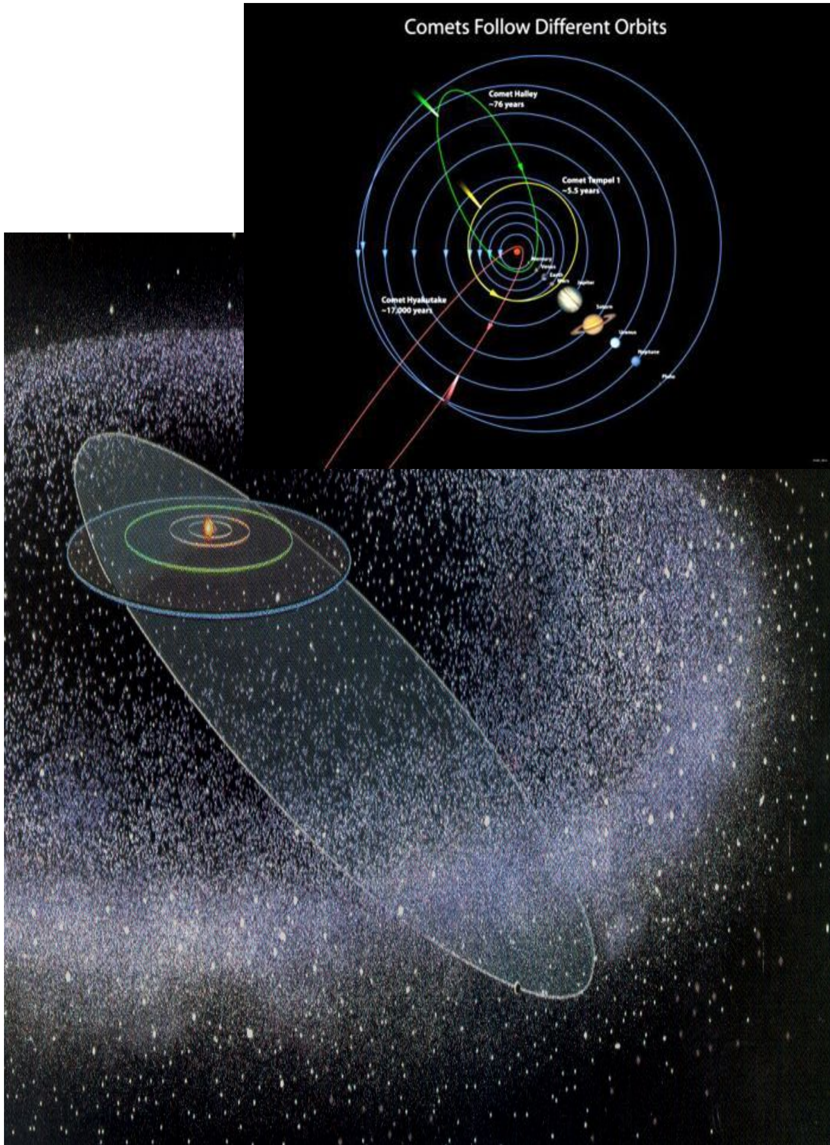
Comparative analysis of gas and dust properties in comets of different dynamical groups

Ivanova Oleksandra

Main goal of analysis

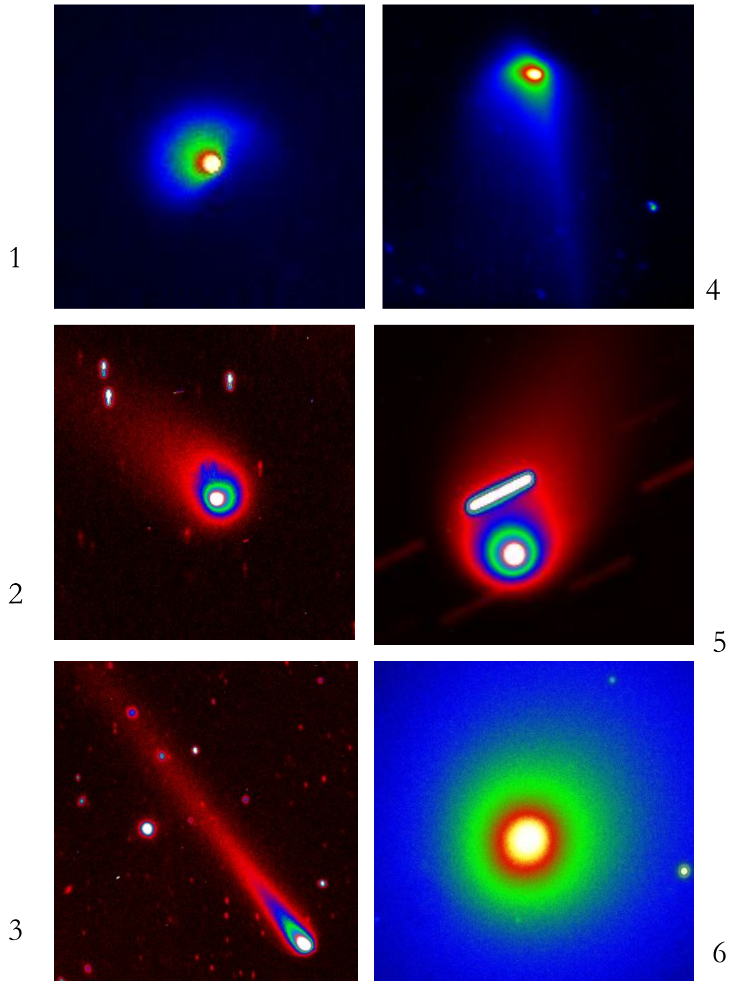


- Comparison of physical properties of the atmospheres and tails in the short- and long-period comets, including dynamically new comets too.

- Analysis of evolution of physical activities of the comets, as function from their distances from the Sun.

- Understanding, how to relate the physical properties of comets from their place of origin

Objects



- Object, which is coming to the inner Solar System for the first time (long-period comets and including dynamical new comets)
- Short-period comets.
- Centaurs

1. 29P/SW1 2. C/2013 V4 (Catalina) 3. C/2014 A4 (SONEAR) 4. 67P/Churyumova-Gerasimenko, 5. C/2010 S1 (LINEAR), 6. C/2009 P1 (Garradd)

Telescopes

- 6-m telescope SAO RAS (Russia)
- 4.1-m telescope SOAR (Chile)
- 2-m telescope (p. Terskol, Russia)
- 2-m Faulkes Telescope of South Siding Spring Observatory (Australia)

- 1.6- m telescope of the National Laboratory for Astrophysics (LNA, Brazil)
- 1.3-m telescope Skalnato Pleso (AI SAS, Slovakia) (in future)
- 1.0 -m telescope (SAO RAS)
- 1.0 -m telescope (Kaurovka observatory, Russia)

- 0.70 -m telescope KAO (p. Lisnyky)
- 0.61 - m telescope Skalnato Pleso (AI SAS, Slovakia)
- 0.60- m telescope (p. Terskol, Russia)

Methods   Photometry

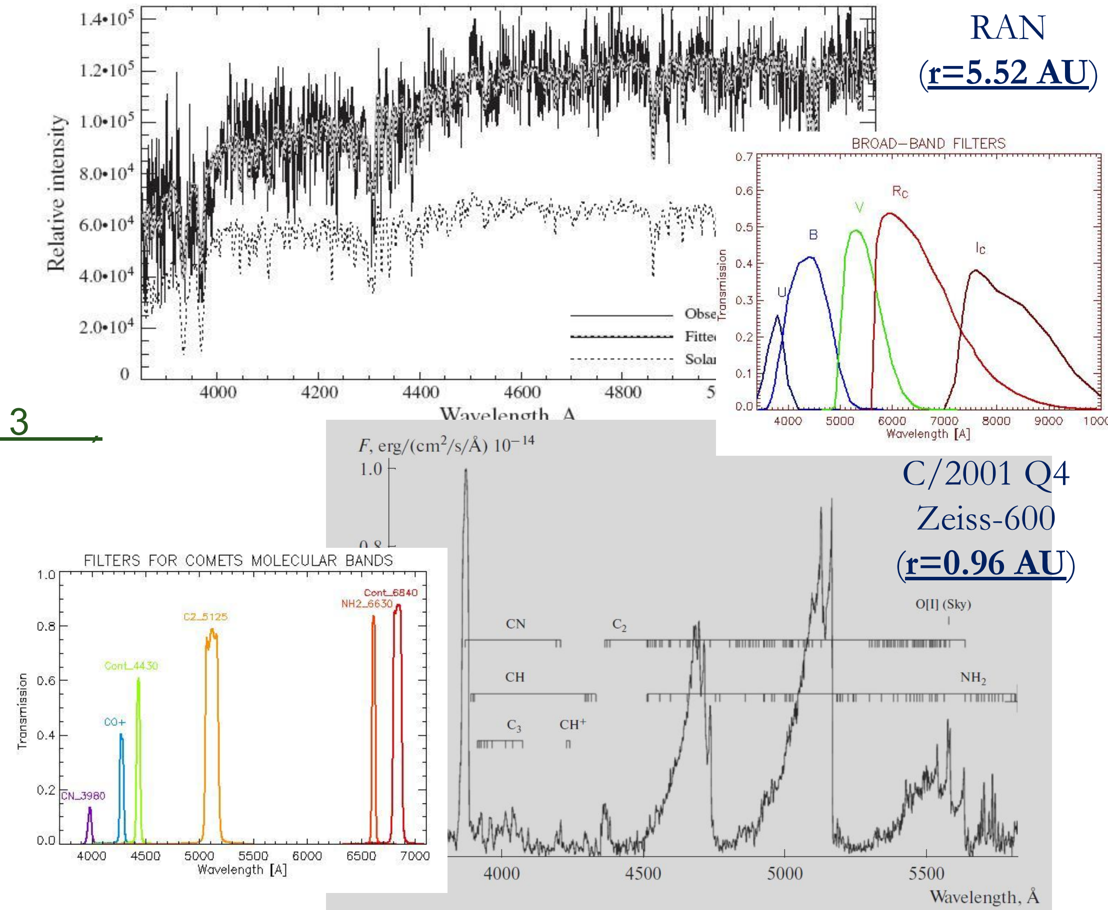
- Broad band filters BVR (heliocentric distances from 8 to 4 AU)

- Dust production rates
- Radius of cometary nucleus
- Morphology of cometary coma
- Color indexes
- Period rotation of cometary nucleus
- Outburst and long lasting activity
- Split of the comets

- Comet filters (at heliocentric distances < 3 ,

- Gas/Dust production rates
- Modeling of dust tails
- Morphology of cometary coma
- Period of rotation of cometary nucleus

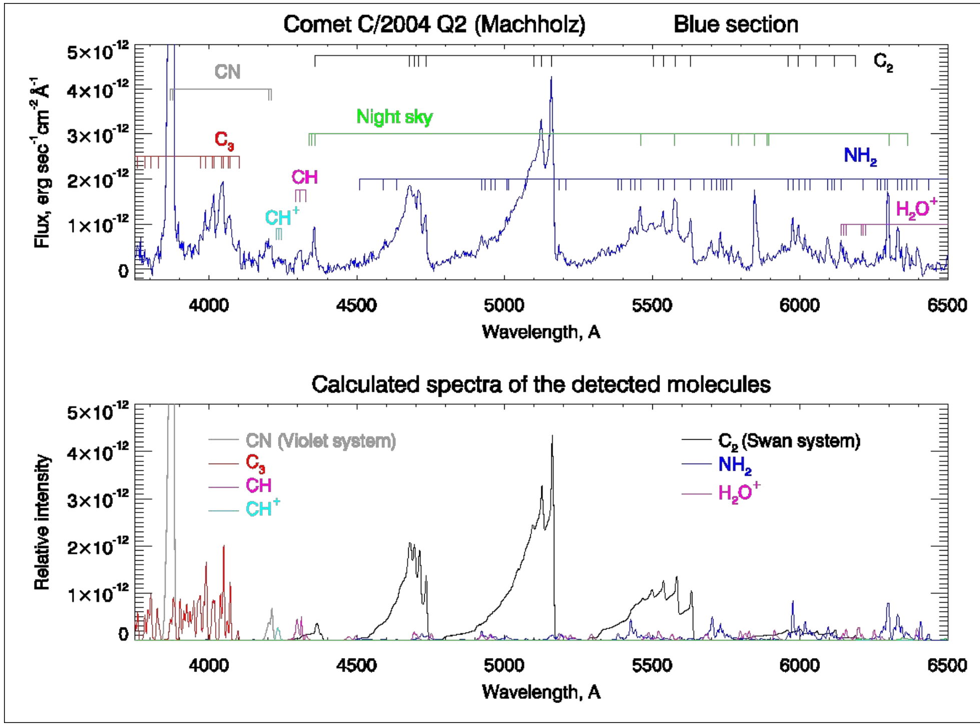
C/2003 WT42
6-m SAO RAN
(r=5.52 AU)



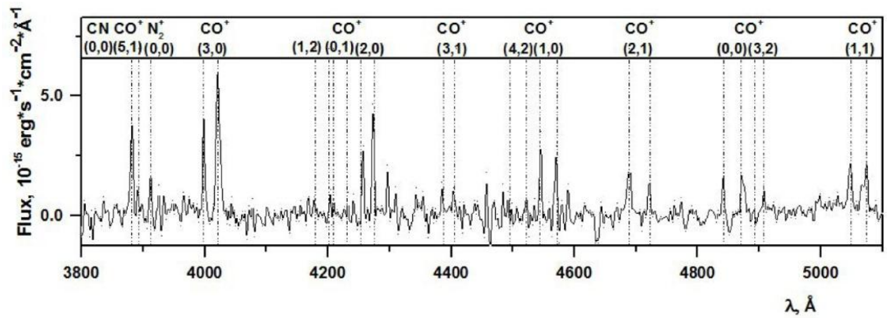
C/2001 Q4
Zeiss-600
(r=0.96 AU)

