

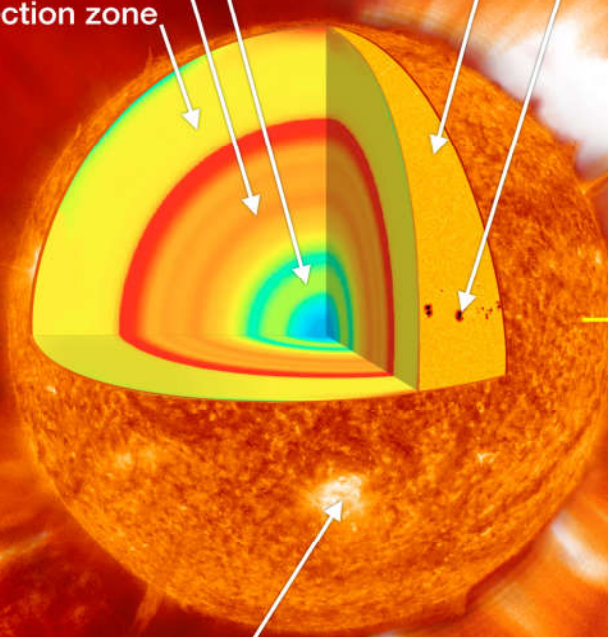
第二章：空间天气因果链

Sun

Internal Structure:

- inner core
- radiative zone
- convection zone

- photosphere
- sunspot



- plage
- corona
- coronal mass ejection

Earth

magnetosphere

- incoming solar wind particles
- polar cusp
- plasmasphere
- atmosphere

photons

solar wind

bow shock

magnetosheath

heliosphere

太阳

行星际空间

地球空间

2.1 太阳及太阳活动

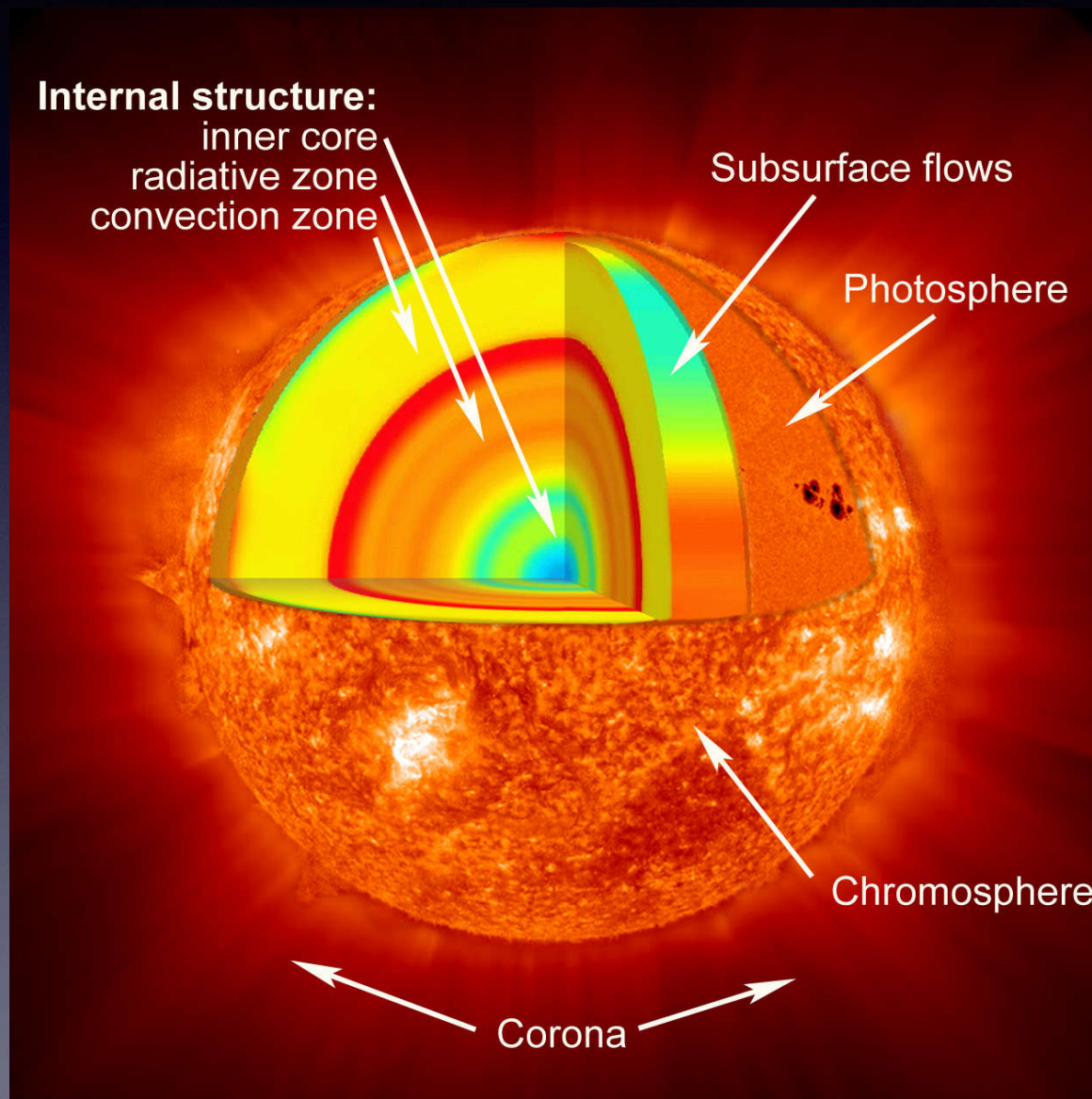
太阳结构

太阳大气

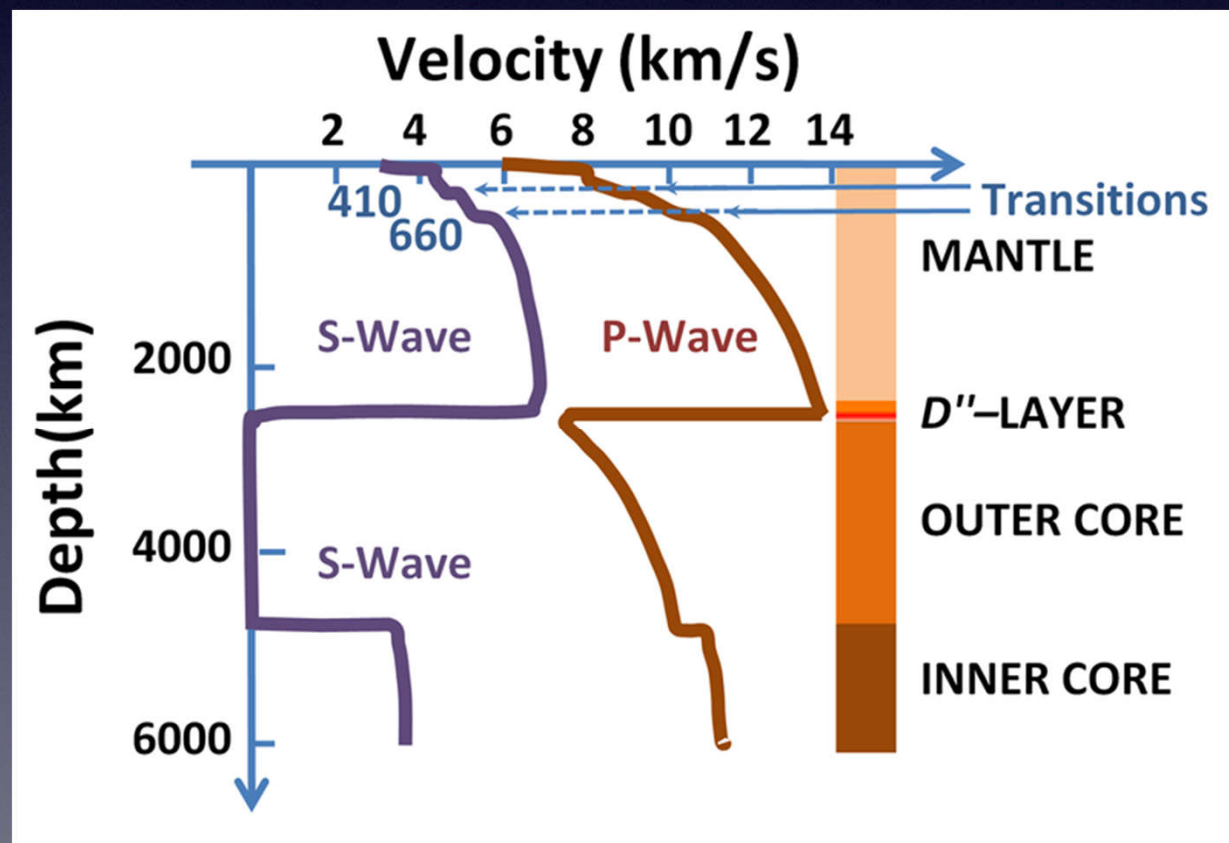
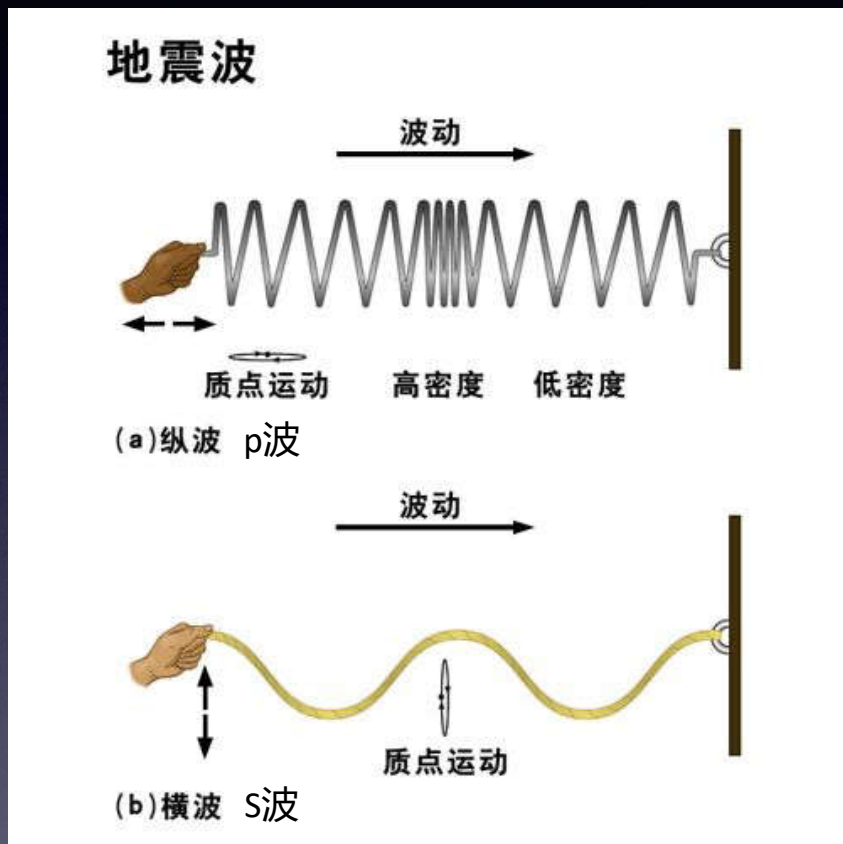
日冕
过渡区
色球层
光球层

太阳内部

对流区
辐射区
内核



地震波：研究地球内部结构的工具



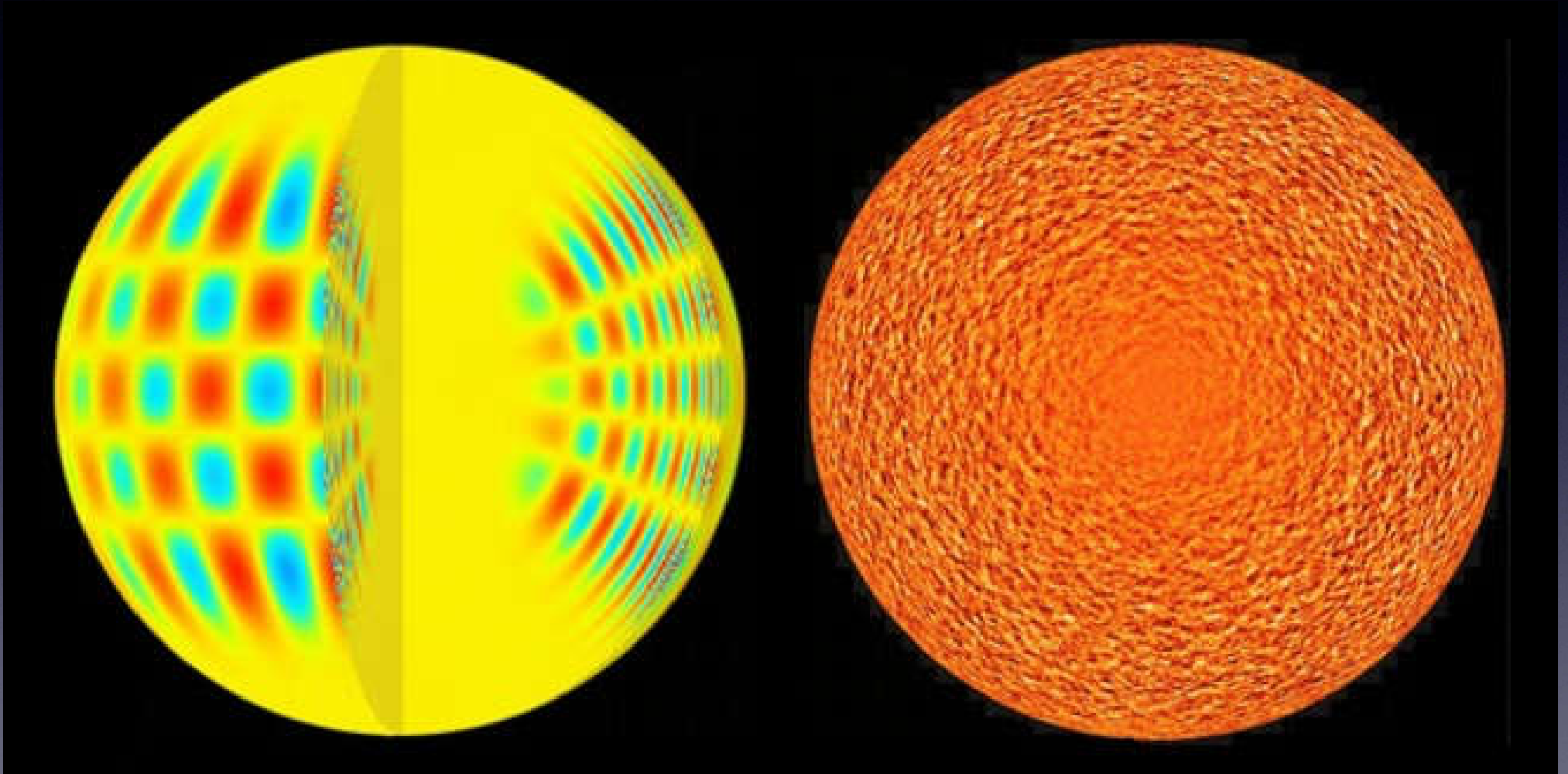
太阳表面5分钟震荡

10 frames per second
600X (10 min/sec)

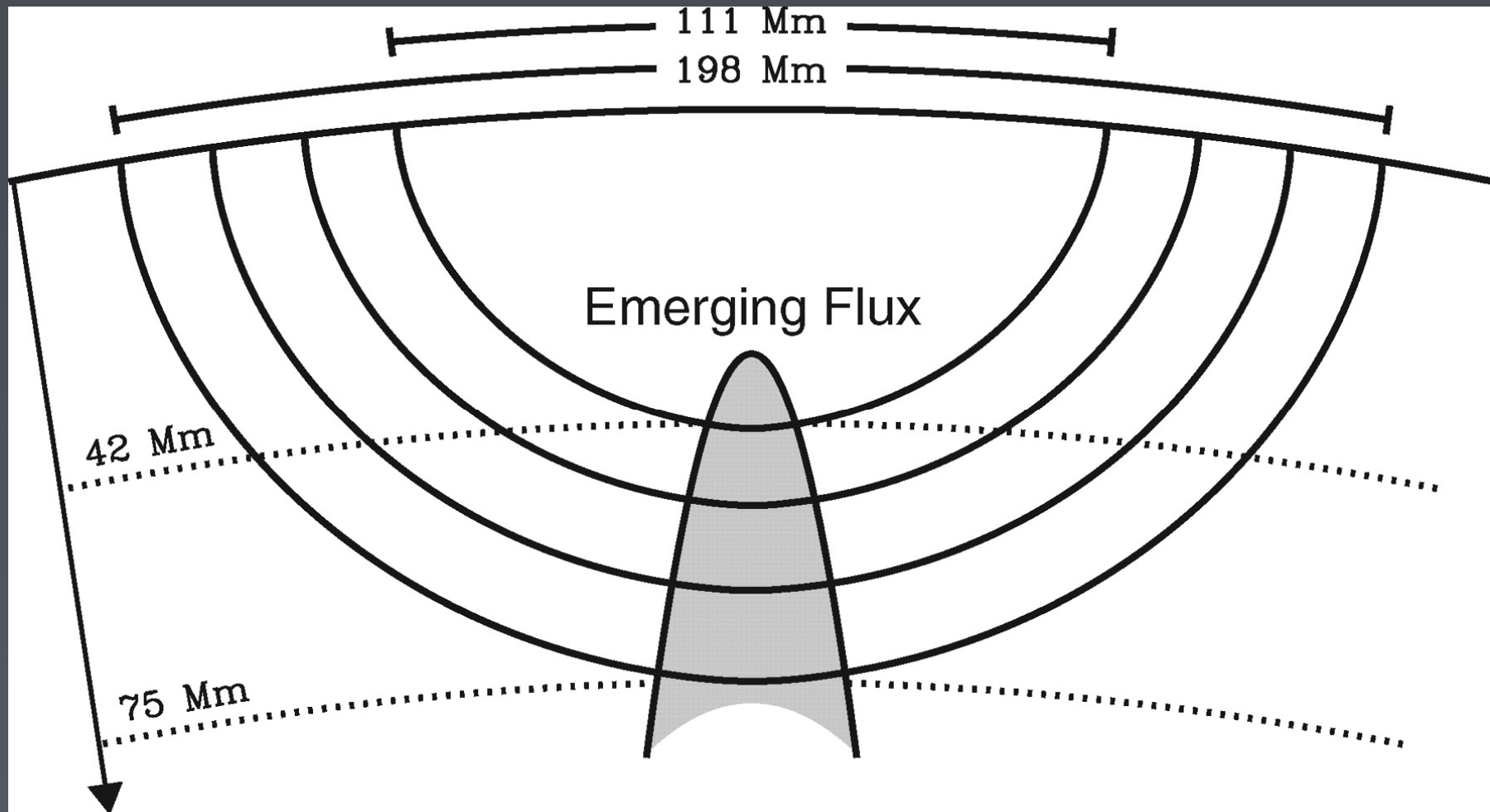
The $l=20$ $m=16$ Mode



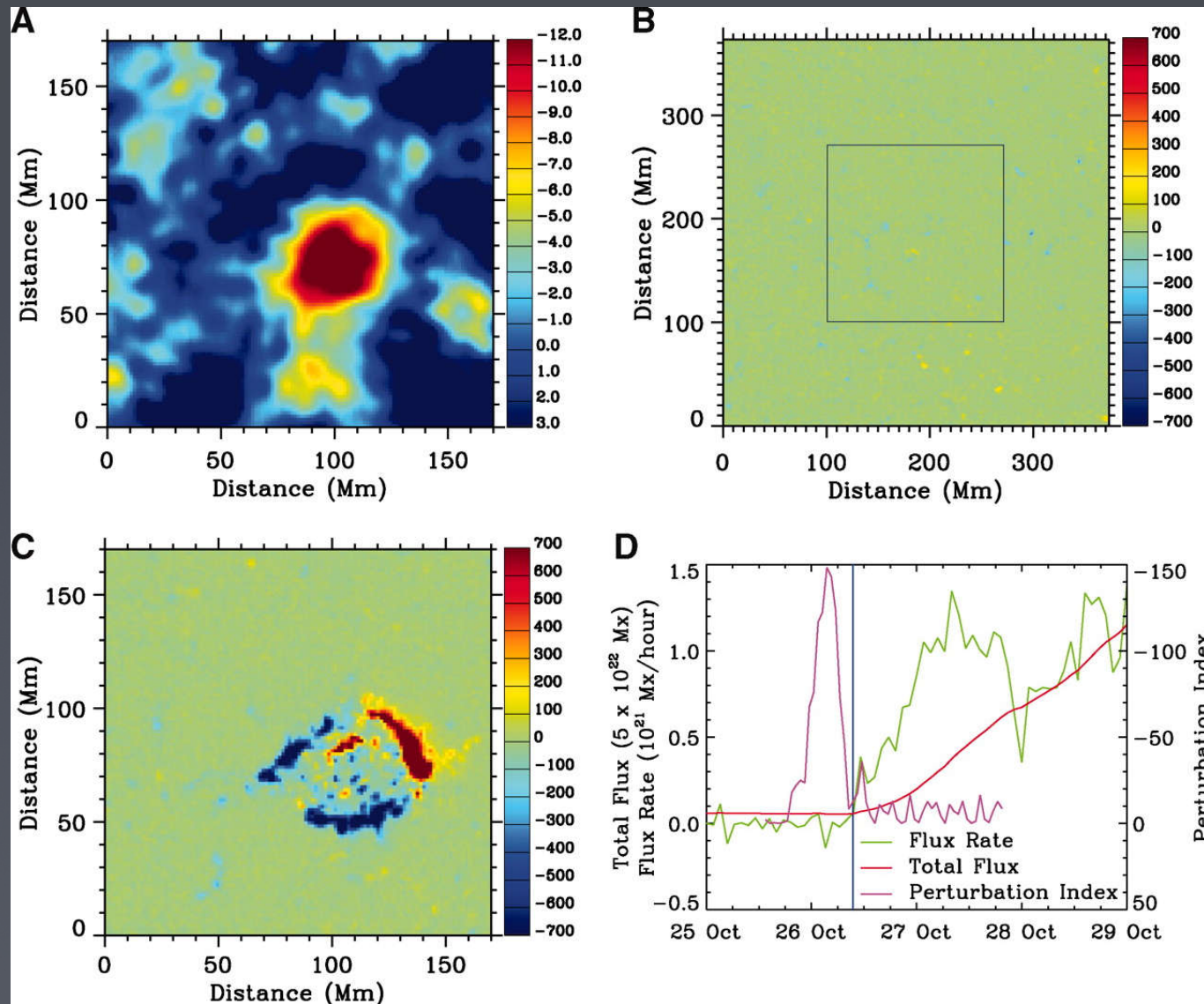
日震学：研究太阳内部结构



声波在太阳内部传播示意图

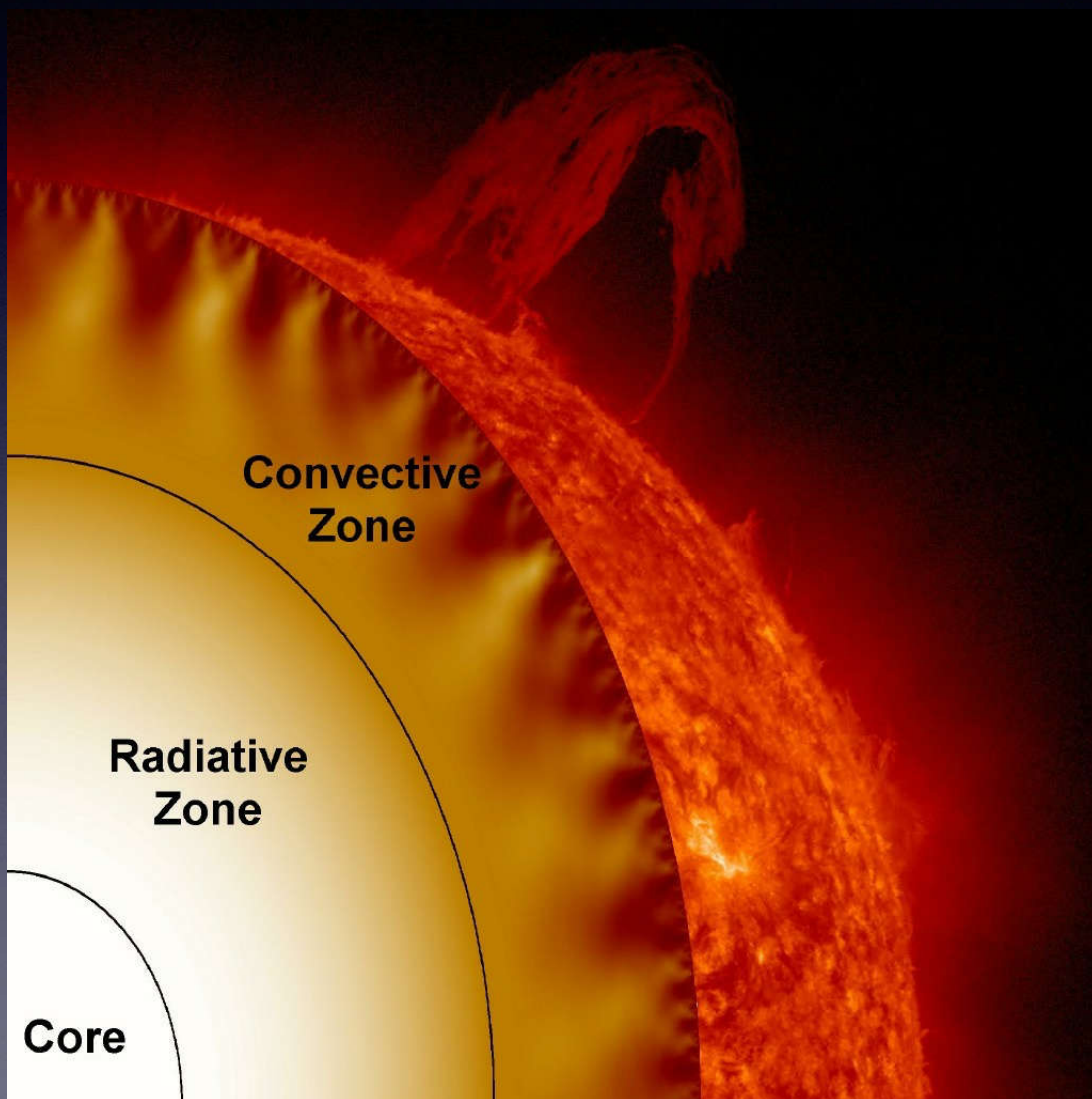


利用声波传播时间扰动提前预知活动区形成



Mean travel-time perturbation map (in seconds) of AR 10488 at a depth of 42 to 75 Mm, obtained from an 8-hour data set centered at 03:30 UT, 26 October 2003.

