A Spectral Analysis of Oort Cloud Comet C/2022 E3 (ZTF)

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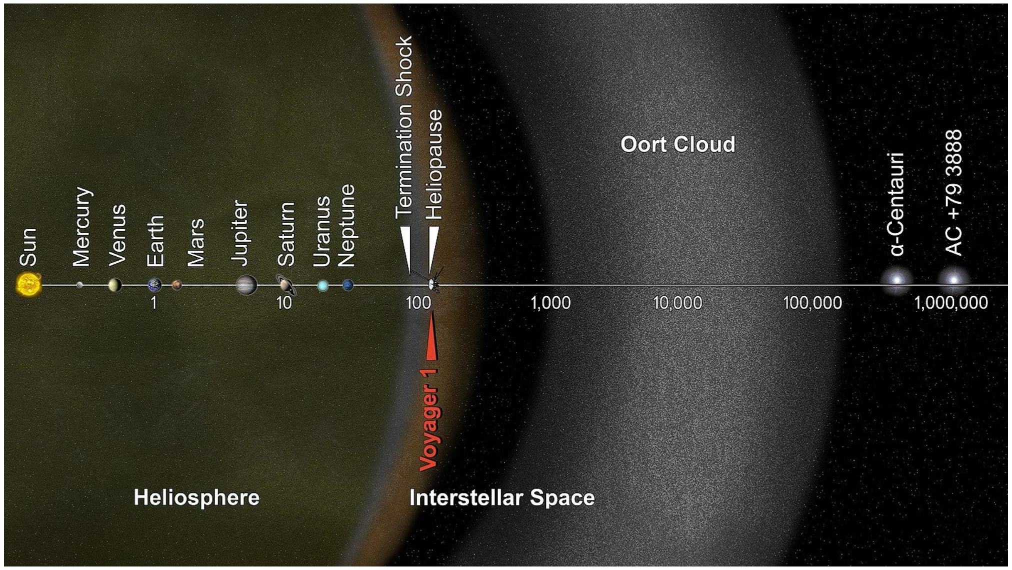
BACKGROUND

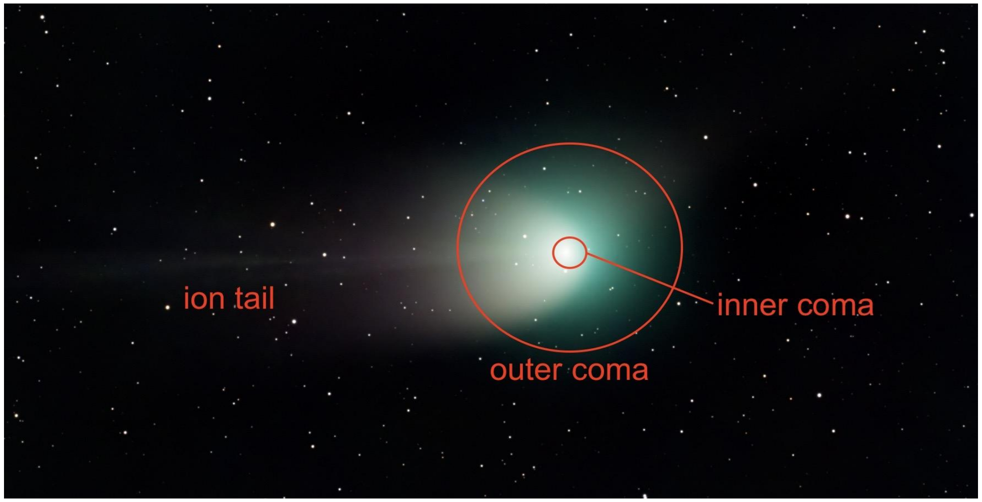
- **Oort Cloud**: Spheroidal body of frozen planetesimals located 2,000-100,000 AU from the sun.
- **Oort Cloud Comets** reveal chemical composition and evolution of early solar system.
    - Comets usually have high concentrations of carbon-chain molecules, water, and nitrogen, species which are critical to biological life.
    - Comparing compositions of proto-stars/young stars to comets can reveal patterns in stellar formation.
- **C/2022 E3 (ZTF)**: Name given to the Oort cloud comet, inbound orbital period ~50,000 years, hyperbolic orbit.

