IO, THE CLOSEST GALILEO'S MEDICEAN MOON: CHANGES IN ITS SODIUM CLOUD CAUSED BY JUPITER ECLIPSE

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We report results of a study of true temporal variations in Io's sodium cloud before and after eclipse by Jupiter. The eclipse geometry is important because there is a hypothesis that the atmosphere partially condenses when the satellite enters the Jupiter's shadow, preventing sodium from being released to the cloud in the hours immediately after the reappearance. The challenge lies in disentangling true variations in sodium content from the changing strength of resonant scattering due Io's changing Doppler shift in the solar sodium absorption line. We undertook some observing runs at Telescopio Nazionale Galileo (TNG) at La Palma Canary Island with the high resolution spectrograph SARG in order to observe Io entering into Jupiter's shadow and coming out from it. The particular configuration chosen for the observations allowed us to observe Io far enough from Jupiter and to disentangle line-of-sight effects looking perpendicularly at the sodium cloud. We will present results which took advantage of a very careful reduction strategy. We remove the dependence from gamma factor, which is the fraction of solar light available for resonant scattering, in order to remove the dependence on the radial velocity of Io with respect to the Sun.

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Galileo's Medicean Moons, Padova, 6 – 10 January 2010

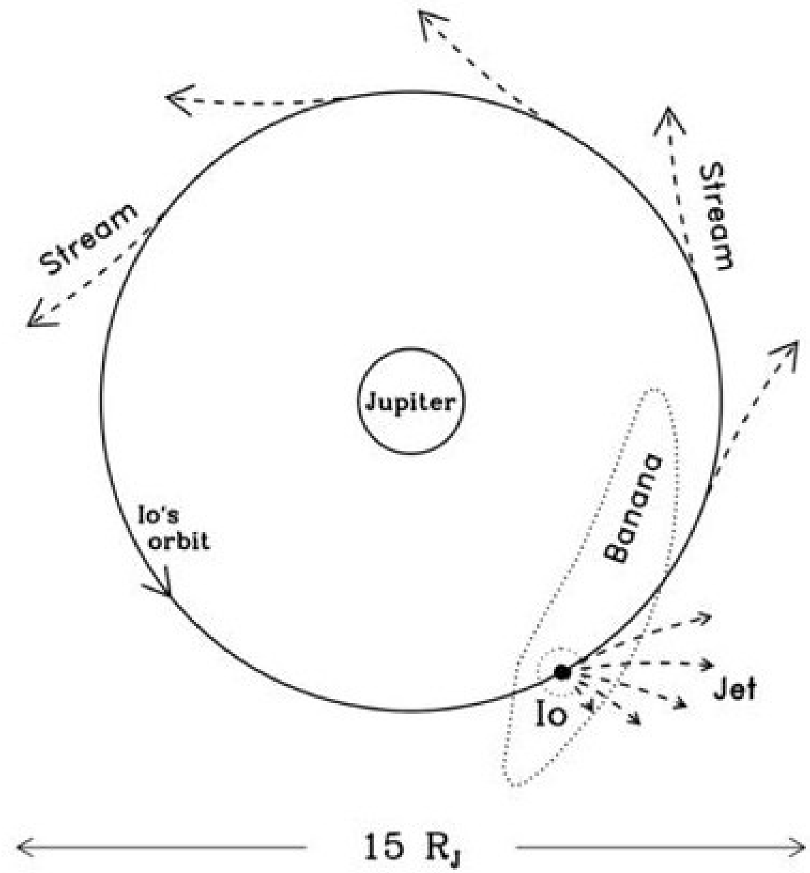
Io Sodium Clouds

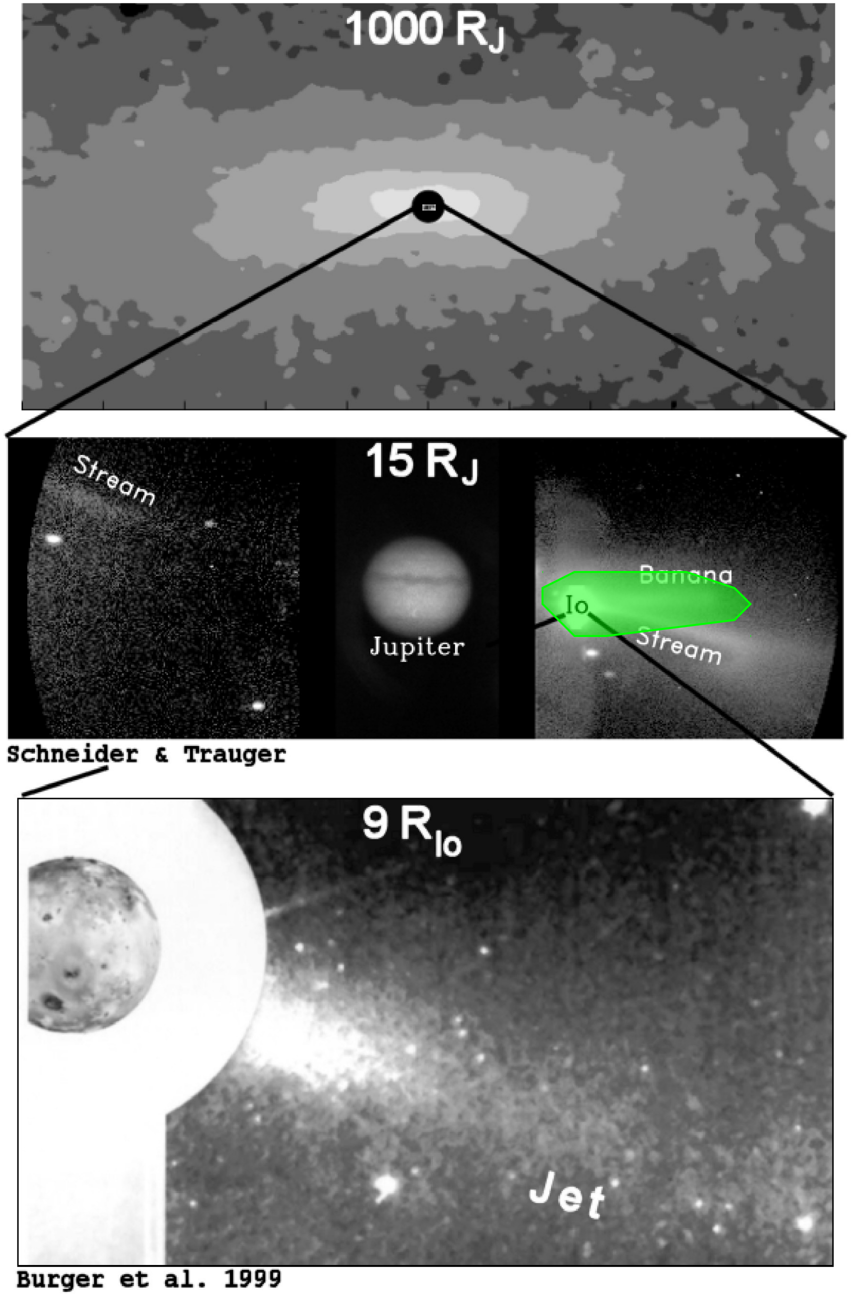
There are three major features in the neutral sodium cloud around Io:

• a banana shaped cloud of slowly escaping neutral atoms;

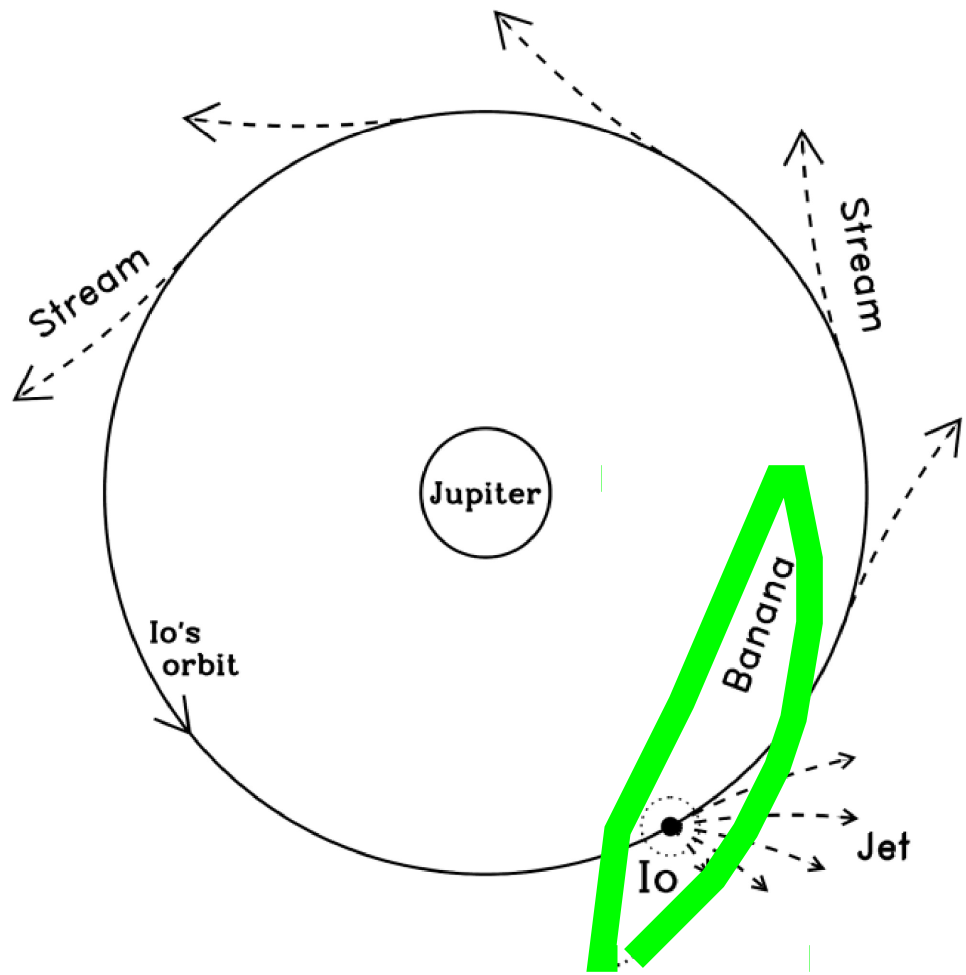
• a fast "jet," produced by pickup ion neutralization in Io's atmosphere;

• a molecular ion "stream" resulting from ionization and pickup of sodium-bearing molecules directly from Io's atmosphere. It is composed of fast sodium atoms which are ejected from the torus by dissociation or dissociative recombination of unidentified molecular pickup ions containing sodium (NaX^+).



