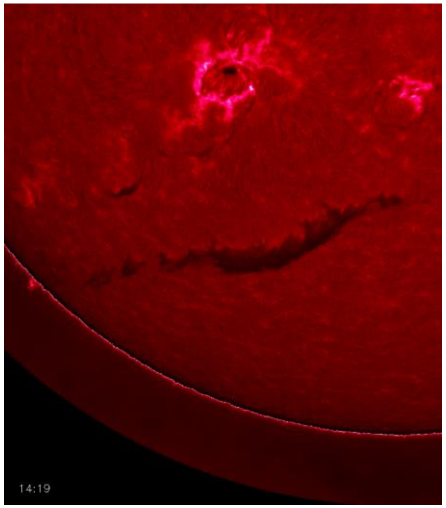


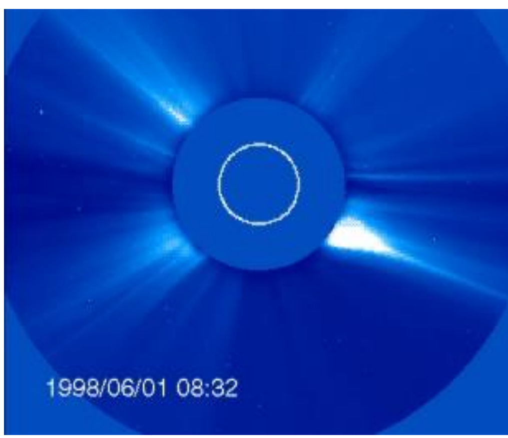
Applied Science:

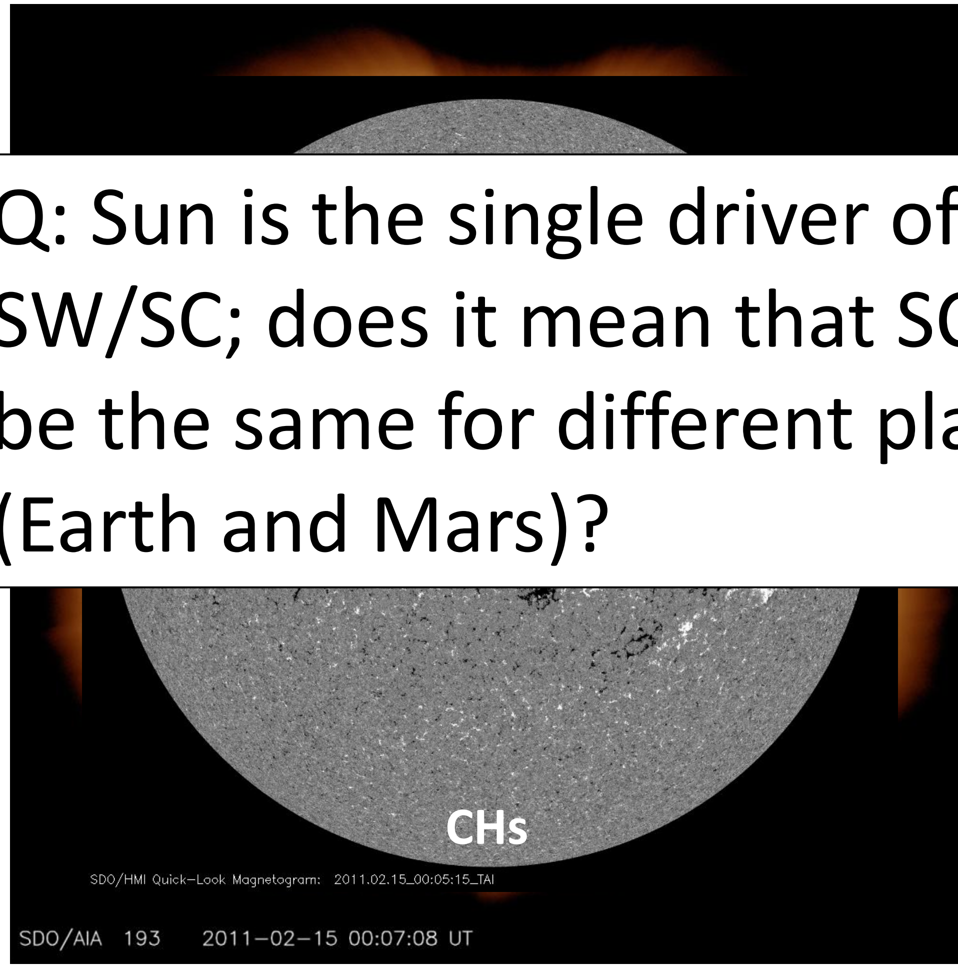
Providi[...] [...]or space [...]er forecasting

Observations are well- (better) defined.
Monitor as long as needed !

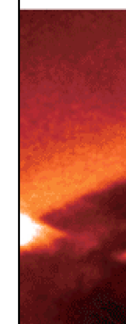
Where on the Sun the SC originates from?







Q: Sun is the single driver of SW/SC; does it mean that SC will be the same for different planets (Earth and Mars)?



Cheung et al. 2014

Space Climate and Unified Sun-Planet System

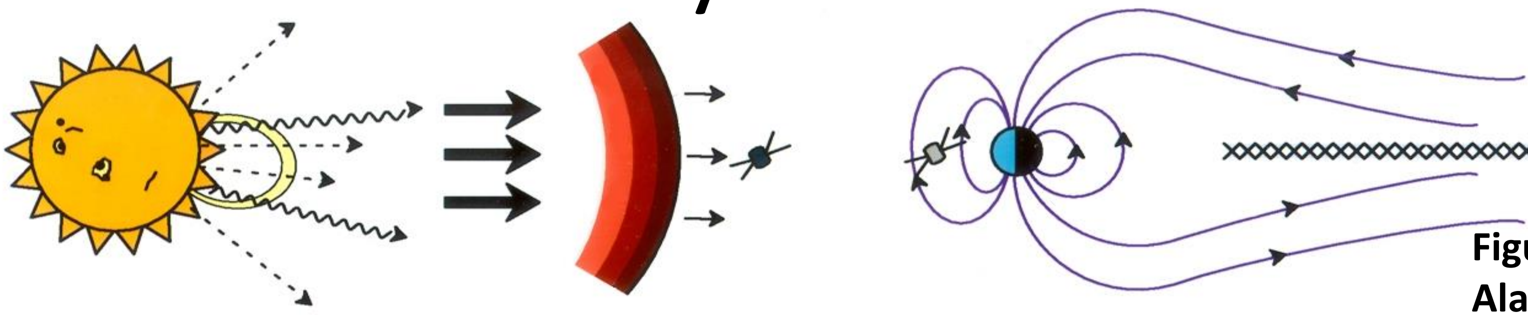


Figure courtesy Alan Aylward

Source/Sun

Evolving magnetic fields
Eruptive events: flares, CMEs, filaments
SEPs
Irradiance variations
[…]
Different spatial and temporal scales (solar cycle)

Transport

IMF, Solar wind, ICMEs, Shocks, GCRs and SEPs

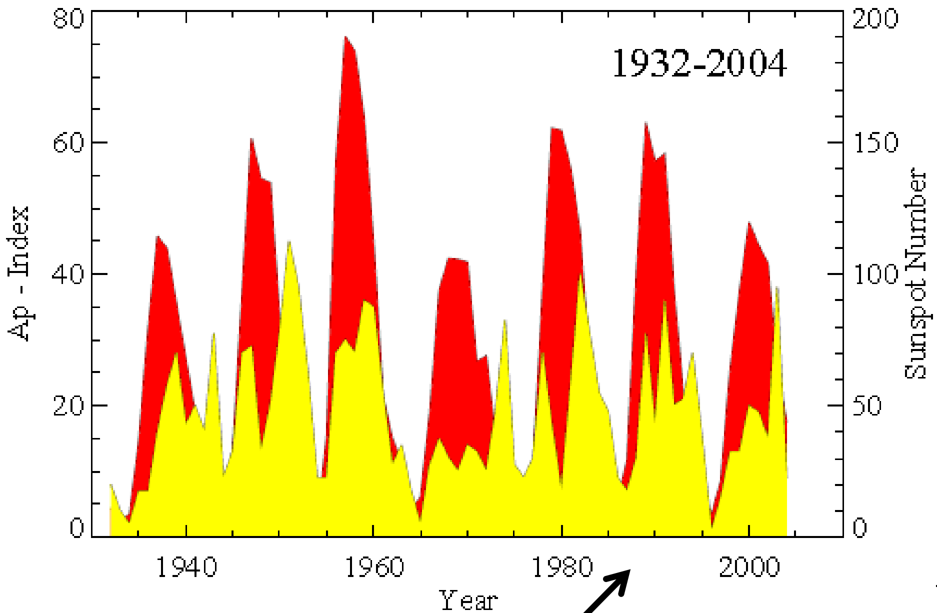
Responding System

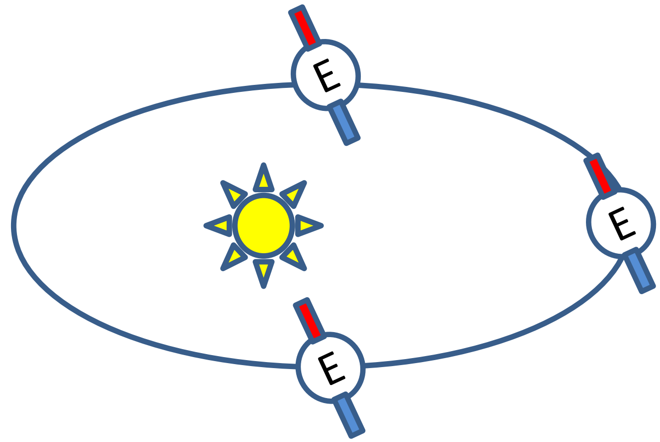
Magnetosphere
Ionosphere
Neutral Atmosphere (Climate)
[…]

Effect on measurements

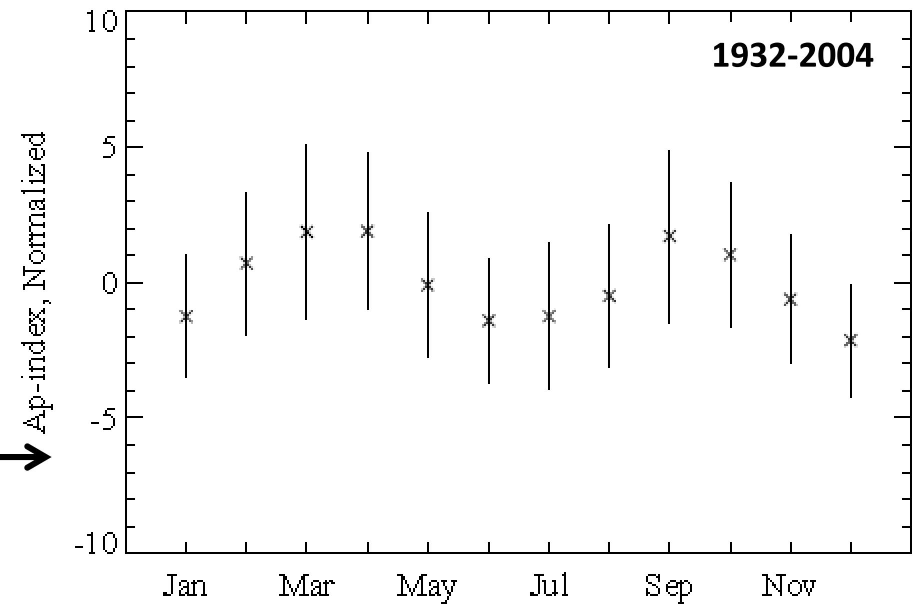
Changes in "Responding System":
Geologic/geophysical/ anthropogenic activity

Space weather, seasons, and climate





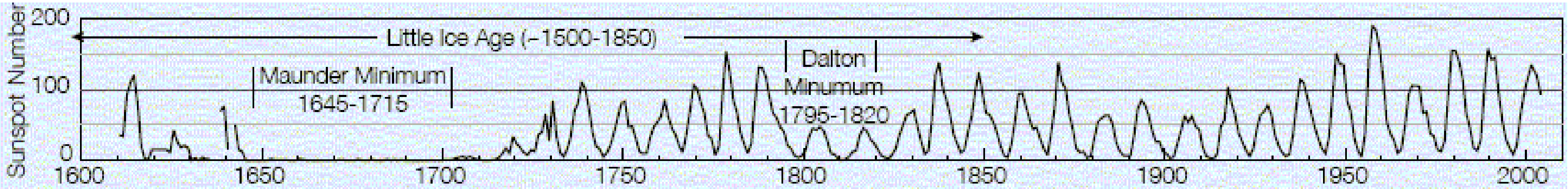
~10-11 year solar cycle
1-year periodicities

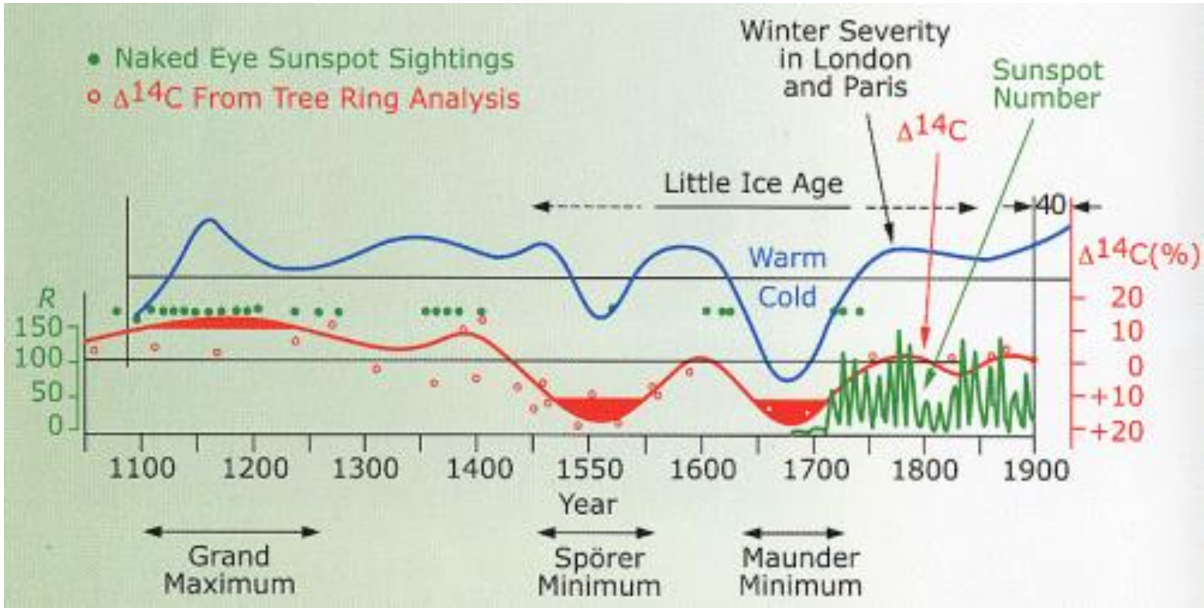


What is Space Climate then?

- Space Climate (SC) represents long-term patterns of Space Weather (SW) in a particular place in heliosphere due to changes in sun activity and system response.
- How long is “long”-term? SC change refers to periods over multiple solar cycles. SC variability is represented by periodic or intermittent changes related SW (cycle).

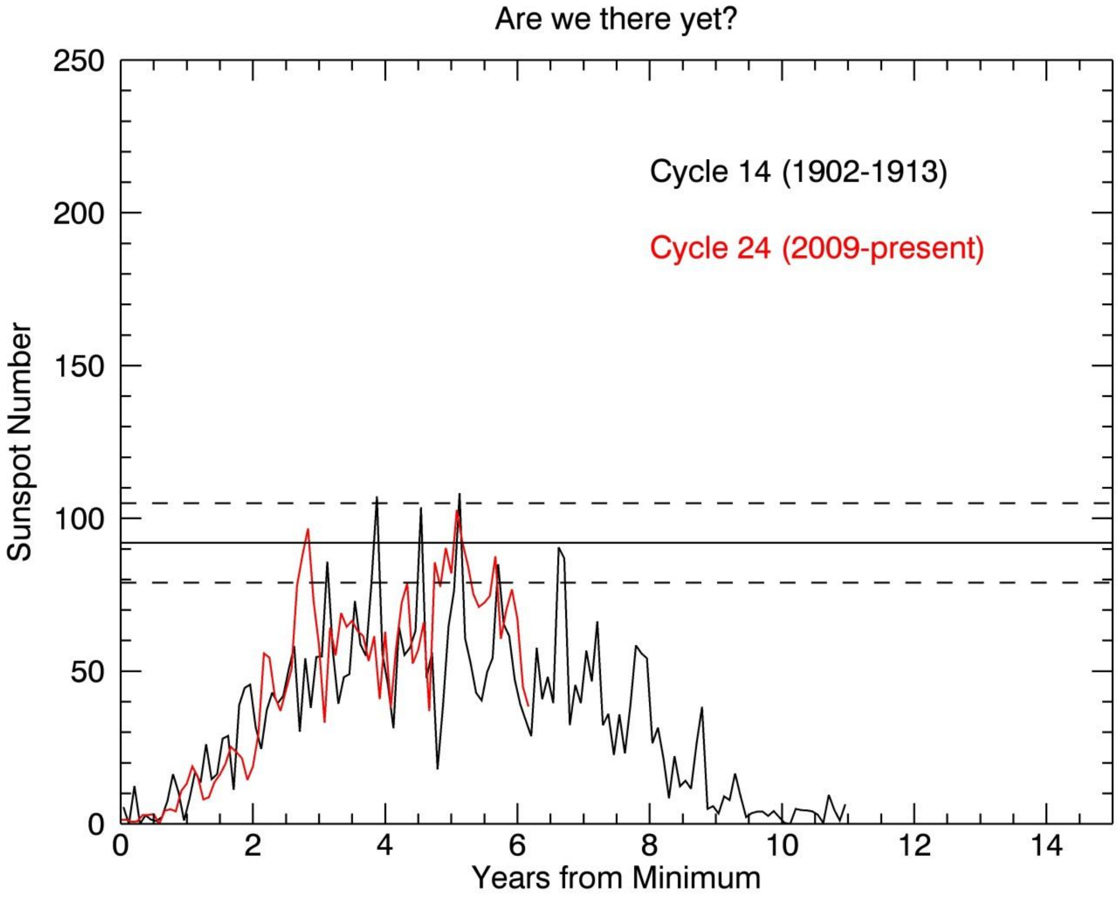
Why Study Space Climate?

