Polarimetry as an effective tool for studying comets: unresolved problems

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Polarization in comets was discovered by Arago in 1819.
Since then, a huge volume of polarimetric observations of comets has been accumulated.

At present it collected in Data Base Comet Polarimetry (DBCP).

Compilation of Comet Polarimetry from Published and Unpublished Sources, 2017. urn:nasa:pds:compil-comet:polarimetry::1.0, NASA Planetary Data System.

This database contains 3441 polarization measurements of 95 comets observed from 1881 to 2016.

It presents aperture measurements of the linear and circular polarization of comets in a wide range of phase angles and wavelengths obtained by photographic, photoelectric and imaging methods of measurements.

- **The numerous measurements of the polarization of comets have led to the following general conclusions:**

✓ Continuum linear polarization arises from the scattering of light by dust particles;

✓ Linear polarization of molecules caused by the resonance fluorescence mechanism;

✓ Continuum linear polarization depends on the phase angle and wavelength.

✓ Typically, comets have a small negative polarization for phase angles 20◦, an inversion from negative to positive polarization around 22, and an initially linear rise in the polarization at larger phase angles with maximum polarization occurs slightly above 90°. Typically, the polarization increases with increasing wavelength.

✓ There are two groups of comets with different values of polarization maximum: the high-polarization comets (high-*P*max) with polarization peak of about 28% at phase angle ≈95° and the low-polarization comets (low-*P*max) with polarization peak of about 10-15% at ≈90°.

✓ There are the differences in degree and plane of linear polarization in the tails and coma of comets as well as in different regions of coma;

✓ Some comets have significant and predominantly circular polarization.

Even after 200 years investigation of comet polarization there are open questions.

Based on the Data Base Comet Polarimetry and the most recent data I will talk about the some problems of comet polarimetry:

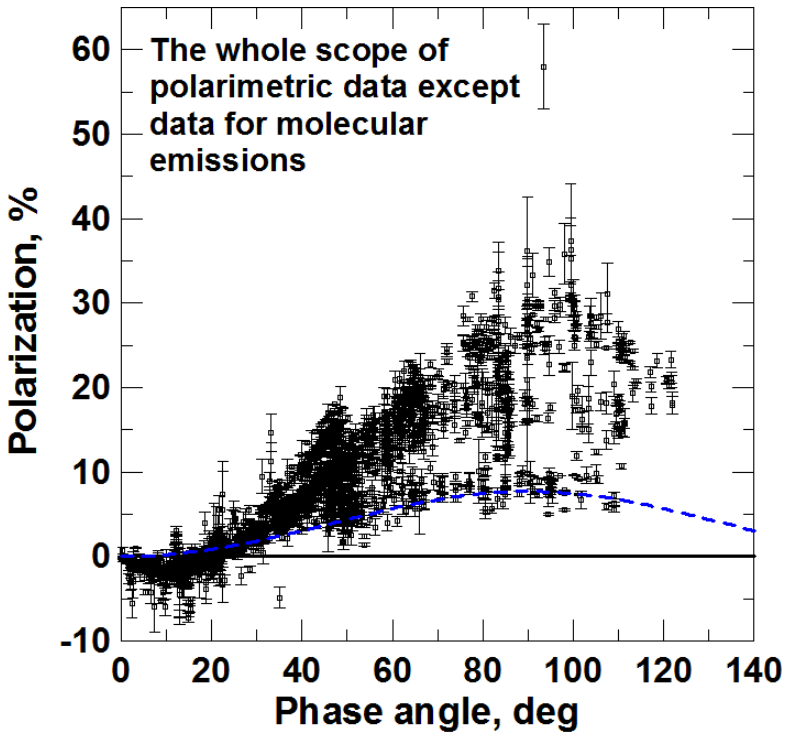
1. Are there differences in the polarization properties of short and long periodic comets? Can polarization shed light on differences in the origin and/or evolution of these two types of comets?

2. Distribution of polarization and color in coma: what does this clarify?

3. How does the polarization of molecular emissions affect the polarization of the continuum and vice versa?

Main disadvantages of DBCP

The whole scope of polarimetric data shows a significant scattering of dots on the synthetic phase dependence of polarization.



