Emissione di polveri dalla cometa 67P/Churyumov-Gerasimenko e loro relazione con la composizione e geomorfologia superficiali

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Introduction

Comets are among **the most primitive bodies** in the Solar System, still containing records of physical processes which led to the early Solar System formation.

The ESA/Rosetta mission orbited the comet 67P/Churyumov-Gerasimenko. After 2.5 years from the end of the mission, the data provided by the 21 instruments on board the Rosetta orbiter and its lander Philae are still giving important clues about 67P formation and evolution.

The Rosetta mission

Rosetta escorted the comet along:

- ***Pre-perihelion***: surface properties mostly influenced by processes occurred at the previous perihelion passage then modified far from the Sun
- ***Perihelion***: activity leading to surface rejuvenation, exposing underlying and most primordial material
- ***Post-perihelion***: nucleus and coma partially renewed from the occurred activity.

Cometary activity: state of the art (1)

- **VIRTIS (imaging spectrometer)**: Variations of water ice amount on the surface during the comet's orbit (Ciarniello et al., 2016); correlation between ejection of dust and water ice (Rinaldi et al., 2016)
- **OSIRIS (camera):** Brightness variations and surface changes due to cometary activity (Tubiana et al., 2015; Hu et al., 2017)
- **GIADA (dust detector)**: dust fluffy and compact particles in the coma, with different distribution (Della Corte et al., 2016)

Cometary activity: state of the art (1)

- **MIDAS (AFM microscope):** collection of compact dust agglomerates and one fluffy particle (Bentley et al., 2016)
- **COSIMA (dust mass spectrometer)**: dust particles composed of organic matter and other anhydrous mineral phases (Fray et al., 2016)
- **ROSINA (gas mass spectrometer)**: retrieval of gas production and activity distributions of different volatile species (Kramer et al., 2017; Läuter et al. 2018)

Outline

- Characterization of **pre-perihelion dust cometary activity** (GIADA) and **link with surface composition** (VIRTIS)

- Characterization of **dust activity** during the entire mission (GIADA) and link with **surface geomorphology** (OSIRIS)

- Identification of the **main drivers and the effects of cometary activity**, by combining measurements of dust morphology and composition, surface geomorphology and composition, gas distribution (MIDAS, COSIMA, ROSINA)

Outline

- Characterization of **pre-perihelion dust cometary activity** (GIADA) and **link with surface composition** (VIRTIS)

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67P/Churyumov–Gerasimenko active areas before perihelion identified by GIADA and VIRTIS data fusion

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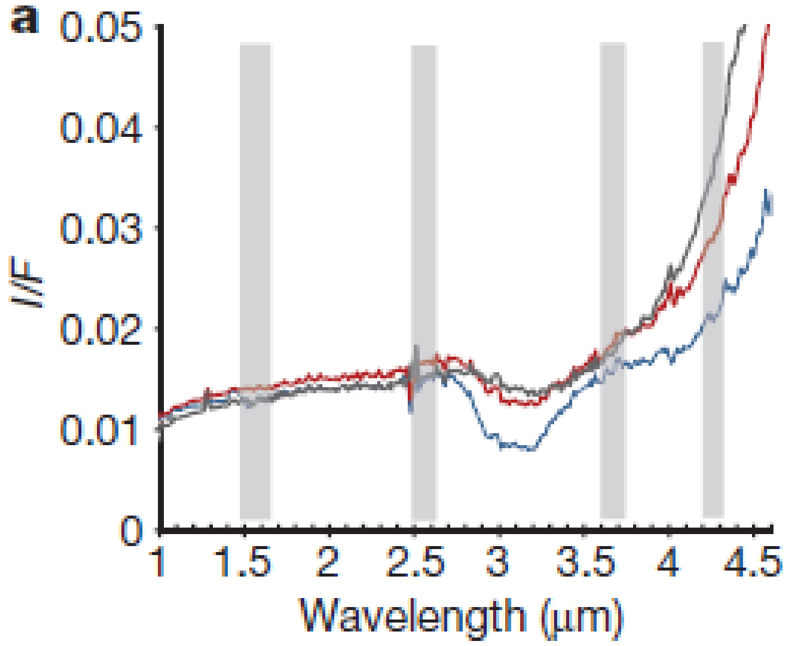
Ice detection: details

VIRTIS/Rosetta data revealed on 67P's nucleus the ubiquitous occurrence of an absorption band at **3.2 µm**, due to organics. This **band shifts shortward at increasing water ice amount**.

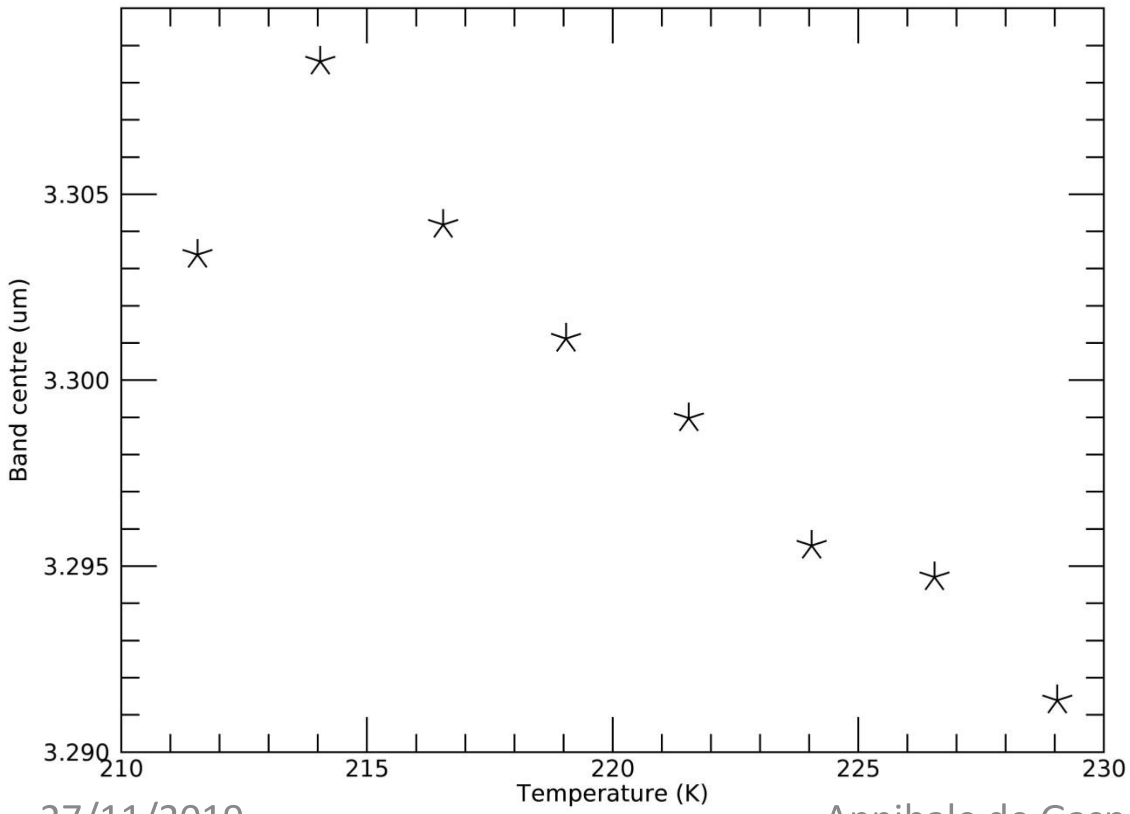


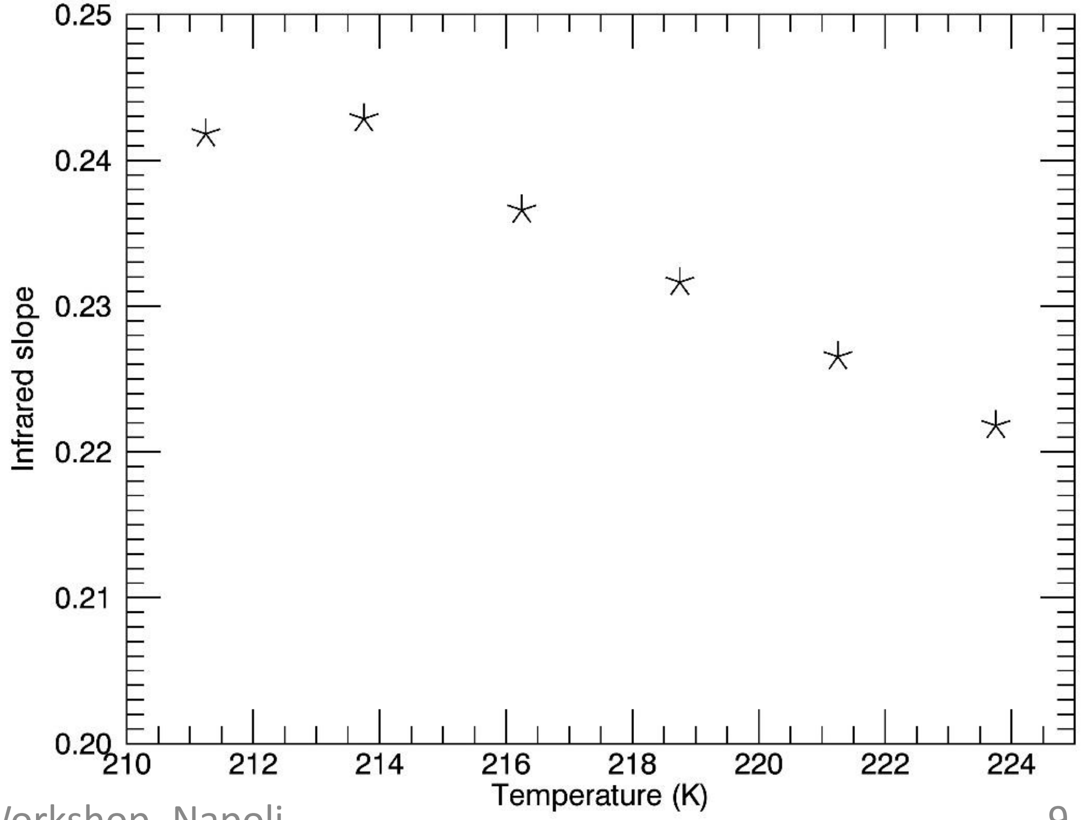
From De Sanctis et al. (2015)

