The absurdly complex problem of settling the galaxy.

… to appear in Acta Futura

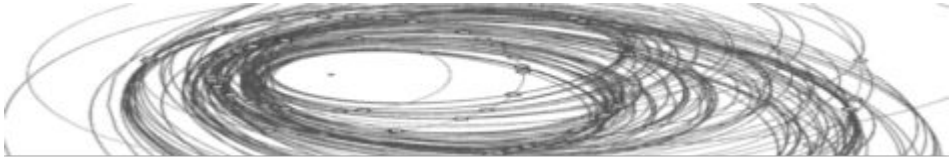
Dario Izzo,
Marcus Martens,
Ekin Ozturk,
Mate Kisantal,
Konstantinos Konstantinidis,
Luis F. Simoes,
Chit Hong Yam,
Javier Hernando-Ayuso

ACT's Interstellar Workshop, ESTEC, 2019

esa

"The Global Trajectory Optimization Competition is an event taking place every one-two years over roughly one month during which the best aerospace engineers and mathematicians world wide challenge themselves to solve a ***nearly-impossible*** *problem of interplanetary trajectory design. The problem is released by the winning team of the previous edition who, also, is free to define entirely the competition rules."*

Global Trajectory Optimization Competitions



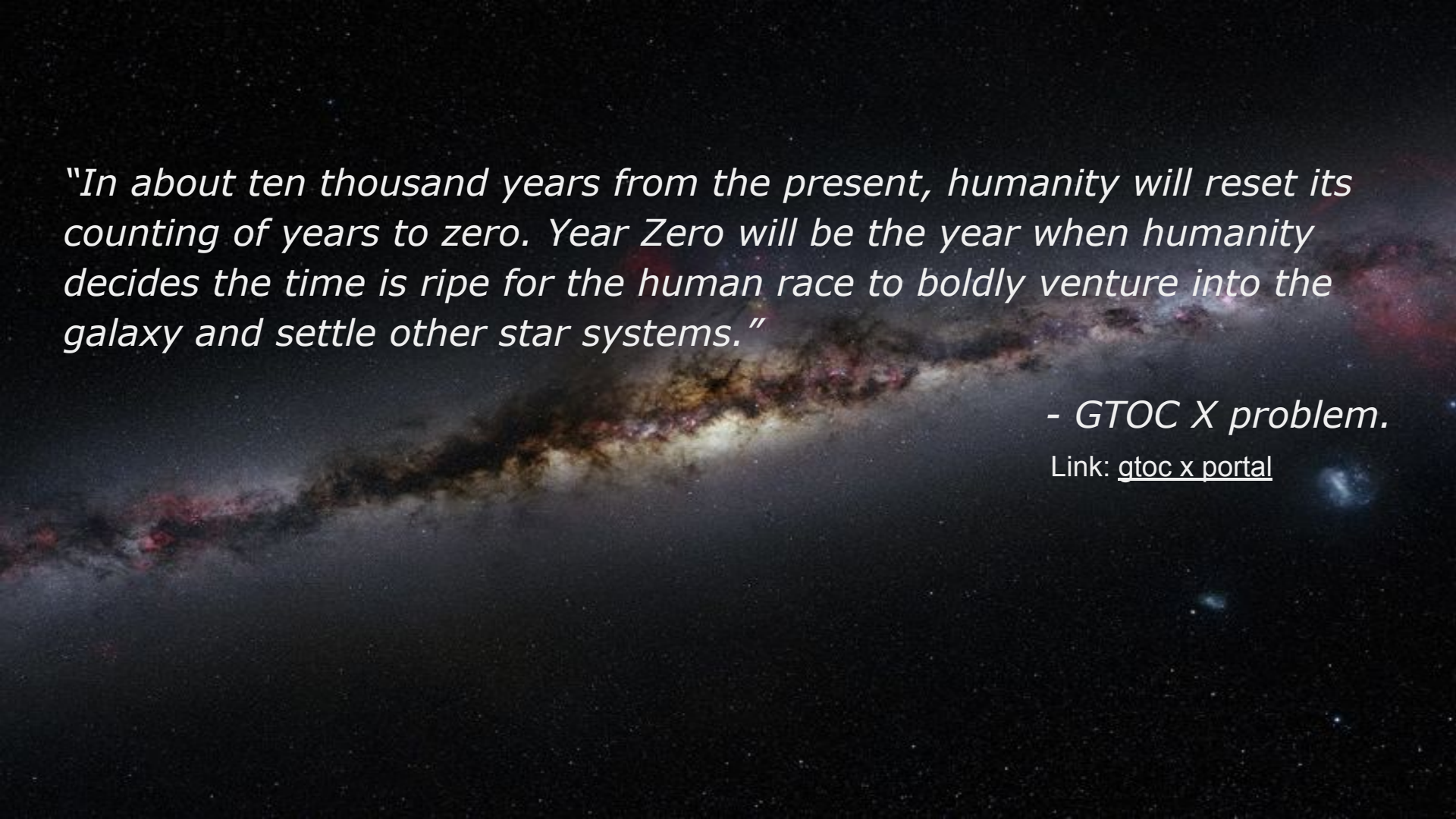
GTOC-X in numbers

Jet Propulsion Laboratory
California Institute of Technology

- 73 teams.
- > 300 scientists.
- 1 month long.
- US, Europe, Australia, India, China, Russia, Canada, Turkey, Korea, Azerbaijan.
- Universities, Space Agencies, Industries, private citizens.

What is the problem going to be?


settlers
of
the
