Open Innovation and AI at ESA's Advanced Concepts Team

L. Summerer, D. Izzo, 14 November 2018

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ACT: Advanced Concepts Team

Created in 2002 *"to **monitor**, **perform** and **foster** research on advanced space systems, innovative concepts and working methods"*

"beyond the horizon multidisciplinary research for space, exploring new approaches to space related R&D (including competition, prizes, games), research for disruptive innovation, developing an expert network at academic level, and providing a capability for fast first look analysis of problems, challenges and opportunities"

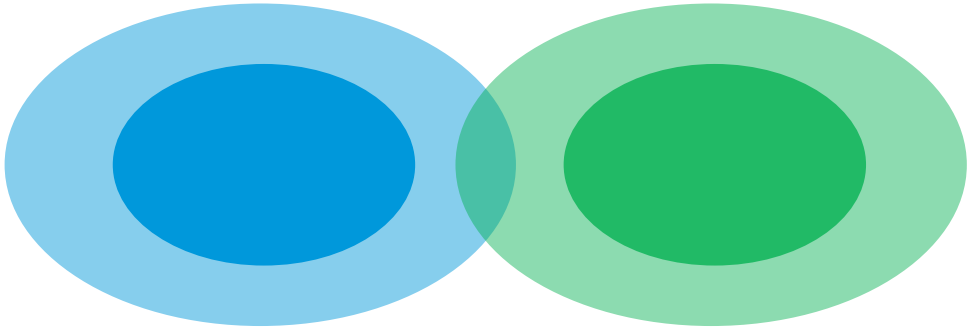
ACT Nature of activities - Exploring beyond planning

no/weak links to space

basic scientific research

Immature, but need for a position

Exploring the *intersections* of disciplines



What if …?
Could we …?
What is needed to …?
By when …?

ACT Research Areas

Fundamental Physics
Impact of new ideas in physics

Biomimetics & Bioengineering
Benefitting from Darwinian evolution to solve engineering problems

Artificial Intelligence
Engineering of intelligent computer systems

Neuroscience
Brain, sleep and microgravity

Advanced Energy Systems
Innovating energy systems

Mission Analysis
Mathematical techniques for future mission analysis

Molecular Engineering
Manipulate and control the properties of molecules for space

Computer Science & Applied Mathematics
Fast, efficient and parallel optimisation techniques

Advanced Propulsion
Explore and review break-through propulsion concepts

Nanotechnology
Benefitting from control at micro/nano scale

Space economics/Space architecture
Novel architecture & economic concepts for space sector

-> www.esa.int/act

Artificial Intelligence

Betting on a long awaited revolution 'about to happen'

Autonomous agents

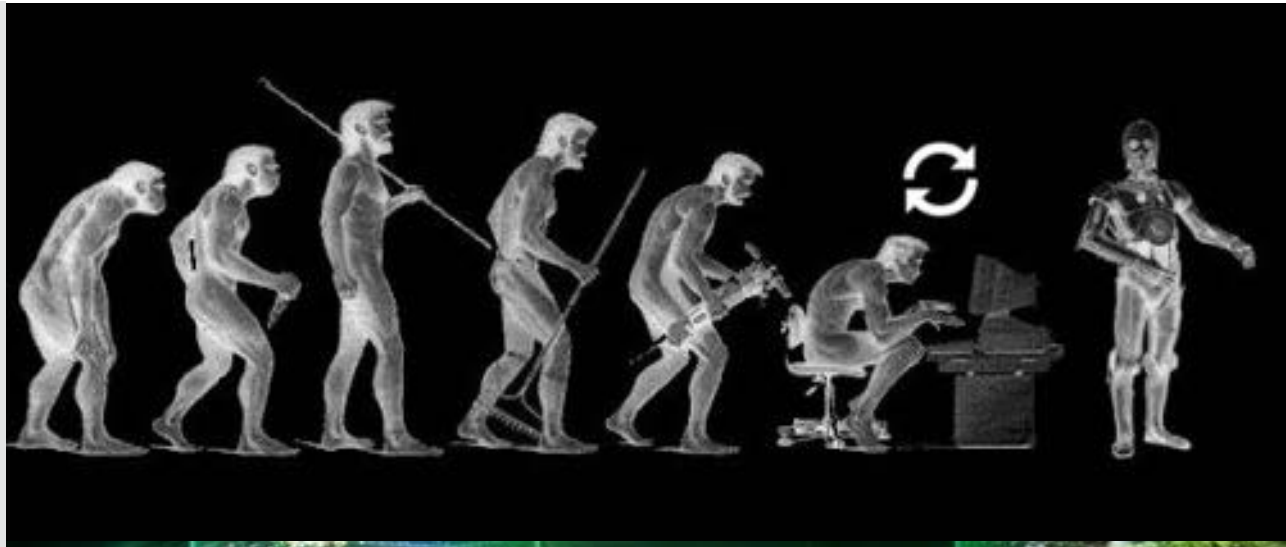
- Neural controllers.
- Swarm intelligence for in-orbit self-assembly
- Optic flow and time-to-contact landings
- Biomimetic Sensing and Actuation

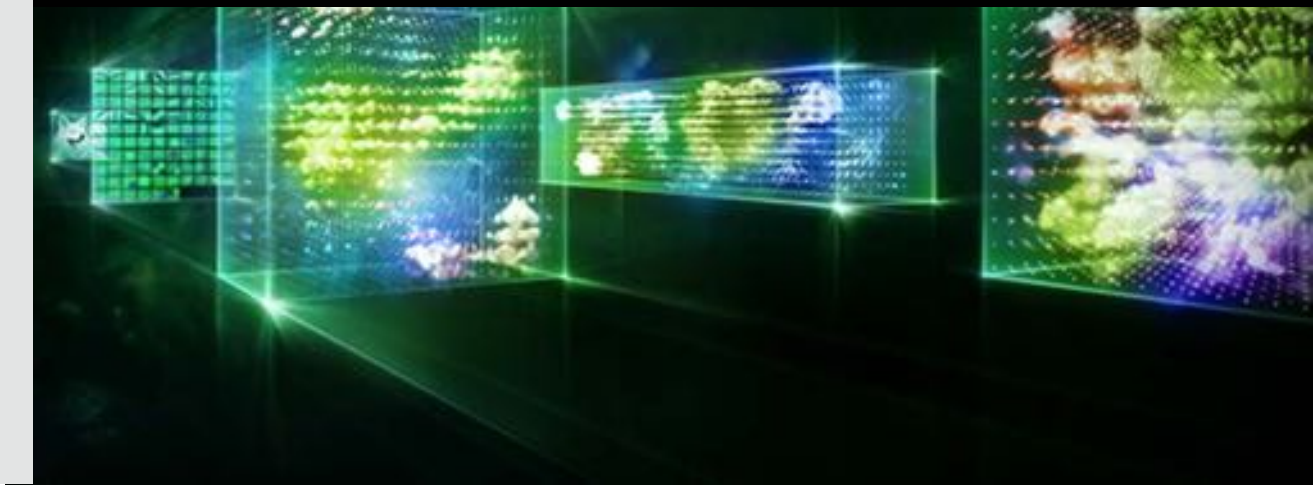
Machine Learning

- Deep learning in Deep space
- On-board real time optimal control
- Learning low-thrust connections

