The meteoroid fluence at Mars due to Comet C/2013 A1 (Siding Spring)

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On October 19, 2014, Comet C/2013 A1 (Siding Spring) will pass within 150,000 km of Mars.

This is closer than all known Earth-comet encounters.

A collision has been ruled out, but Mars and its manmade satellites will pass through the coma and tail.

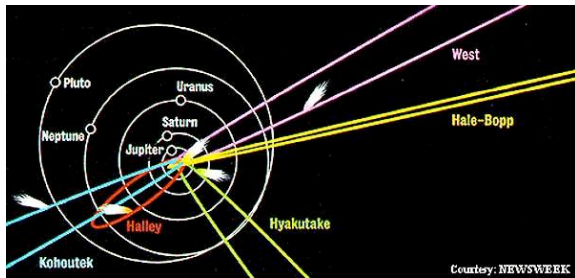Mars will be showered with meteors and satellites will have an increased risk of meteoroid impacts.

Outline

Comet background
Coma model
Recent observations

C/2013 A1 (Siding Spring)
Mars encounter
Mars spacecraft

Comet types: classed by orbit

Type	Orbit	Origin	Examples
Short period	$P < 200$ yrs	Kuiper Belt	Halley
Long period (Oort cloud)	$P \sim 1000$s yrs	Oort cloud	Hale-Bopp, C/2013 A1
Sungrazers	Pass near or plunge into the Sun		C/2012 S1 (ISON)

Comet background
Coma model
Recent observations

C/2013 A1 (Siding Spring)
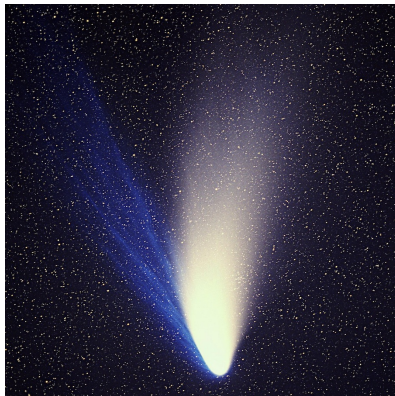Mars encounter
Mars spacecraft

Comet properties

Comet Hartley 2

- Comets are the least reflective objects in the Solar System:
    - Halley has an albedo of about 4%.
    - Asphalt has a albedo of 7%.

- Long period comets contain more volatiles, as short period comets lose much of these in frequent passages around the Sun.

Comet background
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C/2013 A1 (Siding Spring)
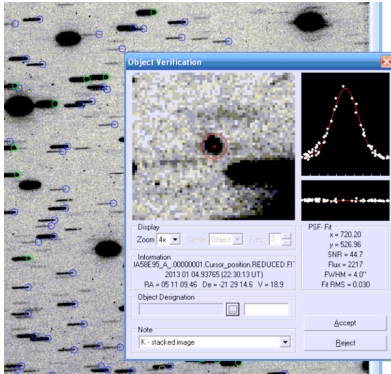Mars encounter
Mars spacecraft

Cometary comae

Comet Hale-Bopp, NASA

- Hale-Bopp:
  - Discovered at 7.2 AU
  - Coma was 1 million km in August 1995

- Siding Spring:
  - Imaged at 10 AU
  - Already active

Comet background
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C/2013 A1 (Siding Spring)
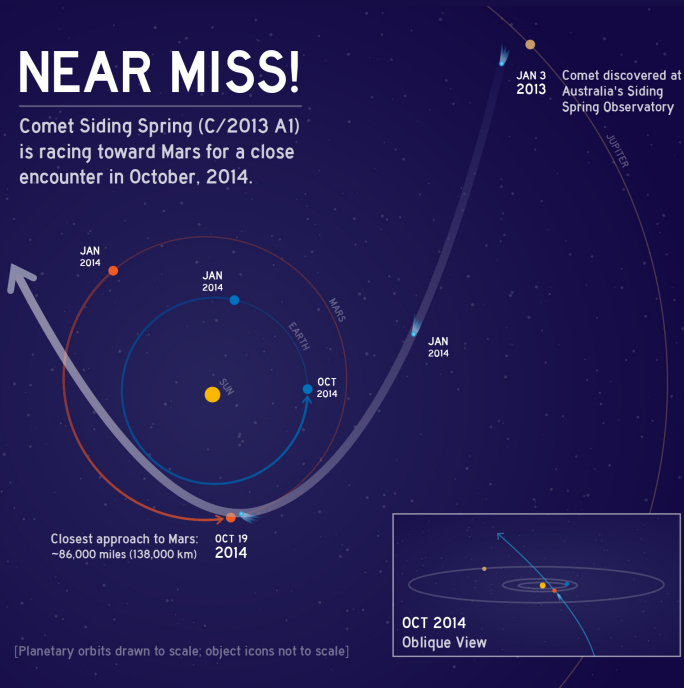Mars encounter
Mars spacecraft

