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MOORHEAD

Python for Astronomy

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Slides/links at: https://github.com/mwcraig/und-2018-talk

Acknowledgements

- Current students
  - Erin Aadland
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  - Nathan Walker
  - Laura Herzog
  - Michael Meraz
  - Connor Stotts
  - Nathan Heidt
  - Hollee Johnson
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  - Juan Cabanela
  - Linda Winkler

Outline

- Python and Jupyter
  - The five-minute overview
- The Astropy project
  - Core package: astropy
  - Relevant affiliated packages
- Graphical interfaces
  - Data reduction
  - Photometry
  - Image viewing
- Science application: per-image magnitude transforms

Getting set up

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- Installation
  - Easiest: Download and install the Anaconda Python distribution
    - Easy to install binary for Mac, Windows, Linux
  - Other options: python.org or Enthought Python distribution
- Launching notebook
  - Open terminal
  - Change to correct directory
  - type: **`jupyter notebook`**
  - wait for browser…

Python

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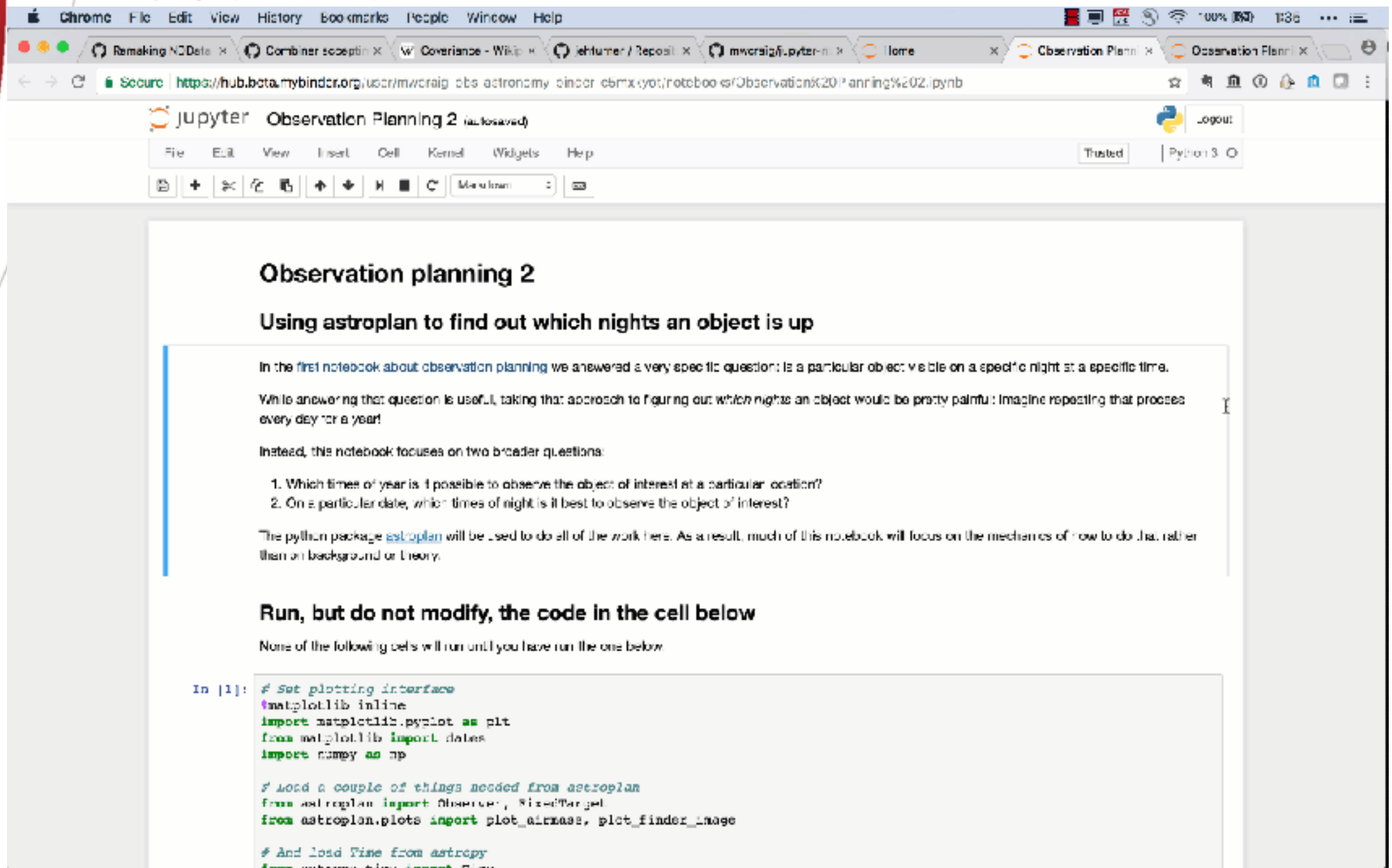
- Rapid adoption in astronomy
- Widely used outside astronomy
- Fast numerical libraries
- Rich set of plotting packages
- Accessible (used in 1st-year physics)
- Powerful
  - analysis environment for LSST
  - pipeline for JWST

Jupyter notebooks

- Combine text, code, output in single document



Jupyter notebook

- Flexible architecture can run on:
  - completely on your laptop, or
  - secure server with authenticated accounts
  - public server without authentication
  - cloud servers
    - To try the notebook you just saw go to:

      https://goo.gl/RG4uLg

      then “Observation Planning 2.ipynb”
    - Server dies after ~1 hour of idle time

The Astropy project

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- http://astropy.org
- Community effort to coordinate development of Python for Astronomy
- All code has
  - open source, permissive license
  - automated tests run on every change
  - extensive documentation

