Data Processing and Progress Update for  PANO SETI

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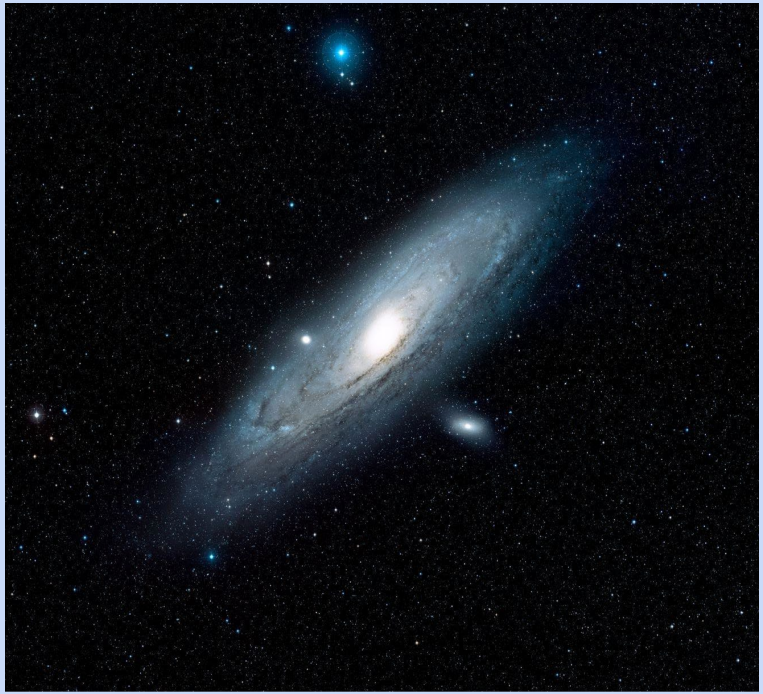
BERKELEY SETI RESEARCH CENTER

Optical SETI

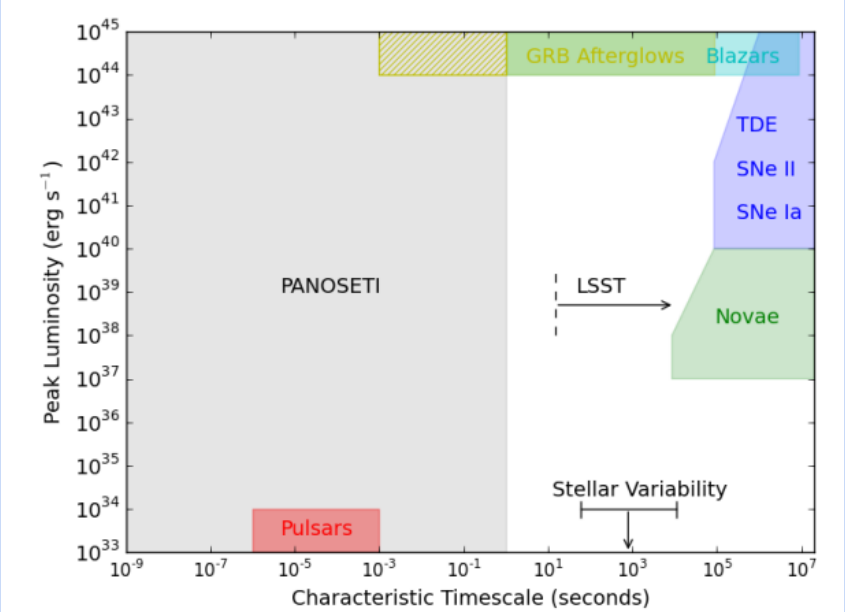
- An extraterrestrial intelligence may already be aware of our existence on Earth.
- Pulsed optical laser signals from deep space may be another method for communication.
  - Galactic WiFi?
  - Energy delivery system?
  - Eavesdropping?



