Exploring the Temporal and Spatial Variability with DEEP-South Database: Application of Multi-aperture Photometry Pipeline

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Outline

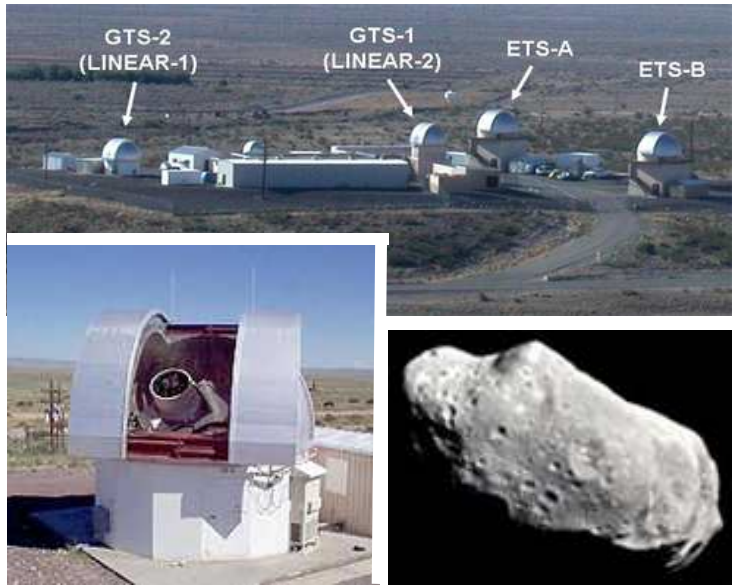
- **Meet the demand of the day:**
  - "As holdings grow, so does the demand for new area of support, such as analysis of massive new data sets to understand how astronomical objects vary with time, described in the 2010 Decadal Survey as the "last frontiers in astronomy" (Berriman & Groom 2011)

- **Multi-aperture Photometry Pipeline & Database**
  - Source detection and High-precision photometry
  - Database indexing with FastBit

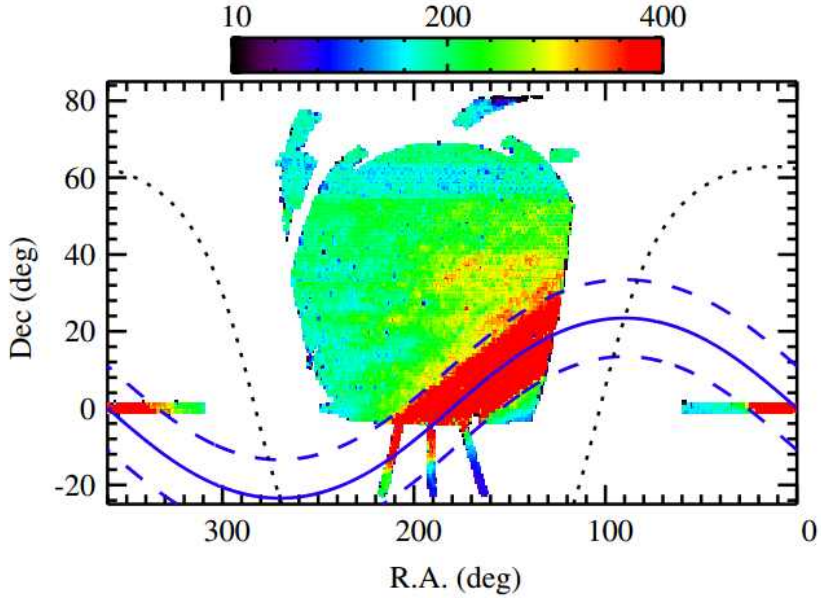
- **Exploring the variable sky with DEEP-South Database**
  - High-signal, single event list (HSSEL) for moving object detection
  - Light curve production for stars and moving objects

Benchmarking the power of massive time-domain databases for exploring the variable sky

- A public LINEAR database contains 5 billion photometric measurements for about 25 million objects. It provides the TIME-DOMAIN information!



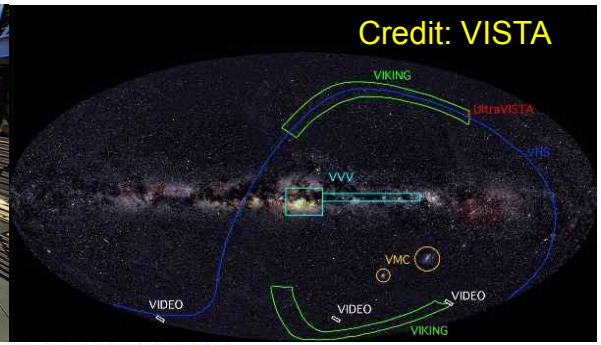
Observation from 2002 Dec. through 2008 Mar.
with 1.016m two telescopes @ USA

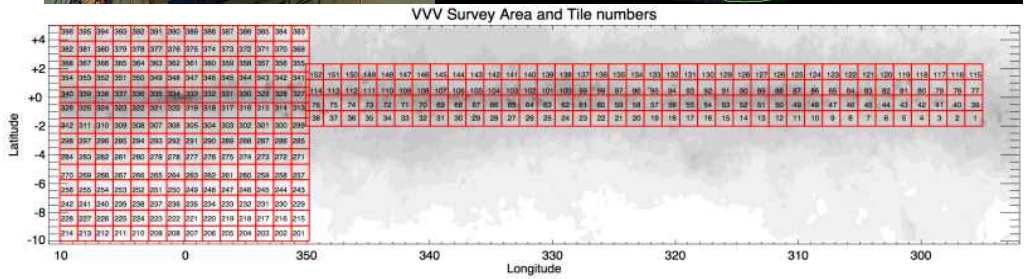


Median # of observations (Sesar+ 2011)

7,000 Periodic variables (Palaversa+ 2013) + Halo Structure/substructure traced by RR Lyrae (Sesar+ 2013) + Optical variability of bright Blazars (Ruan+ 2012)

KMTNet synergy with other time-domain databases?