太阳内部结构



内核: 太阳的产能区

区域: $<0.25R_s$

质量: $\sim 0.5M_s$

能量: 99% 太阳能量

辐射区

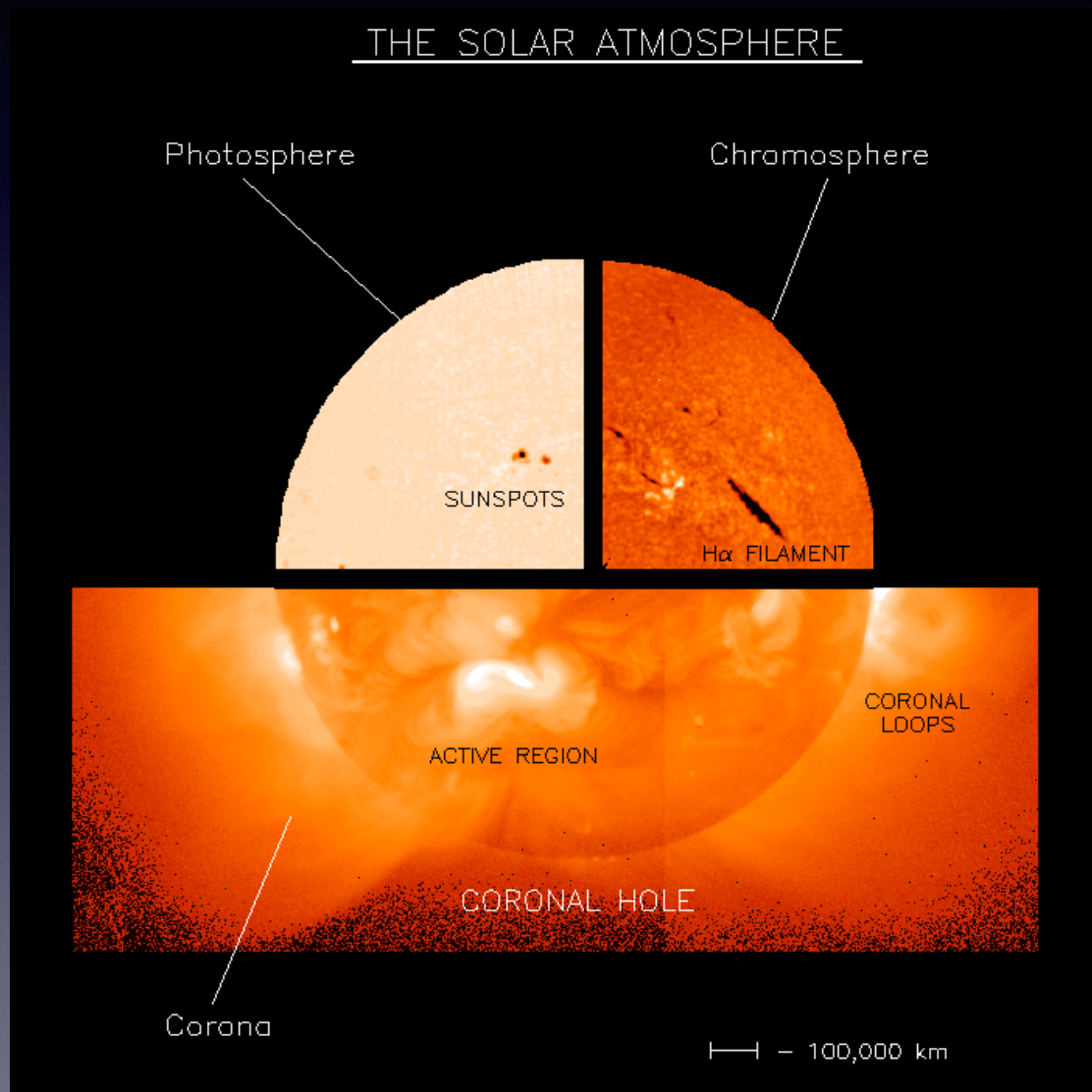
区域: $0.25 - 0.86 R_s$

对流区

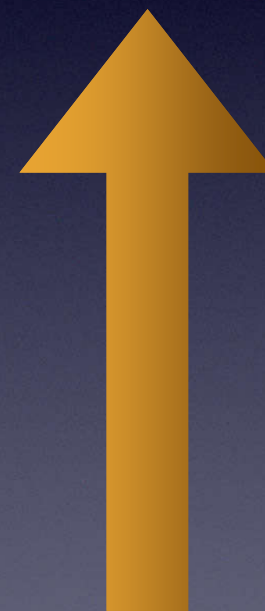
区域: $>0.86 R_s$

能量主要靠对流传播

太阳大气结构



日冕
过渡区
色球层
光球层



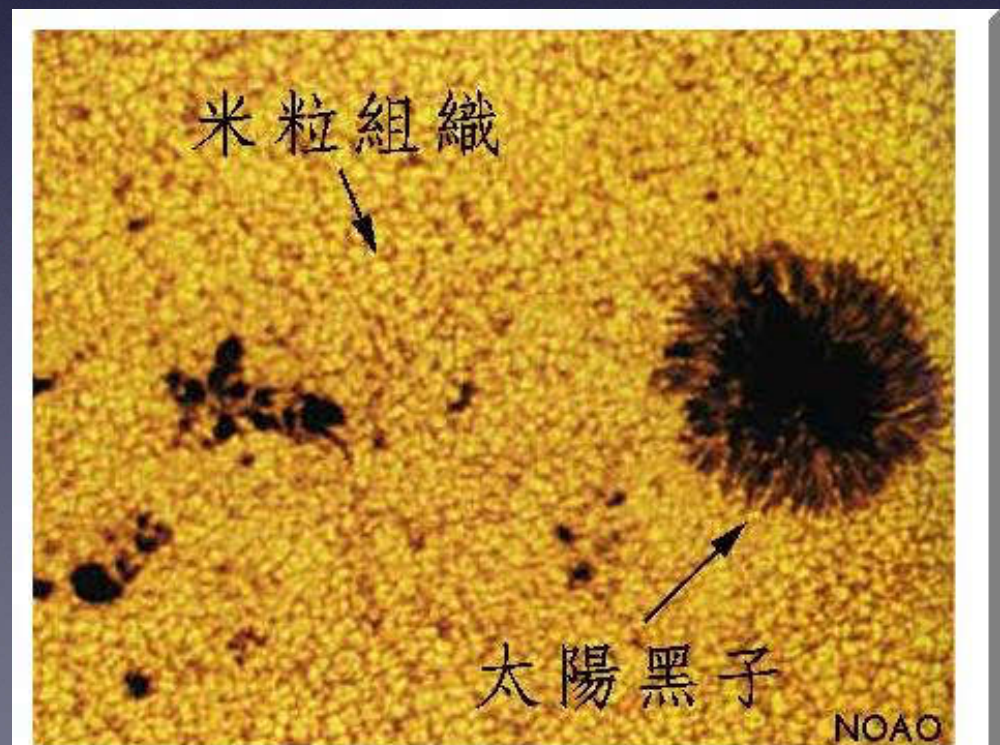
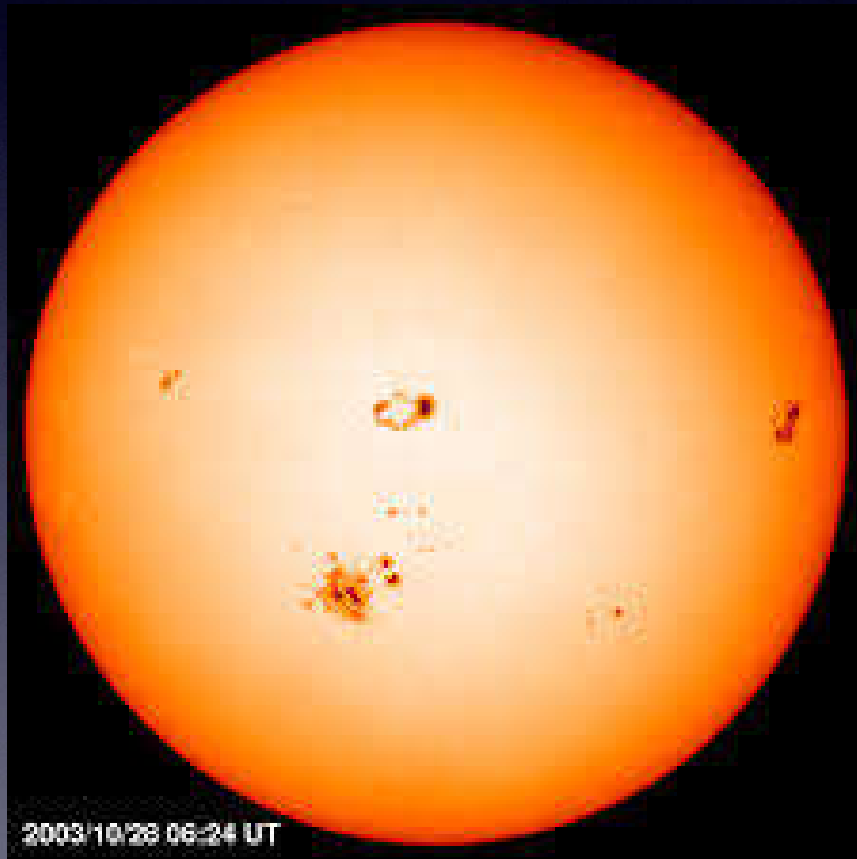
光球层

★米粒组织

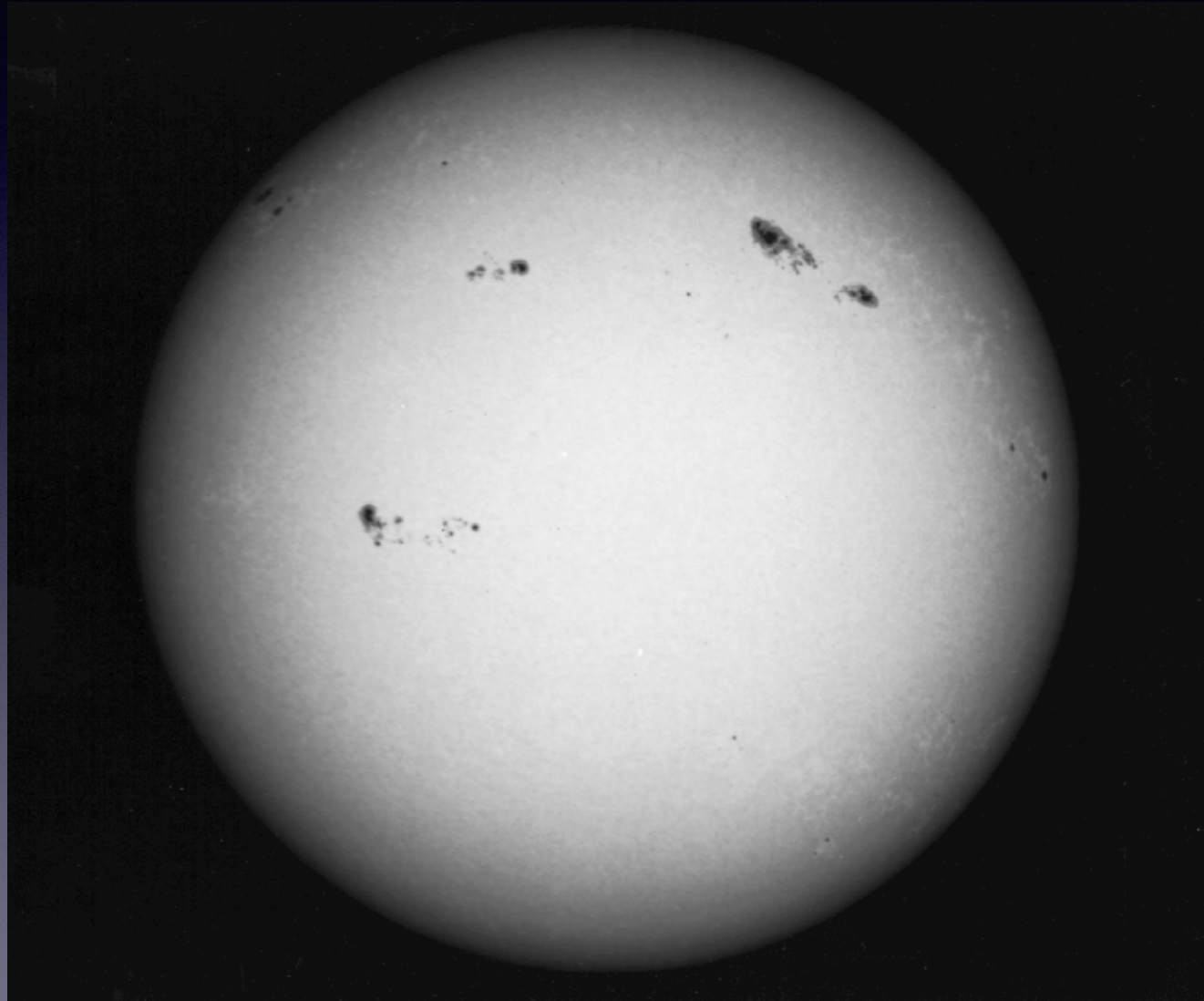
★光斑

★太阳黑子

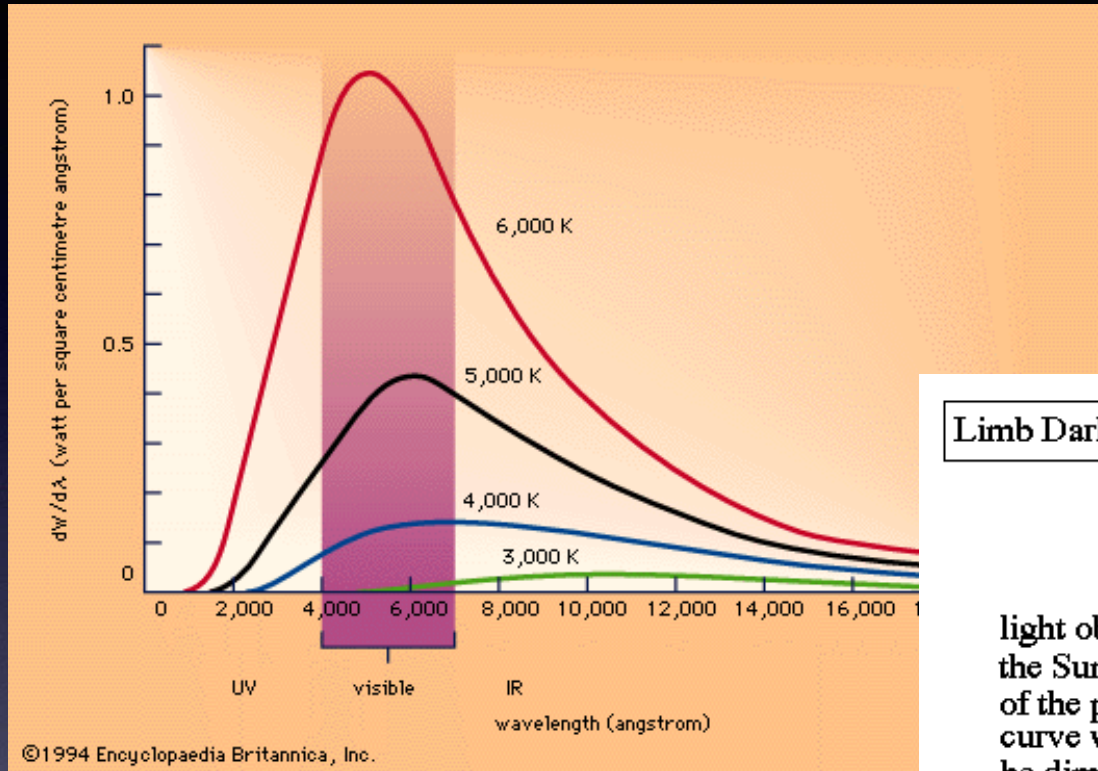
★活动区



光球层临边昏暗现象



光球层临边昏暗现象

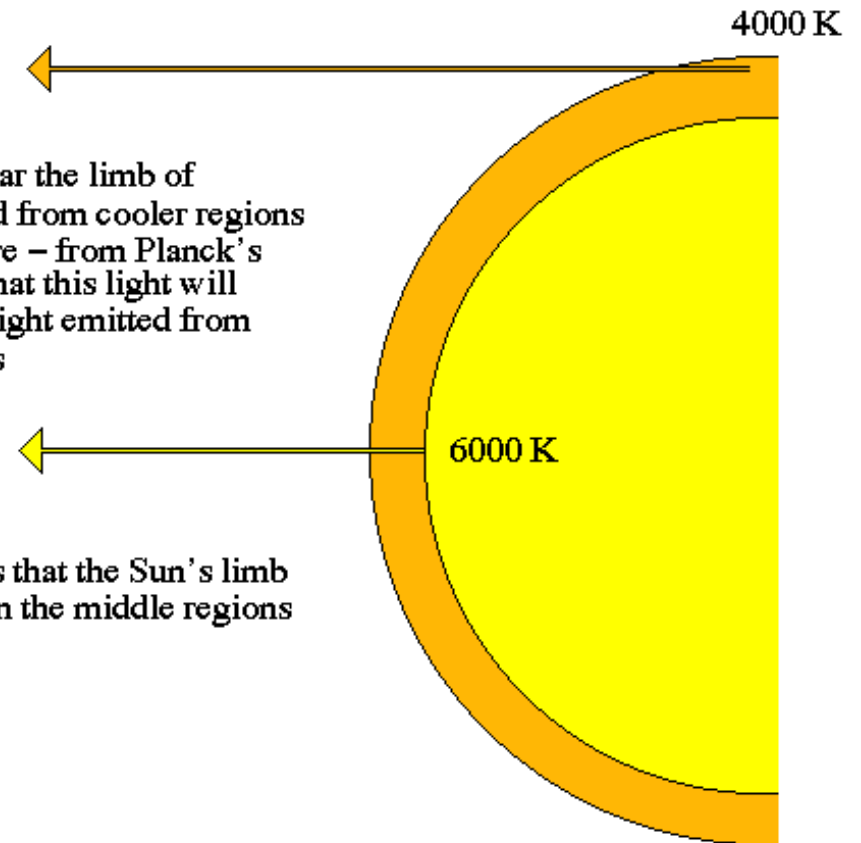


普朗克曲线

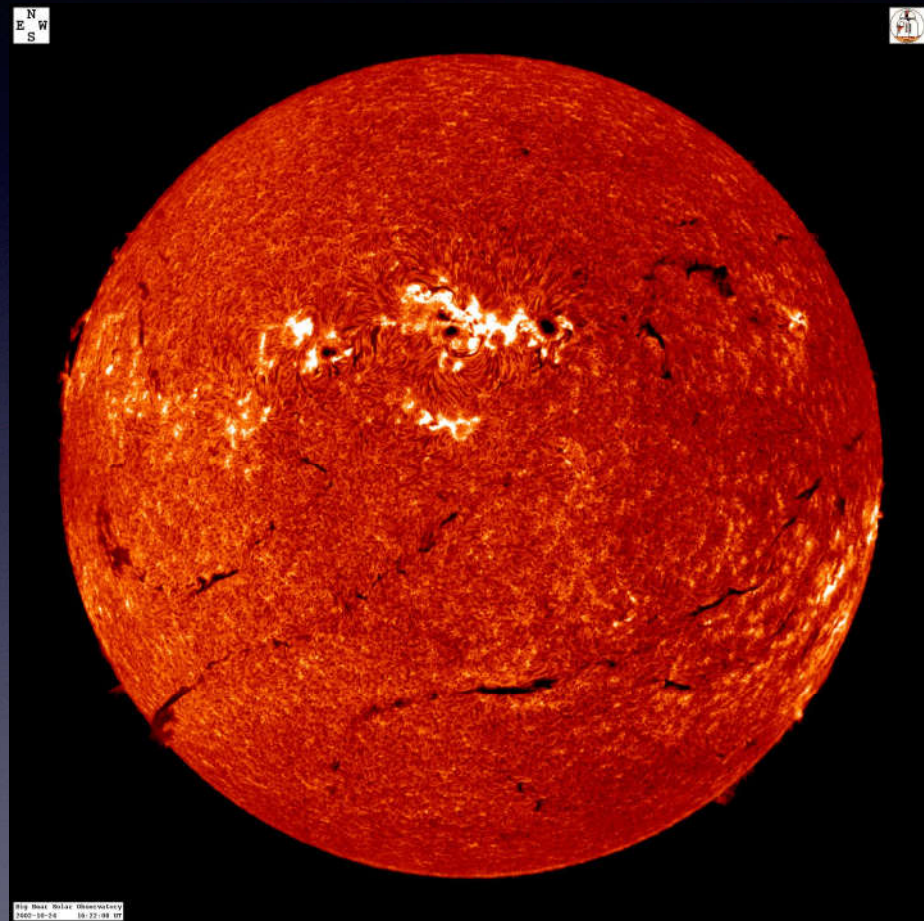
Limb Darkening

light observed near the limb of the Sun is emitted from cooler regions of the photosphere – from Planck's curve we know that this light will be dimmer than light emitted from the hotter regions

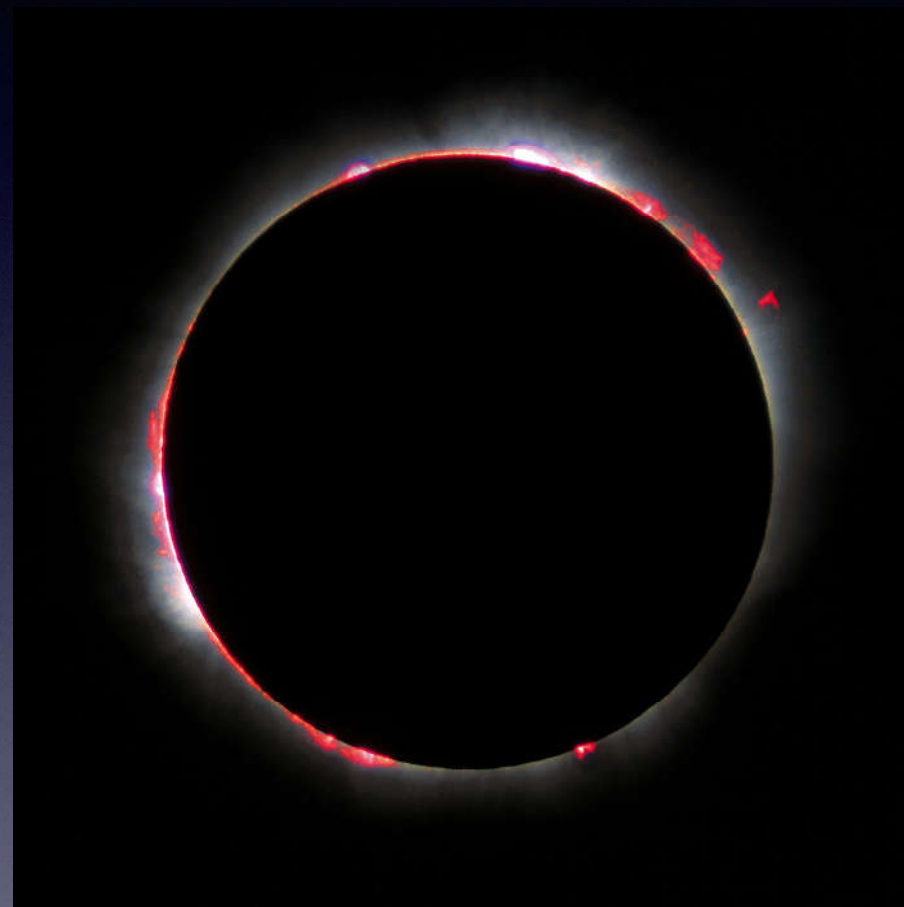
the final effect is that the Sun's limb looks darker than the middle regions