Location of the Oort cloud (in AU)



Credit: NASA / JPL-Caltech, Public domain, via Wikimedia Commons

Diagram of C/2022 E3 (ZTF)



Credit: Carl Crum

PURPOSE

To identify emission lines in the spectrum of the Oort Comet, C/2022 E3 (ZTF) and compare this comet’s chemical composition to other Oort cloud comets in order to discover trends in comet compositions.

HYPOTHESIS

C/2022 E3 (ZTF) will be rich in carbon-based molecules, but due to its extremely long orbital period, it will exhibit several unusual emission features.

MATERIALS

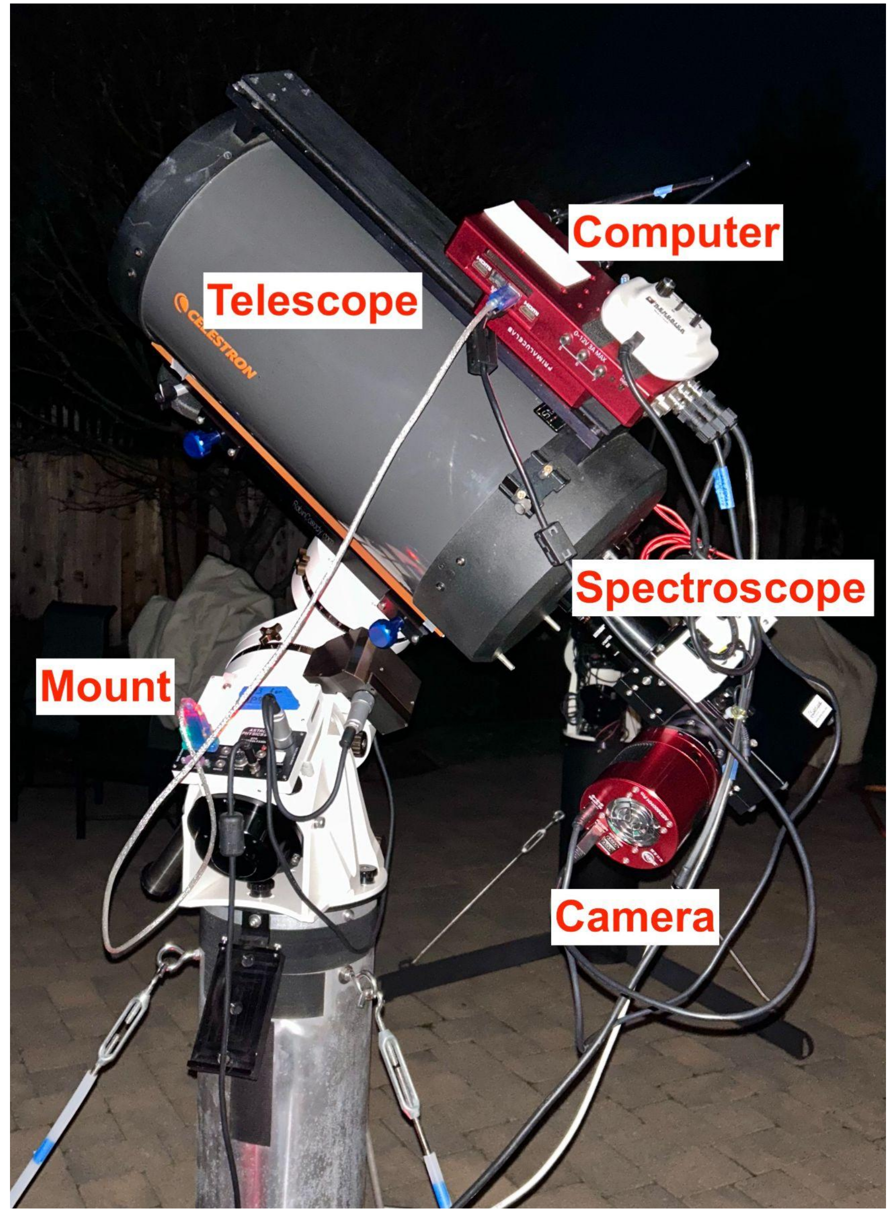
Equipment:

- Shelyak LISA low-resolution (R~1000) spectroscope
- Shelyak calibration module
- Celestron C9.25 schmidt-cassegrain telescope
- ZWO ASI2600MM-Pro camera
- Astro-Physics 900GTO German equatorial mount
- PrimaLuceLabs EAGLE 4 computer

Software:

- SharpCap image capture
- Starry Night 8 planetarium
- PHD2 auto-guiding
- Shelyak Demetra
- RSpec

Data Collection System



Credit: Carl Crum

PROCEDURE

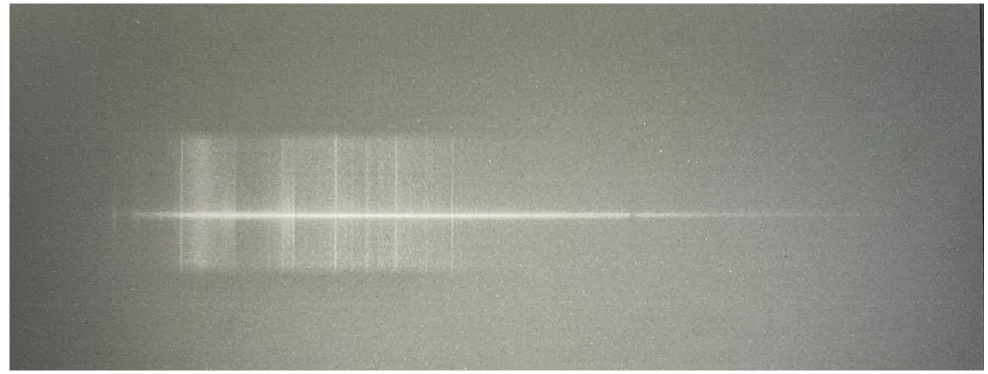
Data Collection on 2/9/2023:

- 7 spectra of outer coma, 15 spectra of inner coma
- 15 spectra of reference A-type star HIP24160
- Neon-argon calibration spectra, incandescent flat frames
- Bias frames, dark frames

Data Reduction:

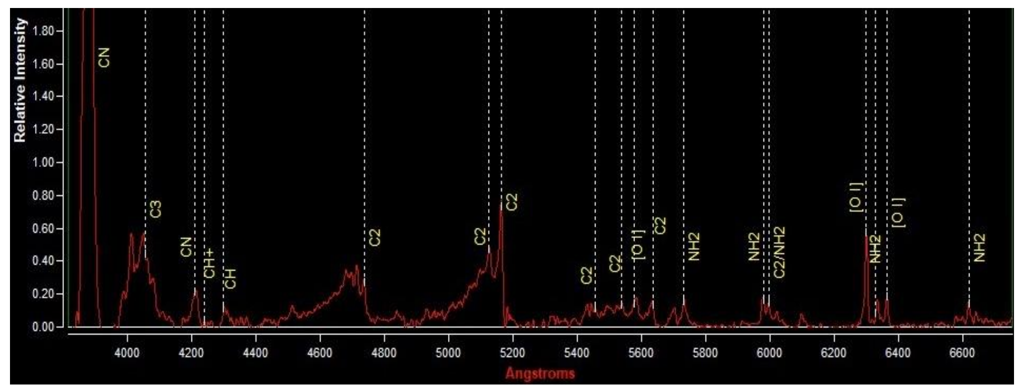
1. Bias, dark, and flat correction
2. Geometric corrections (smile, tilt)
3. Wavelength calibration performed with neon-argon spectra
4. Response curve calculated with HIP24160
5. Cropped to visible domain
6. Subtracted synthetic dust-scattered solar continuum
7. Emission line identification using Brown et al. (1996)

