Image Processing Pipeline for Follow-up Observations with Optical Telescopes

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RET End Summary

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LIGO-G9900704-v1

Outline

I. Multi-Messenger Astronomy and
Project LOOC UP
II. Transients in CCD Images
III. Pre-processing of raw images
IV. Processing approach for
candidate transient identification
V. Future software module development

VI. Educational "Snack" development

GW and Multi-messenger Astronomy

It is expected that gravitational wave bursts will be associated with astrophysical events or processes which are very energetic – and these processes may be accompanied by changes which EM (optical) telescopes can detect.

- Examples: Supernovas, Macronovas (result of a double neutron star merger, or black hole/neutron star merger), Gamma Ray Burst Afterglows.

The LSC currently uses Gamma Ray Bursts (GRB's) and Soft Gamma Ray Repeaters (SGR's) as external "triggers" for gravitational wave bursts. Efforts are currently underway to do ***the opposite*** – to use suspected gravitational wave triggers in order to locate optical counterparts to gravitational wave bursts (project LOOC-UP).

- Potential to provide information such as the position, distance, and source mechanism.

Collaboration Considerations

In search for an astrophysical event using gravitational wave triggers, the LIGO-Virgo network is sensitive to the whole sky, whereas optical telescopes must be pointed to a particular location.

Thus a collaboration with a group of observatories with the following characteristics is desired:

- They should be somewhat **global**
- Should have fairly **wide field of vision** (position determination is imprecise; a few degrees)
- Should be **automated** (many short observations, not scheduled in advance – robotic scopes would be the ideal)

Partnerships

Memoranda of Understanding (MoUs) will be reached with partners who are enthusiastic about participating in the project - and wish to be collaborators in the event of its success.

Potential projects/instruments might include:

- ROTSE
- TAROT
- QUEST
- Pi of the SKY
- Palomar Transient Factory

From GW Observation…

Data from the LIGO-Virgo network would be analyzed *in near real time*, and results for triggers are obtained (time lag of 10-30 minutes).

If all 3 detectors are in science mode, the data will include a position determination of the most likely sky position, (within limits of uncertainty).

The events are recorded to disk, along with pertinent information.

…To EM Observation

Observatories are contacted for follow-up optical imaging.

- Follow-up observations are only initiated if an event candidate is well localized, in the field of view of the telescope, and above some "significance thresholds."

The rate will be limited to a few per week, or several per month.

A major goal (in progress) is to establish a credible "False Alarm Rate," and the proper significance thresholds.

Performing (raw) image analysis on project LOOC-UP's pilot data – specifically identification of *transients* in the images – will assist in establishing these significance thresholds, and false alarm rates.

Optical Transients

Given a sequential set of images of a particular sky position, a ***transient*** is an object that appears to change in time.

- It may not exist in one image but does in another, or it may simply have a significant change in intensity.

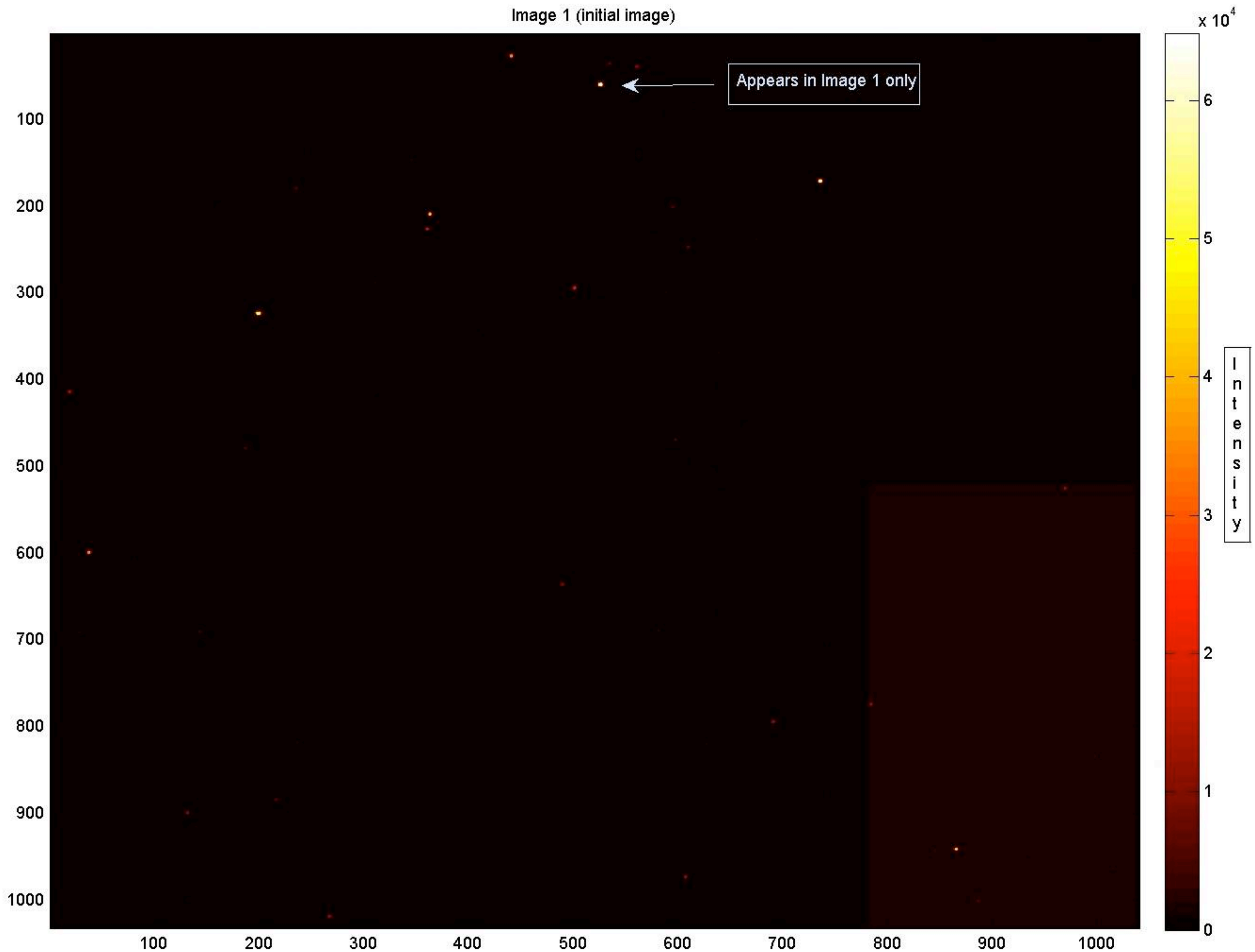
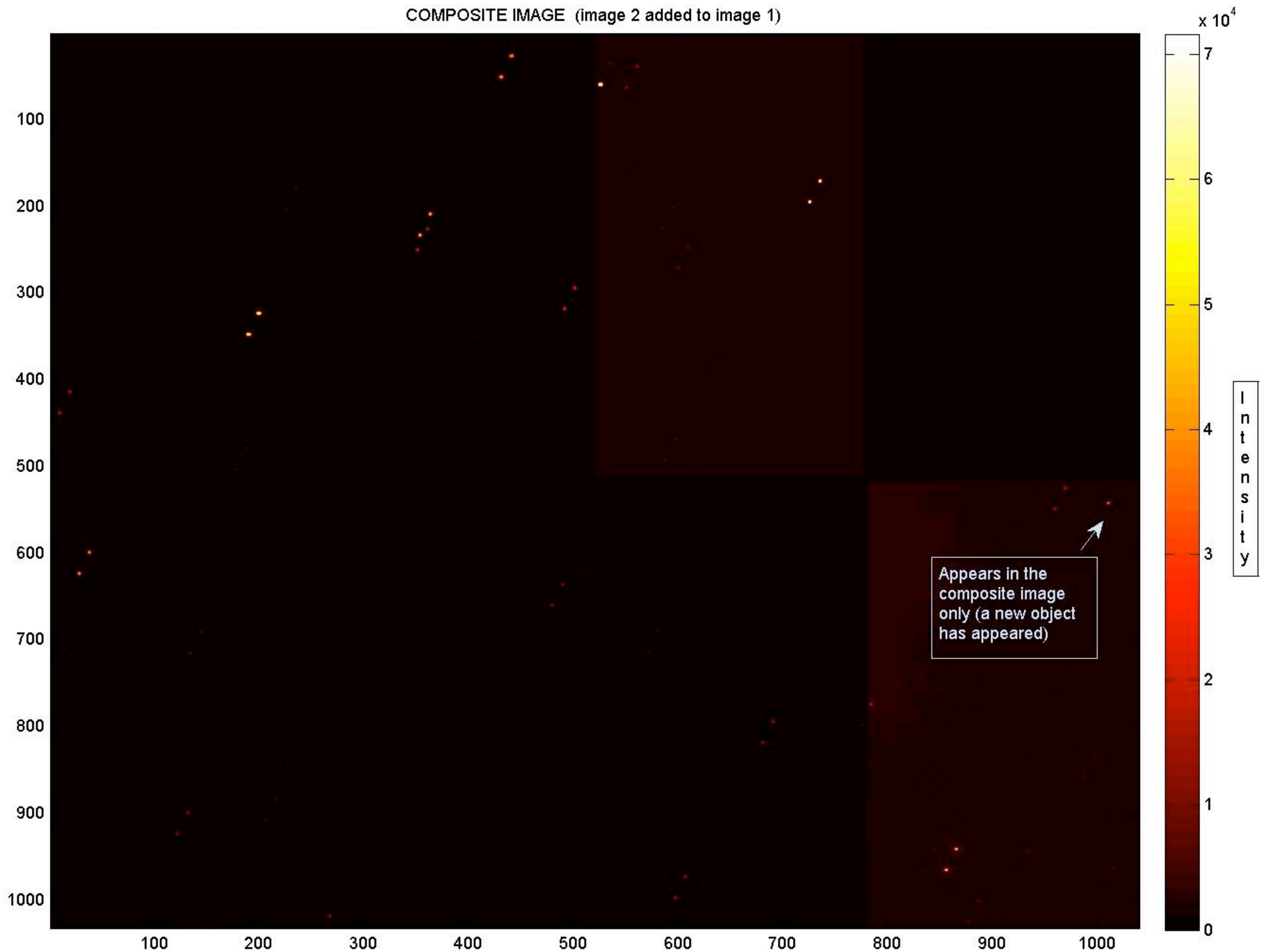


Image 1 (initial image)
Appears in Image 1 only
x 10^4
Intensity
100
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6


COMPOSITE IMAGE (image 2 added to image 1)
100
200
300
400
500
600
700
800
900
1000
Appears in the composite image only (a new object has appeared)
x 10^4
7
6
5
4
3
2
1
0
Intensity

On Transient Identification

Not all transients are events associated with gravitational waves; asteroids, satellites passing into the field of view, meteors, etc. must be excluded – thus the ability to *locate* and *identify* transients is required.

