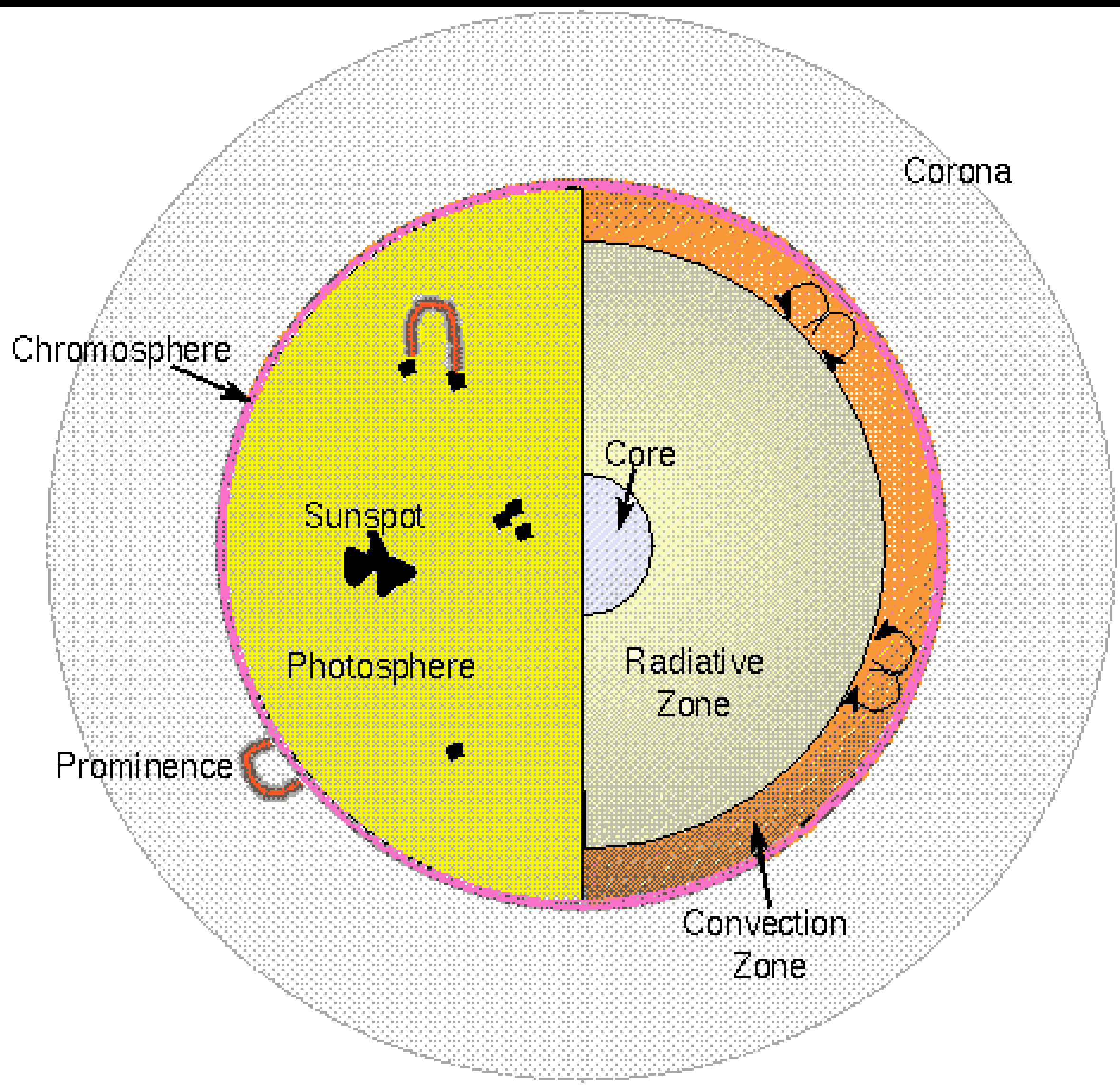
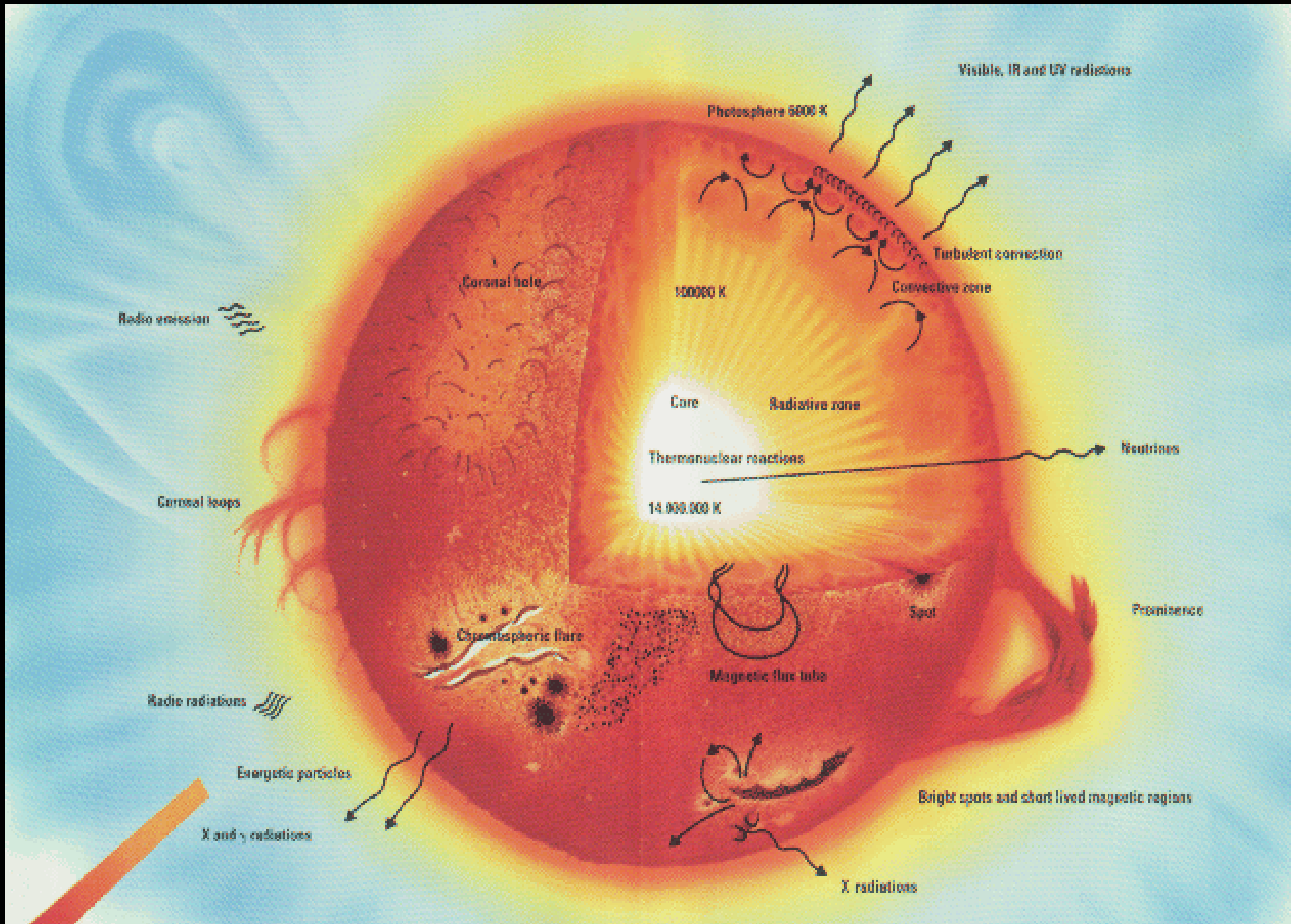
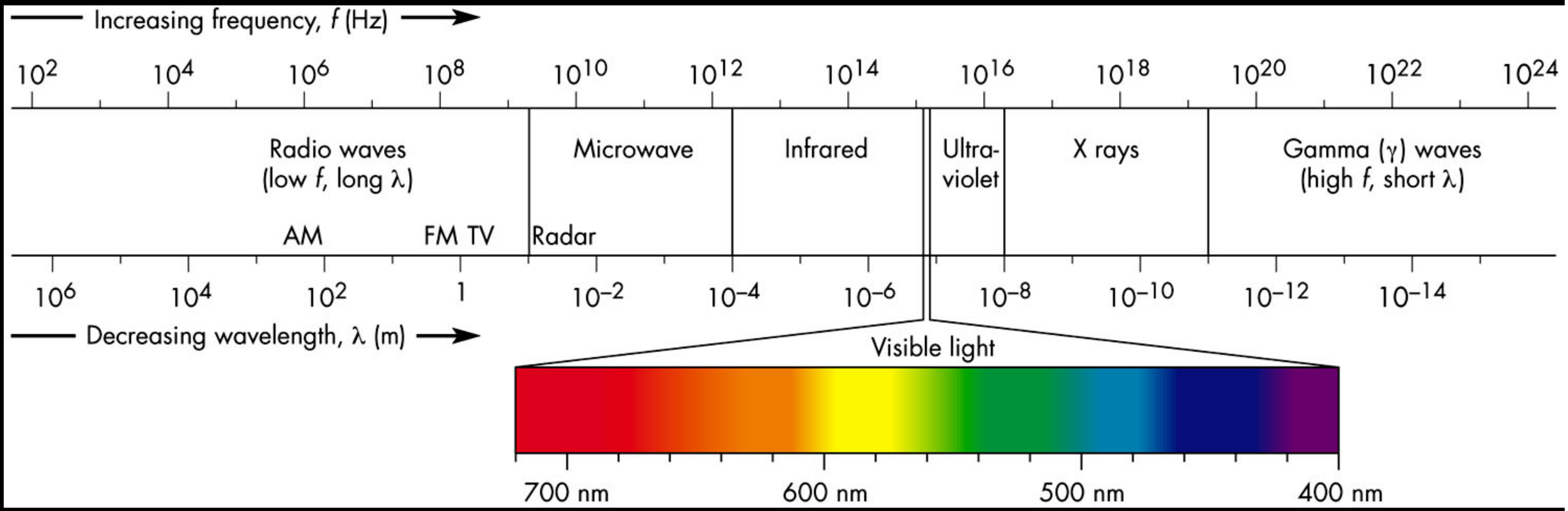
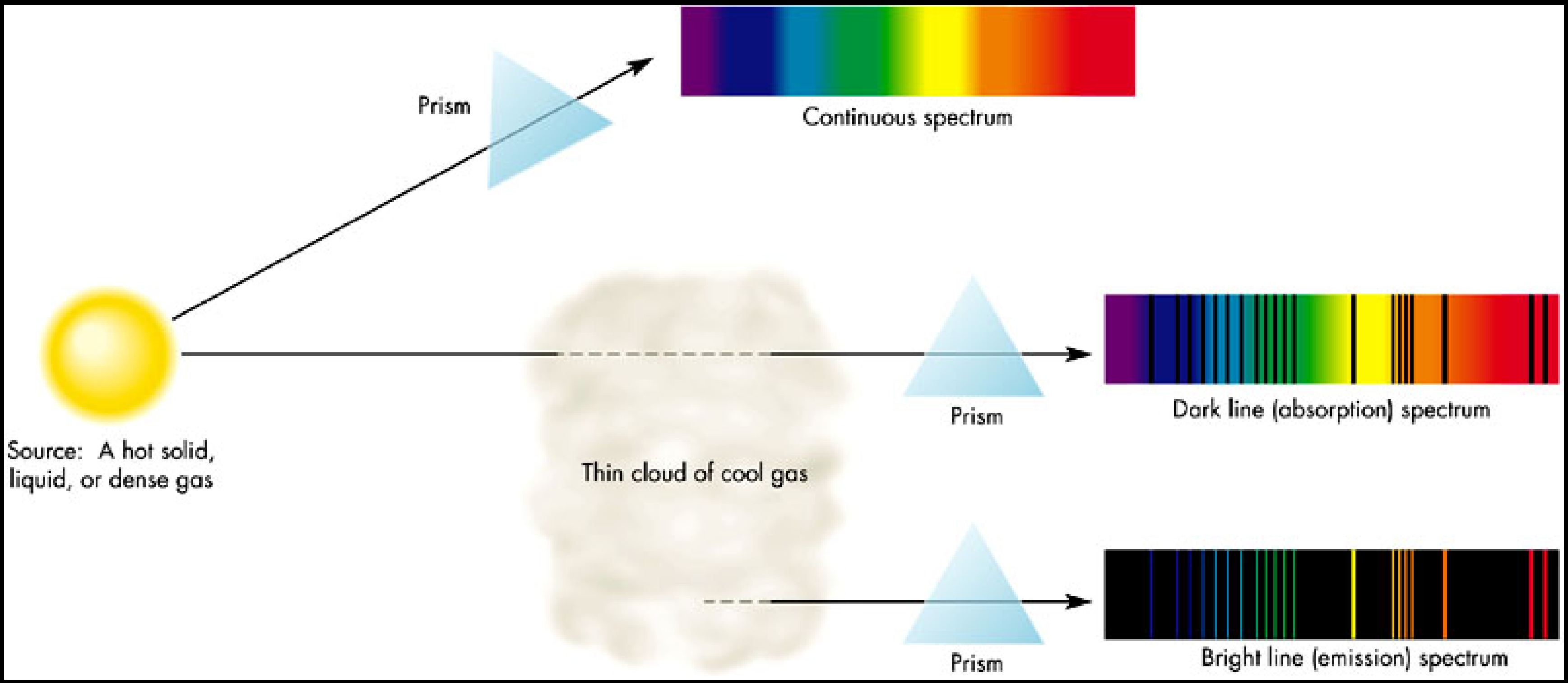

Corona
Chromosphere
Core
Sunspot
Photosphere
Radiative
Zone
Prominence
Convection
Zone

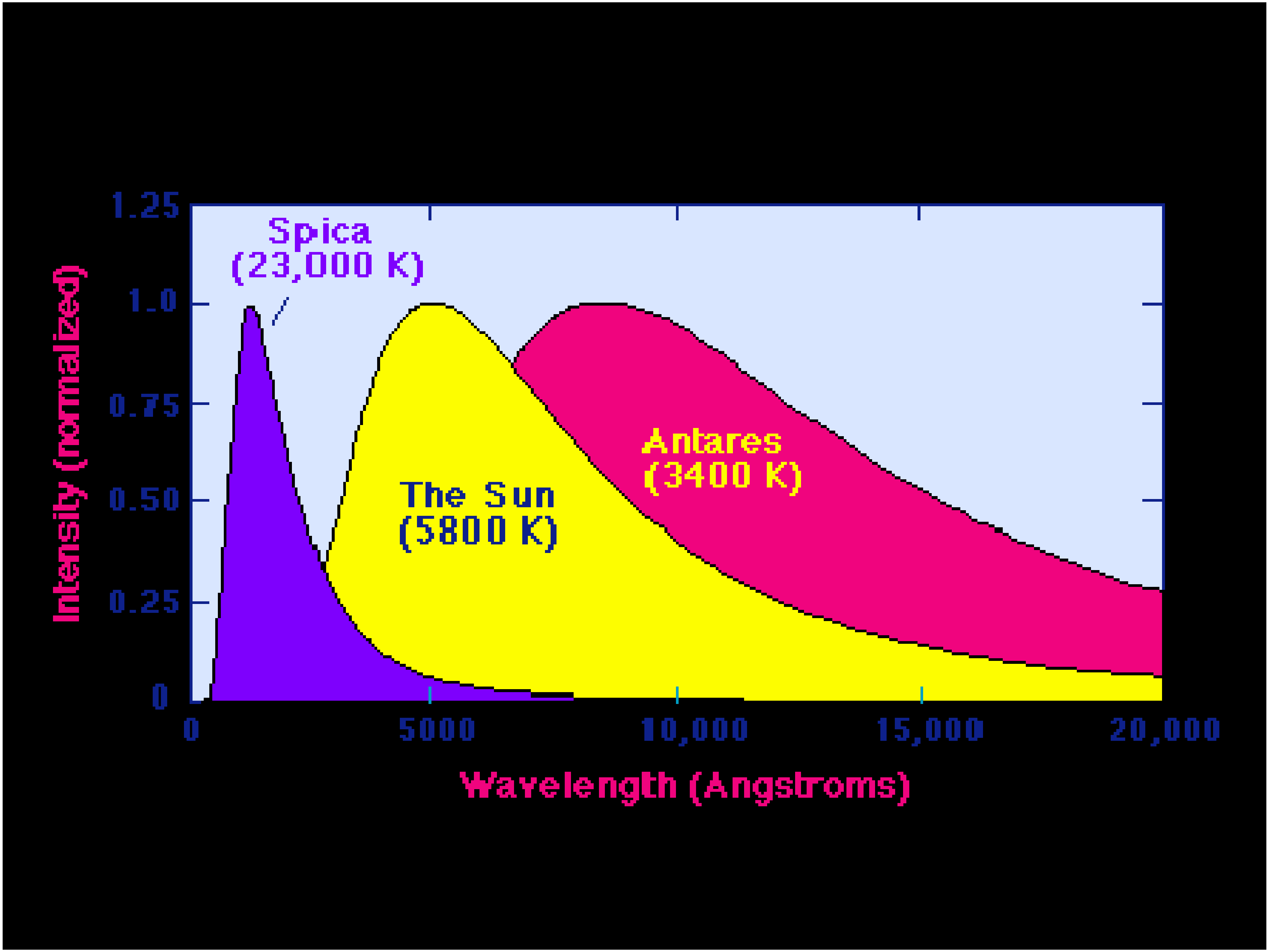

Visible, IR and UV radiations
Photosphere 6000 K
Turbulent convection
Convective zone
Coronal hole
100000 K
Radio emission
Core
Radiative zone
Thermonuclear reactions
Neutrinos
Coronal loops
14.000.000 K
Spot
Prominence
Chromospheric flare
Magnetic flux tube
Radio radiations
Energetic particles
Bright spots and short lived magnetic regions
X and γ radiations
X radiations

The Electromagnetic Spectrum



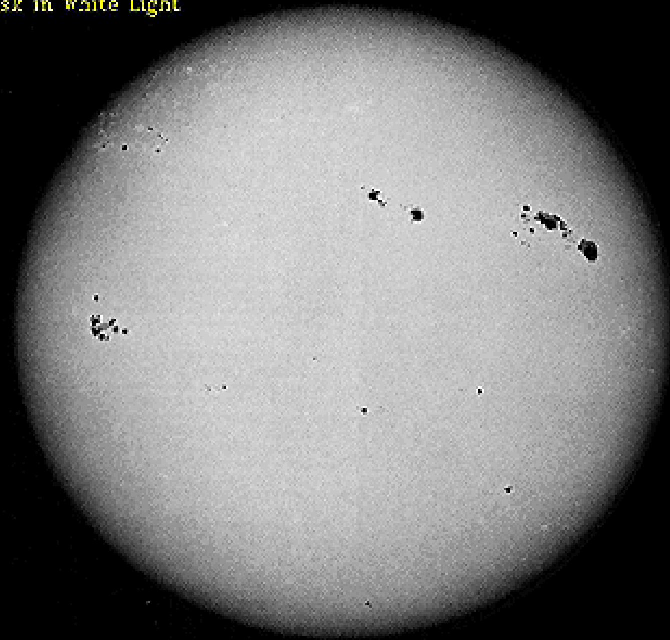
Three Kinds of Spectra





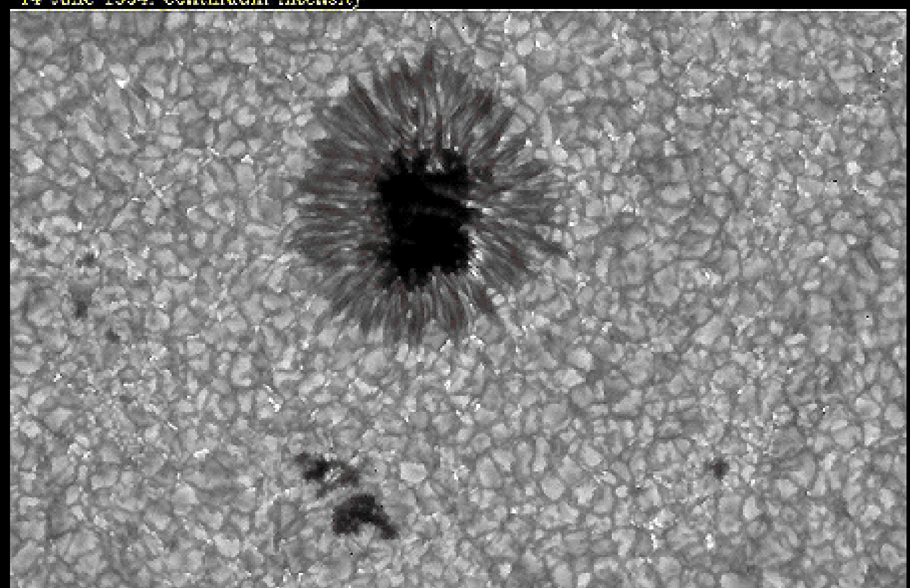
Spica
(23,000 K)
The Sun
(5800 K)
Antares
(3400 K)
Intensity (normalized)
1.25
1.0
0.75
0.50
0.25
0
0
5000
10,000
15,000
20,000
Wavelength (Angstroms)

The Solar Disk in White Light

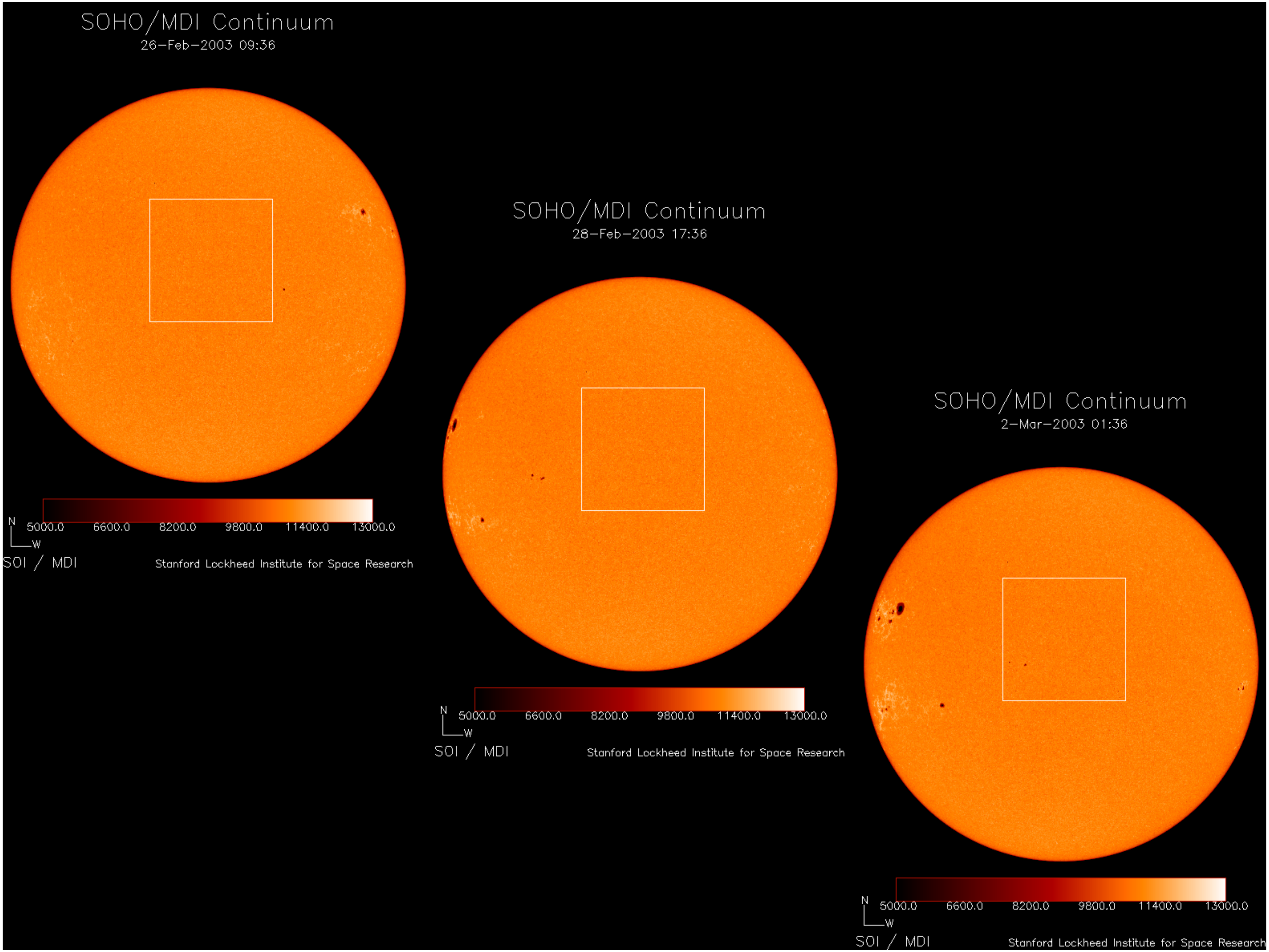


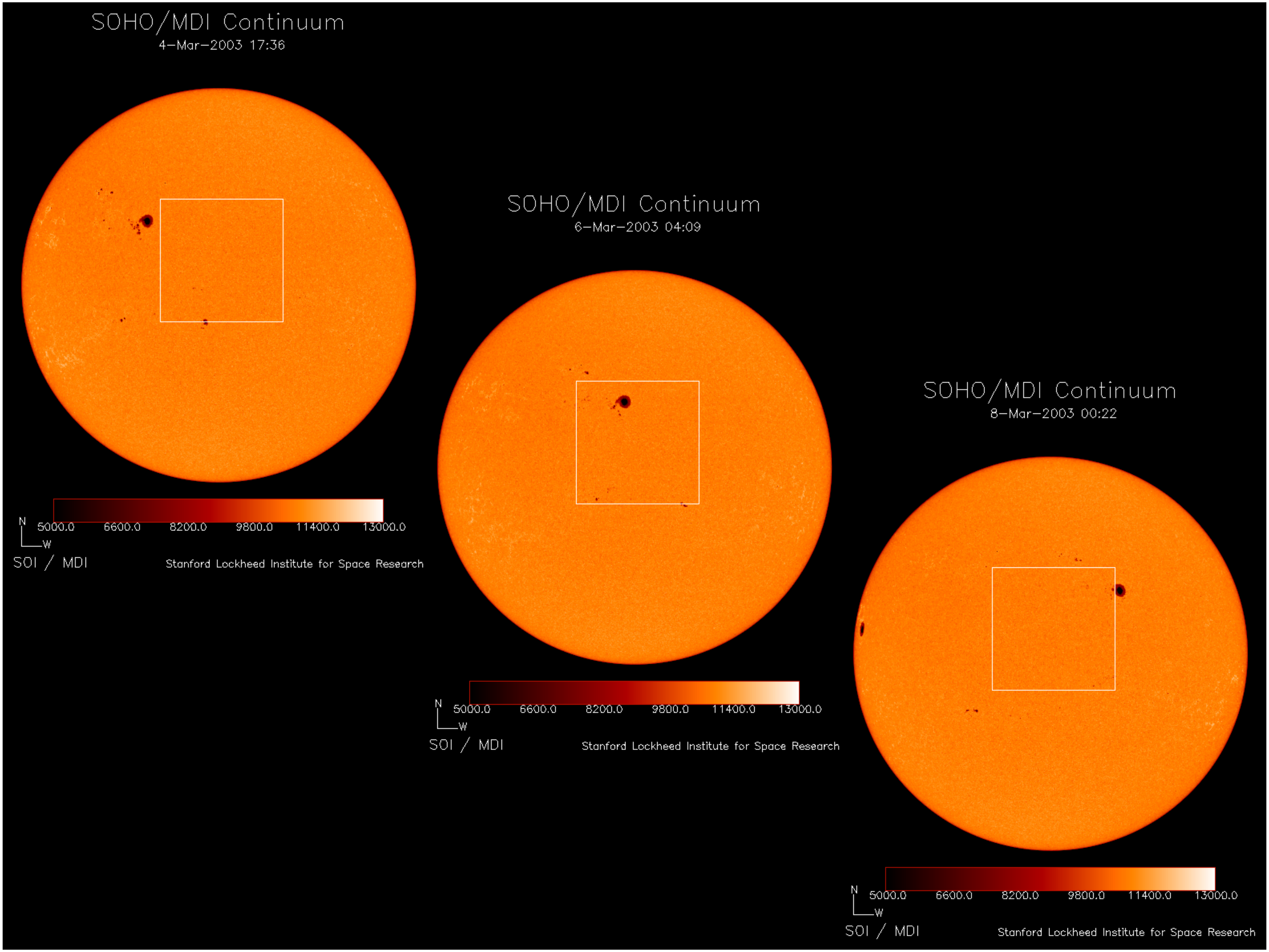
HAO A-001

14 June 1994: Continuum intensity



Source: Kiepenheuer/Uppsala/Lockheed (P. Brandt, G. Simon, G. Scharmer, D. Shine) HAO A-003


SOHO/MDI Continuum
26-Feb-2003 09:36
N
W
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
28-Feb-2003 17:36
N
W
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
2-Mar-2003 01:36
N
W
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research