M31: NASA/ESA

Optical SETI

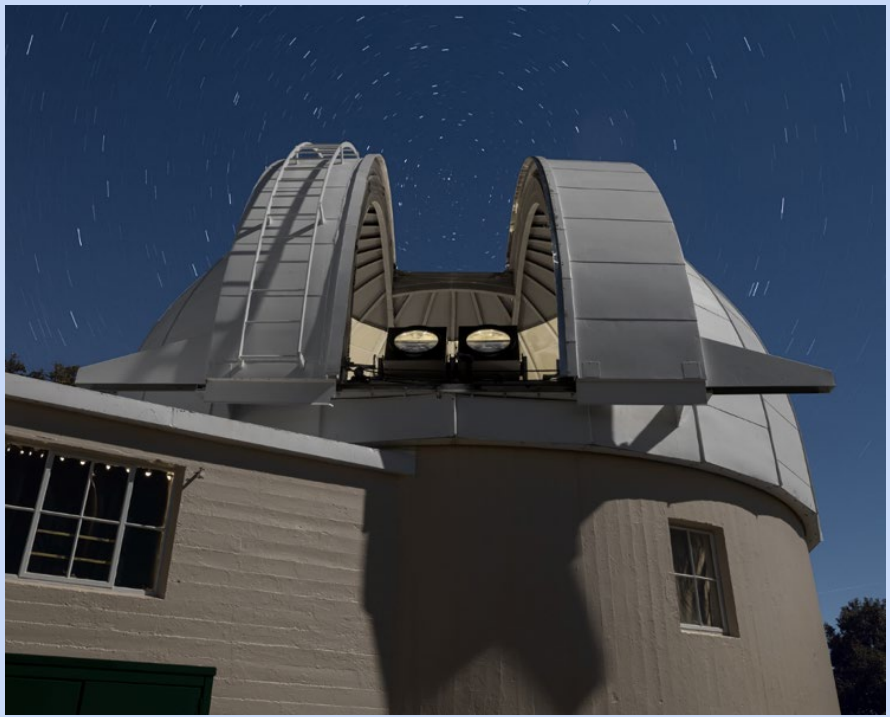
- More energy efficient to transmit a signal in optical bandwidth.
- Wide-beam radio signals can traverse a wide area not power.
- Detection would require dedicated follow-up observation for confirmation.
- The sky is incredibly dark at nanosecond timescales.



Wright et al. 2019

What is PANOSETI?

- Panoramic SETI.
- Currently located at Lick Observatory.
- All-sky all-time survey of pulsed optical transients within nanosecond and second timescales.
- Telescopes function in pairs, observing the same section of sky.
- Applications for SETI research and high-energy astrophysics phenomena.



Laurie Hatch Photography

Maire et al. 2019

The PANOSETI telescope

- 0.46 meter, f/ 1.32 Fresnel lens.
- ~100 square degree field of view.
- 400-750 nanometer bandwidth.
- Fiber optic ports for data transfer and White Rabbit time synchronization system.
- Three telescopes in operation.
- ~700 meter baseline separation.

Brown et al. 2021

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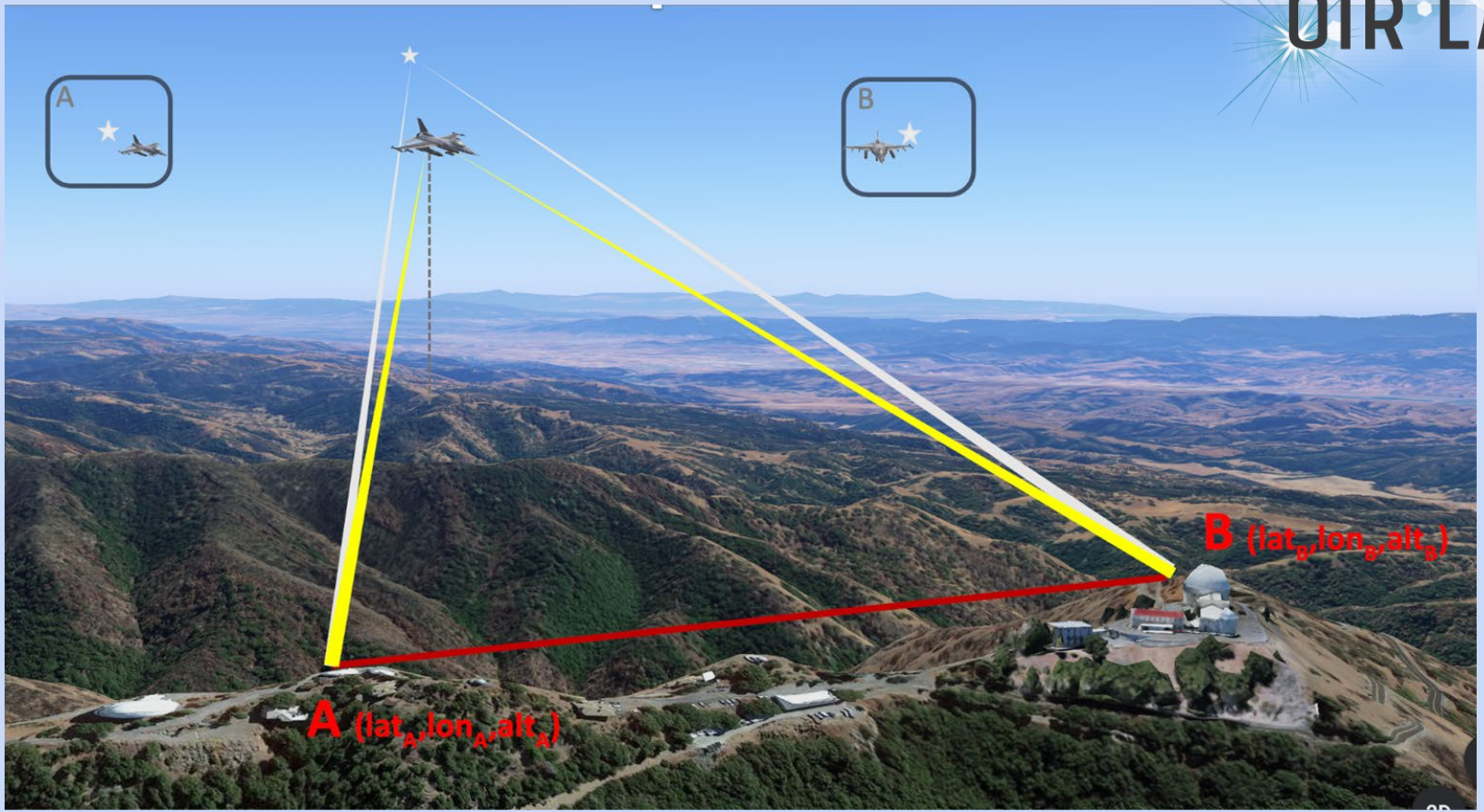