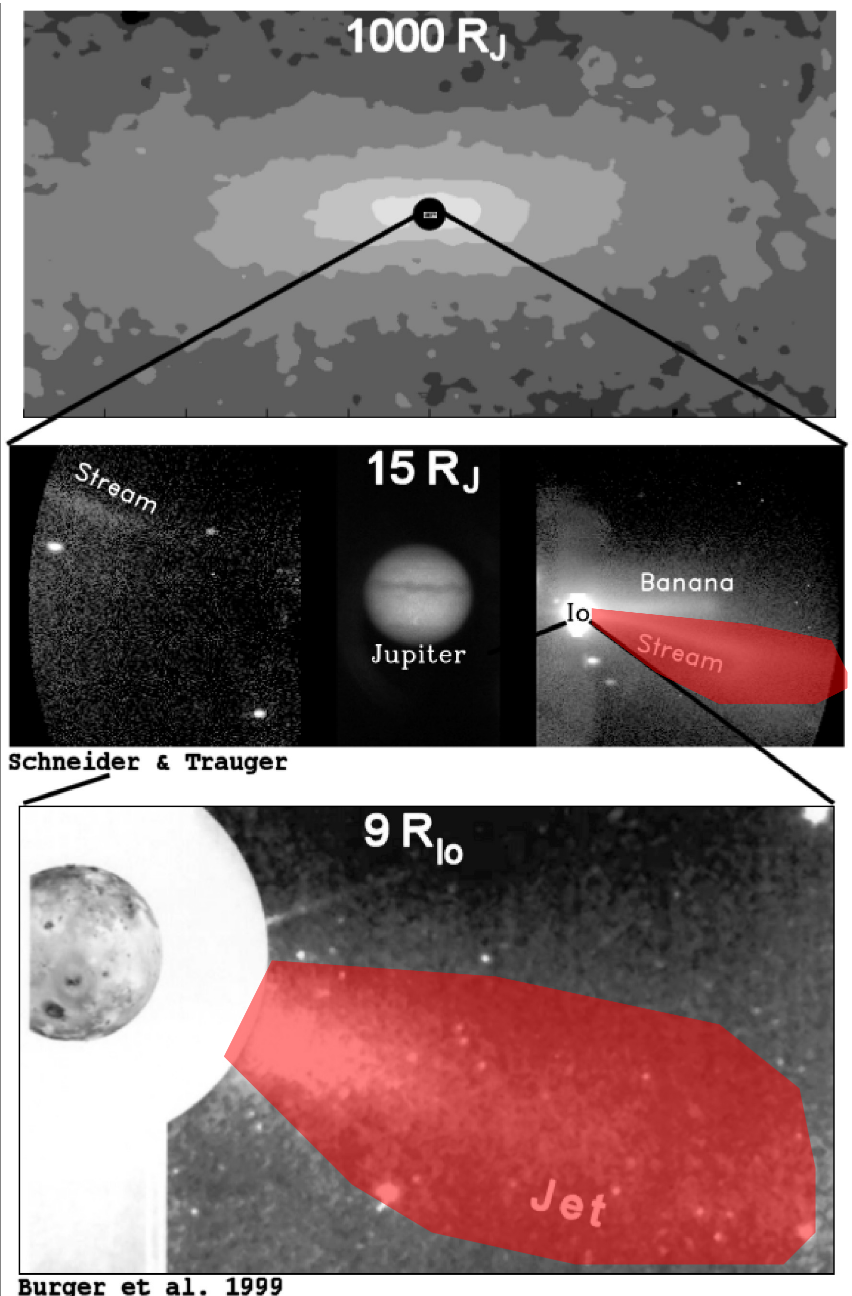


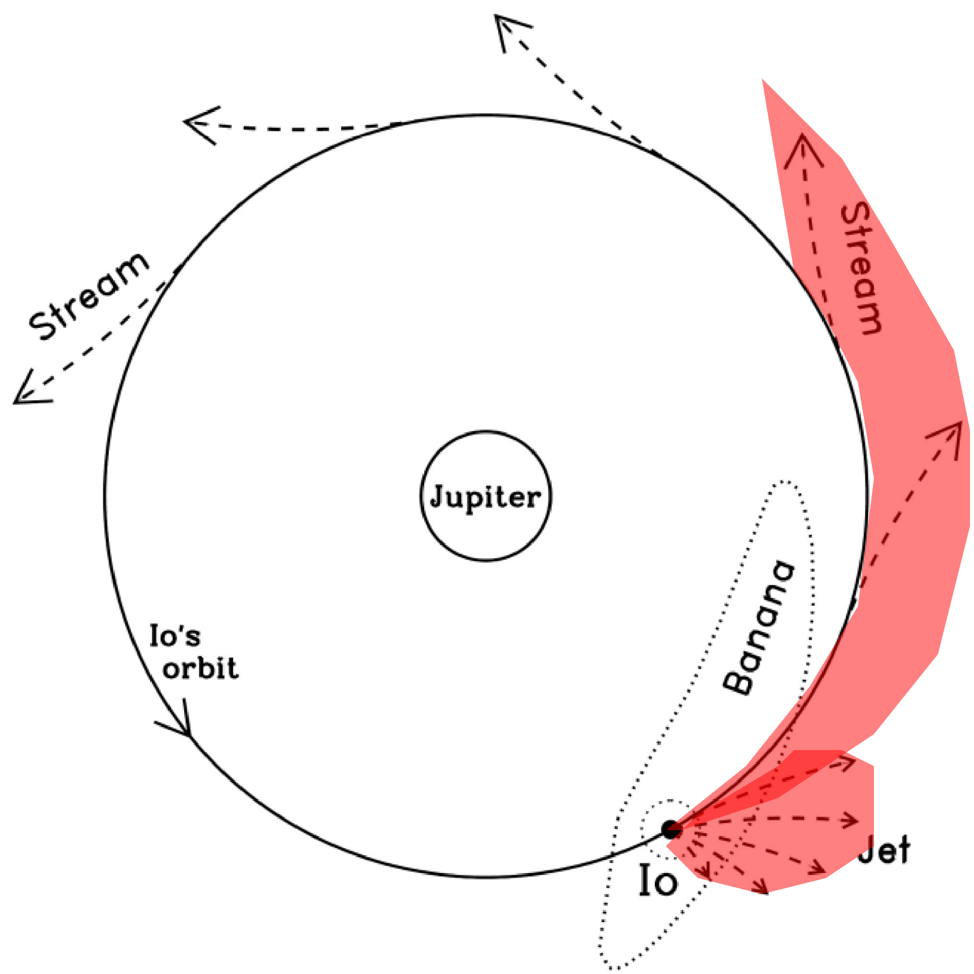
IO SODIUM CLOUDS



The “banana cloud” (Brown 1974) contains slow atoms escaping from the surface, and its shape is controlled by celestial mechanics and by ionization (Burger et al 1999).

