Open Source Projects at the ACT

Pablo Gómez[1], Dario Izzo[1]
[1] Advanced Concepts Team, TEC-SF, European Space Agency

Background

- The open-source / free software movement has been around since ~1983
- Central to modern software development

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- Central to modern software development
- Not as widespread in the space community (except astro)
- Growing a lot in science and software as can be seen e.g. in machine learning

Open source / science at ESA & in Europe

- Huge drive towards open science in EU

HORIZON EUROPE

Plan S
Making full & immediate Open Access a reality

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- Many initiatives inside ESA

Plan S
Making full & immediate
Open Access a reality

essr.esa.int

open.esa.int

Open source / science at ESA & in Europe

- Huge drive towards open science in EU
- Many initiatives inside ESA
- Core part of the ACT culture with several long-term projects
- ACT is operating public gitlab, GitHub accounts for ESA

HORIZON EUROPE

Plan S
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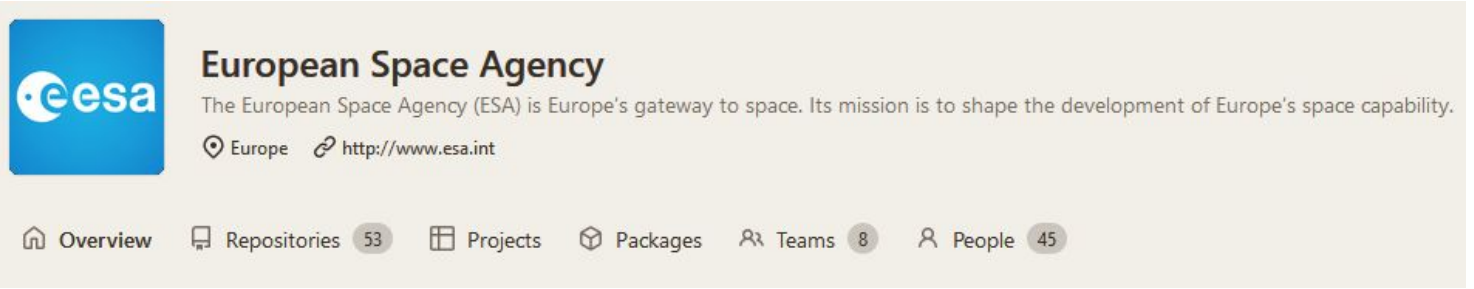
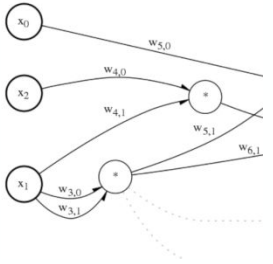


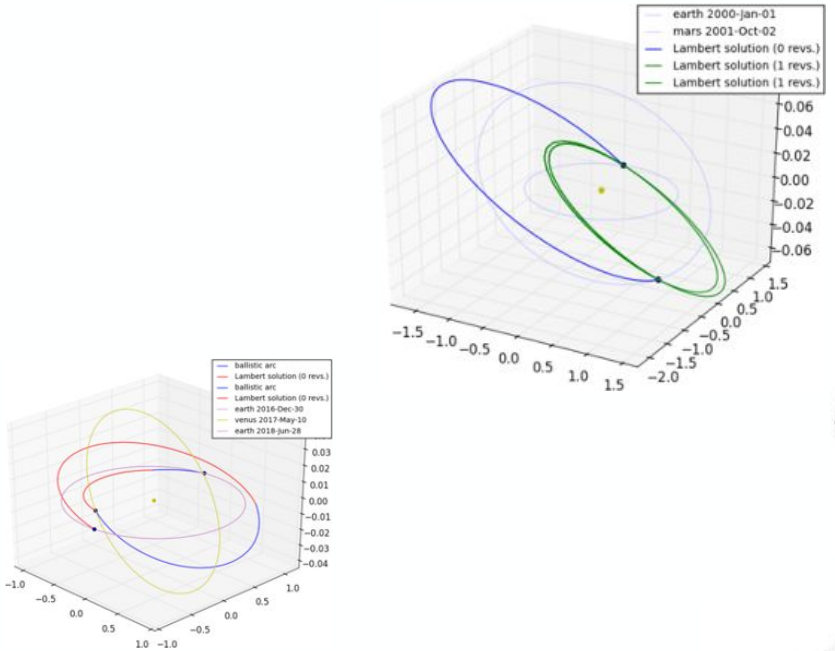
ACT Open-Source Projects - Overview

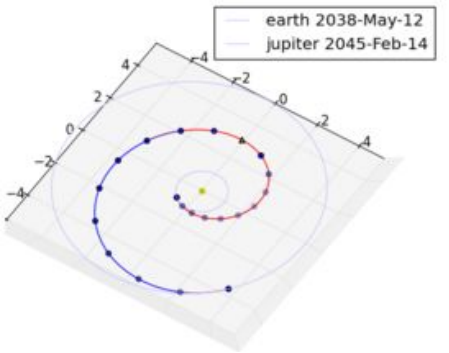
- **pagmo / pygmo (C++ / Python)** - Massively parallel optimization
- **pykep (C++ / Python)** - Astrodynamics and trajectory design
- **audi / pyaudi (C++ / Python)** - Differentiable algebra
- **heyoka (C++ / Python)** - Taylor integration for generic ODEs
- **d-CGP (C++ / Python)** - Differentiable genetic programming
- **torchquad (Python)** - Multidimensional numerical integration on GPUs
- **desolver (Python), LADDS (C++), NIDN (Python), ...**