Methods

Spectroscopy

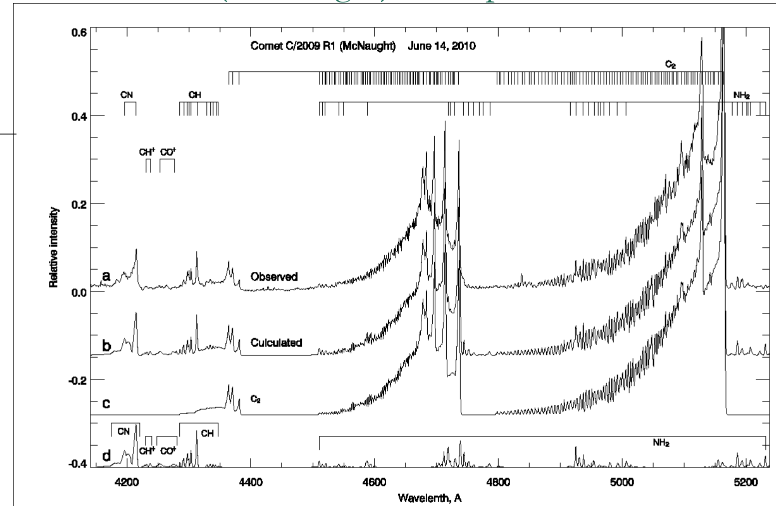


29P/SW1 - 1.6 m Brazil



C/2004 Q2 (Machholz) – 60 cm AAO

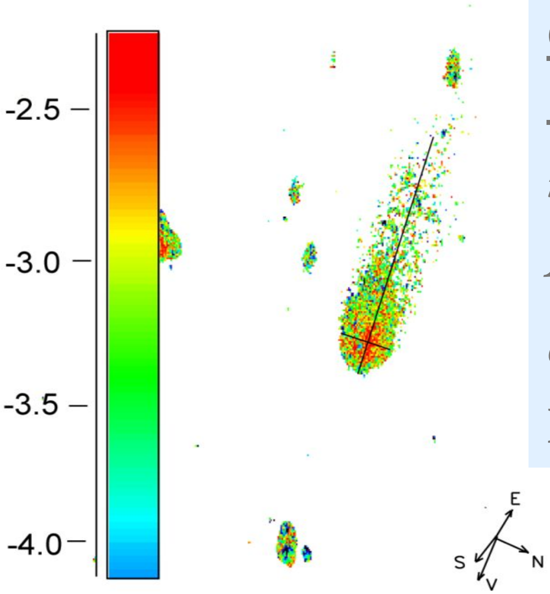
C/2009 R1 (McNaught) – 2m p.Terskol



- Dust production rates
- Gas production rates
- Detection of emission

Methods

Polarimetry



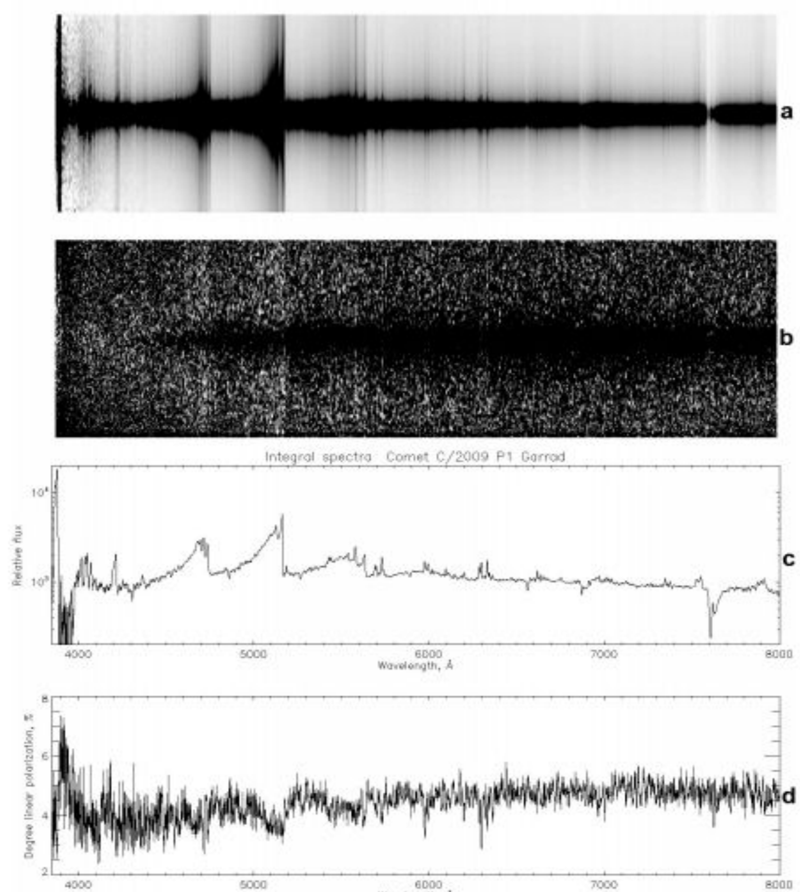
C/2010 S1 (Linear)

r = 5.9 AU

Δ = 5.6 AU

α = 9.2°

Filter R



Study of physical properties of the dust in comets at different heliocentric distances are very important for study of their evolution.

C/2009 P1 (GARRADD)

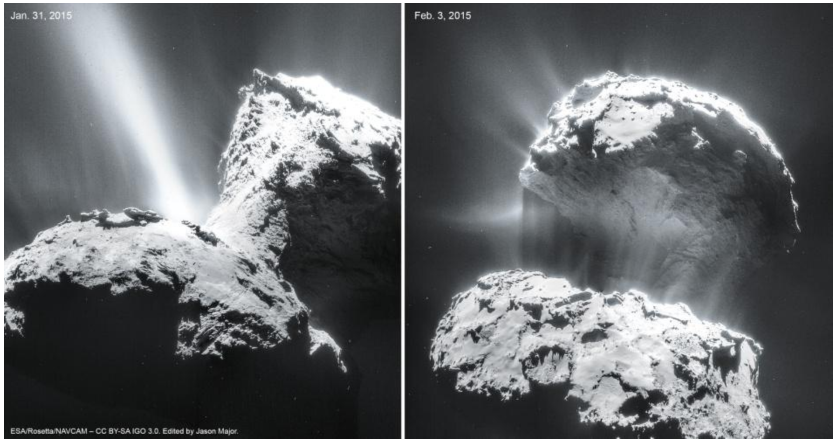
r = 1.71 AU, Δ = 1.38 AU, α = 35.2°

CCD polarimetry of distant comets C/2010 S1 (LINEAR) and C/2010 R1 (LINEAR) at the 6-m telescope of the SAO RAS. Oleksandra V. Ivanova, Janna M. Dlugach, Viktor L. Afanasiev, Volodymyr M. Reshetnyk, Pavlo P. Korsun. Published in Planetary and Space Science, 2014

67P/ Churyumov-Gerasimenko

<u>The Jupiter family comet.</u>

The short period comets have orbital periods <20 years and low inclination. Their orbits are controlled by Jupiter. The short period comets are believed to originate from the Kuiper Belt.



q=1.242335 au

e=0.6404361

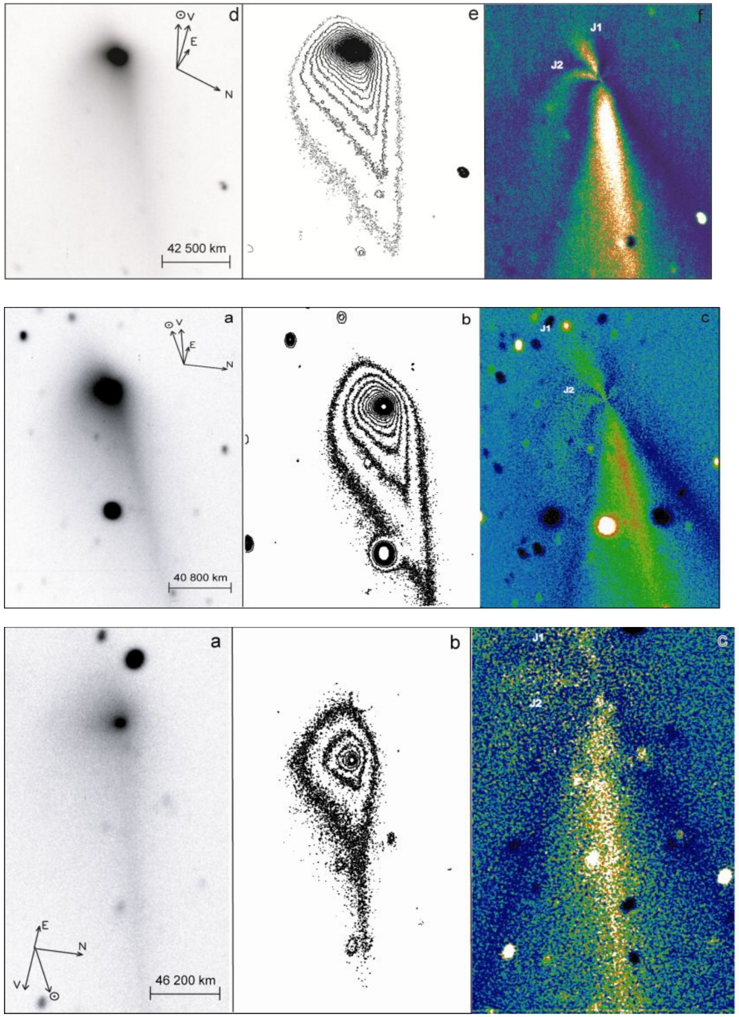
P=6.44

i=7.04 deg

November 8, 2015	December 9, 2015	April 5, 2016
r=1.62 au	r=1.84 au	r=2.72 au
Δ=1.80 au	Δ=1.72 au	Δ=1.81 au
α=33.2°	α=31.8°	α=10.4°

Methods

Photometry



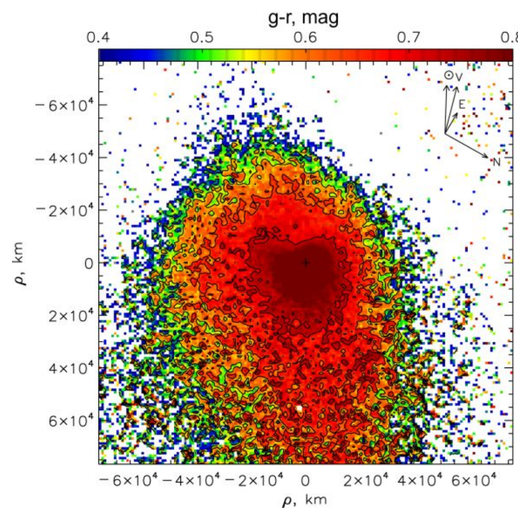
Direct image of the comet

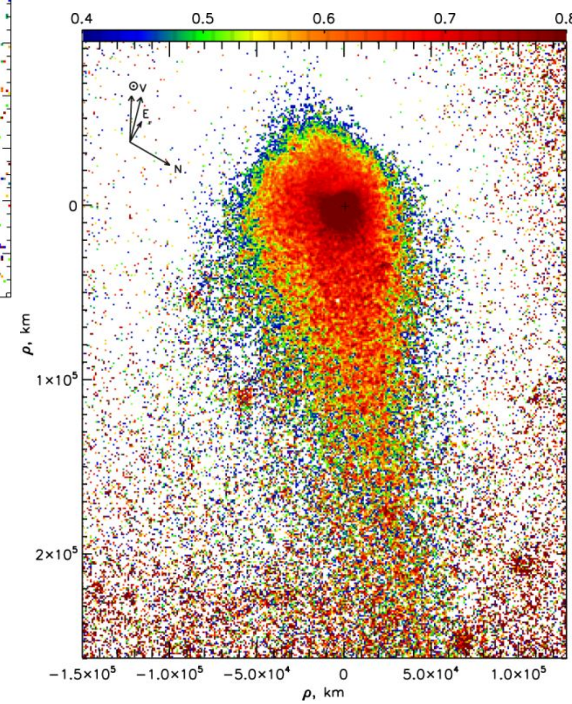
Relative isophots

Image treated by digital filters

Two jets and tail are clearly apparent.

