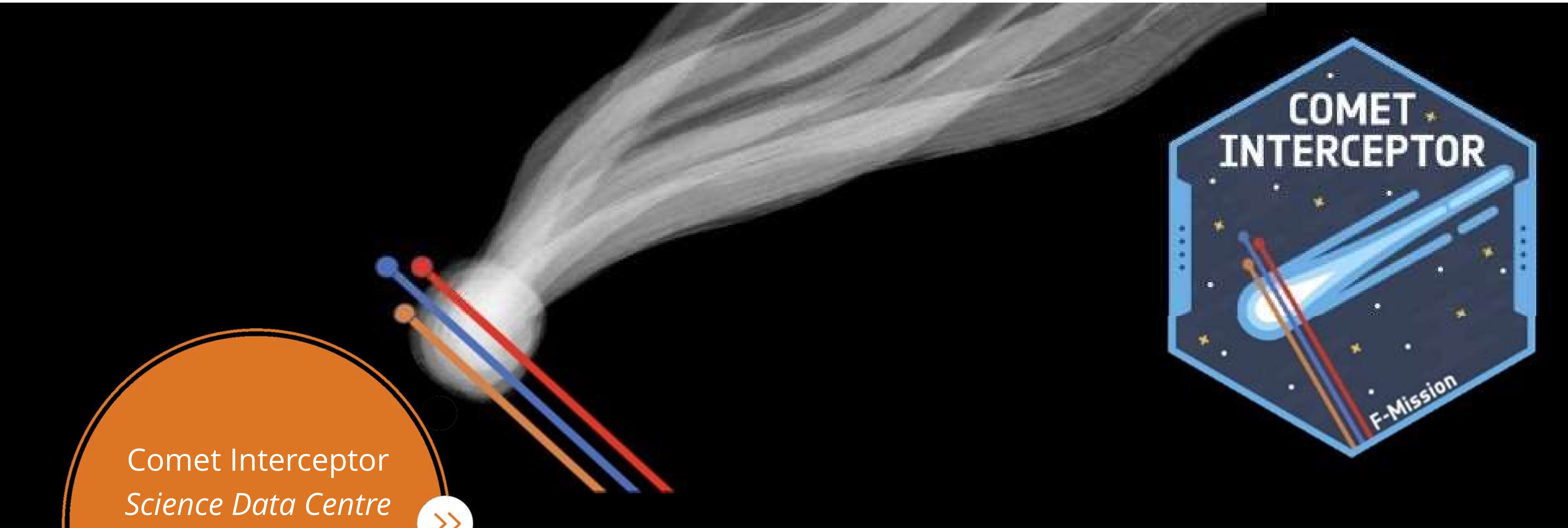

Comet Interceptor
Science Data Centre
DFP
COMPLIMENT

Exploiting multi-point in situ measurements during the Comet Interceptor comet flyby

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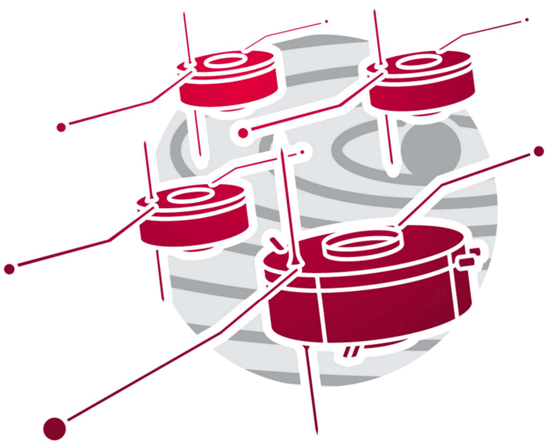
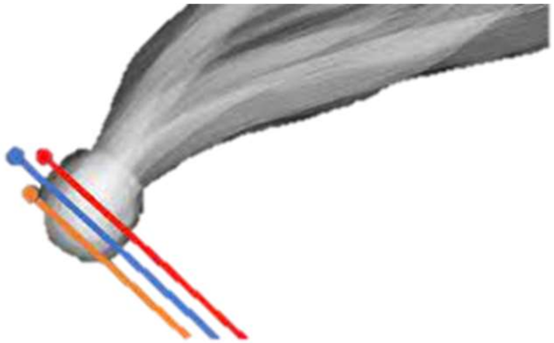
EGU22-6920
COMET-BIRA-COM-HO-009_i1.0, 2022-05-24

Multipoint in situ data analysis



Multipoint data analysis experience from Cluster:

- 4 simultaneous non-coplanar measurement points → 3D gradients
- good cross-calibration (identical instruments) + position & attitude knowledge to extract information from differences
- different approaches needed for closely or widely separated S/C



For Comet Interceptor:

- during flyby the spacecraft are widely separated, in the sense that the separation is on the coma expansion length scale

Multi-point data from Comet Interceptor

B-field

- 3 simultaneous non-coplanar measurement points
- good individual calibration possible (DFP-A/FGM, PS-B2/MAG, DFP-B2/FGM)
- Limited position & attitude knowledge on B2 as the B-field is a vector quantity

