# Things You can Learn about the Sun

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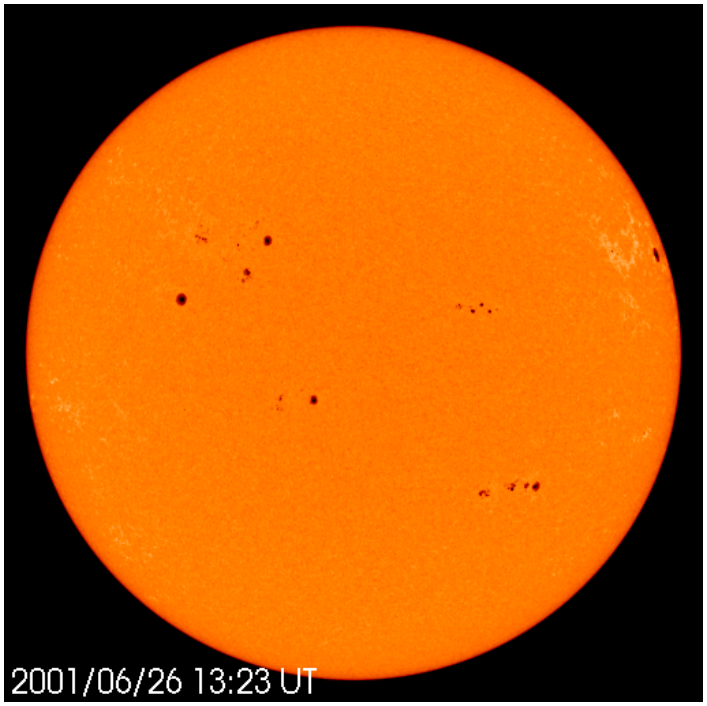
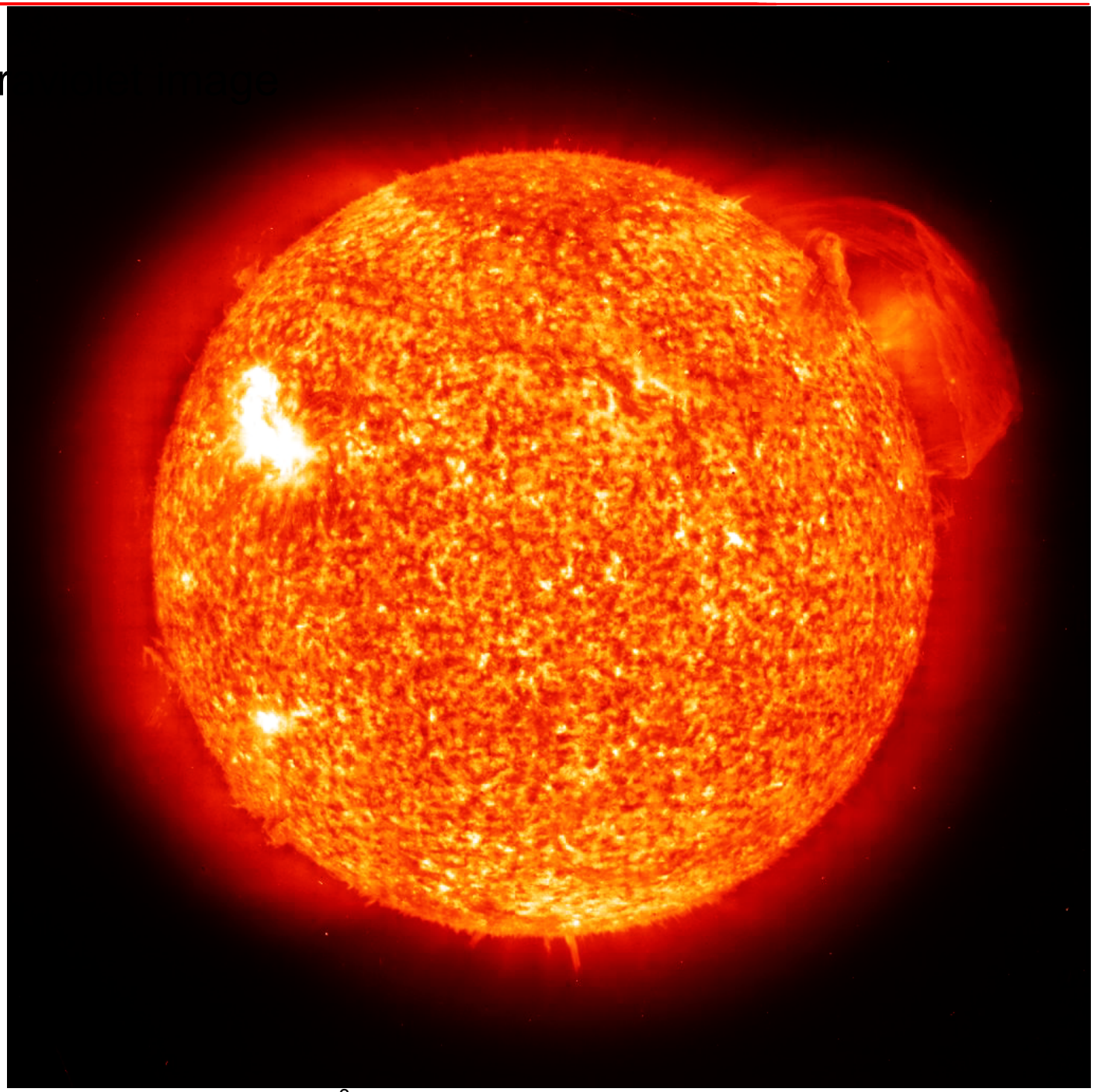
# The Sun in the Visible

- Today!