C/2013 A1 (Siding Spring)

- Discovery:
  - January 3, 2013
  - Rob McNaught
  - 0.5 meter telescope
  - Siding Spring, Australia
- Pre-discovery images located in Catalina Sky Survey
  - Active in earliest images (Dec. 8, 2012)
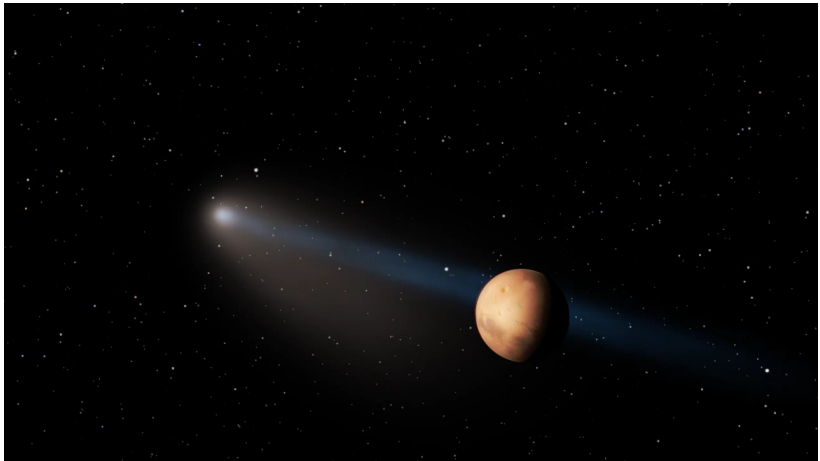- Hyperbolic orbit

NEAR MISS!

Comet Siding Spring (C/2013 A1) is racing toward Mars for a close encounter in October, 2014.

JAN 3 2013 — Comet discovered at Australia's Siding Spring Observatory

JUPITER

JAN 2014

JAN 2014

JAN 2014

OCT 2014

MARS

EARTH

SUN

Closest approach to Mars: ~86,000 miles (138,000 km)

OCT 19 2014

OCT 2014 Oblique View

[Planetary orbits drawn to scale; object icons not to scale]

Image credit: NASA / JPL

Comet background
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C/2013 A1 (Siding Spring)
Mars encounter
Mars spacecraft

Close encounter with mars

Movie credit: Leonid Elenin using SpaceEngine software

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C/2013 A1 (Siding Spring)
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Close encounter with mars

Encounter+0.1days

Comet C/2013 A1 Siding Spring simulation
(1-0.05-1.0-1000(-7-1)-0.2-1e4-10.0-PF-PN-R-003)
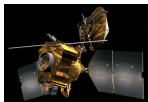(C) 2013 Paul Wiegert - the University of Western Ontario
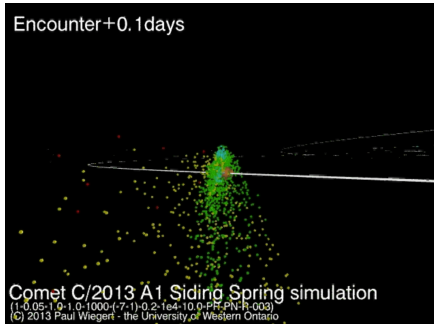
- Comet is north of Mars's orbital plane at closest approach
- Close approach: 131,000 - 145,000 km
- Approach distance nominal value: 138,000 km
- Coma/tail may envelop Mars

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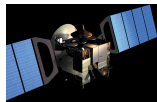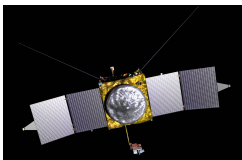Mars encounter
Mars spacecraft

Mars satellites
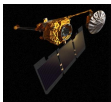
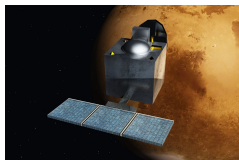Odyssey (NASA)
400 km, 2 hr orbit