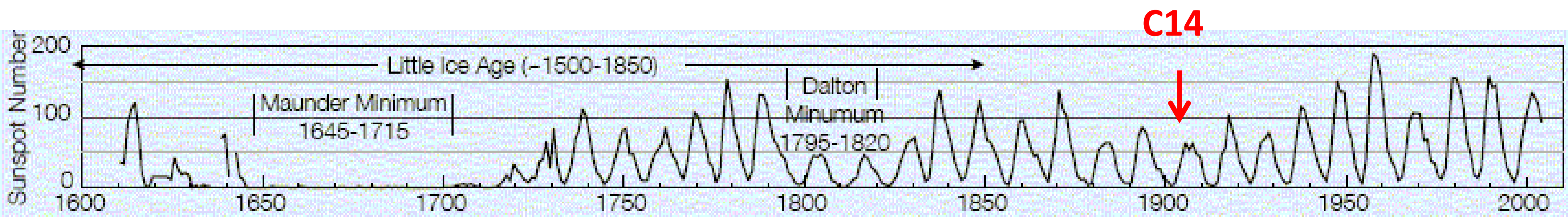




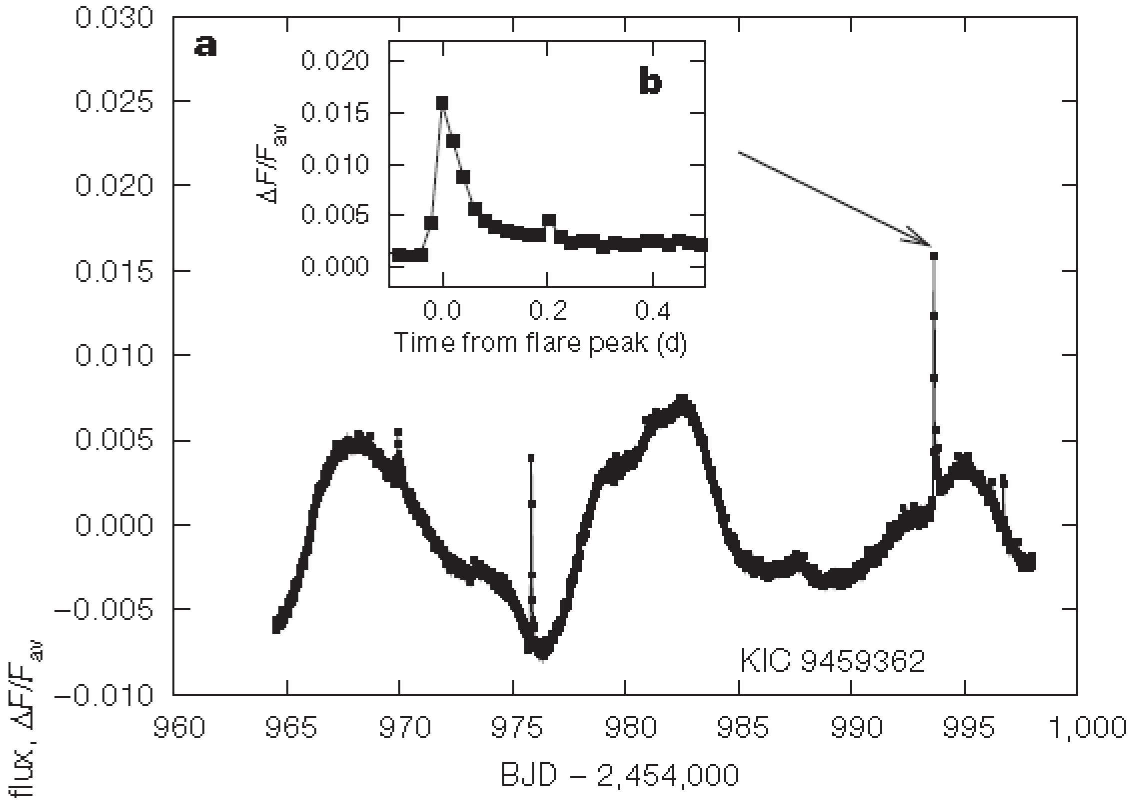
Pieter Bruegel the Elder, “The Hunters in the Snow”, 1565

Solar Cycle 24





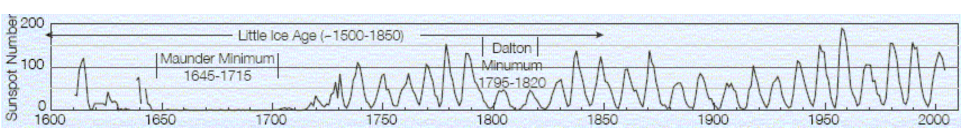
Stellar vs. Solar Flares



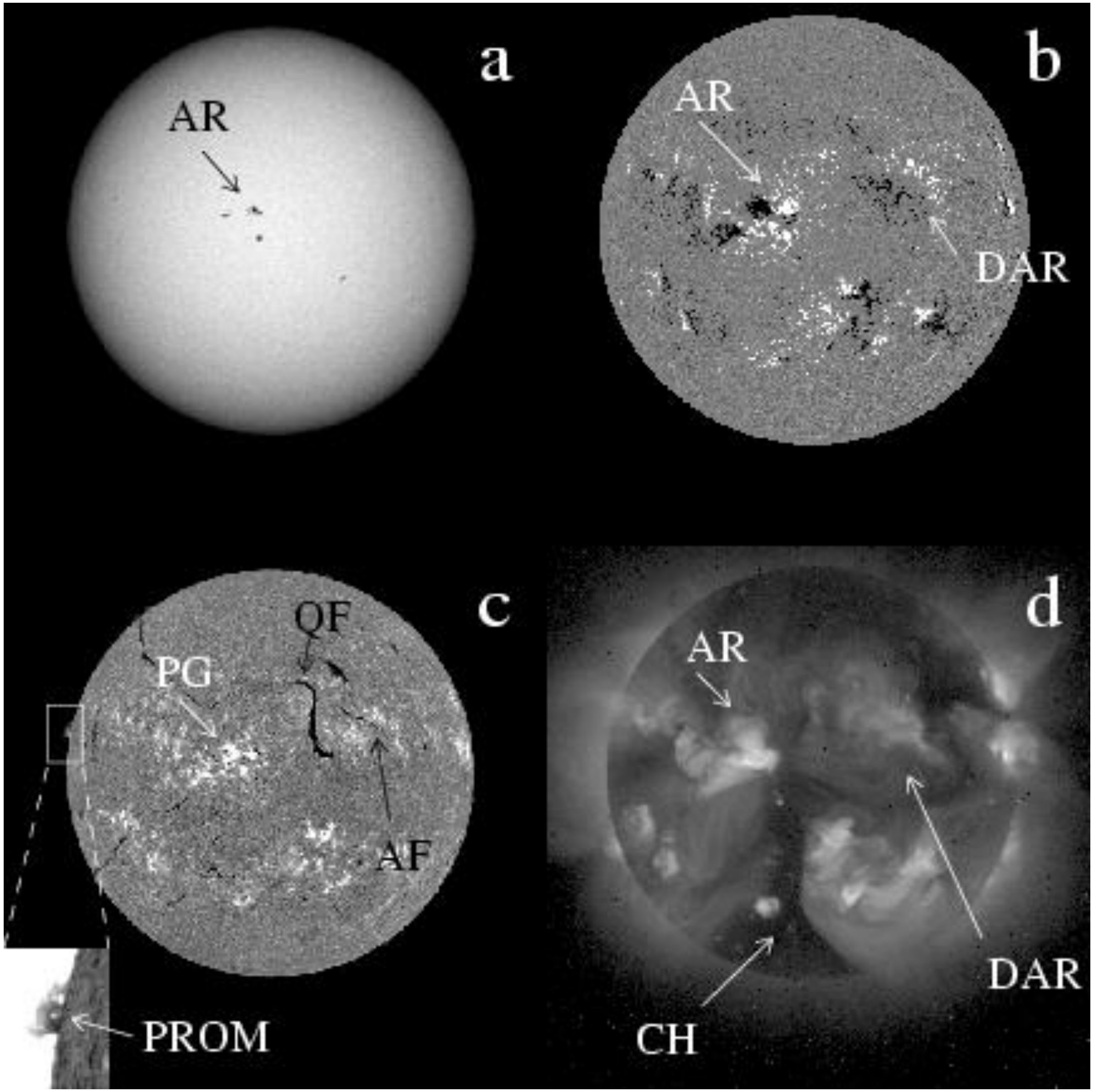
Maehara et al (2012) G-type main sequence star, 5.6 x 10^{34} erg (solar flares ~ 6 x 10^{32} erg)

What to Observe and for How Long?

- Integral measures of solar activity (SSN, plage index).
- Images in different wavelengths (H_α)
- Magnetograms!
- Sun-as-a-star (disk-integrated spectra, radio flux)



a. Photosphere
b. Magnetic field
c. Chromosphere
d. X-ray corona

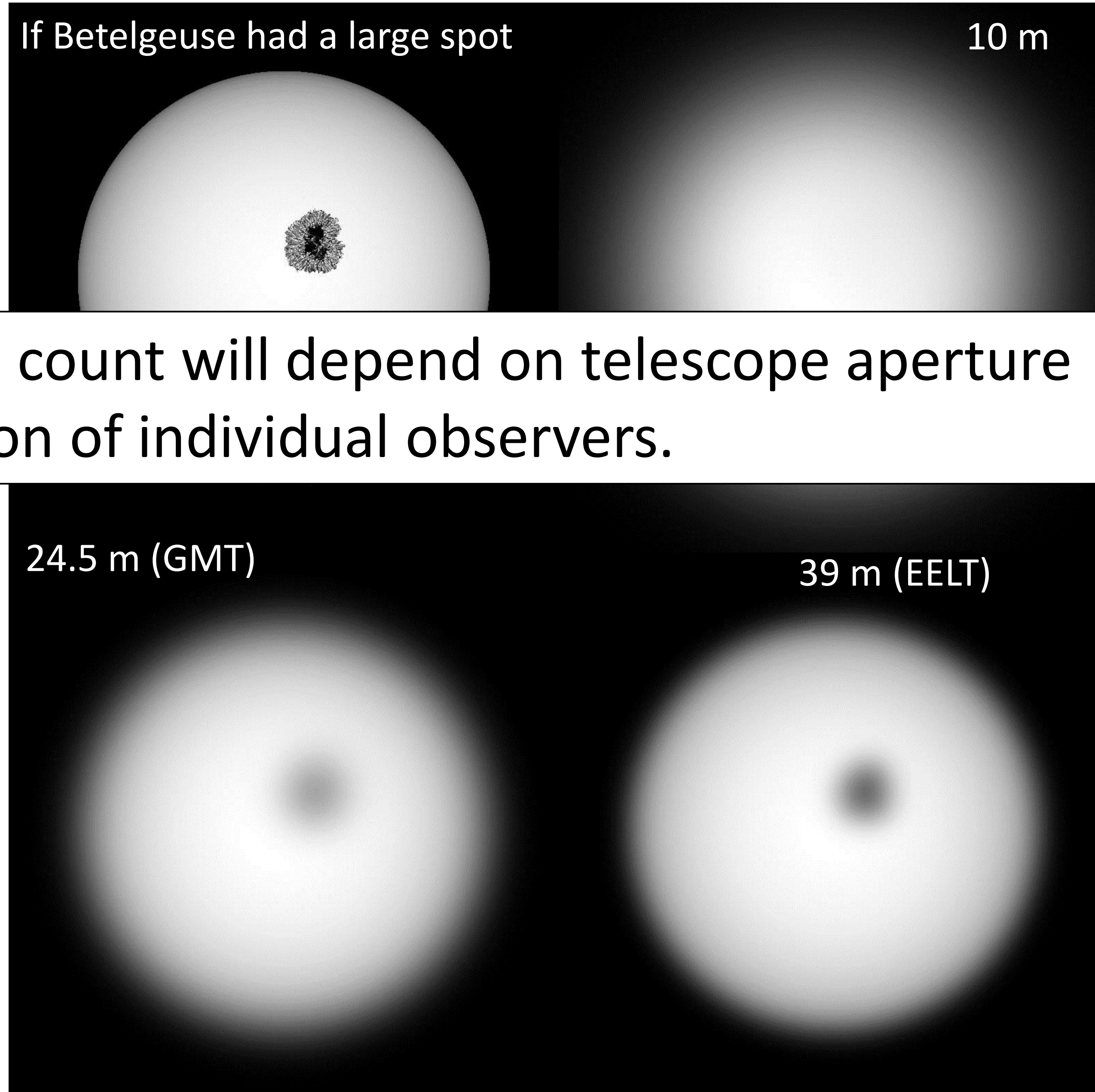


Telescope res

$$\theta = 1.22 \frac{\lambda}{D}$$

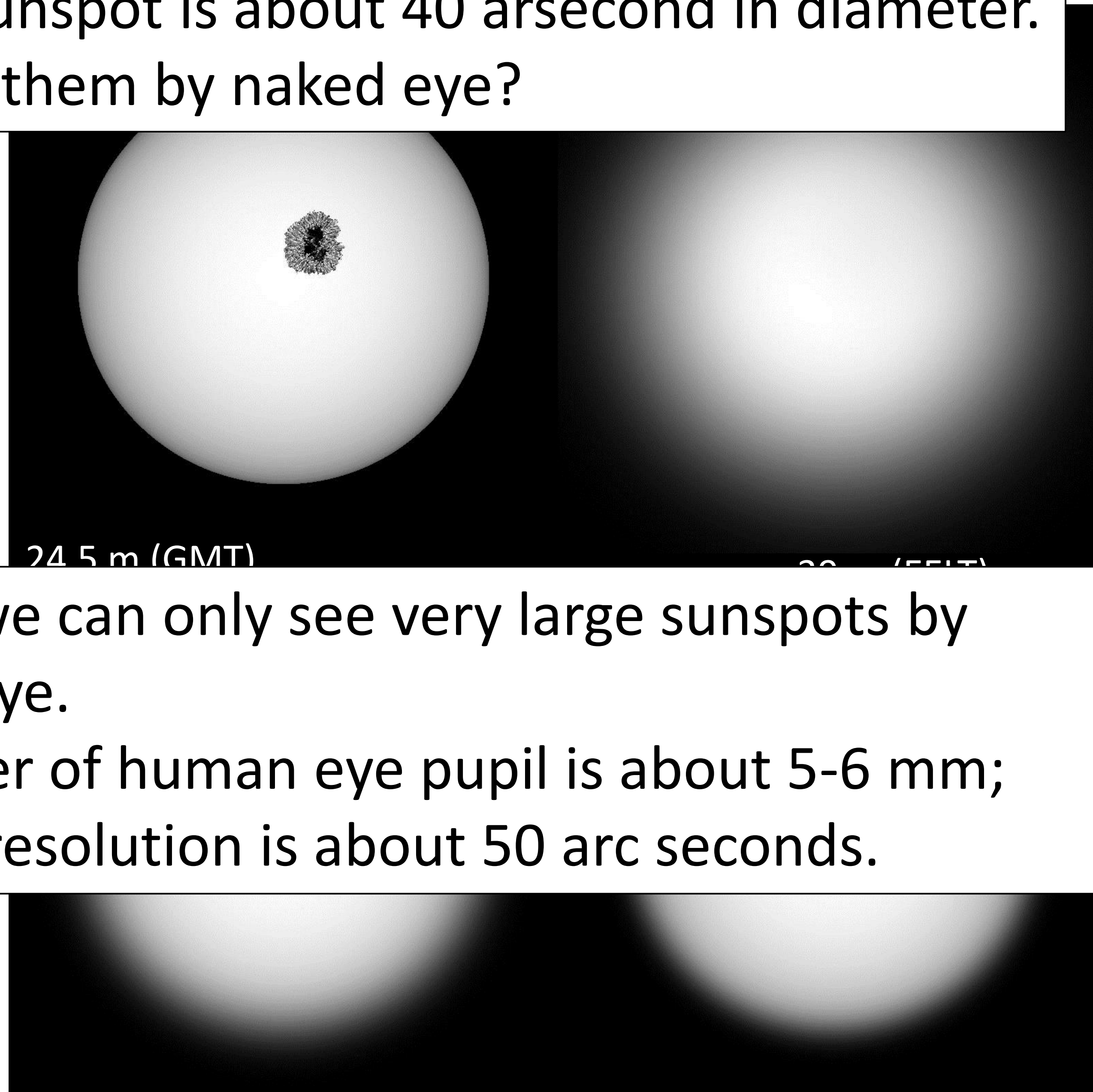
Ex: D=0.1 m, λ=5000A
θ=1.25 arc seconds

Contrast limit ~ 2-3%



Sunspot count will depend on telescope aperture and vision of individual observers.

Q: Typical sunspot is about 40 arsecond in diameter. Will we see them by naked eye?



