

Applied AI for Advancing Space

ESA Advanced Concepts Team

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WE ARE ESA

EUROPE'S GATEWAY TO SPACE

WHAT

22 Member States, 5000 employees

WHY

Exploration and use of space for exclusively peaceful purposes

WHERE

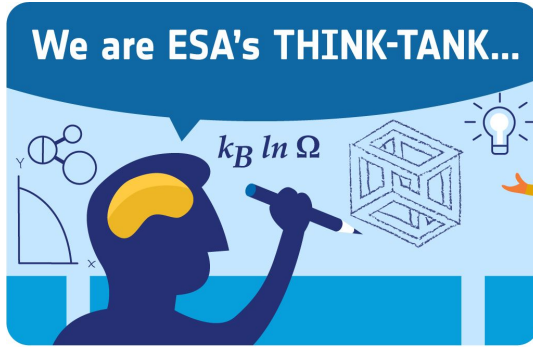
HQ in Paris, 7 sites across Europe and a spaceport in French Guiana

HOW MUCH

€5.72 billion = €12 per European per year



The Advanced Concepts Team (ACT) @ ESA

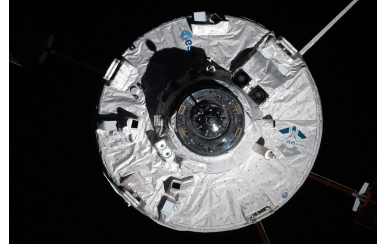


AI applications are pervasive in the space domain



Guidance and Control

Landing, docking, interplanetary transfers, hovering, etc.



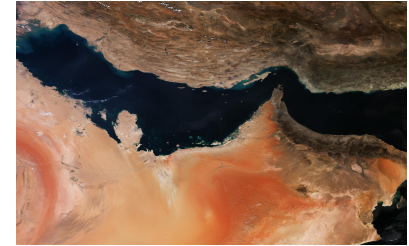
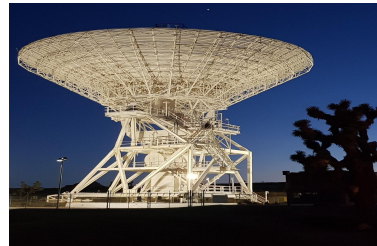
Navigation

Pose estimation, docking, etc.



Payload data processing

Earth observation, space environment, science data, etc.



Ground operations

Health monitoring, Collision Avoidance Systems, etc..

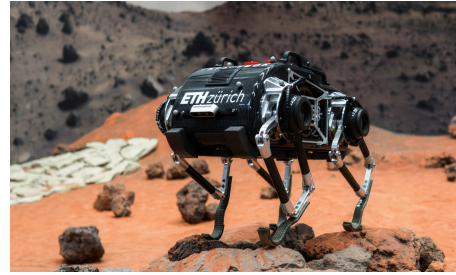


AI applications are pervasive in the space domain



Robotics

Rovers, underwater robotics, path planning and scheduling, automated reasoning, etc.



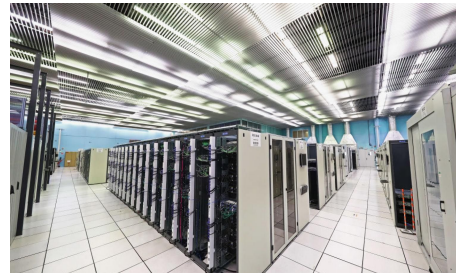
Spacecraft Design

Preliminary phases, multidisciplinary design optimization, concurrent design, etc.

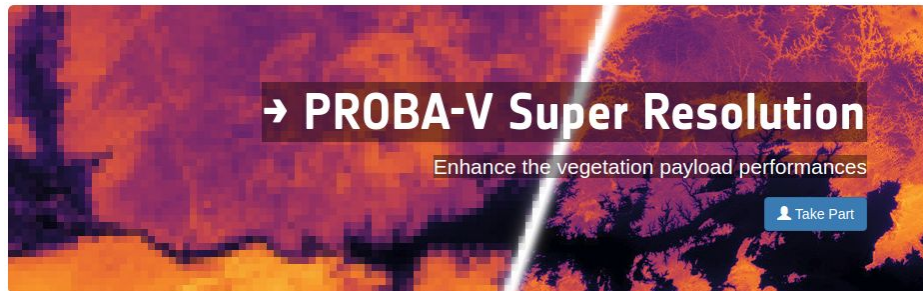


Knowledge management

Ontologies, semantics, document classification, document rating, search, etc.

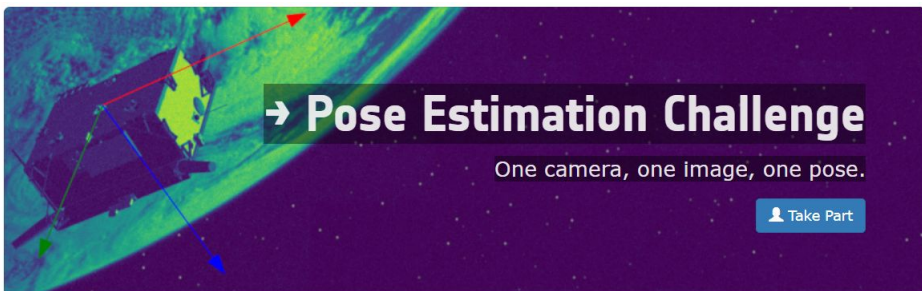


Introduction



→ PROBA-V Super Resolution
Enhance the vegetation payload performances

[Take Part](#)



→ Pose Estimation Challenge
One camera, one image, one pose.

[Take Part](#)

Bonus Round

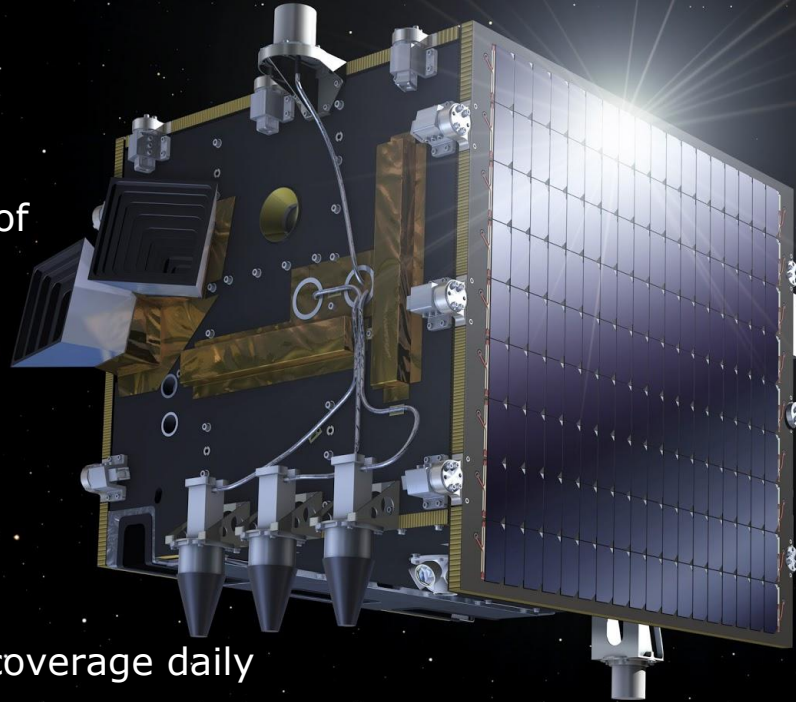
- Collision Avoidance
- Guidance and Control
- Interstellar Space Travel

Proba-V Satellite Image Super Resolution

PROBA-V

Launched 6th May 2013

Space-borne monitoring of
vegetation



Geolocation mean accuracy: $\sim 61\text{m}$
($\pm 50\text{m}$)

FOV / Swath: $102,6^\circ / 2250\text{ km}$

Spectral bands: NIR, RED, BLUE and SWIR

Pixel quality maps for clouds, shadows,
ice, etc.

