Cometary activity of Centaurs: the case of 174P/Echeclus

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A brief history of 174P/Echeclus

→ **Centaur (60558) 2000 EC_{98} discovered on March 3, 2000**

(at Kitt Peak observatory by Spacewatch; Marsden, 2000)

→ Many observations by different observers with **no sign of cometary activity** (Rousselot et al., 2005; Lorin and Rousselot, 2007)

→ **Outburst detected on December 30, 2005** (Choi et al. 2006) at R=13.07 AU (M ≈ 21→14). Renammed 174P/Echeclus

→ Surpising case of outburst because **active zone distinct from 2000 EC_{98}** (Weissman et al., 2006)

Orbital elements :

a	**e**	**q**	**Q**	**i**
10.77	0.45	5.86	15.67	4.3

Our own observations after the outburst :

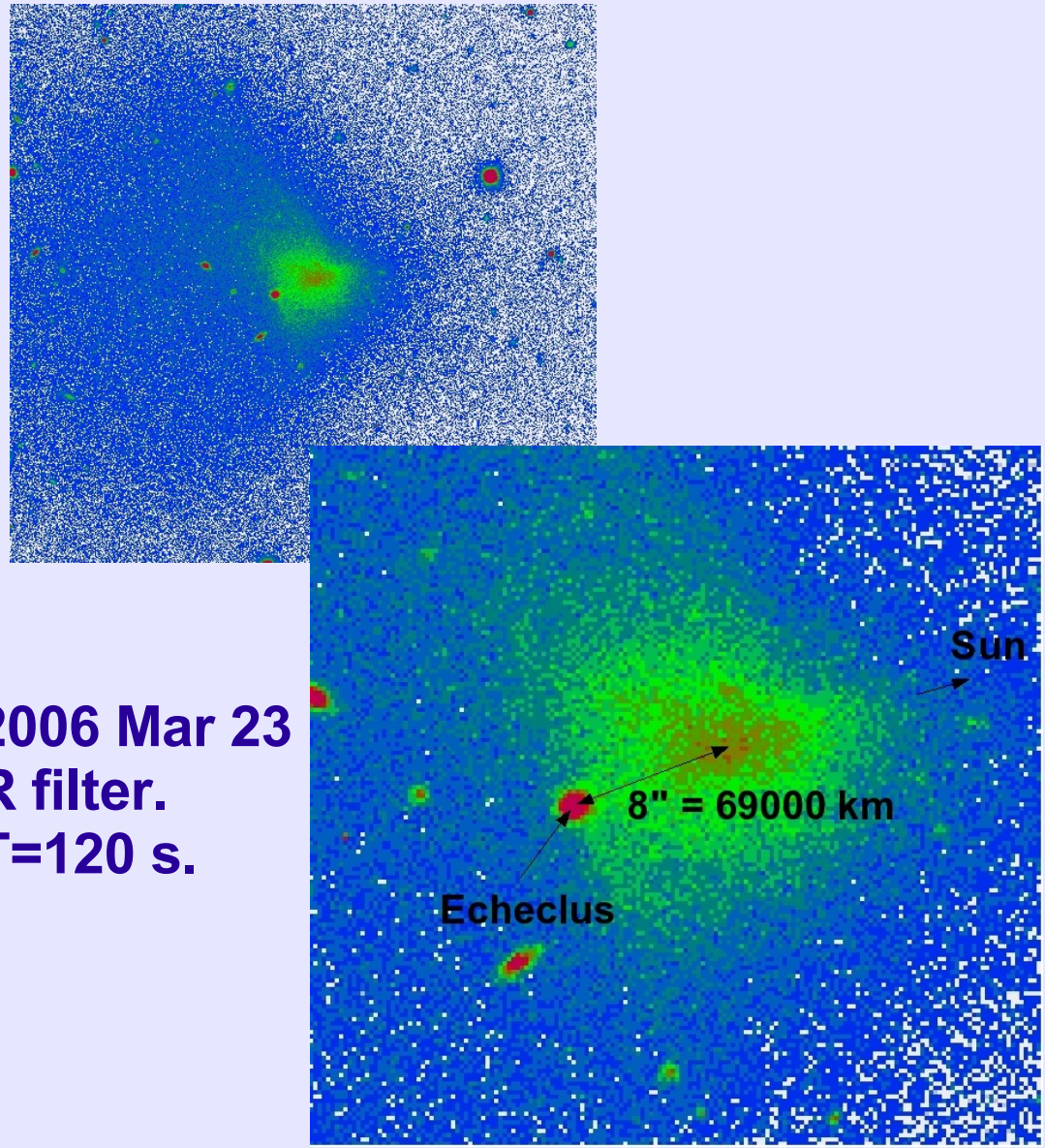
→ DDT on **VLT FORS 1** instrument.

