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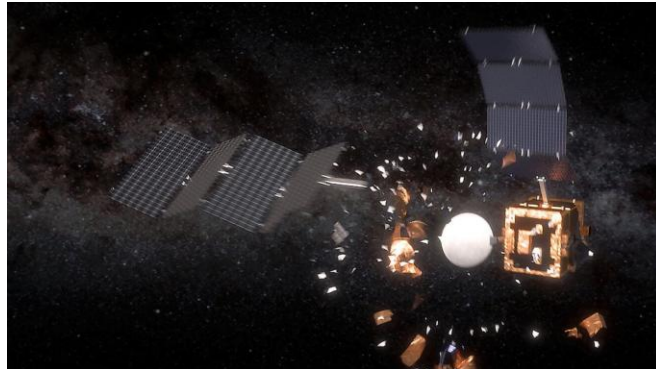
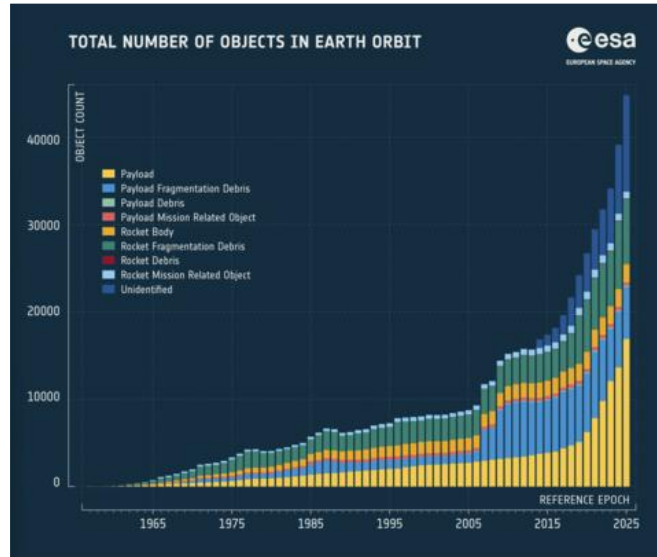
Astrometry of Resident Space Objects with Event- Based Cameras

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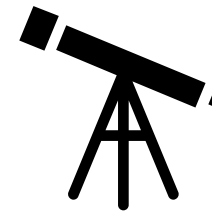
Piazzì 200, Sep 30, 2026, Palazzo Steri, Palermo

The Space Surveillance and Tracking context

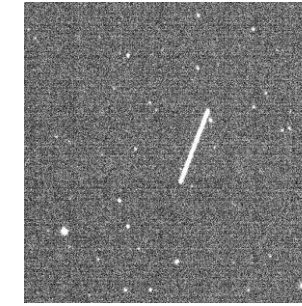


Credits: ESA

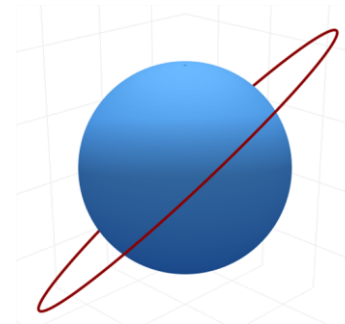
1. Observation



2. Photographic image

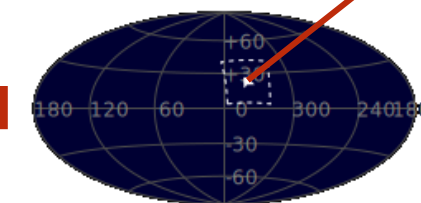


(RA, DEC, t)



4. Orbit determination

3. Target's astrometry



Observing RSOs in Low Earth Orbit (LEO)

→ apparent motion up to 1 deg/s w.r.t. a ground-based observer, even higher for a spaceborne one

Exposure time is a critical parameter to tune in order to catch the target...

... but what if we change the way we encode visual information?

