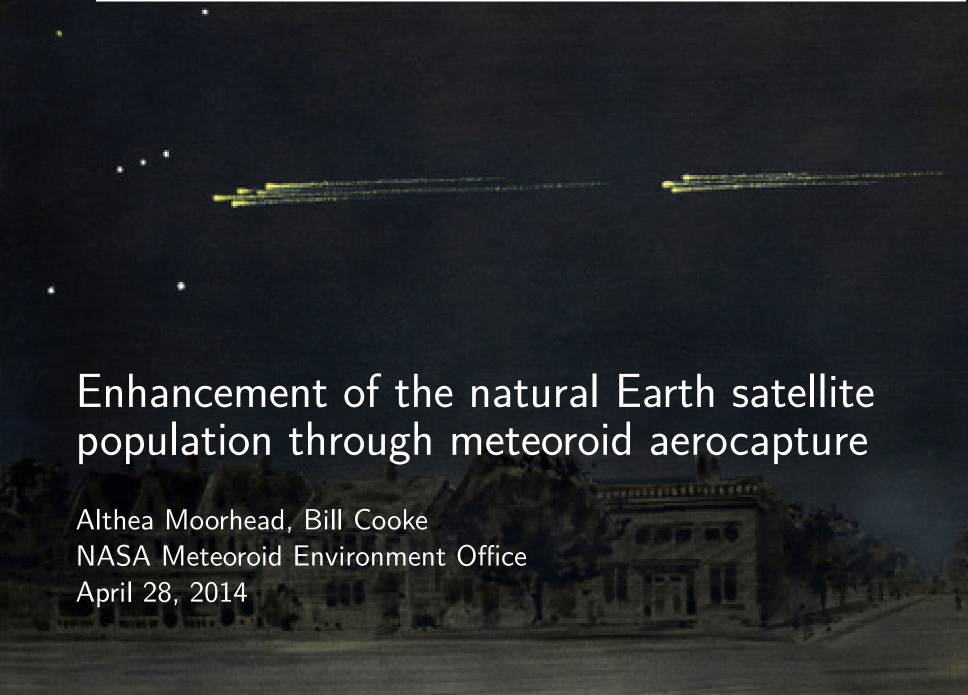


Enhancement of the natural Earth satellite population through meteoroid aerocapture

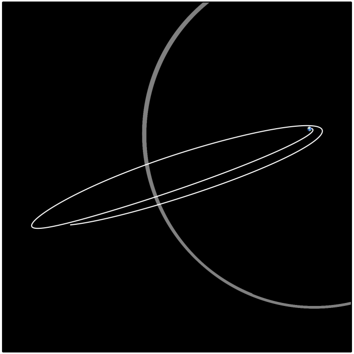
Althea Moorhead, Bill Cooke
NASA Meteoroid Environment Office
April 28, 2014

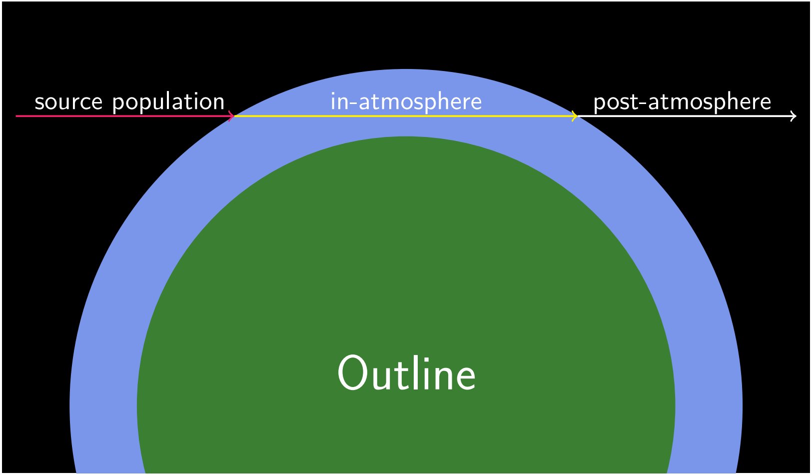
1972 Great Daylight Fireball
Image credit: ANSMET, James M. Baker

