Investigating the physical properties of the outburst of comet 67P/C-G

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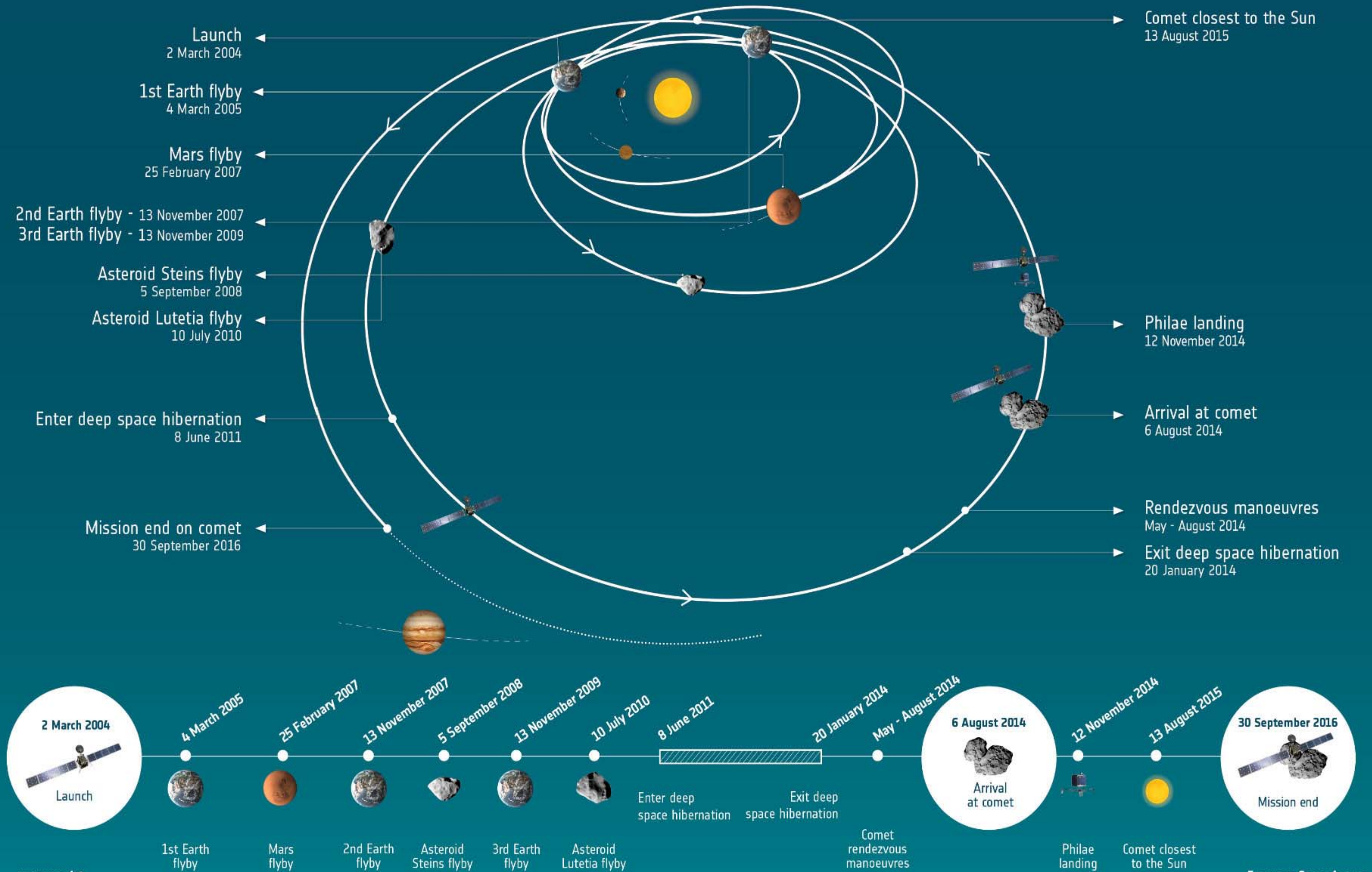
OSIRIS team

→ ROSETTA'S JOURNEY 2004–16



www.esa.int

European Space Agency

Comet 67P

Period ~ 6.45 yrs
$M = 3 \times 10^{12}$ kg
T = 12.4 hrs

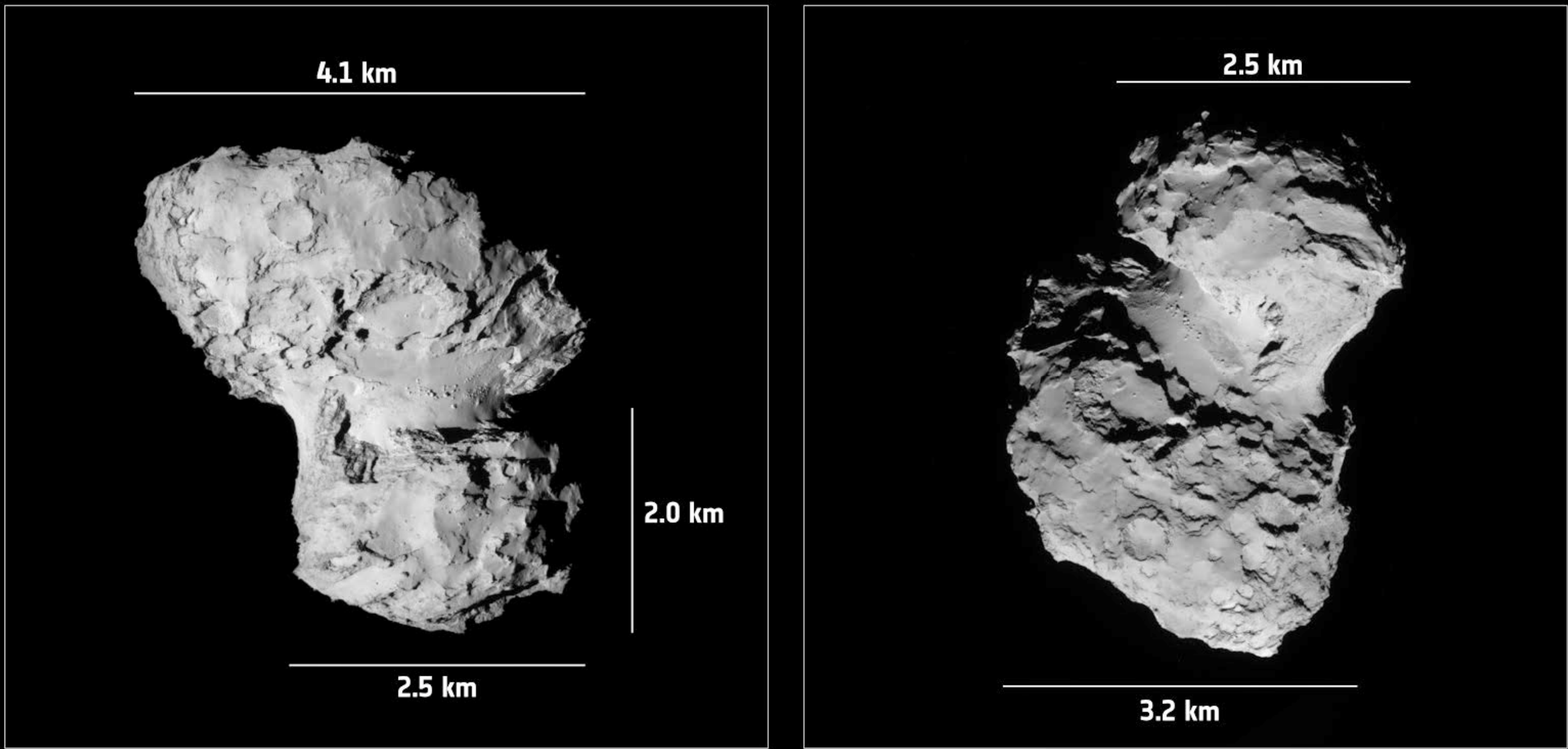


Image: ESA/Rosetta/NAVCAM; Dimensions: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

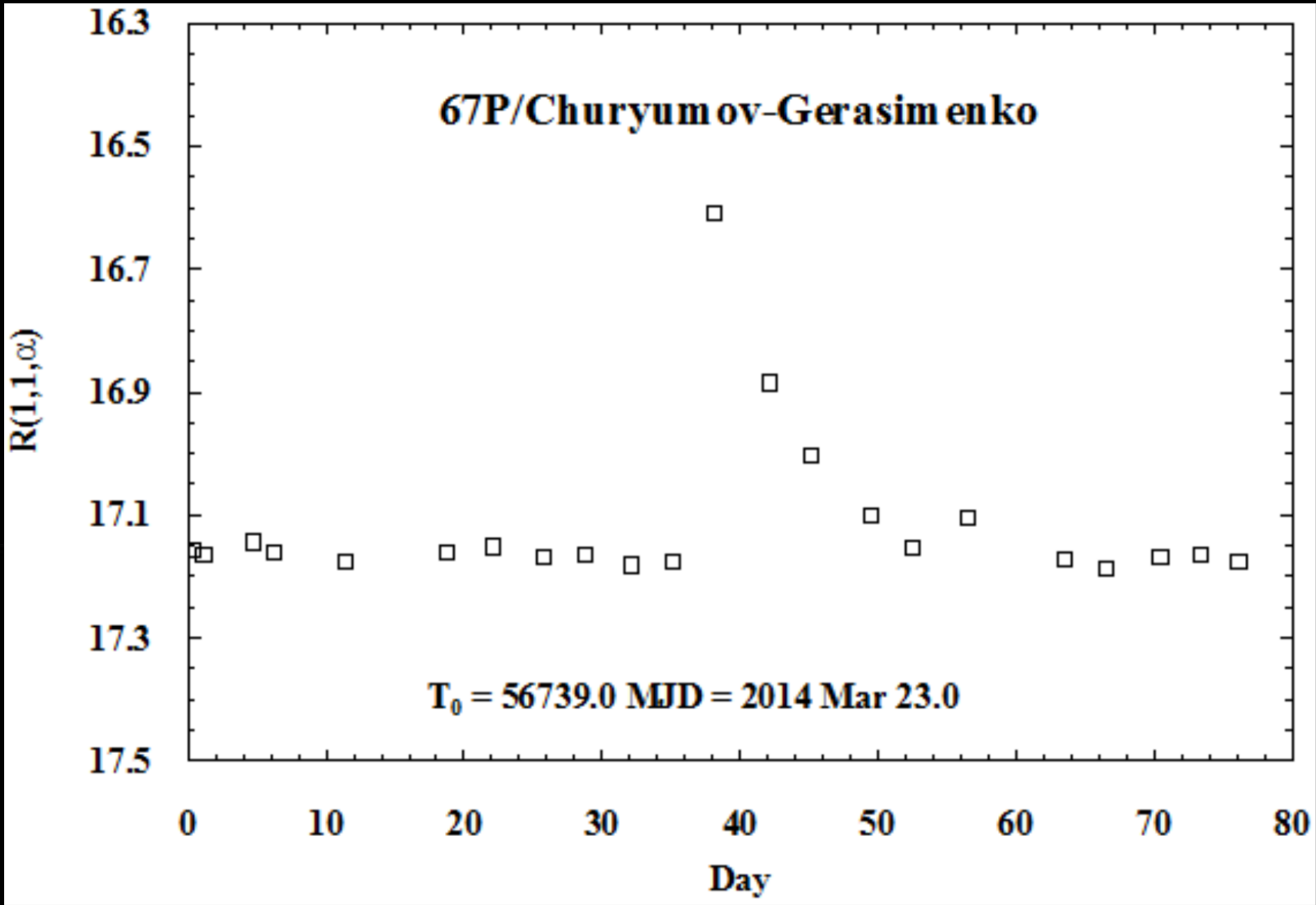
ESA/Rosetta/MPS for OSIRIS Team

Rosetta's target comet is becoming active!?

