

High Resolution Planetary Imaging of Mars, Jupiter, Saturn, Uranus

Current state-of-the-art in Amateur
capabilities, hardware and software

Madison, August 2014

Current state-of-the art in Planetary Imaging

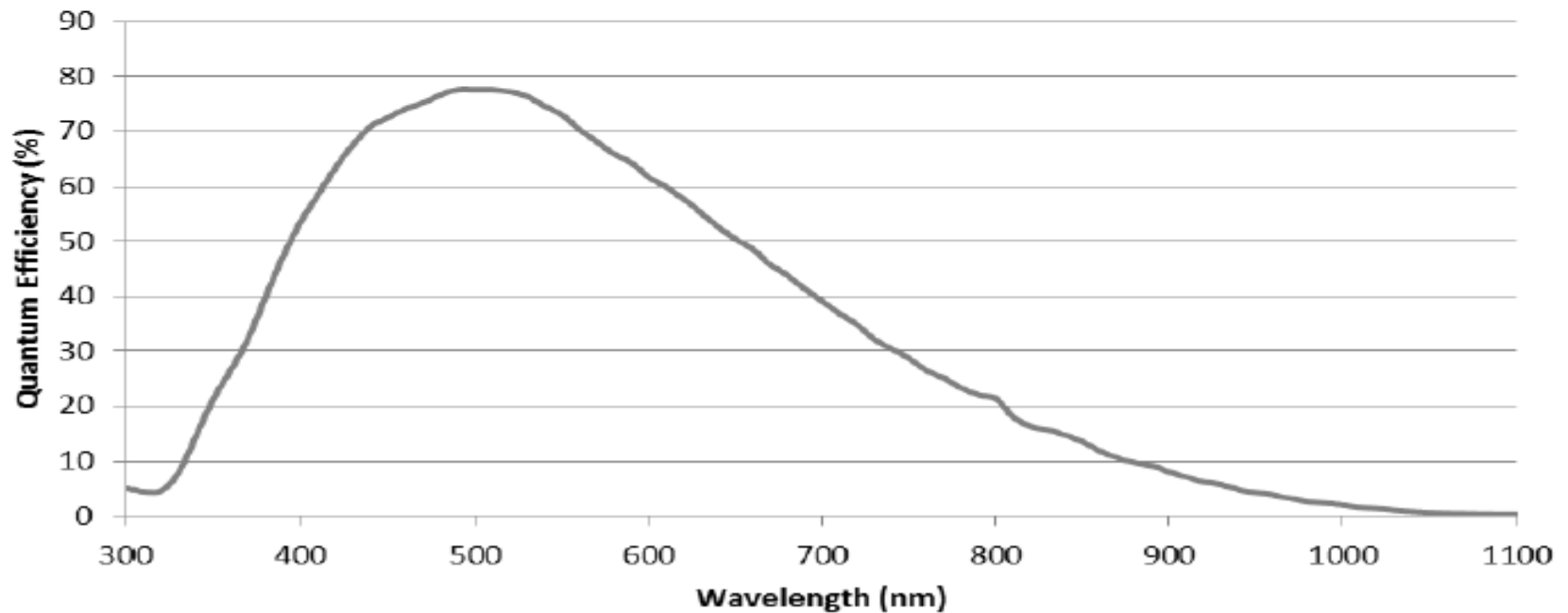
The current evolution of high speed / low noise video cameras available to amateurs allow them to contribute to planetary imaging in three distinct ways:

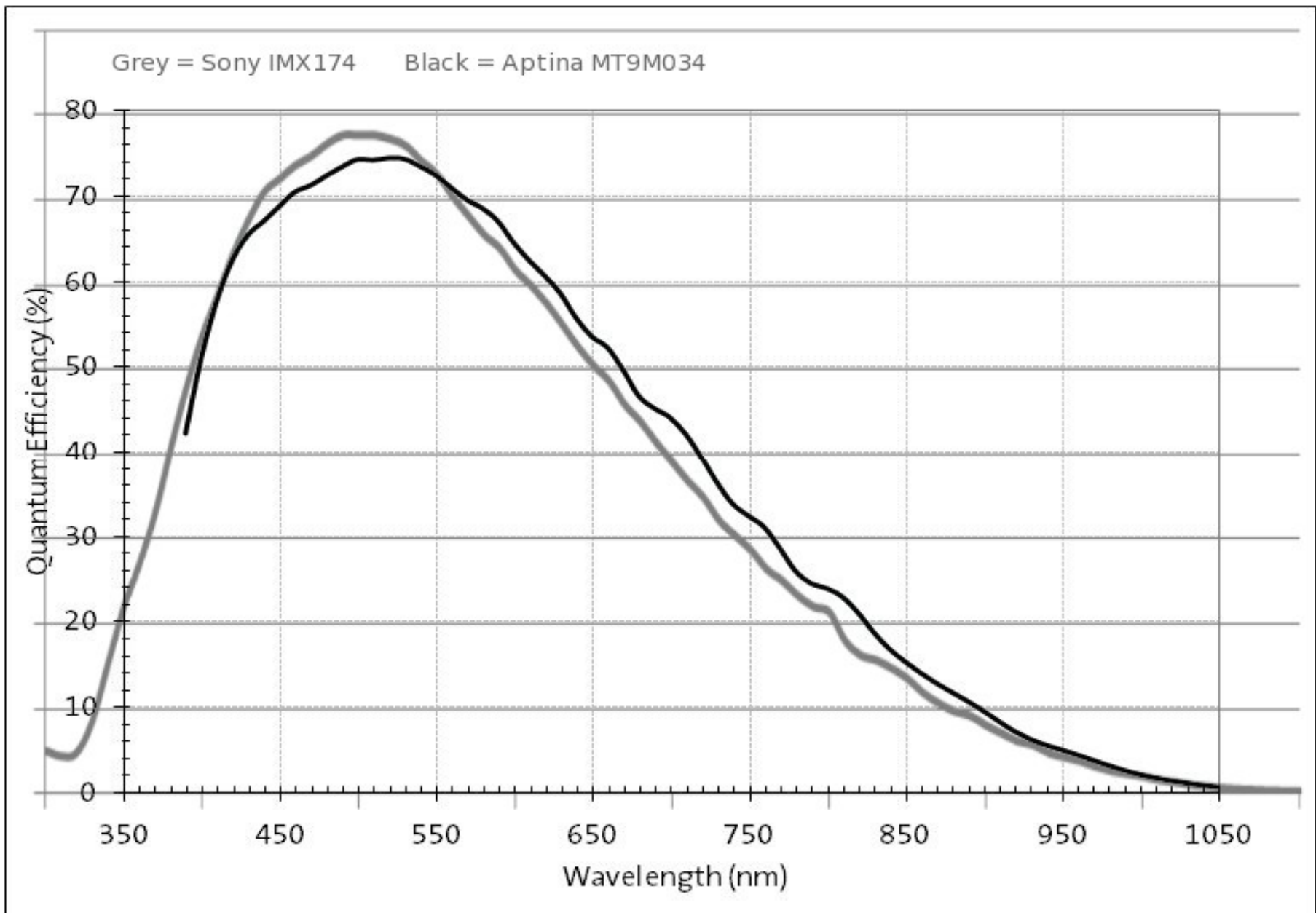
- Visible light feature detection and tracking
- Visible light colour changes, detection and tracking
- Impact / flash / bolide detection

Limited spectral coverage means we are restricted to 350nm – 900nm wavelengths, ie visible plus limited UV / IR.

Measurement	Value	Unit
Quantum Efficiency	76	% at 525 nm
Temporal Dark Noise (Read Noise)	6.83	e-
Signal to Noise Ratio Maximum	45.12	dB
Signal to Noise Ratio Maximum	7.49	Bits
Absolute Sensitivity Threshold	9.77	γ
Saturation Capacity (Well Depth)	32513	e-
Dynamic Range	72.94	dB
Dynamic Range	12.11	Bits
Gain	0.52	e-/ADU

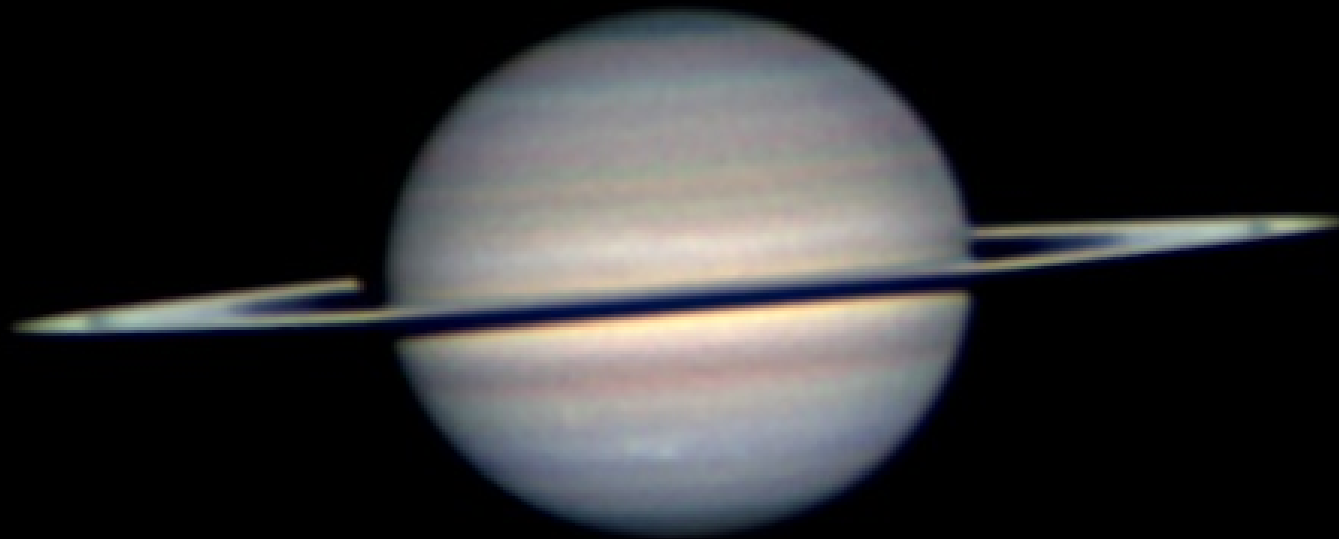
GS3-U3-23S6M





Feature detection

This visible light Saturn image from 2010 demonstrates the ability to detect low surface brightness features .



20th April 2010

April 29, 2010

With the help of amateur astronomers, the composite infrared spectrometer instrument aboard NASA's Cassini spacecraft has taken its first look at a massive blizzard in Saturn's atmosphere. The instrument collected the most detailed data to date of temperatures and gas distribution in that planet's storms.

The data showed a large, turbulent storm, dredging up loads of material from the deep atmosphere and covering an area at least five times larger than the biggest blizzard in this year's Washington, D.C.-area storm front nicknamed "Snowmageddon."

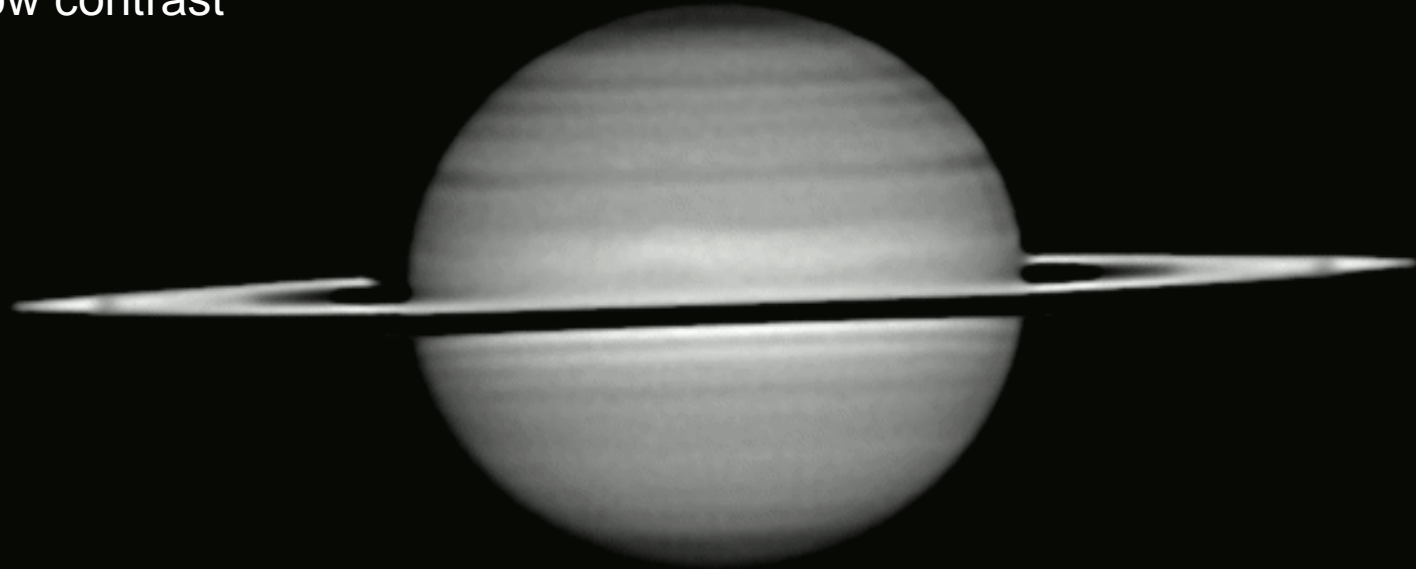
"We were so excited to get a heads-up from the amateurs," said Gordon Bjoraker, a composite infrared spectrometer team member based at NASA's Goddard Space Flight Center in Greenbelt, Md. Normally, he said, "Data from the storm cell would have been averaged out."

