Spectroscopic and photometric albedo of Uranus and Neptune in 2019

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EPSC - 2020

INTRODUCTION

Amateurs contribute to the study of Uranus and Neptune by taking images of a resolution high enough to image their brightest storms. This is done by imaging these planets in red and near infrared wavelengths (600 to 1000 nanometers). Over the past years, collaborations studies between professionals and amateurs have been fruitful and many articles can be found.

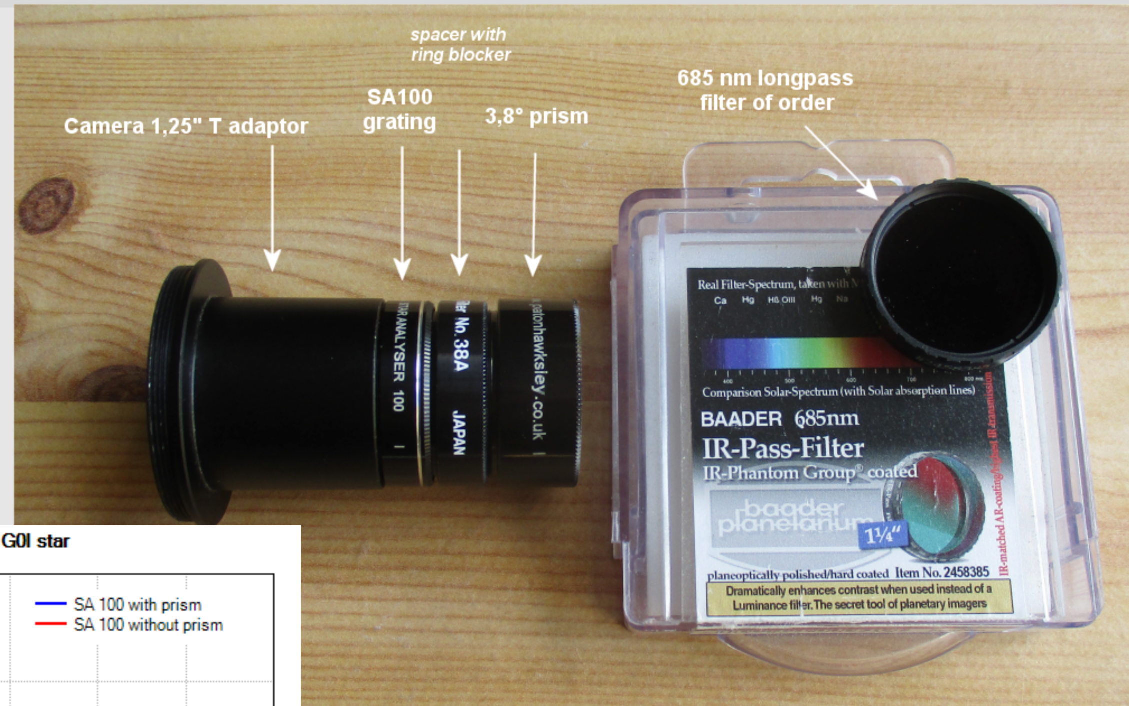
While high resolution imaging remains the main tool to follow these planets, they would benefit from a wider use of the technics of spectroscopy and photometry among the amateur community. In the mid 1990s, an extensive work of calculating full-disk albedo spectra of the four gas giants along with spectro-photometric data has been carried out by Erich Karkoschka (LPL, University of Arizona). In the amateur community, Richard Schmude from the Association of lunar and planetary observer has carried out some systematic surveys of Uranus and Neptune through UBVRI photometry.

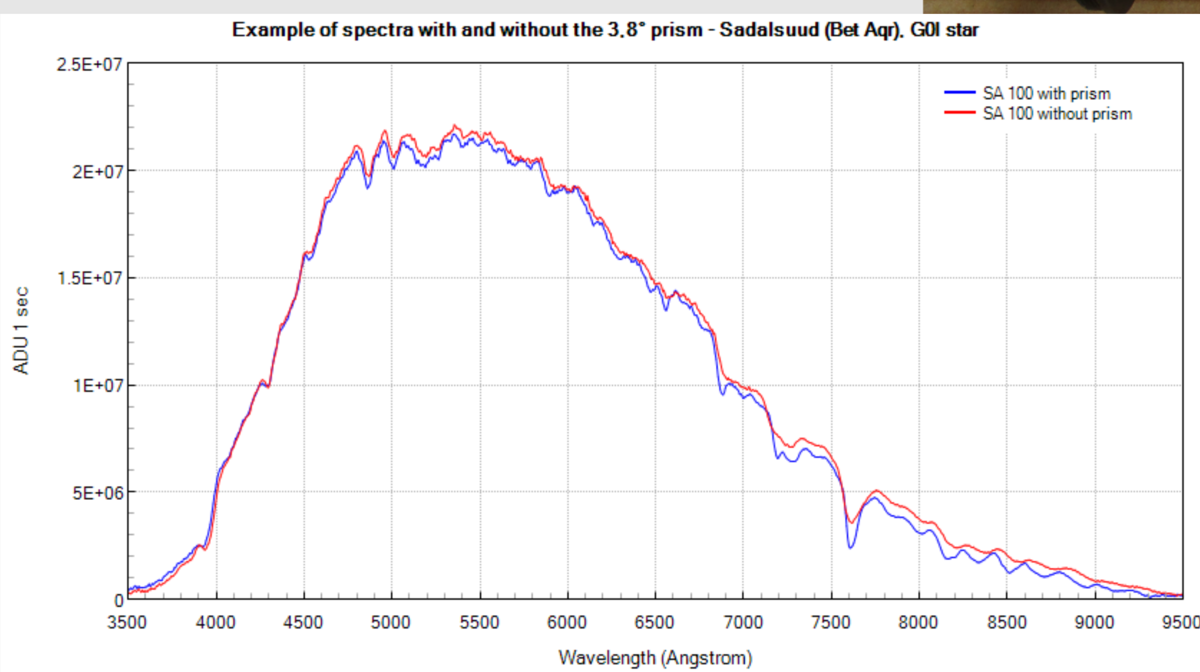
During the summer and winter of 2019-2020, the author has conducted a similar work with his own equipment and this poster presents the results.

Instrumentation and method

The author is using a 305 mm F/5 Newtonian on a Go-to altaz mount system, an ASI290MM b&w camera in 16 bits mode, a Star Analyzer 100 slitless grating equiped with a 3,8° prism. This configuration is called a *grism* and has been described by Christian Buil on his website. It has the advantage of correcting the chromatic coma of the original spectrum (the spectrum is not correctly focused at the same time at all wavelengths). It has also the advantage of providing a noticeable increase in spectral resolution in the red part of the spectrum.

The obtained spectra extend from around 380 to 900/950 nm at a resolution of around 10 nm or less. Due to the slitless configuration, the spectra are sensitive to the optical quality of the telescope, and to the steadiness of the sky during the observation (seeing)
It is also less easy to get spectra of large targets, but Uranus and Neptune, observed at prime focus, are small enough on the detector to produce relatively sharp spectra.





Instrumentation and method

To record the IR part of the spectrum, it is necessary to use a filter of order to avoid the contamination of the second order spectrum that begins around 7500 Angströms (or 750 nm). A 685 nm longpass IR filter is used and the two spectra are carefully merged in order to construct of full spectrum from around 350 nm to 1000 nm.
Below, the two spectra of Uranus on December 3rd, 2019

The softwares used are:

IRIS: processing of the spectra images
Visual Spec: multiwavelength spectral calibration, spectral merging
ISIS: math operations and spectro-photometry
Rspec: basic comparisons and manipulation of the data
Plot Spectra: graphics.

Instrumentation and method: the spectroscopic albedo

The formula to calculate the spectroscopic albedo is found in Erich Karkoschka's Icarus paper [1]

Albedo = (Δr/Ϭ)² x (Planetary ADU spectrum/ Sun ADU spectrum)

Where Δ and r are respectively the geocentric and heliocentric distances of the planet.
The basic method starts from the calculation of the *reflectance spectrum*, which is obtained simply by dividing the direct spectrum of the planet (calibrated in wavelength, but not corrected for the instrumental response) by the spectrum of a solar reference star.

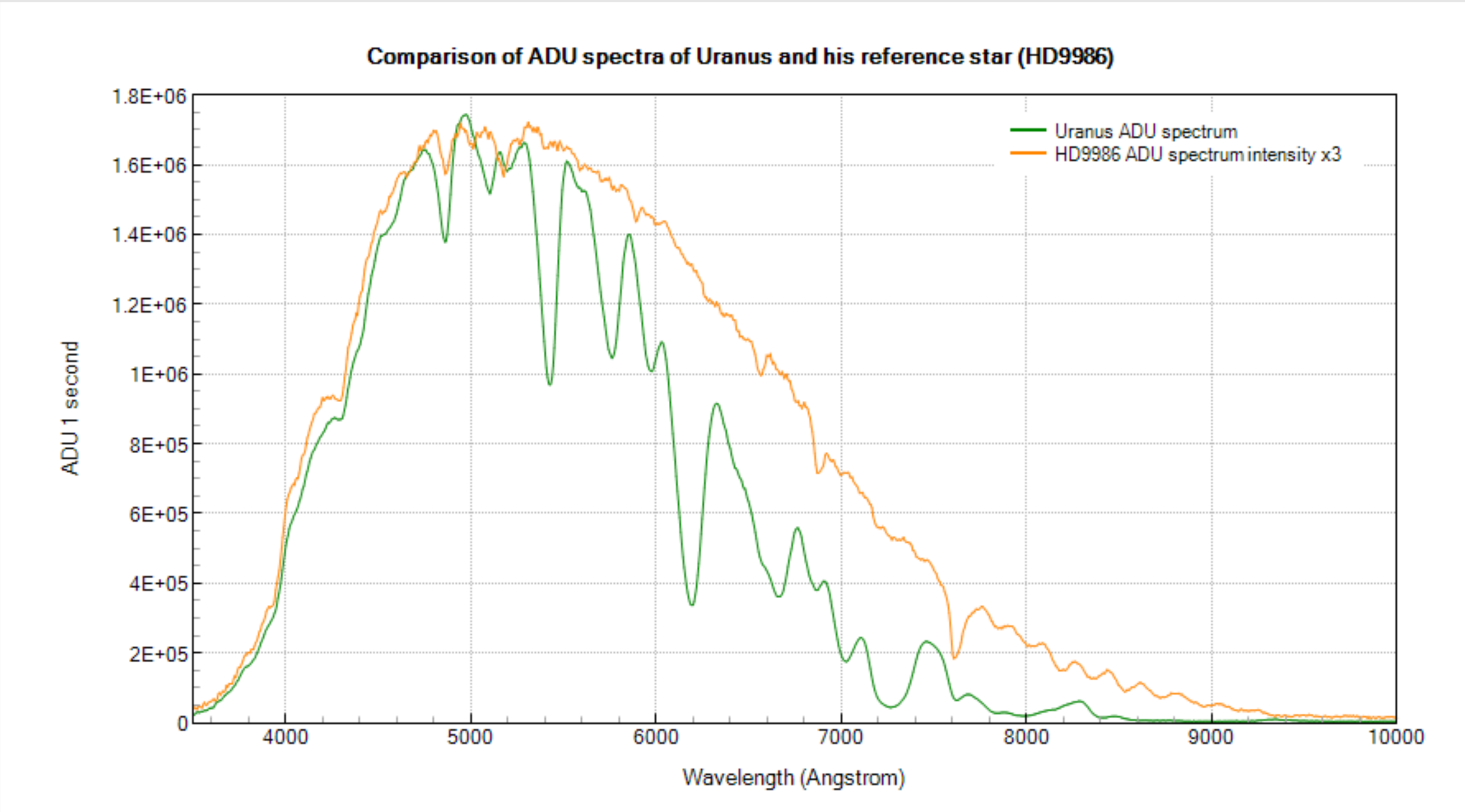
The next step is to correct the intensity of the solar star spectrum, so it matches the intensity that the Sun itself would have. First, we need to calculate how brighter is the Sun in comparison with the star. Here is the formula, starting from a Vmag=+6,75 star:

