

# Electro-magnetic wave emission from the Sun Part - I



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# Talk PLAN

**1 Overview of the Sun (Chronological)**  
(Observational View point, No theory, & a few equations)

**2 Sun's layers and the EM wave emission**  
(Photosphere, Chromosphere, & Corona)  
(White Light,  $H\alpha$ , EUV, & X-ray; Radio in Part-II)

**3 Brief about the Standard Solar Model**  
(Simplified Picture of the Sun)

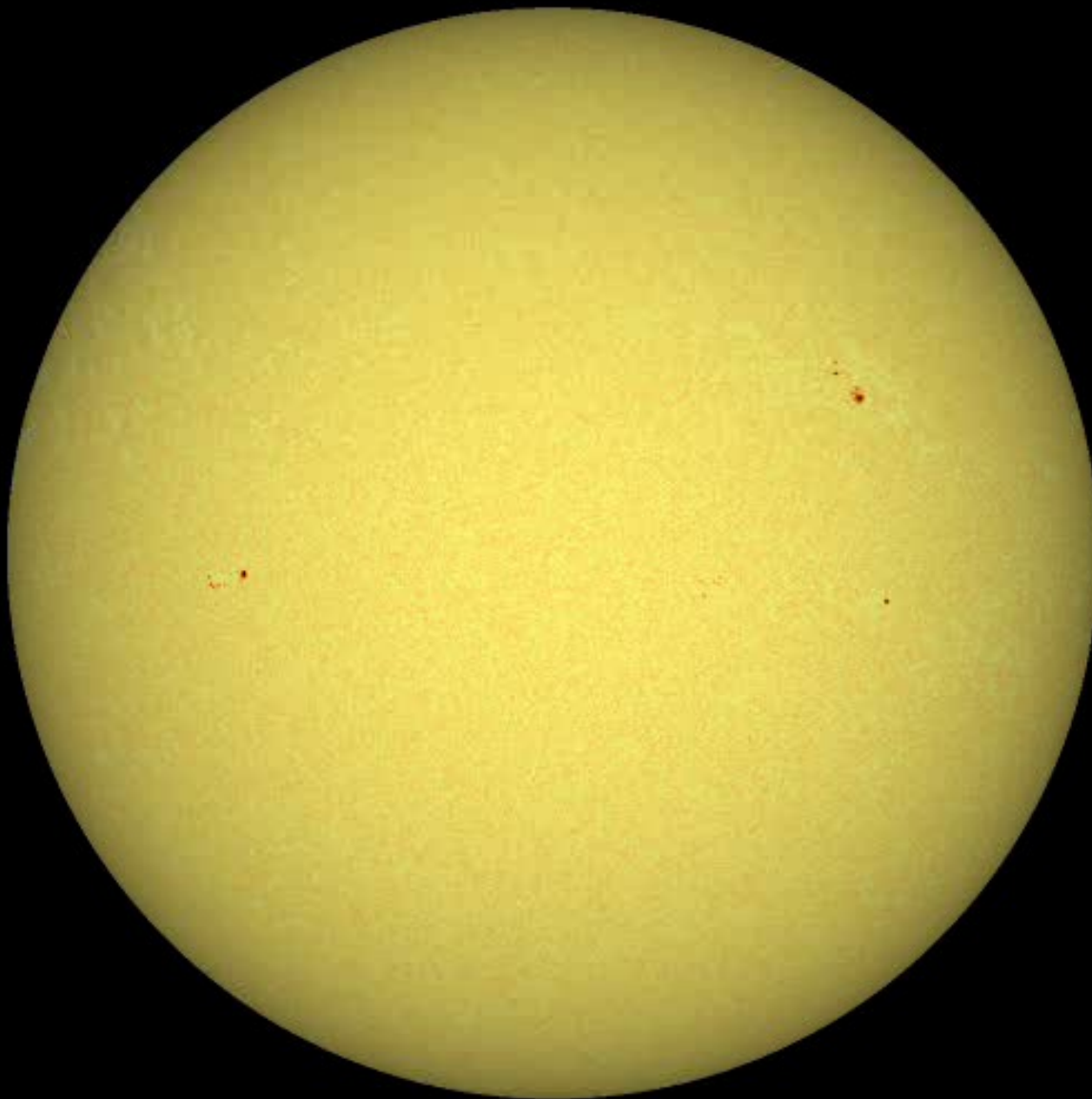
**Note: Not all aspects are covered!!**

# Sun Photosphere



**Photosphere  
Snapshot  
- Dark Patches**

# Optical Sun



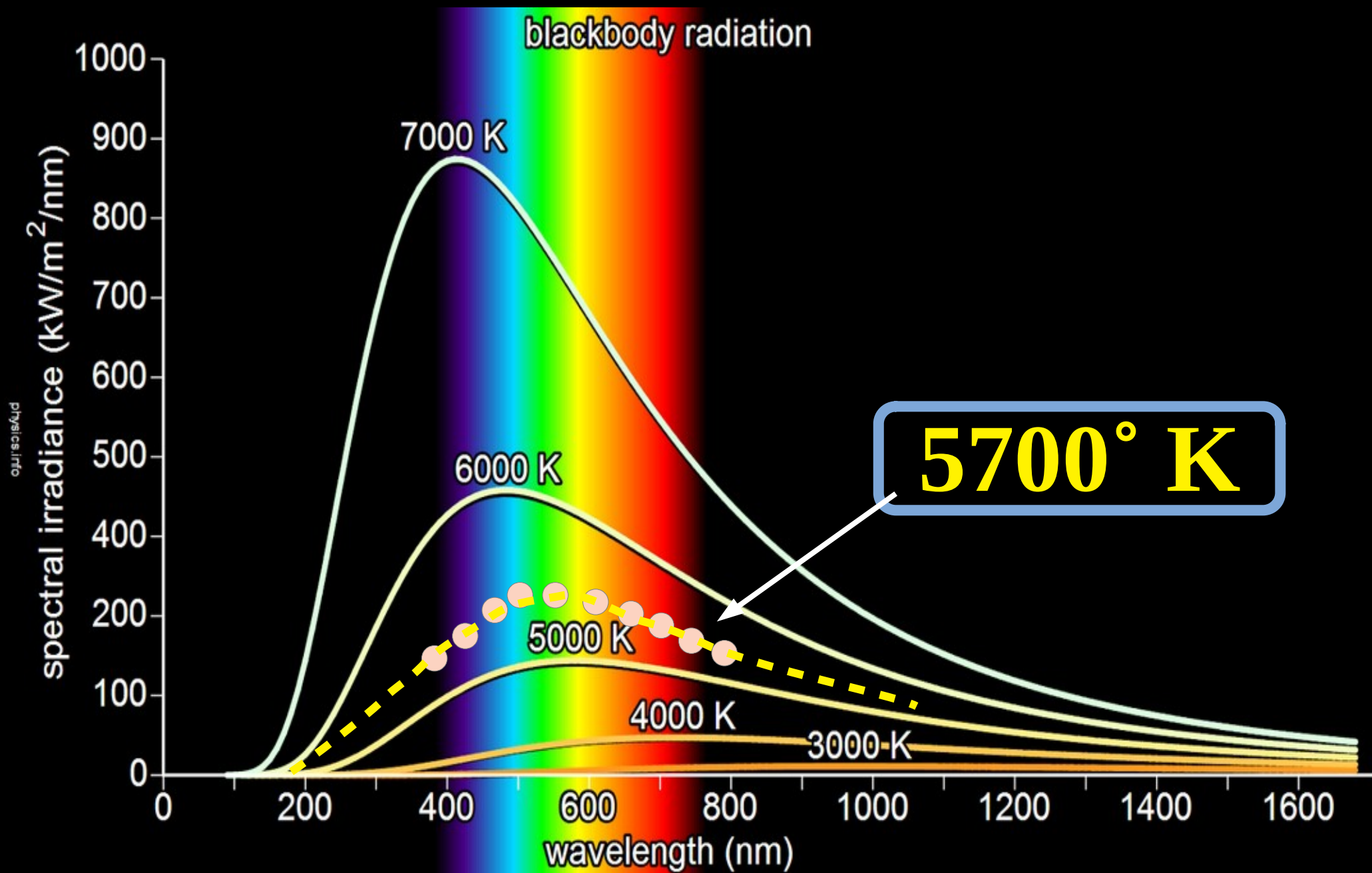
## Photosphere



# Sun Photosphere

## Photosphere :

1. Photosphere is the layer from where the visible part of the electromagnetic radiation emanates.
2. It subtends an angle of  $\sim 0.5$  degree from the Earth when viewed using an optical telescope.
3. If we convert the above angular extent into linear scale, its diameter will measure about  $15 \times 10^5$  km.



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**What are these  
dark patches  
on the Sun ??**

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# Sun Photosphere

## Sunspots :

1. Dark patches that are seen on the solar photosphere.
2. Appear as a single entity or in groups.
3. Last for several days to months.
4. When the number of spots is higher, it is the solar maximum and lower (or no spot), it is the minimum.

