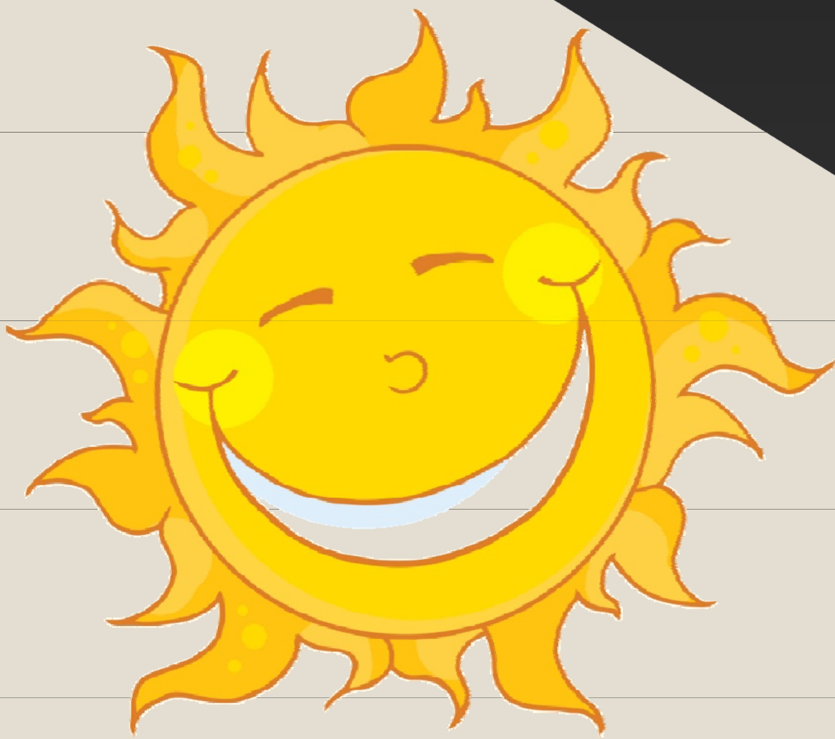
OAWS #16

# Understanding the Universe
## Part 6: The Sun



By Jim Thompson
March 30th, 2017

# Overview

- Where did it come from? → *If time permits*
- What is it doing?
- Where is it heading?

- How do we know what we know?
- What can an amateur see?

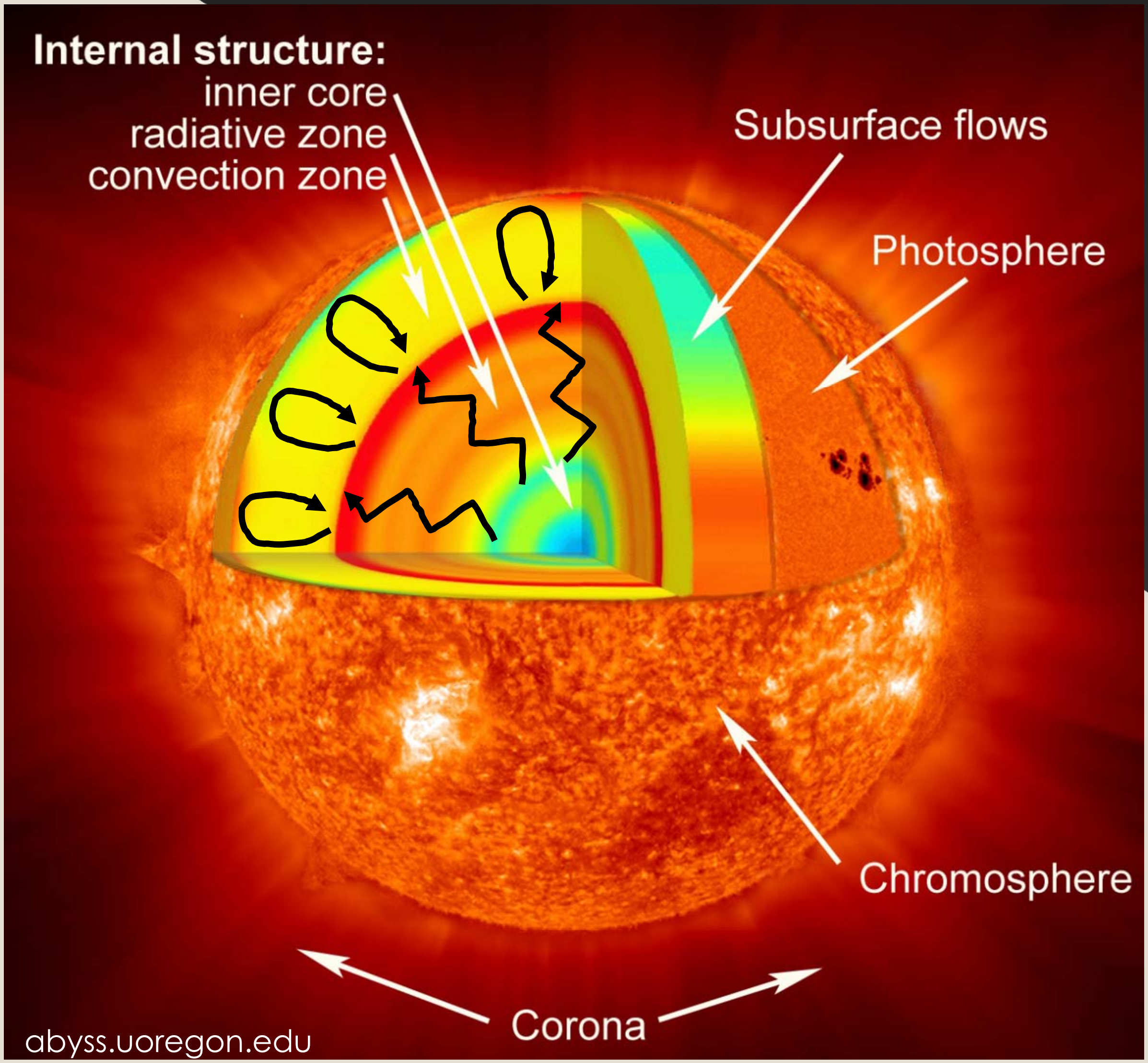
- The Great American Eclipse 2017!

- International Astronomy Day

# Solar Trivia


- spectral type = G2 (yellow/green)
- apparent Mv = -26.7 (4.83 abolute)
- mass = $2x10^{30}$ kg (300k * Earth)
- radius = 696,000 km (109 * Earth)
- composition = 74.9% H, 23.8% He, 1.3% "metals"
- Sun contains ~99.8% of all solar system mass
- Compared to other stars in our galaxy, our Sun is average
- Sun is middle-aged, roughly halfway through a ~10Byr lifespan

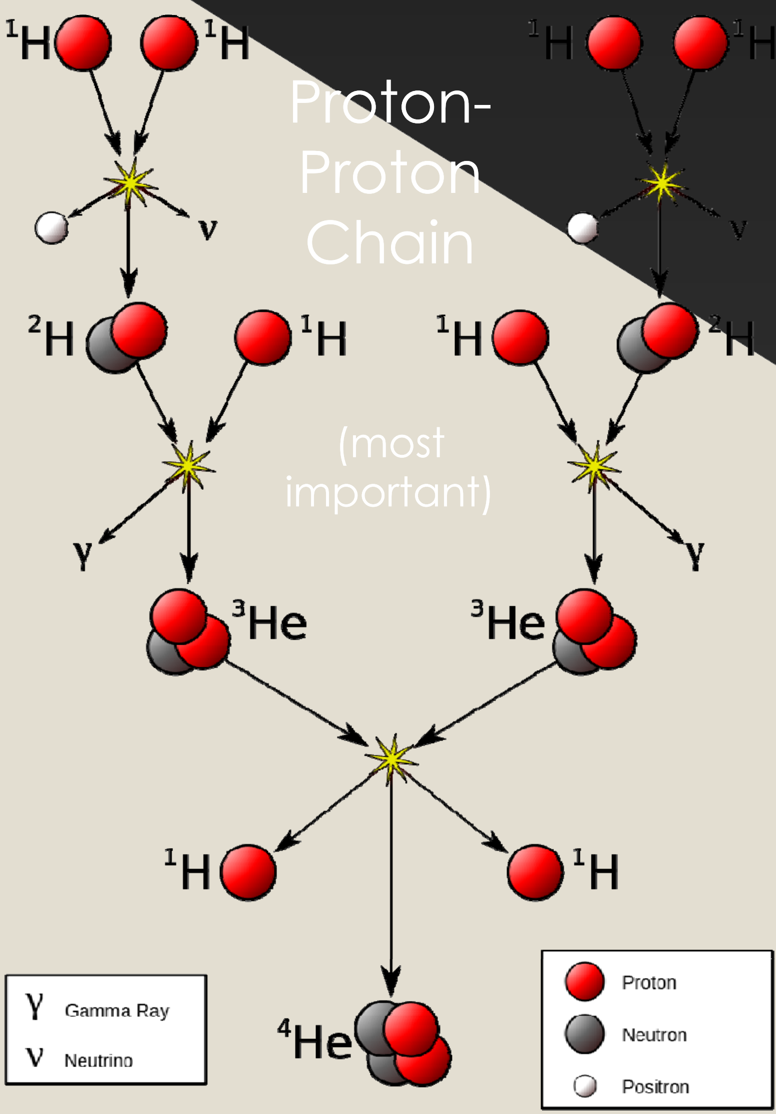
# Anatomy of the Sun




- CORE: fusion engine (25% $R_{sun}$)
- RADIATIVE (25-75% $R_{sun}$)/ CONVECTIVE (75-100% $R_{sun}$) ZONES: transfer energy to surface
- PHOTOSPHERE: photons are free, what we see (peak emission)*
- CHROMOSPHERE: see with Halpha
- CORONA: see during eclipse (or FUV + EUV), hotter than photosphere!

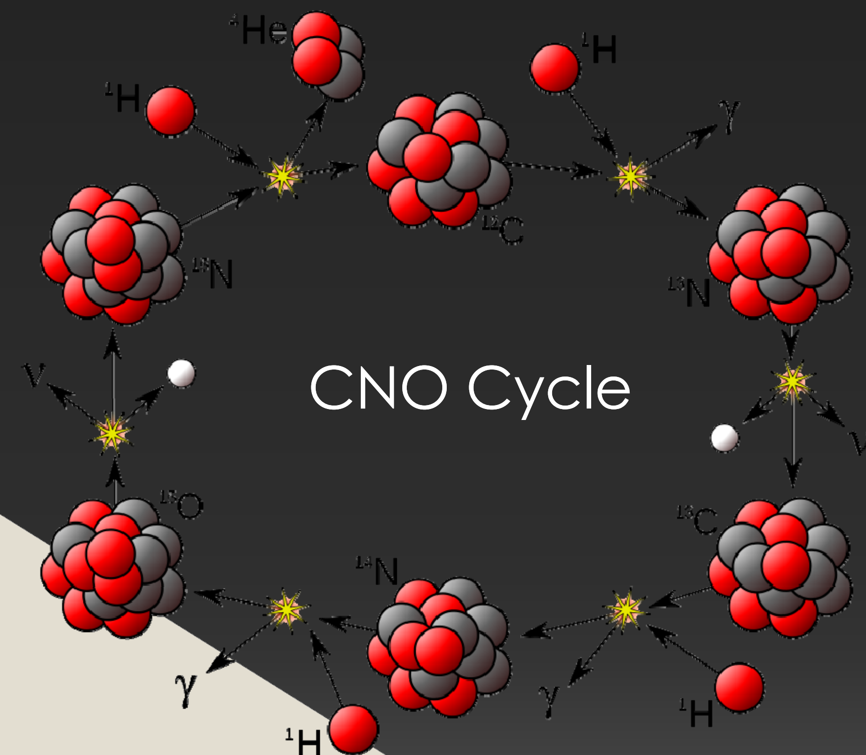
* Takes between 1kyr & 1Myr for a photon produced in the core to make it to the photosphere

# Sun's engine - fusion




Proton-Proton Chain

(most important)



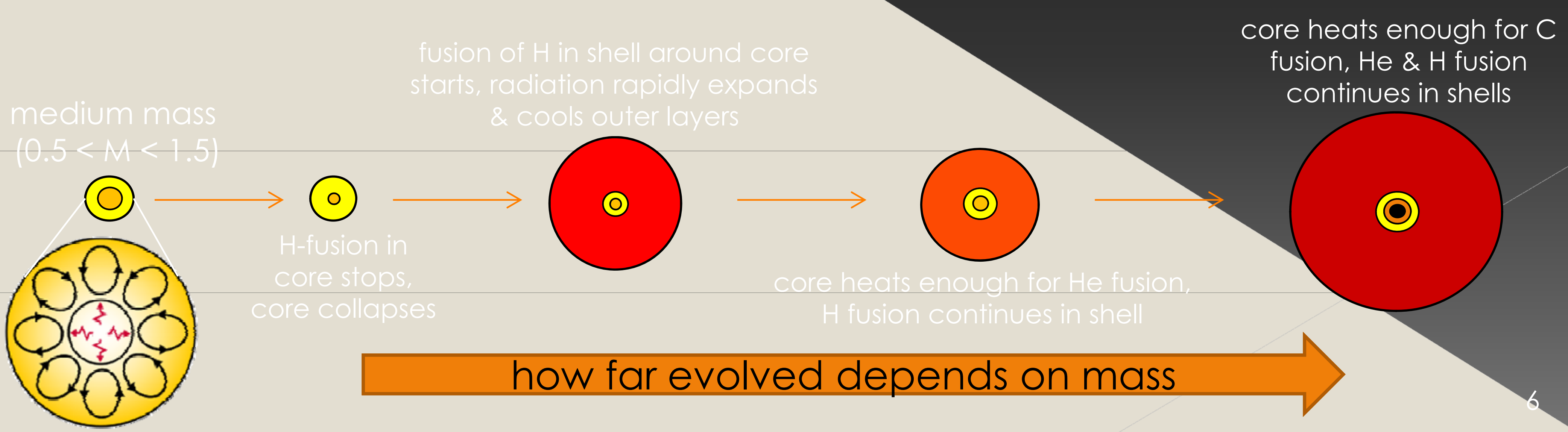

CNO Cycle

- Core energy production ~280 W/m$^3$ (lower than human metabolism)
- ~4 Mtonnes of mass converted to energy per sec – this plus solar wind means Earth-Sun distance increases 1.6cm/yr

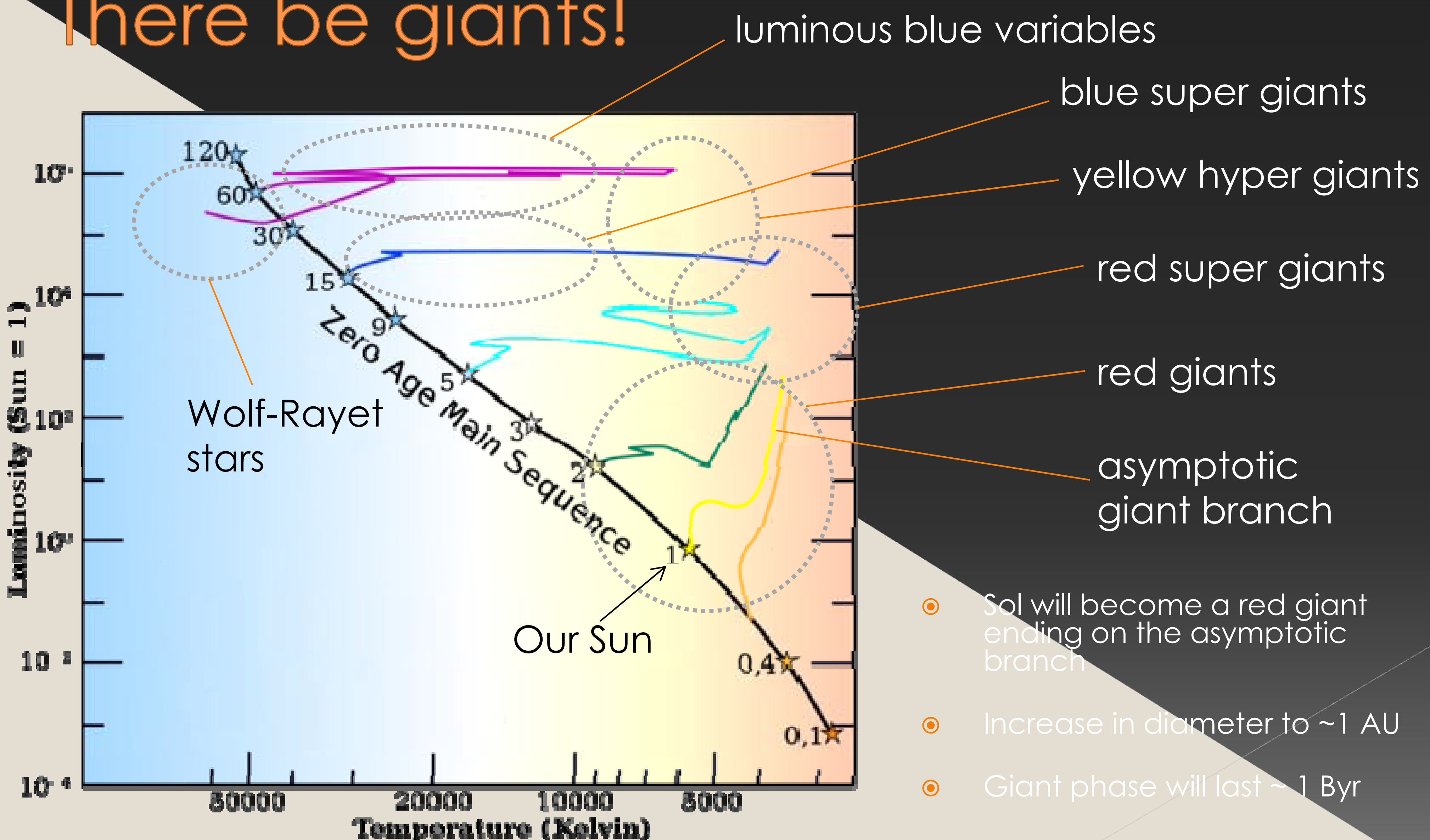
wikipedia.org

# What lies ahead for Sol?

- our star has finite "accessible" supply of fusion-able hydrogen
- when supply of H runs out (5-6 Byr), move to next step in evolution – its giant stage



