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The essential role of amateur astronomers in enabling the Juno mission interaction with the public

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Abstract

JunoCam was added to the payload of the Juno mission largely to function in the role of education and public outreach (E/PO). For the first time, the public is able to engage in the discussion and choice of targets for a major NASA mission. The discussion about which features to image is enabled by a bi-weekly updated map of Jupiter's cloud system, thereby engaging the community of amateur astronomers as a vast network of co-investigators, whose products stimulate conversation and global public awareness of Jupiter and Juno's investigative role. The contributed images provide the focus for ongoing discussion about various planetary features over a long time frame. Approximately two weeks before Juno's closest approach to Jupiter on each orbit, the atmospheric features that have been under discussion and are available to JunoCam on that perijove are nominated for voting, and the public at large votes on what to image at low latitudes, with the camera always taking images of the poles in each perijove. Public voting was tested for the first time on three regions for PJ3 and has continued since then for nearly all non-polar images. The results of public processing of JunoCam images range all the way from artistic renditions up to professional-equivalent analysis. All aspects of this effort are available on:
https://www.missionjuno.swri.edu/junocam/.

1. Introduction

The JunoCam instrument [1] on the Juno spacecraft is returning many good and unexpected scientific results, particularly around Jupiter's poorly explored polar regions [2]. However, the instrument was conceived as a way to engage the public with the Juno mission by direct interaction. The primary goals of the outreach effort are to allow the public: to choose where to point the camera and to process the data we get. To achieve this, four steps were envisioned that are proceeding: planning, discussing, voting and processing. A fifth area is evolving, which involves quantitative analysis of the images. Although the initial "planning" stage absolutely requires input by the entire astronomical community, opportunities are both possible and enthusiastically encouraged in each. This process is ongoing and examples will be shown at each stage.

2. Planning

In order to be informed about what to point at in Jupiter's dynamic atmosphere, we need to know what's there. We rely on the amateur community for this. Anybody taking images of Jupiter is invited to submit them to the Mission Juno / JunoCam site: First log into the Mission Juno site, and link to JUNOCAM. From there, link to "PLANNING" (Figure 1), which brings you to an upload page (Figure 2).

3. Discussion

We then invite the public to select a feature, identified as a "Point of Interest" (Figure 3) and to discuss why that feature deserves to be imaged up close.

4. Voting

We then establish which points of interest will be available on the next orbit. Five voting days start 12 days before perijove. The available points of interest for orbit 5 are shown in Figure 4.

5. Processing

JunoCam images are made available on our web site within 2-3 days of their reception from the spacecraft. The public is free to upload all of their processed images, which have ranged from fanciful to processing to enhance detail and clarity.

6. Analysis

Some participants engage in their own detailed analysis of morphology and motions. An example is shown in Figure 5.

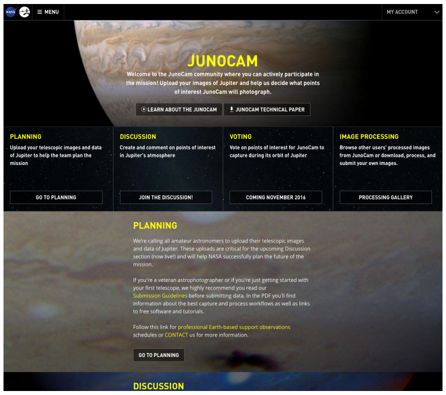

Figure 1: Selections available on the JunoCam link.

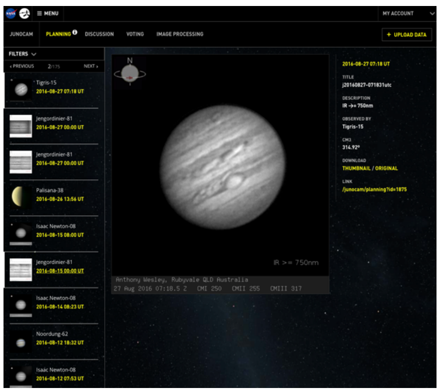

Figure 2. Display and upload page.

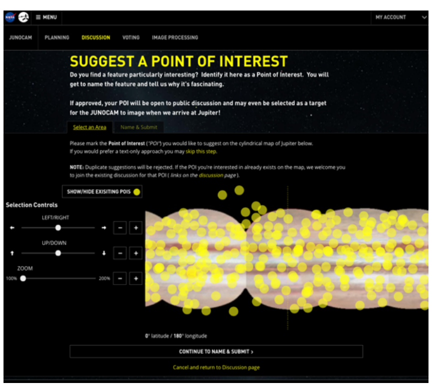

Figure 3. Identification of points of interest page.