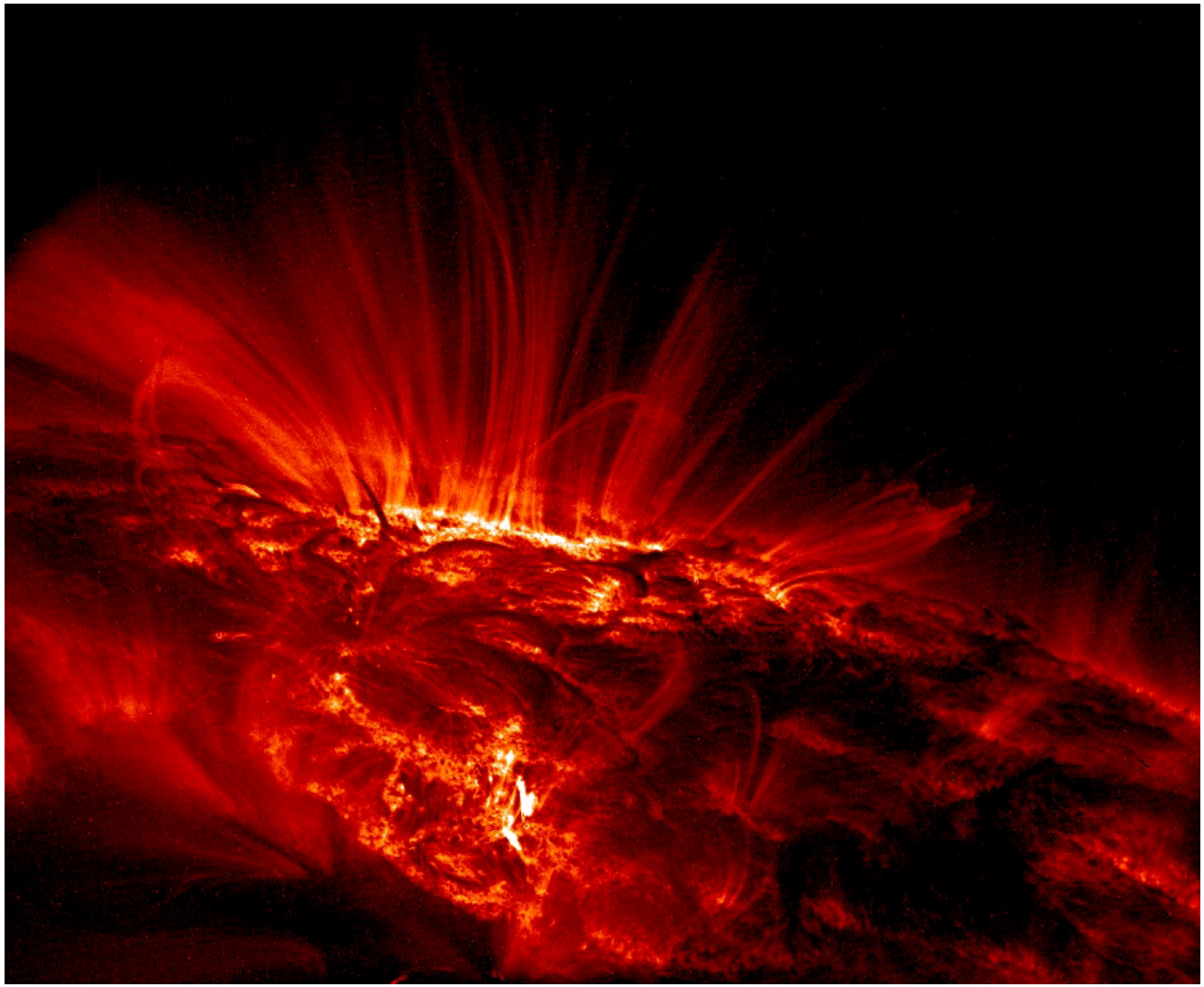
# The Sun in the Extreme Ultraviolet

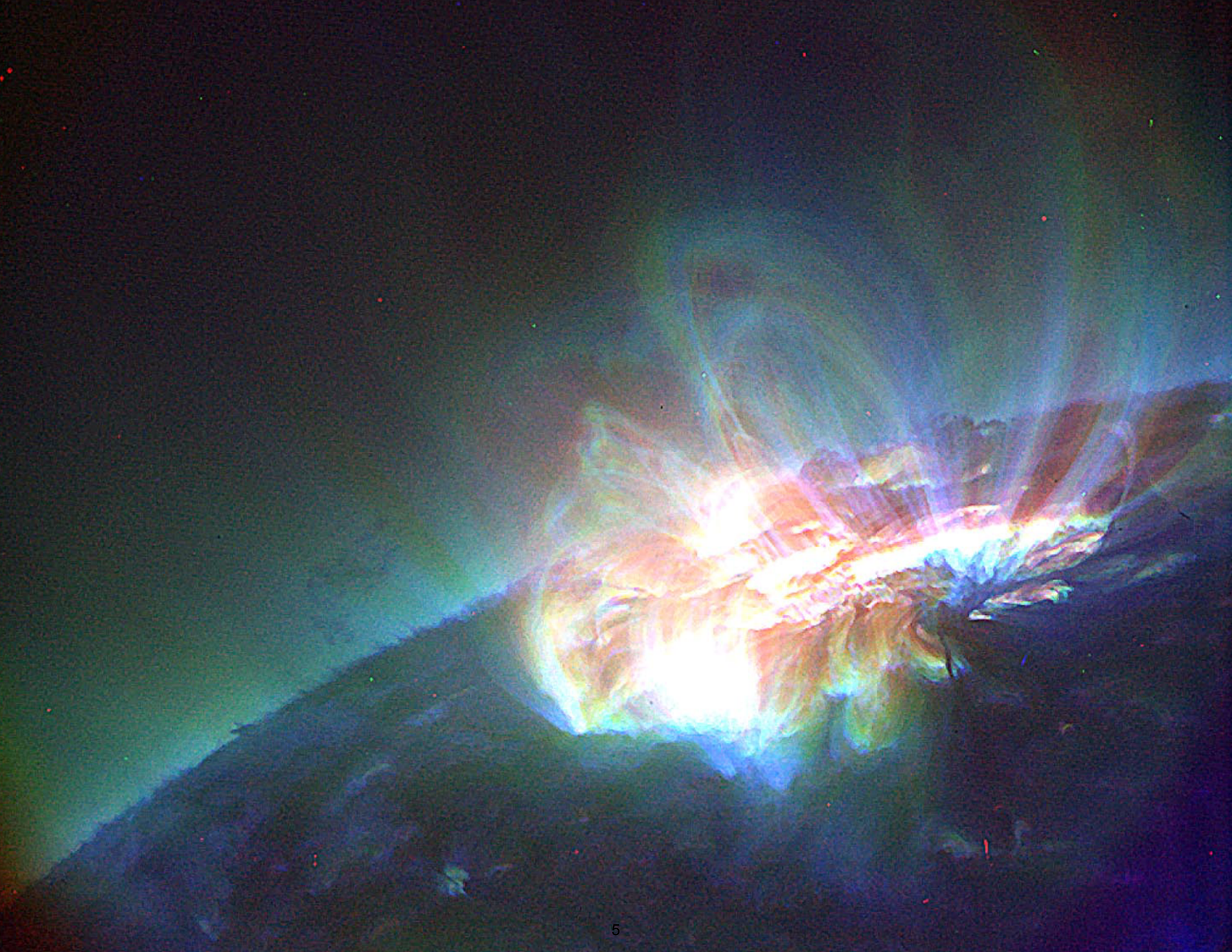
- SoHO extreme ultr… image
  - 304 Angstroms
  - 60,000-80,000 K



# The Sun in X-Rays

- TRACE image at 171 Angstroms
  - 1,000,000 K gas

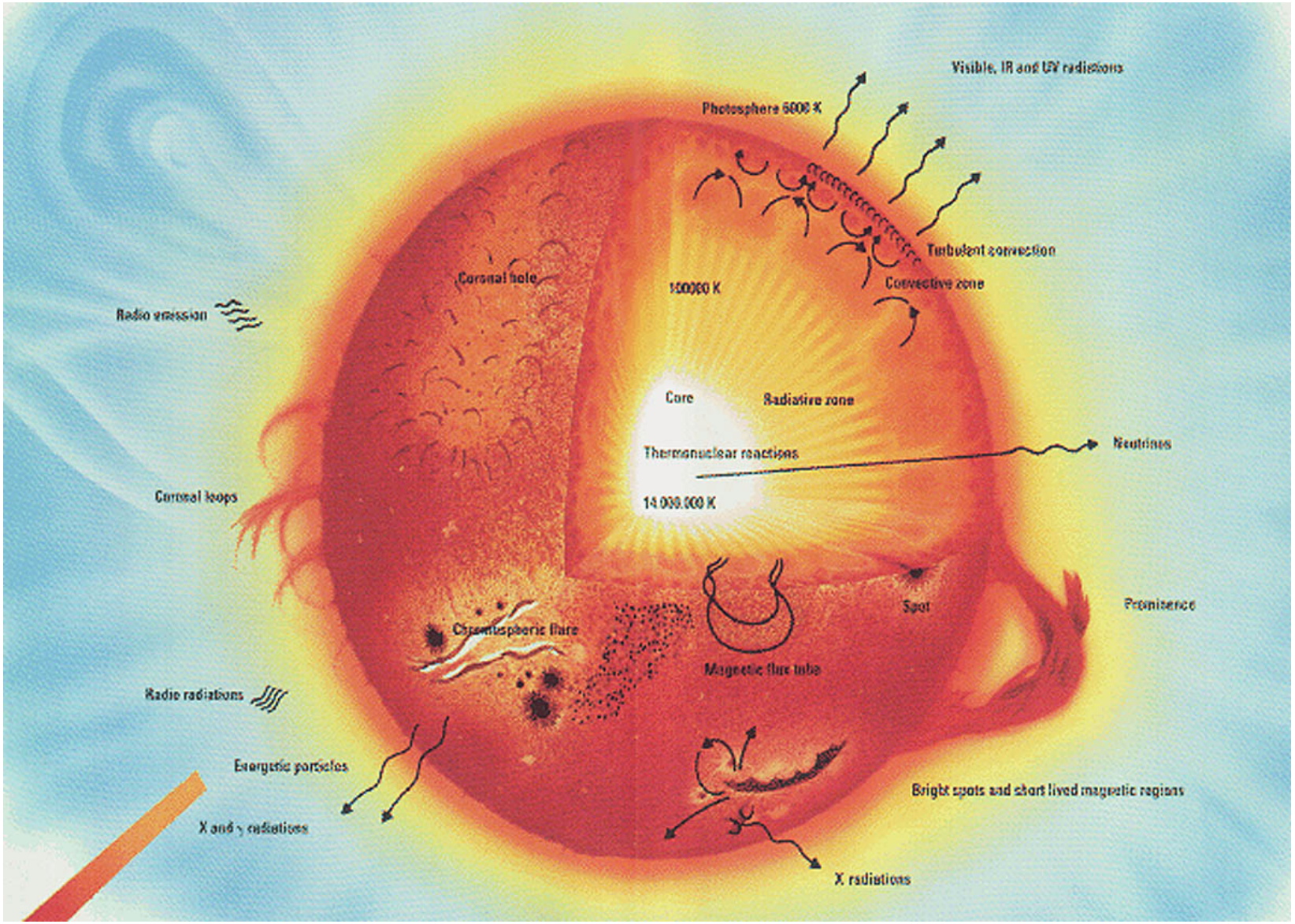




# Vital Statistics of the Sun

- Age:  about 4.5 billion years
- Radius: 696,000,000 km (about 432,500 mi)
  - This is about 109 times the size of the Earth
- Mass: $1.989 \times 10^{30}$ kg
  - About 333,000 times the mass of the Earth
- Surface temperature: 5,500° C  (9,900° F)
- Core Temperature: 14 million degrees C
  - That's 25 million degrees F
- Distance from us: 149,600,000 km (92,956,000 mi)
- Rotation period at equator: 26 days
- Rotation period at the poles: 37 days