Dust

- 2 simultaneous measurement points
- Identical instrument (DFP-A/DISC and DFP-B2/DISC)

Ion density

- 2 simultaneous measurement points
- Different instruments (DFP-A/SCIENA + COMPLIMENT and PS-B1/ICA)

Electron density

- 1 simultaneous measurement point (DFP-A/COMPLIMENT and DFP-A/LEES)
- Option: use inter-satellite link to obtain n_e between A and B1/B2
- good calibration possible (DFP-A/COMPLIMENT)

Model assumptions for CI flyby

Close to the nucleus, we need to rely on models to ingest multi-point data. Some simplifying assumptions that can be made:

- The flyby is fast, so structures might be considered static, i.e. time derivatives are zero, at least for the large-scale structures.
- We may consider spatial structures that are moving at a known speed (e.g. inferred from nucleus rotation).
- Neutral gas structures can be assumed to be radial features; for plasma this may be the case too under certain circumstances.
- Structures sampled in situ can be constrained from remote sensing observations made before or after closest approach ...

Of course, better have firm data in hand than having to make assumptions...

Lessons from a toy problem

We use a simple problem to illustrate what is possible.

Consider the neutral gas production in a flow tube

$$n(r,\varphi,\theta) = \frac{q(\varphi,\theta)}{(r/r_{comet})^{\gamma}}$$

where

- γ describes the radial dependency
- $q(\varphi,\theta)$ is the local gas production rate at the surface
  - $q(\varphi,\theta) = q_0 \left(\frac{1+\cos\psi}{2}\right)^{A}$ with $\psi(\varphi,\theta)$ the solar zenith angle and $A = 2$
  - + superimposed conical jets

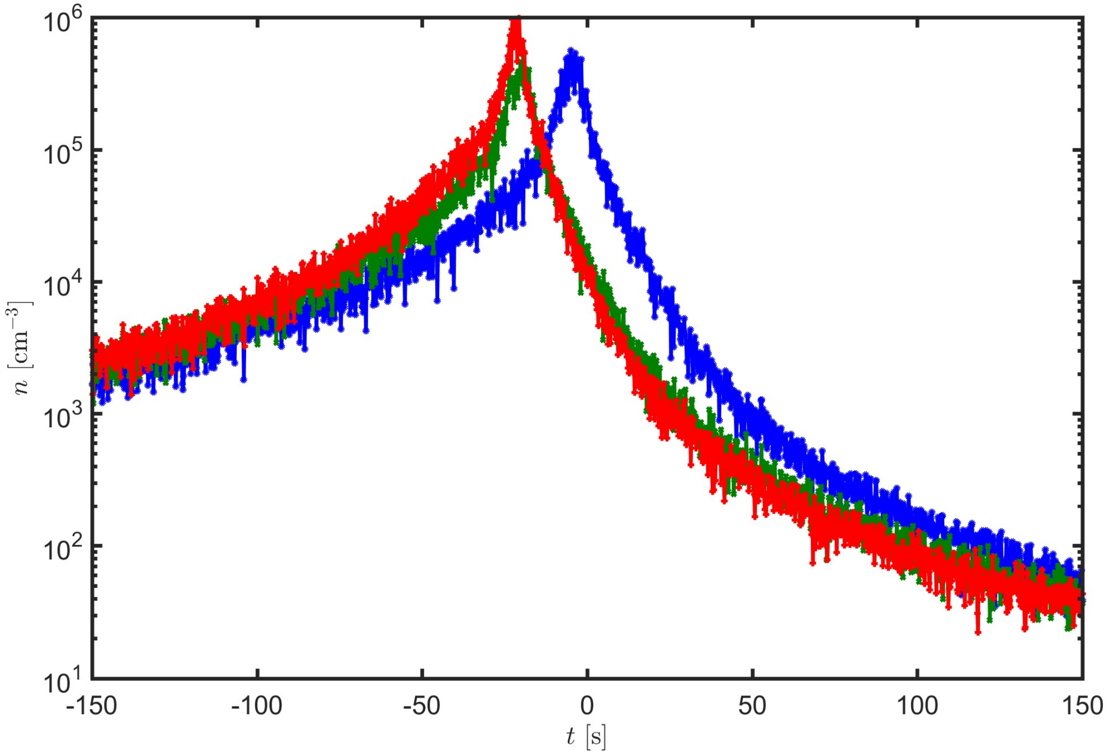
In the example we ignore the comet rotation on the time scale of the flyby.

