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First ALMA Millimeter Wavelength Maps of Jupiter, with a Multi-Wavelength Study of Convection

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Abstract

We obtained the first maps of Jupiter at 1-3 mm wavelength with ALMA in January 2017, just days after the amateur community had reported the emergence of an energetic eruption at ~16.5°S jovigraphic latitude. Our observations, probing below the ammonia cloud deck, show that the erupting plumes bring up ammonia gas from the deep atmosphere.

While models of plume eruptions that are triggered at the water condensation level explain data taken at uv--visible and mid-infrared wavelengths, our ALMA data provide a crucial, hitherto missing, link in the moist convection theory by showing that ammonia gas from the deep atmosphere is indeed brought up in these plumes. HST data show that the plumes reach altitudes well above the tropopause.

1. Introduction

Motivated by the *Juno* mission to Jupiter, numerous ground-based and space-borne telescopes have monitored the planet closely during the past few years, in particular near Perijoves (PJs). Contributing uniquely to this campaign, observations were carried out with the Atacama Large Millimeter/Submillimeter Array (ALMA) in early Jan. 2017, and in May 2018. This abstract is focused on the 2017 data, but preliminary results from 2018 will be shown at the meeting.

In early Jan. 2017, ALMA observed Jupiter's atmosphere for the first time at 1.3 and 3 mm (~233 and ~97 GHz), probing 40-50 km below the visible ammonia-ice cloud (down to ~3--4 bar), i.e., covering the altitude range of the "weather" layer. We obtained global maps of Jupiter, which complement global maps obtained with the Very Large Array (VLA) in the cm wavelength range [e.g., 1], and those obtained with the spatially-confined microwave radiometer (MWR) on *Juno* [4].

Fortuitously, the timing of the ALMA observations was just a few days after amateur astronomer Phil Miles announced the onset of an ``outbreak" in Jupiter's South Equatorial Belt (SEB).

In addition to ALMA (1-3 mm), Jupiter was observed contemporaneously with the VLA (3.5 cm), HST (uv-visible), Gemini (5-µm) , Keck (5-µm spectroscopy), VLT (mid-IR), and Subaru (mid-IR).

2. Results

Longitude-smeared and longitude-resolved maps of Jupiter were constructed. A comparison of the ALMA 1.3-mm and HST maps is shown in Figure 1 [2]. A plethora of structure is seen. Bright areas indicate a higher brightness temperature, assumed to be caused by a lower NH_3 abundance [as in 1], and dark areas indicate a lower brightness temperature, caused by a higher opacity in the atmosphere. The radio-hot belt at 8.5-11^{0}N latitude features prominently, with hot spots and small well-defined dark regions interspersed. The dark regions are small plumes of NH_3 gas, which are likely associated with the small bright clouds in the HST map. The source of the SEB outbreak is also indicated.

The SEB outbreak data were modelled with radiative-transfer calculations using the UC Berkeley codes Radio-BEAR and SUNBEAR [e.g., 1]. We show that the SEB eruption is consistent with a model in which energetic plumes are triggered via moist convection at the base of the water cloud [as modelled by e.g., 3]. The plumes transport ammonia gas from the deep atmosphere to high altitudes, where NH_3 gas is condensing out and the subsequent dry air is descending in neighboring regions. The cloud tops are cold, as shown by mid-infrared data, indicative of an anticyclonic motion, which causes the storm to break up, as expected from similarities to mesoscale convective storms on Earth. The plume particles reach altitudes well above the tropopause.

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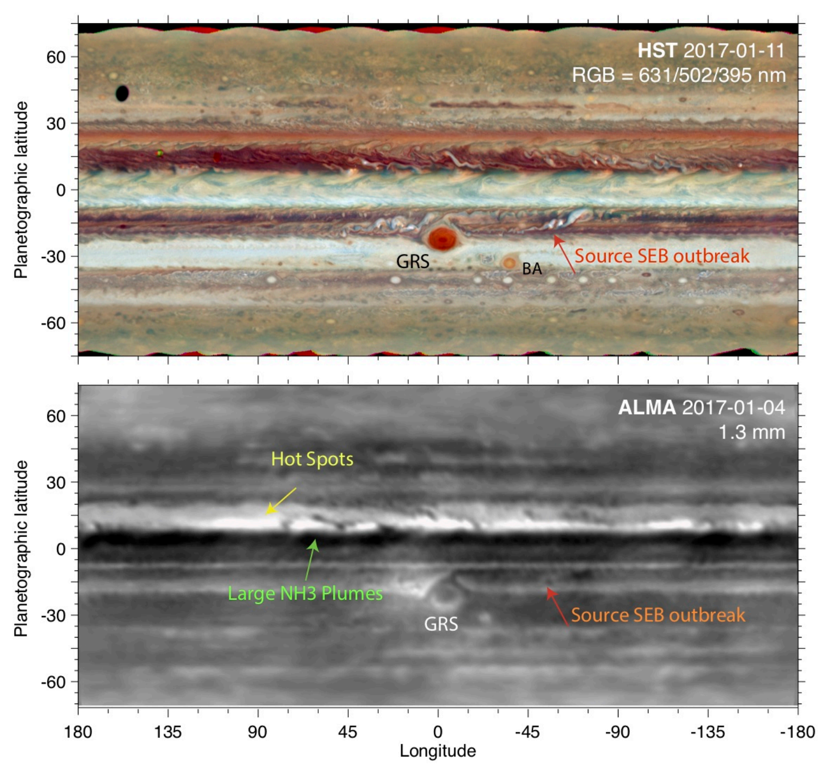

Fig. 1. Top: HST map from 11 Jan. 2017. Bottom: ALMA map at 1.3 mm, constructed from data taken 3-5 Jan. 2017. Various features are indicated, such as the iconic GRS and Oval BA, as well as hot spots, ammonia plumes, and the SEB outbreak. [fig. adapted from 2].