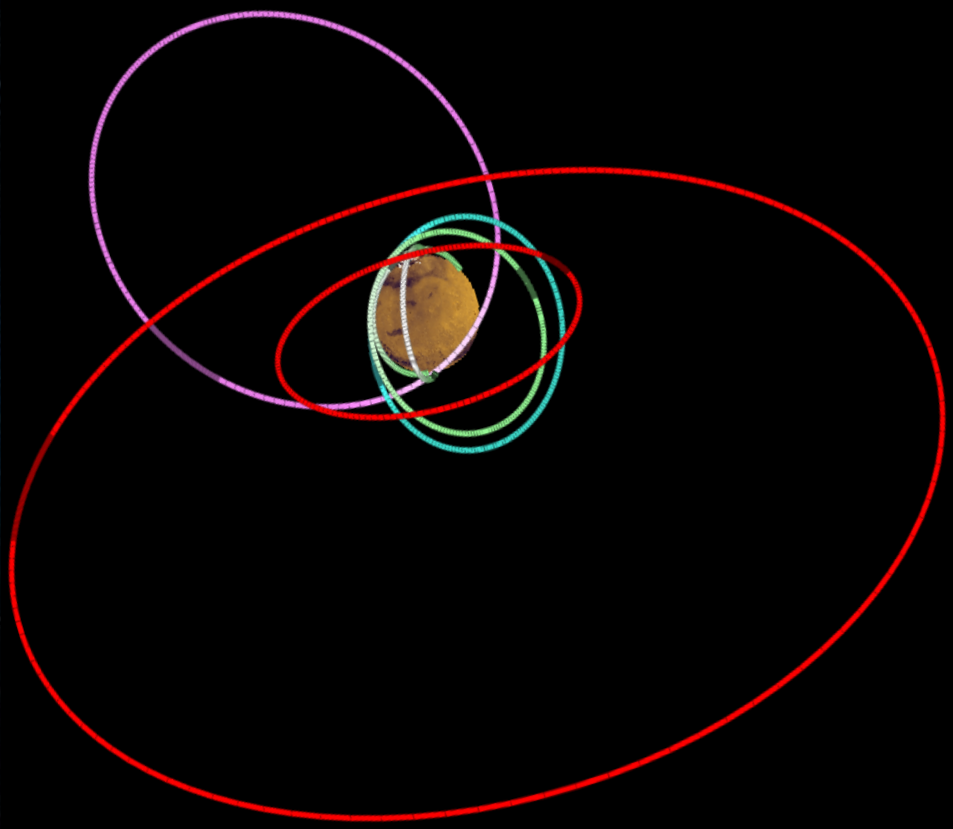
HST Image: Mar 11, 2014



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Comet Siding Spring Encounters Mars

HST Image: Mar 11, 2014

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Panelists:

Joe Guinn*

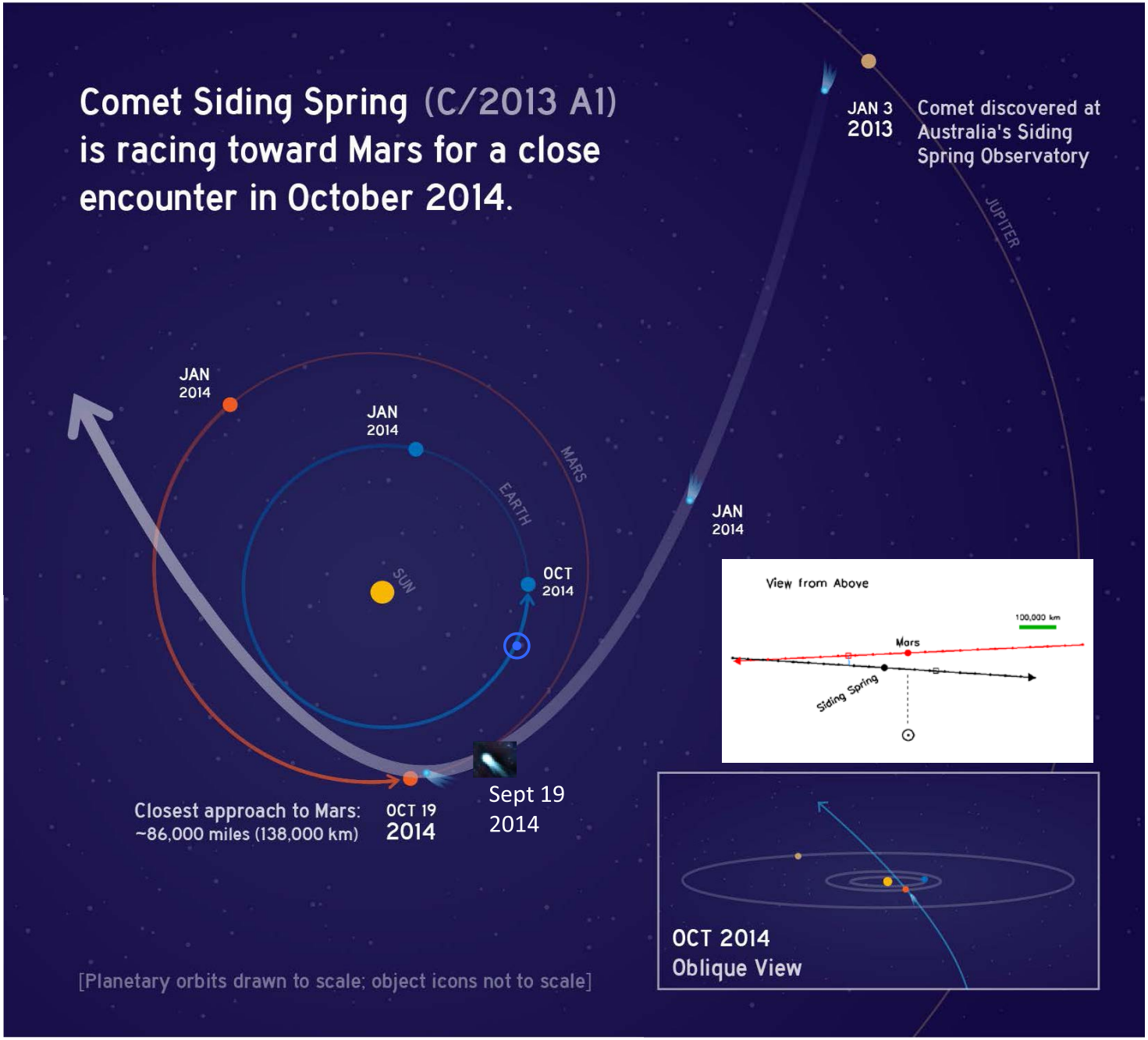
Paul Chodas*

Rob Lock*

Chad Edwards*

Richard Zurek*

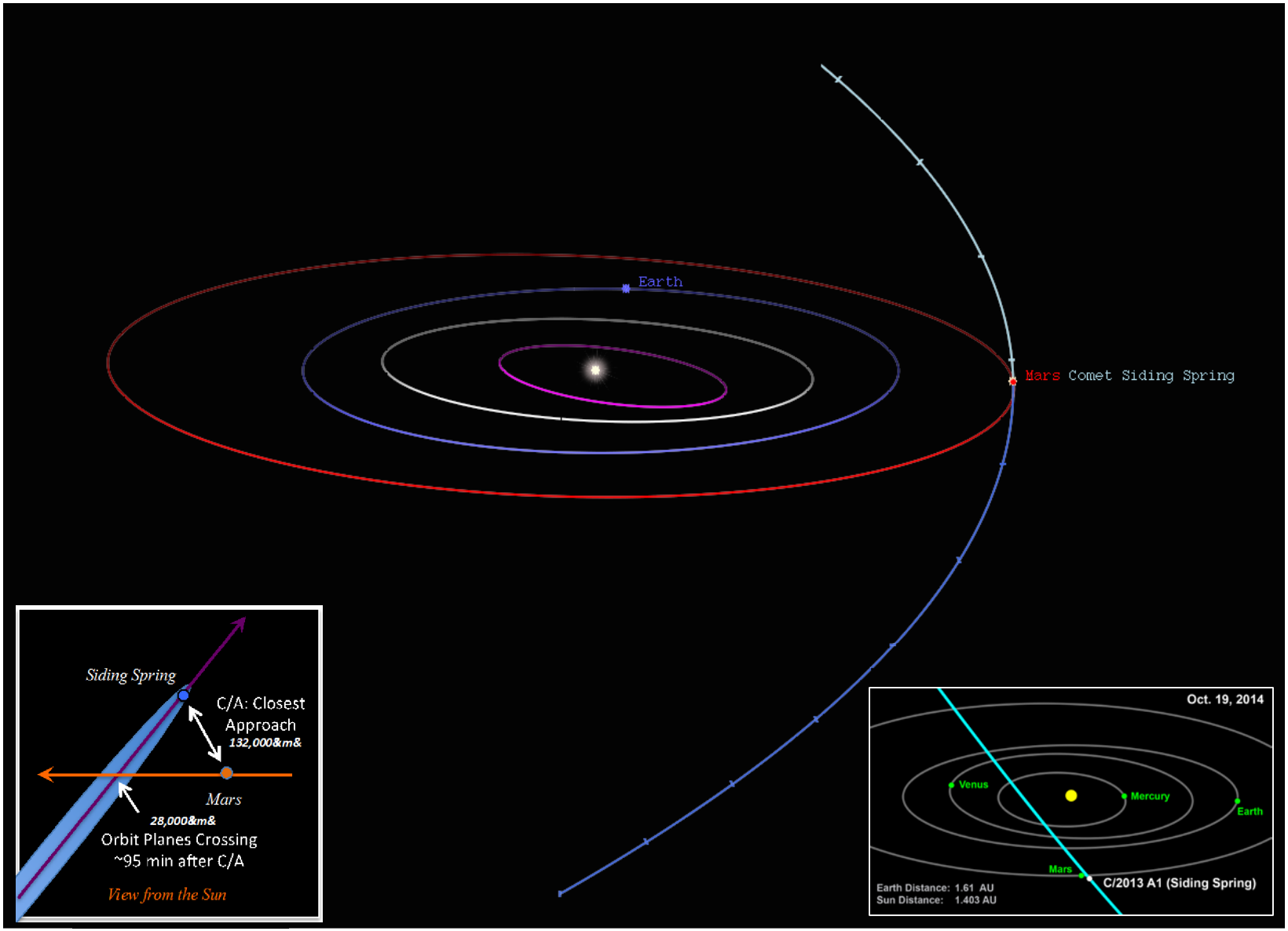
August 5, 2014



CSS 2014 Timeline, Retrograde Orbital Trajectory:

