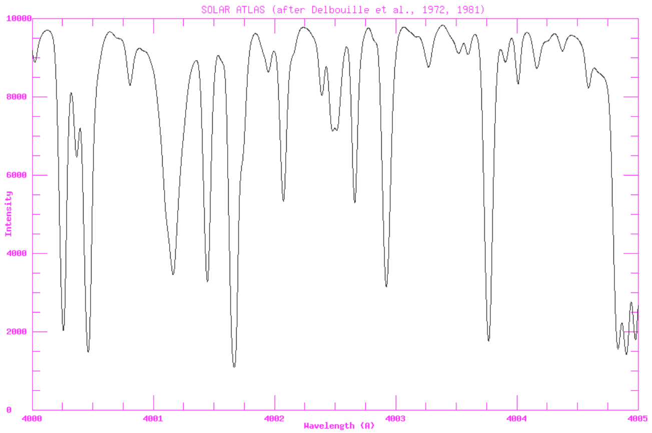
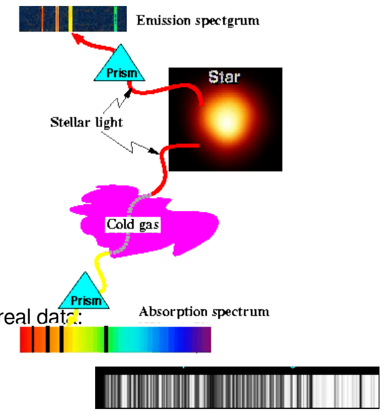
Photons

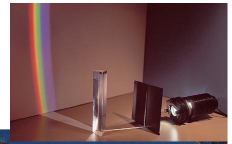
Astronomy is based on observing photons from celestial bodies
temperature, density, velocity, chemical composition



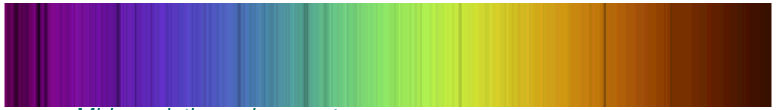
Absorption Spectrum of stars *(silhouette of the cold gas)*

spectrum of blackbody radiation at the photosphere,
some frequencies absorbed by cooler gas
nearer the surface