# Internal Structure of the Sun



# The Photosphere

- Most of the white light we see radiates from the *photosphere* (the visible surface of the Sun).
- The photosphere is *very* thin — only about 500 km!
- Density is only about 0.01 percent (by mass) of that of the air you're breathing.
- Upon close inspection through a telescope, you will see *granulation*. The granules are the tops of convection cells. (The Sun's atmosphere is literally boiling!)
  - Granule diameters are typically 700-1500 km.
  - Individual granules last about 8 minutes on average.

# The Photosphere *(continued)*

- You might also see *pores* through a telescope.
  - Individual magnetic flux tubes can get grouped together by convective motions of the photospheric plasma.
  - When three or four flux tubes merge, the result is a pore, visible in a telescope as a tiny dark dot.
  - Pores are about 1500-2000 km in diameter.
- Much easier to see are *sunspots*.

# Sunspots

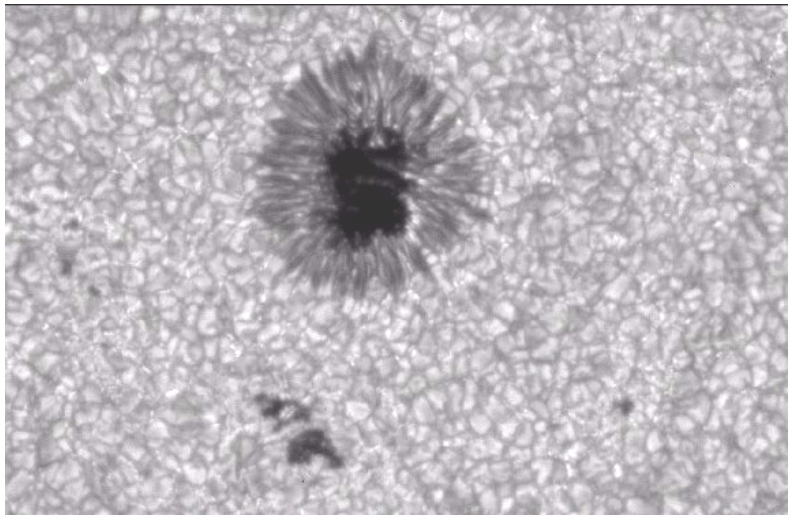
- Sunspots are cooler regions in the photosphere.
  - Between 500° C and 2000° C cooler.  This is why they appear dark compared to their surroundings.
- Strong magnetic fields emanate from sunspots.
- Solar flares (huge explosions of energy) occur in association with sunspots and their strong magnetic fields.
- We don't fully understand yet why sunspots are cooler, but it could be that the magnetic fields are inhibiting convection.
  - Convection transports energy from the interior.  Inhibit convection, and there's less energy at the surface.

# Sunspots *(continued)*

- Sunspots typically grow over a few days and last anywhere from a few days to a few months.
- Viewing sunspot locations over many days allows us to "see" the solar rotation.
  - The Sun rotates *differentially*. That is, the equatorial regions rotate at a different rate than the polar regions.
- Sunspots show two major features visible in white light through any telescope:
  - Umbra: the dark, central part. The umbra is the coolest part of a sunspot.
  - Penumbra: the lighter (and hence warmer) region surrounding the umbra. One often sees filament structure (*convective rolls*) in the penumbra.

# Sunspots *(continued)*

- Here is a high-resolution image of an isolated small spot. Notice the following features:
  - Umbra
  - Penumbra
  - Penumbral filaments (convective rolls)
  - Granules
  - Pores



