Optical and Near-Infrared Contemporaneous Polarimetry of C/2023 A3 (Tsuchinshan-ATLAS)

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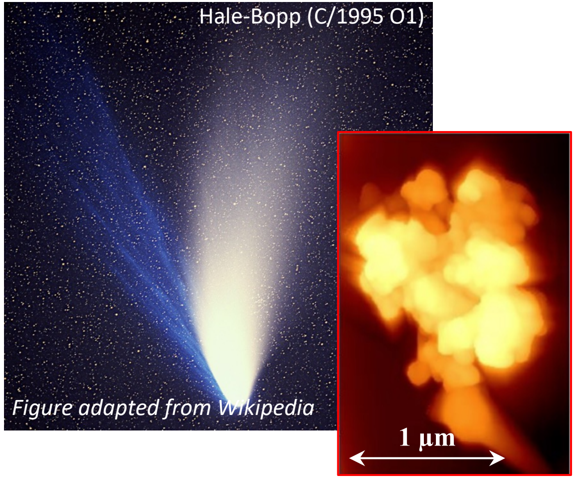
Nayuta User's Meeting, 2025 July 9

Polarimetry in Comets (1)

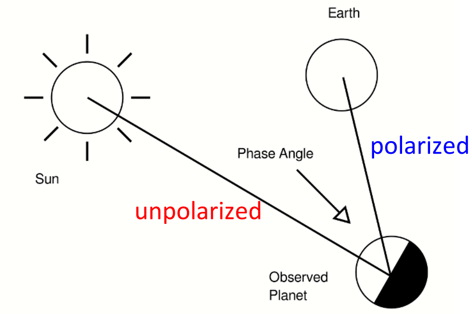
- Cometary dust particle is thought to be the agglomerate of **primitive sub-μm scale monomers**.
- Scattered sunlight from dust comae is **polarized**, where the polarization degree (偏光度; Pr) depends on the dust characteristic (size, porosity, etc.) and the phase angles (位相角; Sun−Comet−Observer).

⇒ Polarimetry covering different phase angles can reveal the comet dust characteristics!

Cometary Dust
(reflected by sunlight)

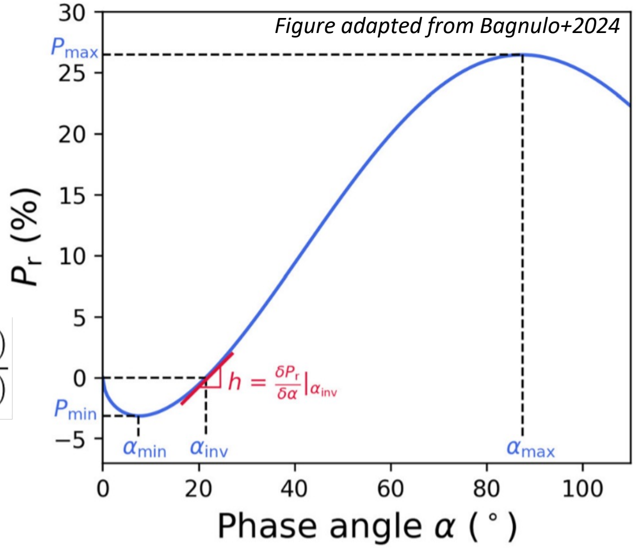


dust particle captured by Rosetta (Mannel+2019)



$$P_r(\lambda) = \frac{F_\perp(\lambda) - F_\parallel(\lambda)}{F_\perp(\lambda) + F_\parallel(\lambda)}$$

Polarization Phase Curve

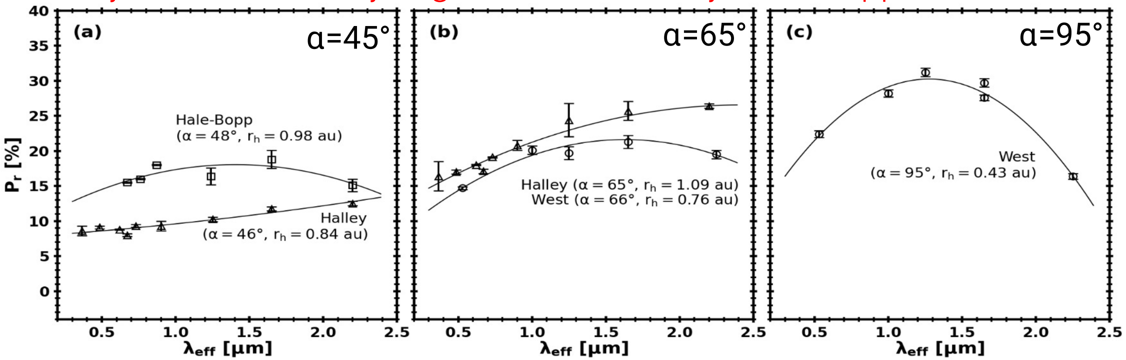


Mannel et al., 2019, Dust of comet 67P/C-G collected by Rosetta/MIDAS: classification and extension to the nanometer scale, A&A, 630, A26
Bagnulo et al., 2024, Polarimetry of Solar System minor bodies and planets, A&A review, 32