MRO (NASA)
300 km, 2 hr orbit

Mars Express (ESA)
300 - 10,000 km
7.5 hr orbit

MAVEN (NASA)
150 - 6,200 km, 4.5 hr orbit
Arrives September 2014

MOM (ISRO)
365 - 80,000 km, 76.7 hr orbit
Arrives September 2014

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C/2013 A1 (Siding Spring)
Mars encounter
Mars spacecraft

Meteoroid impact risks

- Impacts to critical components
- Sudden attitude changes
- Electrostatic/EMP effects may occur, depending on environment and spacecraft charging state
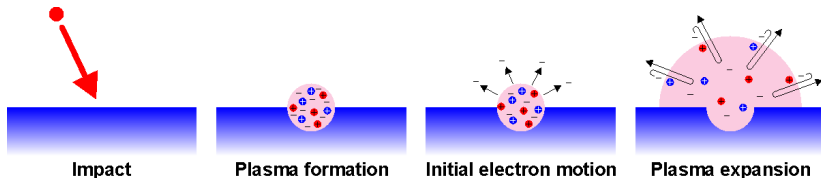

Impact **Plasma formation** **Initial electron motion** **Plasma expansion**

Image courtesy of MEDUSSA

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Mars spacecraft

Meteoroid impact risks

- Encounter speed similar to Perseids at Earth
- Two spacecraft anomalies attributed to Perseids:
    - Landsat 5 lost attitude control during 2009 Perseids
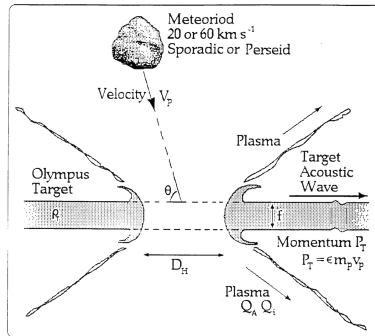   - OLYMPUS satellite lost during 1993 Perseids

Image from McDonnell et al., 1993

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Possible mitigation strategies

- Align solar arrays sunward, edge-on to meteor shower
  - Sun-Mars-comet angle is $90.2°$
- Present hard side to radiant
- Phase orbit to use Mars as a partial shield:
  - Depends on orbit geometry
  - Shower will last a few hours, dependent on coma size (30 min per 100,000 km of coma/tail)
  - Odyssey and MRO have 2 hour orbits

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Particles in the coma and tail of Siding Spring

- Coma and tail contains both gas and particles
- Both grow as heliocentric distance decreases
- <u>Fluence</u> – flux integrated over Mars/spacecraft trajectory
    - Direct measure of spacecraft risk
- We compute the particle fluence at Mars using properties of Siding Spring (magnitude, orbit), supplementing with Halley data (particle albedo, size distribution) where necessary.

Comet background
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The *Giotto* flyby of 1P/Halley

- We have detailed coma data for one comet: Halley.
- Giotto recorded 12,000 impacts.
- Model fits to these data yield:
  - Particle density and albedo
  - Particle size distribution
  - Particle spatial distribution
- Total number of particles derived from Siding Spring magnitude, not Halley.

HMC 68 Image Composite
Comet Halley   14th March 1986

Comet background
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Analytic model

Quantifying the number of $\sim$100 micron[1] or larger particles in the coma/tail:

1. Determine the brightness at the time of the encounter.
2. Use particle albedo to compute the total particle surface area.
3. Combine with Halley-like particle size distribution and material density to compute number of particles.
4. Use r^{-2} spatial distribution to compute the number density.
5. Integrate along the trajectory to get fluence.

Our analytic model can be used to quickly calculate new fluence estimates as comet properties are measured/constrained.
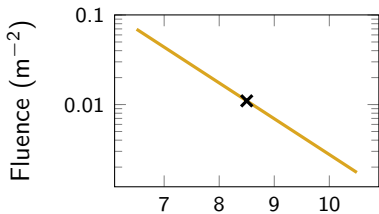
_____

[1]100 micron particles are capable of cutting exposed spacecraft wires. Mass limit is 4×10^{-6} g, actual size limit depends on density

