Deepsky Widefield Mosaics

The Fundamentals of Going Deeper, Wider and Larger

Gabriel Rodrigues Santos

CEDIC ‘24, Linz, Austria, 24 March 2024

Building the Puzzle

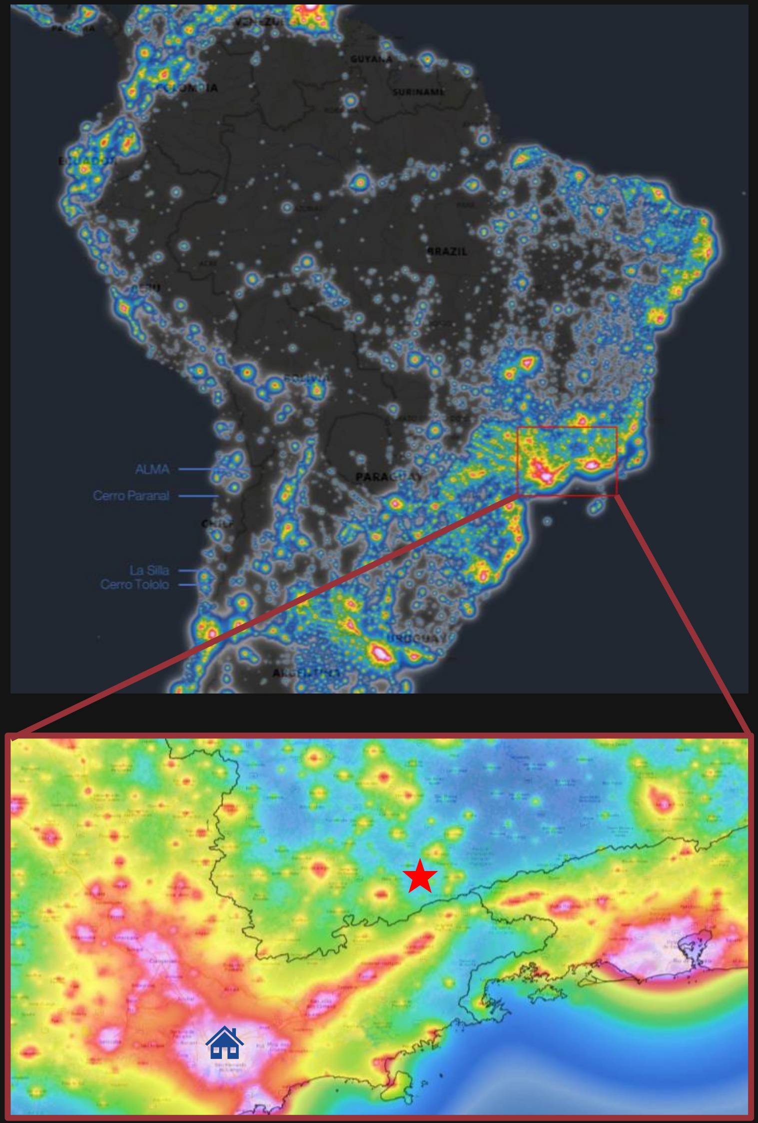
Strategies not to get crazy while making mosaics

Gabriel Rodrigues Santos

CEDIC ‘24, Linz, Austria, 24 March 2024

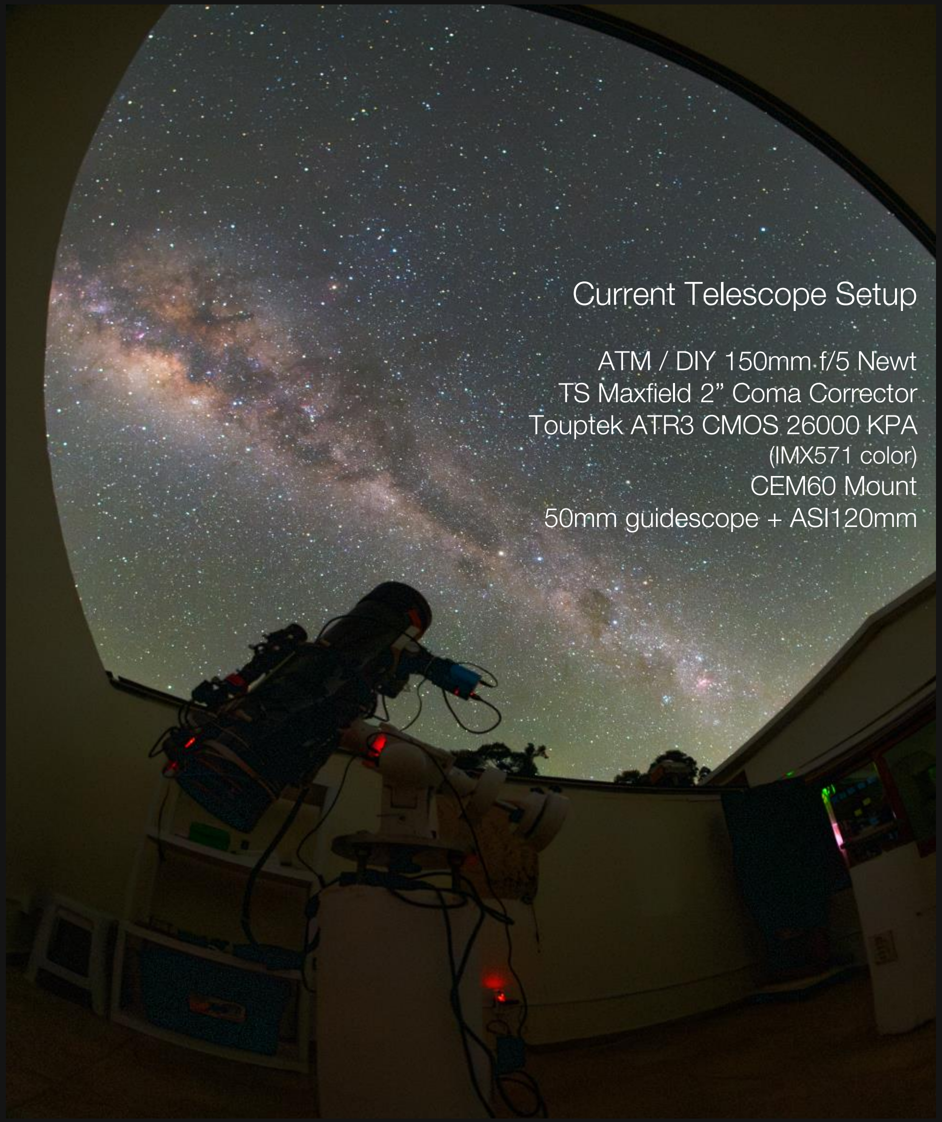
Who am I?

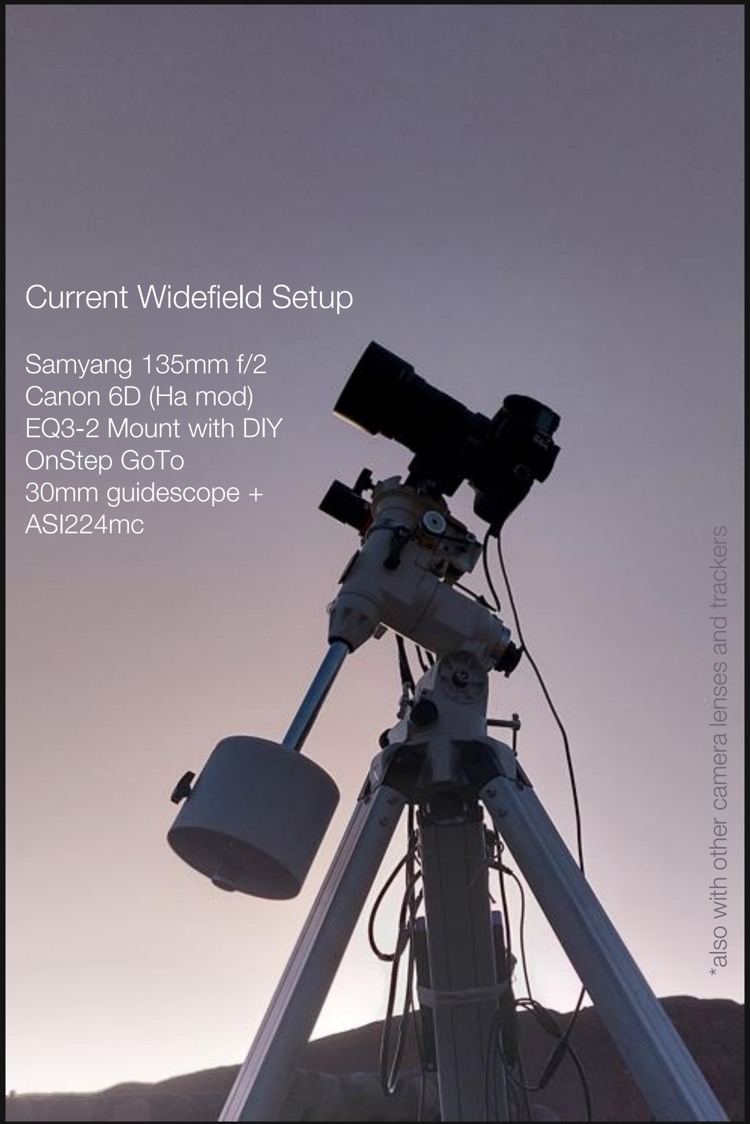
- Brazilian, 24 y.o., Production/Industrial Engineer (University of São Paulo – USP, 2021)
- Ph.D. candidate and researcher (USP/RWTH)
- Amateur astrophotographer since 2012
- Living in São Paulo, traveller astrophotographer from the beginning
- Most images taken from Minas Gerais, Brazil (Bortle 3, 1220m)
- Observatory built (2020-2023)



For more information on observatory: [Santos, G.; Ederoclite, A. An observatory for astronomical imaging: development and future prospects, 2022.]().

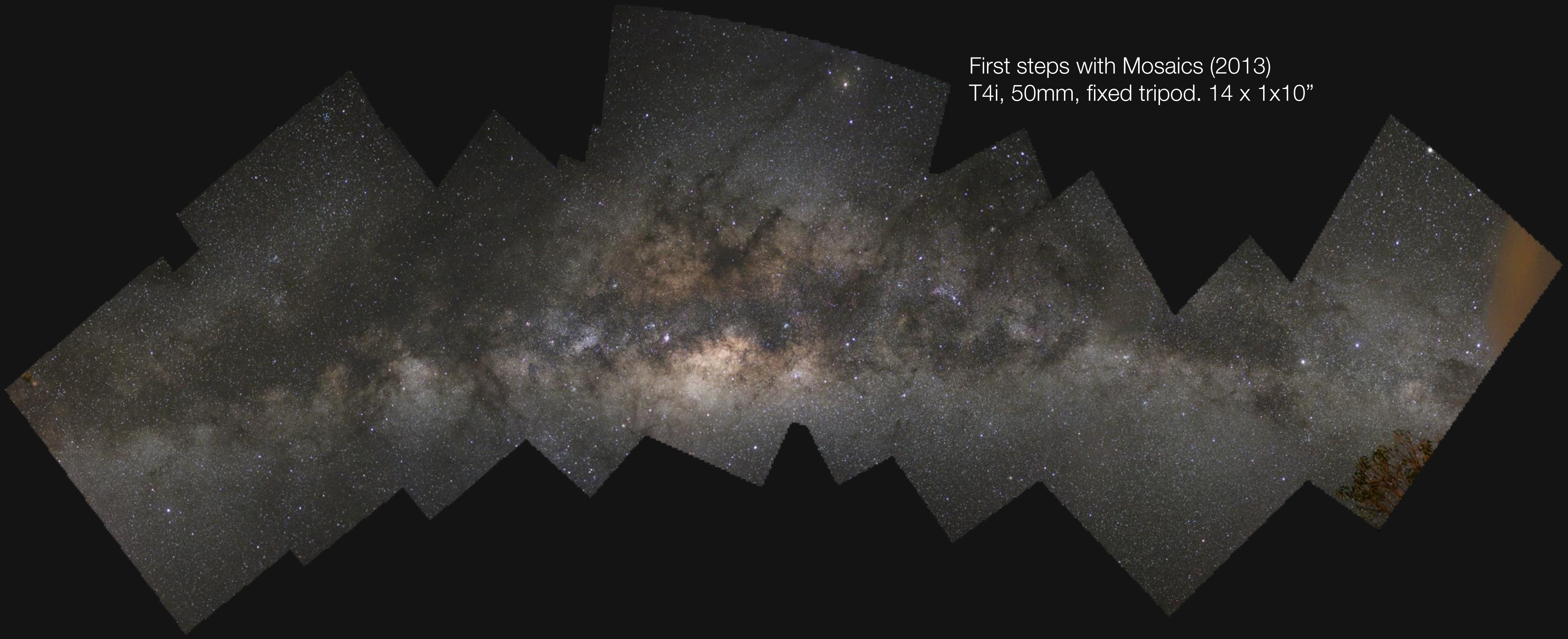
Who am I?





For more information on observatory: [Santos, G.; Ederoclite, A. An observatory for astronomical imaging: development and future prospects, 2022.]

My story with mosaics and my approach



First steps with Mosaics (2013)
T4i, 50mm, fixed tripod. 14 x 1x10”

- Using DSLRs with utmost attention to detail → I’m not cutting corners

M. Toet. Potentials of high-end DSLRs in a CCD dominated environment – Lecture 10, CEDIC’15. Linz: 2015.

O R I O N

THE MAKING OF AN IMAGE

Why am I here

- My goal: help you understand mosaics better

- Overview of some of the key features, challenges and approaches when making mosaics
- Present an introduction to deep sky mosaics
  - Complex topic; this is not an exhaustive presentation!