Telescope resolution:

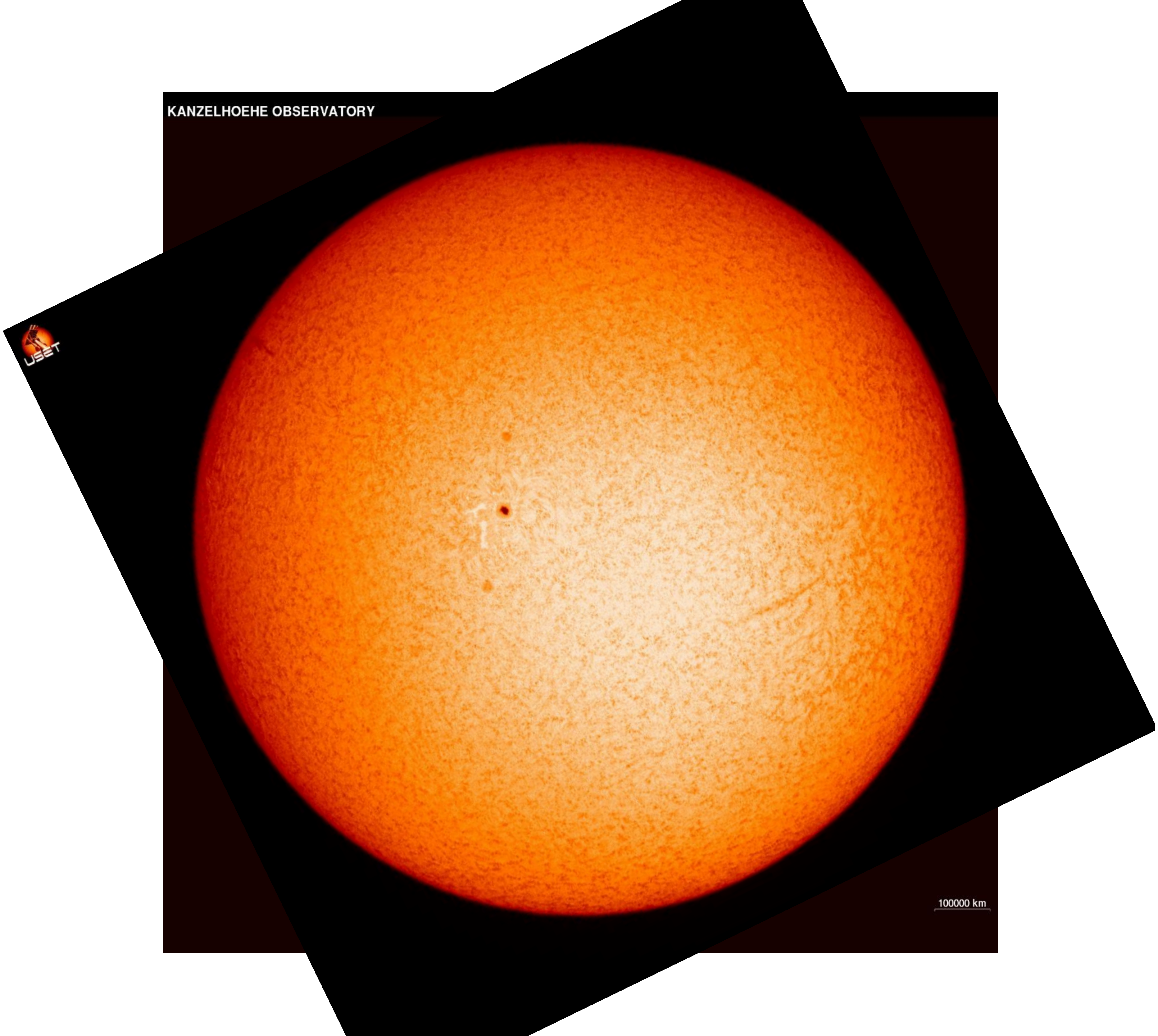
$$\theta = 1.22\frac{\lambda}{D}$$

Ex: D=0.1 m,

θ=1.25 arc se

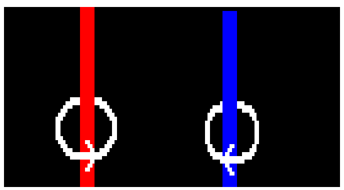
Contrast limi

A: No, we can only see very large sunspots by naked eye.
Diameter of human eye pupil is about 5-6 mm;
Spatial resolution is about 50 arc seconds.

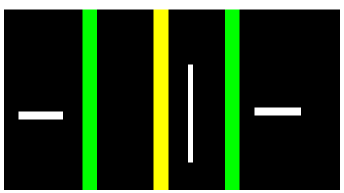

KANZELHOEHE OBSERVATORY
USET
100000 km

Measuring Magnetic Field

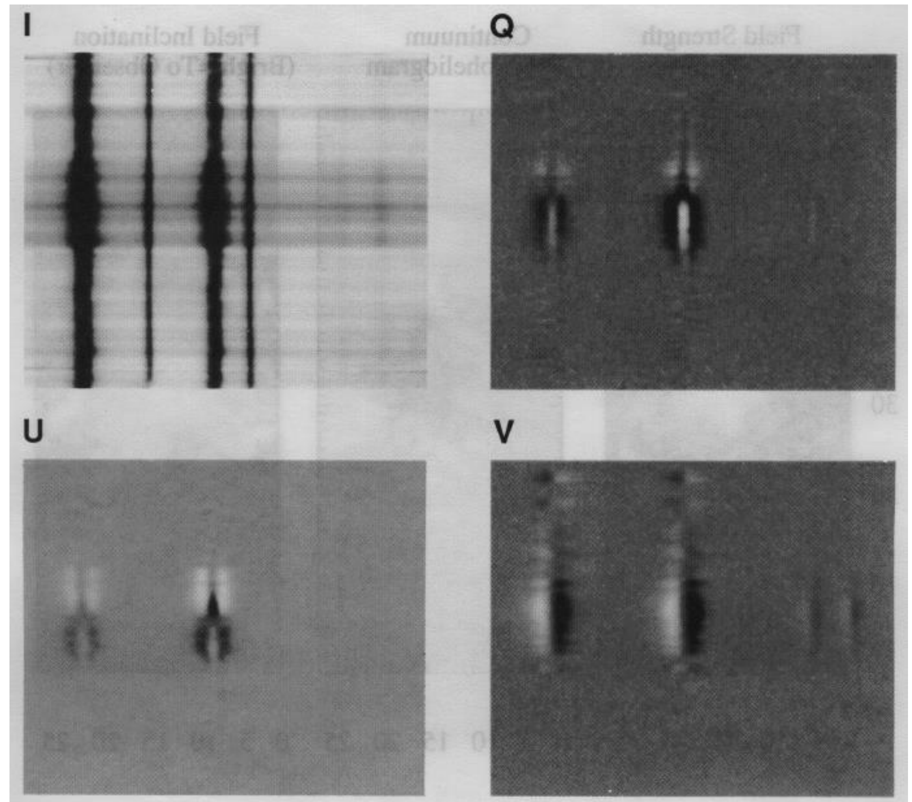
spetral line



B-lonitudinal

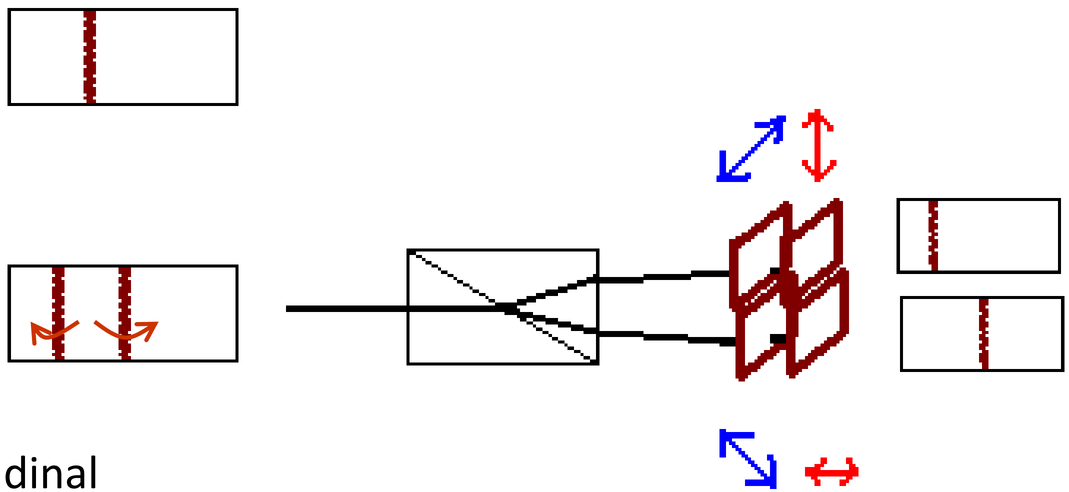


B-transverse



Simple Polarization Analyzer

No magnetic field

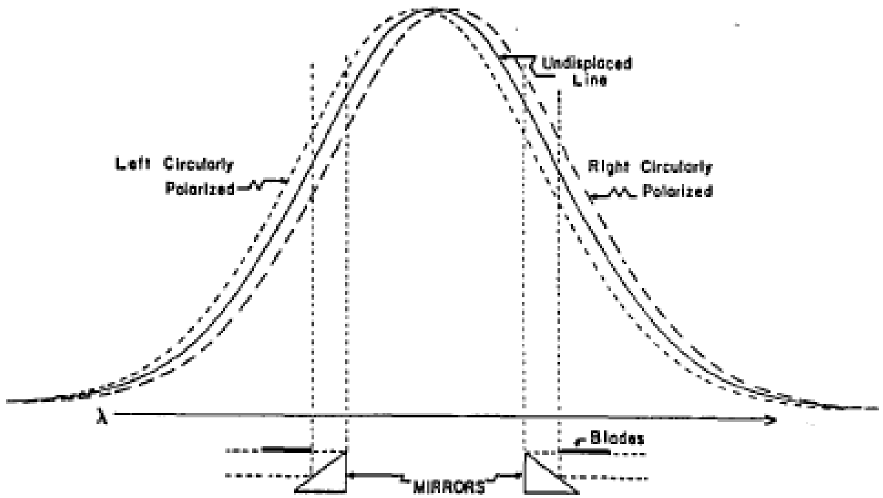


Longitudinal field

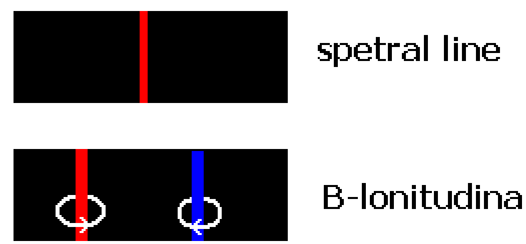
$$\Delta\lambda_H = 4.67\times10^{-5} g\cdot H\cdot\lambda_0^2$$

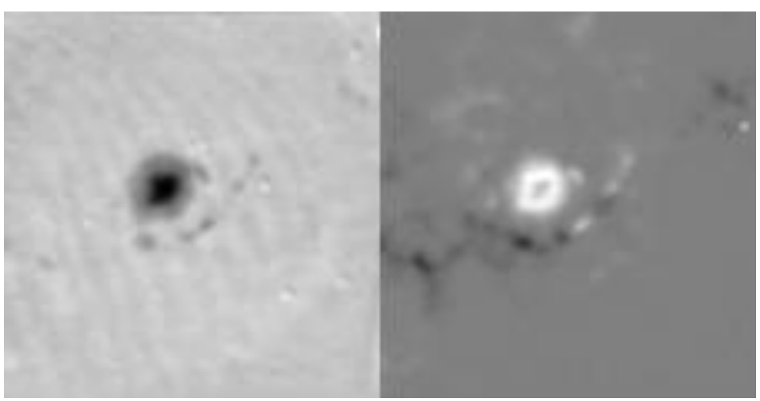
Wollaston + ¼ WP +Polarizer

Babcock-type magnetograph

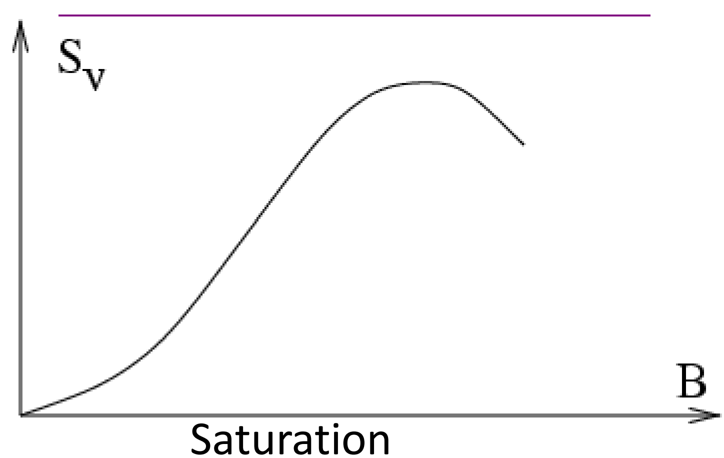


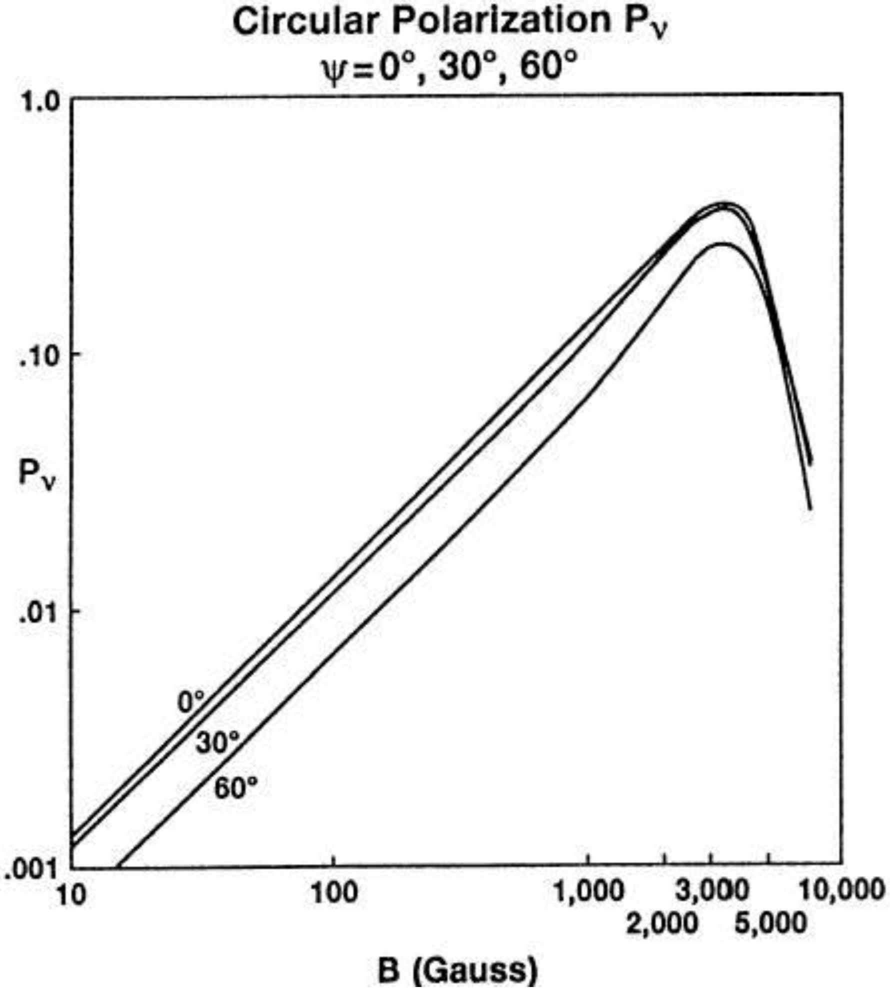
$$\Delta\lambda_H = 4.67\times10^{-5}\, g\cdot H\cdot\lambda_0^2$$

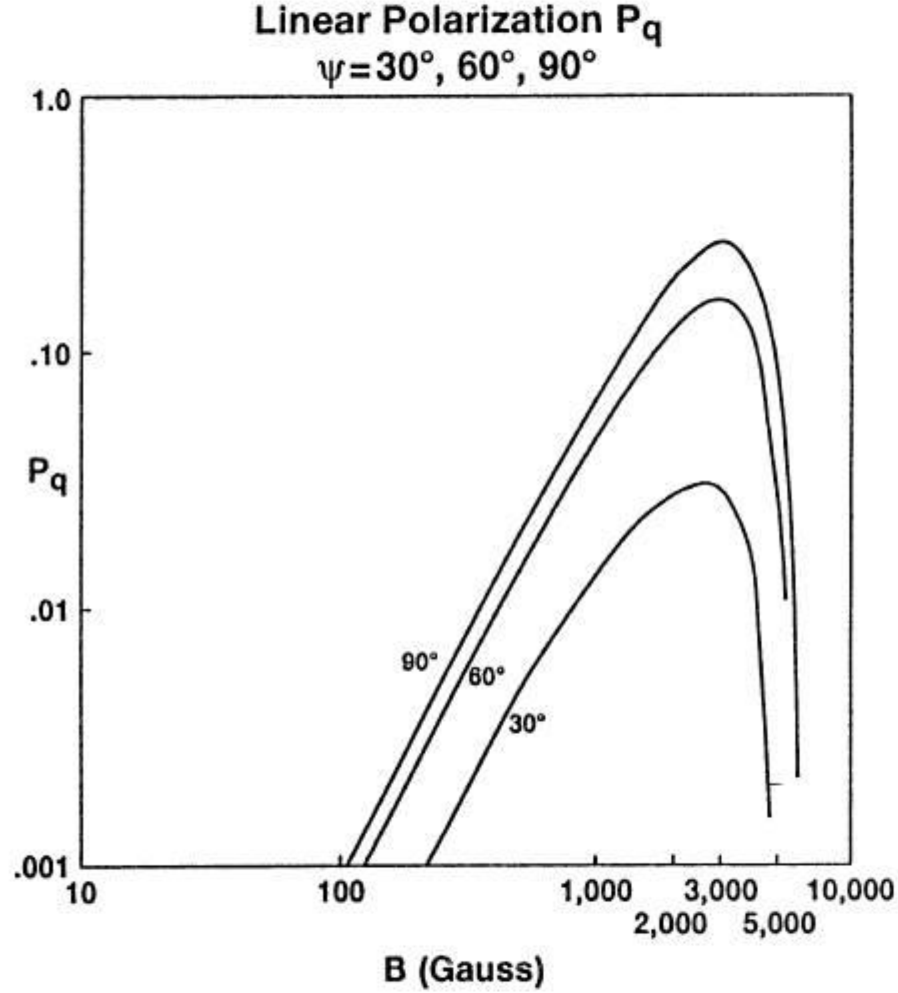




I-continuum B-longitudinal







$$|B|\cos\gamma = C_1(\Delta\lambda)k(\Delta\lambda)(S_V(\Delta\lambda) - S_{V0})$$

