Introduction to Aurora

movie

size (small aurora) ~ constellation

size (large aurora) > constellation

North

South

auroral arc ~ clear
with human eye

diffuse aurora ~
camera detects,
but not human eye

Can be seen as soon as darkness comes (~ third star)

Exposure time = 5~30 sec
(high resolution = low sensitivity)

short exposure (real eye) =
aurora has vertical lines

colors ~ green and red

“red aurora” ~ very rare

Before watching, everybody asks

"Can I see (**beautiful**) aurora **tonight**?"

"Can I see **very beautiful** (or **red**) aurora tonight?"

"Can I see aurora **like this photo**?"

"**What time** can I see aurora tonight?"

"Where is the **best place** to see aurora?"

"**How often** do you see aurora?"

...and some "advanced" people ask

"Is it **cold enough** to see aurora?" (=wrong knowledge)

"Is **solar activity** high enough for beautiful aurora?"

"Is aurora **useful**?"

"**What causes** aurora?, and its **color**?"

After missing aurora: everybody shouts

"**Was there aurora!** last night! --- Why did I miss?"

"Is aurora **white**?!"

After watching, excited people ask

"Was it **big**?.... I mean **How often** do you see aurora like last night?"

"Did I miss **any other aurora** last night? (archive)"

"**Why so beautiful**? Why **moving** so fast?"

Summarizing:

Q1) Prediction (of "**beautiful**" aurora)

Q2) Morphology (**color, motion, location,** etc)

Q3) Logistic ("Am I doing right to see aurora?")

Q4) Curiosity (**spin-off** of aurora research)

To answer the questions, we need to know:

§1. Detecting aurora

§2. Cause of "beautiful" aurora

§3. Meaning of real-time data (Space weather)

§1. Detecting aurora

§2. Cause of “beautiful” aurora

§3. Meaning of real-time data

§1. Detecting aurora

--- methods to detect aurora ---

* Optical (ground)

* Electric current (magnetometer)

* Radar / Riometer

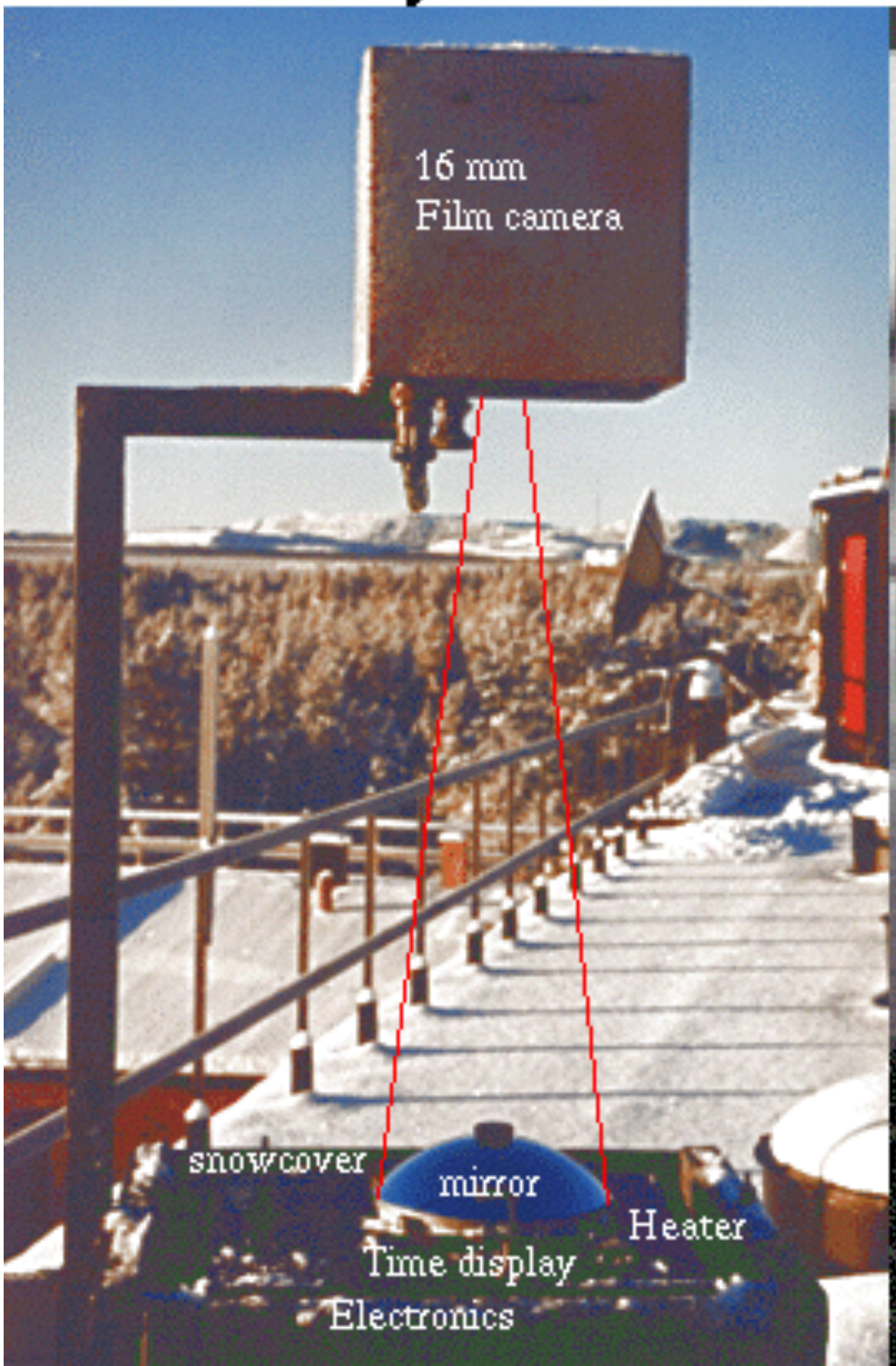
* In-situ (inside aurora)

* In-site (aurora particles)

* Optical (from above)

old system

new camera



http://www.irf.se//Observatory/?link=All-sky_sp_camera

North

movie

East

West

South

2004.01.15
14:30 UT

Probability to see aurora (2003.9 ~ 2005.4, 444 nights)

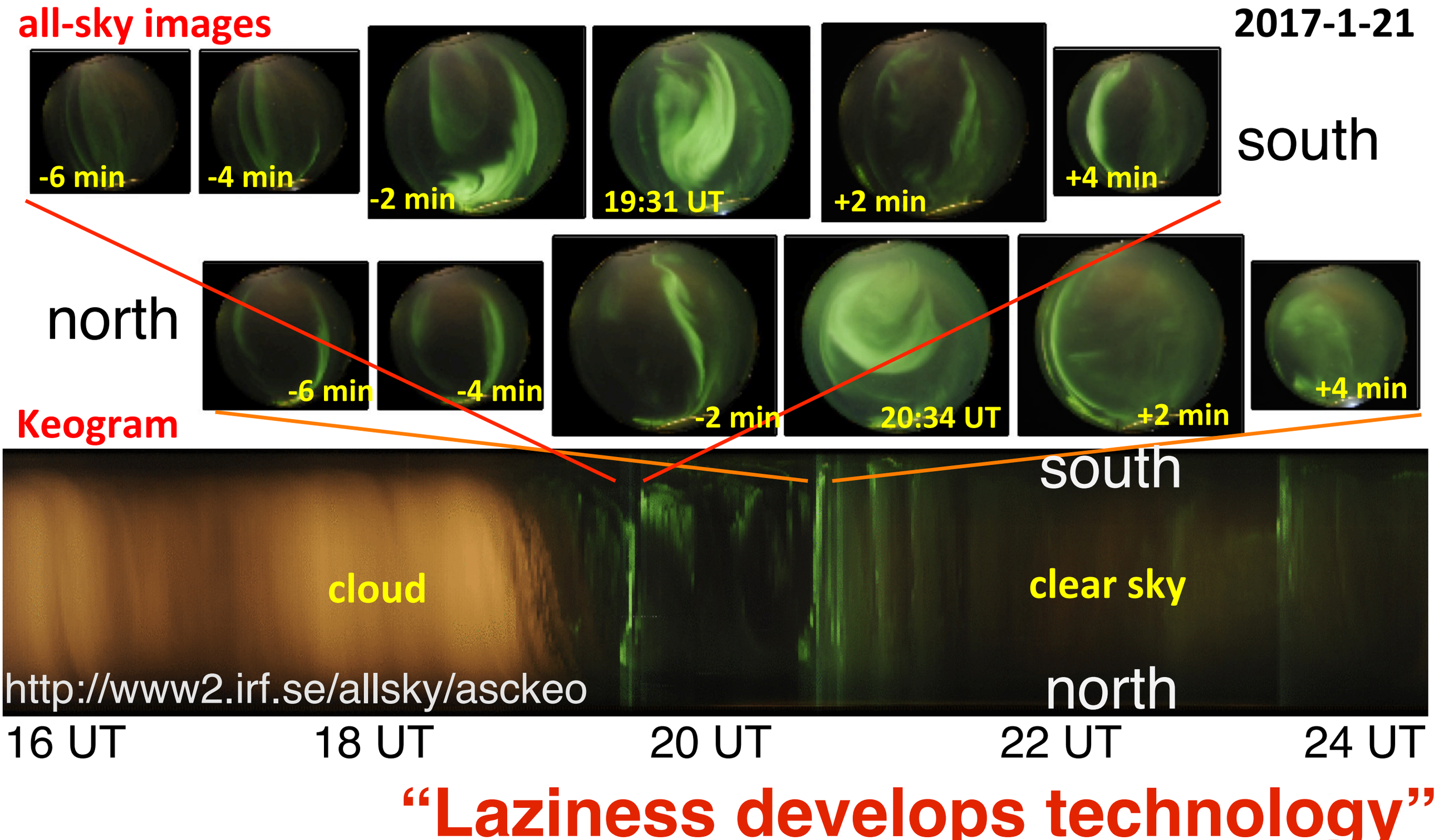
	weak aurora	strong aurora	big dancing aurora	mostly cloudy
if tourist stays only 1 night	**0.61**	**0.57**	**0.35**	**0.42**
if tourist stays 3 nights	**88%** (on one of 3 days)	**86%** (on one of 3 days)	**66%** (on one of 3 days)	**11%** (cloudy all 3 days)

reading from mpeg movie:
http://titan.irf.se/misato/ (under fixing)

Examining mpeg movie takes time

⇒ not optimum for **quick check** of daily activity

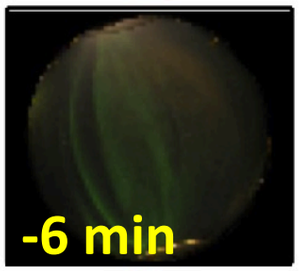
⇒ **Keogram** (only north-south meridian sky)

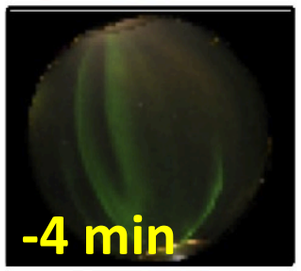


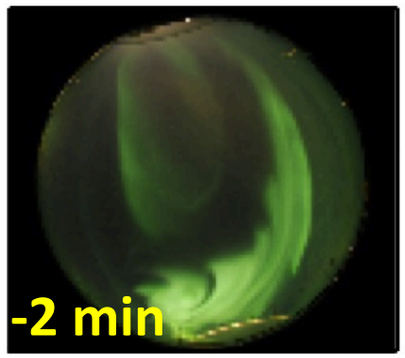
“Laziness develops technology”

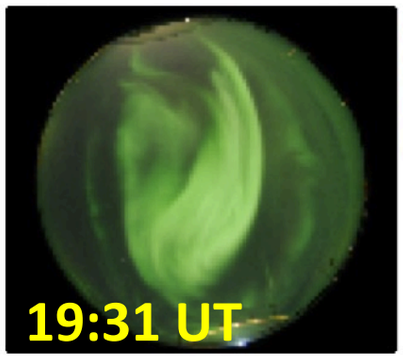
all-sky images

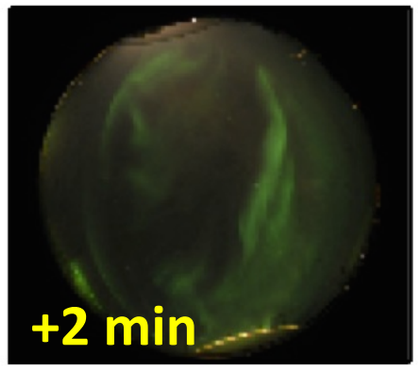
2017-1-21

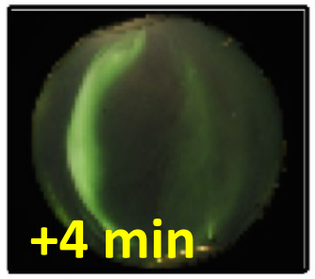






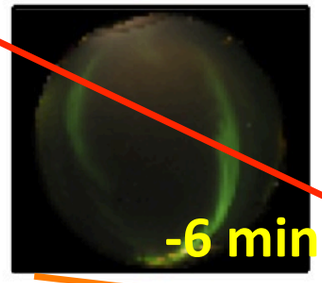


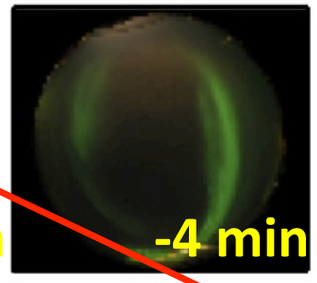


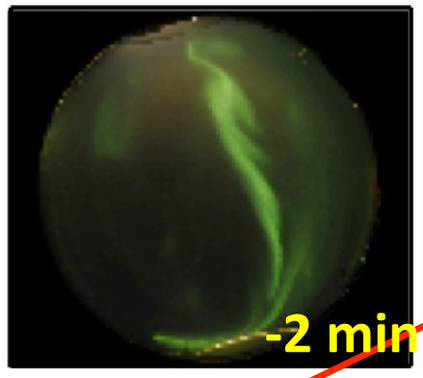


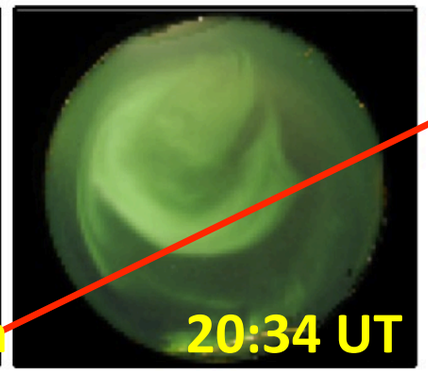
south

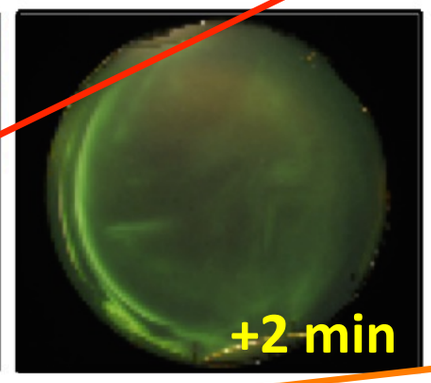
north

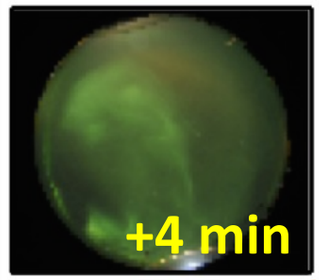












Keogram

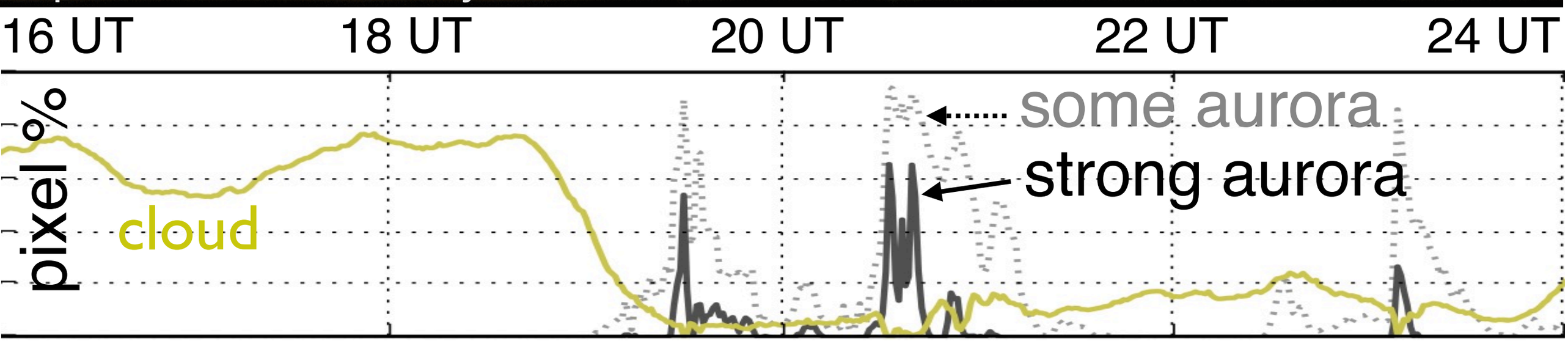
south

cloud

clear sky

http://www2.irf.se/allsky/asckeo

north



§1. Detecting aurora

--- methods to detect aurora ---

* Optical (ground)

* **Electric current (magnetometer)**

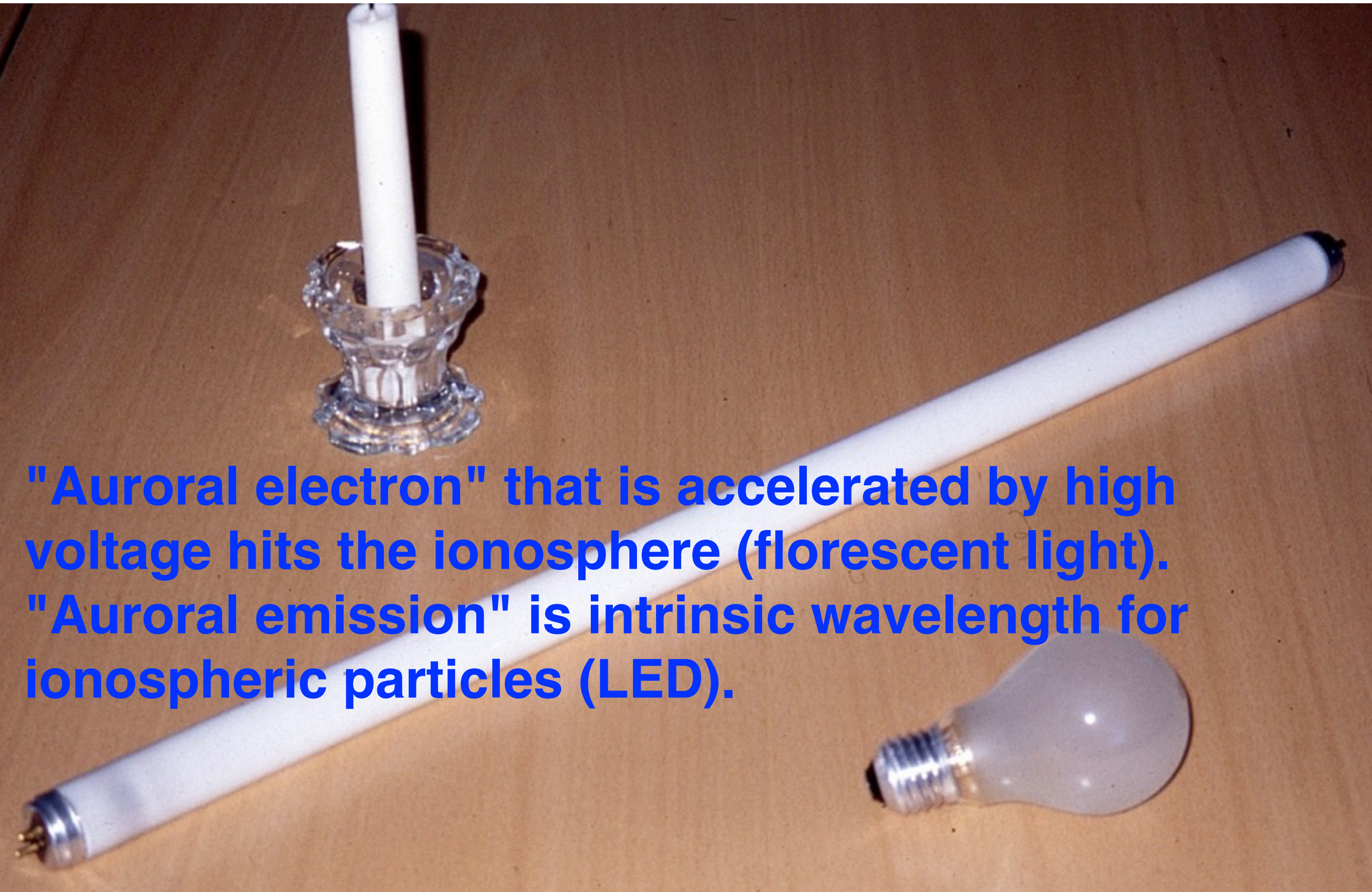
* Radar / Riometer

* In-situ (inside aurora)

* In-site (aurora particles)

* Optical (from above)

emission = 1. oxidation (fire), 2. thermal (bulb lamp), **3. non-thermal (combination of 3a: florescent light + 3b: LED)**



"Auroral electron" that is accelerated by high voltage hits the ionosphere (florescent light).
"Auroral emission" is intrinsic wavelength for ionospheric particles (LED).

