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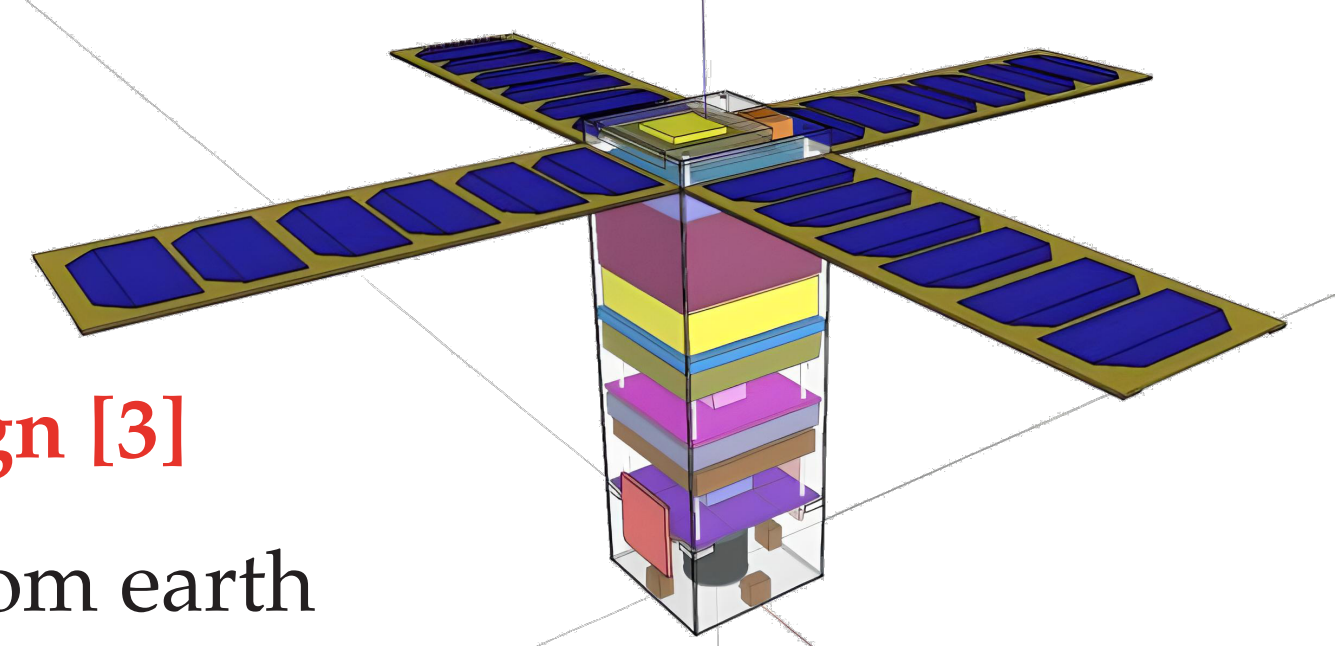
Fast Meteor Detection Toolbox