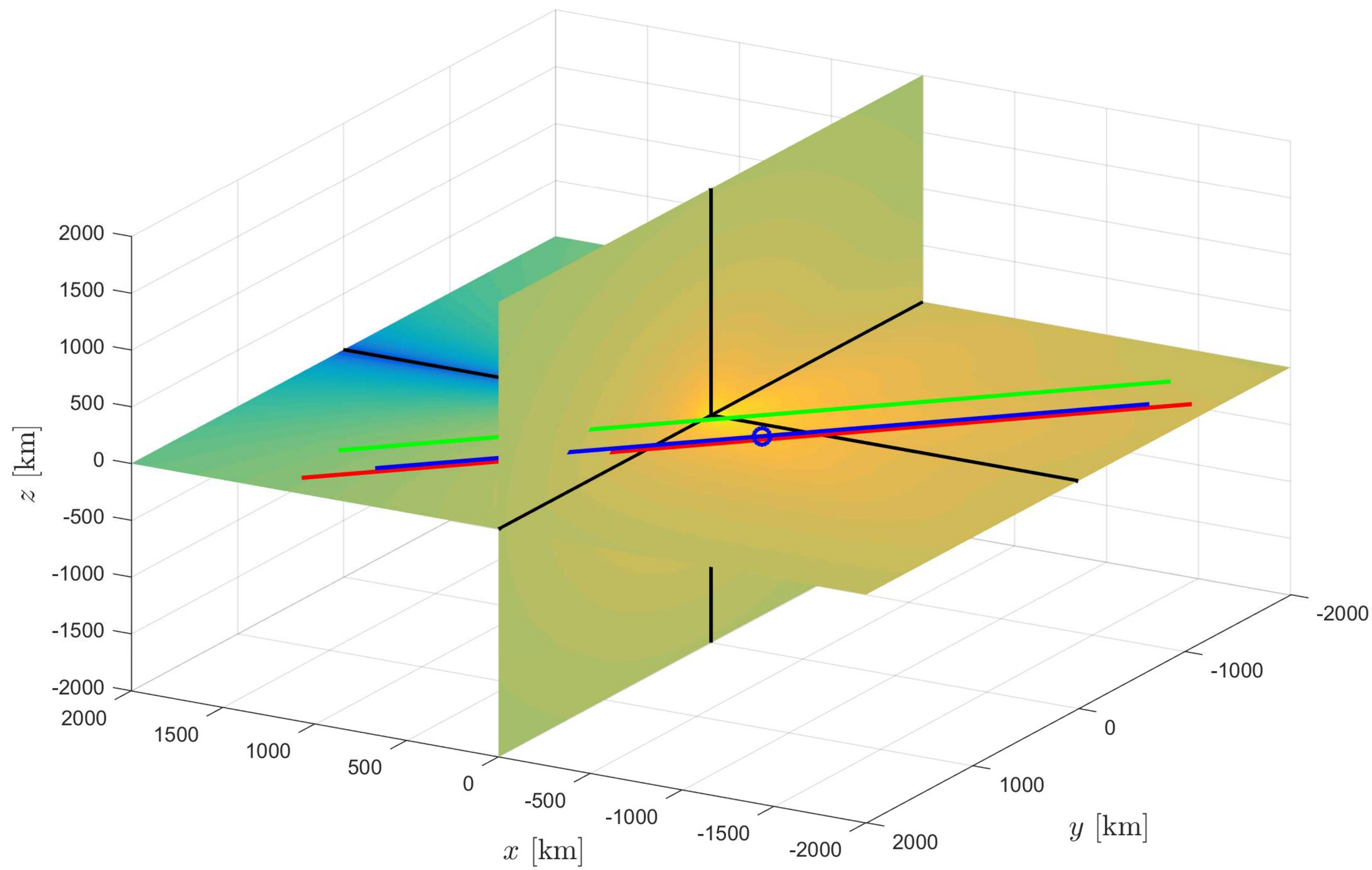
Model comet

We consider a static situation with a day-night asymmetry in the gas production and with “jets”. We fly spacecraft A, B1 and B2 through this environment and record n_A (blue), n_{B1} (green), and n_{B2} (red).

Comet radius r_{comet} = 10 km
Gas production rate Q_{gas} = 100 kg/s
Average gas molecule mass m_{ave} = 18 amu
Neutral gas speed v_{gas} = 1 km/s
Exponent γ = 2.0
Measurement errors of 20%

Flyby speed V_{flyby}= 60 km/s
Closest approach
D_{ca}^{A} = 1000 km
D_{ca}^{B1} = 910 km
D_{ca}^{B2} = 670 km
Along-track separation = 900 km