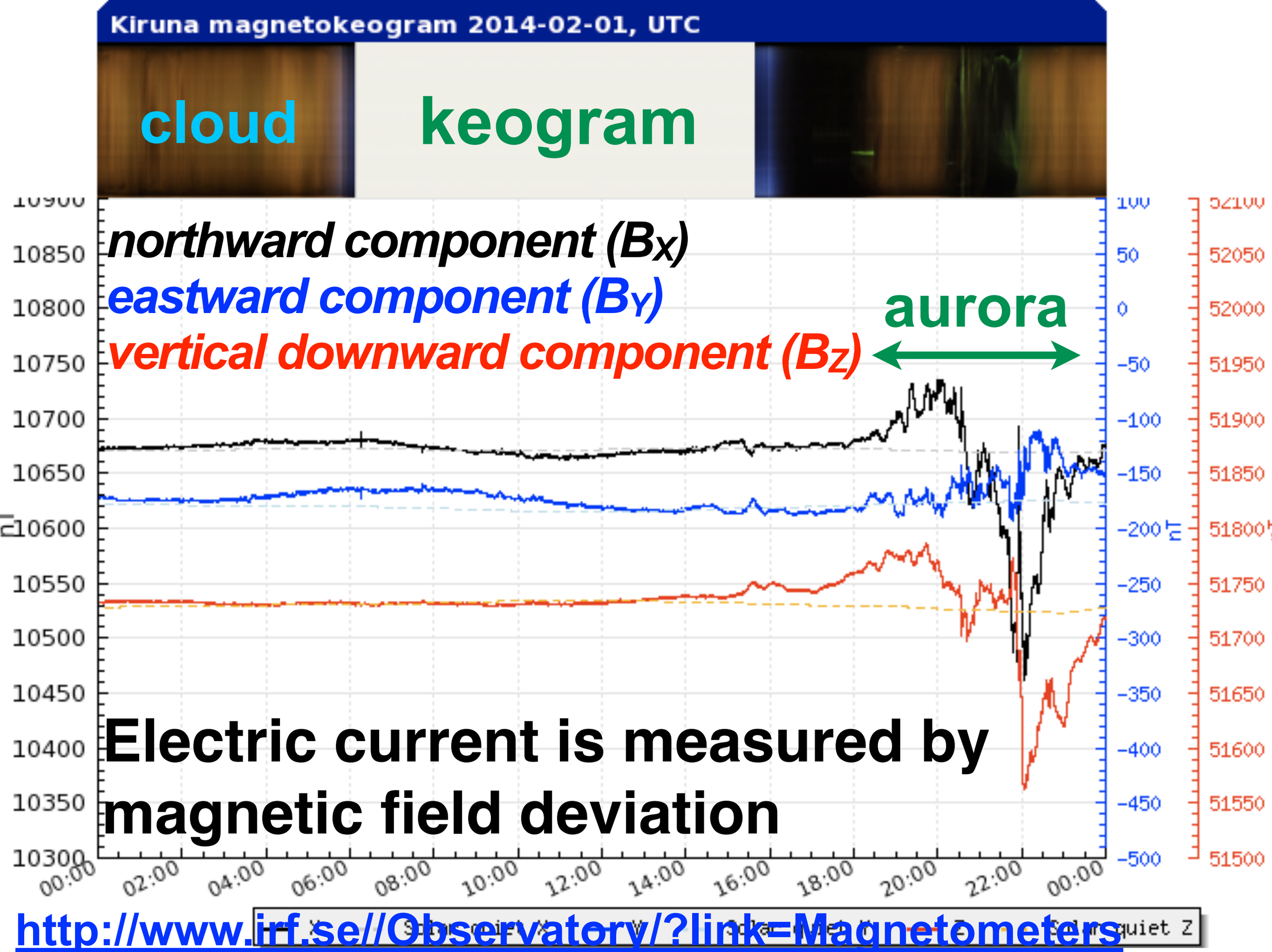
Aurora = AC current

↓

Induced current on ground

Strong electric current on conducting structures of > 100 km length :
(1) high-power line = power failure

Strong electric current on conducting structures of > 100 km length :
(2) pipe line = heating



http://www.irf.se//Observatory/?link=Magnetometers

Kiruna magnetogram 2010–03–10

Deflection (nT)

200
100
0
–100
–200
–300
–400

00 02 04 06 08 10 12 14 16 18 20 22 00

Time (UT)

Kiruna

aurora

AU

AL

500
0
- 500
- 1000
- 1500
- 2000

00 06 12 18 24

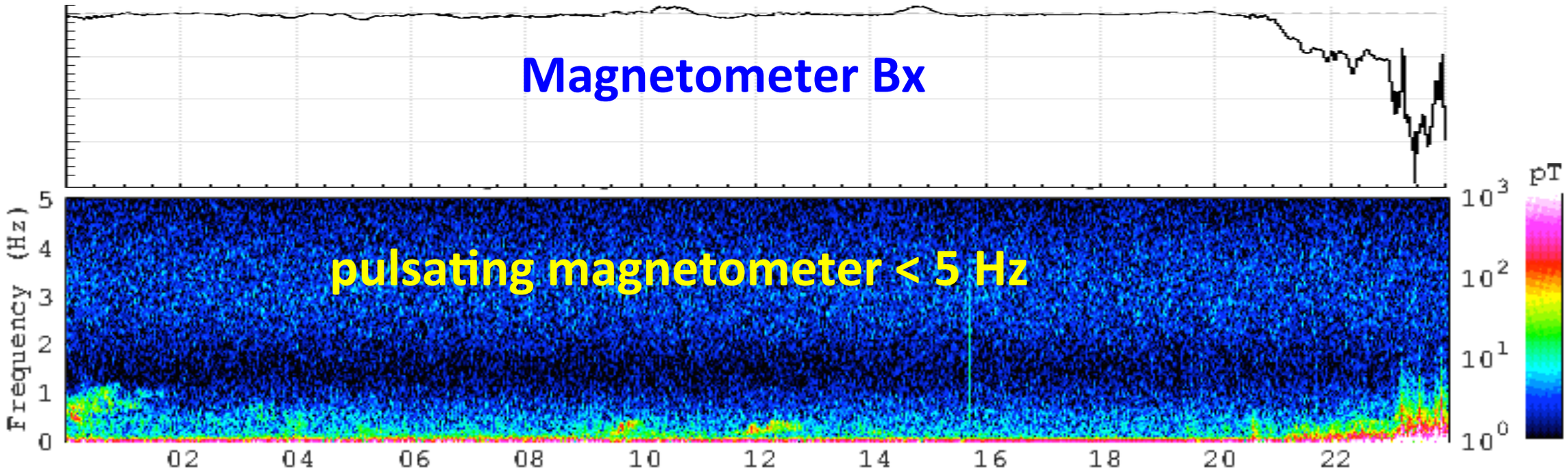
U T

12
11
10
9
8
7
6
5
4
3
2
1

World-wide

aurora

AC component ⇒ pulsation magnetometer



§1. Detecting aurora

--- methods to detect aurora ---

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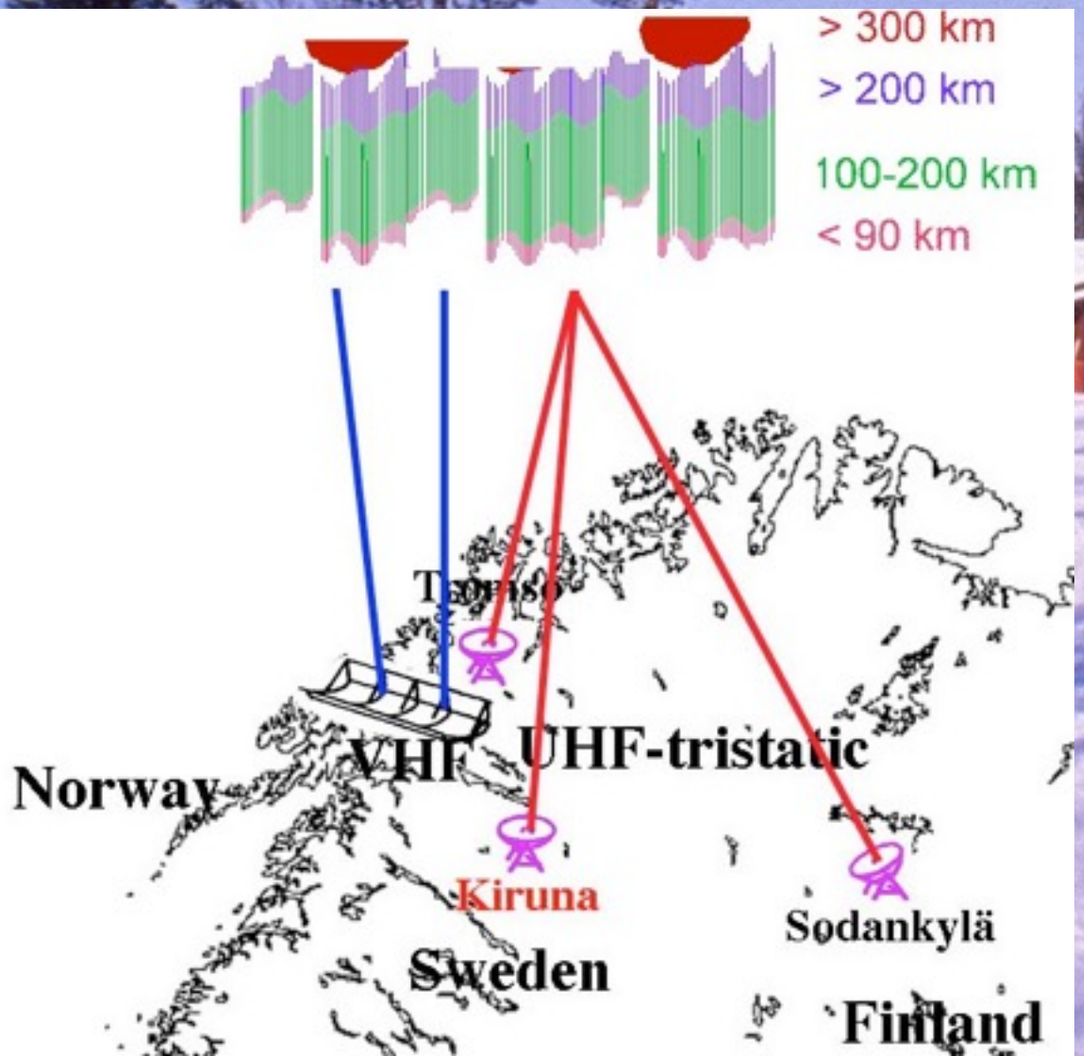
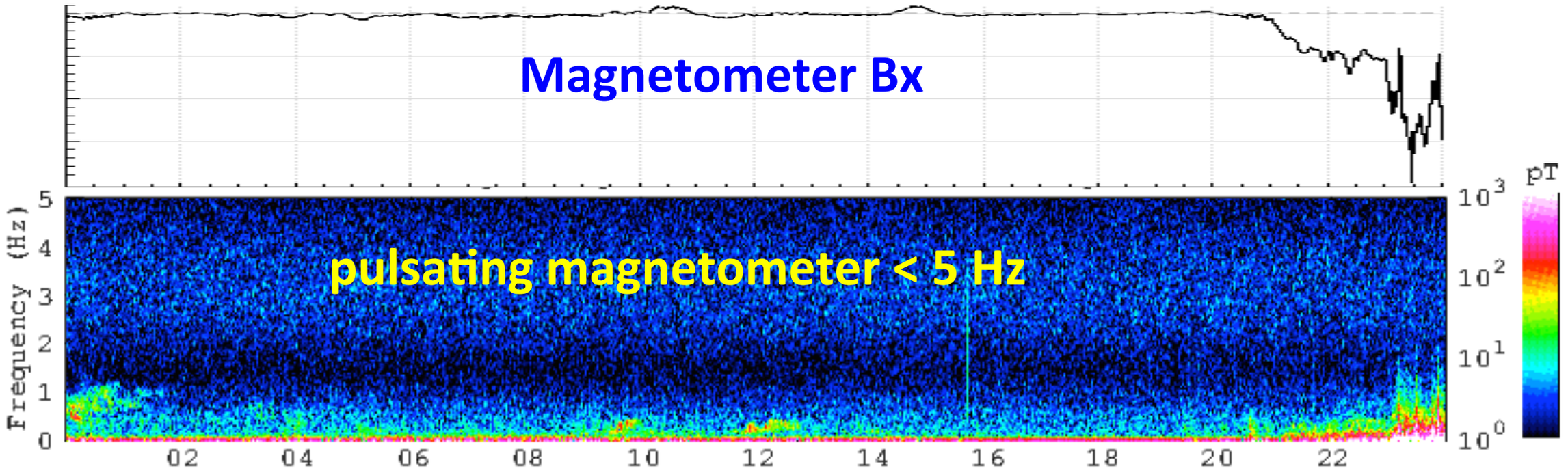
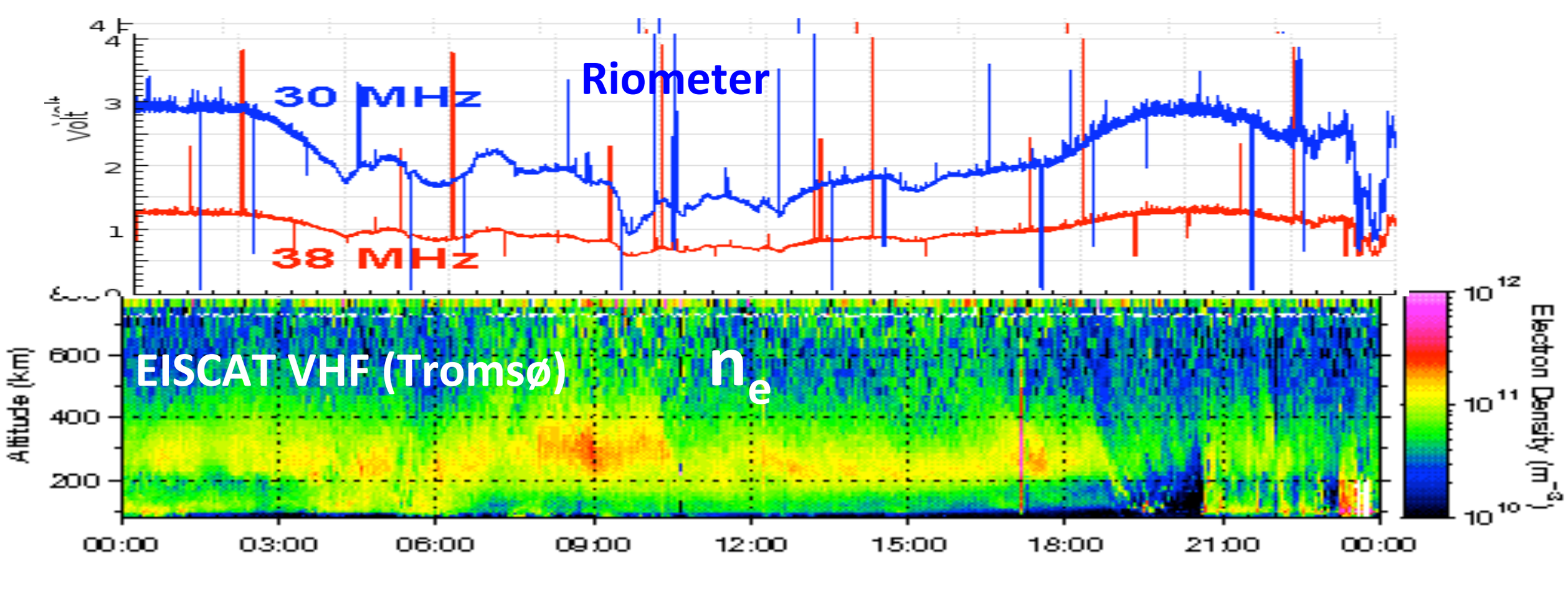
EISCAT ionospheric radar = 3 km from **IRF**



AC component ⇒ pulsation magnetometer





§1. Detecting aurora

--- methods to detect aurora ---

* Optical (ground)

* Electric current (magnetometer)

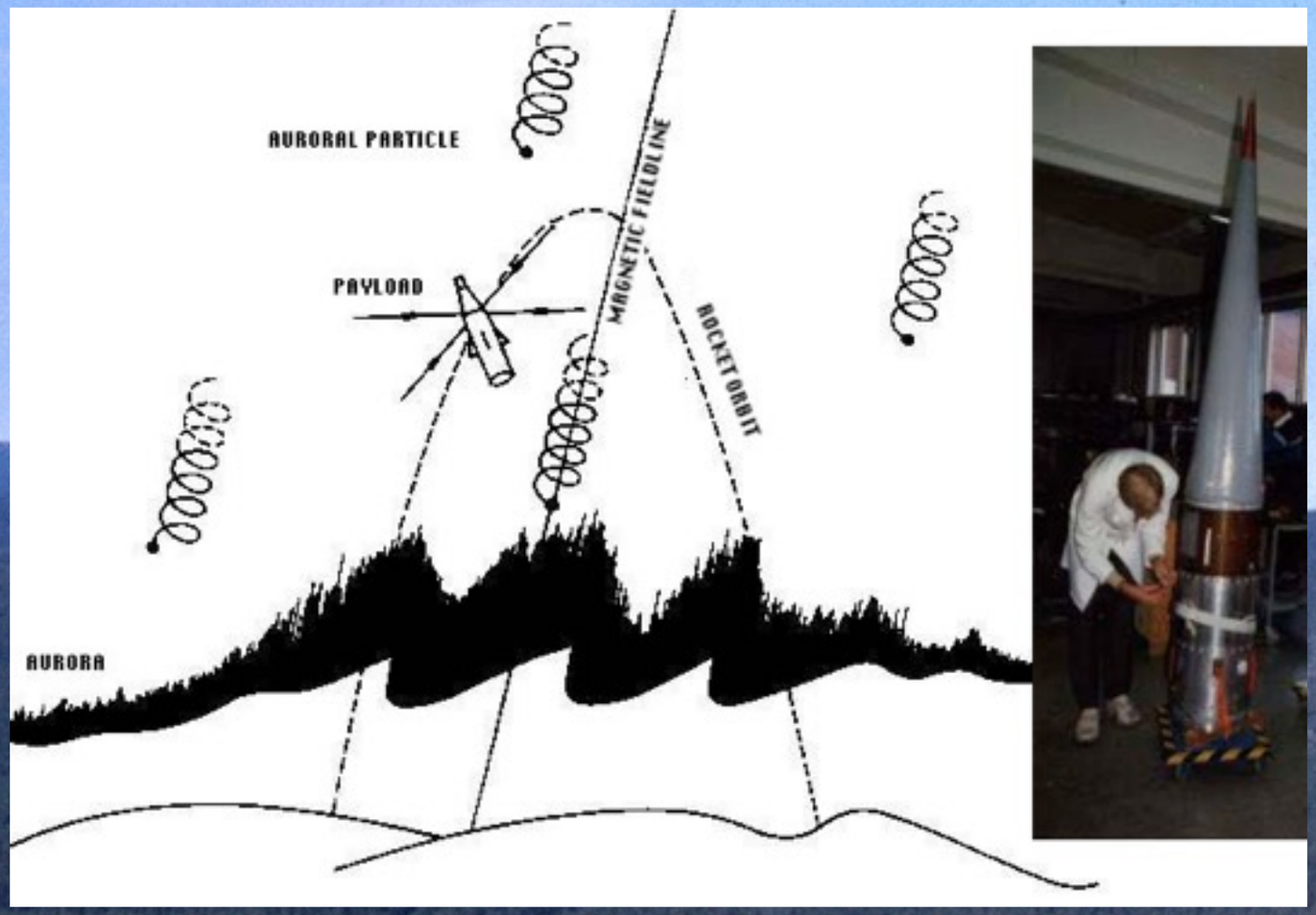
* Radar / Riometer

* **In-situ (inside aurora)**

* In-site (aurora particles)

* Optical (from above)

Esrange (Rocket and Balloon) = 30 km from **IRF**



Many aurora-related facilities in Kiruna !

⇒ Best place to observe aurora

⇒ **You are at the right place**

(Just find a dark spot!)

§1. Detecting aurora

--- methods to detect aurora ---

* Optical (ground)

* Electric current (magnetometer)

* Radar / Riometer

* In-situ (inside aurora)

* **In-site (aurora particles)**

* Optical (from above)

Swedish first satellite (Viking)

detect plasma that causes aurora

@Earth, Mars,,,

§1. Detecting aurora

--- methods to detect aurora ---

* Optical (ground)

* Electric current (magnetometer)

* Radar / Riometer

* In-situ (inside aurora)

* In-site (aurora particles)

* **Optical (from above)**

High above the cloud!

space shuttle (NASA public domain)


Long and thin !
ISS (NASA public domain)

day

Ring over pole
Strong in night

night

IMAGE+Earth (NASA public domain)

VIS Earth Camera

2000/043 02:00 UT (2/12, AM 3:00)

day

night

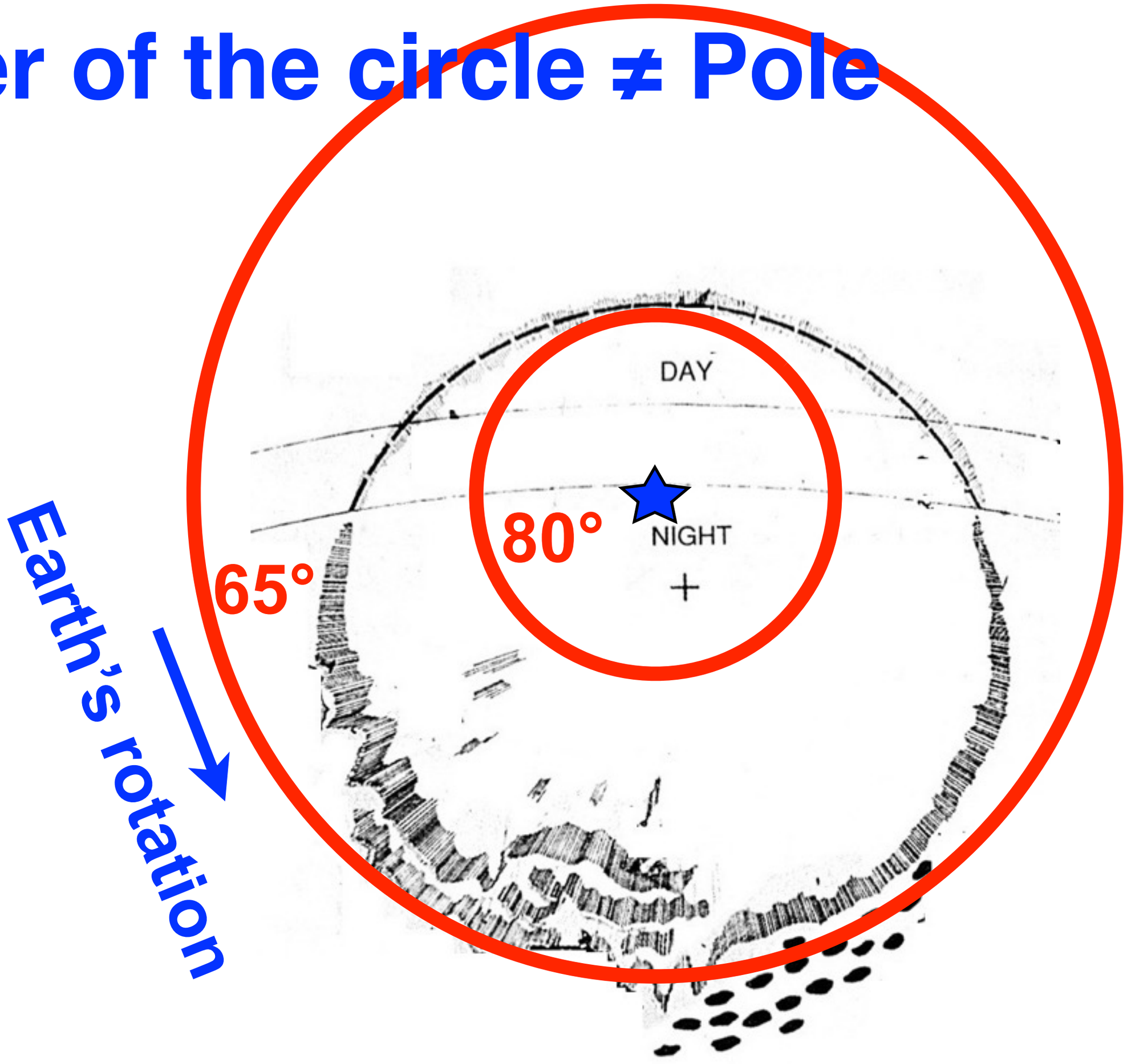
Kiruna

No aurora at pole.
You have to be at right latitude to see aurora.