Best Earth Observing Time in mid-September; Mars C.A. ~ 131,000 km, @ 18:32 UT, 56 km/sec relative (but max danger maybe 100 min later when Mars + s/c cross comet's orbit)

Comet /2013 A1 Siding Spring

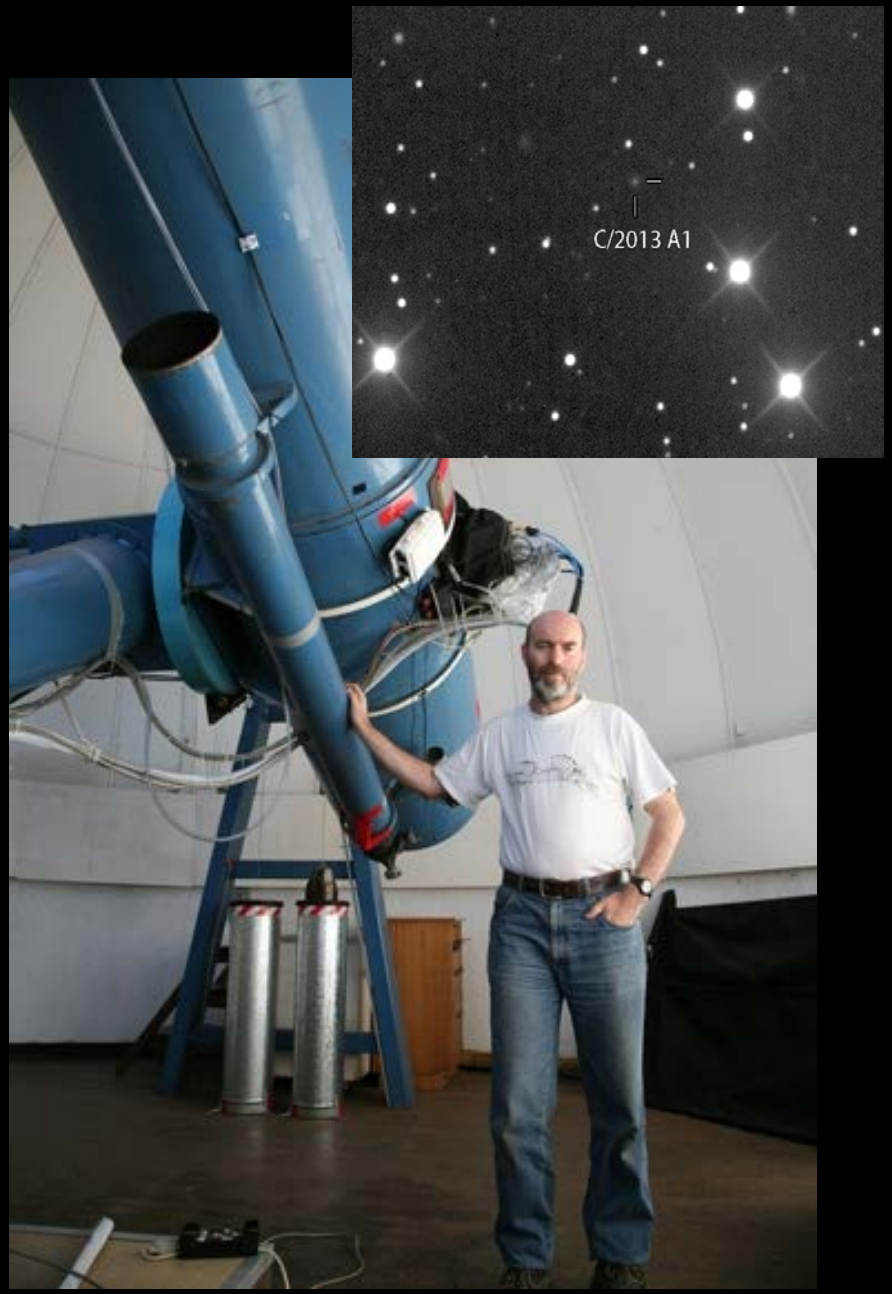


Fun Facts: Mars Close Approach is 131,000 km

- 1/3 the average Earth-Moon distance.
- 1/17 the distance of the closest comet to fly by Earth in the last 500 years.
- 15x the mean distance of Phobos from Mars, 6x the mean distance of Deimos.
- The comet nucleus is only 1 order of magnitude smaller than the moons.
- The outer gaseous coma of the comet will sweep across Mars.

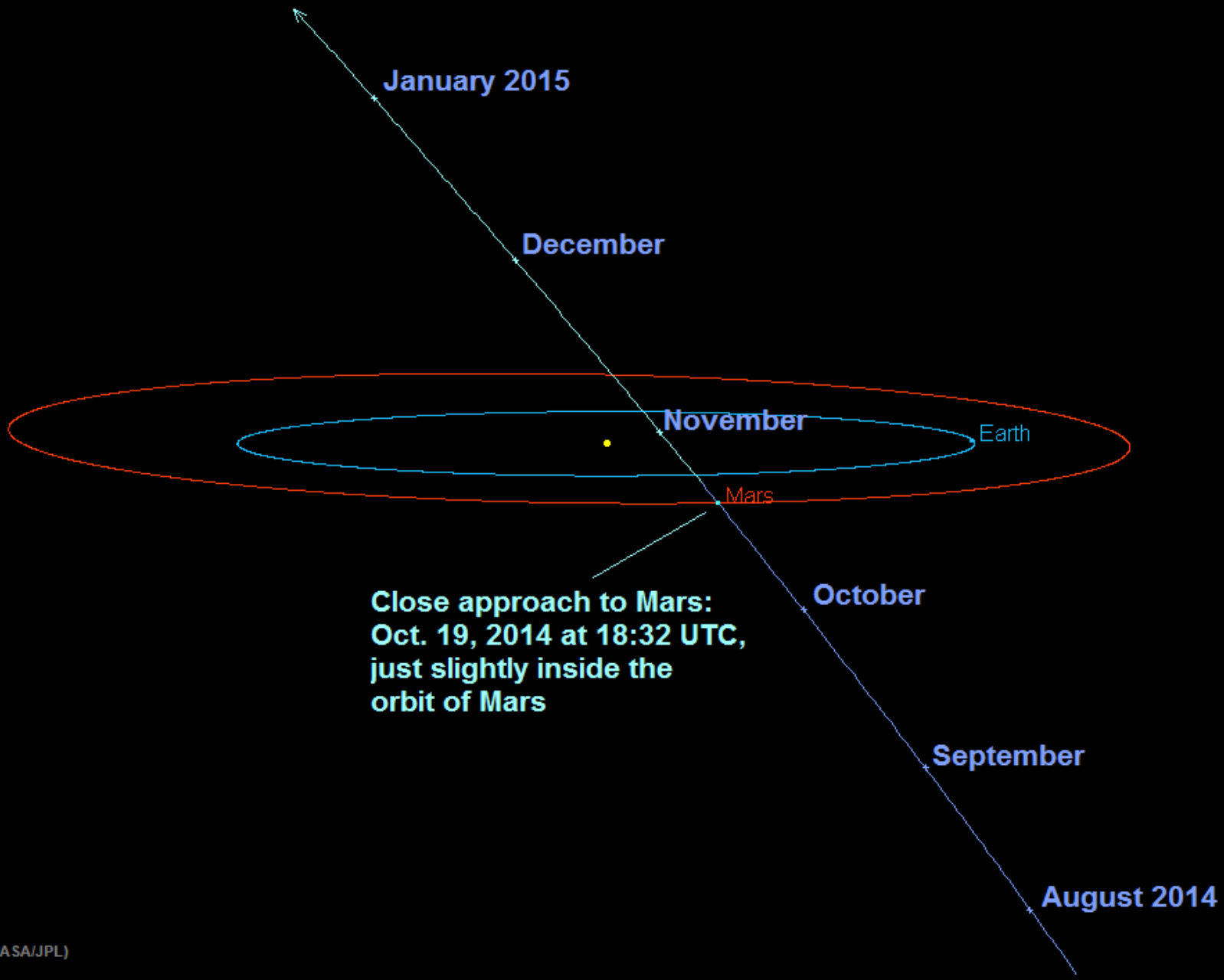
Comet C/2013 A1 (Siding Spring)

- Discovered on 3 January 2013 by Robert McNaught using the 0.5-meter Uppsala Southern Schmidt Telescope at Siding Spring Observatory, Australia
- Within days, an extremely close approach to Mars on Oct. 19, 2014 was predicted (on the Solar System Dynamics website)
- Probability of impact with Mars rose as high as 1 in 600 by early March, but as orbit knowledge got more precise, the probability dropped, and impact was ruled out in the late 2013.
- A “dynamically new”, long period comet.
- Comet is being actively observed with over 600 observations, ~40 per month.



