The Sun (and Moon) from Big Bear

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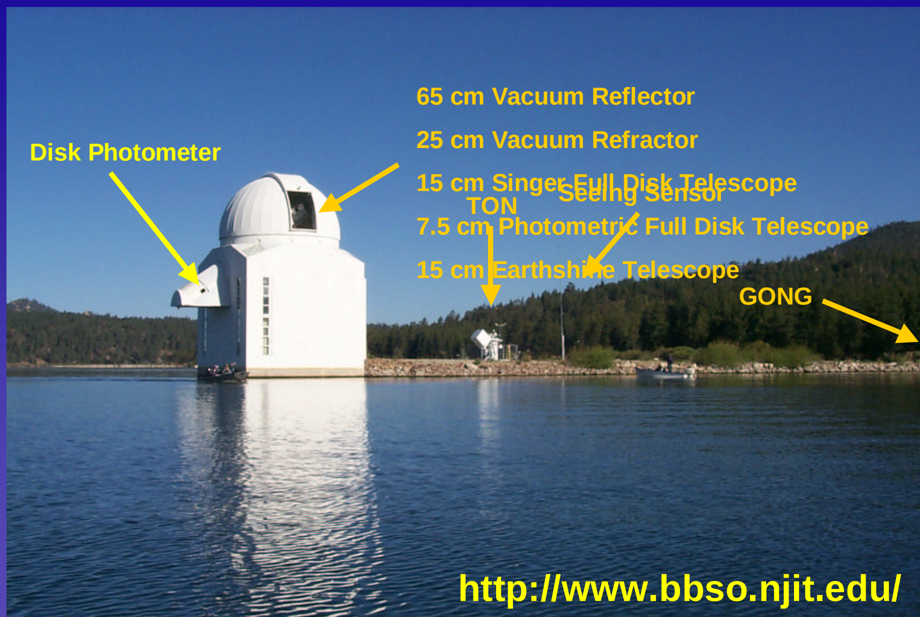

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2 27 Meter Dishes in the Owens Valley Solar Array (OVSA)

Unique in the World

- Array Includes 3 (soon to be 5) 2 meter dishes
- Frequency Agile
- Multiple Baselines

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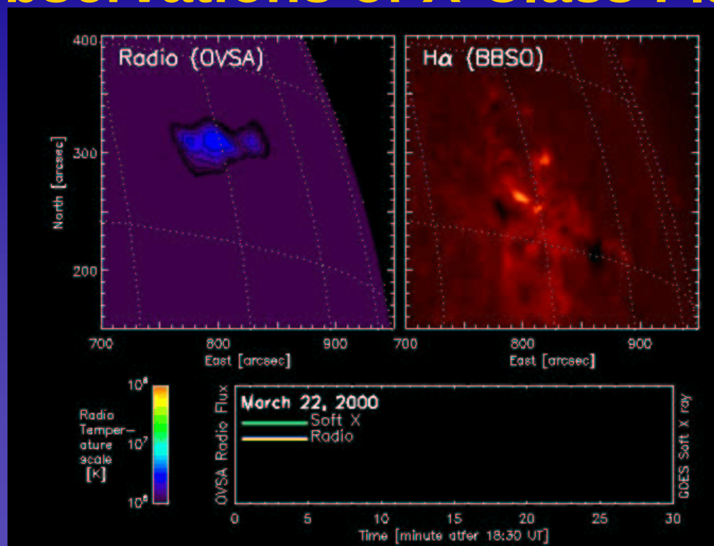
Joint BBSO-OVSA Observations of X-Class Flare



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BBSO White Light Image of Sun 8/20/1999

Sun's Temperature:

- Center: 15,000,000 K
- Surface: 4,000 K
- Corona: 5,000,000 K

Energy Source:

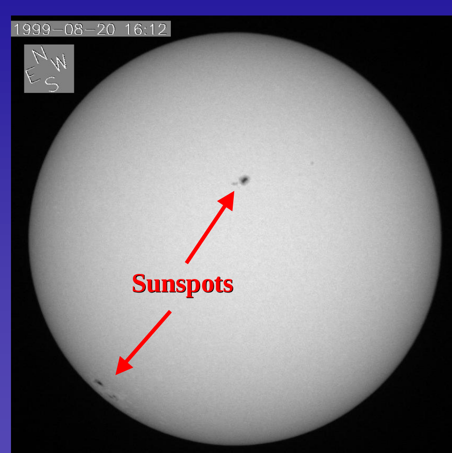
- Nuclear Fusion

Energy Transport:

- Radiative to 0.7 R & >1.0 R
- Convective 0.7-1.0 R

Sun's Rotation:

- 25 days at equator and 35 days near poles



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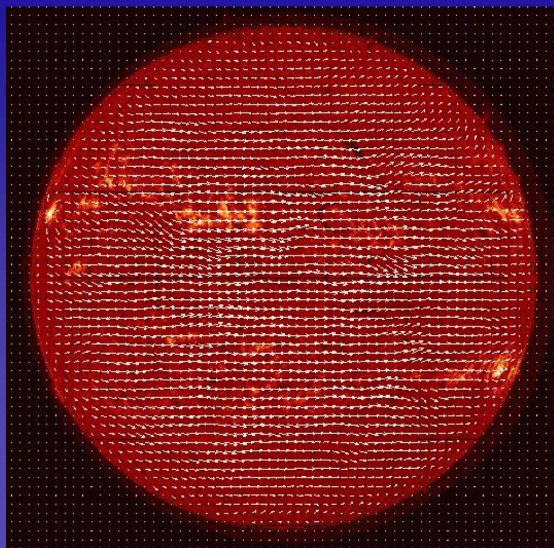
The Sun’s Differential Rotation



- July 12, 2000 Feature Tracking on BBSO Hα images
- Polar rotation slower than equatorial
- Complex motion around active regions

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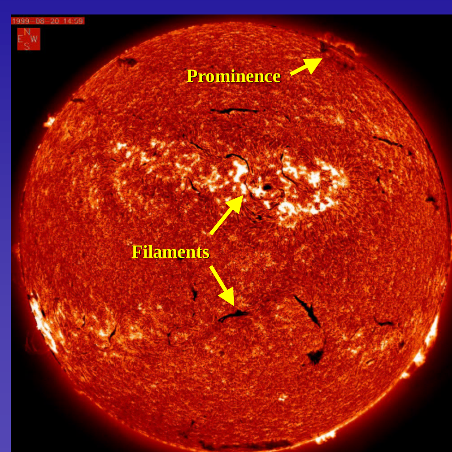
BBSO Hα Image of the Sun

- Image from 8/20/1999 – same day as the white light image
- Filaments and Prominences are cold, dark magnetized material held in magnetic basket above the Sun’s visible surface –suspended in the corona
- Prominence bright against dark backdrop
- Hα sensitive to T=10,000 K – the chromosphere



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Prominence in Hα — BBSO

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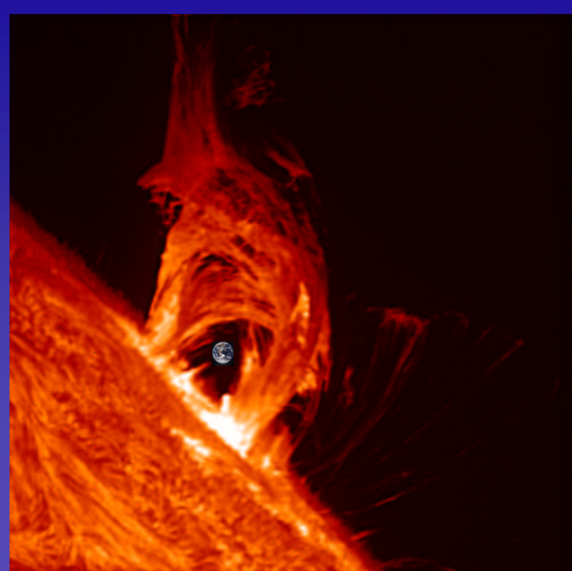
Erupting Prominence in Hα

- 4/15/01
- Erupting prominence returns
- B-pressure beaten by B-tension and gravity
- No CME!



