Limb Redshift of the Fraunhofer Lines in the Solar Spectrum

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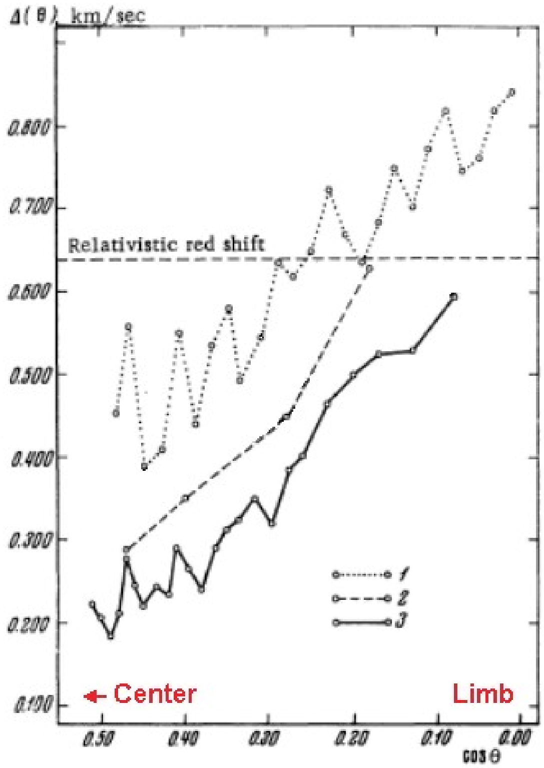
Abstract: Near the limb of the solar disk, the positions of the Fraunhofer lines are shifted toward the red end of the spectrum, compared with their positions at the center of the disk. A possible explanation for this limb effect is the energy loss of the light, when it accelerates unbound electrons in the chromosphere. An even larger redshift is expected when light travels a longer distance in the chromosphere close to solar limb. This difference should be easily detectable during the next solar eclipse.

Introduction

Since 1907, it is an established but unexplained fact that the wavelengths of the Fraunhofer lines depend on the point of observation an the solar disk[1 2]. This systematic deviation from the predictions of the theory of relativity is amazing and can not be generated by turbulence of the plasma. According to the theory of gravitational redshift[3], the redshift at each point of the sun's surface should have the same value $z_{Sun}=2{,}13\cdot 10^{-6}$ or $c\cdot z_{Sun}=638\,m/s$. But Astronomers do not measure a constant shift, as seen in the image[4]. The actual results show a systematic deviation from the expected value. Near the solar center, the redshift is well below the prediction of the theory of relativity. Near the extreme limb the measured redshift even exceeds the relativistic shift.



Red shifts obtained by various investigators :
1) Adam (1959); 2) Adam (1948); 3) Salman-Zade (1968).

Because of the turbulent plasma motions near the solar surface, all values can only be measured quite inaccurate. Radial gas motions with very large velocities[5 B] affect the results, especially near the center of the solar disk. But they scarcely influence measurements near the limb, where tangential winds have much lower speeds.

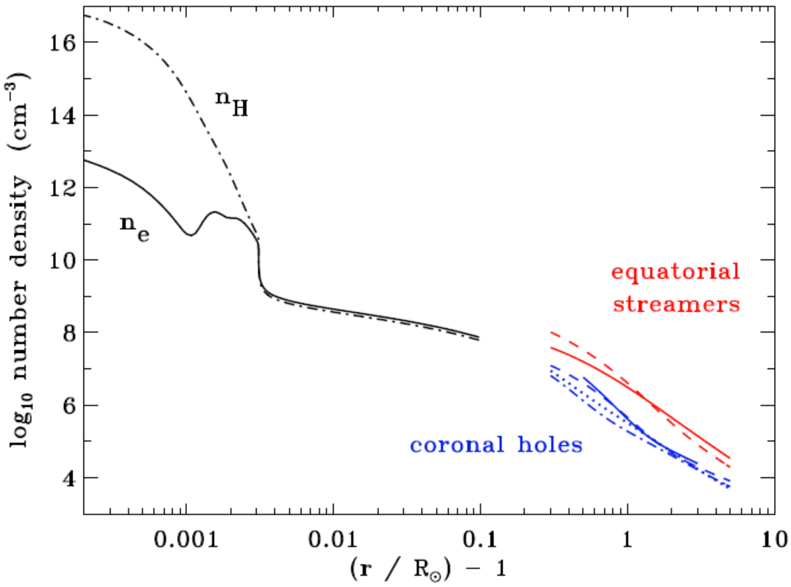
The wavelengths of nearly all lines of the solar spectrum differ from the values that are measured in terrestrial laboratories. Since the "gravity shift" is equal for every emission point on the sun's surface, there must be another physical cause for this position-dependent shift.