Color map g-r

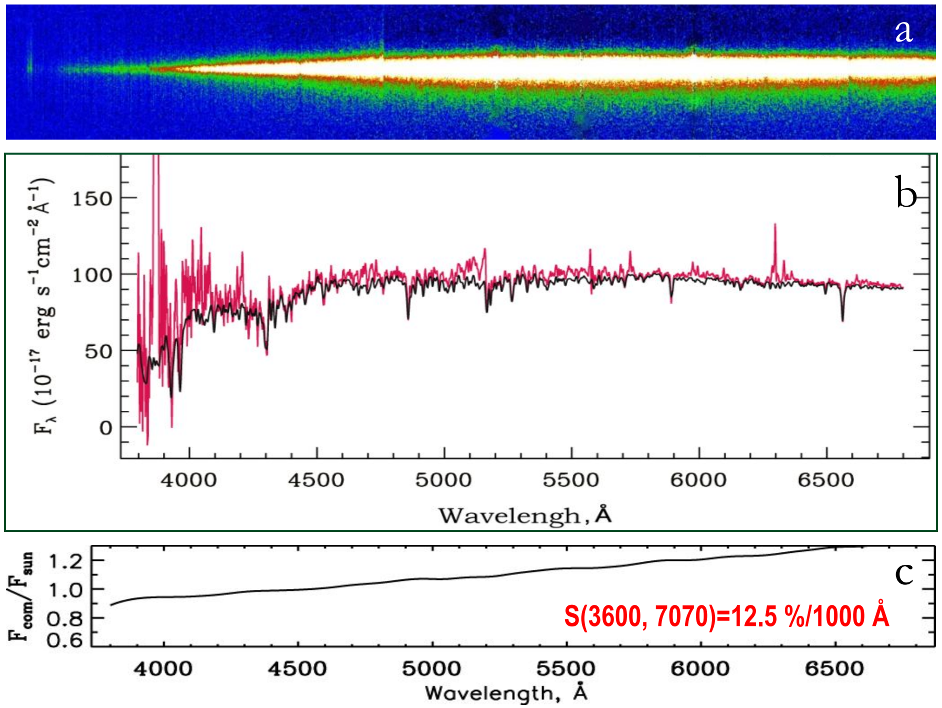




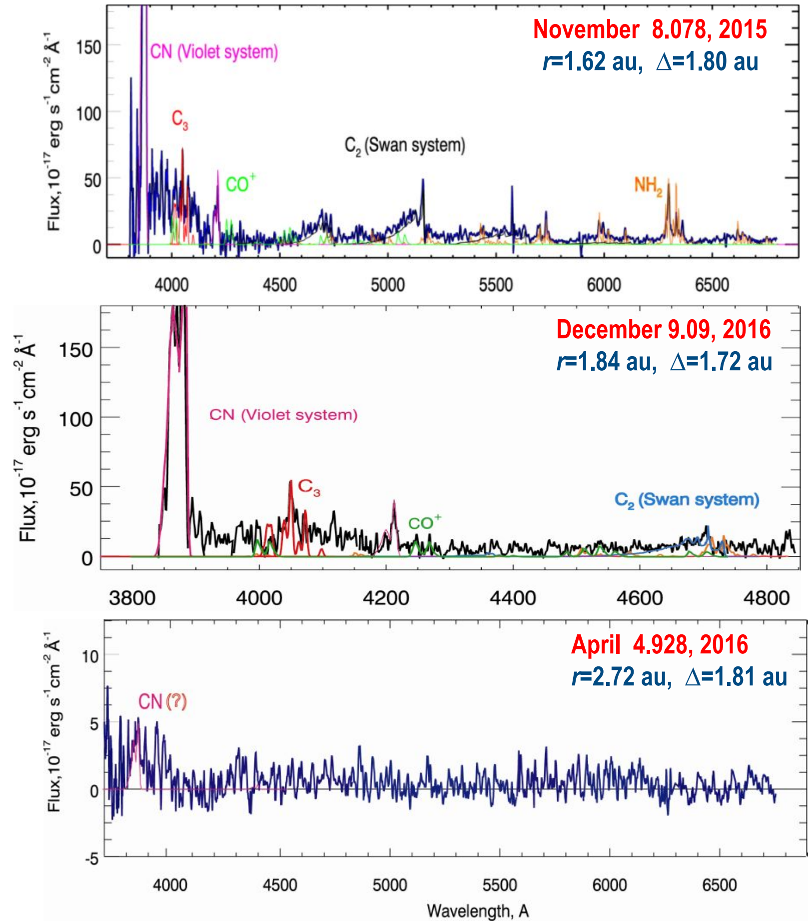
Methods

Spectroscopy

Long-slit spectroscopy of the comet was performed at the 6-m telescope BTA with the multi-mode focal reducer SCORPIO-2. The gratings VPHG2400 (3600–7070 Å, Δλ=5 Å) and VPHG2400 (3600–5100 Å, Δλ=4 Å) and slits 6.1' × 1.0”, 6.1’ × 2.0”were used.



The long-slit spectrum of comet 67P derived on November 8, 2015.
(a) – the raw spectrum; (b) – the distribution of energy in spectrum of the comet; (c) – normalized reddening of the dust continuum vs wavelength.



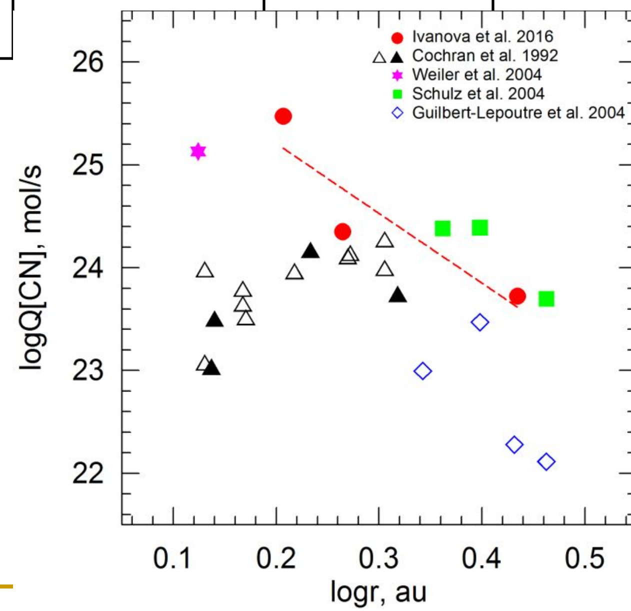
The emission spectra of comet 67P and the modeled spectra for comparison.

Gas production rates in comet 67P

Date of observation, UT (Post-perihelion)	Q, [mol/s]				
	CN	C_3	C_2	NH_2	$Log[C_2/CN]$
Nov. 8.078,2015 r=1.61 au, Δ=1.79 au, α=33.2°	7.05×10^{24}	1.01×10^{24}	2.62×10^{24}	3.54×10^{23}	–0.43
Dec. 9.093, 2015 r=1.84 au, Δ=1.72 au, α=31.8°	2.24×10^{24}	0.72×10^{24}	—	—	—
Apr. 4.928, 2016 r=2.72 au, Δ=1.81 au, α=10.4°	$<5.3\times10^{23}$	—	—	—	—

Summary:

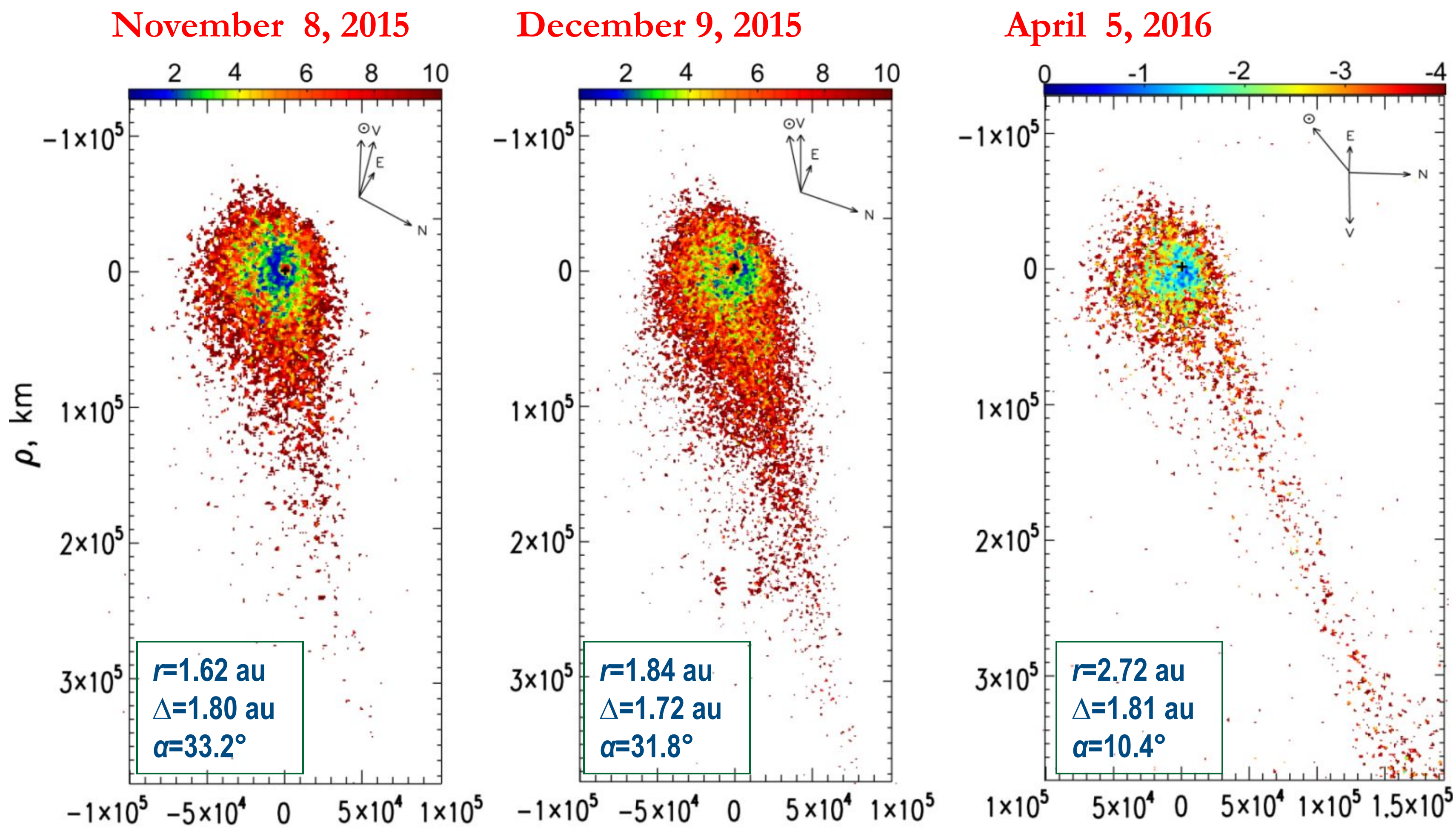
- CN, C_2, C_3, and NH_2 emissions were identified in the spectra of comet 67P on November 8 and December 9, 2015;
- Only CN emission was detected in the spectrum of the comet on April 4, 2016;
- The value $\log[C_2/CN]$=–0.43 corresponds to "Depleted" comets (A'Hearn et al. 1995)



The dependence of CN production rate on the heliocentric distance according to data of different authors. Open and filled symbols are data before and after perihelion.

Methods

Polarimetry

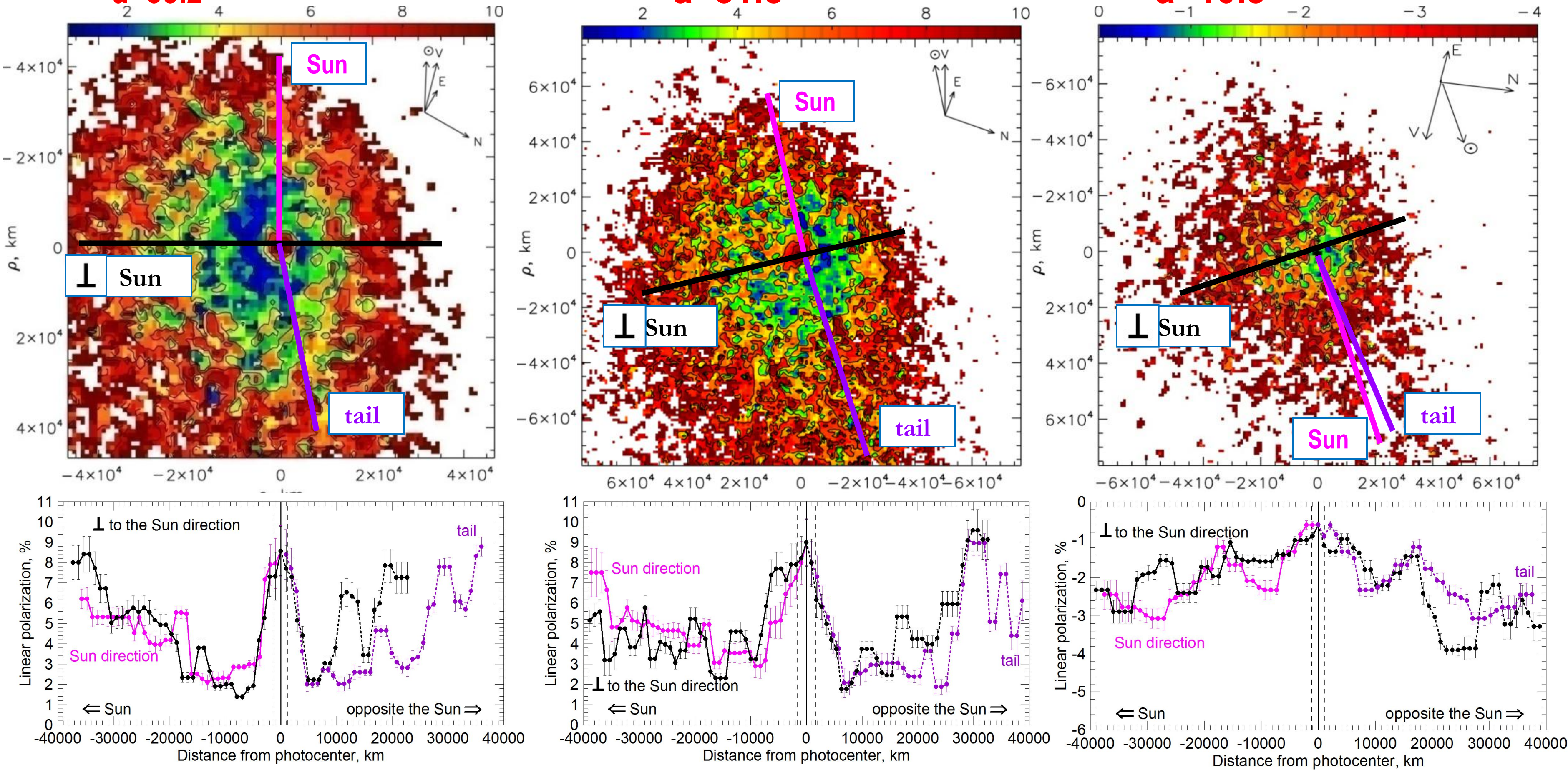


Distribution of linear polarization over the coma of comet 67P.