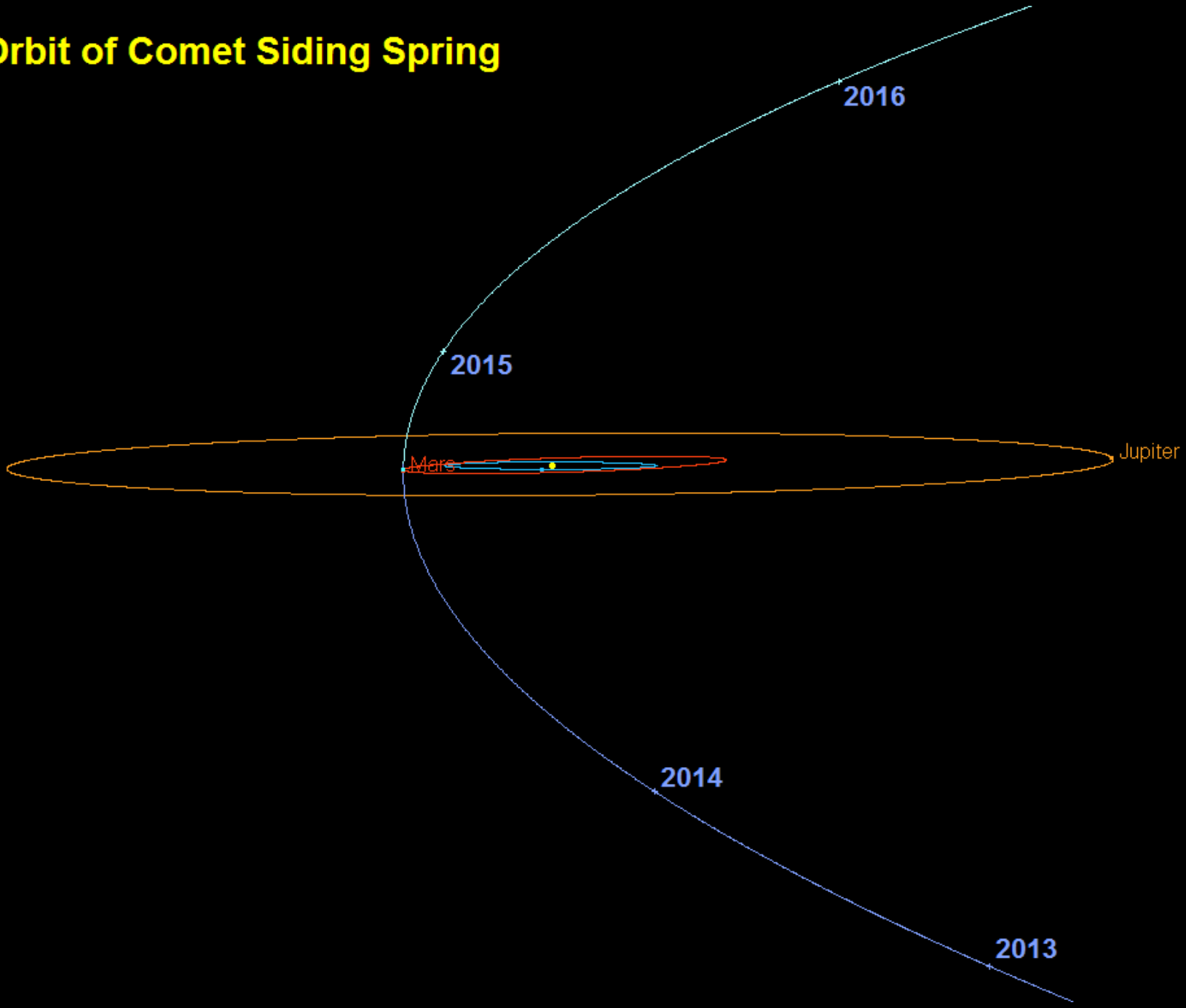
Siding Spring Observatory

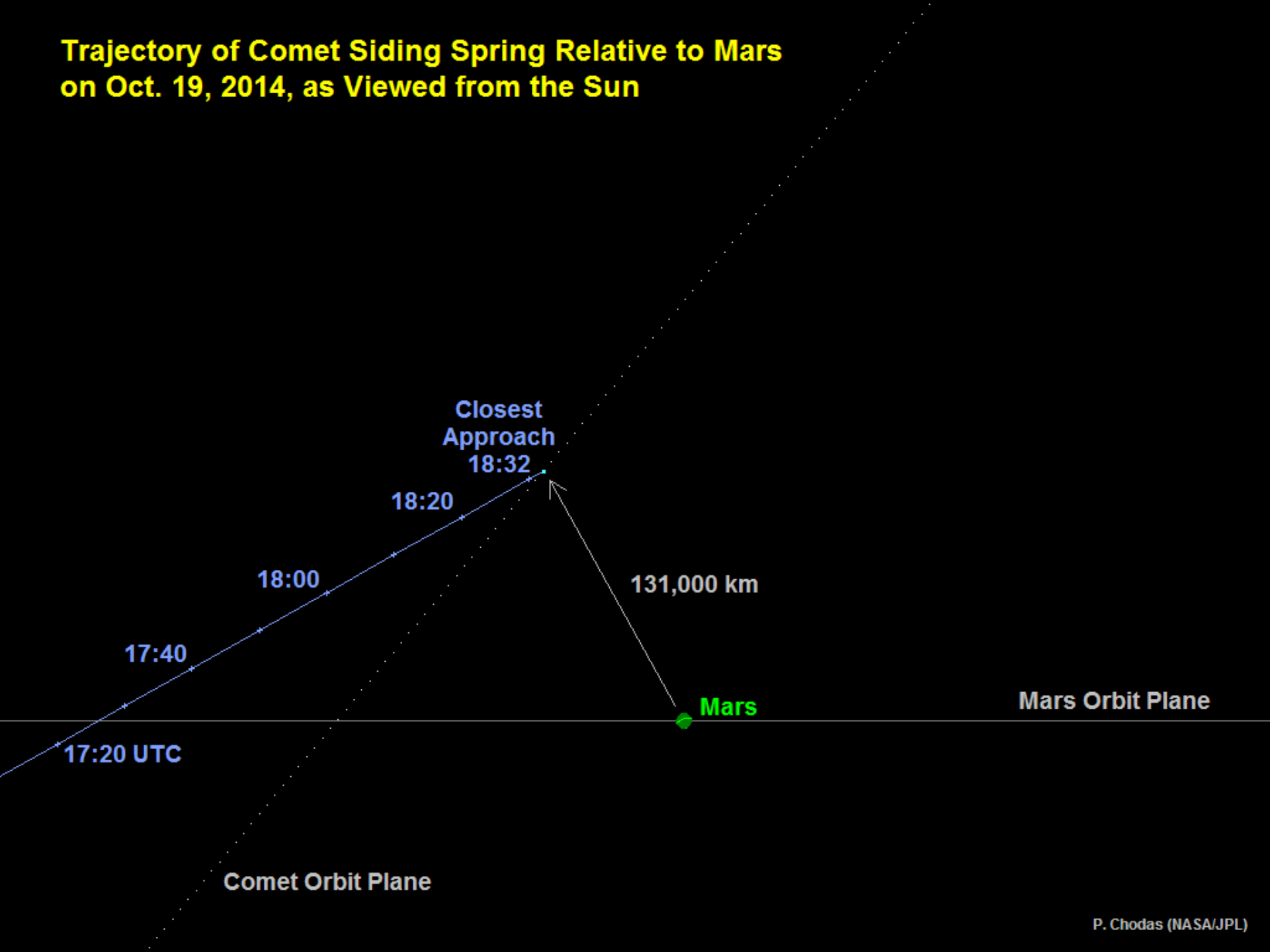
Trajectory of Comet Siding Spring Through the Inner Solar System