Credit: ESA © 2014 MPS for OSIRIS-Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

First outburst detected by OSIRIS

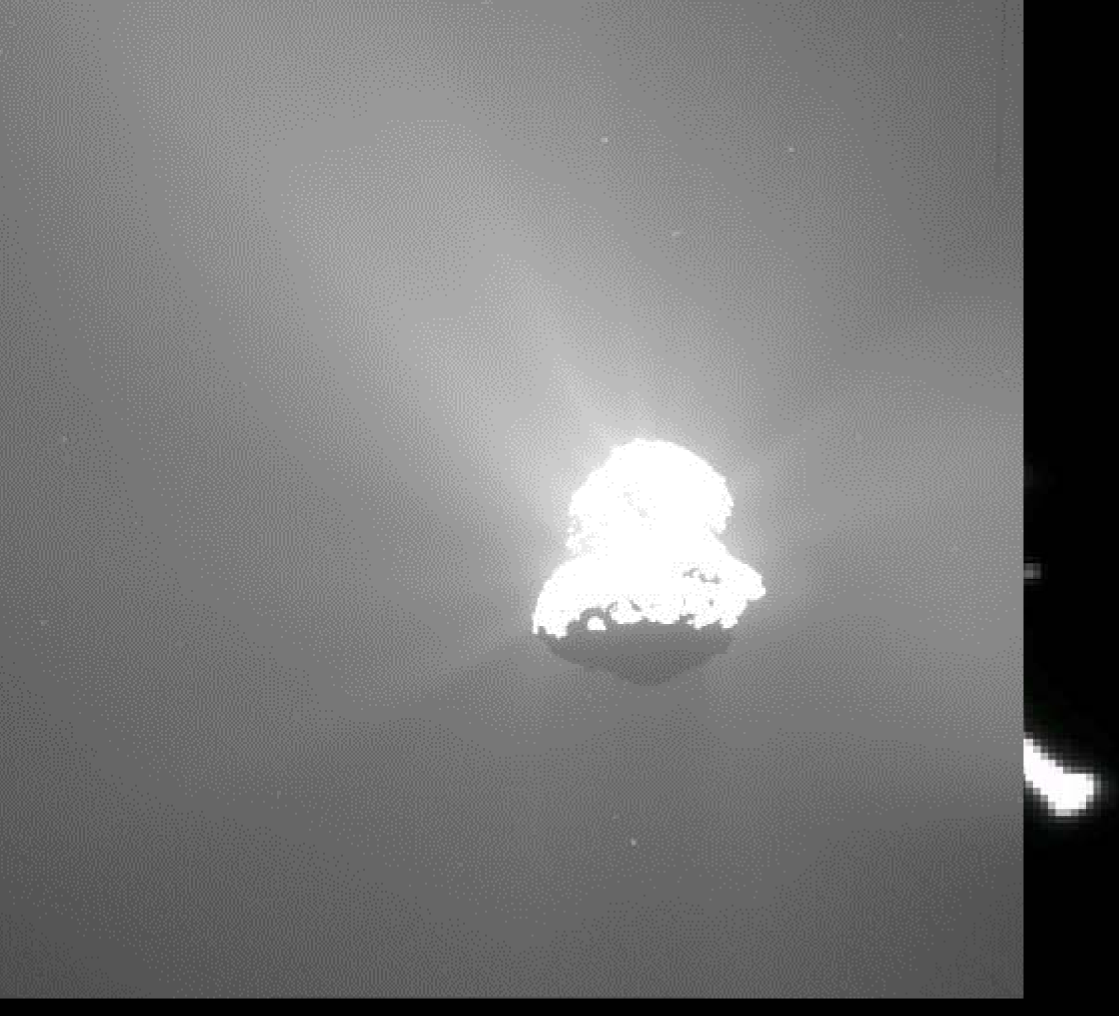
C. Tubiana et al. 2015



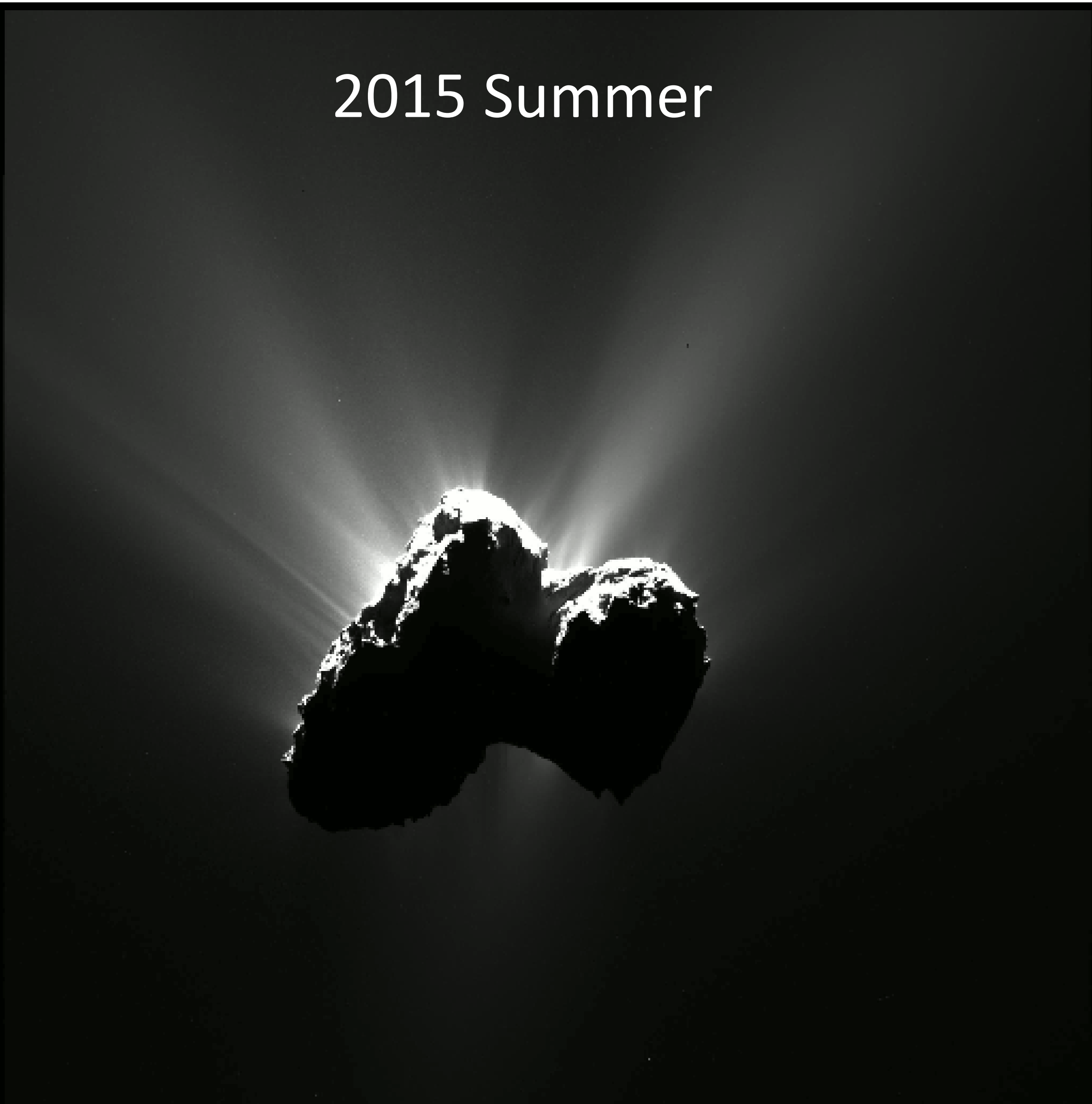
ESA © 2014 MPS for OSIRIS-Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