Evolutionary computations

- Evolving designs to find new solutions

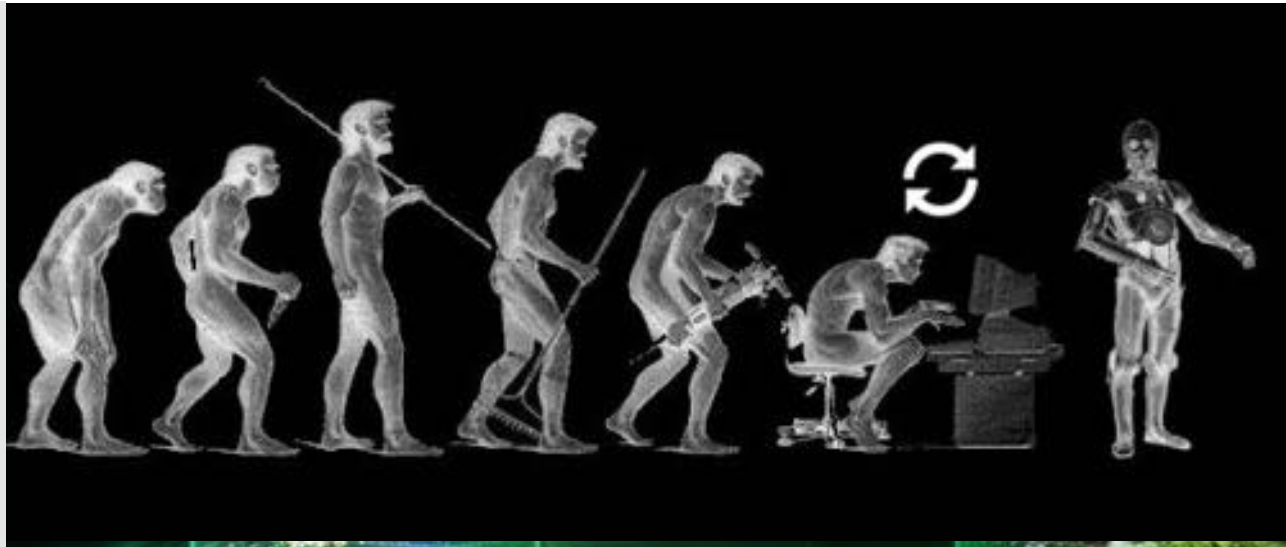


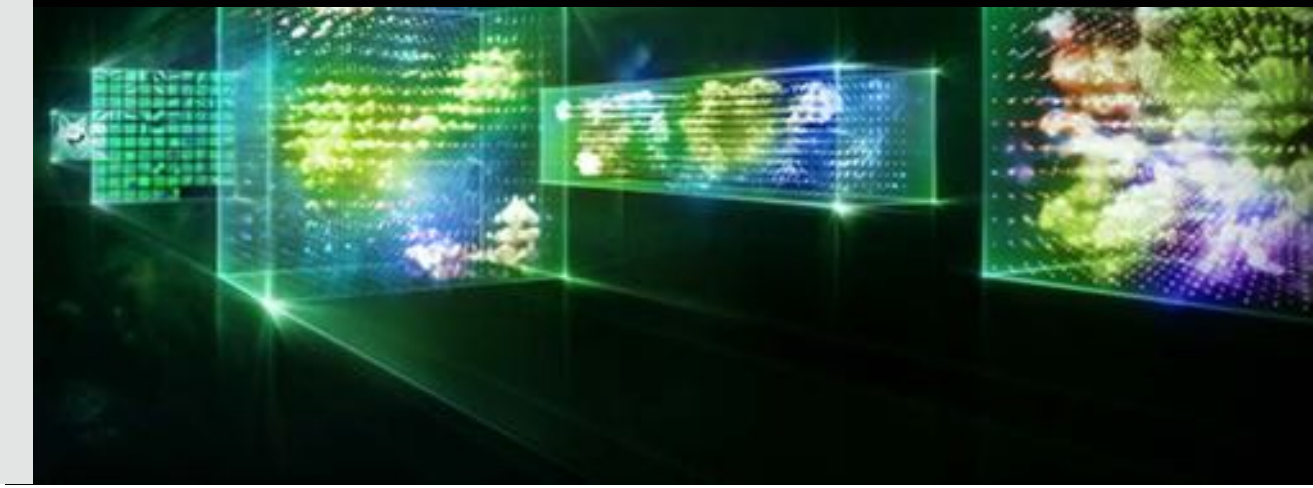


Artificial Intelligence

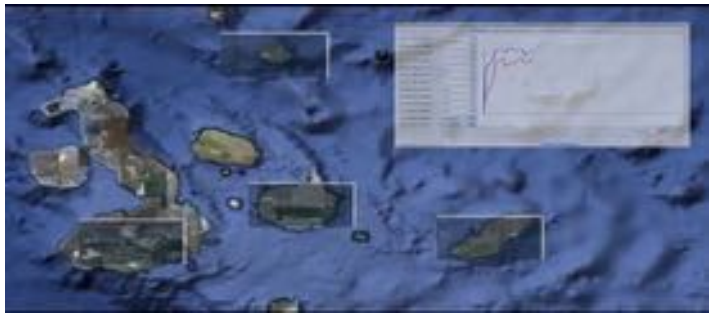
Ongoing Projects

- Deep CNNs for uncooperative targets pose estimation (in collaboration with Stanford)
- Real time embedded optimal control (in collaboration with TU Delft) with supervised (imitation) learning (powered by deep FFNN)
- Super resolution via CNNs
- New algorithms to enhance synergies between Machine Learning and Evolutionary Algorithms
- Neuro-evolution assessment
- Deep Architectures representation using Genetic Programming



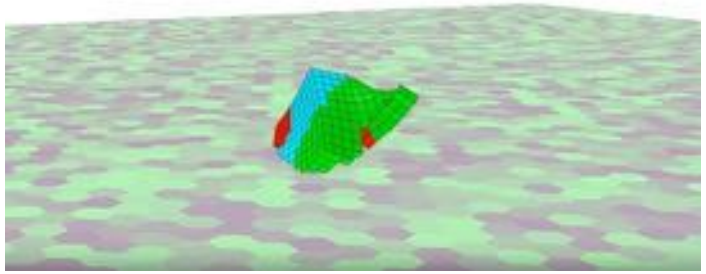


Explored areas – Neurocontrollers



Evolution in robotic islands: ALife in the Galapagos

Reinforcement learning for Spacecraft hovering near unknown small bodies



Morphological evolution of soft robots at different gravity levels

CNN, BP, LSTM, RNN, GP, SR, DE, MCTS

EMD, SIFT

2000

CMA-ES 2003

LFC from Stanford 2004

First DL success, jDE 2006

MOEA/D 2007

Nutonian 2009

A LSTM wins ICDAR handwriting

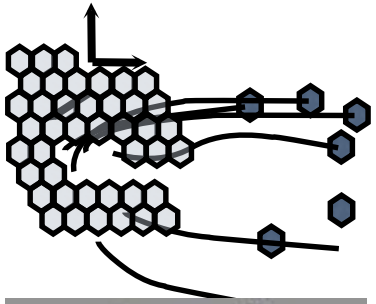
ImageNet 2012

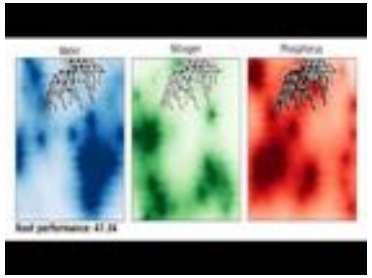
DVS 2013

Alpha GO 2016

Videos at: http://youtube.com/AdvancedConcepts

Explored areas – Swarm Intelligence





Decentralized Formation Flight with collision avoidance: Equilibrium Shaping

Autonomous self-assembly of large space structures

Root Swarm: Sensor webs deployment

ACT MIT SPHERES experiments: first ANN controlling multiple (homogeneous) agents in space