Cassini's radio and plasma wave instrument and imaging cameras have been tracking thunder and lightning storms on Saturn for years in a band around Saturn's mid-latitudes nicknamed "storm alley." But storms can come and go on a time scale of weeks, while Cassini's imaging and spectrometer observations have to be locked in place months in advance.

Jet Propulsion Laboratory, Pasadena, Calif.

Feature detection

Animations are a very good tool for amateurs to use for tracking low contrast features

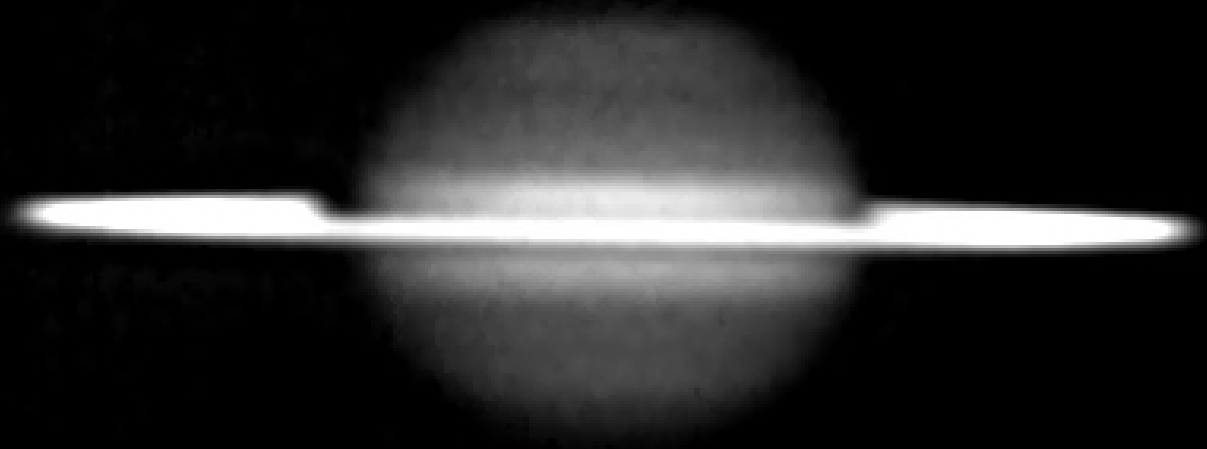


9th June
2010

IR \geq 750nm

Feature detection

CH₄ absorption 889nm



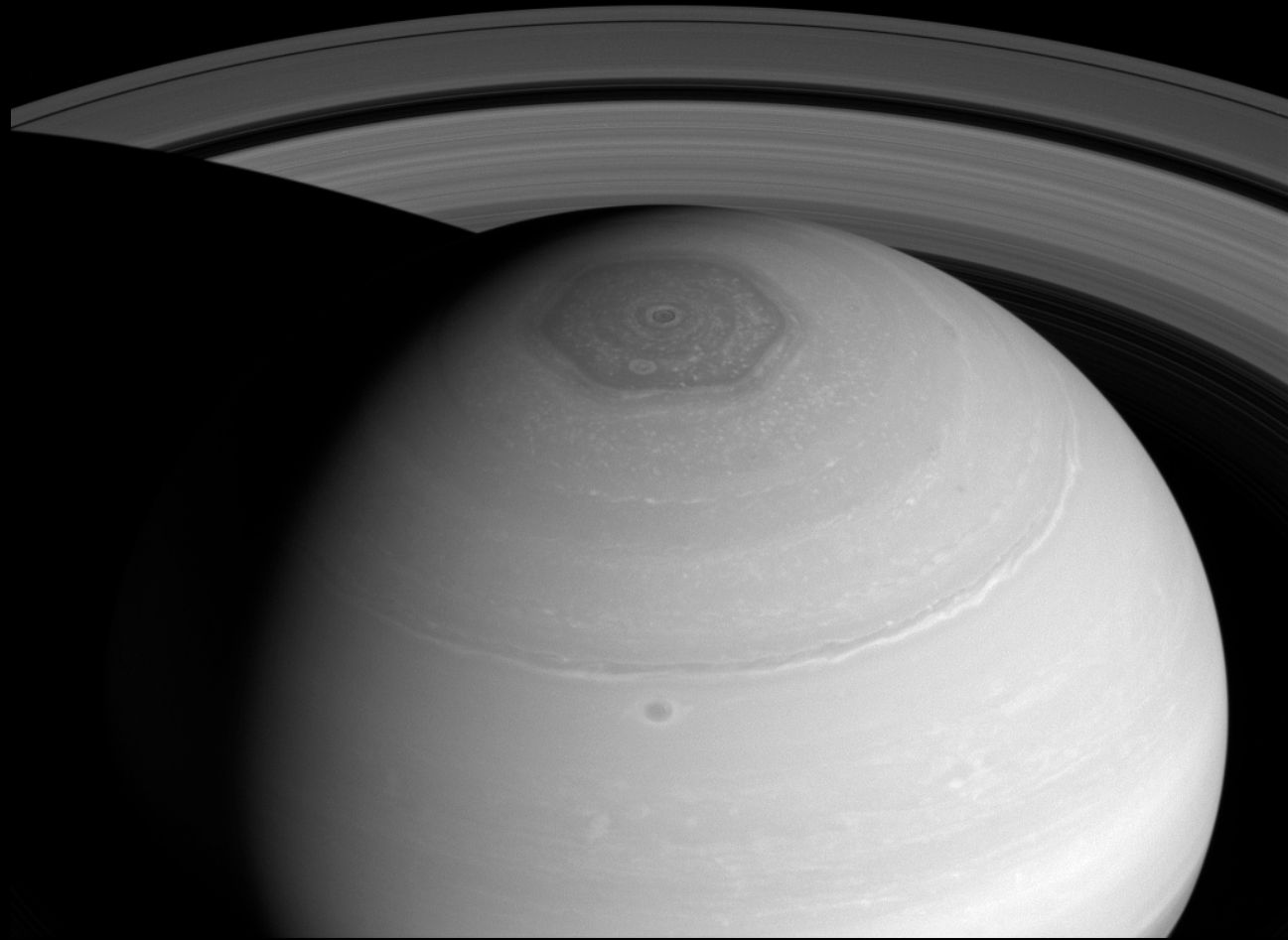
14th May 2010

Saturn + Rhea, CH₄

Credit: NASA/JPL-Caltech/Space Science Institute
Released: July 7, 2014 (Happy 74th Birthday, Ringo) (PIA 18274)

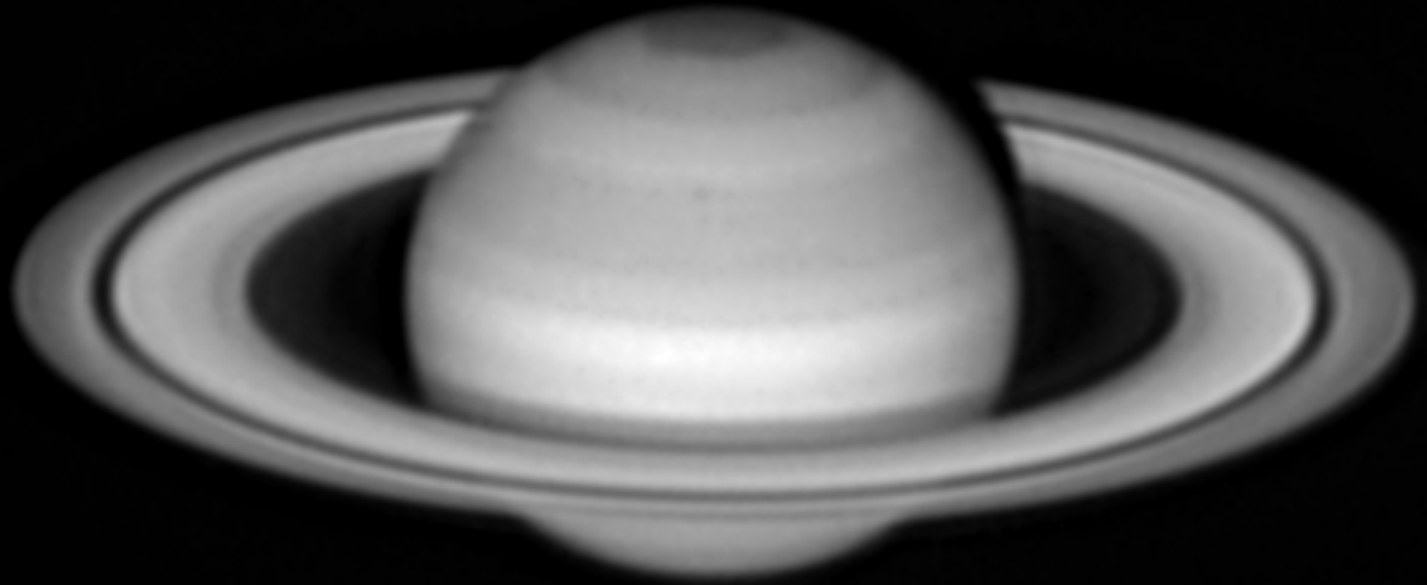
Cassini image showing
polar vortex and
long-lived dark spot

752nm (IR) filter



(Disclaimer: Cassini images released to the public have not been properly calibrated in any way and should not be used for any scientific purpose.)

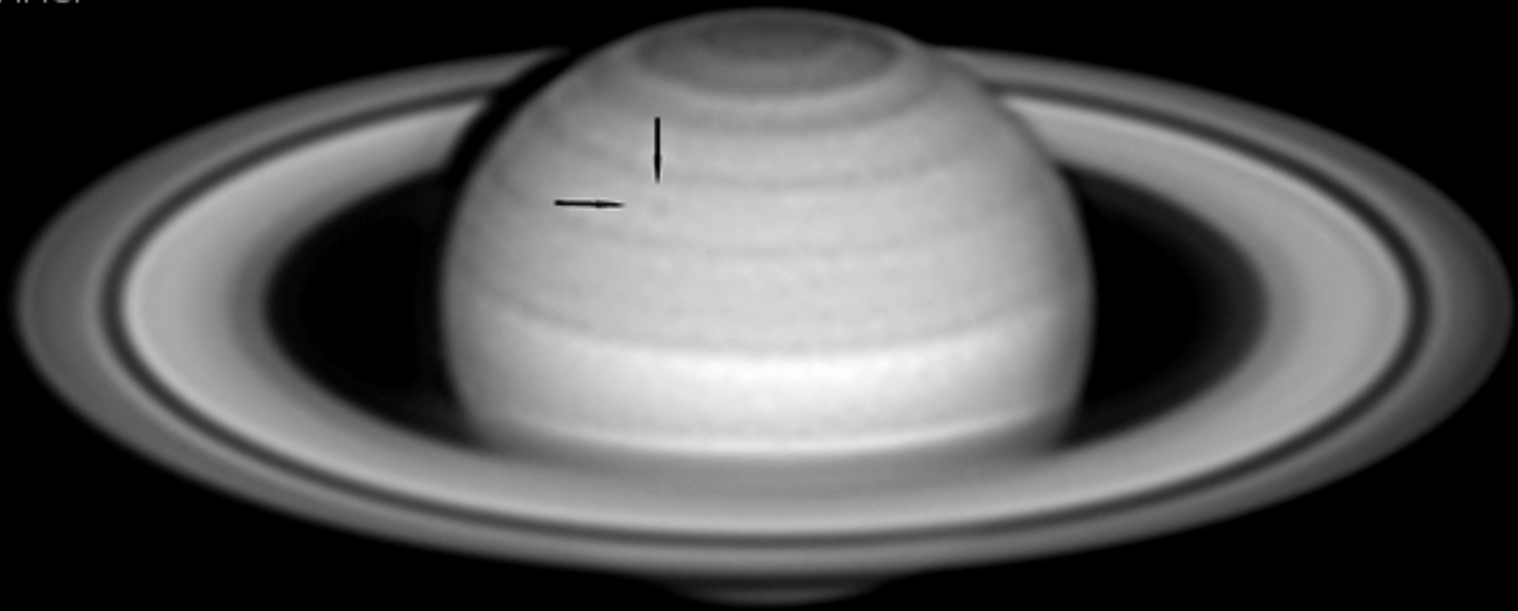
Feature Detection – use of stop-frame animations by amateurs allows easy detection of subtle features.