Mini-outburst from Imhotep in March 2015

J. Knollenberg & Lin et al. 2016



Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

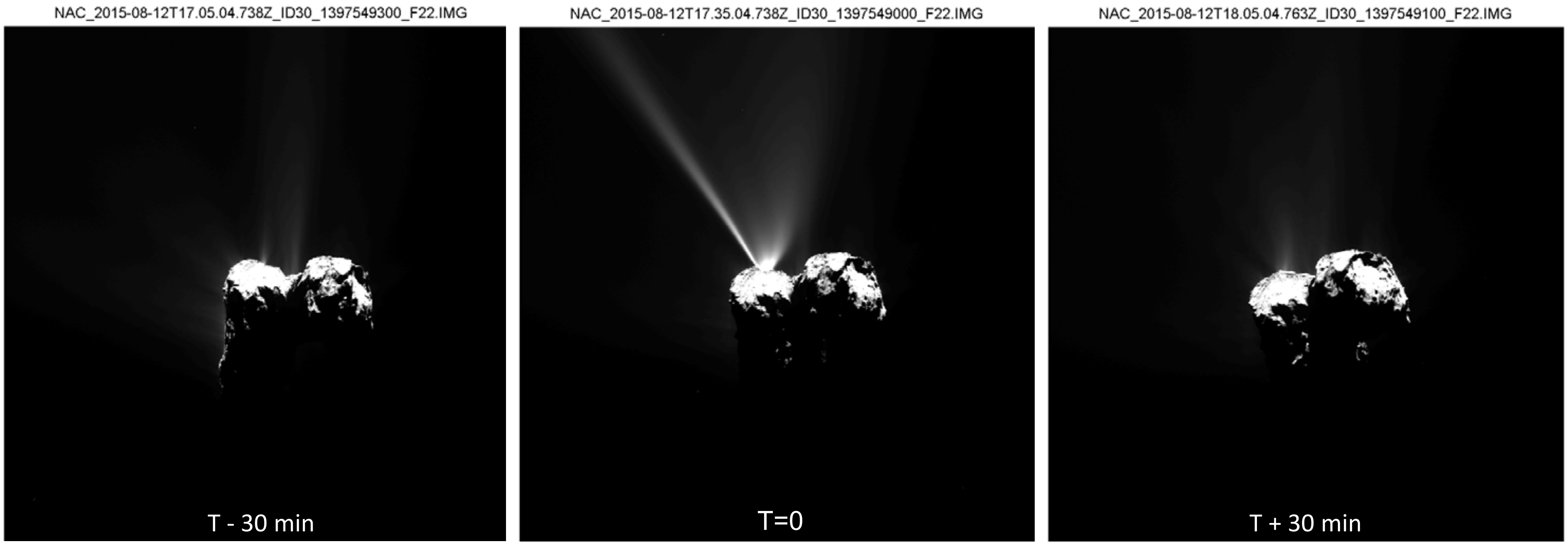

2015 Summer

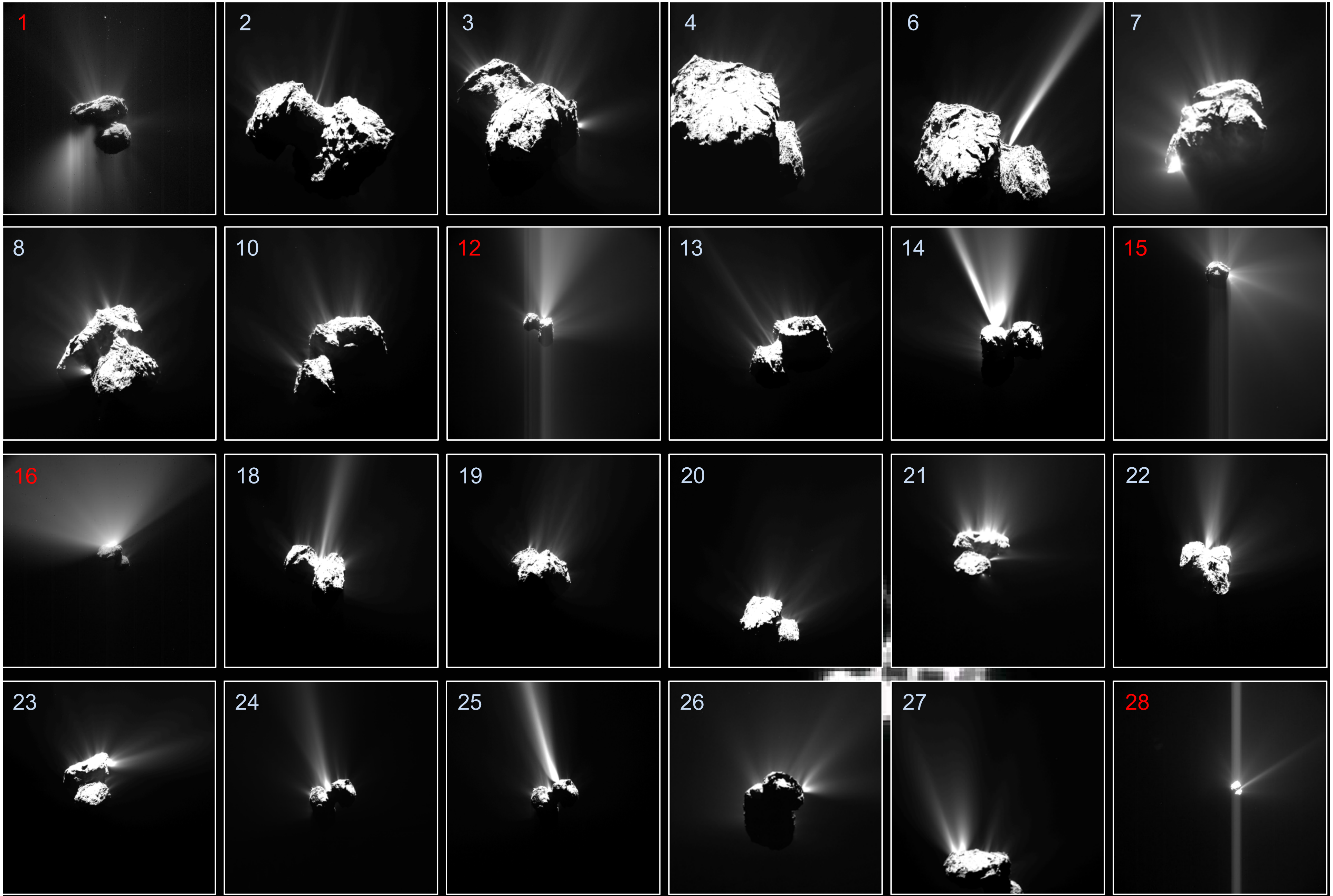
Outbursts Vincent et al 2016

"Outburst":

- transient release of gas and dust
- duration significantly shorter than typical diurnal variations of activity (i.e. a jet can usually be tracked over several hours, an outburst not
- brighter than other features, sometimes brighter than nucleus

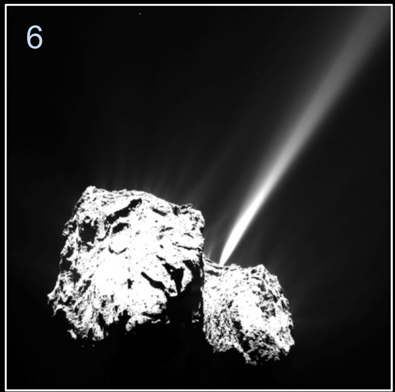
OSIRIS + Navcam have recorded 34 (29+5) transient events from 10 July to 26 September 2015





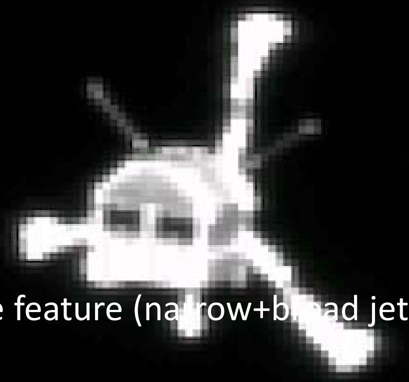
Subset of the brightest NAC and NavCam outbursts

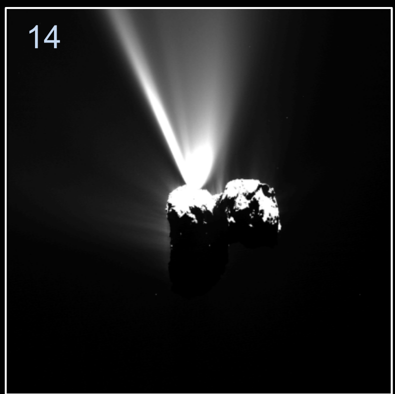
Different types Vincent et al 2016



- Type A: Strong, collimated jets brighter than nucleus, usually dayside
- e.g. 19/07, 29/07, 09/08, 23/08, …

- Type B: Broad fans, shorter in length but as bright as the narrow jets associated to type A outbursts
- e.g. 26/07, 01/08, 26/08, 28/08…





- Type C: Complex outbursts with double feature (narrow+broad jets)
- e.g. 12/08, 28/08, 05/09, …

We see at least 3 morphologies, but they may all be different states of the same physical process. This classification is purely observational.

Transient events from 29 July to 30 Sep. 2015

(pairs of consecutive images + sequences)

~29 events

Start time (UT)	r_h (AU)	SC distance* (km)	pixel scales (m/pixel)	phase angle** (degree)
Difference images				
2015-07-29 13.24.10.76	1.2561033	186.299	3.42	89.8849
2015-08-05 07.10.32.077	1.2469707	253.369	4.67	89.5959
2015-08-05 08.03.57.736	1.2469355	253.263	4.67	896098
2015-08-12 17.20.36.436	1.2432693	331.92	6.13	89.4620
2015-08-16 22.53.06.769	1.2441791	329.730	6.09	89.2077
2015-08-26 08.19.55.322	1.2539818	417.171	7.72	83.6198
2015-08-27 03.12.06.804	1.2552807	403.175	7.46	79.7127
2015-08-28 10.09.51.784	1.2575693	410.290	7.59	73.5676
2015-09-0317.57.22.781	1.2715593	379.504	7.02	86.7103
2015-09-0318.02.22.782	1.2715682	379.577	7.02	86.7482
2015-09-0318.07.22.801	1.2715772	379.651	7.02	86.7859
2015-09-0318.12.22.782	1.2715861	379.726	7.02	86.8237
2015-09-03 18.17.22.812	1.2715950	379.802	7.02	86.8614
2015-09-0318.22.22.799	1.2716039	379.879	7.02	86.8991
2015-09-03 18.27.22.764	1.2716129	379.955	7.03	86.9367
2015-09-03 18.32.22.856	1.2716218	380.035	7.03	86.9744
2015-09-03 18.37.22.857	1.2716307	380.113	7.03	87.0123
2015-09-03 18.42.22.814	1.2716396	380.193	7.03	87.0499
2015-09-03 18.47.22.797	1.2716486	380.273	7.03	87.0875
2015-09-03 18.51.32.792	1.2716560	380.341	7.03	87.1188
2015-09-03 18.22.22.799	1.2716039	379.879	7.02	86.8991
2015-09-05 08.23.55.782	1.2758057	437.494	8.10	99.9797
2015-09-05 08.58.43.857	1.2758816	435.401	8.06	100.08810
2015-09-08 22.40.38.846	1.2863748	336.620	6.22	118.27780
2015-09-10 20.51.22.797	1.2925862	317.807	5.87	119.99520
2015-09-10 21.11.12.538	1.2926324	317.873	5.87	119.99040
2015-09-12 09.41.53.733	1.2978142	329.892	6.09	116.56220
2015-09-12 09.46.53.760	1.2978263	329.819	6.09	116.53830
2015-09-12 09.51.53.715	1.2978384	329.746	6.09	116.51460
2015-09-12 09.56.53.734	1.2978505	329.673	6.09	116.49070
2015-09-23 21.59.37.739	1.3442340	402.277	7.44	71.8011
2015-09-24 22.56.47.769	1.3490112	545.744	10.11	59.6096
2015-09-24 23.31.46.762	1.3491240	549.625	10.18	59.4261
2015-09-25 04.18.13.134	1.3500487	581.974	10.78	58.0488
2015-09-25 05.48.13.288	1.3503399	592.337	10.98	57.6587
2015-09-25 09.09.39.809	1.3509930	615.833	11.41	56.8516
2015-09-25 09.14.38.751	1.3510091	616.419	11.42	56.8326
2015-09-25 09.54.38.764	1.3511390	621.134	11.51	56.6830
2015-09-25 10.39.39.757	1.3512852	626.457	11.61	56.5184
2015-09-25 10.54.38.831	1.3513339	628.232	11.64	56.4644
2015-09-27 11.59.58.773	1.3610773	1006.08	18.67	51.1338
2015-09-30 11.36.45.774	1.3758860	1456.54	27.05	50.2459
2015-09-30 21.34.37.765	1.3780003	1399.90	26.00	50.4653
2015-09-30 23.29.55.513	1.37839	1389.01	25.79	50.5092

