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Starshade Field Testing

Steve Warwick
Tiffany Glassman
Megan Novicki
Suzi Casement
Anthony Harness (CU)
Keith Patterson (JPL)

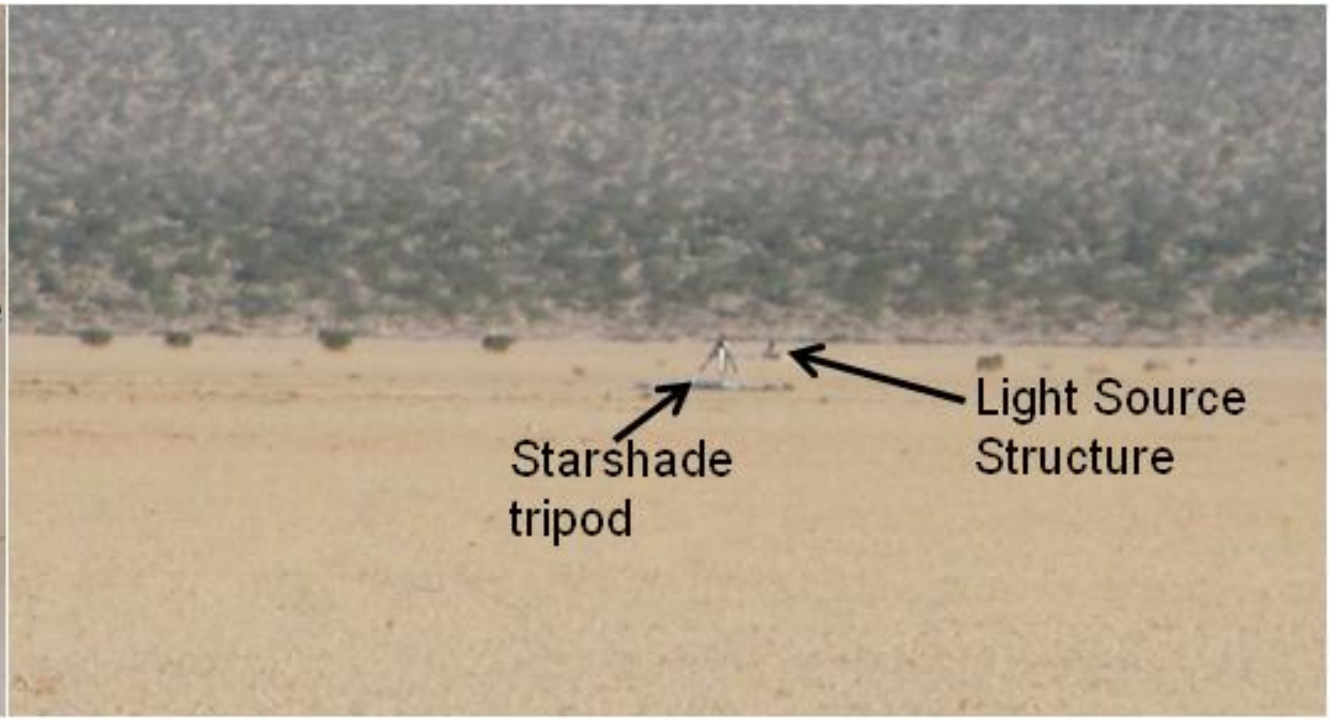
The Field-Testing Project

- Since 2012, our team has used scale starshades to test the diffraction optics over a long baseline
- Testing uses long baselines of 2-4km, with a light source, a starshade, and a camera forming 3 points on a line
- The starshade designed for this test is ~60 cm in diameter – or ~1% of the full scale
- We completed 3 tests at California sites from June 2012 to Feb 2013
- In 2013 a Northrop Grumman TDEM proposal was selected to achieve 2 goals
  - In Field suppression of $1x10^{-9}$
  - Further verification of Starshade optical model performance using different starshade prescriptions and starshades with shape flaws

In this talk: Initial results from the first TDEM Test: May 27th to June 3rd

Limitations of the California Test

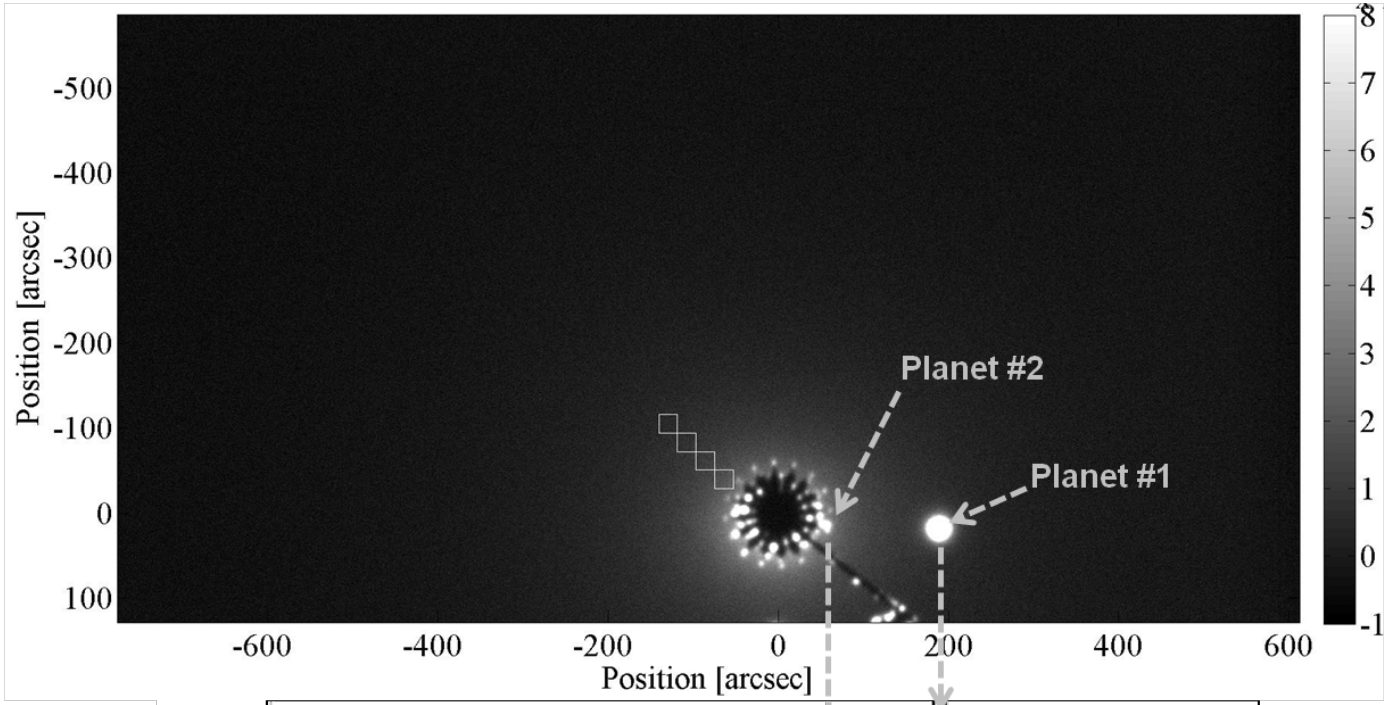
- Lake bed are used so that the light source, LED and Camera can be aligned without worrying about the vertical axis.
- California lake beds cause a few problems
  - Dust in the air is illuminated by the light source, forming a halo around the starshade
  - Seeing causes blurring of the image,
  - Artificial light makes the background of the image not as dark as it should be.

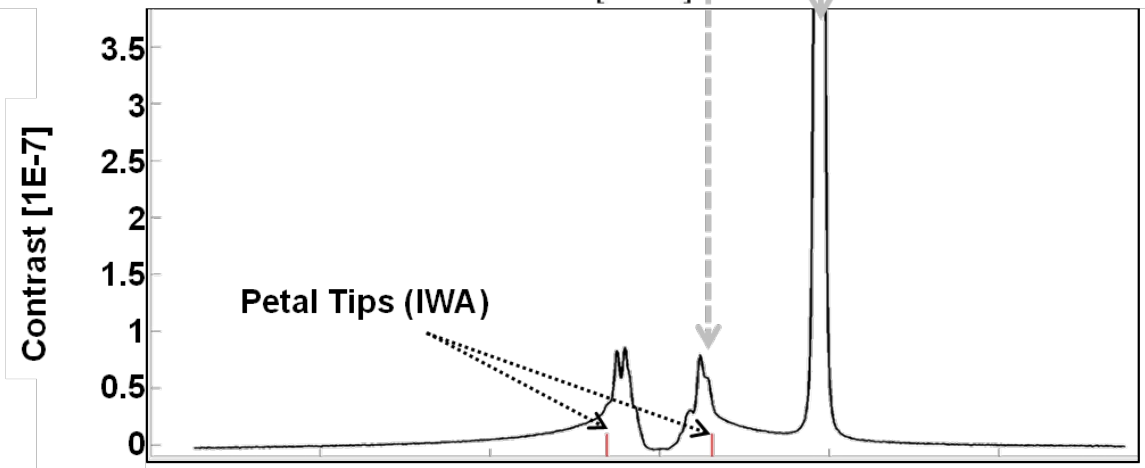


Best California Test Contrast: 1.1x10^{-8}

- Combination of 16, 10 sec images
- Curve is cross section through the image, average of 90 pixel wide strip
- Planet #1 (2x10^{-5}) & Planet #2 (2x10^{-7}) LEDs are indicated
- Regions used to calculate statistics (white boxes)

Distance from center	75"	167"
Mean Background	2.0×10^{-8}	5.6×10^{-9}
3σ Contrast Upper Limit	**1.1×10^{-8}**	**8.5×10^{-9}**





How to improve for the TDEM Tests

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- Dust
  - Look for a site with a harder surface for lower dust
  - Look for a site at higher altitude so thinner air holds less dust aloft
  - Use a narrower light source beam
- Seeing
  - Look for a site at higher altitude so thinner air
  - Use a brighter main source allowing shorter individual exposure times
- Artificial light
  - Look for a site more than 150 miles away from Las Vegas

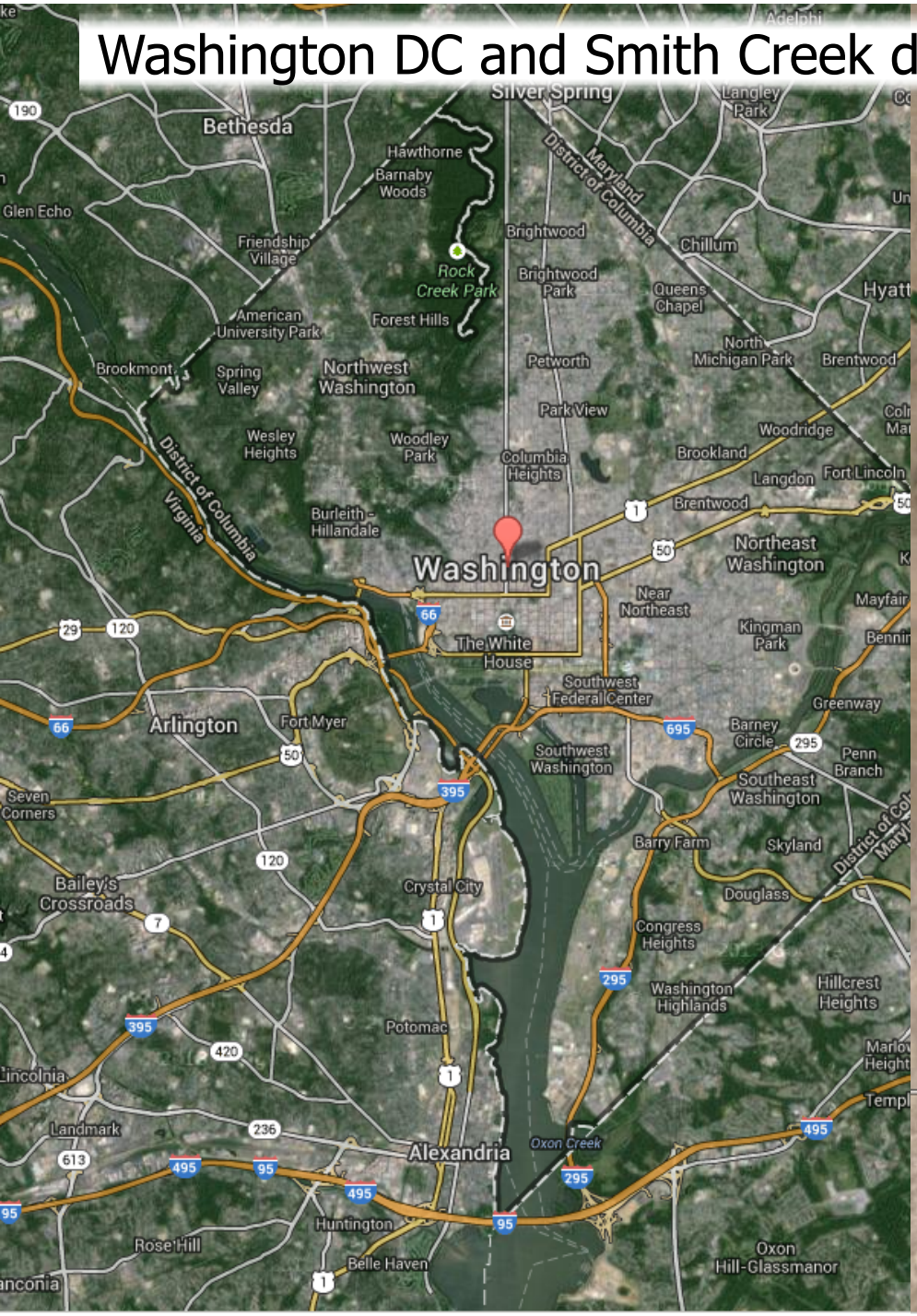
Find a better site, Improve the light source

