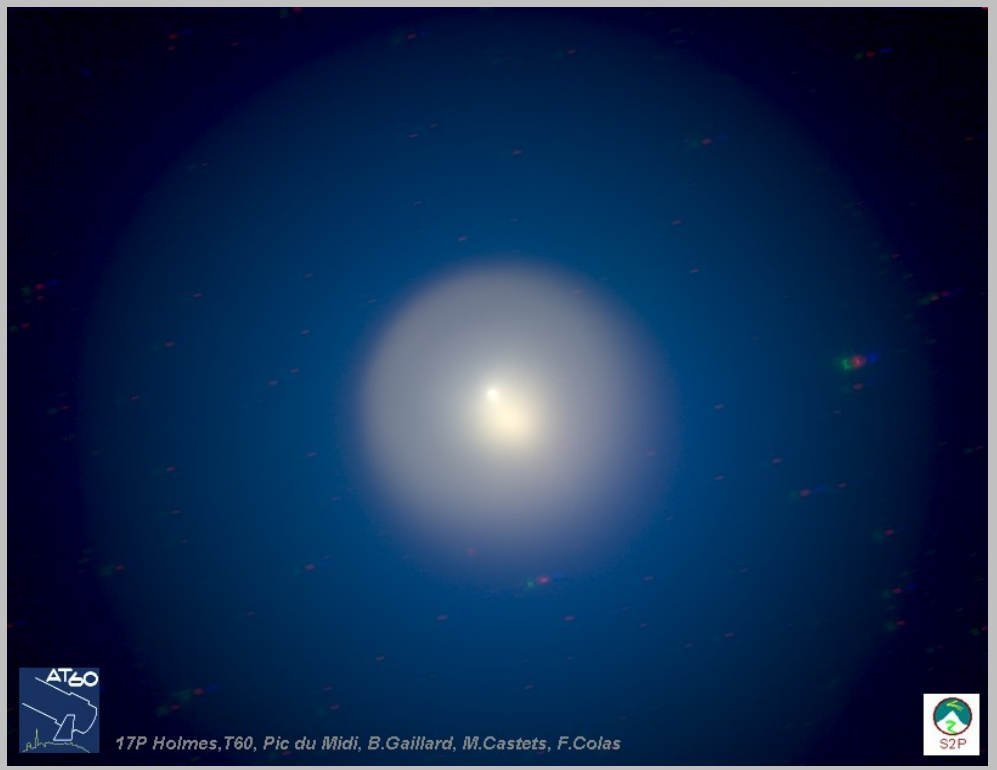
Non-gravitational forces in comets



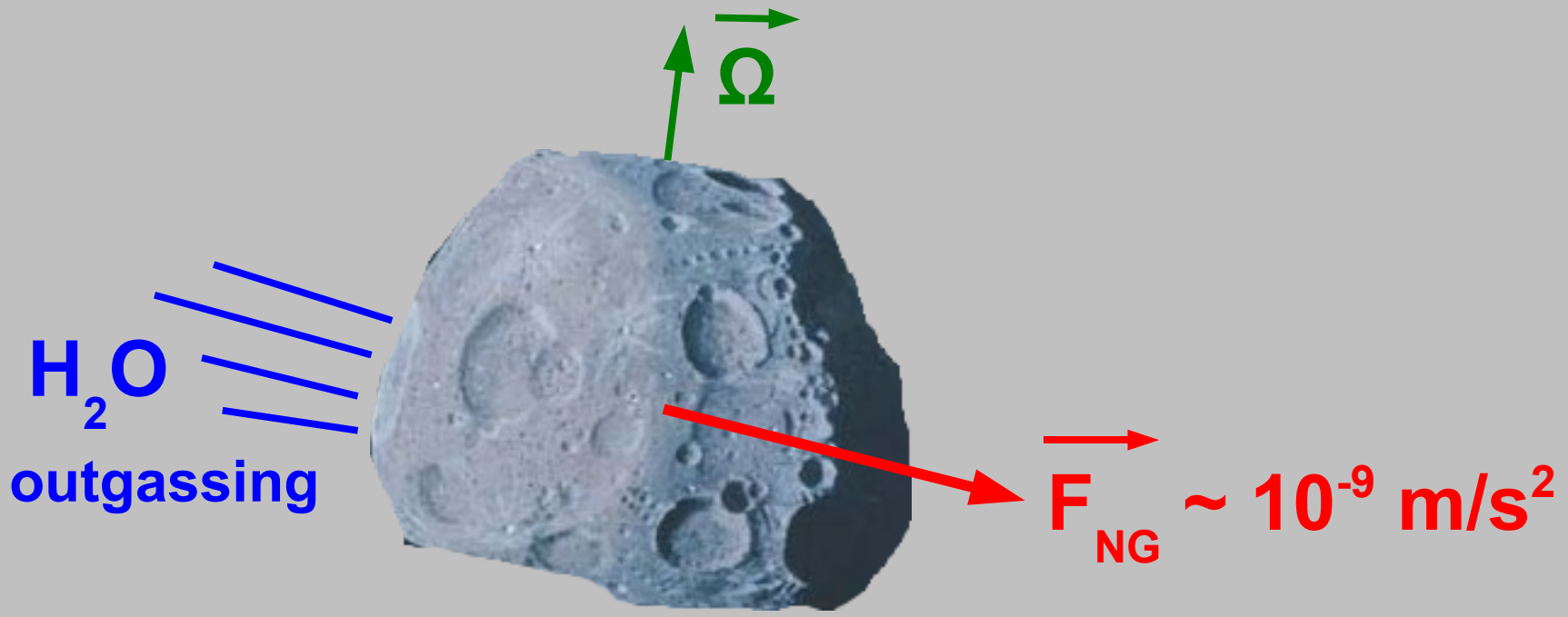
17P / Holmes

F. Colas, L. Jorda, P. Rocher
M. Fouchard, L. Maquet.
D. Hestroffer, C. Babusiaux

IMCCE – Obs de Paris
LAM – Marseille
GEPI – Obs de Paris

Beaulieu sur mer, 2008 october 27-28

NON-GRAVITATIONAL FORCE



- acceleration due to water outgassing
- perturbation of the “gravitational” orbit
- other effects are usually much lower

See Whipple (1950) & Marsden (1968, 1969)

MASS MEASUREMENTS

The effect of the non-gravitational force can yield measurements of the mass of cometary nuclei.

Method:

1. measure the acceleration $\vec{A}_{NG}$ ← astrometry
2. model the force $\vec{F}_{NG}$ ← outgassing model (+ shape)
3. extract the mass (& density) of the nucleus

Only method before ROSETTA to measure the mass of cometary nuclei.

NON-GRAVITATIONAL FORCE