18th March 2013

```
Saturn    18 Mar 2013 17:17.5 Z    CMIII:228.2  
Anthony Wesley, Murrumbateman Australia
```

Red channel



26th July 2014

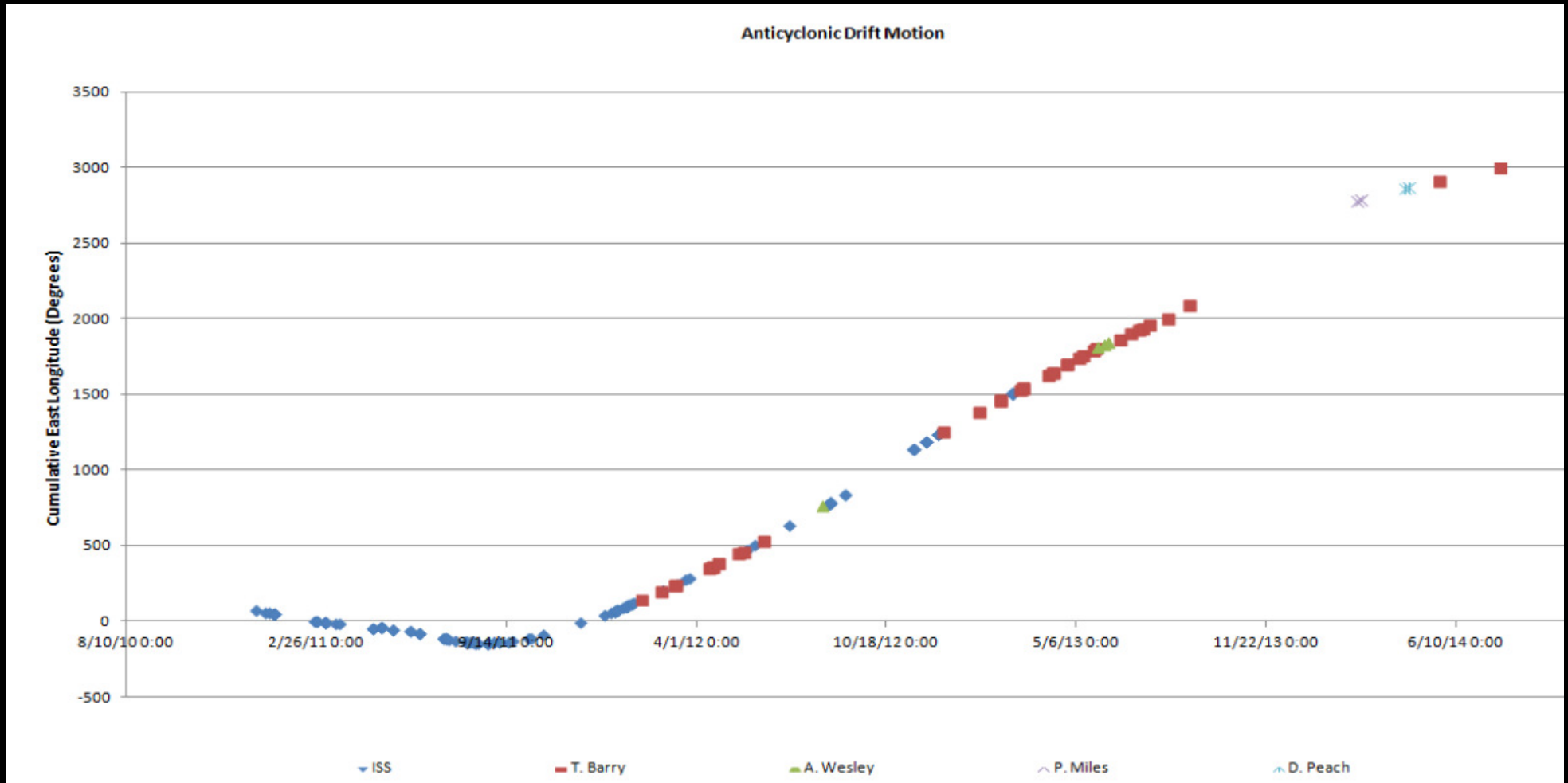
July 26th 2014, 09:17:42 UTC, CMIII 252.3

Dia 17.2", Ring Op Earth 21 degrees, Alt 73 degrees, seeing 7 to 8/10

16" F4.5 Custom Newt working at F16.7 Mark Suchting Primary Antares 1/30th wave Secondary

R Channel Image ZWO ASI120MM-S Trevor Barry Broken Hill Australia

Feature Detection – since early 2012 amateurs have tracked the longitude (S3) of The long-lived dark anticyclonic vortex in Saturns northern hemisphere.



Trevor Barry, 2014

Feature detection – the great storm of 2010/11



Saturn 14 Dec 2010 18:31.8 Z CMIII:265.0
Anthony Wesley, Murrumbateman Australia



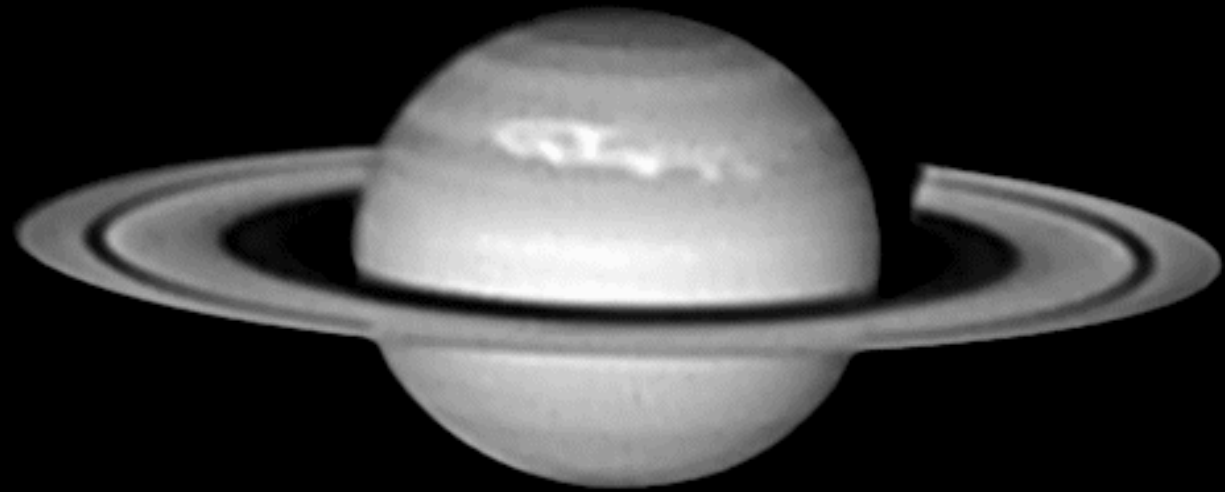
Amateurs tracked the progression of
This major outbreak over several months
With high quality imagery almost every night

Saturn 22 Dec 2010 18:20.4 Z CMIII:265.0
Anthony Wesley, Murrumbateman Australia



Saturn 30 Dec 2010 18:49.2 Z CMIII:287.8
Anthony Wesley, Murrumbateman Australia

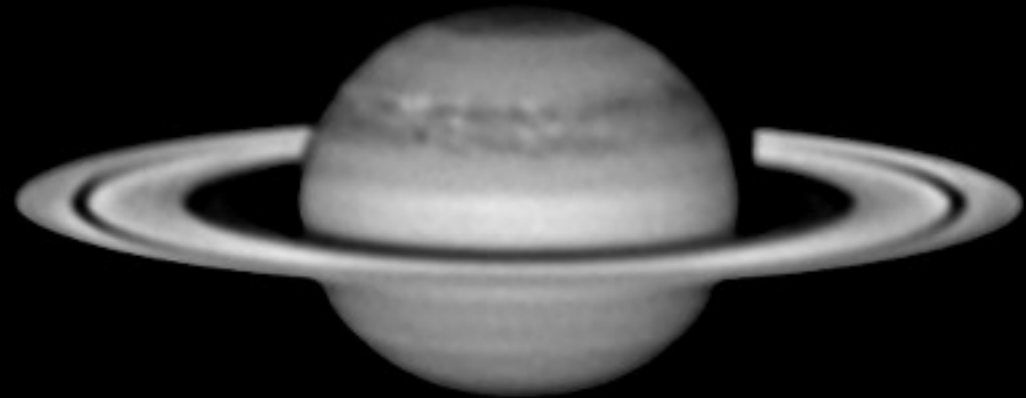
Stop-frame animation shows several interesting features,
The head of the storm as well as anomalous dark spots in the rings.



Saturn 30 Dec 2010 18:33.7 Z CMIII:279.1
Anthony Wesley, Murrumbateman Australia



Saturn 31 Jan 2011 18:17.2 Z CMIII:297.2
Anthony Wesley, Murrumbateman Australia



IR \geq 742nm
2nd March 2011

IR742nm

Saturn 2 Mar 2011 16:01.1 Z CMIII:67.1
Anthony Wesley, Murrumbateman Australia

Colour detection and tracking

Colour is more difficult for amateurs due to uncalibrated cameras and processing techniques that favour feature detection above colour accuracy

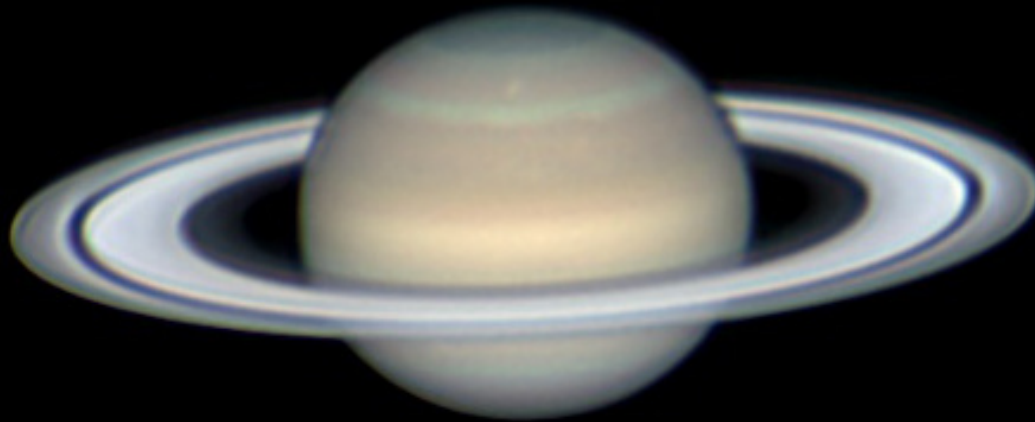


March 2012

Saturn 20 Mar 2012 16:13.8 Z CMIII:7.7
Anthony Wesley, Murrumbateman Australia

In 2012 the north polar region was a uniform dark blue/green.

A light green band extended around the latitude of the great storm of 2010/11



April 2012



May 2012

Saturn 12 Apr 2012 16:38.8 Z CMIII:311.9
Anthony Wesley, Murrumbateman Australia



Colour detection and tracking – with care, and using the rings as a white reference, it's possible to reproduce reasonably accurate colours.

Standard processing techniques can result in some over-saturation of the colours on the disc.

Note the light green colouration exterior to the polar hexagon.

```
Saturn      6 Mar 2013 18:40.9 Z   CMIII:264.5  
Anthony Wesley, Murrumbateman Australia
```

It's apparent that the polar region has undergone substantial colour changes over the period 2012 - 2014