色球层



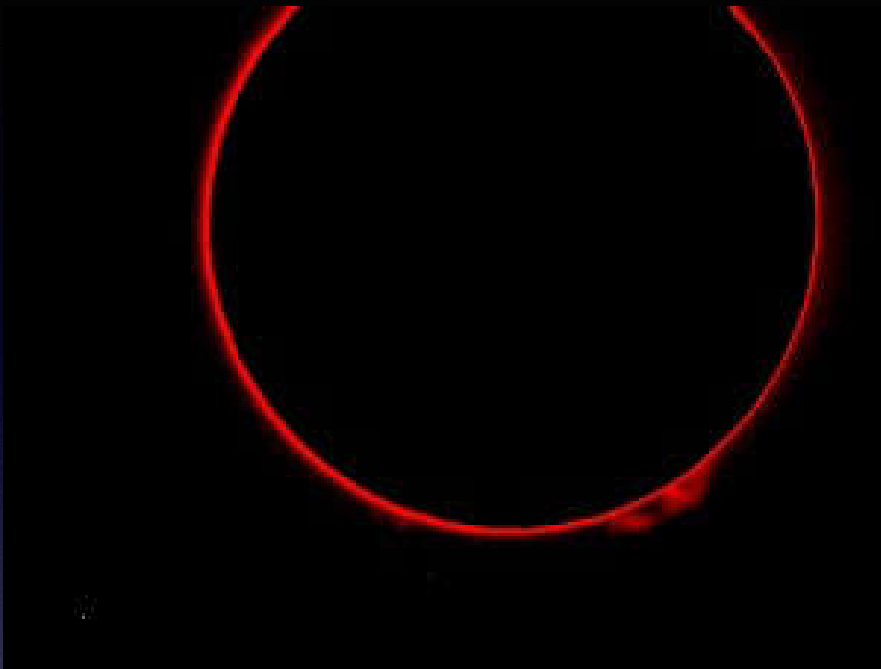
★针状物



★日珥

★暗条

闪光谱：当日全食的食既后几秒钟和生光前几秒钟太阳光球正好被月球完全遮蔽而仅露出圆弧状投影的色球时，用无缝摄谱仪拍摄的色球光谱



TOTAL SOLAR ECLIPSE 3TH NOVEMBER 2013 GABON, MIKONGO II

FLASH SPECTRUM VISUAL SPECTROGRAPH 3001/mm 13:56:04UT



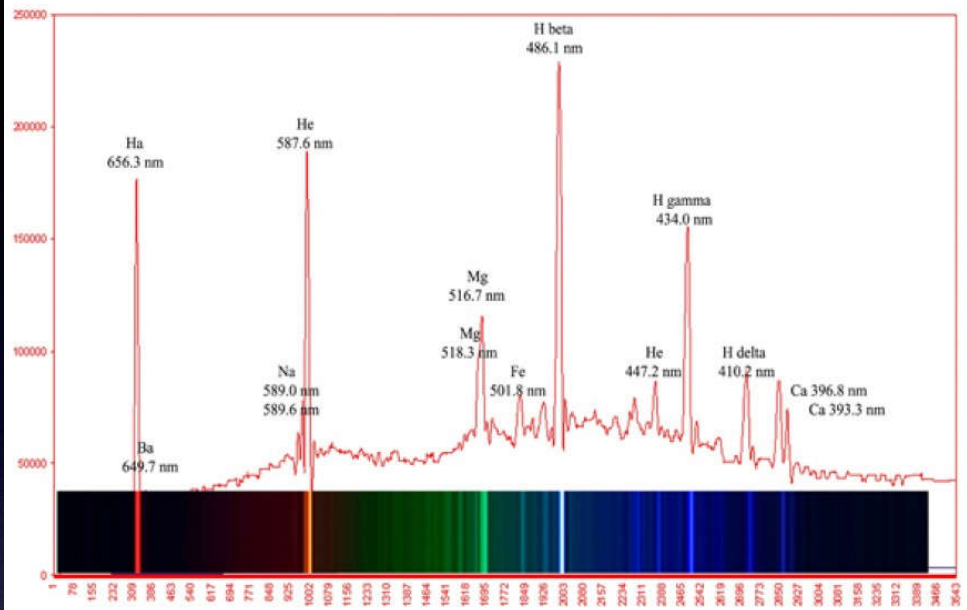
H α FeX
6563Å 6374Å

HeI
5876Å

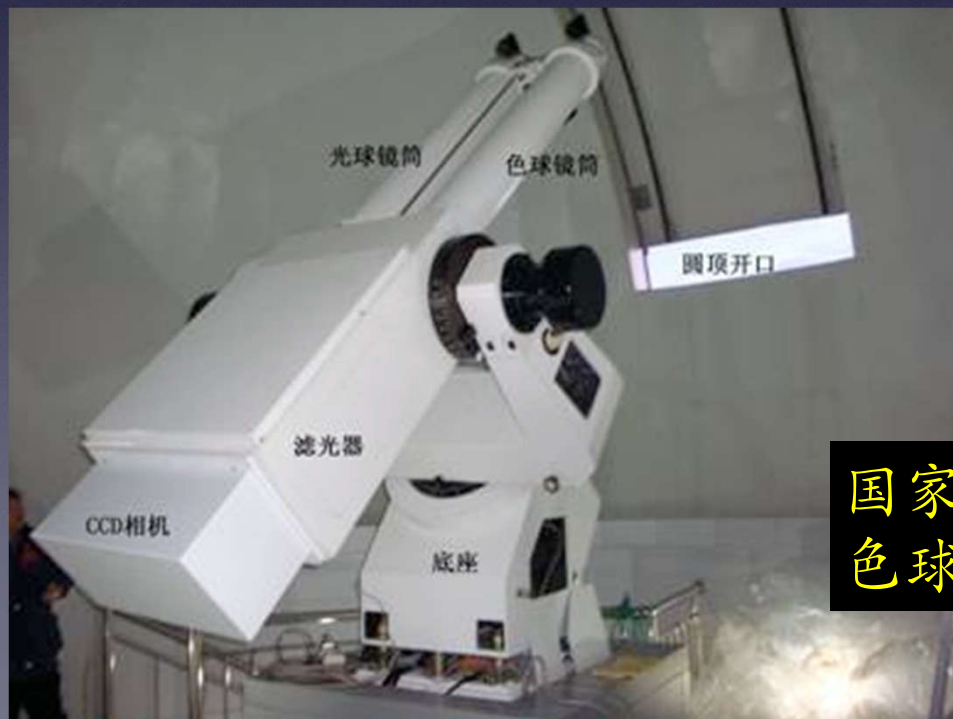
FeXIV
5303Å

H β
4861Å

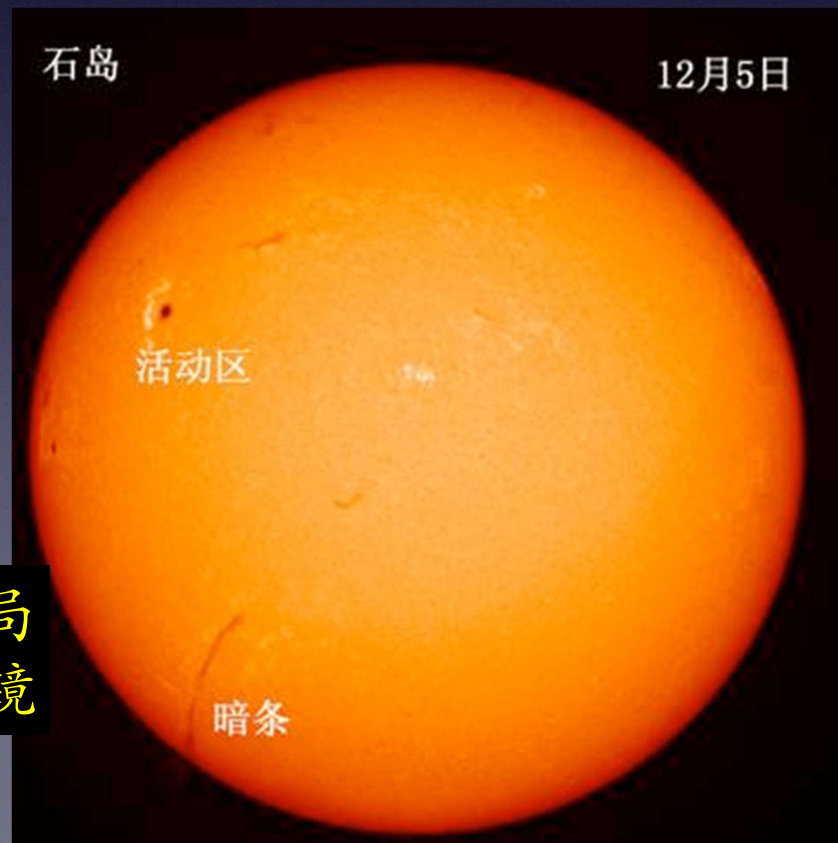
The Solar Chromosphere Spectrum (Flash Spectrum)



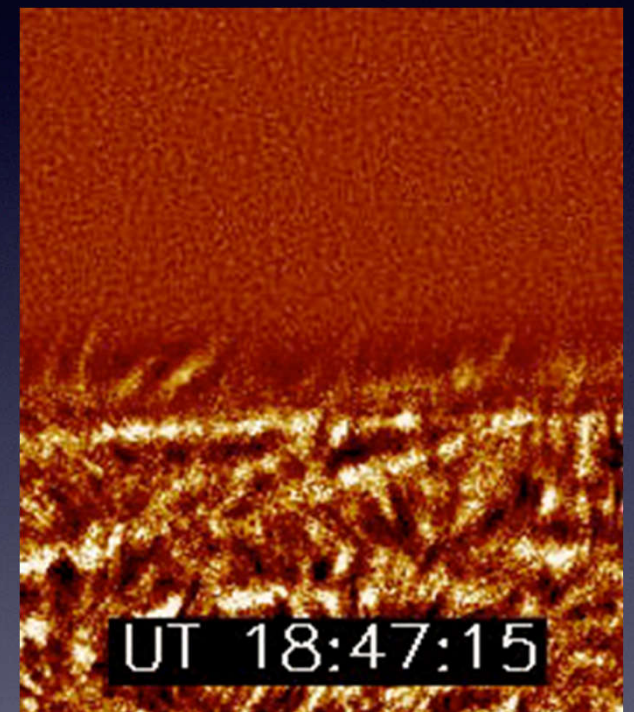
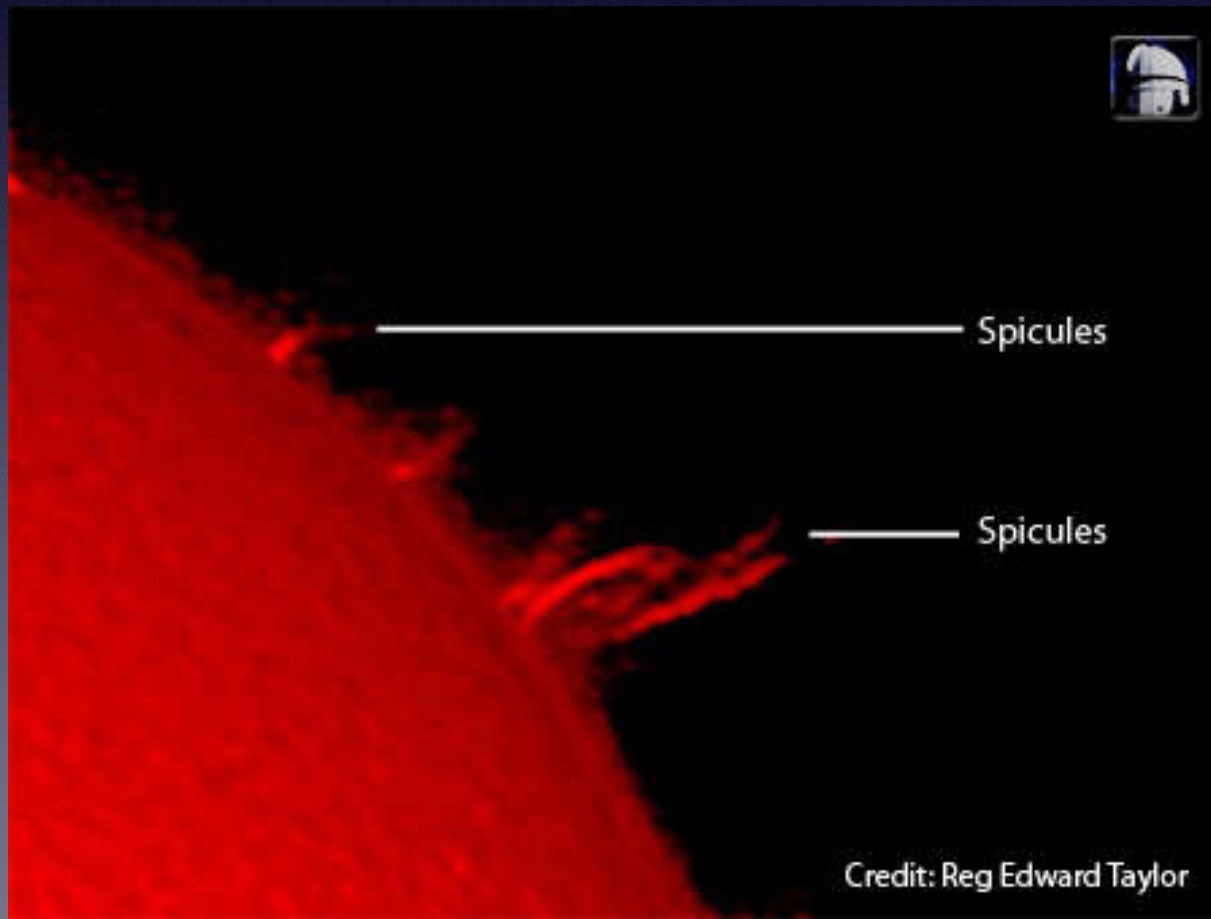
色球望远镜



国家气象局
色球望远镜



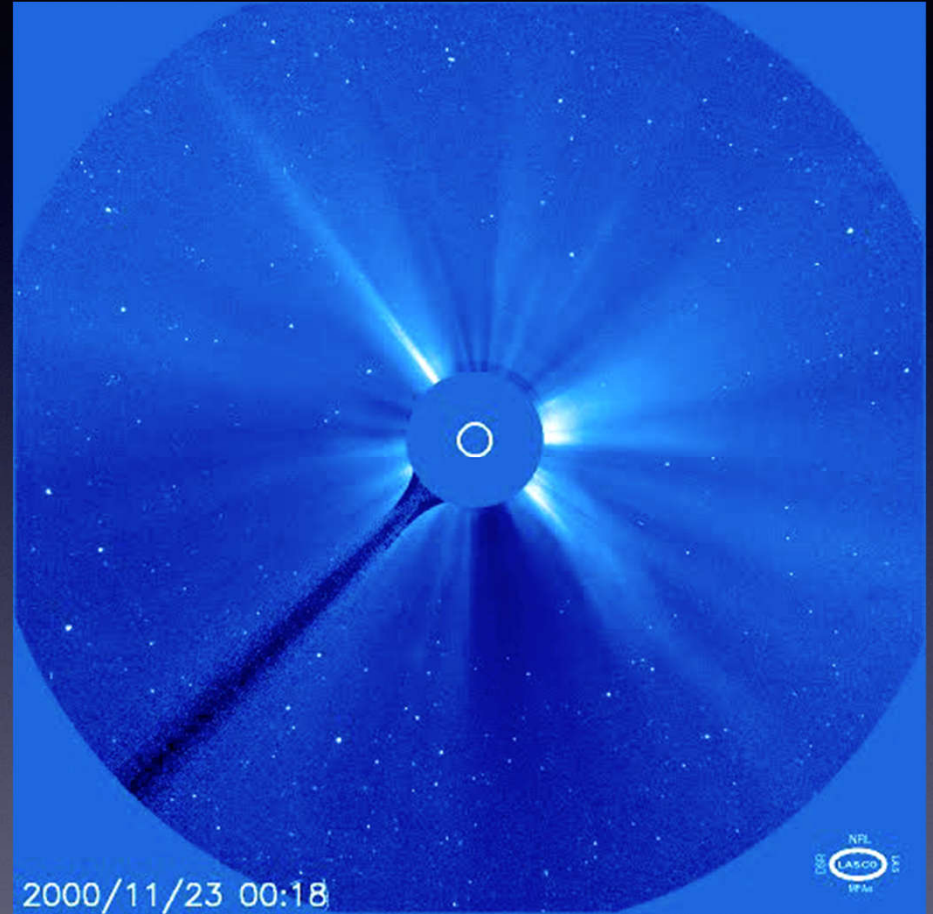
针状物(Spicule)



日冕



日全食时的日冕



日冕仪中的日冕







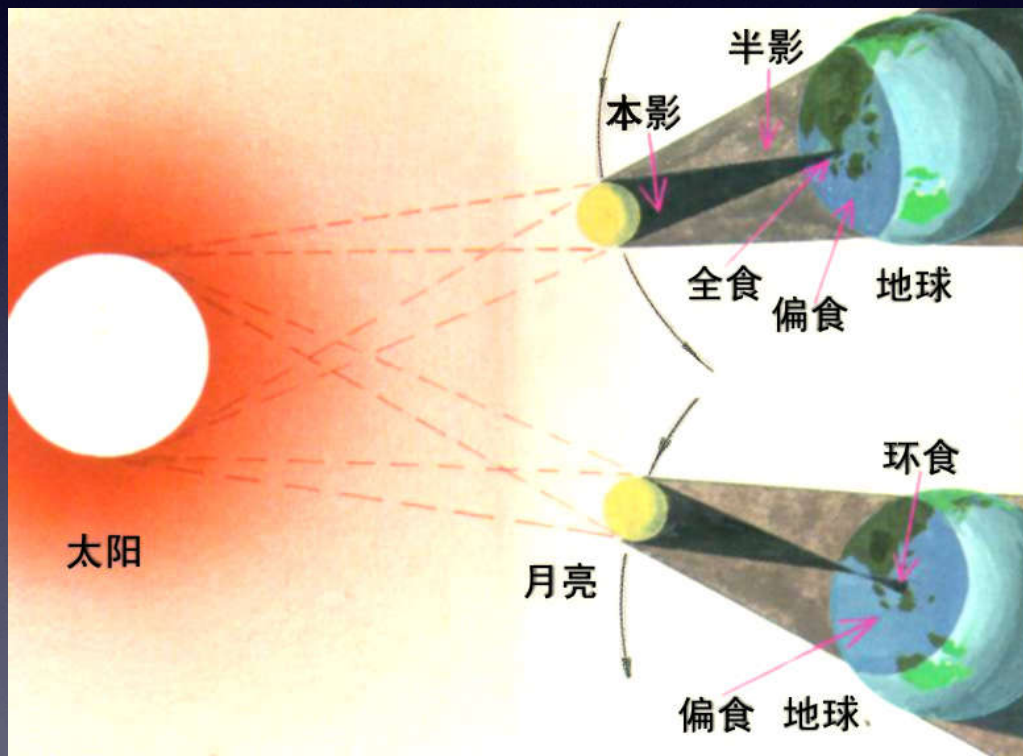
日冕亮度： $10^{-6}I_0$ (太阳边缘)

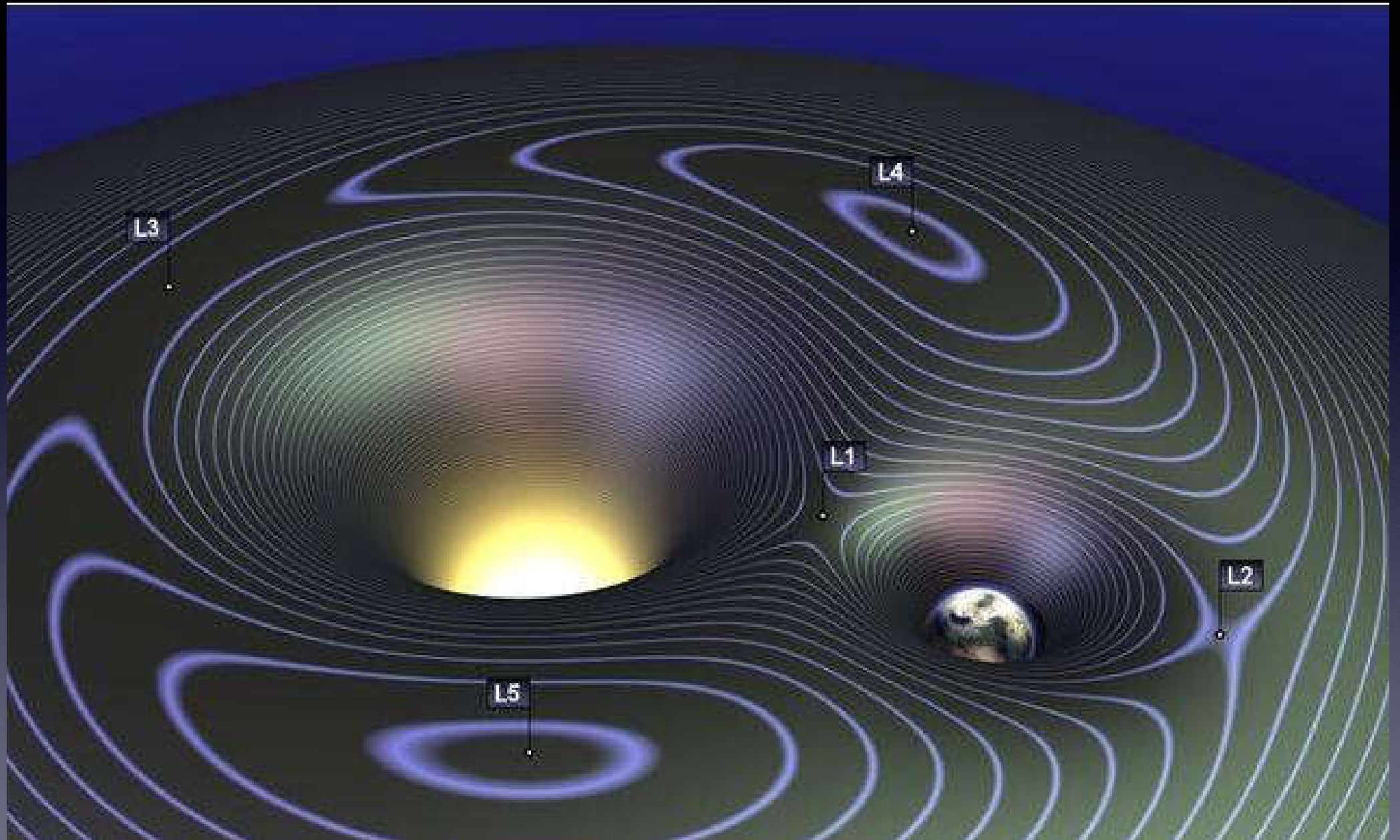
$10^{-9}I_0$ ($5R_s$)

地球海平面出天空： $10^{-2}-10^{-3}I_0$



2009年7月22日全日冕合成图 (湖北宜昌)

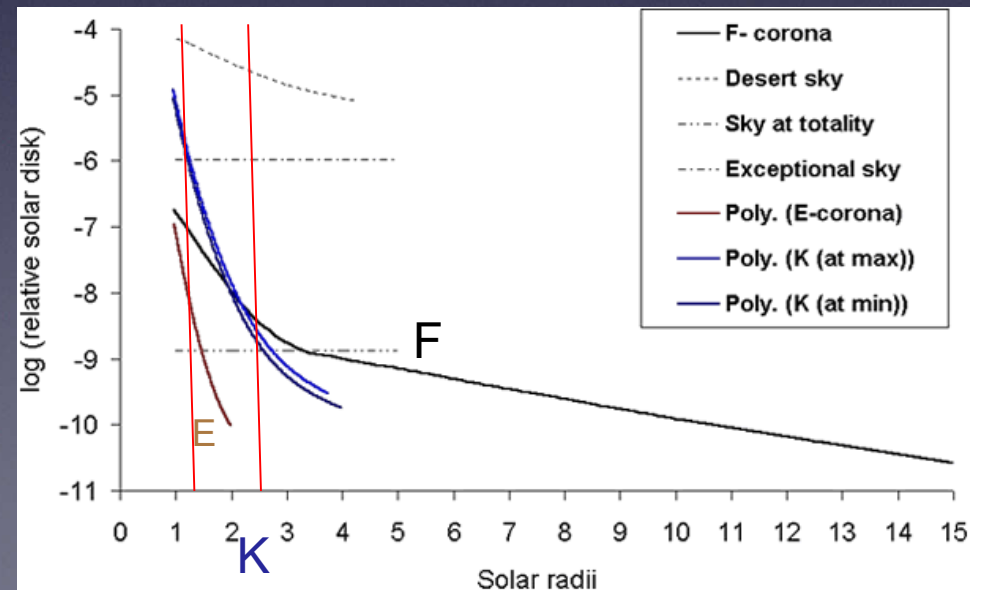




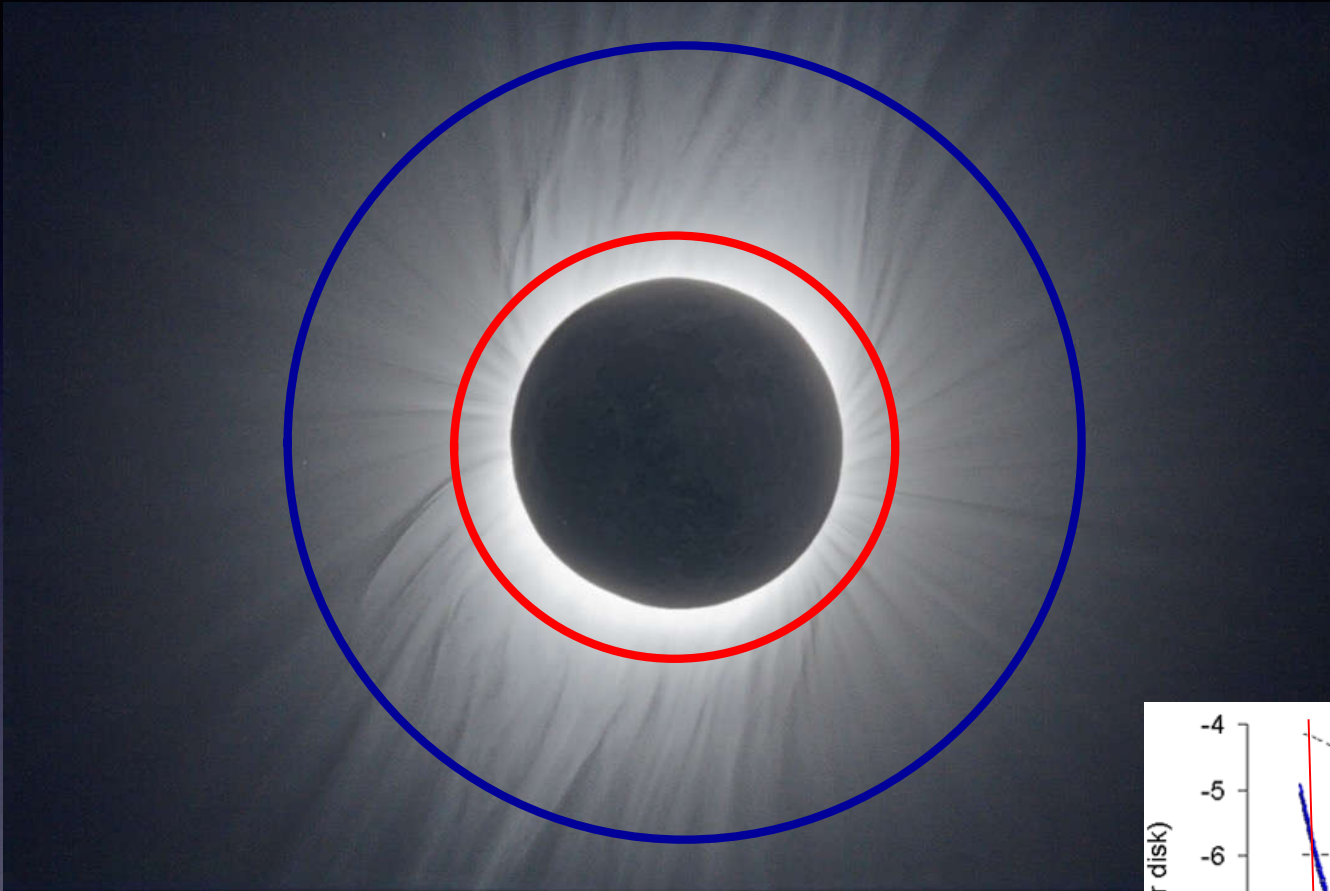


日冕分层

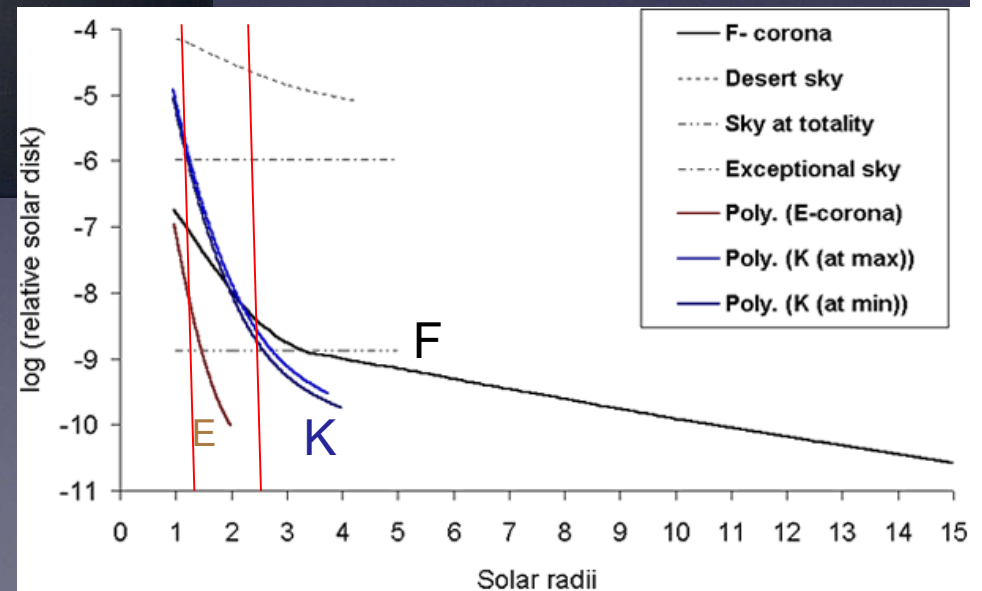
- ▶ **K冕**：在2.3太阳半径以内，由自由电子散射光球的连续光谱。
- ▶ **F冕**：在2.3太阳半径以外，起源于黄道面内行星际尘埃粒子散射光球的光，它的光谱中有夫琅和费线，F冕又称为“内黄道光”。
- ▶ **E冕**：又称L冕，是日冕气体离子发射线的光。