Comet background
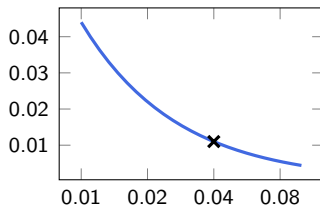**Coma model**
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Analytic model

$$
\sigma_* = \frac{g h^{-\beta}}{a} \left(\frac{2}{\pi}\right)^{\frac{1}{3}} \left(\frac{\rho}{3}\right)^{\frac{2}{3}} 10^{-0.4(M1 - m_{\odot,1\mathrm{au}})} \; \mathrm{au}^2
$$

$$
\times \left(\frac{3-k}{1-k}\right) \left(\frac{m_{\max}^{(1-k)/3} - m_*^{(1-k)/3}}{m_{\max}^{(3-k)/3} - m_{\min}^{(3-k)/3}}\right)
$$

$$
\times \frac{\cos^{-1}(b/r_c)}{b \; r_c}
$$

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Analytic model
Dependence on comet/meteoroid properties

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars
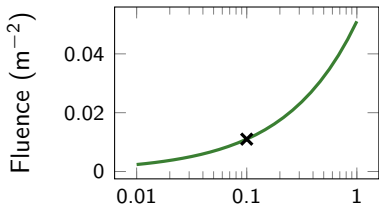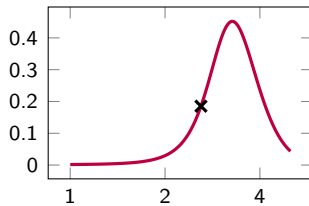
Analytic model
Fluence depends strongly on close approach distance

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
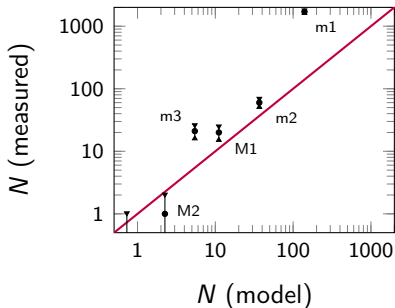Effects at Mars
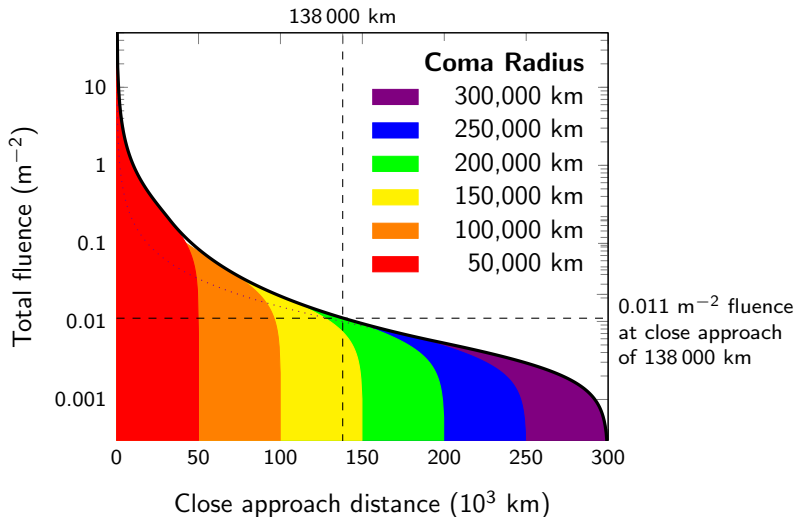
Validation #1: reproducing *Giotto* results

- We test our model by applying it to 1P/Halley
- Using a coma radius of 200,000 km, we can reproduce the flux Giotto recorded
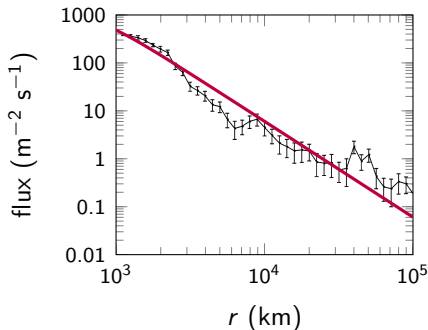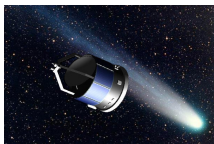
Fulle et al. (2000) data, our model

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Validation #2: reproducing *Stardust* results

- *Stardust* flew 300 km from 81P/Wild 2
- Coma radius was 24,000 km at 1.7 au
- We model impacts per mass channel
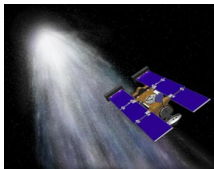
Tuzzolino et al. (2004) data, our model