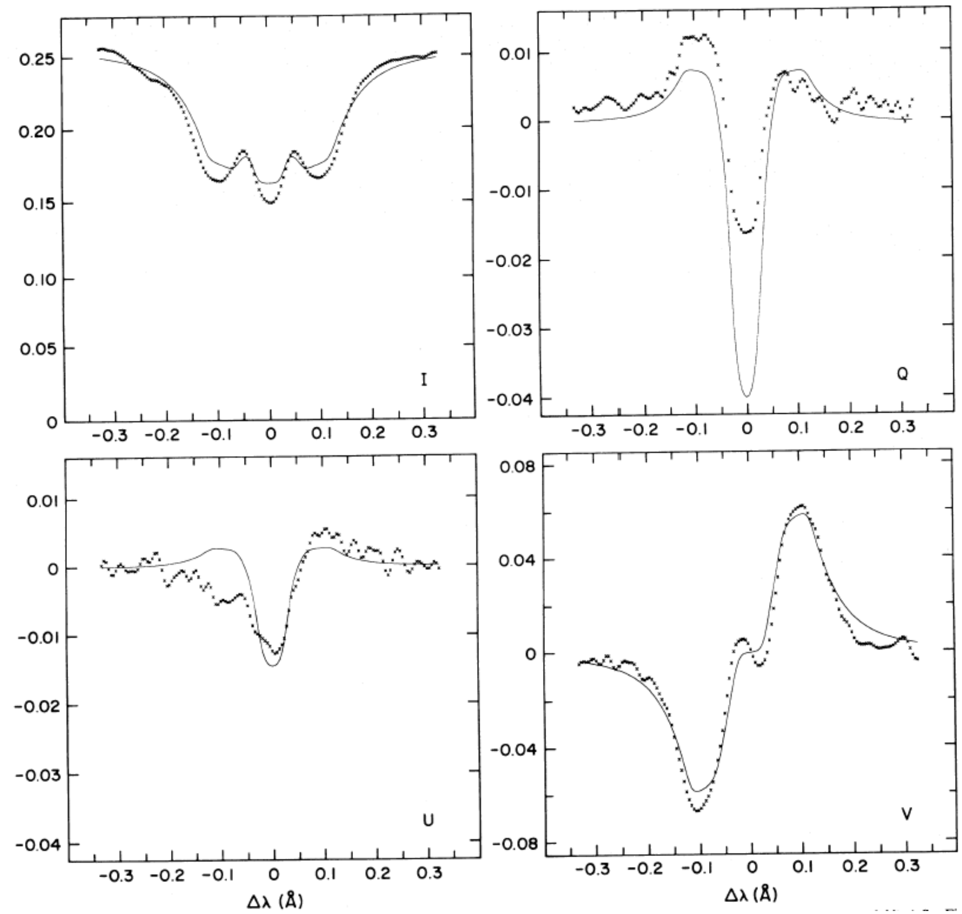
$$|B|\sin\gamma = C_2(\Delta\lambda)\sqrt{k(\Delta\lambda)(S_Q(\Delta\lambda) - S_{Q0})}$$

$$S_Q = \sqrt{\left(\left\langle \frac{Q}{I} \right\rangle\right)^2 + \left(\left\langle \frac{U}{I} \right\rangle\right)^2}$$

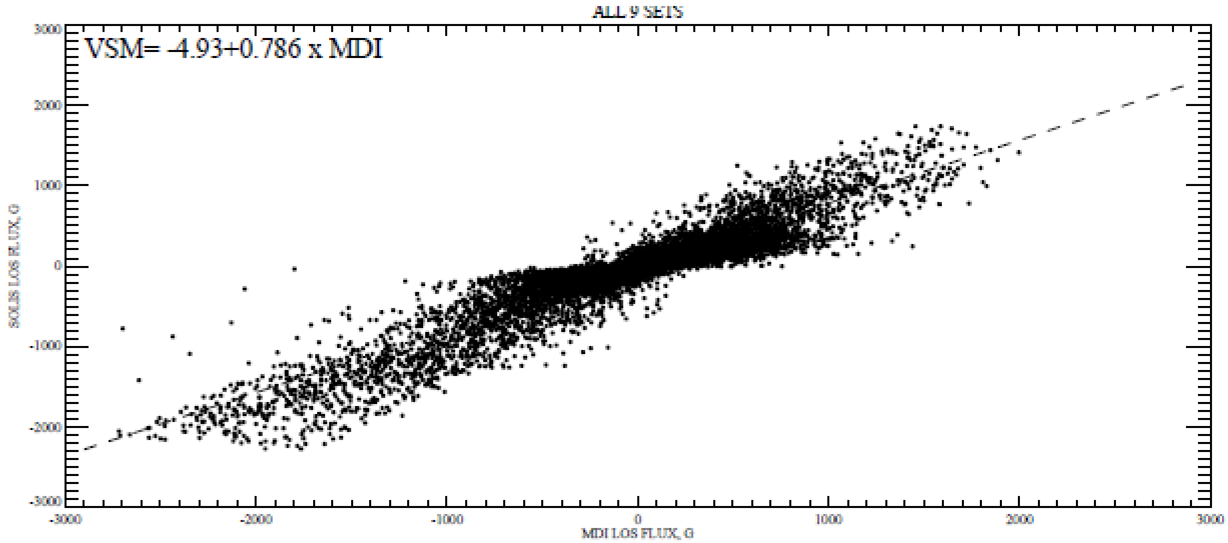
$$S_V = \left\langle \frac{V}{I} \right\rangle$$

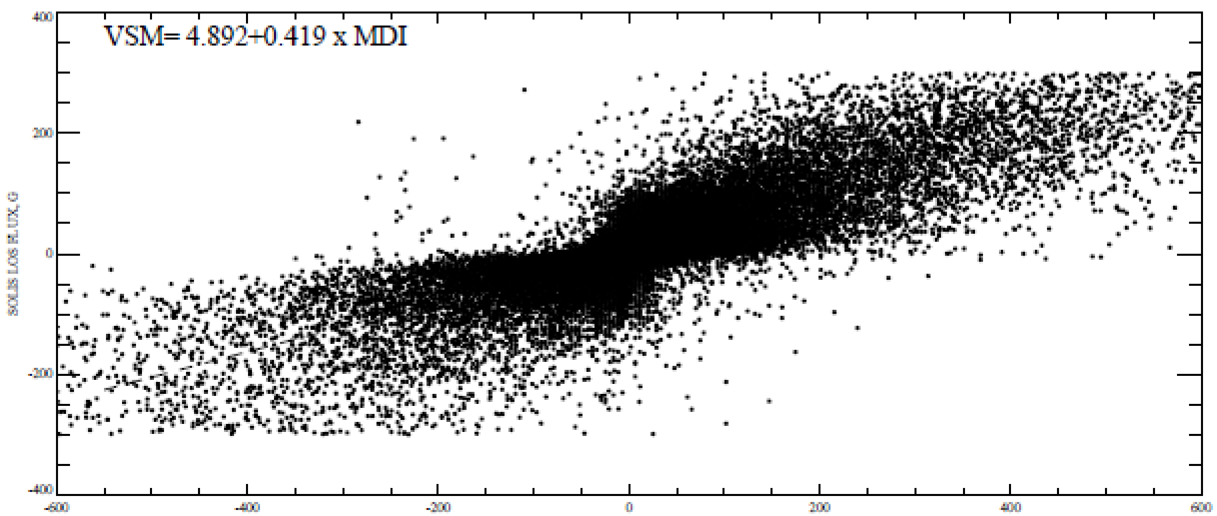
Stokes Polarimeter

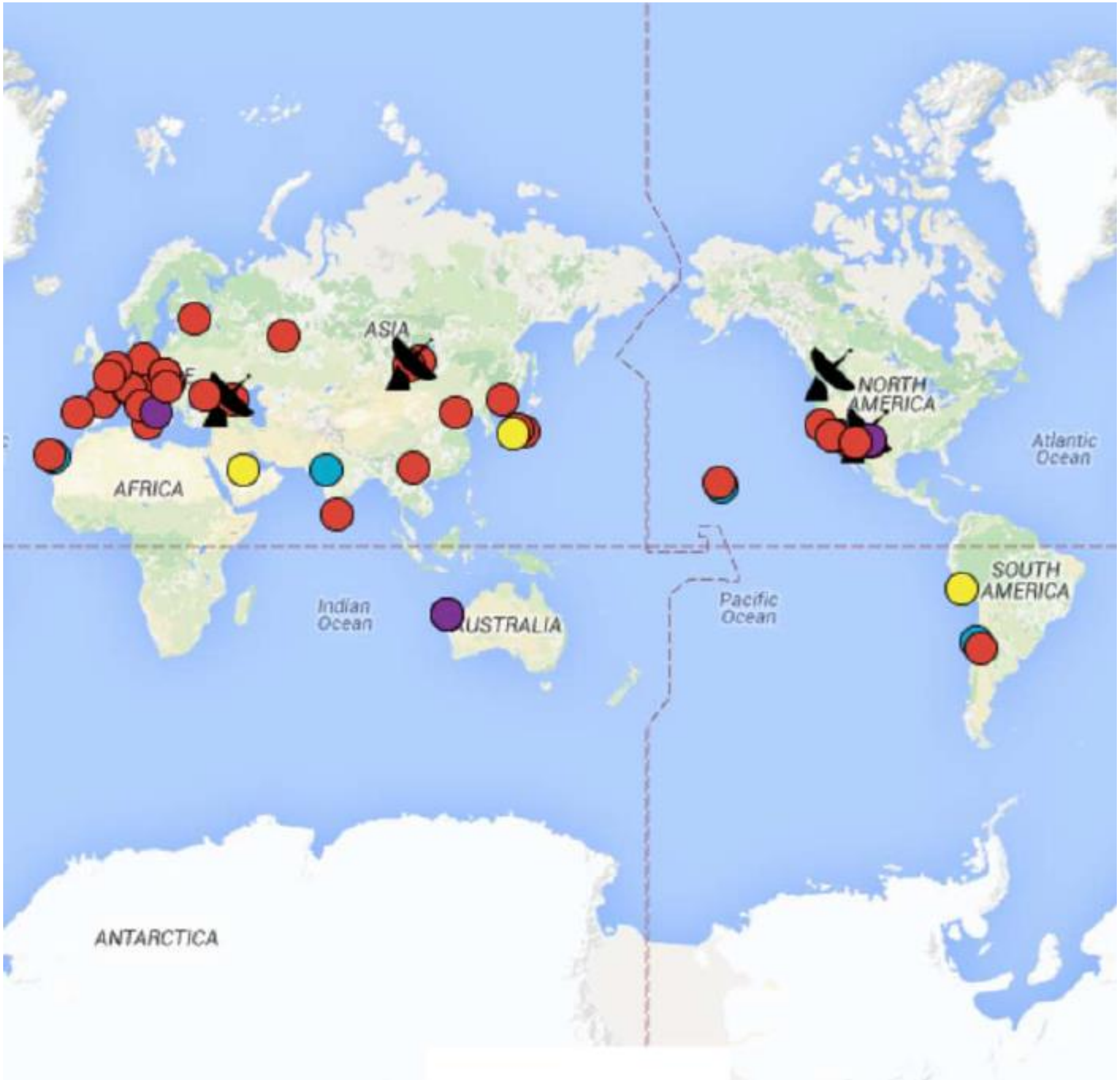
-Spectral synthesis
 (difficult to automate)
-Spectral inversion
 (restrict number of parameters)
$|B|$, γ, χ, λ_c, Γ, $\Delta\lambda_D$, B_1, η_0

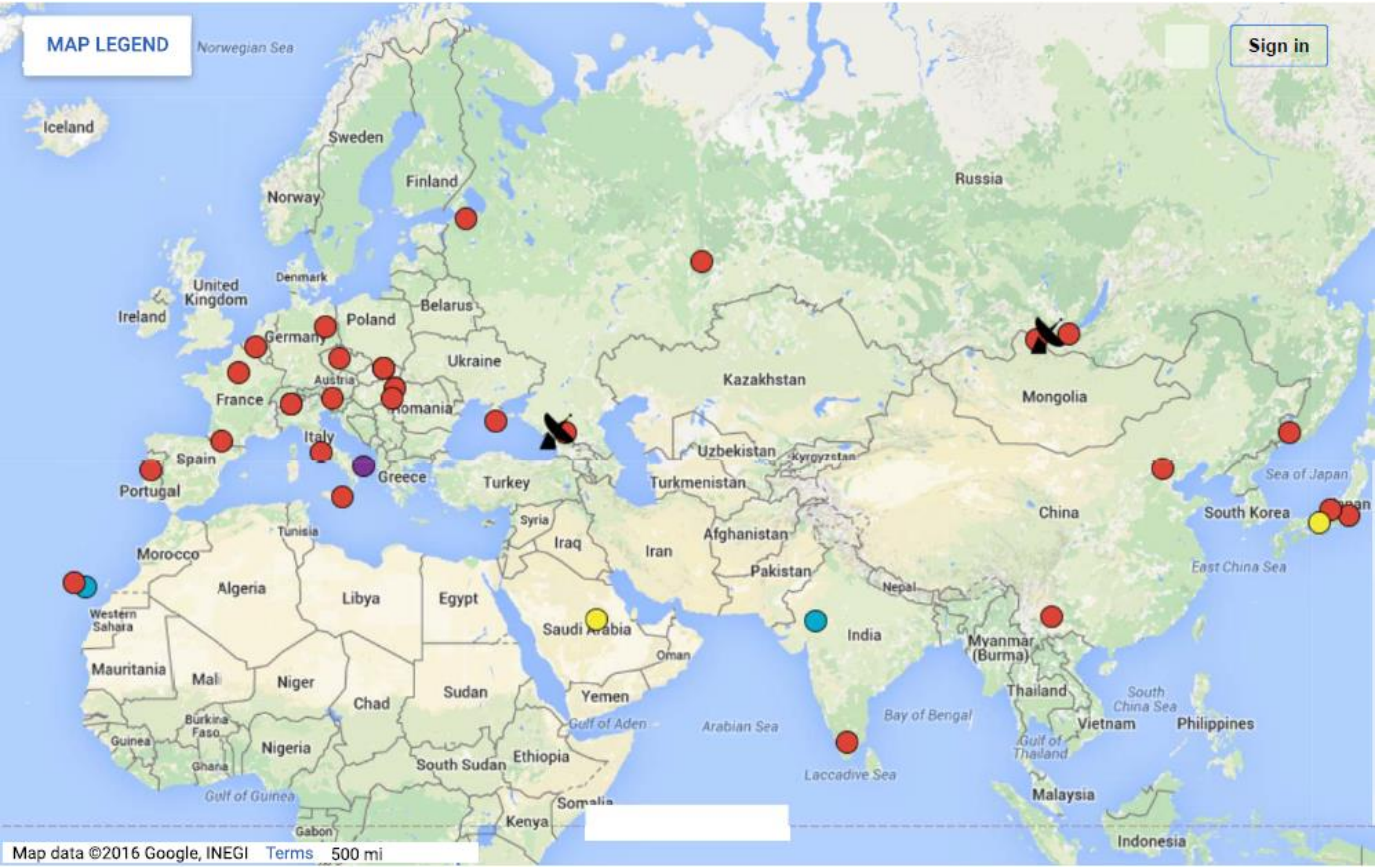


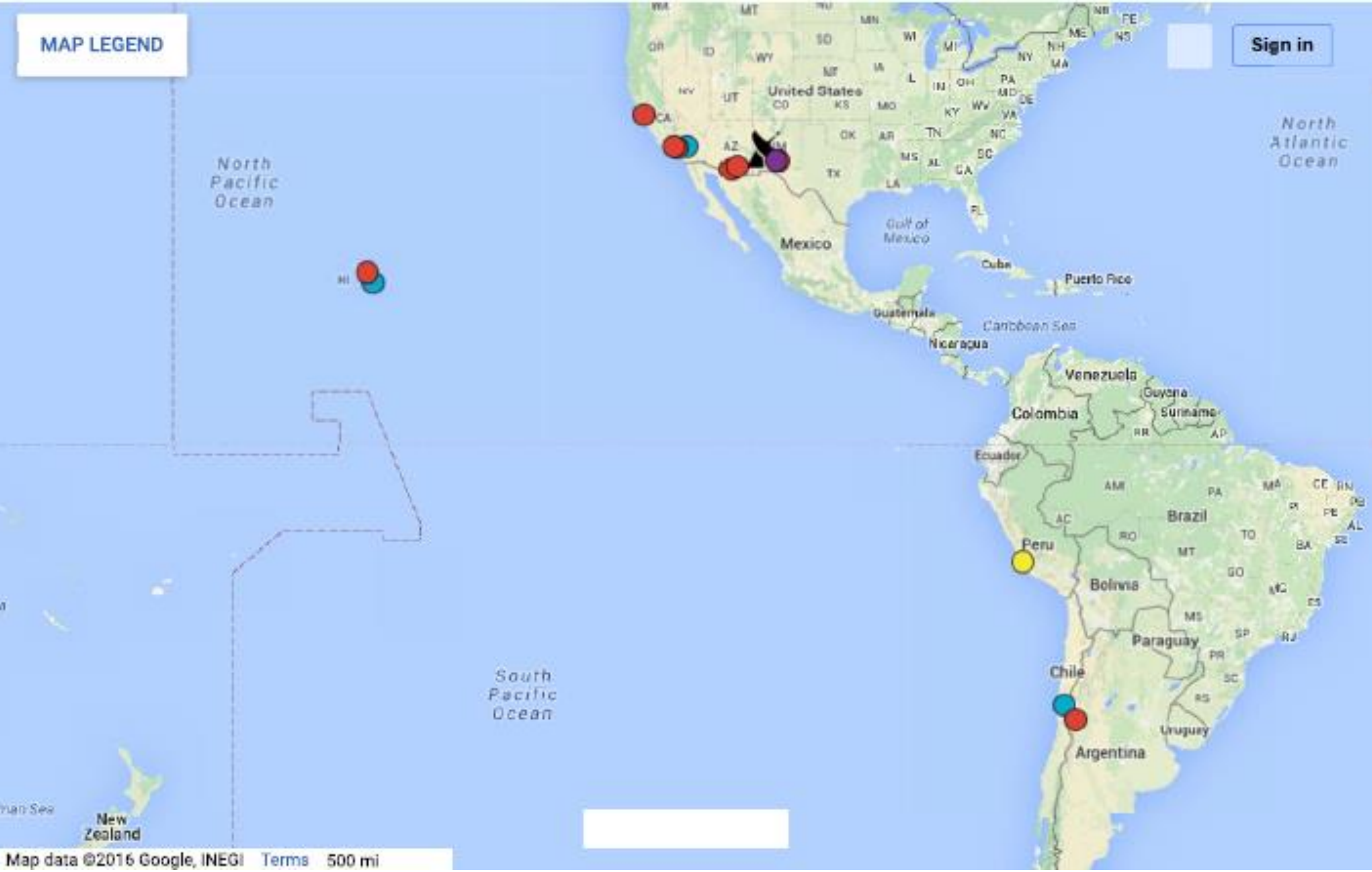
Skumanich & Lites (1987)


