SLA1 Camera Characterization

PSF Candidates in 30s Darks

On May 8, 2024 (UTC) we took various dark exposures with the QHY42 Pro camera.

As they are read in, the darks are scaled to undo zero padding (divided by 16) and the effect of gain (multiplied by 1.39).

They are then combined into a master dark. The master dark is subtracted from the individual darks.

Then we find pixels that (a) exceed a threshold of 200 e- and (b) are brighter than their four nearest neighbors. These are the "hot pixel leaders."

Then we cull the hot pixel leaders whose neighbors fall off too sharply using the following quick criterion for non-PSF-shaped regions: any hot pixel leader that has a neighbor <20% of the peak is not a PSF candidate.

Finally, the region around these candidates is displayed.

Notes

The pixels are 1.5x1.5 arcsec. In seeing of FWHM=3 arcsec, the PSF will have a FWHM=2 pixels.

A better criterion to consider implementing later:

Compute the probability that the 5x5 pixels (with >200 e-) could have been drawn from the PSF shape plus Poisson noise. Essentially chi-squared. Normalize perhaps by the peak value set to 1.0, or normalized by total area.

In [1]:
```
# THIS COMMENT IS THE LONGEST A LINE CAN BE AND STILL RENDER COMPLETELY WHEN

import os, sys
import numpy as np
from astropy import units as u
from astropy.nddata import CCDData
from astropy.io import fits
from ccdproc import ImageFileCollection, combine, subtract_dark, flat_correc
import astroalign as aa
```

```
import matplotlib.pyplot as plt
%matplotlib inline
from math import log10, floor

home_directory = os.path.expanduser('~')

# soft link to directory containing raw images
sessions_directory = os.path.join(home_directory, '2024 SLA Sessions')

uv_project_directory = os.path.join(home_directory, 'Projects', 'uv-transien
analysis_directory = os.path.join(uv_project_directory, 'analyses', '30s_dar

# The path to the first dark on SLA1 is D:/Raw/2024-05-08/03_38_48/Dark30s/0
# The files to be processed need to be mirrored on the local machine
# at ~/2024 SLA Sessions/ using the same subdirectory structure.
capture_date = '2024-05-08'
capture_time = '03_38_48'
object_name = 'Dark30s'

# Amount to scale the image data (typically to undo 0 padding of 12-bit to 1

scale_due_to_padding = 2**4  # This is division by 16

scale_due_to_gain = 1.39  # from QHYCCD manual for gain of 5

scale = scale_due_to_gain / scale_due_to_padding

# threshold for flagging hot pixels

threshold = 200

# discontinuity limit

ratio = 0.2

# subdirectory for the 30-second darks (following SharpCap Pro capture direc
dark_directory = os.path.join(
    sessions_directory,
    capture_date,
    capture_time,
    object_name
)

# exposure duration

dark_exposure = 30.0
dark_exposure_with_ccdproc_units = dark_exposure * u.second

# FITS header confirmation

def confirm_fits_header(image, dimensions, exposure_time, filter):
    header = image.header
    assert header['NAXIS1'] == dimensions[0]
```

```
    assert header['NAXIS2'] == dimensions[1]
    assert header['EXPTIME'] == exposure_time
    if filter:
        assert header['FILTER'].rstrip() == filter

# Reader with optional parameter to scale (divide) the ADU readings

def scaled_image_reader(file, scale=1):
    img = CCDData.read(file, unit=u.adu)
    scaled_data = img.data * scale
    img.data = scaled_data
    return img

# After all the preliminaries, we read in and combine the dark files

dark_files = ImageFileCollection(dark_directory).files_filtered(include_path

darks = [scaled_image_reader(file, scale=scale) for file in dark_files]

for dark in darks:
    confirm_fits_header(dark, (2048, 2048), dark_exposure, None)

combination_method = 'median'  # alternatively, the method can be 'average'

master_dark = combine(darks, method=combination_method)
```

```
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.151953 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.151953 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.152301 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.152301 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.152648 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.152648 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.152995 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.152995 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.153342 from DATE-END'. [astropy.wcs.wcs]
```

```
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.153342 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.153689 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.153689 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.154037 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.154037 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.154384 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.154384 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.154731 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.154731 from DATE-END'.
WARNING: FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -678575.
000000 from DATE-OBS.
Set MJD-END to 60438.155078 from DATE-END'. [astropy.wcs.wcs]
WARNING:astropy:FITSFixedWarning: 'datfix' made the change 'Set MJD-OBS to -
678575.000000 from DATE-OBS.
Set MJD-END to 60438.155078 from DATE-END'.
```

Subtract Master Dark from Darks

In [2]:
```
subtracted_darks = [
    subtract_dark(
        dark,
        master_dark,
        data_exposure=dark_exposure_with_ccdproc_units,
        dark_exposure=dark_exposure_with_ccdproc_units,
        scale=False
    )
    for dark in darks
]
```

Routines for Locating Hot Pixel Leaders

As a first cut, we will search for all pixels that exceed some threshold. These are the "hot pixels."

