Comet coma morphology imaging using CN Cyanogen radical 387nm UV narrowband filter with amateur telescopes
Observations of comets 21P/Giacobini-Zinner and 46P/Wirtanen

Komeettojen koman rakenteen kuvaaminen CN syaaniradikaalin 387nm UV kapeakaistafiltterillä harrastajakaukoputkilla
- Havaintoja komeetoista 21P/Giacobini-Zinner ja 46P/Wirtanen

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The physical processes of cometary activity

Comets are ”Dirty snowballs”

1. Solar heating
   ➔ Sublimation of gas molecules and dust from comet icy surface
2. Solar UV radiation, reaction 1
   ➔ Photodissociation of molecules to ions, radicals and atoms
3. Solar UV radiation, reaction 2
   ➔ Fluorescensty of radicals
   ➔ Continuous light emitting

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Comet spectroscopy

HB Narrowband filter set used by scientists:

- OH (0-0), OH, 309.7/6nm
- NH (0-0), NH, 336.1/6nm
- UV continuum, UC, 344.9/8nm
- CN (∆v=0), CN, 386.9/6nm
- C₂, C3, 406.3/6nm
- CO⁺(2-0), CO⁺, 426.6/6nm
- Blue continuum, BC, 445.3/6nm
- C₂ (∆v=0), C₂, 513.5/11nm
- Green continuum, GC, 525.9/5nm
- H₂O⁺ (0,6,0), H₂O⁺, 702.8/17nm
- Red continuum, RC, 713.3/6nm

Commercial narrowband filters:

- CN ∆v=0: Semrock FF01-387/11
- C₂ ∆v=0 : Semrock FF01-513/13
- CO⁺ 2-0 band: Semrock FF01-427/10

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Transition (vibration band)</th>
<th>Wavelength (nm)</th>
<th>L/N at 1 AU (10⁻²⁰ W)</th>
<th>Mean relative intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂</td>
<td>d''II - a''II, ∆v = -1</td>
<td>473.7 (26-26)</td>
<td>2.40</td>
<td>0.54</td>
</tr>
<tr>
<td>C₂</td>
<td>d''II - a''II, ∆v = 0</td>
<td>510.5 (36-36)</td>
<td>4.00</td>
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<tr>
<td>C₂</td>
<td>a''II - a''II, ∆v = -1</td>
<td>566.3 (36-36)</td>
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<tr>
<td>CN</td>
<td>a''II - a''II, ∆v = 0</td>
<td>569.1 (36-36)</td>
<td>0.7</td>
<td>0.15</td>
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<td>C₂</td>
<td>a''II - X''II, ∆v = -1</td>
<td>1018.0</td>
<td>0.13</td>
<td>0.03</td>
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<td>CN</td>
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<td>1210.0</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>405.2 (35-35)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>350.9 (4-4)</td>
<td>10.0</td>
<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>359.0 (4-4)</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>383.8 (4-4)</td>
<td>2.5 × 10⁻²</td>
<td>1</td>
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<tr>
<td>CN</td>
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<td>421.5 (4-4)</td>
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<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>414.1 (13-13)</td>
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<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>1004.0 (13-13)</td>
<td>10.0</td>
<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>420.5 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>330.0 (19-19)</td>
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<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>306.2 (5-5)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>306.4 (5-5)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>312.2 (6-6)</td>
<td>10.0</td>
<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>436.8 (0-0)</td>
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<td>0.4</td>
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<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>515.4 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>545.5 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>570.0 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>600.0 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>650.0 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
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<tr>
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<td>X''II - X''II, ∆v = 0</td>
<td>695.5 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
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<td>CN</td>
<td>X''II - X''II, ∆v = 0</td>
<td>725.5 (0-0)</td>
<td>10.0</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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Brief history of CN Jet finding and observing

• CN Cyanogen radical B-X (0-0) band at 3883Å was first observed and identified in comet Tebbut (1881 III) by Huggins on 24 June 1881 on the first photographic spectrum ever obtained in a comet (Huggins, 1881)

• The rotational structure of the B-X (0-0) CN radical band was first investigated by McKellar (1940). He suggested that the “abnormal” rotational structure could be due to the direct production of excited radicals from the photodissosiation of their unknown parent.