GALAXY



“In about ten thousand years from the present, humanity will reset its counting of years to zero. Year Zero will be the year when humanity decides the time is ripe for the human race to boldly venture into the galaxy and settle other star systems.”

- GTOC X problem.

Link: gtoc x portal

The problem in more details

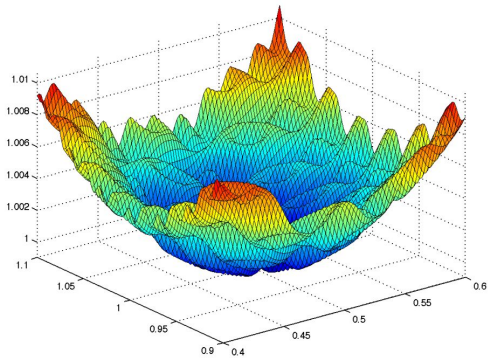
- 100,000 stars spread in a 32 Kpa disc.
- Slow generational ships (World ships? Colony ships?). (0.005% light speed, 80000 gens)
- 90 MYr (~half period of Sol orbit).
- Vessel and star dynamics in the galaxy accounting for rotational curves anomalies.

- 3x Motherships (500 km/s DV, max 200 km/s per impulse, 3 impulse)
  - 10x Settlement Pods (300 km/s DV, max 300 km/s per impulse, 1 impulse, single settlement)
- 2x Fast Ships (1500 km/s DV, max 1500 km/s per impulse, 2 impulse, single settlement)
- 3x Settlement Ships (400 km/s DV, max 175 km/s per impulse, 5 impulses, single settlement) per settlement (Von Neumann self-replicators)

The objective

In a nutshell: settle as many stars as possible as uniformly spread as possible using as little propellant as possible.