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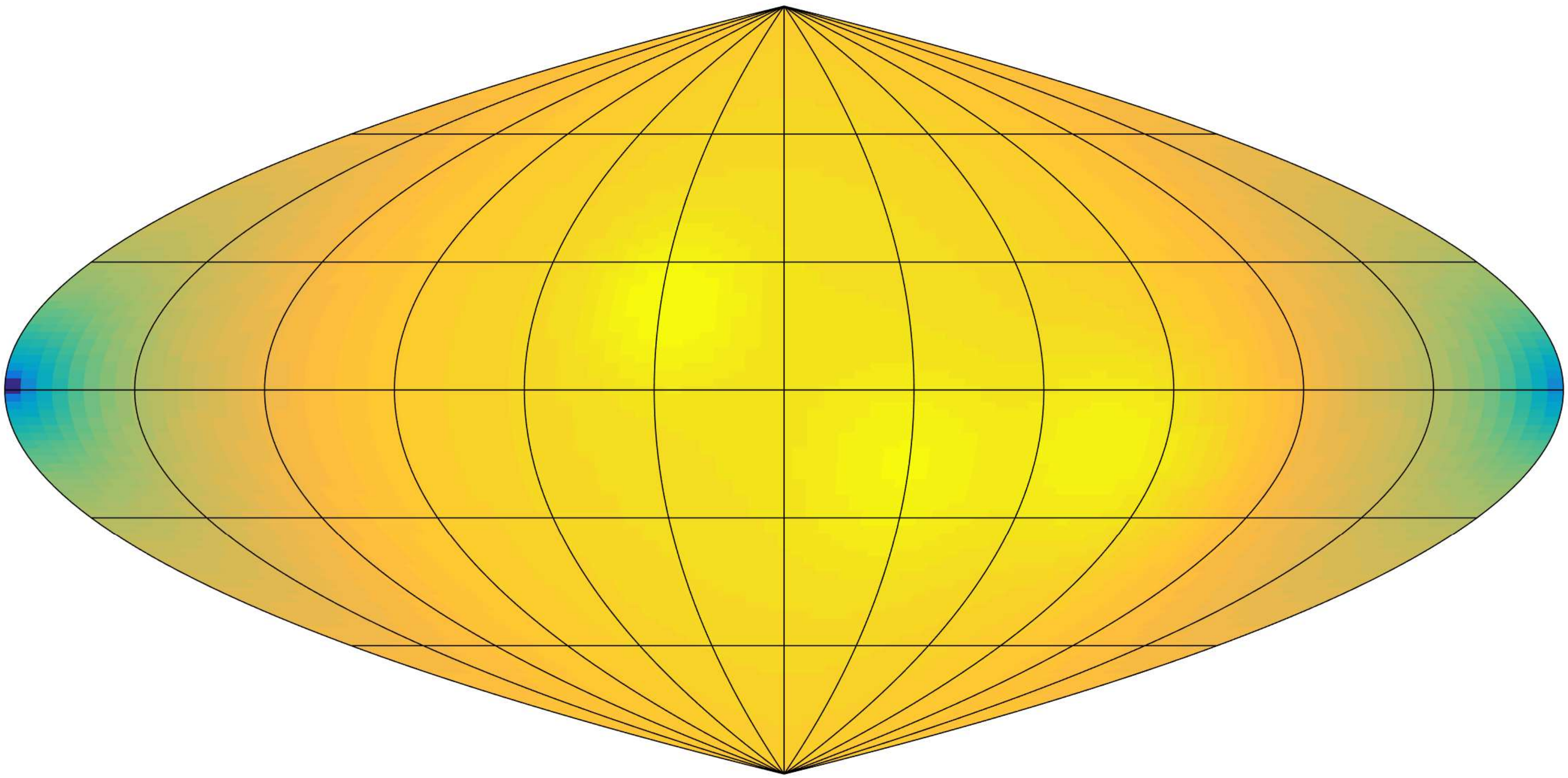


Approach #1

Model: constant outgassing, ignoring jets, determine parameters by least-squares optimization

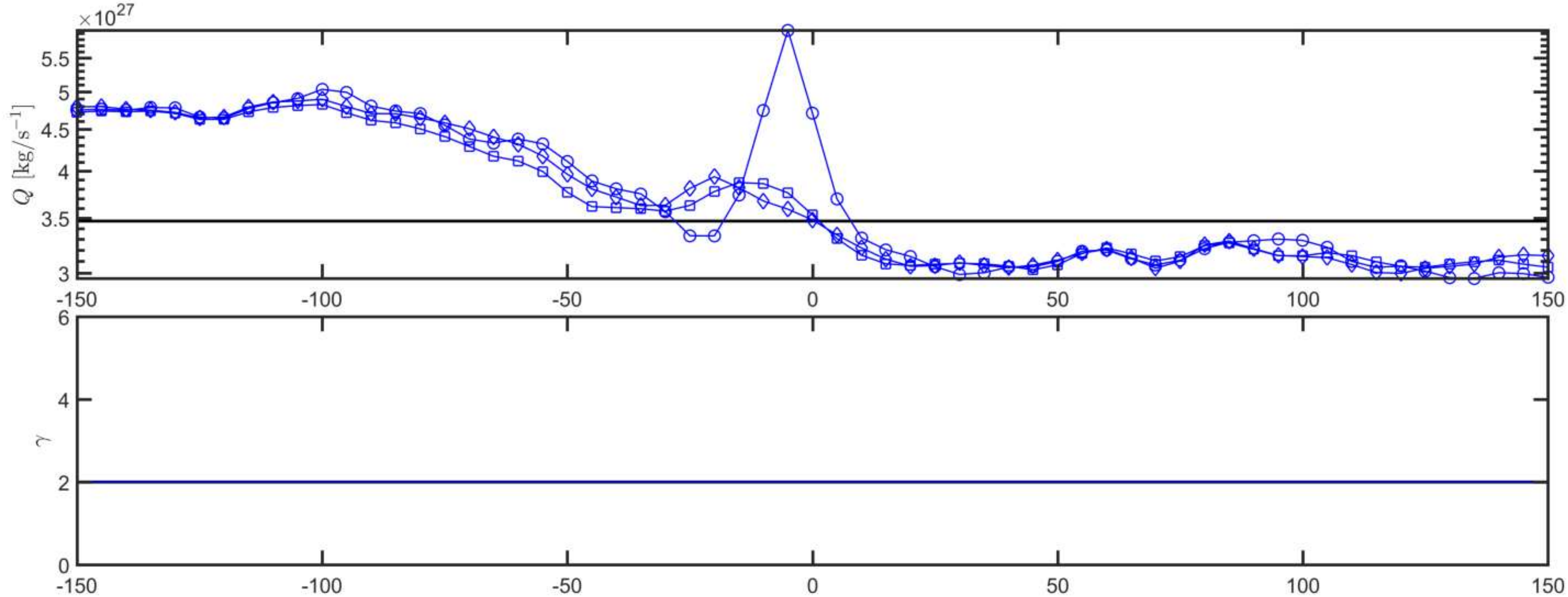
Parameters	S/C	$\boldsymbol{Q}$ [particles/s] 3.472×10^{27}	$\boldsymbol{\gamma}$ 2.000	$\boldsymbol{A}$ 2.000
$\boldsymbol{Q}$	A	3.533×10^{27}		
	A+B1	3.496×10^{27}		
	A+B1+B2	3.510×10^{27}		
$\boldsymbol{Q}, \boldsymbol{\gamma}$	A	3.287×10^{27}	1.988	
	A+B1	3.394×10^{27}	1.995	
	A+B1+B2	3.909×10^{27}	2.018	
$\boldsymbol{Q}, \boldsymbol{\gamma}, \boldsymbol{A}$	A	2.064×10^{27}	1.871	2.265
	A+B1	2.026×10^{27}	1.870	2.252
	A+B1+B2	2.304×10^{27}	1.887	2.262