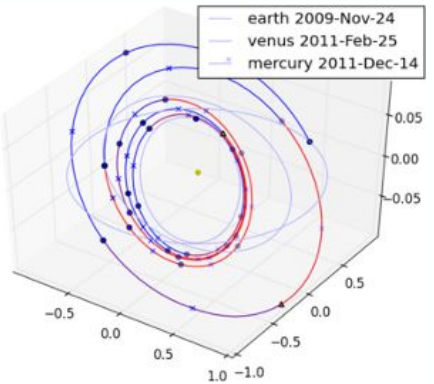


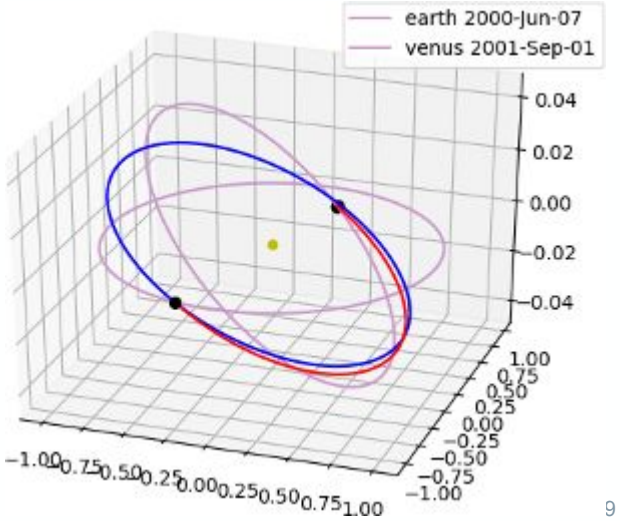
ACT Open-Source Projects - pykep

- Astrodynamics module supporting
  - Direct, indirect, hybrid methods for low-thrust optimization
  - Efficient Keplerian propagators
  - SGP4
  - Support for TLE, SATCAT, …
- Used in numerous papers, GTOCs, …
- 130 760 total downloads on conda
- Since 2016 on pip, later conda
- 24 contributors









ACT Open-Source Projects - pagmo / pygmo

- Library for massively parallel optimization
  - Unified interface to various optimization algorithms (SQP, DE, PSO, BFGS, NSGA2, …)
  - Support for (un)constrained, single / multiple objective, continuous / integer, stochastic / deterministic problems
- Used e.g. in GODOT by OPS-GFA, Pyxel by SCI-FIV
- 834 289 total downloads on conda
- Since 2017 on pip, later conda
- 42 contributors

Open Source - Costs and Benefits

Benefits

- Robustness through users testing

Costs

- For success, proper documentation, user friendliness and robustness matter

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Open Source - Costs and Benefits

Benefits

- Robustness through users testing
- Community contributions
- Visibility for ESA & ACT
- Reduces duplicate / redundant work
- Build to last with best practices

Costs

- For success, proper documentation, user friendliness and robustness matter
- Interaction with community costs time
- Maintenance of web presence (GitHub, conda, pip, …)

Unexpected Encounters

NASA Inquiry: pykep Country of Origin
[redacted]

01/11/2021 20:19

To: dario.izzo@esa.int

Hide Details

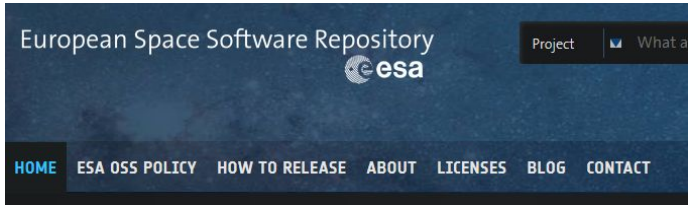
From: [redacted]@nasa.gov>
To: "dario.izzo@esa.int" <dario.izzo@esa.int>

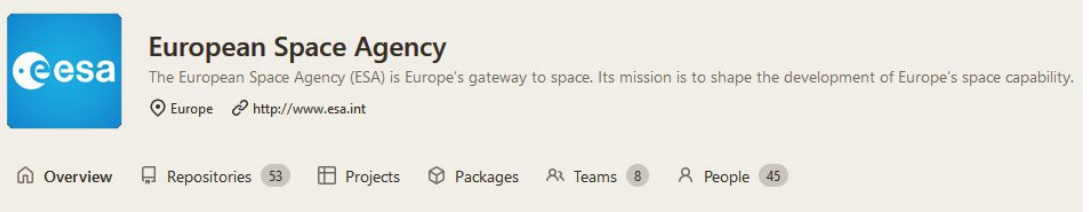
Hello, my name is [redacted] and I am a Supply Chain Risk Management Analyst at NASA. As such, I ensure that all NASA acquisitions of Covered Articles comply with Sections 208 and 514 of the Consolidated Appropriations Act, 2021, Public Law 116-260, enacted December 27, 2020. To do so, the Country of Origin (CoO) information must be obtained from the company that develops, produces, manufactures, or assembles the product(s). Specifically, identify the country where each of the following products were developed and maintained:

(pykep)

Conclusions & Outlook

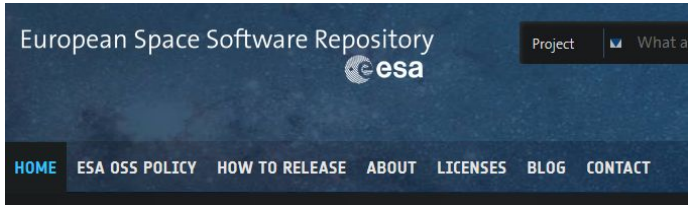
- Open source is the future and helps with:
  - Code quality, maintainability, robustness, documentation, …
  - Engaging the community inside & outside ESA
  - Compliance with Plan-S & co
  - Reducing redundant work

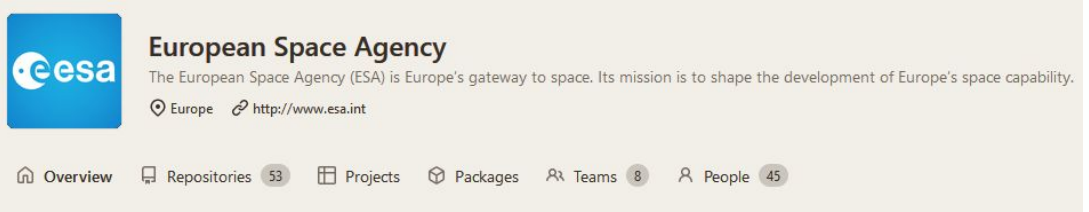




Conclusions & Outlook

- Open source is the future and helps with:
  - Code quality, maintainability, robustness, documentation, …
  - Engaging the community inside & outside ESA
  - Compliance with Plan-S & co
  - Reducing redundant work
- The ACT will continue its efforts
- Open questions:
  - Better funding mechanisms
  - Centralisation (gitlab, GitHub, …)
  - Make open-source part of funding