SOHO/MDI Continuum
4-Mar-2003 17:36
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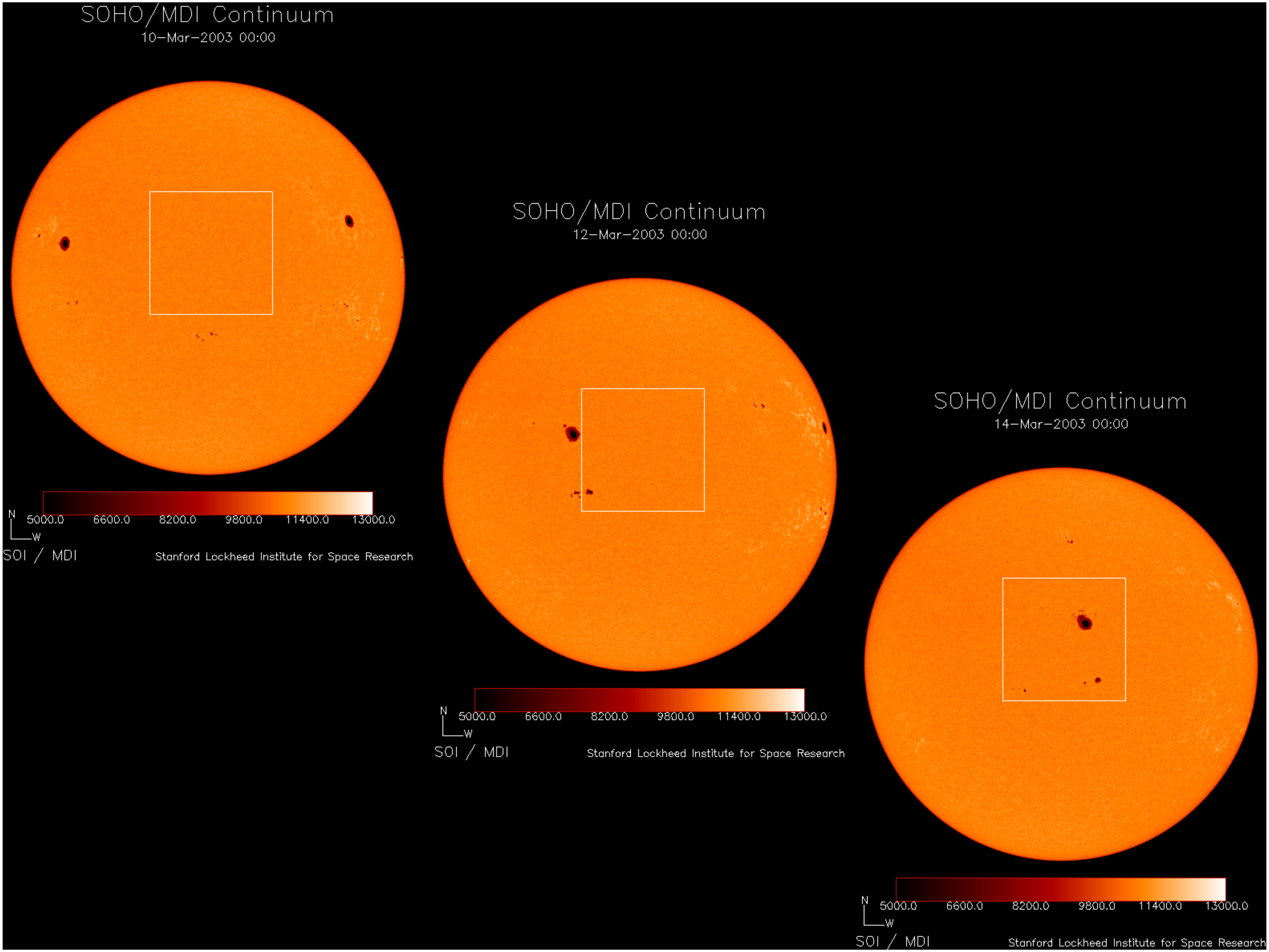
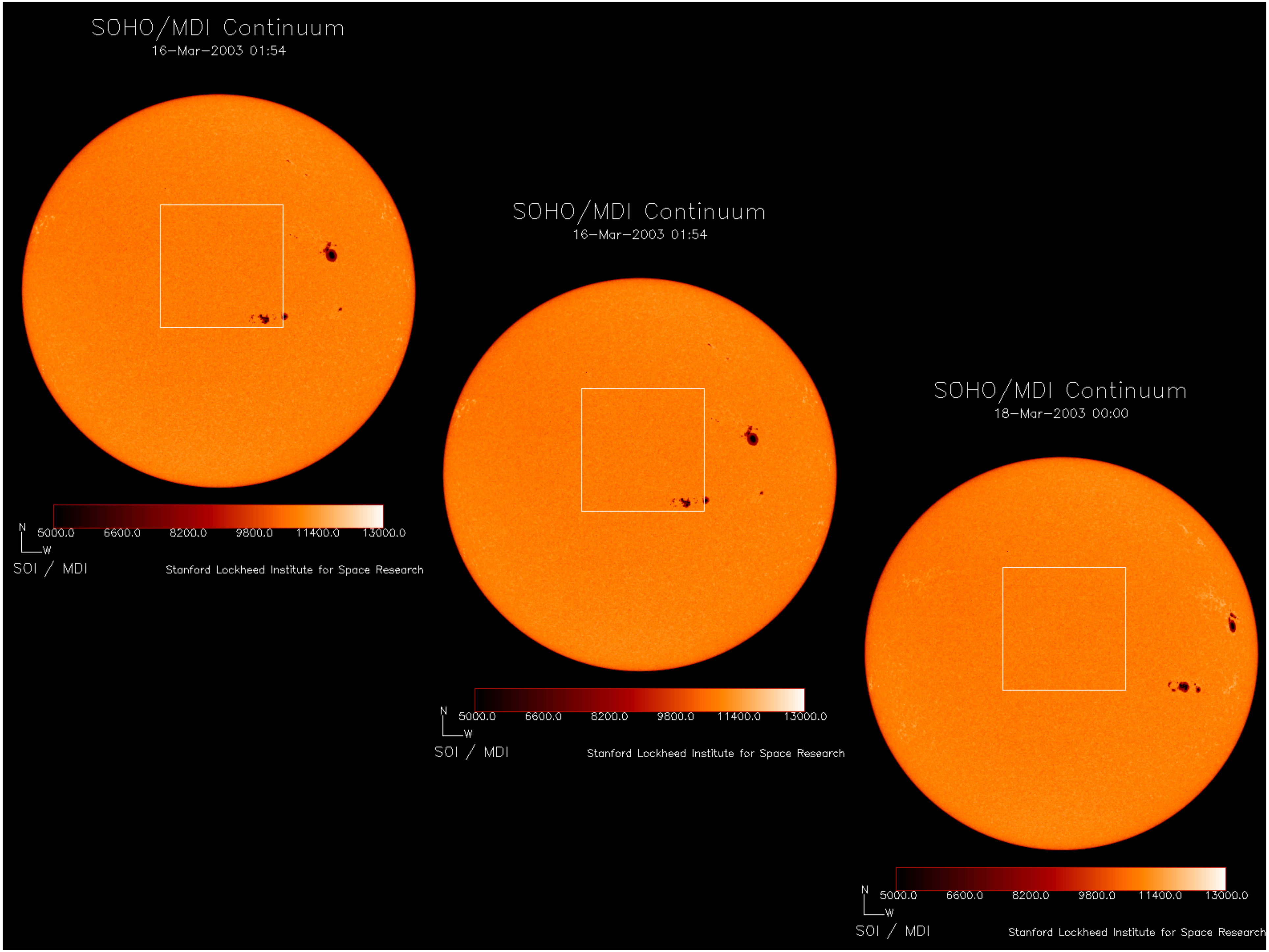
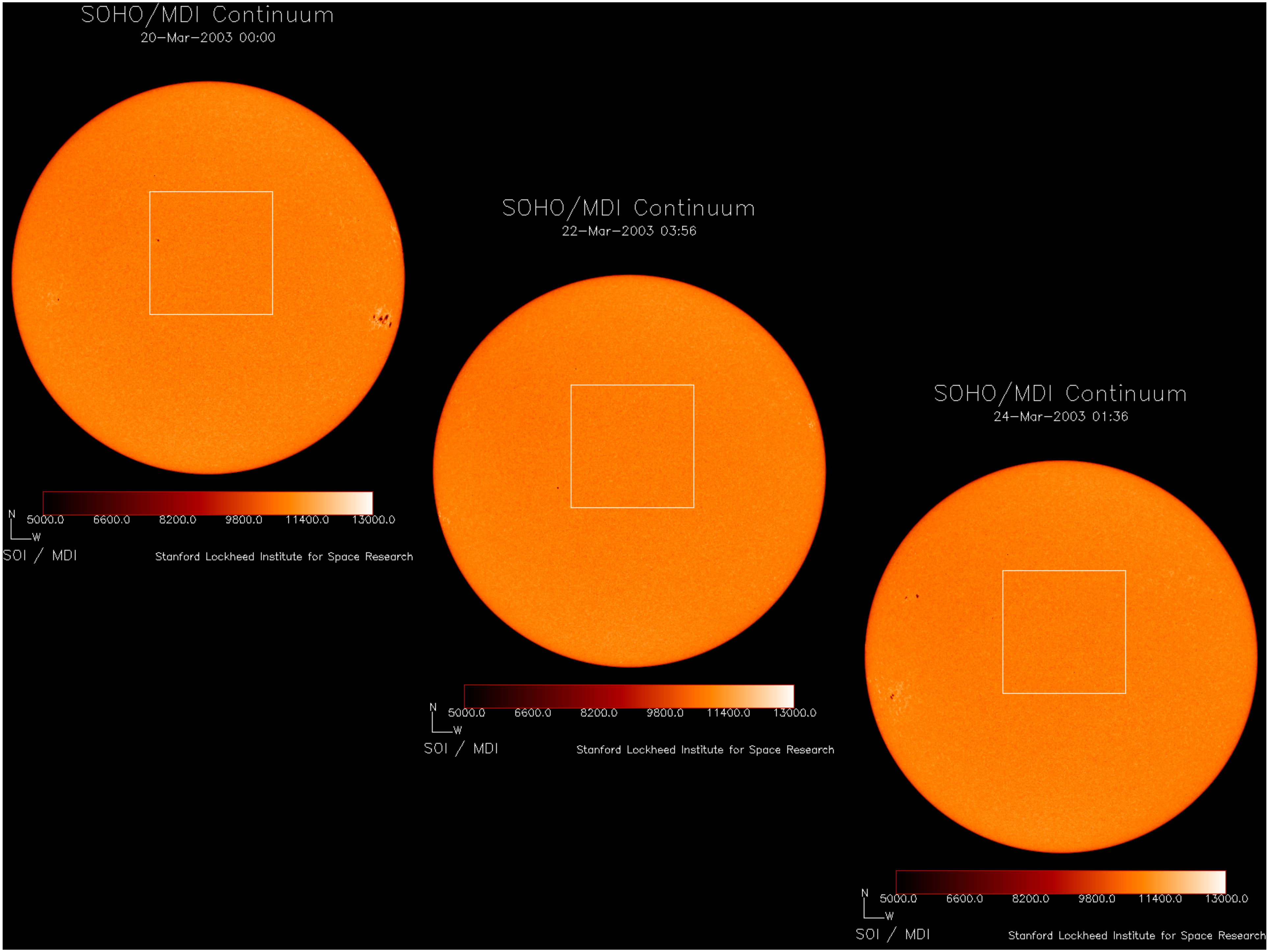
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
6-Mar-2003 04:09
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
8-Mar-2003 00:22
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research


SOHO/MDI Continuum
10–Mar–2003 00:00
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
12–Mar–2003 00:00
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
14–Mar–2003 00:00
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research


SOHO/MDI Continuum
16-Mar-2003 01:54
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
16-Mar-2003 01:54
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
18-Mar-2003 00:00
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research


SOHO/MDI Continuum
20−Mar−2003 00:00
N
W
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SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
22−Mar−2003 03:56
N
W
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
24−Mar−2003 01:36
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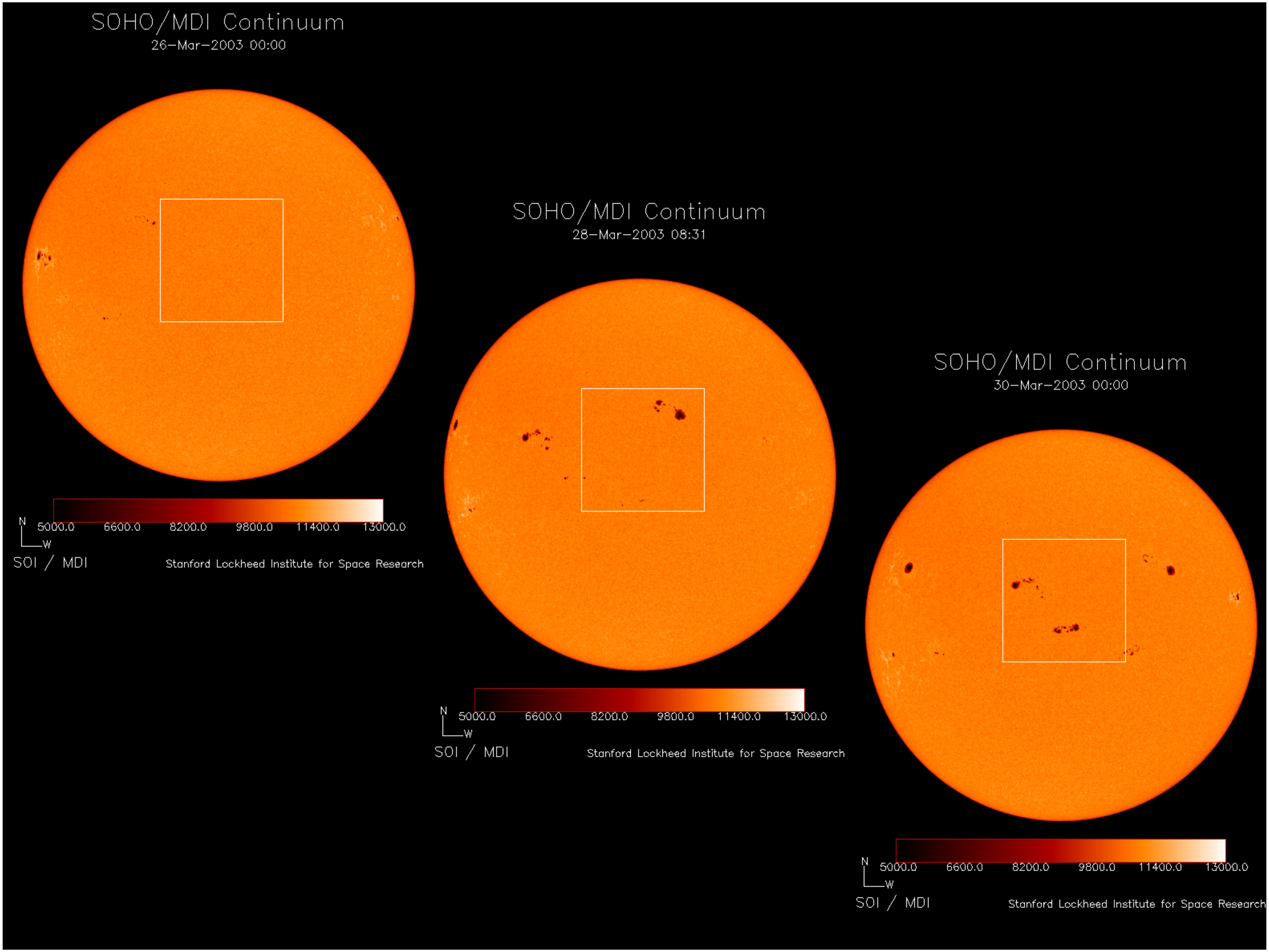
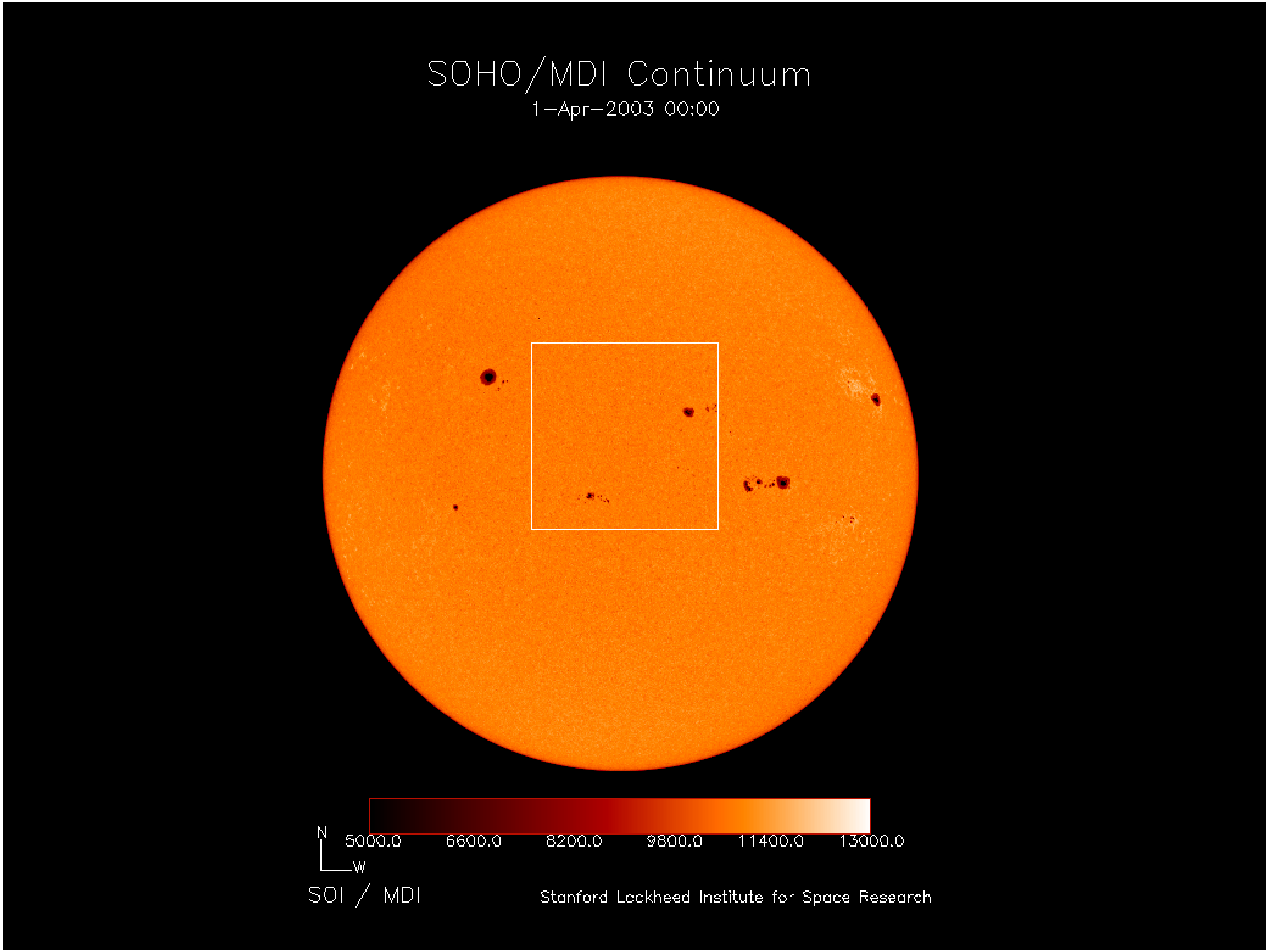
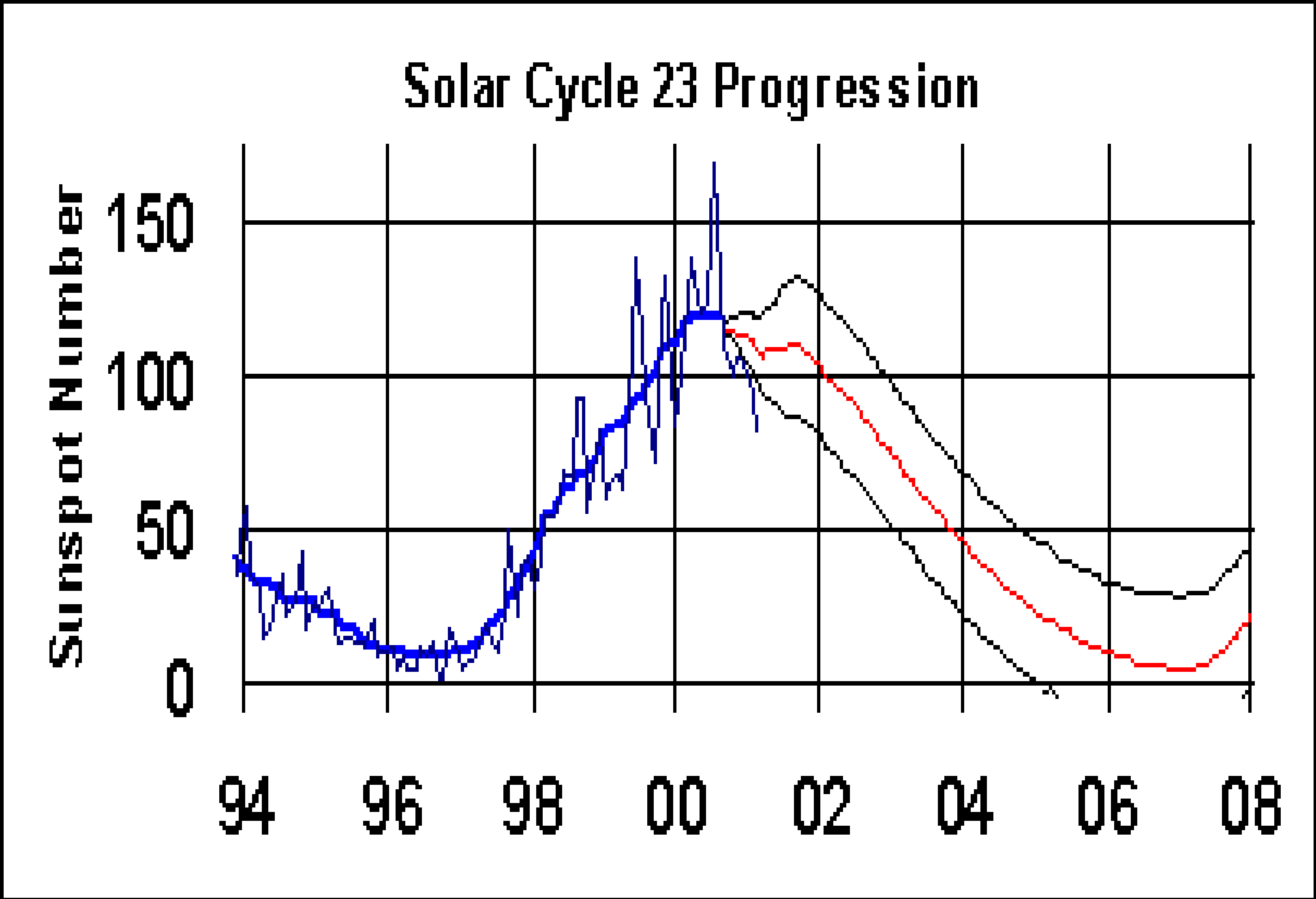
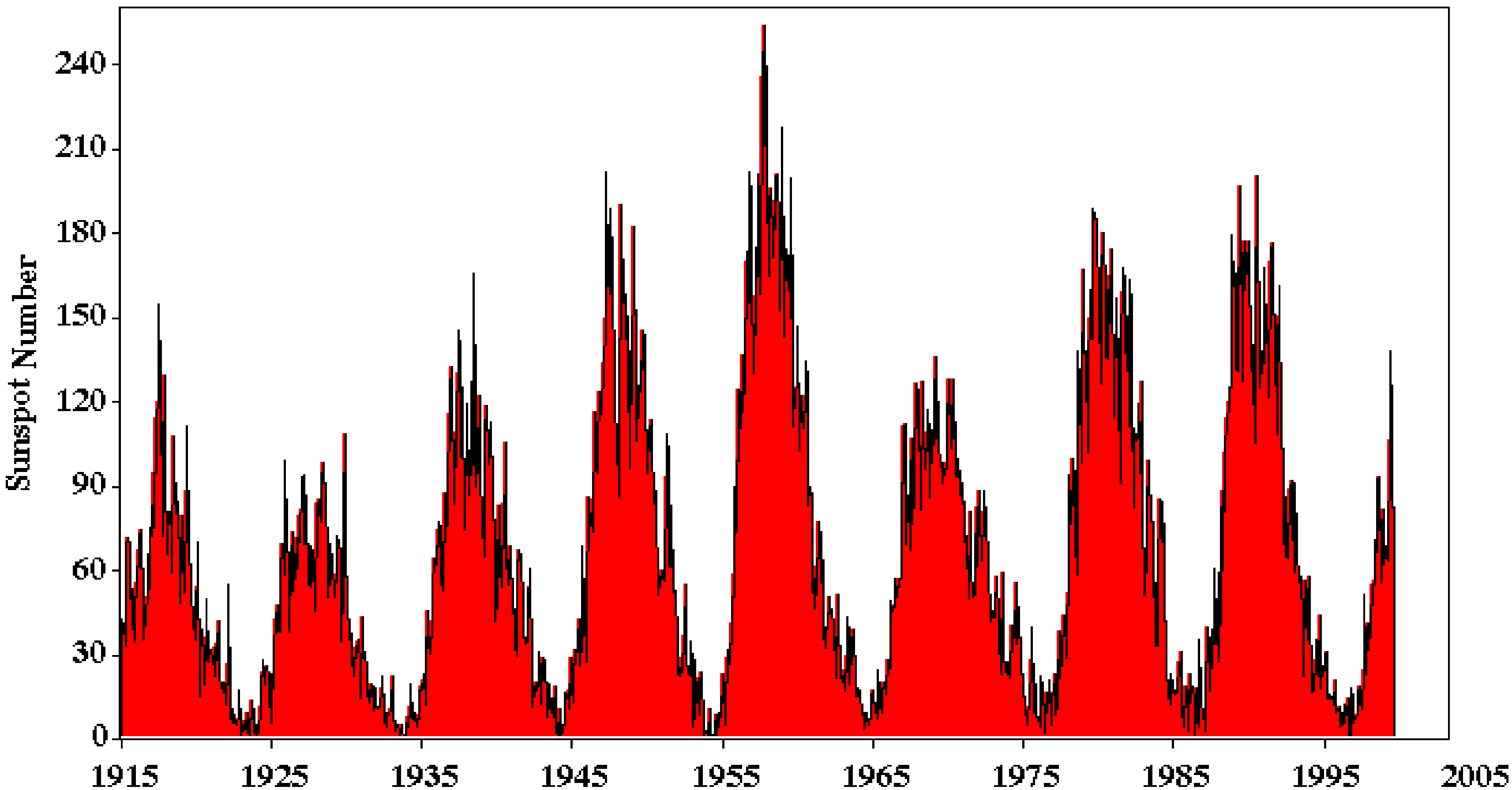
W
5000.0 6600.0 8200.0 9800.0 11400.0 13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research


SOHO/MDI Continuum
26-Mar-2003 00:00
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
28-Mar-2003 08:31
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research
SOHO/MDI Continuum
30-Mar-2003 00:00
N
W
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
SOI / MDI
Stanford Lockheed Institute for Space Research

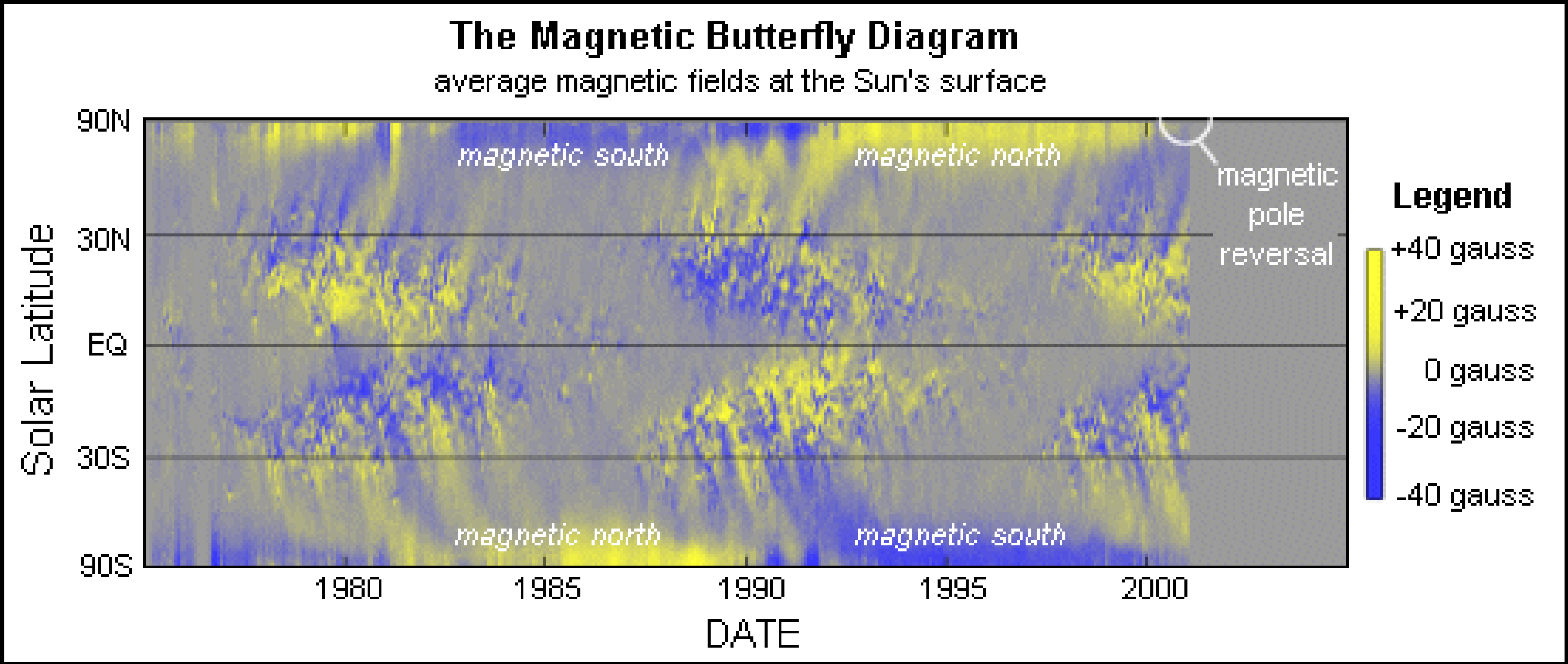

SOHO/MDI Continuum
1-Apr-2003 00:00
5000.0
6600.0
8200.0
9800.0
11400.0
13000.0
N
W
SOI / MDI
Stanford Lockheed Institute for Space Research


Solar Cycle 23 Progression
Sunspot Number
150
100
50
0
94
96
98
00
02
04
06
08

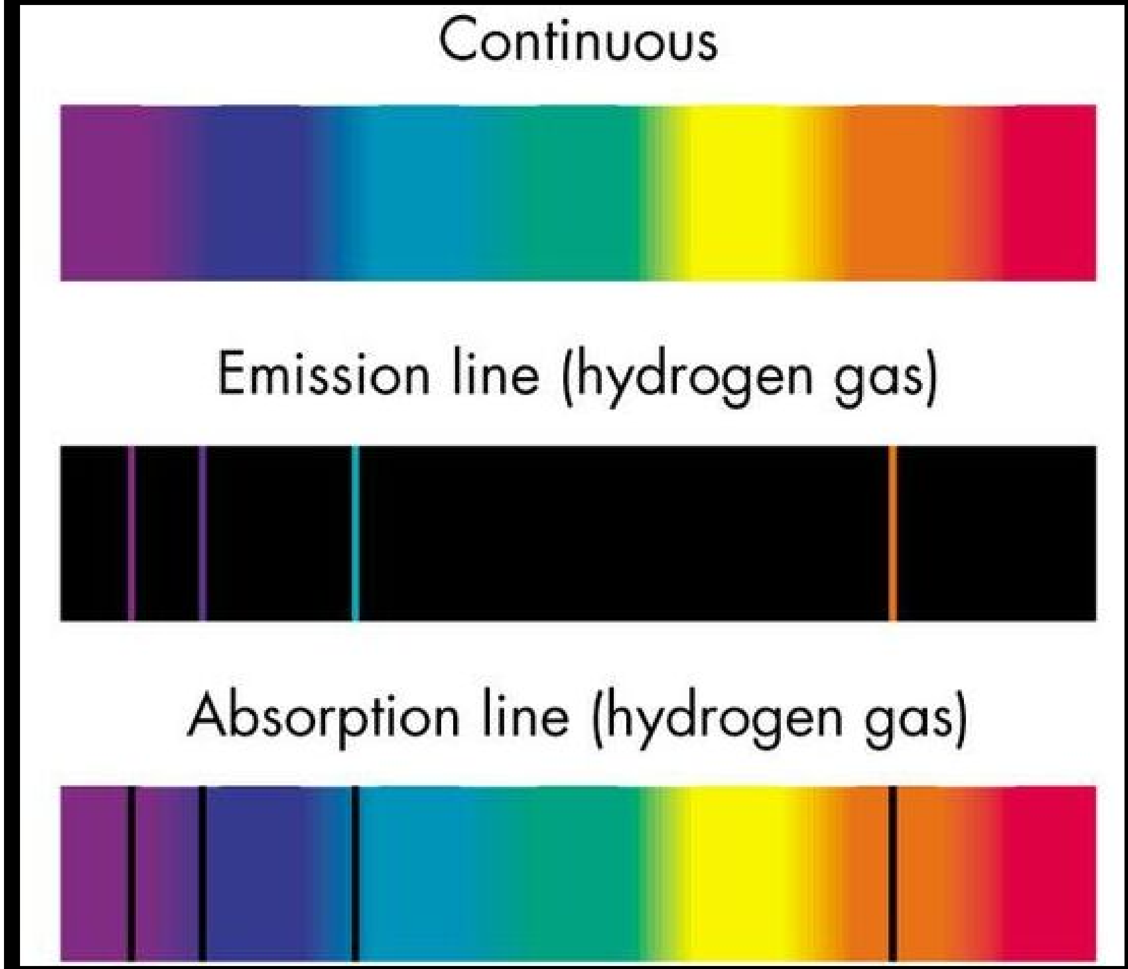
The Solar Cycle On the Rise



Solar Magnetic Field Over Time



Color Spectrum

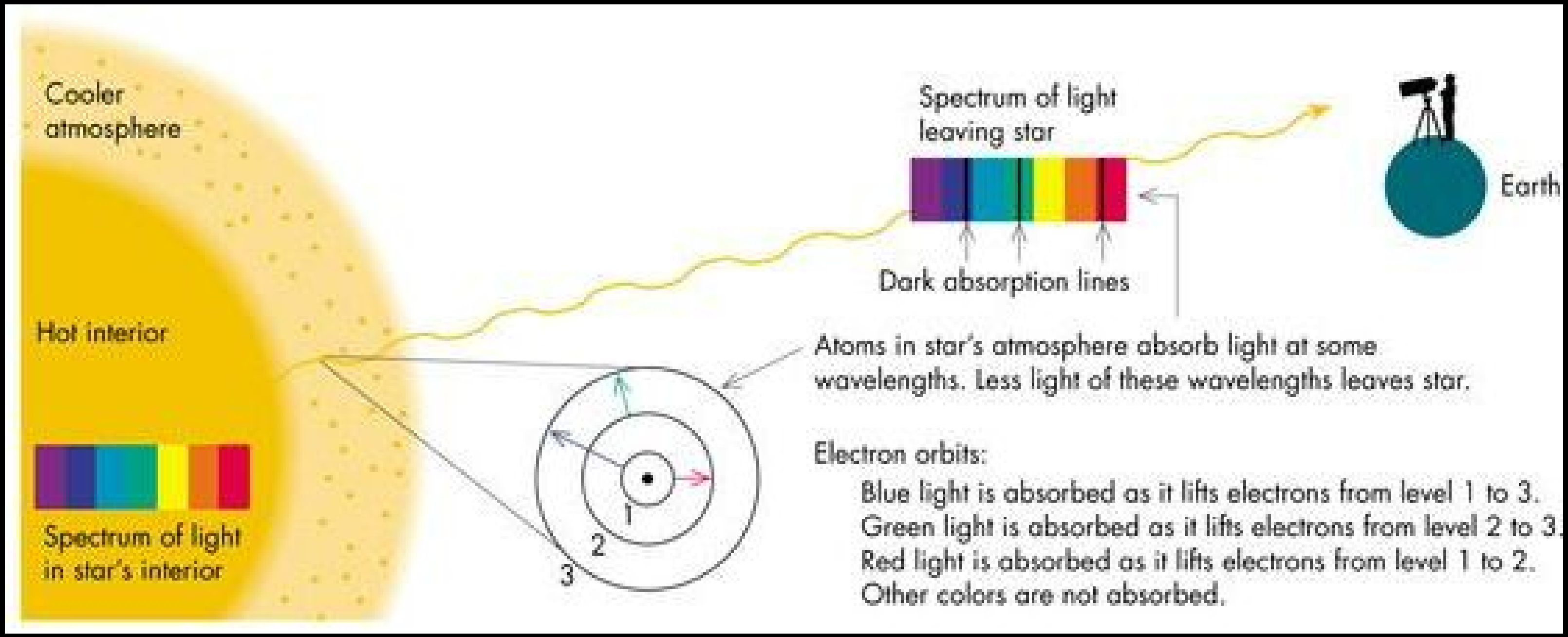


A lot of information is contained in the Color Spectrum of an object (a representation of how the brightness of an object changes with the color or frequency).