Products:

- 300m resolution
- Near global (90%) coverage daily

- 100m resolution
- Global coverage ~ 5 days



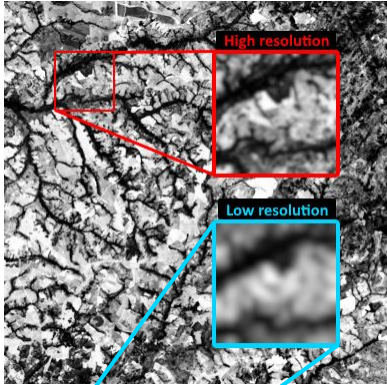
What is Super-resolution?

Single Image SR: Image Processing technique for high fidelity upscaling of single images

Multi Image SR: Fusion of multiple images/frames for the purpose to create a single upscaled image

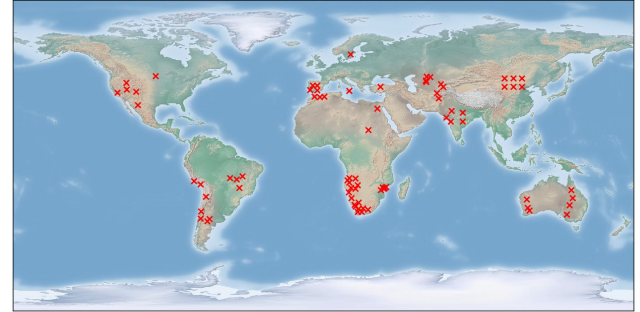


Example taken from: Sunkavalli, Kalyan, et al. "Video snapshots: Creating high-quality images from video clips." *IEEE transactions on visualization and computer graphics* 18.11 (2012): 1868-1879.



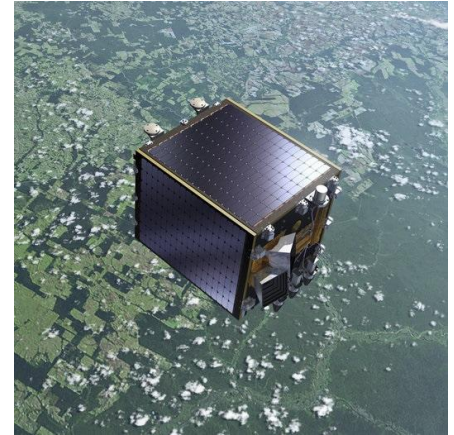
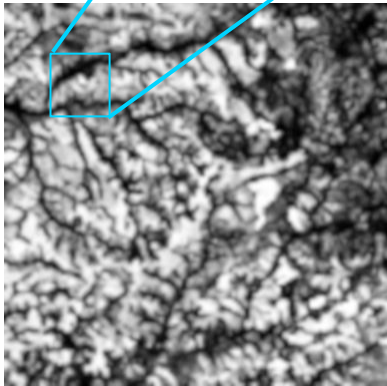
Data from PROBA-V mission:

- 1450 scenes, 74 ROIs
 - ~19 low resolution (LR) per scene
 - one high resolution (HR) target to learn
 - precomputed cloudmaps

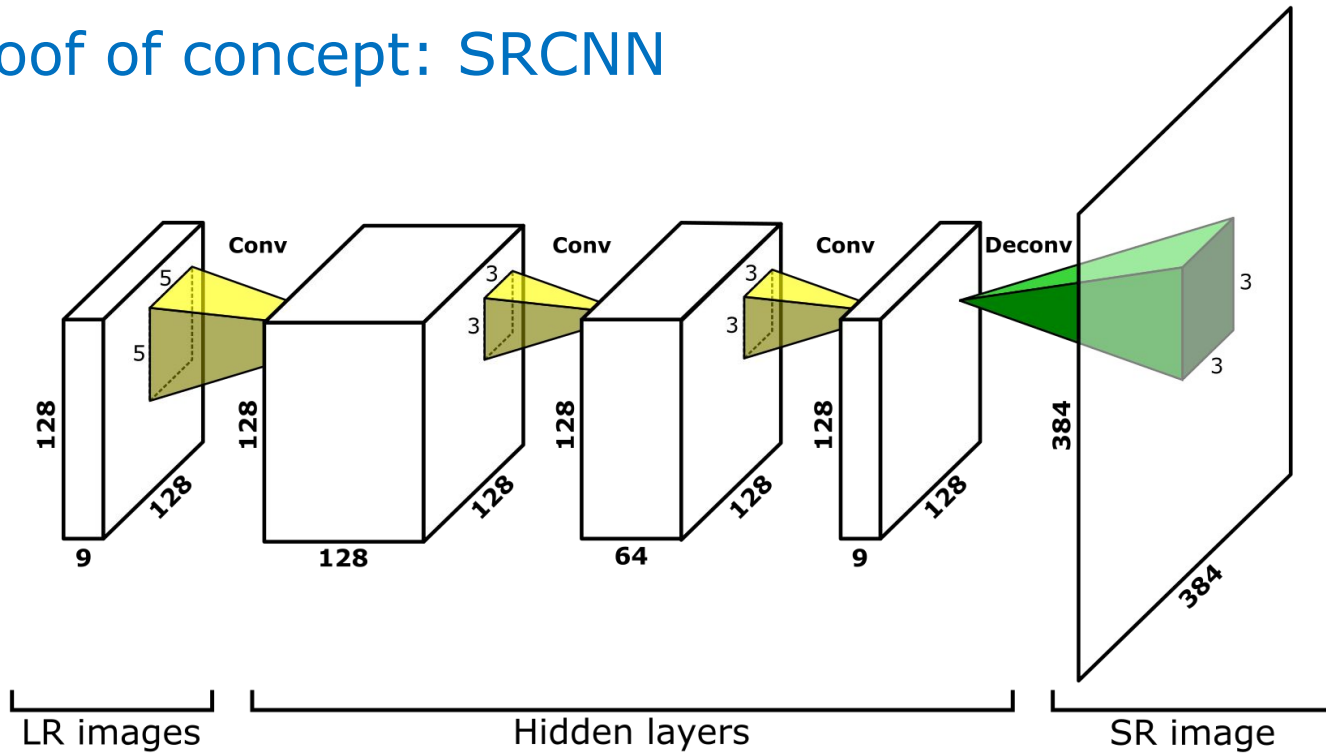


Deep **convolutional neural networks**:

- Exploiting subpixel shifts of LR images
- Goal: Upscaling by a **factor of 3**
- Data-fusion



