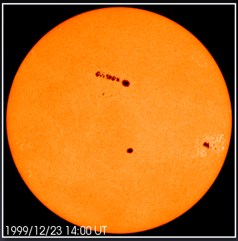
1

The Sun



Koupelis : chapter 11
OpenStax : chapters 15 & 16

Meet the stars

Koupelis : chapter 12
OpenStax : chapters 17 & 18

2

Our Sun is an ordinary yellow star.

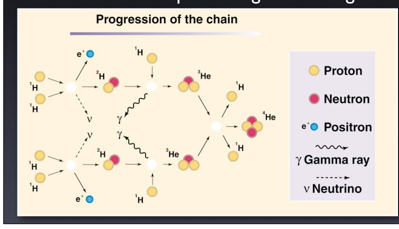
- 109 x diameter of Earth (orbit of Moon fits inside Sun!)
- 333.000 x heavier than Earth
- Density 1.4 gr/cm^3 (comparable to Jupiter)
- Rotation period 24.5 days (more slowly near the poles)
- Surface temp. is T = 5800 K
- Power 3.9 x 10^{26} Watt (at Earth: 1370 W/m^2)

Note: 1 second supplies 500.000 years of energy consumption on Earth…
Note: ‘limb darkening’ of the solar disk.

3

Source of energy:

- Contraction : no - only good for 100 million years
- Nuclear fusion : yes, through the ‘proton-proton’ cycle (via Deuterium and ^{3}Helium to ^{4}Helium) processing: 4 billion kg/sec!



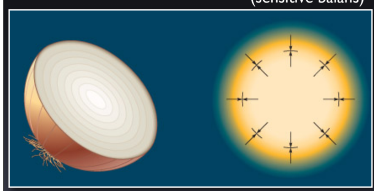
Note: the Sun introduced the neutrino problem…

4

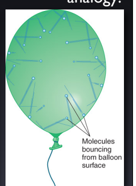
hydrostatic equilibrium

inward gravitational force = outward gas pressure

(sensitive balans)



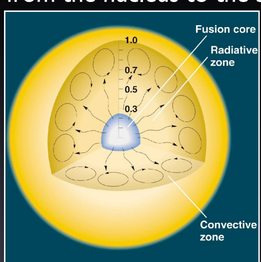
analogy:

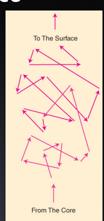


The gas pressure produces a temperature (16 million Kelvin) in the nucleus that is high enough for nuclear fusion (central 25%).

5

Energy transfer from the nucleus to the surface





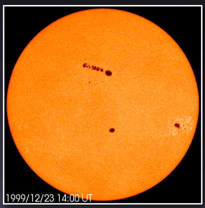
radiation transfer takes ~10^5 years

distinguish: Conduction vs Convection vs Radiation

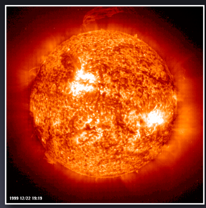
6

The atmosphere of the Sun

- Photosphere (H, He^{+}), with sunspots and granulation
- Chromosphere, with prominences and spicules
- Corona
- Solar wind (and Coronal Mass Ejections)



visible light



Helium emission line

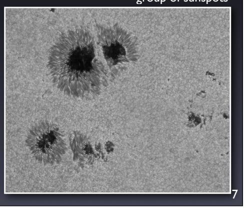
6

7

Photosphere : sunspots

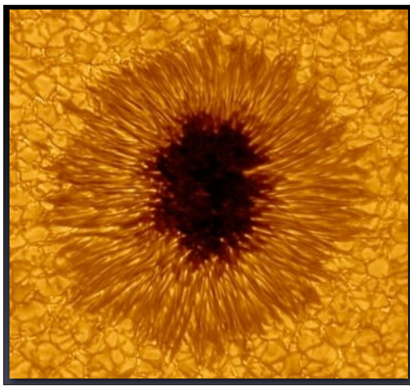
- relatively cool and dark areas
- visible for days to months
- indicate the rotation of the Sun
- appear within 35° latitude from the equator
- appear in cycles of 11, or better, 22 years