Physical model to compute the non-gravitational force :

$$\vec{F}_{NG}(t) = -\, m_w\, \eta \int_{surface} Z_w(\lambda, \varphi)\, v_w(\lambda, \varphi)\, \vec{n}(\lambda, \varphi)\, dS$$

mass of water molecules

transfer efficiency

(CONSTANTS)

[rotational parameters]

sublimation rate

outflow velocity

(THERMAL MODEL)

Ground-based observations

- Visible lightcurves
- [Afρ] parameter
- OH production rates
- OH velocities

Space missions

local normal to the surface

(3D SHAPE)

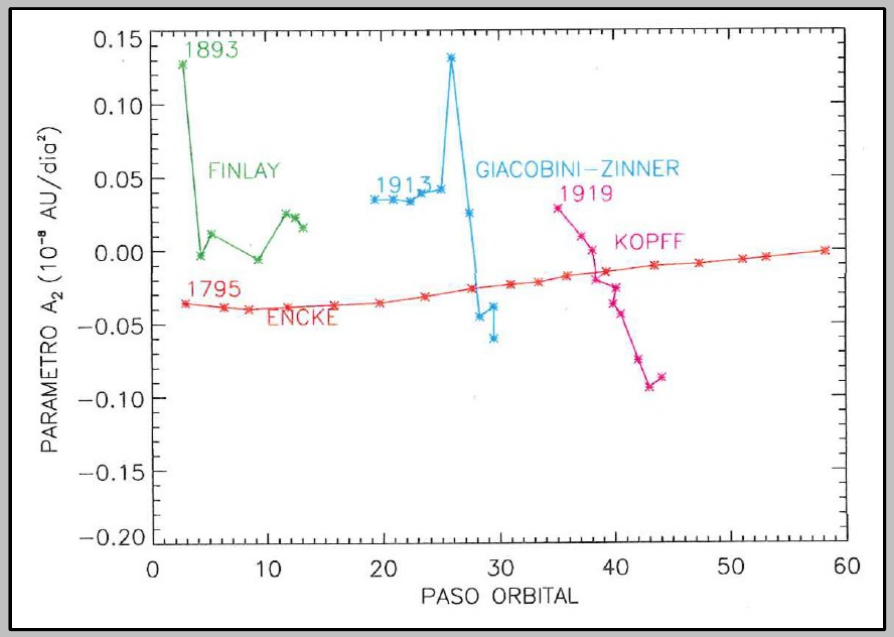
“STANDARD” APPROACH

Model introduced by Marsden (1973):

$$\vec{A}_{NG} = F_1 \vec{n}_r + F_2 \vec{n}_t + F_3 \vec{n}_n$$

$F_i = A_i \; g(r_h) \;\rightarrow\; g$ = based on simplistic model

A_i = coefficients deduced from astrometric measurements



← A_2

(from Gutiérrez 2002)

IMPROVEMENTS

Froeschlé & Rickman (1986), Rickman & Froeschlé (1986) ...

