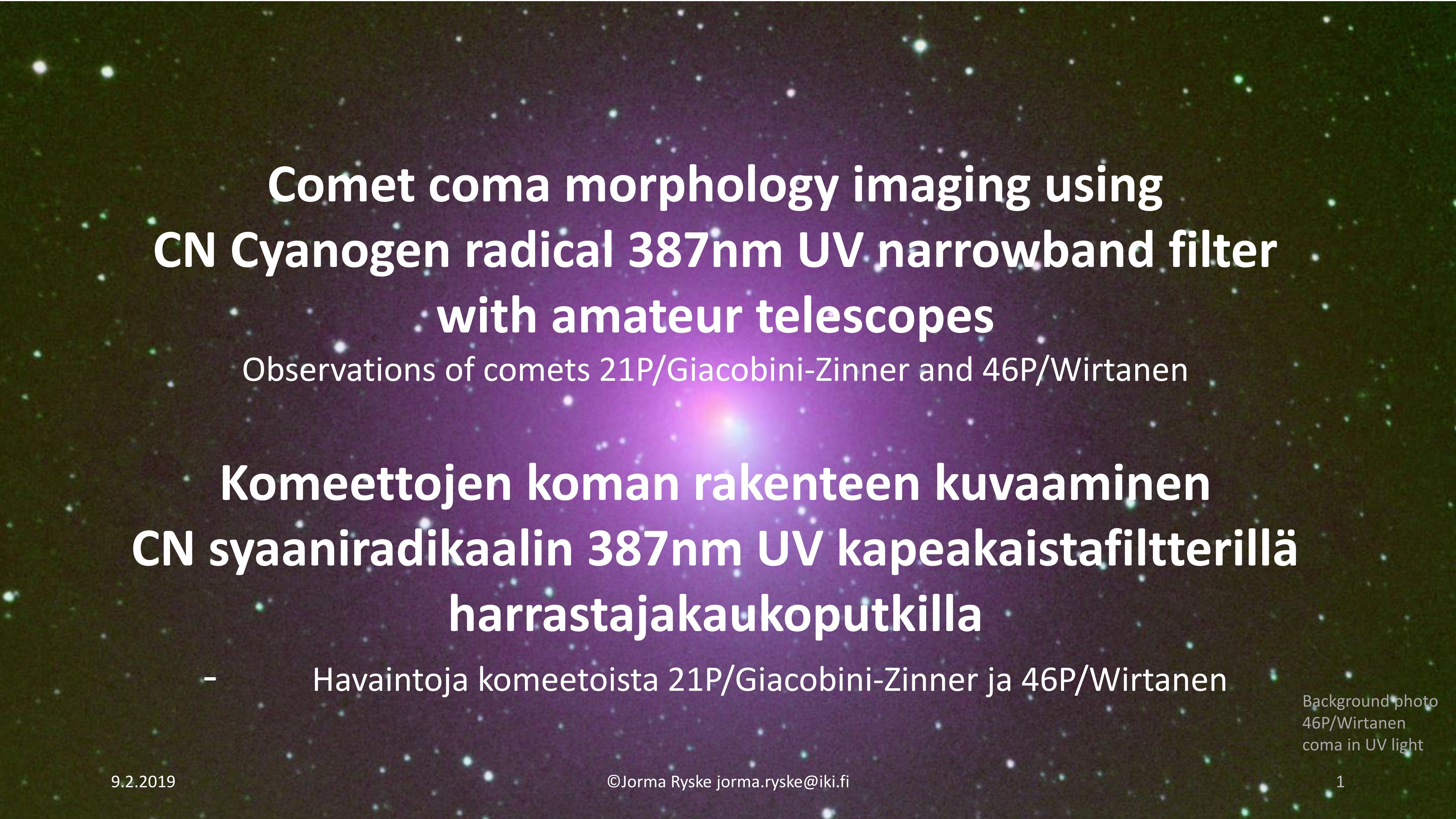


Comet coma morphology imaging using CN Cyanogen radical 387nm UV narrowband filter with amateur telescopes