Polar/VIS (NASA public domain)

The University of Iowa

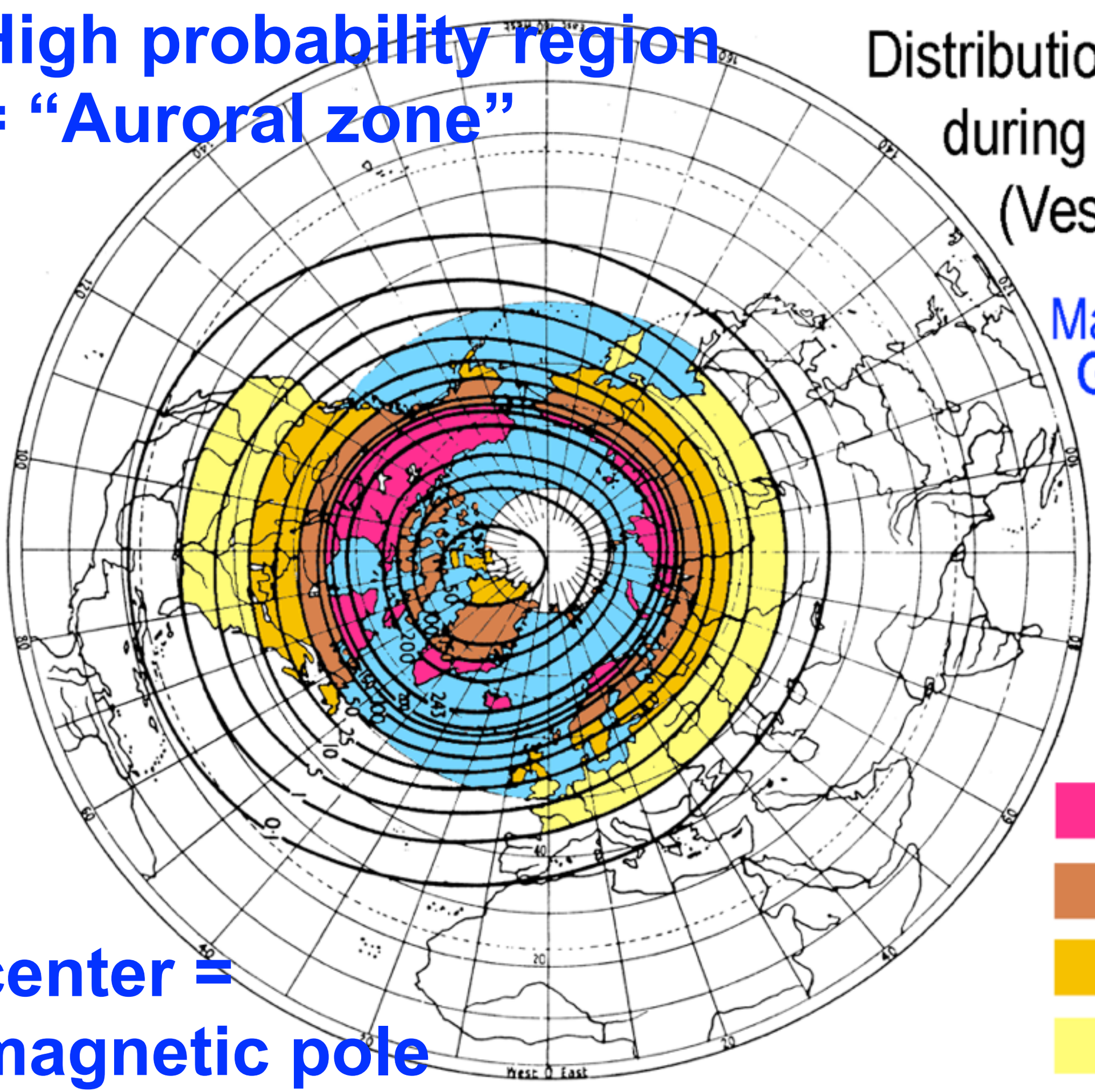
Center of the circle ≠ Pole



High probability region
= "Auroral zone"

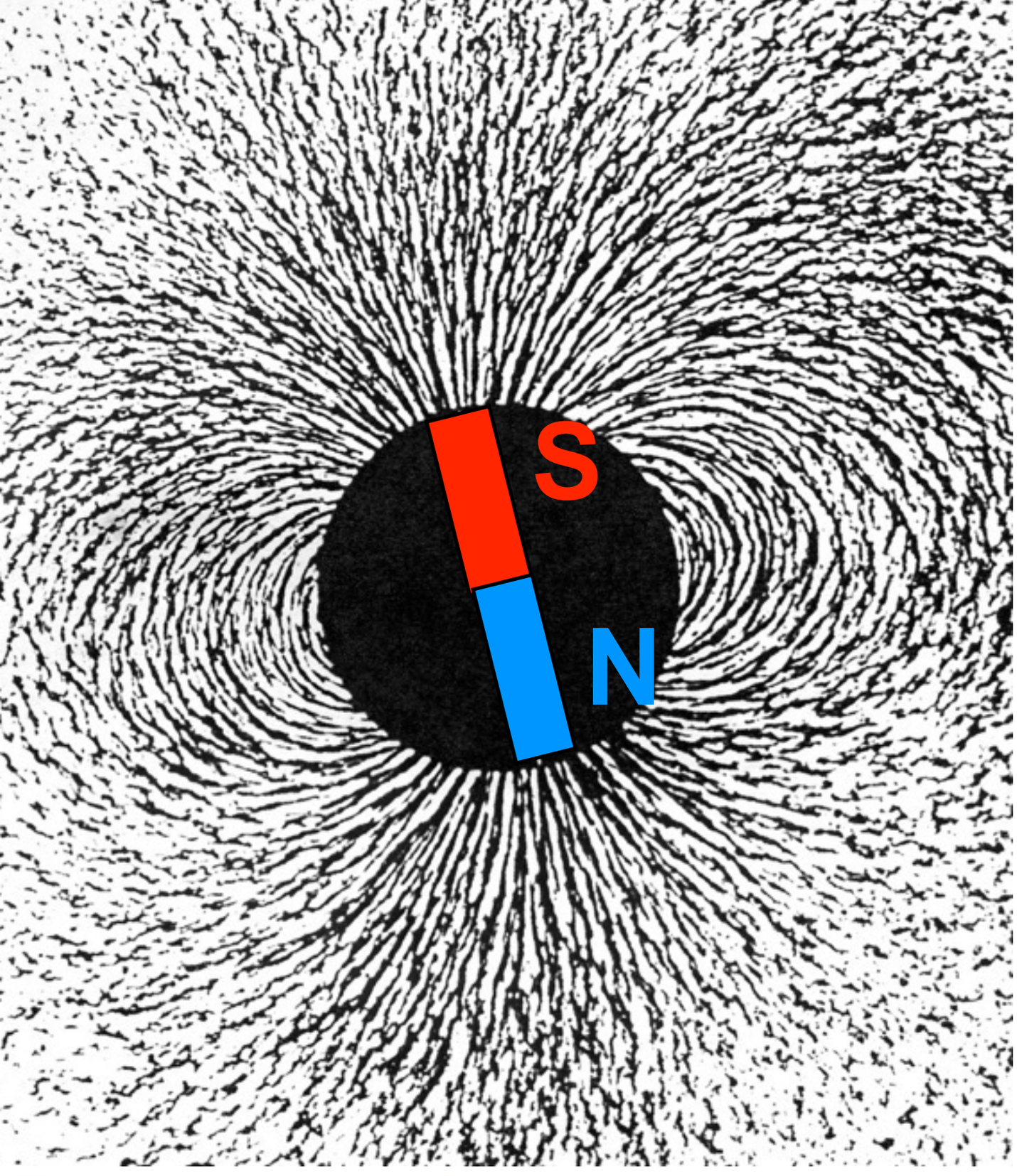
Distribution of aurora
during 1700-1942
(Vestine, 1944)

Match with
Geomagnetic field



>150/year
> 50/year
> 10/year
> 1/year

center =
magnetic pole



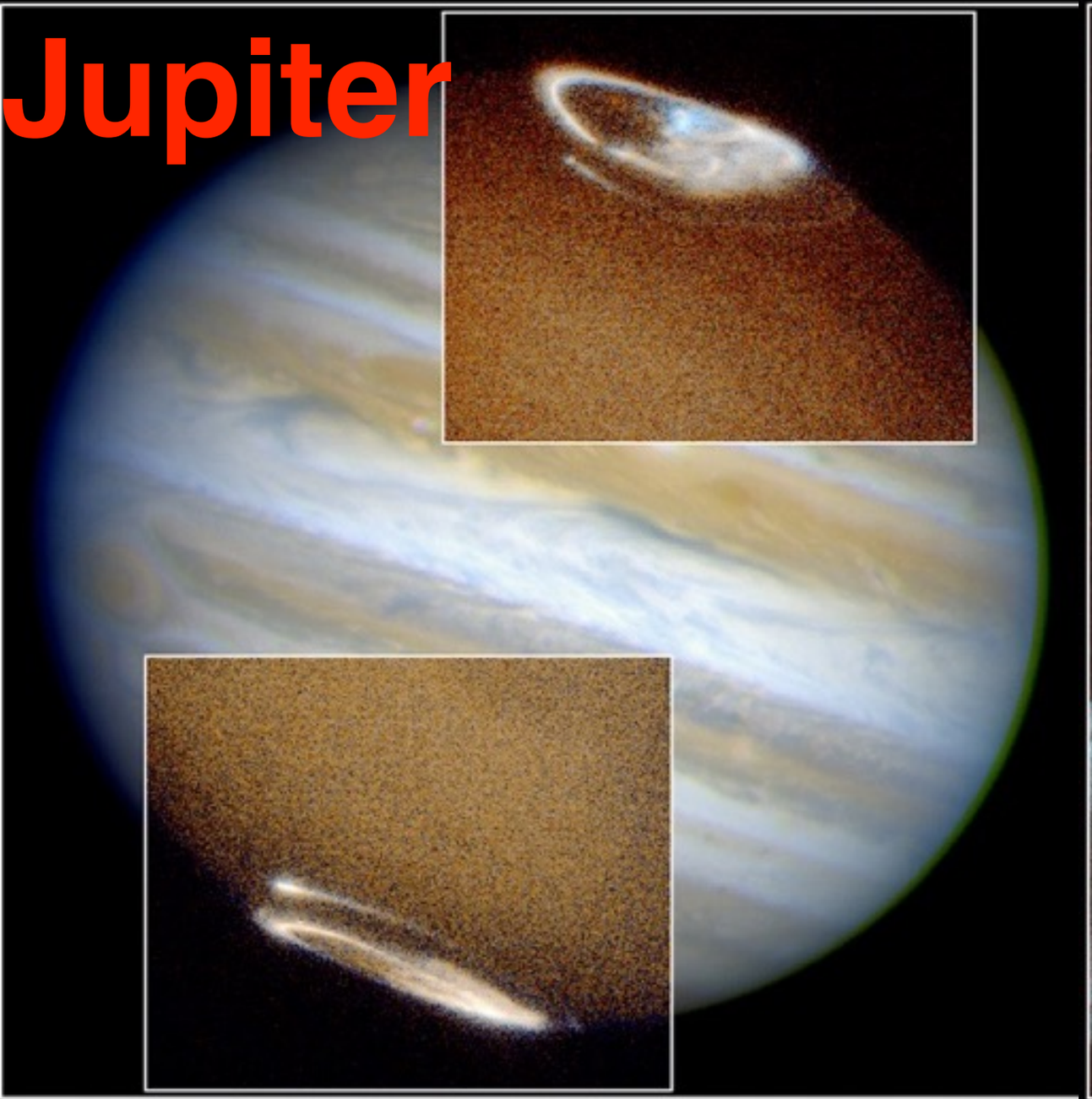
Geomagnetic field essential to aurora

↓

Same for other planets

Because plasma moves only along the magnetic field

Jupiter

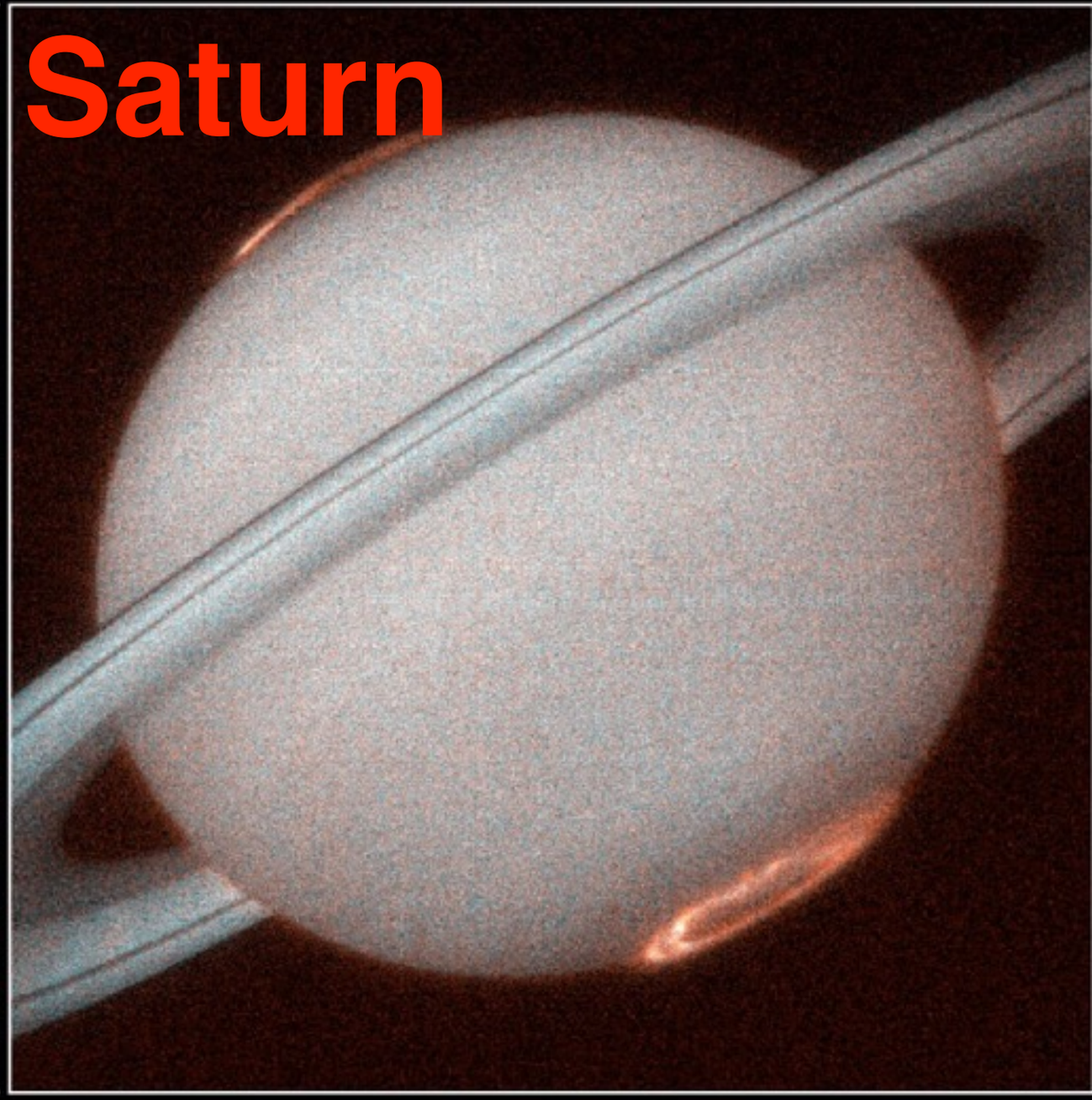


Jupiter Aurora HST • STIS • WFPC2

PRC98-04 • ST ScI OPO • January 7, 1998

J. Clarke (University of Michigan) and NASA

Saturn



Saturn Aurora HST • STIS

PRC98-05 • ST ScI OPO • January 7, 1998 • J. Trauger (JPL) and NASA

Magnetic field + Planetary rotation = Aurora (not related to solar wind!)

Hubble Space Telescope (NASA public domain)

The reason why aurora ~ arctic :

(yes) Geomagnetic field

(no) Cold Climate / Temperature

No relation to temperature, but...

*** cold ~ often clear sky = can see**

*** warm ~ often cloudy = cannot**

Geomagnetic field ⇒ aurora ~ arctic

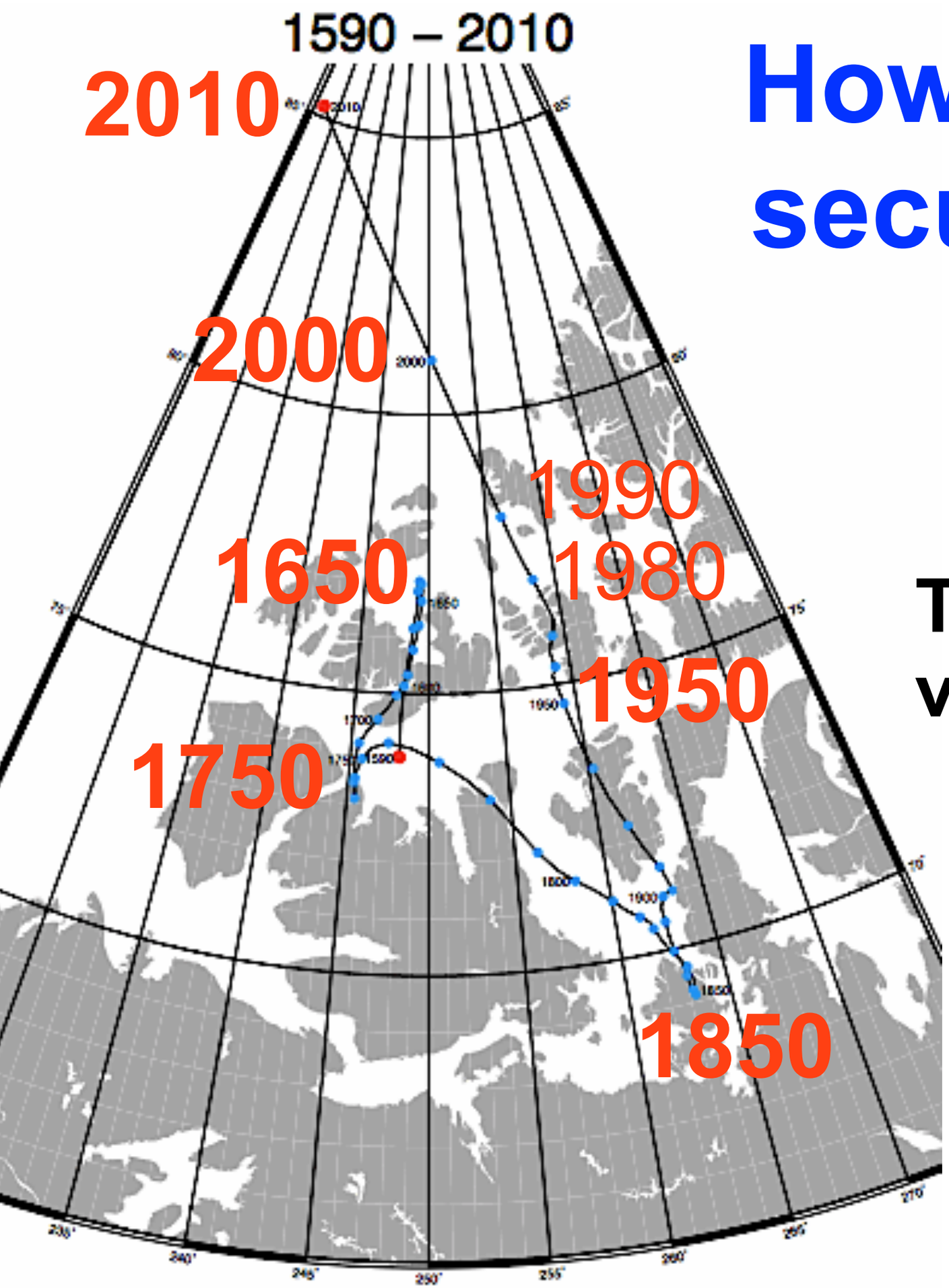
1. Uranus' magnetic pole = @equator

⇒ Aurora@near equator

2. Secular motion of the geomagnetic pole:

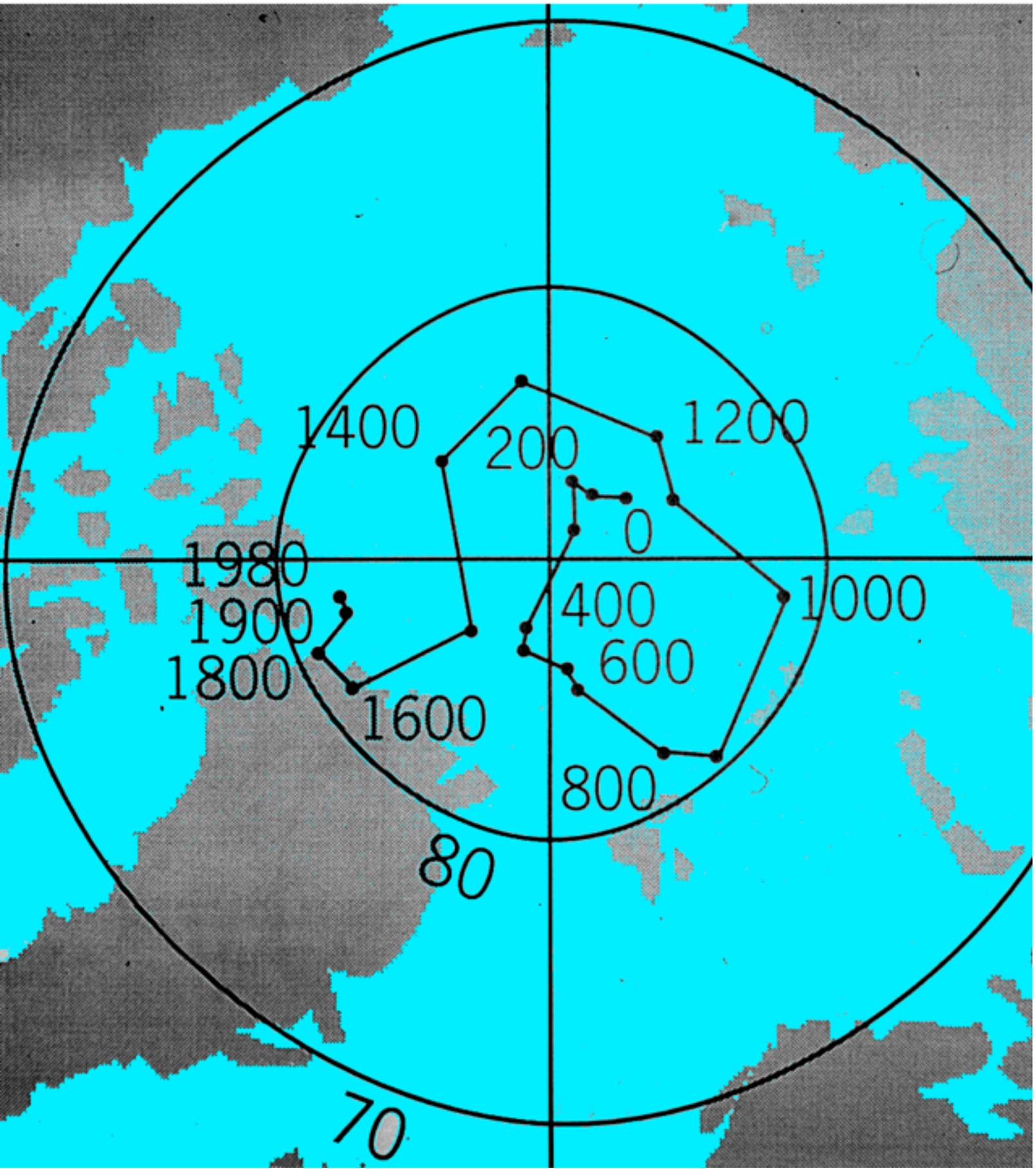
⇒ Secular motion of auroral zone

& Aurora@near equator during reversal



How quick is the secular motion?

The latest 20 year are very quick!



secular motion of magnetic pole

It has been closer to China at B.C.

