Status of ZTF Asteroid Detection & Plans for Asteroid Marshal

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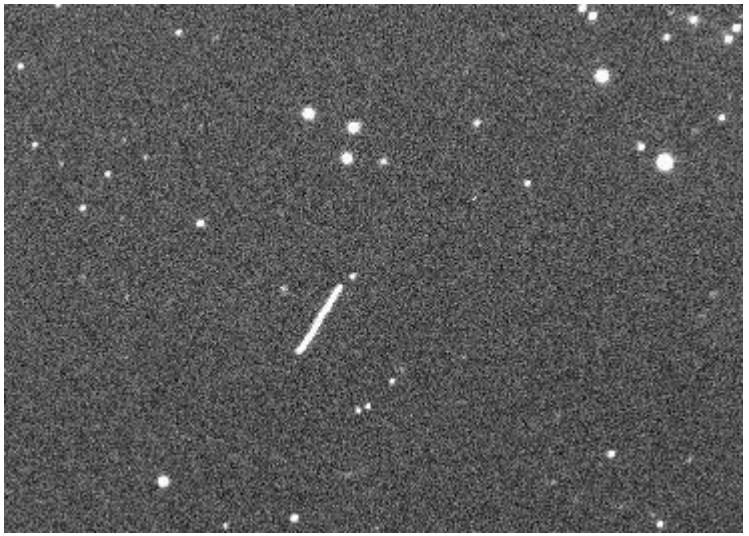
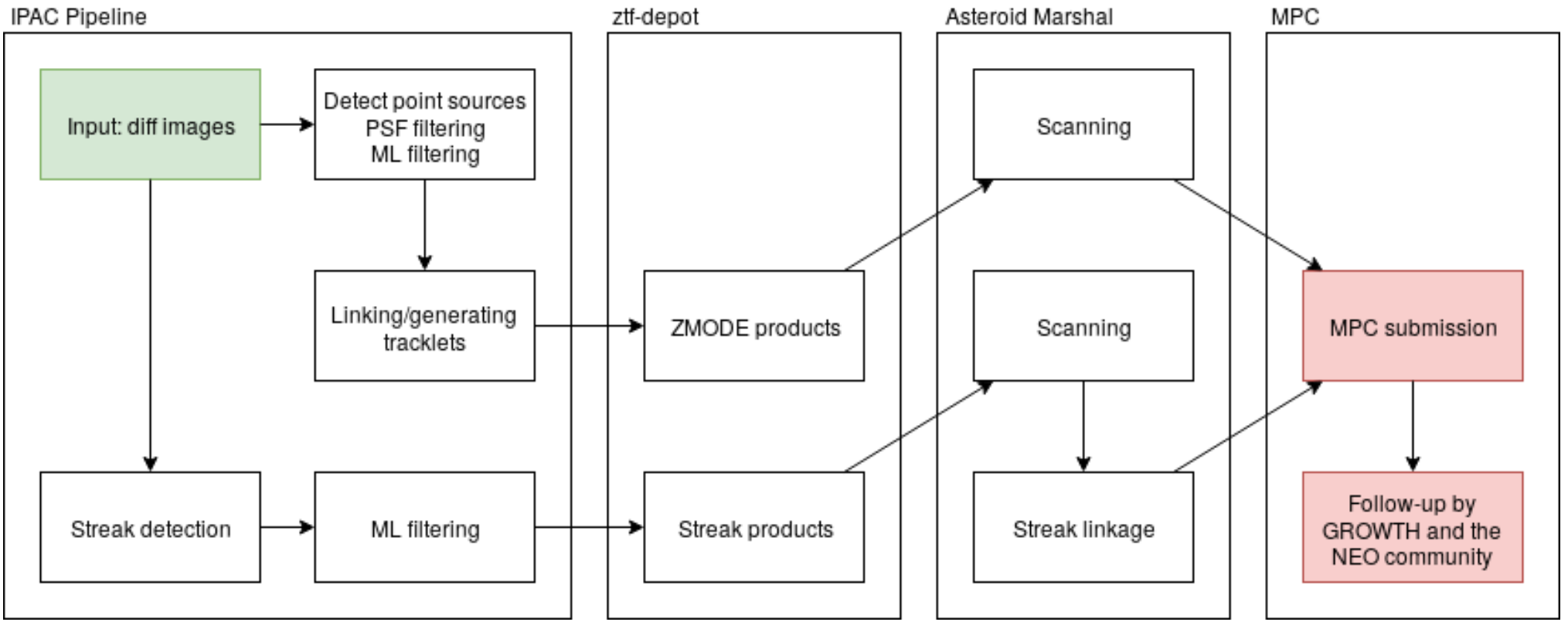
on behalf of the
ZTF Asteroid Detection Team

Asteroid detection with ZTF

- **Detect point-like moving object with ZMODE**
  - Most detections are main-belt asteroids; approximately ~0.1% are far-away NEAs
- **Detect trailed objects (streaks)**
  - Asteroids will trail when less than ~0.02 au from the Earth
  - Some “real” streaks are man-made objects; we do not know until orbital determination



