GTOC11: “Dyson Sphere” Building
Problem Description and Summary of the Results

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Some criterions of GTOC Problem

- Low entry
  - Well-defined dynamics, constraints and objectives
  - It is approachable even by the mathematician who are not familiar with astrodynamics
- Unlimited depth
  - Unusual objective function
  - Many local optima, no obvious solution
  - Combinatorial complexity
  - Dynamical complexity
- Verifiable
  - The problem solutions have to be easily and objectively verifiable.
  - A clear winner has to be declared soon after the competition ends
- Also aim for prompting the academic research of our community

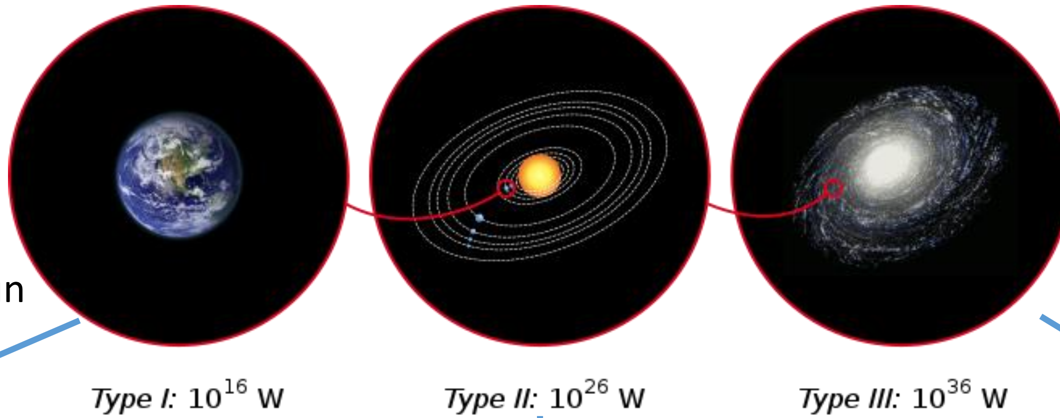
Multiple targets are generally involved for simplified dynamics

Our GTOCX team

- A brainstorming was performed with all previous GTOCX team members of NUDT and XSCC
- Orbital servicing, solar electric station, The Wandering Earth, Setters of the Mars, The Martian, Lunar Constellation, Planetary Defense, etc…

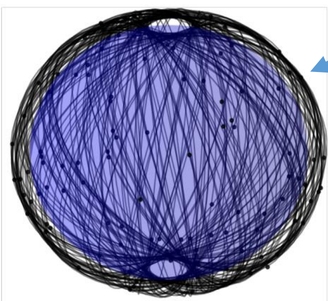
Starting point:

The Kardashev scale is a method of measuring a civilization's level of technological advancement based on the amount of energy it is able to use.



Planetary Type

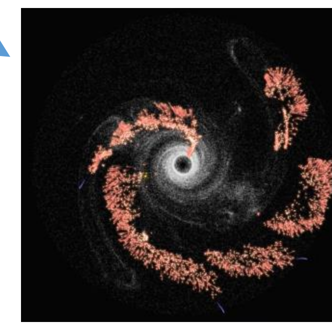
GTOC9: The Kessler Run



Galactic Type

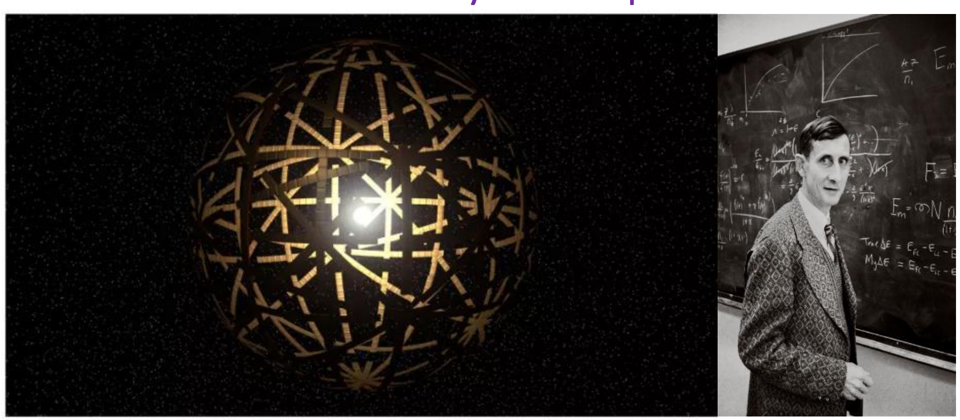
GTOCX:

Settlers of the Galaxy



Stellar Type

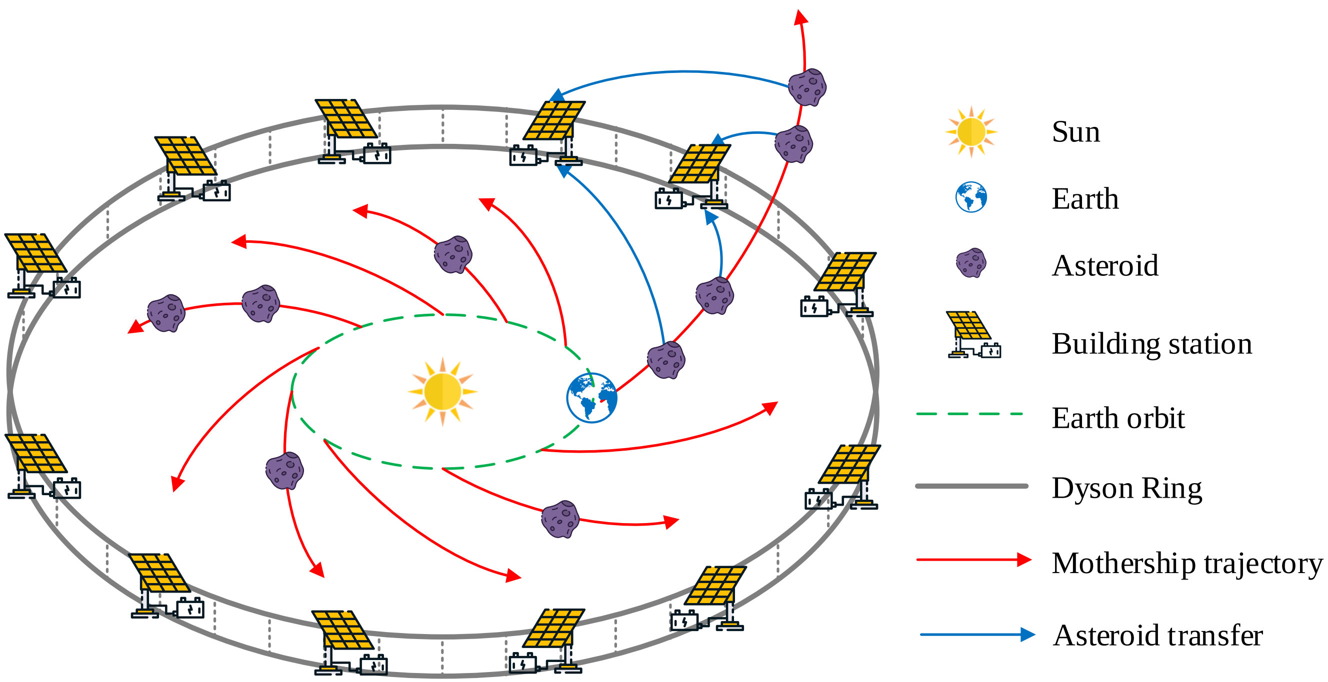
GTOC11: Dyson Sphere



A Dyson sphere is a hypothetical megastructure that completely encompasses a star and captures a large percentage of its power output.