# There be giants!

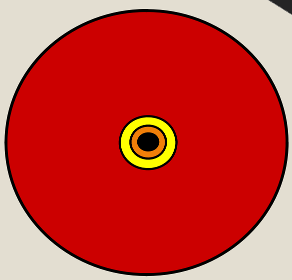



- Sol will become a red giant ending on the asymptotic branch
- Increase in diameter to ~1 AU
- Giant phase will last ~ 1 Byr

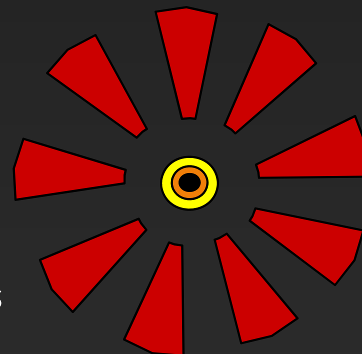
wikipedia.org

# All good things…

medium mass
(0.5 < M < 1.5)

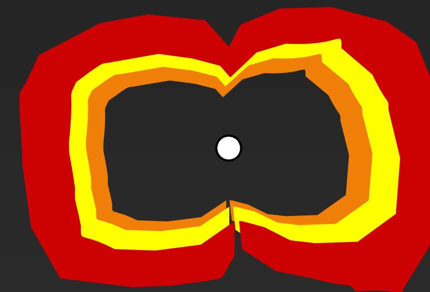


throughout red giant stage (more so at the end), strong solar winds blow outer layers of star into space



once fusion stopped only core remains, surrounded by nebula of star's former outer layers

C or O-type white dwarf
+ planetary nebula



all images: J. Thompson

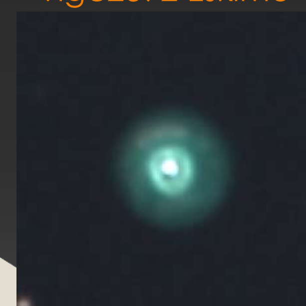
M27 Dumbbell

M57 Ring

M76 Little Dumbbell

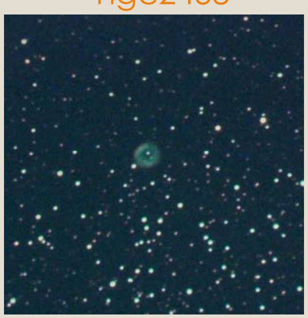
M97 Owl

ngc2392 Eskimo



ngc7008 Fetus

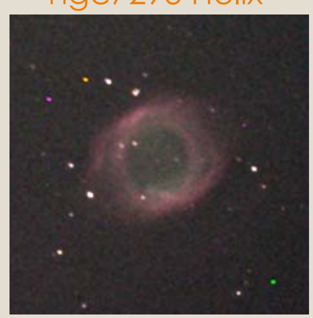
ngc2438



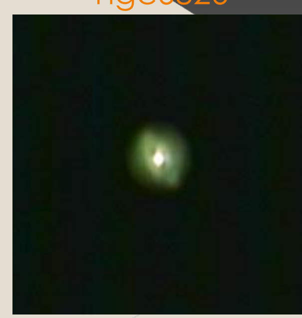
ngc3242 Ghost of Jupiter

ngc7048

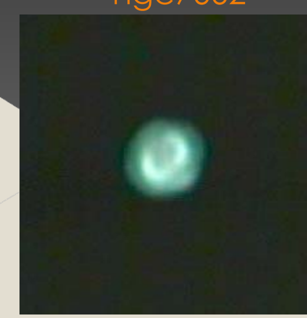
ngc7293 Helix



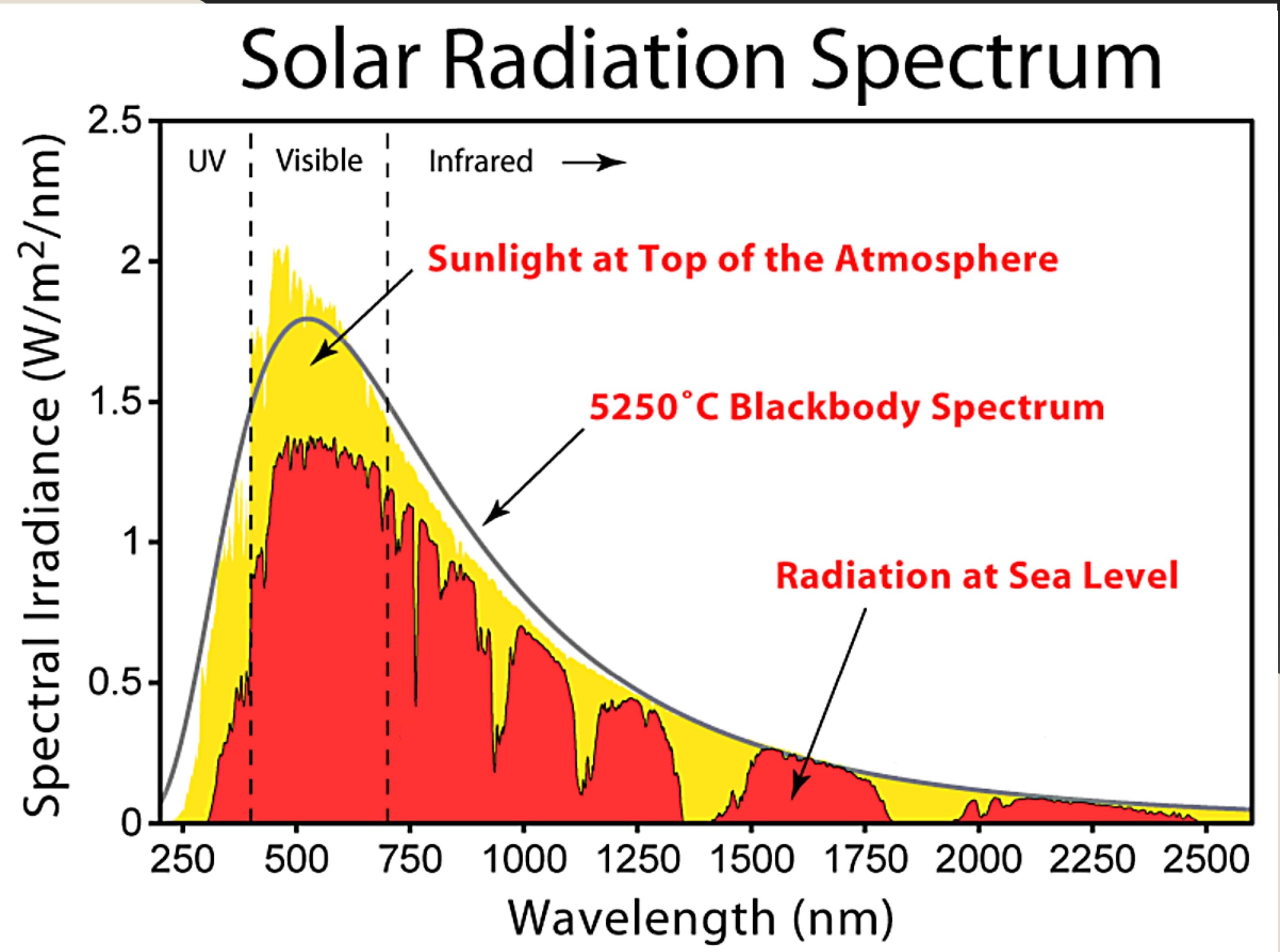
ngc6826



ngc7662



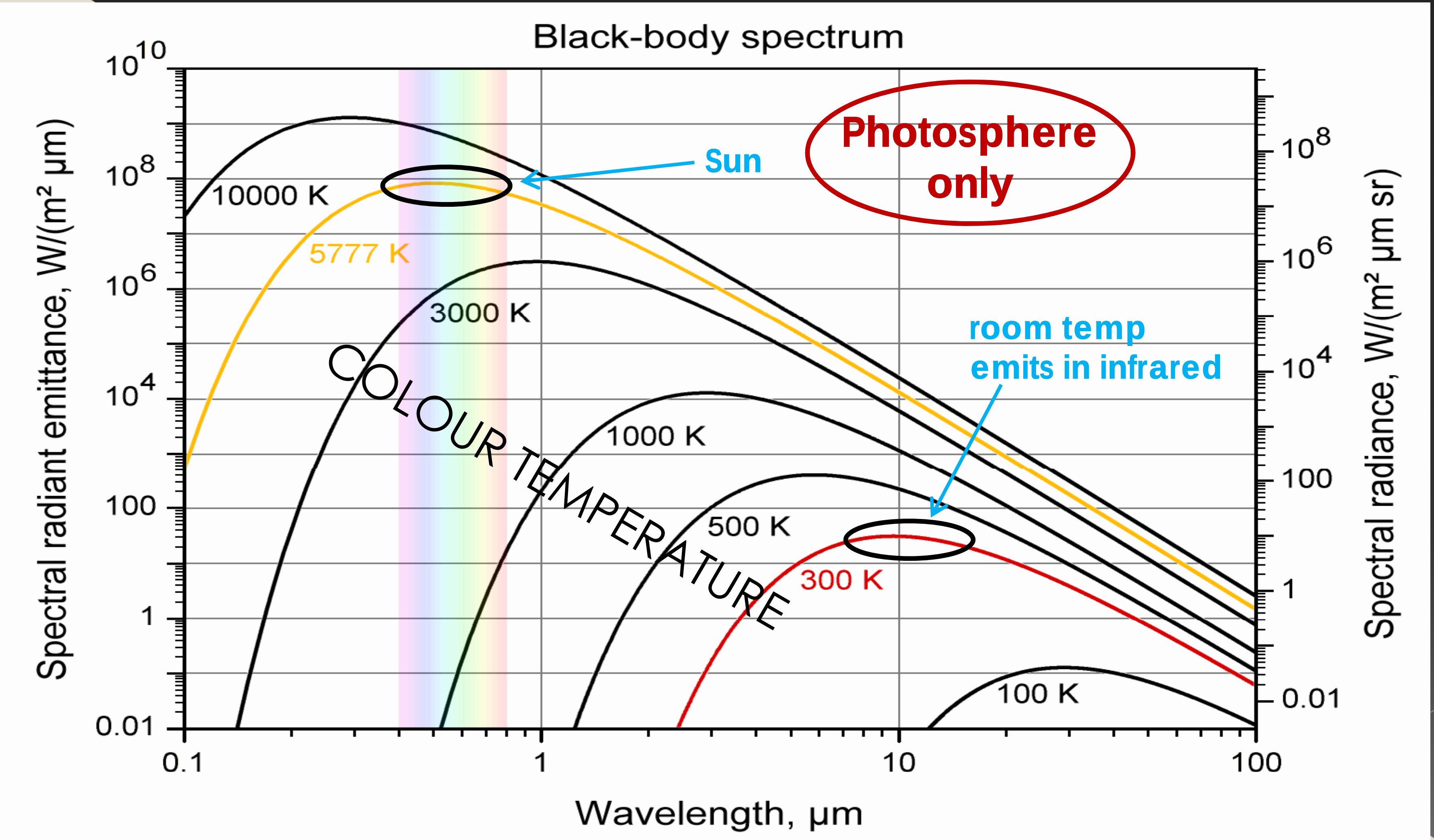
# Solar Observing – Be Safe!




- ½ of Sun's energy is infrared
- without proper protection you're literally cooking your eyes!

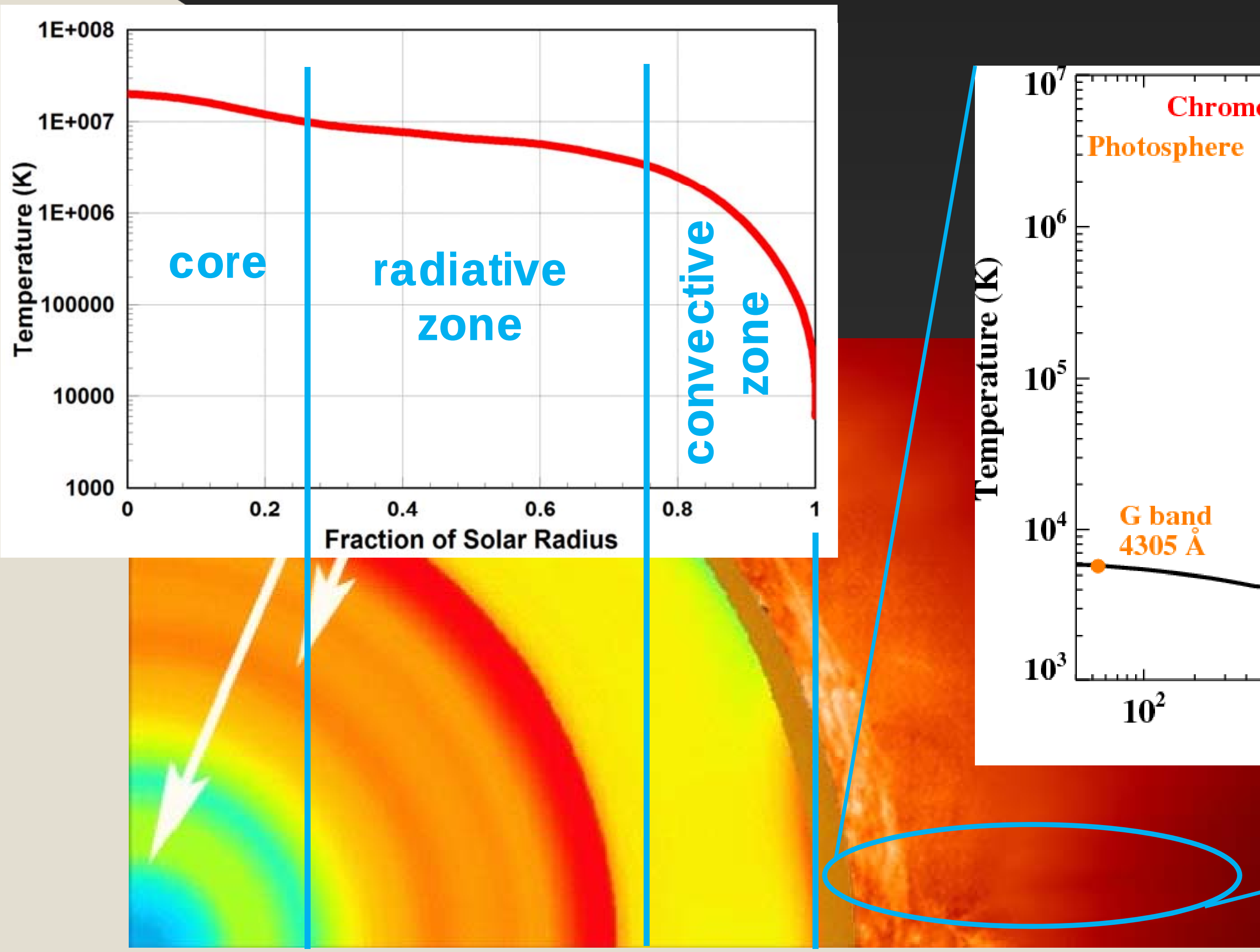
commons.wikimedia.org/ Robert A. Rohde

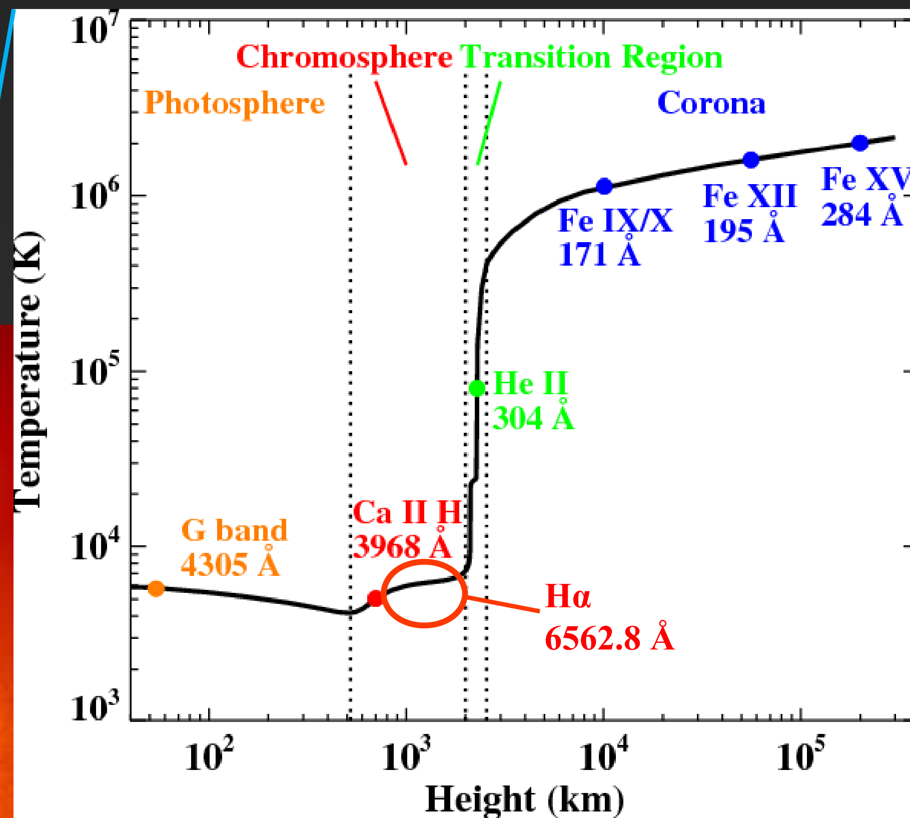
# The Sun is Hot…But How Hot?




