Looking inside Comet 67P/C-G

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I. The Rosetta mission & comet 67P/C-G

II. The internal structures of comets

III. The Imhotep region

IV. Thermal model & method

V. Results and interpretation

VI. Conclusion

Image credit: ESA/Rosetta
I. The Rosetta mission & comet 67P/C-G

The Orbiter:
• Remote and *in-situ* observations of the coma and nucleus
• 11 instruments
• 2 with strong NASA participation

The Lander:
• *In-situ* measurements at the surface of the nucleus
• Power for 3 days of operation
• 10 instruments

Images credit: ESA/Rosetta
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NASA, European Space Agency and Philippe Lamy

Image credit: ESA/Rosetta

2003

2014
I. The Rosetta mission & comet 67P/C-G

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II. The internal structures of comets

See Weissman and Lowry, Structure and density of cometary nuclei, 2007
II. The internal structures of comets

- C-G’s nucleus seems to be primordial rubble pile
- Not formed from pieces of larger parent bodies
- Cycles of sublimation and recondensation forms an “eggshell” on surface
- Ejection and deposition of dust on the surface
II. The internal structures of comets

My PhD: What does SESAME-PP tells us about the internal structure of comets (Lethuillier et al. 2016)?
II. The internal structures of comets

How can the MIRO instrument help understand the internal structure and evolution of cometary nuclei?

- MIRO is a passive microwave radiometer
- Located on the Rosetta orbiter
- Combined with spectrometer to analyze the coma
- Works at two frequencies (190 GHz, 1.6 mm and 562 GHz, 0.5 mm)
- Can help constrain the top layer of the cometary nucleus (down to 10 cm)
Located on the main lobe of the nucleus

Was observed twice by MIRO at very high spatial resolution (20/40 m).

Overserved at 3 AU from the sun before (2014) and after (2016) perihelion
III. The Imhotep region

- Located on the main lobe of the nucleus
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- Overserved at 3 AU from the sun before (2014) and after (2016) perihelion
III. The Imhotep region

Geomorphology of the Imhotep region on comet 67P/Churyumov-Gerasimenko from OSIRIS observations, Auger et al. 2015.
IV. Thermal model & method

Temperature and composition dependent:
- Thermal inertia
- Specific heat
- Electrical properties
IV. Thermal model & method

What assumptions are made?

• The ice is crystalline water ice
• The dust is chondritic in nature
• No significant horizontal changes in the areas observed
IV. Thermal model & method

In order to calculate the illumination we use a 12 million facet shape model of the nucleus and SPICE kernels.

“Full” calculation
- Compute insolation for each tile in the footprint
- Compute temperature profile for each tile in the footprint
- Compute antenna temperature from weighted average

Approximate calculation
- Compute insolation for each tile in the footprint
- Compute beam averaged insolation
- Compute average temperature profile from average insolation
IV. Thermal model & method
IV. Thermal model & method

Outgassing of icy bodies in the Solar System – II: Heat transport in dry, porous surface dust layers

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Radar properties of comets: Parametric dielectric modeling of Comet 67P/Churyumov–Gerasimenko

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V. Results and interpretation

VI. Conclusion
• The electrical properties of the water ice/dust/vacuum mixture is unknown.

• To calculate it we can use mixing laws but each mixing law only applies to certain situation.

• To overcome this problem we use the Hashin & Shtrikman bounds (1962).
IV. Thermal model & method

![Graph showing the dielectric constant of mixture as a function of the fraction of water ice.

- **Upper bound**
- **Lower bound**

The graph illustrates how the dielectric constant of a mixture decreases as the fraction of water ice increases, with the upper and lower bounds representing different scenarios or error margins.

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Input parameters:
- Dust/Ice/Vacuum fraction of the top layer
- Dust/Ice/Vacuum fraction of the bottom layer

Run model for several comet days and nights until it converges to a stable diurnal cycle

Calculate the root mean square difference between the modeled and observed brightness temperatures

Explore parameter space until a global minimum for the root mean square is found.
Using a Python ensemble sampling toolkit for affine-invariant MCMC (emcee: The MCMC Hammer. Foreman-Mackey et al. 2013):
IV. Results and interpretation

- For the first time we obtained a good fit in both the SMM/MM channels for both observations of the Imhotep region.
- Error bar in the model due to uncertainties in the electrical and thermal properties.
- The 2016 fit can be improved by being more selective with the observed areas.
• Big difference between both layers

• We have a thermally insulating layer on the top.

• The thermal inertia decreased between 2014 and 2016.
**IV. Results and interpretation**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Region observed</th>
<th>Thermal inertia (J/m²/K/S¹/²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIRO</td>
<td>All nucleus (2014)</td>
<td>10-50</td>
</tr>
<tr>
<td>MIRO</td>
<td>Imhotep and Ash (September 2014)</td>
<td>10-30</td>
</tr>
<tr>
<td>MUPUS</td>
<td>Abydos (November 2014)</td>
<td>50 – 120</td>
</tr>
<tr>
<td>MIRO</td>
<td>Seth, Ash and Aten (September 2014)</td>
<td>&lt;80</td>
</tr>
<tr>
<td>VIRTIS</td>
<td>Seth, Ash and Aten (September 2014)</td>
<td>40-160</td>
</tr>
<tr>
<td>MIRO</td>
<td>Imhotep (October 2014 &amp; July 2016)</td>
<td>60-64</td>
</tr>
</tbody>
</table>
IV. Results and interpretation

• At both dates we are in presence of top layer composed primarily of porous dust (P > 70 %).

• Between both observations there is small change in the properties.

• The change is not significant when compared to the error bar.
IV. Results and interpretation

- At both dates we are in presence of more compact bottom layer (P < 50 %).
- The water ice volume in the bottom layer is higher than the dust volume (15-20 % more).
- The models seem to imply that there is less water ice and more porosity in 2016 than in 2014.
IV. Results and interpretation

The results and interpretation section discusses the findings from the Rosetta mission and comet 67P/C-G. The internal structures of comets are explored, focusing on the Imhotep region. A thermal model and method are presented, followed by detailed results and interpretation. The conclusion summarizes the findings and implications of the research.
• We obtained for the first time a good fitting model to the high resolution measurements made by MIRO of the Imhotep region.

• We observe a decrease in water ice content and an increase in porosity consistent with a sublimation of water ice in the subsurface as the comet went by perihelion.

• To obtain a good fit, conservative assumptions were made, resulting in error bars on the composition that are as big as the changes observed.

• Explore additional assumptions on the subsurface.

• Explore different geomorphological regions
What’s next?

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