Linear polarization maps: there is a complex structure of the coma in polarized light with areas of high and low polarization

Linear polarization maps in details

November 8, 2015 — α=33.2°   December 9, 2015 — α=31.8°   April 5, 2016 — α=10.3°



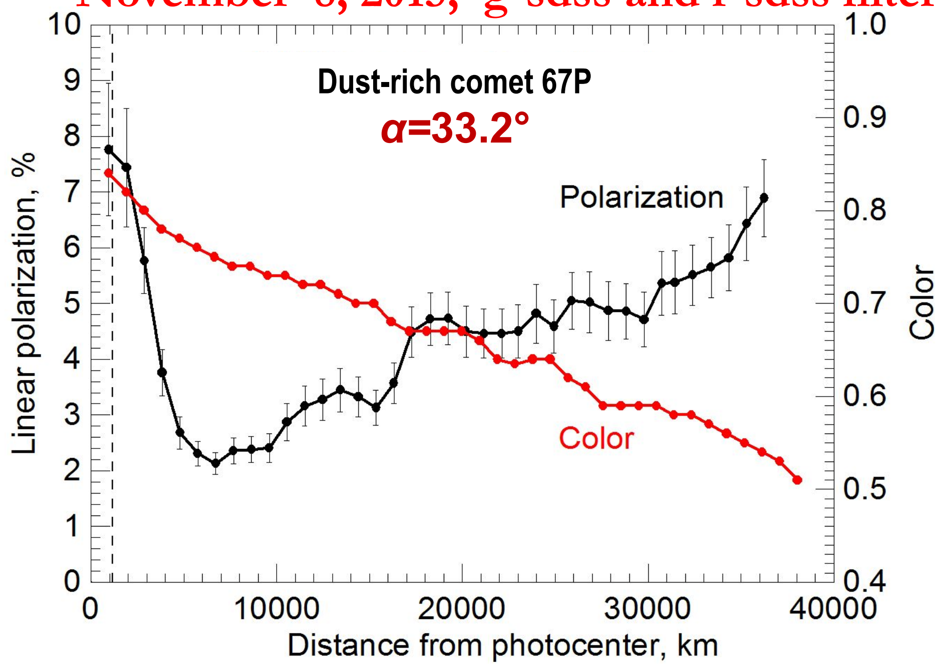
Polarization maps in large scale (top row) and polarization profiles (bottom row)

α=33–32°: – in the near-nucleus area, *P*≈8% and drops sharply to ~2% at projected distance 5000 km;
– coma polarization increases with distance from the nucleus reaching >8% at 36000km.

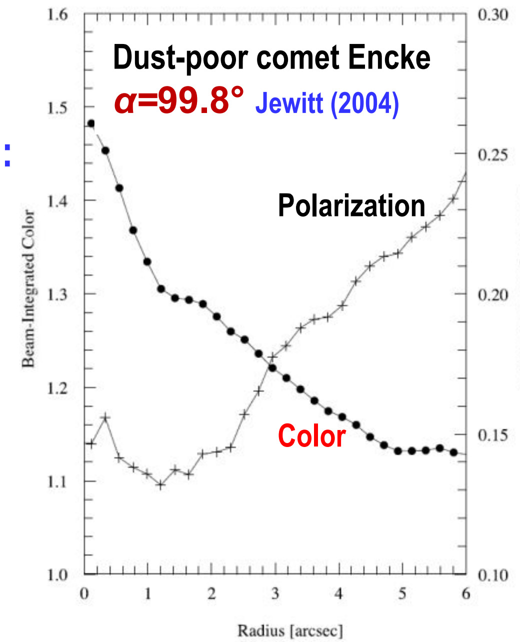
α=10.4°: *P* varies between –0.6% in the near-nucleus area and –3÷–4% in the outer coma.

Comparison of polarization and color

November 8, 2015, g-sdss and r-sdss filter



For comparison: comet Encke



Polarization and color profiles measured within projected concentric annuli as a function of the annulus radius. Left and right axes show the polarization and color. The figure for comet Encke is taken from Jewitt (2004). Trends of polarization and color are very similar for two comets.

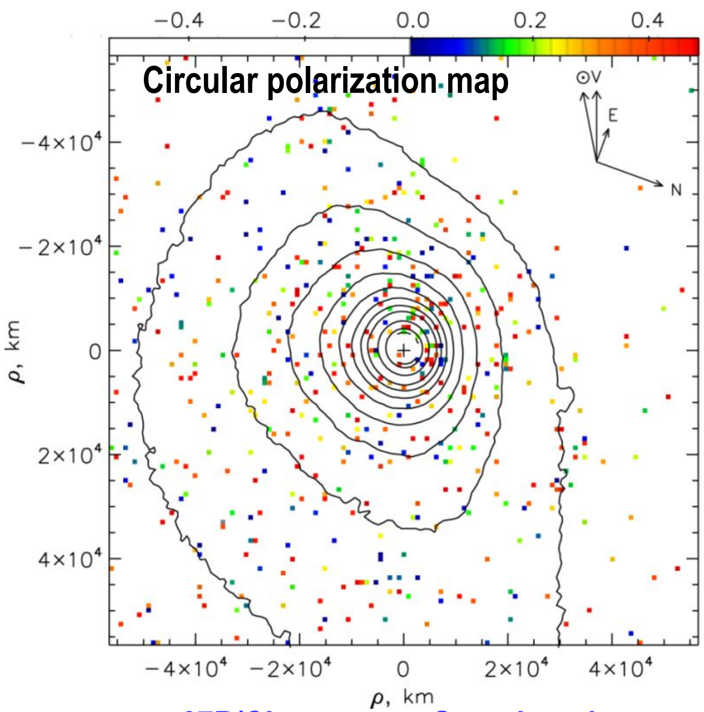
Summary:

- near-nucleus area is redder and more polarized than the adjacent coma;
- the coma becomes more blue with increasing distance from the nucleus;
- near-nucleus polarization drops sharply from ~8% to ~2% at 5000 km;
- polarization of the coma increases with distance from the nucleus, reaching ~8% at 40000 km;
- the radial variations of polarization and color suggests an evolution of the particle properties.

Higher polarization and bluer color measured at larger projected radii are consistent with a decrease in the mean grain size with increasing distance from the nucleus that can be caused by disintegration of porous aggregates.

Circular polarization

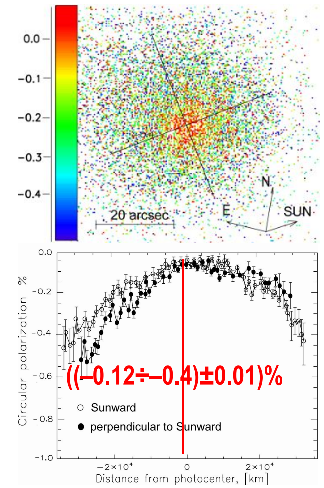
November 08, 2015, α=33.2°



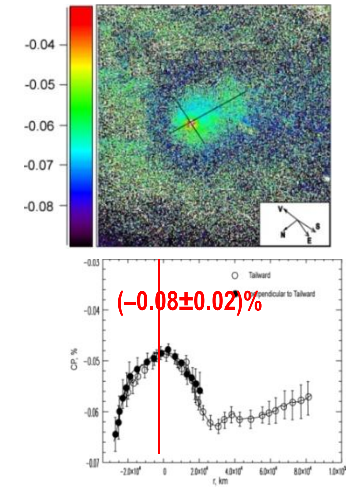
67P/Churyumov–Gerasimenko

Comparison with comets showing CP and comets with CP ≈ 0%

CP in other comets

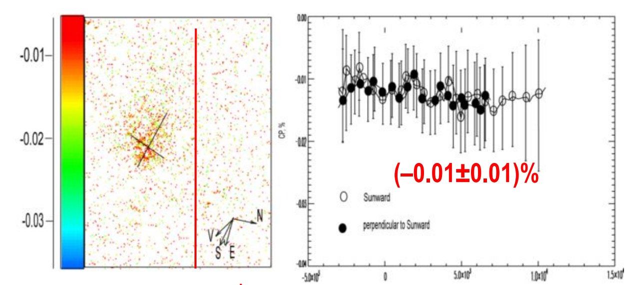


C/2009 P1 (Garradd)

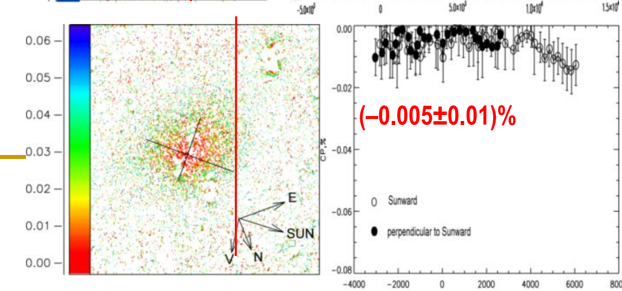


C/2011 R1 (McNaught)

Comets with CP ≈ 0%



290P/Jager



108P/Criffeo

Circular polarization has not been registered in comet 67P

C/2009 P1 (Garradd)

<u>The Oord cloud comet.</u>

The long period comets are believed to originate from the Oord Cloud.

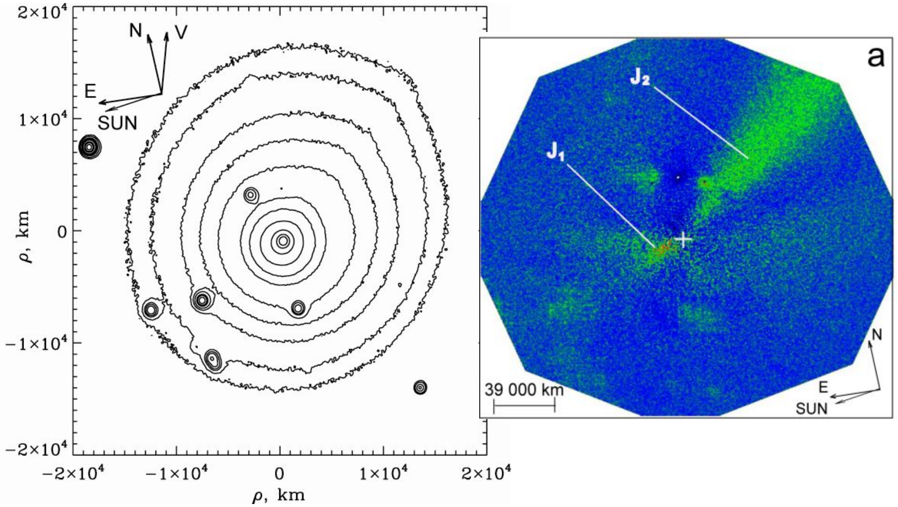
q=1.55126 au

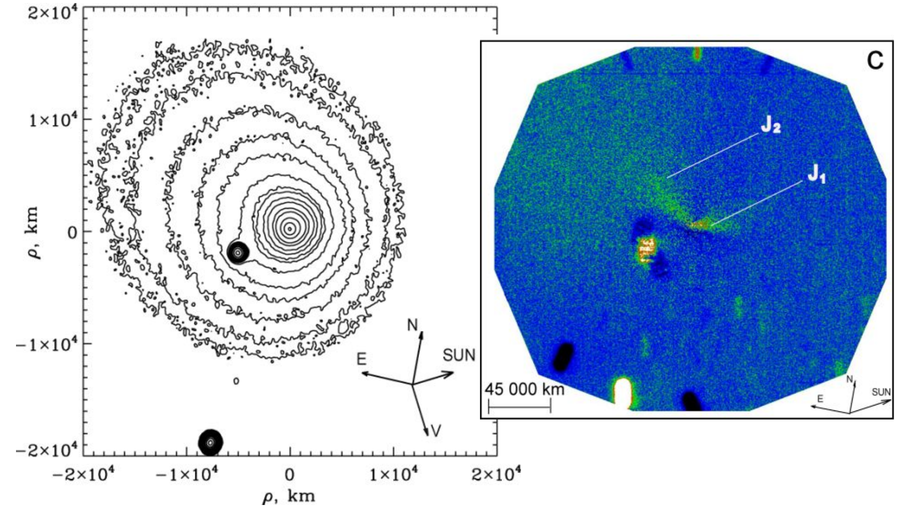
e=1.00024

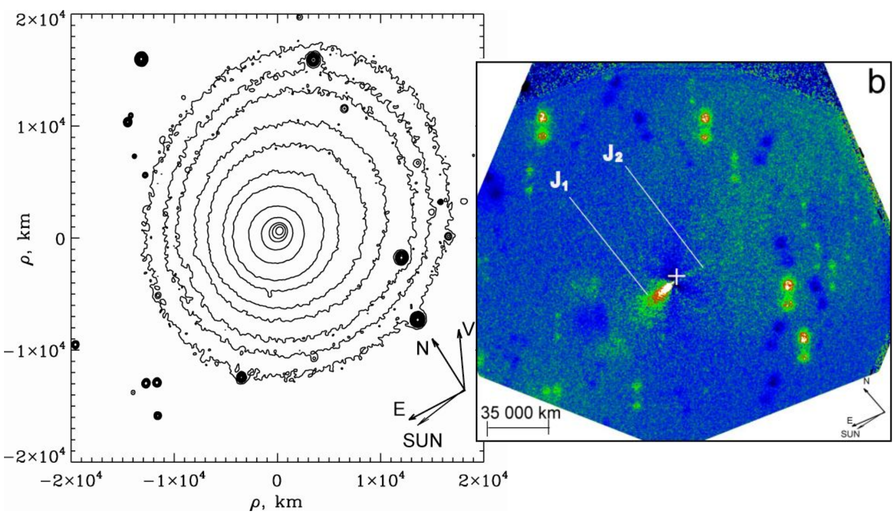
i=106.2 deg

February 2-14, 2012	April 14-21, 2012
r=1.65-1.71 au	r=2.16-2.23 au
Δ=1.53-1.39 au	Δ=1.79-1.96 au
α=35.9-35.3°	α=27.4-26.8°