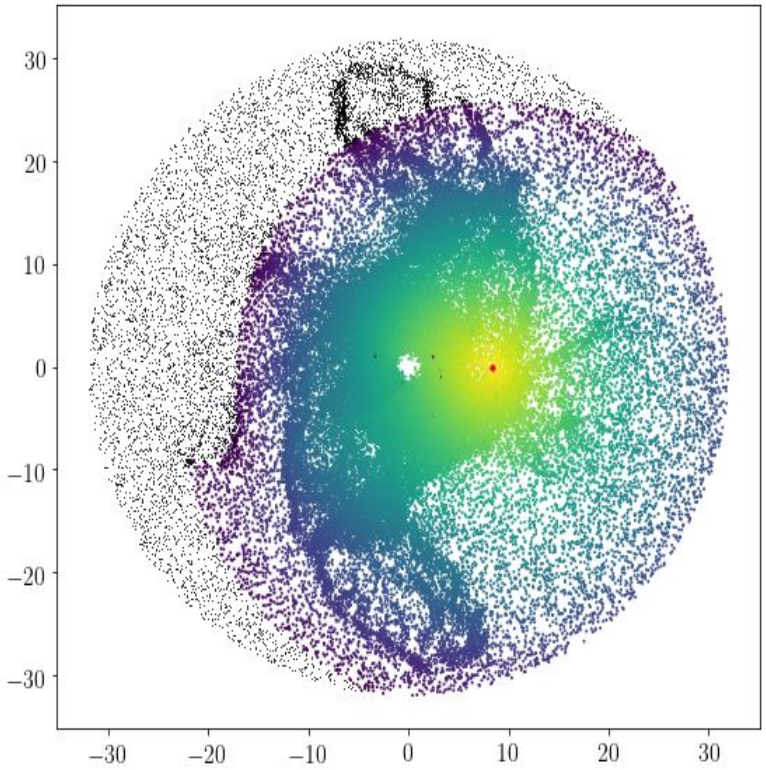
$$J = N\ \eta\ \sigma$$



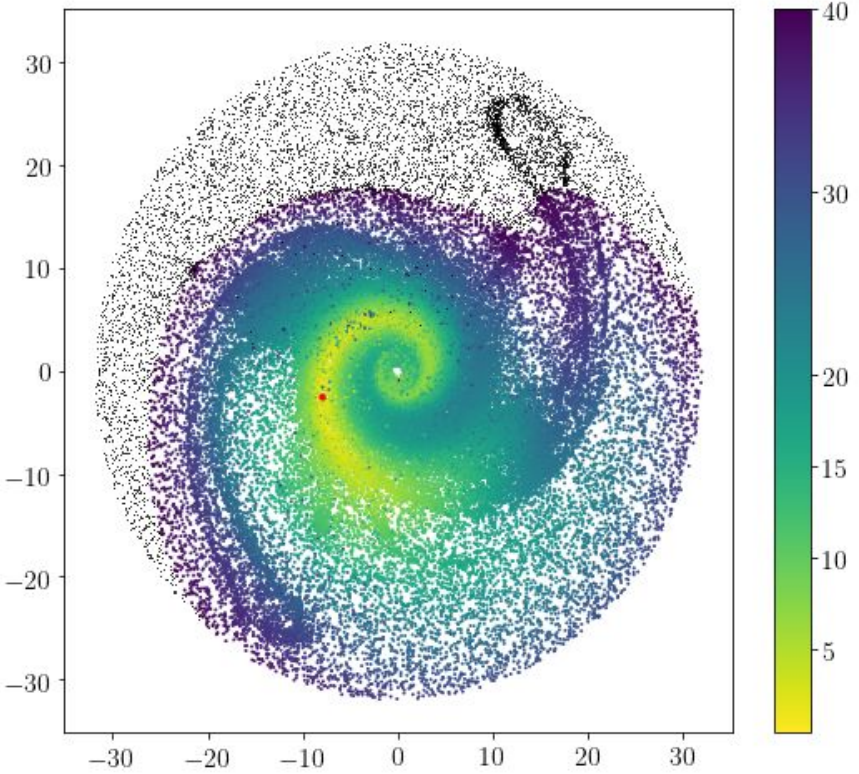
- **N**: Number of stars settled
- η: settlement spatial distribution efficiency
- σ: ΔV efficiency

All terms are in conflict with each other!