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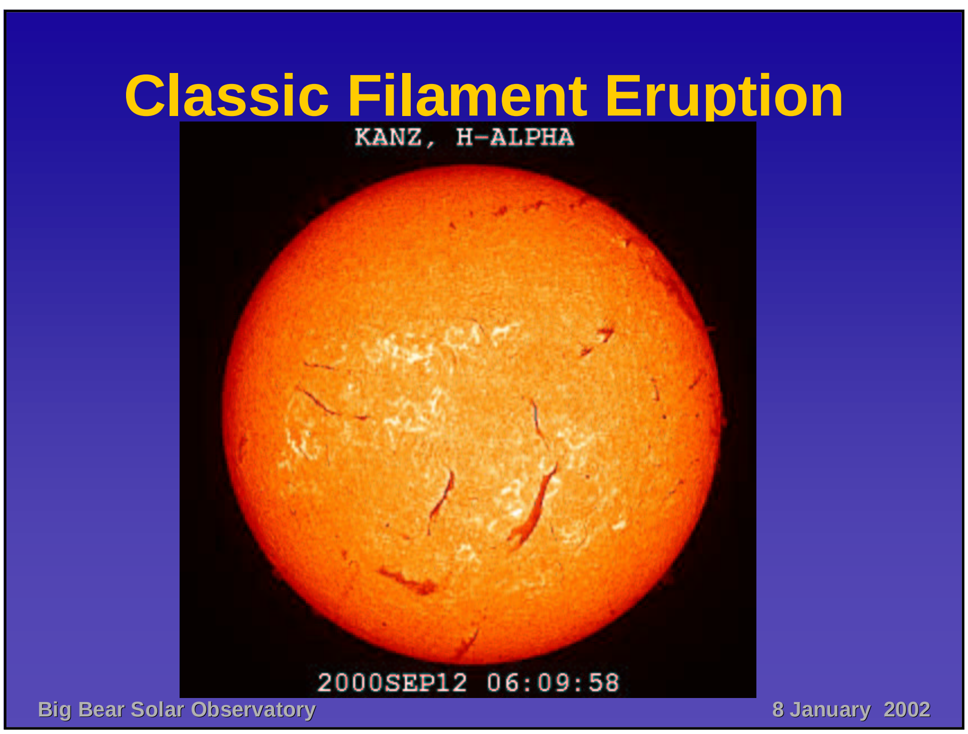
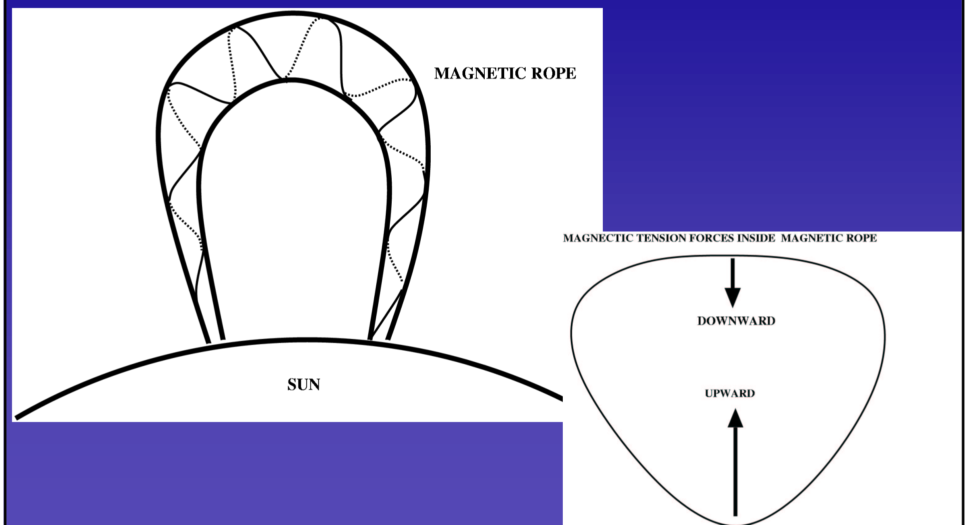
SINGER, H-ALPHA
2001APR15 21:30:25
Big Bear Solar Observatory
8 January 2002


Classic Filament Eruption
KANZ, H-ALPHA
2000SEP12 06:09:58
Big Bear Solar Observatory
8 January 2002

Cartoon of Prominence



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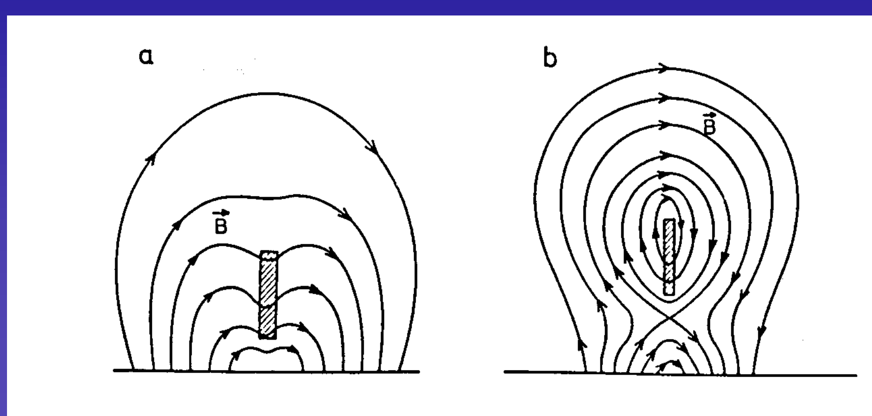
Two Cartoons of Magnetic Basket Holding Prominence/Filament



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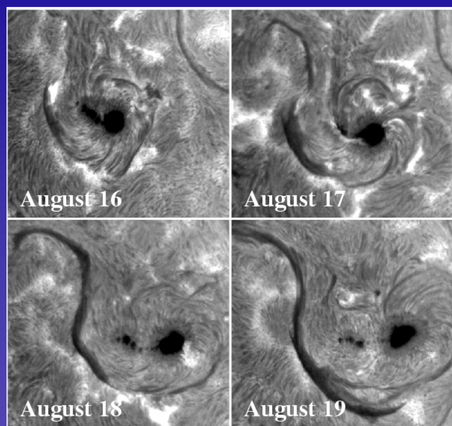
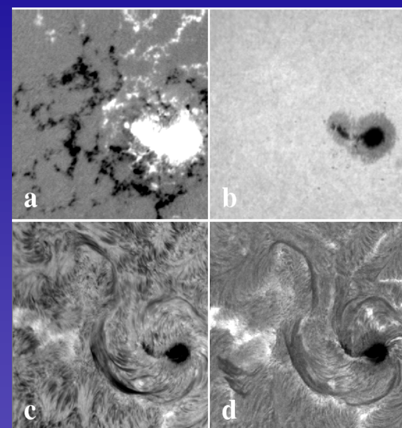
Filament Evolution



Temporal evolution in Hα center line of a sigmoidal filament in active region NOAA 8668 during August 2000.



(a) Videomagnetogram , (b) CaI line wing filtergram, (c) Hα – 0.6 Å filtergram, and (d) Hα center line filtergram.

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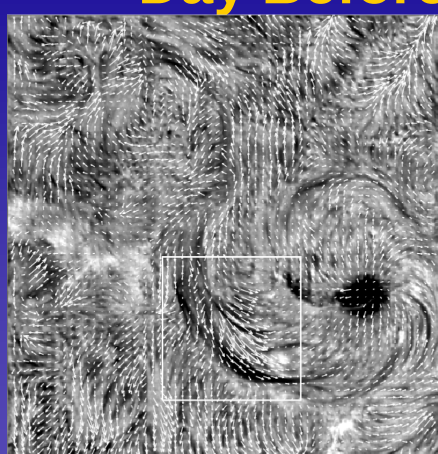
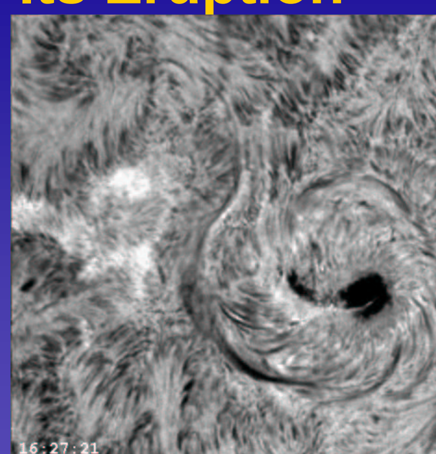
Filament on 8/19/1999 — The Day Before Its Eruption



Average flow map from local correlation tracking of Hα line wing. The FOV is 0.05º x 0.05º.



40 minute time lapse movie of motion from Hα line wing.

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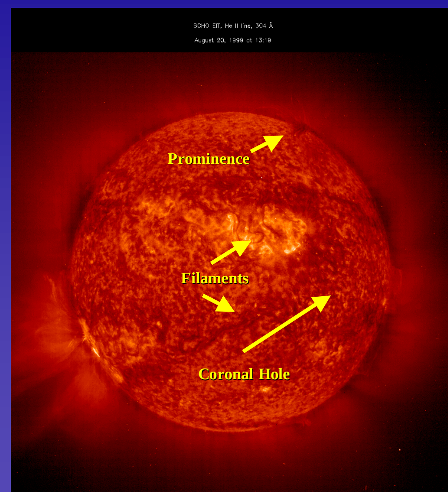
Sun in UV (304 Å) – SOHO/EIT

- 8/20/1999
- Satellite data used in concert with BBSO to understand Sun
- Still see filaments and prominences at T=80,000 K
- See Coronal holes
- See Brightness at Limb



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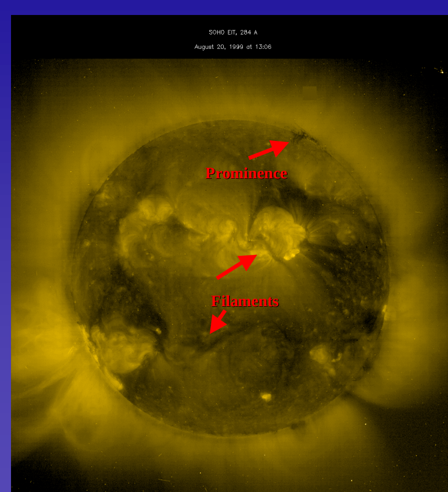
Sun in EUV (284 Å) – SOHO/EIT

- 8/20/1999
- See prominences and filaments dark against the now bright corona
- Temperature sensitivity near 1,500,000 K
- Filaments and prominences fading as corona brightens



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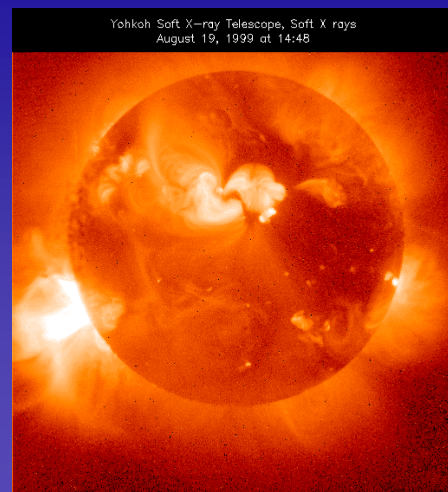
Sun in X-Rays (YOHKOH)