Methods Photometry



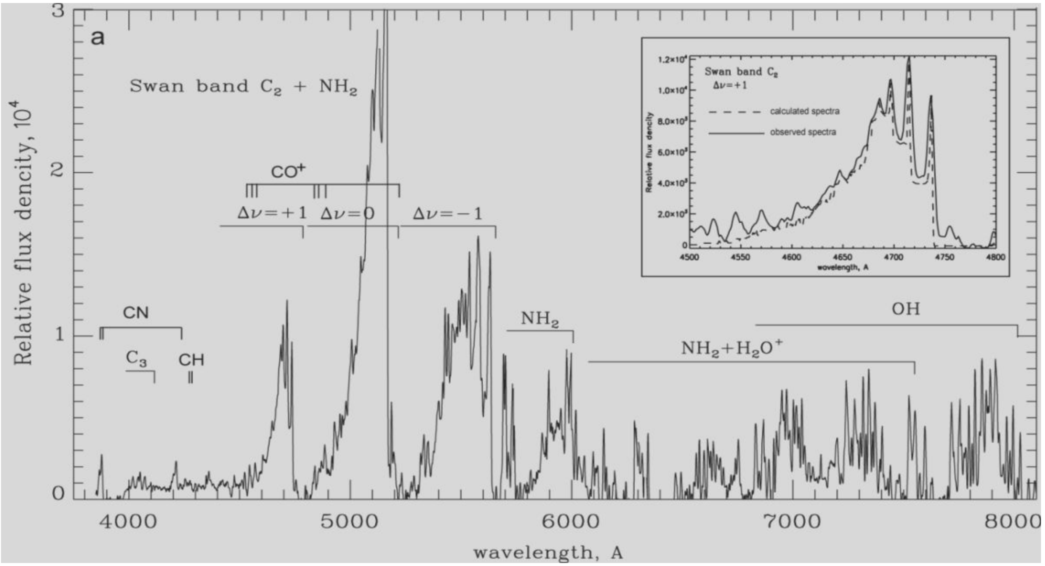


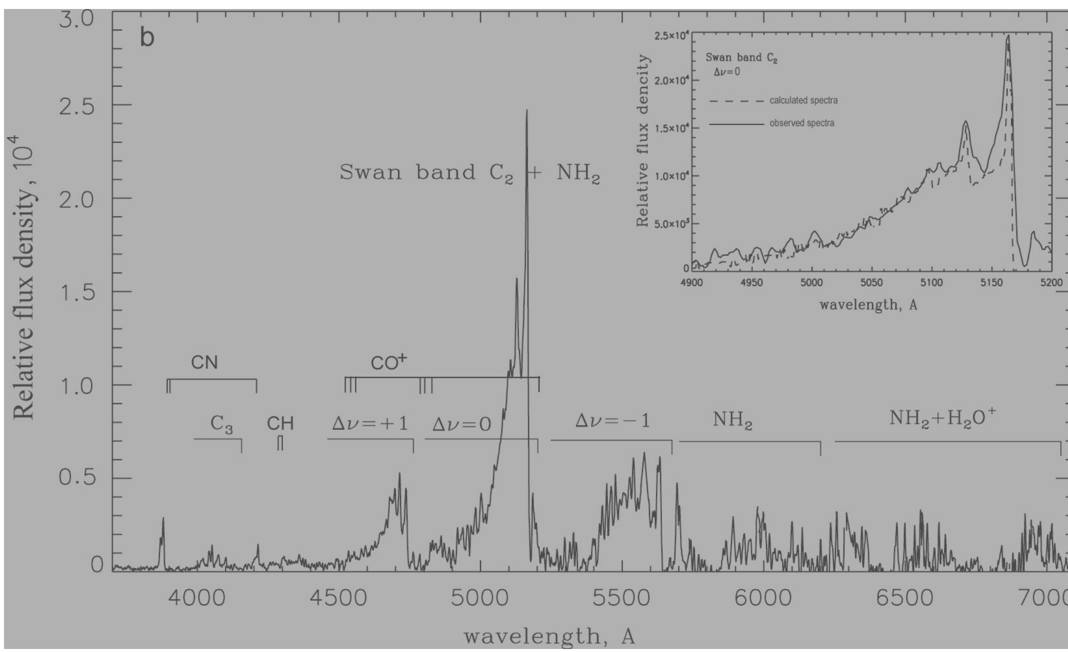


Two features (dust and gas tails) oriented in the solar and antisolar directions were revealed in treated images of comet Garradd that allowed us to determine the period of rotation of the nucleus as **11.1 ±0.8** hours.

Methods

Spectroscopy



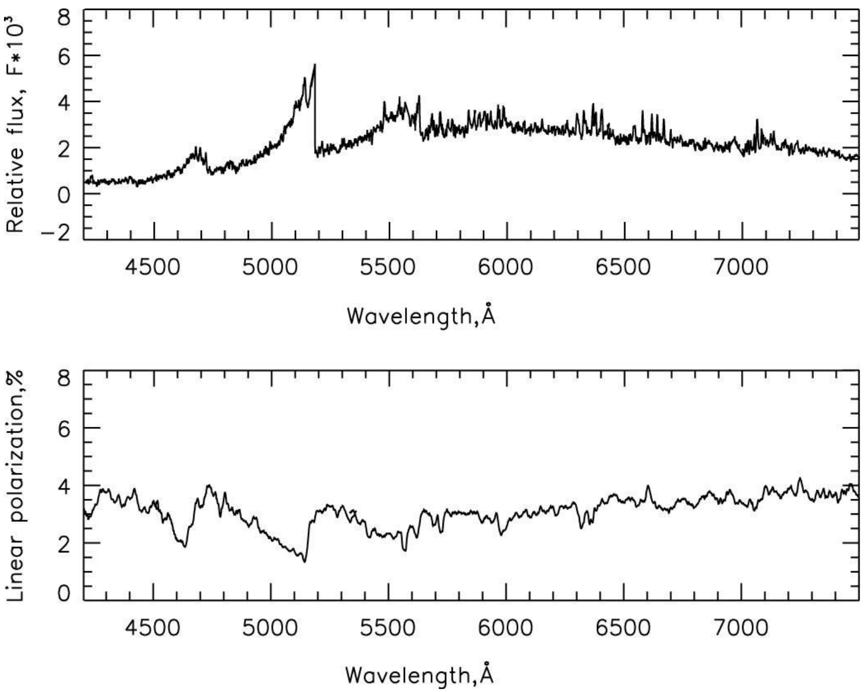


Long-slit spectroscopy of the comet was performed at the 6-m telescope BTA with the multi-mode focal reducer SCORPIO-2. slit 6.1' × 1.0'' was used.

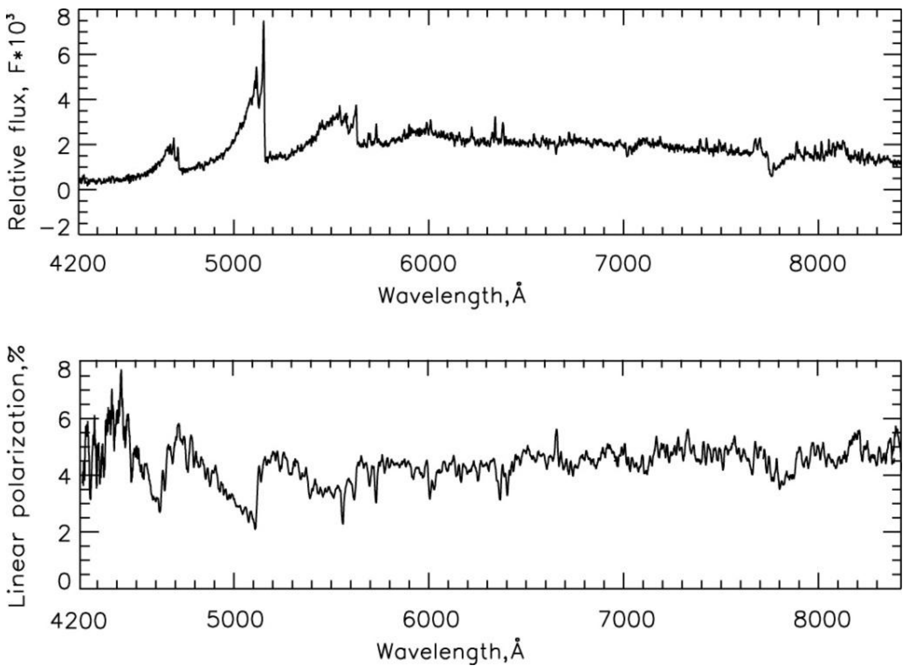
- Emission bands of neutral molecules such as C_2, C_3, CN, CH, and NH_2 as well as CO^+ and H_2O^+ ions were identified in the spectra of the comet Garradd.

•Long-slit spectroscopy of the comet. The comet is "CO-rich"

Methods Spectropolarimetry



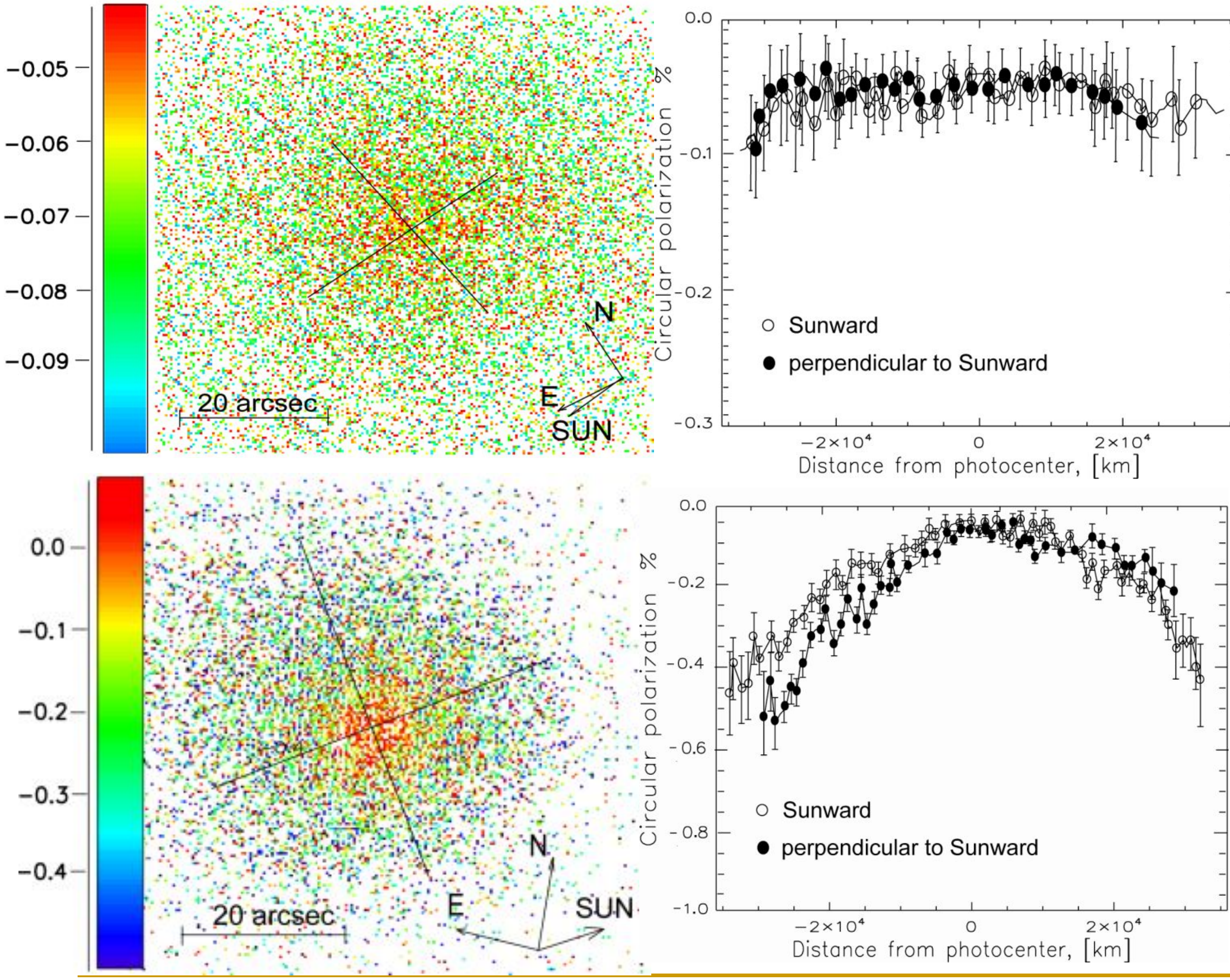
The long-slit spectra of comet Garradd obtained at phase angle 35.9° on February 2.086, 2012. The top and bottom panels display the integral intensity and the degree of linear polarization as a function of wavelength in 3×10 arcsec (3329×11097 km) area around the center of the comet.



The long-slit spectra of comet Garradd obtained at phase angle 27.4° on April 14.864, 2012. The area measured around the optocenter of the comet is 3×10 arcsec (3916×13055 km). The notations are the same as in Fig. 9.

Ivanova O., Rosenbush V.K., Afanasiev V.L., Kiselev N.N., **Polarimetry, photometry, and spectroscopy of comet C/2009 P1 (Garradd),** *2016 accepted to Icarus*

Circular polarization

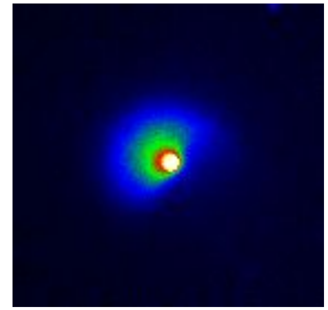


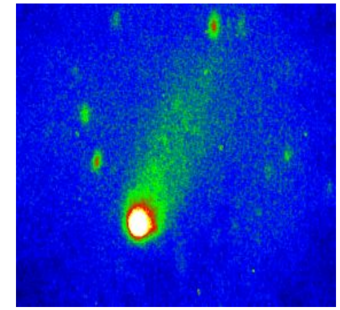
- The significant left-handed (negative) circular polarization was detected at distances up to 3×10^4 km from the cometary nucleus with values from about –0.06% to –0.5% (with errors 0.02%) on February 14 and April 21, respectively.
- There is some systematic increase in the degree of circular polarization to the outer edge of the coma on April 21.