Distinguishing SZA and radial variations (γ and A) simultaneously seems hard.
If A is known, γ can be found accurately, even with a single s/c.

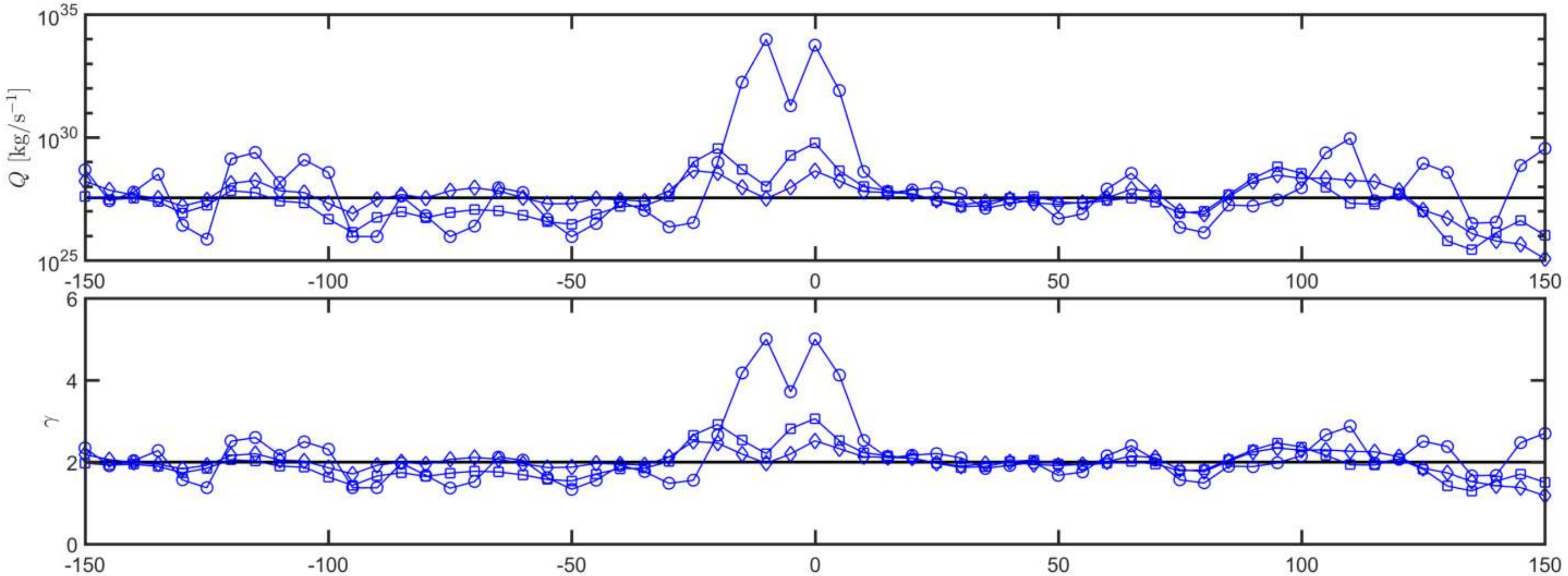
Approach #2

Model: Spatially and temporally variable outgassing, apply the least-squares fitting procedure per sliding t window (half-width ~10 s).