- Focus: broadband widefield deep sky object images
- Concepts can be applied also for other types such as narrowband mosaics

Agenda

The Basics

Starting the puzzle: important concepts for mosaics

What is a mosaic?

Remembering the Field of View formula:

$$FOV = 2\,\mathrm{atan}\frac{d}{2f}$$

Excepting extremely wide-angle lenses, the FOV can be approximated linearly:

$$FOV \cong 57.3\,\frac{d}{f}$$

The FOV can be expanded by using a larger sensor (↑ *d*) or a shorter focal length (↓ *f*)…

… or by combining multiple images!

The combined FOV can be approximated by:

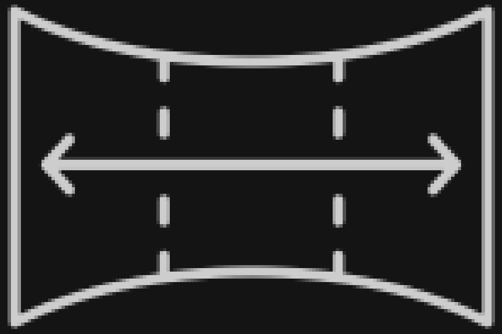
$$FOV_{mosaic} \cong 57.3\,\frac{d}{f} * (\,N - (N-1) * o\,)$$

What is a widefield image?

There is no agreed definition! Let's make this working definition:

Widefield image: FOV > 5° [long axis]

Note *widefields* are not tied to a specific equipment. However, for shorter focal lengths (f < 200mm), photographic camera lenses are typically the only option.



- *FOV: field of view*
- *d: linear dimension of sensor (e.g. 36mm for full-frame width)*
- *f: focal length (optical, effective)*
- *N: number of mosaic panels*
- *o: mosaic overlap percentage*

A mosaic is a special type of astrophotography in which individual *panels* of adjacent fields of the sky are joined to form a single final image – the mosaic itself.

(Some of) The technical challenges of making mosaics

- Key mosaic challenges:

Mosaics can be tricky to **align**

Mosaics can be hard to **join** seamlessly

- There are still additional challenges:
  - Each mosaic can be different from each other
    - It is difficult to automate a lot of the process
    - Some experimentation (and experience) is needed
  - Mosaics generate a lot of data
    - Data management is important
    - A single mosaic FITS/XISF can be several GB in size

Why would you make a mosaic?

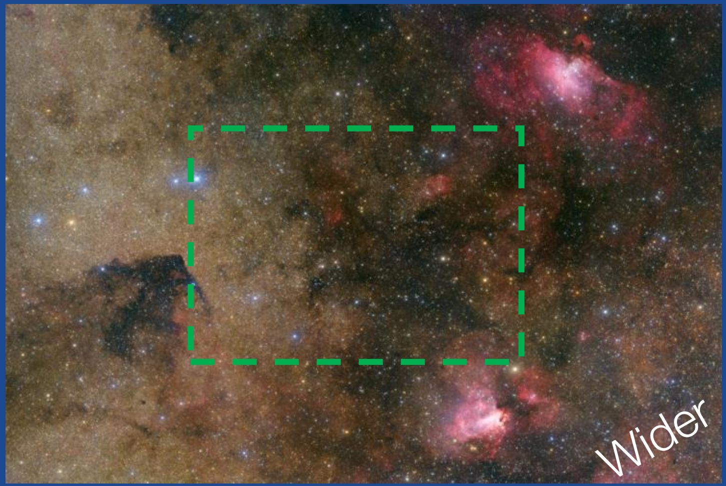
- Limited equipment: expand the possibilities of our existing equipment
- We tend to like the technical challenge – why astrophotography in the first place? ;)

Increased SNR

For a given image scale and ‘efficiency’, aperture triumphs

Increased FOV

Some objects are just too large!



Increased Resolution

Capture a wide field maintaining fine detail and tighter stars!

Some images are only possible as mosaics!

*Signal to Noise Ratio modelling can get fairly complex. The formulae presented here are a simplified model which considers shot noise as the primary noise term.

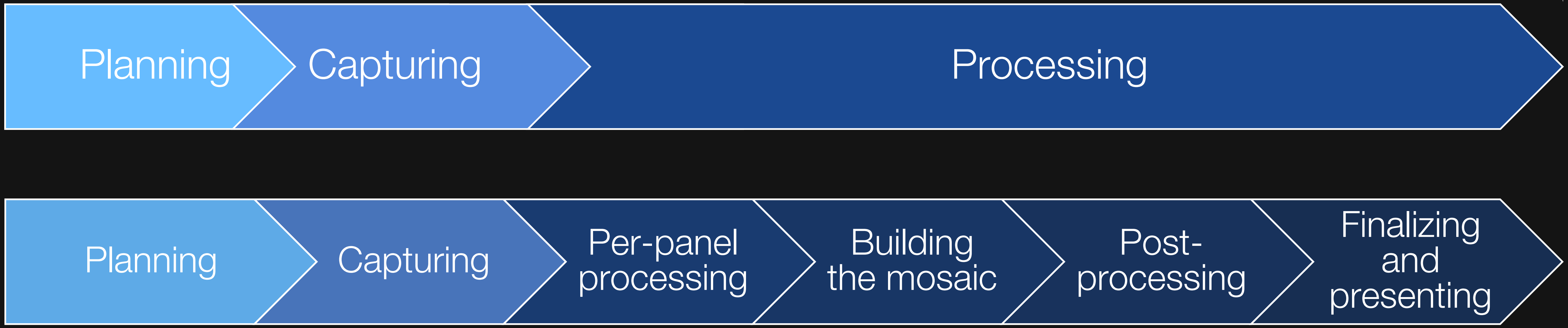
The mosaic-making process

Building the puzzle: from planning to publishing and presenting

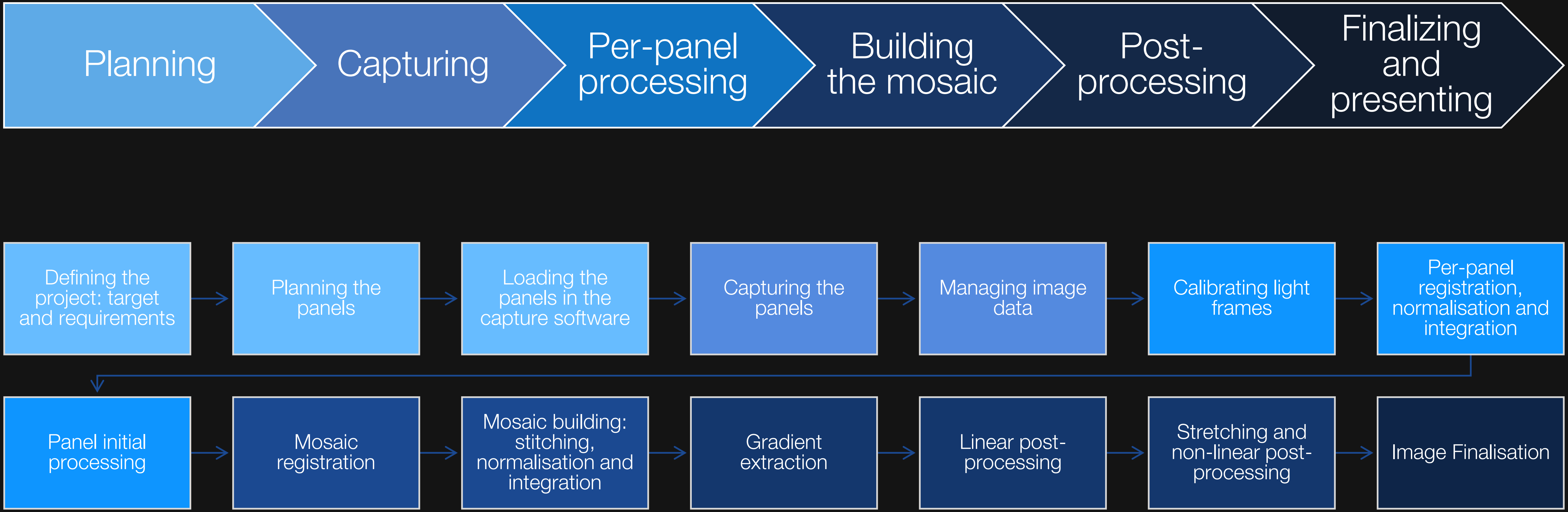
The mosaic-making process

Planning → Capturing → Processing

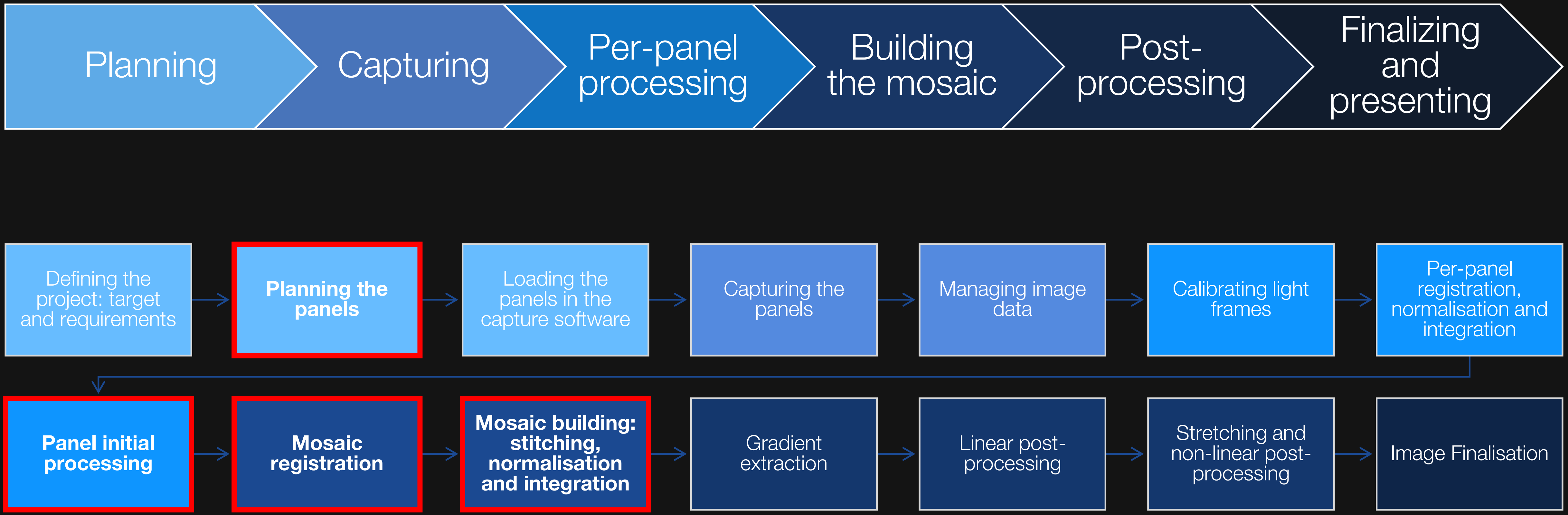
The mosaic-making process



The mosaic-making process

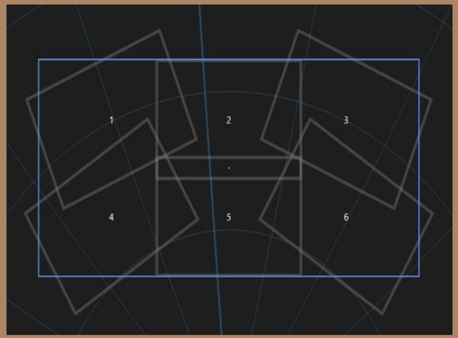


The mosaic-making process



Planning

- Define what to shoot and how to shoot it (and where to shoot it from)
  - Define number of panels, overlap % (initial recommendation: 20% overlap)