astropy code

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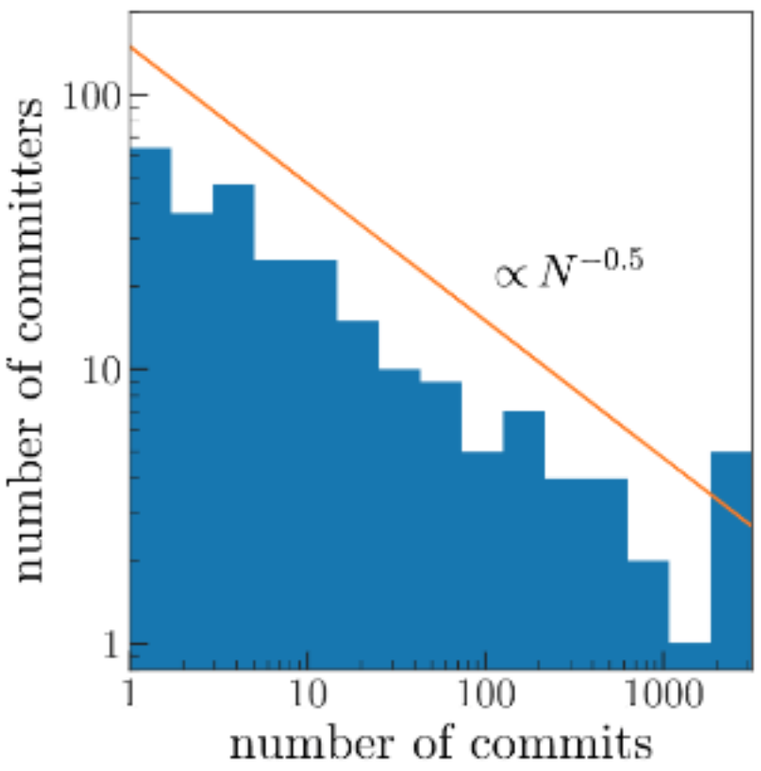
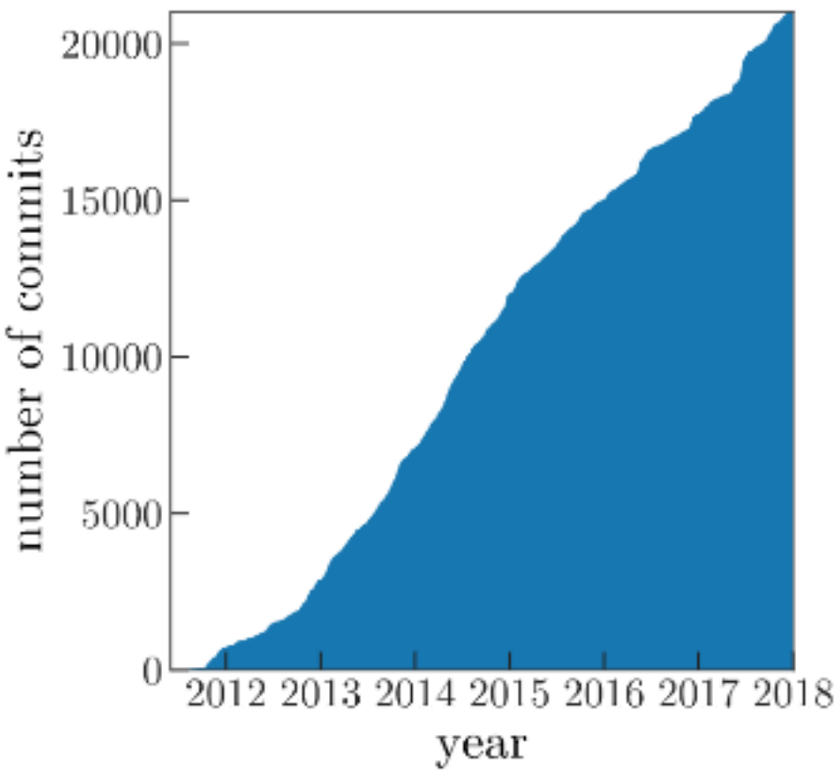
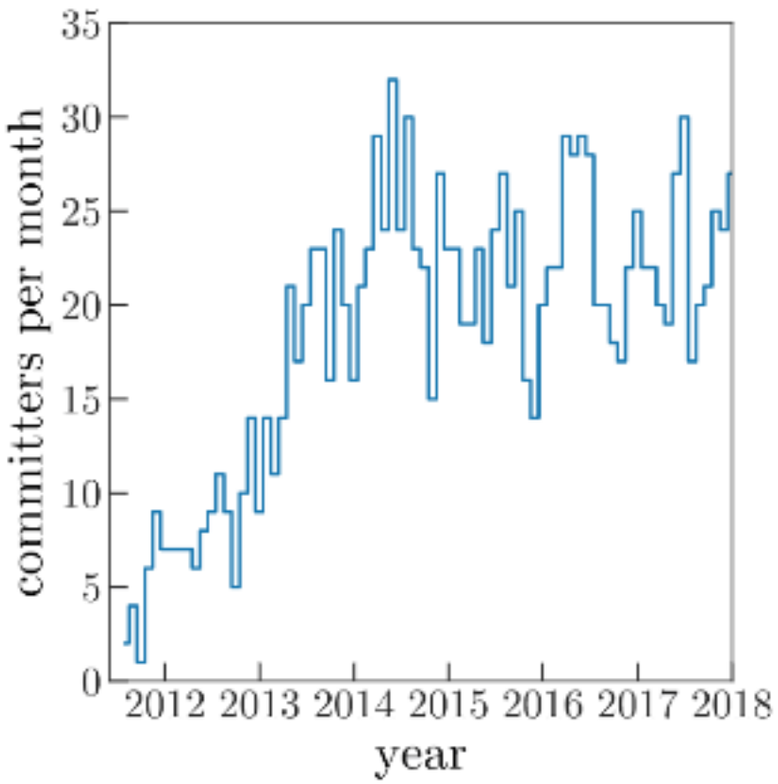
- astropy core
  - components common to most astronomy
- affiliated packages
  - more specialized tools
  - roughly 35 packages (and growing)
- community-developed
  - 3-4 FTE support from STScI
  - 1-2 FTE support from other large organizations
  - over 200 contributors

commit metrics







- From *The Astropy Project: Building An Inclusive, Open-science Project*..., Astropy Collaboration, Price-Whelan et al (2108)
- https://arxiv.org/abs/1801.02634

astropy core

- `astropy` package includes:
  - times (UTC, TT, TAI, TDB..)
  - coordinates (ICRS, FK4, FK5, Galactic, ...)
  - units
  - tables
  - WCS (translates pixels ↔ sky)
  - modeling and fitting
  - Lomb-Scargle periodogram

units

```
>>> import astropy.units as u
>>> u.meter
>>> u.m
>>> u.kilometer
>>> u.km
```

```
>>> q1 = 15 * u.meter
>>> q2 = [4., 8., 15., 16.] * u.k
>>> q2.to(u.femtometer)
```

from: https://github.com/astropy/astropy-workshop

astropy.time

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- (see notebook)
- From:
  https://github.com/mwcraig/obs-astronomy-binder