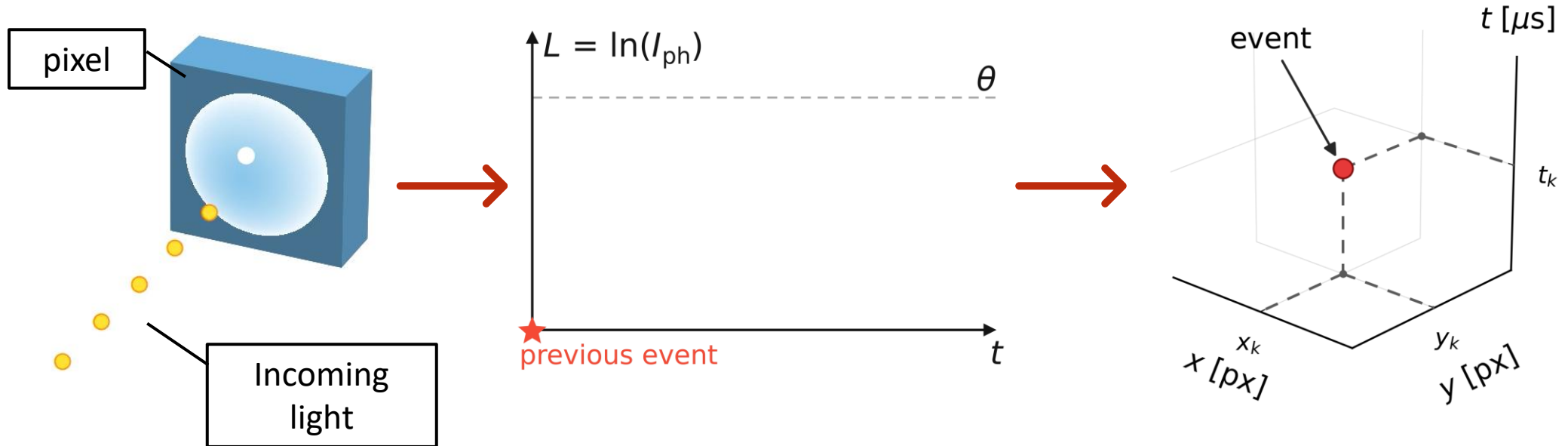


EVENT-BASED CAMERAS



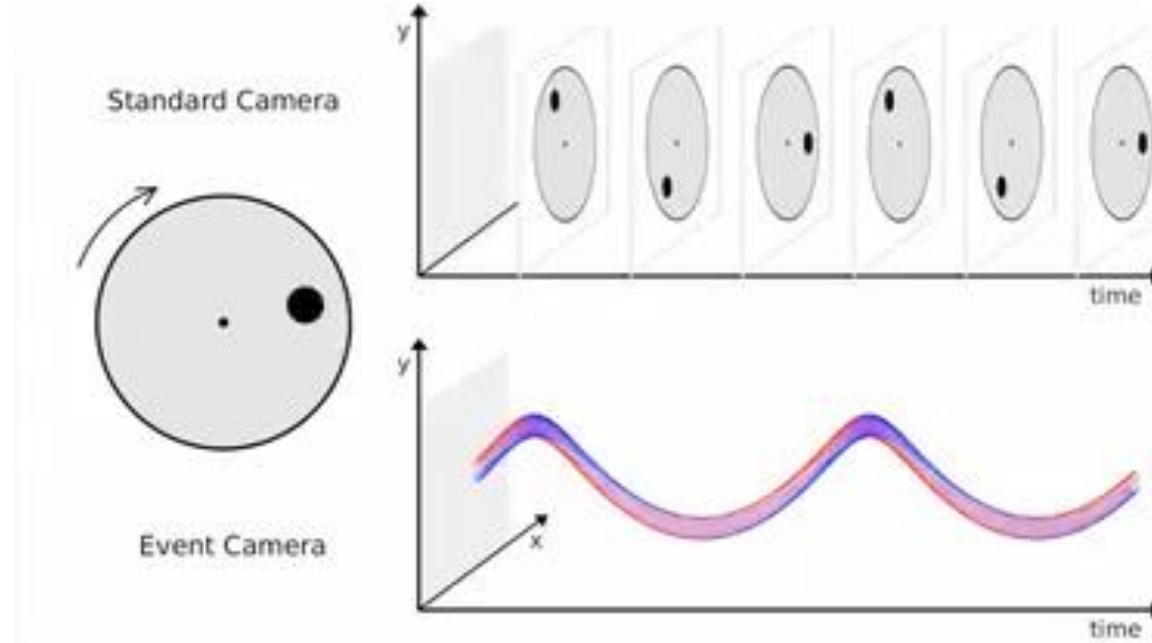
The event-based vision paradigm

- Each pixel is continuously receptive to incoming light as long as the sensor is operative, and it independently and asynchronously records only brightness changes, called events, with microsecond resolution
- Moving objects are easily detectable, while static ones are almost invisible and not recorded



The event-based vision paradigm

- Instead of a conventional 2D image, the output is just a list of asynchronous events. Such list can be visualized as a stream of sparse points in the 3D space xyt describing the pixelwise motion history of the recorded scene



What makes event-based cameras attractive for SST?

Advantages

- Microsecond time resolution
- Contained power consumption and data size
- Small and lightweight cameras



Literature achievements

- Sensor characterization
- Object detection
- Observation of stars and RSOs
- Astrometric calibration



What is missing?

- Astrometric reduction of RSOs

**Is astrometry of resident
space objects with event-
based cameras feasible?**



Observing strategy

- Point towards the sky region where the target RSO is expected to transit
- One camera's sweep of a few seconds to capture both stars and target in a single recording



Credits: Reed et al. (2025)

FOV

FOV ≥ 1 deg, to improve the chance for the target to cross it

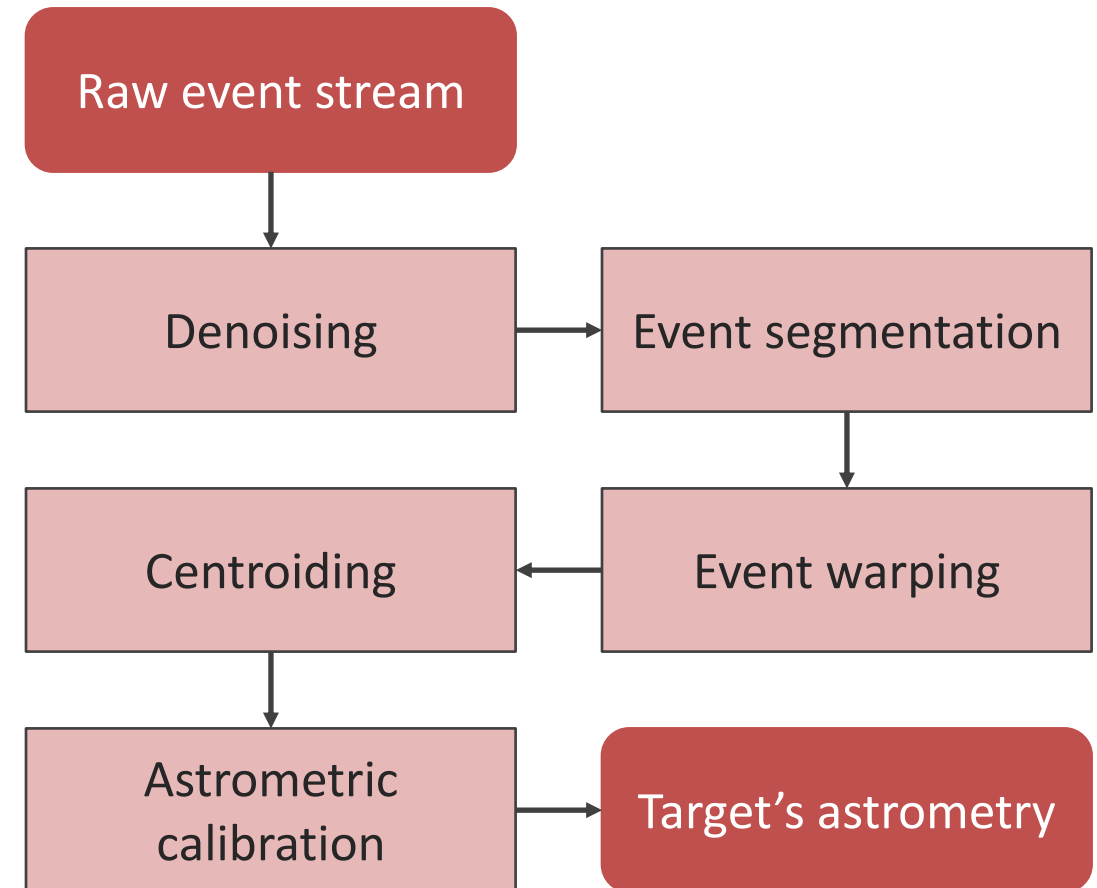
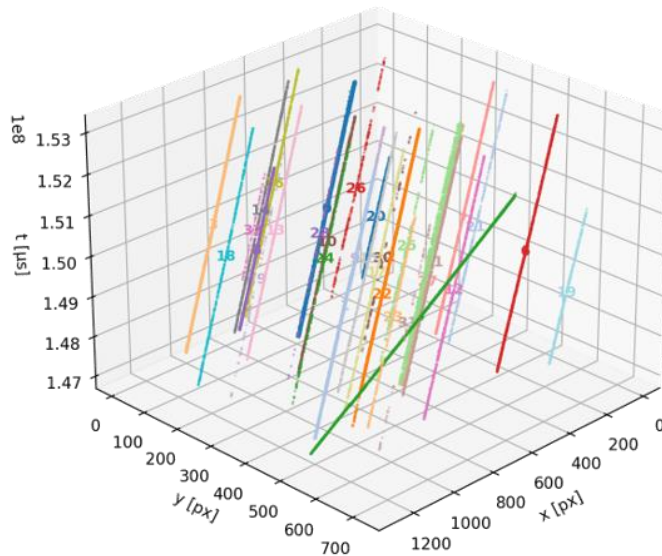
Resolution

