# THE KESSLER RUN:
# ON THE DESIGN OF THE GTOC9 CHALLENGE

BY DARIO IZZO AND MARCUS MAERTENS

ACKNOWLEDGING MANY OTHER PEOPLE FOR THEIR PRECIOUS EARLY AND NOT SO EARLY INPUTS

IT ALL STARTED IN NAPA

# GTOC 8 - WORKSHOP

# OUR GTOC8 TEAM

- By the time of the NAPA workshop no two members of our GTOC8 team were anymore working together.
- A “distributed” initial brainstorming was performed in and after NAPA with all previous GTOC8 team members.

# BACK TO THE NETHERLANDS

"Lets make them compete in real time. On …"

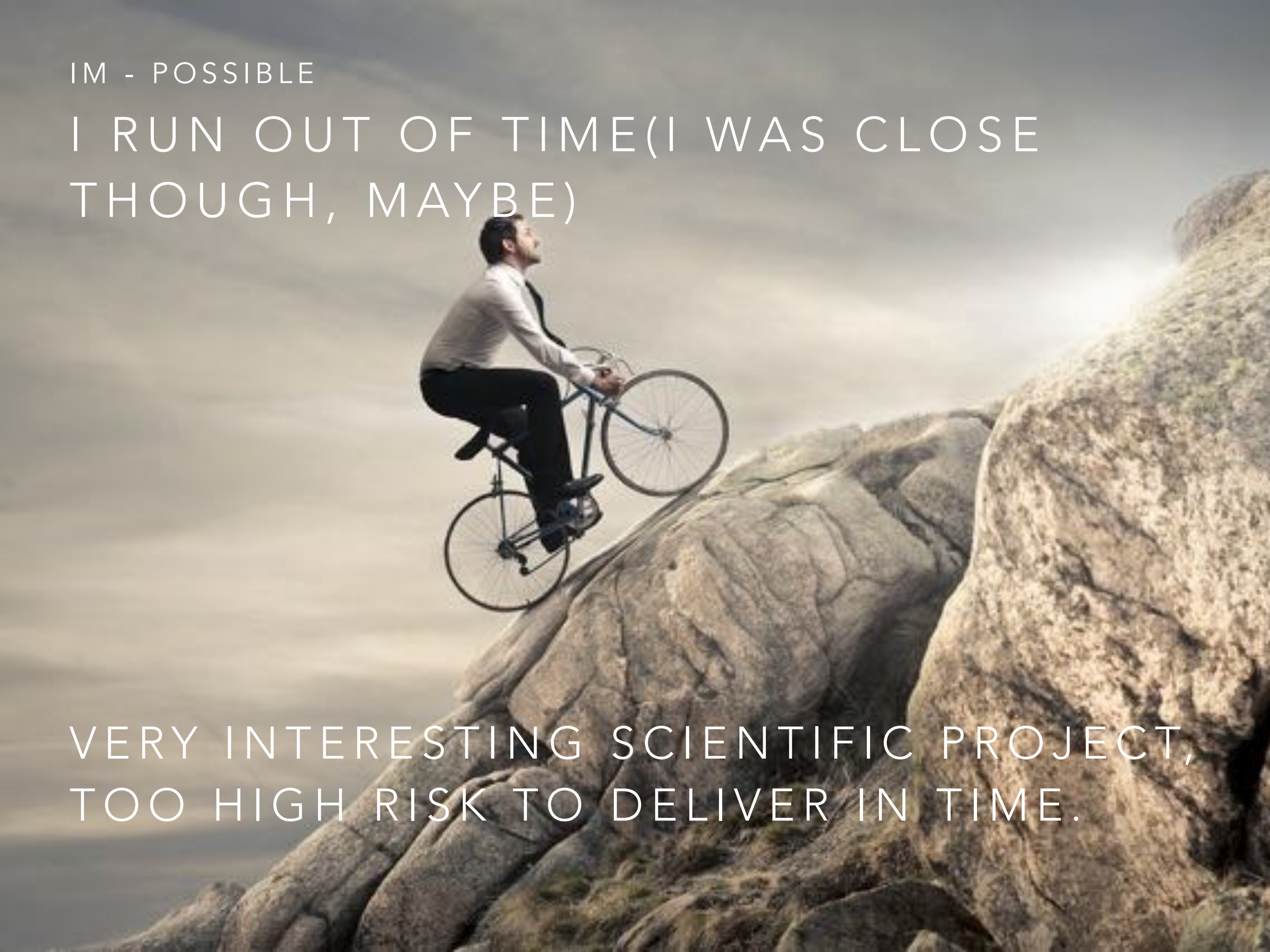
Mining, cyclers, debris, interstellar, three body, solar sails, etc…