Because of the great theoretical importance of the limb redshift, the derivation described below is based solely on known measurements of solar physics and contains no ad hoc assumptions and no adjustable parameters.

(A) May 22, 2014, email: herbertweidner@gmx.de
(B) Spicules have a characteristic upward velocity of 20 km/s

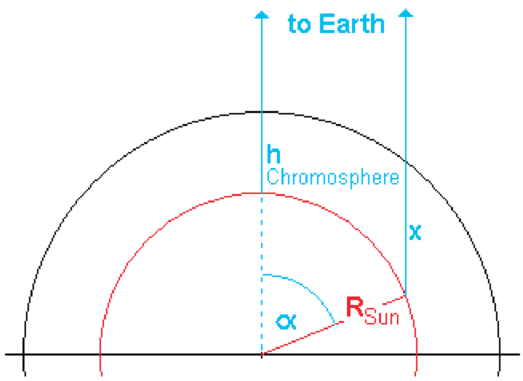
The light path between sun and earth

The sun emits electromagnetic waves of very different wavelengths, which have to pass the chromosphere and the corona. In the range of visible light, both are nearly transparent and due to the high temperature, they contain many unbound electrons. The density depends on the distance from the photosphere[6 7 8 9] and is shown in the picture. As explained[10], every electron is accelerated by the electromagnetic wave and therefore radiates like a dipole antenna *without* preferred direction. Since this secondary Radiation is not directed to the observer, the law of conservation of energy requires that the original electromagnetic wave loses a tiny amount of energy and therefore reduces its frequency. The loss will be hard to detect with a single electron, but an electron density of about $10^{11}\,cm^{-3}$ or more in the chromosphere produces a measurable drop in energy.



Data from Avrett Loeser 2008

Another decisive factor is the length of the light path in the plasma. Starting near the solar limb, the light's way *x* through the chromosphere is longer than the shortest distance *h*, if the light leaves from the center of the solar disk. The chromosphere is roughly 2000 km deep; a thin layer called *solar transition region*[11] follows, where the density of unbound electrons drops suddenly to 1% or lower. In the following areas (the corona and the heliosphere), the density decreases further. Here, the light's energy loss is negligible and nearly equal for both paths, the major loss occurs in the chromosphere.

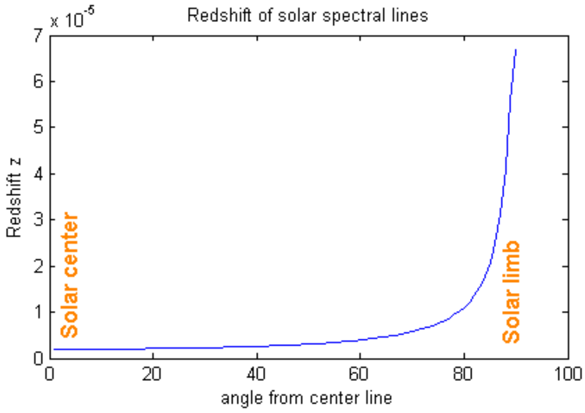


In the picture, two “lines of sight” towards the earth are shown. Since the path length *x* and *h* differ, the energy loss due to Thomson scattering differs too[13], resulting in an unequal redshift.

