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

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

Madison, August 2014

Anthony Wesley, Astronomical Society of Australia

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:

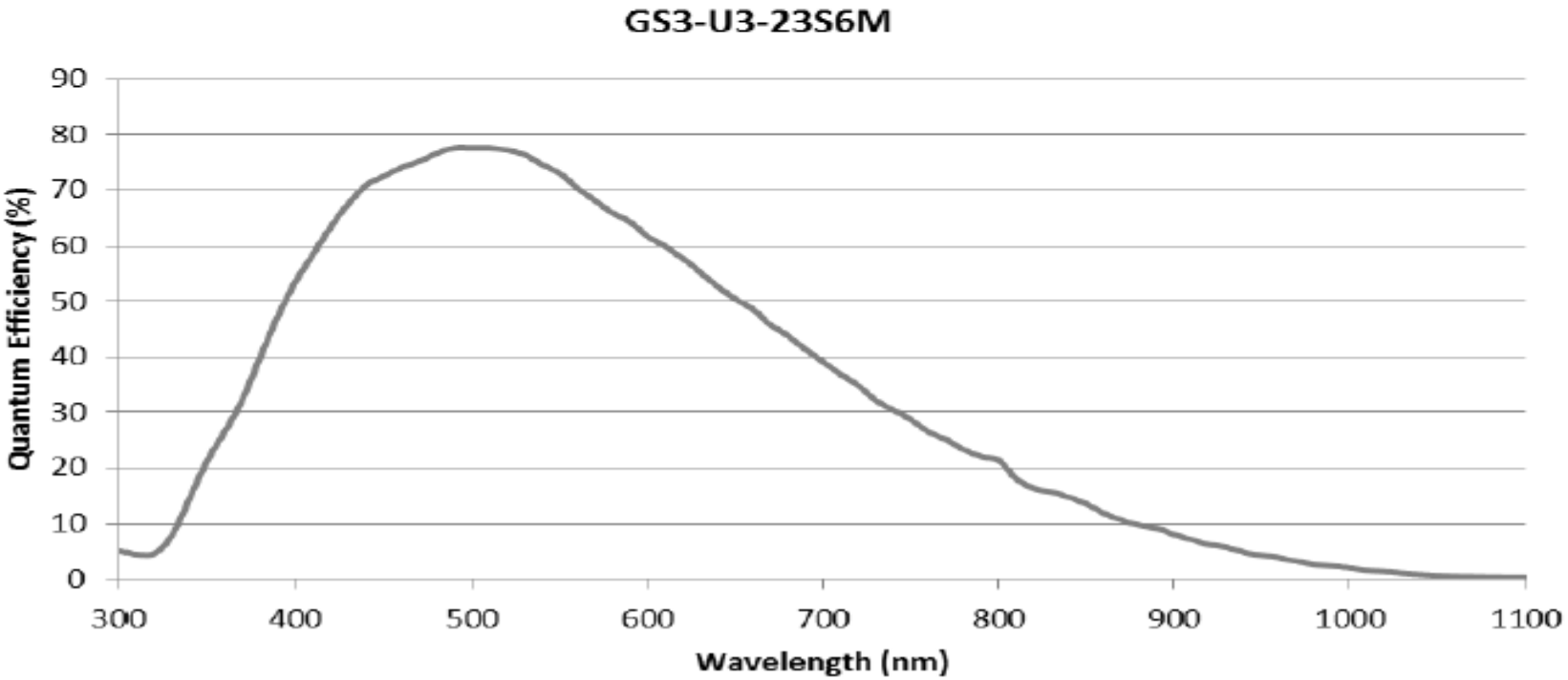
- Visible light feature detection and tracking

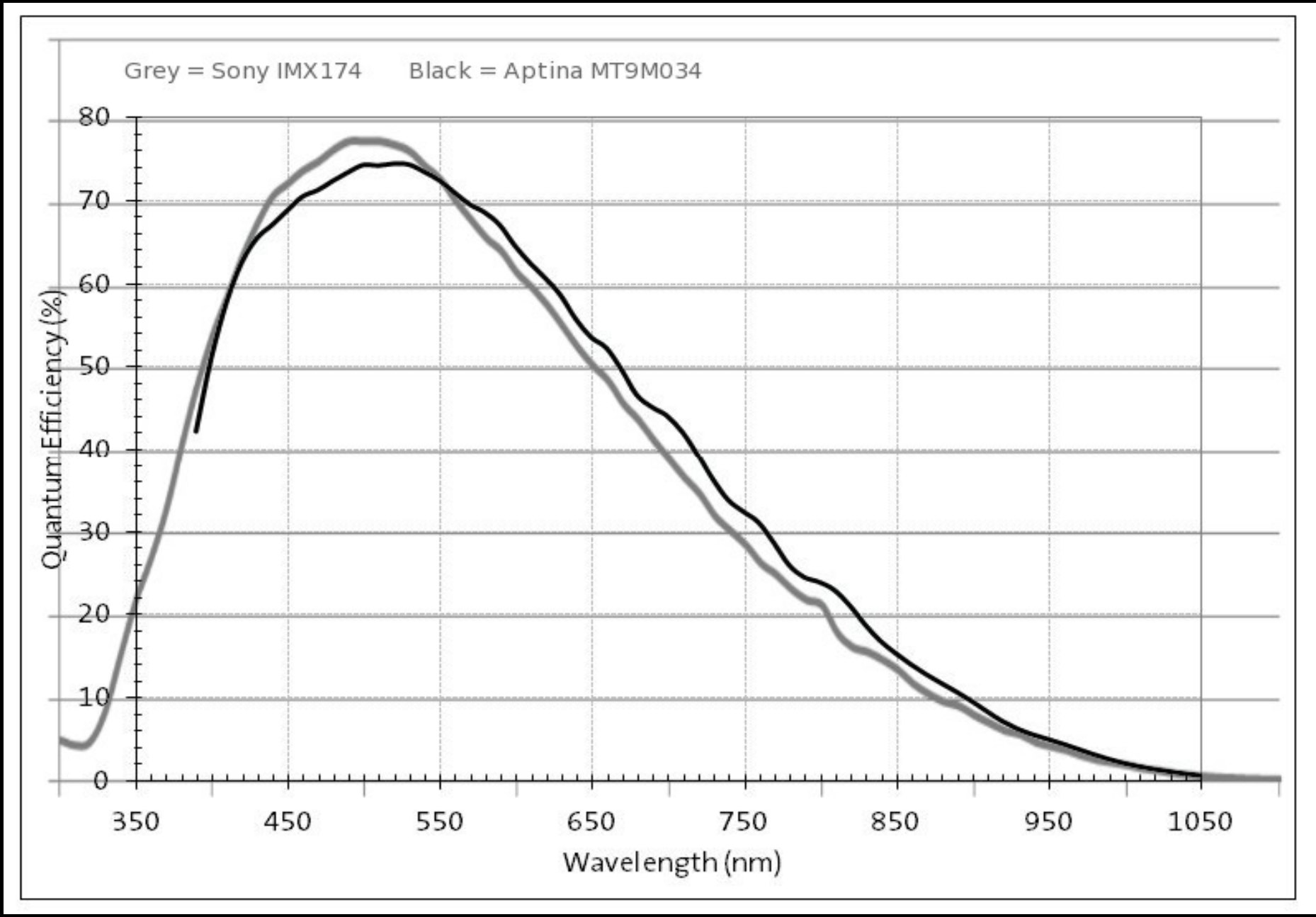
- Visible light colour changes, detection and tracking

- Impact / flash / bolide detection

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

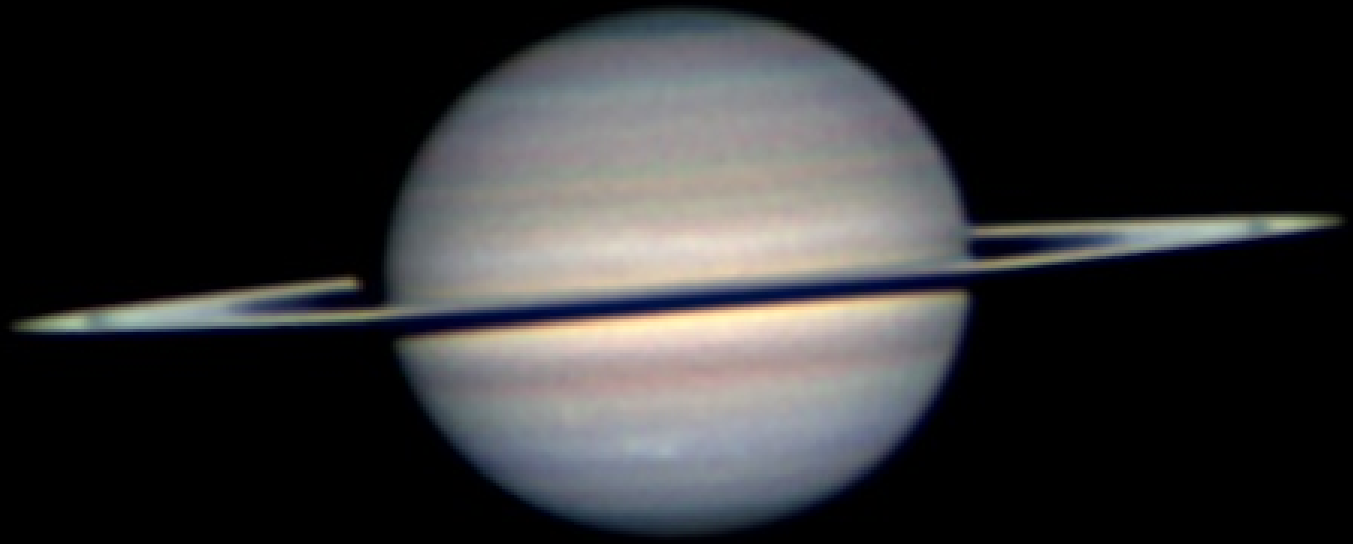
Measurement	Value	Unit
Quantum Efficiency	76	% at 525 nm
Temporal Dark Noise (Read Noise)	6.83	e-
Signal to Noise Ratio Maximum	45.12	dB
Signal to Noise Ratio Maximum	7.49	Bits
Absolute Sensitivity Threshold	9.77	γ
Saturation Capacity (Well Depth)	32513	e-
Dynamic Range	72.94	dB
Dynamic Range	12.11	Bits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




Grey = Sony IMX174
Black = Aptina MT9M034
Quantum Efficiency (%)
80
70
60
50
40
30
20
10
0
350
450
550
650
750
850
950
1050
Wavelength (nm)

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."

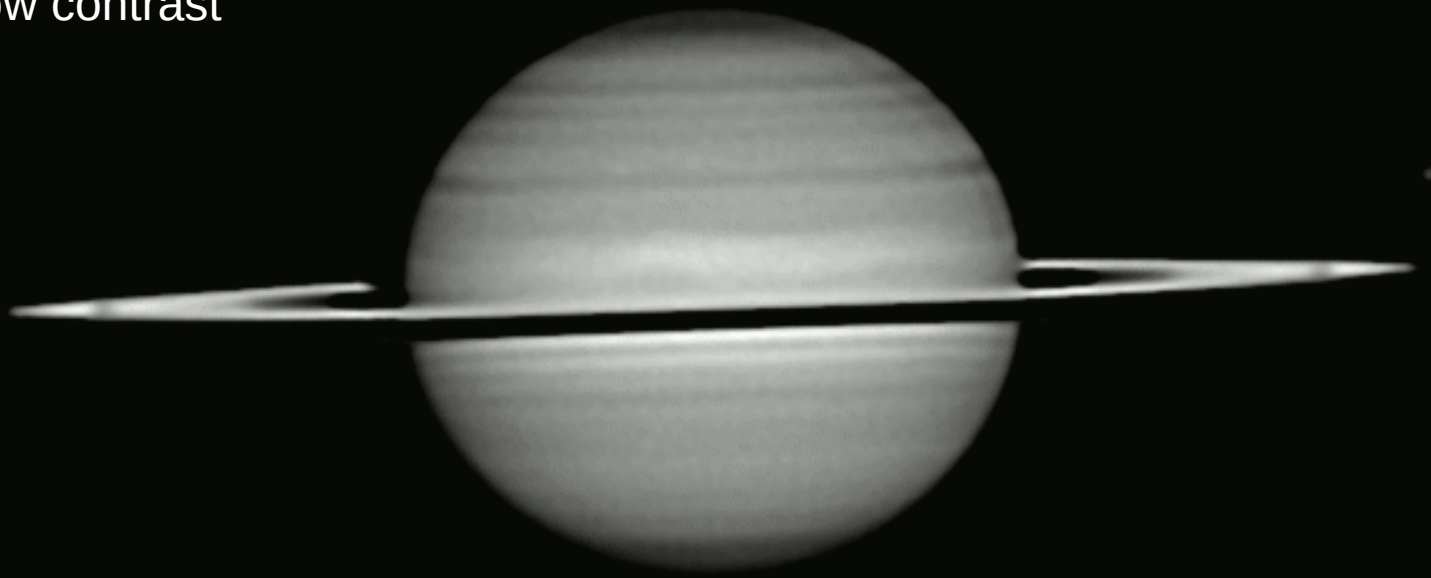
"We were so excited to get a heads-up from the amateurs," said Gordon Bjoraker, a composite infrared spectrometer team member based at NASA's Goddard Space Flight Center in Greenbelt, Md. Normally, he said, "Data from the storm cell would have been averaged out."