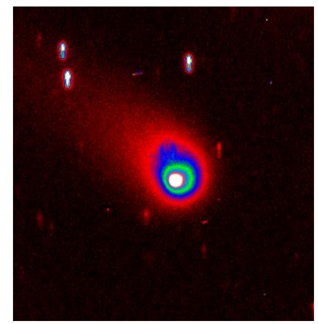
“New” comets and Centaurs

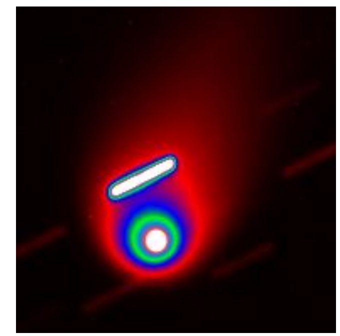
The long-period comets are believed to originate from the Oord Cloud. These comets are coming to the inner Solar system for the first time.
Traditional definition of a dynamically ‘new’ comet, which is the comet visiting our planetary system for the first time, is that it should have its $1/a < 1 \times 10^{-4}$ AU^{-1} (e.g. Oort and Schmidt, 1951).

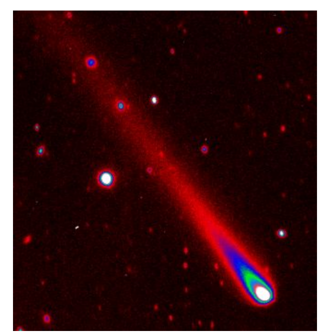
The dynamical behavior of Centaurs is still poorly understood.
Centaurs are objects, whose orbits meet the following conditions.
1. The perihelion distance, q, and the semimajor axis, a, satisfy
$a_J < q < a_N$ and $a_J < a < a_N$, respectively, where a_J = 5.2 AU is the semimajor axis of Jupiter and a_N = 30.0 AU is the semimajor axis of Neptune.

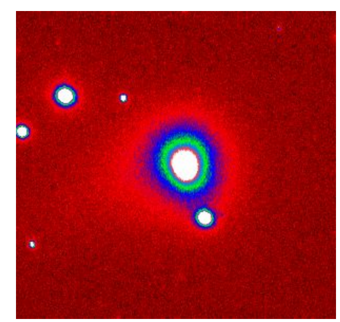
1



4

2


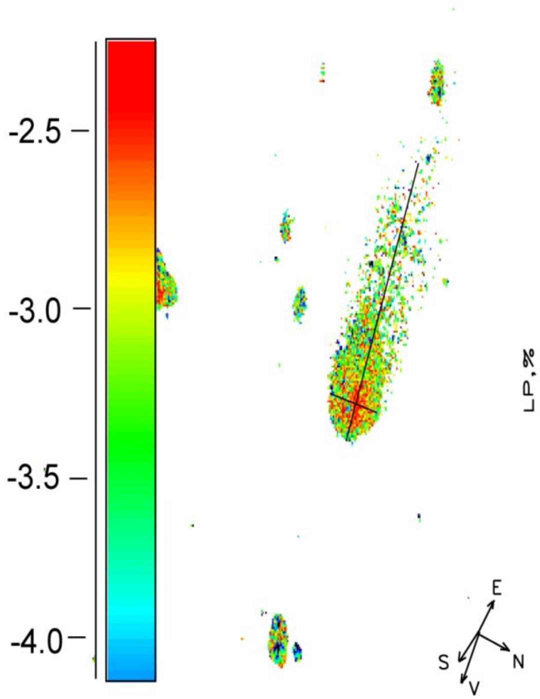

5

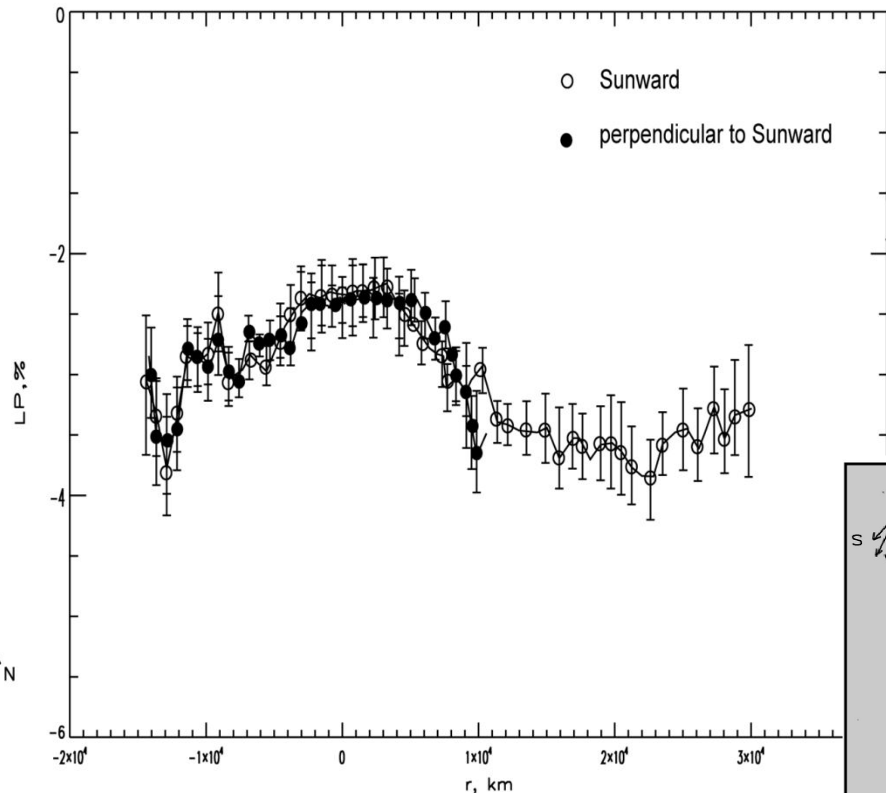
3



6

1. 29P/SW1 2. C/2013 V4 (Catalina) 3. C/2014 A4 (SONEAR) 4. C/2010 R1 (LINEAR), 5. C/2010 S1 (LINEAR), 6. C/2012 J1 (Catalina)

C/2010 R1 (LINEAR)





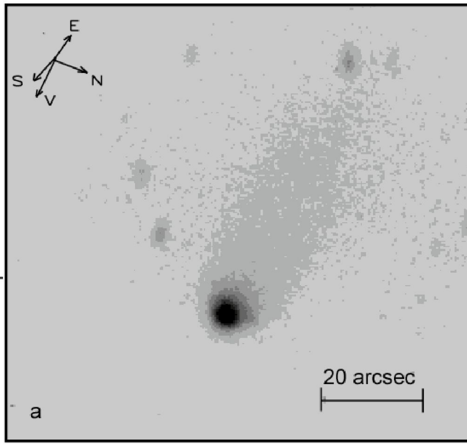
2013, Feb. 6

r = 5.9 AU

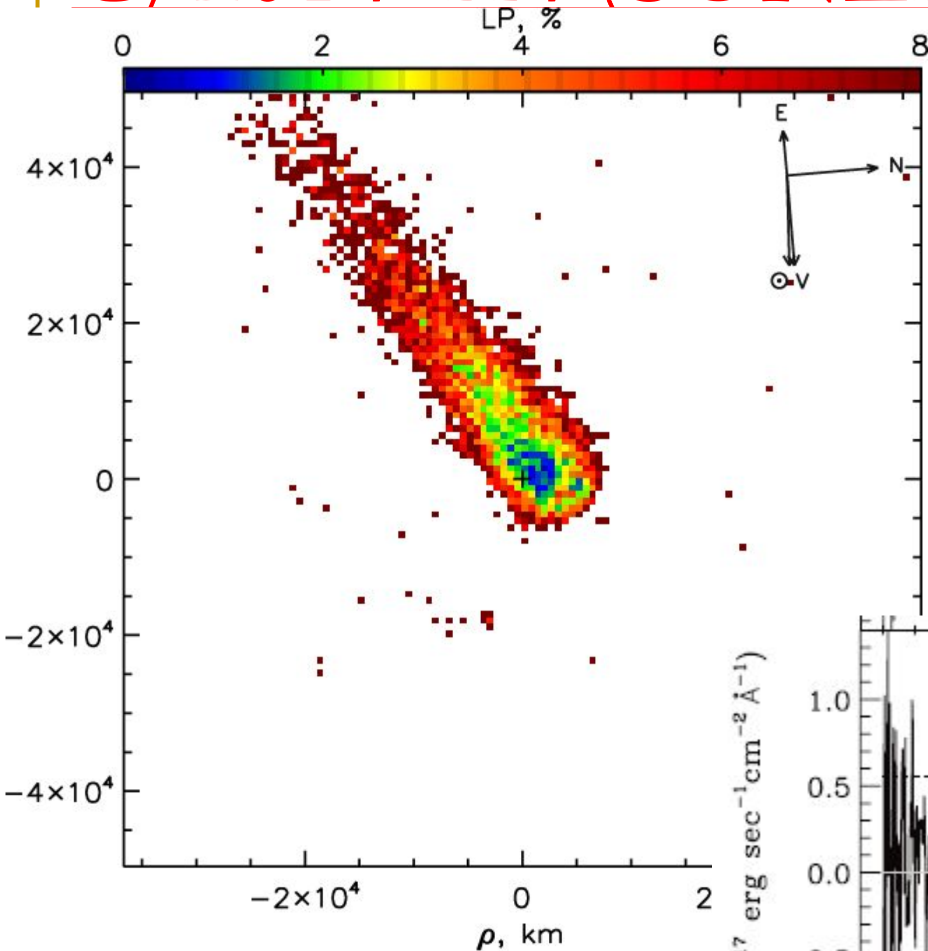
Δ = 5.6 AU

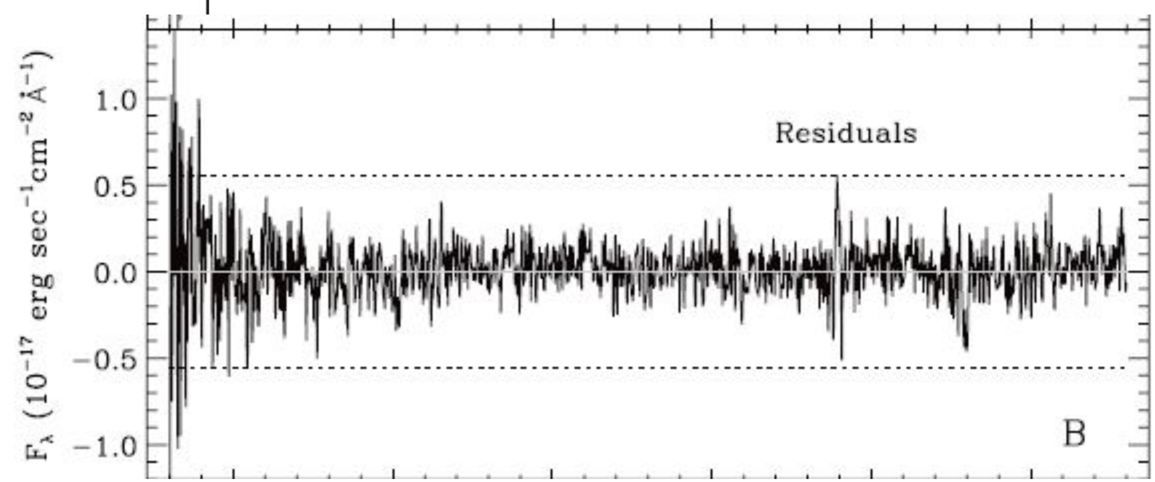
α = 9.2°

Filter R



C/2014 A4 (SONEAR)