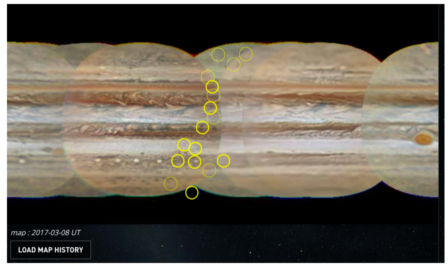

Figure 4. Features available for voting on perijove 5, with winners of the voting shown in bold.

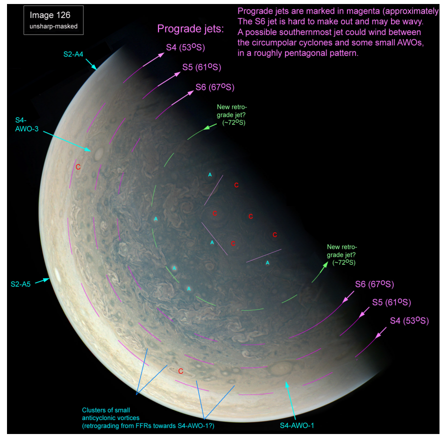

Figure 5. Example of analysis in terms of known latitudinal variability of winds by John Rogers and Gerald Eichstädt posted on the Mission Juno site.

Acknowledgements

This research was funded by the National Aeronautics and Space Administration through the Juno Project. A portion of these funds were distributed to the Jet Propulsion Laboratory, California Institute of Technology. The innovative Mission Juno / JunoCam website was built and is maintained by Radical Media.

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A simplified method to track long-term changes in Jupiter’s belt/zone structure

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Abstract

Jupiter atmosphere is extremely dynamic, showing a variety of phenomena generally organized in dark belts and bright zones which often change in color, width and latitude. It is not unusual that some disappear or reappear. Long-term changes (e.g annual) in this banded pattern need to be tracked by measuring the latitude of belts and zones and examining their coloring. Digital observations with planetary cameras in recent years have introduced many new ways of exploring the planets. In this work we present a methodology and some results of "Averaged Filtered Observations (AFO)", a simple way to measure the bands edges in order of latitude and view the overall contrast or color of the bands. A series of such AFO over several years would give a good record of the changes in latitude, the darkness/brightness/color of the bands, and their shift through time. This work may trigger average observations of this type by amateurs in different spectral bands and not only in Jupiter.

1. Introduction

Early astronomers, recorded the changing appearance of Jupiter's atmosphere. Historical accounts of banding changes can be found in [1,2, 3,4,5]. Amateur astronomers worldwide continue the observation by capturing hi-res images useful for professionals [6]. Moreover, many innovative techniques have been introduced with the use of modern technology and equipment [7,8]. In the following we will provide some information and results of a relatively simple imaging methodology we call "Averaged Filtered Observation (AFO)".

2. Methodology

The basic methods of planetary imaging are presented at [9] and for ~890nm imaging at [10]. Additionally, the AFO methodology, has the following workflow:

1. *Equipment*: typical planetary imaging setups are used, usually consisting of a 8'-20' telescope, a planetary camera and a PC.
2. *Filters:* all types of filters can be used depending on the spectrum we want to examine. In this work we mainly use a ~890nm methane absorption band filter that reveals the relative altitude of the bands. Furthermore the banding structure is better defined.
3. *Capturing:* a long series of videos in order to avoid distortion from discrete features in the band/zones. Longer duration will give a better, smoother average . A total duration capturing about 1/3 of the planet's globe is proposed. We should avoid the presence of the Great Red Spot in our view.
4. *Stacking* with Registax [11] or Autostakkert [12] is done on all individual videos without derotating the images [6].
5. *Processing.* Further image processing (e.g. applying wavelets, adjusting brightness-contrast) is then performed in these or other photo-processing programs like in normal planetary imaging.

3. Observations and results

All AFO’s were obtained with small telescopes during latest Jupiter apparitions. Experiments were mainly made in the methane absorption band at ~890nm. Other filters can be used depending on the spectral band we want to investigate.

