Inversion of cometary dust tail images with $Af\rho$ time-dependent constraints

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1 Introduction

The inversion of cometary dust tails provides an excellent method to infer relevant physical parameters of comets, such as particle velocities, size distribution, dust mass loss rate, and their temporal variation [1]. The method originally developed by Fulle [2] involves the inversion of the overdetermined linear system $\mathcal{A}\mathcal{F} = \mathcal{I}$, where $\mathcal{A}$ is the kernel matrix containing the model dust tail, i.e., the surface density of the sampling particles integrated over time and $1-\mu$ (the ratio of pressure radiation to solar gravity forces, which depends inversely on particle size), $\mathcal{F}$ is the output vector, which contains the time-dependent $1-\mu$ distribution, and $\mathcal{I}$ is the observed surface brightness of the image in a selected region of the (N, M) photographic plane. Owing to the ill-posed nature of the problem, a number of regularizing conditions are usually added to the system of equations in order to find physically meaningful solutions of the vector $\mathcal{F}$, so that the derived dust loss rates vary with heliocentric distance as r^{-2}, and the particle size distribution function vary smoothly with time. However, there are many comets for which asymmetric production rates around perihelion have been detected [3], so that such "symmetric" regularizing conditions would not apply. In addition, those comets which experience sudden outbursts of activity, such as 29P, also constitute clear examples of the inadequacy of such regularizing conditions. In this work, we show a different method to constraint the solution to the system of equations based on the temporal evolution of the $Af\rho$ [4] quantity.

2 Constraints based on $Af\rho(t)$

The system of equations $\mathcal{A}\mathcal{F}$=$\mathcal{I}$ was solved by the algorithm described in [5], that allows to impose linear constraints on the solution vector of an overdetermined system of equations.
Fulle [6] has shown that the the quantity $Af\rho$ may be written as a function of the vector solution $\mathcal{F}$ and the ejection velocities as:

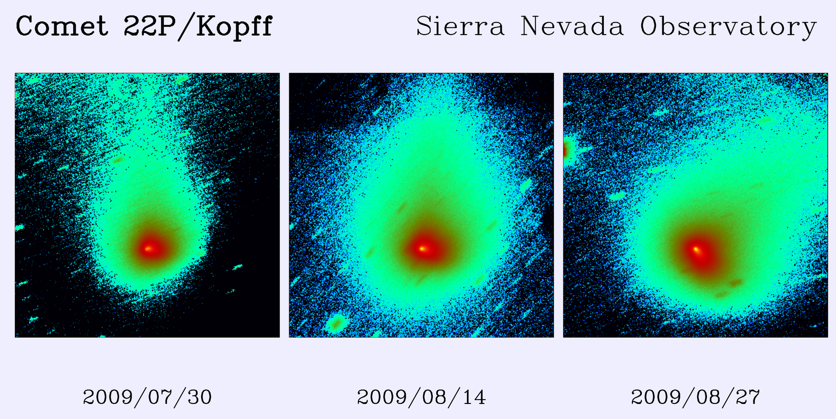
$$Af\rho(t) = \frac{2r^2}{R_0^2}\int_{(1-\mu)_1(t)}^{(1-\mu)_2(t)} \frac{\mathcal{F}(t, 1-\mu)}{v(t, 1-\mu)} d(1-\mu) \qquad (1)$$

where r is the comet heliocentric distance, R_0 is the Sun radius, and $v(t, 1-\mu)$ is the velocity of the particles, which depends on $1-\mu$ and the ejection time t. The integration is performed in the selected range of $1-\mu$, which is time-dependent.
The above equation, after transforming the integral to a discrete summation, actually provides us with a linear constraint on the vector solution $\mathcal{F}$ that can be incorporated as a linear constraint when solving the system of equations $\mathcal{A}\mathcal{F}$=$\mathcal{I}$. Then, if a temporal series of measurements of $Af\rho$ is available, we should be able to constrain our solution vector at the time intervals for which those measurements are given.

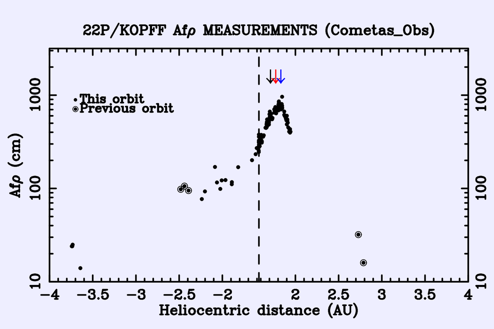
[1] Fulle, M. (2004) *Comets II, M. C. Festou, H. U. Keller, and H. A. Weaver (eds.), Univ. of Arizona Press*
[2] Fulle, M. (1989) *Astron. Astrophys., 217, 283*
[3] A'Hearn et al. (1995) *Icarus, 118,223*
[4] A'Hearn, M. et al. (1984) *AJ 89, 579*
[5] Bartels, R.H., and Conn, A.R. (1980) *TOMS, 6, 594*
[6] Fulle, M. (2000) *Icarus, 145, 239*
[7] Moreno, F. (2009) *ApJS, 183, 33*