Mag-diff = 2,512exp(V_ref - V_Sun)
Mag-diff = 2,512exp(6,75- (-26,75))
Mag-diff = 2,542E+013

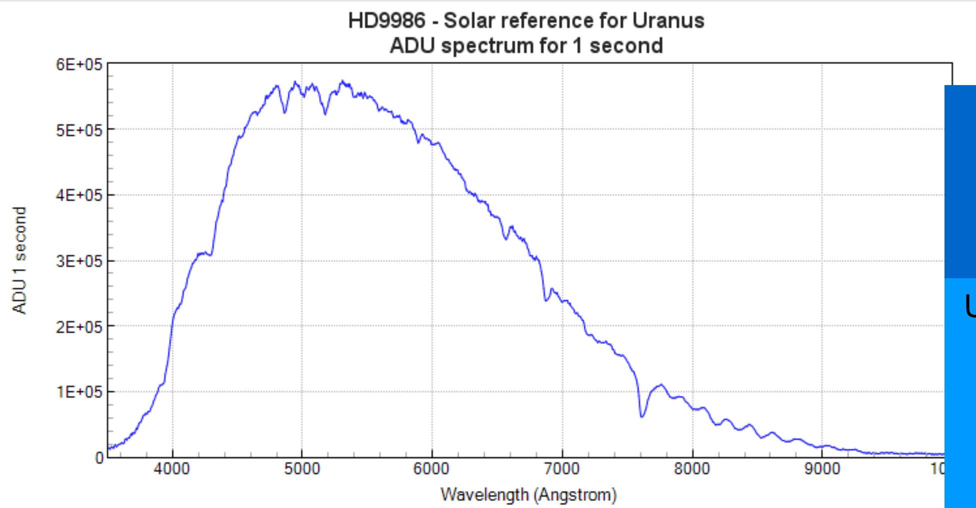
So the Sun is 2,542E+013 brighter than that star (33,511 magnitudes). The spectrum of the star expressed in ADU (for 1 second) is multiplied by this value. Then, the reflectance spectrum of the planet is multiplied by the formula above. The result is the **spectroscopic albedo**, which describes the capacity of the planet to reflect the Sunlight from 0 (complete absorption) to 1 (perfect reflection)

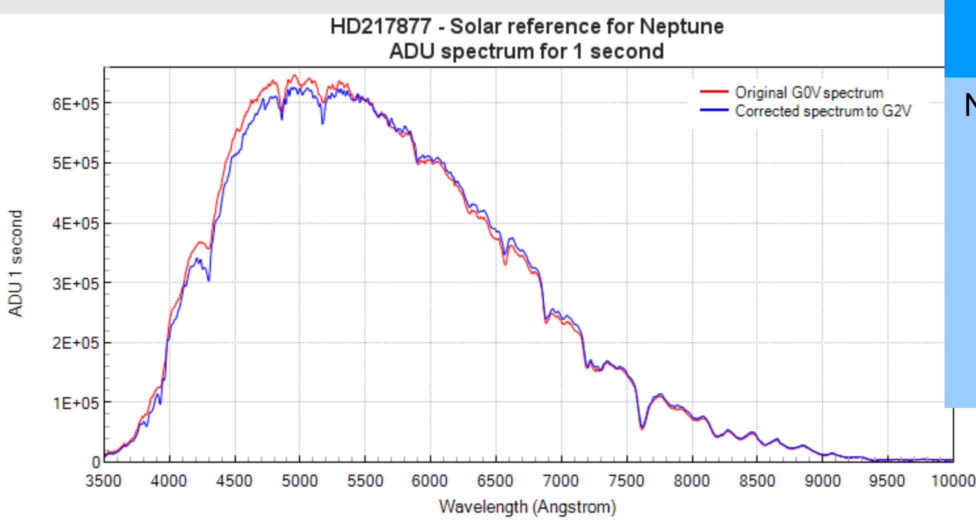
Instrumentation and method: the spectroscopic albedo

As an illustration these are the ADU spectra of Uranus and his solar reference star (see next slides), HD9986. The spectrum of the star is intensified 3 times.



Reference stars - description





Planet	HD number	V mag	Spectral type	Comments
Uranus	HD9986	+6,76	G2V or G3/G5V	The spectral type is a bit ambiguous. The SIMBAD basis ranges it as G2V, but the B-V color index of 0,67 would belong to a more later G type. The source reference lists this star as a "solar twin" with a spectrum "indistinguishable from that of the Sun" [2] In practice the obtained albedo profile looks correct.
Neptune	HD217877	+6,68	G0V	The 0 luminosity class is well visible on the direct spectrum. It has been modified before processing the albedo into a G2V spectrum, with a coefficient spectrum (G0V/G2V)

Instrumentation and method: the photometric albedo

The method to calculate the photometric albedo is found in Dr Richard Schmude's book [3]

First, it is necessary to calculate the normalized magnitudes of the planet. Normalized magnitudes calculate the brightness of a Solar System object as if it was located at one astronomical unit (AU) from the Sun, and one AU from the Earth (see [3] page 166).

The geometric albedo for each color band is given by the formula found in [3] – example for Neptune:

Geometric albedo of Neptune = 10exp(0,4 x (SUN_Nm - NEPT_Nm) - 2 X LOG (SIN σ)

Where Nm means "Normalized magnitude" and σ is the angular size of the radius of the target at a distance of 1AU in degree. To calculate σ R.Schmude gives for Neptune the formula:

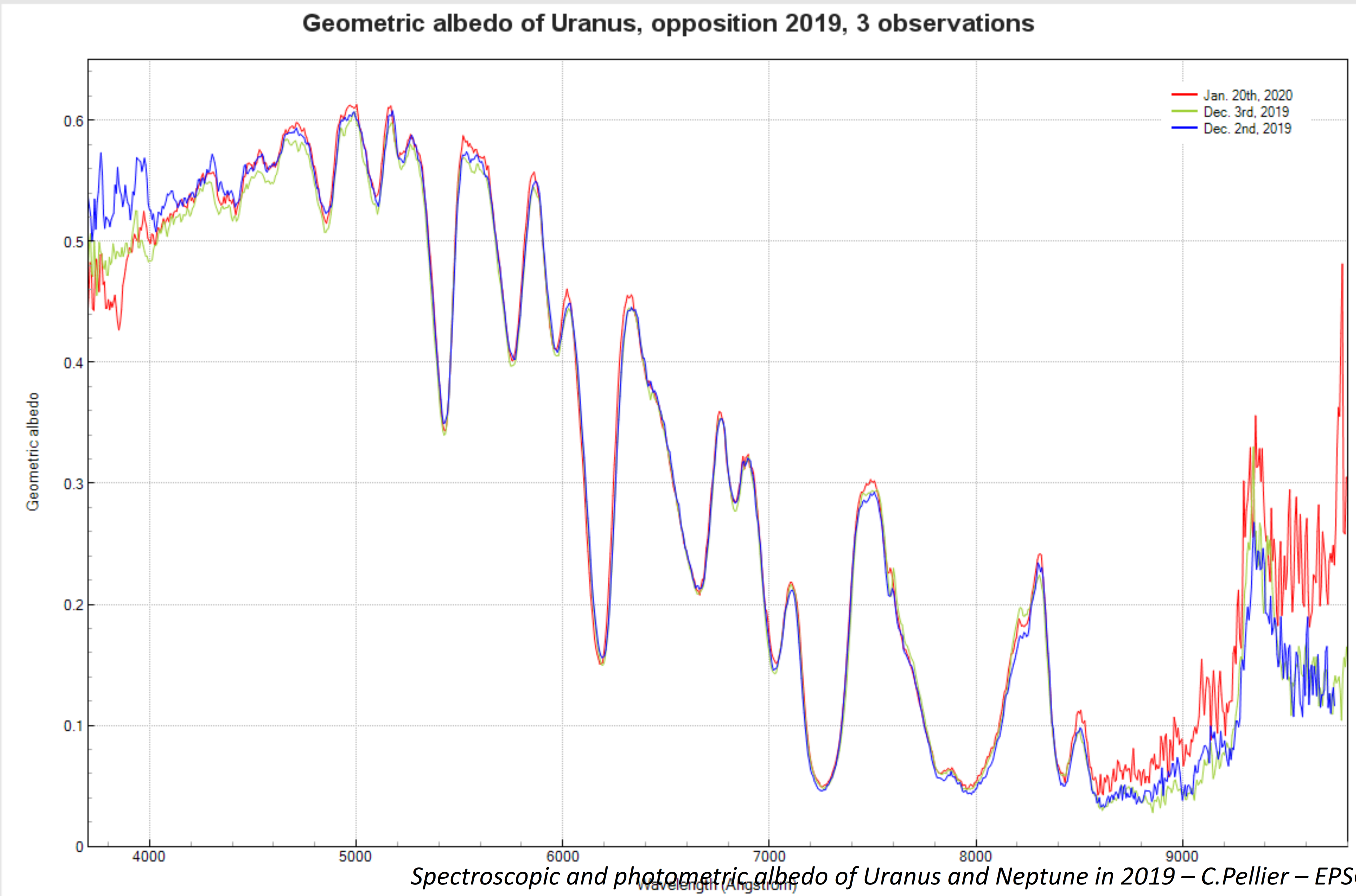
$$\sigma = 0{,}009403 - (6{,}814 \times 10E\text{-}8) \times s + (2{,}602 \times 10E\text{-}8) \times s^2$$

Where s is the sub-Earth latitude on Neptune at the moment of the observation.
For Uranus the formula is the same but with different numerical values.