- 8/19/1999
- Prominences and filaments now gone, but corona is very bright
- Temperature sensitivity about 4,000,000 K
- Higher temperature means sampling higher in the solar atmosphere



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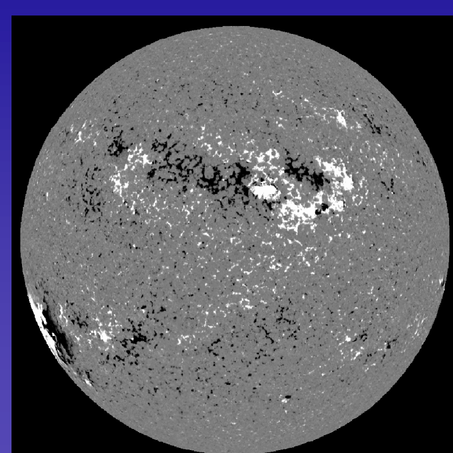
Sun's Magnetic Field -- KPNO

- 8/20/1999
- Magnetogram with bright and dark regions being opposite polarities of the line-of-sight magnetic field
- Filaments/Prominences along the neutral line between opposing polarities



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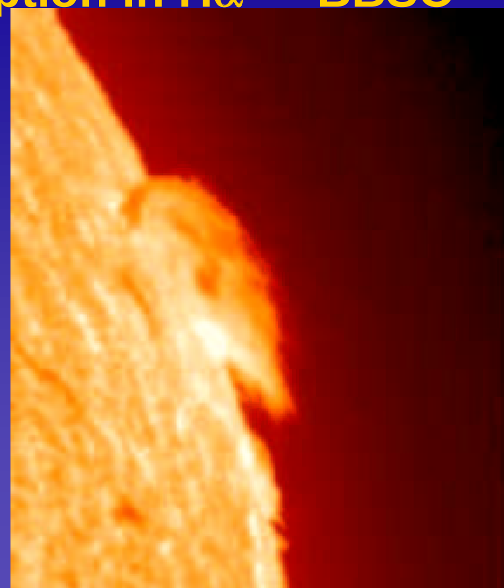
Prominence Eruption in Hα — BBSO

- 6/28/2000
- Prominence eruption
- Coronal Mass Ejection (CME) accompanies
- CME releases 10^{13} kg and 10^{25} J of energy
- Earth-directed CMEs can have geomagnetic effects



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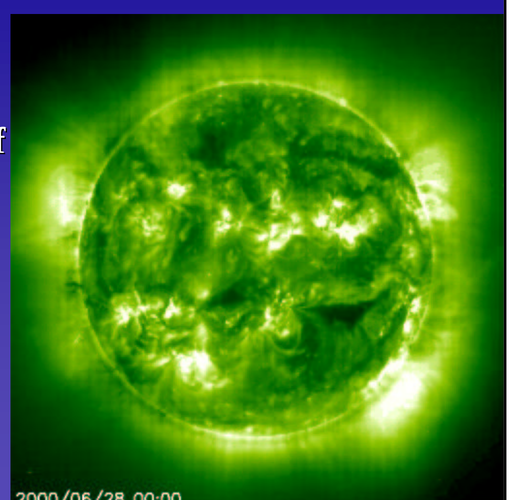
SOHO/EIT 195 Å Image of CME 6/28/2000

- Limb CME seen with 195 Å
- Effective temperature of 195 Å is roughly 1,500,000 K
- Magnetic loops and coronal holes (dark areas) are both apparent



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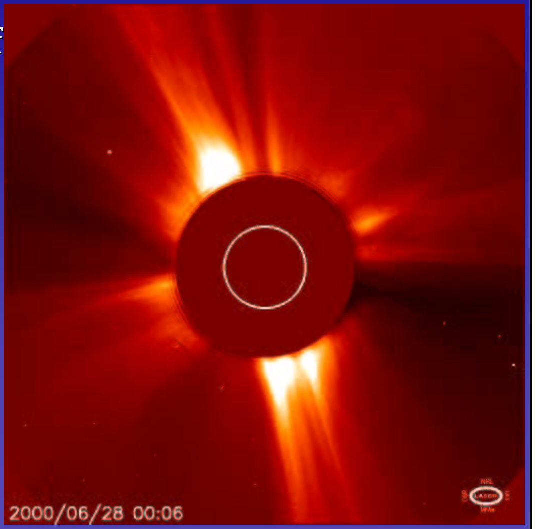
SOHO/LASCO Movie of CME — 6/28/2000

- Coronagraph image of limb CME with small field of view
- Coronagraphy best done from space
- Earth-directed CMEs hard to detect with coronagraph



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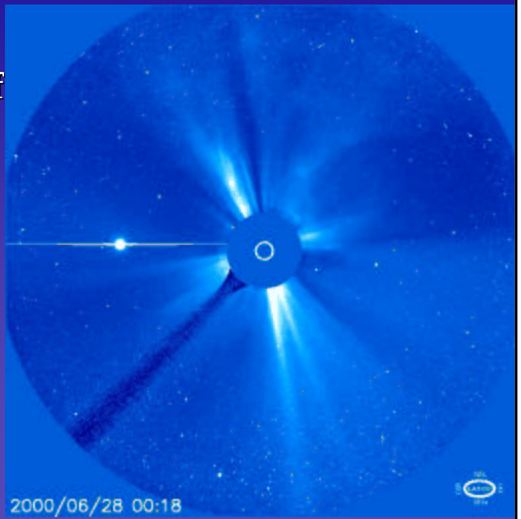
SOHO/LASCO Movie of CME — 6/28/2000

- Coronagraph movie of CME with large field of view.
- Can see stars in field of view



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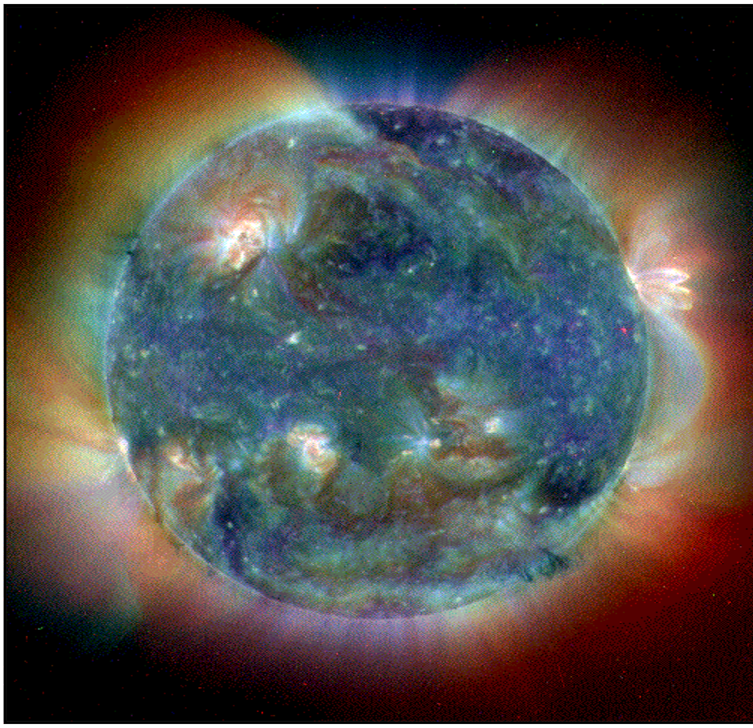

Multi-
Temperature
Vision
of the Sun

Blue:
EIT 171 A
T=1.0 MK

Green:
EIT 195 A
T=1.5 MK

Red:
EIT 284 A
T=2.0 MK

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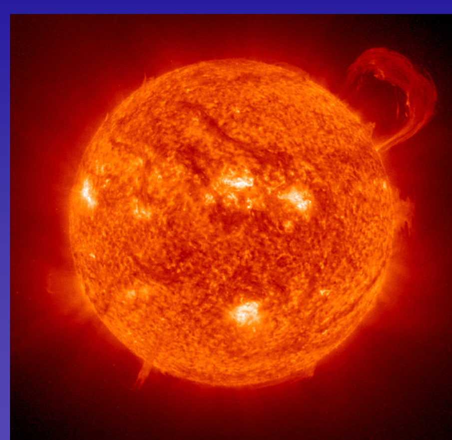
Superprominence

- Large Prominence in eruption, as seen by SOHO/EIT on 9/14/1999
- Image in UV at 304 Å line which is sensitive to temperatures of about 80,000 K



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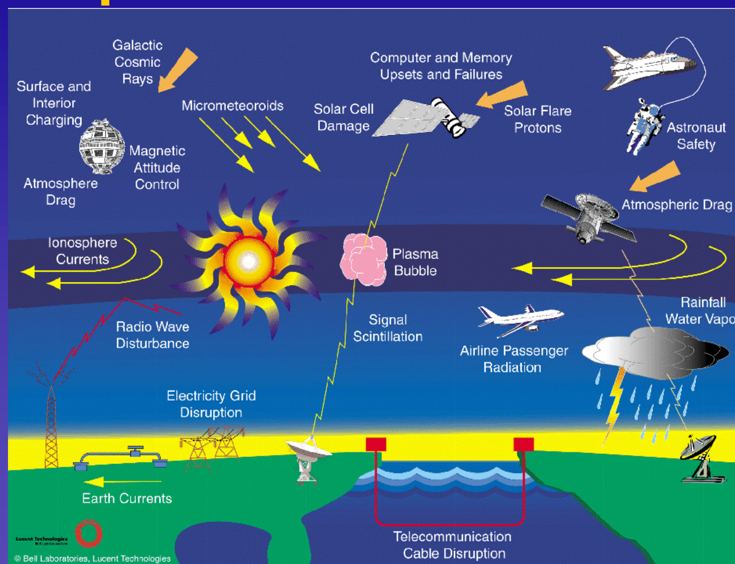
Space Weather Effects