Comet background
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Recent observations

Analytic model
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Effects at Mars

Validation #3: comparison with simulations
4×10^{-6}g particles
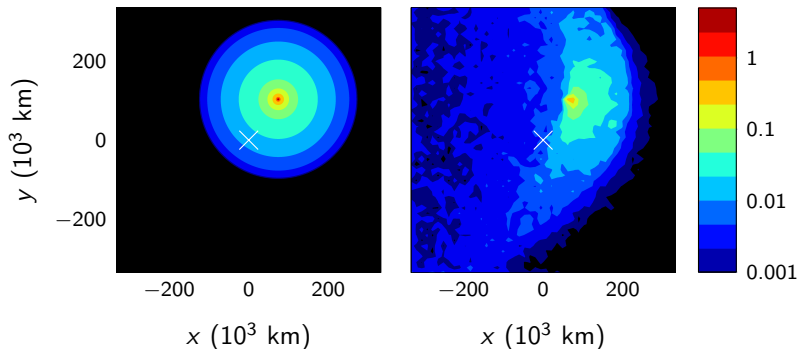
- Analytical model (left) and normalized simulations (right) in plane containing Mars (at origin), perpendicular to trajectory.
- Simulations performed by Paul Wiegert, UWO.

Comet background
Coma model
Recent observations
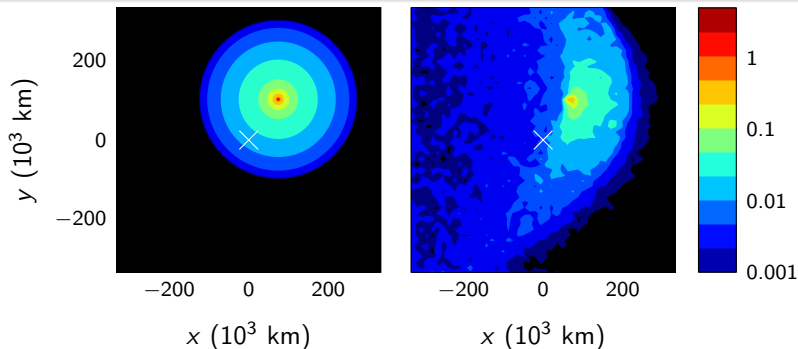
Analytic model
Validation and simulations
Effects at Mars

Validation #3: comparison with simulations
4×10^{-6}g particles

- Small scale simulations do not predict number of particles; fluence on right is multiplied by N_{theory}/N_{sim}.
- Simulations *do* illustrate (modest) deviance from spherical model due to coma asymmetry and tail.

Comet background
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Recent observations

Analytic model
Validation and simulations
Effects at Mars

Validation #3: comparison with simulations
4×10^{-6}g particles
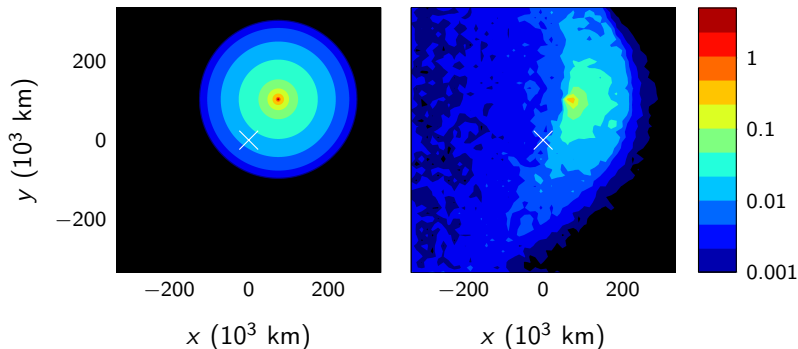
- Simulated coma has large radius (200, 000 km) due to early assumed start of activity (10 AU)
- Effective radius may be smaller – needs further study