Fast Ships - Example

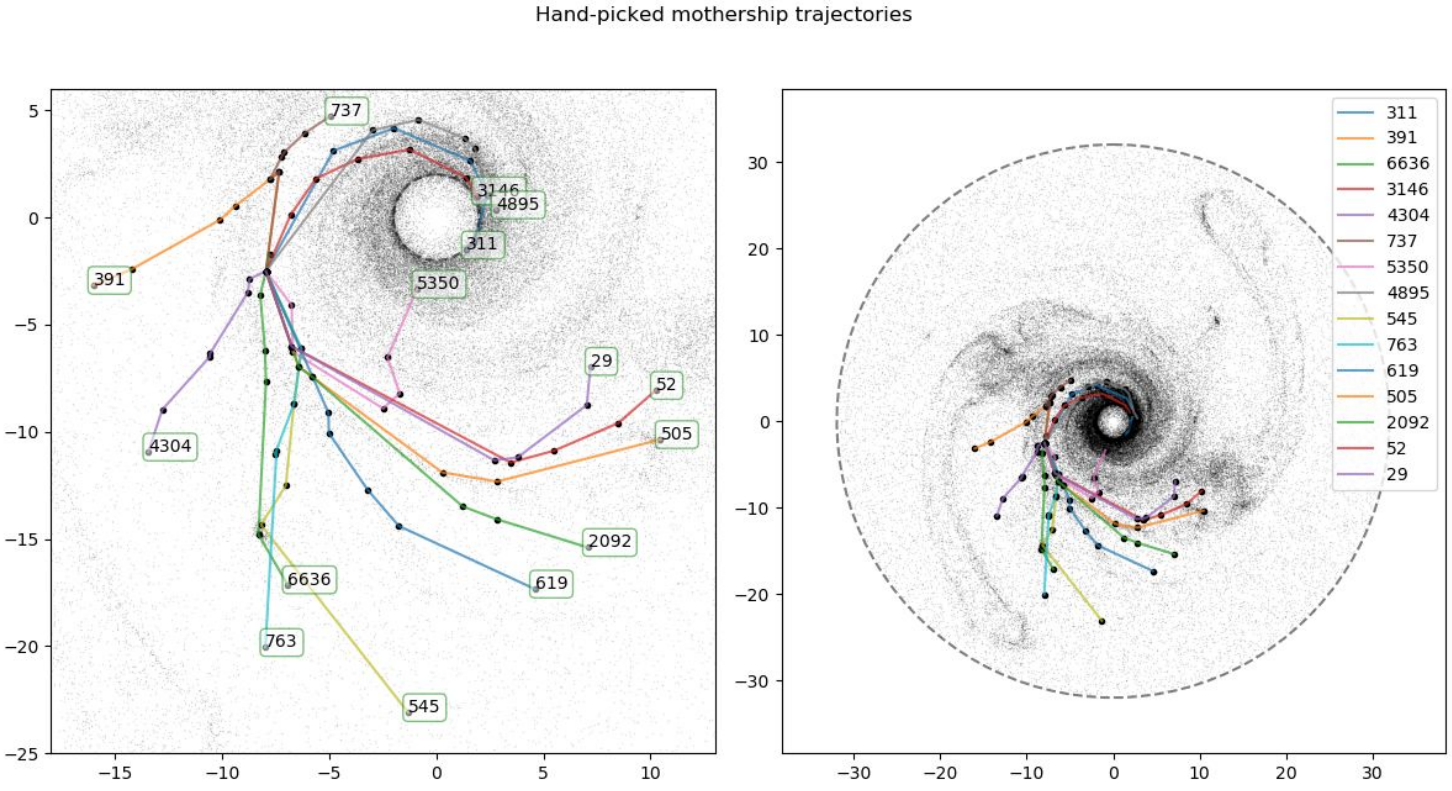


0 MYr



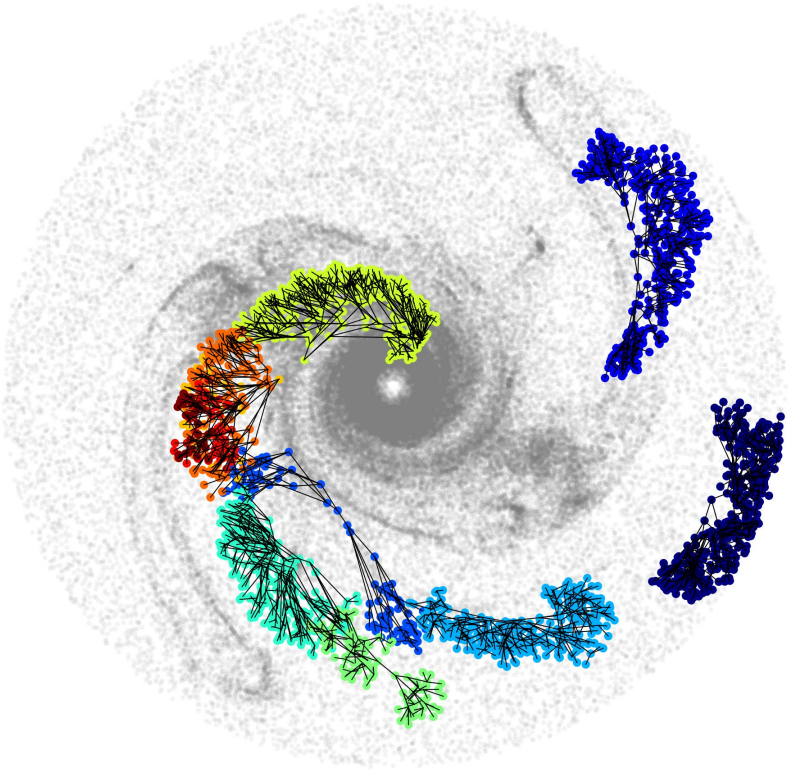
90 MYr

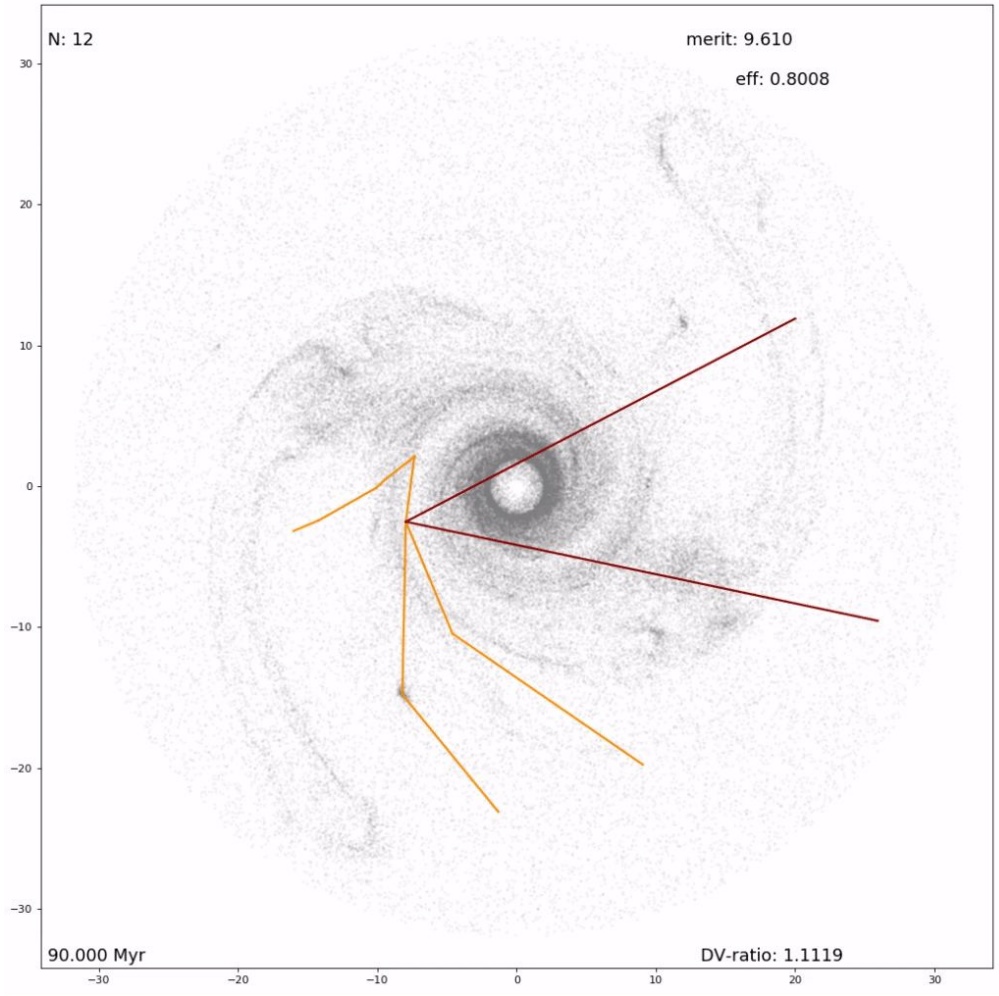
Mother Ships - Example



