Optical observations of comet P/Temple 1

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Observations of comet P/Tempel 1 at optical wavelengths

Before and after impact: monitoring

• Gas production rates
  - „classical“ optical long-slit spectroscopy: CN, C3, C2, NH2
  - variation along heliocentric distance: difference before – after?
  - compare with measurements of parent species at radio, IR

• Dust production rates
  - measure Afrho parameter, compute dust production rate with model
  - variation along heliocentric distance: difference before – after?
  - combine with IR data to determine dust parameters

• Coma morphology
  - presence of jets and/or outbursts
  - new features during impact?
  - duration of new features (jets, shells)?
Example: Long-term monitoring of the gas activity of comet Hale-Bopp

- optical long-slit spectra of comet Hale-Bopp, $r = 4.6 - 2.9$ AU, $r = 2.8 - 12.8$ AU
- derive CN production rates
  comparison with HCN shows no indications for significant additional sources of CN
  dependence of production rates on $r$ indicates near-surface sublimation

Rauer et al., 2003, A&A 397, 1109-1122
Gas production rates of C2H2 and C2H6 from C2 and C3

• Simultaneous long-slit spectra of C2 and C3 (Hale-Bopp observing campaign)

• use chemical model of related C-chemistry (ComChem model, e.g.: Huebner et al., 1987; Boice et al., 1998)

• compute spatial coma profiles of C2 and C3

• scale by factor to measured profiles
determine parent production rates

very good agreement with direct measurements of C2H2 and C2H6

We currently investigate use of simplified model approach.
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Model for computation of dust production rates

- 1-D, isotropic emission
- Euler-equations solved for gas flow
- On surface: T from energy balance (irradiation, sublimation of H\textsubscript{2}O and reradiation)
- active surface fraction, f
- gas production rate scaled from OH observations and f
- dust treated as test particles
- Equation of motion of a spherical dust particle in the gas flow, influenced by gas drag and nucleus gravity
- compute the maximum dust size lifted of the nucleus: \(a_{\text{max}}\) results from the balance of gravity and acceleration due to gas drag
- with the resulting dust terminal velocity \(v(a)\), the dust mass production rate can be determined with assumptions on the albedo, phase function, dust density and dust size distribution using (Jorda 1995):

\[
Q_{M} = \frac{2\pi}{3} \cdot \frac{f \rho}{A_{BD}(\beta)} \left( \int_{a_{1}}^{a_{\text{max}}} \frac{f(a) \cdot a^{2}}{v(a)} \, da \right)^{-1} \int_{a_{1}}^{a_{\text{max}}} \rho_{\text{dust}}(a) \cdot a^{3} f(a) \, da
\]
The dust-to-gas ratio of comet Hale-Bopp versus heliocentric distance.

- Afrho determined in spectra of Hale-Bopp long-term observing campaign
- The Afrho/gas ratio varies more than one order of magnitude
- The dust to gas mass ratio computed with our model remains nearly constant.
- The difference is caused by the variation of dust velocity with heliocentric distance.
Dust velocities versus heliocentric distance

Slope of gas velocity versus distance differs significantly from simple sqrt(r) dependency use gas dynamical model

Resulting dust velocities are in good agreement with observed velocities.
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Comet P/Churyumov-Gerasimenko

Data for Afrho and OH from LOCD data base

Weiler et al., 2004, submitted
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Comet P/Churyumov-Gerasimenko

- observed at Thüringer Landessternwarte Tautenburg, Germany
- 2m Schmidt telescope
- date: 27.3.2003
- FOV: 16,8x16,8 arcmin (sub-frame, total FOV: 3x3 degree)
- R filter
- 36 min exposure time
- comet magnitude: ~14 mag
- $r = 2.6 \text{ AU}, \Delta = 1.7 \text{ AU}$
Comet P/Churyumov-Gerasimenko

- left: R-filter image after subtraction of a mean coma intensity profile (taken in March 2003 with the 2m telescope at TLS)

- right: deviation of the coma intensity from the mean intensity

Comet P/Churyumov-Gerasimenko

-1.93m at Observatoire de Haute Provence, France
-CARELEC medium-resolution spectrograph
-date: 10/11.2.1996
-exposure time: 50 min
-comet magnitude: ~11 mag
-r = 1.3 AU, Δ = 1.2 AU
Comet P/Tempel 1: example for dust model application

Model parameters used:
- $Q(\text{OH}) = 10^{28} \text{ s}^{-1}$  (Osip et al., 1992)
- active fraction: 4.6 %
- nucleus radius: 3 km  (Fernandez et al., 2003)

- maximum grain size: 5-14 cm
- terminal gas velocity: 837-845 m/s

- $r = 1.91 \text{ AU}$, $Q(\text{dust}) = 328 \text{ kg/s}$
- $r = 1.586 \text{ AU}$, $Q(\text{dust}) = 471 \text{ kg/s}$
Observing P/Tempel 1

Before and after impact: monitoring

- Optical imaging in broad-band filters + narrow band (light curve, colour, jets, dependence on r)
- medium-resolution long-slit spectroscopy (CN, C2, C3, NH2)
- capability to switch between imaging and spectra

VLT allows to search for gas emissions „early“ in r (e.g. using FORS)
Observing comet P/Tempel 1

Around impact time:

• Coma morphology
  - follow development of jets, shells

• Gas production rates
  - “classical” optical long-slit spectroscopy: CN, C3, C2, NH2
  - determine increase in activity for species detected

• Dust production rates
  - determine increase in activity for species detected

• Na observations (source from dust particle sputtering?)

• High-resolution spectroscopy
Proposed observations for P/Tempel 1

**During impact:**

Need for high temporal and spatial resolution (1 arcsec ~ 700 km at the comet)

- Switching between spectra and imaging at the same instrument takes time
- May be done in parallel at different telescopes
- Use VIMOS for inner coma (27x27 arcsec) imaging spectroscopy at VLT?
Summary

- Long-slit spectroscopy and imaging observations pre- and post- impact
- High-resolution, narrow band filters around impact
- Use small telescopes (TLS) for (pre-)impact observations of dust coma morphology

Data analysis based on tools developed for previous observing campaigns:
- reduction and analysis of spectra and imaging observations
- hydrodynamical model to compute dust production rates
- chemical model to link daughter species to parent abundances