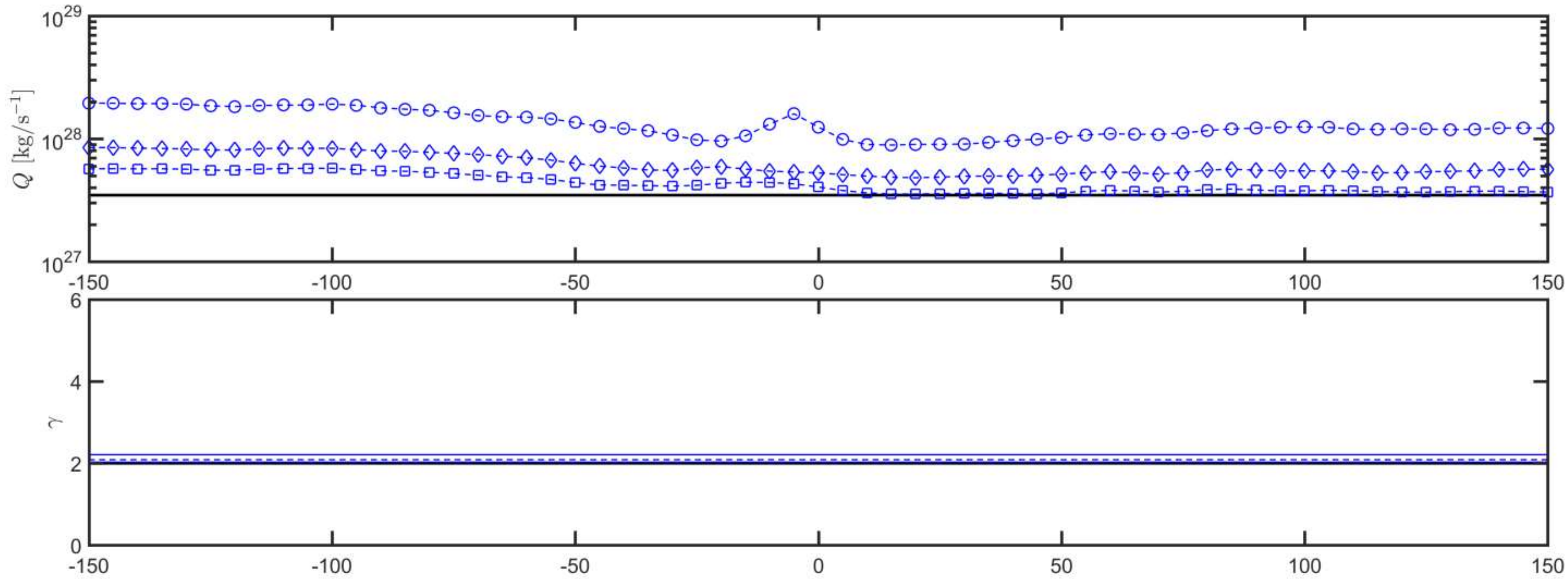
- Determine $Q(t)$ assuming that $\gamma = 2$ is known a priori
- Determine $Q(t)$ and $\gamma(t)$
- Even better: Knowing that $\gamma(t)$ is a physical property, which should not depend on time, use a 2-level optimization to determine $Q(t)$ and a unique γ



Given γ, determination of $Q(t)$ works well, but better with > 1 s/c.



Simultaneous determination of $\gamma(t)$ and $Q(t)$ is troublesome, although the situation improves with more s/c.