Pixel resolution of the 4th generation sensor: 1280 x 720
→ with FOV ≥ 1 deg, pixel scale ≥ 5 arcsec/px

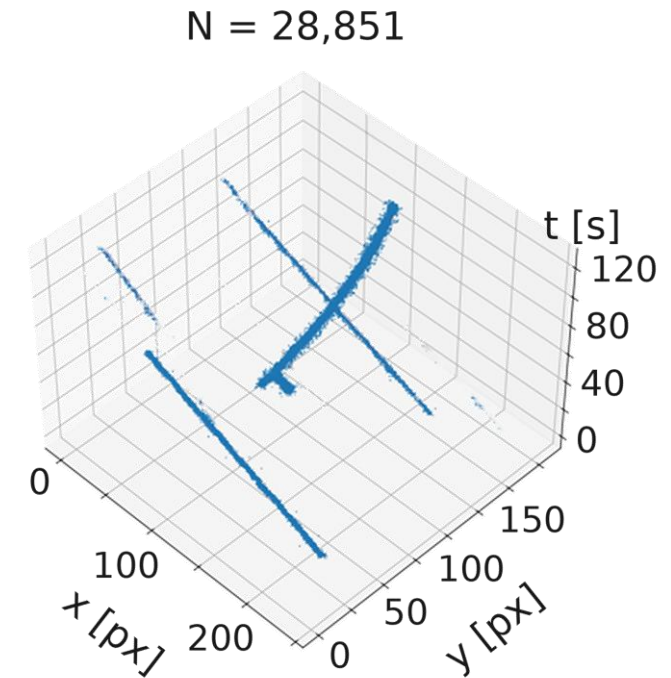
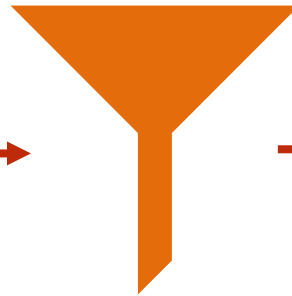
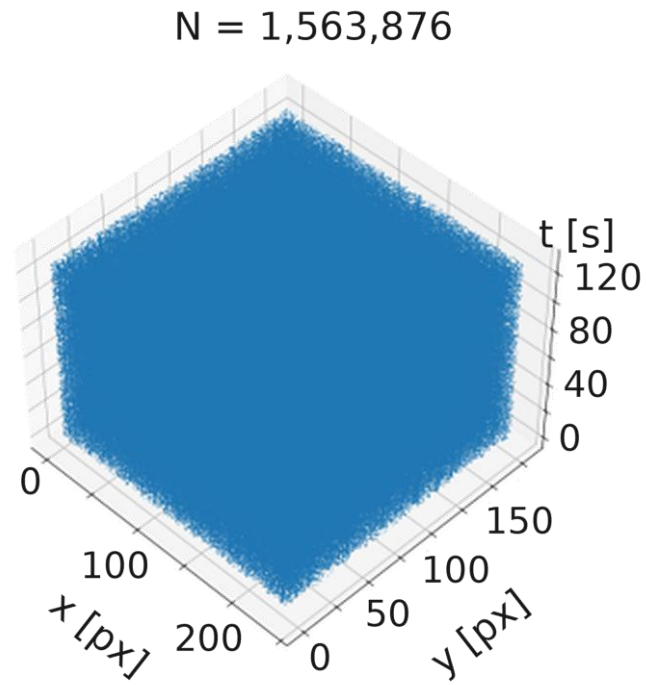
Astrometric reduction pipeline: general design

Assumptions:

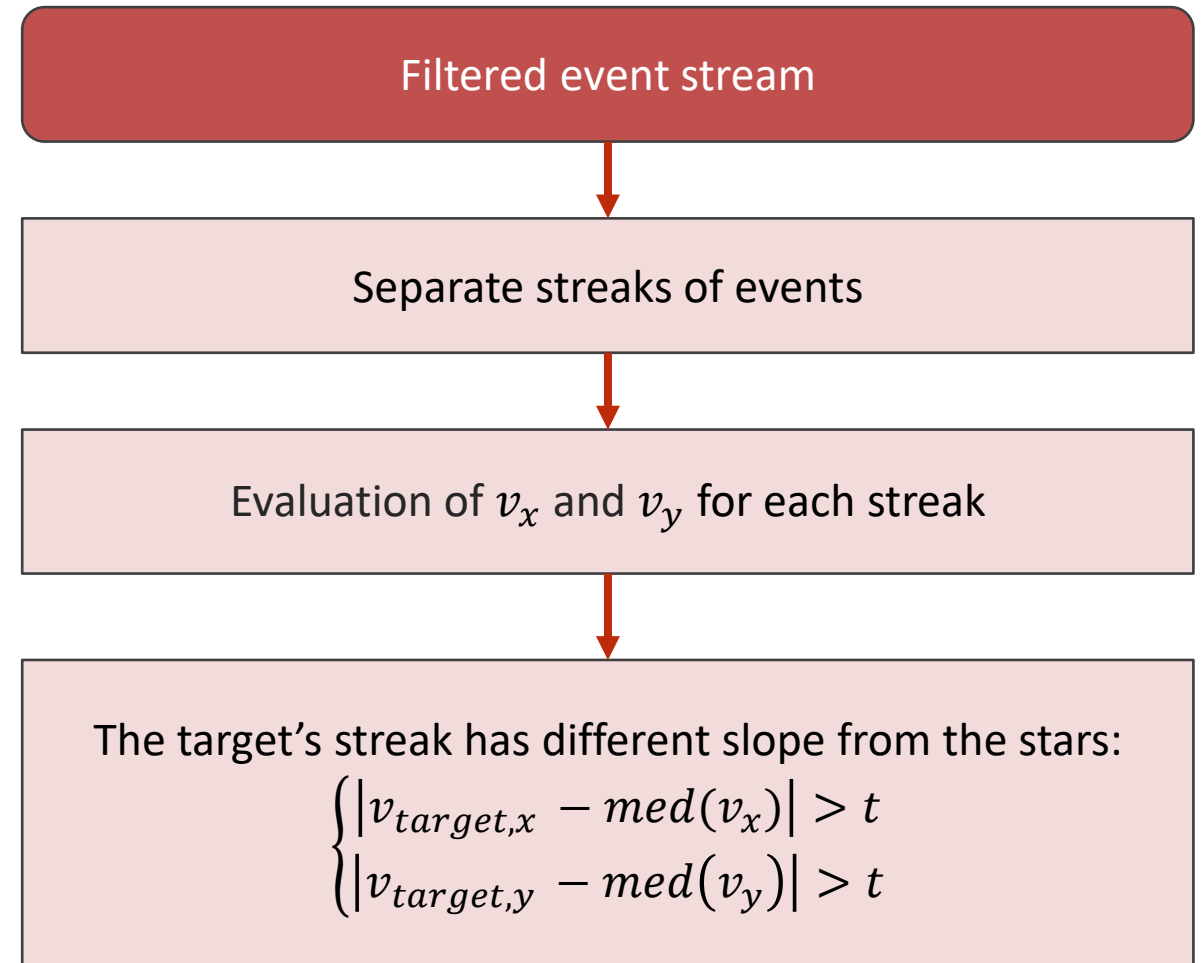
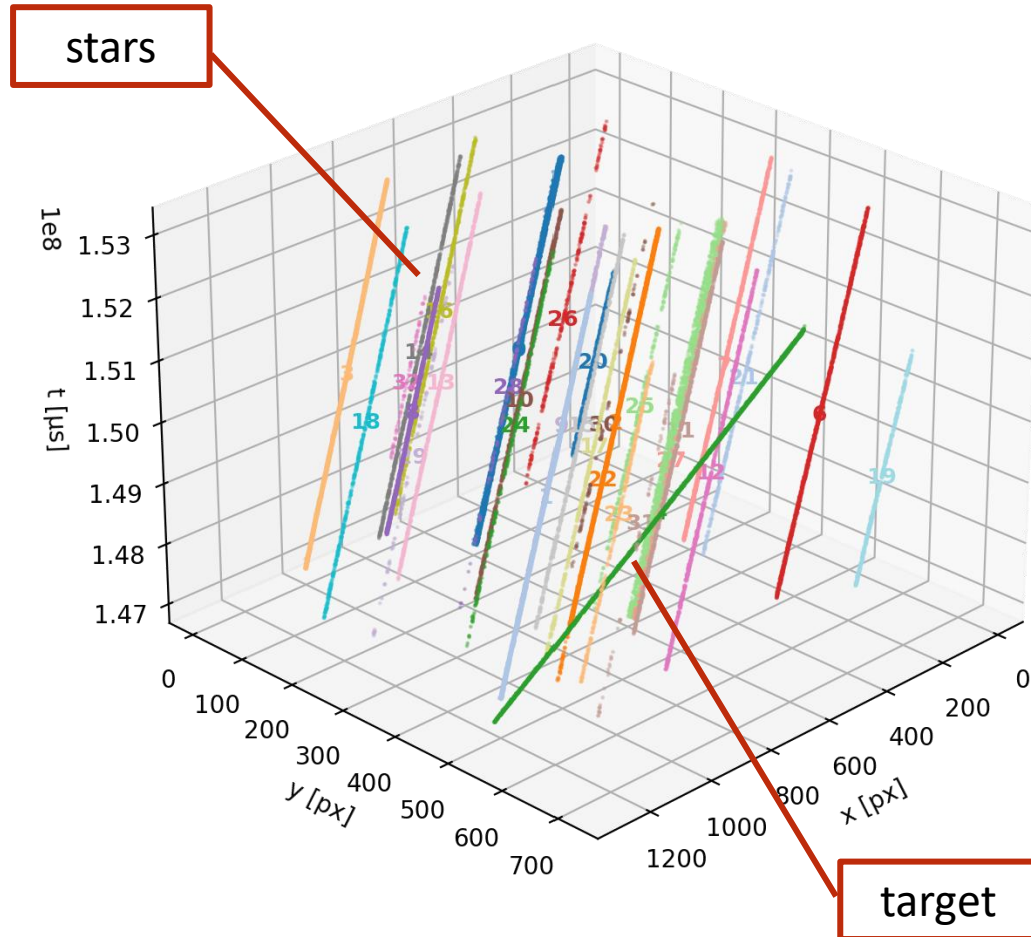
- Objects crossing the FOV are point sources
- Stars and RSOs move along straight lines with constant speed in the FOV → linear streaks of events in the output stream