June 2013

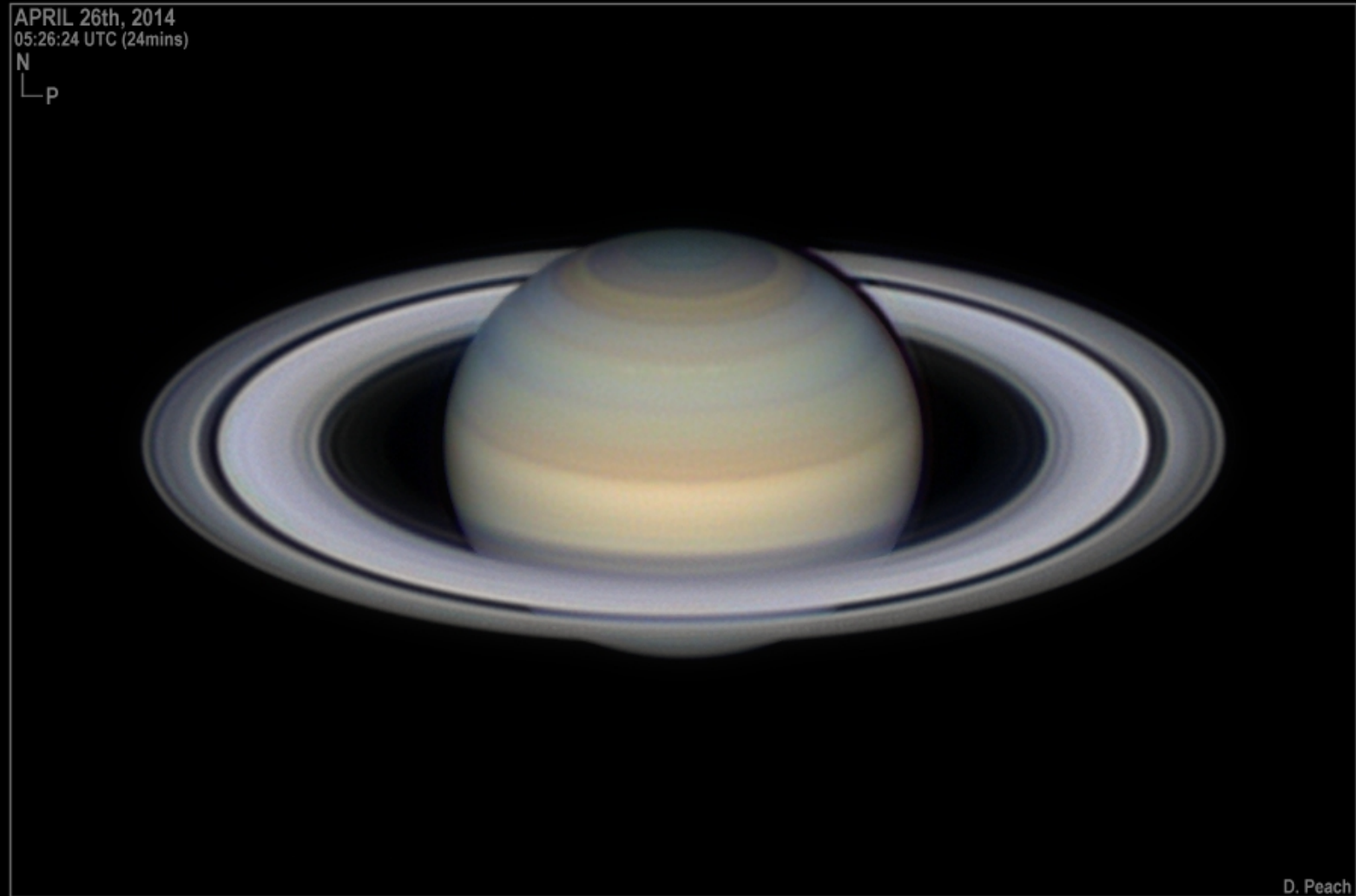


March 2013

```
Saturn    9 Jun 2013 10:21.7 Z    CMIII:335.1  
Anthony Wesley, Murrumbateman Australia
```



This is an accurate representation of the polar colours on Saturn
In April 2014, with only slightly exaggerated saturation.



Confirmation / comparative image from Damian Peach, April 2014



April 2013

Saturn 10 Apr 2013 17:49.6 Z CMIII:176.6
Anthony Wesley, Murrumbateman Australia



June 2013

Saturn 9 Jun 2013 10:21.7 Z CMIII:335.1
Anthony Wesley, Murrumbateman Australia



April 2014



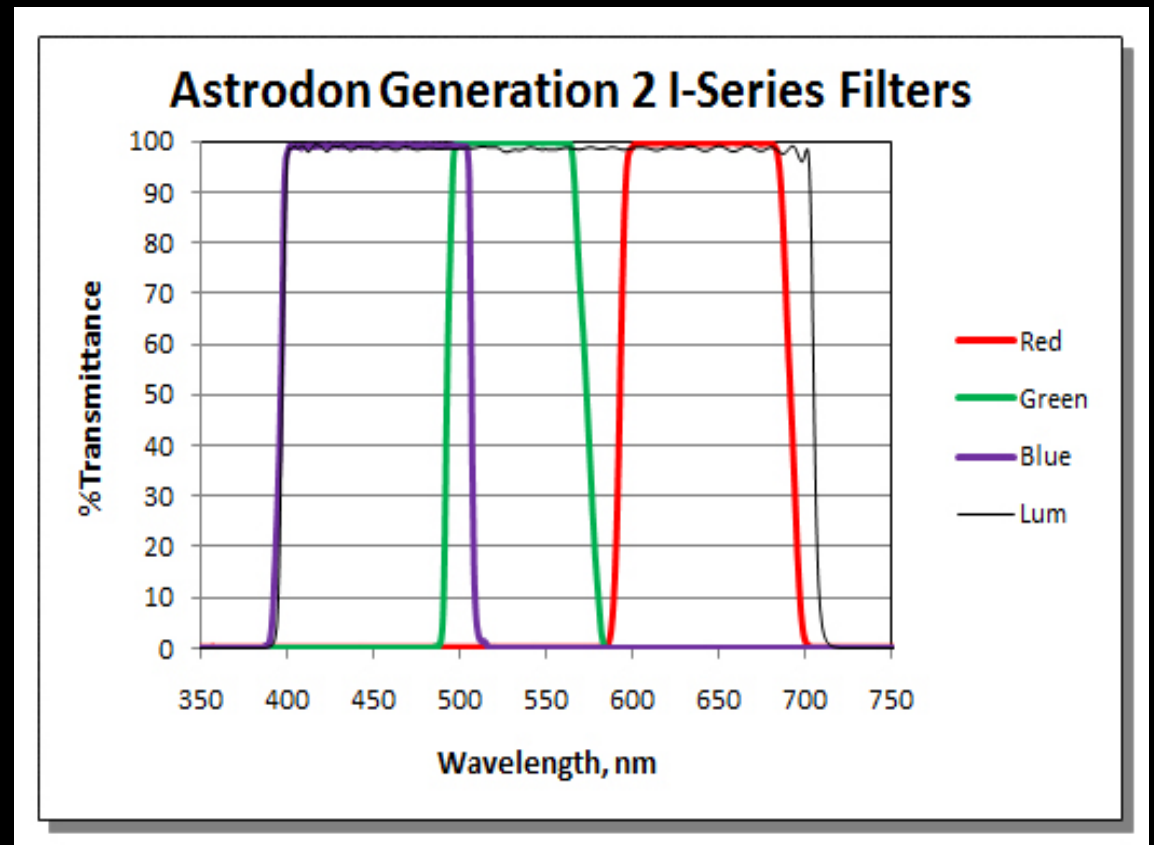
By July 2014 the polar colors have changed significantly

Saturn 22 Jul 2014 09:39.6 Z CMIII:261.8

Anthony Wesley, Murrumbateman Australia

Planetary imaging by amateurs is based around dichroic R/G/B filter sets such as this from Astrodon in the USA:

- High transmission
- Sharp cutoffs
- Very close to “true” RGB



Natural colour image of Jupiter
From August 2010

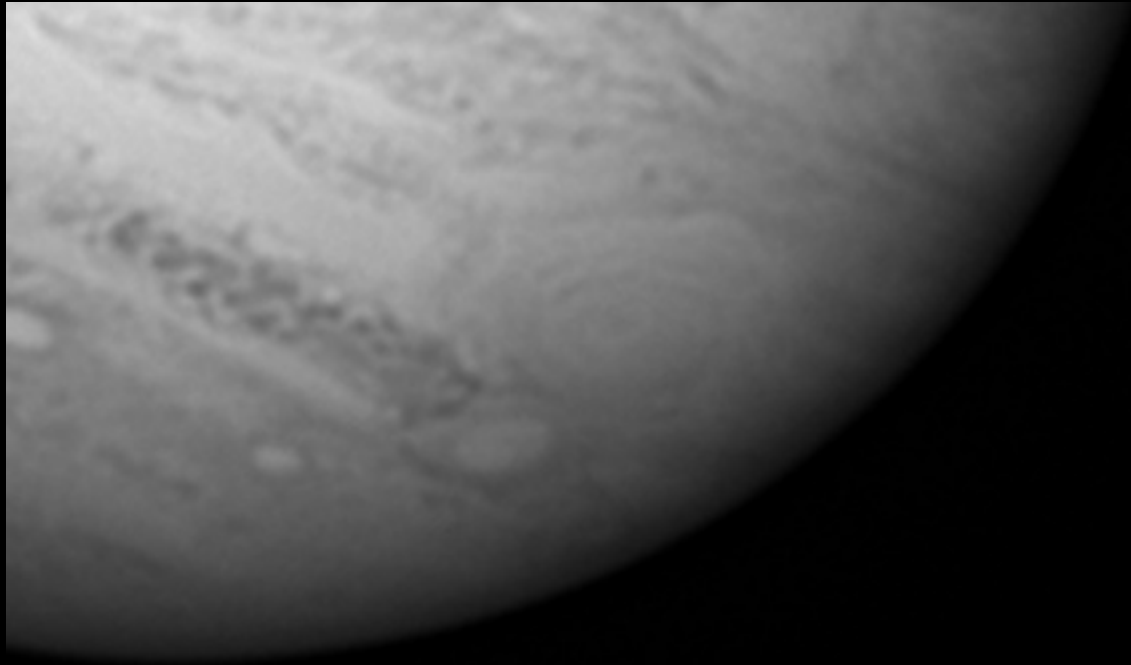
Note the thin green band at
the northern edge of the SEB.

Green is a very unusual colour
to see on Jupiter...

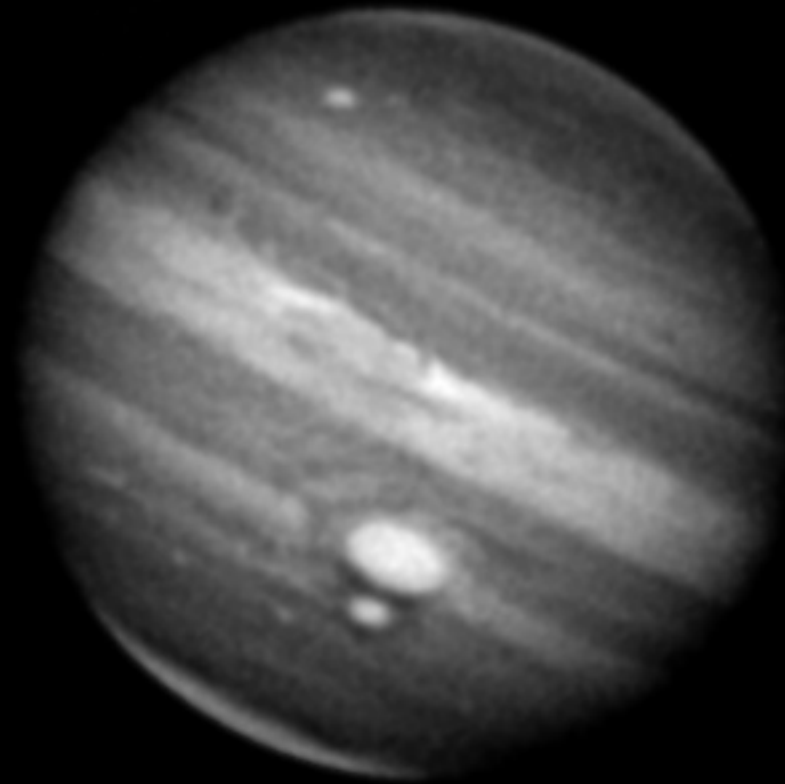


August 30 2010

Enhancement of
Great Red Spot
Showing interior detail
In Red channel.



CH4 absorption image



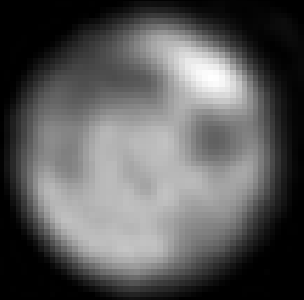
CH4

Anthony Wesley, Exmouth WA Australia
30 Aug 2010 16:44.2 Z CMI 20 CMII 164 CMIII 3



Ganymede and JPL simulator comparison

Anthony Wesley, Exmouth WA Australia
18 Aug 2010 17:36.4 Z



Impact detection -

July 2009

Asteroid impact
(est. 400m dia)

Visible impact debris
easily detected by
amateur class telescopes



Anthony Wesley, Murrumbateman Australia

19 Jul 2009 16:52.0 Z CMI 235 CMII 244 CMIII 335

Anthony Wesley, Astronomical Society of Australia

SEB revival

November 2010

Easily detected by amateur
Class telescopes

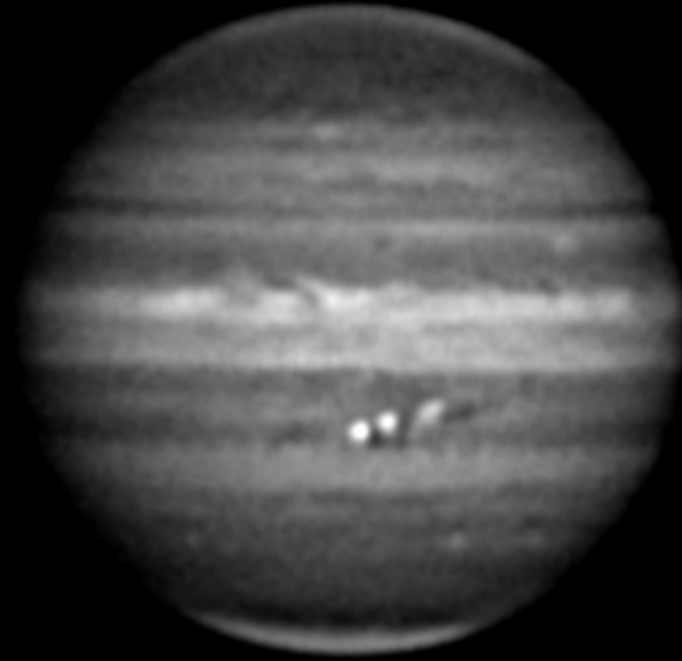


Anthony Wesley, Murrumbateman Australia

17 Nov 2010 10:21.7 Z CMI 27 CMII 290 CMIII 150

SEB revival
November 2010

CH4 absorption images show
clear activity in amateur class
telescopes.