GTOC 11: Dyson Sphere

- To build a preliminary "Dyson sphere"
- The building materials comes from the moving asteroids.
- Asteroids must be transferred to a desired position using ships' propulsion



Merit Function

- The asteroids' mass are expected to be maximized and uniformed in the 12 stations

$$M_{\min} = \min\left\{M_j \mid j = 1, 2, \ldots, 12\right\}$$

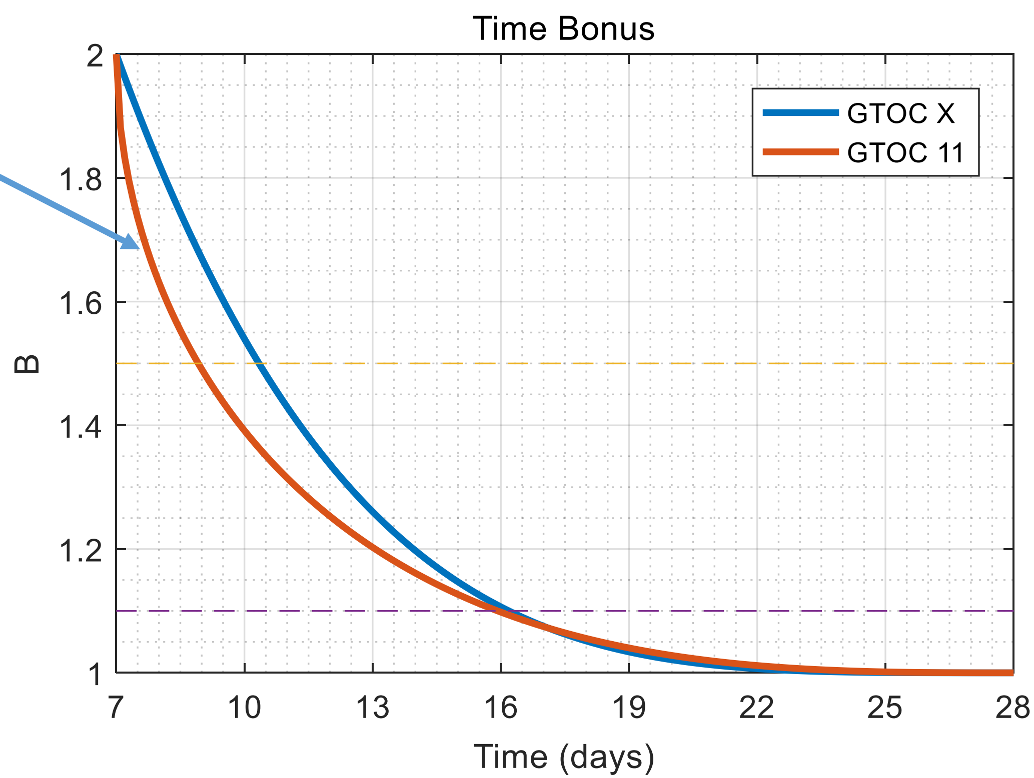
- The target Dyson sphere radius must be as close to the Sun as possible. Solar Radiation Efficacy is an inverse proportion of the square of radius, which is associated to spherical surface area
- ΔV consumed is in the denominator with fixed penalty addition for dry mass

$$J = B \cdot \frac{10^{-10} \cdot M_{\min}}{a_{Dyson}^2 \sum_{k=1}^{10} \left(1 + \Delta V_k^{Total} / 50\right)^2}$$

Merit Function (cont'd)

- High early submission bonus declines rapidly

$$B = 2 - \sqrt{1 - \left(1 - \frac{t_{sub} - t_{start}}{t_{end} - t_{start}}\right)^3}$$



- A bit steep of *B* did make us very nervous, since one could get factor 2 after a full week working on the task.
- Now it seems ok, since most teams could further improve.
- We hope the winner will also have the best absolute score without *B*.