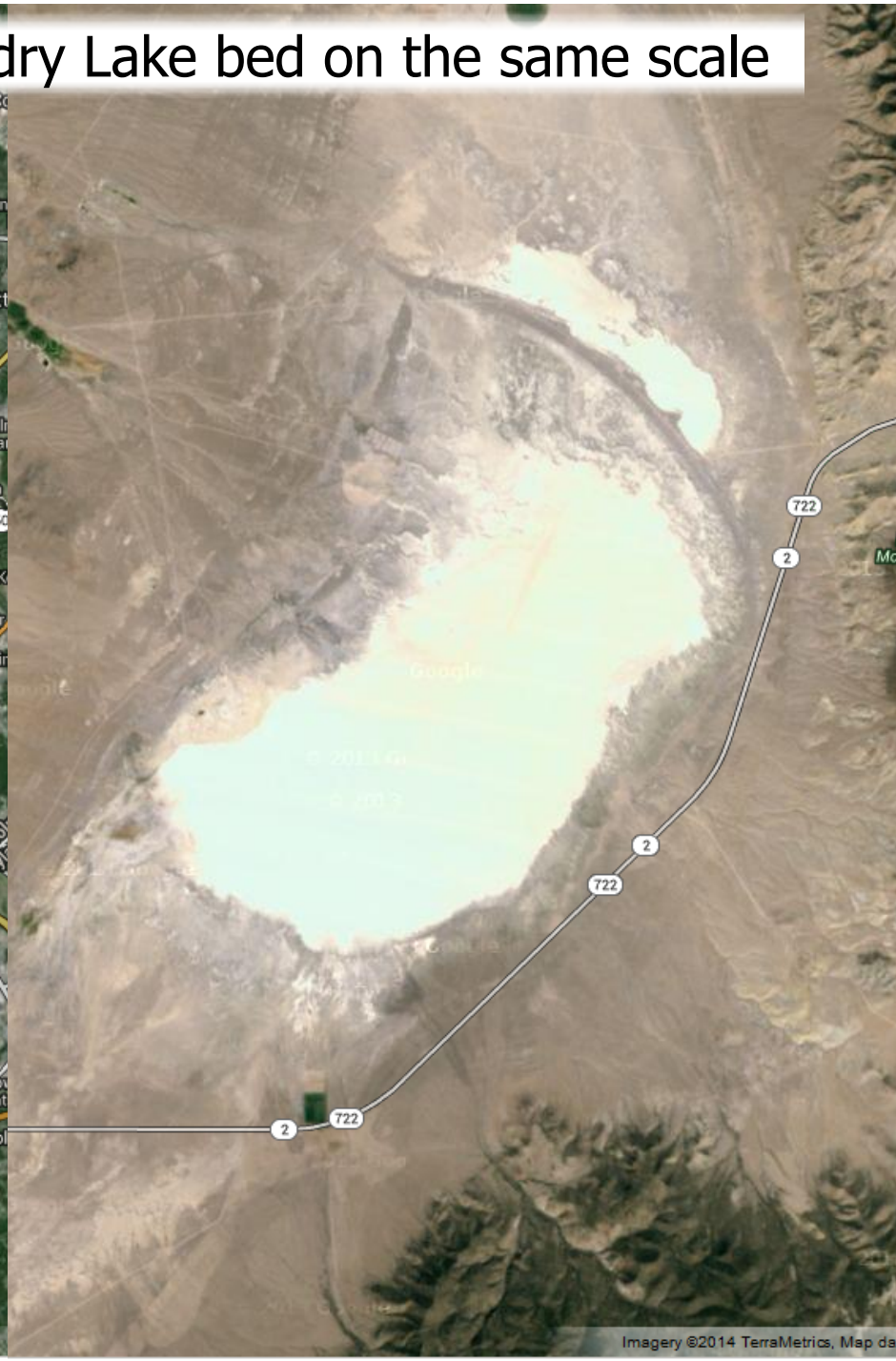
Site selection

- The great basin has many high, dry lake beds
  - Better for dust, atmospheric seeing and dark skies
- Survey took five days, looked at 10 sites and covered 1900 miles
- Smith Creek dry lake bed selected
  - Most optimal site for Access, Surface Hardness, Size, Dust, Wind and Darkness

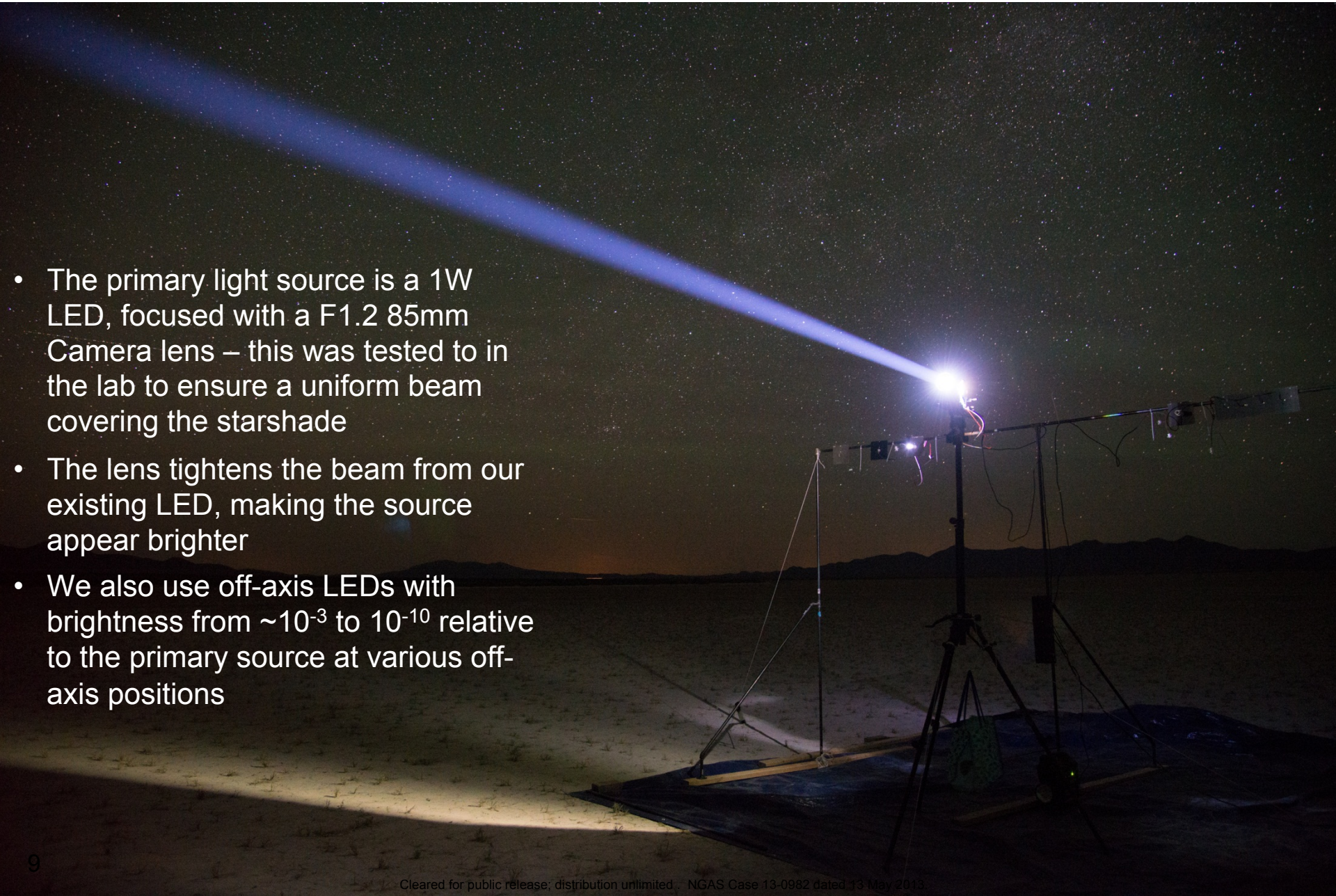

Nevada. Not Quite
What You'd Expect

Washington DC and Smith Creek dry Lake bed on the same scale





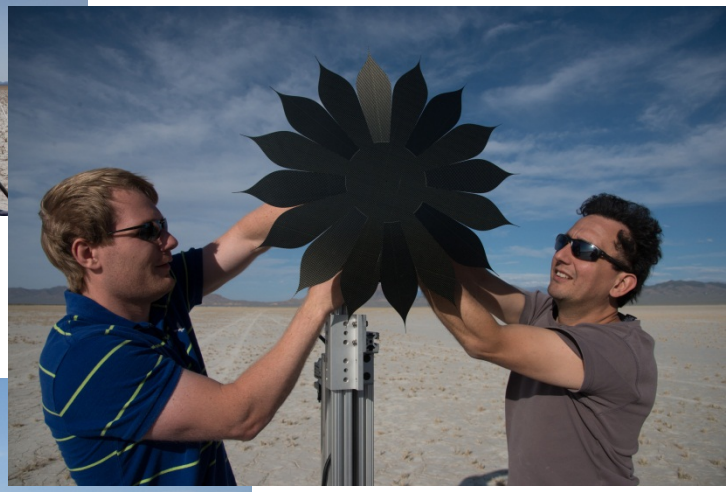
Light Source Improvement



- The primary light source is a 1W LED, focused with a F1.2 85mm Camera lens – this was tested to in the lab to ensure a uniform beam covering the starshade
- The lens tightens the beam from our existing LED, making the source appear brighter
- We also use off-axis LEDs with brightness from ~10^{-3} to 10^{-10} relative to the primary source at various off-axis positions

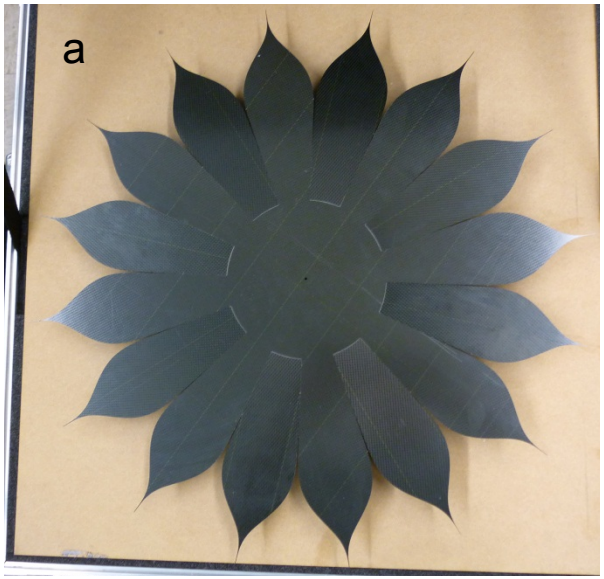
TDEM Field Test #1

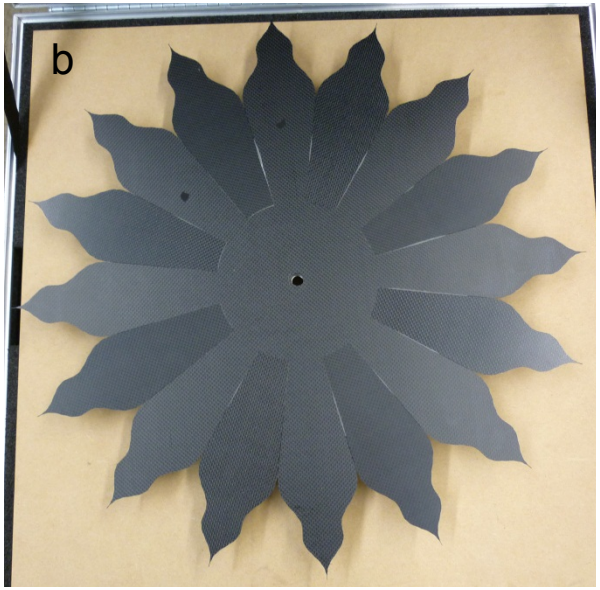
- The first of three field tests that will be carried out on TDEM contract
- Testing carried out over 5 nights From May 28th to the morning of June 2nd
- Testing range is 2km range with the Starshade in the middle