In nature we find continuous spectra, absorption spectra, and emission spectra.

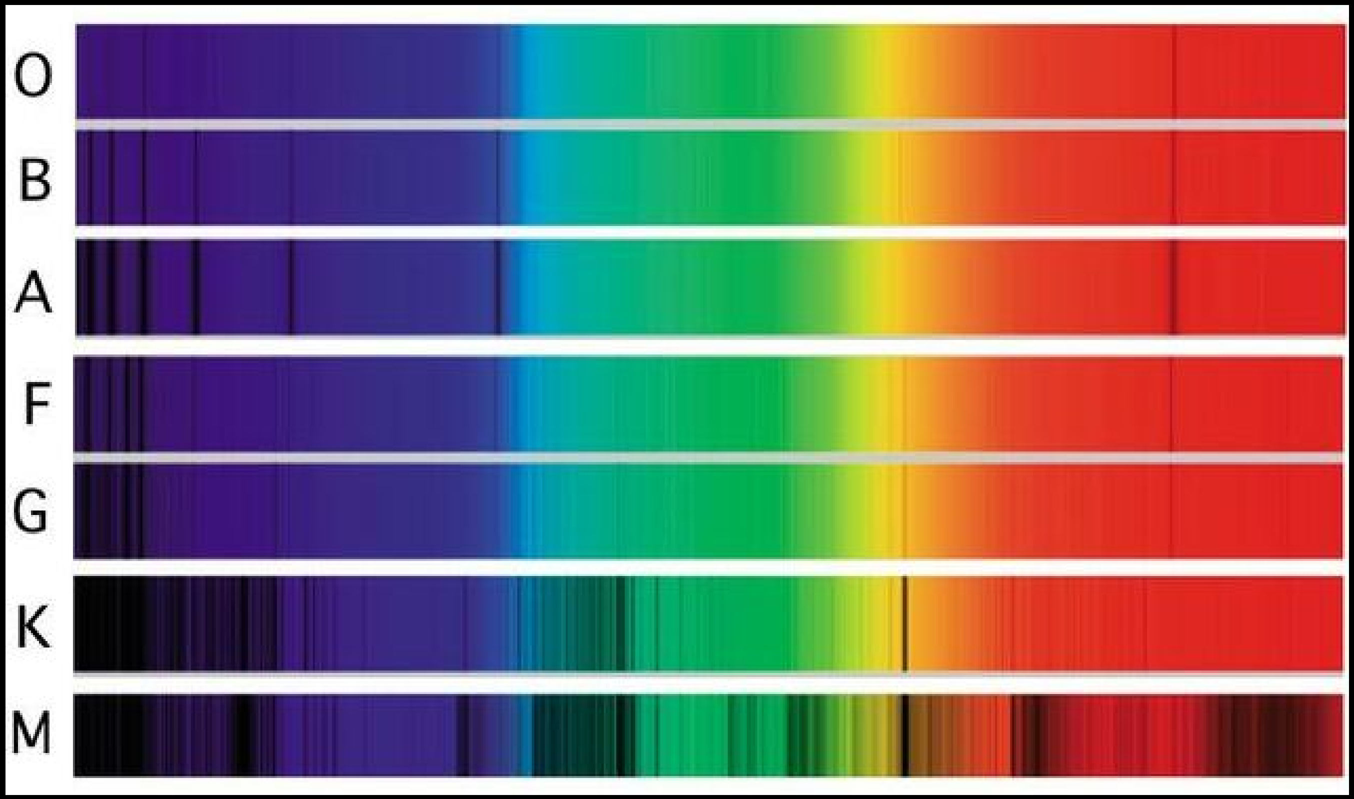
The specific colors that are absorbed or emitted are indicative of the atoms and molecules that are present.

Color Spectrum of Stars



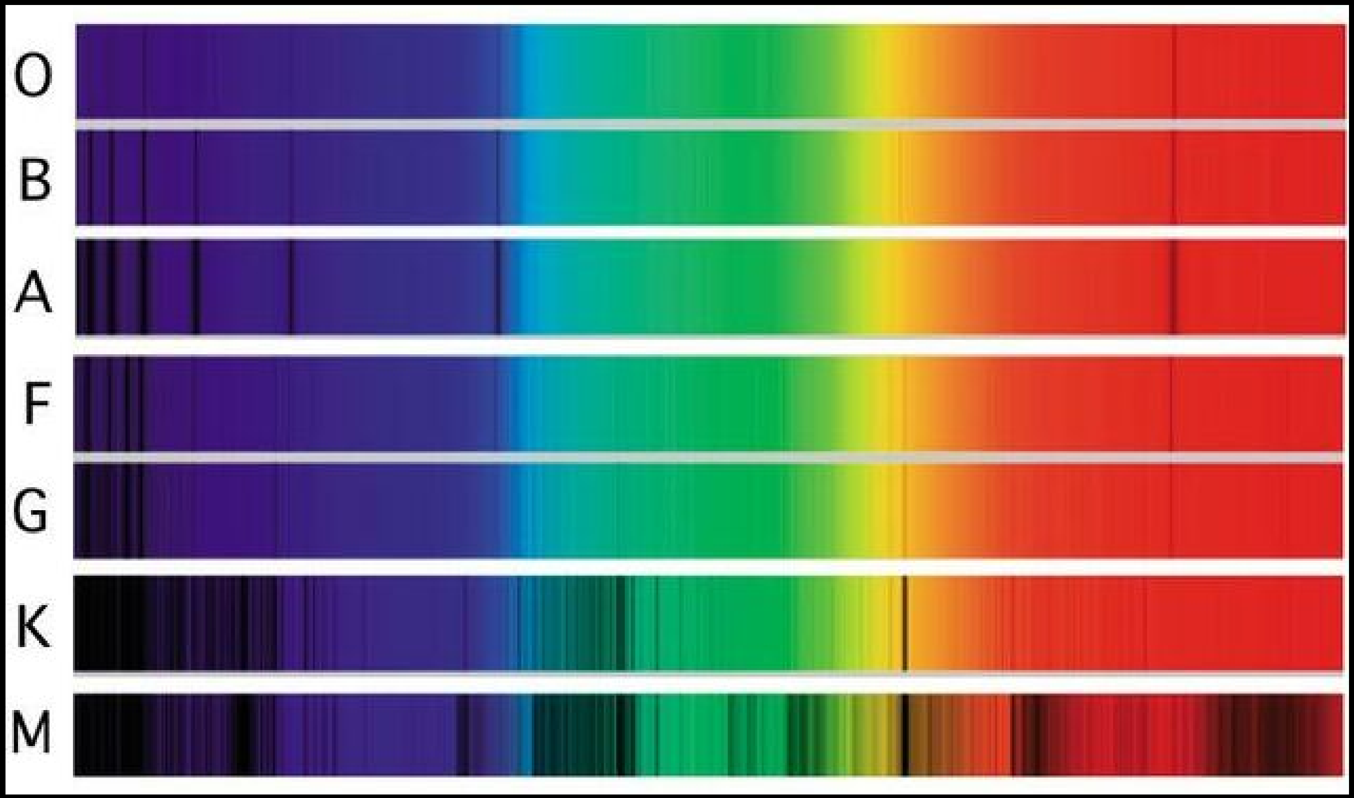
Stellar spectra are actually a combination of continuous and absorption spectra. As we saw, the continuous spectra will reflect the stars temperature (at the photosphere) and the absorption lines embedded in the spectra will be indicative of the material in the solar atmosphere.

Classification of Stellar Spectra



The spectra of seven different stars are shown above along with their classification O B A F G K M

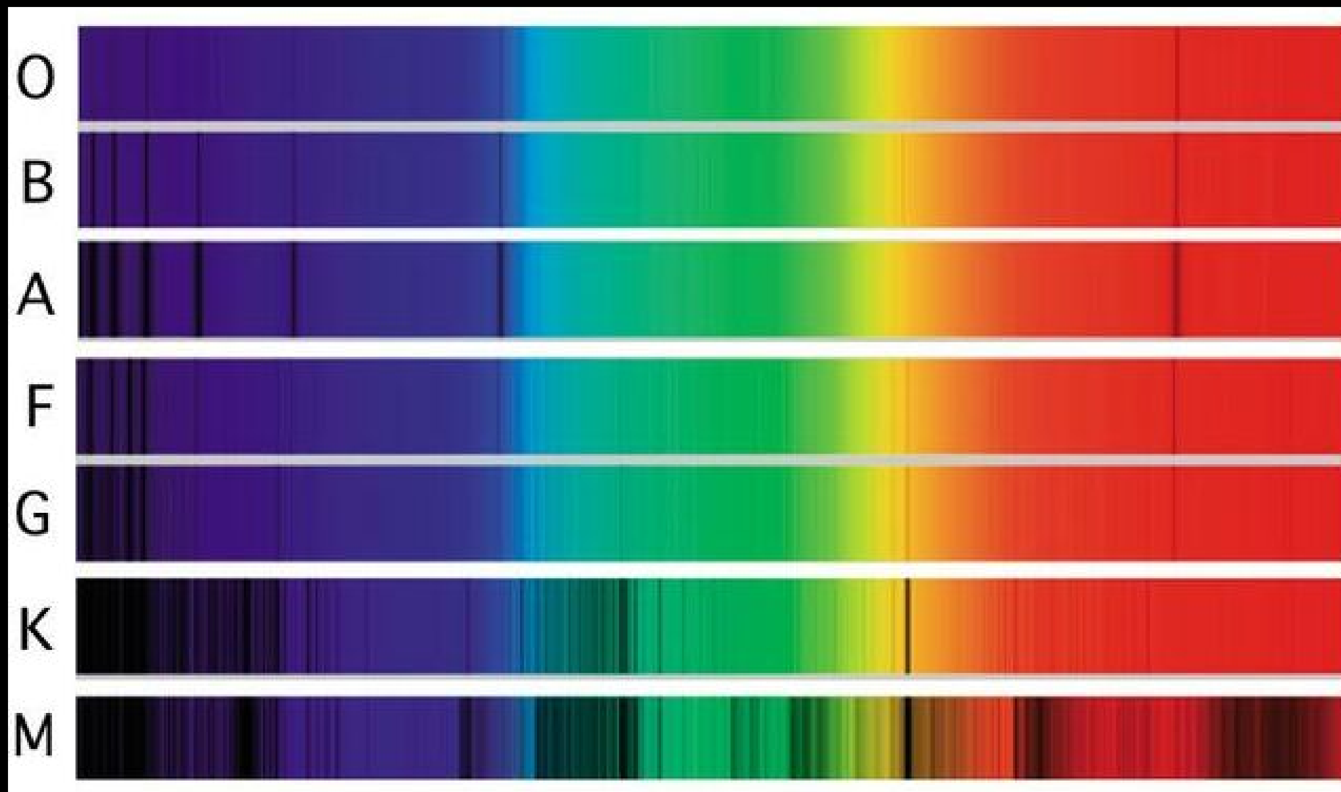
Classification of Stellar Spectra



Originally the spectra were arranged to indicate the strength of the Hydrogen Spectrum (absorption the greatest). Thus the strongest Hydrogen absorption spectra were classified as A (see the H_α line)

Classification of Stellar Spectra

- 40,000 K
- 20,000K
- 10,000K
- 7500 K
- 5500 K
- 4000 K
- 3000K



The classification was then reorganized to reflect the temperature of the star from high (O) to low (M). Note that in the lower temperature categories the blue is not as bright.

Apparent and Actual Brightness

Although two objects (light bulbs) may be equally bright, the one that is closer will appear brighter. We say that the actual brightness of the two objects is the same but the apparent brightness of the closer object is greater.

When we observe stars, we measure apparent brightness. However the actual brightness is indicative of the physical properties of the star.

Apparent Brightness

We use the magnitude scale to measure apparent brightness (based on a scale developed by Hipparchus).

In this scale, the smaller the number the brighter the object [e.g. Polaris (magnitude 2.12) is brighter than Pluto (magnitude 14.5) but dimmer than Jupiter (magnitude -2.9)]

An object that is one magnitude smaller (brighter) is ~2.5 times brighter. (5 magnitudes corresponds to a factor of 100 in brightness).

Object of greater than magnitude 6 are too faint to be seen with the naked eye (away from light pollution).

Objects of magnitude 29 are the faintest objects that can be studied with current technology.

Object	Magnitude	Comment
The Sun	-27.0	
The Moon	-12.7	When closest to the Earth
Venus	-4.6	At its brightest
Jupiter	-2.9	At its brightest
Sirius	-1.6	Brightest northern star
Vega	0.14	
Aldebaran	1.06	
Polaris	2.12	
Delta Ceti	4.04	
Uranus	5.8	At its brightest
Neptune	7.7	At its brightest
Pluto	14.5	At its brightest

Magnitude Difference	Increase/Decrease in Brightness
1	2.512
2	6.310
3	15.851
4	39.817
5	100.022
6	251.256
7	631.157
8	1585.466
9	3982.691
10	10004.522

Brightness Versus Distance

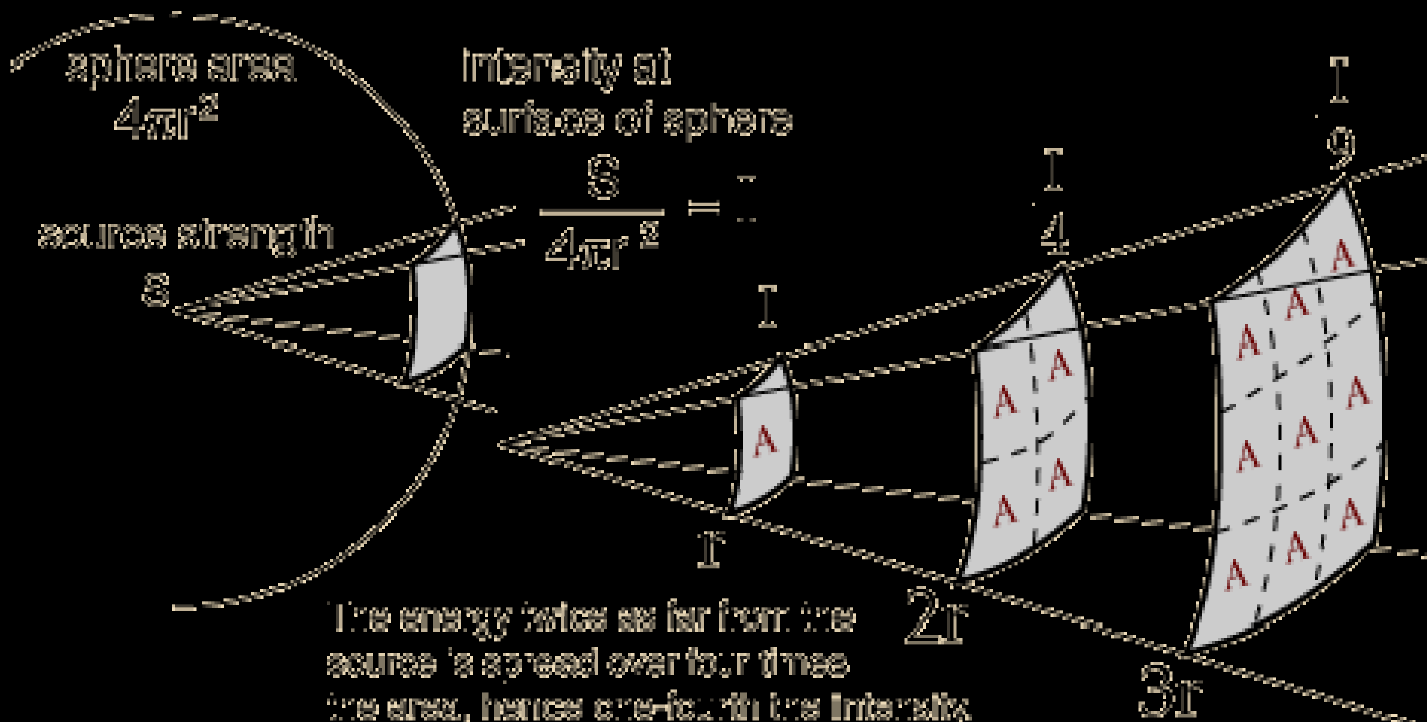
The further away on object is the dimmer it appears

Apparent Brightness =

Actual Brightness / (4*π* Distance*Distance)

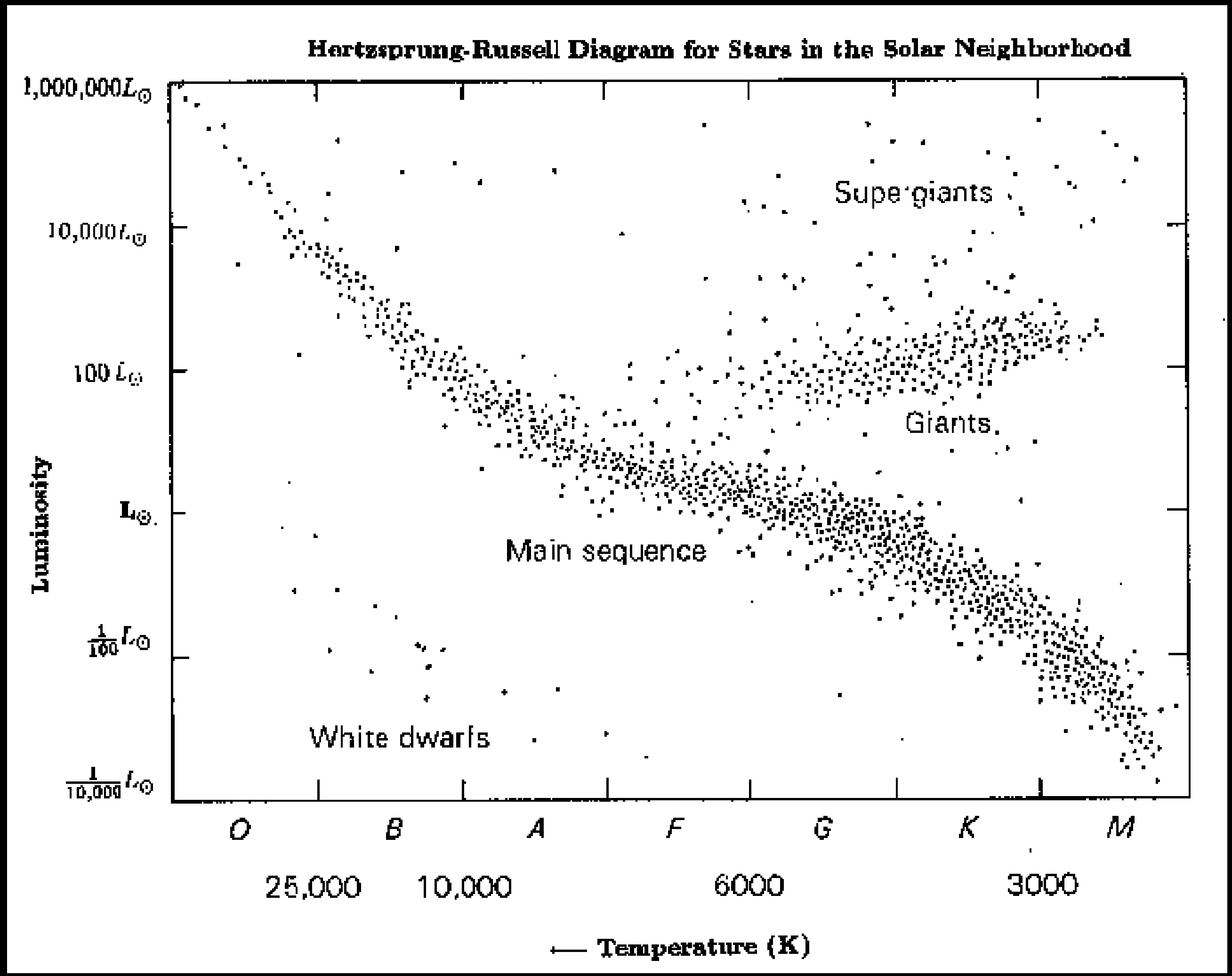
If we can estimate the distance to an object (e.g., using parallax) we can find the actual brightness from the apparent brightness.

The actual brightness is defined as the brightness an object would be if it were 33 light years away

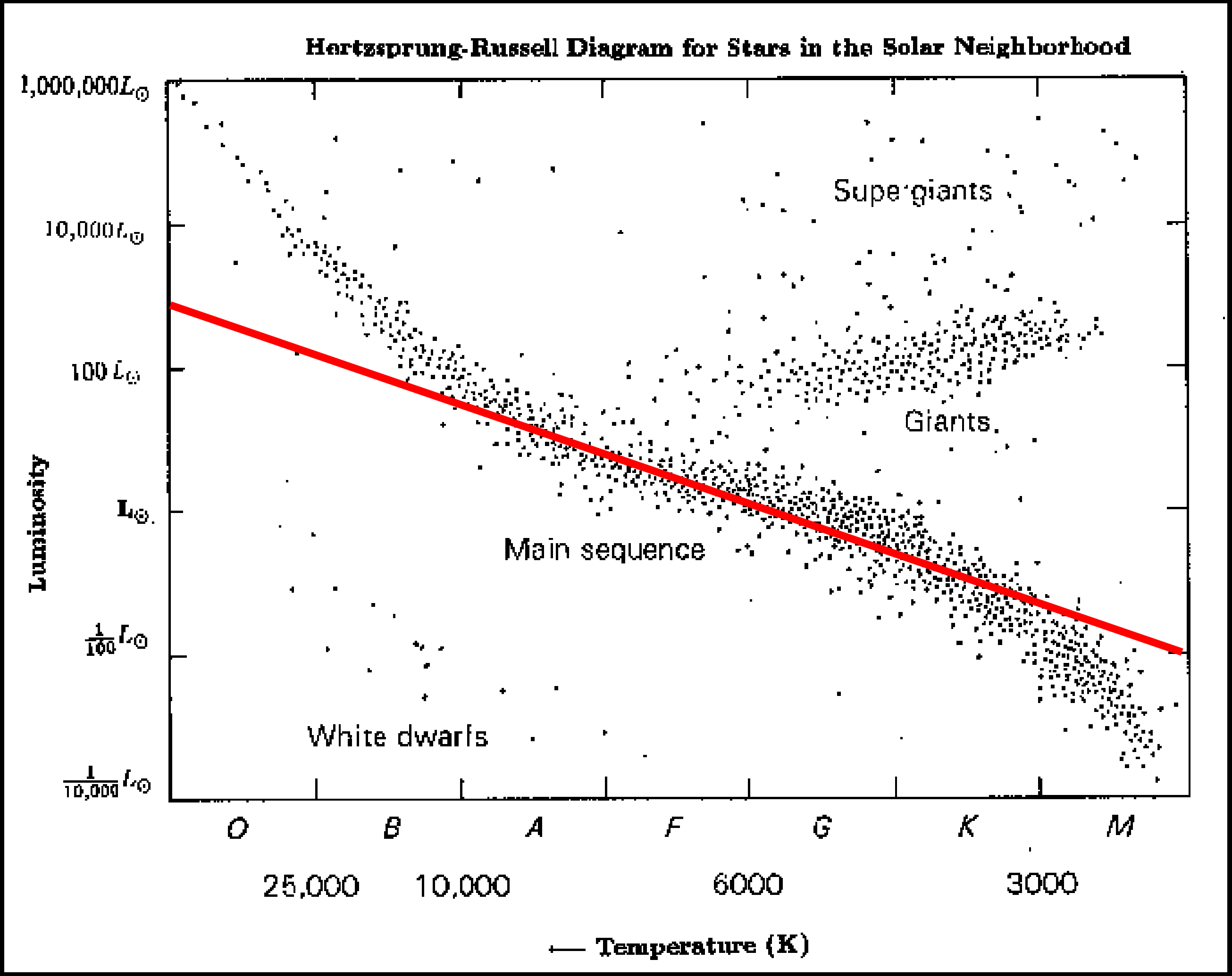


sphere area
$4\pi r^2$
Intensity at
surface of sphere
$\frac{S}{4\pi r^2} = I$
source strength
S
I
$\frac{I}{4}$
$\frac{I}{9}$
A
r
2r
3r
The energy twice as far from the
source is spread over four times
the area, hence one-fourth the intensity.

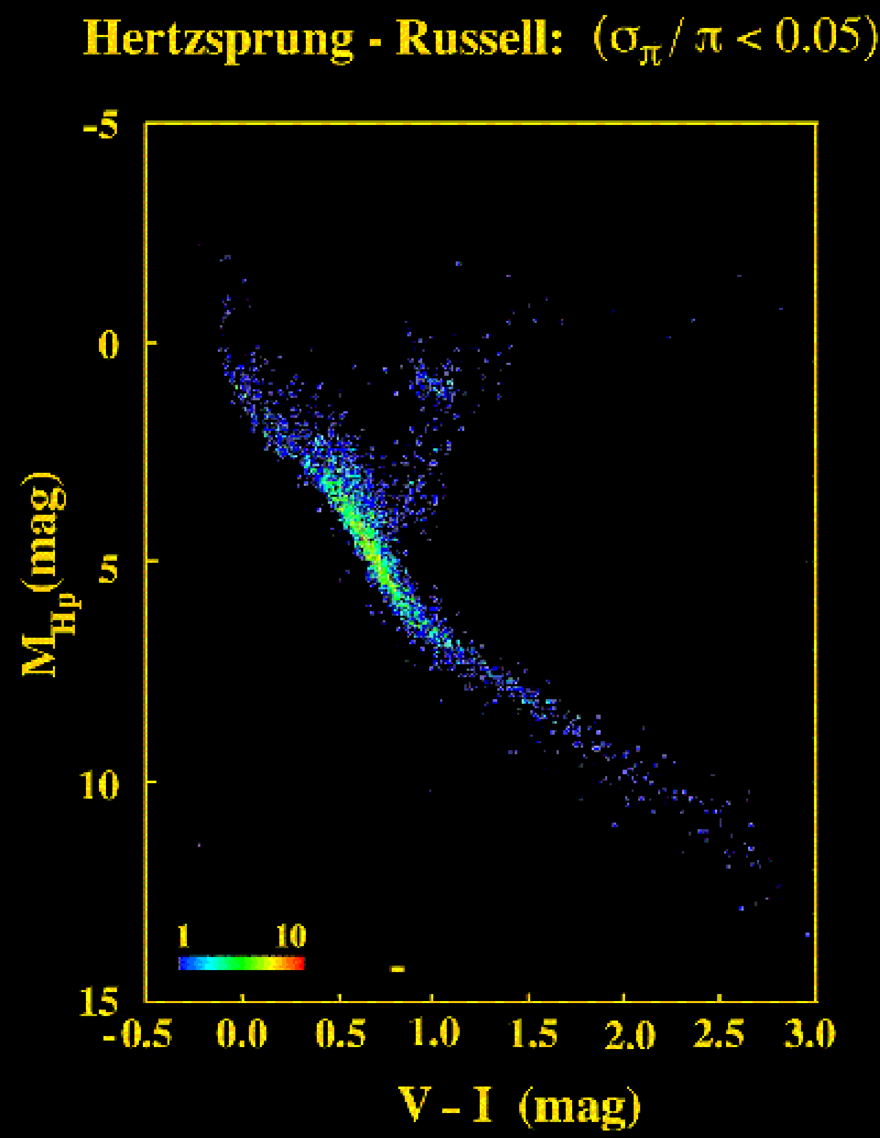
Hertzsprung Russel (Magnitude versus Spectral Type)



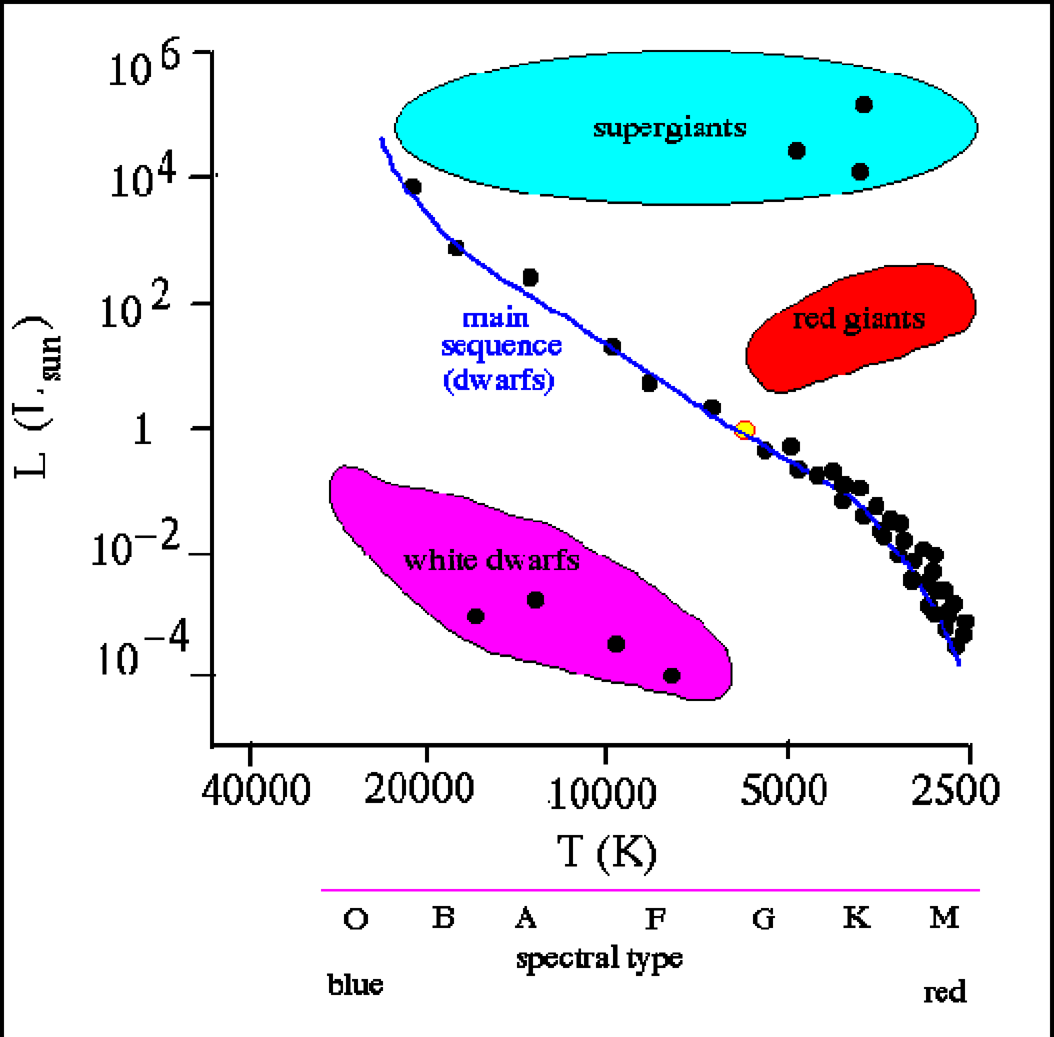
Hertzsprung Russel
(Magnitude versus Spectral Type)

