SDSO 1 - Blog

The Andromeda galaxy, also known as Messier 31, is a galaxy in the constellation Andromeda, lying at a distance of roughly 2.5 million lightyears, making it the closest (non-satellite) galaxy to our Milky Way. Its proximity to our Milky Way and sheer size made it invaluable in building our understanding of galaxies and galactic evolution. Until recently M31 was best known for its large size and brightness in the night sky - that was until the discovery of SDSO 1 in 2021, a massive, seemingly random, patch of [OIII] right next to M31. Amongst amateur astrophotographers and astrophysicists alike, this sparked immense interest and led to various possible explanations for SDSO 1's origin. While some suggested it being an intergalactic shock between the Milky Way and M31, others favoured a galactic origin, along the line of sight of M31.

Having obtained a new wide and deep image of M31, we present strong evidence that solves this mystery. Putting together many lines of evidence, including identification of the central star, we conclude that SDSO 1 is a shock wave in the Milky Way, driven by an invisible planetary nebula moving at Mach 7 relative to the surrounding gas. In addition to the shock wave, we find that the surrounding waves of Halpha emission are not just ordinary Hα cirrus, but are actually formed from gas that is driven off of the planetary nebula, leaving a trail in its wake and giving crucial information on its age. SDSO1 is the first recognized member of a new class of faded planetary nebulae that we have dubbed, "Ghost planetary nebulae" or GPNe. These GPNe are identified at a very late stage where they are slowing their outward expansion and becoming too tenuous and faint to see if it were not for the shock wave and tail.

Starting in December of 2024, our team, composed of members of the Deep Sky Collective, the Polaris Imaging Group, the initial discoverers Marcel D., Xavier S. and Yann S. and our leading researcher Patrick Ogle came together to solve this mystery.

Patrick O., working closely together with the Polaris Imaging group, with lead photographer Mark P. and observatory director Michael R., started photographing M31 in late 2024. Although they already had a lot of data up their sleeves, Patrick wanted to go bigger - why not combine existing, high quality efforts into one dataset and create the deepest, most detailed image of M31 yet? With that idea in mind, the collaboration with the DSC and Marcel D., Xavier S. and Yann S. started. The Deep Sky Collective, which had released a close-up version of M31 in March of '24, contributed its deep widefield datasets from Tarun K., Patrick S. and Sendhil C.. Moreover, our extensive knowledge about coordination and pre- and post-processing, contributed to by Tim S., Carl B. and Steeve B. respectively, would turn out to be of significant use. Finally, Yann S. et al. contributed their original dataset, adding even more exposure time to the project.

In the end, we managed to create a stunning 525h total exposure time image. Note that 312h+ of this consists of [O III], and about 184h in Ha, with the rest found in RGB. All of the data was shot from Bortle 1 - 2 zones, using Takahashi FSQ 106 telescopes running at either an f/3.0 or f/3.6 configuration.

Before getting into any further details, I want to thank everybody who contributed to this project. As always, it was a real pleasure working together with everybody, and we hope that this project sparks significant interest in both the scientific and astrophotographer community.

Science Team

Dr. Patrick Ogle - Scientist (STScl)
Dr. Lewis McCallum - Scientist (St. Andrews)
Dr. Alberto Noriega-Crespo - Scientist (STScI)
Dr. R. Michael Rich - Scientist (UCLA), Polaris Imaging observatory director
Dr. Biny Sebastian - Scientist (STScI)

The Polaris Imaging Group

Mark Petersen - Lead photographer

The Deep Sky Collective

Tim Schaeffer - Coordination
Carl Björk - Pre processing
Steeve Body - Post processing
Tarun Kottary - Photographer
Patrick Sparkman - Photographer
Sendhil Chinnasamy - Photographer

Initial Discoverers

Yann Sainty - Photographer
Marcel Drechsler
Xavier Strottner

Special thanks to:

- *Patrick*, for his amazing research lead and all his explanations along the way.
- *Carl*, who stacked all of our data and who spent countless hours on fixing joint issues and developing a script to tackle our issues.
- *Steeve*, for the outstanding edit you see today.

