

AAS-PROVIDED PDF • OPEN ACCESS

Discovery of Dust Emission Activity Emanating from Main-belt Asteroid 2015 FW412

To cite this article: Colin Orion Chandler *et al* 2023 *Res. Notes AAS* **7** 22

Manuscript version: AAS-Provided PDF

This AAS-Provided PDF is © 2023 **The Author(s)**. Published by the American Astronomical Society.



Original content from this work may be used under the terms of the Creative Commons Attribution 4.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Everyone is permitted to use all or part of the original content in this article, provided that they adhere to all the terms of the licence

<https://creativecommons.org/licenses/by/4.0>

Before using any content from this article, please refer to the Version of Record on IOPscience once published for full citation and copyright details, as permissions may be required.

View the [article online](#) for updates and enhancements.

DRAFT VERSION FEBRUARY 6, 2023
Typeset using L^AT_EX default style in AASTeX631

Discovery of Dust Emission Activity Emanating from Main-belt Asteroid 2015 FW412

COLIN ORION CHANDLER ^{1,2,3} CHADWICK A. TRUJILLO ³ WILLIAM J. OLDROYD ³ JAY K. KUENY ^{4,5,3,*}
WILLIAM A. BURRIS ^{6,3} HENRY H. HSIEH ^{7,8} MICHELE T. MAZZUCATO ^{9,†} MILTON K. D. BOSCH [†] AND
TIFFANY SHAW-DIAZ[†]

¹Dept. of Astronomy & the DiRAC Institute, University of Washington, 3910 15th Ave NE, Seattle, WA 98195, USA

²LSST Interdisciplinary Network for Collaboration and Computing, 933 N. Cherry Avenue, Tucson, AZ 85721

³Dept. of Astronomy & Planetary Science, Northern Arizona University, PO Box 6010, Flagstaff, AZ 86011, USA

⁴University of Arizona Dept. of Astronomy and Steward Observatory, 933 N. Cherry Avenue Rm. N204, Tucson, AZ 85721, USA

⁵Lowell Observatory, 1400 W Mars Hill Rd, Flagstaff, AZ 86001, USA

⁶Dept. of Physics, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, USA

⁷Planetary Science Institute, 1700 East Fort Lowell Rd., Suite 106, Tucson, AZ 85719, USA

⁸Institute of Astronomy and Astrophysics, Academia Sinica, P.O. Box 23-141, Taipei 10617, Taiwan

⁹Royal Astronomical Society, Burlington House, Piccadilly, London, W1J 0BQ, UK

ABSTRACT

We present the discovery of activity emanating from main-belt asteroid 2015 FW₄₁₂, a finding stemming from the Citizen Science project *Active Asteroids*, a NASA Partner program. We identified a pronounced tail originating from 2015 FW₄₁₂ and oriented in the anti-motion direction in archival Blanco 4-m (Cerro Tololo Inter-American Observatory, Chile) Dark Energy Camera (DECam) images from UT 2015 April 13, 18, 19, 21 and 22. Activity occurred near perihelion, consistent with the main-belt comets (MBCs), an active asteroid subset known for sublimation-driven activity in the main asteroid belt; thus 2015 FW₄₁₂ is a candidate MBC. We did not detect activity on UT 2021 December 12 using the Inamori-Magellan Areal Camera and Spectrograph (IMACS) on the 6.5 m Baade telescope, when 2015 FW₄₁₂ was near aphelion.

Keywords: Asteroid belt (70), Asteroids (72), Comae (271), Comet tails (274)

1. INTRODUCTION

Active asteroids are rare (~ 40) bodies that are found in orbits not normally associated with comets, yet they display comet-like activity such as a tail or coma (Jewitt et al. 2015). A small subset (~ 15) of the known active asteroids, the main-belt comets (MBCs), are found to orbit entirely within the main asteroid belt and display comet-like activity indicative of volatile sublimation, such as recurrent activity near perihelion (Hsieh et al. 2015). These objects inform us about, for example, the solar system volatile distribution and, consequently, the origins of terrestrial water.

2. METHODS

To find more members of this elusive population we created the Citizen Science project *Active Asteroids*¹ (Chandler et al. 2018, 2019, 2020, 2021, 2022; Chandler 2022), a NASA Partner. Volunteers examine images of known minor planets we extract from publicly available Dark Energy Camera (DECam) data and classify these images as either active or inactive. Volunteers classified images of 2015 FW₄₁₂ as active, and subsequently we carried out an archival investigation and new telescope observations to further study this object.