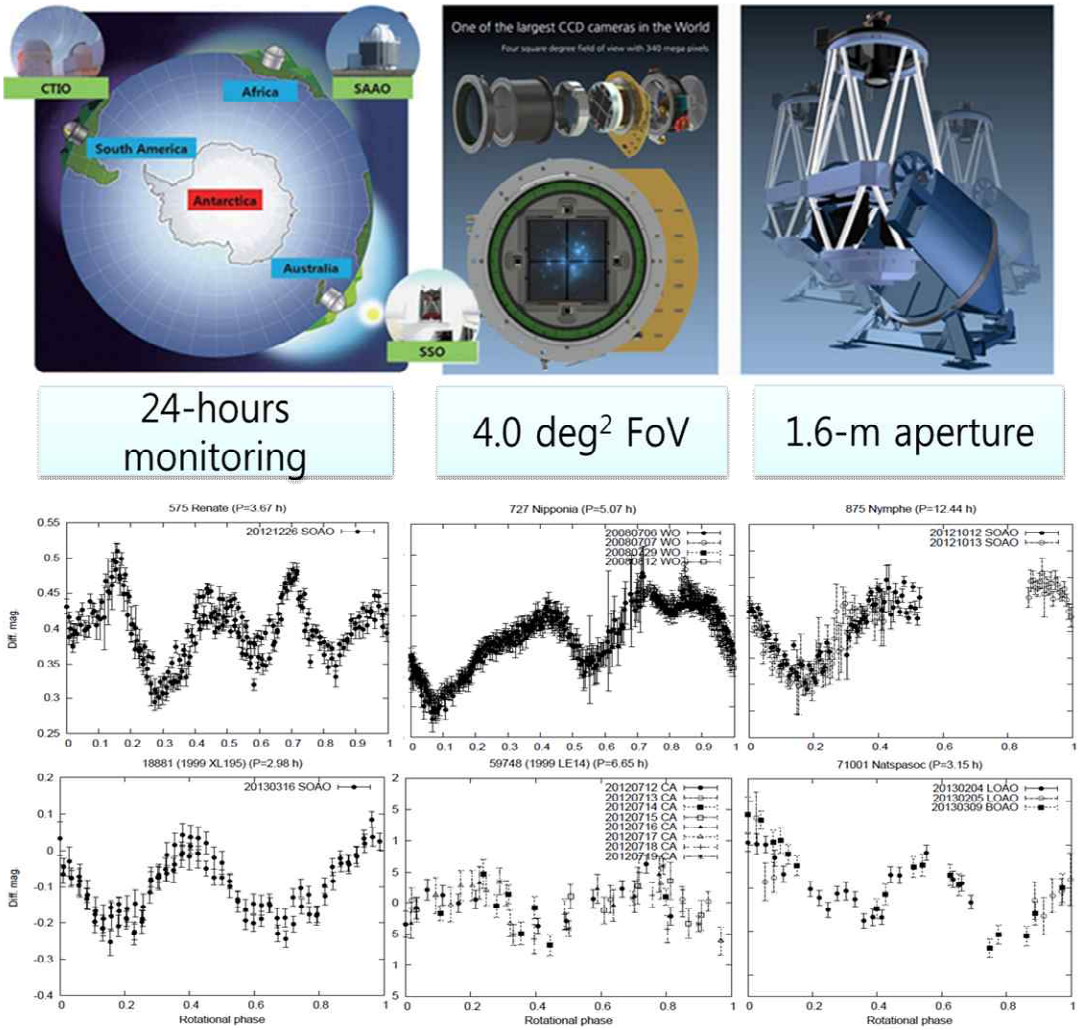
VISTA Variables in The Via Lactea (VVV) public survey

- Galactic Bulge + Disk (540 sq. deg)
- ZYJH + Ks
- Multi-epoch (> 100)
- Catalog: ~10^9 point sources + ~10^6 variable objects
- DR3: 22TB (images)

GAIA DR1: coming soon!

- ~90% of sky can be covered.
- Positions (α, δ) + G magnitude + uncertainties.
- High-cadence measurements for RR Lyrae/Cepheid stars.
- 5-parameter astrometric solution.

KMTNet DEEP-South project (PI. Moon, H.-K.)



Kim et al. 2014

- They investigate the bulk properties of Near-Earth Asteroids, Main-Belt Asteroids, and comets:
  - Orbit and optical size,
  - Surface mineralogy,
  - Spin rate and shape,
  - Transport, evolution, and population
- Based on 24-hour continuous photometric monitoring, each telescope is expected to obtain hundreds of gigabytes of data per night for raw images only.

Purpose of photometric experiments

The task of post-processing for such large amount of data is paramount and we hope to have more robust and efficient approach to identify and characterize temporal and spatial transients.

- How to generate frame/light-curve catalogs?

