Jupiter in 1999/2000. II: Infrared wavelengths

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A report of the Jupiter Section (Director: John H. Rogers)

Several Section observers are now producing valuable images in the near-infrared methane absorption band, at the wavelength of 890nm. These images record high-altitude clouds and hazes. This article discusses the relative selectivity of the filters used by different observers, the features shown by them in 1999/2000, and the aspects that will be of interest for routine monitoring by methane images. These include the polar hoods, the equatorial zone, possibly erupting plume heads, anticyclonic ovals, and large scale disturbances of the major belts.

Introduction

Infrared images add an extra dimension to our perception of the clouds of Jupiter. Light at 890nm is almost all absorbed by methane before it reaches down to the main jovian cloud-tops, so the uppermost clouds and hazes which extend higher appear bright in this methane band, according to their height and thickness.[1,2] Since early studies at the University of Arizona,[1] it has been known that the major methane-bright features of Jupiter's atmosphere are the polar hoods, the major zones (especially when coloured reddish), and anticyclonic ovals. We recently reported the appearance of these features in Isao Miyazaki's methane images from 1995 to 1997.[3]

Several other amateur observers have now obtained methane filters, and are producing valuable images using them. Here we compare the properties of the different filters that are being used.

The important issue is how deep in the jovian atmosphere the image penetrates. The ideal is to have an image that is only sensitive to the high-altitude clouds, not to the albedo of the deeper clouds which is revealed in flanking wavelengths. This is the case with a filter that only passes light within the methane absorption band. However, the methane band is narrow, and some filters extend some way outside it. In that case, the image is a mixture of light from the methane band that probes the upper atmosphere, and a variable amount of light from flanking wavelengths that reveals the dark and bright albedos of the underlying main clouds.

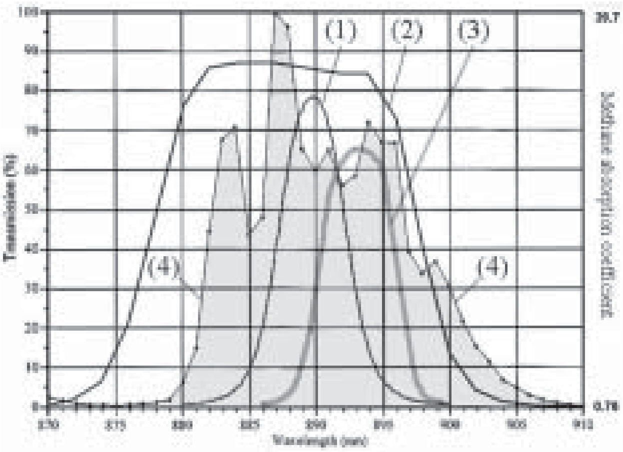


Figure 1. Transmission spectra of methane filters. **(1,2)** Two filters sold by Custom Scientific, Arizona[5] (reproduced by permission): **(1)** FWHM 5nm, used by Antonio Cidadão (since 2001 Jan., so results are not included in this report); **(2)** FWHM 18nm, used by Brian Colville. **(3)** Filter used on Hubble Space Telescope in WFPC2.[8] Compared with: **(4)** the observed profile of the 890nm methane absorption band in the jovian atmosphere.[4]

The surrounding continuum (i.e. unabsorbed) wavelengths are called I-band, and are easily imaged because CCDs have high sensitivity in the near-infrared. I-band covers all wavelengths from the edge of the visible (700nm) to around 1 micron, mainly ~750–950nm. Brian Colville and Tomio Akutsu routinely take high resolution images in this waveband as well as in the methane band, using broad-band filters. These images look like extreme red images, so that visually blue features (such as the NEBs projections) are extremely dark. Other features may have lower contrast but, at hi-res, they show considerable detail because these wavelengths penetrate deep into the cloud deck.

In fact the result from an 890nm filter that extends outside the methane band is more complex than a mixture of absorbed and unabsorbed wavelengths, because there is still some weak methane absorption in the flanking wavelengths. Light subject to weak methane absorption can in principle probe the thickness of clouds in the main cloud layers (down to several bars pressure; the cloud tops are at 0.5–0.7 bars pressure), and suitable filters are used on the *Galileo* and *Cassini* spacecraft for this purpose. However, a broad 890nm filter will pass a mixture of light subject to varying degrees of absorption, so will be more difficult to interpret than in the case of pure strong or weak absorption.