Polarimetry in Comets (2): Optical vs. NIR

Wavelength	Optical ($\lambda < 1$ μm)	Near-Infrared ($\lambda > 1$ μm)
Filters	R, I	J, H, K
Data Samples	common (~100 comets)	rare (~10s comets); difficult to obtain high-quality data
Contamination source	Gas emission	Dust thermal emission (especially at small solar distance)
Instruments	Pyeongchang 0.6-m/SQUIDPOL	NAYUTA 2.0-m/NIC

Optical-NIR contemporaneous polarimetry is extremely rare!
(only obtained for very brights comets, Halley, Hale-Bopp, and West)

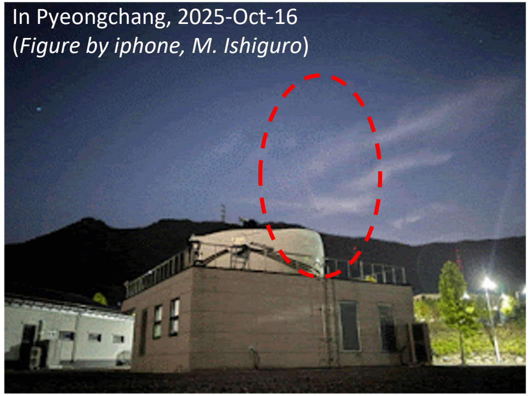


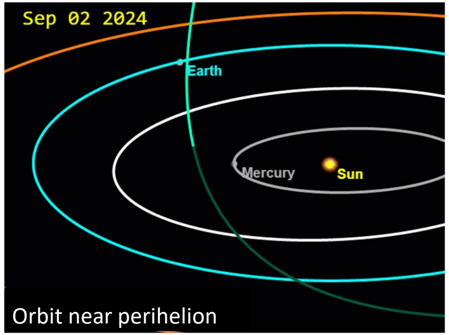
Tsuchinshan-ATLAS (C/2023 A3)

ほしぞら情報2024年10月 NAOJ

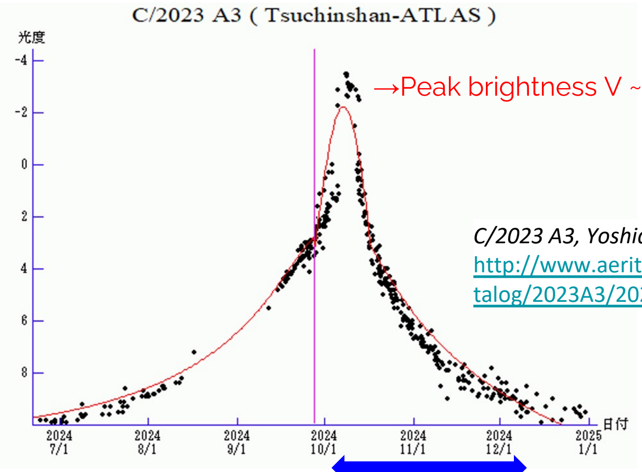
（解説）紫金山・アトラス彗星の観察チャンス（2024年10月）

Figure adapted from Wikipedia





Orbit near perihelion



→Peak brightness V ~ −4 mag!