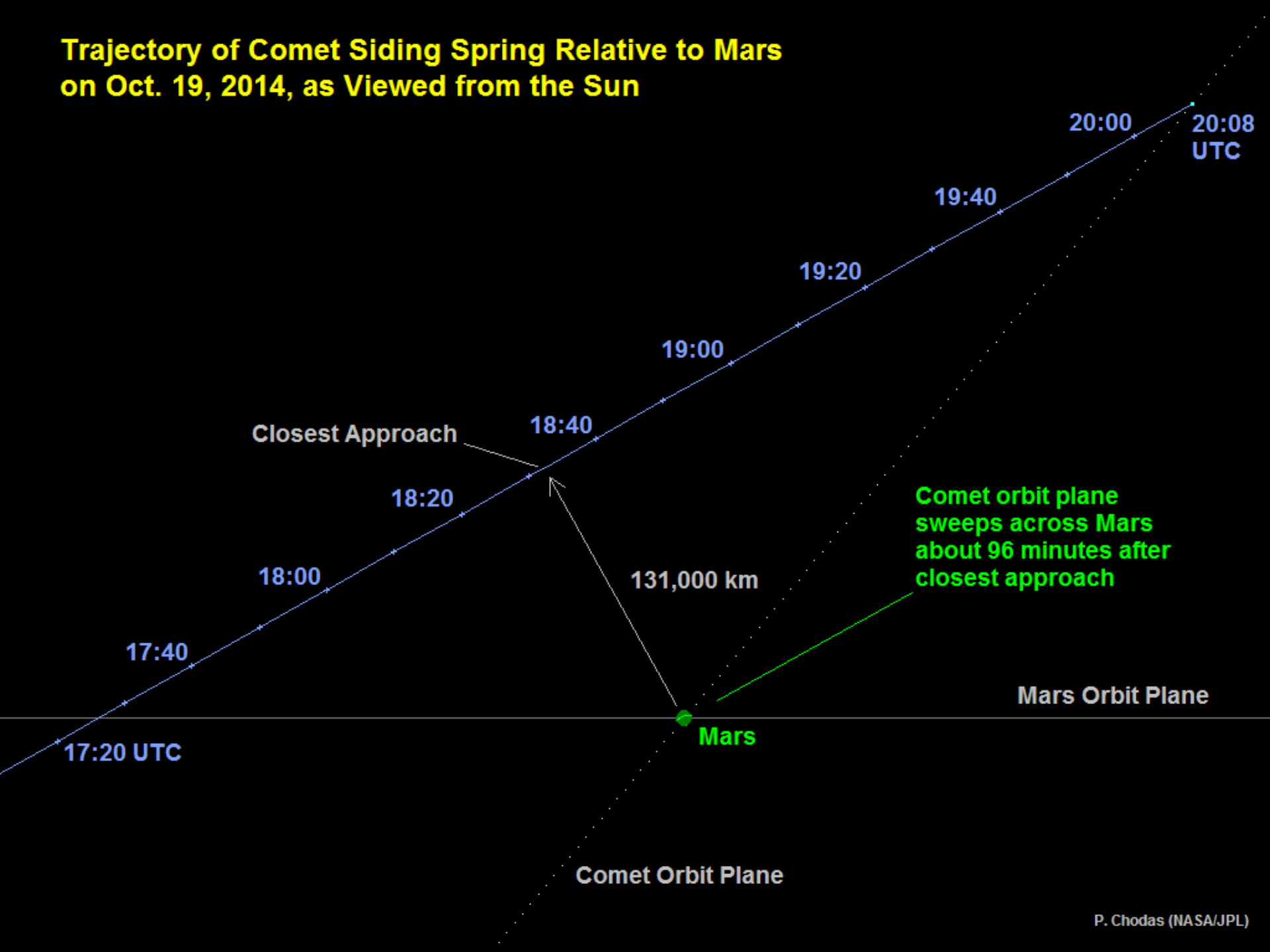


P. Chodas (NASA/JPL)

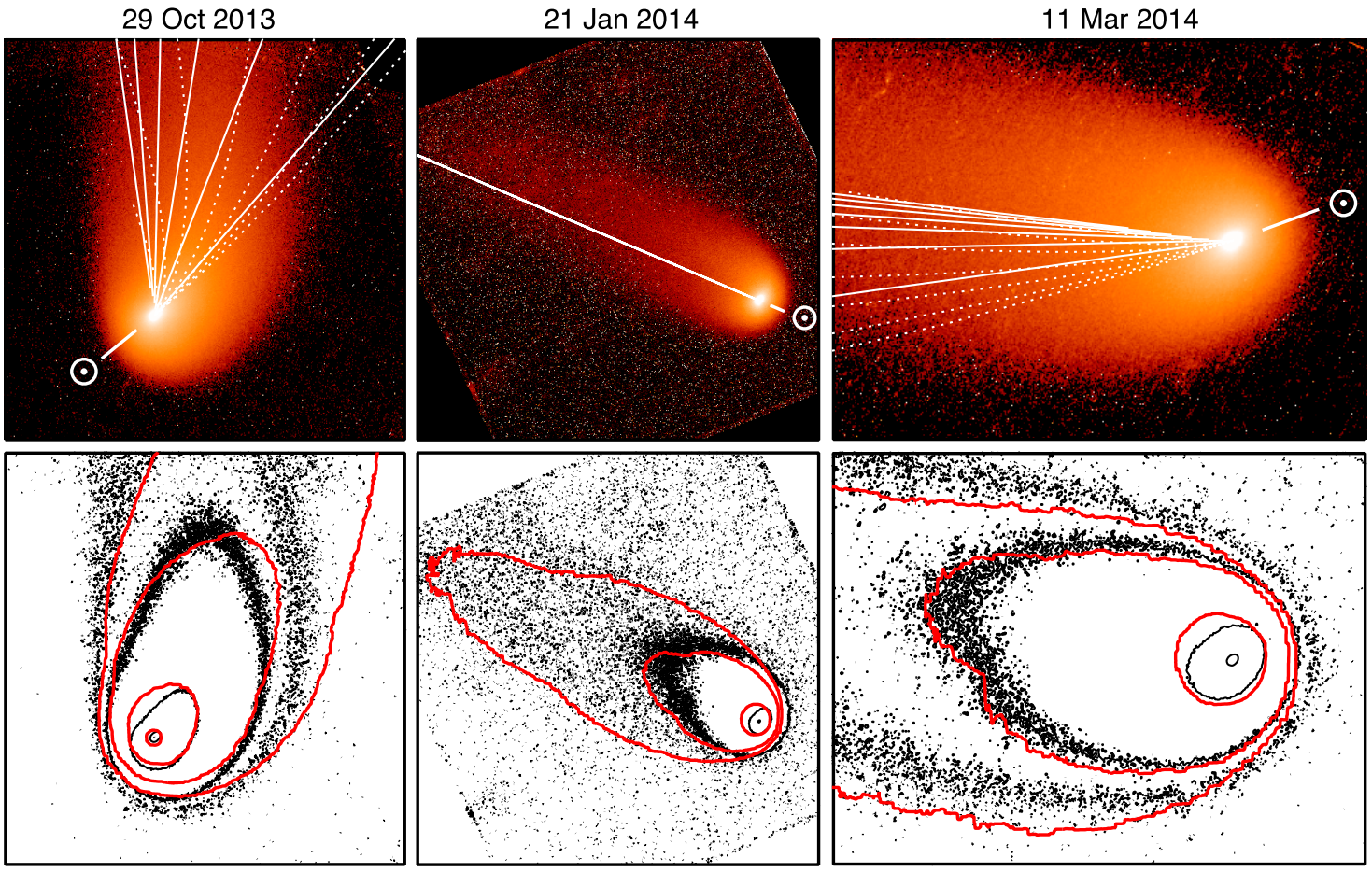
Orbit of Comet Siding Spring




Trajectory of Comet Siding Spring Relative to Mars
on Oct. 19, 2014, as Viewed from the Sun
Closest
Approach
18:32
18:20
18:00
17:40
17:20 UTC
131,000 km
Mars
Mars Orbit Plane
Comet Orbit Plane
P. Chodas (NASA/JPL)


Trajectory of Comet Siding Spring Relative to Mars
on Oct. 19, 2014, as Viewed from the Sun
20:00
20:08
UTC
19:40
19:20
19:00
18:40
Closest Approach
18:20
18:00
17:40
17:20 UTC
131,000 km
Comet orbit plane
sweeps across Mars
about 96 minutes after
closest approach
Mars Orbit Plane
Mars
Comet Orbit Plane
P. Chodas (NASA/JPL)