The **increase of water ice** amount can be also revealed by a **flattening of the VIS/NIR spectral slope** (Ciarniello et al., 2017)

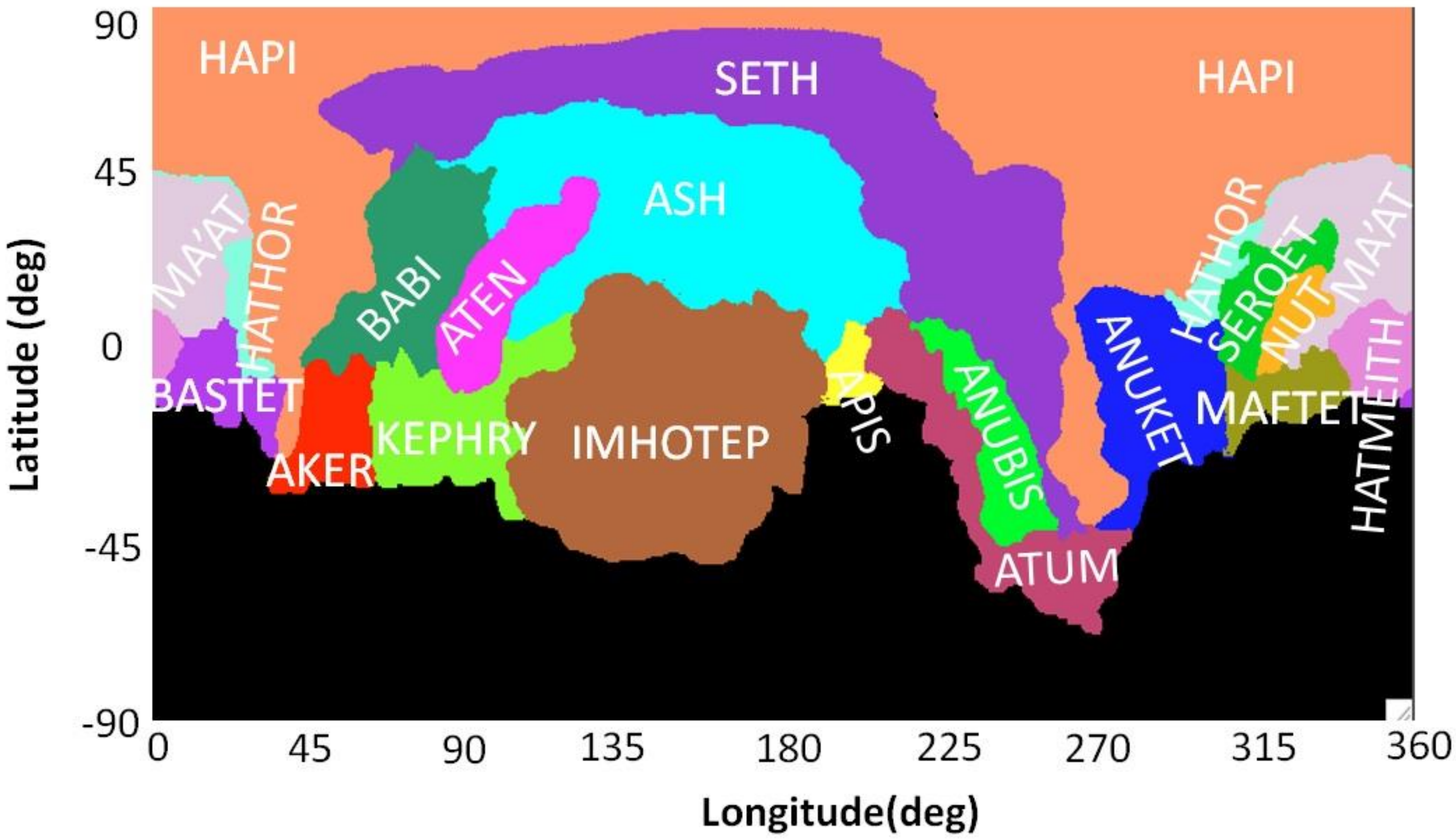
Ice detection: details

In the entire VIRTIS pre-perihelion dataset, a band center shift and an infrared slope change with temperature has been observed, probably due to water ice exposition caused by a weak cometary activity (Longobardo et al., 2017)





Surface geomorphology: details



From El-Marry et al. (2015) and Thomas et al. (2015)

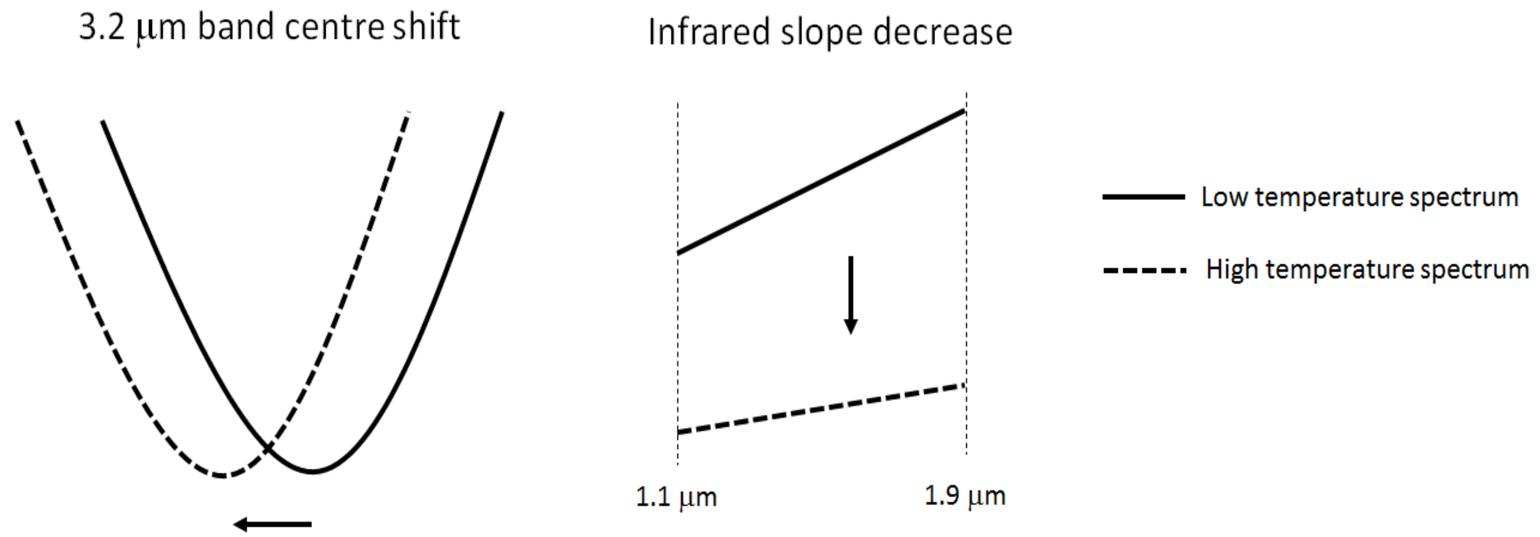
VIRTIS and GIADA datasets

For both instruments we considered the data from **August 2014 to January 2015**

- **VIRTIS** (imaging spectrometer): 4.2 million infrared spectra (after filtering for incidence and emission angles, and S/N ratio)
- **GIADA** (dust detector), in particular the detections by subsystems:
  - **GDS** (Grain Detection System): measurement of dust velocity
  - **IS** (Impact Sensor): measurement of dust grain momentum
  - **GDS+IS**: measurement of dust velocity, momentum and mass

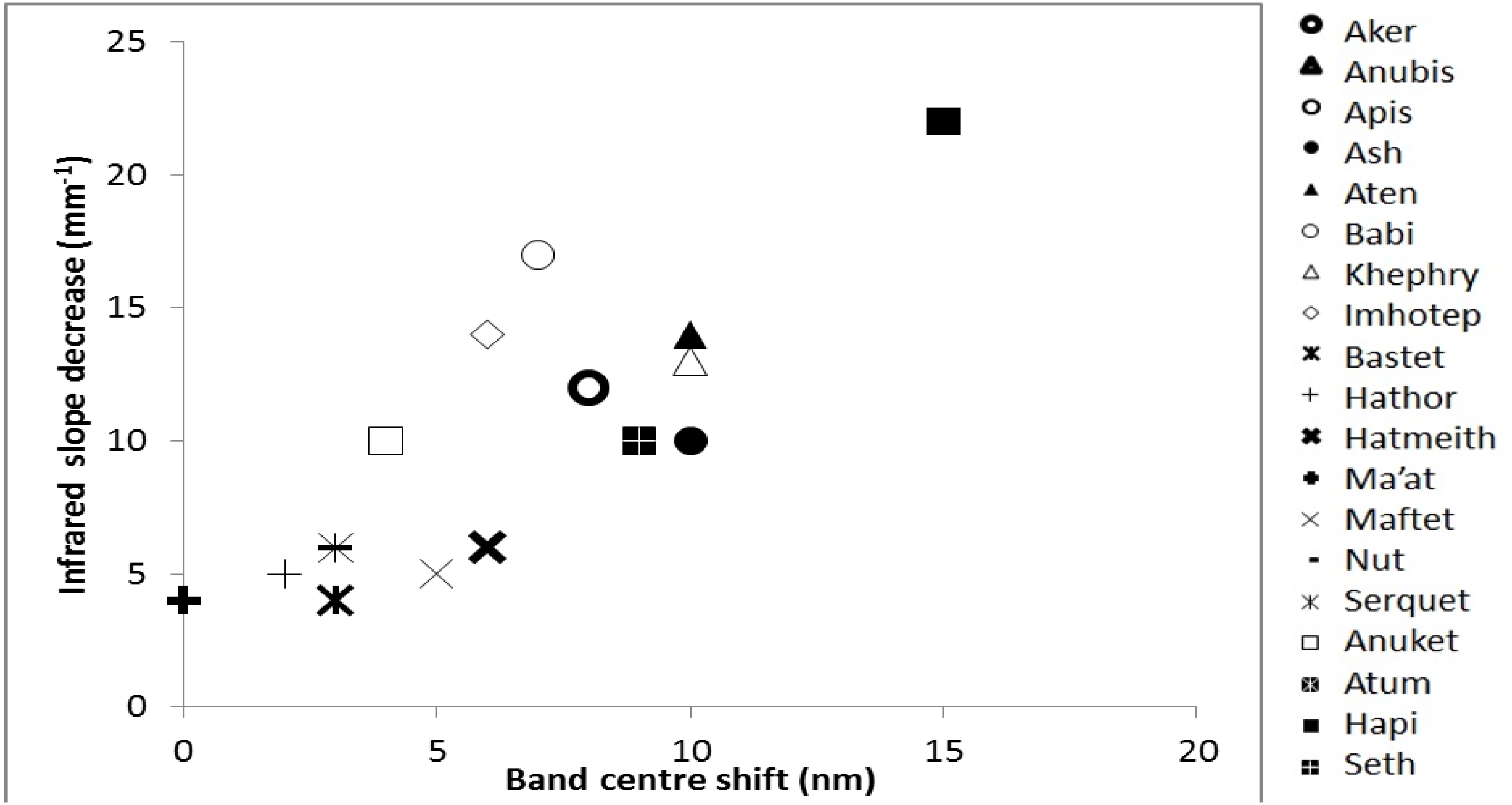
Analysis of VIRTIS data (1)