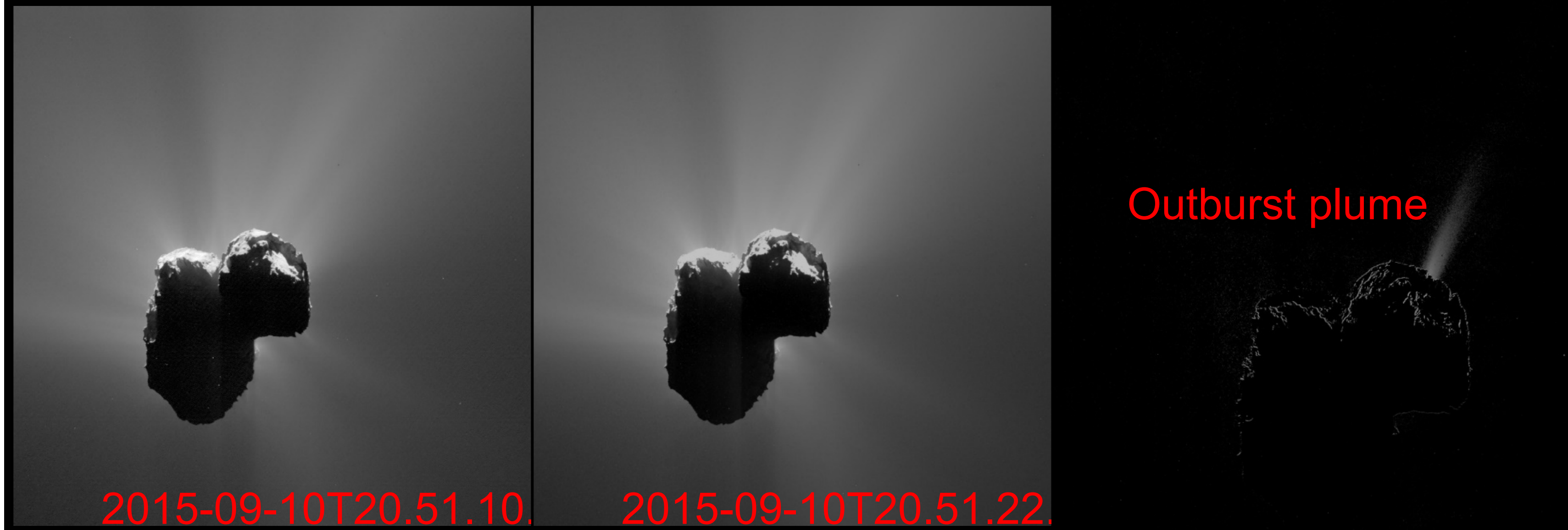
~4 sequences

Time span of used sequences				
2015-08-12 (WAC, UV375) 07.01 20.20	1.24330 1.24326	338.898 329.475	34.00 33.05	89.7335 89.3681
2015-08-22 08-23 (WAC, UV375) 21.46 02.11	1.24916 1.24938	333.872 334.503	133.96 134.24	88.5106 88.2005
2015-09-03 (WAC, UV375) 17.37 18.51	1.27152 1.27166	379.214 380.338	76.14 76.38	86.5581 87.1176
2015-09-12 (NAC, ORANGE) 22.30 23.25	1.29969 1.29982	320.395 319.853	5.92 5.91	112.76830 112.487

Outburst from Comet 67P/C-G July 29, 2015

ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Outburst from Comet 67P/C-G Sep. 10, 2015

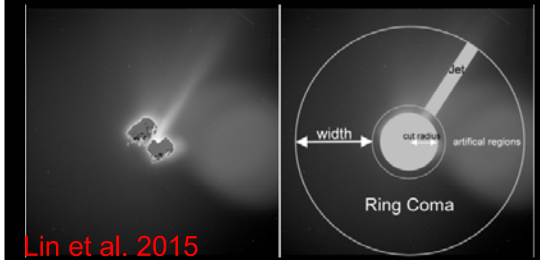


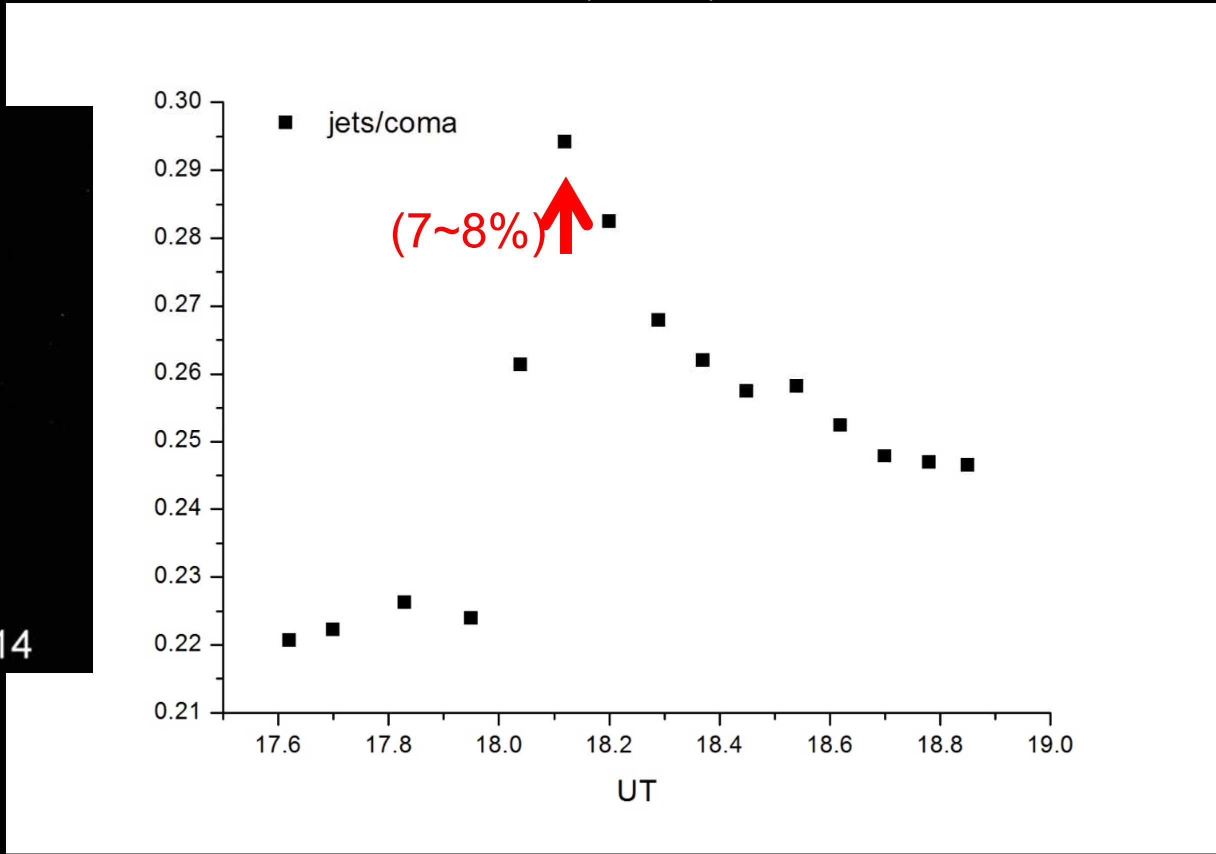
Brightness variation

(4 sequences)

MTP020P- STP072_OUTBURST_004

2015-09-03 (18:02-22)

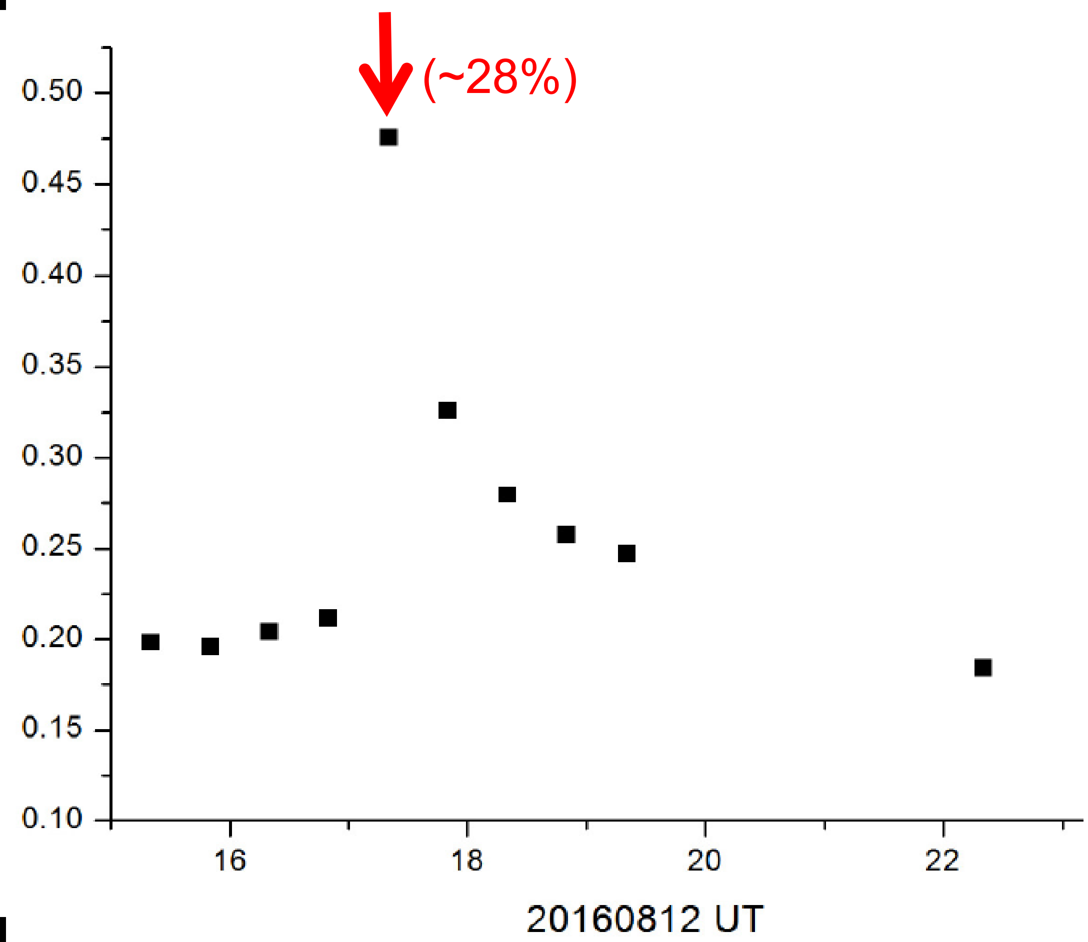




10.13.43.674 (F14) 10.14.17.915 (F13) 10.14.49.428 (F41)

MTP019P-STP069_COLOR_MAP_003

2015-08-12



Brightness slopes

Radial Surface Brightness Profiles in Cometary Dust Coma

A spherically symmetric, steady-state coma

number density ~ inverse square law

$$N_1(r) = \frac{1}{4 \pi r^2 v_{gr}} \frac{dN}{dt}$$

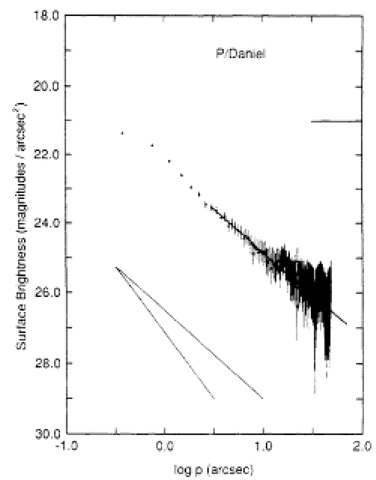
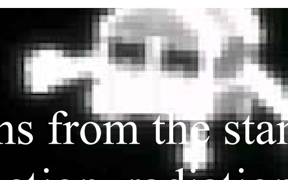


Figure 6. Surface brightness profile of P/Daniel. The gradient of the profile is consistent with m = -1. The straight lines indicate m = -1 and m = -1.5. The line through the data has m = -1. Figure from Jewitt and Meech (1987a).

Surface brightness profile (a constant slope of -1)

a nucleus producing a steady-state dust outflow



Differences from this value are said to indicate variations from the standard model, which can be caused by temporal changes in dust production, radiation pressure, or alteration of the physical characteristics of the grains (fragmentation, sublimation, changes in optical properties, etc.).