While some observatories have image processing capacity, and will return the results of image analysis to the LSC, some will only be able to provide raw images.

With the assistance of Amber Stuver, a large portion of my work this summer as RET has involved ***developing software that will be used to automate the image analysis in locating transients, utilizing MATLAB***.

Steps for Transient Identification

The following steps have been identified thus far for image processing:

1. FITS File Head Parameter Extraction
2. CCD Mosaic Assembly
3. Image Calibration
4. Dithered Image Assembly
5. Image Shift Calculation
6. Image Subtraction
7. Candidate Transient Identification
8. Luminosity Curve Calculation
9. Classification
10. FAR Estimation

The Images

The images are stored in a FITS file format – a NASA image file standard - which contains important information in a header about the image itself, and how it is stored (for reconstruction).

MATLAB has built in functions to read the data and extract the header parameters like:

- Sky coordinates of image
- Exposure time
- Filters used
- Date
- Observatory
- Etc.

Image Reconstruction and Calibration

Each image is actually a mosaic of CCD's (8 on the MDM 8K CCD) which must be properly assembled to produce the image.

- This step has been completed (Amber) but since the full resolution images are VERY large (~100 MB per image) we used 2x2 pixel averaged images that were also produced by the observatory.

CCD noise and other artifacts can be removed from the images by proper calibration.

- These results are incomplete (Amber)– experts must be contacted to clarify some existing issues.

Visualizing the Images

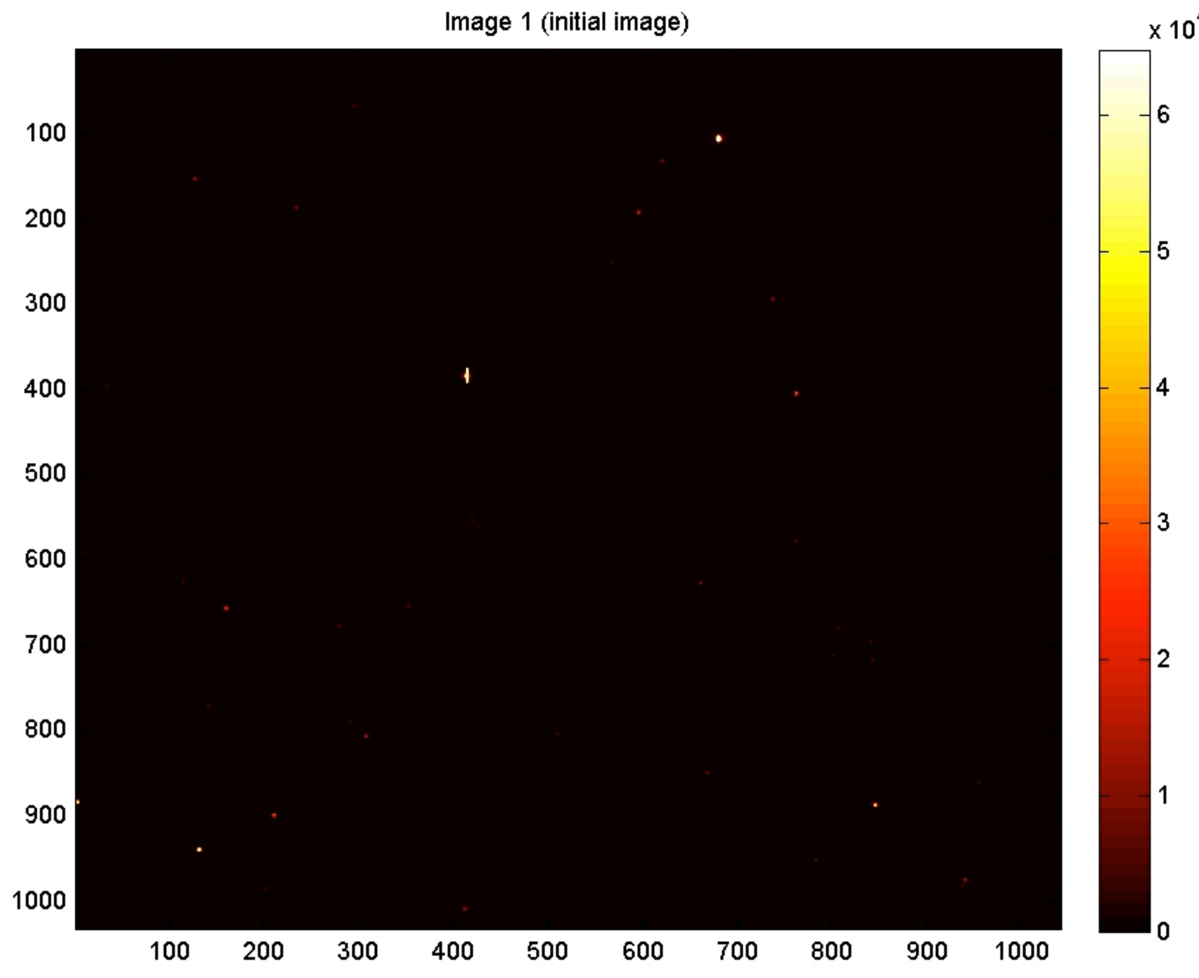
The image data is stored in a matrix variable by MATLAB as a 1032 (row) x 1040 (col) matrix of intensity values which may be mapped to various colormaps.

The range of intensity values typically varies from 0 to approximately 64800; objects which may have had higher intensities map to a “saturated” value of the colormap’s maximum intensity.

Different colormaps are useful for revealing various objects, and image characteristics.

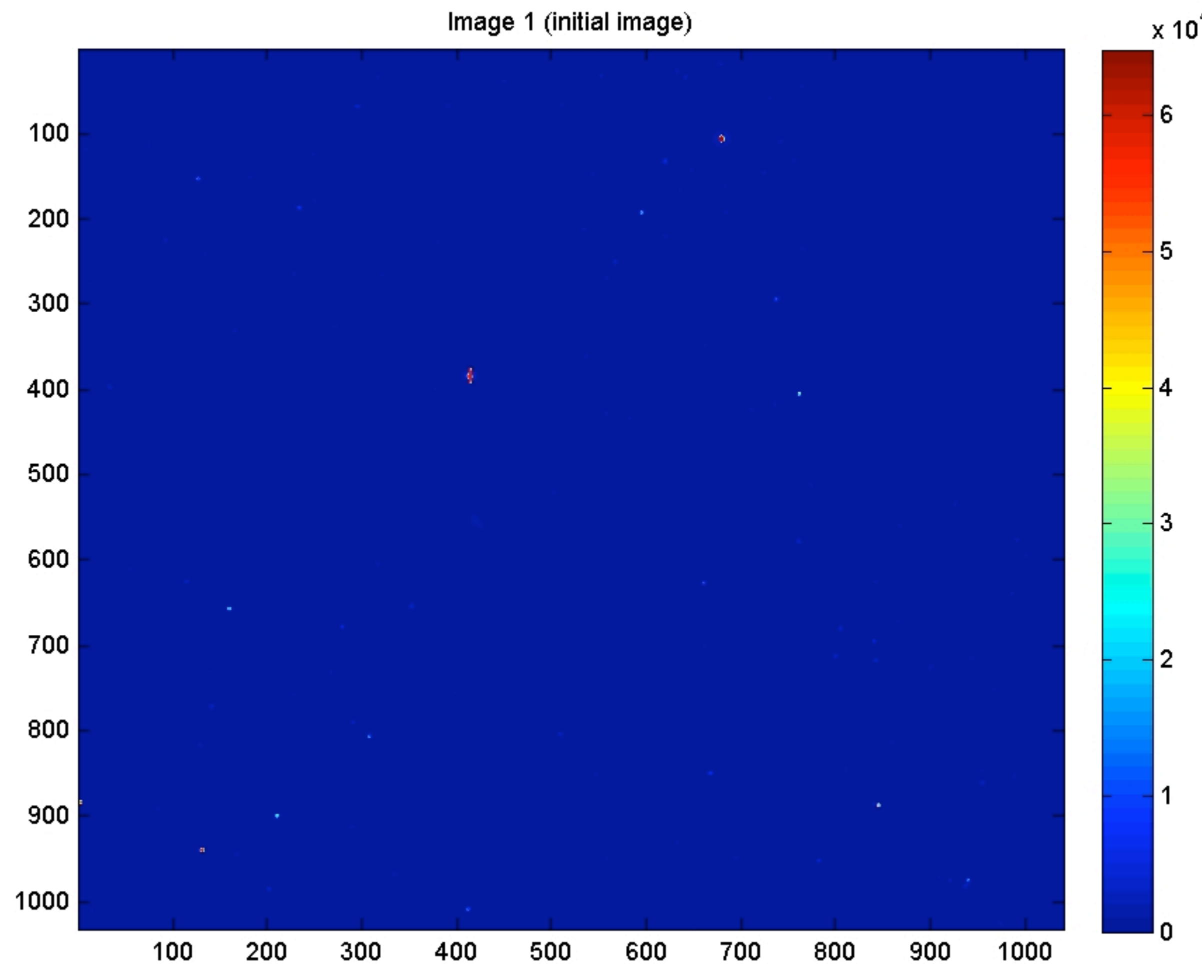
“Hot”

The “hot” colormap is good for getting a sense of relative intensities of objects.



“Jet”

More & fainter objects can be seen utilizing the “jet” colormap.



“Flag”

The “flag” colormap reveals that an image may contain many small differences in intensity values not otherwise visible to the eye.