Workflow


IPAC Pipeline
ztf-depot
Asteroid Marshal
MPC
Input: diff images
Detect point sources
PSF filtering
ML filtering
Linking/generating
tracklets
Streak detection
ML filtering
ZMODE products
Streak products
Scanning
Scanning
Streak linkage
MPC submission
Follow-up by
GROWTH and the
NEO community

Status of ZMODE

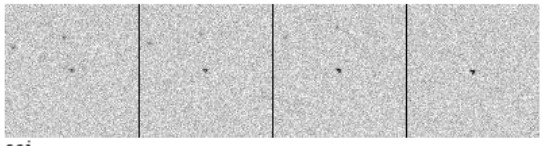
- **IPAC pipeline emits ZMODE products by PT noon**
  - MPC report and digest scores of intra/inter-night tracklets
  - Stamps of science and reference images
  - IPAC pipeline will label known SSOs
- **Review of ZMODE tracklets is usually done within 1-2 hours after they are emitted**
  - QA is done via a Jupyter notebook running on a workstation at IPAC

ZMODE review notebook

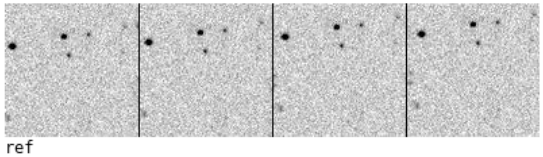
Jupyter QtConsole

File Edit View Kernel Window Help

```
     ZTF0021  C2018 03 06.36116 11 58 41.28 +39 56 00.8          16.76r      I41
```

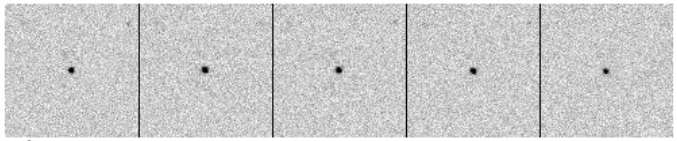


sci

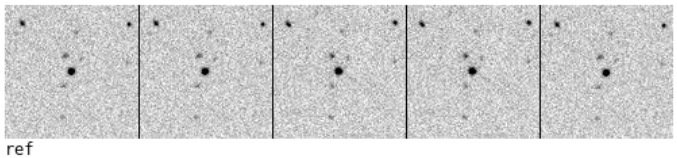


ref

```
Desig.    RMS NEO N22 N18 Hun Pho MB1 MB2 MB3 Hil JTr  MC Pal Han JFC
ZTF0021  0.28  97  36   0   0   0   0   0   0   0   0   3   0   0   1

!!! Possible NEO !!! Possible NEO !!! Possible NEO !!! Possible NEO !!! Possible NEO !!!

63/72 objects remaining... [a]ccept or [r]eject (default: r)?
================================================================================
     ZTF0009* C2018 03 06.26587 10 17 52.58 +17 25 40.0          18.21r      I41
     ZTF0009  C2018 03 06.28951 10 17 52.59 +17 25 40.0          18.15r      I41
     ZTF0009  C2018 03 06.29050 10 17 52.59 +17 25 40.1          18.12r      I41
     ZTF0009  C2018 03 06.29248 10 17 52.59 +17 25 40.0          18.29r      I41
     ZTF0009  C2018 03 06.31314 10 17 52.60 +17 25 39.8          18.39r      I41
```