Corresponding author: Colin Orion Chandler
coc123@uw.edu

* National Science Foundation Graduate Research Fellow

† Active Asteroids Citizen Scientist

¹ <http://www.activeasteroids.net>

3. RESULTS

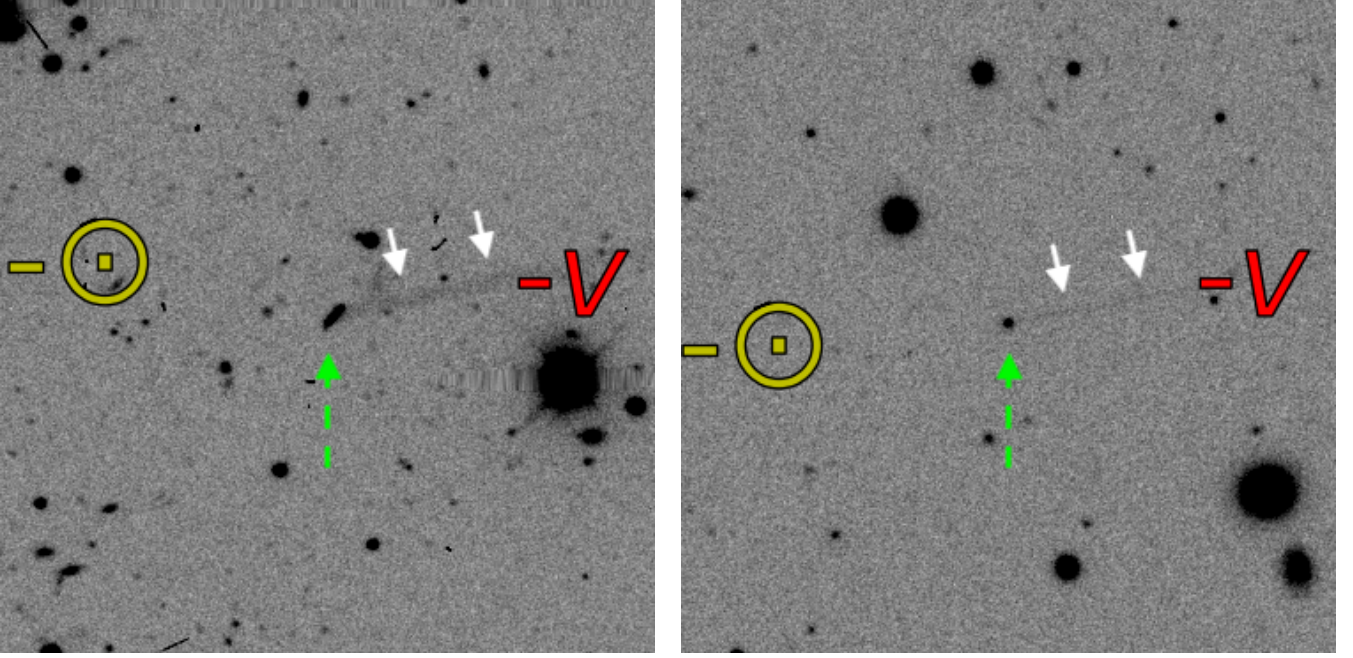


Figure 1. 2015 FW₄₁₂ (green dashed arrow) displays a tail (white arrows) in the anti-motion ($-v$) direction in these images from the DECam on the Blanco 4 m telescope (Cerro Tololo Inter-American Observatory, Chile). Also indicated is the anti-solar ($-\odot$) direction. The FOV is about $126'' \times 126''$. **Left:** 430 s VR-band, UT 2015 April 13 (Program 2015A-0351, PI Sheppard, observers S. Sheppard, C. Trujillo). **Right:** 40 s VR-band, 2015 April 18 (Program 2013B-0536, PI Allen, observers L. Allen, D. James).