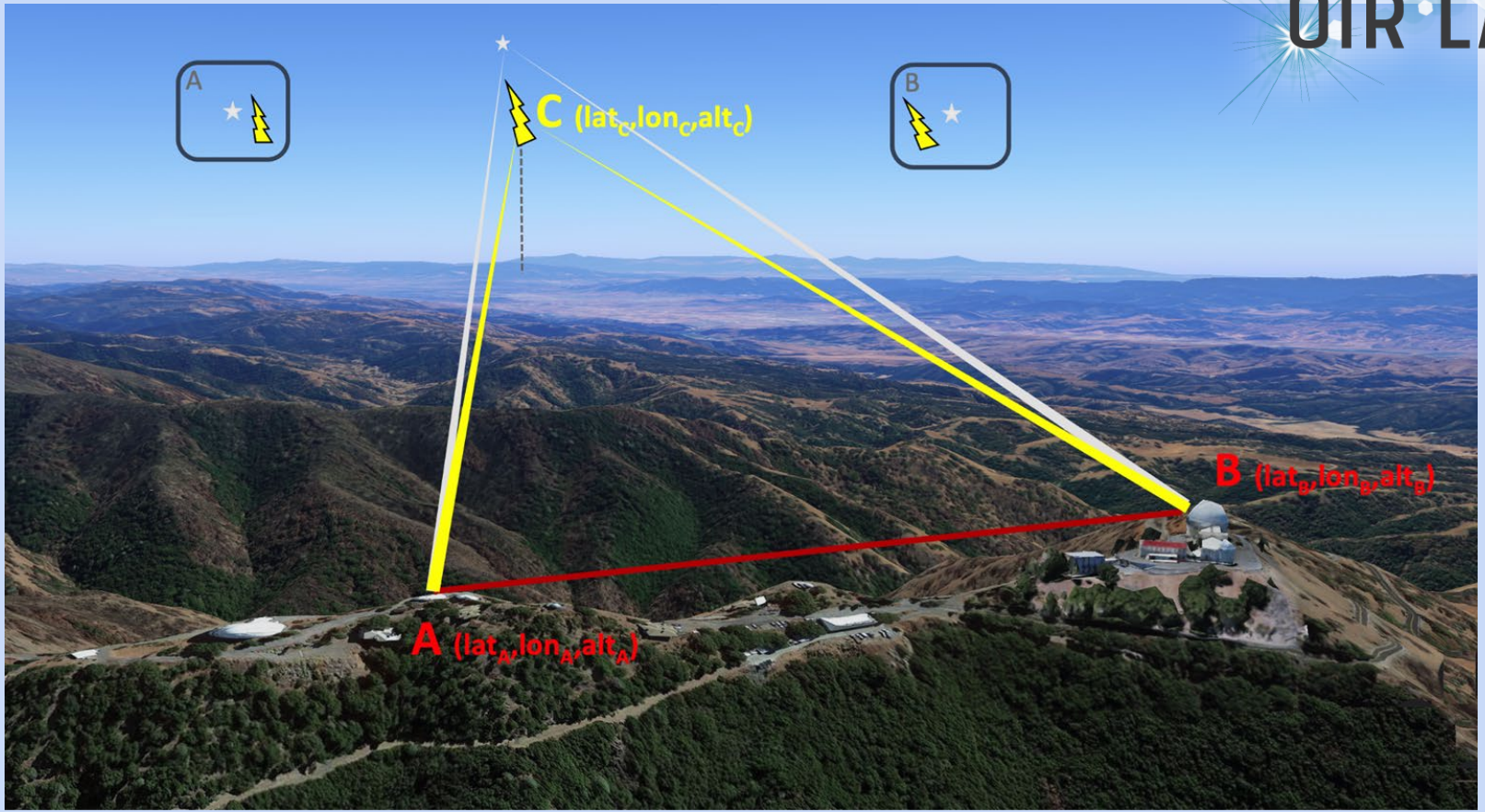
A
B
C (lat$_C$,lon$_C$,alt$_C$)
B (lat$_B$,lon$_B$,alt$_B$)
A (lat$_A$,lon$_A$,alt$_A$)

