

Recent contributions of amateur astronomers to the study of planetary atmospheres from Venus to Neptune

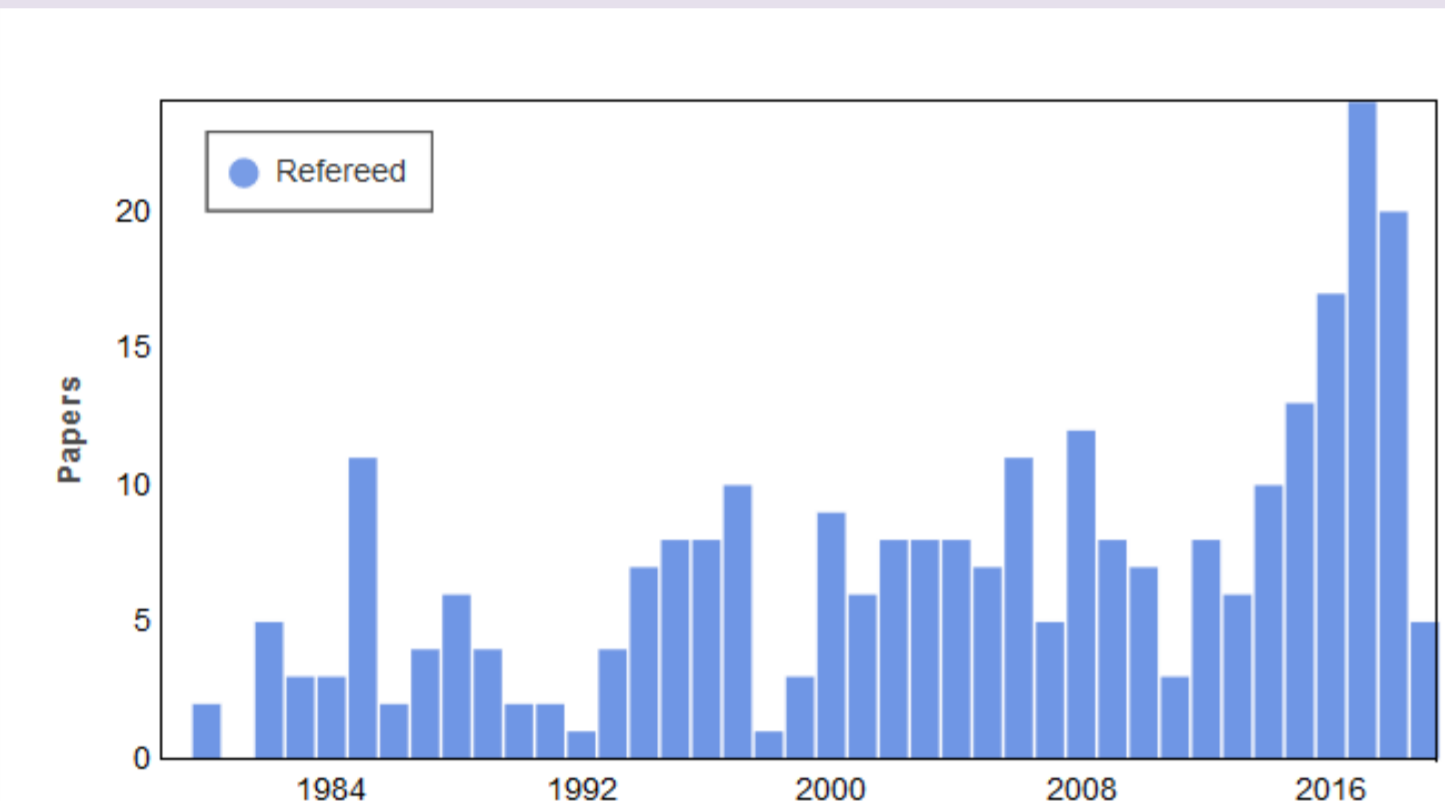
R. Hueso [ricardo.hueso@ehu.es] (1), A. Sánchez-Lavega (1), M. Delcroix (2)