- Dark Patches

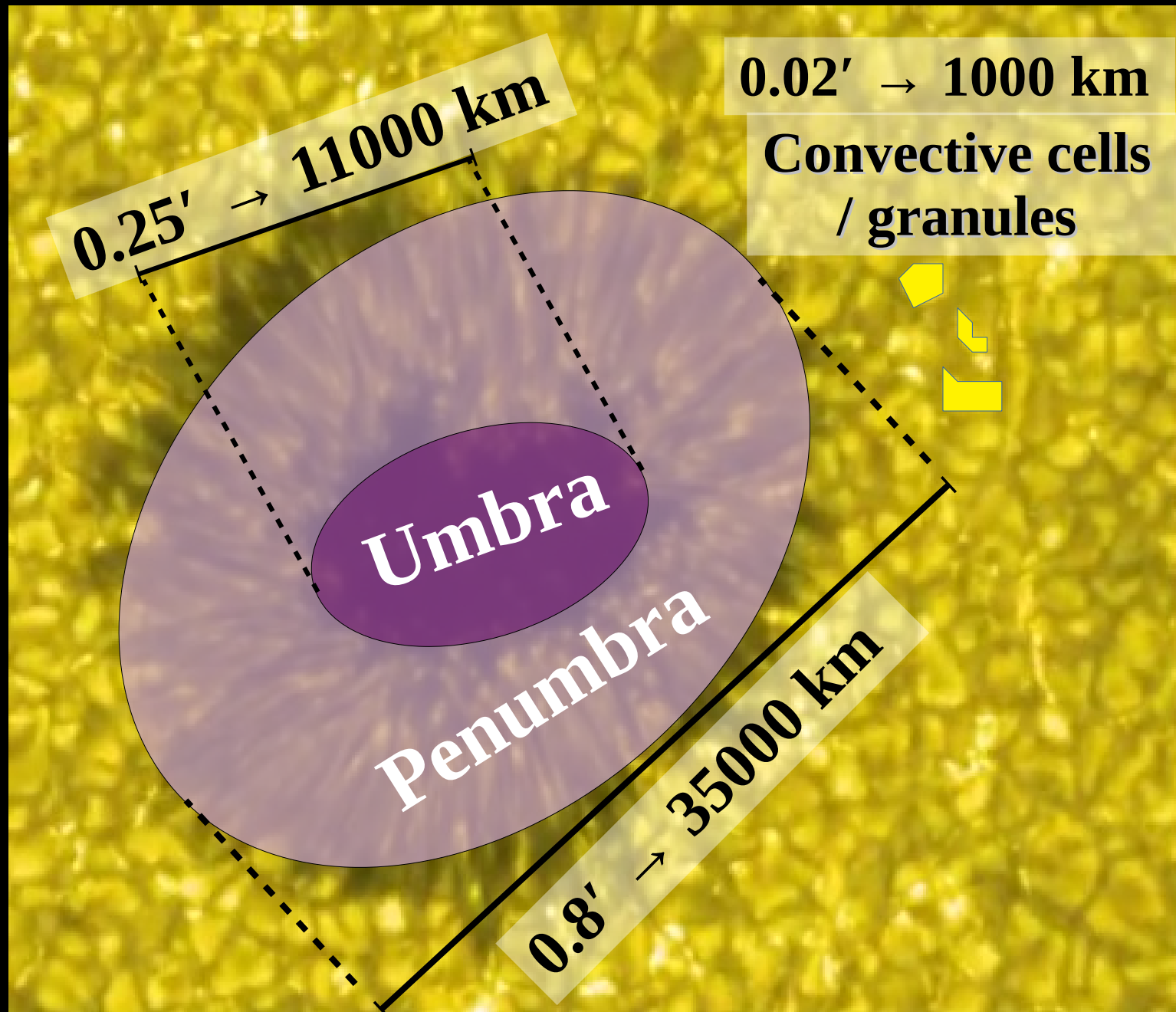
# Sunspot Snapshot

## Morphology



# Sunspot Snapshot

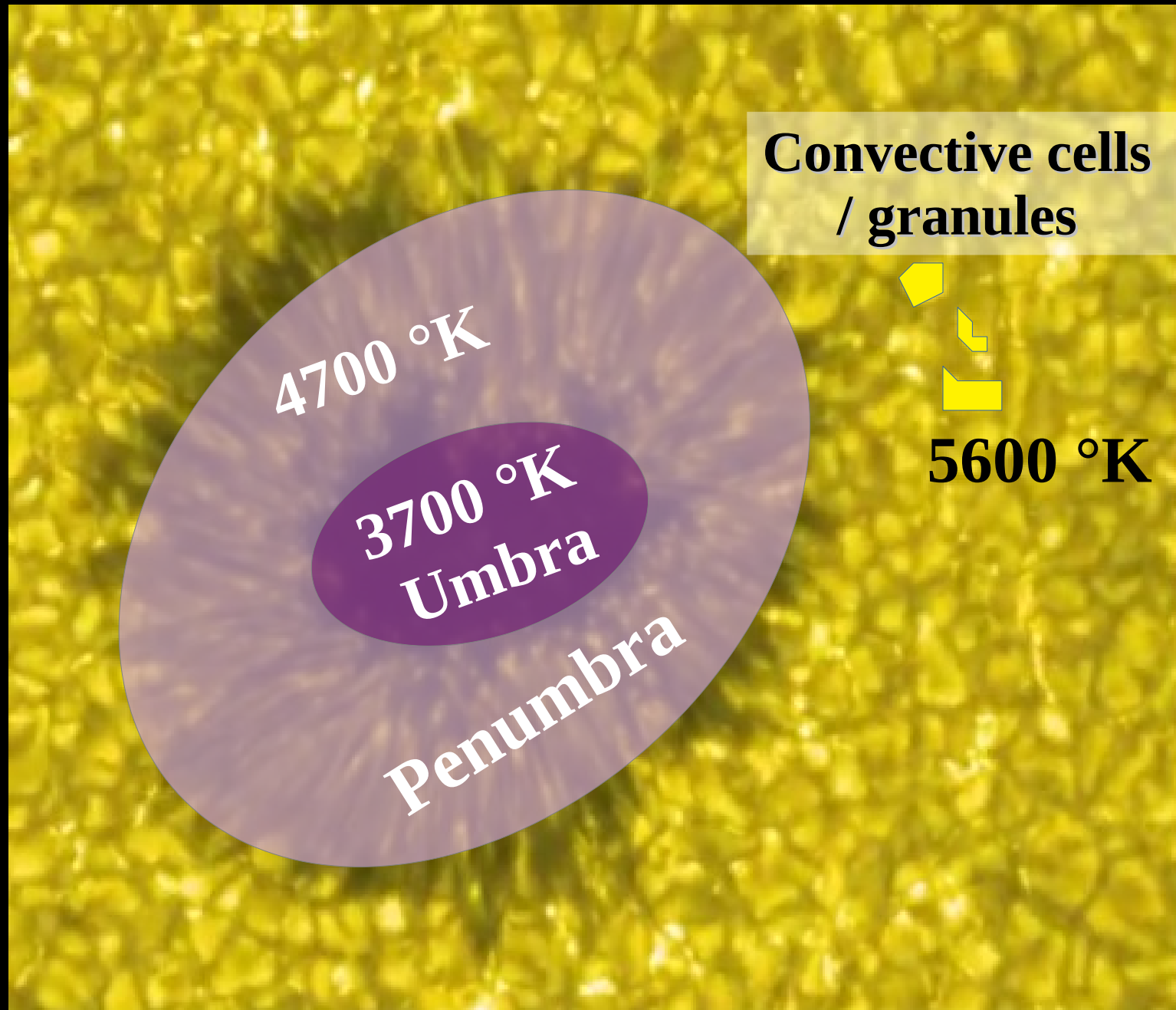
## Dimensions



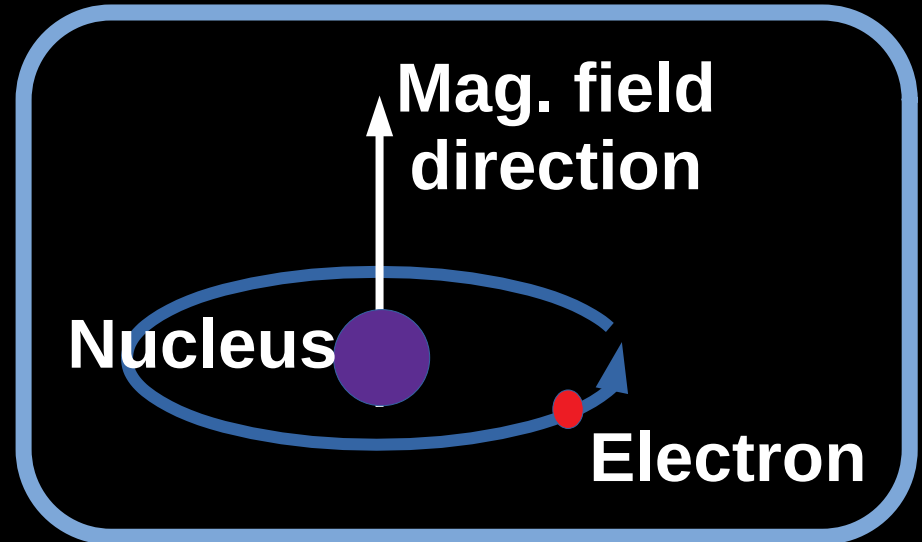
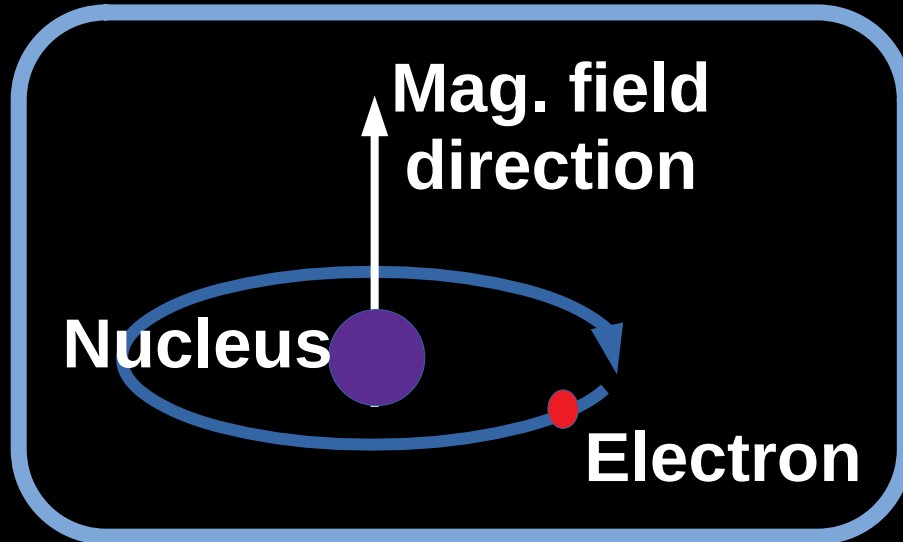