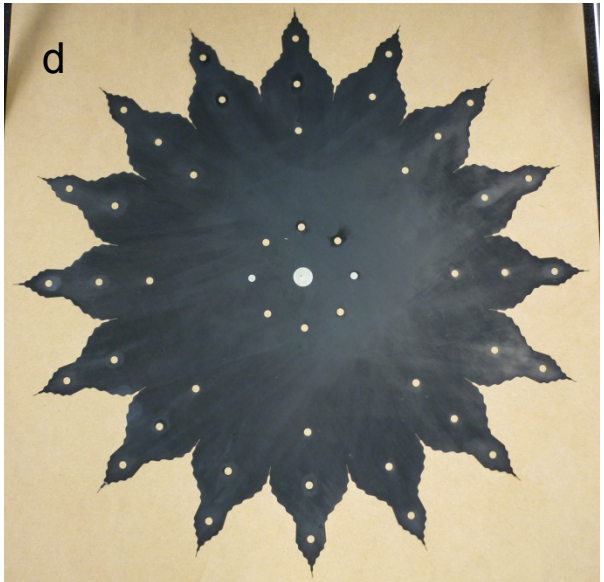


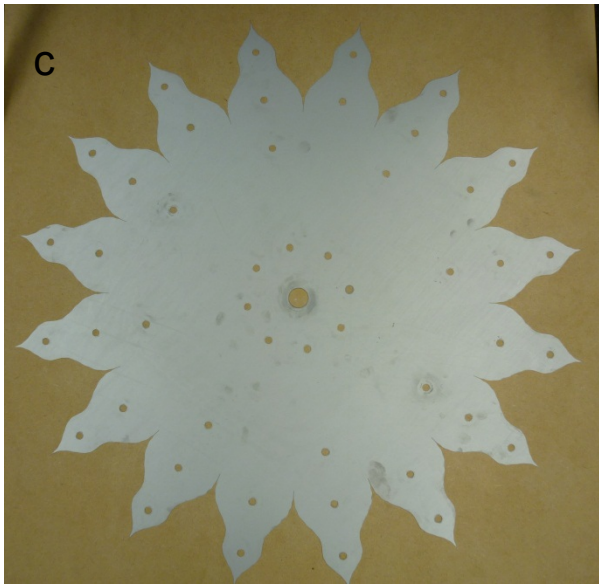
Starshades Tested

- 4 Starshades were tested
  a. Hypergaussian built by Northrop Grumman, Same starshade as tested previously
  b. Numerically determined IZ5, built by Northrop Grumman to JPL prescription
  c. Numerically determined IZ5, built by JPL to identical prescription
  d. Numerically determined HS25, built by JPL





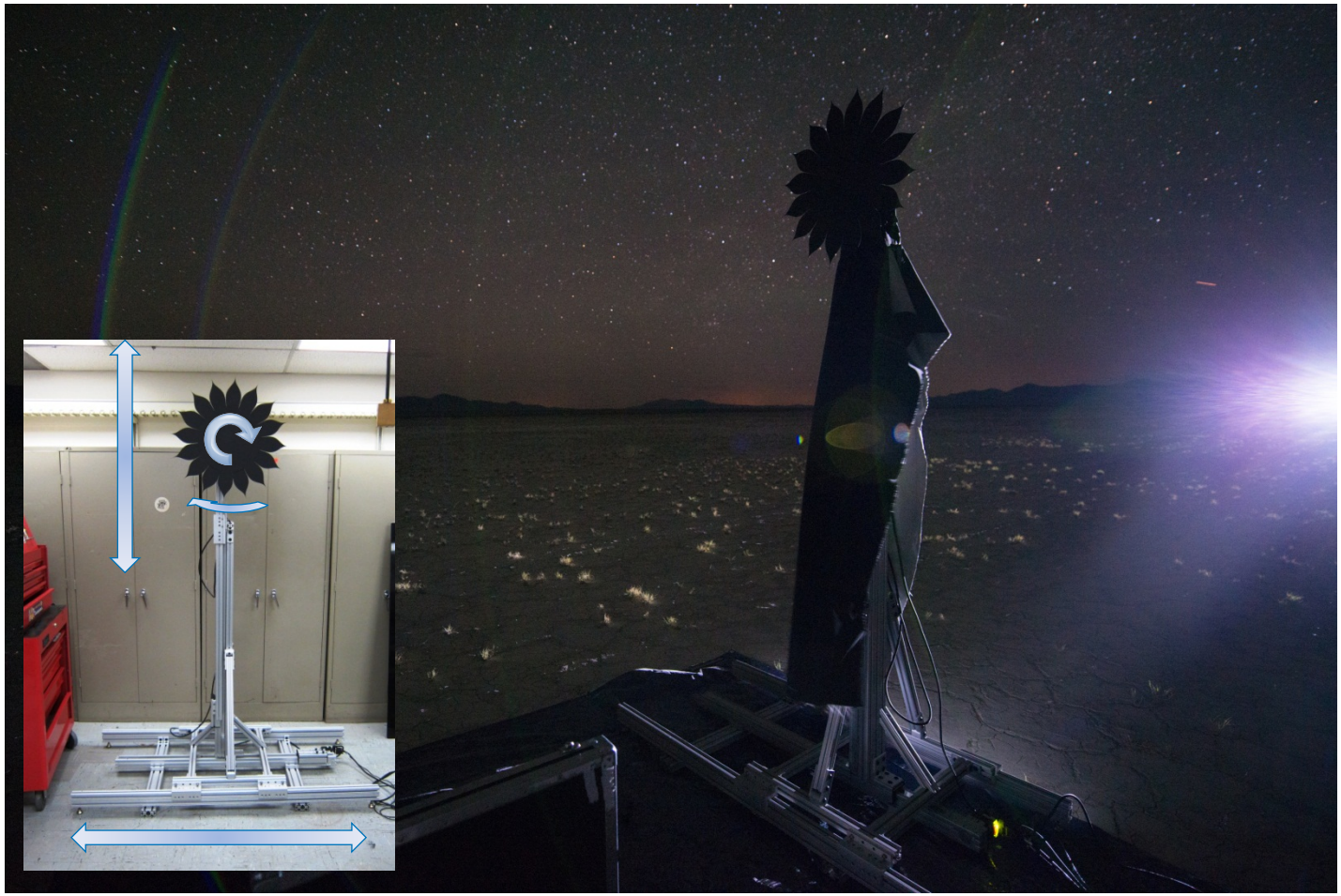




Automated Starshade Mount

- Built by Northrop Grumman and University of Colorado to support Desert Testing

- Provides accurate and repeatable positioning of the Starshade in 4 axes.
  - Horizontal
  - Vertical
  - Rotation about vertical
  - And starshade spin



Telescope and Camera

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- The telescope is 8 inch (20 cm) Celestron
  - Aperture stops (2 cm, 4 cm, and 6 cm) were added after the first test to provide a better match of telescope resolution to starshade angular size
- The camera is an electrically cooled CCD with a selectable filter wheel
  - Included neutral density (ND) filters to allow large dynamic range between observations with limited exposure time range
  - Also included BVR filters to measure Starshade frequency response
  - ND and Color filters calibrated by measuring their response in the lab and convolved with the spectra of the LED source, telescope mirror, and CCD

The Purpose of the TDEM

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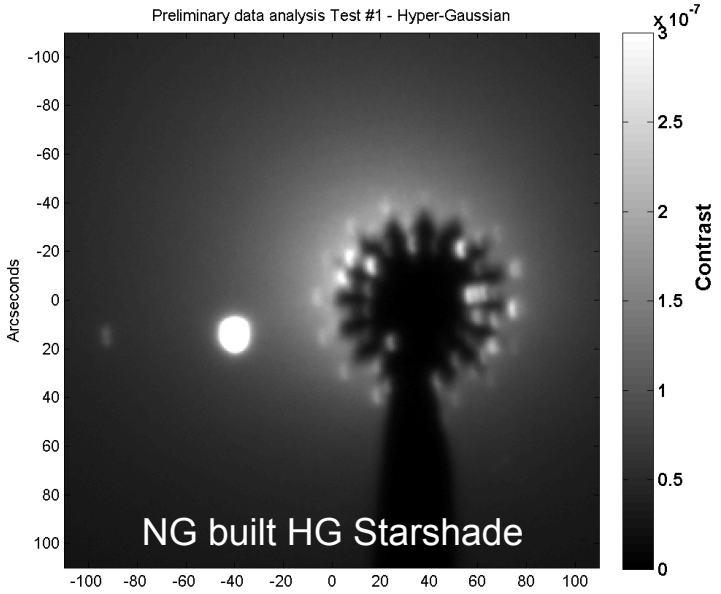
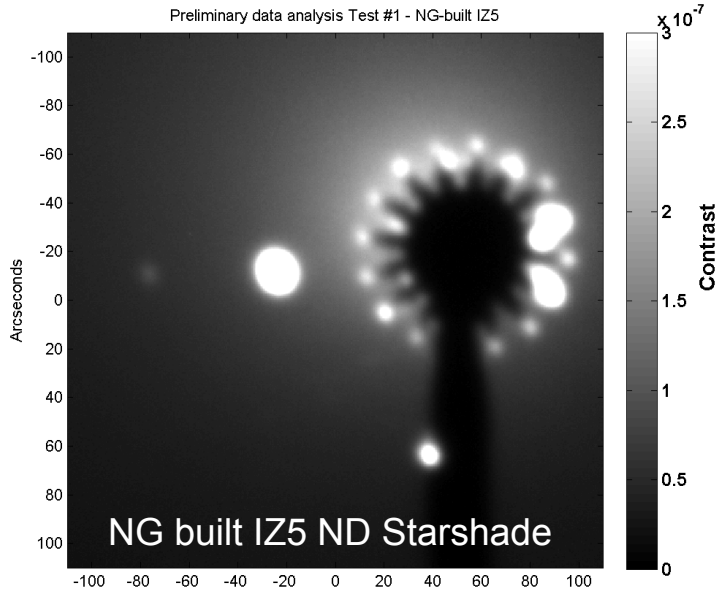
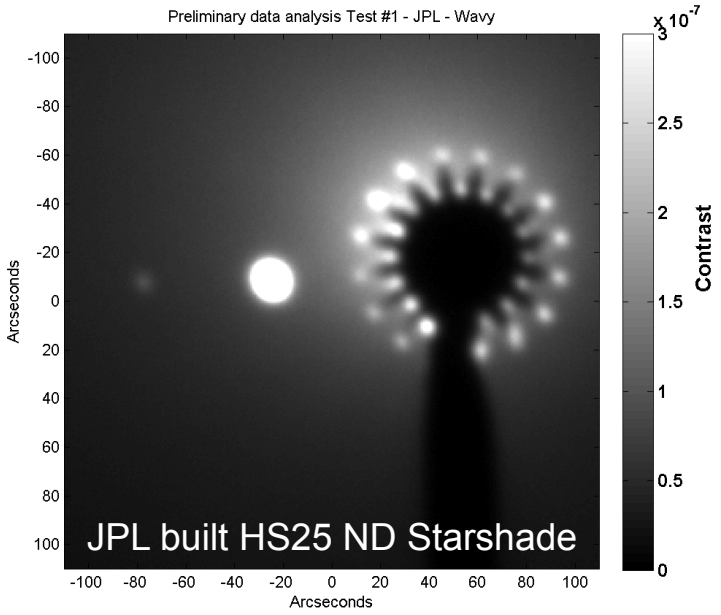
- Milestone #1: Demonstrate, using a starshade, contrast better than 10^{-9}, at all radii past the starshade tips, in 50% bandwidth light.
- Milestone #2: Demonstrate agreement between the measured and predicted contrast resulting from a range of starshade shapes.
- To Achieve Milestone #1 We are testing:
  - Different starshade shapes: Hypergaussian, and two versions of Numerically Determined.
  - Color response to Blue, Visible and Red Filters
- To Achieve Milestone #2 We are testing:
  - Different starshade shapes: Hypergaussian, and two versions of Numerically Determined.
  - Effect of Tilt; when the starshade is not exactly perpendicular to the optical line of sight

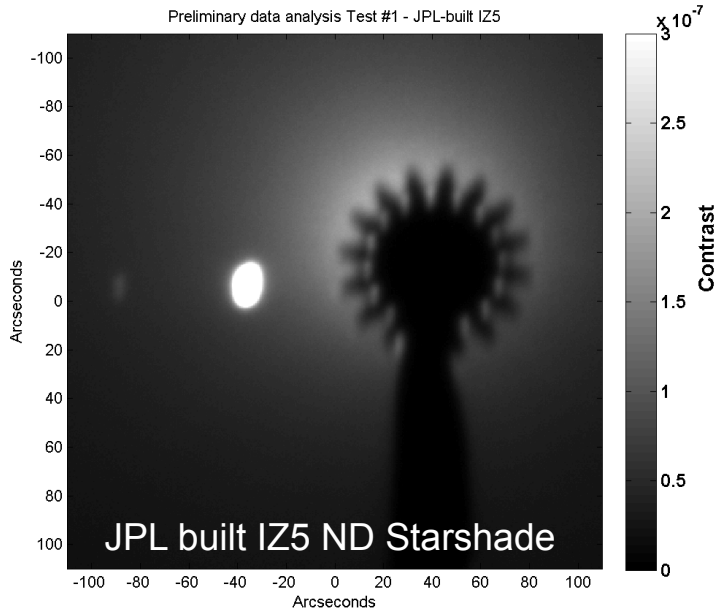
Results from this test will guide Tests 2 and 3