In principle, it may be possible to retrieve a more selective methane image from a less selective one by subtracting a broad I-band image. Some observers are now experimenting with this technique.

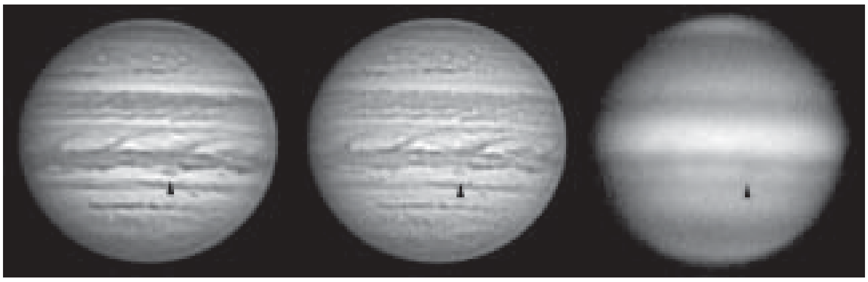


Figure 2. White light, red-light, and methane images by Miyazaki, 1999 Sep.6d 20h 57m, CM1=43, CM2=189, CM3=40; methane image 3 min later. The Little Brown Spot in NTropZ is near the CM, overlapping a methane-dark patch.

Methane filter selectivity

The most precise profile of the 890nm methane absorption band in the jovian atmosphere[4] shows that it has significant absorption from 880 to ~905nm, and ~90% absorption at cloud-tops from 882 to 897nm. In Figure 1, this is compared with the transmission spectra of two filters used by amateur observers.

Because of the narrowness of the methane band and the extreme darkness of the planet within it, successful methane-band imaging requires long exposures and correspondingly good equipment. Jupiter is about one-tenth as bright in this band as in nearby continuum wavelengths. There is a trade-off between methane selectivity and exposure time and cost. A narrower filter generally gives better selectivity, but requires very long exposures, and costs considerably more than a broader one. Prices quoted recently for methane filters have ranged from around $250 to $700 depending on bandwidth.

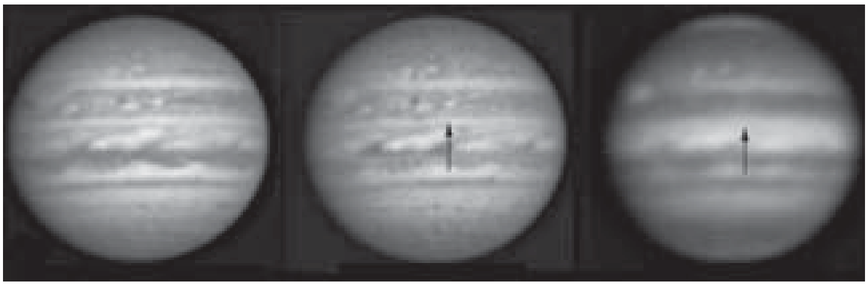
Table 1 lists the filters used by our contributors and by spacecraft that have viewed Jupiter. The simplest estimate of selectivity is the full-width at half-maximum (FWHM), i.e. the wavelength range within which the filter transmits more than 50% of the incident light.

Here I offer preliminary estimates of the selectivity of images presented by amateurs and spacecraft, from visual impressions of the key features shown in them. A rigorous assessment would be technically challenging and is beyond the scope of this brief report. It could be done, either from very accurate comparisons of the spectra of the filters with that of Jupiter, or from precise photometric comparisons of accurately calibrated raw images of Jupiter. For our present analysis, the images presented have all been processed in different ways by the observers. Thus the apparent selectivity may depend on the image resolution and signal-to-noise ratio (in a blurred or noisy image, key spots are less visible). It may also depend on the processing (contrast enhancement, unsharp masking, or sharpening, any of which may be routinely applied by a given observer, especially given the extreme limb darkening in this waveband). Observers find that adding several images is an effective way of reducing noise while preserving resolution, but even this is limited by the rotation speed of the planet. Observers producing hi-res images may be tempted to apply more enhancement which makes them appear less selective than they are, because they then reveal albedo features that would not have been seen in a raw image.

