Tools for solar system science

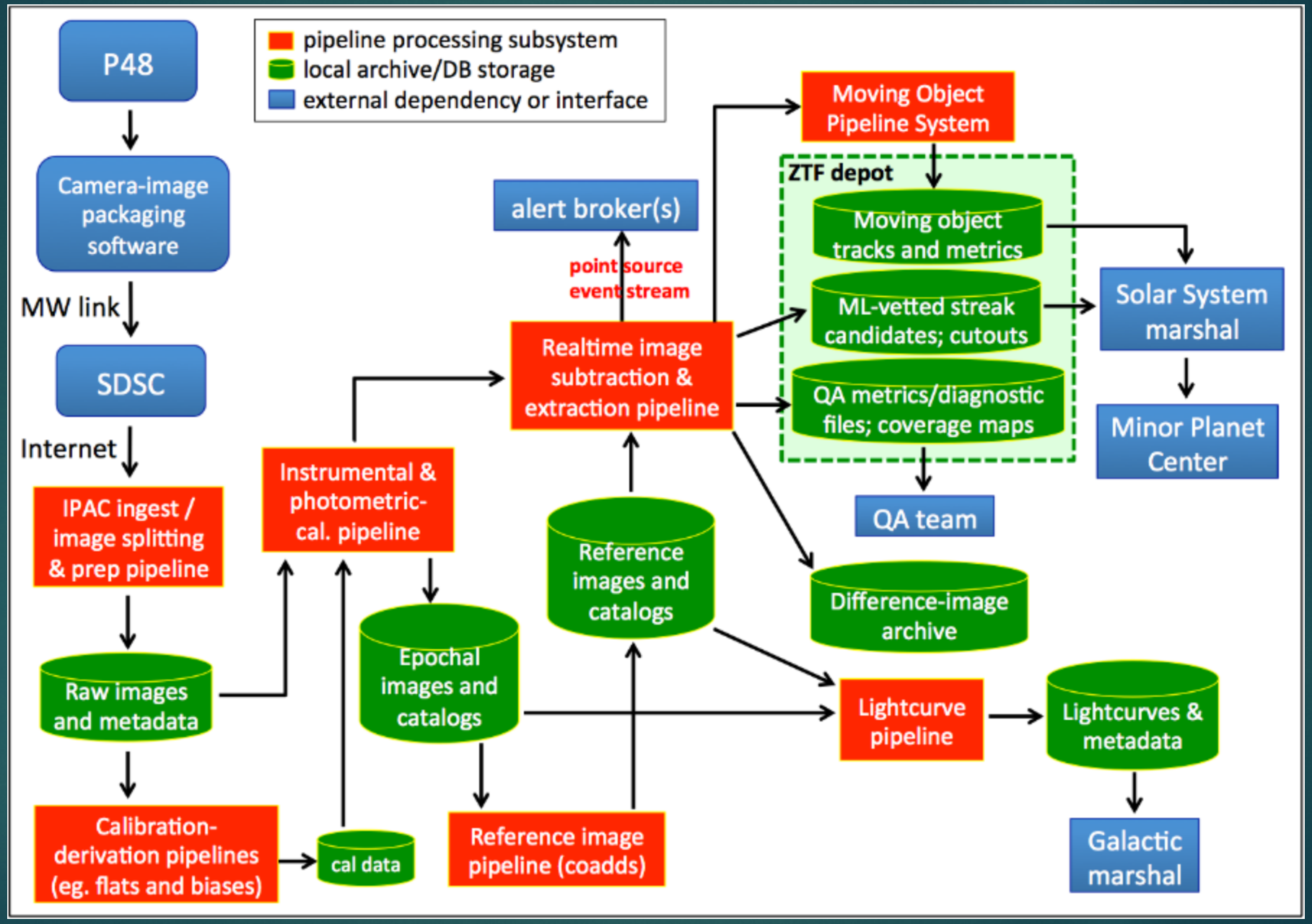
QUAN-ZHI YE & THE ZTF SOLAR SYSTEM TOOLS DEV GROUP

We love acronyms...

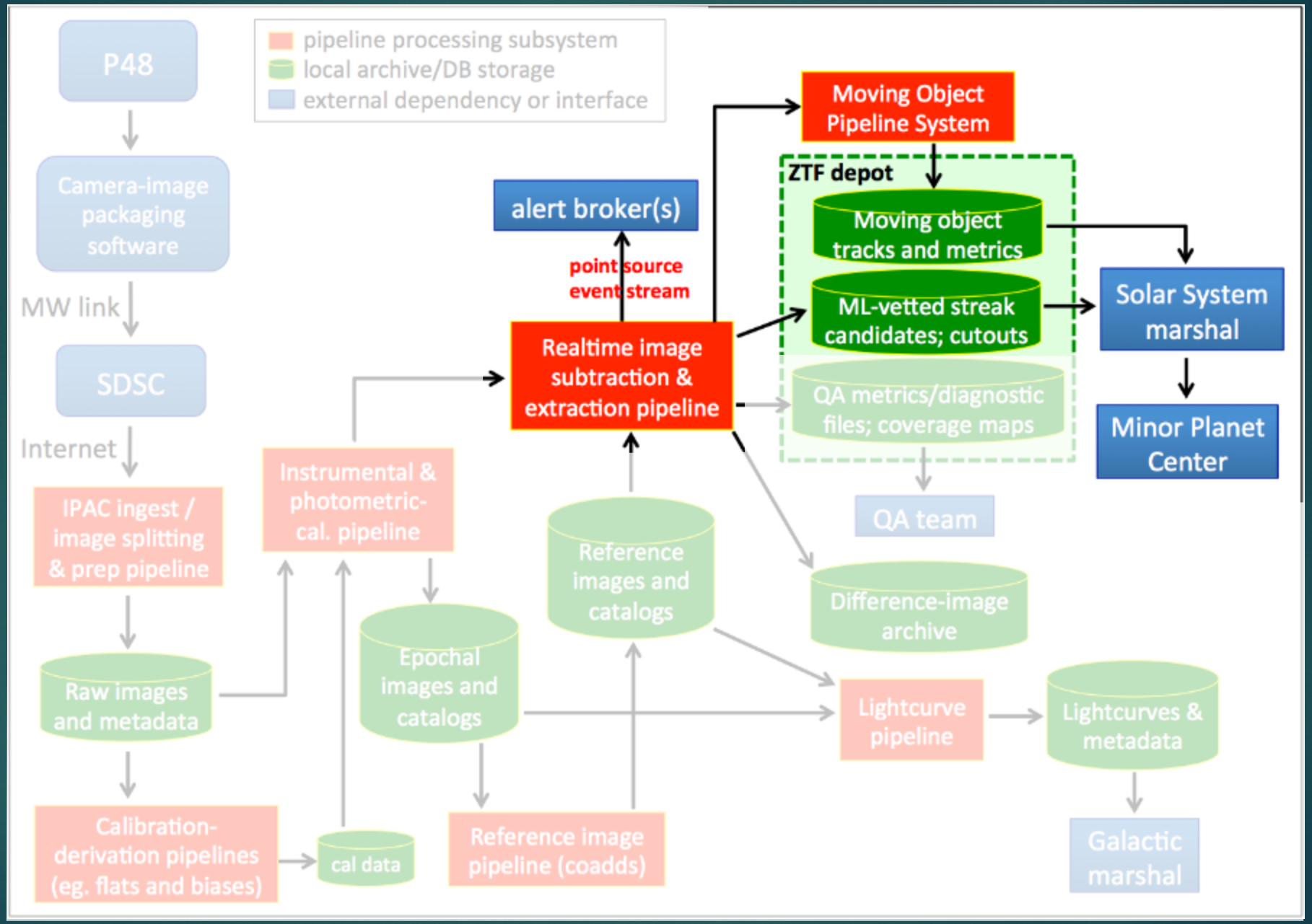
- NEO = Near Earth Object
- SFR = Superfast Rotator
- MPC = IAU Minor Planet Center
- SSO = Solar System Object