# Sunspots *(continued)*

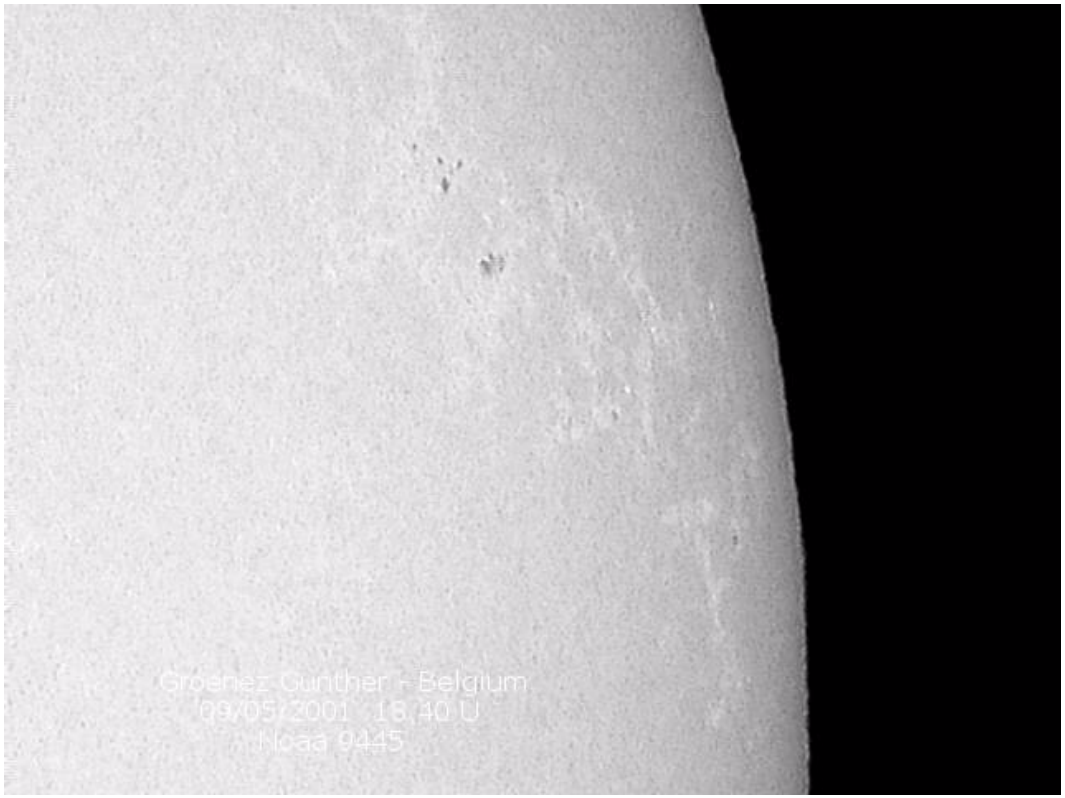
- Sunspots occur singly, in pairs, or in groups.
  - Sunspot groups comprise anywhere from two up to a dozen or more sunspots.
- Sunspots most frequently occur in pairs.
  - A large magnetic flux tube breaks through the surface in one spot and goes back down through the other spot.
- Sunspots occur within *active regions*.
  - You can see active regions in a telescope as bright *plages* of emission.
- Sunspot activity occurs on an eleven-year cycle (the *solar cycle*, or the *sunspot cycle*).

# Sunspots!

- A large sunspot group
  - Taken by an amateur astronomer in Belgium, using a 5.7-inch refractor
  - Notice the *umbrae*, *penumbrae*, and *light bridges*.

# Sunspots!

- Notice the *faculae* (bright network)
  - Faculae are the boundaries of convection *supergranules*.

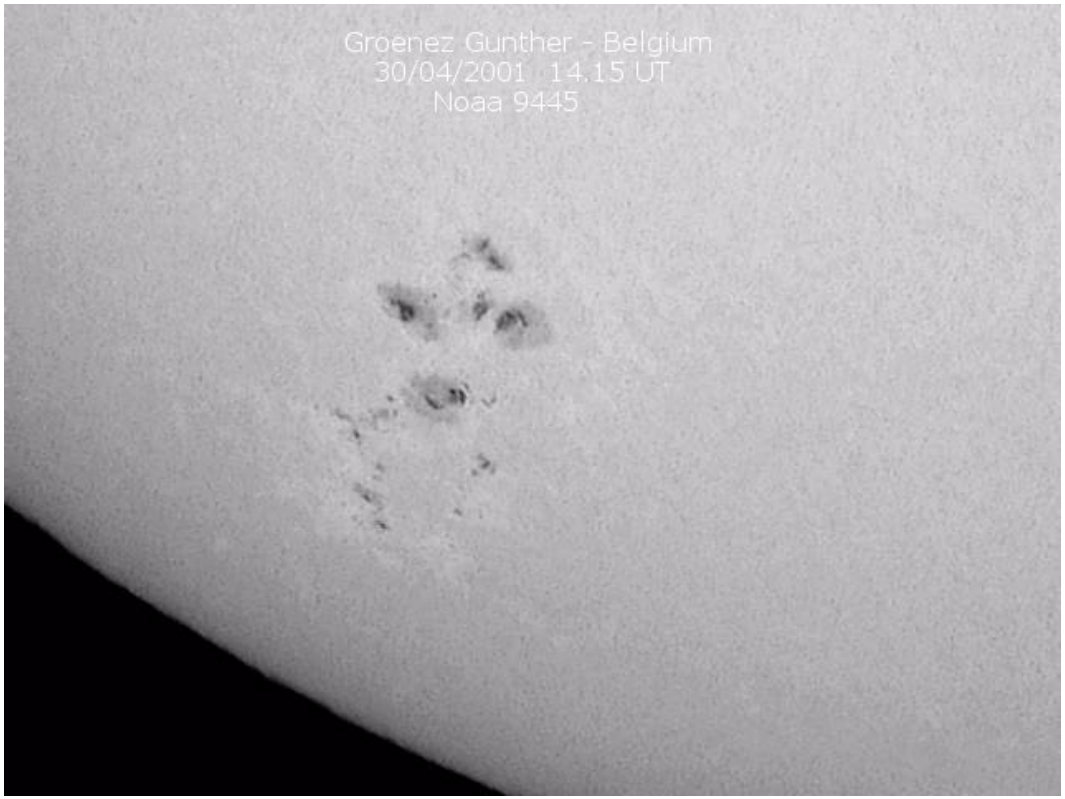


# Sunspots!

- A single spot (notice the *light bridge* and the penumbral filaments).
- Surrounding, notice the *granulation*, and *pores*.