(1) UPV/EHU, Bilbao (Spain), (2) Société Astronomique de France, Paris, France



Abstract: During the last two decades amateur contributions to professional publications in the field of planetary astronomy have increased exponentially [1-2]. Technical **advancements in instrumentation** and the **collaboration of amateurs with professional astronomers** have flourished making some amateur observers essential actors in planetary astronomy with **regular scientific contributions and a capacity to perform unique discoveries** [3-5]. The role of amateurs and citizen scientists is also acknowledged in missions such as the Juno mission [6] or in large projects like Europlanet 2020 RI, which has organized several activities aimed to increase the participation of amateur astronomers in planetary science. Here we review some of the current trends and recent collaborations in professional and amateur studies of planetary atmospheres. We also explore how funding sources like Europlanet 2024 RI will boost the participation of more amateur and professional astronomers.

Amateur involvement in Planetary Science



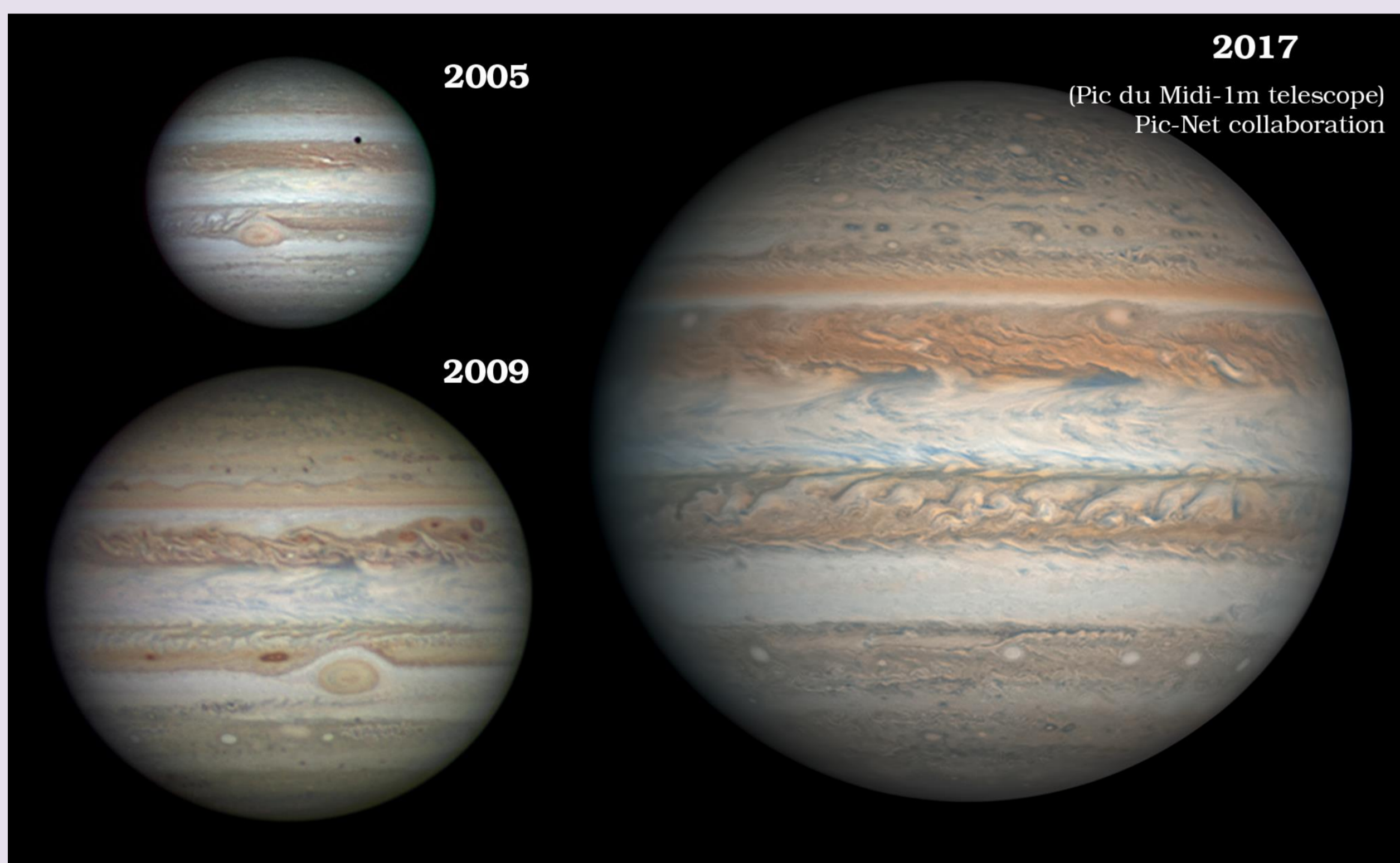
The history of astronomy is rich in achievements performed by amateur observers. Amateurs provide useful data in most topics related with astronomy and enjoy the freedom to observe their preferred objects. Working together they provide many small telescopes able that accumulate much more observing time that the ensemble of professional telescopes. A simple examen of the scientific literature through their most popular databases exemplifies that the number of "amateur" collaborations in the scientific literature has doubled in the last decade.

