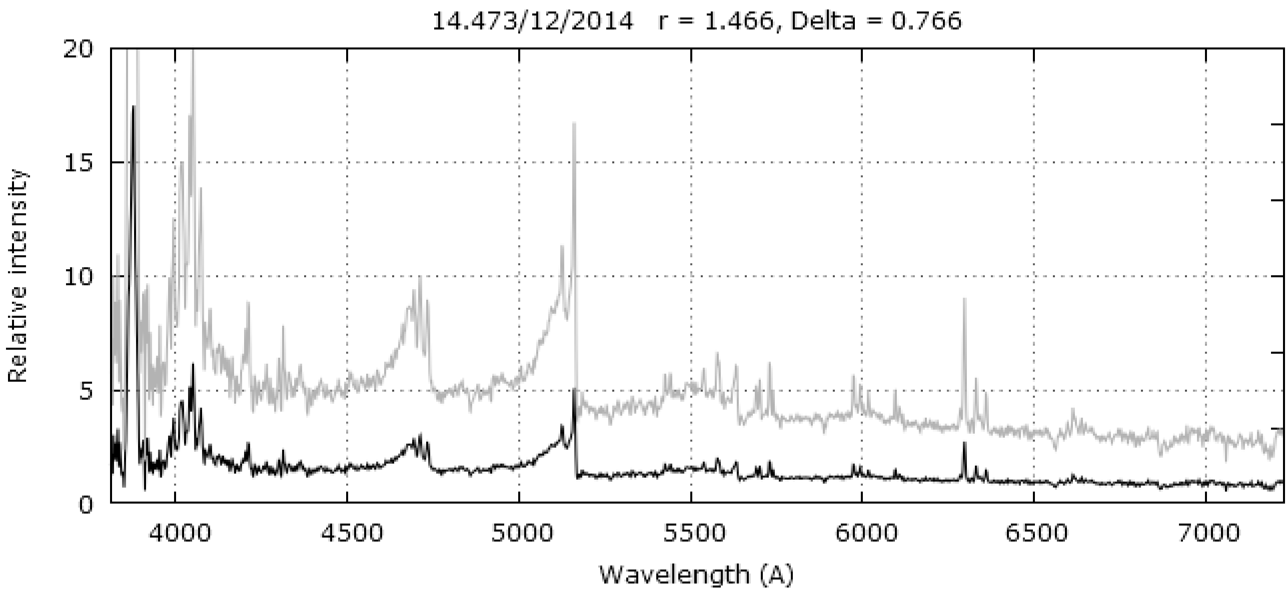
Comet C/2014 Q2 (Lovejoy) ARAS observations   By Paolo Berardi

The recent comet, discovered by the Australian amateur astronomer Terry Lovejoy and designated C/2014 Q2, has become an exciting spectroscopic target thanks to its brightness and comfortable position in the sky for northern hemisphere observers. It reached visual magnitude 3.9 in mid-January shining fairly high in the northern sky (it wasn't expected to become this bright).

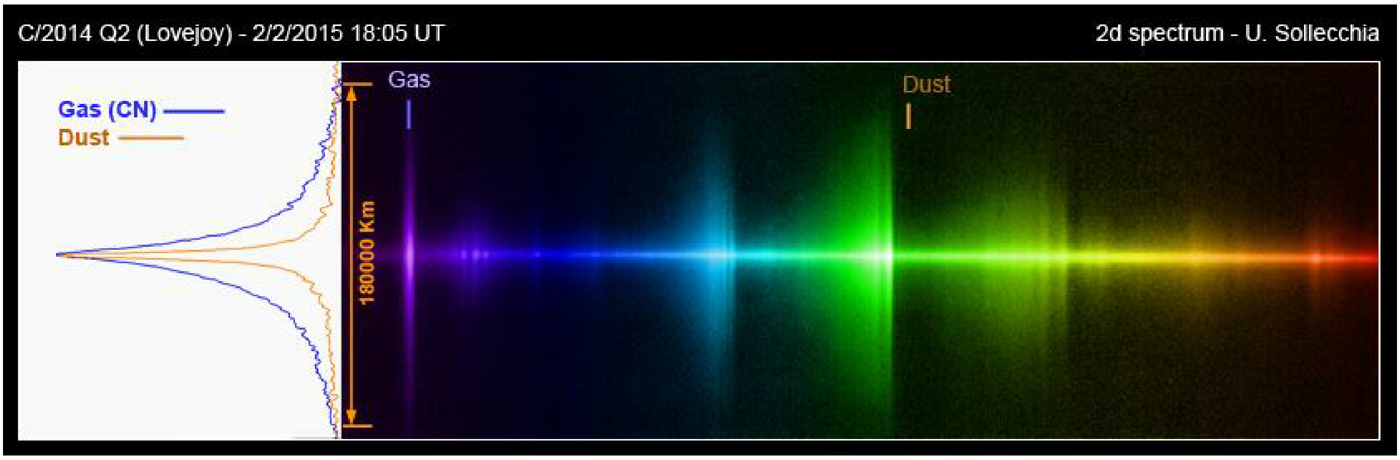
During the approach, comet C/2014 Q2 has crossed the sky from south to north so, as expected, the first spectrum of ARAS observers group arrived from an Australian amateur. On 14 December 2014, Terry Bohlsen observed the comet, shining at mag ~ 6.3, taking a spectrum with Lisa spectrograph.



Black line shows the spectrum scaled by the strongest feature while gray line profile has an expanded ordinate to better show the weaker features. Date, heliocentric (r) and geocentric (Delta) distances are shown at the top.

We can see several features that are very common in spectra of comets approaching the Sun. Most of them are due to electronic transitions in radicals having a resonance-fluorescence excitation mechanism. Radicals are produced from photodissociation of parent molecules hit by the Sun light. The complex bands have fine structures, discernible in high resolution spectra, originated from vibrational and rotational levels of molecules.

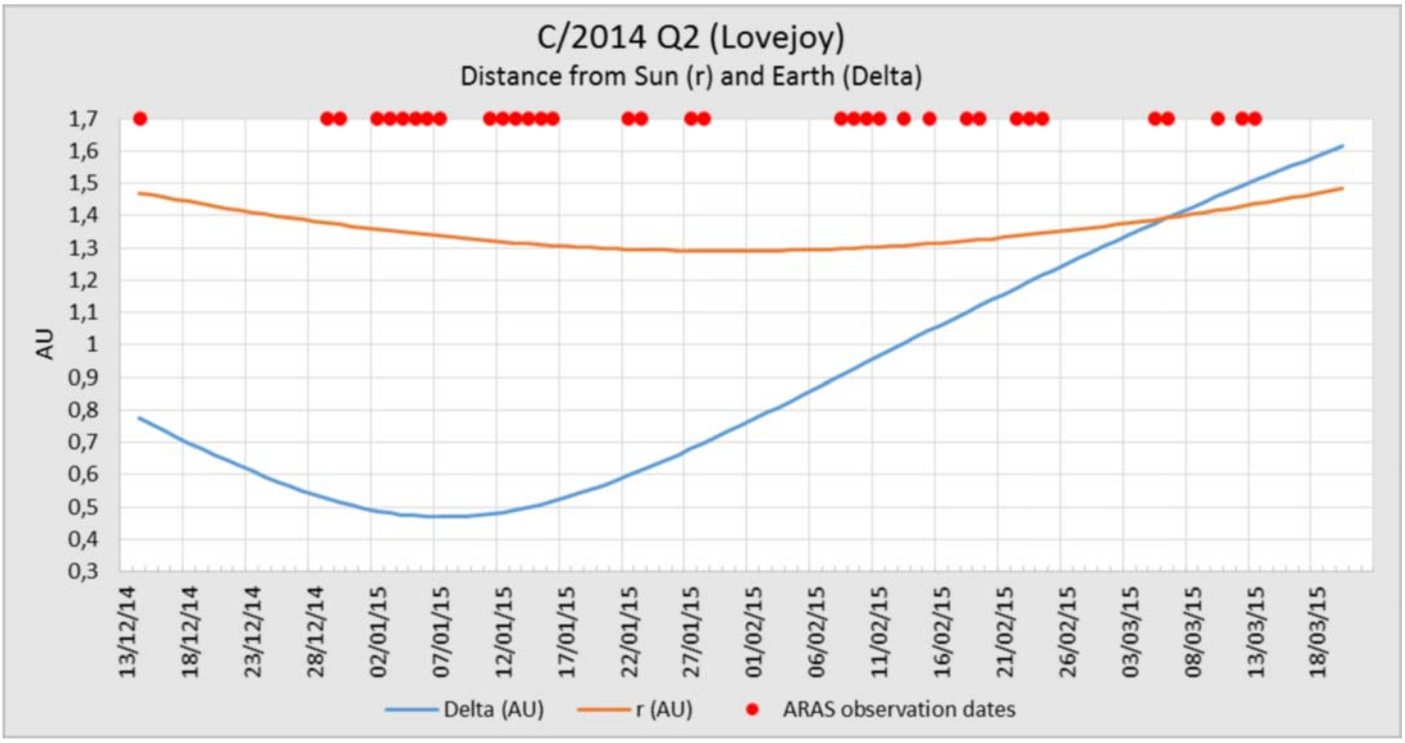
Being the light we receive from comets a combination of emissions due to gases released by the cometary nuclei material and sunlight reflected by dust grains, we also have a continuum in the spectrum (mostly concentrated in false nucleus zone). You may have an idea of the different spatial distribution of gases and dust in C/2014 Q2 comet looking at two-dimensional spectrum obtained with a long-slit spectrograph.