- A real time competition requires a reliable automated validator that avoids submitting the thrust history.

- Back in Sept. at ESA, I spent a week trying to develop a robust low-thrust validator (only two body)

IM - POSSIBLE

# I RUN OUT OF TIME(I WAS CLOSE THOUGH, MAYBE)



VERY INTERESTING SCIENTIFIC PROJECT, TOO HIGH RISK TO DELIVER IN TIME.

- Requirements for a GTOC problem:
- A “nearly impossible” problem. No teams should be able to say “I found the global best” -> always space for improvements
- Unusual objective function
- New ideas and algorithms encouraged (enough with BS! .. Beam Search ..)
- Not a mere academic exercise aim for real world relevance
- Low entry level but unlimited depth
- The problem solutions have to be easily and objectively verifiable.
- A clear winner has to be declared soon after the competition ends.
- If possible the competition format should be innovated.

- # Starting points:

- Izzo, Dario, et al. "**Evolving solutions to TSP variants for active space debris removal.**" Proceedings of the 2015 Annual Conference on Genetic and Evolutionary Computation. ACM, 2015

- Simões, Luís F., et al. "**Multi-rendezvous Spacecraft Trajectory Optimization with Beam P-ACO.**" European Conference on Evolutionary Computation in Combinatorial Optimization. Springer, Cham, 2017.

The J2 effect combined with a “remove them all” constraint had just the right complexity to fulfil almost all the requirements by itself