→ 2 observing nights: **23 and 30 March, 2006 (R=12.9 AU)**

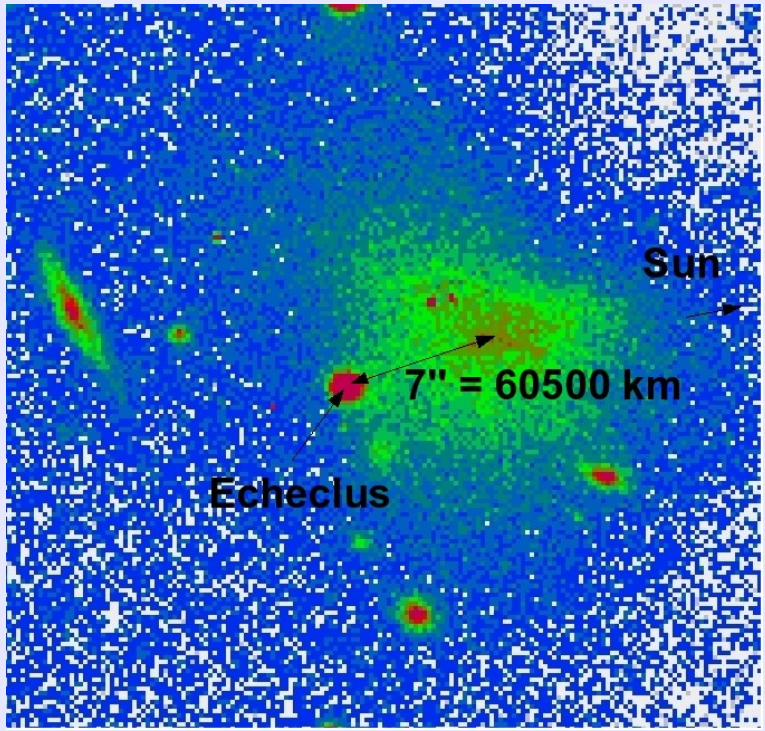
→ 23 March:
- 3 images R filter, T=120 s (2048x2048, 0.2"/pix)
- 2 images V filter, T=145 s
- 2 images B filter, T=145 s
- 7 long slit spectra, T=585 s

→ 30 March:
- 3 images R filter, T=120 s (2048x2048, 0.2"/pix)
- 2 images V filter, T=145 s
- 2 images B filter, T=145 s

Images



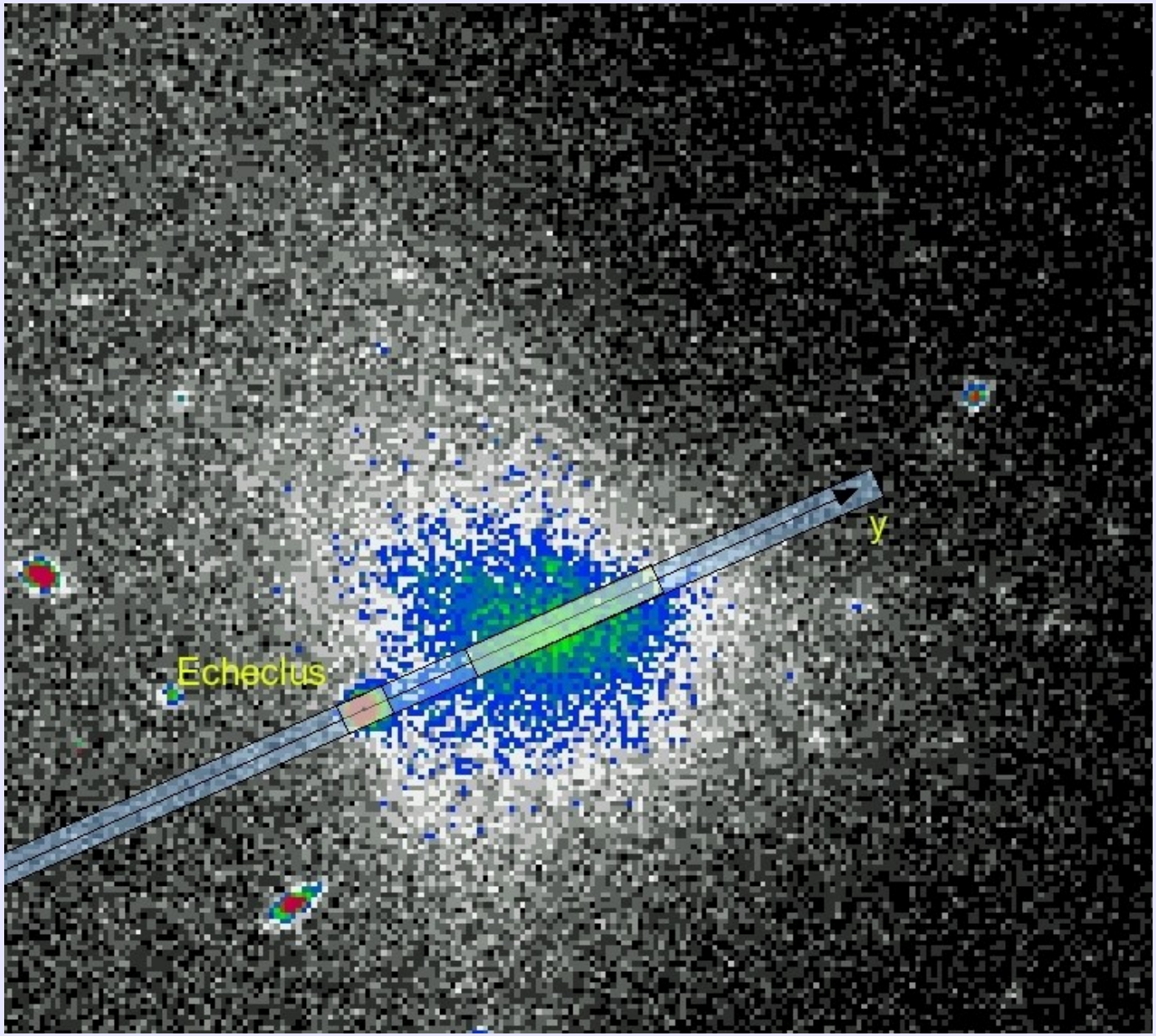
2006 Mar 23
R filter.
T=120 s.



