Attitude Control for Small Satellites

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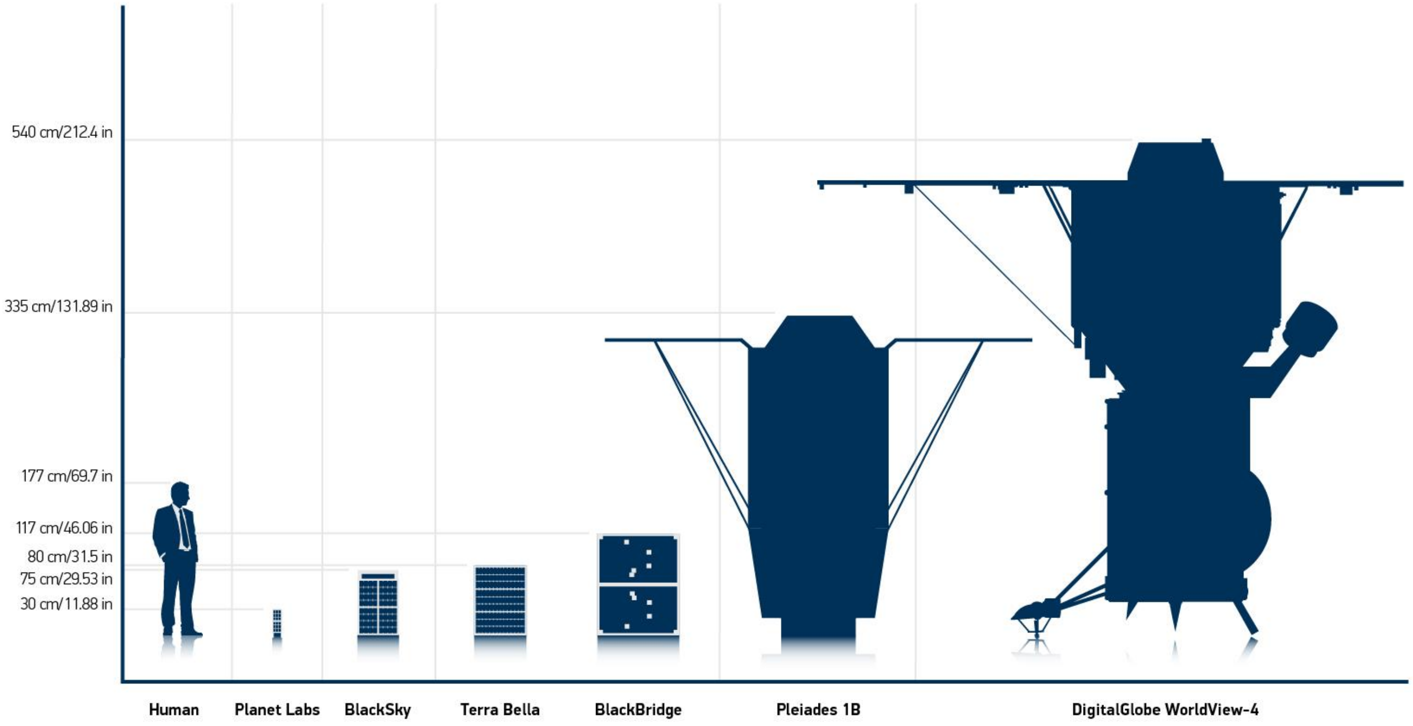
Introduction

- International space station
- 420 tons
- 73x120x20 meters
- Biggest man-made space object
- Most expensive (~$150 Bln)

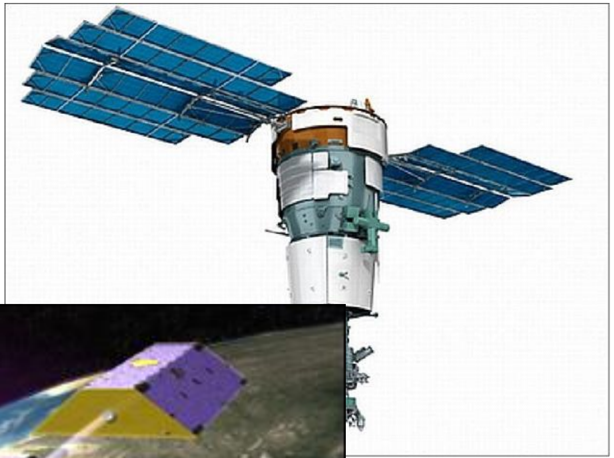
How big are the usual satellites?

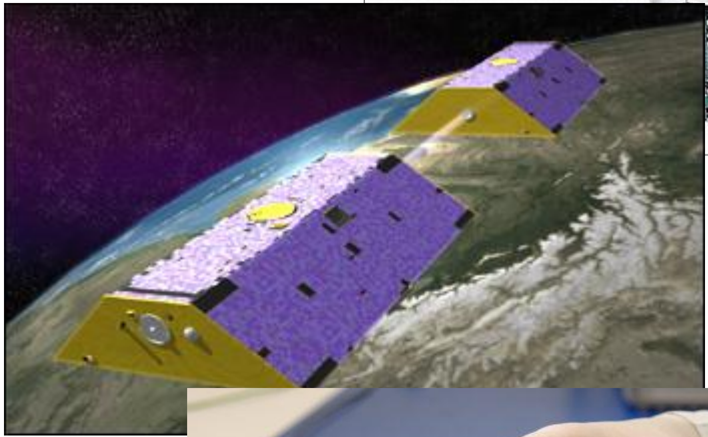


Comparison of Remote Sensing satellites

Classification

- Large (> 1000 kg)
- Medium (500-1000 kg)
- Mini (100-500 kg)
- Micro (10-100 kg)
- Nano (1-10 kg)





