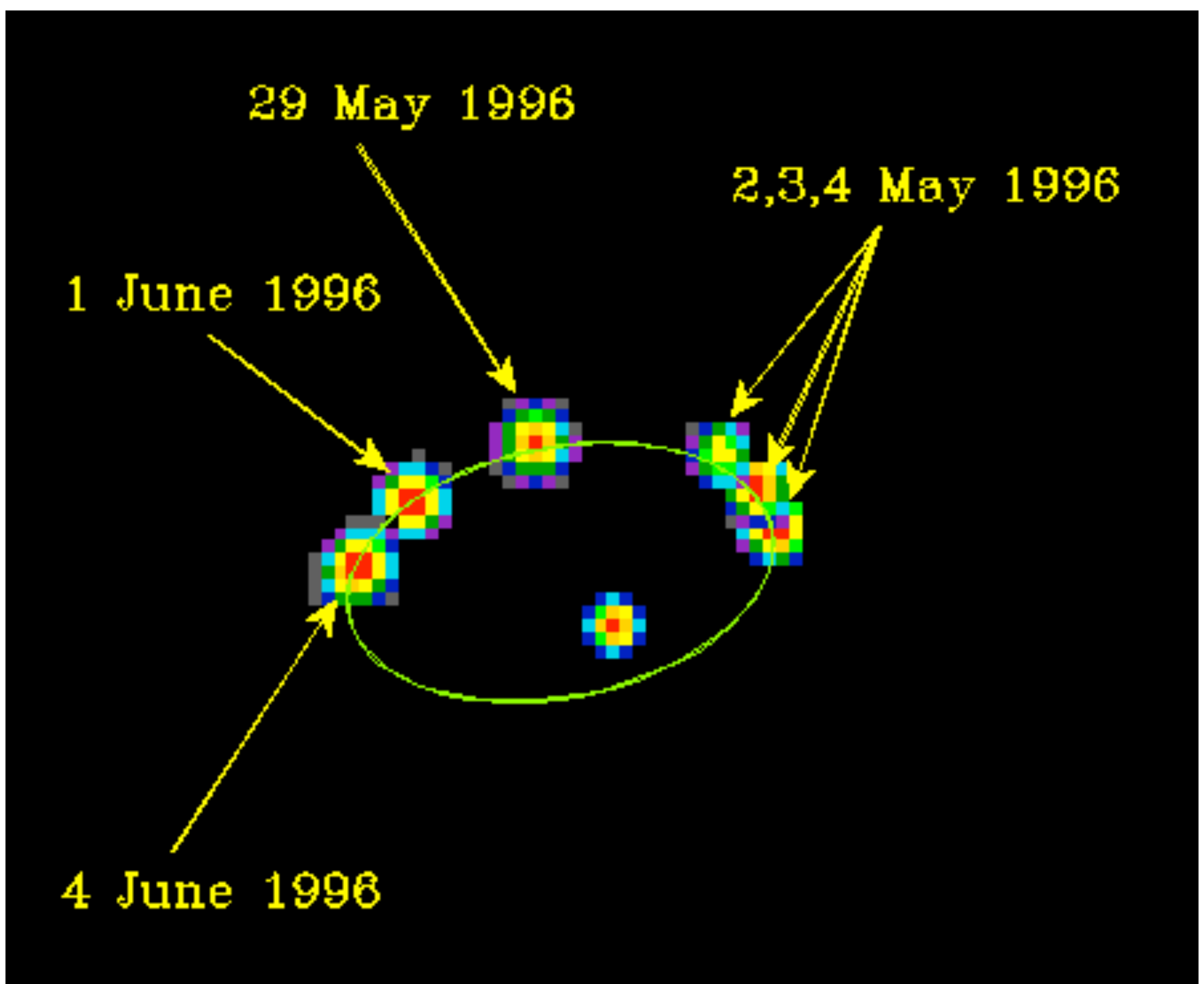
Astronomy 150: Killer Skies
Lecture 20, March 7

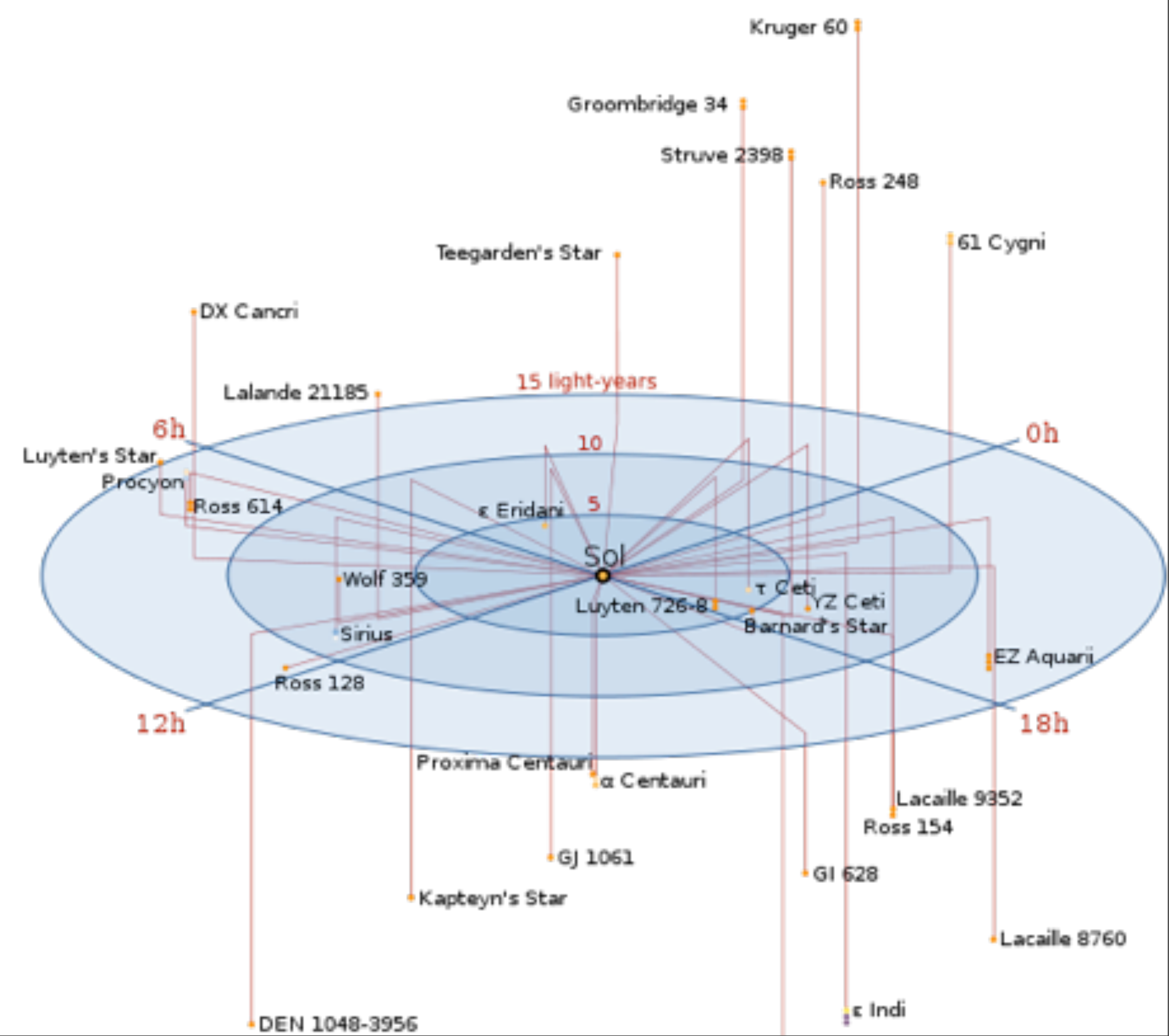
Assignments:

- HW6 was due at start of class
- HW7 due next Friday at start of class
- Night Observing finished

Last time: Properties of Stars

Today: Properties of Stars and Stellar Evolution





Solar Storm Update

Recall: Sun is near peak of sunspot cycle

- maximum of solar activity

this week: huge coronal mass ejection!

- aimed right at earth!
- raised alarms!

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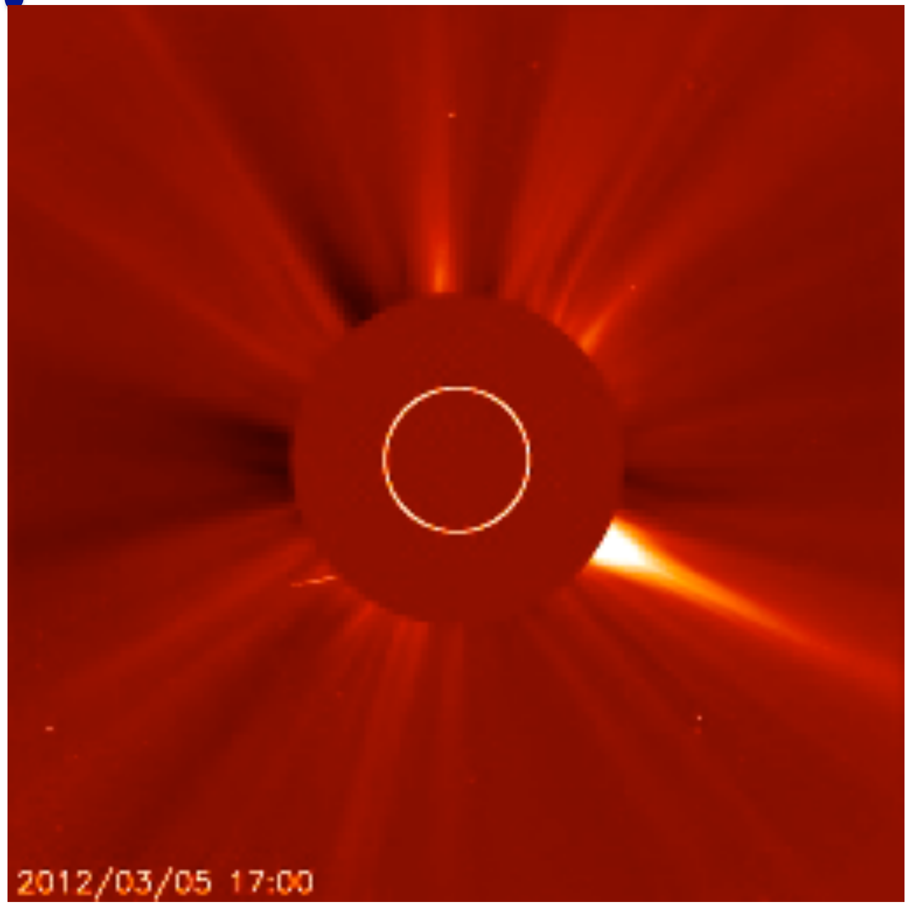

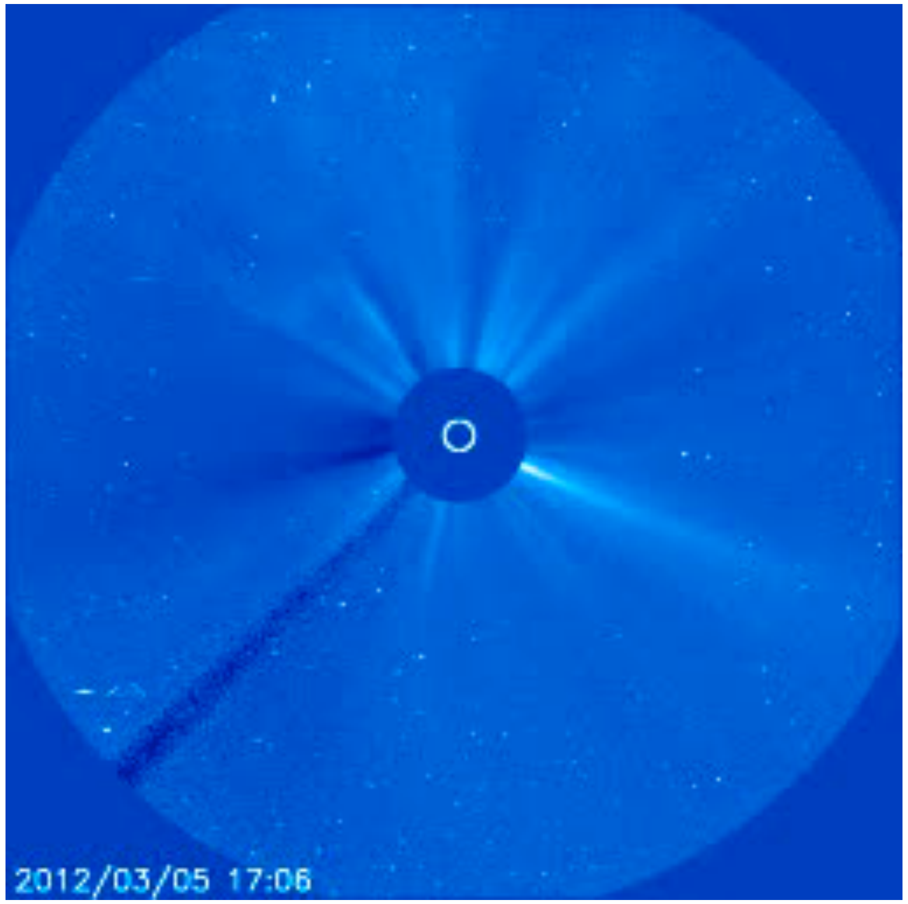

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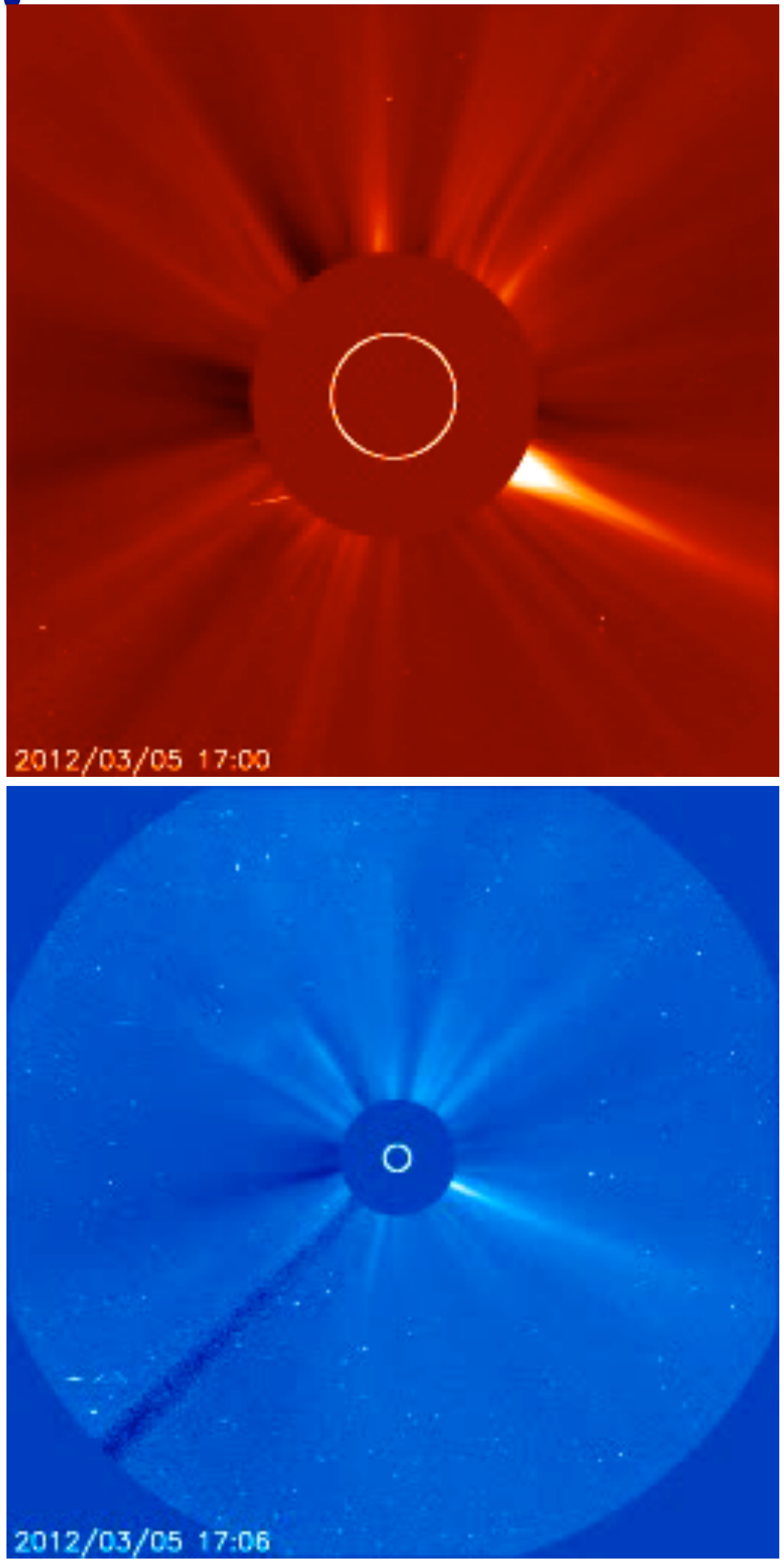
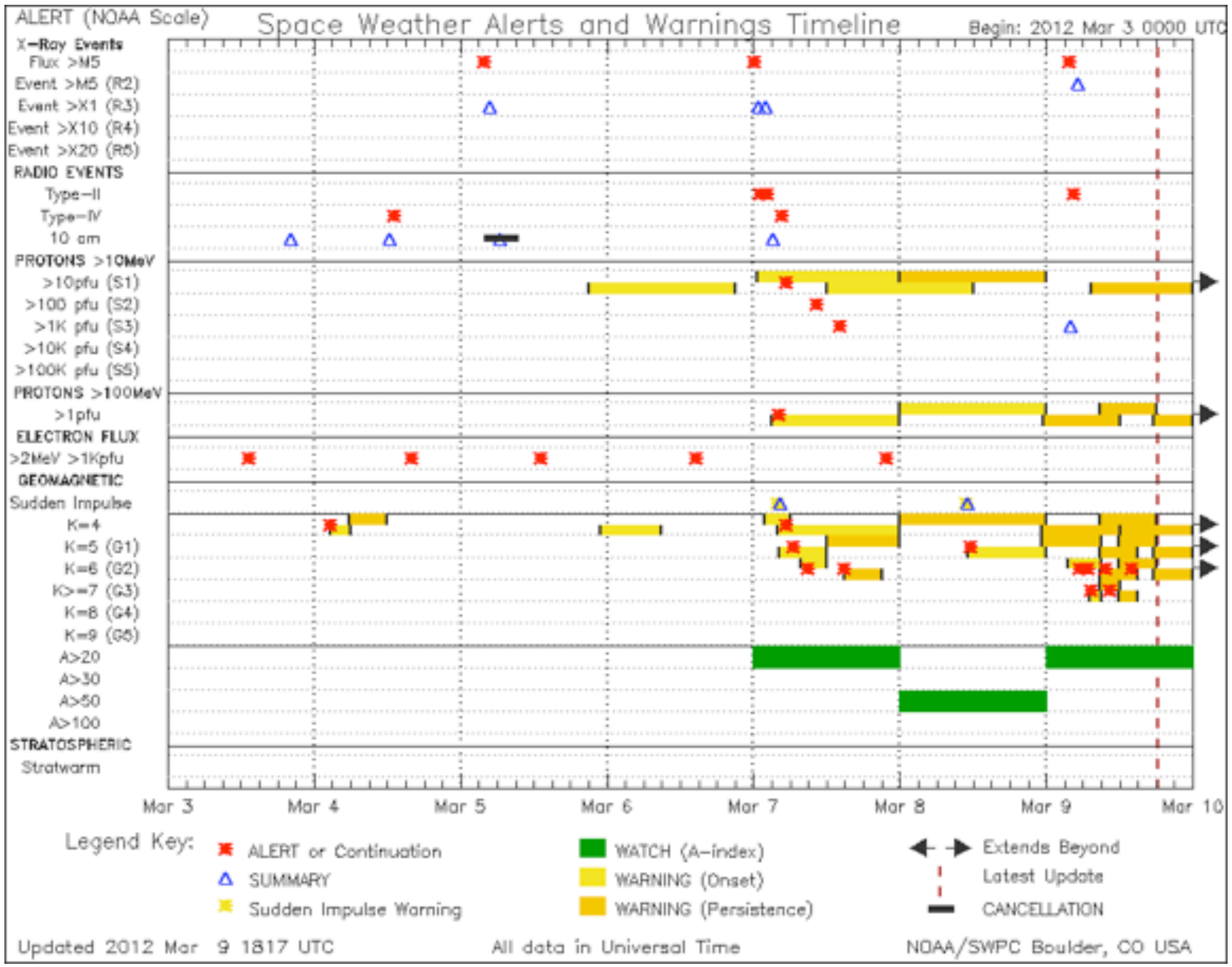