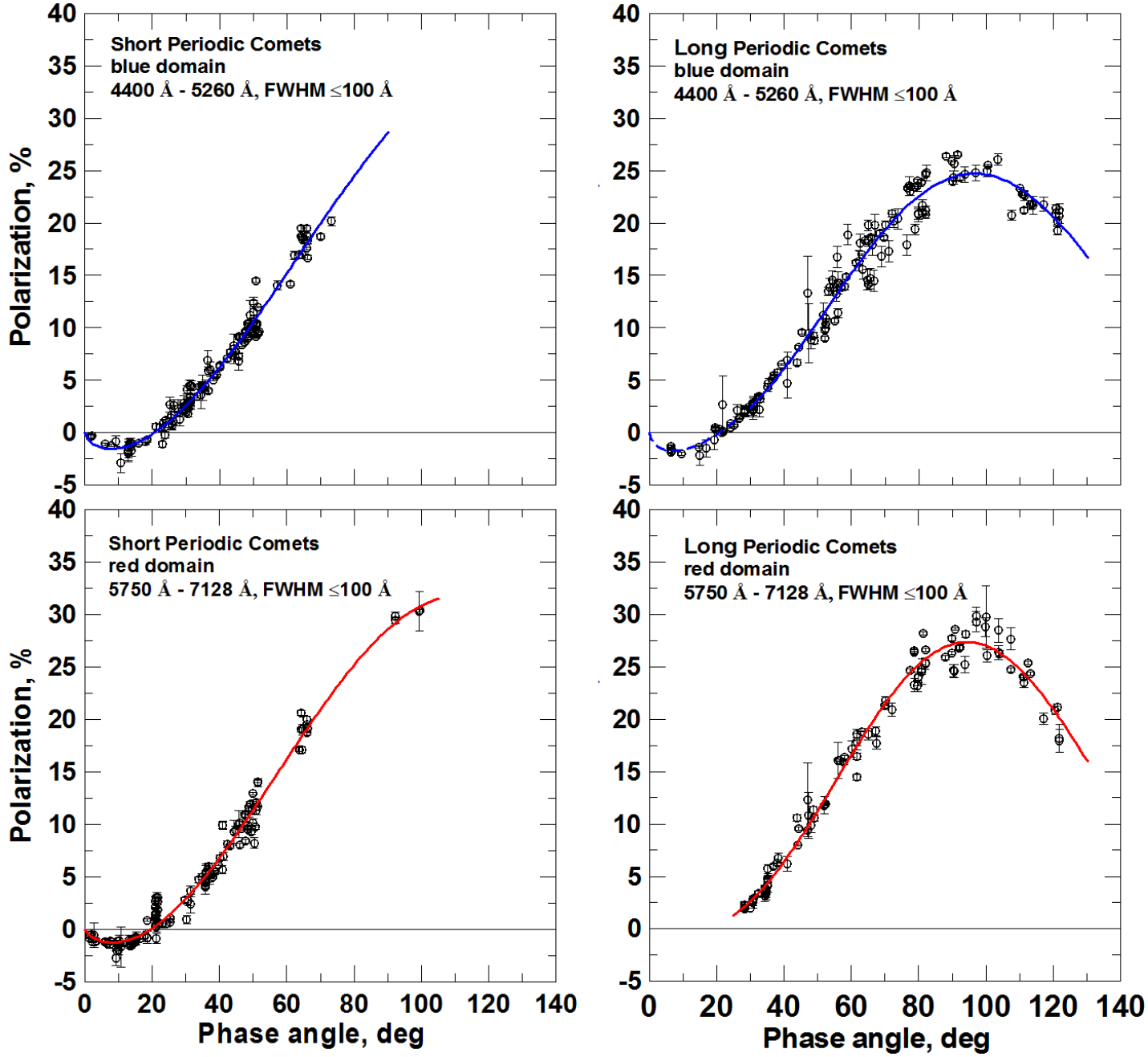
- ✓ Most data obtained for different areas of coma, predominantly for “whole coma”;
- ✓ Non-system filters with different λ/FWHM values were used.

Therefore, the question arises:

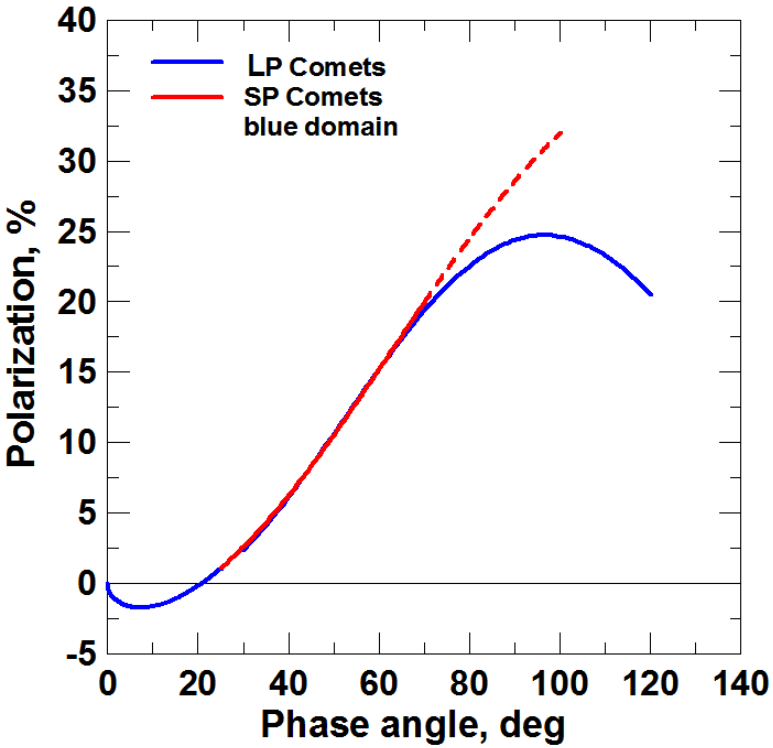
What useful information can be obtained using the database?

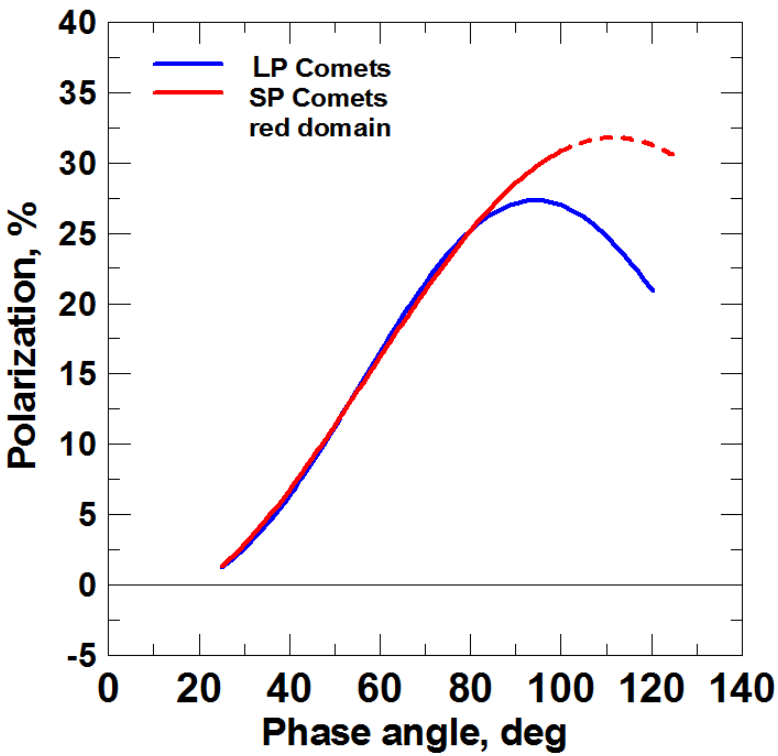
We have constructed synthetic polarization curves for short and long periodic comets in the blue and red domain spectra.