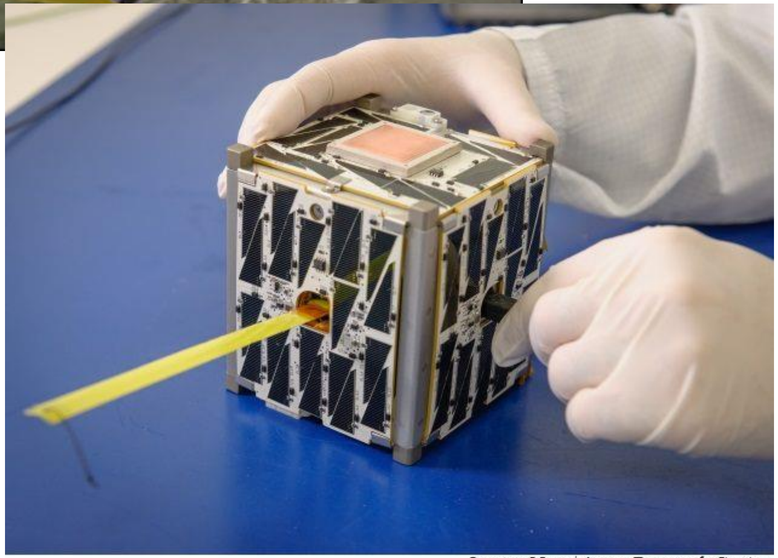
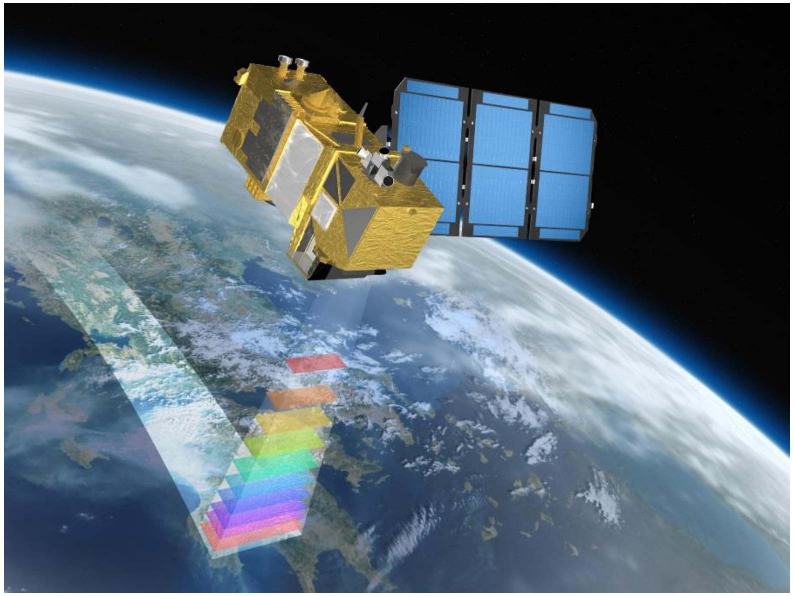
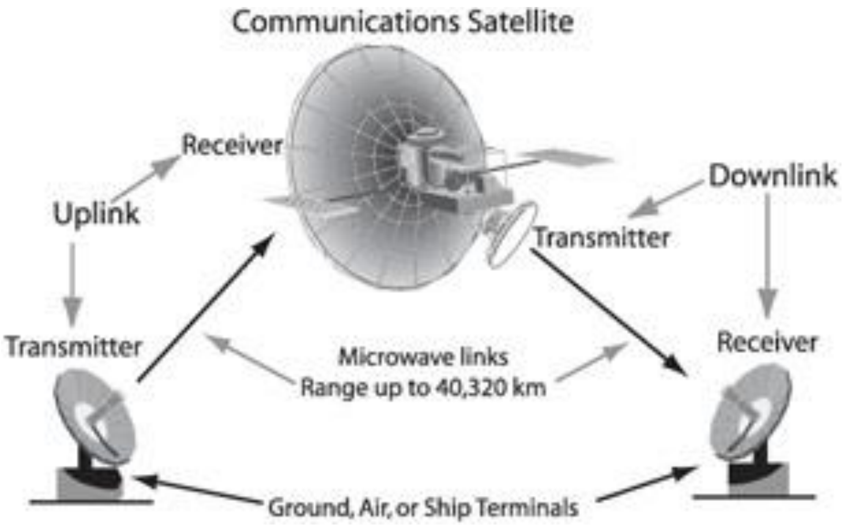