ZTF Solar System = 4 experiments

- Experiments that make use of all ZTF data
  - Streaking asteroid survey (streaks): Caltech, NCU
  - Long-term monitoring of comets: Caltech, UMD
- Dedicated surveys
  - Twilight survey (twilight time only): Caltech, NCU
  - Search for SFRs (dedicated high-cadence survey): NCU



Masci et al. (2017)



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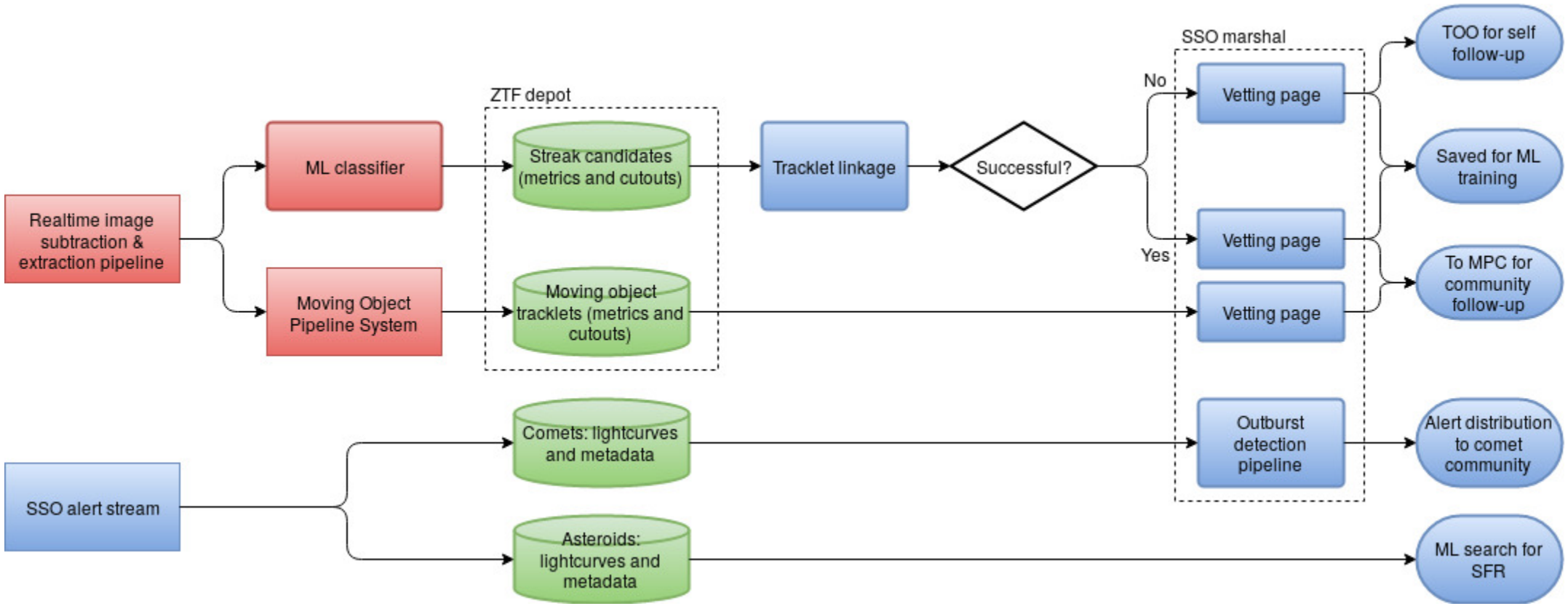
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Successful?
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TOO for self follow-up
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Alert distribution to comet community
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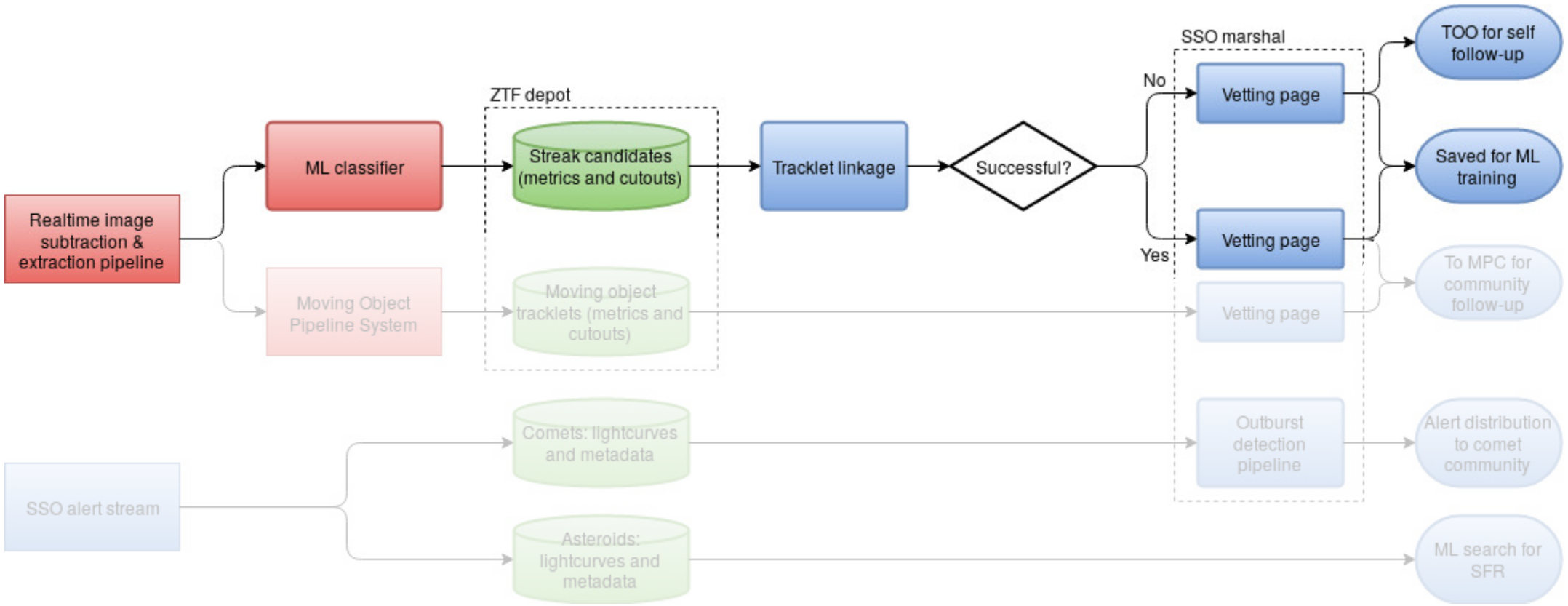
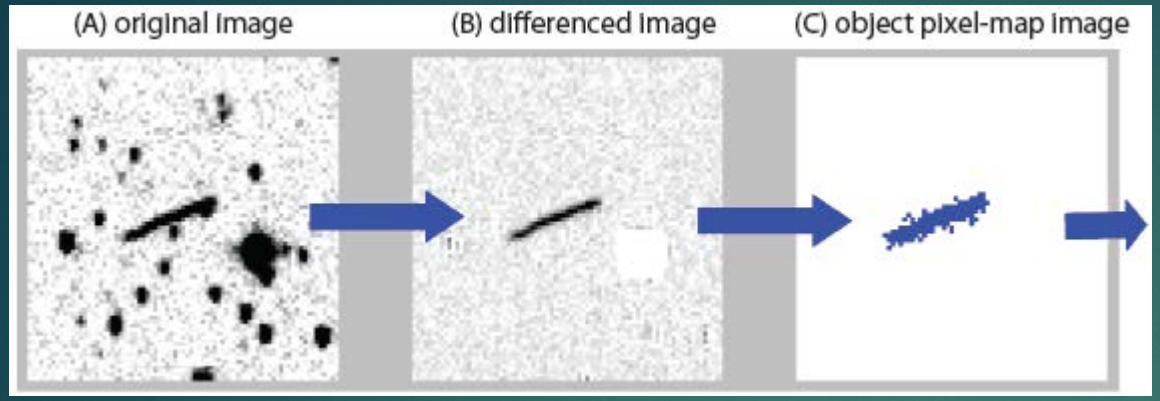
Comets: lightcurves and metadata
Asteroids: lightcurves and metadata
ML search for SFR