The author used the most recent magnitudes of the Sun found in Willmer [4]

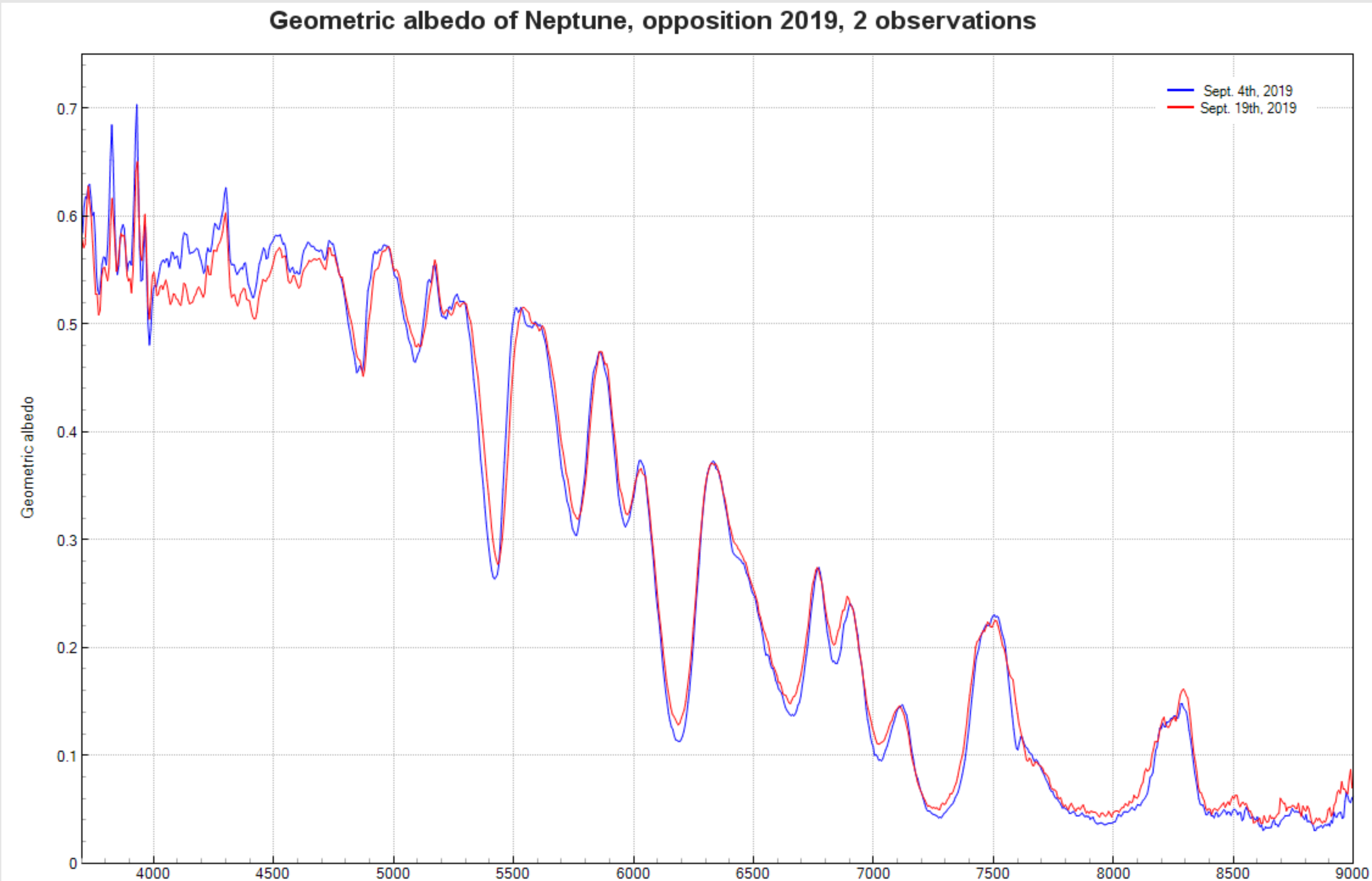
Geometric albedo of Uranus - Results

Uranus has been observed on three occasions on December 2nd and 3rd 2019, January 20th 2020. The results are in excellent agreement from 400 to 900 nm with slight discordances in near UV and far near IR, where the data has a low signal to noise ratio, and where the wavelength calibration is less accurate. The observation of Dec. 3rd is considered to be the most reliable.



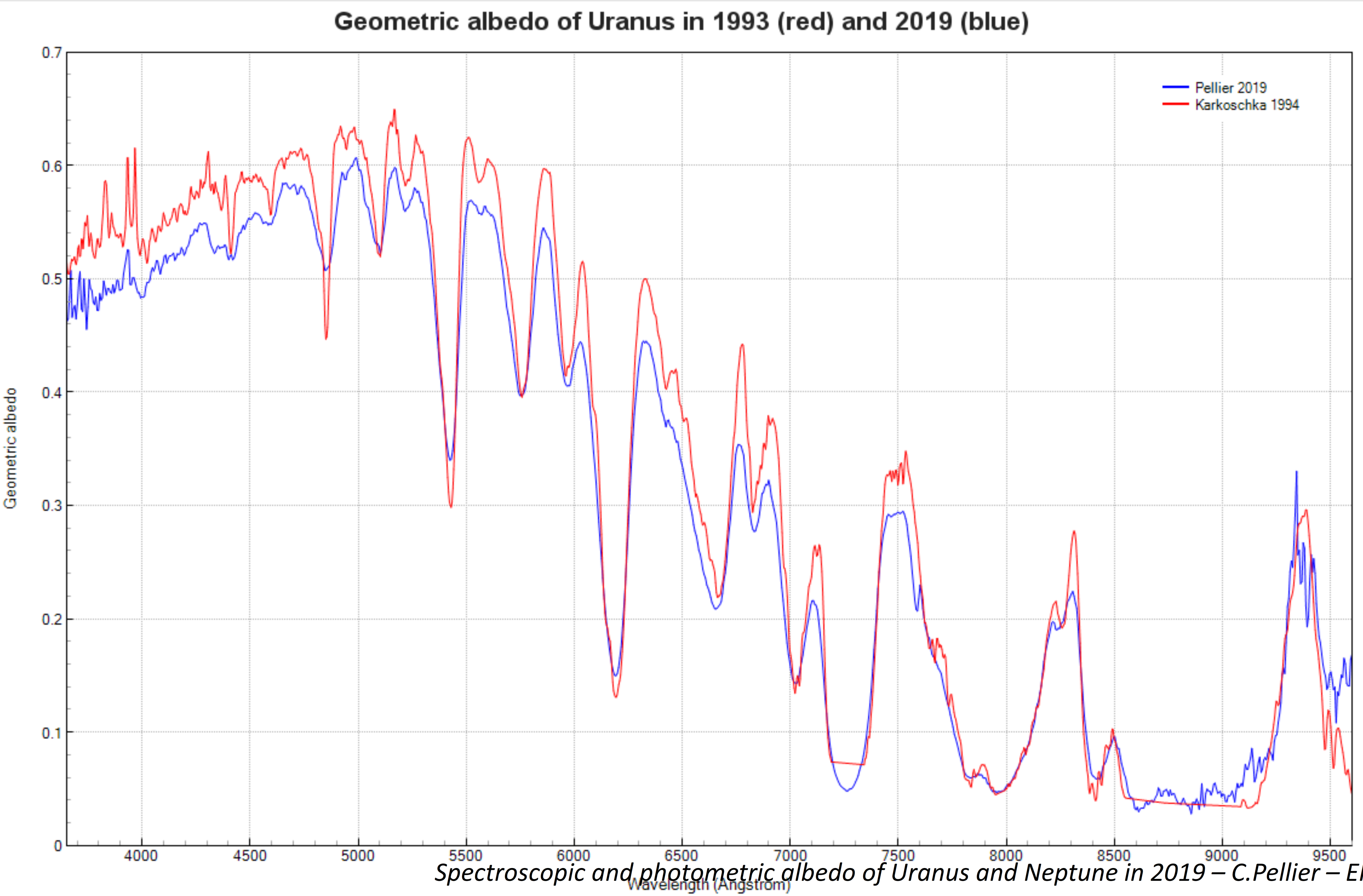
Geometric albedo of Neptune - Results

Neptune has been observed on two occasions on September 4th and 19th 2019. The results are in excellent agreement from 450 to 900 nm. These results in particular demonstrate the influence of the seeing on the data. The observation on Sept. 4th has been taken in very good to excellent seeing and shows a slightly improved spectral resolution.