Image: Nasa/ Ames Research Center

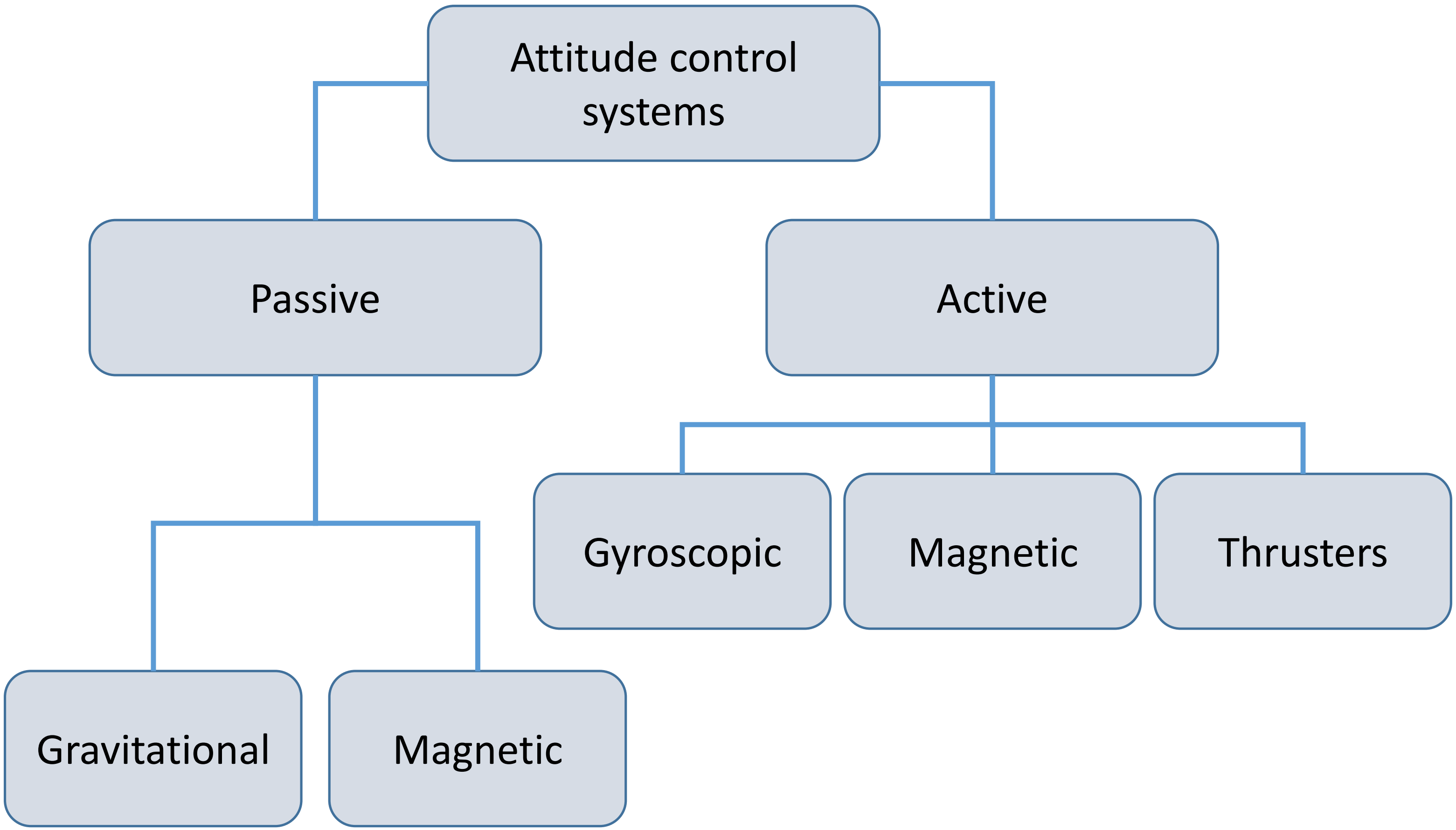
Why do we need attitude control?

- Recharge batteries
- Look at the interesting region
- Communicate with Earth



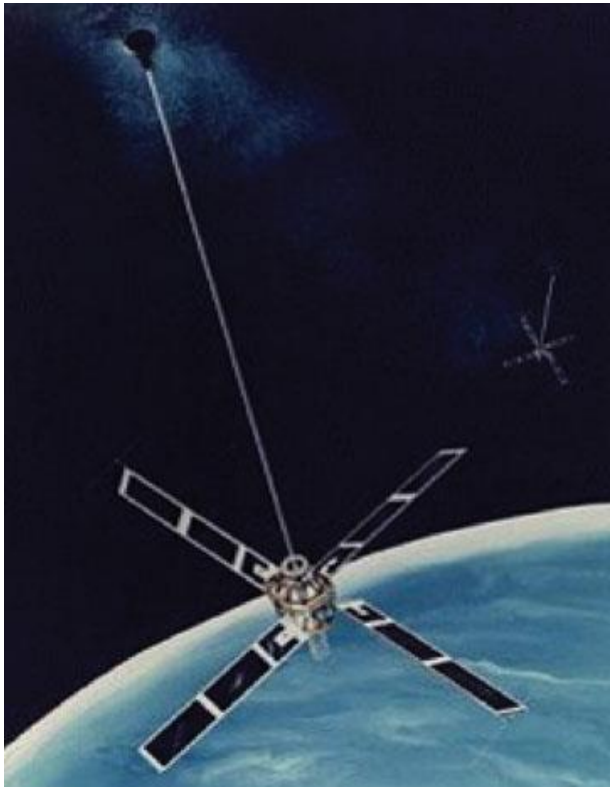


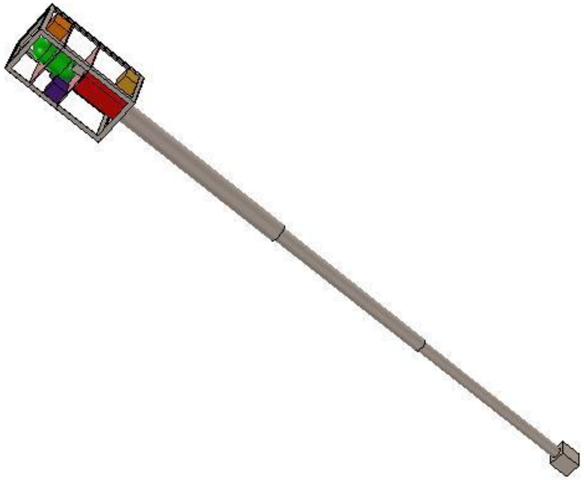
How we can control it?



Gravitational attitude control

- Main idea – use natural dynamics
- We got equilibriums – install cameras/antennas so they always look at the Earth
- Satellite must have special mass distribution