group of sunspots



7

8



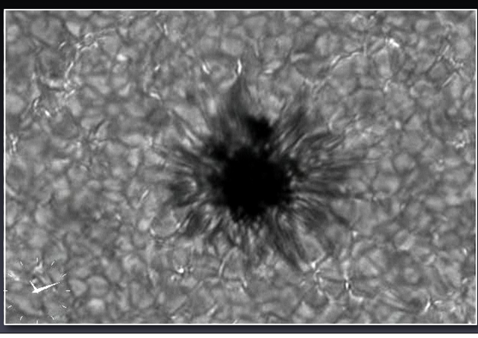
Umbra and Penumbra

T_{umbra} ~ 4000 K

8

9

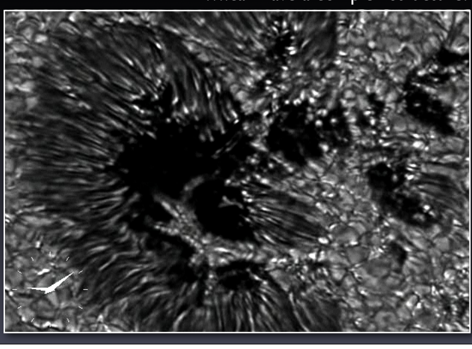
Sunspots…



9

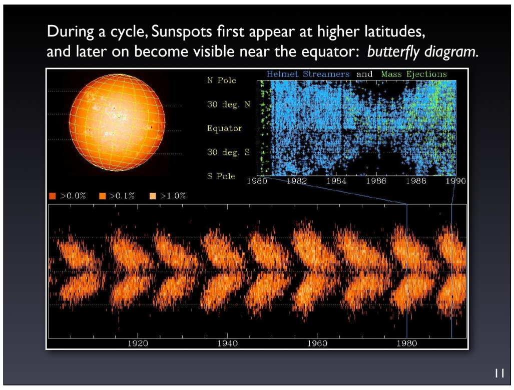
10

….can have a complex structure.

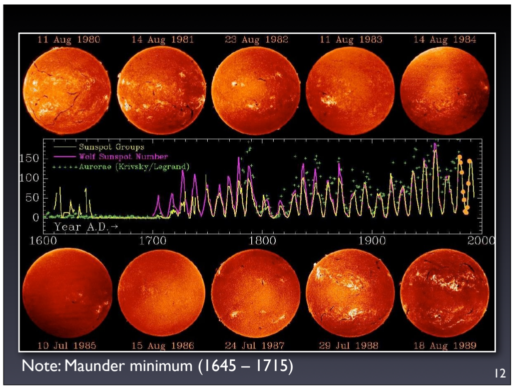


10

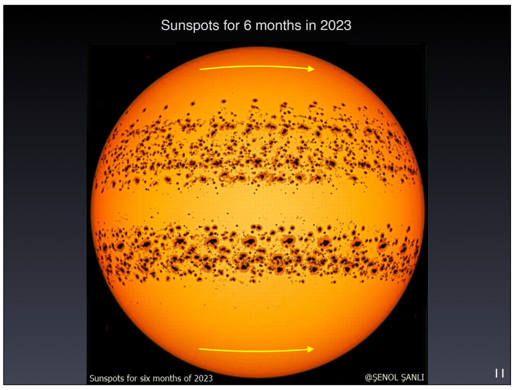
11


During a cycle, Sunspots first appear at higher latitudes, and later on become visible near the equator: *butterfly diagram.*
N Pole
30 deg. N
Equator
30 deg. S
S Pole
Helmet Streamers and Mass Ejections
1980
1982
1984
1986
1988
1990
>0.0%
>0.1%
>1.0%
1920
1940
1960
1980
11