Then each hot pixel is examined to see if it is the brightest relative to its eight nearest neighbors. If it is, it is added to the list of leaders. (A small bit of tie-breaking code is incorporated.)

In [3]:
```
from collections import namedtuple

Pixel = namedtuple('Pixel', 'x y value')
PSFCandidate = namedtuple('PSFCandidate', 'center neighbors')

def is_winner_or_tied(candidate_leader, i, j, data):
    return candidate_leader.value >= data[j, i]

def is_leader(candidate_leader, data):
    data_height, data_width = data.shape
    for offset_y, offset_x in [(-1, 0), (0, 1), (1, 0), (0, -1)]:
        j = floor(candidate_leader.y + offset_y)
        i = floor(candidate_leader.x + offset_x)
        if j < 0 or j >= data_height or i < 0 or i >= data_width:
            continue
        if not is_winner_or_tied(candidate_leader, i, j, data):
            return False
    return True

def find_hot_pixel_leaders(data, threshold):
    # first we simply find all the hot pixels
    data_height, data_width = data.shape
    exceedances = data > threshold  # an array of true-false values
    values_of_exceedances = data[exceedances]
    exceedance_indices = np.nonzero(exceedances)  # a crafty way of getting
    # all of the hot pixels are candidate leaders
    candidate_leaders = np.transpose([exceedance_indices[1], exceedance_indi
    leaders = []
    for i in range(candidate_leaders.shape[0]):
        row = candidate_leaders[i]
        candidate_leader = Pixel(row[0], row[1], row[2])
        if is_leader(candidate_leader, data):
            leaders.append(candidate_leader)
    return leaders
```

Find the Hot Pixel Leaders

Now we classify all the pixels whose values exceed the threshold as hot pixels. From among these, only the ones which are brighter than their four nearest neighbors are declared to be “leaders.”

In [4]:
```
# there will be a list of leaders for each dark

hot_pixel_leaders_for_darks = [
    find_hot_pixel_leaders(subtracted_dark.data, threshold) for subtracted_d
]
```

Routines for Finding PSF Candidates

In [5]:
```
def is_too_discontinuous(candidate_psf, i, j, data, ratio):
    return data[j, i] < ratio * candidate_psf.value

def is_candidate_psf(candidate_psf, data, ratio):
    data_height, data_width = data.shape
    for offset_y, offset_x in [(-1, 0), (0, 1), (1, 0), (0, -1)]:
        j = floor(candidate_psf.y + offset_y)
        i = floor(candidate_psf.x + offset_x)
        if j < 0 or j >= data_height or i < 0 or i >= data_width:
            continue
        if is_too_discontinuous(candidate_psf, i, j, data, ratio):
            return False
    return True

def find_psf_candidates(leaders, data, ratio):
    candidates = [leader for leader in leaders if is_candidate_psf(leader, d
    return candidates
```

Find the PSF Candidates

In [6]:
```
candidates_for_darks = [
    find_psf_candidates(hot_pixel_leaders, subtracted_darks[k].data, ratio)
    for k, hot_pixel_leaders in enumerate(hot_pixel_leaders_for_darks)
]
```