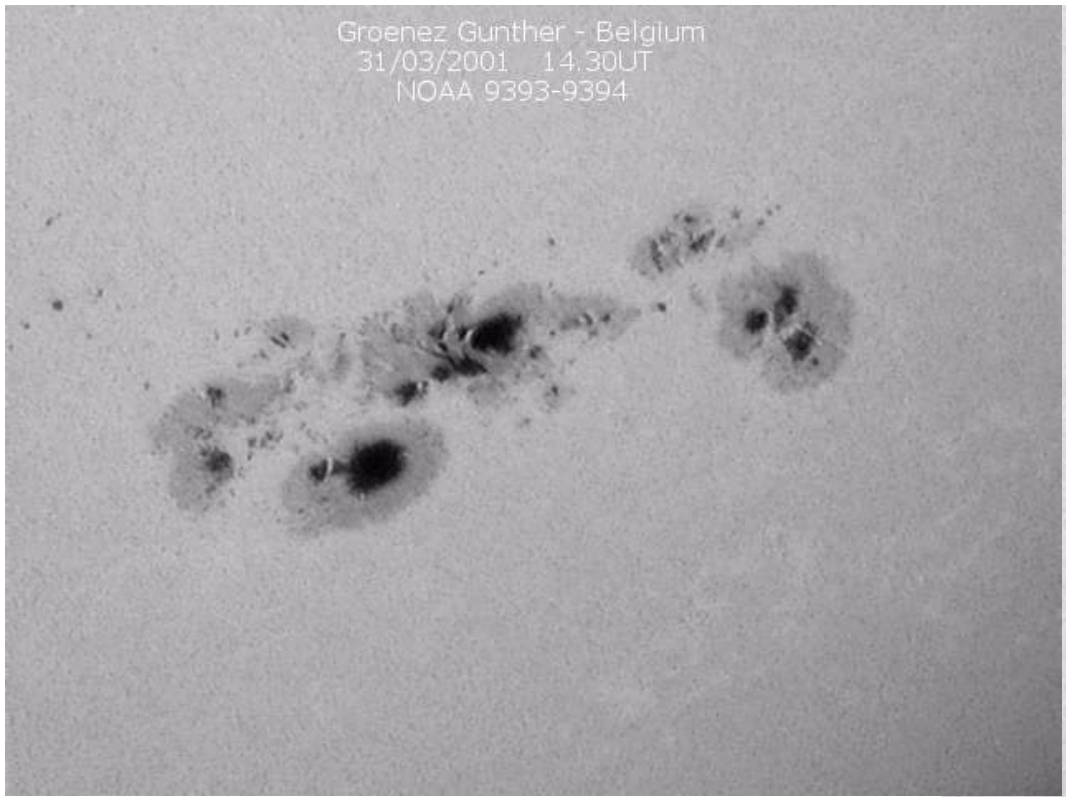
# Sunspots!

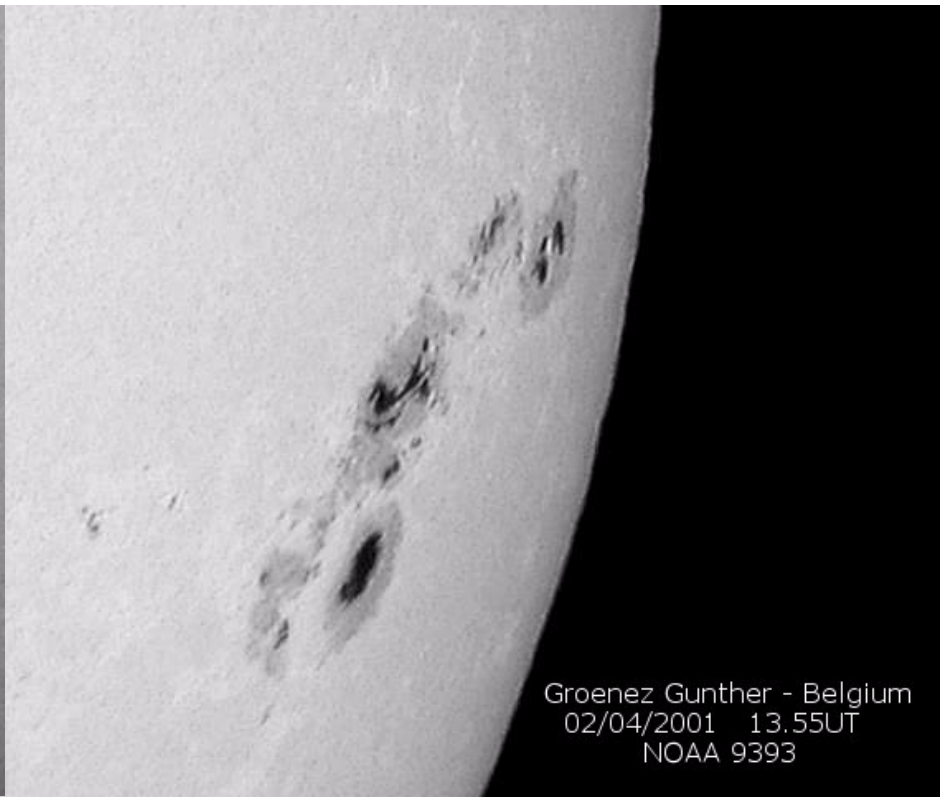
- Another complex group.



# Sunspots!

- Two views (taken two days apart) of a beautiful and complex spot group.