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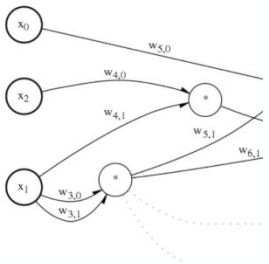
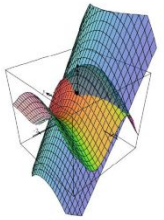




torchquad

desolver

NIDN

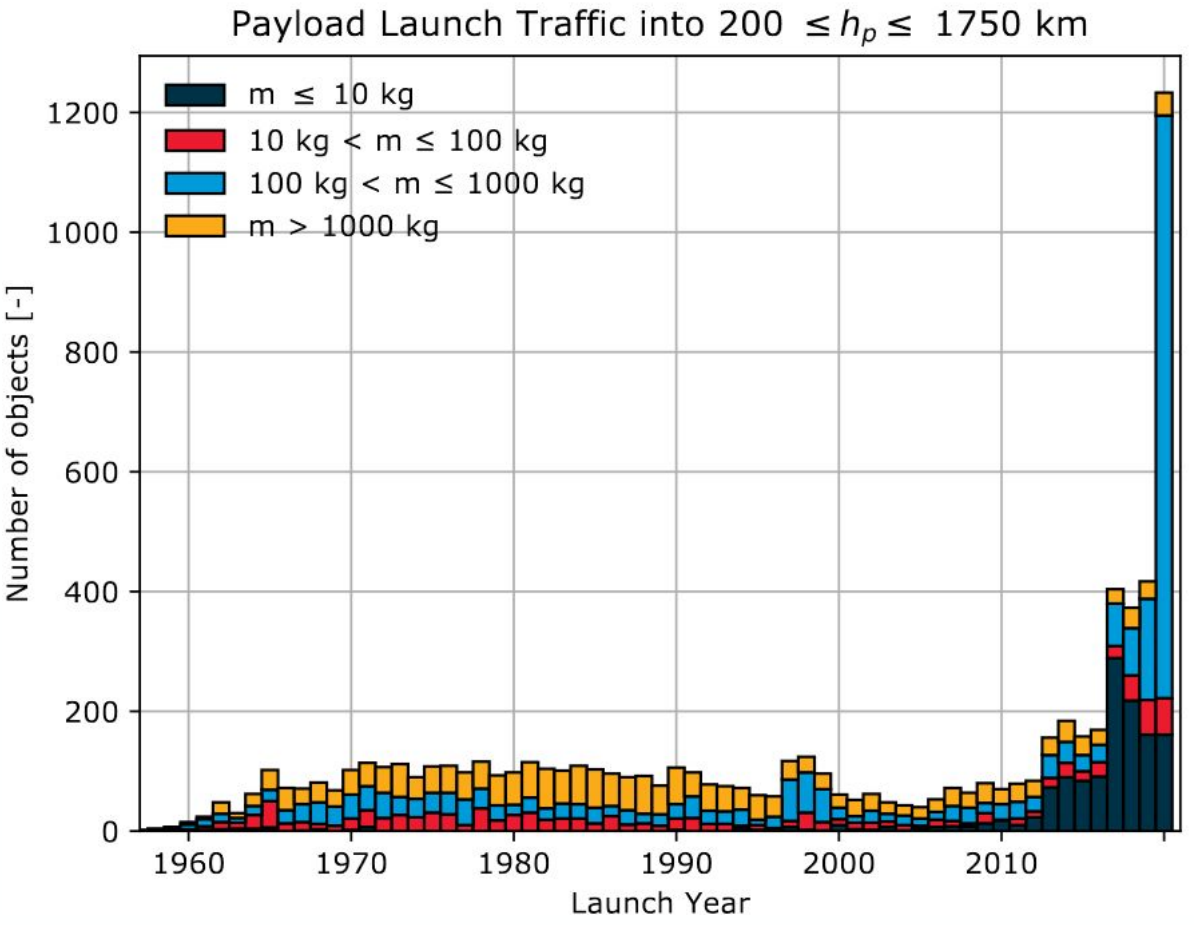
LADDS: Fast Numerical Simulations for the Collisional Dynamics of Large N-Body Systems

Pablo Gómez[1], Fabio Gratl[2], Dario Izzo[1]
[1] Advanced Concepts Team, TEC-SF, European Space Agency
[2] Chair for Scientific Computing in Computer Science, Technical University Munich

Background

Before

- Closed-source
- FORTRAN or similar
- Application-specific
- Small-scale



ESA's Annual Space Environment Report

Background

Before

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- FORTRAN or similar
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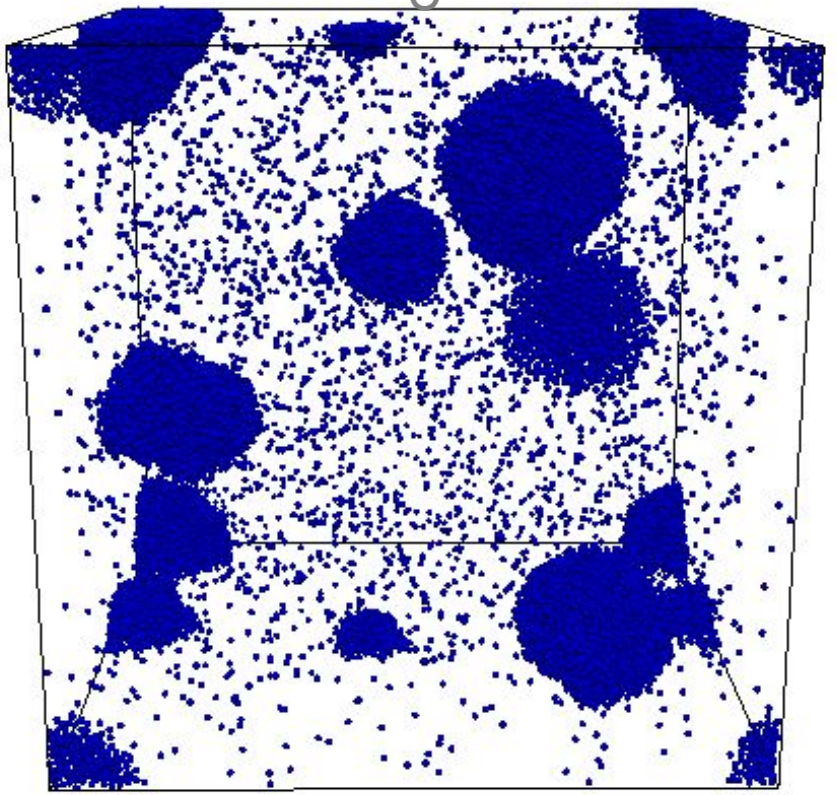
- Small-scale