Starshade Images









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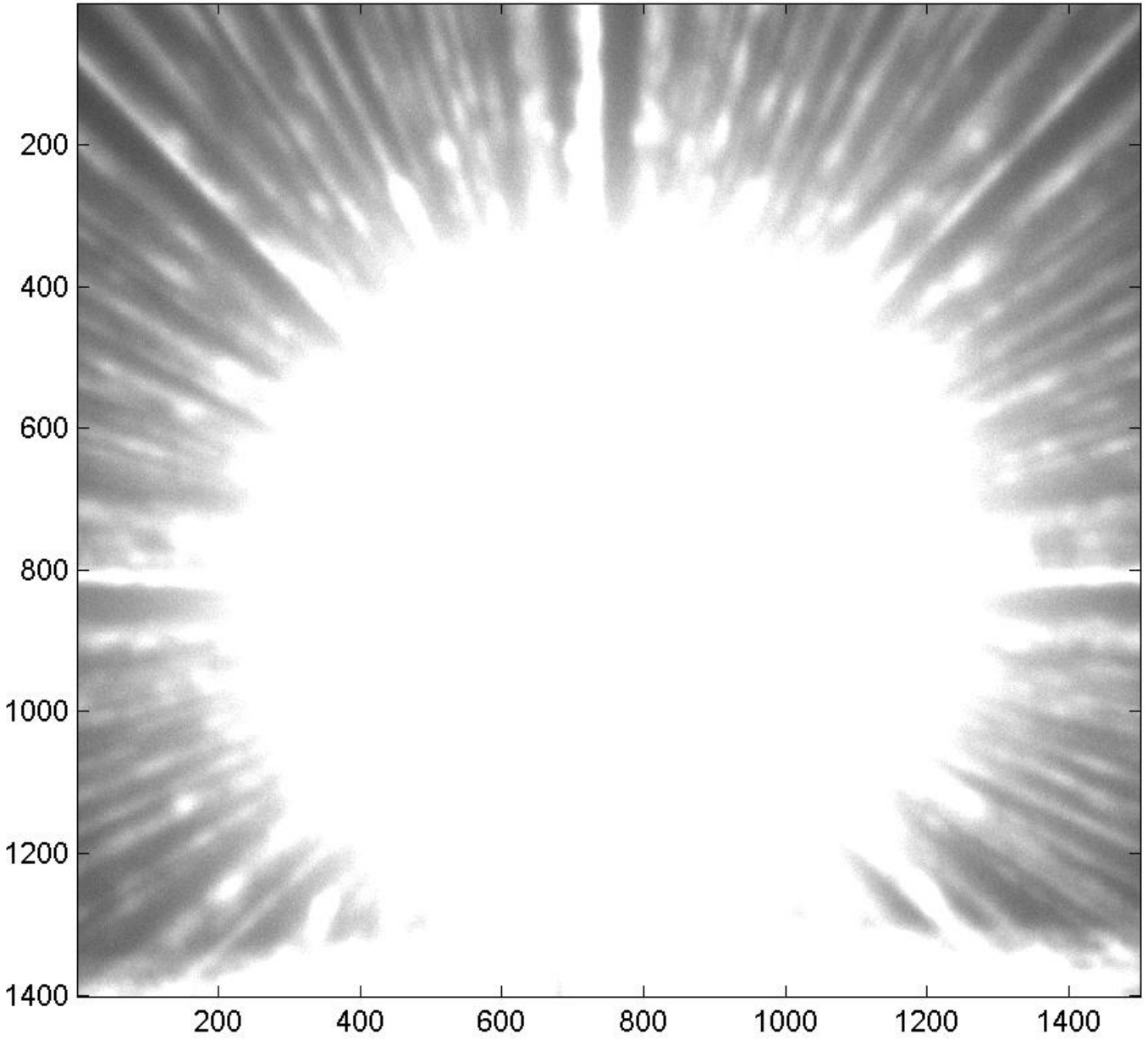
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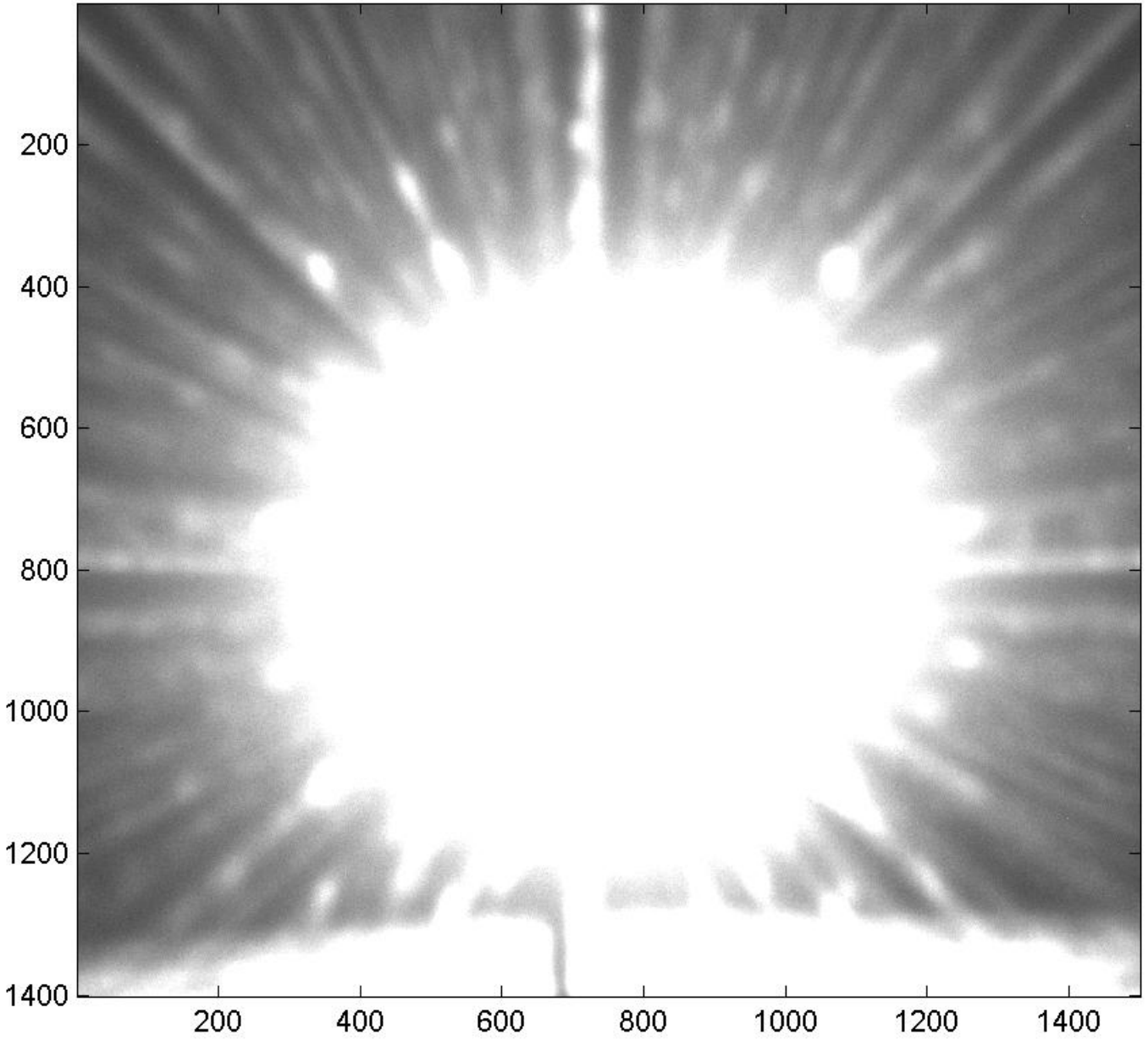
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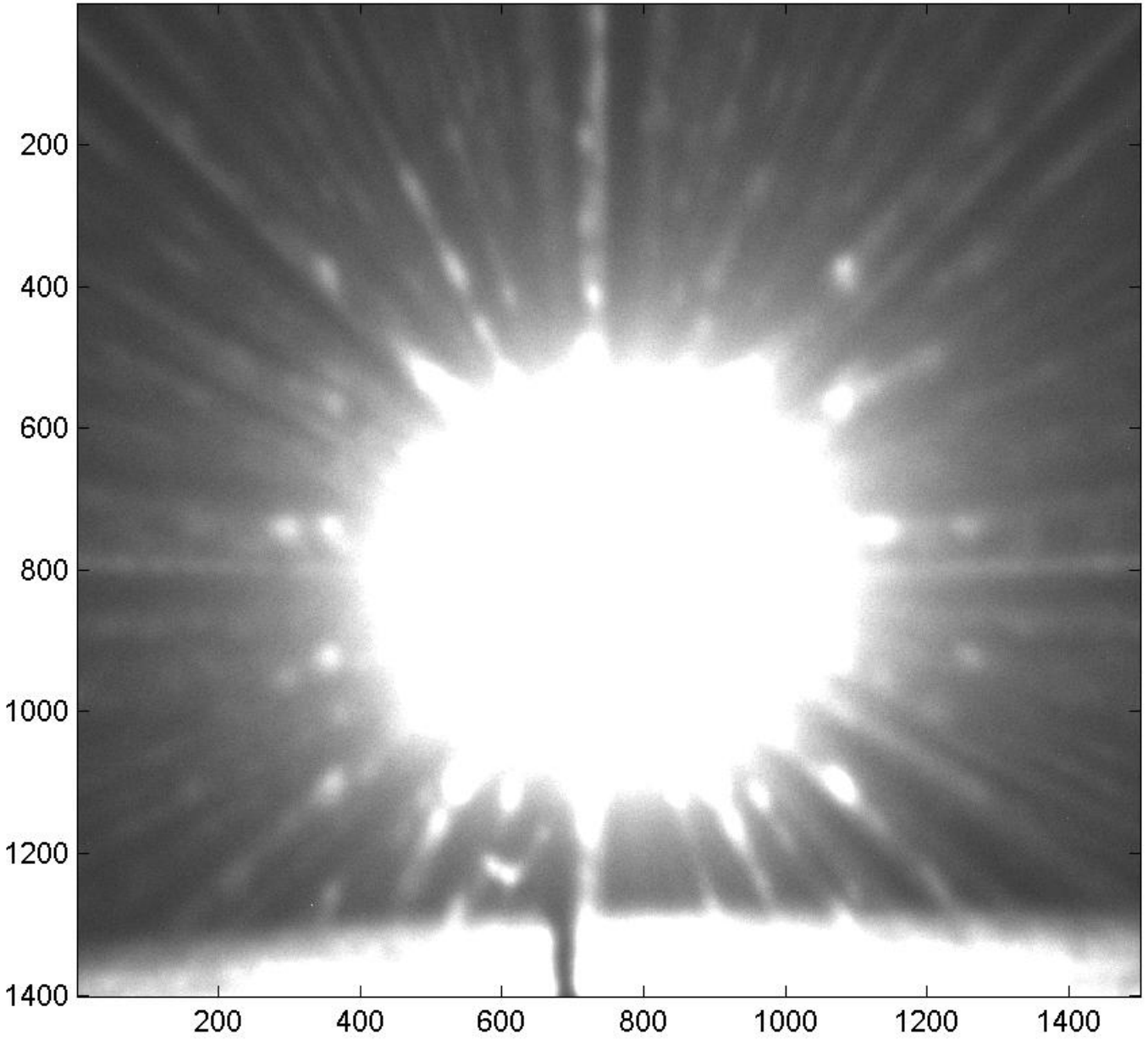