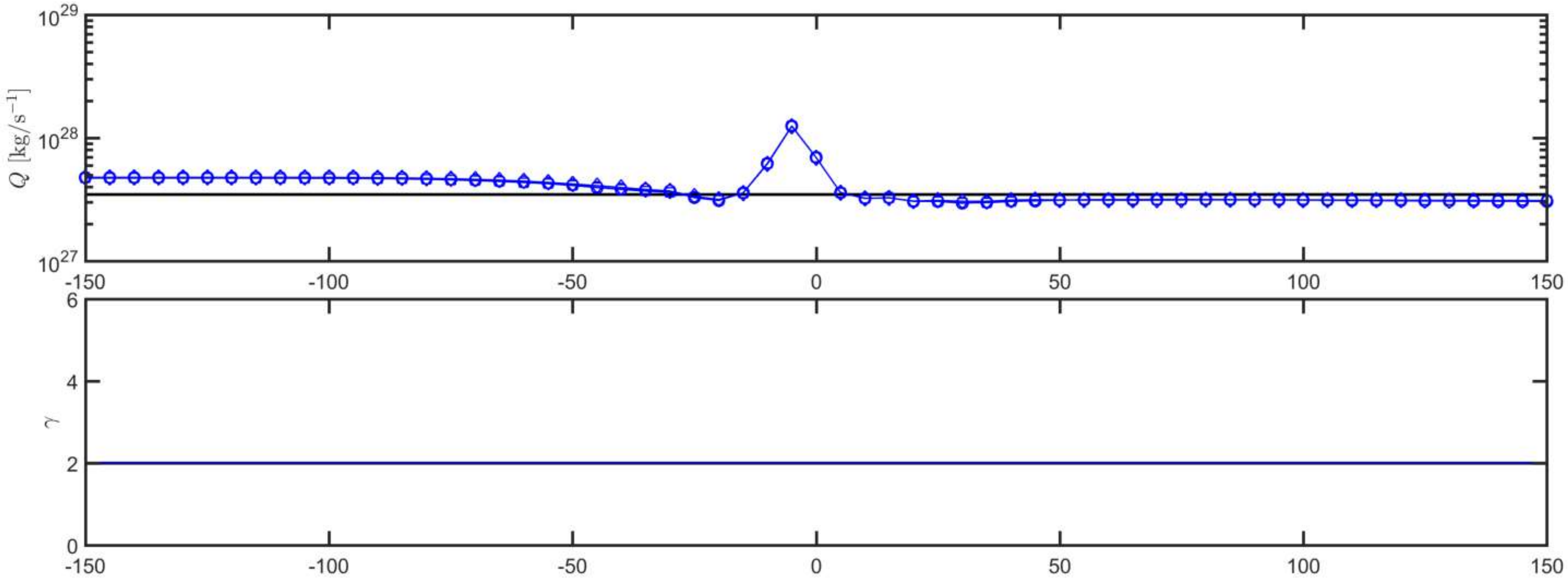


Simultaneous determination of γ and $Q(t)$ is fine, especially with > 1 s/c. Small deviations in the optimal γ lead to systematic changes in $Q(t)$, but the shape of the profile is OK.

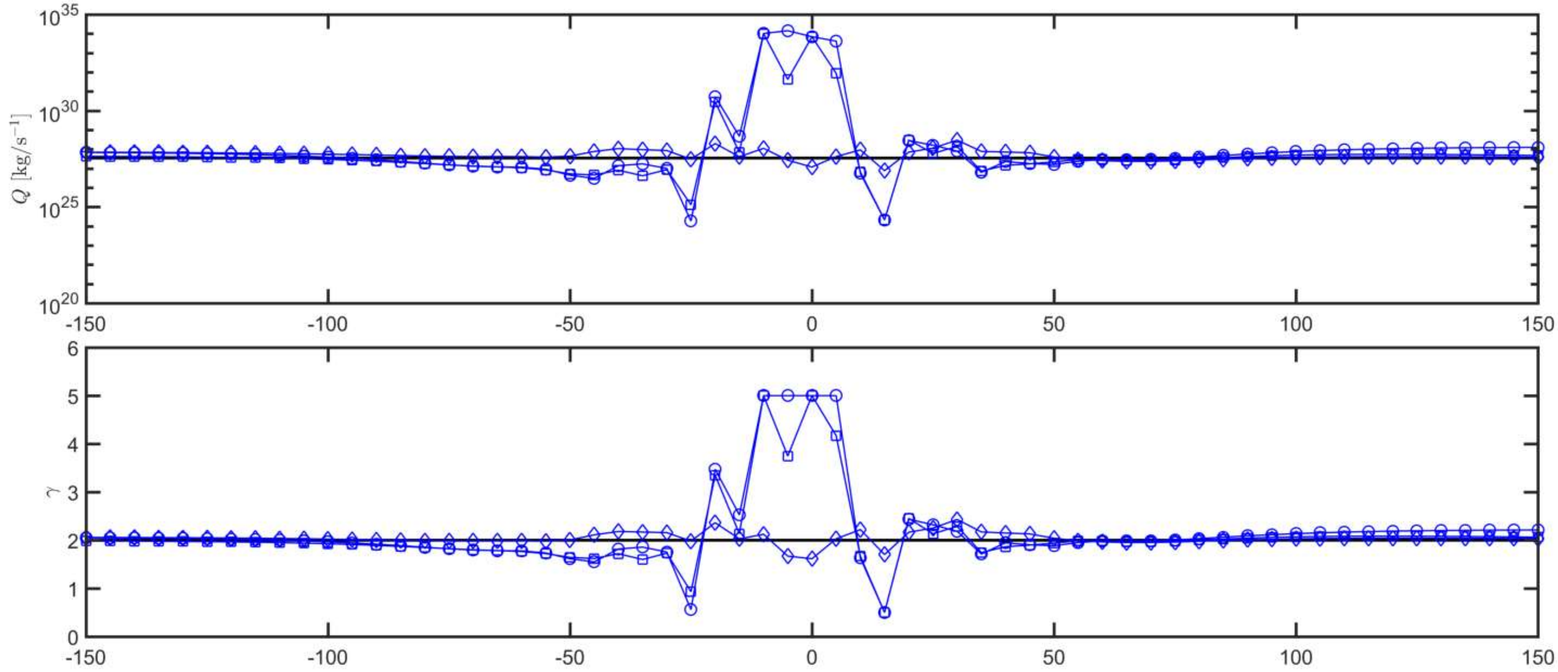
Approach #3

Model: Spatially and temporally variable outgassing, determine $\gamma(\varphi, \theta)$ and $Q(\varphi, \theta)$ along the spacecraft track by applying the same least-squares fitting procedure per sliding position window (angular half-width ~10°).