What we do

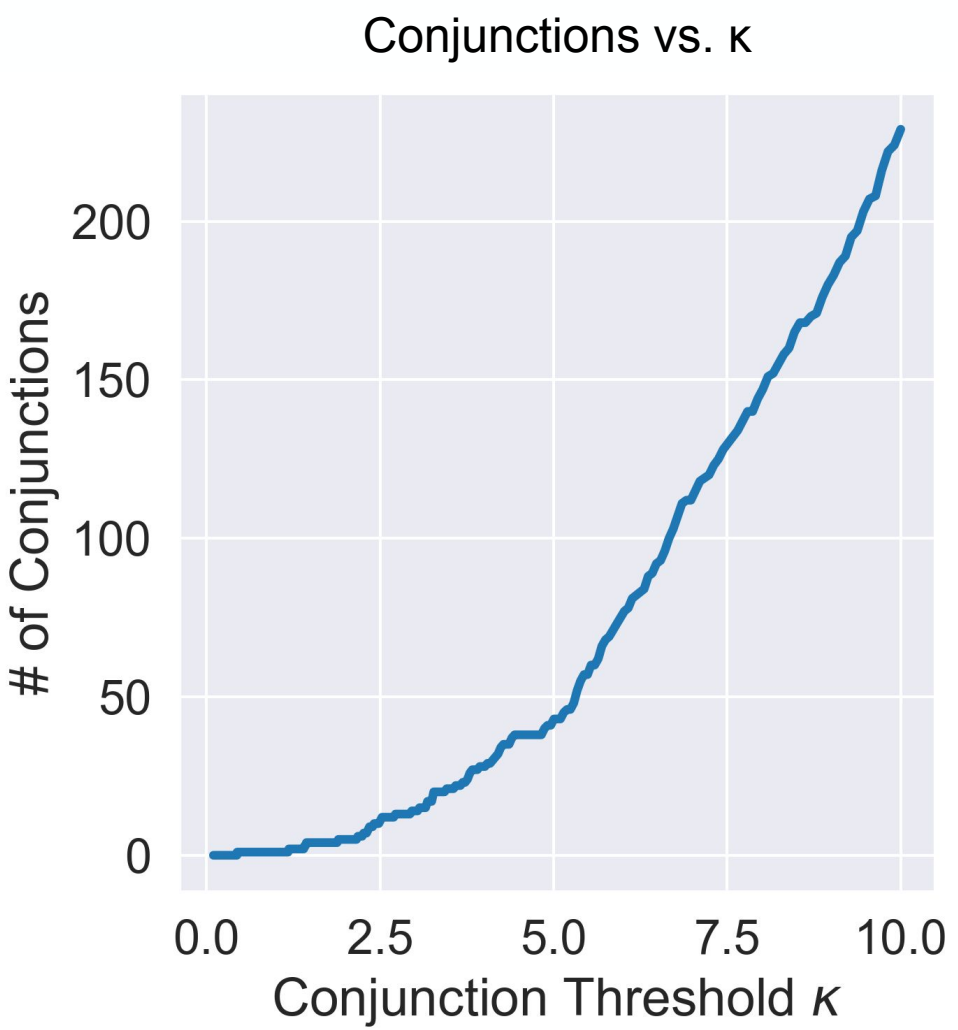
- Collaboration of TUM, ACT and Space Debris Office
- Open-source, C++17
- Large-scale (thousands of cores)
- Use high-performance computing tools
- Fully modular