First proof of concept: SRCNN

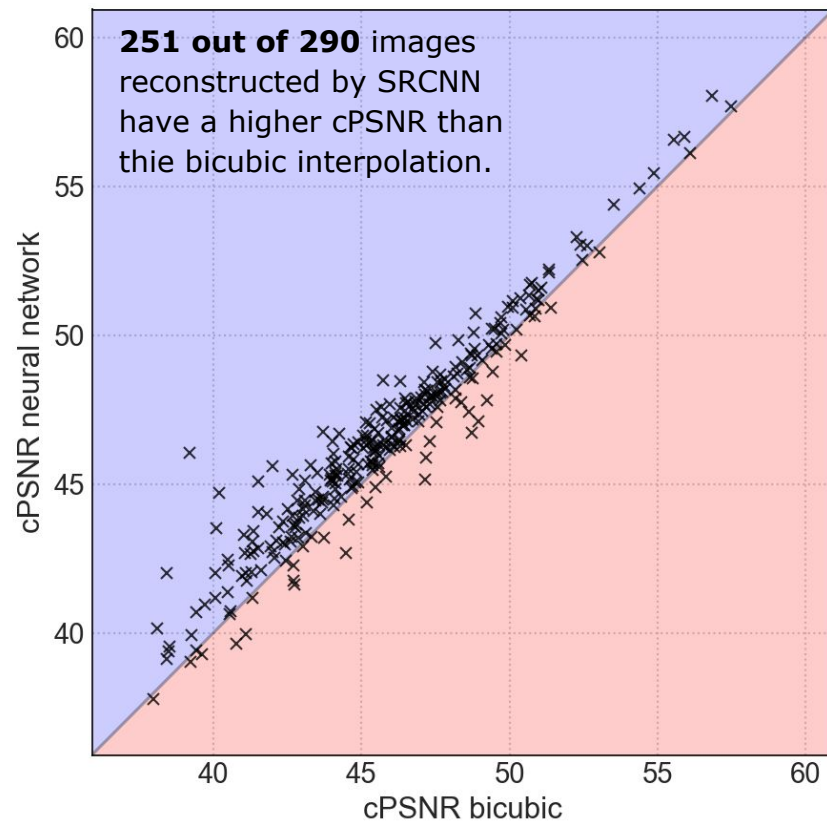
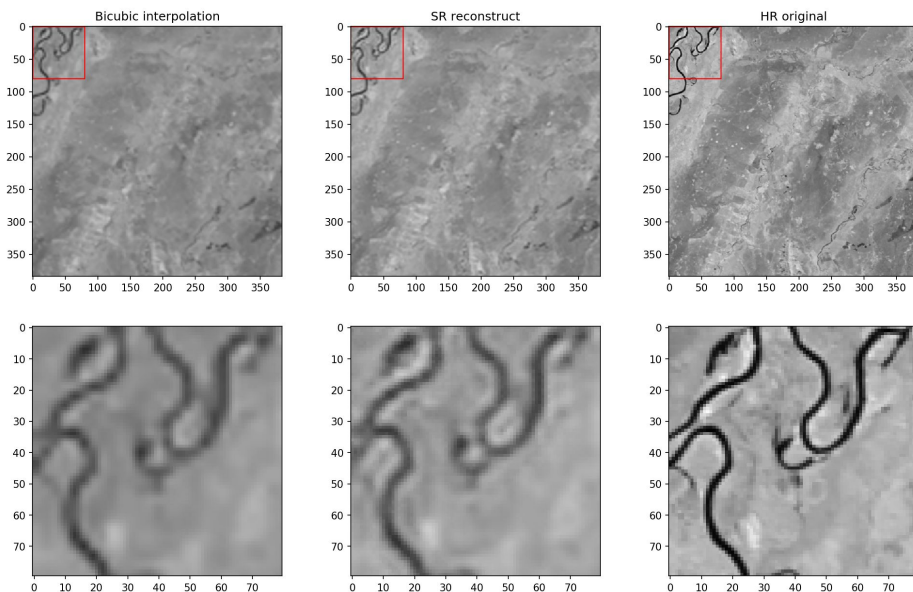


Network inspired by: Dong, C., Loy, C. C., He, K. M., Tang, X. O. "Image super-resolution using deep convolutional networks", IEEE Transactions on Pattern Analysis and Machine Intelligence, 2016, 38(2): 295–307.

Published: Märtens, M., Izzo, D., Krzic, A., and Cox, D. "Super-resolution of PROBA-V images using convolutional neural networks", *Astrodynamics*, 2019. <https://doi.org/10.1007/s42064-019-0059-8>


Results of SRCNN

- Baseline: **bicubic interpolation**
- Quality metric: **cPSNR**
- PSNR modified for
 - image registration
 - bias in pixel intensity
 - clouds



→ PROBA-V Super Resolution

Enhance the vegetation payload performances

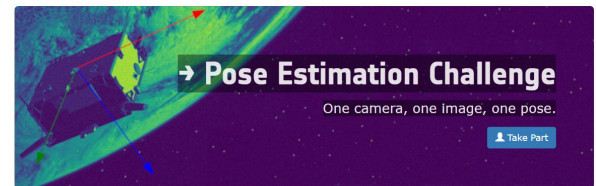
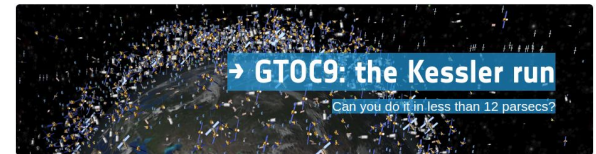
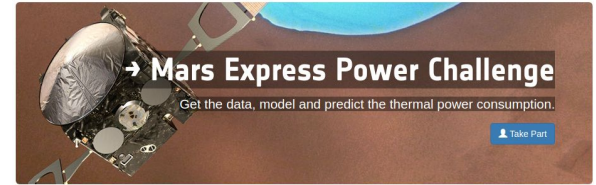
 Take Part

<https://kelvins.esa.int>

Kelvins Portal: compete to excel



- Fundamental to innovation IS asking the correct questions.
- A dedicated competition portal for space AI: Kelvins, reach the absolute zero (error).
- Targeting AI at large, machine learning and data mining communities in particular.
- Portal: <https://kelvins.esa.int/>
- Competitions run so far: Star-trackers, Mars-Express Power consumption, Satellite Pose Estimation over PRISMA, Space Debris Removal tugs (GTOC9), Proba-V super resolution, Star Tracker Identification.



Kelvins Portal: Super Resolution competition



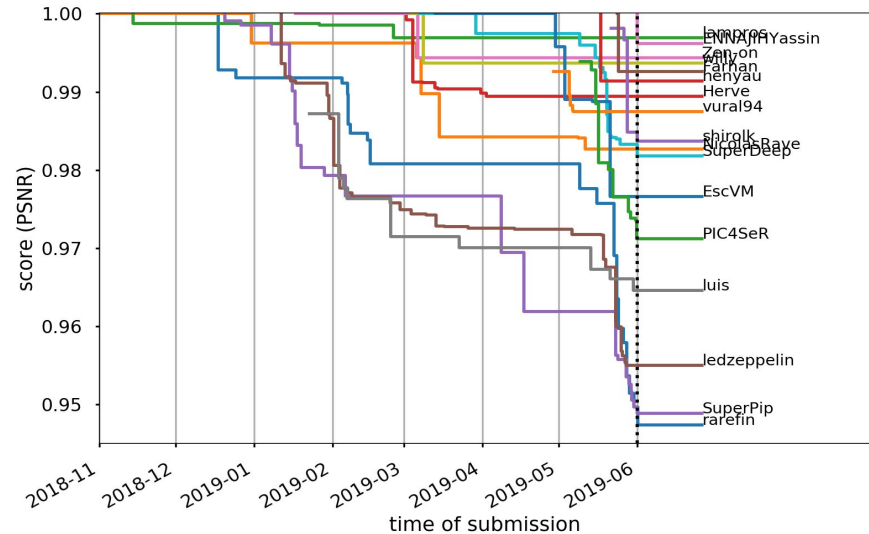
Details on the competition:

- 6 month duration
- 70 registered teams
- 17 teams improved baseline solution
- 412 submissions (on average **2.25 submission per day**)

Name	Submissions	Last Submission	Best Submission	Final Score
SuperPip	43	May 31, 2019, 9:39 p.m.	May 31, 2019, 9:39 p.m.	0.9474466476281652
rarefin	46	May 31, 2019, 11:34 p.m.	May 31, 2019, 11:34 p.m.	0.9477450367529225
ledzeppelin	86	May 31, 2019, 4:58 p.m.	May 27, 2019, 12:25 p.m.	0.9576339586408439
luis	9	May 30, 2019, 7:44 a.m.	May 30, 2019, 7:44 a.m.	0.9626599626701344
PIC4SeR	15	May 31, 2019, 4:59 p.m.	May 31, 2019, 4:59 p.m.	0.9721971077481462

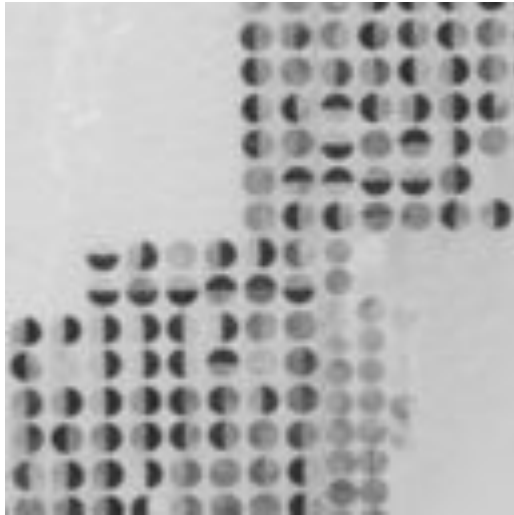
Winner: Team **SuperPip**

Image Processing and Learning Group
Politecnico di Torino, Italy



Results of Kelvins competition

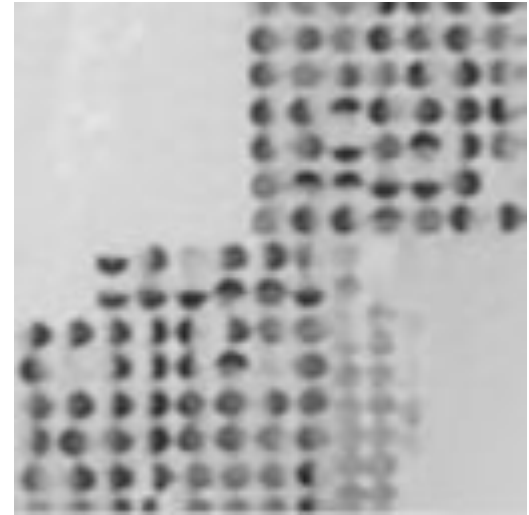
Ground Truth High Resolution



Baseline (bicubic interpolation)



Super Resolution (SuperPip)



References, Links and further outcome



Selected Scientific Publications

Main publication: Märtens, M., Izzo, D., Krzic A., Cox, D.: „*Super-resolution of PROBA-V images using convolutional neural networks*“, in *Astrodynamics*, 2019.

<https://doi.org/10.1007/s42064-019-0059-8>

Competition winner: Molini, A.B., Valsesia, D., Fracastoro, G. and Magli, E.: “*DeepSUM: Deep neural network for Super-resolution of Unregistered Multitemporal images.*” in *IEEE Transactions on Geoscience and Remote Sensing*, 2019.

<https://doi.org/10.1109/TGRS.2019.2959248>

Open Source Software

Luís F. Simões: Embiggen module, a toolkit to work with Proba-V competition data (<https://github.com/lfsimoes/probav>)

Team Rarefin: HighRes-net: Multi Frame Super-Resolution by Recursive Fusion (<https://github.com/ElementAI/HighRes-net>)

Team SuperPip: DeepSUM: Deep neural network for Super-resolution of Unregistered Multitemporal images (<https://github.com/diegovalsesia/deepsun>)

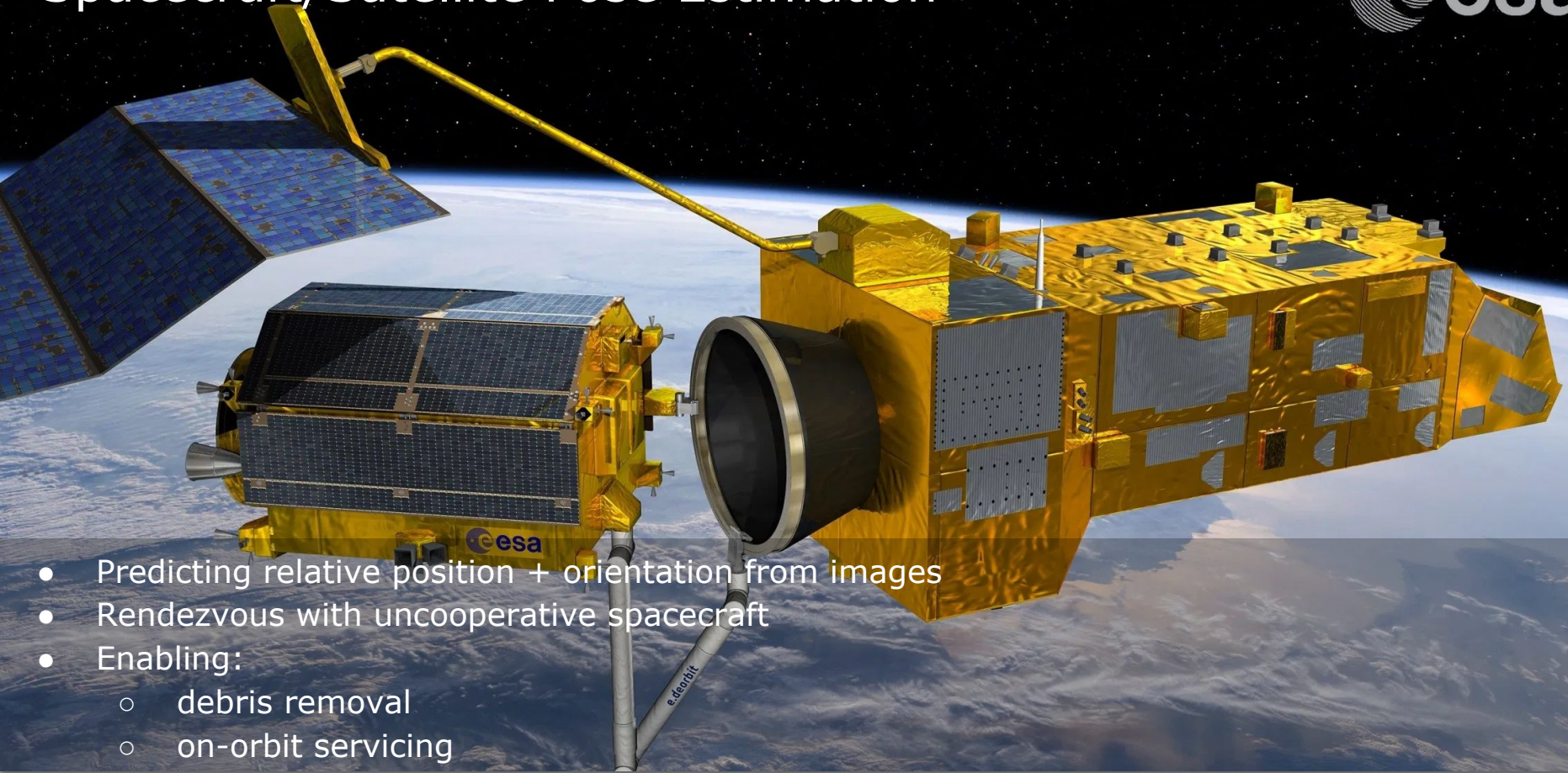
Links

Kelvins competition portal: <https://kelvins.esa.int>

Proba-V distribution portal (by VITO): <https://remotesensing.vito.be/case/proba-v-0>