Method:

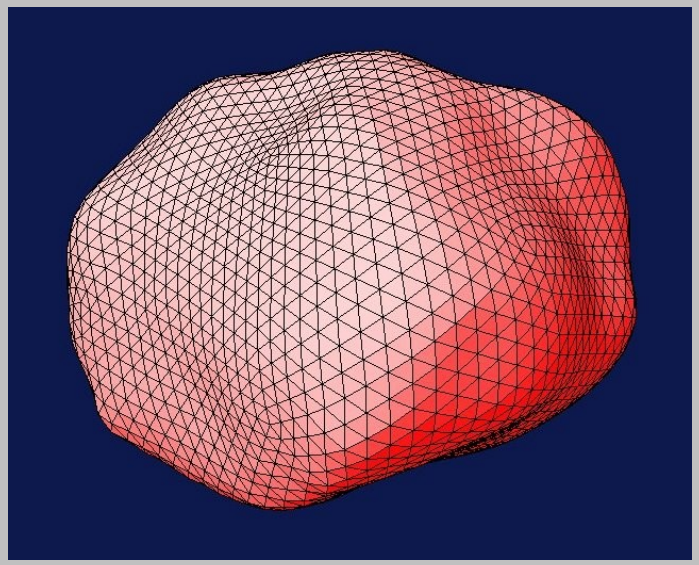
- uses a better thermal model to calculate the NGF
- three components $h_i(r_h)$ instead of $g(r_h)$
- assumes spherical isotopic nuclei

Results:

- better fit of astrometric measurements for some comets
- correlation: $\Delta P \approx A_2$ and asymmetry of H_2O production
- density of 1P/Halley: 300-700 kg/m^3 (Rickman 1989)

IMPROVEMENTS

Davidsson et al. (2007)



Method:

- **"LEAM" (improved) thermal model**
- **fit of water production rate**
- **activity pattern = free parameter**
- **can use shape model derived from space missions (DI)**
- **restricted to "well-known" comets**

Results:

- **density of 9P/Tempel 1: 200-700 kg/m^3**

IMPROVEMENTS

Needed measurements:

- astrometric measurements (GAIA)
- water production curve or equivalent
- water outgassing velocity

Errorbar in the mass determination (9P/Tempel 1):

- astrometry (derived ΔP) ~ 10 – 20 %
- activity parameters ~ 50 %

"STANDARD" APPROACH

Advantages:

- only 3 parameters (A_i) need to be fitted
- huge available database of measurements

Limitations:

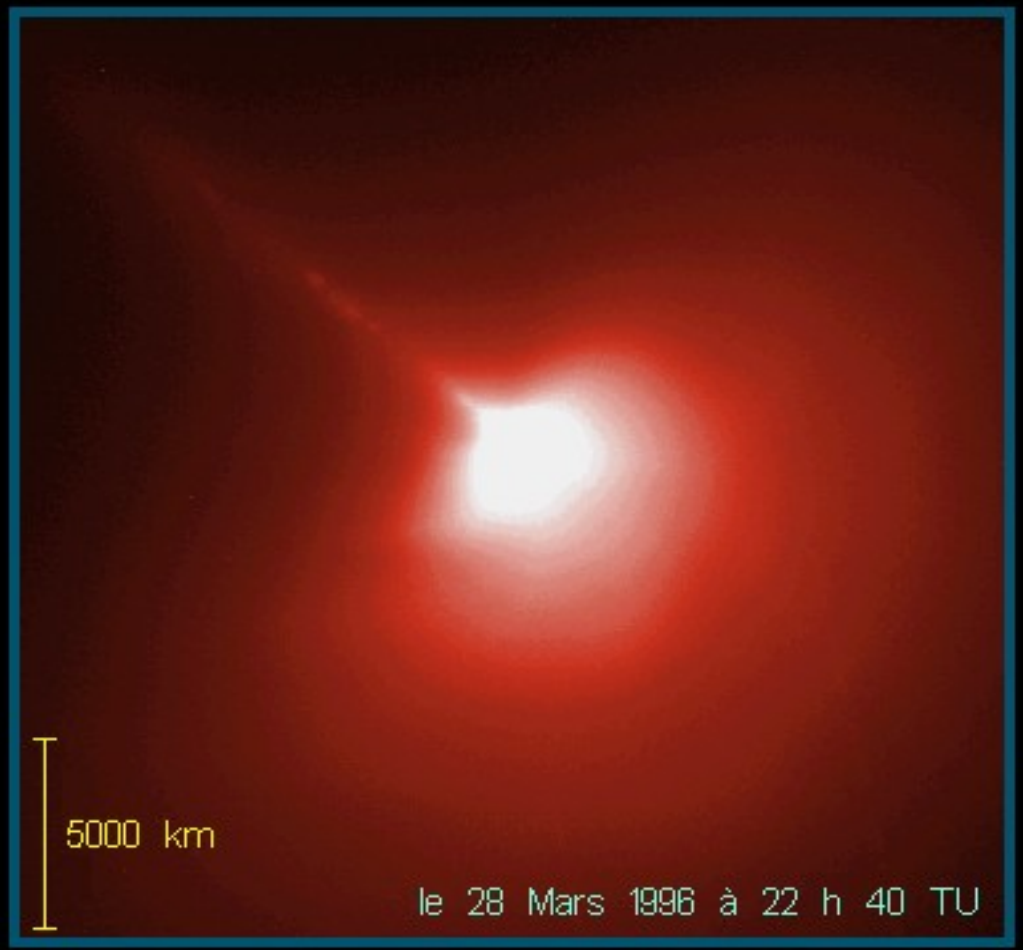
- the "activity" parameter $g(r_h)$ is incorrect:
  - symmetric w/respect to perihelion (Yeomans and Chodas 1989)
  - activity variations with r_h don't follow $g(r_h)$
- the astrometry has a low accuracy (jets ...)