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Validation #3: comparison with simulations
4×10^{-3}g particles
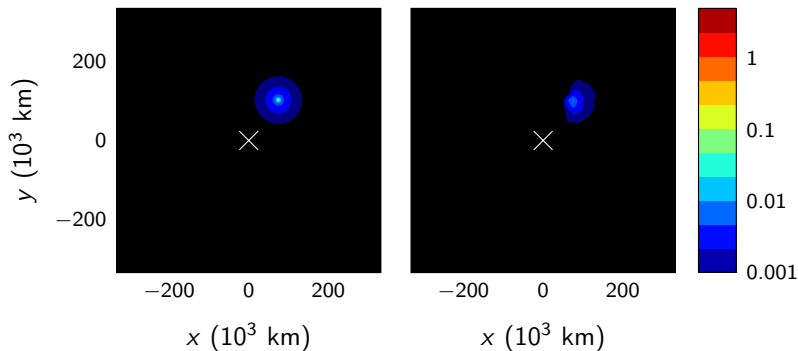
- Larger particles:
  - Have lower ejection velocity
  - Are less subject to radiative forces

Comet background
Coma model
Recent observations

Analytic model
Validation and simulations
Effects at Mars

Validation #4: comparison with independent studies

- Parallel effort to model coma particle dynamics: Vaubaillon et al., 2014
- Uses $Af\rho$ rather than magnitude to scale dust production.
- Results agree to within an order of magnitude ... with the same input parameters

Nodes (2014)

Comet background
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Analytic model
Validation and simulations
Effects at Mars
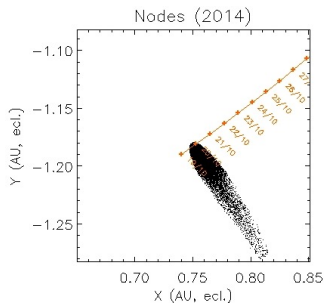
Martian meteor shower
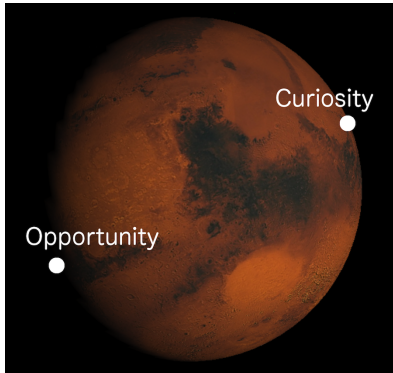
- Meteor shower will accompany Siding Spring
- ZHR for 10^{-6} g particles $\sim$ 30,000,000 at Mars
- Subradiant near Opportunity at dawn
- MarsExpress may see up to 1000 meteors per minute
  - 10,704 km^2 FOV
  - $m \gtrsim 3$ g
  - Numbers from Anastasios Margonis

Comet background
Coma model
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Analytic model
Validation and simulations
Effects at Mars

Meteoroid impact risks

1966 Leonids by A. Scott Murrell

- Average flux of 100 micron or larger meteoroids in low Earth orbit is 5×10^{-6} m^{-2} per hour
- Fluence due to Siding Spring is 500 times higher (5 years of LEO exposure)
- There has never been an event like this near Earth in recent memory, with the possible exception of the 1966 Leonids.

Comet background
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Analytic model
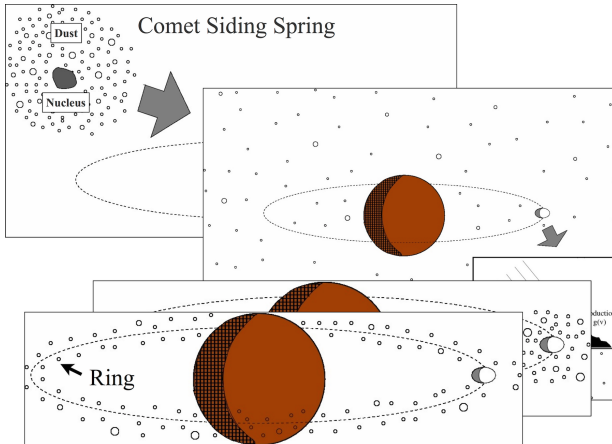Validation and simulations
Effects at Mars

Effects on the Martian atmosphere

- Atmospheric effects
  - Energy deposition:

$$\mathrm{KE} = \int \frac{d\sigma}{dm} m \; dm \times \frac{v^2}{2} \times \pi r_M^2$$

  - 1.14 megatons of TNT equivalent
  - 0.006% of solar irradiance: insignificant
- Metal deposition probably more important
  (John Plane, Leeds)

Comet background
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Effects on the Martian system

Impact ejecta from the moons could last months or years
(Apostolos Christou, Armagh)