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

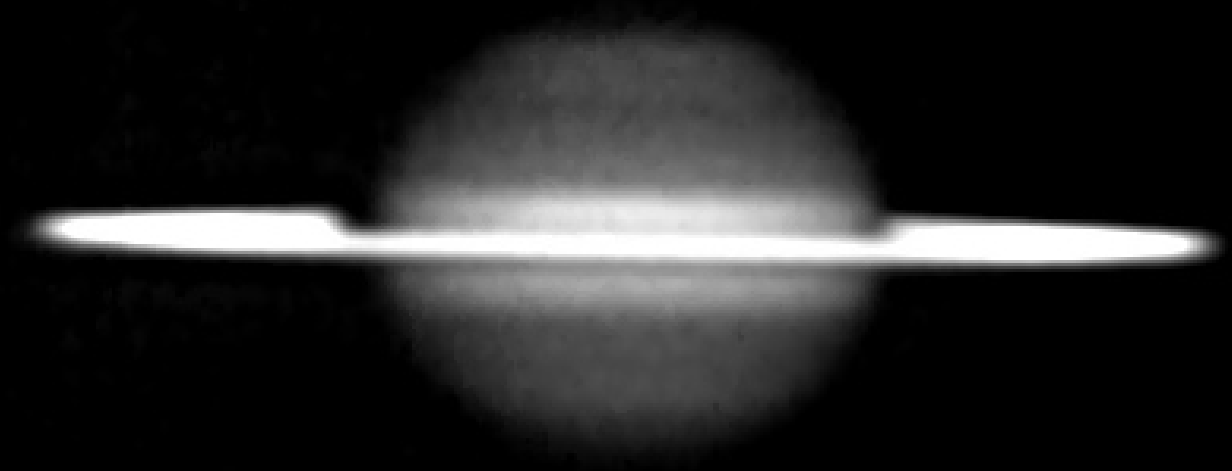


9th June 2010

IR >= 750nm

Feature detection

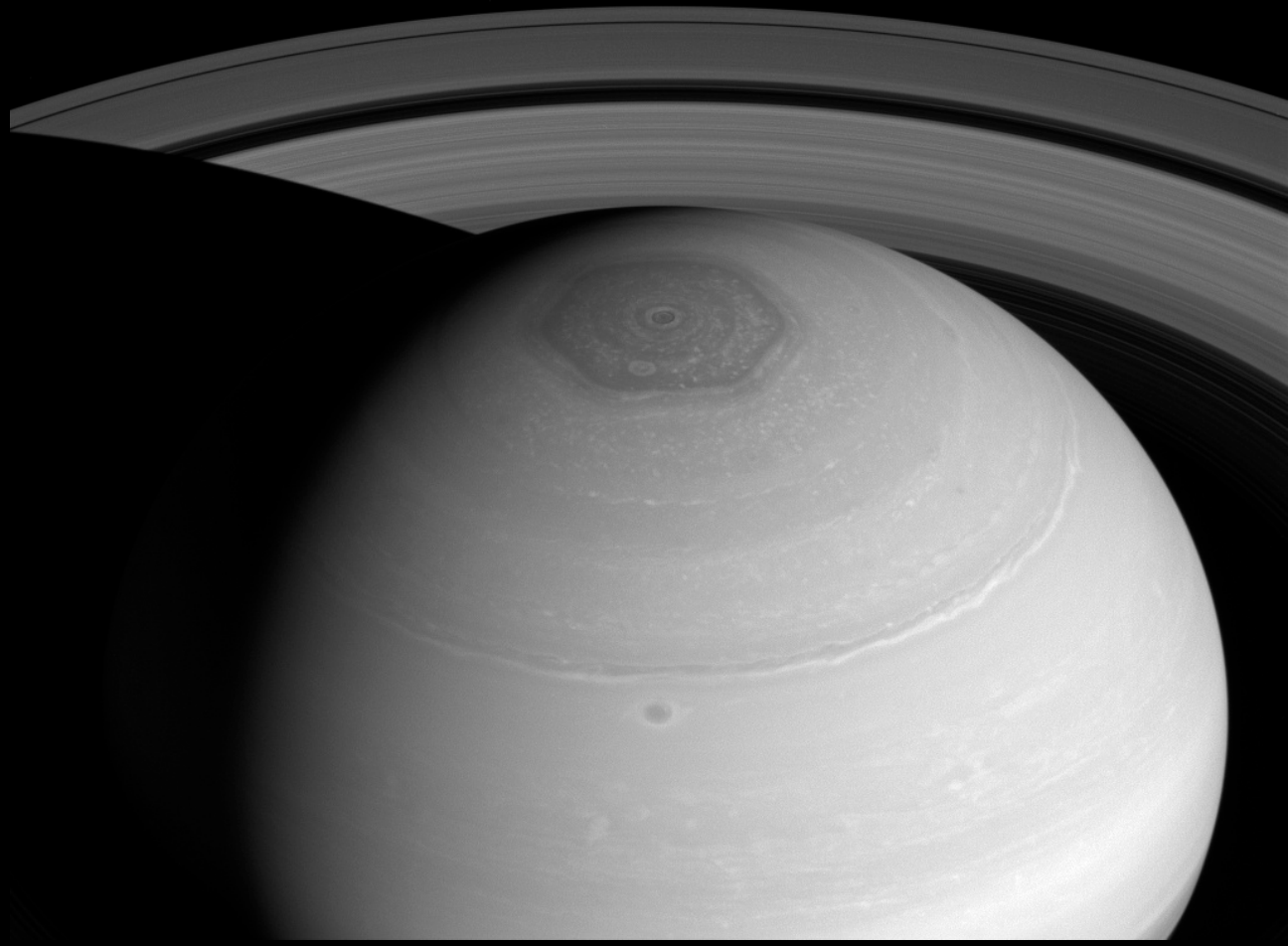
CH4 absorption 889nm



14th May 2010

Saturn + Rhea, CH4

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

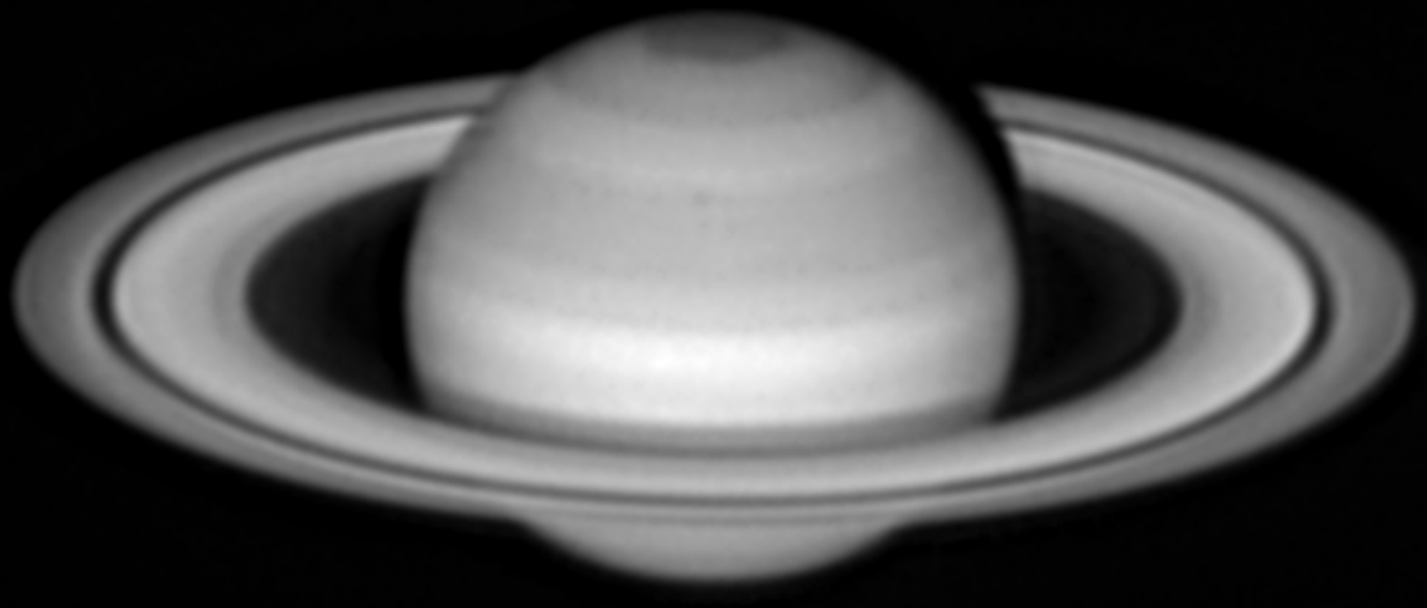


Cassini image showing
polar vortex and
long-lived dark spot

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.)

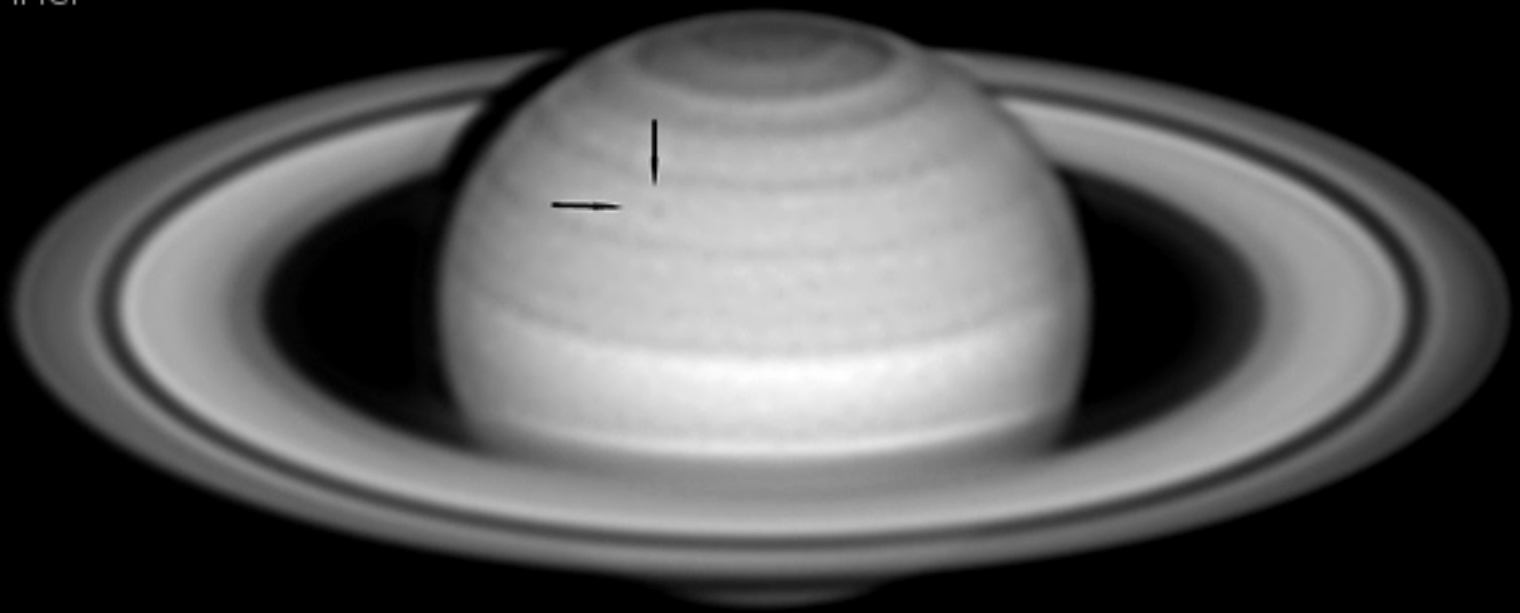
Feature Detection – use of stop-frame animations by amateurs allows easy detection of subtle features.