At very large heliocentric distances (r), comets spectra are essentially continuous (solar type). As comets approach the Sun, gas emissions becomes predominant, starting with first species CN (r < 3 AU), C3 and NH2 (r < 2 AU), C2 (r < 1.5 AU). Comets that get closer show several atomic lines in their spectra like Na (r < 0.8 AU) and other metals lines Fe, Cr, Ni,… (r < 0.1 AU) due to vaporization of grains.

The indicated distances are approximate. Sometimes NH2 and C2 (or CN and C3) emissions appears at the same time. Na emission lines intensity depends strongly on heliocentric radial velocity of comet because the Doppler shifted Na solar absorption lines modulate the fluorescence process. Not all comets have identical abundances of the parent species and gas-to-dust ratio may also vary with comet "age" (i.e. periodic comets can lose part of volatile elements due to frequent approaches to the Sun). The parameters C2/CN and C3/CN lines intensity ratio tell us if the comet is “carbon-chain depleted” or “typical” (it seem to be the C/2014 Q2 case).

Follows a graph showing the comet distance from Sun and Earth during the approach. Red marks on top relating to ARAS observations.



The C/2014 Q2 heliocentric distance was always below 1.5 AU with a minimum value of 1.29 AU on perihelion.

During the observing period, comet Lovejoy showed a relatively large amount of gas compared to dust. That is why the coma appears in photos with an intense green-blue tint. Indeed, in the optical spectrum of C/2014 Q2 we find strong emission bands of radicals CN (388 nm), C_2 (three dominant bands from 450 to 565 nm), C_3 (405 nm), NH_2 (several bands from 520 to 740 nm). See also the color distribution in 2d spectrum showed above.

Spectra also reveal a strong contribution from atomic oxygen, one of the source elements of light in auroras. The forbidden lines of oxygen are located at 5577A (green line) and 6300/6364A (red doublet). Much of the cometary oxygen is contained in H_2O ice that undergo photodissociation producing also excited atoms. Thus, the line at 6300A can be used to estimate the H_2O production rate.

Also molecular ion lines can be found on cometary spectra due to photolytic processes and chemical reactions in the comae. Could be the presence of H_2O^+ lines around 620 nm in comet Lovejoy observed spectra. Generally, strongest CO^+ emissions bands in UV/blue spectral region are responsible for the blue appearance of the ion tail in color images of comets.

It should be noted that high resolution ARAS spectra show a very large number of emission lines, including many I wasn't able to identify (apart radical band structures). It would be desirable an in-depth analysis.

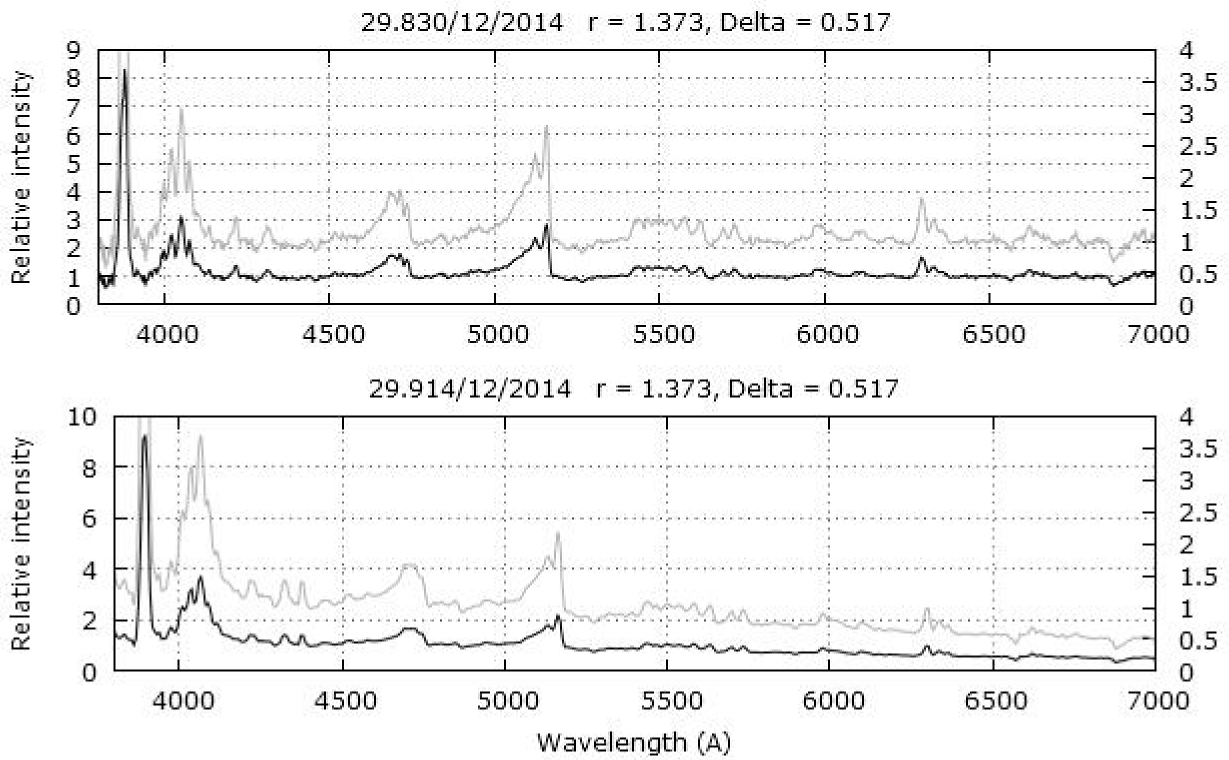
Spectral data in standard FITS are collected and made available through ARAS webpage:

http://www.astrosurf.com/aras/Aras_DataBase/Comets/Comets/Comets.htm

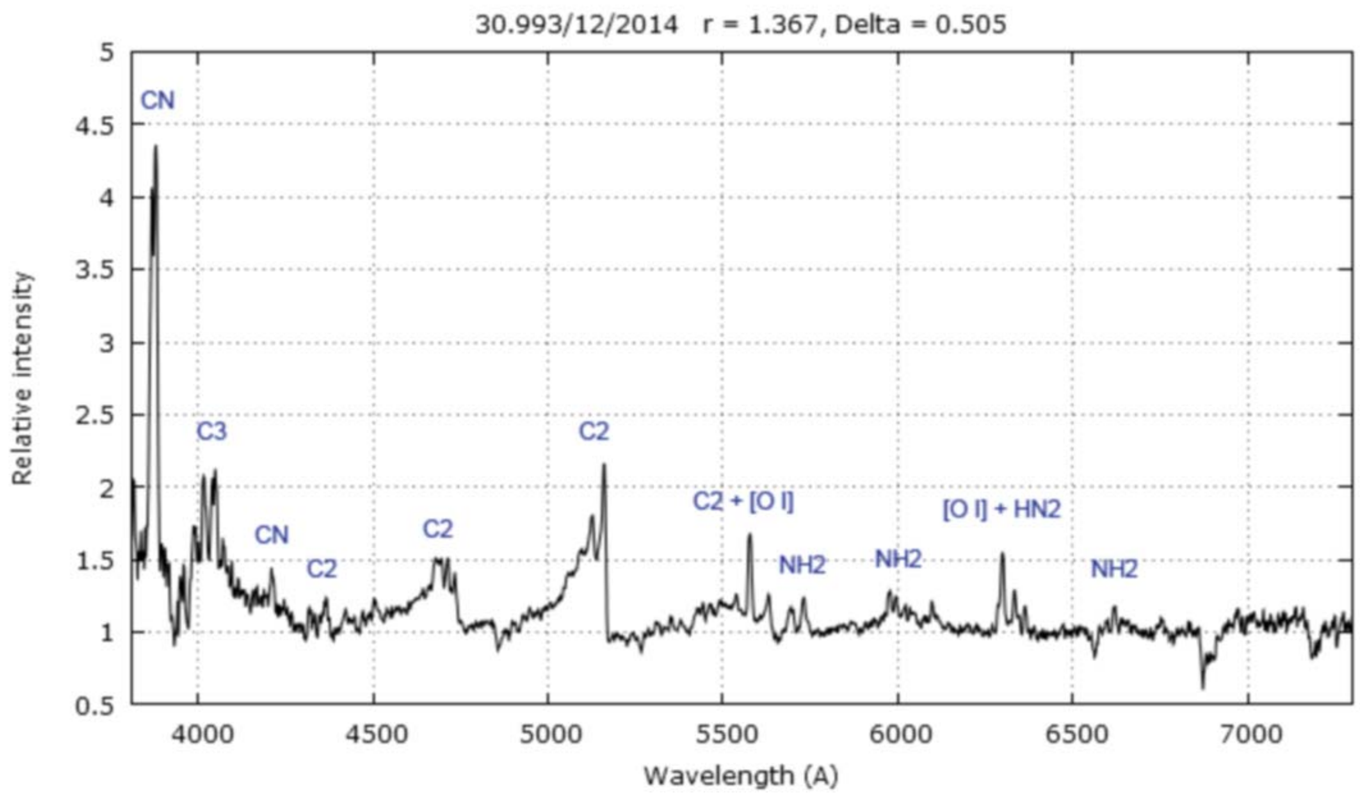
Many of them relating to false nucleus and inner coma (see specific cases in the name of files). Some profiles are divided by a solar analog spectrum (Moon or G2V type star), so the resulting spectrum is a combination of reflectance continuum and gas emissions. Other profiles are Sun spectrum subtracted, showing only the emission components.

We used a wide range of spectrographs/gratings and, thanks to comet brightness and actual powerful equipment, we were able to push resolving power up to R=50000! May be this is the first time a comet was observed with such a high detail by amateurs.

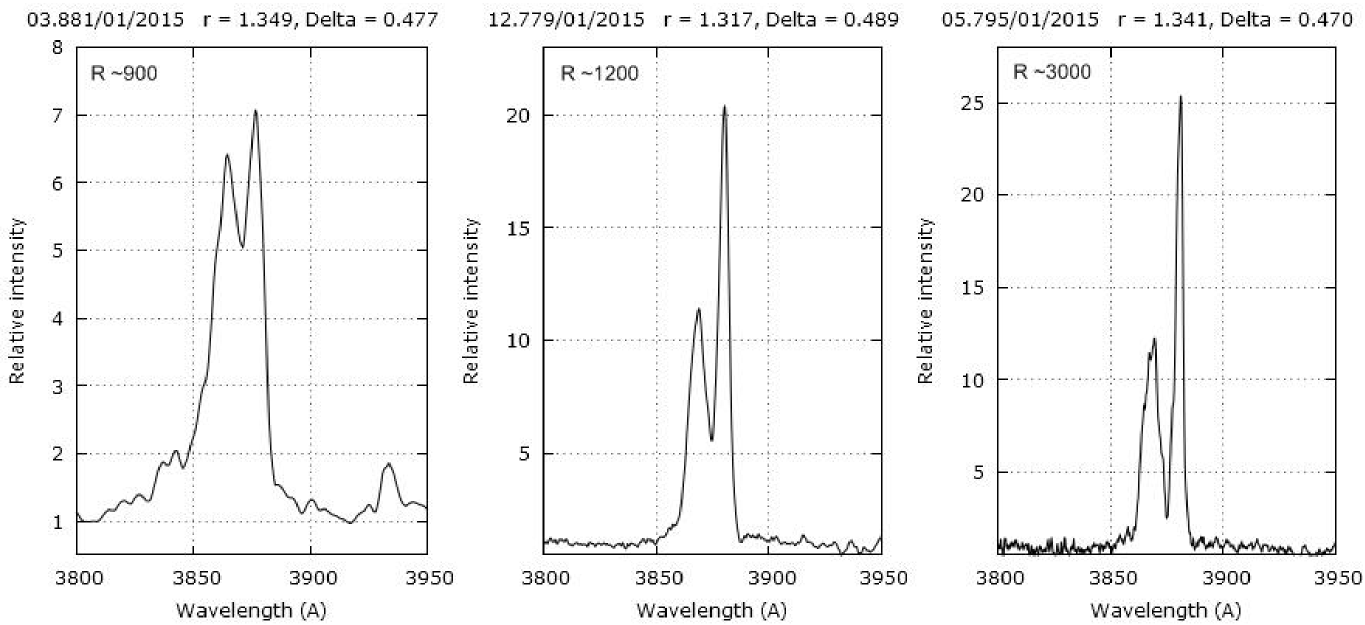
Northern hemisphere observers taken first spectra on 29 December 2014. Umberto Sollecchia and Pierre Dubreuil have observed the comet at low altitude above the horizon (V mag ~ 4.7) with a DIY spectrograph and an Alpy 600 respectively:



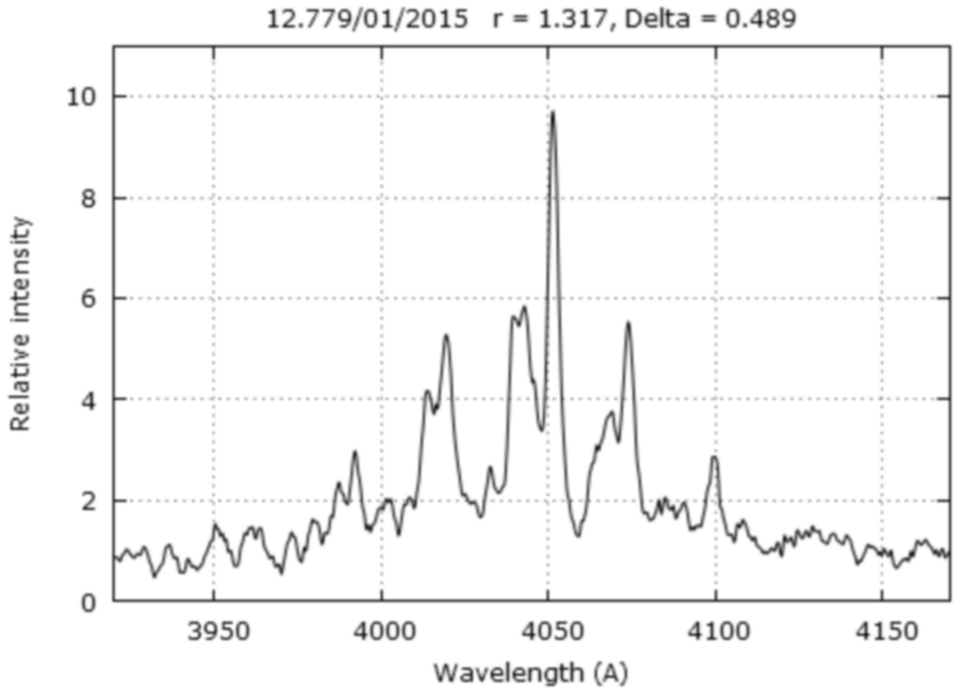
Spectrum by Jacques Montier (30/12/2014) with labels on main emission features (note there might be a terrestrial contribution of auroral 5577A emission line):