ALL 9 SETS
VSM= -4.93+0.786 x MDI
SOLIS LOS FLUX, G
MDI LOS FLUX, G


VSM= 4.892+0.419 x MDI
SOLIS LOS FLUX, G
MDI LOS FLUX, G


ASIA
NORTH AMERICA
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
Pacific Ocean
ANTARCTICA


MAP LEGEND
Sign in
Norwegian Sea
Iceland
Sweden
Finland
Norway
Russia
Denmark
United Kingdom
Ireland
Belarus
Poland
Germany
Ukraine
Austria
France
Romania
Kazakhstan
Mongolia
Italy
Spain
Portugal
Greece
Turkey
Uzbekistan
Kyrgyzstan
Turkmenistan
Sea of Japan
South Korea
China
Tunisia
Syria
Iraq
Iran
Afghanistan
Morocco
Algeria
Libya
Egypt
Pakistan
East China Sea
Nepal
Western Sahara
Saudi Arabia
India
Myanmar (Burma)
Oman
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Thailand
South China Sea
Burkina Faso
Gulf of Aden
Arabian Sea
Bay of Bengal
Vietnam
Philippines
Guinea
Nigeria
South Sudan
Ethiopia
Gulf of Thailand
Ghana
Laccadive Sea
Malaysia
Gulf of Guinea
Somalia
Kenya
Gabon
Indonesia
Map data ©2016 Google, INEGI
Terms
500 mi

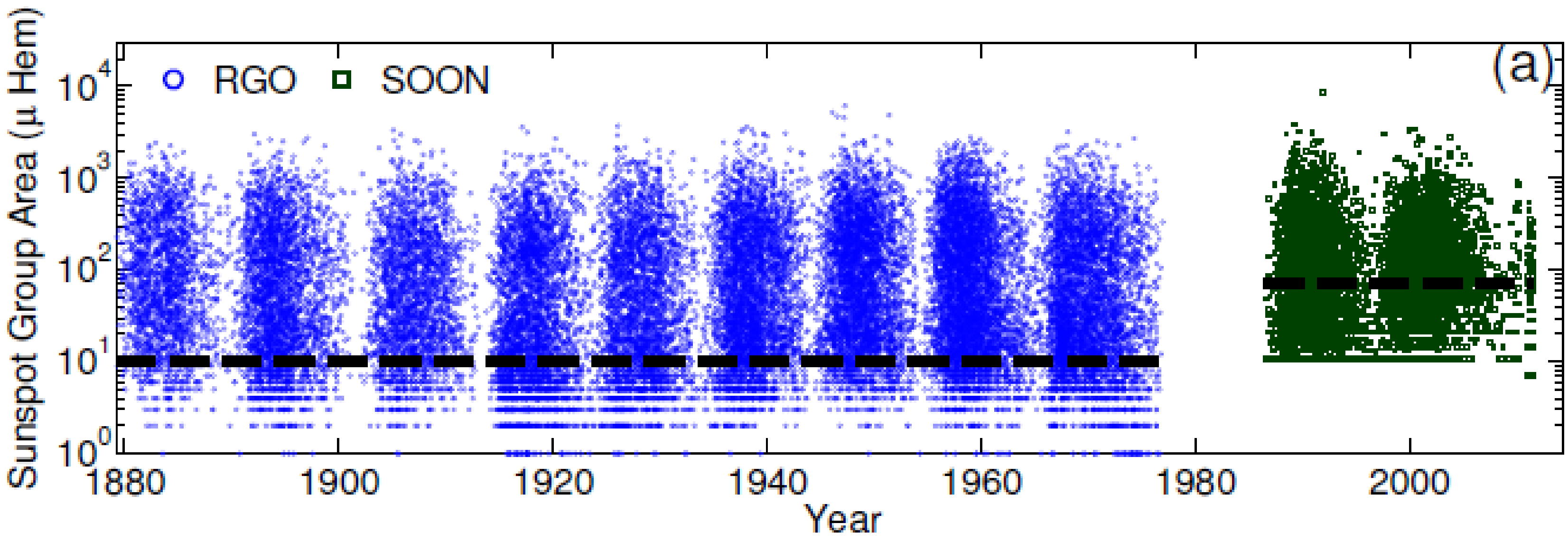

MAP LEGEND
Sign in
North Pacific Ocean
North Atlantic Ocean
United States
Mexico
Gulf of Mexico
Cuba
Puerto Rico
Guatemala
Caribbean Sea
Nicaragua
Venezuela
Guyana
Suriname
Colombia
Ecuador
Brazil
Peru
Bolivia
Paraguay
Chile
Uruguay
Argentina
South Pacific Ocean
New Zealand
Map data ©2016 Google, INEGI
Terms
500 mi

Some current issues

- Long-term SC datasets are often *adhoc* collections.
- Lack of coordination between national programs/observatories (non-uniform/ duplicate data).
- No critical evaluation (what do we need to observe, what is missing etc).
- Lack of long-term planning (not well-defined goals, diminishing funding, aging facilities).
- Data preservation...

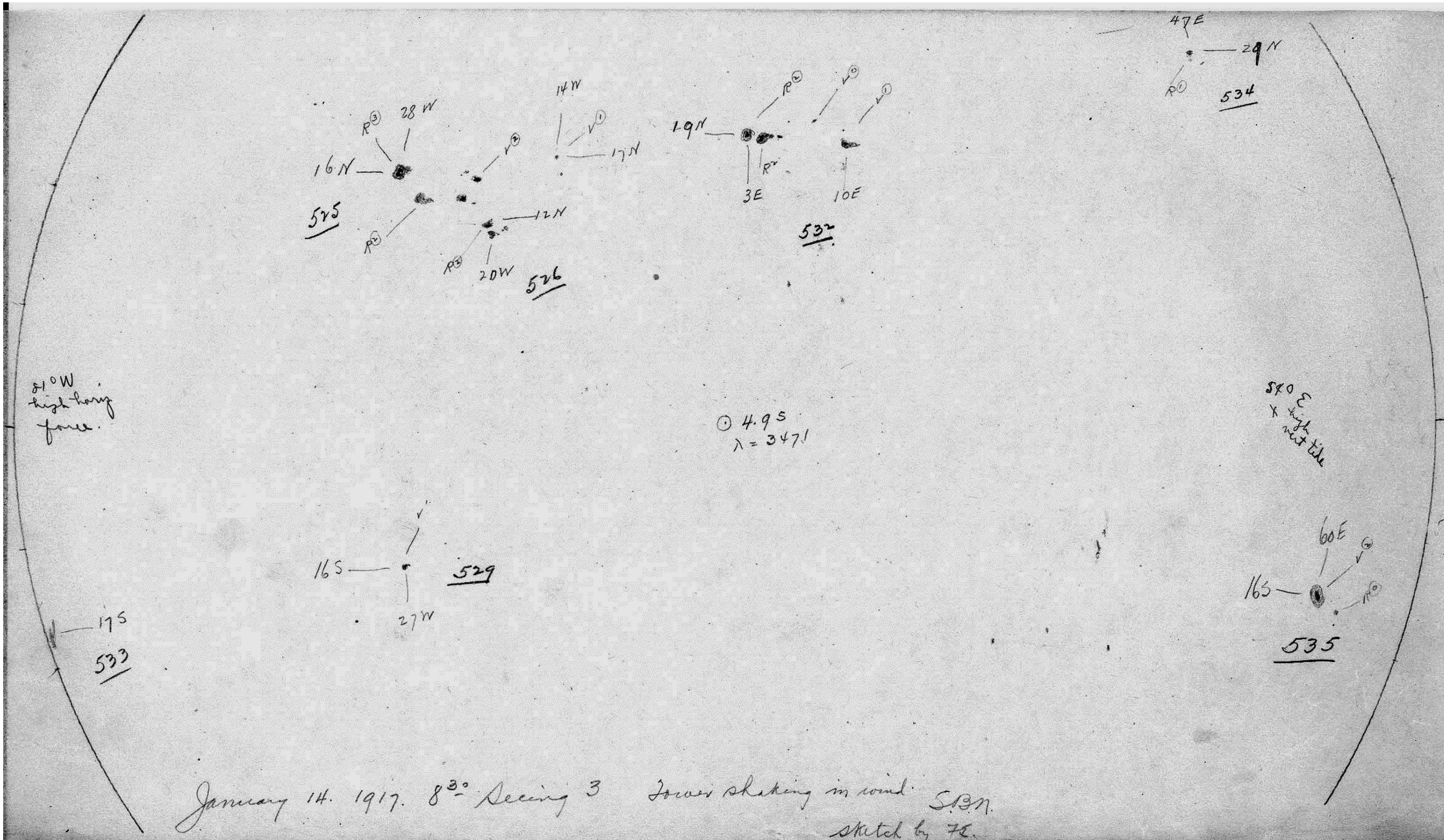
Data non-uniformity: different observatories

- April 1874-1976 measurements of the area and position of sunspots from the Royal Greenwich Observatory (RGO).
- In 1874–1885: the RGO, + Harvard College, the Melbourne Observatory, Dehra Dûn in India, and the Royal Alfred Observatory, Mauritius).

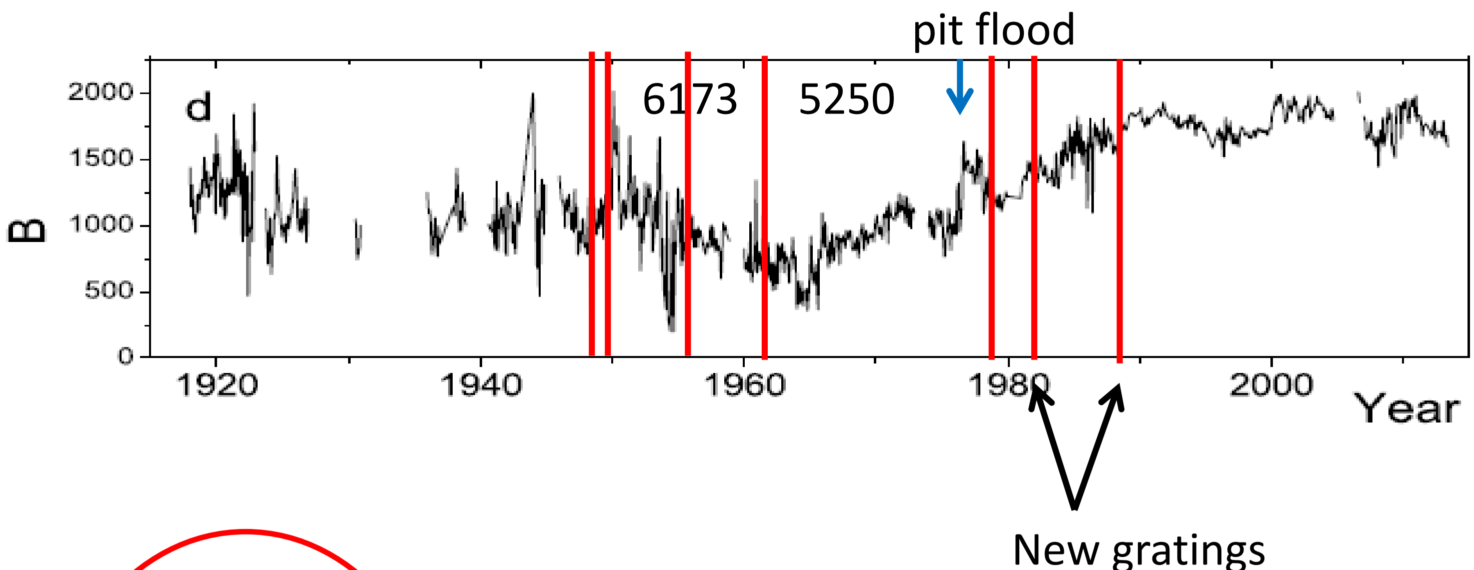


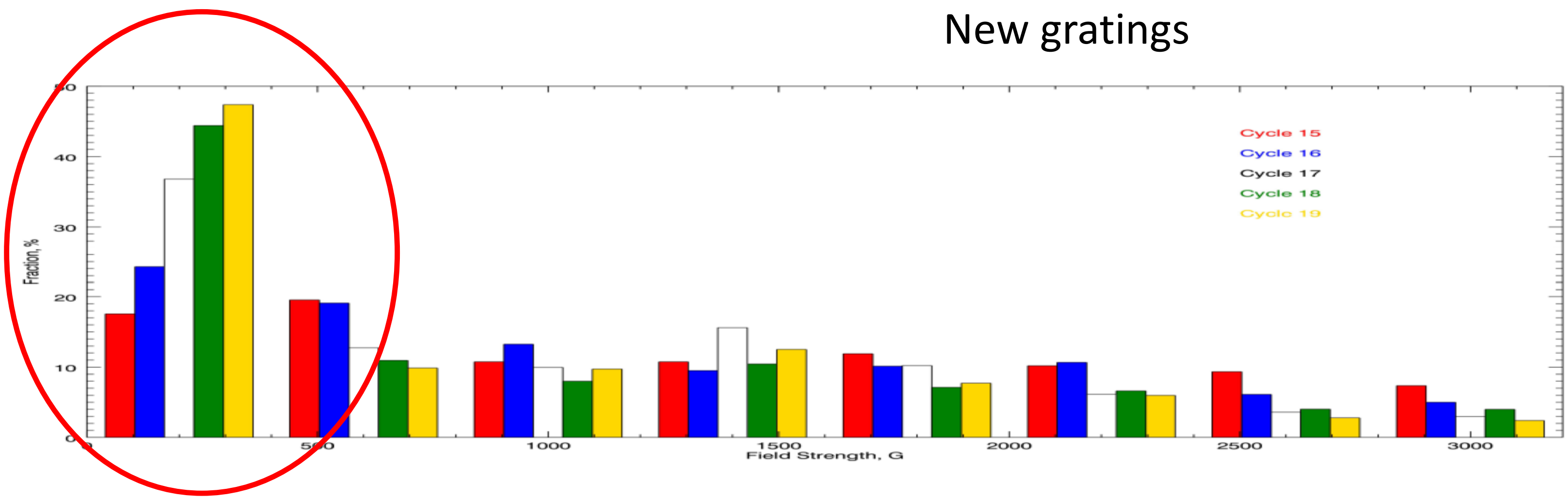
- In 1977, the US Air Force (USAF) started compiling data on sunspot areas, active regions and their flare activity using the observations from its Solar Optical Observing Network (SOON).

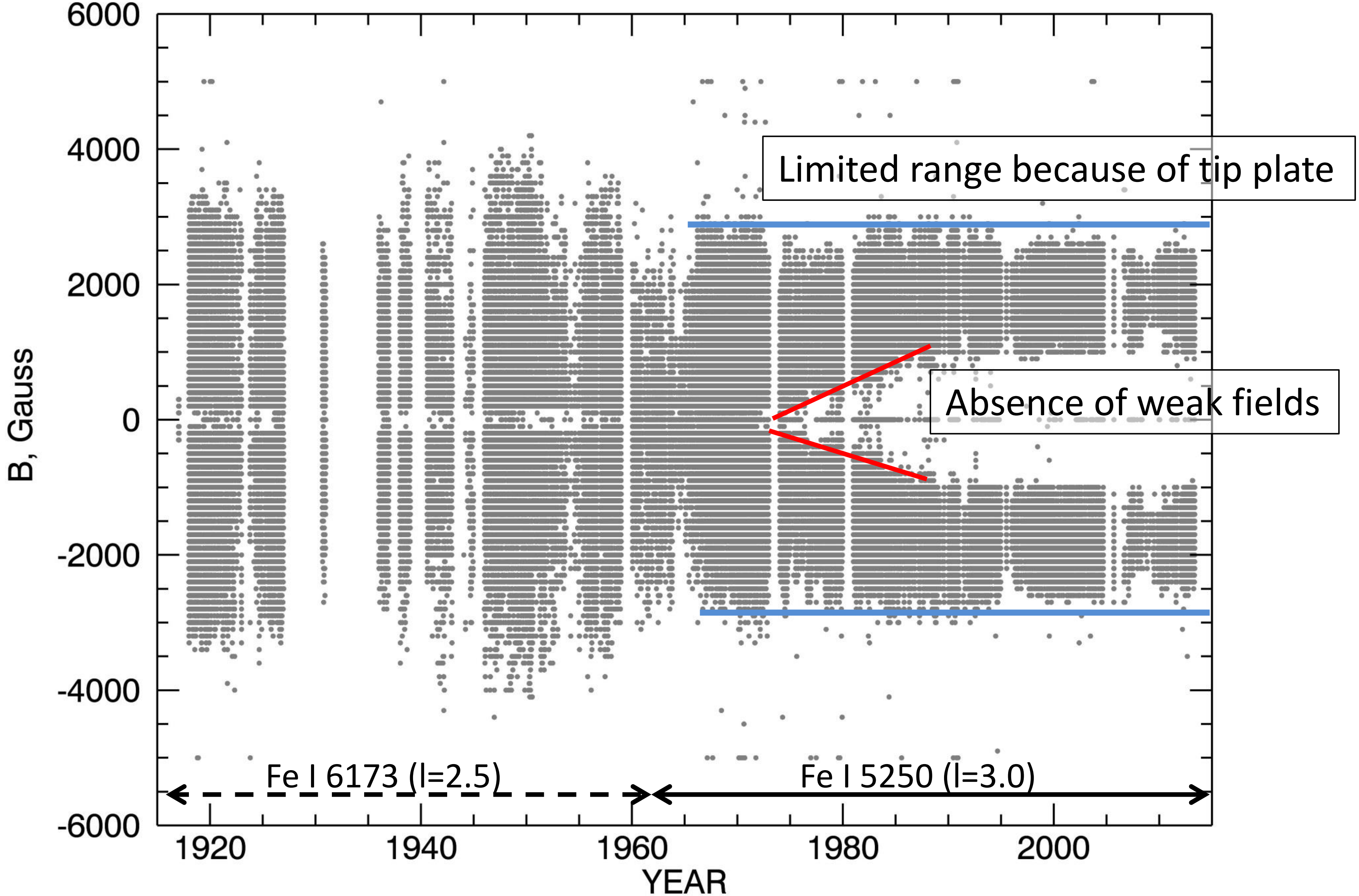
Data non-uniformity: same observatory



Beware of Systematics in Historical Data.