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

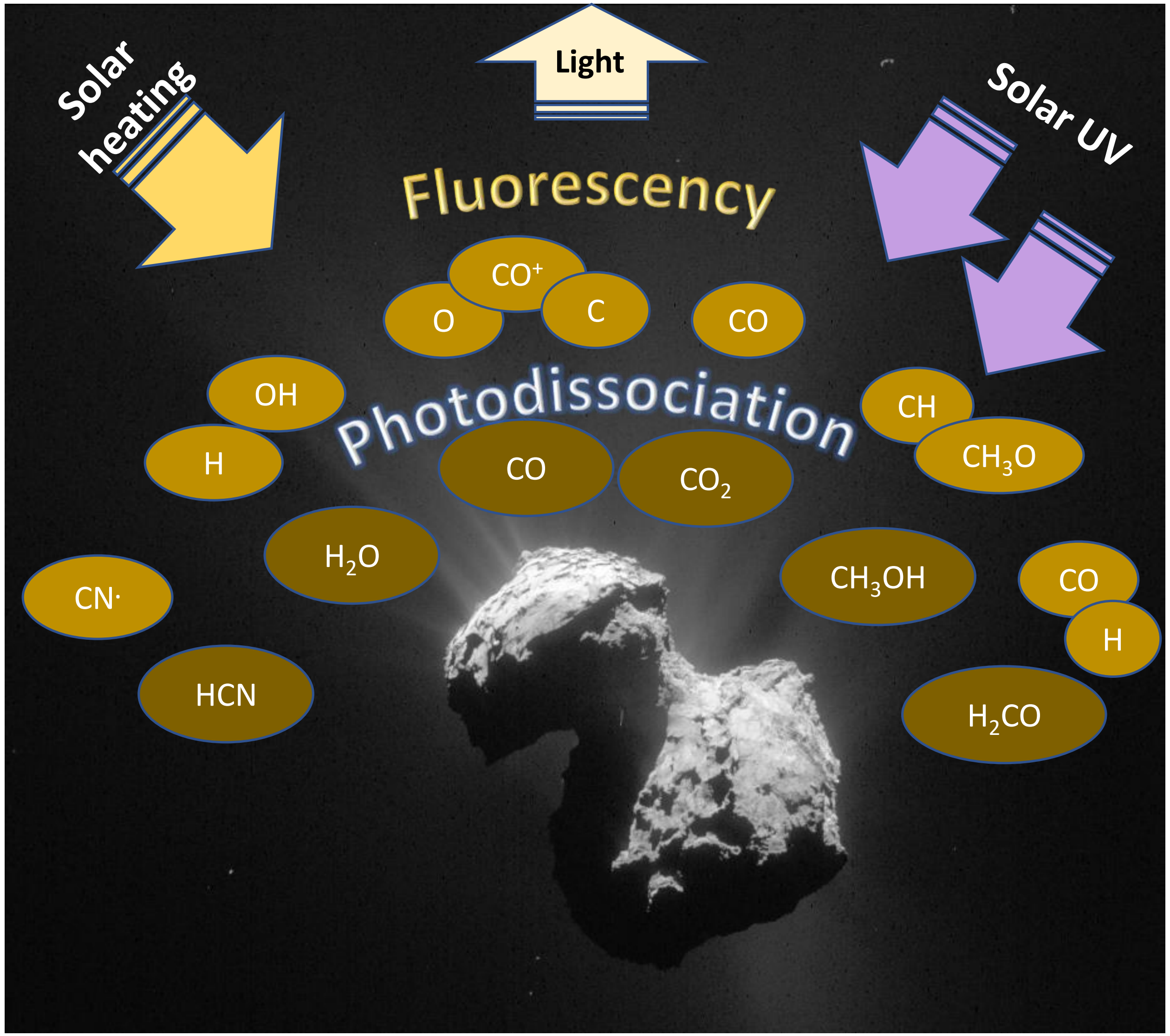
Background photo
46P/Wirtanen
coma in UV light

©Jorma Ryske jorma.ryske@iki.fi

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**
   → Fluorescensy of radicals
   → Continuous light emitting



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 (Δv=0), CN, 386.9/6nm**
- C_3 , C3, 406.3/6nm
- **CO^+(2-0), CO+, 426.6/6nm**
- Blue continuum, BC, 445.3/6nm
- **C_2 (Δv=0), C2, 513.5/11nm**
- Green continuum, GC, 525.9/5nm
- H_2O^+ (0,6,0), H2O+, 702.8/17nm
- Red continuum, RC, 713.3/6nm

Commercial narrowband filters:

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

C2 , 513nm

CN, 387nm

CO+, 427nm

N. Biver: Cometary spectroscopy 179

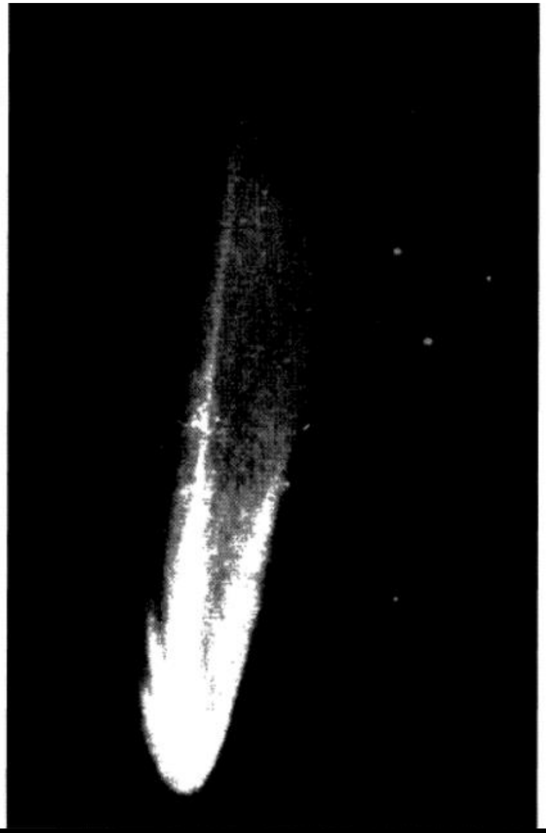
Table 2. Main visible lines of comets.