IO SODIUM CLOUDS

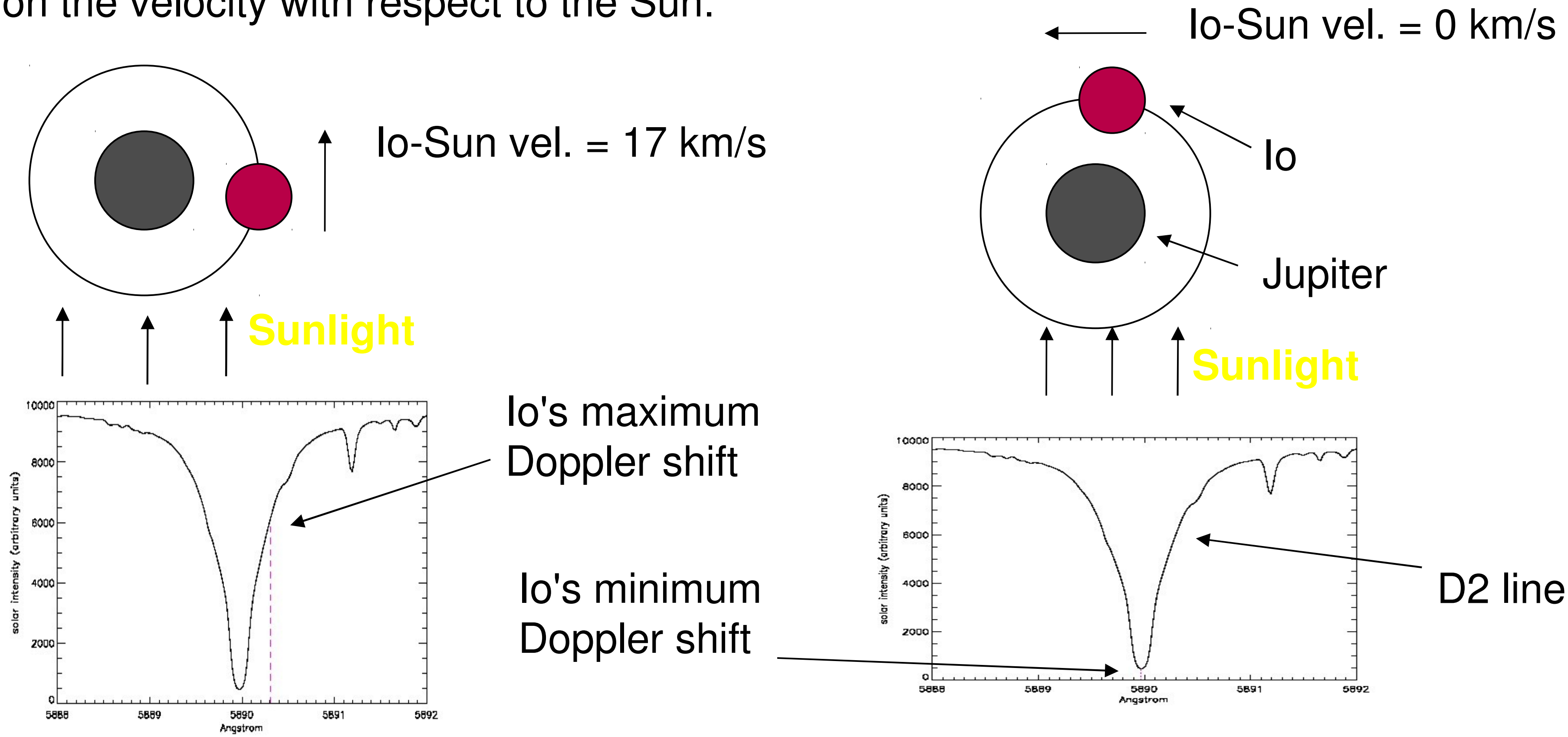


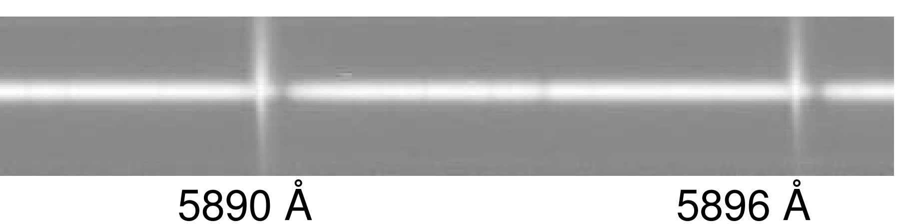


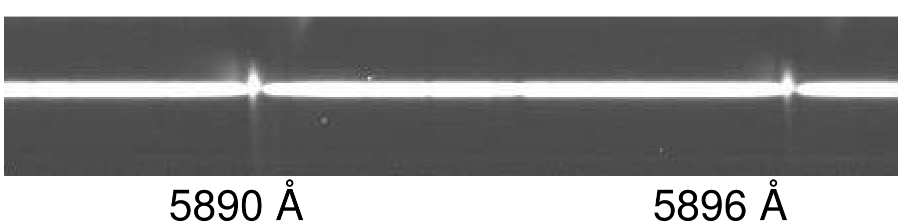
The "jet" and "stream" (1992, 1999) showed that Io's ionosphere and Jupiter's magnetosphere interacted (Schneider & Trauger 1995).