Key take-aways from the research paper

Having obtained a new wide and deep image of M31, we present strong evidence that solves this mystery. Putting together many lines of evidence, including identification of the central star, we conclude that SDSO 1 is a shock wave in the Milky Way, driven by an invisible planetary nebula moving at Mach 7 relative to the surrounding gas. In addition to the shock wave, we find that the surrounding waves of Halpha emission are not just ordinary Hα cirrus, but are actually formed from gas that is driven off of the planetary nebula, leaving a trail in its wake and giving crucial information on its age. SDSO1 is the first recognized member of a new class of faded planetary nebulae that we have dubbed, "Ghost planetary nebulae" or GPNe. These GPNe are identified at a very late stage where they are slowing their outward expansion and becoming too tenuous and faint to see if it were not for the shock wave and tail.

The central star, EG Andromedae (EG And), is a symbiotic white dwarf binary - a white dwarf that is orbiting close to a red giant. It is the second brightest UV-emitting star in the region, after the unassociated star nu And. Using parallax and proper motion measurements obtained from ESA's Gaia satellite, we know the exact distance and relative speed of EG And. Spectroscopic observations also tell us its Doppler velocity along the line of sight. Together, this gives a stellar velocity of 107 km/s through the surrounding gas, enough to drive a shock that emits strongly in the [O III] 500 nm line.

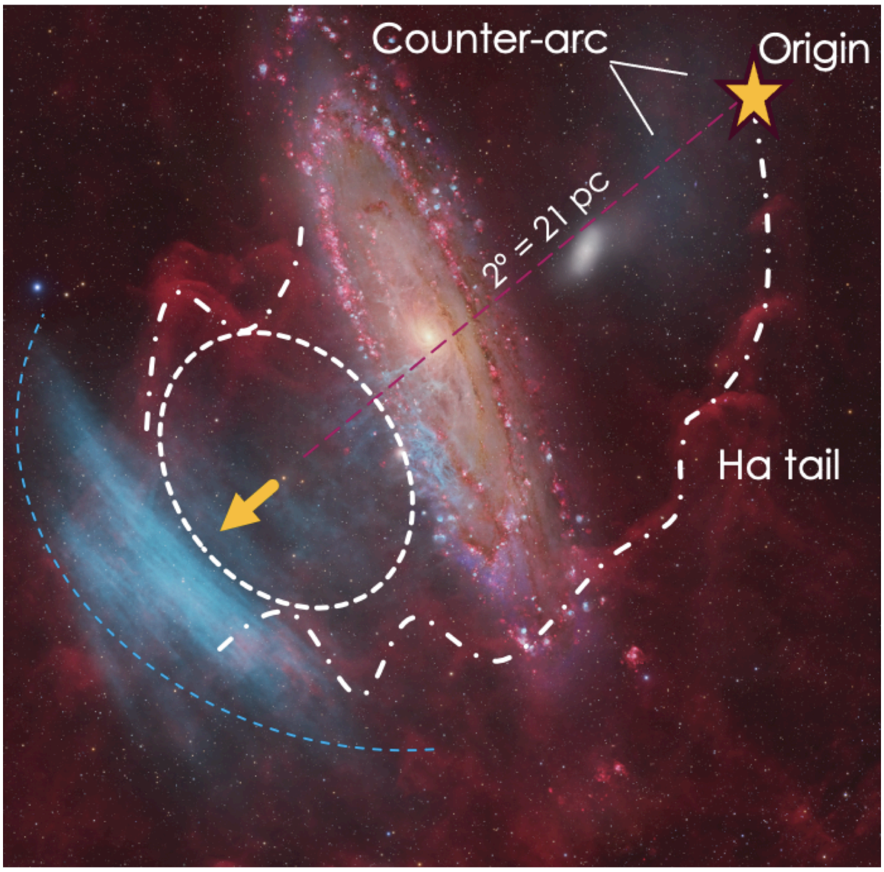
But one question remains: how do we observe something considered invisible? The shell of the ghost planetary nebula is invisible because it has expanded to such a great diameter (20 pc) and has become so tenuous that it cannot be captured with existing telescopes. Gas that is shocked by the planetary nebula as it speeds through the Milky Way is compressed and heated to 100,000 K, a temperature that causes oxygen to glow strongly in the [O III] line, the strongest emission from SDSO 1. Turbulence at the interface between the bow shock and the planetary nebula shell causes gas to be lifted and ablated from the shell, leaving a comet-like tail of gas. In fact, there are two tails, an Halpha tail driven off of the front of the shell, and an [O III] tail, consisting of shock-heated gas that is dragged along behind the planetary nebula in its wake. The latter may be seen as a series of 'jets' that appear to be launching from M31, but in fact are most likely trailing behind SDSO 1.