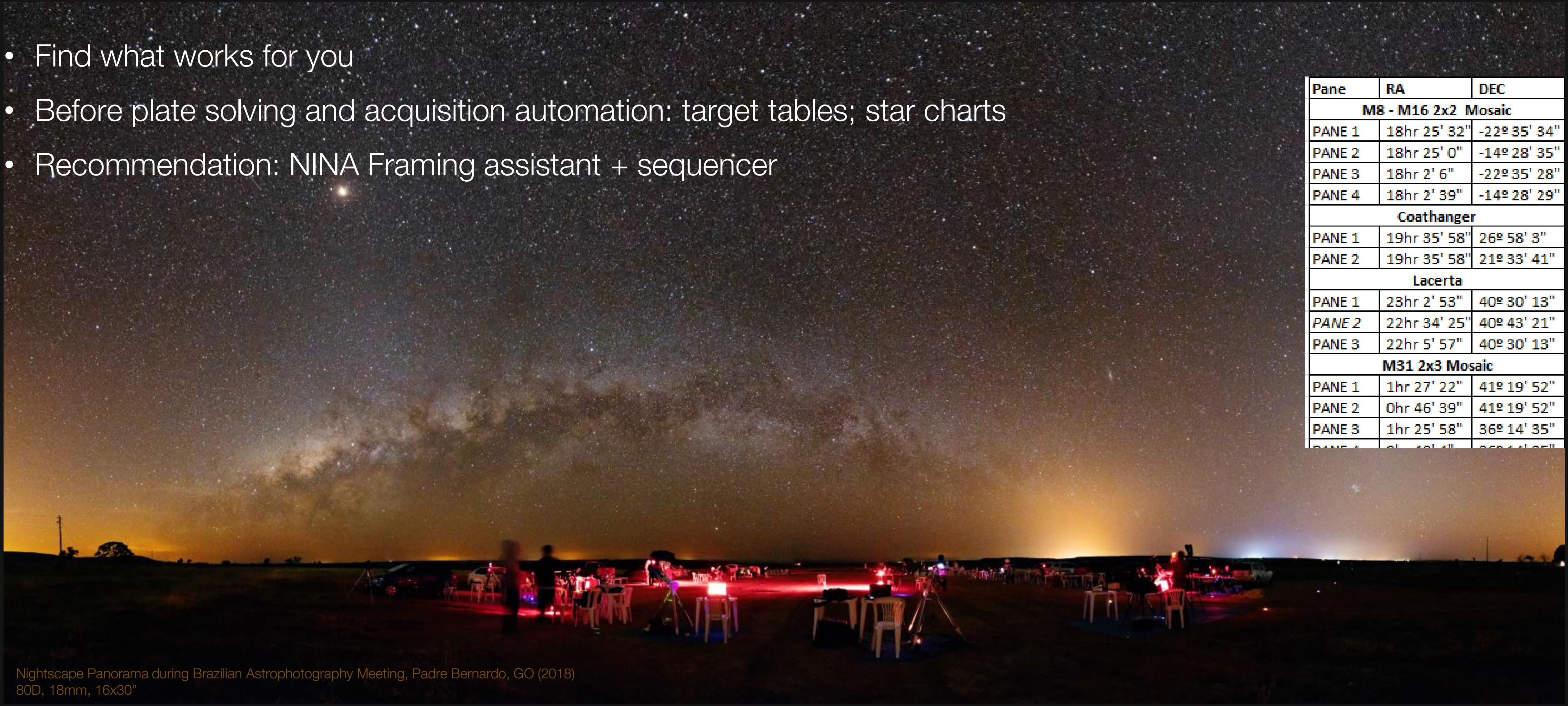
Challenge	Recommendation	Examples
Mosaics can be tricky to align	Plan mosaics aligned to the equatorial grid (0° or 90°)* Be careful near the poles with panel rotations Simpler pointing and no meridian-flip problems, at the cost of possible cropping of jagged frames when object of interest is at 45° to the grid (especially Milky Way core) *unless you have a repeatable field rotator and confidence on its flat-fielding calibration	 
Mosaics can be hard to join seamlessly	Shoot from the darkest skies possible Bortle 4 OK, Bortle 3 or better is desirable Photograph objects near meridian crossing and at altitude > 30°	 
	Optimise and assess full calibration (pre-processing) Understand and employ full calibration routine. Especially flat-fielding. ***“Check your flats, they tell you how deep you can get!”*** *(Neyer, 2015)*	

F. Neyer. Chasing Faint Objects - Image Processing Tips and Tricks. Lecture 06, CEDIC’15. Linz, 2015.

Planning: examples

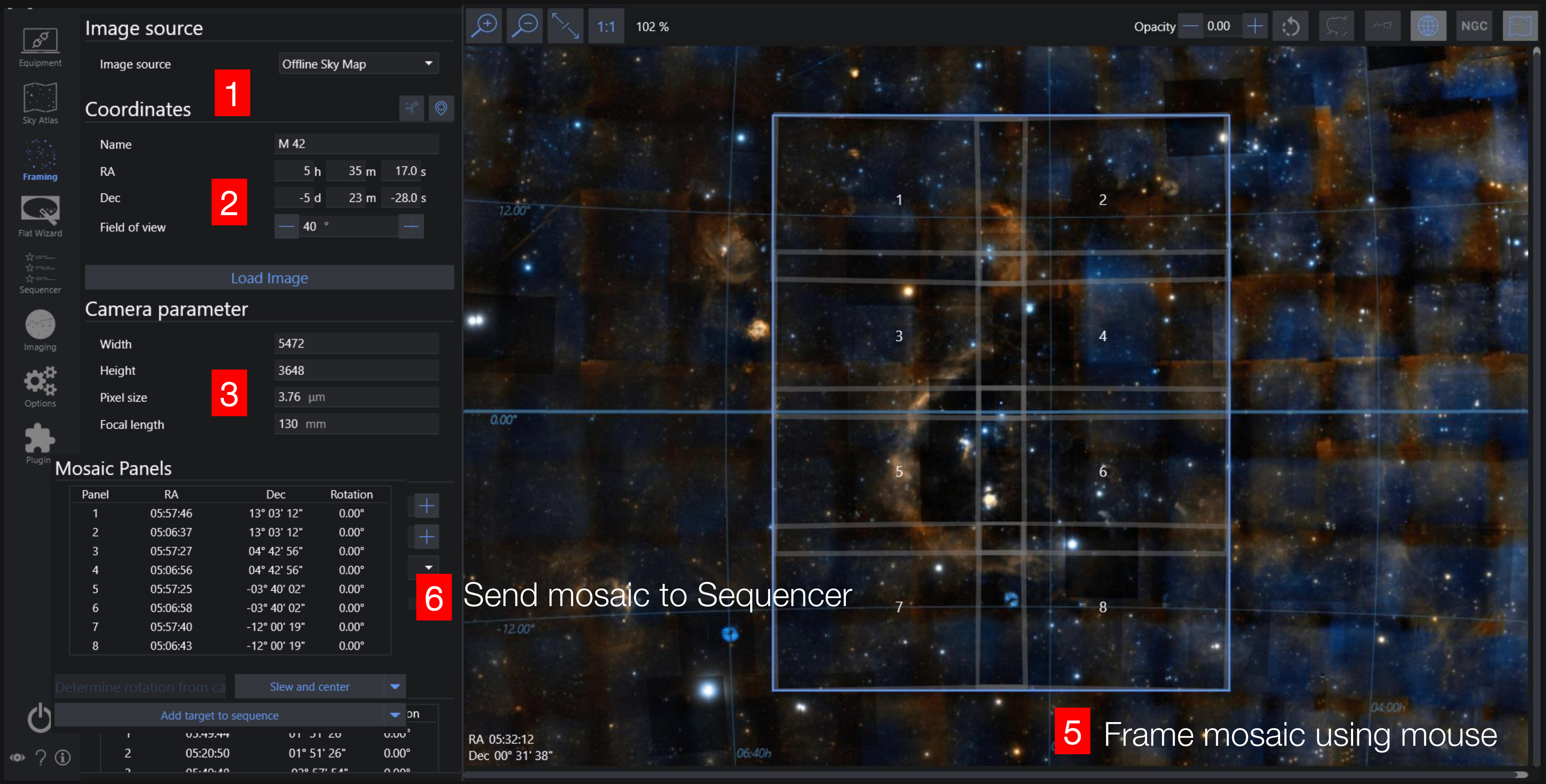
- Find what works for you
- Before plate solving and acquisition automation: target tables; star charts
- Recommendation: NINA Framing assistant + sequencer

Pane	RA	DEC
M8 - M16 2x2 Mosaic		
PANE 1	18hr 25' 32"	-22º 35' 34"
PANE 2	18hr 25' 0"	-14º 28' 35"
PANE 3	18hr 2' 6"	-22º 35' 28"
PANE 4	18hr 2' 39"	-14º 28' 29"
Coathanger		
PANE 1	19hr 35' 58"	26º 58' 3"
PANE 2	19hr 35' 58"	21º 33' 41"
Lacerta		
PANE 1	23hr 2' 53"	40º 30' 13"
PANE 2	22hr 34' 25"	40º 43' 21"
PANE 3	22hr 5' 57"	40º 30' 13"
M31 2x3 Mosaic		
PANE 1	1hr 27' 22"	41º 19' 52"
PANE 2	0hr 46' 39"	41º 19' 52"
PANE 3	1hr 25' 58"	36º 14' 35"



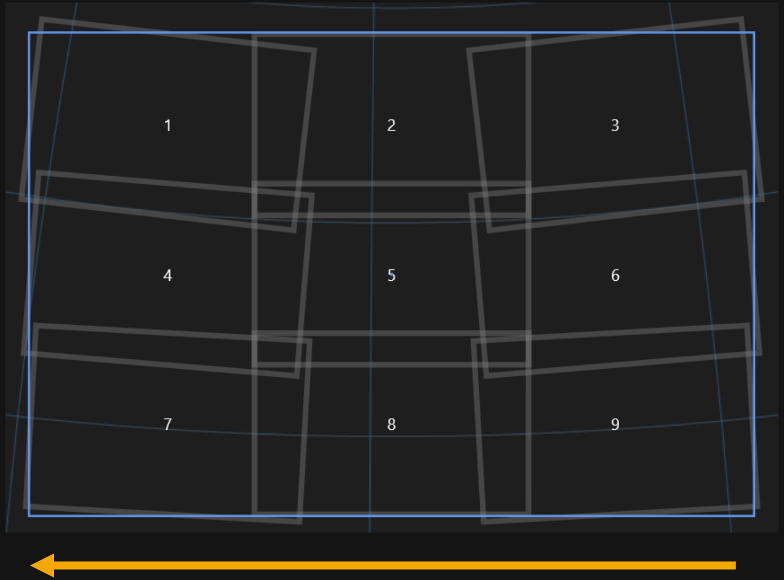
Nightscape Panorama during Brazilian Astrophotography Meeting, Padre Bernardo, GO (2018)
80D, 18mm, 16x30"

Planning a mosaic with N.I.N.A. Framing tab



Planning a mosaic with N.I.N.A. Framing tab – Pro Tip!

The problem

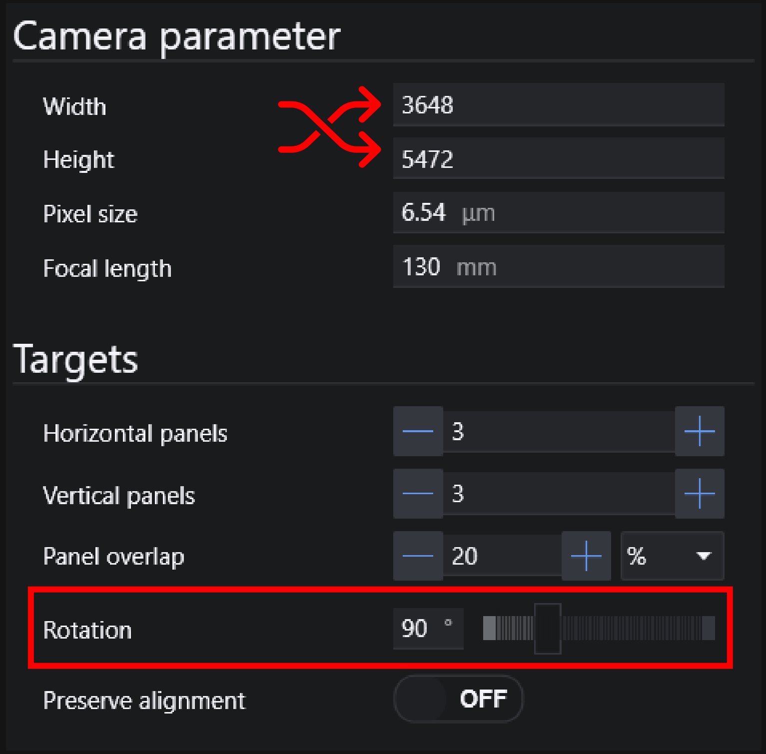


Increasing RA = Later meridian crossing

Ideally, this mosaic should go:
3 -> 6 -> 9 -> 8 -> 5 -> 2 ->1 -> 4 -> 7

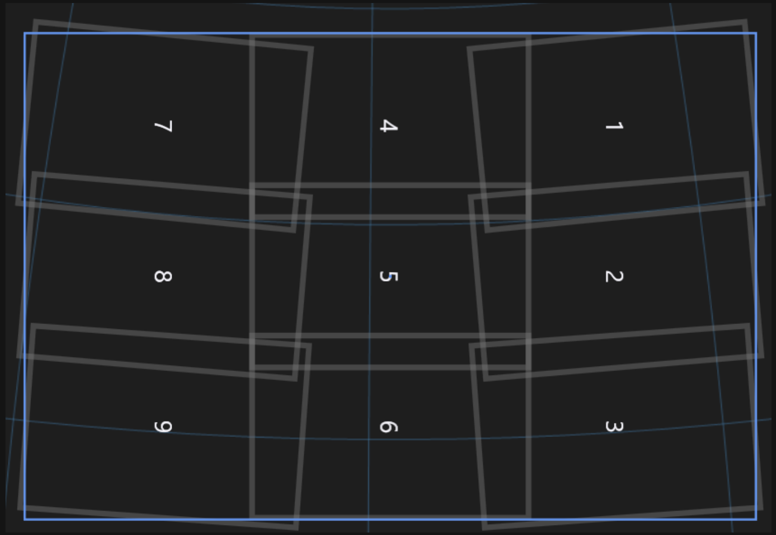
Optimises the shooting time "working against the Earth's rotation"

"Hacking" a solution



Problem solved!

Importing the mosaic panels into the Sequencer should give the right panel order right away.



An improvement suggestion to NINA developers ;)

Capturing data

- In general, capturing data from a mosaic is no different than capturing single-field DSO images
- **Automate** as much as possible
  - Plate-solving for accurate field pointing (aim at pointing error < 1% FoV)
  - Having an automated setup can save frustration (and sleep); and might allow for smaller overlaps (10-20%)
- Mosaics **can also be done manually** (especially for extremely widefield camera lenses and DSLRs)
  - Can be exhausting for large multi-panel mosaics: recommended for **10 panels or less**
  - Have a **sturdy and repeatable** pointing device (tripod head or directly on equatorial mount)
  - Ball heads vs. 3-way heads vs. geared head. *Opinion: a good ball head is preferred to a mediocre 3-way*
  - Use stars in the camera **live view** to aid pointing, and increase your overlap > 30%
  - **Practice** makes perfect (train during daytime)
- **Keep track** of the mosaic progress and completion
  - You do not want to have a missing frame or hole in your mosaic after a trip
- **File management** is also important. Large mosaics generate a lot of data!