⇓

Many old record of aurora in China

First page of Taoism text “Zhuangzi” 369-286 B.C,

鵬（大鵬）

鳳凰

不死鳥（phenix）

龍（dragon）

赤気／白気

奇星

天狗

天界の旗・織・矢

北光 { Northern Light (UK) / Norrsken (SE) / Nordlys (NO)

極光 { Polarlicht (DE) / ポリャルニェ・シヤニヤ(R)

狐尾光 Revontuli (FI)

Aurora (Eos)
(Greek Myth → French)

dragon / phenix
= ancient aurora in China

wounding, green body
= dragon

flying, green body with some red
= phenix

flying = phenix

flying = phenix

flying = phenix

movie

end of §1

start of §2

§2. Cause of “beautiful” aurora

What means “Beautiful”?

* **naturally emit** (but, not as bright as moon)

* **with color** (but, not as colorful as rainbow)

* **rare** (but, more often than rainbow)

* **various forms** (not as various as red sky)

There are other important reasons:

movie

move fast!

movie

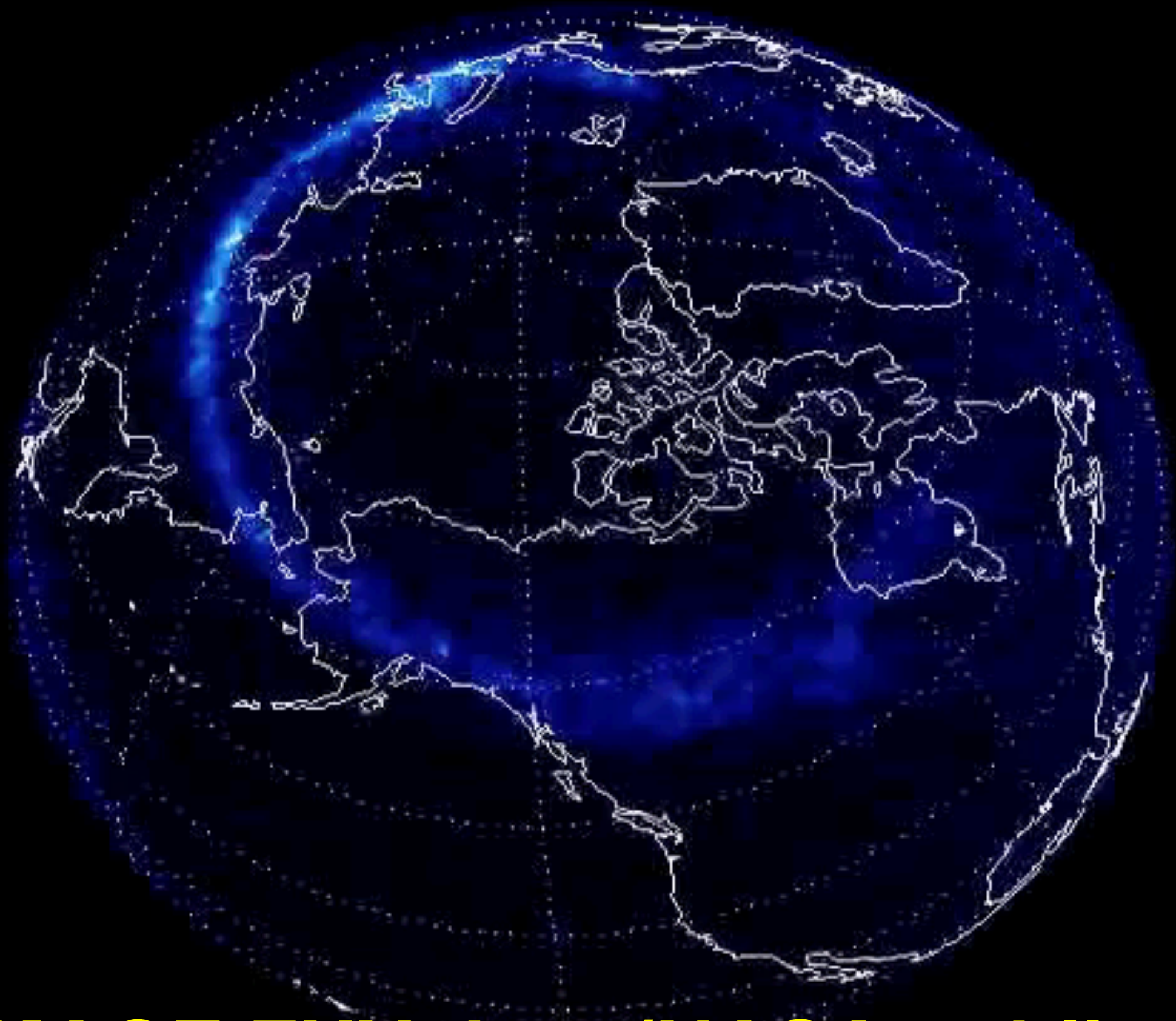


IMAGE FUV data (NASA public domain)

IMAGE–FUV–SI12, 2000–07–15–13:30:06

movie

2003.11.18
16:30 UT

every 6 sec

Aurora moves fast over entire sky !

⇒ Photo is completely different from reality.

Aurora for good photo is a weak stable one in only one part of sky.

Attractive aurora is too large and too quickly-moving for any photo

§2. Cause of “beautiful” aurora

“Beautiful” scientifically means

*** naturally emit**

*** with color**

*** rare**

*** various forms**

*** move fast**

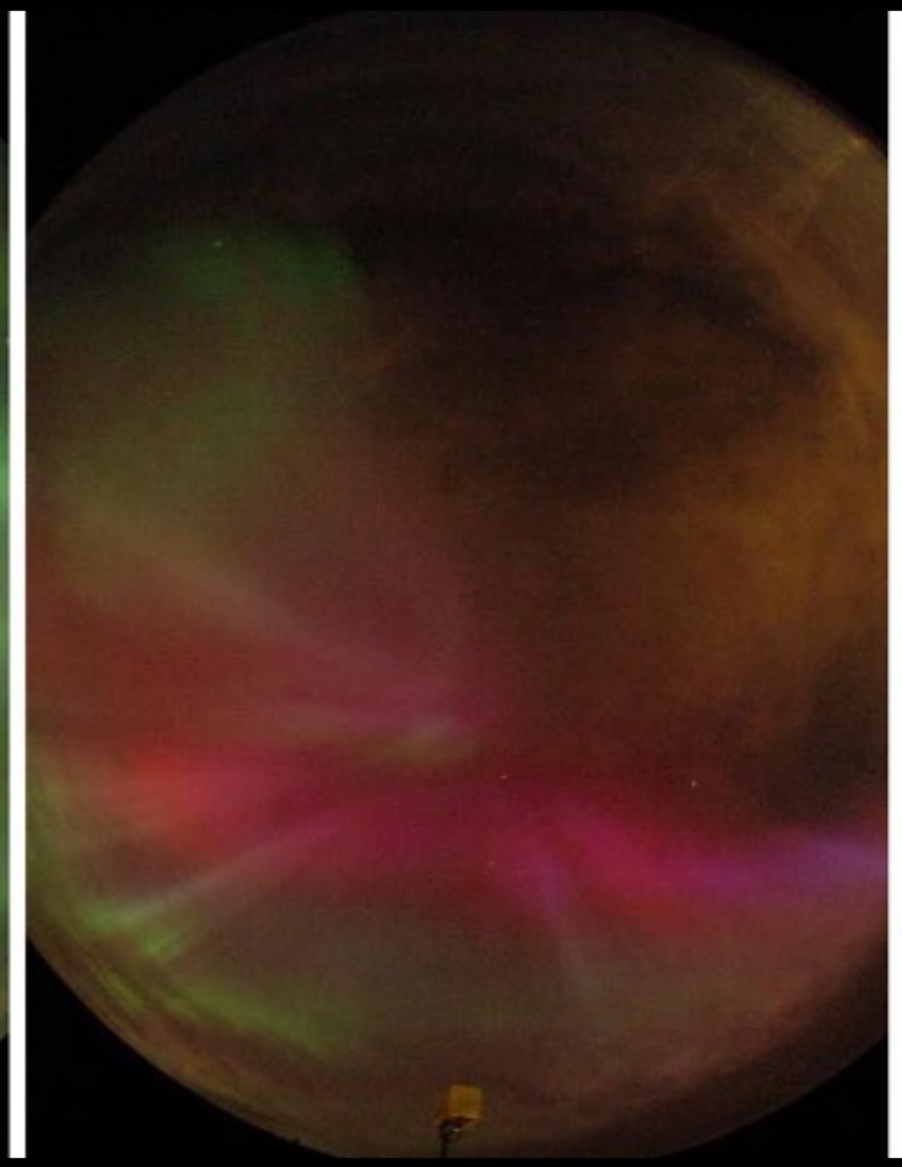
*** entire sky** (like milky way)

§2. Cause of “beautiful” aurora

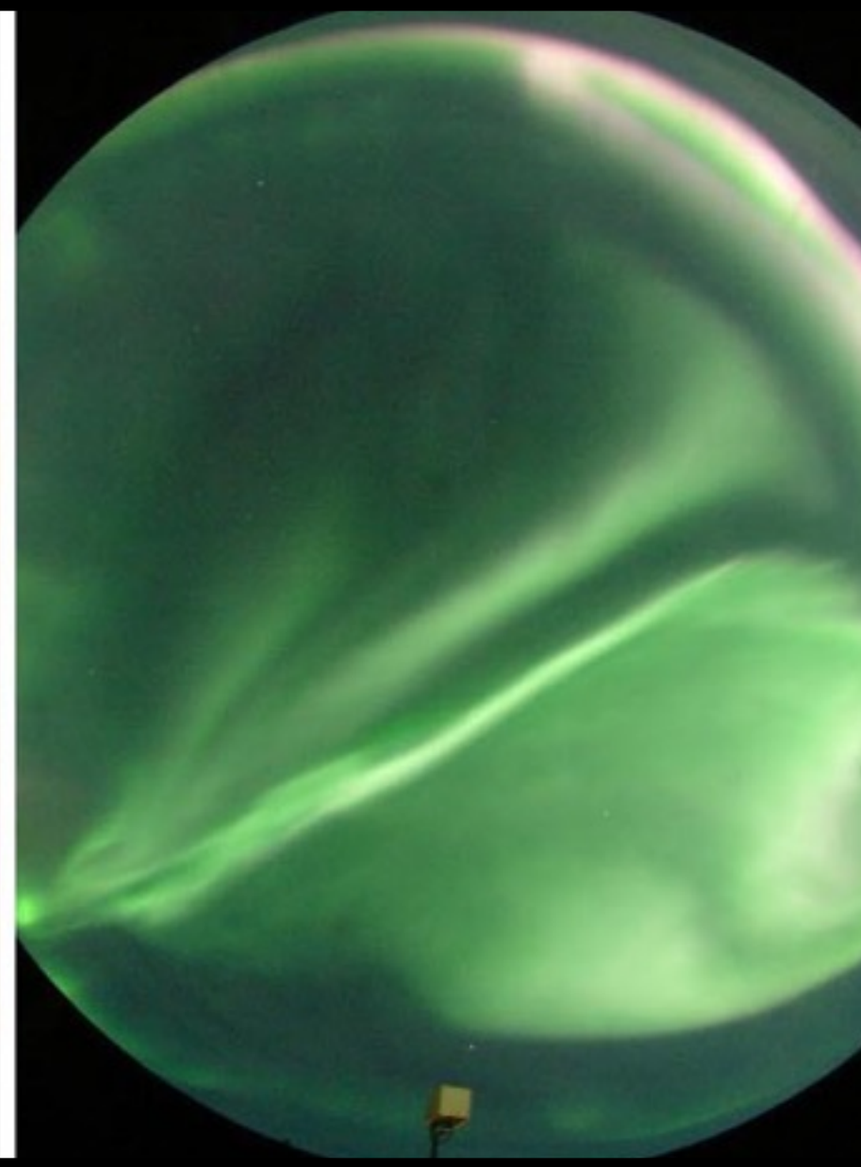
* emission (florescent light)
* cause of color
* rareness (geomagnetic pole)
* cause of variety
* cause of motion
* entire sky (global scale)

Colors of aurora

green

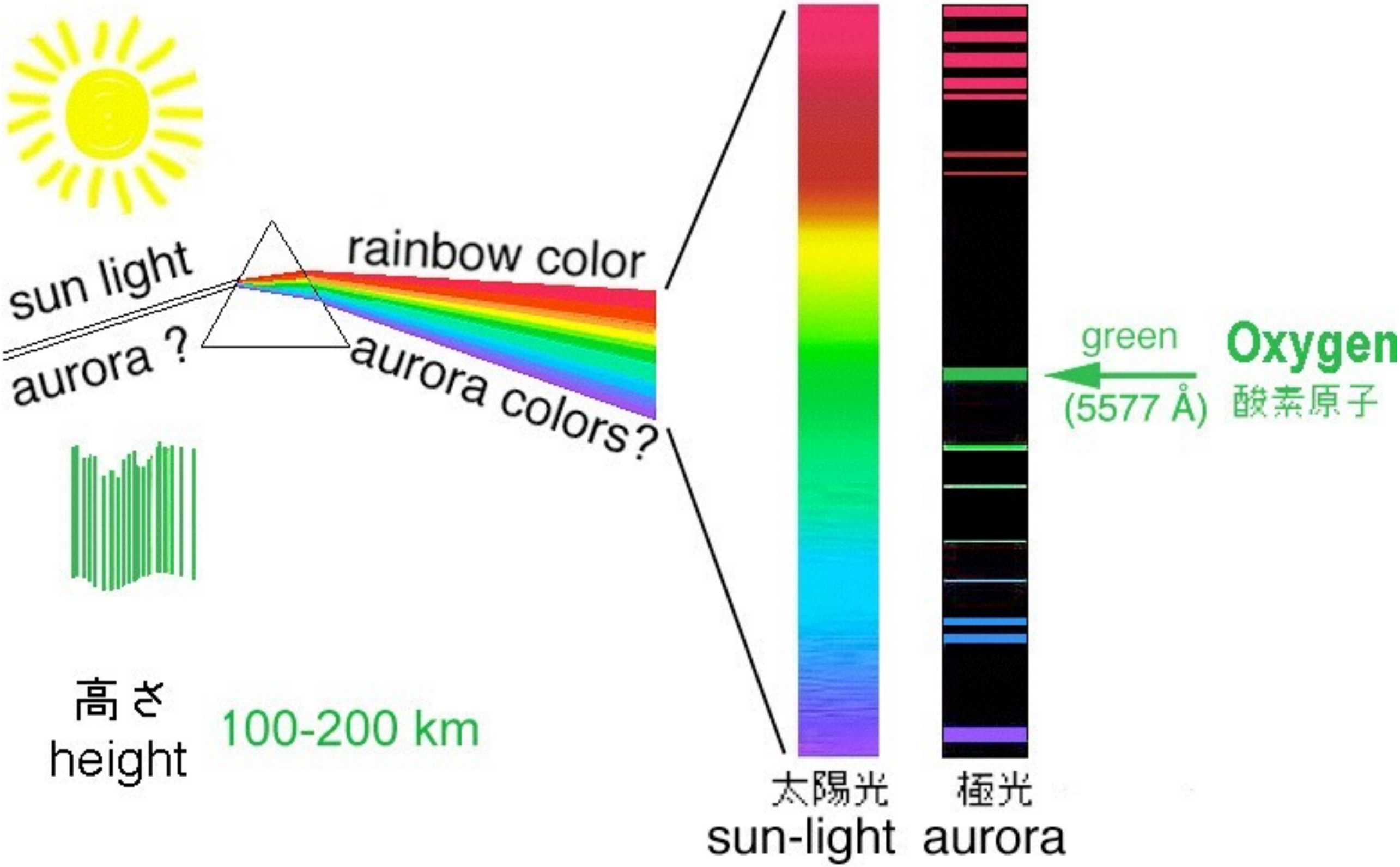


red + blue



green + pink

Green = Oxygen Atom



green

movie

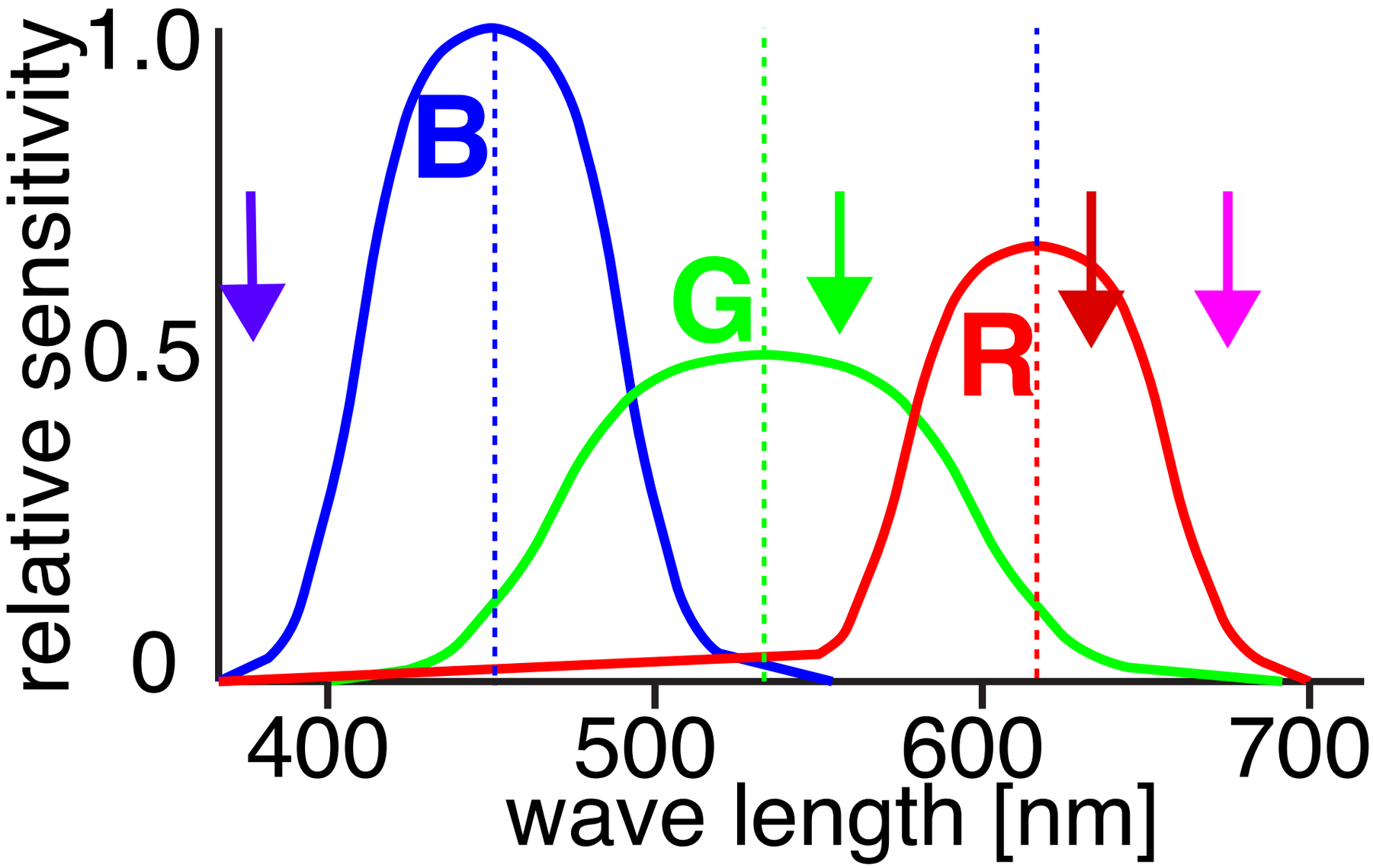
green + many colors

green + many colors

color depends of film

Why different color appearances?

⇒ because of the RGB filtering method



≈ color of filter or CCD

(≠ color of aurora)

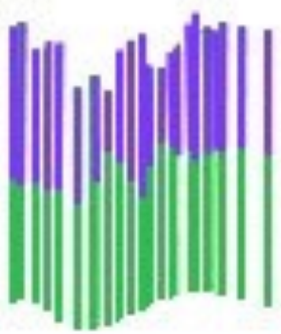
Blue-purple = Nitrogen Ion

only April and September

> 200 km

blue-purple
(4278 Å)

far-purple
(3914 Å)



N_2^+
窒素分子イオン

極光
aurora

blue-purple

movie

blue-purple

Pink = Nitrogen Molecule

Mainly during early September or late March (sunshine is important)