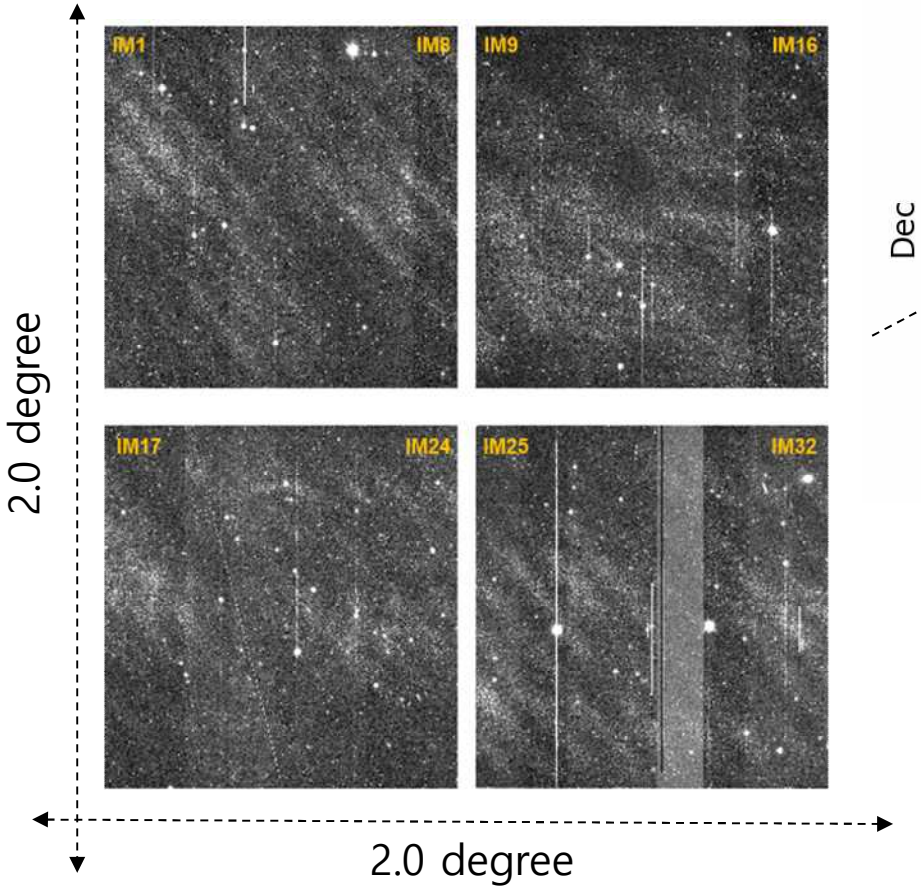
1. Real-time alert stream: rapid identification and follow-up
2. Daily/Monthly/Annual data release production: deep static-sky science and statistical studies of variability

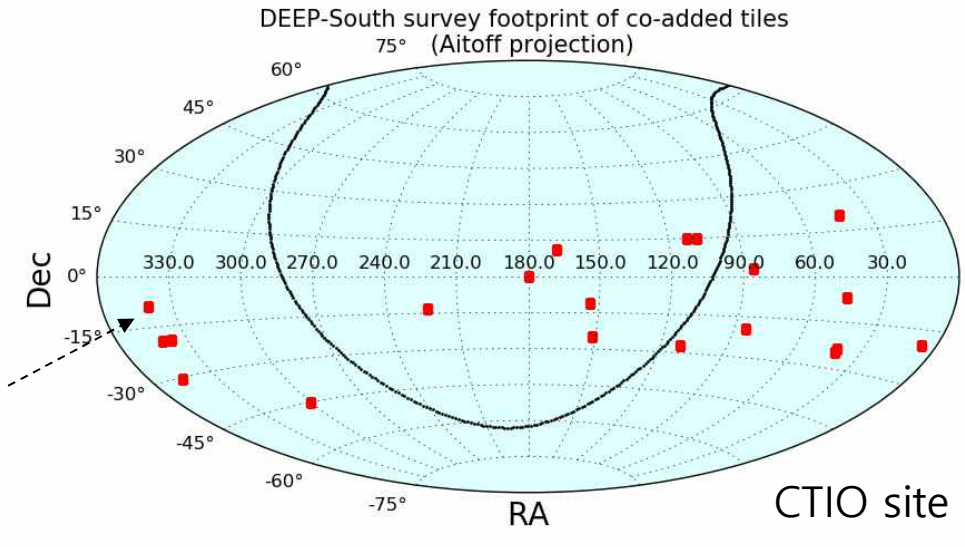
- How do you provide faster access to the results of observations?

1. Accuracy
2. Scalability

Experimental data sets: Test Fields

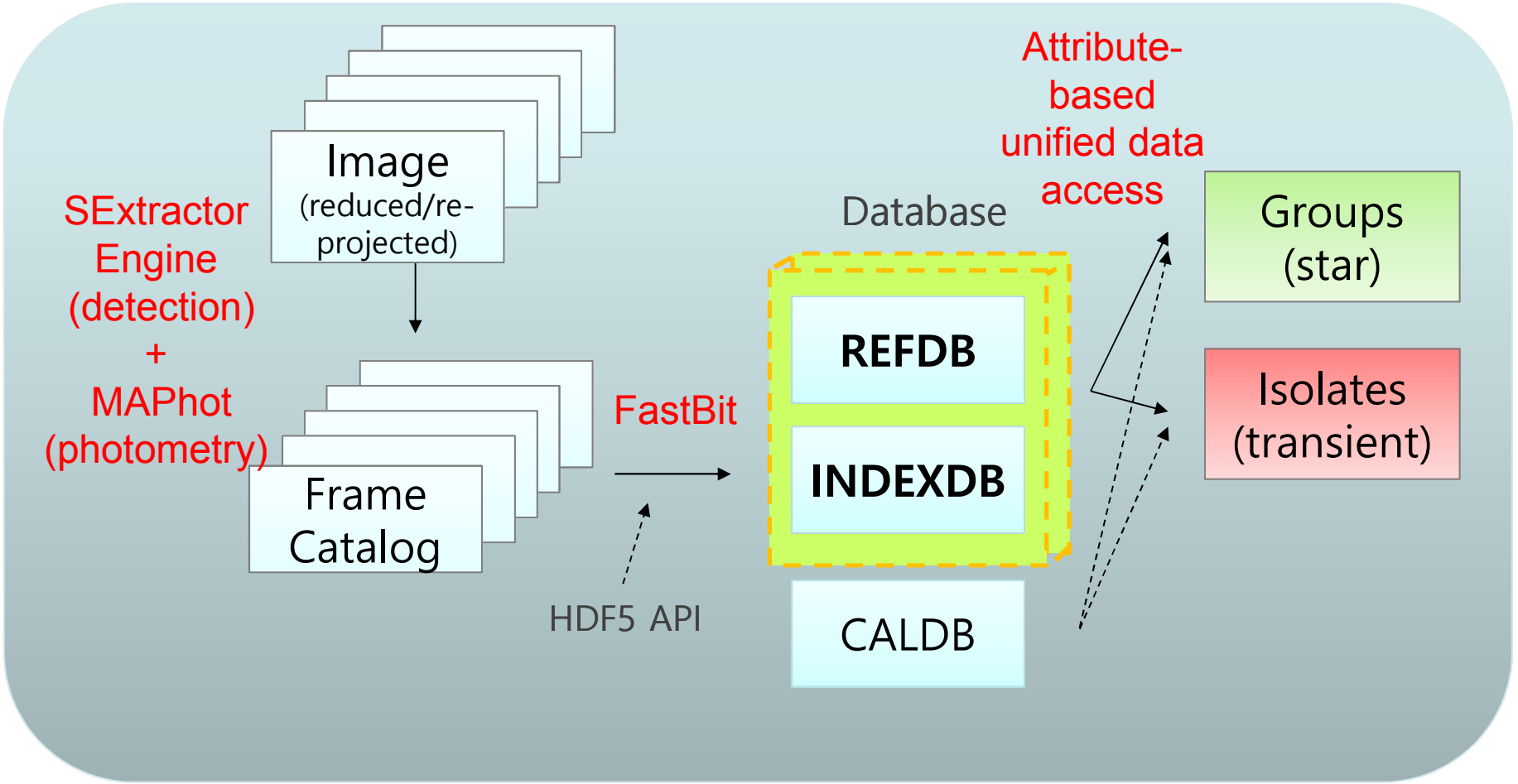
- Pre-processing: overscan, bias, & flat field correction.
- Post-processing: crosstalk/bad pixel corrections, FITS header fix, cosmic-ray removal, & two-step astrometric calibration.