- For each geomorphological region, calculation of average 3.2 band center and the average infrared spectral slope (calculated between 1.1 and 2.0 μm) in temperature bins of 5°
- A trend of band center and infrared slope as a function of temperature may indicate diurnal and ongoing activity (i.e. change of water ice content)



Analysis of VIRTIS data (2)

Pearson coefficient: **0.8 (high correlation)**



GIADA high-level products (1)

- ***Type of particles***

We built two families of particles, basing on Della Corte et al. (2015):

Compact particles include GDS-IS detections, IS detections, GDS detections (single particles)

Fluffy particles include GDS detections (showers). Each shower is assumed to be due to a fragmentation of a unique fluffy particle.

GIADA high-level products (2)

- ***Analysis of dust showers***

A shower is defined by all particles detected at a temporal distance lower than 1 second with respect to the previous detection

For each shower, a histogram of velocities is built. The most populated bin gives the velocity of the parent fluffy particle

<u>(hereafter number of fluffy particles = number of showers)</u>

- ***Velocity of IS detections*** given by the empirical relation $v=Am^{\gamma}$, where A and γ depend on heliocentric distance and phase angle (Della Corte et al., 2016)

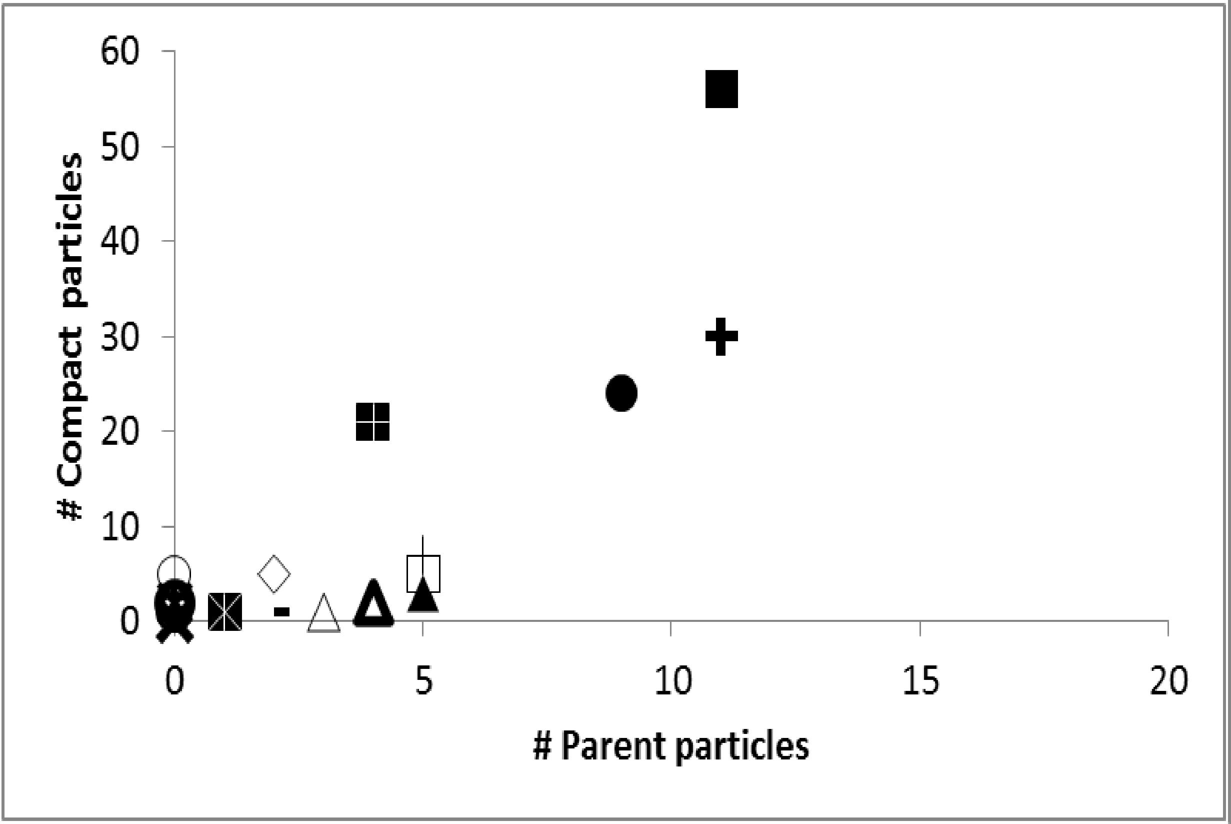
Dust traceback

- Time of flight of each dust particle is derived by:
  - considering the spacecraft altitude at detection;
  - assuming a ***uniformly accelerated motion for the first 11 km*** (Ivanovski et al., 2017) and a ***constant speed*** beyond.

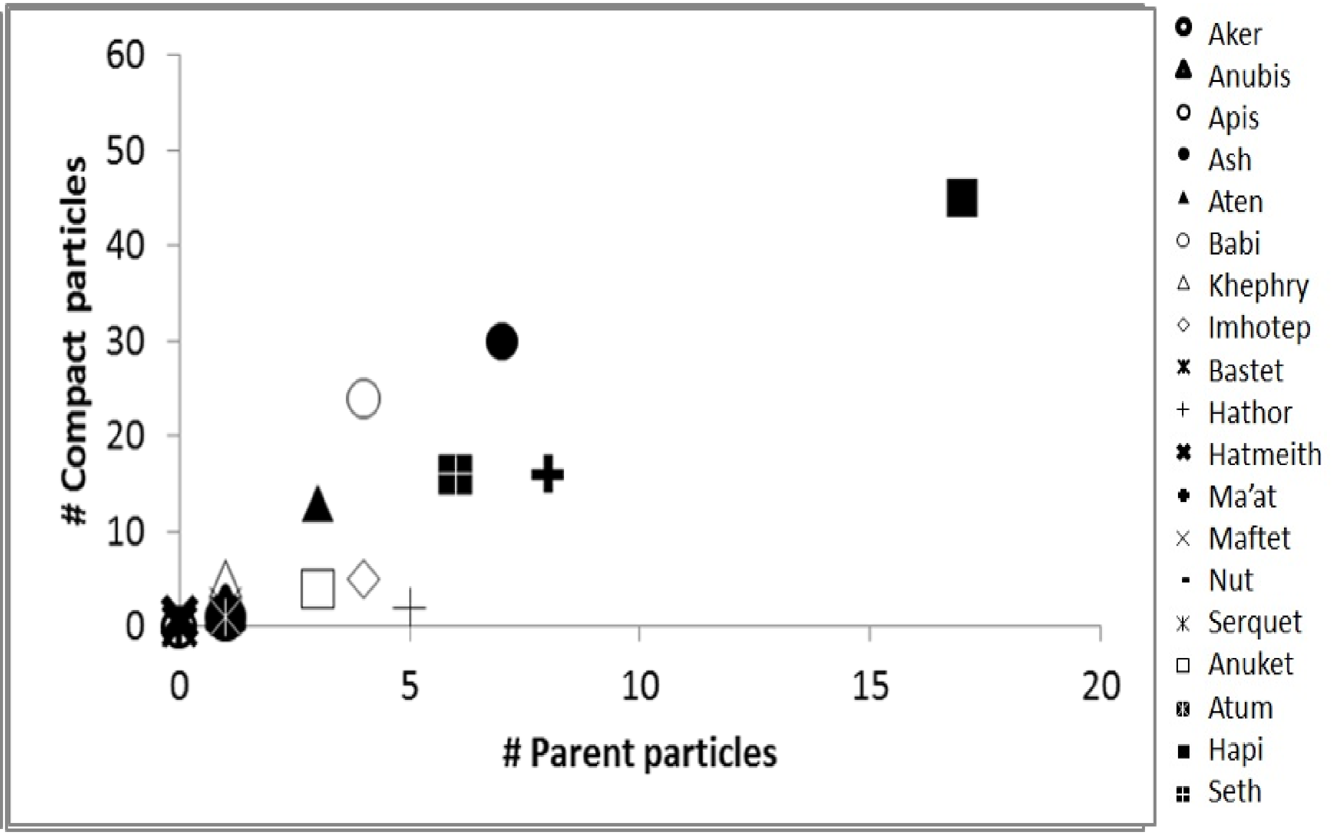
- Taking in consideration also the comet rotation, we defined the **ejecting *surface regions***