Streak detection



Status of streak detection system

- Prototype demonstration on iPTF was originally developed by Adam Waszczak in 2014
- The new ZTF streak detection/ML-vetting system was developed jointly by IPAC and NCU and has been implemented into ZSDS
- **For NEO surveys, time is critical!** New system is not simply a x10 version of the iPTF prototype



Waszczak et al. (2017)

- Pixel-map image is very useful for initial identification of streaks
- However it cannot precisely define the end position of the asteroid
- MPC orbital solution suggests that the residual of iPTF streak measurements is 2” on average (typical residual 0.5”)

PSF fitting of the streaks

$$g[x',y'] = b + \frac{F}{L}\frac{1}{2\sigma(2\pi)^{1/2}}\exp\left[-\frac{y'^2}{2\sigma^2}\right]\left\{erf\left[\frac{x'+\frac{1}{2}L}{\sigma\sqrt{2}}\right] - erf\left[\frac{x'-\frac{1}{2}L}{\sigma\sqrt{2}}\right]\right\}, \quad (1)$$

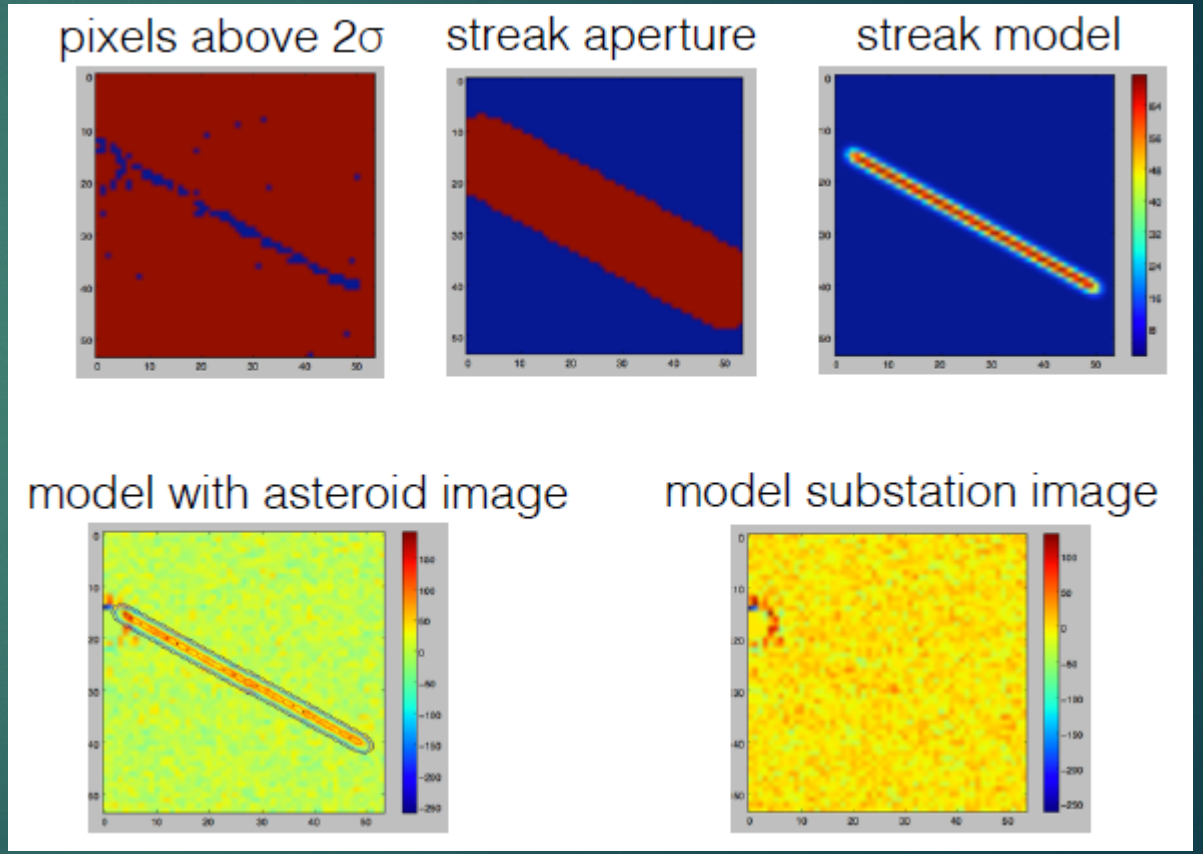
where

$$erf[z] = \frac{2}{\pi}\int_0^z \exp[t^2]dt \quad (2)$$

and

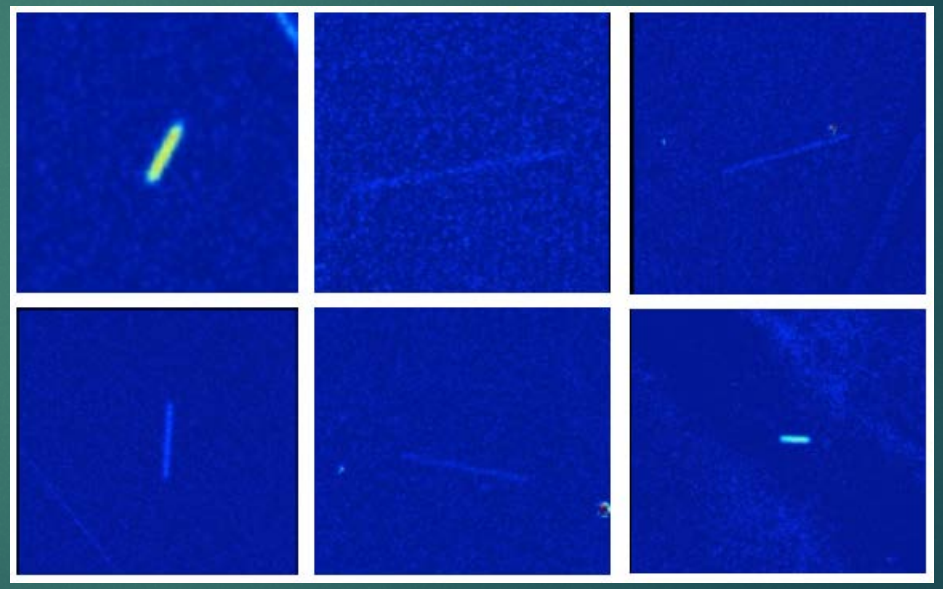
$$x' = (x - x_c)\cos\theta + (y - y_c)\sin\theta, \quad (3)$$
$$y' = -(x - x_c)\sin\theta + (y - y_c)\cos\theta, \quad (4)$$

Veres et al. 2012, Lin et al. 2015



Training set

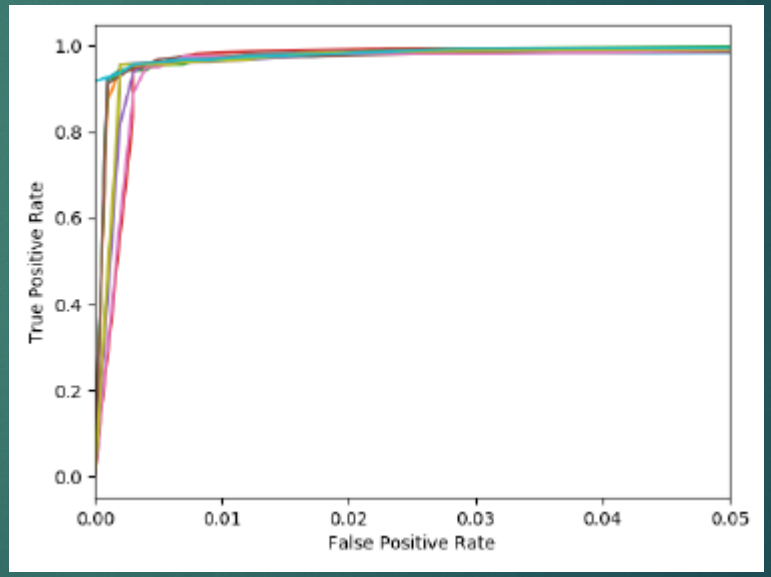
- Using real asteroid detection as ML training set is not efficient because:
  - Streaks are rare (only accumulated 240 over the entire iPTF era)
  - Heavily biased towards brightest asteroids
- We turn to synthetic streaks
- Now: 20,000 synthetic streaks as training set