Tutorial materials

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https://github.com/astropy/astropy-workshop

affiliated packages

- image reduction
  - ccdproc
    - make masters
    - apply calibration masters to data
    - align and combine based on WCS (reproject)
    - cosmic ray removal (astroscrappy)
- photometry
  - photutils
    - background removal
    - aperture photometry
    - PSF photometry
  - sep
    - [technically, not affiliated]
    - Internals of SExtractor, wrapped in Python

affiliated packages

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- catalog query/data retrieval
  - astroquery provides Python interfaces to
    - Simbad
    - Vizier (VSX, APASS, …)
    - Gaia
    - NIST
    - IRSA dust extinction
    - …
- Planning
  - astroplan
    - airmass/visiblity charts
    - basic finding charts
    - observation scheduler/optimizer
- Visualization
  - ginga
    - framework for writing visualization tools

Data reduction

- Snippet for reducing one image

```
ccd = ccdproc.CCDData(img, unit=u.adu)
ccd.header['exposure'] = 30.0  # for dark subtraction
nccd = ccdproc.ccd_process(ccd, oscan='[201:232,1:100]',
                           trim='[1:200, 1:100]',
                           error=True,
                           gain=2.0*u.electron/u.adu,
                           readnoise=5*u.electron,
                           dark_frame=master_dark,
                           exposure_key='exposure',
                           exposure_unit=u.second,
                           dark_scale=True,
                           master_flat=master_flat)
```

Data reduction

Coordinators:
Steve Crawford (@crawfordsm)
Michael Seifert (@MSeifert04)
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Yoonsoo P. Bach (@ysBach)
Kyle Barbary (@kbarbary)
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Christoph Deil (@cdeil)
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Nathan Heidt (@heidtha)
Elias Holte (@Sondanaa)
Anthony Horton (@AnthonyHorton)
Jennifer Karr (@JenniferKarr)
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Stefan Nelson (@stefannelson)
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Zè Vinícius (@mirca)
Josh Walawender (@joshwalawender)
Nathan Walker (@walkerna22)
Jiyong Youn (@hletrd)

Data reduction: reducer

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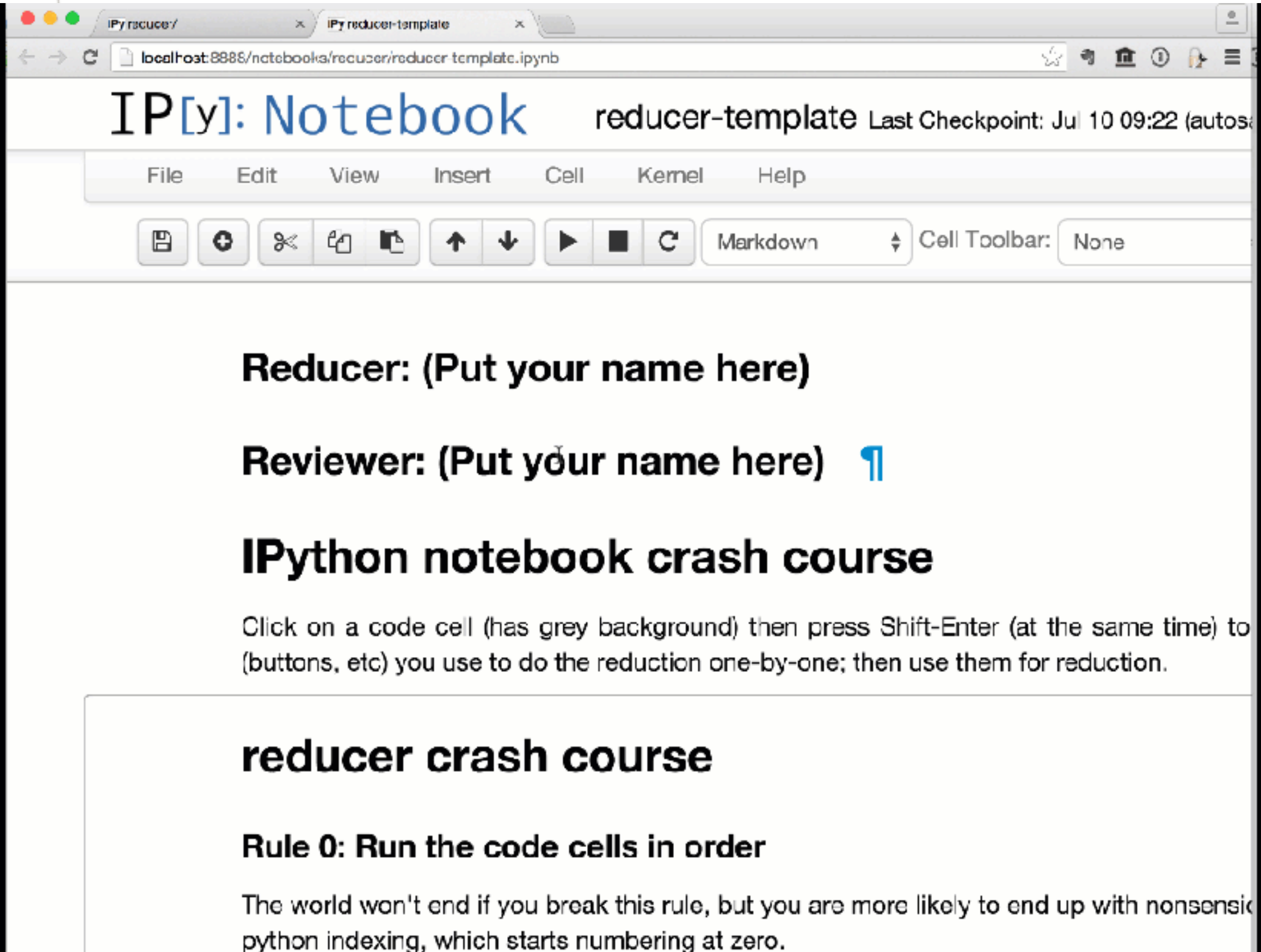