At this early stage in our programme, these factors are not standardised, and I simply assess the selectivity according to visibility of key features in the images as presented.

The best criteria for selectivity seem to be the brightness of the NEBs projections/festoons, and of the S. Tropical Zone. In the most selective filters, the dark NEBs projections/festoons are invisible or hardly visible, and the STropZ is no brighter than the STZ. With decreasing selectivity, the NEBs projections/festoons are darker (they are very dark in near-infrared continuum, especially in 1999/2000), and the STropZ is brighter.

Among amateurs, Miyazaki and Cidadão (in the next apparition), both using 5nm filter width, appear to have the most selectivity (Figures 2, 4). The Pic du Midi uses an even narrower filter,[6] but the images appear less selective (Figures 6, 7); however this is probably because they have high resolution and strong enhancement. Among the spacecraft,



Figures 3–7 all show triplets of visible, red or infrared, and methane-band images, that include the GRS and South Temperate ovals BE and FA, all visible as methane-bright ovals. In most cases, image processing has been left as done by the observers.

Figure 3. White light, I-band, and methane images by Akutsu, 1999 Sep.4d 17h 12m, CM1=310, CM2=113; methane image 5 min later. This shows the new bright rifts in the SEB, one rotation after Figure 9d of ref.12; they are just visible in the methane image (arrowed).

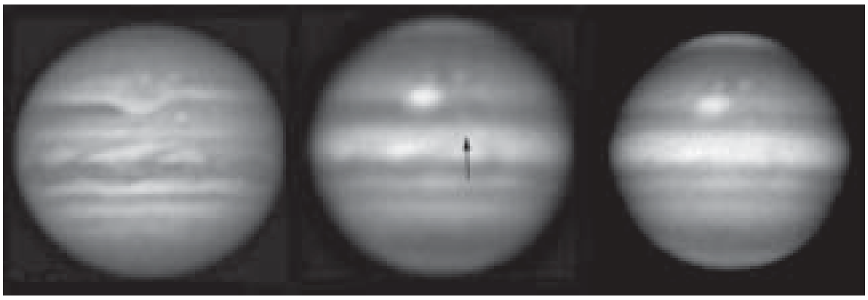


Figure 4. Comparison of simultaneous methane images by Akutsu and Miyazaki (adjusted so that both show a similar brightness range). *Left:* White light image (Akutsu): 1999 Nov.11d 11h 50m, CM1=59, CM2=65. *Centre*, methane image (Akutsu), 11h 54m. *Right*, methane image (Miyazaki), 12h 13m. A bright spot in SEB f. the GRS is arrowed, and is equally visible in both images. The NEBs dark projections-festoons are more visible in Akutsu's than Miyazaki's image.

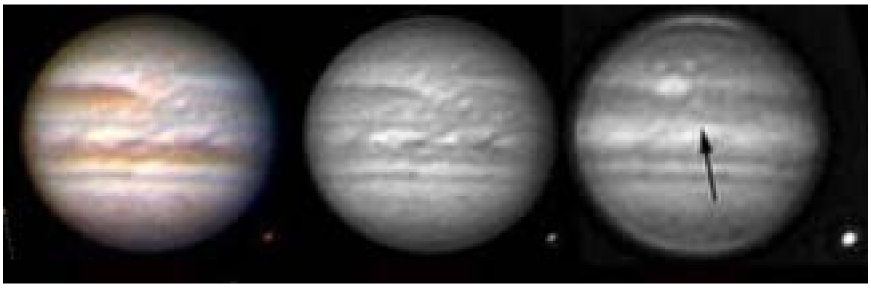


Figure 5. Colour, red-light, and methane images by Colville, 1999 Nov.30d 02h 43m; CM1=206, CM2=70; methane image 24 min later. A bright spot in SEB f. the GRS is arrowed. The South Equatorial Disturbance is passing the GRS (see Figure 6 of Ref.12) and its main complex, on the f. side, shows incipient structure in the methane image. Ganymede is near the Nf. limb.