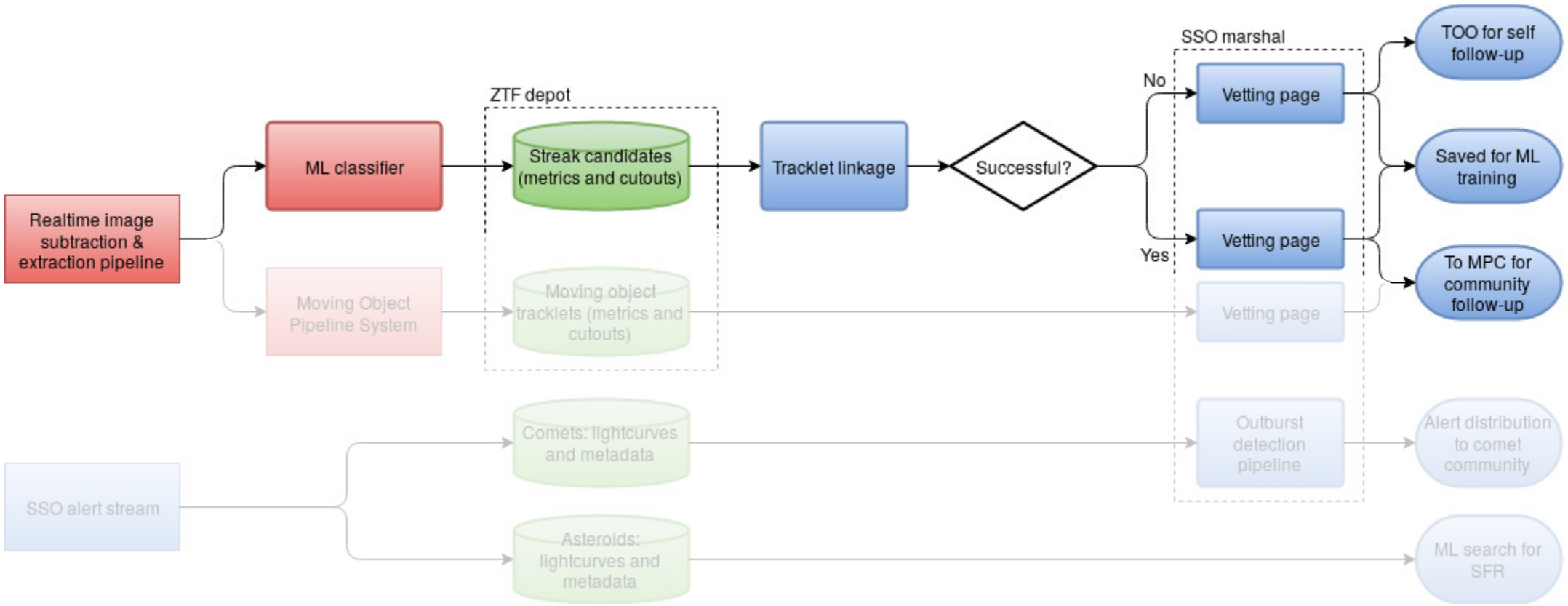
Result and next step

- Using real streaks as test set
- Significant improvement after the implementation of the PSF-fitting and synthetic training set, **20x reduction** of ML-vetted candidates!

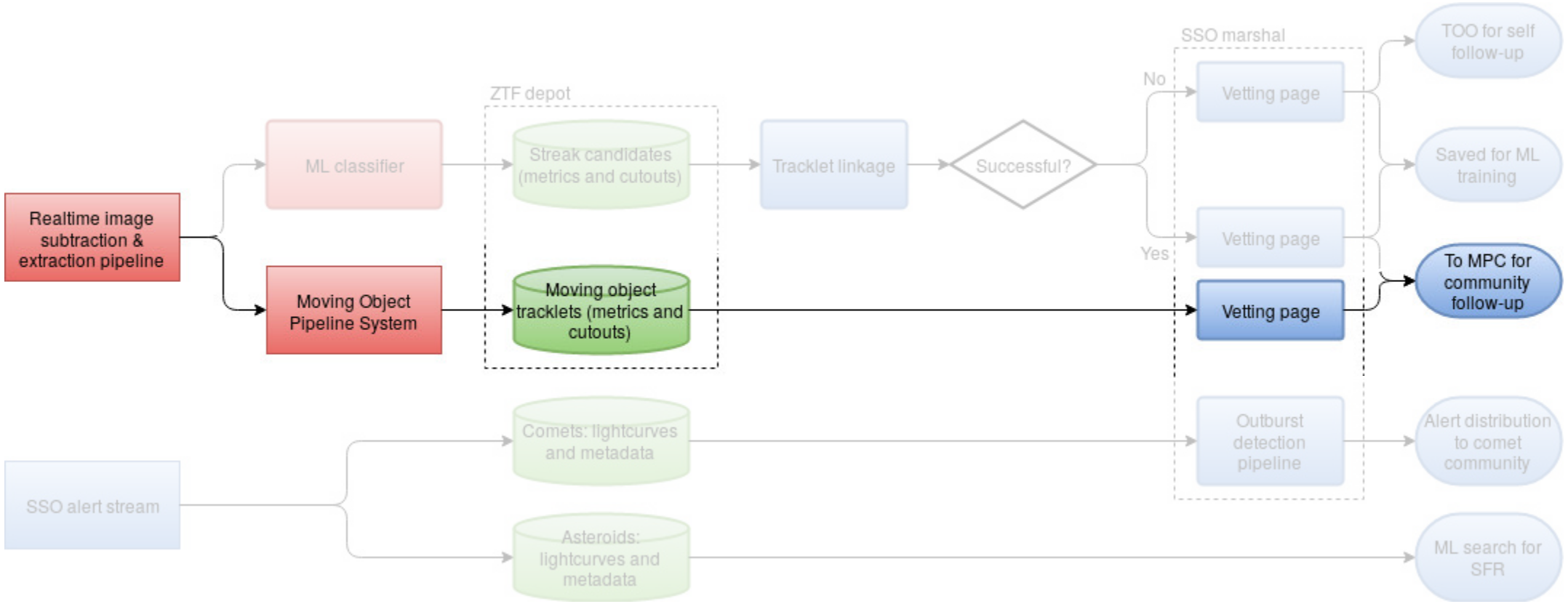
- **Still, we expect 1,000 to 2,000 ML-vetted candidates per night**
- Lacking manpower + resource to handle this amount of candidates
- Next step: automatic search for streaks with converged orbital solutions