OBSERVATIONS ....

COMETS ....

Comète HYAKUTAKE 1996 B2

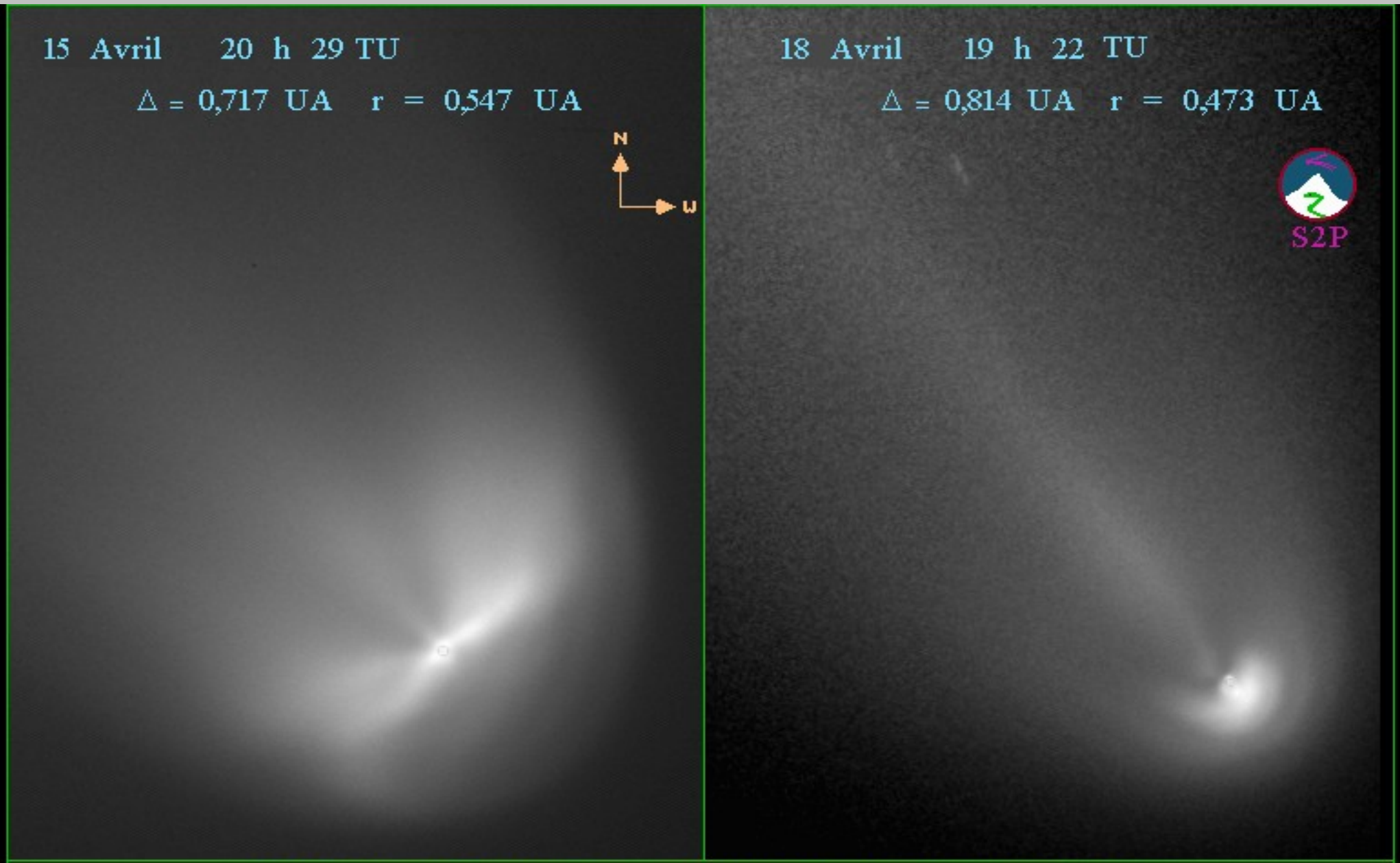
EVOLUTION RAPIDE DE PETITS FRAGMENTS SÉPARÉS DU NOYAU



Observatoire du Pic-du-Midi , télescope T1m