2006 Mar 30
R filter. T=120 s.

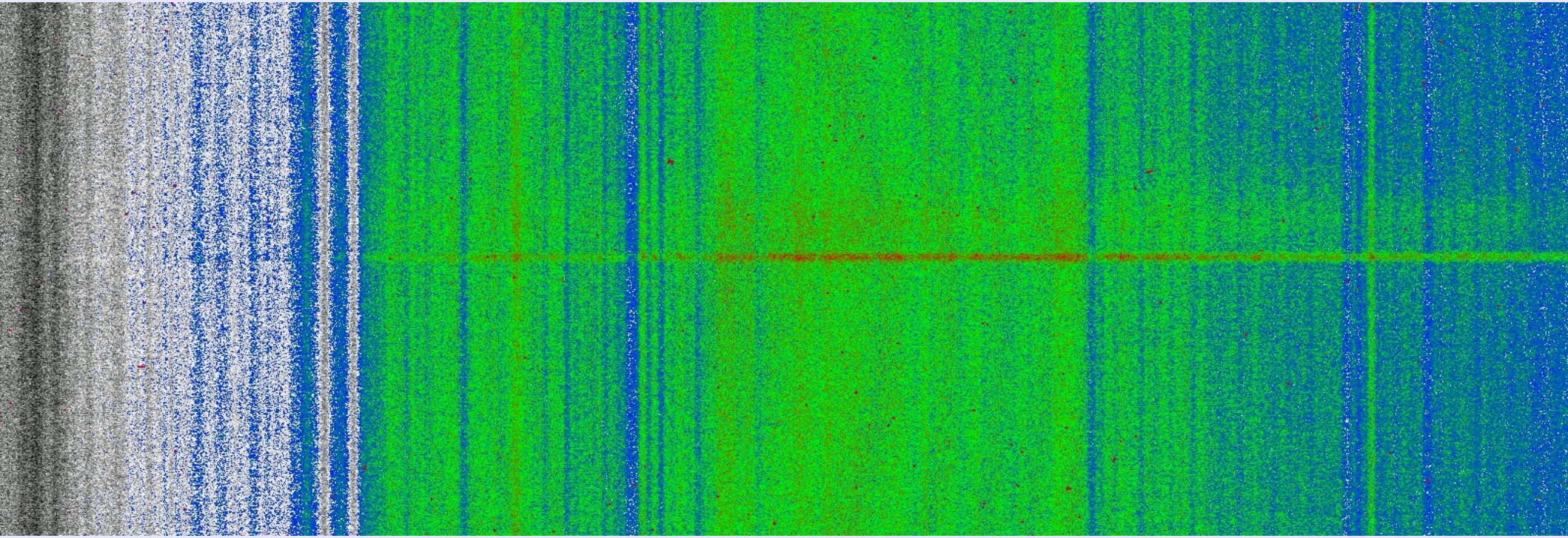
Coma center distinct from Echeclus !

Visible spectroscopy

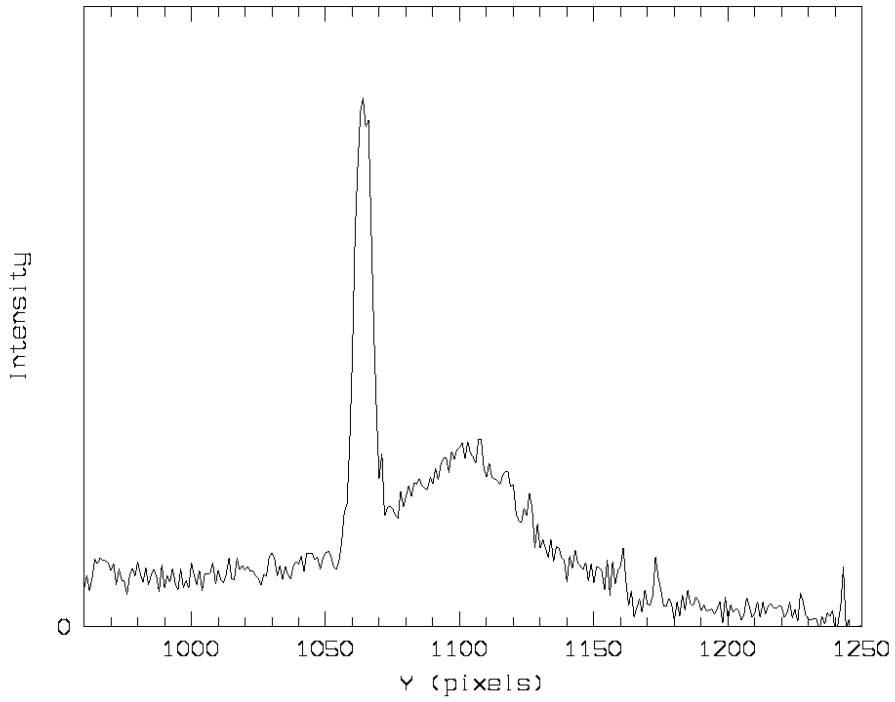


Slit width : 1.3 arcsec
Spectral resolution : 600 (FWHM=7.4 Å)
7x585 s

Raw spectrum (central region) :