6000
4000
2000
0
-2000
-4000
-6000
B, Gauss
1920
1940
1960
1980
2000
YEAR
Limited range because of tip plate
Absence of weak fields
Fe I 6173 (l=2.5)
Fe I 5250 (l=3.0)

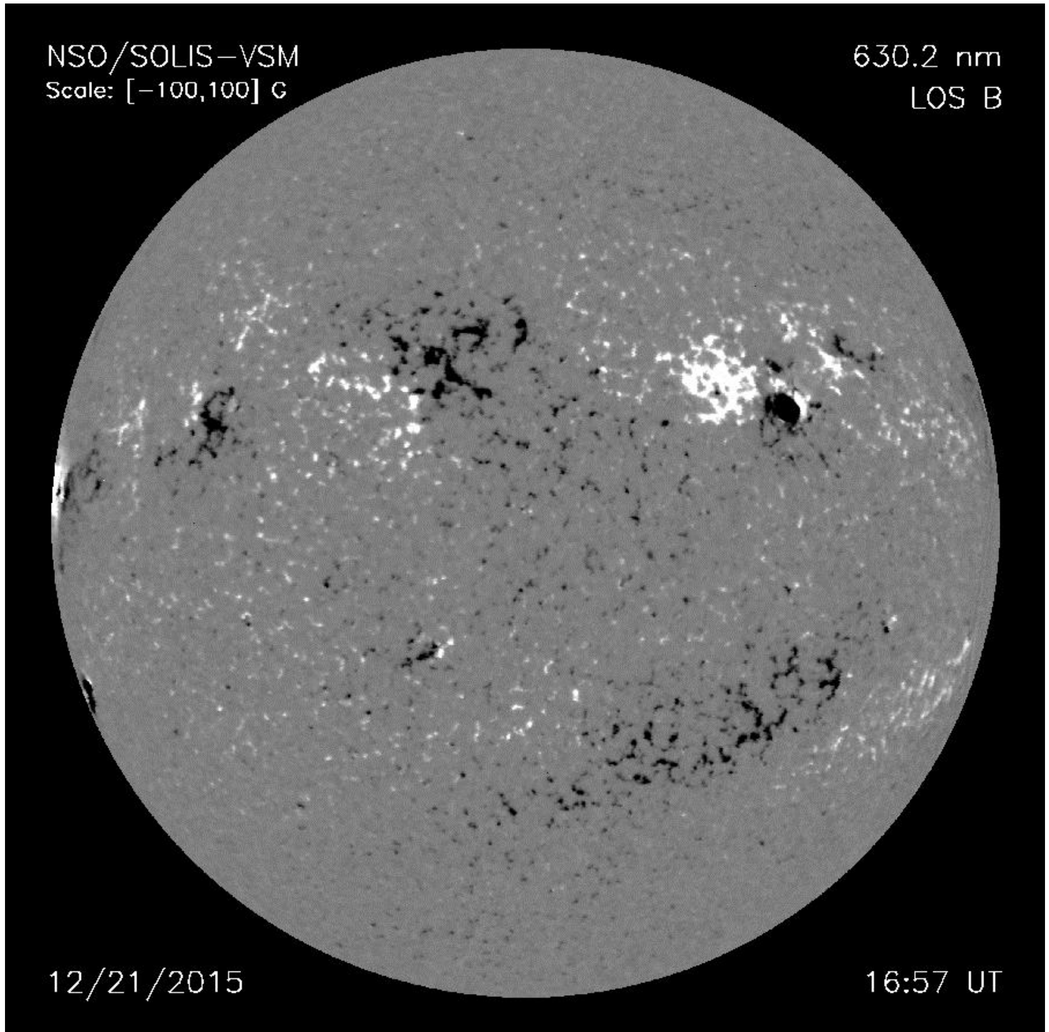
What to record about the SC data?

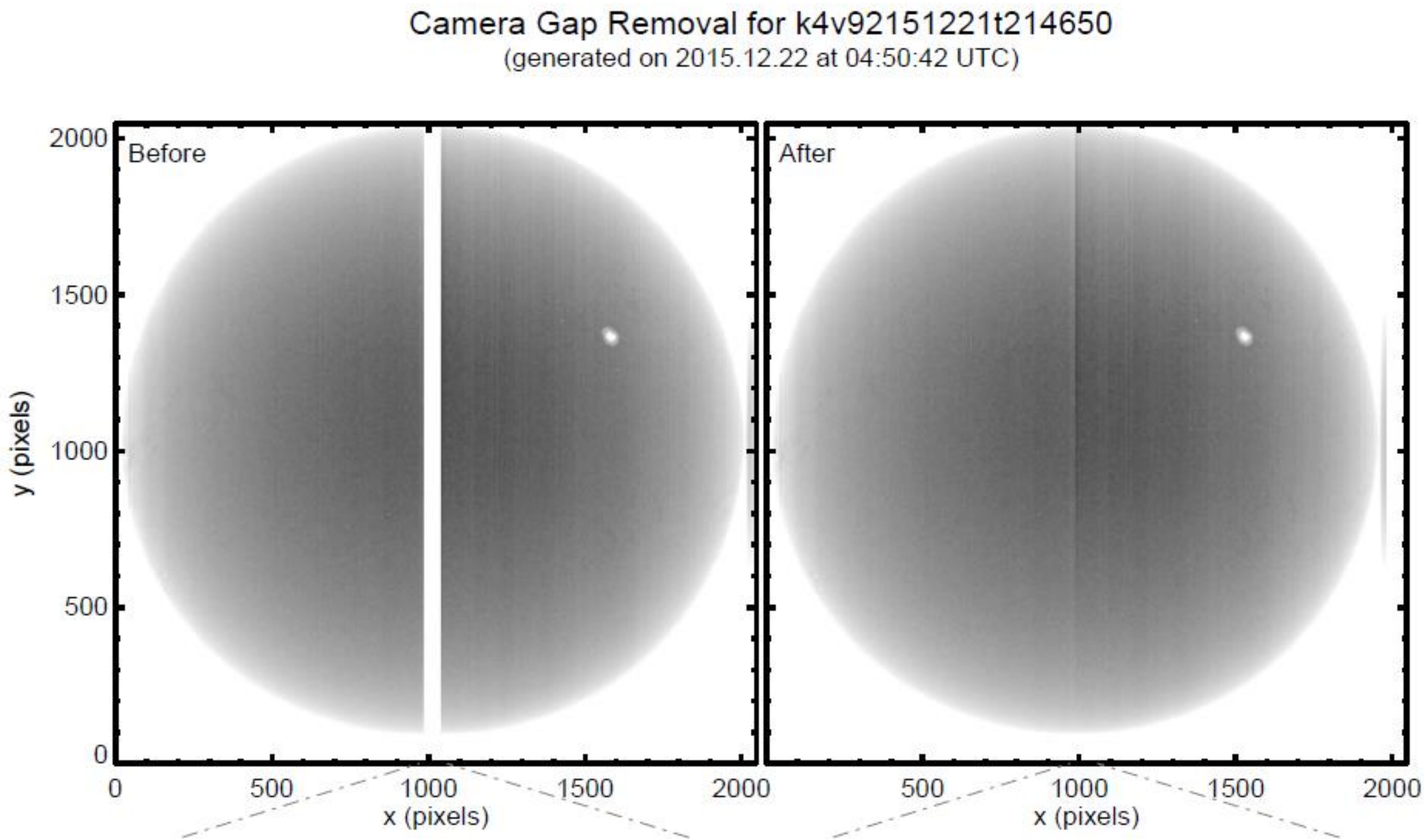
- Everything! Ex: sunspot number and undocumented changes in methodics, MWO sunspot field strength measurements.
- Wavelength, time of observations, pixel size, linear dispersion, place of observations, data reduction version?
- If something was not done - record it.

- Think about somebody reading your paper or using your data in 15 years, would they recognize something that today seems obvious “everybody knows that” type of info?

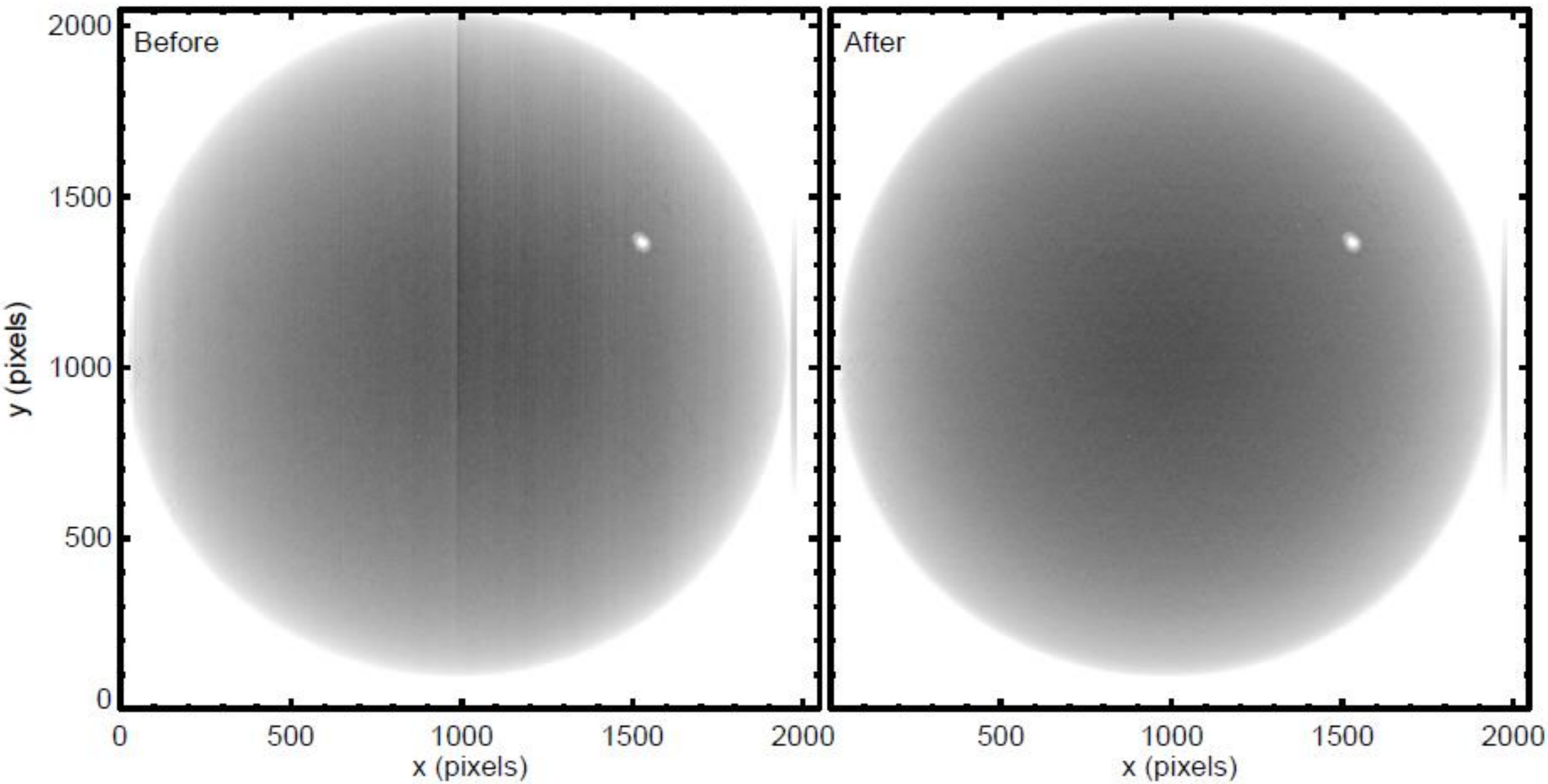
Example of modern data description

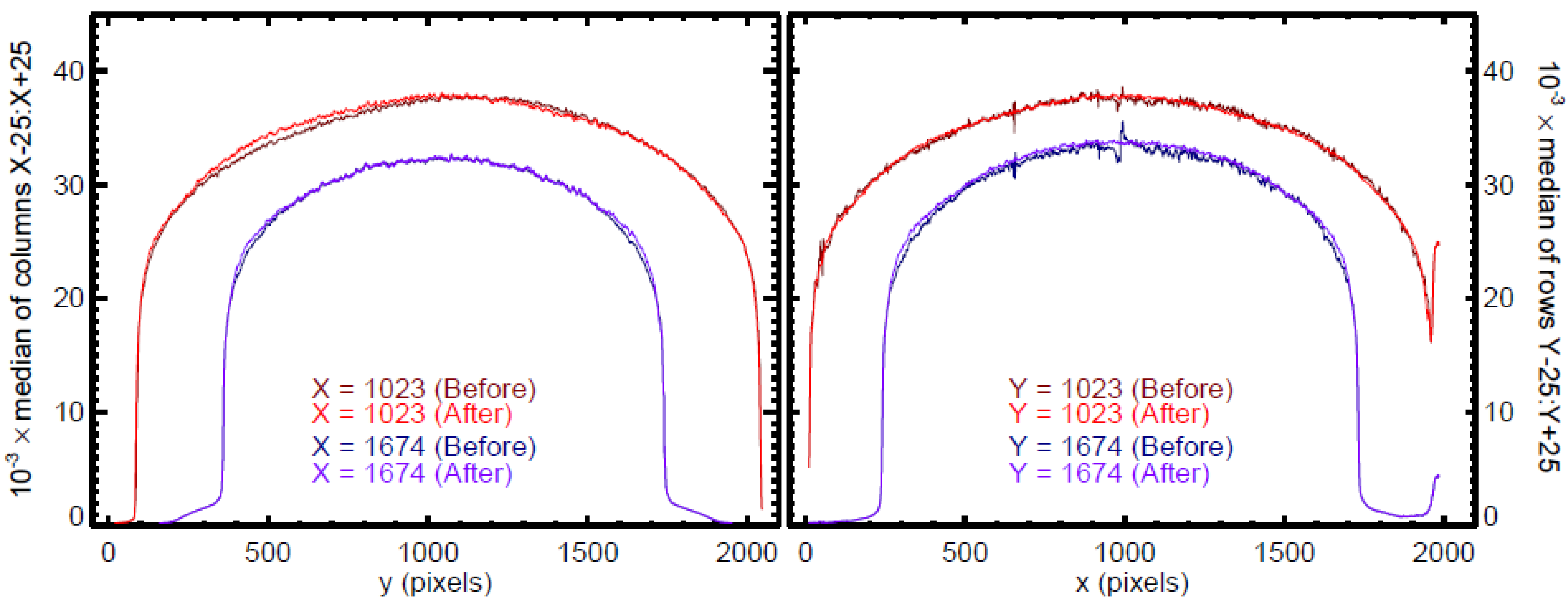
Example of modern data




Camera Gap Removal for k4v92151221t214650
(generated on 2015.12.22 at 04:50:42 UTC)
Before
After
y (pixels)
x (pixels)
x (pixels)
0
500
1000
1500
2000

Intensity Normalization for k4v92151221t214650
(generated on 2015.12.22 at 04:50:42 UTC)