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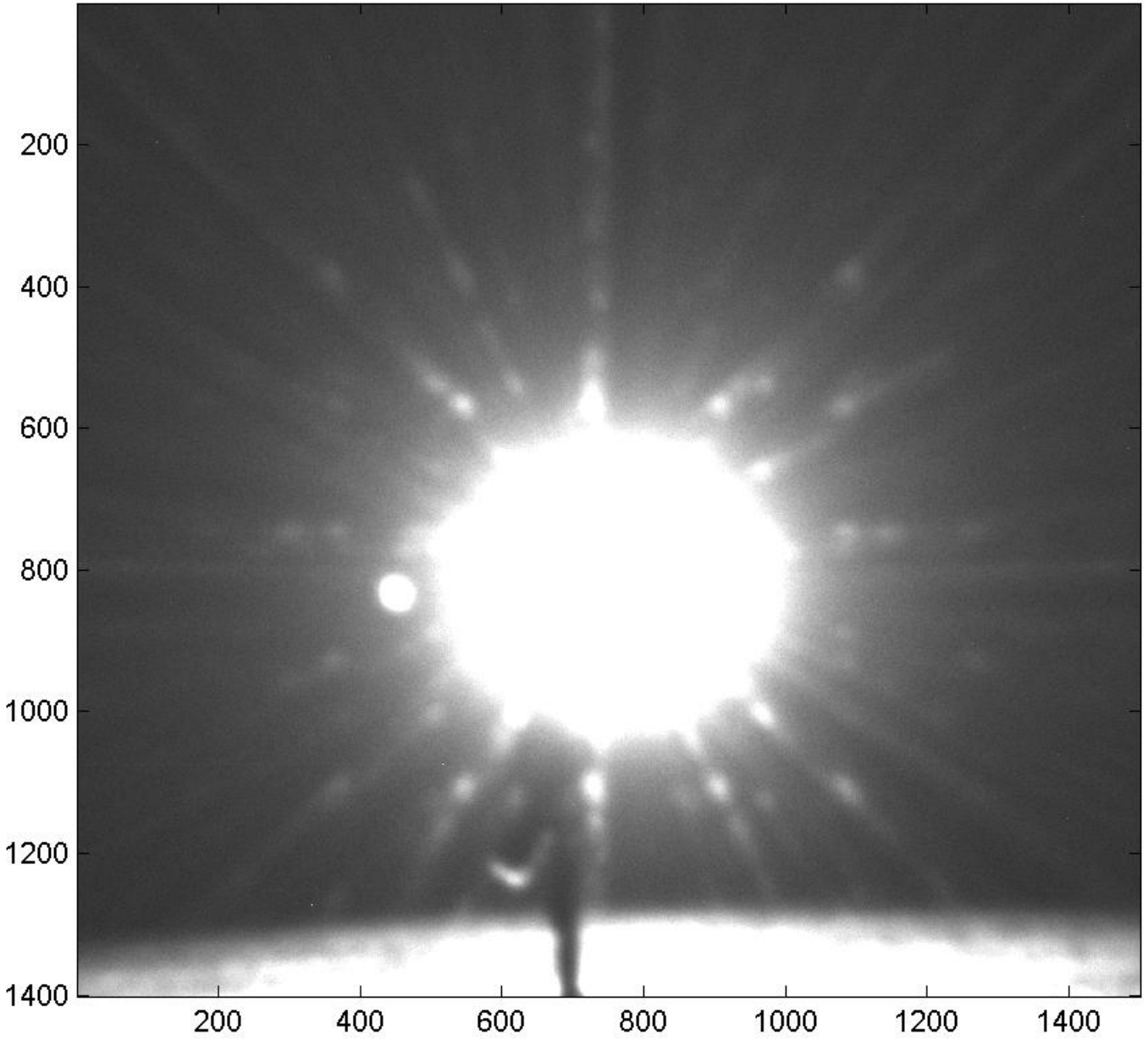
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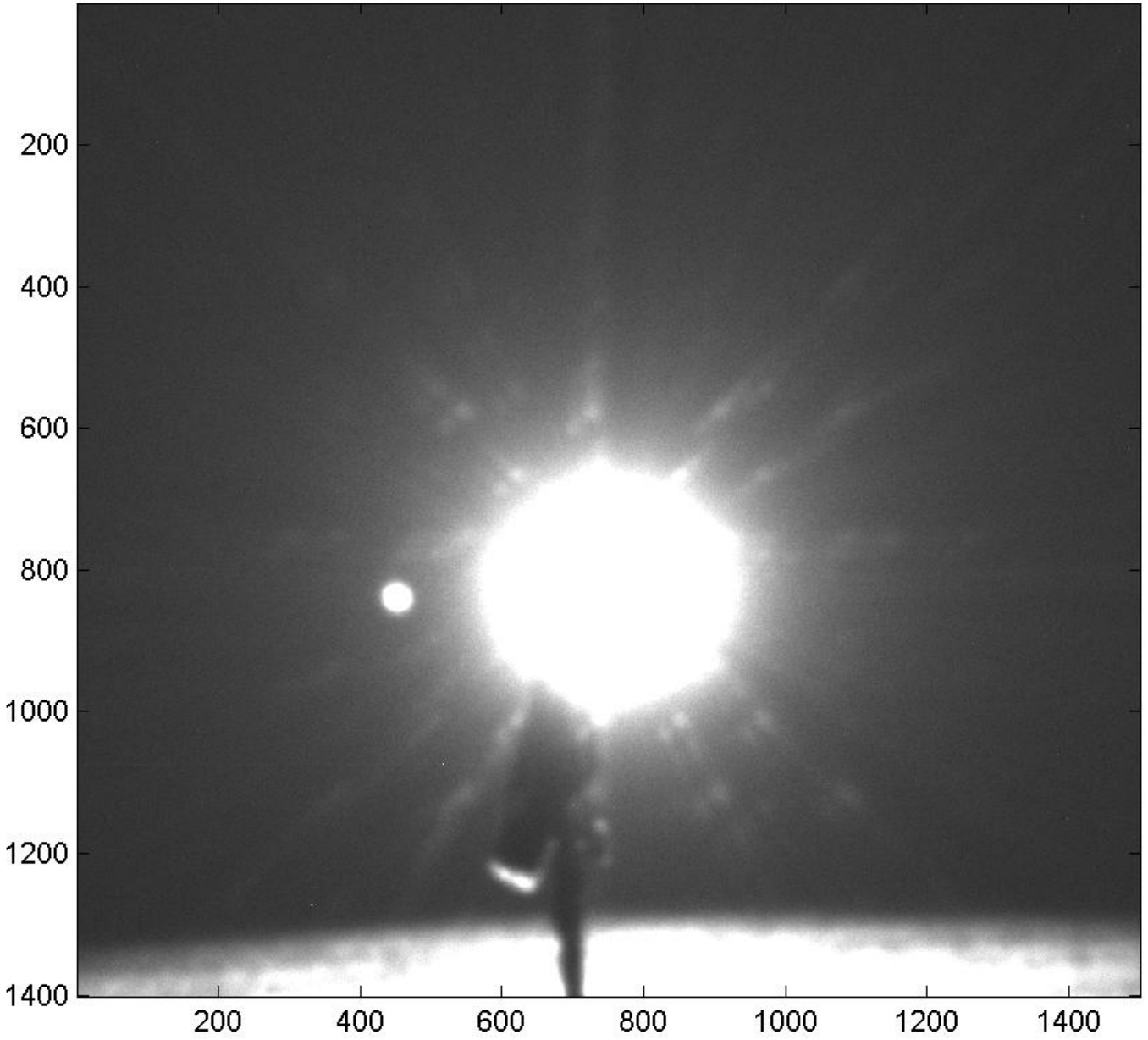
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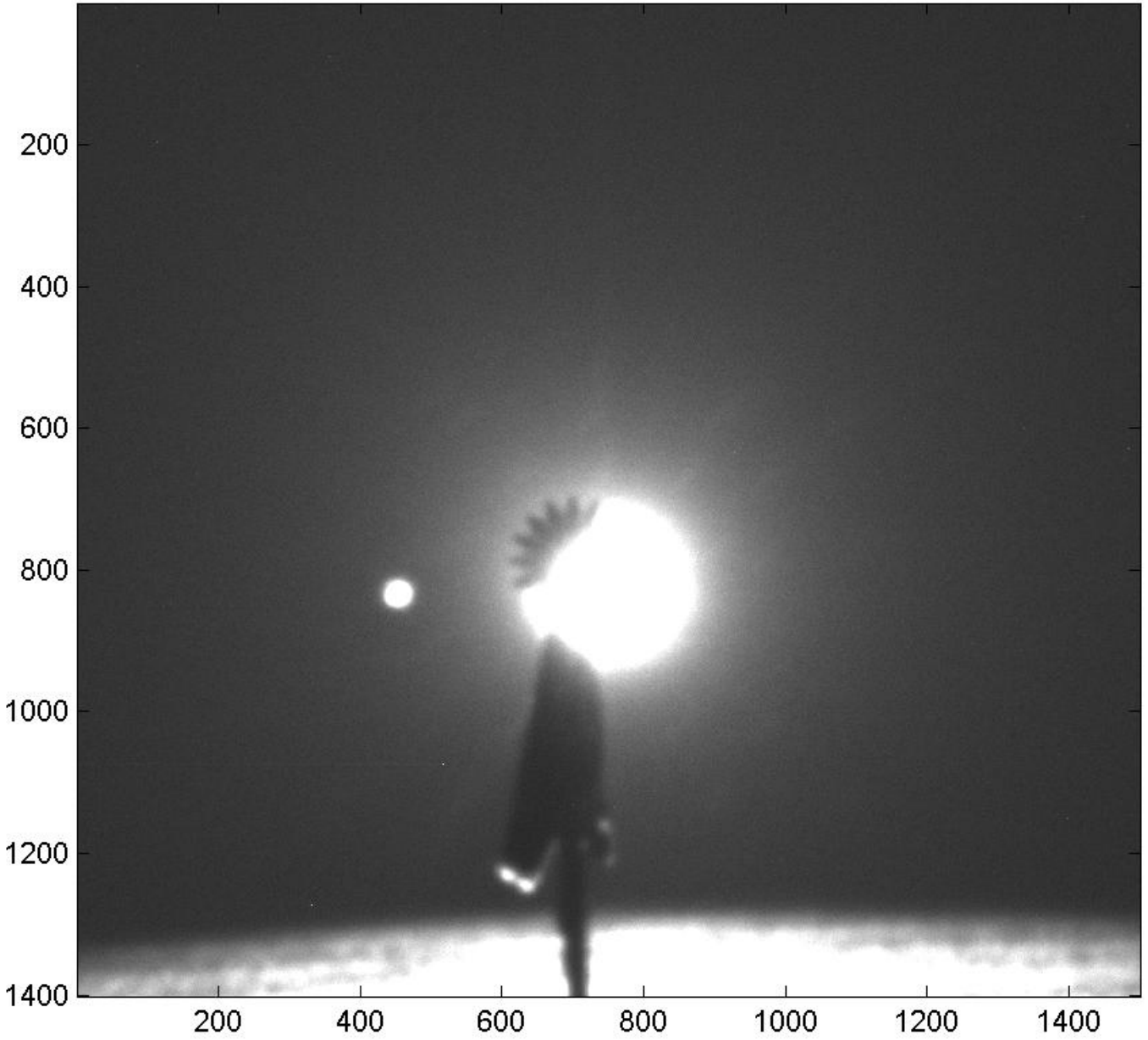
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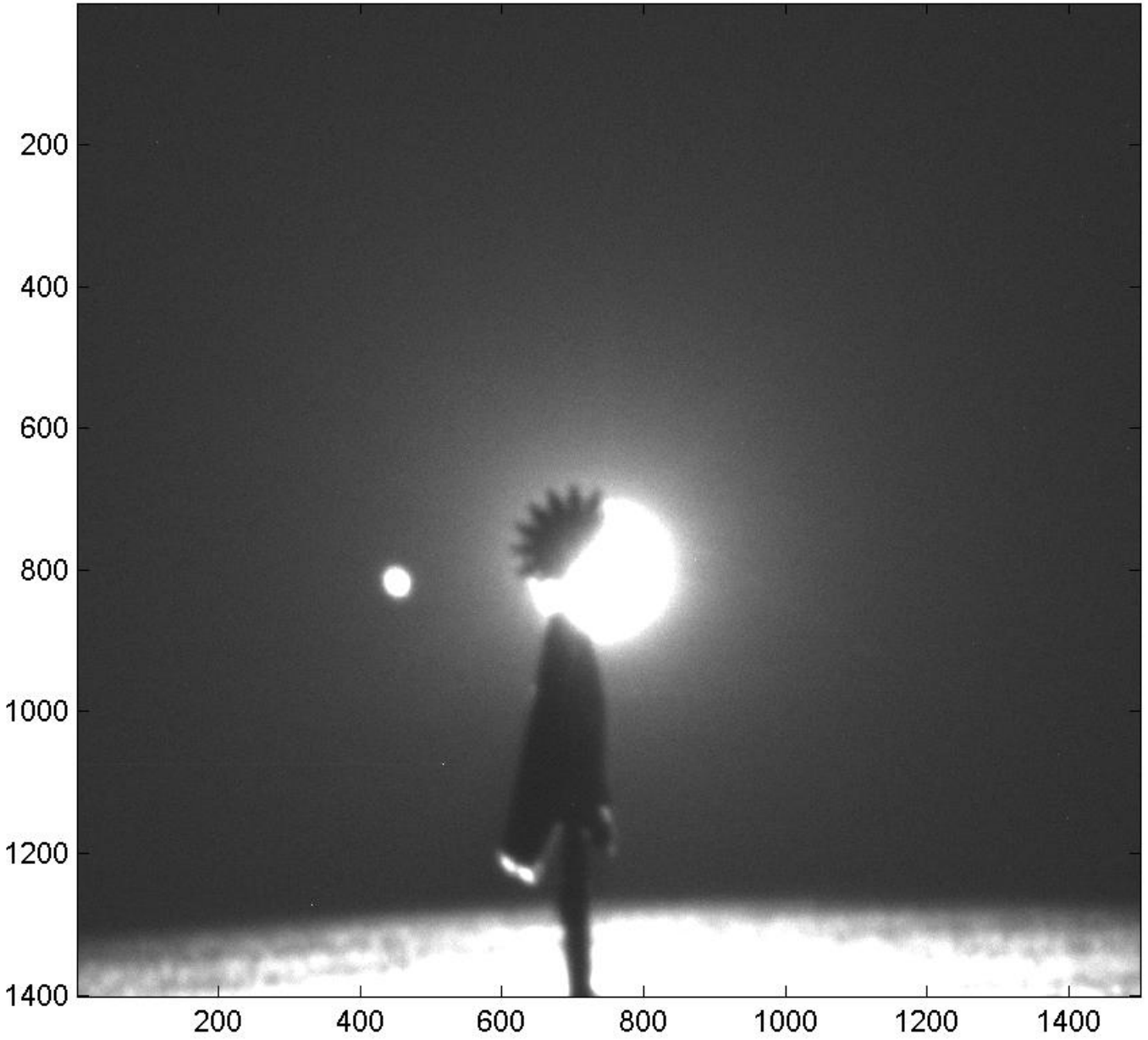