reducer

- jupyter notebook with interactive widgets
- Try it at: https://goo.gl/rgyLf6

Photometry, currently

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- Wrapper around photutils to
  - detect stellar sources in an image
  - perform aperture photometry, with
  - rejection of outlying background pixels
- GUI on the way
  - Ideas?
  - Wish list?
- NOTE: all aperture photometry in rest of talk done in AstroImageJ

Image viewer in notebook

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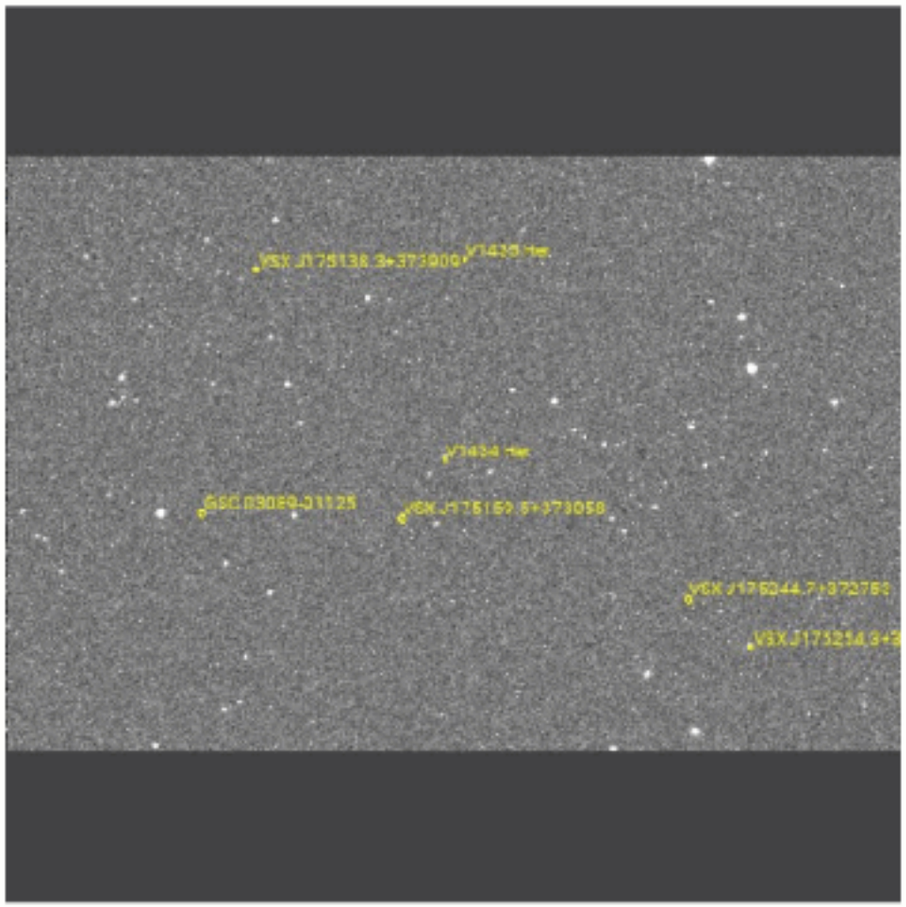
```
catalog.observe(overlay_catalog, names='value')
```

```
In [15]: hb
```



RA: 268.24648°, Dec: 37.656364

Catalog: None, VSX, AAVSO, AJ Index

268.04505 | 37.559528

```
In [16]: ra, dec = (268.029349, 37.545377)
         coord = SkyCoord(ra, dec, unit='deg')
         cat = data[catalog.value[0]]
         cat_coords = SkyCoord(cat['RAJ2000'], cat['DEJ2000'])
         idx, _ = coord.match_to_catalog_sky(cat_coords)
```

star 92/VSX J175159.5+373058

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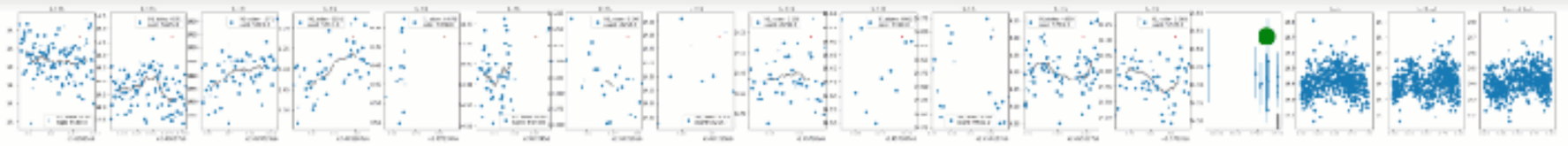
Chrome File Edit View History Bookmarks People Window Help 100% 2:36

localhost:8889/notebooks/image-viewer-matt-version-functions-removed.ipynb

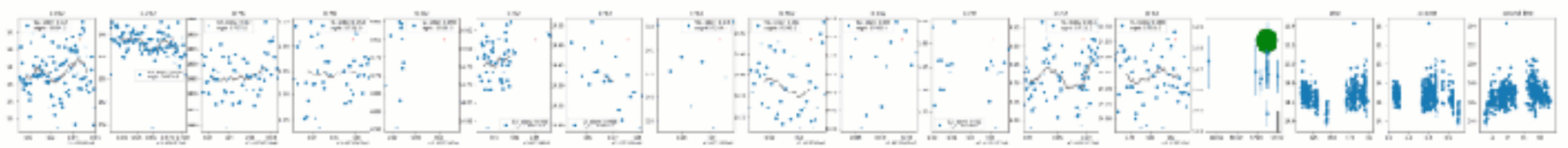
jupyter image-viewer-matt-version-functions-removed Last Checkpoint: 9 hours ago (autosaved) Logout