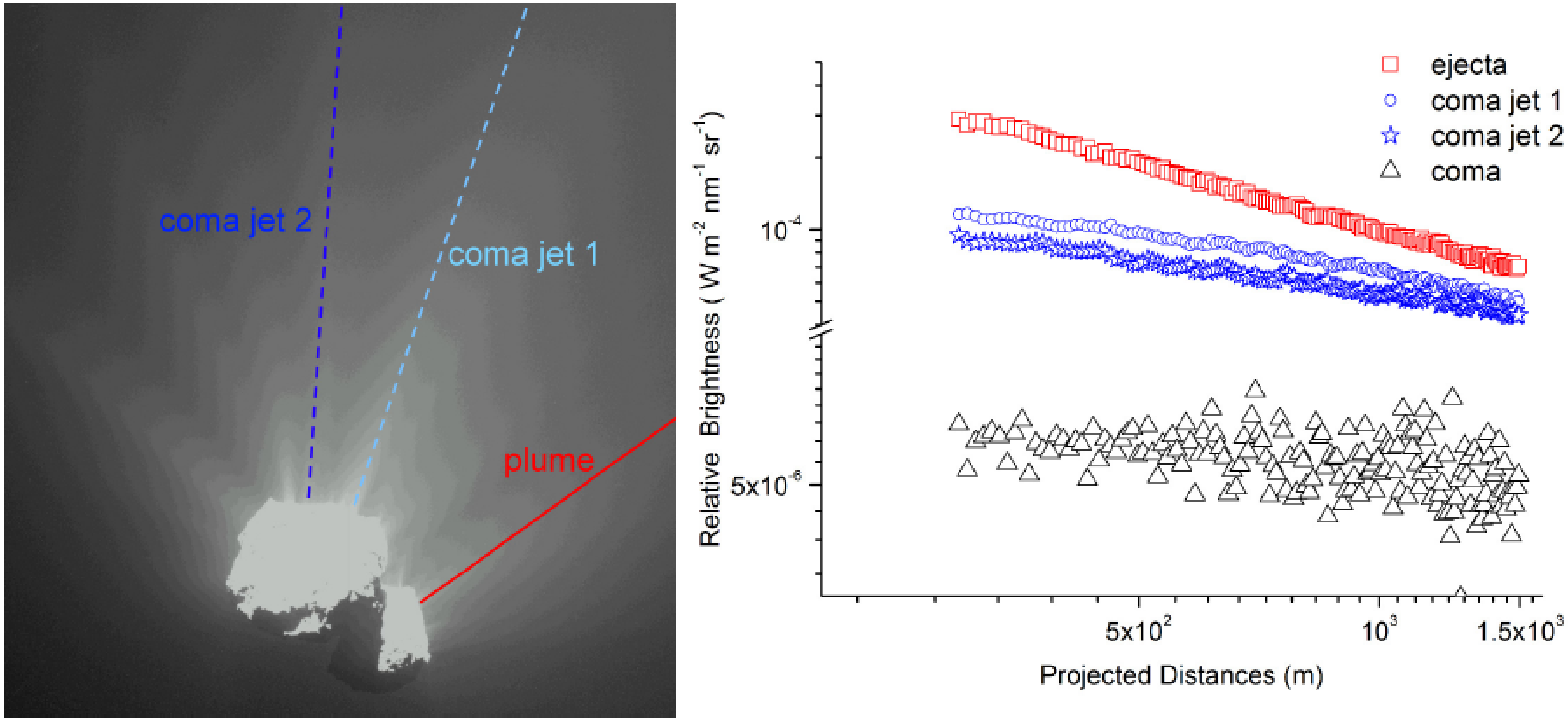
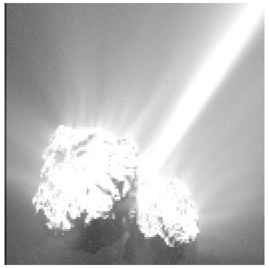
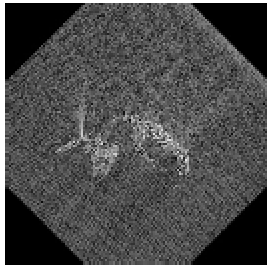
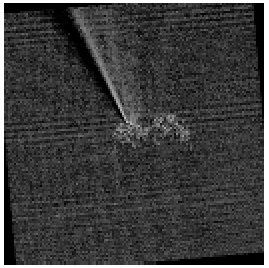
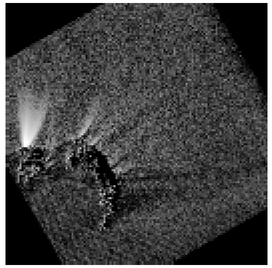
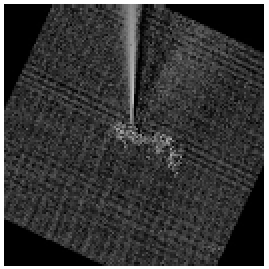
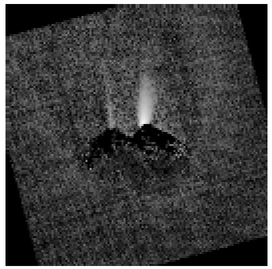


Fig. 4. The brightness slopes with log-log scale (right-panel) measured from the outburst plume (red square), coma jets (blue circle and star) and background coma (black troangle) in OSIRIS image (left-panel) obtained on September 23 2015, respectively

Type A: Strong, collimated jets Type B: Broad fans

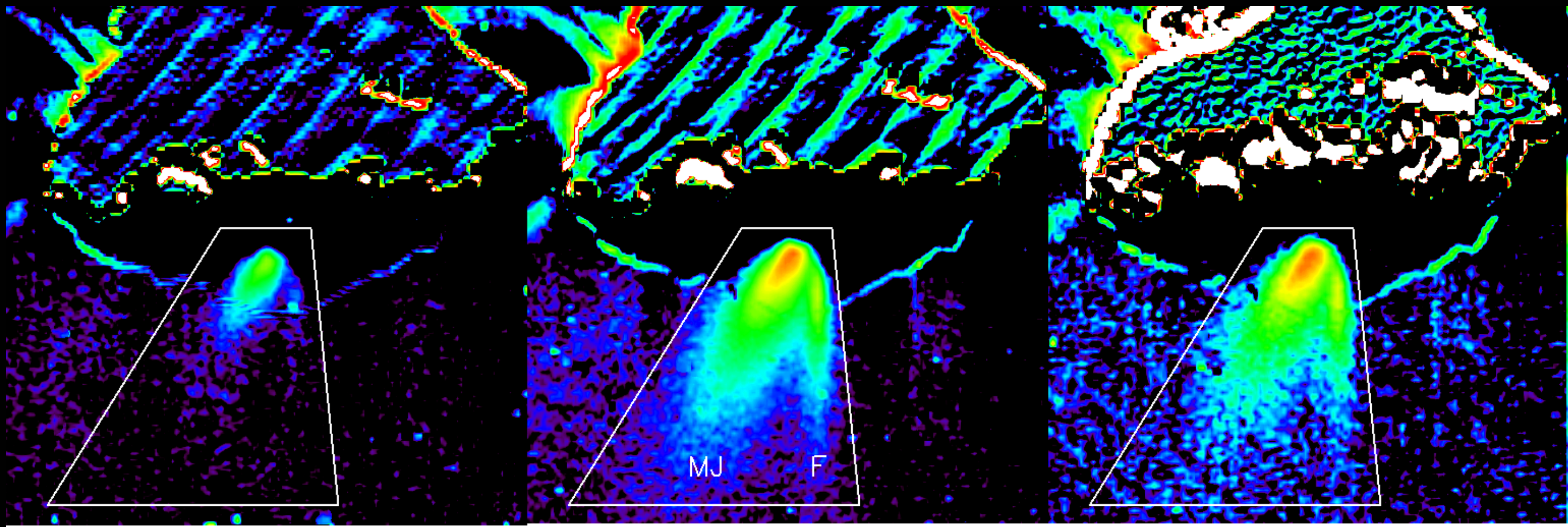
Date/time/slope/range(m)		Date/time/slope/range(m)	
2015-07-29 13.24.10.76 -0.304 (200-4400)		2015-08-05 07.10.32.077 -1.247 (50-1500)	
2015-08-12 17.20.36.436 -0.643 (300-2000)		2015-08-05 08.03.57.736 -2.123 (500-2000)	
2015-08-12 17.20.36.436 -0.503 (300-2000)		2015-08-16 22.53.06.769 Bigger one (right) -1.575 (300-2000)	

useful hits to identify corresponding mechanism !?

The ejection mass

March outburst from nightside of comet 67P/C-G

Knollenberg et al. 2016



Co-registered, cleaned and zoomed difference images in UV375 (left- and middle-panel) and VIS610 (right-panel) filters.

$$L_\lambda = f_{coma} \frac{p}{\pi} \frac{\phi(\alpha)}{\phi_0} \frac{f_{\theta,\lambda}}{r_h^2}$$

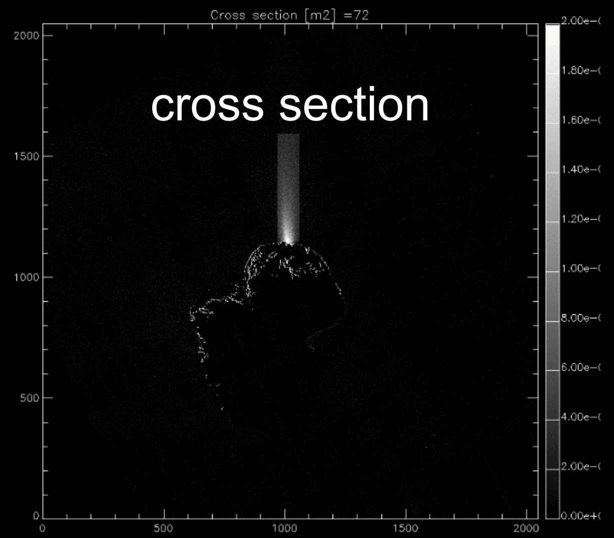
P: geometric albedo of the dust particle at wavelength **λ**

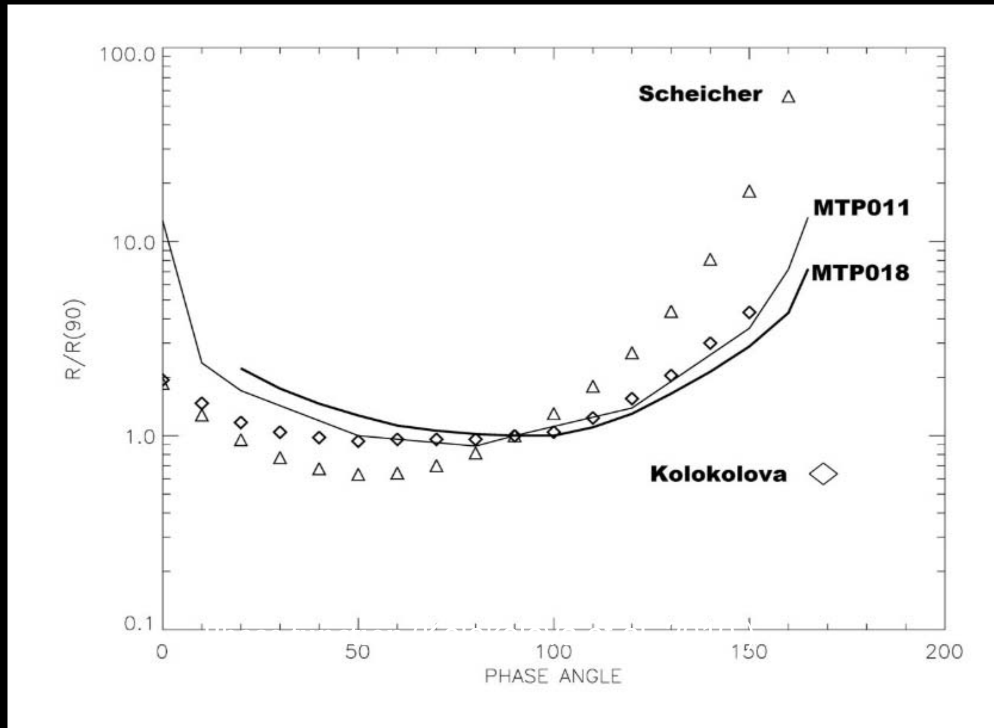
$\phi(\alpha)$: the phase function at phase angle **α**

f(**θ**,**λ**) : the specific solar flux (W m^{-2} nm^{-1})

r_h : the heliocentric distance (AU)