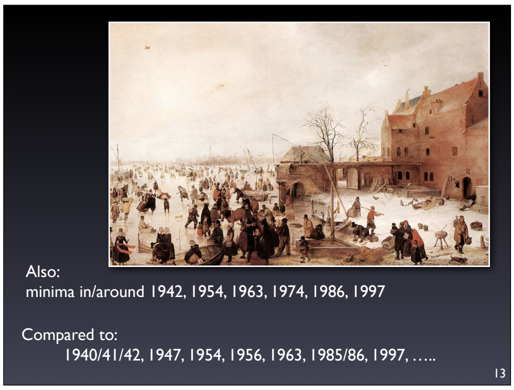
12


11 Aug 1980
14 Aug 1981
23 Aug 1982
11 Aug 1983
14 Aug 1984
Sunspot Groups
Wolf Sunspot Number
Aurorae (Krivsky/Legrand)
150
100
50
0
Year A.D.→
1600
1700
1800
1900
2000
10 Jul 1985
15 Aug 1986
24 Jul 1987
29 Jul 1988
18 Aug 1989
Note: Maunder minimum (1645 – 1715)
12

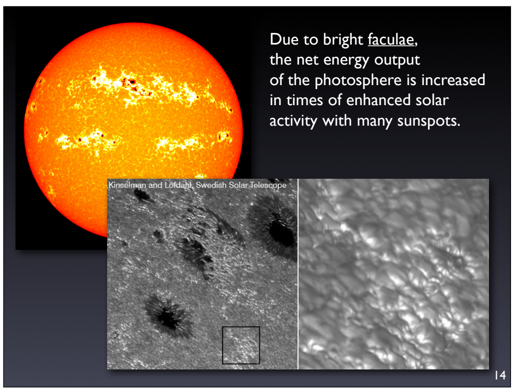
13

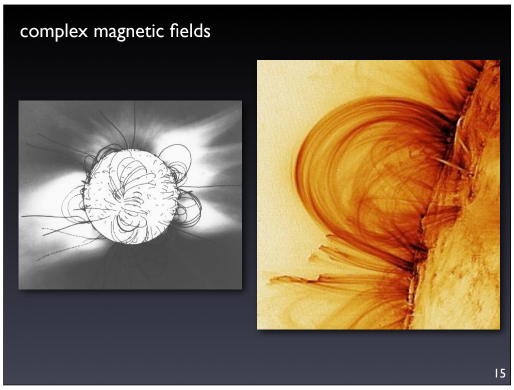

Sunspots for 6 months in 2023
Sunspots for six months of 2023
@ŞENOL ŞANLI
11

14

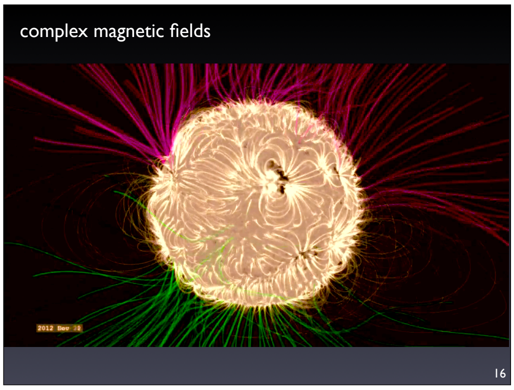

Also:
minima in/around 1942, 1954, 1963, 1974, 1986, 1997
Compared to:
1940/41/42, 1947, 1954, 1956, 1963, 1985/86, 1997, …..
13

15

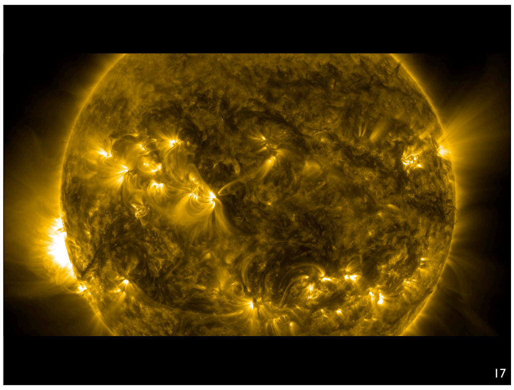

Due to bright faculae,
the net energy output
of the photosphere is increased
in times of enhanced solar
activity with many sunspots.
Kinselman and Lofdahl, Swedish Solar Telescope
14