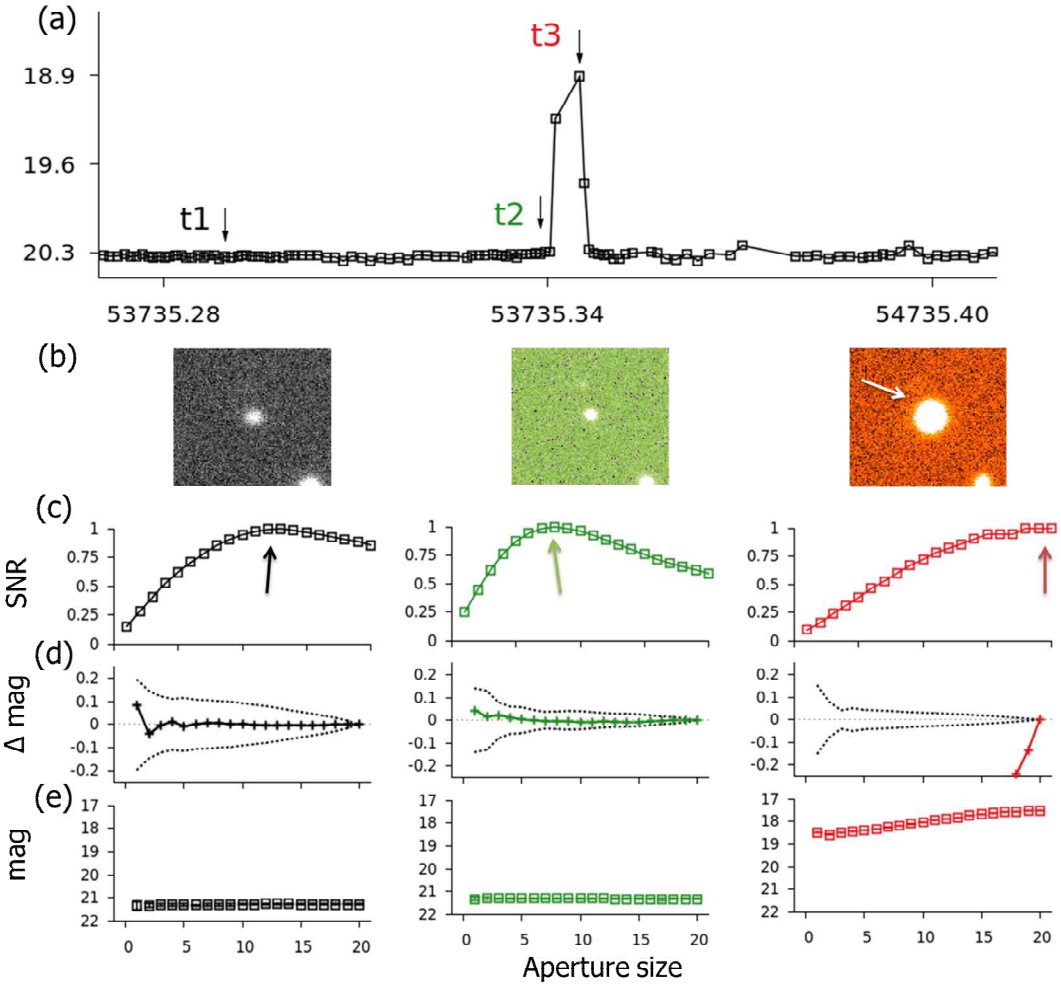
Obs. data	Fields (frames)	Exp. Time (sec)
20150411	4 (106)	30 ~ 120
20150422	2 (57)	45 ~ 70
20150424	2 (73)	45 ~ 70
20150526	2 (48)	15 ~ 60
20151018	4 (103)	27 ~120
20151114	5 (158)	11 ~ 81

Flowchart of our proposed algorithm: detection, measurement, and cataloging the sky



- REFDB: Master catalog
- INDEXDB: All frame catalogs
- CALDB: Calibration catalog