Results: fluffy vs compact particles

Before traceback (coma)
Pearson coefficient: **0.8 (high correlation)**



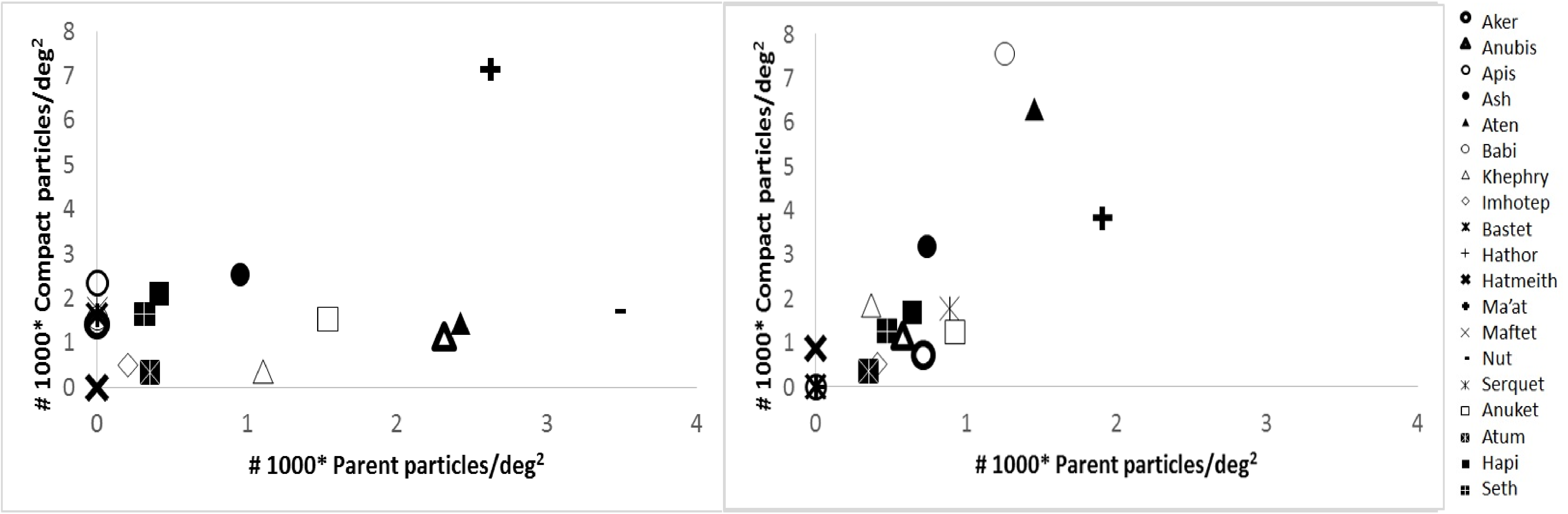
After traceback (nucleus)
Pearson coefficient: **0.9 (very high correlation)**



Results: fluffy vs compact particles for area unit

Before traceback (coma)
Pearson coefficient: **0.2 (no correlation)**

After traceback (nucleus)
Pearson coefficient: **0.7 (high correlation)**



Interpretation of GIADA results

- **High correlation** between the two studied categories of particles source regions, i.e. the source of the two different types of particles is likely the same.

- This source regions correlation compared with the dust spatial distributions in the coma, where fluffy and compact distributions are different, suggests that the correlation is not maintained in the coma because the fluffy and compact particle average speed are different

GIADA vs VIRTIS

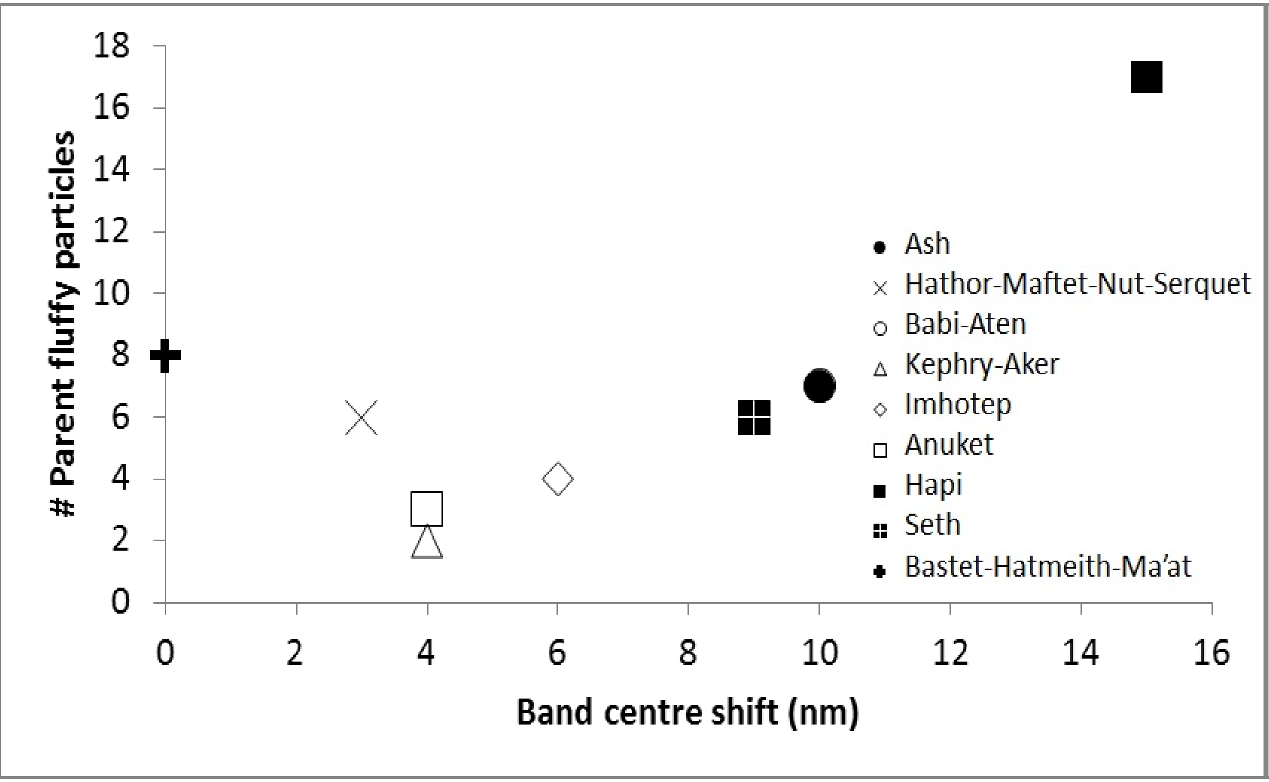
We compared the number of **fluffy and compact particles** detected by GIADA in each region with the **band center and infrared slope change with temperature** measured by VIRTIS in each region.

In order to have a reliable comparison:

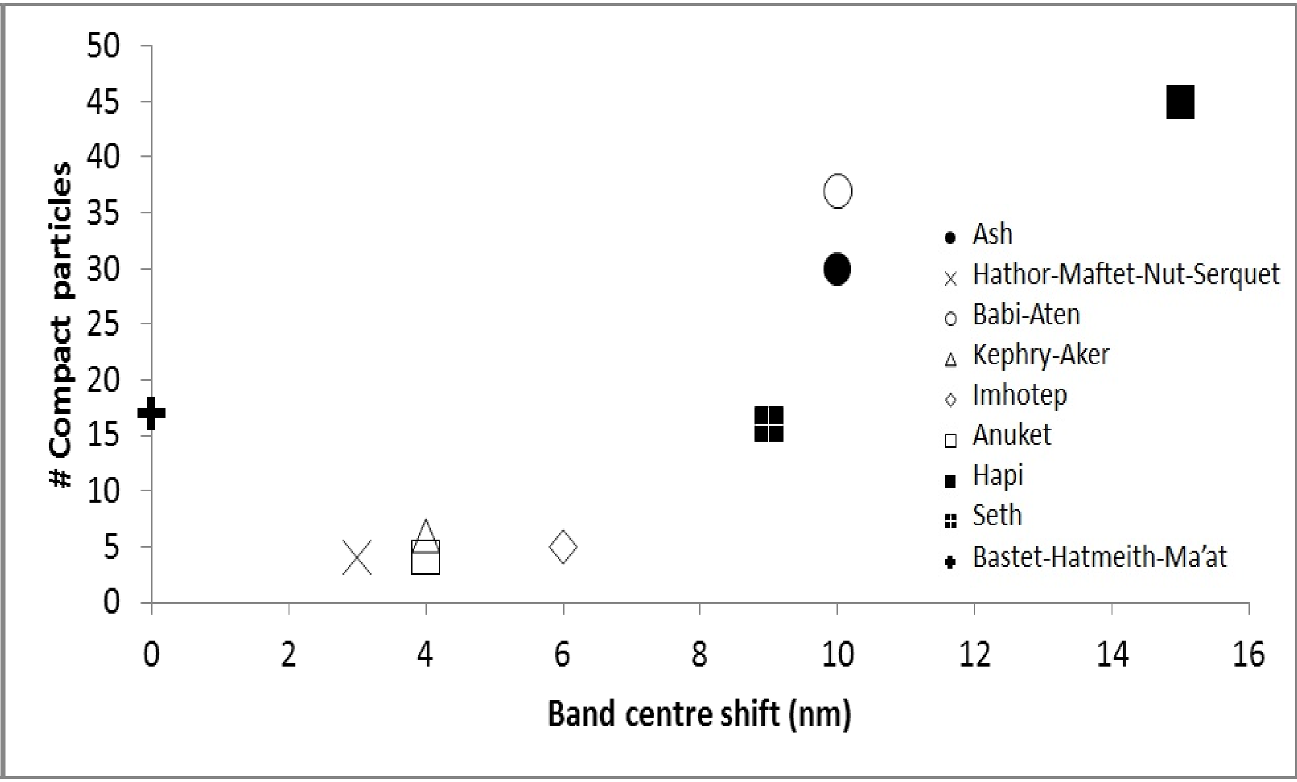
- We considered only regions having a quite high temperature coverage (>15 K)
- We merged comet’s regions in order to have extensions of at least 5000 deg^2, in order to improve the statistics