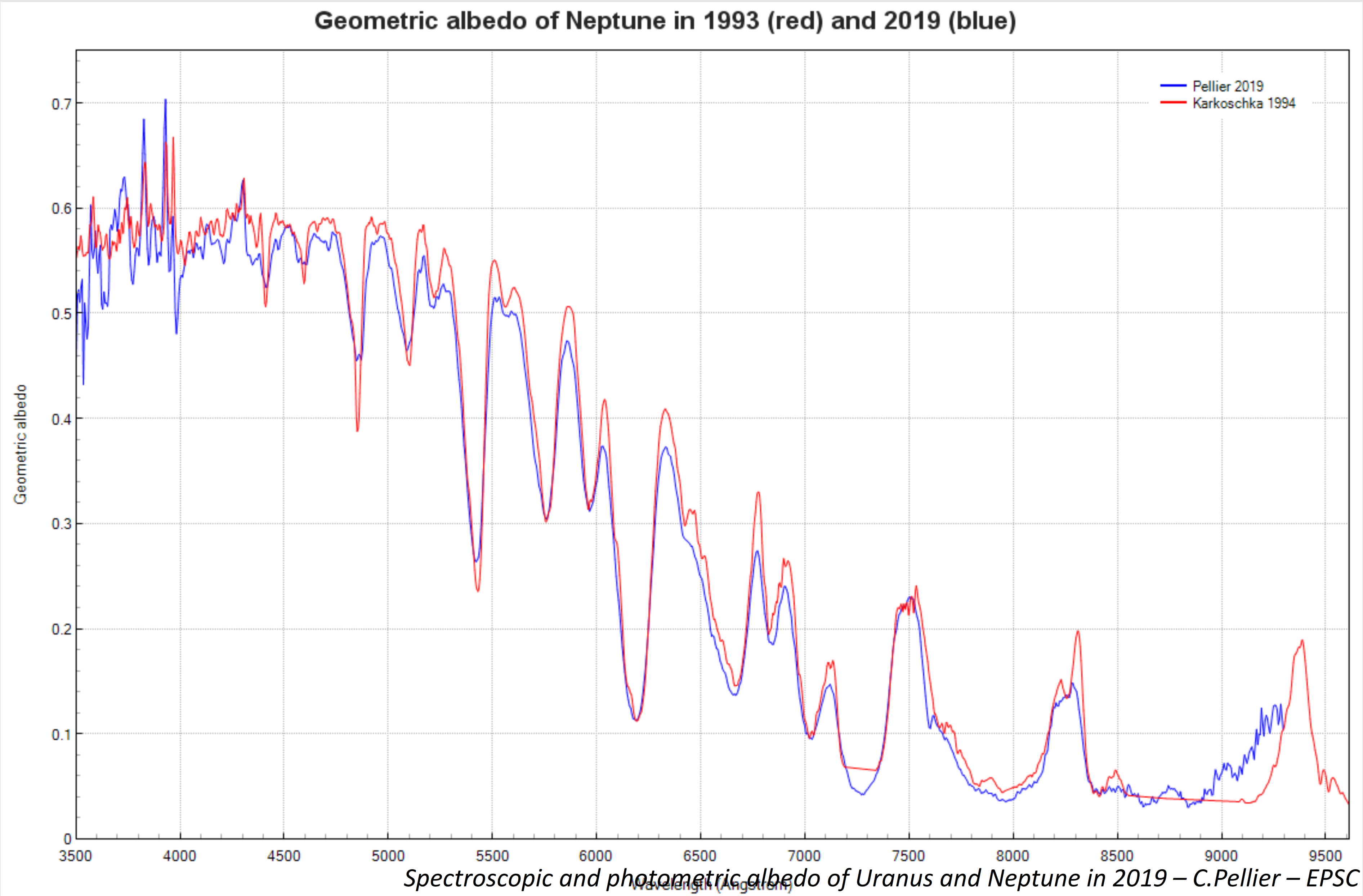
Geometric albedo of Uranus – Comparison with Karkoschka (1994)

The comparison of the albedo of Uranus calculated by the author in 2019 looks slightly, but noticeably, fainter than that observed by Erik Karkoschka in July of 1993 [1]. Part of the difference could be due to the lower spectral resolution of this work. However, the results obtained with photometry (next slides) would be coherent with a fainter Uranus in 2019. Moreover, no such a difference is found when comparing data for Neptune (next slide)



Geometric albedo of Neptune – Comparison with Karkoschka (1994)

The comparison of the albedo of Neptune calculated by the author in 2019 looks rather similar to that observed by Erik Karkoschka in July of 1993 [1]. It would be very slightly fainter, but the difference is too small and is likely to be due entirely to the lower spectral resolution.



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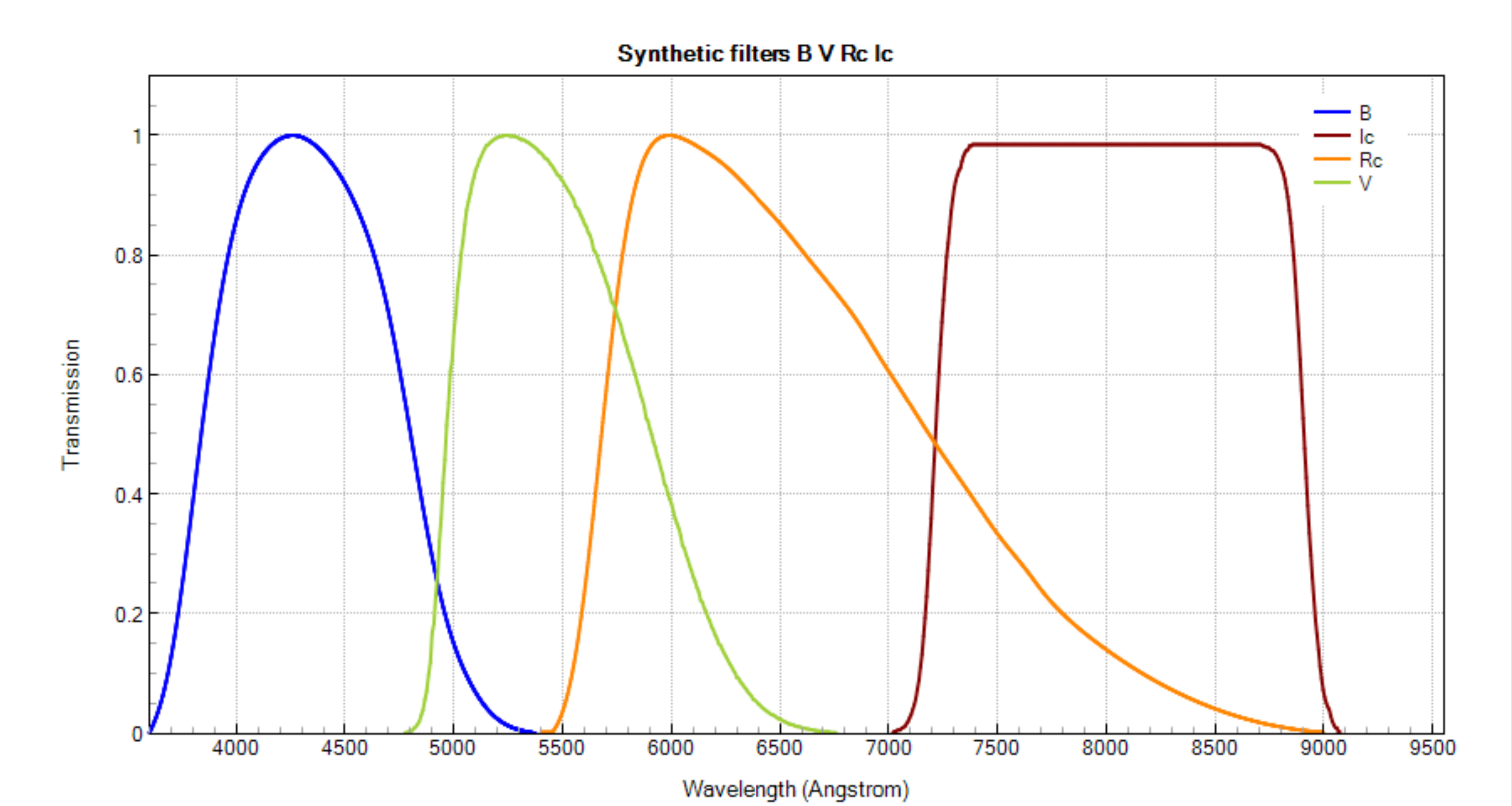
Photometry - method

The author has built an experimental method of reducing the spectra into photometric BVRI magnitudes of the Johnson-Cousin system, in order to make comparisons with other kind of works. The right way to do this is through the spectro-photometry method, which supposes to correct a spectrum into absolute flux (in energy by CM2 for 1 second and for 1 Angström), which will be convolved into photometric fluxes through synthetic BVRI filters. Christian Buil **has explained on his website** how he is proceeding. However the method does not seems to fit the author's equipment and target for two reasons:

1) It supposes to find the real spectrum an adjacent bright, non variable star with known magnitudes. This is rarely the case especially since the equipment limits the useful magnitude to around 8.

2) Calculate the absolute flux spectrum is a step which may introduce small errors due to the average quality of the spectra that can be obtained.

To solve those problems, the author has chosen a custom method derived from the **usual photometric reduction** as proposed by the American Association of Variable Stars Observers (AAVSO). The spectra are used as ADU spectra calculated for a 1 second exposure, uncorrected for the instrumental and atmospheric response, and convolved into BVRI synthetic spectra.



Photometry - method

The AAVSO method supposes to calculate two coefficients of transformation: the color transformation (that plots the instrumental bvri magnitudes with the real BVRI magnitudes), and transformation of magnitudes which is plotting the instrumental color index (such as B-b) against the real color index (like B-V). To get those two coefficients, the author has observed a set of bright stars near the polar region of the sky at elevations from 80 to 85°, in order to eliminate the atmospheric absorption as much as possible. The color transformation coefficients (TB, TV, TRc and TIc) are easy to find and works into the equations. However, this method has failed to produce useful magnitude transform coefficients (Tv_bv etc.), for some reasons, possibly because these coefficients are sensitive to the elevation of the observed objects. The equation is:

$$Vvar = \Delta v + Tv\_bv * \Delta(B-V) + Vcomp$$

Whith Vvar= Vmag of the variable star, v/b= instrumental magnitudes, V/B=catalogues magnitudes, Vcomp= Vmag of comparison star.

The author has then experimentated a custom method that is using the same color transform coefficients on all targets, *but* re-calculated magnitudes coefficients for each session:

1) A first reference star is observed;
2) A second reference star is observed, and the magnitudes transformations are hand-modified in order to find the known magnitudes of that second star starting from those of the first star;
3) The final target is observed (planet or variable star), and its magnitudes are calculated through the stable color transform coefficients, and the hand modified magnitudes transform coefficients.