Propulsion and Constraints

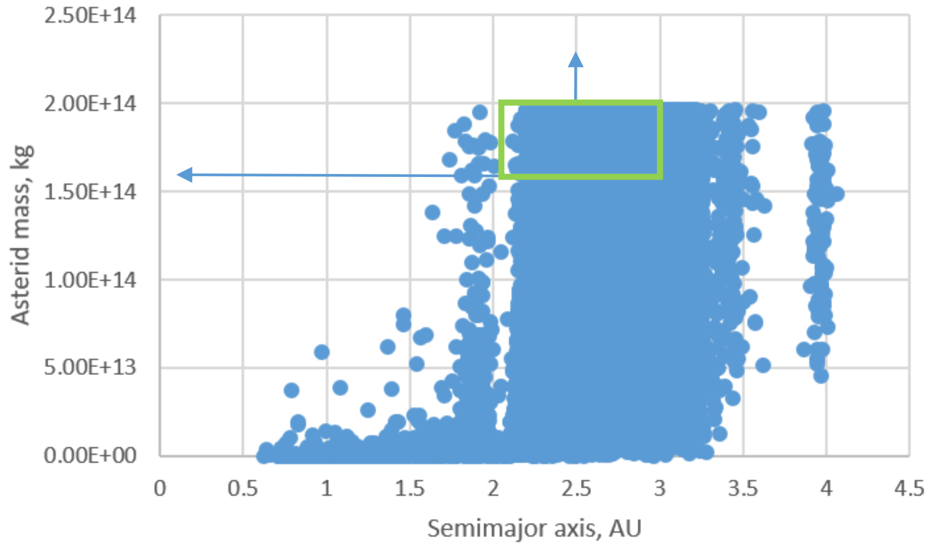
- The asteroids are activated by 10 motherships
- Constant Acceleration: 1e-4m/s^2
- Mass flow α= 6e-9/s

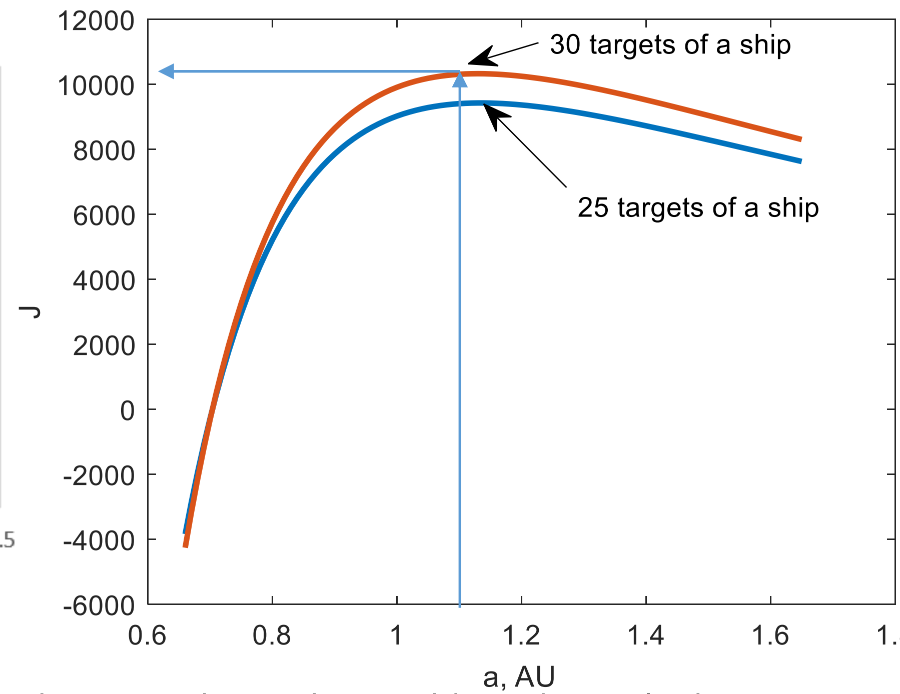
$$m^{ast}(\Delta t) = m_0^{ast}(1 - \alpha \cdot \Delta t)$$

  A Later Correction was given.

- Dyson Sphere radius R⩾0.65AU
- A free Flyby Velocity is given smaller than 2km/s
- Phasing separation of 30° is specified for 12 building stations
- At least 90 days separation to avoid conducting different building missions in parallel

Can we guess the optimum?