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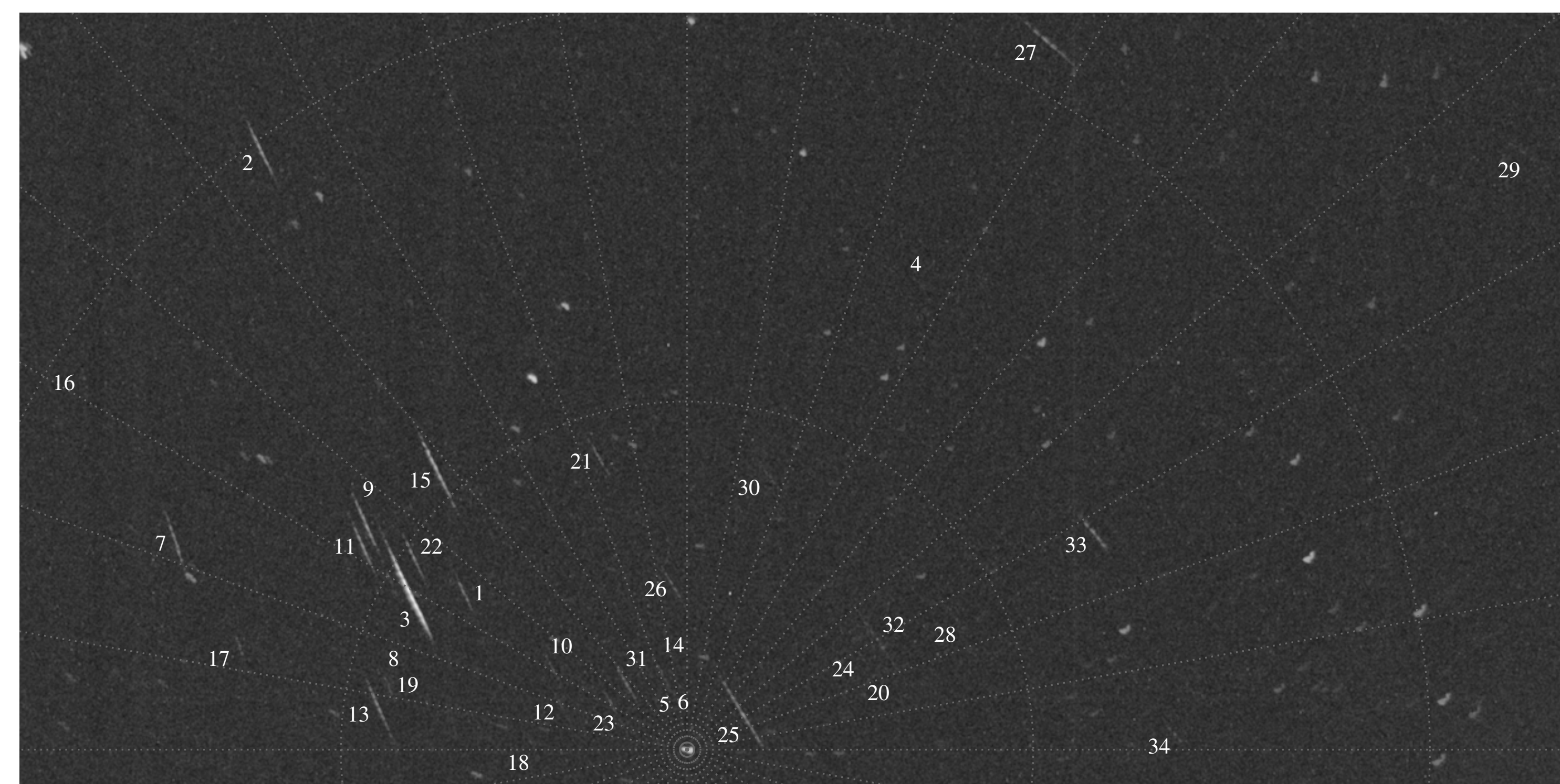


CONTEXT

- **Detection and characterization of meteoroids** and space debris that enter into our atmosphere
 - From satellite (CubeSat) [1, 2]
 - From weather balloon
 - **From aircraft observation campaign [3]**
- Better observation conditions than from earth
- Greyscale input videos, output tracks (= positions of meteors)
- **Real-time constraints & Challenges**
 - Non-stabilized cameras, noisy video sequences
 - Limited computational power: $\lesssim 10$ Watts
 - **Embedded systems** (RPI, Jetson, ...) & RISC architectures [4]
- LIP6/ALSOC & IMCCE joint-team: <https://www.imcce.fr/recherche/campagnes-observations/meteors/2022the>

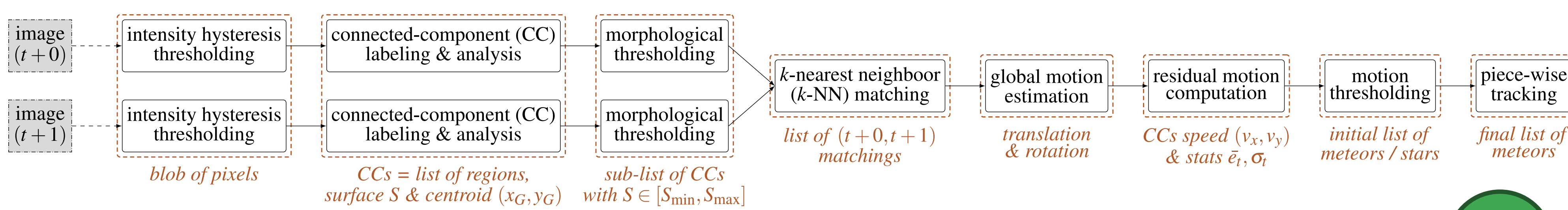


2022 τ -HERCULIDS METEOR CLUSTER



Composite closeup view of the 34 τ -Herculids meteor cluster (duration: 7.5 s) from an airborne observation campaign [3]. Center: *Ursa Minor* constellation.