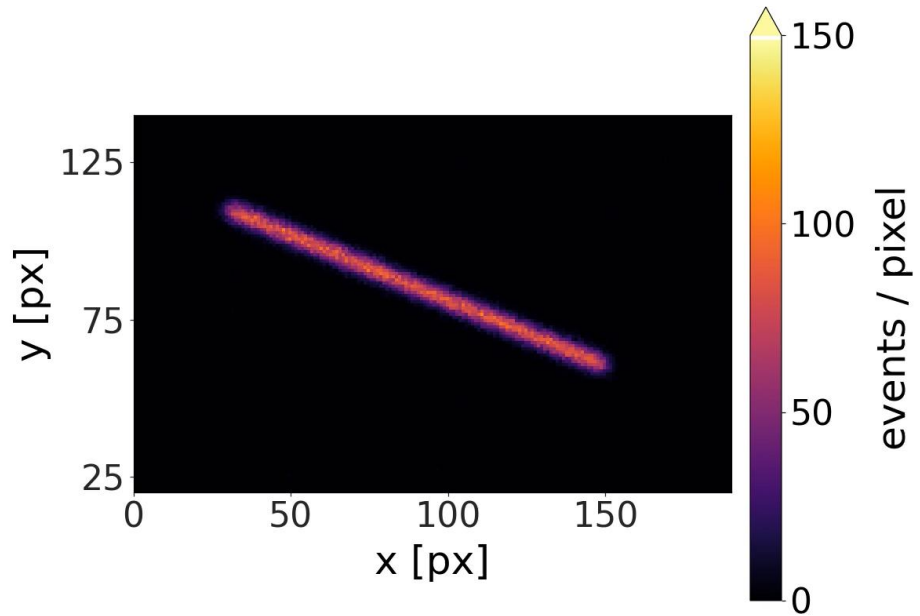
Astrometric reduction pipeline: denoising



Astrometric reduction pipeline: event segmentation



Astrometric reduction pipeline: event warping and centroiding



- Linear uniform motion model:

$$\mathbf{x}_{k,w} = \mathbf{x}_k + \mathbf{v}(t_{ref} - t_k)$$

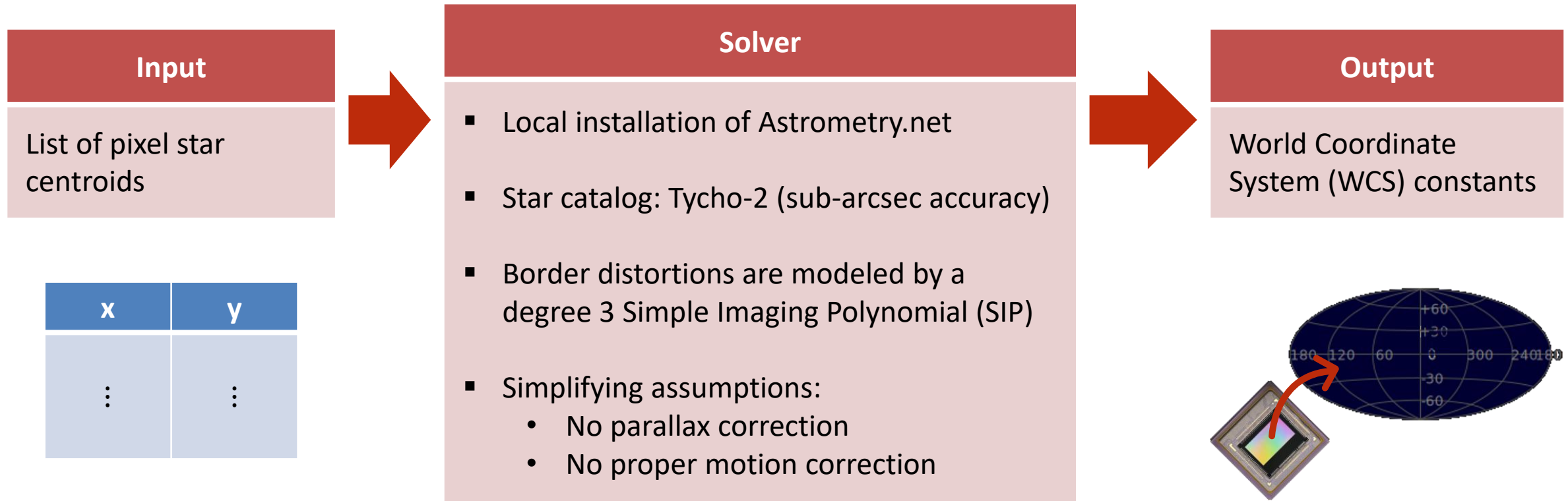
t_{ref} : timestamp of the closest target's event to the FOV's center
→ the target's blob of warped events is less affected as possible by border distortions when computing its centroid

Result: every streak in the 3D stream is mapped into a 2D blob in the xy plane → traditional centroiding and astrometric calibration techniques can be applied