Spacecraft/Satellite Pose Estimation



- Predicting relative position + orientation from images
- Rendezvous with uncooperative spacecraft
- Enabling:
 - debris removal
 - on-orbit servicing

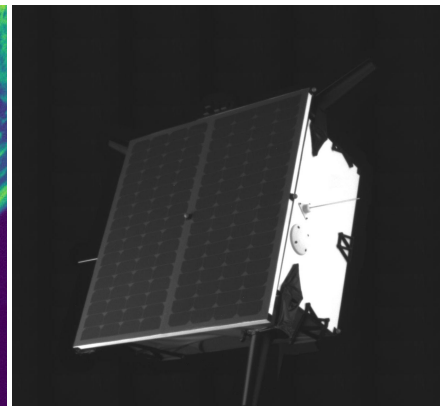
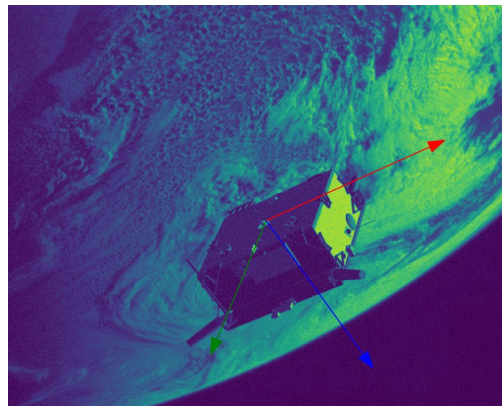
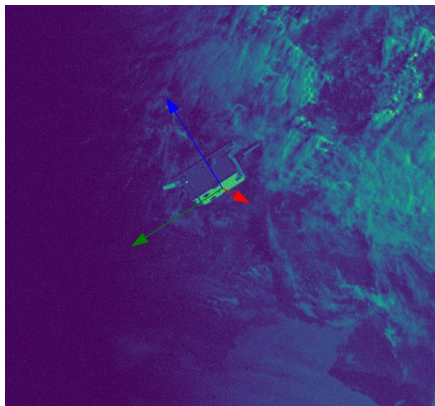
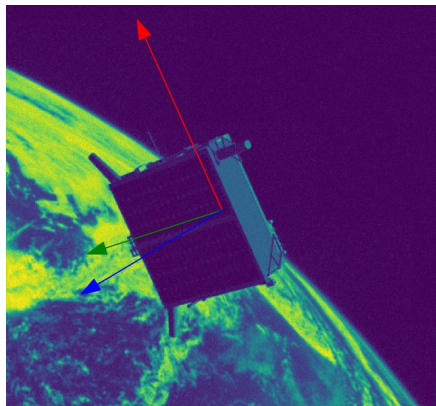


The Dataset



Data from the PRISMA mission (Swedish Aerospace Corporation)

- 15 000 computer generated images of a spacecraft (~4.6GB)
- 300 images of satellite mock-up generated at Stanford Labs
- **Challenge:** purely vision-based inference of pose
 - relative position and attitude



Computer generated images (pose overlaid)

Camera captured image



Kelvins Portal: Pose estimation competition



Details on the competition:

- 5 month duration
- ~70 registered teams
- 36 teams improved baseline solution

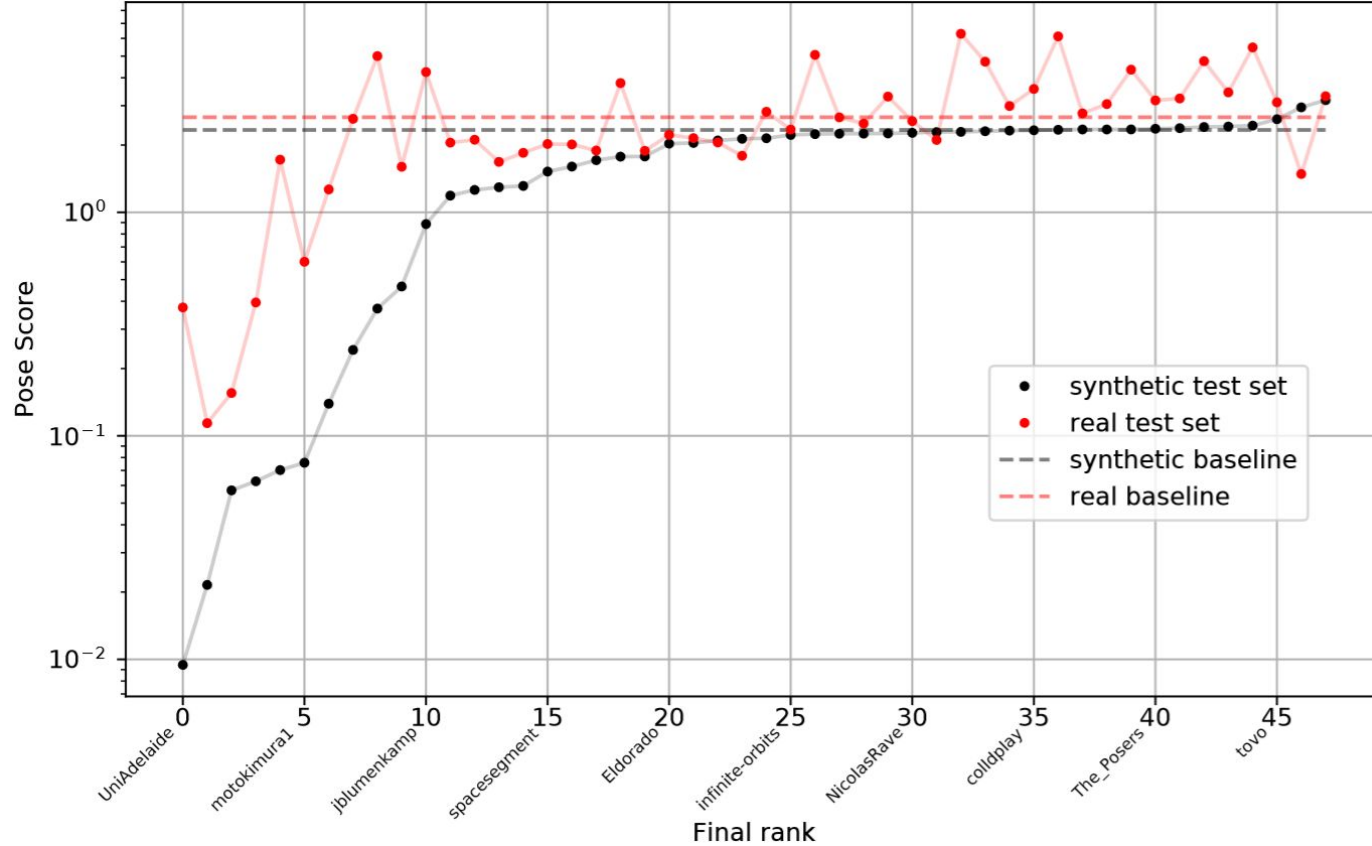
Results

Rank	Name	Real Image Score	Best Score
1	UniAdelaide	0.3752442418711471	0.009449622064660844
2	EPFL_cvlab	0.11397767001637173	0.02153775817984222
3	pedro_fairspace	0.1554876108763784	0.057050185272129426
4	stanford_slab	0.3950914435276558	0.06262229611857424
5	Team_Platypus	1.7201238117705309	0.07028457489821285
6	motokimura1	0.6011030833737907	0.07582034748337328
7	Magpies	1.265914546465023	0.1393022728680455
8	GabrielA	2.6209116199390117	0.24234980739500175
9	stainsby	5.000442762375624	0.3710962867057655
10	VSI_Feeney	1.5993459458340495	0.46582876551354907