complex magnetic fields
15

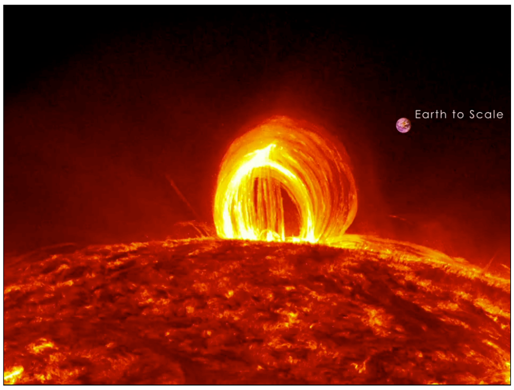
16


complex magnetic fields
16

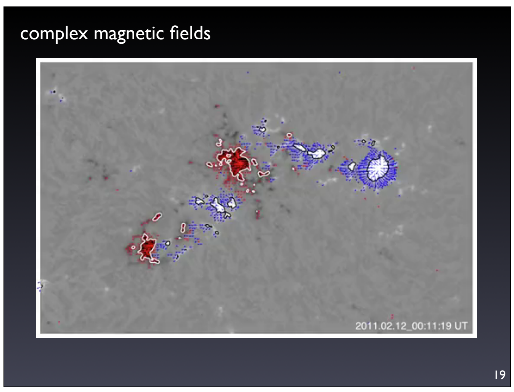
17


17

18


Earth to Scale

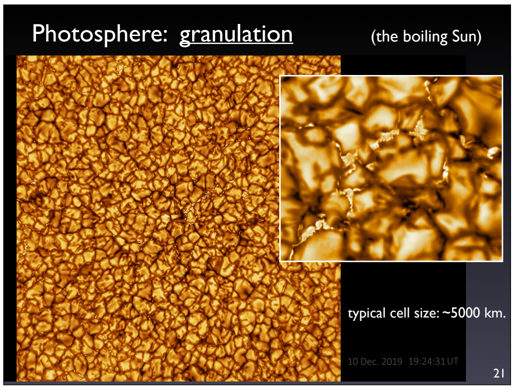
19


complex magnetic fields
2011.02.12_00:11:19 UT
19

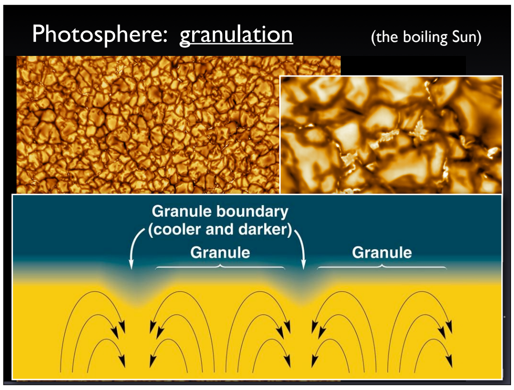
20


From July 5 - 17, 2017, NASA spacecraft observed a sunspot as it grew and eventually rotated out of view.
2017 Jul 7 04:40:00.000
20

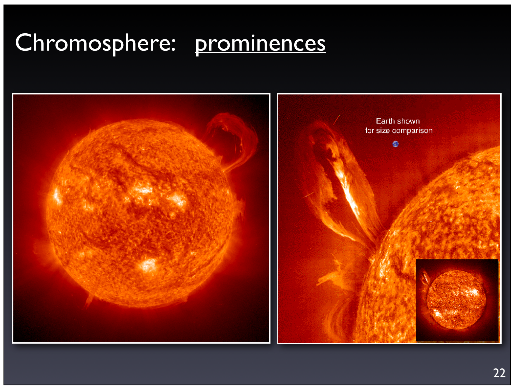
21


Photosphere: granulation
(the boiling Sun)
typical cell size: ~5000 km.
10 Dec. 2019 19:24:31 UT
21

22


Photosphere: granulation
(the boiling Sun)
Granule boundary
(cooler and darker)
Granule
Granule