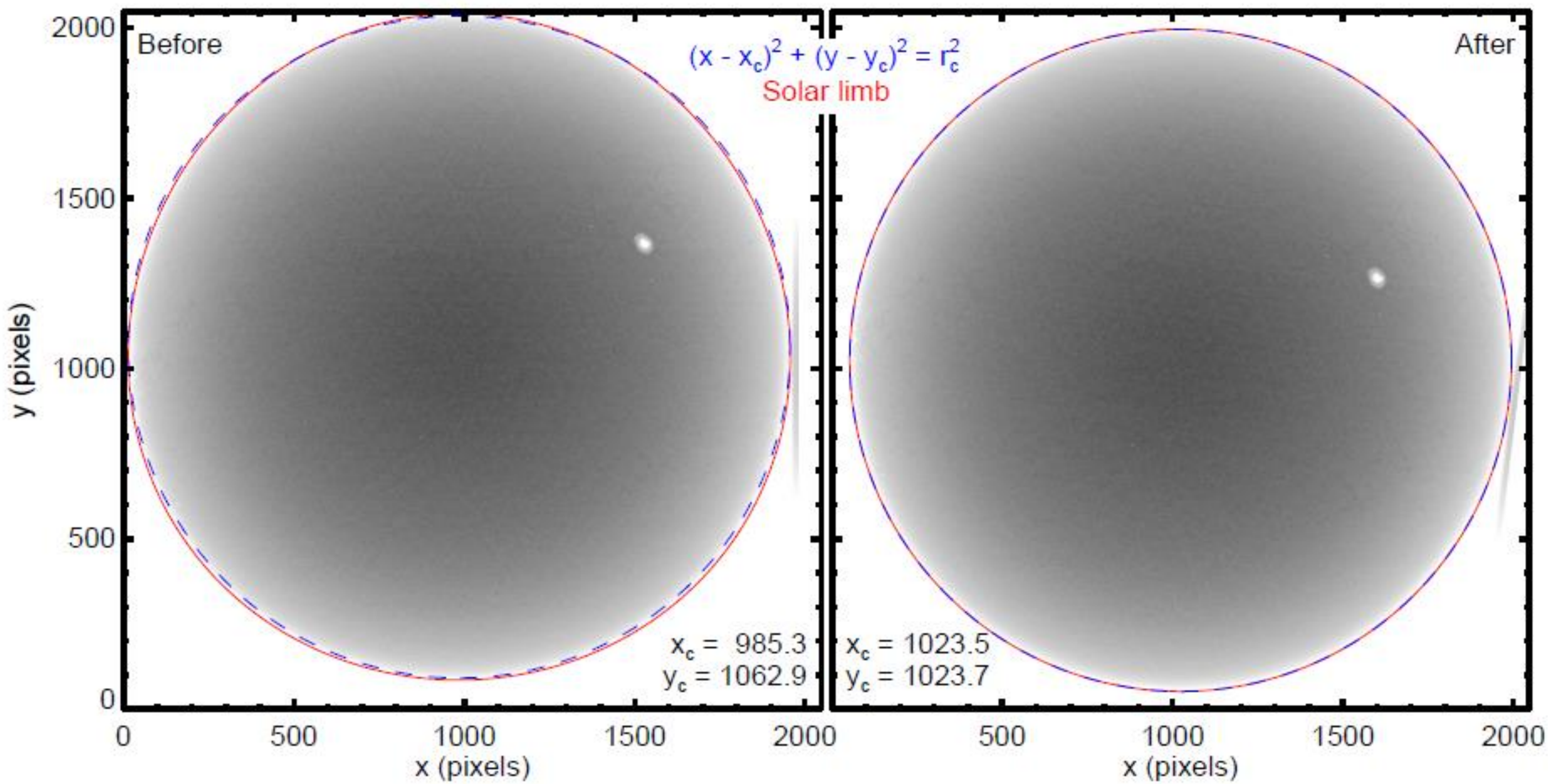




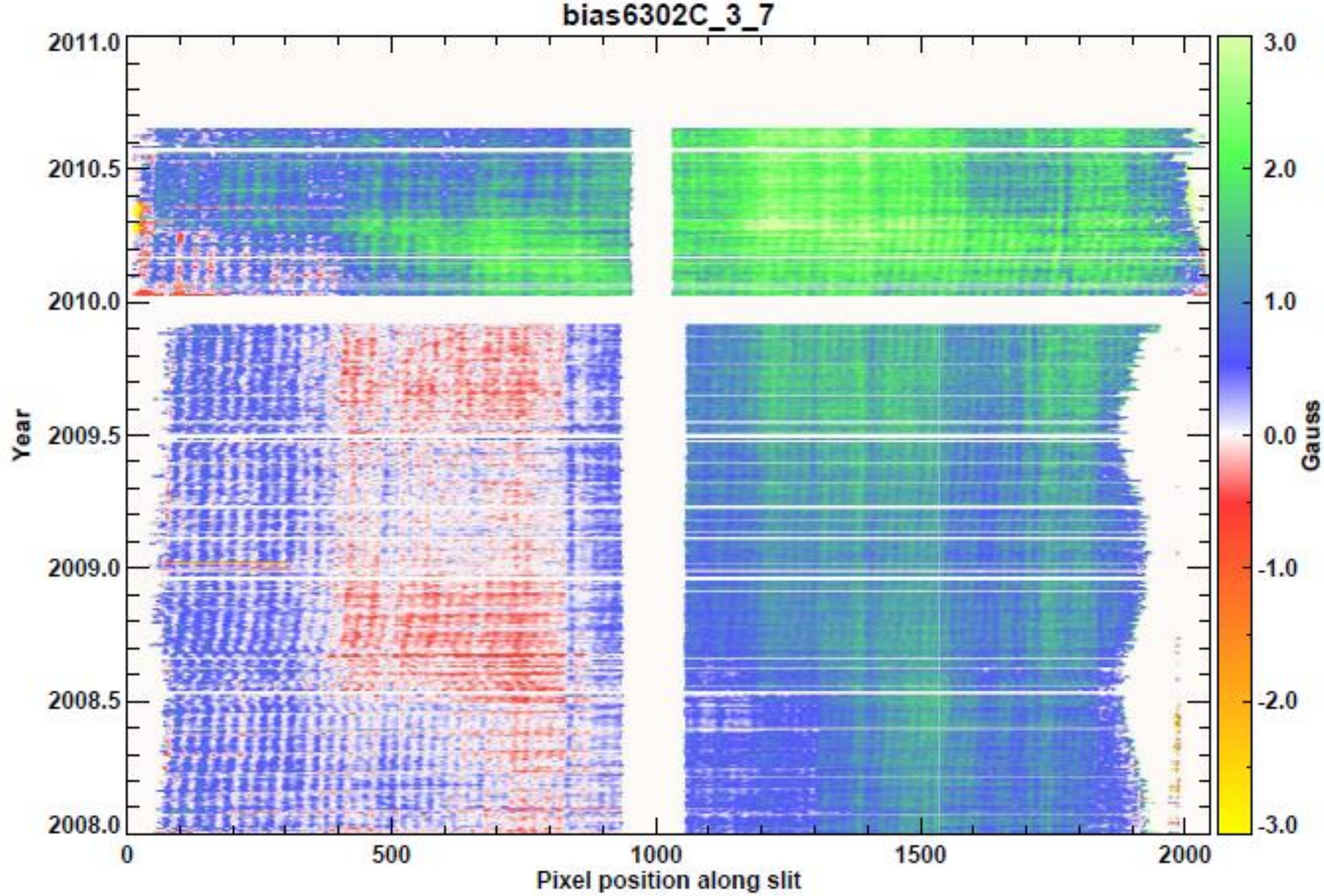
10^-3 × median of columns X-25:X+25
X = 1023 (Before)
X = 1023 (After)
X = 1674 (Before)
X = 1674 (After)
y (pixels)
Y = 1023 (Before)
Y = 1023 (After)
Y = 1674 (Before)
Y = 1674 (After)
x (pixels)
10^-3 × median of rows Y-25:Y+25

Geometric Distortion Correction for k4v92151221t214650

(generated on 2015.12.22 at 04:50:42 UTC)



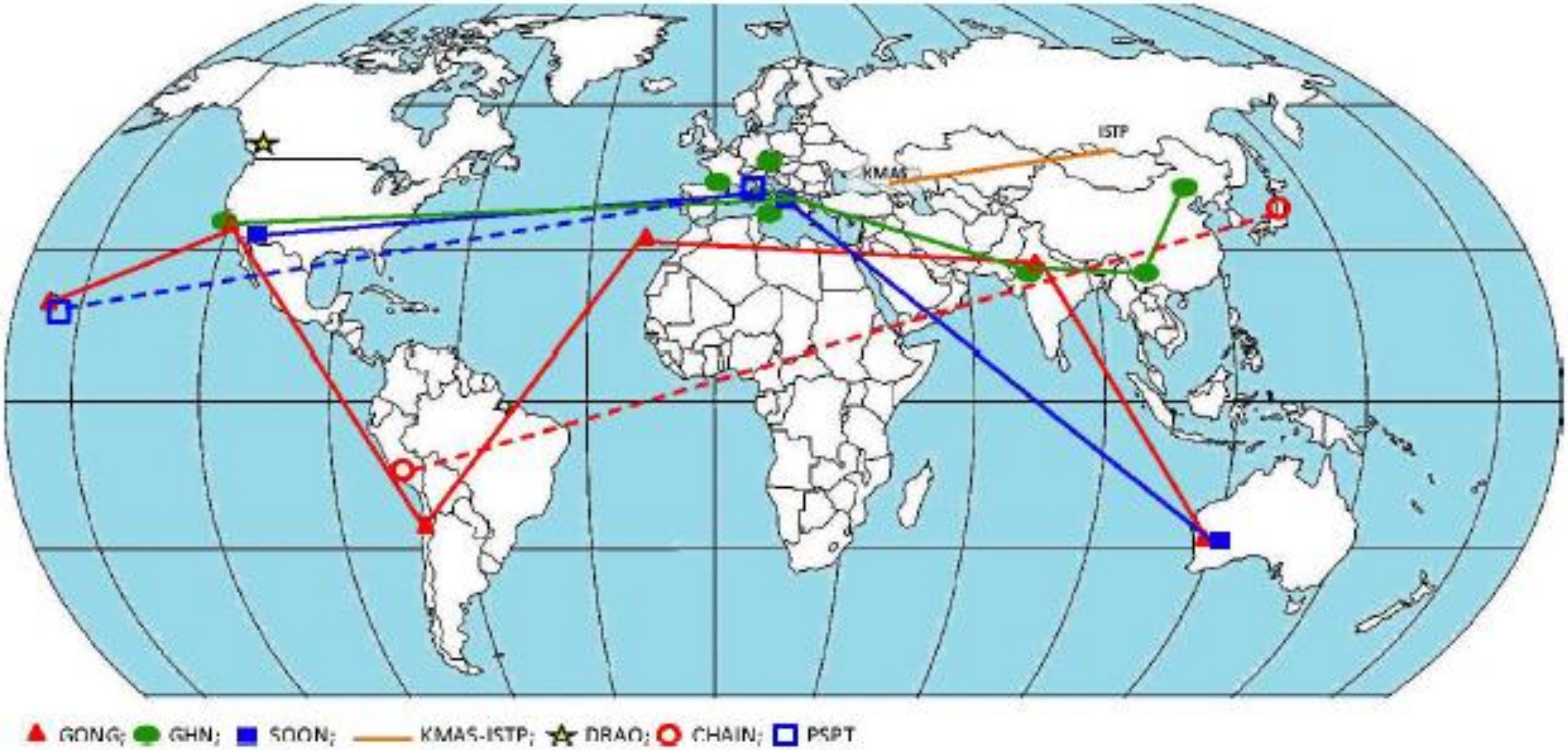
[Known issues]

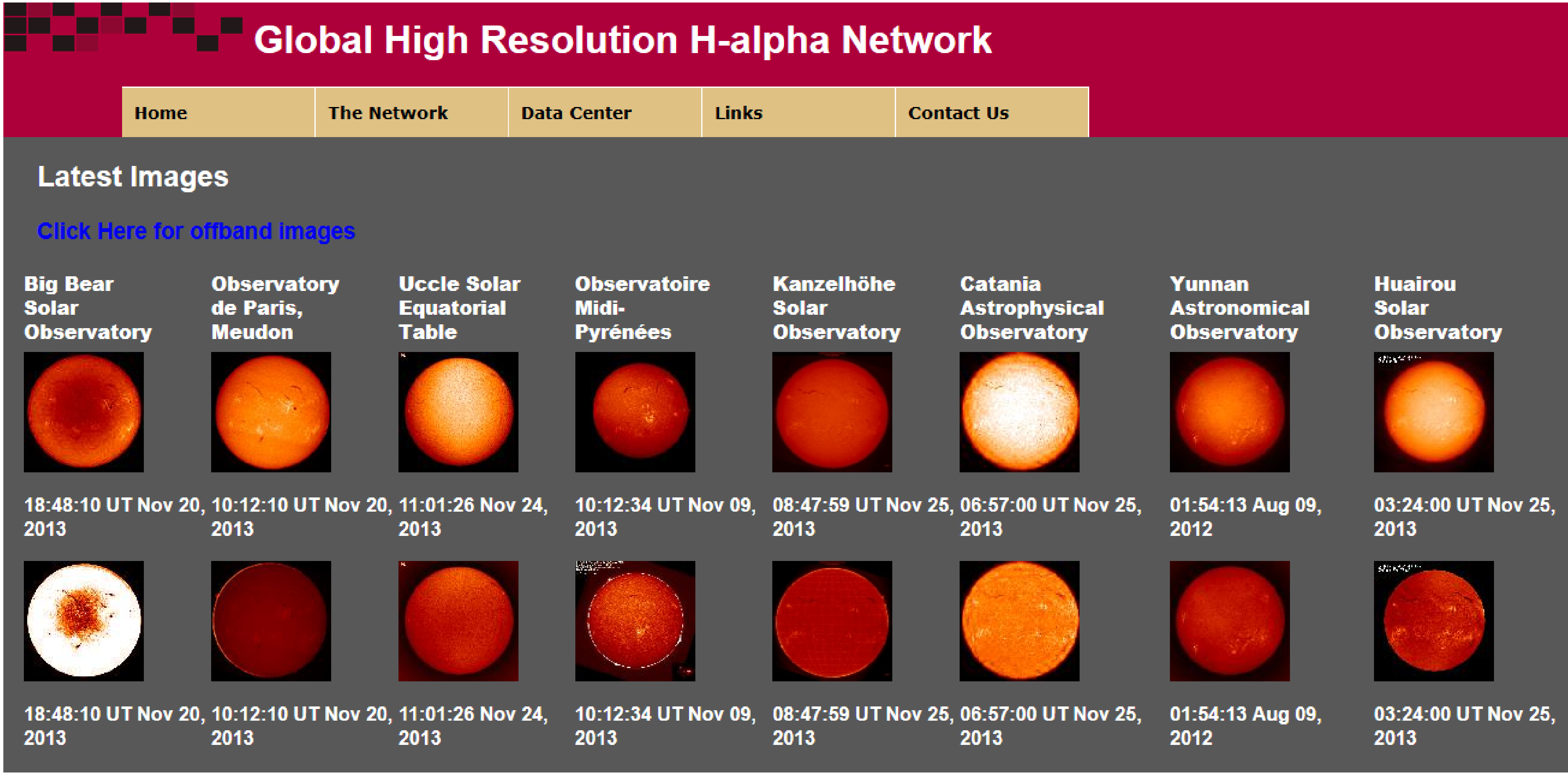


bias6302C_3_7
Year
2011.0
2010.5
2010.0
2009.5
2009.0
2008.5
2008.0
0
500
1000
1500
2000
Pixel position along slit
Gauss
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0

Networks

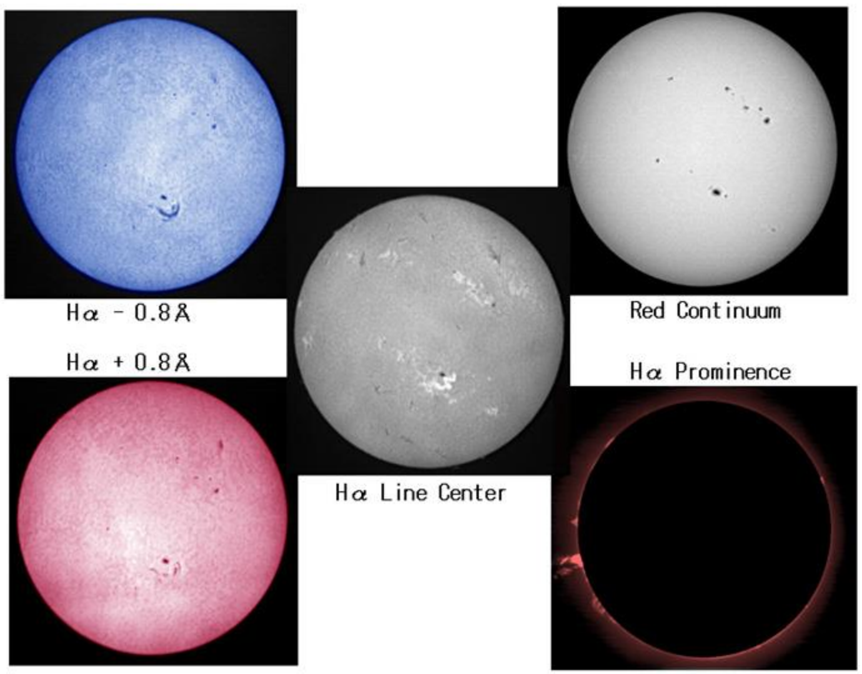
- Networks (late-1950th): “Sun Service" program (USSR, mid-1950th-2010), the Solar Observing Optical Network (SOON, 1970th-present), helioseismology networks, GONG (1995-present) , global high resolution H-alpha network (GHN).


ISTP
KMAS
GONG; GHN; SOON; KMAS-ISTP; DRAO; CHAIN; PSPT

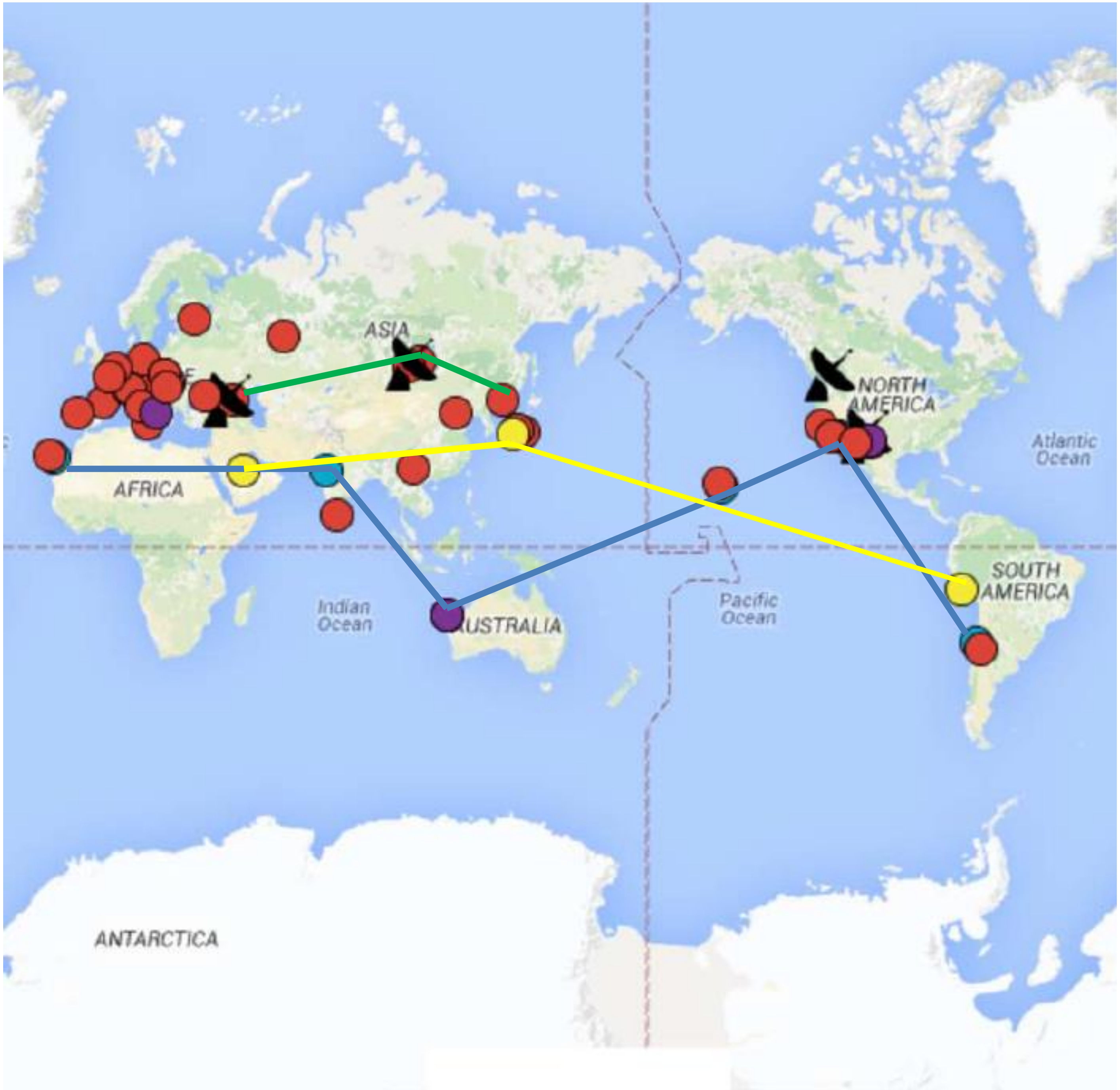


http://swrl.njit.edu/ghn_web/

Continuous H_{α} Imaging Network (CHAIN)