Y-axis luminosity profile (sky background subtracted) →



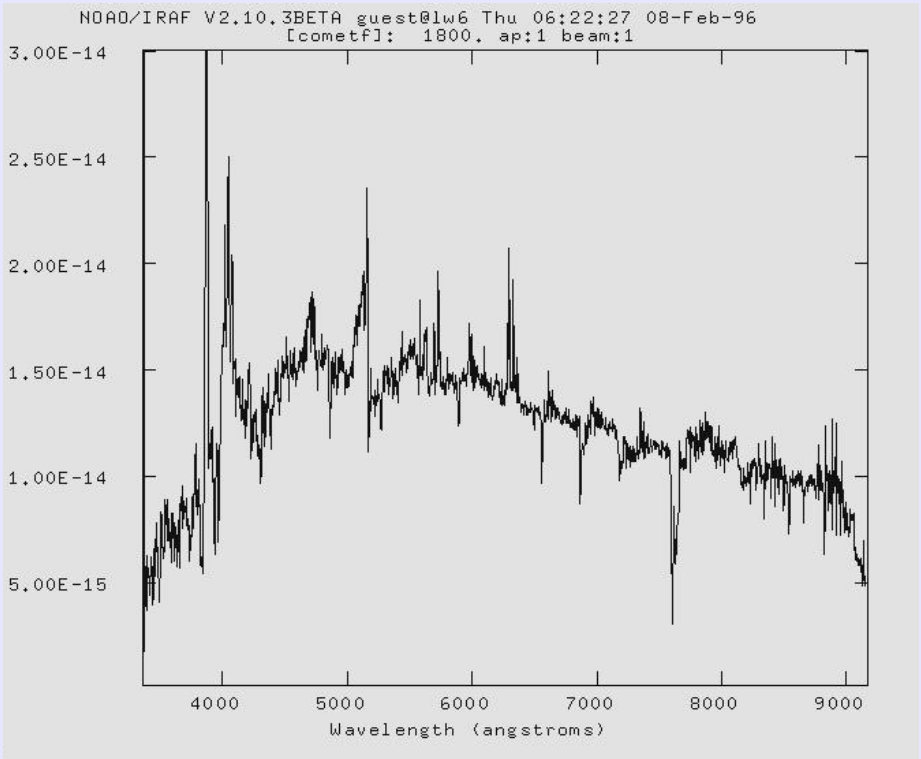
Spectrum of the coma (with solar spectrum for comparison)