The calculated energy loss

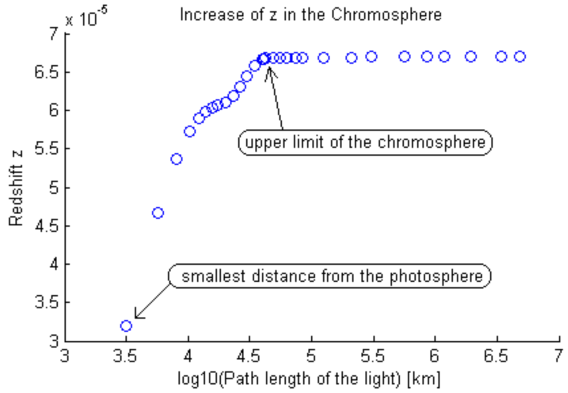
To evaluate the total energy loss caused by the accelerated free electrons between sun and earth, it is wrong to suppose, a bullet called Photon with a typical energy 3 eV is scattered by unbound electrons. In the language of classical electrodynamics, many electrons in a huge area called Fresnel zone[13] are accelerated by the electric component of the wave and every electron radiates a tiny amount of energy like a dipole, thus reducing the frequency of the whole wave. This frequency reduction has already been proven[12]. Here[13] is shown, that the redshift z can be calculated by

$$z = w \int_0^D n_e \, ds \quad \text{with} \quad w = \frac{3 q_e^4 \mu_0^2}{512 \pi m_e^2} = 2.33 \cdot 10^{-30} m^2$$



There is no adjustable parameter. All, you need is the density n_e of unbound electrons along the light path. In the vicinity of the solar surface, the density varies in a complicated way and can only be specified in tabular form. To allow a numeric calculation, the electron density was tabulated as a function of the distance from the sun[9]. The table ends at seven times the radius of the sun, because the energy losses of the remaining distance to the earth causes no significant differences.

To determine the loss along a longer path, numerical integration must be used, the result was calculated with MATLAB, the program is listed below (*Redshift near the limb*). The upper picture shows the result, which corresponds approximately the measured values[14 15]. The high redshift is surprising, because light arriving from the center of the solar disk (angle = 0) has – due to the oscillating electrons – the redshift $z_{Center} = 2 \cdot 10^{-6}$. That is nearly the same value, which is predicted by gravitational redshift for every point near the surface of the sun.

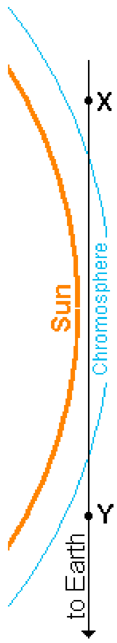


The second image shows that the the excess redshift is possibly caused by the overestimated electron density of the inner chromosphere. Reducing the electron density in the innermost layer (0..140 km) of the chromosphere from $5.6 \cdot 10^{12} / cm^3$ to $1 \cdot 10^{12} / cm^3$ halves the redshift.

In any case, the computed values near the limb are much higher than near the center, but they are difficult to measure with a reasonable accuracy. The method described below should enable a more accurate measurement of the redshift and of the electron density in the chromosphere.

Along the Solar Limb

Imagine two light sources in the corona with a common line of sight. The one called X is farther than the center of the sun ("behind" the sun), the other, called Y, is closer. The light from source X must travel a long distance through the chromosphere and loses more energy by Thomson scattering compared to the light coming from source Y. How big is the additional redshift of light from X?

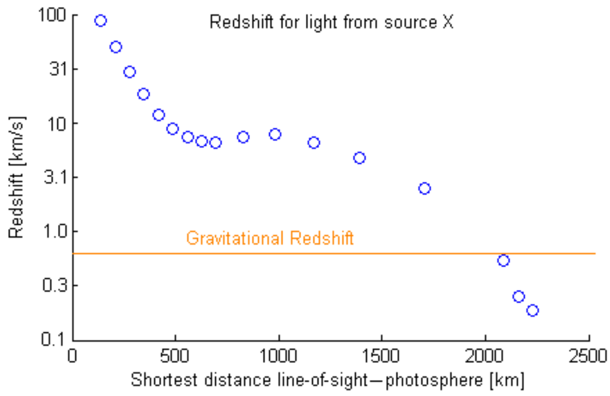


To determine the loss along both paths, numerical integration must be used. The resulting redshift is calculated with MATLAB, the program is listed below (*All along the limb A*). In order to simplify the program, the selectable distances are taken from the entries in the first row of the table ne(). The possible indexes are the line numbers of this table.