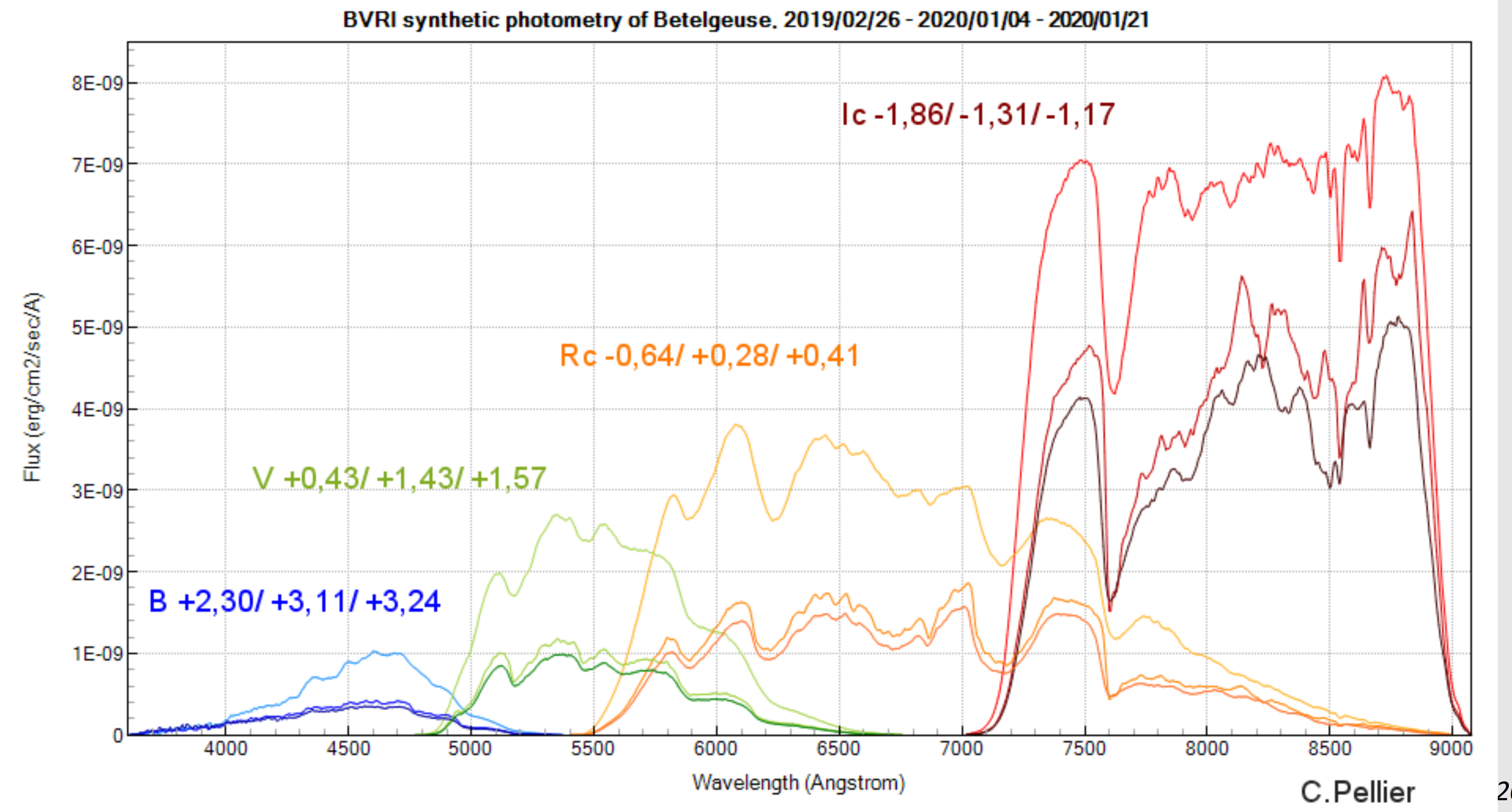
The method is simplified by observing all objects at the same elevation (within 0,5° or less) in order to drop out of the equation the atmospheric terms.

So far, this unconventional method looks to have produced correct results. It has been tested with good results on several variable stars in 2018 and 2019 such as the cepheids Zeta Gemini and X Cygni, the pulsating red giant R Leonis, the red supergiant Betelgeuse. It has also been tested on Uranus and Neptune thanks to the work of the ALPO. So far the precision looks to be:

- V band: very good to excellent with a precision around 0,01 magnitude
- B band: good to very good with a precision around 0,02 magnitude
- Rc and Ic bands: the precision is more uncertain and the error is at least 0,05 magnitude, or more.

Photometry - method

As an example, here are some observations made during the winters of 2019 and 2020 on the red supergiant Betelgeuse (Alf Ori). During the winter of 2020, the star experienced a historical drop of luminosity that drew attention from more observers than usual, encouraging them to calculate magnitudes in the Rc and Ic bands.
The author observed the star at three occasions on February 26th, 2019, January 4th and 21th, 2020. Here is a graph displaying the BVRI spectra with magnitudes values. The left scale is in flux, the flux of the star has been calculated starting from the spectrum of Phi2 Orionis, an orange giant (K0III) which is the main reference star. Comparison with AAVSO data is on next slide.
The graph is showing some more details: uneven dimming following each band (more intense in V and Rc) as well as the deepening of TiO bands (despite the natural low resolution of the grating).



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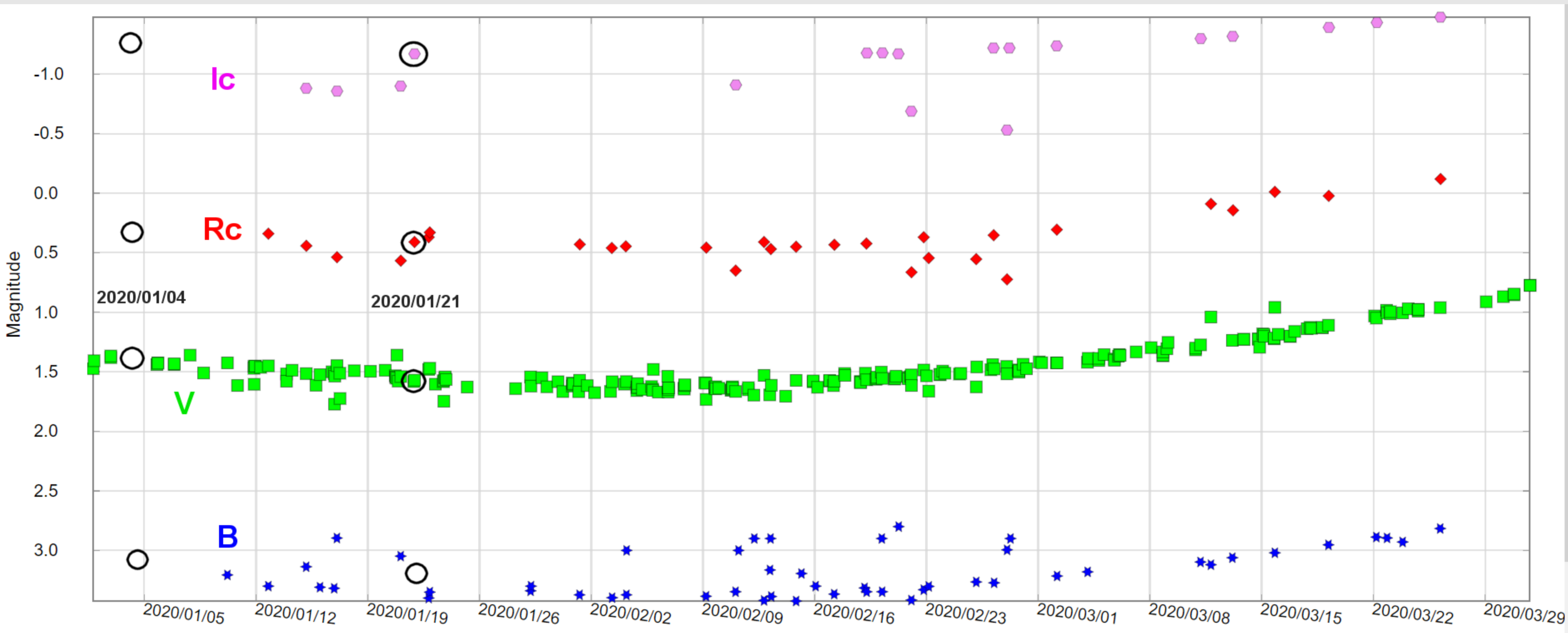
Photometry - method

Here are the observations by the author circled in black displayed against the results obtained by AAVSO observers from January 1st to 21th, 2020. Three results has been submitted from the latter in V, Rc, Ic. Results in V are in perfect agreement. Results in B looks quite coherent as well but the author felt that there was an error of 0,1 mag (see below) and did not submit the results. Results in Rc and Ic look good as well. Only two observers apart of the author submitted results in these two bands during the period, the results of the author being in perfect track with one of them, the other being slightly off this possible good track.

Background noise problem: For each one of the three observations, the author found that his results in the B band was systematically brighter from the AAVSO track by -0,1 mag. The error looks confirmed by the fact that the B-V color index of the star is then not respected. The author thinks that even if it is substracted during processing, the remaining background noise of the spectra is mistaken with true signal, and could lower the accuracy of the results whenever the brightness of a given target is very low, this being the case for Betelgeuse in the B band. This does not look to be a problem when the brightness is average or high.