Molecule	Transition (electronic - vibration band)	wavelength (width)[a]	L/N at 1 AU 10^{-20} W	mean relative intensity
C_2	$d^3\Pi_g - a^3\Pi_u\ \Delta v = +1$	473.7 nm (−20 nm)	2.40	0.54
C_2	$d^3\Pi_g - a^3\Pi_u\ \Delta v = 0$	516.5 nm (−30 nm)	4.50	1
C_2	$d^3\Pi_g - a^3\Pi_u\ \Delta v = -1$	563.6 nm (−30 nm)	2.1	0.47
C_2	$d^3\Pi_g - a^3\Pi_u\ \Delta v = -2$	619.1 nm (−30 nm)	0.7	0.15
C_2	$A^1\Pi_u - X^1\Sigma_g^+\ \Delta v = +1$	1010.0 nm	0.13	0.03
C_2	$A^1\Pi_u - X^1\Sigma_g^+\ \Delta v = 0$	1210.0 nm	0.05	0.01
C_3	$A^1\Pi_u - X^1\Sigma_g^+\ v = 000 - 000$	405.2 nm (35 nm)	10.0	0.4
CN	$B^2\Sigma^+ - X^2\Sigma^+\ v = 1 - 0$	359.0 nm (−4 nm)		
CN	$B^2\Sigma^+ - X^2\Sigma^+\ \Delta v = 0$	388.3 nm (−4 nm)	2.5–4.5[b]	1
CN	$B^2\Sigma^+ - X^2\Sigma^+\ v = 0 - 1$	421.5 nm (−4 nm)	≈0.2	0.07
CN	$A^2\Pi_i - X^2\Sigma^+\ v = 1 - 0$	914.1 nm (+15 nm)	≈0.7	0.20
CN	$A^2\Pi_i - X^2\Sigma^+\ v = 0 - 0$	1093.0 nm (+15 nm)	≈0.9	0.26
CH	$A^2\Delta - X^2\Pi_r\ v = 0 - 0$	430.5 nm (9 nm)	0.92	
NH	$A^3\Pi_i - X^3\Sigma^-\ \Delta v = 0$	336 nm (10 nm)	0.4–0.9	0.05
OH	$A^2\Sigma^+ - X^2\Pi\ v = 1 - 0$	282.6 nm	$0.8–2.7 \times 10^{-3}$	0.04
OH	$A^2\Sigma^+ - X^2\Pi\ v = 0 - 0$	306.4 nm (+5nm)	$15–83 \times 10^{-3}$	1
OH	$A^2\Sigma^+ - X^2\Pi\ v = 1 - 1$	312.2 nm (+6 nm)	$1.2–4.2 \times 10^{-3}$	0.07
OH	$A^2\Sigma^+ - X^2\Pi\ v = 0 - 1$	346.8 nm	$0.05–0.3 \times 10^{-3}$	0.01
NH_2	$A^2A_1 - X^2B_1$ (0,12,0)–(0,0,0)	515 nm	0.551	
NH_2	$A^2A_1 - X^2B_1$ (0,11,0)–(0,0,0)	545 nm	0.279	
NH_2	$A^2A_1 - X^2B_1$ (0,10,0)–(0,0,0)	570 nm	0.299	
NH_2	$A^2A_1 - X^2B_1$ (0, 9,0)–(0,0,0)	600 nm	0.313	
NH_2	$A^2A_1 - X^2B_1$ (0, 8,0)–(0,0,0)	630 nm	0.534	
NH_2	$A^2A_1 - X^2B_1$ (0, 7,0)–(0,0,0)	665 nm	0.175	
NH_2	$A^2A_1 - X^2B_1$ (0, 6,0)–(0,0,0)	695 nm		
NH_2	$A^2A_1 - X^2B_1$ (0, 5,0)–(0,0,0)	735 nm		
Some ion lines, observed far from the nucleus:				
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 4 - 0$	379 nm (2 nm)		0.8
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 3 - 0$	401 nm (2 nm)		0.9
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 2 - 0$	426 nm (2 nm)		1.0
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 1 - 0$	455 nm (3 nm)		0.7
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 2 - 1$	470 nm (3 nm)		0.6
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 1 - 1$	504 nm (4 nm)		0.2
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 0 - 1$	549 nm (5 nm)		0.5
CO+	$A^2\Pi_i - X^2\Sigma^+\ v = 0 - 2$	622 nm (6 nm)		0.5
H_2O+	$A^2A_1 - X^2B_1\ v = 0,8,0 - 0,0,0$	616 nm		
H_2O+	$A^2A_1 - X^2B_1\ v = 0,3,0 - 0,0,0$	620 nm		
H_2O+	$A^2A_1 - X^2B_1\ v = 0,2,0 - 0,0,0$	670 nm		
OH+	$A^3\Pi_i - X^3\Sigma^-\ v = 1 - 0$	336 nm (−4 nm)		
OH+	$A^3\Pi_i - X^3\Sigma^-\ v = 0 - 0$	362 nm (−5 nm)		
OH+	$A^3\Pi_i - X^3\Sigma^-\ v = 0 - 1$	403 nm (−4 nm)		

[a] A "−" (resp. "+") sign means that the band extends to shorter (resp. longer) wavelengths from the band head given here;

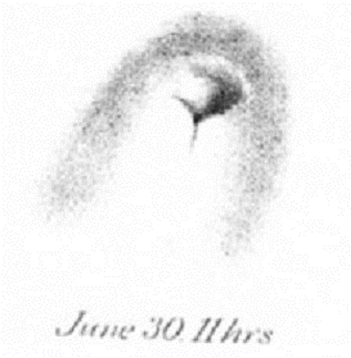
- $H_2O \to$ OH, H;
- HCN $\to$ CN;
- C_2H_2, $C_2H_6 \to C_2$;
- $NH_3 \to NH_2$, NH.

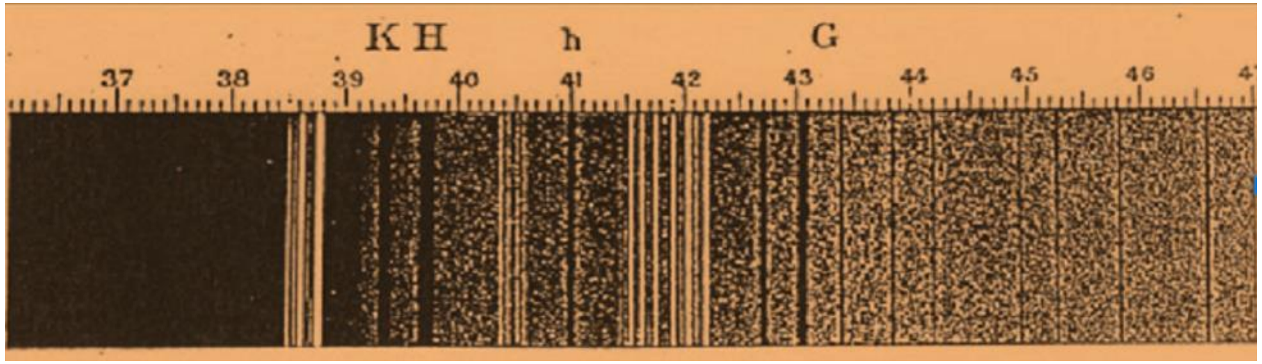
Brief history of CN Jet finding and observing