3.1 Jupiter AFO in the ~890nm band

In the ~890nm we captured the rotation of Jupiter for about 3h and 10min when the GRS was not visible. This produced about 164000 low resolution frames that were combined (stacked) without derotating them. After some smooth wavelet processing it resulted the image of Fig.1. All discrete features disappeared and a smooth average of the banding structure brightness is captured.

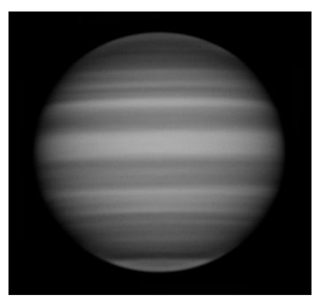

Figure 1. *The AFO result on Jupiter,15, April 2017, 18:20 - 21:30UT, Average brightness of Bands and Zones at ~890nm, (0.35m telescope, ASI290mm cam., Hutech BPF filter)[N is up], A calibrated version (presented at [13,14]) of this obs. could reveal the relative average height of each belt and zone.*

3.2 Comparing annual AFO's

The long term-variability of the banding structure and brightness can be tracked by comparing annual AFO's. The phase angle effect (PAE) must be considered when comparing average images at different epochs. So the planetary software WinJupos [15] was used (that calculates the PAE) to make two AFO maps from the latest apparitions of Jupiter that span 90 degrees in longitude [Fig.2].

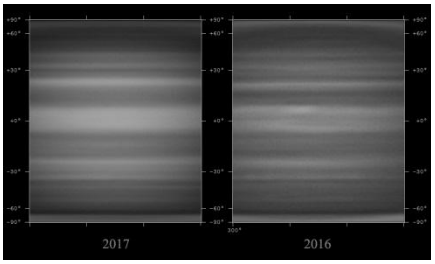

Figure 2. *A comparison of Jupiter's AFO made in the latest apparitions (left 2017/04/15 and right 2016/02/26-2016/03/20)*

3.3 Measurements of Belts/Zones Latitudes

The belts occur in almost the same latitudes in every apparition but sometimes their edges shift becoming narrower, broader or even disappear completely [2]. With the use of just one AFO image and the use of WinJupos software [15] we may measure the latitude of belt and polar hood edges. We measured the average latitudes in the AFO image of Fig.1 in 14-18 different positions of every edge. In the last column the typical Latitude of the belt is presented. By measuring annually with this method long term banding changes can be tracked.

Belt/Zone Region edge	No of Measured Positions	Average B"[°] (Jovigraphic latitude)	Standard Deviation (σ)	Typical B" [°]
SP hood	14	-67,09	0,56	
S3TBn	15	-41,50	0,31	-43
SSTBs	14	-39,47	0,32	
SSTBn	16	-34,90	0,34	-37..-36
(STZ)				
STBs	16	-32,26	0,40	-32
STBn	16	-25,32	0,37	-29..-27
STropZ				
SEBs	16	-21,39	0,35	-20
SEBn	16	-8,21	0,38	
EZ				
NEBs	16	8,28	0,57	
NEBn	16	21,30	0,33	17
NTropZ				
NTBs	16	24,68	0,25	24
NTBn	16	32,28	0,29	+31..+32
NTZ				
NNTBs	15	34,85	0,31	+35..+36
NNTBn	14	40,24	0,45	+39..+40
NNTZ				
N3TBs	18	42,96	0,35	43
NP hood	14	69,87	1,06	

Table 1. *Latitude measurements of main Belts and Polar hood edges from AFO image of Figure 1.*

3.4 The AFO method in the visual spectrum

The AFO can be used also to track colorization changes in the atmosphere of Jupiter

3.5 The AFO method in other planets

AFO can also be used in Saturn and possibly in Uranus and Neptune though for ice giants may be rather challenging. In Saturn it is not as useful as in Jupiter because Saturn presents very few discrete features, so the banding structure is much more uniform in simple planetary observation.

4. Summary and Conclusions

New technology and image processing techniques allow many new methods of planetary observations. We presented the AFO methodology and some preliminary results on Jupiter. Measurements of the belts and zones latitudes can be easily made in just one AFO image. A simple comparison of annual images made with AFO in the 890 nm wavelength range can easily show significant long-term changes in the belt/zone pattern. The use of AFO in the visual band can also reveal colour changes from year to year.

Acknowledgements

I would like to thank my wife Dimitra and my sons John & George, for their patience and support. Special thanks to John Rogers for making comments.