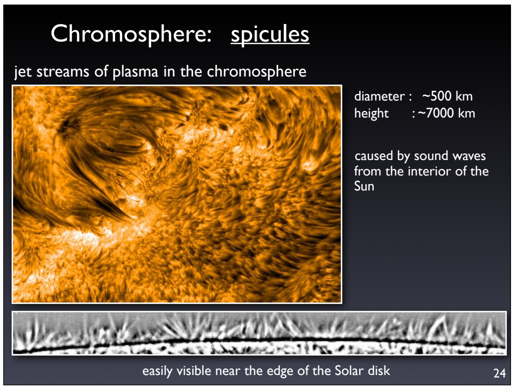
23


Chromosphere: prominences
Earth shown
for size comparison
22

24


the development of a prominence
23

25


Chromosphere: spicules
jet streams of plasma in the chromosphere
diameter : ~500 km
height : ~7000 km
caused by sound waves from the interior of the Sun
easily visible near the edge of the Solar disk
24

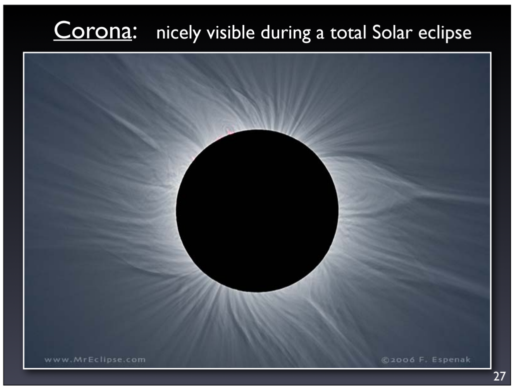
26


Corona: nicely visible during a total Solar eclipse
25

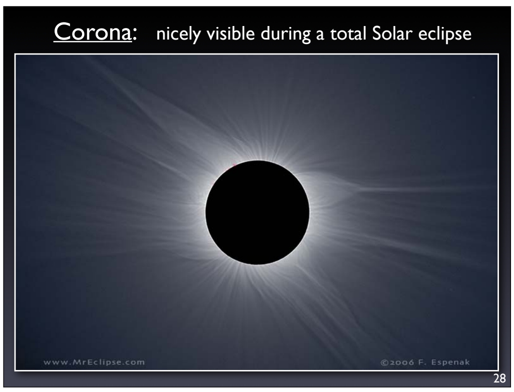
27


Corona: nicely visible during a total Solar eclipse
www.MrEclipse.com
©2006 F. Espenak
26

28

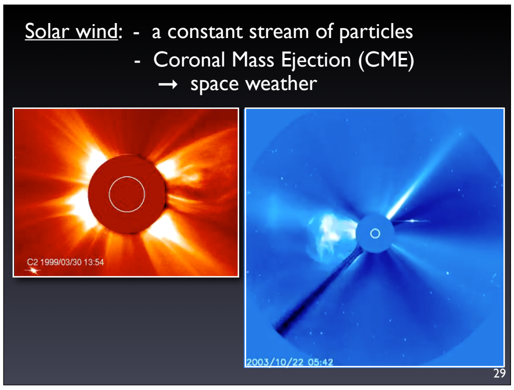

Corona: nicely visible during a total Solar eclipse
www.MrEclipse.com
©2006 F. Espenak
27

29

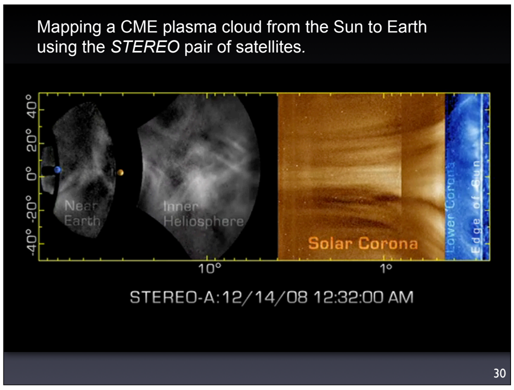

Corona: nicely visible during a total Solar eclipse
www.MrEclipse.com
©2006 F. Espenak
28

30

31


Solar wind: - a constant stream of particles
- Coronal Mass Ejection (CME)
→ space weather
C2 1999/03/30 13:54
2003/10/22 05:42
29