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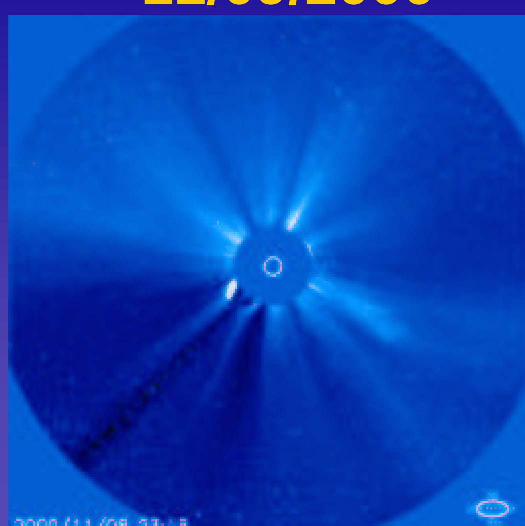
LASCO CME and Uh Oh! — 11/09/2000



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LASCO CME and Uh Oh! — 11/05/1997

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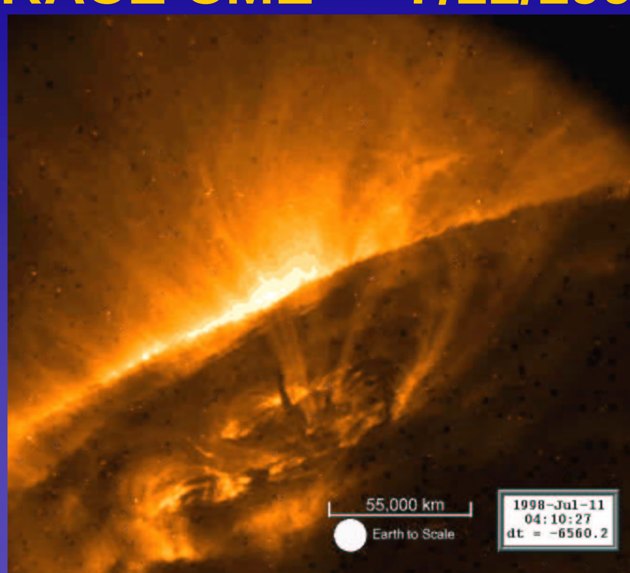
TRACE CME — 7/11/1998



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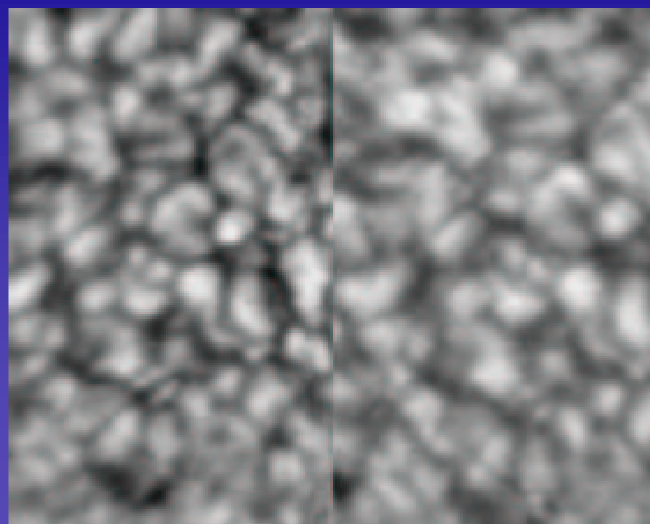
Low Order Adaptive Optics

- High resolution observations of the Sun from ground require adaptive optics to correct for the turbulence of the earth's atmosphere
- Prototype results shown

Corrected | Uncorrected



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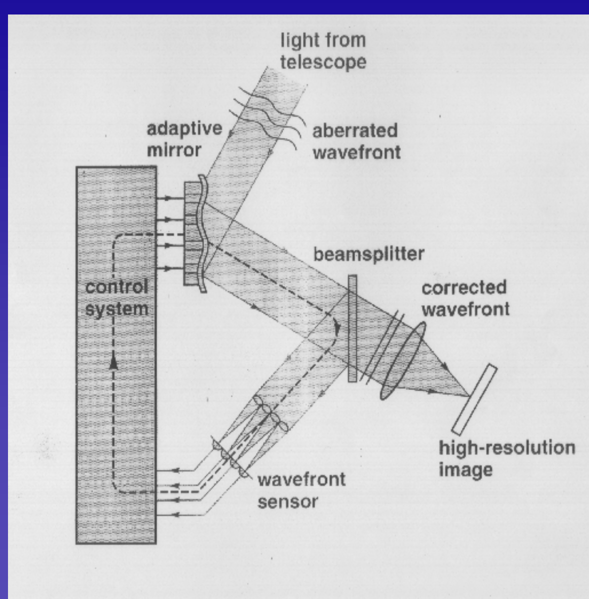
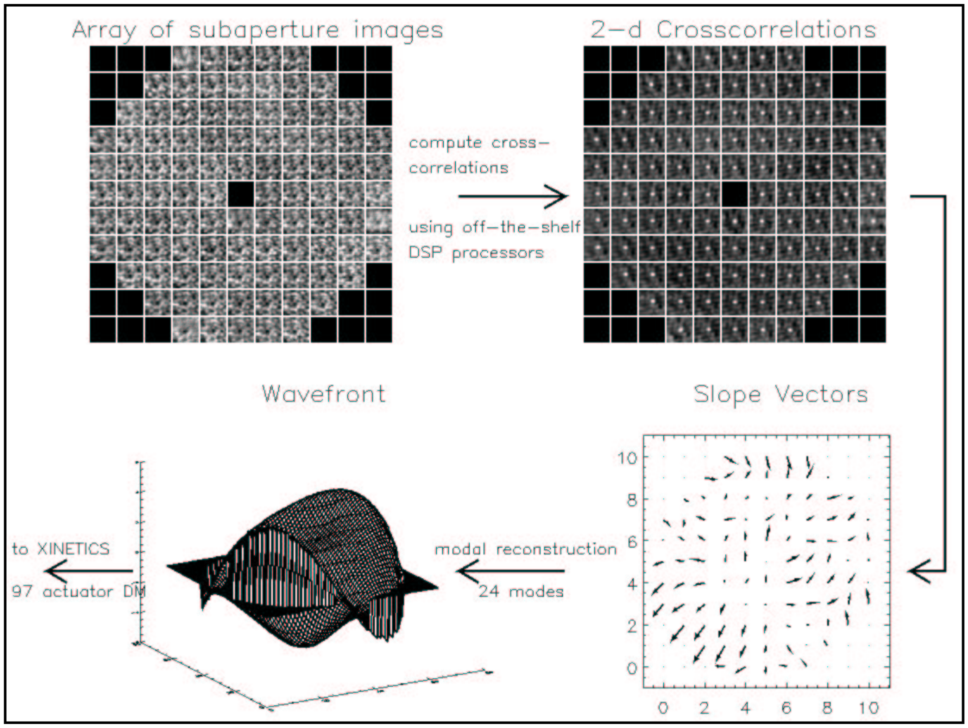
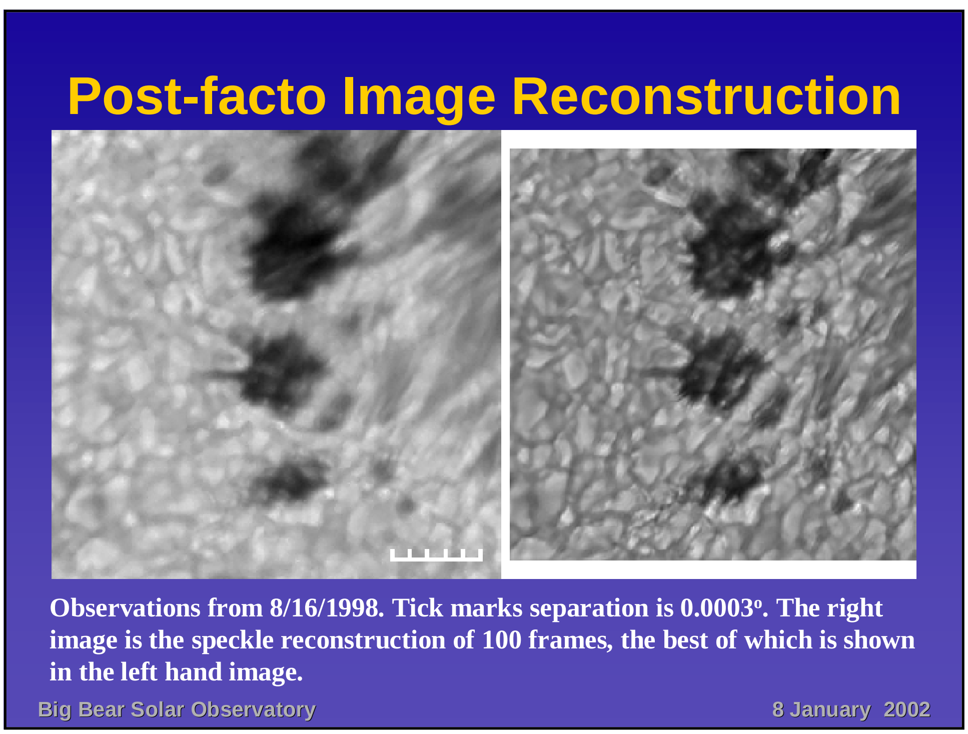
Adaptive Optics Principle