  • Computed model of CN radical in comets compared to observations
Brief history of CN Jet finding and observing

CN Cyanogen radical gas jets observed directly first time from comet P1/Halley at 1986


- https://www.nature.com/articles/324649a0
  - Michael F. A'Hearn, Susan Hoban, Peter V. Birch, Craig Bowers, Ralph Martin, Daniel A Klinglesmith III
  - University of Maryland, Perth Observatory, NASA-Goddard Space Flight Center

- Research team used Perth Observatory 24” Planetary Patrol Telescope, CCD and CN radical 387nm emission band filter at 1986-04

- "The jets seen in CN light appear to be of much higher contrast, broader, longer and in totally different orientations"
- Radially enhanced image processing was used
- Earlier theories had been that it is possible to observe detailed coma features only in the continuum reflected by dust particles
4*P Coma Morphology Campaign

- 4*P Coma Morphology Pro-am program
  - Comet ISON (C/2012 S1) in 2012
  - 41P/Tuttle-Giacobini-Kresak (41P/TGK) in 2017
  - 45P/Honda-Mrkos-Pajdusakova (45P/HMP) in 2017
  - 46P/Wirtanen in 2018
  - https://www.psi.edu/41P45P46P

Organizers

- The Planetary Science Institute
  - Private, nonprofit 501(c)(3) corporation
  - Dedicated to Solar System exploration
  - Headquartered in Tucson, Arizona
  - https://www.psi.edu/

- University of Maryland, Lowell Observatory
  - The Comet Wirtanen Observing Campaign
  - http://wirtanen.astro.umd.edu/

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CN Cyanogen radical emission wavelength 387nm filters – Semrock FF01-387/11-27

- Semrock FF01-387/11-27, 27mm diameter filter, mounted to normal 1,25” filter ring (from ”junk box”)
- Semrock filter originally made for laser fluorescence microscopy, antireflective coatings insufficient to astrophotography
- Substrate thickness 2,0 mm ➔ Need its own focus point

Semrock filter transmission spectrum

Red leak possible if CCD has sensitivity at >1000nm. Note atmospheric H₂O absorption also.

Semrock filter scanned by Maryland University
Black line=transmission, Blue=CN emission

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## CCD Camera

### QSI690 specs and spectral sensitivity

<table>
<thead>
<tr>
<th>Feature</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD Manufacturer &amp; Model</td>
<td>Sony ICX814</td>
</tr>
<tr>
<td>CCD Architecture</td>
<td>Interline Transfer</td>
</tr>
<tr>
<td>Microlens</td>
<td>Yes</td>
</tr>
<tr>
<td>Anti-blooming</td>
<td>Yes - 800x suppression</td>
</tr>
<tr>
<td>Imager Size: (WxH)</td>
<td>12.48mm x 9.98mm</td>
</tr>
<tr>
<td>Pixel Array (WxH):</td>
<td>3388 x 2712 active (9.19 Mpx)</td>
</tr>
<tr>
<td>Pixel Size:</td>
<td>3.69µm x 3.69µm</td>
</tr>
</tbody>
</table>

### Typical Values

- **Pixel Full Well Depth**: 18,000 e-
- **Absolute Quantum Efficiency**: Peak: 77% at 560nm
- **Pixel Dark Current**: <0.002 electrons/second at -10°C
- **Intrinsic Read Noise**: 3.1 electrons RMS
- **Dynamic Range**: 75db

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![Spectral Response Graph](image)
Telescope and mount used

Telescope
• TS Boren-Simon 12" f/2.8 PowerNewton Astrograph
  • 305mm/1200mm Newton
  • TS2Korrr 2" Newtonian Coma Corrector and 0.73x Reducer
  • Focal length measured 906mm / f2.9