Earth-grazing meteoroids

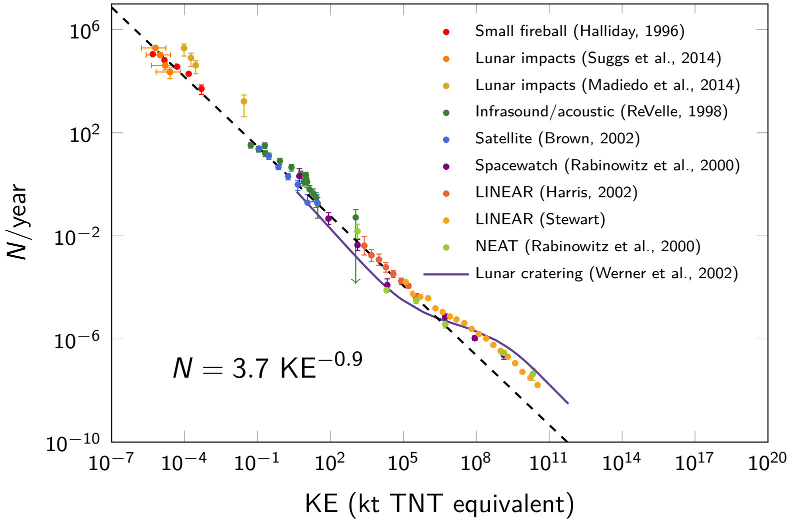
Questions:

- How many re-exit?
- How many are aerocaptured?
  - Ratcliff et al. (1993)
  - Hills & Goda (1997)
  - Hunten (1997)
- Can they become natural Earth satellites?
  - Granvik et al. (2012)