極光

aurora

only after largest CMEs

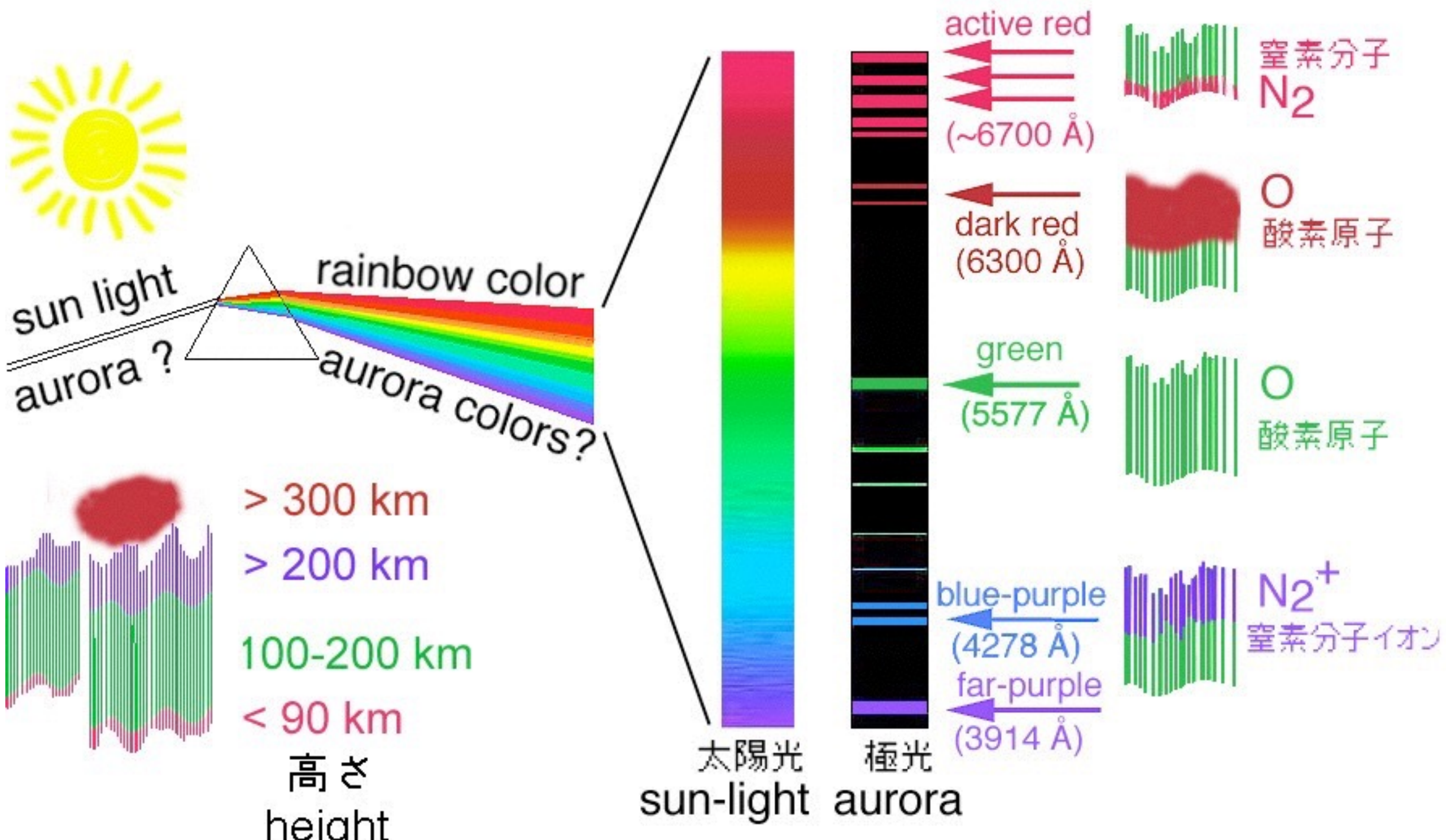
Red = Oxygen

Very Rare, but now have chance to see during next few years

movie

red

Four major colors are determined by composition of the ionosphere

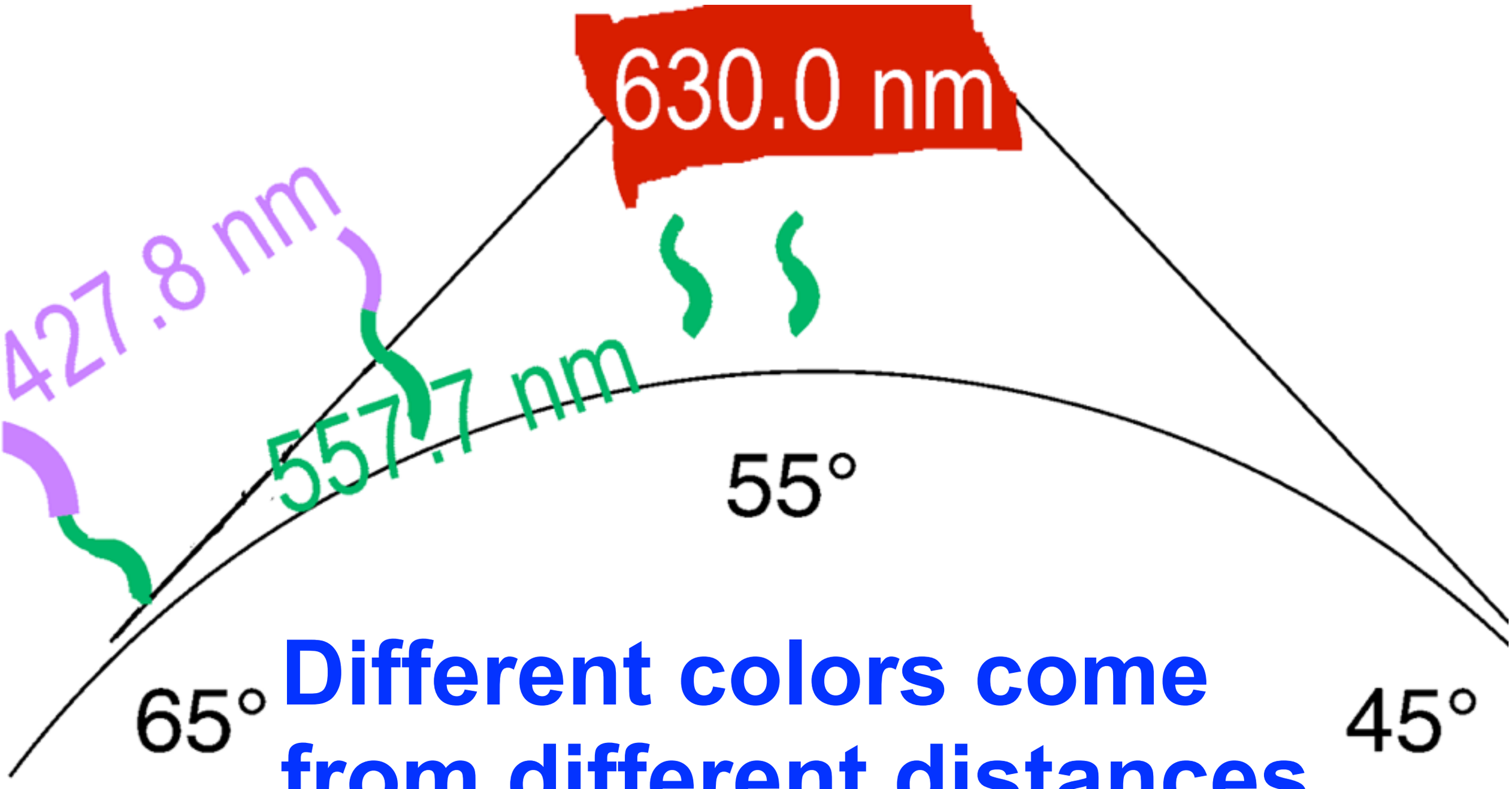


many colors

movie

many colors

2003.11.20
14:48 UT



Different colors come from different distances.

Schematic diagram (exaggerated) of auroral locations for different colours.

1. To have aurora, a planet must have both:

   Magnetic field & Ionosphere (& Atmosphere)

2. Color tells composition:

   Green = Oxygen

   Blue-purple = Nitrogen

⇒ Can check condition for life!

§2. Cause of “beautiful” aurora

* emission (florescent light)
* color (ionosphere)
* rareness (geomagnetic pole)
* cause of variety
* cause of motion
* entire sky (global scale)

movie

2004.03.10
23:01 UT

quiet-to-rapid motion

only one minute!

16:29 UT

16:30 UT

18:48 UT

18:51 UT

184754ut

185055ut

18:54 UT

18:56 UT

185336ut

185617ut

214/860401

Largest activity = quick & midnight

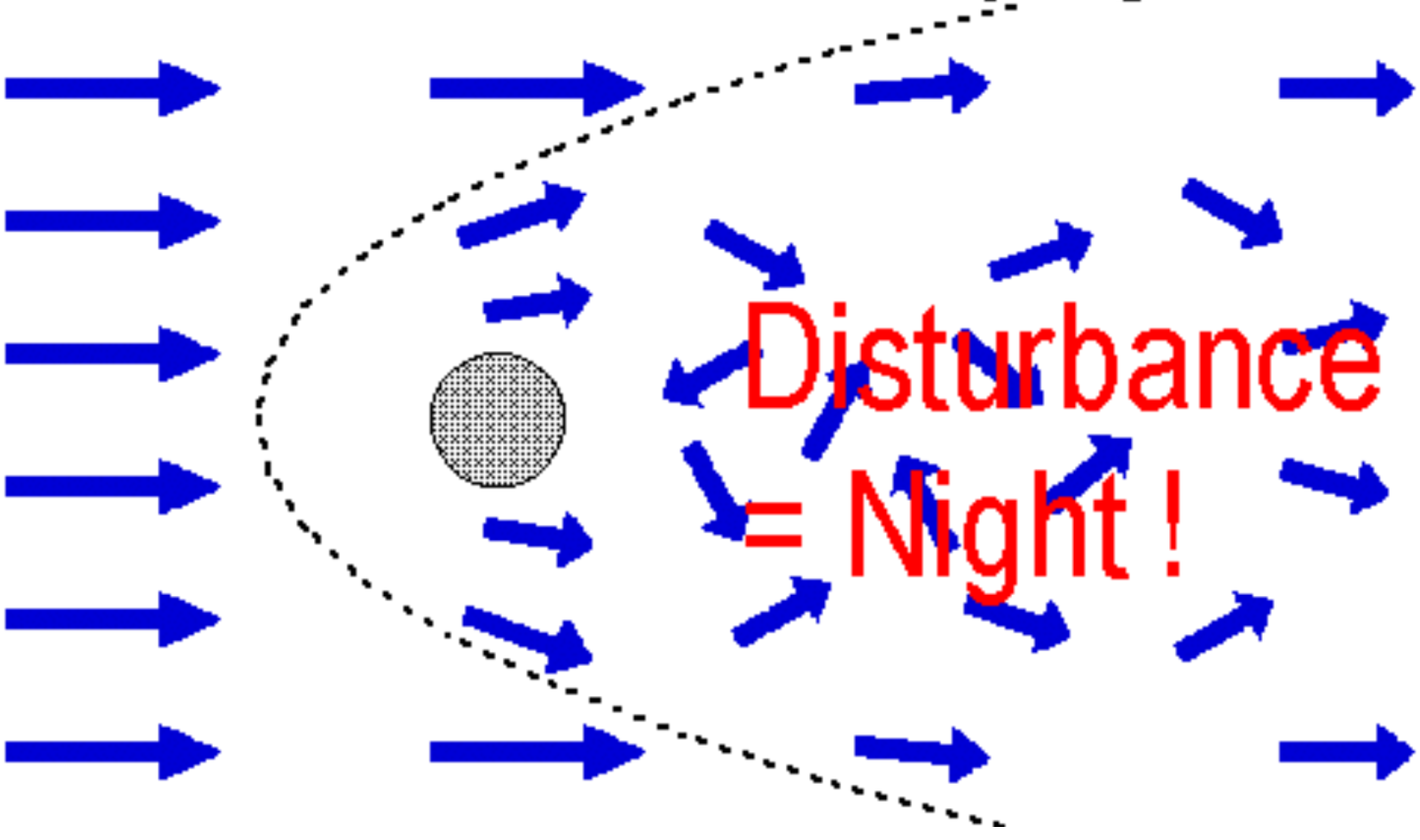
Why midnight?

⇒ Solar wind energy is stored there.

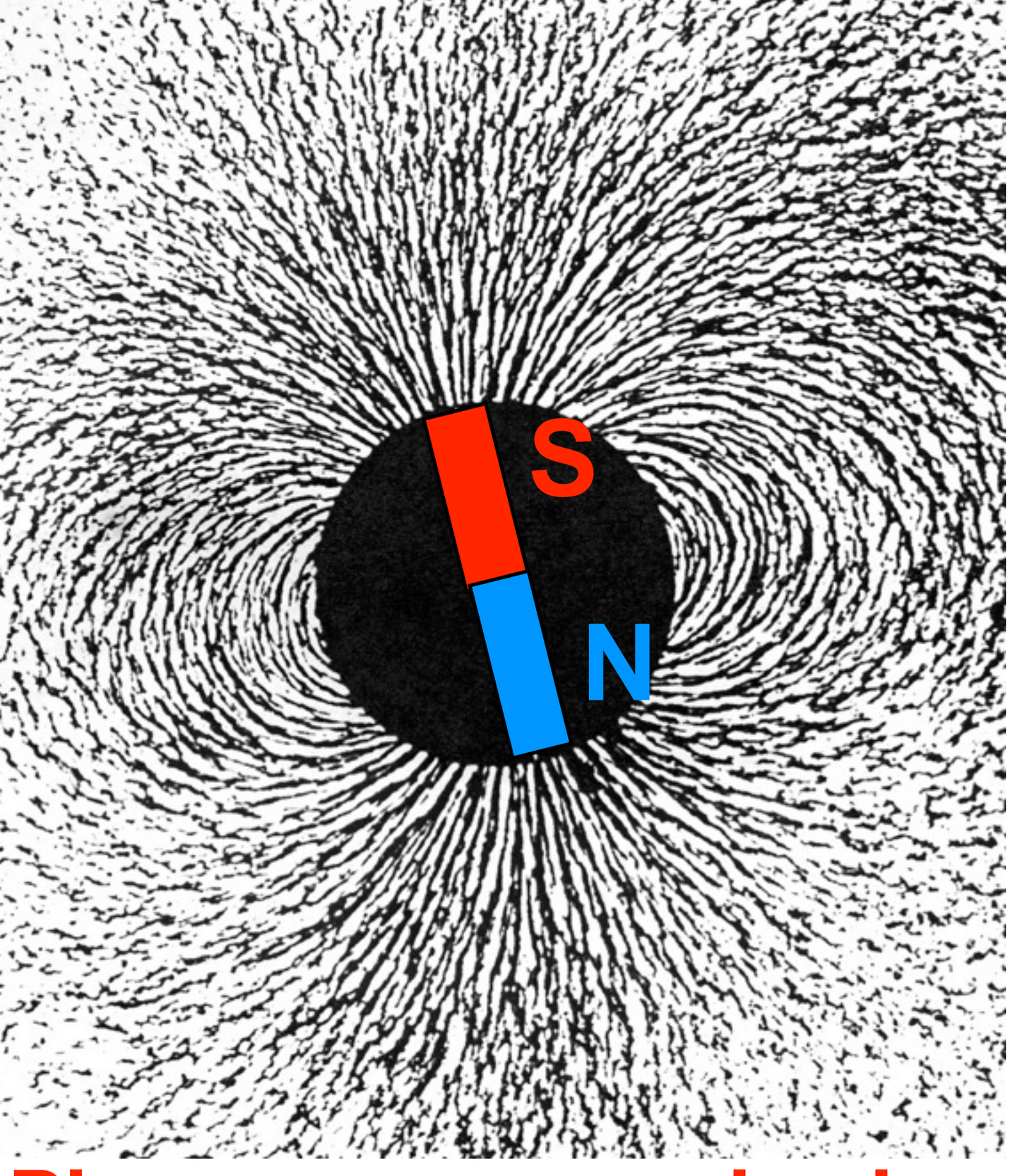
Solar Wind Flow

cf. water flow

Earth = obstable (e.g. rock)



Source plasma is disturbed due to interaction



Plasma moves only along the magnetic field

solar wind

Enter along magnetic field (compus direction) from nightside

Solar wind

solar wind

Hit atmosphere that emit light

* Cause of moderate motion

= plasma disturbance moves the start location of the auroral electron

* Cause of explosive motion (named as “substorm”)

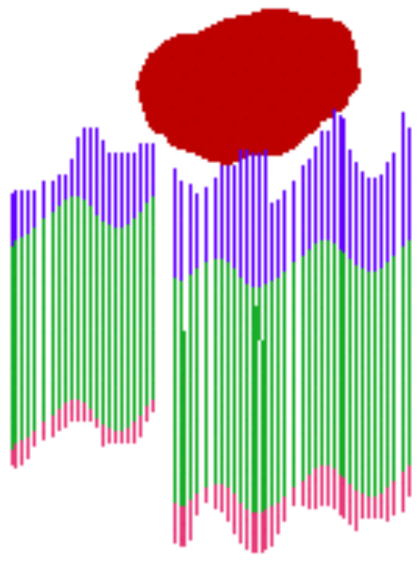
= not well understood

§2. Cause of “beautiful” aurora

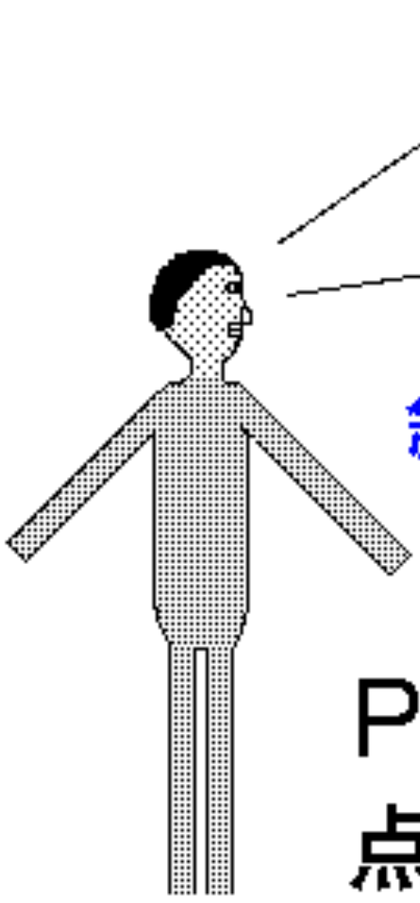
* emission (florescent light)
* color (ionosphere)
* rareness (geomagnetic pole)
* cause of variety
* motion (interaction + ???)
* entire sky (global scale)

* One reason is viewing angle

他のオーロラ
Other aurorae

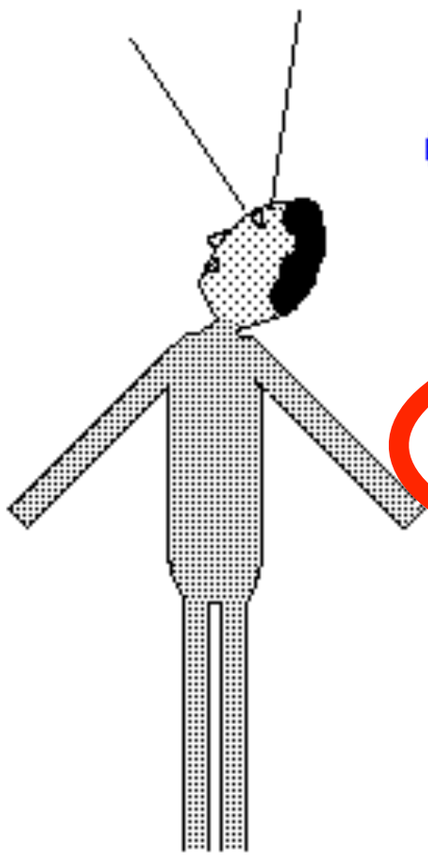


高さ height
> 300 km
> 200 km
100-200 km
< 90 km



ordinary view
斜め下から見る(普通)

Pulsating Aurora
点滅するタイプ



over the zenith (lucky)
真下から見る(幸運)

(1) Corona
コロナ

(2) Black aurora
暗黒筋

in zenith

corona = zenith

movie

movie

omega band = after midnight

2005.01.12
02:00 UT

movie

pulsation = late after midnight

red = only special condition of sunspot

§2. Cause of “beautiful” aurora

* emission (florescent light)
* color (ionosphere)
* rareness (geomagnetic pole)
* variety (time, angle, etc)
* motion (interaction + ???)
* entire sky (global scale)

end of §2

start of §3

§3. Meaning of real-time data

* Weather (search for clear sky)
* All-sky camera (shown in §1)
* Magnetometer (shown in §1)
* Solar wind
* Solar surface
* Others

A collection of data link is found at
http://www.irf.se/~yamau/manual/irf_data.html

Real time data from the Kiruna All-S

http://www.irf.se/allsky/rtasc.php

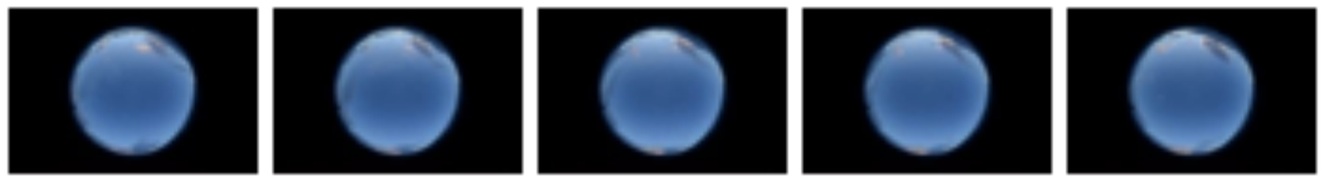
webmail Telia-ZwQGMh5A IRF-data

Kiruna

Abisko

Latest picture from the Kiruna All-Sky camera at: 2010-03-

Geomagnetic coordinates. More about image orientation.