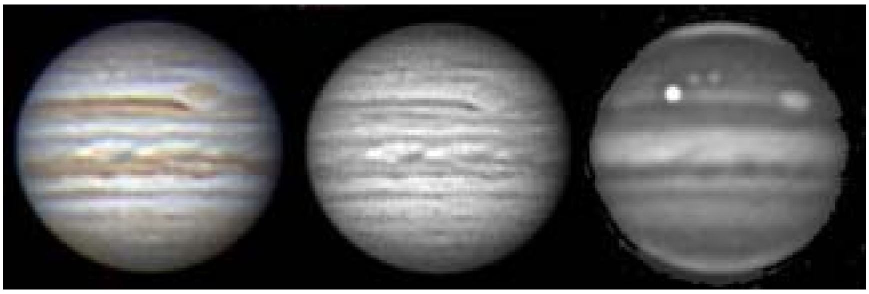


Figure 6. Colour and red-light images by Miyazaki, 2000 March 3d 10h 08m, CM1=186, CM2=50, CM3=308; and a methane image from the Pic du Midi,[7] 2000 March 5 (with satellite bright in transit). In the colour image, note a change in the SEB p. the GRS, in contrast to the earlier appearance (shown in Figure 3 of Part I of this report): it has developed a light orange SEBZ, with a dark blue-grey streak Np. the GRS, typical of the quiet SEB prior to episodes of 'fading'. Also note that oval BE and FA are closer together than in previous images; they are about to merge.

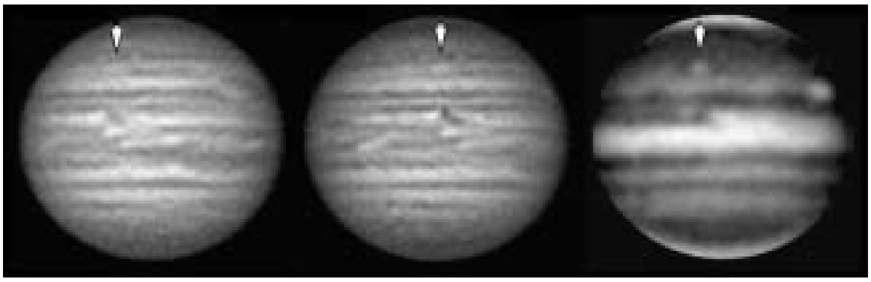


Figure 7. Visible, I-band, and methane images from the Pic du Midi. Visible image 2000 April 7d 13h 45m; I-band image (centre) 13h 07m; methane image (right) 13h 26m. This shows two important features. Ovals BE and FA have merged to form a single oval, BA (arrowed). Immediately north of it, the main complex of the South Equatorial Disturbance is strongly shown in I-band, and has become a striking discontinuity in the methane band. The GRS is near the f. limb. (Pic du Midi images from Ref.7, reproduced by kind permission of Dr. J. Lecacheux.)