Raw Cometary Spectrum

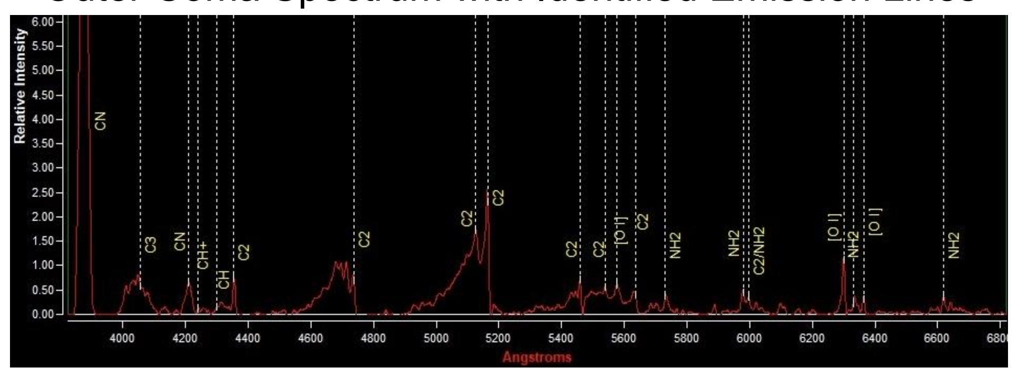


Credit: Carl Crum

Inner Coma Spectrum with Identified Emission Lines



Outer Coma Spectrum with Identified Emission Lines



PROMINENT COMET EMISSION FEATURES (Å)

Comet Species	C/1996 B2 (Hyakutake)*	C/2000 WM1 (LINEAR)*	C/2014 Q2 (Lovejoy)*	C/2016 R2 (PanSTARRS)*	C/2019 Y4 (ATLAS)*	C/2020 F3 (NEOWISE)*	C/2022 E3 (ZTF)
C_2	4700, 5150, 5600	4700, 5150, 5600	4700, 5150, 5600		4355, 4700 5150, 5600	4700, 5150, 5650, 6000	4355, 5150, 5600, 6000
C_3	4000-4100	4000-4100	3950-4100	4050	3950-4100	3900-4140	4000-4100
CN	3900, 4200	4200, 6240	3900, 4200		3900, 4200	3880, 4200	3880, 4200
NH_2	5445, 5750, 6000, 6350, 6600, 7000	5500, 5750, 6000, 6350	5500, 5750, 6000, 6350		5500, 5700, 6000, 6350, 6600	4750, 5200, 5500, 5750, 6000, 6350, 6750	4750, 5200, 5500, 5750, 6000, 6350, 6600
CH, CH^+		CH^+: 4225-4270	CH: 4300	CH: 4300	CH: 4300	CH: 3885, 4315	CH: 4300 CH^+: 4240
H_2O^+		5800-7100					6160, 6200
CO, CO^+		CO: 4935, 6245, 6260, 6270 CO^+: 4250		CO^+: 4050, 4250, 4600, 4700, 5100			
[O I]	5577, 6300, 6364	5577, 6300, 6364	5577, 6300, 6364	5577, 6300, 6364	5577, 6300, 6364	5577, 6300, 6364	5577, 6300, 6364

*See bibliography

COMET EPHEMERIDES**

Positional Data	C/1996 B2 (Hyakutake)	C/2000 WM1 (LINEAR)	C/2014 Q2 (Lovejoy)	C/2016 R2 (PanSTARRS)	C/2019 Y4 (ATLAS)	C/2020 F3 (NEOWISE)	C/2022 E3 (ZTF)
Eccentricity	0.999891647	1.000242782	0.9977739282	0.9963073874	0.9992252122	0.9991780265	1.001088207
Period (yrs)	97942.59993	N/A	13956.12613	704.7487057	5895.720256	6787.094221	N/A