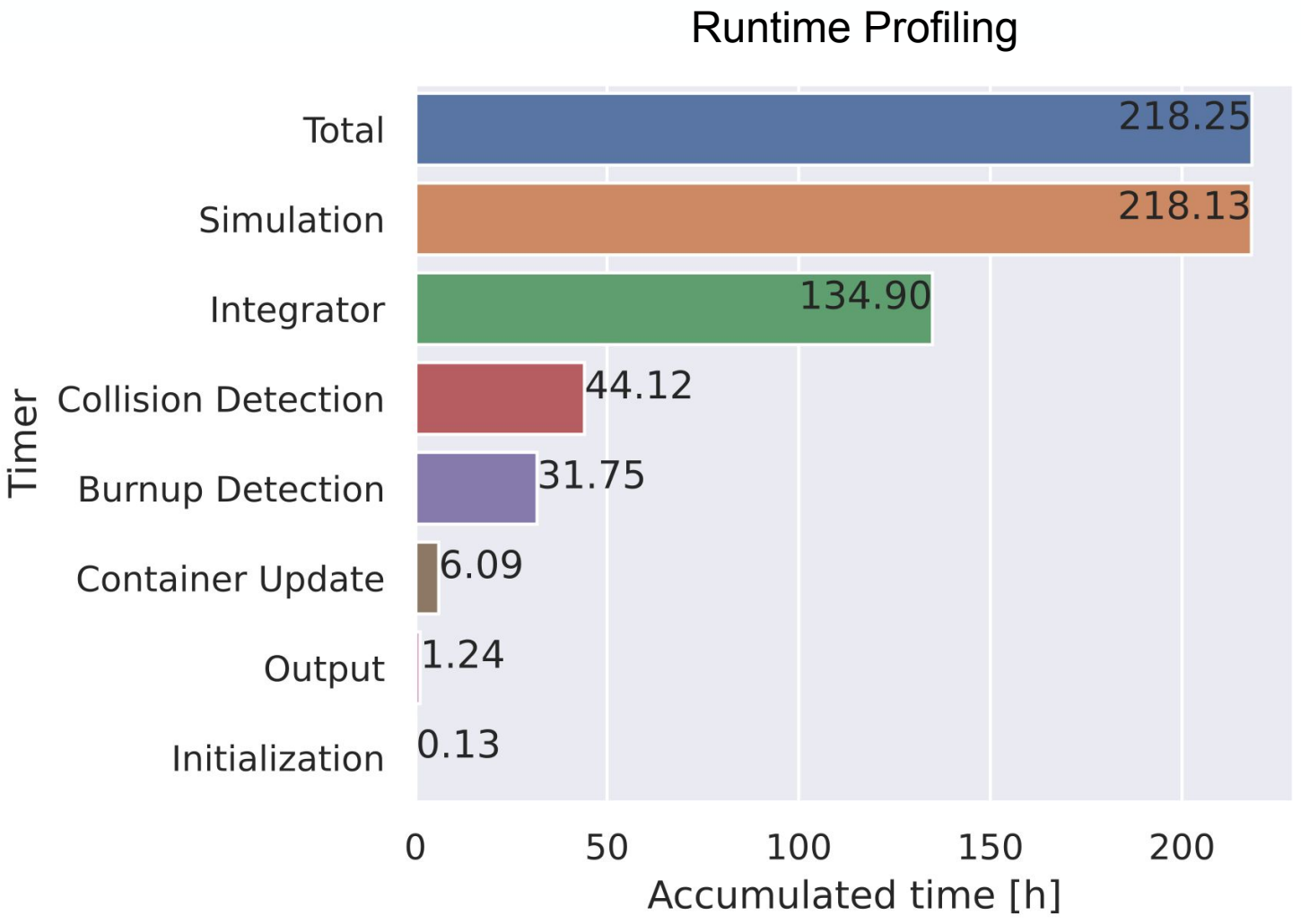
AutoPas



Gratl *et al.* 2019

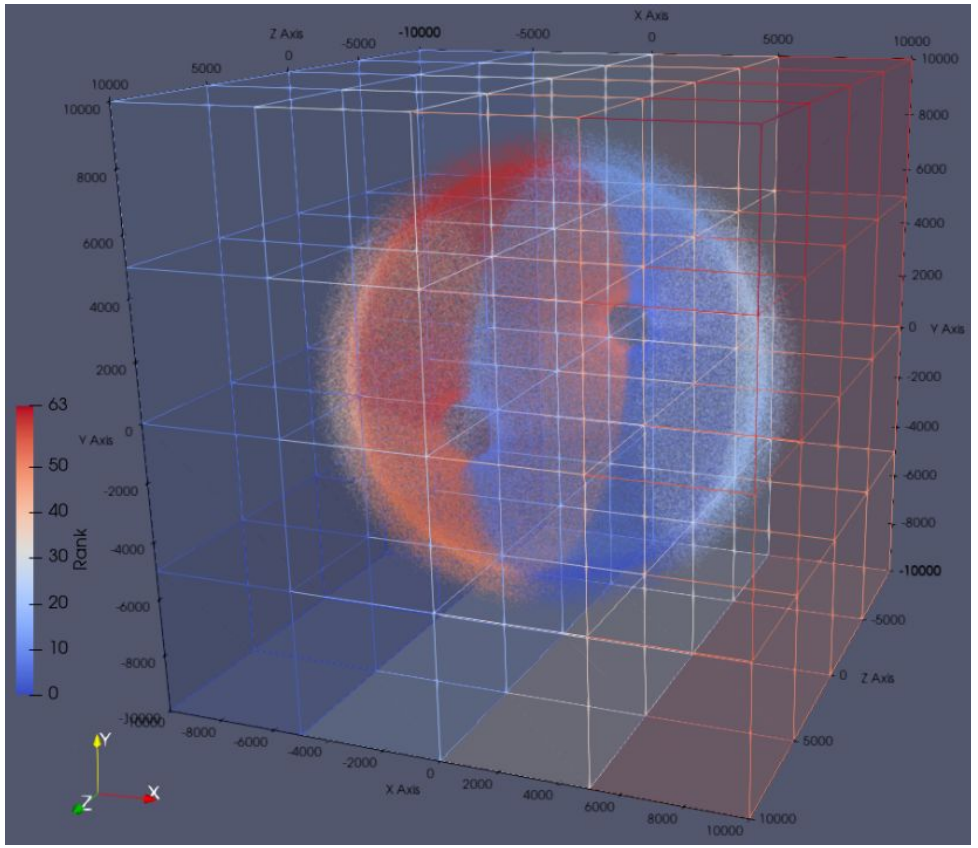
Small-scale - 16 024 Particles, 1 Node, 20 Years