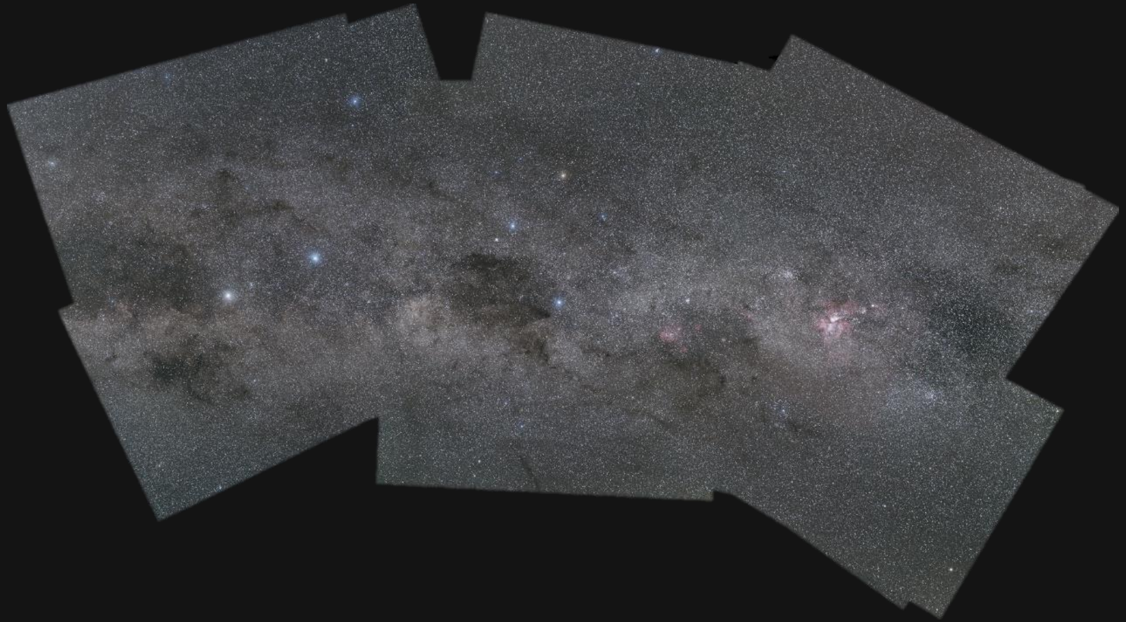
Per-panel integration

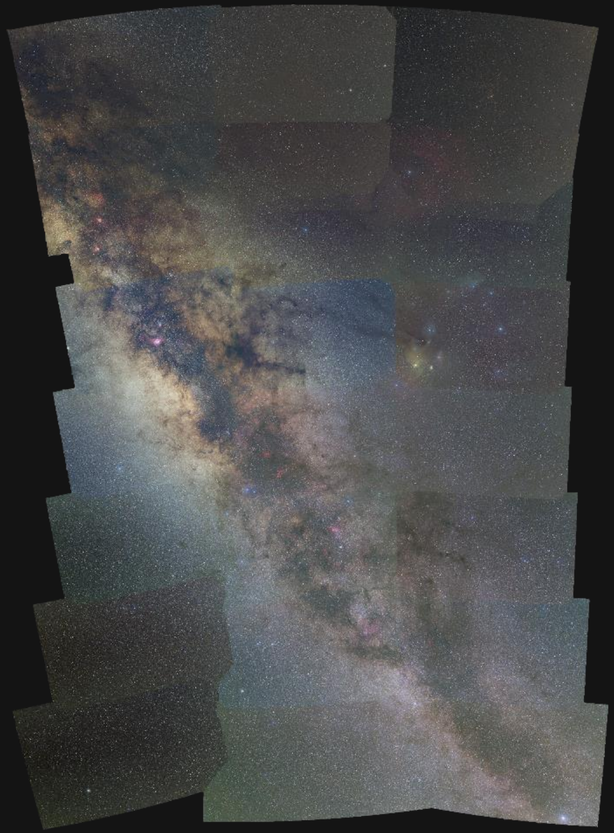
- A mosaic is a collection of several single field images
- Follow standard pre-processing / integration (reduction) routines per panel
  - Special attention to calibration
- At the end you should have good master integration files per panel

The main challenge: putting the puzzle together

- Building mosaics (joining) is the most challenging part, which can be broken down into:

Mosaics can be tricky to align	Mosaics can be hard to join seamlessly
Registration and Projection	Normalisation and gradient management





Approaches to building the mosaic

- Software options:

Astrophotography software

PixInsight

GMM PMM

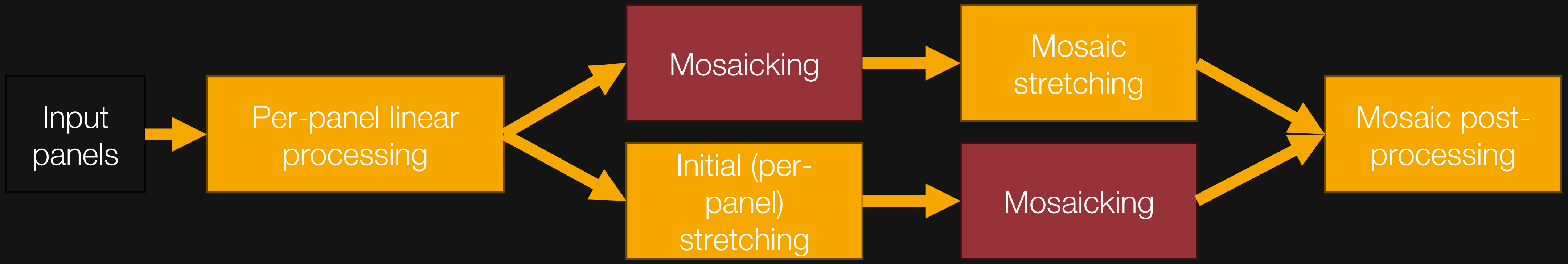
RegiStar

Daytime photography "panorama" software

Ps

PTGui

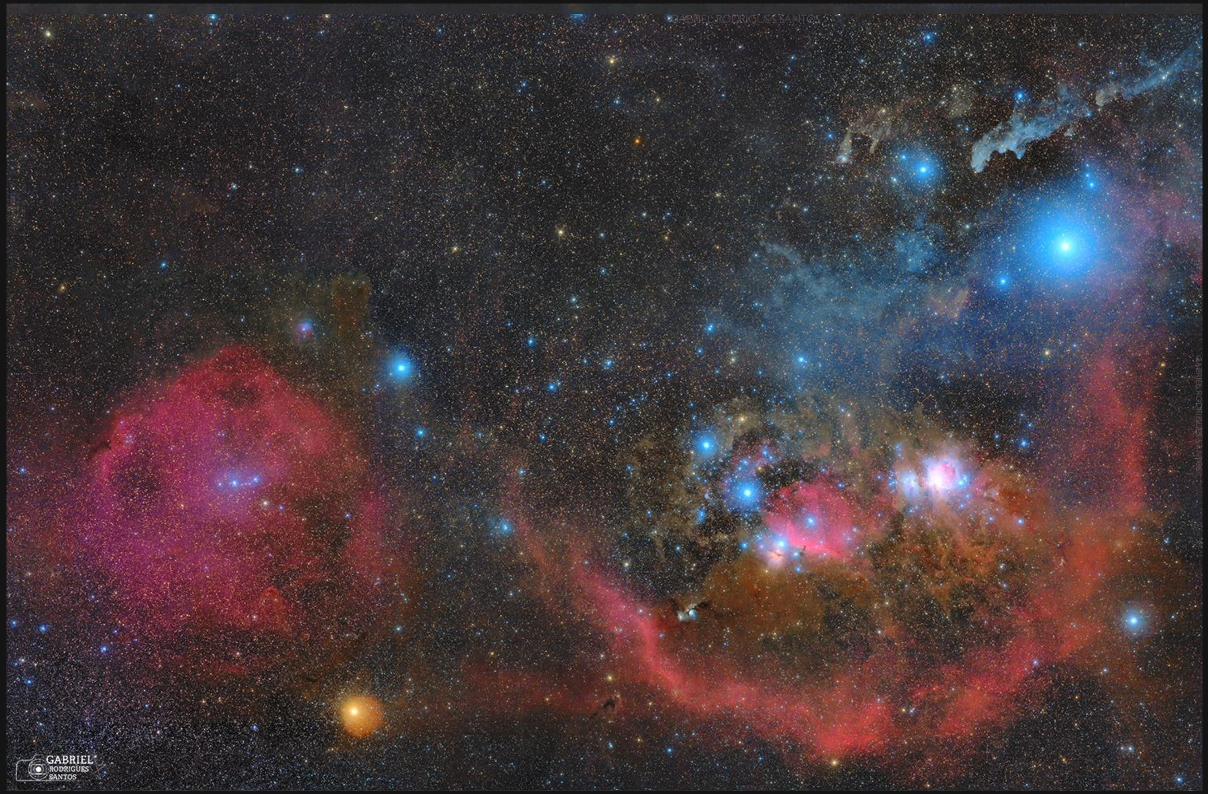
- Two basic questions:
  - What per-panel processes to apply?
    - Gradient extraction per-panel prior to mosaicking?
  - When to build the mosaic?
    - Linear vs non-linear mosaicking?
- Recommendations:
  - Linear mosaicking renders the best results / flexibility: try it first.
  - Per-panel gradient extraction may be needed. Be careful!
  - Daytime photography software are faster and can lead to good results for very large non-linear mosaics



GMM: GradientMergeMosaic | PMM: PhotometricMosaic (by John Murphy)
Both tools are used for joining the mosaic. PixInsight also has other tools to register mosaics.

The dangers of gradient overcorrection

- Gradient overcorrection leads to washed-out images, can hide faint nebulosity, and not show natural nebulosity / sky background gradients (e.g. Milky Way)
- Unresolved stars can lead to local overcorrection
- Faint diffuse nebulosity can be obliterated (e.g. Barnard's Loop, zeta Oph)
- Verify your background extraction:
  - Stars help mask errors → assess also with starless
  - Compare to other images of the region
- Start addressing the problem at root:
  - Shoot from darkest skies (minimize light pollution)
  - Assess and apply calibration correctly