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Predictive maps for Juno perijoves and identification of significant features

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Abstract

At each Juno perijove, JunoCam takes hi-res images of selected latitudes along the sub-spacecraft track, as determined by public voting. To inform this target election process, we use the continuous coverage of Jupiter's visible clouds by amateur imaging, and the tracking of features from those images by the JUPOS project, to identify the features which are expected to be visible at the upcoming perijove. We produce a predictive map for each perijove, and subsequently annotate the JunoCam images to locate the known jets and circulation. Up to perijove 5, this collaboration has contributed to hi-res imaging of several long-lived circulations in northern and southern hemispheres, of major new convective outbreaks in the North and South Equatorial Belts, and of the North Temperate Belt maturing after a cyclic outbreak.

1. Introduction

NASA's Juno orbiter performs a very close pass ('perijove', PJ) over Jupiter every 53 days. At each perijove the 'public outreach' camera, JunoCam, takes hi-res images of selected latitudes along the sub-spacecraft track, as determined by public voting [1,2]. Due to data volume limitations, only around 15 images can be returned on each perijove, including some which are reserved for scientific studies of the polar regions, and ~5-12 of lower latitudes. Amateur ground-based imaging is important in keeping track of visible features and predicting what will be available for imaging.

The NASA JunoCam team post regular maps made from recent amateur images on the JunoCam web site [https://www.missionjuno.swri.edu/junocam], with numerous 'points of interest' (POIs) nominated by members of the public, and about two weeks before each perijove, they post the most recent map with available POIs, and invite the public to vote on which will be imaged.

We complement this procedure by tracking all visible features, producing a predictive map on which known features of interest are identified for each perijove, and making recommendations for public voting.

2. Methods

Jupiter is almost continuously imaged by amateurs around the world, whose images are posted on several global databases, mainly PVOL2, ALPO-Japan, and JunoCam. The JUPOS project [http://jupos.org] analyses these images with the WinJUPOS software suite to produce maps of the planet every 10 days during the apparition, and to measure the positions of all visible 'spots' so that features can be tracked. In the 2015/16 apparition, 60981 measurements were made. From these, charts of longitude versus time were produced for spots in all latitude ranges. Our final report on the 2015/16 apparition [3] shows the level of detail obtained in the analysis and the consequent understanding of the atmospheric processes.

To inform the JunoCam target election procedure for each perijove, we take the best recent JUPOS map, and the latest JUPOS drift rates for major features in each latitude band, and 'roll forward' each latitude band (between ~9º and 43º, N and S), to produce a predictive map for the date of the next perijove. (We do not normally change L3 of features at higher or lower latitudes, because they are rapidly moving and/or changeable.) The predicted sub-Juno track is overlaid on this map so as to forecast what features of interest will be visible. These are matched to a subset of the nominated POIs (or new POIs), and recommendations for the public voting are posted on various forums accordingly.