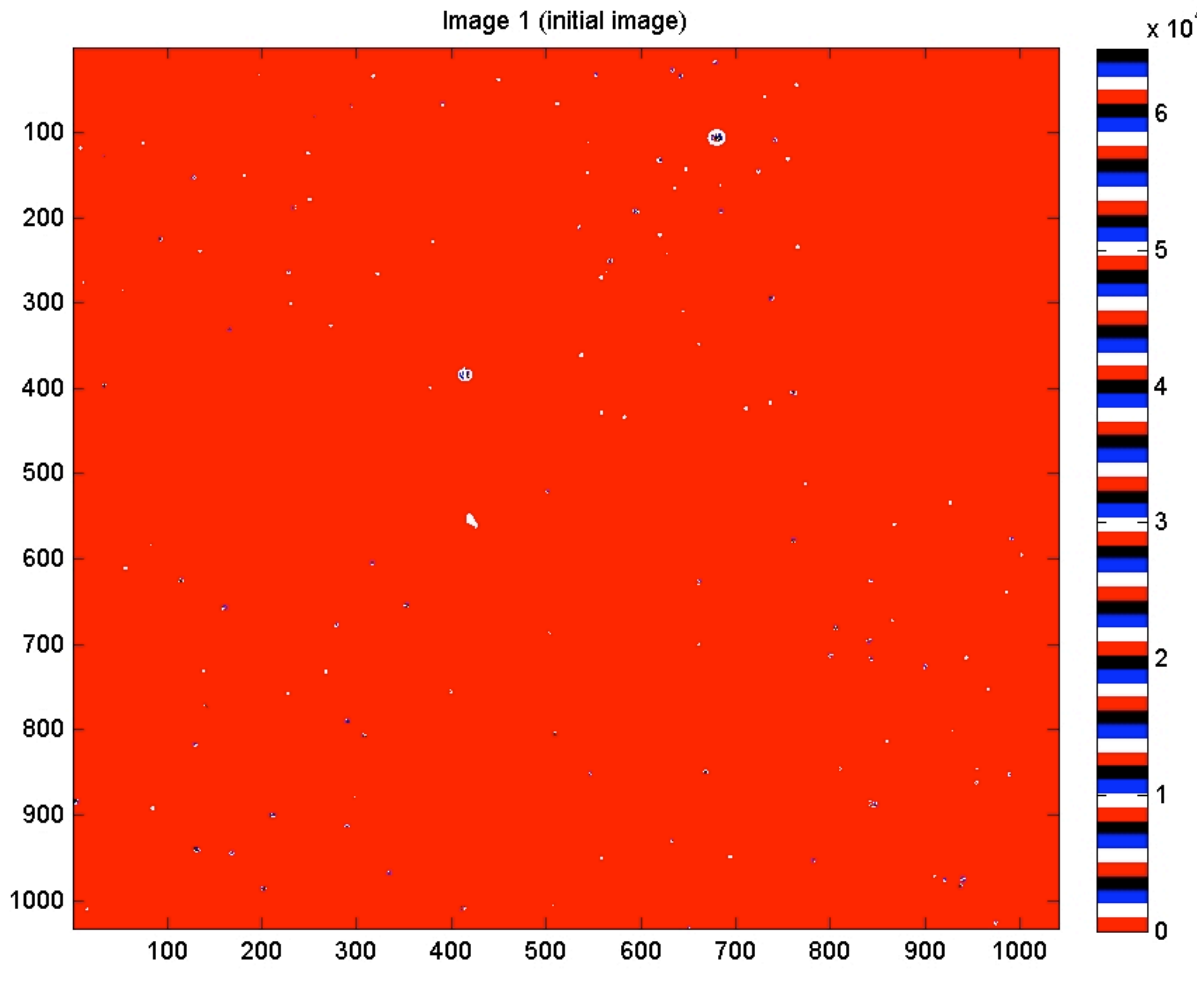


Image Shifts

Since successive observations are not necessarily perfectly aligned, the shift in location (pixels) of stars must be calculated in order to perform a transient search.

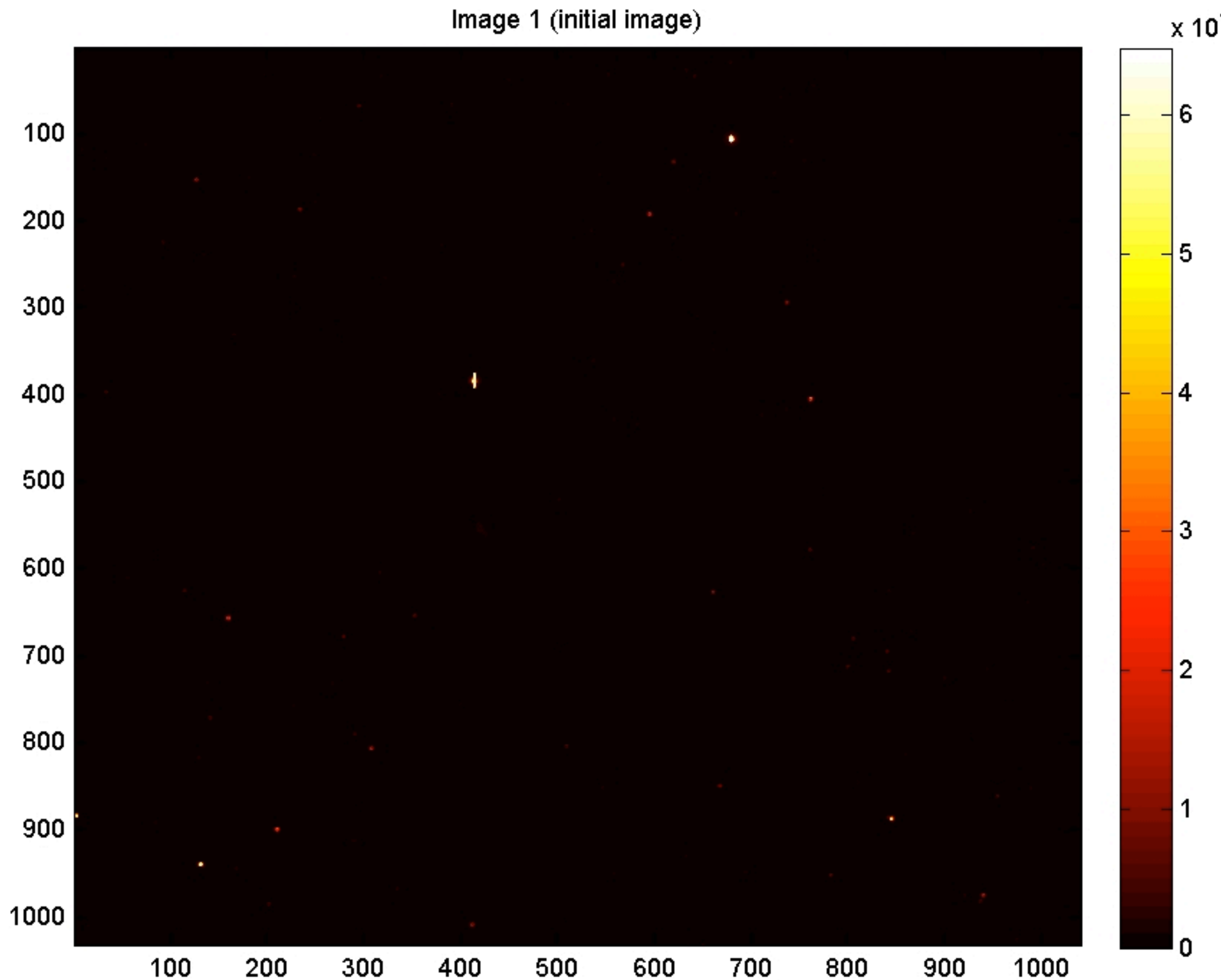
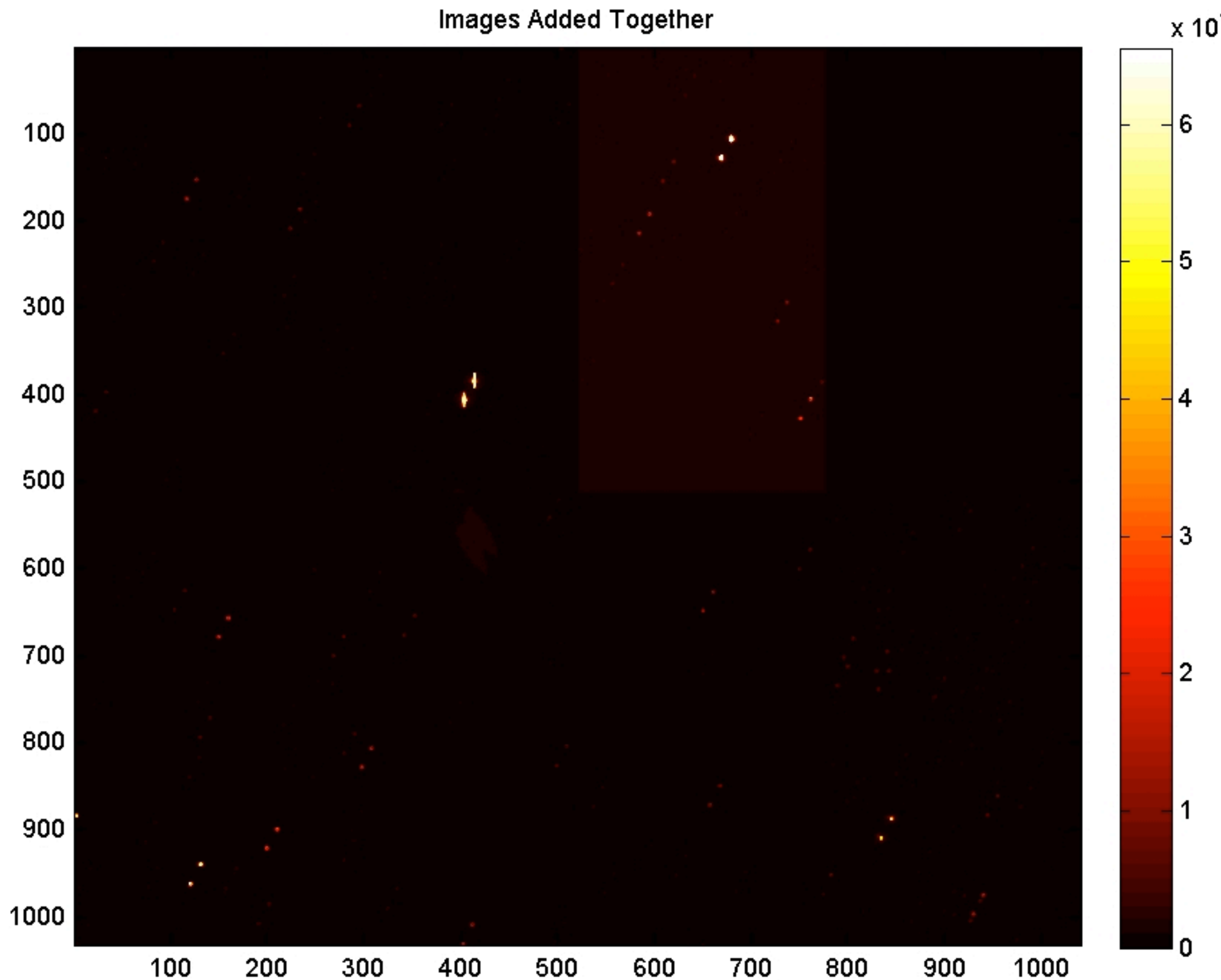


Image 1 (initial image)
x 10^4
6
5
4
3
2
1
0
100
200
300
400
500
600
700
800
900
1000



Images Added Together
x 10^4
6
5
4
3
2
1
0
100
200
300
400
500
600
700
800
900
1000

Calculating the Shift

The alignment problem was attacked using a “brute-force” approach: find bright pixels, identify stars as clusters of bright pixels, locating the same objects in a subsequent image.