Synthetic polarization curves for SP and LP comets



Approximation of synthetic phase-polarization dependences of short and long periodic comets

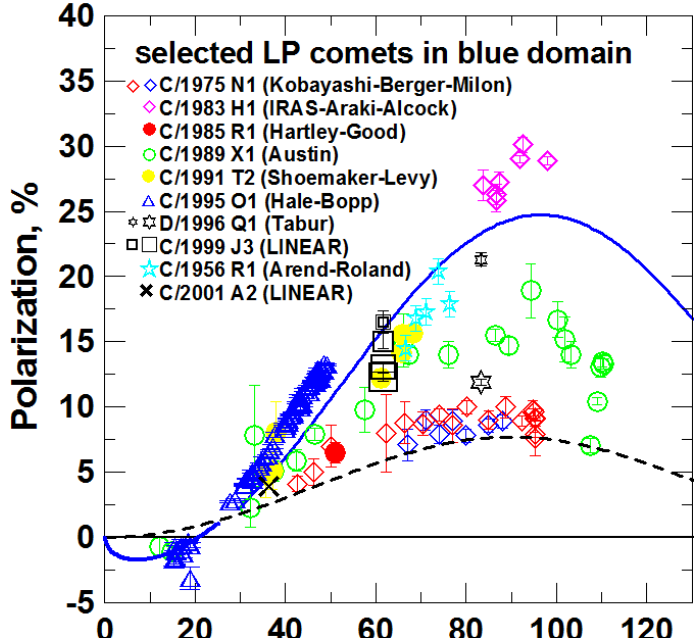


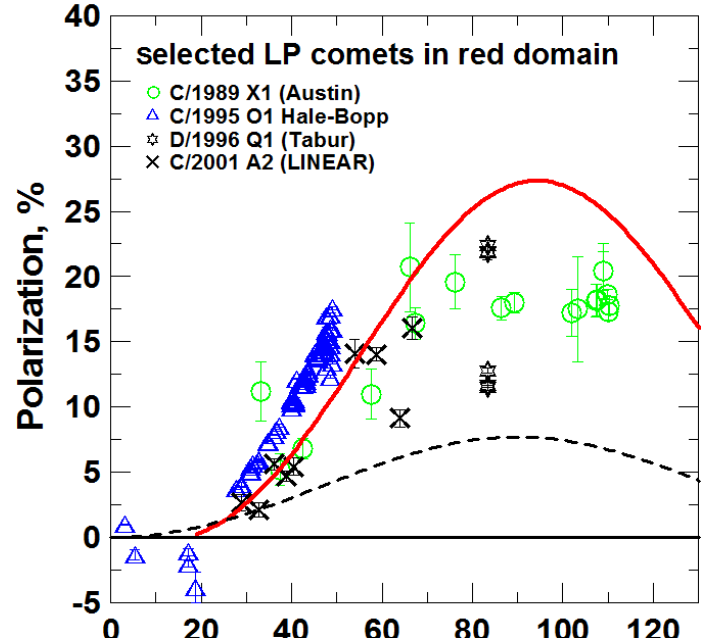


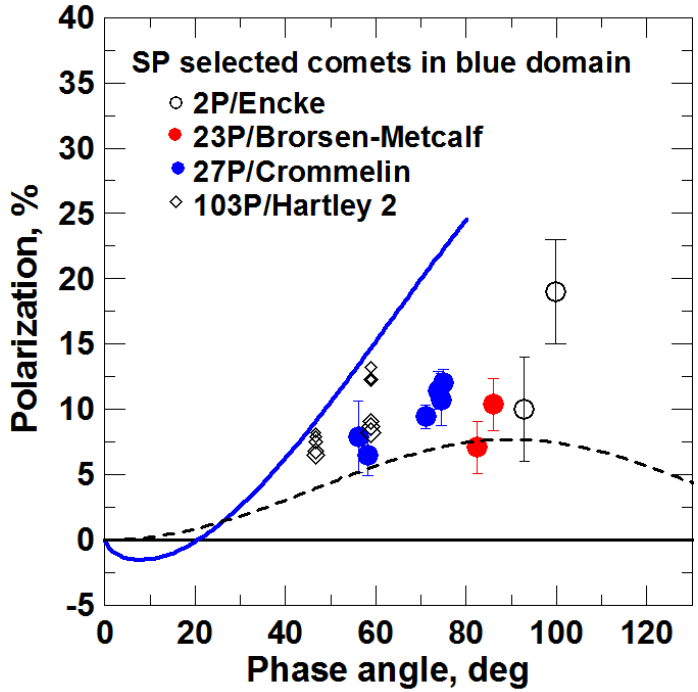
An initially linear rise in the polarization at larger phase angles of SP and LP comets coincide.