SEB Outbreak (3 regions) from left to right:

L2 = 294.3, lat = -17.3

L2 = 289.3, lat = -15.2

L2 = 282.2, lat = -13.1

Methane band (CH4 absorption)

Anthony Wesley, Murrumbateman Australia

17 Nov 2010 10:34.1 Z CMI 34 CMII 297 CMIII 158

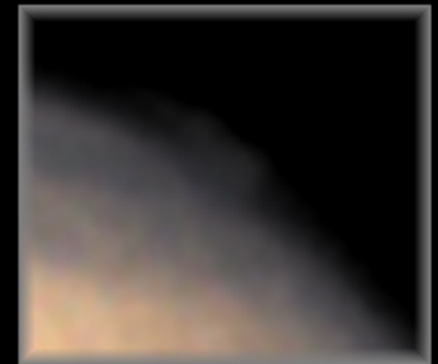
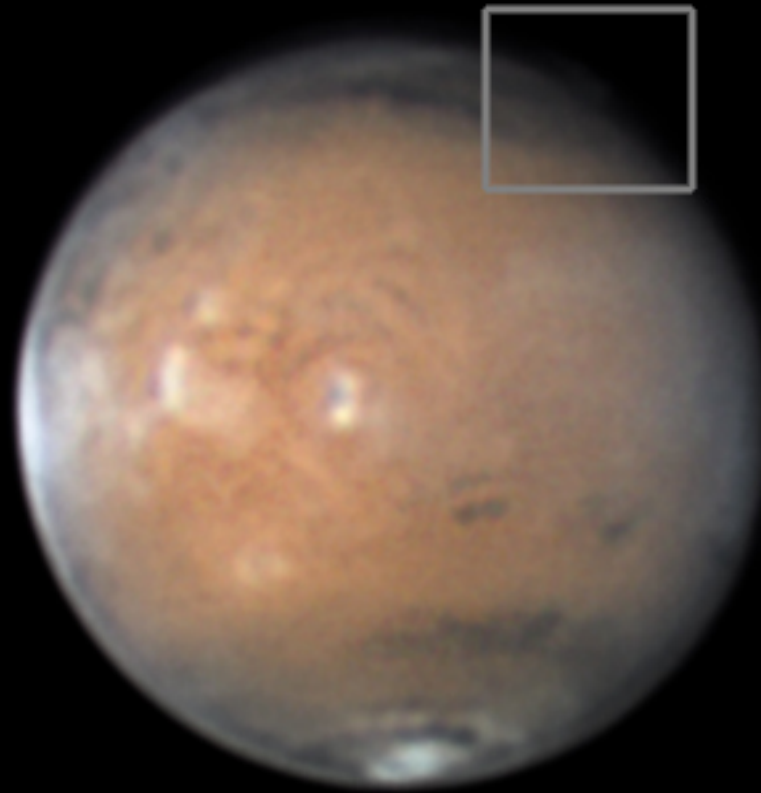
Bright visual fireball on Jupiter, June 2010

Also note the green band at northern edge of the SEB.



Jupiter + Fireball

Anthony Wesley, Broken Hill Australia
3 Jun 2010 20:31.6 Z CMI 299 CMII 33 CMIII 209

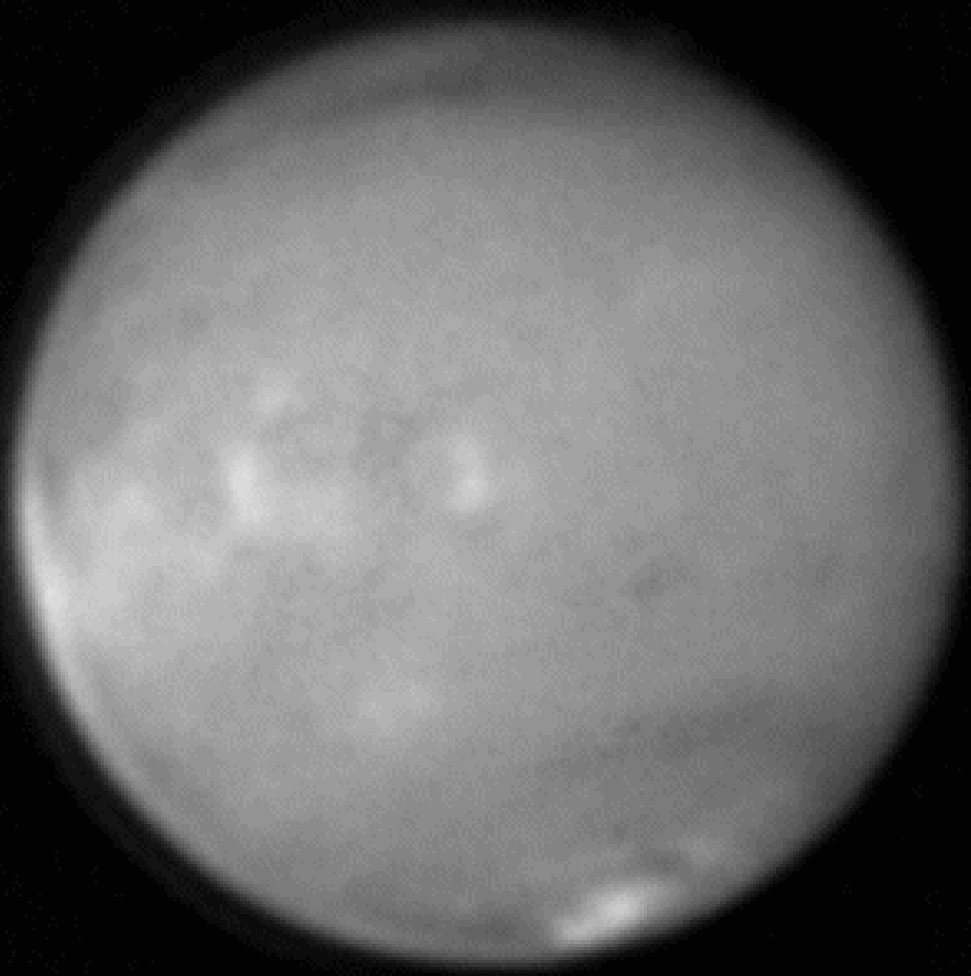


*200% enlargement of
highlighted region*

Feature detection on Mars, 2012

Mystery Cloud on Mars / 19 March 2012 / Wayne Jaeschke

Anthony Wesley, Astronomical Society of Australia



One again stop-frame animation
is critical to clearly show this as
a real feature.