CNN, BP, LSTM, RNN, GP, SR, DE, MCTS — EMD, SIFT — 2000

CMA-ES — 2003

LFC from Stanford — 2004

First DL success, jDE — 2006

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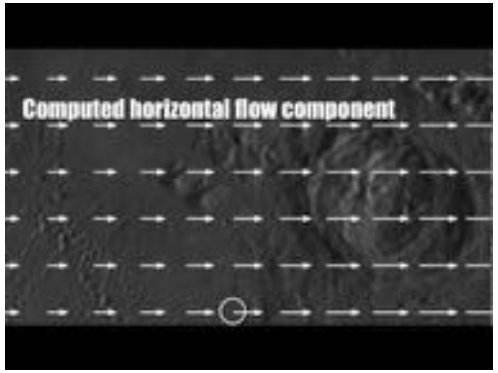
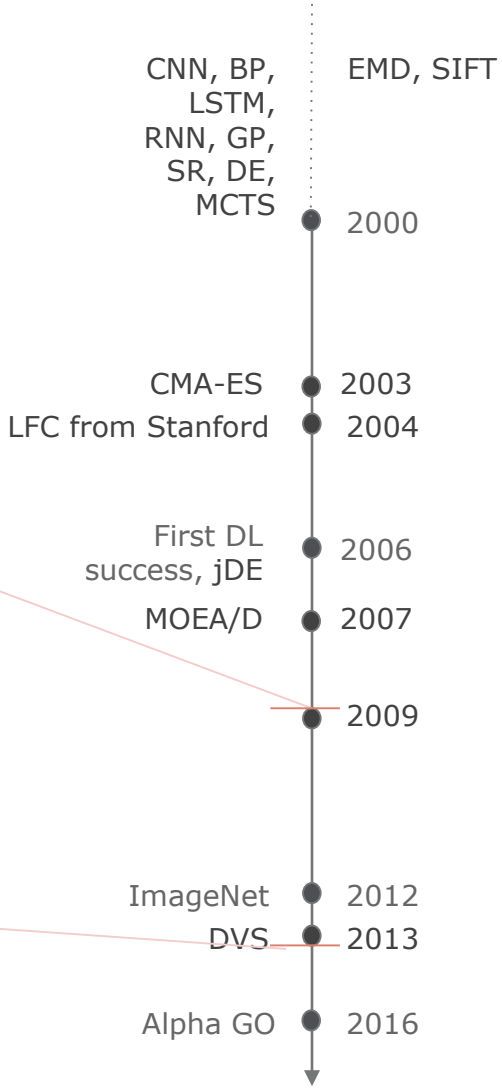
Explored areas – Biomimetic Sensing and Actuation



Optic flow based lunar landing: from bees to Apollo

Scent of science: from a female chasing moth to the chase of methane on Mars



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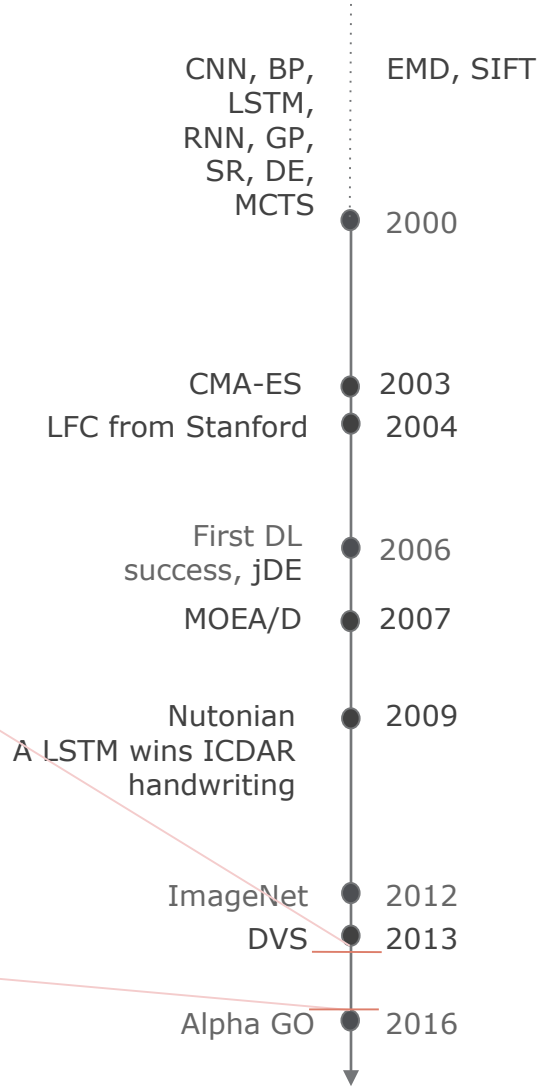
Explored areas – Vision

Astro Drone - gamification for the acquisition of vision data-sets

Learning “to see” in zero gravity - from stereo vision to monocular vision (using the MIT SPHERES platform)



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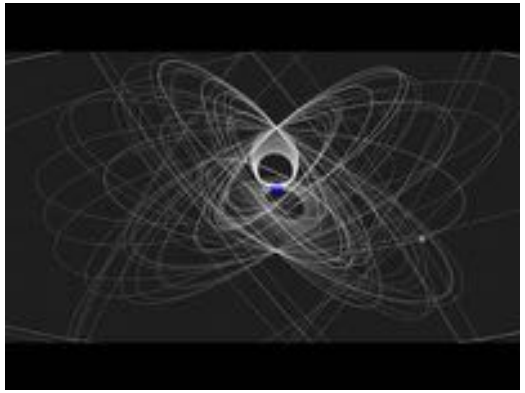
Explored areas – Evolution and smart search



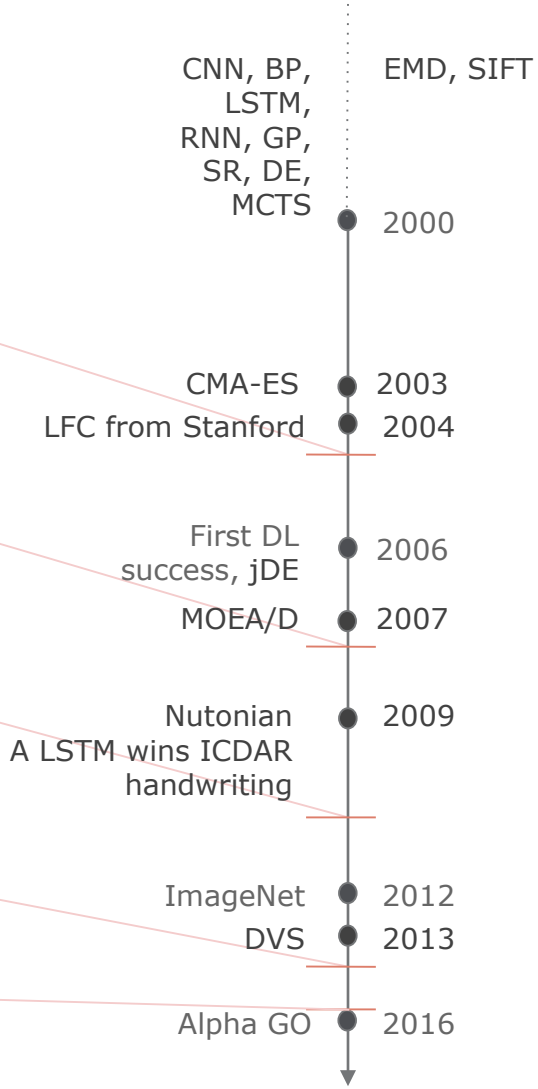
Evolution of Interplanetary Trajectories

Parallel evolution in modern CPU architectures, the island model, PyGMO

Novel tree search paradigms: Monte Carlo Tree Search, Ant Colony Optimization, Lazy Race Tree Search

Humies Gold medal - “for Human-Competitive Results Produced by Genetic and Evolutionary Computation”

1st place in the 8th edition of GTOC - “The America’s cup of rocket science”