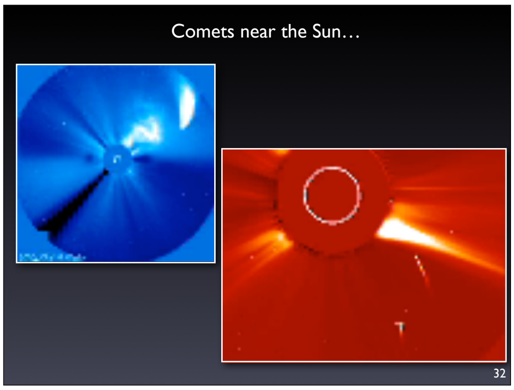
32


Mapping a CME plasma cloud from the Sun to Earth using the *STEREO* pair of satellites.
-40° -20° 0° 20° 40°
Near Earth
Inner Heliosphere
Solar Corona
Lower Corona
Edge of Sun
10°
1°
STEREO-A:12/14/08 12:32:00 AM
30

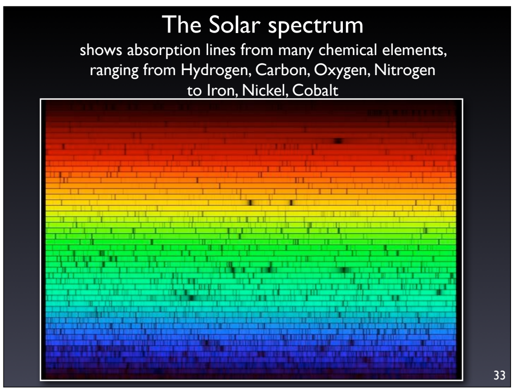
33

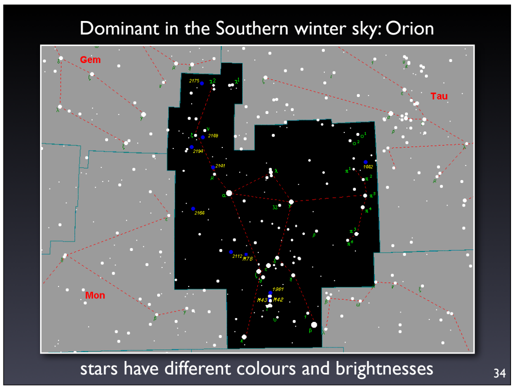

Aurora due to extreme Solar winds
31

34

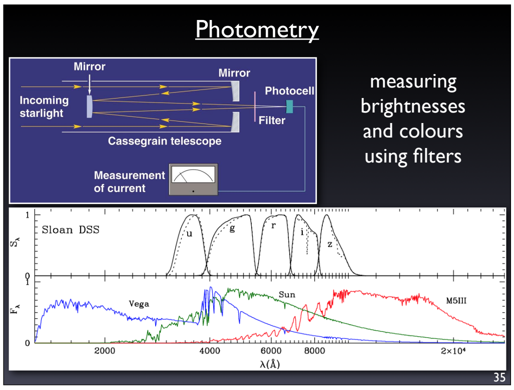

Comets near the Sun…
32

35

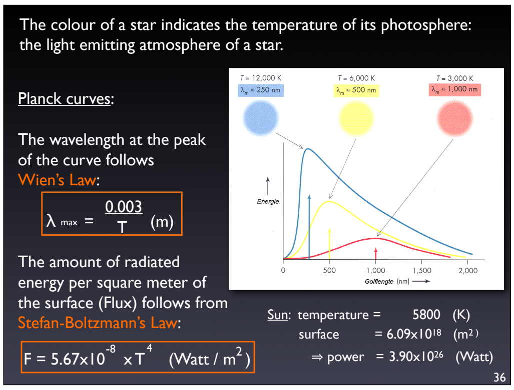

The Solar spectrum
shows absorption lines from many chemical elements,
ranging from Hydrogen, Carbon, Oxygen, Nitrogen
to Iron, Nickel, Cobalt
33


Dominant in the Southern winter sky: Orion
Gem
Tau
Mon
stars have different colours and brightnesses
34