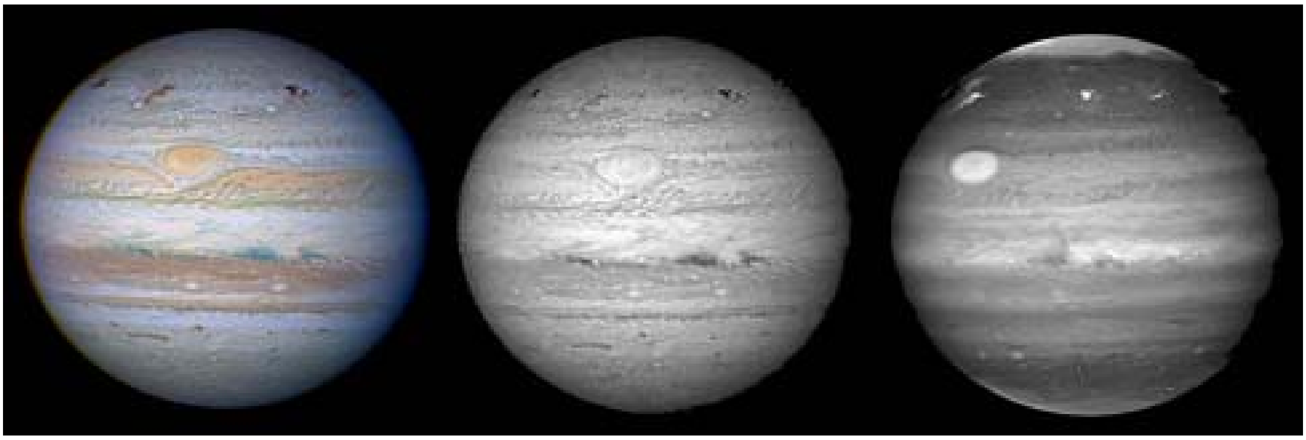


Figure 8. Colour, I-band (957nm), and methane images from the Hubble Space Telescope, taken on 1994 July 21–22 during the comet crash. These images may not give a fair impression of the HST's methane selectivity; NEBs projections are particularly dark in this methane image, but this may have been a real variation due to a thinning of the usual haze all across the EZ in 1994. We have no recent HST methane images for comparison. However, an HST map in 1996[9] also showed the dark NEBs projections faintly, suggesting that the HST methane filter is less selective than some others. Several other special features of 1994 can be seen in this image set (and also in an HST image set from 1994 July 16). These were: the comet impact sites (very dark in visible light, bright in methane band); a dusky STropZ (blue in visible, dusky in methane); SEB colour following an SEB Revival (red in visible light, pale in I-band, pale in methane); and the southern Equatorial Zone and EB (bright in visible but dark in methane, in contrast to its methane-brightness from 1996 onwards). (HST-WFPC2 images due to the imaging team led by Dr Heidi Hammel; original images obtained from NASA by Tan Wei Leong.)

Cassini shows very selective images (Figure 9) (to be discussed in our 2000/2001 report). The *Galileo* Orbiter has a rather wide filter but it is precisely matched to the shape of the methane band;[2] of course it has been unable to image the whole planet, but the methane images do appear to be very selective, in that dark NEBs projections are almost or completely invisible (Figures 10, 11).

The images by Akutsu (Figures 3, 4) and the Hubble Space Telescope (HST; Figure 8) do show the dark NEBs projections, clearly though faintly, and a fairly bright STropZ. This is surprising as both use filters only 6.5nm wide; HST's nominal transmission is well within the methane band (Figure 1, curve 3). However, these filters may let in a small amount of light above 897nm which has weaker methane absorption,

Table 1 Methane filter specifications

Observer	*Telescope*	*CCD camera*	*Filter/FWHM*	*Exposure*
T. Akutsu	320mm Refl.	Teleris 2, Lynxx PC	893nm/6.5nm	20s
B. Colville	305mm Refl.	Pixel ST-237	889nm/18nm	10–20s
F. Mellilo	203mm Refl.	SX MX-5	890nm/10nm	
I. Miyazaki	404mm Refl.	Lynxx PC	893nm/5nm	90s
A. Cidadão	254mm Refl.	SBIG ST-5c	889nm/5nm	60–240s
Pic du Midi	1m Refl.		893nm/4.4 nm	30s
HST	WFPC2		893nm/6.4nm	
Galileo	SSI		889nm/16nm	
Cassini	ISS		891nm/10nm	

In the upper half are the observers who contributed methane band images in 1999/2000. Cidadão began to take them in 2001 Jan. Data are also given for the Observatoire du Pic du Midi [Refs. 6,7], and for spacecraft that have imaged Jupiter in this waveband. *Cassini* data were kindly provided by Dr Robert West (*pers. com*.).
Filter/FWHM: methane filter's central wavelength and full width at half maximum. Typical single-exposure times are indicated (some observers add several together).

so the images probably represent a mixture of strong and weaker methane absorption. (The conclusions for HST are tentative because the images available were taken in previous years; see Figure 8 caption.)

The broadest filter in use is Colville's, and these images are clearly less selective than others (Figure 5). The dark NEBs projections are clearly visible (though still fainter than the NEB, in contrast to their appearance in I-band). This filter admits some continuum light below 882nm (Figure 1, curve 2).