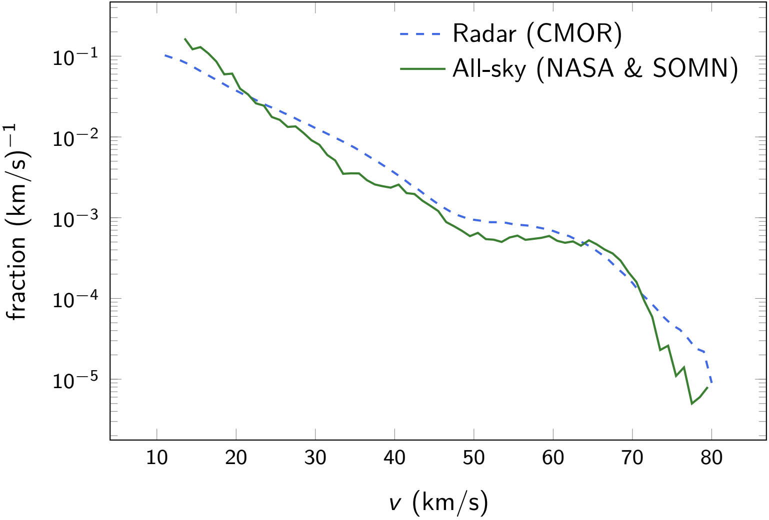



source population
in-atmosphere
post-atmosphere
Outline

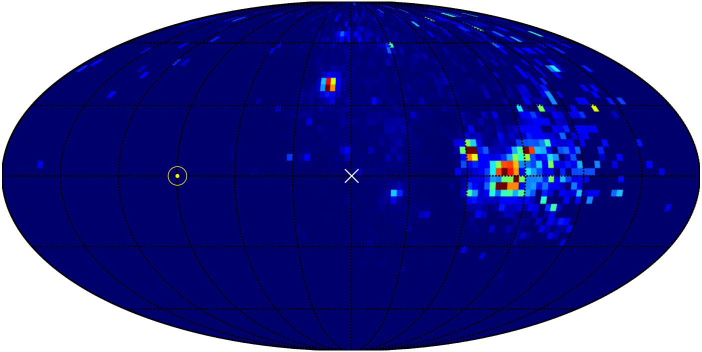
Number and Size



Velocity

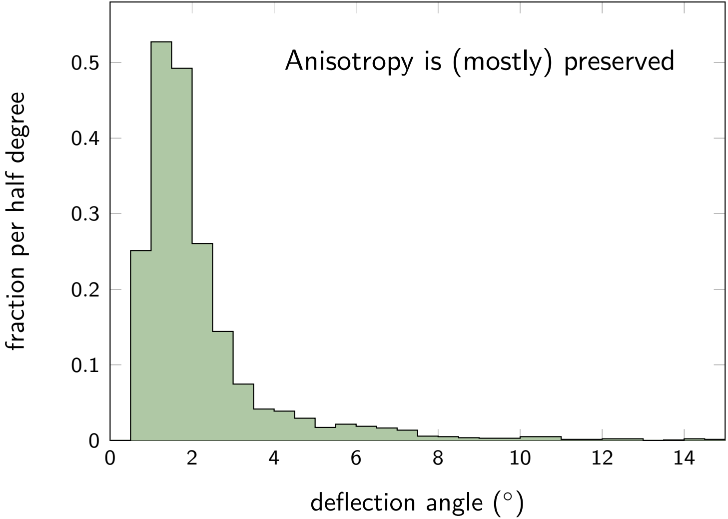

Radar (CMOR)
All-sky (NASA & SOMN)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
fraction $(\text{km/s})^{-1}$
10
20
30
40
50
60
70
80
v (km/s)

Directionality

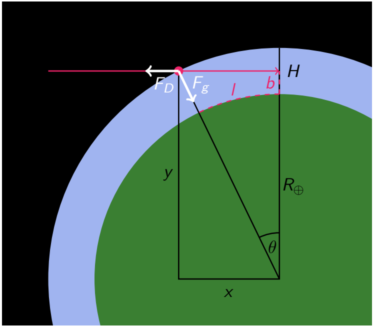


Data from NASA All-Sky Fireball Network
and Southern Ontario Meteor Network

Directionality



The trajectory in the atmosphere



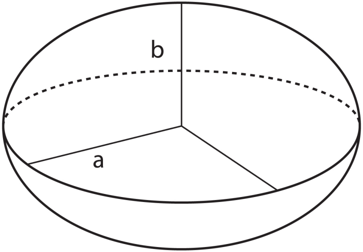
- Compute trajectory under Earth's gravity and atmospheric drag

$$\vec{F}_g = -\frac{GM_\oplus m}{r^2}\hat{r}$$

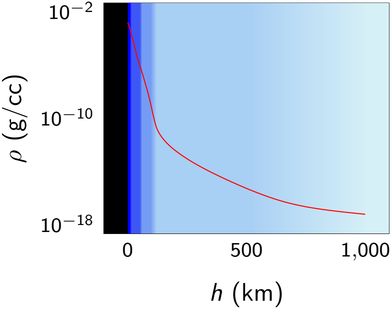
$$\vec{F}_D = -\frac{1}{2}\rho_a v^2 C_d A \hat{v}$$

Model Earth

Earth as ellipsoid



MSIS-E 90 model



"in-atmosphere" = within 100 km of the surface

Ablation

- Meteoroid ablation is a function of mass and velocity (Ceplecha, 2000):

$$\dot{m} = -\sigma C_d A \rho_d^{-2/3} \rho m^{2/3} v^3$$

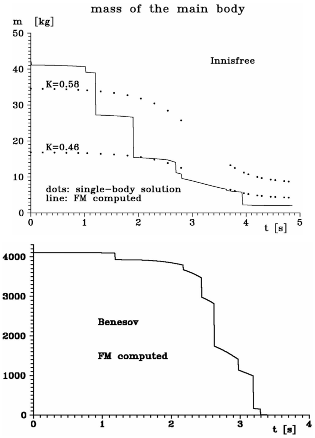
- Meteoroids modeled as spheres ($C_d = 0.47$, $A = 1.21$)
- Effective ablation coefficient (σ) includes some fragmentation