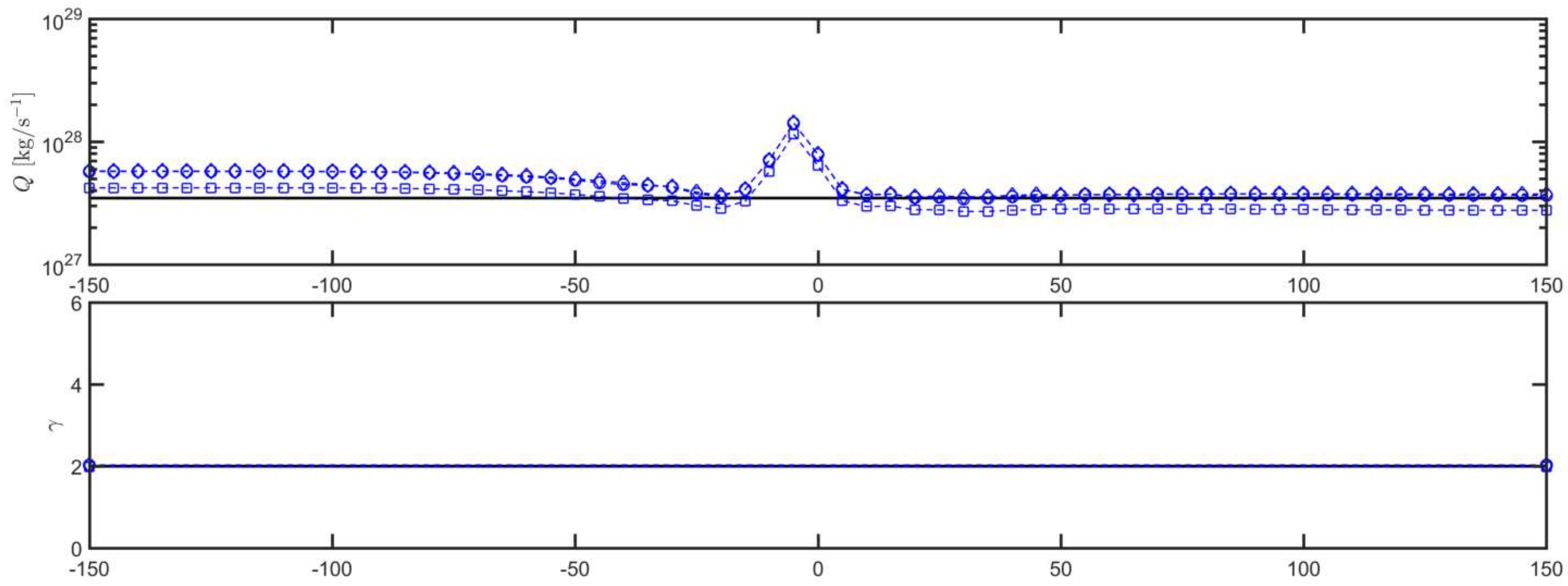
Better model: Knowing that $\gamma(\varphi, \theta)$ is a physical parameter, which should not depend on time, we use a 2-level optimization to determine a unique γ and $Q(\varphi, \theta)$.



Given γ, determination of $Q(\varphi, \theta)$ works well, even with a single s/c.



Simultaneous determination of $\gamma(\varphi,\theta)$ and $Q(\varphi,\theta)$ is not good, but the situation improves with more s/c.



Simultaneous determination of γ and $Q(\varphi, \theta)$ is fine, even with 1 s/c.

But of course only $Q(\varphi, \theta)$ below the s/c trajectories is found.

Conclusions and Outlook

- Multipoint data analysis tools are useful.
  - Sometimes even works with a single spacecraft
  - The more spacecraft, the better.
  - Being able to make physical assumptions helps.

- In situ sampling only provides limited information in terms of angular coverage of the comet surface.
  - Trade-off possible between radial, along-track and across-track separation of the spacecraft.

- Move to multi-instrument data analysis
  - Proper intercalibration of instruments will be needed
  - Combine in situ and remote sensing data

THANK YOU!
MORE INFO?

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Description of a toy problem

We use a 2D toy problem to illustrate what is possible.

Consider the neutral density to be

$$n_{gas}(r,\theta) = \frac{q_{gas}(\theta)}{v_{gas}} \left(\frac{r_{comet}}{r}\right)^2$$

with θ the solar zenith angle and $q_{gas}(\theta)$ the local gas production rate.

Let the net amount of ionization created in a stream tube be proportional to the neutral density n_{gas}^{γ} with a certain power γ.

Assuming radial transport of electrons along the streamline one then has

$$n_e(r,\theta) = \frac{\alpha}{3-2\gamma} \frac{q_{gas}^{\gamma}(\theta)}{v_{gas}^{\gamma+1}} \frac{r_{comet}^{2\gamma}(r - r_{comet})^{3-2\gamma}}{r^2}$$

In summary, the electron density depends on r and θ, with

- parameter γ describing the radial dependency
- and $Q_{gas}(\theta) = 4\pi r_{comet}^2\, q_{gas}(\theta)$ giving the distribution as a function of θ.