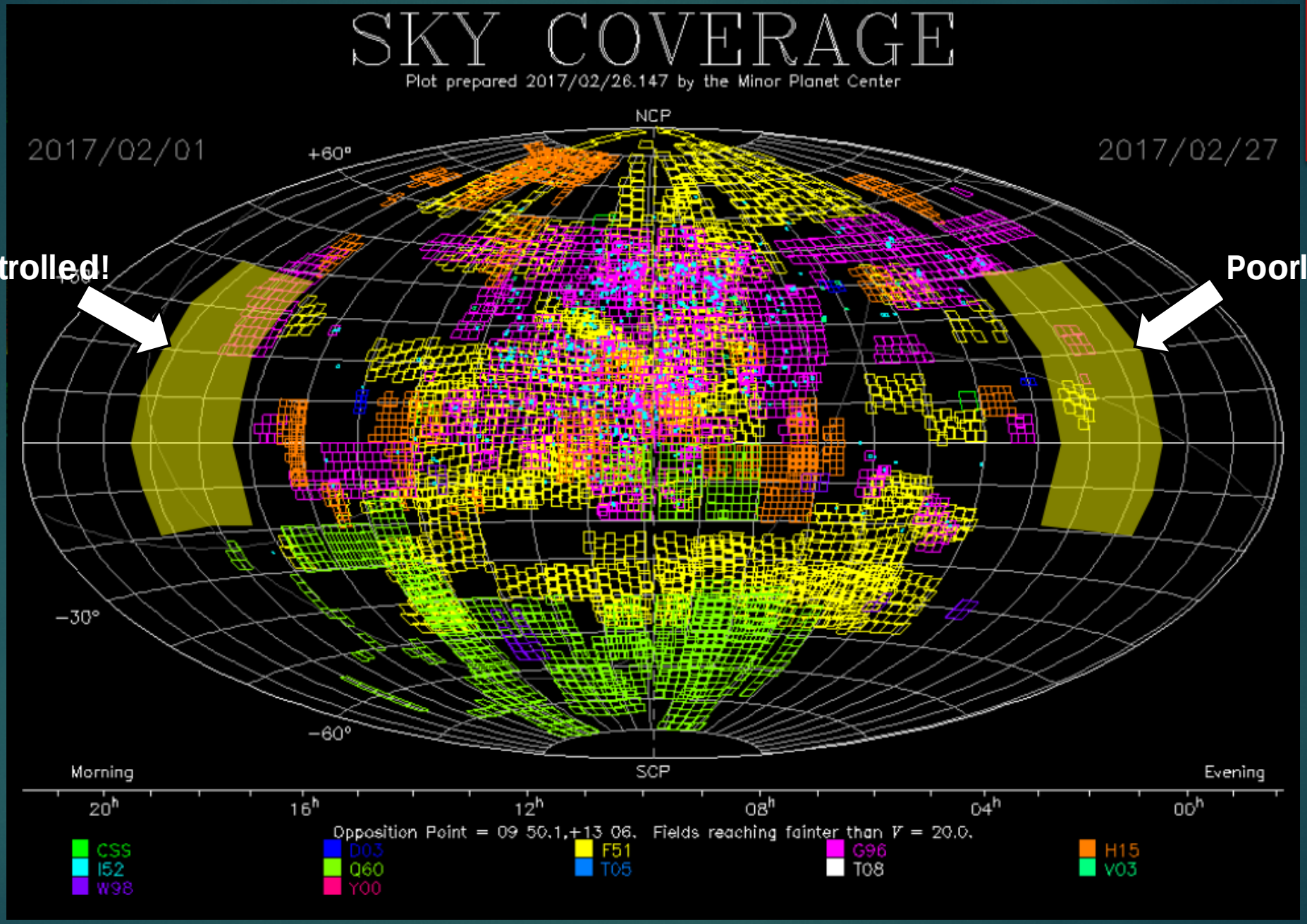


Streak detection



Point-source moving objects



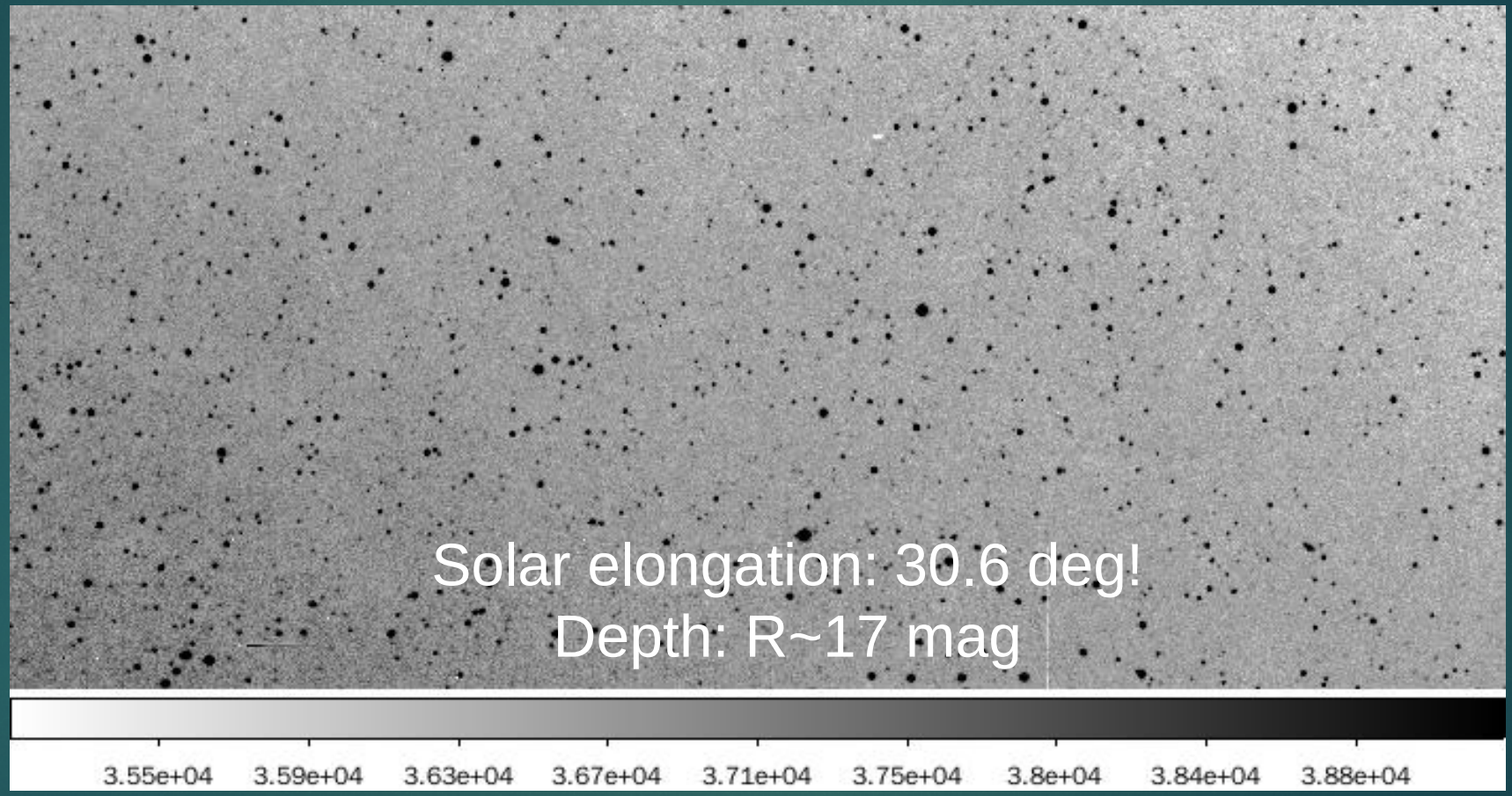


Lead: Quan-Zhi Ye (Caltech)

Unique science enabled by ZTF-TS

- NEOs arriving from the sunward direction (e.g. Chelyabinsk impactor in 2013)
- First-ever systematic ground-based survey of Sun-approaching comets
- Asteroids that are inside the Earth's orbit: Atiras, Apoheles, Earth Trojans