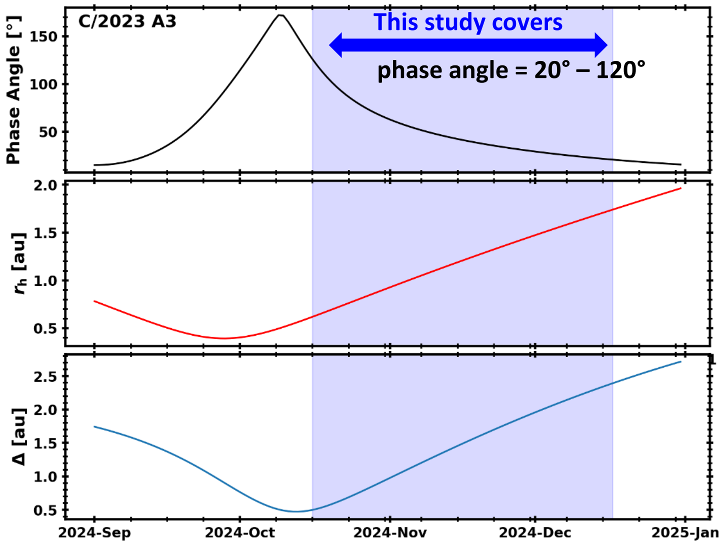
Period covered by our polarimetric study

C/2023 A3, Yoshida's homepage, http://www.aerith.net/comet/catalog/2023A3/2023A3.html

NAOJ, 紫金山·アトラス彗星の観察チャンス, Oct 2024, https://www.nao.ac.jp/astro/sky/2024/10-topics05.html

Wikipedia, C/2023 A3 (Tsuchinshan-ATLAS), https://en.wikipedia.org/wiki/C/2023_A3_(Tsuchinshan%E2%80%93ATLAS)

Summary of Observations (1)



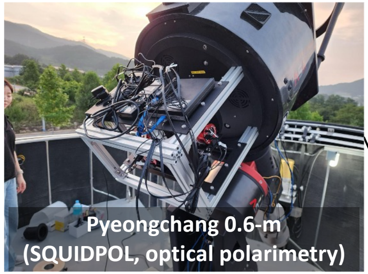
- **Objective**: To obtain comprehensive polarimetry data of Tsuchinshan-ATLAS covering wide range of wavelength (0.6–2.5 μm) and phase angles (20°–120°).

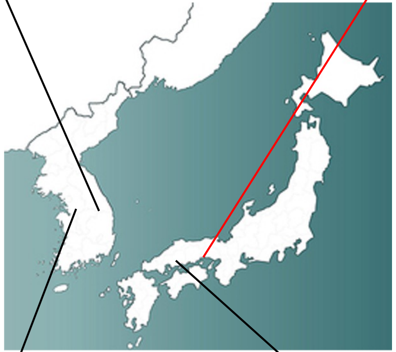
- **Instruments**
  - **SNU / SQUIDPOL** : Optical (*Rc, Ic*) imaging polarimetry
  - **NHAO / NIC**: Near-IR (*J, H, Ks*) imaging polarimetry
  - **HHO / HONIR**: Spectro-polarimetry (optical & NIR)
  - **SAO / LISA**: Spectroscopy

Observation key points 👍

- Coordinated observation among the observatories.
- Key phase angles = 45°, 65°, and 90°
  (to directly compare with the data from Halley, Hale-bopp, and West)
- Simultaneous spectroscopy to investigate the possible gas contamination

Summary of Observations (2)





Observation Log (2024.10.16 – 12.17)