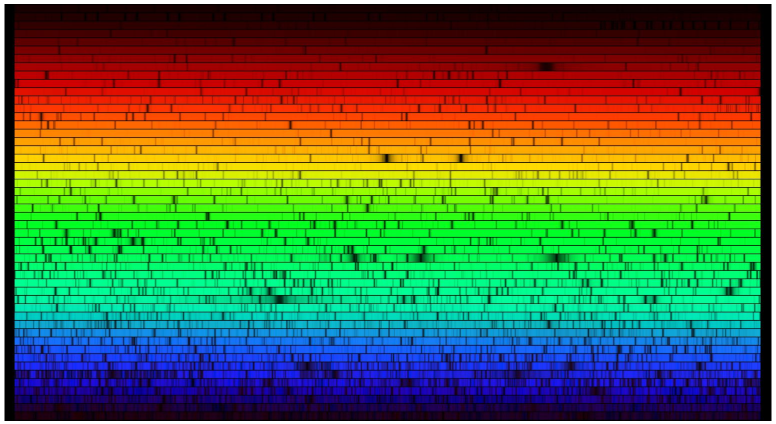


NSO Solar telescope



Mid-resolution solar spectrum

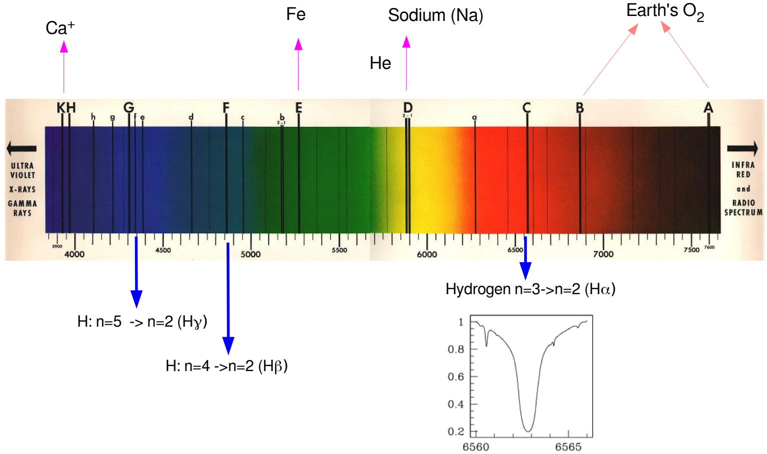
High-resolution



Optical Spectrum of the Solar lights ---- Fraunhofer lines

from www.harmsy.freeuk.com/fraunhofer.html

absorption features: flux deficit in the blackbody radiation spectrum



Energy Levels for a hydrogen atom

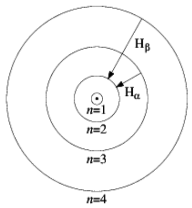
Example: hydrogen atom ($p^+ + e^-$) -------- Bohr's model for hydrogen

planetary-like orbits

Electro-static potential $U=-\frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$

Virial theorem: $\langle E\rangle=\langle E_{kin}\rangle+\langle U\rangle=\frac{1}{2}\langle U\rangle=-\frac{1}{4\pi\epsilon_0}\frac{e^2}{2r}$

Planets: r arbitrary; atom: infinite possibilities?



but quantized angular momentum (Bohr)

Angular momentum of the orbit

$$J=\mu v r\approx m_e v r=n\hbar=n\frac{h}{2\pi}$$

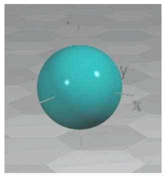
r is quantized, and so is E.

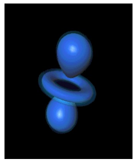
discreet energy levels (n=1,2,3....)

$$-\frac{1}{4\pi\epsilon_0}\frac{e^2}{2r}=-\frac{1}{2}m_e v^2=-\frac{1}{2}\frac{(n\hbar)^2}{m_e r^2}$$

So, $r=r_n=4\pi\epsilon_0\frac{\hbar^2 n^2}{m_e e^2}\sim 0.5\,\text{Å}\,n^2\propto n^2$

$$E_n=-\frac{m_e e^4}{2(4\pi\epsilon_0\hbar)^2}\frac{1}{n^2}=-\frac{13.6\ eV}{n^2}$$

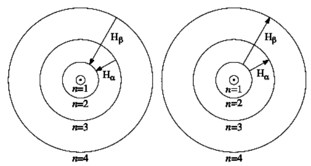




Reality: electron clouds probability functions

Photon-matter interaction and spectral lines

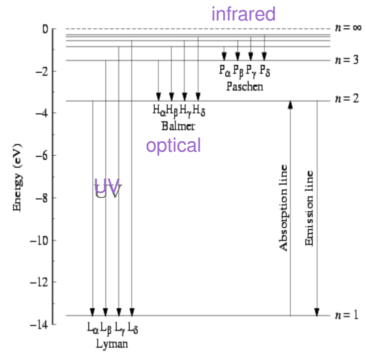
absorption vs. emission



$$E_n=-\frac{13.6eV}{n^2}$$

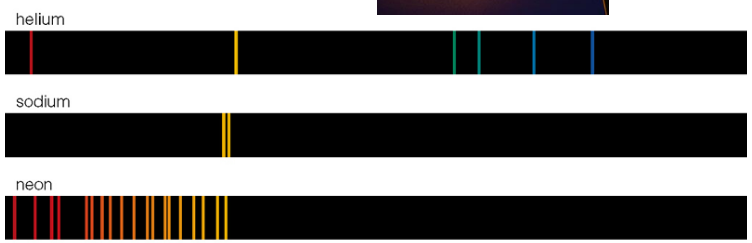
to excite an electron from $n=1 \rightarrow n=2$,