2015, Nov. 5

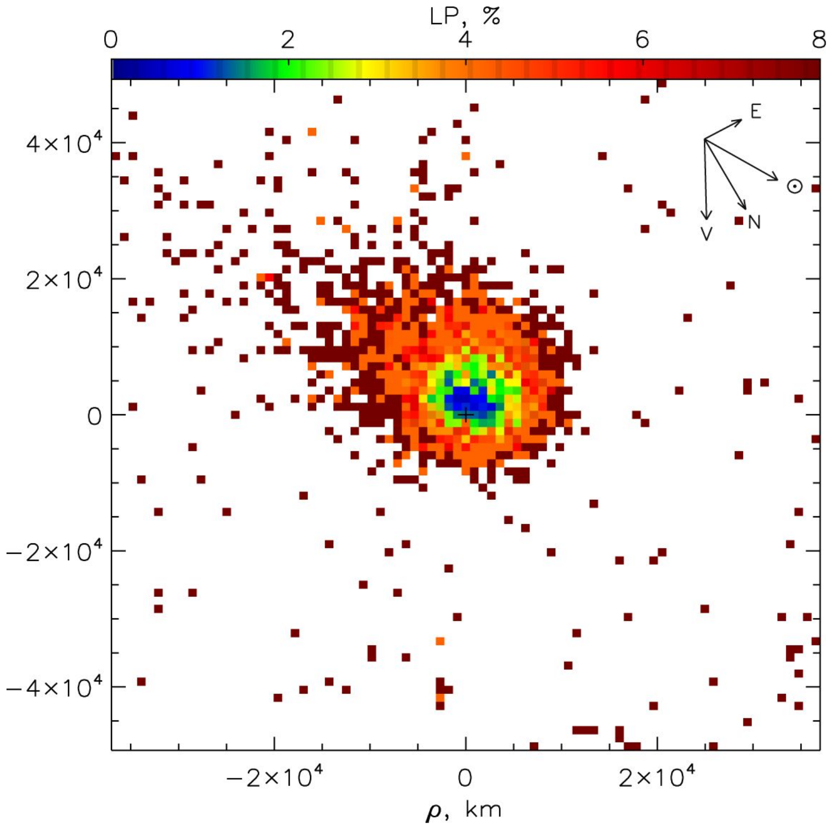
r = 4.21AU

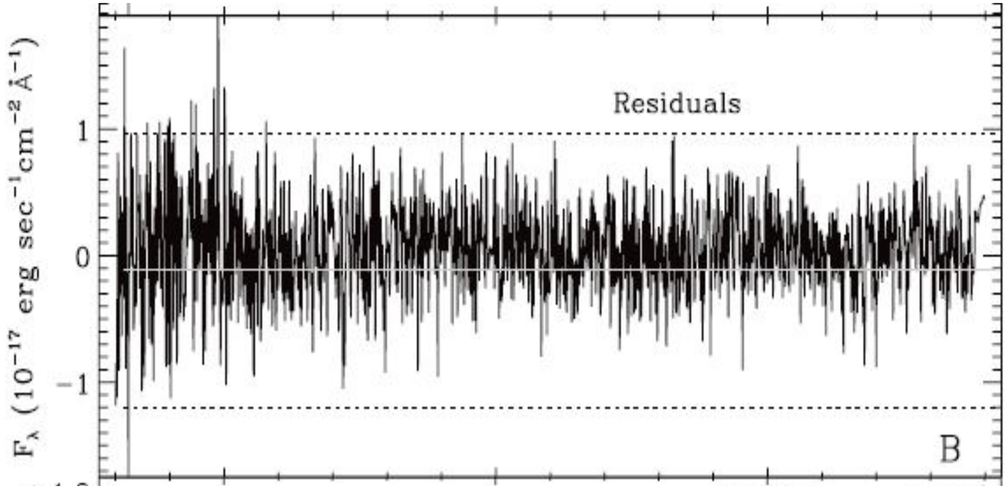
Δ = 3.28 AU

α = 4.9°

Filter R

C/2013 V4 (Catalina)





<u>2015, Nov. 6</u>

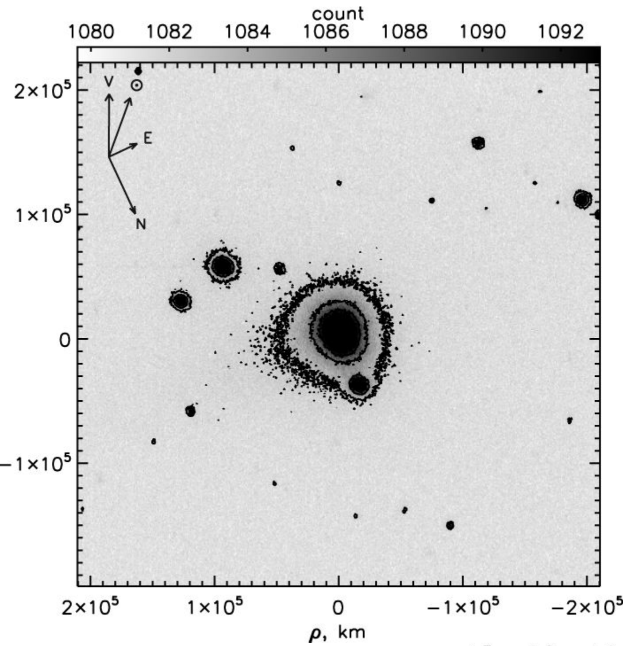
r = 5.19 AU

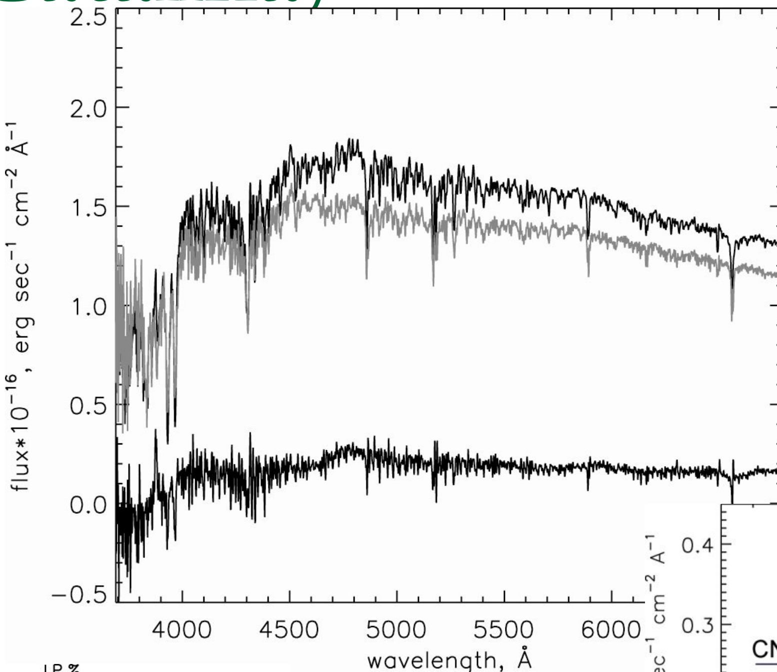
Δ = 4.96 AU

α = 9.4°

Filter R

C/2012 J1 (Catalina)