File Edit View Insert Cell Kernel Widgets Help Trusted Python 3



```
/Users/ncraig/Development/astronomy/Glowing-Pancakes/notebook_functions.py:107: FutureWarning: pd.rolling_mean is deprecated for ndarrays and will be removed in a future version
  plt.plot(pd.rolling_mean(times, 20, center=True),
/Users/ncraig/Development/astronomy/Glowing-Pancakes/notebook_functions.py:108: FutureWarning: pd.rolling_mean is deprecated for ndarrays and will be removed in a future version
  pd.rolling_mean(mags, 20, center=True),
```

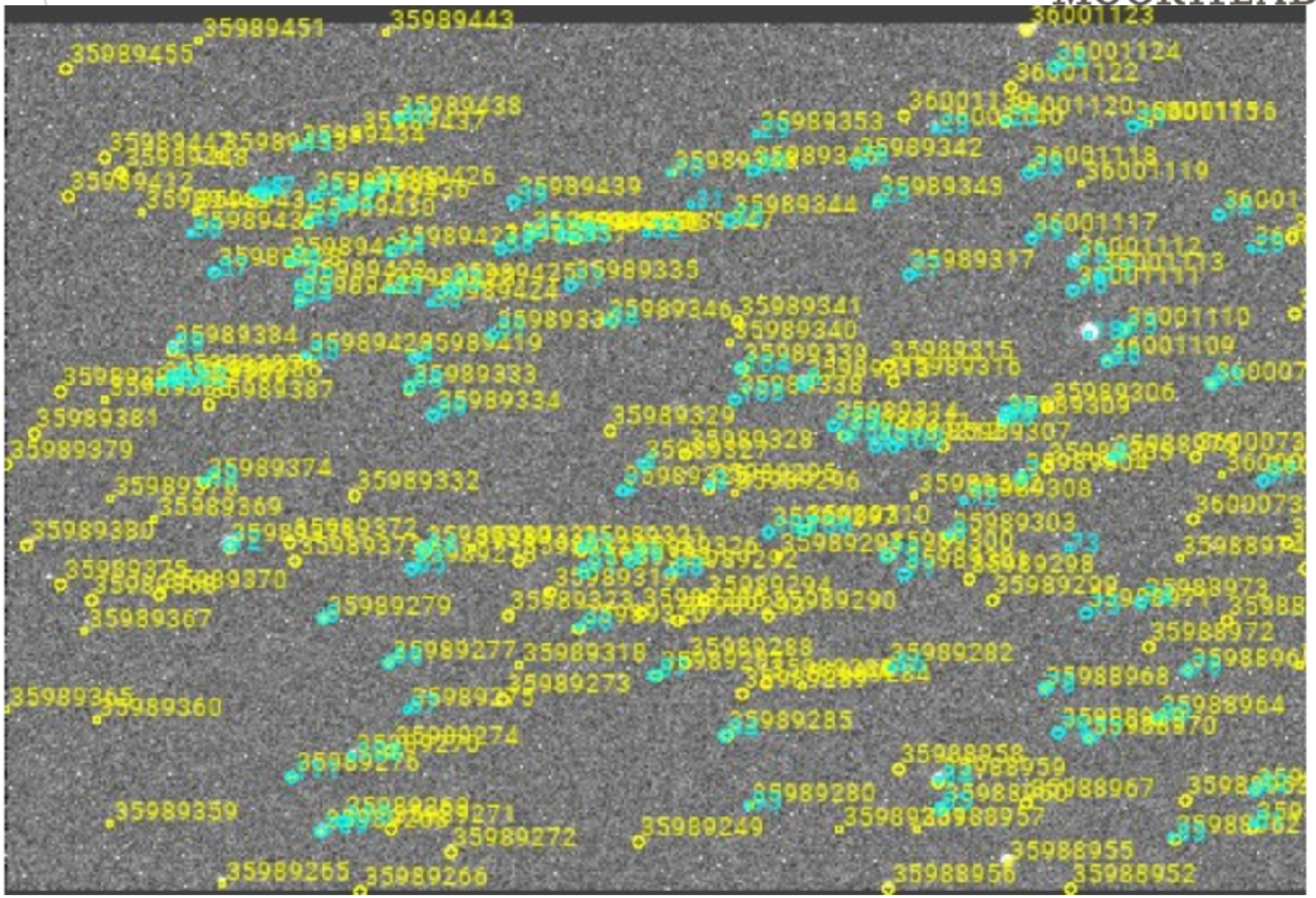
```
92 0.162831525306
Finding optimal frequency:
 - Estimated peak width = 0.00372
 - Using 5 steps per peak; omega_step = 0.000743
 - User-specified period range:  0.01 to 10
 - Computing periods at 844780 steps
Zooming-in on 5 candidate peaks:
 - Computing periods at 1000 steps
[ 1.63595153  0.80163933]
```



```
/Users/ncraig/Development/astronomy/Glowing-Pancakes/notebook_functions.py:107: FutureWarning: pd.rolling_mean is deprecated for ndarrays and will be removed in a future version
  plt.plot(pd.rolling_mean(times, 20, center=True),
/Users/ncraig/Development/astronomy/Glowing-Pancakes/notebook_functions.py:108: FutureWarning: pd.rolling_mean is deprecated for ndarrays and will be removed in a future version
  pd.rolling_mean(mags, 20, center=True),
/Users/ncraig/Development/astronomy/Glowing-Pancakes/notebook_functions.py:69: RuntimeWarning: Mean of empty slice
  mean = np.nanmean(mags)
/Users/ncraig/anaconda/envs/gw/lib/python3.6/site-packages/numpy/lib/nanfunctions.py:1427: RuntimeWarning: Degrees of freedom <= 0 for slice.
  keepdims=keepdims)
```

```
93 0.286789883567
Finding optimal frequency:
 - Estimated peak width = 0.00441
```