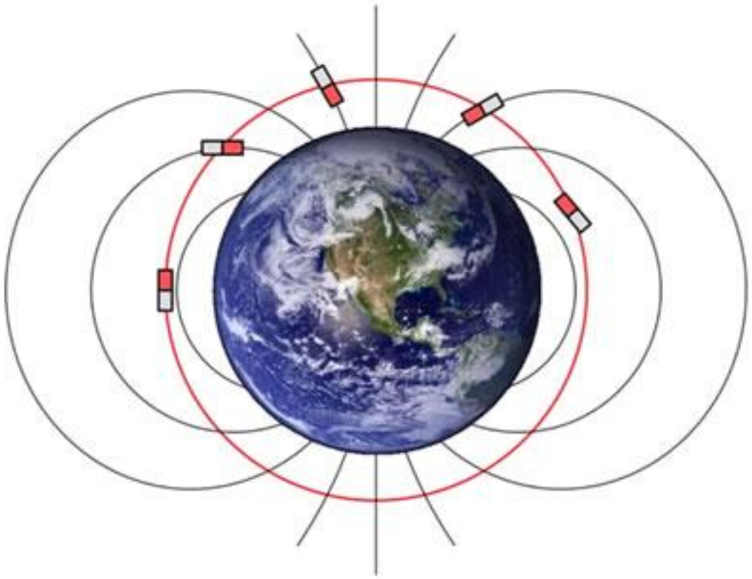


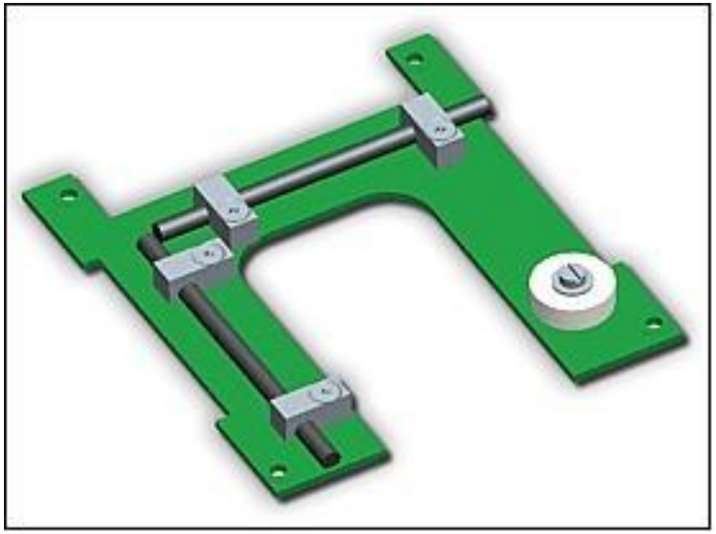
Problems:

- Low accuracy
- There are 4 different stable equilibriums

Passive magnetic control

- Magnets
- Hysteresis rods

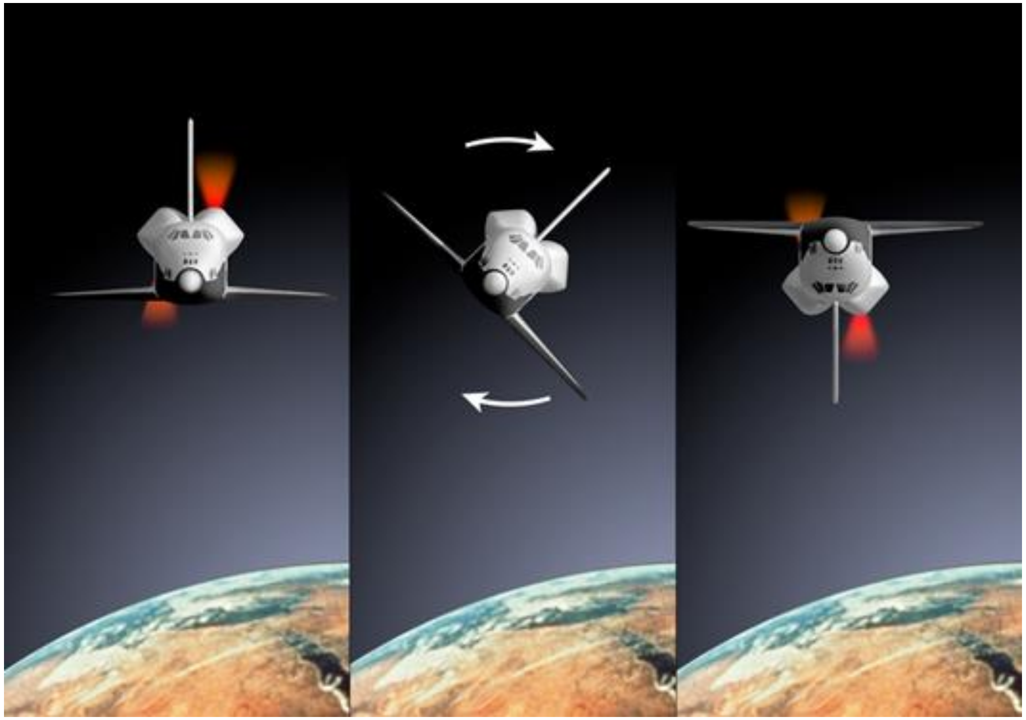




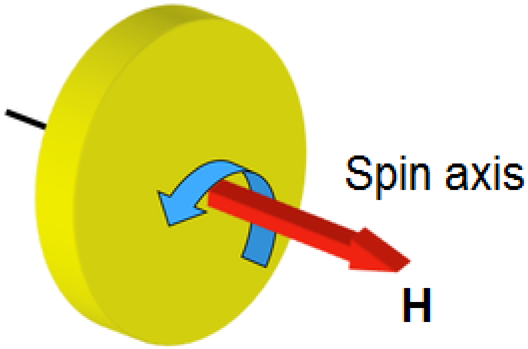
- Trace local geomagnetic field
- Allow angular velocity dampening

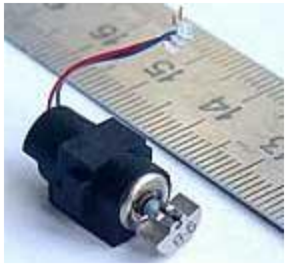
Thrusters

- Do not require external fields (gravity or magnetic)
- Produce large torque – perform fast maneuvers
- Spend propellant