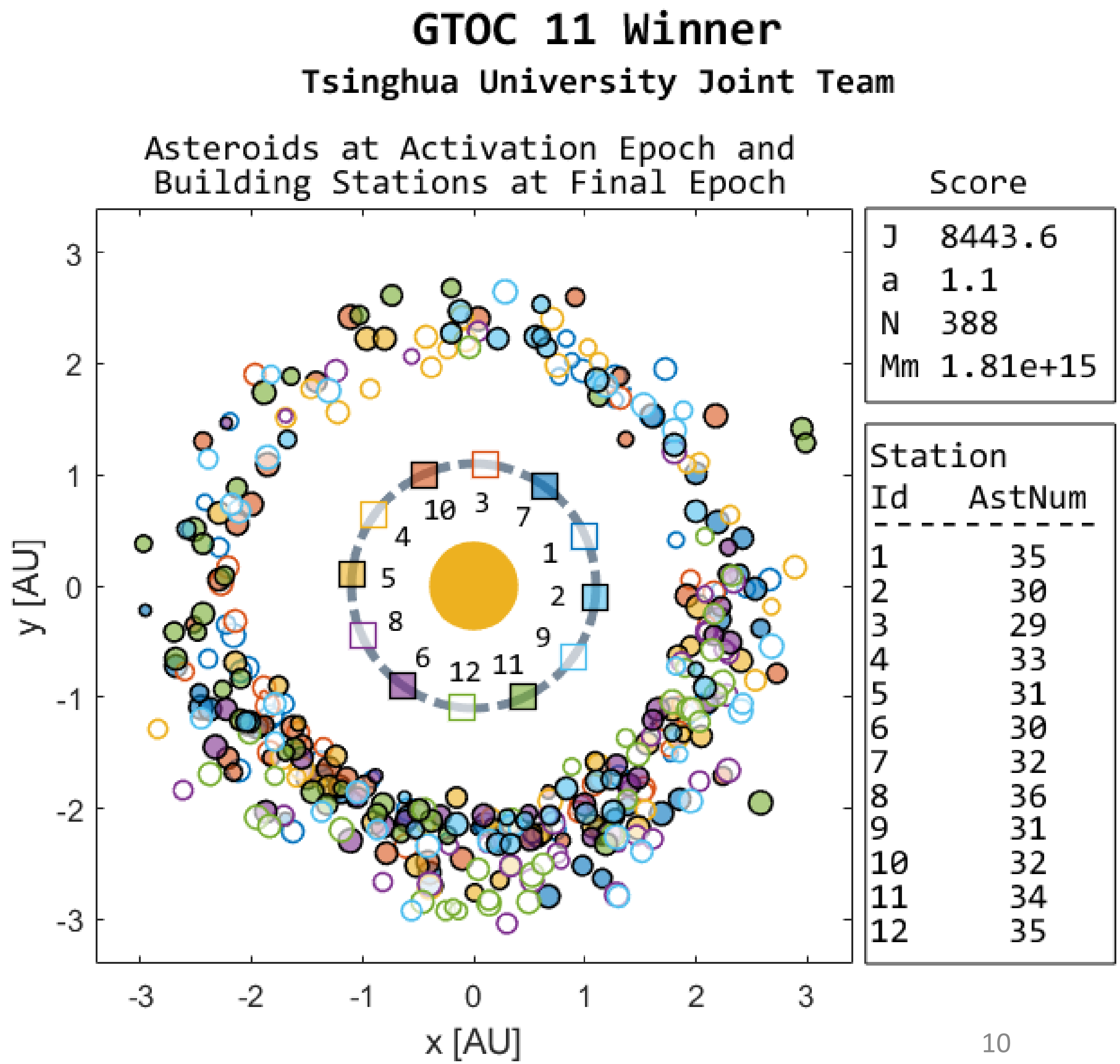




- Method: Edelbaum approach for Low-thrust trajectories. Taking the solution to 0.65AU as reference, there is the best tradeoff on the radius.
- Assumption:
  - 0.5km/s of **ΔV** for a flyby leg. 30 or 25 targets for each ships (that go to 0.65AU).
  - Average asteroid mass is desired about 1.8e14kg (with average asteroid radius of 2.5AU), the targets m>1.6e14kg, over 6000 targets in the set (large enough?)
- Most important part: maximum the asteroid mass as well as the number of flybys

Winning solution

Tsinghua&509 won the competition and reached 1.1 AU with 388 asteroids
On average 0.42km/s for a flyby leg



Rankings (top 20 teams)

