(Charge collection and emission at)

A light tether mission at Jupiter

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*** Jovian missions are requiring in power and propulsion**

Power for EJSM missions

Jupiter Europa Orbiter (NASA): 0.54 kW RPS

Jupiter Ganymede Orbiter (ESA): 51 m^2 SA

But... Solar illumination weak

Present (thermocouple) RPSs inefficient, ^{238}Pu lacking

(US National Research Council Report, 2009)

(Chemical) Propulsion for EJSM:

JEO launch mass = 5040 kg

2646 kg, propellant

1490 kg, flight system mass + launch vehicle adapter

JGO launch mass = 4362 kg

2562 kg, propellant

1147 kg, flight system mass + launch vehicle adapter

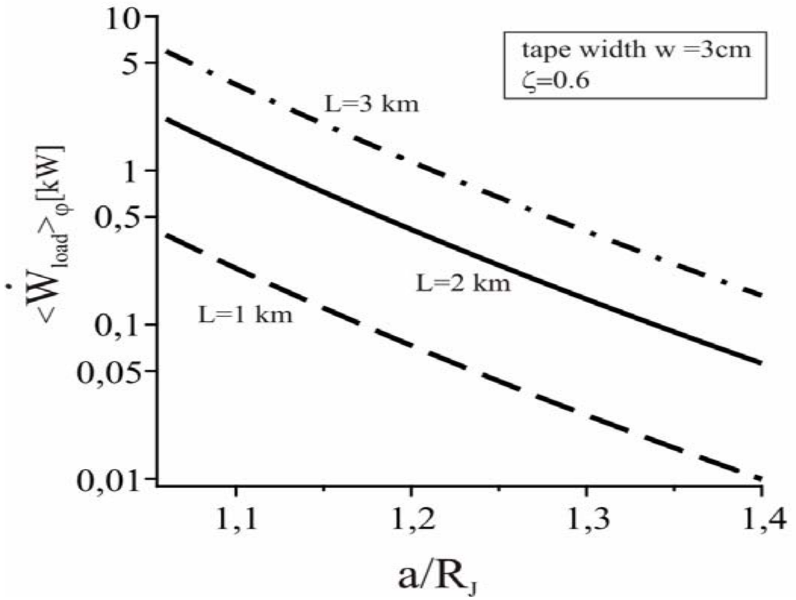
*** Electrodynamic Tethers can provide power and propulsion**

Jovian magnetic field **B** induces ambient (*motional*) field $\mathbf{E_m}$ in tether frame
$\mathbf{E_m}$ drives current from plasma into tether
B exerts Lorentz force on tether current (which can also power a load)

But Tether current is ambient dependent
It needs no propellant but must act over large number of orbits
Must repeatedly visit high **B**, high plasma density N_e near Jupiter
Critical issue: Dose accumulates when crossing Radiation Belts

- Small tether mission-stage here proposed:
Motion on circular equatorial orbits below Belts (start at 1.3 – 1.4 R_J)

- Lorentz drag makes spacecraft slowly spiral in (over months)
generating substantial power at load because of deep Jovian gravity well



Use no tilt, no offset magnetic dipole,

Divine-Garrett thermal-plasma models

Power load next to hollow cathode

Tether kept taut by spinning

Neglect Hollow cathode impedance

Ion current collection / Ohmic losses

Decay time $\propto$ $M_{SC} / wL^{5/2}$

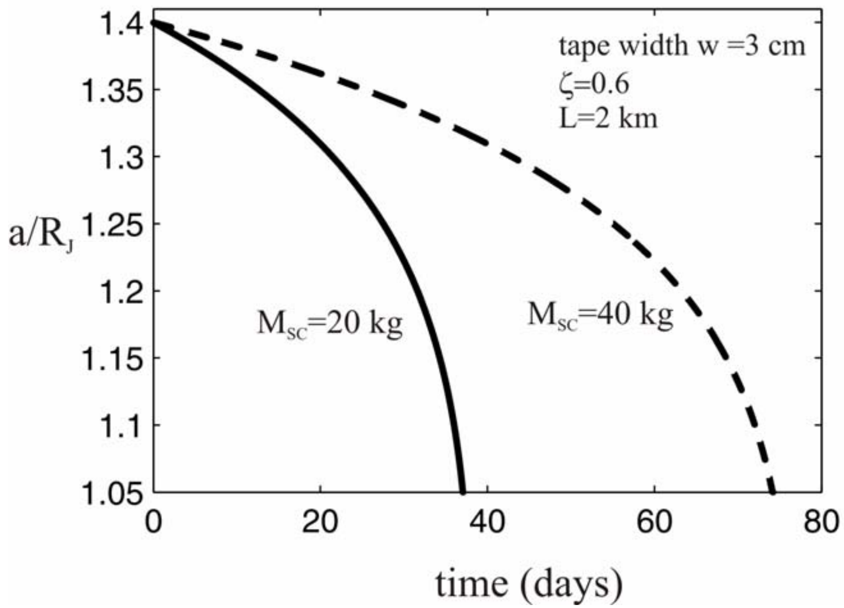
Energy generated from 1.3 to 1.05R_J

~ 820 w×month / 40kg

Prograde orbit for maximum power

at efficiency = 10/19

(anodic length segment = 0.6)