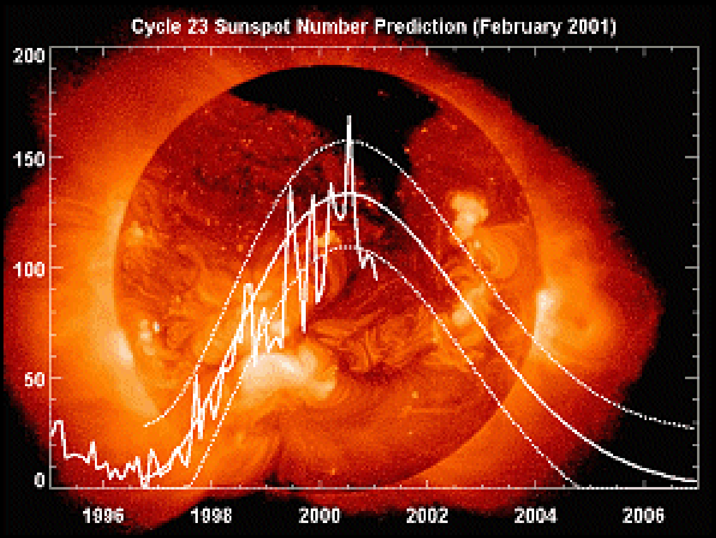


Hertzsprung Russel (Magnitude versus Spectral Type)



Hertzsprung Russel
(Magnitude versus Spectral Type)

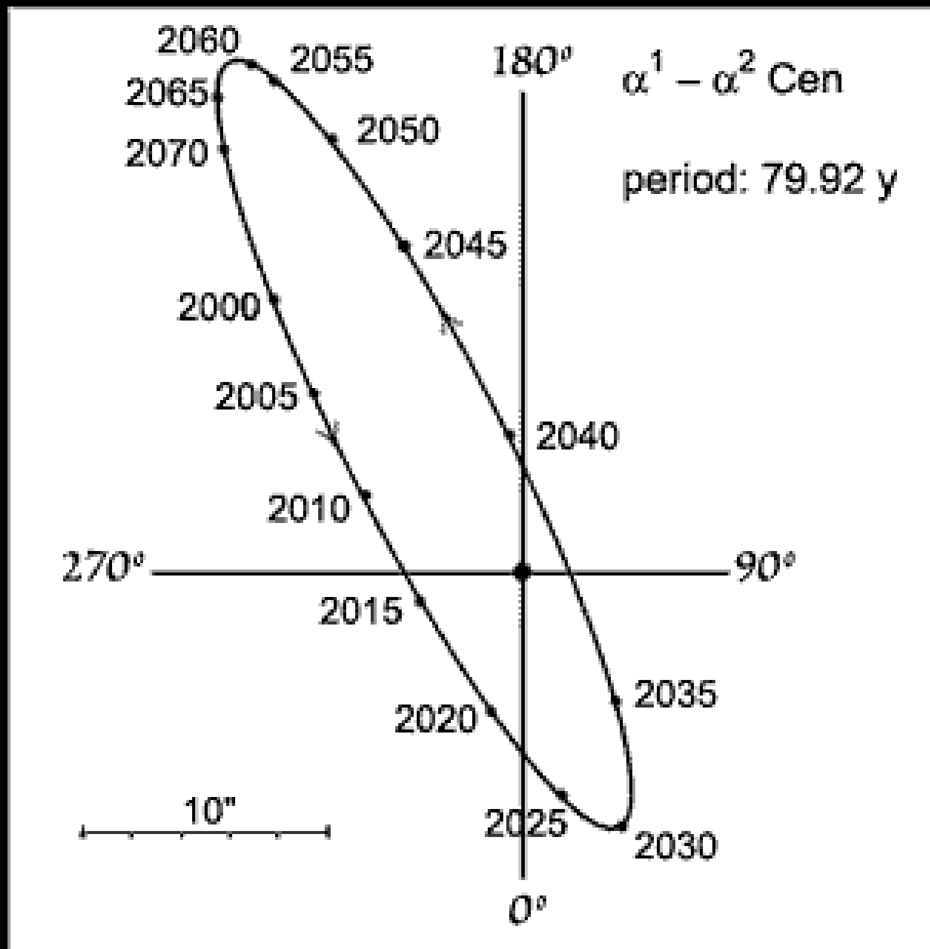




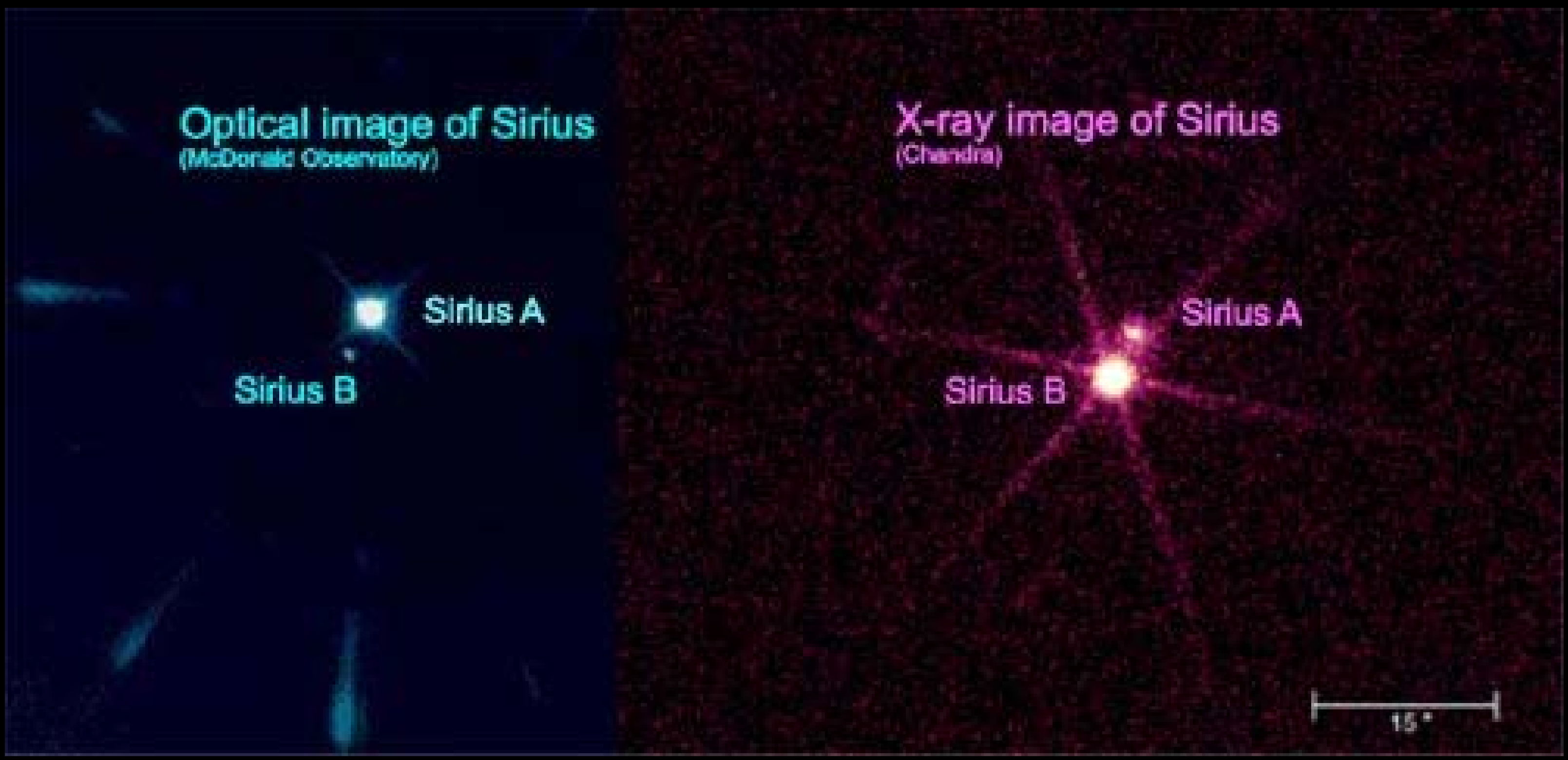
Cycle 23 Sunspot Number Prediction (February 2001)
200
150
100
50
0
1996
1998
2000
2002
2004
2006

Visual Binaries

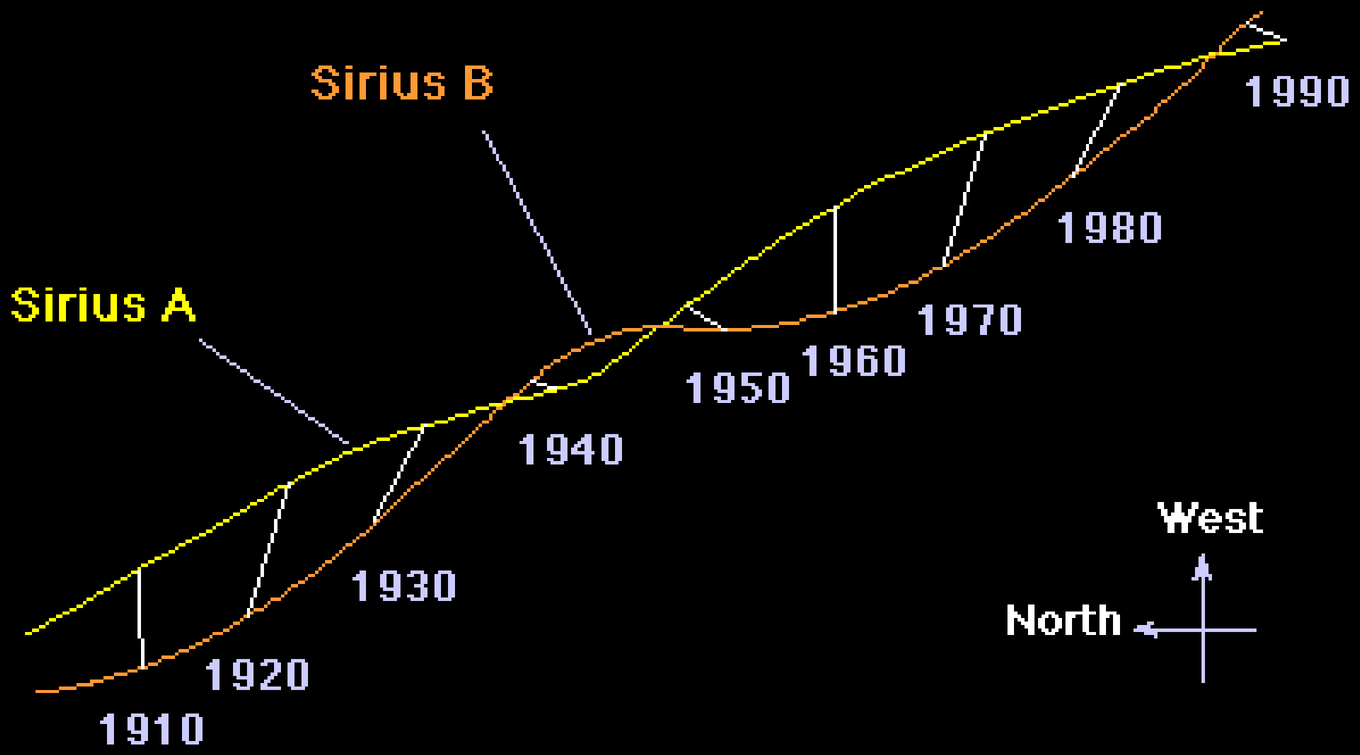
Visual Binary



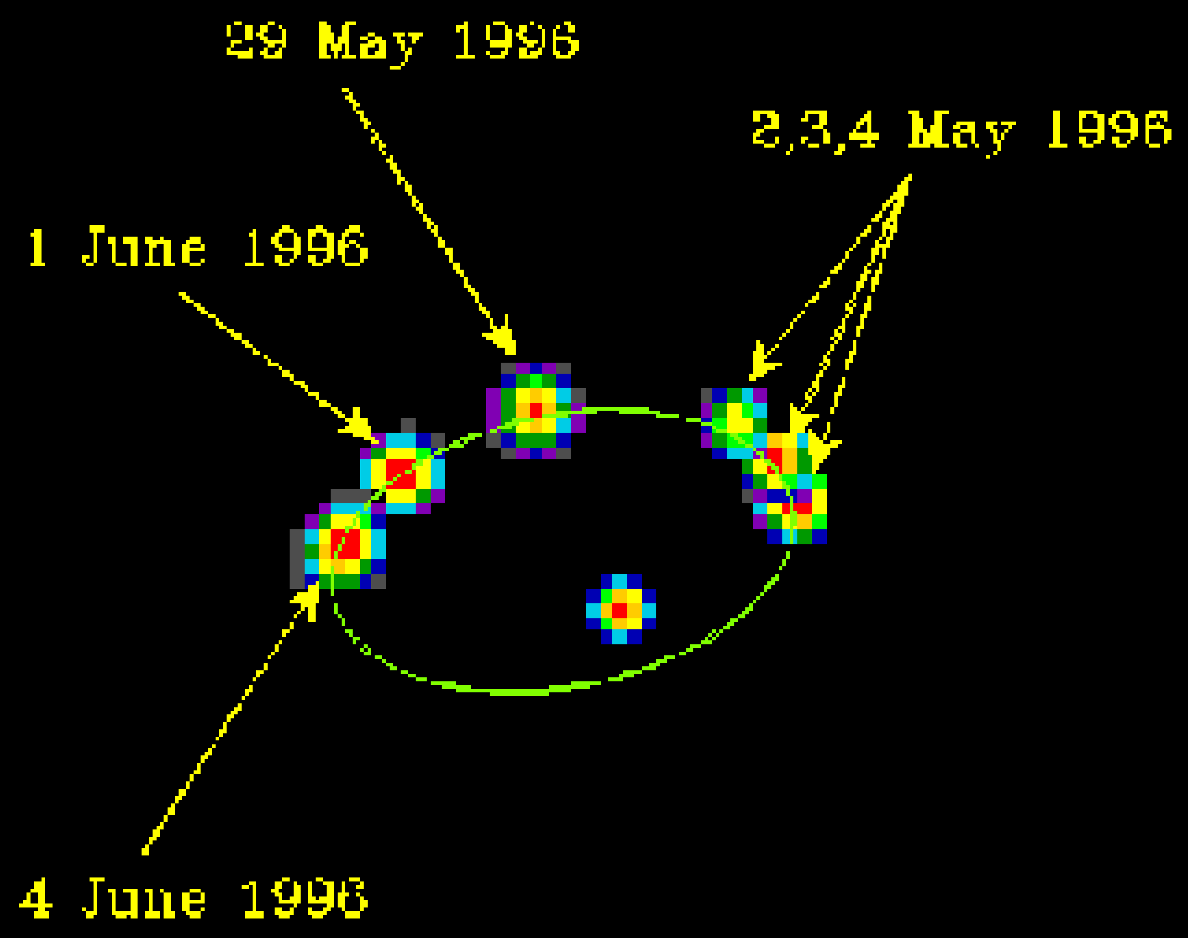
Visual Binary



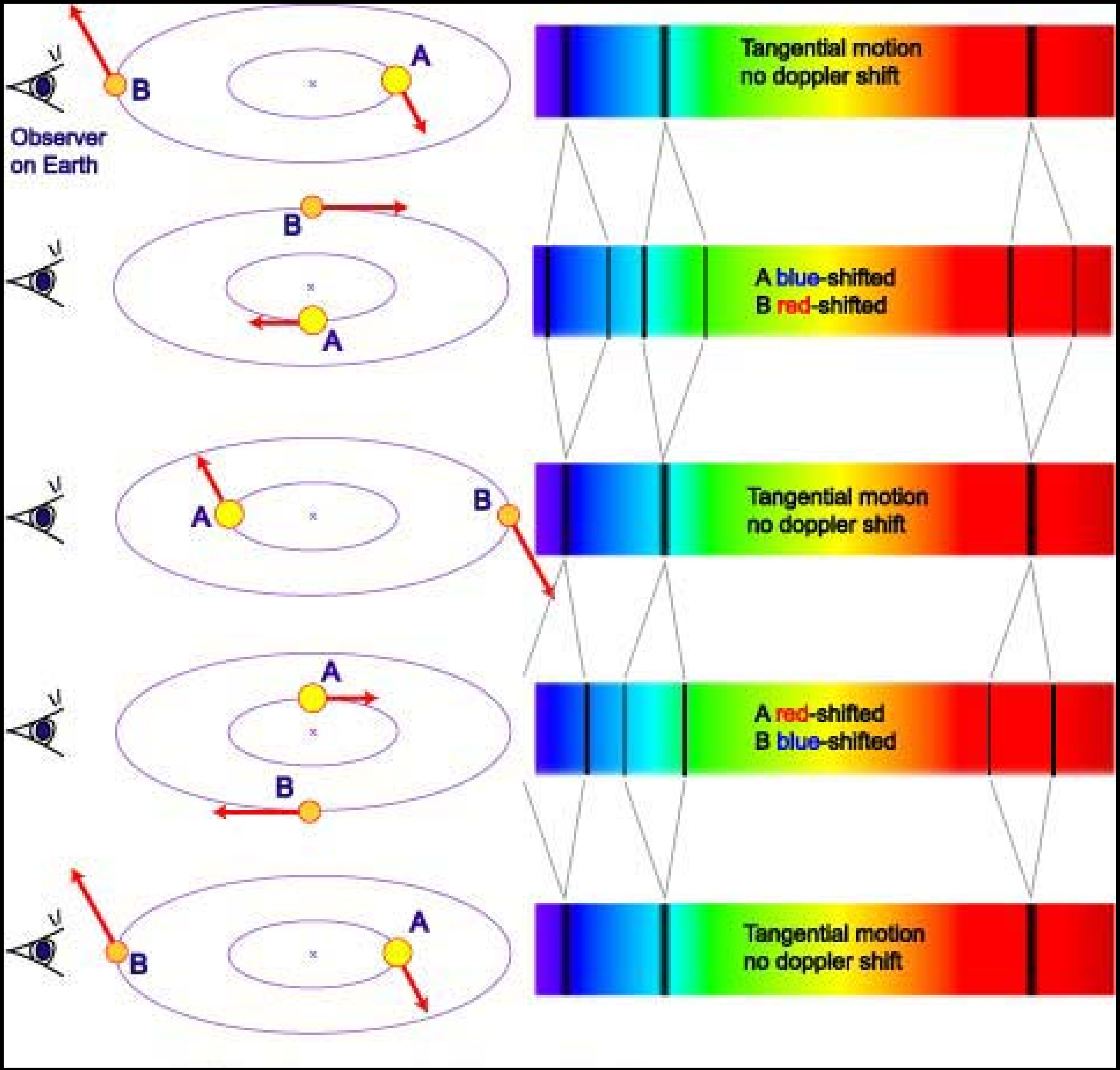
Visual Binary



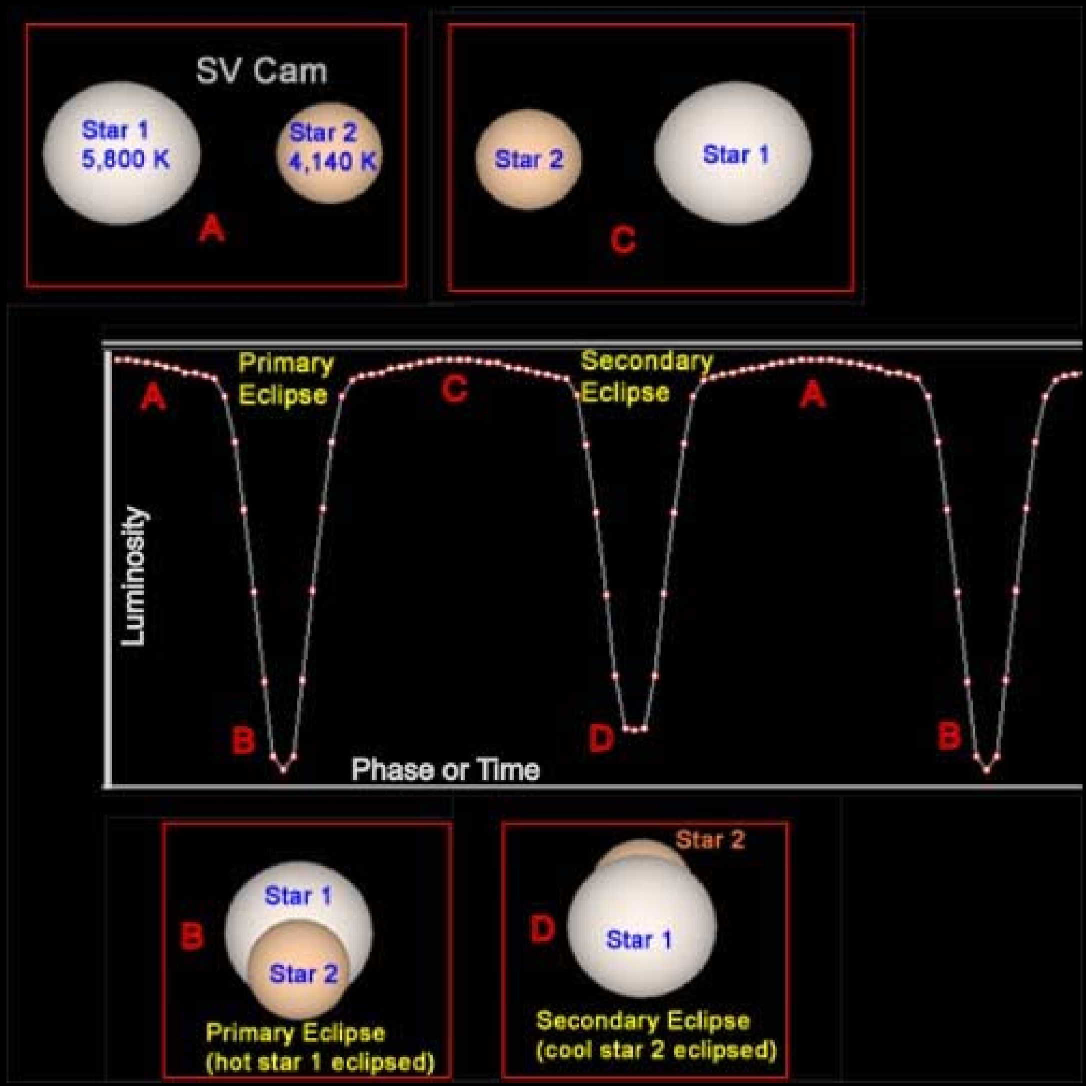
Spectral Binary



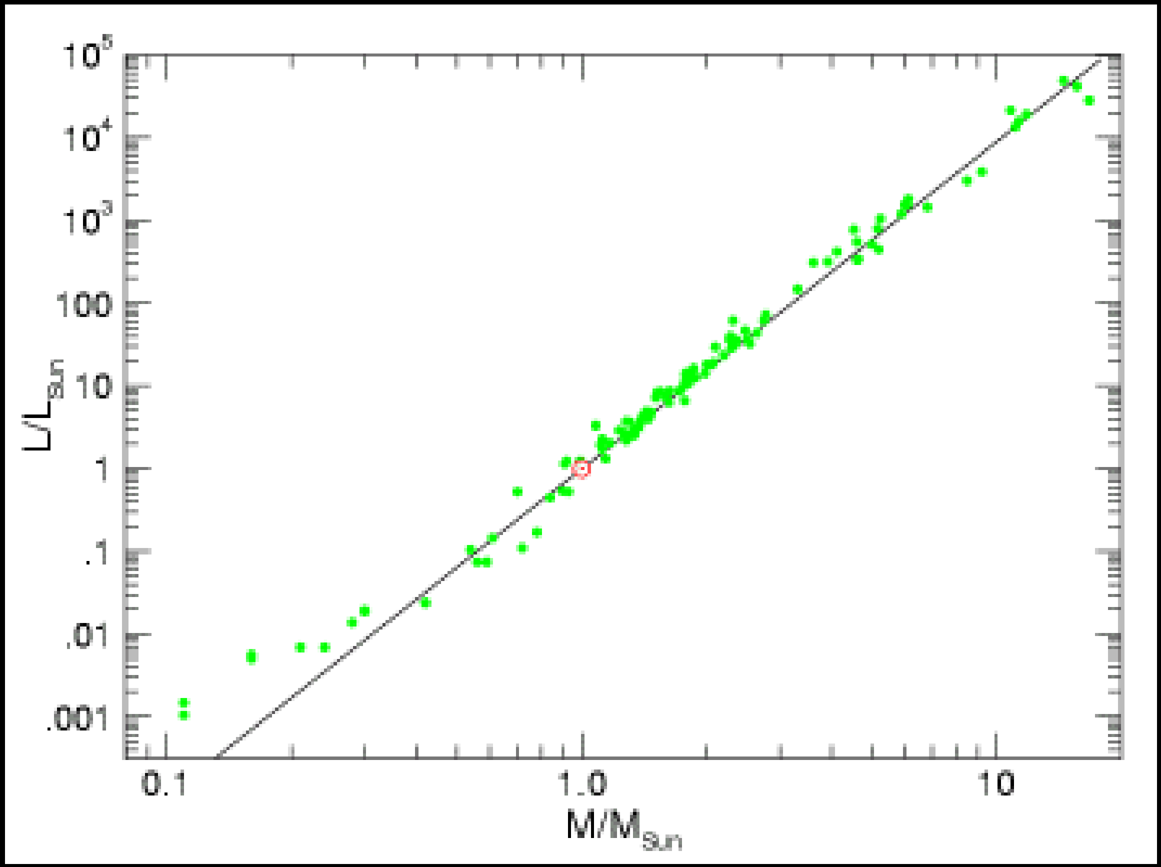
Spectral Binary



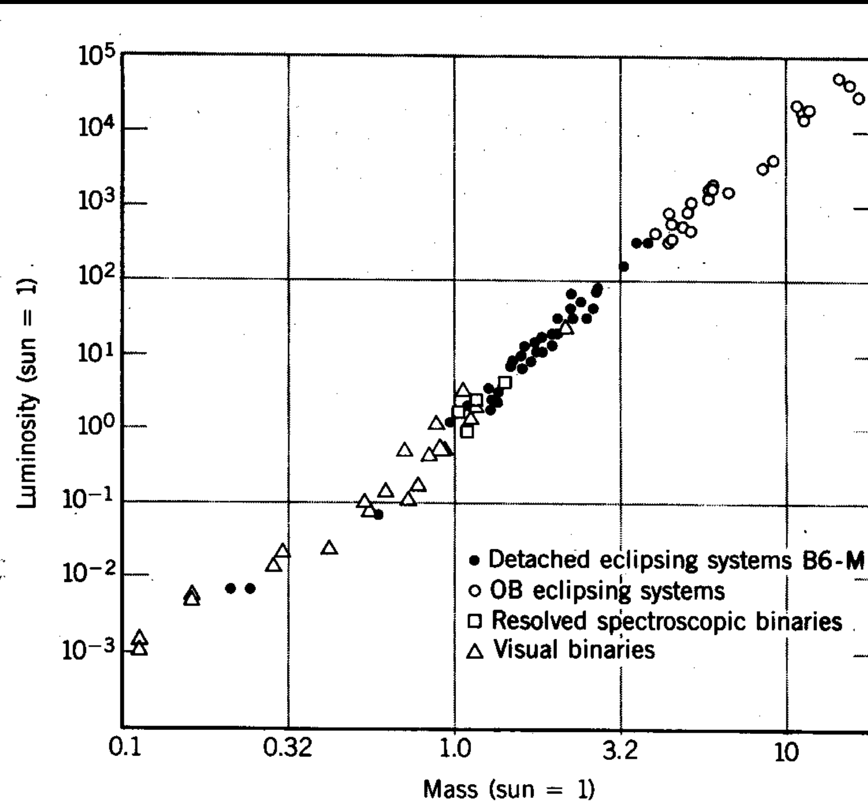
Eclipsing Binary



Mass-Luminosity (Brightness) Relationship



Mass-Luminosity (Brightness) Relationship

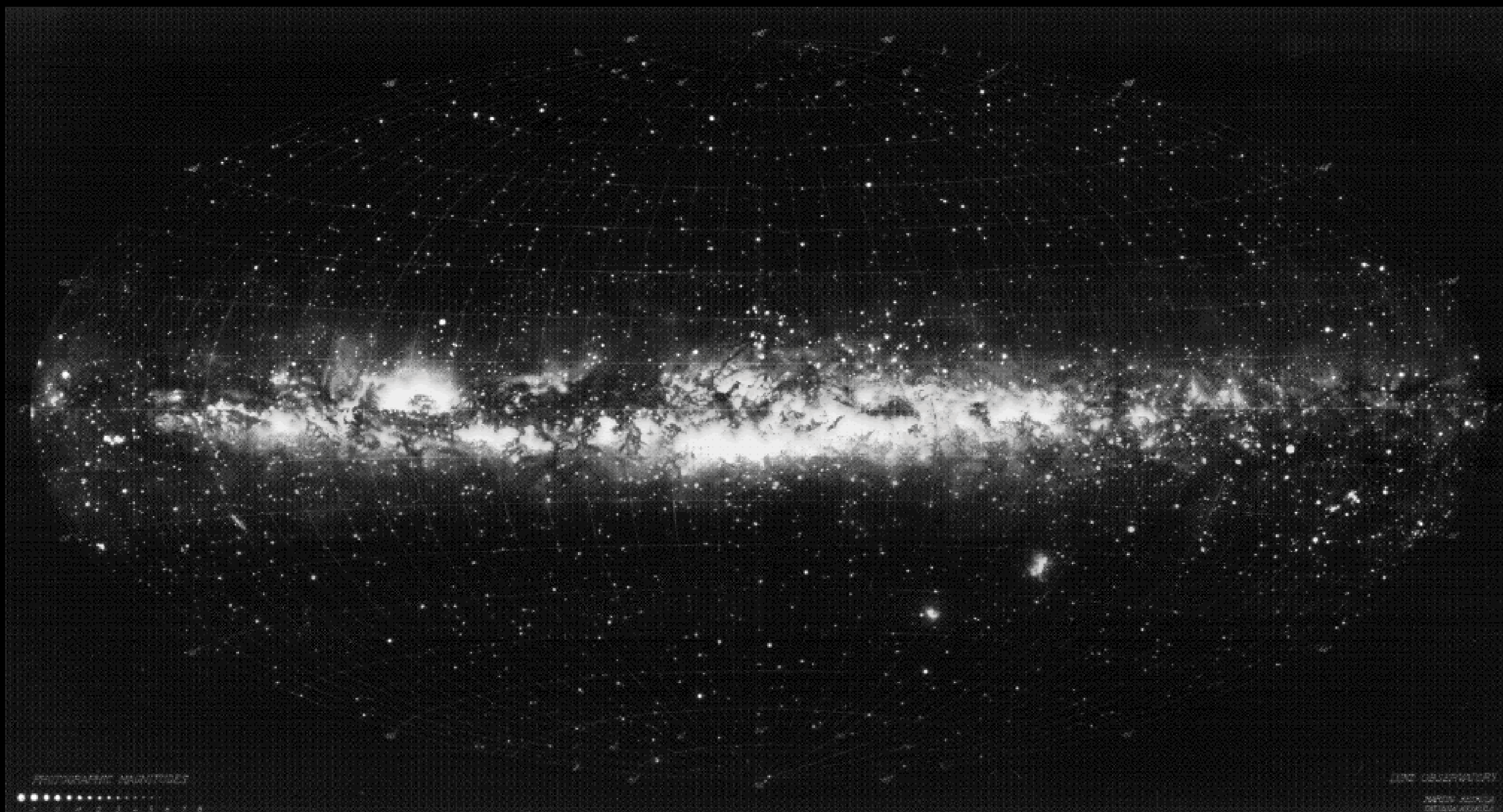


The mass – luminosity relation for stars, as determined from binary systems, in which the individual masses can be found.