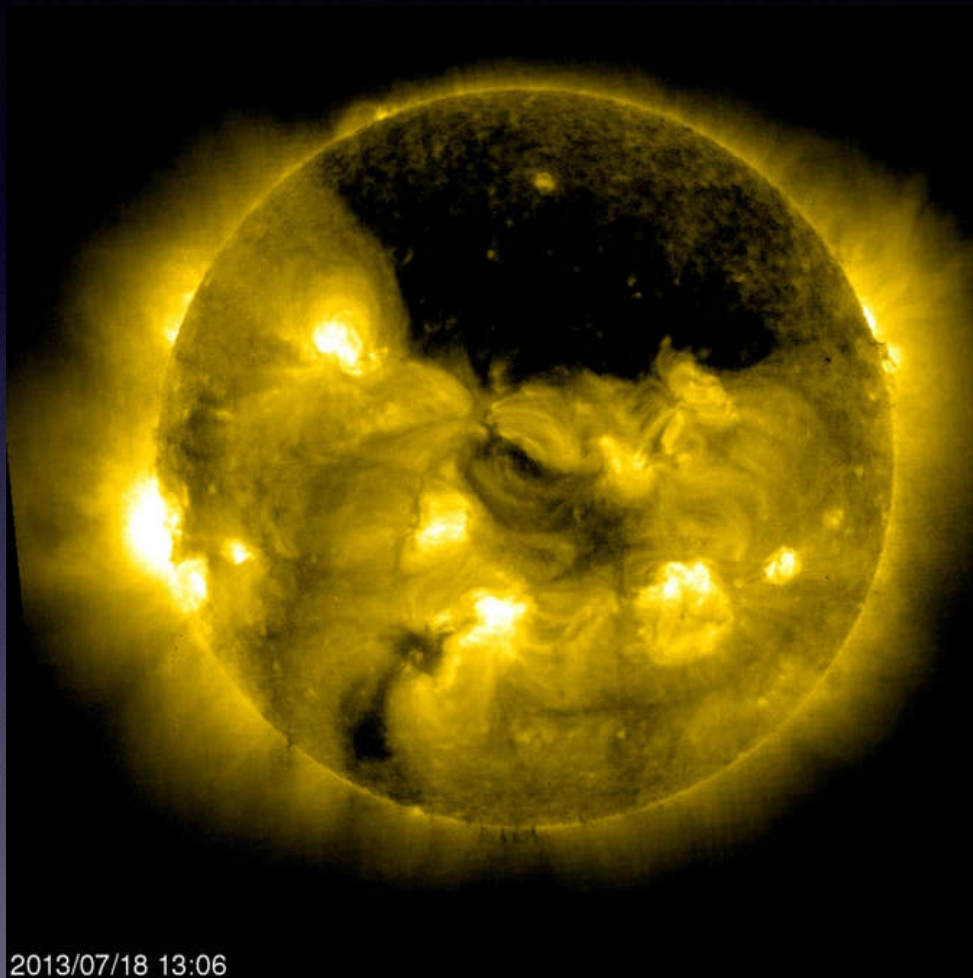
日冕分层



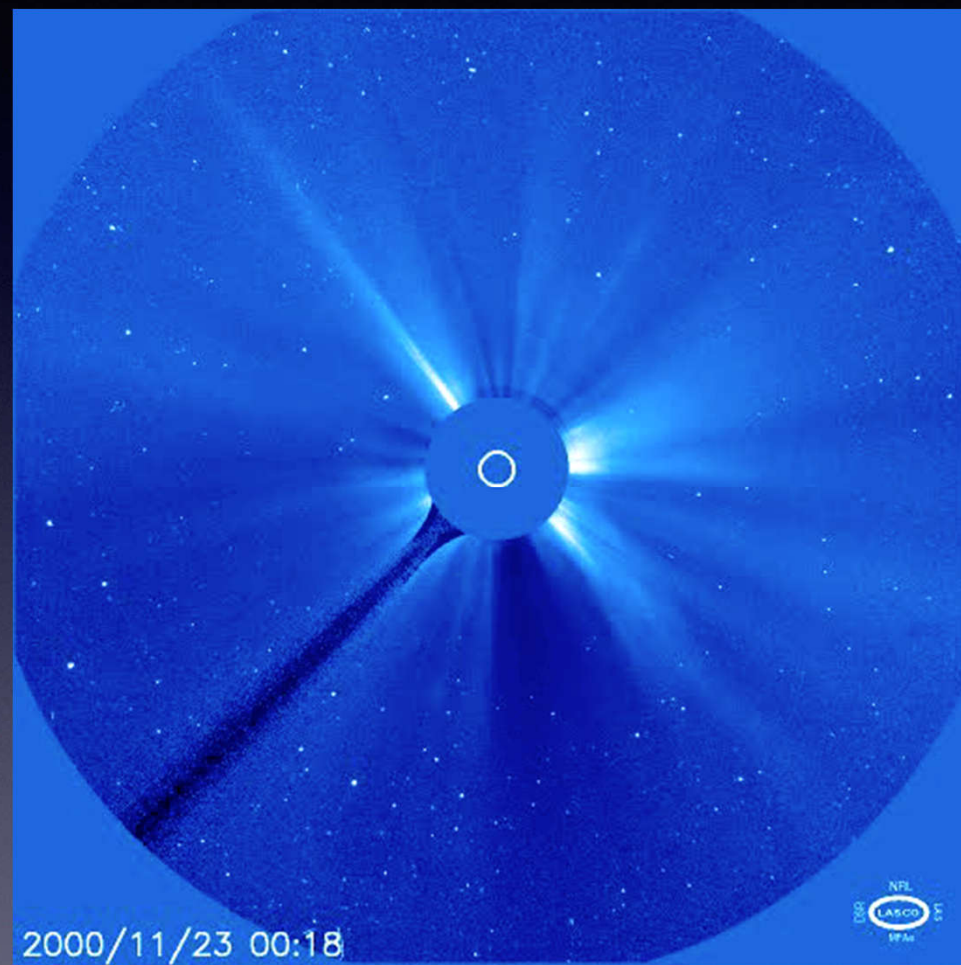
- ★ 内冕: $1-1.3R_s$
- ★ 中冕: $1.3-2.3R_s$
- ★ 外冕: $>2.3R_s$



日冕中的活动现象



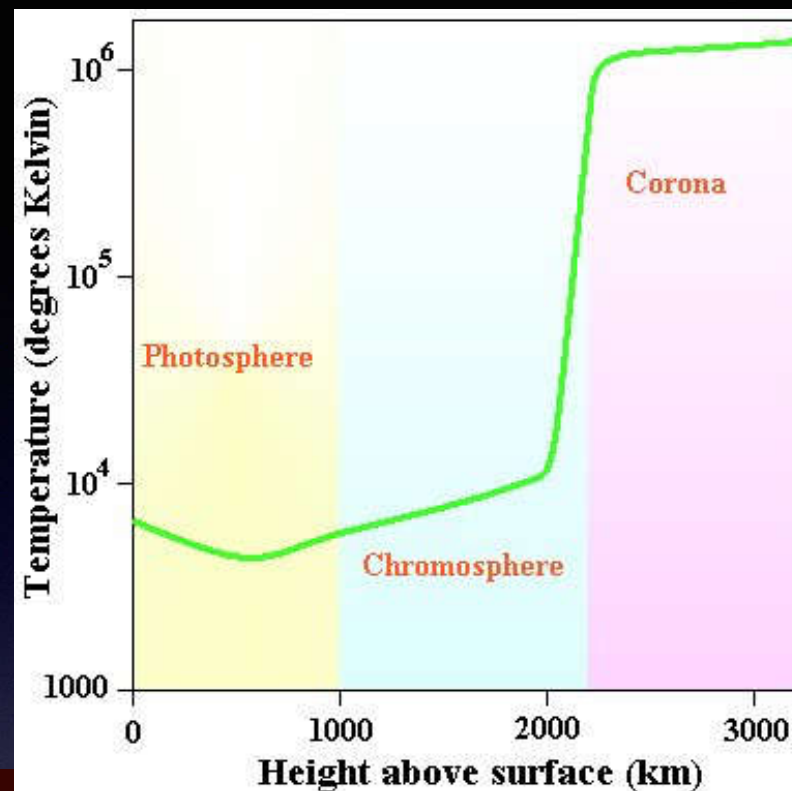
冕洞



日冕物质抛射

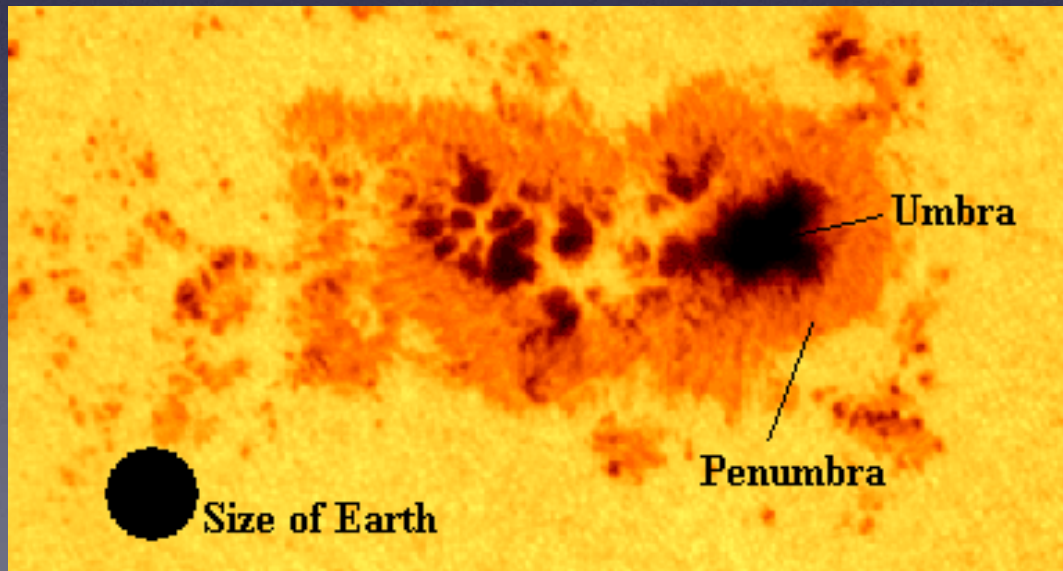
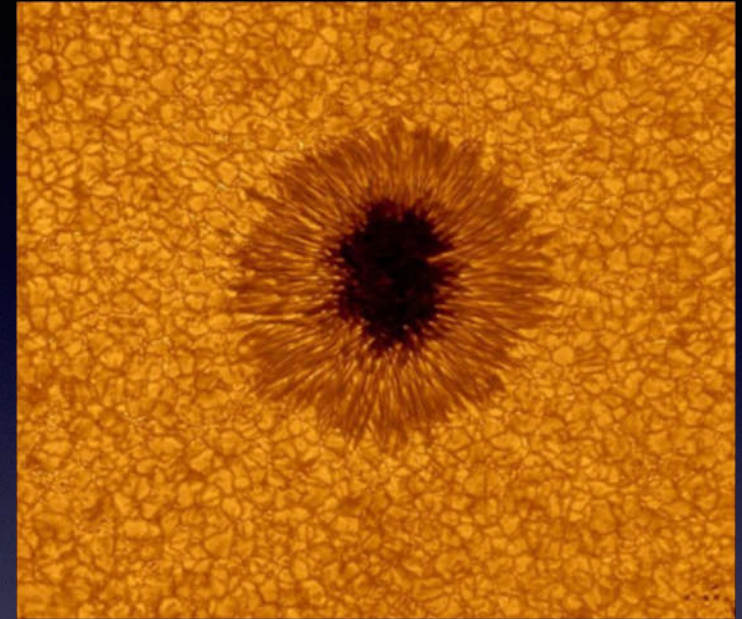
太阳大气特征