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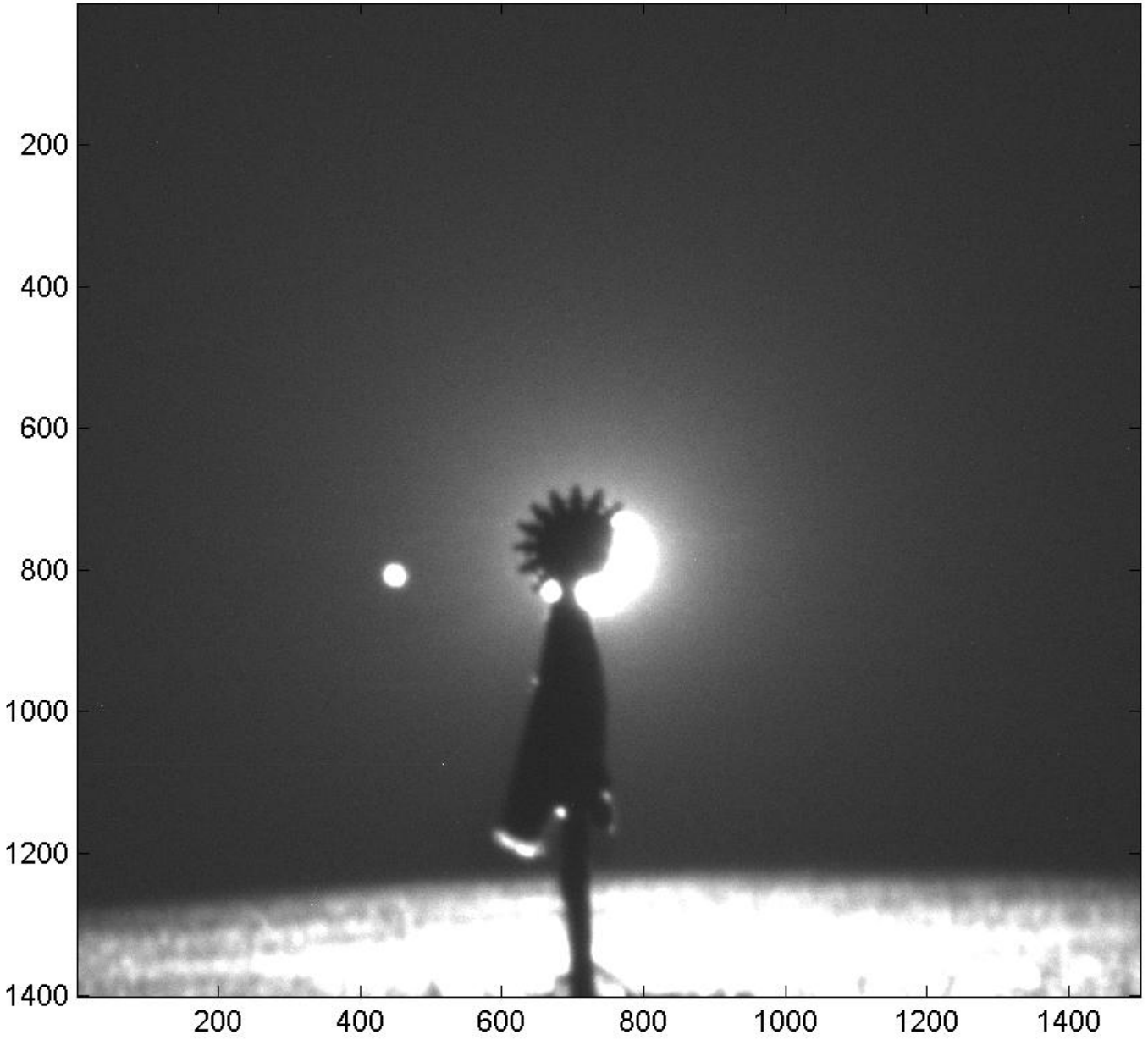
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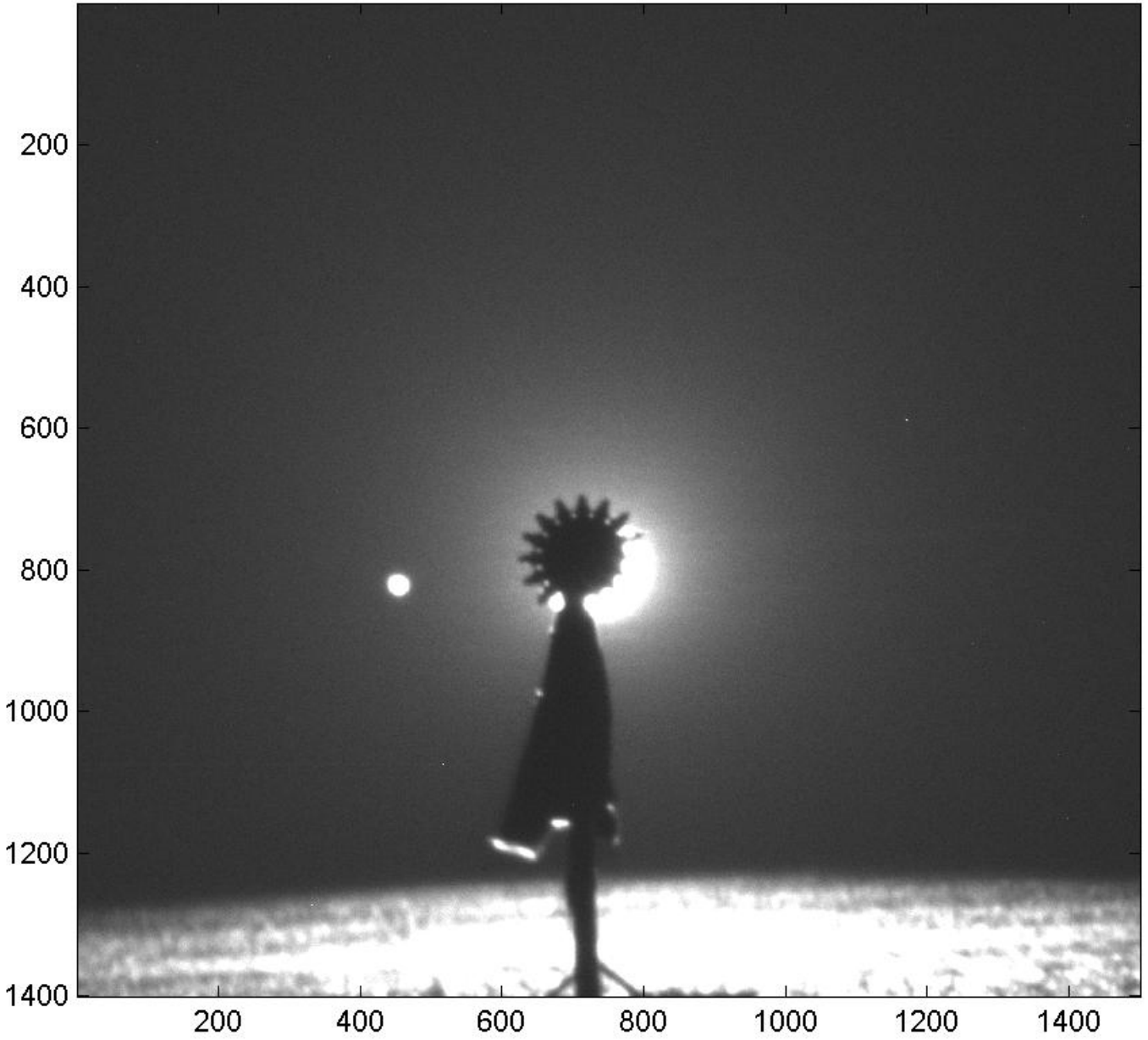
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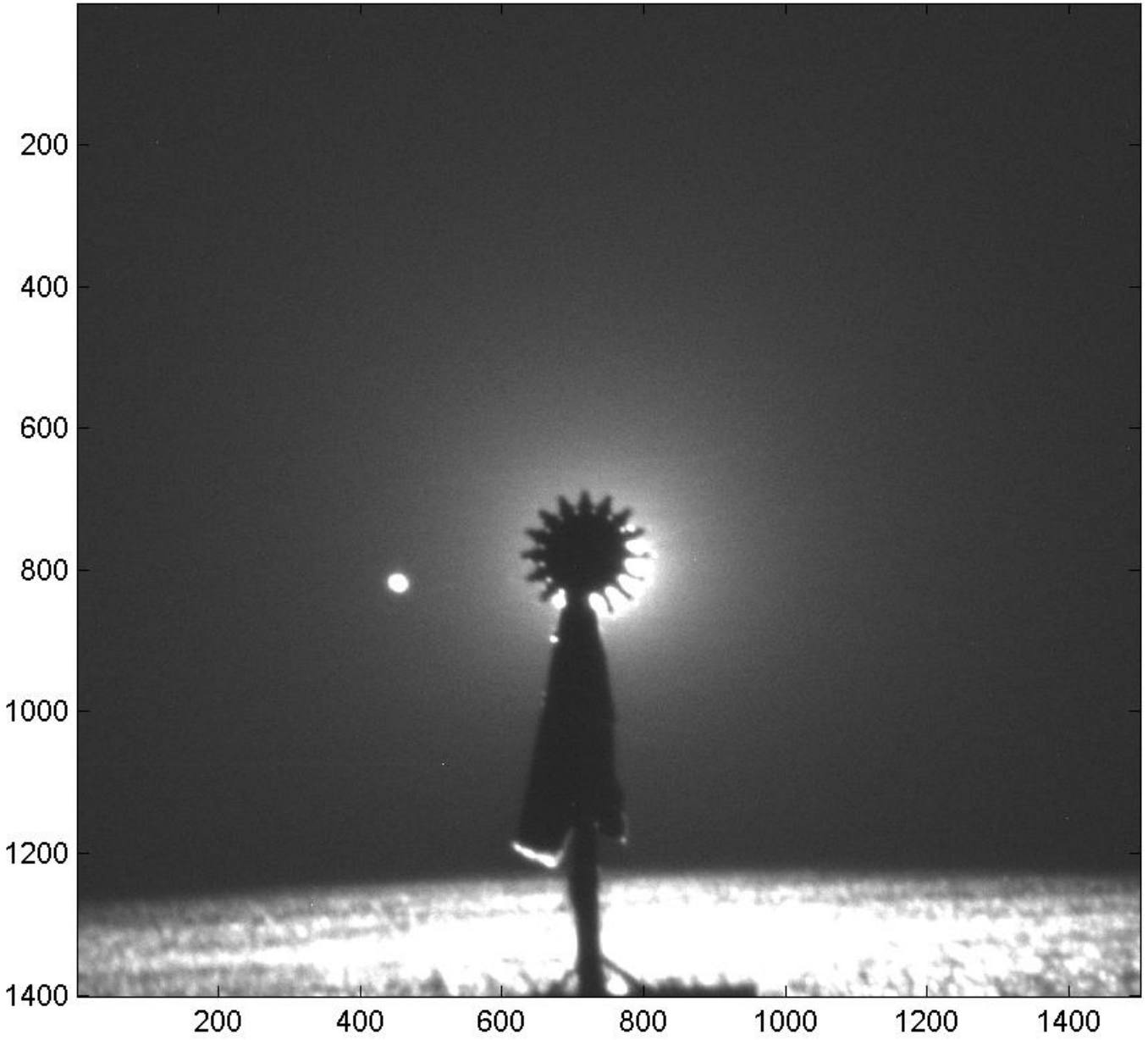
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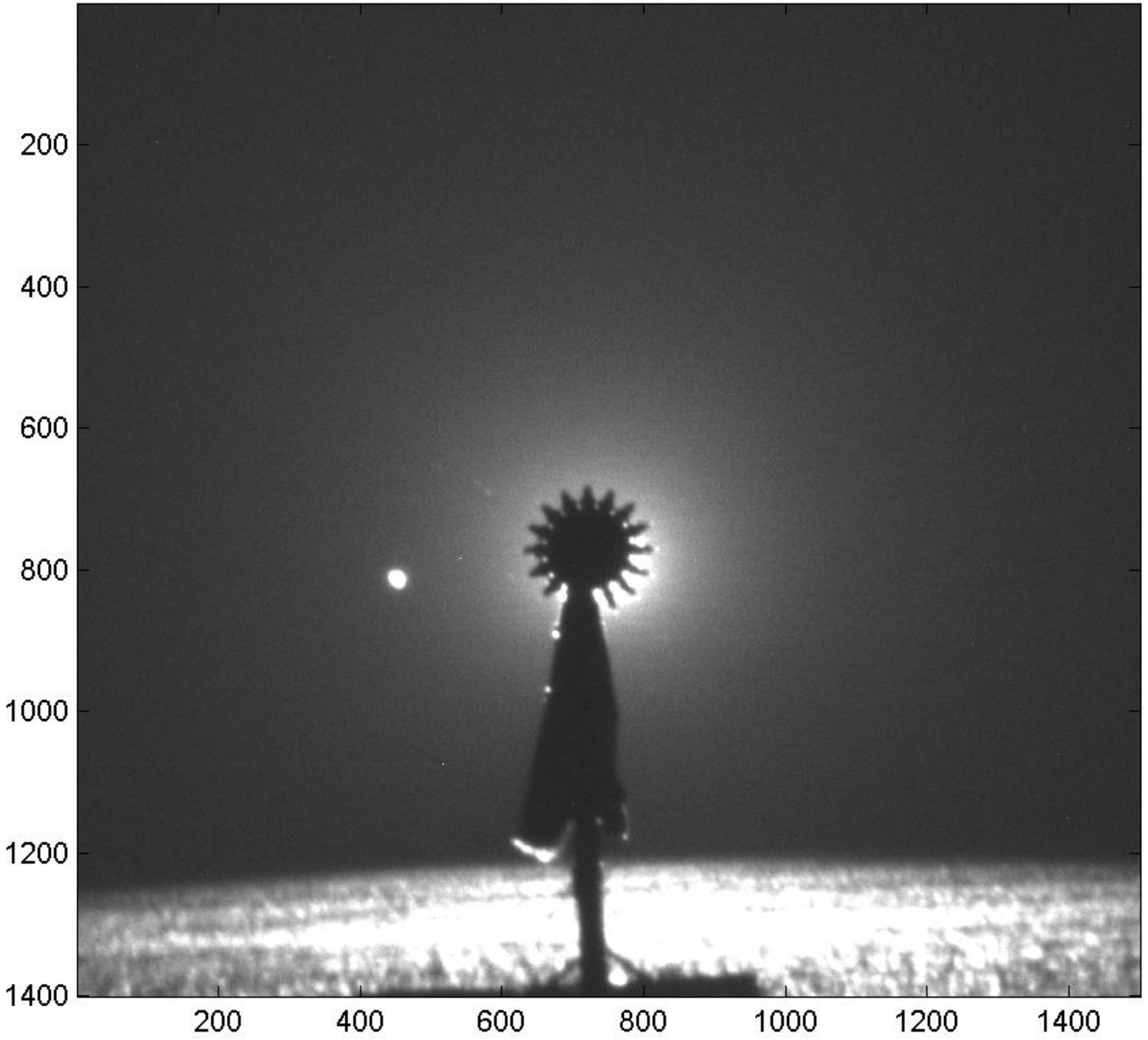