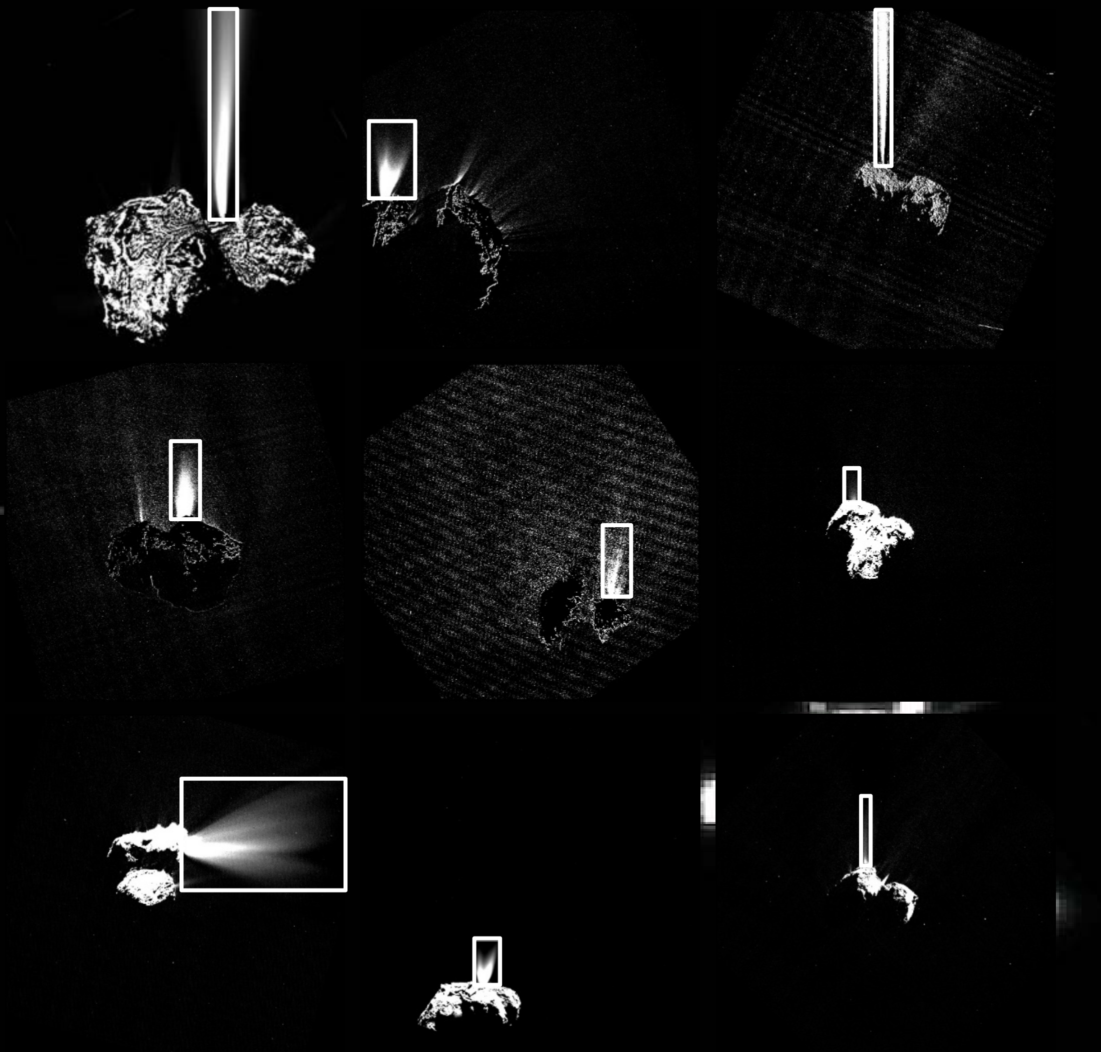
f_{coma} : the dust filling factor (the fraction of a pixel covered by dust)

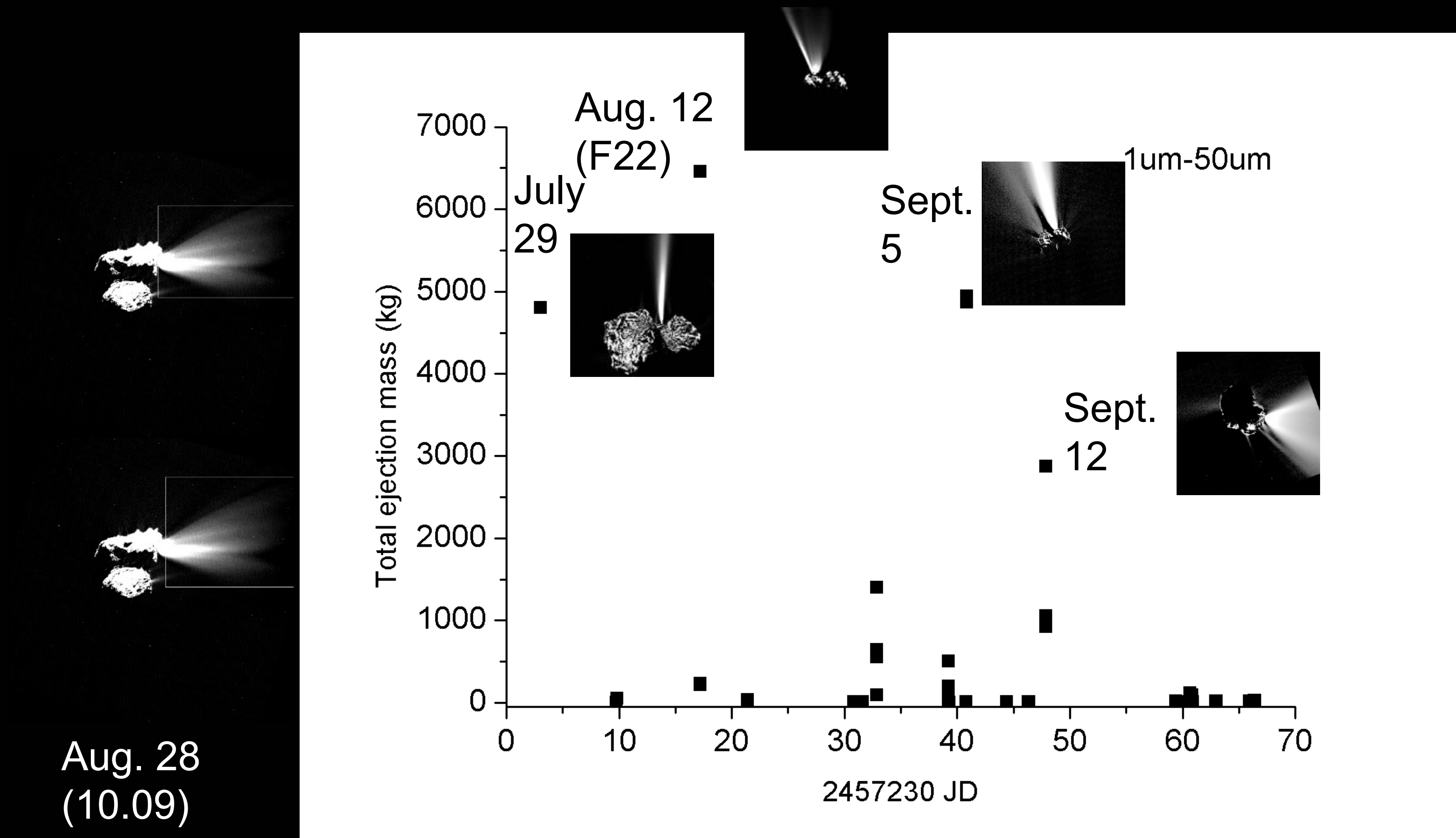




Difference Images (F22)

Time interval
6.3s~19.6s

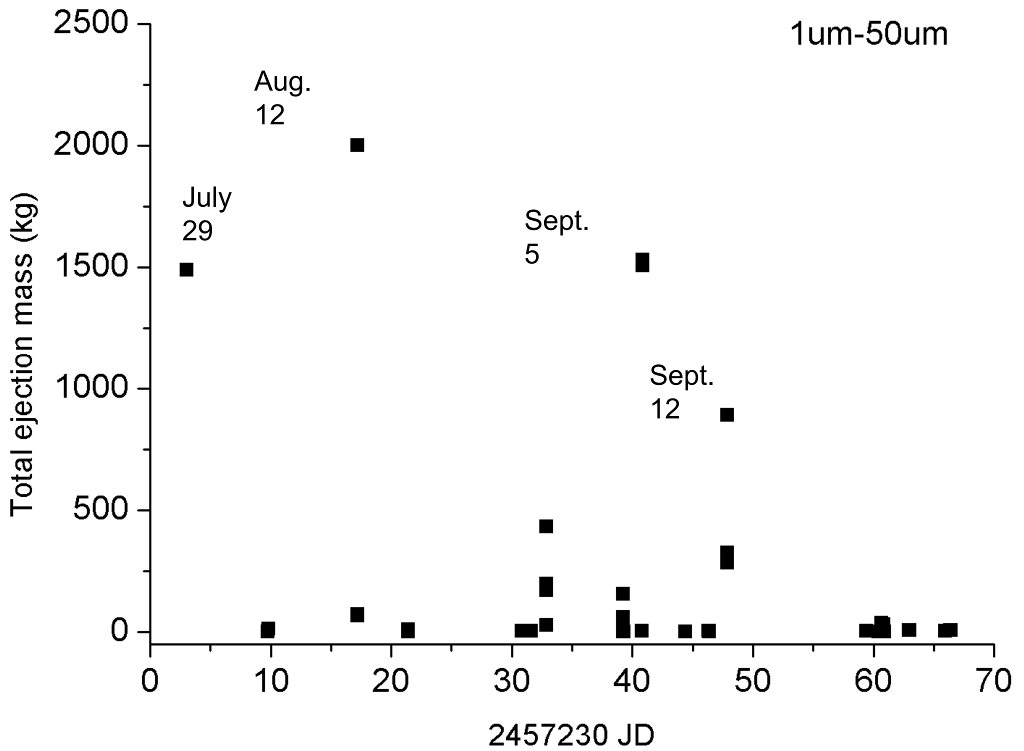




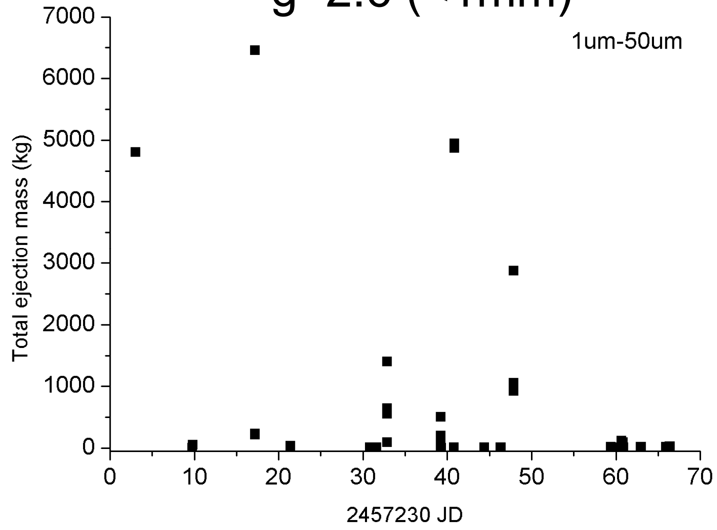
Aug. 12
(F22)
July
29
Sept.
5
1um-50um
Sept.
12
Total ejection mass (kg)
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
2457230 JD
Aug. 28
(10.09)