For a more detailed breakdown of how we identified SDSO 1 as a GPN, please refer to our research paper.

Interesting features in our image

SDSO 1 - a part of a Ghost Planetary Nebula

The star of the show - SDSO 1. Discovered in 2021 by Yann S. et al, this obscure [O III] nebula has now been identified as the first of its kind Ghost Planetary Nebula (GPN). With this new dataset our team is able to show the true extent and morphology of SDSO 1. Moreover, as noted earlier, turbulence at the interface between the bow shock and the planetary nebula shell lifts and ablates gas, forming a comet-like tail. In this case, the faint [O III] emission observed between SDSO 1 and M31 corresponds to such a tail, consisting of shock-heated gas trailing behind the nebula. Importantly, M31 is not physically associated with this emission—it merely lies along the same line of sight. Similarly, the brightest Ha emissions in the region are formed from gas that is driven off of the shell of the planetary nebula, leaving a trail in its wake.
Finally, a tenuous [O III] signal was identified to the west of M31, right next to M110. We suggest this emission traces back to the SDSO 1 shock or tail, near the nebula's point of origin.
For a more detailed analysis of these emissions associated with the GPN, please refer to the research paper.



A visual representation of the GPN associated with SDSO 1
Reproduced from Ogle et al. (2025)

Pre-Processing techniques applied

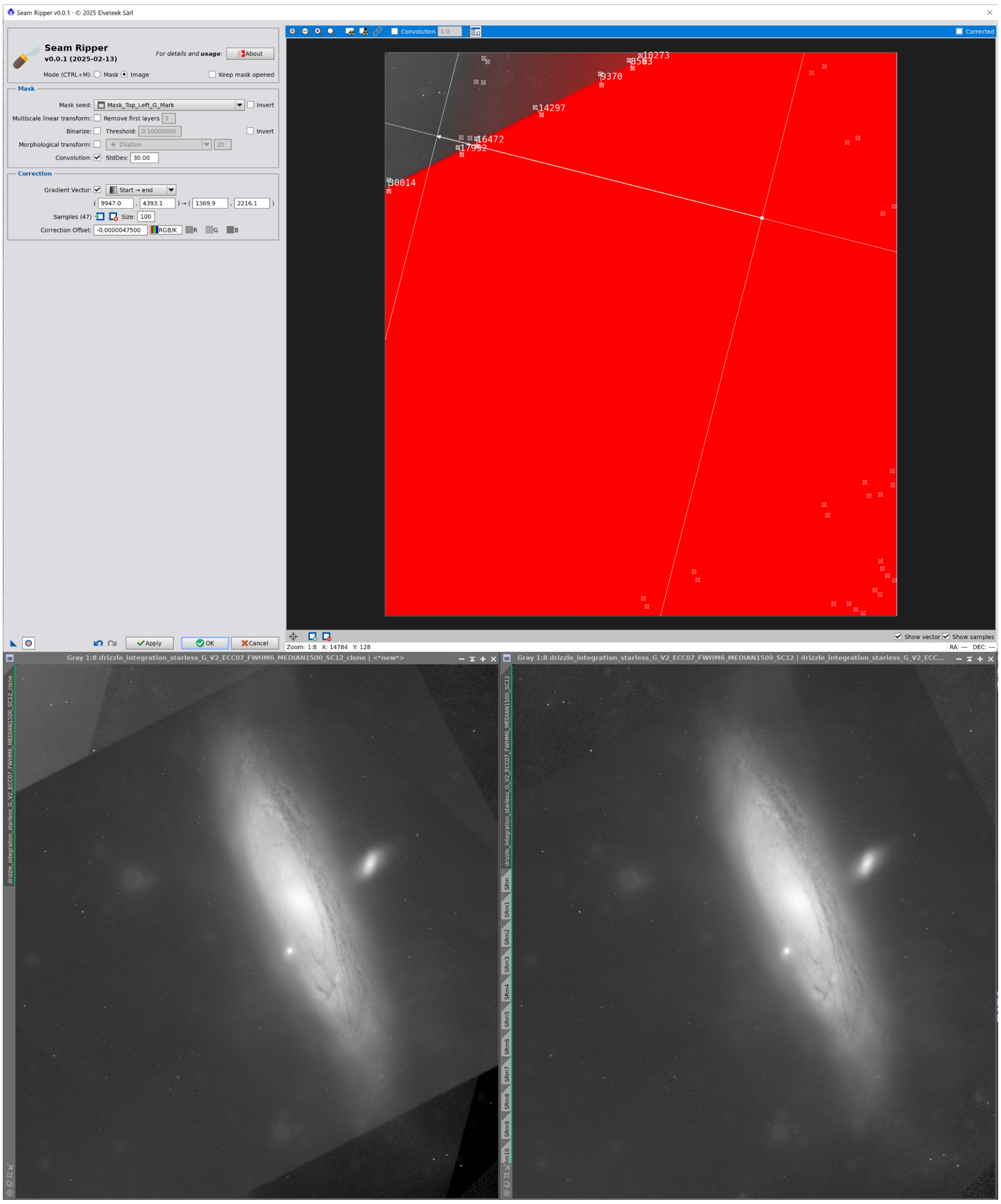
Seam ripping

Unlike collaborative projects such as those from the DSC, this project was initiated only after all data had already been captured, and therefore lacked a coordinated framing of the object of interest. With contributions from five different astrophotographers, the dataset included overlapping fields of view, which resulted in visible, undesired seams between them. While this wouldn't pose a problem for most projects since the FOV can be cropped down to exclude any seams, this project strictly required the full FOV, leading to a problem: How do we neutralise seams in the final stack?

In an attempt to solve this problem, Carl B. developed a script tackling this problem. The first step was a proof of concept, where each field of view was drizzled separately, resulting in drizzle weights files that accurately characterised each FOV. These drizzle weights were subsequently converted into masks using Multiscale Linear Transformation (removing the first three layers) and then binarized. Morphological Transformation was then applied to the masks as needed - using either dilation or erosion - to selectively grow or shrink masked regions. Finally, as the various fields of views have gradual edges, a Convolution is applied that allows the seam to disappear completely, eliminating any residual edge lines.