frame-by-frame transform

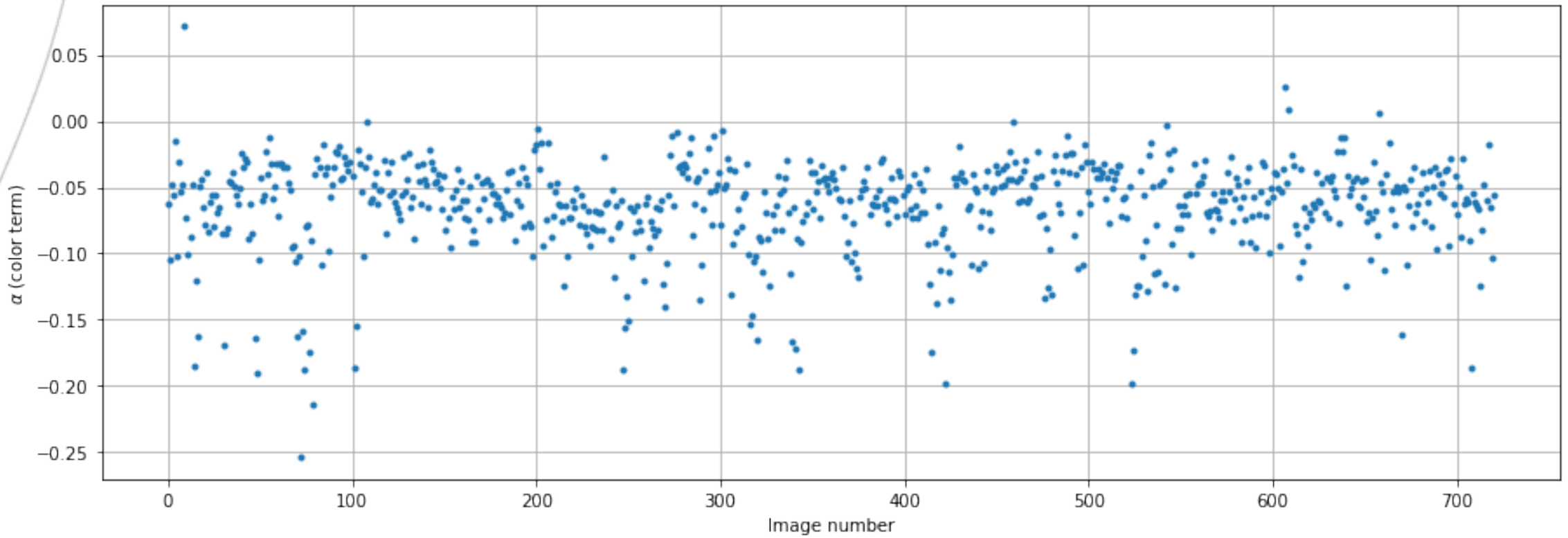


frame-by-frame transform

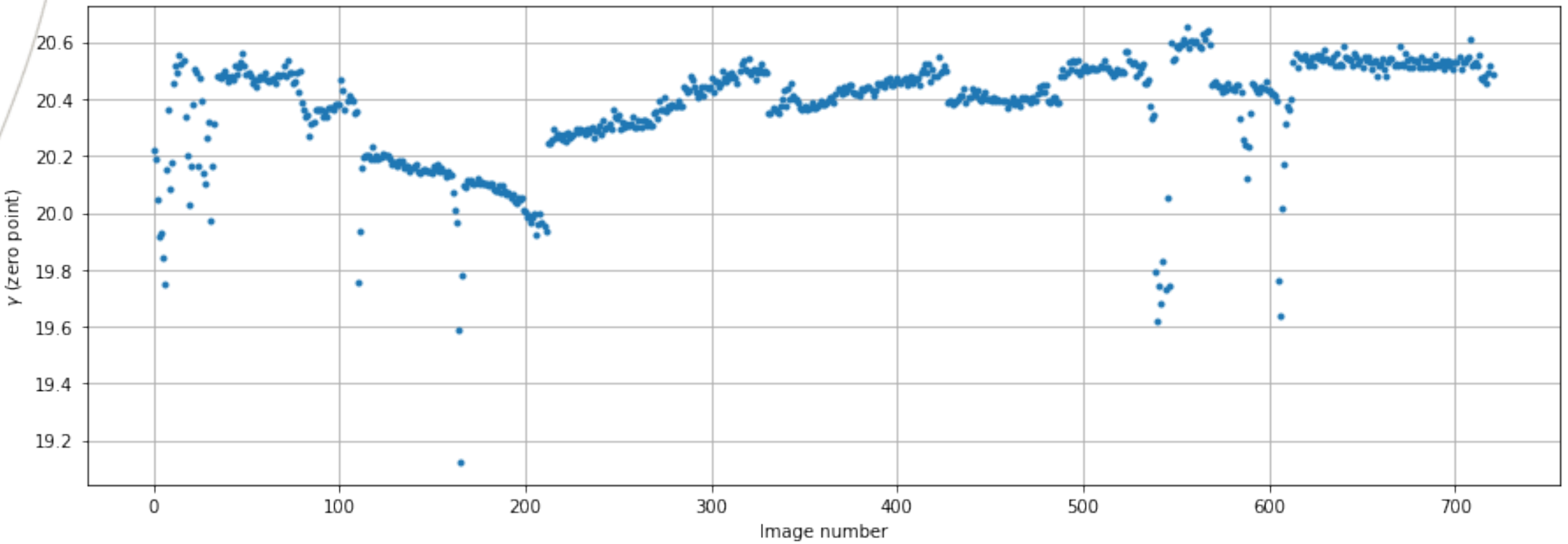
- match photometer star to APASS
  - Filter APASS: $\delta r < 0.05, \quad \delta(B-V) < 0.1$
  - Transform APASS r to R
- for each frame:
  - calculate transform coefficients including color correction