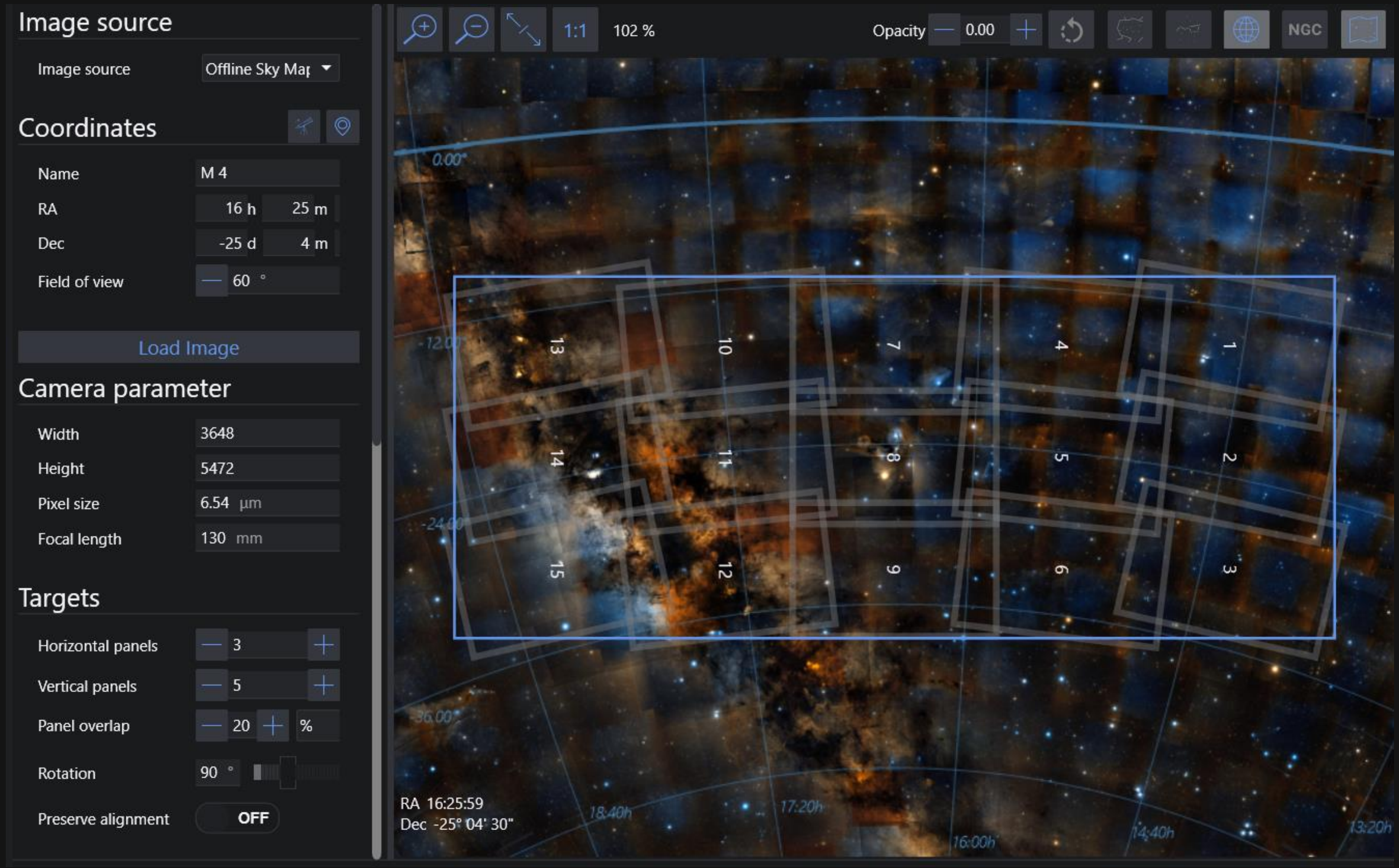


Mosaics in Practice

Planning and processing workflows with two case studies

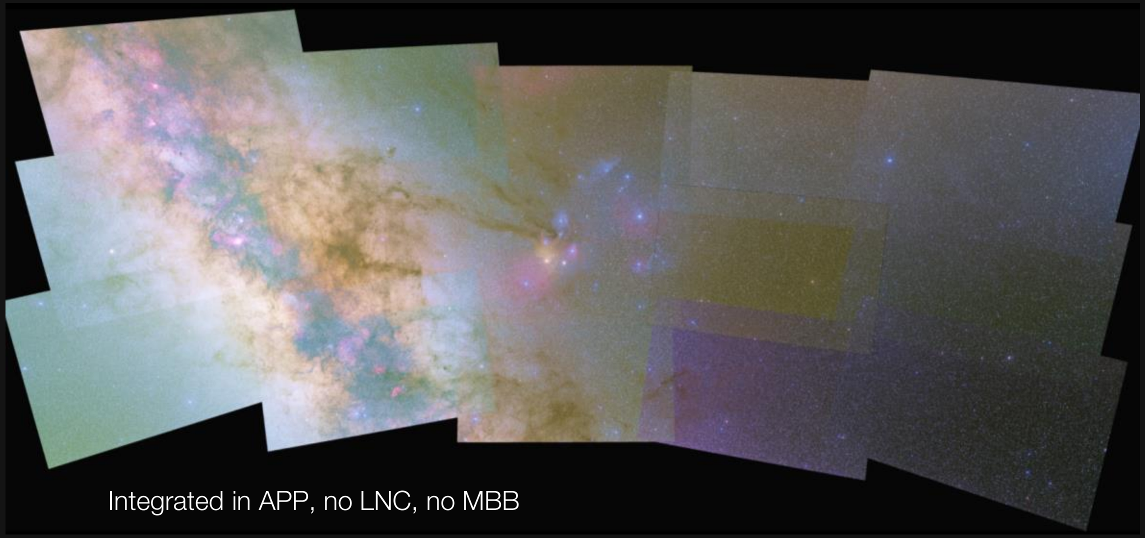
Milky Way Center 3x5 135mm from Atacama Planning

- Goal: deep mosaic of the center of the Milky Way, using the time under the Atacama desert skies
- NINA Planner
- Odd number of panels in RA/DEC
  - Panel 8 as mosaic reference
- Increasing Panel # with RA
  - Optimise shooting time
- Shoot all panels in a single night
  - May repeat in next nights
  - Minimise gradients
- Generate target sequence
- Captured on 18.04.2023 as I slept ☺

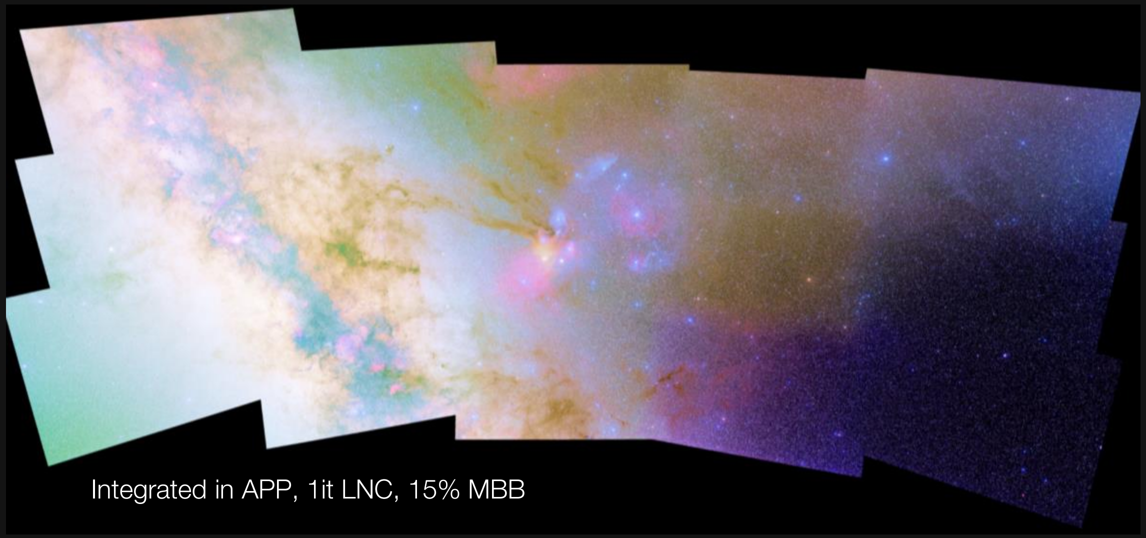


Milky Way Center 3x5 135mm from Atacama
Initial processing and preparation for mosaic stitching

- Standard per-panel pre-processing
- Decided to make a first-pass per-panel background correction
  - Imperfect flat-fielding for extreme stretching levels + slight background sky gradient
- Difficult to find background references in Milky Way center panels (13-15)
  - Dark nebulae in the Milky Way are not the same as “background sky” outside Milky Way
  - Dense starfield can lead to bad gradient models
  - Decide to follow without background extraction for panels 13-15



Integrated in APP, no LNC, no MBB

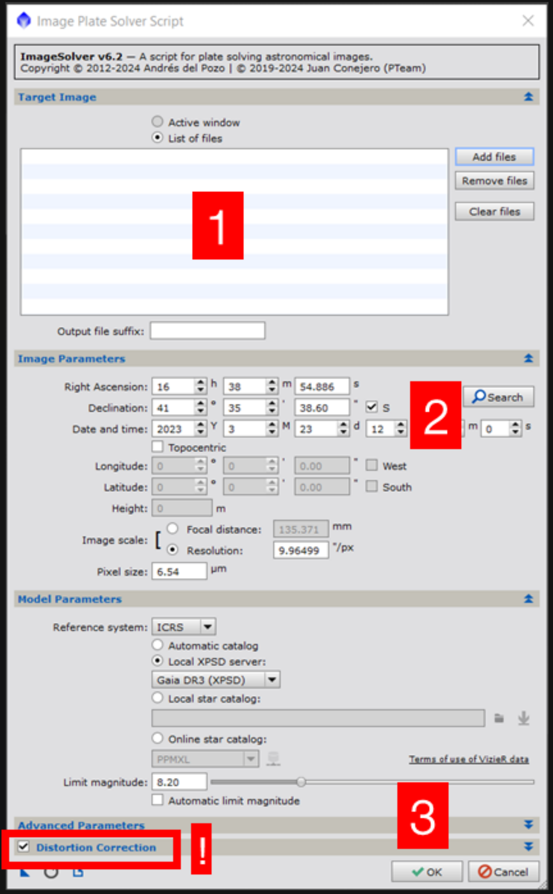


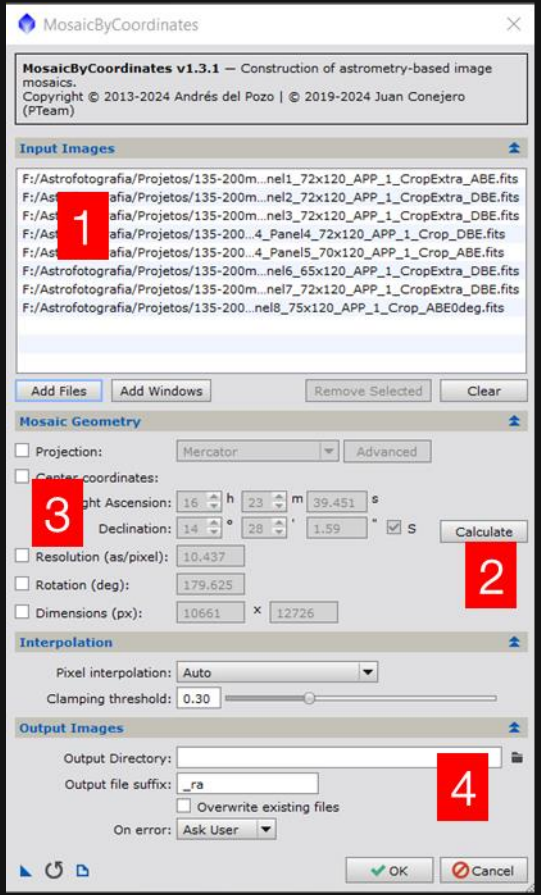
Integrated in APP, 1it LNC, 15% MBB

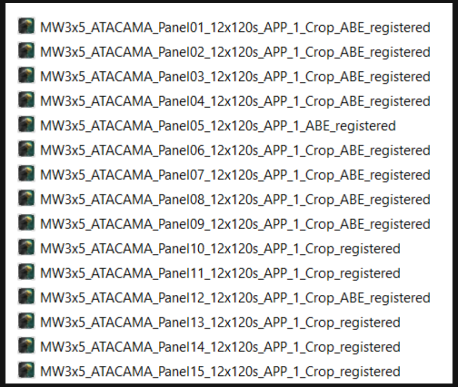
Milky Way Center 3x5 135mm from Atacama Mosaicking

PixInsight

Plate-solve all individual panels + Gradient Extraction (P1-P12) → MosaicByCoordinates for complex registration







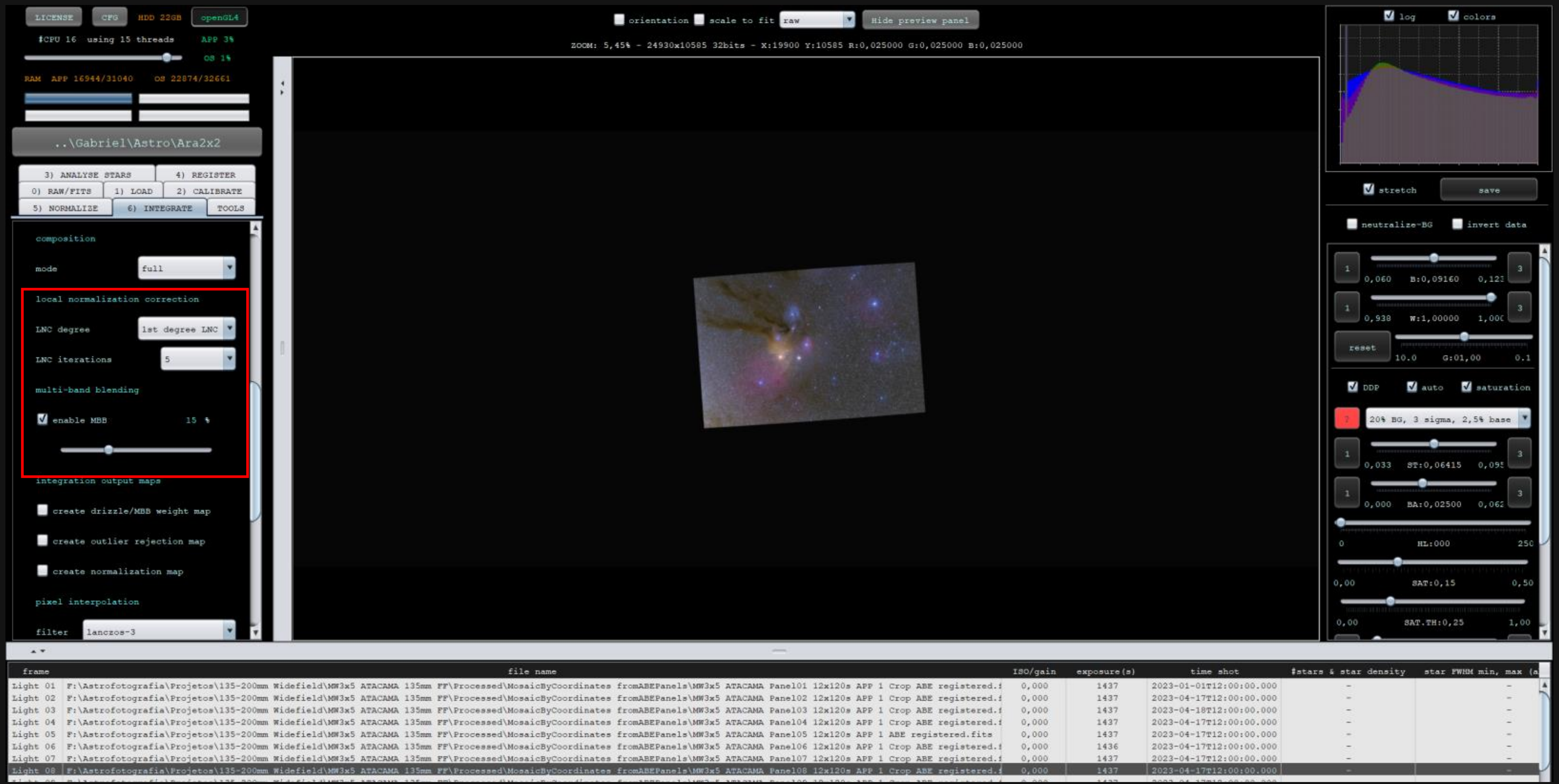
Milky Way Center 3x5 135mm from Atacama Mosaicking

Plate-solve all individual panels + Gradient Extraction (P1-P12)

→ MosaicByCoordinates for complex registration

→ First atttempted to use APP with standard settings

→ Failed normalisation in Panel 15 – possible problem with APP or with skipping background sub.