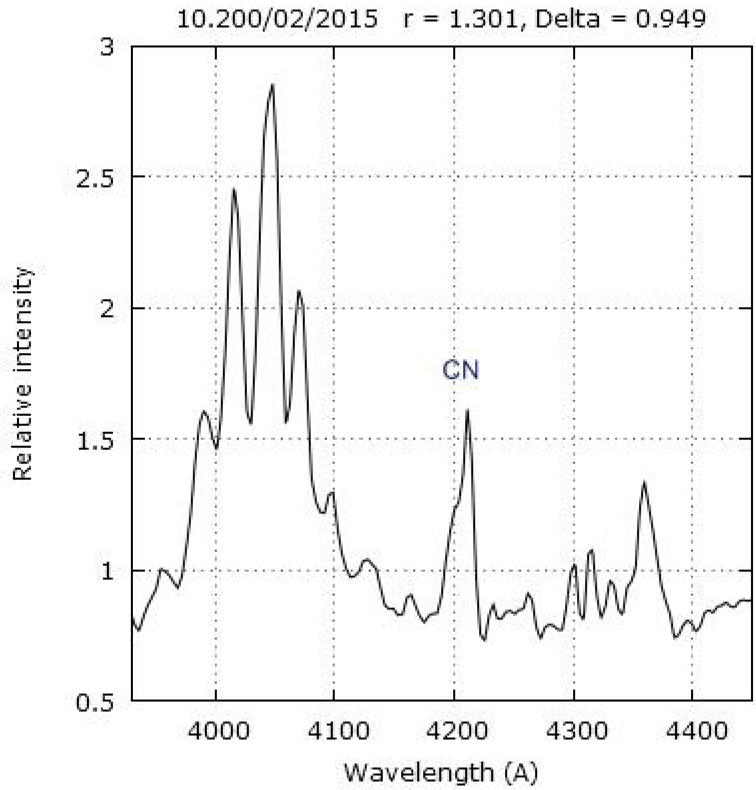
The CN electronic transitions produce the strong emission peak around 3875A. It is composed of two close branches (R-branch and P-branch). They are influenced by the presence of Fraunhofer absorption lines in the solar spectrum, so they strongly vary with heliocentric radial velocity of comet due to the Doppler shift (Swings effect, the same about Na D lines mentioned above). Also the heliocentric distance and the motion of radicals within the comet (cometary atmosphere is not stationary) have an impact, smaller, on their shape. The resolution allows the distinction of P and R branches but is still insufficient to resolve the rotational lines fine structure. CN bands in ARAS spectra by Joan Guarro, Christian Buil and Paolo Berardi (note the effect of spectral resolution on branches separation):



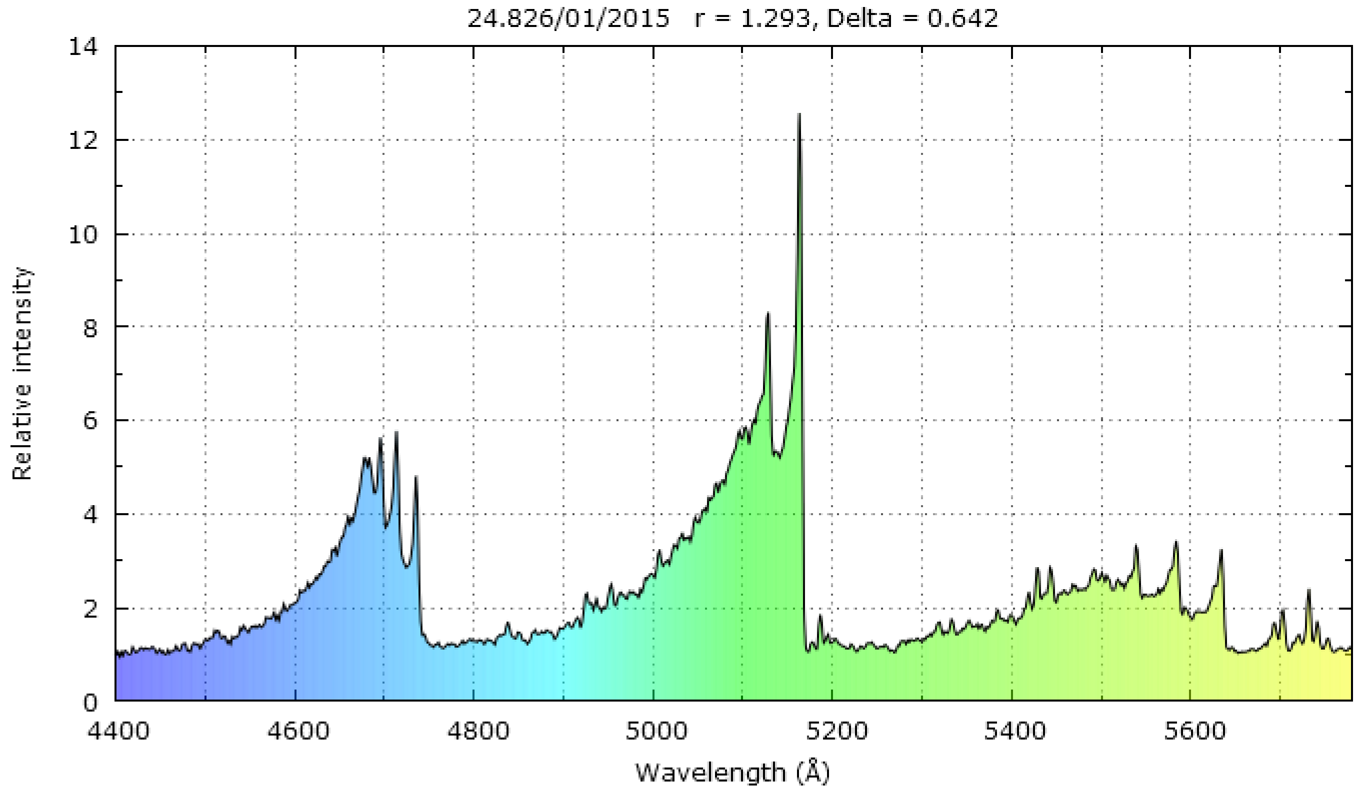
Basic structure of main C3 emission band. Since the difficulty of exciting C3 in the laboratory, identification of many lines is missing (lines attributable to this radical span from 3350 to 4700A). Spectrum by Christian Buil taken with a Lhires III spectrograph and 600 l/mm grating:



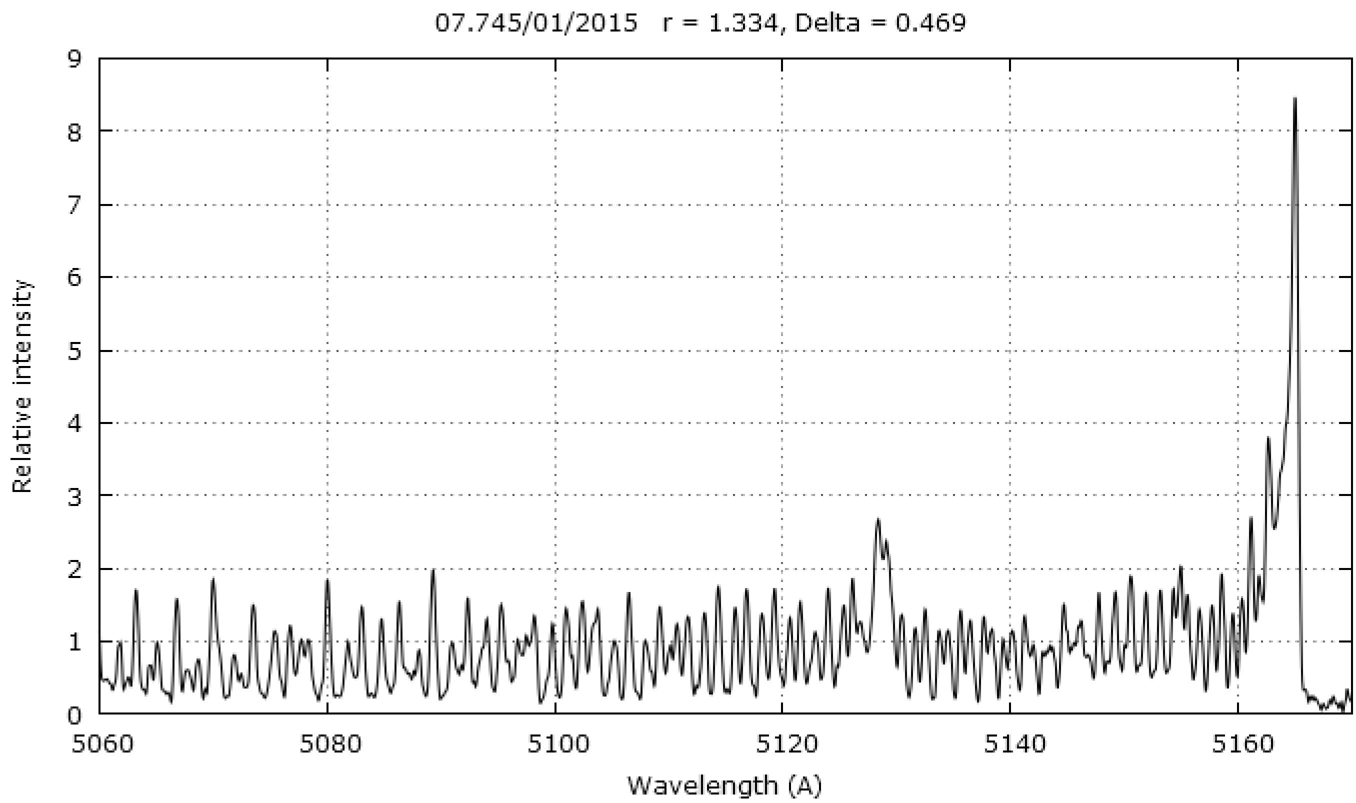
Another CN band from 4190 to 4215A is clearly visible in low-res profile by Jim Edlin (Lisa spectrograph):