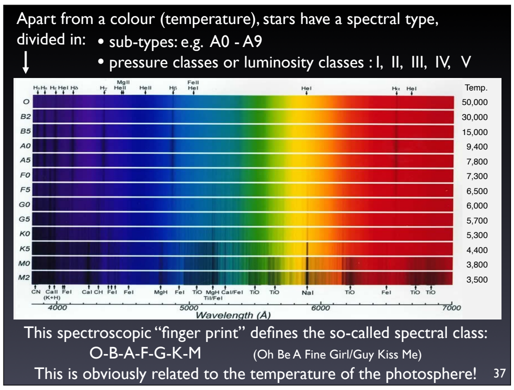
36


Photometry
Mirror
Mirror
Incoming starlight
Photocell
Filter
Cassegrain telescope
Measurement of current
measuring brightnesses and colours using filters
Sloan DSS
u
g
r
i
z
Vega
Sun
M5III
2000
4000
6000
8000
2×10⁴
λ(Å)
35

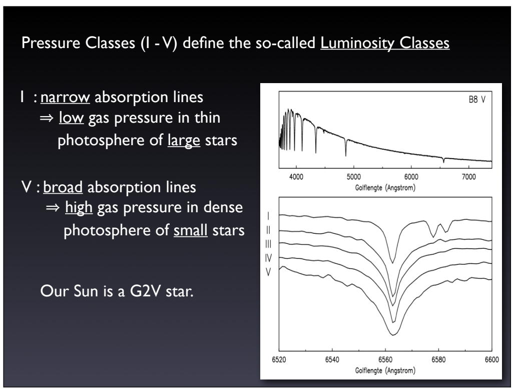
37


The colour of a star indicates the temperature of its photosphere: the light emitting atmosphere of a star.
Planck curves:
The wavelength at the peak of the curve follows Wien's Law:
λ max = 0.003 / T (m)
The amount of radiated energy per square meter of the surface (Flux) follows from Stefan-Boltzmann's Law:
F = 5.67x10-8 x T4 (Watt / m2)
T = 12,000 K
T = 6,000 K
T = 3,000 K
Energie
Golflengte (nm)
Sun: temperature = 5800 (K)
surface = 6.09x1018 (m2)
⇒ power = 3.90x1026 (Watt)
36

38


Apart from a colour (temperature), stars have a spectral type, divided in:
• sub-types: e.g. A0 - A9
• pressure classes or luminosity classes : I, II, III, IV, V
Temp.
O 50,000
B2 30,000
B5 15,000
A0 9,400
A5 7,800
F0 7,300
F5 6,500
G0 6,000
G5 5,700
K0 5,300
K5 4,400
M0 3,800
M2 3,500
Wavelength (A)
This spectroscopic "finger print" defines the so-called spectral class:
O-B-A-F-G-K-M (Oh Be A Fine Girl/Guy Kiss Me)
This is obviously related to the temperature of the photosphere!
37

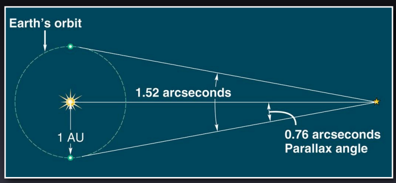
39


Pressure Classes (I - V) define the so-called Luminosity Classes
I : narrow absorption lines
⇒ low gas pressure in thin photosphere of large stars
V : broad absorption lines
⇒ high gas pressure in dense photosphere of small stars
Our Sun is a G2V star.
B8 V
Golflengte (Angstrom)
I
II
III
IV
V
Golflengte (Angstrom)

40

Determining the intrinsic luminosity of a star requires knowledge of the distance to that star.

Using the Parallax we measure distances to (nearby) stars.



1 parsec = distance at which a star has a parallax angle of 1 arc-second.

1 parsec = 3.26 light years

More distant stars have smaller parallax angles.

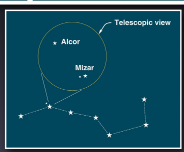
39

41

Stars also show Proper Motions:

(e.g. the Big Dipper)

Similar proper motions of a group of stars can be used to determine the distance to the group.