S2P

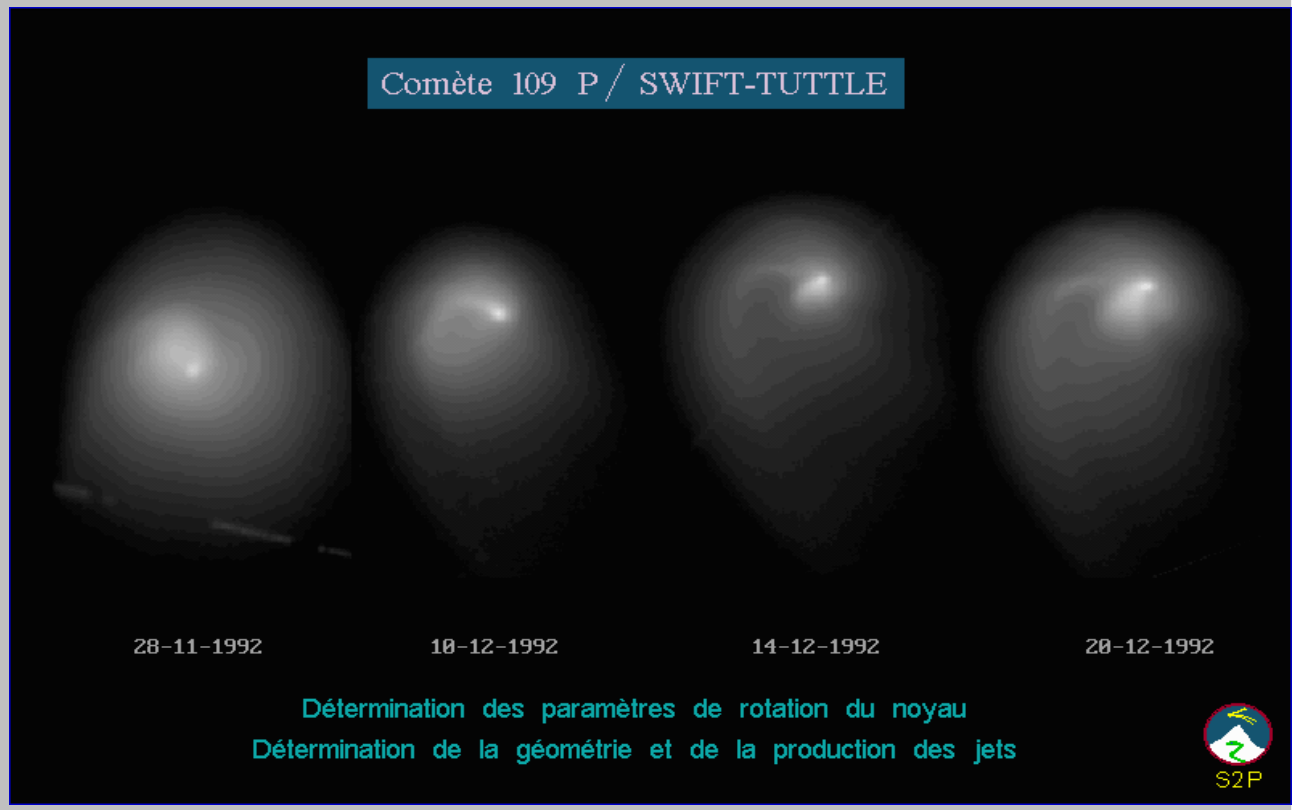
COMETS ....



COMETE HYAKUTAKE : ERUPTION LE 15 AVRIL 1996
16 jours avant le périhélie

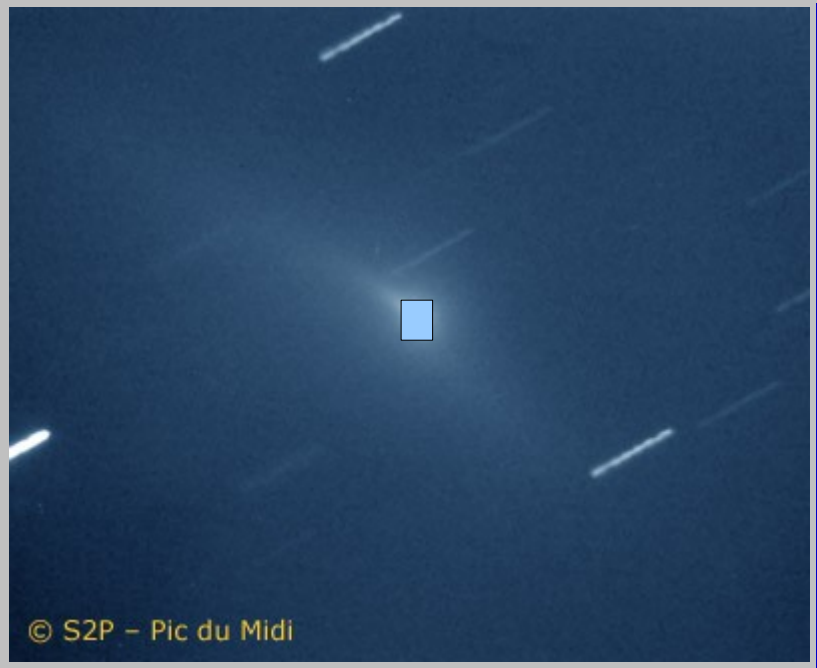
COMETS ....