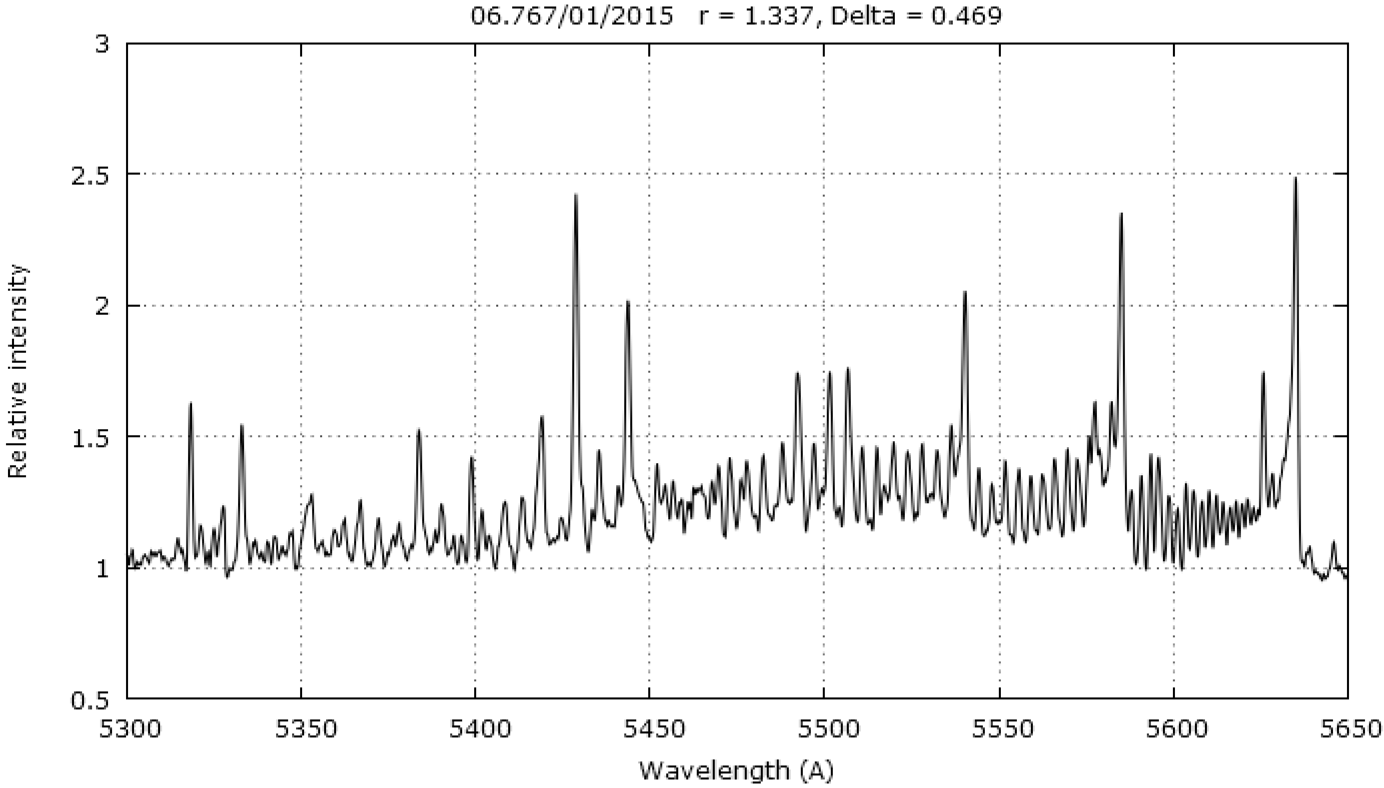
The main Swan bands of diatomic carbon C2 in a low-resolution spectrum (Lisa, R ~1200) by David Boyd, plotted with ISIS/Gnuplot and a modified script for coloration by Serge Golovanow. Some NH2 lines are included in the spectral interval:



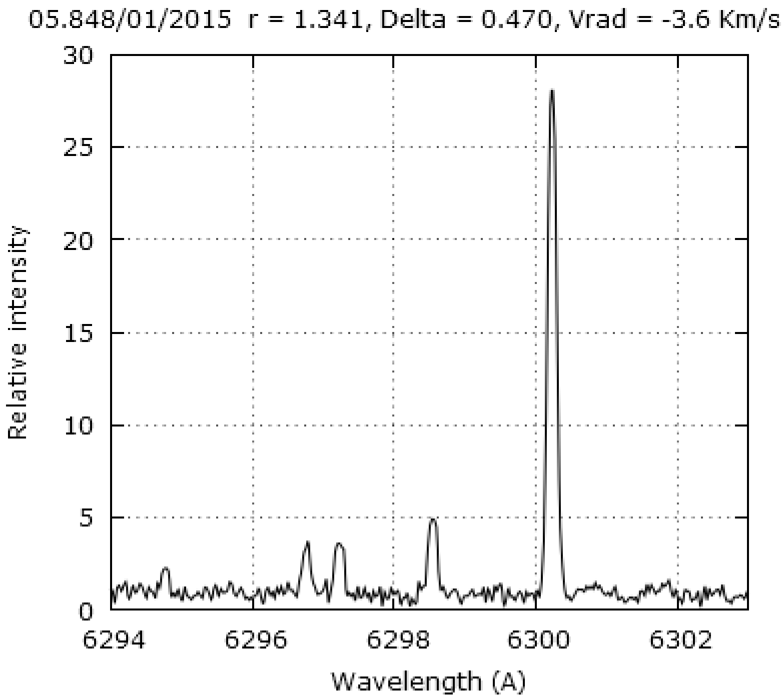
The first third of the most prominent Swan band with discerned fine structure (it need more resolution to resolve completely the rotational lines). High resolution spectrum by Christian Buil (eShel spectrograph, R ~11000). This is part of an excellent comet spectrum that span from 4280 to 7350A:



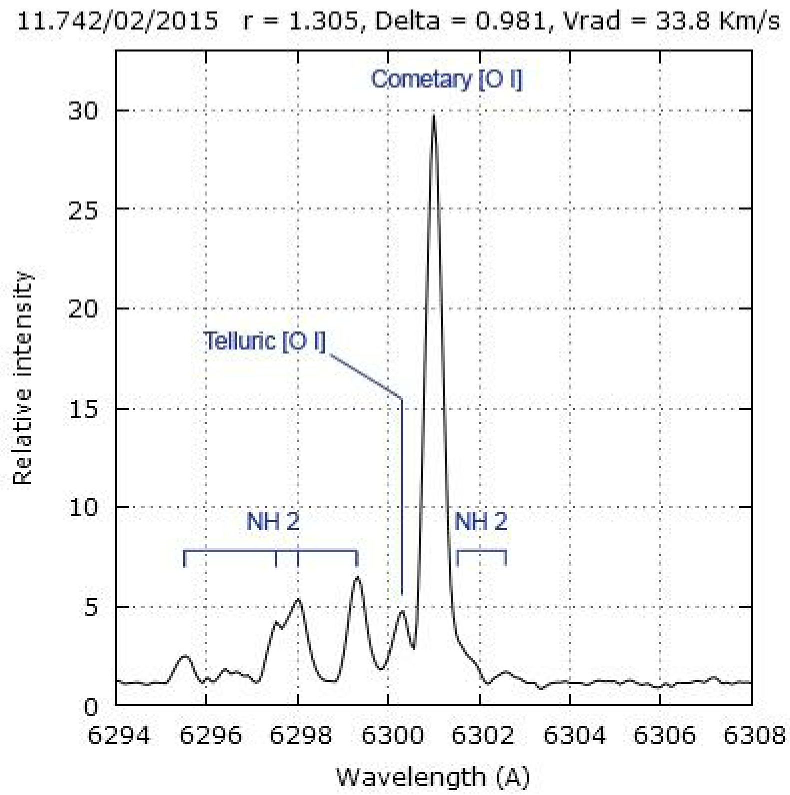
The Swan band from 5300 to 5650A range. Spectrum R ~ 5000 by Paolo Berardi (Lhires III, 1200 l/mm grating):