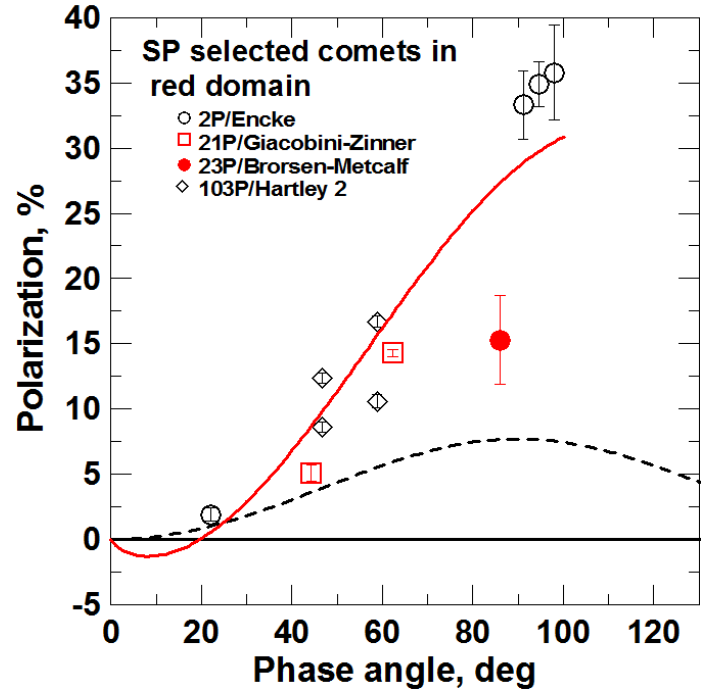
Do the polarization maxima differ for short- and long-period comets? The question is open. More observations are needed.

Comets with a non-typical phase polarization dependence









It is obvious that both short and long periodical comets belong to the the high-polarization (high-Pmax) and low-polarization (low-Pmax) comet groups.

How real are these polarization classes of comets?
Or each comet has its proper behavior of polarization depending on dust properties?

There are several points of view on the reasons for the difference in polarization these groups of comets.

As it was shown in Kolokolova et al. (2007), comets can be divided into two groups: type I, characterized by high gas/dust ratio, low polarization, and a weak or absent 10 μm silicate feature, and type II, for which a low gas/dust ratio, high polarization, and strong silicate feature are typical. Such a difference in the distribution of the dust within the coma results from different size or porosity of particles that makes particles in low-*P*max comets more massive and, thus, concentrating near the nucleus.

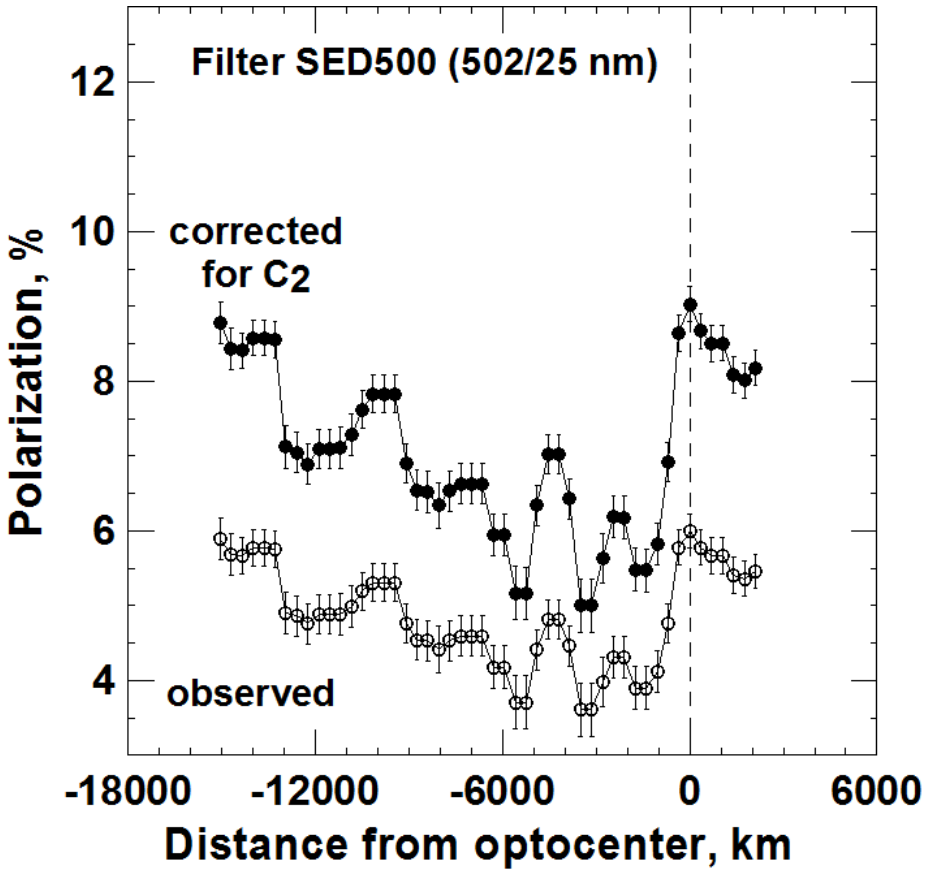
Another point of view is that the observed difference in the maximum polarization of comets is due to different composition of their dust. Zubko et al. (2016) reject gas contamination. They believe that the maximum polarization range from 7% up to more than 30% can be reproduced by the variations in the relative abundance of weakly absorbing particles (e.g., silicates) and highly absorbing particles (e.g., carbonaceous materials).