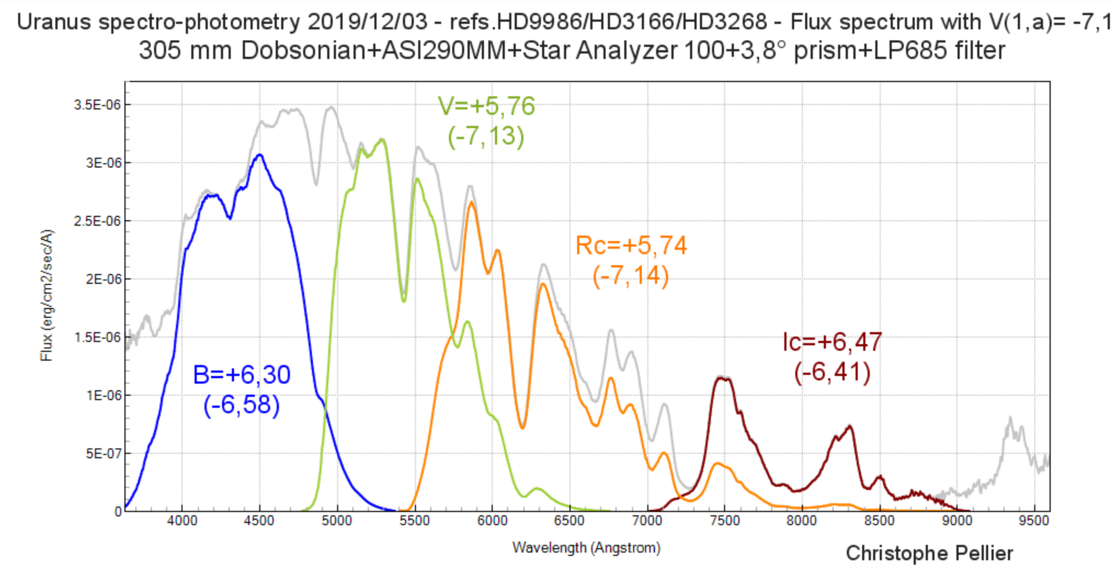


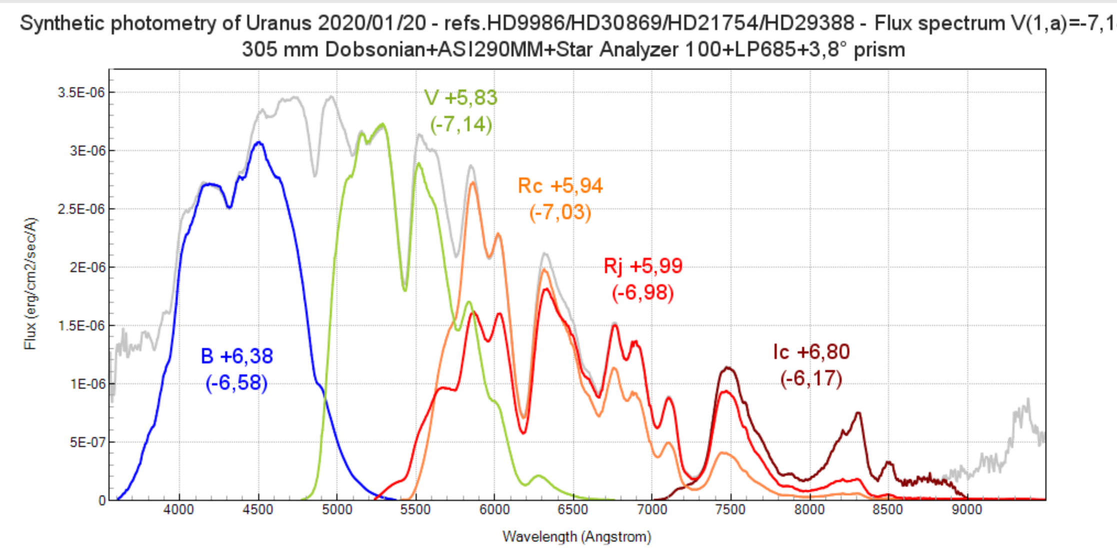
Photometry – results on Uranus

Here are photometric results obtained on Uranus on two night. B and V are coherent with ALPO values obtained on the most recent years [5], but Rc and Ic are significantly brighter. Apparent magnitude and absolute magnitudes are presented. The absolute planetary magnitude is a fictitious magnitude calculate as if the planet was found at 1 AU from the Sun, and 1 AU from Earth. V(1, alpha) and B (1, alpha) have almost identical values on the two dates, but values for Rc(1, alpha) and Ic(1, alpha) presents serious variations.

The background noise problem described in the previous section on the photometric method could be part of the problem, but fails short to satisfy the explanation since only the Ic band is really faint, and since the difference between the ALPO results appears much more larger than the 0,1mag error detected on Betelgeuse. As far as the author knows, no reason seems to explain the difference should it be found on any kind of error in the method employed, even if of course it is not excluded.

An additional Rj band (original Johnson band) has been calculated for the 20th of January, since values for that band are available in the SIMBAD basis and correspond to some older photometric work on Uranus and Neptune.





Star		Uranus Magnitudes B	V	Rc	Rj	Ic
HD29388	A6V	6,34	5,82	5,95	6,04	6,71
HD30869	F7V	6,38	5,83	5,93	5,93	6,80
HD9986	G2V	6,40	5,81	5,95	6,04	6,84
HD21754	K0III	6,40	5,84	5,91	5,93	6,84

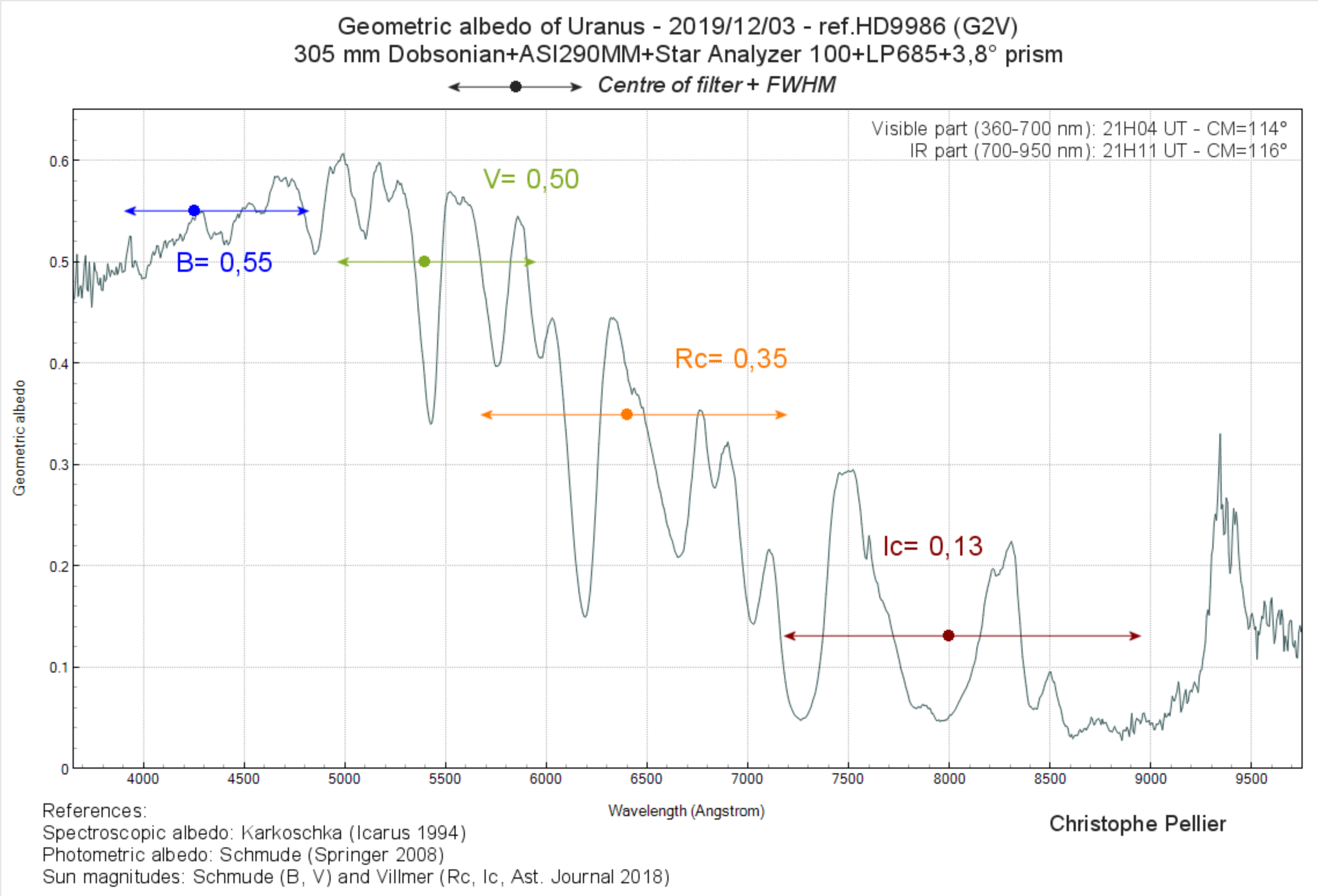
Christophe Pellier

Photometry – results on Uranus

This is now the spectroscopic albedo along with the photometric albedos (dec. 3rd only).
The geometric albedo for each color band is given by the formula found in Schmude [3]

Geometric albedo = 10exp(0,4 x (SUN_Nm - Target_Nm) - 2 X LOG (SIN Ϭ)

Where Nm means "Normalized magnitude" and Ϭ is the angular size of the radius of the target at a distance of 1AU in degree



Photometry – results on Uranus

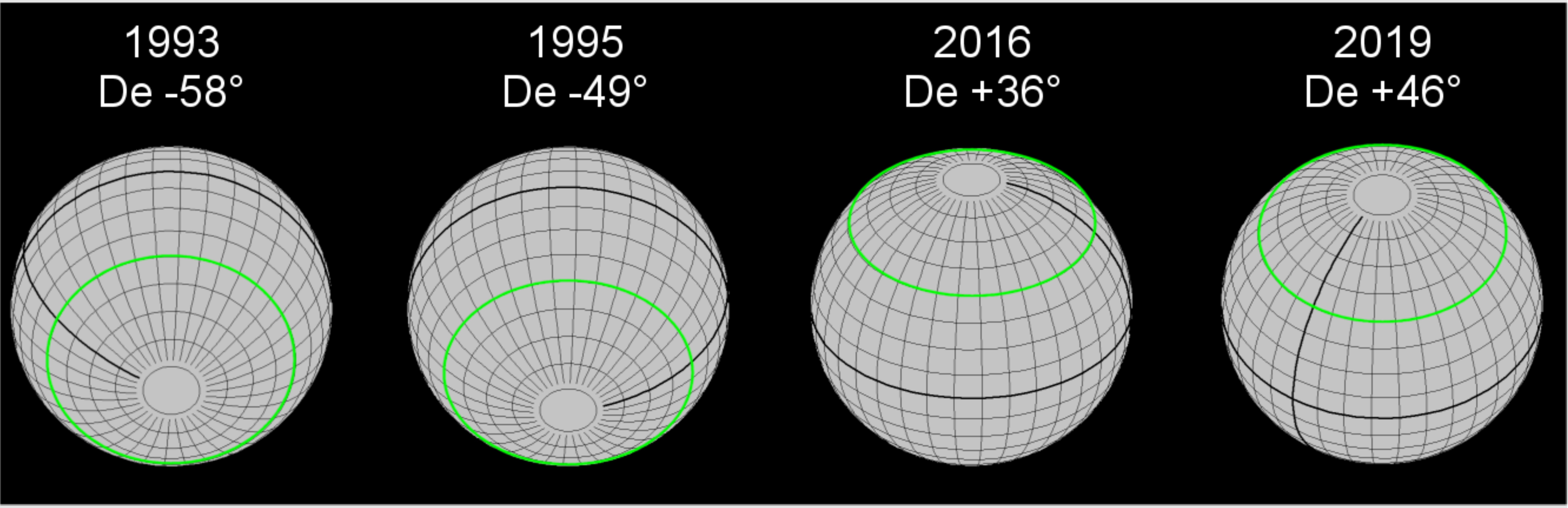
To make comparisons, the author has re-calculated all albedo values of the photometric data provided by Karkoschka for his observations of 1993 [1] and 1995 [6] with the same Sun magnitudes he found from Willmer [3], and added the results obtained by Schmude on 2016 (B, V) and 2010 (R, I).