We identified ~ 20 archival images of 2015 FW₄₁₂ (semi-major axis $a = 2.76$ au, eccentricity $e = 0.16$, inclination $i = 13.7^\circ$, perihelion distance $q = 2.32$ au, aphelion distance $Q = 3.21$ au, Tisserand parameter with respect to Jupiter $T_J = 3.280$; retrieved UT 2023 January 25 from JPL Horizons; [Giorgini et al. 1996](#)) with clear indications of dust emission activity in the form of a thin tail approximately aligned with the object's orbit plane (Figure 1). Notably, 2015 FW₄₁₂ is a MBC candidate with characteristics consistent with membership of this class, specifically activity occurring near perihelion, and orbiting within the main asteroid belt. On UT 2015 April 13, when 2015 FW₄₁₂ was at a heliocentric distance $r_h = 2.40$ au (inbound to perihelion), $\alpha = 3.1^\circ$ phase angle, and $\nu = 320.1^\circ$ true anomaly, the visible angular tail length as projected on the sky was $\sim 44''$, corresponding to $\sim 4.5 \times 10^3$ km at 1.4 au from Earth. We did not detect activity in four 200 s WB4800-7800 filter exposures we acquired with the Inamori-Magellan Areal Camera and Spectrograph on the Magellan 6.5 m Baade telescope on UT 2021 December 12 (PI Trujillo, observer C. Trujillo), when 2015 FW₄₁₂ was at $r_h = 3.10$ au, outbound towards aphelion.

ACKNOWLEDGEMENTS

General: We thank Dr. Mark Jesus Mendoza Magbanua (University of California San Francisco) for his continuous and timely feedback on our project.

Citizen Science: We thank Elizabeth Baeten (Belgium) for moderating the Active Asteroids forums. We thank our NASA Citizen Scientists that examined 2015 FW₄₁₂: Al Lamperti (Royersford, USA), Alice Juzumas (São Paulo, Brazil), Bill Shaw (Fort William, Scotland), Brian K. Bernal (Greeley, USA), C. J. A. Dukes (Oxford, UK), Clara Garza (West Covina, USA), Dr. David Collinson (Mentone, Australia), Emilio Jose Rabadan Sevilla (Madrid, Spain), @graham_d (Hemel Hempstead, UK), Graham Mitchell (Chilliwack, Canada), Ivan A. Terentev (Petrozavodsk, Russia), Jayanta Ghosh (Purulia, India), Leah Mulholland (Peoria IL, USA), Martin Welham, (Yatton, UK), Megan Powell (Cobham, UK), Michael Jason Pearson, (Hattiesburg MS, USA), Michele T. Mazzucato (Florence, Italy), Sergey Y. Tumanov, (Glazov, Russia), Stikhina Olga Sergeevna (Tyumen, Russia), Thorsten Eschweiler (Übach-Palenberg, Germany), Tiffany Shaw-Diaz (Dayton, USA), and Virgilio Gonano (Udine, Italy) . We also thank Marvin W. Huddleston (Mesquite, USA). Many thanks to Cliff Johnson (Zooniverse) and Marc Kuchner (NASA) for their ongoing guidance.

Funding: This material is based upon work supported by the NSF Graduate Research Fellowship Program under grant No. 2018258765 and grant No. 2020303693. C.O.C., H.H.H., and C.A.T. acknowledge support from the NASA Solar System Observations program (grant 80NSSC19K0869). W.J.O. acknowledges support from NASA grant 80NSSC21K0114. This work was supported in part by NSF awards 1950901 (NAU REU program in astronomy and planetary science). Computational analyses were run on Northern Arizona University’s Monsoon computing cluster, funded by Arizona’s Technology and Research Initiative Fund.

Software & Services: World Coordinate System corrections facilitated by *Astrometry.net* (Lang et al. 2010). This research has made use of NASA’s Astrophysics Data System, the Institut de Mécanique Céleste et de Calcul des Éphémérides SkyBoT Virtual Observatory tool (Berthier et al. 2006), and data and/or services provided by the International Astronomical Union’s Minor Planet Center, SAOImageDS9, developed by Smithsonian Astrophysical Observatory (Joye 2006).

Facilities & Instrumentation: This project used data obtained with the Dark Energy Camera (DECam), which was constructed by the Dark Energy Survey (DES) collaboration. This research uses services or data provided by the Astro Data Archive at NSF’s NOIRLab. Based on observations at Cerro Tololo Inter-American Observatory, NSF’s NOIRLab (NOIRLab Prop. ID 2013B-0536; PI: L. Allen; NOIRLab Prop. ID 2015A-0051; PI: S. Sheppard). Magellan observations made use of the Inamori-Magellan Areal Camera and Spectrograph (IMACS) instrument (Dressler et al. 2011); PI C. Trujillo.