Mount
• iOptron CEM60

Backyard "observatory"
• Located in Finland, Helsinki
• Heavy light pollution
Approximating imaging systems 387nm “photon budget” relative sensitivity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Component</th>
<th>Unit</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture area</td>
<td>12” Boren-Simon</td>
<td>707 cm²</td>
<td>1.00</td>
</tr>
<tr>
<td>F ratio</td>
<td>F4 + TS2Korrr 0.75=&gt;2.9</td>
<td>2.9</td>
<td>1.00</td>
</tr>
<tr>
<td>CN Filter transmission</td>
<td>Semrock FF01-387/11</td>
<td>94%</td>
<td>0.94</td>
</tr>
<tr>
<td>CCD Absolute QE at 387nm</td>
<td>QSI690 / Sony ICX814</td>
<td>60%</td>
<td>0.60</td>
</tr>
<tr>
<td>CCD pixel size area</td>
<td>ICX814, 3.69µm bin2</td>
<td>54µm²</td>
<td>1.0</td>
</tr>
<tr>
<td>Airmass</td>
<td>Zenit</td>
<td>1.0 = (1/Airmass)</td>
<td>1.0</td>
</tr>
<tr>
<td>Comet CN rate ratio</td>
<td>46P/Wirtanen 18.12.2018 (21P/G-Z 15.9.2018)</td>
<td>Q(CN)= 1.17E+25 MOL/s (Q(CN)= 3.8E+25 MOL/s)</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Relative sensitivity ratio ”Ryske-index”</strong></td>
<td>0.56</td>
</tr>
</tbody>
</table>
Example of flat challenges:
• Too few 387nm photons, too much visible light photons
  ➞ CCD chamber edges reflect visible light photons in flat

• Some plastic diffusers absorb practically all UV
• My current flat box uses 5m of ”UV/Pink” led stripe and baking papers (!) as diffuser
• Dark & Bias calibration images as normal
Autoguiding comet using PHD

- PHD used in “Comet tracking mode”
  - Comet tracking parameters from Carte du Ciel
  - RA and Dec rates converted from Arcsec/hr to Pixels/hr, which parameters can be calculated from autoguider ccd/cmos pixel size and telescope focal length
- 1 pixel accuracy needed for comet’s optocenter max movement within single exposure to achieve quality image
Image processing

PixInSight

1. Calibration, as normally (Bias, Dark, Flat)
2. Registering, as normally using comet registering
3. Integration, as normally from comet registered images
   • Coma morphology and CN jets can be quite fast moving and rotating, so typically integration should be between 30min to 60 min stacks to avoid coma morphology detail’s smearing
4. Crop square images of those integrated images of which will be CometCIEF processed
   • Typically 1000x1000px cropped images, or about 20 arcminutes square depending of coma size
   • Comet optocenter exactly centerized
     • PI – Process - Geometry - DynamicCrop
   • Save in fits format to be uploaded to CometCIEF facility
     • No need for histogram transformation
CometCIEF processing

  - https://www.psi.edu/research/cometimen

1. Division by Azimuthal Median
2. Image file in fits format where comet optocenter exactly centered
3. Center pixel of exact optocenter/image
4. Submit, processing takes few seconds
5. Download enhanced image
Comparison and test of Semrock FF01-387/11-27 and HB CN filter

- 21P/Giacobini-Zinner images 21. and 31.8.2018
- Filter comparison by University of Maryland & Lowell Observatory, Matthew Knight

2018-08-21

Ryske 12” Boren-Simon ➔ Newton F2.9 ➔
Semrock 387nm
Astrodon R

Lowell Observatory
➡ 42” RC John S. Hall Telescope
31” Telescope ➔
HB CN
HB RC

2018-08-31
Comet observations @387nm

21P/Giacobini-Zinner – 21.8.2018
https://www.taivaanvahti.fi/observations/show/77114

21P/Giacobini-Zinner - 3.9.2018
https://www.taivaanvahti.fi/observations/show/77387

21P/Giacobini-Zinner - 16.9.2018
https://www.taivaanvahti.fi/observations/show/77676

64P/Swift-Gehrels - 14.10.2018
https://www.taivaanvahti.fi/observations/show/78693

46P/Wirtanen - 26.12.2018
https://www.taivaanvahti.fi/observations/show/79906

46P/Wirtanen - 11.1.2019, CN gas jet rotation animation
https://www.taivaanvahti.fi/observations/show/80336
http://spaceweathergallery.com/indiv_upload.php?upload_id=150891

46P/Wirtanen, animation, CN Cyanogen radical gas jets rotating and forming a pinwheel shape around comets nucleus. Observing time 11 hours at night 11/12.1.2019.
Thank you

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