Comet background
Coma model
Recent observations

Brightness monitoring
Observational constraints
Comparison with Hale-Bopp

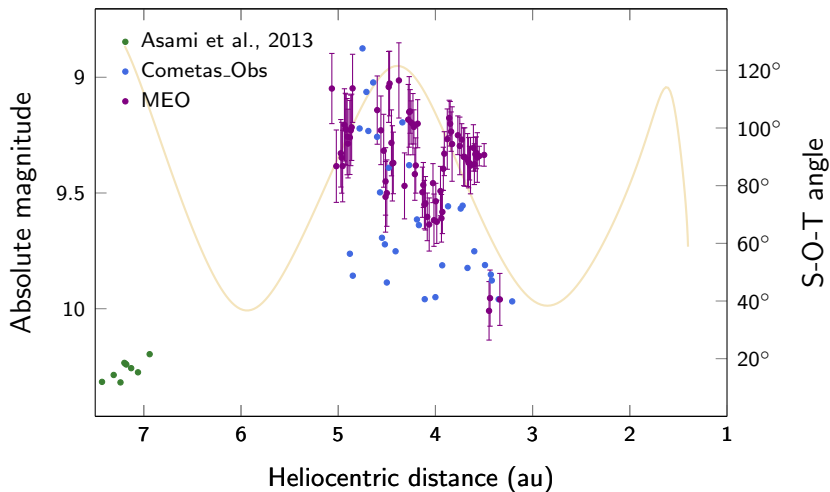# Brightness monitoring

1 m at Siding Spring

Hubble

Multiple efforts to monitor Siding Spring:

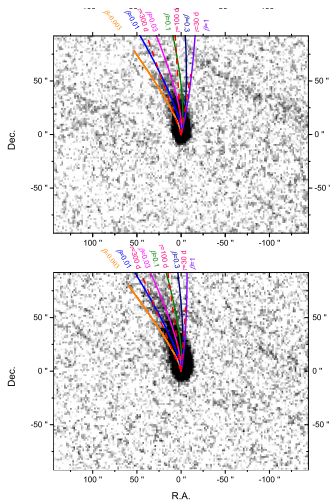- NMSkies, 0.5m (MEO)
- Siding Spring, 1m (MEO)
- Siding Spring, 2m (Christou, Armagh)
- NEOWISE
- Hubble (PI: Jian-Yang Li)

Comet background
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Brightness monitoring

Comet background
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Brightness monitoring
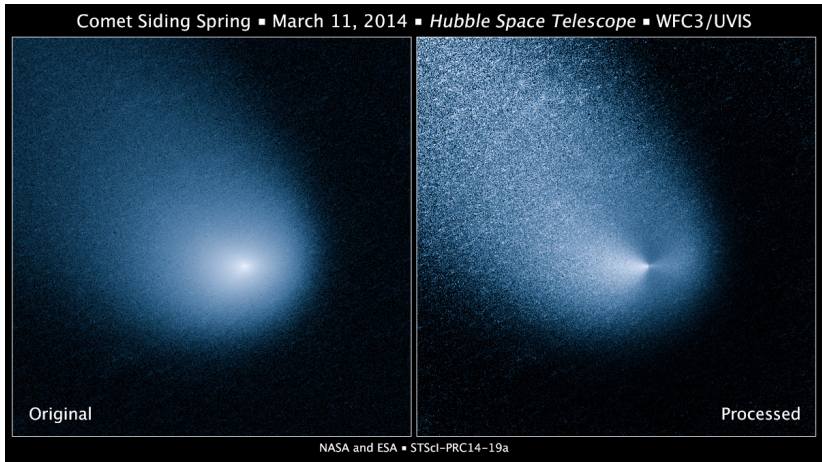Observational constraints
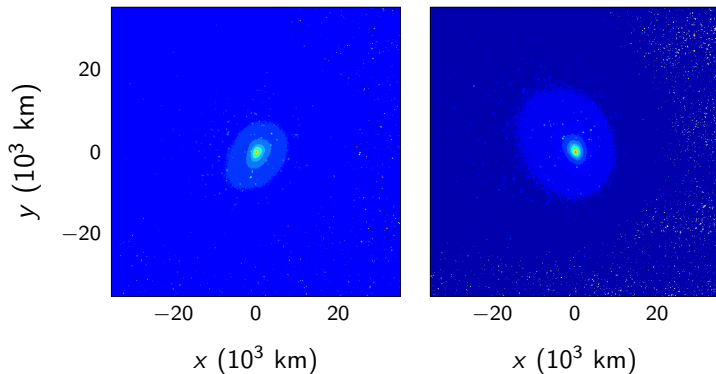Comparison with Hale-Bopp