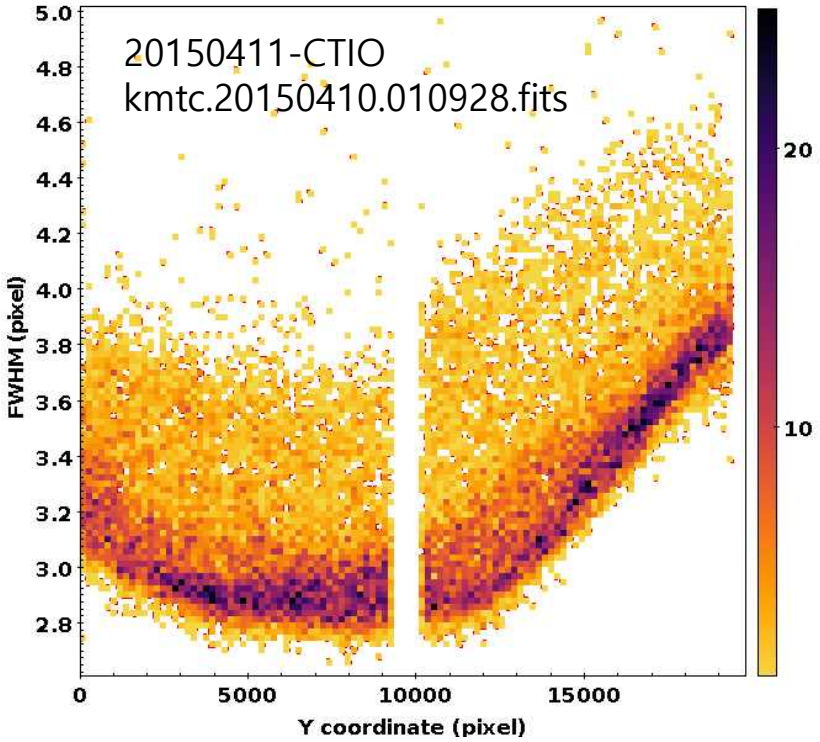
[Step 1] Generate Frame Catalogs: Multi-Aperture Photometry Technique with SExtractor Engine

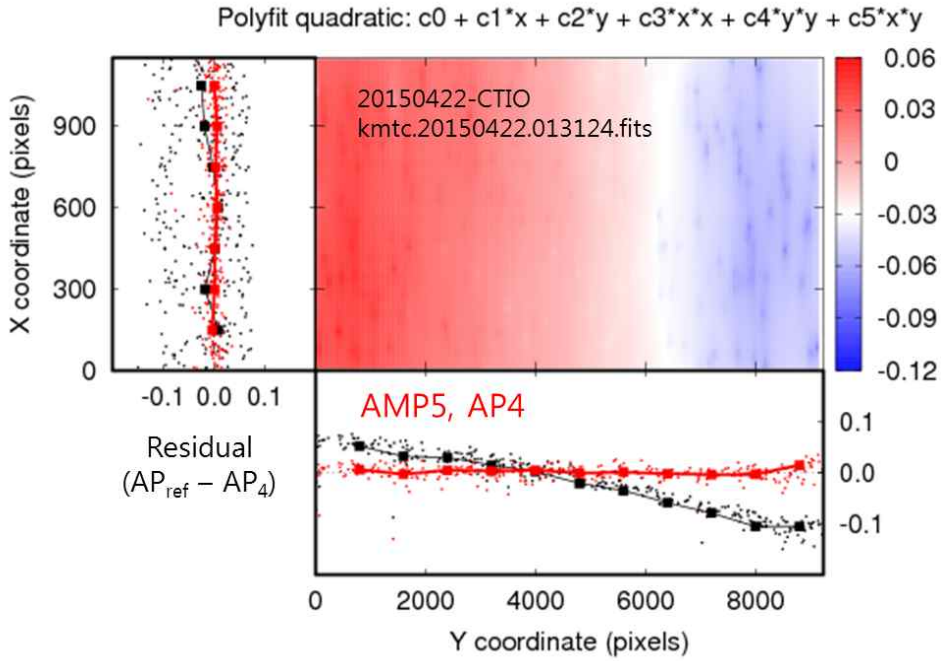


Example of multi-aperture indexing photometry for one star through epochs t1 to t3.

- SExtractor (Bertin & Arnouts 1996): builds a automated detection of objects with several useful PIXEL/BLIND parameters.
- Multi-aperture technique (Chang et al. 2015): determine the optimized aperture (with maximum S/N) individually for each object at each epoch.

Field distortion correction: ΔAP_i (x, y, Δmag, weight)