APP settings (recommendations):

- 3) ANALYSE STARS > #stars target: 2000-3000
- 4) REGISTER > disable registration (done with MosaicByCoordinates)
- 5) NORMALIZE > advanced, multiply-scale
- 6) INTEGRATE: average, no outlier rejection
  - LNC: start with degree 1, iterations 3. Increase iterations first
  - MBB: 15% (about the same as mosaic overlap %)

To see the full APP-only mosaic workflow (works most of the times!) check out the tutorial videos by Mabula Haverkamp (APP developer) ☺

Milky Way Center 3x5 135mm from Atacama
Mosaicking

Plate-solve all individual panels + Gradient Extraction (P1-P12)

→

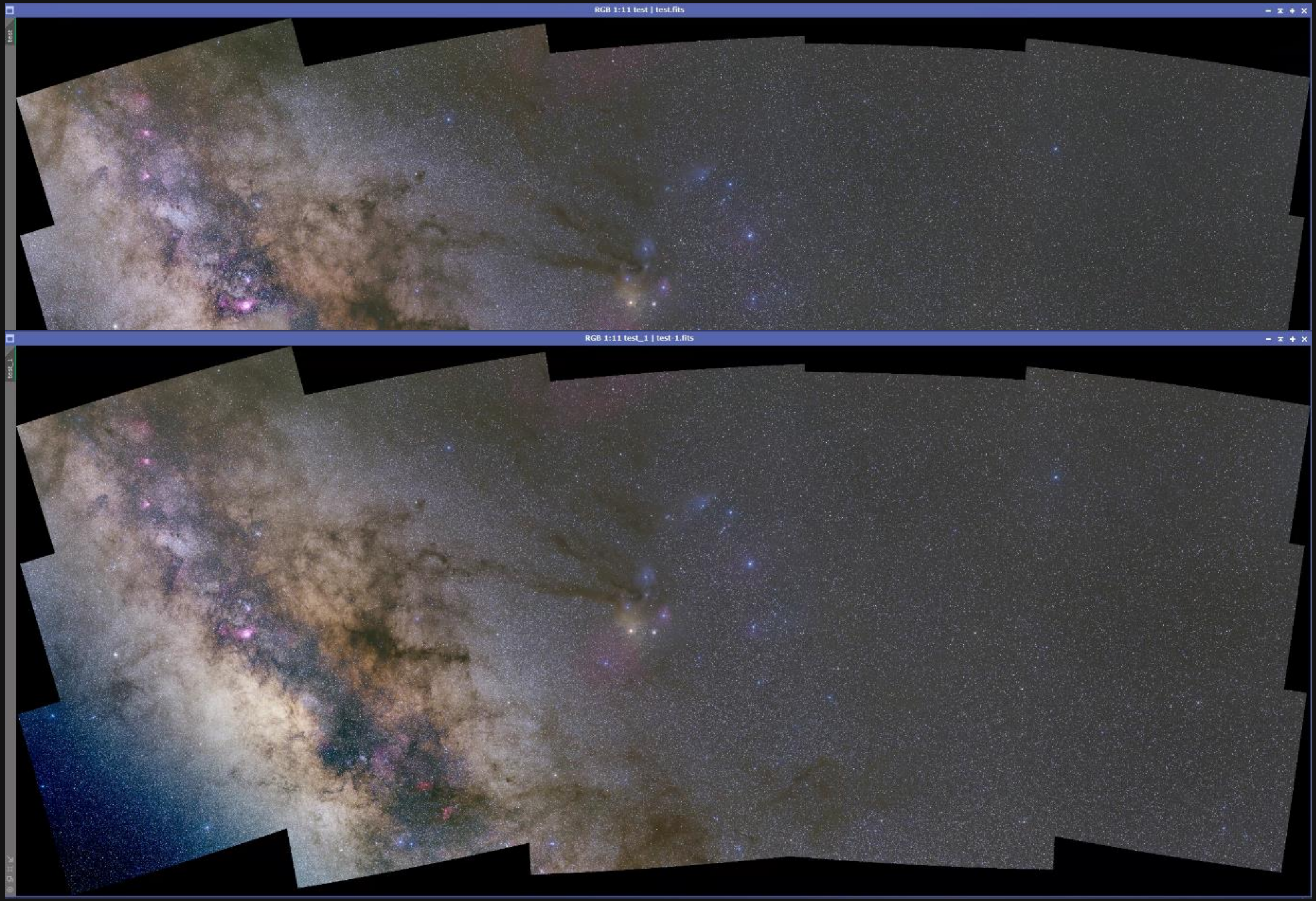
MosaicByCoordinates for complex registration

↓

First atttempted to use APP with standard settings

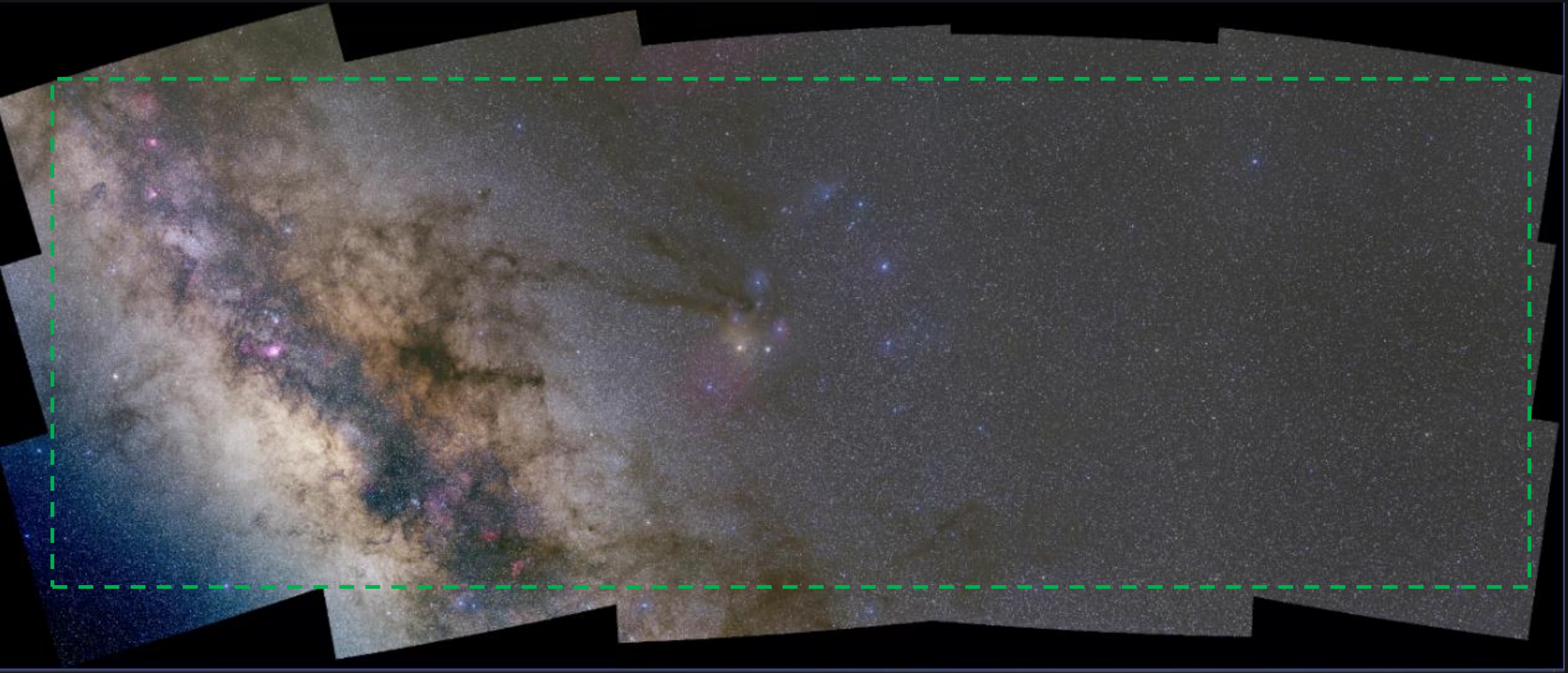
←

Failed normalisation in Panel 15 – possible problem with APP or with skipping background sub.



*use only additive normalization

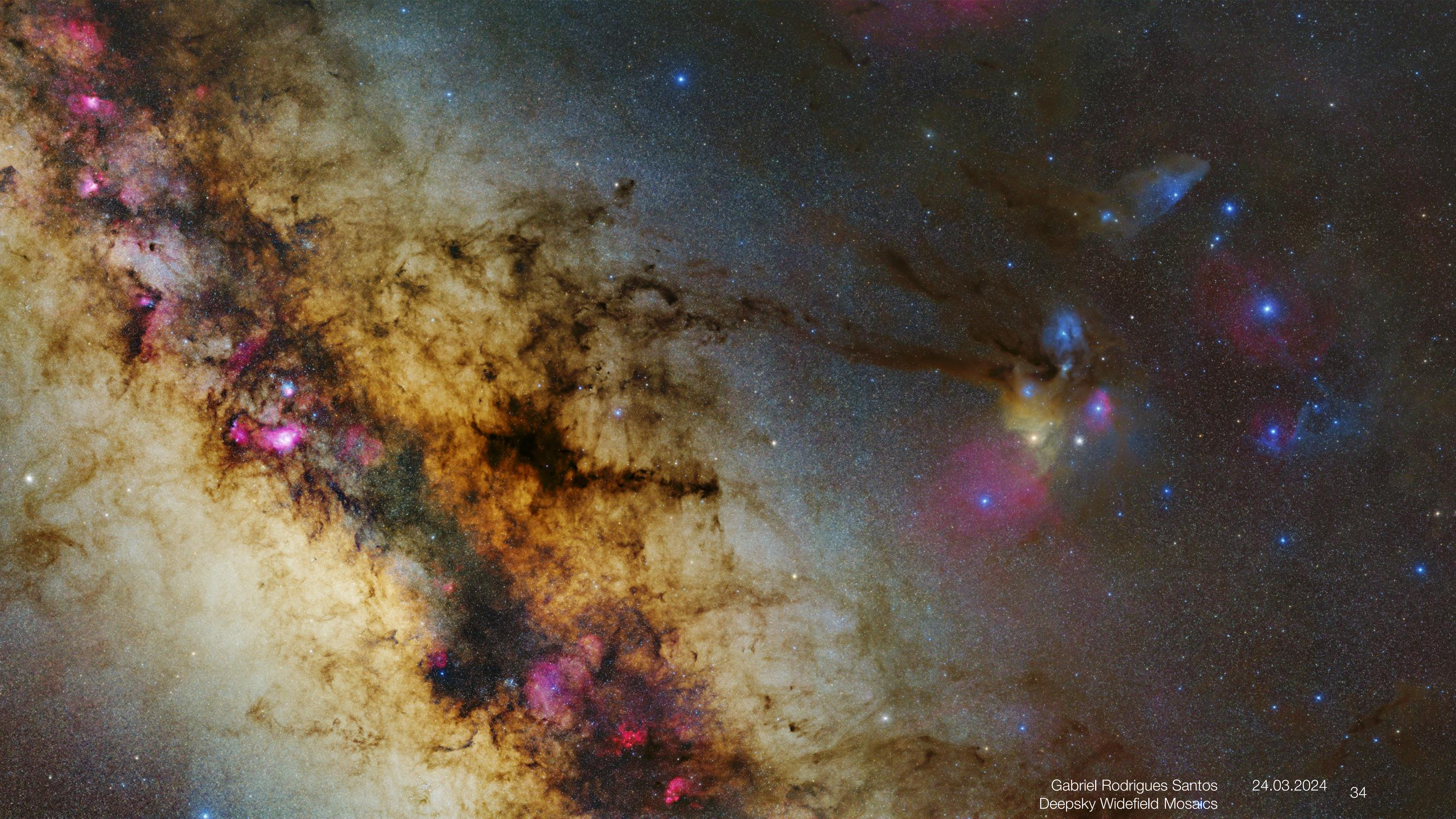
Milky Way Center 3x5 135mm from Atacama
Mosaicking



Milky Way Center 3x5 135mm from Atacama
Final result

Panels: 15 (3x5)
Total subframes: 180

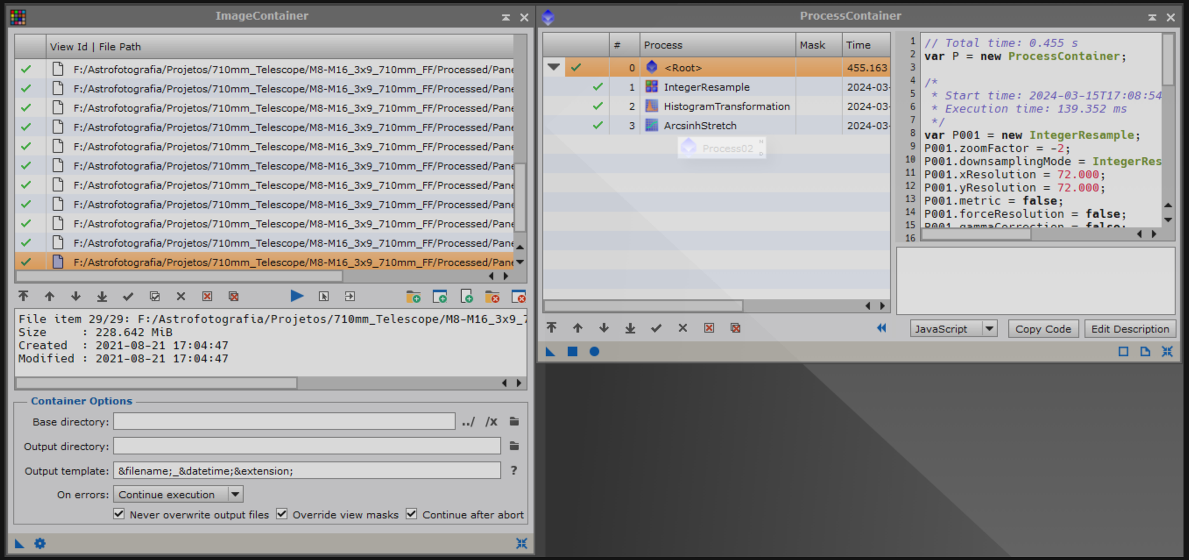
Total project folder size: 74GB
Final mosaic resolution: 23367 x 8090 (189MP)