$$R_{APASS} - R_{inst} = \alpha(B-V)_{APASS} + \gamma$$

Color coefficient



zero point

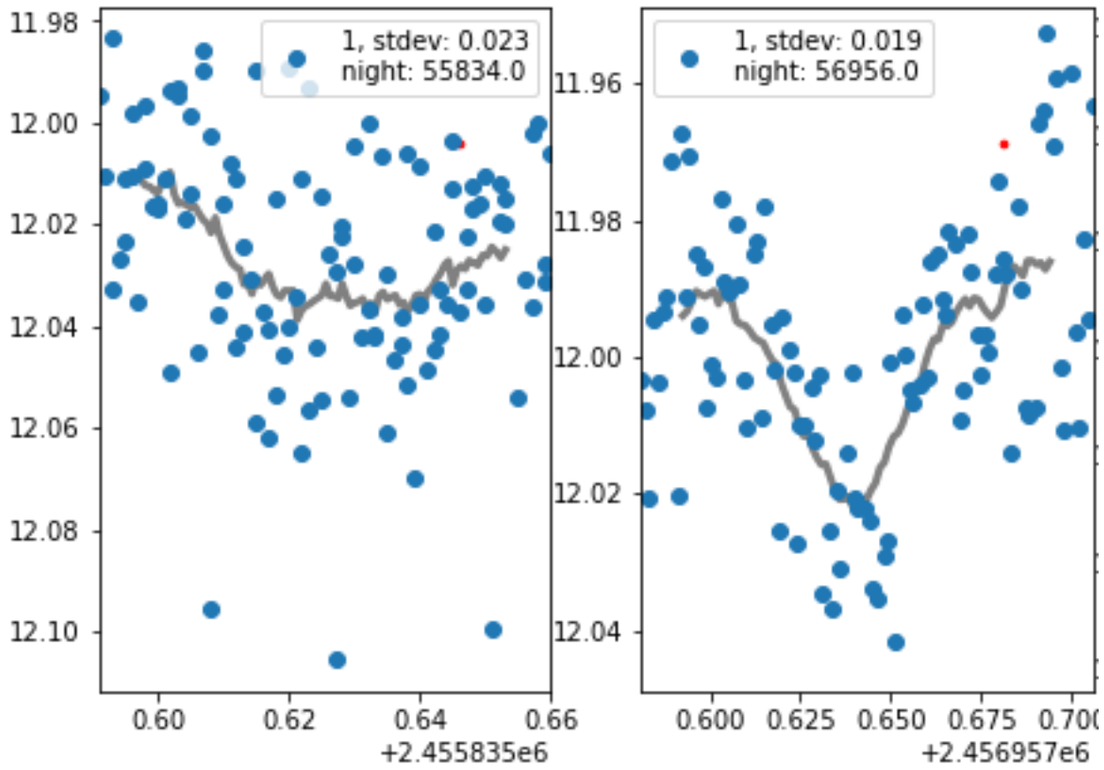

20.6
20.4
20.2
20.0
19.8
19.6
19.4
19.2
γ (zero point)
0
100
200
300
400
500
600
700
Image number

transform all stars

- match each star to APASS
  - No quality restriction on APASS stars
- frame-by-frame
  - Apply transform for that frame to all stars