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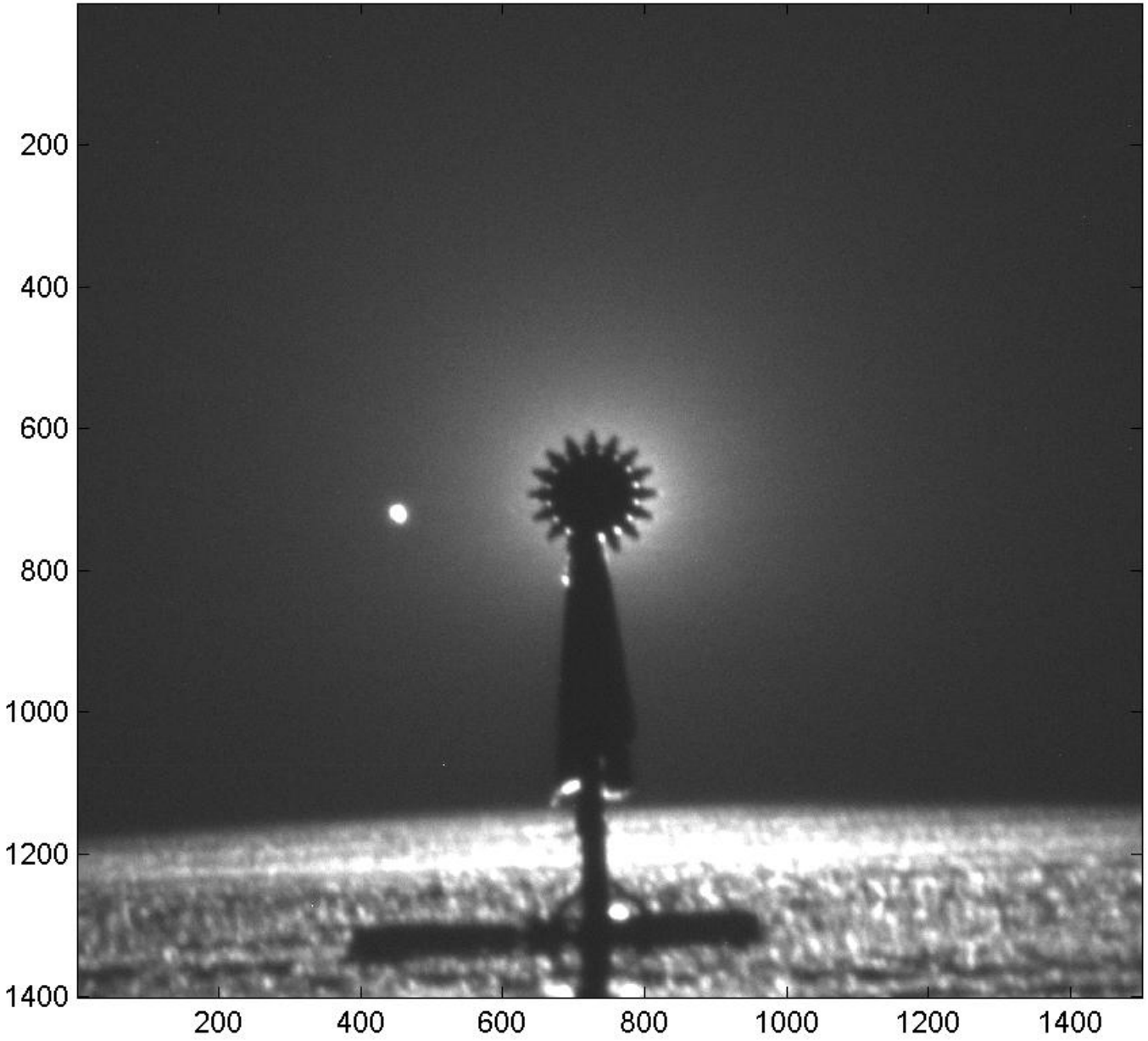
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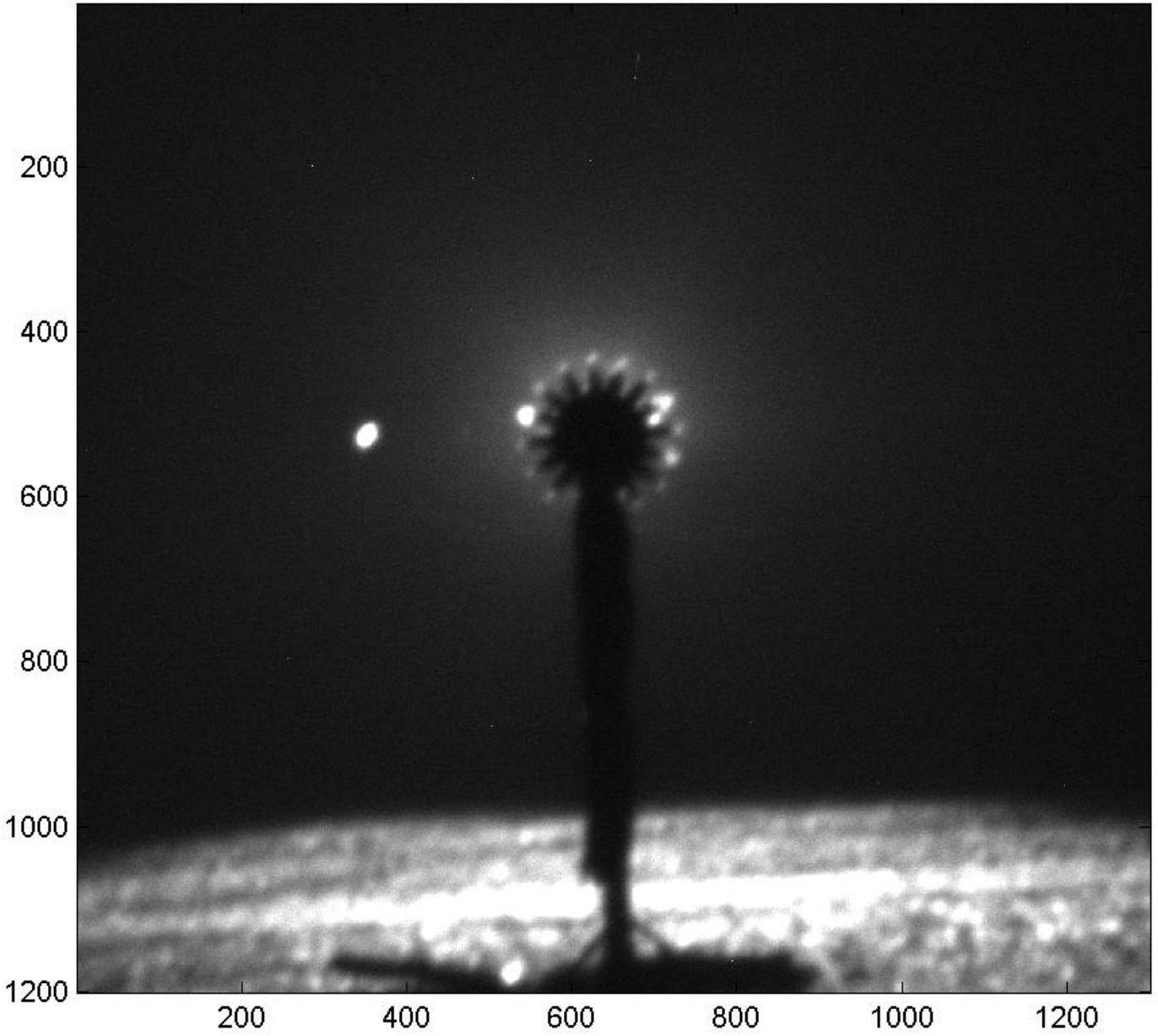
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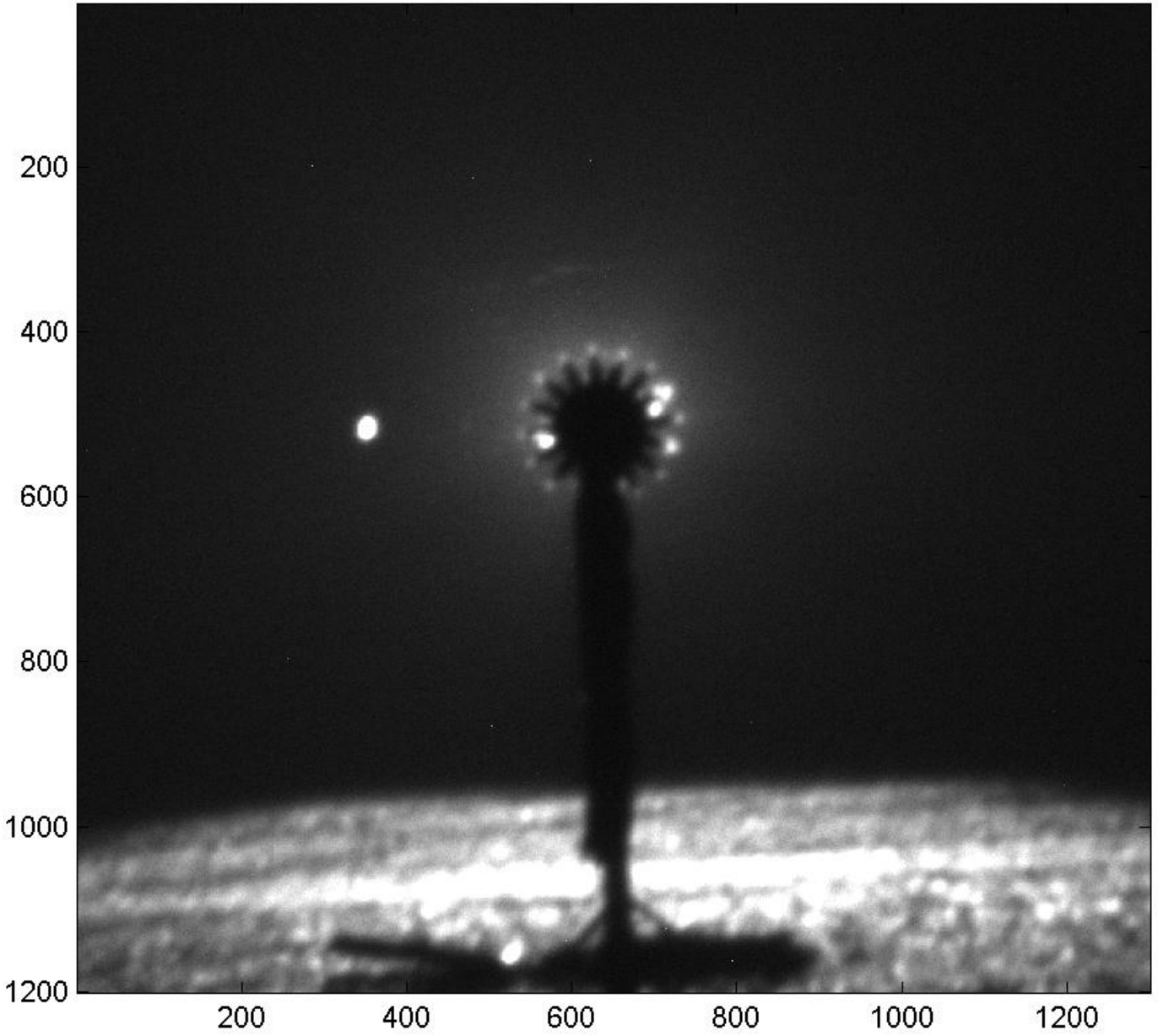