commons.wikimedia.org

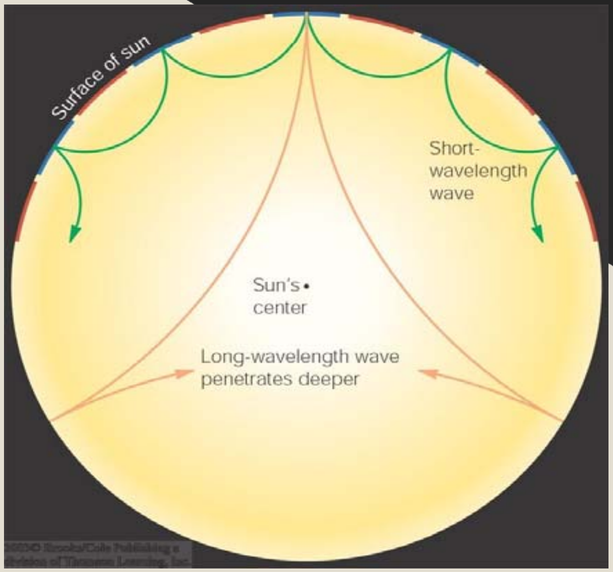
# More than meets the eye

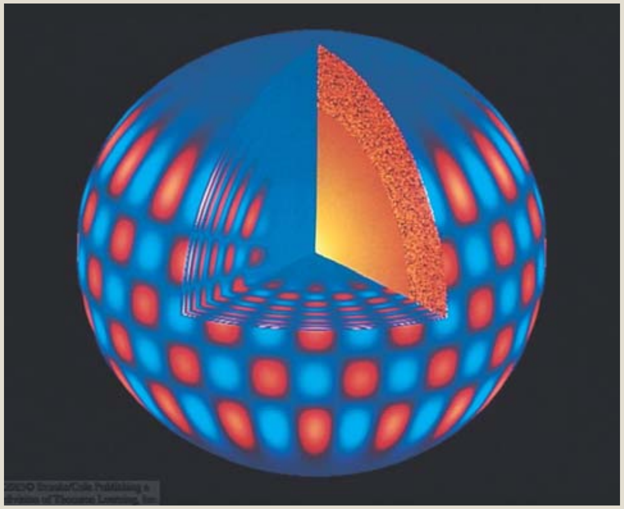


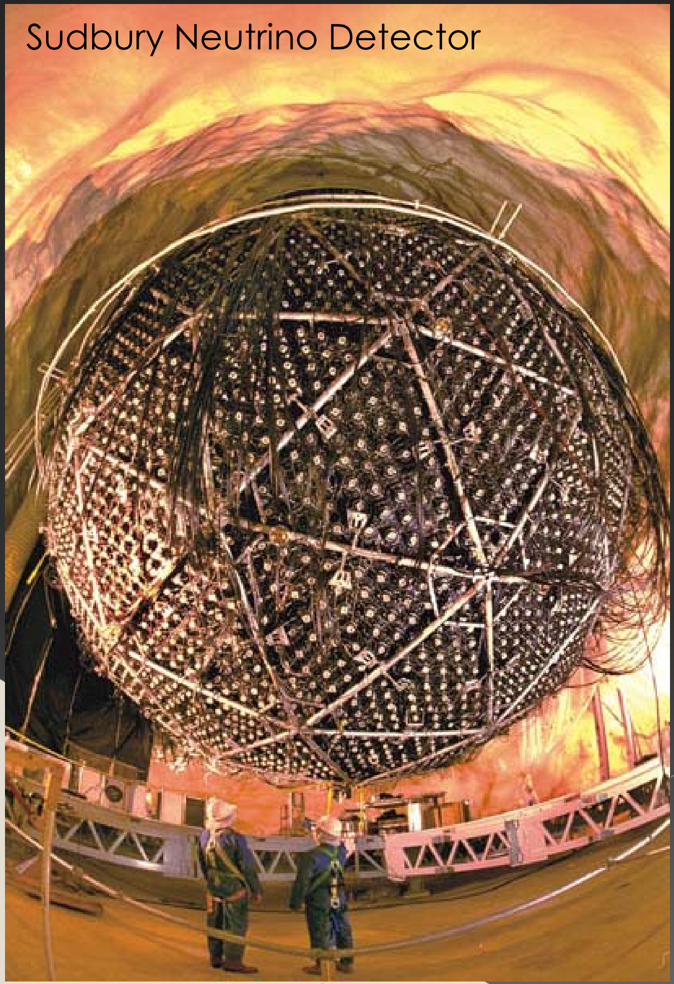

http://www.aanda.org, "Response of the solar atmosphere to magnetic field evolution in a coronal hole region ", S. H. Yang

# How NASA Peels the Onion - Inside



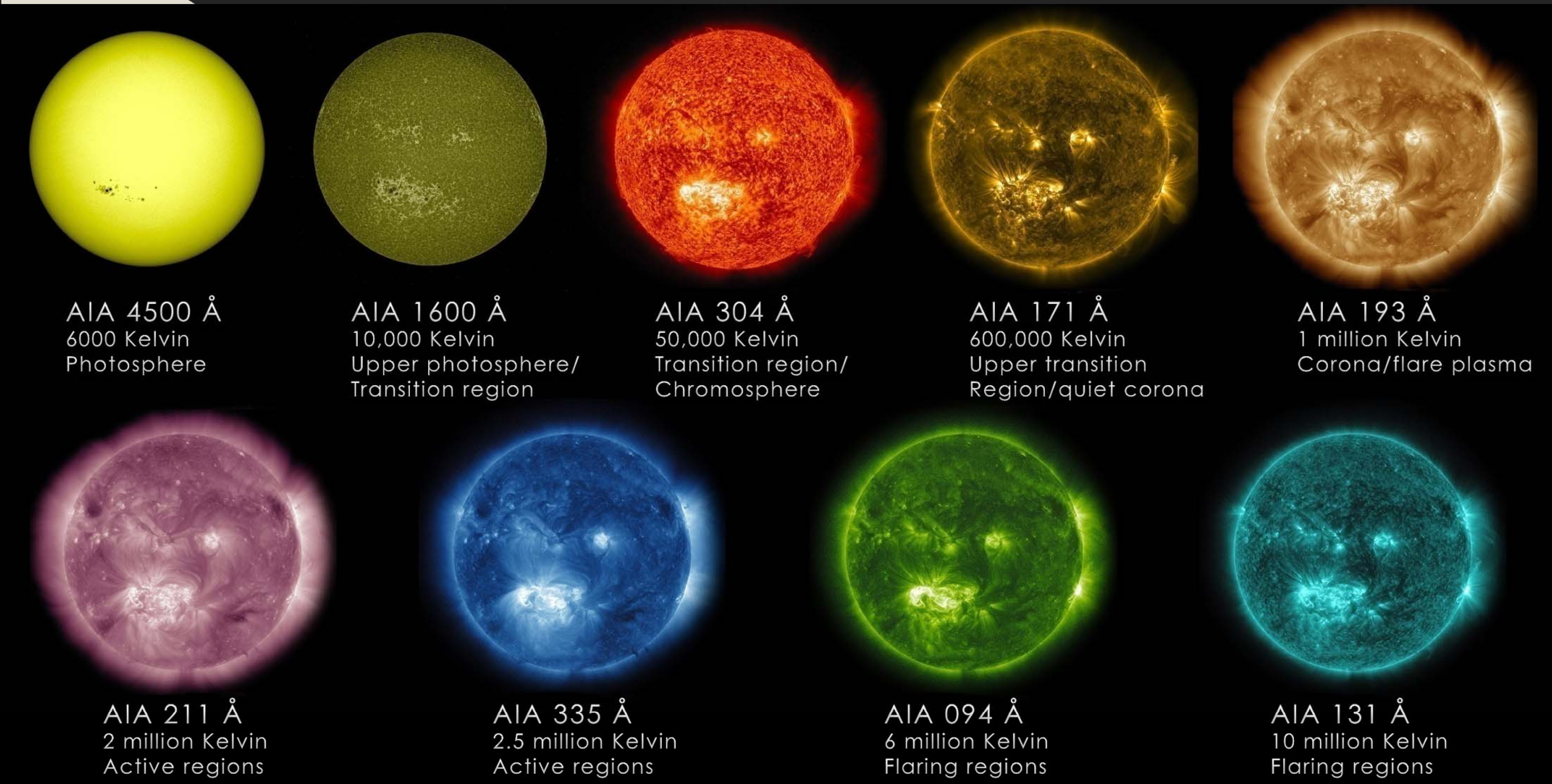



- Solar interior is opaque – can't use photons to observe
- Helioseismology: analyse vibration patterns visible on surface
- Neutrino Detectors: count neutrinos of various flavours to understand what is happening in core

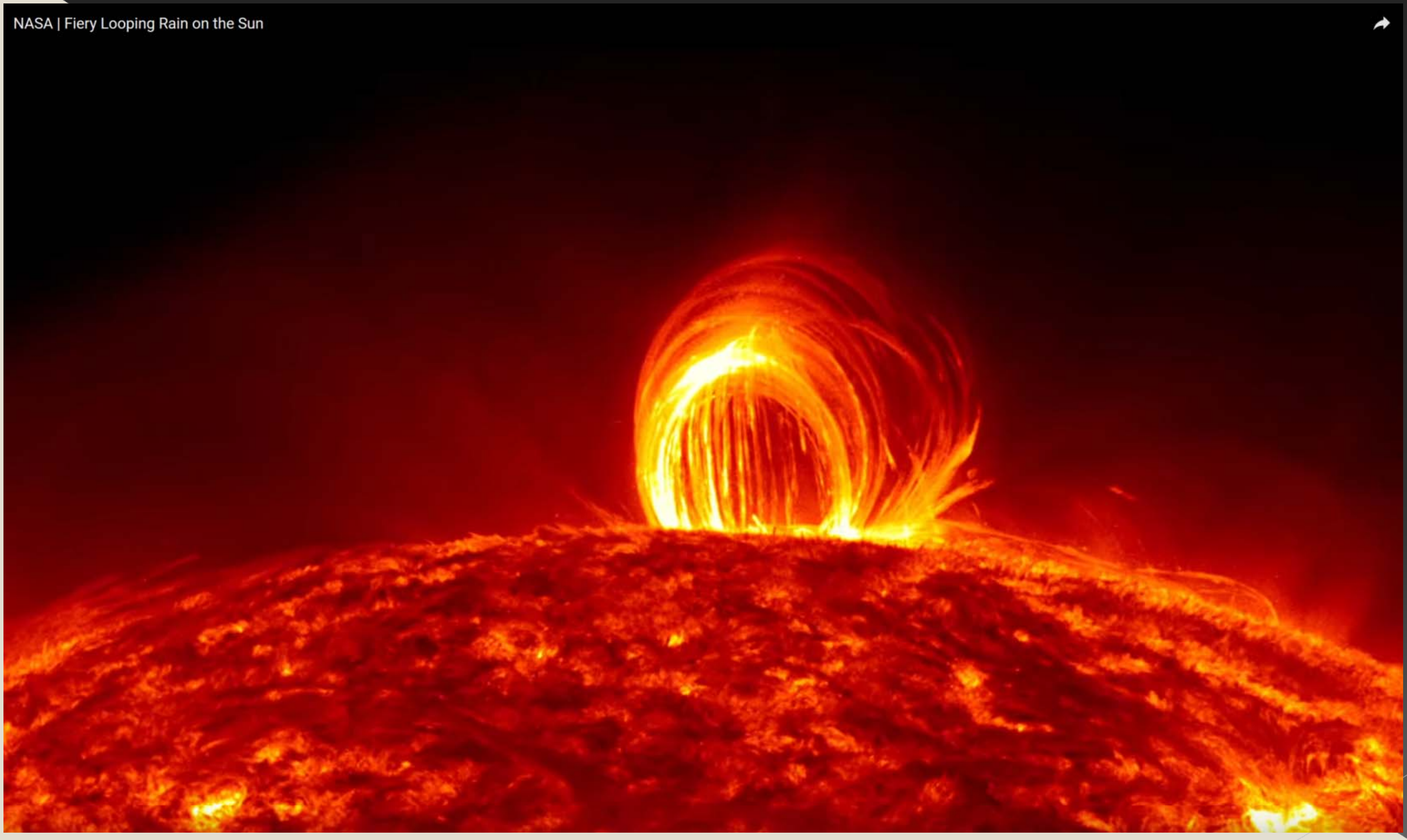



PPTX "The Sun" by Shana Nash (from Slideplayer.com)

# How NASA Peels the Onion - Outside



# The Good Stuff




https://www.youtube.com/watch?v=lpzCSZ7Eerc

NASA/SDO/Goddard Space Flight Center

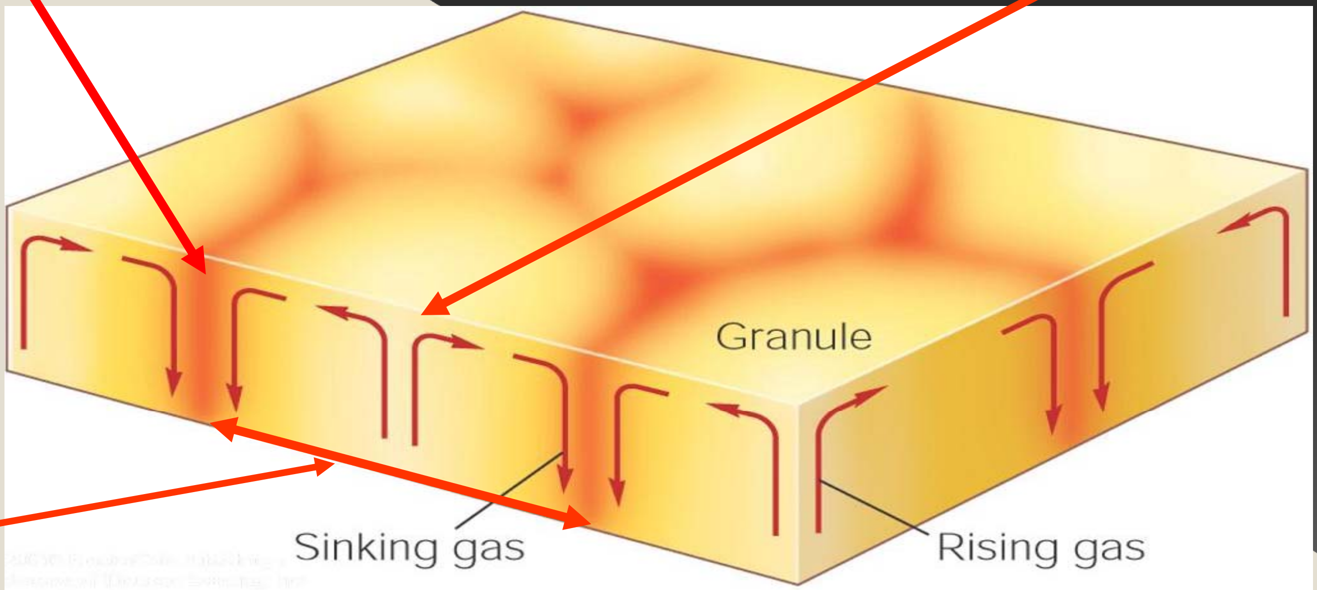
# Convection in Photosphere

Energy generated in the sun's center must be transported outward. In the **photosphere**, this happens through…

**Convection:**

Cool gas sinking down

Bubbles of hot gas rising up



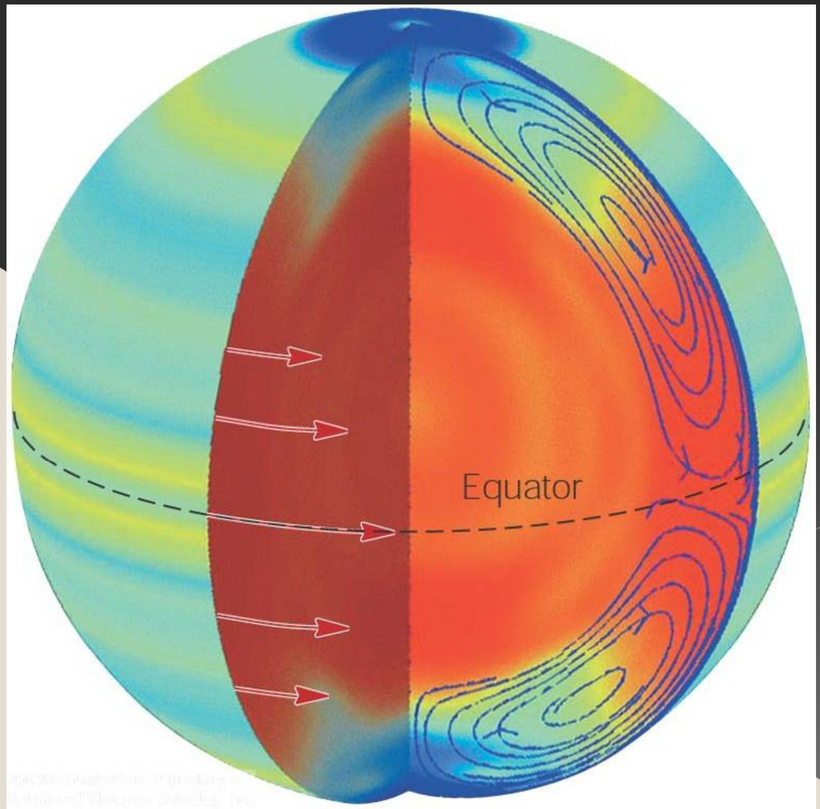

about 1000 km

Granules (bubbles) last for about 10 – 20 min.