SPACE DEBRIS - ACTIVE REMOVAL - MULTIPLE MISSIONS - REMOVE THEM ALL

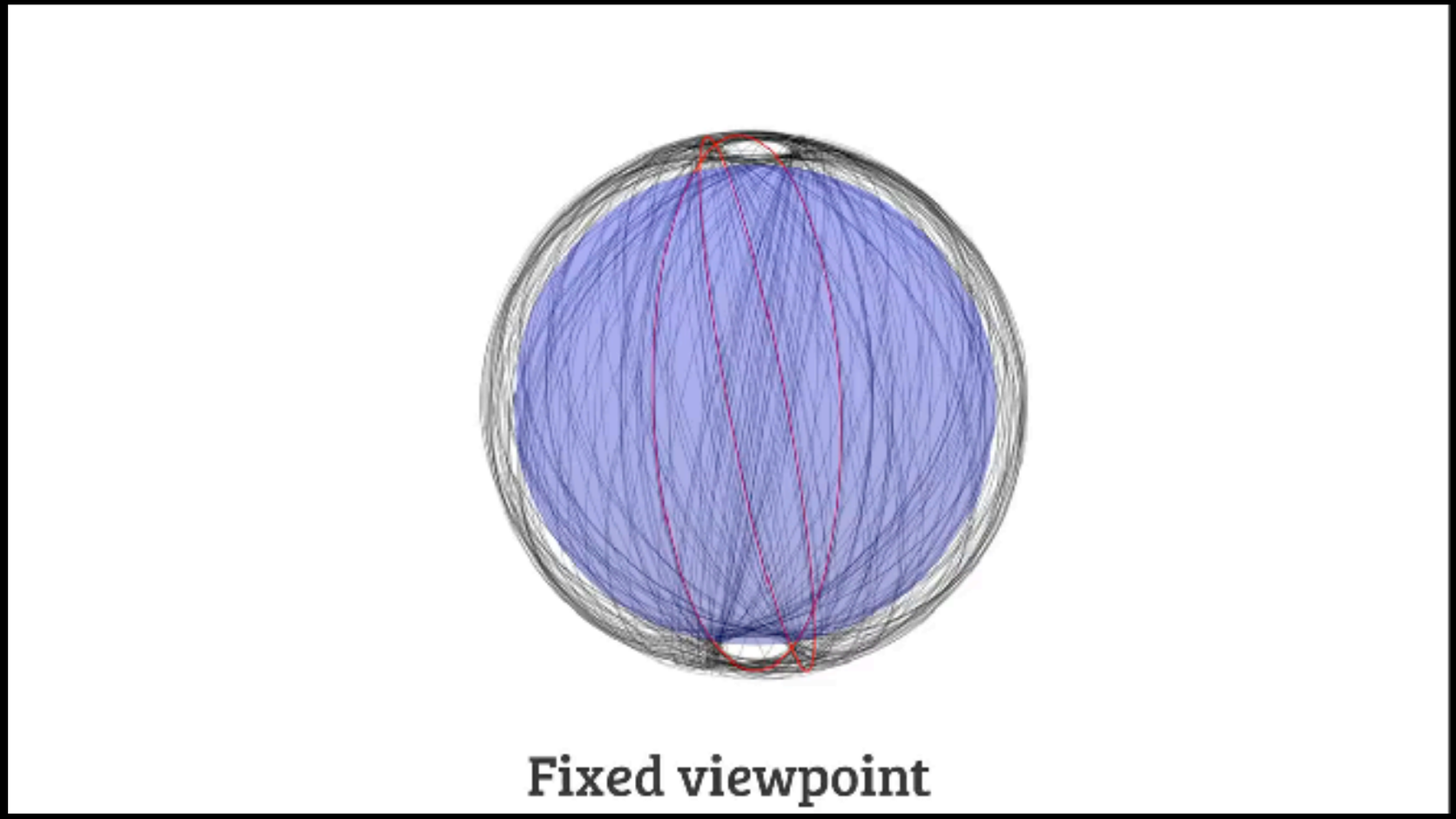
# THE KESSLER EFFECT

I DID THE KESSEL RUN

UNDER 12 PARSECS

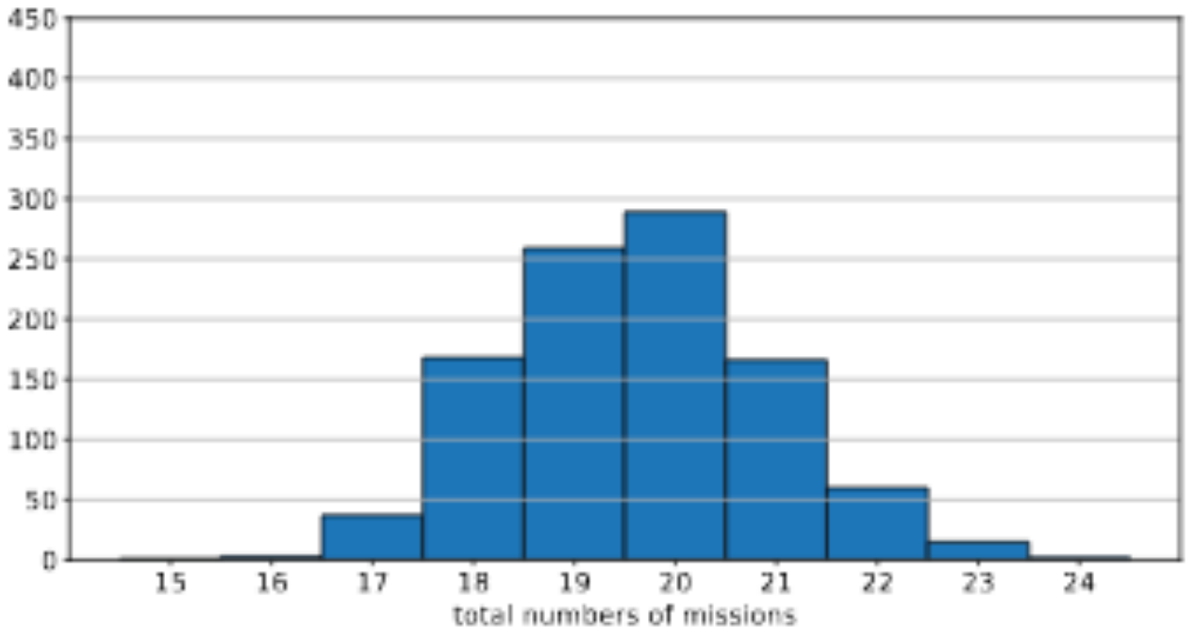