Milky Way from M8 to M16 - 3x9 telescope
Behind the scenes

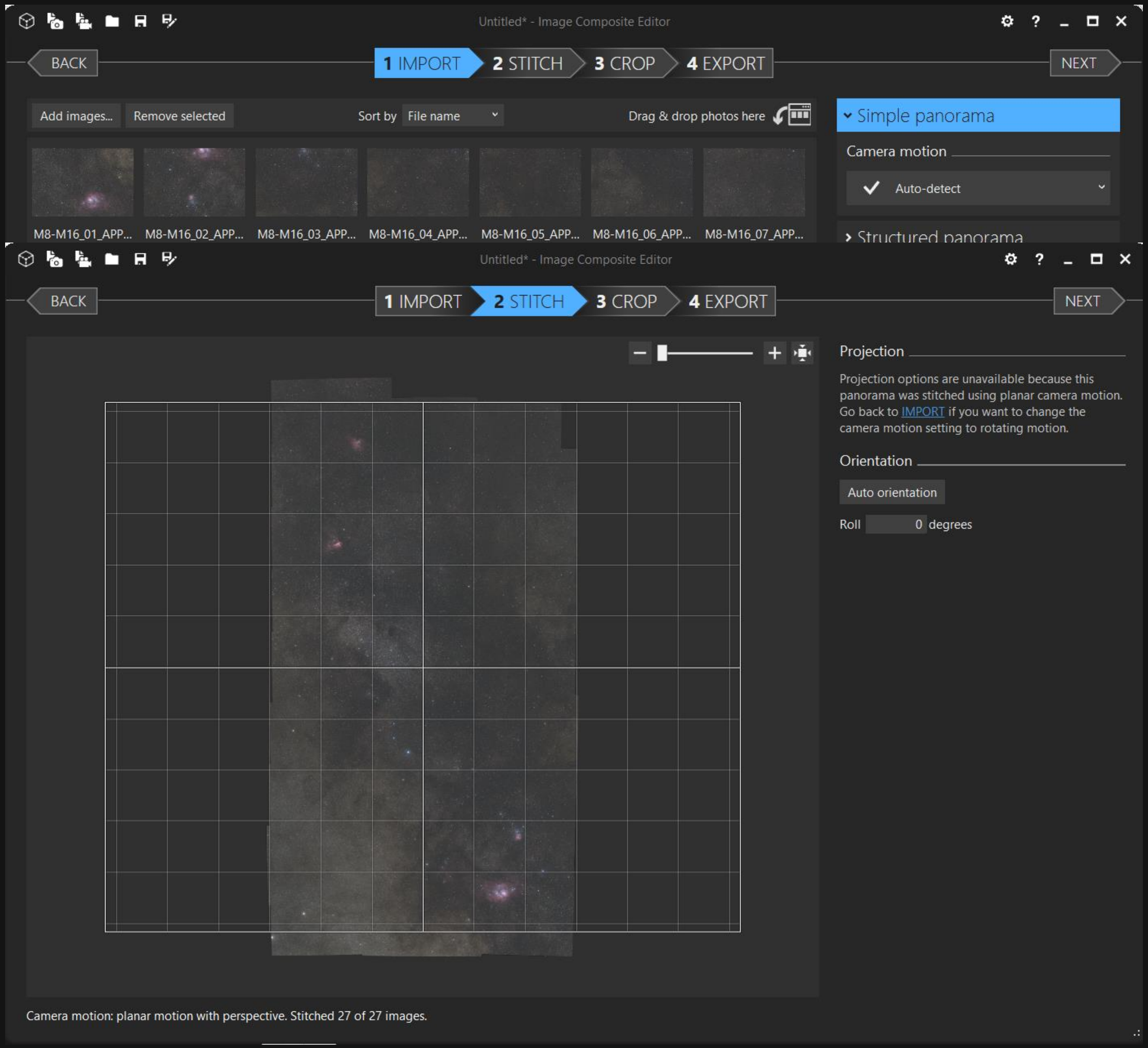
Milky Way from M8 to M16 - 3x9 telescope
Per-panel processing

- An example of a large-scale telescope mosaic that was too much to be handled with traditional astrophototo software and my computer hardware
- Decided to use follow a non-linear mosaic stitching with ImageCompositeEditor
- PixInsight process automation per panel
  - ImageContainer + ProcessContainer:
    - Resize to 50%
    - Initial stretching
    - Save panels as 16bit TIFFs



Milky Way from M8 to M16 - 3x9 telescope
Mosaic assembly with ImageCompositeEditor (ICE)

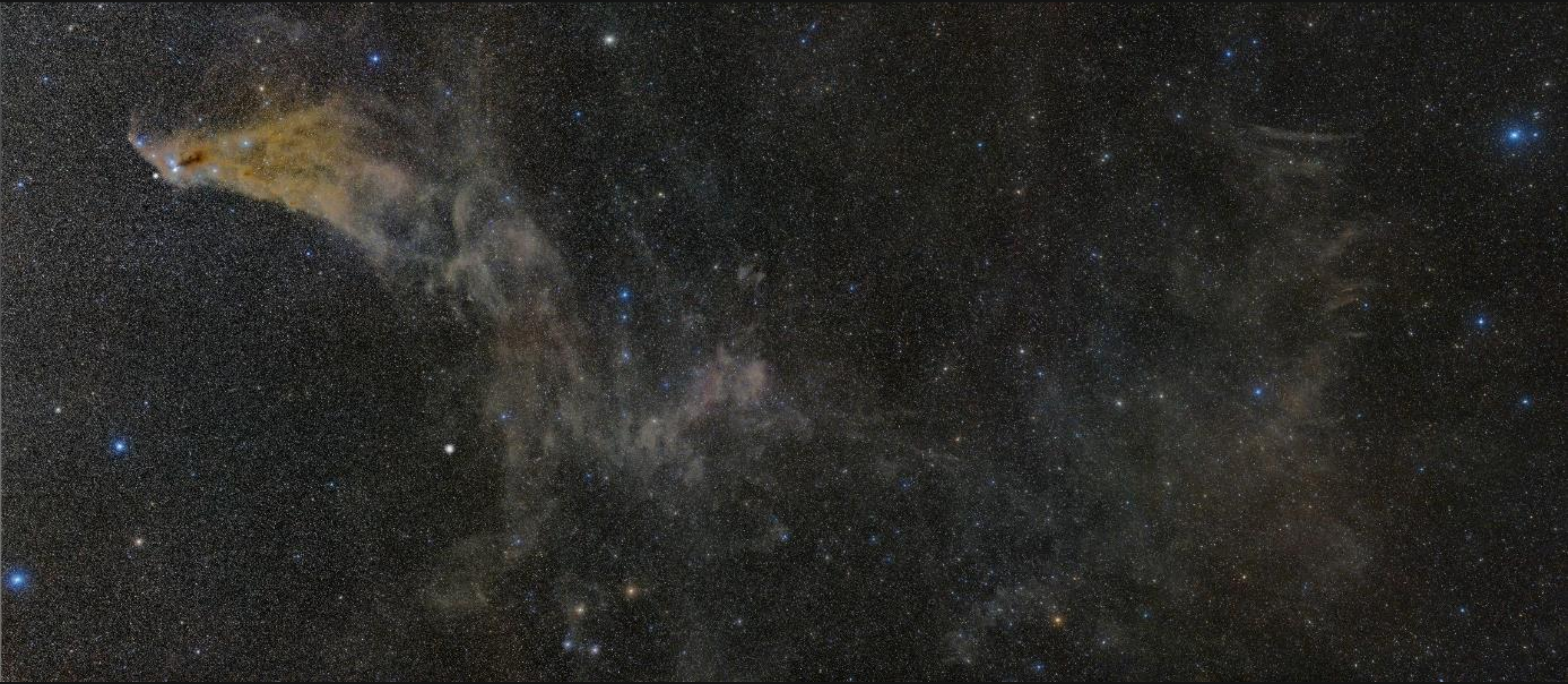
- An example of a large-scale telescope mosaic that was too much to be handled with traditional astrophototo software and my computer hardware
- Decided to use follow a non-linear mosaic stitching with ImageCompositeEditor
- PixInsight process automation per panel
  - ImageContainer + ProcessContainer:
    - Resize to 50%
    - Initial stretching
    - Save panels as 16bit TIFFs
- Stitching in ICE
  - No user controls ➔ if it works, great!
  - For larger mosaics (wider field): excellent UI for choosing the projection type and centre coordinates
  - Algorithm “dissolves” the panels minimizing gradients (no averaging, with no user control of parameters)
  - Exported as 16bit TIFF



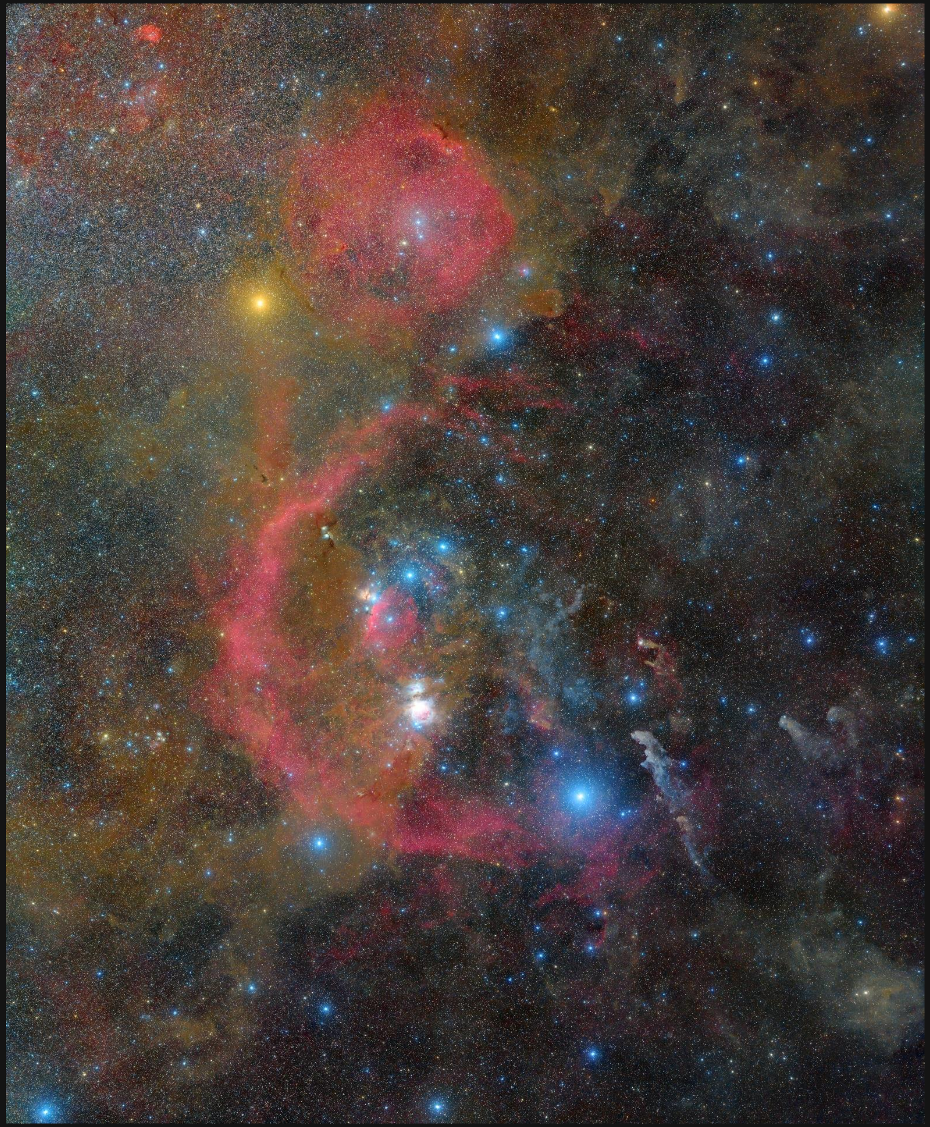
Milky Way from M8 to M16 - 3x9 telescope
Assembled mosaic with initial per-panel stretch