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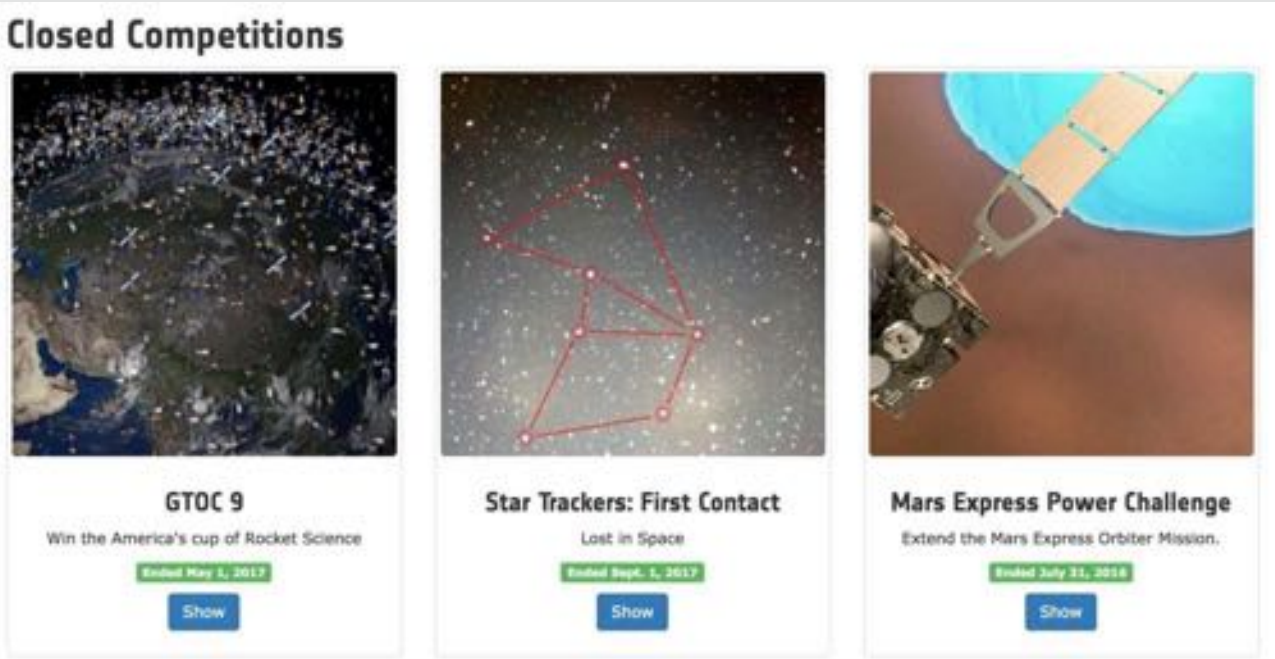
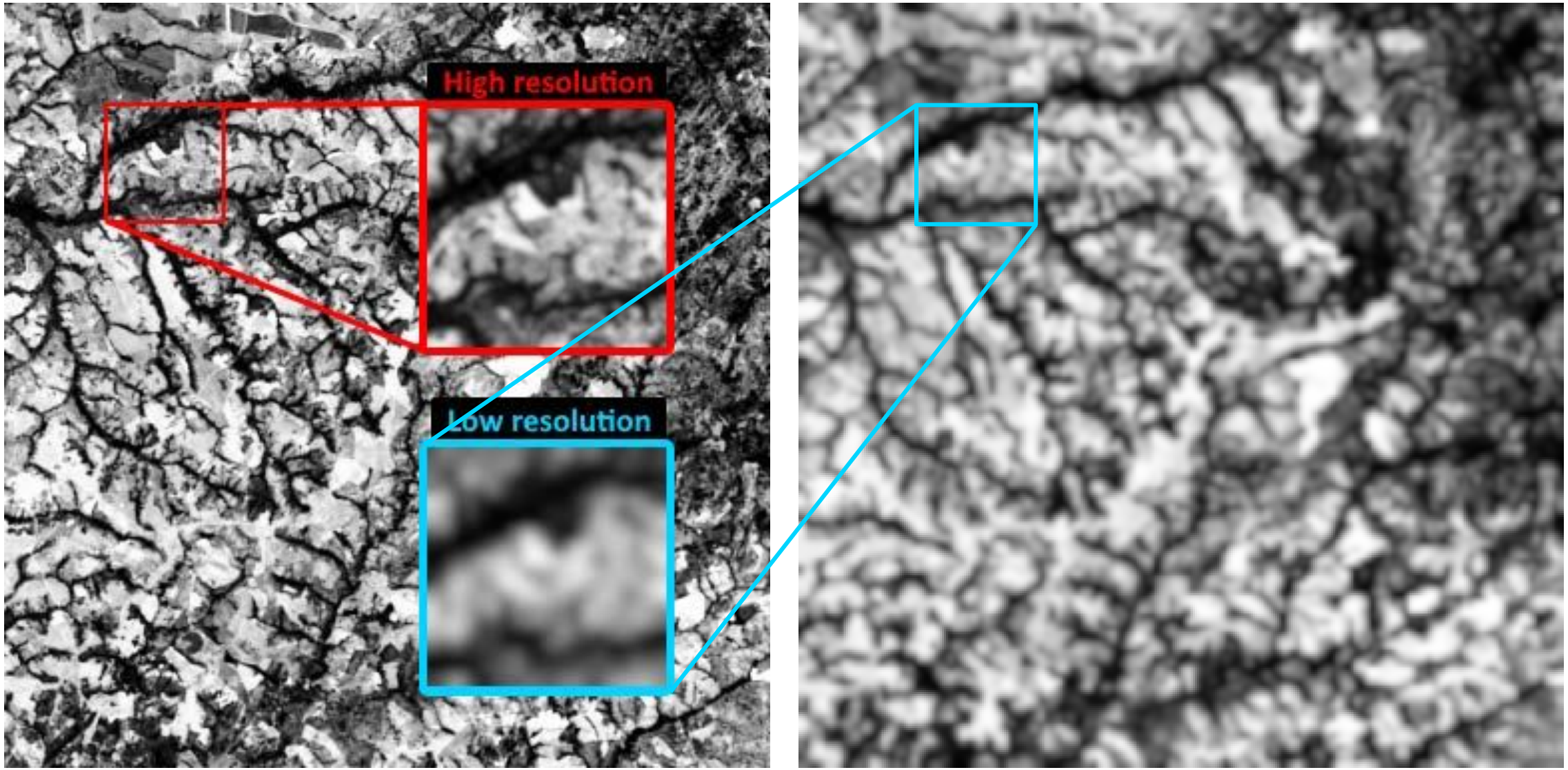
New Working Methods

Kelvins Portal: compete to excel

- Open science to foster competitive spirit and healthy scientific competitions
- Dedicated competition portal: Kelvins, reach the absolute zero (error)
- Harnessing ACT experience from GTOCs



High and low resolution in comparison



Super-resolution

- Optical Super-resolution: improving an optical system beyond diffraction-limit
- **Geometrical Super-resolution:** Increasing resolution by image processing

- SISR (Single Image Super-resolution)
  - Inverting image degradation
  - Ill-posed problem

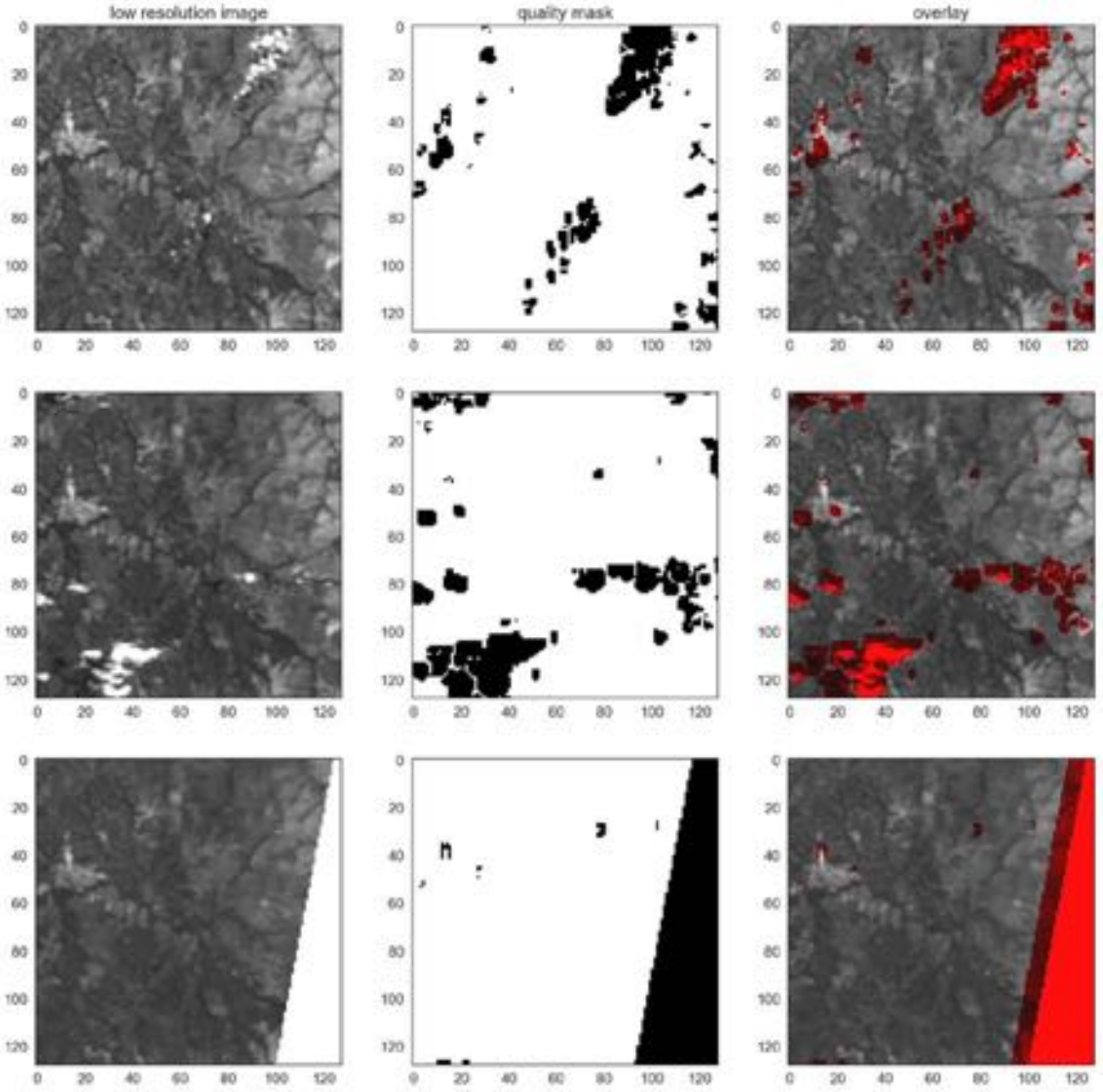
Ledig, Christian, et al. "Photo-Realistic Single Image Super-Resolution Using a Generative Adversarial Network." *CVPR*. Vol. 2. No. 3. 2017.