Green Light / 20 March 2012 / 2:15ut - 2:51ut / W. Joeschke

Anthony Wesley, Astronomical Society of Australia

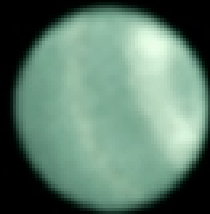
URANUS - RG610 filter

33 mins de-rotation

N
└─P

False colour

RG610 filter



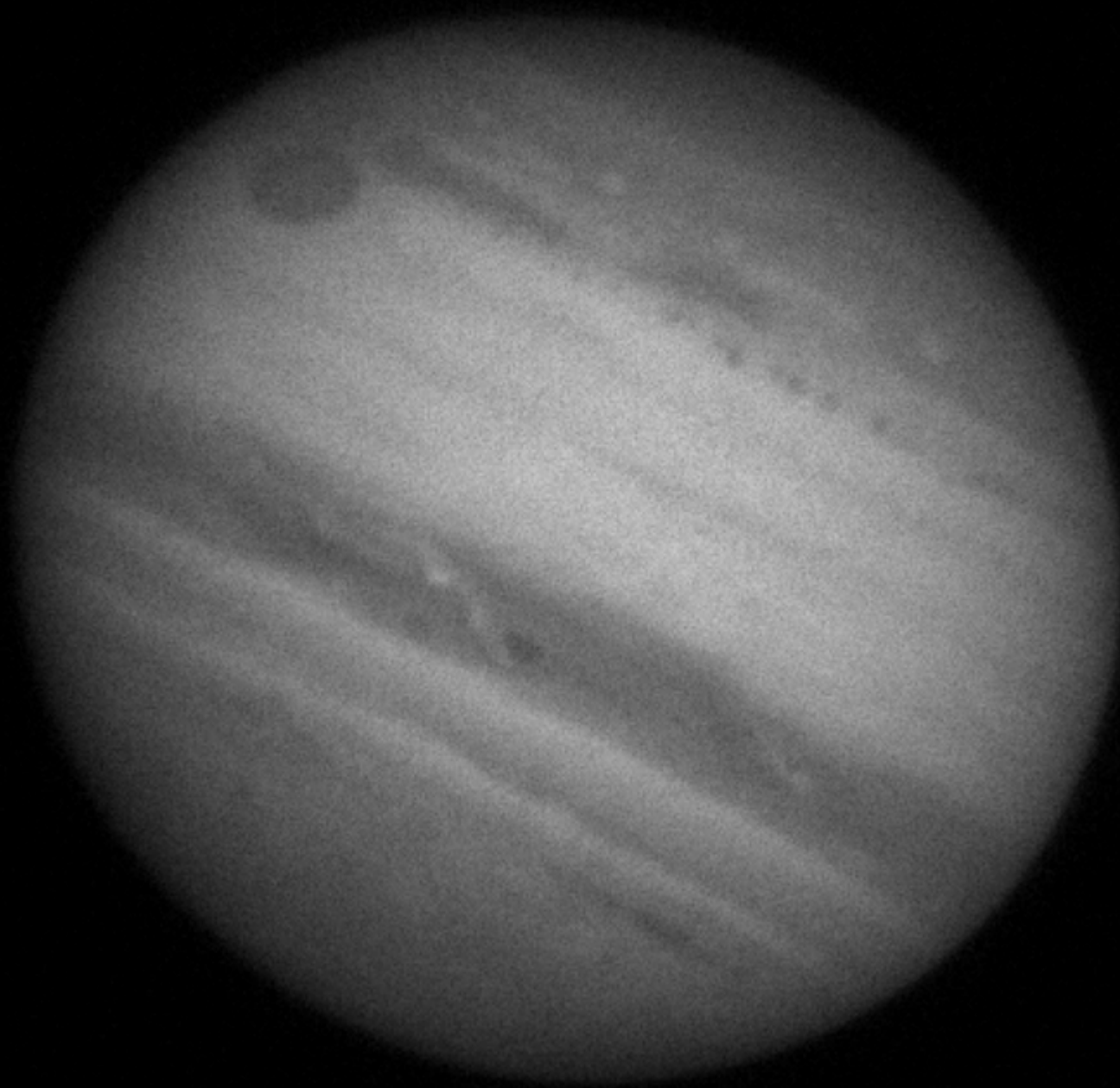
00:08 UTC
CML=224.0

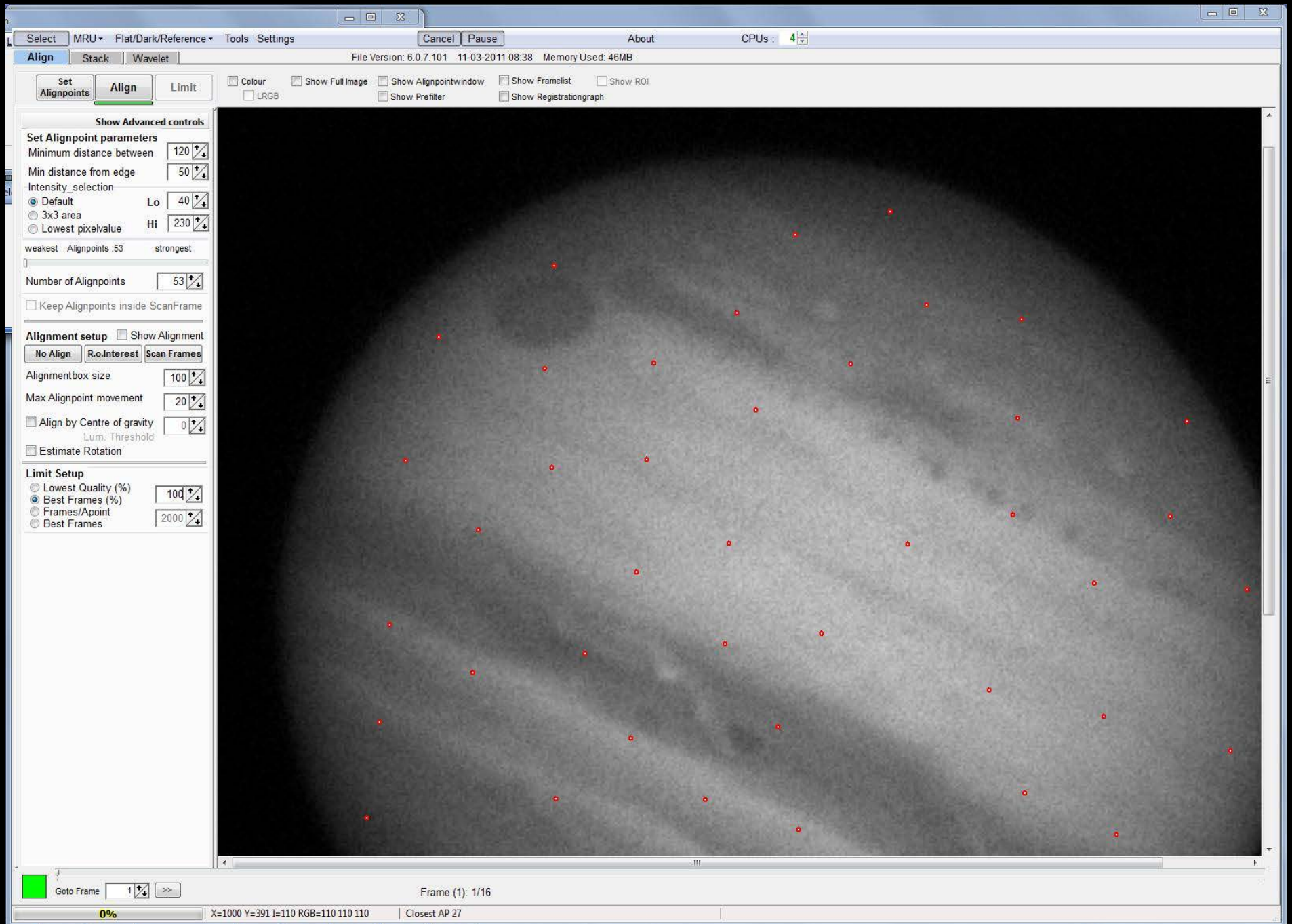
00:08 UTC
CML=224.0

Eq Diam: 3.68" Alt: 42°

October 2013

D. Peach





Amateur Planetary Imaging

The screenshot shows the Wavelet processing window of a software application. The interface includes a menu bar with 'Select', 'MRU', 'Flat/Dark/Reference', 'Tools', and 'Settings'. Below the menu bar are buttons for 'Align', 'Stack', and 'Wavelet'. The 'Wavelet' tab is active, showing a 'Process' section with 'Do All' and 'Save image' buttons. A 'Wavelets' panel on the left contains options for 'Automatic', 'Hold Wavelet Setting', 'Waveletscheme' (Dyadic and Linear), 'Initial Layer' and 'Step Increment' spinners, and 'Wavelet filter' (Default and Gaussian). A 'Layer' list shows six layers (1:1 to 6:6) with checkboxes and '1.0' preview values. 'Available schemes' and 'Load/Save Scheme' buttons are also present. The main image area displays a grayscale planetary image. On the right, a 'Functions' panel includes buttons for 'Histogram', 'Gamma', 'Colour Mixing', 'View Zoomed', 'View Compare', 'View Stacks', 'Flip and Rotate', 'RGB Align', 'RGB Balance', 'Resize Image', 'Denoise/Deringing', 'Wavelet Filter', 'Masking', 'Show Linegraph', and 'Cropping Area'. Below this is a 'Contrast/Brightness' section with sliders and spinners for 'Contrast' (set to 100) and 'Brightness' (set to 0). At the bottom right, a 'Copy To' section has radio buttons for 'Current Image' and 'Clipboard Image', and a 'Clipboardfront' button. The status bar at the bottom shows '100%' zoom, 'Do_all processing', and coordinates 'X=689 Y=72 Stack=1 RGB=raw(0 1.022E5 0)'.

Amateur Planetary Imaging

The screenshot displays the Wavelet software interface, which is used for processing astronomical images. The main window shows a grayscale image of Jupiter with its characteristic bands and the Great Red Spot. The interface is divided into several panels:

- Top Panel:** Contains menu options (Select, MRU, Flat/Dark/Reference, Tools, Settings), buttons for Cancel and Pause, and system information (About, CPUs: 4, File Version: 6.0.7.101, 11-03-2011 08:38, Memory Used: 226MB).
- Process Panel:** Includes buttons for Process, Do All, Save image, Realign_with Processed, Stack Again, Show Full Image, and Show Processing Area.
- Wavelets Panel:** Features options for Automatic, Hold Wavelet Setting, Waveletscheme (Dyadic (2^n) and Linear), Initial Layer, Step Increment, Wavelet filter (Default and Gaussian), Layer selection (1:1, 2:2, 3:3, 4:4, 5:5, 6:6), and Available schemes.
- ResizeImage_Panel:** A floating window with buttons for Save Image and Original, checkboxes for Flip X and Flip Y, a Resize Ratio (%) of 66, a Resize Image button, Image size (950x950, 1440x1440), a checked Maintain Aspectratio option, a Use settings button, and a Filters section (Bell, B-Spline, Lanczos, Mitchell).
- Functions Panel:** A grid of buttons for various image processing functions: Histogram, Gamma, Colour Mixing, View Zoomed, View Compare, View Stacks/size, Flip and Rotate, RGB, RGB Balance, Resize Image, Denoise/Deriving, Wavelet Filter, Masking, Show Linegraph, and Cropping Area.
- Contrast/Brightness Panel:** Includes Hold and Reset buttons, and sliders for Contrast (set to 100) and Brightness (set to 0).
- Copy To Panel:** Features Load to and Difference buttons, and radio buttons for Current Image and Clipboard Image.

The status bar at the bottom shows a 100% zoom level, the text "Do_all processing", and coordinates "X=313 Y=42 Stack=1 RGB=raw(0 30490 0)".



o:\saturn\20140722\093809UTC\c\2\q00000-2.fit

Select MRU Flat/Dark/Reference Tools Settings Cancel Pause About CPUs: 4

Align Stack Wavelet File Version: 6.1.0.8 06-05-2011 15:46 Memory Used/Free/Total: 46/3599/4096Mb

Set Alignpoints Align Limit

Colour Show Full Image Show Alignpoints Show Framelist Show Prefilter
 LRGB Show ROI Show Aligndata Show Registrationgraph

Show Advanced controls

Set Alignpoint parameters

Minimum distance between: 70
Min distance from edge: 20

Intensity_selection

Default Lo: 120
 3x3 area Hi: 230
 Lowest pixelvalue

weakest Alignmentpoints: 12 strongest

Number of Alignpoints: 0

Keep Alignpoints inside ScanFrame

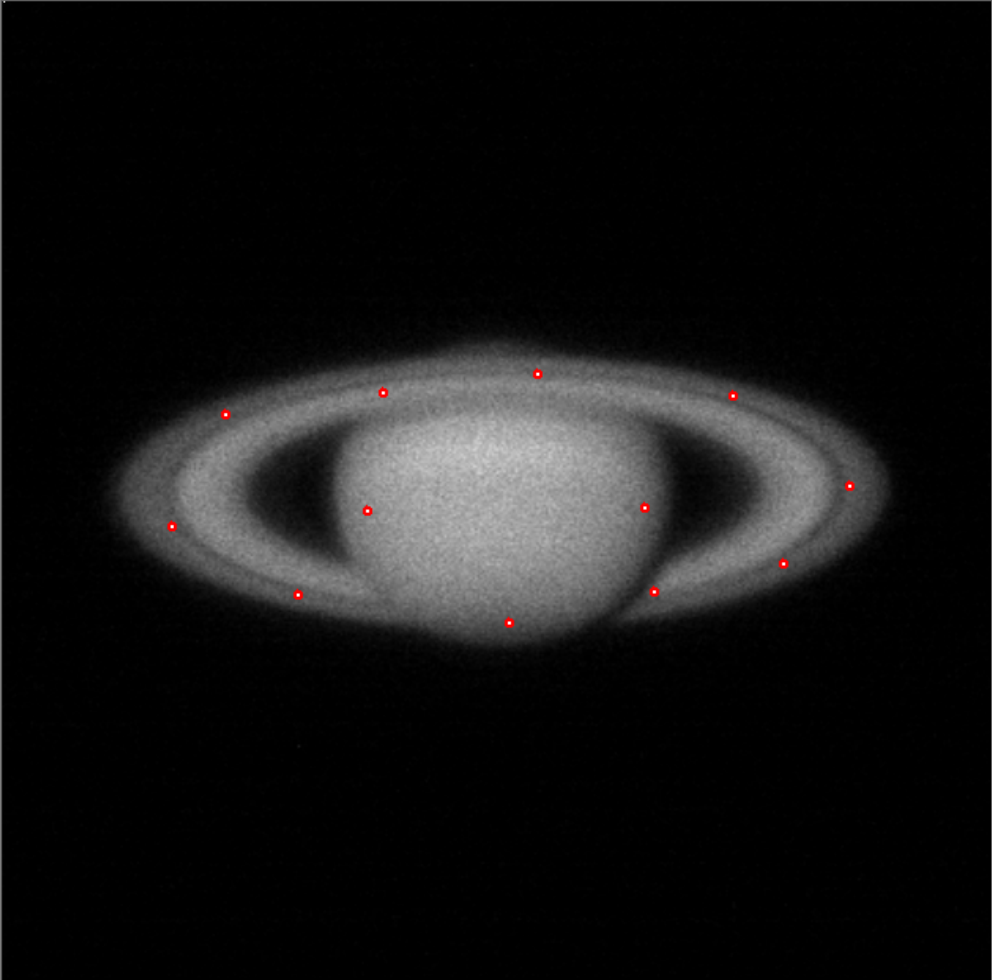
Alignment setup Show Alignment

Alignmentbox size: 60
Max Alignpoint movement: 20

Align by Centre of gravity Lum. Threshold: 100
 Estimate Rotation

Limit Setup

Lowest Quality (%) 100
 Best Frames (%) 5000
 Frames/Alignpoint
 Best Frames



Goto Frame: 1 Frame (1): 1/3000

0% X=320 Y=284 I=166 RGB=166 166 166 Closest AP 5

Amateur Planetary Imaging

o:\saturn\20140722\093809UTC\c\2\q00000-2.fit

Select MRU Flat/Dark/Reference Tools Settings Cancel Pause About CPUs: 4

Align Stack Wavelet File Version: 6.1.0.8 06-05-2011 15:46 Memory Used/Free/Total: 124/3518/4096Mb

Process Do All Save image Realign_with Processed Stack Again Show Full Image Show Processing Area Show AlignPoints

Wavelets Reset Wavelets

Automatic
 Hold Wavelet Setting

Waveletscheme
 Dyadic (2^n) Linear

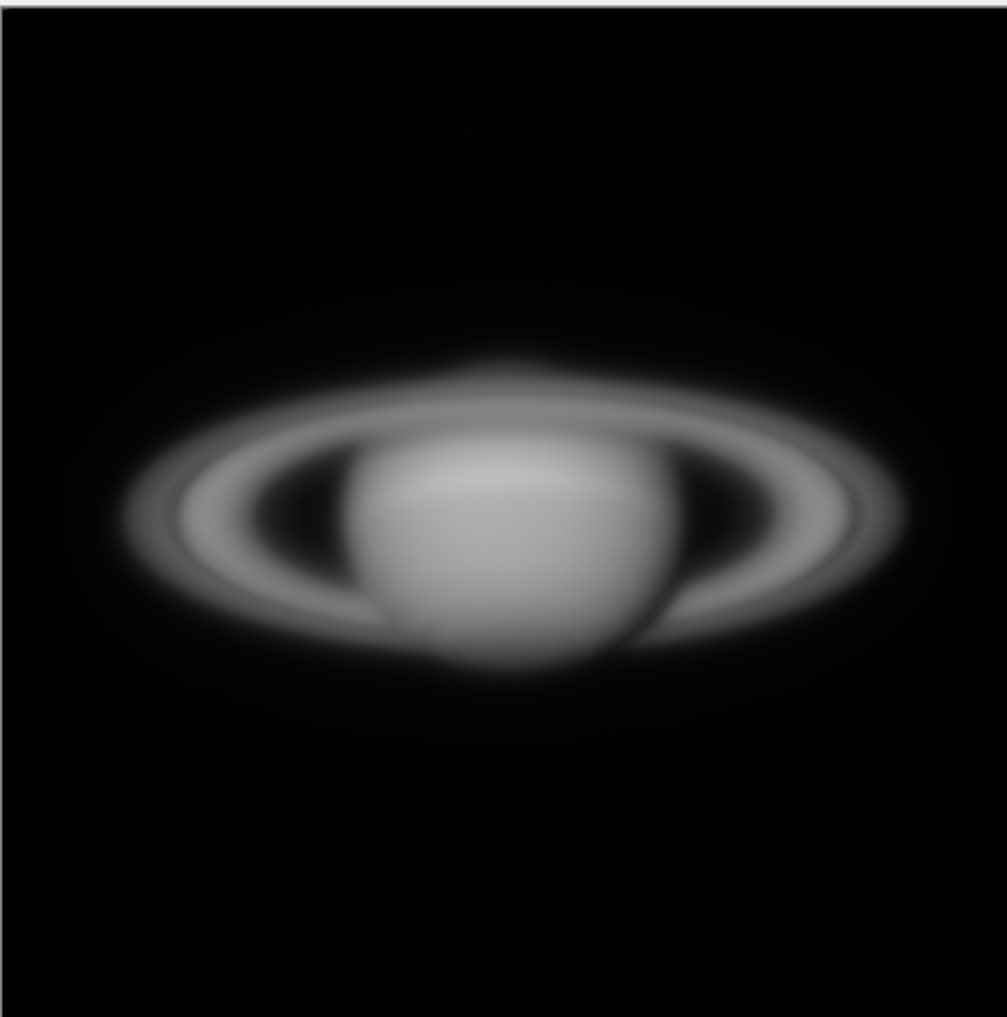
Initial Layer 1 Step Increment 1

Wavelet filter
 Default Gaussian

Layer	Preview
<input checked="" type="checkbox"/> 1 : 1	1.00
<input checked="" type="checkbox"/> 2 : 2	1.00
<input checked="" type="checkbox"/> 3 : 3	1.00
<input checked="" type="checkbox"/> 4 : 4	1.00
<input checked="" type="checkbox"/> 5 : 5	1.00
<input checked="" type="checkbox"/> 6 : 6	1.00