All Along the Watchtower: Space Weather Monitoring

http://www.swpc.noaa.gov/SWN/

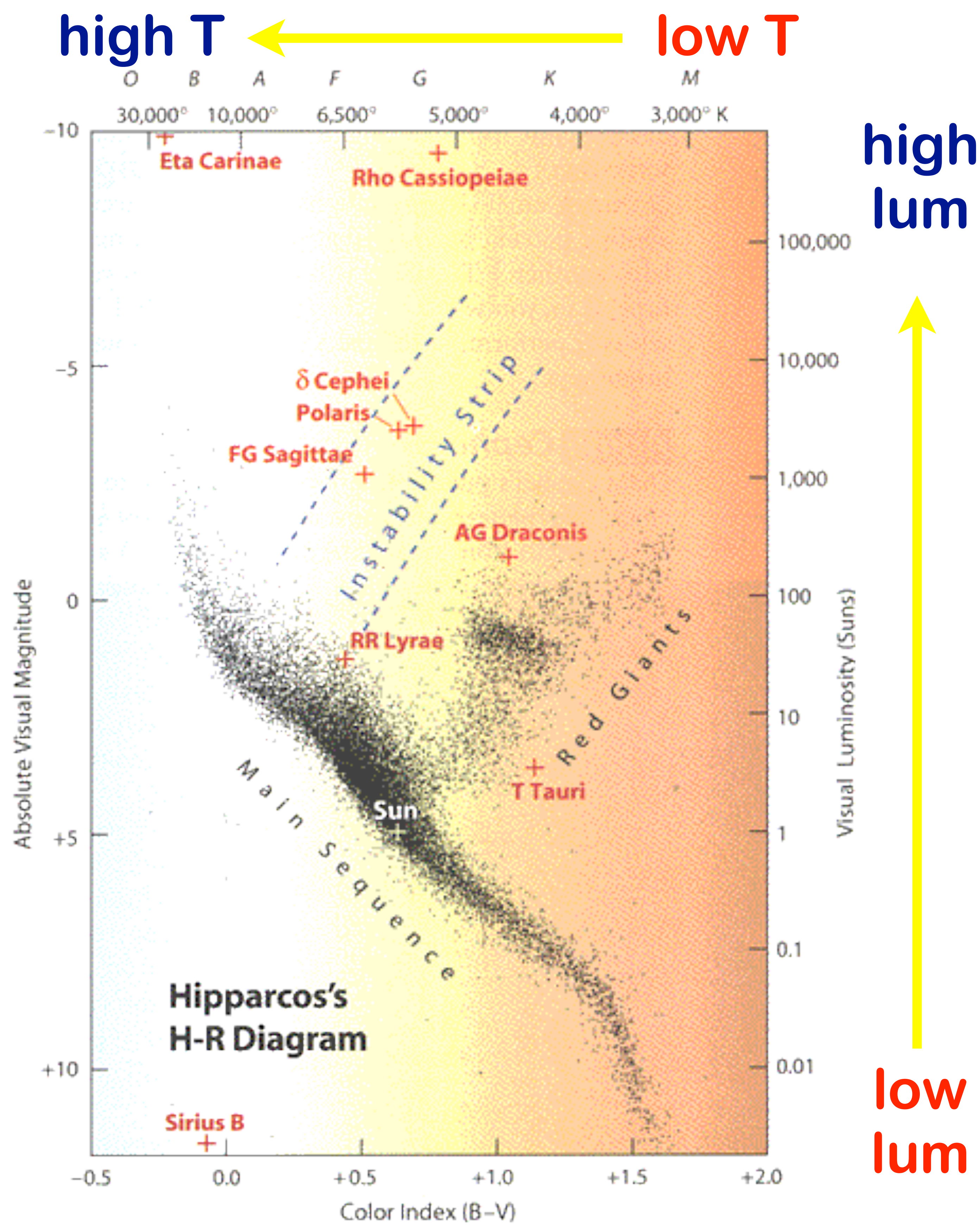
Alert page:

http://www.swpc.noaa.gov/alerts/alerts_timeline.html



A Census of Stars: The Real Data

HR diagram plots L vs T



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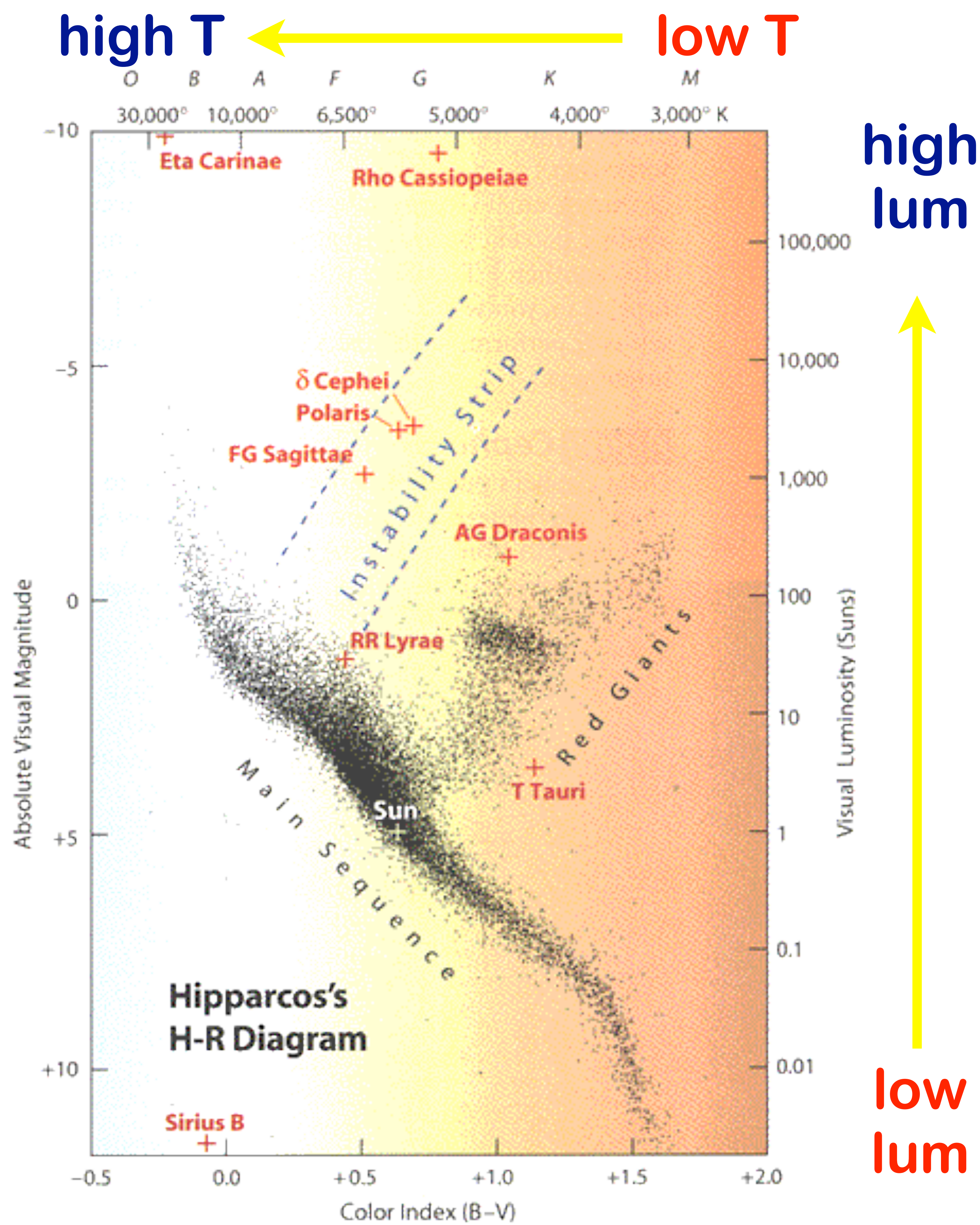

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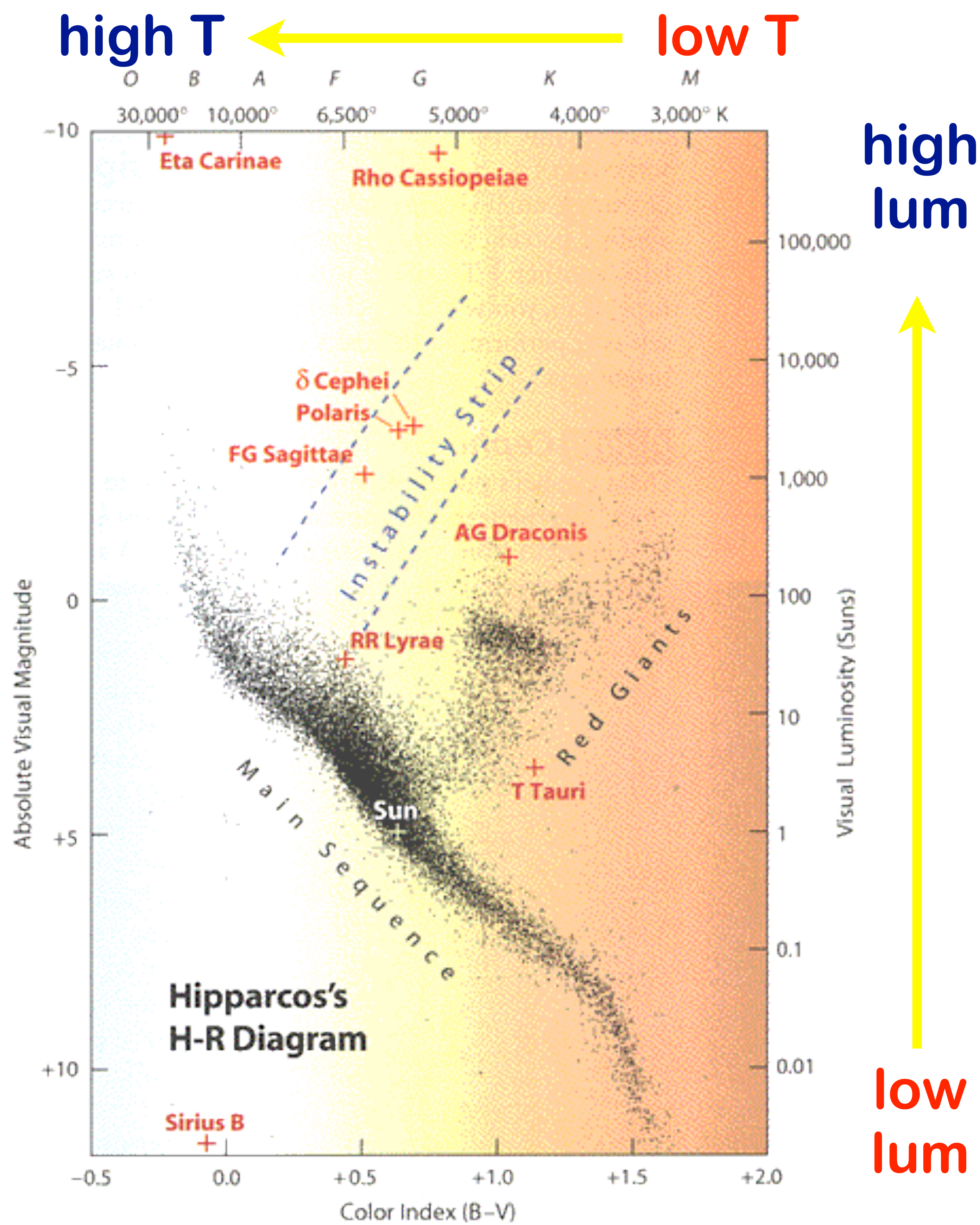

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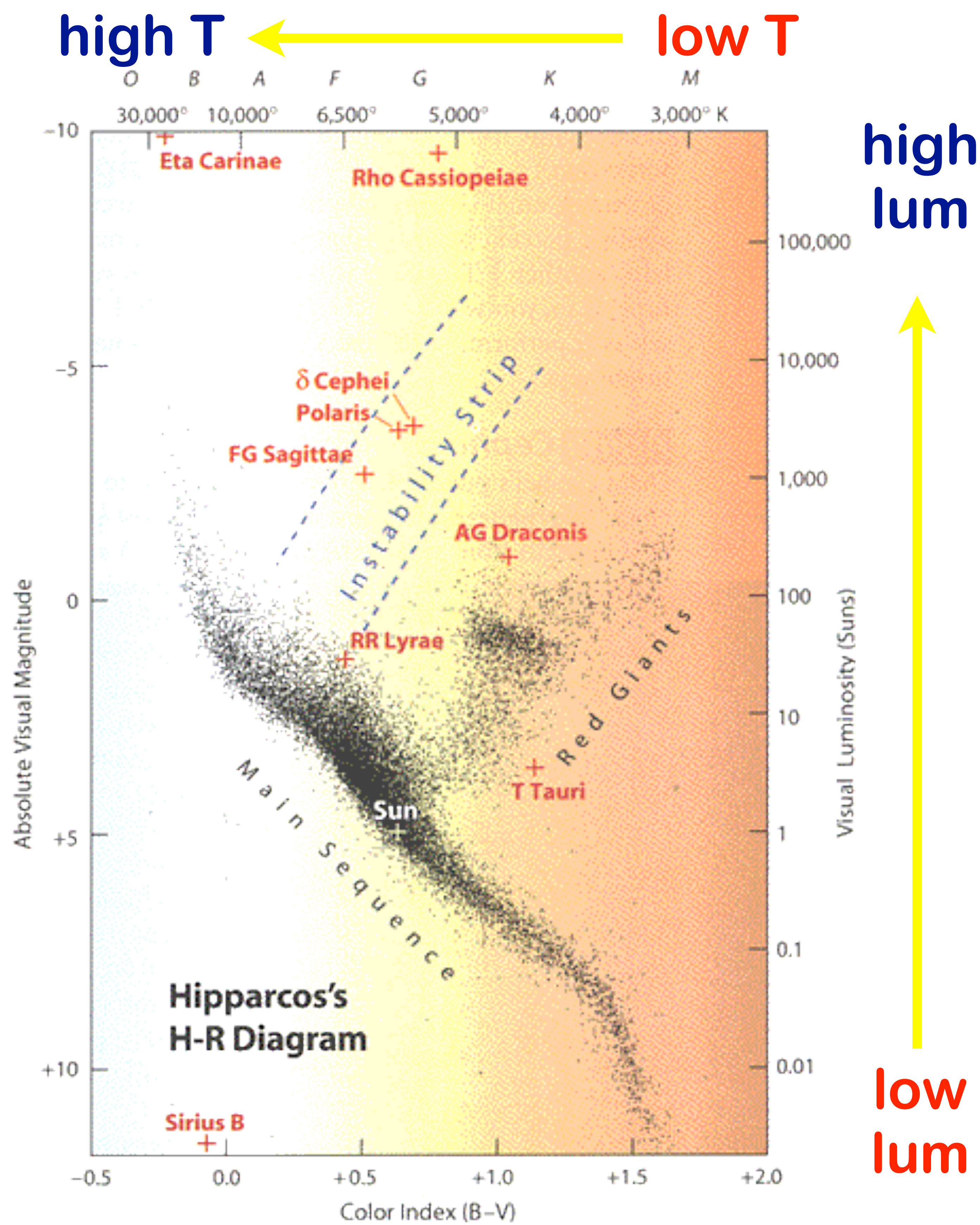
- **large range in T**, from 3000K to 30,000 K



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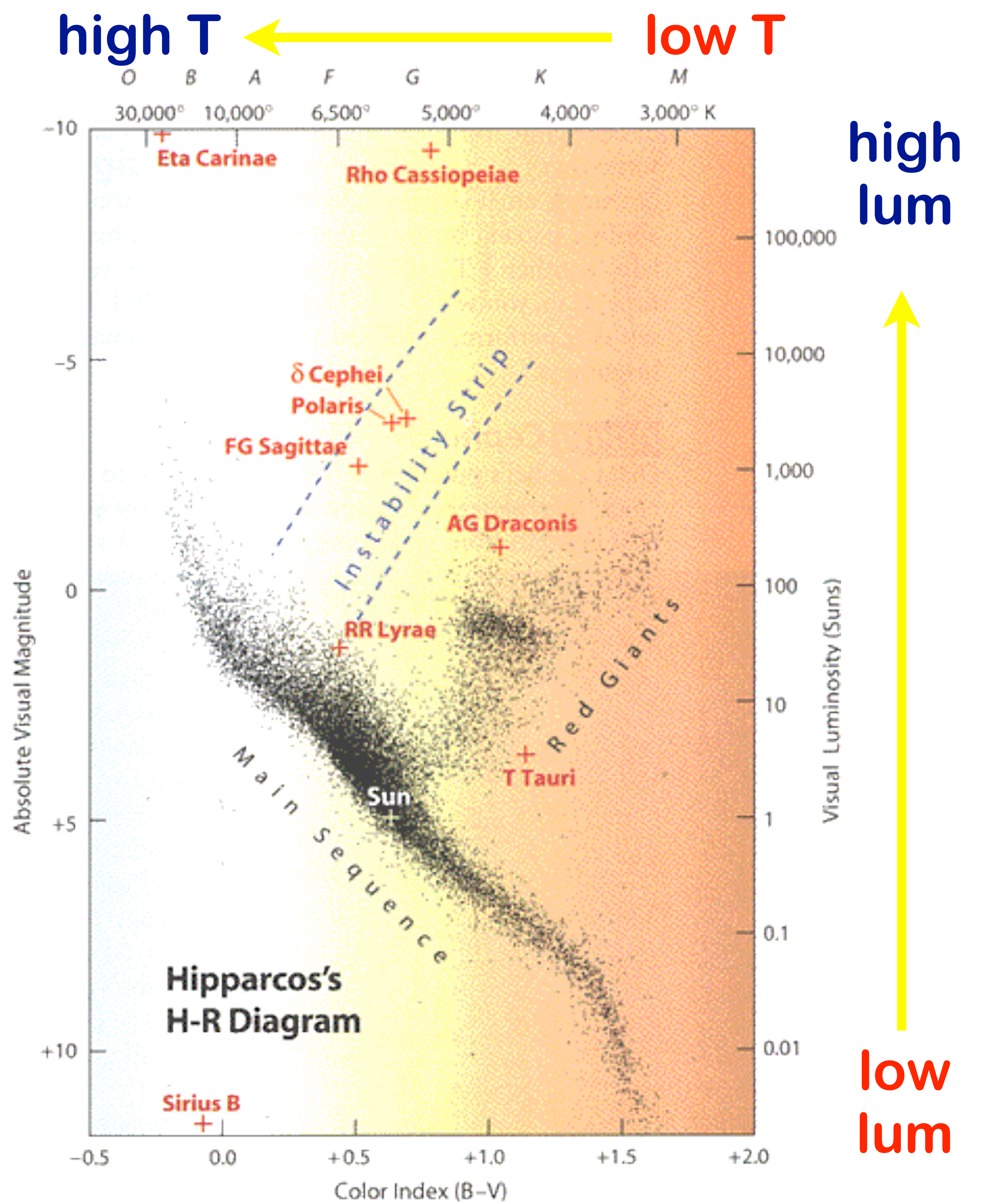

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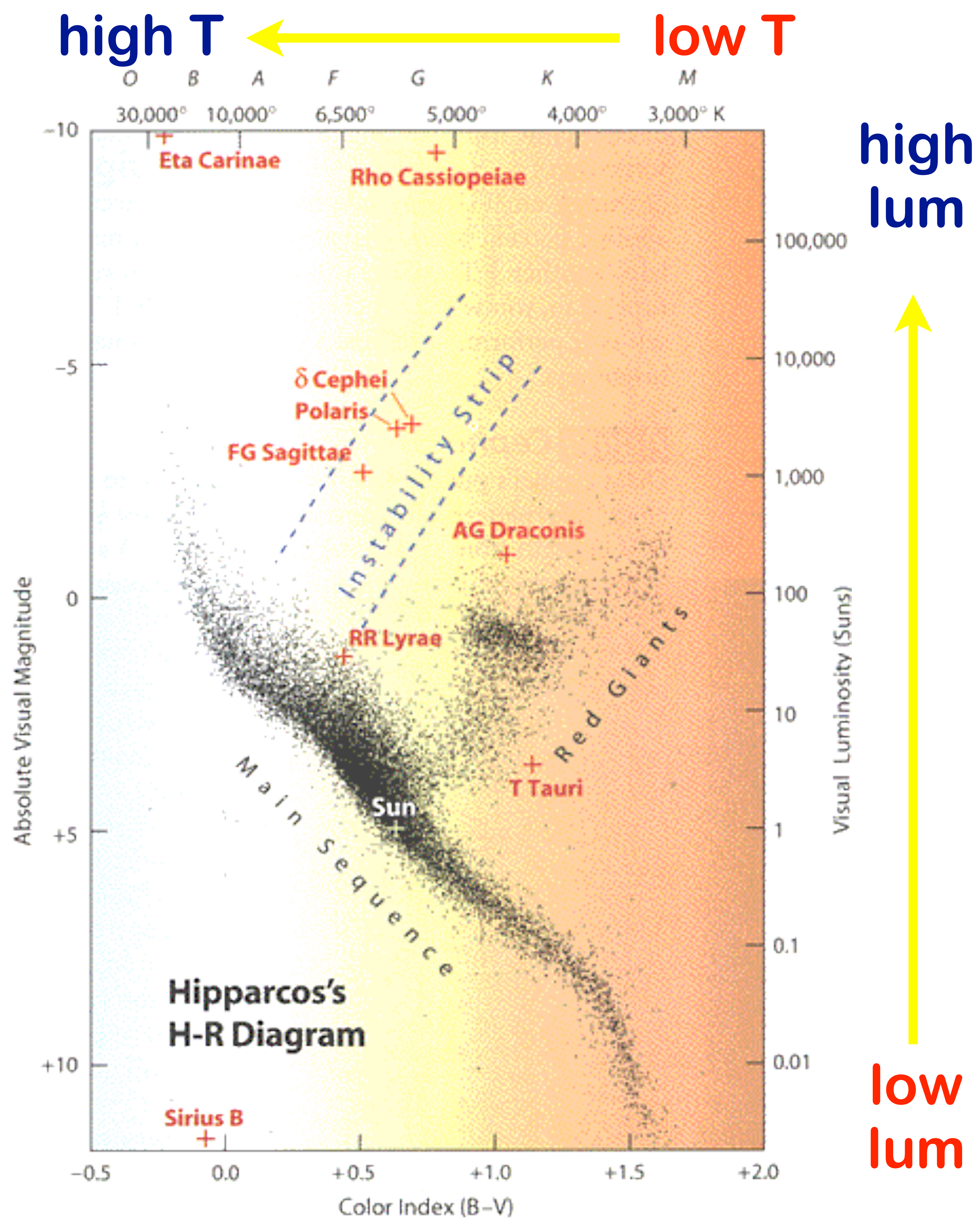