Results: GIADA vs VIRTIS (1)

Pearson coefficient: **0.7 (high correlation)**

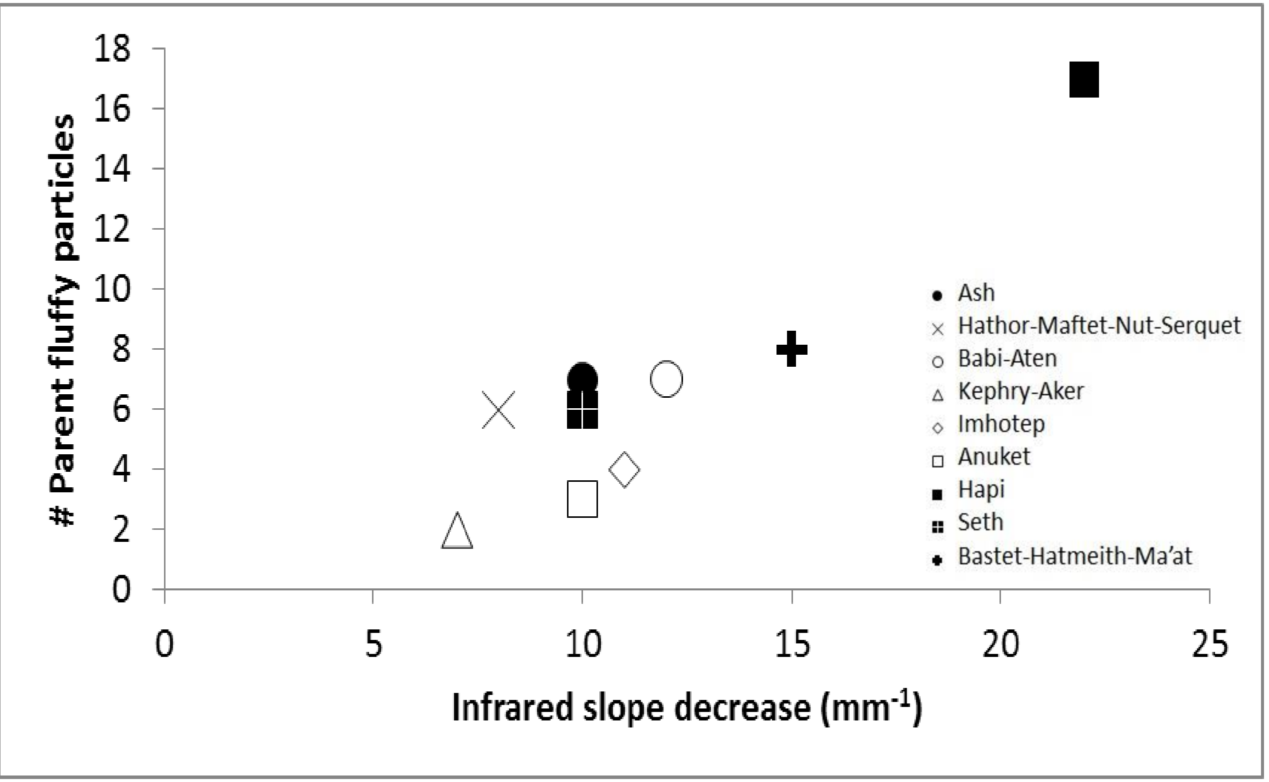


Pearson coefficient: **0.8 (high correlation)**

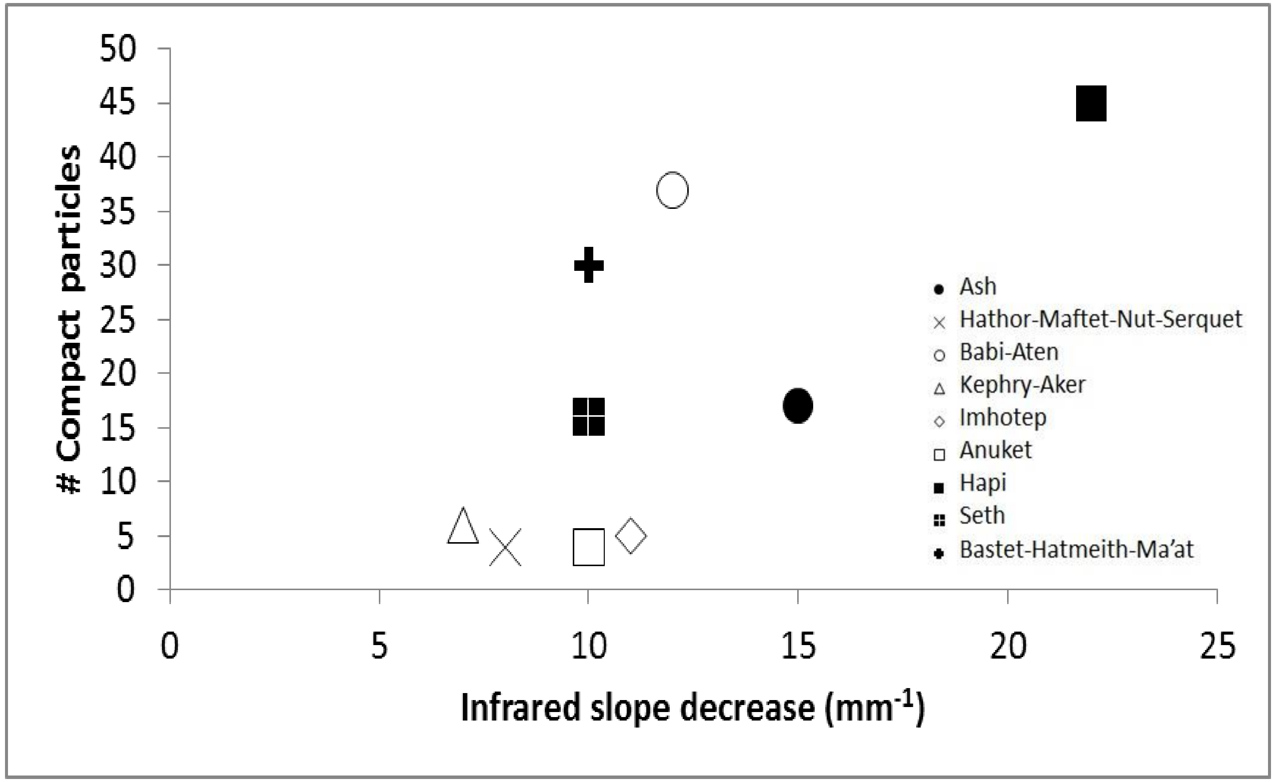


Results: GIADA vs VIRTIS (2)

Pearson coefficient: **0.9 (very high correlation)**



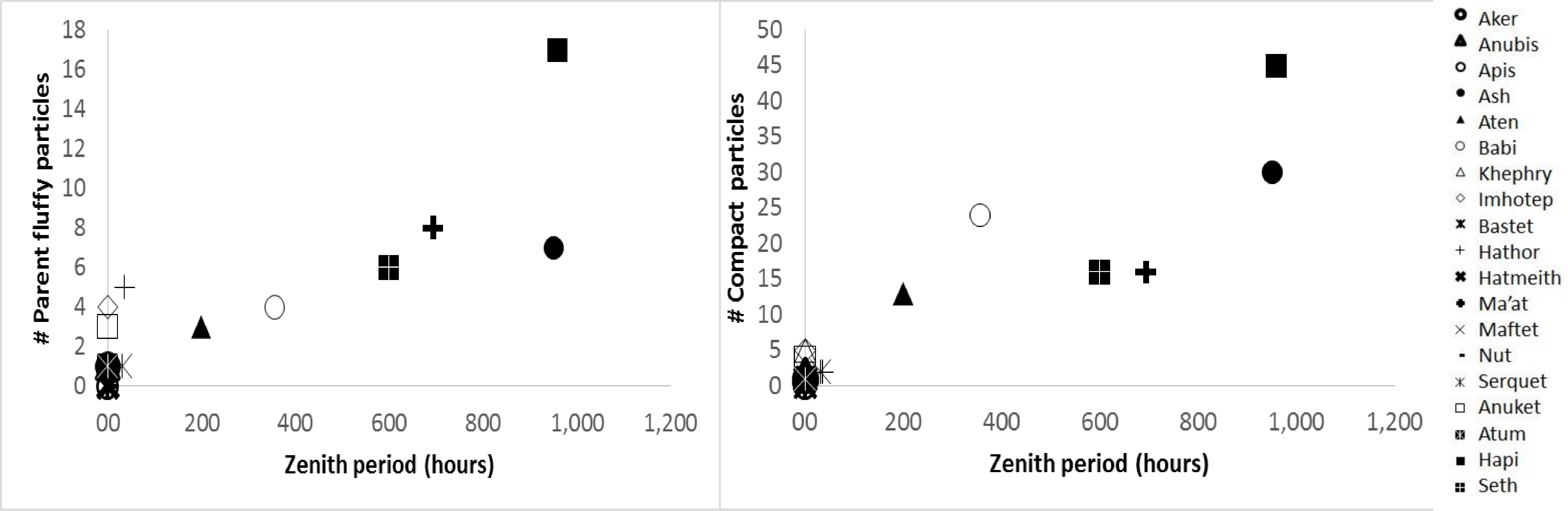
Pearson coefficient: **0.7 (high correlation)**



Results: GIADA vs illumination

Pearson coefficient: **0.9 (very high correlation)**

Pearson coefficient: **0.9 (very high correlation)**



Conclusions

Correlation between:

- *Fluffy and compact particles*: their source is the same
- *GIADA detections and VIRTIS temperature shifts*: weak cometary activity exposes water ice, affecting IR spectra
- *Emission of dust particles and illumination*: illumination is the main source, if not the only, driver of cometary activity (at least at pre-perihelion)

Outline

- Characterization of **pre-perihelion dust cometary activity** (GIADA) and **link with surface composition** (VIRTIS)

- Characterization of **dust activity** during the entire mission (GIADA) and link with **surface geomorphology** (OSIRIS)

- Identification of the **main drivers and the effects of cometary activity**, by combining measurements of dust morphology and composition, surface geomorphology and composition, gas distribution (MIDAS, COSIMA, ROSINA)

Goals

1. Extension of the **traceback** procedure to the entire GIADA dataset
2. Probe a possible **relation between dust particles morphology and the surface geomorphology** of the regions from where they are ejected (are fluffy aggregates ejected preferably in rough, less processed terrains?)