CSS Observed by HST



CSS Observed by NEOWISE

29 Jul 2014

Comet Siding Spring in the Close Approach B-Plane

Uncertainty traced with
1000 Monte Carlo points

Mars

To Sun

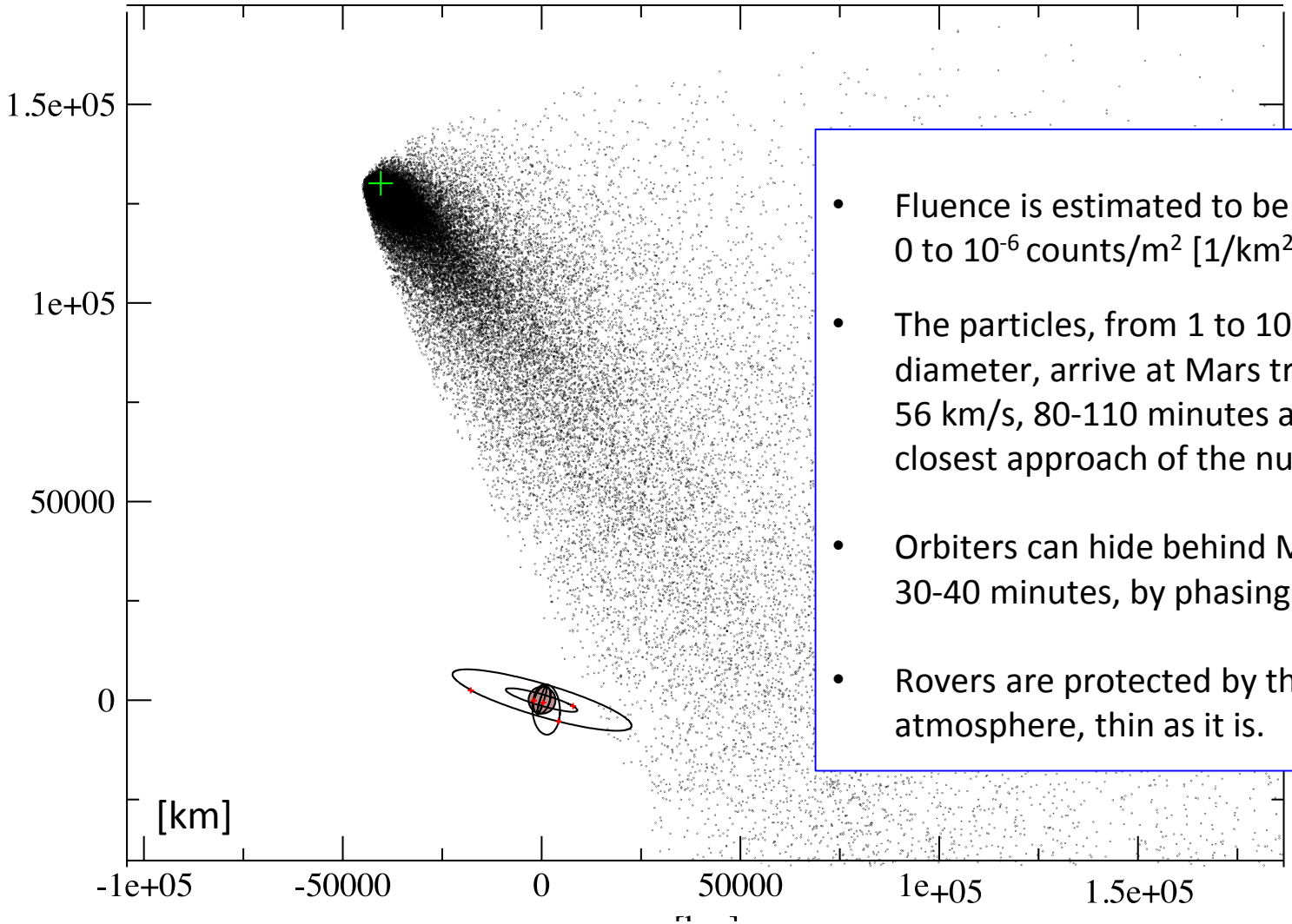
100000 km

P. Chodas (NASA/JPL) 7/17/14

Comet Modeling

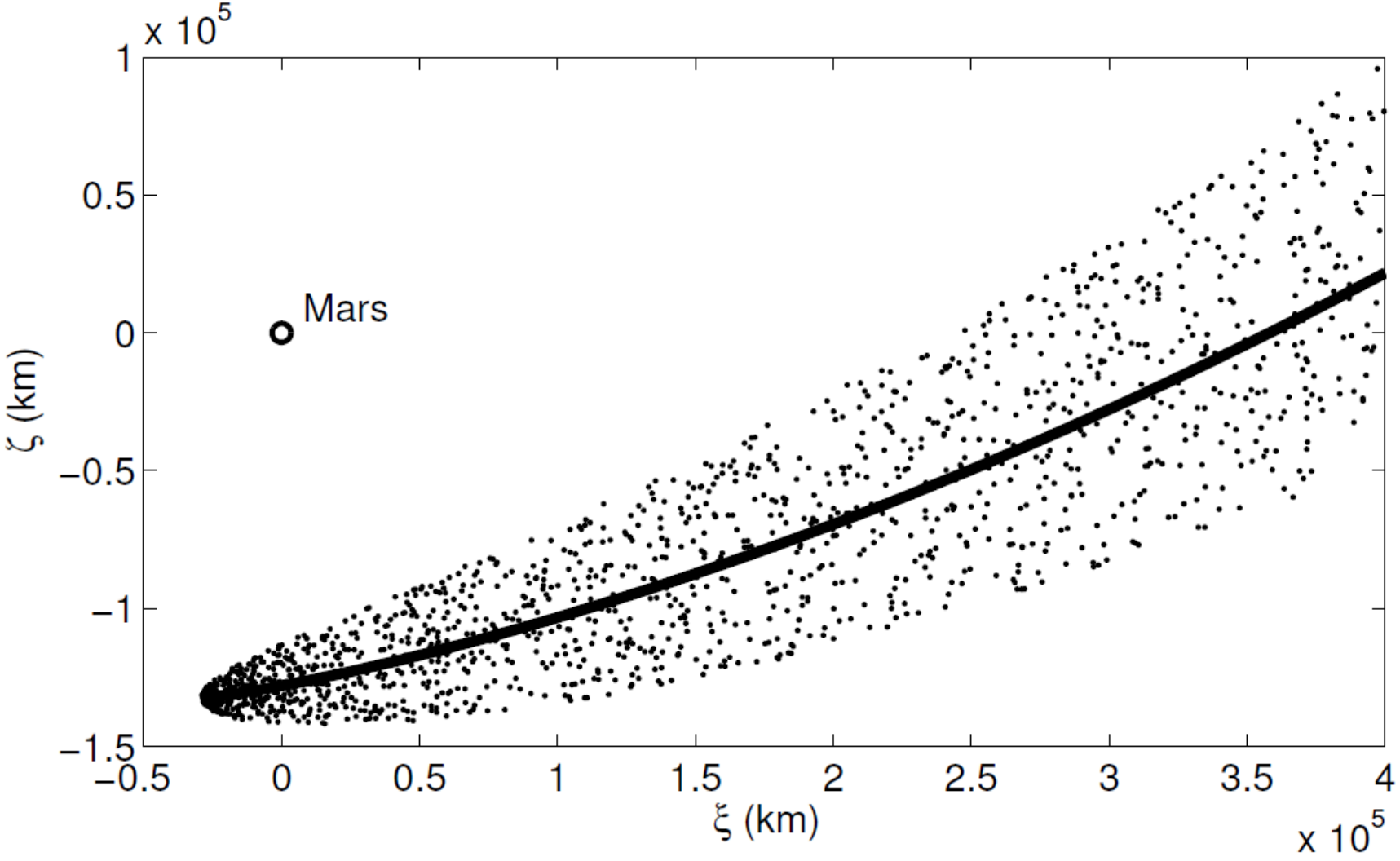
- **Model the comet-produced dust distribution as a function of time**
  - In fall of 2013, two modeling groups were selected through the MEP Critical Data Products program to help with this:
    - *Pasquale Tricarico, Nalin H. Samarasinha, Mark Sykes,* ***PSI***
    - *Tony Farnham, Mike S. P. Kelley, Dennis Bodewits,* ***U. Maryland***
  - Also participating, providing time-of-arrival of comet nucleus and debris:
    - *Davide Farnocchia, Paul Chodas, Steven Chesley,* ***JPL Solar System Dynamics Group***
  - Reports have been or will soon be submitted for publication
    - P. Tricarico et al., *Astrophysical Journal Letters*, 787, L35, 2014
    - Farnocchia et al., *in press*, *Astrophysical Journal*
    - Farnham et al., in preparation
  - Original reports and overview available on http://mepag.jpl.nasa.gov/cdp.cfm
- **Results of the modeling activity**
  - Modeling results were constrained using available observations of the comet.
  - Provided arrival timing & duration of the comet-associated particle flux at Mars.
  - Characterized the comet-derived particles in terms of size and number density.

Modeled Particle Field

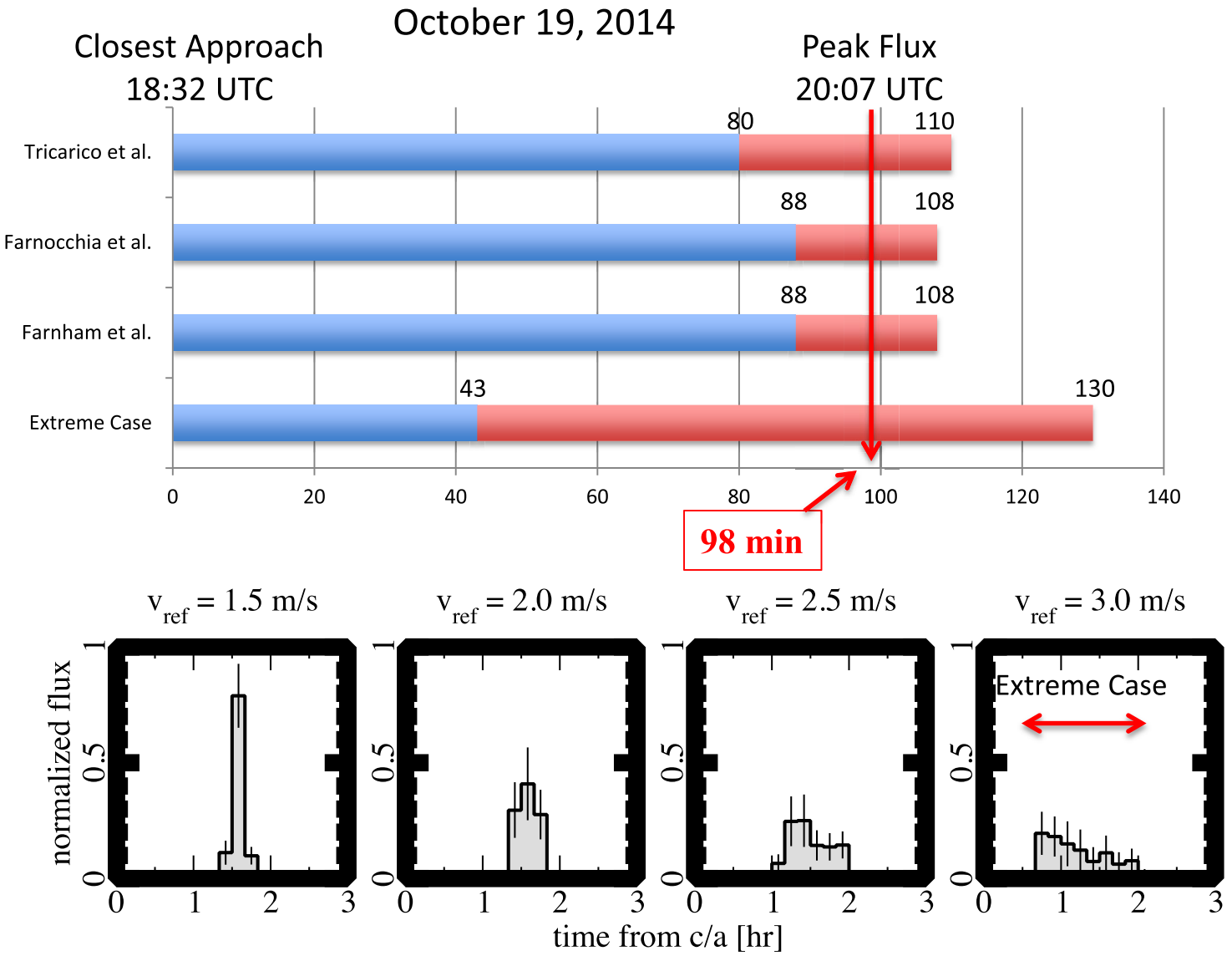


- Fluence is estimated to be in the 0 to 10^{-6} counts/m^2 [1/km^2] range
- The particles, from 1 to 10 mm in diameter, arrive at Mars travelling 56 km/s, 80-110 minutes after closest approach of the nucleus.
- Orbiters can hide behind Mars for 30-40 minutes, by phasing in orbit.
- Rovers are protected by the Mars atmosphere, thin as it is.