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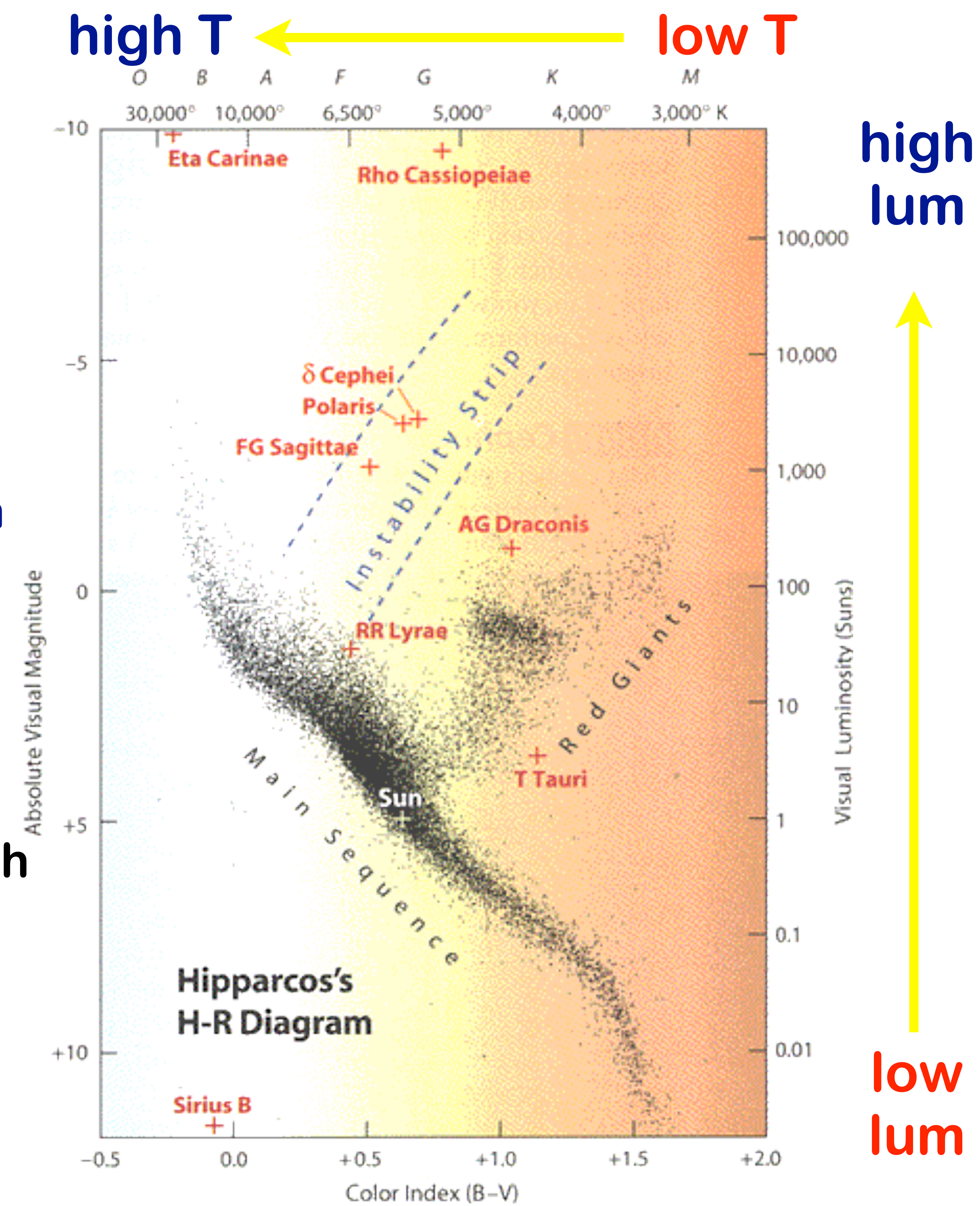

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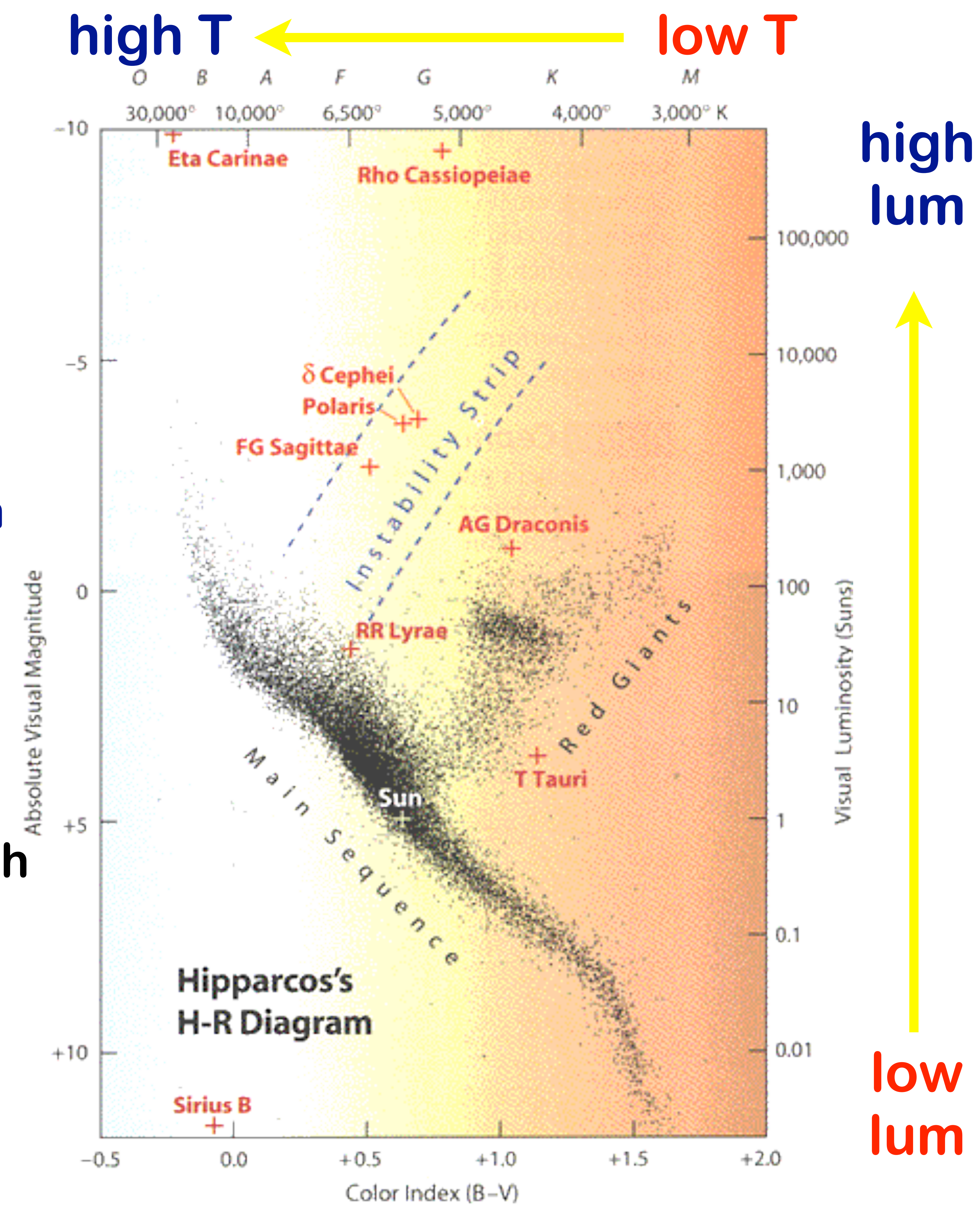

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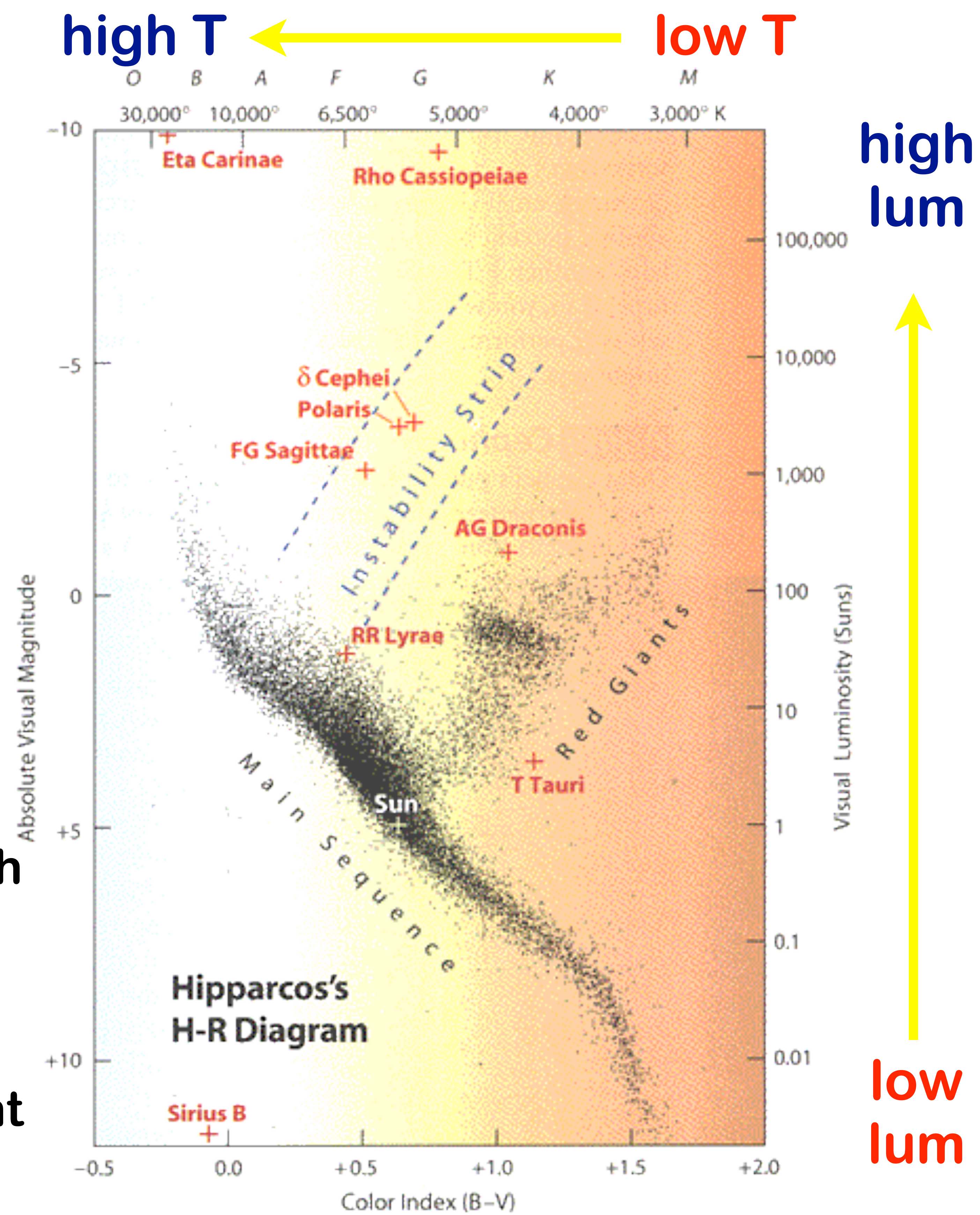
- Q: what makes stars have different L and T on main sequence?

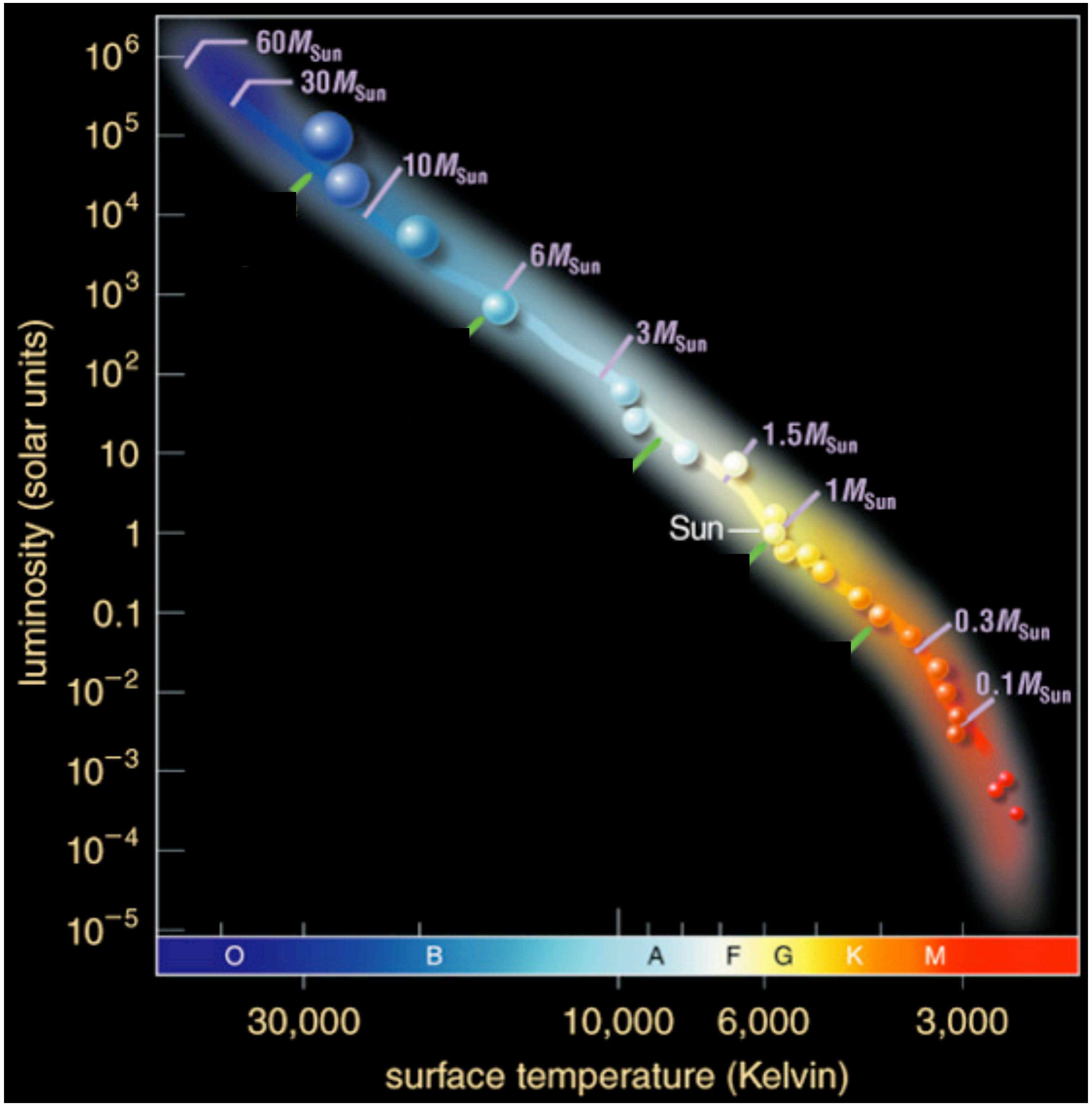


A star's mass is its most important property!

The main sequence is a sequence of different star masses!

More massive stars are hotter, brighter, and bluer

Less massive stars are cooler, dimmer, and redder



Lifespan

A star's mass controls its life

- more mass, more hydrogen fuel
- But, much greater luminosity = "burn rate"

$$L \propto M^4$$

- High mass stars "burn" fuel much faster than low mass stars

But stars have finite fuel supply

- burn by fusion
- fuel is mass M available to fuse $E \propto M$

Energy available to shine:

E = all energy ever emitted by star = fuel supply

$$\begin{array}{ccccc} \text{fuel} & = & \text{burn rate} & \times & \text{lifespan} \\ E & = & L & \times & \tau \end{array}$$

solve for lifespan

$$\tau = \frac{E}{L} \propto \frac{1}{M^3}$$

- inverse cube!
- lifespan decreases strongly for higher mass stars

Lifespan

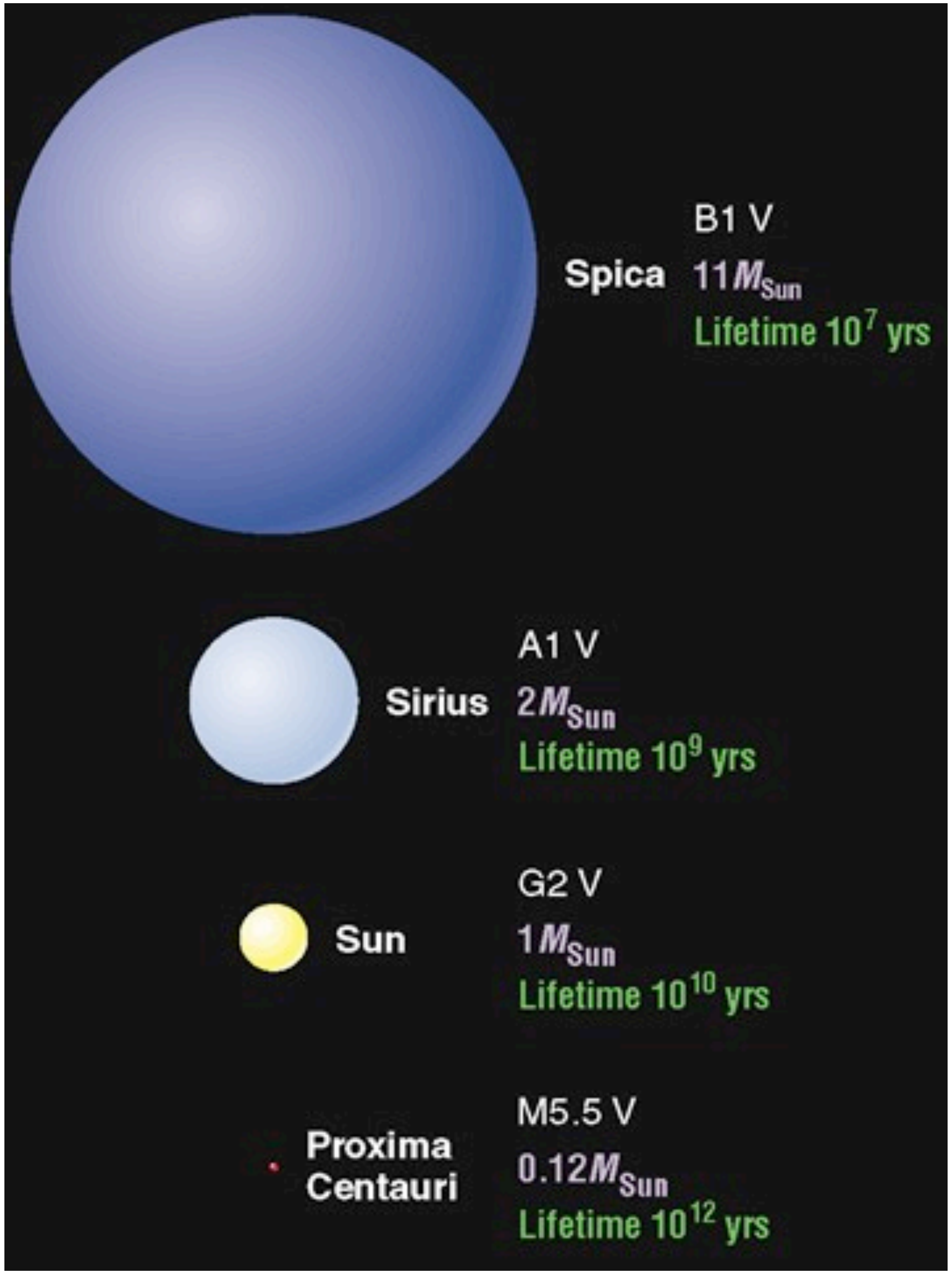
Star main sequence lifespan controlled by mass

- drops strongly vs mass

Leads to short lives for high mass stars!

And long lives for low mass stars

- 20 M_{sun}: few million year lifespan
- 1 M_{sun}: 10 billion year lifespan
- 0.1 M_{sun} >100 billion year lifespan = longer than age of Universe



High mass stars = Hummers
Low mass stars = Priuses

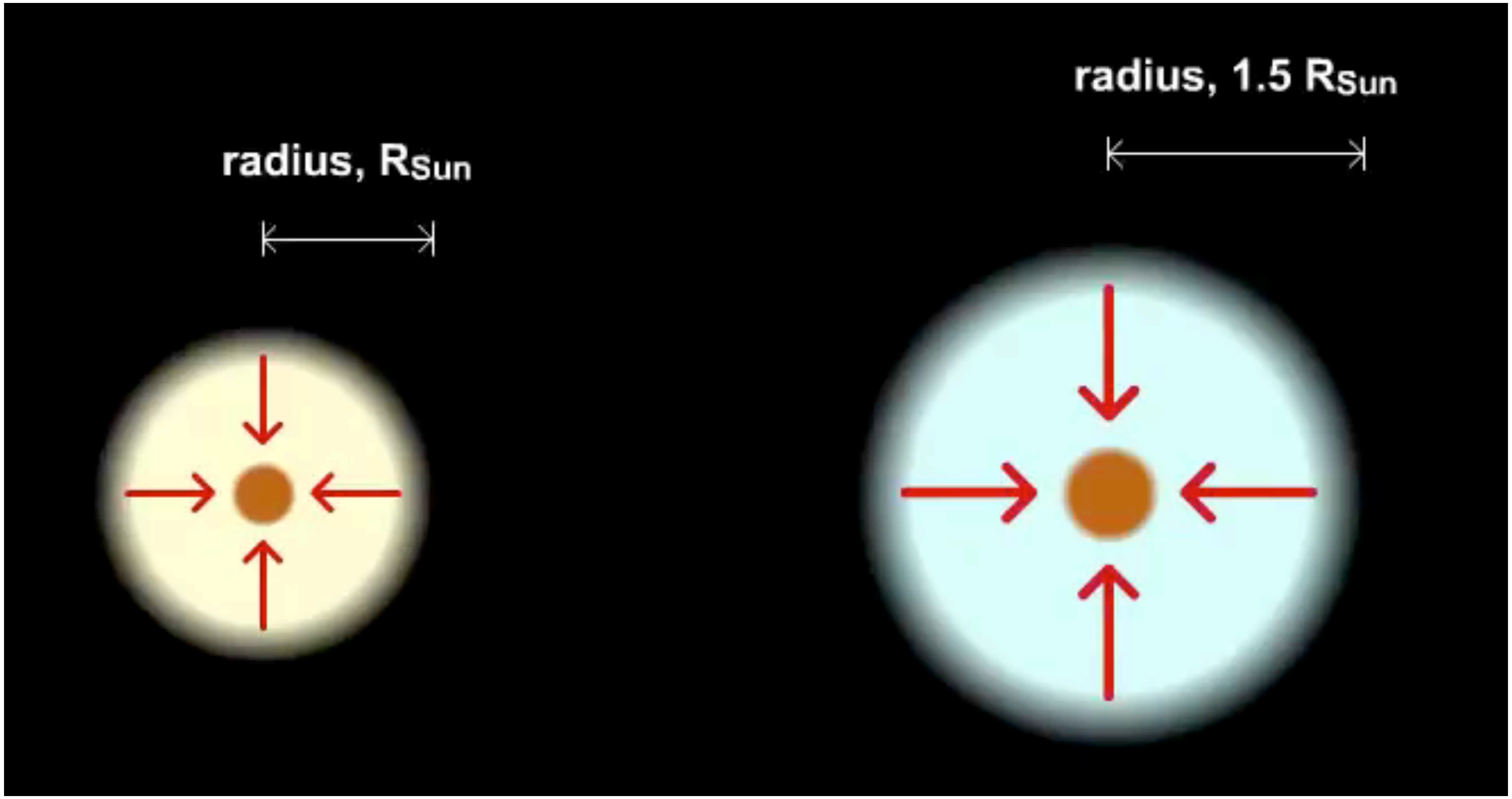
High-mass stars:
"gas guzzlers"

- High luminosity, large, blue
- Live short lives, millions of years

Low-mass stars:
"fuel efficient"

- Low luminosity, small, red
- Long-lived, hundreds of billions of years

What causes high-mass stars to live short lives?