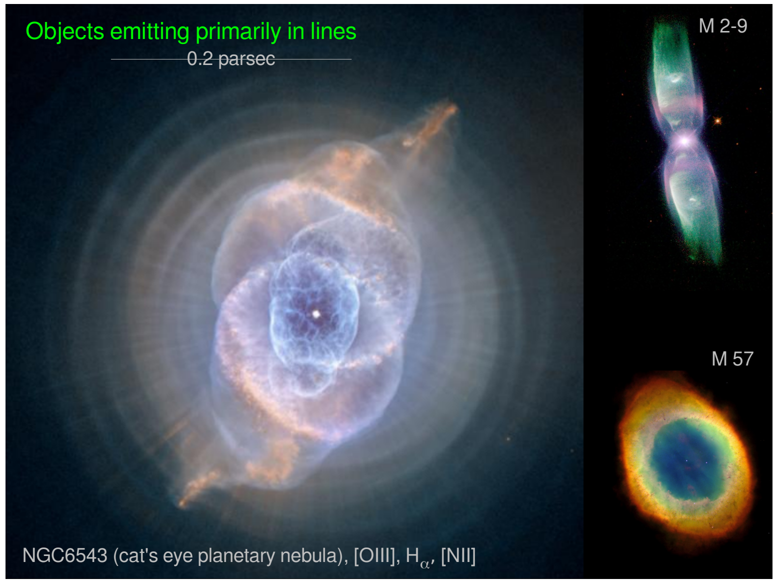
$$E=\frac{hc}{\lambda}=E_2-E_1=(-3.4eV)-(-13.6eV)$$



Everyday applications of spectral lines:

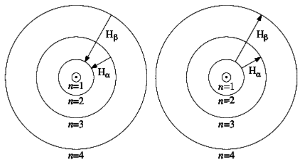
neon lights, street lights, energy-efficient light bulbs...





Types of Spectral Lines

Atomic transitions:
Hydrogen



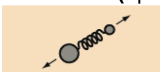
He, Li, ... $E_n = -\frac{13.6\,eV}{n^2}$

sometimes hyper-fine transitions related to spin

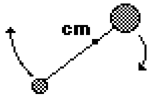
Molecular transitions: hierarchical

electronic: **quantized orbits ~ eV optical or UV**

vibrational: **quantized shaking ~ 10^{-1} eV infrared(~μm)**

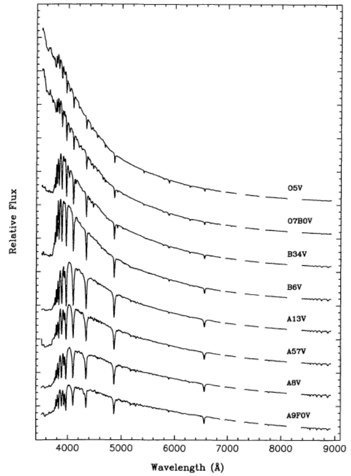


rotational: **quantized rotation ~ 10^{-4} eV microwave (~mm)**

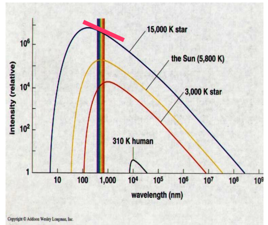


Spectra of stars much **hotter** than the Sun

O stars ~40,000K, H ionised, see He and He^+ (and highly ionized metals in UV)
B stars ~15,000 K, H largely ionised, but strong, neutral He
A stars, ~8,000 K, H very strong

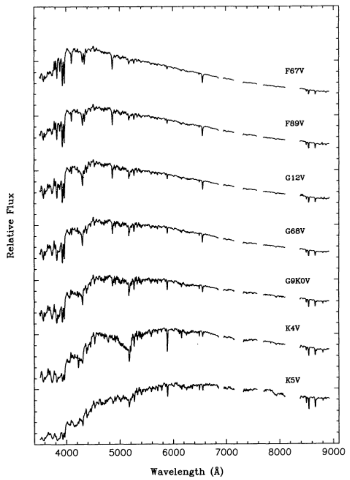


Silva & Cornell, 1992, Astroph.J.Supp. 81, 865

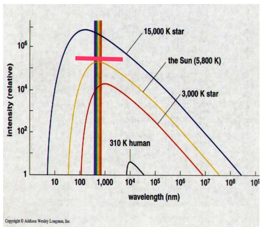


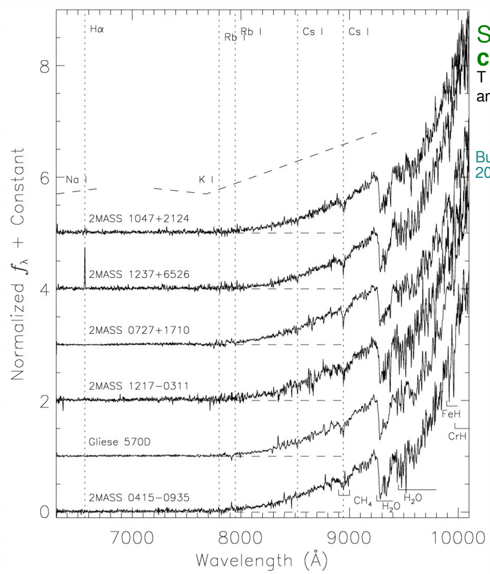
Spectra of stars **similar to** the Sun

F stars ~6,700K, H less strong, Na, Mg, Ca^+ becoming stronger
G stars ~5,600 K, H largely neutral, strong neutral/singly-ionised metal lines
K stars, ~4,400 K, neutral metals dominate, molecules appearing