An all-sky all-time observatory

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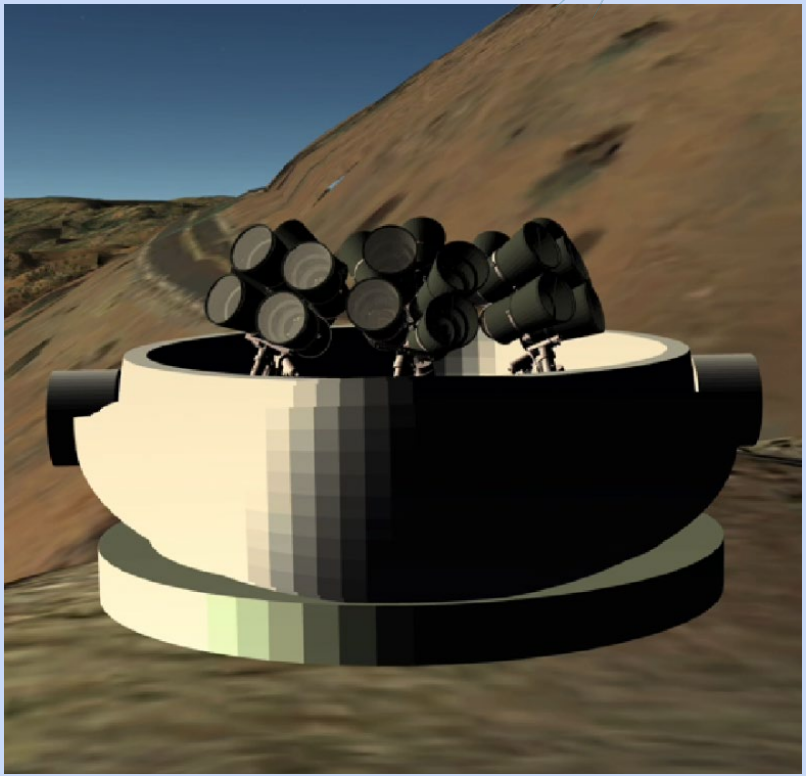
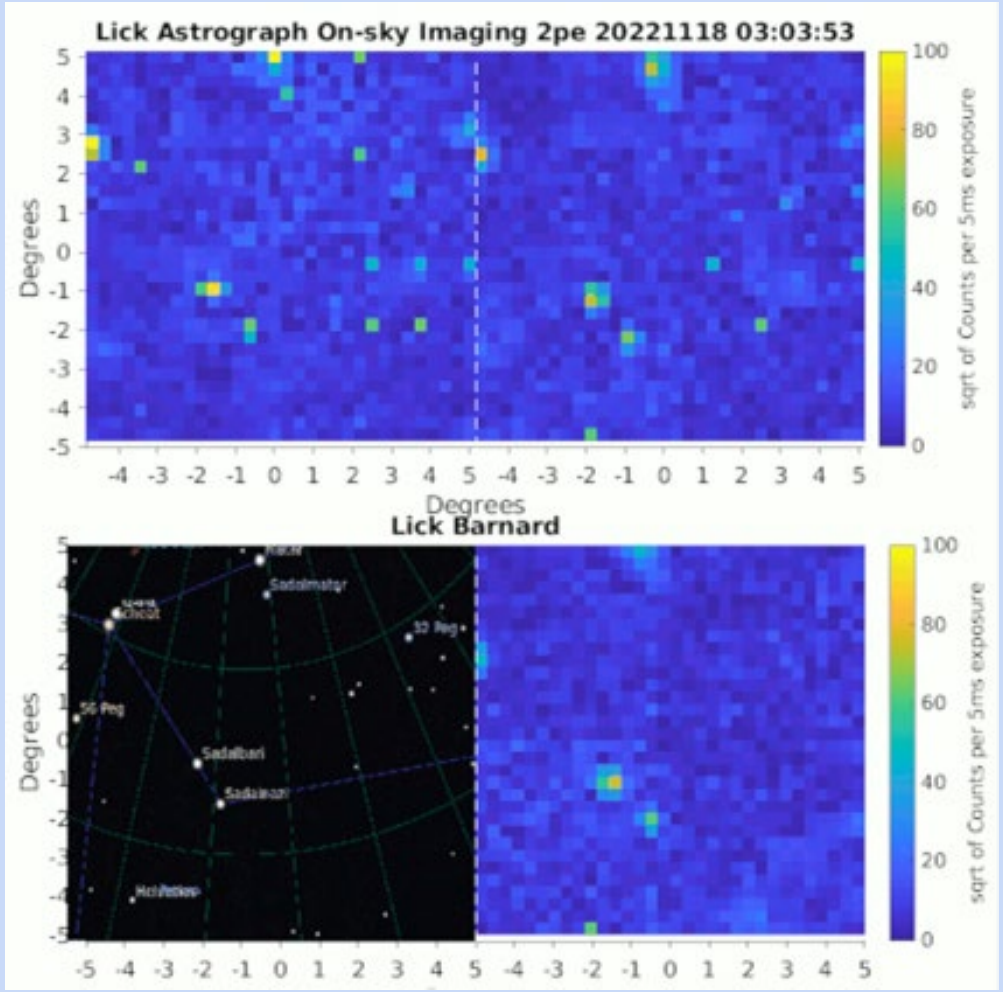
- Maximizing sky-coverage increases chances of intercepting a pulsed signal.
- Separating two observatories enables coincidence detection.
- The PANOSETI observatories will cover a large fraction of the Northern night sky.