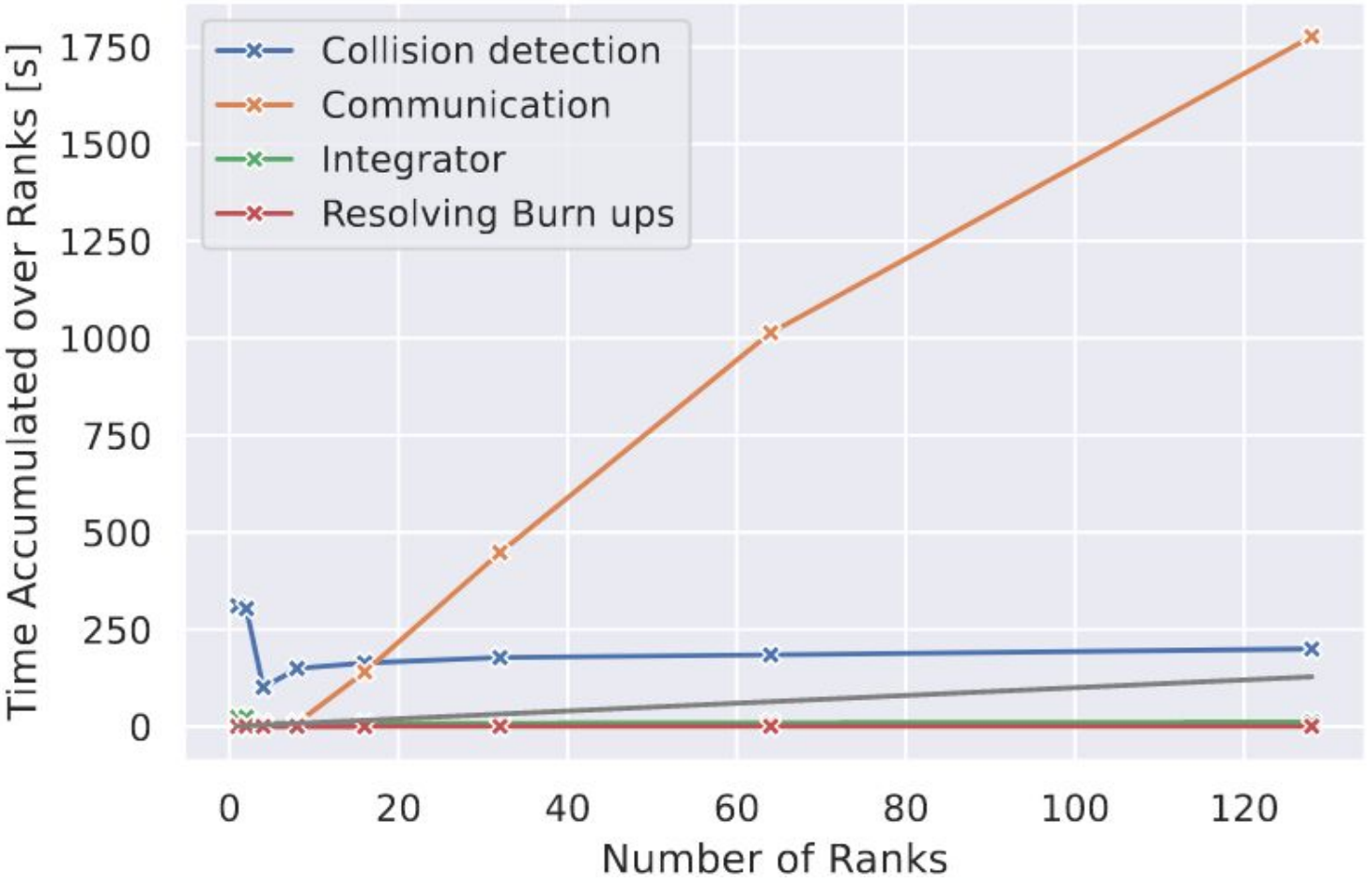


Performance - 614 515 Particles, up to 128 ranks

Domain Splitting

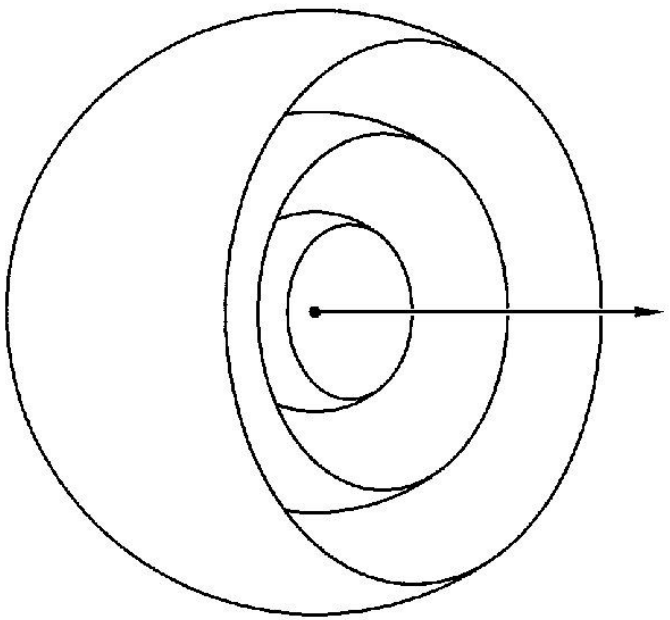


Runtime Profiling



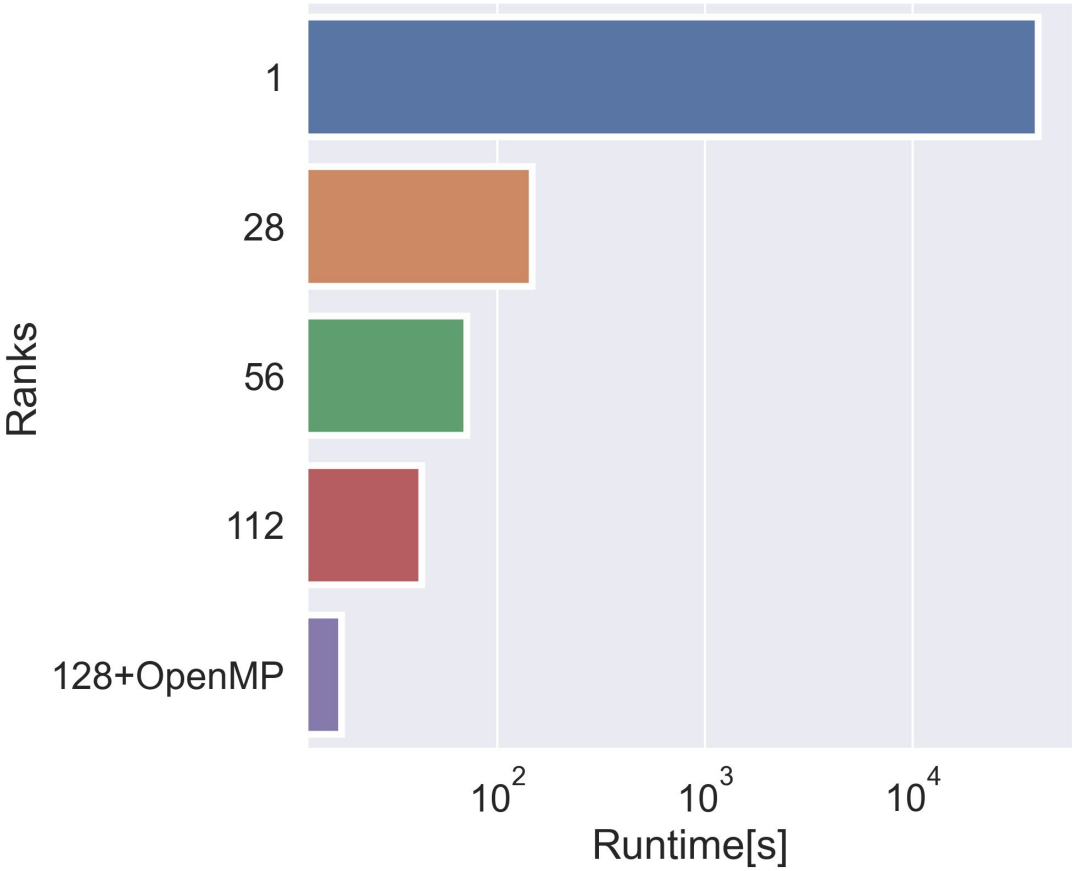
Performance - 614 515 Particles, up to 128 ranks