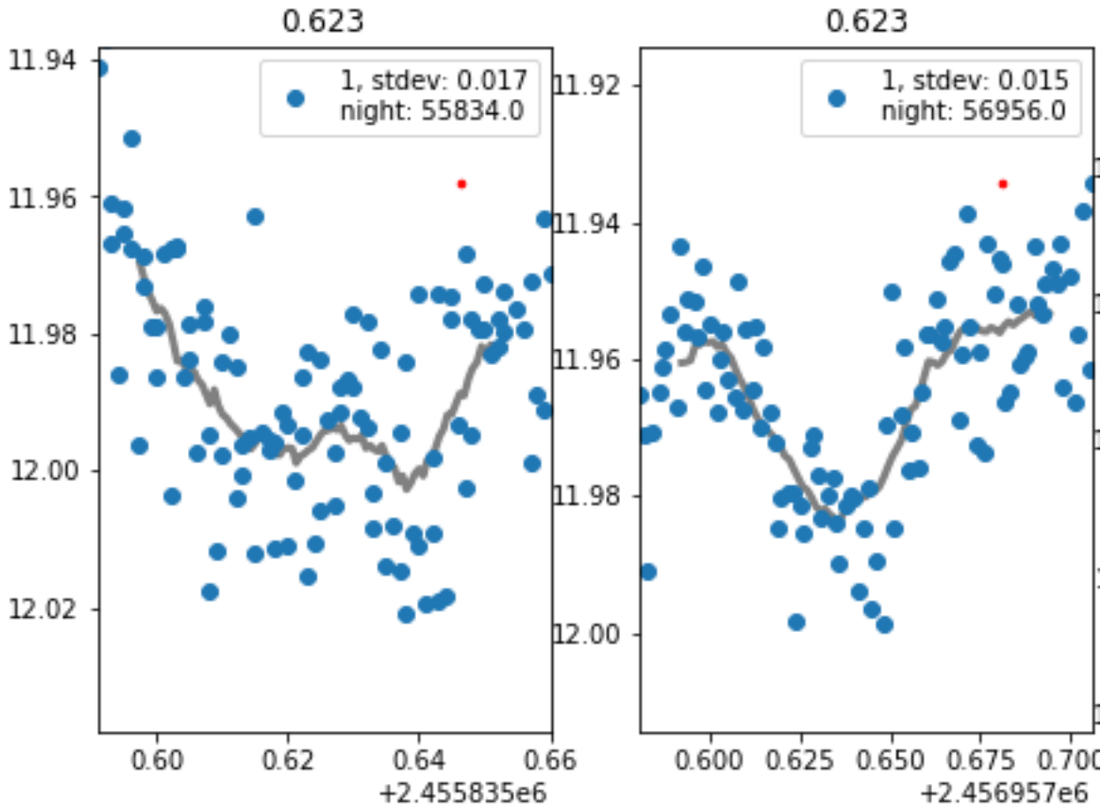
No color term

- TrES-3, two transits
- Corrected for zero point only

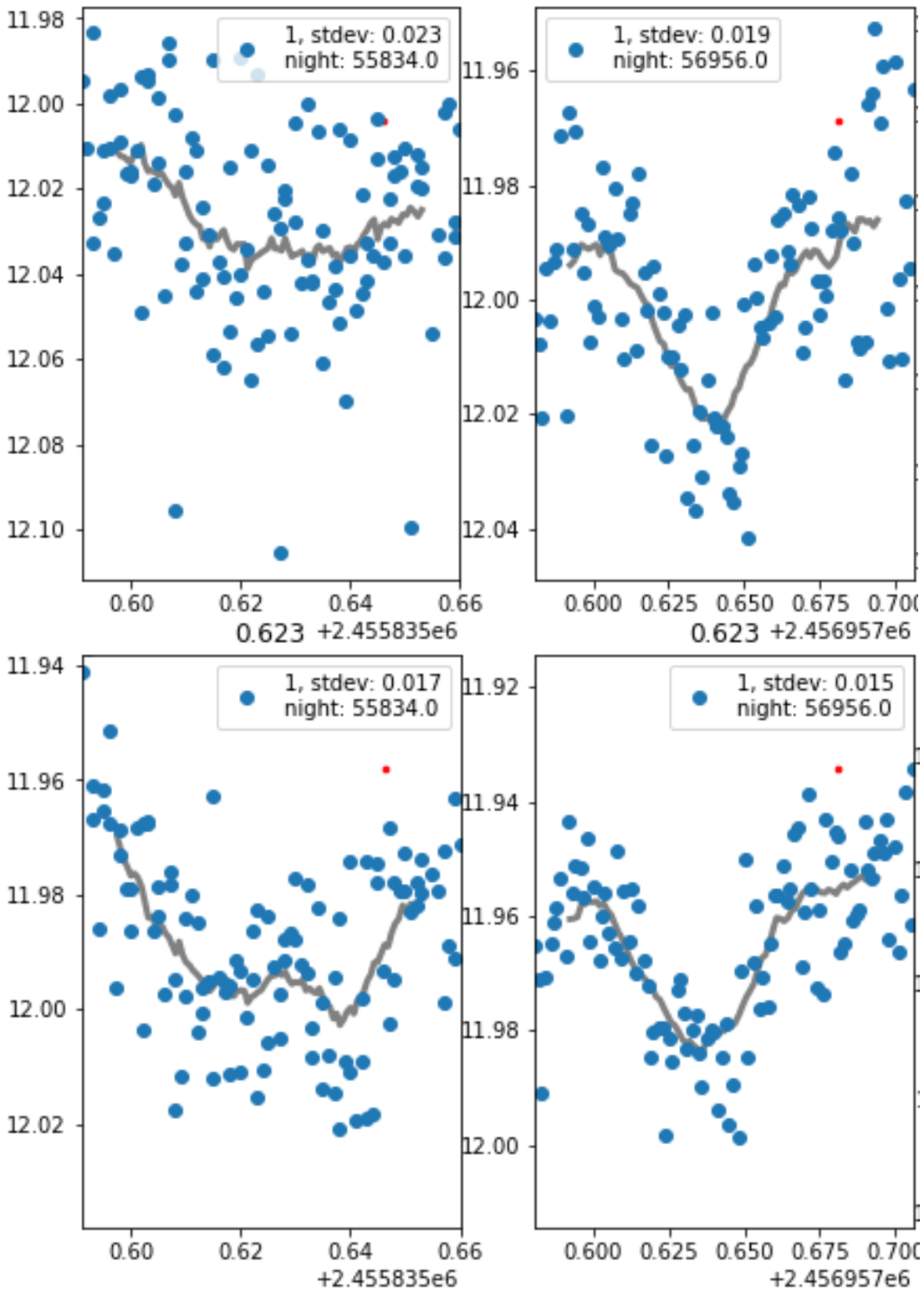


Linear color term

- Same two nights, linear color correction



do color corrections!



Next steps

- Instrumental colors vs APASS colors
- Test in other filters
- More robust period estimation
- Bundle photometry code into one package
  - package name?
- Address installation

Questions?

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Slides/links at: https://github.com/mwcraig/und-2018-talk

Links

- lemon: http://lemon.readthedocs.org/en/latest/
  - end-to-end data reduction and photometry
- OSCAAR: http://oscaar.github.io/OSCAAR/
  - Focuses on exoplanet transit measurements
- gatspy: http://www.astroml.org/gatspy/
  - fast Lomb-Scargle implementation
- conda-build-all: https://github.com/SciTools/conda-build-all
  - eases the pain of building packages
- sep: http://sep.readthedocs.org/en/v0.5.x/
  - Photometry (uses internals from SExtractor)
- astroquery: http://astroquery.readthedocs.org/
  - Search a variety of online data sources from python.
- ginga: https://ejeschke.github.io/ginga/
  - Image viewer framework (and a reference viewer)
- ccdproc: http://ccdproc.readthedocs.org/en/latest/
  - Data reduction
- photutils: https://photutils.readthedocs.org/en/latest/
  - Photometry (including, but not limited to, IRAF-equivalents)
- AstroImageJ: http://www.astro.louisville.edu/software/astroimagej/
  - Very nice graphical interface with sophisticated fitting and graphing
- reducer: http://reducer.readthedocs.org/en/latest/
  - Widget-interface to ccdproc reduction
- glowing-waffles: https://github.com/glowing-waffle/glowing-waffles
  - Very much work-in-progress, examples from today will be up there by Tue, 3/22/16
- feder_image_shuffle: https://github.com/mwcraig/feder_image_shuffle
  - Among other things, makes jpeg images and gallery pages, also demonstrates interacting with Github API.
- msumastro: https://github.com/mwcraig/msumastro
  - Infrastructure for adding metadata (largely telescope specific)