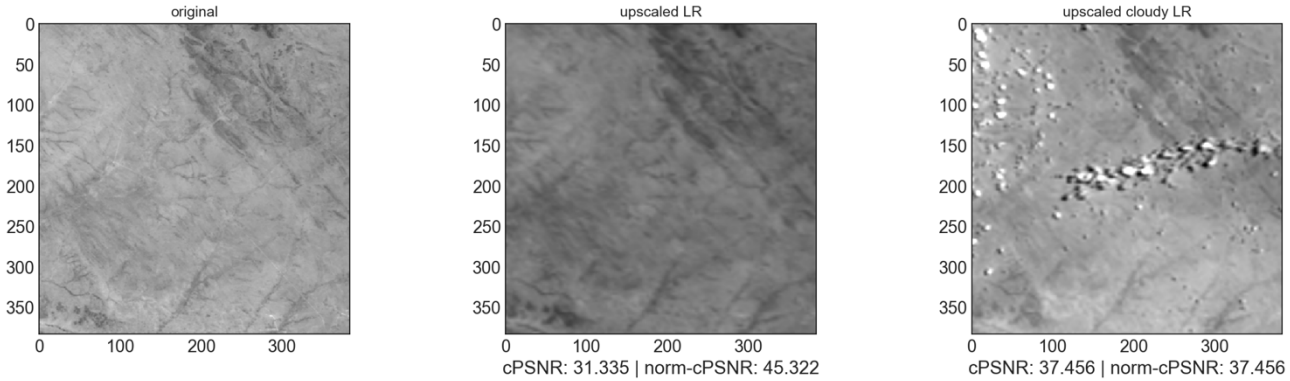
- MISR (Multi Image Super-resolution)
  - Video enhancements by fusing close frames
  - From multiple low to single high resolution
  - Deblurring / Denoising

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.

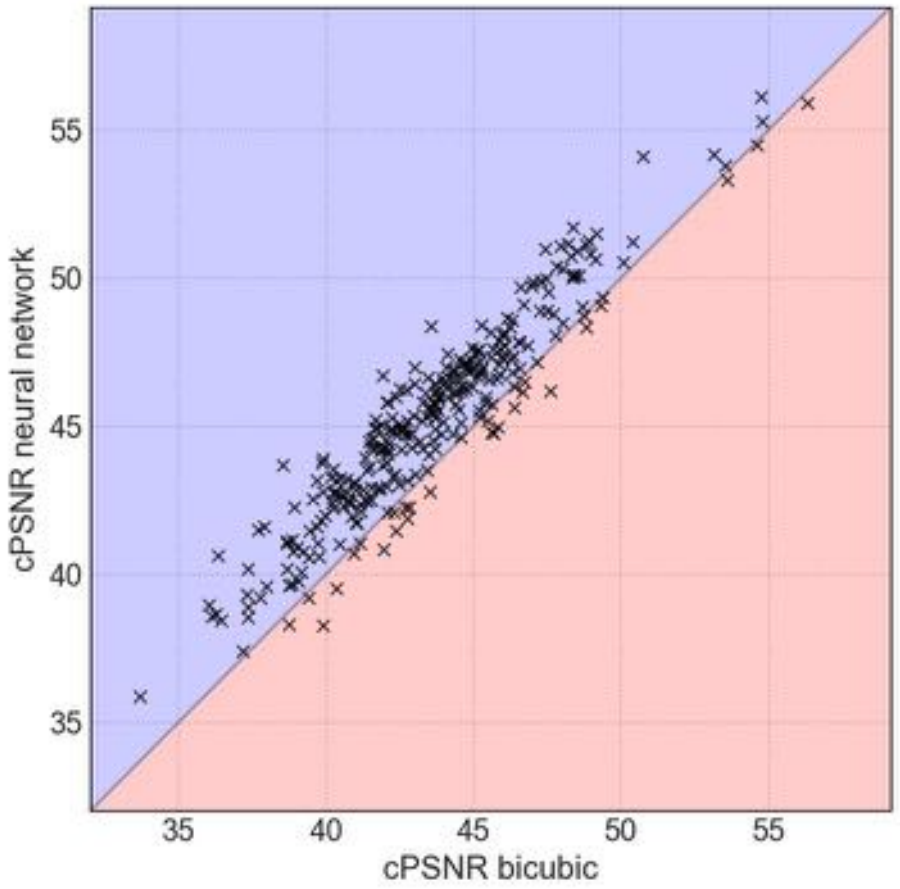
Super-resolution on satellites?

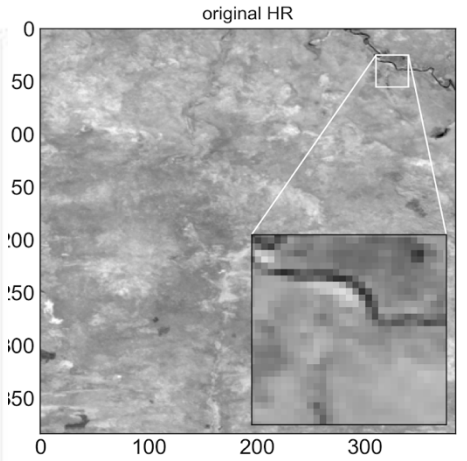
- **Single-pass Super-resolution** available in staggered sensor arrays
  - SPOT-5, ZY-3, TLC, SkySat-1
  - Post-processing on ground
- SPOT-5: two 5m shifted images by 0.5px are interleaved to 2.5m sampling
- Many ongoing cubesat projects
- **Multi-pass Super-resolution** still largely unexplored due to several challenges
  - Changes in cloud coverage
  - Changes in illumination
  - Changes in scene
  - Image registration