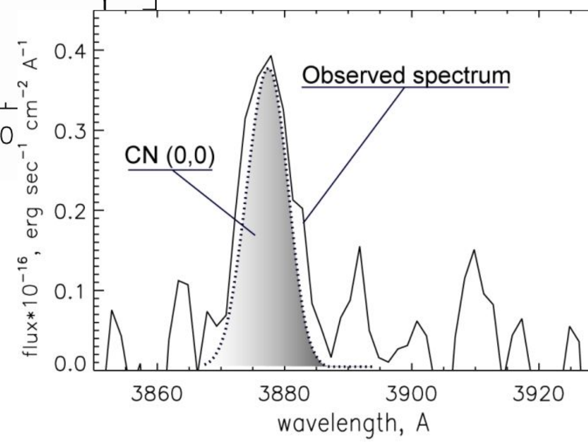


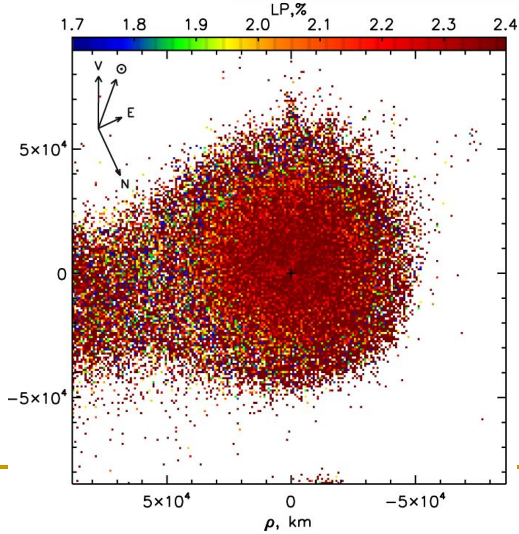
<u>2012, Nov. 15</u>

r = 3.17 AU

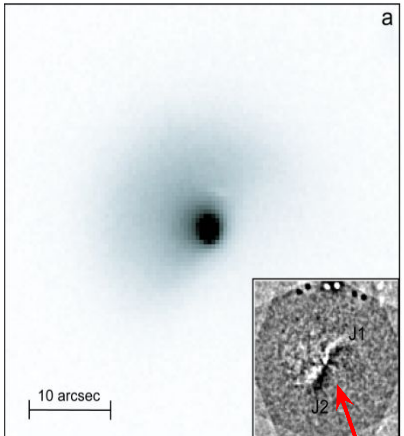
Δ = 2.45 AU

α = 14.02

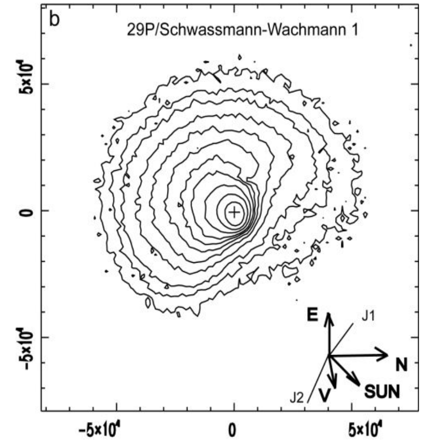




29P/Schwassmann-Wachmann 1



Intensity



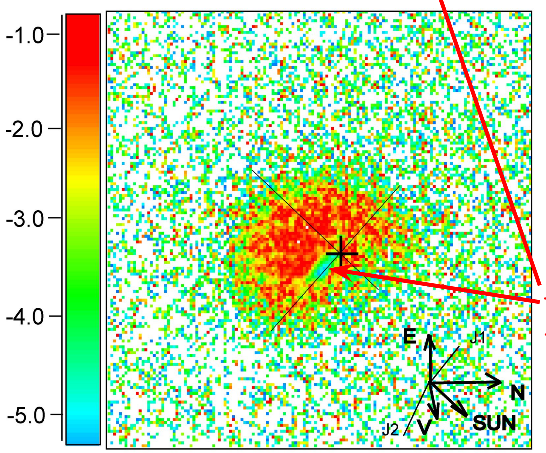
2012, Feb 14

r = 6.26 AU

Δ = 5.51 AU

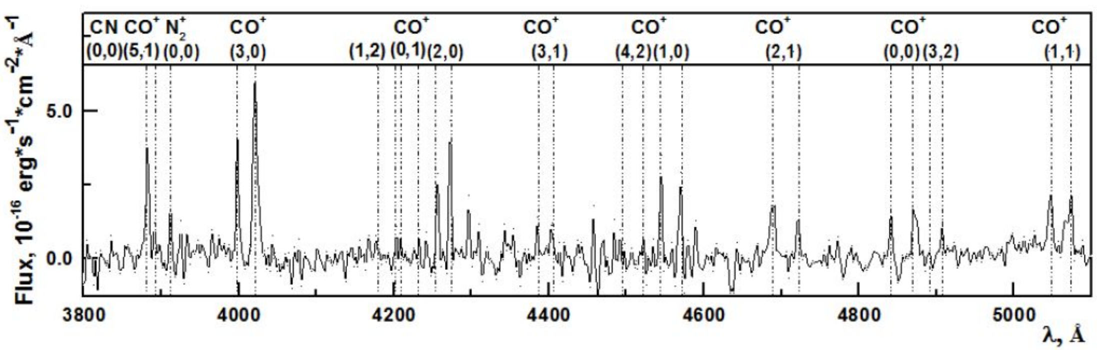
α = 6.3°

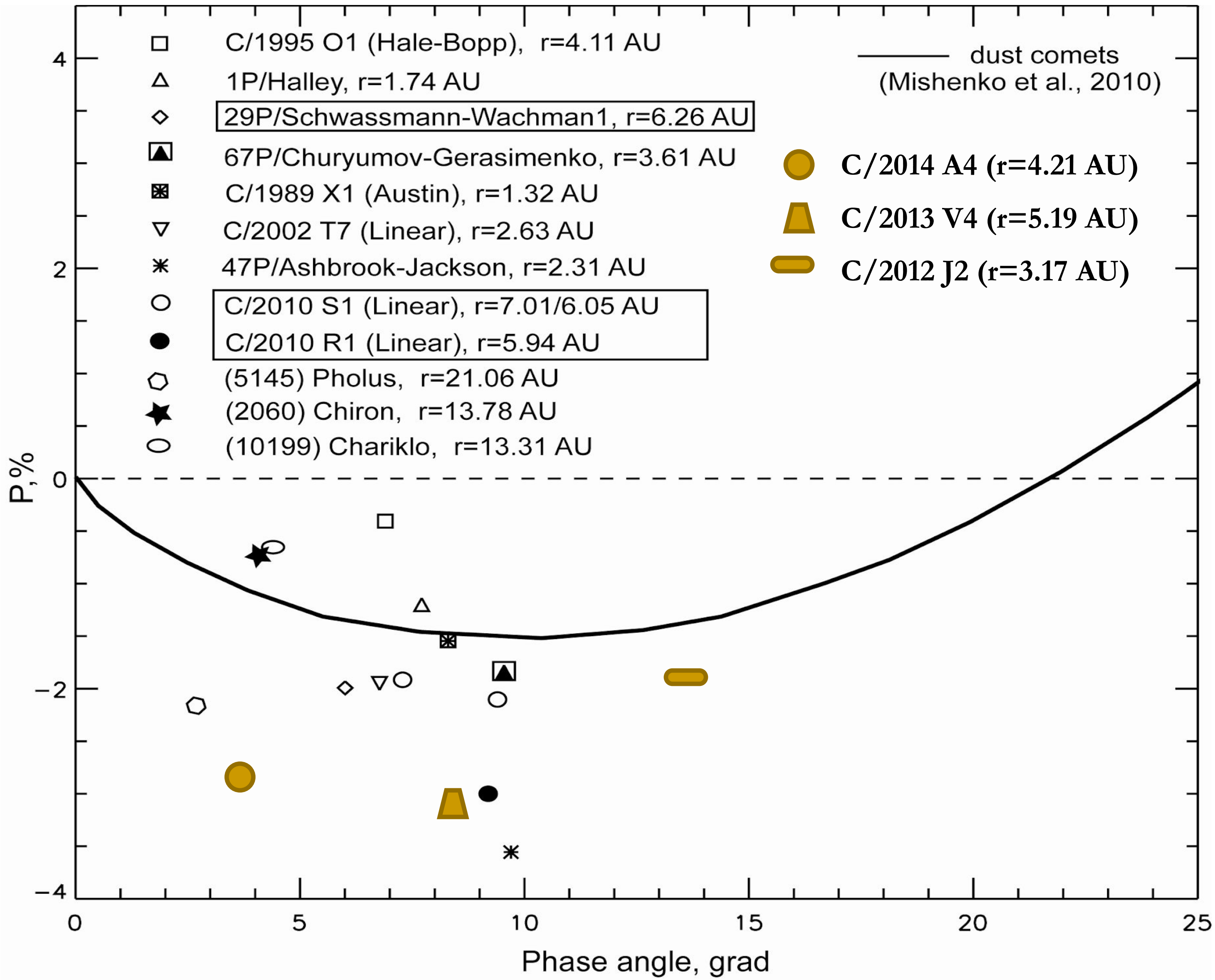
Filter 6840 Å



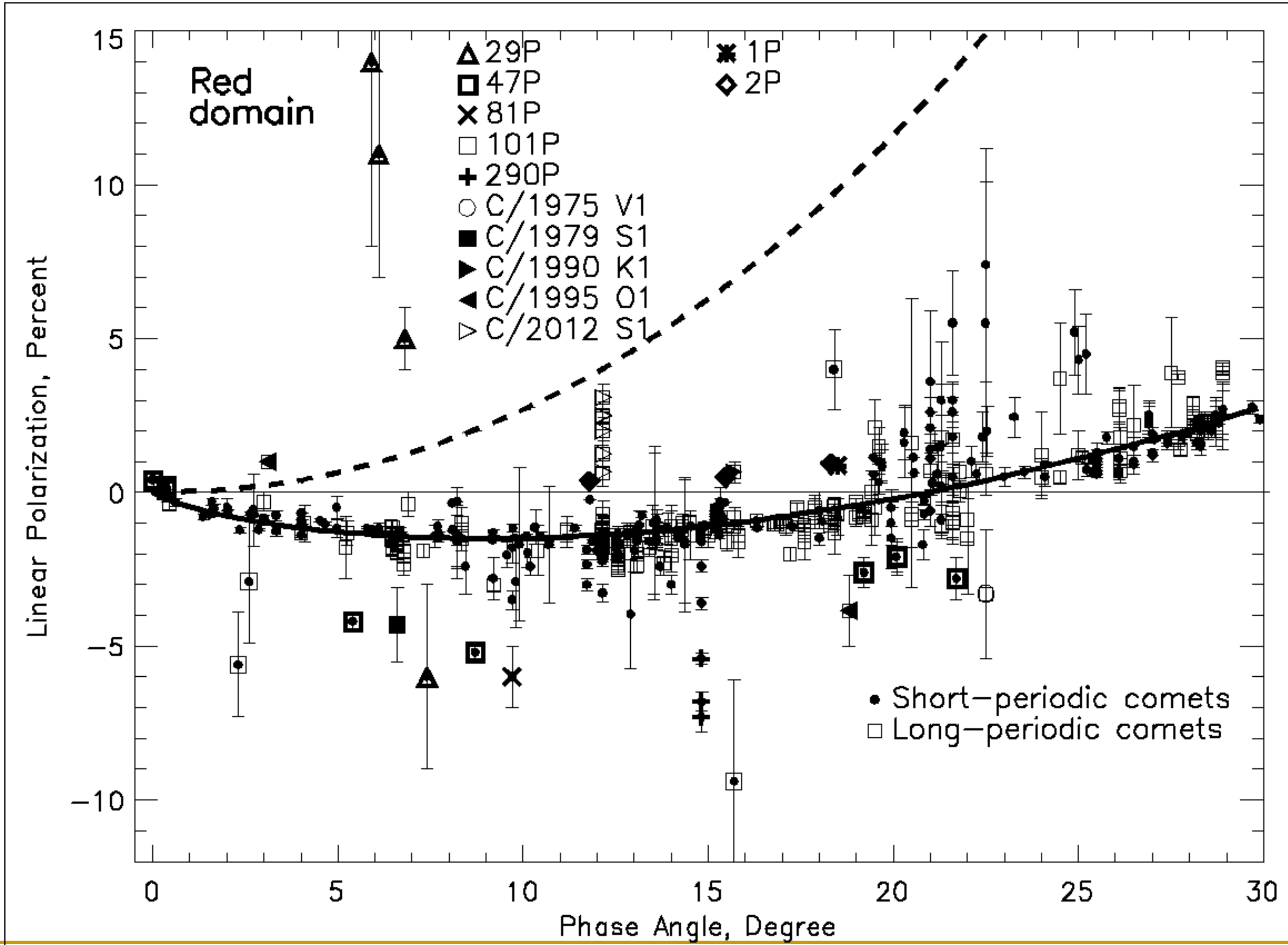
Linear polarization

jet



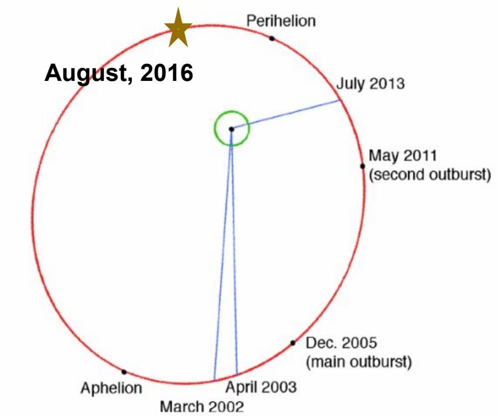


C/1995 O1 (Hale-Bopp), r=4.11 AU
1P/Halley, r=1.74 AU
29P/Schwassmann-Wachman1, r=6.26 AU
67P/Churyumov-Gerasimenko, r=3.61 AU
C/1989 X1 (Austin), r=1.32 AU
C/2002 T7 (Linear), r=2.63 AU
47P/Ashbrook-Jackson, r=2.31 AU
C/2010 S1 (Linear), r=7.01/6.05 AU
C/2010 R1 (Linear), r=5.94 AU
(5145) Pholus, r=21.06 AU
(2060) Chiron, r=13.78 AU
(10199) Chariklo, r=13.31 AU
dust comets
(Mishenko et al., 2010)
C/2014 A4 (r=4.21 AU)
C/2013 V4 (r=5.19 AU)
C/2012 J2 (r=3.17 AU)
P, %
Phase angle, grad
4
2
0
−2
−4
0
5
10
15
20
25



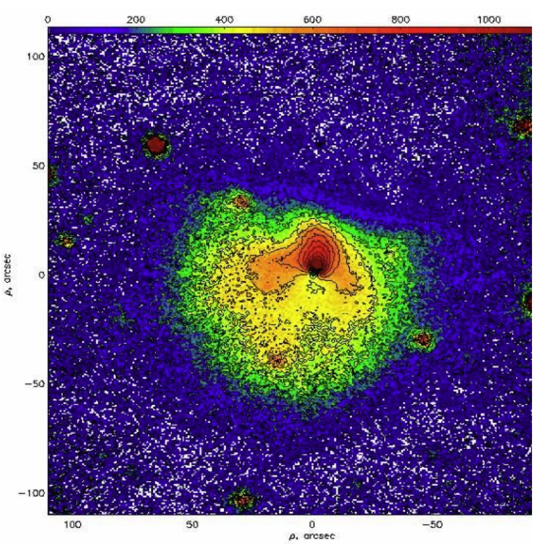
Red domain
29P
47P
81P
101P
290P
C/1975 V1
C/1979 S1
C/1990 K1
C/1995 O1
C/2012 S1
1P
2P
Short−periodic comets
Long−periodic comets
Linear Polarization, Percent
Phase Angle, Degree
15
10
5
0
−5
−10
0
5
10
15
20
25
30

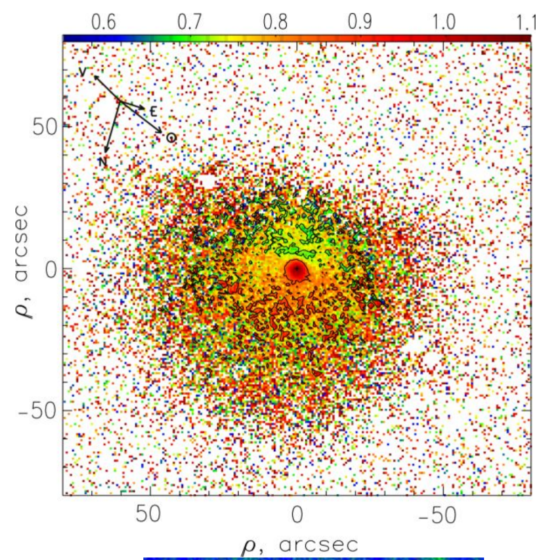
174P/Echeclus

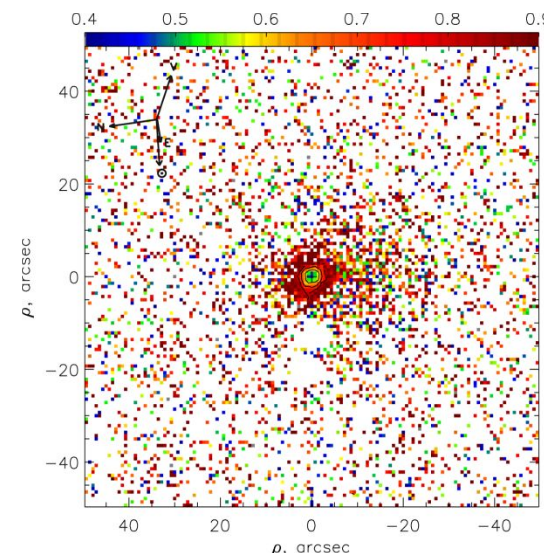


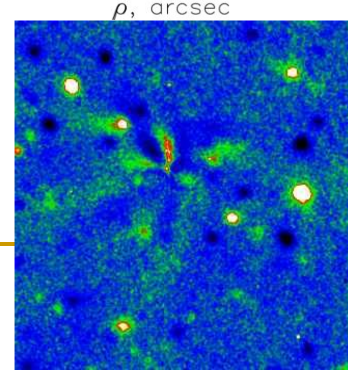
We obtained new observations of an outburst of Centaur 174P/Echeclus at a heliocentric distance of 6.2 au and determined dust production rates and dust colors. We found changes in the dust productivity and morphology of the coma compared to the last outburst. Based on photometrical data, we analyzed the color slope using the model of agglomerated debris particles.

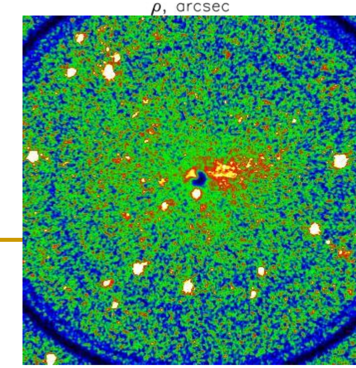
Article in preparation



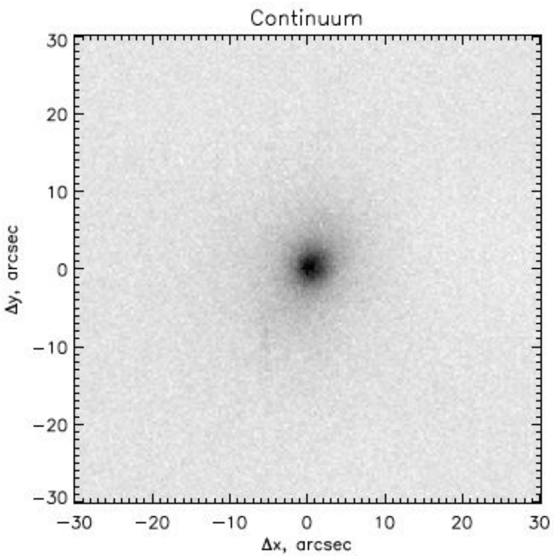


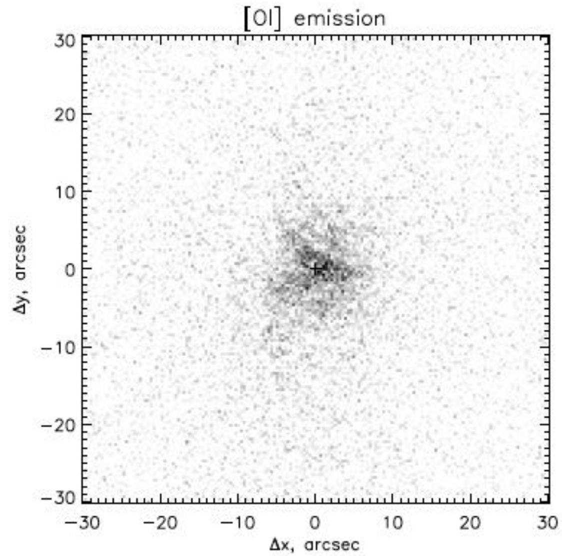






PRODUCTION RATE $Q(O^1D)$





Radial velocity:

From observations: 9.3 ± 0.3 km/s

From Ephemeris: 9.5 km/s

$$Q(\mathrm{O}^1\mathrm{D}) = \frac{4}{3} 4\pi \Delta^2 I_{tot}/h\lambda,$$

Table 2. $Q(O^1D)$ **production rate for comets**

Comet	Date, UT	r, au	$Q(O^1D)$, atom/s
Bennet 1970 II[1]	Apr 18,1970	0.841	$2.8 \cdot 10^{28}$
1P/Halley[2]	Jan 16, 1986	0.790	$2.9 \cdot 10^{30}$
C/1990 V (Austin)[3]	May 16, 1990	1.035	$1.2 \cdot 10^{28}$
C/1995 O1 (Halle-Bopp)[4]	Mar 5, 1997	1.029	$3.21 \cdot 10^{30}$
252P/(LINEAR)[5]	Apr 5, 2016	1.030	$6.1 \cdot 10^{25}$

$$I_{tot} = 8.4 \cdot 10^{-12}\, erg\, s^{-1}\, cm^2$$

$$\boxed{Q(\mathrm{O}^1\mathrm{D}) = 6.1 \cdot 10^{25} \quad atom/s}$$

[1]Delseme and Combi, 1976; [3]Schultz et al., 1993; [4]Morgenthaler et al., 2001;
[5]This work

Thank you!