Array of subaperture images
2–d Crosscorrelations
compute cross–
correlations
using off–the–shelf
DSP processors
Wavefront
Slope Vectors
to XINETICS
97 actuator DM
modal reconstruction
24 modes


Post-facto Image Reconstruction
Observations from 8/16/1998. Tick marks separation is 0.0003°. The right image is the speckle reconstruction of 100 frames, the best of which is shown in the left hand image.
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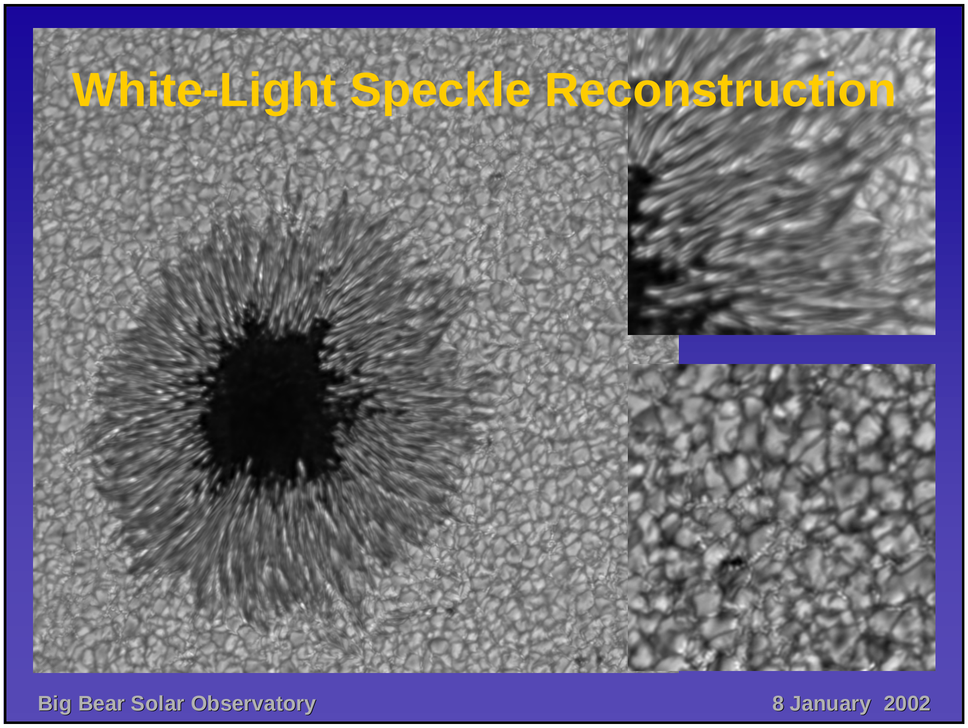
8 January 2002


White-Light Speckle Reconstruction
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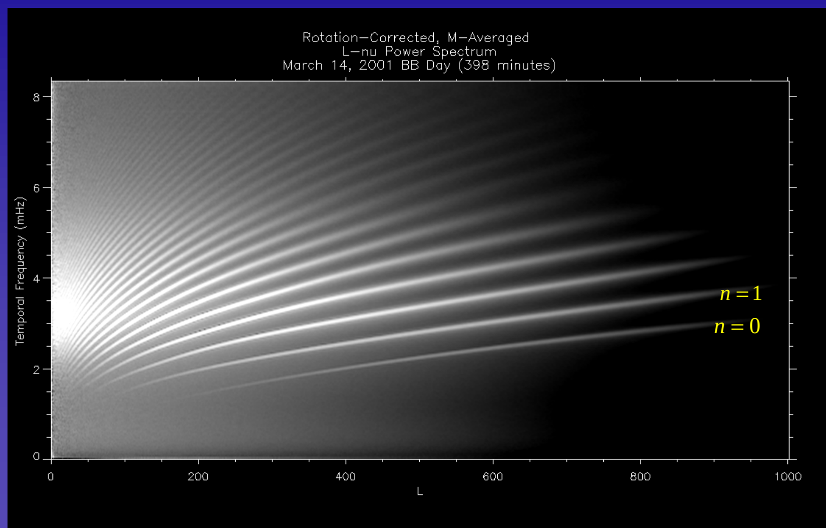
Reconstruction of Another Place A Day Later
Big Bear Solar Observatory
8 January 2002

Normal Modes of the Sun

$$\left(\nu_{n,l} \propto 2n + l + \varepsilon\right)$$



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Helioseismic Results from BBSO Data

- Sun's differential rotation changes to solid body rotation at the base of the convection zone
- Site of solar dynamo immediately beneath the convection zone
- Determine the run of internal pressure and density such that P/ρ is determined to 0.5%
- The Sun does not have a convective core
- Seismic age of the Sun is 4.6 GY
- No astrophysical solution to the Sun's neutrino deficit

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The Sun in Time

- Using solar f-modes ($\omega^2 = GM_{Sun}/R_{Sun}^3$) to determine the Sun's radius and its evolution
- Reveals that Sun's radius changes over cycle are too small to play a role in its luminosity changes ($\Delta L/L = 4\Delta T/T + 2\Delta R/R$)
- Open question: Is the Sun hotter or cooler at activity maximum?

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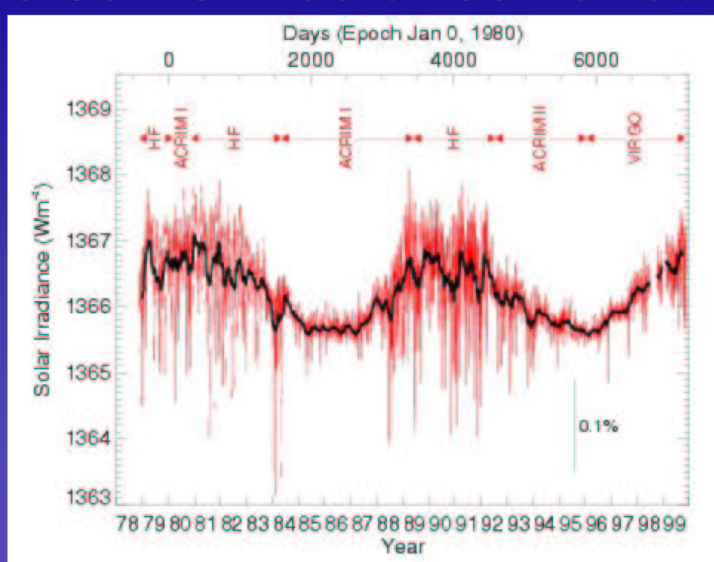
The Sun's Irradiance Variations



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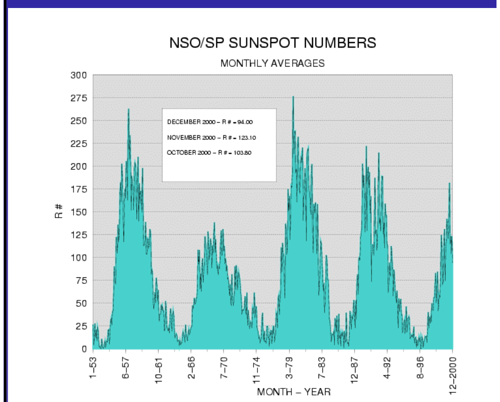
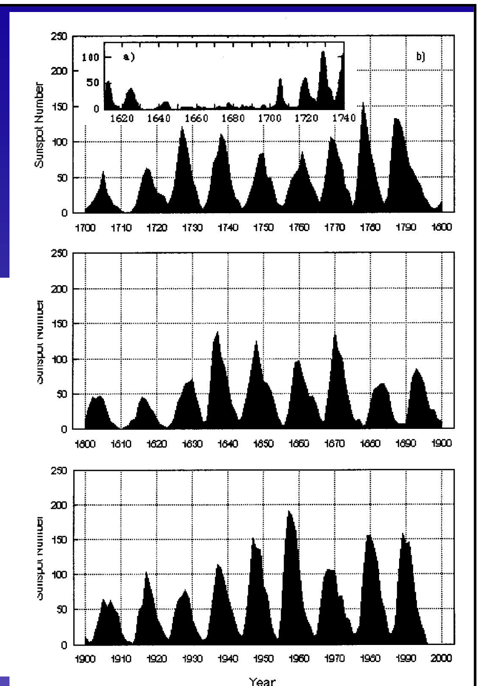
Sunspot Number