The figure on the left illustrates 281 refereed articles in NASA ADS containing "amateur" in their abstracts excluding bulletins, proceedings and minor publications. This is a lower limit to a much larger sample of "amateur astronomy" related papers.

25% of this sample encompass different themes in planetary science with half of them corresponding to topics in planetary atmospheres

Planetary Atmospheres & amateur astronomy:

The dynamic nature of the atmospheres of Jupiter, Saturn, Mars and Venus make frequent observations of them an essential requirement to understand their atmospheres. Over the last decade many amateur astronomers have mastered high-resolution observations of bright planets. Thanks to fast-acquisition cameras and image processing techniques, a large number of amateur observers now obtain images that can beat seeing effects and reach the diffraction limit of their telescopes. The amateur community provides regular observations that can discover the onset of storms in Jupiter [7] or Saturn [8-9], discover unusual events in Jupiter [3-4] or Mars [8], or that can be used to study the global dynamics of these planets [10-12] including also Venus [13-14]. Recent advancements allow amateurs to contribute to the study of exceptionally bright features in Uranus [15] and are now used regularly to monitor the atmospheric activity of Neptune [16-17].

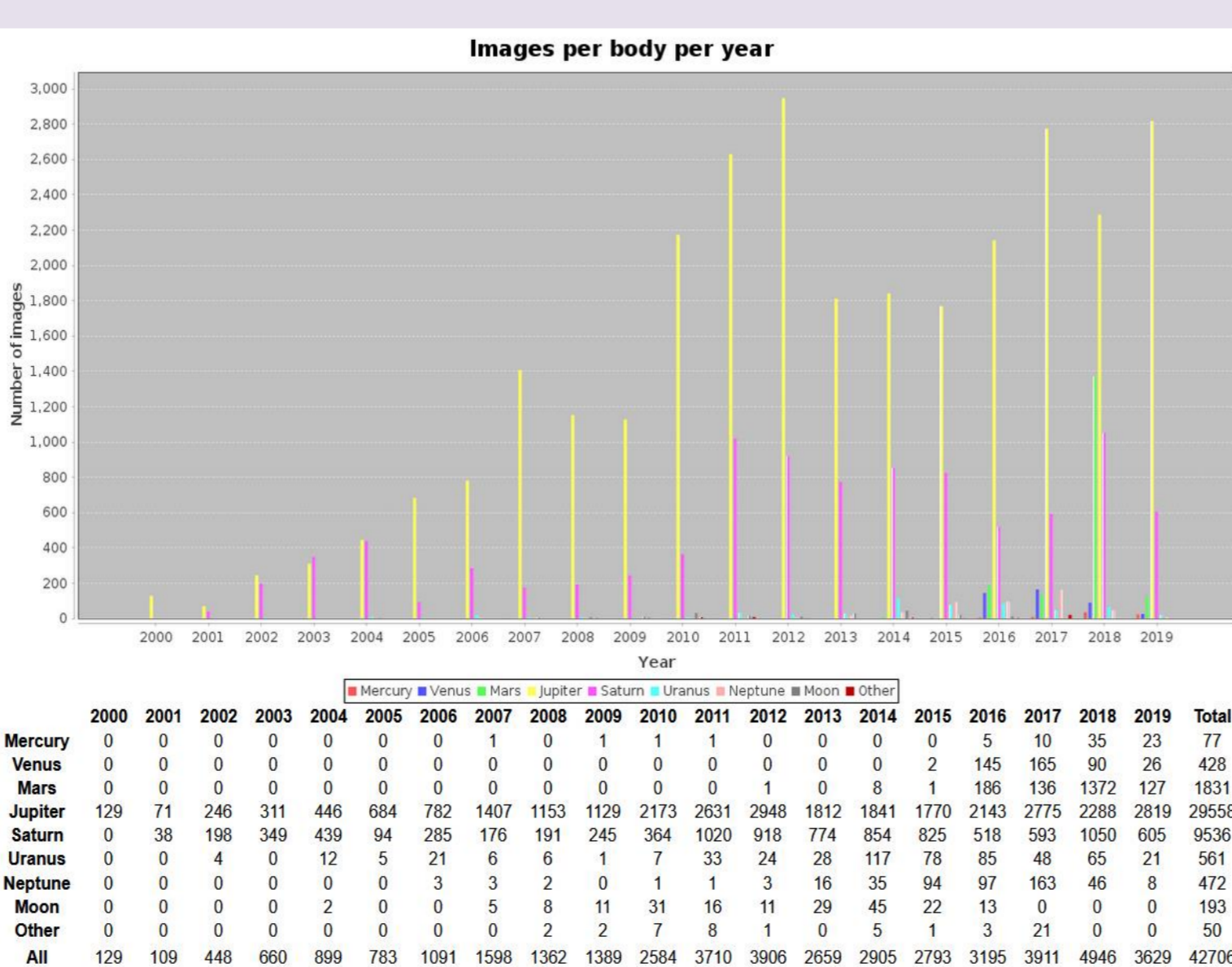
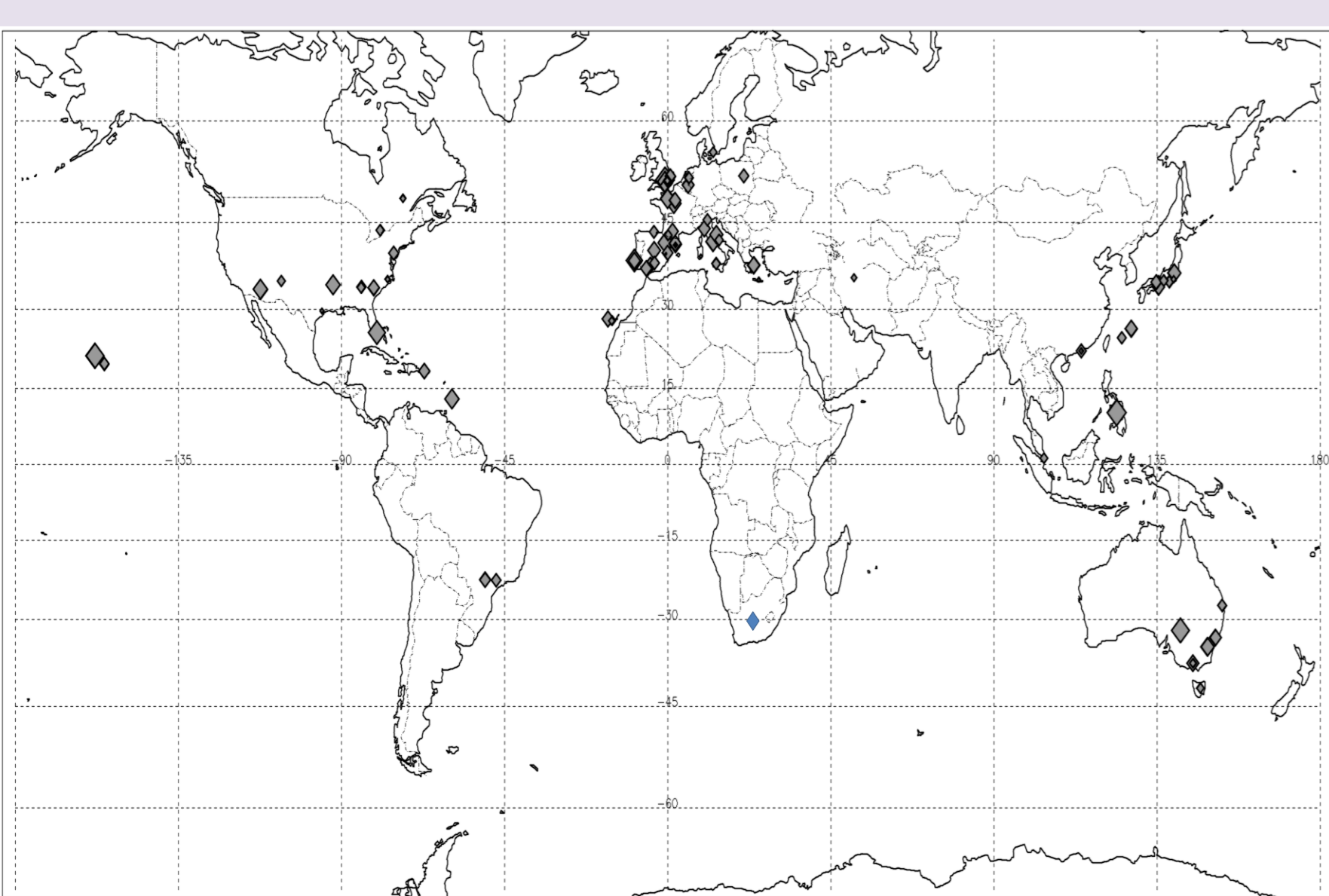