* Mission science capabilities

- Nearby observations of planet interior

  ⇒ high resolution determination of gravity / magnetic fields
  bulk abundance of water

- Long-time data to determine atmospheric variability over different time scales

  Spatially resolved observations to understand transport processes

- Below the inner (*Halo*) ring there are charged grains

  Start near the strongest Lorentz resonance at 1.4 R_J

  Grain-tether intetaction makes for an interesting dusty-plasma problem

- Active experiment:

  Spinning tether emits beam of secondary electrons half of the time

  Secondaries experience magnetic mirroring, produce auroras

* Grain dynamics and charge evolution

Typical grains (not quite spherical) have 'radius' R ~ 0.02 - 50 microns,

Density ~ 2 g/cm^3, Mass ~ 10^{-19} - 10^{-9} kg

A grain acquires (positive / negative) charge $Q \propto R$ from balance of

thermal electron collection

against

thermal ion collection + *photoelectron / secondary electron emission*

Actually, charge equilibrium-time is typically longer than

grain flight-time as the grain moves into different ambient conditions

At 1.4 R_J ($\Omega_{orb} = 2\Omega_J$) there is a (strongest) Lorentz resonance

arising from the $g^2{}_2$ Schmidt coefficient (about 0.45 Gauss)

Grain dynamics and charge evolution must be jointly solved

Typically, gravitational (F_g) and magnetic (F_{mag}) / electric (F_{el}) forces are dominant

F_g varies as R^3 / a^2 (a is Jovian radial distance)

$F_{mag} \sim Q \ v_{orb} B \sim R / a^{7/2}$ $\quad$ ($v_{orb} \propto 1 / \sqrt{a}$, $B \sim 1 / a^3$)

$F_{el} \sim Q \ v_{cor} B \sim R / a^2$ $\quad$ ($v_{cor} \propto a$)

($v_{cor} B$ is the *motional* electric field in a non-orbiting frame)

The ratio F_{mag} / F_g varies as $1 / R^2 a^{3/2}$

F_{el} / F_g varies as $1 / R^2$

* Auroral sounding of atmosphere

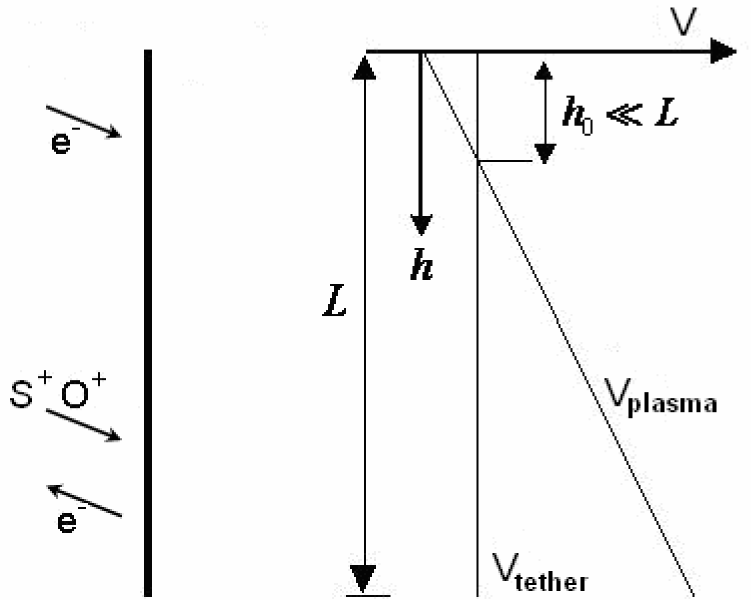
Rotation-averaged gravity-gradient torque on spinning tether vanishes
Averaged magnetic torque must then vanish too

This torque vanishes under hollow cathode (HC) operation on a tether end *a* (over half the spin period) **if** masses at ends *a* and *b* are chosen properly
⇒ ~ zero torque over the other half period **only** if end *b* carries no HC

Then current = 0 at **both** ends:
tether electrically *floating*

It attracts ions on nearly its full length ⇒ secondary electrons from yield γ form beam along **B**

Particle and energy flux grow with distance *h* from tether top



Beam electron flux much weaker than ambient thermal flux

$$\Phi_b(h) = N_e \Omega_e w \sqrt{\frac{m_e}{m_i}} \frac{\gamma(eE_t h)}{2\pi \cos(dip)} \qquad (\Omega_e \text{ gyrofrequency})$$