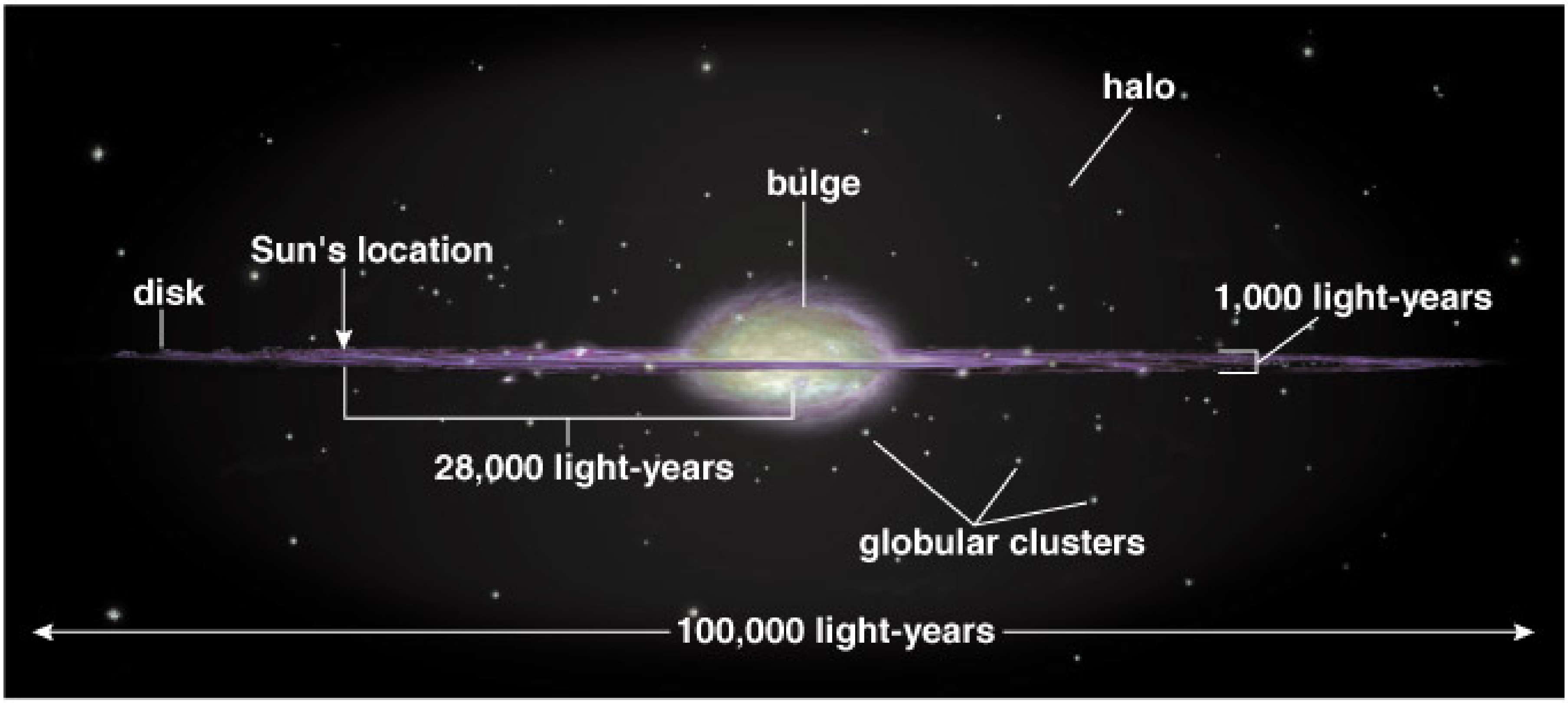
Open Star Clusters

- Group of loosely packed stars
- Located in the Galactic Disk
- Contain up to about 1000 stars
- Approximately 30 LY across
- Contain younger stars

Milky Way Galaxy Earth View



Milky Way External View



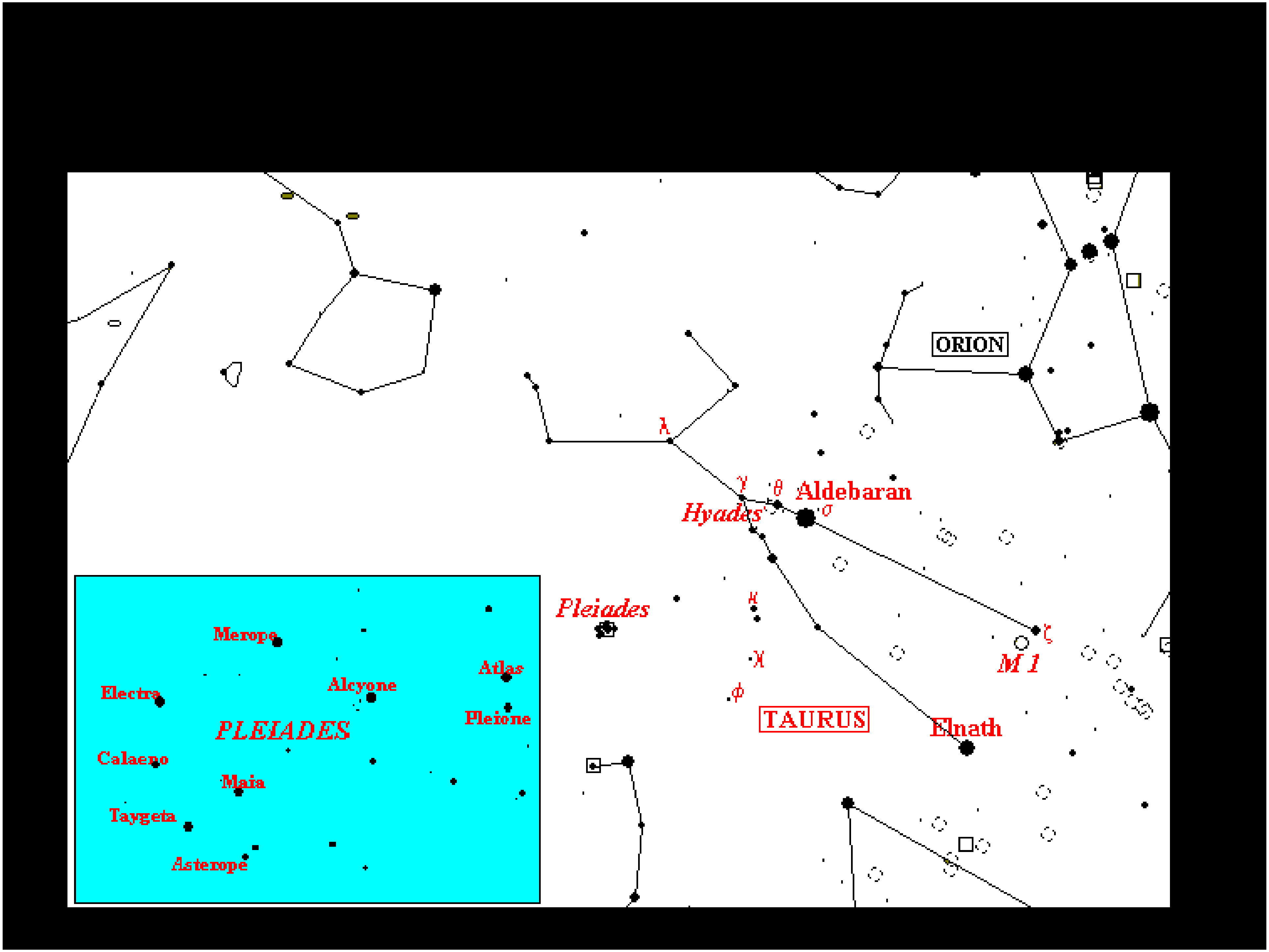
(b)

Globular Star Clusters

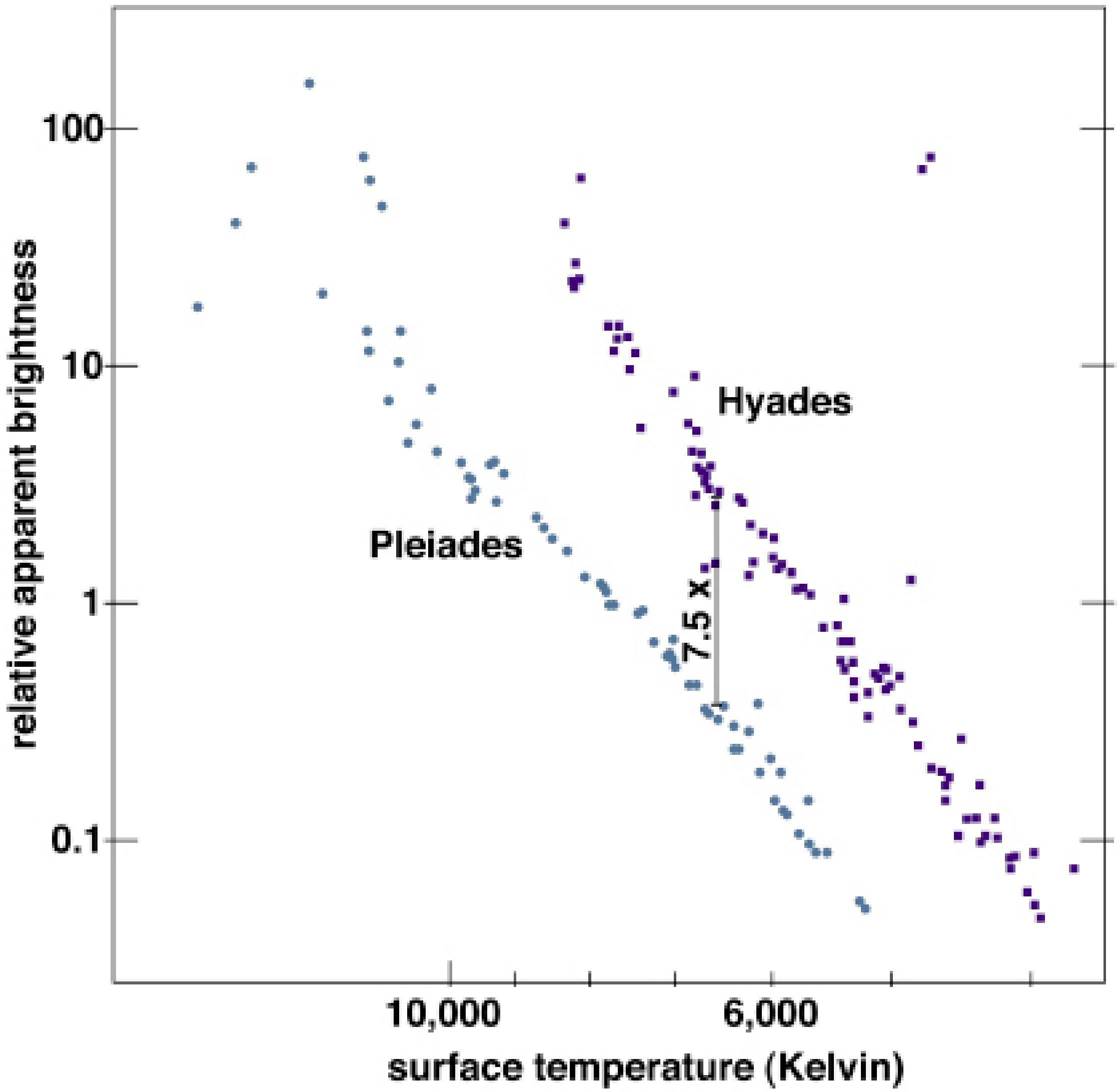
- Group of densely packed stars
- Located in the Galactic Halo
- Central region Contains up to about 10000 stars in a region a few LY across
- Contain older stars

Open Cluster: Pleiades

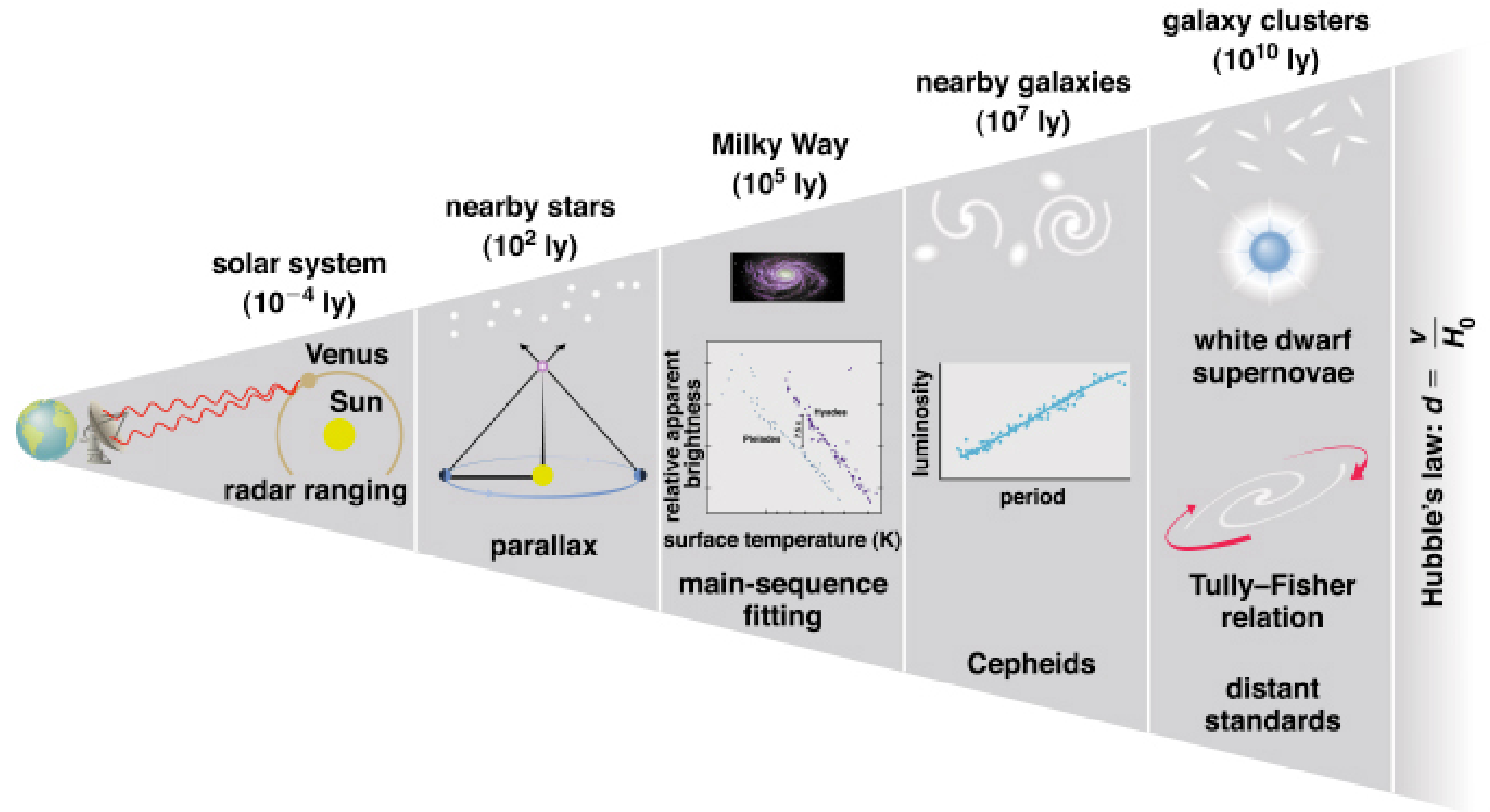
- ~ 430 LY from Earth
- ~ 3000 stars
- ~ 13 LY across


ORION
Aldebaran
Hyades
Pleiades
M 1
TAURUS
Elnath
Merope
Atlas
Alcyone
Electra
PLEIADES
Pleione
Calaeno
Maia
Taygeta
Asterope

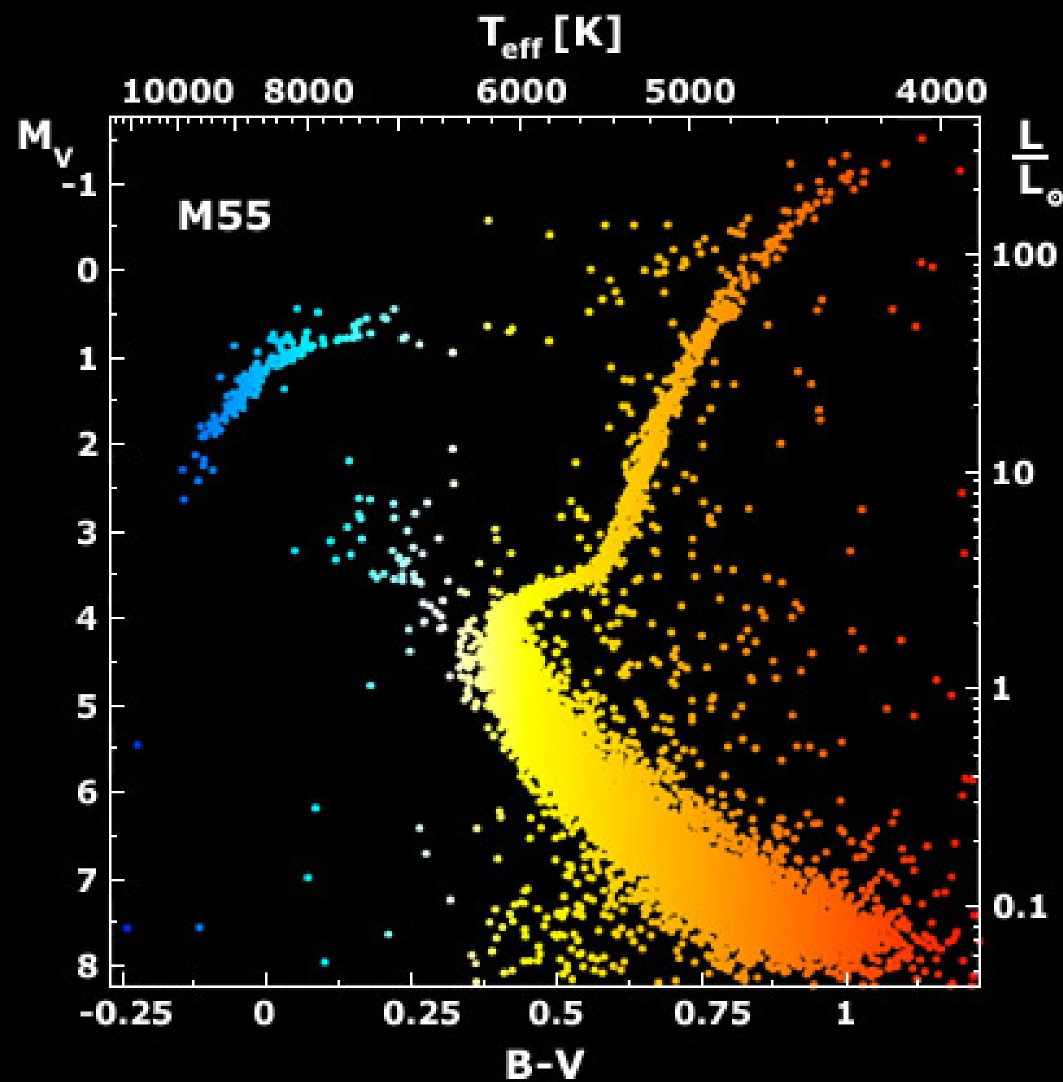
Open Cluster: Hyades ~150 LY



100
10
1
0.1
relative apparent brightness
Hyades
Pleiades
7.5 x
10,000
6,000
surface temperature (Kelvin)


solar system
(10^{-4} ly)
Venus
Sun
radar ranging
nearby stars
(10^{2} ly)
parallax
Milky Way
(10^{5} ly)
relative apparent brightness
surface temperature (K)
main-sequence fitting
nearby galaxies
(10^{7} ly)
luminosity
period
Cepheids
galaxy clusters
(10^{10} ly)
white dwarf supernovae
Tully–Fisher relation
distant standards
Hubble's law: $d = \frac{v}{H_0}$

Globular Cluster M55

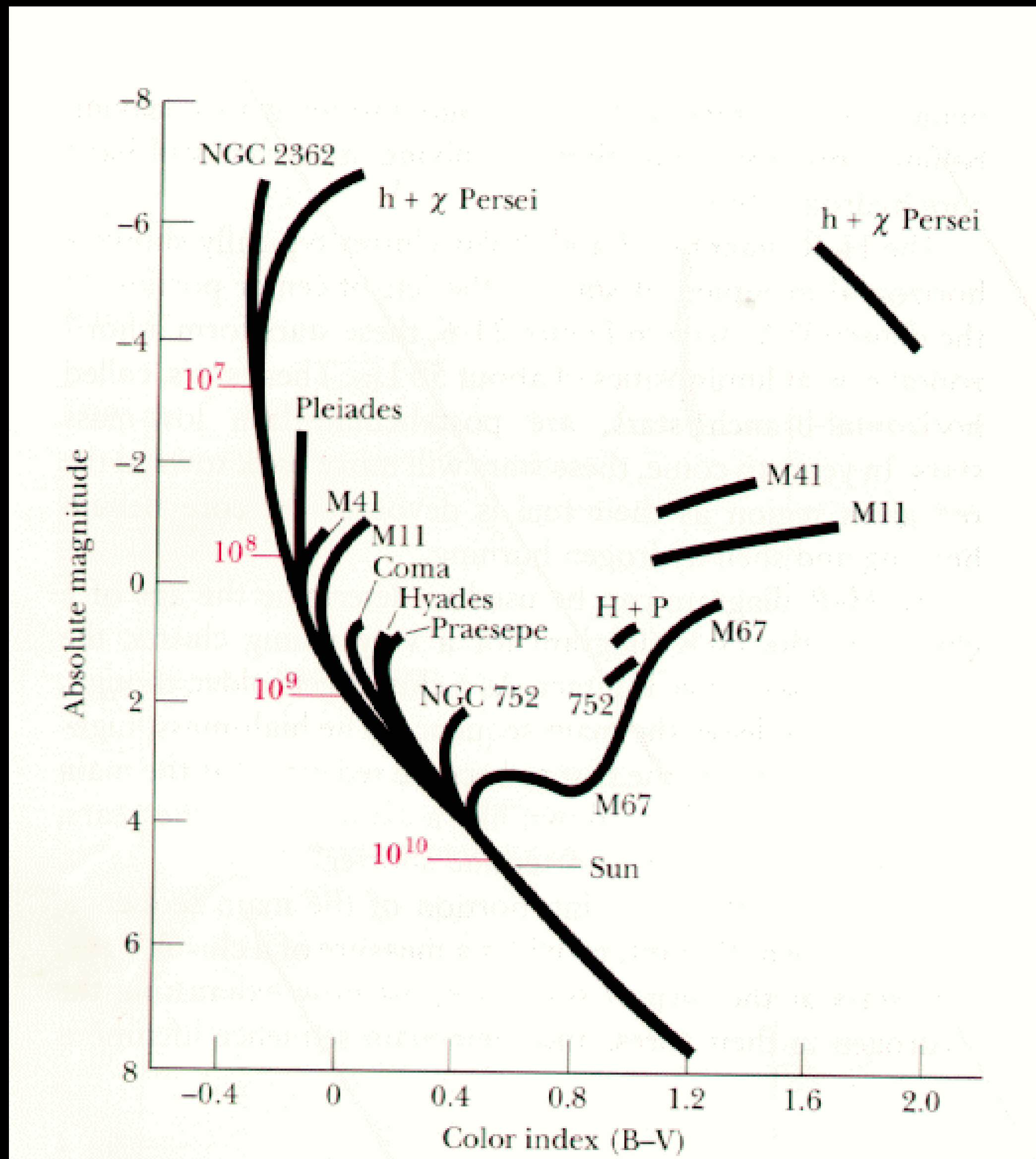


T_eff [K]
10000
8000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
M55
L / L_⊙
100
10
1
0.1
-0.25
0
0.25
0.5
0.75
1
B-V

Globular Cluster NGC 6093

Hubble Heritage

PRC99-26 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)



Absolute magnitude
-8
-6
-4
-2
0
2
4
6
8
NGC 2362
h + χ Persei
h + χ Persei
10^7
Pleiades
M41
M11
Coma
Hyades
Praesepe
10^8
M41
M11
H + P
M67
10^9
NGC 752
752
M67
10^{10}
Sun
−0.4
0
0.4
0.8
1.2
1.6
2.0
Color index (B–V)

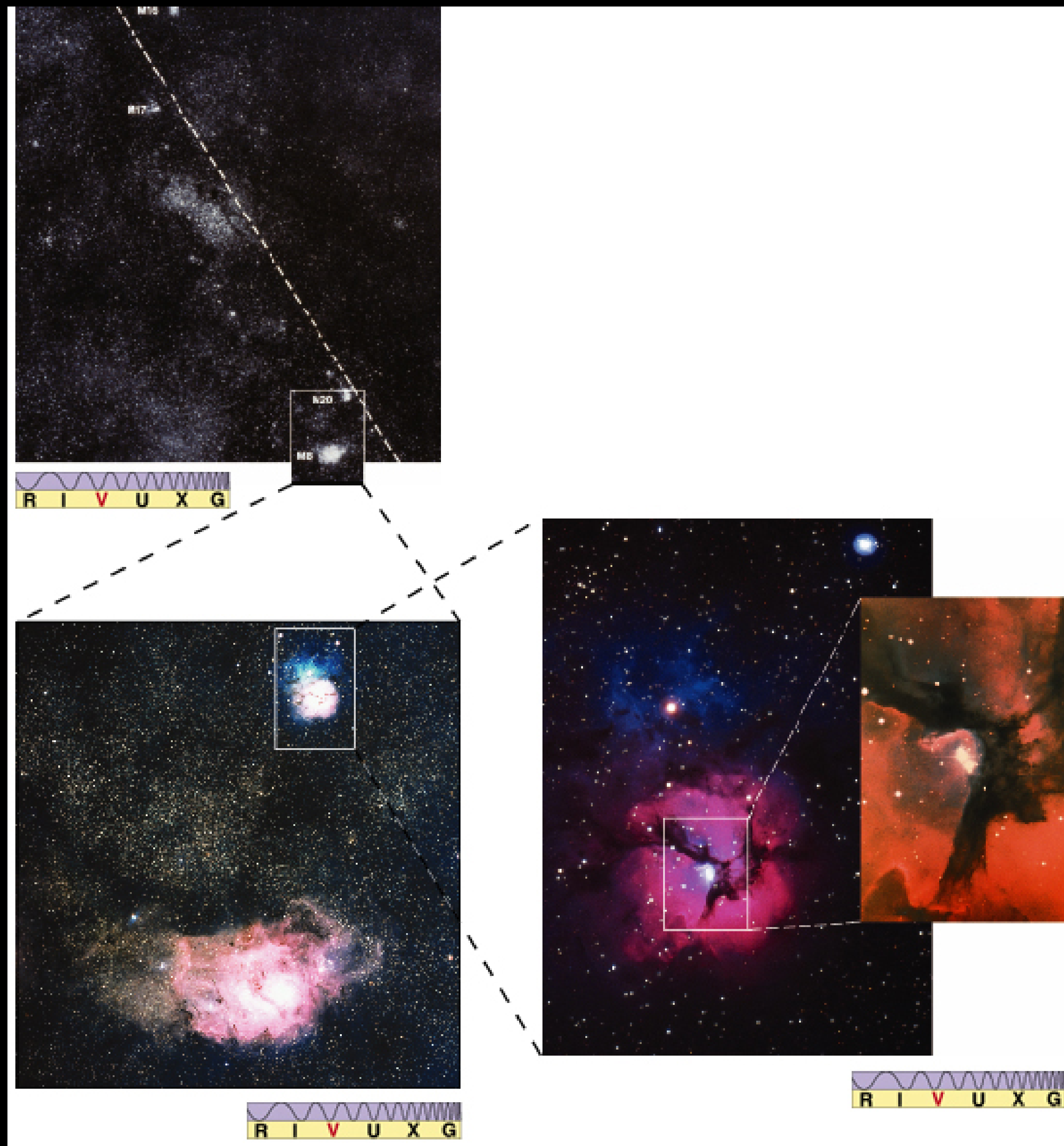
Stellar Formation: Interstellar Medium

Image of a swath of sky from horizon to horizon showing the Milky Way (Galaxy containing the Sun).

Bright regions are concentrations of stars, the darker regions exists because light coming from stars has been absorbed or scattered by material ("dust") as it travels the stars and Earth.

Interstellar Medium: Refers to the material in the region of space between stars.

Stellar Formation: Nebula



Stellar Formation

1) Molecular Clouds, Nebulae
2) Fragmentation and Collapse of Molecular Clouds
3) Formation of Protostars
4) Birth of a Star
5) Evolution of a Star

Molecular Clouds, Nebulae

99% of the material in the interstellar medium is composed of very low density gas (mainly Hydrogen with some Helium and other material)

On average the density is very low, .1 molecules per cm^3 (air we breath 10^{19} molecules per cm^3, best vacuum on earth 10^3 molecules per cm^3). Thin enough that light from stars far away can reach us.

1% of the interstellar medium is dust: grains composed of carbon, metals, silicates and ice that are about $5x10^{-7}$ m in diameter and the density is about 1 per million m^3.

Molecular Clouds, Nebulae

The interstellar medium is not uniform however half of the gas occupies 2% of the volume. These relatively high density regions are known as nebulae (or clouds).

These nebulae can have densities of 10,000 molecules per cm^3

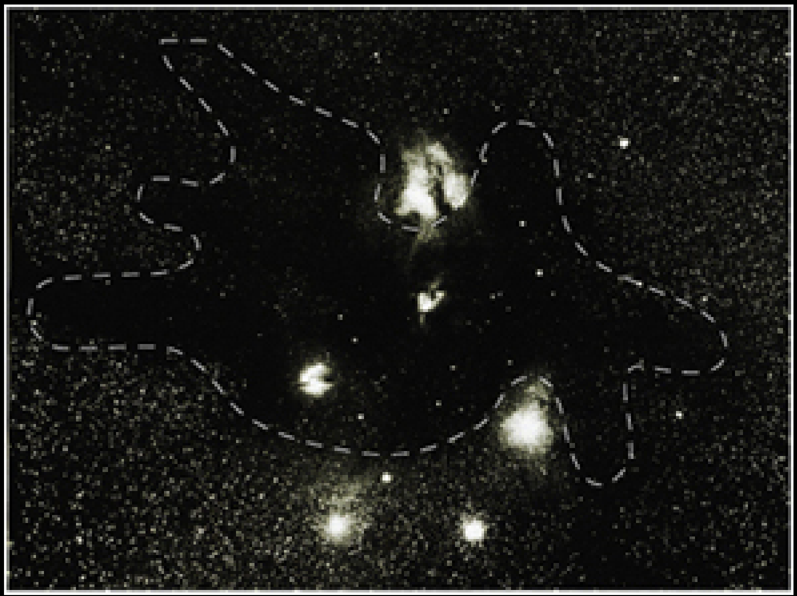
The regions can be extremely cold with temperatures of 10 K

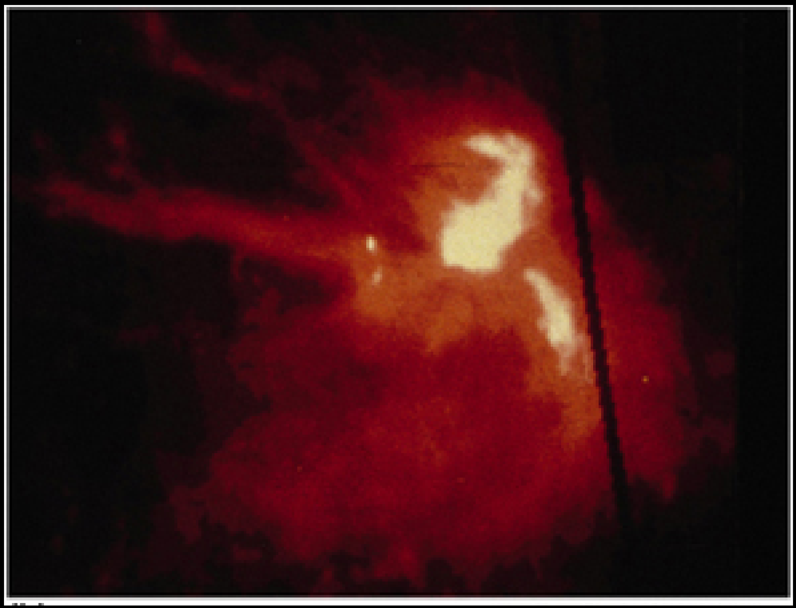
These nebulae are fertile regions of star formation

Molecular Clouds, Nebulae: Dark (Absorption) Nebula

Dark nebula contain enough dust to be opaque at visible (and higher) wavelengths but may allow radio waves to pass through.

The dust in a dark nebula can be heated by starlight and re-radiate at infrared wavelengths and thus be visible in the infrared.





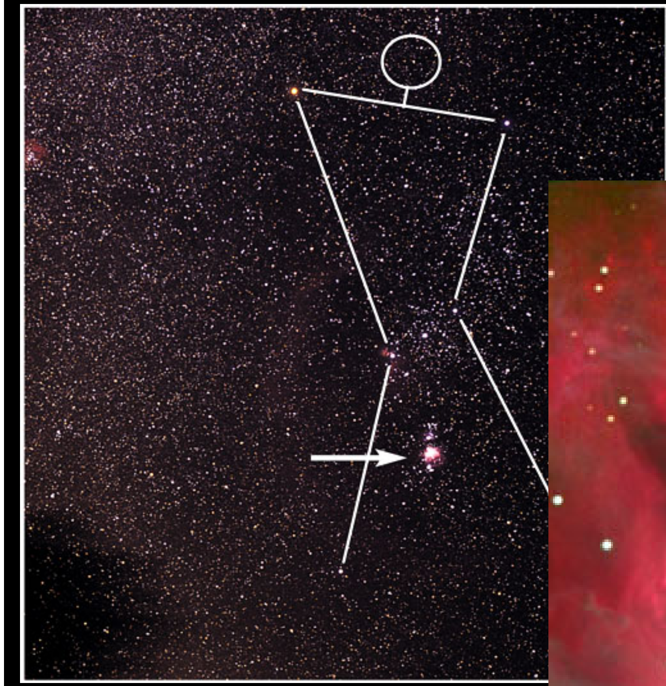
Molecular Clouds, Nebulae
Dark (Absorption) Nebula

Molecular Clouds, Nebulae
Emission Nebula

An emission Nebula is a hot ionized cloud surrounding a hot luminous star (O or B).