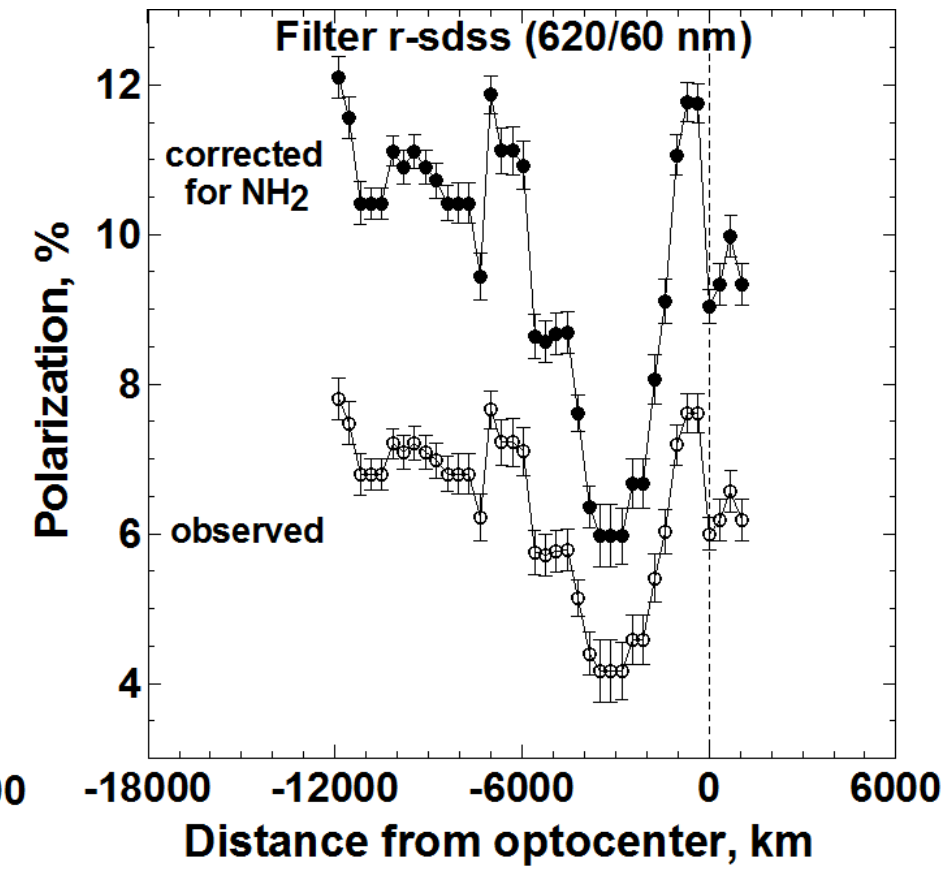
It is necessary to take into account some effects that affect the observed polarization.

Gas contamination .

Polarization vs the area of coma and distance from nucleus.

2P/Encke: observed and corrected polarization for the gas contamination

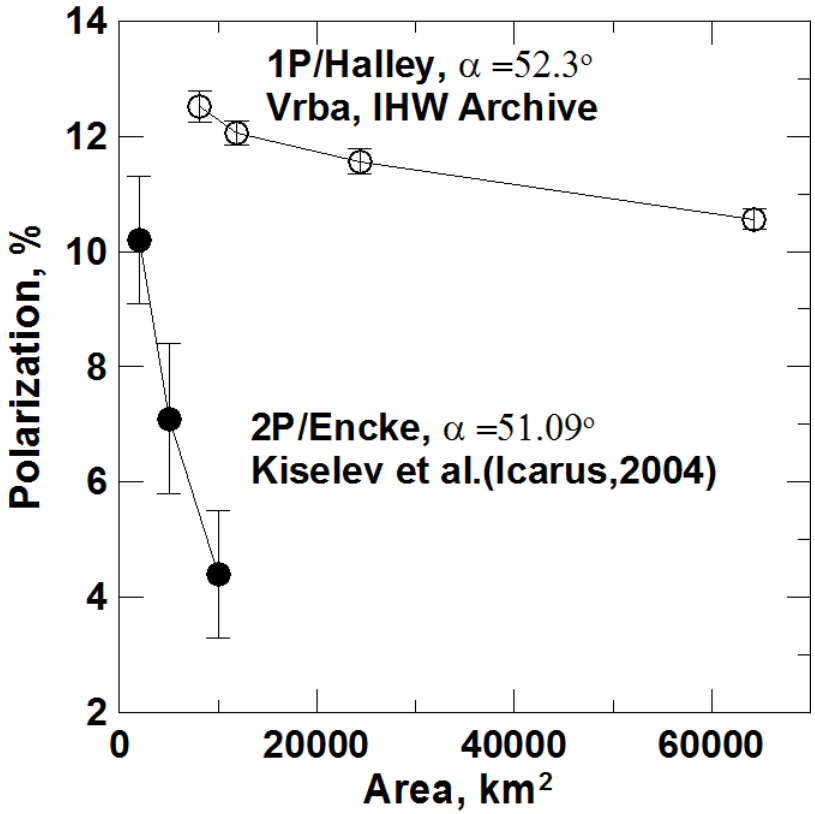




Gas contaminated continuum is less polarized.

Gas contamination is real effect . It is maximal for gas rich comets

Polarization vs the area of coma



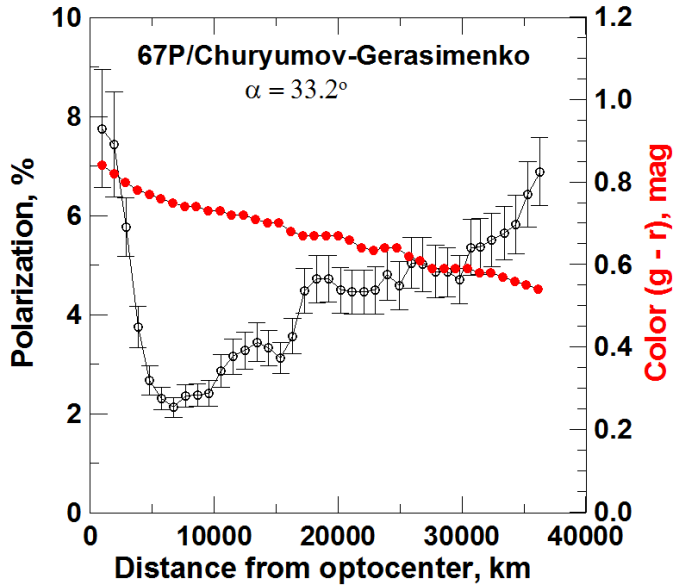
The high-polarization comets have extended dust comae.

Polarization slightly depends from area of coma.

The low-polarization comets show slightly extended dust comae which concentrated near the nucleus.