Gyroscopic systems

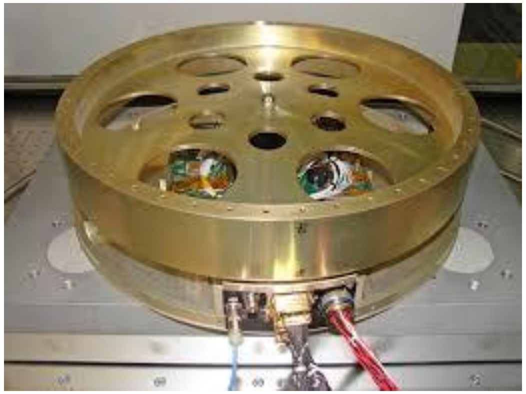




Cell phone vibration motor

$$\mathbf{H} = \mathbf{I}\boldsymbol{\Omega}$$

Spacecraft reaction wheel

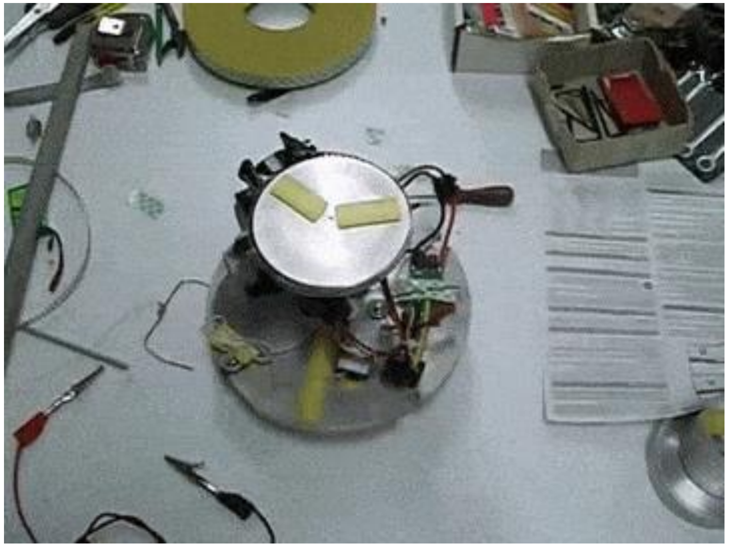


How do they work?

- Angular momentum conservation law

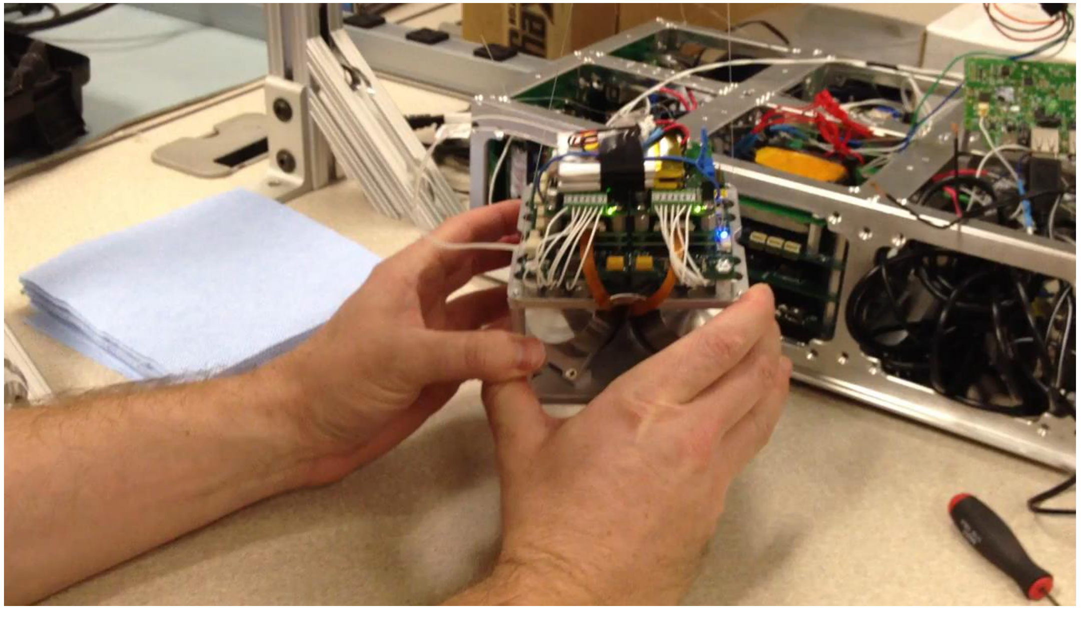
$$\mathbf{K} = \mathbf{H} + \mathbf{J}\boldsymbol{\omega} = const$$

- Change angular velocity of reaction wheel – change angular velocity of the satellite



Reaction wheels systems

- Three RW allow 3-axis control (usually 4 for redundancy)
- Precise
- Decent torque – fast maneuvers
- Can be fitted even in CubeSats

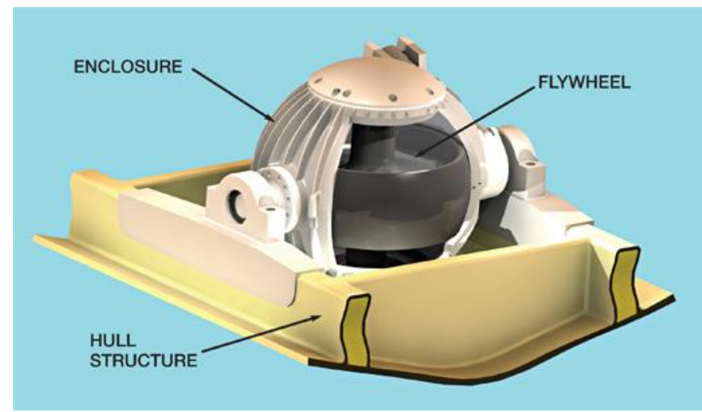


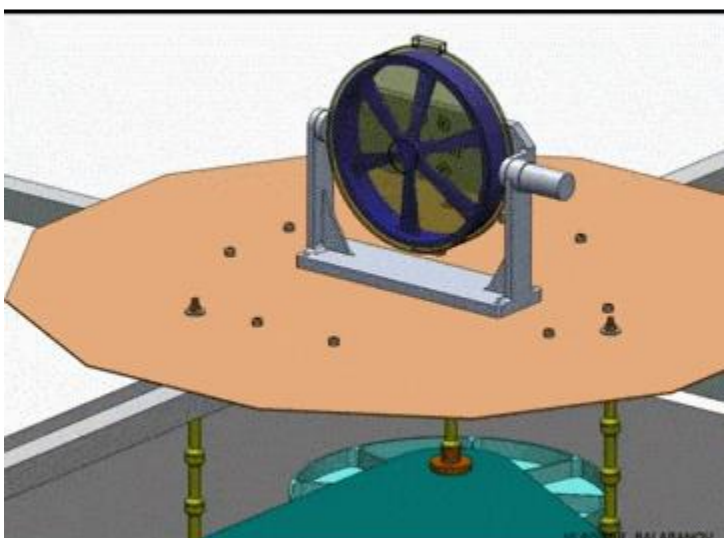
Produced torque:

$$\mathbf{M} = -\dot{\mathbf{H}} - \boldsymbol{\omega} \times \mathbf{H}$$

Control Moment Gyros

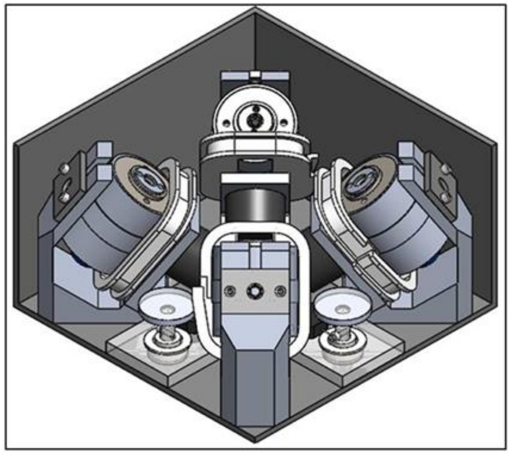
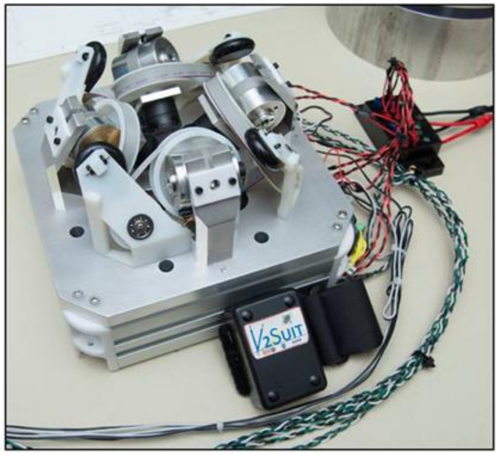
- Same idea
- We change axis of rotation – produce more torque
- Large, usually used for heavy satellites
- Complex mathematics for control

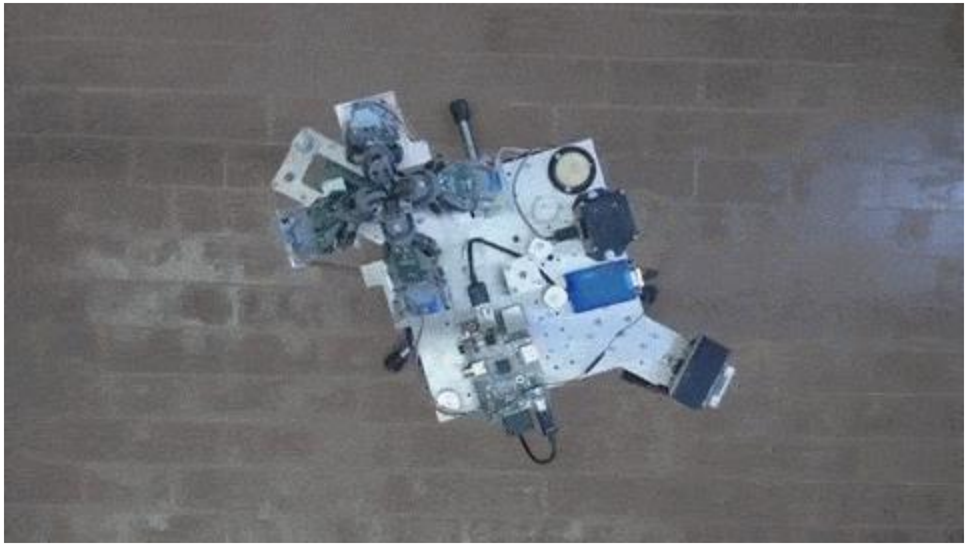




Control Moment Gyros

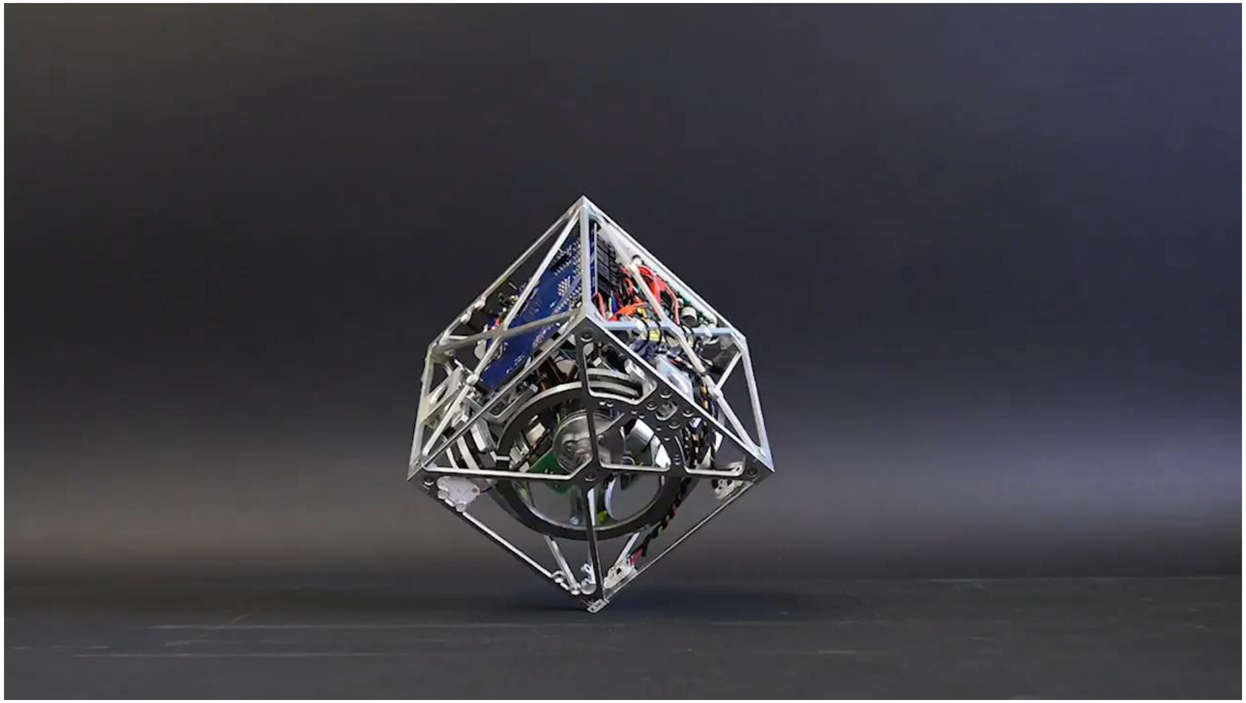
- Usually system of 4 CMGs
- Pyramid type