Features of interest

Here we note the features that are of interest in methane images, and especially their aspect in 1999/2000. (In 1998/99, the appearance was very much as in 1997.[3]) This therefore follows on from Part I of our 1999/2000 report.[12]

Polar hoods

The latitude of the edge shows interesting variations.[3] Although all methane filters show the polar hoods well, both high resolution and high selectivity are needed to document the variations reliably.

Equatorial Zone

The thick high haze over the EZ is variable; there was a broad dark Equatorial Band in methane images in 1994 (HST; Figure 8) and 1995 (Miyazaki)[3] but the EZ has appeared uniformly methane-bright since. There may also be variation in the visibility of the NEBs festoons through the high haze, both individually (as their blueness also varies) and collectively (as the festoons and EB were particularly prominent at visible wavelengths in 1999/2000). As we have not had uniformly good methane images in previous years, the best comparison is with the 2000/2001 apparition, when most festoons faded again visually. Both Miyazaki's images (with higher selectivity) and Akutsu's images (with higher resolution) seem to show more of the projections/festoons in 1999/2000 than in 2000/2001. There are indications that some of the projections/festoons were more visible than others in methane images. However the visually dark EB was not methane-dark in 1999/2000.

High selectivity is obviously most useful for studying these features, but less selective images may be probing an interesting intermediate level in the equatorial haze. Controlled photometry of the images may be needed to reach definite conclusions.

White plumes in EZ and mid-SEB

These are of interest to jovian meteorologists, but reliable detection of them in amateur methane images may require further technical improvements. In the EZ, only diffuse brighter areas tend to be seen; possibly the locally erupting plumes do not penetrate the overlying haze. The bright white spots that often erupt in mid-SEB f. the GRS were shown by *Galileo* and *Cassini* to have methane-bright thunderclouds in their cores.[2,11] All our observers do occasionally record them (Figures 3–5), but it is difficult to know whether they are really detecting the small, short-lived methane-bright core, or contamination with the larger white cloud area that is so bright in the surrounding continuum. These spots are only rarely detectable in Miyazaki's methane images. High resolution and high selectivity would seem to be crucial for resolving these thunderstorms.

Anticyclonic ovals

Methane images were crucially important in this apparition for tracking ovals BE and FA as they approached and merged.[13,14] After the merger, methane images proved that only a single large anticyclonic oval had emerged. (Unfortunately, because Jupiter was so close to the Sun, only professional methane images covered the merger, but the principle was demonstrated). They are also important for tracking small anticyclonic ovals in the N.N. Temperate region, including two in 1999/2000;[3,12] some of these ovals, especially Little Red Spots which have low visual contrast, would hardly have been detected without them. For these purposes, the selectivity is not very important; the main thing is to show the oval, and the better resolution of Colville's images makes this easier.

Large-scale disturbances of SEB and NEB

First, the SEB showed large methane-dark patches associated with SEBs jetstream spots in 1999/2000, as also during the previous outbreak in 1995,[3] and this phenomenon deserves more study.

Secondly, in 1999/2000, there were methane-dark patches along the NEBn/NTropZ, especially around the Little Brown Spot and adjacent barge [Figure 2; Ref.12]. Similar diffuse dark patches were even more evident in the next apparition when the NEB expansion event was complete; they formed a large-scale pattern of waves most of the way round the expanded NEB [Figure 9; Ref.15]. Dark areas like that associated with the LBS were enhancements of these waves. This wave pattern had never been clearly visualised or tracked before. Interestingly, it was not present when the NEB was in a similar expanded state in 1994 (Figure 8).

Thirdly, the South Equatorial Disturbance showed remarkable structure in methane images. This was not obvious in 1999, but some images showed it developing (Figure 5), and it was revealed as spectacular in the Pic du Midi's images on 2000 April 7 (Figure 7). The same structure was clearly recorded in professional and amateur images in the following apparition.[15] Methane images thus gave crucial new data on the structure of the Disturbance, and allowed it to be tracked reliably even when it was visually inconspicuous.

So in 2000/2001, methane images became unexpectedly important in revealing these phenomena. Both high- and low-selectivity images can contribute valuably to tracking largescale patterns of these types.