Low Mass Star:

Lower Pressure
Lower Temperature
Slower Fusion
Lower Luminosity

High Mass Star:

Higher Pressure
Higher Temperature
Rapid Fusion
Higher Luminosity

Main Sequence: Properties Summarized

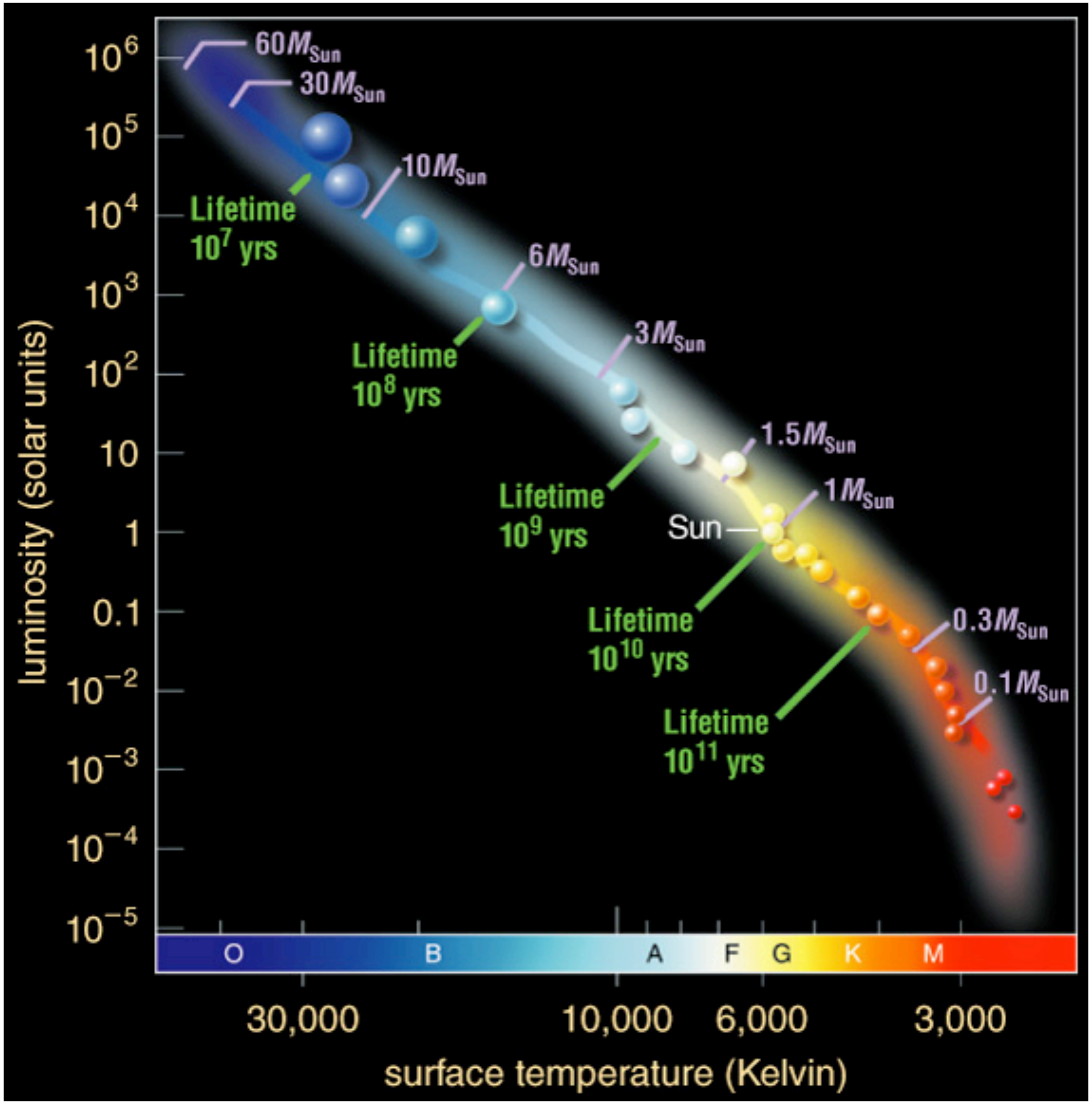
Main sequence is a sequence in star mass

high T:

- high luminosity
- high mass
- large size
- short lifespan

low T:

- low luminosity
- low mass
- small size
- long lifespan



iClicker Poll: Stars then and now

Imagine all stars formed soon after big bang

- born with a full range of masses from $0.1M_{sun}$ to $100\ M_{sun}$
- 13 billion years ago
- no stars born afterwards

If so, what main sequence stars would we see today?

A. only low-mass stars

B. only high-mass stars

C. stars of all masses

D. no stars would be left today

Star Lifespans and Cosmic History

The universe is 14 billion years old

- The Sun's lifespan: 10 billion years
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- none have had time to die yet: live "forever"

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conclude: star formation is continuous and ongoing

- should be able to see stars being born
- should be able to see stars dying

The Mosquito Dilemma

It's like a mosquito (lifespan ~2 weeks) trying to understand humans.

They don't live long enough to watch humans be born and die, so they have to extrapolate.

How do we understand stars that live for millions or even billions of years?

http://news.uns.purdue.edu/html3month/2004/040823.Williams.fallwnv.html

Family Jewels?

The HR diagram can tell us a lot of information about stars, how they work, and how they die.

It reveals the family secrets of the stars.

Recall:

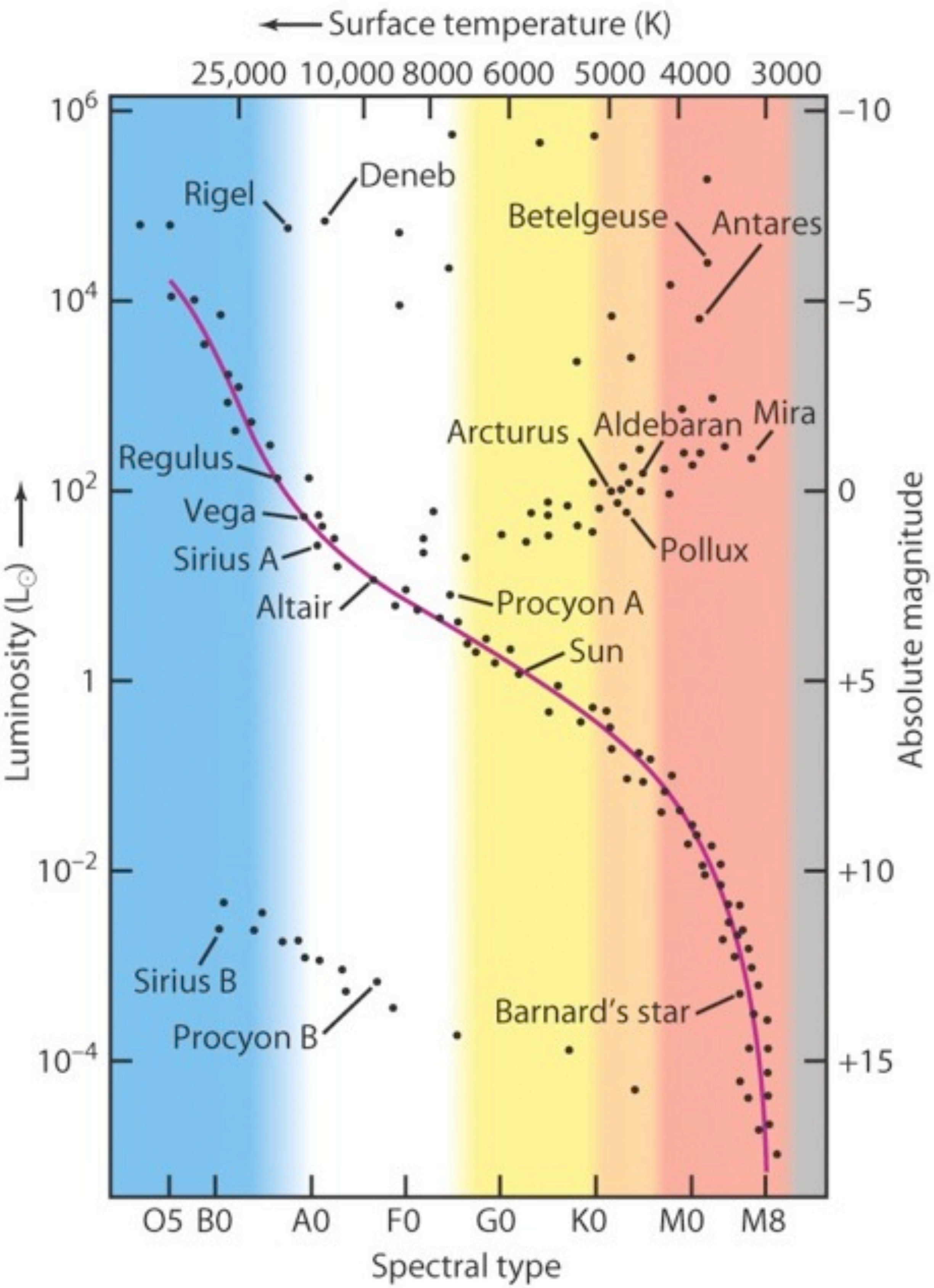
We already know the Sun's life stages

- main sequence
- red giant
- white dwarf

And Sun is typical main sequence star

- so we should see other stars going through the late stages

The H-R Diagram



How does the size of a star near the top left of the H-R diagram compare with a star of the same brightness near the top right of the H-R diagram?

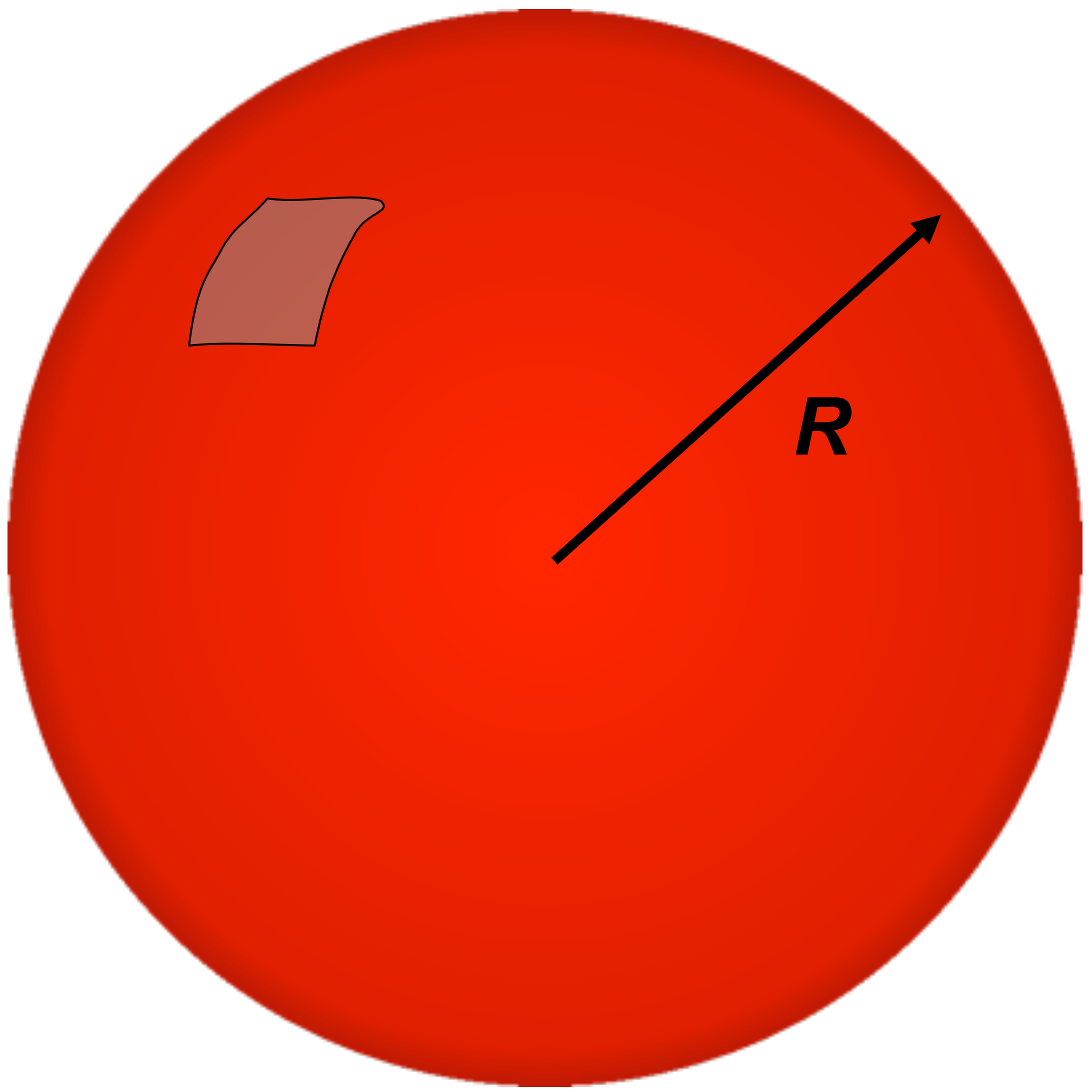
Luminosity

Bright but cool stars must be large

- cooler surface: less blackbody radiation in each patch of area
- so if very luminous, must have a lot of area: L ~ area ~ R^2
- Giants & Supergiants

Dim hot stars must be small

- White dwarfs



http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related

Earth

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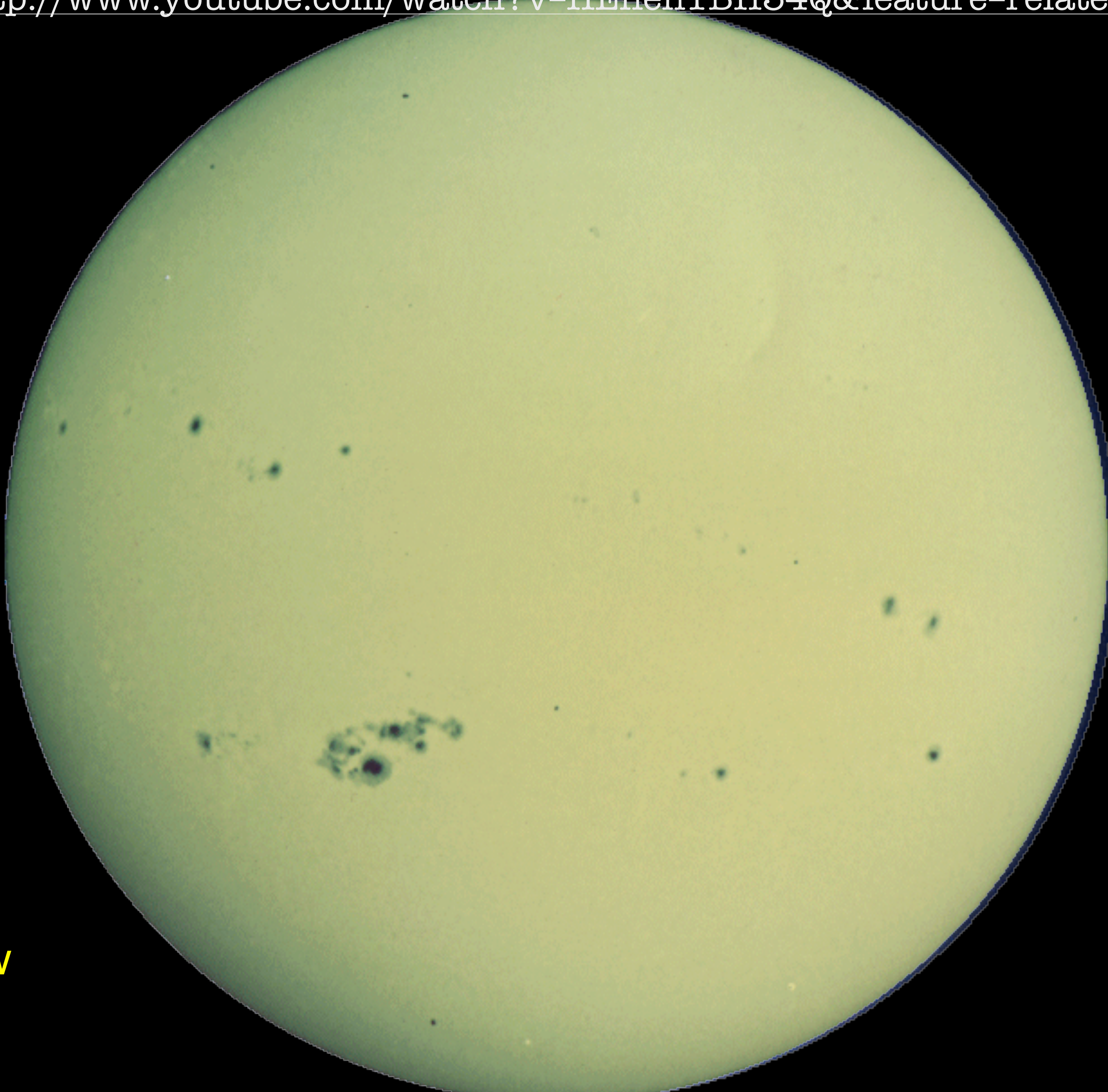
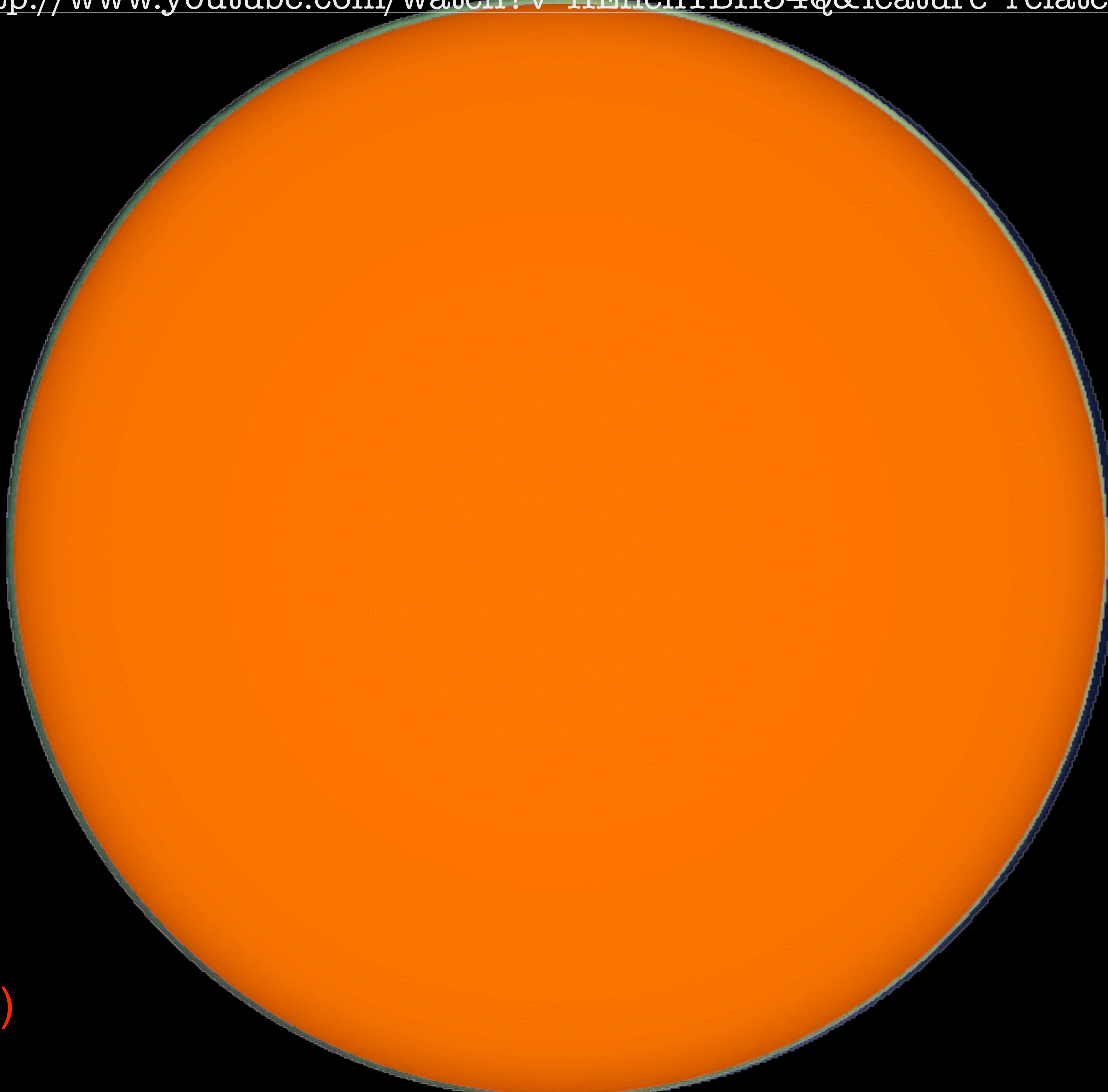