Example of continuous advancement in image quality results.

All observations processed by the same amateur astronomer (Damian Peach, UK). Some amateurs are recently able to observe using 1-m size telescopes (images acquired in 2017) providing a spatial resolution better than ever before. The key to success here is the personal experience and the time dedicated by amateurs to their best possible outcome.

The power of sharing data!

A key element for collaboration is sharing data online. The two most important databases where amateurs post their data are ALPO Japan (<http://alpo-j.asahikawa-med.ac.jp/>) and PVOL (<http://pvol2.ehu.eus>). The latter has a database structure, can be searched for specific data easily [18] and is integrated in the Virtual European Solar and Planetary Access (VESPA) query portal. Figures below show the distribution of observers collaborating with PVOL and the number of observations that can be accessed in the database for each planet.



Current trends in Pro-Amateur collaborations in Planetary Atmospheres

PVOL2 contains a list of **37 scientific publications** that have used or are based in amateur data from the database, including publications in major scientific journals such as Nature, Science and other high-profile journals [See Refs. 3-5 and 7]. Scientific topics are varied. Ranked by topics these publications cover **Jupiter atmosphere Dynamics (17 publications); Saturn's atmosphere (7); Venus (2); Mars (1); Uranus (1) and Neptune (2)**. Other topics include **Technical (4), Educational topics (2) and Citizen Science (1)**.