- Also, distances to nearby objects were calculated to verify offset calculations.

Early on, some significant “threshold” limits had to be applied – for example, ***what constitutes a bright pixel?***

- Too high of an intensity value, and insufficient pixels would be identified for offset calculations; too low, and correlating stars (clusters of pixels) becomes problematic.

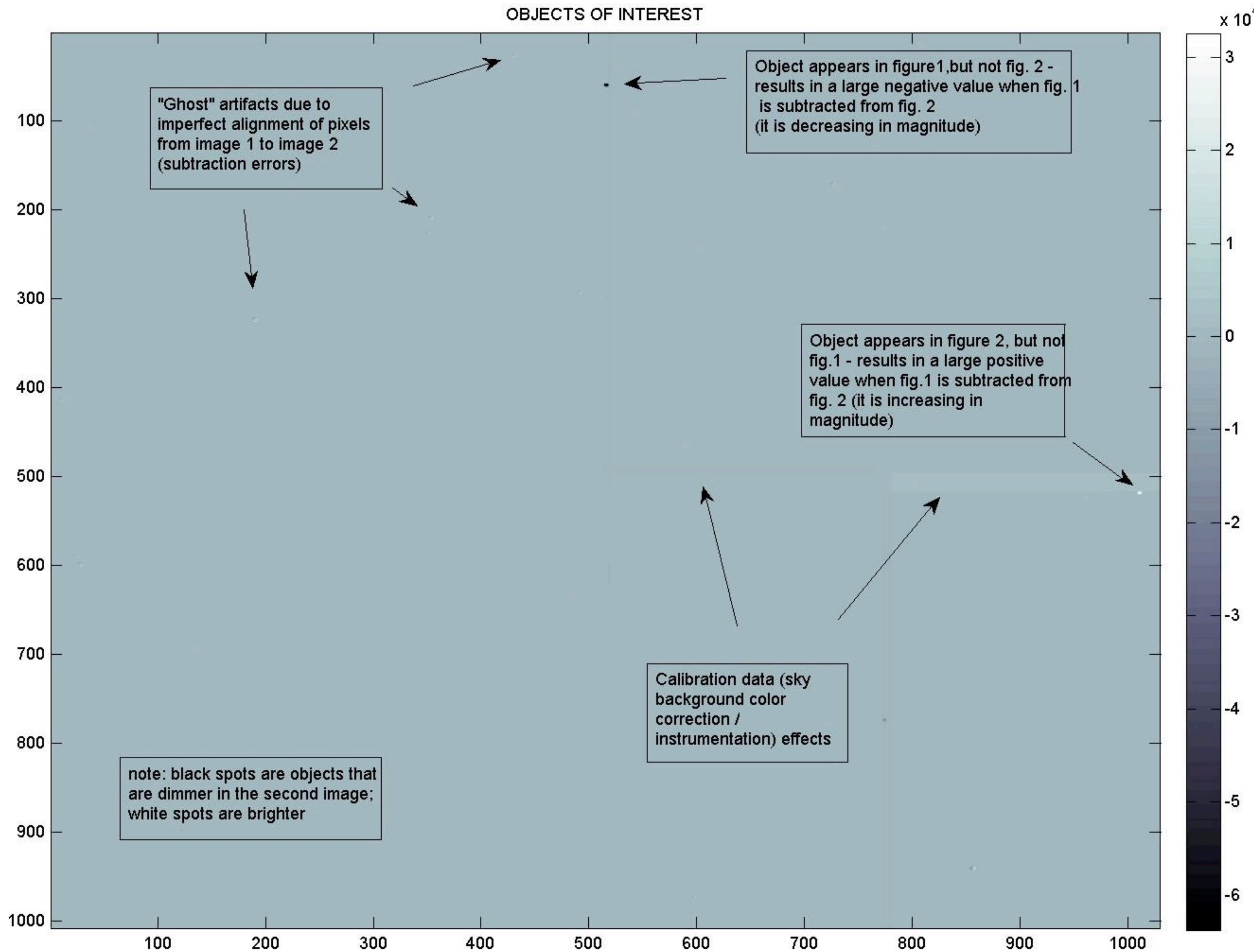
In processing the images tested, an intensity value of 15,000 was chosen as a minimum (on a scale of 1 to 10, this would equal about 2.5 – thus fairly faint stars are being included).

Image Subtraction

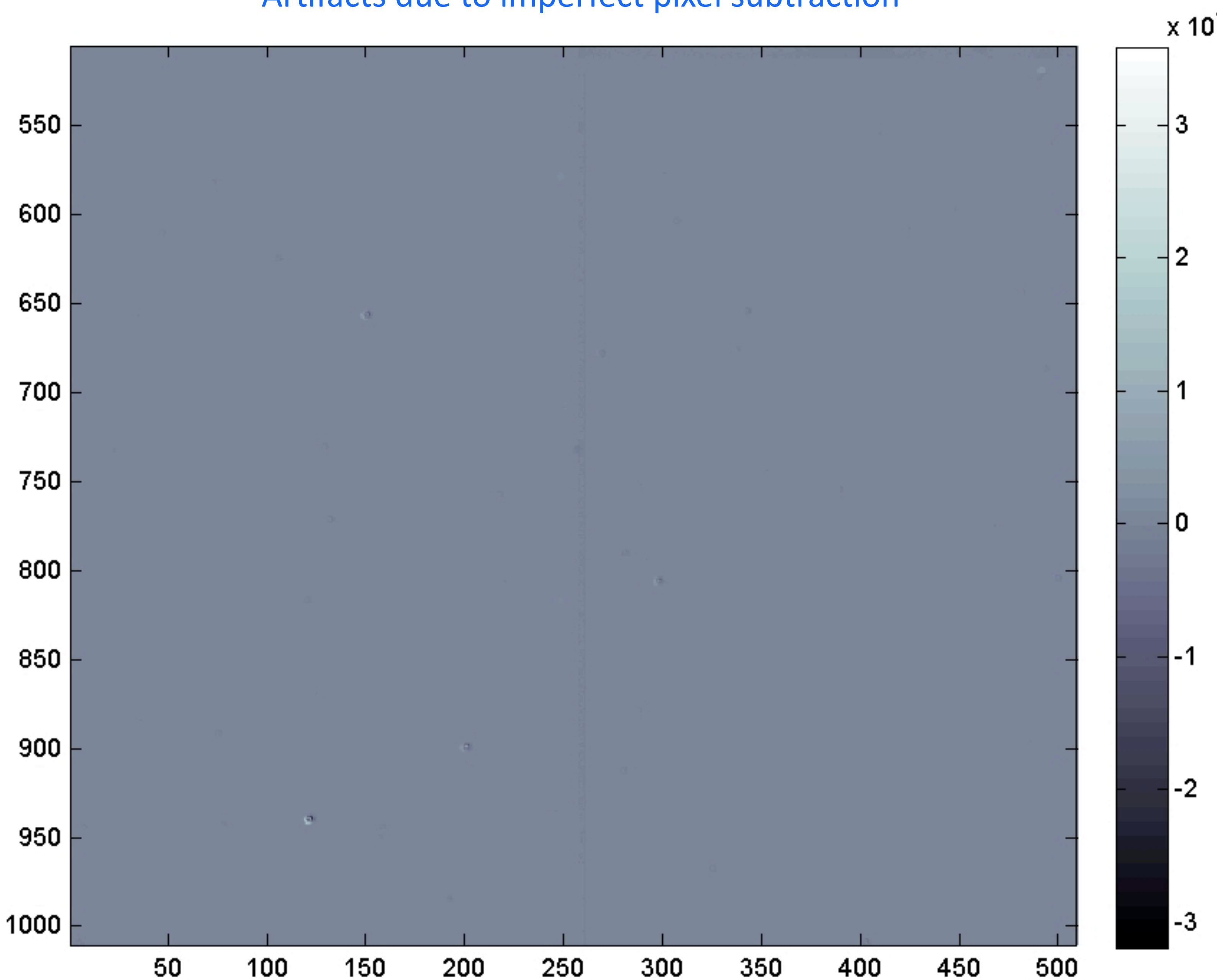
The resulting aligned data files are then subtracted (image2 – image1) to produce an image which MAY contain transients.

- It is expected that there will be NO transients in most images.