- ★温度越来越高
- ★厚度越来越大
- ★亮度越来越低



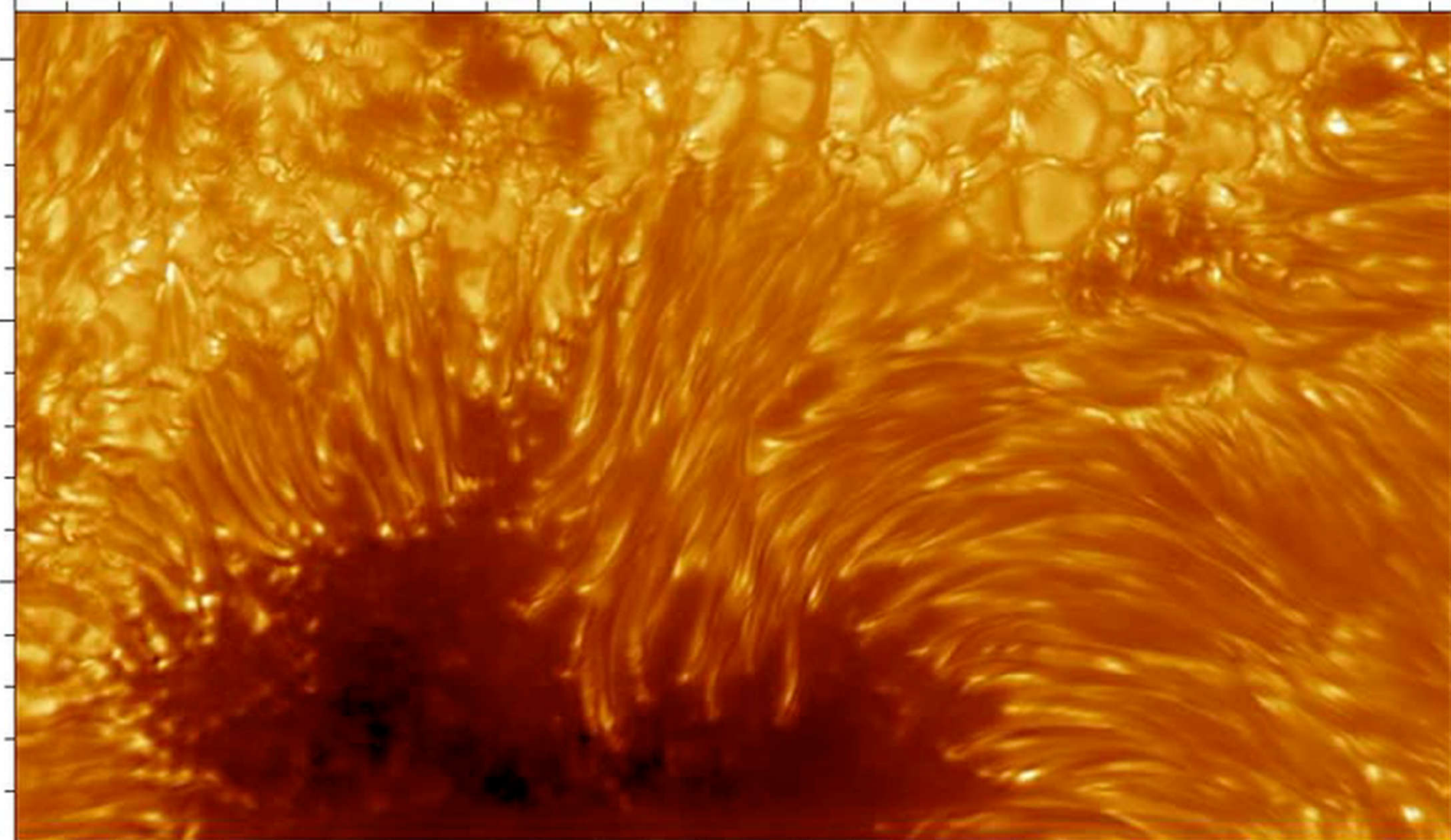
典型的太阳现象：太阳黑子

太阳黑子：太阳表面上的黑色斑点，有瞬变的、集中的磁场。是光球层中较冷的区域。



G-Band, 15 July 2002, Swedish 1-m solar telescope

00:00:00



distance in units of 1000 kilometers

黑子数

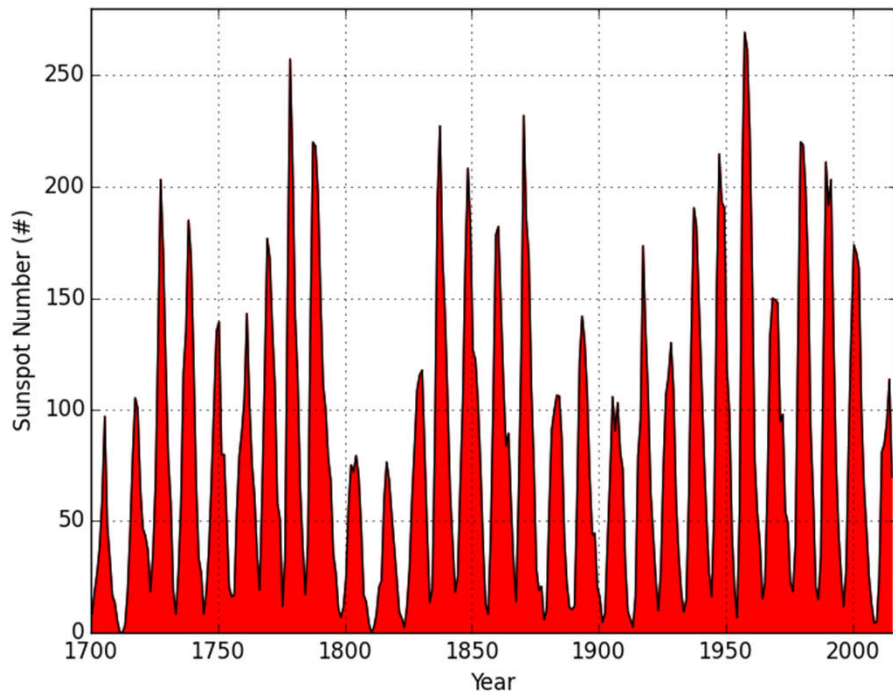
太阳黑子相对数：

$$R=k (10g+f)$$

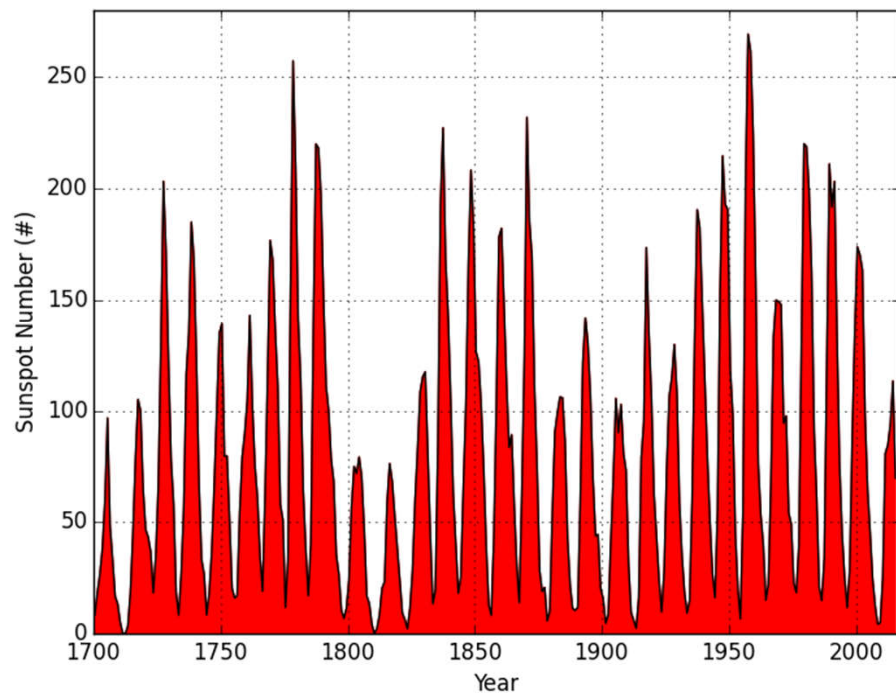
g: 太阳黑子群数

f: 可见日面上太阳黑子的总数

k: 换算系数

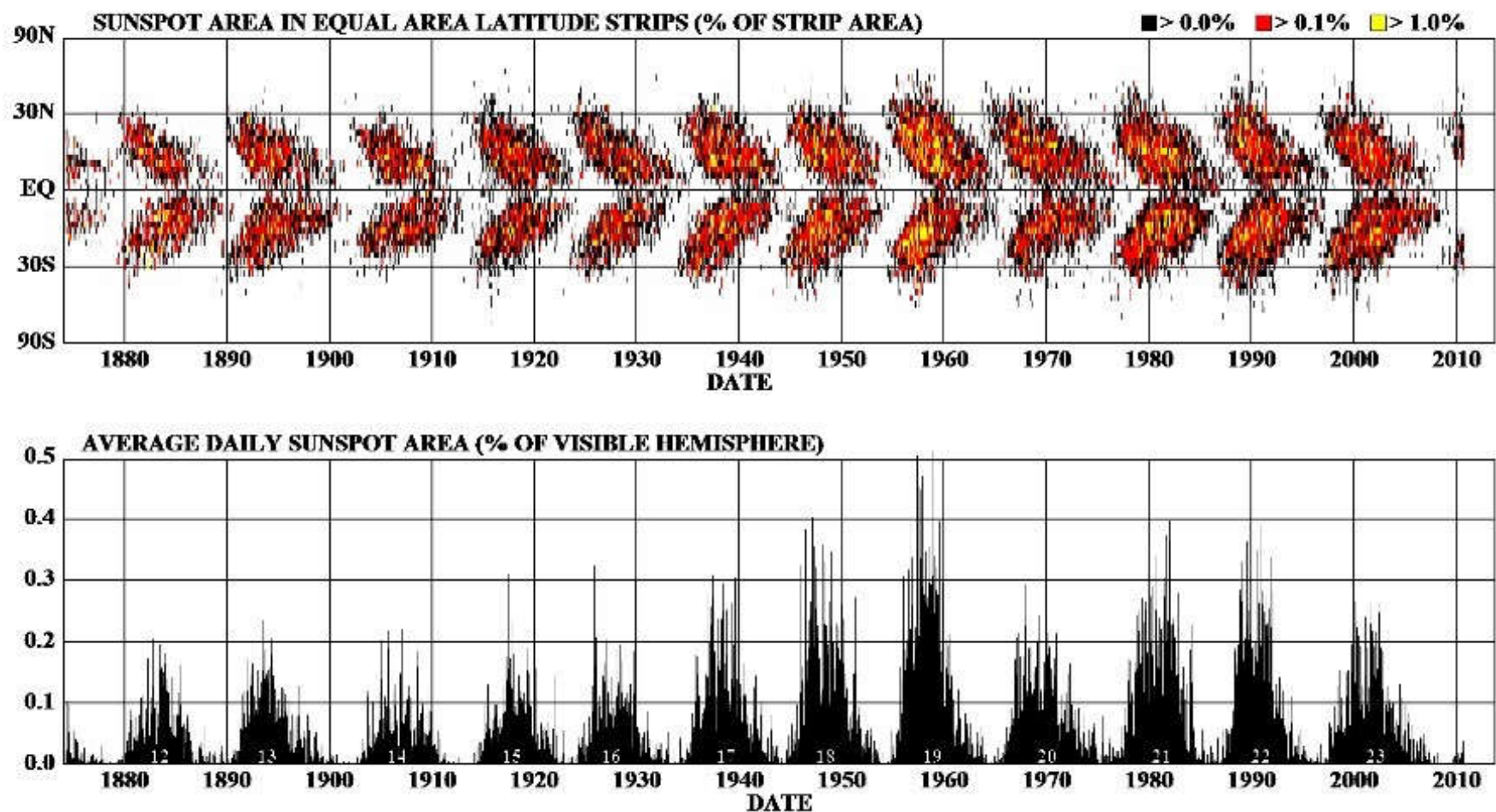


黑子的周期性

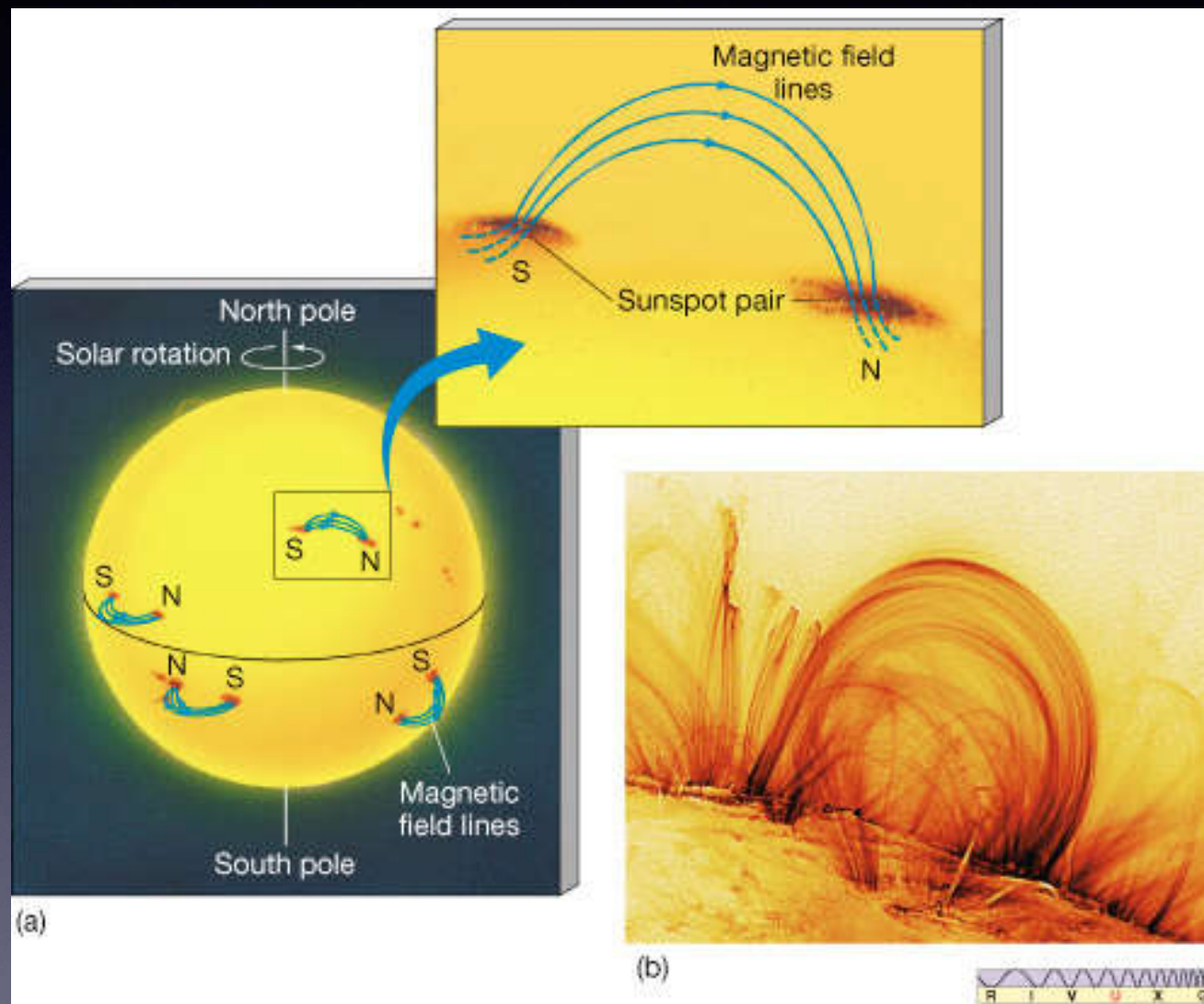


- 平均具有11年的周期变化
(最长13.6年, 最短为9年)
- 黑子数最少的1755年开始至1766年为第1个太阳活动周

太阳黑子位置和面积随时间变化图

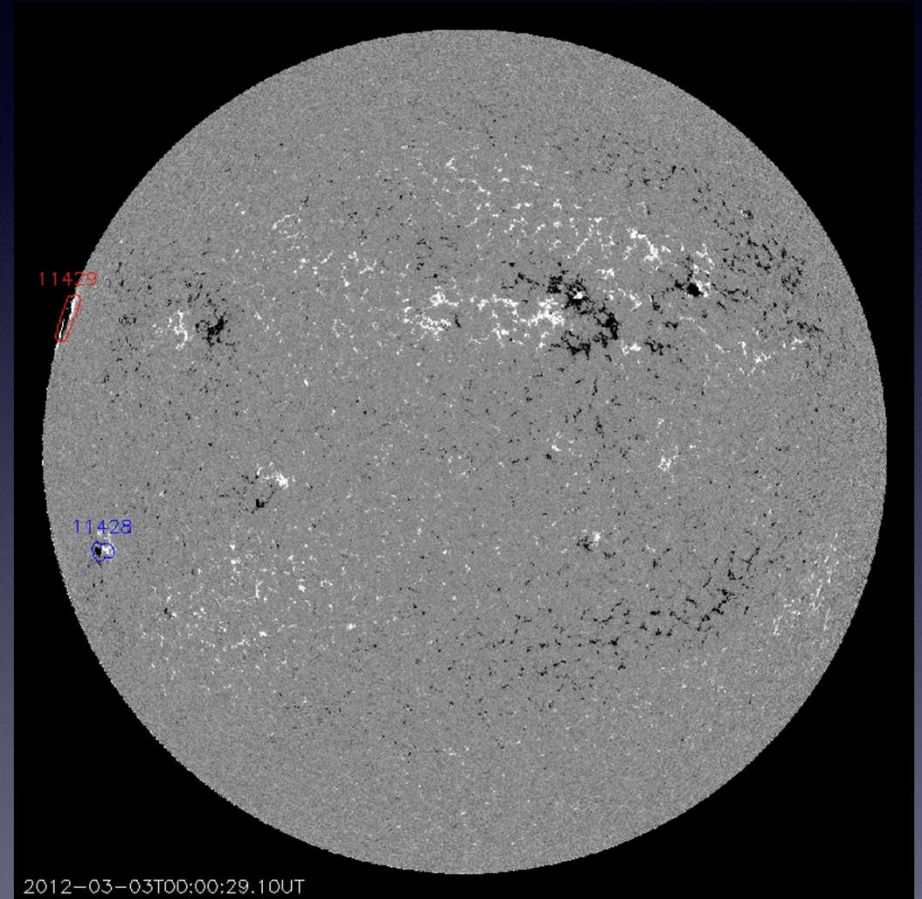


黑子的磁场

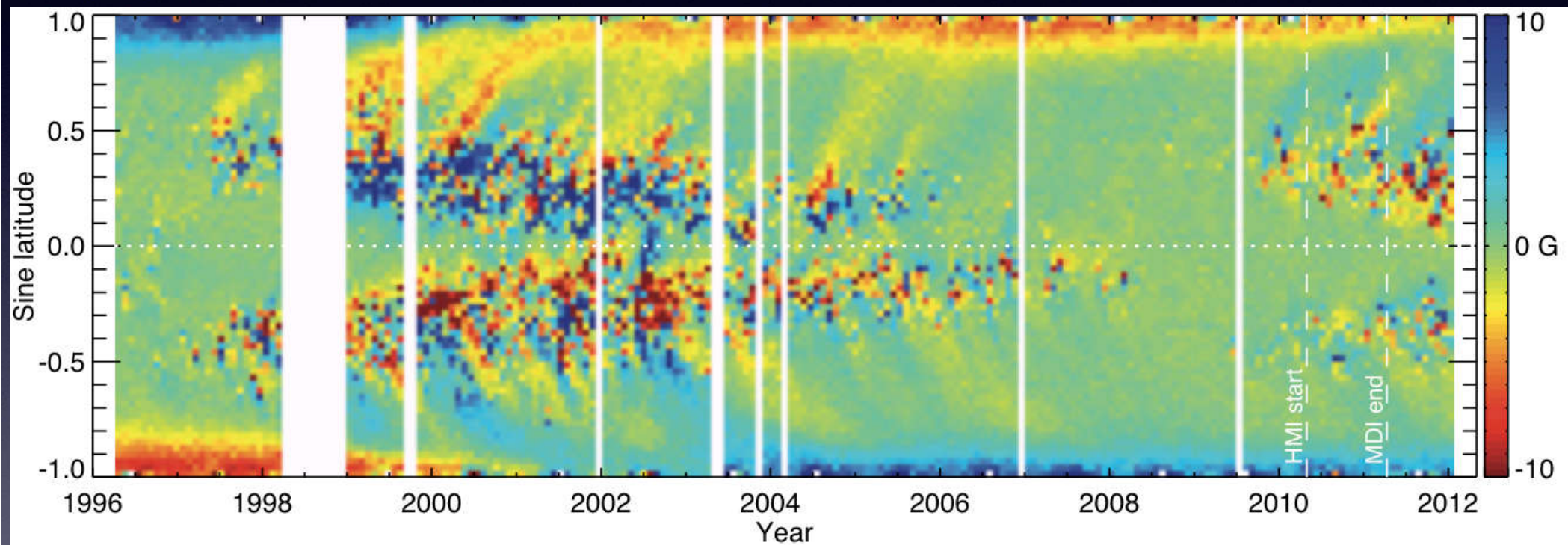


典型的太阳现象：太阳活动区

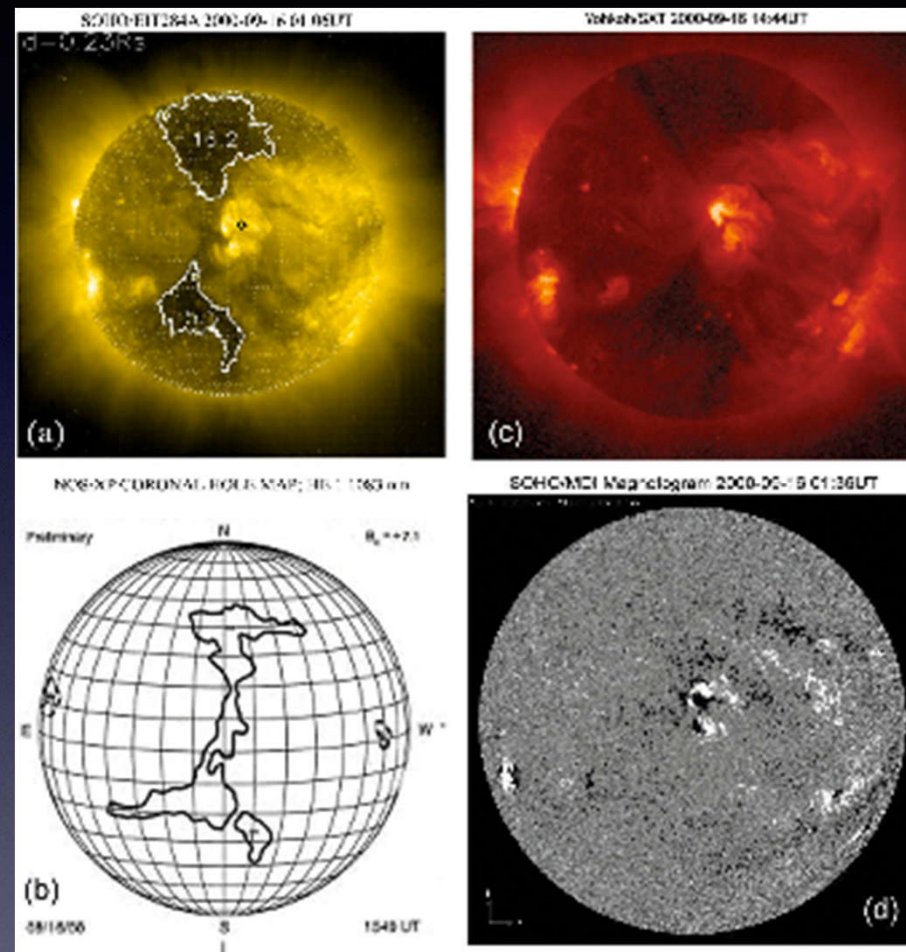
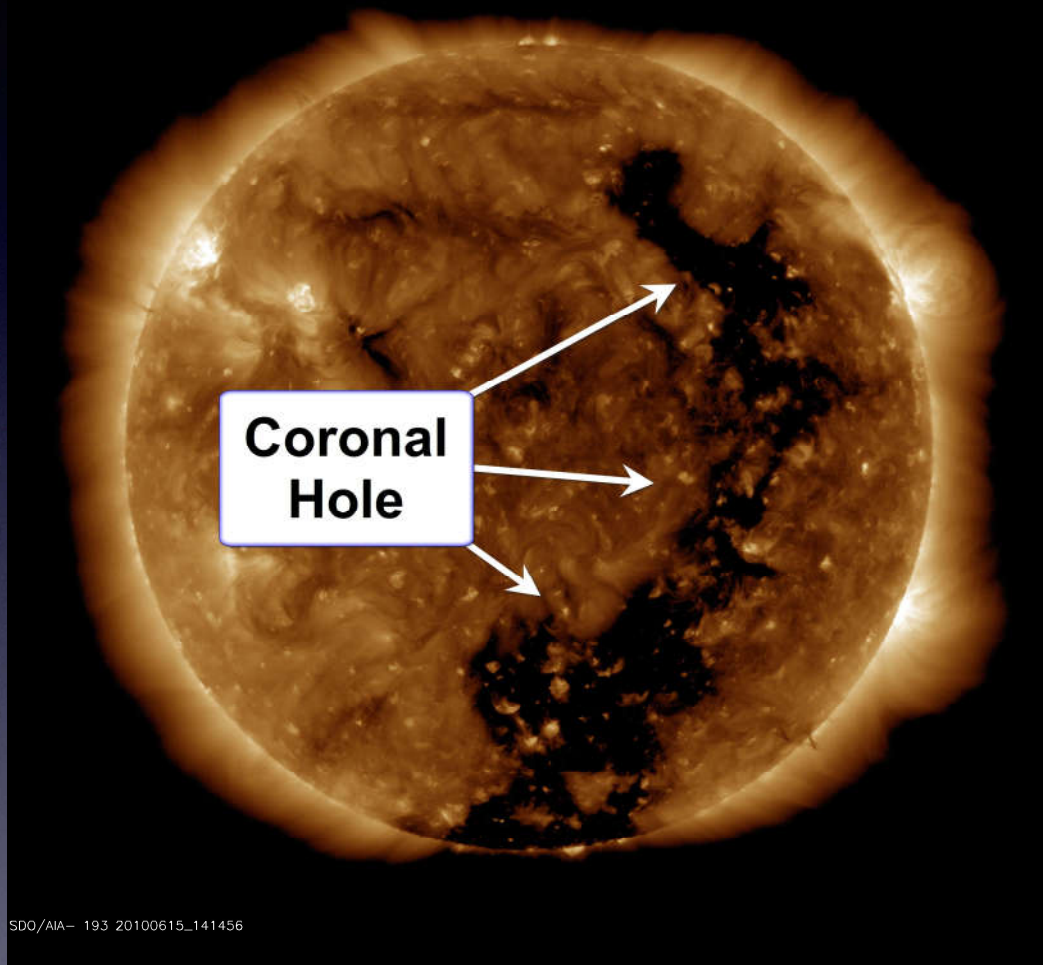
- ☑ 日面上以黑子群为主要标志，以及由黑子群周围光斑、谱斑、暗条等所组成的局部区域。
- ☑ 太阳剧烈爆发活动（耀斑、日冕物质抛射等）主要产生的区域。



活动区位置随时间的变化



典型的太阳现象：冕洞



低温（0.5日冕温度）、低密度(0.2日冕密度)

冕洞辐射谱段

4500Å



335Å



304Å



211Å



195Å



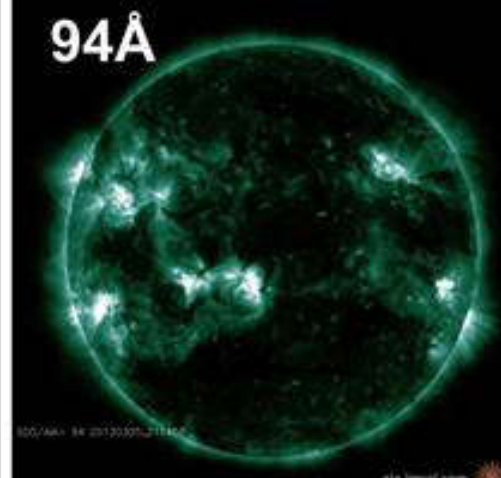
171Å



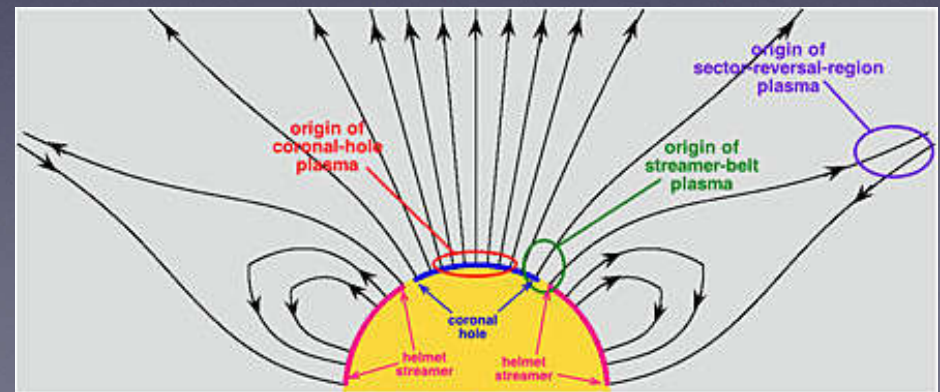
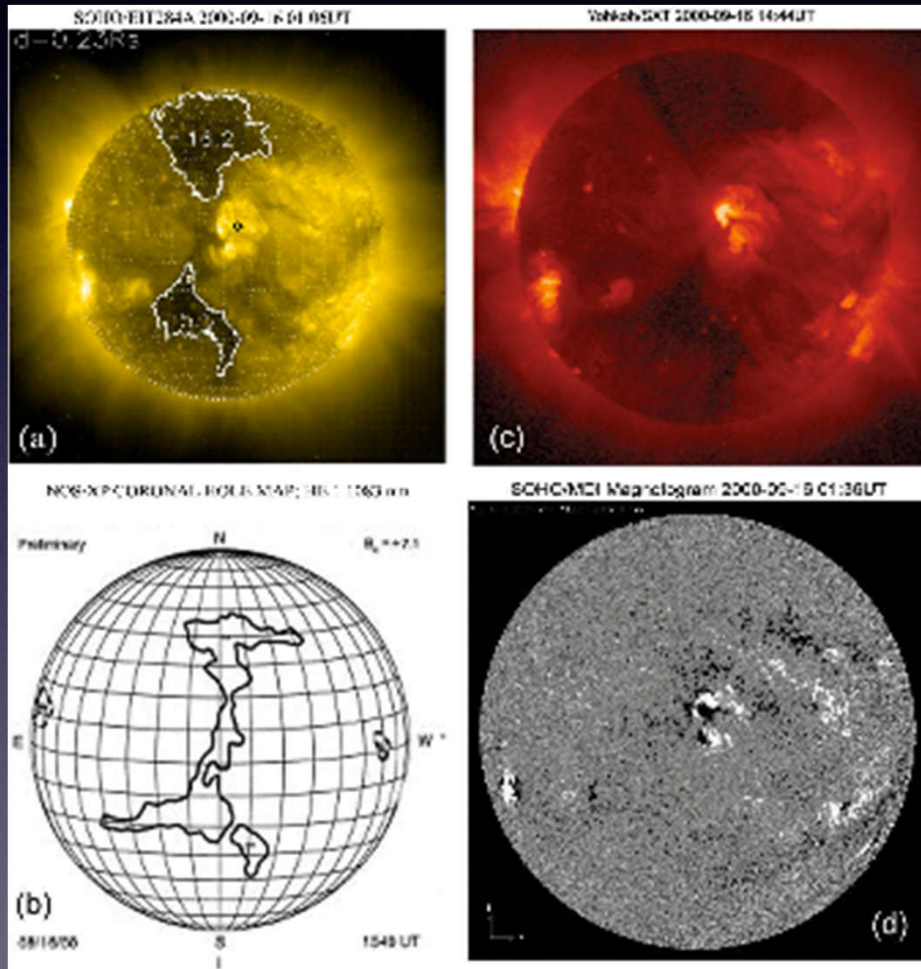
131Å



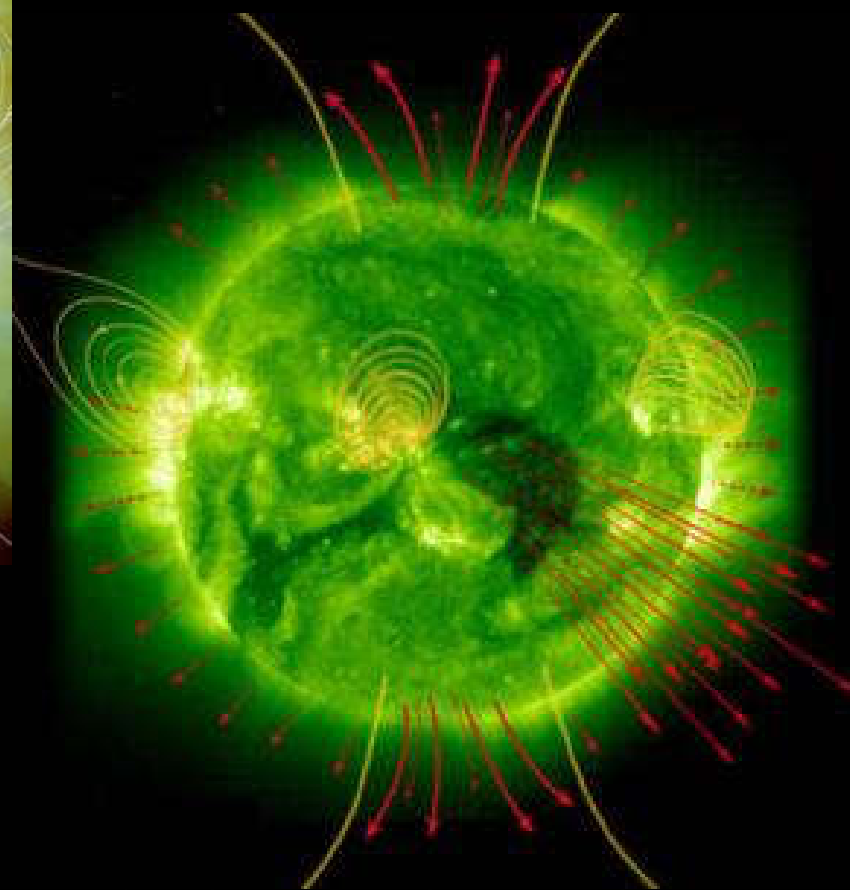
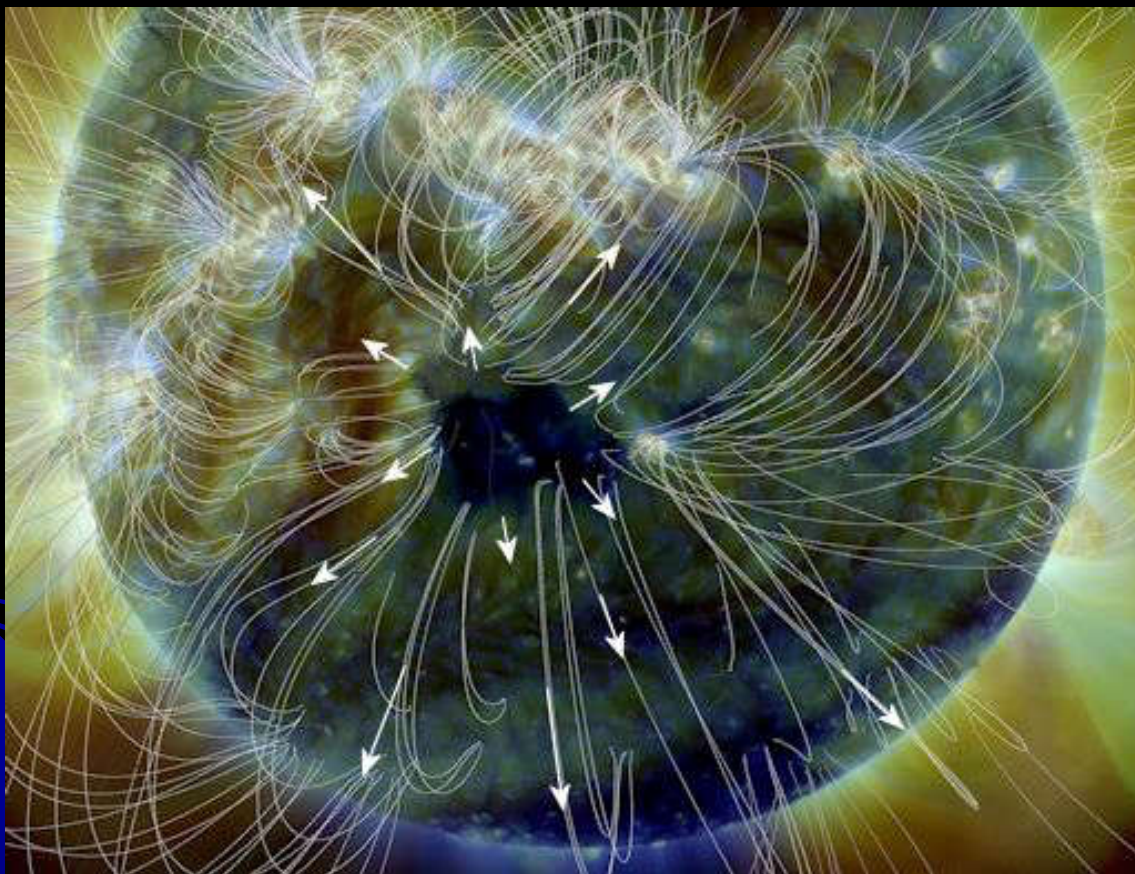
94Å



冕洞的结构



冕洞的磁场：开放场



冕洞的寿命

1973/06/01

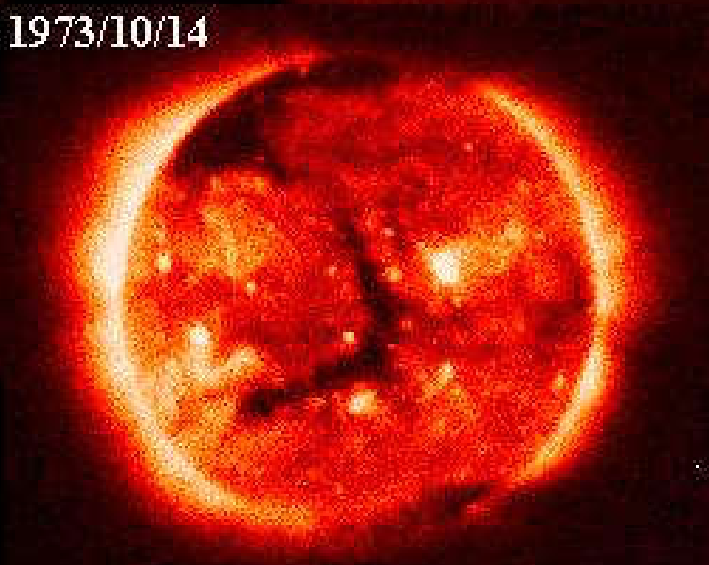
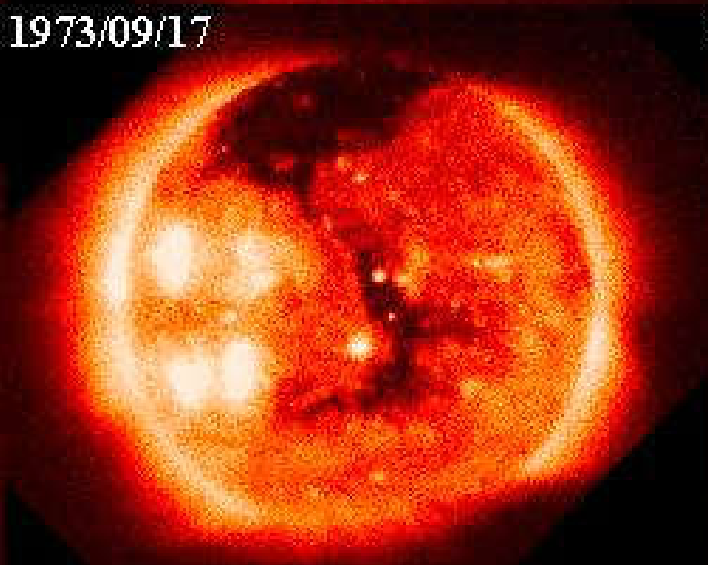
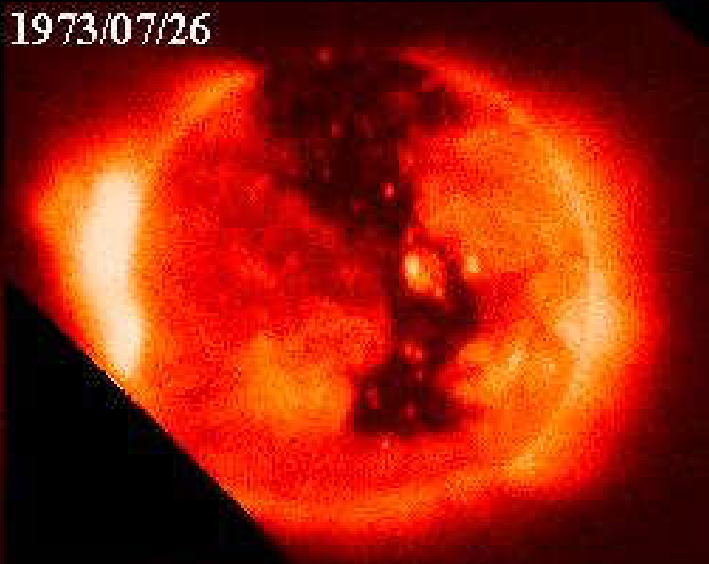
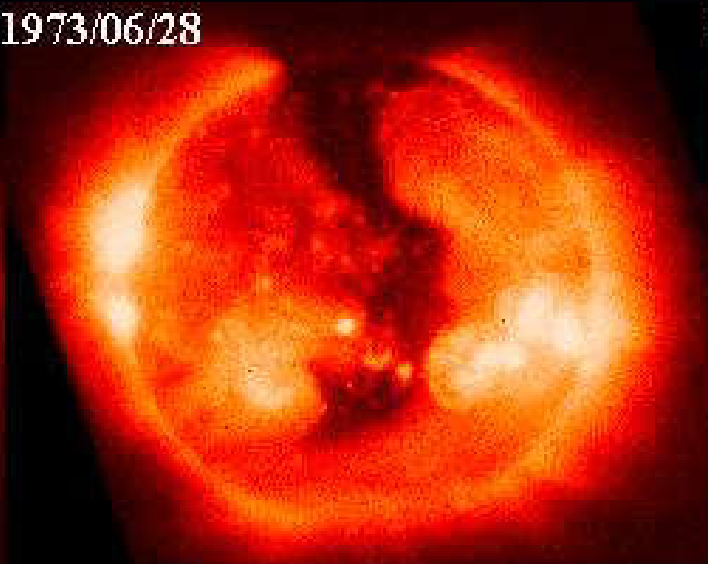
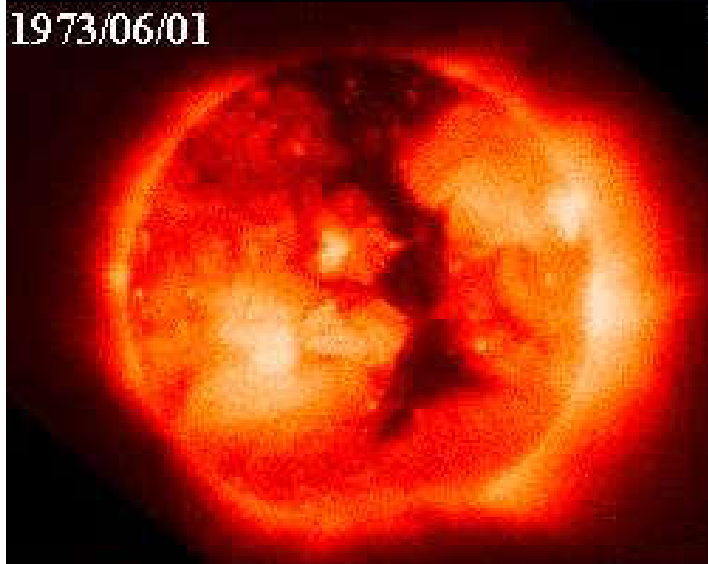
1973/06/28