Brightness Changing due to Illumination Geometry

Neutral Sodium emits light through Resonant Scattering, so, *were the abundance be constant*, its intensity should depend on the amount of sunlight available for scattering, i.e. on the velocity with respect to the Sun.

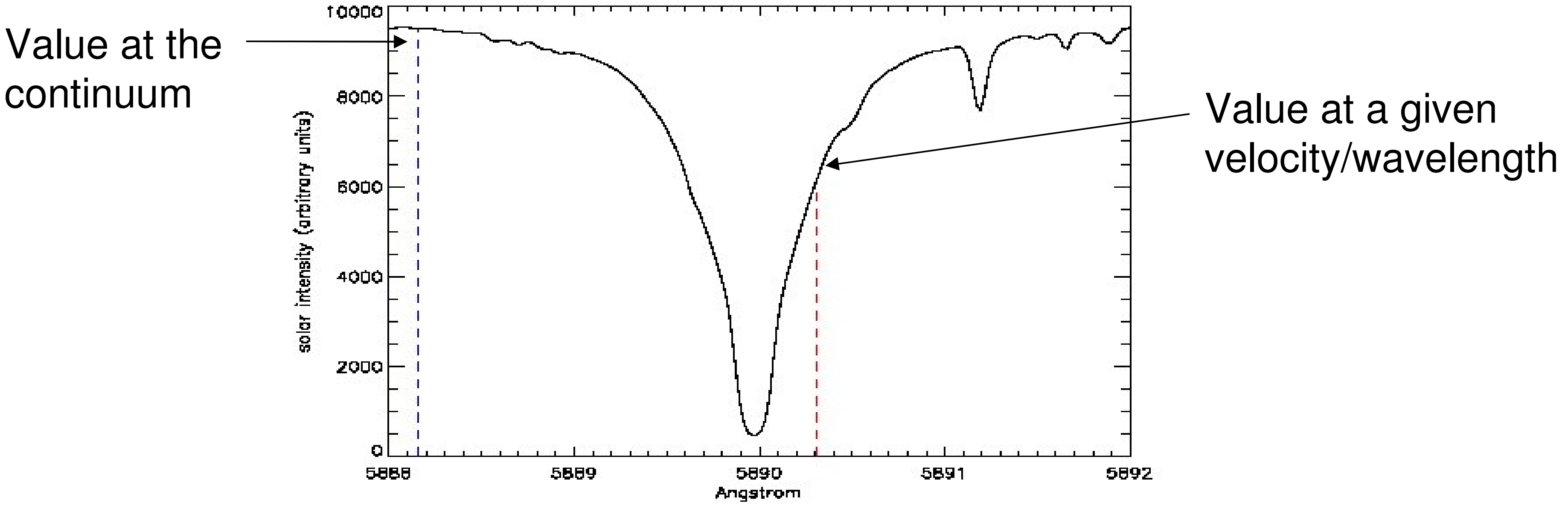






Brightness Changing due to Illumination Geometry

A quantitative way to measure the intensity changes due to the different geometry is the γ factor.

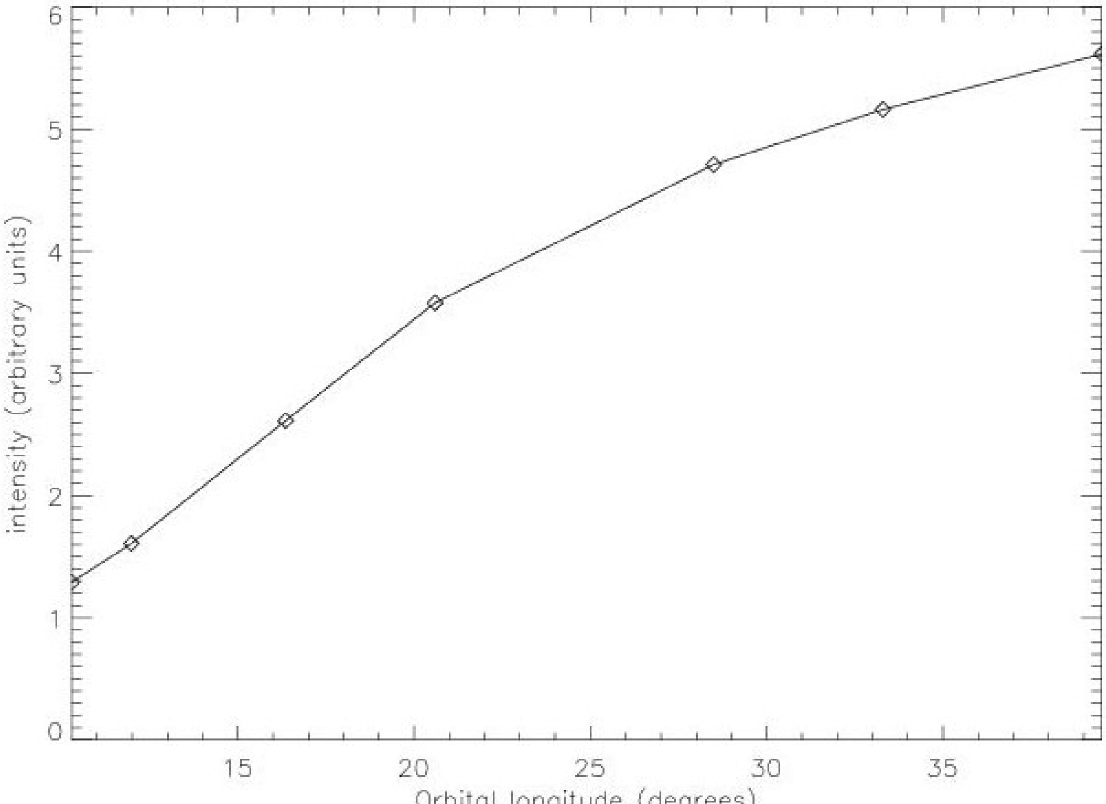


$$\gamma = \frac{\text{Value at a given wavelength}}{\text{Value at the continuum}}$$

At conjunctions, Io-Sun relative velocty is zero, γ factor is small and there is small amount of solar photons available for resonant scattering, and the cloud is fainter.