Janssen's photograph of
Comet C/1881 K1
on 30th June 1881

- 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.
- ”The fluorescense spectrum of the CN radical in comets” J.M.Zucconi, M.C.Festou Astron Astrophys. 150, 180-191 **(1985)** http://adsabs.harvard.edu/full/1985A%26A...150..180Z
  - 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

Nature Vol. 324 1986 ”Cyanogen jets in comet Halley”

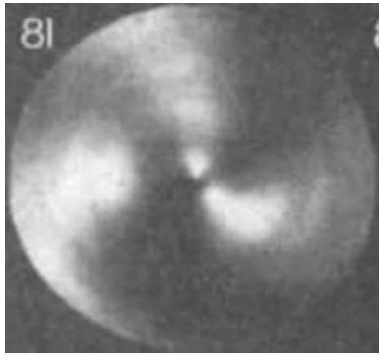
- https://www.nature.com/articles/324649a0
  - Michael F. A’Hearn, Susan Hoban, Peter V. Birch, Craig Bowers, Ralph Martin, Daniel A Klinglesmith III
  - University of Maryland, Perth Observatory, NASA-Goddard Space Flight Center
- Research team used Perth Observatory 24” Planetary Patrol Telescope, 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

Cyanogen jets in comet Halley

Michael F. A’Hearn*, Susan Hoban*,
Peter V. Birch†, Craig Bowers†,
Ralph Martin† & Daniel A. Klinglesmith III‡

* Astronomy Program, University of Maryland, College Park, Maryland 20742, USA
† Perth Observatory, Bickley, Western Australia 6076, Australia
‡ NASA-Goddard Space Flight Center, Greenbelt, Maryland 20771, USA

Current theory holds that jets, spirals and other detailed features in cometary comae are visible only in the continuum reflected by the dust particles. It has generally been thought that these features could not be seen in the emission bands of the typical neutral species, at least in part because the neutral parent molecules expand in directions perpendicular to any linear feature in a time short compared with that required to travel the length of the features. Consequently, the daughter species normally observable at optical and ultraviolet wavelengths are produced by dissociations that take place far from the point of origin of the gas. Here we present images of comet Halley taken in the light of CN emission,



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

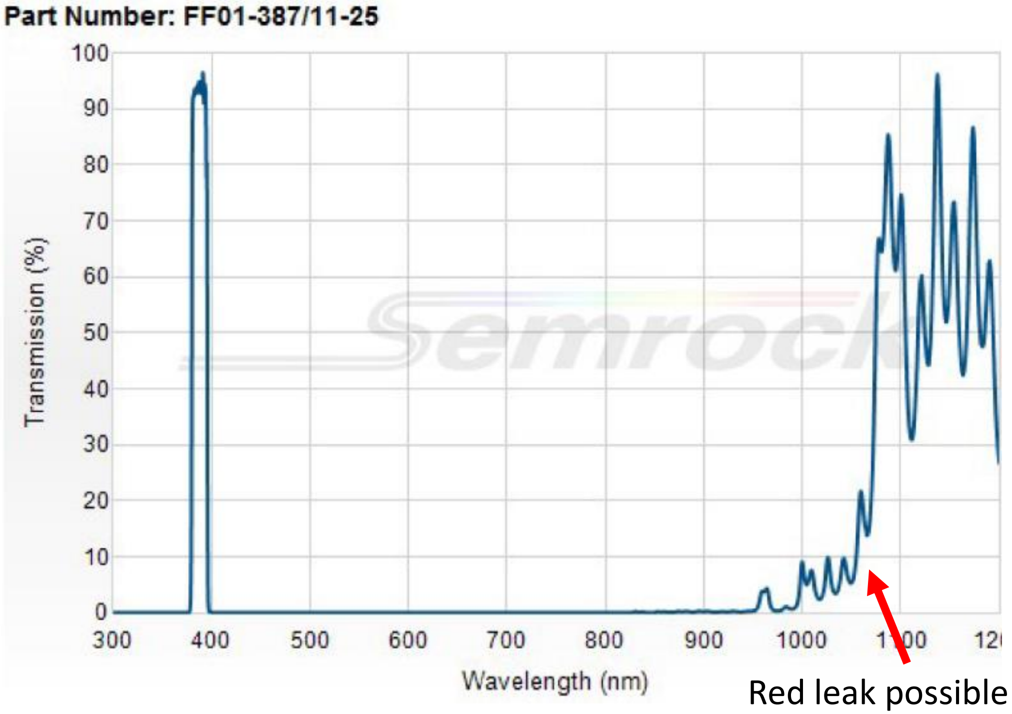
Organizers

- **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/

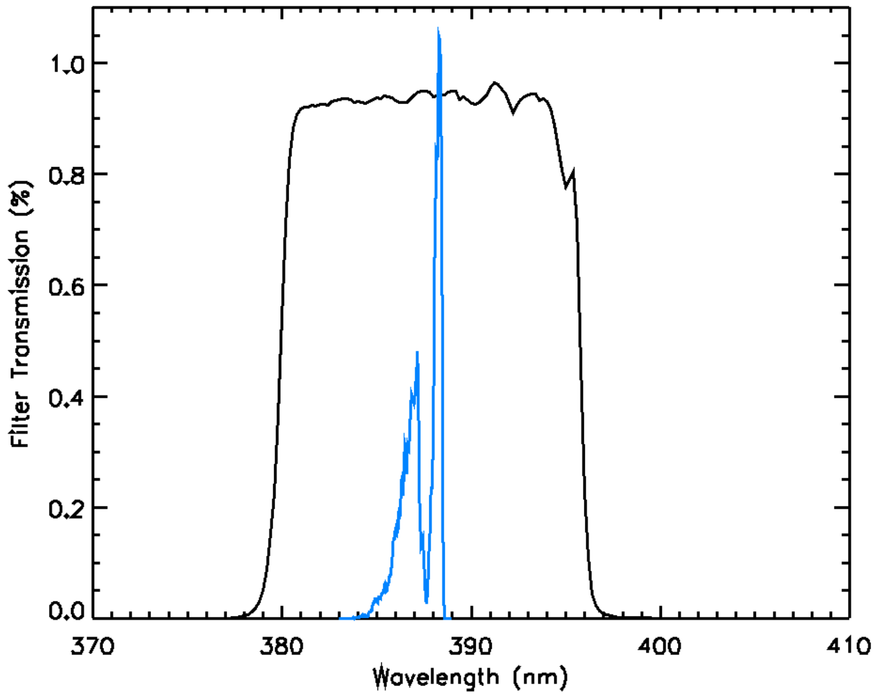
CN Cyanogen radical emission wavelength 387nm filters – Semrock FF01-387/11-27