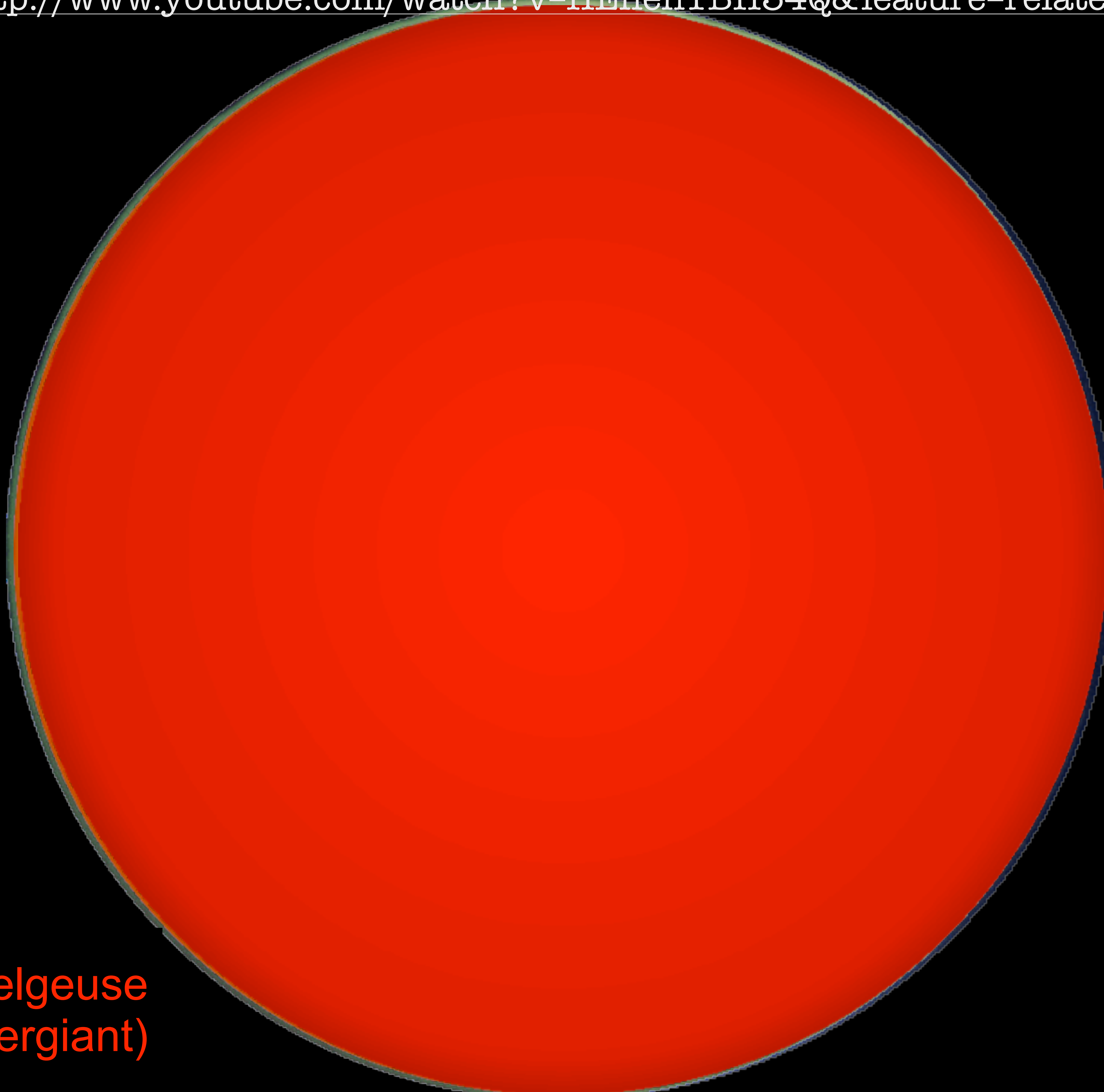
Sun
(Yellow
dwarf)

http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related



Arcturus
(Red giant)

http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related



Betelgeuse
(Red supergiant)

http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related

Betelgeuse
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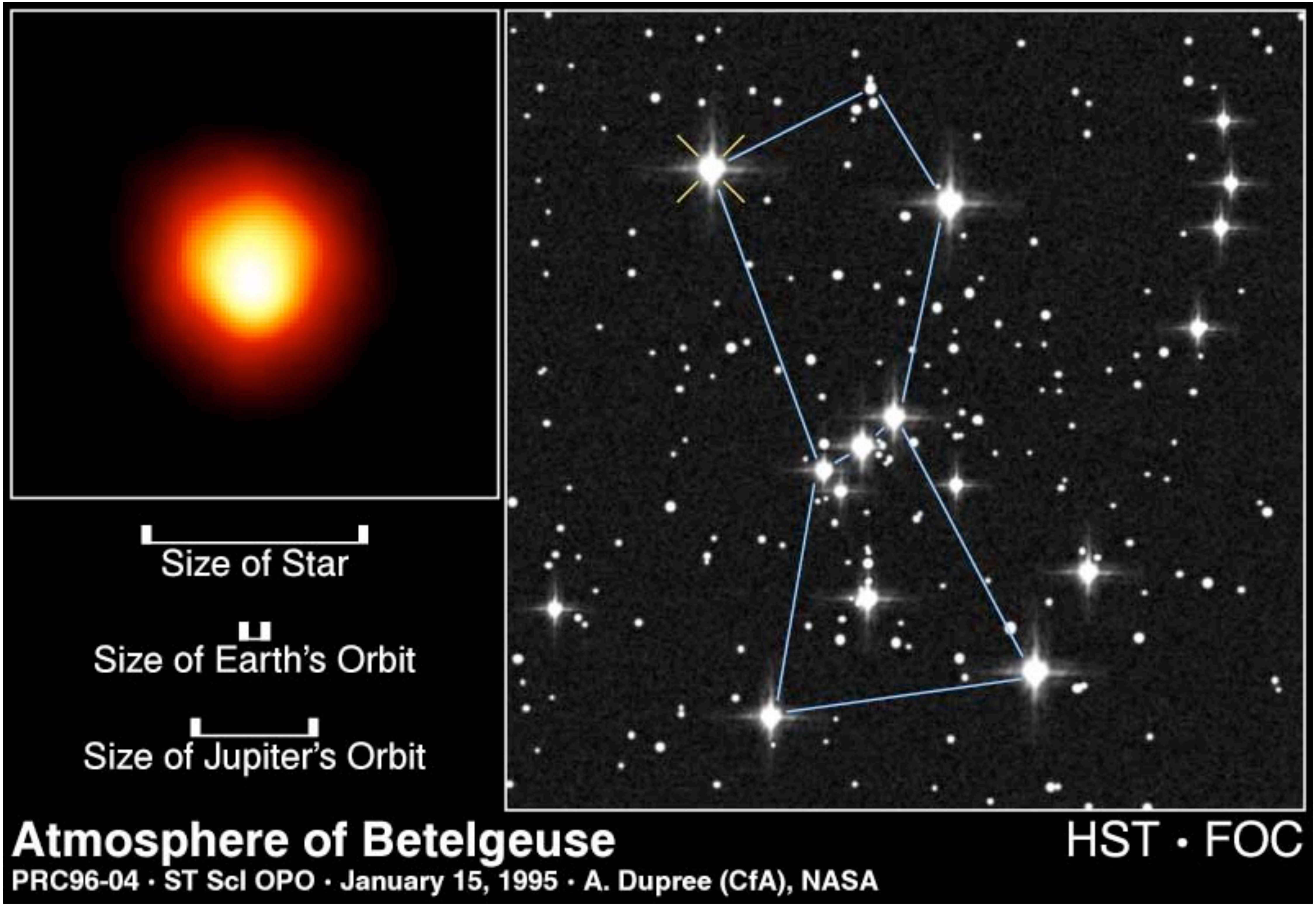
Truly Supergiant Stars...



HR Diagram and Stellar Evolution

Bright cool stars must are giants: stars that have just left main sequence phase

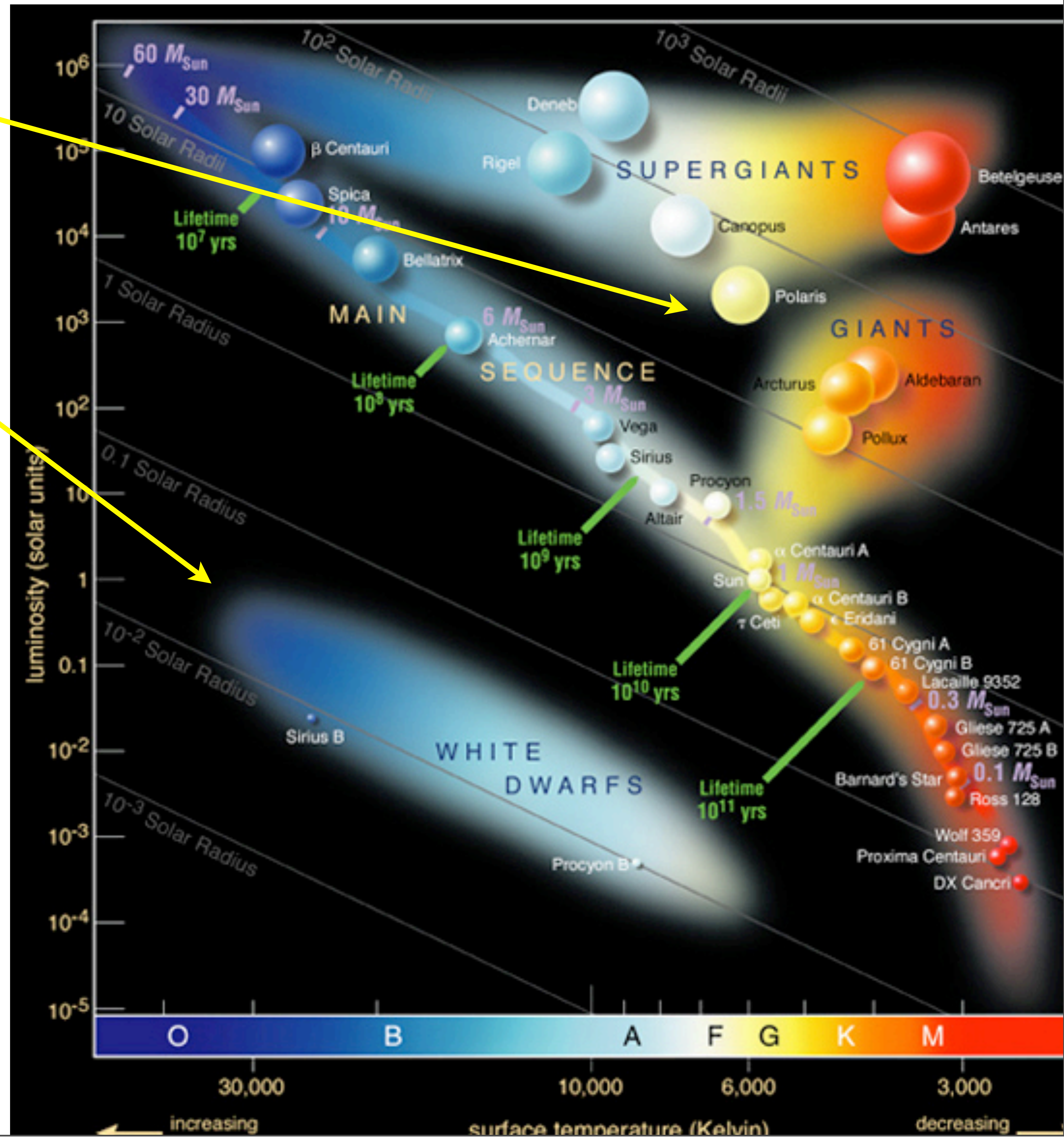
Dim hot stars must be small: white dwarfs--corpses of stars that have died as the Sun will

In both cases, they are somewhat rare.

- 90% of stars are on Main Sequence
- 10% are giants

Why? Time!

- 90% of stars' lives spend on main sequence
- only 10% spent in giant phase



The Evolution of Stars

a star's fate set by its mass

simulation: 10,000 stars born at same time,
with range of masses

all stars:

- formed in gas clouds
- first burn hydrogen to helium: main sequence phase
- main sequence stars are hydrogen burning

but final stages depend on mass

low mass: $M<0.8M_{sun}$

- lifespans longer than age of Universe
- none have died yet: live "forever"

intermediate mass: $0.8M_{sun}<M<8M_{sun}$

- after main sequence, become red giants
- finally: white dwarf and ejected planetary nebula

high mass: $M>8M_{sun}$

- after main sequence: a new story

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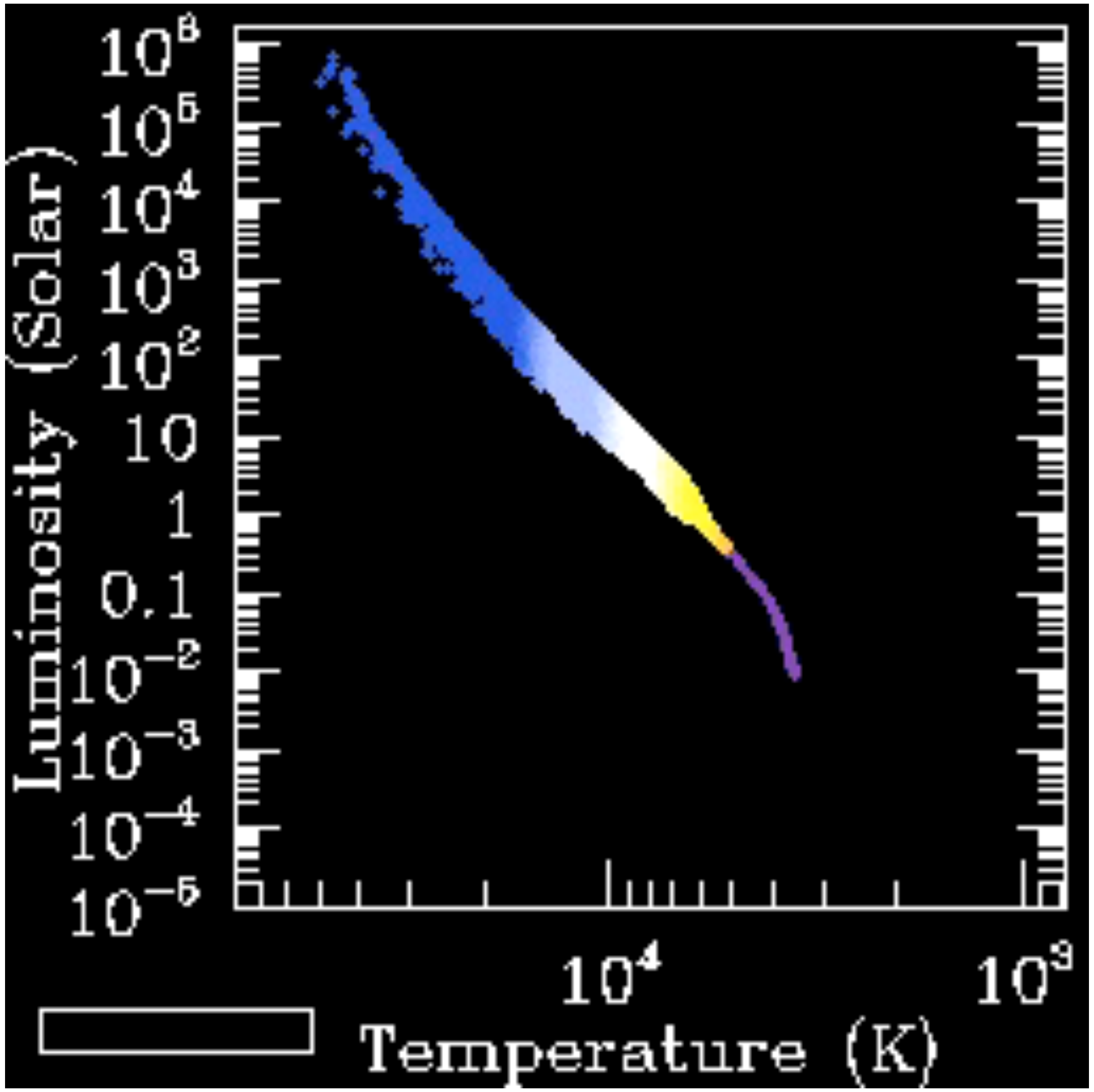

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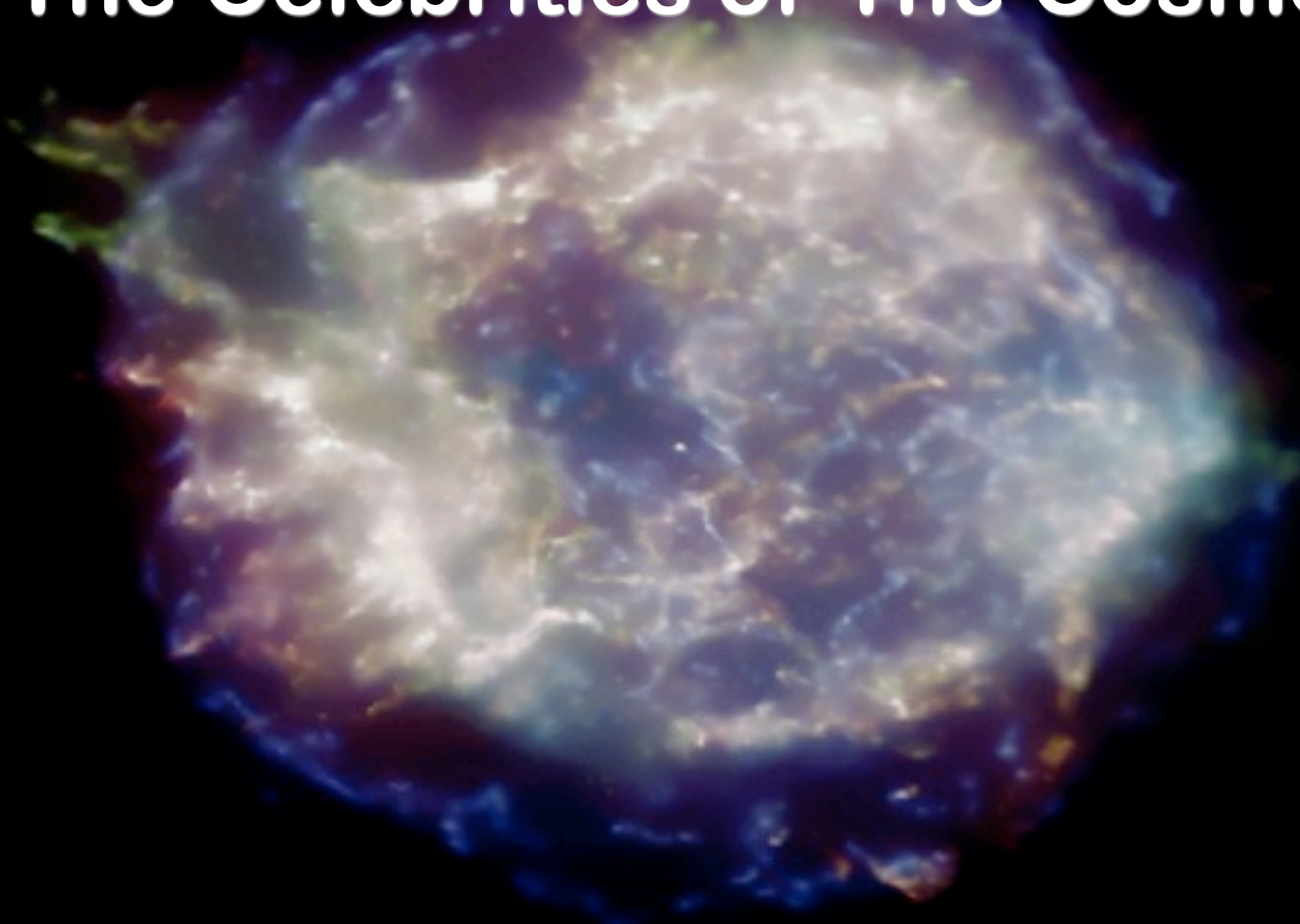
Massive Stars:
The Celebrities of The Cosmos



High-Mass Stars:
The James Dean of Stars

Live Fast

Star life is struggle vs gravity

Nuclear fires keep hot, stable

Die Young

- Fuel exhaustion ⟹ collapse
- Core becomes dense, “bounce”
- Shock wave launched ⟹ explosion!