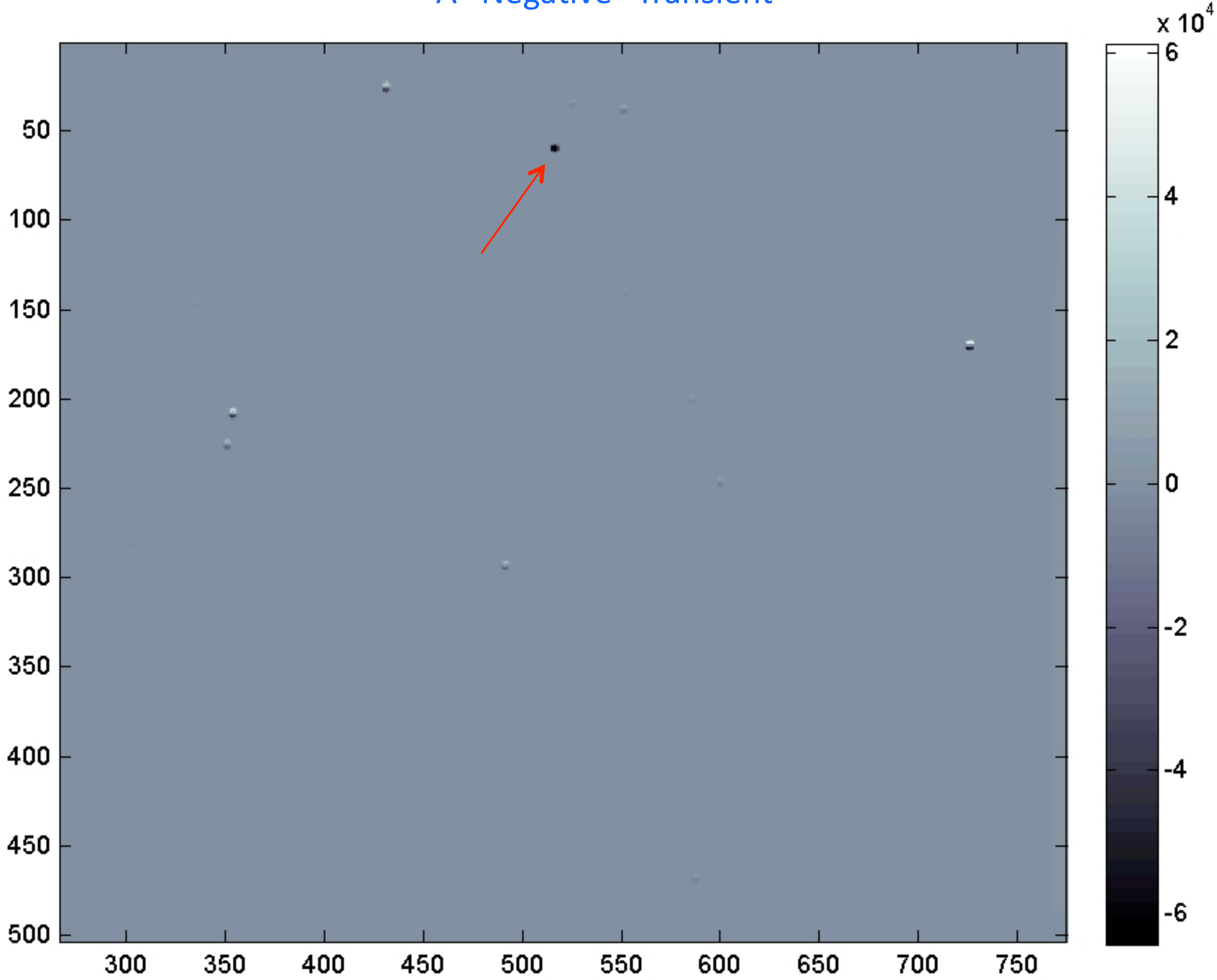
However, some candidate transients emerged in ALL images processed…


OBJECTS OF INTEREST
"Ghost" artifacts due to imperfect alignment of pixels from image 1 to image 2 (subtraction errors)
Object appears in figure1,but not fig. 2 - results in a large negative value when fig. 1 is subtracted from fig. 2 (it is decreasing in magnitude)
Object appears in figure 2, but not fig.1 - results in a large positive value when fig.1 is subtracted from fig. 2 (it is increasing in magnitude)
Calibration data (sky background color correction / instrumentation) effects
note: black spots are objects that are dimmer in the second image; white spots are brighter
x 10^4

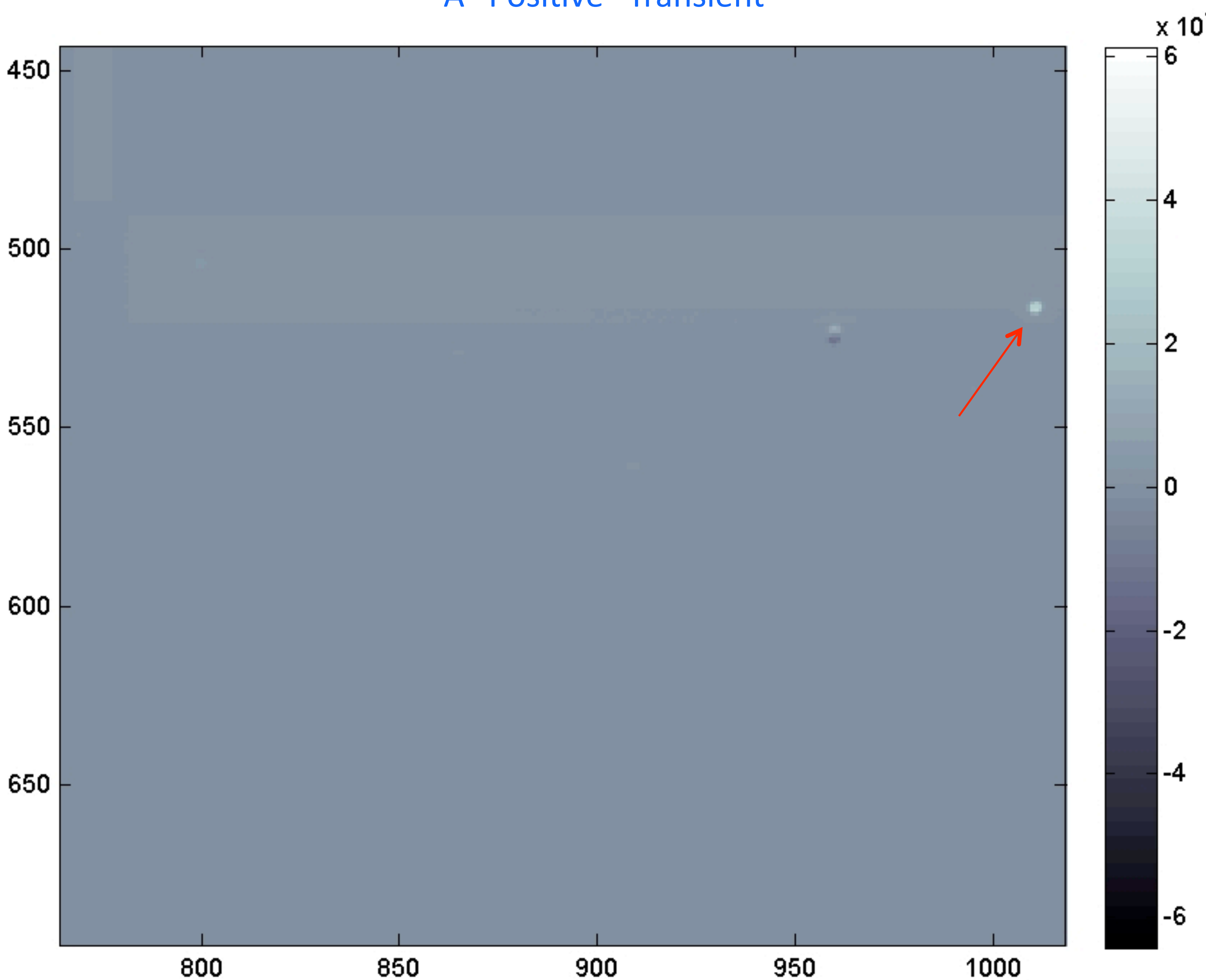
Artifacts due to imperfect pixel subtraction



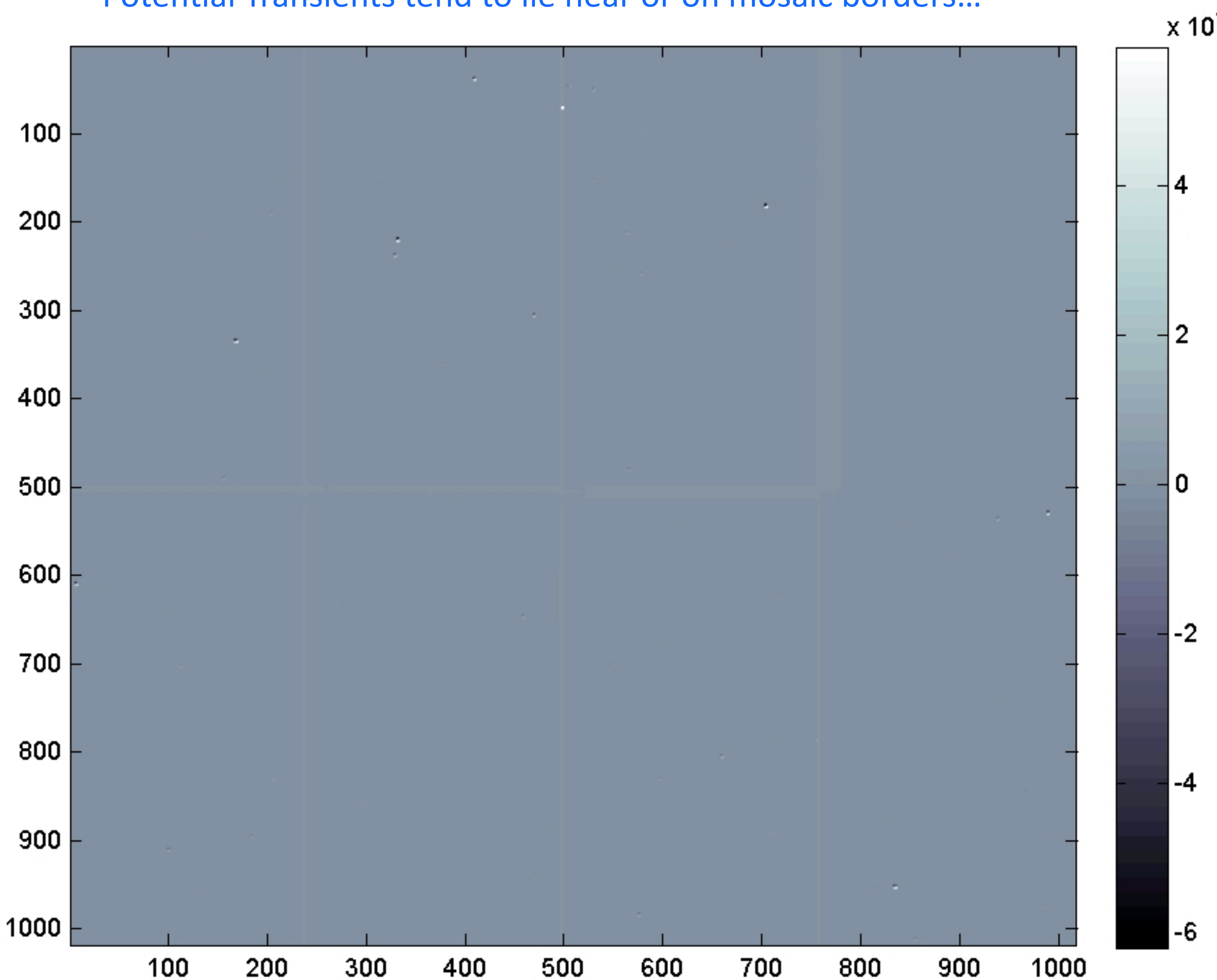
A “Negative” Transient



A "Positive" Transient



Potential Transients tend to lie near or on mosaic borders…



Identifying the Transients

A module was developed to evaluate subtracted images, and identify transients which are genuine.