- Sunspot number 1620 – 2000





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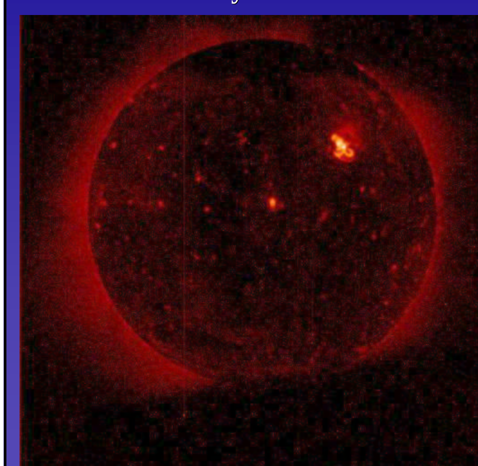
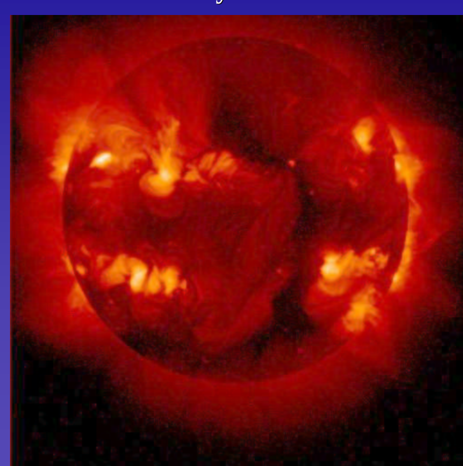
The Sun in X-Ray Light

Solar Activity Minimum --1996



Solar Activity Maximum--2000



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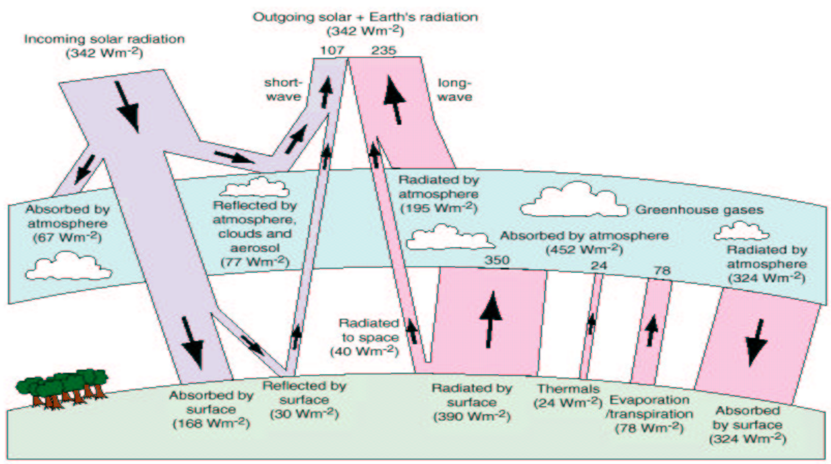
What about Climate Change? Where Does the Sunlight Go?



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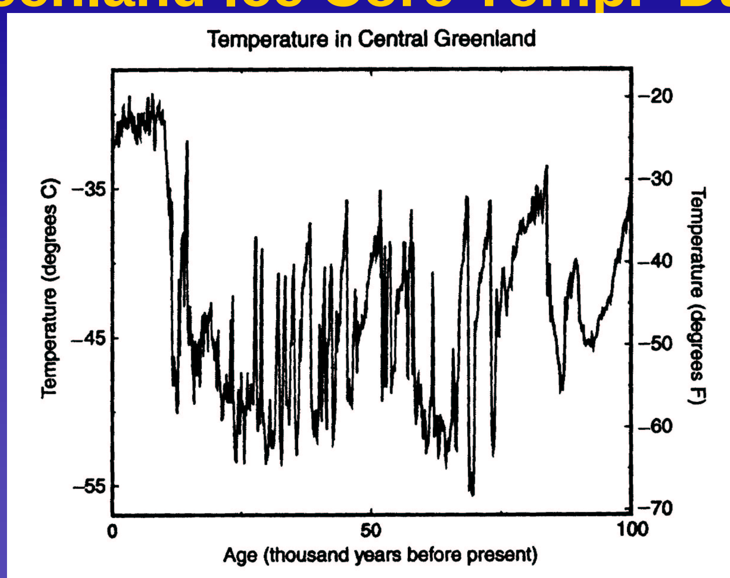
Greenland Ice Core Temp. Data



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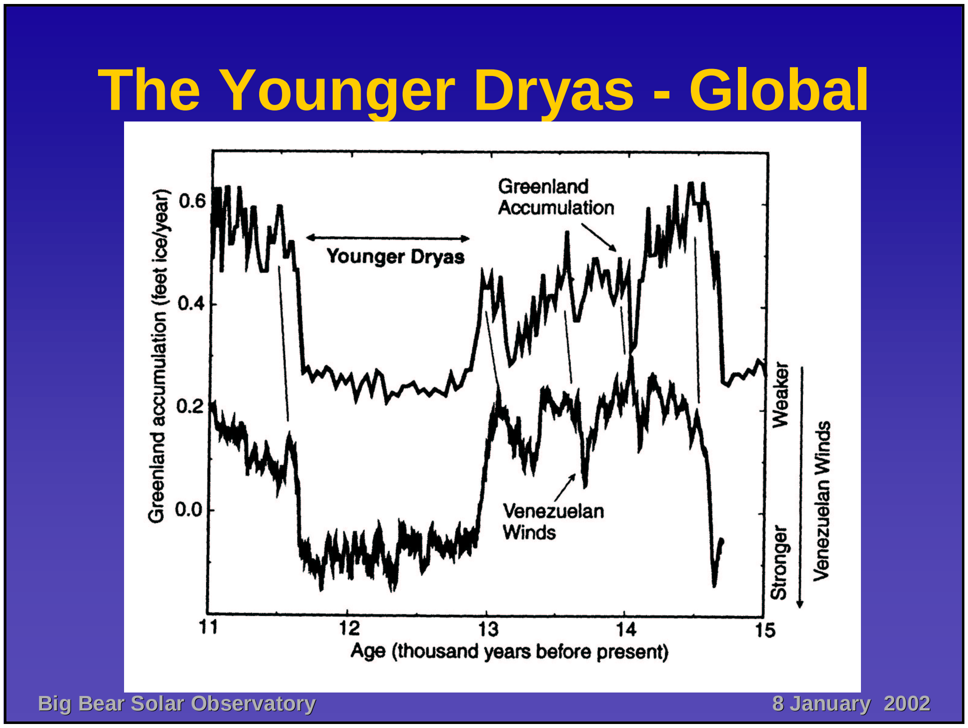
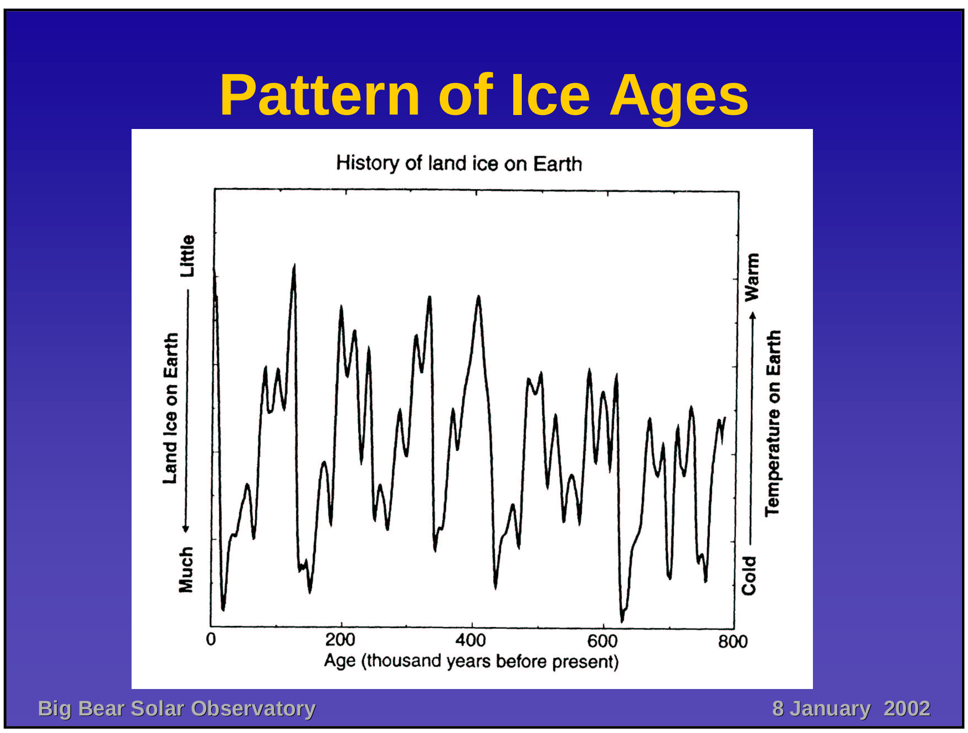

The Younger Dryas - Global
Greenland Accumulation
Younger Dryas
Venezuelan Winds
Greenland accumulation (feet ice/year)
0.6
0.4
0.2
0.0
11
12
13
14
15
Age (thousand years before present)
Weaker
Stronger
Venezuelan Winds
Big Bear Solar Observatory
8 January 2002


Pattern of Ice Ages
History of land ice on Earth
Land Ice on Earth
Little
Much
Temperature on Earth
Warm
Cold
0
200
400
600
800
Age (thousand years before present)
Big Bear Solar Observatory
8 January 2002

Albedo ⇔ Climate Heat Engine

Net solar power reaching Earth

$$P_{Earth}^{in} = C_{Sun} \pi R_{Earth}^2 (1 - A)$$

and re-radiated to space

$$P_{Earth}^{out} = 4\pi R_{Earth}^2 \sigma \varepsilon T_{Earth}^4 = P_{Earth}^{in}$$

Fractional Change in net *to* Earth

$$\frac{\delta P_{Earth}^{in}}{P_{Earth}^{in}} = \frac{\delta C_{Sun}}{C_{Sun}} - \frac{\delta A}{1 - \mathrm{A}}$$

Global and seasonal average is $A \sim 0.30$

-Shortwave input (visible, 0.5 μm, 6000 K)