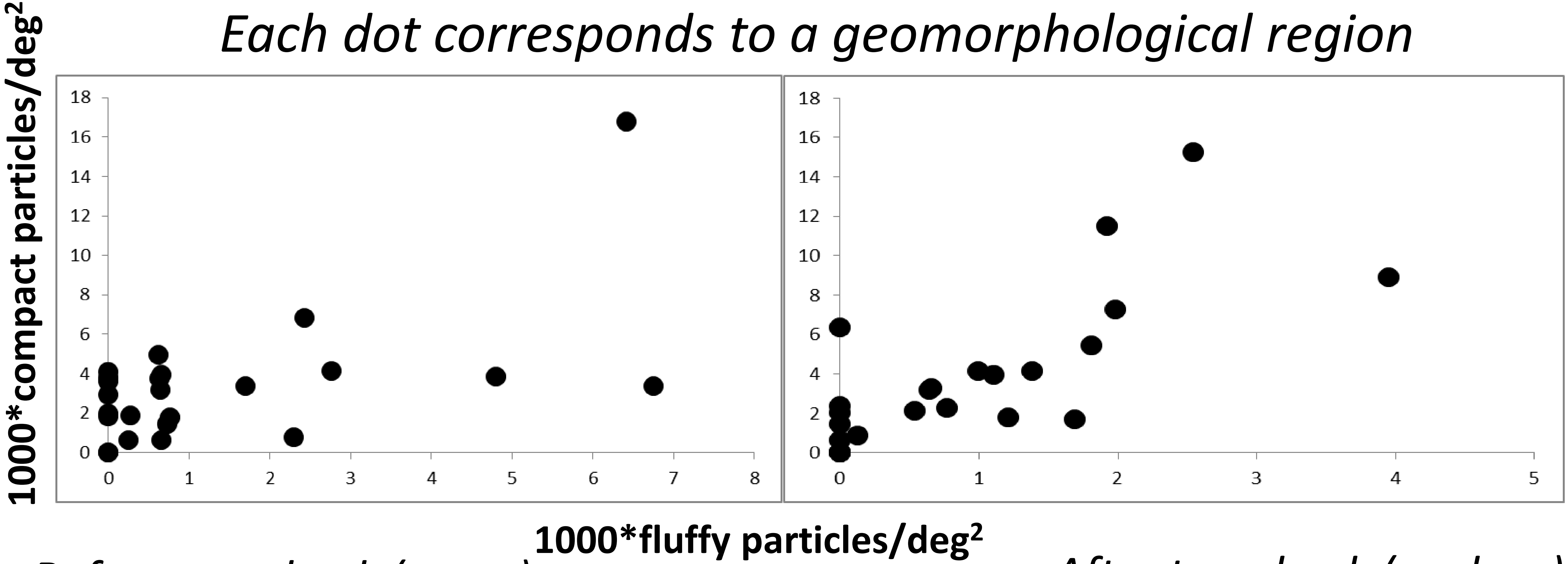
Rosetta periods classification

The definition relies on Della Corte et al. (2016)

Period	Orbital Stage	from	to	Orbital distance (AU)	Spacecraft altitude (km)
0	1st inbound arc	01/08/14	21/01/15	3.6-2.5	23±17
1	2nd inbound arc	22/01/15	31/03/15	2.5-2.0	40±30
2	Pre-perihelion	14/04/15	30/06/15	1.9-1.4	150±30
3	Perihelion	01/07/15	31/10/15	1.3-1.6	340±160
4	1st post-perihelion	01/11/15	22/02/16	1.6-2.4	300±200
5	2nd post-perihelion	23/02/16	15/09/16	2.4-3.8	9±9

Results: Period 0

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

0.2 (no correlation)

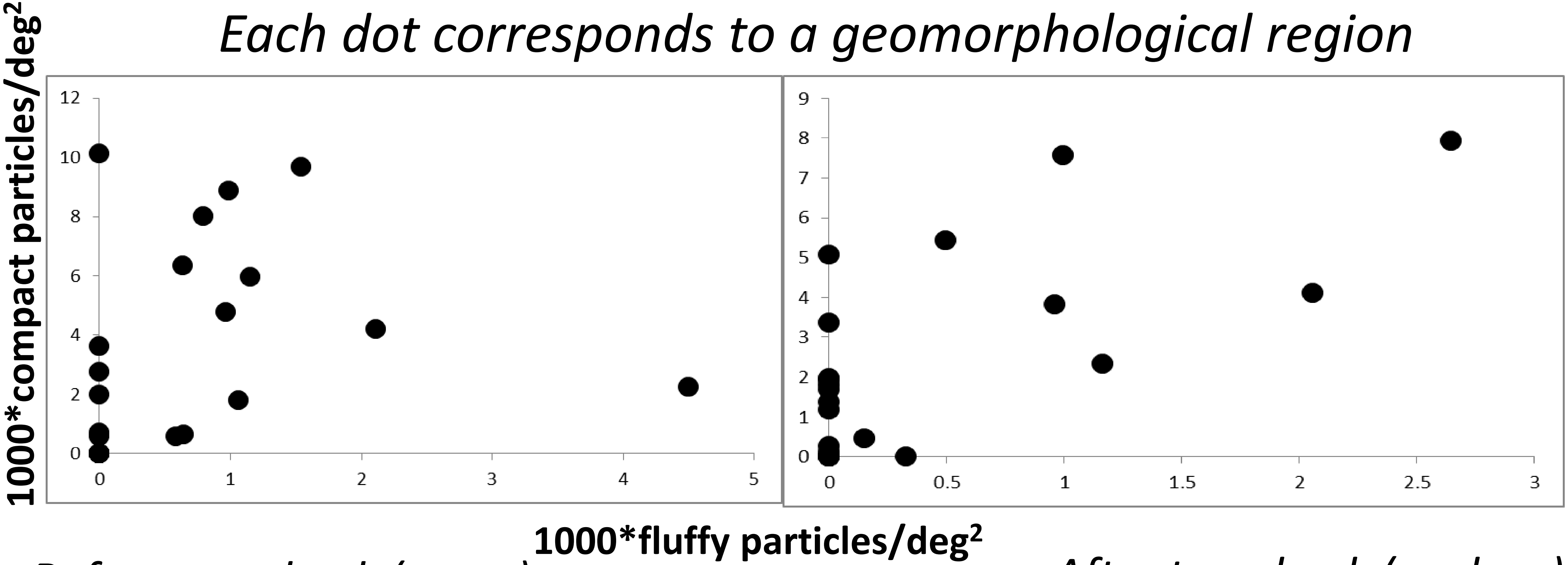
After traceback (nucleus)

Pearson coefficient:

0.7 (high correlation)

Results: Period 1

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

0.1 (no correlation)

After traceback (nucleus)

Pearson coefficient:

0.7 (high correlation)

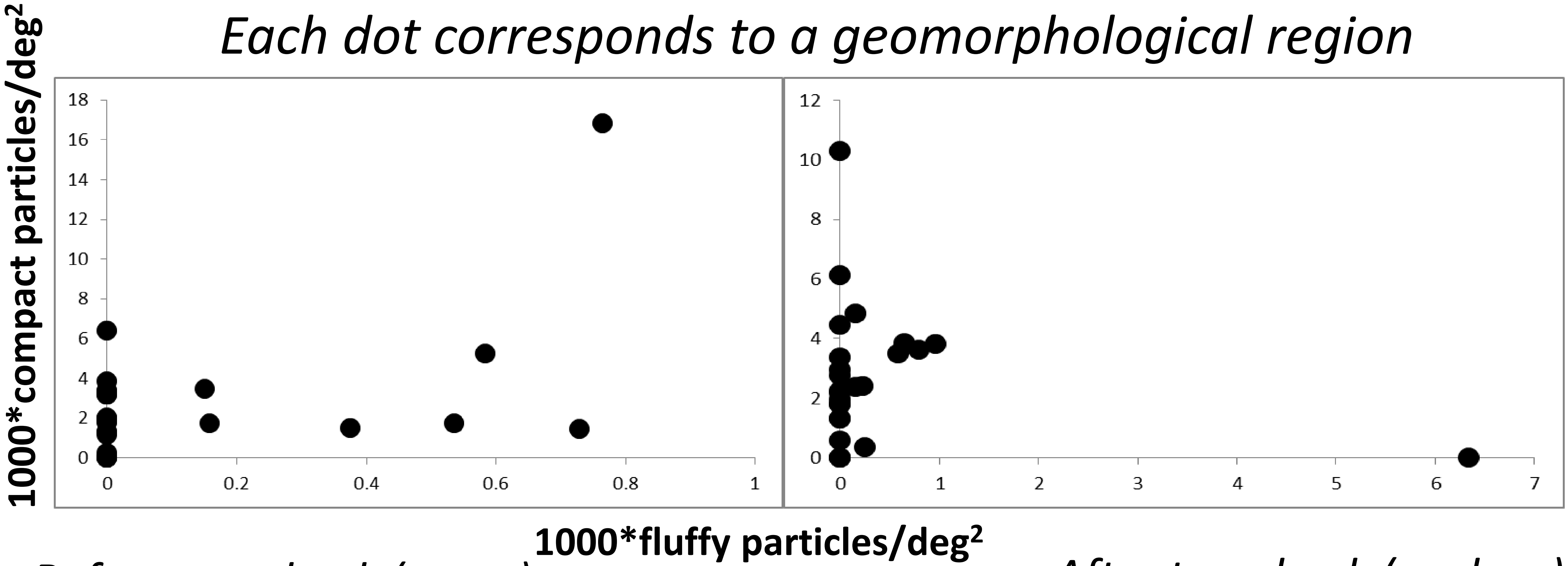
Interpretation: Periods 0-1

We confirm the results obtained by Longobardo et al. (2019):