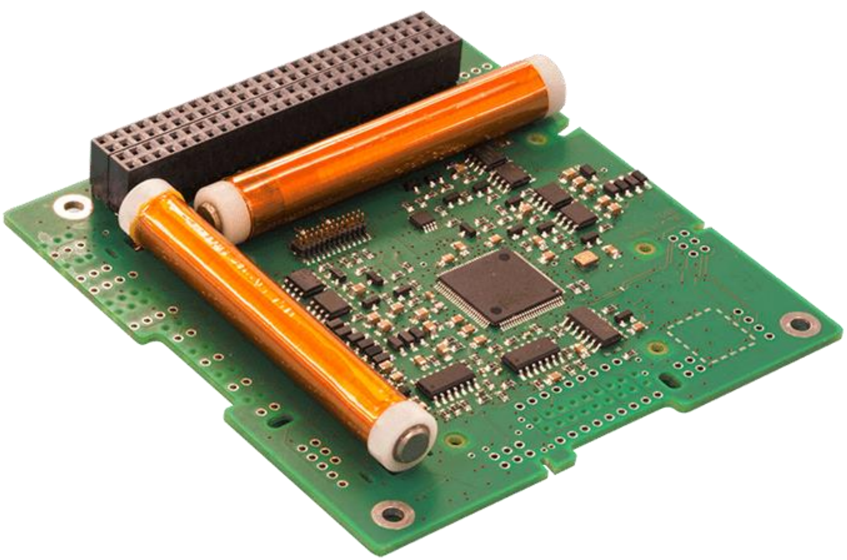
What we can achieve?

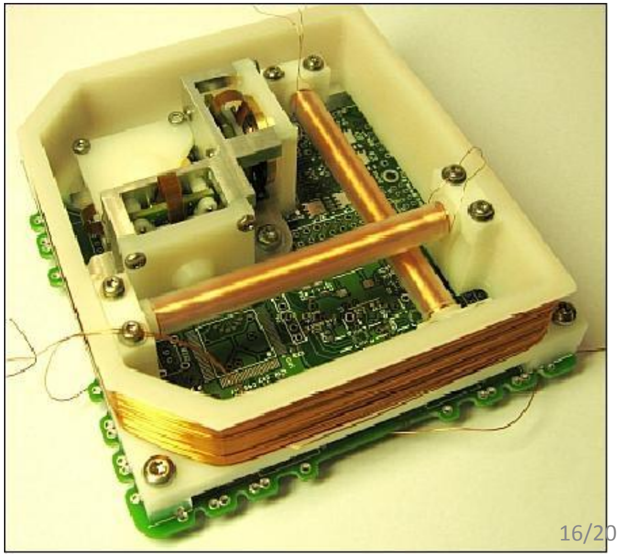
- High accuracy
- Fast maneuvers
- Complex motion



Problems

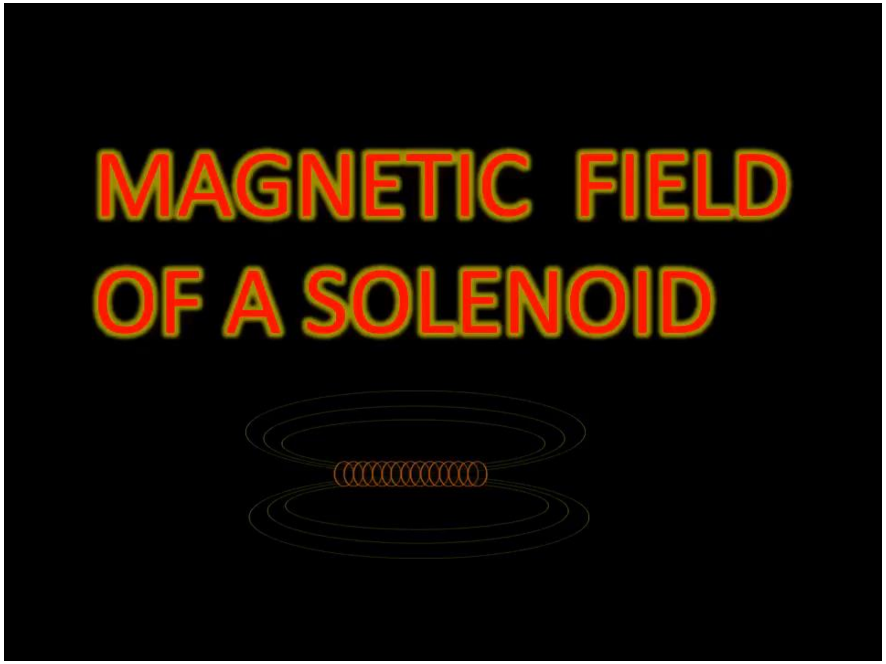
- Saturation – we cannot increase rotation speed
- Singularity – sometimes we cannot produce torque in some direction
- A lot of noise
- We need other supplementary attitude control system
- Thrusters in high orbits (or deep space), magnetorquers in LEO





What are the magnetorquers?