Gas of the cloud is excited by ultraviolet light from the star and thus emits light (red observed can be associated with hydrogen).

Molecular Clouds, Nebulae
Emission Nebula



Molecular Clouds, Nebulae
Reflection Nebula

Reflection Nebula dusty cloud surrounding a star. The dust reflects starlight. Dust grains are more effective at scattering blue light (like our atmosphere).

Thus surrounding gas (reflection nebula) appears blue.

Light coming directly from the star will appear red because the blue light has scattered away.

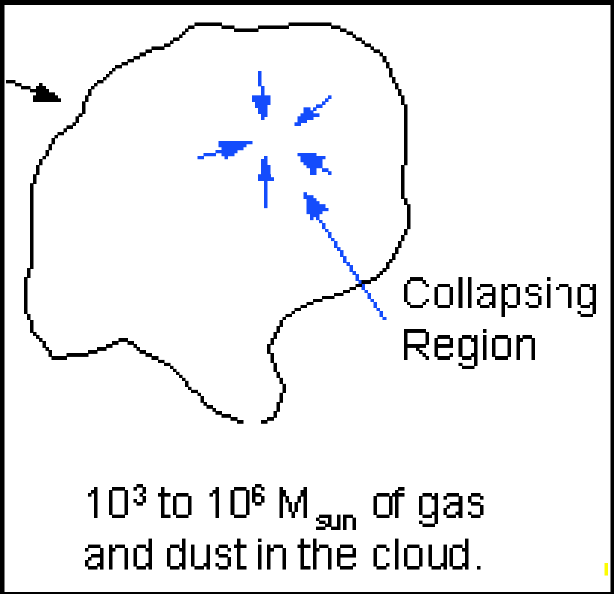
Molecular Clouds, Nebulae
Reflection Nebula

Fragmentation and Collapse of Molecular Clouds

Molecular Clouds do not generally collapse to form a single star.

The clouds fragment into many clumps which when they attain a critical mass collapse to form stars.

10-1000 stars may be formed from a cloud.



Fragmentation and Collapse of Molecular Clouds

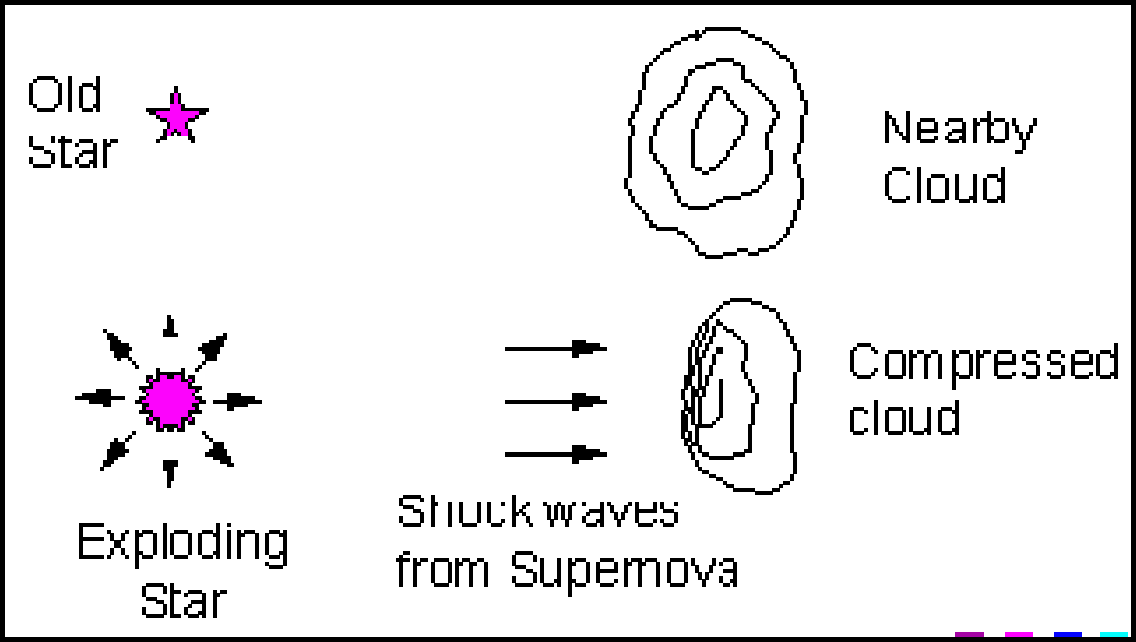
How does this cloud fragmentation and collapse start?

Accretion: build up of small clouds of gas and dust into larger ones with the necessary mass to focus the collapse. Random, Slow

Fragmentation and Collapse of Molecular Clouds

How does this cloud fragmentation and collapse start?

Compression: Supernova blast create pressure waves that propagate through the cloud.

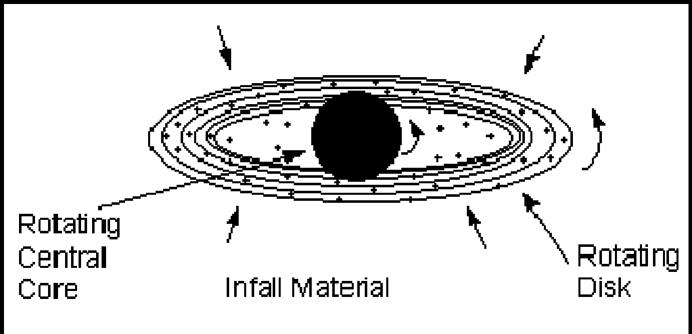


Fragmentation and Collapse of Molecular Clouds

As the cloud collapses gravitationally:

A dense central core forms

The rotational speed of the cloud and core increases



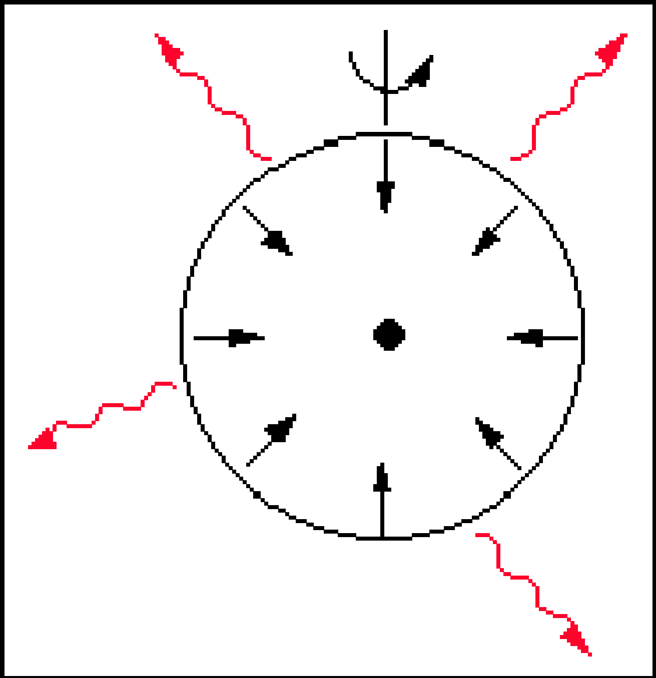
Fragmentation and Collapse of Molecular Clouds

As the cloud collapses gravitationally:

Gravitational potential energy is converted to heat and radiation.

The escaping radiation allows the collapsing cloud to remain relatively cool.

The collapsing cloud is very bright because of the escaping (infrared radiation)

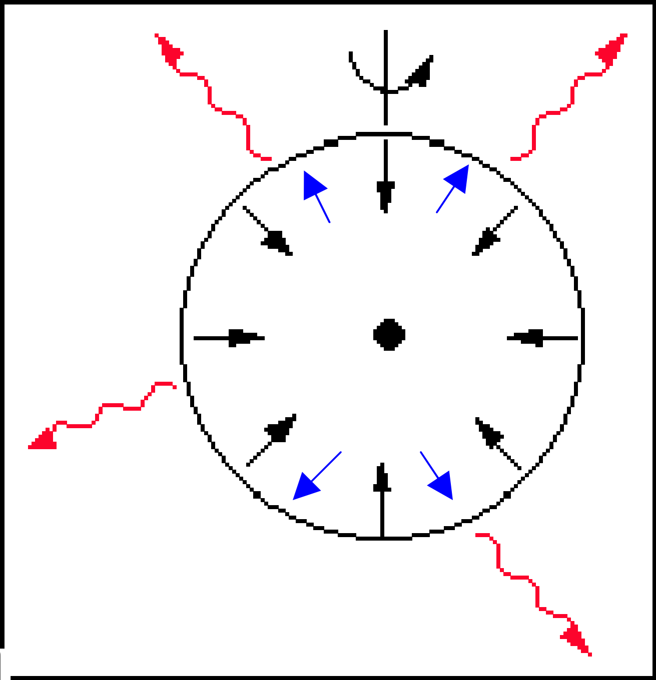


Formation of a Protostar

At this point the density of the core region is such that it becomes opaque (can not see into it, photosphere).

Energy less able to escape the core thus temperature and supporting pressure rise. Collapse may slow.

Protostar still very bright as radiation produced by gravitational collapse in the outer regions escapes



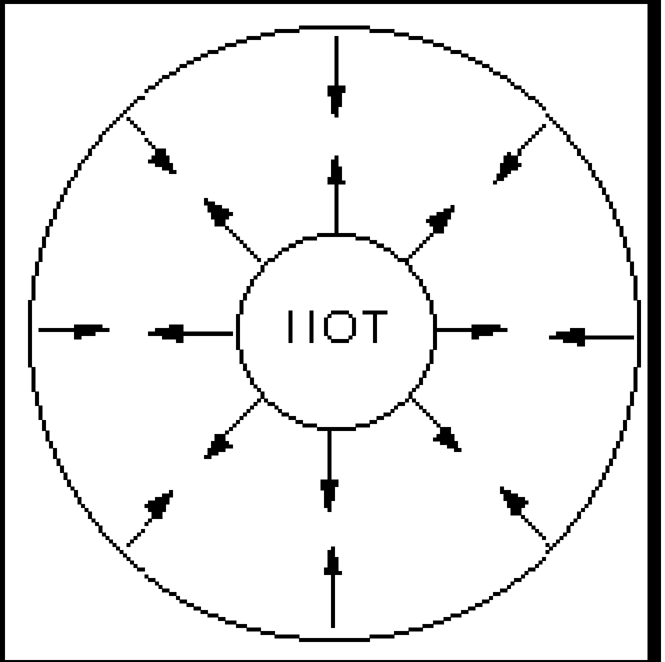
Birth of a Star

As cloud collapses the temperature of the core continues to increase.

The protostar continues to diminish in intensity as increasing density makes more of the star opaque.

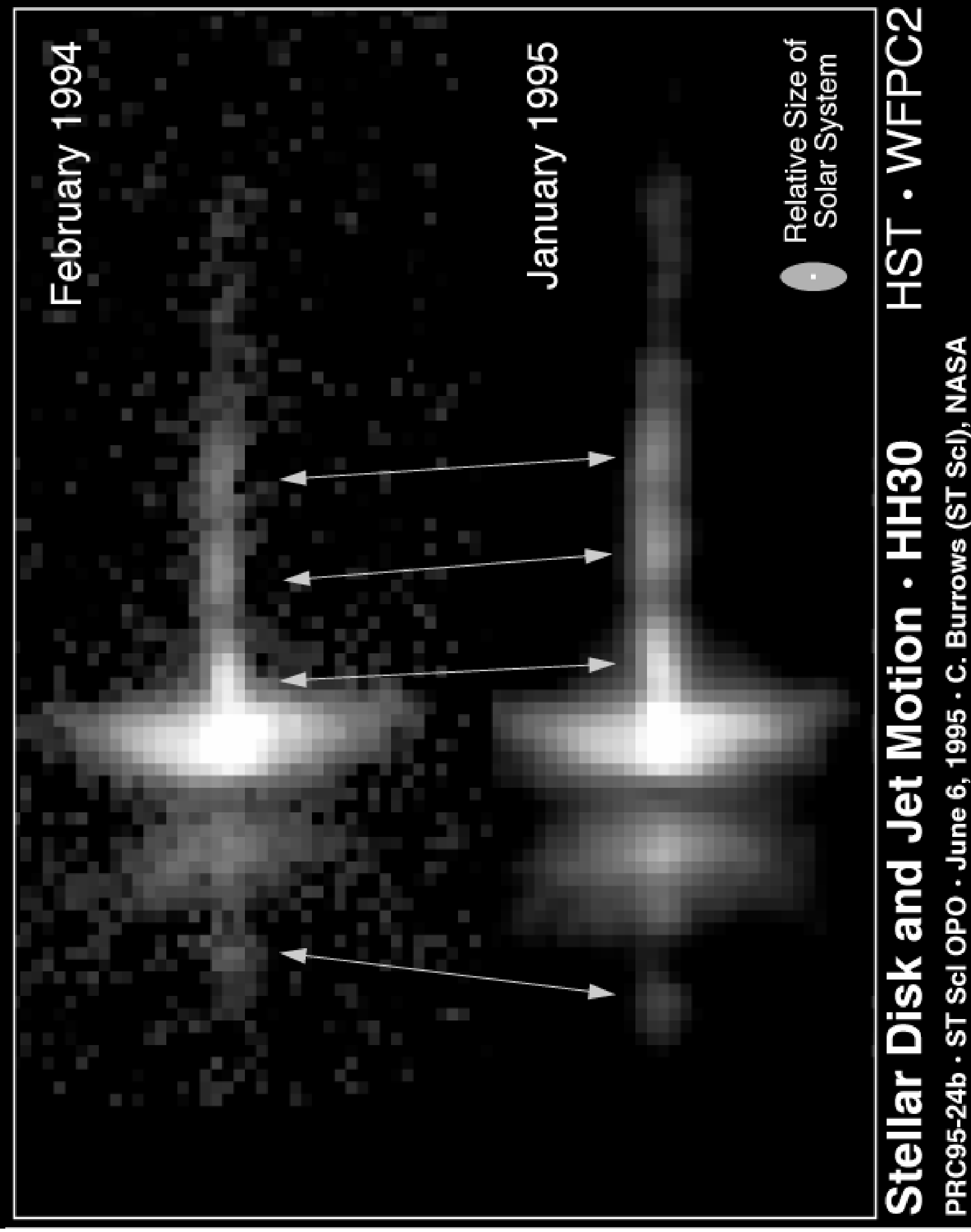
When the core reaches 10,000,000K, nuclear fusion is initiated. (Mass must exceed 8% M_s)

The outward pressure balances the gravitational collapse.

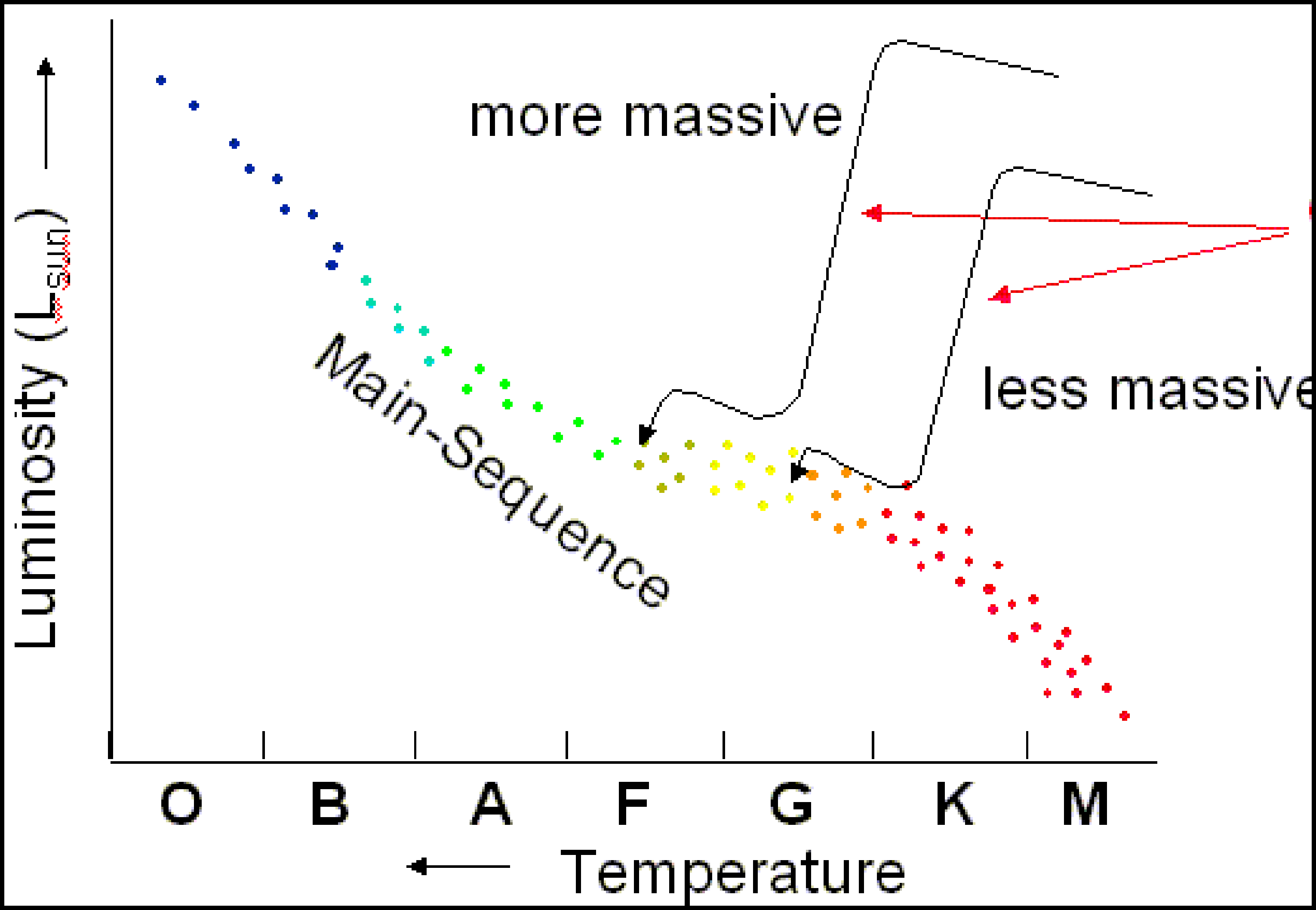


Birth of a Star

Strong winds may be initiated about this time which may clear out much of the external material.



Birth of a Star:
Entering Main Sequence



Formation of a Star

Mass(Msun)	Lifetime(years)
1	$\sim 10^{10}$
5	$\sim 10^{8}$
10	$\sim 10^{7}$

Formation of a Star:
Time to Main Sequence

Mass(Msun)	Time(106 years)
15	0.16
5	0.7
2	8
1	30
0.5	100

Evolution of Low Mass Star
($M < 8 M_s$)

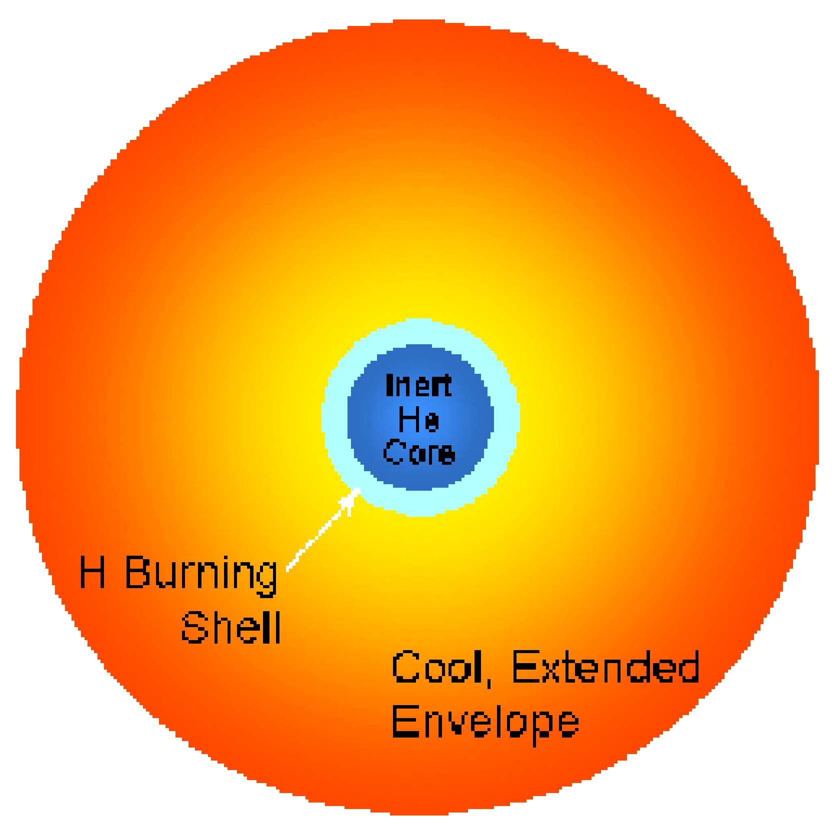
After about 10 billion years on the Main Sequence, the Hydrogen burning in the core is complete.

The core stops burning and thus begins to collapse under gravity.

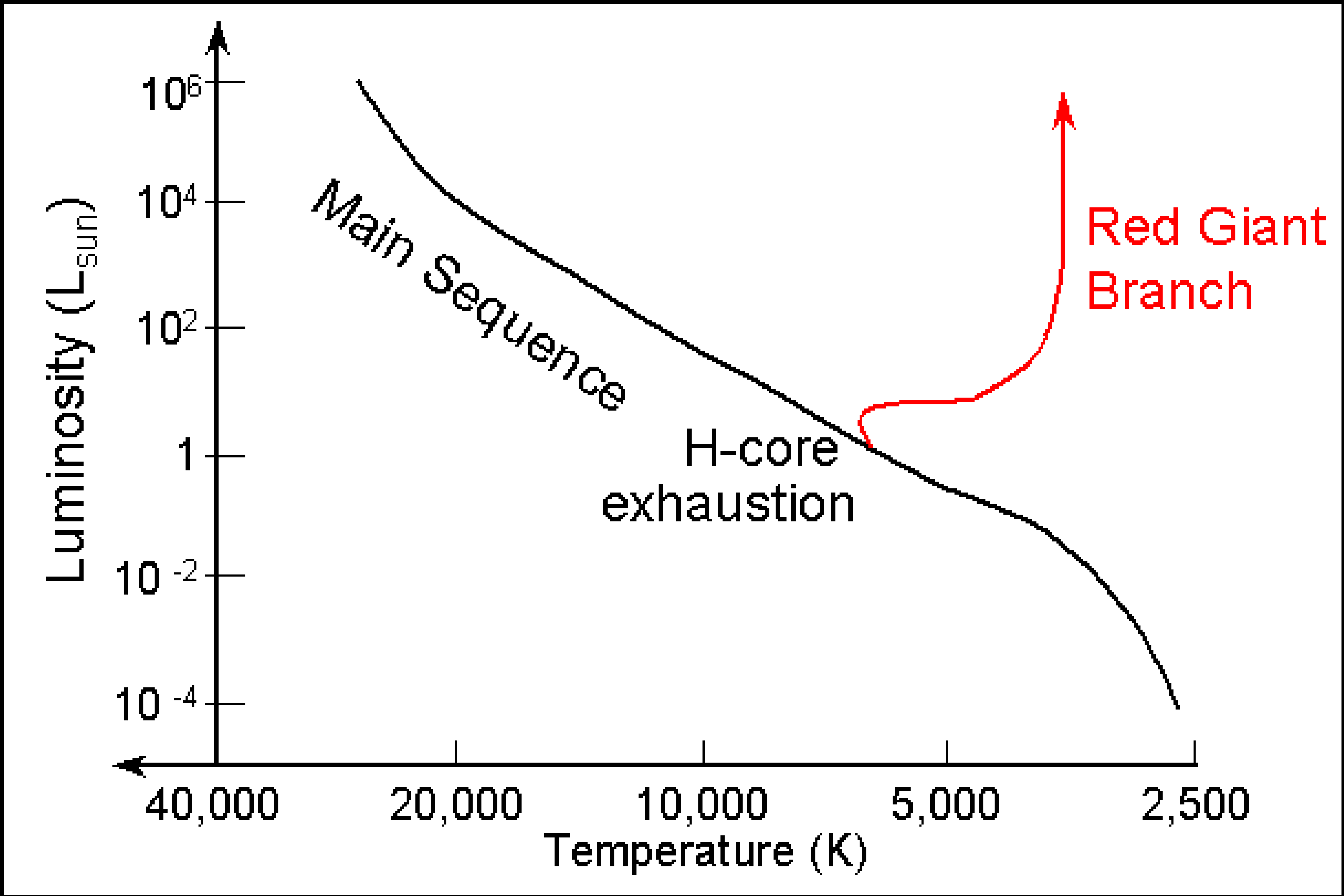
As the core collapses it heats up causing the hydrogen to burn aggressively in the surrounding shell.

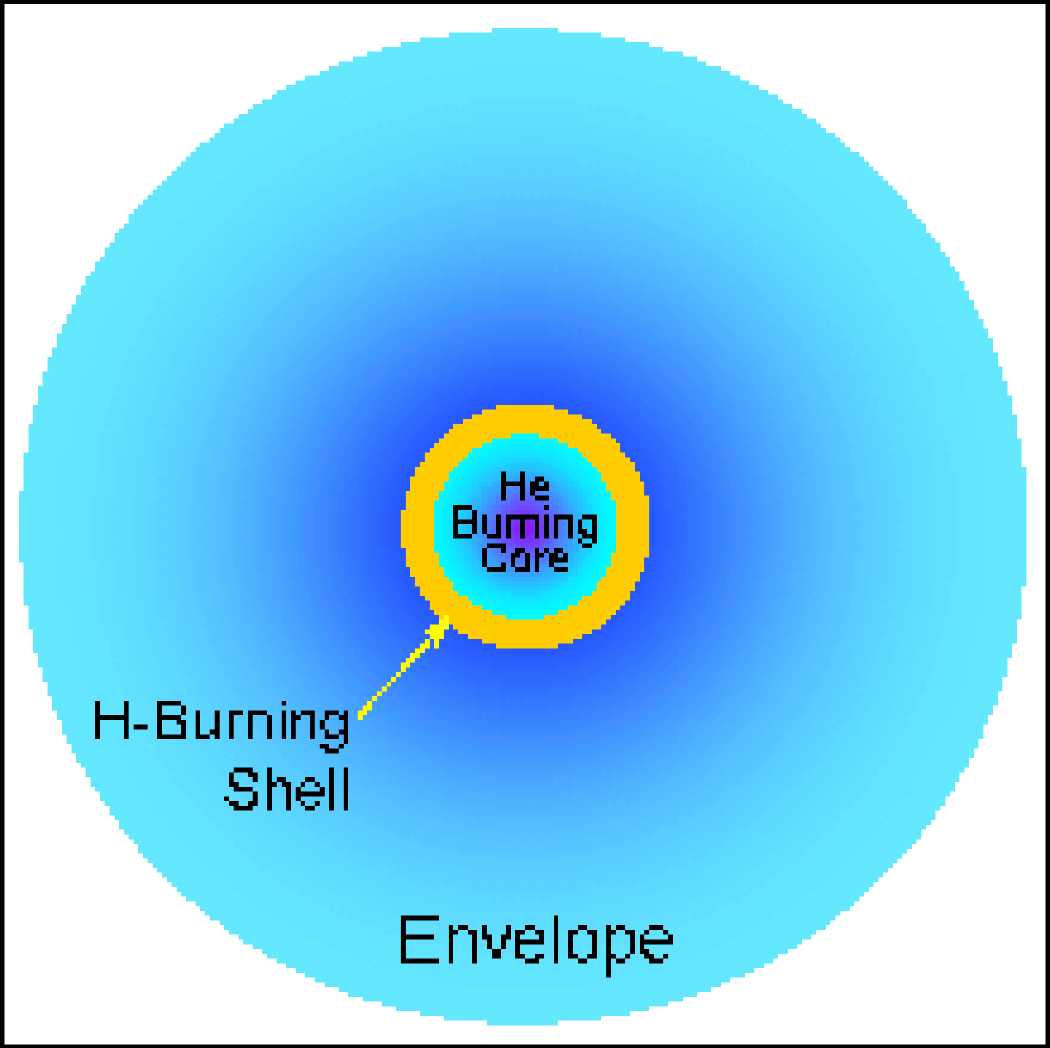
This burning causes the outer envelope to expand.

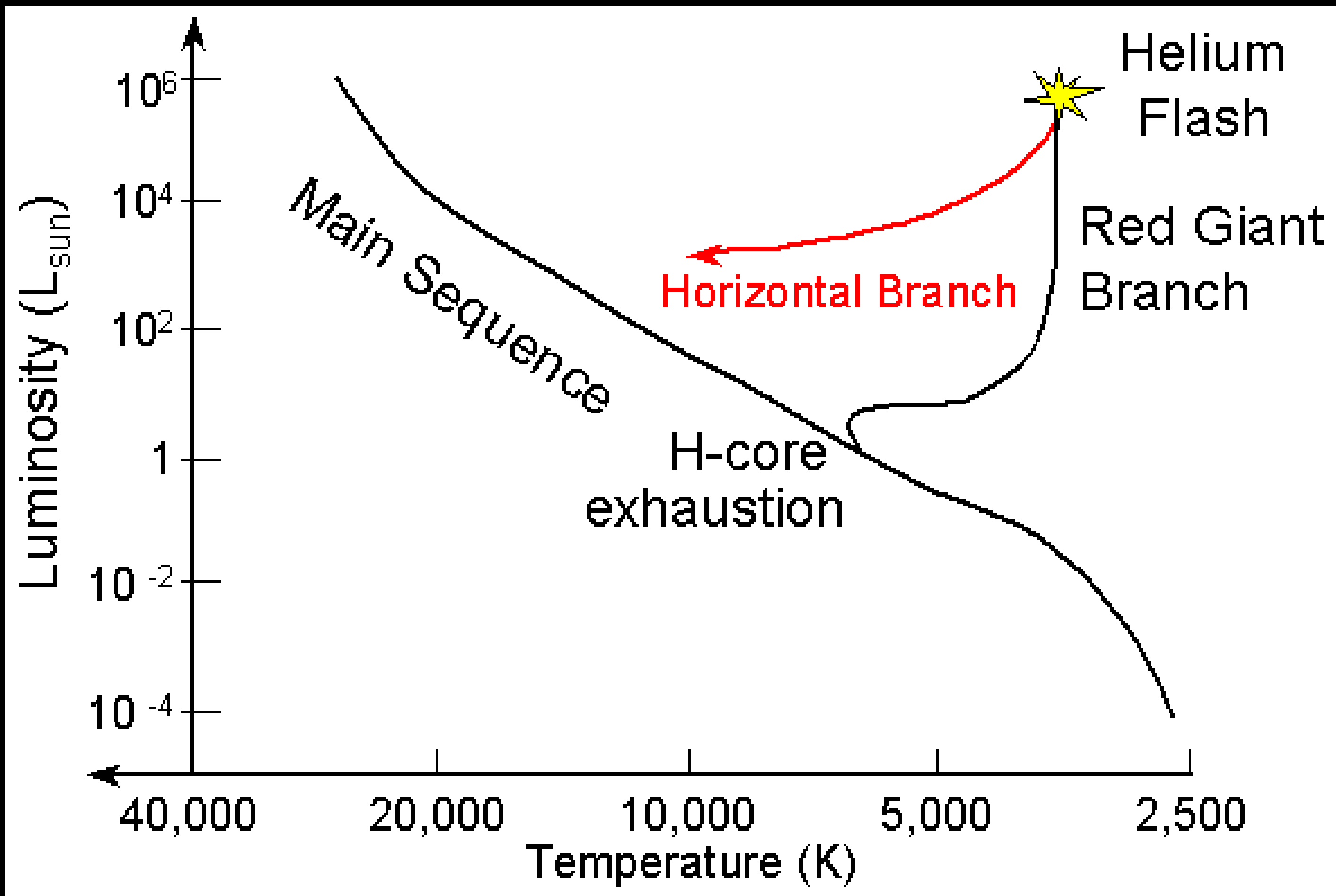
Red Giant forms brighter and larger.