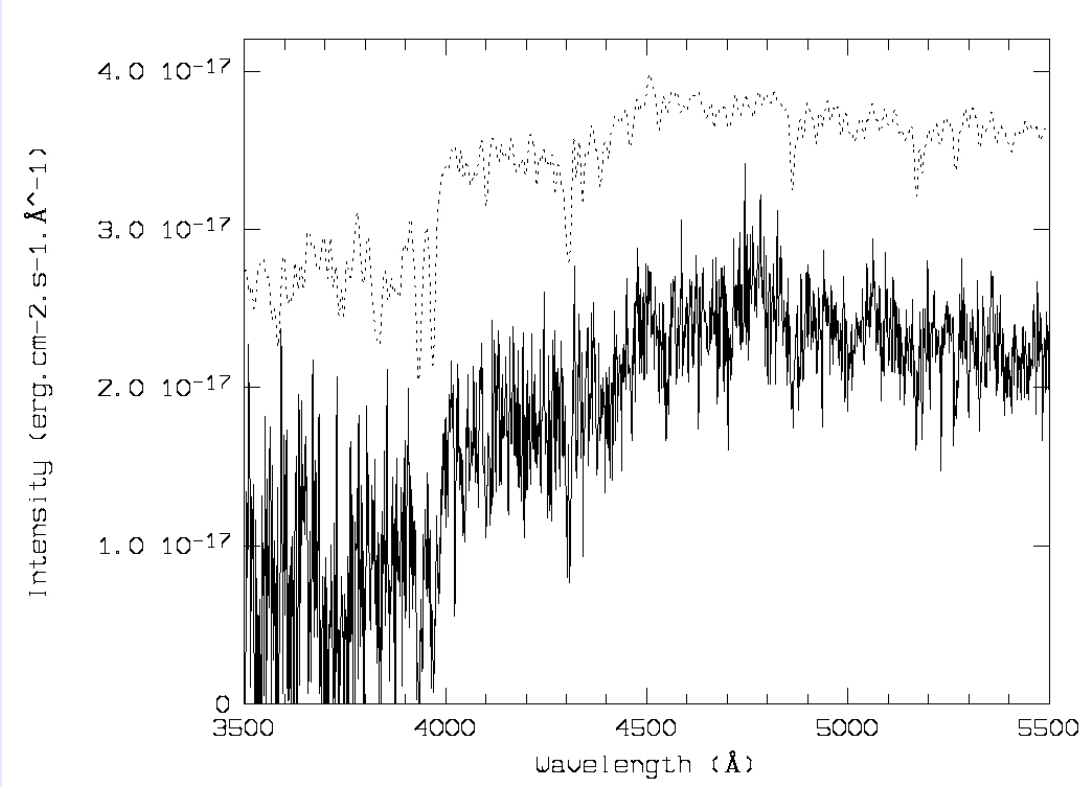
→

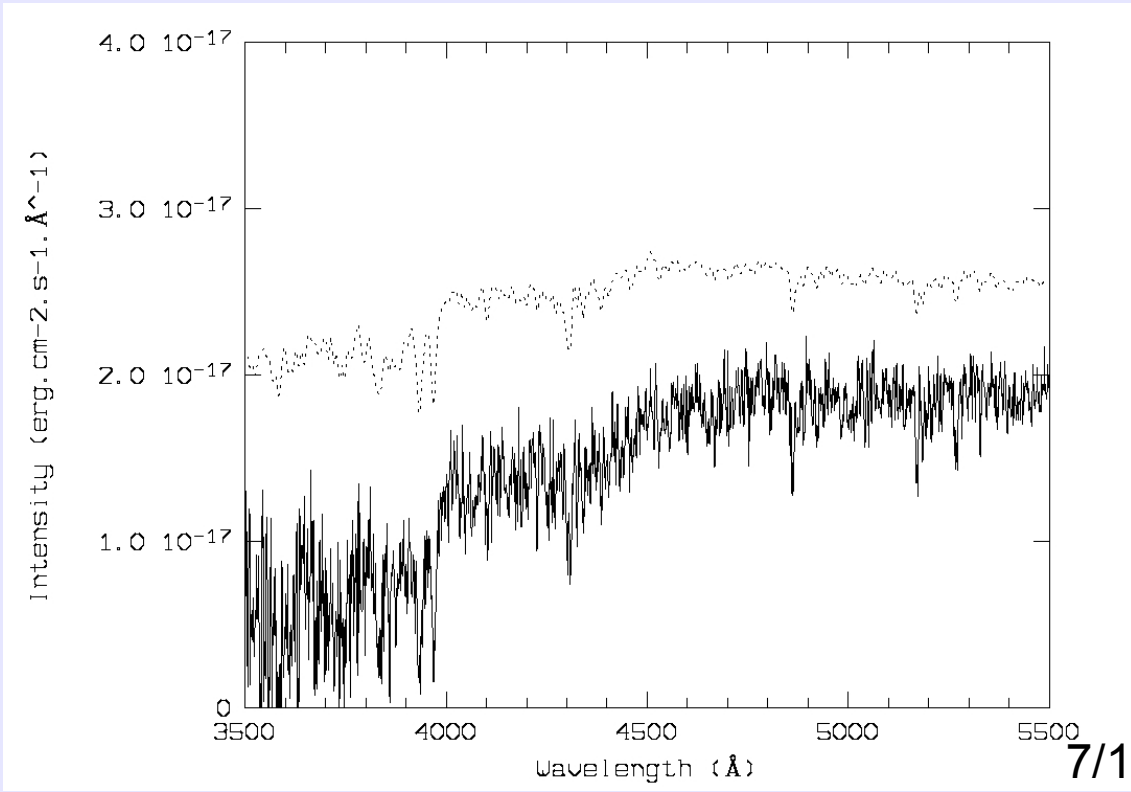
Spectrum of Echeclus (with solar spectrum for comparison)

↓

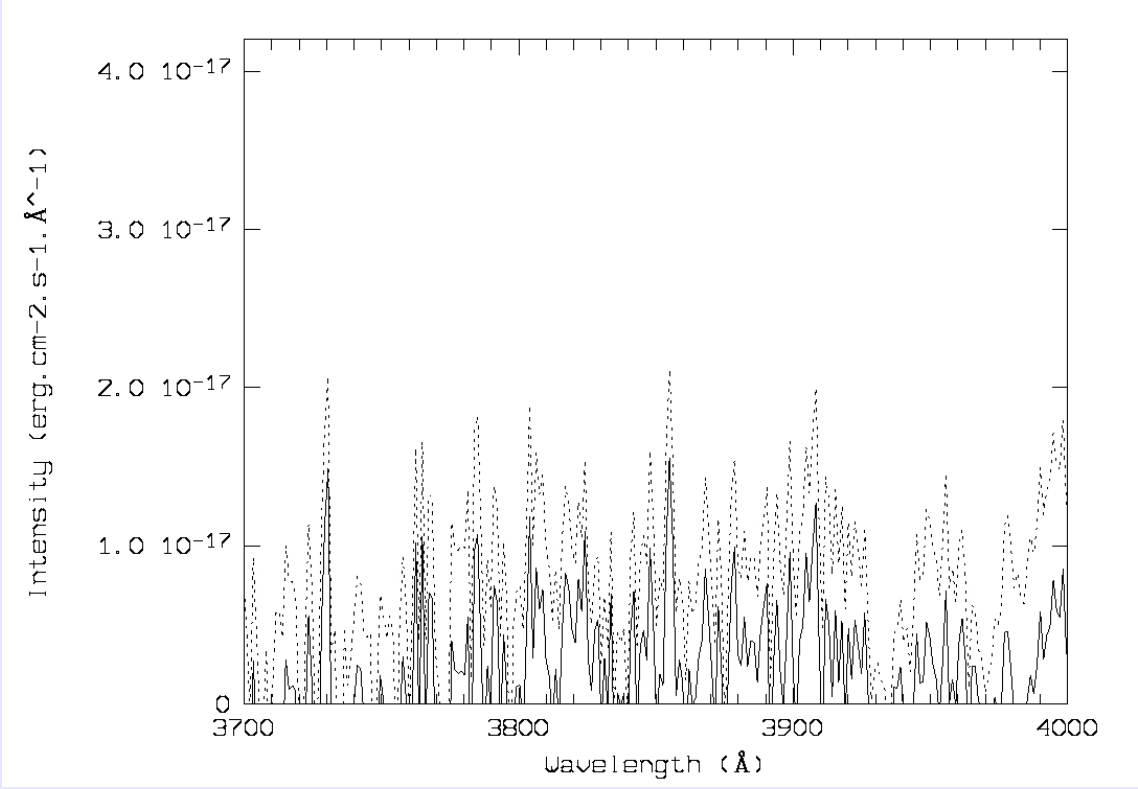
For comparison : spectrum of comet Hyakutake (1.5-m ESO, Zwitter et al., 1996):