- Semrock FF01-387/11-27, 27mm diameter filter, mounted to normal 1,25” filter ring (from ”junk box”)
- Semrock filter originally made for laser fluorescense 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 H_2O absorption also.

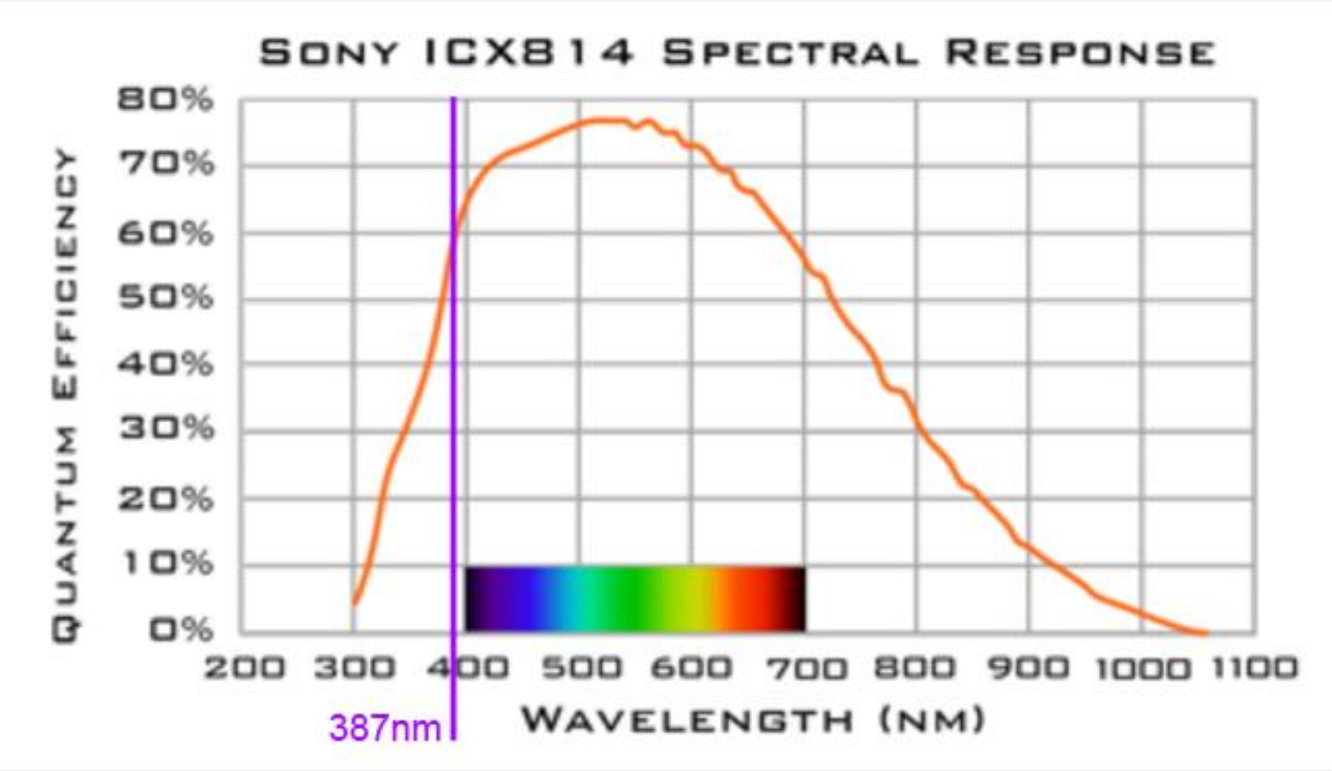


Semrock filter scanned by Maryland University

Black line=transmission, Blue=CN emission

CCD Camera
QSI690 specs and spectral sensitivity

Feature	Standard
CCD Manufacturer & Model	Sony ICX814
CCD Architecture	Interline Transfer
Microlens	Yes
Anti-blooming	Yes - 800x suppression
Imager Size: (WxH)	12.48mm x 9.98mm
Pixel Array (WxH):	3388 x 2712 active (9.19 Mpx)
Pixel Size:	3.69µm x 3.69µm
	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



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

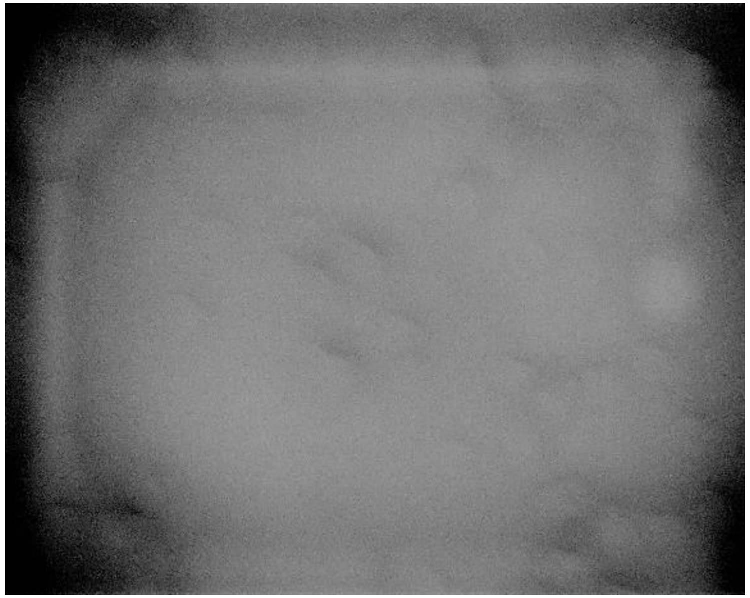
Backyard ”observatory”