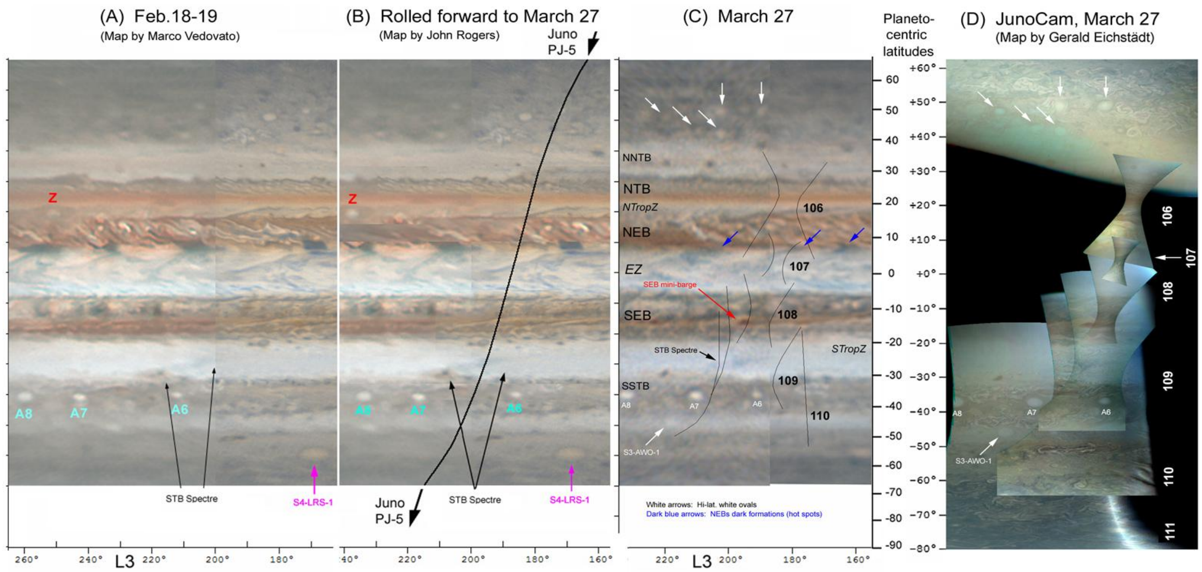

Figure 1. (A) Map on Feb.18-19, by the JUPOS team. The following observers contributed images for maps (A-C): D. Peach, C. Foster, J-J. Poupeau, P. Maxson.
(B) Predictive map for PJ5 on March 27, 'rolled forward' from the previous map, with some features of interest identified and the sub-Juno track overlaid.
(C) Map from amateur images on March 27, by the JUPOS team, with locations of JunoCam images overlaid.
(D) Map from JunoCam images on March 27 at PJ5, made by G.E.

3. Results

Figure 1 illustrates our mapping sequence for perijove 5. Up to PJ5, our recommendations have always been among the 'elected' targets.

After each perijove, with the JunoCam images processed and projected by the JunoCam team and by G.E., annotated versions of them are posted on the JunoCam web page [https://www.missionjuno.swri.edu/junocam] and BAA web page [https://www.britastro.org/section_front/15], identifying the features of interest and putting them in context of the known jets.

From PJ3 to PJ5, this collaboration has contributed to hi-res imaging of:

--Long-lived anticyclonic ovals at 41ºN (NN-LRS-1) and 41ºS (SS-AWOs);

--The North Temperate Belt, reviving over the months following a great outbreak which was discovered at the time of PJ2 [see separate abstract];

--A new convective outbreak in the South Equatorial Belt, imaged at PJ3 a month after it appeared, which could be compared with the normal convective region (at PJ4), and an undisturbed region (PJ5);

--In the South Temperate Belt, a two-year-old cyclonic circulation called the STB Spectre (PJ5).

High latitudes contain many ovals in the JunoCam images, and we can identify the long-lived ones and their motions, even up to 72ºS. Future JunoCam images could enable us to correlate their variable drift rates with their changing local environments.

Acknowledgements

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About Jupiter's Reflectance Function in JunoCam Images

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Abstract

NASA's Juno spacecraft has successfully completed several perijove passes. JunoCam [1] is Juno's visible light and infrared camera. It was added to the instrument complement to investigate Jupiter's polar regions, and for education and public outreach purposes. Images of Jupiter taken by JunoCam have been revealing effects that can be interpreted as caused by a haze layer. This presumed haze layer appears to be structured, and it partially obscures Jupiter's cloud top.

With empirical investigation of Jupiter's reflectance function we intend to separate light contributed by haze from light reflected off Jupiter's cloud tops, enabling both layers to be investigated separately.

1. Introduction

JunoCam is the visible light and near infrared Education and Public Outreach camera of NASA's Juno mission. In order to analyze images from Jupiter, we created an approach to approximating Jupiter's reflectance function. The appearance of a convex, smooth and matte white body with a solid surface, illuminated by a single point source of white light, is well approximated by the Lambert illumination model. At the 1-bar level, Jupiter is a reasonably good approximation to a MacLaurin spheroid, hence a convex body. At Jupiter's distance, the sun approximates a point source of light. Thus, settings can be completed to a Lambertian scenario for the Sun - Jupiter system; let's call it *Jupiter's Lambert model*. Dividing actual Jupiter images by Jupiter's Lambert model helps to enhance local features on Jupiter, and it reveals global deviations of Jupiter's reflectance properties from the simple Lambertian scenario.

Especially in the twilight zone of Jupiter's terminator, and in proximity of Jupiter's limb, light scattered or absorbed in Jupiter's atmosphere adds net brightness to the Lambert model. Other models try to approximate these atmospheric effects.

The approach presented here attempts to model the brightening as a structured layer of light-scattering and absorbing haze. Goals are a better understanding of Jupiter's haze layer, as well as obtaining a better enhancement of the underlying cloud tops on the basis of JunoCam images.