The results are all in coherence with a planet fainter at the end of the 2010's than in the middle of the 1990's.
B and V magnitudes of the author are equal to those of Schmude, even if the equipement and the method used are completely different. Rc and Ic present differences of around half a magnitude or more, which is a lot.
The reader may also refer to the results obtained by Schmude et al. In [8] that show a similar trend in the V band with in particular a minimum value corresponding to the passage of the planet by its 2006 equinoxe.

	Observer	B	V	Rc	Ic
ALBEDO	Karkoschka (1993)	0,58	0,53		
	Karkoschka (1995)	0,58	0,52		
	Schmude (2016)	0,55	0,51		
	Pellier (2019)	0,55	0,51 or 0,50	0,35	0,12
Normalized Magnitude	Karkoschka (1993)	-6,63	-7,18		
	Karkoschka (1995)	-6,64	-7,17		
	Schmude (2016, 2010)	-6,58	-7,14	-6,77	-5,61
	Pellier (2019)	-6,58	-7,13	-7,08	-6,3

Photometry – results on Uranus: discussion

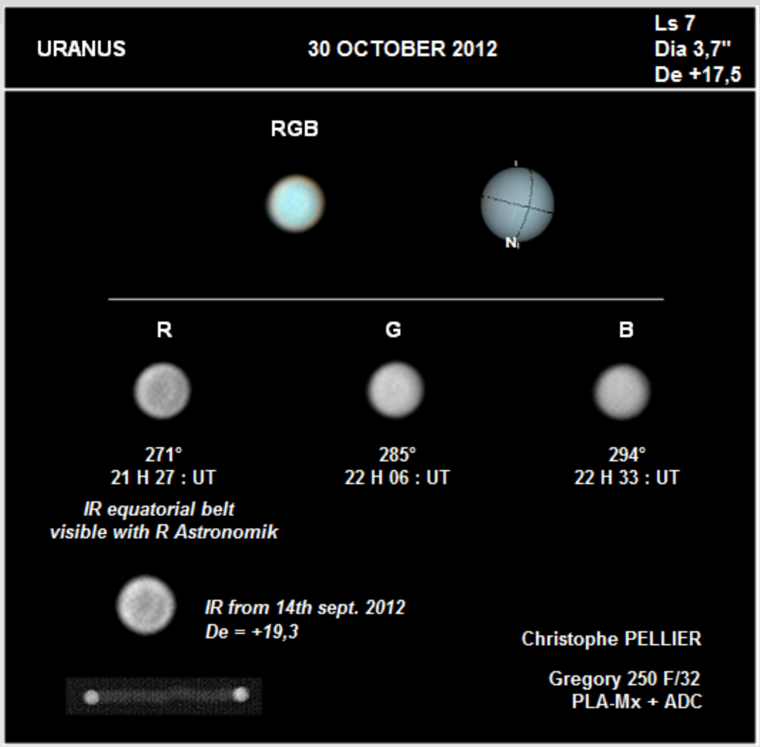
If correct, the photometric evolution of the planet could be explained first by the geometry. Uranus is now known to experience brightening of a wide polar region when approaching solstices in long wavelengths, which might contributes to the brightness of the planet even in visible wavelengths. The author has measured the border of the bright polar region in infrared on Hubble images and it appears to be remarkably identical on both hemisphere around 41/42° north or south. On the figure beneath, the green circle roughly outlines the limit of that polar region. So the first reason why the luminosity of the planet changes is because the apparent surface of the polar region evoluates with the time, becoming wider when the tilt is more important. In the mid-90's, the polar axis of Uranus was more tilted toward us than during the 2010's. Only in 2019, this tilt reached the same value as it was back in 1995.
One second reason why the planet would be currently fainter is because even if the apparent surface is the same, the intrinsic brightness of the polar region was not identical for both periods. We also know that the southern polar brightening faded when approaching the equinoxe of 2007, and that the current north polar brightening was gradual since that same equinoxe. It is then possible that the current brightening is not as strong, if true, it could be a seasonal effect since it is now northern spring on Uranus while it was southern summer during the 90's.

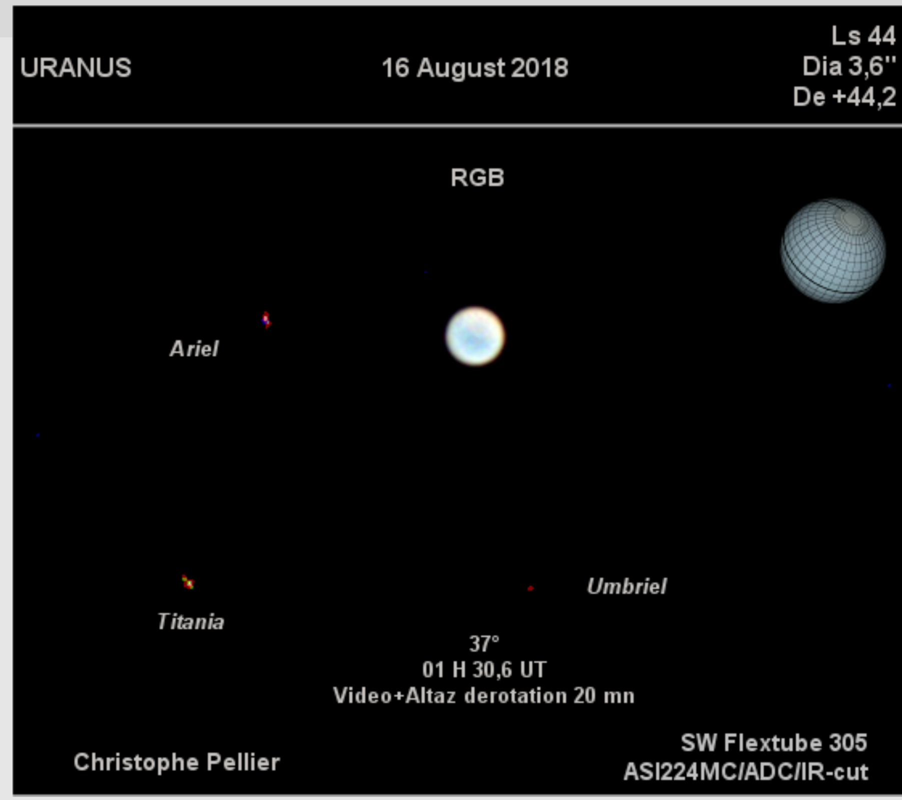


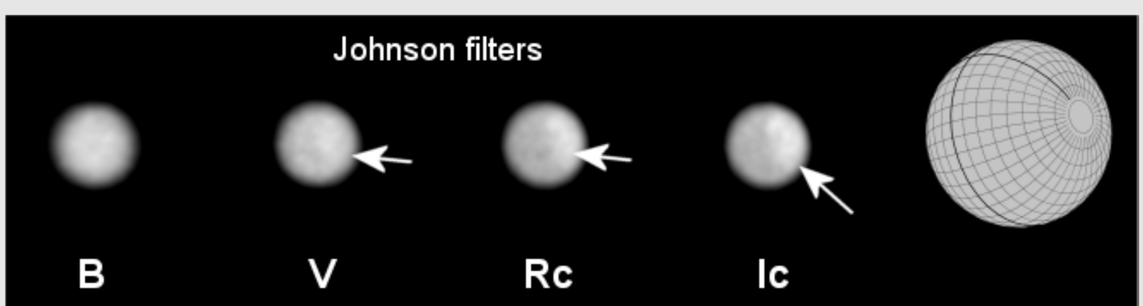
Photometry – results on Uranus: discussion

Recent amateur images in true colors proves that the brightening of the polar region is detectable in visible wavelengths, especially in red light, but also in green light. Early in the 2010's only a very moderate polar brightening was present, with a stronger equatorial belt. Since 2016-2017, the brightening of the polar region has been more and more visible and intense.

In 2020 January, the author imaged the planet through BVRI Johnson filters and although the quality is poor, the serie shows that the polar brightening is barely perceptible through Johnson V. Thus, the brightening influences the brightness of the planet in that band as well.