-Longwave output (IR, 15 μm, 255 K)

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The Earth's Albedo is Highly Variable

- **Local albedo depends upon:**
  - Surface type
  - Solar zenith angle (time of day)
  - Meteorology (clouds)

	Clear	Overcast
Land	0.16	0.50
Ocean	0.08	0.44
Desert	0.23	
Snow	0.68	

- **The global albedo varies with the seasons**
  - North/South land symmetry
  - Snow/ice cover

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Climate is very sensitive to A

- **Te=255K is the temperature at 6 km**
  - Atmosphere transparent to 15 mm radiation
  - Not the surface temperature (287 K)
- **Linearization of the power balance gives dT/DA~-1.5K/0.01**
  - Similar to that observed in models
  - Real data are sparse and ambiguous
- **Greenhouse effect on A uncertain**
  - Doubling CO2 will likely increase T by 1.5-4.5K
  - Clouds increase (type changes) but snow/ice decrease

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Satellites are the standard way to measure the albedo

- **Low-earth orbit (few 100 km)**
- **Observe one spot (10 km) at at time; average over pixels**
- **Incomplete space/time coverage**
- **Expensive**
- **Tough to calibrate at a fraction of a percent**
- **Subject to failures (none now working)**
- **Complex scene models required to analyze data**
- **Precision of about 0.7%**

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Earthshine is Reflected from the Earth to Illuminate Moon

- Ghostly glow of the dark part of the lunar disk
- E/S ~Albedo X geometry X moon properties
- Intensity varies during the month
  - Largest when phase ~$\pm\pi$ (full earth, crescent moon)
  - Smallest when phase ~0 (full moon, crescent earth)
- Measured by A. Danjon (1927-34) and J. Dubois (1940-1960)

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Earthshine and the Earth

- Measure and Simulate Earth's reflectance and spectra and their variations.
  - Reflectance from BBSO
  - Spectra from Palomar
- Principal Non-BBSO Collaborators
  - Steve Koonin, Caltech

    Titus Brown, Caltech

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Earthshine

- Net Sunlight Reaching Earth Drives the Climate
- About 30% of Incident Sunlight Reflected by Our Blue Earth
- Origin of Earthshine First Explained by DaVinci

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Simulations of Albedo

- Scene Models from Earth Radiation Budget, where earth is divided into 12 scenes
- Take cloud cover data from web, updated every 6 hours (www.intellicast.com)
- Snow and ice cover from Canadian Center for Climate Modeling and Analysis (www.ccma.bc.ec.gc.ca)
- Calculate albedo for parts of the Earth in earthshine

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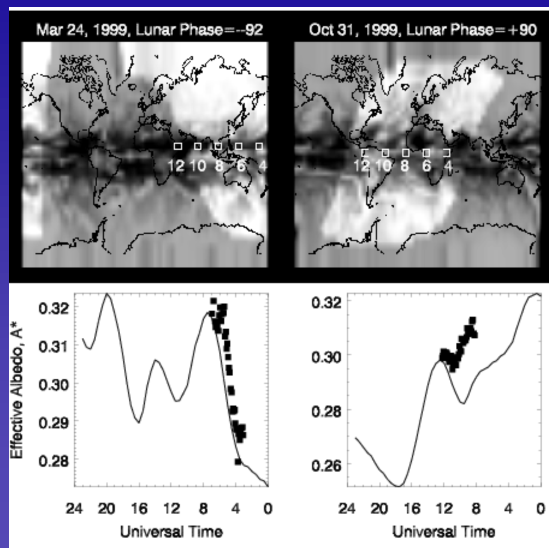
Two Typical Nights



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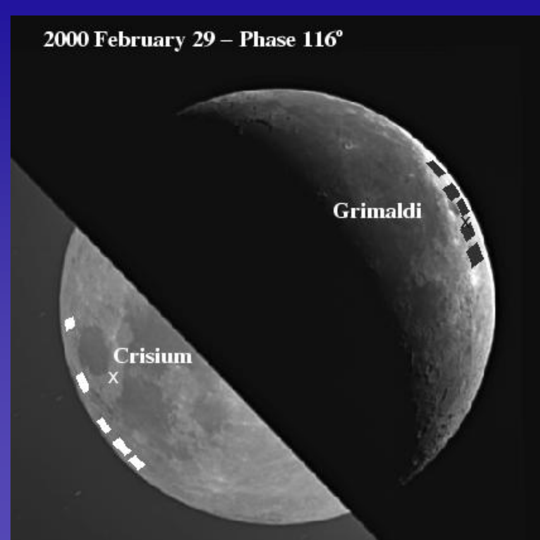
Observations of the Earthshine

- Our fiducial points – chosen to be in the highlands near the lunar limb
- Each has its own lunar phase function



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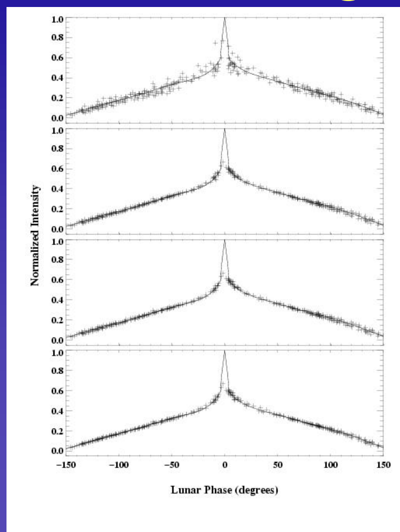
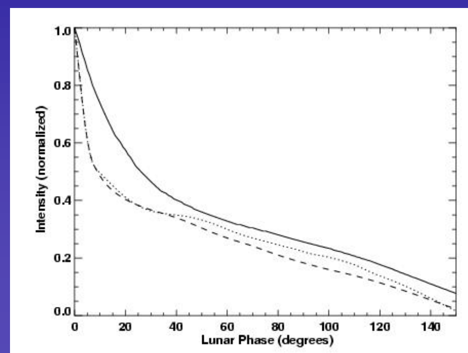
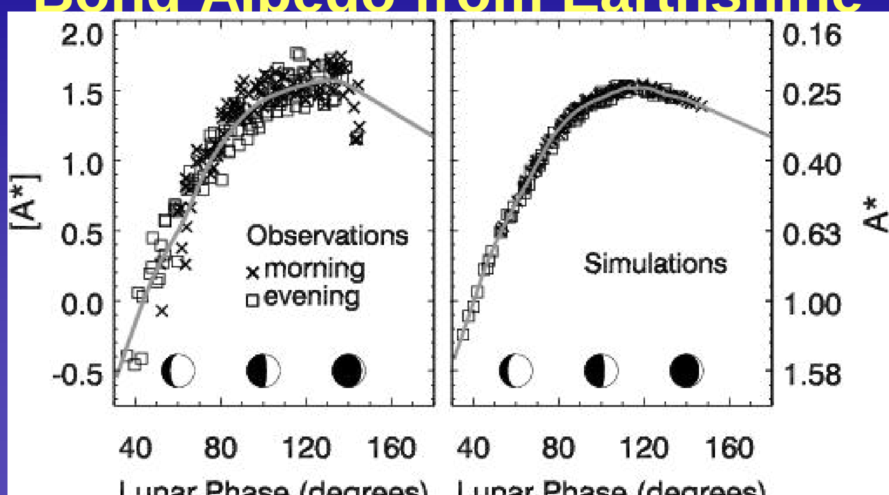
The Lunar Phase Function – Scattering from the Moon



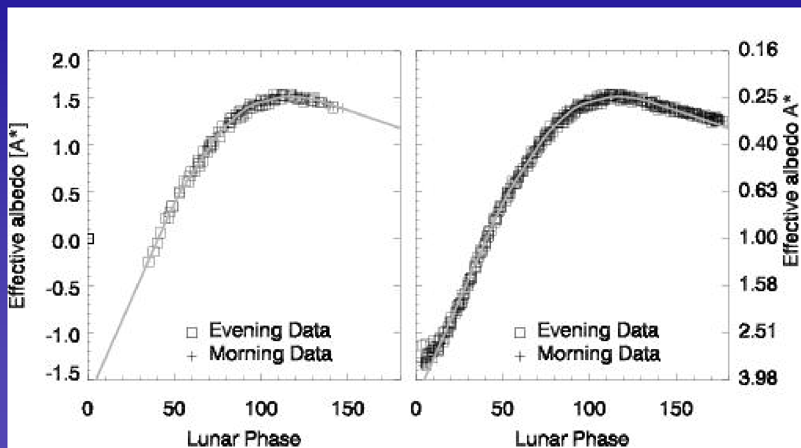
- Danjon's Lunar Phase Function vs. Ours for Morning and Evening



Observations (A=0.297±0.005) & Simulations (A=0.296±0.002) of Bond Albedo from Earthshine



Earthshine Simulations vs. Whole Earth Albedo



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The Earth's Albedo: Results

- From 1999-2000 observations : A=0.297±0.005
- From 1999-2000 simulations: A=0.296±0.002
- The difference in errors is due 20% seasonal variation in observations (10% in simulations)
- Some 1994-1995 results imply albedo that is 2.5%±1.8% larger