sci



ref

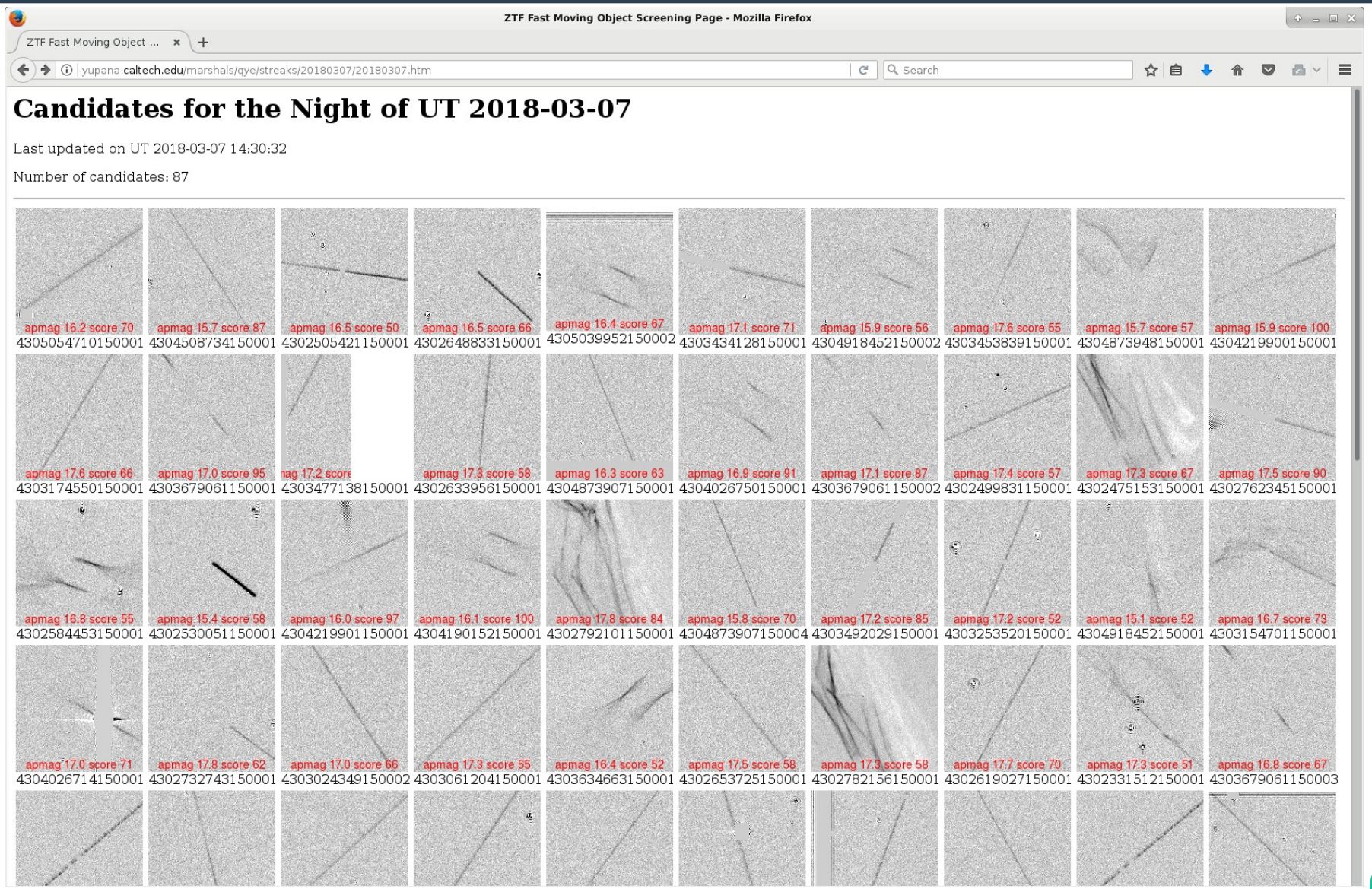
```
Desig.    RMS NEO N22 N18 Hun Pho MB1 MB2 MB3 Hil JTr  MC Pal Han JFC
ZTF0009  0.08  97  21   0   0   0   0   0   0   0   0   3   0   0   0

!!! Possible NEO !!! Possible NEO !!! Possible NEO !!! Possible NEO !!! Possible NEO !!!

62/72 objects remaining... [a]ccept or [r]eject (default: r)?
```

Status of streak detection

- **IPAC pipeline emits streak products “on-the-fly”**
  - Condensed summary file, MPC reports, stamps from the differenced image
- **All stamps in the night are posted on yupana ~6:30 PT in the morning for the scanning team**
- **Scanning is usually done by noon PT**
- **Scanners identify possible reals; the team lead makes final decision, links different sightings, and makes MPC submission**

  (MPC submission requires a streak to be sighted for 2+ times)

Streak screening page



Performance so far

- **On a perfect night*, ZTF can:**
  - produces ~80,000 detections of ~20,000 unique asteroids, including ~10 NEAs and comets
  - discover ~50 new asteroids (mostly main-belts)
- **As of Mar 20, 2018:**
  - 531,725 observations (~10% of all MPC observations from Dec 3, 2017 to Mar 20, 2018)
  - 32,765 unique asteroids
  - 244 new asteroids, including 3 NEOs

*: Statistics based on the observations conducted during the reference building phase

Overall Status

- **Operation-level:**
  - Point-source component is ready for survey operation
  - Streak component is usable, but ML part needs more work
- **Collaboration-level**
  - Asteroid Marshal is at alpha phase; needs more work too

Problems – 1. streaks

- **Several ML models exist; need to be benchmarked**
  - Some miss many fainter streaks while others generate a lot of garbage – “optimal point” not yet reached
  - Performance of different streak ML model needs thorough evaluation

  Response: 1. gauge the efficiency of different ML models using known NEAs

  2. working with the ZTF-ML group to construct a better real/bogus sample

  3. explore Deep Learning as an alternative ML method

Problems – 2. marshal

- **Still largely rely on email for communication**
- **Marshal needs more work to streamline communication/coordination**
  - Desired functionalities:
    - On-page labeling and commenting
    - Streak linking tool
    - DB to keep track of labeling, submission etc.
    - Follow-up coordination with GROWTH marshal
  - Different requirement vs. other ZTF/GROWTH marshals (also the iPTF asteroid marshal); might be easier to start from scratch

Immediate Plans

- **Keep on doing daily review of ZMODE, streak products, submission to MPC as necessary**
- **Streak ML improvement**
  - Building up a “clean” streak real/bogus sample using available ZTF data; benchmark different ML models; explore different ML methods
  - Moves towards real time scanning with Asian/European collaborators
- **Marshal development**
  - Focus on key functionalities: on-page labeling/commenting; streak linking tool