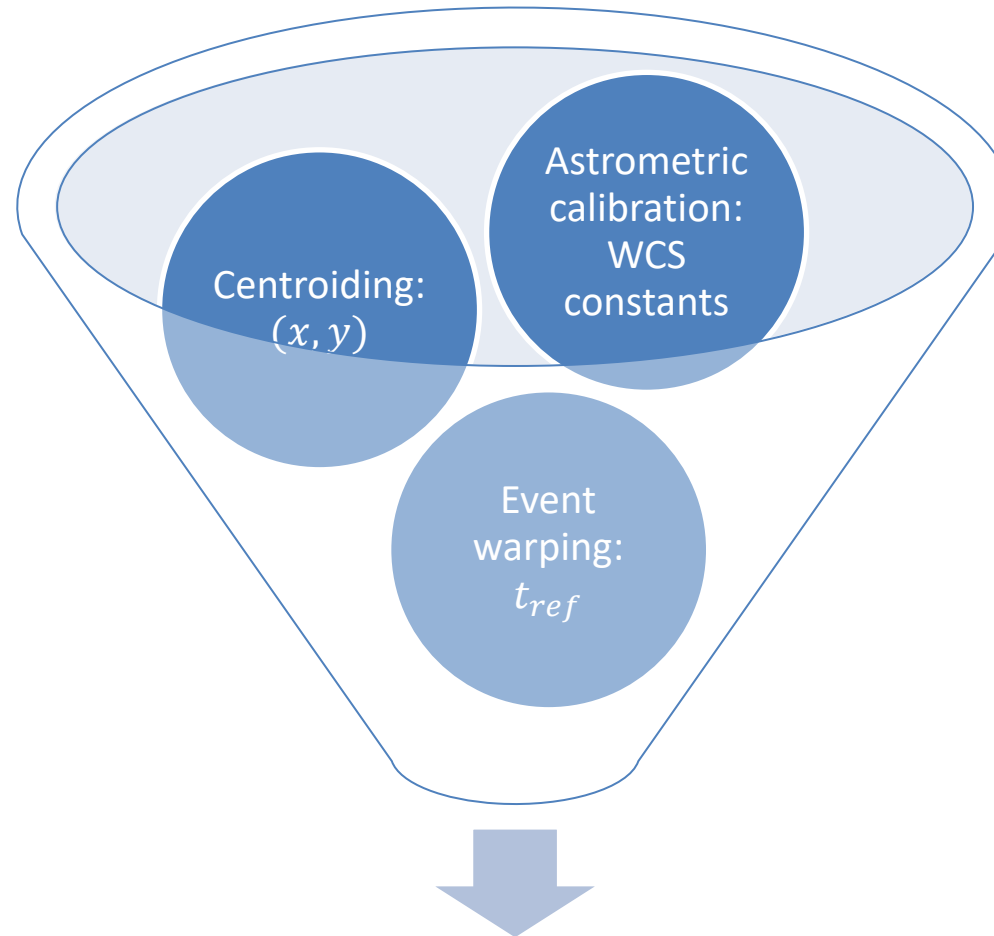
- Centroiding by weighted mean:

$$\mathbf{x}_c = \frac{\sum_{i=1}^N I_i \mathbf{x}_{w,i}}{\sum_{i=1}^N I_i}$$

Astrometric reduction pipeline: astrometric calibration



Astrometric reduction pipeline: output target's astrometry



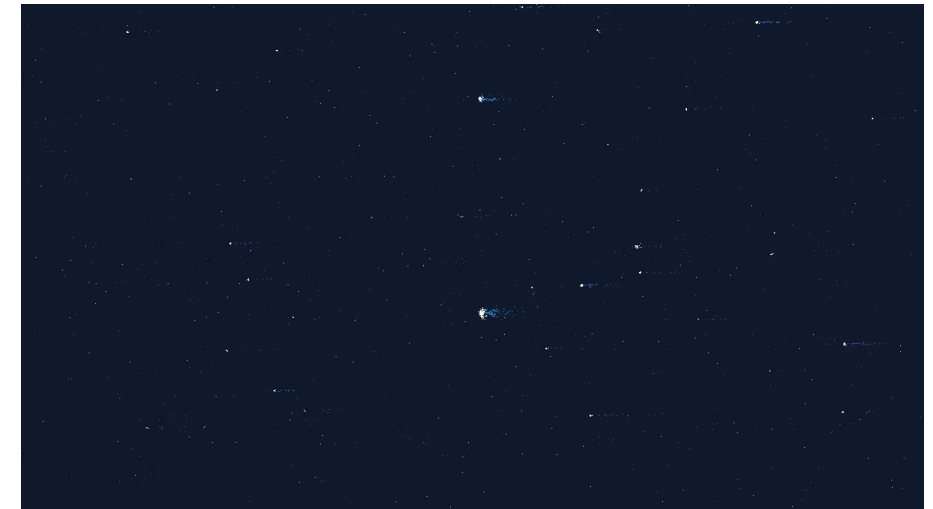
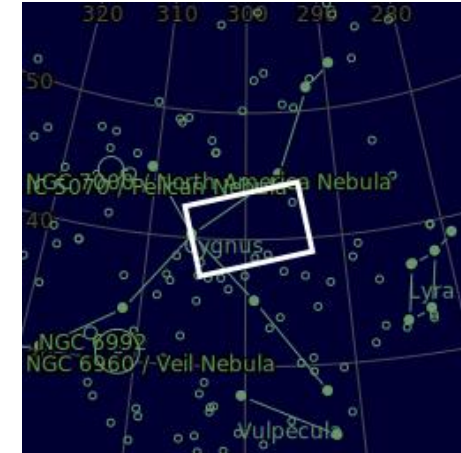
Topocentric measurement:

(RA, DEC, t_{ref})