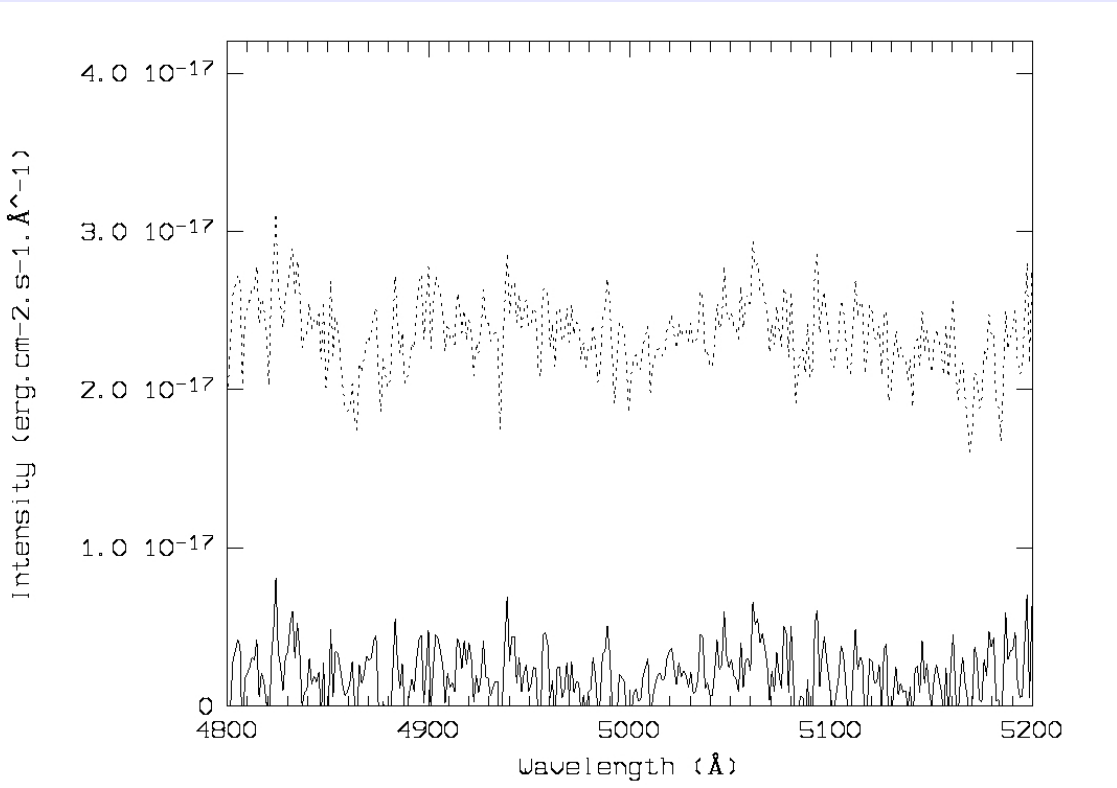




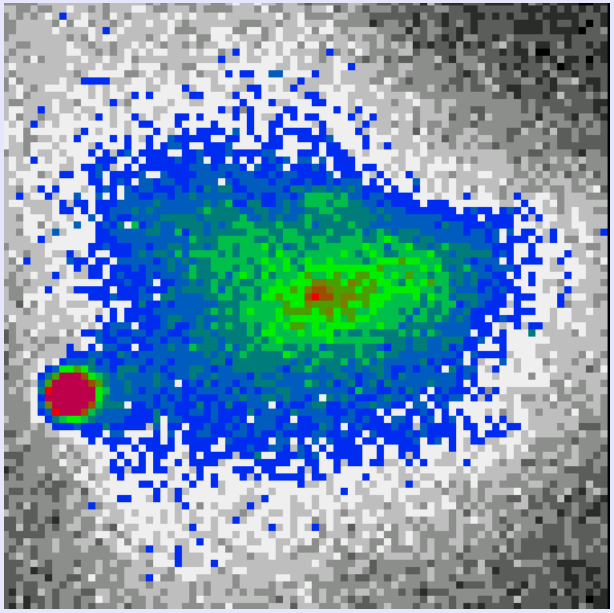
No CN lines after solar continuum subtraction →



No C_2 lines after solar continuum subtraction →



Estimation of the fragment size



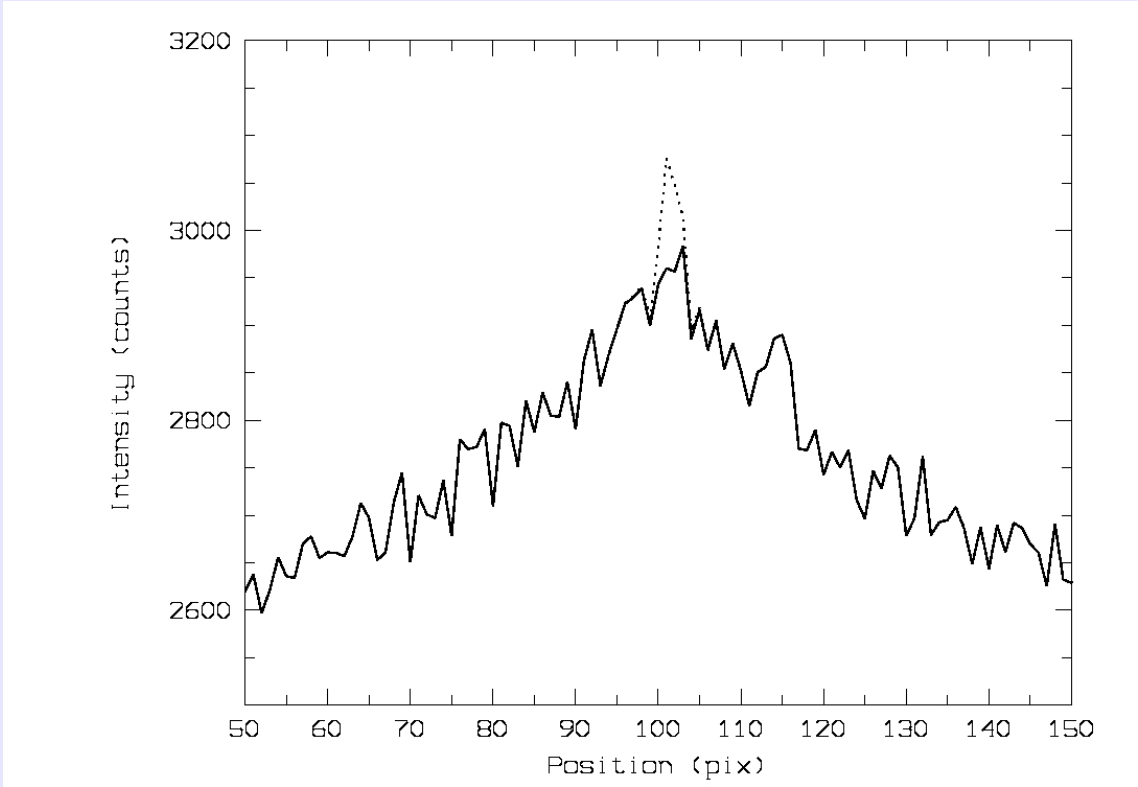
A false image of a punctual object with a known magnitude is added to the average coma image.