B-Plane footprint of Comet Tail

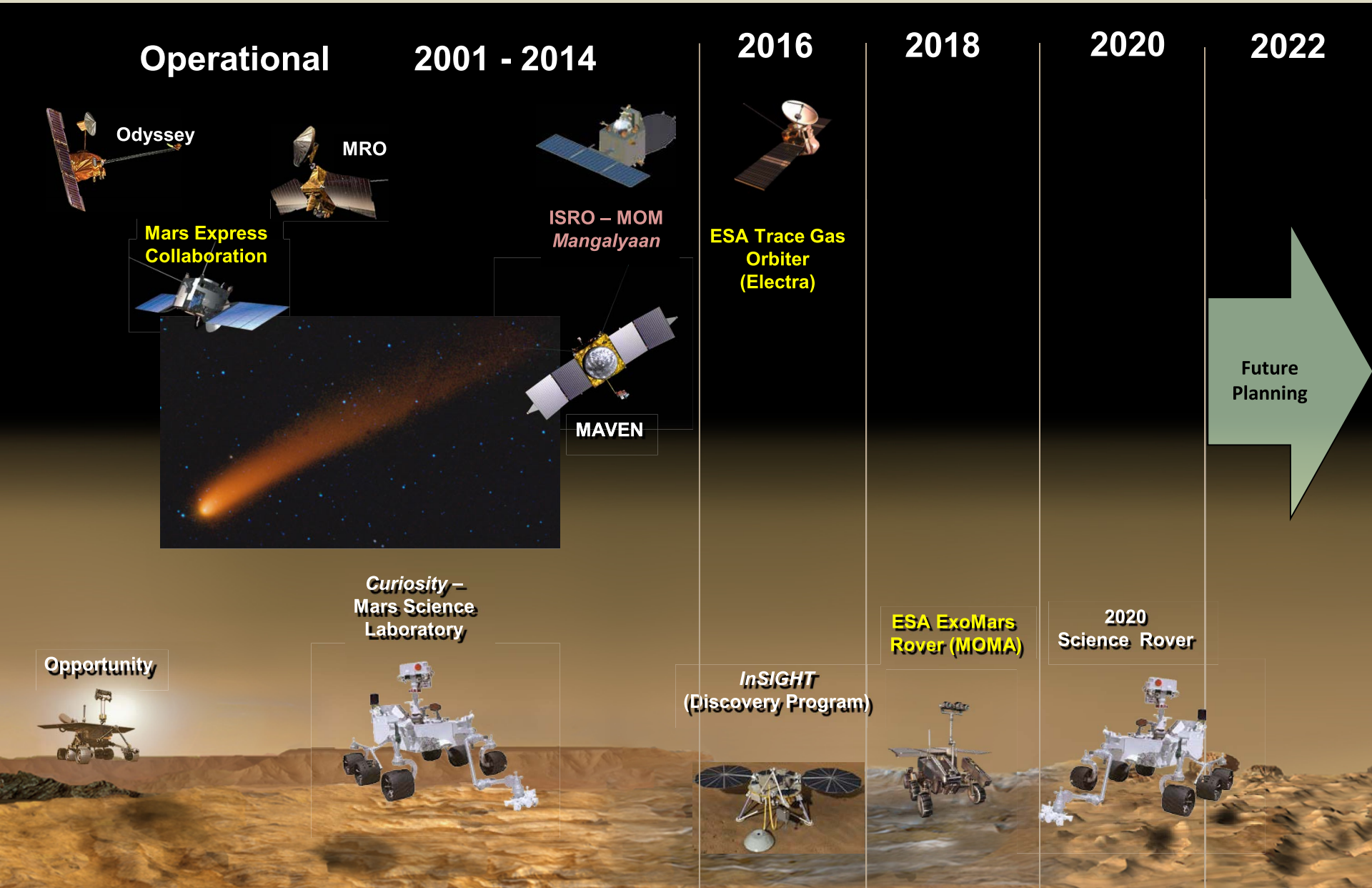


Time of Maximum Flux



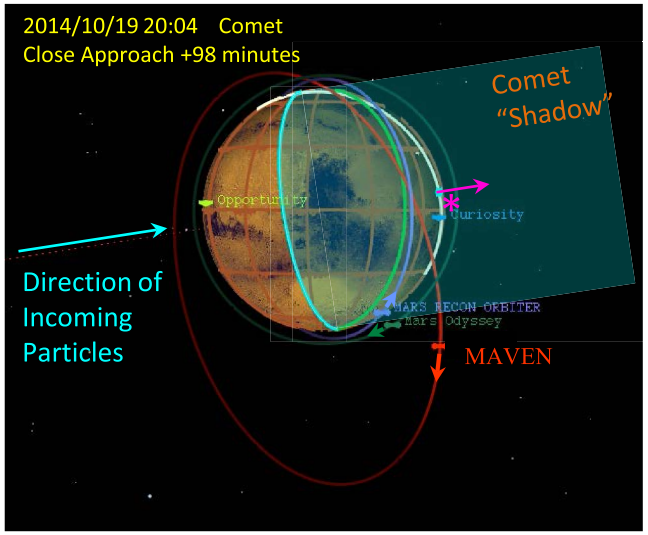
P. Tricarico et al., ApJL, 787, L35, 2014

Mars Exploration



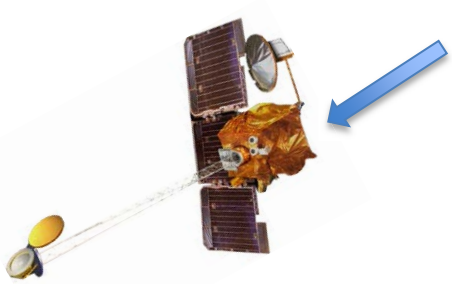
Protecting NASA Space Assets at Mars

- Curiosity and Opportunity are protected by Mars' Atmosphere
- MRO, Odyssey, and MAVEN plan to perform small trim maneuvers to hide behind Mars
  - Protects the orbiters from all likely particles
- **IF** the Comet becomes more active than expected, Orbiters have the option to present "best" attitudes to Comet Particle Flow (MAVEN plans this)
  - Each orbiter project found an attitude that balances particle impingement with;
    - Communication
    - Solar power generation
    - Science Observations
    - Thermal constraints