Improved Domain Splitting

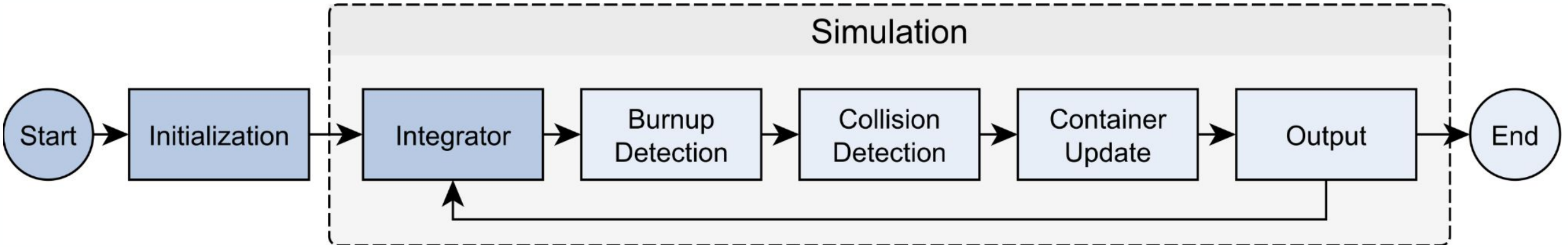


Littlejohn & Rensch 1997

Runtime Profiling



LArge-scale Deterministic Debris Simulation - 0.1.1



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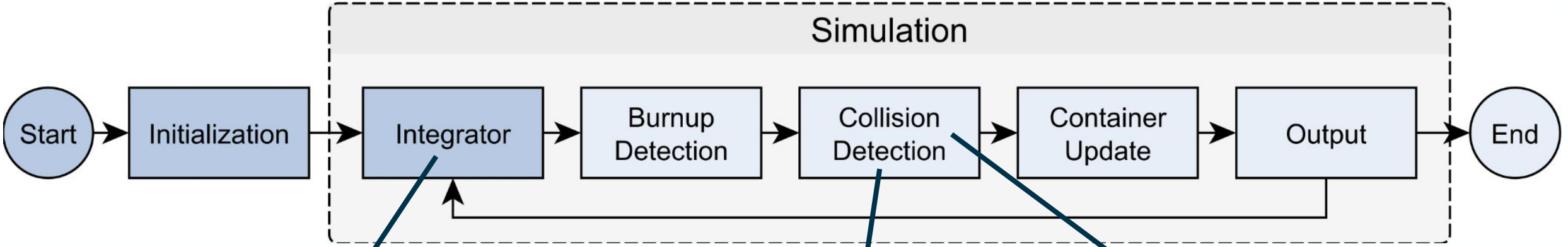