A closer look to these publications shows that in the last years new trends in the analysis of amateur data have emerged. These are:

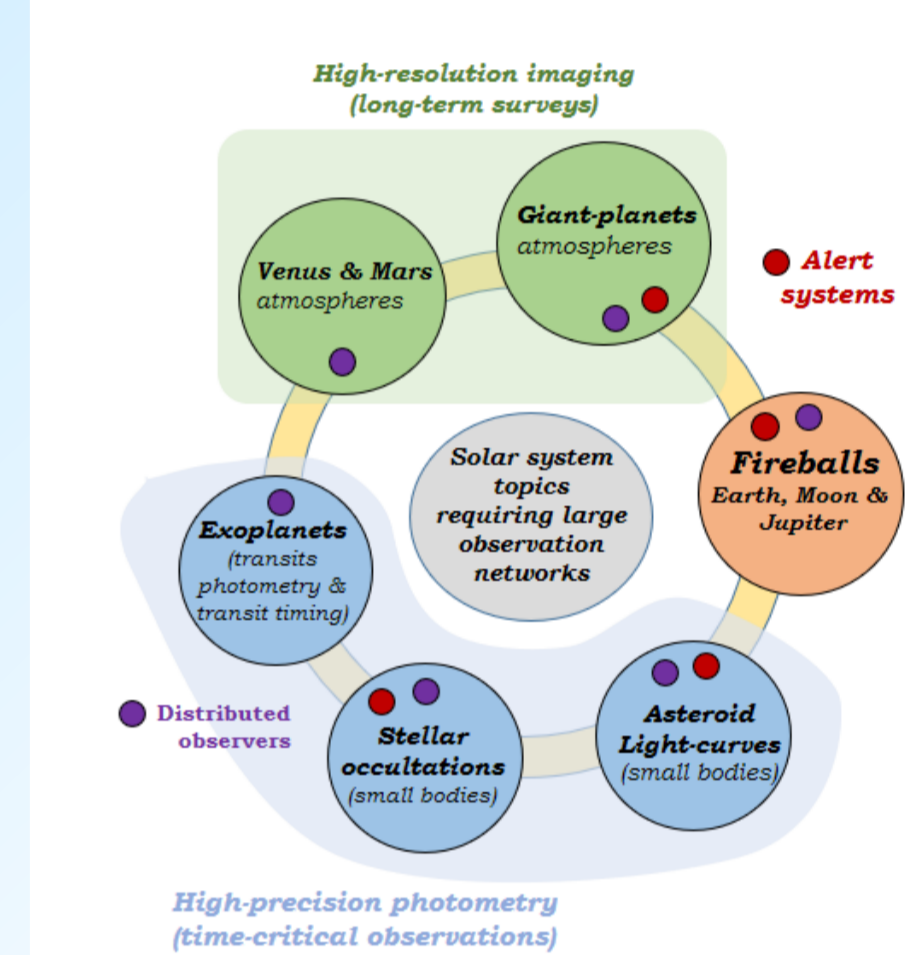
- **Unique discoveries** requiring nearly continuous surveys of the planets (i.e. **impacts [3, 4] and highly unusual atmospheric events [5]**)
- The **amount of amateur images typically used** in professional studies of the solar system has increased dramatically in the last years. There is a need to archive not only the initial images but also **details of their navigation** and quick tools for analysis. For instance current studies based on amateur observations of Saturn's atmosphere **make use of several hundred images [19]** and **cover periods of time of up to decades [20]**.
- **Improved quality** and data from larger telescopes. Some amateur astronomers are getting access to use 1-m telescopes producing even better observations more and more often. Some organizations such as Europlanet have provided occasionally the means to access 1-m telescopes.