Brightness Changing due to Illumination Geometry

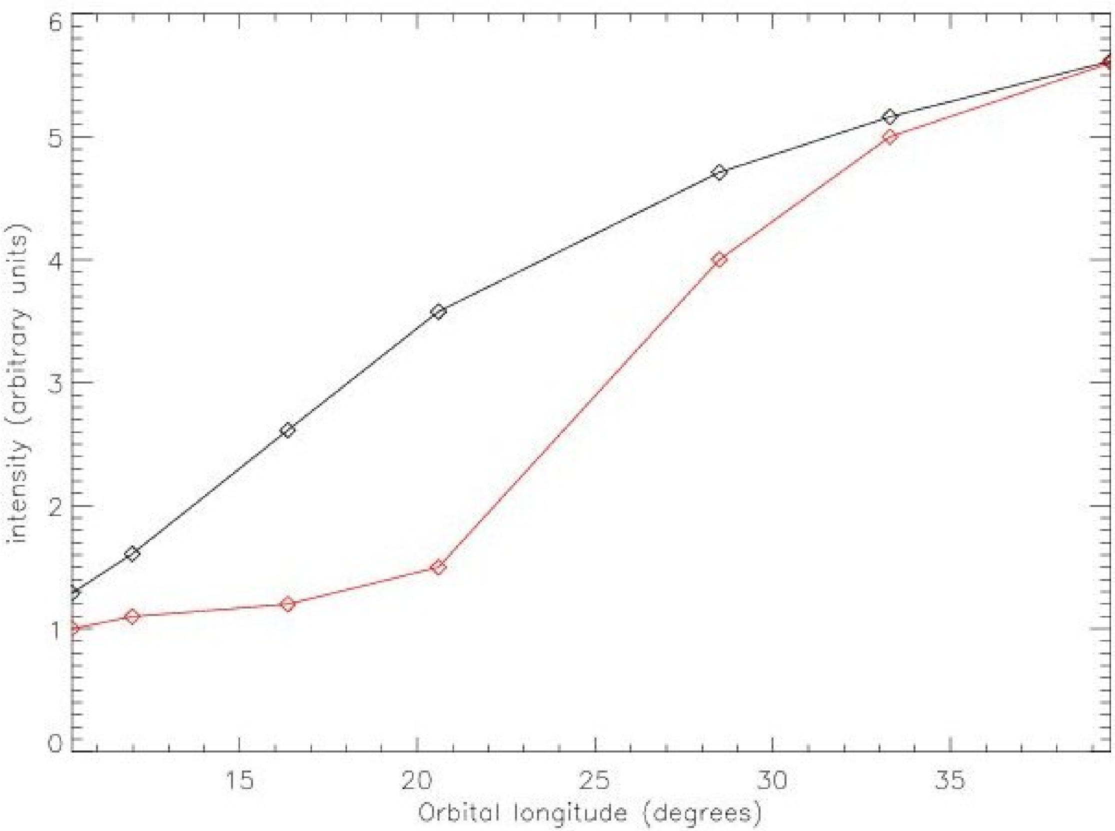
As the γ factor increases after the superior conjunction (occultation), Sodium atoms see more solar photons, and the intensity of the cloud increases.



How a non – condensing cloud does behave.Here the orbital longitude is counted counterclockwise starting from the superior conjunction point.

Scientific Goals: a Condensing Exosphere

Some past observations showed some evidence of post-eclipse brightening, i.e. the sodium cloud immediately after the eclipse is less bright than it should be, and reaches the expected values of luminosity hours after the reappearance. One possible explanation is condensation of sodium at the surface during eclipses by Jupiter, which would prevent NaCl (principal source of Na atoms) to be released. This is the fascinating hypothesis we want to test.



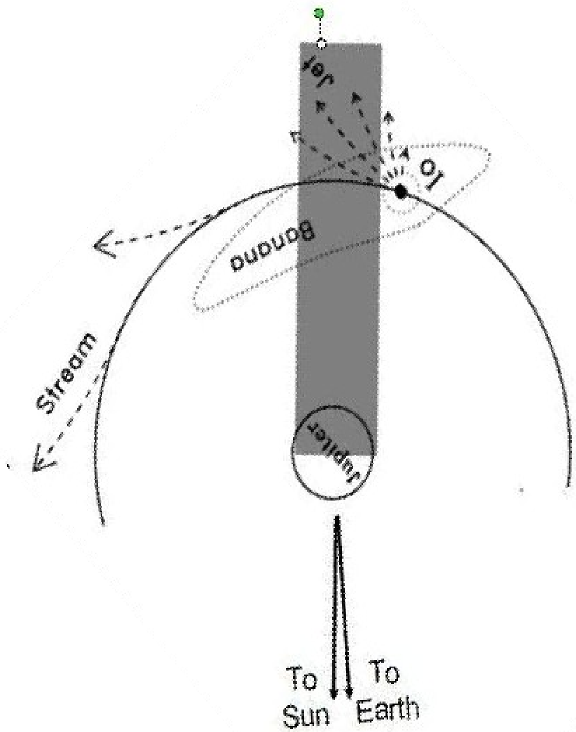
If the condensation hypothesis is correct, we expect the actual behaviour of the cloud to be like the red line: starting less bright than the expected, and reaching the black (theoretical) line hours after the reappearance.