1973/07/26

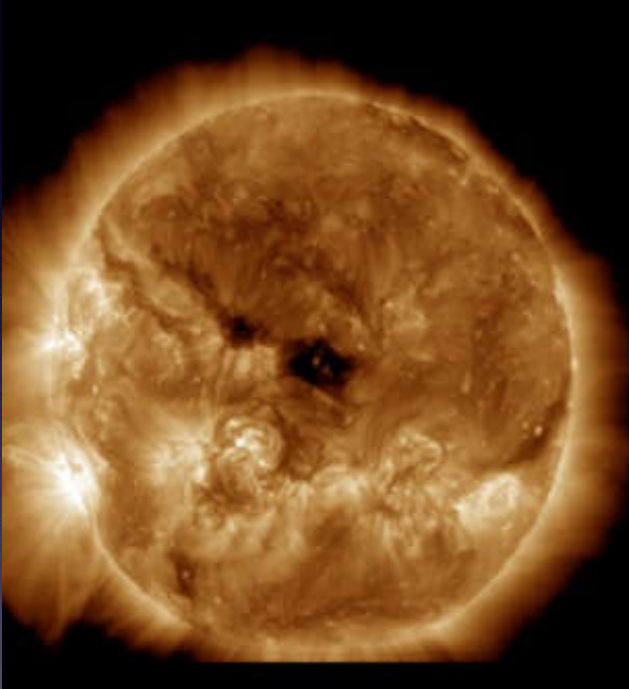
1973/08/21

1973/09/17

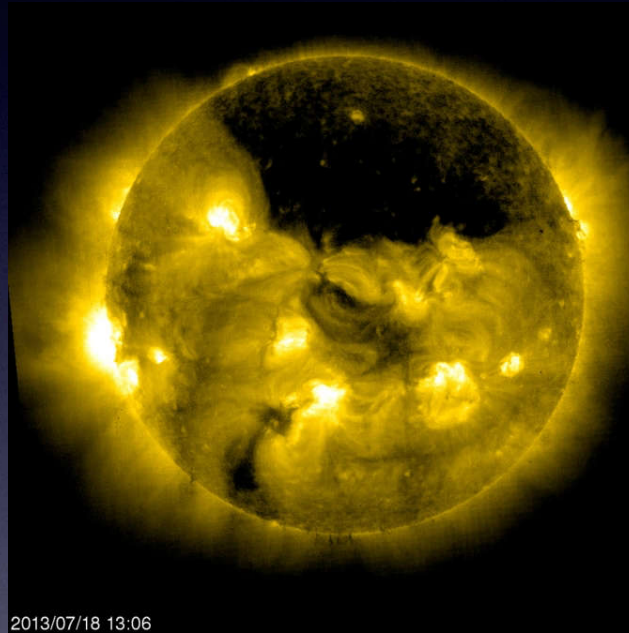
1973/10/14



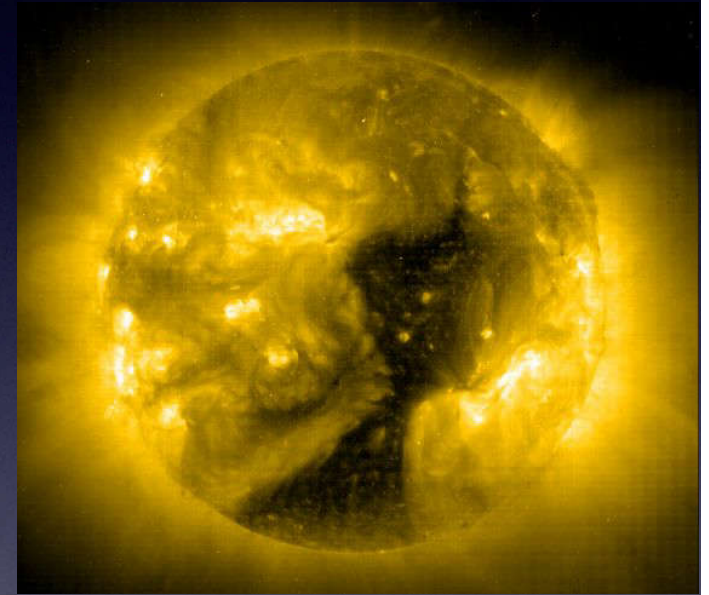
冕洞的分类（根据位置）



孤立冕洞



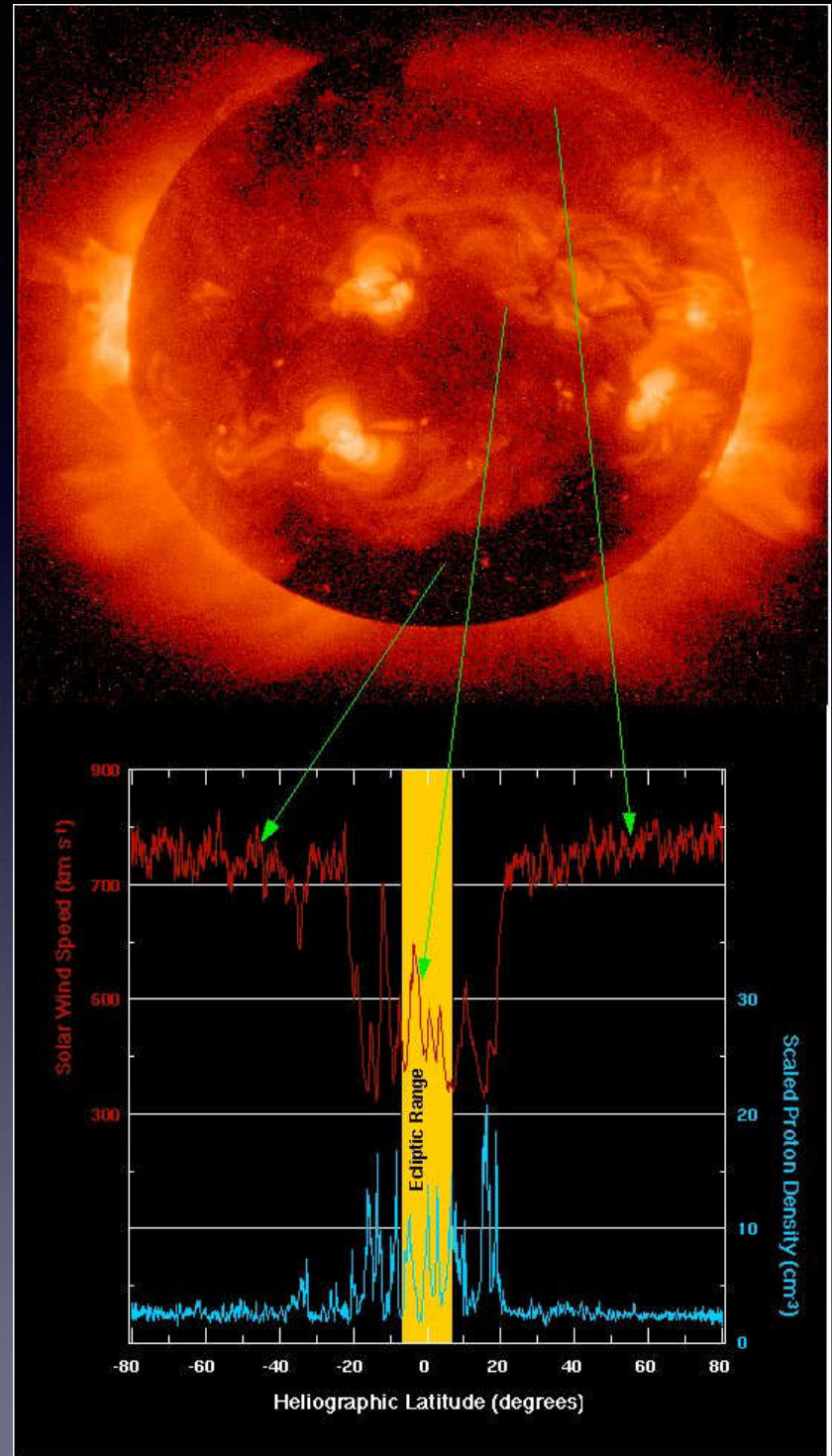
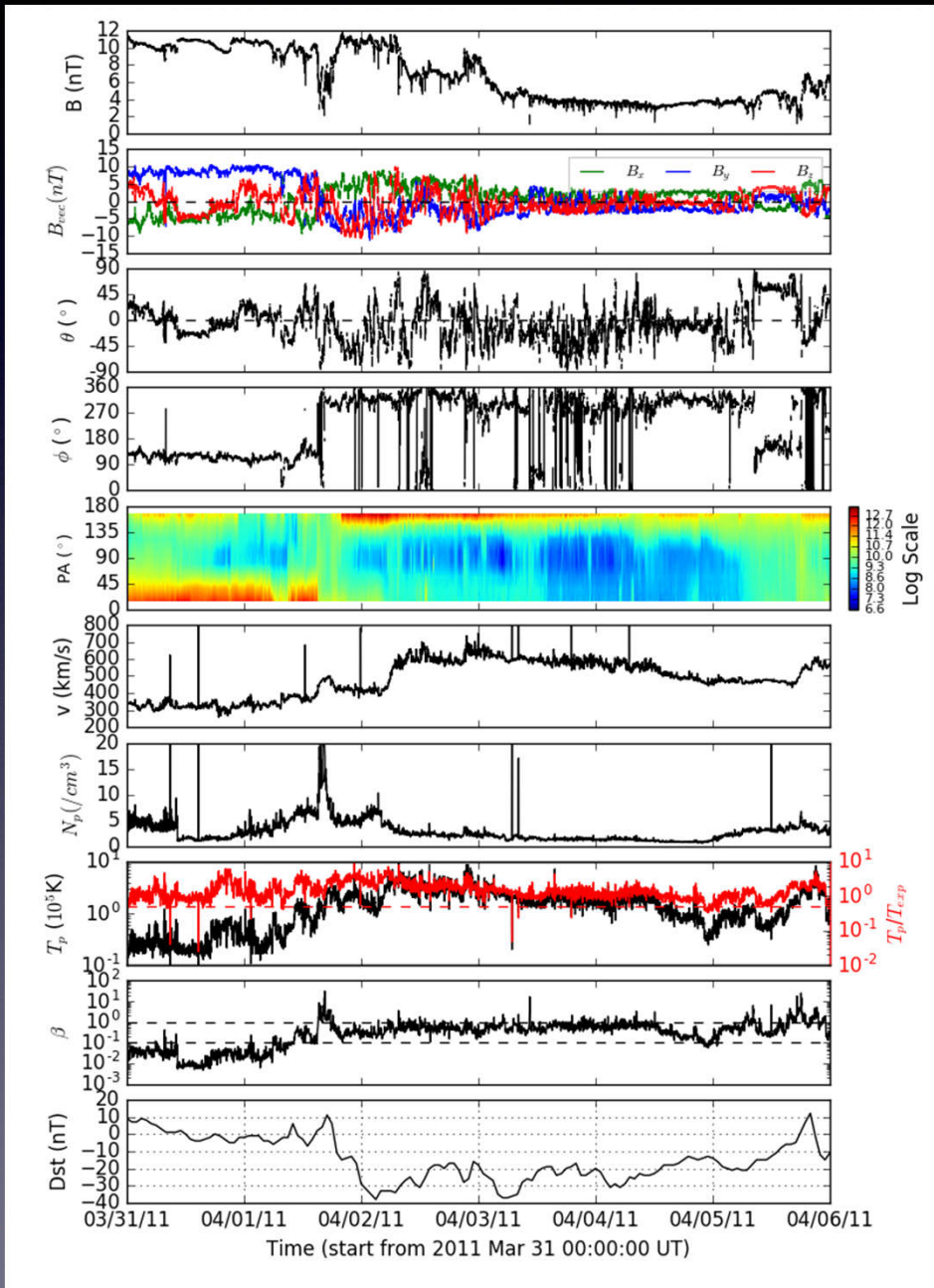
极区冕洞



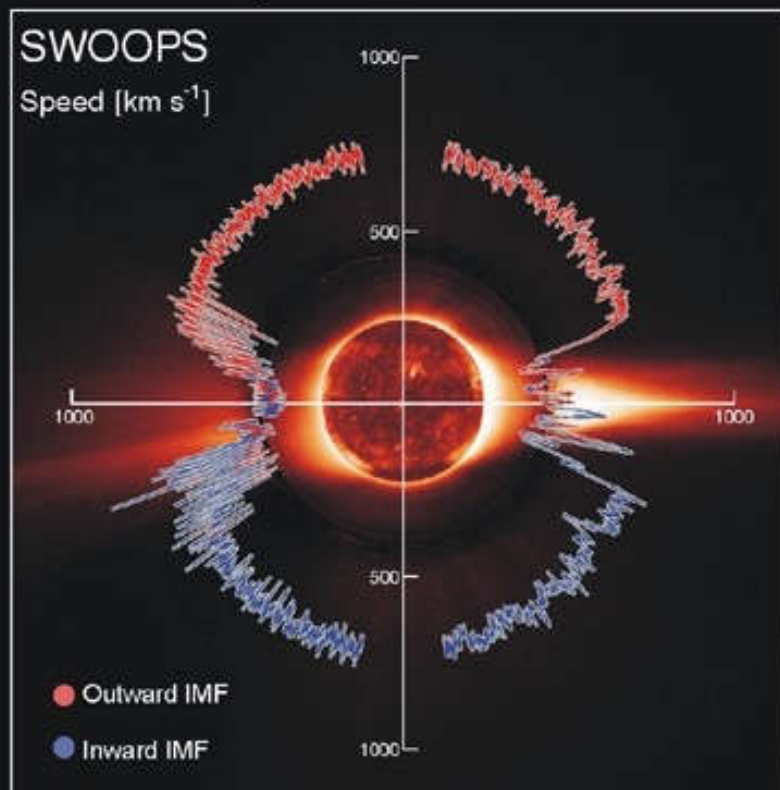
延伸冕洞

冕洞的总面积：可达全球的1/5，一般为5%左右

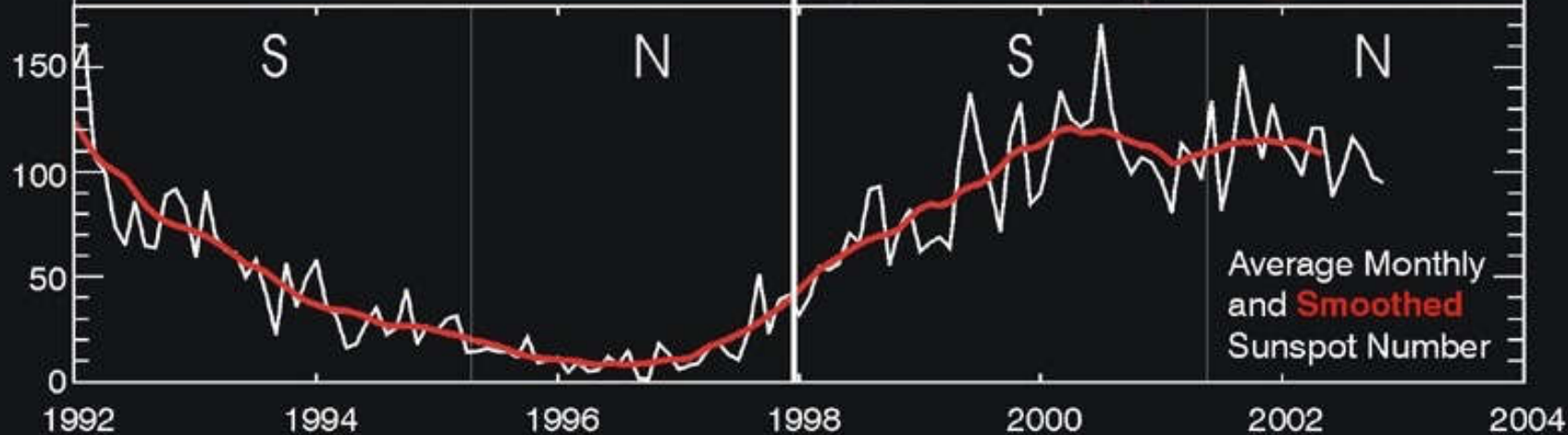
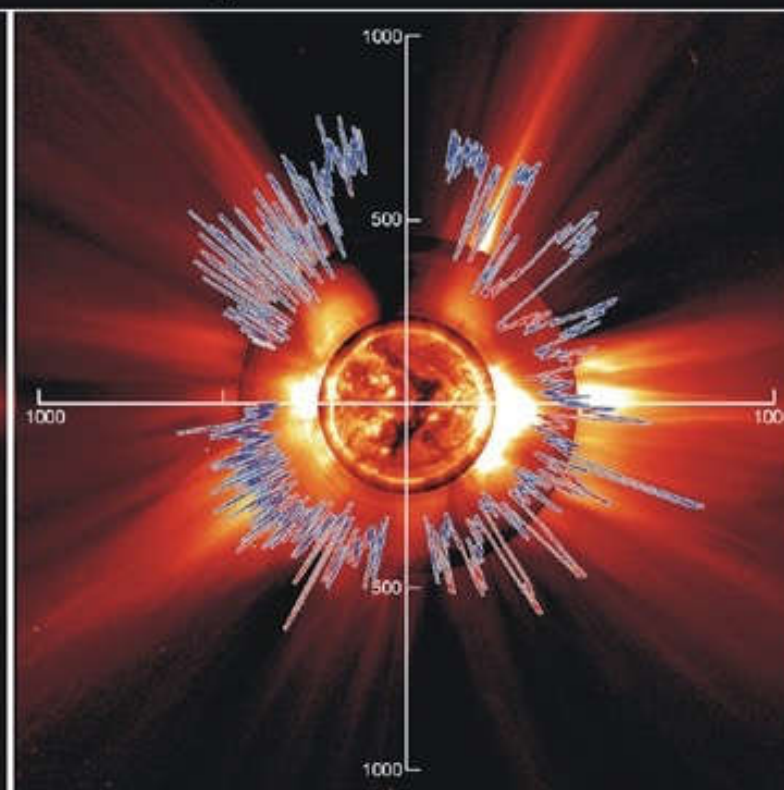
冕洞：高速太阳风的起源



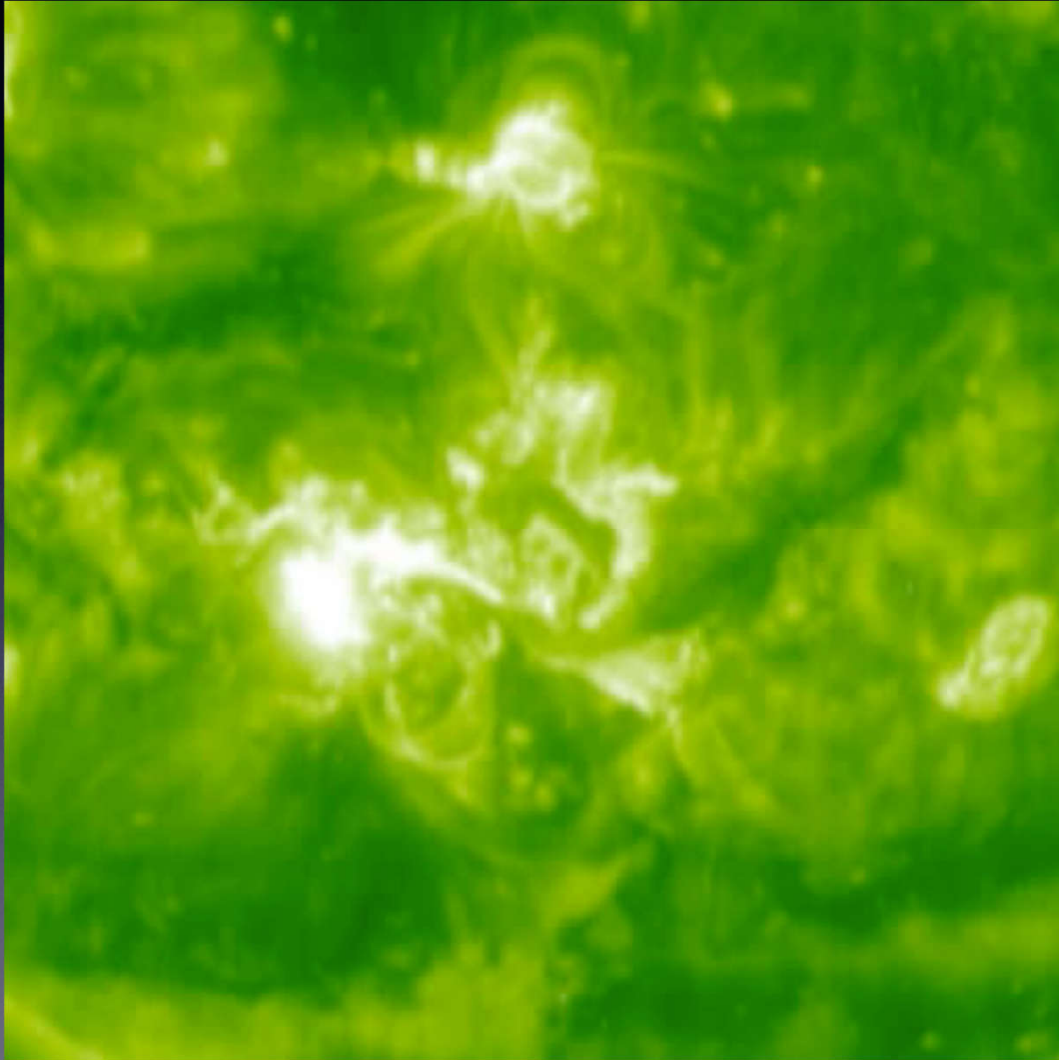
Ulysses First Orbit



Ulysses Second Orbit



典型的太阳现象：耀斑



耀斑： 太阳亮度突然、快速和强烈的变化。

耀斑能量： 10^{20}J - 10^{25}J

~几百万个亿吨级氢弹

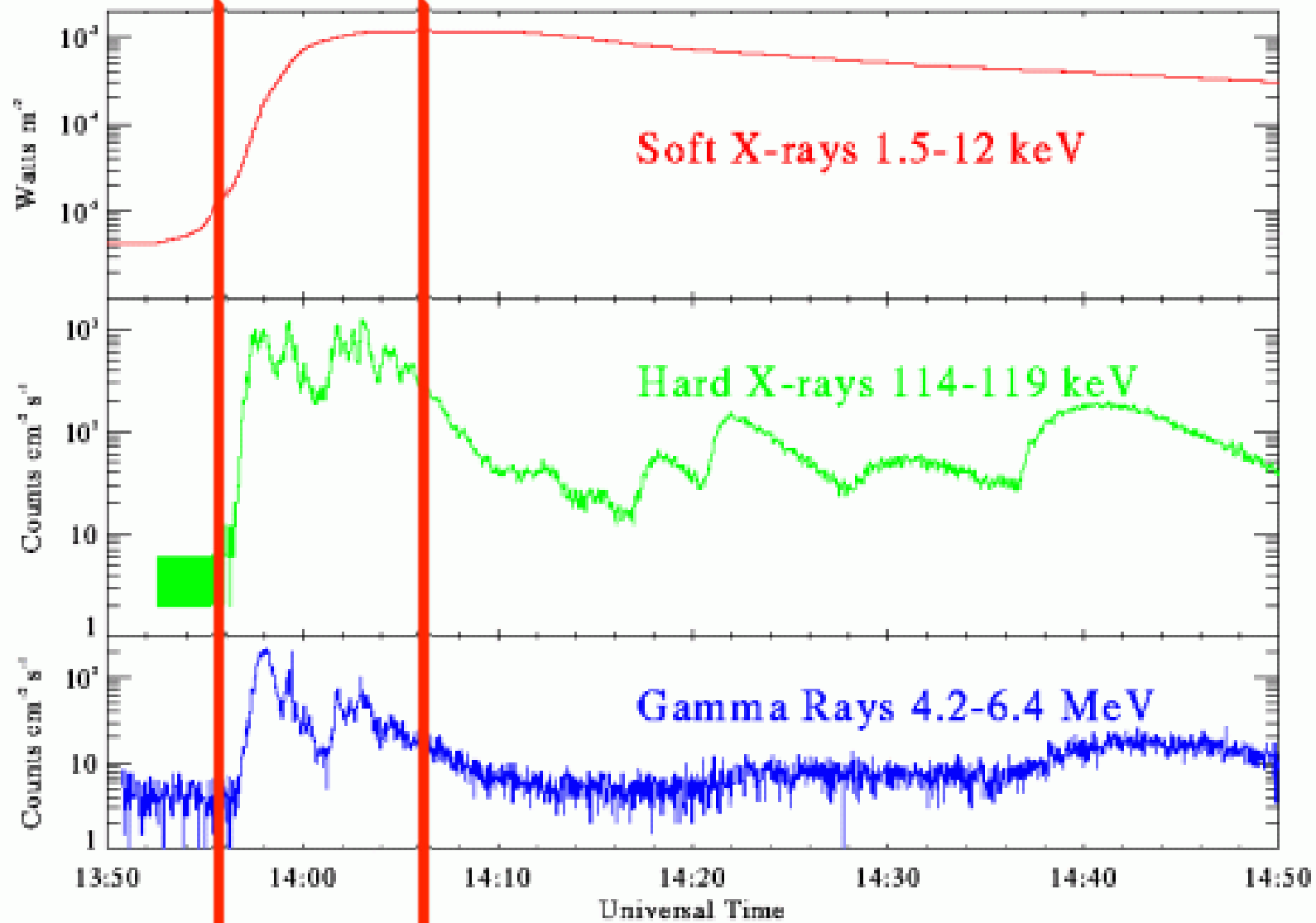
~ 10^7 倍地球火山的能量爆发

<太阳每秒发射总能量的1/10

电磁辐射： 电离层、热层扰动

加速粒子： 太阳高能粒子事件

Solar Flare on 6 March 1989



预脉冲相

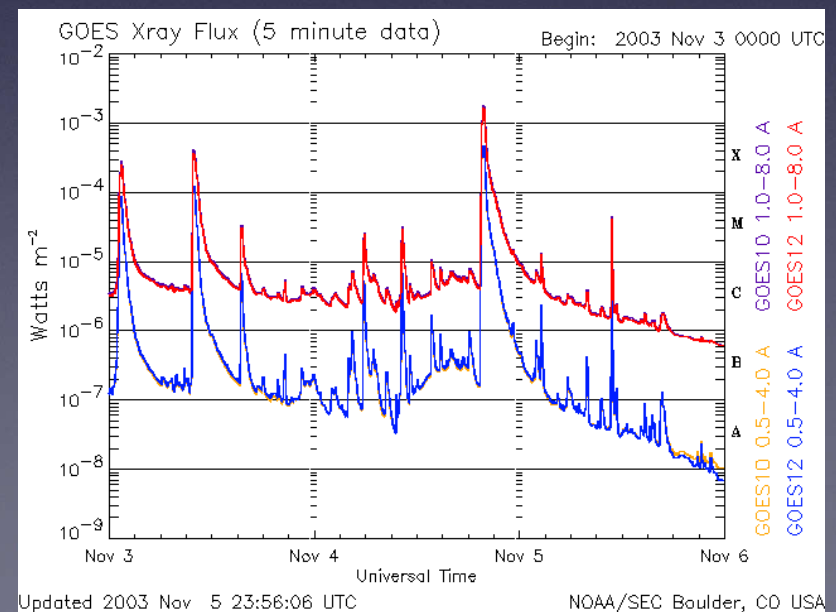
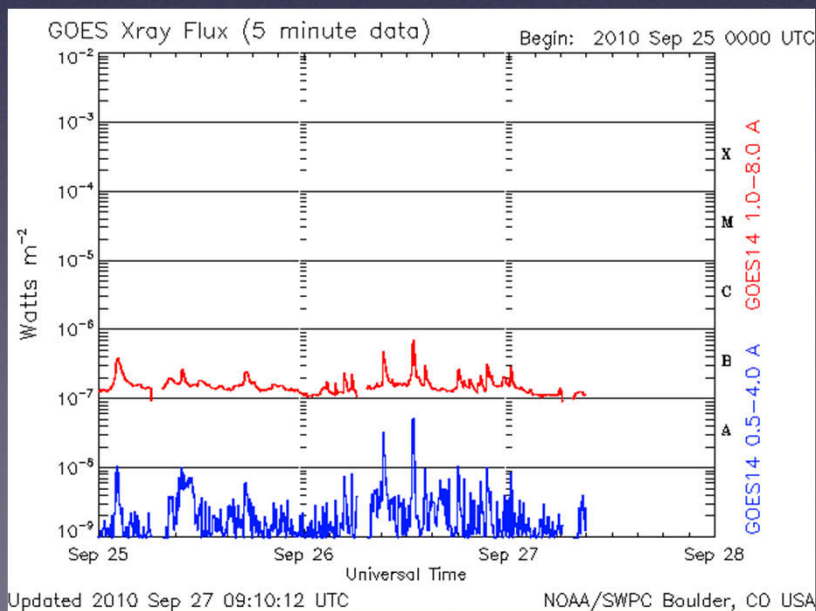
爆发相