One possible result is:
Smallest distance = 139 km
Start distance = 13927 km
z = 0.000296 → 88.8 km/s
Lambda = (500 + 0.148) nm

This means that both points X and Y have the distance ~14000 km from the photosphere, they are located in the corona. The redshift of the light from source Y is negligible. The light from X travels through the chromosphere, the minimum distance between the *line-of-sight* and the photosphere is 139 km. The energy loss in the electron-rich chromosphere causes the redshift z = 0.000296, whereby a wavelength 500 nm is redshifted by 0.148 nm. This difference can be measured easily.

An interpretation as a Doppler shift would mean an incredible tangential wind velocity of 88.8 km/h at the solar limb at a height of 139 km from the photosphere. At each point of the solar limb, this wind would have to blow in the same direction: away from the earth.



If the distance between the *line-of-sight* and the photosphere increases, the redshift decreases because the light from source X passes through regions of lower electron density. With another MATLAB-program (*All along the limb B*) the redshift was computed for different minimum distances to the photosphere.

The distance-dependent redshift is a sensitive measurement method for determining the electron density in the chromosphere. The redshift of $c \cdot z_{Sun} = 638\, m/s$ (predicted by the theory of relativity) is exceeded significantly for a wide range of possible distances line-of-sight – photosphere and the differnece should be clearly measurable. If the light sources X and Y emit the same energy, the spectral lines on earth should appear either as twins ($\Delta\lambda \approx 0.1\, nm$) or – if they merge – are characterized by unusual wide FWHM.

To confirm this prediction, spectral lines originating in the corona must be analyzed at different distances from the solar limb. No easy job next to the very bright solar disk. During the next total solar eclipse on March 20, 2015, the solar disk is covered by the moon to allow these measurements even by ground-based observatories. Good luck!