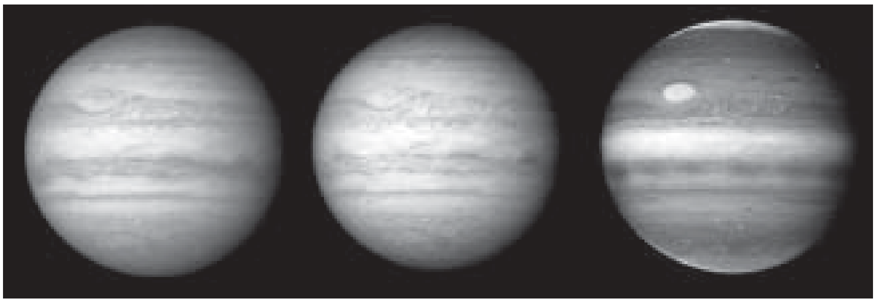


Figure 9. White light, red-light, and methane images by the *Cassini* spacecraft, 2000 Oct. 8. The NEBs projections-festoons are invisible in the methane image. Also note the large scale diffuse wave pattern over the NEB; this was conspicuous in 2000/2001, and hinted at in some images from 1999/2000 (Figures 3, 6).

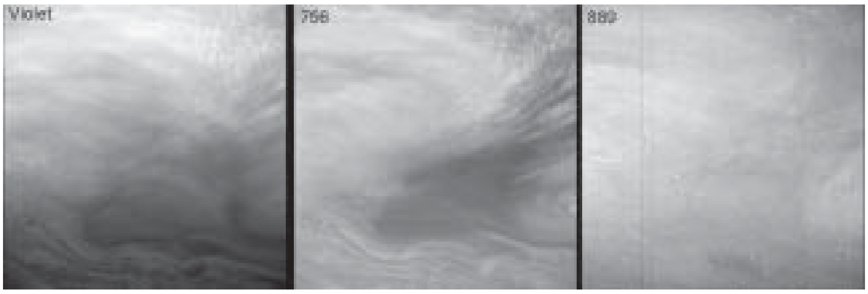


Figure 10. Violet, I-band (756nm), and methane images of a single NEBs projection, from the *Galileo* Orbiter, at the E4 encounter on 1996 Dec.19. In accordance with its blue colour, the NEBs projection has low contrast in violet, but very high contrast in I-band. It is only dimly and incompletely visible in this highly stretched methane image. Both violet and methane images are dominated by reflective haze that overlies the main weather systems, but this haze is largely transparent in I-band. (*Galileo* SSI Team/NASA; original images obtained from the Planetary Data System.[10])

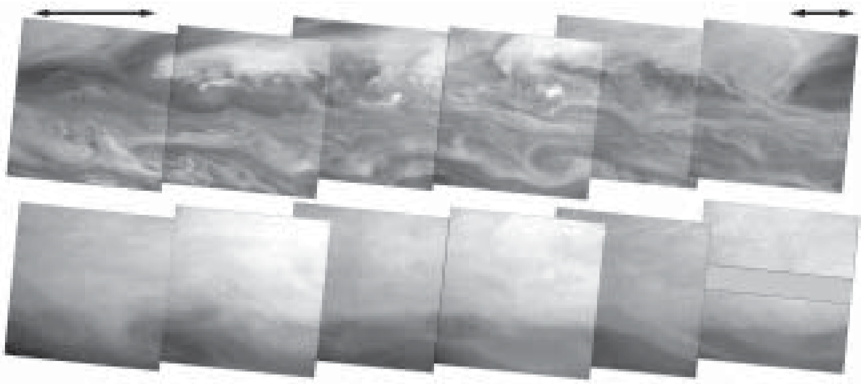


Figure 11. I-band (756nm) and methane images of the NEB with two NEBs projections, from the *Galileo* Orbiter, at the C20 encounter on 1999 May 4. Lines at top indicate the positions of the two NEBs projections. Both are very dark in I-band but completely invisible in the methane band. (There is a band of missing data in one of them but most of the area is shown.) (*Galileo* SSI Team/NASA; original images obtained from the Planetary Data System.[10])

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