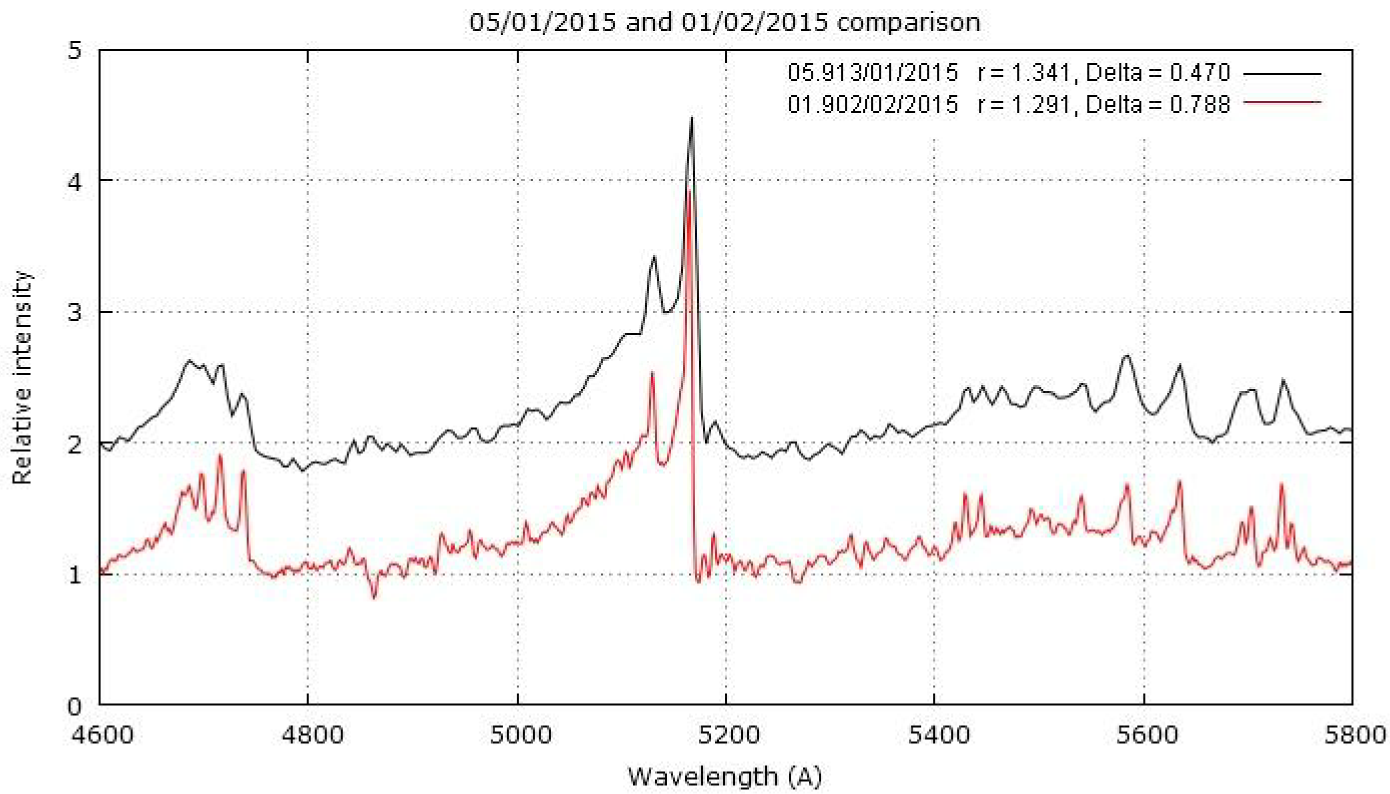
The oxygen [O I] 6300.304A line in a very high resolution spectrum (R ~50000). Christian Buil, VHIRES spectrograph. Some NH2 lines are visible to the left of the oxygen line. The geocentric radial velocity value is added in the title:



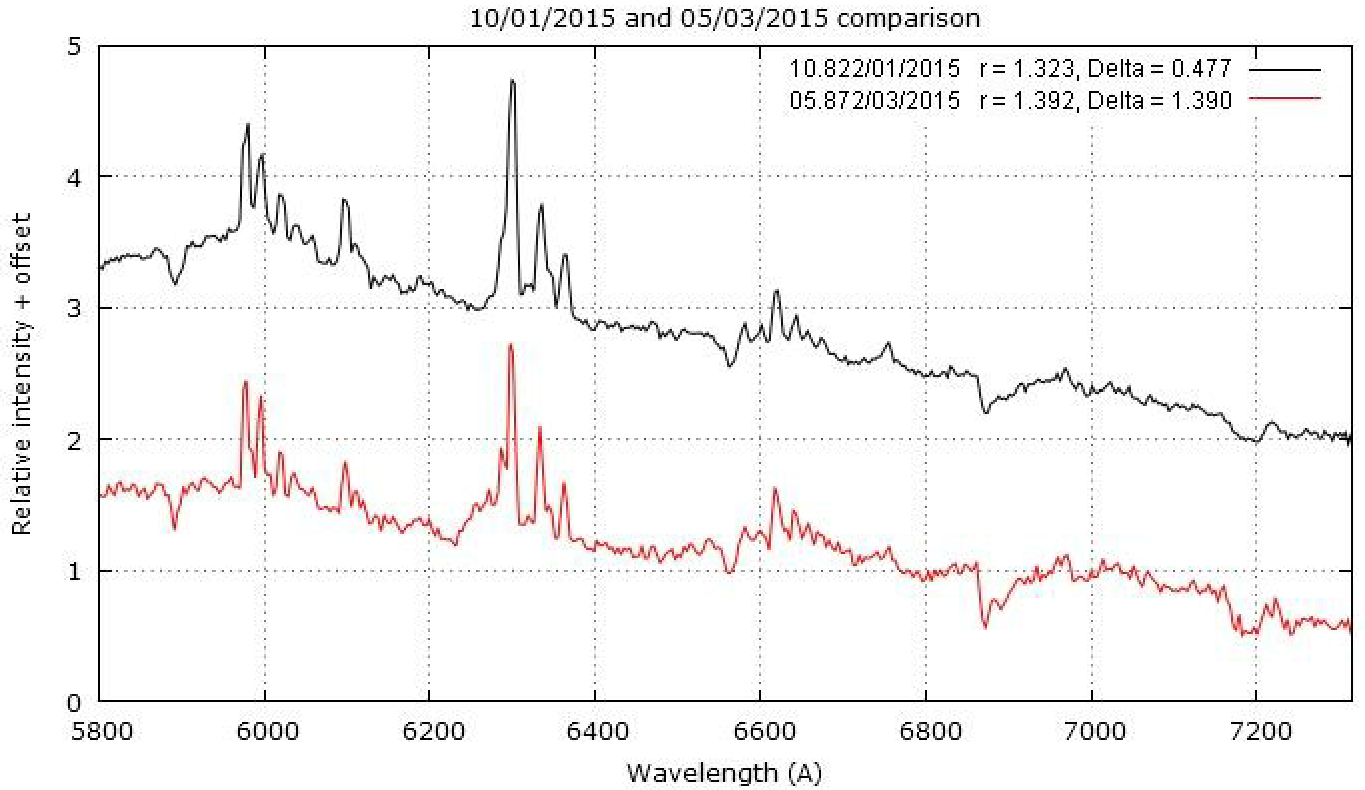
In low-res spectra, cometary [O I] 6300A is blended with airglow oxygen line (telluric origin) and nearby NH2 lines (0,8,0 band). High resolution spectra allow to separate oxygen line from the NH2 band members but cometary emission remains coincident with telluric line. In several long-slit observations (Lhires III) I have been able to check that airglow contribution was only a little fraction of cometary emission. That was clearly confirmed by a subsequent observation made when the comet moved away and geocentric velocity produced an appreciable red-shift of its spectrum (R ~15000, Lhires III, 2400 l/mm grating):