Lick Astrograph On-sky Imaging 2pe 20221118 03:03:53
Degrees
Degrees
sqrt of Counts per 5ms exposure
Lick Barnard
Sadalmelik
Sadalbari
Sadalsuud
56 Peg
10 Peg
Degrees
sqrt of Counts per 5ms exposure

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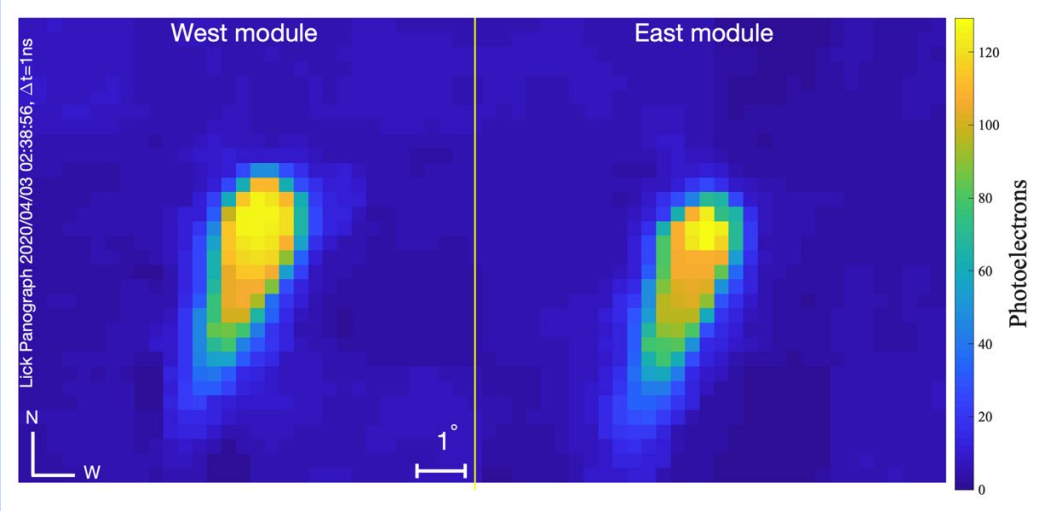