# A FIRST VERSION OF THE PROBLEM

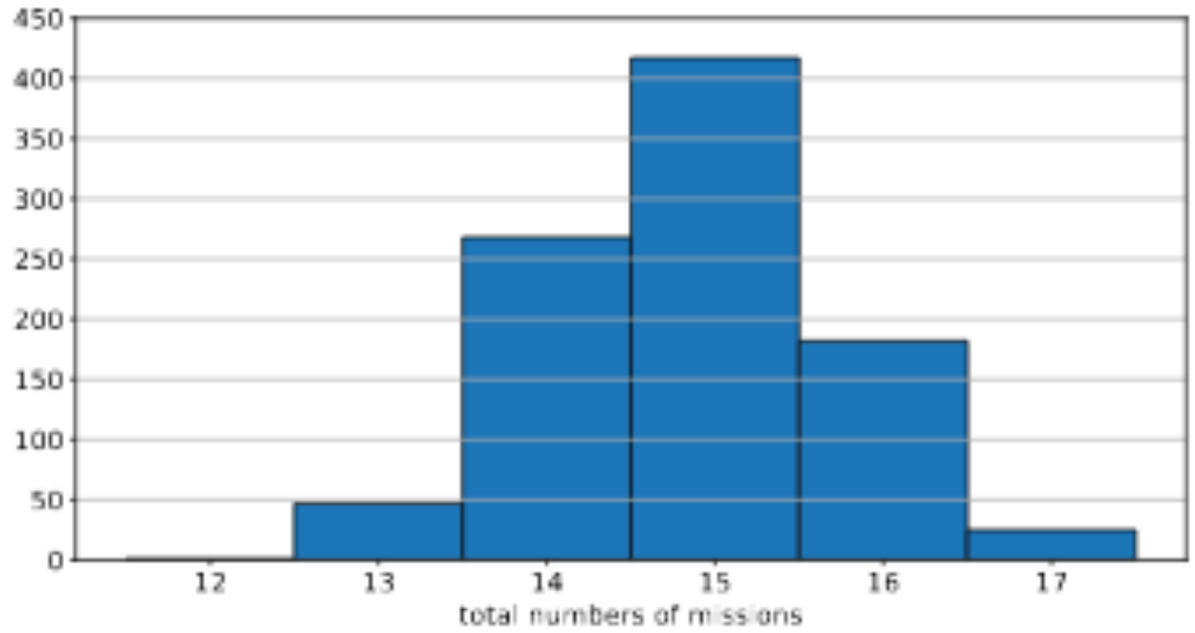
- 123 debris orbits (different from the final ones)
- Minimize the number of missions
- Perform a dry run to explore the complexity