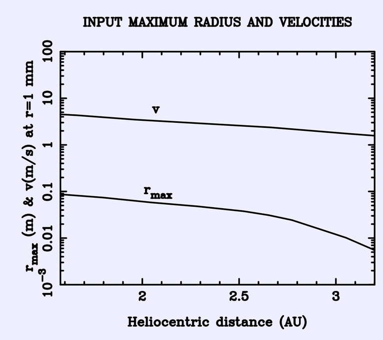
3 Application to comet 22P/Kopff

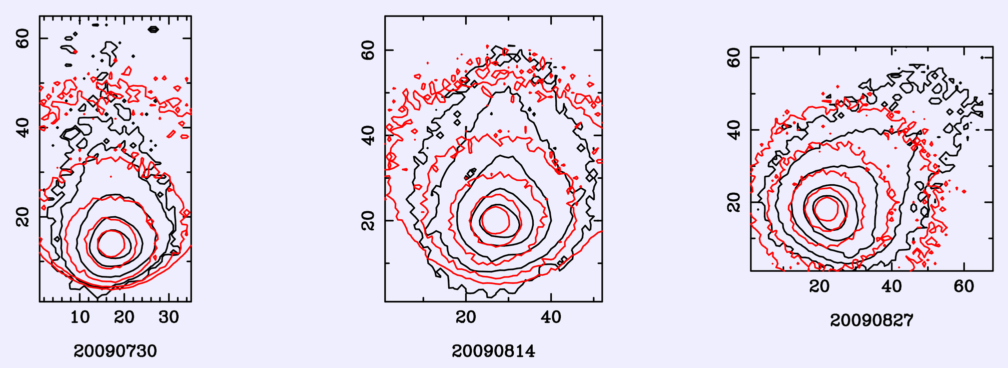
We have already applied the technique described in section 2 to the inversion of a set of coma images of comet 29P/Schwassmann-Wachmann 1, see [7]. Here we will focus on the application of the procedure to some very recent images of comet 22P/Kopff obtained at Sierra Nevada Observatory 1.52-m telescope during last summer. We obtained a series of images during the nights of July 30th, August 14th, and August 27th, at comet heliocentric distances of 1.71, 1.77, and 1.83 AU post-perihelion, respectively. We used a R Johnson filter, in combination with a CCD camera having a FOV of 7.8'× 7.8' with a spatial scale of 0.46"/px. The physical dimensions of the images shown below are about 1.6×10^5 km.



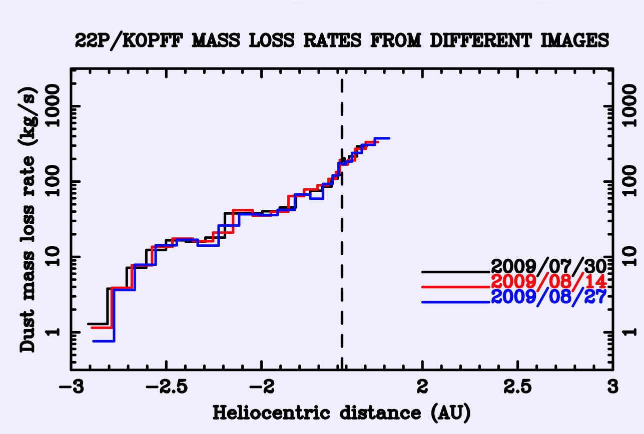
The $Af\rho$ measurements were provided by the Spanish amateur association *Cometas_Obs*. The input parameters concerning the time dependence of the maximum ejected particle radius and velocity are shown below. The velocity is assumed to be $v \propto (1-\mu)^{1/2}$. For this preliminary application, we used a simple model of isotropic particle ejection, so that this cannot obviously fully account for the observed asymmetry in the coma.

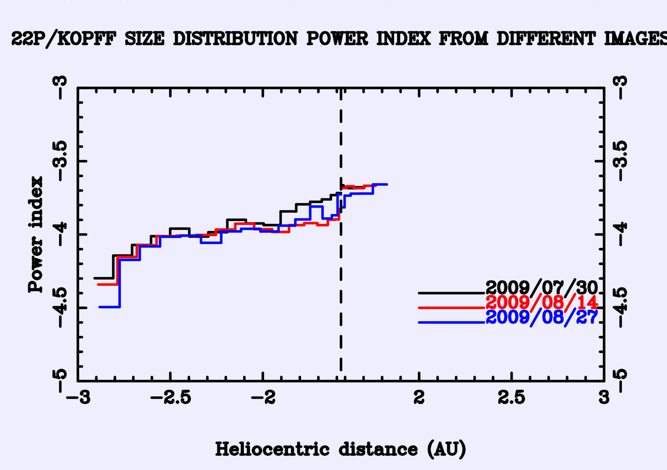






The observed (black) and modeled (red) isophotes are shown in the previous panel. The derived dust mass loss rates, and the size distribution power index for each image are shown below. Owing to the $Af\rho$ constraints, both the dust loss rates and the derived size distribution functions (fitted to power law) from different images display very similar behavior with time. The asymmetry around perihelion in the production rate reflects the asymmetric behavior displayed by $Af\rho$. In conclusion, the use of regularizing $Af\rho$ constraints on the inverse tail procedure constitutes a promising technique to interpret the dust environment from comets.





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