渐变相 (主相)

耀斑分类：按耀斑强度分

	In mks system(Wm^{-2})	In cgs system($\text{erg cm}^{-2} \text{s}^{-1}$)
A	$x < 10^{-7}$	$x < 10^{-4}$
B	$10^{-7} \leq x < 10^{-6}$	$10^{-4} \leq x < 10^{-3}$
C	$10^{-6} \leq x < 10^{-5}$	$10^{-3} \leq x < 10^{-2}$
M	$10^{-5} \leq x < 10^{-4}$	$10^{-1} \leq x < 10^{-2}$
X	$10^{-4} \leq x$	$10^{-1} \leq x$

x = peak flux in the 0.1 to 0.8 nm range

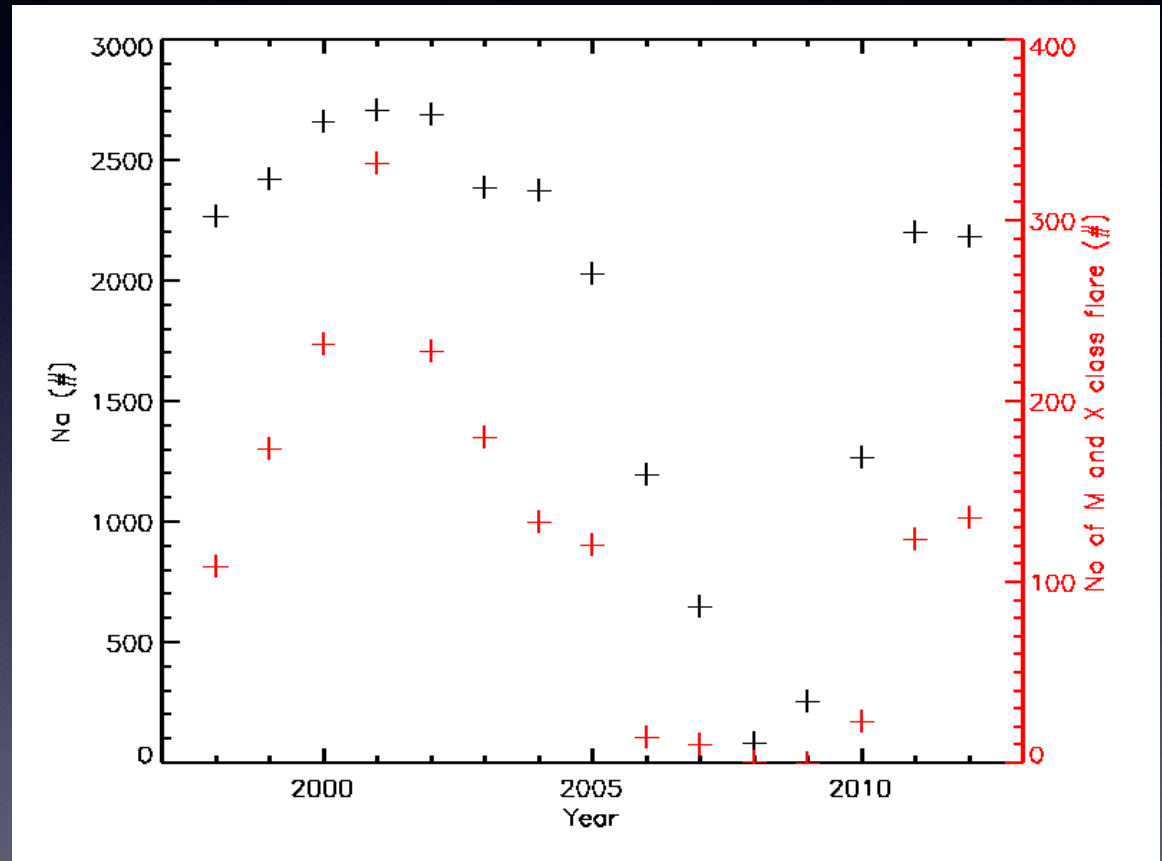


耀斑分类：按观测设备和手段分

光学耀斑：发射可见光增强辐射，并可用单色光观测到

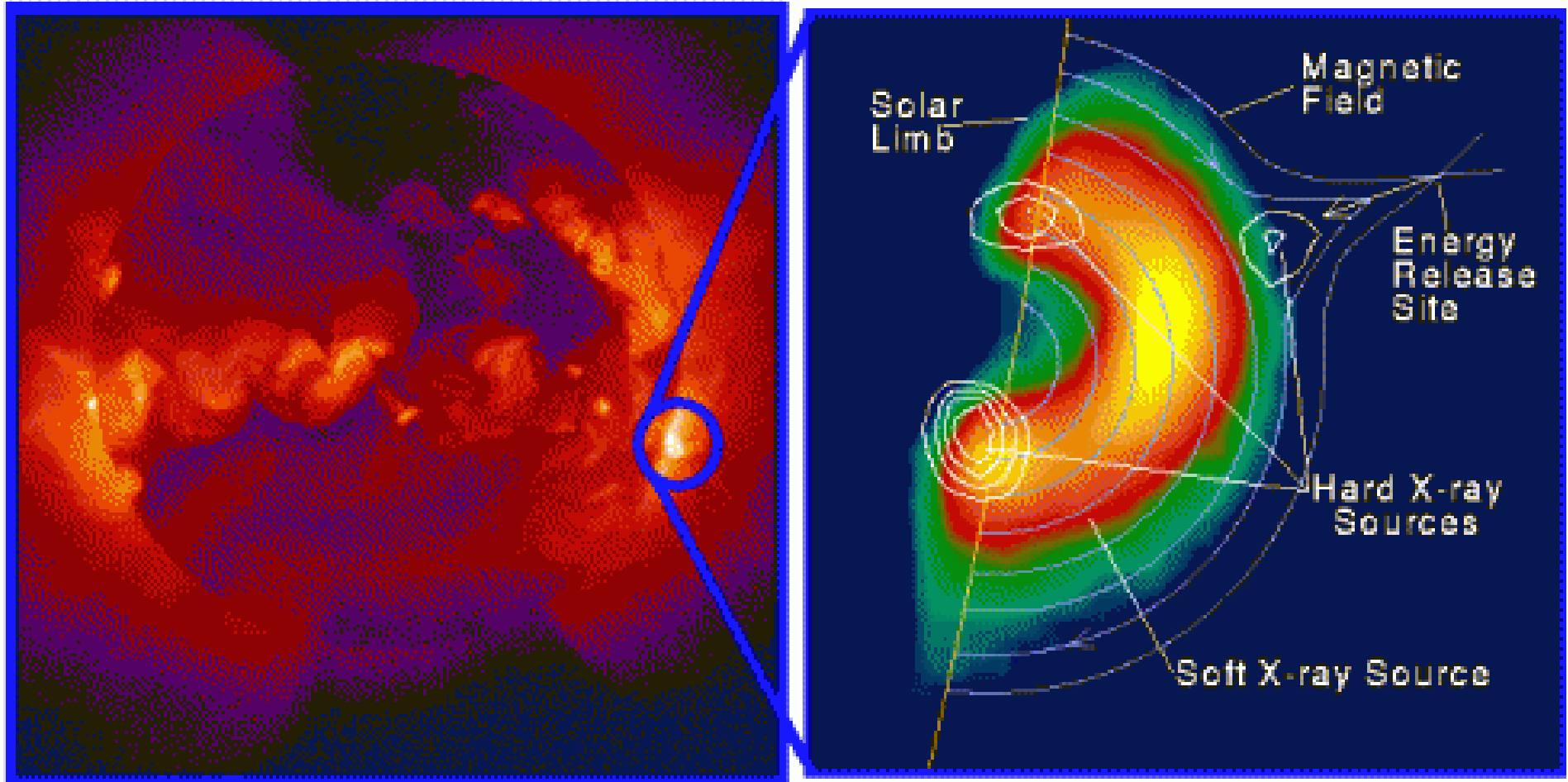
X光耀斑：用X光观测到的

白光耀斑：在白光照片上可以看到，这种耀斑极为罕见



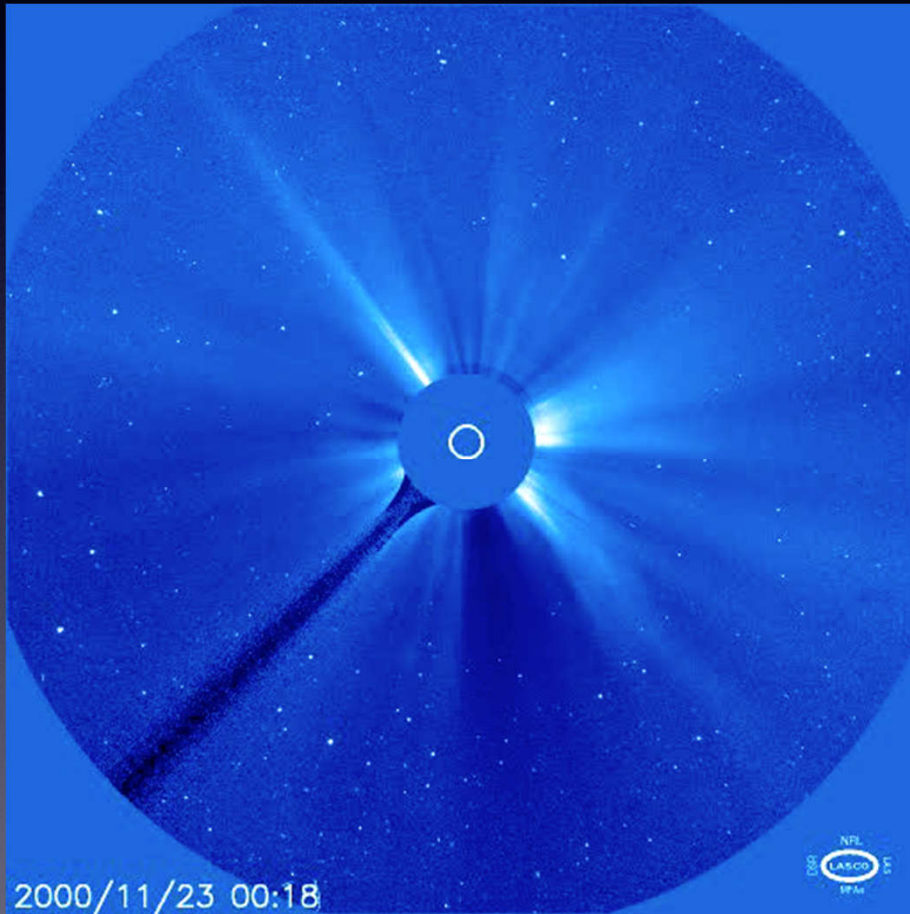
近一段时间年耀斑数变化图

太阳耀斑模型



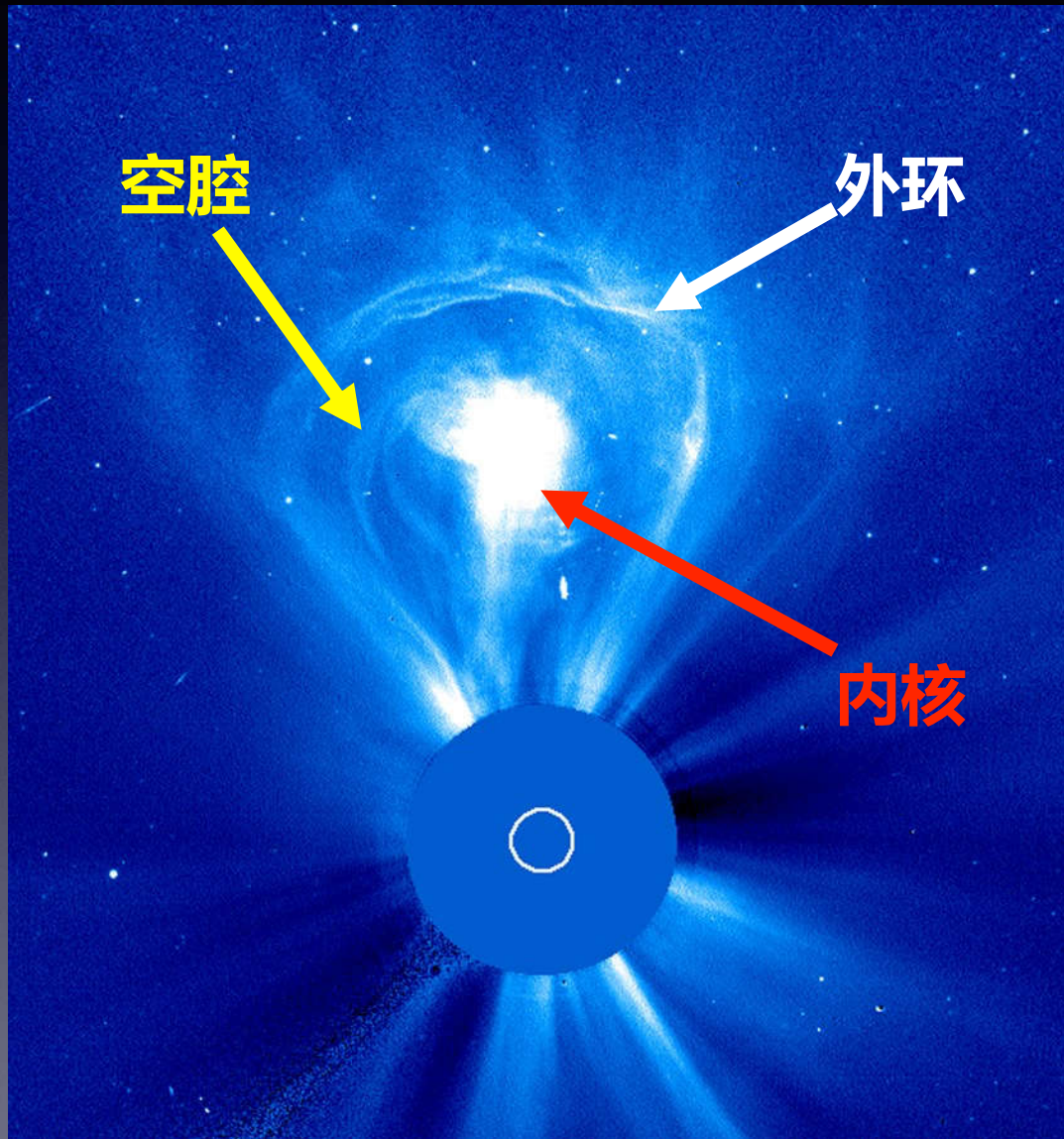
Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

典型的太阳爆发活动：日冕物质抛射



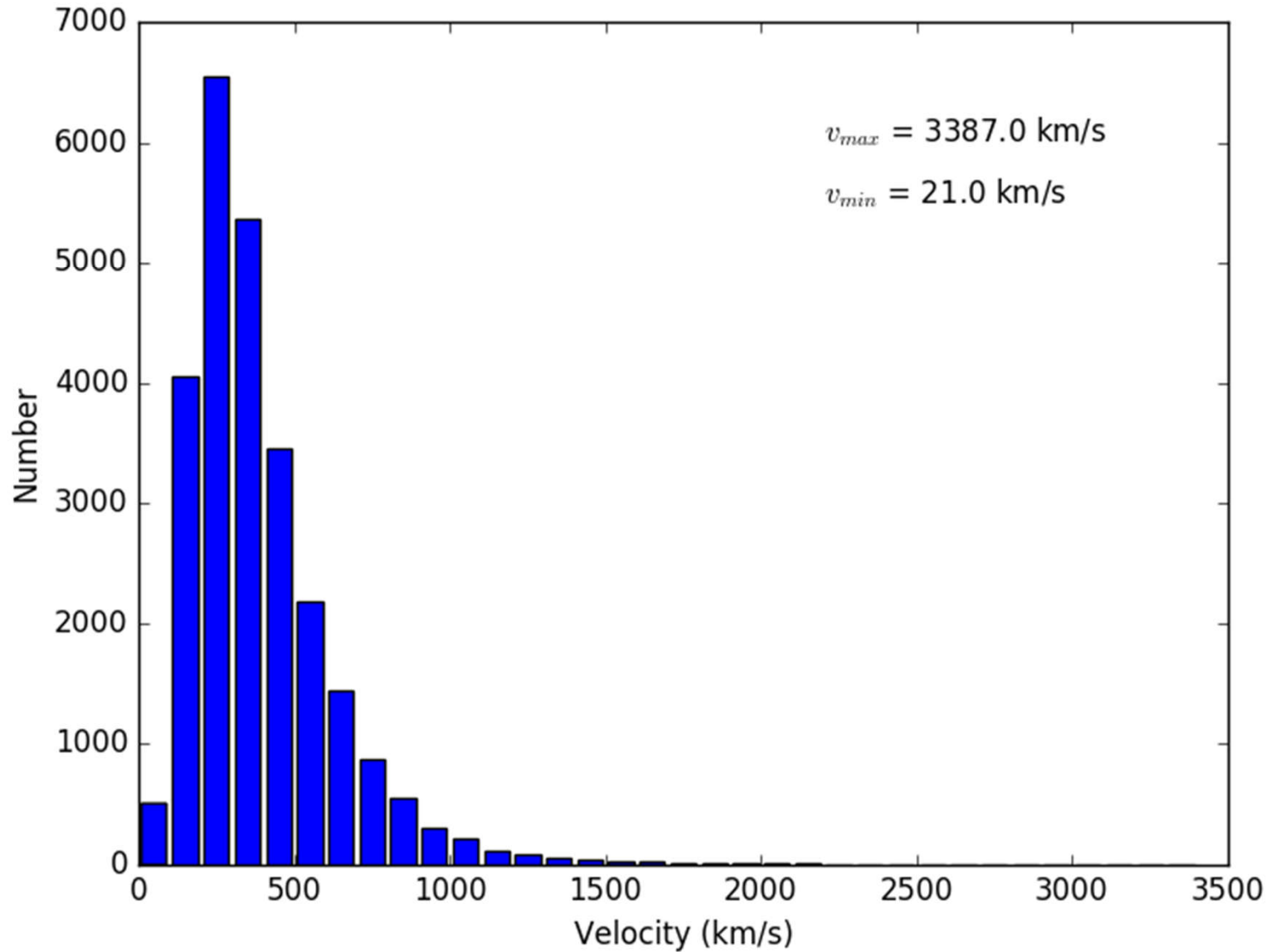
- ★ 日冕磁场和等离子体的爆发，在几分钟至几小时时间尺度内日冕结构发生明显变化并伴有可观测的物质抛射
- ★ 最早于1971年9月通过OSO-7上搭载的白光日冕仪观测到。

日冕物质抛射结构



- ★亮的外环： $10^{14} - 10^{16}g$ 物质，足点基本上位于日面固定位置
- ★暗的空腔：是有较强磁场的低密度区域
- ★亮的内核：通常是平均携有 $10^{14}g$ 等离子体的爆发日珥物质。