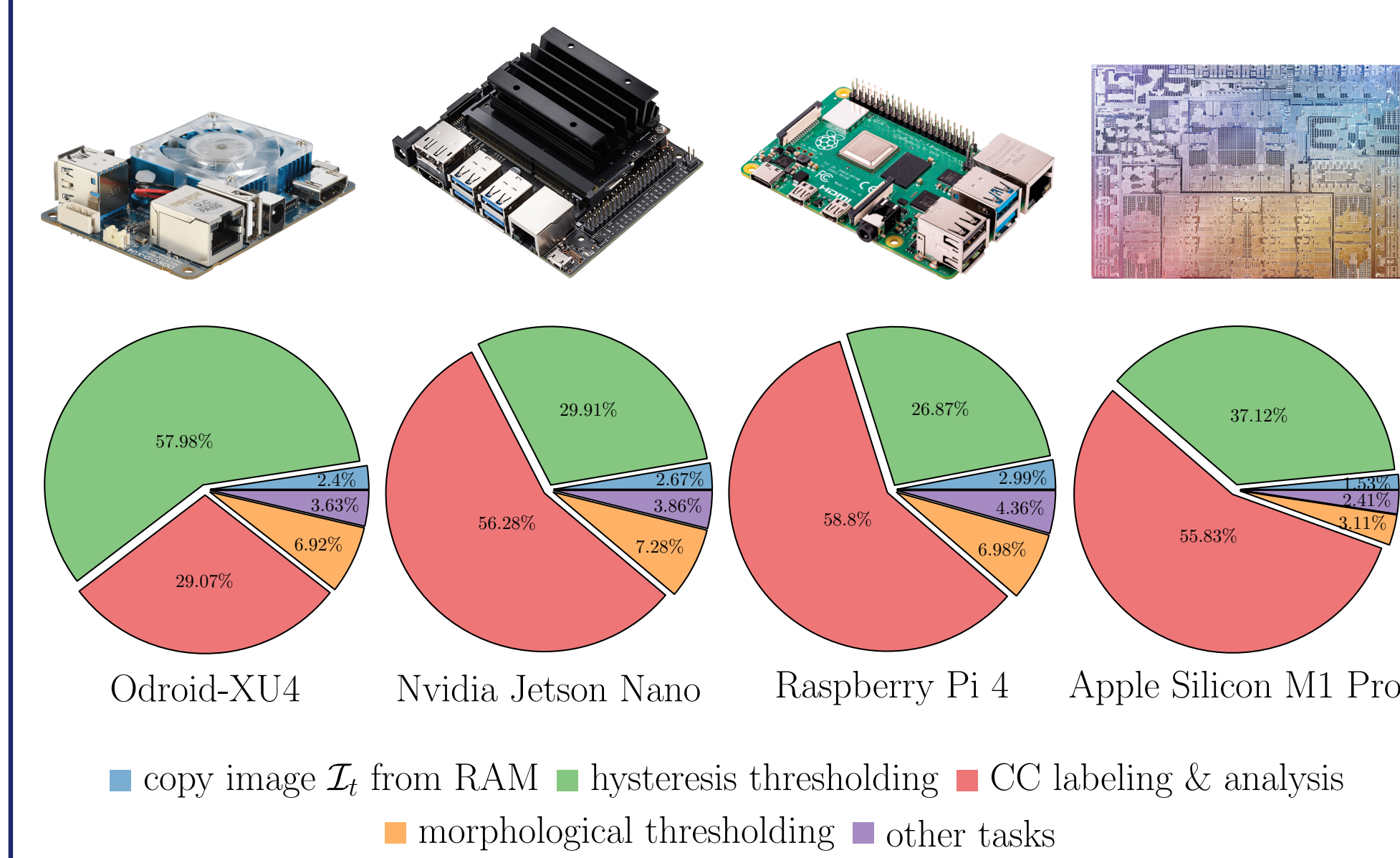
FMDT: COMPUTER-VISION DETECTION CHAIN



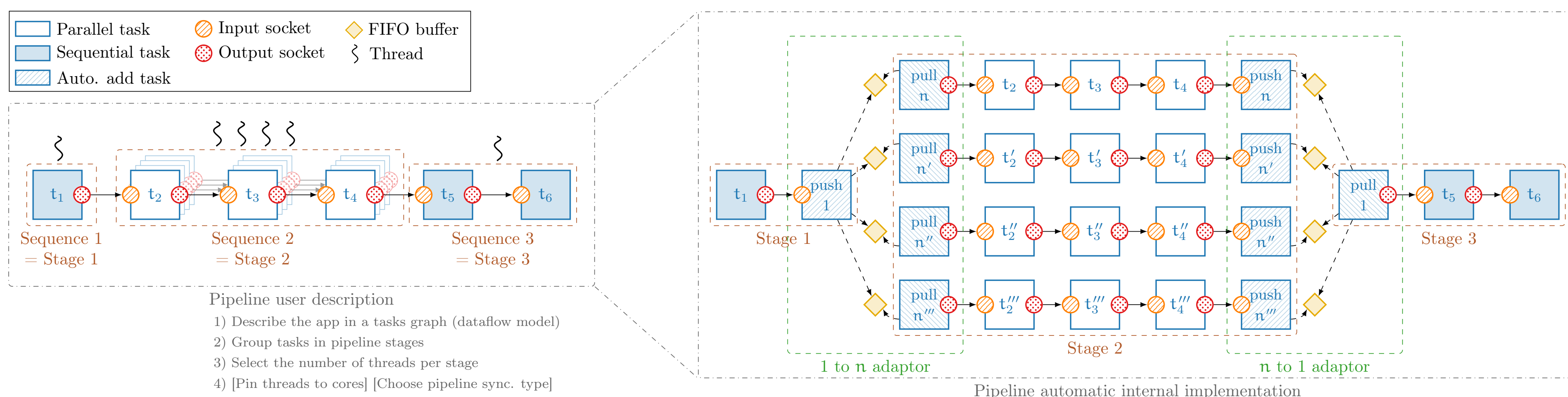
- Source code available on GitHub: <https://github.com/alsoc/fmdt>



SEQUENTIAL TIME DISTRIBUTION



TASKS GRAPH AND MULTI-THREADING WITH AFF3CT

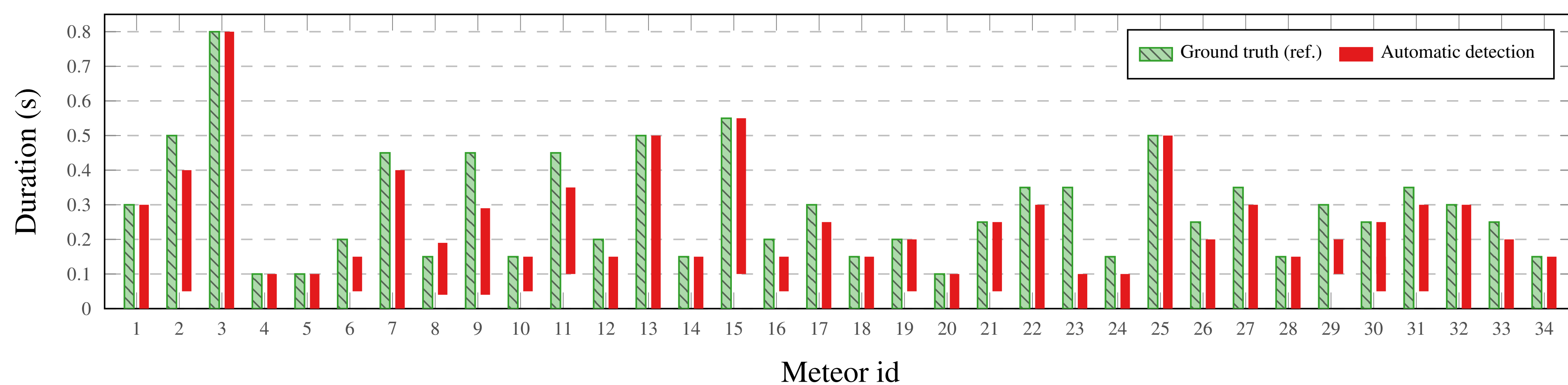


AFF3CT pipeline parallel construct.

A **3-stage pipeline** using the AFF3CT DSEL [5] has been implemented:

- 1) Copy image \mathcal{I}_t (sequential stage)
 - 2) Costly processing tasks from hysteresis to morphological thresholding (**parallel stage**)
 - 3) Lightweight processing tasks from k -NN to tracking (sequential stage)
- Design choice: most tasks of stage 3 are parallel but they are run on a single thread
 - Image processing results from \mathcal{I}_t are **memorized** for iteration $t + 1$
 - **Dependency**: stage 3 tasks require memorized $t - 1$ statistics
 - **Tracking is mainly a sequential task**, history management of statistics