PPTX "The Sun" by Shana Nash (from Slideplayer.com)

# It's Not Magic, It's Magnetism

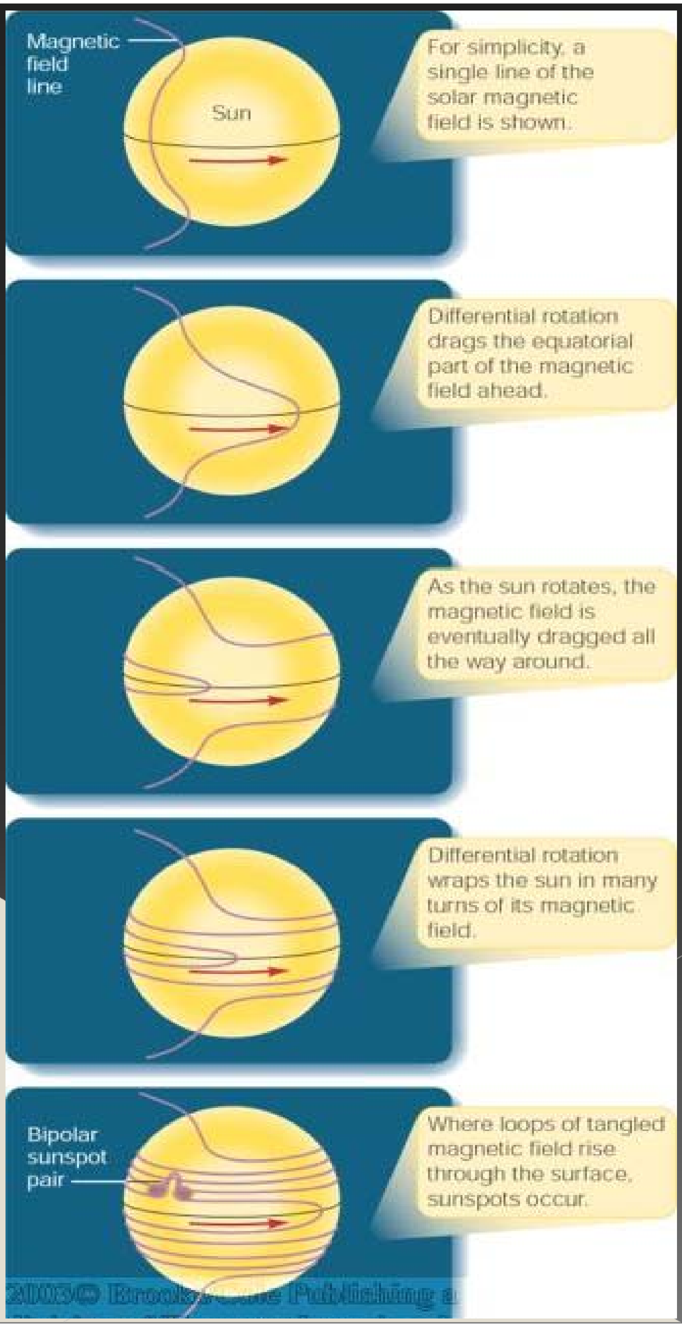
- Plasma has electric charge – affects magnetic fields & visa-versa
- Sun rotates faster at equator (25 days @ equator, 27.8 days at 45°)
- differential rotation winds up magnetic field lines
- field lines loop, cross, break, combine…very complex
- a lot of energy tied up in Sun's magnetic field (important later)




PPTX "The Sun" by Shana Nash
(from Slideplayer.com)

# The Solar Magnetic Cycle

- As field lines wind-up, can tangle and exit surface of photosphere (ie. sunspot)
- After 11 years magnetic pattern becomes so complex the field structure re-arranges itself
- New magnetic field structure similar but reversed
- After field orientation reversed, cycle repeats

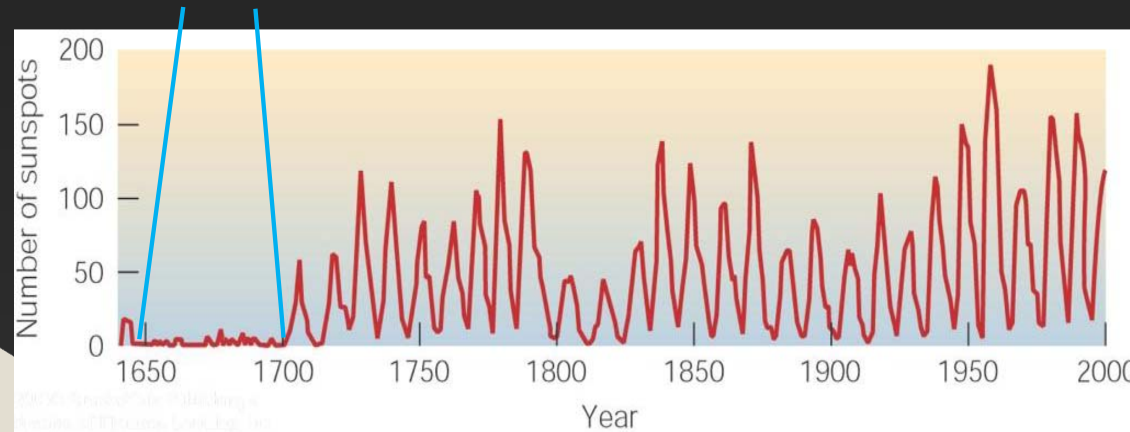



PPTX "The Sun" by Shana Nash (from Slideplayer.com)

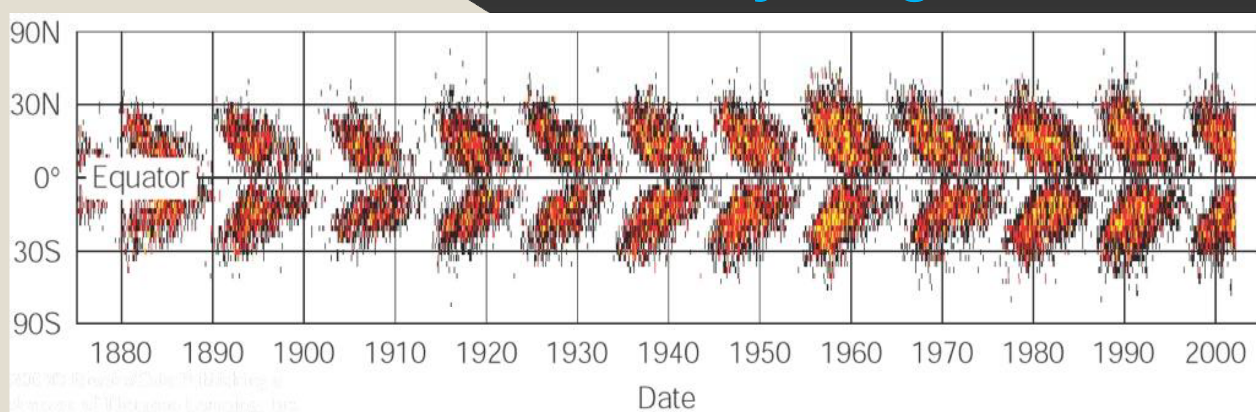
# Seeing Spots

- Cycle start – sunspots at higher lat's
- As cycle ends – sunspots near equator
- Number of spots tracks w/ complexity of magnetic field
- Sunspot observing used to monitor solar activity
- Activity fluctuates over long time scales also (not just every 11yrs)

**Maunder Minimum**




**Maunder Butterfly Diagram**




PPTX "The Sun" by Shana Nash (from Slideplayer.com)

# What if I also like onions ?

- Core – Radiative – Convective = forget it!
  (unless you want to build neutrino detector in your basement)
- Photosphere = white light
- Lower Chromosphere = calcium II - K
- Mid-Upper Chromosphere = hydrogen II - $\alpha$
- Corona = total solar eclipse (naked eye)

# White Light Observing

- view visual band at safe intensity
- several options available – use existing scope
- most economical way to observe Sun

britastro.org/mercury2016


## Rear Projection

- project image onto white background
- many people view at same time
- not the best image – see sunspots only
- use a junk eyepiece! (will get cooked)
- cheapest solution

www.starizona.com,
www.365astronomy.com


## Solar Filter

- glass or thin film blocks 99.999% of light
- attach over front of scope
- larger scopes use part-aperture
- improved image – sunspots & some granulation
- reasonably affordable solution

naked eye solar glasses ~$0-20

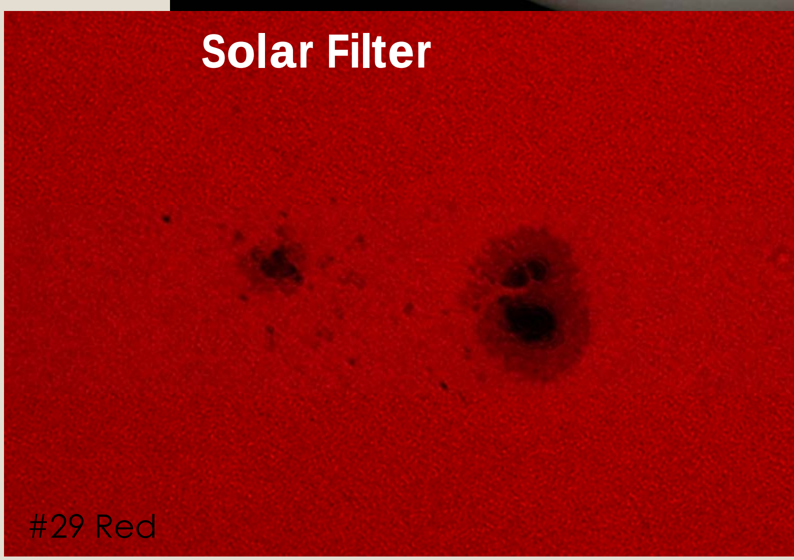
www.flickr.com/photos/alexandra4
Alexandra Hart

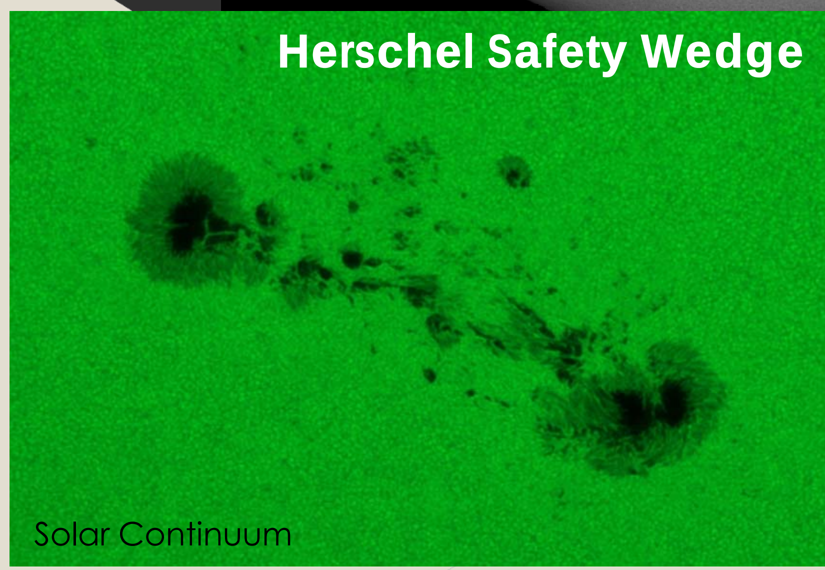
## Herschel Safety Wedge

- wedge prism directs 4.6% to eye, rest out back
- insert into focuser, then eyepiece into wedge
- refractors only, 6" or smaller
- best image – lots of sunspot & granule detail
- most expensive solution ($800 CAD)

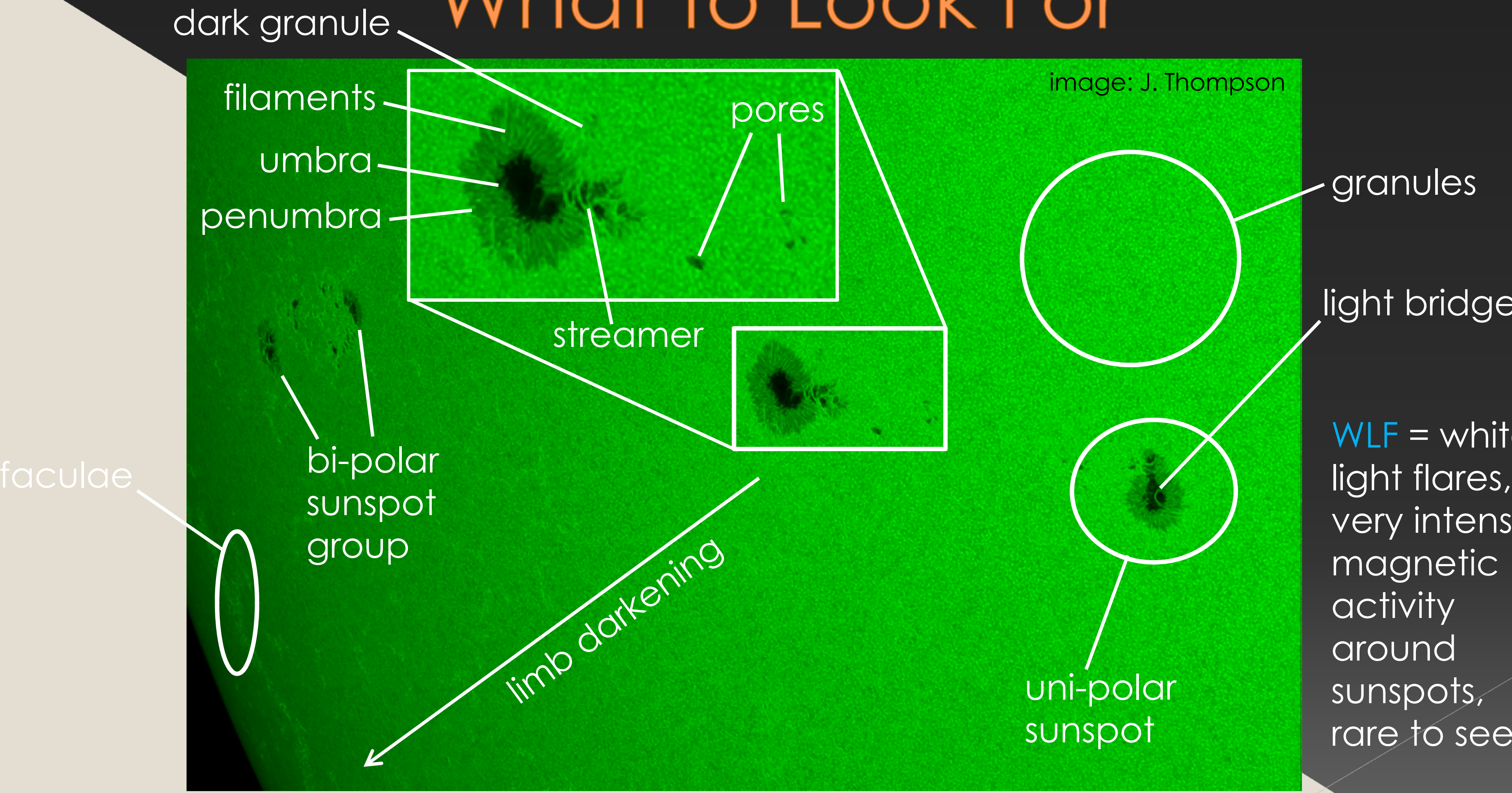
# White Light Observing – Examples





# What to Look For



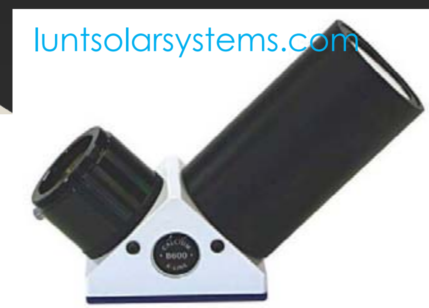

WLF = white light flares, very intense magnetic activity around sunspots, rare to see

- SUNSPOT: concentration of magnetic field lines, disrupts convection so cooler, often in pairs N-S
- FACULAE: local bright spots between granules, due to decreased magnetic activity, see easier at limb, linked to sunspot formation
- GRANULES: visualization of convection cells in photosphere, light-hot-rising, dark-cool-sinking
- LIMB DARKENING: gradual solar disk darkening as you move towards limb, optical affect
- PORES: small dark spots, start granule size in areas with faculae, larger ones may grown into sunspots
- LIGHT BRIDGE/STREAMER: bright band cutting into umbra & sometimes penumbra, usually thin

# Calcium II-K Observing

- view narrow (0.5-80Å) band in NUV (393-398nm)
- use your existing scope + ERF (energy rejection filter)
- expensive way to "observe" Sun **- camera only!**







daystarfilters.com

## Screw-On Filter

- most affordable of methods ($350)
- provides good images but not "the best"
- very flexible to use

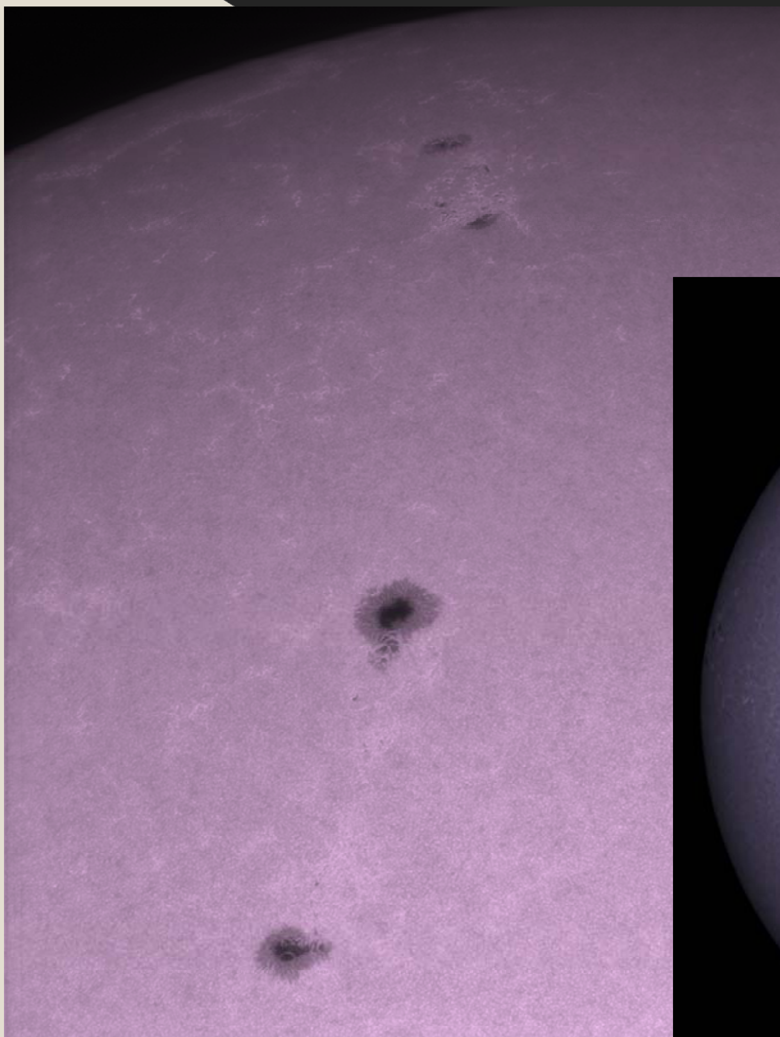
## Fixed Etalon

- etalon typically gives more accurate band pass than screw-on filter
- "can" give sharper image than screw-on
- only Lunt Ca-K module available, Coronado PST no longer for sale
- relatively expensive ($800-2000)