18th March 2013

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

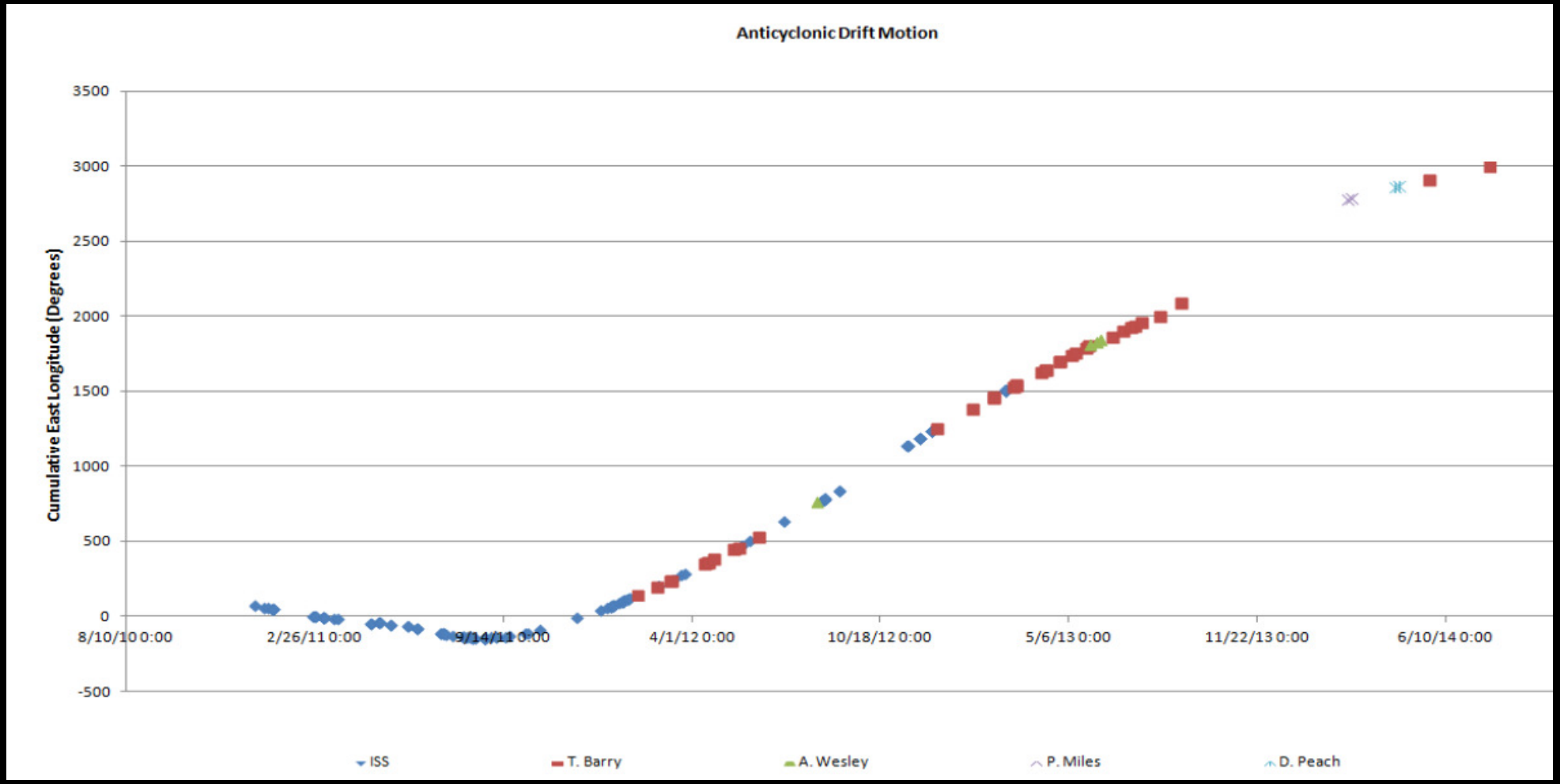
Red channel



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

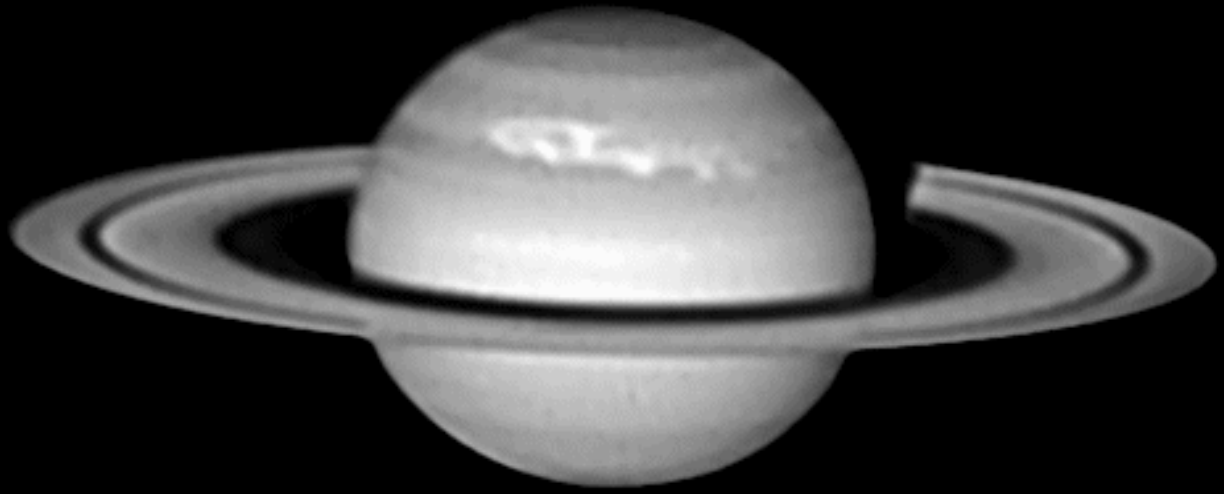
Saturn 14 Dec 2010 18:31.8 Z CMIII:265.0
Anthony Wesley, Murrumbateman Australia

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

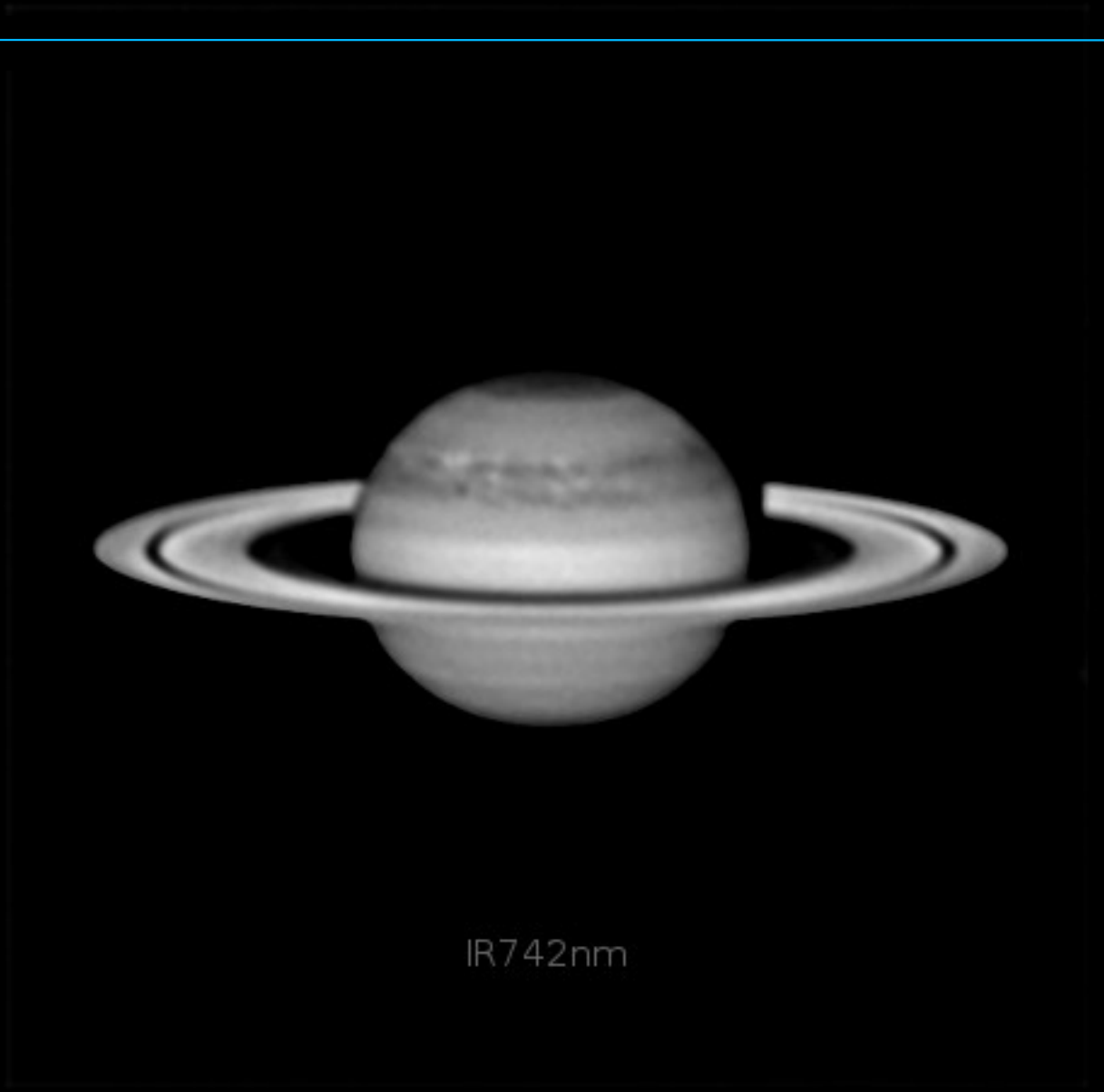
Saturn 30 Dec 2010 18:49.2 Z CMIII:287.8
Anthony Wesley, Murrumbateman Australia

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 >= 742nm
2nd March 2011

Colour detection and tracking

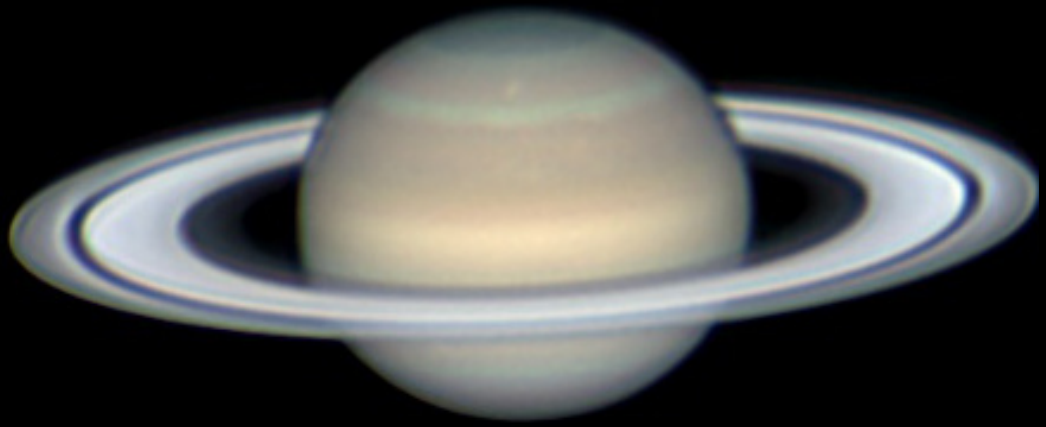
Colour is more difficult for amateurs due to uncalibrated cameras and processing techniques that favour feature detection above colour accuracy

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

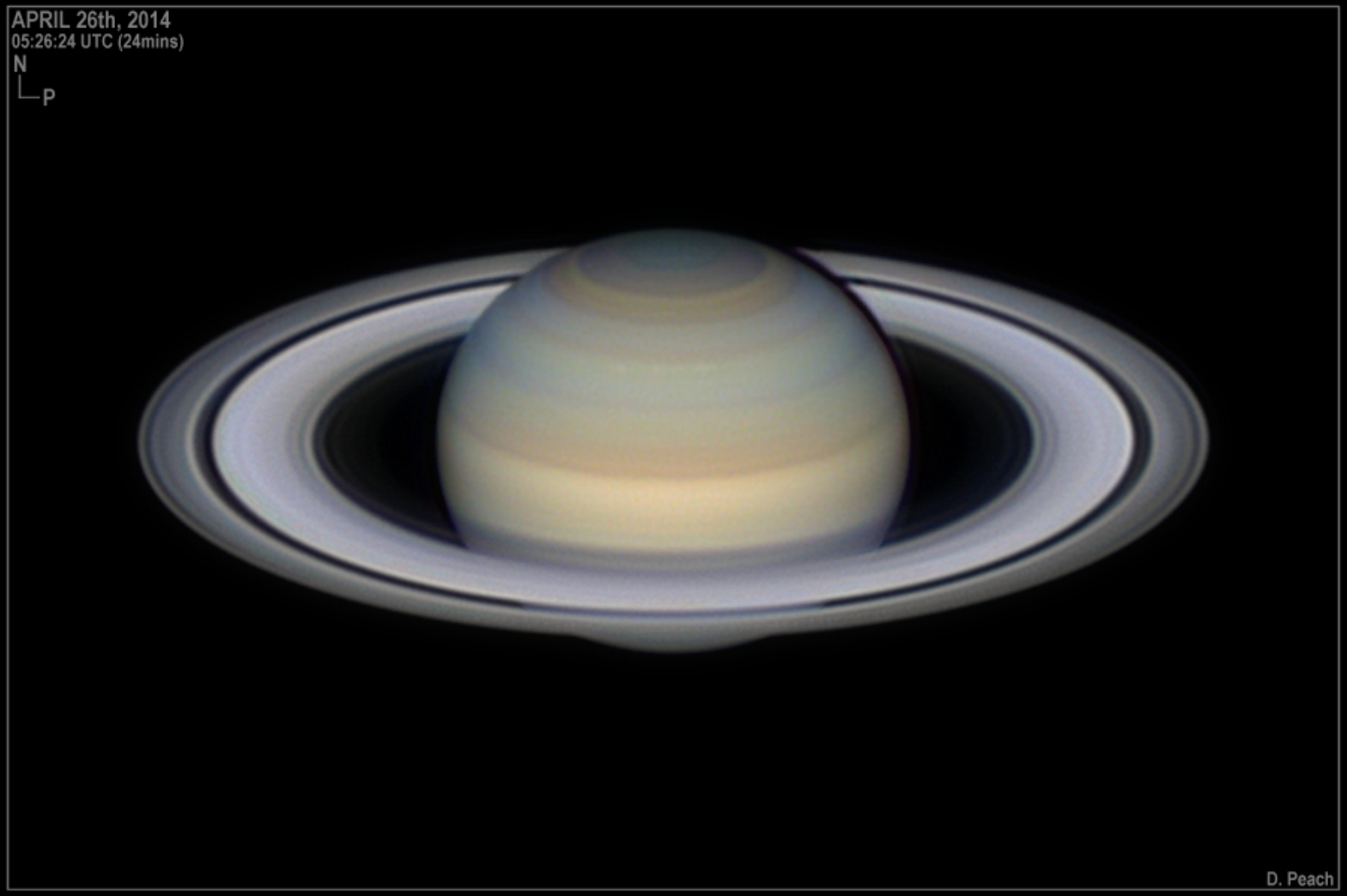
It's apparent that the polar region has undergone substantial colour changes over the period 2012 - 2014

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

Amateur Planetary Imaging

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

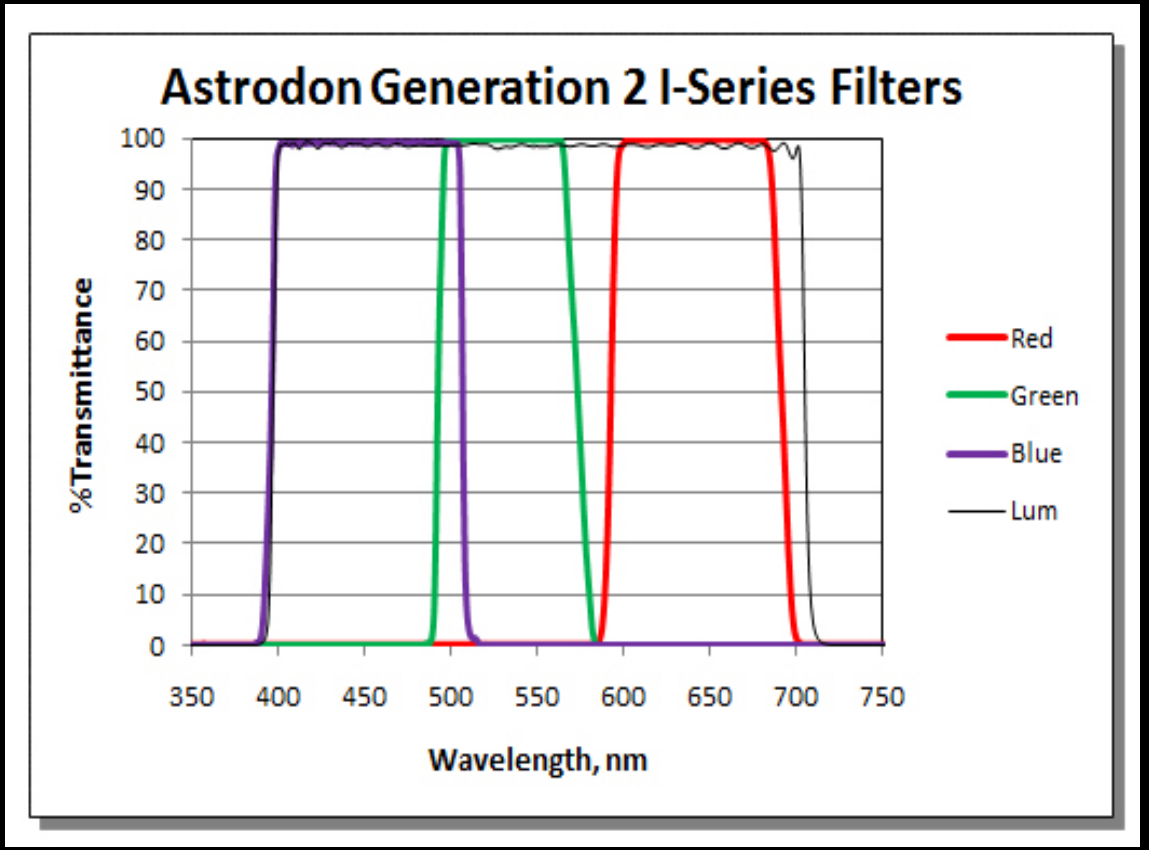
Anthony Wesley, Astronomical Society of Australia