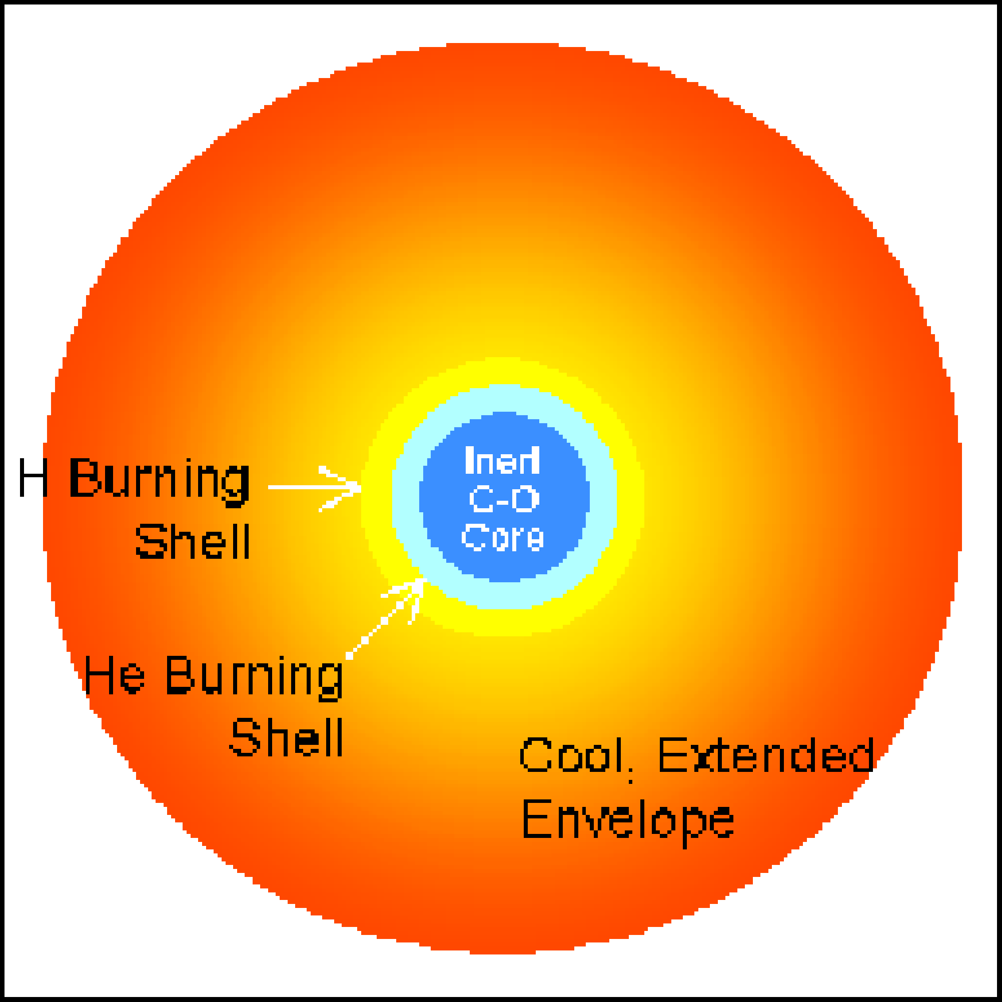


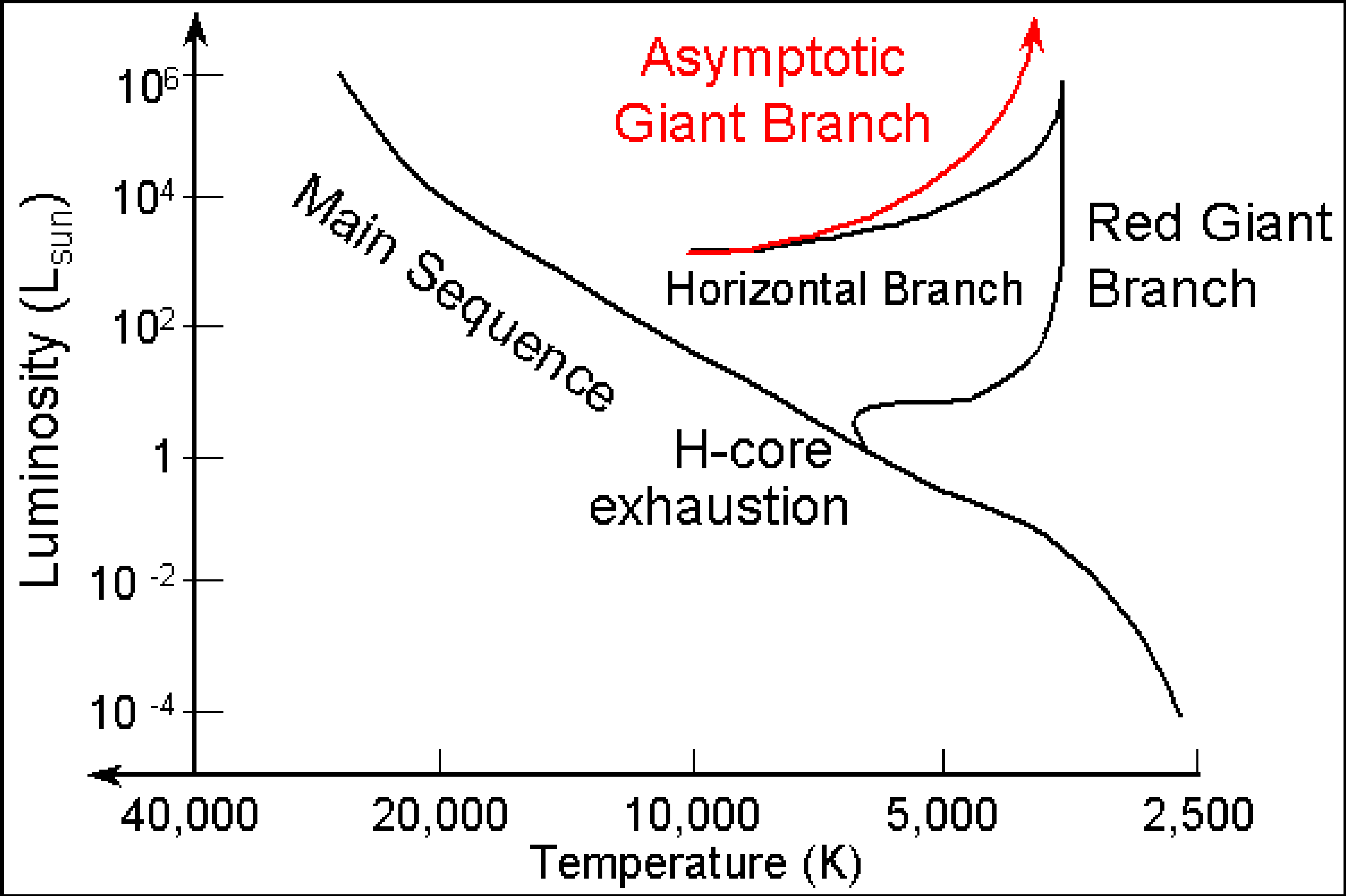
Evolution of Low Mass Star




He
Burning
Core
H-Burning
Shell
Envelope

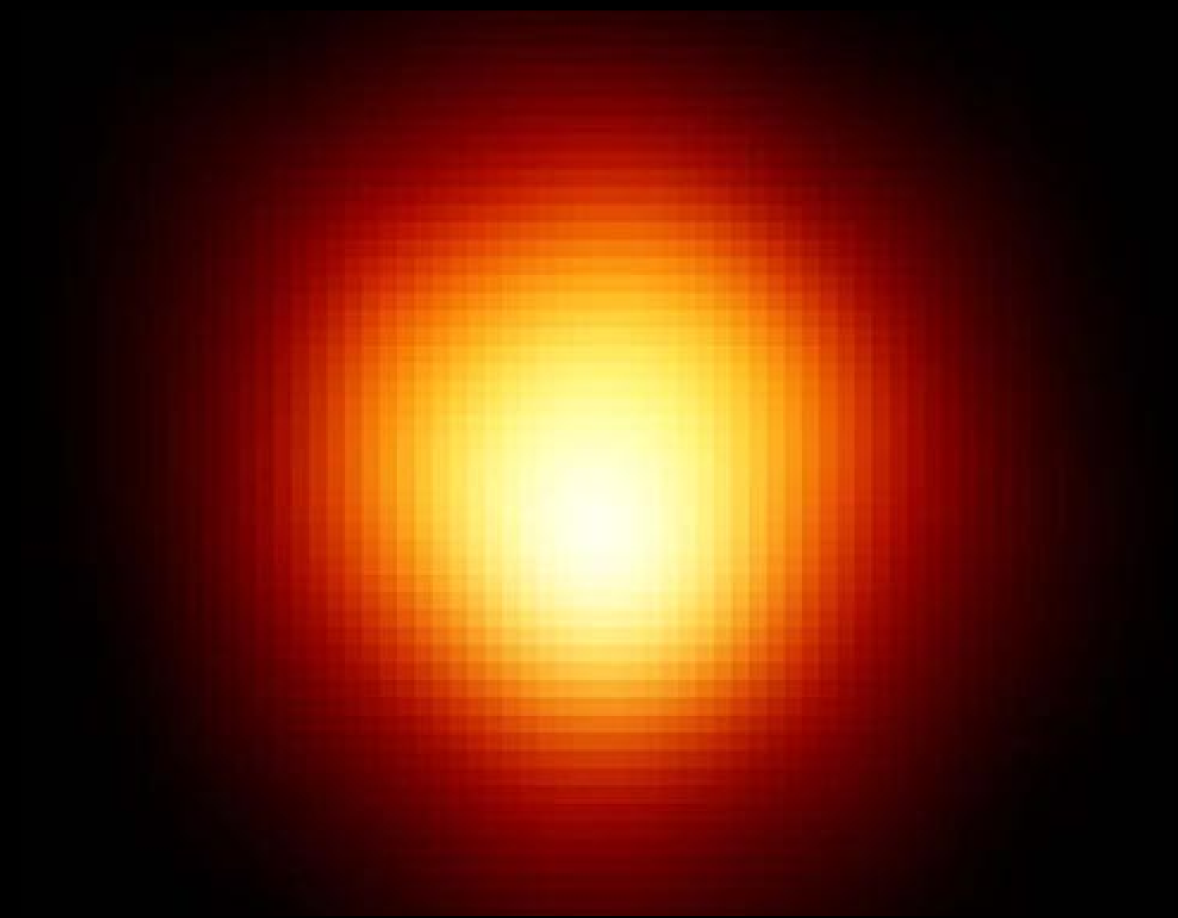

Helium
Flash
Red Giant
Branch
Horizontal Branch
Main Sequence
H-core
exhaustion
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

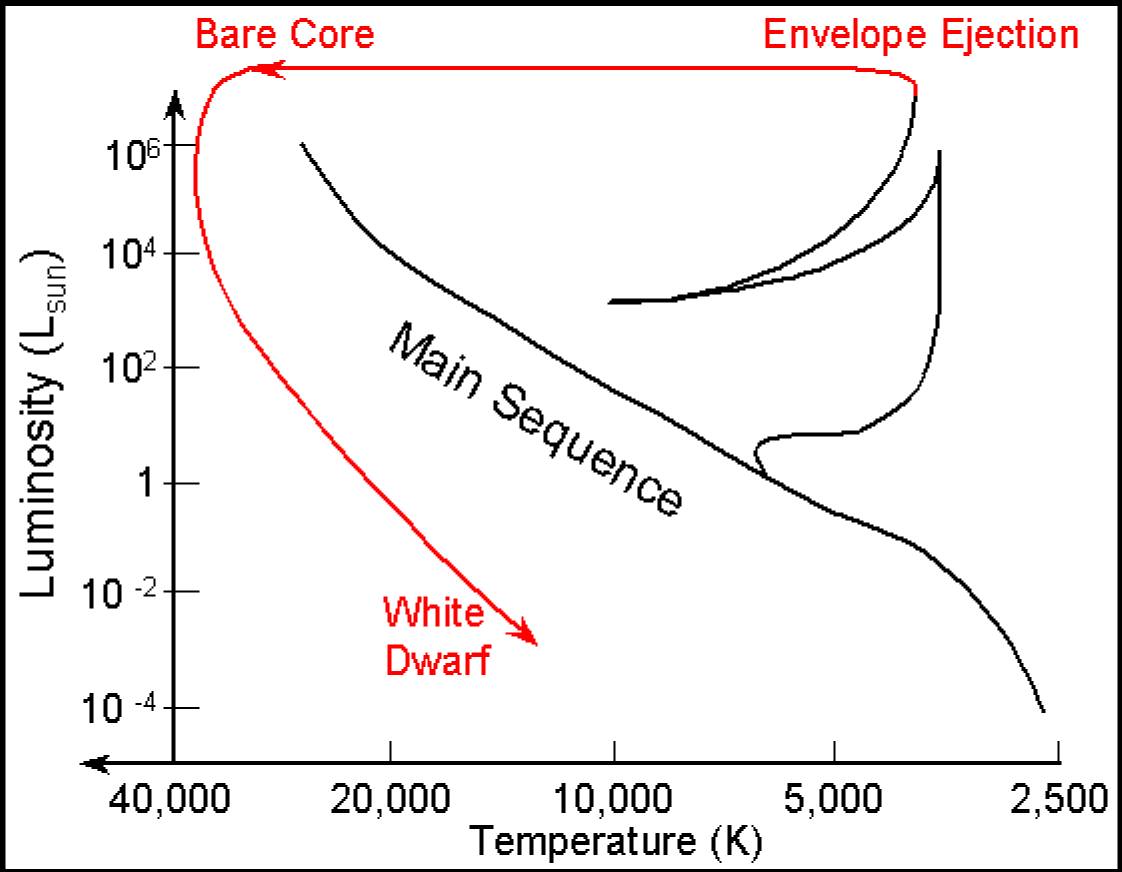

H Burning
Shell
Inert
C-O
Core
He Burning
Shell
Cool, Extended
Envelope



Asymptotic
Giant Branch
Red Giant
Branch
Horizontal Branch
Main Sequence
H-core
exhaustion
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

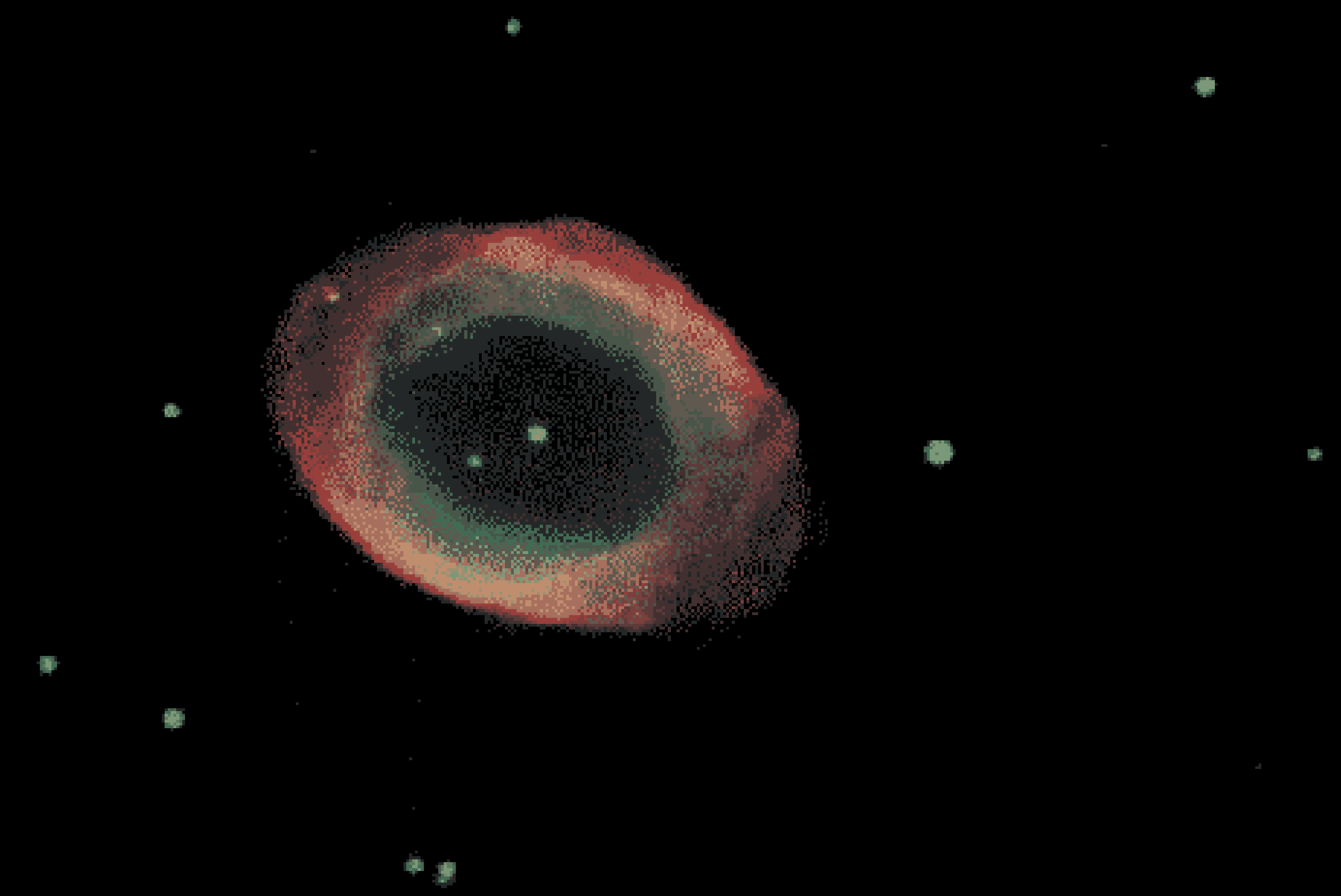
Betelgeuse: Super Red Giant





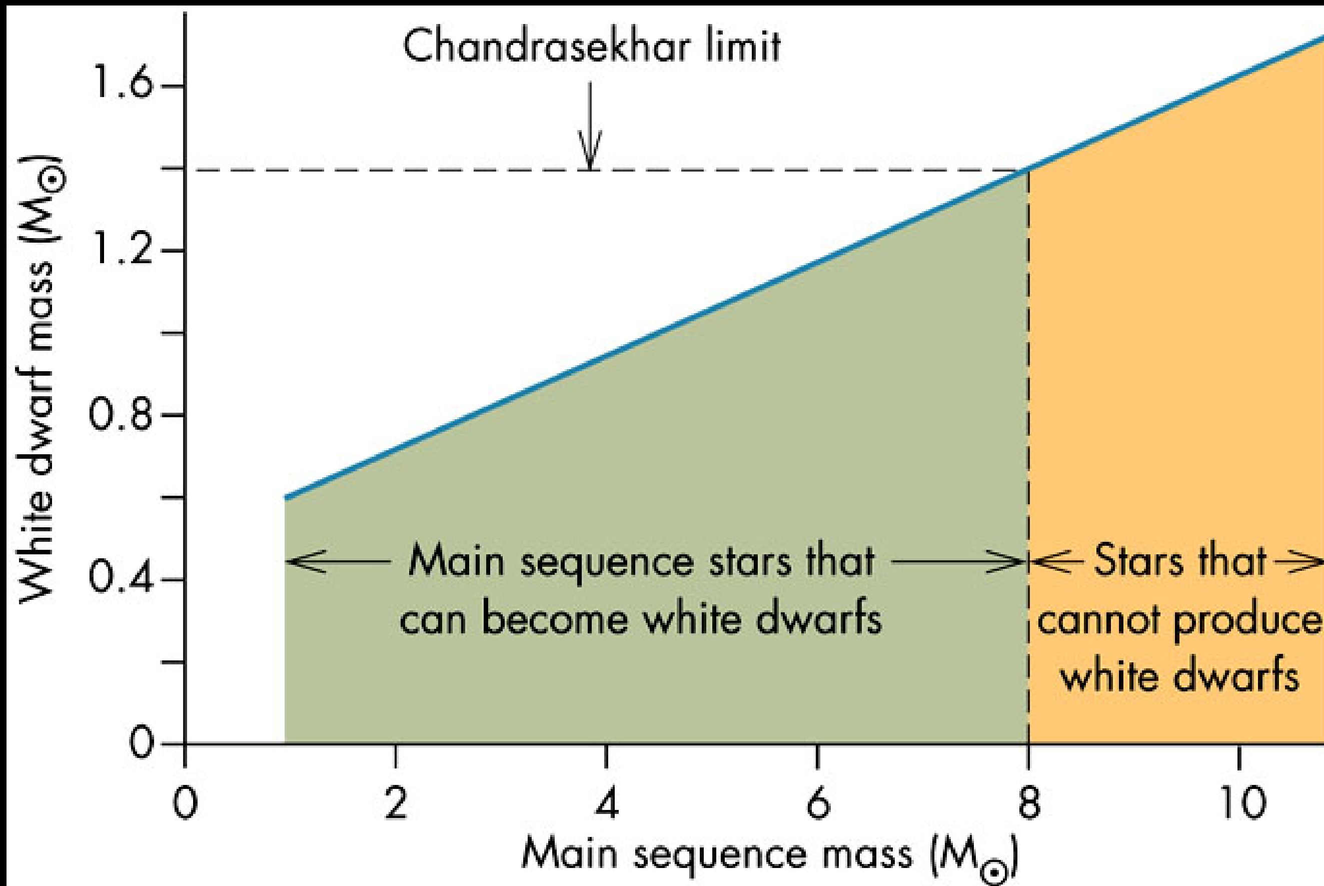
Bare Core
Envelope Ejection
Main Sequence
White
Dwarf
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

Planetary Nebula



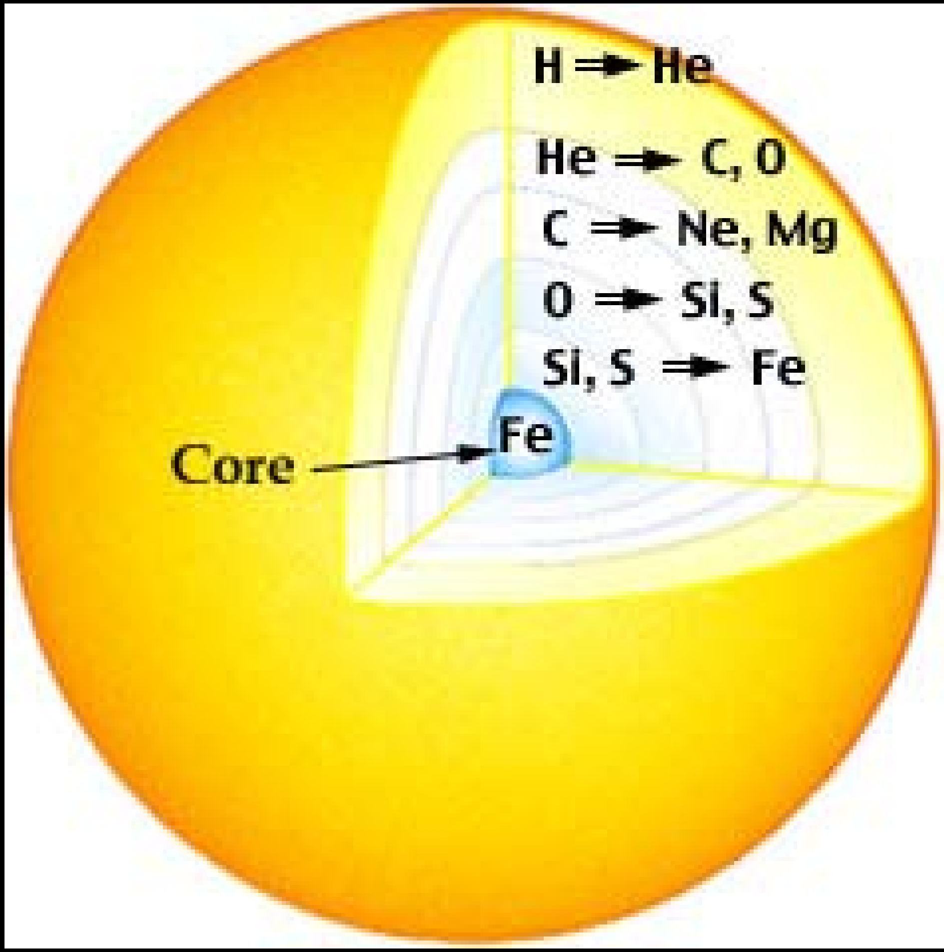
White Dwarf: Planetary Nebula

Evolution of High Mass Star ($M < 8\ M_s$)



Stars that have a main sequence mass of greater than 8 times M_s will not form white dwarfs (white dwarfs that add mass to exceed 1.4 times M_s will start to collapse again).

Evolution of High Mass Star (M < 8 M_s)



In these stars, there is enough mass to compress and raise the temperature of the core high enough to start the fusion of Oxygen and beyond. With such a high mass each element burns quickly.

Evolution of High Mass Star (M < 8 M_s)

The burning of the high mass star is quick. A star with a mass 20 Ms will burn:

Hydrogen in 10 million years

Helium for 1 million years

Carbon for 1000 years

Oxygen for 1 year

Silicon for 1 week

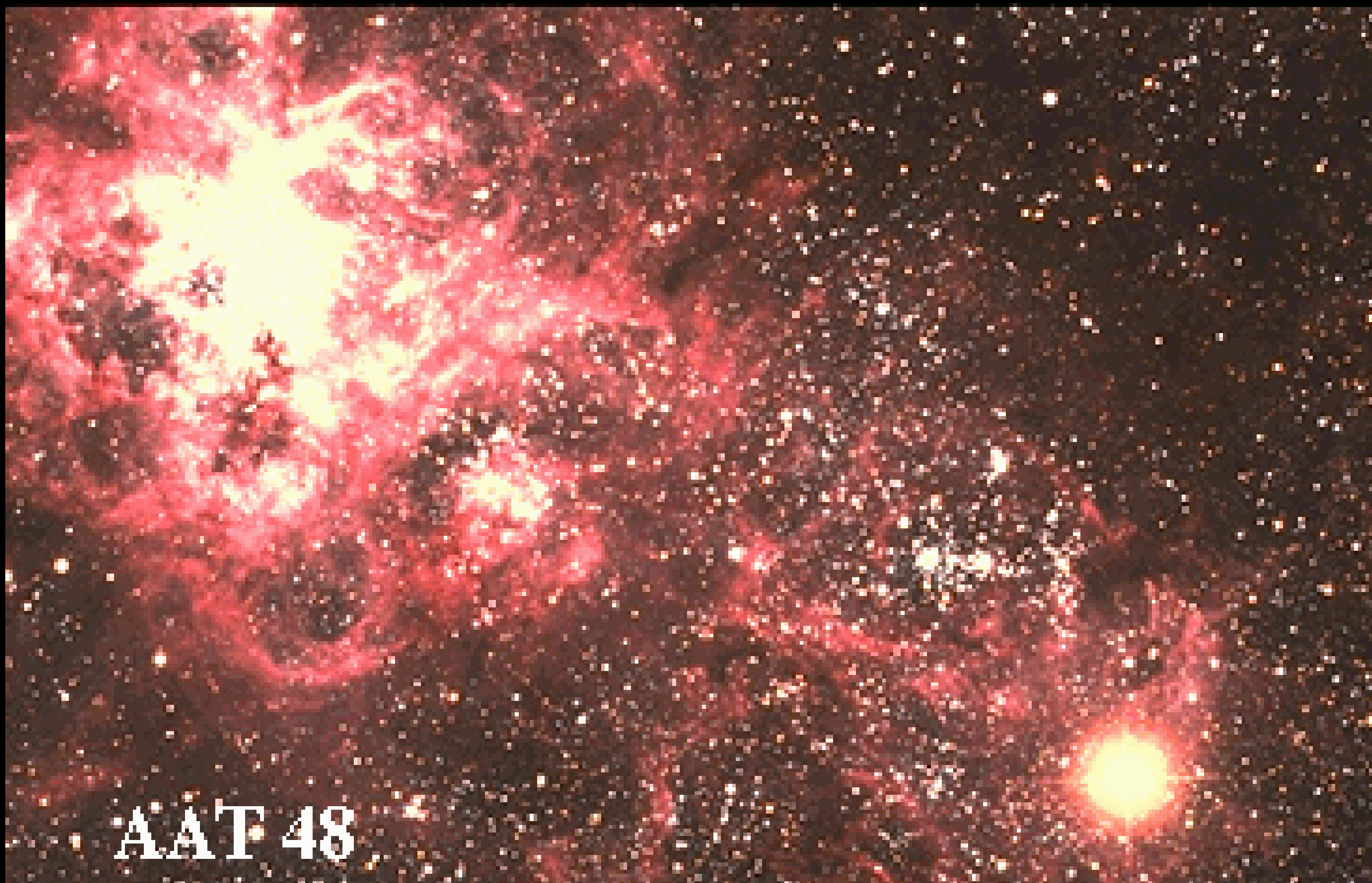
Evolution of High Mass Star ($M < 8\ M_s$)

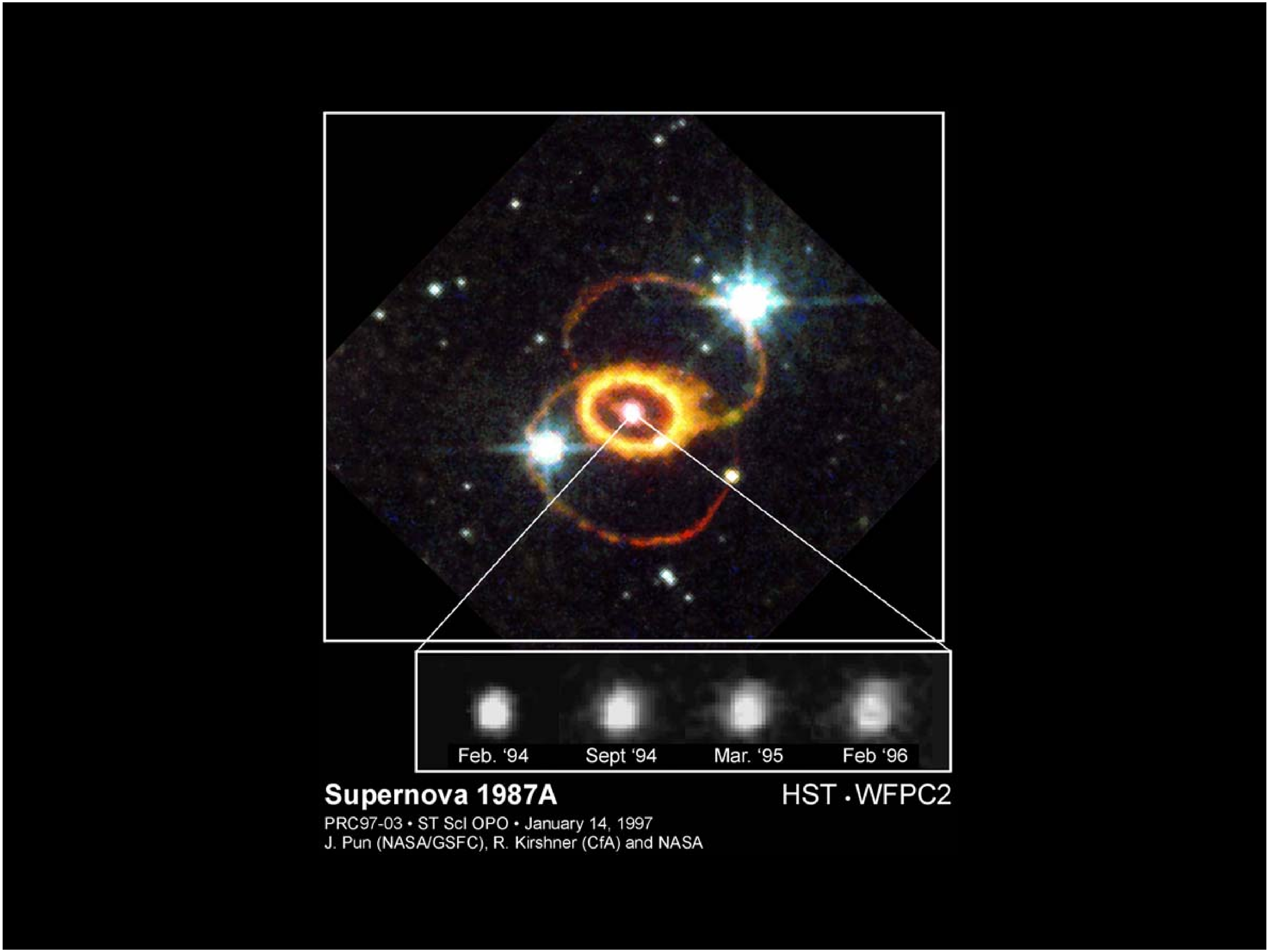
The Silicon Fuses to Iron and the star is doomed. Iron needs energy to be fused, it does not produce energy from fusion so the star looses its source of energy.

