Active Solar Sail Designs for Chip-Scale Spacecraft

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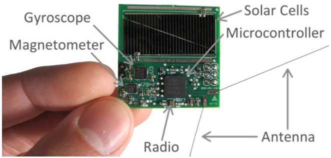
Outline

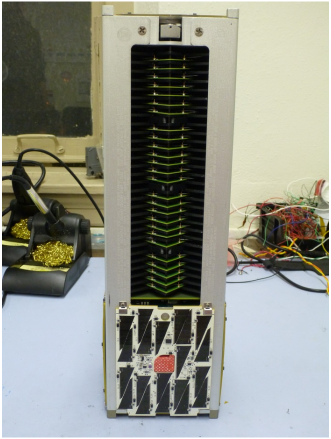
Introduction to Sprites

Chip-scale Spacecraft

Chipsats have

- Low-cost manufacture and launch
- Mass producible
- Synergistic missions





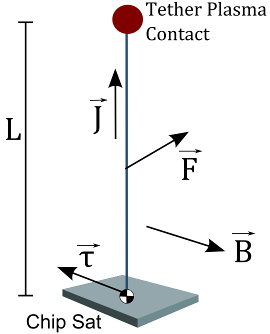
Trajectory Control

Chip-scale propulsion has unique challenges

- Low power
- Limited mass budget

Some solutions:

- Lorentz force augmentaiton
- Electrodynamic tethers
- Solar sailing



Solar Sails

Chipsats and solar sailing

Chipsats are natural solar sails

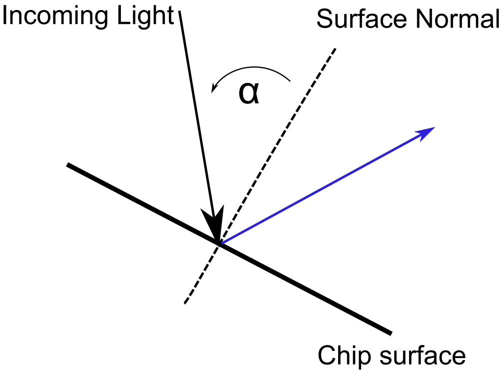
- Rigid body
- Surface area to mass ratio
- Manueverability

Solar Radiation

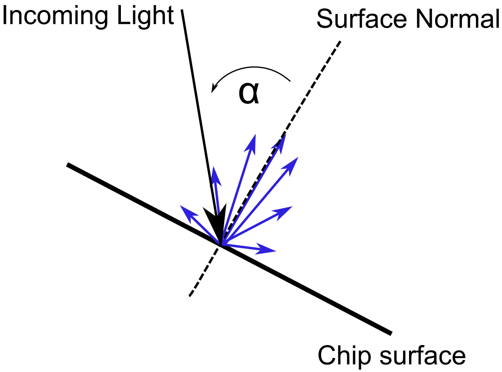
Light can interact with a material in a number of ways, varying with wavelength

- Specular reflection
- Diffuse reflection
- Apsorption
- Transmittance

Specular reflection



Diffuse reflection



Solar Radiation Pressure (SRP)

$$\vec{P}_{SR} = \frac{W}{c}\hat{r} \tag{1}$$

W is the solar energy flux and c is the speed of light

$$\vec{F}_{SR} = 2PA\cos\alpha * \left[\left(2\eta_{sr}\cos\alpha + \frac{2}{3}\eta_{dr}\right)\hat{\boldsymbol{n}} + (\eta_{ab} + \eta_{dr})\hat{\boldsymbol{e}}_S\right] \tag{2}$$

where η_{sr},η_{dr}, and η_{ab} are the specular reflection, diffuse reflection, and absorption coefficients, and $\eta_{sr} + \eta_{dr} + \eta_{ab} = 1$

Active solar sailing

Solar sails can adjust SRP force

- Surface shape
- Light interactions

For chip-scale spacecraft

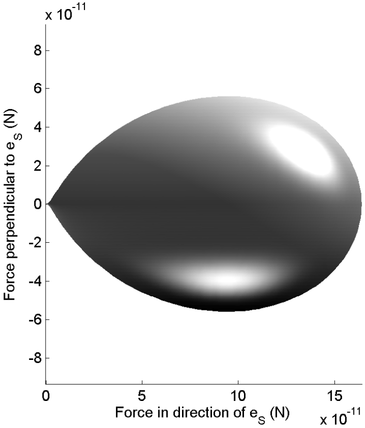
- Electrochromic coatings
- MEMs adjustible mirrors