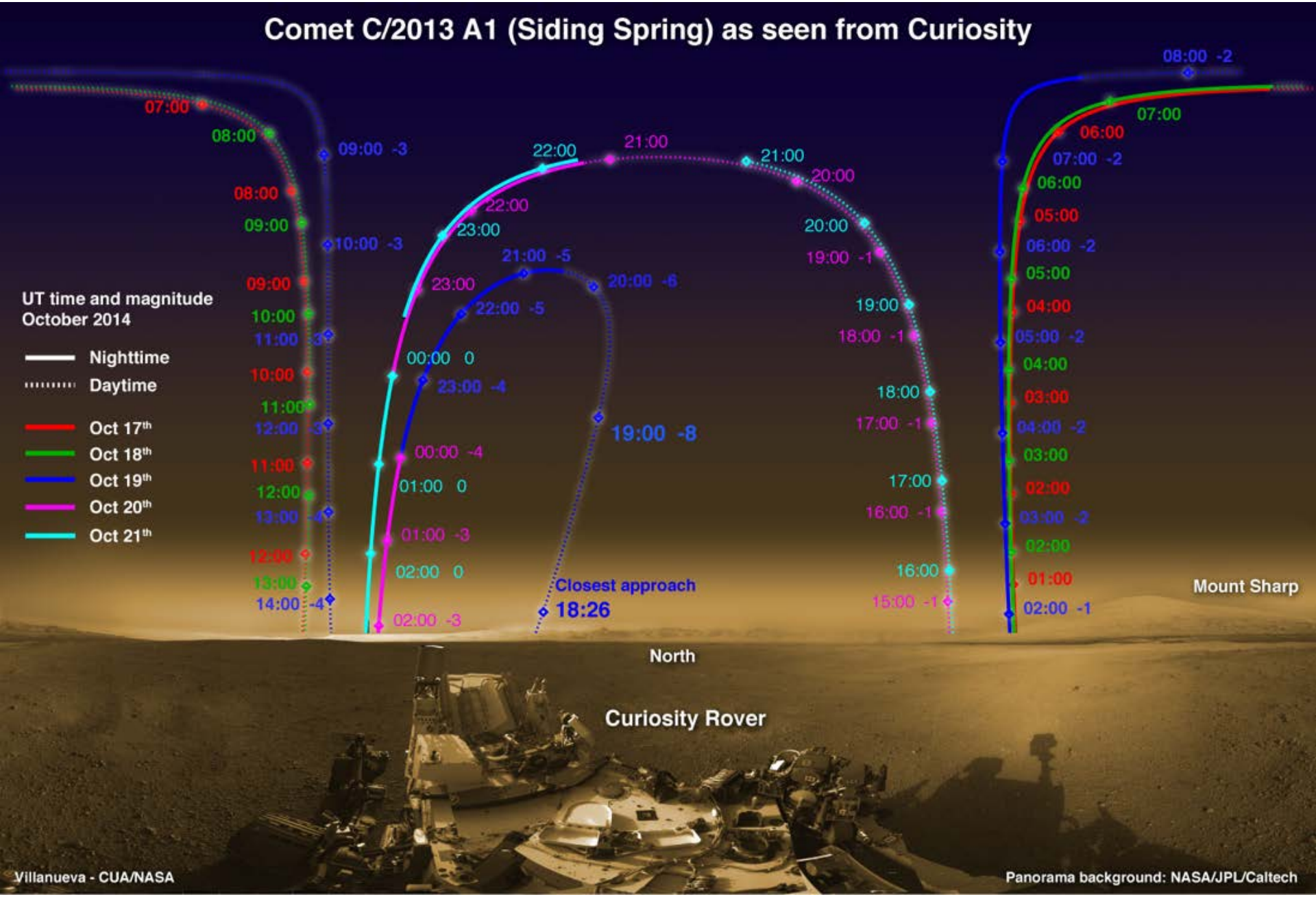


MAVEN

MRO

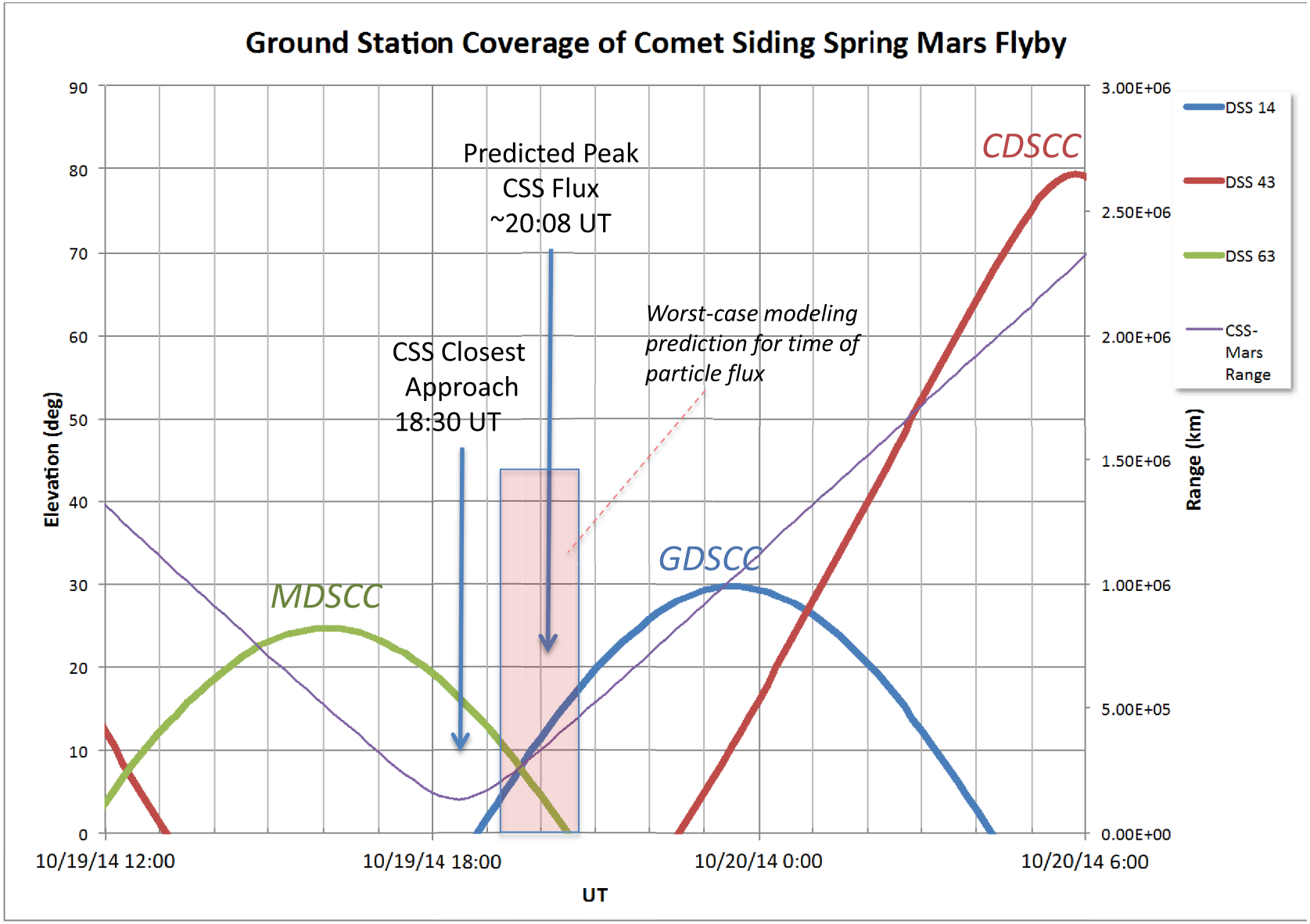


Odyssey

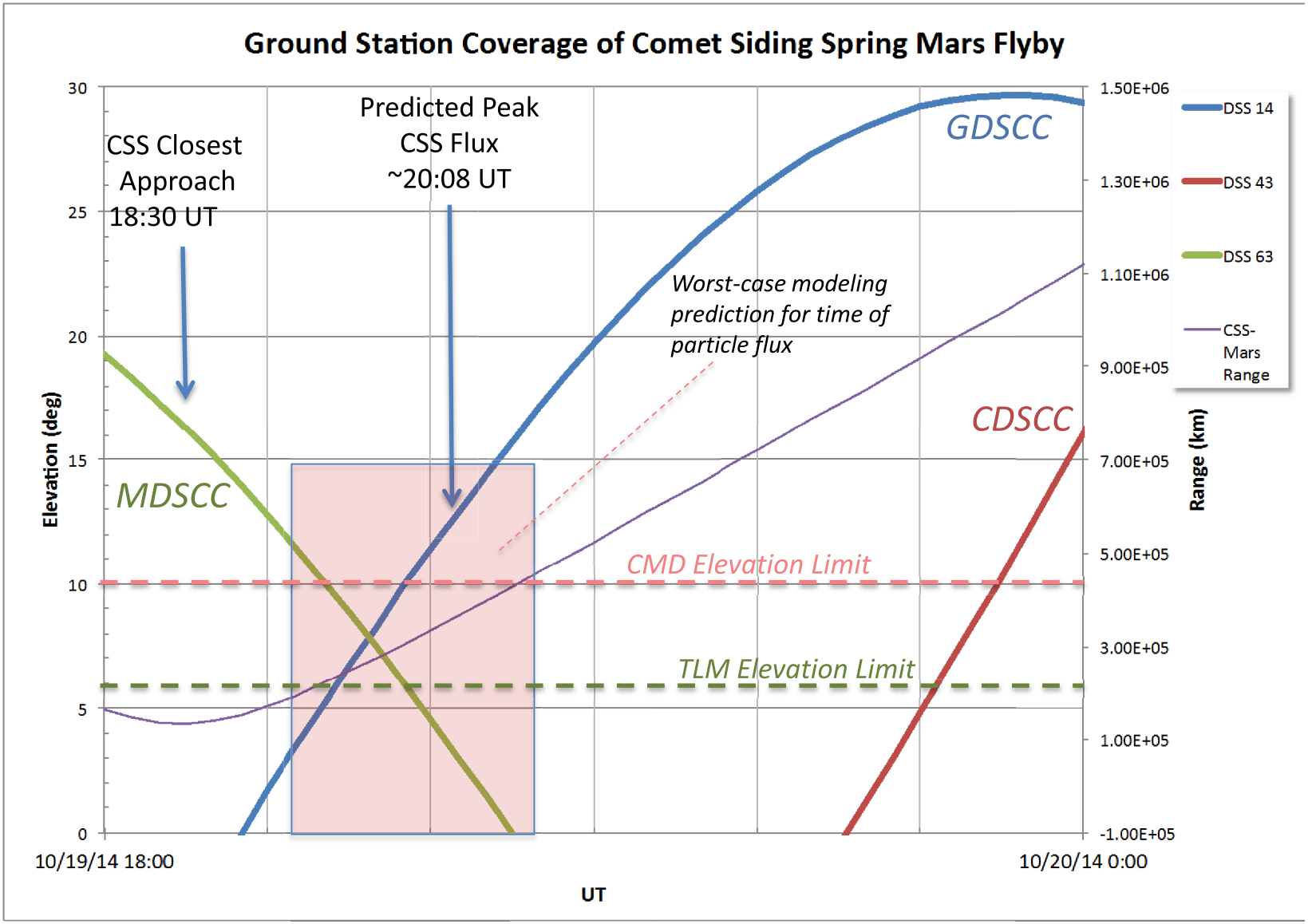

Comet C/2013 A1 (Siding Spring) as seen from Curiosity
UT time and magnitude
October 2014
Nighttime
Daytime
Oct 17th
Oct 18th
Oct 19th
Oct 20th
Oct 21st
Closest approach
18:26
Mount Sharp
North
Curiosity Rover
Villanueva - CUA/NASA
Panorama background: NASA/JPL/Caltech

DSN Communications Strategy

DSN Coverage



DSN Coverage (Madrid-Goldstone Handover)



Orbiter Communication Strategies

Orbiter	Nominal Attitude	Mitigation Attitude
ODY	HGA: 40 kbps	MGA: 40 bps
MRO	HGA: 3 Mbps	LGA: 40 bps
MAVEN	LGA: 100 bps	
MEX (ESA)	LGA: S-band Beacon	
MOM (ISRO)	HGA: 1 kbps	n/a

Planned DSN Configuration: GDSCC

DSS14

ODY X-band
MRO X-band

DSS25

MRO X-band
MVN X-band

DSS26

MVN X-band
ODY X-band

DSS15

MEX X-band
MEX S-band

DSS24

MOM S-band

Also:
- ODY X-band RSR
- MRO X-band RSR
- MOM S-band RSR
- MEX S-band RSR
- MVN X-band RSR

C/SS Encounter Goals for Mars Assets

- **Survive: Low fluence & orbit phasing take care of that**
- **Science Objectives Focus on Two Areas: 1) the comet itself and 2) its potential impact on the Mars atmosphere.**
- **For the comet, the goals are:**
  - First-ever resolution of the nucleus of a long-period comet.
    - MRO HiRISE: 140 m/pixel on a nucleus ~ 500 to 2500 m across
  - Characterize C/SS coma & tail: Particle size, gas composition, activity.
    - Warning: The Mars spacecraft instruments weren't designed for high-spectral resolution gas survey or for imaging diffuse, faint objects (as compared to Mars), but we will see what we can do.
    - The best instruments for comet composition may well be on MAVEN, which will follow orbit insertion on Sept. 21 with maneuvers and instrument deployments as they transition to their nominal science orbit.
- **For Mars, the goals are:**
  - Observe impacts of cometary gas & dust on the Mars atmosphere.
    - Upper Atmospheric heating (>150 km)
    - Ionospheric enhancement
    - Cloud seeding?