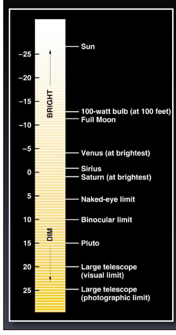
Note the double star Mizar & Alcor!

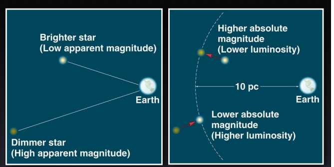
Single stars like our Sun are not common!
Most stars are in binary systems.

40

42

Apparent versus Absolute luminosities (intrinsic luminosity)
(see list of bright stars in the book)





One step in magnitude is a factor 2.5 in luminosity.

The magnitude scale measures faintness!

Absolute Magnitude = Apparent Magnitude if the star is at a distance of 10 parsec

41

43

Some of the brightest stars:

Star		Apparent magnitude	Distance (light years)	Absolute magnitude	Type
Sun		−26.72	–	4.8	G2V
Sirius	(α CMa)	−1.46	8.6	1.4	A1Vm
Canopus	(α Car)	−0.72	74	−2.5	A9II
Arcturus	(α Boo)	−0.04	34	0.2	K1.5IIIp
Rigel	(β Ori)	0.12	1400	−8.1	B8Iae
Betelgeuse	(α Ori)	0.50	1400	−7.2	M2Iab
Aldebaran	(α Tau)	0.85	60	−0.3	K5III

42

44

Herzsprung- Russel diagram

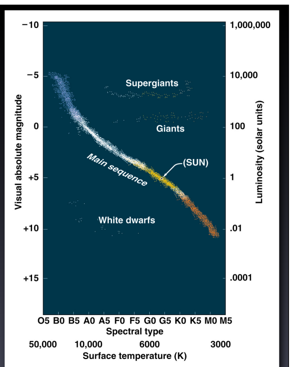
shows the relation between

LUMINOSITY
(absolute magnitude)

and

SURFACE TEMPERATURE
(colour or spectral type)

Our Sun is a star on the Main Sequence



43

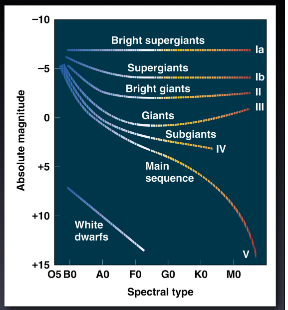
45

46

Pressure Classes
define the so-called
Luminosity Classes

Ia, Ib, II, III, IV, V

Note:
luminosity class
and
apparent magnitude
provide
the distance to a star!!



our Sun is a G2-V star

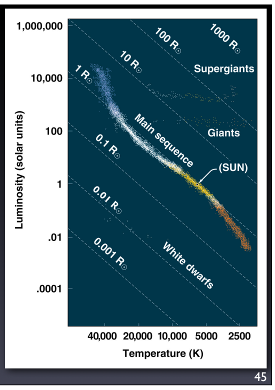
44

47

Colour (temperature)
&
Size (radiating surface)

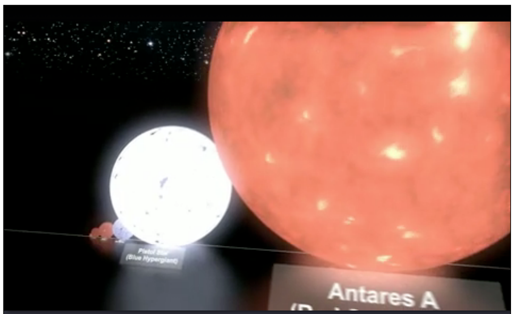
determine the
Absolute Luminosity
of a star.

We distinguish
dwarf and giant stars.



45

48



46

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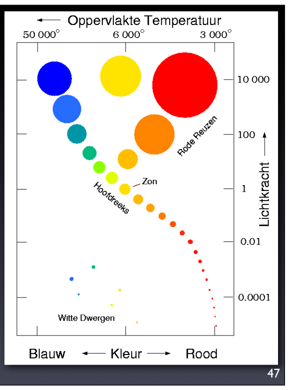
In summary:

Note the
range in

Mass
Temperature
Diameter
Luminosity



47