Milky Way from M8 to M16 - 3x9 telescope
Final processed image

Corona Australis – 2x3 @ 135mm



Orion – a real patchwork



Orion
2x4 Mosaic

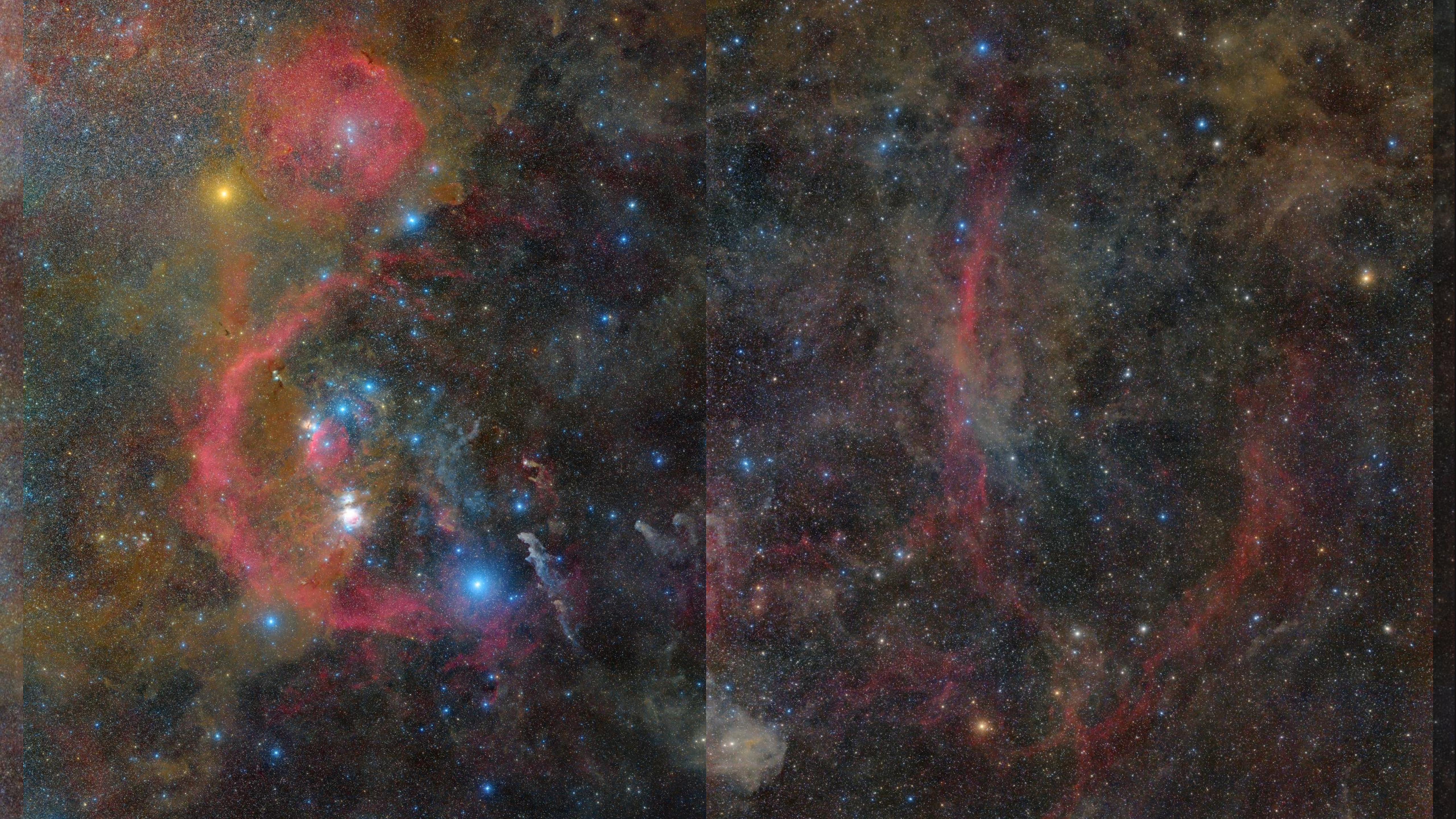
6Da + 135mm
12.23 + 01.24

4.6h total

Eridanus Loop
2x4 Mosaic

6Da + 135mm
11.21

4.3h total



Extra topics and take-home messages

Completing the puzzle

More advanced approaches … and a bright future ahead

- Photometry-based panel joining
  - PixInsight PhotometricMosaic (by John Murphy)

- Using an even wider field to model the background of the main imaging system locally
  - Technique perfected by Wei-Hao Wang for mosaics
  - Similar to Multiscale Gradient Correction by V. Peris

PixInsight

RESOURCES LICENSES DOWNLOADS DEVELOPER COMMUNITY GALLERY

Home > Resources > Software Tutorials > Multiscale Gradient Correction

Multiscale Gradient Correction

By Vicent Peris (PTeam/OAUV)
Published April 8, 2020

The Multiscale All-Sky Reference Survey (MARS)

The Next Generation of Gradient Correction and Mosaic Construction Tools

Current gradient correction and mosaic generation techniques have severe limitations. In the case of gradient correction, traditional methods such as our DynamicBackgroundExtraction tool (DBE), as well as existing third-party copies, are based on samples located over supposedly 'free' sky background regions to generate an interpolated model of the gradients in the image. Despite the advanced statistical data analysis algorithms implemented in these tools, this is a highly inaccurate and inefficient way to model gradients. Firstly, most reasonably deep astronomical images exclude free sky background areas. Secondly, even with the availability of free sky data, we cannot model gradients over regions occupied by any objects of interest using these techniques.

For mosaic construction, current techniques are based on normalization functions calculated exclusively on overlapping mosaic areas, where an initial frame acts as the reference to build the entire mosaic. A mosaic cannot be constructed reliably using these methods because each newly added tile must be adapted to the existing partial mosaic, which has its own gradients. On the other hand, this assembly technique cannot reconstruct the object structures globally in the mosaic since we are adapting the mosaic tile by tile, not as a whole.

The multiscale gradient correction algorithm, created by PTeam member Vicent Peris in 2020, is an elegant and efficient solution to overcome all of these limitations based exclusively on observational data. With multiscale gradient correction and its generalized variants, we can design and implement a new generation of gradient modeling, mosaic construction, and image normalization tools that will render existing techniques and applications obsolete. You will no longer have to rely on guessed background samples located at subjectively chosen locations or allow a supposedly 'intelligent' system to produce a whole new image for you without your control. We'll give you tools and techniques to model gradients and build mosaics based on true, accurate observational data, preserving the authenticity of your images and maximizing their documentary value to the greatest technically possible extent.

Image of Messier 45 (Pleiades) before and after multiscale gradient correction. Image courtesy of Edoardo Luca Radice (PTeam).

PixInisght MARS project for an all-sky reference model can be **revolutionary!**

Conclusion

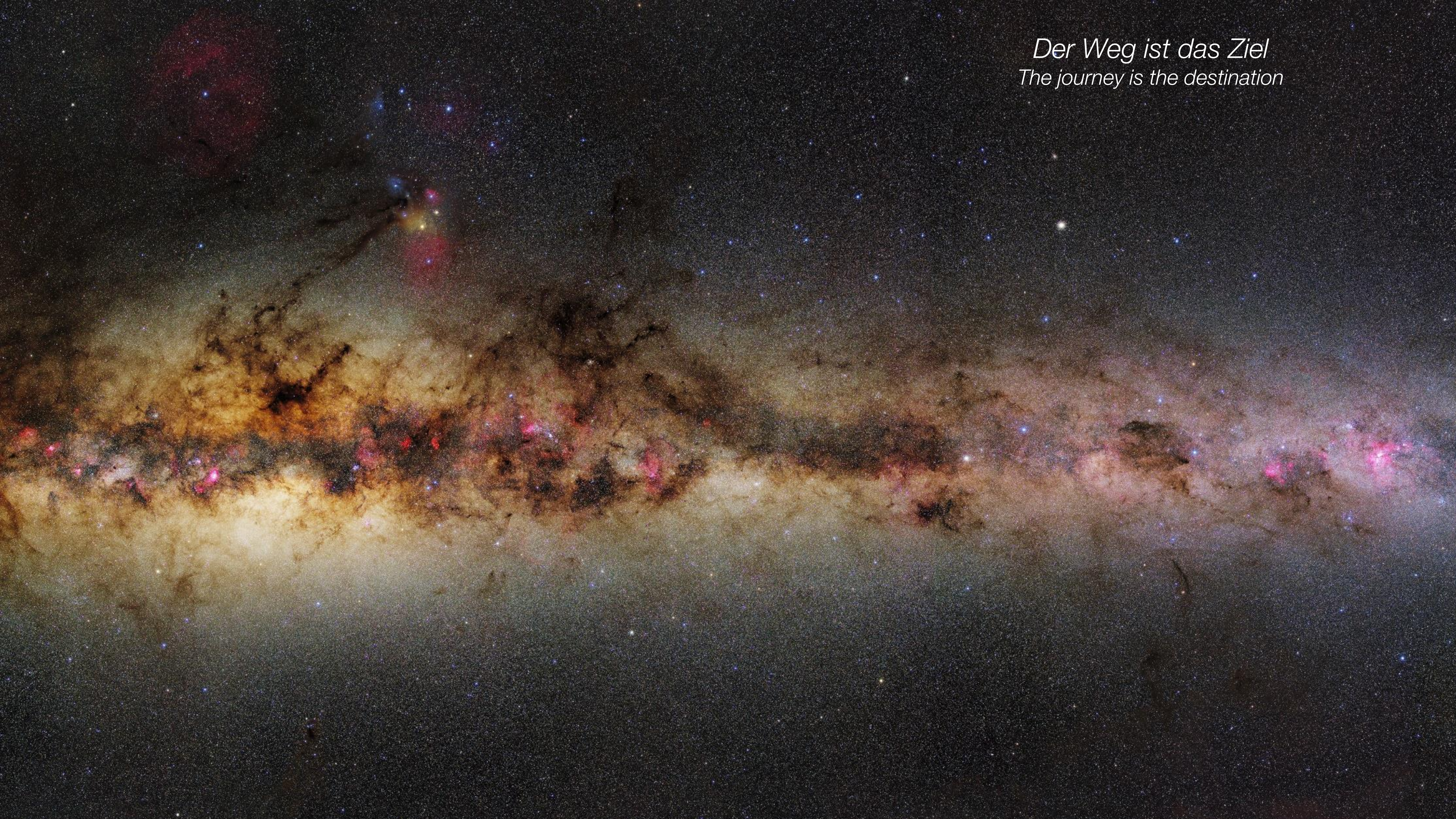
- Mosaics allow a new perspective on widefield astrophotography, reaching higher SNRs, with wider fields and higher resolution
- Take a methodical approach: attention to detail during the entire process, careful processing
- Mosaics can be fun! And hopefully you will be encouraged to give them a try:
    - Start with simpler mosaics: 2-4 panels
- Mosaics take a lot of time and effort and space, but some images are only possible as mosaics!

Beginnings and endings

Der Weg ist das Ziel
The journey is the destination

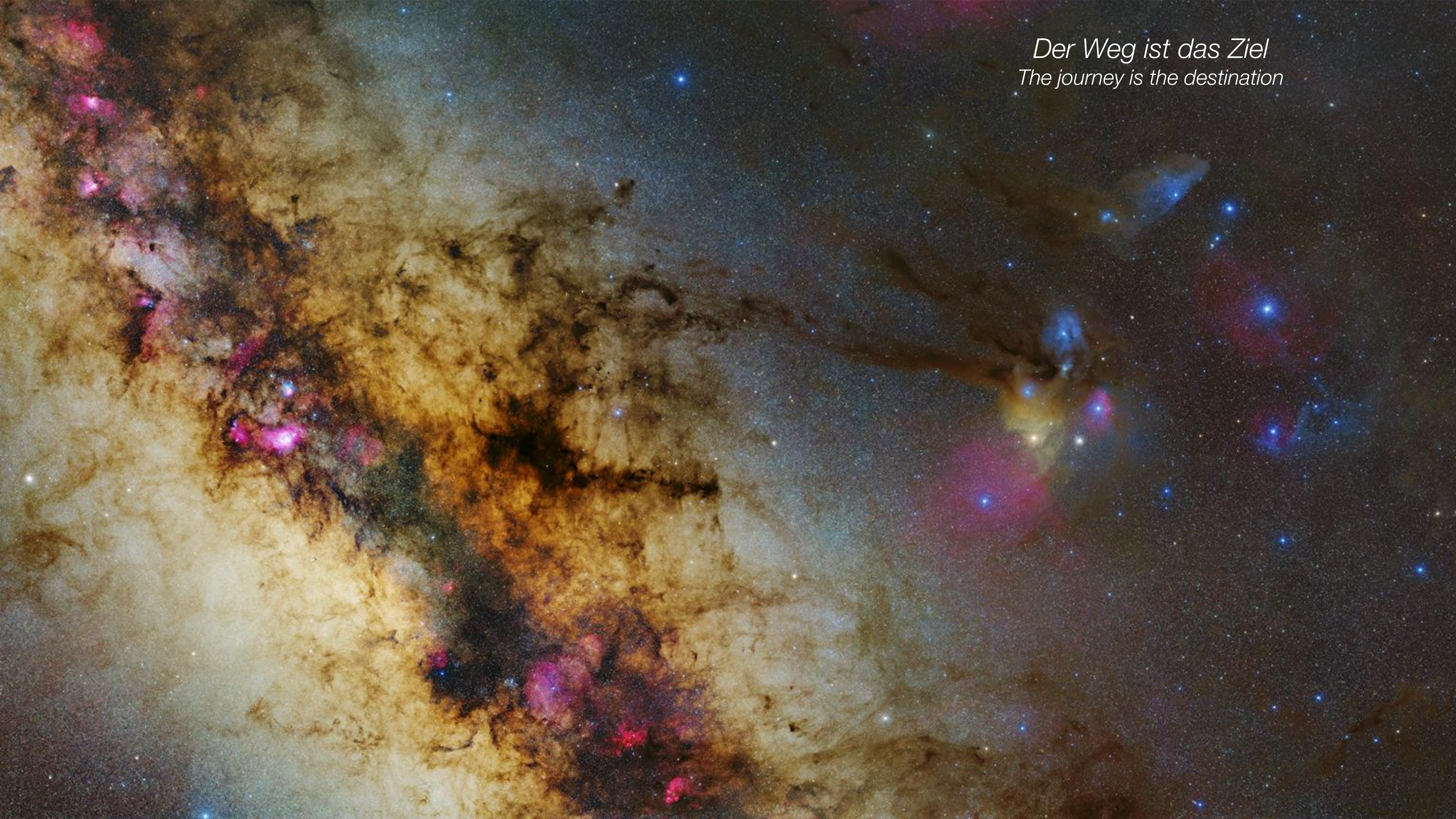
Milky Way
1x6 Mosaic
San Pedro de Atacama

6Da + 28mm
04.2023
6.3h total


Der Weg ist das Ziel
The journey is the destination

Der Weg ist das Ziel

The journey is the destination




Thank you very much!
Gabriel Rodrigues Santos
gabrielrsantos99@gmail.com
https://www.astrobin.com/users/grsotnas
grsotnas
CEDIC
Deepsky Widefield Mosaics
The Fundamentals of Going Deeper, Wider and Larger
CEDIC 2024, Linz, Austria, 24 March 2024