Here, another threshold limit must be set – by how much must a pixel's intensity vary from the background in order to be considered significant, after subtraction? Since the majority of background intensities have very low values (on the scale of tens), and mosaic border values typically range between +/-100 to +/-300, a limiting intensity value in the thousands was found to be appropriate.

Modules which were analogs of those previously developed to locate stars were utilized to locate candidate transients, storing pertinent information in a new matrix variable (intensities, size, X & Y coordinates).

Thresholding Rationale

A threshold cut is then made on transient candidates; only those with an increase or decrease in magnitude of 50% above background intensity are considered genuine. This limit was set high intentionally – the initial image subtraction produced similar transients with large changes in magnitude near mosaic boarders (intensity of 9 on a scale of 1 to 10).

If a lower threshold is used (10%), transient candidates ***will*** surface; however upon visual inspection all appear on or near a mosaic border. Further cuts are possible using the size of the cluster of pixels corresponding to transient (when small).

Future Work

Luminosity Curve Generations

- For identified transients, how does the luminosity (brightness) change over the observations?

Transient Classification

- Is this a real transient? If so, what kind is it (supernova, etc.)? The luminosity curve will be useful here.

False Alarm Rate Estimation

- What is the chance that we identify a transient as being a "real" one by accident? A simulation program written by an IREU student (Greg Dooley – Kate's brother) will help here.

Educational Science “Snack” Development

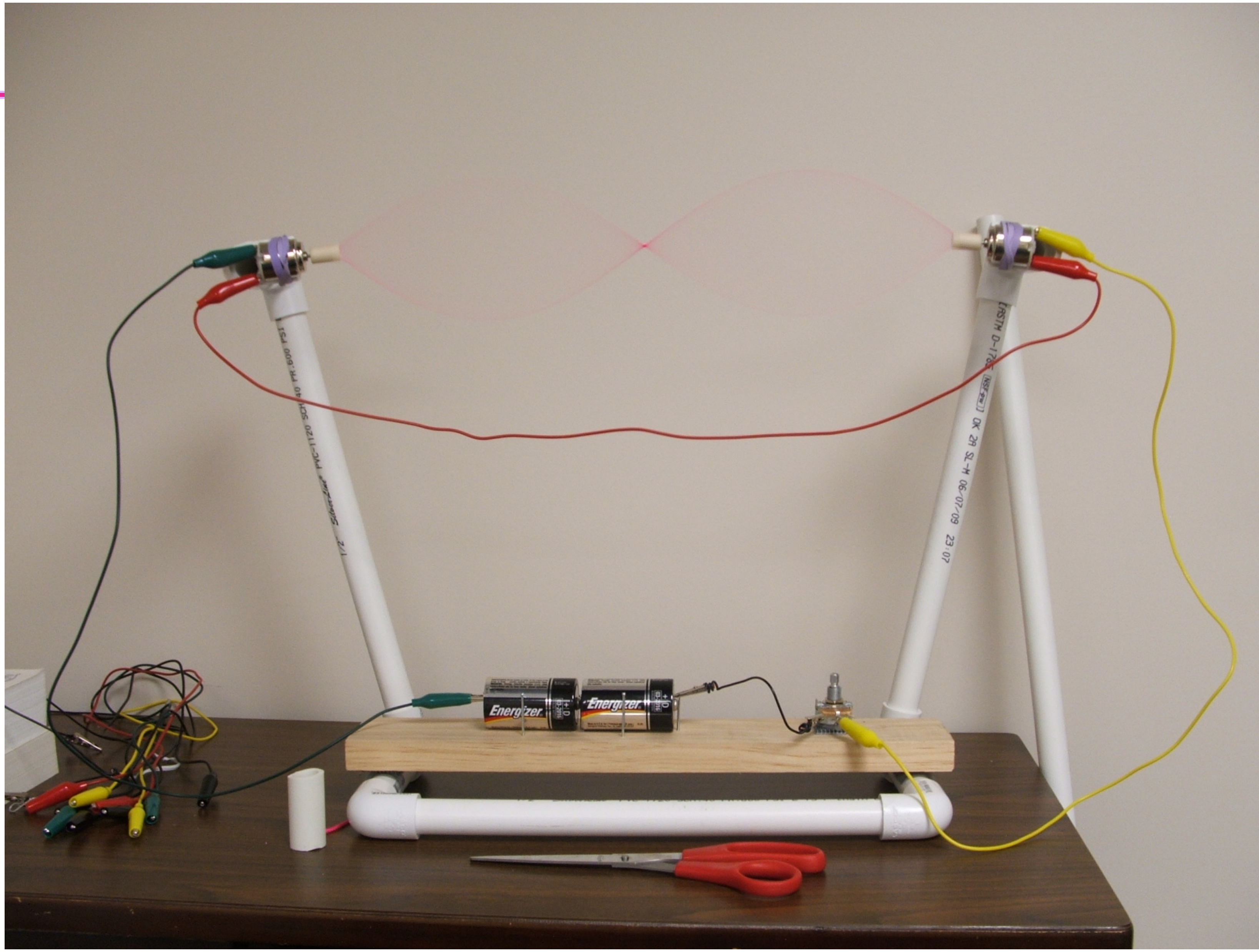
What's a "Snack"?

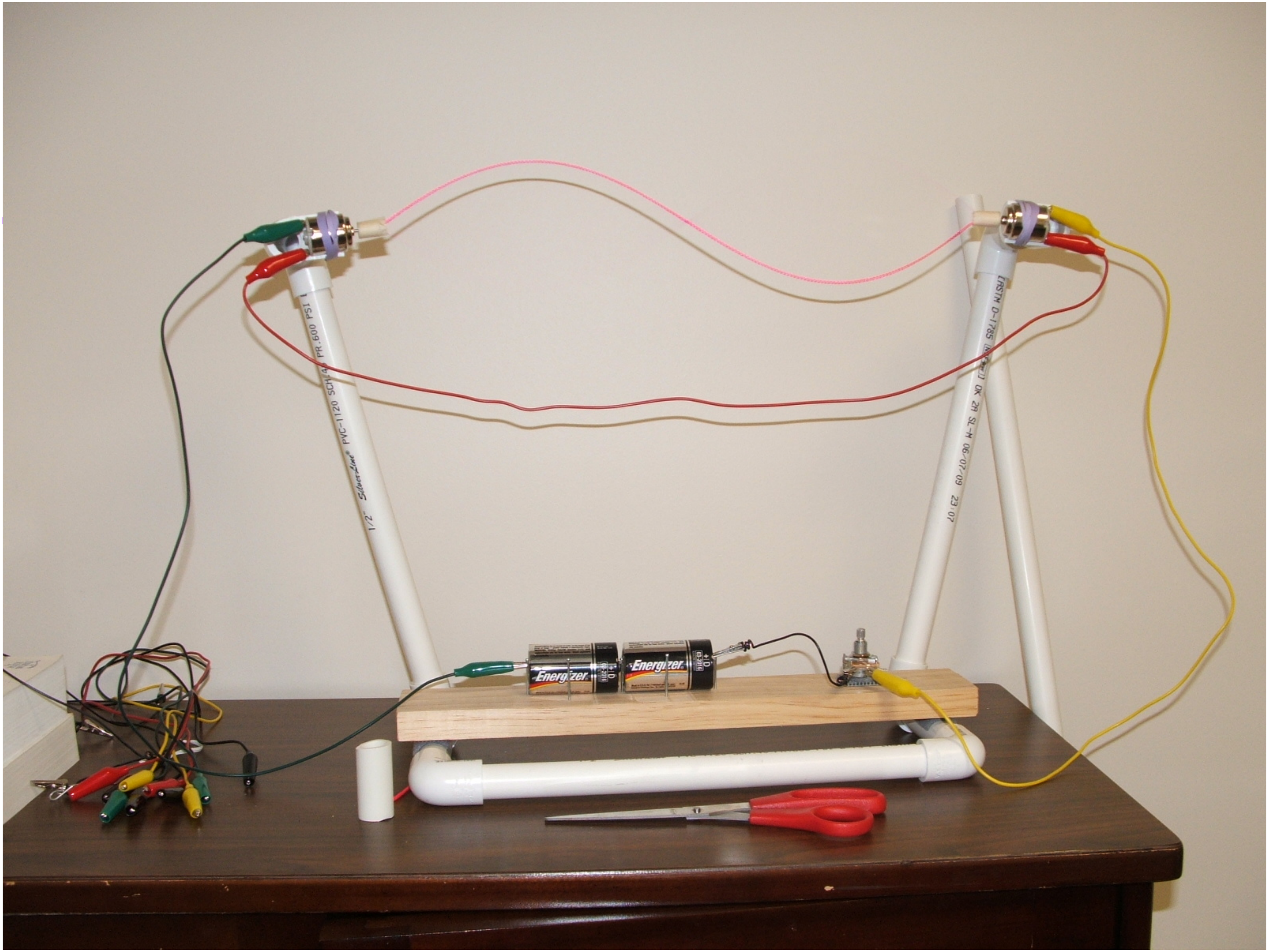
In addition to Image processing software development, I have also constructed two science education "snacks" while at LIGO this summer.

A snack is a small-scale, inexpensive teaching tools similar in concept to the large-scale exhibits the Exploratorium in San Francisco houses and sells; the LIGO Science Education center contains some of these full-scale exhibits. At one time, a "cookbook" was published with construction diagrams for these… hence the smaller versions came to be known as snacks…

While exhibits may cost in excess of $10,000.00   snacks are intentionally as cheap as possible (teachers have little resources).