Appendix: Programs for MATLAB

The file Limb.zip contains the following three programs and the data "electron density" and may be requested by mail from herbertweidner@gmx.de

```
%Redshift near the limb, Herbert Weidner
%Light starting from the limb
load ne %Daten from Avrett Loeser 2008
%ne(:,1) %=r/Rsol-1, r=height over photosphere
%x=ne(:,2); %=log10(r/Rsol-1)
%y=ne(:,3); %=log10(ne)
plot(ne(:,2),ne(:,3)), xlabel('log10(r/Rsol-1)')
ylabel('log10(ne)'), title('electron density outside the sun')
%breakpoint before next line
Rsol=696.34e6; %Hchromo=2e6; %[m]
w=2.33e-30; %[m²]
for alpha=1:90
    x=Rsol*sin(alpha*pi/180);
    %2e6 < x < 52,8e6; ->xmax/Rsol-1=0,076
    summe=0; %Integration up to r/Rsol-1=6
    for k=1:length(ne(:,1))-1 %all density values
        h1=(1+ne(k,1))*Rsol; h2=(1+ne(k+1,1))*Rsol;
        y1=sqrt(h1^2-x^2); y2=sqrt(h2^2-x^2); %distance=y2-y1
        nem=(10^(ne(k,3))+10^(ne(k+1,3)))/2;
        summe=summe+1e6*nem*(y2-y1); %cm³->m³
        qq(k,1)=(y2-y1); qq(k,2)=w*summe;
    end
    z(alpha)=w*summe;
end
plot(z), xlabel('angle from center line')
ylabel('Redshift z'), title('Redshift of solar spectral lines')
%breakpoint before next line
qq(1,3)=qq(1,1);
for k=2:length(ne(:,1))-1
    qq(k,3)=qq(k,1)+qq(k-1,3); end
scatter(log10(qq(:,3)/1000),qq(:,2))
xlabel('log10(Path length of the light) [km]'), ylabel('Redshift z')
title('Increase of z in the Chromosphere')
```

```
%All along the limb A, Herbert Weidner
%Light starting behind the limb in the corona
load ne %Data from Avrett Loeser 2008
%ne(:,1) %=r/Rsol-1, r=height over photosphere
%x=ne(:,2); %=log10(r/Rsol-1)
%y=ne(:,3); %=log10(ne)
plot(ne(:,2),ne(:,3)), xlabel('log10(r/Rsol-1)')
ylabel('log10(ne)'), title('electron density outside the sun')
Rsol=696.34e6; Hchromo=2e6; %m, ~ne(17,1)
w=2.33e-30; %[m²]
%now choose an INTEGER index for the min. distance
%Distance depends on the first row in the table ne()
minh=1; %min. distance from photosphere, integer! 0<minh<~20
x=ne(minh,1)*Rsol;
fprintf('\nSmallest distance= %4.0f km\n',x/1000);
x=(x+Rsol)^2;
%now choose an index for the start distance
Start=23; %Index in ne(), integer! minh<Start<30
fprintf('Start distance= %6.0f km\n', ne(Start,1)*Rsol/1000);
v=0; %von minh bis Start verdoppeln, dann weiter bis TabEnde
for k=minh:length(ne(:,1))-1 %all density values
    h1=(1+ne(k,1))*Rsol; h2=(1+ne(k+1,1))*Rsol;
    y1=sqrt(h1^2-x); y2=sqrt(h2^2-x); %distance=y2-y1
    nem=(10^(ne(k,3))+10^(ne(k+1,3)))/2;
    v=v+1e6*nem*(y2-y1); %cm³->m³
    if k==Start, v=2*v; end %Start->minDistance->Start
end
z=w*v; fprintf('z= %g -> %4.1f km/s\n',z,z*3e5);
lam=500;
fprintf('Lambda= (%g + %g) nm\n',lam,z*lam);
```

```
%All along the limb B, Herbert Weidner
%Light starting behind the limb in the corona
load ne %Data from Avrett Loeser 2008
%ne(:,1) %=r/Rsol-1, r=height over photosphere
%x=ne(:,2); %=log10(r/Rsol-1)
%y=ne(:,3); %=log10(ne)
plot(ne(:,2),ne(:,3)), xlabel('log10(r/Rsol-1)')
ylabel('log10(ne)'), title('electron density outside the sun')
Rsol=696.34e6; Hchromo=2e6; %m, ~ne(17,1)
w=2.33e-30; %[m²]
%now choose an INTEGER index for the min. distance
%Distance depends on the first row in the table ne()
for minh=1:17 %min. distance from photosphere, 0<minh<~20
    x=ne(minh,1)*Rsol;
    fprintf('\nd=%4.0f km ',x/1000);
    x=(x+Rsol)^2;
    Start=23; %Index in ne(), integer! minh<Start<30
    %fprintf('Start distance= %6.0f km\n', ne(Start,1)*Rsol/1000);
    v=0; %von minh bis Start verdoppeln, dann weiter bis TabEnde
    for k=minh:length(ne(:,1))-1 %all density values
        h1=(1+ne(k,1))*Rsol; h2=(1+ne(k+1,1))*Rsol;
        y1=sqrt(h1^2-x); y2=sqrt(h2^2-x); %distance=y2-y1
        nem=(10^(ne(k,3))+10^(ne(k+1,3)))/2;
        v=v+1e6*nem*(y2-y1); %cm³->m³
        if k==Start, v=2*v; end %Start->minDistance->Start
    end
    z=w*v; fprintf('z=%g -> %4.1f km/s',z,z*3e5);
    rs(minh,1)=ne(minh,1)*Rsol/1000; %km
    rs(minh,2)=w*v;
    rs(minh,3)=w*v*3e8; %m/s
end
scatter(rs(:,1),log10(rs(:,3)/1000))
xlabel('Shortest distance line-of-sight - photosphere [km]')
ylabel('log10(Redshift) [km/s]')
title('Redshift for light from source X')
```