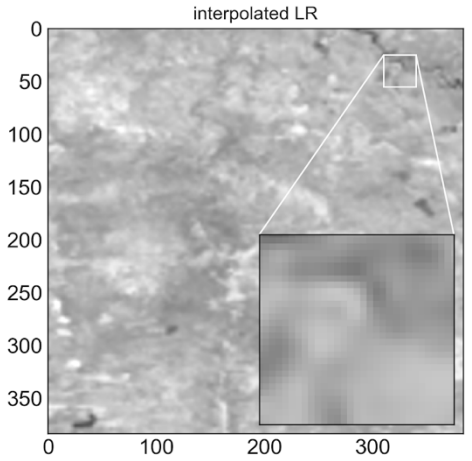


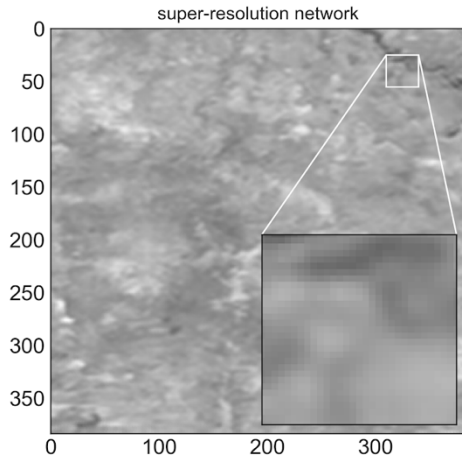


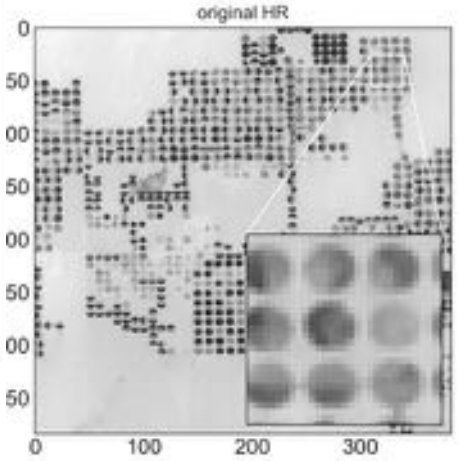
Preliminary results

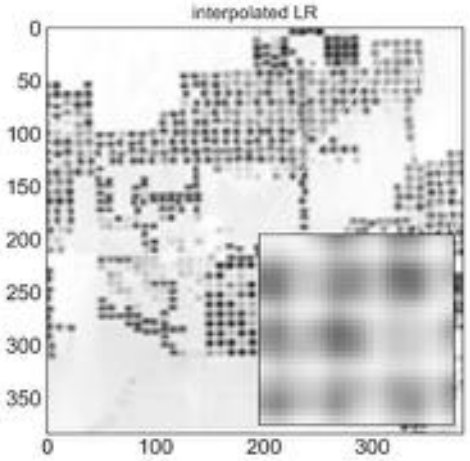


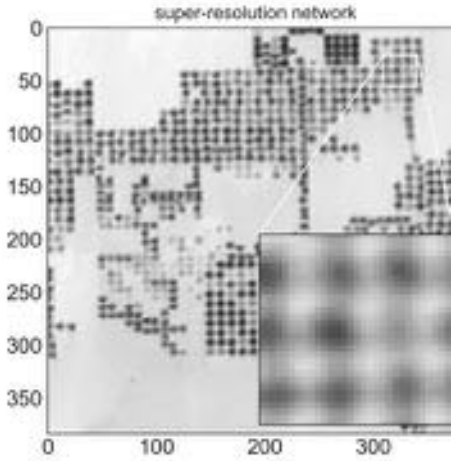




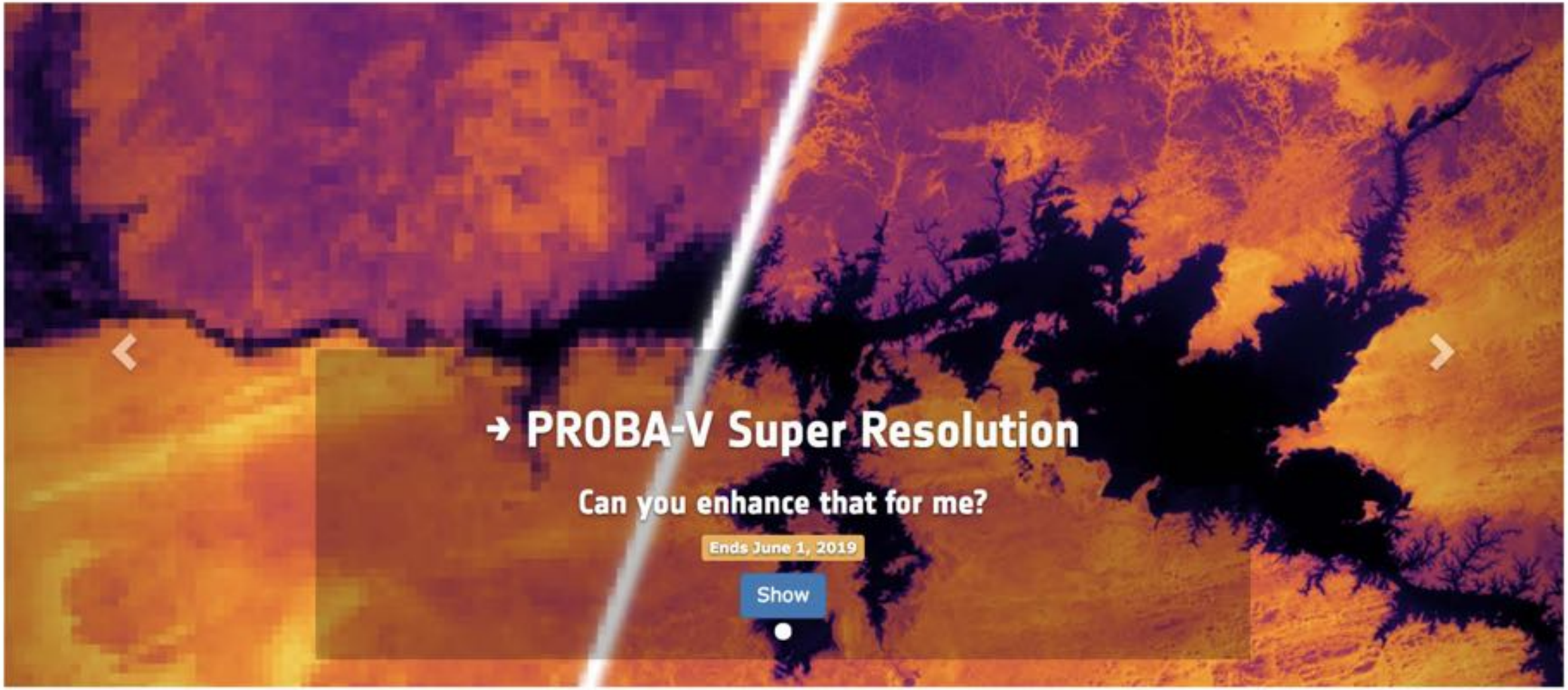








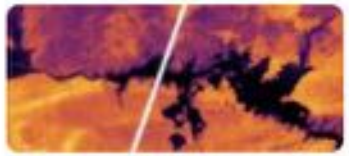
Competition



https://kelvins.esa.int

Kelvins

Kelvins About Competitions PROBA-V Super Resolution Leopold



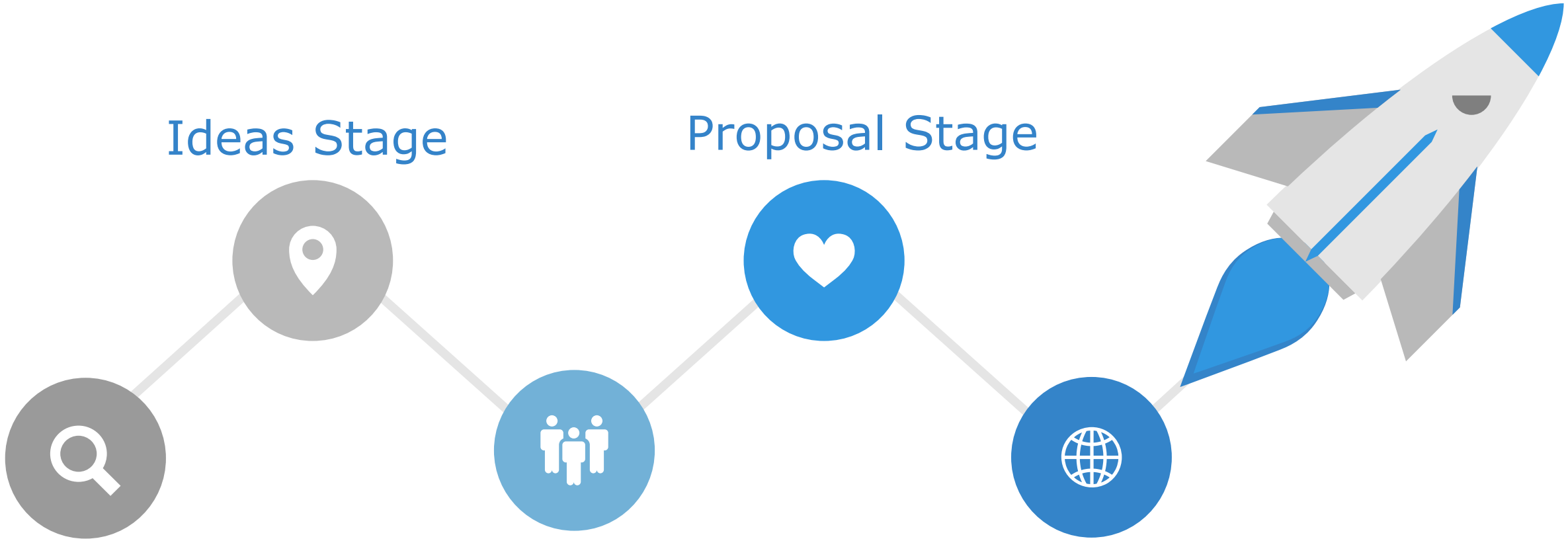
Nov. 1, 2018, 4 a.m. UTC Timeline June 1, 2019, 4 a.m. UTC