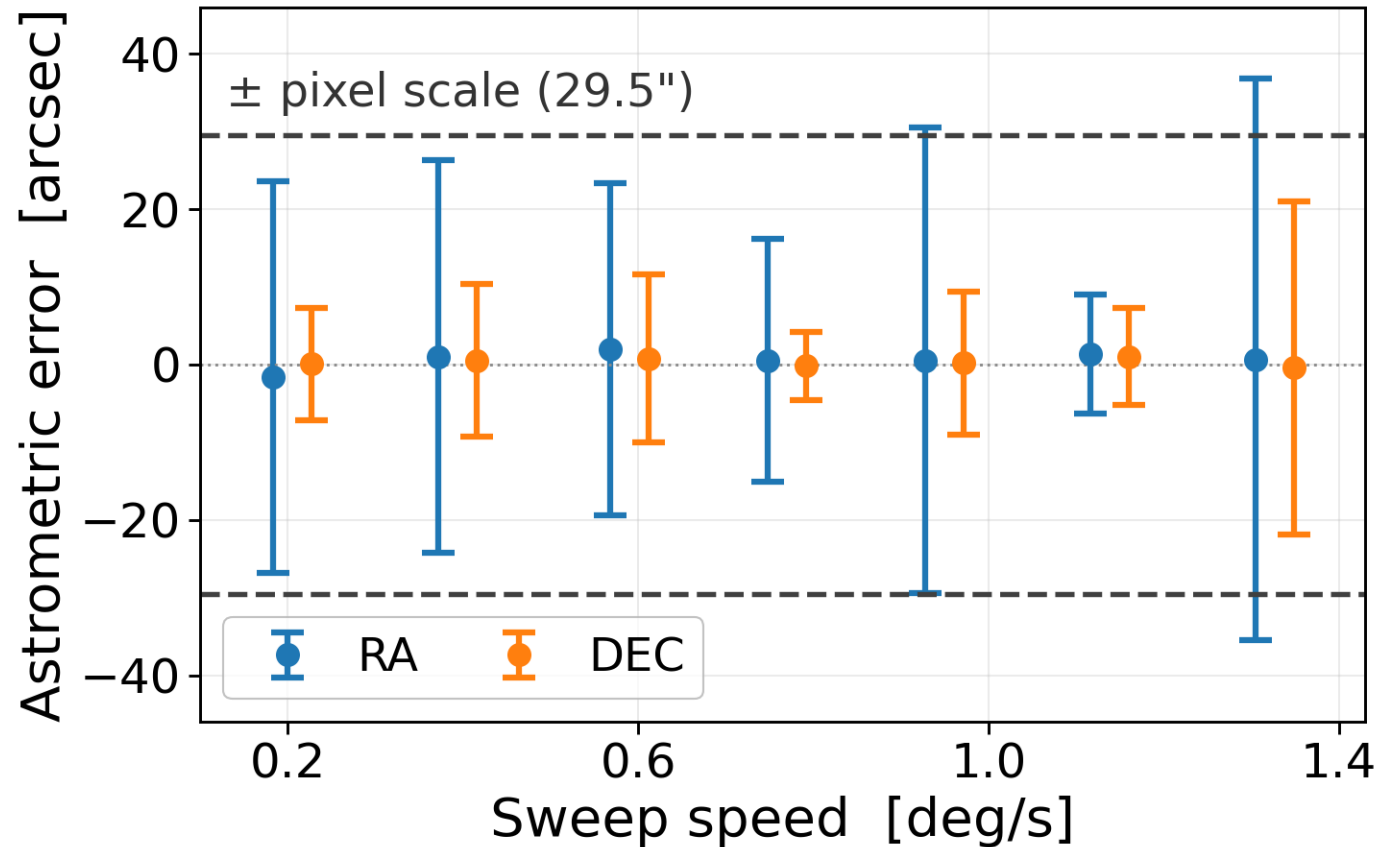
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Validation with real sky observations: dataset

- Recording from the dataset by Reed et al. (2025): sweep maneuver over the same star field in the Cygnus constellation at 10 increasing speed values
- Optical setup:
 - FOV: $10.2^\circ \times 5.7^\circ$
 - Pixel resolution: 1280×720
 - Pixel scale: 29.5 arcsec/px
- Since there is no target in general, the mid-recording time is set as reference for event warping



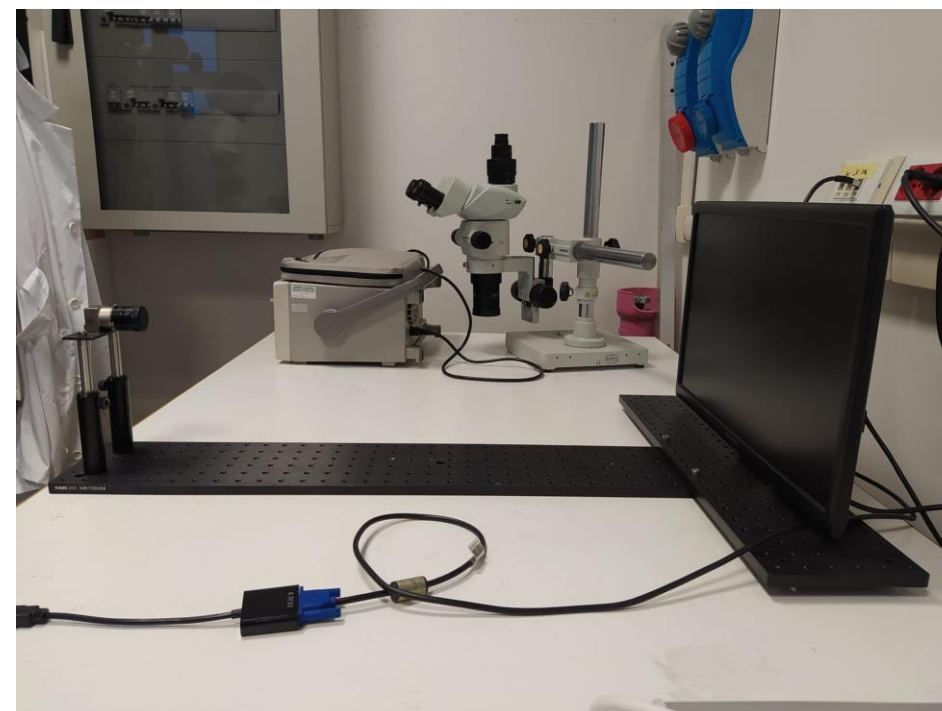
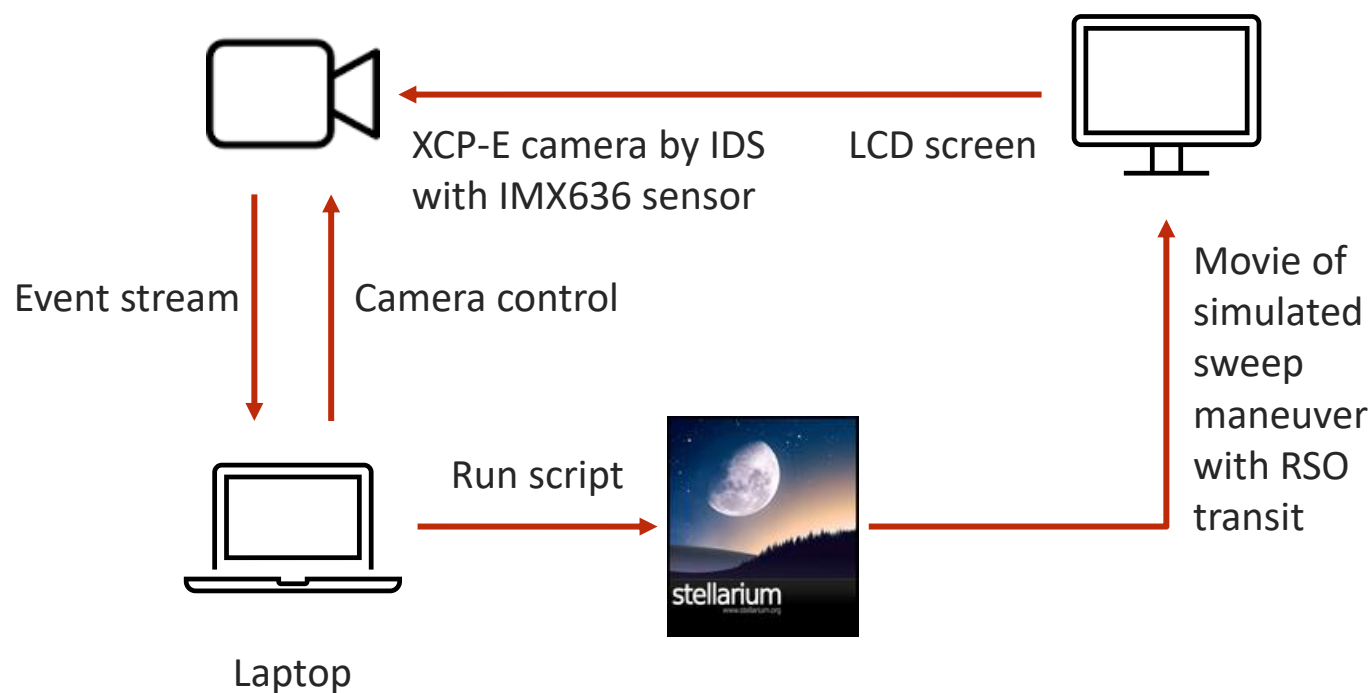
Validation with real sky observations: results