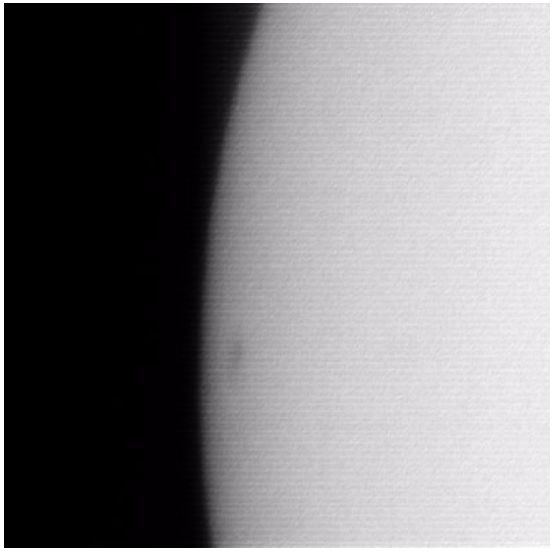
# Observing Projects You Can Do

- Sunspot counts
  - Make sunspot counts at the telescope (demonstration after the talk)
- Drawings of sunspot details
  - Use high magnifications at the telescope
  - It's not as hard as you think!
- View the Sun in H-alpha
  - flares, prominences, etc.
  - Use 12-inch telescope on top of Building 1
- Follow sunspot groups over days and weeks
  - *See* the rotation of the Sun
  - Try to detect the Sun's differential rotation
- Observe a large spot or group over hours to days
  - Watch how the spot structure noticeably changes over just a couple of hours
    - size
    - shape
    - penumbra
    - faculae
- Observe the *Wilson Effect* in spots near the limb of the Sun

# Observing Projects You Can Do *(continued)*

- Determine the fraction of the Sun's disk occupied by sunspots
- Challenging phenomena for visual observing:
  - sunspot light bridges
    - watch them change
  - granulation
    - do you *really* see it?
  - penumbral rolls
  - pores (very tough)
  - umbral points (very tough)
  - white light flares (rare)
- Fourier Transform Spectrometer (FTS)
  - Arsen Hajian's project
  - extremely accurate radial velocities (a couple of meters per second)
  - later in the summer

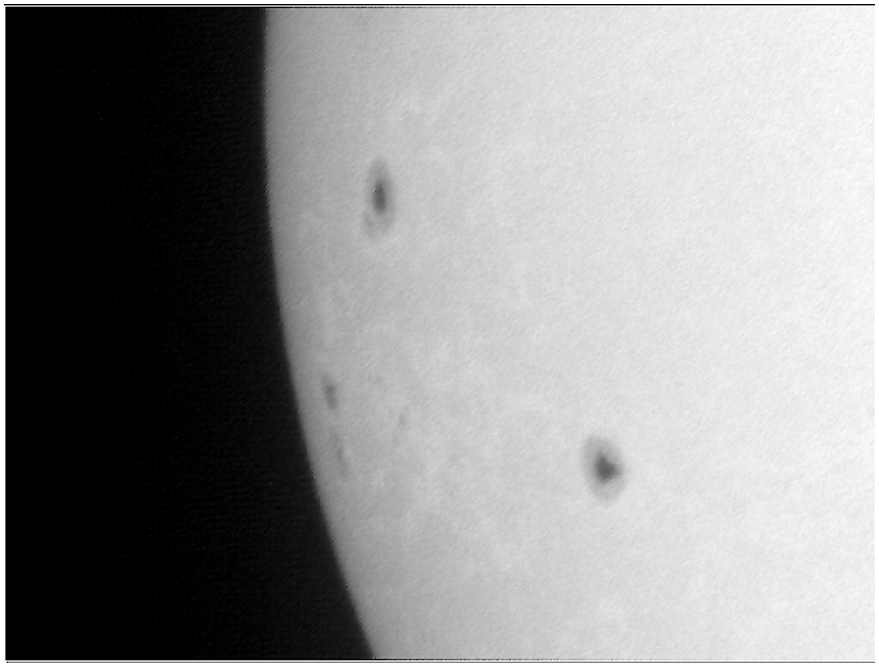
# Instruments: Things *Will* Go Wrong!



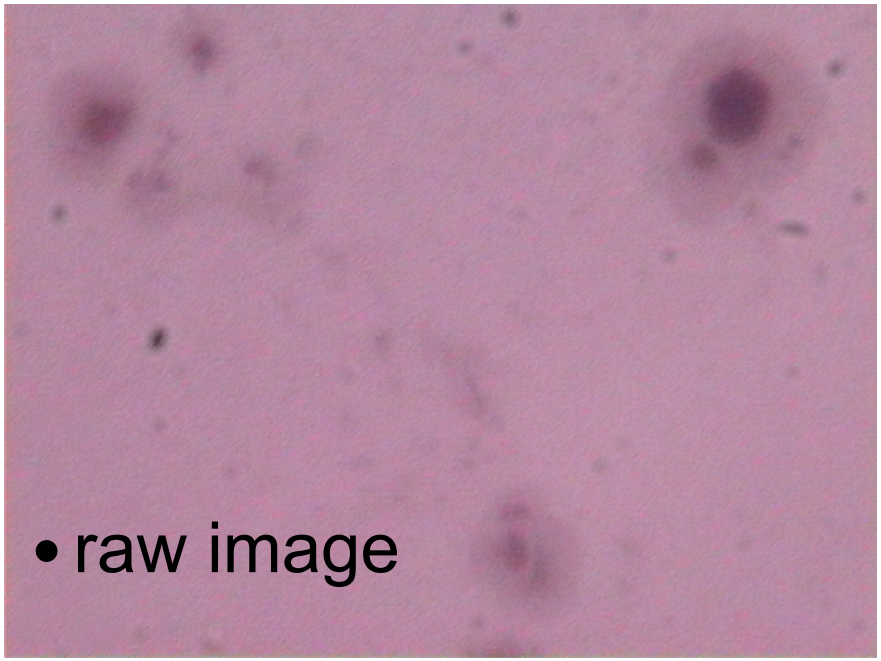
- Blurriness: IR contamination
- Horizontal striping: webcam CCD running hot (dead fan batteries!)