METEORS AUTOMATIC DETECTION EFFICIENCY



REFERENCES

- [1] N. Rambaux et al. Meteorix: a CubeSat mission dedicated to the detection of meteors. In *COSPAR*, 2018.
- [2] M. Millet et al. Meteorix: High performance computer vision app. for Meteor detection from a CubeSat. In *COSPAR*, 2022.
- [3] J. Vaubaillon et al. A 2022 τ -herculid meteor cluster from airborne experiment: automated detection, characterization and consequences for meteoroids. *Astronomy & Astrophysics*, September 2022. (Submitted).
- [4] L. Lacassagne and B. Zavidovique. Light Speed Labeling for RISC architectures. In *ICIP*. IEEE, 2009.
- [5] A. Cassagne et al. A DSEL for high throughput and low latency software-defined radio on multicore CPUs. *Wiley Concurrency and Computation: Practice and Experience*, July 2022. (Submitted).

EXPERIMENTATION RESULTS

- Video resolution: **1920x1200 (HD)**
- GNU compiler: `-O3 -march=native`
- **Odroid-XU4** – Feb. 2016 – 28 nm proc.
 - 4 \times **LITTLE ARMv7 Cortex-A7** CPU @ 1.4 GHz
 - 4 \times **Big ARMv7 Cortex-A15** CPU @ 1.5 GHz

| | Conf. [†] | FPS | \mathcal{L} (ms) | \mathcal{E} (mJ) | \mathcal{P} (W) |
|------|--------------------|-----|--------------------|--------------------|-------------------|
| Seq. | <i>LITTLE</i> | 7 | 142.6 | 403.7 | 2.82 |
| Seq. | <i>Big</i> | 14 | 70.4 | 274.6 | 3.88 |
| Pip. | 1L/4L/1L | 26 | 361.8 | 153.1 | 4.04 |
| Pip. | 1B/4B/1B | 42 | 216.1 | 159.9 | 6.74 |
| Pip. | 1/8/1 | 59 | 324.0 | 127.5 | 7.53 |
- Nvidia **Jetson Nano** – Mar. 2019 – 20 nm proc.
 - 4 \times **ARMv8 Cortex-A57** CPU @ 1.479 GHz

| | Conf. [†] | FPS | \mathcal{L} (ms) | \mathcal{E} (mJ) | \mathcal{P} (W) |
|------|--------------------|-----|--------------------|--------------------|-------------------|
| Seq. | – | 34 | 29.0 | 114.9 | 3.93 |
| Pip. | 1/2/1 | 66 | 76.5 | 77.8 | 5.21 |
| Pip. | 1/4/1 | 91 | 98.5 | 68.1 | 6.25 |
- **RaspberryPi 4** model B – Jun. 2019 – 28 nm proc.
 - 4 \times **ARMv8 Cortex-A72** CPU @ 1.5 GHz

| | Conf. [†] | FPS | \mathcal{L} (ms) | \mathcal{E} (mJ) | \mathcal{P} (W) |
|------|--------------------|-----|--------------------|--------------------|-------------------|
| Seq. | – | 20 | 48.7 | 156.5 | 3.19 |
| Pip. | 1/2/1 | 28 | 181.9 | 130.5 | 3.75 |
| Pip. | 1/4/1 | 30 | 310.8 | 123.4 | 3.79 |
- Apple Silicon **M1 Pro** – Oct. 2021 – 5 nm proc.
 - 2 \times **E-core ARMv8 Icestorm** CPU @ ≈ 2.0 GHz
 - 8 \times **P-core ARMv8 Firestorm** CPU @ ≈ 3.0 GHz

| | Conf. [†] | FPS | \mathcal{L} (ms) | \mathcal{E} (mJ) | \mathcal{P} (W) |
|------|--------------------|------|--------------------|--------------------|-------------------|
| Seq. | <i>E-core</i> | 60 | 16.1 | 34.0 | 2.04 |
| Seq. | <i>P-core</i> | 206 | 4.8 | 30.4 | 6.27 |
| Pip. | 1E/2E/1E | 118 | 42.0 | 19.7 | 2.33 |
| Pip. | 1P/2P/1P | 409 | 12.4 | 25.8 | 10.55 |
| Pip. | 1/8/1 | 1280 | 14.6 | 21.8 | 27.98 |

[†] Pipeline config.: [stage 1, # of threads] / [stage 2, # of threads] / [stage 3, # of threads]
FPS: frames per sec., \mathcal{L} : latency per frame, \mathcal{E} : energy consumption per frame, \mathcal{P} : instant power