2. DeLambertianing

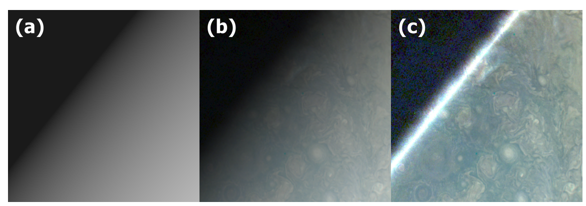

Figure 1: (a) Crop of south-polar projection of Lambert model for square-root encoded image `JNCE_2017086_05C00116`; (b) crop of south-polar projection of decompanded and square-root encoded image `JNCE_2017086_05C00116`; (c) crop of radiometrically linearized and de-Lambertianed south-polar projection of image `JNCE_2017086_05C00116`.

The Lambert illumination model calculates the cosine of the angle between the surface normal and the vector from the respective illuminated surface point to the illuminating point light. This value can be obtained by calculating the (standard) scalar product between the two vectors, normalized to unit length:

$$\cos(\vec{u},\vec{v}) = \frac{\vec{u}\cdot\vec{v}}{||\vec{u}||\cdot||\vec{v}||}. \quad (1)$$

The required vector from Jupiter to the sun can be retrieved from SPICE trajectory data stored in appropriate SPICE kernels via the NAIF/SPICE `spy.exe` tool, or by including the SPICE library into the respective processing software. Calculation of the surface normal of a spheroid is provided by the SPICE library, too, but for the processing discussed here, the calculation has been implemented independently. This applies also to the required JunoCam camera model. The latter is required to assign a color band and a vector to a pixel in raw JunoCam images. A Lambert model, a JunoCam image of Jupiter, and a de-Lambertianed version are shown in Figure 1 in a cropped south-polar projection.

Note the good but still imperfect matching between polar projections of the Lambert model and of the JunoCam image. This small discrepancy shows up as a bright twilight zone in the de-Lambertianed projection.

3. Haze and Light Scattering

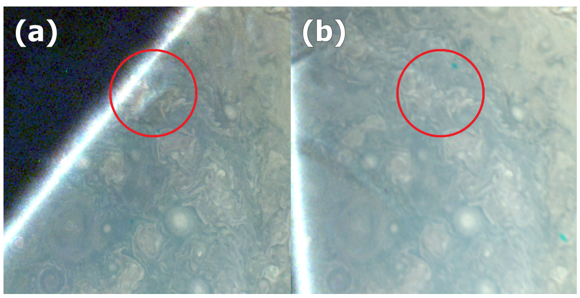

Figure 2: (a) Crop of radiometrically linearized and de-Lambertianed south-polar projection of image `JNCE_2017086_05C00116`; (b) crop of radiometrically linearized and de-Lambertianed south-polar projection of image `JNCE_2017086_05C00121`.

Figure 2 shows an example of the particularly evident dependence of the appearance of haze features from the solar incidence angle. Haze features are more distinct near the terminator. This effect might be attributable either to the height of the haze above the 1-bar level, to variable optical density of the haze, or to the slope of a ripple in the haze horizon.

Note the overall brighter tone in the right tile (b) of Figure 2. This hints at the apparent brightness of the haze being correlated to the emission angle.

4. Light curves

Along Juno's trajectory, JunoCam took — and is going to take — several images of the same patch of Jupiter's surface. Figure 3 shows map projecions of five consecutive RGB images taken during perijove 5, together with according maps of solar incidence, and emission angles with respect to Juno. Such series of

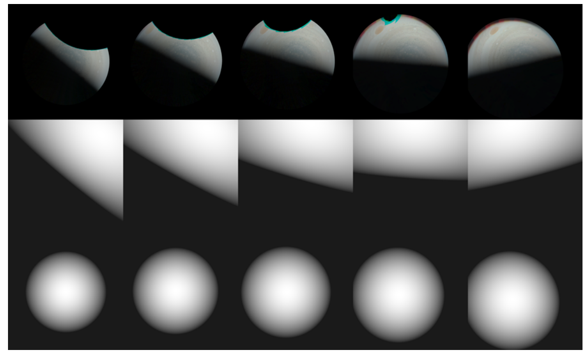

Figure 3: 1st row: Radiometrically square-root encoded south-polar projection of RGB images `JNCE_2017086_05C00113` to `JNCE_2017086_05C00119`. 2nd row: Corresponding square-root of cosine of solar incidence angles. 3rd row: Corresponding square-root of cosine of emission angles.

images allow for inferring curves of apparent brightness as functions of solar incidence and of emission angles for individual surface points separately.