Available schemes

Load Scheme Save Scheme



Functions

Histogram	Gamma	Colour Mixing
View Zoomed	View Compare	View Stacksize
Flip and Rotate	RGB Align	RGB Balance
Resize Image	Denoise/Deringing	Wavelet Filter
Masking	Show Linegraph	Cropping Area

Contrast/Brightness Hold Reset

Contrast 100 Brightness 0

Copy To Load to Difference

Toggle
 Current Image
 Clipboard Image

100% Calculating wavelets done | X=0 Y=26 Stack=1267 PT=3 RGB=raw(0 256 0) user(1 1 1)

Amateur Planetary Imaging

o:\saturn\20140722\093809UTC\c12\q00000-2.fit

Select MRU Flat/Dark/Reference Tools Settings Cancel Pause About CPUs: 4

Align Stack Wavelet File Version: 6.1.0.8 06-05-2011 15:46 Memory Used/Free/Total: 124/3519/4096Mb

Set Alignpoints Align Limit

Colour Show Full Image Show Alignpoints Show Framelist Show Prefilter
 LRGB Show ROI Show Aligndata Show Registrationgraph

Show Advanced controls

Set Alignpoint parameters

Minimum distance between: 70

Min distance from edge: 20

Intensity_selection

Default Lo: 120

3x3 area Hi: 230

Lowest pixelvalue

weakest Alignmentpoints: 15 strongest

Number of Alignpoints: 3

Keep Alignpoints inside ScanFrame

Alignment setup Show Alignment

No Align R.o.Interest Scan Frames

Alignmentbox size: 60

Max Alignpoint movement: 20

Align by Centre of gravity Lum. Threshold: 100

Estimate Rotation

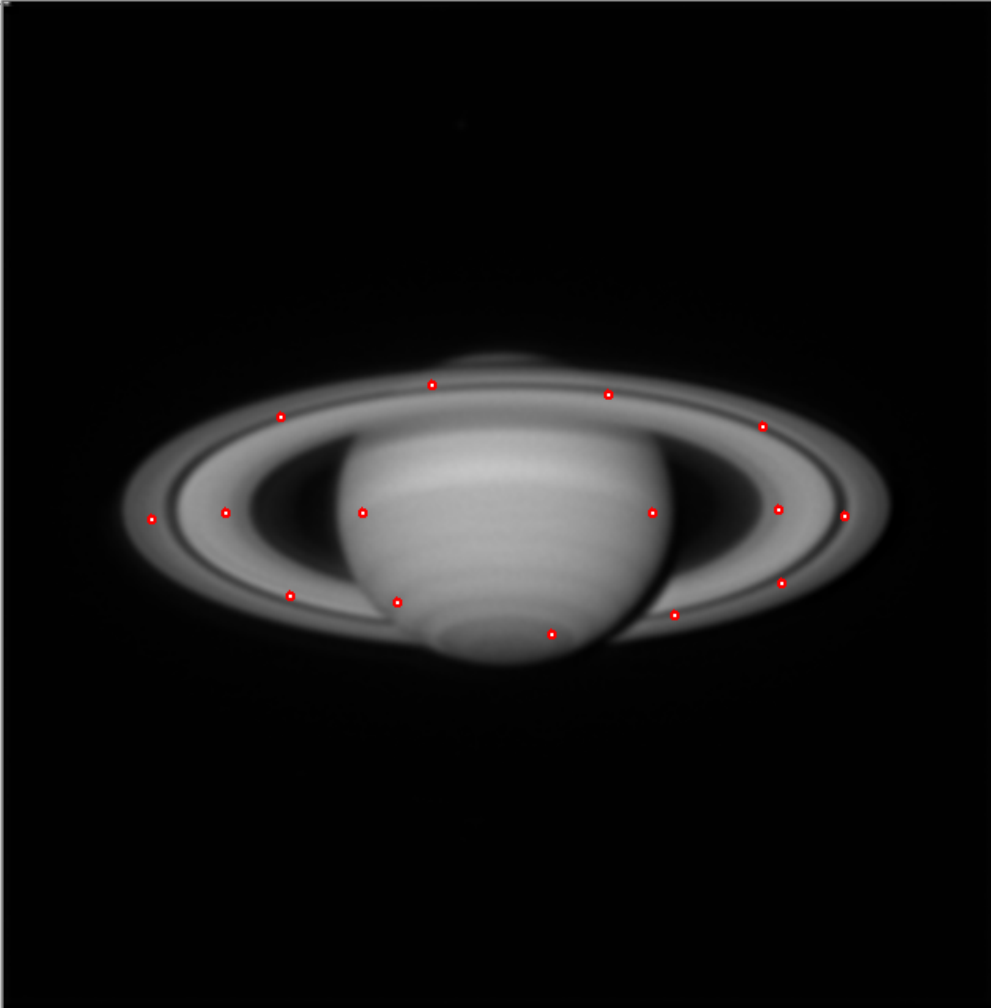
Limit Setup

Lowest Quality (%) 100

Best Frames (%) 5000

Frames/Apoint

Best Frames



Goto Frame 1 >>> Frame (508): 1/3000

100% X=18 Y=320 I=1 RGB=1 1 1 | Closest AP 13

The screenshot displays the Wavelet software interface for planetary image processing. The main window shows a grayscale image of a planet with rings. The interface includes a menu bar (Select, MRU, Flat/Dark/Reference, Tools, Settings), a toolbar (Process, Do All, Save Image, Realign_with Processed, Stack Again), and a status bar (File Version: 6.1.0.8, Date: 06-05-2011 15:46, Memory Used/Free/Total: 136/3507/4096Mb, CPUs: 4).

Wavelets Panel:

- Reset Wavelets
- Automatic
- Hold Wavelet Setting
- Waveletscheme: Dyadic (2^n) Linear
- Initial Layer: 1, Step Increment: 1
- Wavelet filter: Default Gaussian

Layer Panel:

Layer	Preview
<input type="checkbox"/> 1 : 1	1.0
<input type="checkbox"/> 2 : 2	1.0
<input checked="" type="checkbox"/> 3 : 3	22.0
<input checked="" type="checkbox"/> 4 : 4	1.0
<input checked="" type="checkbox"/> 5 : 5	1.0
<input checked="" type="checkbox"/> 6 : 6	1.0

Available schemes: s20140110.nrv

Functions Panel:

- Histogram, Gamma, Colour Mixing
- View Zoomed, View Compare, View Stacksize
- Flip and Rotate, RGB Align, RGB Balance
- Resize Image, Denoise/Deringing, Wavelet Filter
- Masking, Show Linegraph, Cropping Area

Contrast/Brightness Panel:

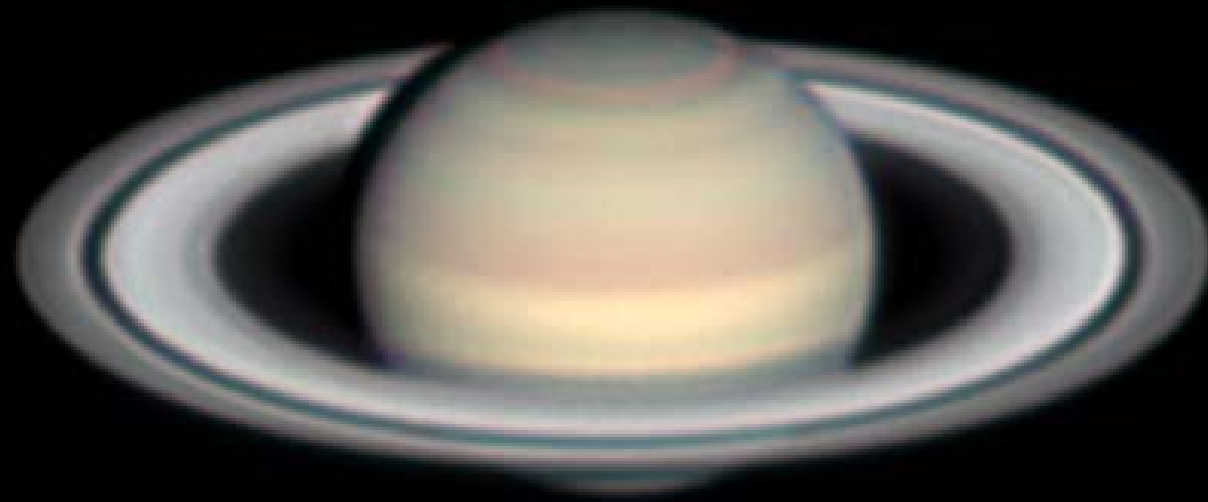
- Hold, Reset
- Contrast: 100
- Brightness: 0

Copy To Panel:

- Copy To, Load to, Difference
- Toggle: Current Image, Clipboard Image

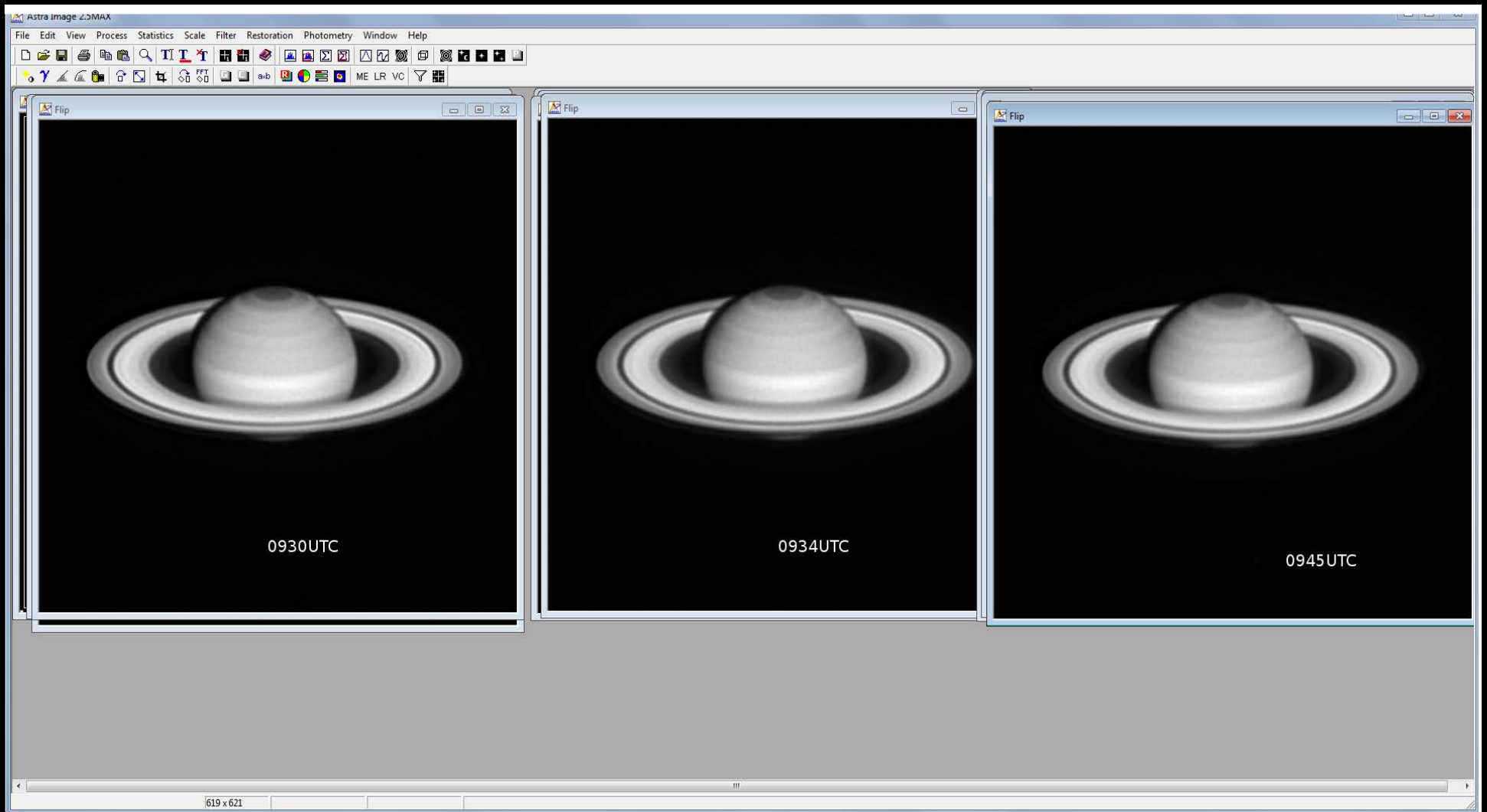
Status Bar:

- 100% (Progress)
- Do_all processing
- Stacking Range: 0-65535



Saturn 22 Jul 2014 09:39.6 Z CMIII:261.8
Anthony Wesley, Murrumbateman Australia

Amateur Planetary Imaging



Using WinJupos to merge images with derotation

Amateur Planetary Imaging

Start with
Image measurement

WinJupos shows
a template
based on datetime
for you to place
around the image

Moons are also
shown on the
template, as is
any phase or
shadows

e.g. ring shadow

The screenshot displays the WinJupos 10.1.6 software interface. The main window is titled "Measurements of Saturn images: 2014-07-22-0944.5-AW-IR750". The interface includes a menu bar (Program, Recording, Analysis, Lists, Administration, Tools, Window, ?) and a toolbar with buttons for "Open image (F7)", "Ephemerides (F8)", "Reset", "Save (F2)", and "Load (F3)".