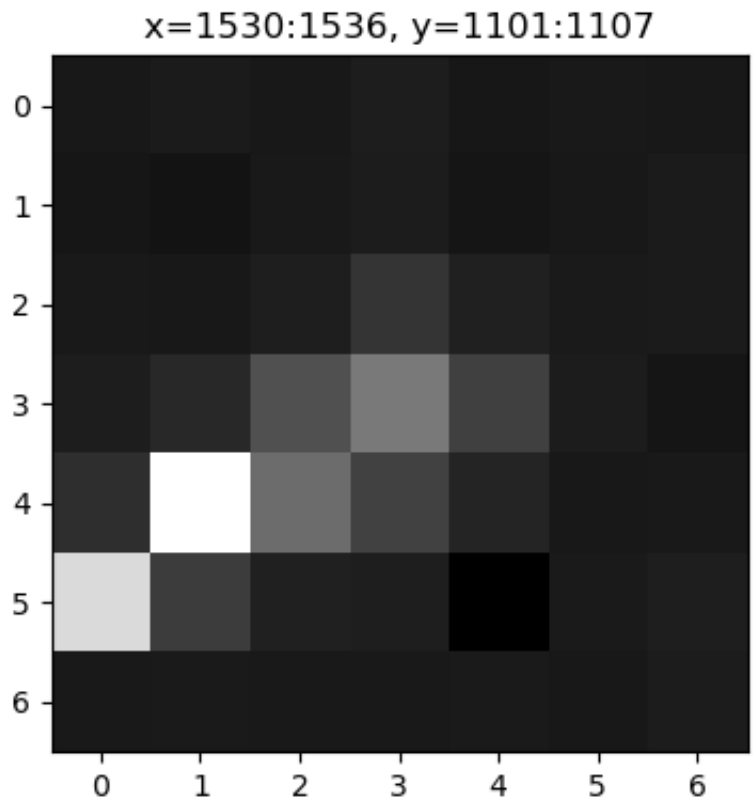
Display the Candidates

In [7]:
```
DISPLAY_HALF_RANGE = 3
DISPLAY_FULL_RANGE = 2 * DISPLAY_HALF_RANGE + 1
```

```
def display_candidate(candidate, data):

    data_height, data_width = data.shape

    lower_x = floor(candidate.x - DISPLAY_HALF_RANGE)
    upper_x = floor(lower_x + DISPLAY_FULL_RANGE)
    slice_x = slice(lower_x, upper_x)
    lower_y = floor(candidate.y - DISPLAY_HALF_RANGE)
    upper_y = floor(lower_y + DISPLAY_FULL_RANGE)
    slice_y = slice(lower_y, upper_y)

    fig_size_x = 4
    fig_size_y = 4

    # a bit of fussy code for dealing with display near the edges
    # check x edges
    if (lower_x < 0):
        lower_x = 0
        fig_size_x *= upper_x / DISPLAY_FULL_RANGE
    elif (upper_x > data_width):
        upper_x = data_width
        fig_size_x *= (data_width - lower_x) / DISPLAY_FULL_RANGE
    # check y edges
    if (lower_y < 0):
        lower_y = 0
        fig_size_y *= upper_y / DISPLAY_FULL_RANGE
    elif (upper_y > data_height):
        upper_y = data_height
        fig_size_y *= (data_height - lower_y) / DISPLAY_FULL_RANGE

    fig, axes = plt.subplots(1, 1, figsize=(fig_size_x, fig_size_y))

    print("{} is a PSF candidate with neighbor values:".format(candidate))

    for offset_y, offset_x in [(-1, 0), (0, 1), (1, 0), (0, -1)]:
        j = floor(candidate.y + offset_y)
        i = floor(candidate.x + offset_x)
        if j < 0 or j >= data_height or i < 0 or i >= data_width:
            continue
        print("    x={}, y={}, value={}".format(i, j, data[j][i]))

    title = "x={}:{}, y={}:{}".format(lower_x, upper_x - 1, lower_y, upper_y

    subframe = data[lower_y:upper_y, lower_x:upper_x]

    axes.imshow(subframe, cmap='gray')
    axes.set_title(title, fontsize=12)
    plt.tight_layout()
    plt.show()

for k in range(len(candidates_for_darks)):
    candidates = candidates_for_darks[k]
```

```
    subtracted_dark_data = subtracted_darks[k].data
    if len(candidates) > 0:
        print('Displaying candidates for dark {}'.format(dark_files[k]))
        for candidate in candidates:
            display_candidate(candidate, subtracted_dark_data)
    else:
        print('No candidates for dark {}'.format(dark_files[k]))
```

```
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00001.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00002.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00003.fits
Displaying candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_
38_48/Dark30s/00004.fits
Pixel(x=1533.0, y=1104.0, value=403.3606249999999) is a PSF candidate with n
eighbor values:
    x=1533, y=1103, value=114.11031250000008
    x=1534, y=1104, value=165.6271875
    x=1533, y=1105, value=172.01250000000005
    x=1532, y=1104, value=231.91281249999997
```



```
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00005.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00006.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00007.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00008.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00009.fits
No candidates for dark /Users/brian/2024 SLA Sessions/2024-05-08/03_38_48/Da
rk30s/00010.fits
```