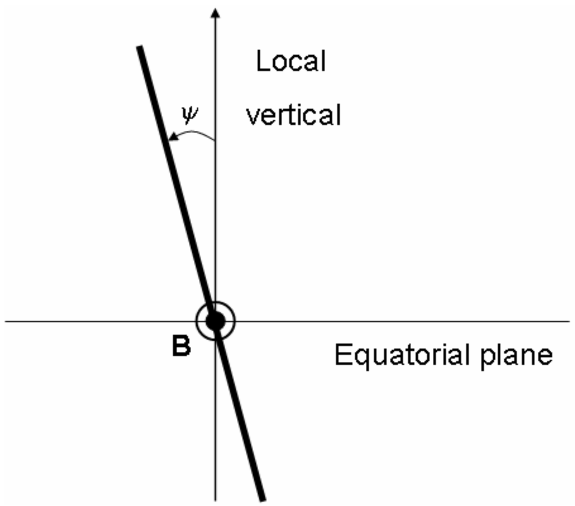
Beam/ambient density ratio very small

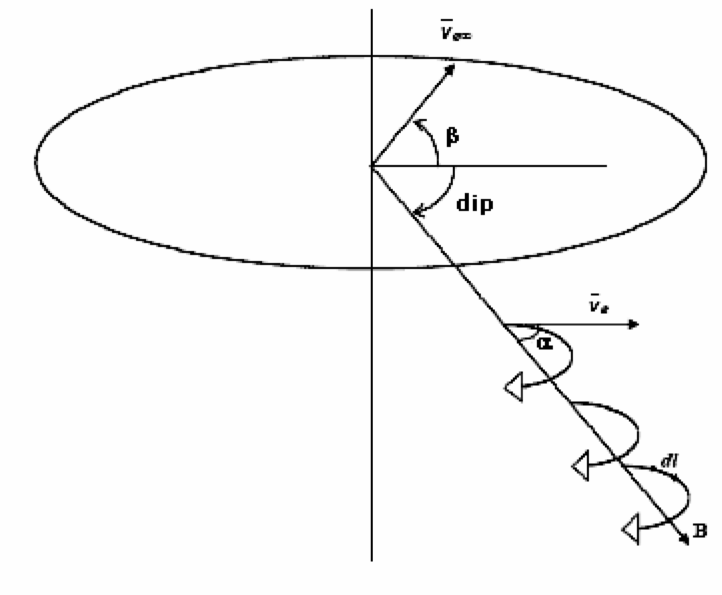
$$\frac{N_b}{N_e} = \frac{\Omega_e w}{\sqrt{eE_t h / m_e}} \sqrt{\frac{m_e}{m_i}} \frac{\gamma(eE_t h)}{4\sqrt{2}\cos^2(dip)}$$

- *Dip* is here the angle between **B** and the plane perpendicular to the tether (the *magnetic dip* in case of vertical tether)

Here the *dip* varies because

-the tether rotates
- the magnetic dip varies on the orbit

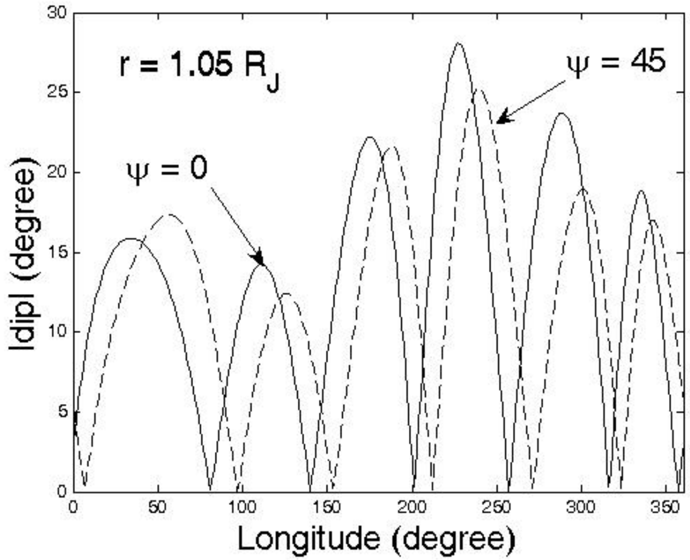




$\mathbf{u_t} = \mathbf{u}_r\cos\psi + \mathbf{u}_\varphi\sin\psi$

$$\sin dip = \mathbf{u_B}\cdot\mathbf{u_t}$$

$$= \frac{B_r \cos\psi + B_\varphi \sin\psi}{\sqrt{B_r^2 + B_\theta^2 + B_\varphi^2}} \quad \text{(VIP4 model)}$$



* Pitch-angle α distribution

$$\frac{\Phi_b(h,\alpha)}{\Phi_b(h)} = \frac{2/\pi}{\sqrt{\sin^2\alpha - \sin^2 dip}}$$

* Simplest loss-cone pitch

$$\sin^4\alpha_{lc} = \frac{1}{L^5(4L-3)}, \qquad L \equiv \frac{a}{R_J}$$

$\Rightarrow$ **Pitch range in e-beam**

$$dip(t) < \alpha < \alpha_{lc}(L)$$