Science Observations* - *Preliminary*

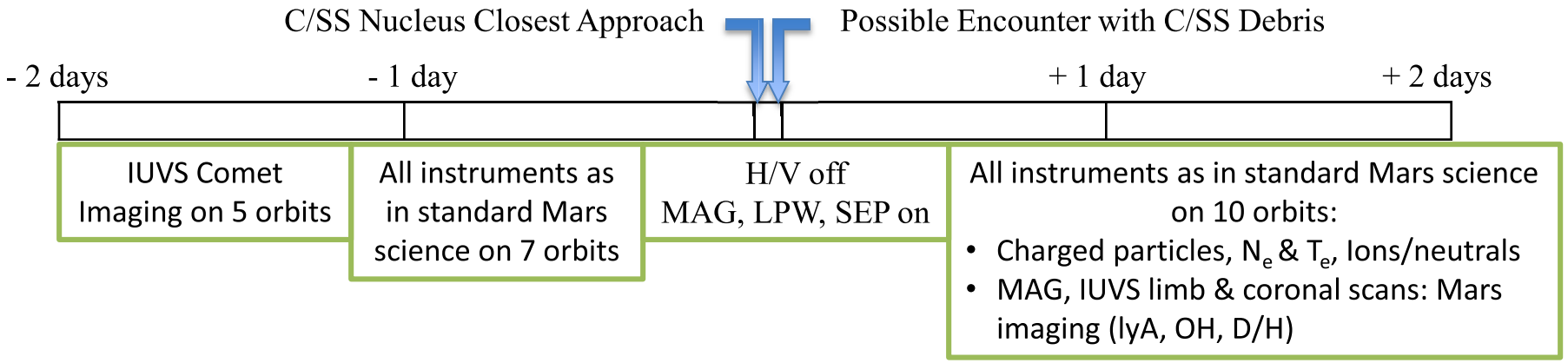
NASA Missions

Target	Observation Objective	MRO						ODY		ROVERS		MAVEN[1]		
		HiRISE	CTX	CRISM	MCS	MARCI	SHARAD	THEMIS VIS & IR	HEND/NS	PANCAM	MastCAM CHEMCAM?	IUVS	LPW,MAG, SEP	NGIMS,STATIC SWEA,SWIA
Comet	Comet General Features					❖		❖		◆	◆	◆	◆	
	Comet Nucleus: Size, Shape & Rotation	◆												
	Comet Activity: Jets & Variable Brightness	◆	◆	❖				❖				◆		
	Comet Coma: Variability, particle size, gas composition	◆	❖	◆	◆	◆		◆				◆		
	Comet Tail: Particle Size		◆	❖	❖	❖		❖				◆	◆	
Mars Response	Mars Upper Atmosphere Composition: Neutrals, ions & electrons; meteor trails						❖		❖	◆	◆	◆	◆	◆
	Mars Lower Atmosphere: Temperature and Clouds			❖		❖		❖		❖	❖	❖		

Key: major contribution ◆ contribution ❖

[1]*Conducted only if transition to science orbit is nominal*

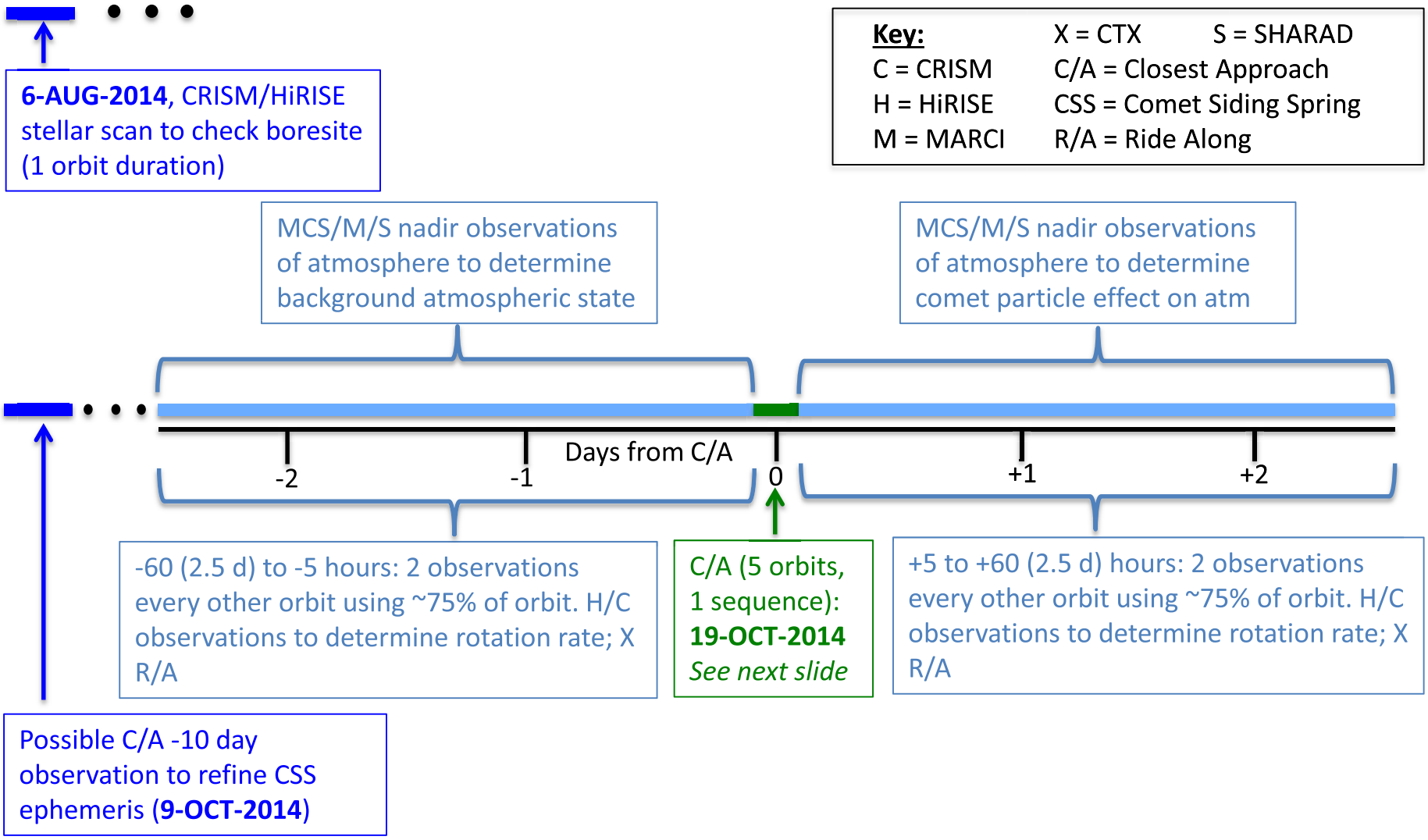
Science Observations* - *MAVEN*



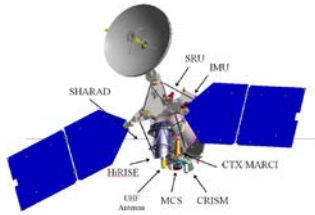
MAVEN Example

- Science operations begin 2 days early to observe Mars, interrupted for safety during peak dust time, resume for 2 days post encounter, then resume nominal transition plan.
- Pre-encounter imaging to determine activity level, composition, gas/dust, etc. Also view Mars as baseline for post-encounter effects.
- Spacecraft in safe configuration during close encounter and dust tail passage, implies safest attitude and instrument High Voltage (H/V) off.
- Periapsis of 4.5 hr orbit is behind Mars at predicted time of peak dust flux.

C/SS Observations by MRO



Science Observations* - *MRO*



C/SS Nucleus Closest Approach

Possible Encounter with C/SS Debris

- 2 days | - 1 day | + 1 day | + 2 days

Periodic C/SS Observations each 2hr orbit	C/A	Periodic C/SS Observations on each 2hr orbit

MRO Example

Center time for C/SS particle encounter with Mars: 20:07 ± 10 min UT

C/SS C/A 18:31 UT

16:38:26 | 17:39:30 | 18:12:16 | 19:01:52 | 19:43:51 | 20:46:49

C/A – 1 orbit:
2 CRISM + 13 HiRISE scans
Various line times to provide different exposures; CTX R/A

C/A orbit:
2 CRISM + 10 HiRISE scans + CTX R/A
Shortest line times for best resolution; MCS obs of coma (TBD)

C/A + 1 orbit:
2 CRISM + 13 HiRISE scans
Various line times to provide different exposures, CTX R/A

Key: C/A = Closest Approach; R/A = Ride-Along

Nadir observations

C/SS observations

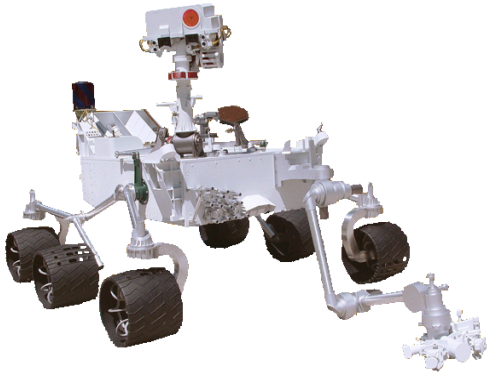
Science Observations* - *Mars ODY*

- **Objective**:
  - Emphasis on the unique contributions to be made by THEMIS: moderate resolution infrared spectral imaging.
- **THEMIS: 3 proposed, prioritized observations:**
  - Obtain highest possible spatial resolution images over as much of the coma as possible during one observing period (±26 hr?).
    - Image coma as close to closest approach to Mars as possible.
  - Obtain complete coverage of the coma and tail at moderate spatial resolution.
  - Obtain an *image of the entire coma and tail above the Mars limb* to provide context of the coma relative to the known temperature and gas and dust opacity of the Mars atmosphere.
- **Neutron Spectrometer and HEND:**
  - Nominal observations while in nadir-point attitude to monitor effects on neutral and charged particle fluxes.

Science Observations* - *Opportunity & Curiosity*

- When the comet is at closest approach, the local times at Opportunity and Curiosity will be early morning and late afternoon, respectively, so the comet would be viewed thru the dayside sky.
  - It is also mid-southern spring, a time when extensive dust storms may occur, further reducing visibility.

- Best viewing will be pre-dawn and post-dusk on the encounter sol, but several hours before and after closest approach.



Preparations

- **Phasing Maneuvers**
  - July 2 MRO 1st of 2 phasing maneuvers (OTM 37)
  - August 5 ODY phasing maneuver, if required
  - August 27 MRO 2nd of 2 phasing maneuvers (OTM 38)
  - October 9 MAVEN will combine with 3rd period reduction maneuver (PRM-3) during transition to science orbit
- **Get Comet Encounter Observation Sequences finalized**
- **Interactions with Comet Science Community**
  - Ongoing: Participation in Coordinated Investigations of Comets (CIOC) forum
  - August 11: Workshop involving Mars Projects and other Comet Observers
    - Give status on Mars spacecraft comet observing plans; seek comment from community.
    - Review latest observations and observation plans.
  - September 19: Virtual Meeting between Mars Projects and Comet Scientists
    - Give status on final science observing plans by Mars Projects.
    - Review latest observations.
- **September 19: Provide update on mitigation status and observation planning**
- **October 19: Closest Approach of Comet Siding Spring to Mars**
  - *Prime observing campaign ±2.5 days around nucleus closest approach*

Back-Up