**JPL Solar System Dynamics database

ANALYSIS

- **C_2**, **C_3**, **CN**, and **NH_2** were detected in every comet **EXCEPT** for C/2016 R2 (PanSTARRS).
  - **C_2** detected in C/2022 E3 (ZTF) from *4355-6000Å*, similar to C/2019 Y4 (ATLAS) and C/20202 F3 (NEOWISE)
  - **NH_2** detected in C/2022 E3 (ZTF) from 4750-6600Å, similar to C/20202 F3 (NEOWISE)
- **CH** was detected in every comet at *4300Å* **EXCEPT** for C/1996 B2 (Hyakutake).
- **CH^+** (*4240Å*) and **H_2O^+** (*6200Å*) were **ONLY** detected in C/2000 WM1 (LINEAR) and C/2022 E3 (ZTF).
- **[O I]** G/R ratios for C/2022 E3 (ZTF)
  - Intensity ratio of $I_{5571Å}$ / ($I_{6300Å}$ + $I_{6364Å}$), or Green/Red, is diagnosis for parent molecule that dissociates to form the excited O atoms
  - Outer coma: 0.42
  - Inner coma: 0.23
- **Hyperbolic orbits (e > 1)** were **ONLY** exhibited by C/2000 WM1 (LINEAR) and C/2022 E3 (ZTF).

CONCLUSION

Across the data, the species C_2, C_3, CN, and NH_2 were prevalent in all comets except C/2016 R2 (PanSTARRS), which suggests that C/2022 E3 (ZTF) is a chemically typical Oort cloud object. In relation to other comets, C/2022 E3 (ZTF) exhibited very similar C_2 emissions as C/2019 Y4 (ATLAS) and C/2020 F3 (NEOWISE), and NH_2 emissions comparable to those of C/2020 F3 (NEOWISE). C_2 and C_3 are produced from the photodissociation of more complex carbon chain molecules, such as C_2H_2, C_2H_6, and C_3H_4 (Weiler 2011), which supports the first condition of our hypothesis. The next most prevalent species, CH, was identified in all comets except C/1996 B2 (Hyakutake), further supporting the chemical normalcy of C/2022 E3 (ZTF) and indicating the presence of CH_4. Observations with a higher resolution spectroscope are necessary to affirm the existence of CH^+, which was only tentatively identified in C/2000 WM1 (LINEAR) and C/2022 E3 (ZTF). Another anomaly was the lack of CO and CO^+ detected in C/2022 E3 (ZTF), which contradicts its high G/R ratios. For example, C/2016 R2 (PanSTARRS), which contained an unusually high abundance of CO^+, exhibited a ratio of 0.23 ± 0.03 (Opitom et al. 2019). Since the G/R ratios for C/2022 E3 (ZTF) were uncorrected for Doppler shift and low-resolution line blending, higher resolution observations are required to detect CO and CO^+, and to calculate more accurate G/R ratios. From the ephemeris data, only C/2000 WM1 (LINEAR) and C/2022 E3 (ZTF) were observed to have hyperbolic orbits. However, even though they share similar chemical compositions and orbits, no other trends were found between cometary composition and orbital characteristics. Thus, our hypothesis remains inconclusive.

NEXT STEPS

- Use a high-resolution spectroscope, such as the Shelyak LHIRES III, to differentiate specific lines within prominent emission features.
- Research electron transitions for specific prominent emission lines.
- Calculate absolute flux by comparing spectrum to photometrically standard stars.
- Calculate accurate G/R ratios (Morrison et al. 1997) to better approximate H_2O and CO abundances.
- Calculate a Haser model (Haser et al. 2020) to model gas production and outflow rates.
- Compare the chemical compositions of Jupiter-family comets and interstellar objects with C/2022 E3 (ZTF).
- Record spectra of other bright Oort cloud comets, such as C/2020 V2 (ZTF) and C/2023 A3 (Tsuchinshan-ATLAS), and characterize their chemical compositions.

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