With a two-sigma intensity the faintest object that can be added is a magnitude 25 object.

Such a magnitude corresponds to a fragment with D=8.3 km (for ρ_R=0.04).

With 1-sigma and ρ_R=0.10,

D = 3.6 km

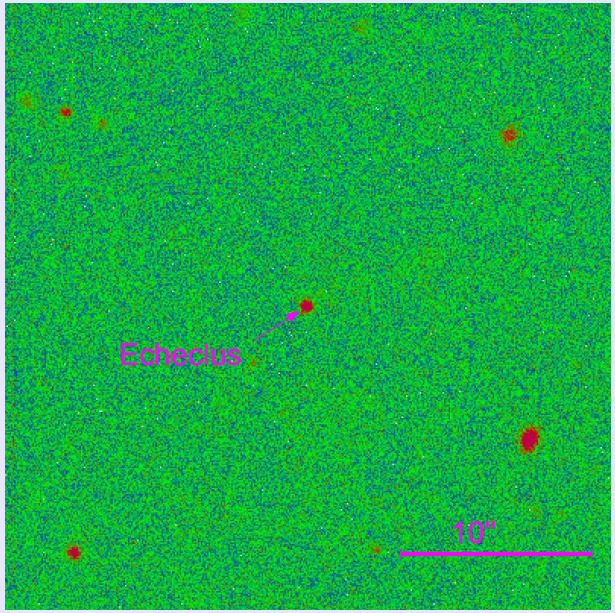


Consequently $D_{max} \approx$ 8.3 km

(Echeclus: D ≈ 60-90 km and $\rho_v \approx$ 1.8-4.4%; Stansberry et al., 2005 (Spitzer))

Vertical profil with artificial object (dashed line)

Search for the activity / satellite before outburst

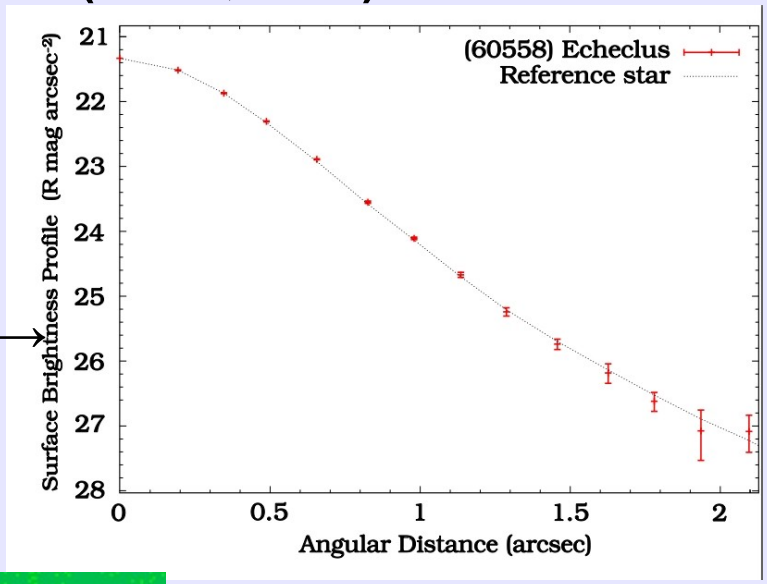


Mainly two large series of images obtained in 2001 and 2003 :

← - NTT: 26 and 27 April 2001 (R=15,2 AU)

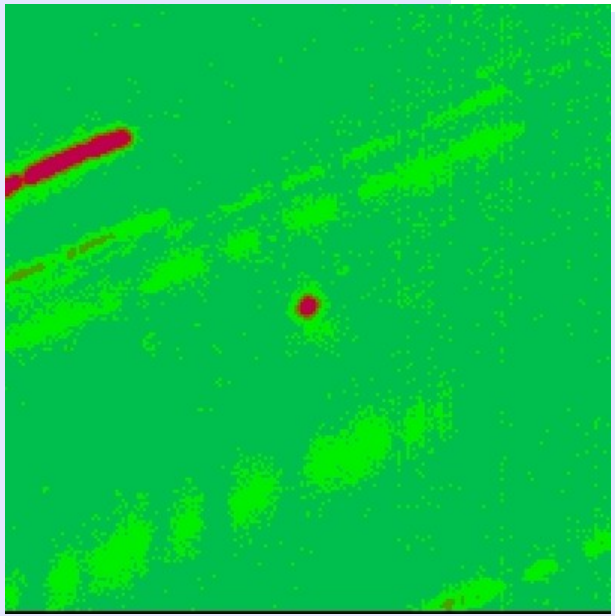
- T3.60-m: 10-12 April 2003 (R=14,5 AU)

No cometary activity detected with NTT observations up to mag 27/arcsec^2 (Rousselot et al., 2005; Lorin and Rousselot, 2007) →



NTT data : no « satellite » apparent up to $M_R \approx 25$ for both nights.