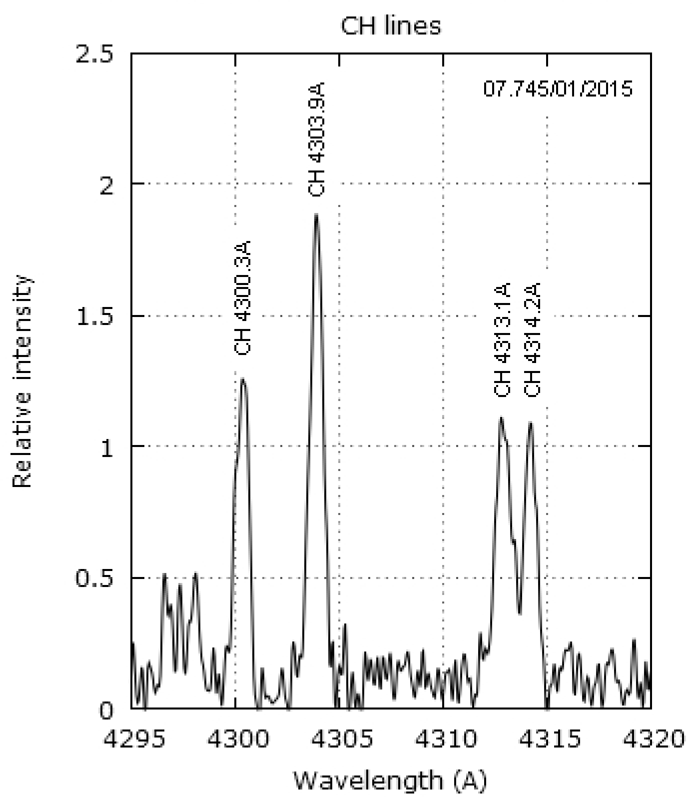
Spectral evolution of spectrum between 5/1 (Nico Montigiani/Massimiliano Mannucci, Lhires III 150) and 1/2 (David Boyd, Lisa):

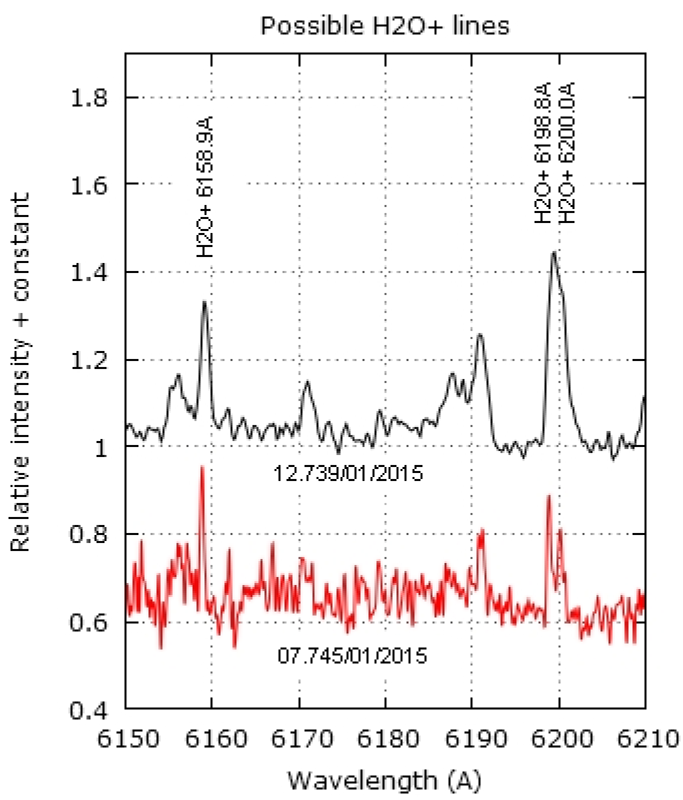


Spectral evolution of red part of spectrum between 10/1 (Francois Cochard, Alpy 600) and 5/3 (Hubert Boussier, Lisa):

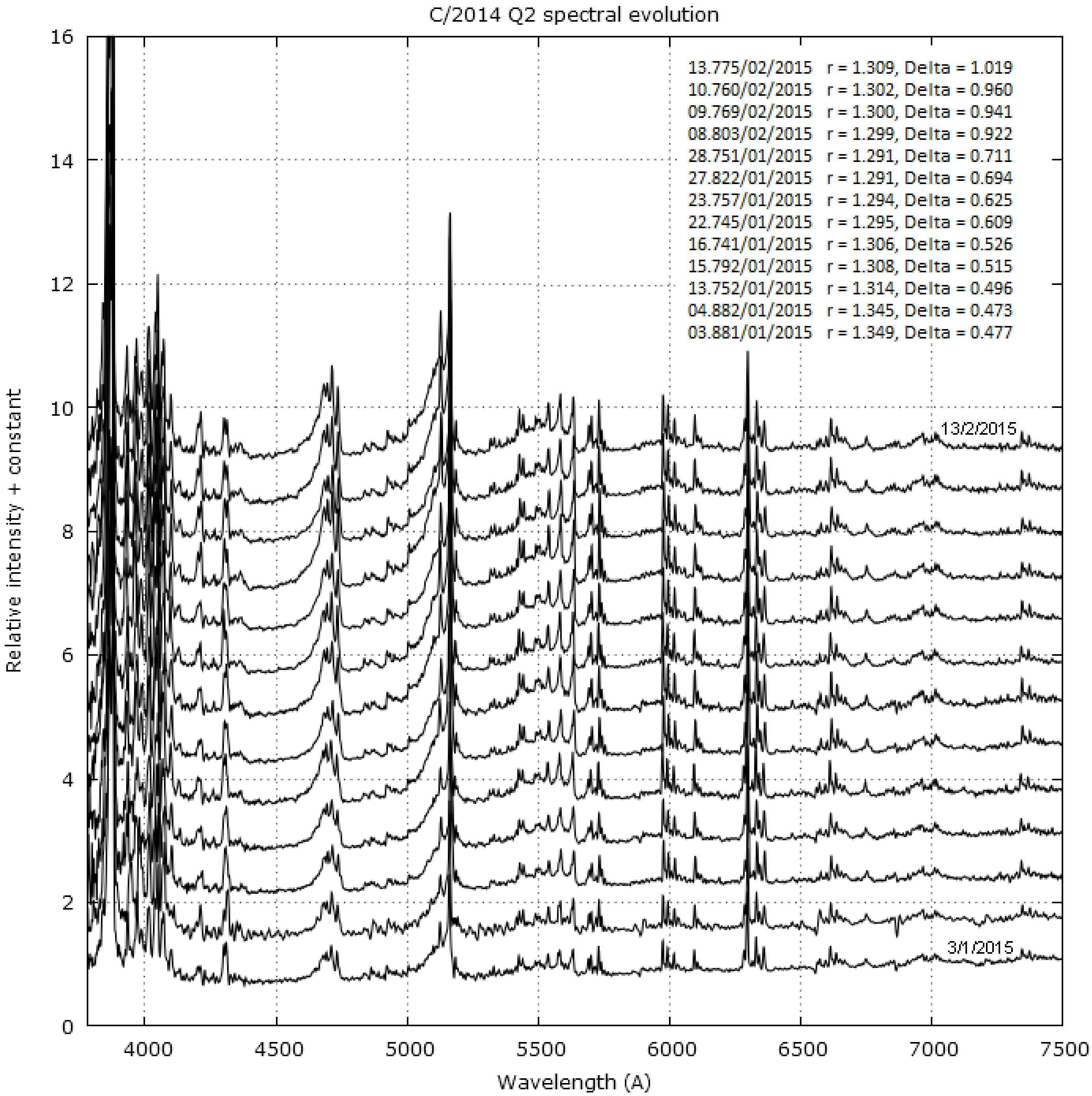


CH radicals derive from CH2, in turn by methane CH4, the probable parent molecule. Some lines of CH band near 4314A are clearly visible in high resolution spectrum (R ~11000, eShel spectrograph) by Christian Buil. Also lines of H2O+ ion with doublet at 6198 and 6200A could be present near 6200A in a pair of spectra (eShel - 7/1, Lhires III 1200 – 12/1). Unfortunately we have not comet tail spectra to confirm the H2O+ lines:

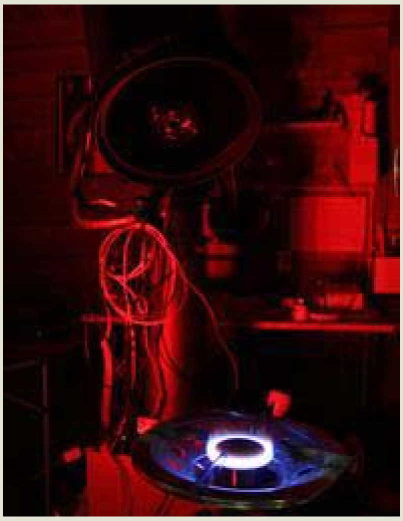




The great series of low-resolution spectra by Joan Guarro, obtained with B60050-VI DIY spectrograph (note this is a subset, there are other observations with a wide temporal coverage).