# Sunspot Snapshot

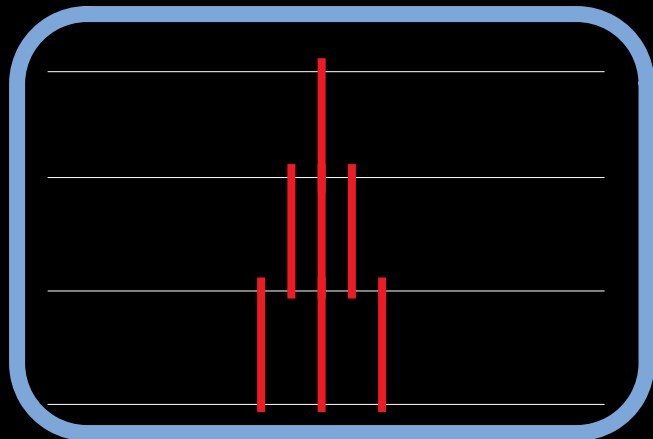
Temperature



# Zeeman Effect



$$\Delta E \propto e B / m_e$$



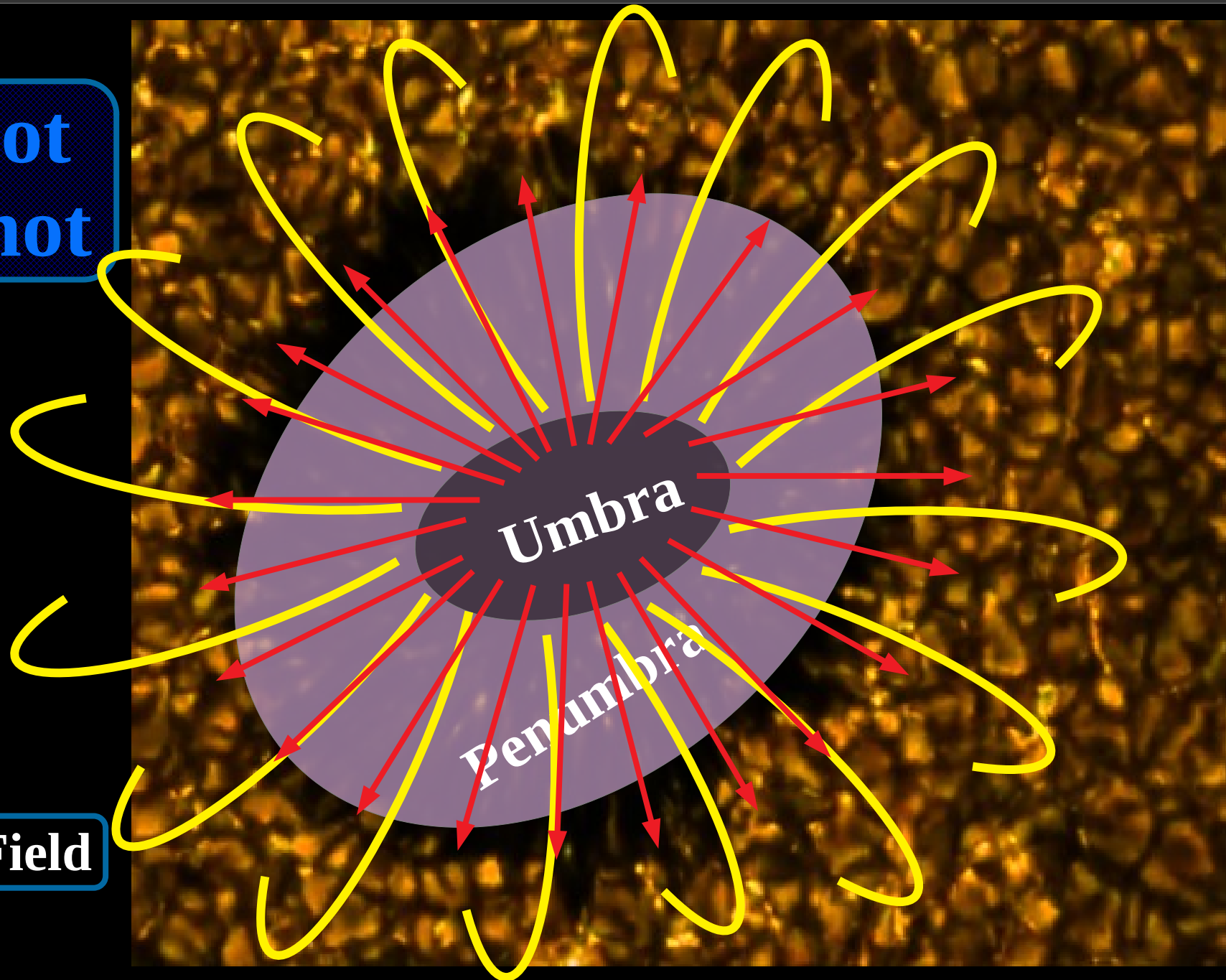
Normal spectrum  $B = 0$

Zeeman spectrum  $B = \text{low intensity}$

Zeeman spectrum  $B = \text{high intensity}$

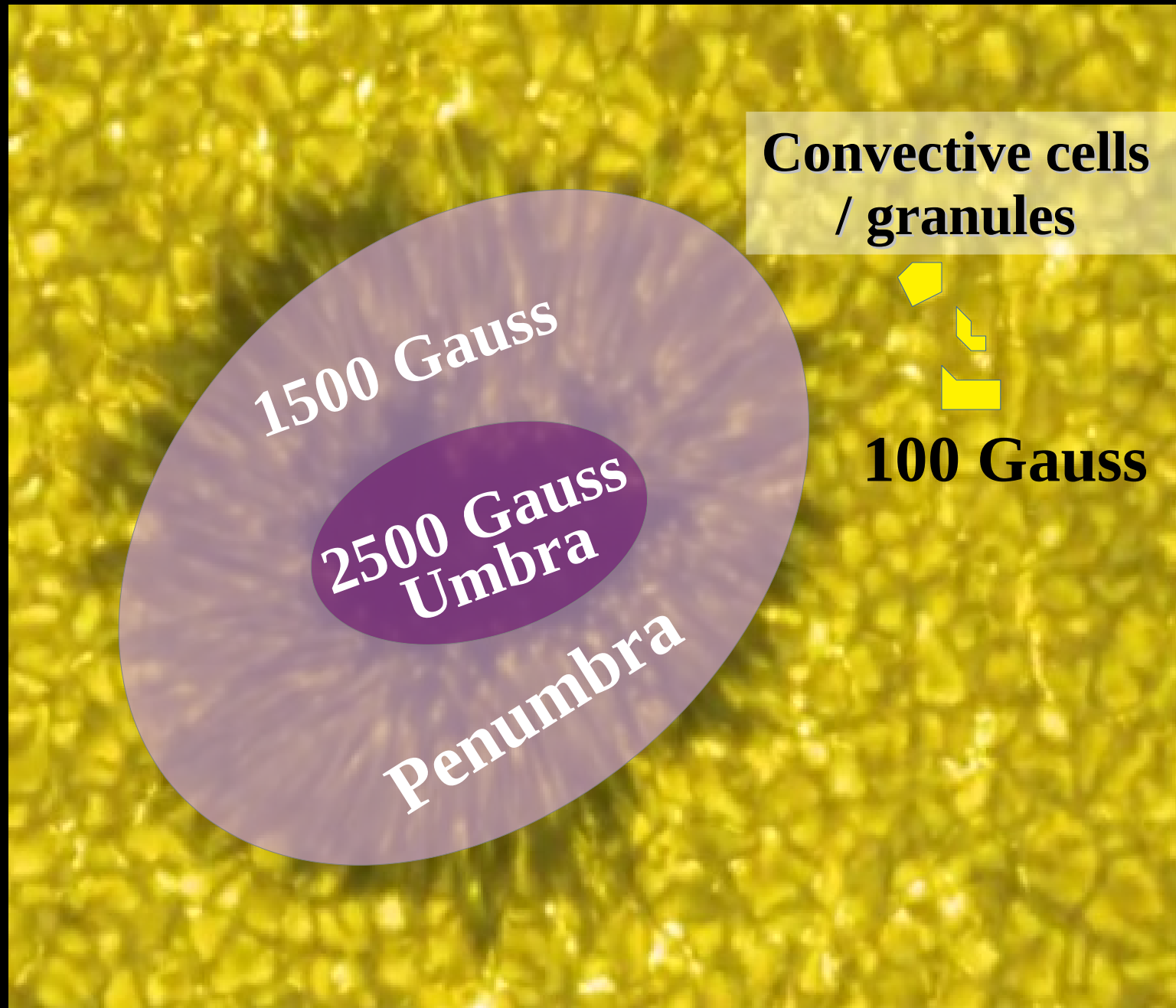


# Sunspot Snapshot



**Magnetic Field**

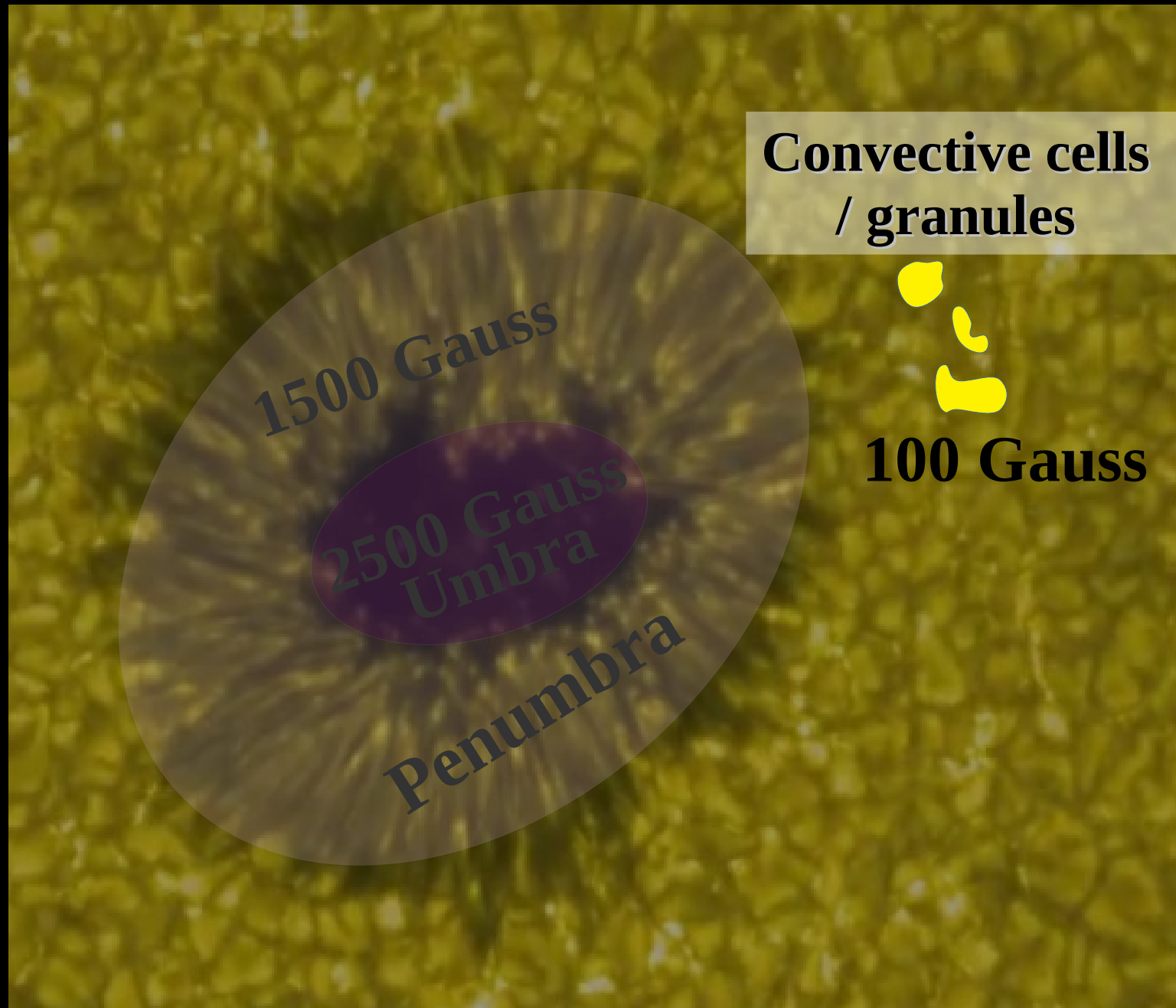