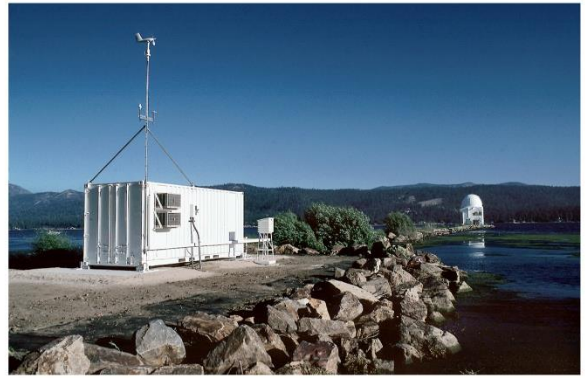


http://www.kwasan.kyoto-u.ac.jp/CHAIN/



ASIA
NORTH AMERICA
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
Pacific Ocean
ANTARCTICA

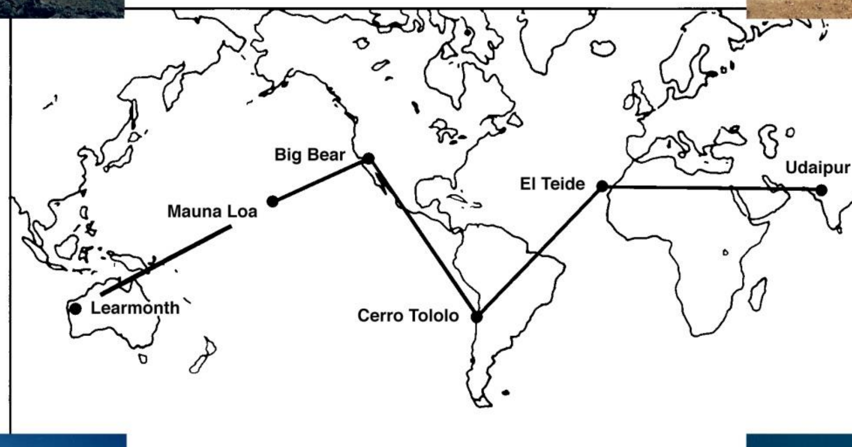
Mauna Loa



Big Bear

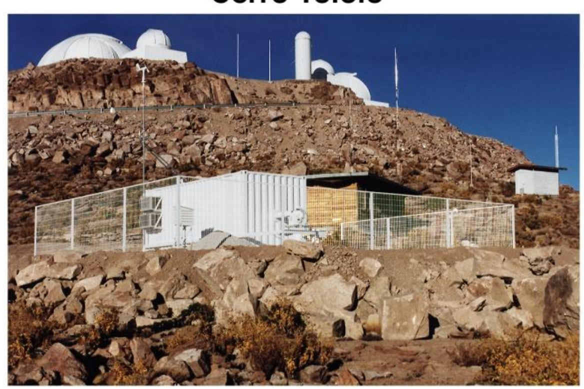
Udaipur

Global
Oscillation
Network
Group



Learmonth

Cerro Tololo



El Teide

GONG: The Global Oscillation Network Group

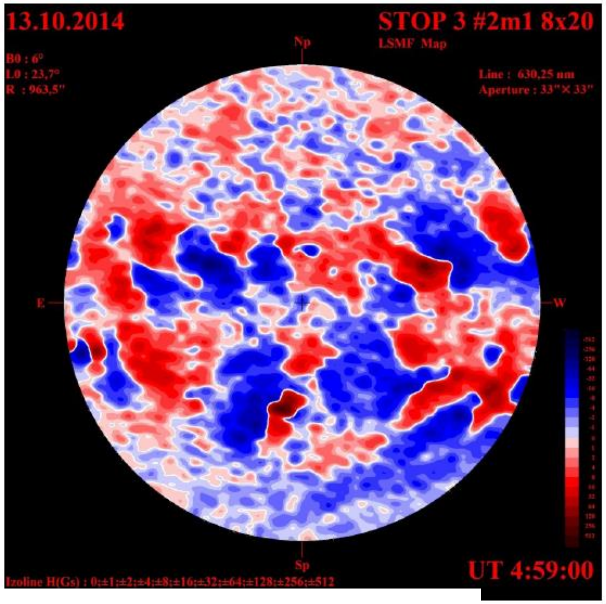
- Operating since 1995
- Original goal: helioseismology, now also space weather
- Two instruments:
  - Michelson Interferometer
    - helioseismology Doppler velocity, intensity and LOS magnetic field
    - 1k x 1k full-disk images in Ni I 676.8 nm
    - 60-sec cadence
  - H_α filter system
    - H-α intensity
    - 2k x 2k full-disk images
    - 60-sec cadence at a given site, 20-sec cadence from network

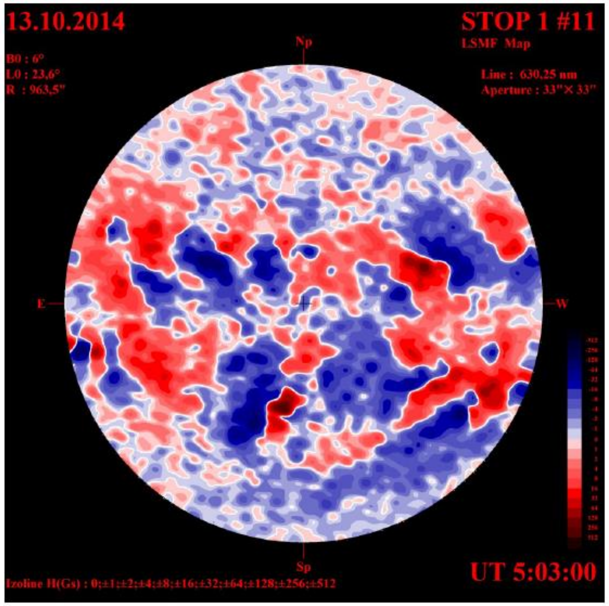
Basic Data from GONG

The above images are returned in near-real time and are available on the Internet

Dopplergrams for helioseismology. Left – full velocity field. Right – oscillatory velocity field

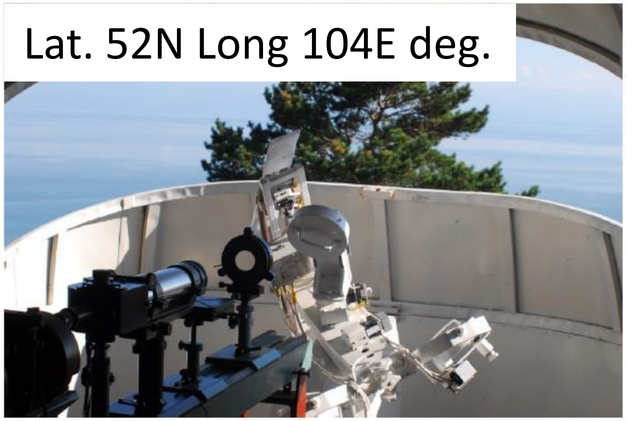
Solar Telescope of Operational Prognosis (STOP-2)

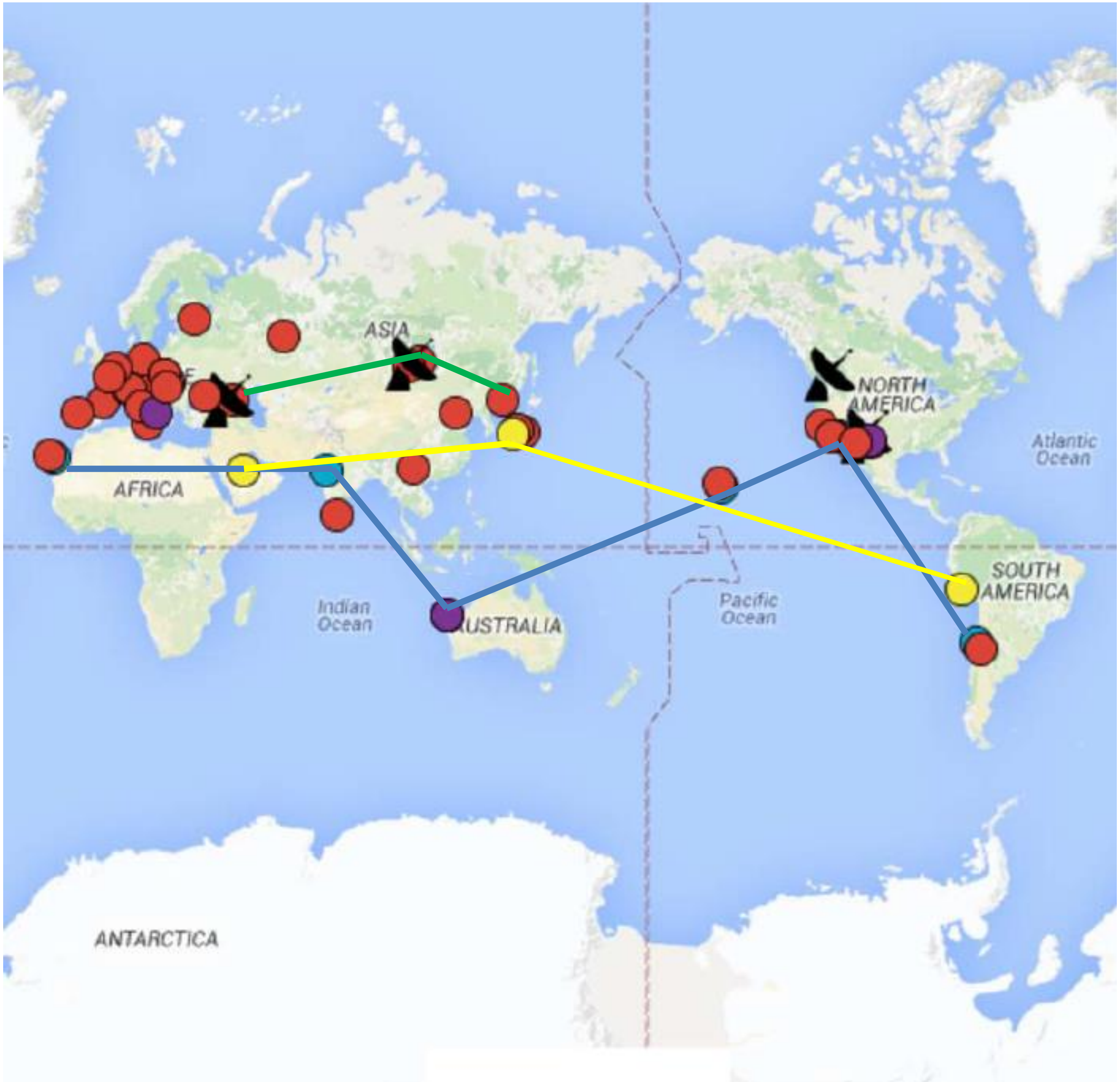




Lat. 44N Long 42E deg.

Lat. 52N Long 104E deg.



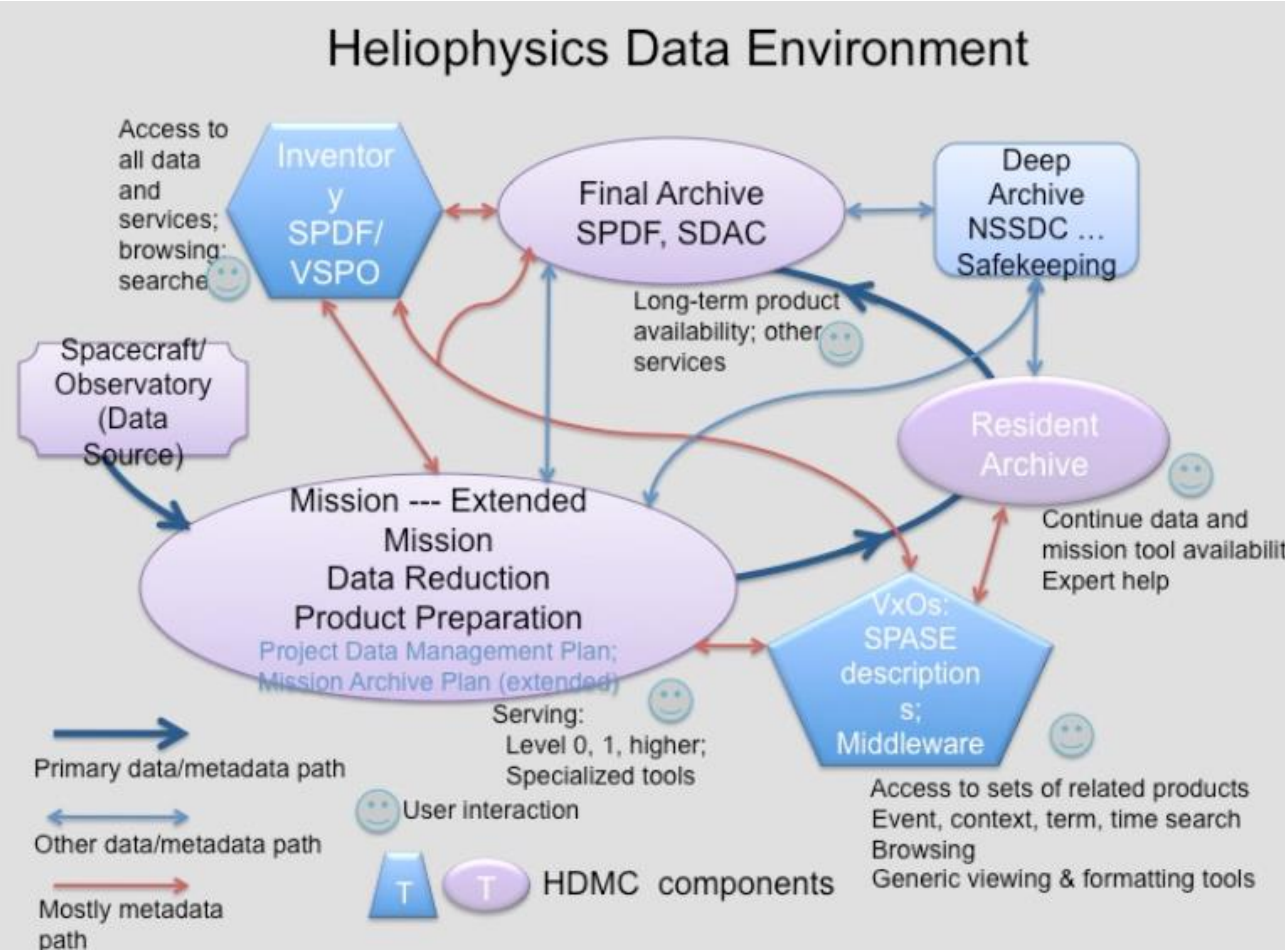

ASIA
NORTH AMERICA
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
Pacific Ocean
ANTARCTICA

Precision Solar Photometric Telescopes (PSPT)

- In 1996-97, differential photometry with high 0.1% accuracy. The PSPT takes full-disk images in the blue (409.4nm) and red (607.1nm) continuum, Ca II K line core (393.4 nm) and wing (393.6 nm) with a narrow and wide spectral bandpasses. MLSO (Hawaii, USA) and the Osservatorio Astronomico di Roma (Italy).

Data Access

- Individual site datasets (e.g., SOLIS, GONG, SDO)
- Data summary sites (e.g., solarmonitor.org, SDAC, VSO)
- Lack of unified interface between users and data providers.
- Lack of standardization
- Large size of datasets (how to search for specific events? Can we "decompose" images on prime components? Meta-data)
- How to ensure preservation of data?


Heliophysics Data Environment
Access to all data and services; browsing; searche
Inventor y SPDF/ VSPO
Final Archive SPDF, SDAC
Deep Archive NSSDC … Safekeeping
Long-term product availability; other services
Spacecraft/ Observatory (Data Source)
Resident Archive
Mission --- Extended Mission Data Reduction Product Preparation
Project Data Management Plan; Mission Archive Plan (extended)
Continue data and mission tool availabilit
Expert help
VxOs: SPASE description s; Middleware
Serving: Level 0, 1, higher; Specialized tools
Primary data/metadata path
User interaction
Other data/metadata path
Access to sets of related products
Event, context, term, time search
Browsing
Generic viewing & formatting tools
T
T
HDMC components
Mostly metadata path

Historical Data Preservation

Digitized sunspot drawings:

- NGDC collection at ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-imagery/photosphere/sunspotdrawings.
- Hungarian historical solar drawings (1872–1919, fenyi.solarobs.unideb.hu/HHSD.html).
- The 1932–1979 data from the “Catalogues of solar activity” of Russian “Solar Service” program www.gao.spb.ru/database/csa/main_e.html.
- Sunspot drawings from MWO ftp://howard.astro.ucla.edu/pub/obs/drawings
- The Debrecen Photoheliographic Data archive fenyi.solarobs.unideb.hu/deb_obs_en.html
- Historical Archive of Sunspot Observations (HASO) at the University of Extremadura (Spain)

Ca II K line Spectroheliograms:

- MWO (1915–1985, only raw data remain).
- Kodaikanal Observatory (1907–2007) were digitized with 16-bit density resolution (https://kso.iiap.res.in//data).
- Evans facility at NSO/Sacramento Peak (1965–2002, the NSO Digital Library at diglib.nso.edu/ftp.html).
- Arcetri Astrophysical Observatory (1926-1974, www.oa-roma.inaf.it/solare/cvs/arcetri.html)
- National Astronomical Observatory of Japan (1917–1970, solarwww.mtk.nao.ac.jp/en/db_ca.html
- Observatoroir de Paris/Meudon (1893-1999, bass2000.obspm.fr/gallery2/main.php?g2_itemId=9081).

Full disk H-alpha observations:

- BBSO (http://sfd.njit.edu/).
- NSO/SP flare patrol (1960–2002, 1 min, ftp://vso.nso.edu/flare_patrol_h_alpha_sp/).

IAU WG on Coordination of Synoptic observations of the Sun