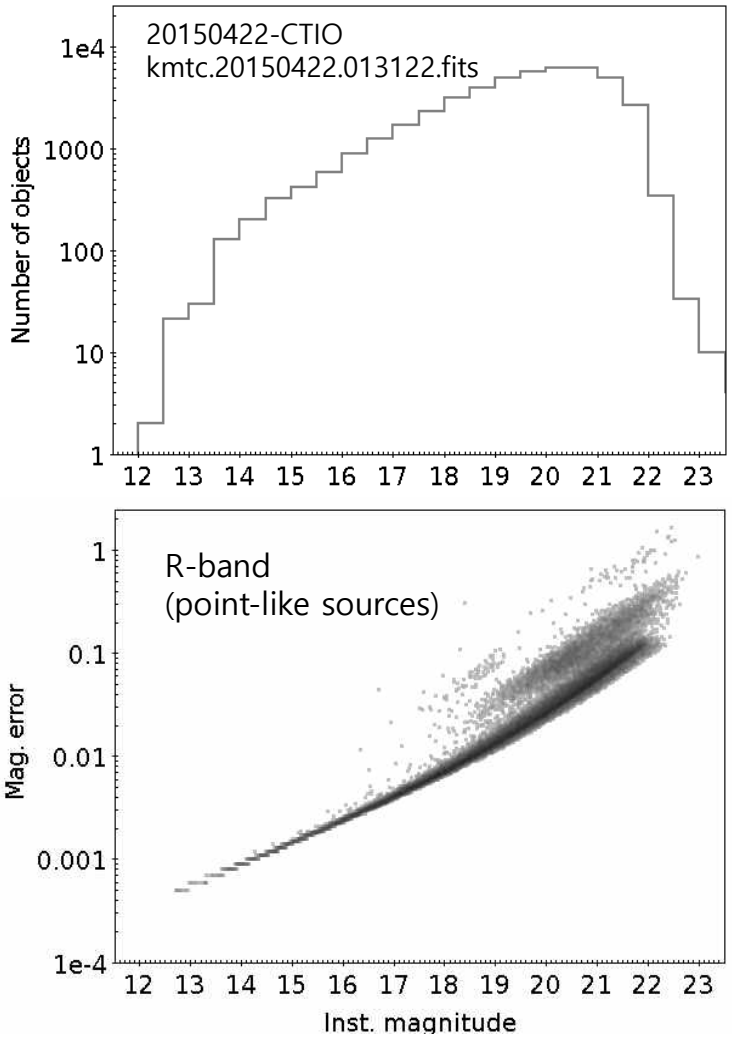




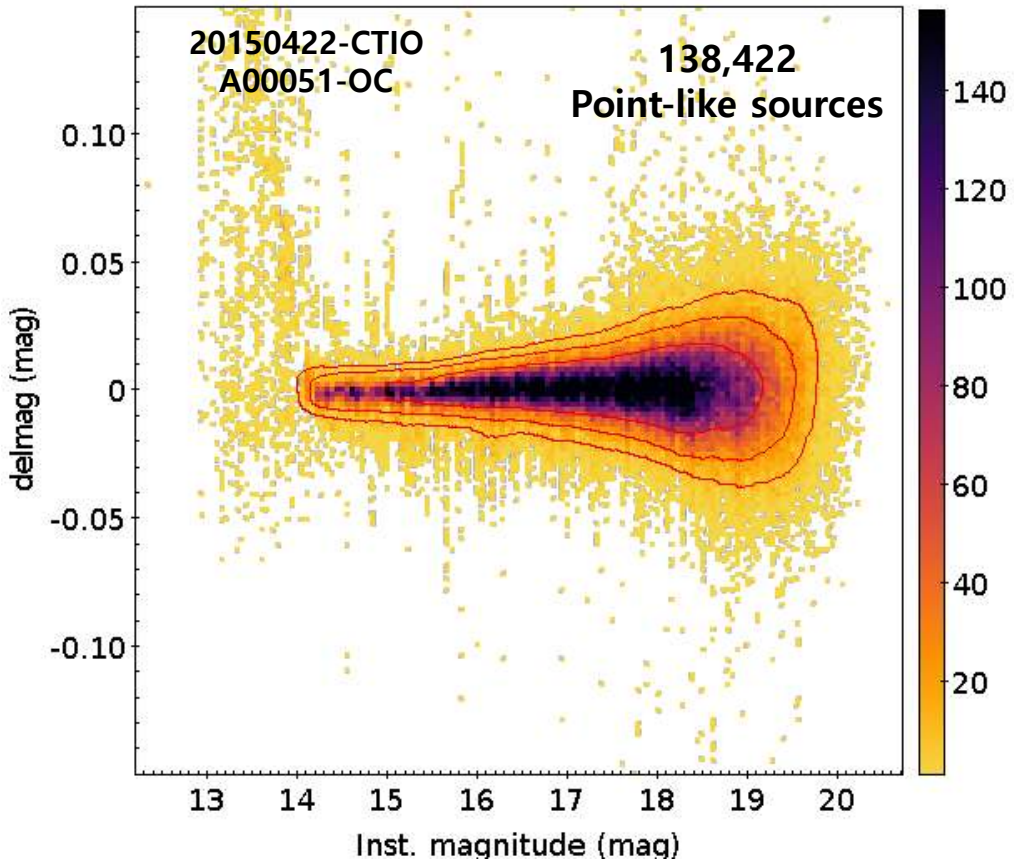
- Use FWHM assuming a gaussian core in a frame (PSFex + Sextractor)
- Variations in the PSF with field position (& with time) ~ 50%

- It will cause a position dependence in the aperture corrections.
- While the data are somewhat incomplete, a clear trend is present.

Checks on photometry



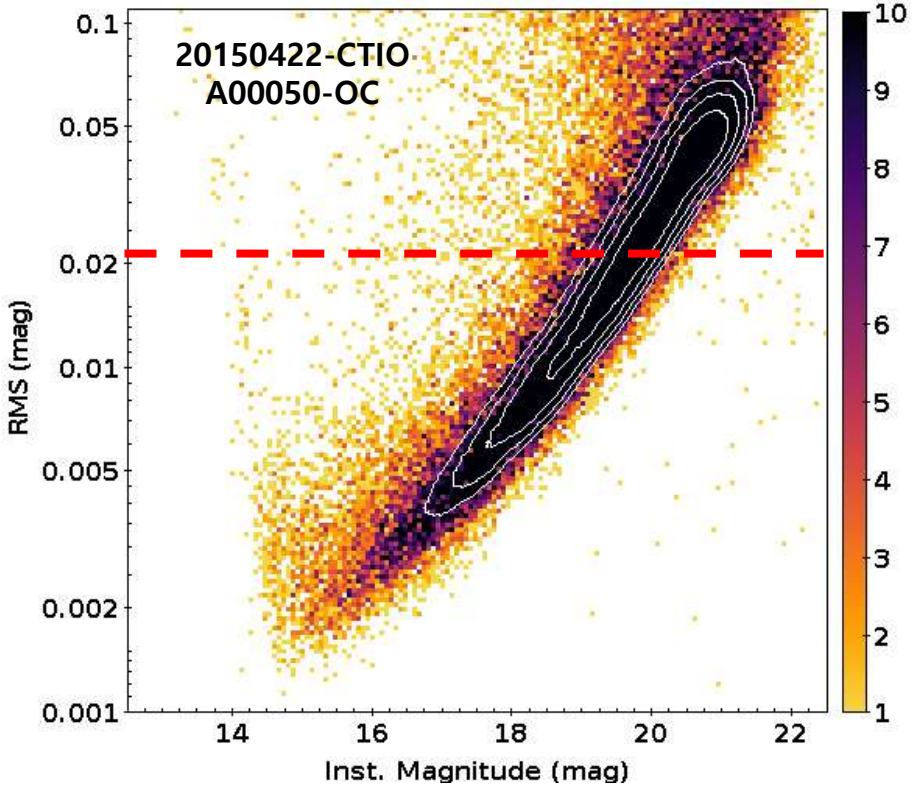
- Magnitude error vs. Instrumental magnitude