# Sunspot Snapshot



## Magnetic Field

# Sunspot Snapshot

Granules



# Sunspot Snapshot

Convective cells  
/ granules

## Granules :

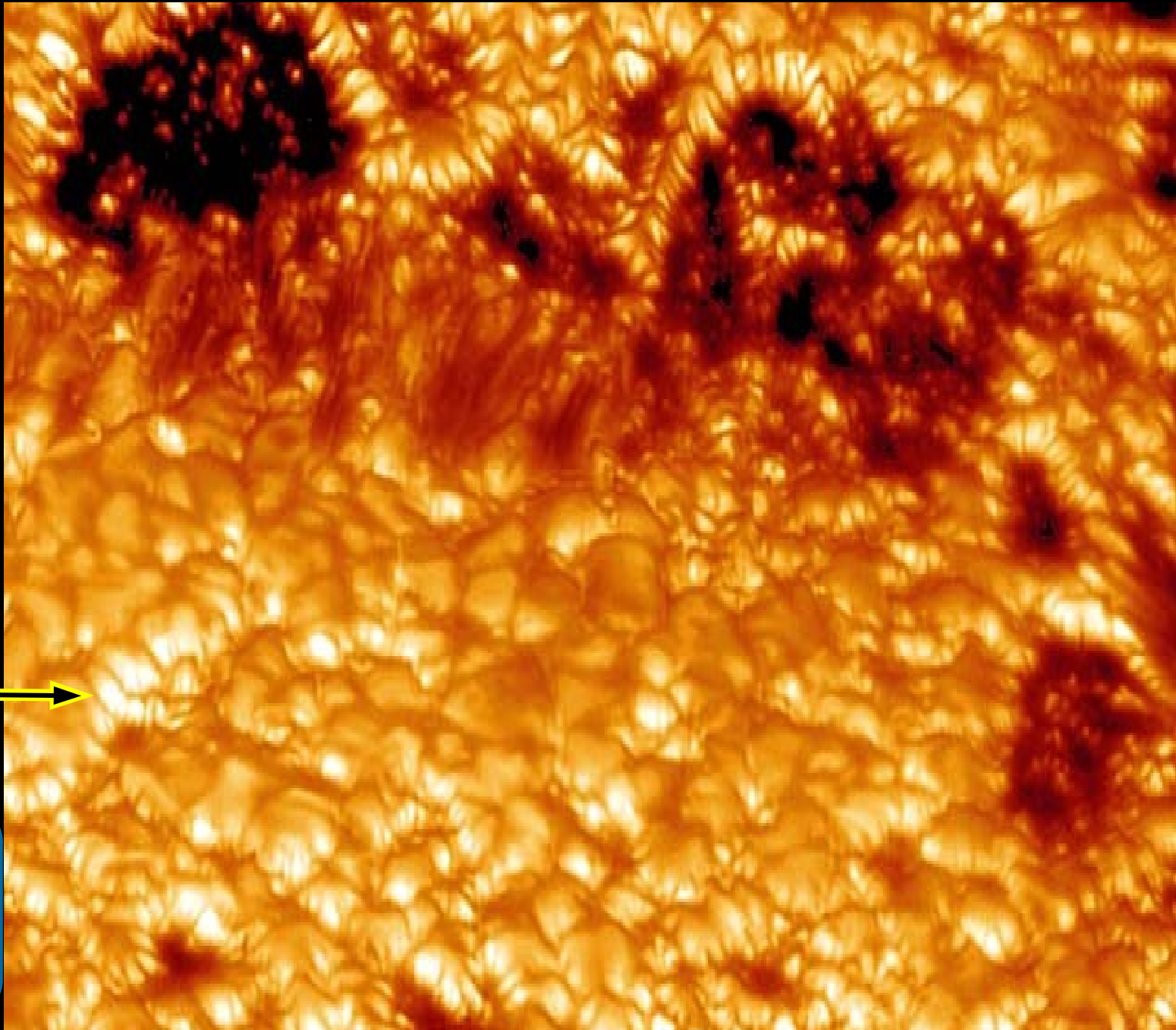
1. Ascending stream cells due to turbulent convection.
2. Hot gases move upward, appear brighter whereas the cool gases move downward, appear darker.
3. Excess temperature  $\sim 100^\circ$  (wrt ambient).
4. Size  $\sim 1''$ ; Lifetime  $\sim 3-8$  sec; Velocity  $\sim 0.5$  km/s.