Dec 2016 iPTF experiment



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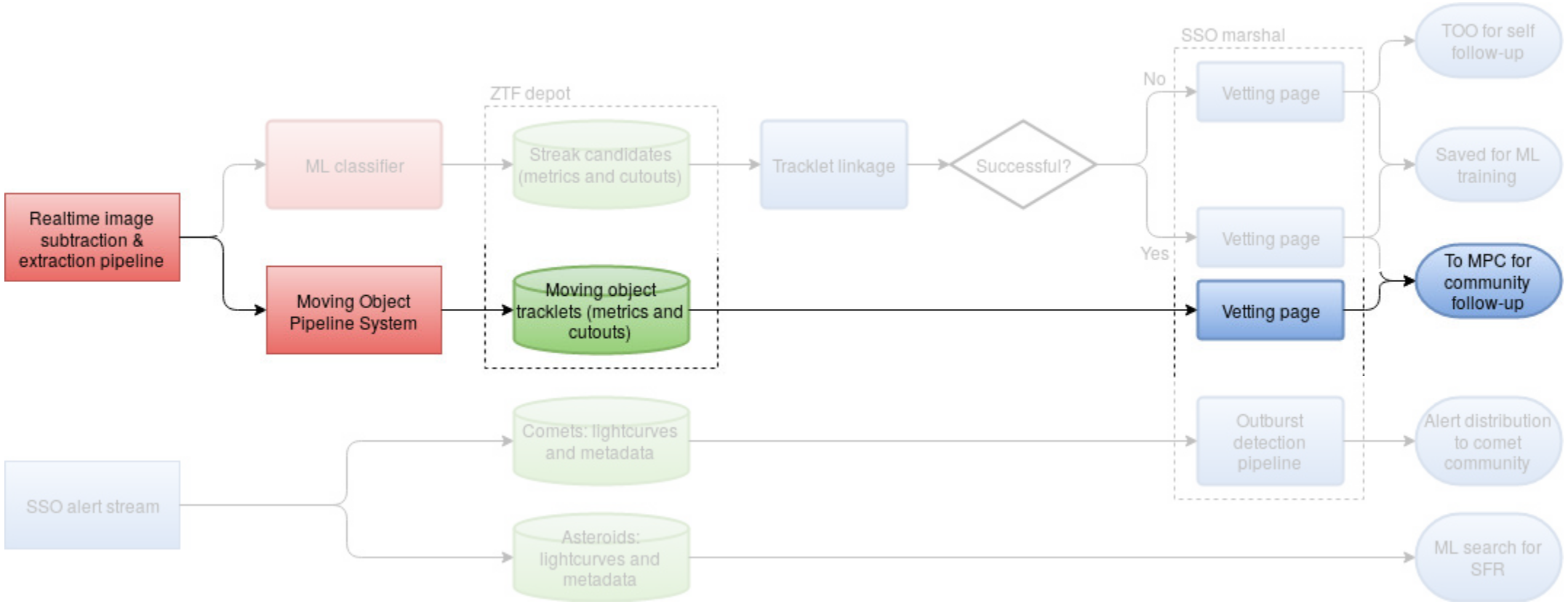
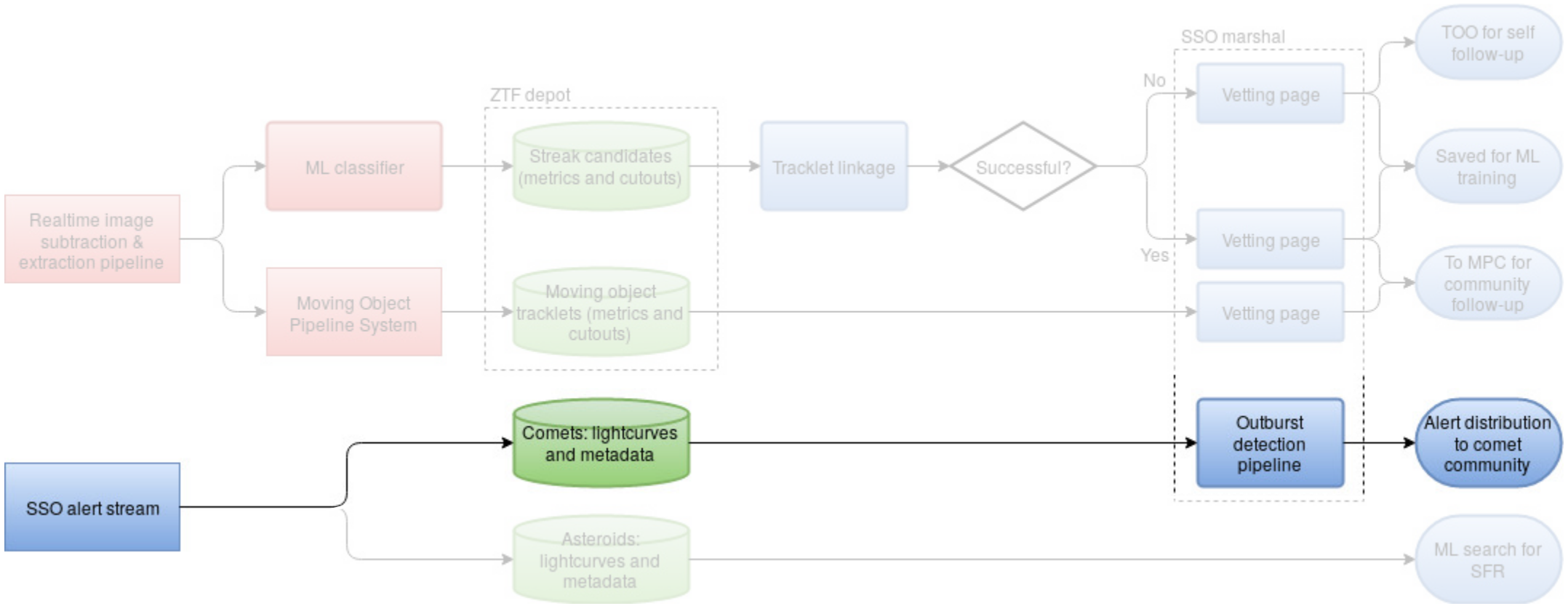
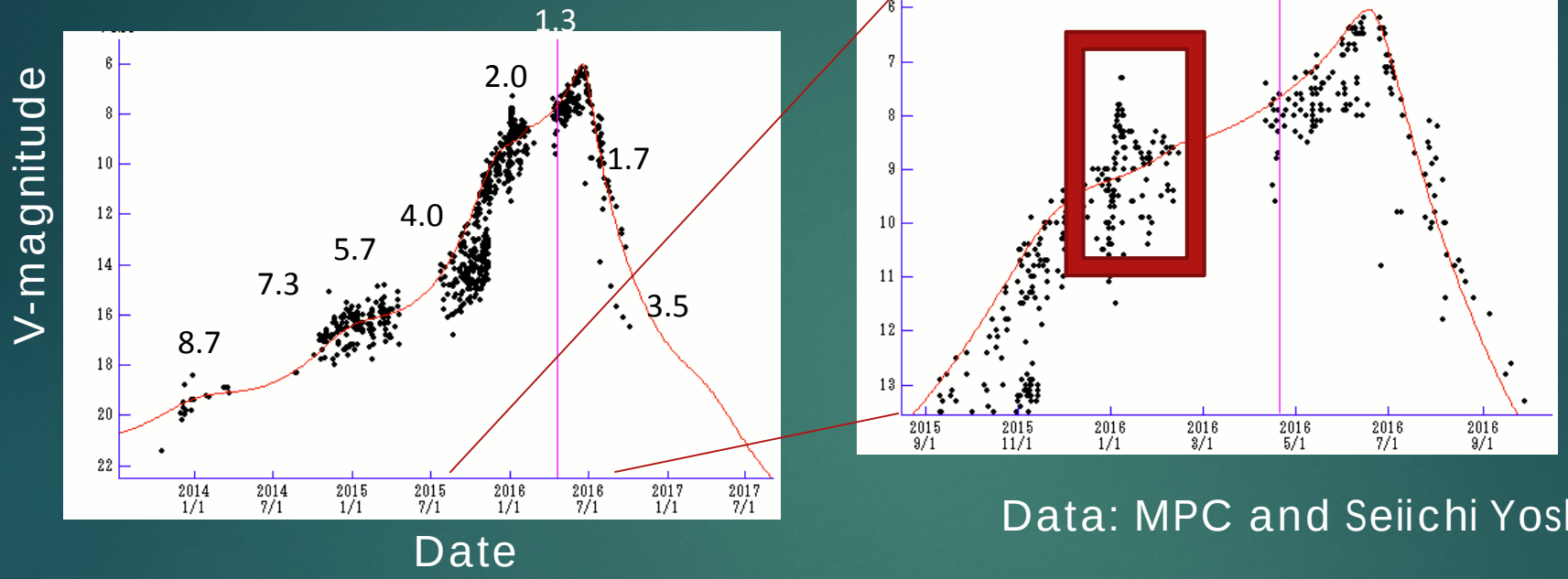