Our solution strategy

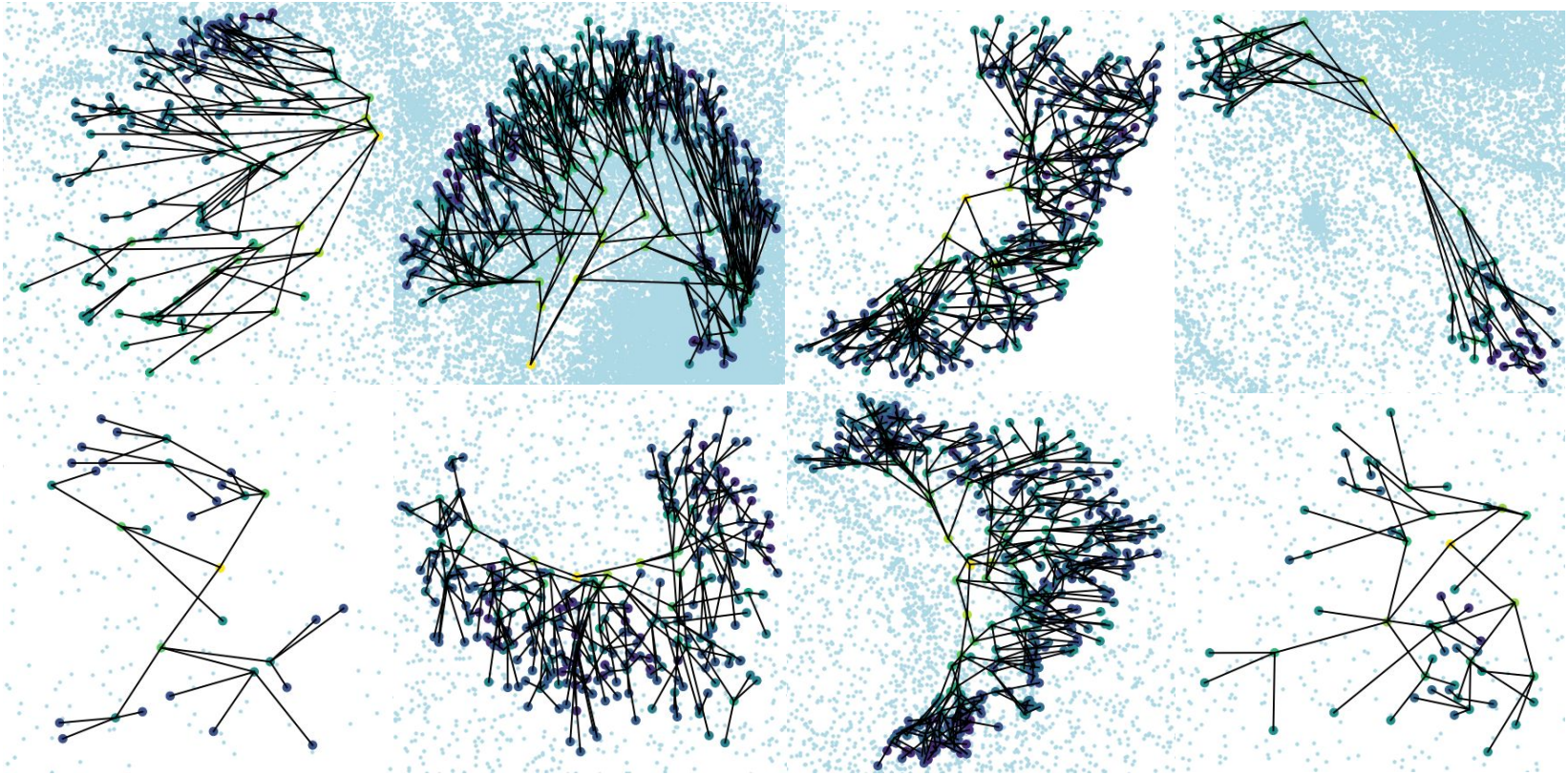
1. Find initial fleet
    a. Motherships - where and when
    b. Fast ships - which star
2. Grow settlement trees
    a. Concurrently
3. Reduce sub-optimality in distribution
    a. Pruning
4. Reduce DV consumption
    a. Shortcutting
    b. Re-topologising
    c. Stretching leaves