T 3.60-m data : no « satellite » apparent up to $M_R \approx 26$ when co-adding all the images (total integration time = 7.5 hrs) →



Conclusion for Echeclus

Our observations:

→ Confirm the existence of a distinct source of cometary activity

→ No apparent emission lines

→ Source of cometary activity smaller than 8 km

The origin of the coma remains a mystery, different hypotheses can be done:

→ **fragment detached from Echeclus** (but why does it appear close to Echeclus for several months ??)

→ **Echeclus has a small satellite** which is the real source of cometary activity (not detected up to $M_R \approx 26$ but could be fainter)

→ **The cometary activity is due to another object** with a similar orbit (but activity claimed by Choi for 27 Jan and Feb 5, 2000, based on analysis of NEAT archives)

Future work:

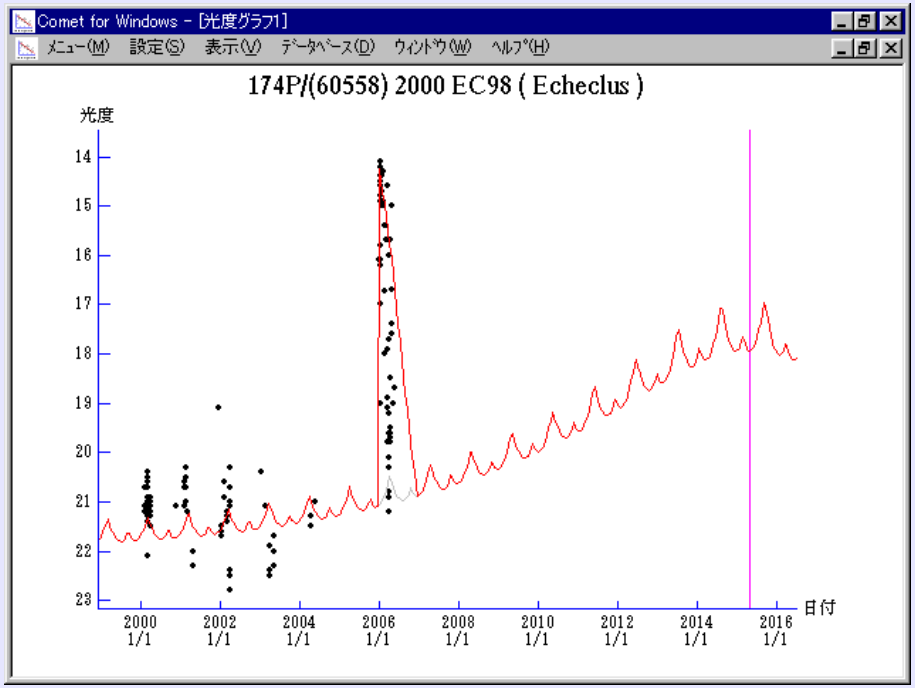
→ **Modeling of the images**: ejection velocity (Choi and Weissman, 2006: 500-800 $m.s^{-1}$; Halley's comet outburst observed at 14.3 AU v=14.5 $m.s^{-1}$), dust production rate (from 70 to 660 $kg.s^{-1}$; Bauer et al. 2006; Choi and Weissman 2006), $Af\rho$ parameter (about 10^4 cm; Bauer et al. 2006), dust size... Collaboration with E. Epifani and M. Fulle.

→ **Upper production rates** to be computed for molecular species.

General statistics for Centaurs

Different Centaurs have also presented a cometary activity far to the Sun (≈5-13 AU):

- **Chiron** (discovered in 1977, activity detected in 1989 and observed from 8.45 to about 18 AU to the Sun, CN detected at 11,26 AU)
- **39P/Oterma** (discovered in 1943)
- **29P/Schwassmann-Wachmann 1** (discovered in 1927)
- **C/2000 B4 (165P/LINEAR)**
- **C/2001 M10 (NEAT)**
- **C/2001 T4 (166P/NEAT)**
- **C/2004 PY42 (167P/CINEOS)**
- **P/2004 A1 (LONEOS)**
- **P/2005 S2 (Skiff)**
- **P/2005 T3 (Read)**



Total: **11 objects for ≈70 known Centaurs (about 16%) (SDO+ Centaurs: 189)**

The importance of 174P/Echeclus outburst is unique !

Mechanism for cometary activity ?

- **Water**: too refractory, cannot drives cometary activity farther than 5 AU to the Sun

- **CO**: supervolatile that can drive such an activity but would also be efficient farther than 30 AU (TNOs)

- **Amorphous → Crystalline phase transition of water**: seems to be consistent with the observations (Jewitt, 2006)

Implication: **the TNOs must be constituted of amorphous water ice**.
But: recent observations reveals that 100% of KBOs observed with sufficiently good S/N show crystalline water ice (4 objects / 7 with water detected (/16 TNOs); Trujillo 2006). Previous cometary activity ?