Silva & Cornell, 1992, Astroph.J.Supp. 81, 865

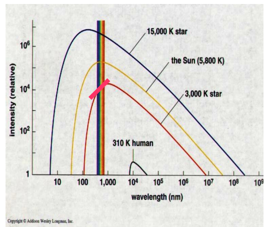




Spectra of stars much **cooler** than the Sun

T dwarfs ~1000K, show H_2O and methane (CH_4) absorption lines

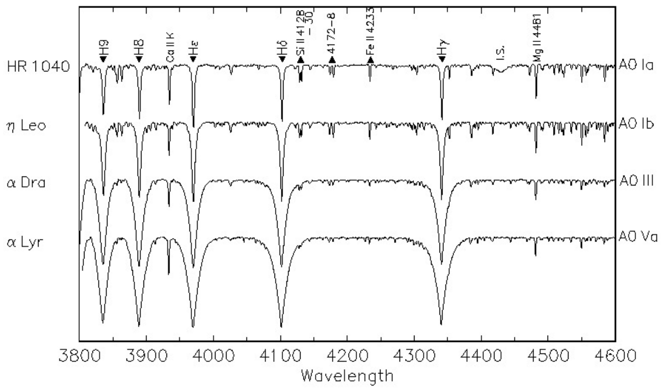
Burgasser et. al. Astrophysical Journal 2003, 594,510



Lines tell not just about temperature, but also density

Denser → more collisions → more disturbances of atoms/ions → wider lines
Stronger gravity → scale height smaller → see down to denser regions

"Rule" I learned: normal star, Balmer up to 14, White dwarf, up to 8: higher levels (size ~ n^2) cannot exist



THE ASTROPHYSICAL JOURNAL, 707:971–978, 2009 December 20 doi:10.1088/0004-637X/707/2/971

FIRST RESULTS FROM THE SWARMS SURVEY. SDSS 1257+5428: A NEARBY, MASSIVE WHITE DWARF BINARY WITH A LIKELY NEUTRON STAR OR BLACK HOLE COMPANION

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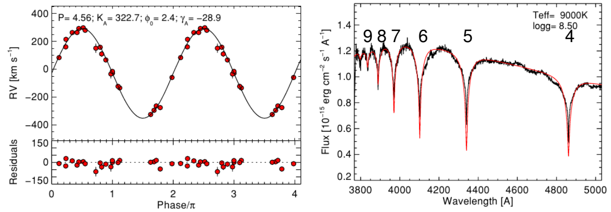
ABSTRACT

We present the first results from the SWARMS survey, an ongoing project to identify compact white dwarf (WD) binaries in the spectroscopic catalog of the Sloan Digital Sky Survey (SDSS). The first object identified by SWARMS, SDSS 1257+5428, is a single-lined spectroscopic binary in a circular orbit with a period of 4.56 hr and a semiamplitude of 322.7 ± 6.3 km s^{-1}. From the spectrum and photometry, we estimate a WD mass of $0.92^{+0.28}_{-0.32} M_\odot$. Together with the orbital parameters of the binary, this implies that the unseen companion must be more massive than $1.62^{+0.20}_{-0.25} M_\odot$, and is in all likelihood either a neutron star or a black hole. At an estimated distance of 48^{+10}_{-19} pc, this would be the closest known stellar remnant of a supernova explosion.

Key words: binaries: close – binaries: spectroscopic – supernovae: general – white dwarfs



"Rule" I learned: normal star, Balmer up to 14, Normal WD (log g=8.0), up to 8.