The electron density ne

Rel. height r	log10(r)	log10(electrons/cm³)
2.0000000e-004	-3.6989700e+000	1.2750000e+001
3.0000000e-004	-3.5228787e+000	1.2500000e+001
4.0000000e-004	-3.3979400e+000	1.2200000e+001
5.0000000e-004	-3.3010300e+000	1.2000000e+001
6.0000000e-004	-3.2218487e+000	1.1700000e+001
7.0000000e-004	-3.1549020e+000	1.1400000e+001
8.0000000e-004	-3.0969100e+000	1.1200000e+001
9.0000000e-004	-3.0457575e+000	1.0950000e+001
1.0000000e-003	-3.0000000e+000	1.0800000e+001
1.1900000e-003	-2.9244530e+000	1.0800000e+001
1.4140000e-003	-2.8495506e+000	1.1200000e+001
1.6800000e-003	-2.7746907e+000	1.1250000e+001
2.0000000e-003	-2.6989700e+000	1.1150000e+001
2.4500000e-003	-2.6108339e+000	1.1000000e+001
3.0000000e-003	-2.5228787e+000	1.0600000e+001
3.1000000e-003	-2.5086383e+000	1.0000000e+001
3.2000000e-003	-2.4948500e+000	9.4000000e+000
4.0000000e-003	-2.3979400e+000	9.0000000e+000
5.0000000e-003	-2.3010300e+000	8.9000000e+000
6.0000000e-003	-2.2218487e+000	8.8500000e+000
8.0000000e-003	-2.0969100e+000	8.7000000e+000
1.0000000e-002	-2.0000000e+000	8.6000000e+000
2.0000000e-002	-1.6989700e+000	8.4500000e+000
5.0000000e-002	-1.3010300e+000	8.1000000e+000
1.0000000e-001	-1.0000000e+000	7.9000000e+000
3.0000000e-001	-5.2287875e-001	7.4000000e+000
6.0000000e-001	-2.2184875e-001	6.8000000e+000
1.0000000e+000	0.0000000e+000	6.2000000e+000
2.0000000e+000	3.0103000e-001	5.1000000e+000
4.0000000e+000	6.0205999e-001	4.3000000e+000
6.0000000e+000	7.7815125e-001	4.0000000e+000

[1] Paul Marmet, Redshift of Spectral lines in the Sun's Chromosphere, http://www.newtonphysics.on.ca/chromosphere
[2] L. A. Higgs, The Solar Red-shift, Monthly Notices of the Royal astronomical Society, Vol. 121, No. 5, 1960
[3] http://en.wikipedia.org/wiki/Gravitational_redshift
[4] R. Salman-Zade, Limb Effect of the Fraunhofer Lines in the Solar Spectrum, Soviet Astronomy-AJ Vol. 13/3, page 466-472, 1969
[5] M. Kirk, The Anatomy of Chromospheric Flares, New Mexico State University 2013
[6] M. Loukitcheva et al., The chromosphere above sunspots at millimeter wavelengths, http://arxiv-web3.library.cornell.edu/pdf/1403.3436v1.pdf
[7] J. F. Lemaire, Determination of coronal temperatures from electron density profiles, http://arxiv.org/ftp/arxiv/papers/1112/1112.3850.pdf
[8] M. Aschwanden, Chromospheric height and density measurements in a solar flare observed with rhessi, http://hesperia.gsfc.nasa.gov/mission_book/Aschwanden2002.pdf
[9] Avrett, E.H., Loeser, R.: 2008, Models of the Solar Chromosphere and Transition Region from SUMER and HRTS Observations: Formation of the Extreme-Ultraviolet Spectrum of Hydrogen, Carbon, and Oxygen. Astrophys. J. Supp. 175, 229 – 276.
[10] H. Weidner, Inherent Energy Loss of the Thomson Scattering, http://vixra.org/abs/1312.0079
[11] http://en.wikipedia.org/wiki/Solar_transition_region
[12] C.S.Chen et al. “Investigation of the mechanism of spectral emission and redshifts of atomic line in laser-induced plasmas”. Optik 120 (2009) 473-478
[13] H. Weidner, The Hubble constant H0 is not constant, but proportional to the density of free electrons, http://vixra.org/abs/1405.0209
[14] Yi-Jia Zheng, Solar Coronal Heating and Limb Effect, http://arxiv.org/ftp/arxiv/papers/1305/1305.5659.pdf
[15] Appenzeller, I., and Schroter, E., H., 1967, ApJ, 147, 1100