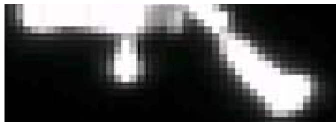
size distribution of $n_{(rd)} \sim rd^{-g}$

g~3.7 (<1mm) @perihelion (Fulle et al 2016)



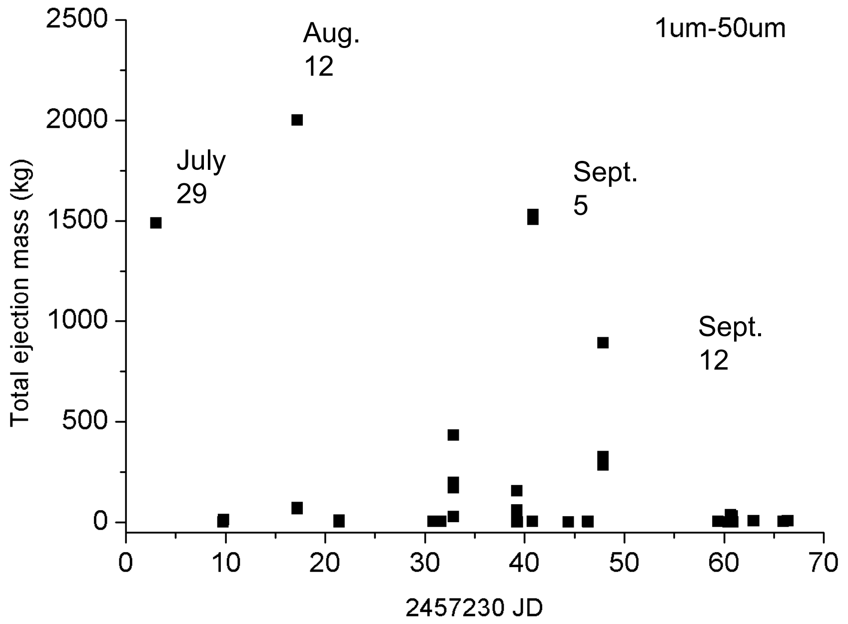
g~2.6 (<1mm)

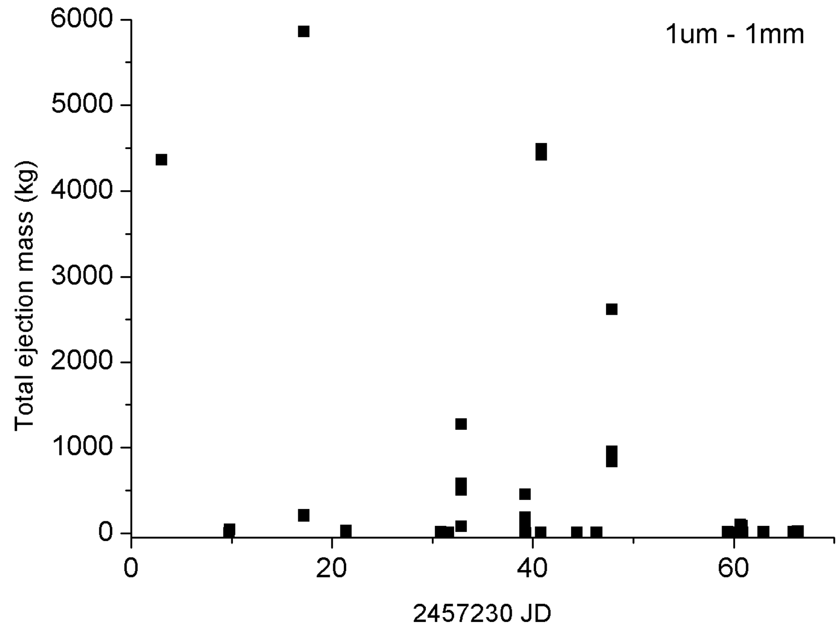




size distribution of $n_{(rd)} \sim rd^{-g}$

g~3.7 (<1mm) @perihelion (Fulle et al 2016)





Discussion and Summary

- Brightness slopes

outburst plume (0.81~1.08); coma jets (0.67~0.88) ; background coma (0.36~0.78) @1.2~1.4 au (~3000 m NAC, 25000 m WAC)

coma jets (0.95~1.48) ; background coma (0.41~0.59) @ 3.3~3.5 au (~10000 m WAC)

Coma jets → different physical properties in between 3.3-3.5 au and 1.2-1.4 au

Outburst plume X a extreme cause (steeper or shallower), is close to steady-state, instead.

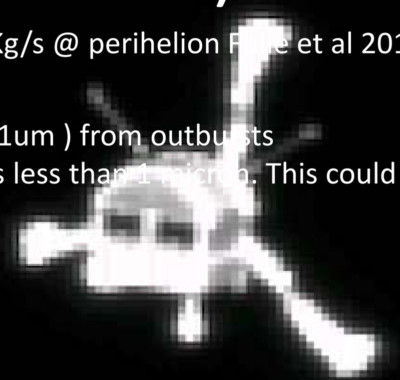
- The Ejection Mass (g~3.7, 1um-1mm)

July 29, 2015 → 4550 Kg if 18min -> ~4Kg/s if 5min -> 15 Kg/s (1500 Kg/s @ perihelion Fulle et al 2016)

But size distribution (3.7 ?) / size range (1um-1mm?)

VIRTIS-H (thermal environment) →high temperature, meaning smaller size particles (< 1um) from outbursts

(VIRTIS-H data are providing strong constraints on the size distribution, for particle sizes less than 1 micron. This could allow a better constraint of ejected dust mass)



- Excess brightness

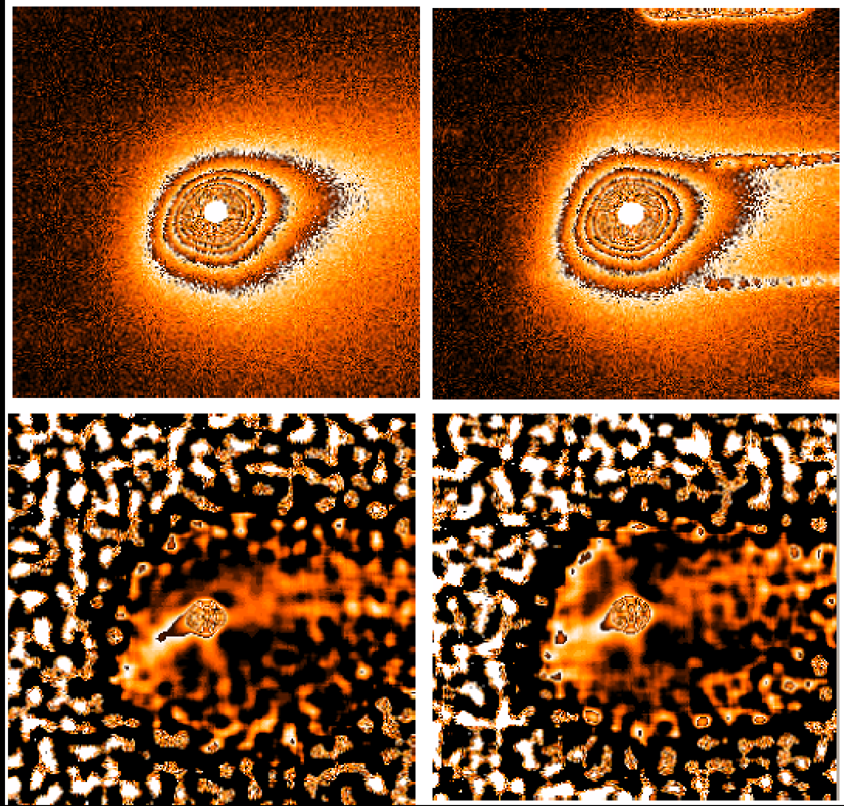
Outburst plume ~ few % to 30%

Coma jets activities ~ 10%-25% (~ perihelion) <--- > 3%-10% @ 3.3-3.5 au (August – September 2014)

Thank you for your attention

Hermann et al. detected a difference around the 22-23 August.