- Located in Finland, Helsinki
- Heavy light pollution

Approximating imaging systems 387nm “photon budget” relative sensitivity

Parameter	Component	Unit	Ratio
Aperture area	12” Boren-Simon	707 cm^2	1.00
F ratio	F4 + TS2Korrr 0.75=>2.9	2.9	1.00
CN Filter transmission	Semrock FF01-387/11	94%	0.94
CCD Absolute QE at 387nm	QSI690 / Sony ICX814	60%	0.60
CCD pixel size area	ICX814, 3.69µm bin2	54μm^2	1.0
Airmass	Zenit	1.0 = (1/Airmass)	1.0
Comet CN rate ratio	46P/Wirtanen 18.12.2018 (21P/G-Z 15.9.2018)	Q(CN)= 1.17E+25 MOL/s (Q(CN)= 3.8E+25 MOL/s)	1.0
		Relative sensitivity ratio ”*Ryske-index*”	**0.56**

UV flat, calibration images



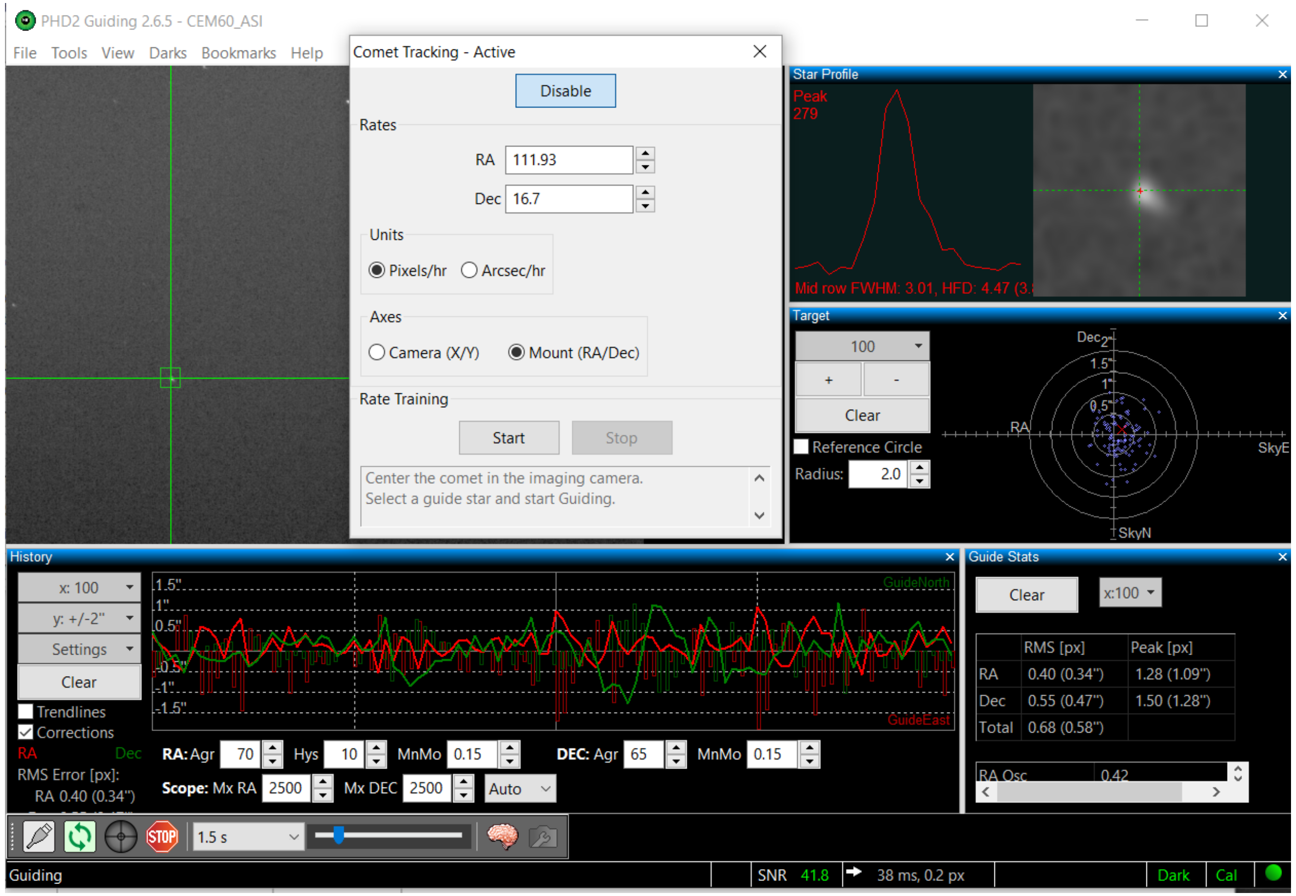
Example of flat challenges:

- 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

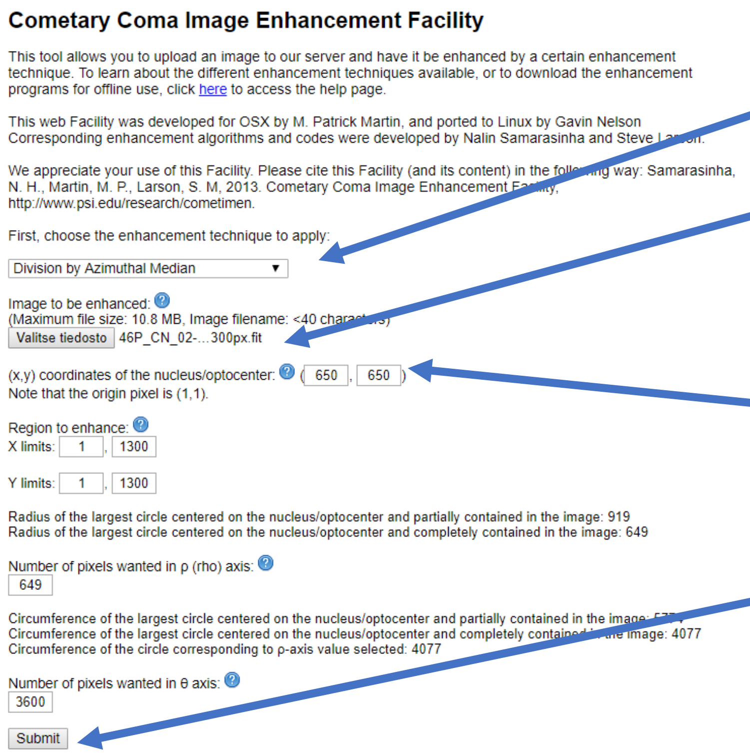
Image processing

PixInSight

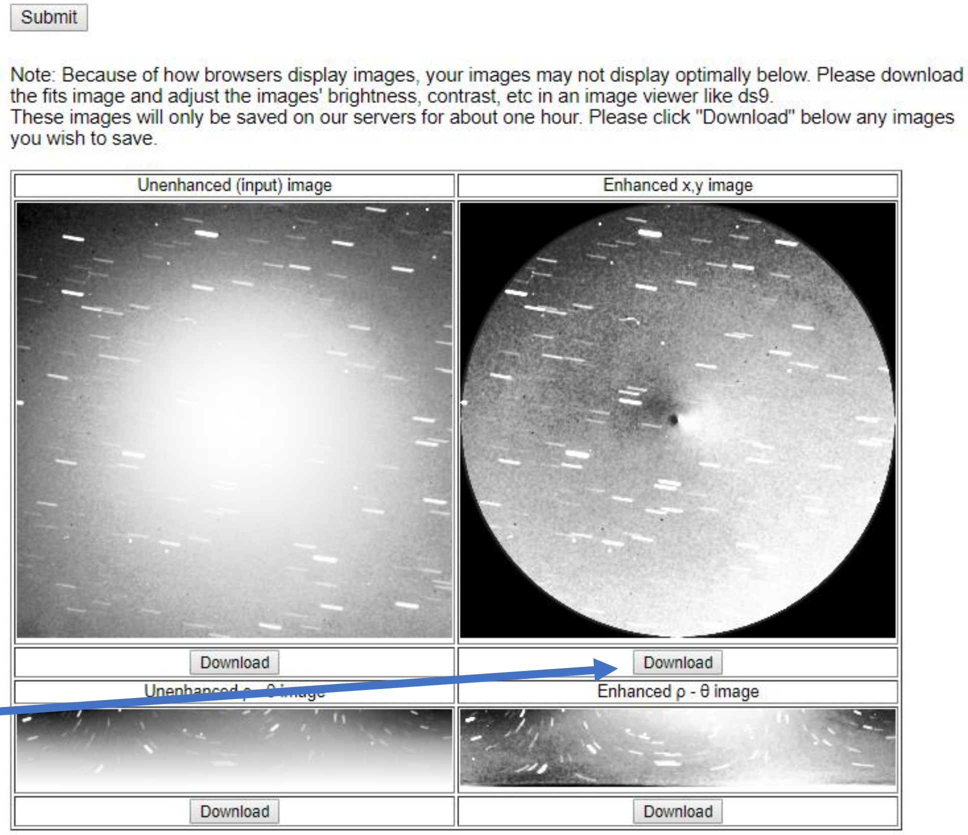
1. Calibration, as normally (Bias, Dark, Flat)
2. Registering, as normally using comet registering
3. Integration, as normally from comet registered images
   - Coma morphology and CN jets can be quite fast moving and rotating, so typically integration should be between 30min to 60 min stacks to avoid 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

- Samarasinha, N. H., Martin, M. P., Larson, S. M, 2013. Cometary Coma Image Enhancement Facility
  - https://www.psi.edu/research/cometimen



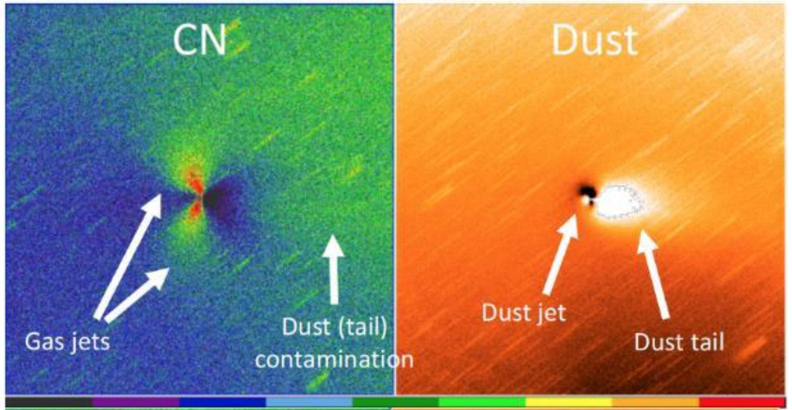
1. Division by Azimuthal Median
2. Image file in fits format where comet optocenter exactly centered
3. Center pixel of exact optocenter/image
4. Submit, processing takes few seconds
5. Download enhanced image