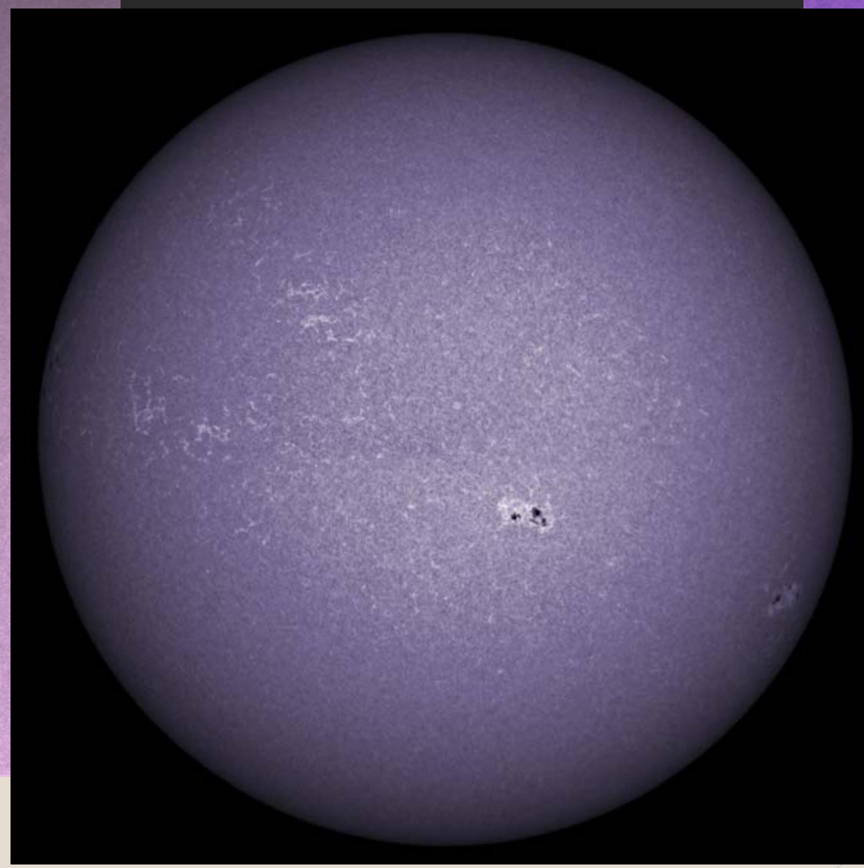
## Adjustable Etalon

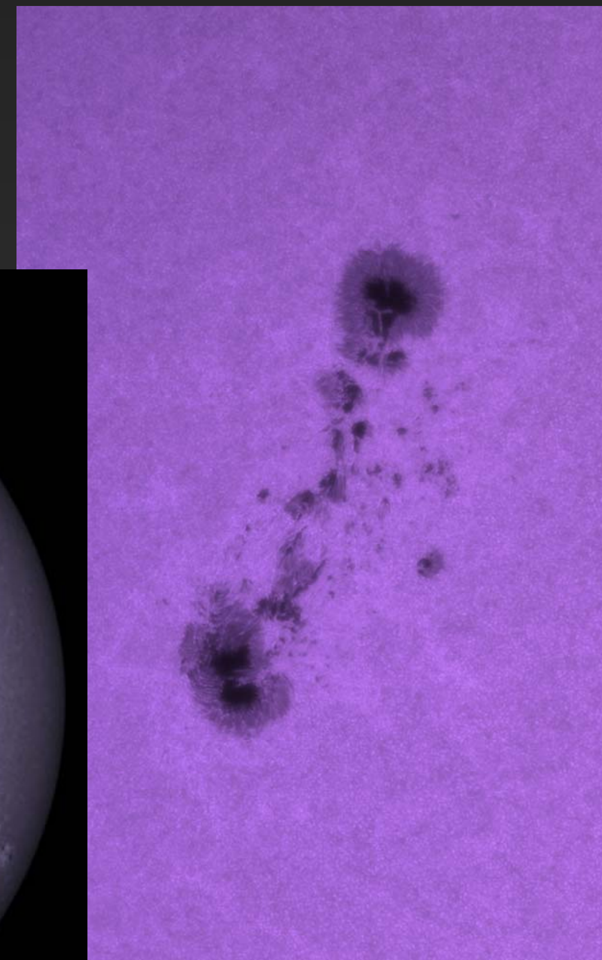
- use very accurate temperature controlled etalon
- provides excellent detail
- very expensive! ($1200 – 6000)

# Calcium II Observing – Examples



Baader Herschel Wedge
+ Omega Optical Ca-K

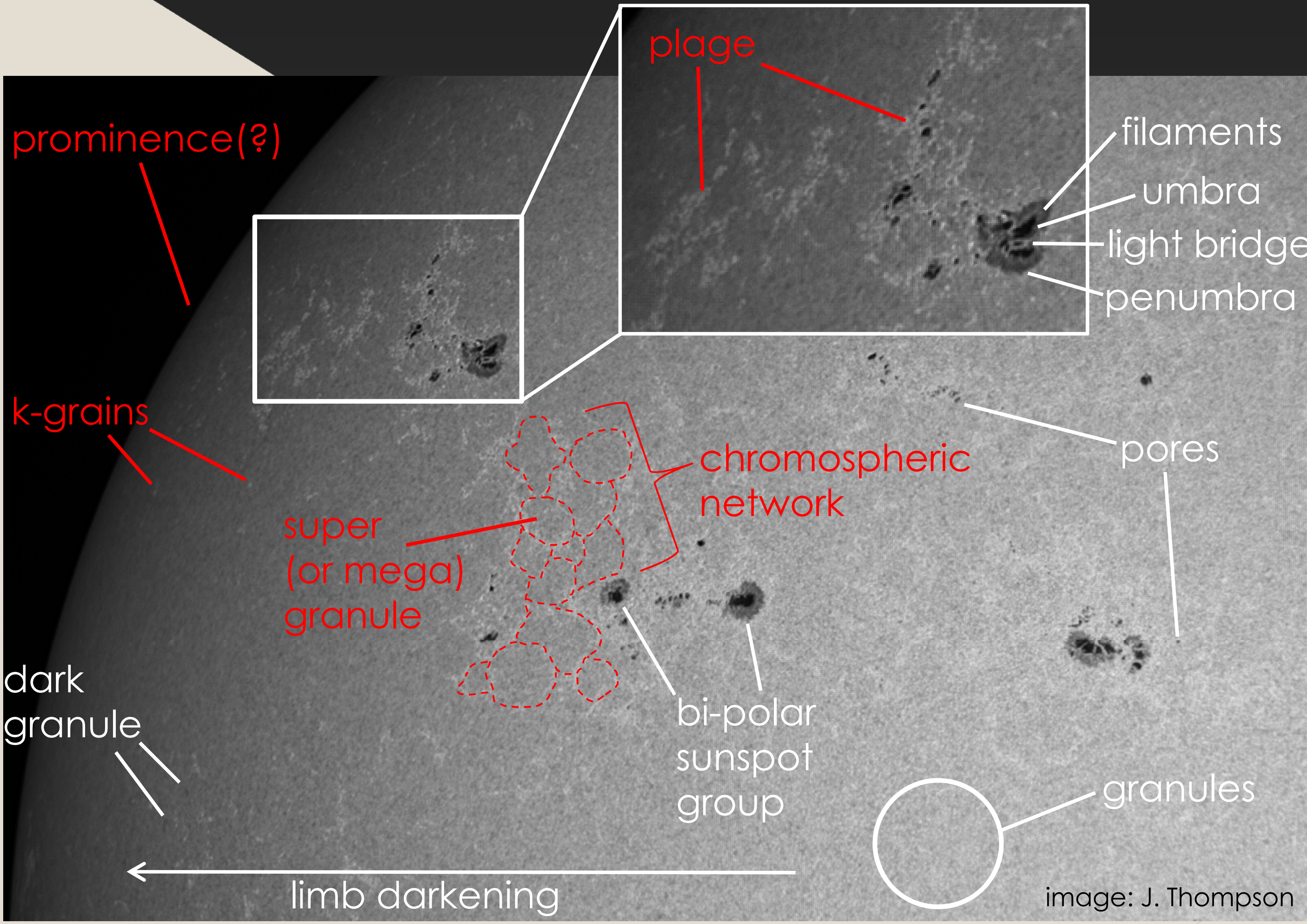


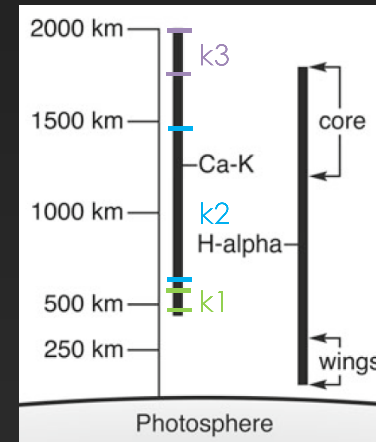


all images: J. Thompson

# What to Look For

Jamey L. Jenkins,
*Observing the Sun: A Pocket Field Guide*




Most Ca-K filter systems are K1-K2 sub-band

- K-GRAINS: small bright points, away from other activity, within middle of super granule, short lived (~10min)
- PLAGE: French for "beach", patchy bright regions w/ higher temp., found most often near sunspots, visible predominantly in Ca-K, mark area of increased magnetic activity, connection to faculae unclear
- CHROMOSPHERIC NETWORK: weak but bright background pattern, overlays super-granules in photosphere (large scale convective pattern), last day or so
- SUPER GRANULE: single cell within network, ~30,000km size

# Hydrogen II-α Observing

- very narrow (0.3-0.7Å) band in dark red (656.28nm)
- all options require tuneable etalon
- most expensive way to observe Sun - & most interesting!



meade.com
luntsolarsystems.com

daystarfilters.com


## Tilt Tuned Etalon

- tuning of waveband achieved by finely adjusting angle of etalon (thumbscrew or pressure)
- etalon paired with blocking filter
- can stack etalons for better contrast
- use with existing scope – refractor only
- $1000-8000

## Dedicated Hα Scope

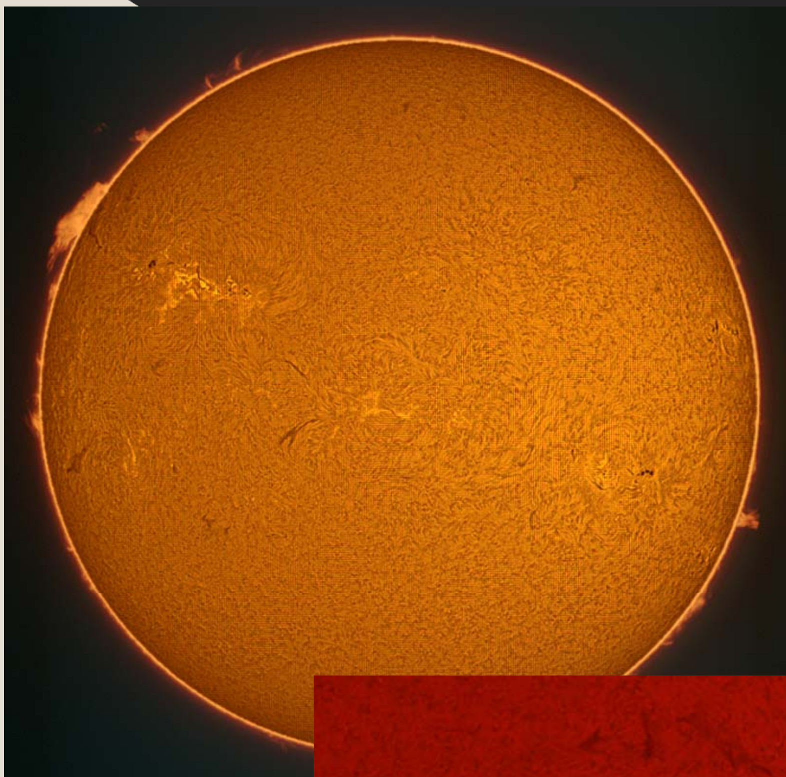
- same tilt tuning & blocking filter as when buy etalon separately
- can stack etalons for better contrast
- can only use scope for solar viewing
- $1200-10,000

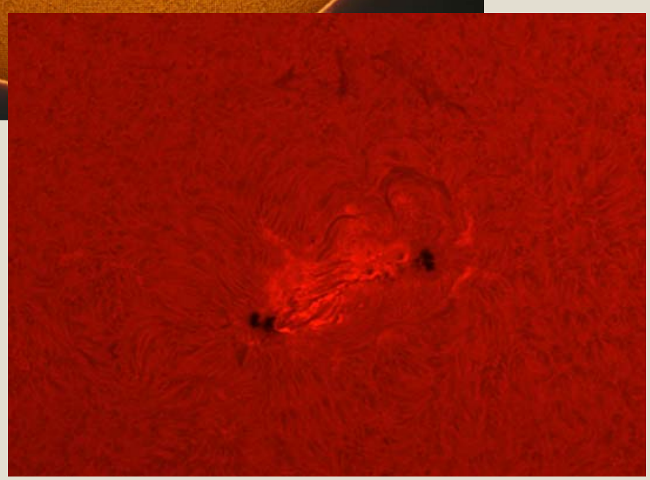
## Temp. Tuned Etalon

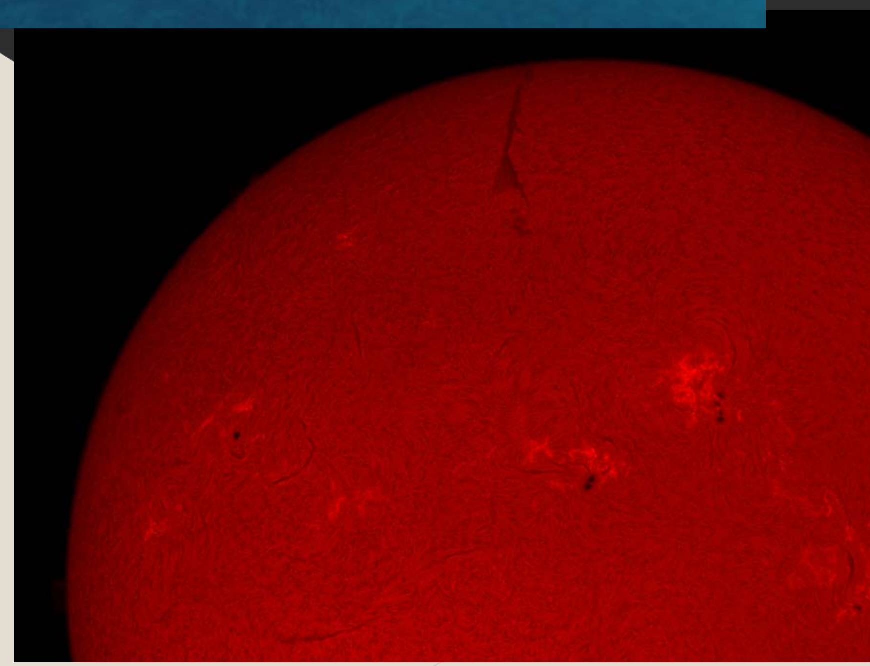
- use very accurately controlled etalon (changes thickness with T)
- provides excellent detail
- very expensive! ($1200 – 16,000)

much cheaper DIY tilt-tuned possible but poor performance

# Hydrogen II-α Observing – Examples





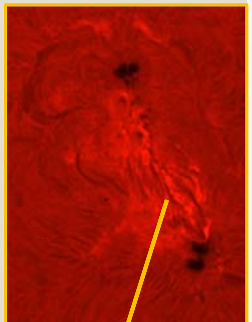


all images: J. Thompson

# What to Look For

- SPICULES: individual jets of hot gas, moving vertically at up to 50,000 kph, last ~10min
- FIBRILS: spicules that are stretched & distorted by nearby magnetic activity (sunspot)
- PROMINENCE: cloud of gas above surface
- FILAMENT: a prominence viewed from above
- FLARE: sudden extreme release of energy stored in magnetic field of an active region

- EMERGING FLUX REGION: area of increasing magnetic activity (growing plages, start of sunspots)
- ARCH FILAMENT SYSTEM: kind of fibril in active regions, joins areas of opposite magnetic poles