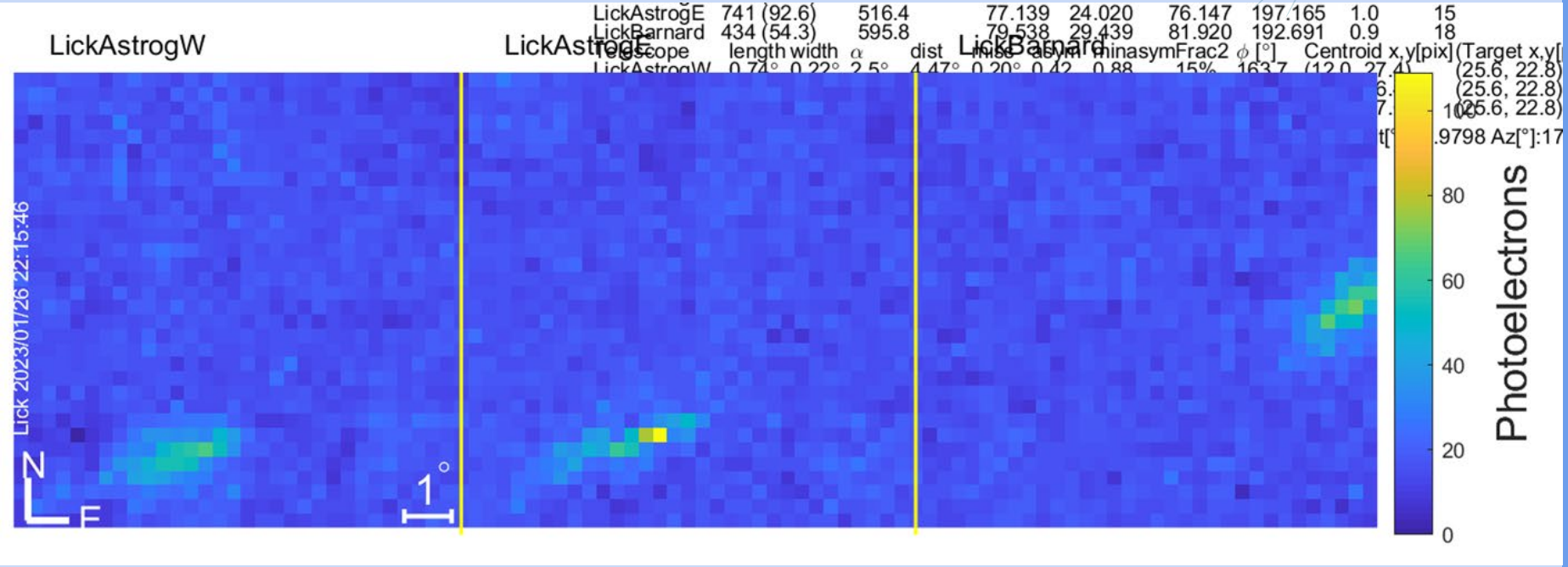
Science objectives of PANOSETI

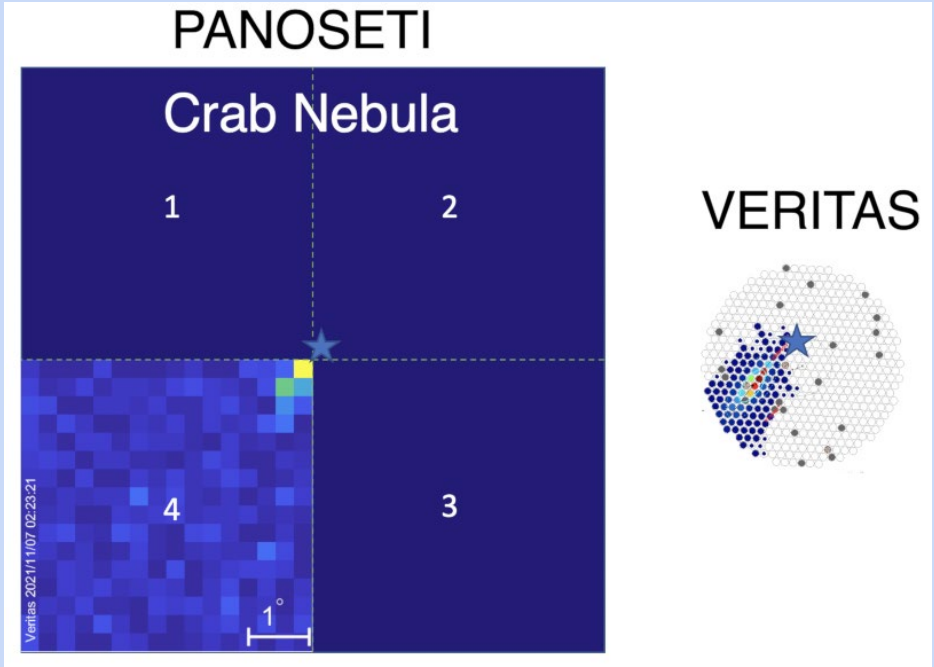
- Optical SETI
  - Pulsed optical laser technosignatures
- Cherenkov shower detection
  - Cosmic rays
- Optical counterpart searches for:
  - Fast radio bursts
  - Gamma ray bursts
  - Dark matter self-annihilation