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

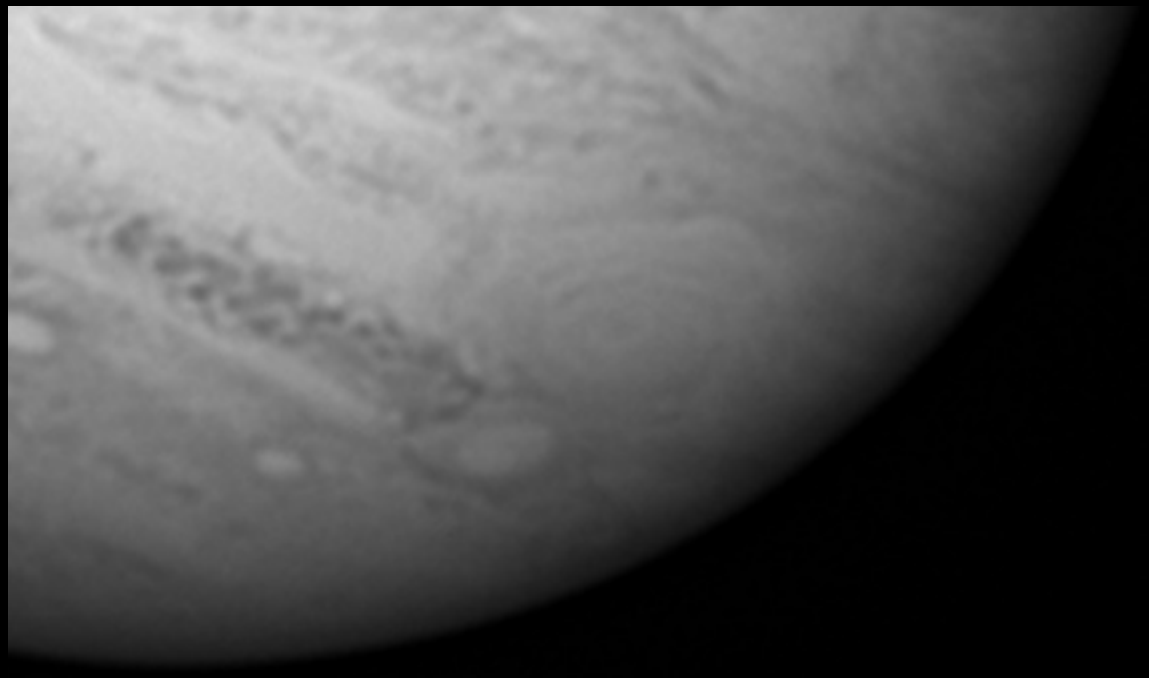
Note the thin green band at the northern edge of the SEB.

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

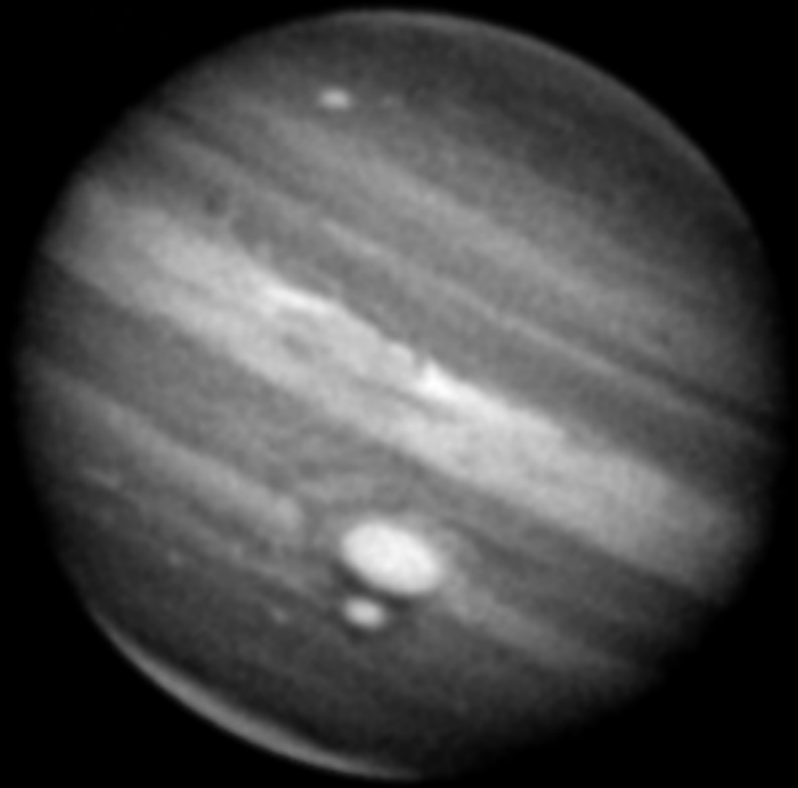
August 30 2010

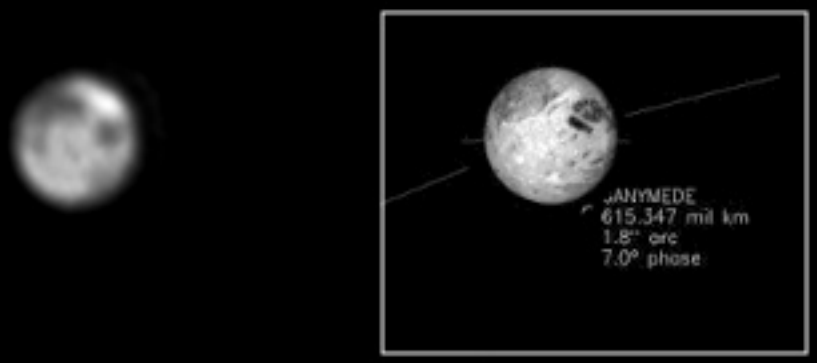
Anthony Wesley, Astronomical Society of Australia

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



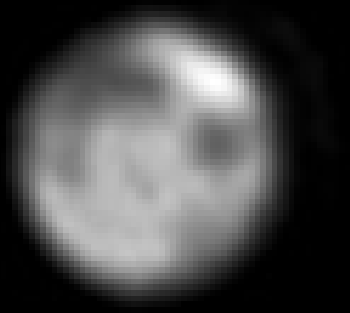
CH4 absorption image

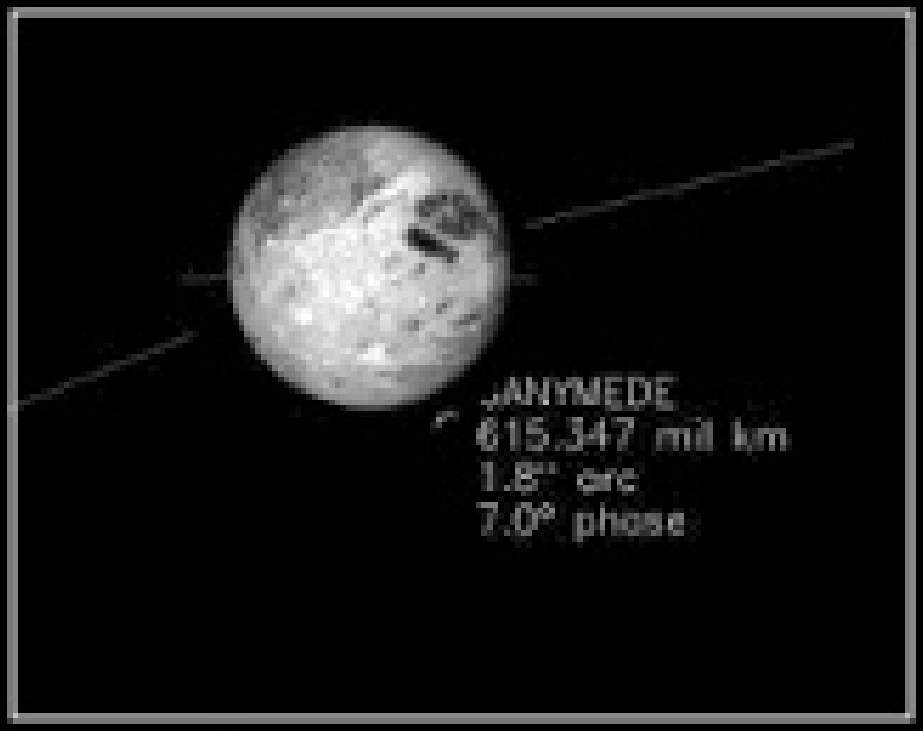




Ganymede and JPL simulator comparison

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




GANYMEDE
615.347 mil km
1.8" arc
7.0° phase

Impact detection -

July 2009

Asteroid impact
(est. 400m dia)

Visible impact debris
easily detected by
amateur class telescopes

SEB revival

November 2010

Easily detected by amateur Class telescopes

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)

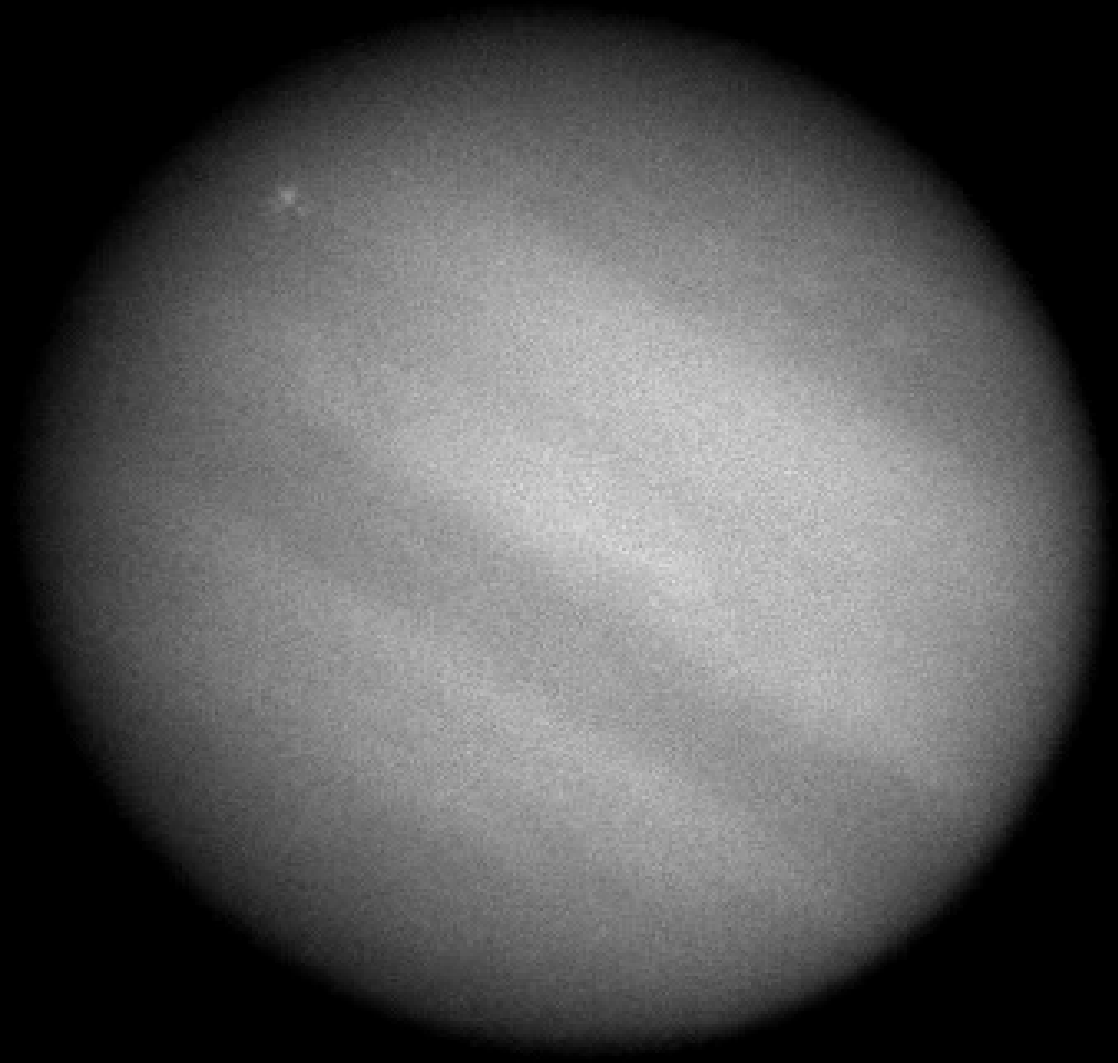
Anthony Wesley, Murrumbateman Australia
17 Nov 2010 10:34.1 Z CMI 34 CMII 297 CMIII 158