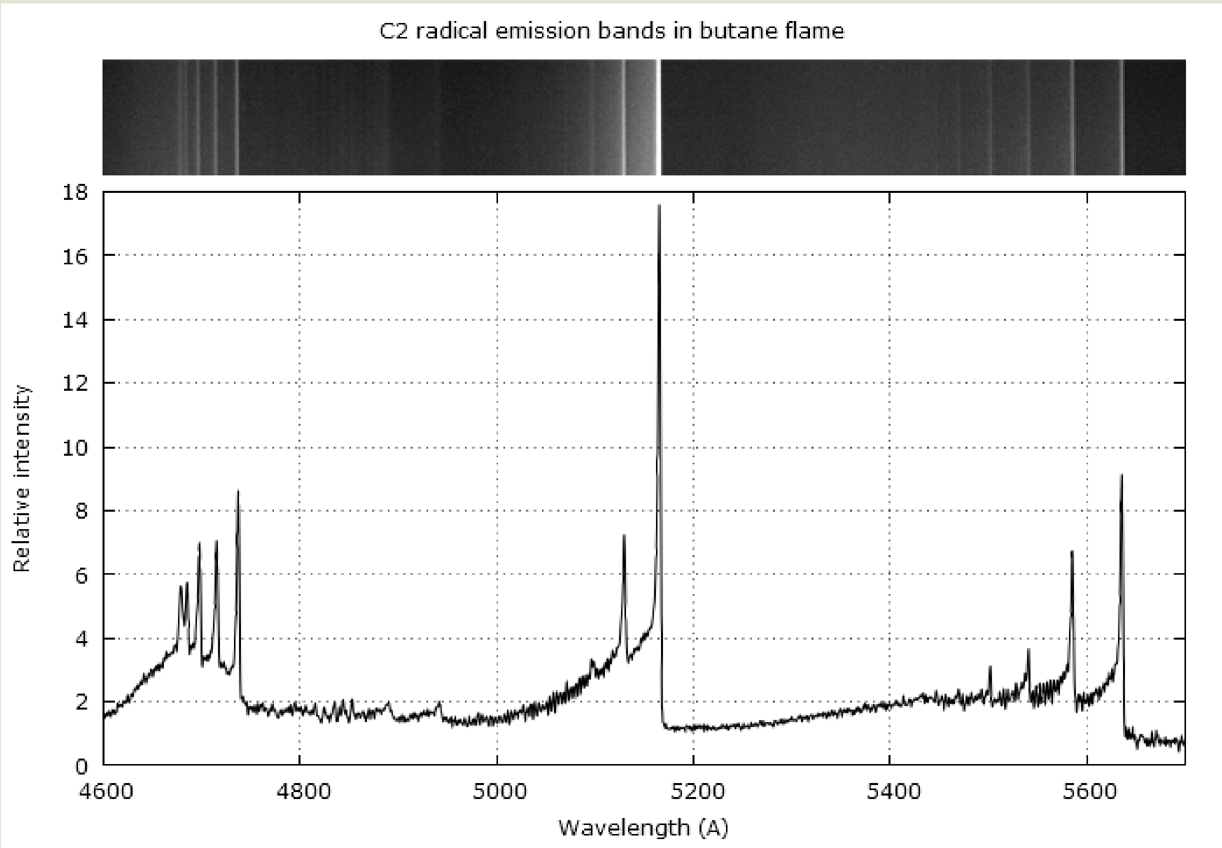


A homemade comet spectrum



C2 radicals are continuously produced by molecules dissociation in the flame of any hydrocarbons such as butane used for this "laboratory" experience. Then, you can observe the Swan emission bands in the spectrum of its flame. Note the color of the flame is not green but more bluish due to a strong CH emission band near 4315A (not included in the profile below). The spectrum is obtained using a Lhires III spectrograph with 600 l/mm grating (two spectral region joined to include the three main Swan bands). Note the analogy with the dominant C2 bands observed in the comet Lovejoy spectrum.

The famous emission bands bear the name of discoverer, William Swan, that studied laboratory flames and describes them to the Royal Society of Edimburgh in 1856. Gian Battista Donati was first to report the appearance of Swan bands in a comet spectrum (Tempel) in 1864 and William Huggins, in 1868, confirmed their presence in the spectrum of comet Winnecke.



C/2014 Q2 ARAS observers

P. Berardi
T. Bohlsen
H. Boussier
D. Boyd
C. Buil
F. Cochard
P. Dubreuil
J. Edlin
J. Guarro
M. Mannucci
J. Montier
N. Montigiani
U. Sollecchia

References

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Nicolas Biver, LESIA, UMR8109 du CNRS, Observatoire de Paris-Meudon.

A High-Resolution Catalogue of Cometary Emission Lines
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The cometary fluorescence spectrum of cyanogen: a model
M. Kleine, S. Wyckoff, P. Wehinger
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Feldman, P. D.; Cochran, A. L.; Combi, M. R.
Comets II, M. C. Festou, H. U. Keller, and H. A. Weaver (eds.), University of Arizona Press, Tucson, 745 pp., p.425-447

Observations of O (1S) and O (1D) in Spectra of C/1999 S4 (LINEAR)
Anita L. Cochran, William D. Cochran
arXiv:astro-ph/0108065

Astrophysics - A modern perspective
K.S. Krishna Swamy
New Age International (P) Ldt., Publisher

Computational Spectroscopy: Methods, Experiments and Applications
Edited by Jörg Grunenberg - ISBN: 978-3-527-32649-5

About ARAS initiative

Astronomical Ring for Access to Spectroscopy (ARAS) is an informal group of volunteers who aim to promote cooperation between professional and amateur astronomers in the field of spectroscopy.

To this end, ARAS has prepared the following roadmap:

- Identify centers of interest for spectroscopic observation which could lead to useful, effective and motivating cooperation between professional and amateur astronomers.
- Help develop the tools required to transform this cooperation into action (i.e. by publishing spectrograph building plans, organizing group purchasing to reduce costs, developing and validating observation protocols, managing a data base, identifying available resources in professional observatories (hardware, observation time), etc.
- Develop an awareness and education policy for amateur astronomers through training sessions, the organization of pro/am seminars, by publishing documents (web pages), managing a forum, etc.
- Encourage observers to use the spectrographs available in mission observatories and promote collaboration between experts, particularly variable star experts.
- Create a global observation network.

By decoding what light says to us, spectroscopy is the most productive field in astronomy. It is now entering the amateur world, enabling amateurs to open the doors of astrophysics. Why not join us and be one of the pioneers!

Be Newsletter

Previous issues :

http://www.astrosurf.com/aras/surveys/beactu/index.htm

Searching for new Be Stars

Andrew Smith and Thierry Lemoult

New ARAS Page

http://www.astrosurf.com/aras/be_candidate/auto-be-candidate.html

Comet C2014_Q2 LOVEJOY

spectra gathered in ARAS data base

http://www.astrosurf.com/aras/Aras_DataBase/Comets/Comets/Comets.htm

Contribution to ARAS data base

From 01-03 to 31-03-2015

D. Boyd
C. Buil
J. Edlin
J. Guarro
J. Montier
J. Powles
U. Sollecchia
P. Somogyi
F. Teyssier

Further information :
Email francoismathieu.teyssier at bbox.fr

Submit your spectra

Please :
- respect the procedure
- check your spectra BEFORE sending them

Resolution should be at least R = 500
For new transcients, supernovae and poorly observed objects,
SA spectra at R = 100 are welcomed

1/ reduce your data into BeSS file format
2/ name your file with: _novadel2013_yyyymmdd_hhh_Observer
novadel2013: name of the nova, fixed for this object

Exemple: _chcyg_20130802_886_toto.fit

3/ send you spectra to
Novae, Symbiotics : François Teyssier
Supernovae : Christian Buil
to be included in the ARAS database

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