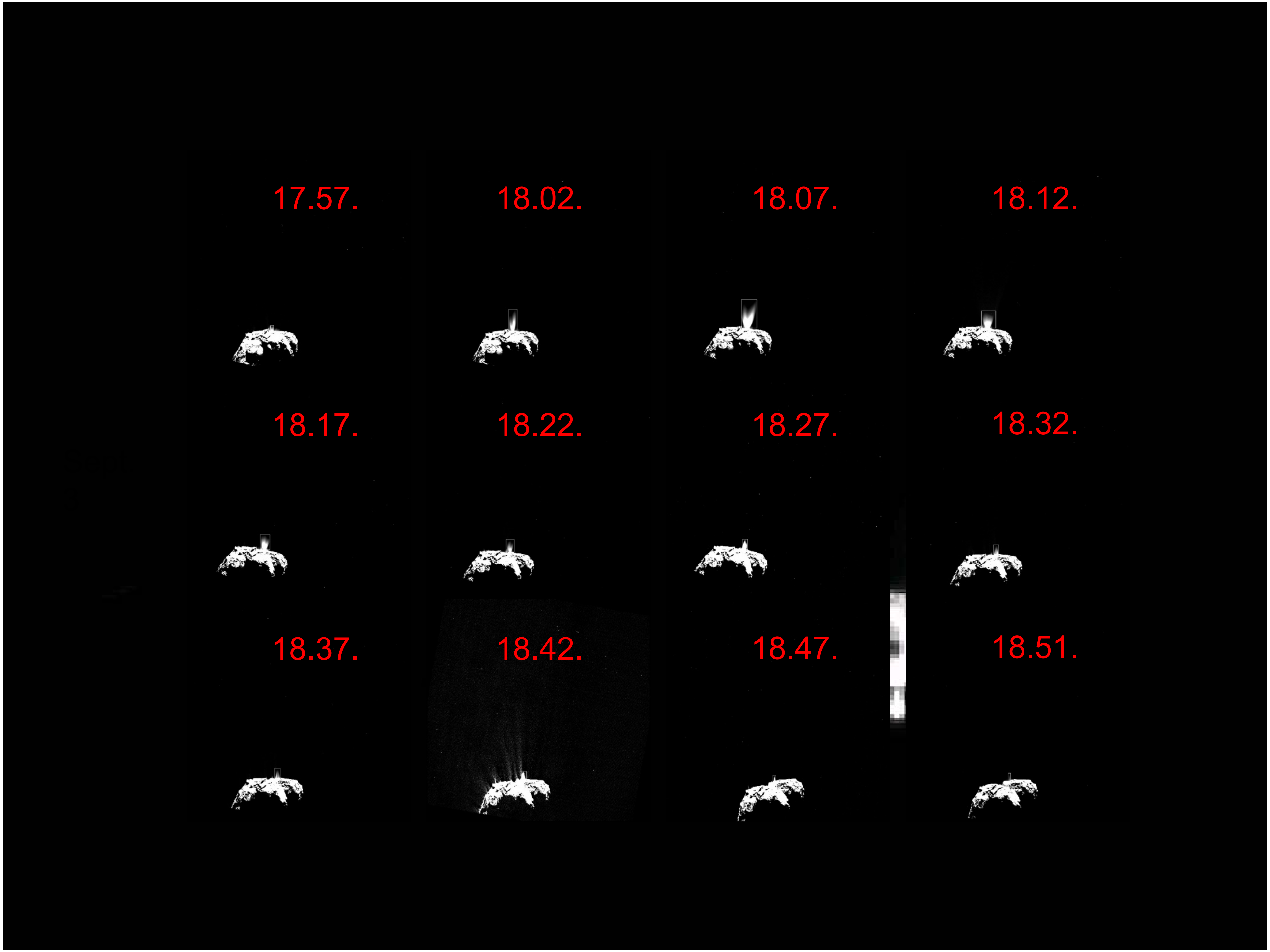
Figure 10 Dust arc in the coma of 67P. The images show the isophote pattern of the comet on 22 August 2015 (top left panel), the isophote pattern of the coma on 23 August 2015 (top right panel), and the respective adaptive Laplace filtered versions of the comet image on both observing epochs (bottom left panel for 22 August 2015, bottom right for 23 August 2015). The isophote pattern on 22 and 23 August 2015 differ in the northeastern coma quadrant. The Laplace filtered image of 23 August 2015 displays a straight short jet-like structure at near-nucleus position angle 20 deg and an arc-let structure at the end of the jet, extending into southwestern direction. Both features are not present in the coma the day before. Image orientation is: North up, East to the left, image scale is 63000 x 61000 km at the distance of the comet.



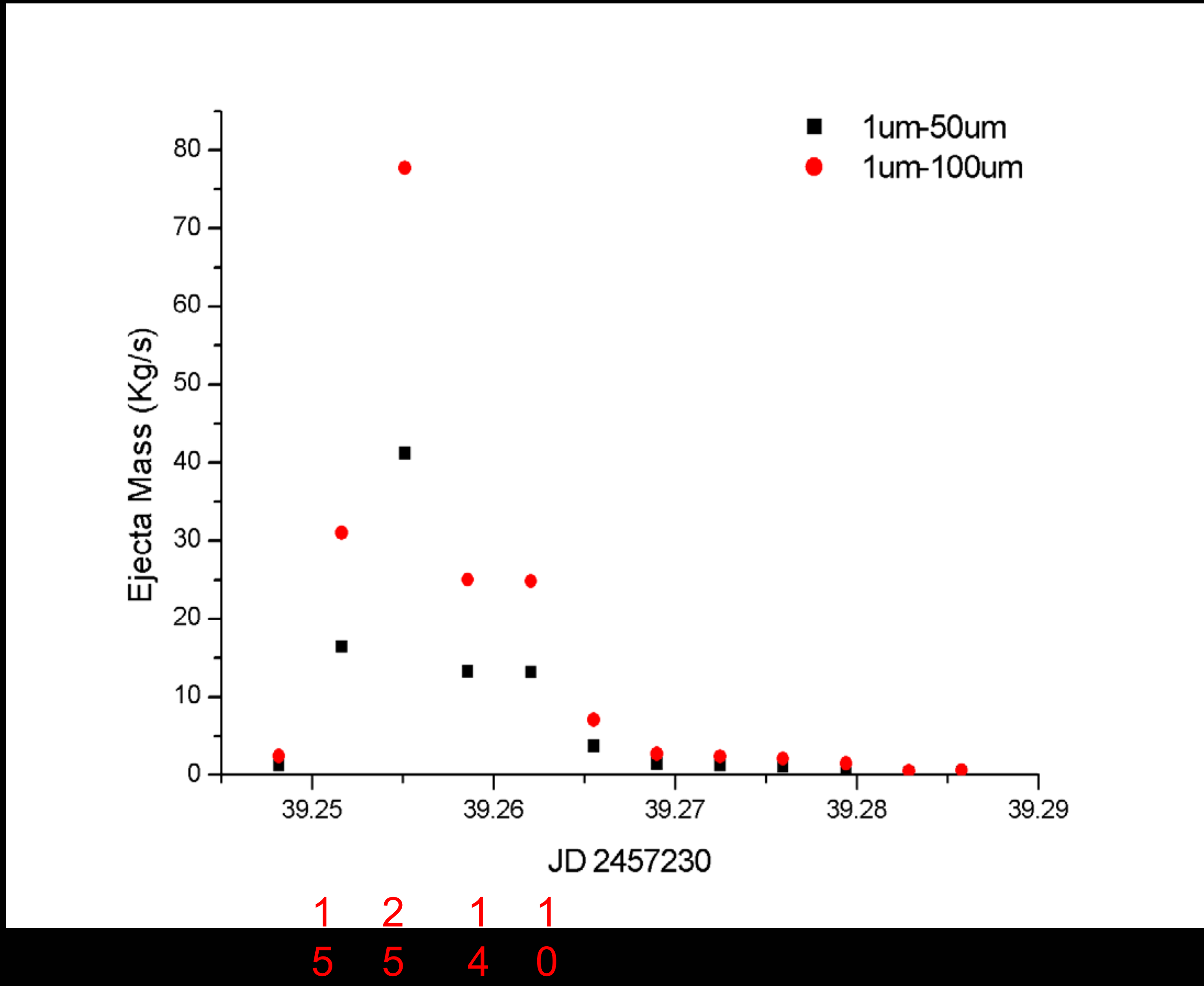
Start time (UT)	cross section (m^2)	total mass ($1\mu m$-1mm) (kg)	mass ejection rates (kg/s)	time interval (sec)
2015-07-29 13.24.10.760	20234.0	4550.	4.21/15.16	(1080/300)
2015-08-05 07.10.32.077	82.4	2.0	0.29	(6.29)
2015-08-05 08.03.57.736	1917.3	41.7	3.79	(11.01)
2015-08-12 17.20.36.436	269008.6	5857.5	19.52	(300)
2015-08-16 22.53.06.769	1287.5	28.0	2.79	(10.05)
2015-08-26 08.19.55.322	509.1	11.1	1.15	(9.6)
2015-08-27 03.12.06.804	396.3	8.6	0.74	(11.68)
2015-08-28 10.09.51.784	26712.9	1270.7	93.30	(13.62)
2015-09-03 17.57.22.781	654.9	14.3	1.19	(12.02)
2015-09-03 18.02.22.782	8253.1	179.7	14.95	(12.13)
2015-09-03 18.07.22.801	20854.3	454.1	37.44	(12.03)
2015-09-03 18.12.22.782	6668.7	145.2	12.07	(12.07)
2015-09-03 18.17.22.812	6642.9	144.6	11.98	(12.07)
2015-09-03 18.22.22.799	1884.1	41.0	3.42	(12.01)
2015-09-03 18.27.22.764	725.4	15.8	1.31	(12.02)
2015-09-03 18.32.22.856	654.6	14.3	1.18	(12.11)
2015-09-03 18.37.22.857	566.0	12.3	1.02	(12.12)
2015-09-03 18.42.22.814	401.3	8.7	0.73	(12.12)
2015-09-03 18.47.22.797	132.7	2.9	0.26	(11.06)
2015-09-03 18.51.32.792	151.3	61.5	0.30	(11.08)
2015-09-03 18.22.22.799	1570.0	3.3	2.85	(12.01)
2015-09-05 08.23.55.782	431.657	9.4	0.85	(11.05)
2015-09-05 08.58.43.857	204424.0	4451.2	14.84	(300)
2015-09-08 22.40.38.846	310.432	6.8	0.61	(11.12)
2015-09-10 20.51.22.797	468.571	10.2	0.85	(12.03)
2015-09-10 21.11.12.538	383.75	8.4	0.81	(10.27)
2015-09-10 21.11.12.538	28.2102	0.6	0.06	(10.27)
2015-09-12 09.41.53.733	38359	835.2	2.78	(300)
2015-09-12 09.46.53.760	43901.7	955.9	3.19	(300)
2015-09-12 09.51.53.715	119808	2608.7	8.69	(300)
2015-09-12 09.56.53.734	43040.5	973.2	3.12	(300)
2015-09-23 21.59.37.739	652.382	14.2	1.29	(10.99)
2015-09-24 22.56.47.769	48.5774	1.1	0.08	(13)
2015-09-24 23.31.46.762	220.441	4.8	0.47	(10.23)
2015-09-25 04.18.13.134	4727.39	102.9	10.68	(9.64)
2015-09-25 05.48.13.288	1262.81	27.5	2.86	(9.629)
2015-09-25 09.09.39.809	3916.96	85.3	6.55	(13.01)
2015-09-25 09.14.38.751	2587.71	56.3	5.51	(10.2)
2015-09-25 09.54.38.764	315.871	6.9	0.58	(11.92)
2015-09-25 10.39.39.757	186.713	4.1	0.31	(12.96)
2015-09-25 10.54.38.831	326.525	7.1	0.59	(12.06)
2015-09-27 11.59.58.773	819.695	17.8	1.49	(12.01)
2015-09-30 11.36.45.774	652.942	14.2	2.67	(11.04)
2015-09-30 21.34.37.765	921.168	20.1	1.82	(11.02)

Time span of used sequences

2015-08-12 (WAC, UV375) 07.01 20.20	1.24330 1.24326	338.898 329.475	34.00 33.05	89.7335 89.3681
2015-08-22 08-23 (WAC, UV375) 21.46 02.11	1.24916 1.24938	333.872 334.503	133.96 134.24	88.5106 88.2005
2015-09-03 (WAC, UV375) 17.37 18.51	1.27152 1.27166	379.214 380.338	76.14 76.38	86.5581 87.1176
2015-09-12 (NAC, ORANGE) 22.30 23.25	1.29969 1.29982	320.395 319.853	5.92 5.91	112.76830 112.487



17.57.
18.02.
18.07.
18.12.
18.17.
18.22.
18.27.
18.32.
18.37.
18.42.
18.47.
18.51.


1um-50um
1um-100um
Ejecta Mass (Kg/s)
0
10
20
30
40
50
60
70
80
39.25
39.26
39.27
39.28
39.29
JD 2457230
15
25
14
10