In the next step, PixelMath and a field-of-view mask were used to apply a linear offset to the image. However, since some fields were not perfectly flat, corrective equations were introduced to apply a gradual adjustment in a specified direction. These equations and directions were calculated individually for each field of view.

As this approach proved to be useful, a fully featured PixInsight script was developed:
DSC Processing Suite > SeamRipper
SeamRipper allows users to produce masks and/or apply a correction to an image. It features all the operations mentioned above and adds a rich graphical user interface allowing to draw/move/resize/rotate a vector that represents the gradient direction. Additionally, samples can be added to the image allowing to visualize the effectiveness of a correction. As samples are computationally intensive, only samples affected by a correction are shown - this is achieved by identifying affected samples and linking them to the closest unaffected sample. This in turn allows to display the difference in median between two samples as well as allowing to color them - green for acceptable differences, red for undercorrection and finally white for overcorrection)
Note that the changes are marginal, typically lying in the 10e-6 to 10e-8 range, such that a 32bit representation of the median is required to see a change in value.
SeamRipper is expected to be publicly released in August.



Illustrations showing the application of Seam Ripper - © Carl Björk

Continuum Subtraction

To achieve ideal continuum subtraction in the [O III] band, Patrick O. wrote a Python script which we call Color Continuum Subtraction (CCS), to better estimate the [O III] band continuum by logarithmically interpolating the continuum between the B and G bands in each pixel of our images.
For further information about CCS, please refer to page 5 of the research paper.

For any further questions about the project, feel free to leave a reach out to us.

If you want to see our image in greater detail, feel free to go to our website gallery, where the image is uploaded in full resolution (13496 × 14954 px), enabling you to explore the picture by yourself and being able to zoom in on every tiny detail!

Integration overview

The final integration count, from only 5 photographers is:

Filter		Integration time	Count	
[O III]	:	312h50m	[1142]	
Ha	:	184h35m	[932]	(Science stack: 148h05m [713])
R	:	15h48m	[315]	
G	:	14h32m	[301]	
B	:	27h34m	[652]	

TOT: 555h19m [3342]

Per Contributor:		Integration time	Count
Mark P.	:	249h14m	[1457]
Tarun K.	:	120h10m	[773]
Patrick S.	:	116h00m	[745]
Yann S.	:	36h30m	[219]
Sendhil C.	:	33h25m	[148]

TOT: 555h19m

A massive thank you to everyone's efforts!

We hope that you enjoy this image!

Text written by Tim Schaeffer, co-ordinator of the project and fact checked & proofread by the team.