- Home
- Problem
- Rules
- Data
- Submission Rules
- Scoring
- Leaderboard
- Submission
- Discussion

Leaderboard

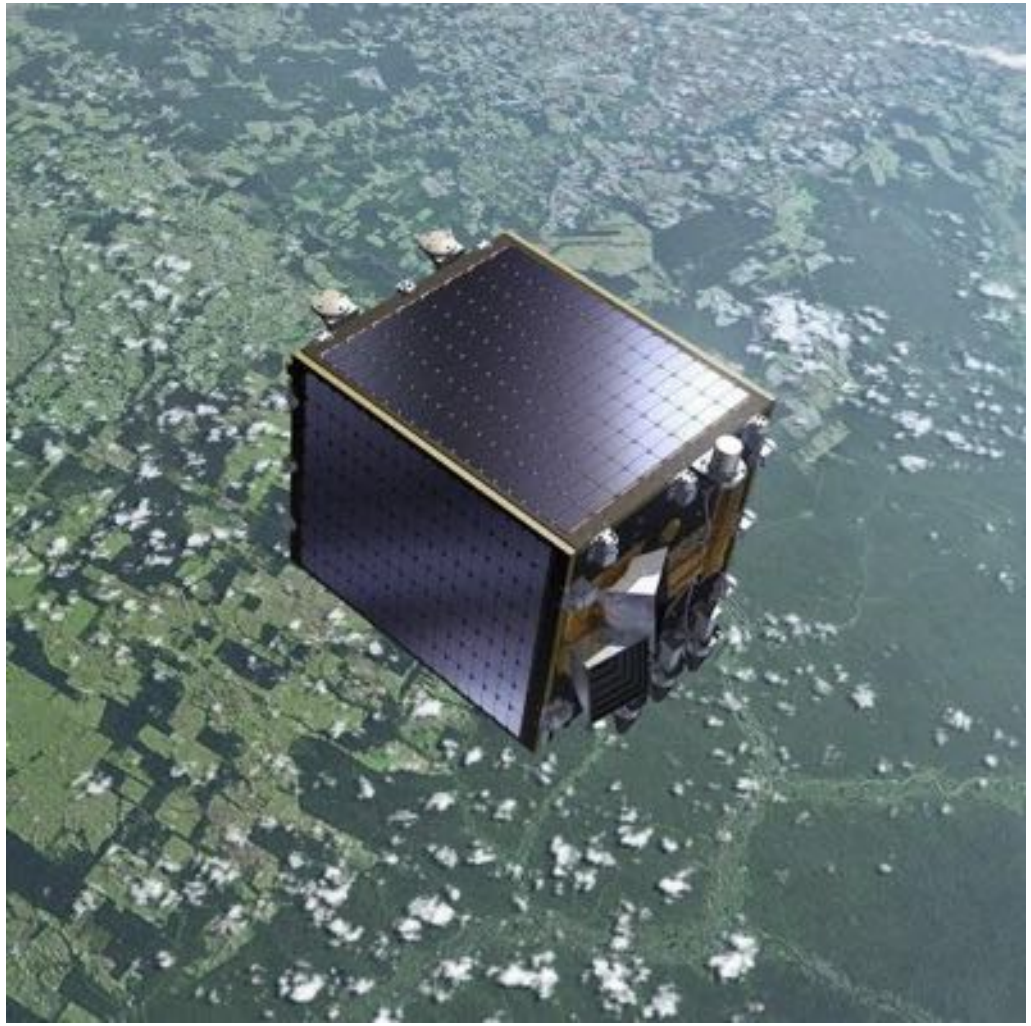
Name	Submissions	Last Submission	Best Submission	Best Score
lampros	3	Nov. 14, 2018, 4:06 a.m.	Nov. 14, 2018, 4:06 a.m.	0.998738103138126
	baseline			1.00000007339574
rarefin	7	Nov. 14, 2018, 1:48 p.m.	Nov. 1, 2018, 1:08 p.m.	1.00000007339574
NicolasRave	1	Nov. 1, 2018, 7:39 p.m.	Nov. 1, 2018, 7:39 p.m.	1.00000007339574

Open Space Innovation Platform



About PROBA-V

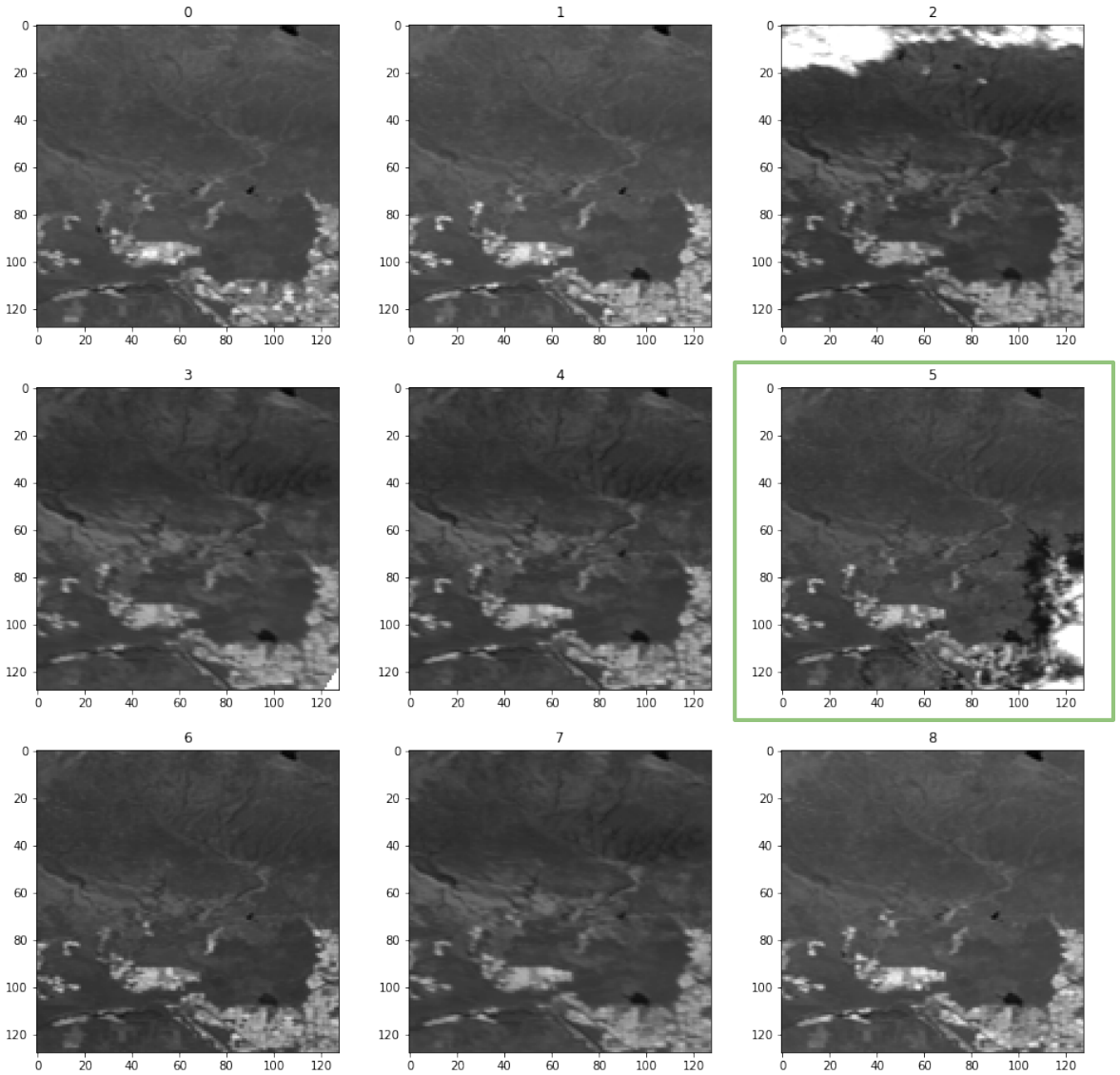
- Launched 6th May 2013
- Provides Space-borne monitoring of vegetation
- Products:
  - 300m resolution
    - Near global (90%) coverage daily
  - 100m resolution
    - Global coverage ~5 days
- Geolocation mean accuracy: ~61m (±50m)
- NIR, RED, BLUE and SWIR
- Pixel quality maps for clouds, shadows, ice, etc.