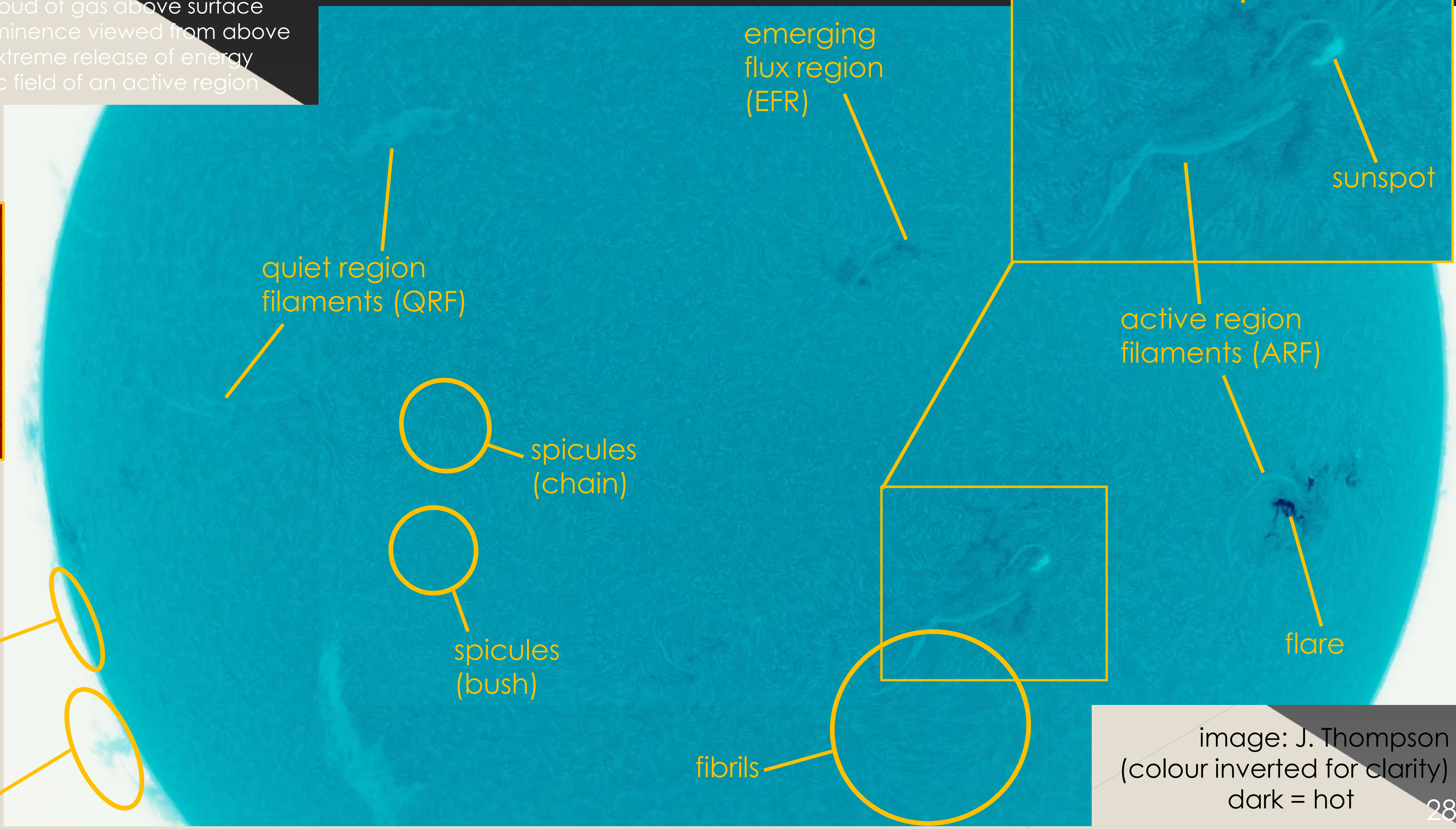
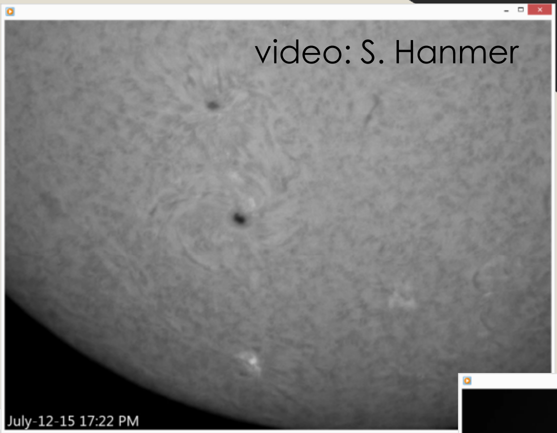



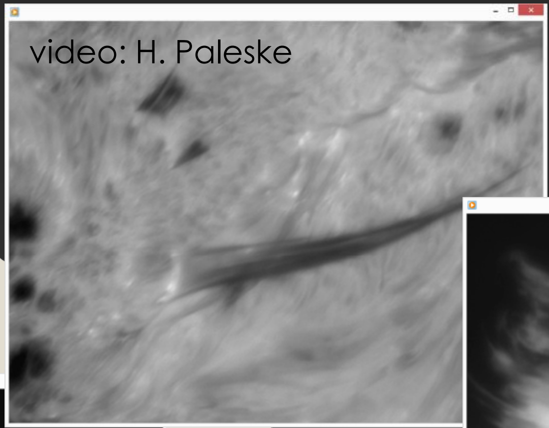

image: J. Thompson
(colour inverted for clarity)
dark = hot

# Sun Is An Active Place

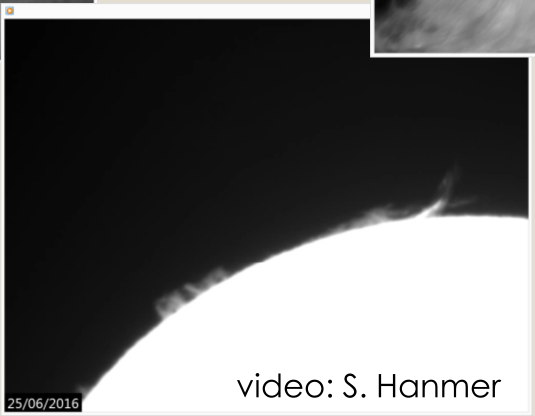
- Features change visibly over course of 5-10min – esp. in Hα
- Makes Sun most dynamic of observing targets



video: S. Hanmer


video: H. Paleske


video: J. Thompson



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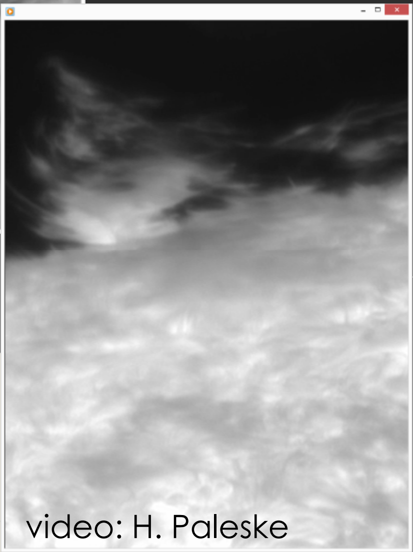
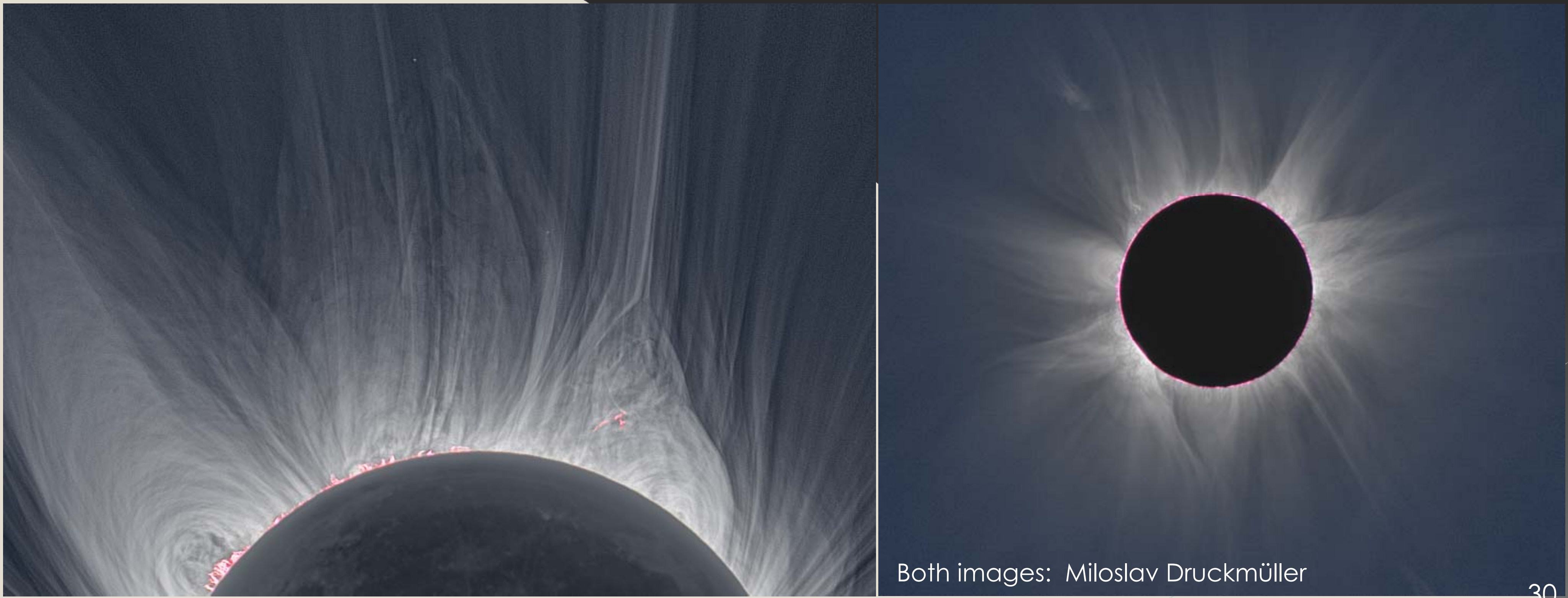

video: H. Paleske

# Corona Observing

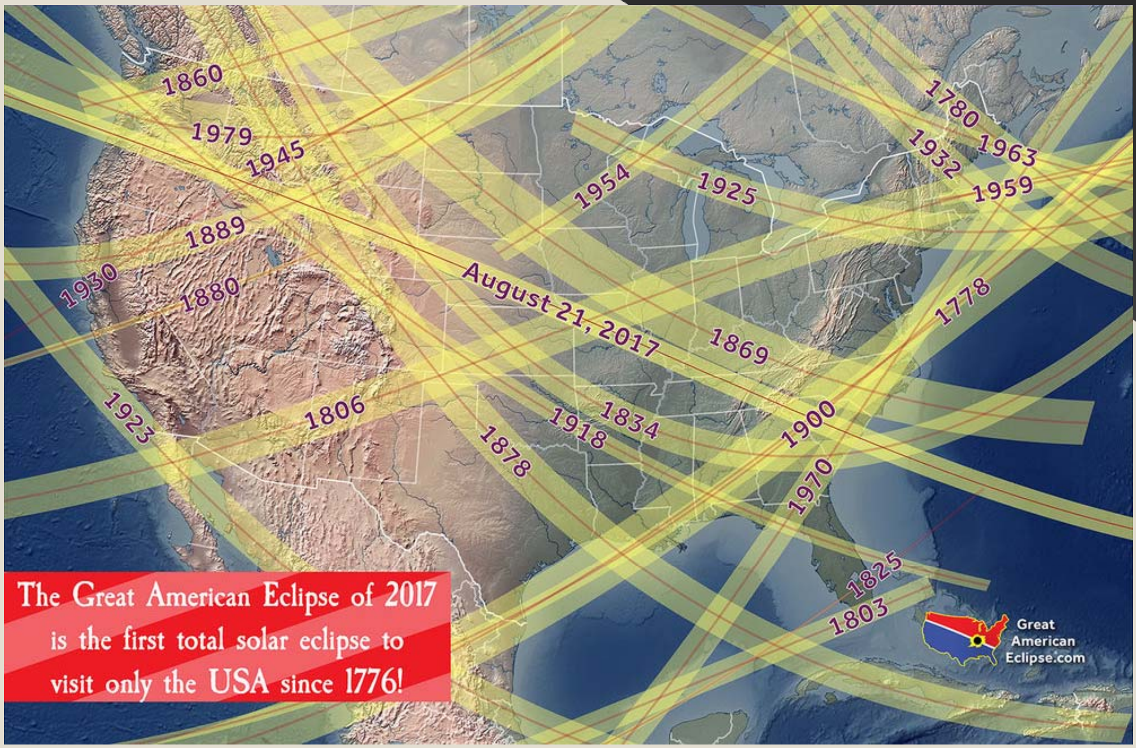
- 1/1,000,000th as bright as photosphere
- only opportunity to observe is during total eclipse
- no filters req'd, chromosphere visible also



Both images: Miloslav Druckmüller

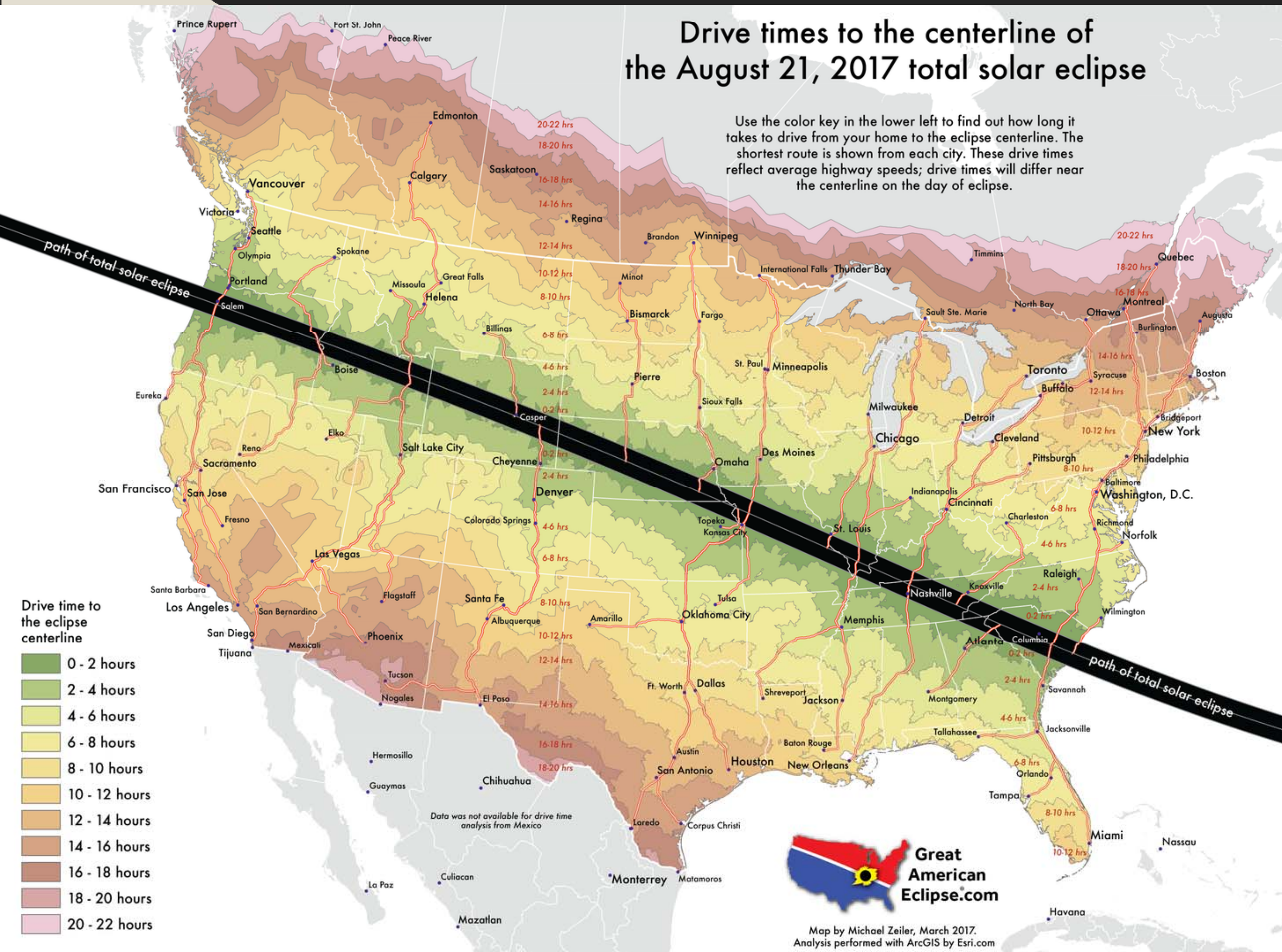
# The Great American Eclipse of 2017

- Technically all total solar eclipses are great!
- Happens to be first time since 1776 that TSE observable in USA alone
- US media has cranked up the hype-o-meter