LickAstrogW
LickAstrogE
LickBarnard
LickAstrogE 741 (92.6) 516.4 77.139 24.020 76.147 197.165 1.0 15
LickBarnard 434 (54.3) 595.8 79.538 29.439 81.920 192.691 0.9 18
Telescope length width α dist Pulse asym Rinasym Frac2 ϕ [°] Centroid x,y[pix] (Target x,y[
LickAstrogW 0.74° 0.22° 2.5° 4.47° 0.20° 0.42 0.88 15% 163.7 (12.0, 27.4)
(25.6, 22.8)
(25.6, 22.8)
(25.6, 22.8)
.9798 Az[°]:17
Lick 2023/01/26 22:15:46
N
E
1°
100
80
60
40
20
0
Photoelectrons

What has PANOSETI seen so far?

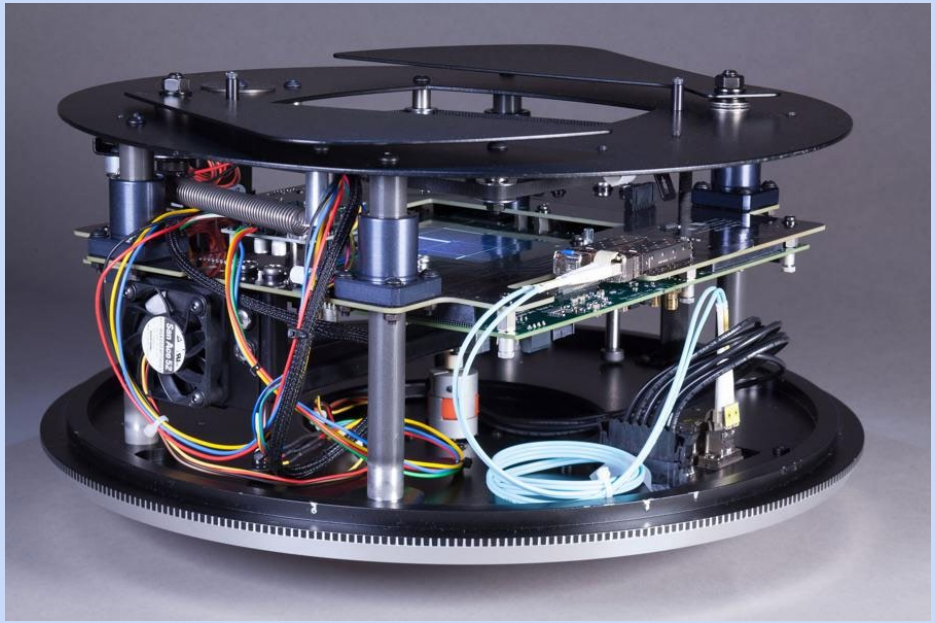
- PANOSETI telescopes observed the Crab Nebula with 12-meter VERITAS T4 and T2 telescopes.
- Three Cherenkov shower detections are considered to be likely gamma ray emissions from the Crab Nebula.
- The energies of these sources were measured to be 15, 36, and 51 TeV.



Maire et al. 2022

Data processing for PANOSETI

- Sixteen 8x8 pixel sub-arrays of Hamamatsu silicon multi-pixel photon counters form a 32x32 pixel array.
- Each quadrant has a 10 Gb/s network connection.
- 0.31° pixel scale.
- 528-byte data packets are recorded using Wireshark and specialized software developed by Berkeley team.