Facilities: CTIO:4m (DECam), Magellan:Baade (IMACS)

Software: astropy (Robitaille et al. 2013), Matplotlib (Hunter 2007), NumPy (Harris et al. 2020), pandas (Reback et al. 2022), SAOImageDS9 (Joye 2006), SciPy (Virtanen et al. 2020)

REFERENCES

- Berthier, J., Vachier, F., Thuillot, W., et al. 2006, in *Astronomical Data Analysis Software and Systems XV* ASP Conference Series, Vol. 351 (Orem, UT: Astronomical Society of the Pacific), 367
- Chandler, C. O. 2022, PhD thesis, Northern Arizona University, Flagstaff, Arizona, USA
- Chandler, C. O., Curtis, A. M., Mommert, M., Sheppard, S. S., & Trujillo, C. A. 2018, *Publications of the Astronomical Society of the Pacific*, 130, 114502, doi: [10.1088/1538-3873/aad03d](https://doi.org/10.1088/1538-3873/aad03d)
- Chandler, C. O., Kueny, J., Gustafsson, A., et al. 2019, *The Astrophysical Journal Letters*, 877, L12, doi: [10/gg3qw6](https://doi.org/10/gg3qw6)
- Chandler, C. O., Kueny, J. K., Trujillo, C. A., Trilling, D. E., & Oldroyd, W. J. 2020, *The Astrophysical Journal Letters*, 892, L38, doi: [10/gg36xz](https://doi.org/10/gg36xz)
- Chandler, C. O., Oldroyd, W. J., & Trujillo, C. A. 2022, *The Astrophysical Journal*, 937, L2, doi: [10.3847/2041-8213/ac897a](https://doi.org/10.3847/2041-8213/ac897a)
- Chandler, C. O., Trujillo, C. A., & Hsieh, H. H. 2021, *The Astrophysical Journal*, 922, L8, doi: [10/gnmckw](https://doi.org/10/gnmckw)
- Dressler, A., Bigelow, B., Hare, T., et al. 2011, *Publications of the Astronomical Society of the Pacific*, 123, 288, doi: [10.1086/658908](https://doi.org/10.1086/658908)
- Giorgini, J. D., Yeomans, D. K., Chamberlin, A. B., et al. 1996, *American Astronomical Society*, 28, 25.04
- Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, *Nature*, 585, 357, doi: [10.1038/s41586-020-2649-2](https://doi.org/10.1038/s41586-020-2649-2)
- Hsieh, H. H., Denneau, L., Wainscoat, R. J., et al. 2015, *Icarus*, 248, 289, doi: [10.1016/j.icarus.2014.10.031](https://doi.org/10.1016/j.icarus.2014.10.031)
- Hunter, J. D. 2007, *Computing in Science & Engineering*, 9, 90, doi: [10.1109/MCSE.2007.55](https://doi.org/10.1109/MCSE.2007.55)
- Jewitt, D., Hsieh, H., & Agarwal, J. 2015, in *Asteroids IV* (Tucson, Arizona: University of Arizona Press), 221–241
- Joye, W. A. 2006, in *Astronomical Data Analysis Software and Systems XV* ASP Conference Series, Vol. 351, 574–
- Lang, D., Hogg, D. W., Mierle, K., Blanton, M., & Roweis, S. 2010, *Astronomical Journal*, 139, 1782, doi: [10.1088/0004-6256/139/5/1782](https://doi.org/10.1088/0004-6256/139/5/1782)
- Reback, J., jbrockmendel, McKinney, W., et al. 2022, *Pandas-Dev/Pandas: Pandas 1.4.2*, Zenodo, doi: [10.5281/zenodo.6408044](https://doi.org/10.5281/zenodo.6408044)
- Robitaille, T. P., Tollerud, E. J., Greenfield, P., et al. 2013, *Astronomy & Astrophysics*, 558, A33, doi: [10/gfvntd](https://doi.org/10/gfvntd)
- Virtanen, P., Gommers, R., Oliphant, T. E., et al. 2020, *Nature Methods*, 17, 261, doi: [10.1038/s41592-019-0686-2](https://doi.org/10.1038/s41592-019-0686-2)