Syndyne calculations

Ye & Hui, 2014

- Ye & Hui, 2014:
  - Shape of cometary tail is influenced by gravity and radiation pressure
  - "Mostly large particles" based on curvature of tail
  - Low ejection velocity based on compactness of the coma
- Low ejection velocity
  = compact coma
  = much lower fluence at Mars

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Hubble observations

Comet Siding Spring ▪ March 11, 2014 ▪ *Hubble Space Telescope* ▪ WFC3/UVIS

Original

Processed

NASA and ESA ▪ STScI–PRC14–19a

Comet background
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Comparison with Hale-Bopp

Hubble observations

The coma does appear to be expanding slowly

Comet background
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Brightness monitoring
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Heliocentric magnitude: Hale-Bopp

Hale-Bopp had three phases of activity pre-perihelion (Kidger, 1997)

- $\propto r^{-5}$ at large distances
- $\propto r^{-1}$ around 4 au (a "standstill")
- $\propto r^{-3.5}$ at smaller heliocentric distances

Kidger notes that ice sublimation begins around 4 au

Comet background
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Brightness monitoring
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Heliocentric magnitude: Hale-Bopp

Image credit: A. Kammerer

Comet background
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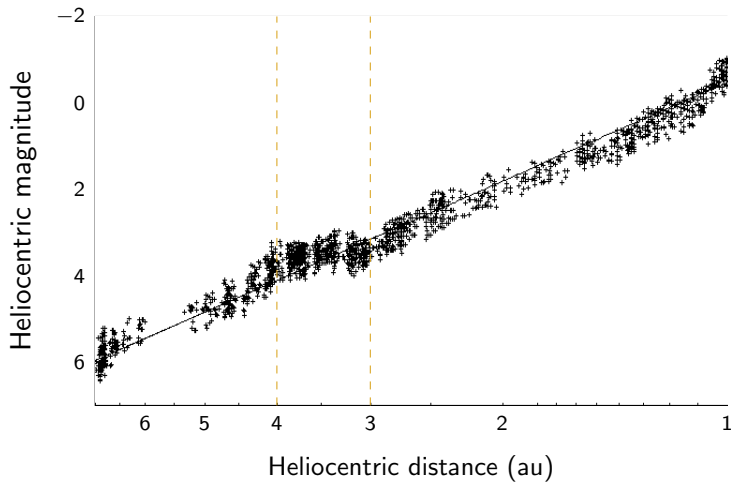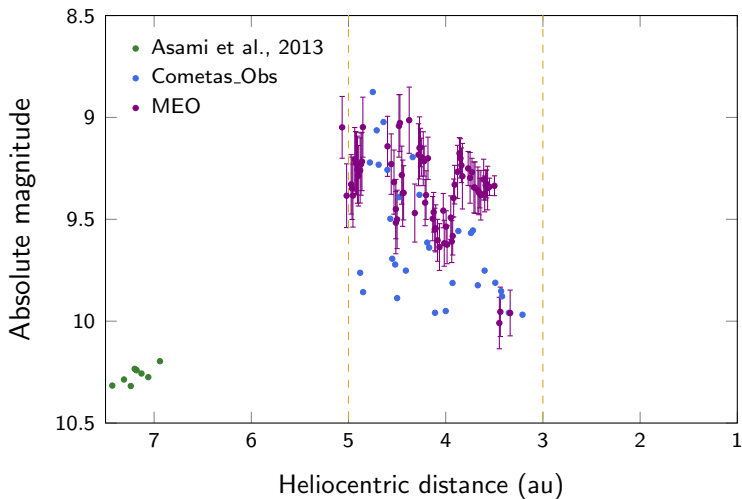
Brightness monitoring
Observational constraints
Comparison with Hale-Bopp

Heliocentric magnitude: Siding Spring

Summary

- Comet C/2013 A1 (Siding Spring) will have close encounter with Mars on October 19, 2014
- Mars and spacecraft will pass through coma and tail containing meteoroids
- Meteoroids (4.19×10^{-6} g or larger): $\sim 1\%$ chance of impact per square meter due to coma and tail
- Continued monitoring is needed to better predict future behavior