- Special coils with currency
- Produce dipole moment
- Change current – change dipole moment
- Three magnetorquers – we can create any dipole



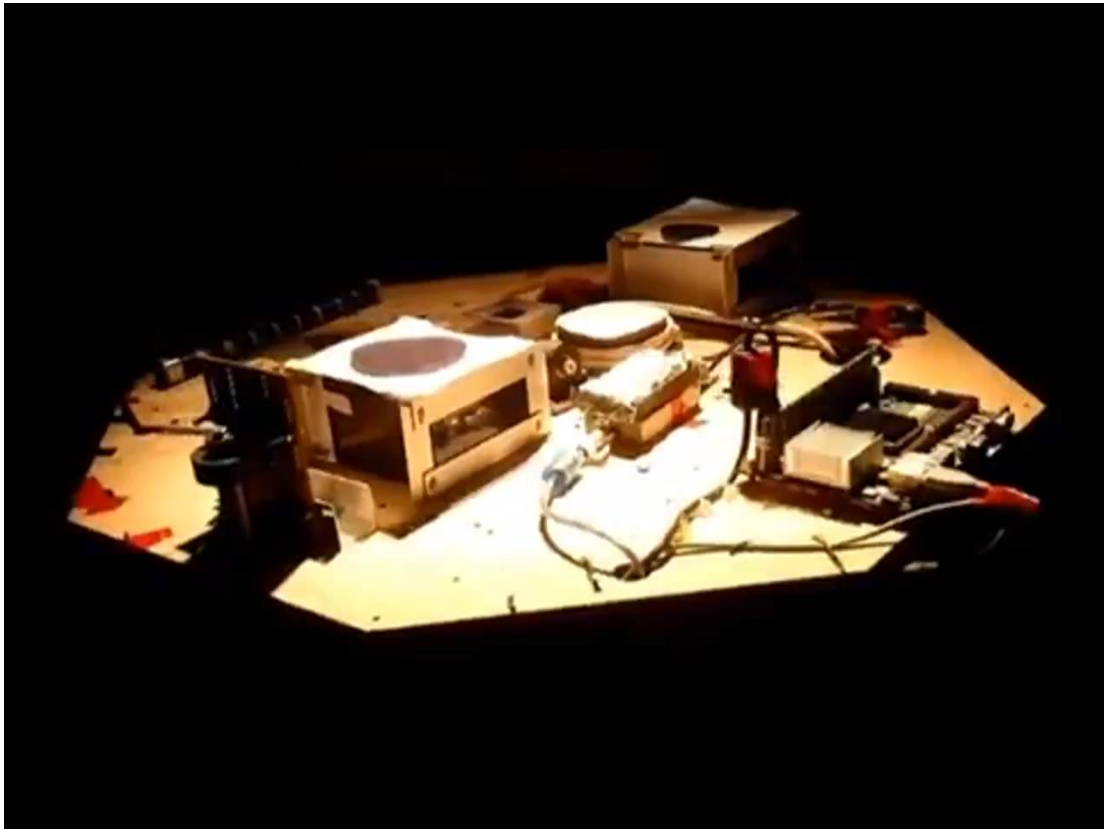
- Cannot produce control torque parallel to magnetic field:

$$\mathbf{M} = \mathbf{m} \times \mathbf{B}$$

- Cannot provide three-axis and precise control by itself
- Usually just a supplementary system

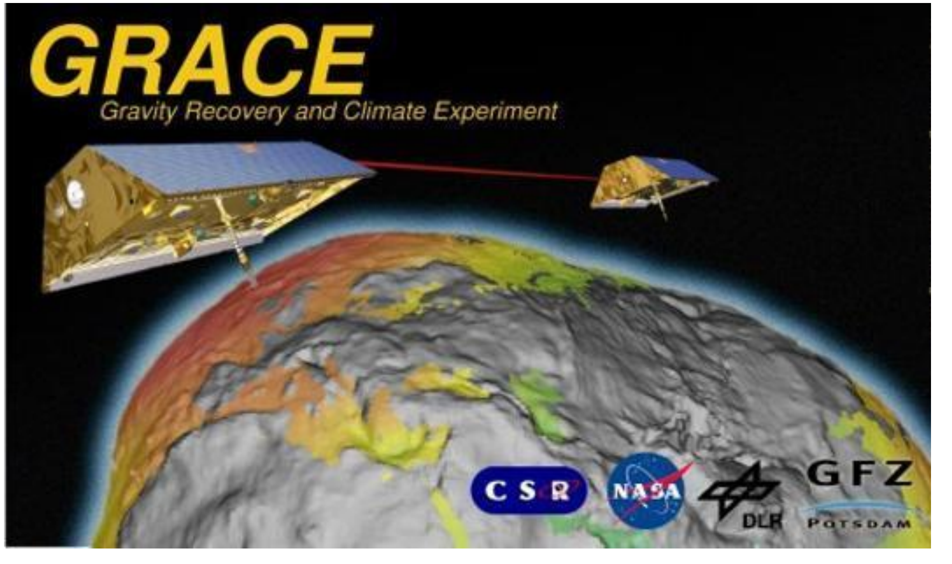
How we can use them?

- Angular velocity dampening after launch
- -Bdot algorithm – using only magnetometer can almost stop the satellite



Purely magnetic attitude control

- Provide low accuracy
- Usually used to ensure asymptotic of equilibrium
- Different approaches: LQR, PD-controller, sliding mode control etc.
- Usually used onboard: CubeSats, scientific missions



Questions?

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