- A solution was obtained for the first 7 sweep speeds, from 0.2 to 1.3 deg/s; above that, the low-pass behaviour of the event-based pixel leaves too few stars
- Mean error below 1 arcsec in RA and DEC, standard deviation in general within the pixel scale, however no clear correlation with the sweep speed

Indoor testbed

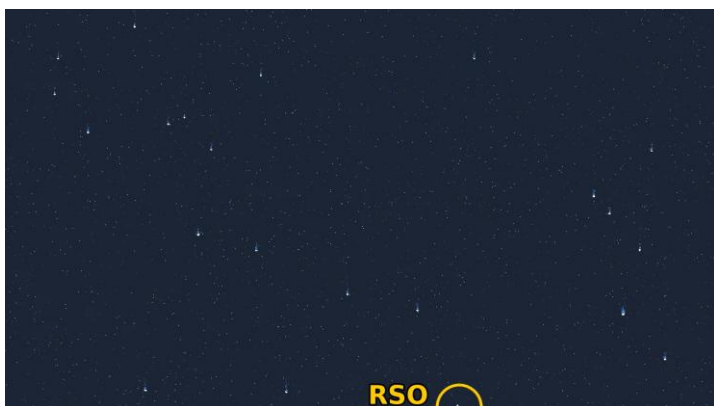
- If the pixel scale decreases, will the pipeline still yield a calibration error within the pixel scale?
- No other public recordings with the same observing strategy and smaller pixel scale → preliminary testbed for indoor simulations



Indoor testbed

Simulated scenario

- FOV: 2 deg
- Pixel scale: 5.9 arcsec/pixel
- Sweep speed: 0.08 deg/s
- target: Sentinel satellite in LEO from ESA Copernicus orbit state vectors ($h \approx 700$ km; apparent motion ≈ 0.6 deg/s)

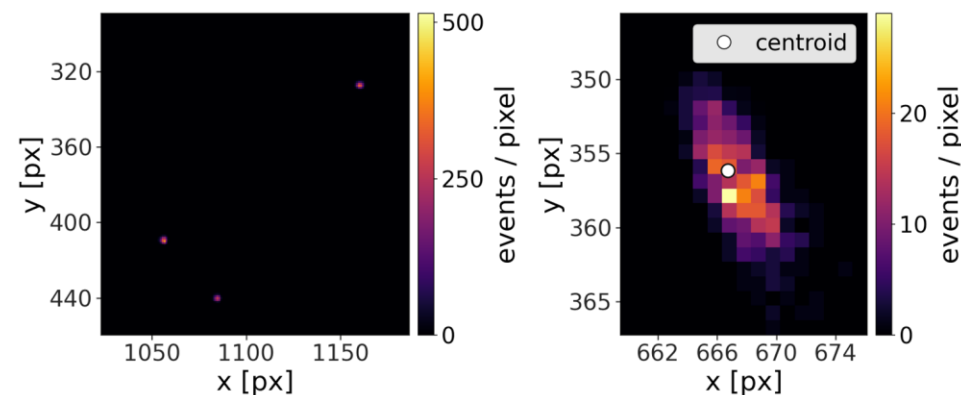


Astrometric reduction pipeline



Astrometric calibration error

- Mean value ~ 1 mas
- Max. standard deviation: 1.882 arcsec $\approx$ three times smaller than the pixel scale
- Remark: the 60 Hz refresh rate doesn't allow for smooth simulation of higher sweep speeds



Conclusions and future directions

Processing pipeline

- Current implementation of event segmentation, warping and centroiding works well with point sources → next: proper processing of both point and extended sources
- Explore neural networks to improve denoising and object detection
- Parallax and proper motion correction to further reduce the astrometric calibration error

Sensor and testbed

- In the dark, the event-based pixel acts as a low-pass filter:
 - fast signals are attenuated
 - the dimmer the object, the larger the delay between on-chip light and output events
- Characterize the time delay for different magnitudes and speeds
- The lower resolution w.r.t. traditional cameras may not allow for precise orbit determination
- More realistic indoor testbed: dark enclosure, collimation lens, high-refresh-rate projector

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