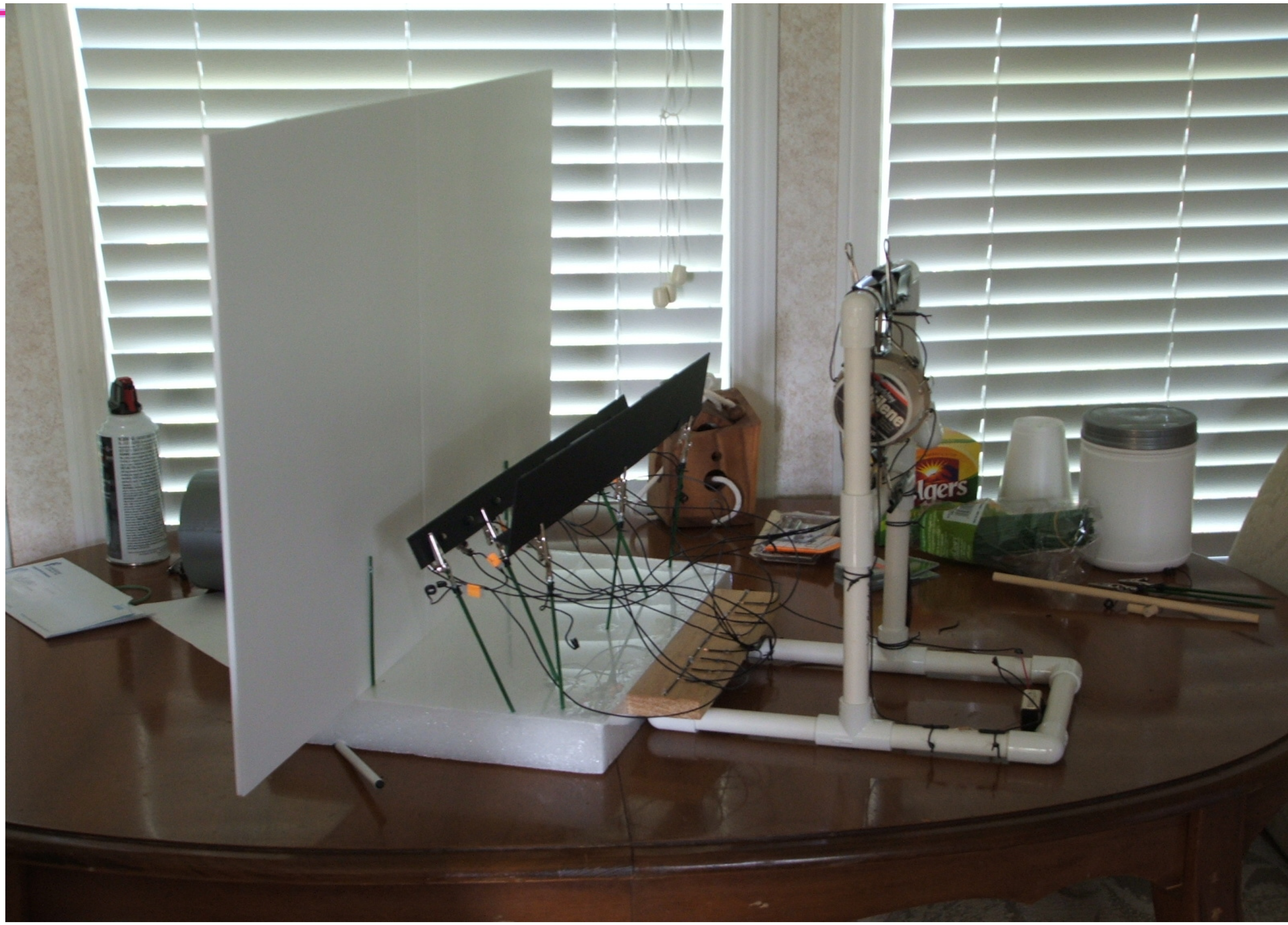
String Machine – and Exploratorium snack (for demonstrating standing waves)



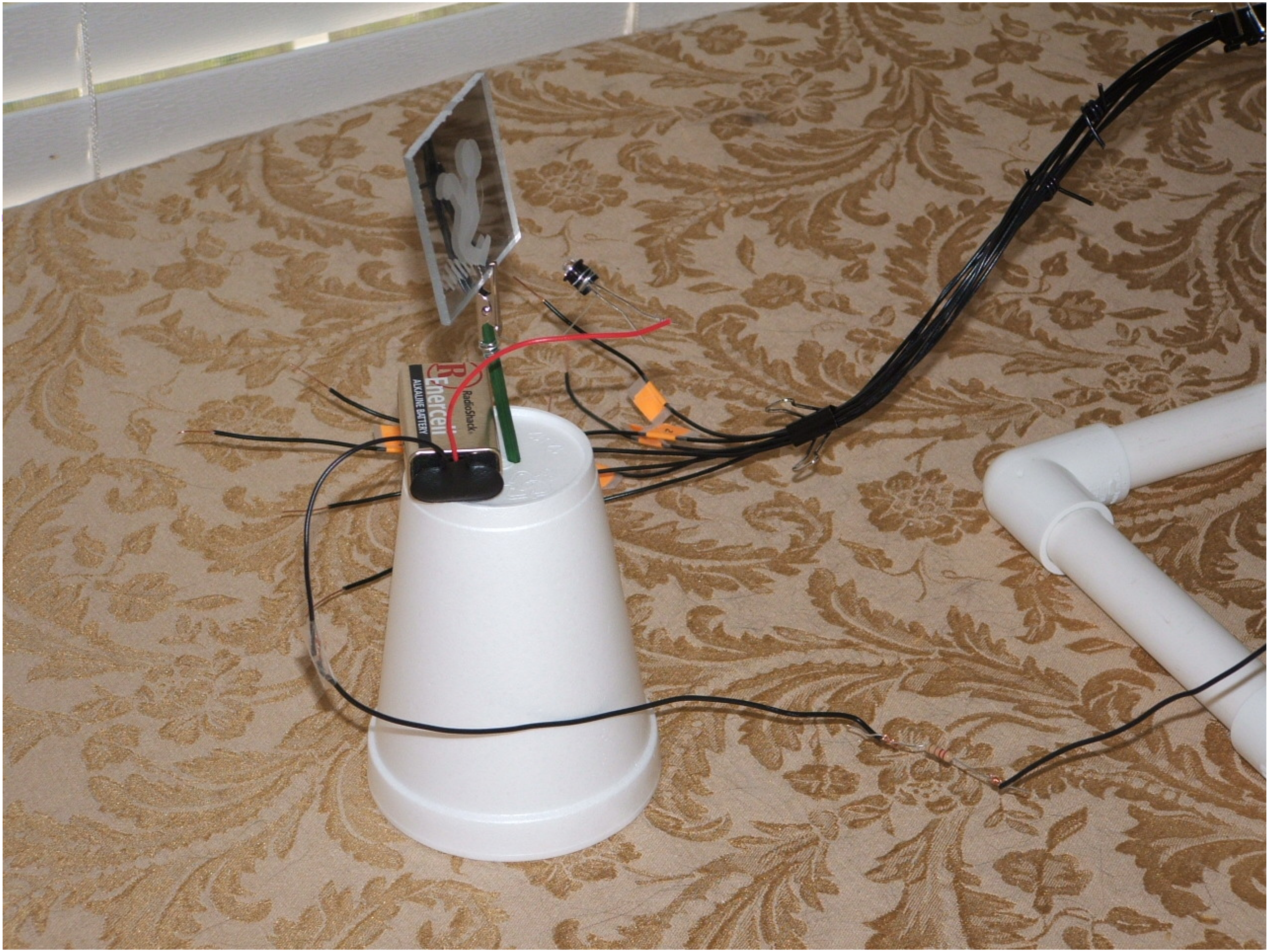

Energizer
Energizer

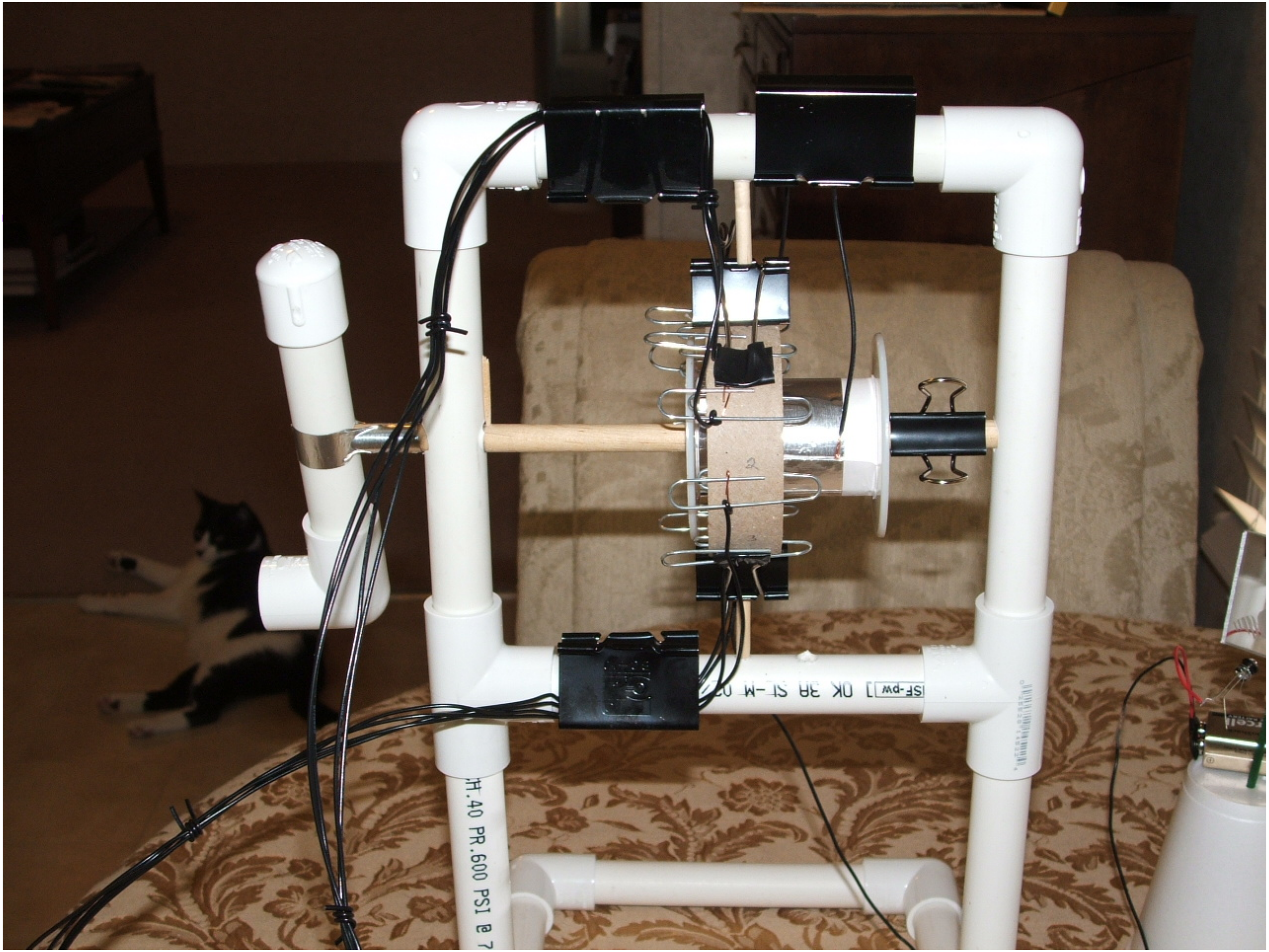
Reflected Motion

Related science topics: light, reflection, diffuse vs. specular reflection, & elementary electronic circuit design (resistors, diodes, series circuits, energy conversion)