Comet outbursts



Lead: Dennis Bodewits (UMD)

Example: C/2013 X1 (Pan-STARRS)



Data: MPC and Seiichi Yoshida

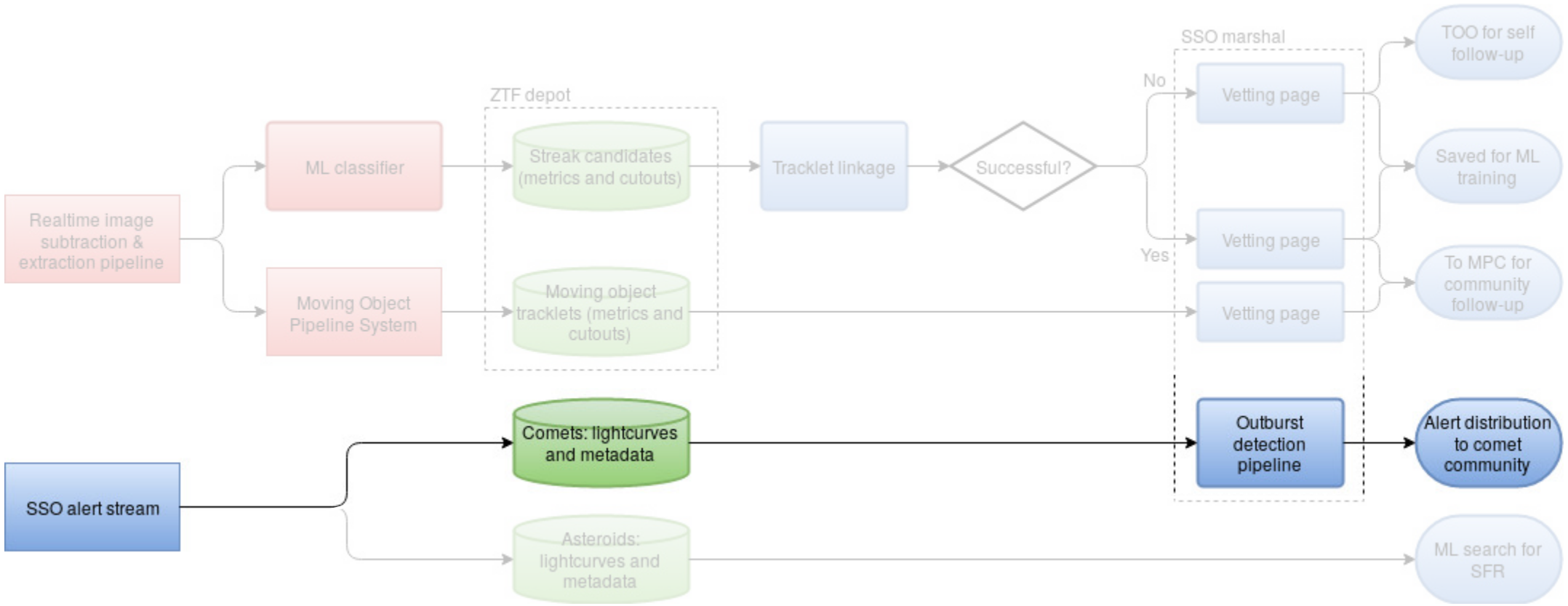
- Currently there are no high-quality, consistent, long-term comet light curve measurements
- Scatter: Naked eye/CCD/different locations/different apertures/dust-to-gas ratio
- **Large uncertainties in current comet lightcurves prohibit meaningful quantitative analysis**
- **Bias towards comets with 'high expectations': faint/distant comets not sampled.**

Aims Outburst Monitor

- Discover and characterize outbursts down to 1 mag increase
  - Characterize magnitude
  - Characterize power spectrum
  - Measure duration
  - Measure decay time
  - Assess required energy
  - Correlate baseline activity: hints?
- ZTF as an early warning system
  - Accurate measurement of baseline activity
  - Use follow-up to investigate fragmentation, gas composition