# Faculae

Little Torches



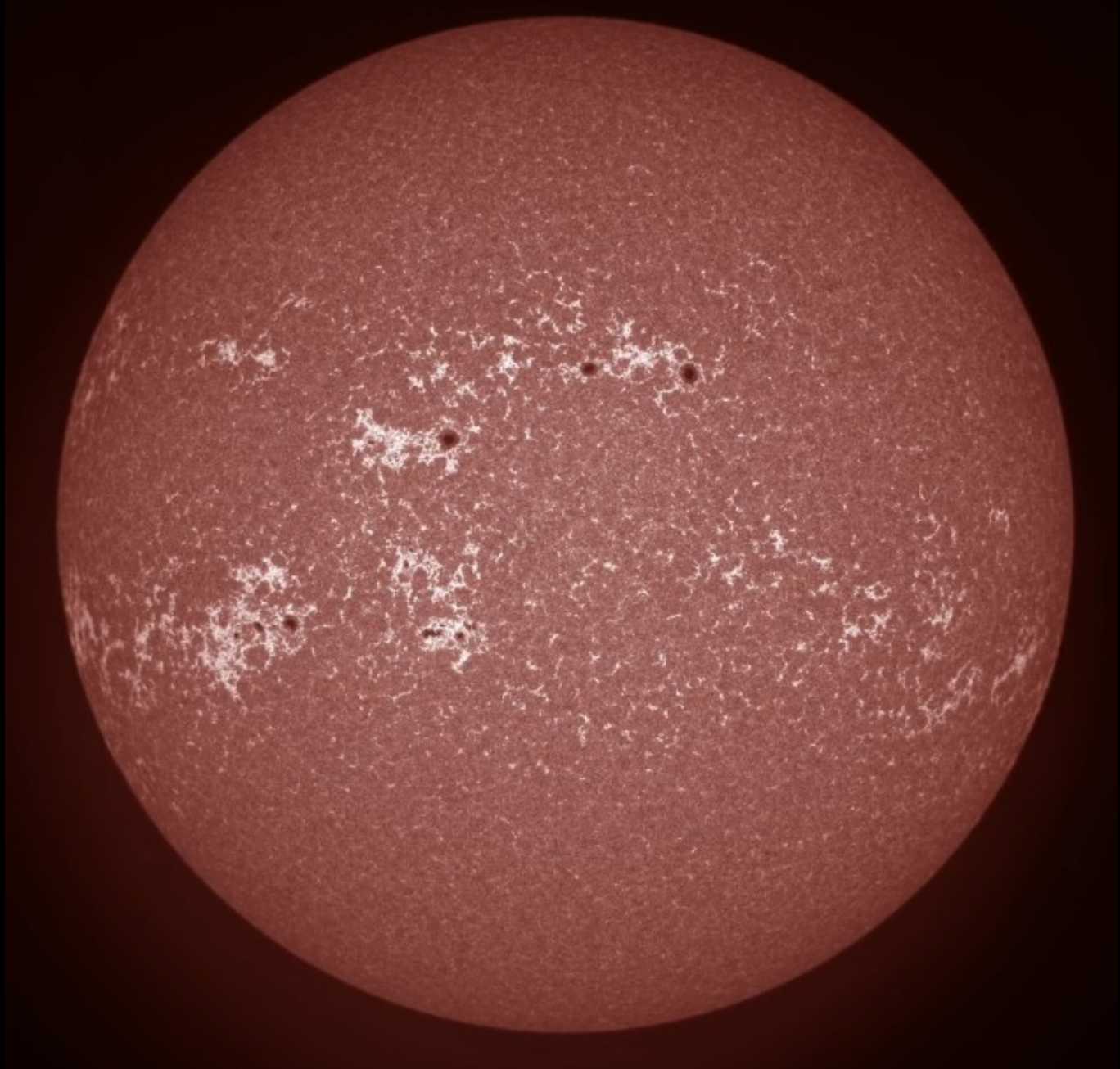
Bright patches  
or spots seen  
around sunspots





# Faculae

**1700 Å  
AIA image**



# Faculae

## Faculae:

1. Extended bright speckled regions tend to form around the sunspots, but, live longer than Sunspots.
2. Hotter than the background.
3. Discernible in  $1700 \text{ \AA}$  images.
4. Form due to concentration of magnetic field lines around sunspots or on the quiet background.

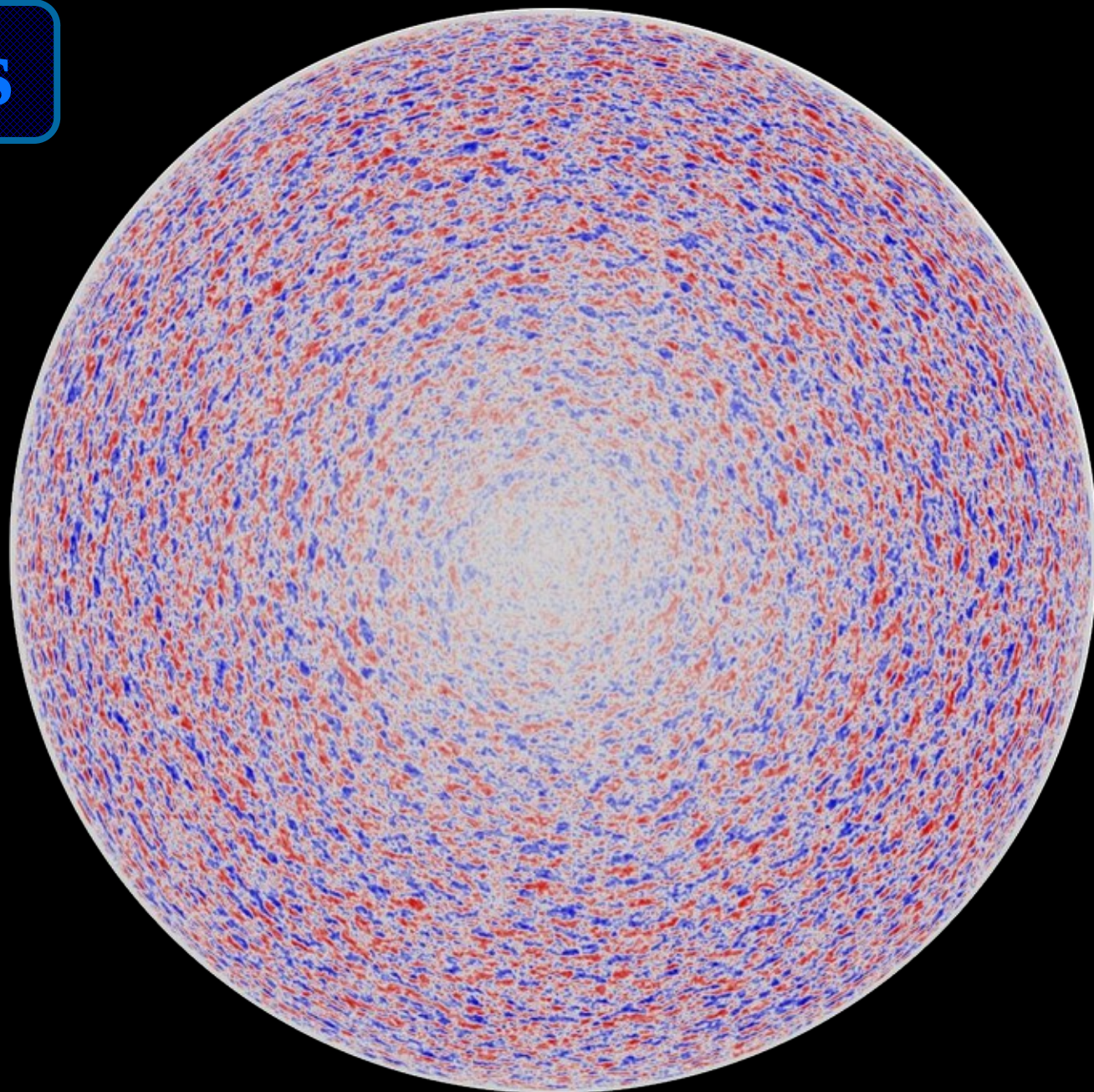
or spots seen  
around sunspots



# Supergranules

**Blue – Toward observer**  
**Red – Away Observer**

**Dopplergram**  
**(MDI / SOHO)**  
**Bubble size 30 Mm**





# Supergranules

## Supergranulation :

1. Signatures of large-scale non-linear thermal convection; horizontal spatial scale size  $\sim 30\text{-}35$  Mm.
2. Evolution time scale  $\sim 24\text{-}48$  hours.
3. Horizontal flow speed  $\sim 300\text{-}500$  m/s; Vertical flow speed  $\sim 20\text{-}30$  m/s.
4. At higher atmospheric heights, supergranules are believed to be fragmented to mesogranules and regular granules.

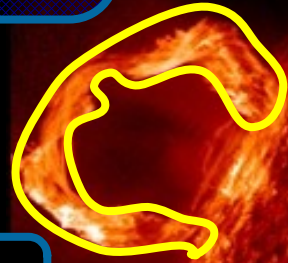
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# What are the Structures seen on the Chromosphere ??

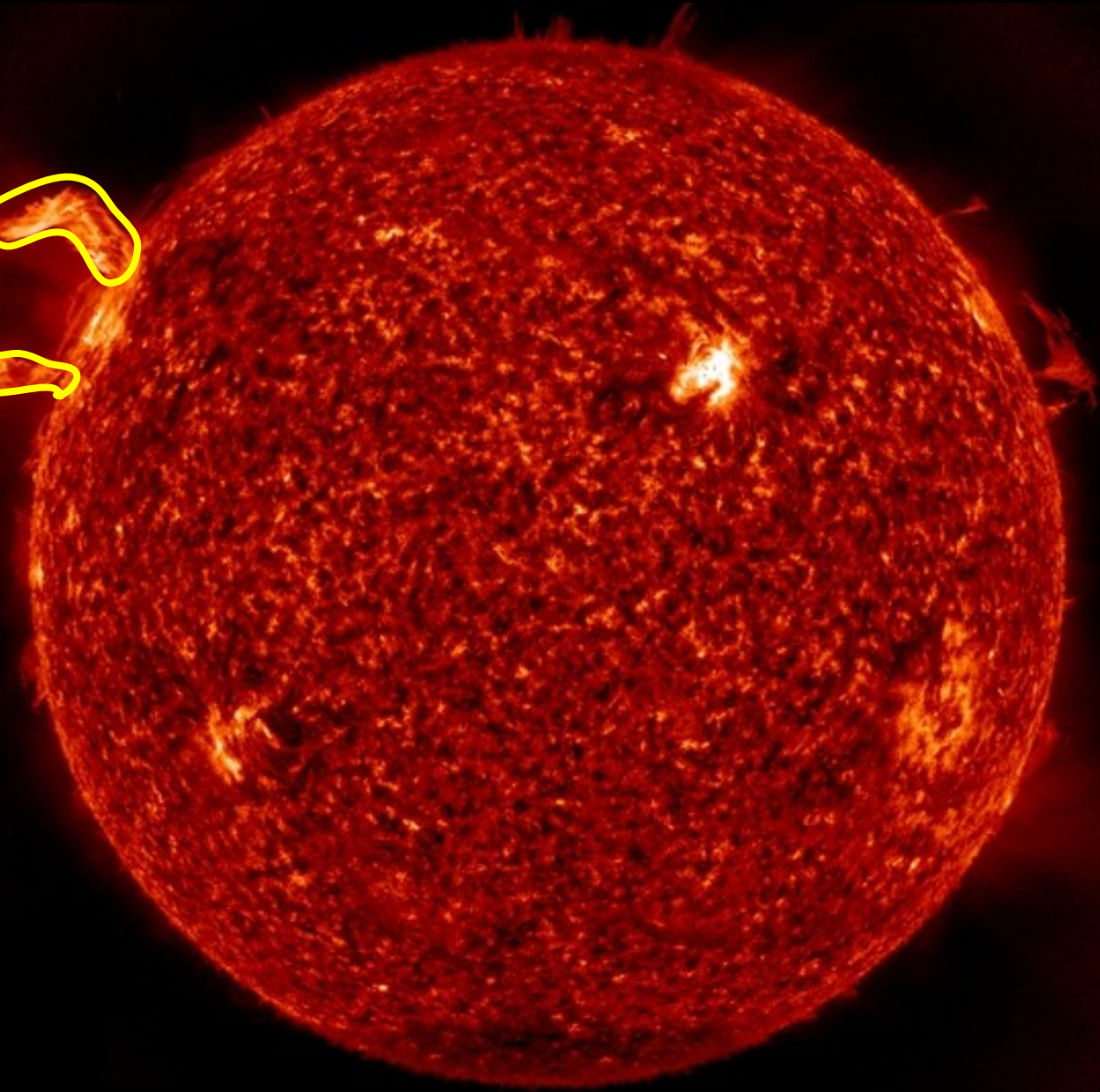
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# Sun Chromosphere