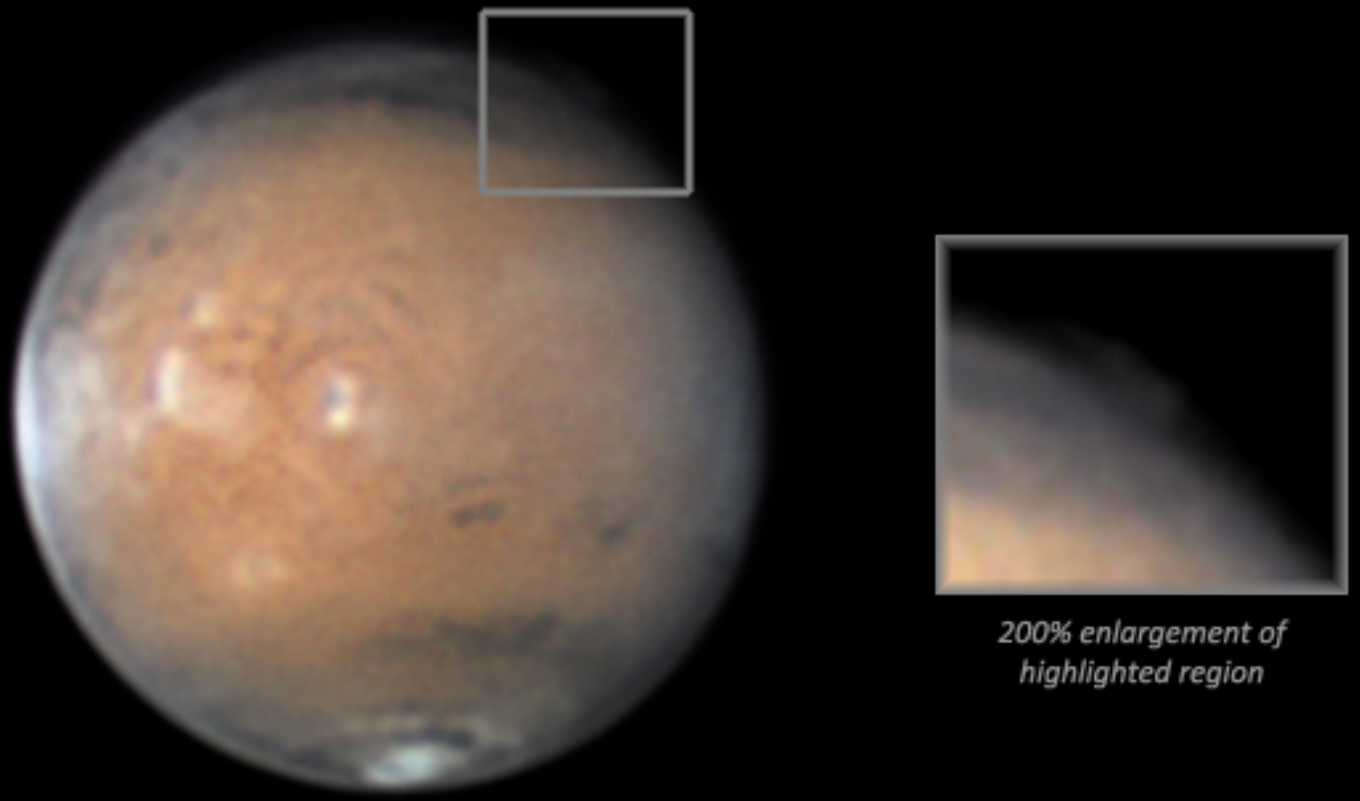
Bright visual fireball on Jupiter, June 2010

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

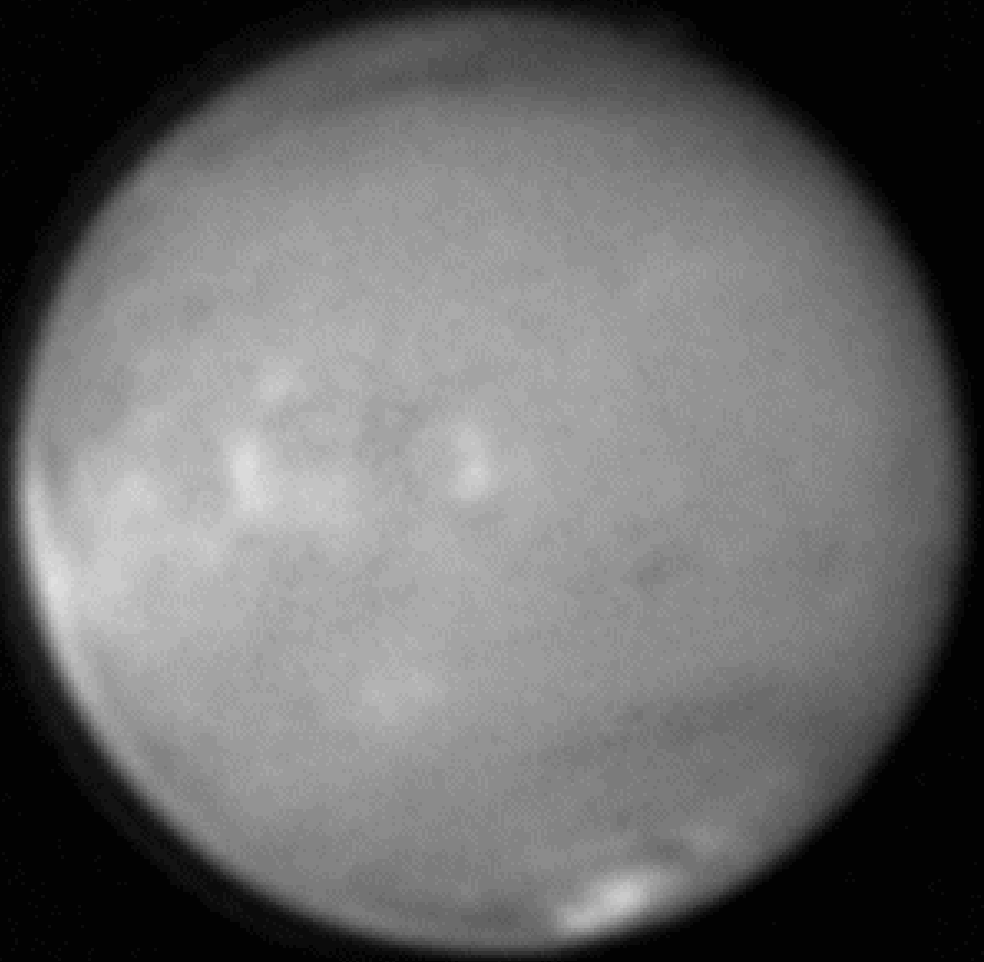




200% enlargement of highlighted region

Feature detection on Mars, 2012

Mystery Cloud on Mars / 19 March 2012 / Wayne Jaeschke



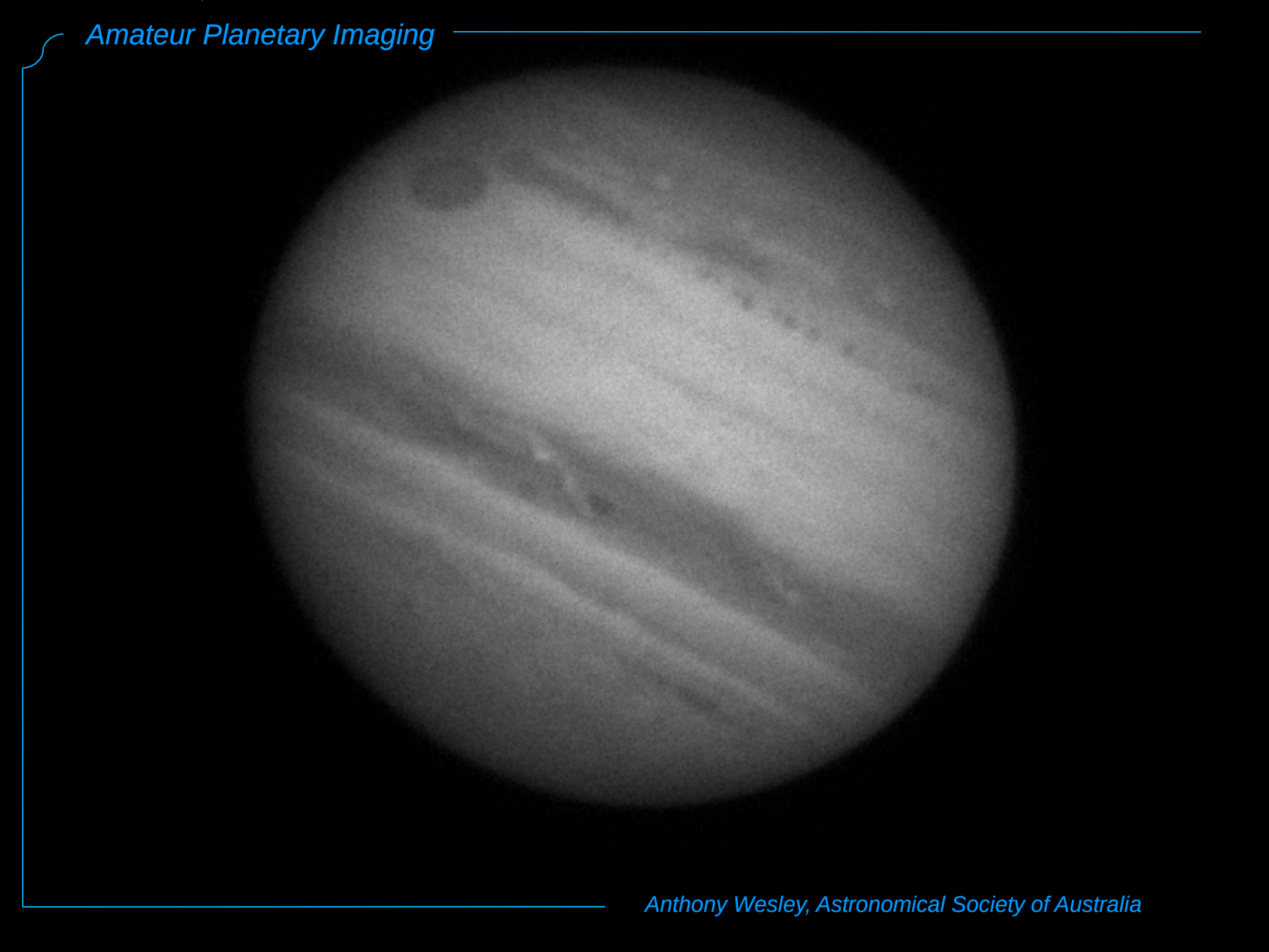
One again stop-frame animation is critical to clearly show this as a real feature.