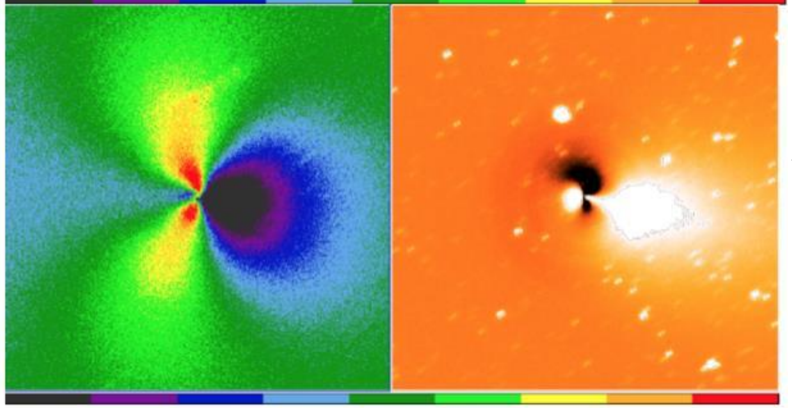


Comparison and test of Semrock FF01-387/11-27 and HB CN filter

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

2018-08-21

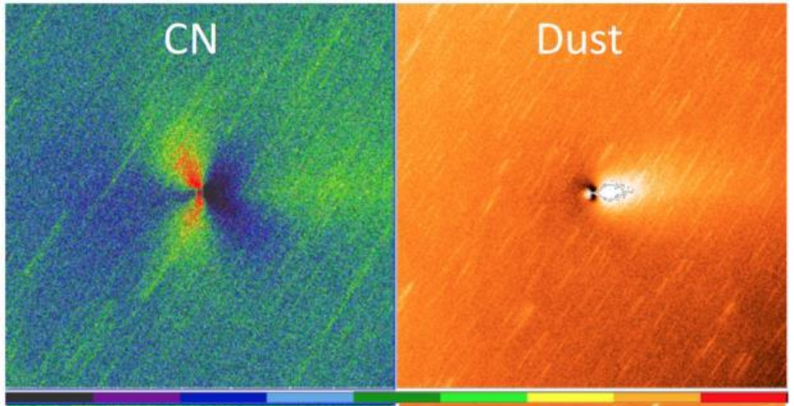


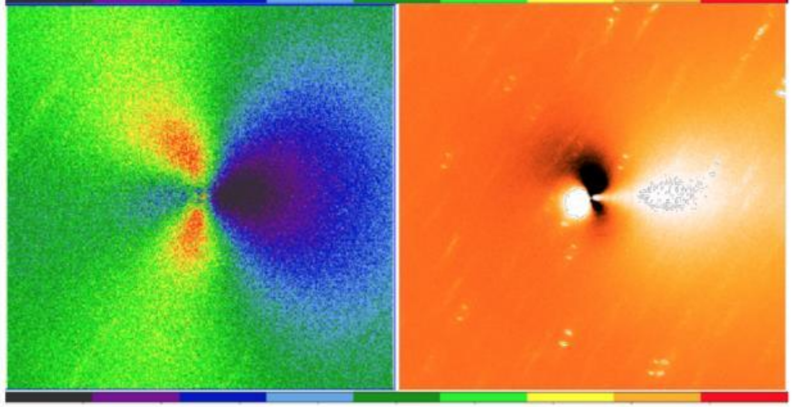


Ryske 12” Boren-Simon
← Newton F2.9 →
Semrock 387nm
Astrodon R

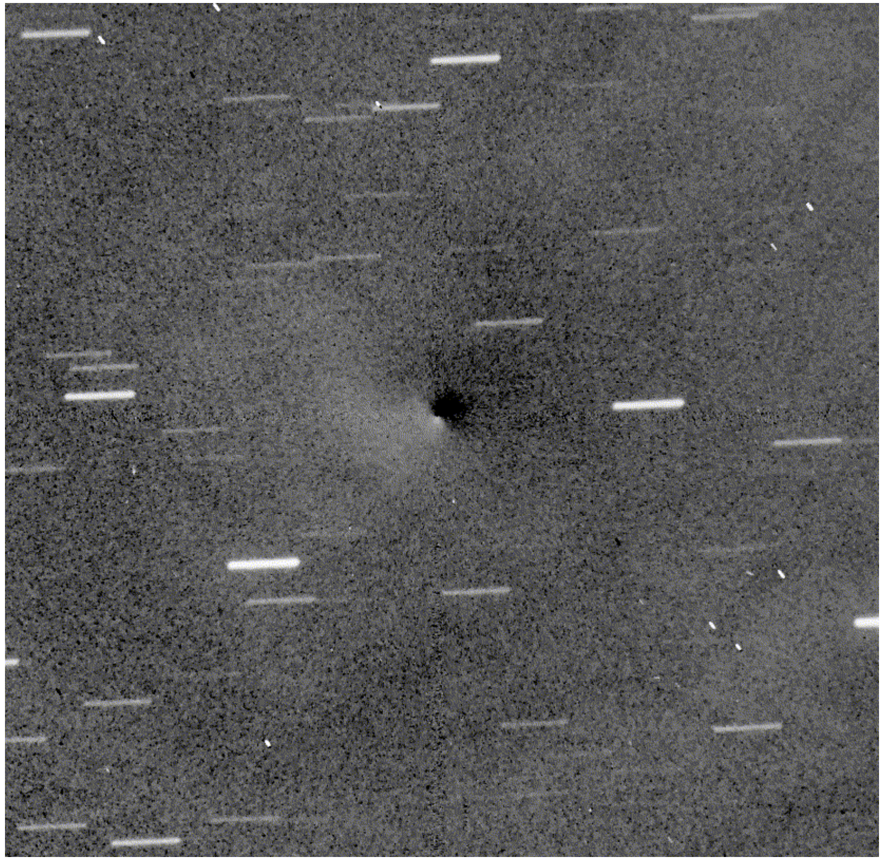
Lowell Observatory
←42” RC John S. Hall Telescope
31” Telescope →
HB CN
HB RC

2018-08-31





Comet observations @387nm



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.

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

Thank you

Jorma Ryske
jorma.ryske@iki.fi

Background photo
21P/Giacobini-Zinner
3.9.2018