Future data and possible tools in PVOL

- Addition of **Navigation information** (storing and serving WinJupos ims navigation files provided by users).
- **Online tools** to quick navigate images and show quick processing of the data for selection of the data.
- **PVOL Mapping: Capability to perform image projections from the online server using the ims files and running mapping tools.**

Europlanet 2024 Research Infrastructure (2020-2023)

The list of topics includes those highlighted in the figure



The list of activities includes:

- Workshops (open calls)
- Training (open calls)
- **Coordination of Ground-based campaigns**
- **Funding to participate in observations at professional telescopes**
- Development of alert systems
- **Improvements in data access (PVOL and others)**

A human side in Pro-Am collaborations

Non paid amateur astronomers and citizen scientists dedicate strong efforts to their observations and analysis. Acknowledging the talent, effort and dedication they put into acquiring valuable data is essential. Providing opportunities for them to meet together and network with professionals has proven very successful in the context of the Juno mission ground-based support program and in the success of the JunoCam instrument. The image below illustrates participants in a second JunoCam pro-am meeting organized with support from Europlanet 2020 RI.



References: [1] Mousis et al.: Instrumental methods for professional and amateur collaborations in planetary astronomy, *Exp. Astron.*, 38, 91, 2014. [2] Kardasis et al.: The need for professional-amateur collaboration in studies of Jupiter and Saturn. *JBAA* 126,29-39 (2016). [3] Sánchez-Lavega et al.: The impact of a large object on Jupiter in 2009 July, *ApJ*, 715, L155-L159, 2010. [4] Hueso et al.: First Earth-based detection of a Superbolide on Jupiter, *The Astrophysical Journal Letters*, Vol. 721, L129-L133, 2010. [5] Sánchez-Lavega et al. An extremely high altitude plume seen at Mars morning terminator. *Nature*, 518, 525-528, 2015. [6] Rogers JH, Jupiter and the Juno mission: the amateur's contribution. *J.Brit.Astron.Assoc.* 126, 197-200, 2016. [7] Sánchez-Lavega et al., Depth of a strong jovian jet from a planetary-scale disturbance driven by storms, *Nature*, 451, 437-440, 2008. [8] Sánchez-Lavega et al., Deep winds beneath Saturn's upper clouds from a seasonal long-lived planetary scale storm, *Nature*, 475, 71-74, 2011. [9] Sánchez-Lavega et al., A complex storm system and a planetary-scale disturbance in Saturn's north polar atmosphere in 2018, *Nat. Astr.*, submitted, 2019. [10] Hueso et al., Jupiter cloud morphology and zonal winds from ground-based observations before and during Juno's first perijove, *GRL*, 44, 4669-4678, 2017. [11] Fischer et al., Analysis of a long-lived, two-cell lightning storm on Saturn, *A&A*, 621, A113, 2019. [12] Hueso et al., Saturn atmospheric dynamics one year after Cassini..., *Icarus*, submitted, 2019. [13] Sánchez-Lavega et al., Venus cloud morphology and motions from ground-based images at the time of the Akatsuki orbit insertion, *ApJ*, 833, L7, 2016. [14] Peralta et al., Morphology and Dynamics of Venus's Middle Clouds with Akatsuki/IR1, *GRL*, 46, 2019. [15] Sromovsky et al.: Episodic bright and dark spots on Uranus. *Icarus*, 220, 6-22 (2012). [16] Hueso et al., Neptune long-lived atmospheric features in 2013-2015 from small (28-cm) to large (10-m) telescopes, *Icarus*, 295, 89-109 (2017). [17] Molter et al., Analysis of Neptune's 2017 bright equatorial storm, *Icarus*, 321, 324-345 (2019). [18] Hueso et al.: The Planetary Virtual Observatory and Laboratory (PVOL) and ..., *PSS*, 150, 22-35, 2017. [19] Sánchez-Lavega et al.: A complex storm system and planetary-scale disturbance in Saturn's north polar atmosphere in 2018, *Nat. Astron.* (submitted). [20] Hueso et al.: Saturn atmospheric dynamics one year after Cassini: Long-lived features and time variations in the drift of the Hexagon, *Icarus*, in press.

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