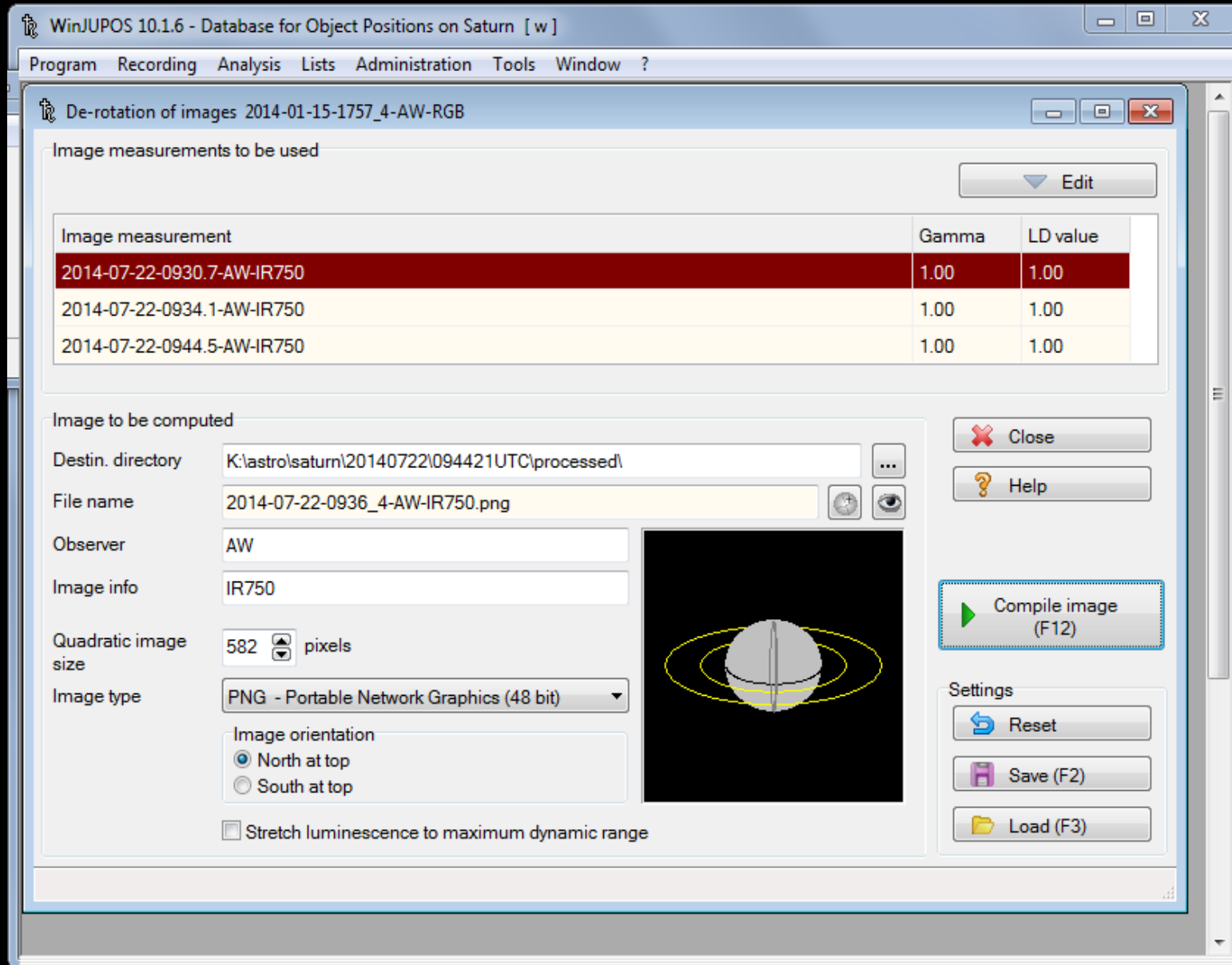
Measurement fields include:

- CM1: 6.3°, CM2: 261.9°, CM3: 264.5°, CLat: +25.3°, X: -3.375, NR, Y: -1.626
- Date: 2014/07/22 [yyyy/mm/dd]
- UT: 09:44.5 [hh:mm.t]
- Geogr. longit.: -149 00 [±ddd°mm']
- Geogr. latit.: -35 00 [±dd°mm']

Other fields include "Observer" (AW) and "Image info" (IR750). A central image shows a Saturn template with a ring shadow, labeled with "N" (North) and "P" (Pole). The status bar at the bottom indicates the date and time (2014/07/22 09:44.5), the file path (K:\astro\saturn\20140722\094421UTC\processed\20140722-0944.tif), and technical details (Ø 214.1 pixels, 0.081" / pixel, RotA 0.23°).

Multiple measurements are then combined using derotation to the midpoint time.

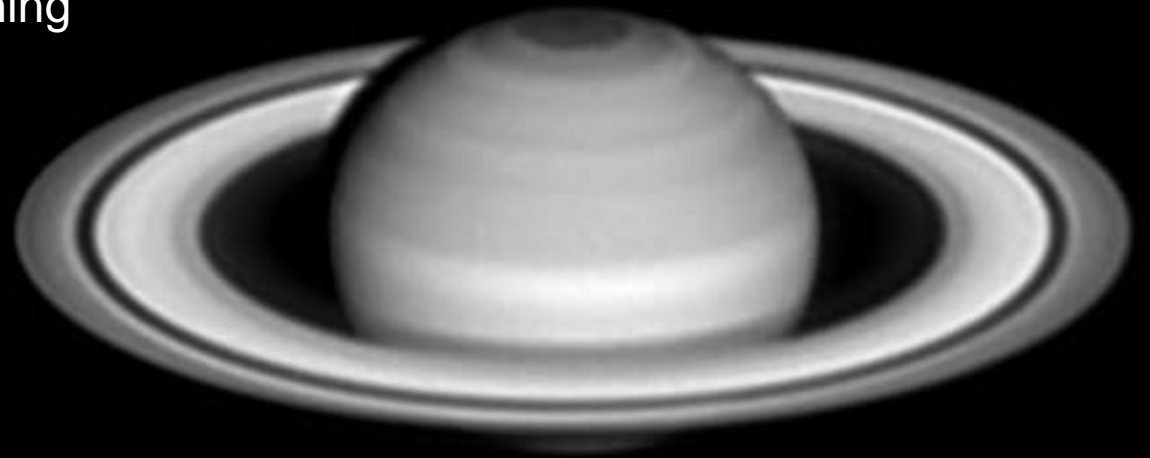
Eg here we have 3 images with a midpoint time of 0936.4 UTC



This is the resulting image.

WinJupos uses LAMBERT limb darkening heuristic, with parameter from 0.0 – 1.0 representing the reflection profile of an ideal diffuse body.

Limb darkening must be taken into account when combining multiple images from different times.



[1] Brightness profile of ideal diffuse reflecting bodies according to LAMBERT

$$h_s = h * (\vec{S}_0 \cdot \vec{I}_0)$$

S_0 - Surface vector/normal (3D) of a surface point, normalized

I_0 - Illumination vector (3D) of the surface point, normalized

h - Normal brightness of the surface point

h_s - Observed brightness of the surface point

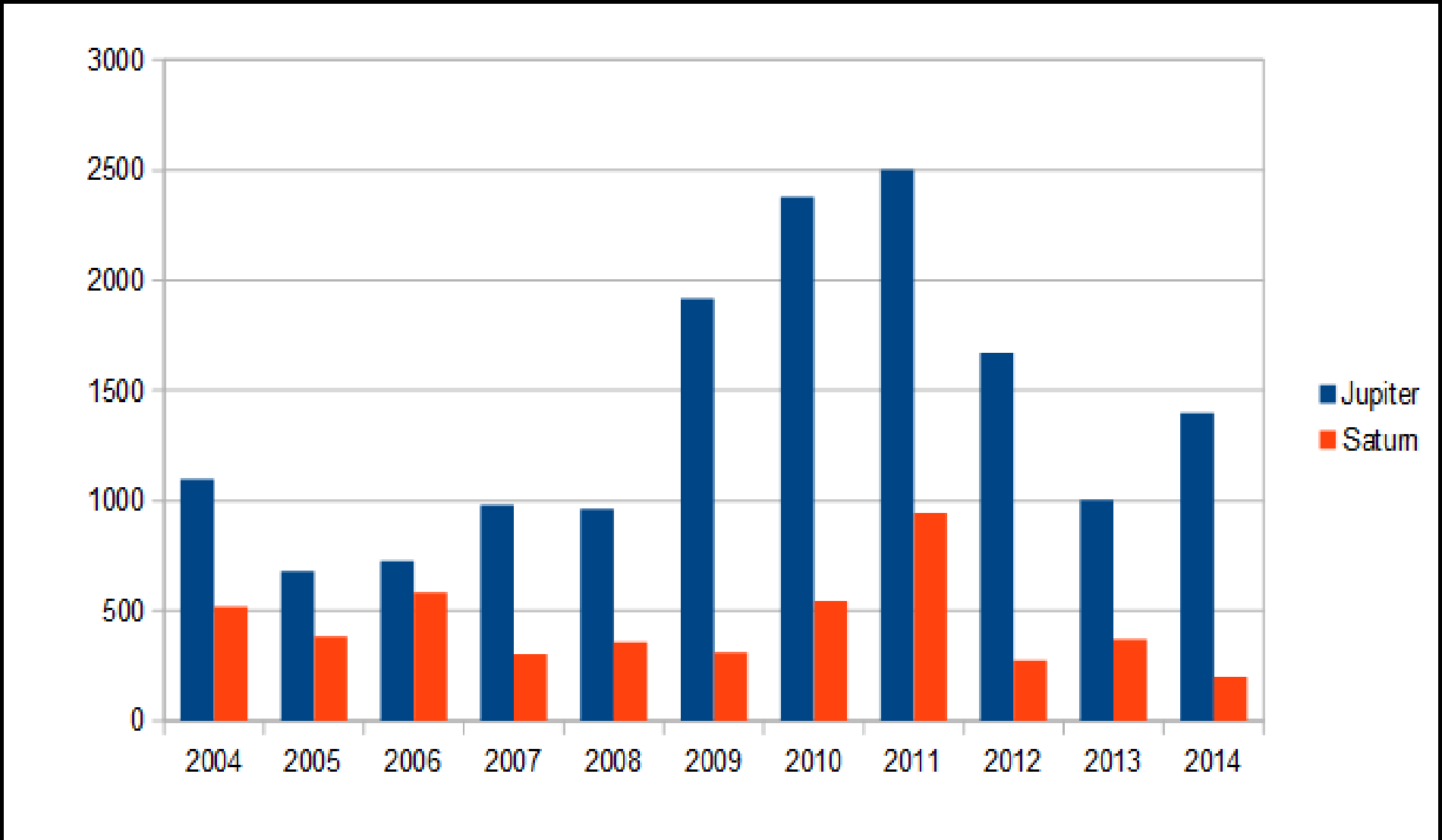
Future Software

- More sophisticated image alignment and stacking algorithms
- Reproject frames – cylindrical map
- Stack on that model
- Allow much longer capture runs to be combined into a single cylindrical map that can be projected onto a 3D model.



Jupiter, 23 July 2010
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Contributions to ALPO from 2004 - 2014



Planetary imaging remains one of the most challenging and difficult of all amateur disciplines.

Good results require multi-disciplinary skills covering astronomy hardware and specialised software.

Difficulties include:

- Narrow field of view
- Long focal length
- Extreme dependence on seeing conditions

- Skills that are orthogonal to other, more traditional and easier, amateur pursuits.



Voyager 3 team

From left to right: Daniel Sundström, Torbjörn Holmqvist, Peter Rosén, Göran Strand, Johan Warell, Martin Högberg, and Roger Utas.