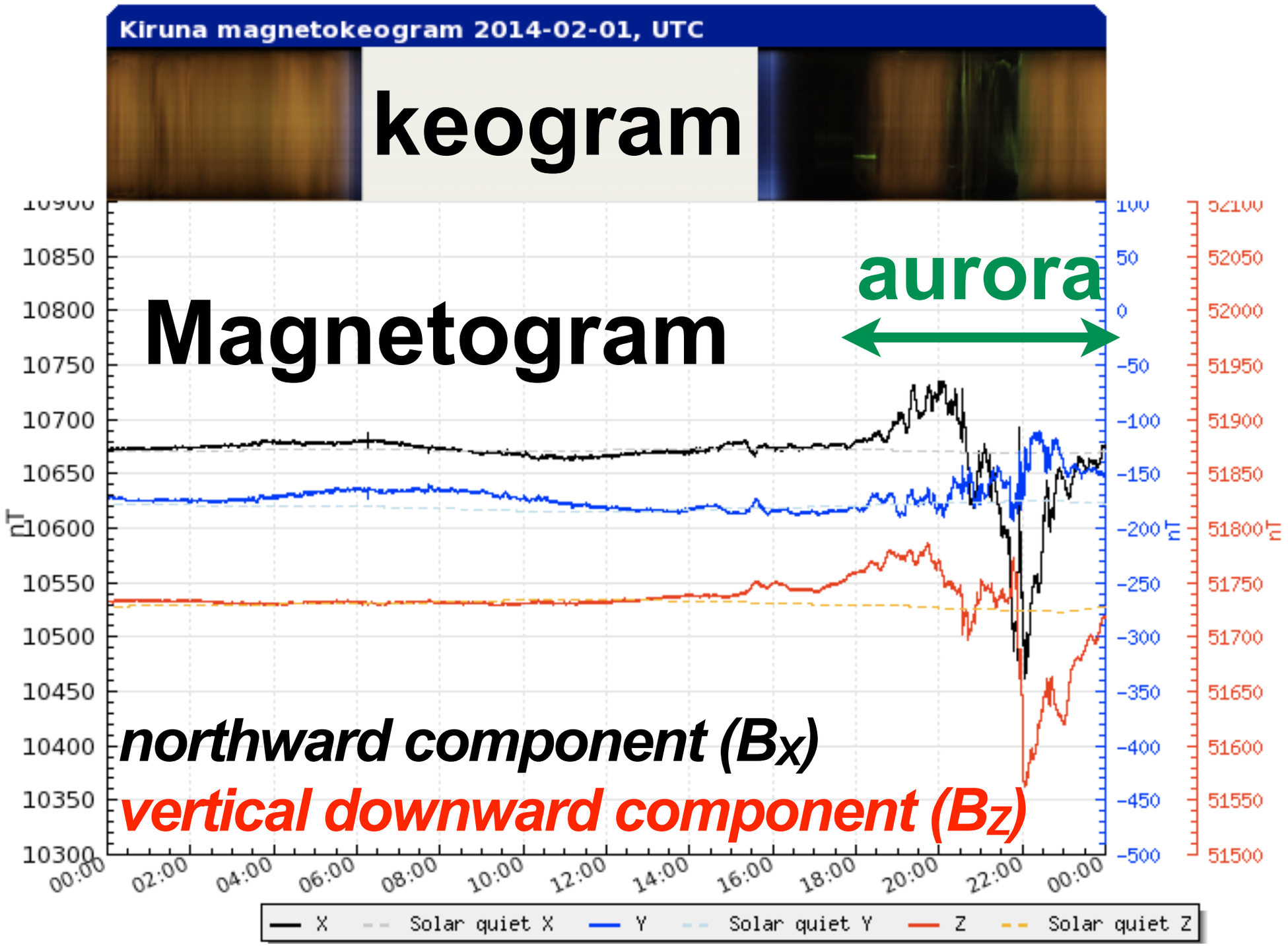


4 min ago 3 min ago 2 min ago 1 min ago 0 min ago

All Sky Cameras

http://www.irf.se//Observatory/?link=All-sky_sp_camera

Get Kiruna plot in pdf format



http://www.irf.se//Observatory/?link=Magnetometers

Real-time AE Index Daily Plot

http://wdc.kugi.kyoto-u.ac.jp/ae_realtime/201003/index_20100310.html

webmail Telia-ZwQGMh5A IRF-data

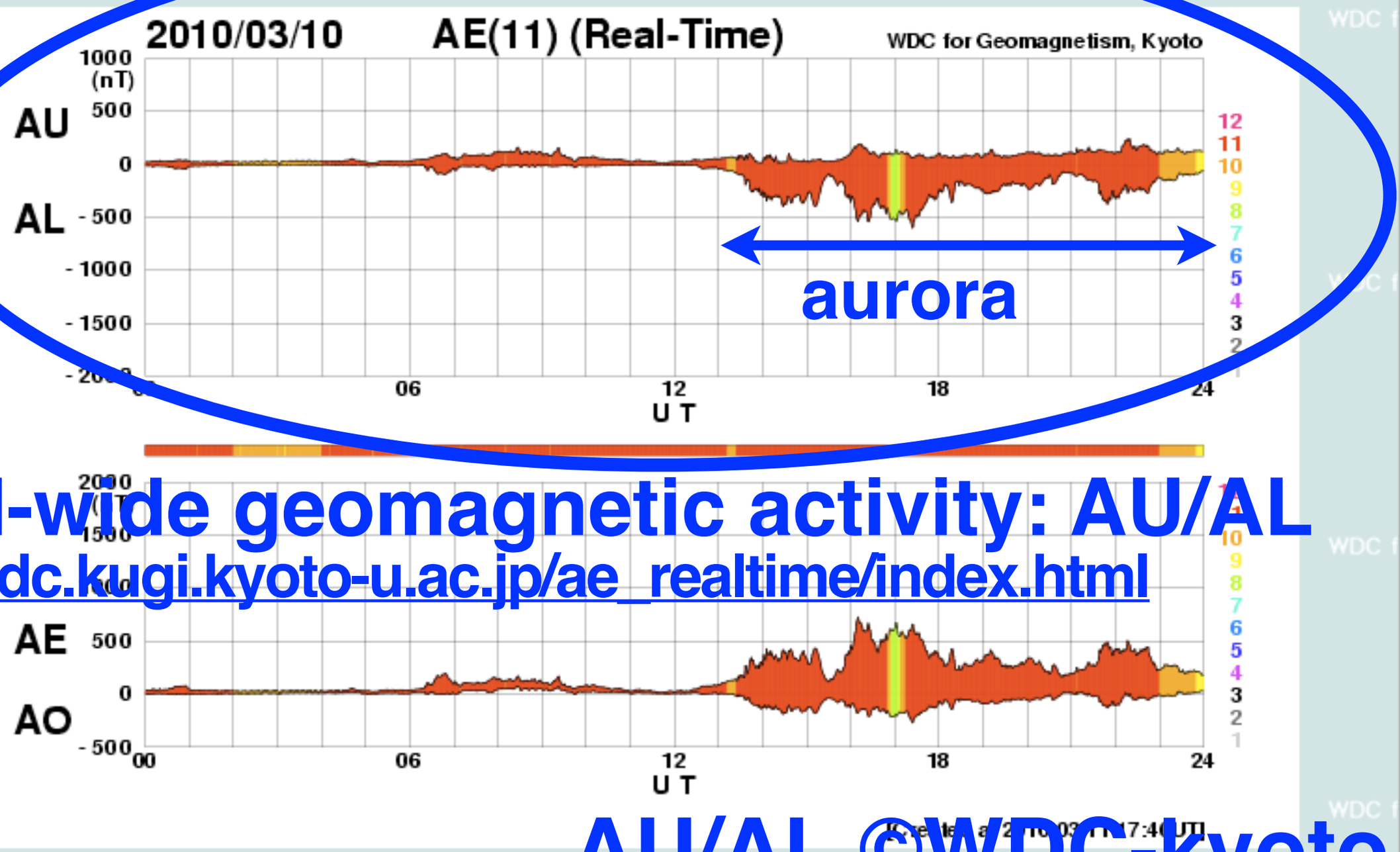
< 2010/03

01 02 03 04 05

06 07 08 09 10

11

Link to Top Page , Last Day , Next Day



world-wide geomagnetic activity: AU/AL

http://wdc.kugi.kyoto-u.ac.jp/ae_realtime/index.html

AU/AL ©WDC-kyoto

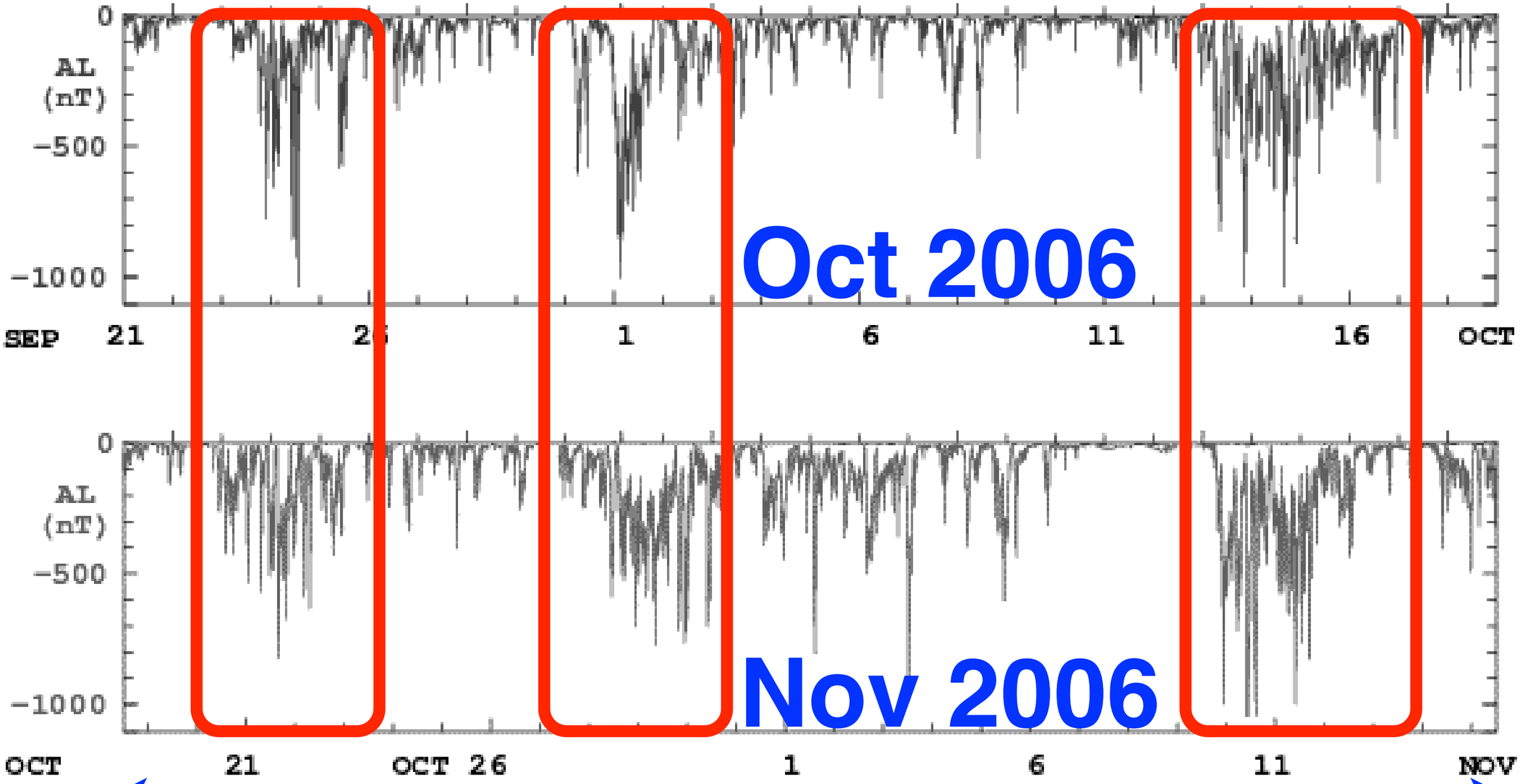
Note! These data are only for non-commercial monitoring purpose.

The number of stations used to derive the index is shown in color. The color scale is displayed at the right of the plot. Users should note that a loss of only one station could miss significant disturbance events. Users should also note that the real-time AE indices can include noise and baseline shift since we use raw

Can we make long-term prediction?

Using global monitor (AL) of the aurora's electric current, let's check long-term activity

http://wdc.kugi.kyoto-u.ac.jp/aeasy/index.html

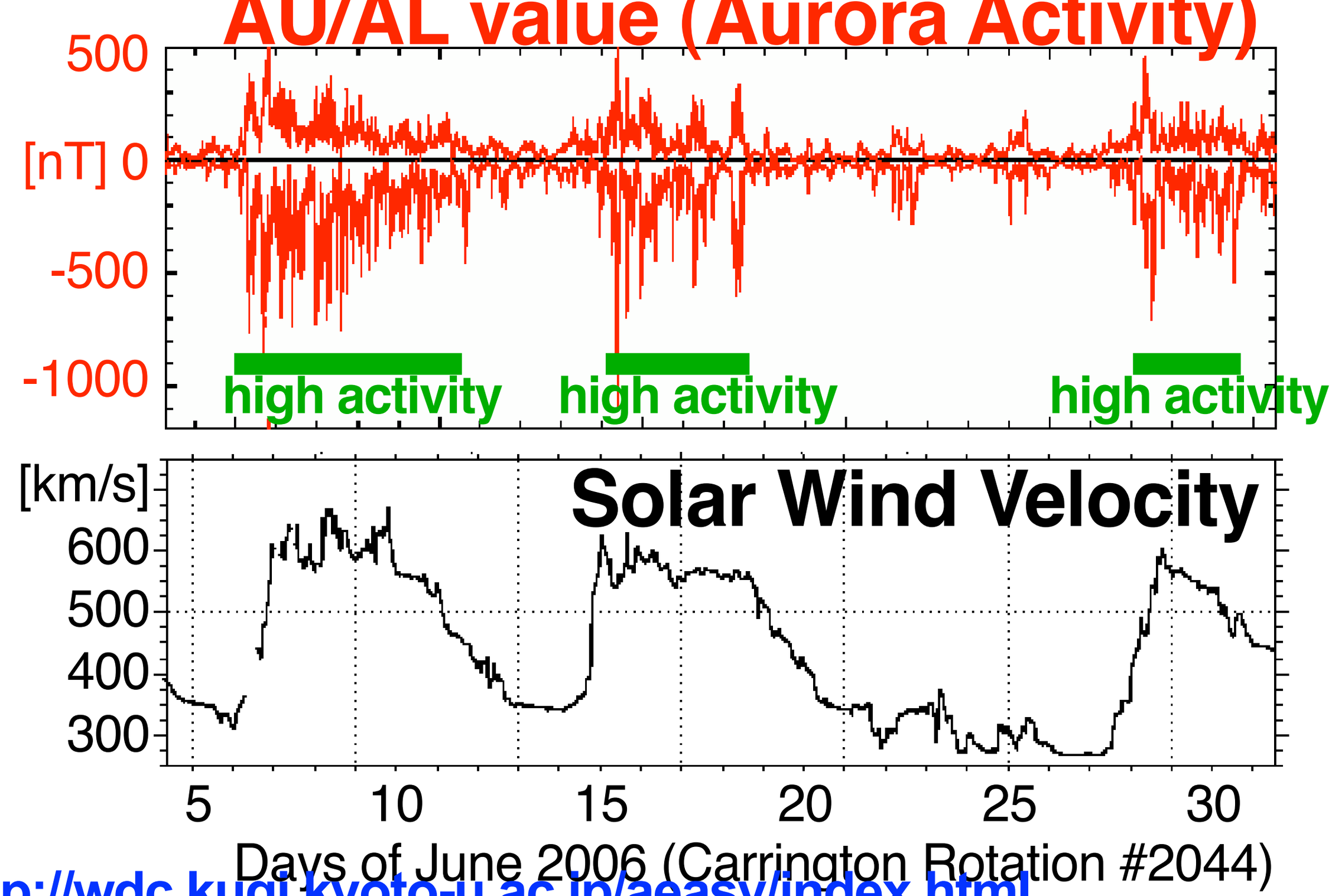


about 27 days = rotation period of sun!

There are periods of high/low activities

These periods returns every 27 days

⇒ WE CAN PREDICT (but @solar minimum)



http://wdc.kugi.kyoto-u.ac.jp/aeasy/index.html

http://umtof.umd.edu/pm/

High/low activities corresponds to fast/slow solar wind ⇒ WE CAN PREDICT

Solar wind

High chance to see “strong” aurora

(1) When solar wind is fast

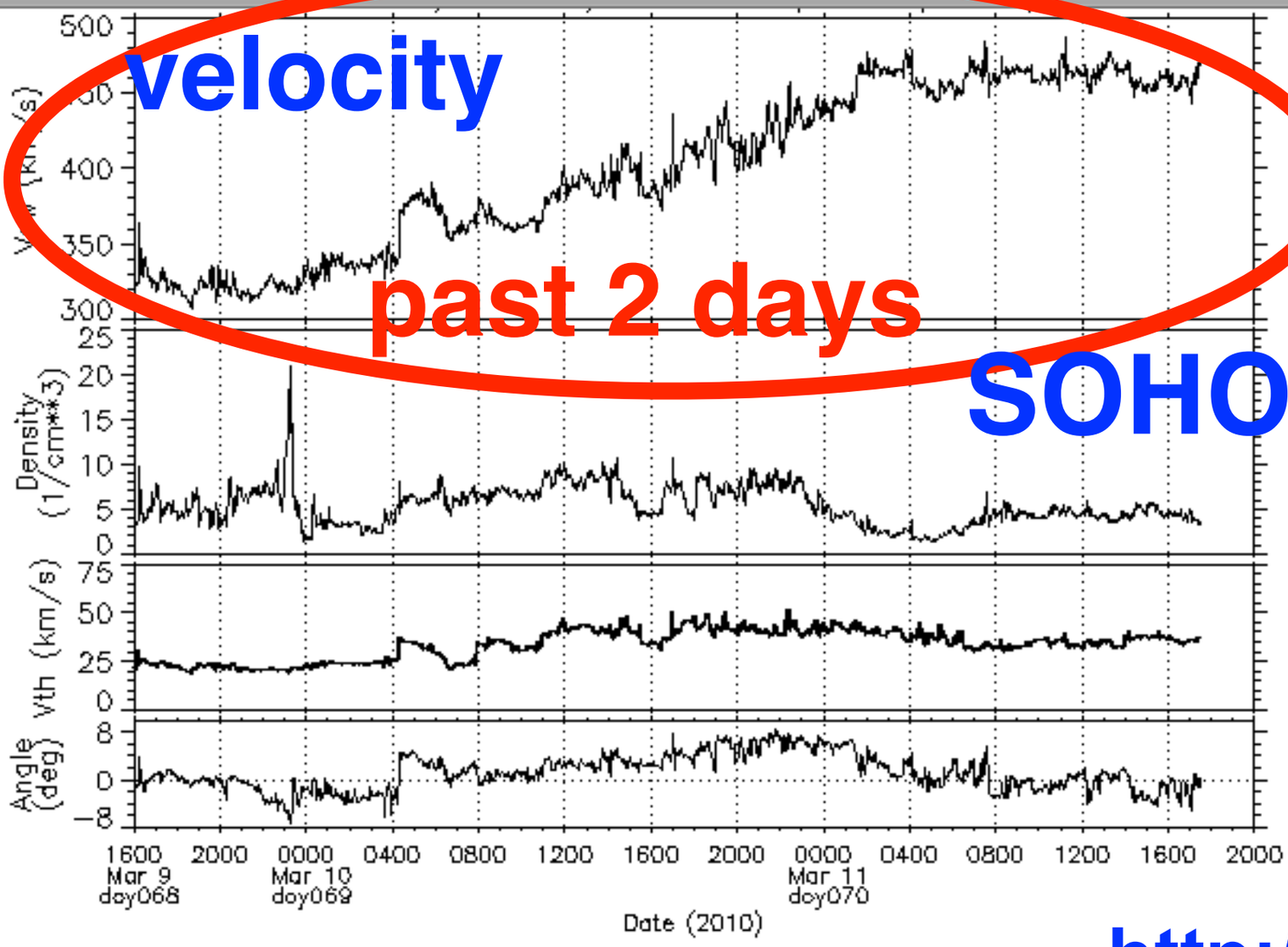
(2) When solar wind magnetic field points specific direction

Both data is available over the internet

MTOF Proton Monitor

http://umtof.umd.edu/pm/

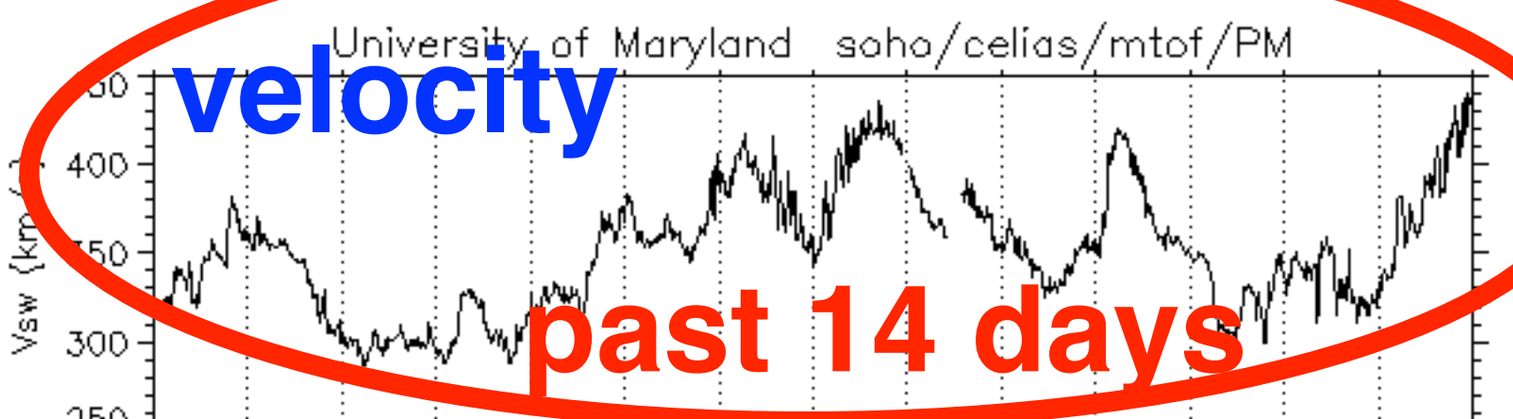
webmail Telia-ZwQGMh5A



SOHO ©ESA&NASA

http://umtof.umd.edu/pm/

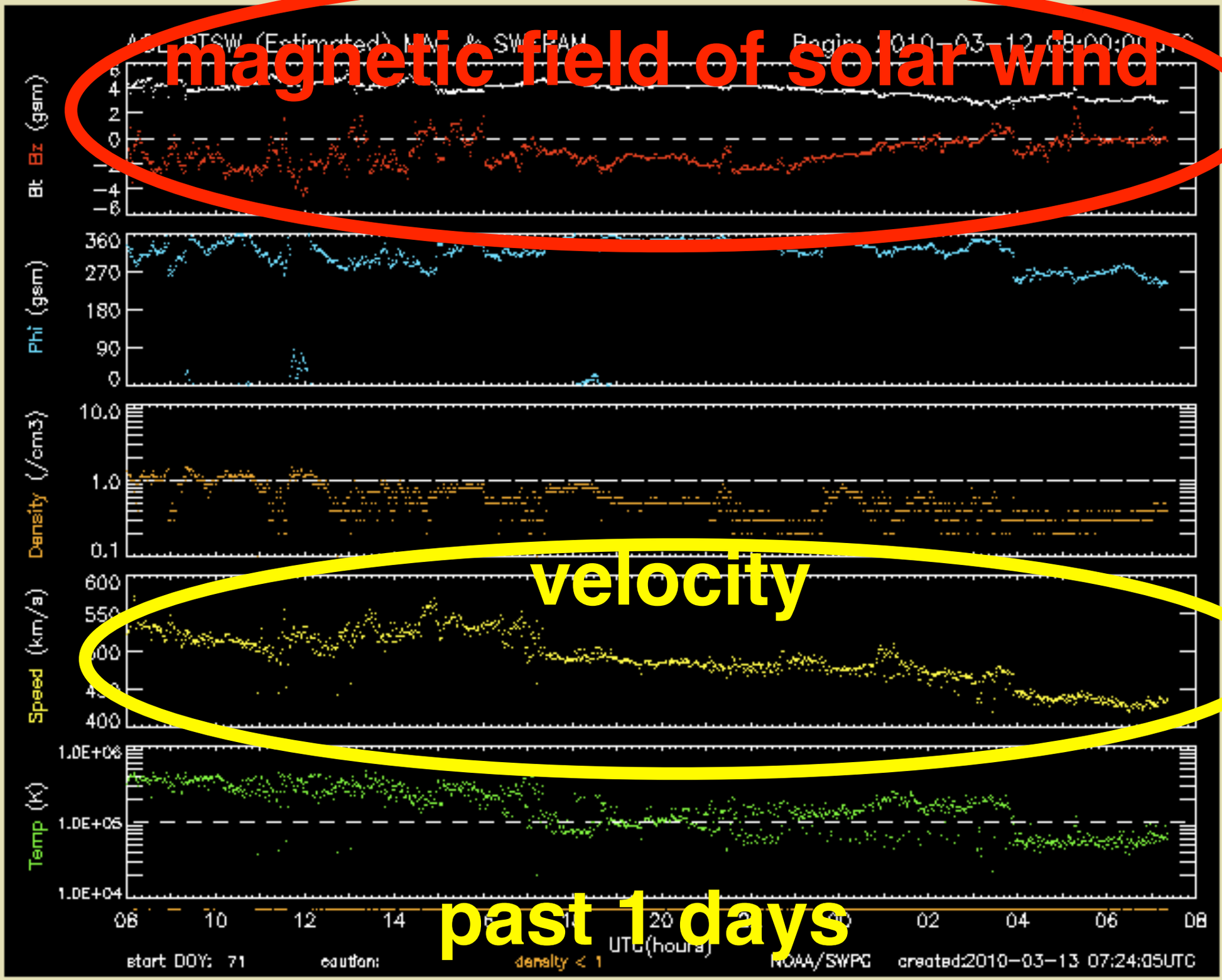
Data ending at 2306 GMT on Mar 10, 2010 (ascii data available)