Prominence



$H\alpha$  / 6563 Å





# Sun

## Chromosphere

### Prominence :

#### Prominence

1. Denser and cooler chromospheric plasma confined to large scale magnetic loop / arch / arcade.
2. Temperature  $\sim 8200 \text{ }^{\circ}\text{K}$  ; Height  $\sim 0.2 - 1.0 R_{\odot}$
3. Called as prominence above the limb; Appear brighter against the faint background (corona).
4.  $B \sim 2\text{-}20 \text{ G}$  (Quiet) &  $\sim 100 \text{ G}$  (Active Region)

#### Prominences

BBSO, H-ALPHA 0.00

# Sun Chromosphere

**Bright patches**

**Dark Lanes**

2014JUL02 18:20:17

BBSO, H-ALPHA 0.00

# Sun Chromosphere

Plages :

1. Plage (Beach / seashore) – Elevated structures around the sunspots (or superpenumbra)
2. Regions of higher intensity in  $H\alpha$  & Ca-II (H&K) lines.
3. Magnetic field (B) - Higher than the photospheric background and lower than the sunspot B;  $\sim 250$  G.
4. Temperature  $\sim 8000$  °K.

2014JUL02 18:20:17

BBSO, H-ALPHA 0.00

# Sun Chromosphere

Bright patches

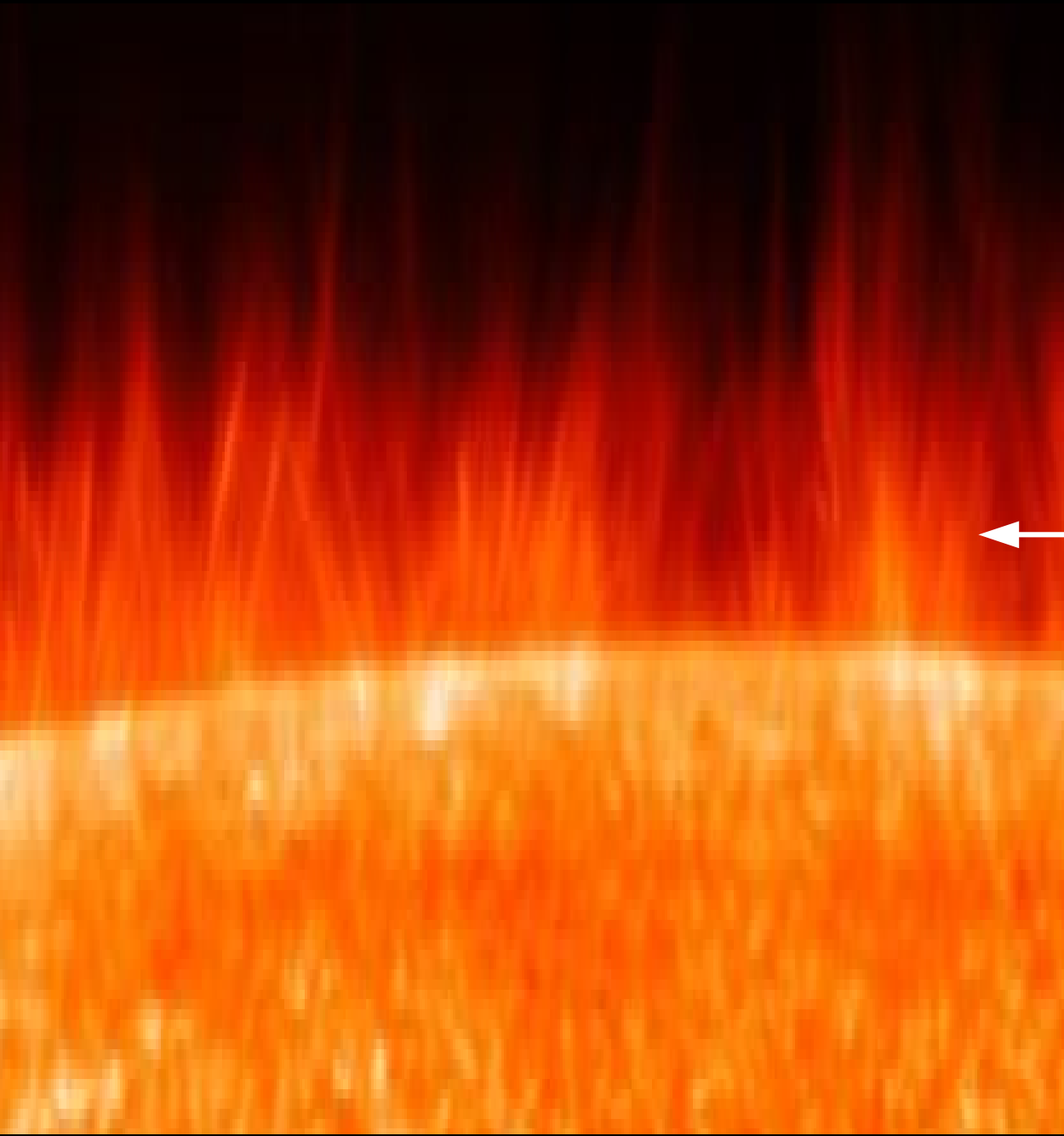
## Filaments:

1. Prominence above the disk is called a filament.
2. Width  $\sim 10$  Mm.
3. Appears dark due to absorption of background radiation.
4.  $B \sim 2\text{-}20$  G (Quiet) &  $\sim 100$  G (Active Region).

2014JUL02 18:20:17

# Sun Chromosphere

Spicules





# Sun

## Chromosphere

### Spicules:

1. Hair / forest like structures seen above the limb.
2. Dynamic plasma jets with diameter  $\sim 0.1$  Mm.
3. Lifetime  $\sim 10$  minutes; Represent transverse oscillations – signatures of traveling MHD waves.
4. Rise speed  $\sim 20$  km/s & mass flux  $\sim 10^{10} \text{ cm}^{-2}\text{s}^{-1}$
5.  $B \sim 10$  G (Quiet) &  $\sim 50$  G (Active Region).

# The CORONA



**The effect of blocking the photospheric light  
Happens naturally in an Eclipse**



# The CORONA

X-ray  
EUV  
White-light  
Radio

EUV 171 Å  
SWAP / PROBA2  
Total Solar Eclipse

Transition Region ↔ 1 AU

S. R. Cranmer et al. *ARAA*, 2019, 57, 157

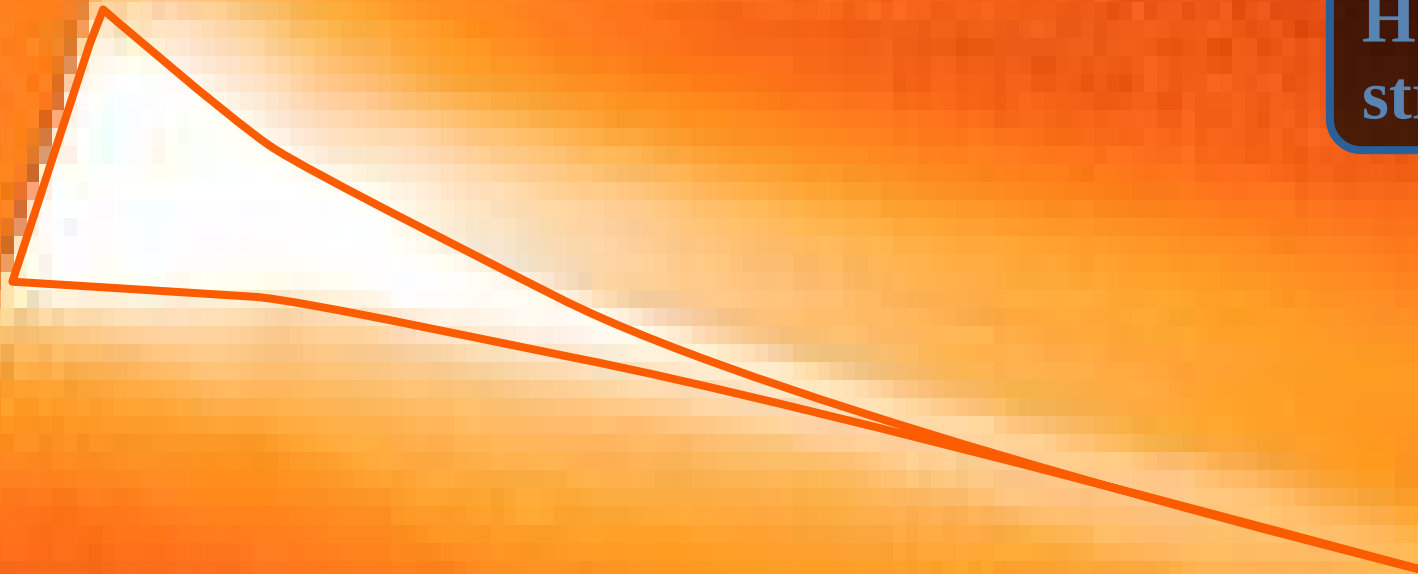
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# What are the Structures in the Corona ??