Implemented: Symplectic 4th-order Yoshida

Prospective: Higher-order symplectic, heyoka

Implemented: Deterministic autopas detection

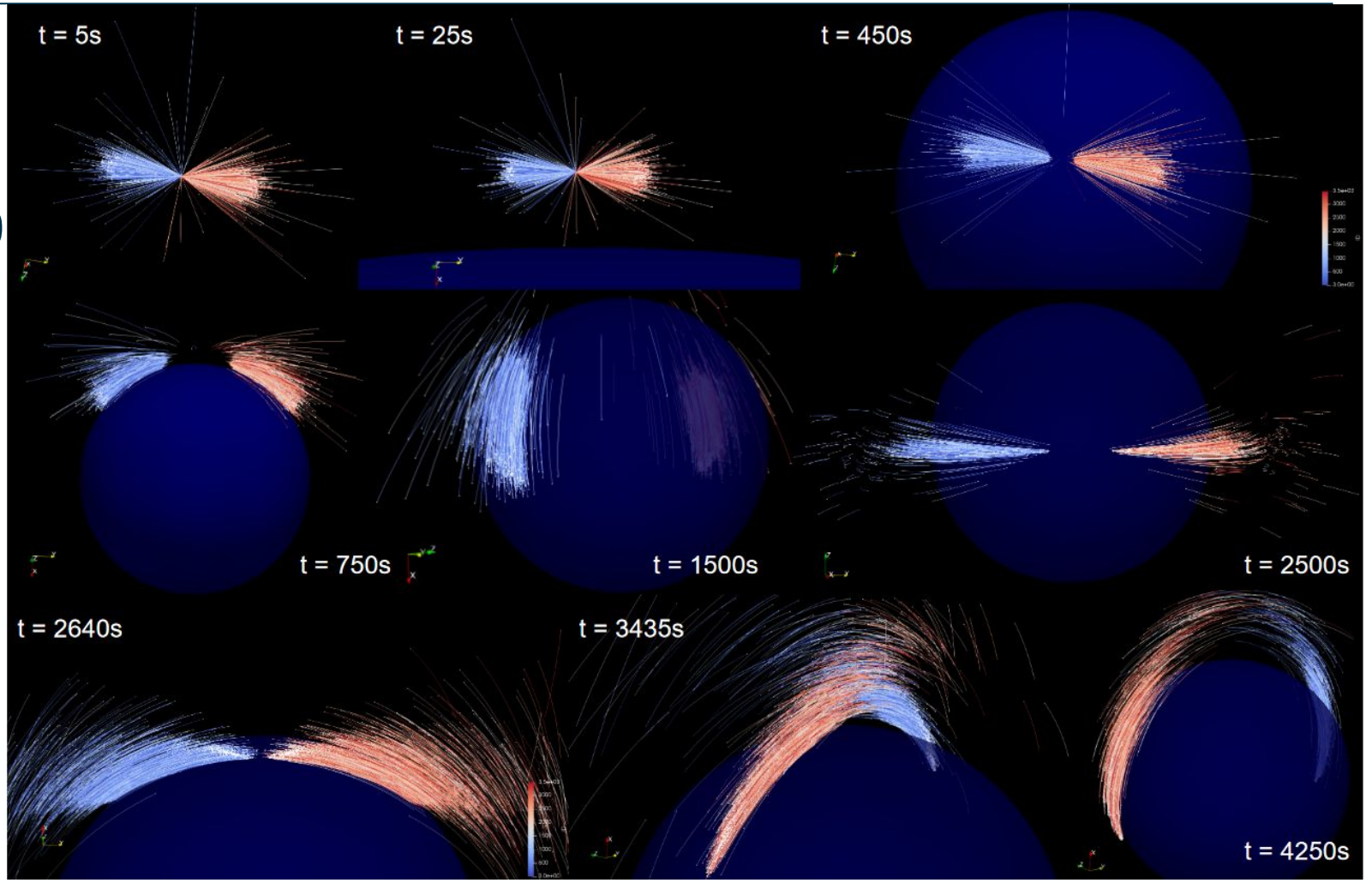
Prospective: Statistical Cubes Method

Implemented: NASA Breakup Model

Prospective: Higher-fidelity models

NASA Breakup Model

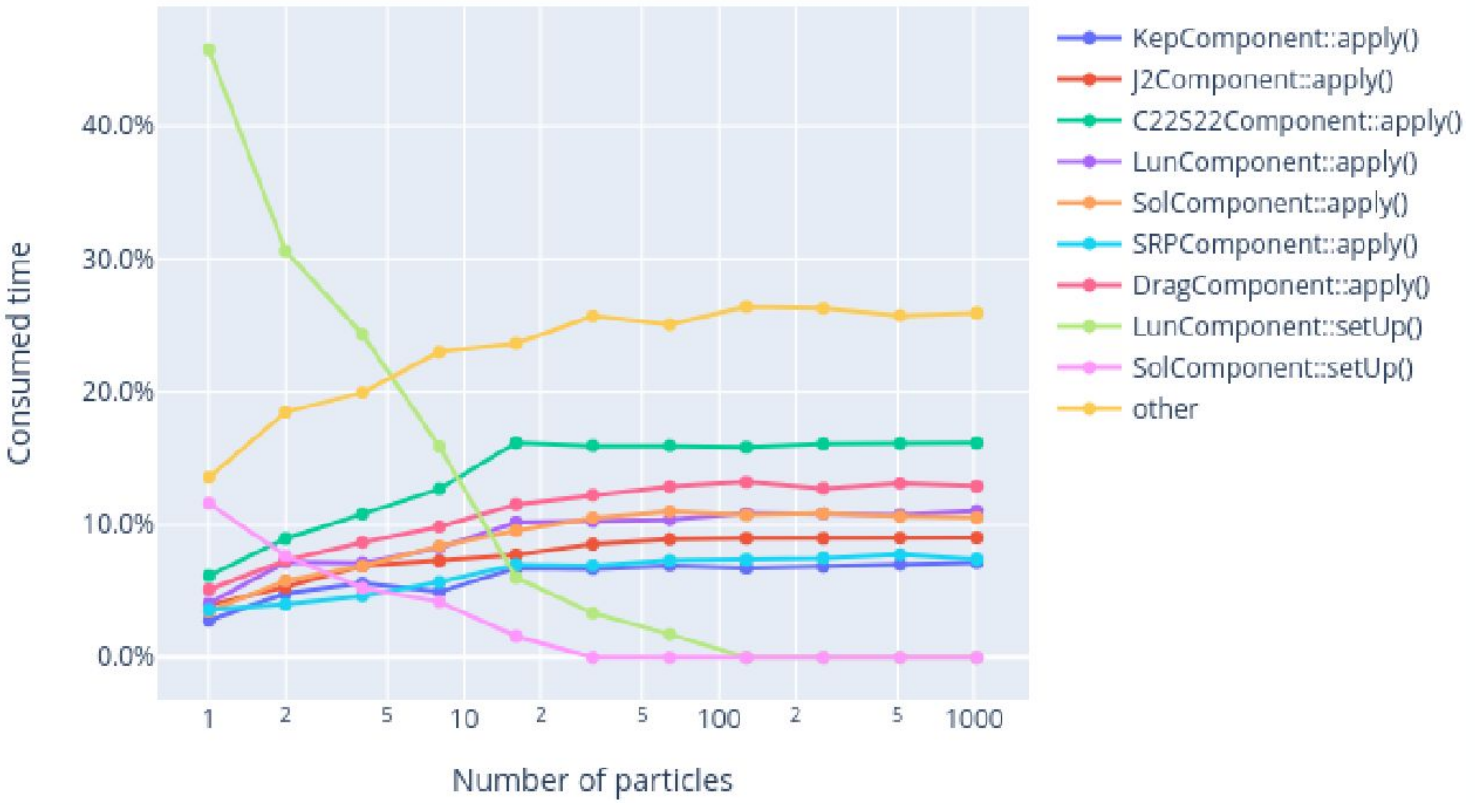
- Modern C++17
- Open-source under GPL-3.0 license
- Automated tests
- Validated against existing implementations
- Extensive technical documentation



Exemplary Break-up Event

Propagator

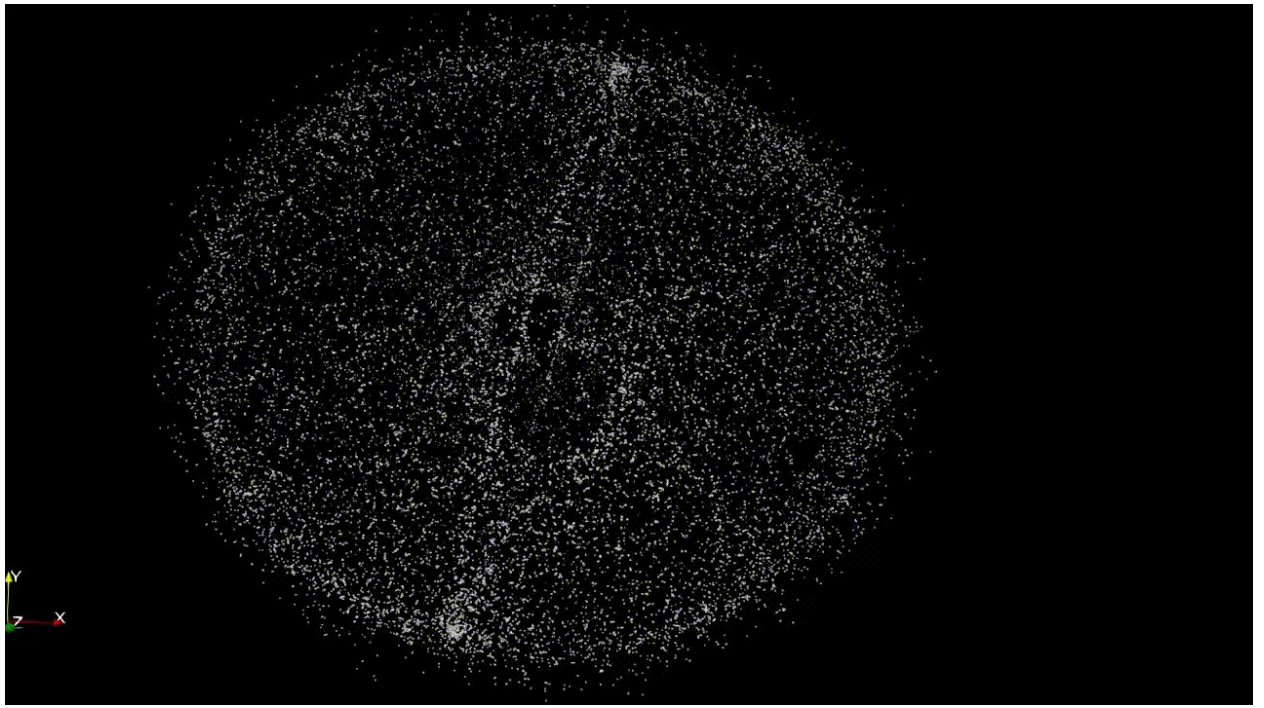
- Modern C++17
- Open-source under GPL-3.0 license
- Automated tests
- Validated against heyoka
- Extensive technical documentation



Bösing 2021

Conclusion & Outlook

- Building a foundation for follow-up research
- Modular design
- Use state-of-the-art tools
- Follow software best practices
- Bring tools from other fields to ESA / space



Visualization of large particle simulation

Thanks!

Code open-source available

https://github.com/esa/LADDS/

https://github.com/FG-TUM/OrbitPropagator/

https://github.com/esa/NASA-breakup-model-cpp

https://github.com/AutoPas

Thank you for your attention!