Applications of these light curves range from optical models of Jupiter's haze layer over image enhancement to more realistic and seamless fly-over animations.

5. Summary and Conclusions

As it turns out, challenges and approaches of processing JunoCam images of Jupiter require an explicit or implicit understanding of the optical properties Jupiter's haze layer. The favored explicit approach allows for describing structure in the haze layer.

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Improving a 1 meter telescope in order to follow giant planets in a pro-am collaboration. Next step : an affordable adaptive optic system.

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Abstract

Pic du Midi observatory is known for a long time to produce some of the best planetary images. That's the result of a strong collaboration between professionals and amateurs these last 15 years [1]. The technique is still improving, and we even consider the possibility to use an adaptive optic system next year. This affordable system, developed in collaboration with Imagine Optic could also interest other observatories with telescopes in the 0.5 to 2m range. However just with the lucky imagining method, we already have done a lot of publications with the astronomers of Bilbao University [2], [3].

1. Introduction

In order to obtain high resolution images of the solar system in the visible part of the spectrum, a 1 m telescope is a good compromise. You also need a very good site with good seeing conditions and that's what we have at the Pic du Midi observatory, near the border between France and Spain at an altitude of 3000m. Because of that, the 1 m telescope of the Pic du Midi observatory is one of the best in the world in this field. But planetary observing is time consuming and it became more and more obvious that a strong team was necessary to make a good survey. So we are building a team of professional and amateurs to use the telescope as much as possible. The telescope belongs to Observatoire Midi Pyrénées but is used by a team of the "Observatoire de Paris" (IMCCE - LESIA) only for planetary topics.

2. Improvements

The first big step was the use of fast cameras. They became better, faster and cheaper! But with a 17m nominal focal length, the cameras usually used by amateurs are most of the time too small for a planet like Jupiter. It's only since few years that we have cameras with a sensor both fast and large enough for a telescope that big. With the improvement of the image quality, it became more and more obvious that a refraction corrector was necessary. So we add one. Now the images are so good that we discovered some minor optical defaults which are limiting the image quality for some position of the telescope. We started to think to characterize the defaults and correct them with an affordable system of adaptive optics. It's based on a simple deformable mirror with 40 actuators, and a wave front sensor. The goal is to have a final product available in 2018. If it works, this new product can be put on the market, and may be interesting for other telescopes between 0.5 and 2m.

3. Figures

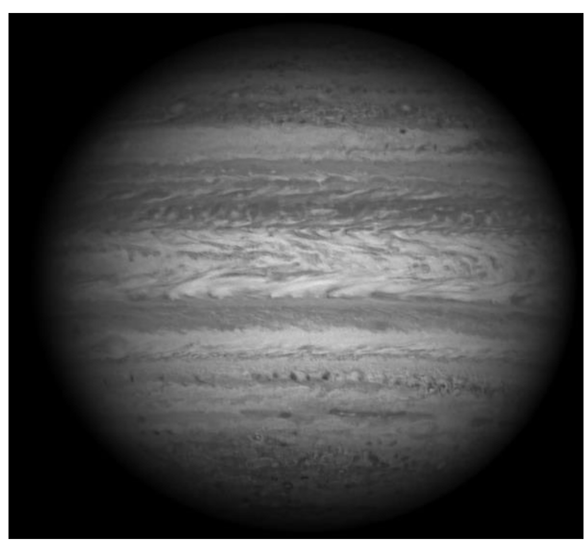

Figure 1: Jupiter seen with the 1 m telescope of the Pic du Midi observatory 2014/10/14.

Figure 1: This global map of Jupiter has been obtained with the 1 meter telescope of the Pic du Midi observatory.

4. Summary and Conclusions

We already have very good result with the 1 meter telescope. Our goal is to have more and more people in the team in order to make a survey has long as possible of Jupiter, Uranus and Neptune. The next step is an OA system, we want to make it work on the 1 meter telescope and also make it available on the market to help other observatories to produce high resolution images of the solar system with middle size telescopes.

References

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[2] Jupiter's zonal winds and their variability studied with small-size telescopes. Astronomy & Astrophysics, Volume 554, id.A74, 11 pp

[3] Episodic bright and dark spots on Uranus. Icarus, Volume 220, Issue 1, p. 6-22

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