Leave a Beautiful Corpse

- Ultradense “cinder”
  - neutron star/black hole
- Most material ejected at high speed

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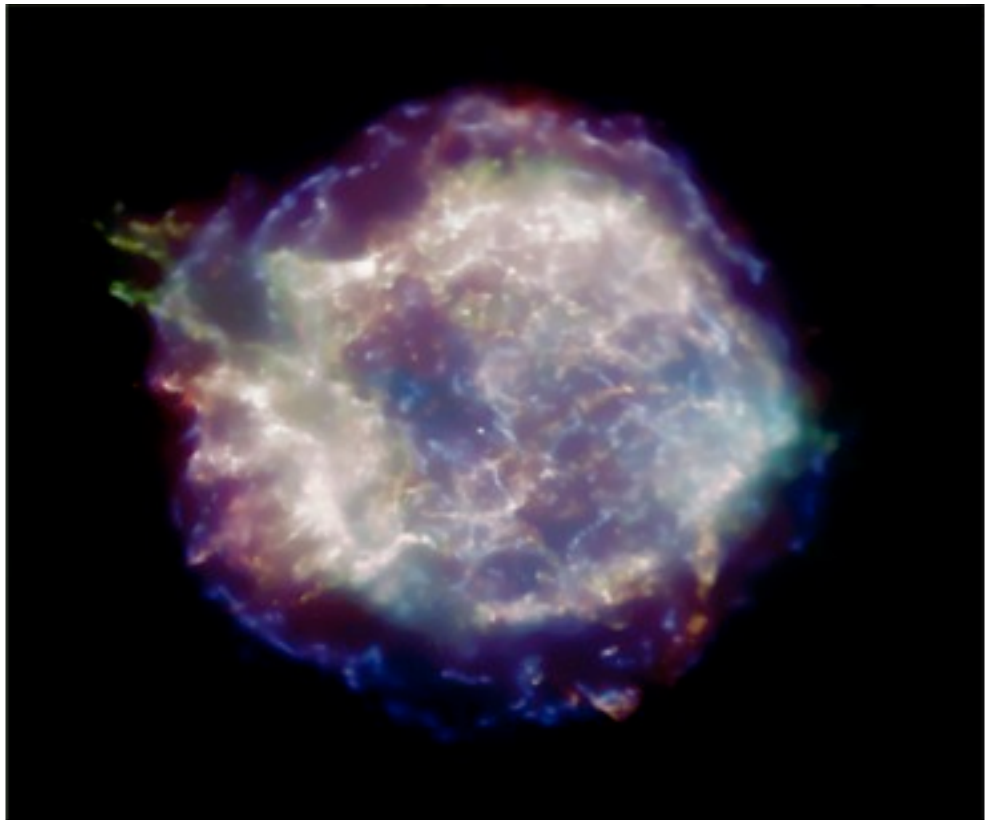

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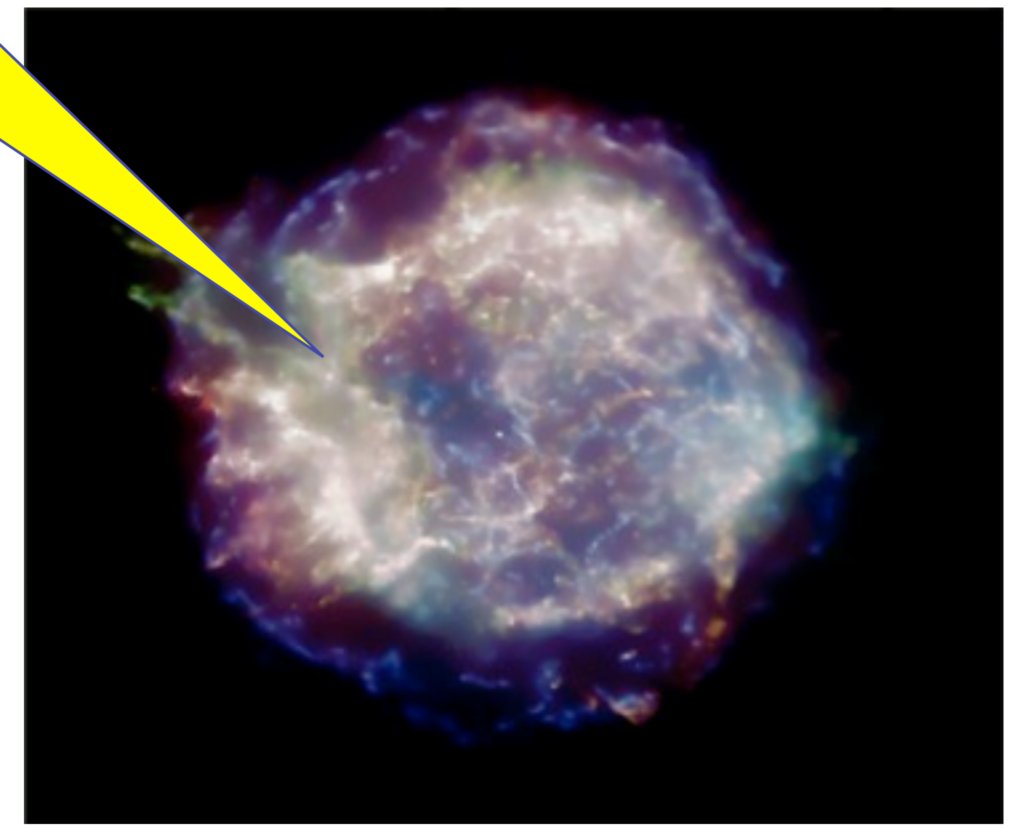

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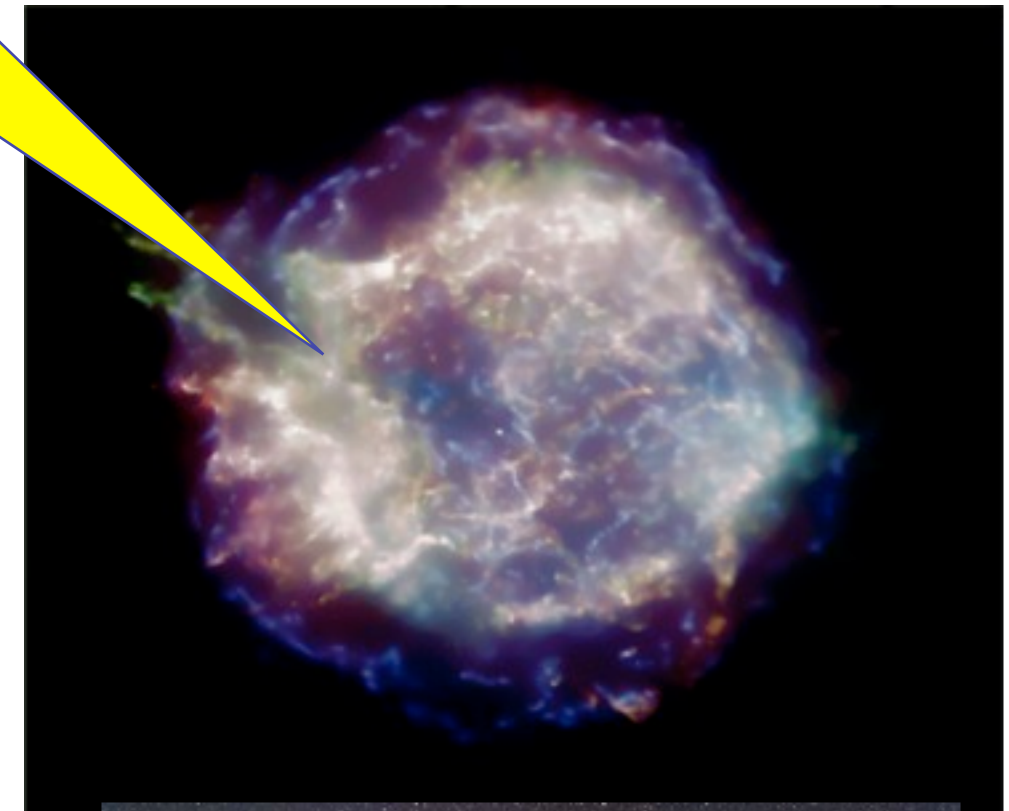

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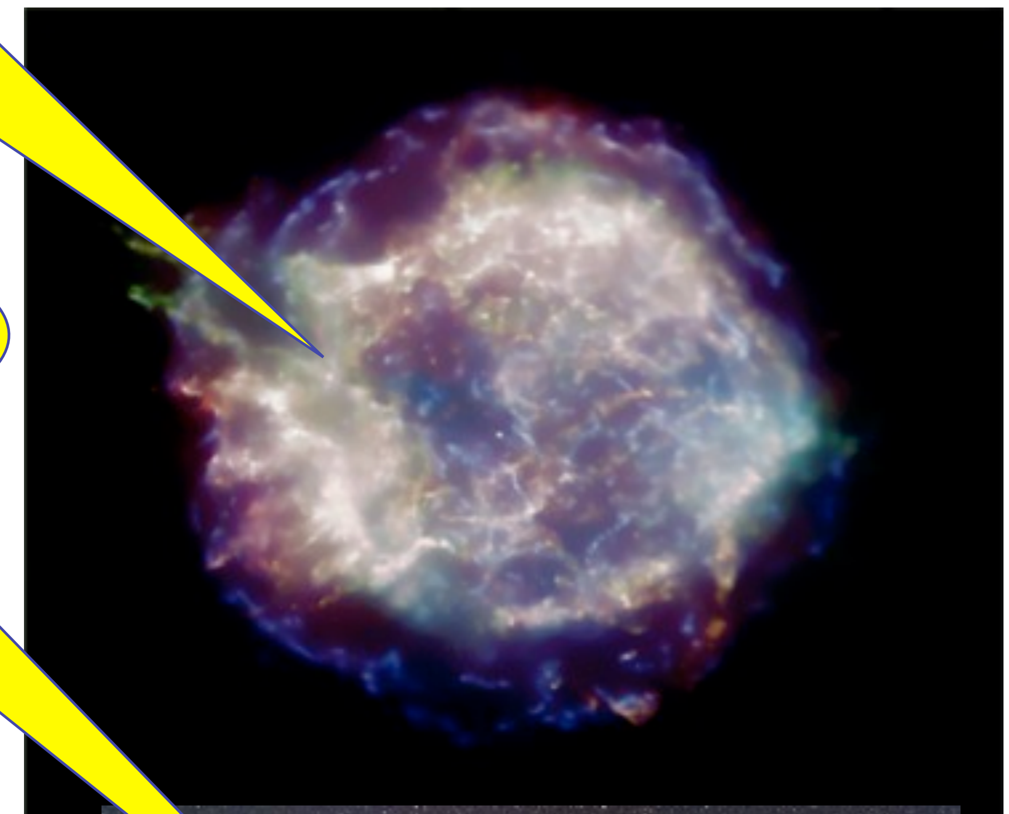
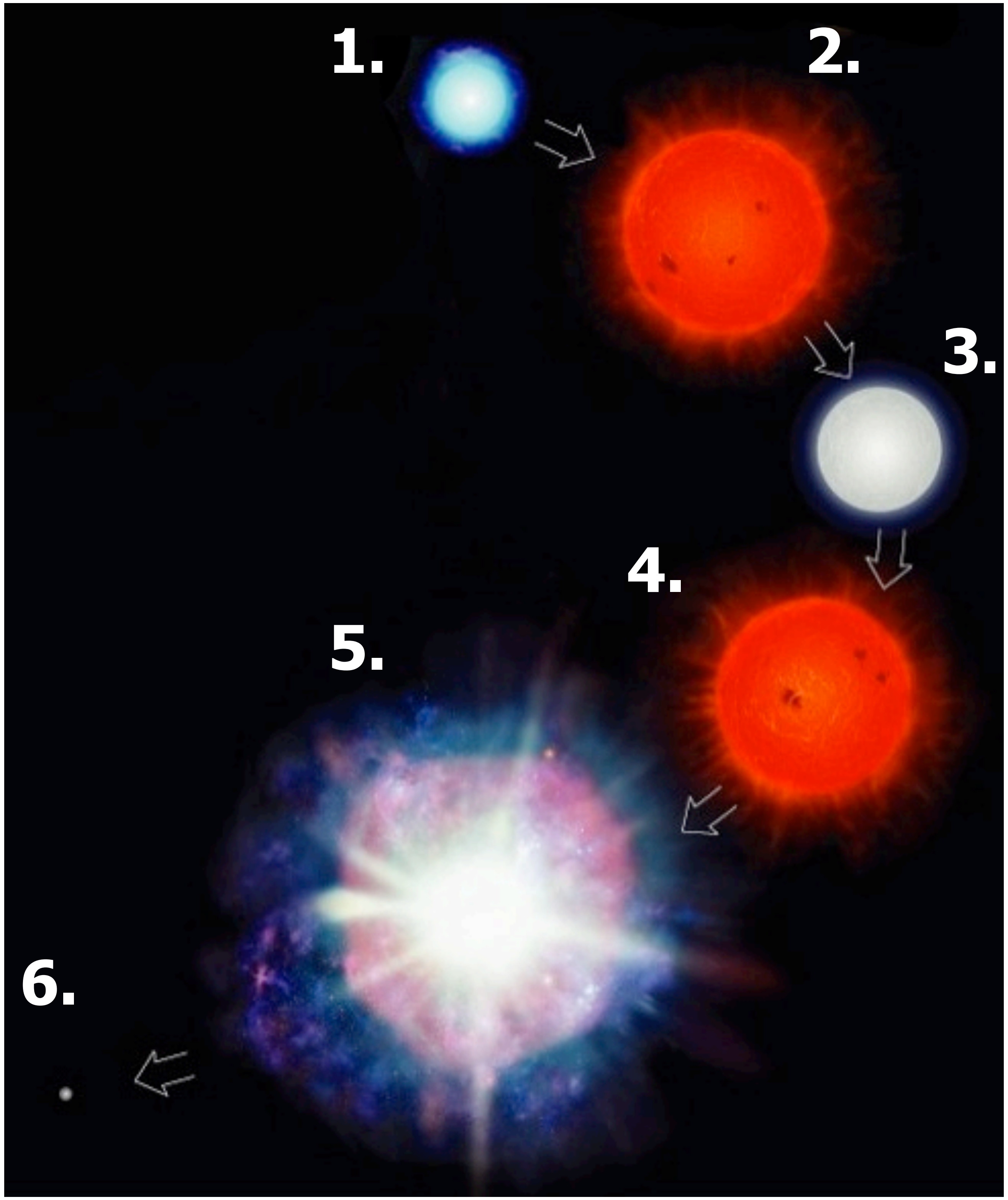


The Fate of a Massive Star

1. Main Sequence
2. Red Supergiant
3. Blue Supergiant
4. Red Supergiant II
5. Supernova!
6. Neutron star or black hole

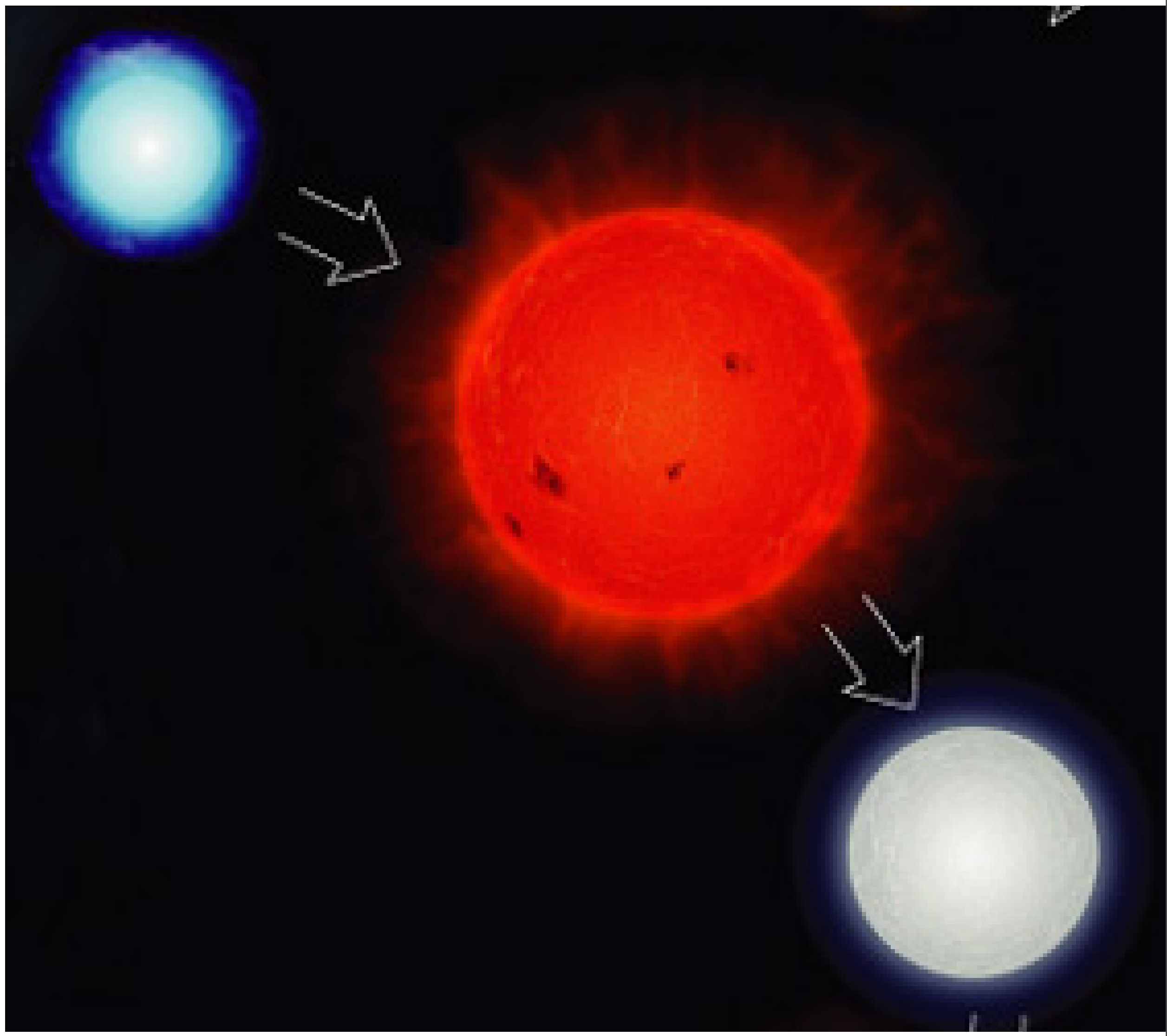


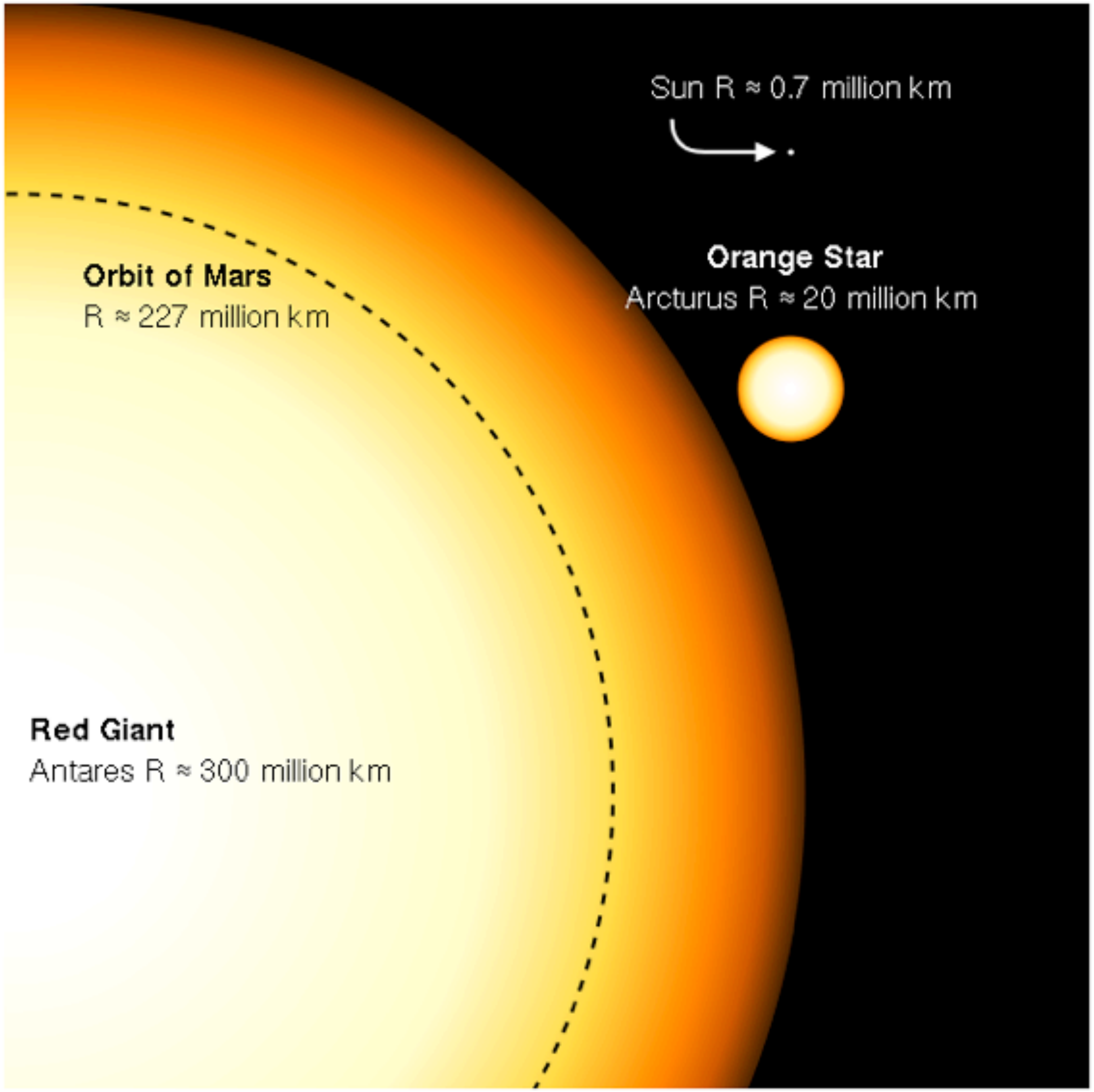
Initial stages are similar to those of the Sun

Main Sequence: H fuses to He in core

Red Supergiant: H fuses to He in shell around contracting He core

Blue Supergiant: He fuses to C in core




Sun R ≈ 0.7 million km
Orange Star
Arcturus R ≈ 20 million km
Orbit of Mars
R ≈ 227 million km
Red Giant
Antares R ≈ 300 million km

Massive Stars: Late Stages

Recall Sun's evolution

- main sequence: H "burns" = fuses to He
- red giant: He burns to carbon
- but too cool to burn carbon, so fusion stops
- white dwarf formed, planetary nebula ejected

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  - with outer shell burning H to He

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Recall Sun's evolution

- main sequence: H "burns" = fuses to He
- red giant: He burns to carbon
- but too cool to burn carbon, so fusion stops
- white dwarf formed, planetary nebula ejected