Catastrophic fragmentation

- Occurs when ram pressure exceeds material strength:

$$S < \rho v^2$$

- Model fragmentation:
  - 20% chance of fragmentation every 0.1 s
  - 0-50% reduction in primary mass



Ceplecha & ReVelle, 2005

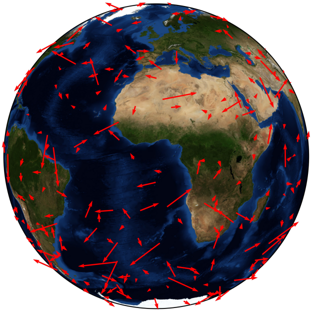
Meteoroid composition

Fireball meteoroid properties by type:

Type	%	ρ_d	σ	S
Iron	3	7.8	0.07	200
Stony	29	3.7	0.014	30
Carbonaceous	33	2.0	0.042	10
Cometary	30	0.75	0.1	1
		g/cc	s^2/km^2	MPa

Ceplecha (2001)
Hills & Goda (1993)

Surviving population



Out of 10^7 incident meteoroids:

	Grazers	**Aerocaptures**
	27,250	10,589
Ablation	18,307	5,040
Frag.	16,754	5,146

Numbers are per year for meteoroids greater than 1 cm in diameter

Simulations

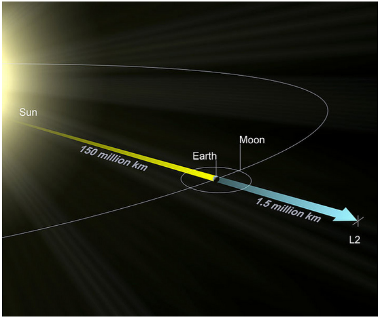
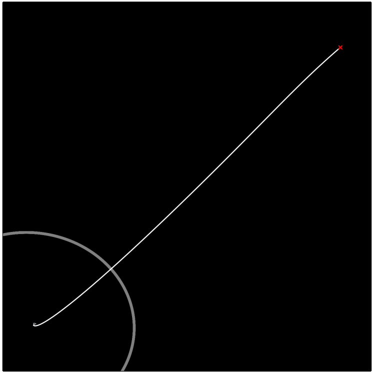


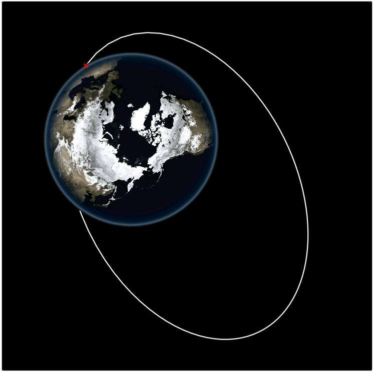
Image credit: NASA

- Simulations include Sun, Earth, and Moon
- Used *Mercury*, Bulirsch-Stoer method
- Random start between J2K and J2K + 19 years (Metonic cycle; Granvik et al., 2012)