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

October 2013

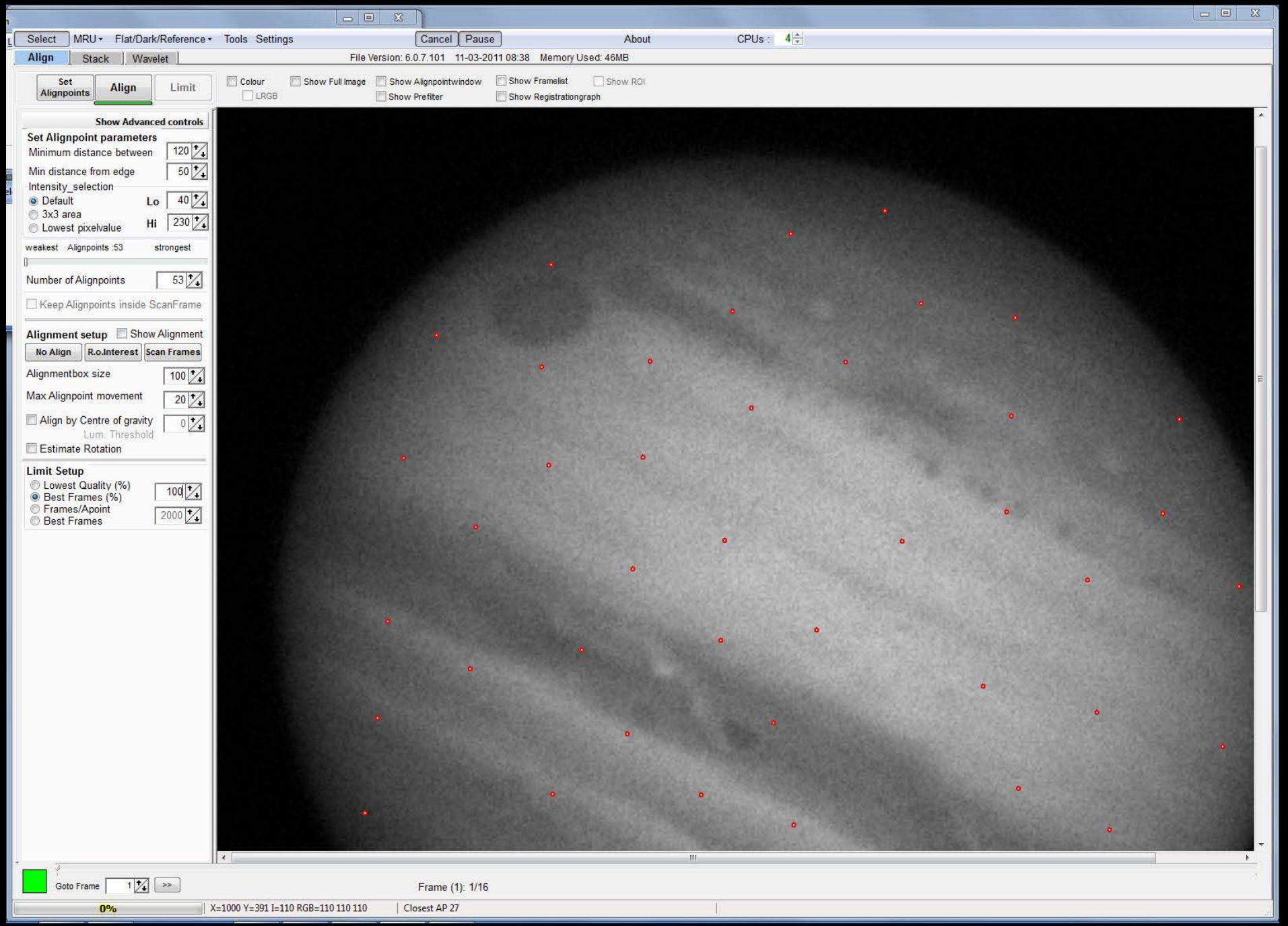
Amateur Planetary Imaging

Anthony Wesley, Astronomical Society of Australia



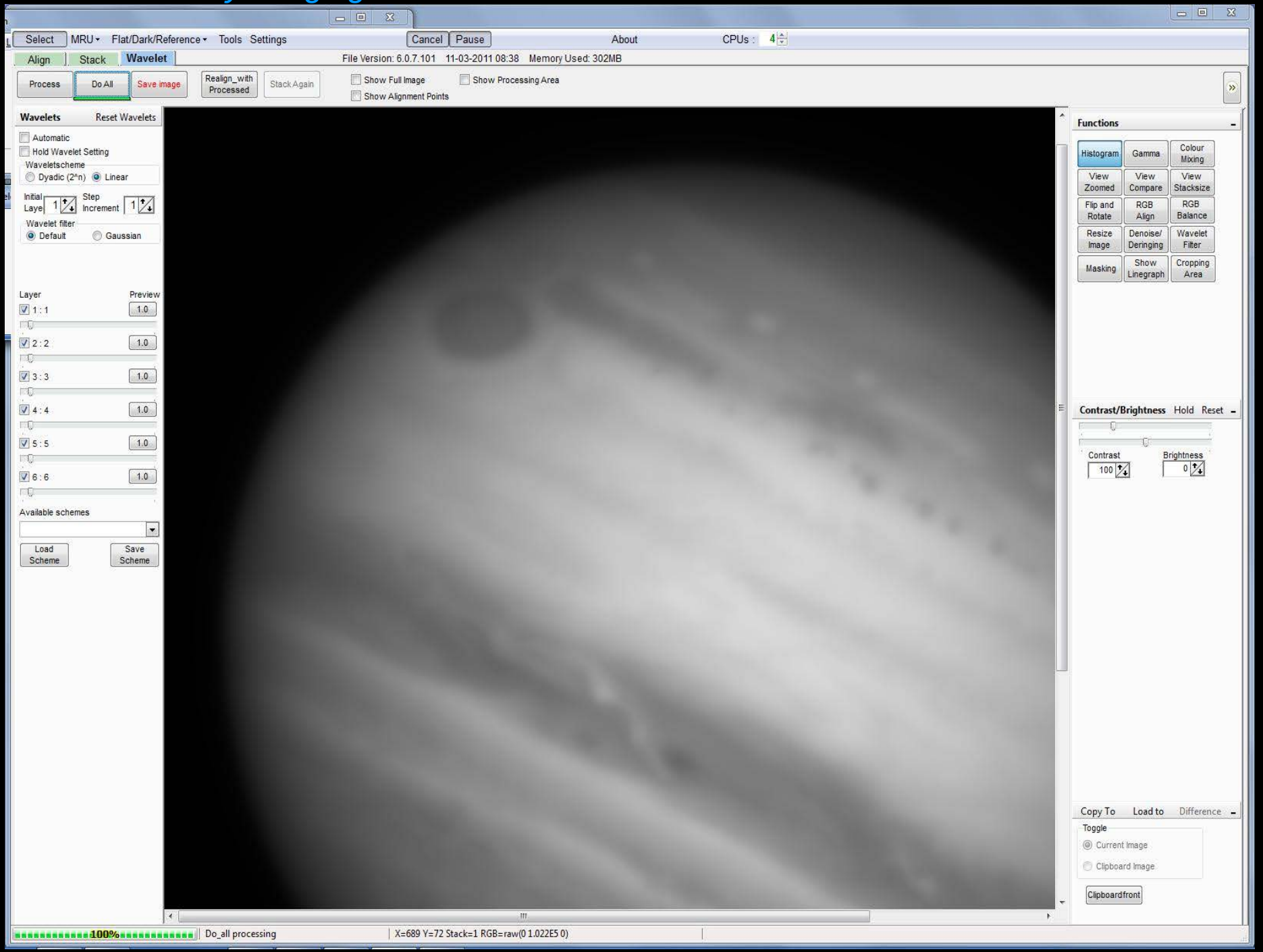
Anthony Wesley, Astronomical Society of Australia

Amateur Planetary Imaging



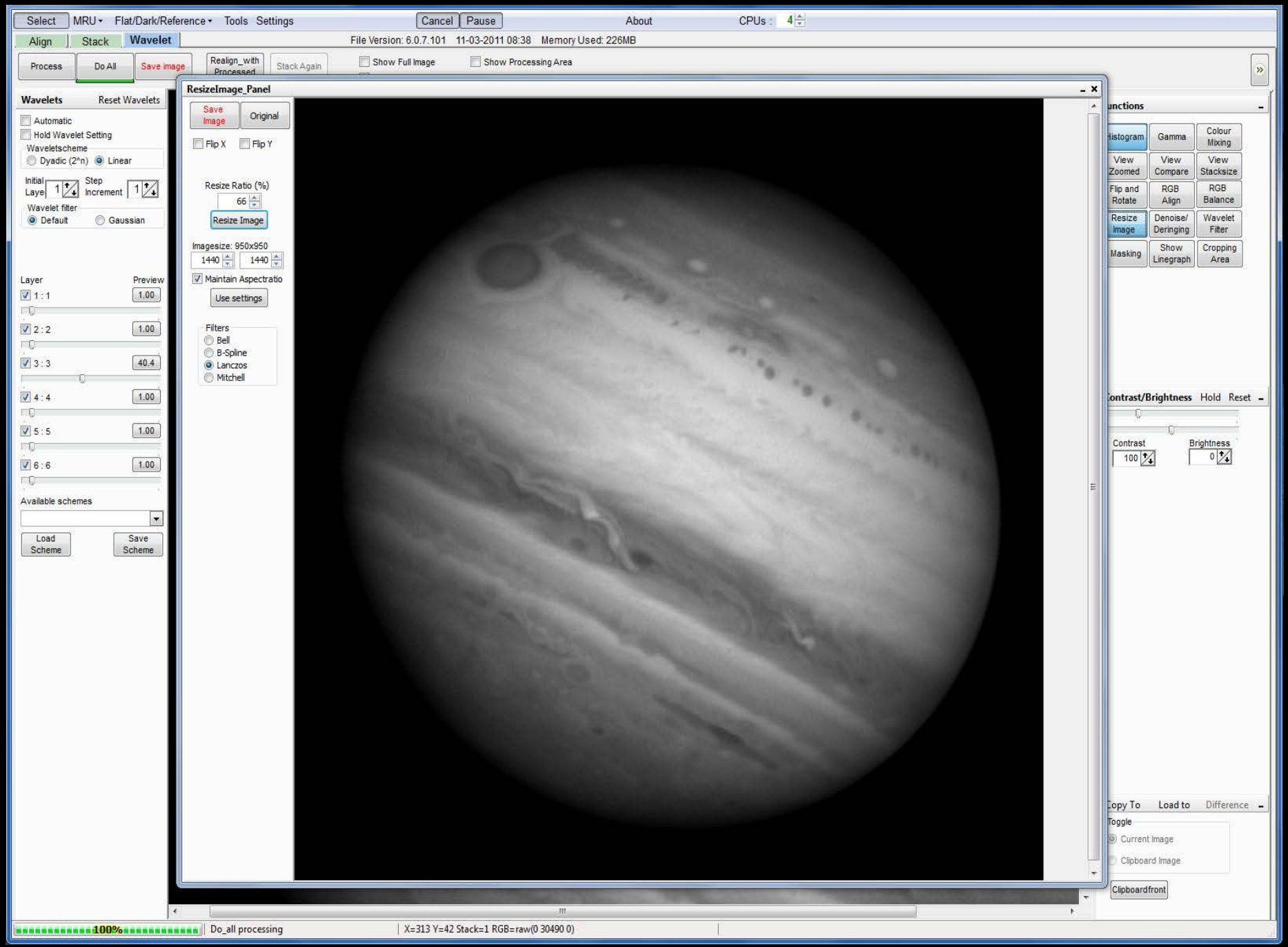
Anthony Wesley, Astronomical Society of Australia

Amateur Planetary Imaging



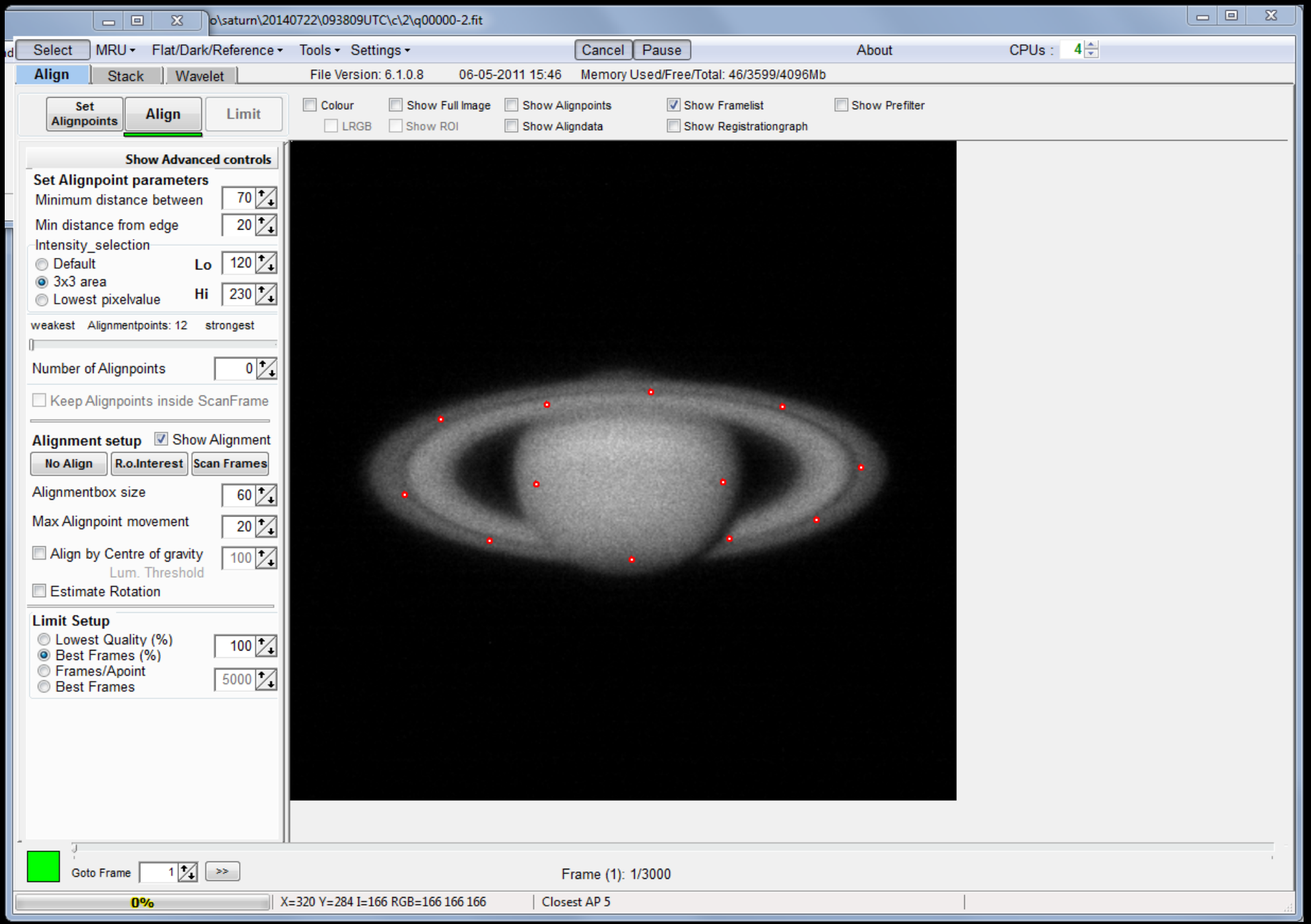
Anthony Wesley, Astronomical Society of Australia