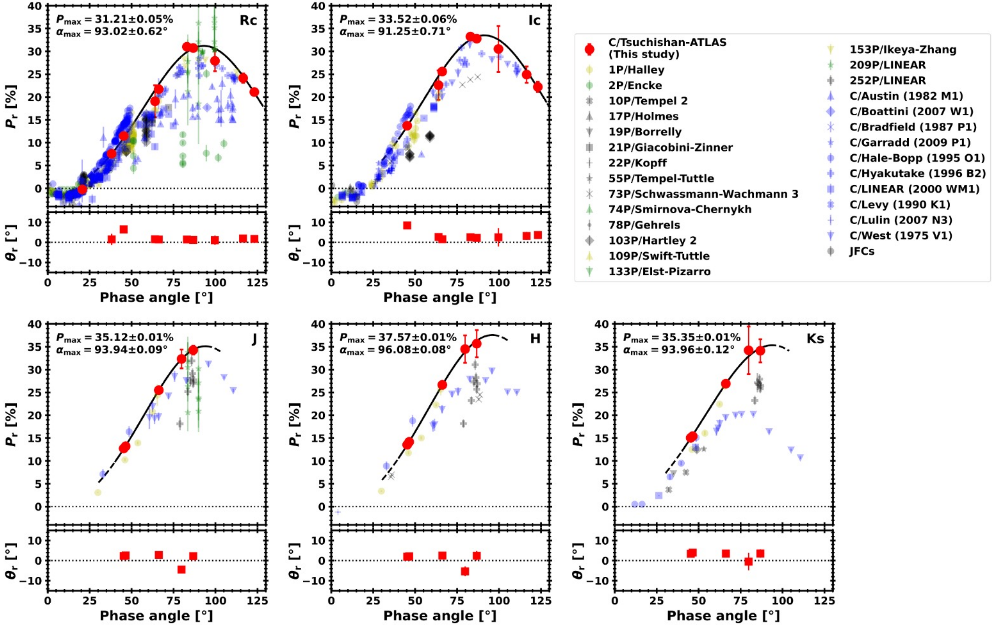
UT Date (1)	Mode (2)	Filter/Wavelength (3)	r_h [au] (6)	Δ [au] (7)	α [°] (8)
SNU/SQUIDPOL Observer: Geem J. & Lim B.					
2024-10-16.41	impol	Rc, Ic	0.63	0.51	123.18
2024-10-17.42	impol	Rc, Ic	0.64	0.53	116.50
2024-10-20.42	impol	Rc, Ic	0.70	0.60	99.67
2024-10-23.42	impol	Rc, Ic	0.76	0.69	**86.74**
2024-10-24.43	impol	Rc, Ic	0.78	0.72	83.00
2024-10-30.44	impol	Rc, Ic	0.90	0.92	**66.14**
2024-10-31.43	impol	Rc, Ic	0.92	0.96	63.96
2024-11-12.42	impol	Rc, Ic	1.14	1.37	**45.25**
2024-11-19.43	impol	Rc	1.27	1.60	38.08
2024-12-17.42	impol	Rc	1.75	2.40	20.61
NHAO/NIC Observer: Takahashi J.					
2024-10-23.42	impol	J, H, Ks	0.76	0.69	**86.71**
2024-10-25.39	impol	J, H, Ks	0.80	0.75	79.78
2024-10-30.40	impol	J, H, Ks	0.90	0.92	**66.22**
2024-11-11.40	impol	J, H, Ks	1.12	1.34	46.46
2024-11-12.39	impol	J, H, Ks	1.14	1.37	**45.28**
HHO/HONIR Observer: Akitaya H., et al.					
2024-10-20.41	sppol	OPT[a]	0.70	0.60	99.76
2024-10-30.44	sppol	OPT	0.90	0.92	**66.13**
2024-11-12.42	sppol	OPT	1.14	1.37	**45.25**
SAO/LISA Observer: Seo J., et al.					
2024-10-30.42	spec	VIS[b]	0.90	0.92	**66.17**
2024-10-31.41	spec	VIS	0.91	0.96	64.01

Result (1): Polarization Phase Curve

We successfully obtained PPCs for five bands (Rc, Ic, J, H, Ks).

Main results:

- PPC trends are not so different from other comets, but generally show high polarization degree, implying dust-rich environment of Tsuchinshan-ATLAS[1)].
- Maximum polarization degree (Pmax) tends to increase with respect to the wavelength (Pmax ≅ 31, 34, 35, 38, 35 % at R, I, J, H, Ks, respectively).
- Maximum polarization degree (Pmax) consistently occurs around phase angle α_max~90°.



One of the most fully-covered dataset of comet polarimetry!
(α=20–120˚, λ=0.5–2.5 μm)

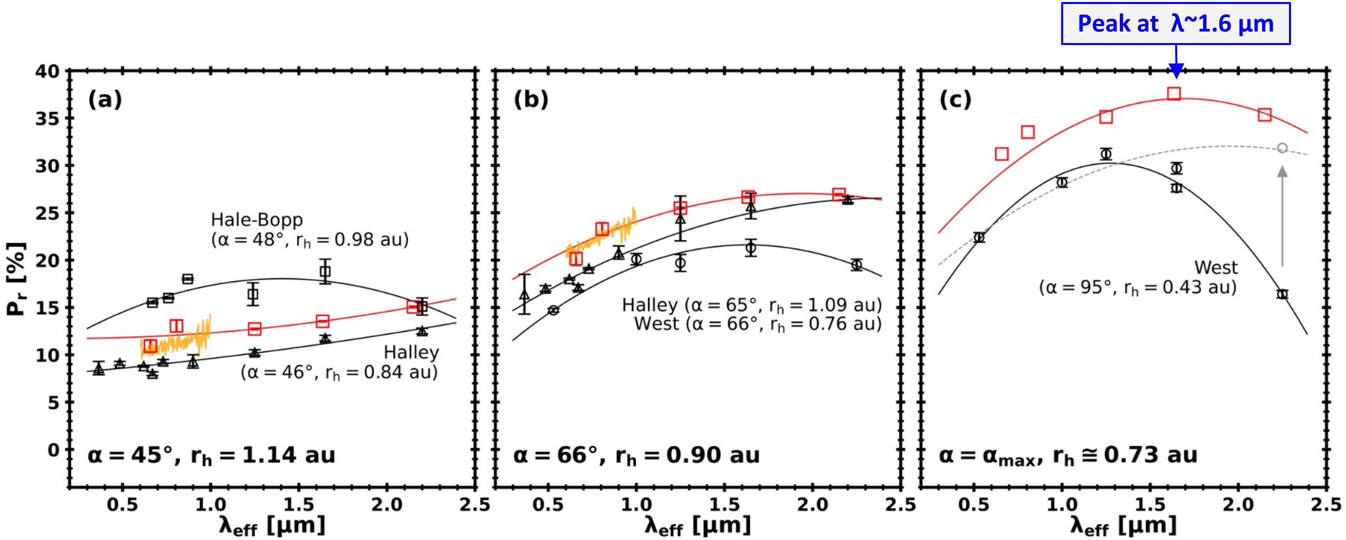
1) *Levasseur-Regourd et al., 1996, Evidence for two classes of comets from their polarimetric properties at large phase angles, A&A, 313*