Observations

In 2007 and 2009, we undertook four observations to test the hypothesis of condensation of Io's atmosphere on the surface. These observations took advantage of high quality of italian Telescopio Nazionale Galileo (TNG) at La Palma Canary Island. We observed high resolution spectra of Io two times while entering into Jupiter's shadow and two times while coming out.

SARG @ TNG:
High resolution échelle spectrograph
Diameter of the telescope: 3,6 m
Resolution: 115000
Dispersion: 0,022 Angstrom/pix
Slit dimensions in the sky: 26,7 x 0,4 arcsec
Na filter

Observations



The eclipse geometry is important. We want:
- to remove line-of-sight effects looking at the cloud perpendicularly;
- to observe Io entering/exiting eclipse well before/after it hides behind Jupiter’s disk;
- to disentangle true variations in sodium content from the changing strength of resonant scattering.

Reduction Steps

As we wanto to study the Na emission from the cloud, we have to remove the sunlight reflected from Io's surface. So, for the purposes of this research, besides bias and flat fielding, the telluric lines removal and the sunlight subtraction.

The conversion between ADUs and kR has been done using the well calibrated Jupiter's intensity of 5.4 MR/A. Knowing the g factor (from the γ factor, under the assumption of optically thin cloud) is also possible to get the column density N and therefore the amount of sodium present.

1 Rayleigh = $(10^6/4\pi)$ photons cm^{-2} s^{-1} sr^{-1}

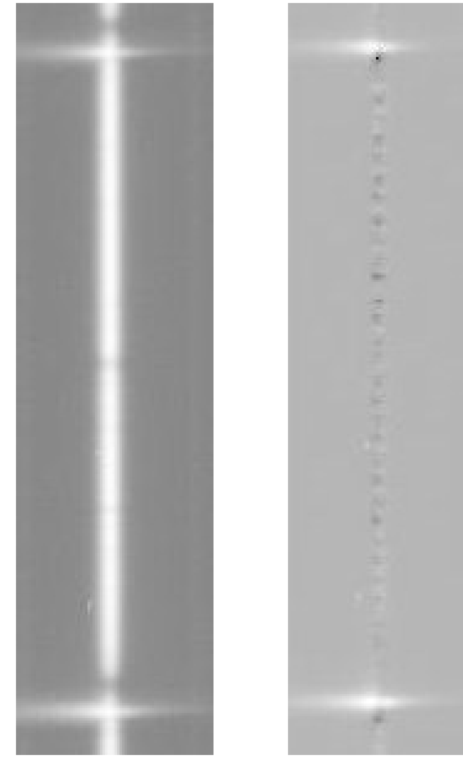
[N] = atoms cm^{-2};

[g] = photons s-1 atoms-1

Intensity (kR) = g * N * $(4\pi/10^9)$;

$$g \equiv \left[\gamma \cdot \pi F_{sun}(.59) \cdot \frac{\lambda^2}{c} \right] \frac{\pi e^2}{mc} f$$