- IR filter added

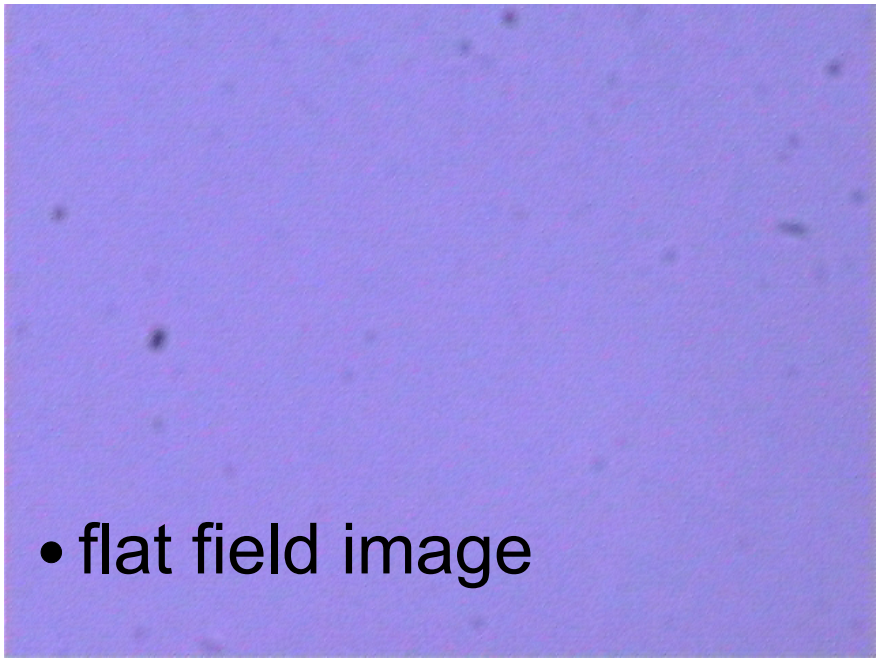
- Air-cooled webcam CCD (no more lines)
- But now the focus is a bit off



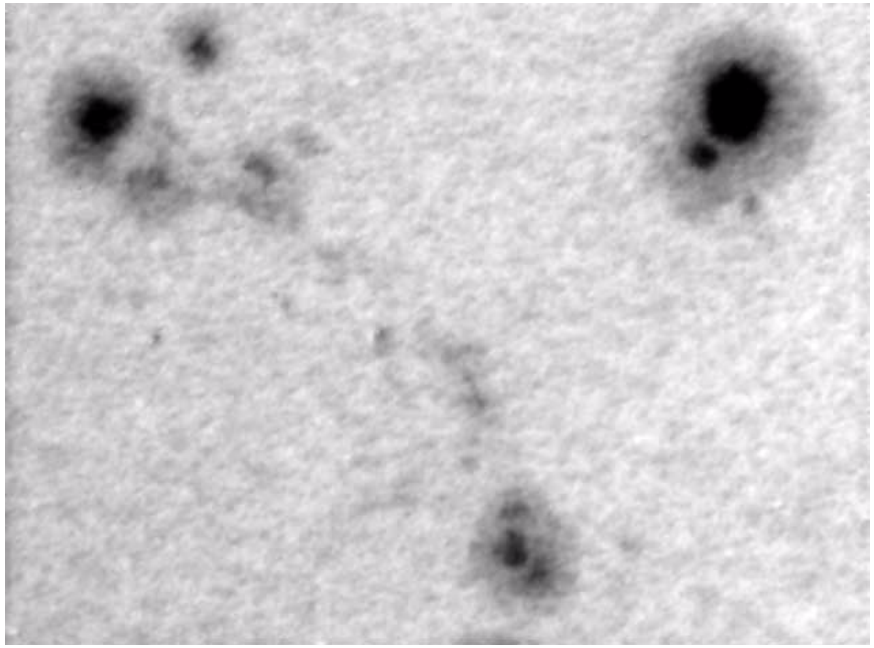
# Got an Image?  You're Not Done Yet!



- raw image



- flat field image



- processed image:
  - grayscale
  - flat field
  - intensity stretch

This was done with a cheap webcam and eyepiece projection with a 4.7-inch refractor

# Solar Physics Topic You Can Learn (and Report!)

- Convection and granulation
- Supergranulation
- p-mode oscillations
  - pressure waves in the solar atmosphere
  - the famous "5-minute" oscillations
  - What do they tell you about the Sun's interior structure?
- g-mode oscillations
  - gravity waves
  - Have they been seen yet?
  - Who is looking for them?
  - What do they tell us about the Sun?
- Radiative transfer
  - What different kinds of information show up in different wavelength bands?
  - What is "optical depth"?
- Magnetohydrodynamics (MHD)
  - Influences of a strong magnetic field on the fluid motions of an ionized gas
  - How is this related to solar flares?

# Solar Physics Topic You Can Learn (and Report!) *(continued)*

- Solar flares
  - How do they work?
  - How are they related to sunspots, magnetic fields, and active regions?
- The solar magnetic field
  - What is a dynamo?
  - How is the Sun's magnetic field generated?
  - Where?
  - How does it affect what we see in the photosphere?  Chromosphere?  Corona?
- The solar magnetic cycle and its observational effects
- Sunspot structure
  - umbra, penumbra
  - magnetic fields
  - plasma flow patterns
- Penumbral structure (convective rolls)
- Light bridges
- Umbral points
- Pores

# Solar Physics Topic You Can Learn (and Report!) *(continued)*

- The Wilson effect
  - How does it work?
  - Who was Wilson?
- Prominences and arcades
- What is the solar chromosphere?
- What is the solar corona?
- What are coronal mass ejections?
  - How do they affect the Earth?
- How does solar activity affect the Earth's magnetic field?
- How does solar activity affect Earth-orbiting spacecraft?
- How do solar filters work?
  - broadband white light filters
  - narrow-band filters such as H-alpha