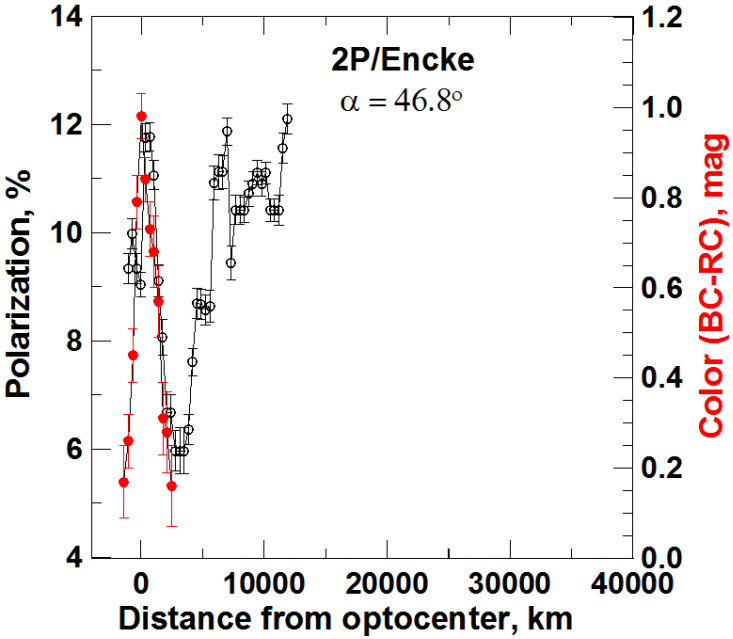
Therefore, the polarization strongly depends on the size of the coma observed.

Change of polarization and color of comets 67P/C-G and 2P/Encke at comparable distances from the nucleus



67P/C-G JF class, dust-rich comet, extended dust coma, high-Pmax type

At the distance about 1500 km the polarization was at ~8% .Within the range of 1500–7000 km the polarization dropped sharply reaching ~2%. Then, polarization gradually increased, reaching ~6% at about 35000–40000 km. Dust colour gradually decreases with the distance from the nucleus, from about 0.8^m to 0.5^m,



2P/Encke JF class, optically dust-poor comet, dust is concentrated near the nucleus

high-Pmax type for near the nucleus region of coma

low-Pmax type for large region of coma

The behavior of polarization and color with the distance from the nucleus of comet Encke is qualitatively similar to that in comet 67P/C-G . , although the quantitative changes in polarization and color with distance from the nucleus of both comets are different.

Conclusion 1

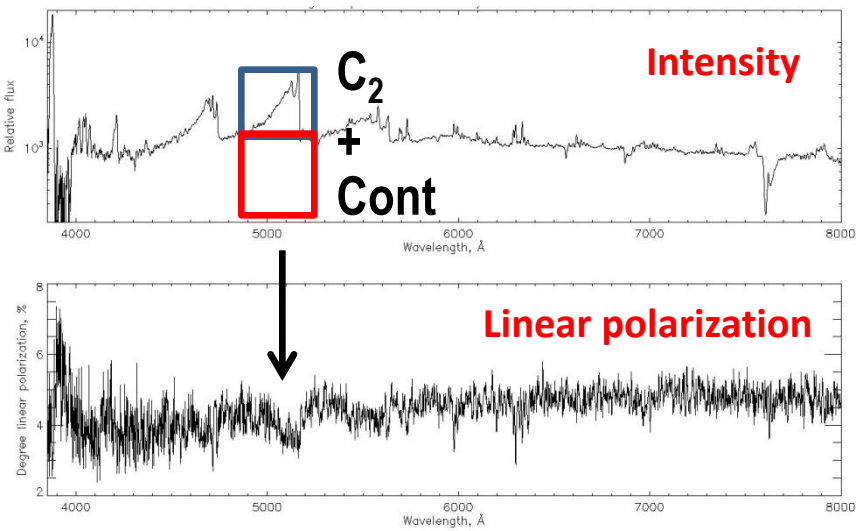
More polarimetric observations with the narrow-band cometary filters are need to clarify a classification issue of comets.

Imaging polarimetry with high resolution is need to study difference in the polarization properties of jet's dust and diffuse dust from surface.

Creation of Data Base Comet Imaging Polarimetry

Special polarimeter? Special telescope?

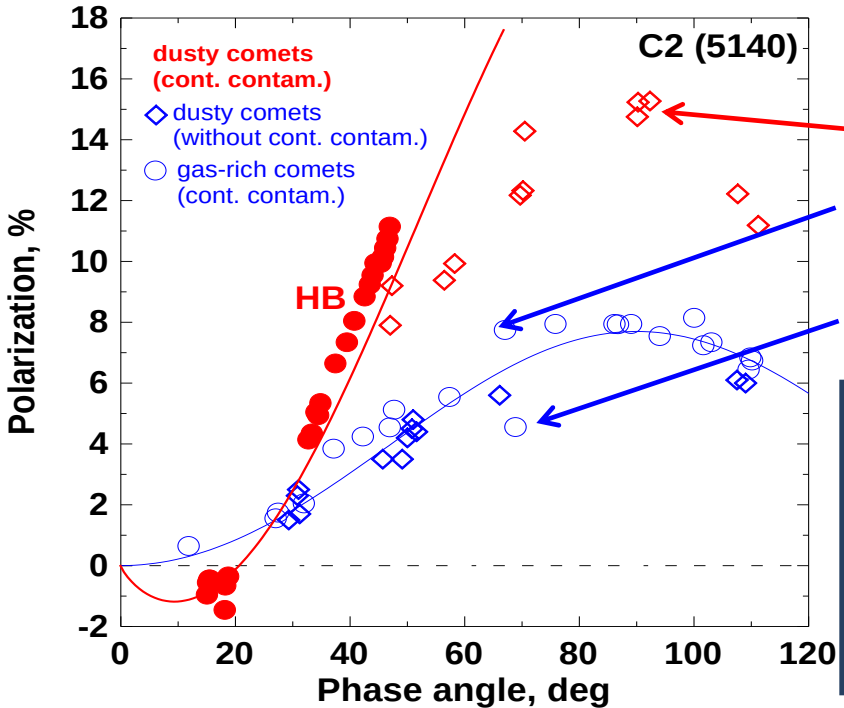
Effect of continuum contamination on polarization of molecular emissions



Data on the polarization of molecular emissions in comets are still rare.