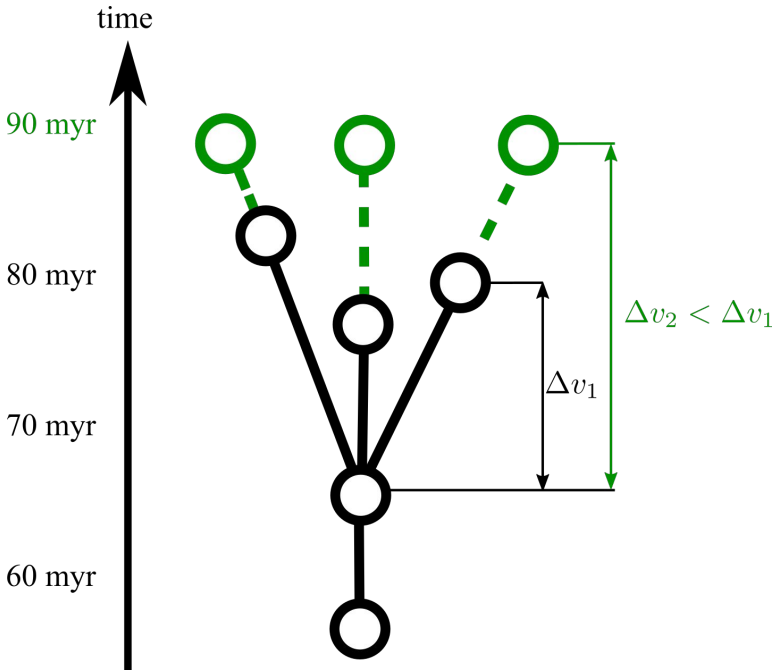
- Concurrent search from nodes
- Spatial distribution is favoured at first, star number later on
- Difficult to settle uniformly across theta
- As the number of star grows the settlement efficiency decreases.

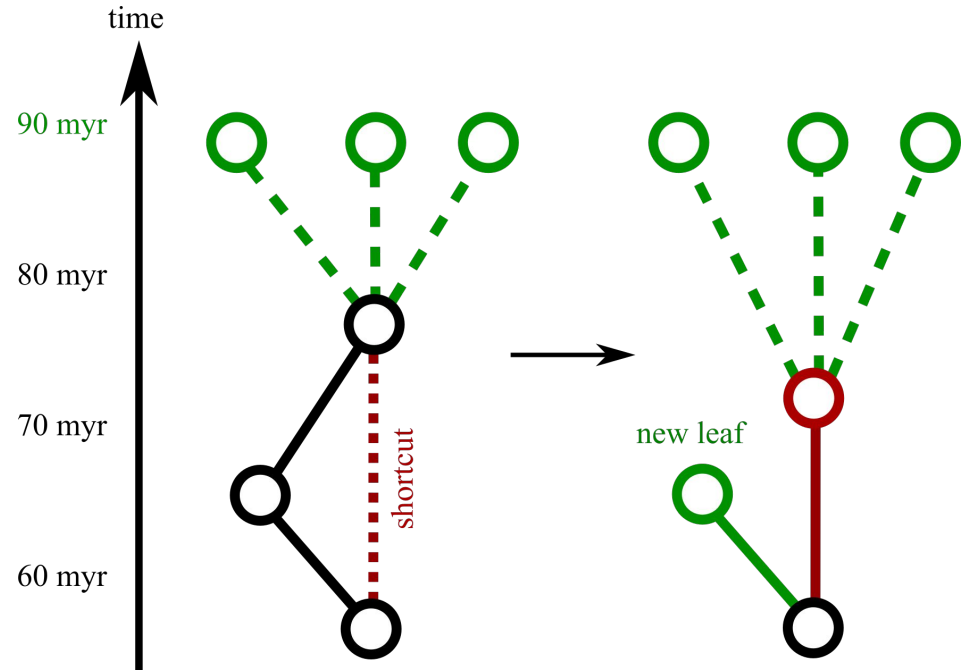
Settlement trees in all shapes



Optimization for Δv (fuel consumption)

- Goal: settle the same stars but spend less Δv
- Trick: Trade travel time against Δv (move slower, arrive later)





Optimization for Δv (fuel consumption)

- Goal: settle the same stars but spend less Δv
- Trick: Find recursively **mass-optimal equivalent subtrees** by rewiring transfers