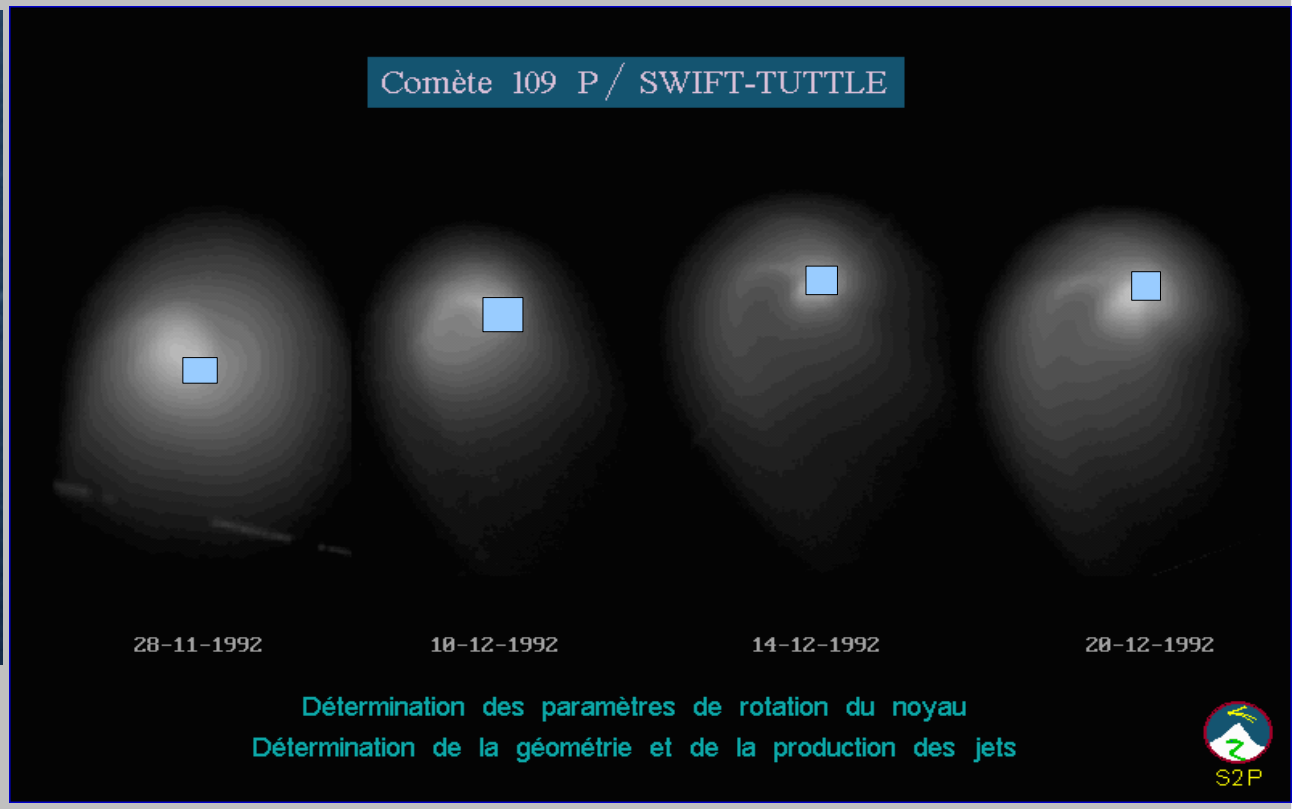

© S2P – Pic du Midi


Comète 109 P / SWIFT-TUTTLE
28-11-1992
10-12-1992
14-12-1992
20-12-1992
Détermination des paramètres de rotation du noyau
Détermination de la géométrie et de la production des jets
S2P


Comète 17P - Holmes
24 oct 18h
25 oct 6h
25 oct 18h
26 oct 6h
T1M - Pic du Midi - Station de Planétologie des Pyrénées
S2P

COMETS WITH GAIA....