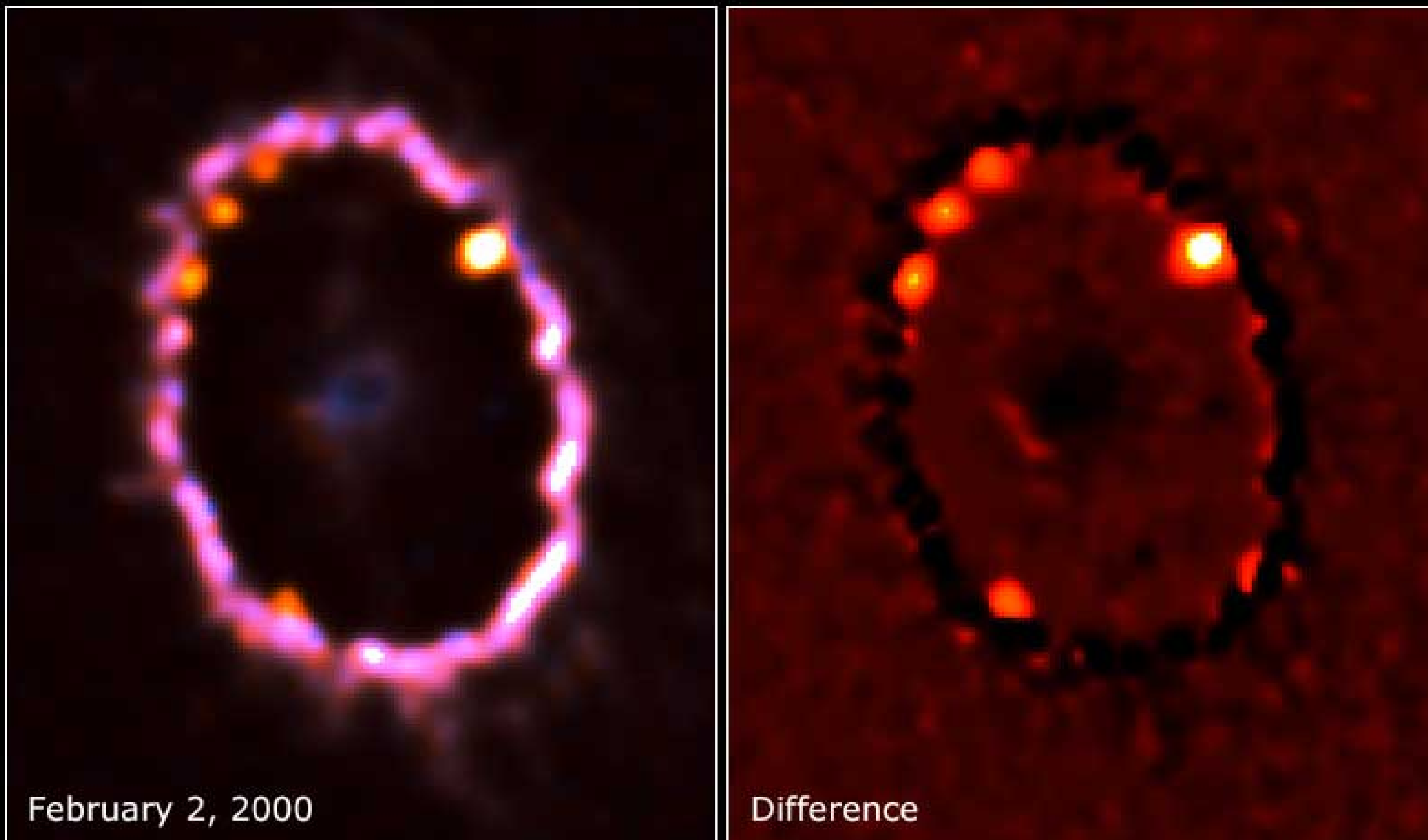
The star collapses below the size expected if all of the neutrons are forced together as tightly as possible. It has gone too far and bounces back with a vengeance: Super Nova explosion. This collapse to explosion takes about 1 second.

Super Nova 1987A

Super Nova 1987A


AAT 48


Feb. '94
Sept '94
Mar. '95
Feb '96
Supernova 1987A
HST • WFPC2
PRC97-03 • ST ScI OPO • January 14, 1997
J. Pun (NASA/GSFC), R. Kirshner (CfA) and NASA



Supernova 1987A in the Large Magellanic Cloud **HST** • WFPC2

NASA, P. Challis and R. Kirshner (CfA), P. Garnavich (University of Notre Dame) and The SINS Collaboration • STScI-PRC00-11

Hubble Ultra Deep Field

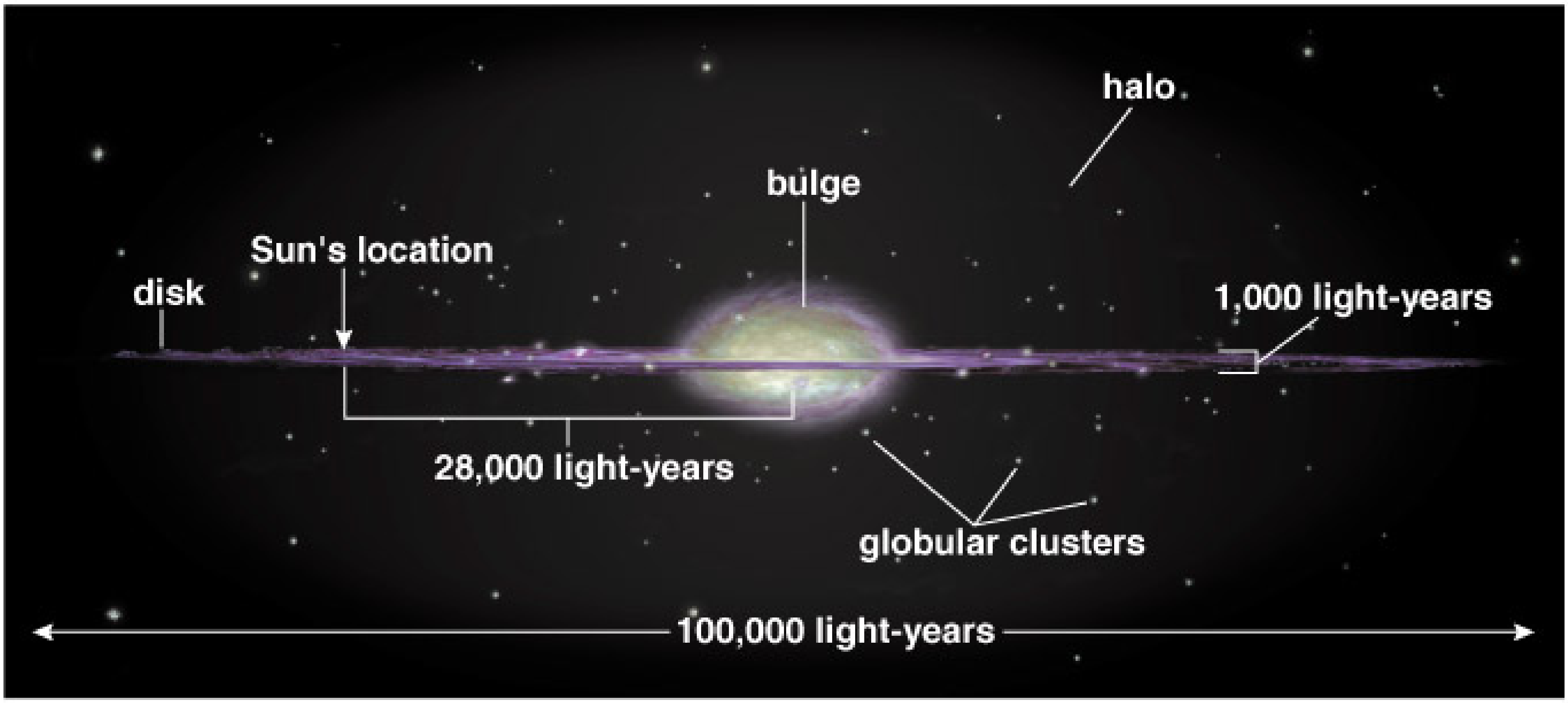
- Deepest visible light picture of the universe
- Objects as old as 13 Billion years
- Magnitude 30 objects may be detected
- 800 total exposures totaling over 10^6 s compiled over 400 orbits
- It would take 12.7 million pictures of this size to cover the sky

Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a

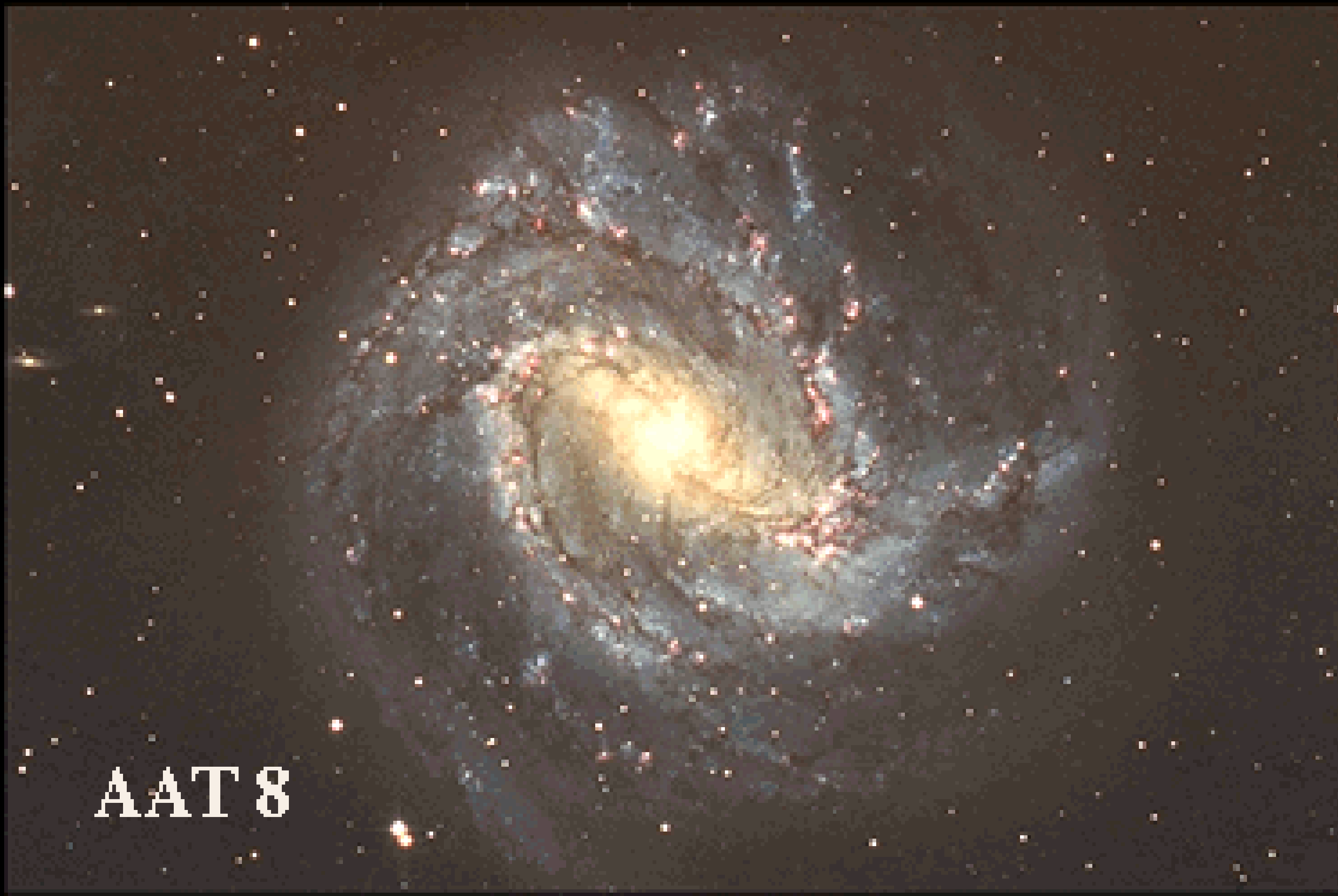
Milky Way External View



(b)

Spiral Galaxies: Properties

- Disk component. White disks with stars forming circular orbits about the galactic center. Contains cool gas and dust with some hot ionized gas. Active star formation.
- Yellowish spheroidal component comprised of bulge and halo containing little cool gas or dust. Older stars and lower mass.
- Spiral Arms (sometimes eminating from radial bar)
- Generally larger in size


AAT 8


M100 ©Anglo-Australian Observatory
Photo by David Malin

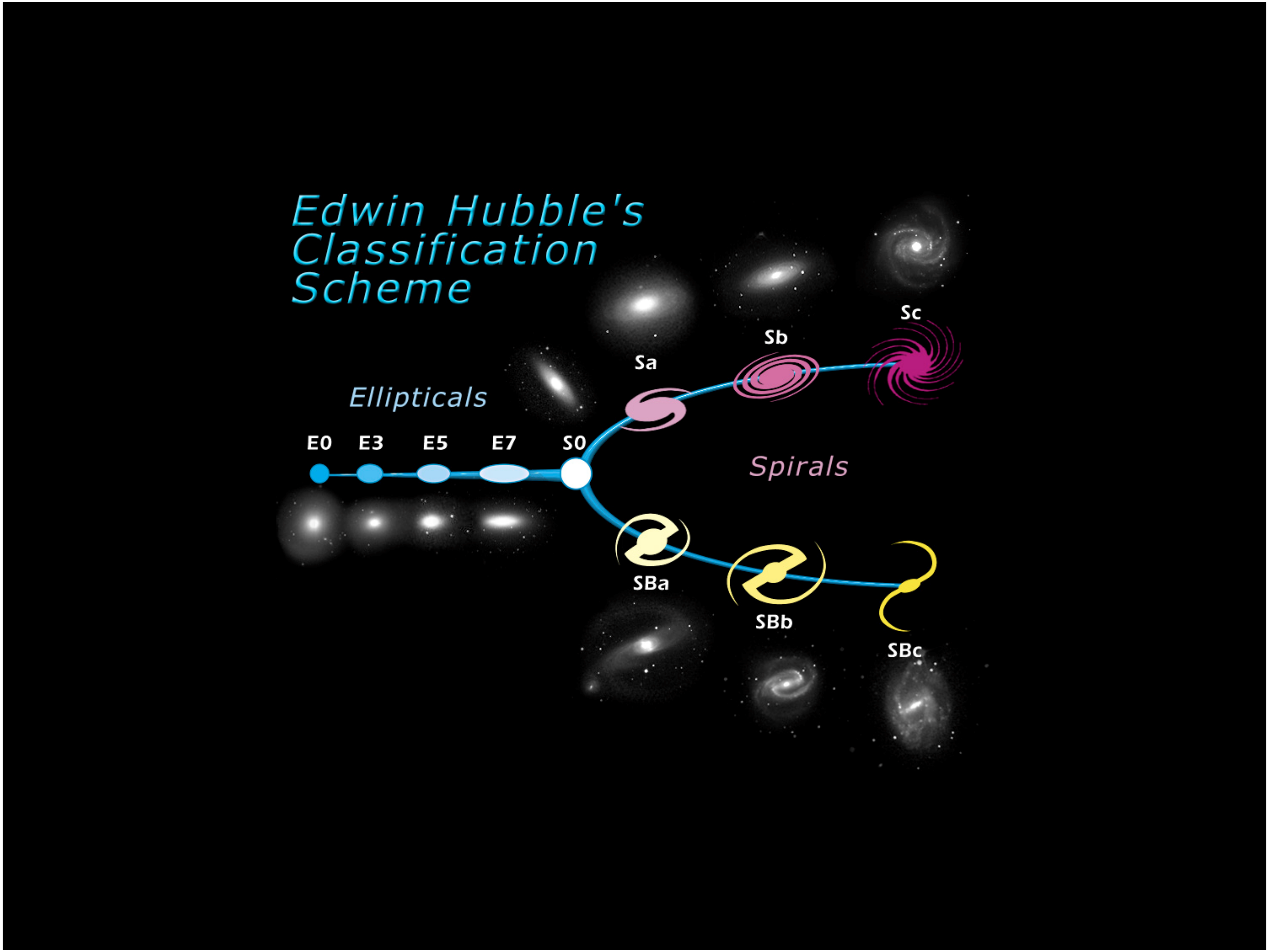
Elliptical Galaxies: Properties

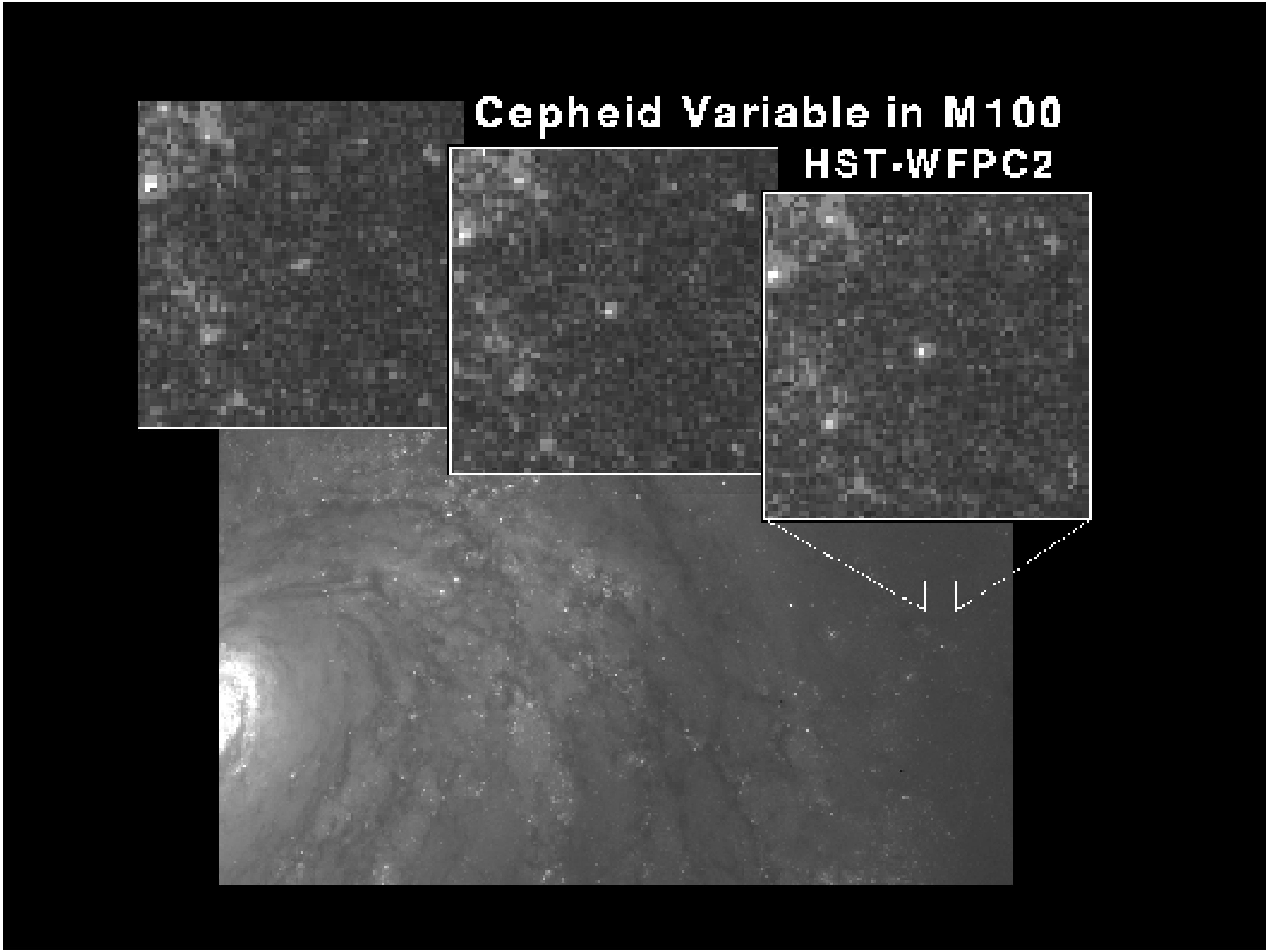
- More rounded football shaped. No disk
- Redder
- Little cool gas or dust
- Generally smaller though there are large ellipticals
- Contain mainly older stars

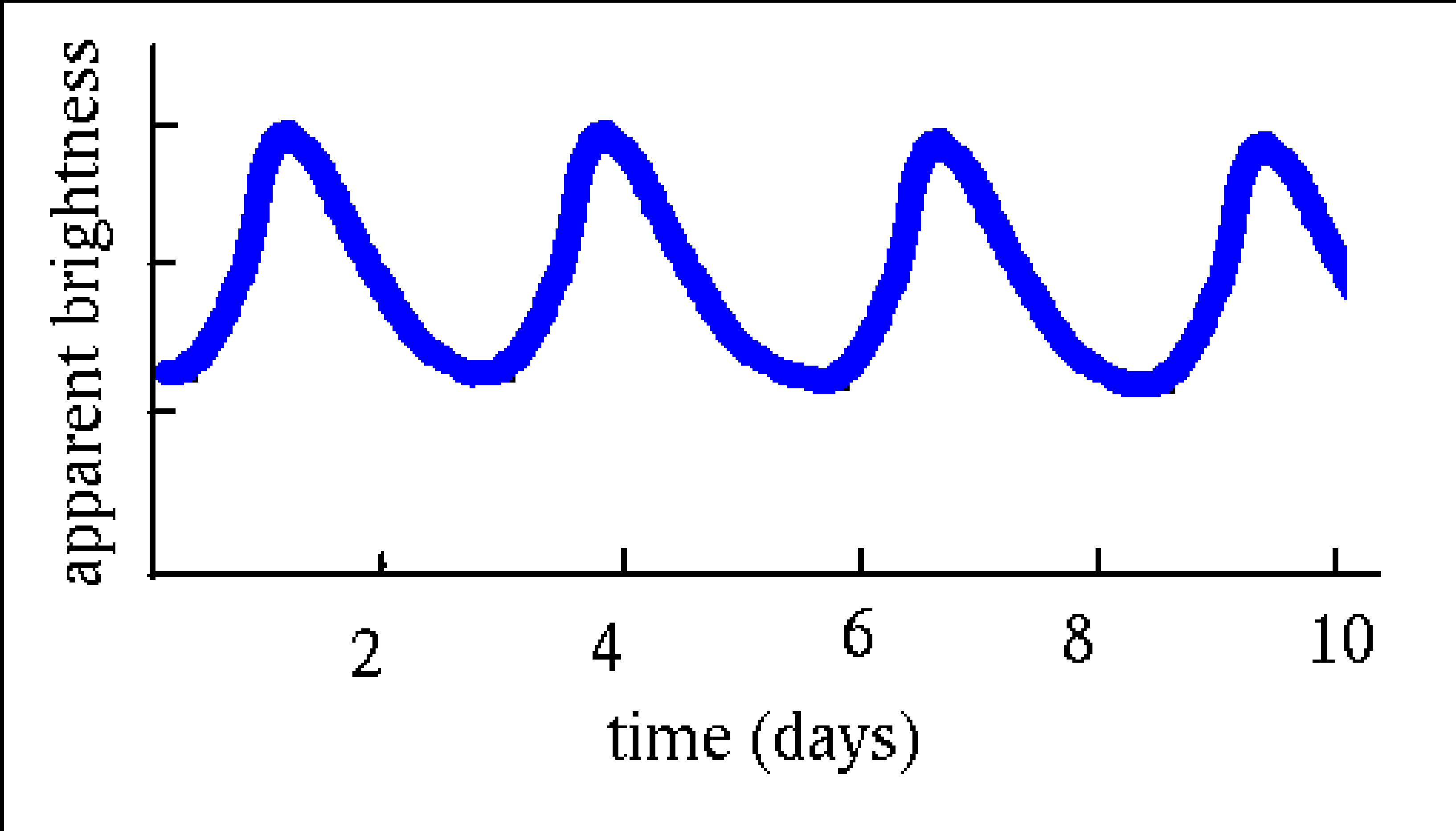
Elliptical Galaxy

M87 © Anglo-Australian Observatory
Photo by David Malin

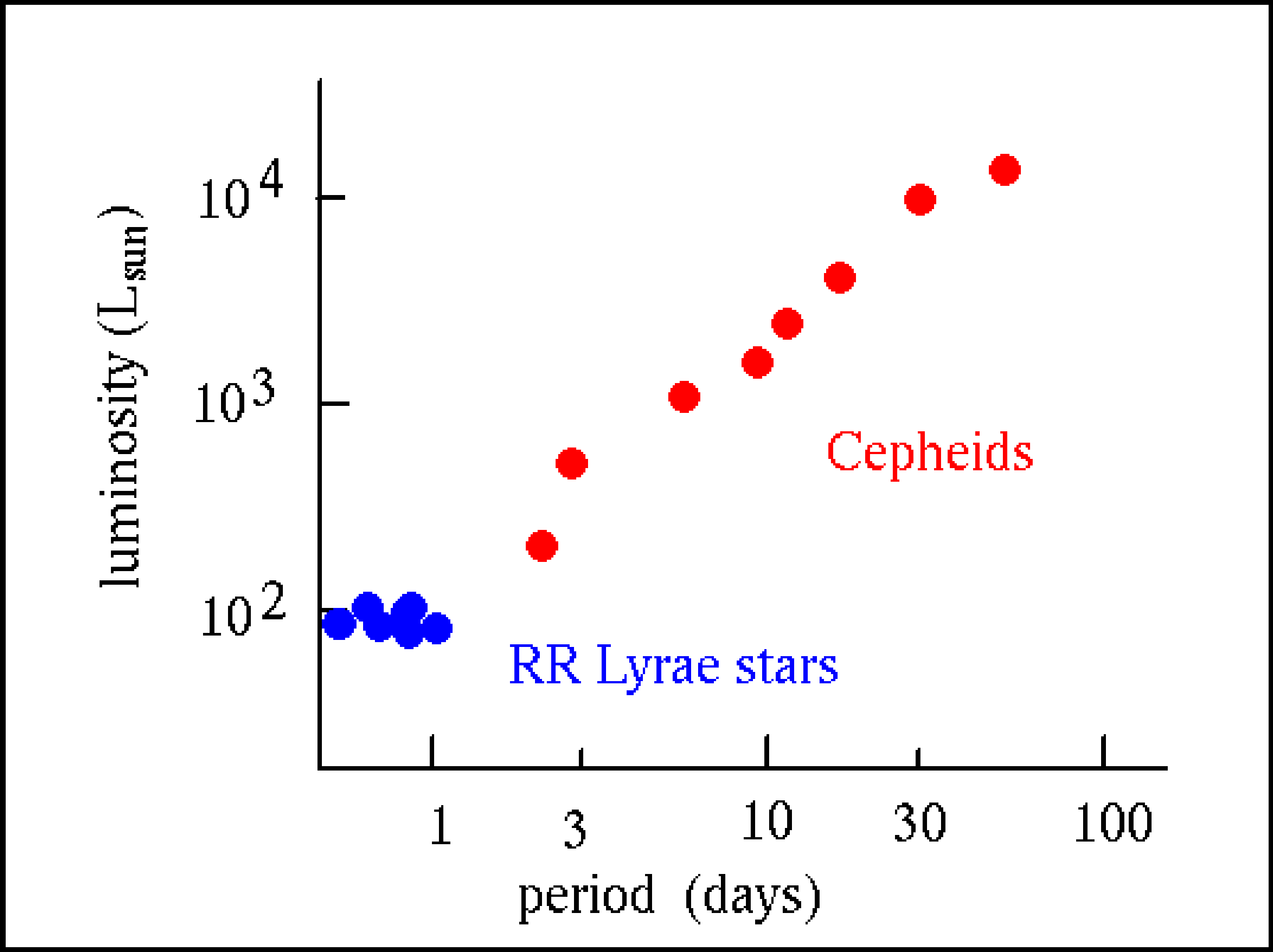
Irregular Galaxies: Examples


Edwin Hubble's
Classification
Scheme
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
SBa
SBb
SBc


Cepheid Variable in M100
HST-WFPC2



apparent brightness
2
4
6
8
10
time (days)



luminosity (L_{sun})
10^4
10^3
10^2
Cepheids
RR Lyrae stars
1
3
10
30
100
period (days)

Hubble's Law: $v = H_0 d$

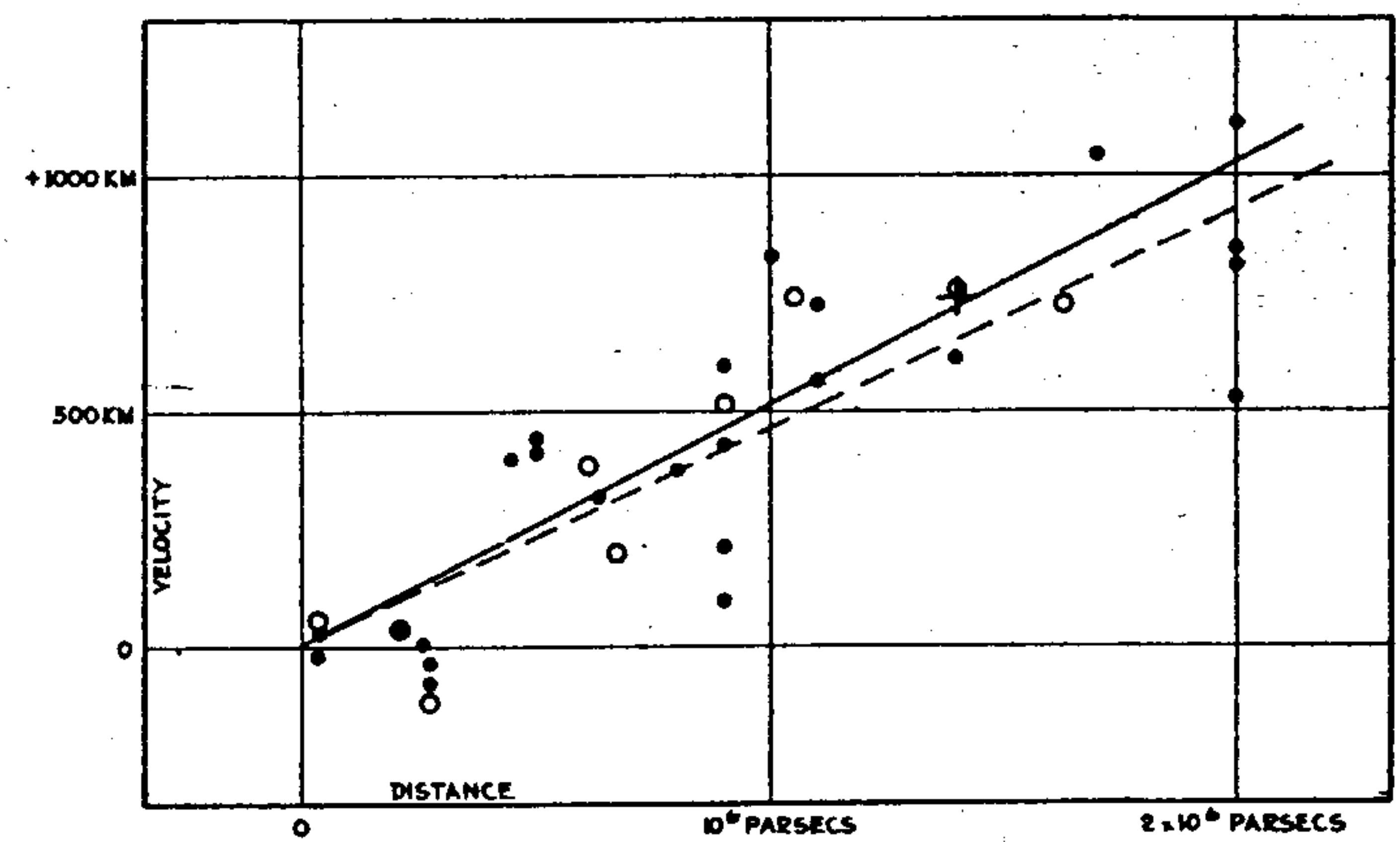


FIGURE 1

Distance to Galaxies

- Ranging
- Parallax
- Main Sequence Fitting
- Cepheid Variable Stars (Henrietta Leavitt 1912)
- White Dwarf Supernovae
- Tully-Fisher Relation