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# Coronal Structure

Helmet  
streamer



WL 5300 - 6400 Å

# Coronal Structure

## Coronal Helmet Streamer :

1. White conspicuous helmet like structure seen in WL coronagraph image.
2. These form above Active Regions.
3. Signature of plasma streaming out along magnetic field lines.
4. Source of slow solar wind (100 – 200 km/s).

Helmet  
streamer

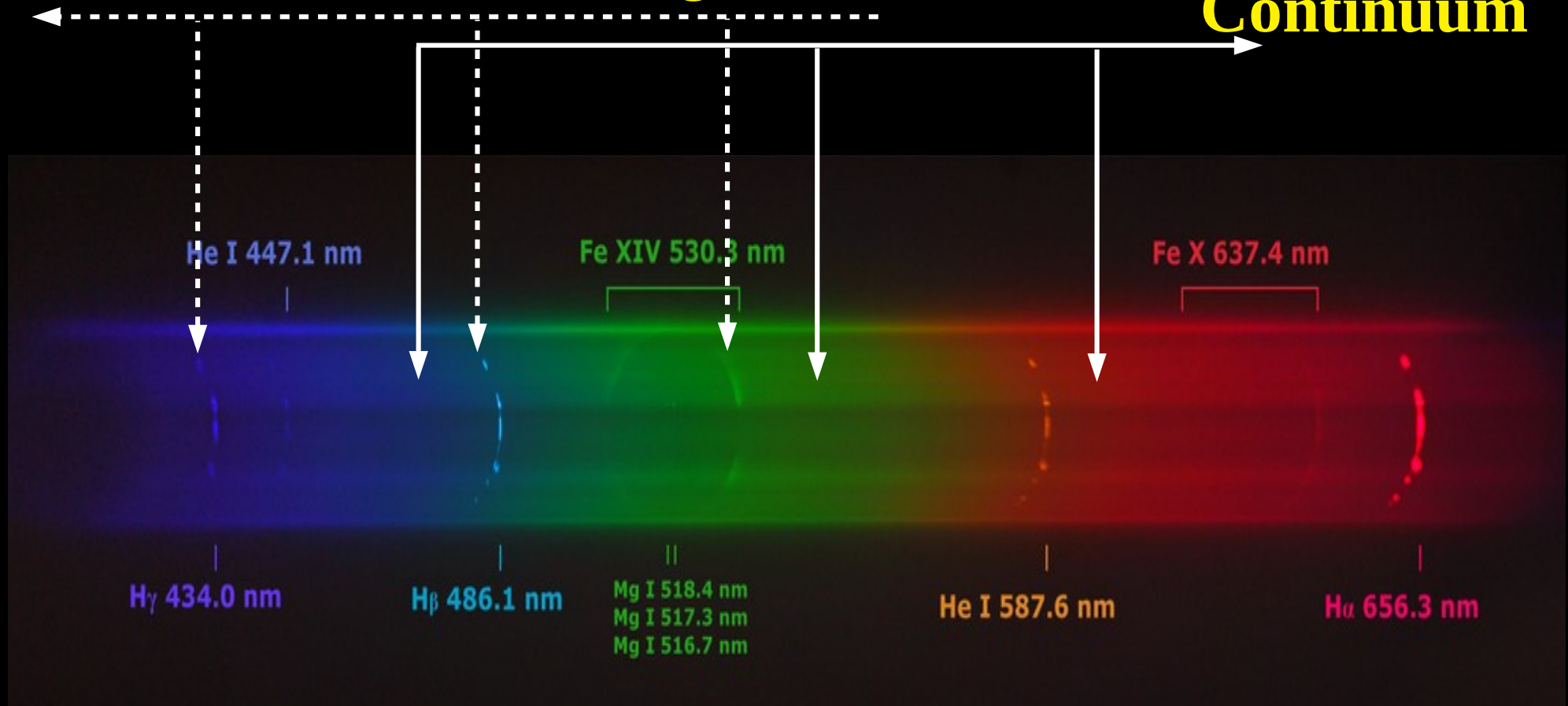
WL 5300 - 6400 Å



# Coronal Streamer

Line emission + broadening

Continuum



# Coronal Streamer

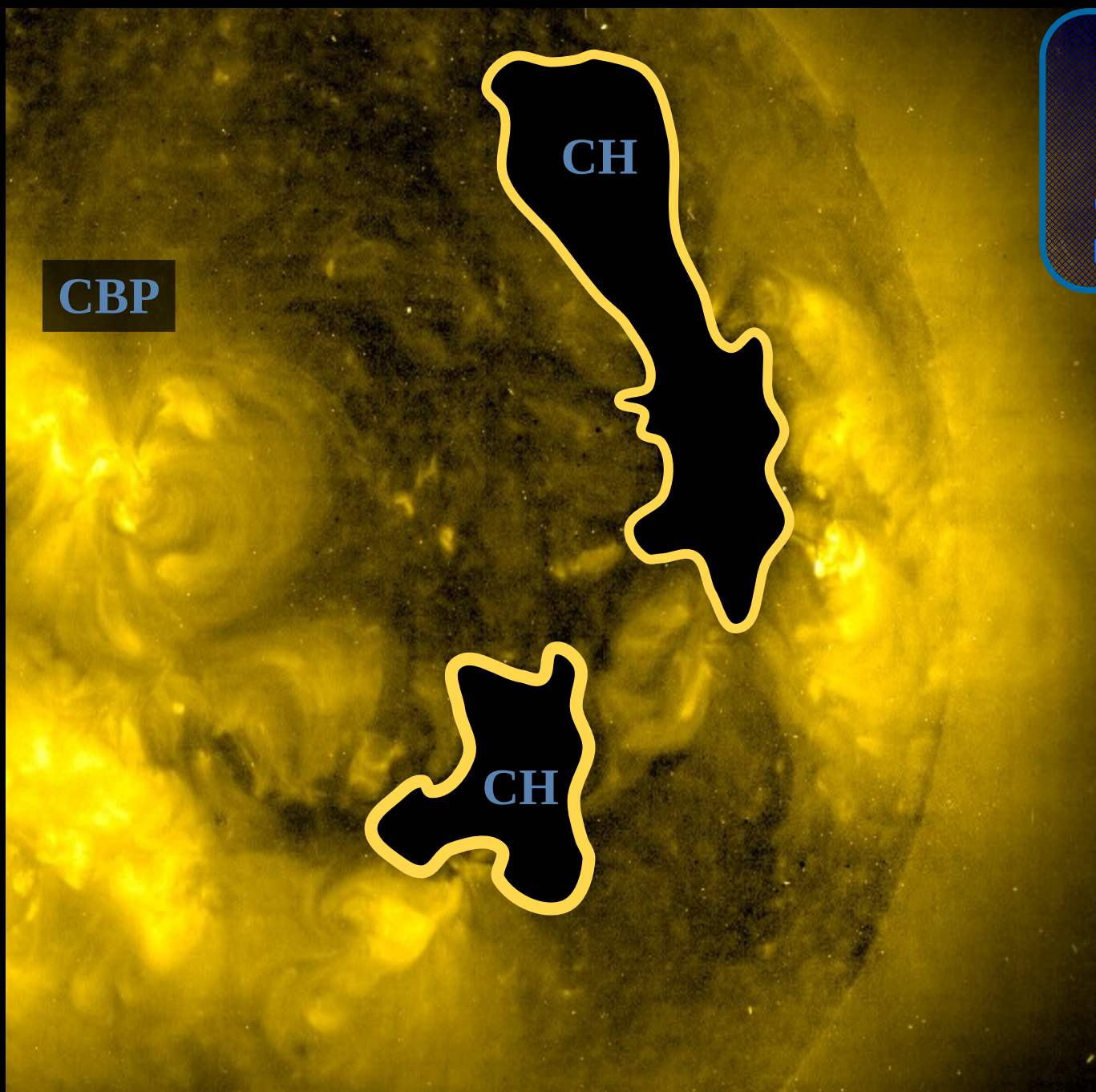
## Coronal Streamers:

1. Seen due to scattered photospheric light
2. Ionized Iron → Indicating Million Kelvin plasma
3. Spectral broadening → 200-500 km/s
4. Ion density →  $10^{36}$  particles/sec
5. Ion speed → 200–400 km/s



# **EUV & X-ray Corona**

**The Spectral observations carried out by Edlen further indicated the EUV & X-ray emission from the Solar Corona.**



# Coronal Structure

X-ray  
Image

(S/Ca/Al/Mn)  
Fe-VII - Fe-XIV  
2-32 Å ( $\geq 2$  MK)  
5 – 40 keV

Coronal Holes (CH)  
Coronal X-ray Bright  
Points (CBP)

# Coronal Structure

CBP

CH

X-ray  
Image

## Coronal Bright Points :

1. Regions that appear brighter in X-ray images.
2. These are associated with Active Region Loops or Interconnecting loops.
3. Due to heating of thermal plasma.