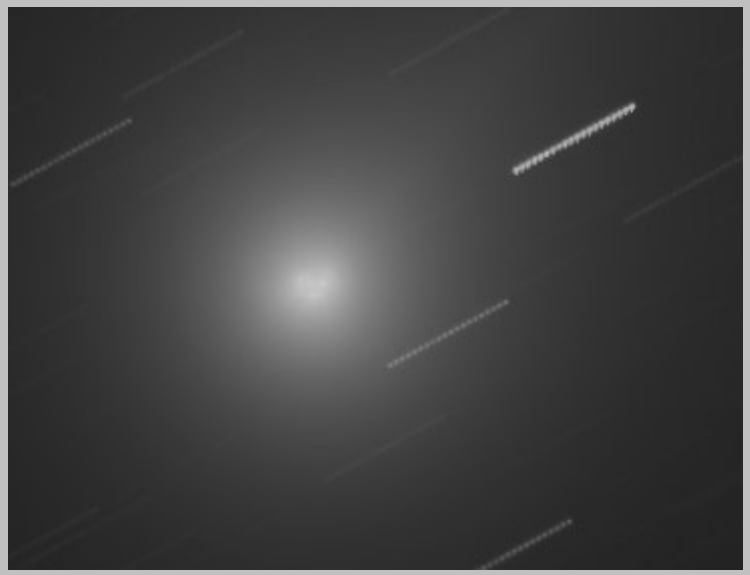


COMETS FROM GROUND....

COMETS WITH GAIA....

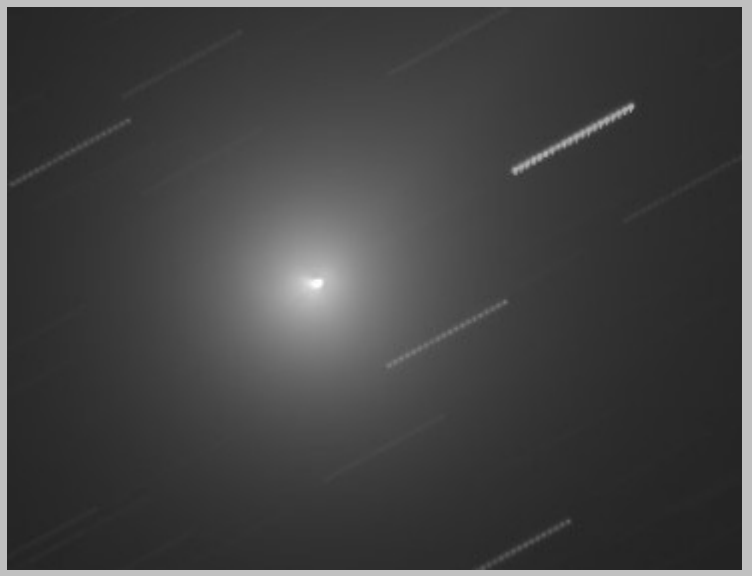
COMETS WITH GAIA

View from ground



Profile 1/R
pseudo nucleus (fwhm=2arcsec)