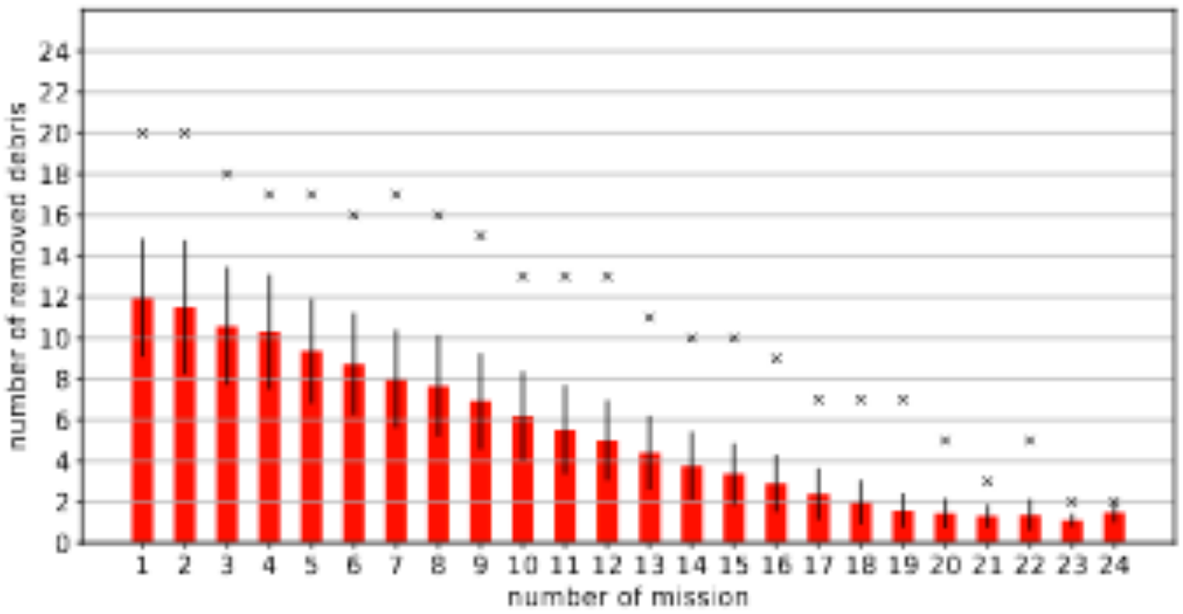
Fixed viewpoint

# 1000 runs

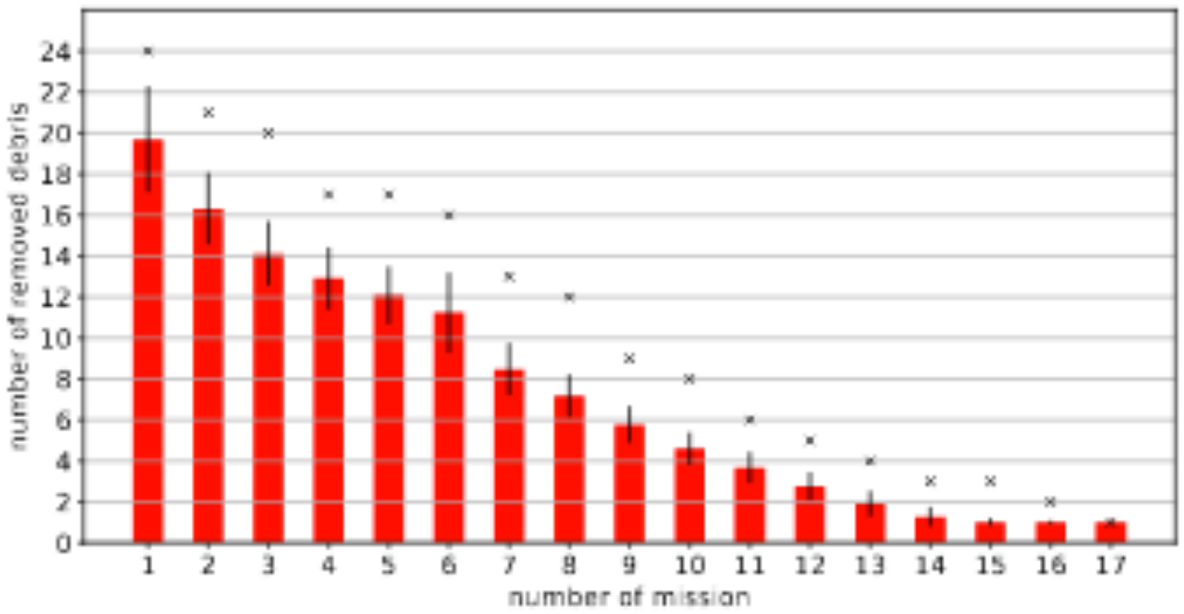



# Greedy




# BS - bw100



LETS TRY A GLOBAL (NOT INCREMENTAL) APPROACH

# SET COVER PROBLEM

# ISSUES

- 10 is not 12. Remember? it has to be difficult to make it in less than12 missions (parsec)
- Multiple teams ending up with the same score (the quickest then wins)
- Too deterministic (set cover is, the database not, still…)

# SOLUTIONS

- Increase the orbits “distance” w.r.t. available DV and make it 12.