Design Space

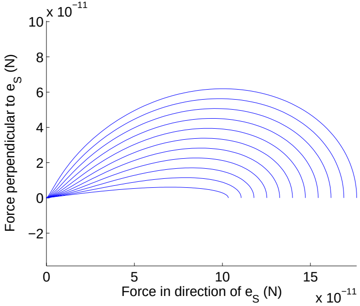
Force with an adjustible mirror

$$\vec{F}_{net} = 2PA\cos\alpha * \left[\left(2\eta_{sr}\cos\alpha + \frac{2}{3}\eta_{dr}\right)\boldsymbol{\hat{n}} + (\eta_{ab} + \eta_{dr})\boldsymbol{\hat{e}}_S\right] + 2PA_m\cos^2\alpha_m\hat{n}_m \quad (3)$$

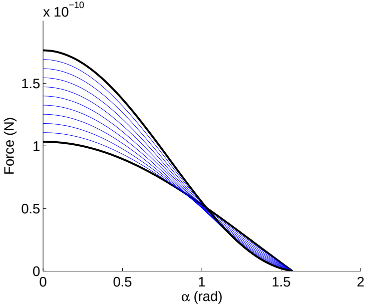
Available force given optical parameters



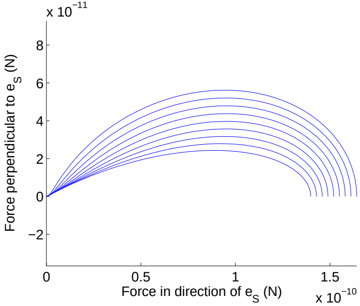
Effect of increasing specular reflection at the cost of absorption, force direction



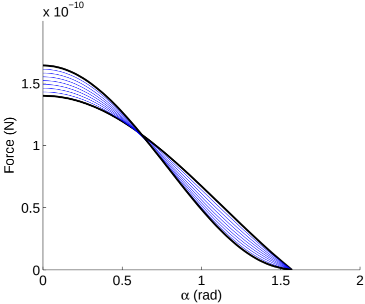
Effect of increasing specular reflection at the cost of absorption, relative force magnitude



Effect of increasing specular reflection at the cost of diffuse reflection, direction



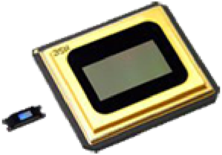
Effect of increasing specular reflection at the cost of diffuse reflection, magitude

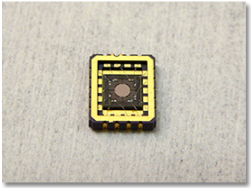


MEMs Actuated Mirrors

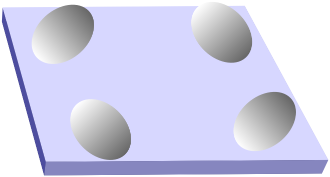
Currently available:

- Texas Instruments DLP chipset has a large array of mirrors with ± 15 degree discrete motion.
- Mirrorcle technologies has a two-axis mirror chip, with analog motion. Their integrated mirror sizes currently range from .8 to 1.7 mm with $\pm$ 5 degree.





Pinwheel configuration.



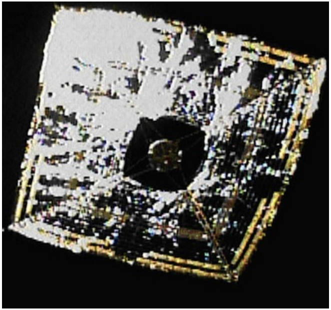
$$\vec{\tau}_{net} = \Sigma \vec{r}_i \times \vec{F}_{mi} \qquad (4)$$

For a chip scale spacecraft, this can allow roughly

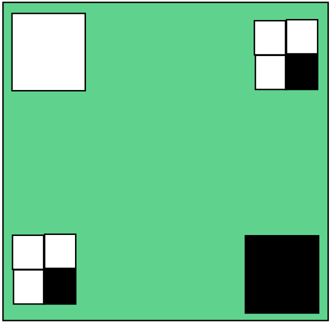
- Torque 1.5×10^{-13} Nm
- Spin-up time to 3 rpm 9 hr
- Slew 1 deg/min

Electrochromic Materials

- IKAROS liquid crystal panels switch between specular and diffuse reflection
- Tungsten-oxide electrochromic windows are switchable between .6-.05 transmittance in the visible band, with applied voltages of 3-5 V
- Antimony-based films can switch between around .7 reflectance and zero transmittance to .1-.3 reflectance and .5 transmittance



Chipsat with electrochromic panels at each corner



- Torque 1×10^{-12} Nm
- Slew 10 deg/min

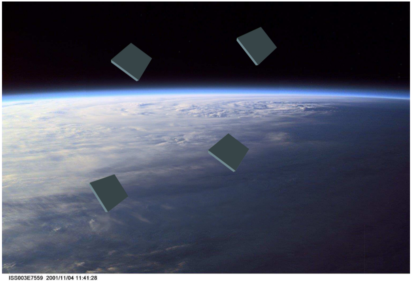
Conclusion

Challenges

- Space environment
- Chipsat scale

Rewards

- High agility solar sails
- Control of attitude-orbit coupling
- Chipsat swarm dynamics



Questions?