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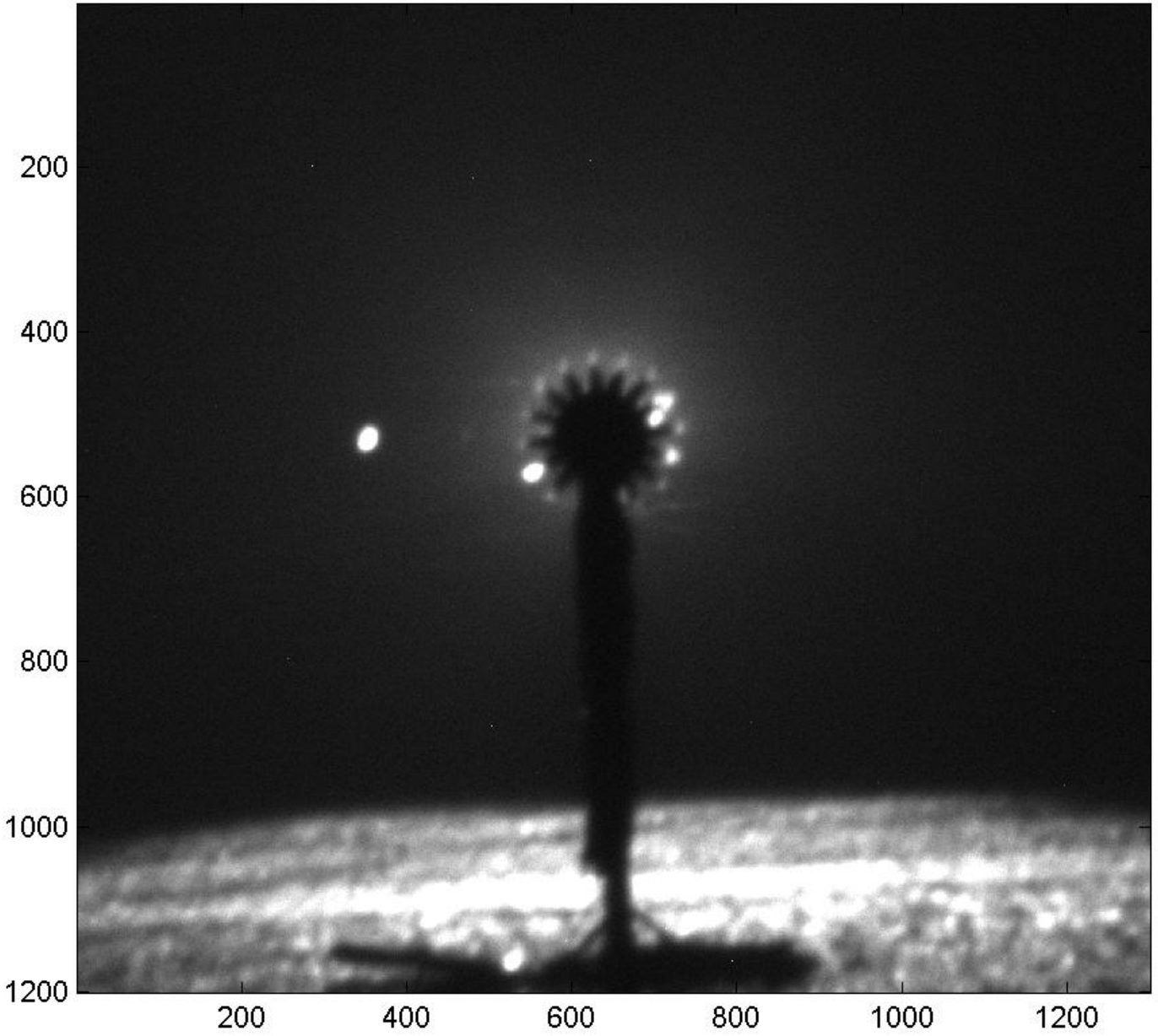
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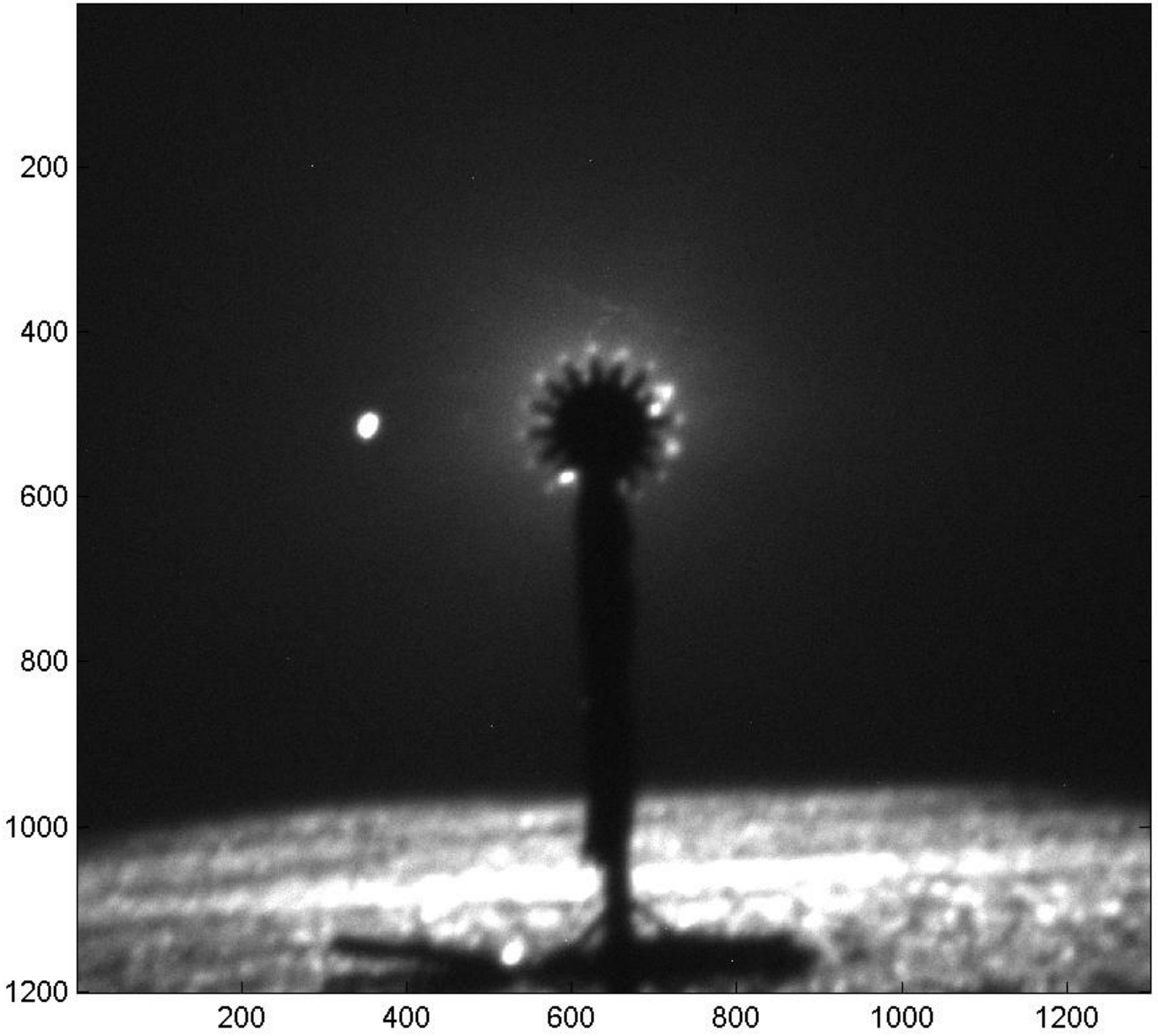
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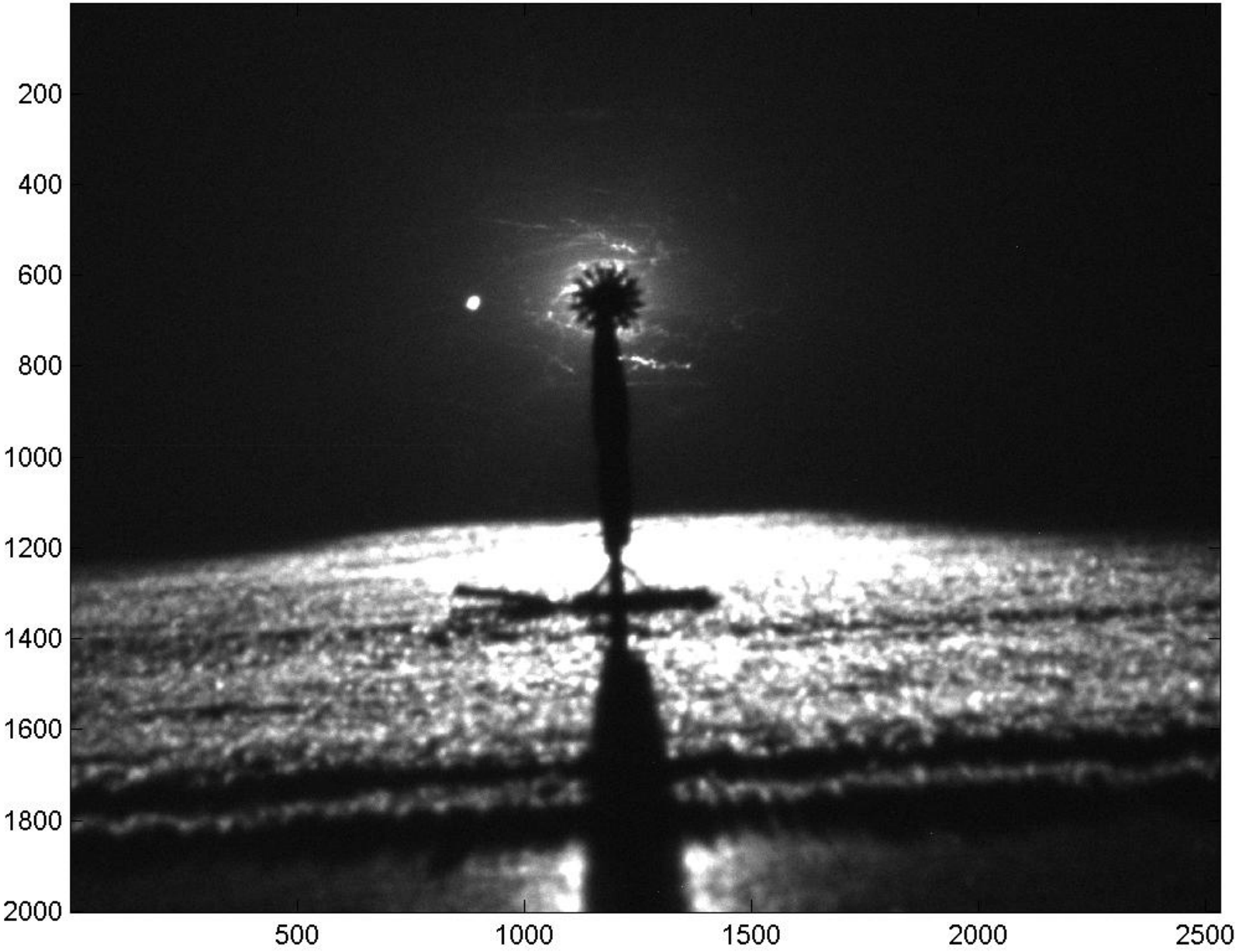
Bugs in the System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