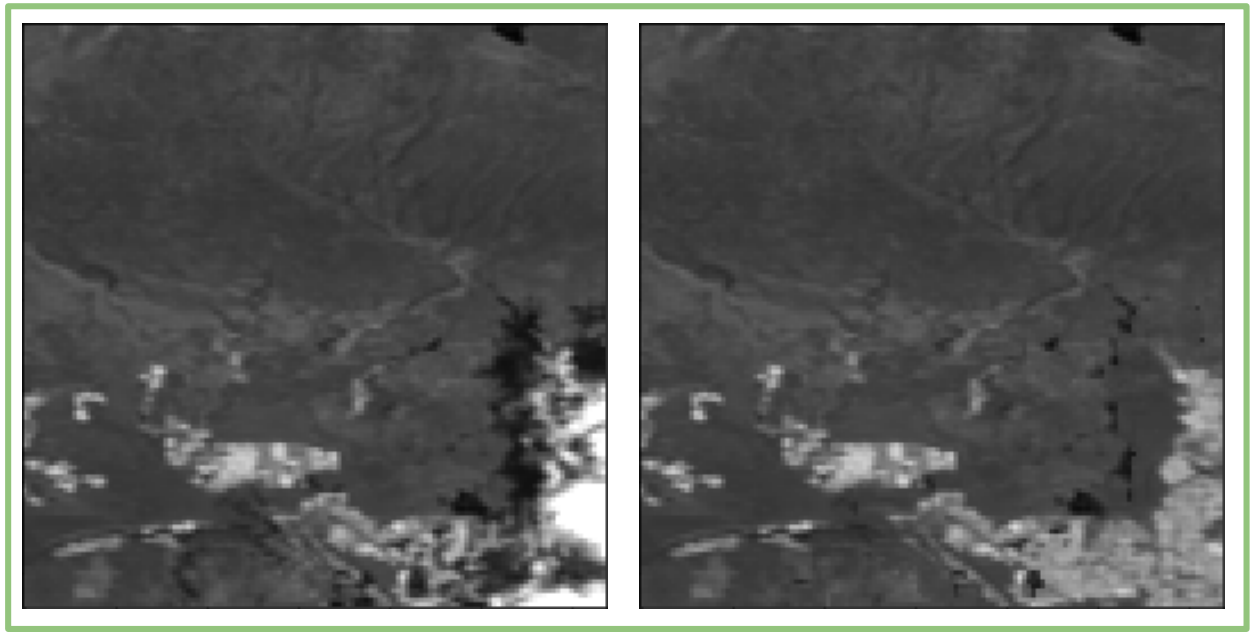


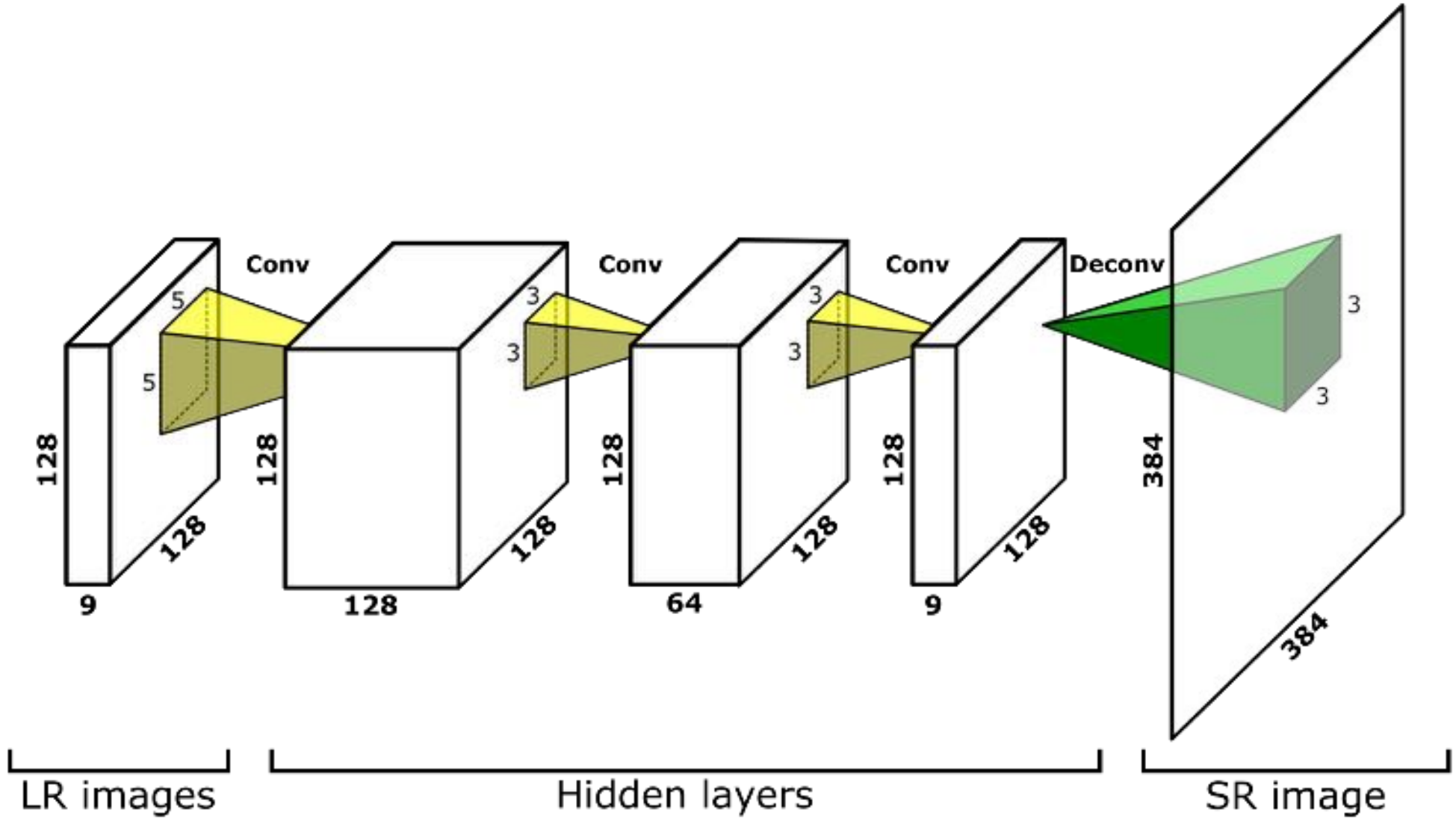
Gathering longitudinal data

- 74 hand-selected ROIs
  - Geographical and vegetational "interesting" structures
  - Expected low cloud coverage
- One month of observations for each ROI
- Level L2A (radiometrically and geometrically Top-Of-Atmosphere reflectance)
- Plate Carré projection
- 300m resolution (**LR**)
  - Cloud coverage less than 40%
  - 128x128px, 16bit grey-scale
- 100m resolution (**HR**)
  - Cloud coverage less than 25%
  - 384x384px, 16 bit grey-scale
- In total: **1450 datapoints**, each consisting of
  - One HR
  - On average 19 LRs
  - Quality maps for all images

Cloud-patching





- Blending images to compensate for lost information

Demonstration