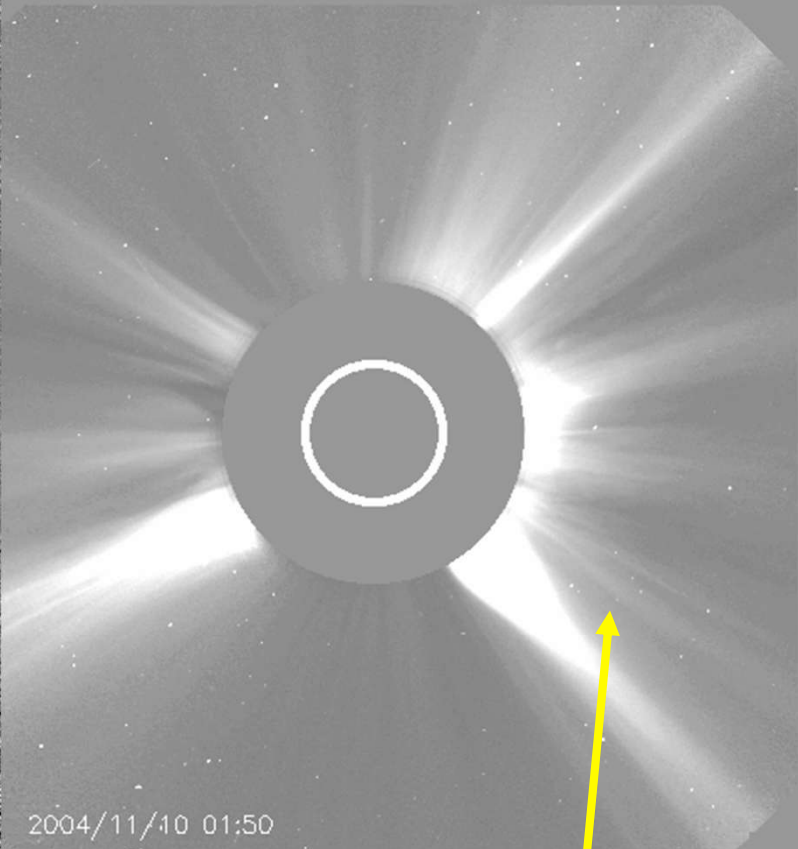
日冕物质喷射的速度



最快的日冕物质抛射



EIT 2004/11/10 02:00

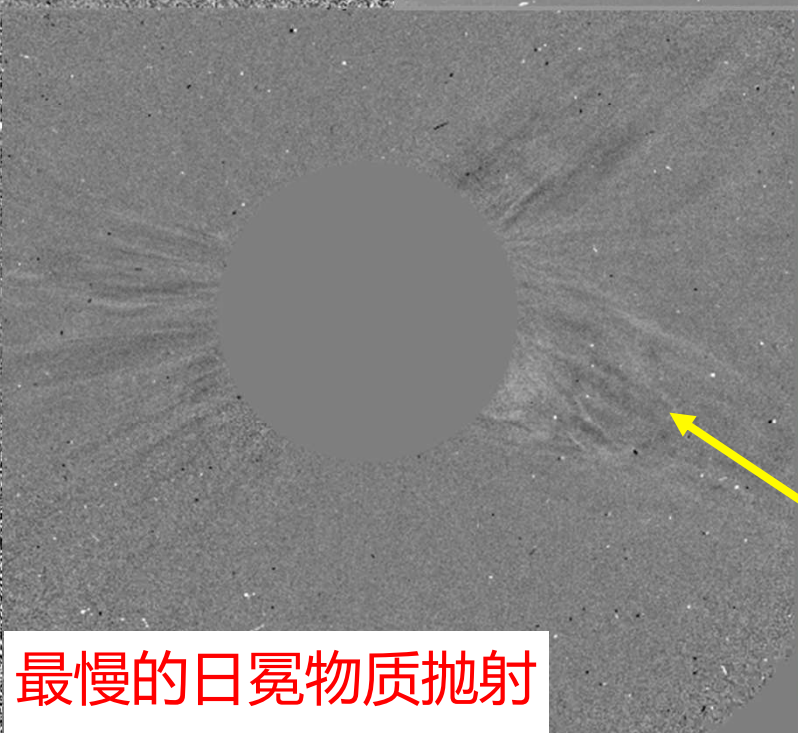


2004/11/10 01:50

3387 km/s



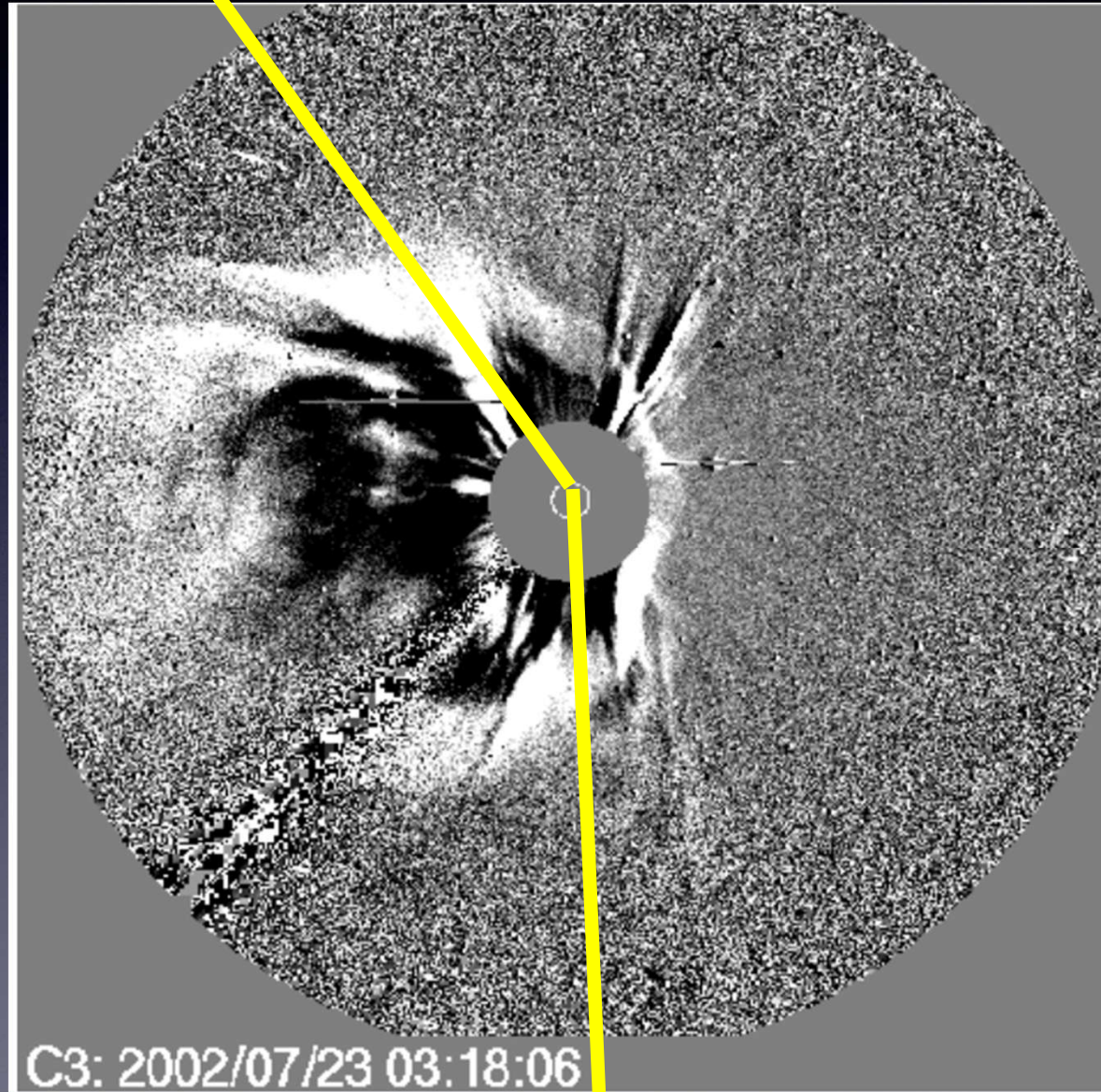
EIT 2005/05/05 04:12



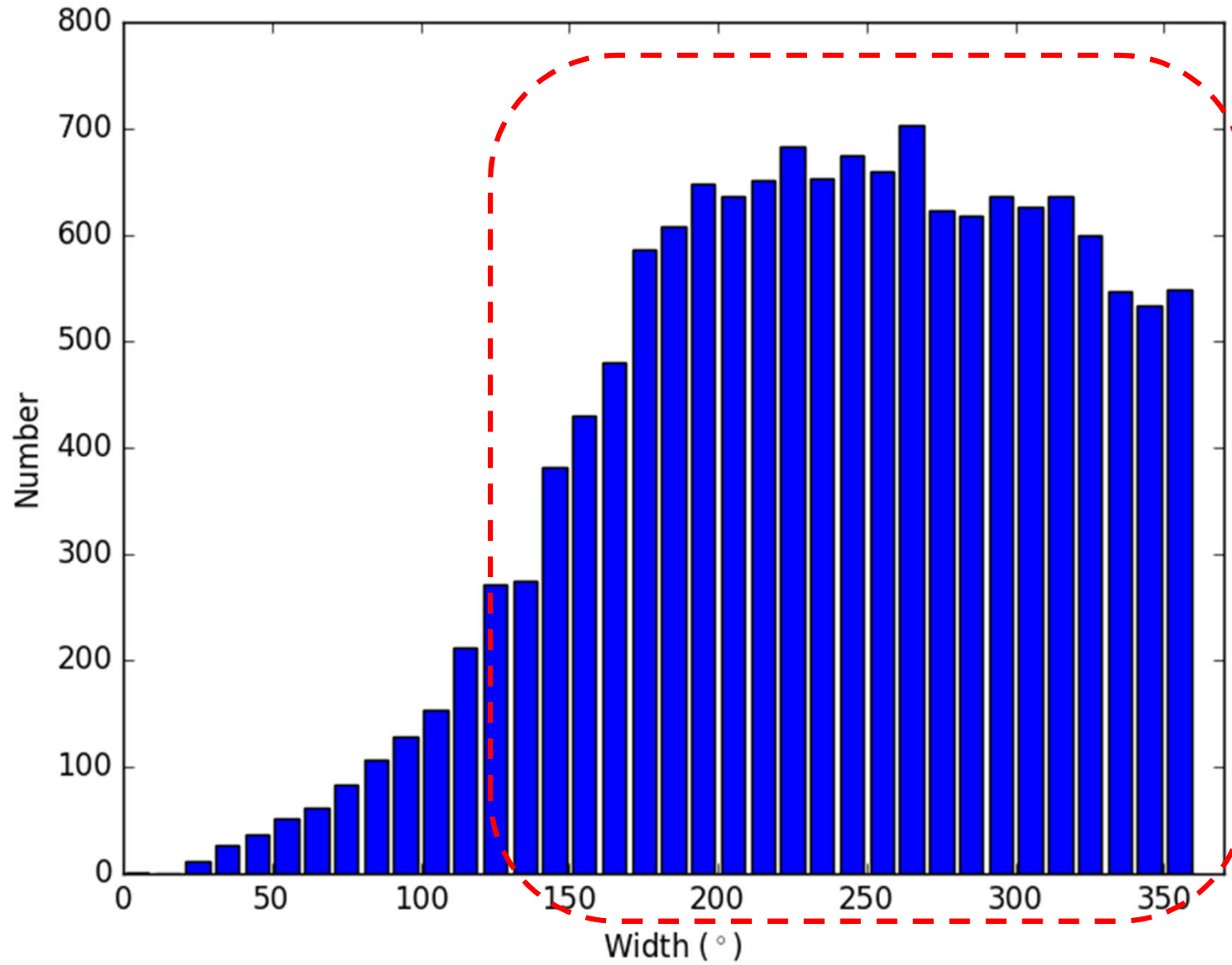
21 km/s

最慢的日冕物质抛射

日冕物质抛射角宽度



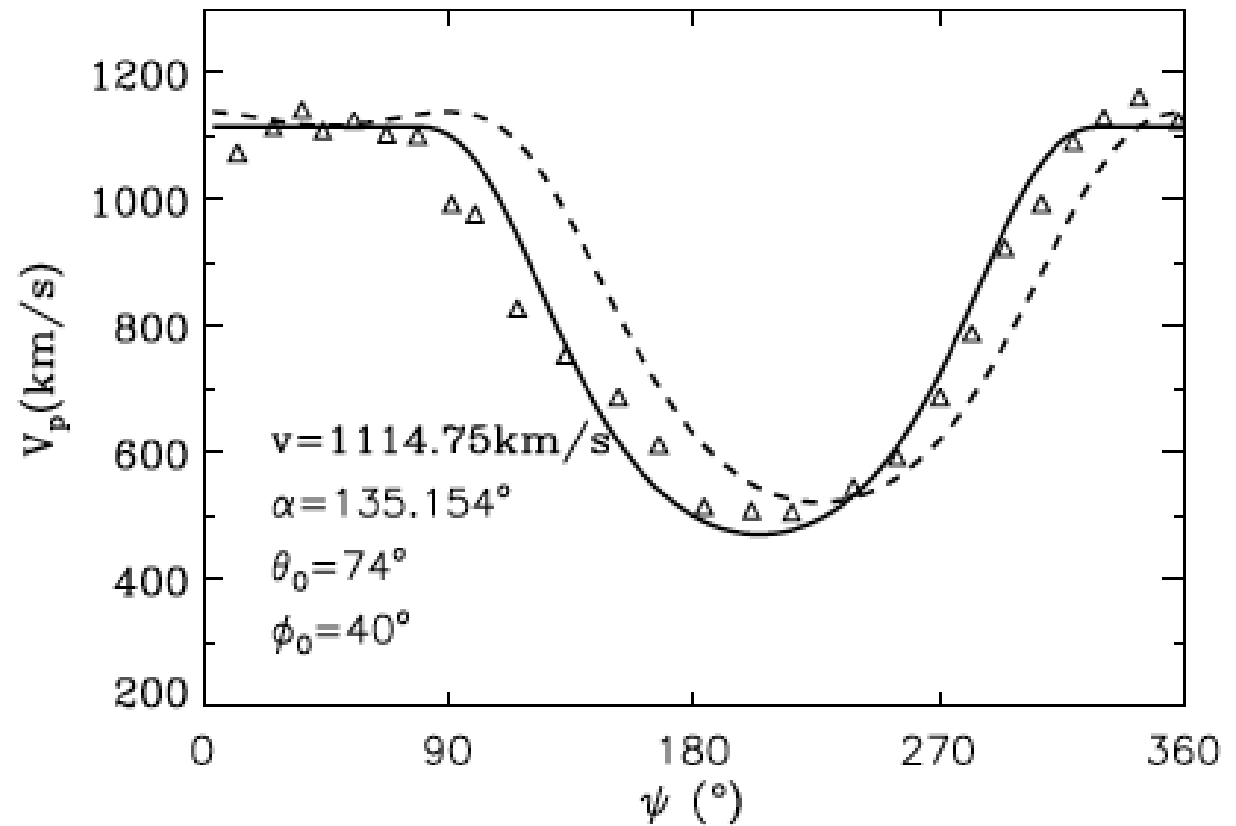
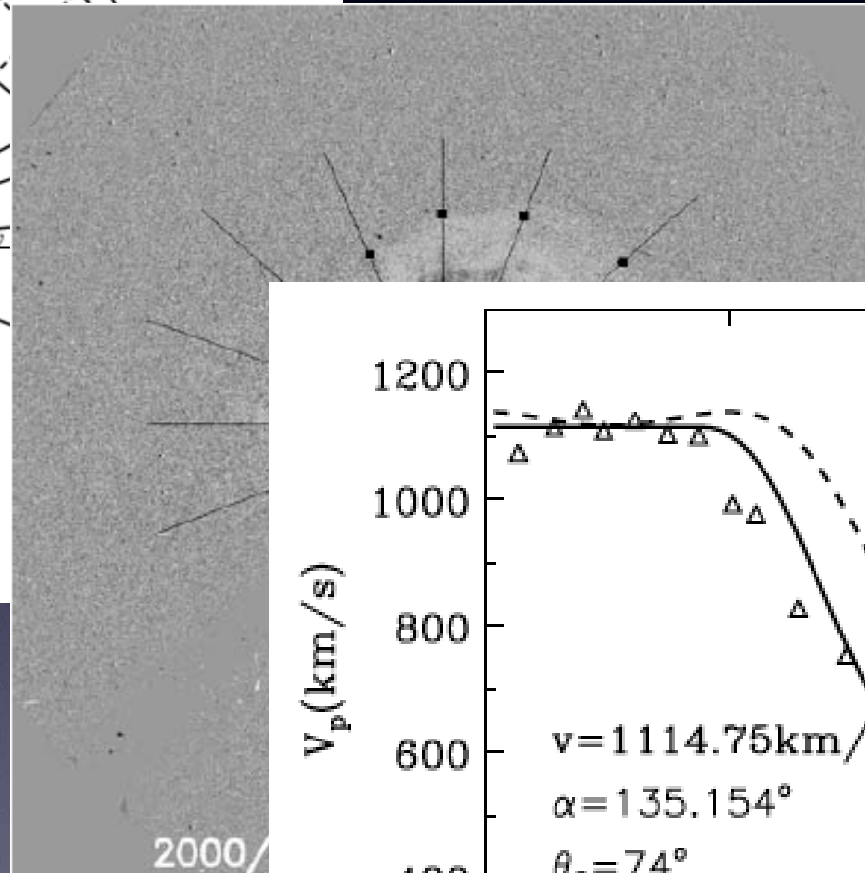
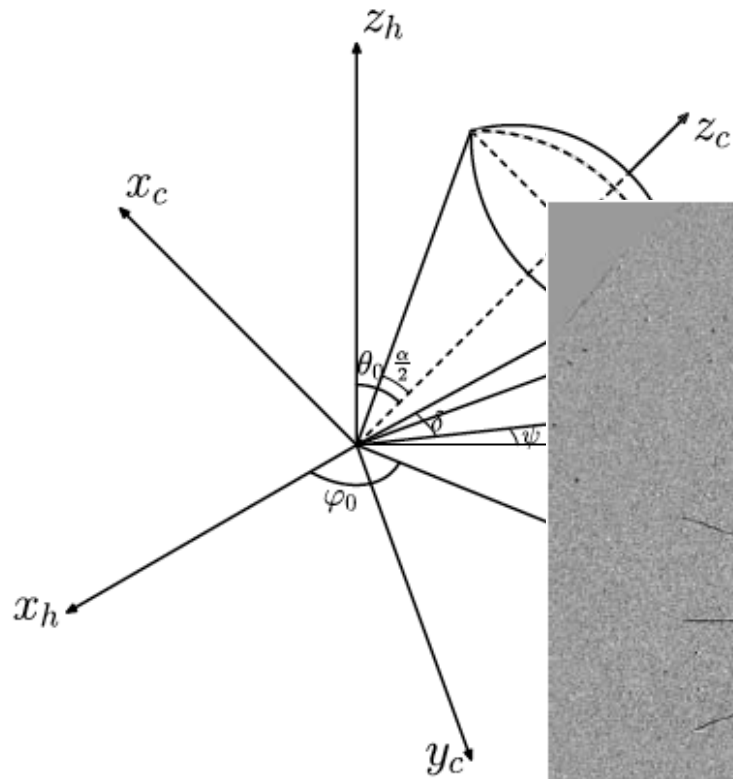
日冕物质抛射的宽度分布



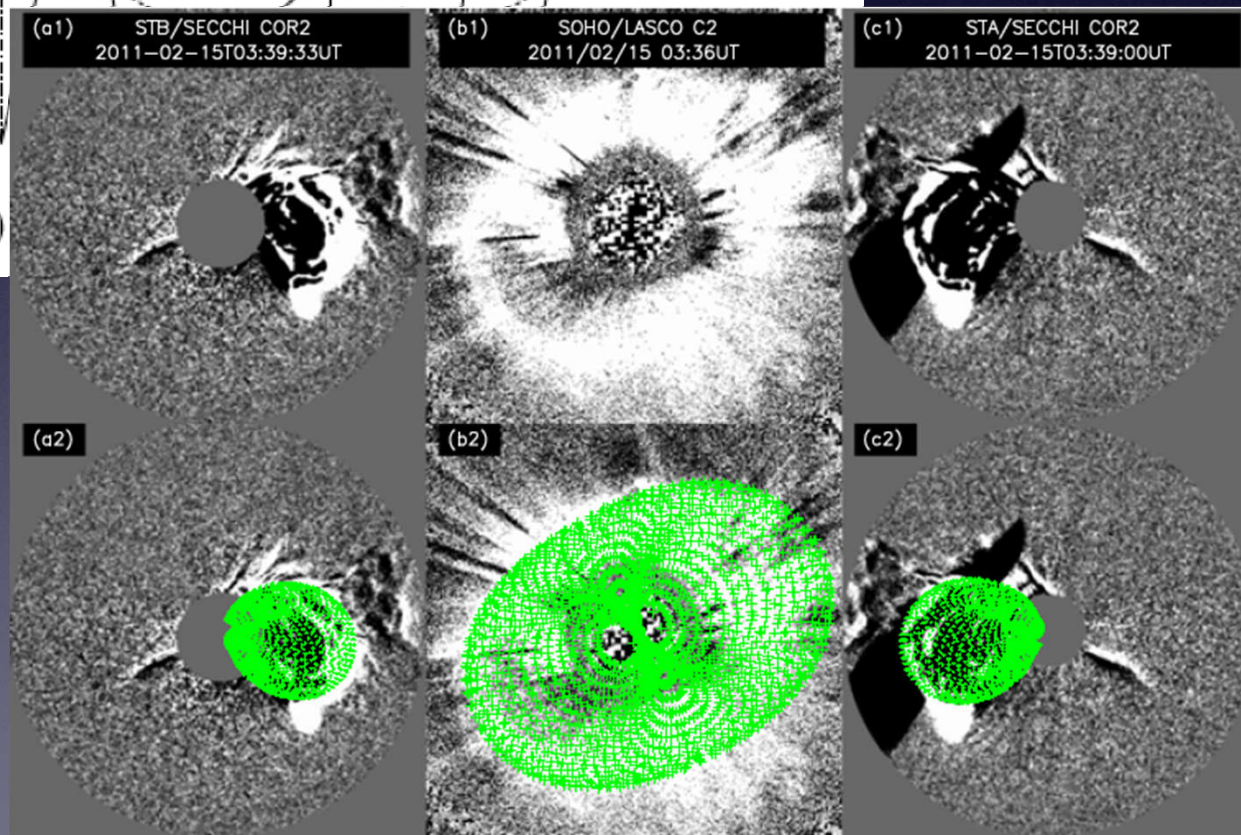
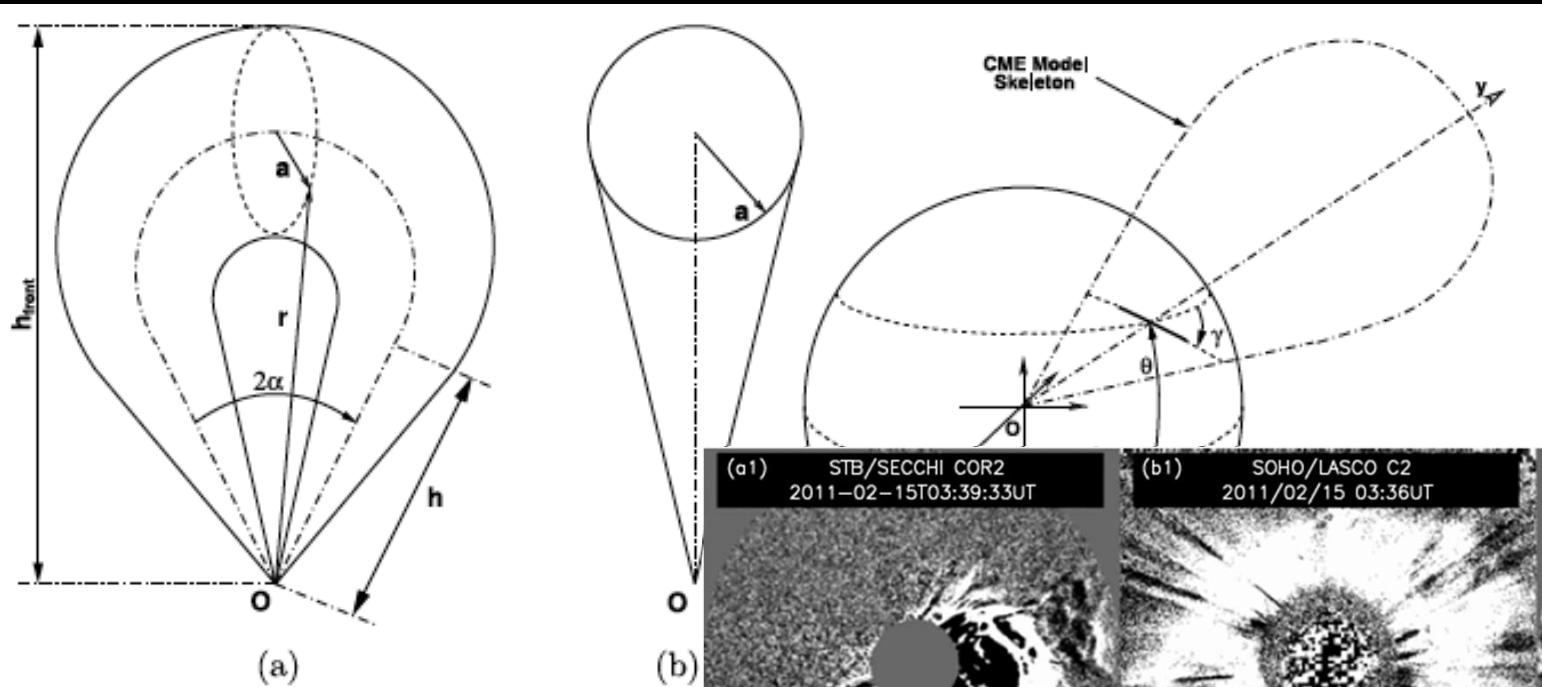
投影效应



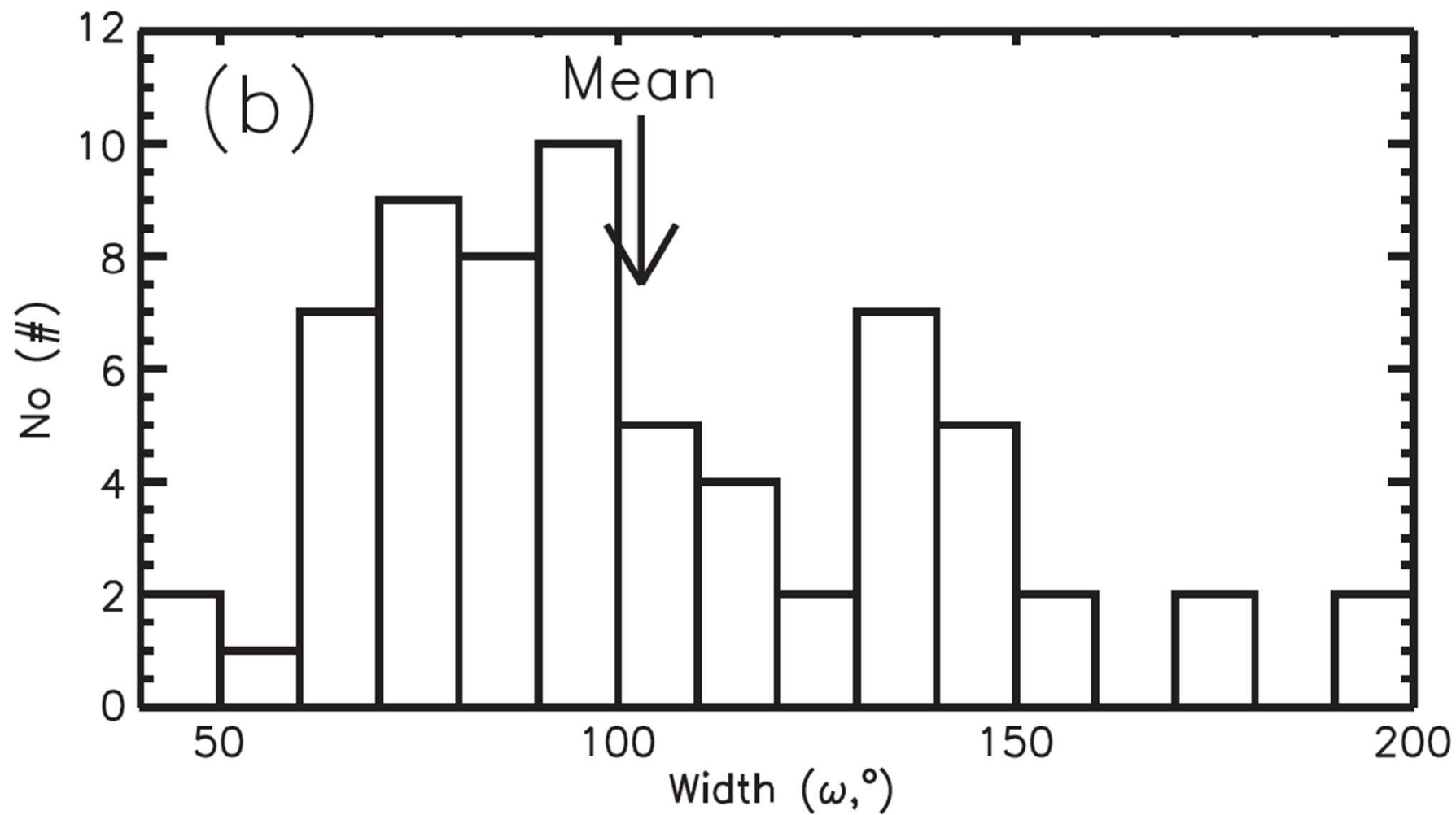
如何获取日冕物质抛射的三维参数:冰淇淋追模型



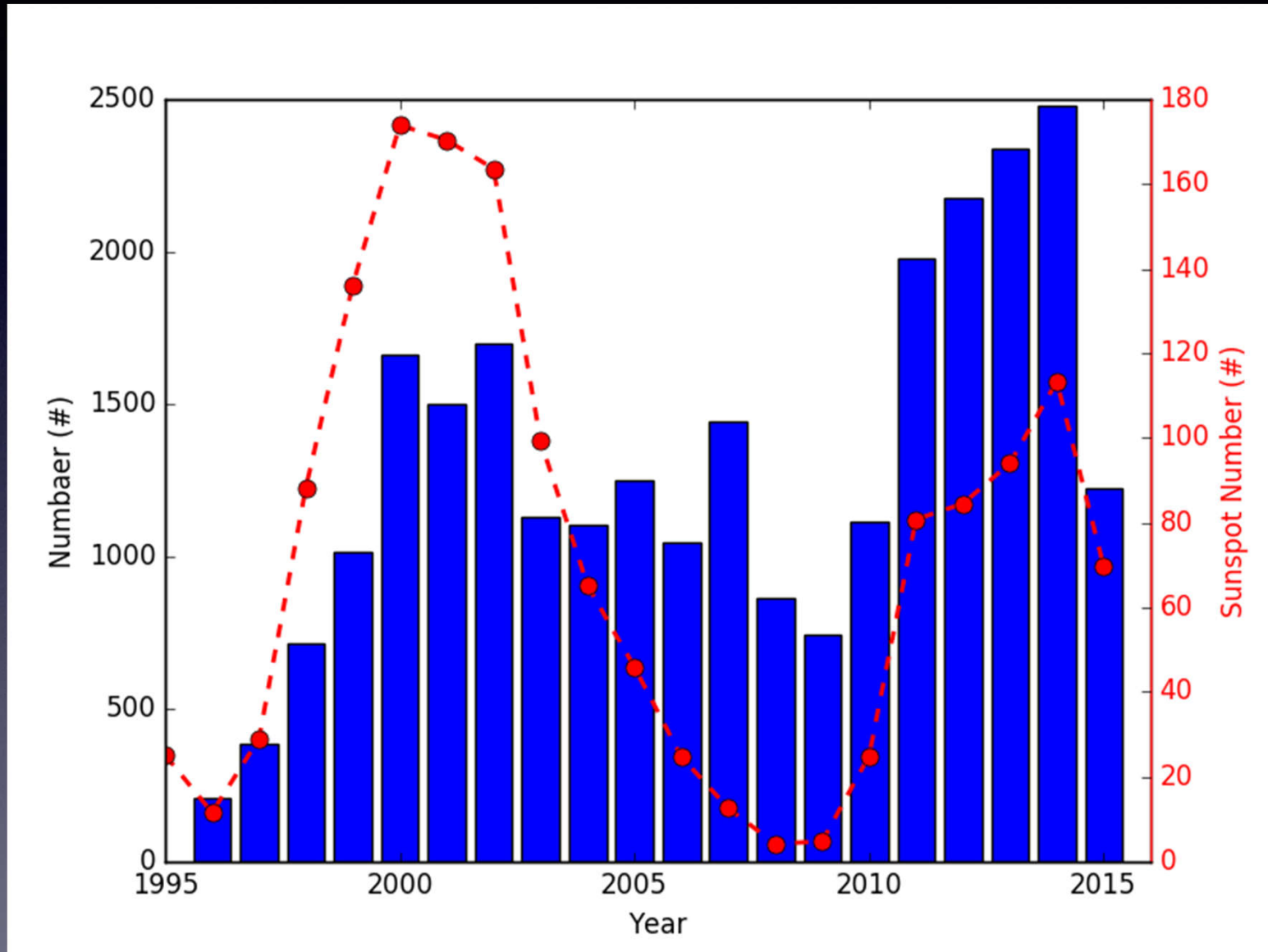
如何获取日冕物质抛射的三维参数:GCS模型



日冕物质抛射的三维宽度分布



日冕物质抛射的发生率



日冕物质抛射和其它太阳活动的相关性

Activity Class	Linear Correlation		Cycle 21	Cycle 22
	r	N ^a	Amplitude	Amplitude
CMEs	—	—	11.5; 9 ^b	11 ^c
Sunspot number	0.94	23	12	11
Interplanetary shocks: SCs	0.91	23	3.8	3.3
EPLs	0.86	21	14	8
H α flares \geq 1 hour	0.86	22	32	14
10.7-cm GRF bursts	0.85	23	11.5	9
Type II bursts	0.84	23	13	10
Disappearing filaments	0.84	21	2.5	3
H α flares \geq Importance 1	0.79	22	41	14
Interplanetary shocks: spacecraft	0.64	14	7.8	—

日冕物质抛射速度演化与耀斑通量的关系