SWPC ACE RTSW MAG & SWEPAM 24-hour Updating Plot

http://www.swpc.noaa.gov/ace/MAG_SWEPAM_24h.html

webmail Telia-ZwQGMh5A IRF-data



magnetic field of solar wind

velocity

past 1 days

ACE

©NOAA

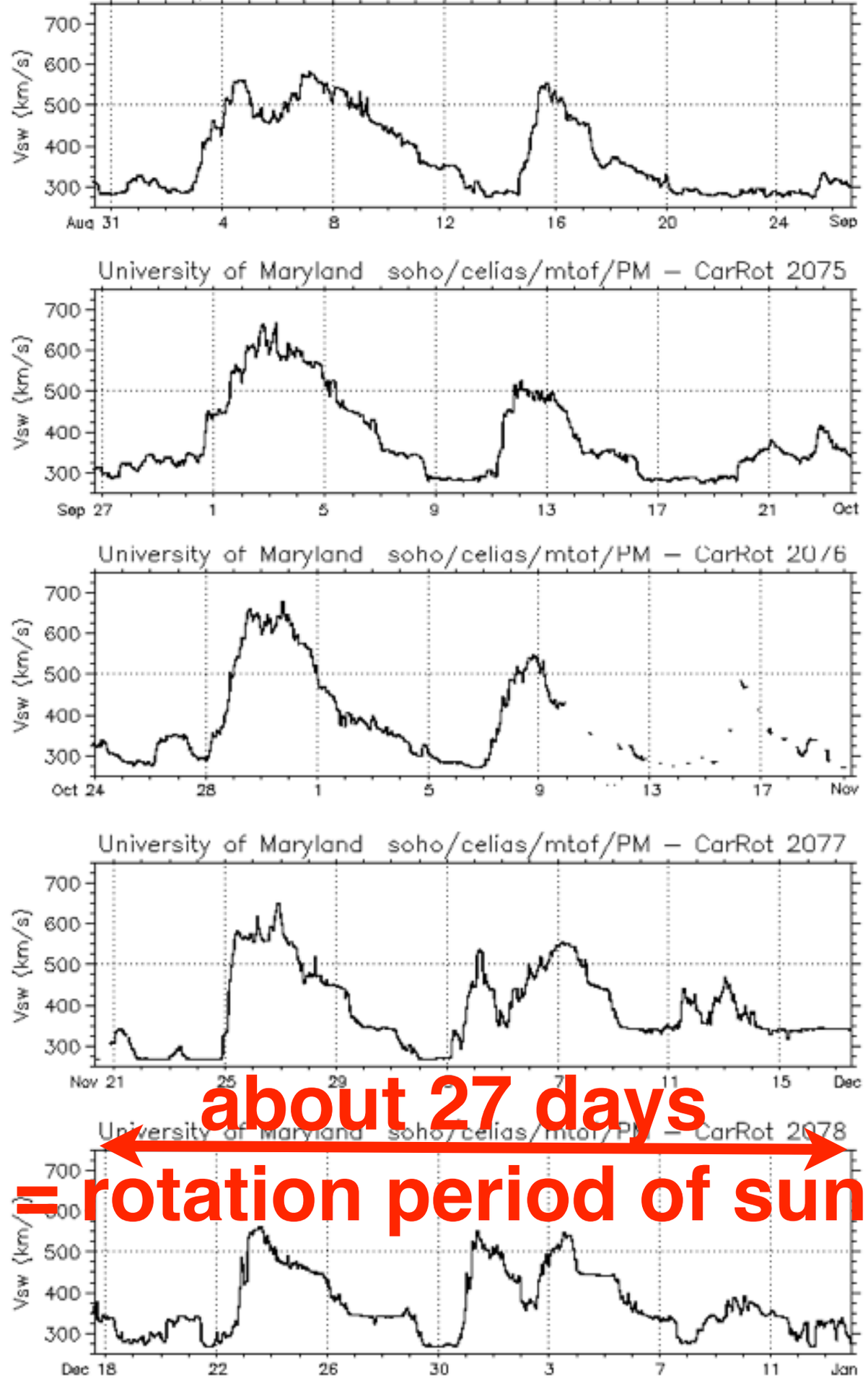
ACE Dynamic Plots

http://www.swpc.noaa.gov/ace/MAG_SWEPAM_24h.html

Long-term behavior of the Solar Wind

* Sun’s rotation (~27 days)
* Sunspot cycle (~11 year)
* Longer cycle (> 100 years)

1. Solar Minimum

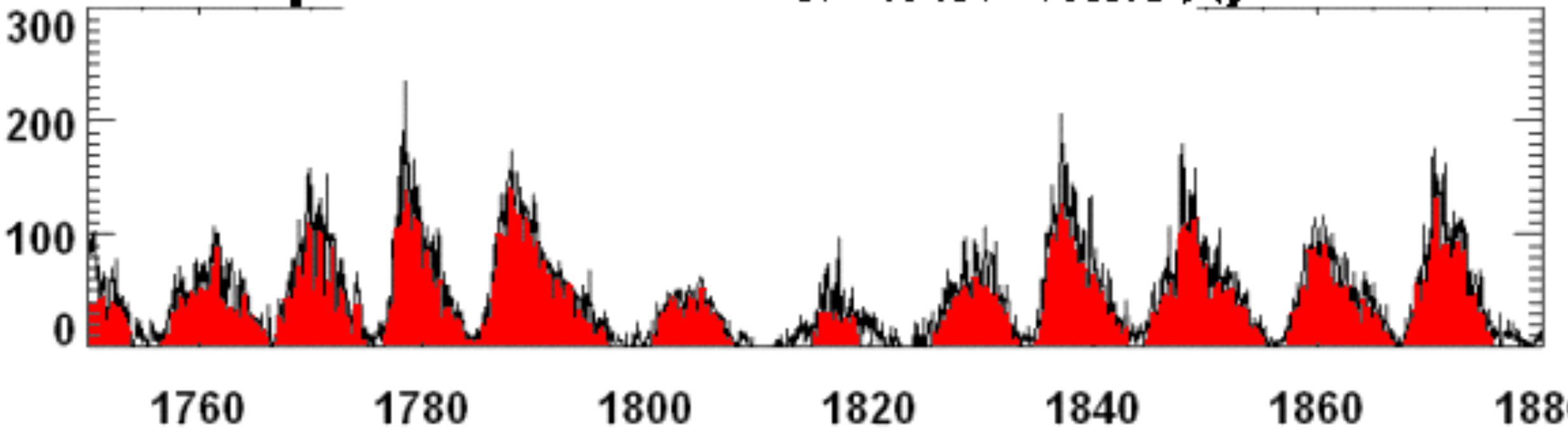


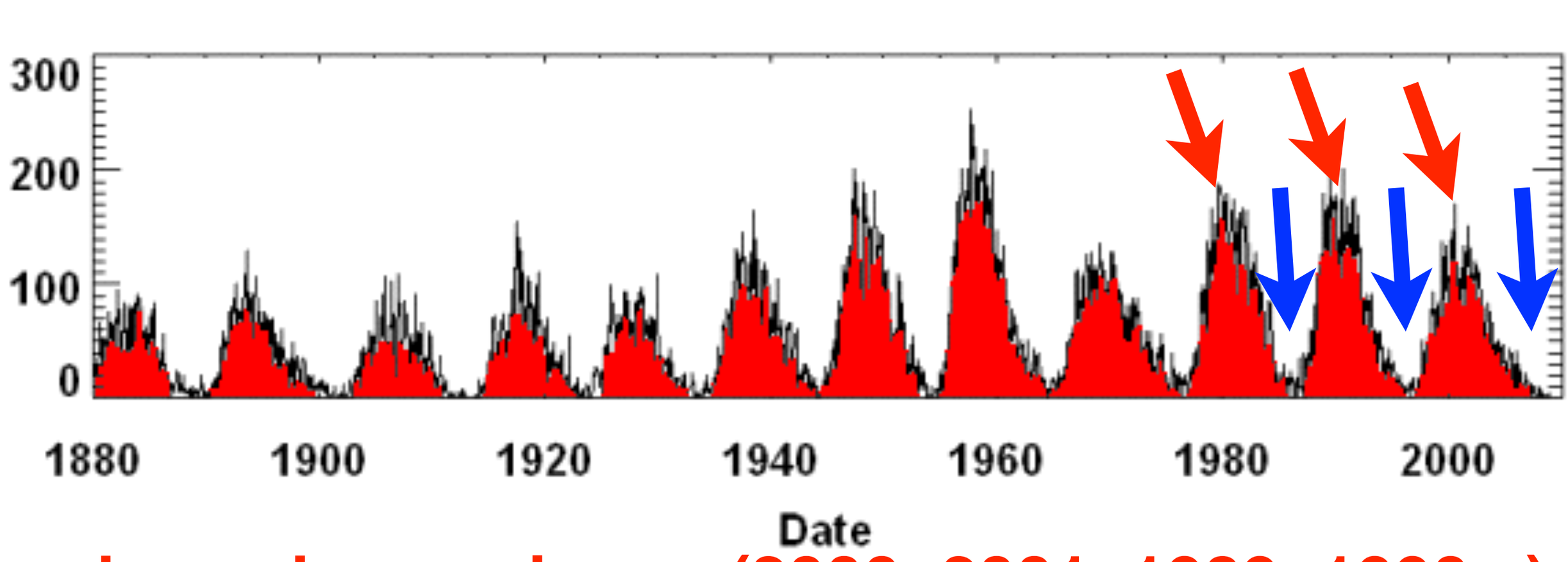
about 27 days

= rotation period of sun!

http://umtof.umd.edu/pm/

Sunspot numbers (太陽黒点数)　1750~





peak = solar maximum (2000~2001, 1989~1990,,,)

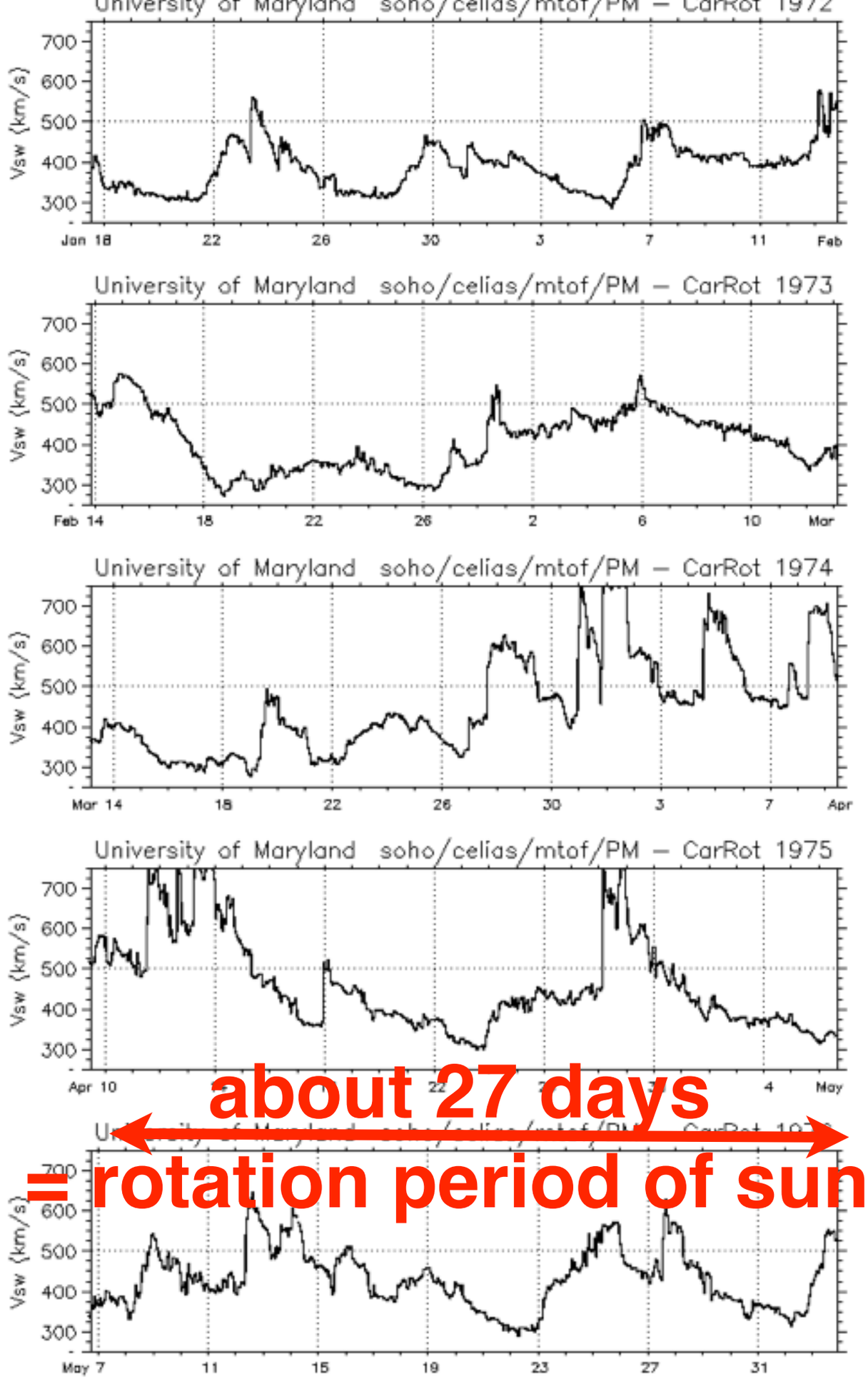
bottom = solar minimum (2006~2009)

during Solar Minimum:

1. One can “predict” a month before.

2. But, sometimes we see good aurora even when the solar wind is slow (difficult to predict this type of aurora)

2. Solar Maximum



http://umtof.umd.edu/pm/

during Solar Maximum:

1. One cannot "predict" a month before.

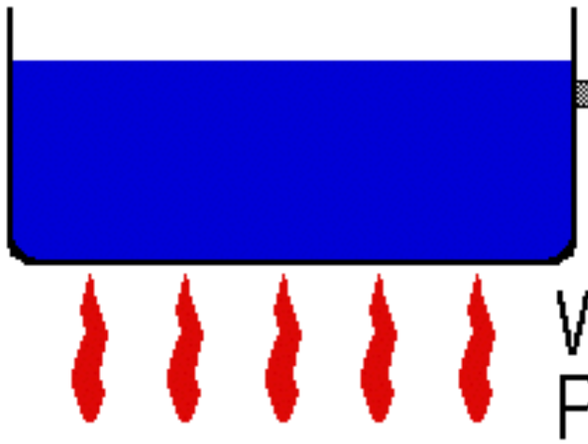
2. But, activity is generally high such that chance is high if one stays three nights

There is slight difference between aurora during Solar Minimum and aurora during Solar Maximum.

This is because solar surface activity is different.

Solar Surface

because all the energy comes from Solar Corona in the form of Solar Wind

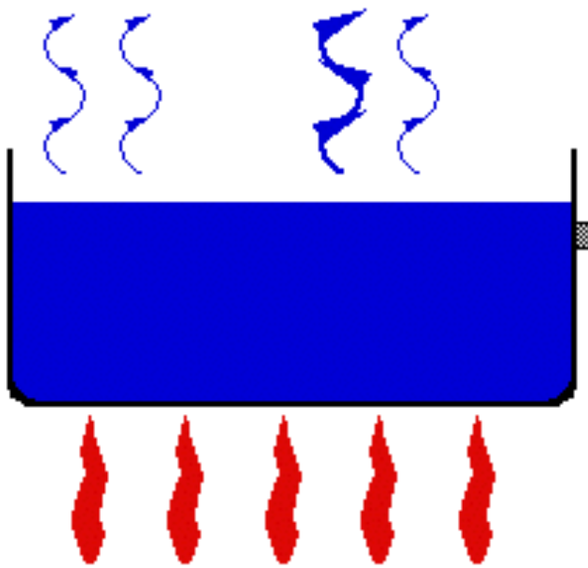


Sun is boiling !

太陽表面では
プラズマが沸騰している

Water / Earth : 100 °C
Plasma / Sun : 6000 °C

Solar Minimum : evaporation only

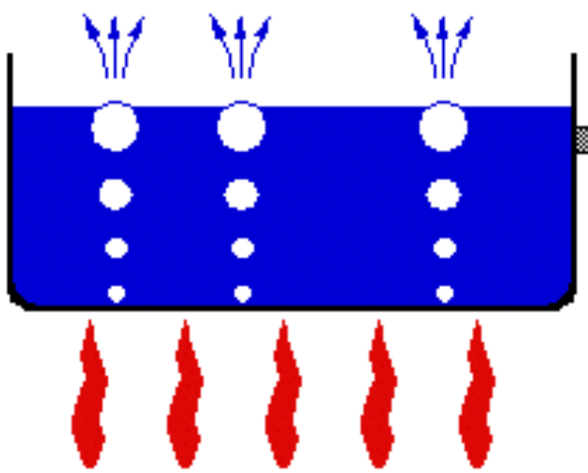


from **coronal hole**
(repeat every month)

濃淡＋1ヶ月の自転

~ 27 days recurrence

Solar Maximum : explosion of bubles



from **Sunspot**

黒点の爆発

~ sunspot

continuous & bursty

evaporation explosion

Minimum **Maximum**

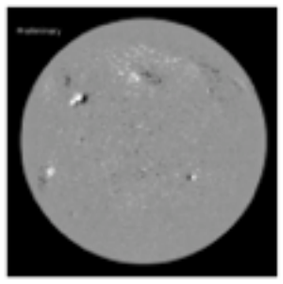
SOHO/LASCO

Sun images

Solar images at SDAC

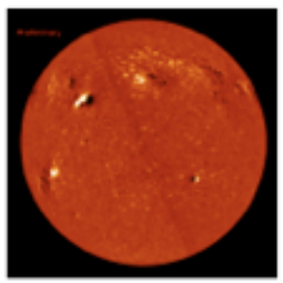
http://umbra.nascom.nasa.gov

webmail Telia-ZwQGMh5A IRF

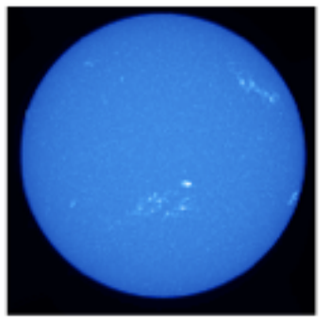


Photospheric longitu
magnetograms from
National Solar Obse
vector spectromagne
(VSM) at Kitt Peak
2010/03/12 16:30 U

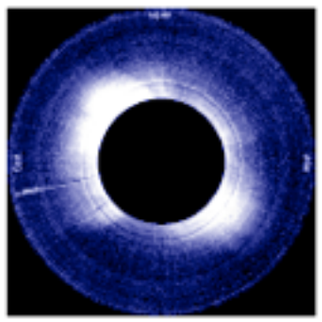
He I 10830 Å spectr
from the U.S. Natio
Observatory at Kitt
[2009/11/27 18:57



Ca II 8542 Å longitu
magnetograms from
National Solar Obse
vector spectromagne
(VSM) at Kitt Peak
2010/03/12 20:26 U



RISE/PSPT Ca II K
from HAO's Mauna
Observatory (Hawa
2010/02/23 19:12:2



White-light Mk. 4 c
images from the Hig
Observatory Mauna
Observatory (Hawa
raw image [2010/0
]

http://umbra.nascom.nasa.gov/images/latest.html

Space weather site

SpaceWeather.com -- News ... and ne

http://www.spaceweather.com/

webmail Telia-ZwQGMh5A IRF-data

spaceweather

News and information abo

AURORA ALERTS | SUBMIT YOUR PHOTOS!

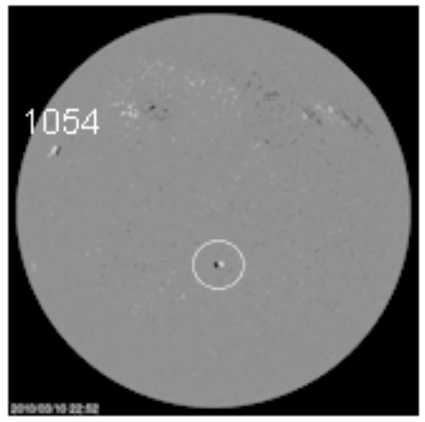
SPACE WEATHER

Current conditions

Solar wind
speed: **506.8** km/sec
density: **0.9** protons/cm^3
explanation | more data
Updated: Today at 1745 UT

X-ray Solar Flares
6-hr max: **B2** 1220 UT Mar11
24-hr: **B2** 1220 UT Mar11
explanation | more data
Updated: Today at: 1745 UT

Daily Sun: 11 Mar. 10



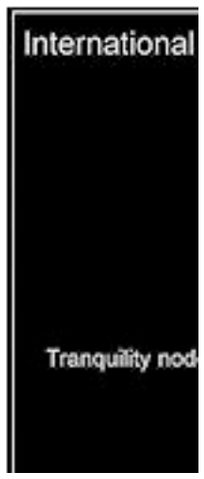
New sunspot 1054 poses no threat for strong solar flares. Another new sunspot may be emerging at the circled location. This is a magnetic map of the sun, temporarily standing in for the usual white-light image. Credit: SOHO

What's

NEW AND IMPI
or iPod Touch i
satellite tracker.
now works in al

AURORA WA
magnetic field an
Circle. High-latitu

SPACE STAT
new room to the
breathtaking pan
spending their sp
Earth below. Las
Ewers photograp
Hofgeismar, Ger



http://www.spaceweather.com

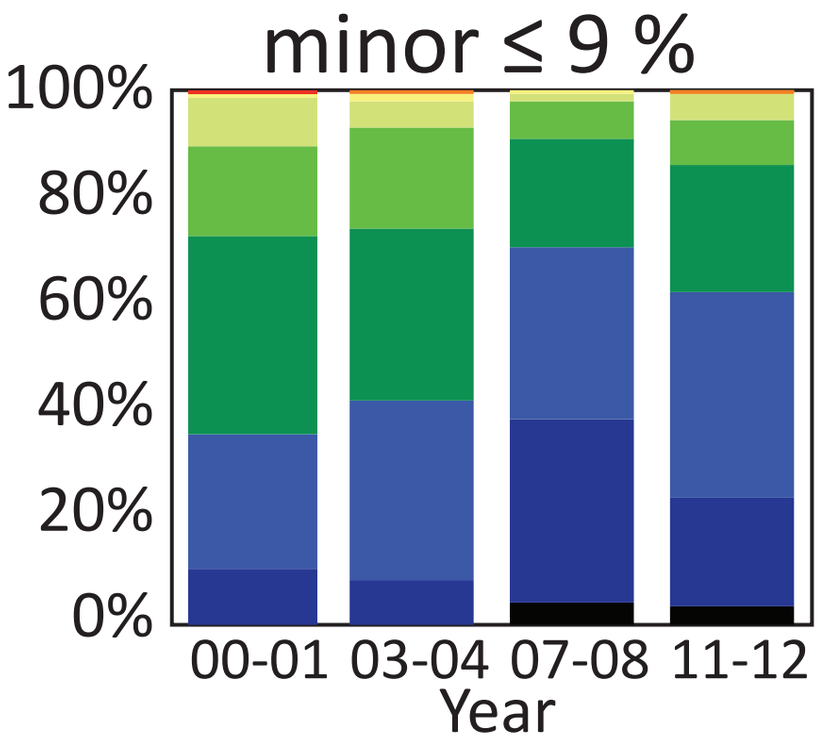
Everybody asks

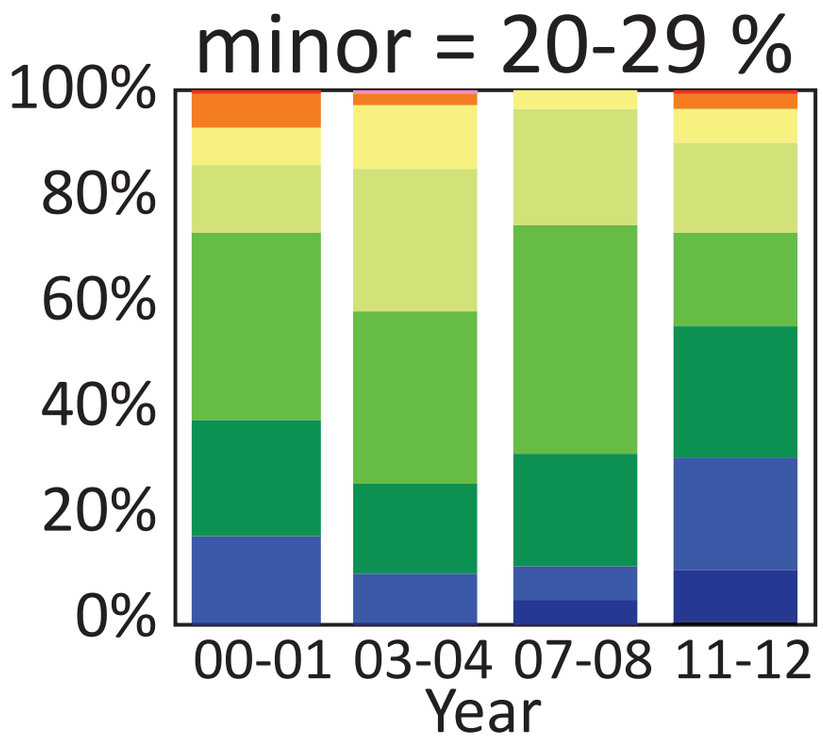
“Can I see aurora tonight?”