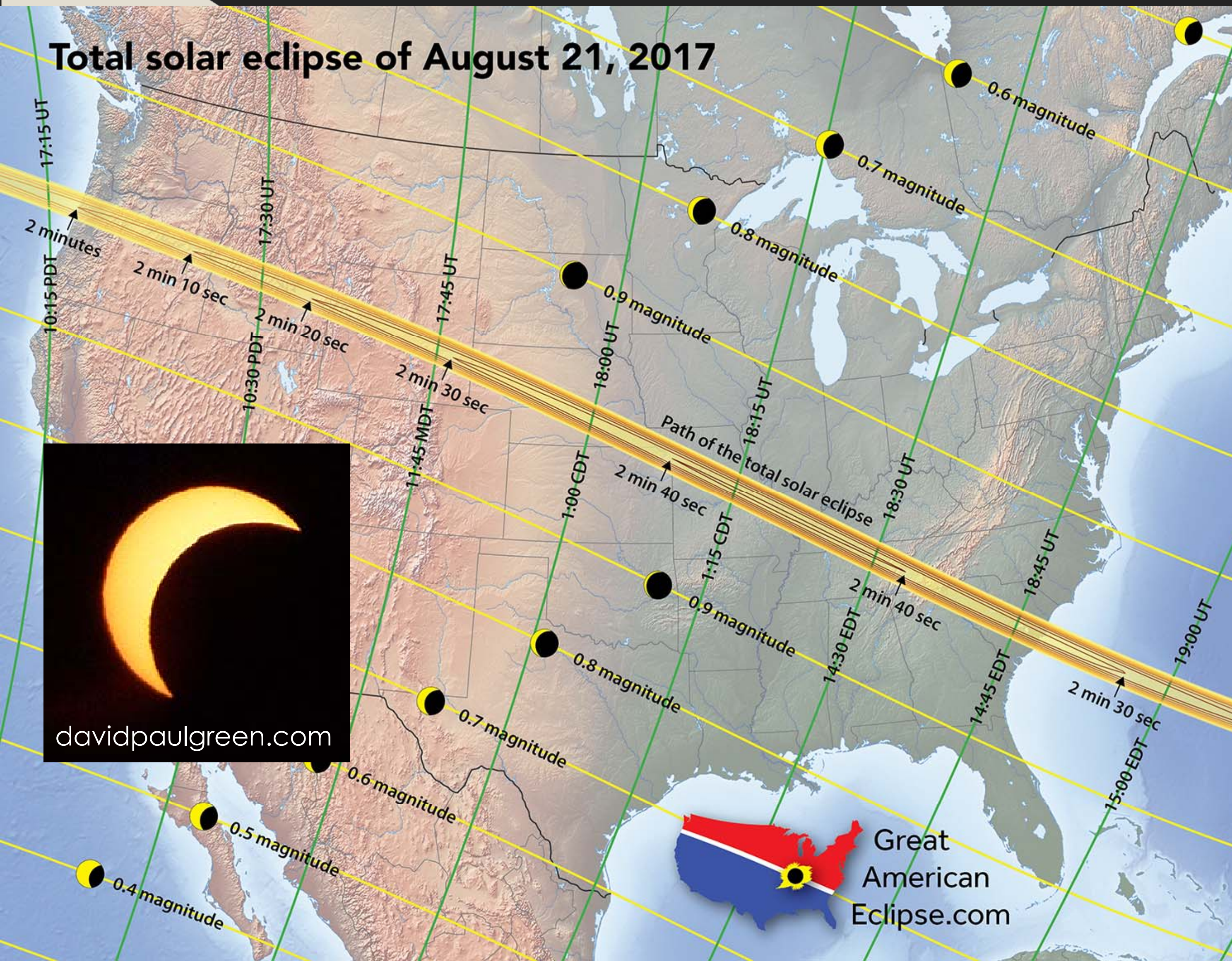

greatamericaneclipse.com

# Totality or Bust

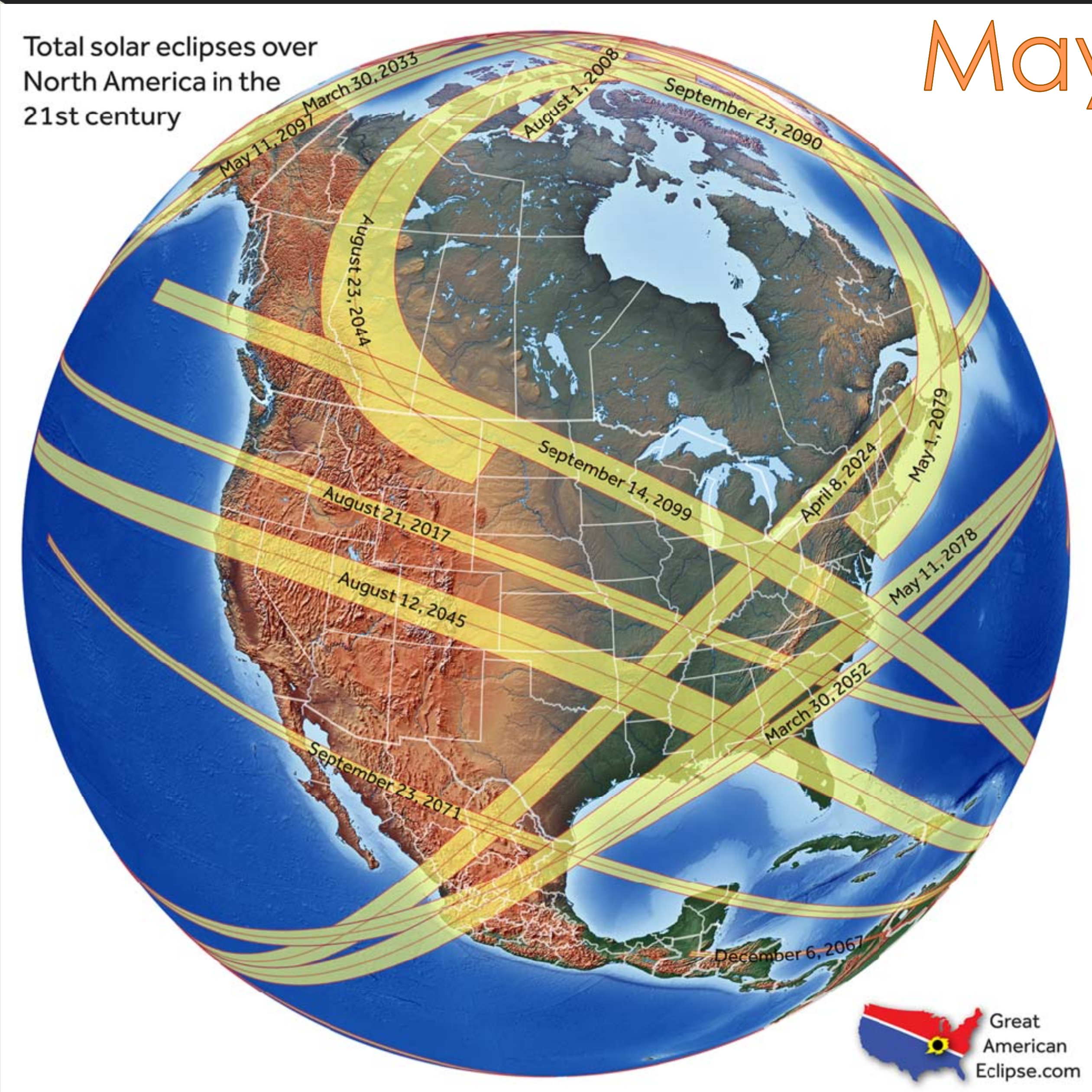



- Ottawa two day's drive (or one very long day) from path of totality
- If you plan on making the trip, but haven't made plans yet…you're probably too late

# For Those At Home




- From Ottawa ~70% partial solar eclipse, w/ max @ 2:35pm EDT
- If you plan to observe/ photograph, solar filter required at all times




# Maybe Next Time

- Next driving distance total eclipse: April 8, 2024
- Path of totality follows St. Lawrence Seaway

# Astronomy Day 2017

- **ASTRONOMY DAY**: Saturday, April 29th, 2017
- All day sidewalk astronomy event at Chapters Silver City
- Way more fun than you imagine!
- Success depends 100% on volunteers

**PLEASE JOIN US!**

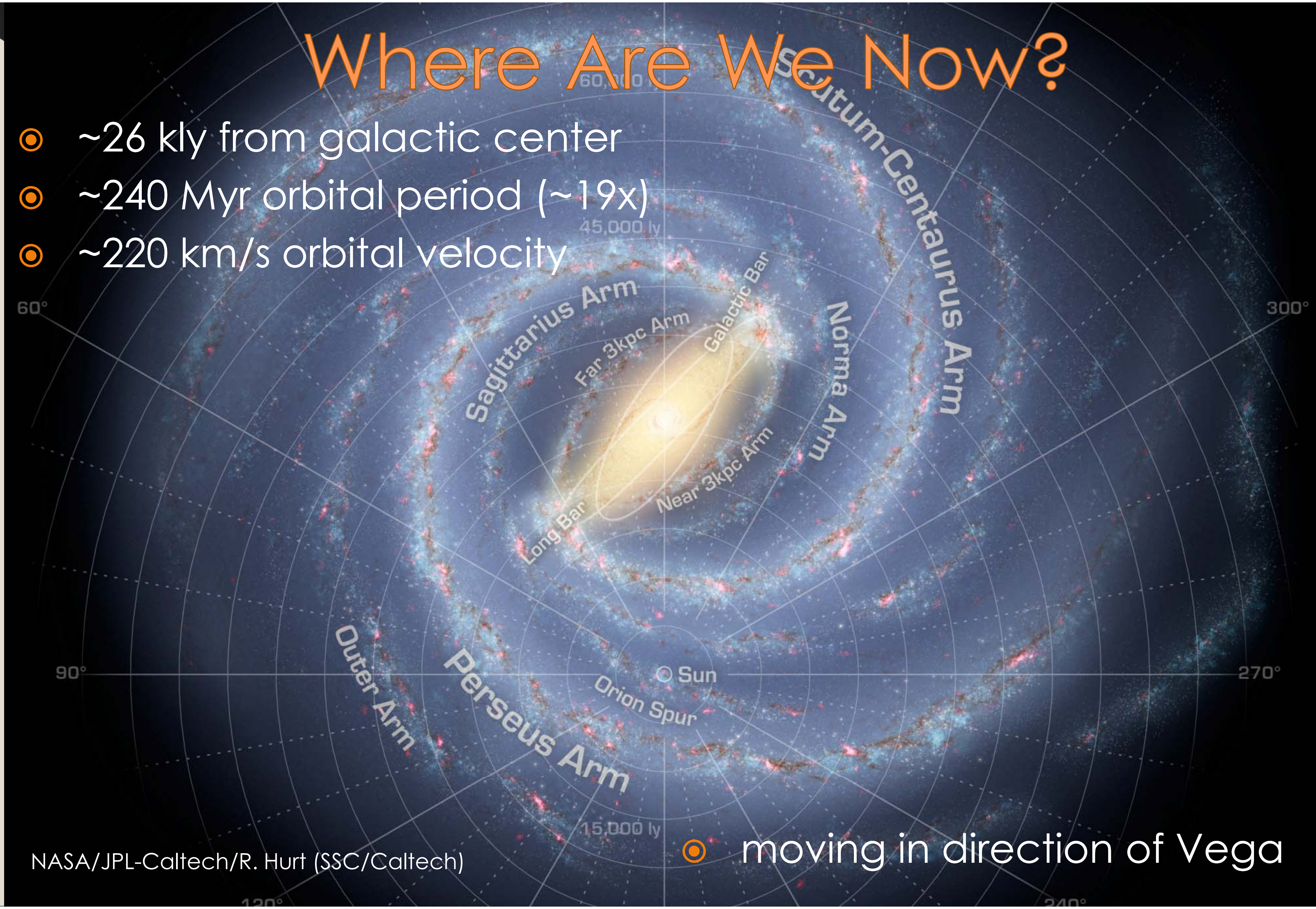
# IAD – Sharing w/ Friends & Family


# If Time Permits…

**Where did the Sun come from?**

# Where Are We Now?

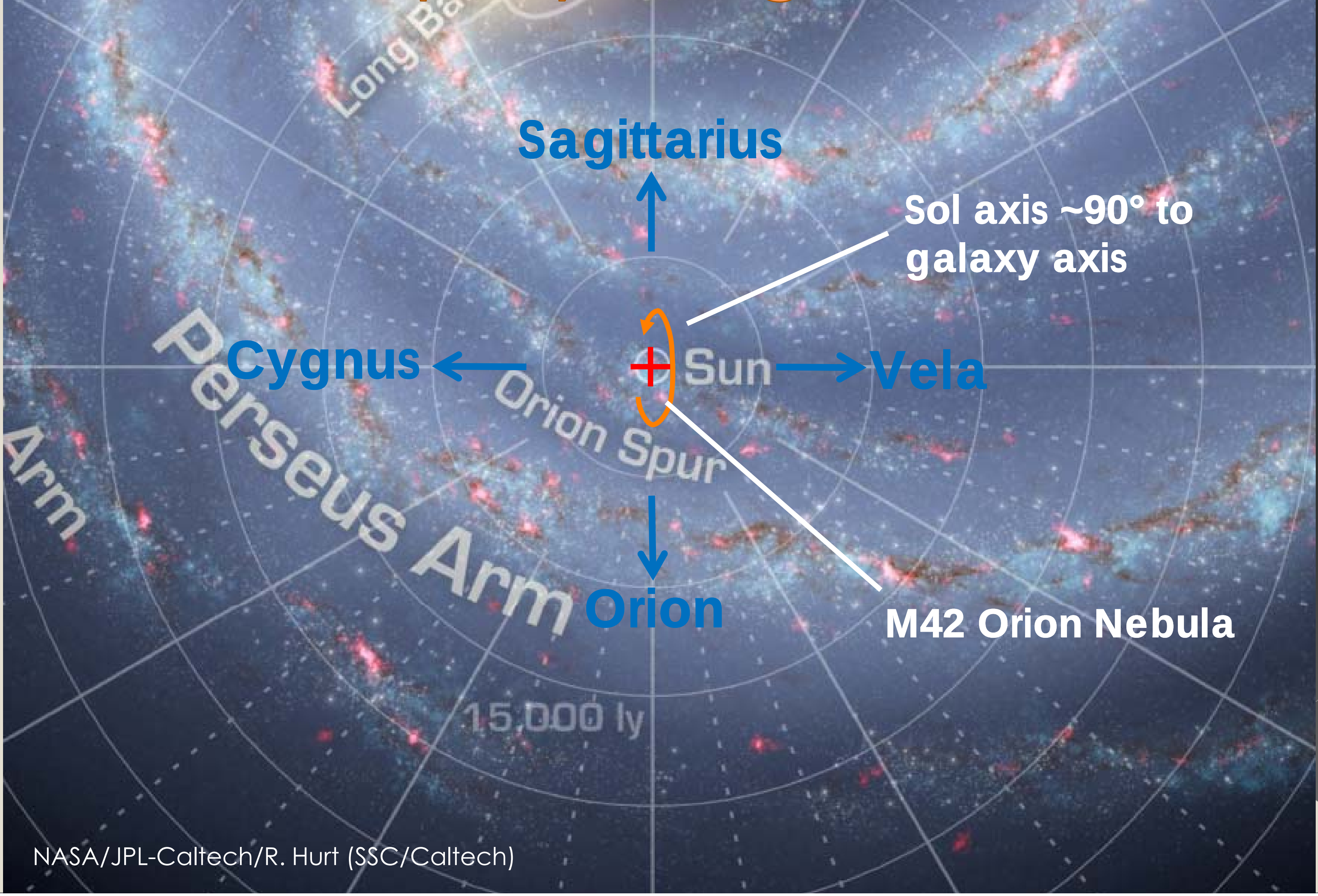
- ~26 kly from galactic center
- ~240 Myr orbital period (~19x)
- ~220 km/s orbital velocity




NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

- moving in direction of Vega

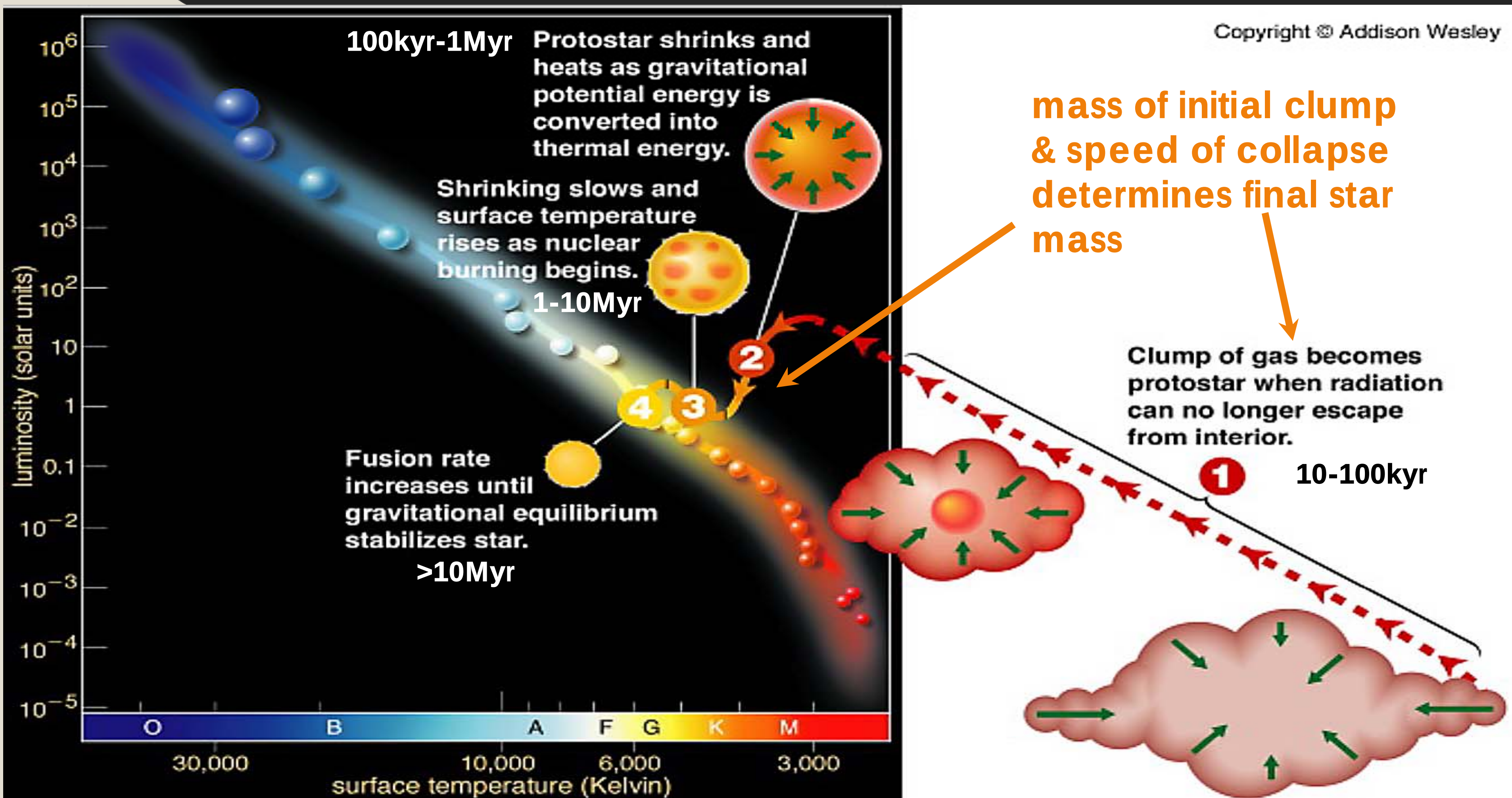
# Our Deepsky Neighbourhood




NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

# Getting Into the "Main Sequence"

*




ircamera.as.arizona.edu

- Sol age ~4.6Byr, M-W age ~ 13.2 Byr

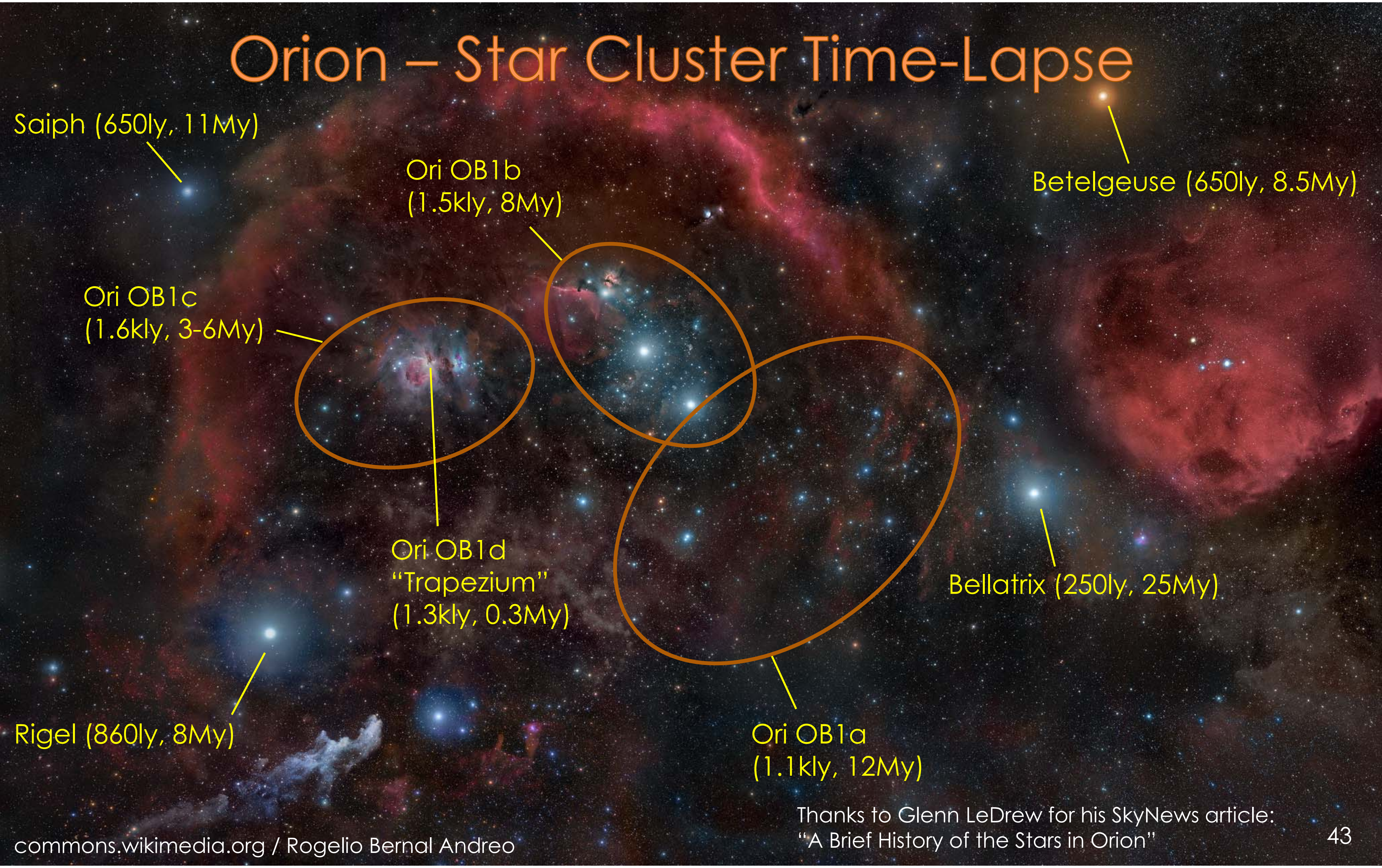
# (Winter) Milky Way – Star Cluster Smorgasbord


Dick Locke,
www.dl-digital.com/astrophoto

# Closer Look at a Stellar Nursery


NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team

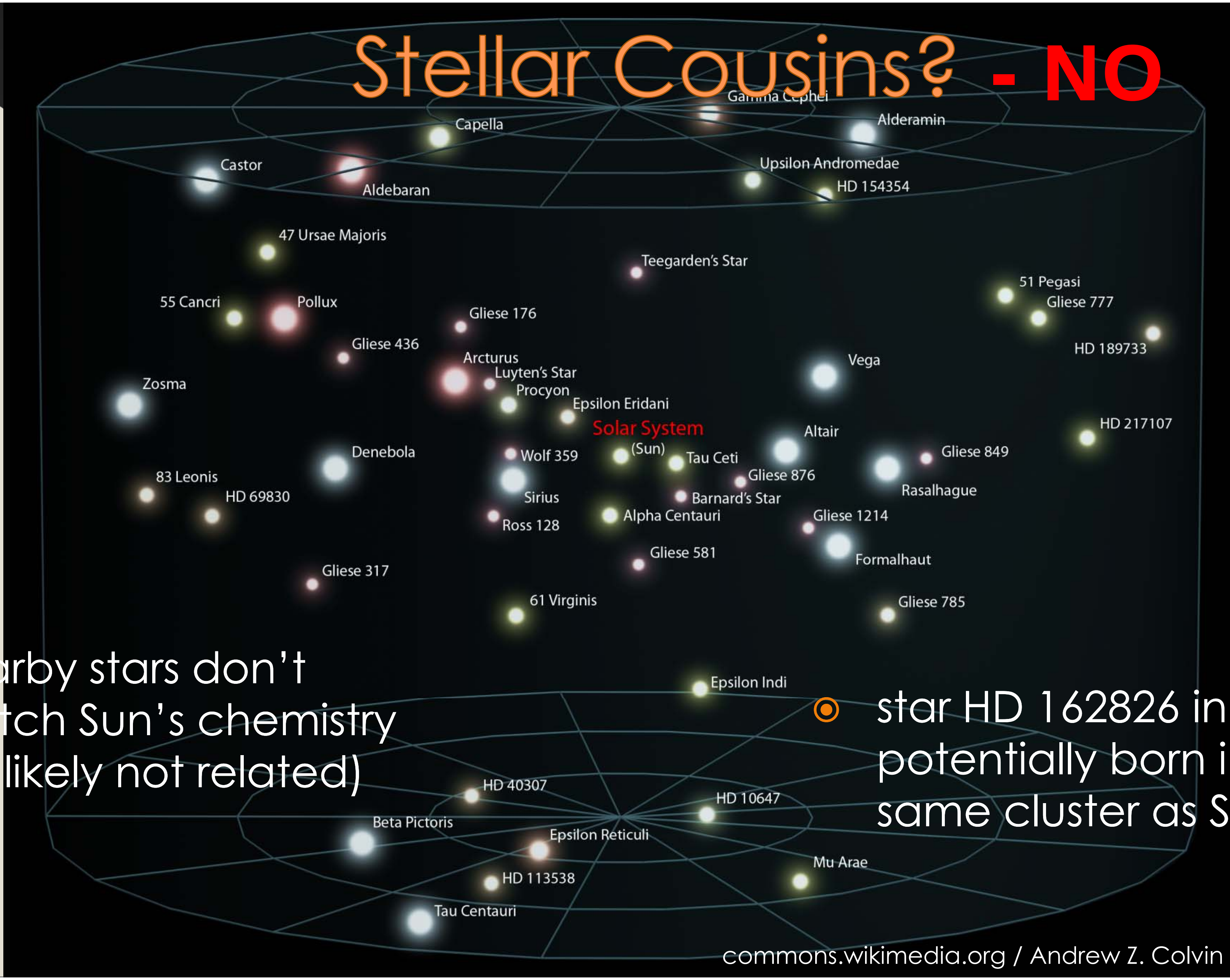
# Orion – Star Cluster Time-Lapse




commons.wikimedia.org / Rogelio Bernal Andreo

Thanks to Glenn LeDrew for his SkyNews article:
"A Brief History of the Stars in Orion"

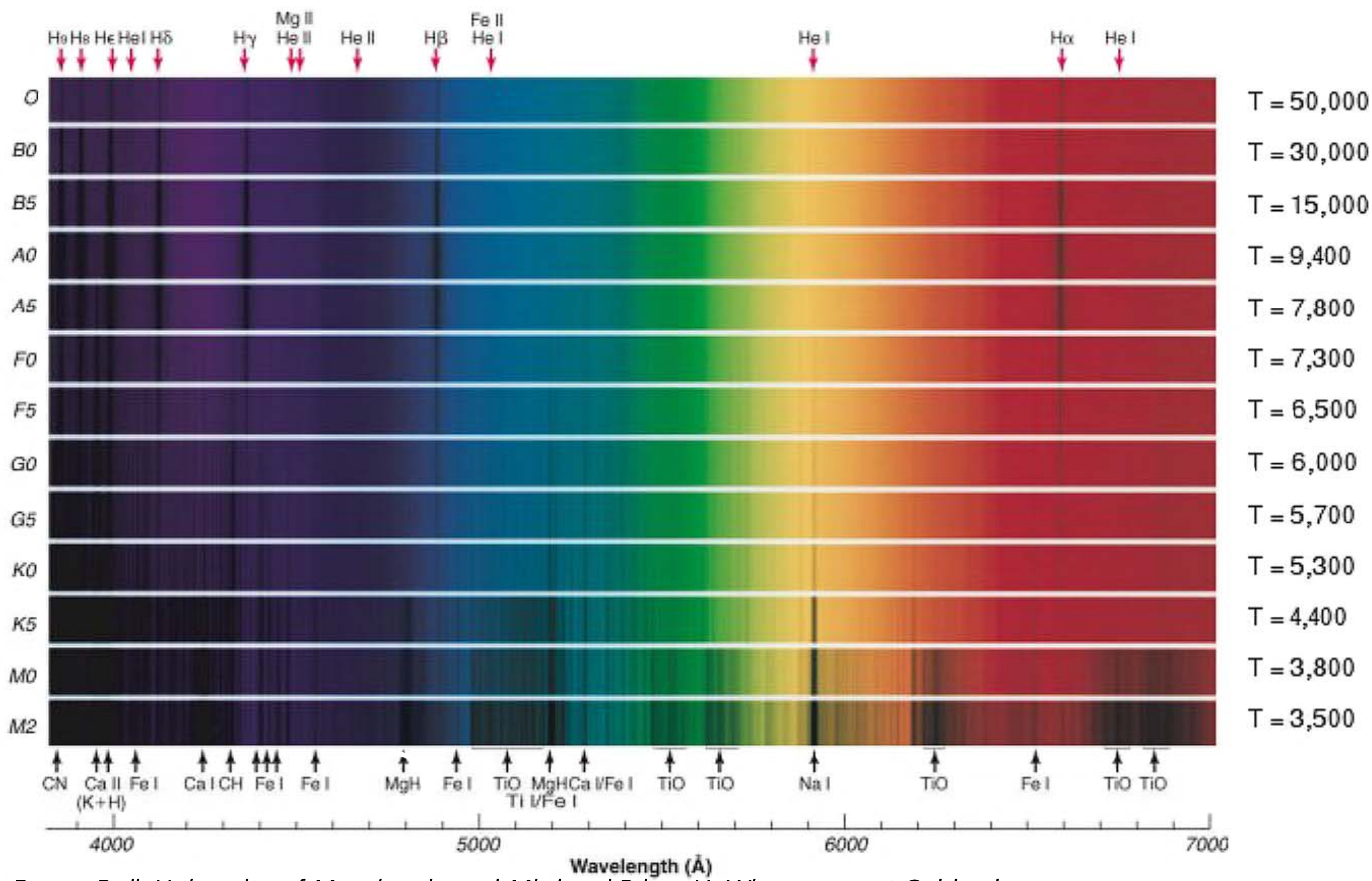
# Stellar Cousins? - NO




- nearby stars don't match Sun's chemistry (ie. likely not related)
- star HD 162826 in Herc. potentially born in same cluster as Sun

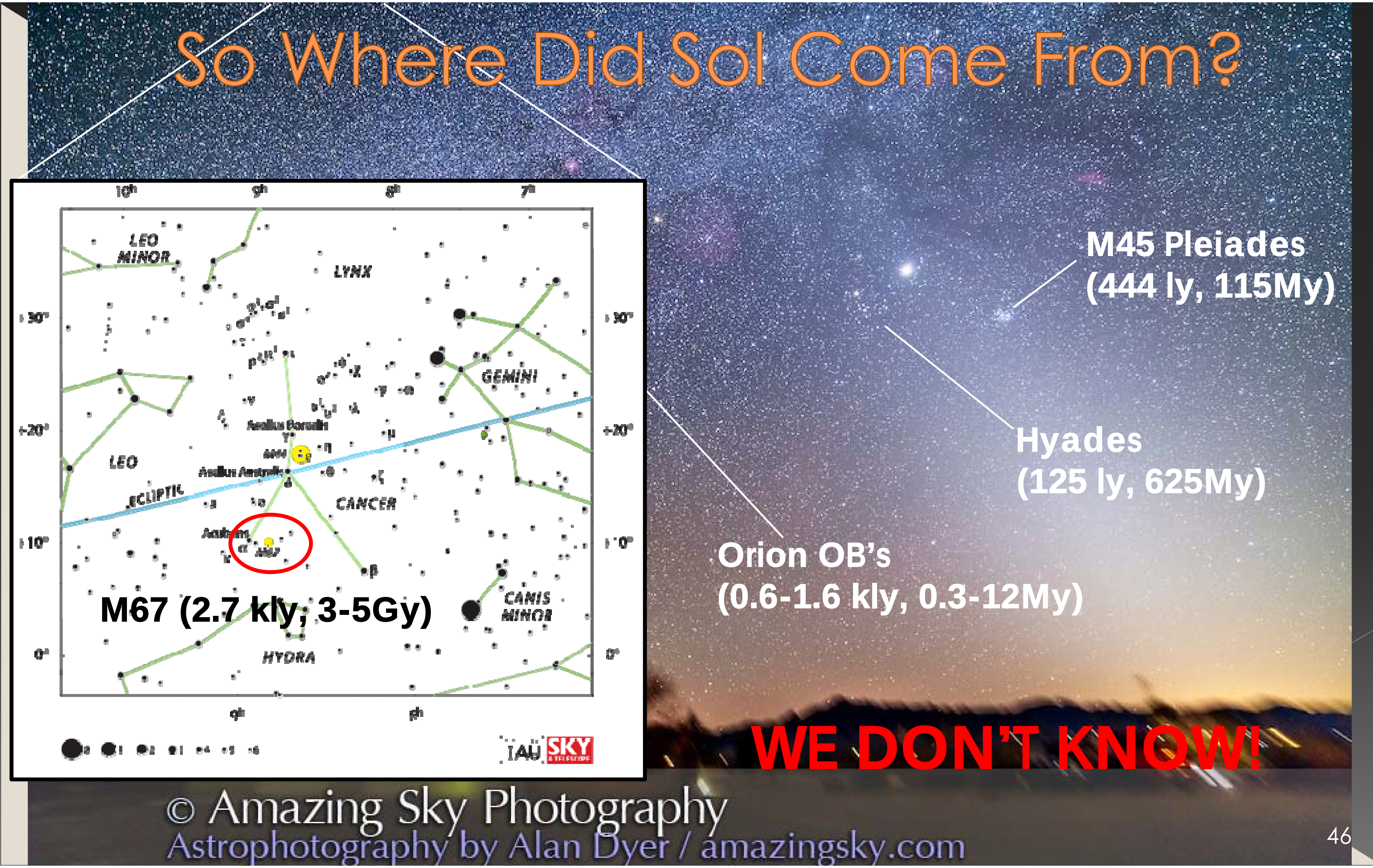
commons.wikimedia.org / Andrew Z. Colvin

# Taking a Star's Fingerprints




*Roger Bell, University of Maryland; and Michael Briey, U. Wisconson at Oshkosh*

- elements in star's atmosphere absorb photons at specific wavelengths
- intensity of line indicates amount of element


So Where Did Sol Come From?
LEO MINOR
LYNX
GEMINI
LEO
ECLIPTIC
CANCER
CANIS MINOR
HYDRA
M67 (2.7 kly, 3-5Gy)
M45 Pleiades
(444 ly, 115My)
Hyades
(125 ly, 625My)
Orion OB's
(0.6-1.6 kly, 0.3-12My)
WE DON'T KNOW!
© Amazing Sky Photography
Astrophotography by Alan Dyer / amazingsky.com

# If Time Permits…

**Why is the solar corona so hot?**

# All Thanks to Hannes Alfvén

- 1942 Hannes Alfvén suggests existence of electromagnetic-hydrodynamic (MHD) waves, and said all the right conditions exist for these waves to exist on the Sun
- 1958 Eugene Parker suggests MHD waves exist in solar corona
- Alfvén received the 1970 Nobel Prize in Physics for his pioneering work in MHD
- 1999 Aschwanden, et al. & Nakariakov, et al. report detection of Alfvén waves in solar corona loops using data from Transistion Region And Coronal Explorer (TRACE) spacecraft
- 2007 Tomczyk, et al. report detection of Alfvénic waves in images of solar corona from the National Solar Observatory in NM. It is proposed at that time by other scientists that Alfvén waves may be the explanation for the heating of the corona
- 2011 to today, scientists using observational data and simulation to understand how Alfvén waves heat the corona, now believe turbulence in the waves play important role

# Alfvén Wave Turbulence Heating