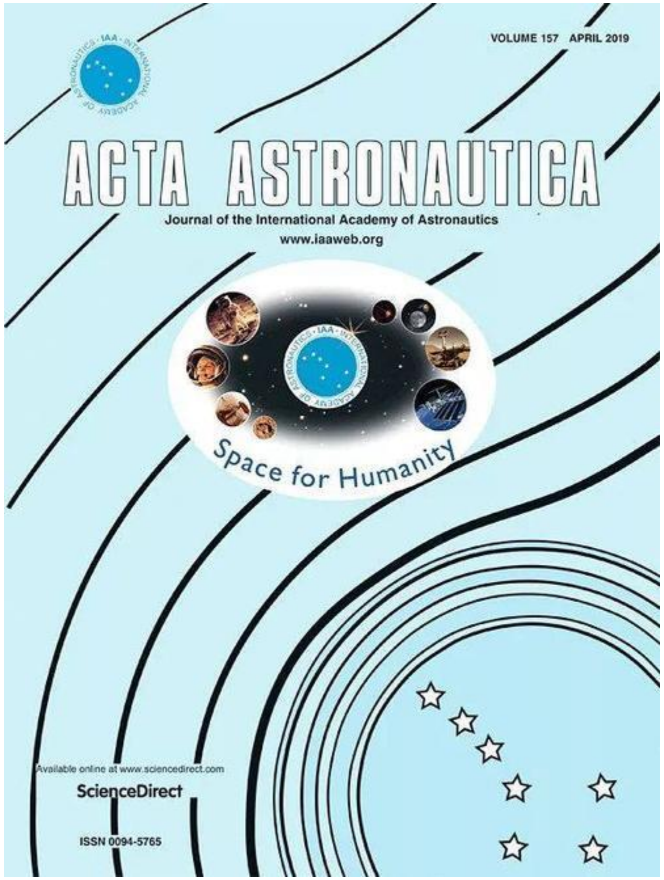
Rank	Team Name	M_{min}	a_{Dyson}	N	J
1	TsinghuaLAD&509	1.81364E+15	1.1	388	8443.6306
2	ACT&Friends	2.0125E+15	1.320	301	6359.7249
3	theAntipodes	1.27672E+15	1.05	293	5992.2984
4	UT Austin	1.13283E+15	1.1	235	5885.4693
5	ASRL	1.10046E+15	1.09	209	5525.3888
6	The Eccentric Anomalies	1.89224E+15	1.3	346	5487.5434
7	HIT	1.08546E+15	1.1	250	5208.3463
8	GHWZZ	1.50229E+15	1.4	294	4794.4686
9	ASTL-NUAA	1.03068E+15	1.1	213	3735.1602
10	Team_BIT&ITNS	8.00267E+14	1	199	3532.7044
11	Pursuance Team	7.20367E+14	1.2	157	3277.9964
12	DLR	9.00578E+14	1.2	133	3249.3739
13	IDRL & ECNS	9.67251E+14	1.3	160	3223.9013
14	BUAA_ADMLab	1.02691E+15	1.187	185	2729.9735
15	BUAA	9.31363E+14	1.151	174	2622.1224
16	TeamJena	5.9348E+14	1.2	138	2376.2598
17	AU-LU	5.49777E+14	1.164	148	1556.5912
18	The Aerospace Corporation	4.07086E+14	2	71	694.95773
19	ACSER	8.82037E+13	1.678	12	250.94933
20	Iowa State University	1.07086E+14	1.8	51	150.8727

Full leaderboard:
https://gtoc11.nudt.edu.cn/GTOC?page=competition&y=leaderboard

Special Section of AA

A special section of Acta Astronautica is also being organized and will allow the publication of outstanding methods and solutions produced.

- First submission date
  - 1 Jan 2022
- Final submission date
  - 1 Mar 2022
- Guest editors
  - Ya-zhong Luo
  - Dario Izzo
  - Hong-Xin Shen



This is the second time gtoc papers published in the special section of AA

Conclusions

- GTOC11 works in concert with GTOC9 and GTOC X to echo three civilization types: Planetary type, Stellar Type and Galactic type
- Multiple factors (final orbit selection, ΔV consumption, targets mass and amount, et al) are designed in the Merit function
- Both Impulsive and Continuous propulsions are involved
- 94 teams registered, new record of registered teams
- **Congratulations** to the winning team,

Tsinghua University

and Shanghai Institute of Satellite Engineering