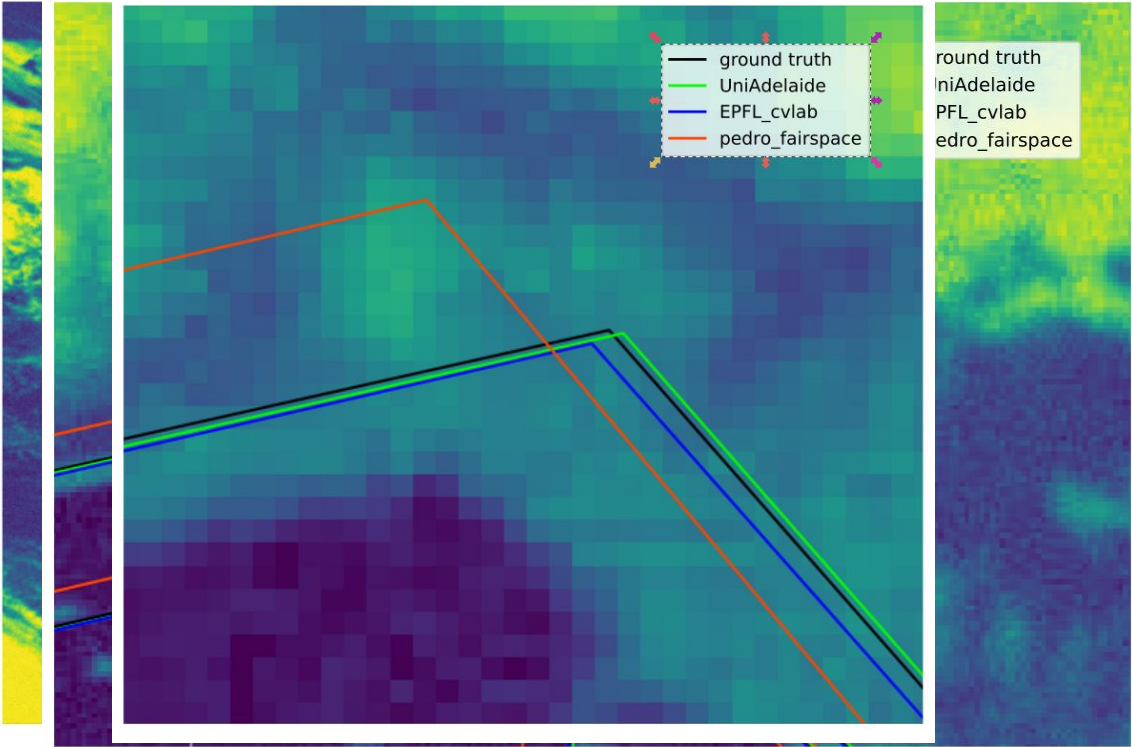
- Winning team: **University of Adelaide** (average pose error < 1°)
- Best on real images: **EPFL CVLab** (error ~ 6.5°)
- Top submissions combined keypoint matching with deep learning



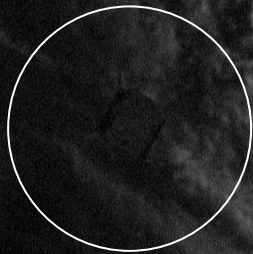
Final results in comparison



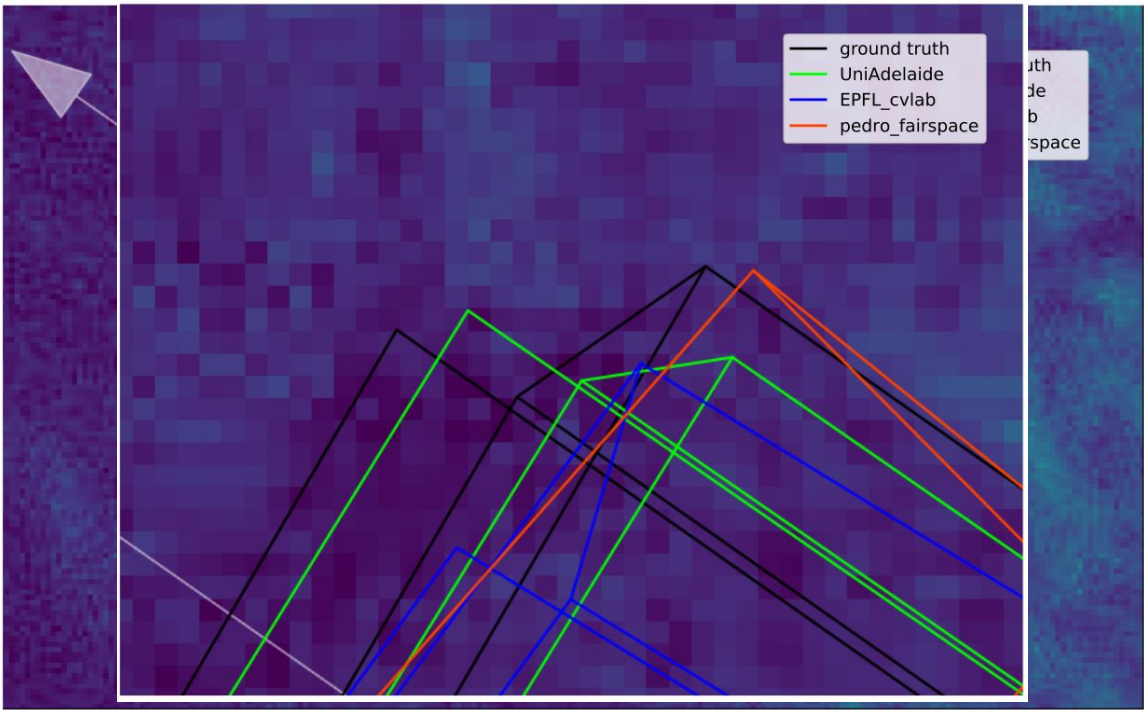
Accuracy - Example 1



Where is ~~Waldo~~ Tango?