Fe-VII - Fe-XIV  
2-32 Å ( $\geq 2$  MK)  
5 – 40 keV

Coronal Holes (CH)  
Coronal Bright  
Points (CBP)



# Coronal Structure

CBP

CH

X-ray  
Image

## Coronal Holes :

1. Regions that appear darker in X-ray images.
2. Are associated with coronal open magnetic field lines.
3. Dark due to lower X-ray emission wrt to Bg.
4. Are sources of fast solar wind (300–700 km/s).

(In)  
Fe-VII - Fe-XIV  
2-32 Å ( $\geq 2$  MK)  
0.5 – 40 keV

Coronal Holes (CH)  
Coronal Bright  
Points (CBP)



# Coronal Structure

EUV  
Image

Coronal  
Loops

Fe-IX  
171 Å ( $\geq 2$  MK)



# Coronal Structure

## Coronal Loops :

Structures that appear brighter due to hot ions trapped in arch like structures anchored to bipolar magnetic field regions.

EUV  
Image

Coronal  
Loops

Fe-IX  
171 Å ( $\geq 2$  MK)

# Coronal Structure

Coronal Plumes  
(Polar)

Plasma flow speed  
10 – 100 km/s  
Alfven Velocity  
140 – 1000 km/s

O-XI  
1030 Å (2 MK)

Thin streamer like structures  
- Associated with Open B lines

# When Sun Is Active ...

Flares

X-ray  
EUV  
H $\alpha$   
WL  
Radio

EIT / EUV

Coronal Transient



# When Sun Is Active ...

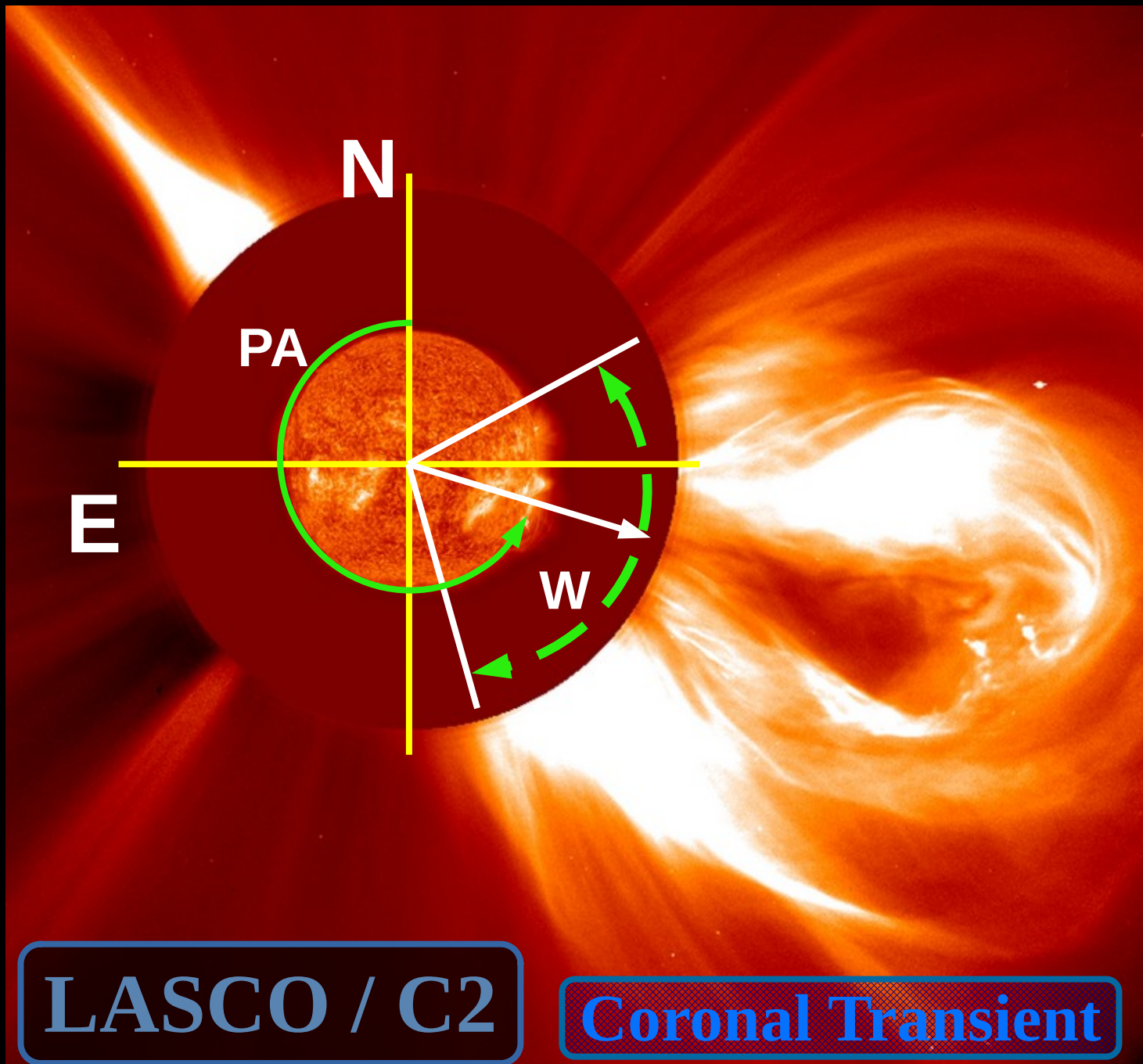
## CMEs

Mass  $\sim 10^{16}$  g  
V  $\sim 100 - 3000$  km/s  
KE  $\sim 10^{36}$  joule

## White-Light

## Coronal Transient

## LASCO / C2



# Standard Solar Model

**SSM:**

**A reasonable theoretical framework that explains major observable solar phenomena**

**Assumptions:**

- 1. Sun evolves hydrostatically**
- 2. Energy transport – Conduction, Convection, radiation, neutrino losses**
- 3. Thermo-nuclear reaction inside the core is the only source of energy**
- 4. Initially homogeneous, primordial composition of H & He, and convection is predominant.**

# Standard Solar Model

**SSM:**

**These 4 assumptions gave 4 basic equations.**

**Sun evolves hydrostatically: Pressure = Gravity**

$$\frac{dP}{dr} = -\frac{Gm\rho}{r^2}$$

$P \rightarrow$  Pressure

$r \rightarrow$  radius

$m$  &  $\rho \rightarrow$  mass & density

$$P = \frac{\rho T R}{\mu}$$

$T \rightarrow$  Temperature

$R \rightarrow$  Gas constant

$\mu \rightarrow$  mean molecular weight

# Standard Solar Model

**SSM:**

**These 4 assumptions gave 4 basic equations.**

**Energy Transport: Convection & Radiation dominant  
Radiation transport & Conduction transport**

$$\frac{dT}{dr} = \frac{-3}{4ac} \frac{\kappa \rho}{T^3} \frac{L}{4\pi r^2}$$

$T \rightarrow$  Temperature

$a \rightarrow$  radiation constant

$\kappa$  &  $\rho \rightarrow$  opacity & density

$L \rightarrow$  Luminosity

$$\frac{dT}{dr} = \left(1 - \frac{1}{\gamma}\right) \left(\frac{T}{P}\right) \left(\frac{dP}{dr}\right)$$

$\gamma \rightarrow$  ratio of specific heats

$$\gamma \rightarrow \frac{C_P}{C_V}$$



# Standard Solar Model

**SSM:**

**These 4 assumptions give 4 basic equations.**

**Thermo-nuclear reaction inside the core is the only source of energy**

$$\frac{dL}{dr} = 4\pi r^2 \epsilon$$

$L \rightarrow$  Luminosity

$r \rightarrow$  radius

$\epsilon \rightarrow$  energy generation rate

Nuclear Fusion Reaction  
p-p cycle & CNO cycle

Fusion requires high  
temperature & density

# Standard Solar Model

**SSM:**

**These 4 assumptions give 4 basic equations.**

**Initially homogeneous, primordial composition of H & He, and convection is predominant.**

**Initial abundances are estimated from the relative amounts of H & He since they are the indicators of evolution.**

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**To summarize the  
above discussion**

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**Chromosphere**  
**Layer thickness ~ 2500 km**

$$1.7 \times 10^5 \text{ km}$$

# Corona

$T = 2 \times 10^4 - 2 \times 10^6 \text{ K}$   
 Num. Density =  $10^8 \leftrightarrow \text{few e}^- \text{ cm}^{-3}$

$$6.96 \times 10^5 \text{ km}$$

Convective transport  
 $T = 2 \times 10^6 \leftrightarrow 5600 \text{ K}$   
 $D = 0.2 \text{ g cm}^{-3} \leftrightarrow 2 \times 10^{-7} \text{ g cm}^{-3}$

Radiative transport  
 $T = 7 \leftrightarrow 2 \times 10^6 \text{ K}$   
 $D = 20 \leftrightarrow 0.2 \text{ g cm}^{-3}$

$$5.2 \times 10^5 \text{ km}$$

**Photosphere**  
Layer thickness = few 100 km

$T = 5600 \text{ K}$   
 $D = 2 \times 10^{-7} \text{ g cm}^{-3}$



# So far we saw the overview of different structures on the Sun

**So far we saw the overview  
of different structures on the Sun  
using Optical,  $H\alpha$ , EUV, and X-Ray**

**Note : Not ALL structures were discussed  
Radio emission?? - Part II**

**So far we saw the overview  
of different structures on the Sun  
using Optical,  $H\alpha$ , EUV, and X-Ray**

Thank you ALL

**Organizers**

(SU-UZB, COSPAR, ISWI, SCOSTEP, e-CALLISTO)

**Participants**

**IIA & GBR observatory staff**