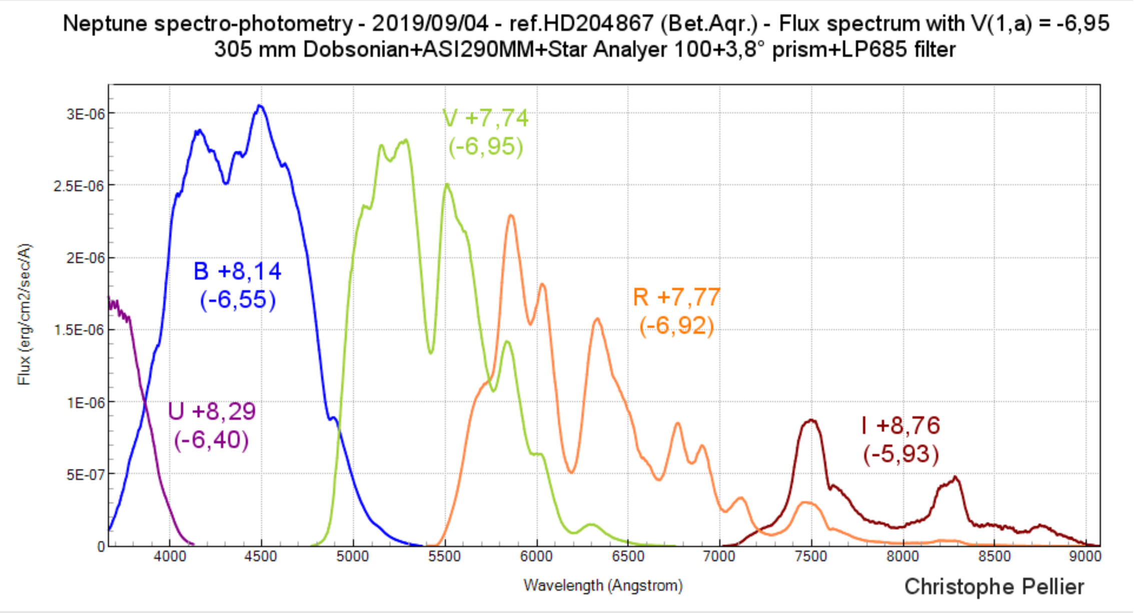


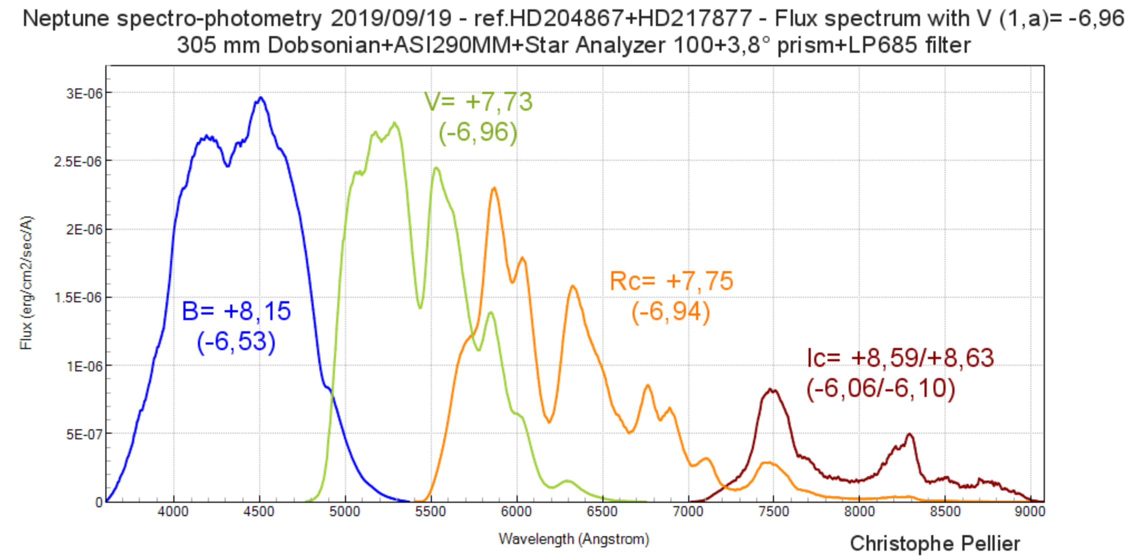




Photometry – results on Neptune

Here are photometric results obtained on Neptune on two night. Although consistent between the two dates, the results are a bit less different from ALPO values (see next slide)
Main reference star for photometry is Sadalsuud (Beta Aquarius)





Photometry – results on Neptune

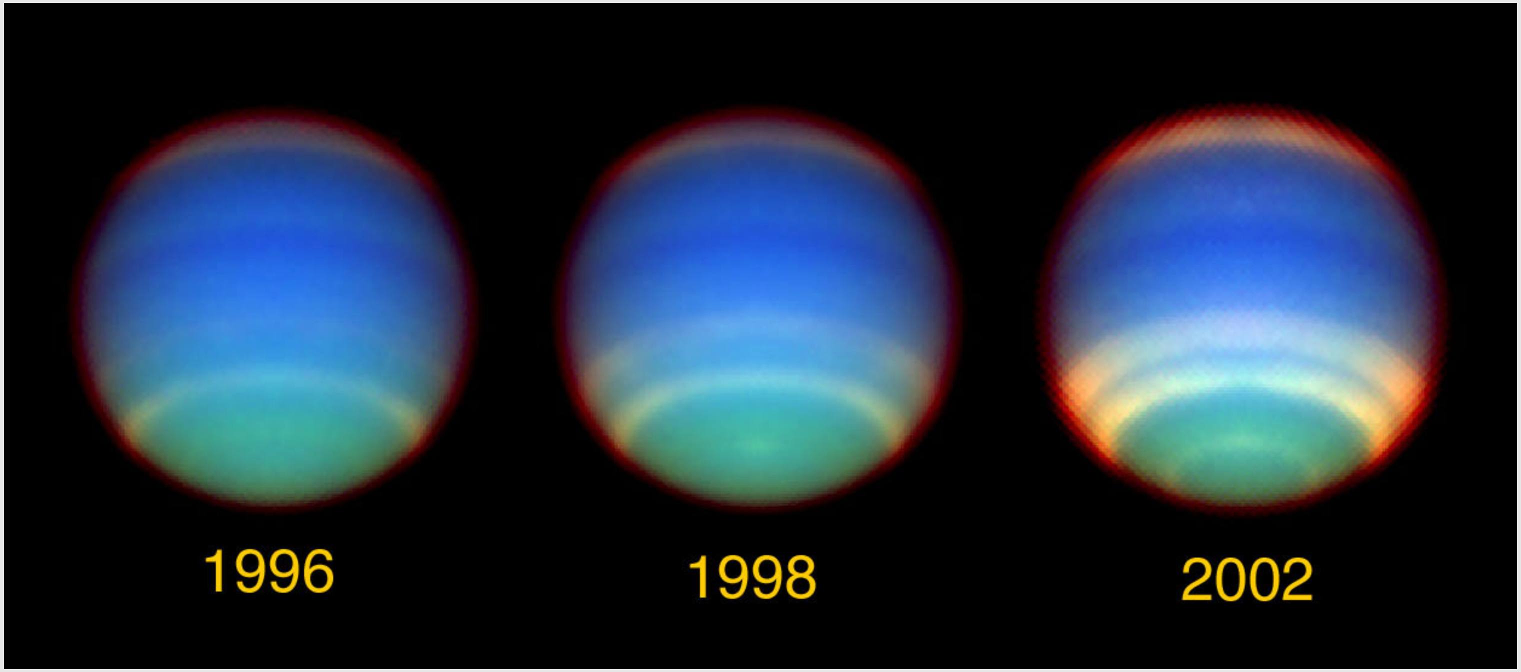
Results present a bit more variations for Neptune. In particular the ALPO results look brighter than Pellier and Karkoschka. Apart of this, there look to be a tendency in long-term brightening in the V band (absolute magnitude) that is consistent with the brightening observed of the planet in infrared wavelengths (see for example [7]). The period covers the passage from southern spring to southern summer (solstice in 2005).

Another good reference is Schmude [9]

	Observer	B	V	Rc	Ic
ALBEDO	Karkoschka (1993)	0,55	0,43		
	Karkoschka (1995)	0,56	0,44		
	Schmude (2016)	0,58	0,46		
	Pellier (2019)	0,55	0,45	0,3	0,1
Normalized Magnitude	Karkoschka (1993)	-6,53	-6,92		
	Karkoschka (1995)	-6,55	-6,94		
	Schmude (2016, 2010)	-6,59	-6,98		
	Pellier (2019)	-6,55	-6,96	-6,93	-6

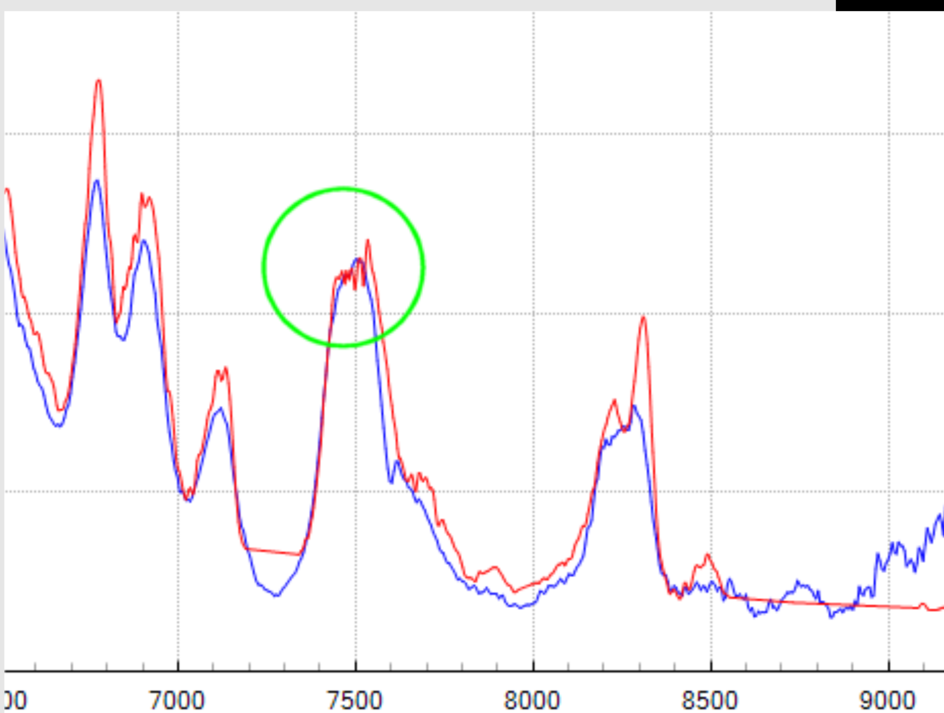
Photometry – results on Neptune: discussion

There looks to be a tendency in long-term brightening in the V band that is consistent with the brightening observed of the planet in infrared wavelengths. The period covers the passage from southern spring to southern summer (solstice in 2005)
Beneath: false color HST images taken during late southern spring. The bright belts come from an infrared image.



Results on Neptune: discussion

Finally, an interesting detail emerges from the spectroscopic data. As seen on previous slides, the albedo of Neptune of this work looks just slightly fainter than that of Karkoschka, the main explanation being the lower spectral resolution. It is then interesting to note that there is at least one wavelength of the spectrum that does not look to present this fainting. The pic of continuum near 750 nm looks equal to that of Karkoschka. If true, it could mean that in reality it is brighter. If true again, there could be a link to the increased IR convective activity observed on Neptune those past decades – see illustration on this 685 nm image taken by the author and colleagues at the Pic du Midi in 2016.



References

Website of the author

[1] Karkoschka E., "Spectrophotometry of the Jovian Planets and Titan at 300 to 100 nm Wavelength: The Methane Spectrum", ICARUS 111 (1994)
[2] Gray, R. O et al. "Contributions to the Nearby Stars (NStars) Project: Spectroscopy of Stars Earlier than M0 within 40 Parsecs: The Northern Sample. I." full paper
[3] Schmude R., "Uranus, Neptune, Pluto and how to observe them" (Springer, 2008)
[4] Willmer A., "The Absolute Magnitude of the Sun in Several Filters" Full paper
[5] Schmude R. "ALPO observations of the remote planets in 2016-2017" JALPO60-3-Summer-2018
[6] Karkoschka E., "Methane, Ammonia, and Temperature Measurements of the Jovian Planets and Titan from CCD-Spectrophotometry", ICARUS 133 (1998)
[7] Hueso R. et al, "Neptune long-lived atmospheric features in 2013–2015 from small (28-cm) to large (10-m) telescopes"
[8] Schmude R. et al "Large Brightness Variations of Uranus at Red and Near-IR Wavelengths" arxiv
[9] Schmude R. et al "The Secular and Rotational Brightness Variations of Neptune" arxiv