Result (2): Wavelength Dependence

- We examined the wavelength dependence of polarization degree (Pr) at three phase angles $\alpha = 45°$, $65°$, and α_max (~90°)

  1) Pr Increases with increasing wavelength (λ) ➡️ Polarimetric color is "red" (ΔP/Δλ > 0).
  2) The slope moderates at near-IR (peak around λ~1.6 μm; "depolarization") ⇒ Possibly related to the dust monomer size[1].
  3) Imaging polarimetry (SQUIDPOL & NIC) and spectropolarimetry (HONIR) show consistent trends.

Overall, polarimetric properties of Tsuchishan-ATLAS dust is similar to that of other comets.
⇒ Dust properties of comets are likely similar regardless of the birthplaces (***gas-planet forming region*** OR ***outer region***).



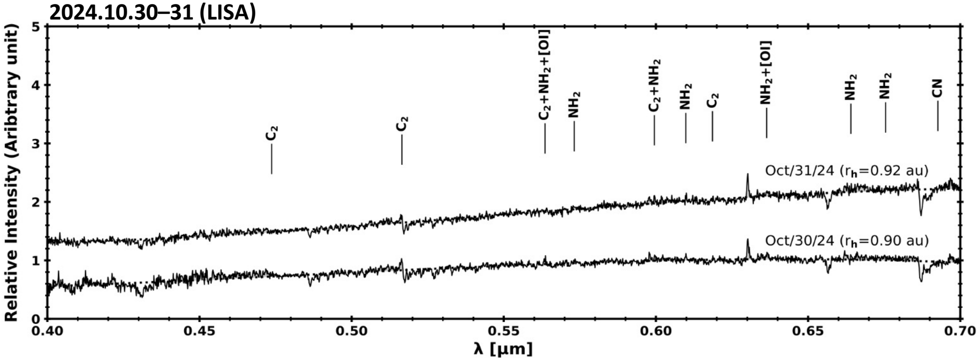
1) Kolokolova & Kimura, 2010, *Effects of electromagnetic interaction in the polarization of light scattered by cometary and other types of cosmic dust, A&A, 513, A40*

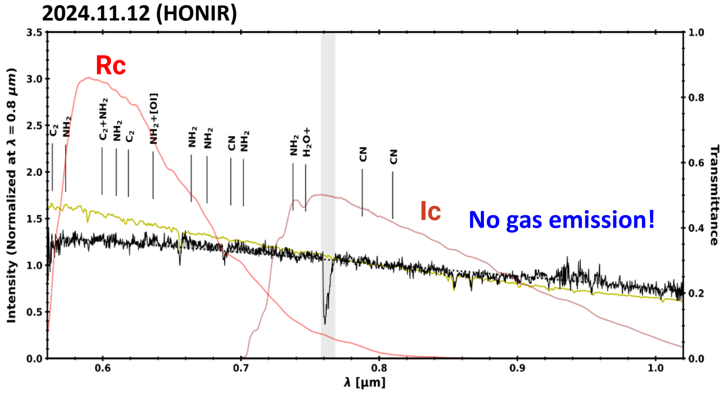
Contamination by gas emission?

- Polarization degree of comets (especially in optical) can be underestimated by the gas fluorescence emission (C_2, CN, etc.)[1].