THE ASTROPHYSICAL JOURNAL, 719:1123–1131, 2010 August 20 doi:10.1088/0004-637X/719/2/1123

THE (DOUBLE) WHITE DWARF BINARY SDSS 1257+5428

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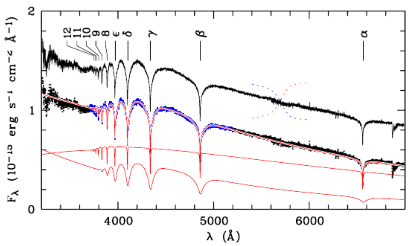
ABSTRACT

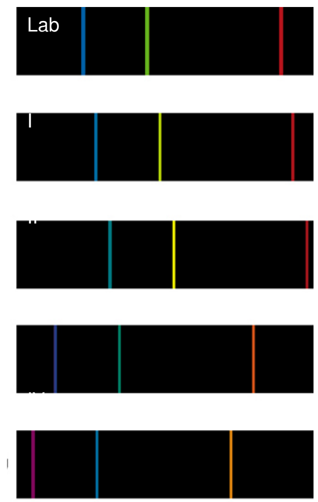
SDSS 1257+5428 is a white dwarf in a close orbit with a companion that has been suggested to be a neutron star. If so, it hosts the closest known neutron star, and its existence implies a great abundance of similar systems and a rate of white dwarf neutron-star mergers similar to that of the type Ia supernova rate. Here, we present high signal-to-noise spectra of SDSS 1257+5428, which confirm an independent finding that the system is in fact composed of two white dwarfs, one relatively cool and with low mass and the other hotter and more massive. With this, the demographics and merger rate are no longer puzzling (various factors combine to lower the latter by more than 2 orders of magnitude). We show that the spectra are fit well with a combination of two hydrogen model atmospheres, as long as the lines of the higher-gravity component are broadened significantly relative to what is expected from just pressure broadening. Interpreting this additional broadening as due to rotation, the inferred spin period is short, about 1 minute. Similarly rapid rotation is only seen in accreting white dwarfs that are magnetic; empirically, it appears that in non-magnetized white dwarfs, accreted angular momentum is lost by nova explosions before it can be transferred to the white dwarf. This suggests that the massive white dwarf in SDSS 1257+5428 is magnetic as well, with $B \simeq 10^5$ G. Alternatively, the broadening seen in the spectral lines could be due to a stronger magnetic field, of $\sim 10^6$ G. The two models can be distinguished by further observations.

Key words: binaries: close – stars: individual (SDSS J12573

the observed Balmer lines. From a more detailed look at the spectral fits of Badenes et al. (2009), one sees that these poorly match the narrow cores of lower Balmer lines and underpredict the higher Balmer lines. The presence of the higher Balmer lines is indicative of lower gravity, since these lines are very sensitive to pressure broadening (the size of a hydrogen atom is quadratically proportional to the upper level of the transition). Combined with the wide wings shown by the lower Balmer lines, which require high gravity, this supports the idea that the observed spectrum of SDSS 1257+5428 is produced by more than one DA white dwarf.



Doppler Shifts: blue-shift & red-shift



$$\frac{\Delta\lambda}{\lambda} = \frac{v_{rad}}{c}$$

Finding out velocities for any moving objects

1) Expansion of the universe

2) Detecting planets around other stars

3) Finding black holes

4) Measuring stellar masses in binaries

5) Rotation of the galaxy

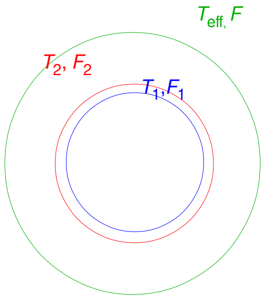
6)...

... getting out of the way of a fire engine

Extra Note: Equation of Radiative Transfer

One last hurdle towards constructing a physical star:

Every layer in the star with $T = T(r)$ absorbs all radiation and emits as a blackbody $F = \sigma T^4$



Temperature $T_2 = T_1 + \frac{dT}{dr} dr < T_1$

Net flux $F = F_1 - F_2 = \sigma (T_1^4 - T_2^4) \sim 4 \sigma T^3 \frac{dT}{dr} dr$

Where $dr \sim$ *diffusion length* $\sim l_{mfp} \sim \frac{1}{n\sigma} \sim \frac{1}{\kappa\rho}$

Detailed derivation: Equation of radiative transfer:

$$F = -\frac{16 \sigma T^3}{3 \kappa \rho} \frac{dT}{dr}$$

Or $$\frac{dT}{dr} = -\frac{3 \kappa \rho}{16 \sigma T^3} \frac{L_r}{4 \pi r^2}$$