- Distributions of **fluffy and compact** dust particles are **correlated on the nucleus**
- This correlation is **not** maintaned in the **coma due to different velocity** of the two dust populations

Results: Period 2

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

0.1 (no correlation)

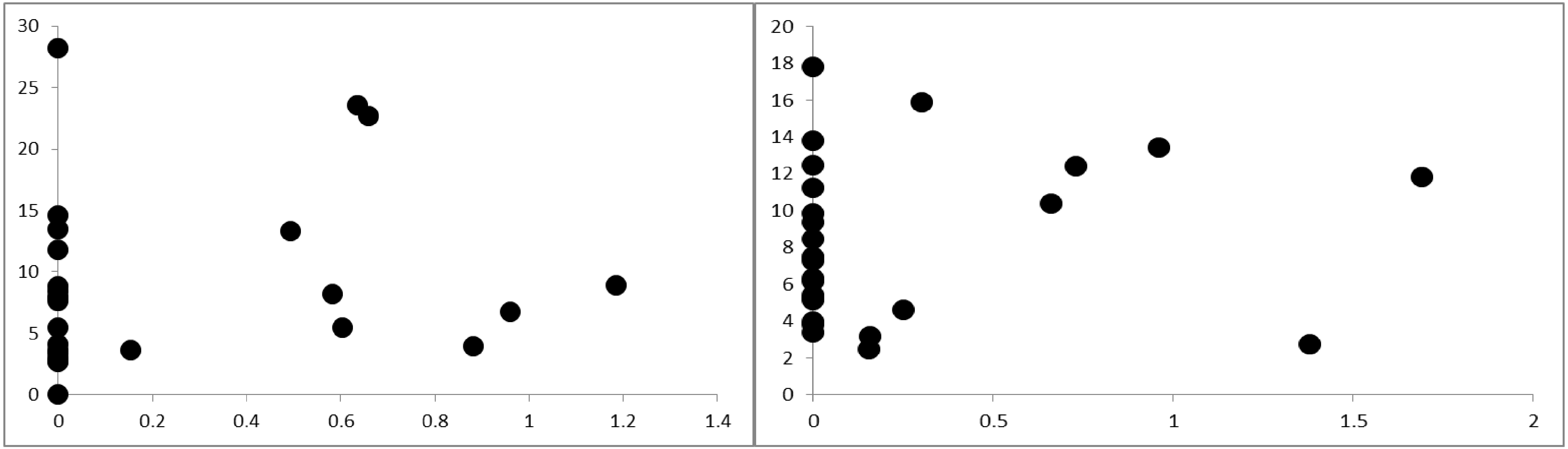
After traceback (nucleus)

Pearson coefficient:

-0.1 (no correlation)

Results: Period 3

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

0.1 (no correlation)

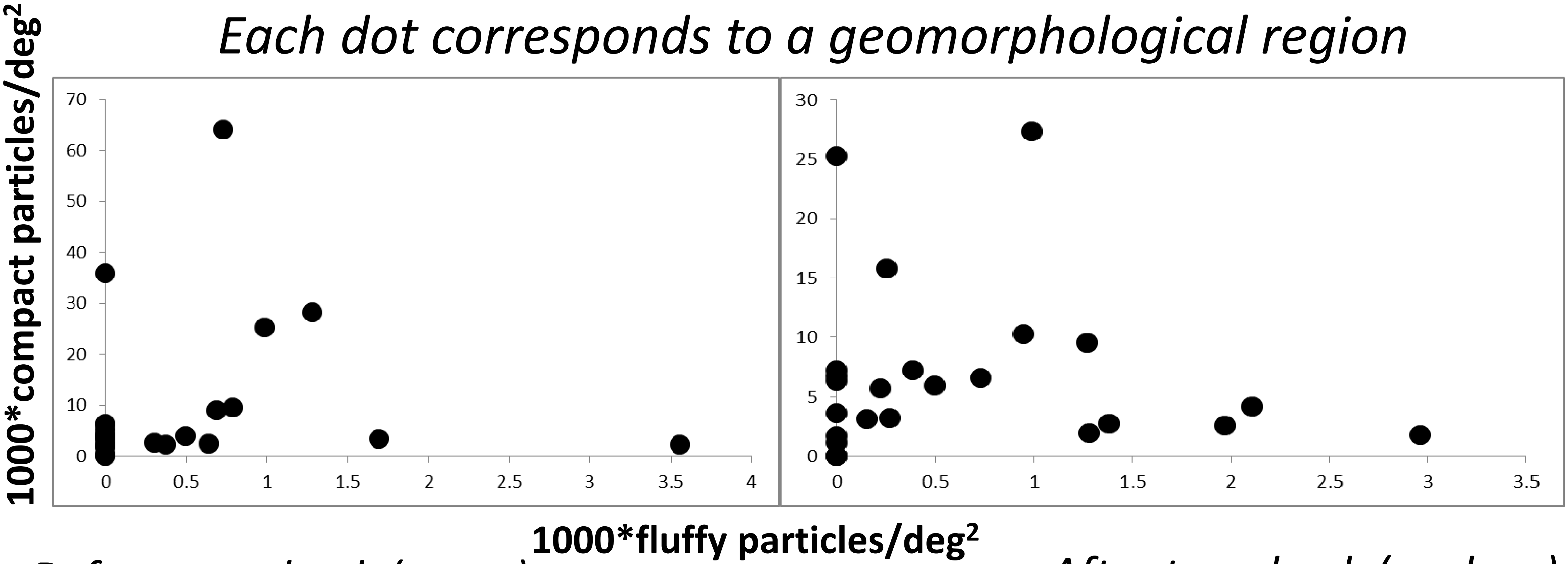
After traceback (nucleus)

Pearson coefficient:

0.1 (no correlation)

Results: Period 4

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

-0.1 (no correlation)

After traceback (nucleus)

Pearson coefficient:

0.1 (no correlation)

Interpretation: Periods 2-3-4

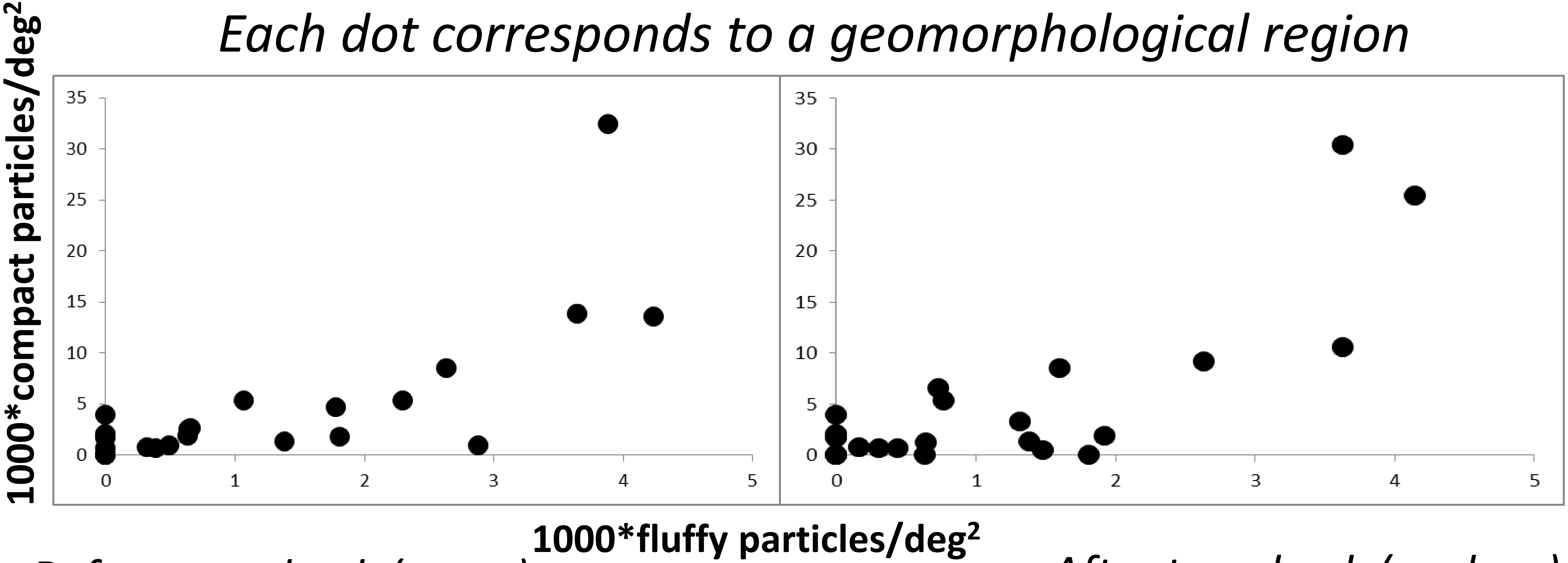
Distributions of fluffy and compact particles are not correlated on the nucleus. However, this result is unlikely, because:

- The higher spacecraft altitudes of these periods lead to **uncertainty** on the emitting regions **comparable with the area of the regions** theirselves.
- Models predict that the **motion** of fluffy dust particles is **no longer linear** above 40 km

These periods will be no longer considered in the following.

Results: Period 5

Each dot corresponds to a geomorphological region



Before traceback (coma)

Pearson coefficient:

0.8 (high correlation)

After traceback (nucleus)

Pearson coefficient:

0.9 (very high correlation)

Interpretation: Period 5

Distributions of fluffy and compact particles are correlated at the nucleus and in the coma.

This is likely due to the low spacecraft altitude, that does not allow the two dust population to separate.

Correlation between fluffy and compact dust particles is maintained up to at least 9 km.