Rosetta/Osiris comet 67P: Vincent et al. 2016

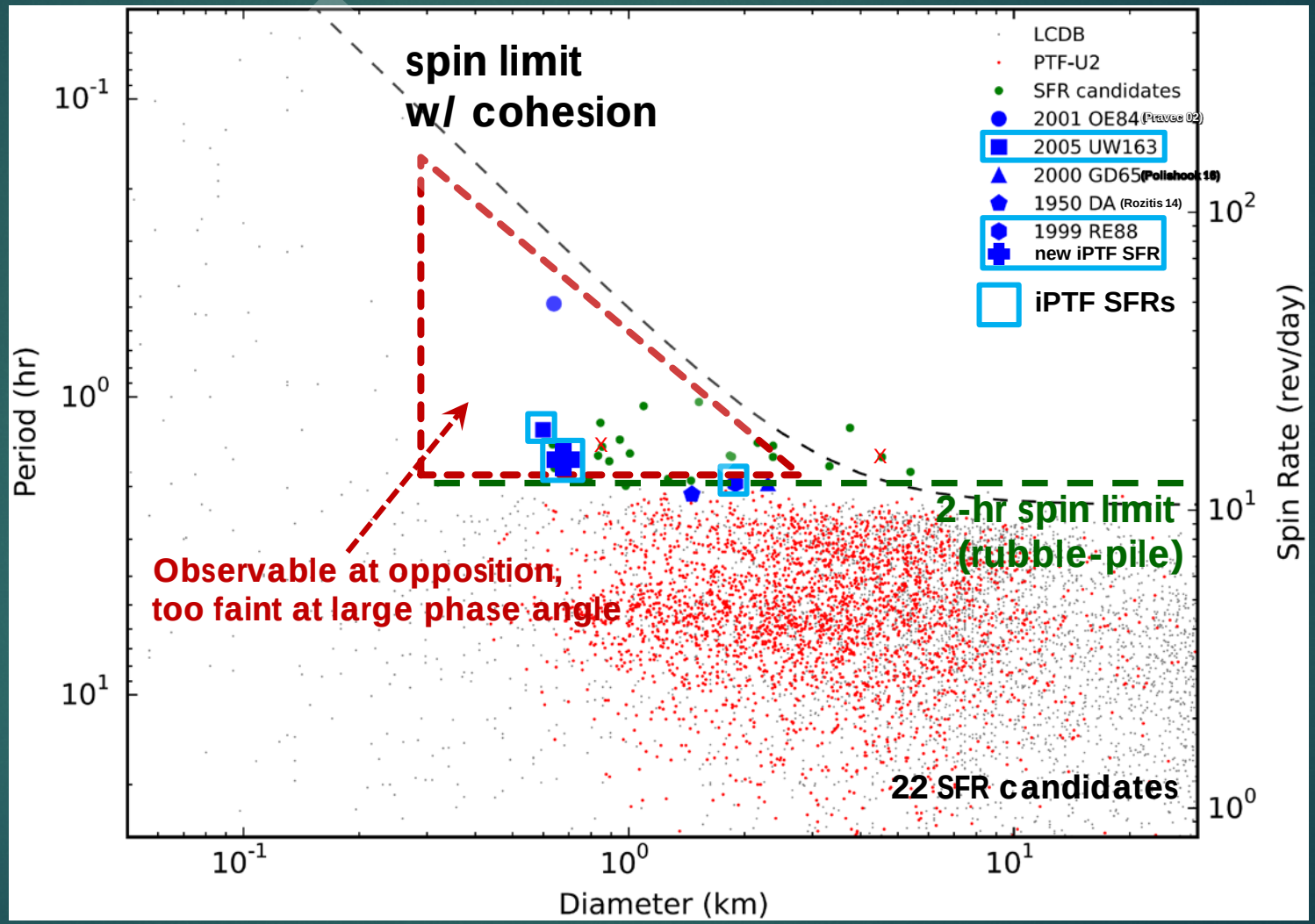
Comet outbursts



Status

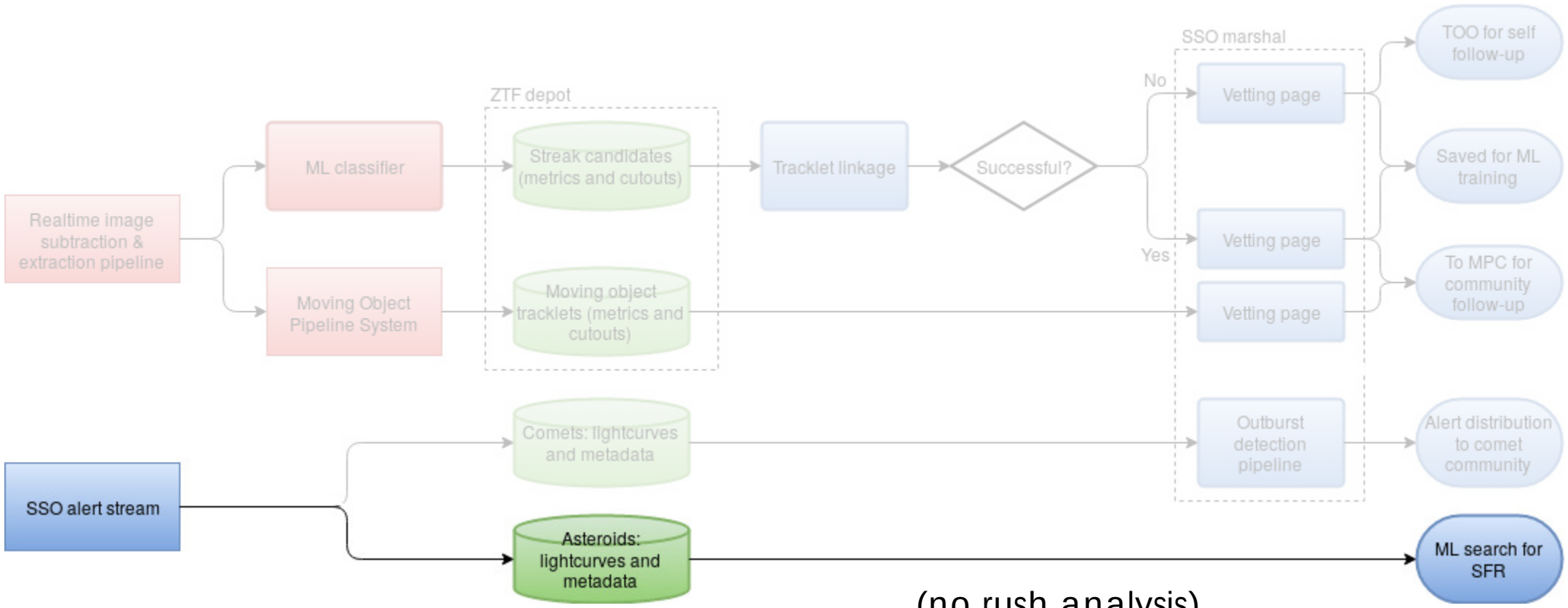
- Comets are extended sources with variable shape; dedicated photometry pipeline is needed
- A Pilot Program with LCOGT (lead by UMD) is underway
  - Focus on a single comet (41P/Tuttle-Giacobini-Kresak)
  - Monitors gas (*g'*) and dust (*r'*) content of the coma
  - High cadence (3 hr) follow-up on outburst
  - Develop automated data reduction procedures, establish follow-up routines and alert distribution

Search of SFRs



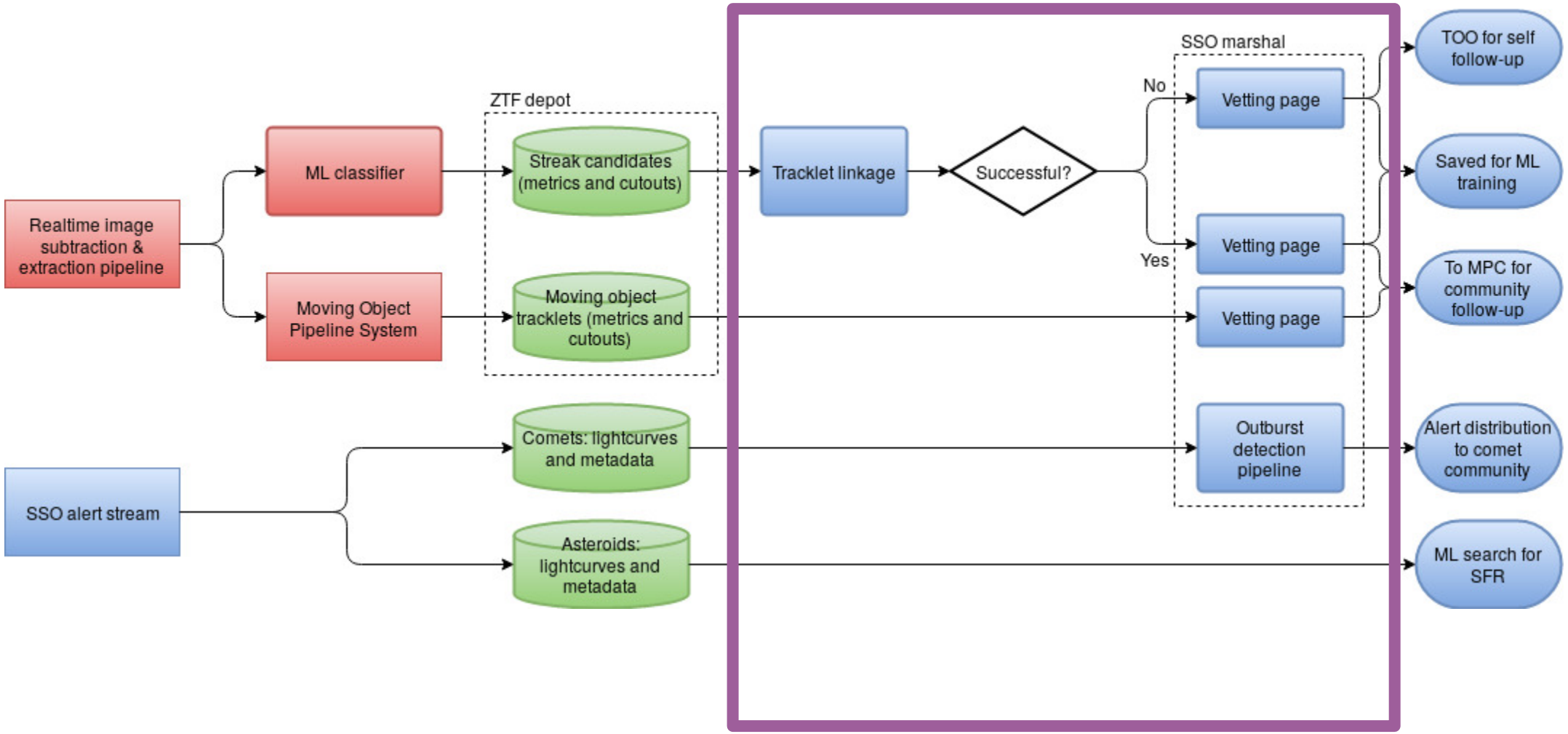
Lead: Rex Chang (NCU)

SFR survey



(no rush analysis)

Next step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