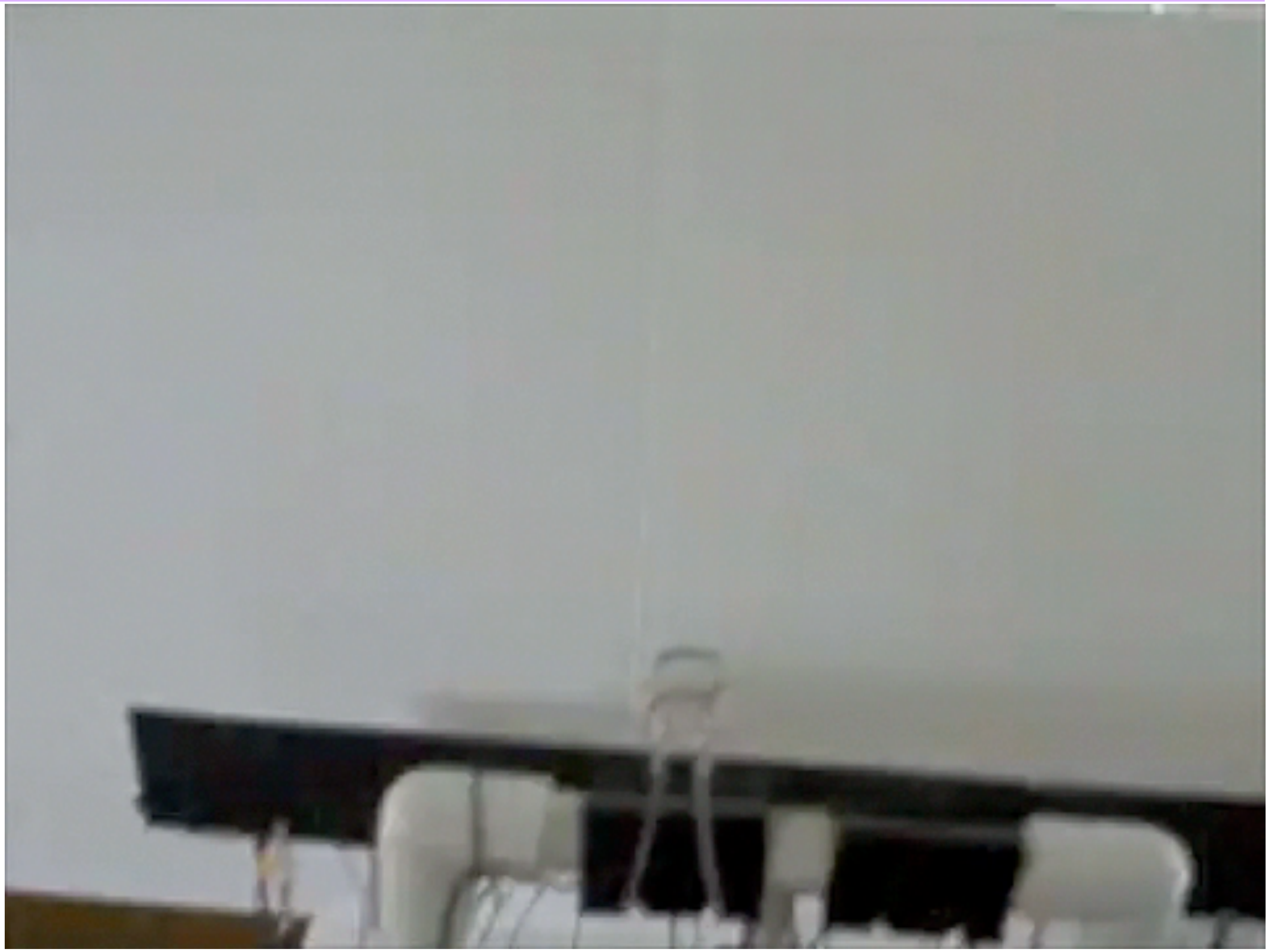

Berkley
Trilene
Super-Strong
High-Impact
Fishing Line
75 YD.
Made & Printed in USA


RadioShack
Enercell
ALKALINE BATTERY




Brew a Fresh
Cup Every Time.
Folgers

Special thanks to: Gary, Bryan, Augie, and Matt for their assistance!



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The figure exhibits wave-like motion.

Summary of Accomplishments

1. Became familiar with LIGO Science and the LOOC-UP project
2. Became familiar with the science potential of optical follow-ups of candidate GW events (GRB, SN, etc.)
3. Became competent in MATLAB programming and algorithm development for LOOC-UP
4. Worked on developing first astronomical image processing pipeline for LOOC-UP
   4a. Defined code requirements
   4b. Developed modules to meet requirements
5. Developed educational "snack" prototype, and additional snack for SEC.

Emergency Slides

Thresholding

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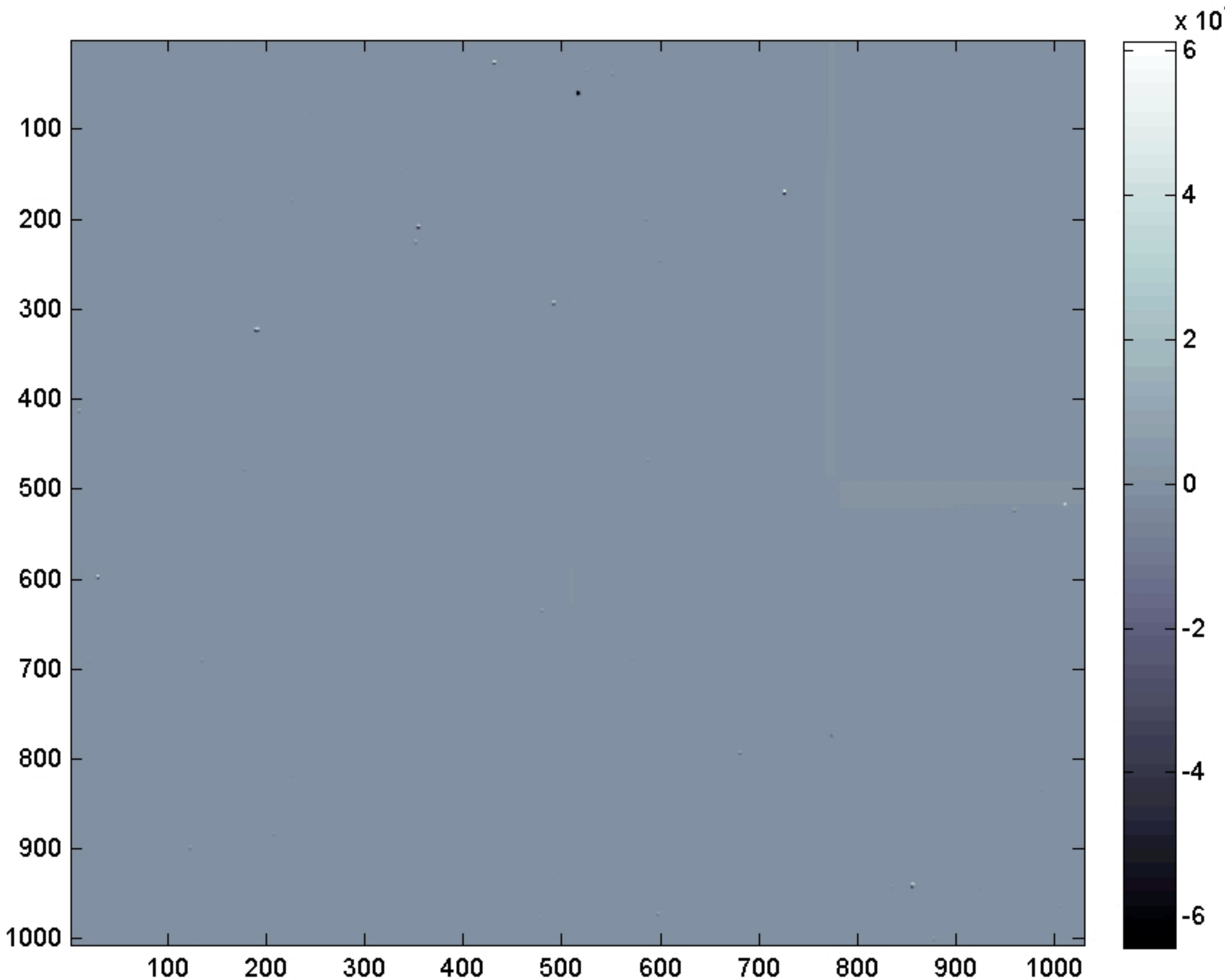
Results of Thresholding

NGC2976_003 minus NGC2976_002: threshold intensity +/- 12000 or 10%

possible transient found at location	possible transient found at location
x = 1011	x = 516
y = 516	y = 60
Intensity = 14129	Intensity = -29611
Size = 20	Size = 28



x 10^4
6
4
2
0
-2
-4
-6
100
200
300
400
500
600
700
800
900
1000
100
200
300
400
500
600
700
800
900
1000