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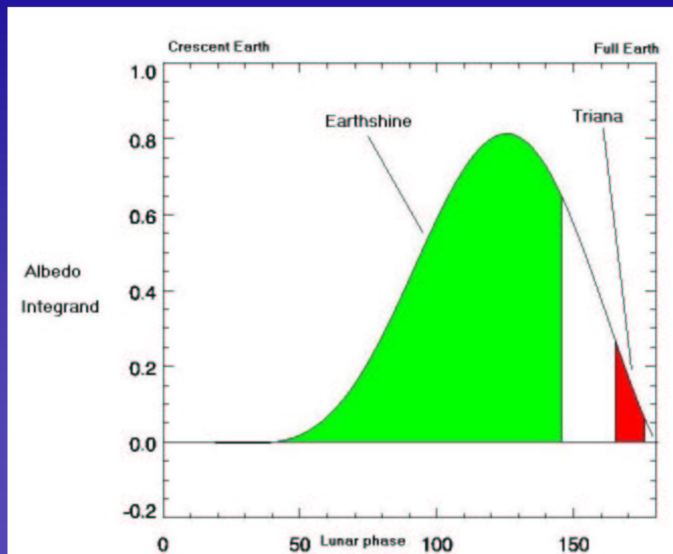
Bond Albedo Integrand



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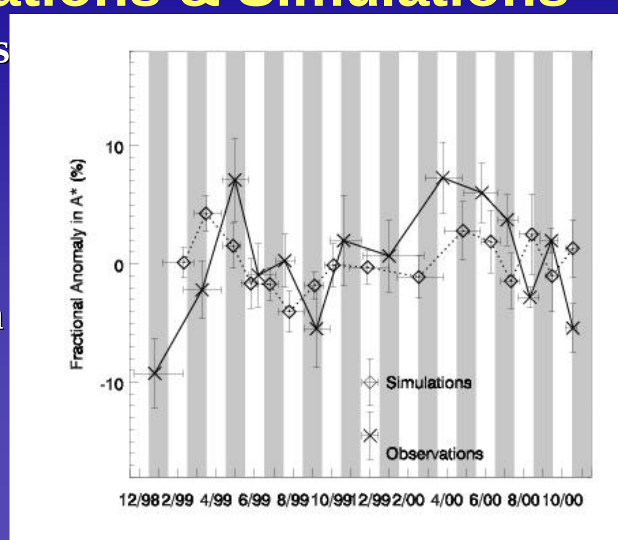
Seasonal Changes: Observations & Simulations

- Observations show 20% seasonal variations
- Too much smoothing in simulations



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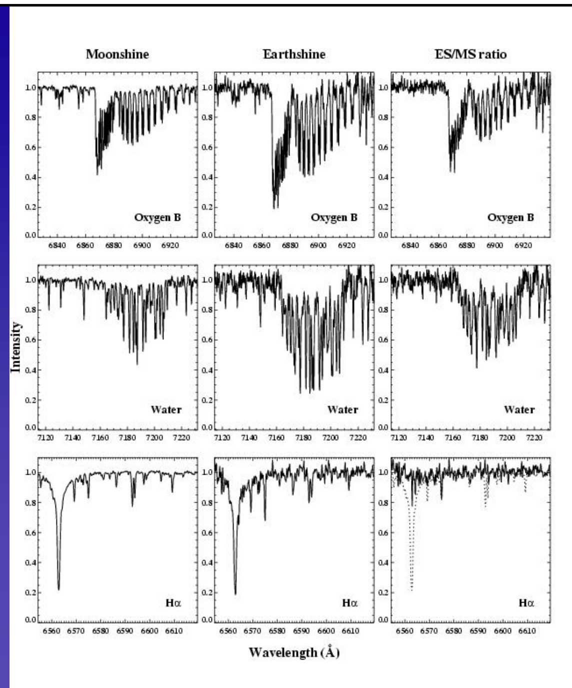
Some Spectral Results from 60'' on Mt. Palomar



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Research

- All aspects of solar activity
- Instrumentation
- Spectro-polarimetry in the visible and NIR
- Synoptic full disk observations
- Space weather predictions and forecast
- Solar irradiance variability
- Helioseismology
- Coordinated observing campaigns
- Earthshine measurements

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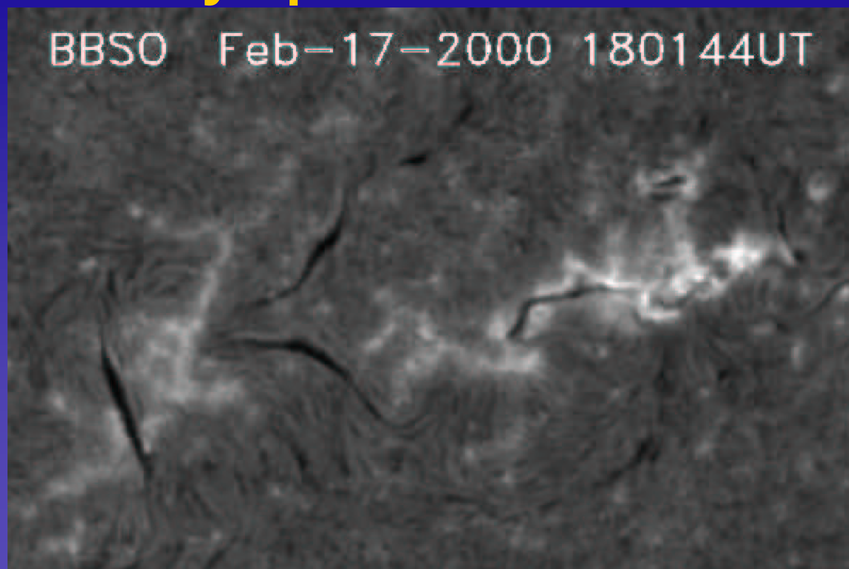
Sympathetic Flares



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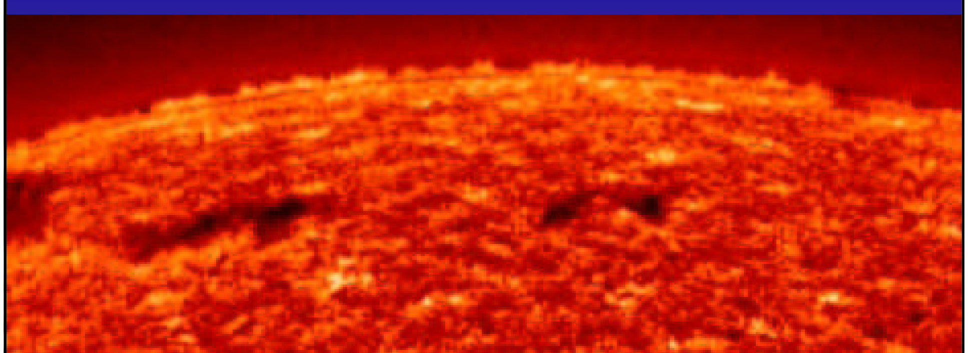
Mercury Transit



November 15, 1999

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New Jersey Institute of Technology

Public Research University

- **8,200 students in 76 programs (Bachelor/PhD)**
  - College of Science and Liberal Arts
    - Physics Department
    - Center for Solar Research
      - Big Bear Solar Observatory
      - Owens Valley Solar Array
        - NJIT's remote research facilities

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Overview

- **Overview**
  - Sun is a Unique Astrophysical Laboratory
  - Touchstone for all of astronomy
- **Hα**

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Research

- All aspects of solar activity
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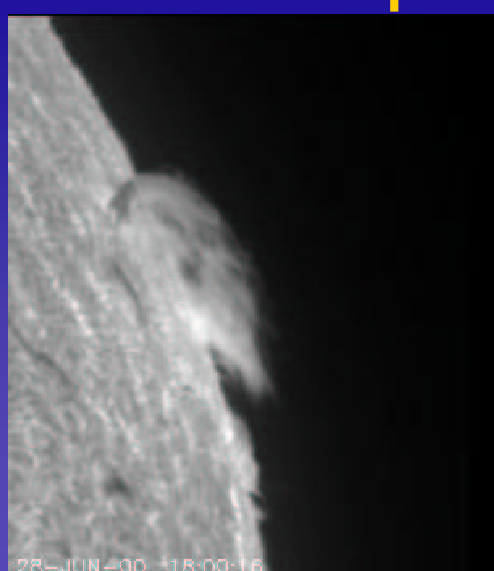
Prominence Eruption



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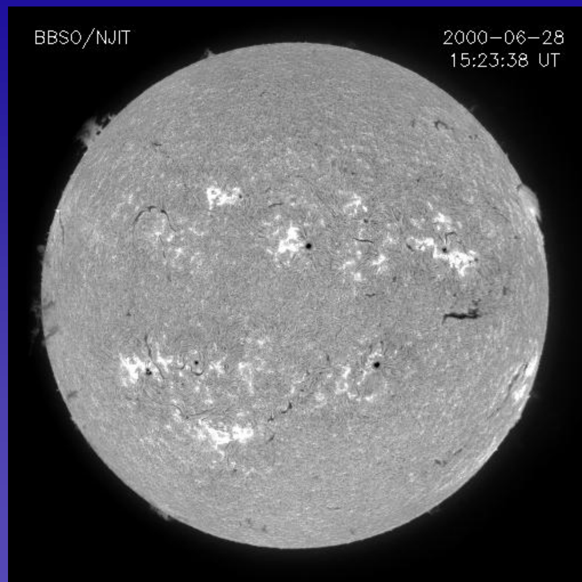
Hα Image



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The earth's albedo is highly variable

- **Local albedo depends upon:**
  - Surface type
  - Solar zenith angle (time of day)
  - Meteorology (clouds)

	Clear	Overcast
Land	0.16	0.50
Ocean	0.08	0.44
Desert	0.23	
Snow	0.68	

- **The global albedo varies with the seasons**
  - North/South land symmetry
  - Snow/ice cover

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