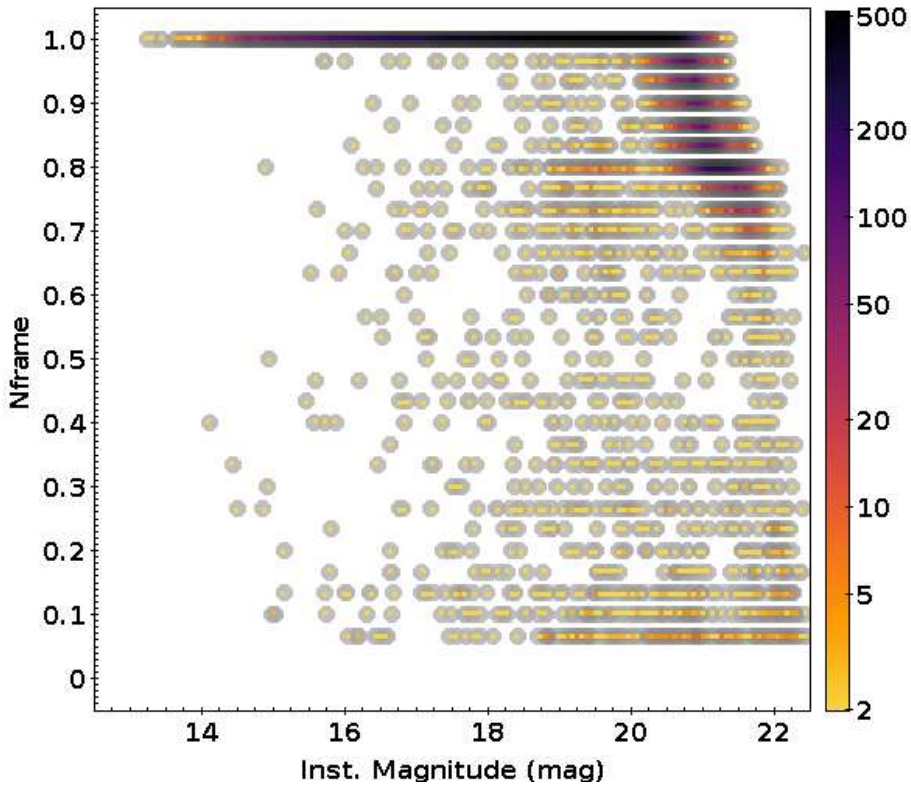


- Internal consistency

Photometric accuracy

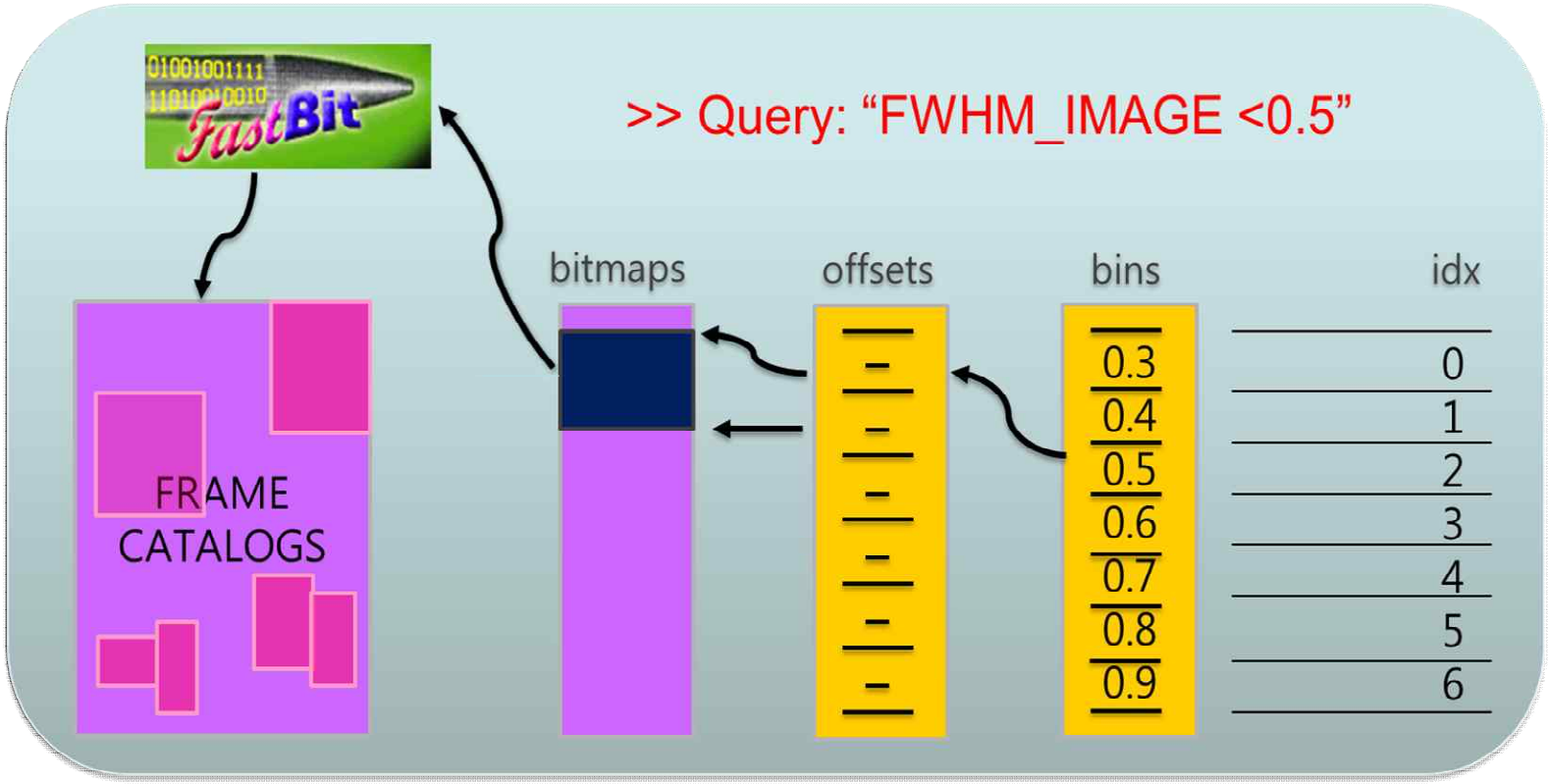
- The RMS (left) and data recovery (right) plot for repeat measurements of all point sources.
- The internal photometric calibration is expected to be good to a level of 2% or better at the bright magnitude range.