In massive stars:

more mass = more gravity = more pressure = much hotter

- also begin on main sequence: H burns to He
- but when core is He "ash", contract, heat, can easily burn He to carbon
  - with outer shell burning H to He
- then when core is carbon "ash", contract, heat, fuse carbon to oxygen

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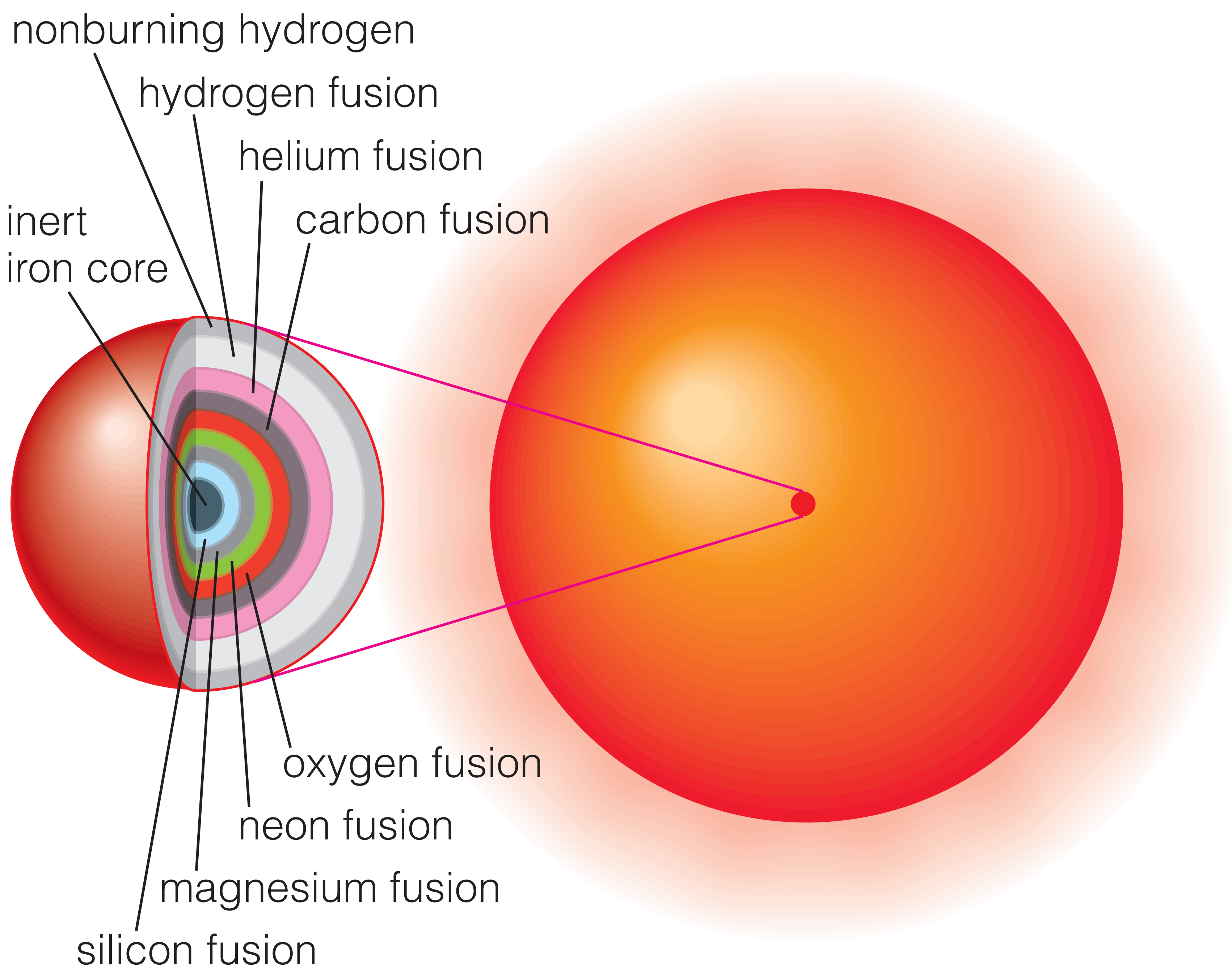
and so on:

- then core fusion of oxygen to neon
- neon to magnesium
- and so on up to iron

Massive Star Pre-Supernova



“onion-skin” structure

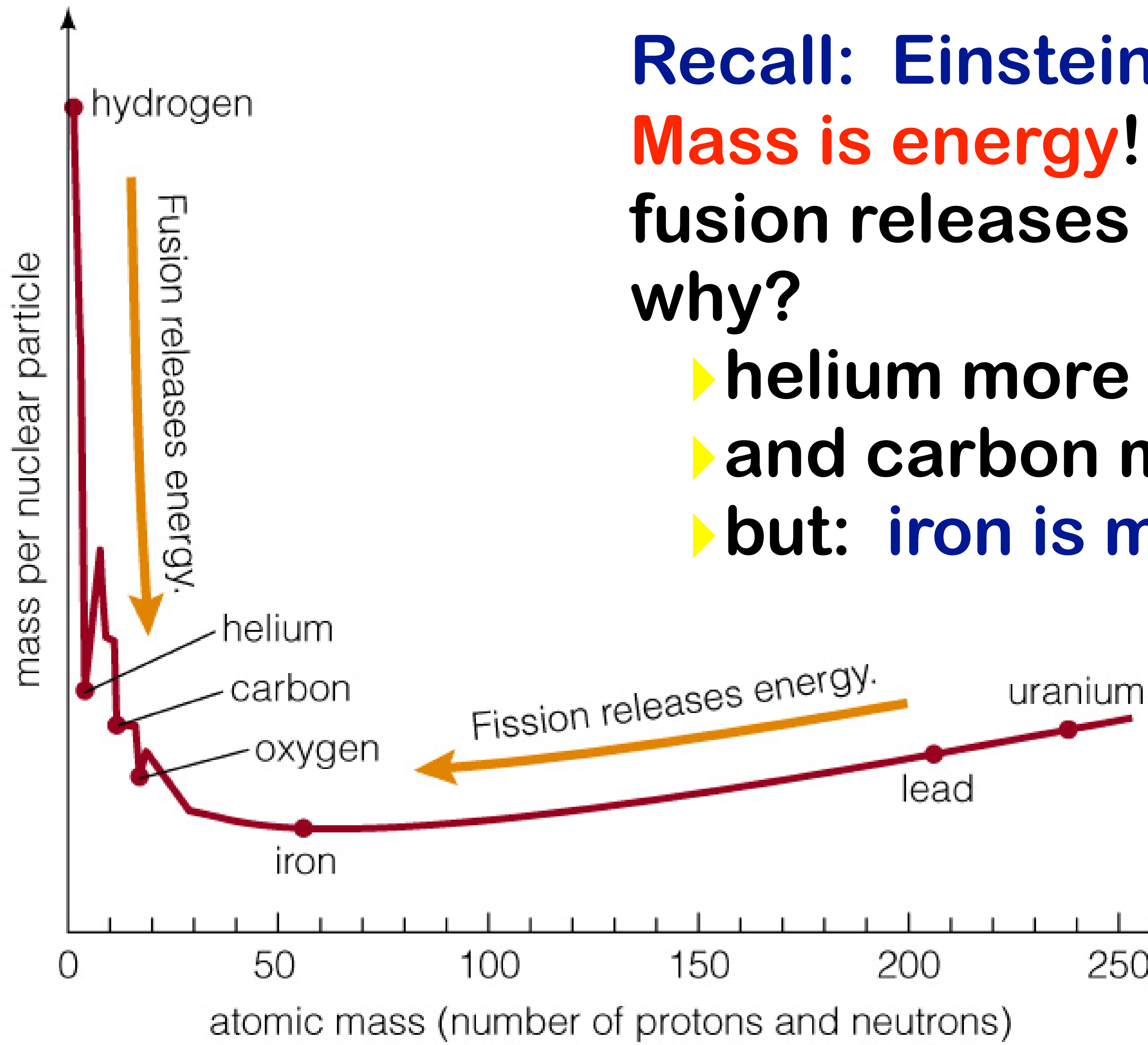
star’s shells are “memory” of previous burning phases

Each stage of core fusion is shorter than the last...

Table 8-1 | Heavy-Element Fusion in a 25-$M_\odot$ Star

Fuel	Time	Percentage of Lifetime
H	7,000,000 years	93.3
He	500,000 years	6.7
C	600 years	0.008
O	0.5 years	0.000007
Si	1 day	0.0000004

Iron - Dead End



Recall: Einstein says $E = mc^2$

Mass is energy!

fusion releases this mass energy

why?

- **helium more stable than hydrogen**
- **and carbon more than helium**
- **but: iron is most stable of all**

Neither fusion nor fission releases energy from iron

Fusion stops once have iron core

The End: Supernova!

Nuclear reactions cease in the core

- Gravity > Pressure
- forces unbalanced: star accelerates!

The core collapses in less than 1/10th of a second

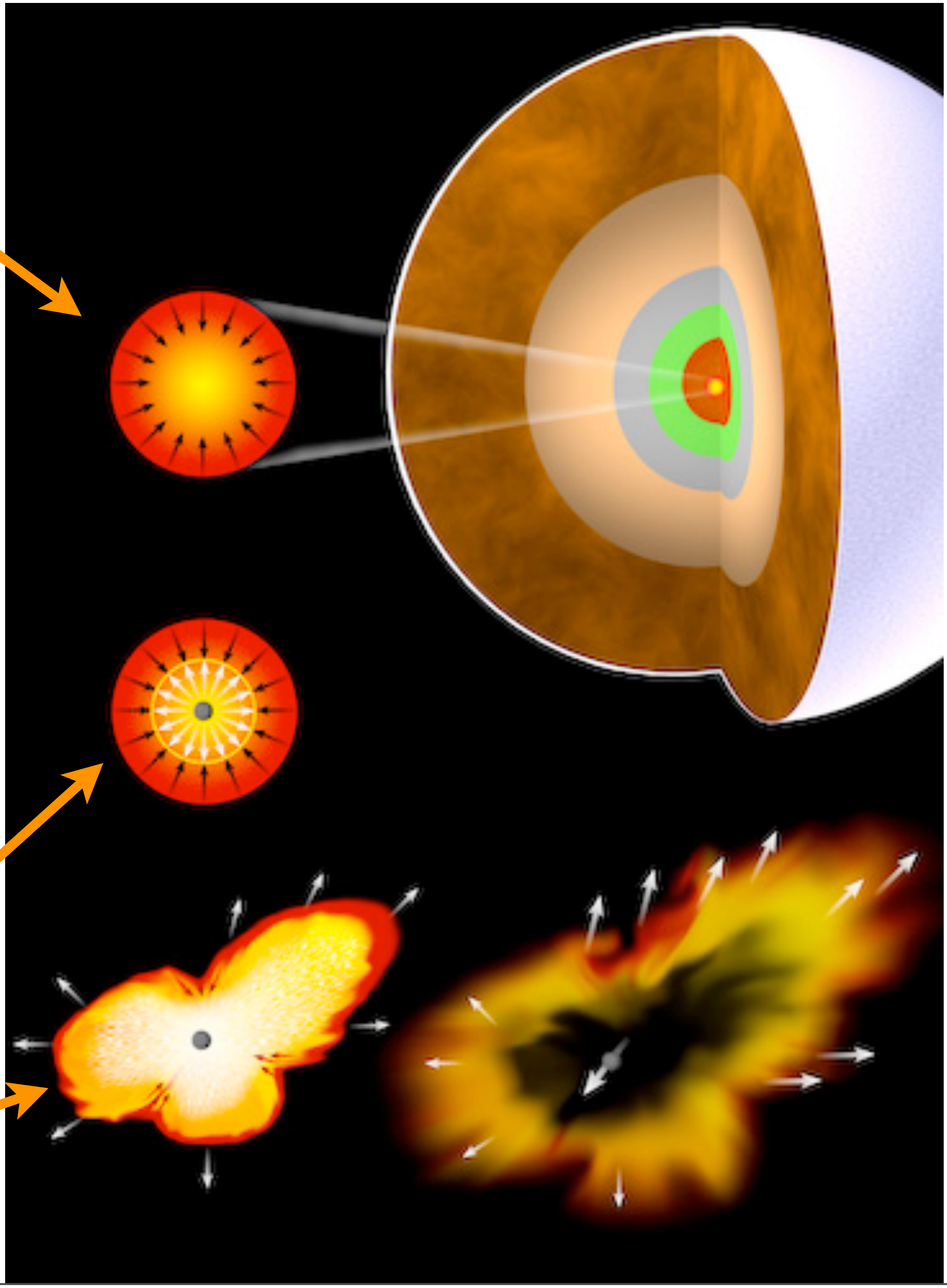
- infalling material accelerated to 10% speed of light

Core of star compressed to ultrahuge density

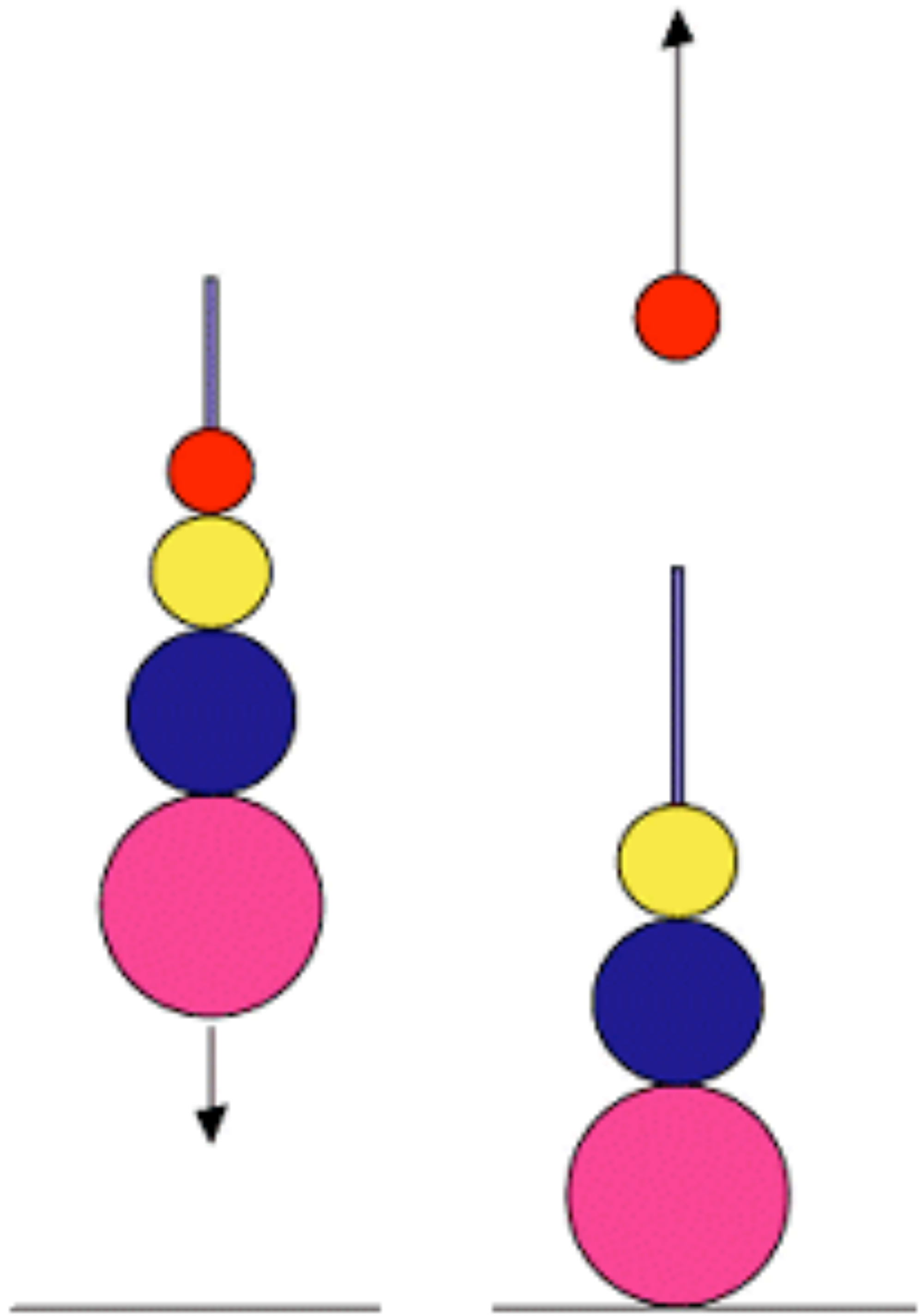
- core nuclei crushed into sea of neutrons
- neutrinos released

eventually core forms ultradense solid

- gas layers falling on to core “bounce” off it
- Triggers an intensely energetic rebound
- Shatters the star in a supernova explosion



AstroBlaster Demo



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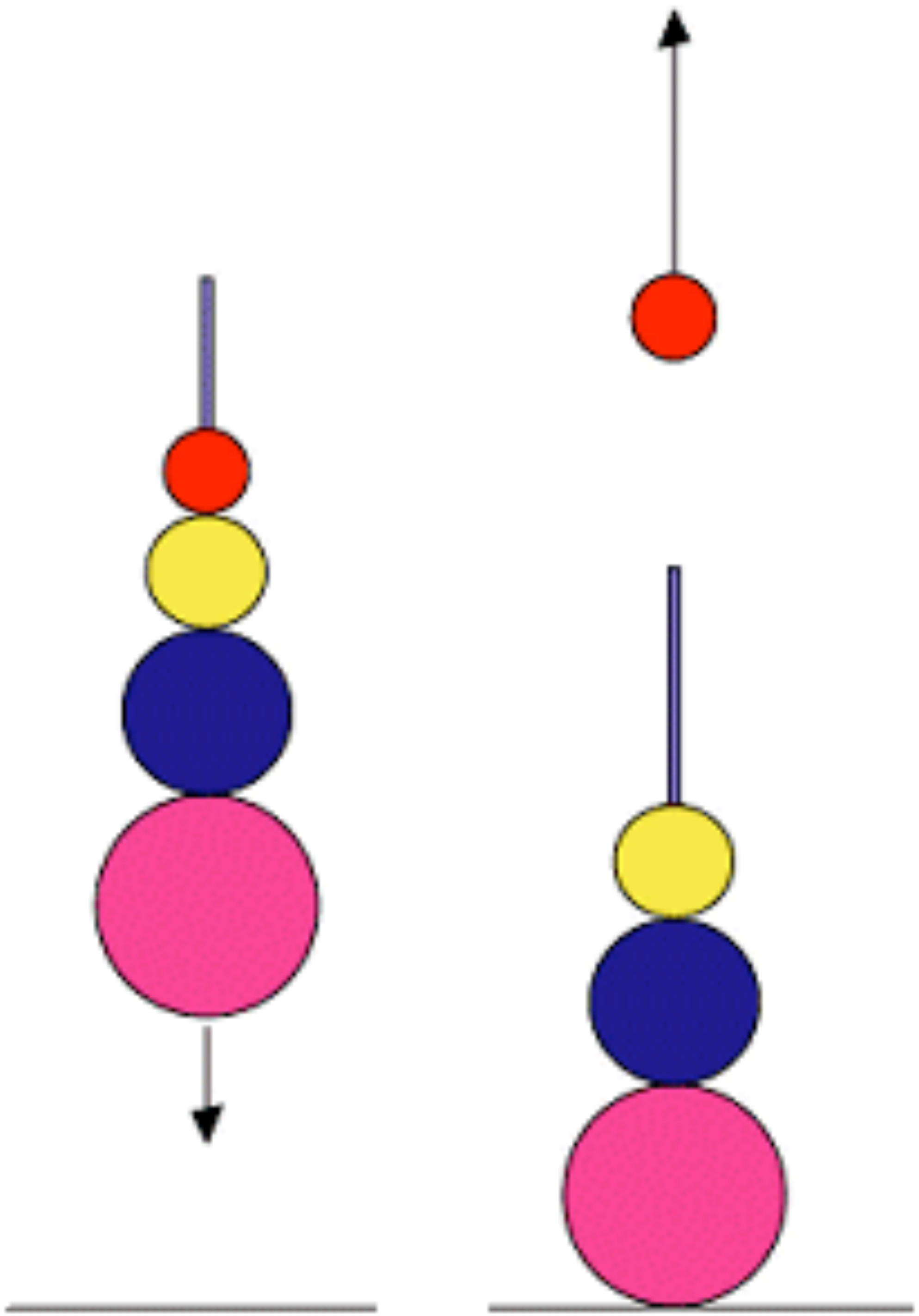