View from space

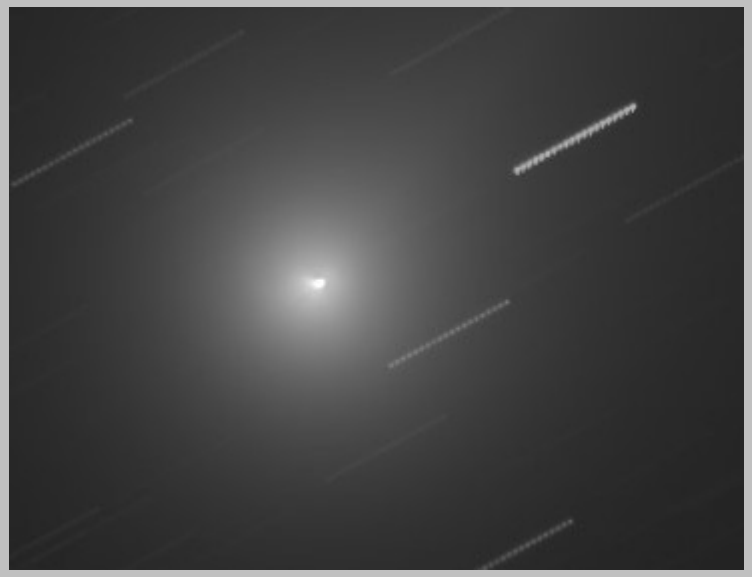


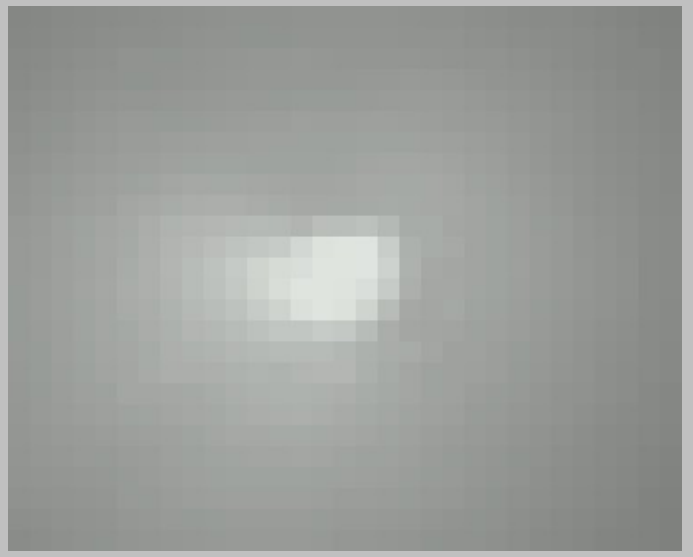
Profile 1/R
Pseudo nucleus (fwhm=2arcsec)
PSF from the nucleus

A 1 km nucleus at 1 UA => 1 mas !

Mag (Nucleus) = Mag (Comet) +5

COMETS WITH GAIA



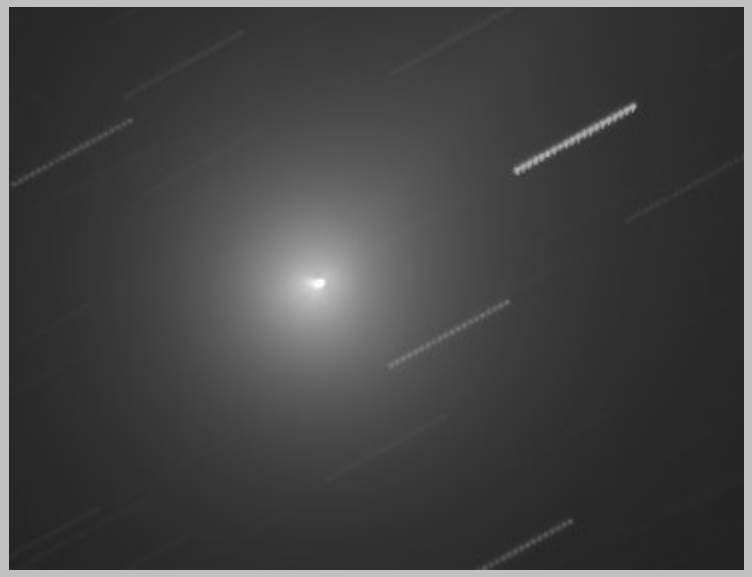


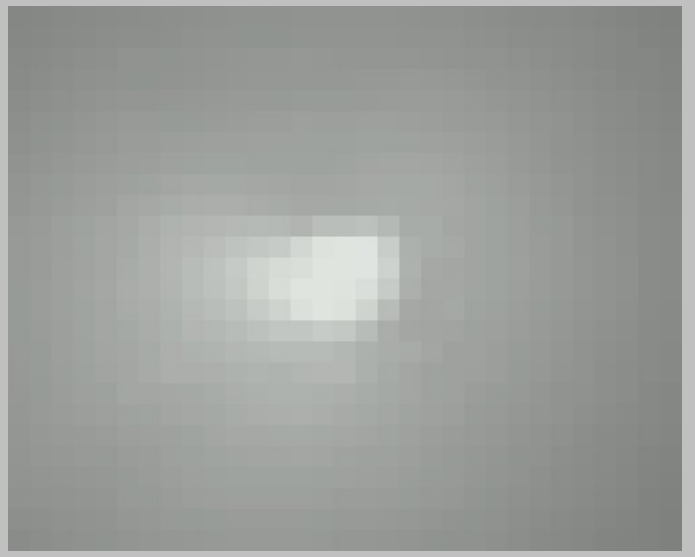
We need to have accurate position in order to compute orbitals elements
So we will be able to compute non gravitational **acceleration**

For comet 9P/tempel 1 with ground observations

Non gravitational accelerations are fitted with the changes of the orbital period and of the perihelion argument
ΔP = 2 min +/- 0.5
$\Delta\omega$= 0.2” +/- 0.1
(2006, Davidsson et al) => ρ bulk = 450 kg m-3 +/- 250 ....

COMETS WITH GAIA





We need to have accurate position in order to compute orbitals elements
So we will be able to compute non gravitational **acceleration**

How many points are needed ? => how many points could be measure during one return

NONGRAVITATIONAL FORCE

Physical model to compute the nongravitational force :

$$\vec{F}_{NG}(t) \approx - m_w \, Q_w \, \vec{u}_w$$

- m_w : mass of water molecules
- Q_w : water production rate (ACTIVITY)
- $\vec{u}_w$: "effective" outflow velocity (THERMAL MODEL)

Ground-based observations

- Visible lightcurves
- [Afρ] parameter
- OH/CN production rates
- OH velocities
- Rotational parameters
- Active zones
- ....

NONGRAVITATIONAL FORCE

We need many ground based observations !

$$\vec{F}_{NG}(t) \approx - m_w Q_w \vec{u}_w$$