Before After



Io

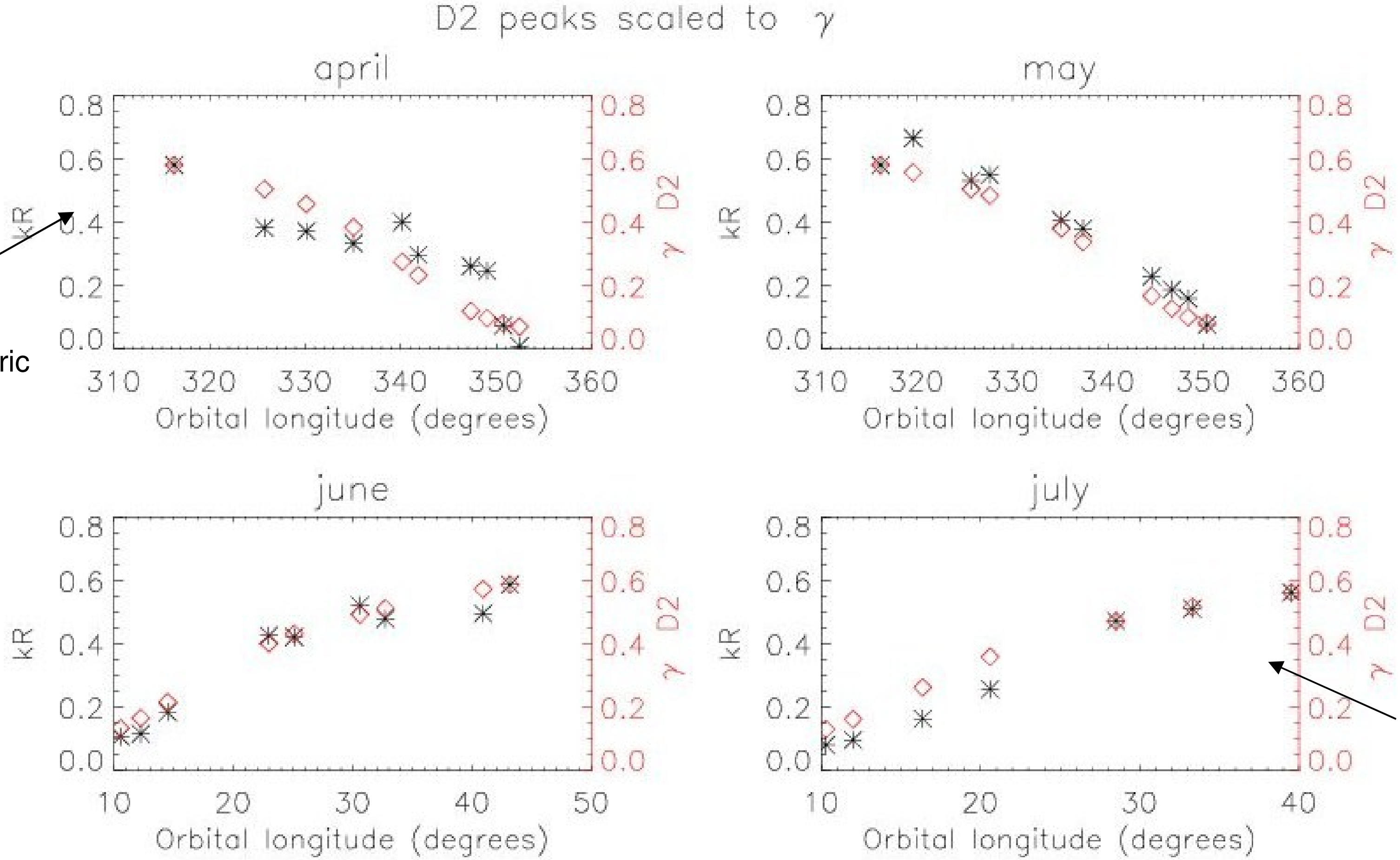
Jupiter

=> 5.4 MR/Angstrom

Preliminary Results

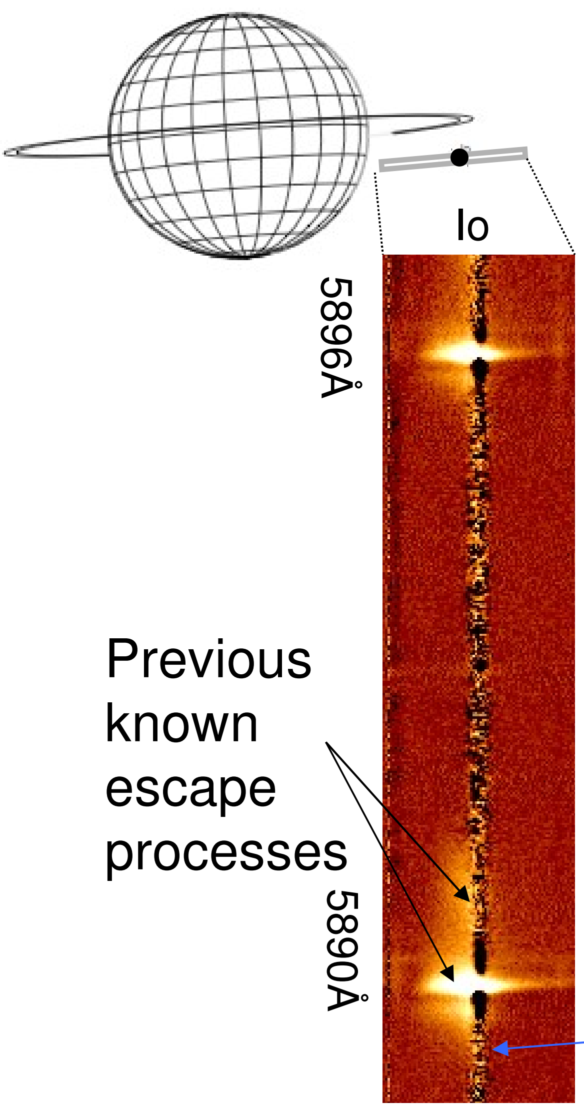
These are the preliminary results from our work. Some results (see e.g. July) seem to support the condensation hypothesis, but further steps are required to understand the outliers (see e.g. April). April & May: before eclipse; June & July: after eclipse.

Non-photometric night?

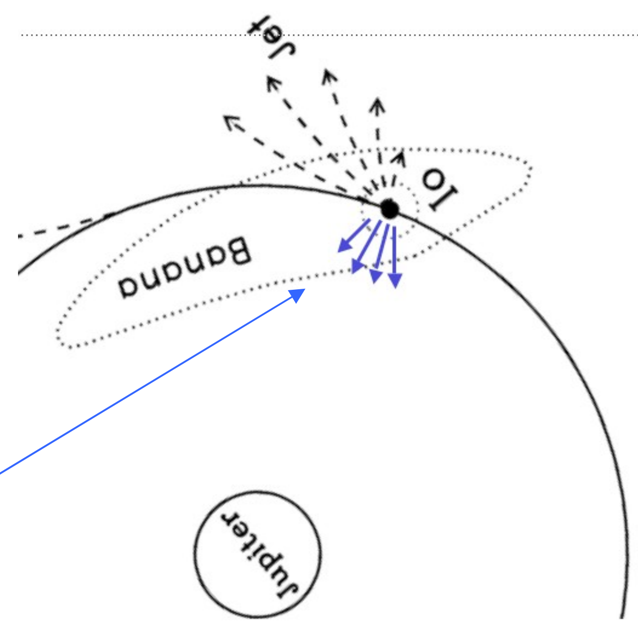


Strong evidence for condensation (intensity rises more slowly than the expected trend)

Breaking News: TNG Discovers New Atmospheric Escape Process



During the reduction steps of this work, a new atmospheric escape process has been discovered. It is a blue – shifted ejection (towards Jupiter) of a few tens of km/s. This is the first new escape process discovered in the jovian system in 15 years, enabled by TNG/SARG's high spectral/spatial resolution & sensitivity, and support for planetary observations
This could also have possible ramifications for other moons, Mars, Venus & extrasolar planets.
Much more in the forthcoming works.



References and Acknowledgements:

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