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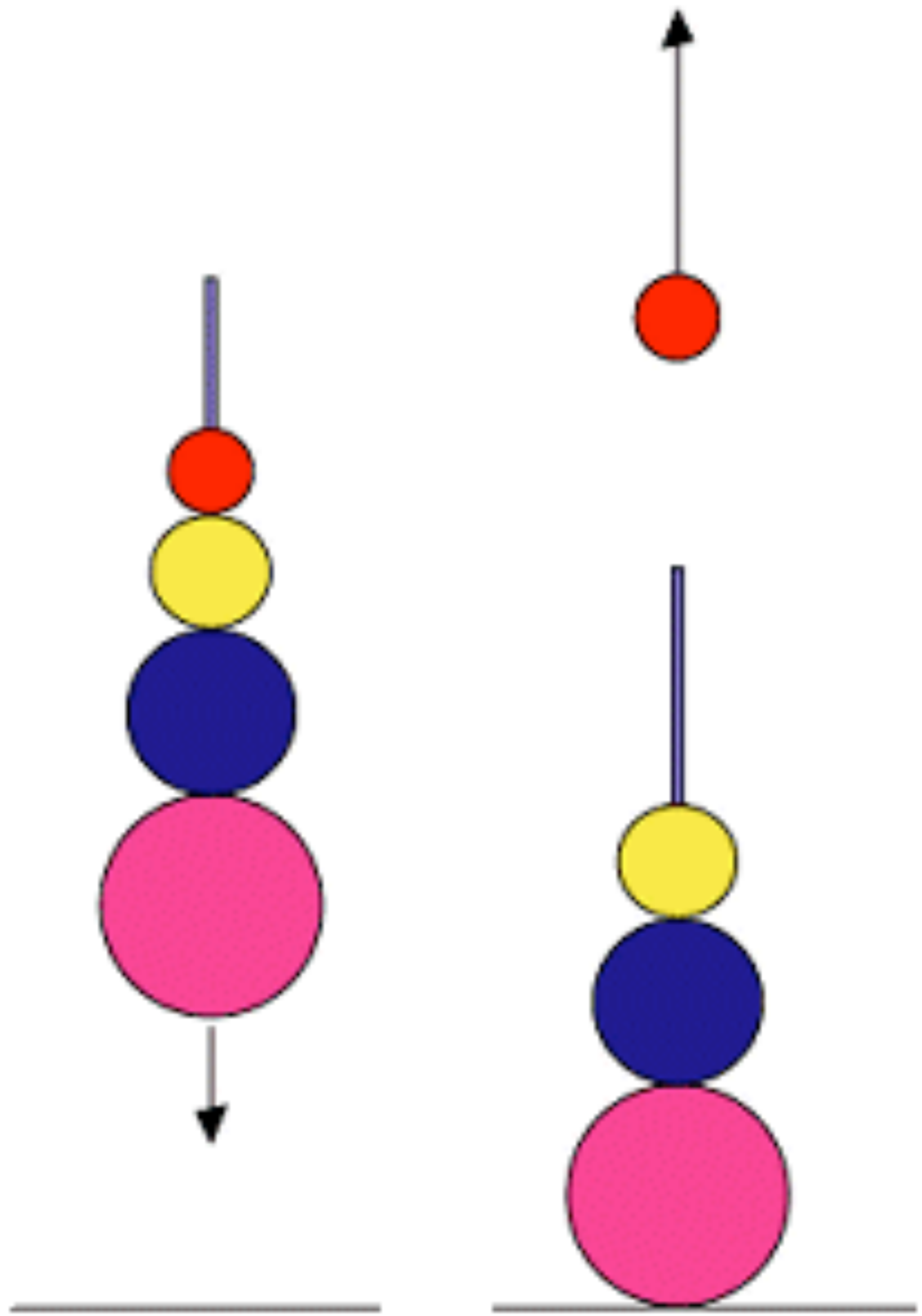

Supernova Explosions

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The Death of Massive Stars

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>8 M_{sun}

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…but don't get too close…

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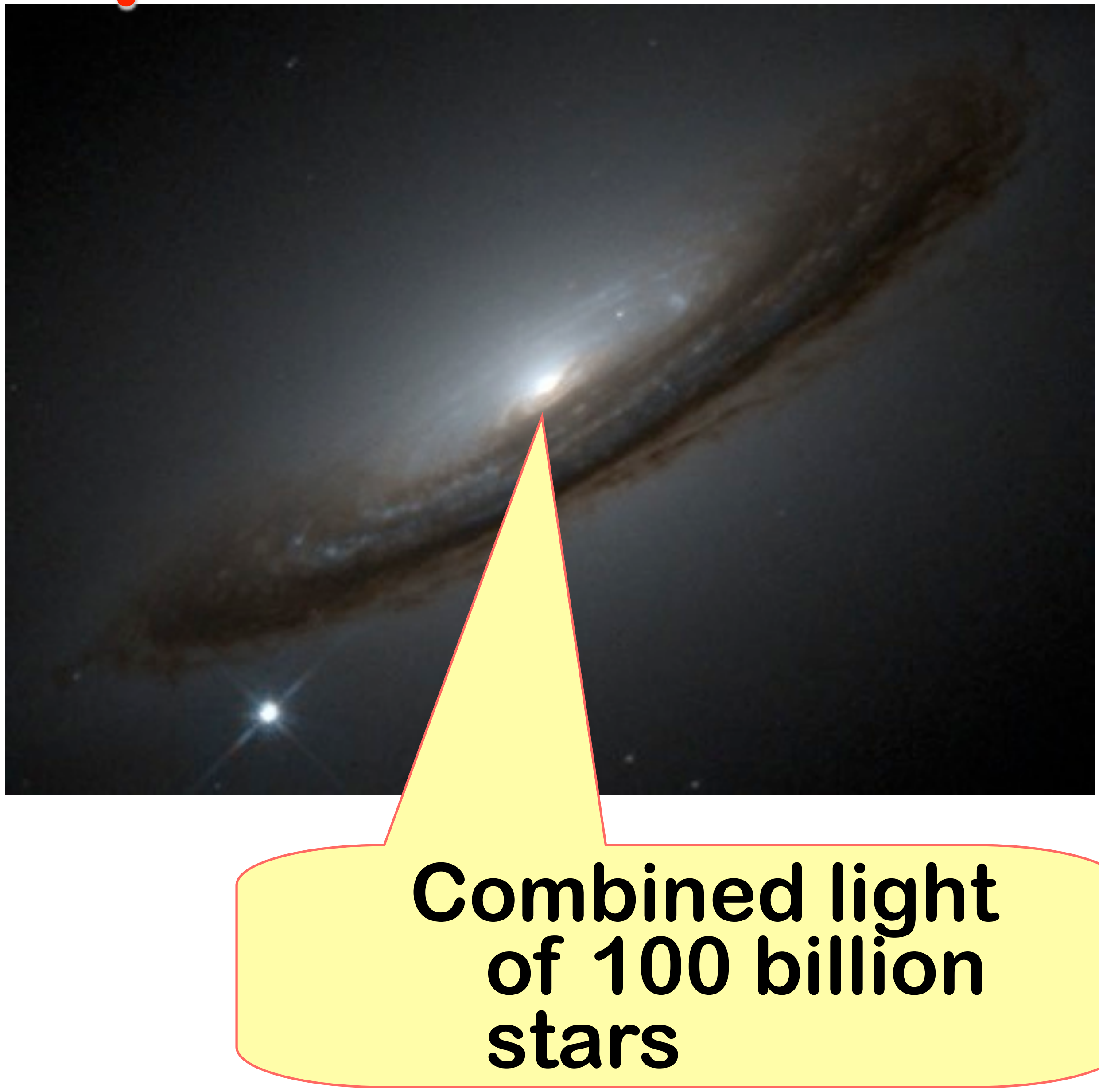

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Historical Supernovae

Supernova explosions are rare:

- Fewer than 1% of stars die this way
- None seen in our Galaxy for 300 years

The Sun will die…

- But not this way (not an explosion!)
- And not for billions of years
- Sleep well tonight!

Supernova Explosions in Recorded History

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1054 AD

- Europe: no record

Supernova Explosions in Recorded History

1054 AD

- ➢Europe: no record
- ➢China: “guest star” 天關客星

近屏星北行端拱二年七月丁亥出北河星西北稍暗微有芒彗指西南淳化
元年正月辛巳出軫宿逆至張七十日經四十度乃不見景德二年八月甲辰
出紫微天棓側孛孛然如粉絮稍入垣內歷御女華蓋凡十一日沒三年三月
乙巳出東南方大中祥符四年正月丁丑見南斗魁前天禧五年四月丙辰出
軒轅前星西北大如桃速行經軒轅大星入太微垣掩右執法犯次將歷屏星
西北凡七十五日入濁沒明道元年六月乙巳出東北方近濁有芒彗至丁巳
凡十三日沒至和元年五月己丑出天關東南可數寸歲餘稍沒熙寧二年六
月丙辰出箕度中至七月丁卯犯箕乃散三年十一月丁未出天囷元祐六年
十一月辛亥出參度中犯掩側星壬子犯九斿星十二月癸酉入奎至七年三
月辛亥乃散紹興八年五月守婁魯分也九年二月壬申守亢陳分也乾道二
年三月癸酉出太微垣內五帝坐大星西微小色青白淳熙八年六月己巳出
奎宿犯傳舍星至明年正月癸酉凡一百八十五日始滅嘉泰三年六月乙卯
出東南尾宿間色青白大如填星甲子守尾嘉定十七年六月己丑犯尾宿嘉

宋史 卷五十六 天文志

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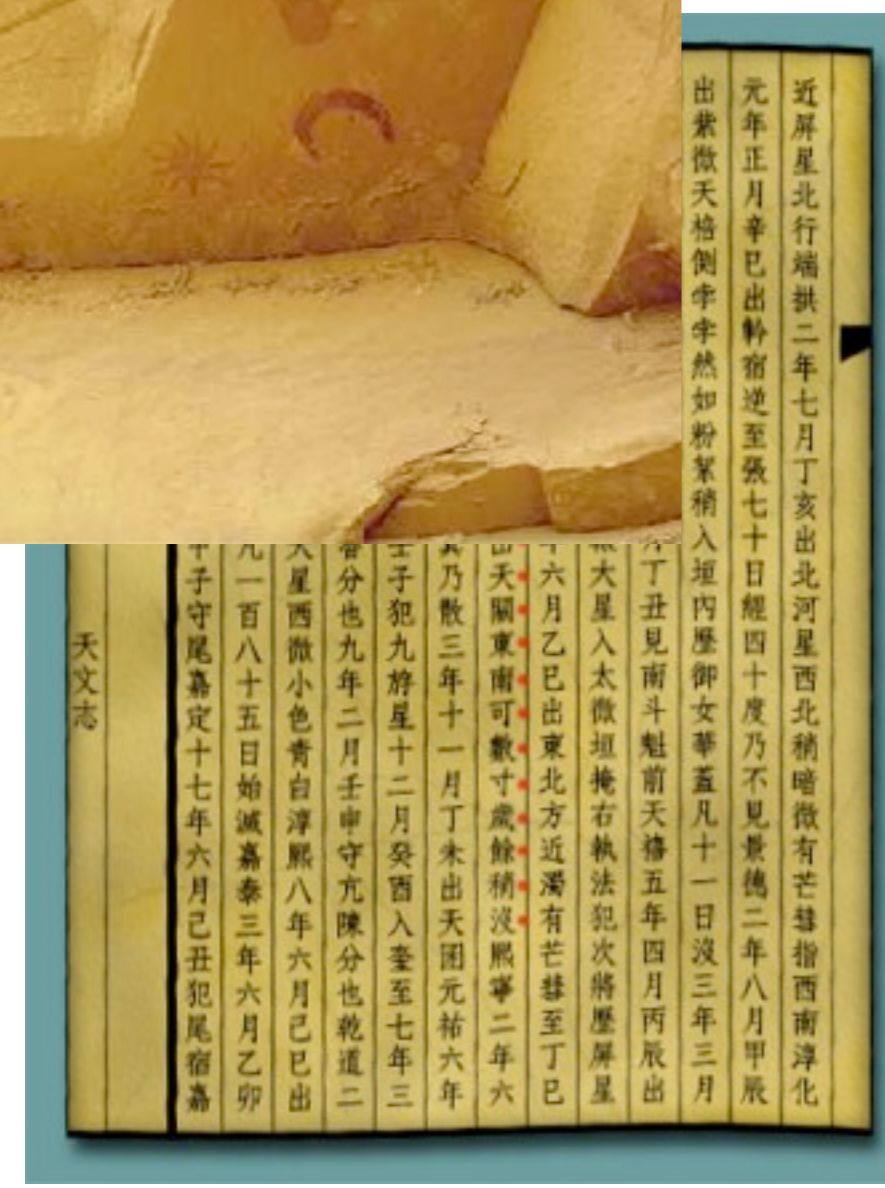
- Anasazi people
  Chaco Canyon, NM:
  painting



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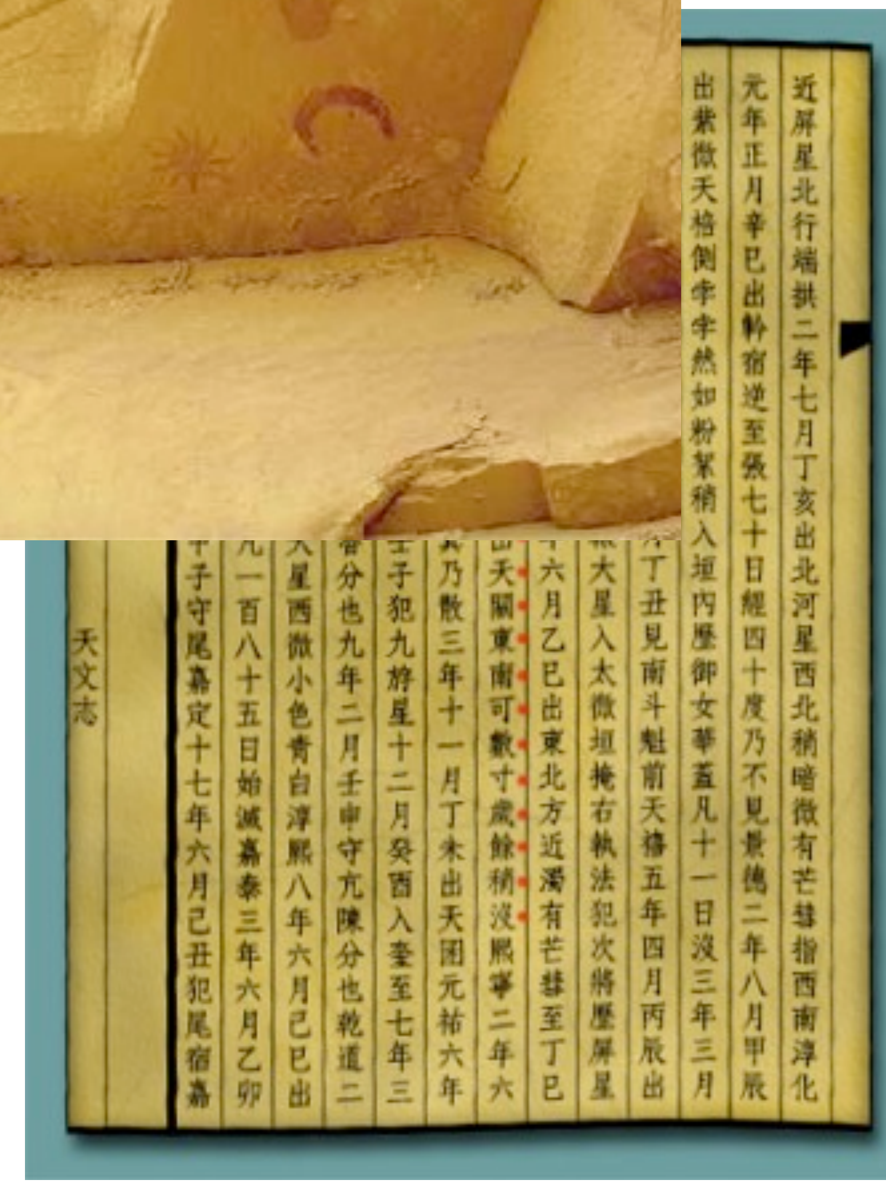

Modern view of this region of the sky:

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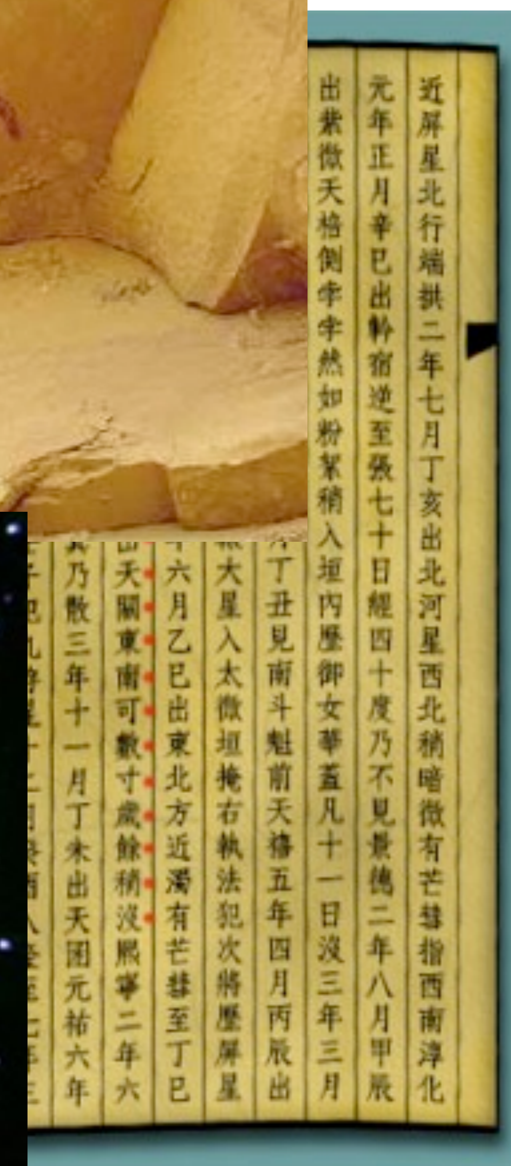

Modern view of this region of the sky:

Crab Nebula—remains of a supernova explosion

Supernova 1054 Today

The Crab Nebula is a supernova remnant

The remains of Supernova 1054

Comparing its size with its speed of expansion reveals an age of nine or ten centuries

Just when the “guest star” made its visit

Supernova Explosions in Recorded History

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November 11, 1572

Tycho Brahe

A “new star” (“nova stella”)

Supernova Explosions in Recorded History

November 11, 1572

Tycho Brahe

A “new star”
(“nova stella”)

Distantiam verò huius stellæ à fixis aliquibus in hac Caßiopeiæ constellatione, exquisito instrumento, & omnium minutorum capacj, aliquoties obseruaui. Inueni autem eam distare ab ea, quæ est in pectore, Schedir appellata B, 7. partibus & 55. minutis: à superiori verò

Modern view (X-rays):

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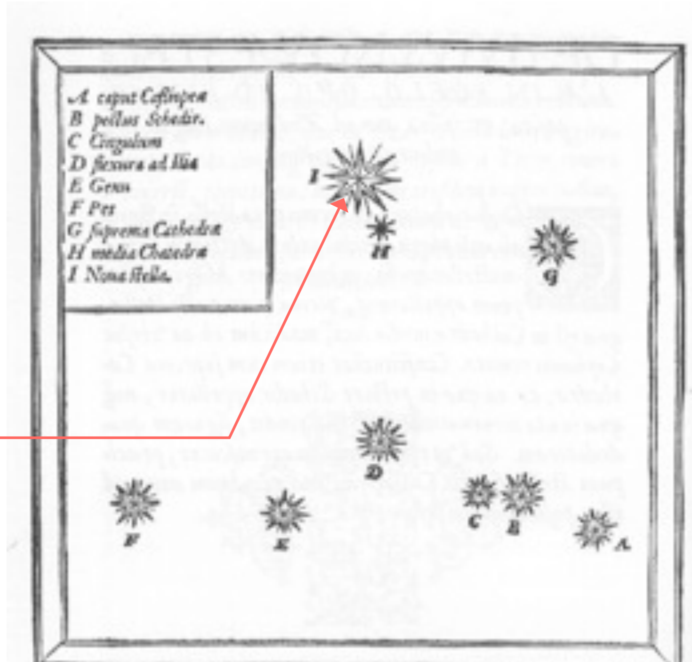
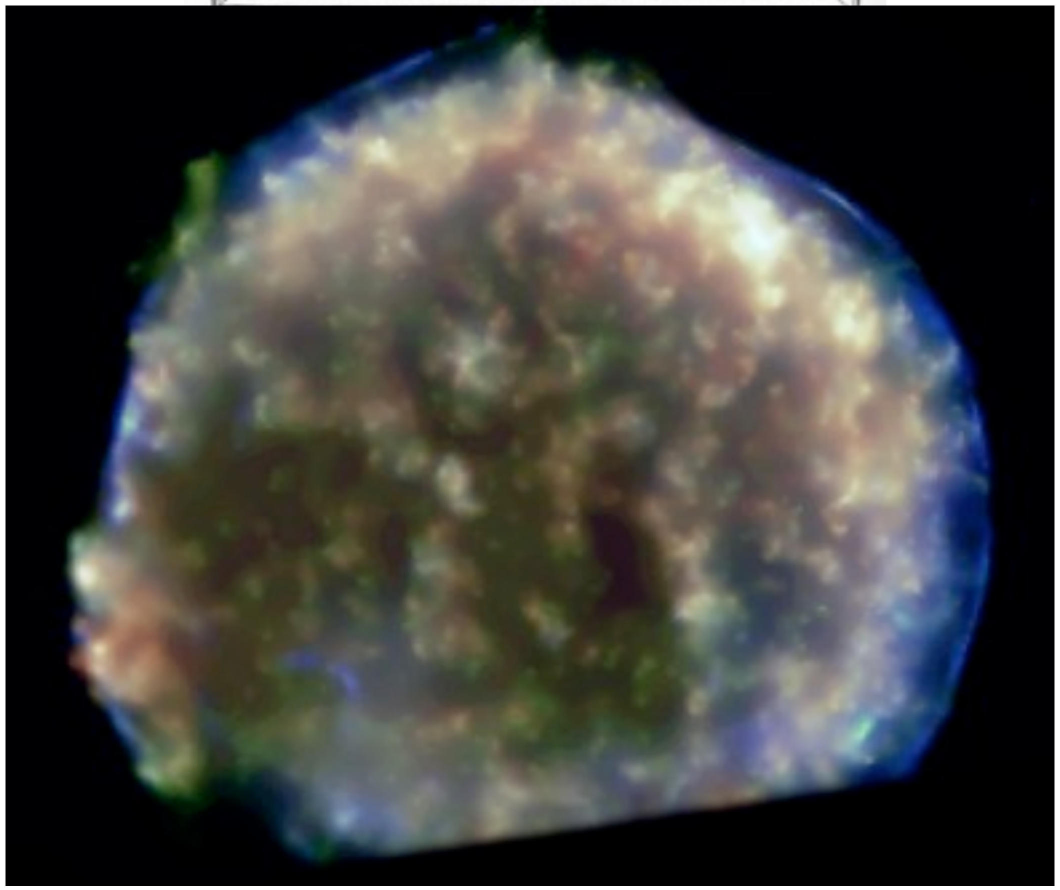


Modern view (X-rays):

- **remains of a supernova explosion**



November 11, 1572
Tycho Brahe

On the 11th day of November in the evening after sunset ... I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining ... and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky ...

I was so astonished of this sight ... A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world.

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Where was he wrong?

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