- Introduce the mass penalty factor: strategy for mass allocation not trivial and adding an interesting trade-off.

- Heuristics become necessary also with a database of precomputed trajectories.

- Tune the increasing cost cleverly as to allow last minute great ideas to win last minute.

WE WERE WATCHING

# HIGHLY ADDICTIVE LEADERBOARD

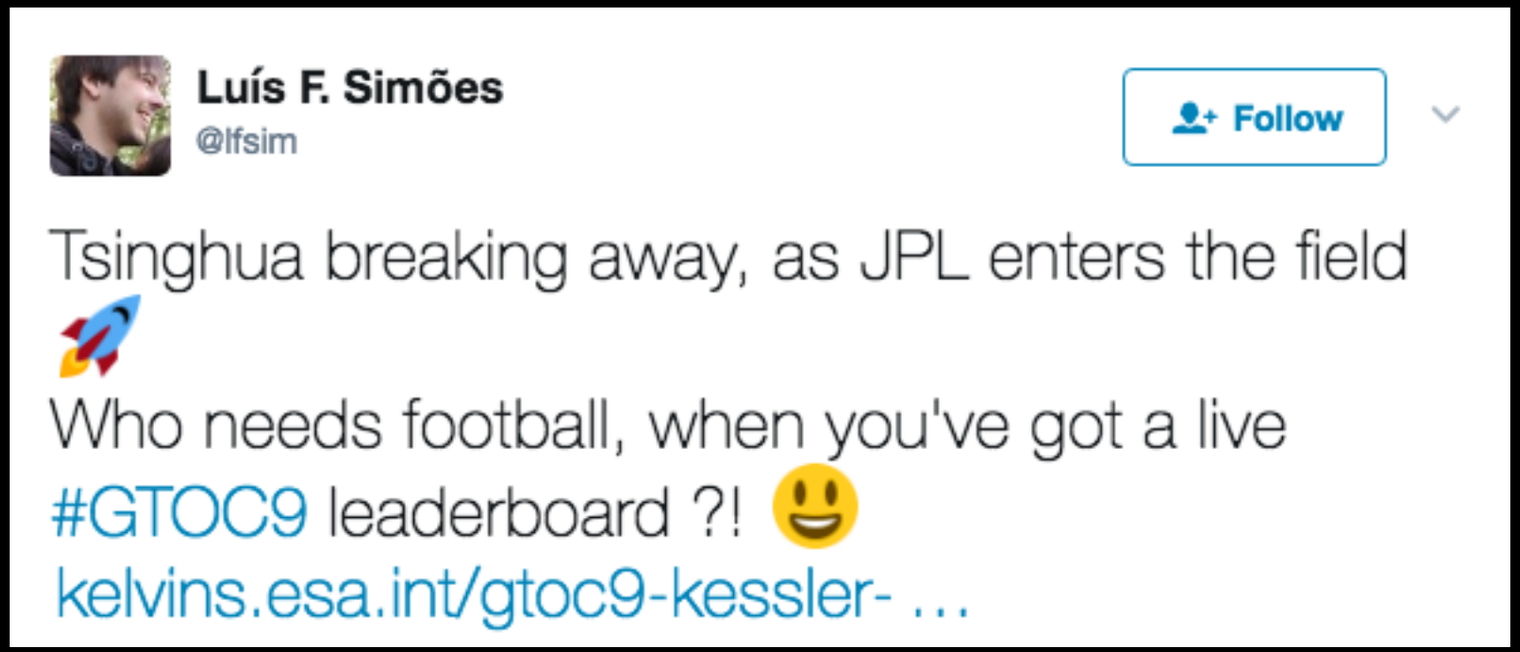
#3

**Liam Smith** @liam_smith7 · May 2

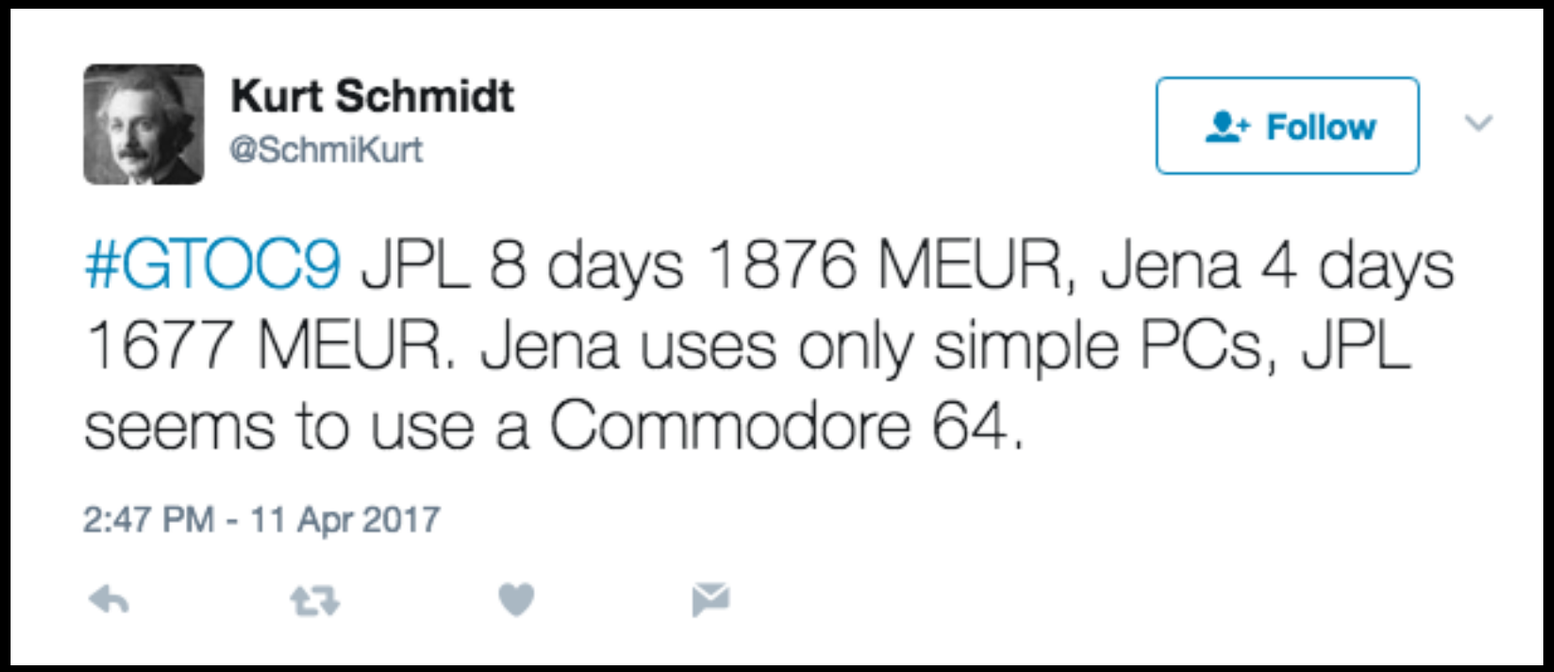
#GTOC9 Already can't wait for #GTOCX

1

# #2


Luís F. Simões
@lfsim
Follow
Tsinghua breaking away, as JPL enters the field
Who needs football, when you've got a live
#GTOC9 leaderboard ?!
kelvins.esa.int/gtoc9-kessler- …

# #1


Kurt Schmidt
@SchmiKurt
Follow
#GTOC9 JPL 8 days 1876 MEUR, Jena 4 days 1677 MEUR. Jena uses only simple PCs, JPL seems to use a Commodore 64.
2:47 PM - 11 Apr 2017

THANKS TO EVERYBODY FOR MAKING THIS EDITION A SUCCESS

# NUMBERS ON GTOC 9

Number of different countries: 19
Teams in the final leaderboard: 36
Registered teams: 69
Registered institutions: 125
Scientists registered: ~320
Missions submitted: ~1200