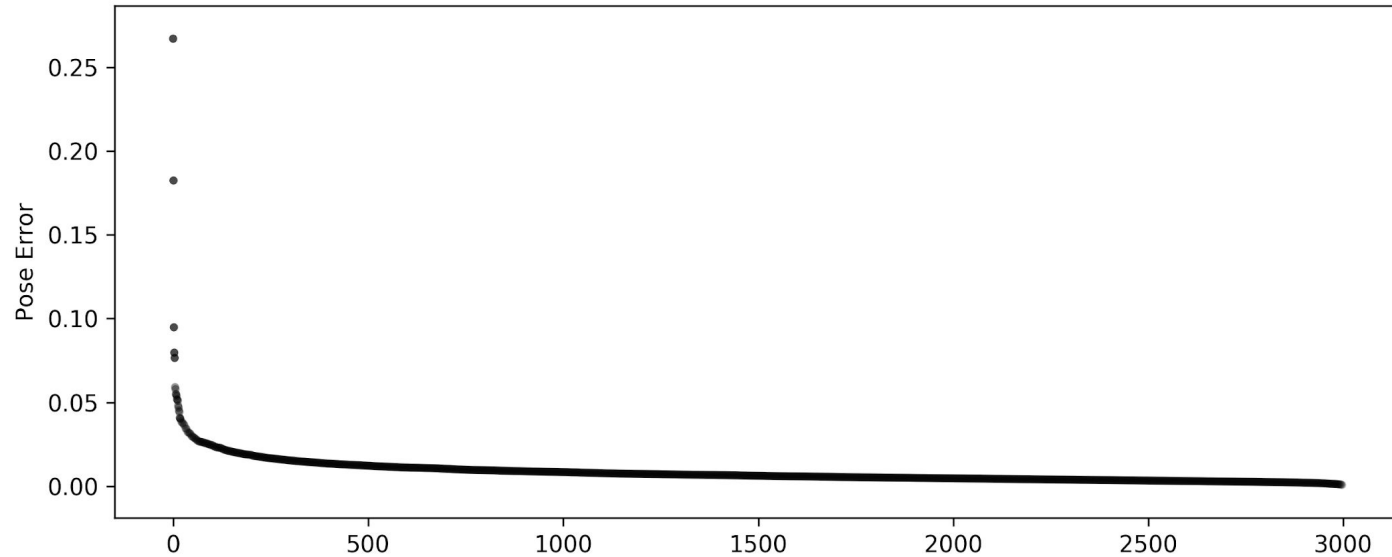


Accuracy - Example 2



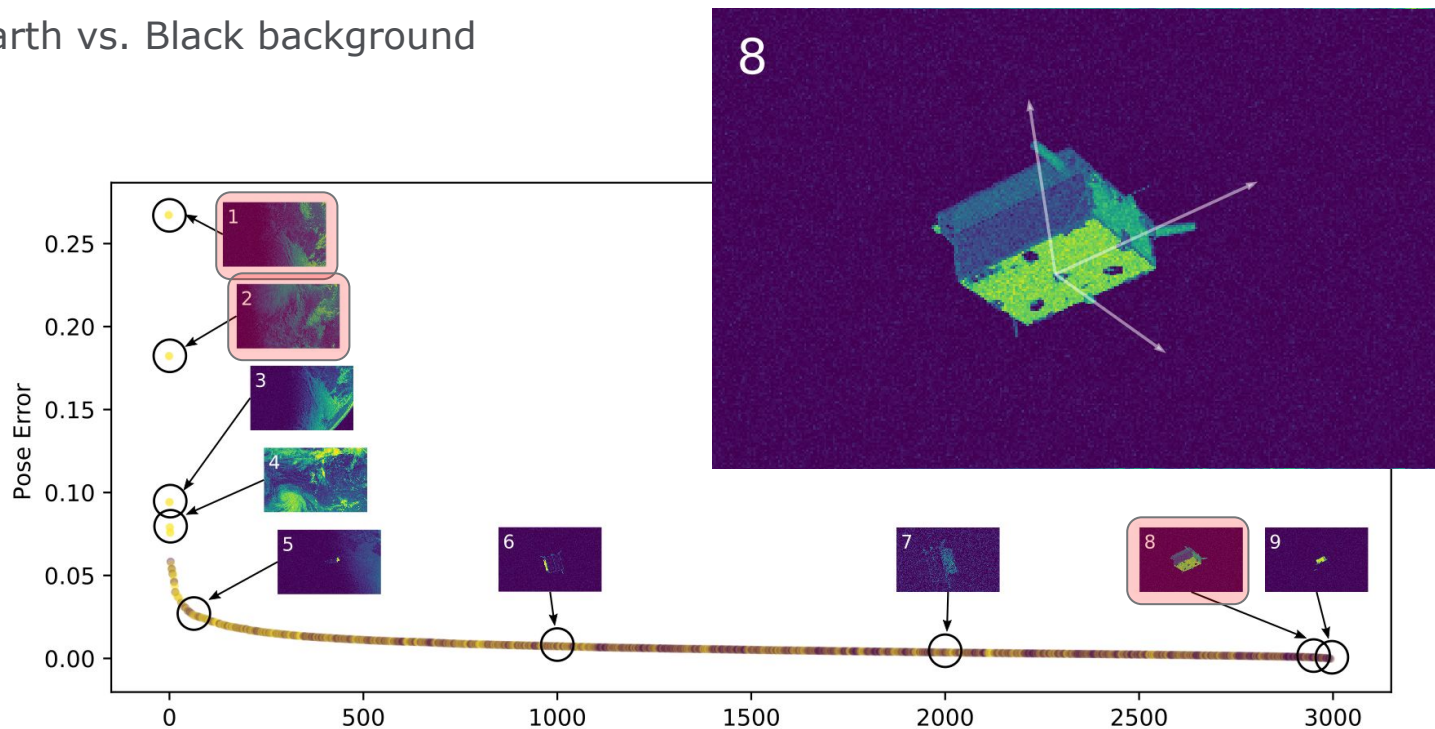
Which samples are difficult?

- “Super Pose Estimator” - best prediction for each sample
- Performance \sim difficulty
- Ranking test samples



Influence of the background

- Earth vs. Black background



References, Links and further outcome



Selected Scientific Publications

Main paper: Kisantal M., Sharma S., Park T. H., Izzo D., Märtens M., D'Amico S. "Satellite Pose Estimation Challenge: Dataset, Competition Design and Results" (currently under submission)

<https://arxiv.org/abs/1911.02050>

Dataset generation: Sharma S., D'Amico S. "Pose Estimation for Non-Cooperative Rendezvous Using Neural Networks" In AAS/AIAA Astrodynamics Specialist Conference, Ka'anapali, Maui, HI, January 13-17 (2019).

<https://arxiv.org/pdf/1906.09868>

Competition winner: Chen, B., Cao, J., Parra, A. and Chin, T.J. "Satellite Pose Estimation with Deep Landmark Regression and Nonlinear Pose Refinement" In Proceedings of the IEEE International Conference on Computer Vision Workshops. (2019)

<https://arxiv.org/abs/1908.11542>

Open Source Software

Pedro F. Proença: network and model weights (<https://github.com/pedropro/UrsoNet>)