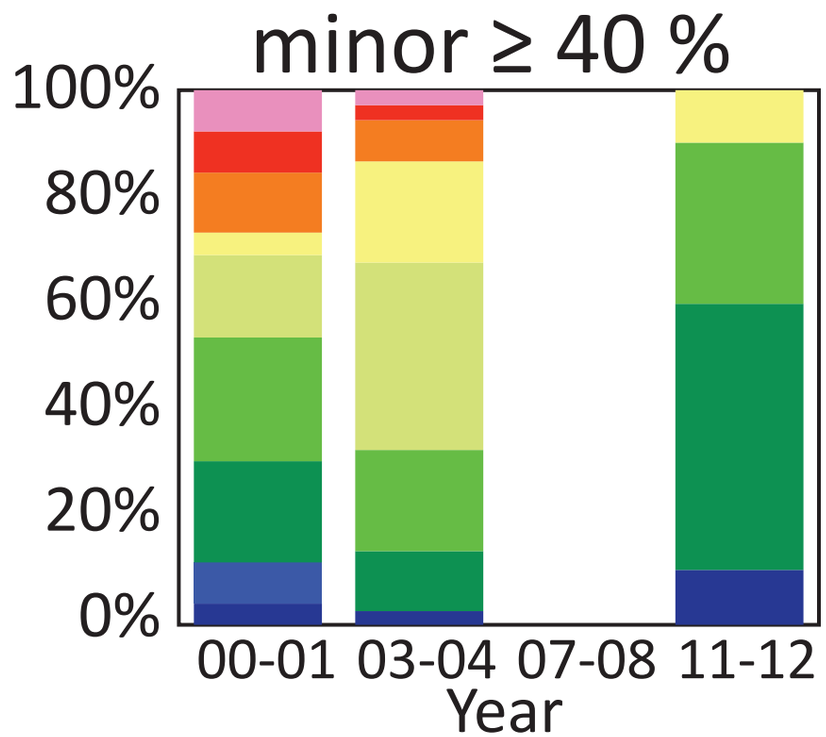
and **what time?**

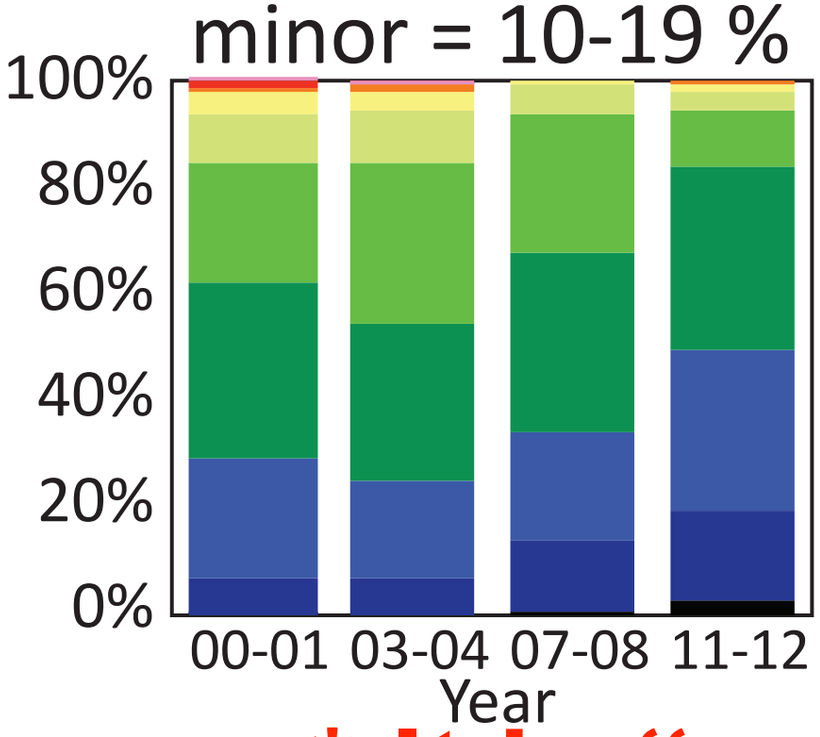
not easy like weather forecast

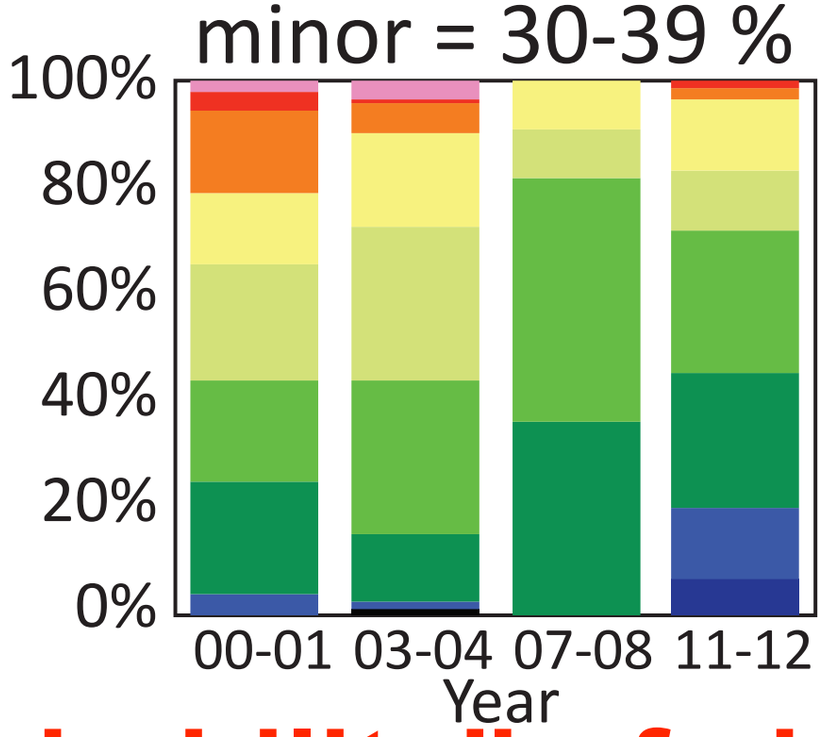
NOAA 1-day prediction of “storm”

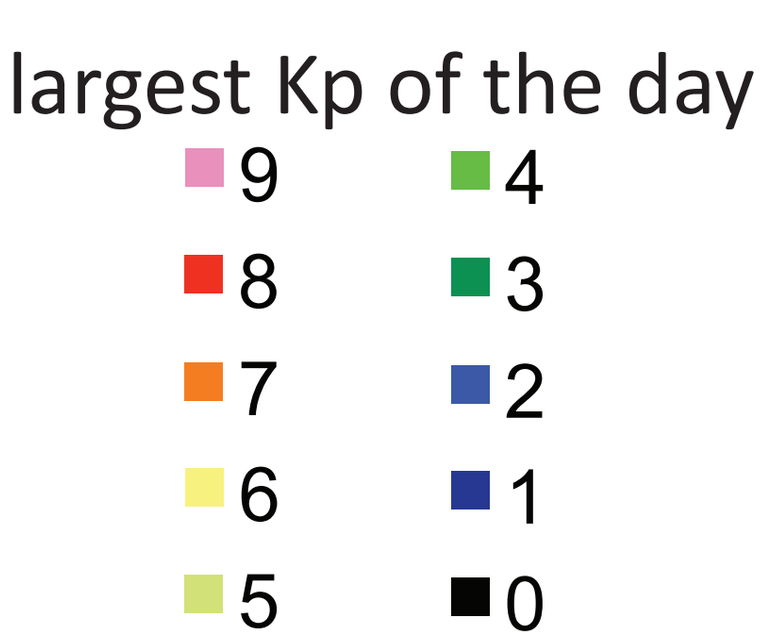






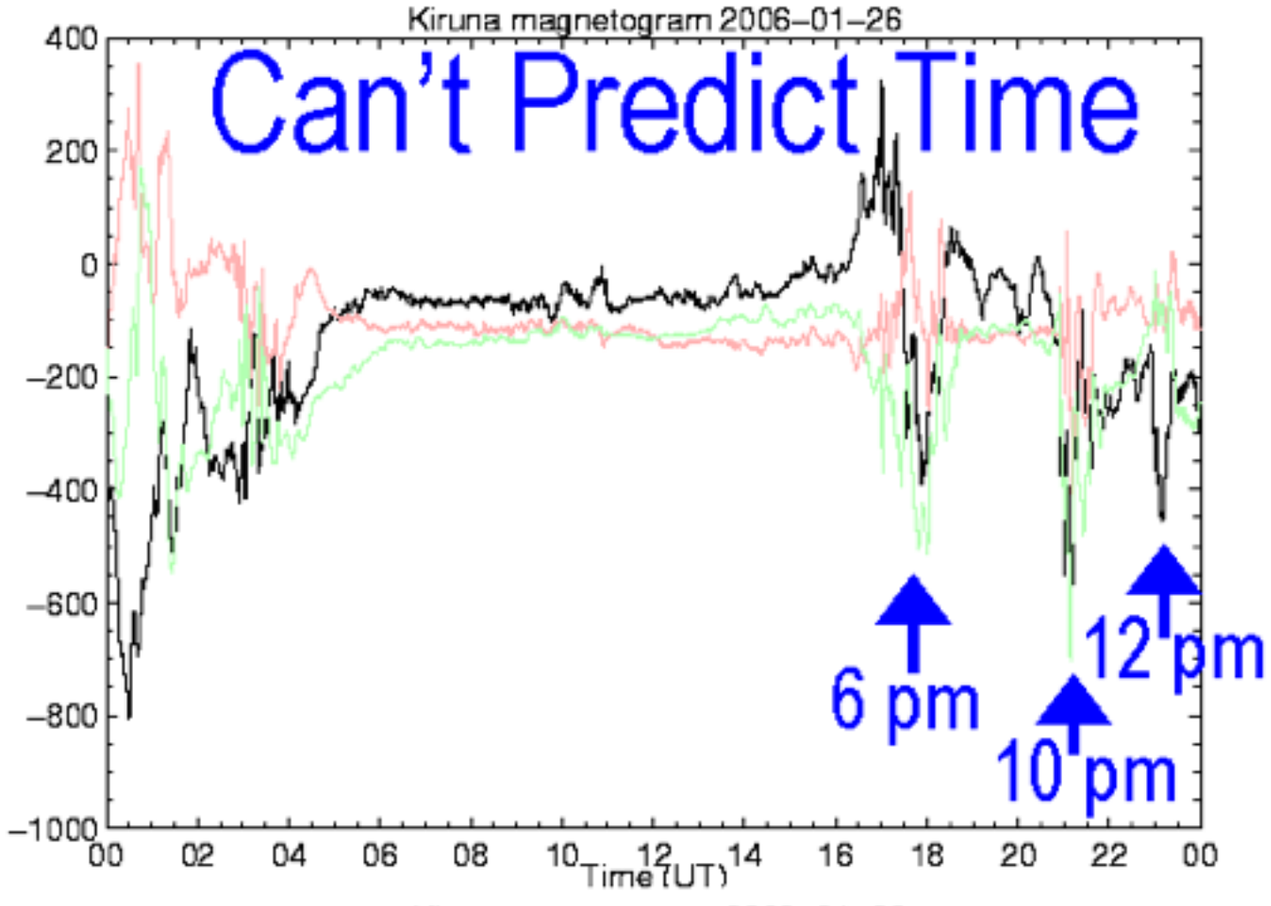




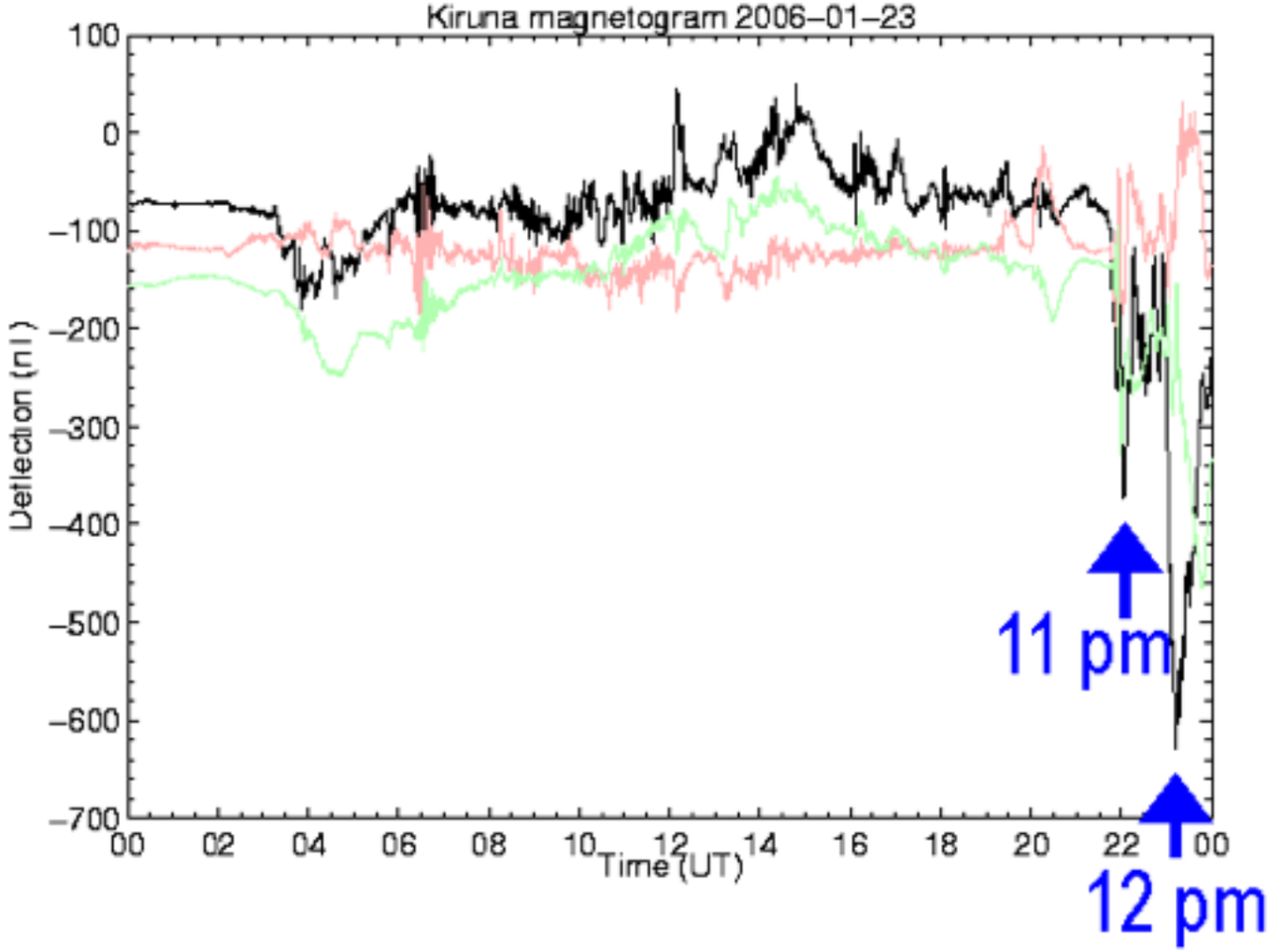


*** It is “probability” of chance**

*** Different between different years**



No way to predict time



This is why tourists miss the aurora

Why do tourists miss aurora ?

* **Check the sky only once an hour**

* **Check the sky in turn with friends.**
  = The friend tells you "**It WAS beautiful !!**"

* **Check the sky under street-lights**
  = Go back before the eye is tuned to darkness

* **Check only half of the sky**

* **“Cloudy now” does not mean “cloudy all night”**

* **Mistake weak aurora as cloud**
  !!! Use digital camera to monitor the color !!!

* **Found weak one, but too cold to wait break up**
  !!! Wear warm & walk around to keep warm !!!

* **Yes, there was no aurora (very rare if not cloudy)**

and

Cloudy now does not mean cloudy all night.

Some aurora can be seen through could!

movie

2006.04.04
23:12:20 UTC

over cloud

end of §3

start of Appendix

Sound of Aurora ? **nobody knows.**

Aurora ⇔ Season : **some relation, but...**

*** solstice = less, but long night**

*** equinox = more, but short night**

➙ same chance to see aurora

➙ other factors (weather) determine

movie

spring time

2005.04.11
19:57 UT

Why do we research aurora ?

* Unknown

  → somebody must study

* Unknown + Beautiful

  → attract scientists

* Requires high-tech

  → attract sponsor for research

Aurora promotes:

Myth & Tales (dragon/phenix),

Philosophy (莊子),

Arts (poem, music, paintings),

and Science.

©Dr. Takeshi Ohtake

How to take photo/video

* Think about taking stars (use night-view mode)

* Never use flash

* Include something (tree, house) to compare the size

* Street light should be blocked

* Need tripod (or automatic shutter)

* Your hand will be cold!

* The battery of your camera will be cold.

* The lens will be wet if you take inside (warm) from cold.

* Color depends on lens, film, paper etc.

* flush light is useful

old version

Real time data from the Kiruna All-S

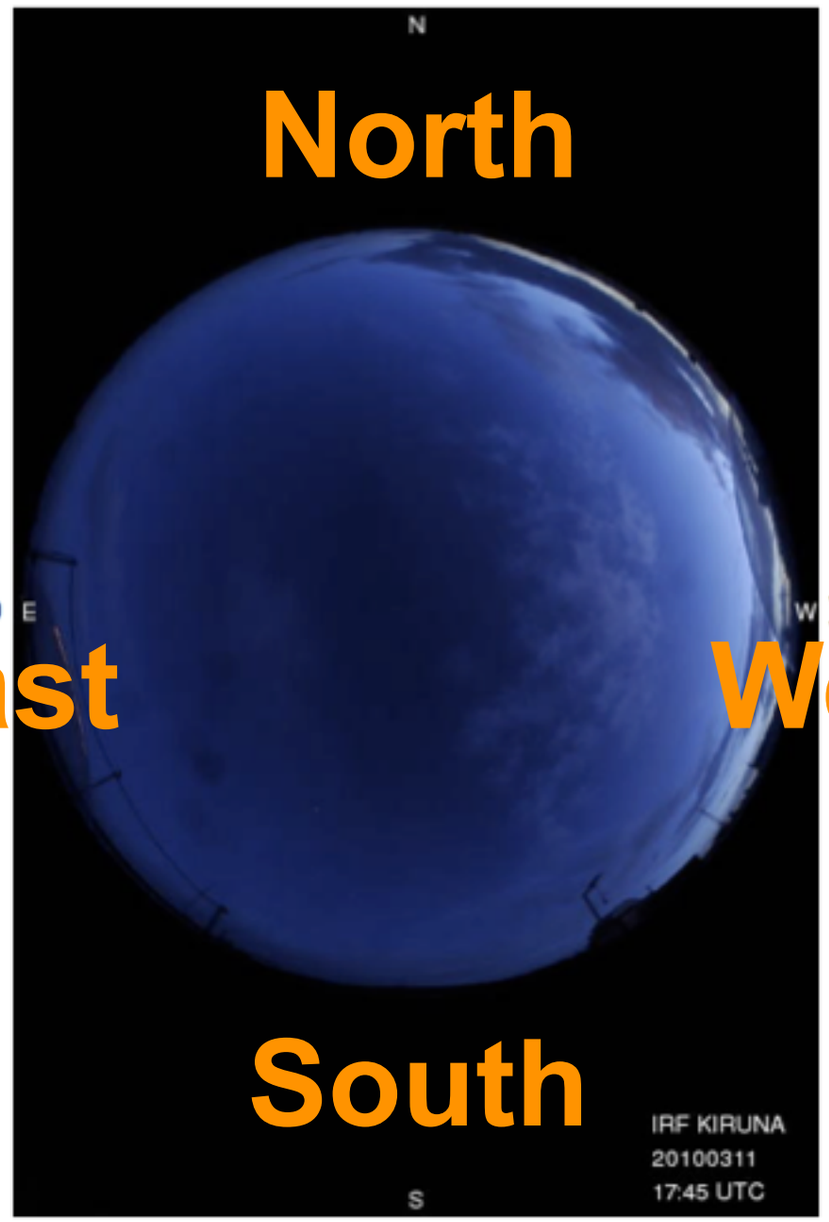
http://www.irf.se/allsky/rtasc.php

webmail Telia-ZwQGMh5A IRF-data

Kiruna

Latest picture from the Kiruna All-Sky camera at: 2010-03-

http://www.irf.se/allsky/rtasc.php



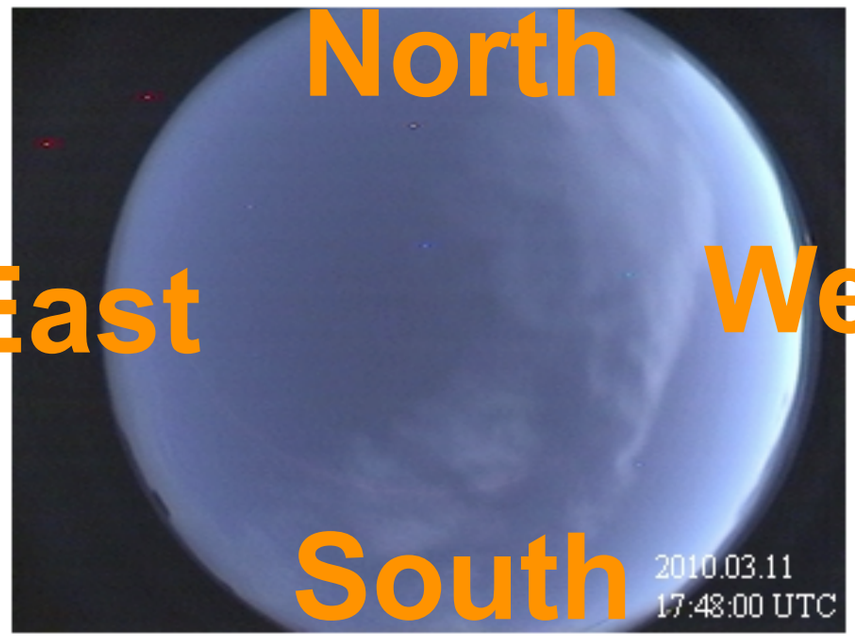
Geomagnetic coordinates. More about image orientation.

Abisko

SKY in

http://titan.irf.se/misato/abisko/sky_a

webmail Telia-ZwQGMh5A IRF-data



This real-time aurora and blue-sky camera system is developed by Misato Observatory in Japan. The camera is installed in Abisko tourist station in Abisko, Sweden in collaboration with Swedish Institute of Space Physics.

http://titan.irf.se/misato/abisko/sky_abisko/hoge2.html

Before watching

"Can I see (**very beautiful**) aurora **tonight**?"

"Can I see aurora **like this photo**?"

"**What time** can I see beautiful aurora tonight?"

"Where is the **best place** to see beautiful aurora?"

"**How often** do you see beautiful aurora?"

"Is it **cold enough** to see aurora?" (=wrong knowledge)

"Is **Solar activity** high enough for beautiful aurora?"

"Is aurora **useful**?"

"**What causes** aurora?, and its **color**?"

After watching/missing

"**Was there aurora**? ---- **Why did I miss it**?"

"Is aurora **white**?"

"Was last night's aurora **big**?"

"**Why so beautiful**? Why **moving** so fast?"