A part of these data is not suitable for analysis due to the effect of continuum contamination.

Intensity and linear polarization of comet Garradd as a function of wavelength (Feb 14, 2012 , phase angle 35.2 deg).



Comets with strong continuum (dusty comets):

without correction for continuum contamination

corrected for continuum contamination.

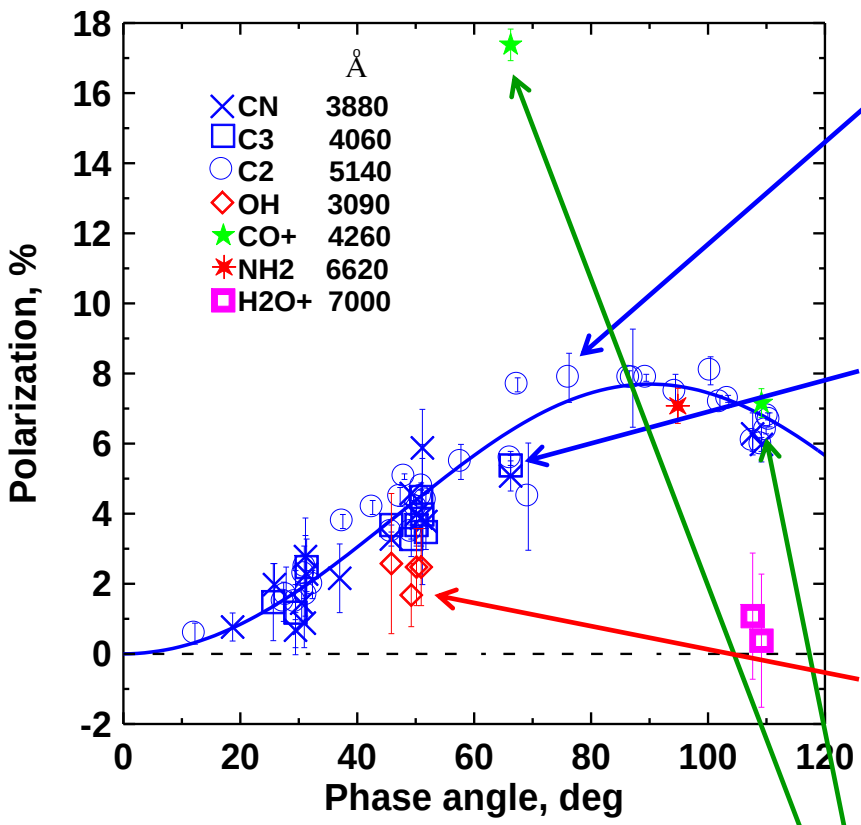
Comets with low continuum (gas-rich comets)

The observed polarization of gas emissions increases due to contamination by continuum.

and vice versa

Polarization of continuum decreases due to contamination by gas emissions.

Polarization for different cometary emissions



Phase angle dependence of polarization for CN, and C_2 is in a good agreement with the theory of the fluorescence (Le Borgne and Crovisier 1987).

Polarization of the C_3 band is similar to that of C_2 and CN bands. But a high polarization (P_{max} = 19%) should be expected from the theory.

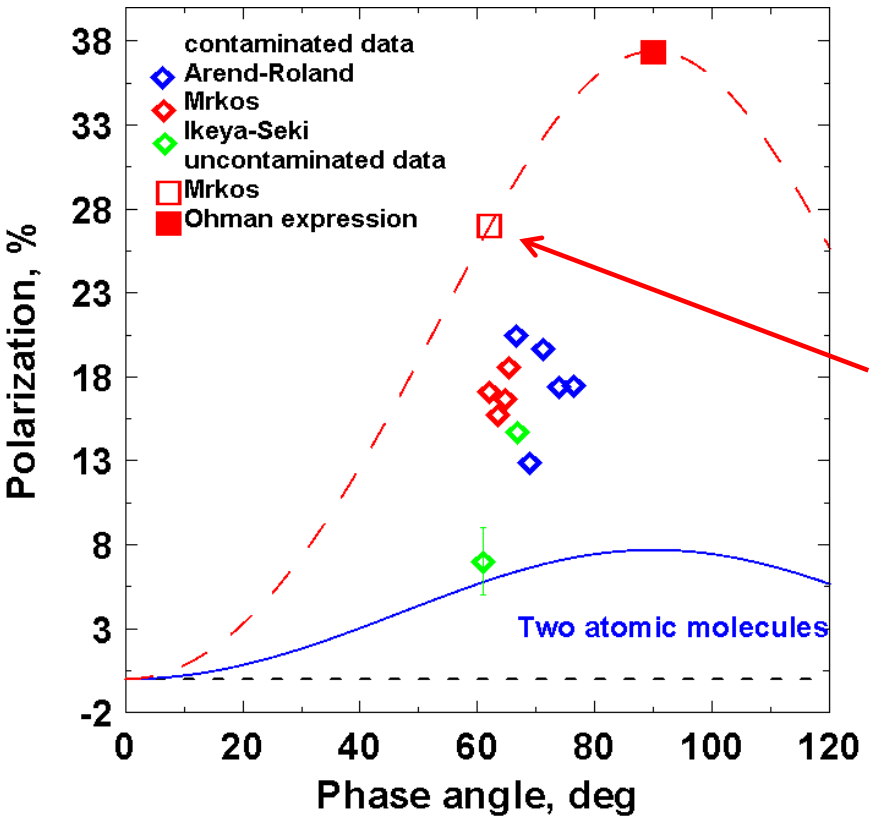
This is puzzling!