Links

Kelvins competition portal: <https://kelvins.esa.int>

Stanford Space Rendezvous Lab: <https://damicos.people.stanford.edu/>



Bonus Round 1: Collision avoidance



Latest competition
On Kelvins

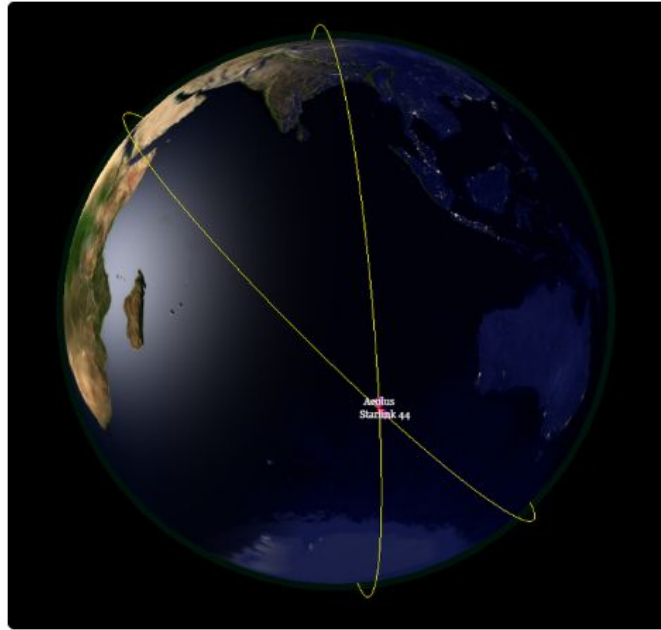
*"Estimating
collision risk"*

**Breaking all
records:**

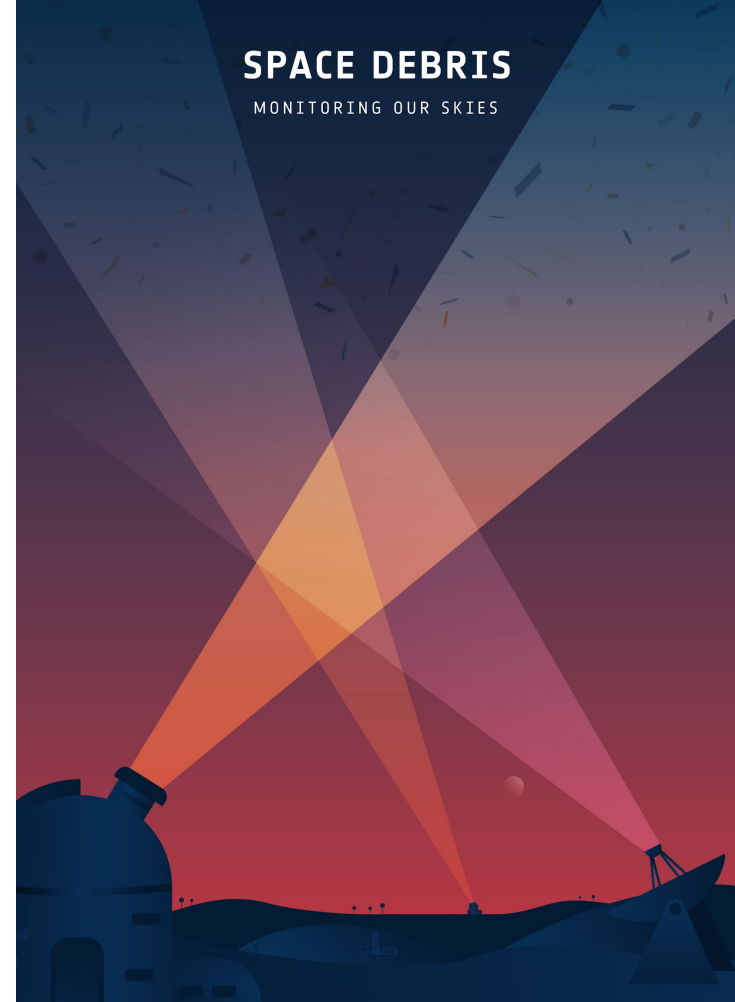
~100 participants
~1000 submissions

Evaluation:
ongoing!

For the first time ever, ESA has performed a 'collision avoidance manoeuvre' to protect one of its satellites from colliding with a 'mega constellation' [#SpaceTraffic](#)



♡ 1,605 3:36 PM - Sep 2, 2019

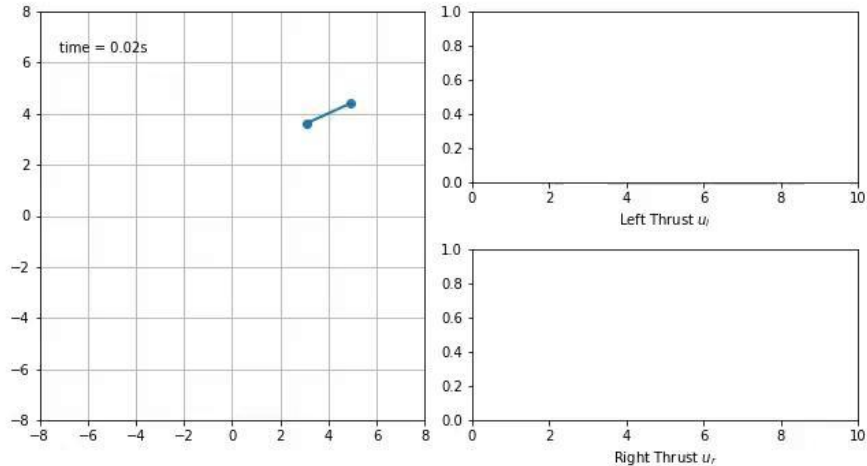


Bonus round 2: Autonomous Guidance and Control

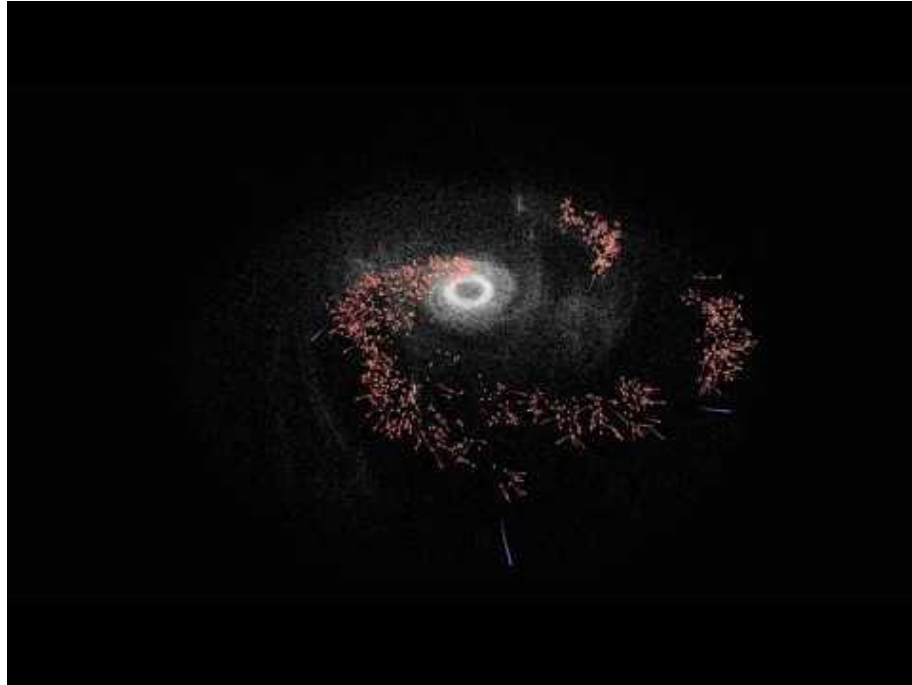


(Deep) neural networks for guidance and control: G&CNETs

- Robust controllers that can fly autonomously
- Fast on-board evaluations
- Train controller by imitation learning from optimal trajectories
- Hardware test-bed: Quadcopters



Bonus round 3: Interstellar space travel



How we settled the galaxy: https://coolrunning.github.io/gtocx_pres/#/

Thank you for your attention!



Please visit us online

<https://esa.int/act>

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