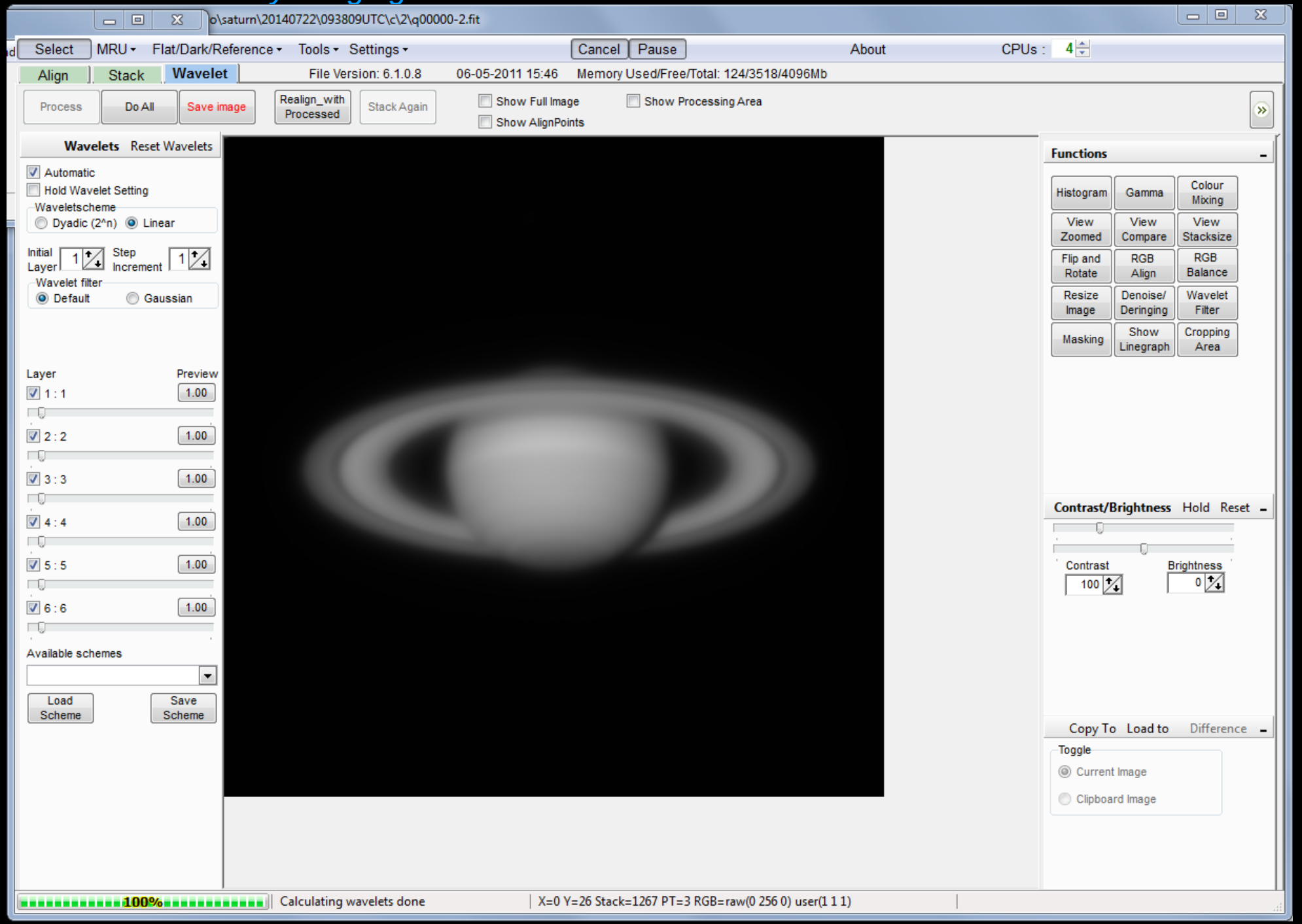
Amateur Planetary Imaging

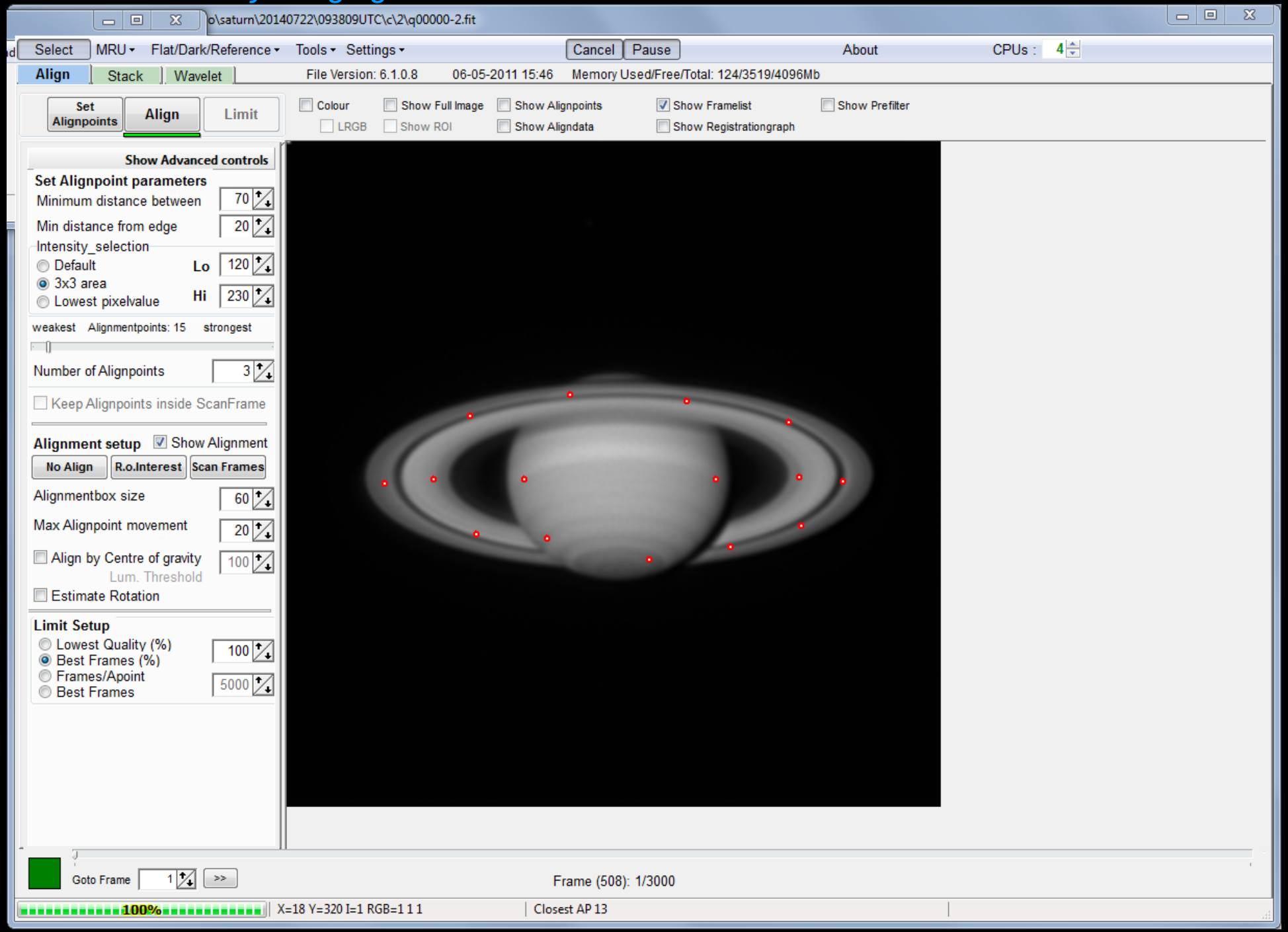


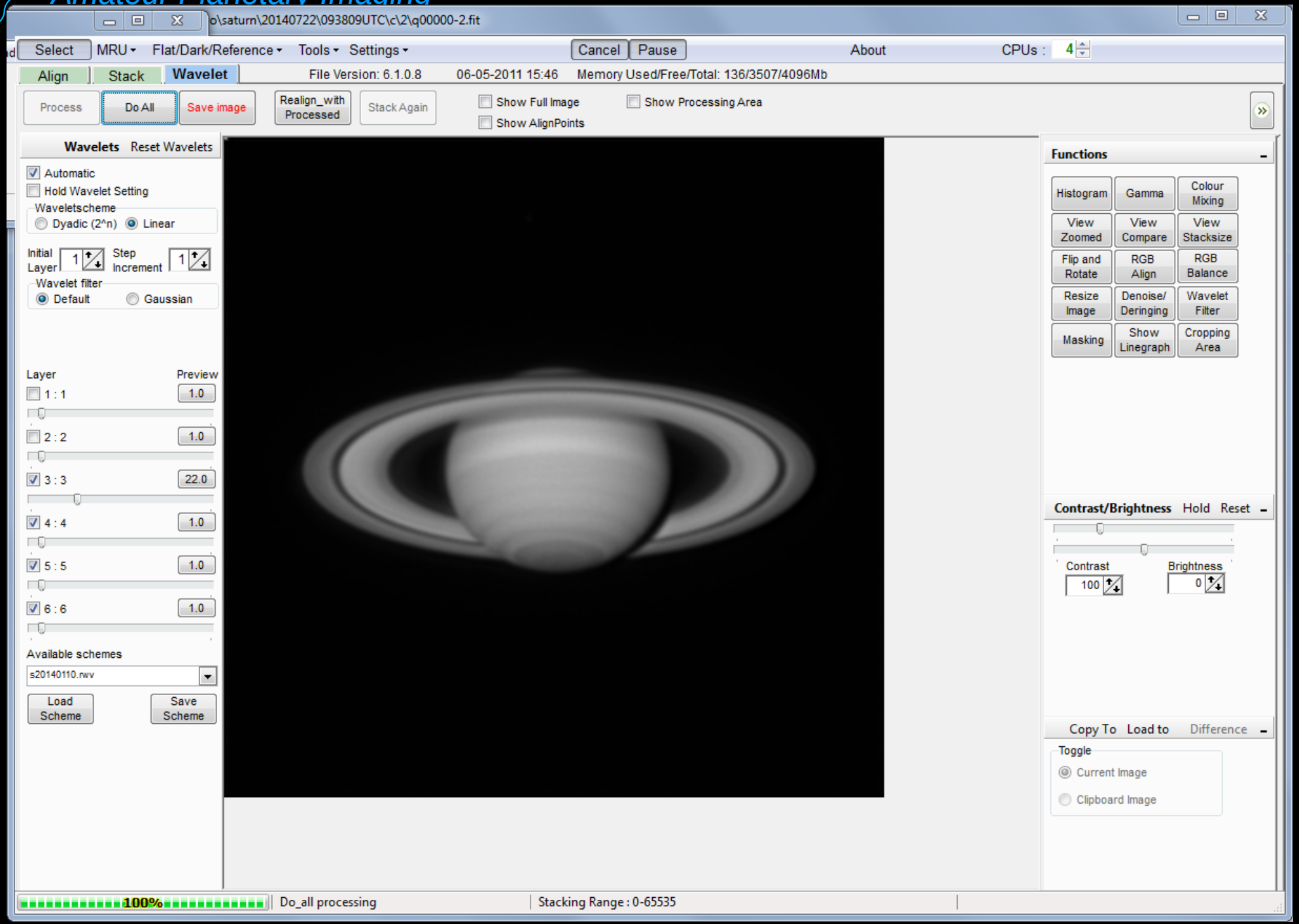
Anthony Wesley, Astronomical Society of Australia

Anthony Wesley, Astronomical Society of Australia

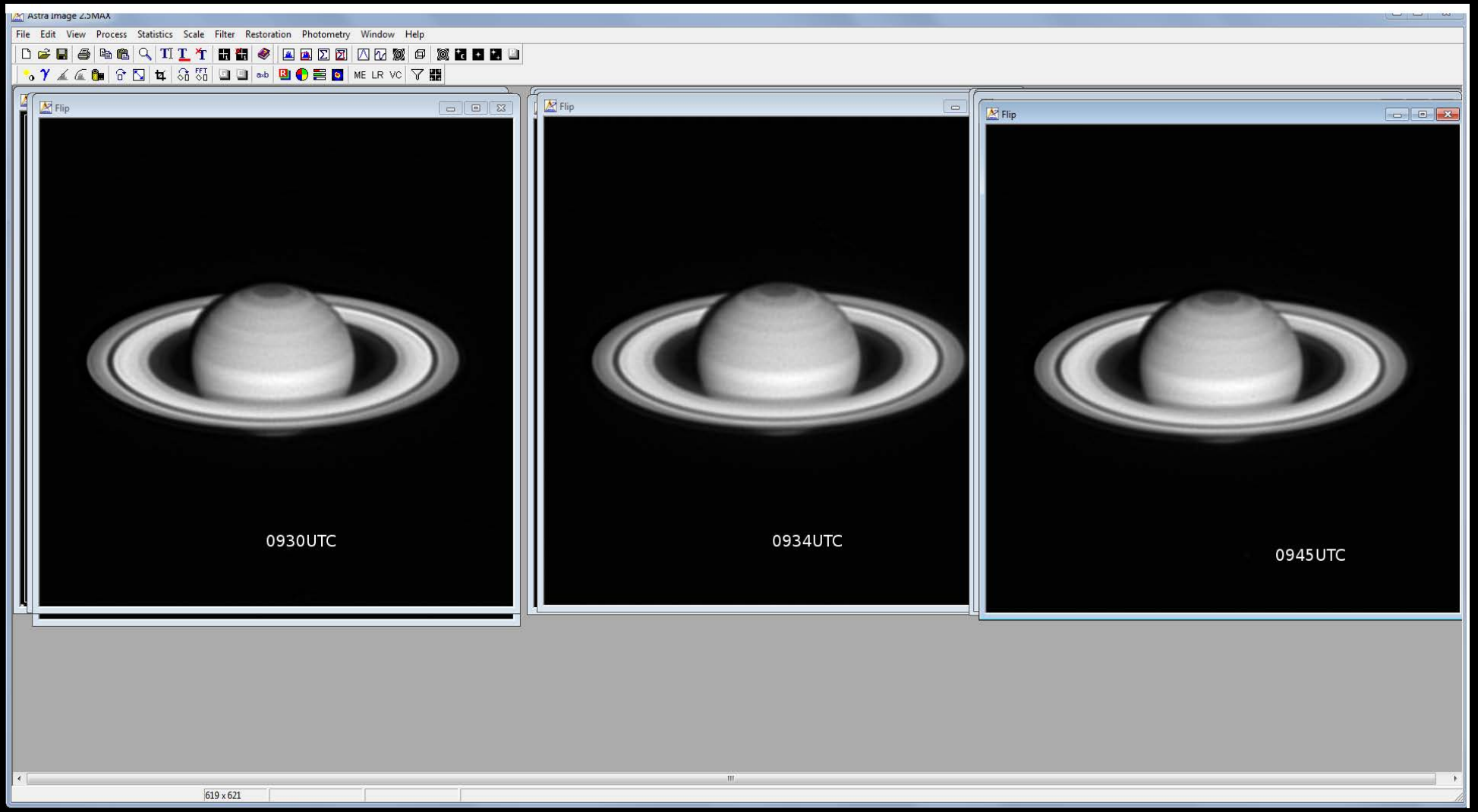

o\saturn\20140722\093809UTC\c\2\q00000-2.fit
Select
MRU
Flat/Dark/Reference
Tools
Settings
Cancel
Pause
About
CPUs : 4
Align
Stack
Wavelet
File Version: 6.1.0.8
06-05-2011 15:46
Memory Used/Free/Total: 46/3599/4096Mb
Set Alignpoints
Align
Limit
Colour
Show Full Image
Show Alignpoints
Show Framelist
Show 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
3x3 area
Lowest pixelvalue
Lo 120
Hi 230
weakest Alignmentpoints: 12 strongest
Number of Alignpoints 0
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 100
Lum. Threshold
Estimate Rotation
Limit Setup
Lowest Quality (%) 100
Best Frames (%)
Frames/Apoint 5000
Best Frames
Goto Frame 1
>>
Frame (1): 1/3000
0%
X=320 Y=284 I=166 RGB=166 166 166
Closest AP 5


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
Step Increment
Wavelet filter
Default
Gaussian
Layer
Preview
1 : 1
2 : 2
3 : 3
4 : 4
5 : 5
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
Brightness
100
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)


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: 124/3519/4096Mb
Set Alignpoints
Align
Limit
Colour
LRGB
Show Full Image
Show ROI
Show Alignpoints
Show Aligndata
Show Framelist
Show Registrationgraph
Show Prefilter
Show Advanced controls
Set Alignpoint parameters
Minimum distance between 70
Min distance from edge 20
Intensity_selection
Default
3x3 area
Lowest pixelvalue
Lo 120
Hi 230
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 100
Lum. Threshold
Estimate Rotation
Limit Setup
Lowest Quality (%) 100
Best Frames (%)
Frames/Apoint 5000
Best Frames
Goto Frame 1
>>
Frame (508): 1/3000
100%
X=18 Y=320 I=1 RGB=1 1 1
Closest AP 13