Polarization of the OH band is smaller than that expected according to the theory of resonance fluorescence ~ 10% (Le Borgne et al.1987).

Polarization data for the CO^+ band are contradictory.

There are no the theoretical predictions for **the CO^+ H_2O^+, and NH_2 bands.**

Polarization of the Na emission



Polarization of the D1+D2 Na lines was measured only for three comets: C/1956 R1 (Arend-Roland), C/1957 P1 (Mrkos), and C/1965 S1 (Ikeya-Seki).

Only one value *P* = 27% at α=62.1° was obtained for the uncontaminated Na emission in comet Mrkos. This corresponds to the value P(90°) = 37.4% according to Öhman's expression.

Varshalovich and Chorny (1979) developed the method for determination of weak magnetic field on the basis of measurements of relative intensity and polarization of resonant radiation scattered in D1 (5896 Å) and D2 (5890 Å) Na lines.

So, the detail measurements polarization in D2 line are needed.

Conclusion 2

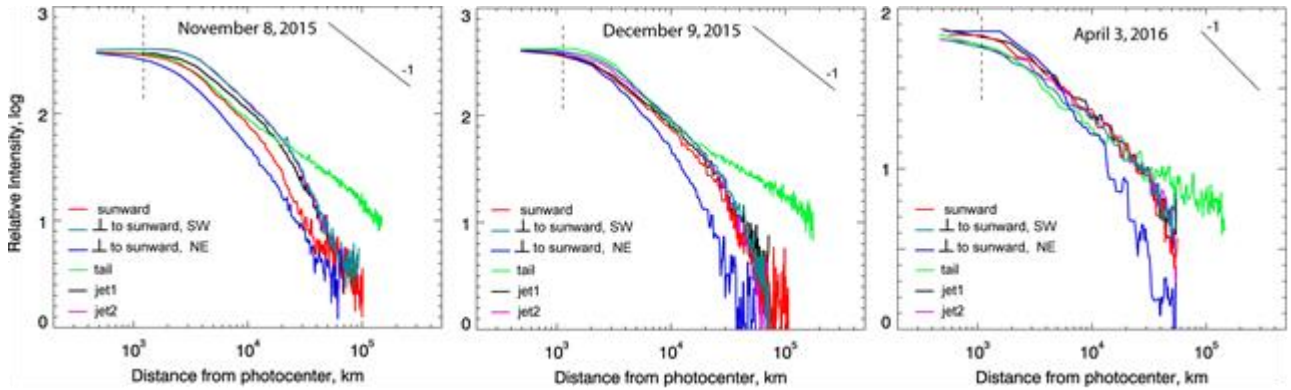
The main objective of this study is to attract the attention of observers and theorists to problems of polarimetry of gas emissions in comets:

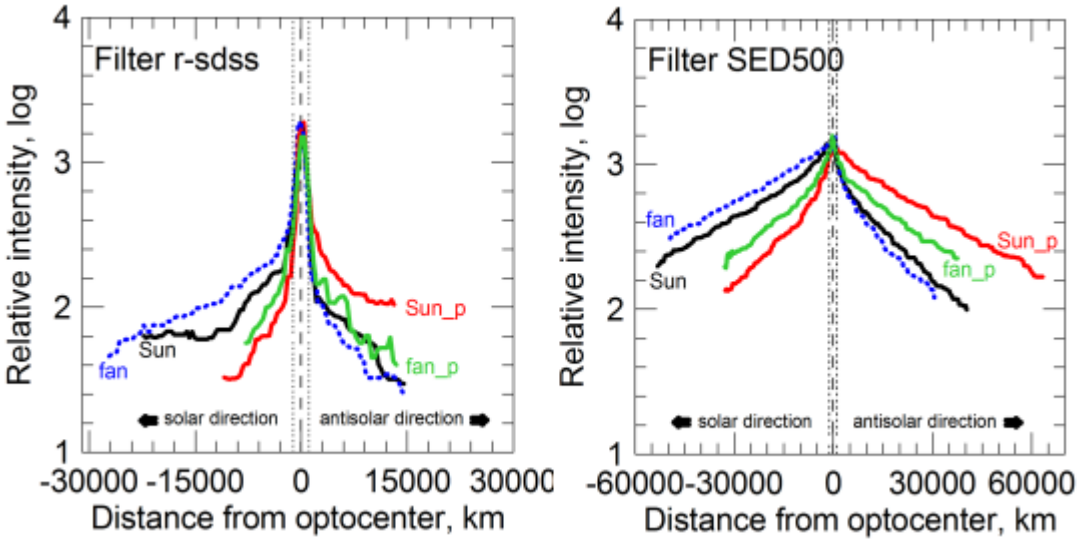
- ✓ **Phase-angle dependence of polarization for the CN and C_2 is in a good agreement with theory.**
- ✓ **Phase-angle dependences of polarization for the OH, CO^+, H_2O^+, NH_2 and Na are still unknown in details.**
- ✓ **Measurements of relative intensity and polarization of resonance radiation of the D1 and D2 Na lines can be used for determination of weak magnetic fields in comets.**
- ✓ **Current cometary polarimetry does not resolve molecular bands.**
  A detailed theoretical investigation is necessary.

Thank You for attention!

Acknowledgments

SOC and LOC of Astronomical Instutute of CAS and Europlanet for grant.


November 8, 2015
December 9, 2015
April 3, 2016
-1
Relative intensity, log
sunward
⊥ to sunward, SW
⊥ to sunward, NE
tail
jet1
jet2
Distance from photocenter, km


Filter r-sdss
Filter SED500
Relative intensity, log
Sun
fan
Sun_p
fan_p
solar direction
antisolar direction
Distance from optocenter, km