End states

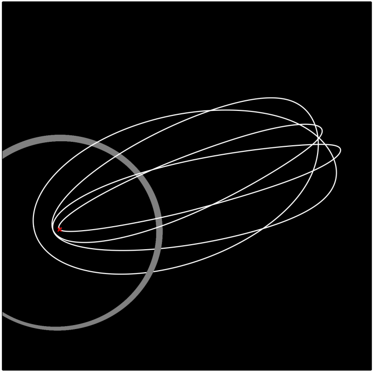


Leaving Earth's Hill sphere

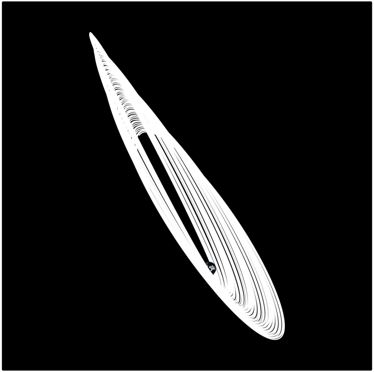


Atmospheric re-entry

End states

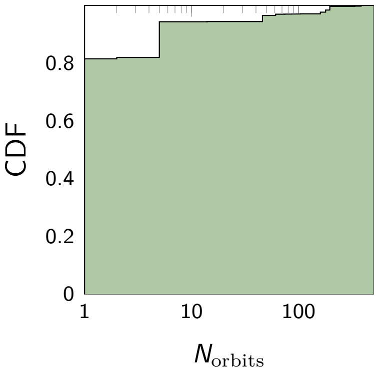


Re-entry or escape
after several orbits



Re-entry or escape
after many orbits

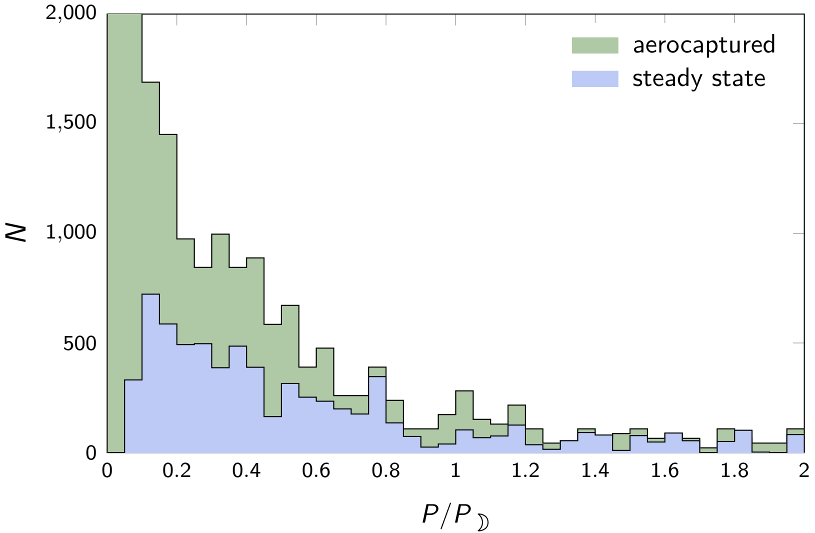
Steady-state population



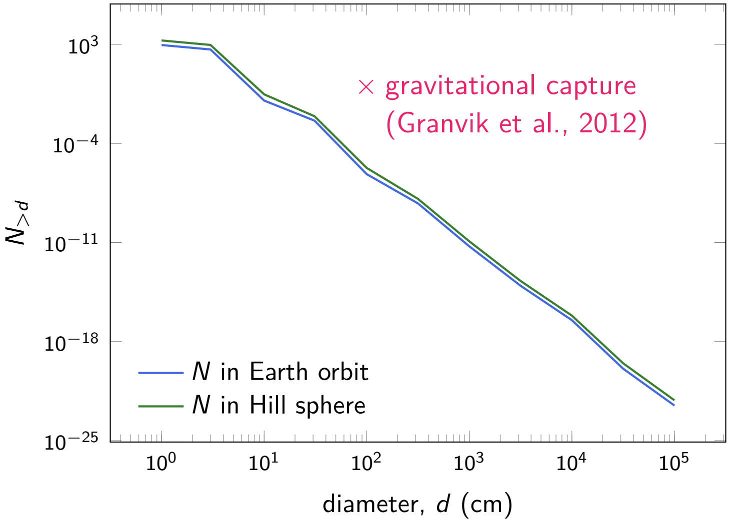
Using time spent in near-Earth space and in orbit:

	Number
Outbound	3,000
Orbiting	1,600

Period distribution



Size dependence



Conclusions and future work

- 0.2% of large meteoroids re-exit the atmosphere
- Meteoroid aerocapture can maintain a population of small (cm-sized) NES's
    - $\sim$ 3,000 in near-Earth space
    - $\sim$ 1,500 orbiting in near-Earth space
- Gravitational capture (Granvik et al., 2012) dominates for meter-sized bodies
- Future work:
    - Convolve results with meteoroid directionality