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: 136/3507/4096Mb
Process
Do All
Save image
Realign_with Processed
Stack Again
Show Full Image
Show AlignPoints
Show Processing Area
Wavelets
Reset Wavelets
Automatic
Hold Wavelet Setting
Waveletscheme
Dyadic (2^n)
Linear
Initial Layer
Step Increment
Wavelet filter
Default
Gaussian
Layer
Preview
1 : 1
2 : 2
3 : 3
4 : 4
5 : 5
6 : 6
1.0
22.0
Available schemes
s20140110.rwv
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%
Do_all processing
Stacking Range : 0-65535

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



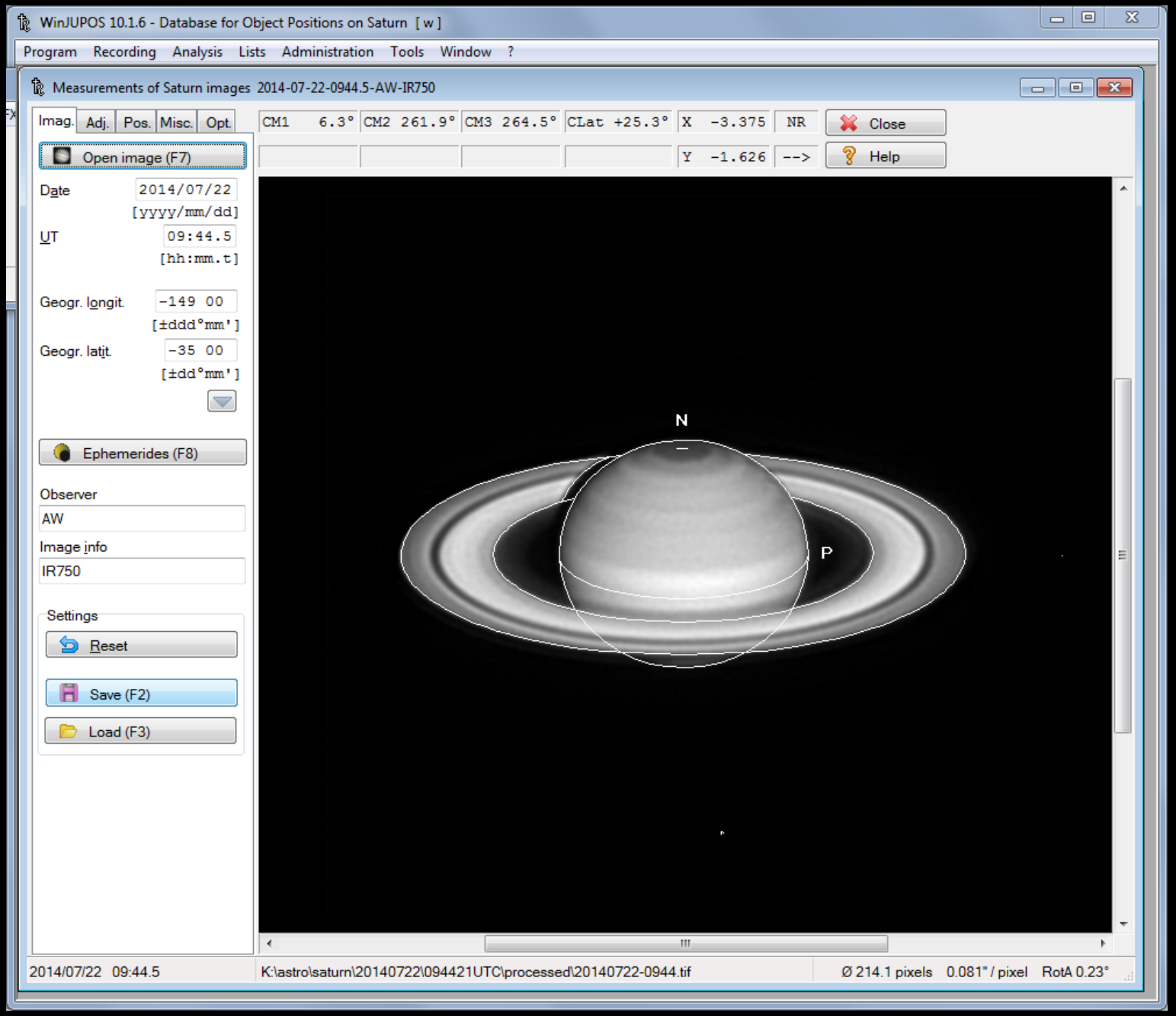
Using WinJupos to merge images with derotation

Start with
Image measurement

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

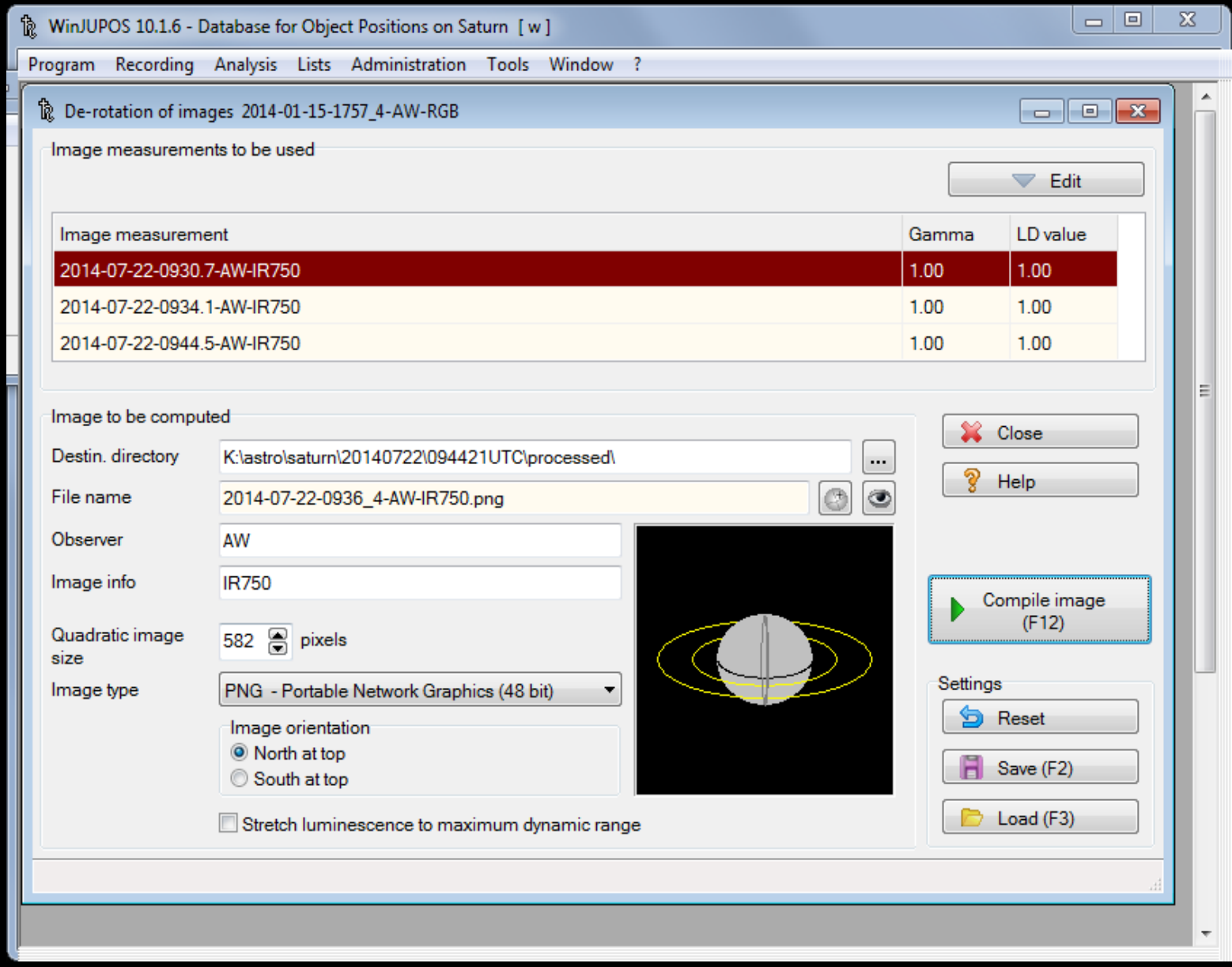
Moons are also
shown on the
template, as is
any phase or
shadows

e.g. ring shadow



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

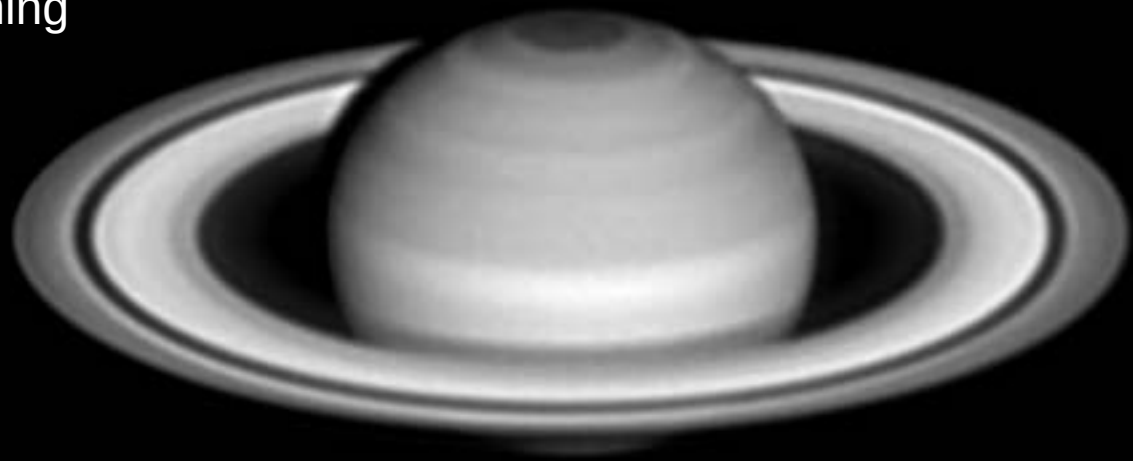
Eg here we have 3 images with a midpoint time of 0936.4 UTC



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

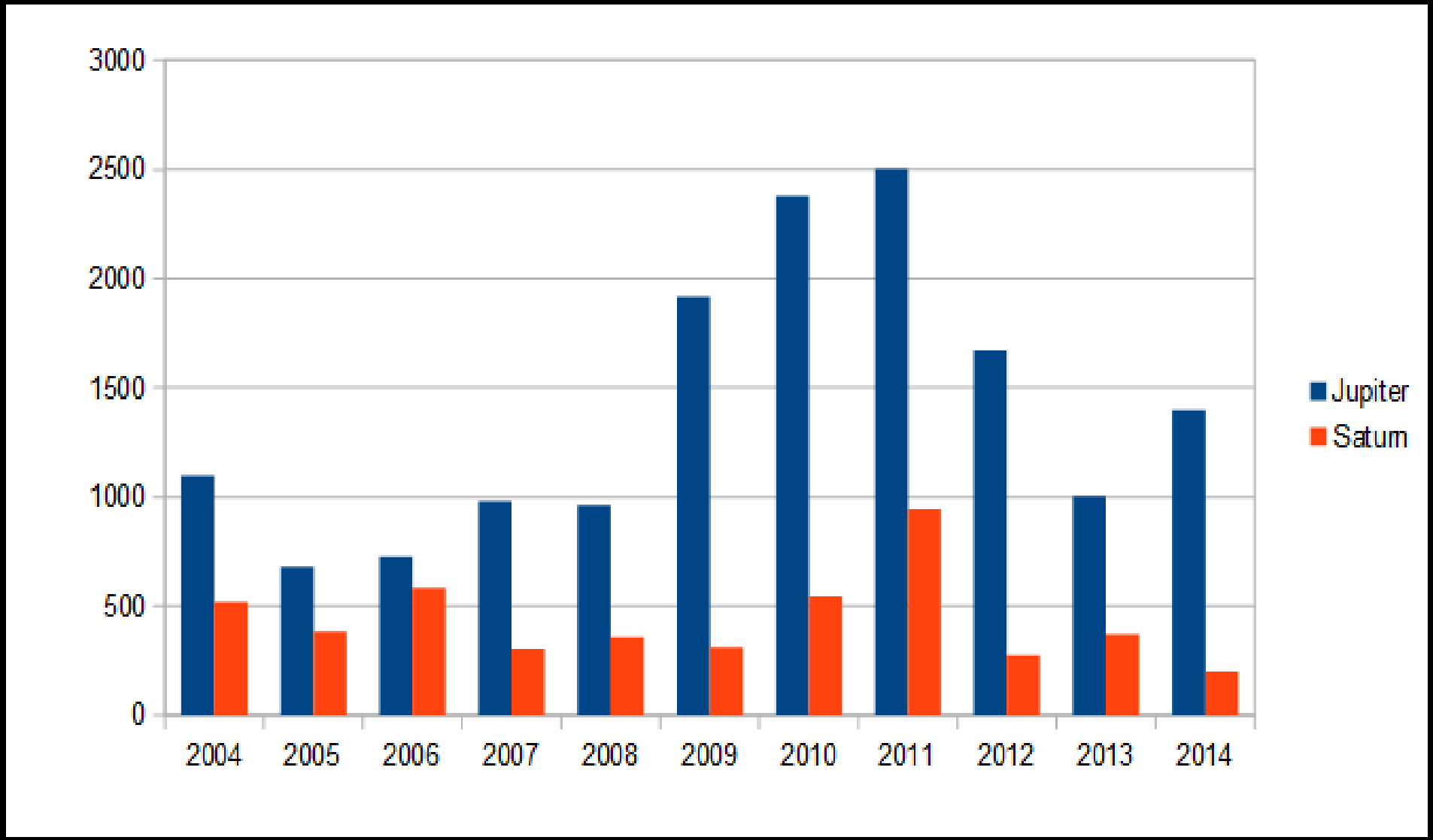
Future Software

- 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.

Amateur Planetary Imaging

Anthony Wesley, Astronomical Society of Australia

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.