Rough and smooth terrains (1)

For periods 0, 1 and 5, we calculated the **fraction of fluffy particles** emitted from **rough and smooth terrains**, respectively. Rough and smooth terrains were defined by El-Maarry et al. (2015, 2016).

% fluffy	0	1	Perihelion	5
Rough terrains	25±4	21±4		14±2
Smooth terrains	24±4	12±3		29±5

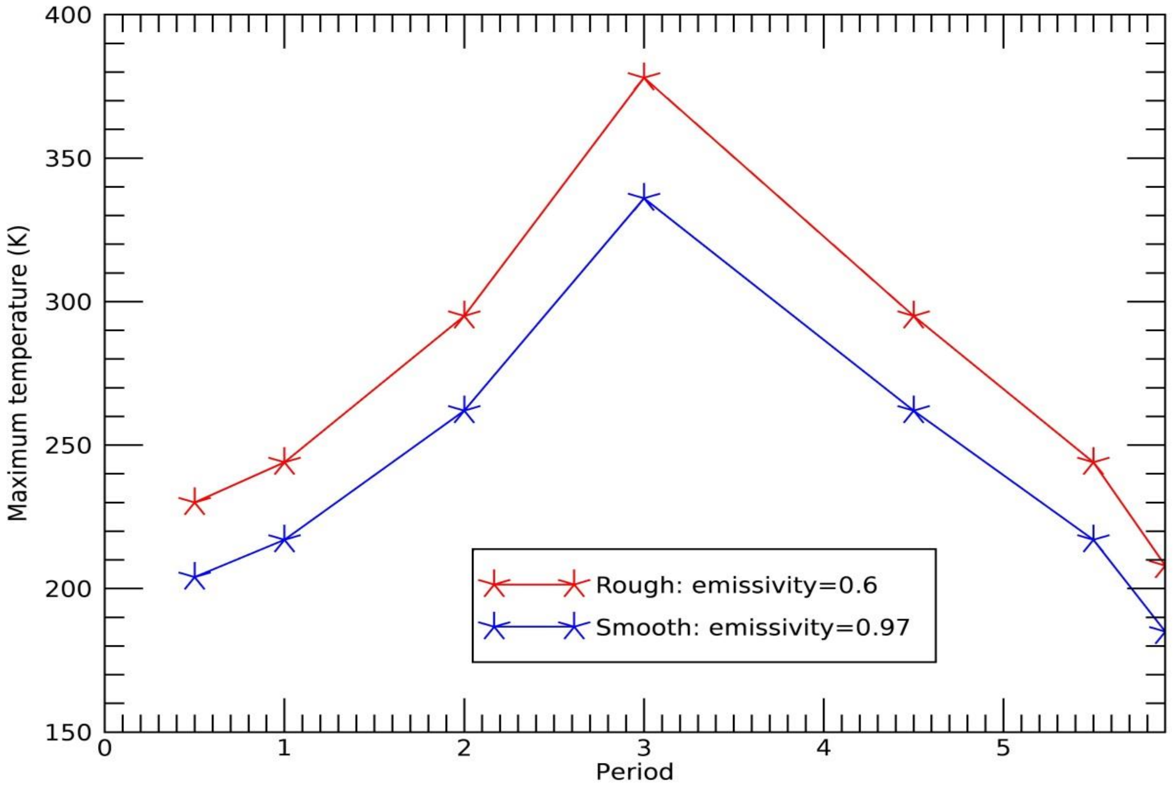
Rough and smooth terrains (2)

% fluffy	0	1	Perihelion	5
Rough terrains	25±4	21±4		14±2
Smooth terrains	24±4	12±3		29±5

With increasing cometary activity, we could expect an increasing fraction of compact particles (and thus a decreasing of fluffy ones) (e.g., Bockelee-Morvan et al., Guttler et al., 2019).

In rough terrains the minimum fraction of fluffy particles is reached after perihelion. ***Do different thermal properties of these terrains delay cometary activity?***

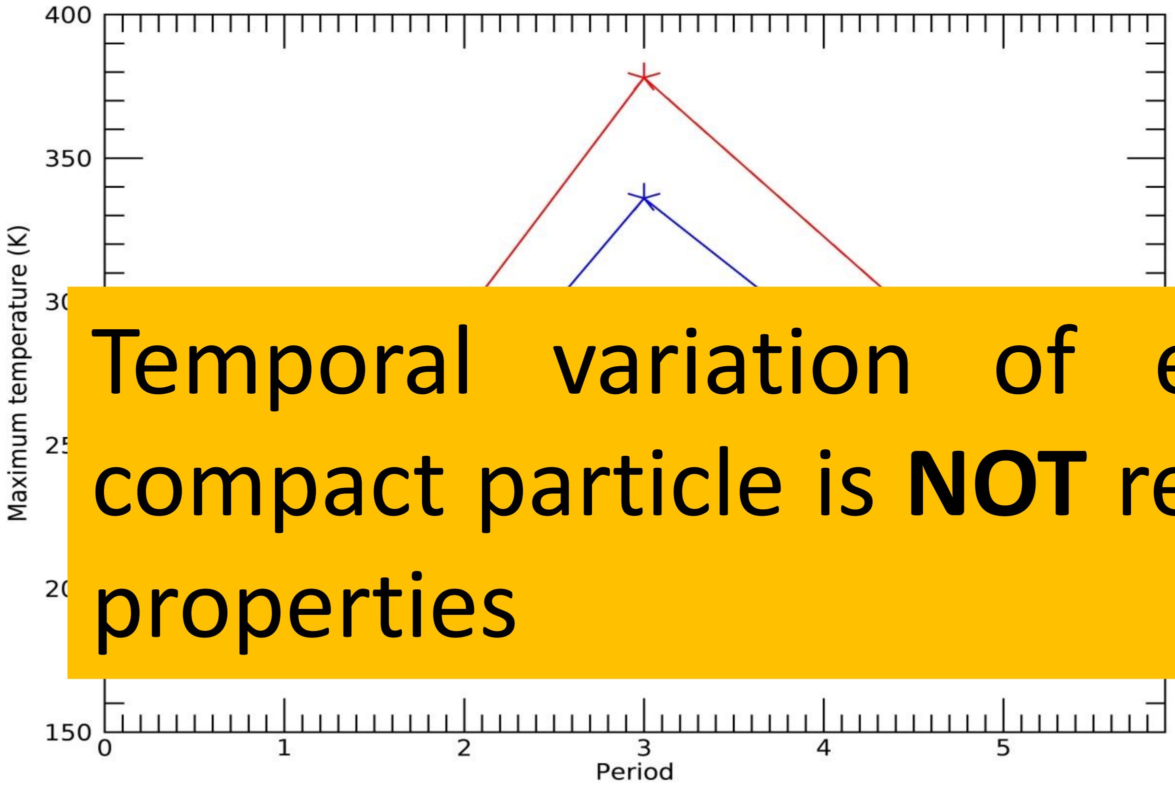
Thermal behavior



Thermal simulations (Rinaldi et al., 2019) evidenced that the **temporal temperature behavior is the same** in rough and smooth regions

Thermal inertia in rough and smooth terrains is also expected to be **similar** (Marshall et al., 2018)

Thermal behavior



Thermal simulations (Rinaldi et al., 2019) evidenced that the

Temporal variation of emission of fluffy and compact particle is **NOT** related to surface thermal properties

Thermal inertia in rough and smooth terrains is also expected to be **similar** (Marshall et al., 2018)

Dust re-deposition

Basing on existing literature (Shultz et al., 2015; Blum et al., 2017; Pajola et al., 2017), we can assume that the **dust ejected at orbital distance >3.0 AU is re-deposited dust**, whereas «direct emission» occurs for lower orbital distances. Thus, we redefined the orbital stages.

Period	Orbital Stage	Orbital distance (AU)
0A	1st inbound arc	3.6-3.0
0B		3.0-2.5
1	2nd inbound arc	2.5-2.0
5A	2nd post-perihelion	2.4-3.0
5B		3.0-3.8

Relative variation of fluffy particles

% fluffy (variation wrt period 0A)	0A	0B	1	Perihelion	5A	5B
Rough Terrains	0	+16%	+7%		-3%	-2%
Smooth Terrains	0	-10%	-16%		+2%	+1%

Uncertainties are about 3%

When approaching perihelion, the fraction of fluffy particles increase in rough terrains and decreases in smooth regions. After perihelion, it comes back to the initial values in both terrains.

***Fluffy particles are more abundant in rough, more pristine terrains*.**

Conclusions

- **Fluffy and compact particles are spread beyond** an altitude of at least **9 km** from the comet surface.
- At altitudes larger than 70 km, our traceback procedure is poorly reliable, and 3D+t models are necessary to reproduce the motion of fluffy particles
- **Fluffy particles are more abundant in rough terrains**, in line with their lower evolution degree
- **The abundance of** fluffy and compact ejected particles is **not related** to surface’s **thermal properties.**

Outline

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- Identification of the **main drivers and the effects of cometary activity**, by combining measurements of dust morphology and composition, surface geomorphology and composition, gas distribution (MIDAS, COSIMA, ROSINA)

Starting from traceback procedure…

- **Integration with numerical models**: refining assumptions, extension of traceback to perihelion period
- **Extension of dust activity vs illumination** to the entire dataset
- **Coma vs nucleus:** dust activity maps compares with exposition of water ice (VIRTIS, OSIRIS)
- **Physical properties of dust** from different terrains: looking for simultaneous GIADA-MIDAS detections

Starting from traceback procedure…

- **Composition of dust from different terrains**, possible by means of GIADA-COSIMA and GIADA-VIRTIS data fusion
- Possible **development of a cometary dust analog**, based on obtained results
- **Dust vs gas activity**: comparison of dust activity (GIADA) with gas density and activity (ROSINA, VIRTIS) to reveal gases correlated with dust emission during the different stages of the comet’s orbit

The proposal has been approved on *19th June 2019*.

The kick-off meeting was held on *2nd September 2019.*

http://www.issibern.ch/teams/characterof67p/