- From spectroscopic observations (LISA and HONIR), we confirmed that gas contamination of Tsuchishan-ALTAS is negligible (<1 %) compared to the dust continuum level.

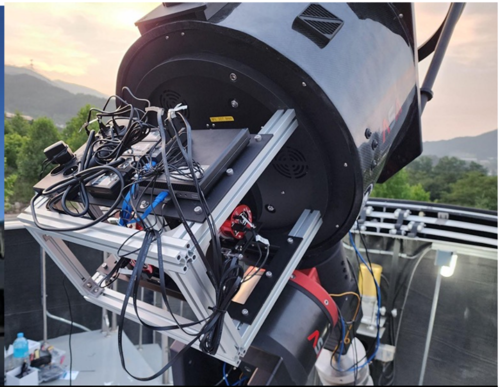
- This is consistent with the previous report[2] and dust-rich environment of Tsuchinshan-ATLAS derived from high polarization degree.

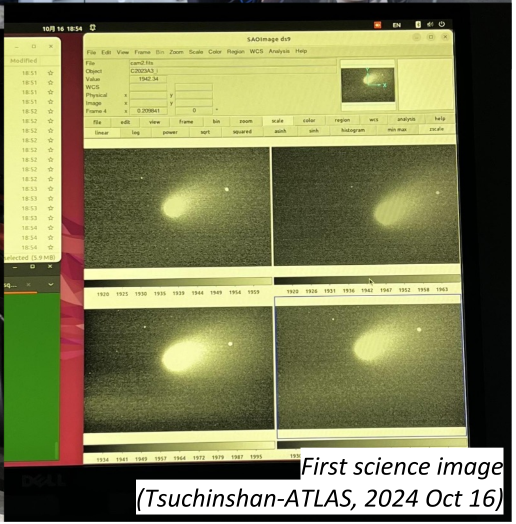




1) Kiselev et al., 2001, *Analysis of Polarimetric, Photometric, and Spectroscopic Observations of Comet C/1996 Q1 (Tabur), SoSyR, 35, 480*
2) Tang et al., 2024, *The Spectrum of C/2023 A3 Indicates a Depleted Composition, AAS Research Notes, 8, 269*

Pyeongchang 0.6-m/SQUIDPOL





First science image
(Tsuchinshan-ATLAS, 2024 Oct 16)

SQUIDPOL *(Jin et al. 2025, in prep)*

- **SNU Q**uadruple **I**maging **D**evice for **POL**arimetry

- Pyeongchang 0.6-m telescope
- Installed in 2024 July, first science image in 2024 Oct

- **Filters** B, V, Rc, Ic (*phot & pol*) / U (*only phot*)
- **FOV** 15.6' x 10.7'
- **Pixel scale** 0.45"/pix
- **Limiting mag** ~ 17 mag (*Rc*, 5-σ)
- Available ***four components of Stokes Parameters*** (Q, U) at single exposure.

⇒ Great scientific synergy with NAYUTA—NIC is expected!

Summary

本研究では、2024年末に地球へ接近した大彗星Tsuchinshan-ATLAS（C/2023 A3）に対し、可視光および赤外線領域における**同時偏光観測**を実施しました。これは、過去の大彗星West（1976年）、Halley（1986年）、Hale-Bopp（1997年）に続く4例目の試みとなります。

可視光観測にはソウル大学で新たに導入されたSQUIDPOLを、赤外線観測には西はりま天文台のNICを用いました。さらに、ソウル大学1m望遠鏡および東広島1.5m望遠鏡を用いて、分光観測および分光偏光観測も同時に実施しました。

観測の結果、合計**5つの波長域（Rc、Ic、J、H、Ks）において**、位相角に対する偏光度および偏光最大値（Pmax）を導出することに成功しました。

主な分析結果は以下の通りです。

- 偏光度は波長が長くなるにつれて増加する傾向を示し、偏光最大値も同様に波長とともに増加しました。
- 偏光度は**Hバンド（1.6 μm）で最大となり**、その後わずかに減少する「脱偏光（depolarization）」現象が見られました。
- 得られた偏光度は、彗星のガス輝線による影響を受けていないことを確認しました。

結論として、**Tsuchinshan-ATLAS彗星の偏光特性は、これまで観測されてきた3つの大彗星と一致する傾向を示しました**。これは、彗星の形成場所（巨大ガス惑星近傍か太陽系外縁か）に関わらず、そのダストの性質が非常に類似していることを示唆しています。