Data processing for PANOSETI

- Configuration file
- Python scripts
  - Translates hexadecimal-encoded data to photon counts
  - Generates a video file centered around a chosen time for a telescope
  - Records transient centroid positions to a CSV file for later follow-up
  - Coincident source identification

```
    'Peak Count': [],
    'Time': [],
    'Threshold': [],
    'File Path': []
}

print('\nIdentifying centroids...')

with os.scandir(path) as files:
    file_count = 0
    for file in files:
        if file.is_file():
            file_count += 1

with open('config.json', 'r') as file:
    config = json.load(file)
count_threshold = config["count_threshold"]

with os.scandir(path) as files:
    j=0
    bar = progressbar.ProgressBar(max_value=file_count)

    for file in files:
        if file.is_file():
            file_name = os.path.basename(file.name)
            file_data = np.load(str(path)+'/'+str(file_name), allow_pickle=True)

            for sequence in file_data:
                i=0
                for frame in file_data[i]:

                    threshold_image = frame.data > count_threshold

                    labeled_array, feature_number = ndimage.label(threshold_image)
                    centroids = ndimage.center_of_mass(threshold_image, labeled_array, range(1, fe

                    events['Pixel Locations'].append(centroids)
                    events['Peak Count'].append(len(centroids))
                    events['Time'].append(convert_unix_time(frame.timestamp))
                    events['Threshold'].append(count_threshold)
                    events['File Path'].append(path+file_name)
                    i+=1
        j+=1
        bar.update(j)

output_file = pd.DataFrame(events)
output_file.to_csv(path+'/events.csv', index=False)
print(f'\n\nEvent log written to {path}/events.csv\n')
```

```
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    },

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    }
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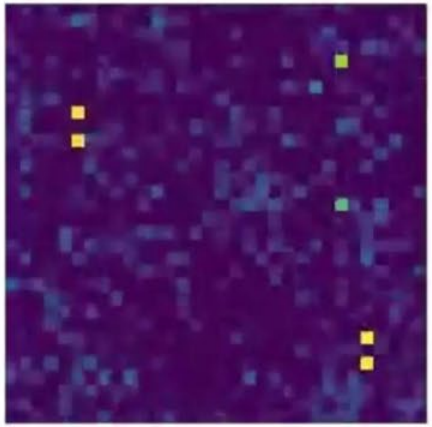
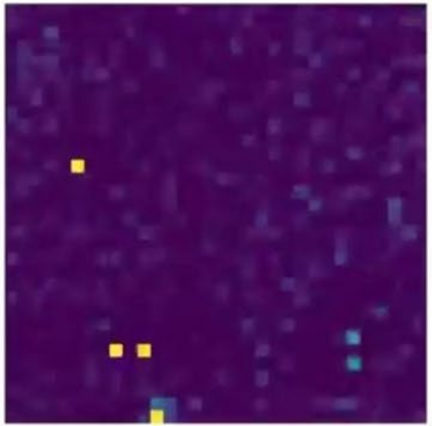
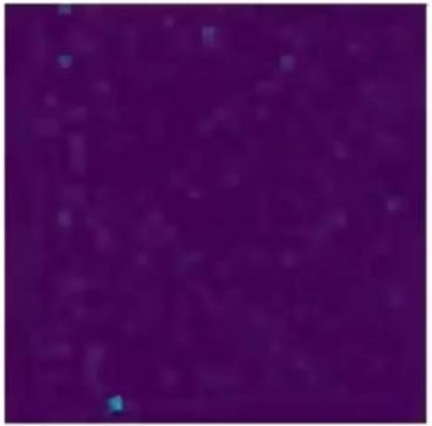
PANO SETI Frame 9771 of 290924



Astrograph W



Astrograph E



Barnard

Data processing for PANOSETI

- Airplanes and satellites represent sources of noise.
- Implementation of automated interface with public flight and satellite data.
- Airplane sources travel faster across FOV than satellites.
- Pulse height mode for events exceeding a photoelectron count threshold, for high-frequency pulses.
- Standard imaging mode for lower-frequency pulses.

The future of PANOSETI

- Three telescope sites currently at Lick Observatory.
- Expanding partnerships with high-energy astrophysics programs.
- PANOSETI has received funding to fabricate and commission 10 telescopes within the next year; European Research Council.
- PANOSETI will ultimately have 100s of telescopes deployed worldwide.