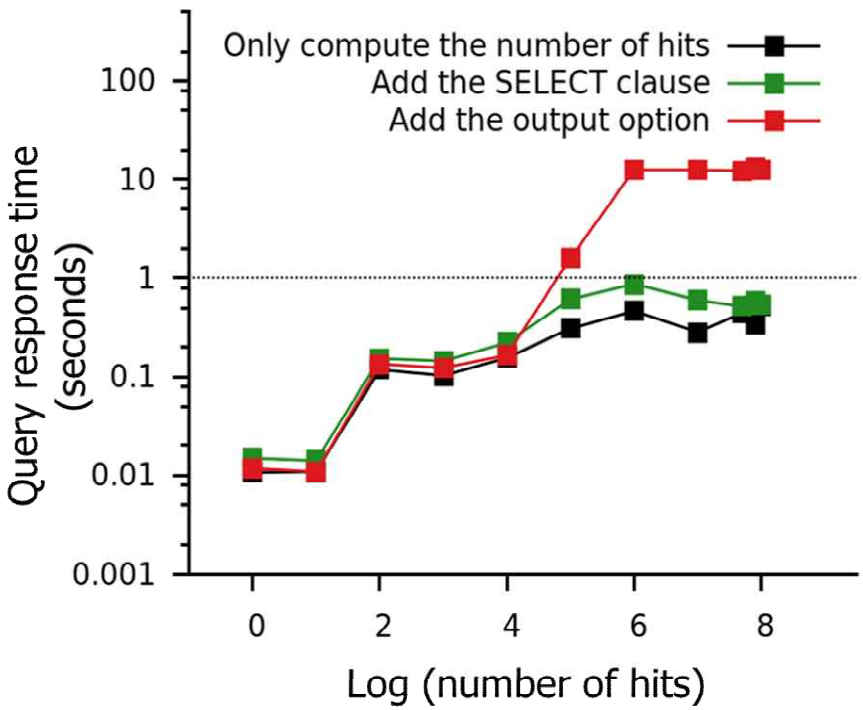
[Step 2] Database Indexing: more than a bit faster

- After the photometry step, the entire catalog database is indexed with FastBit (Wu et al. 2009):
  - It provides the indexing and querying functions
  - The bitmap indexes are stored as arrays in a user specified location
  - It returns the number hits or coordinates of the selected data from query.

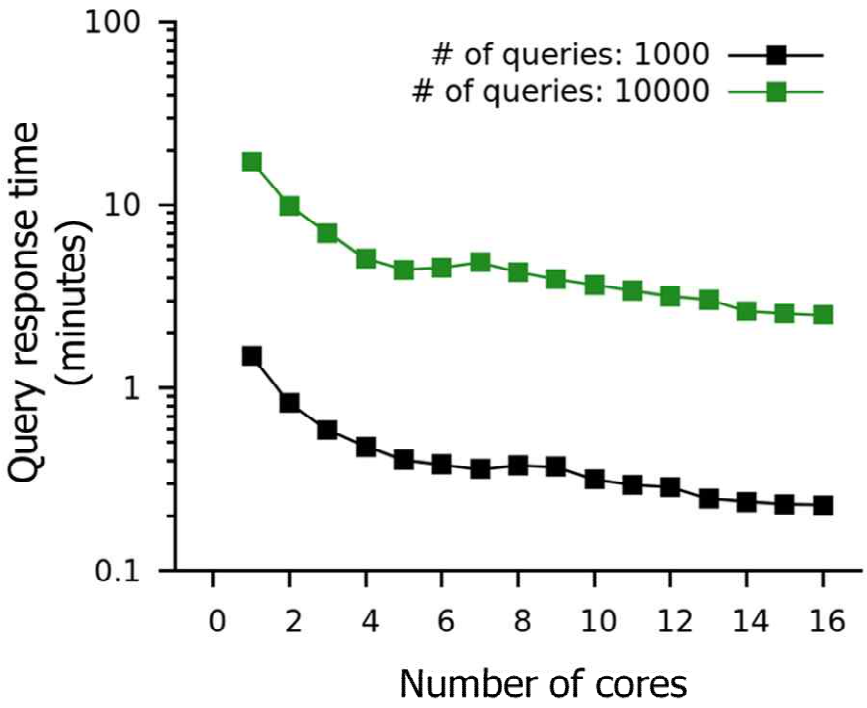


Elapsed time for processing query

Single core



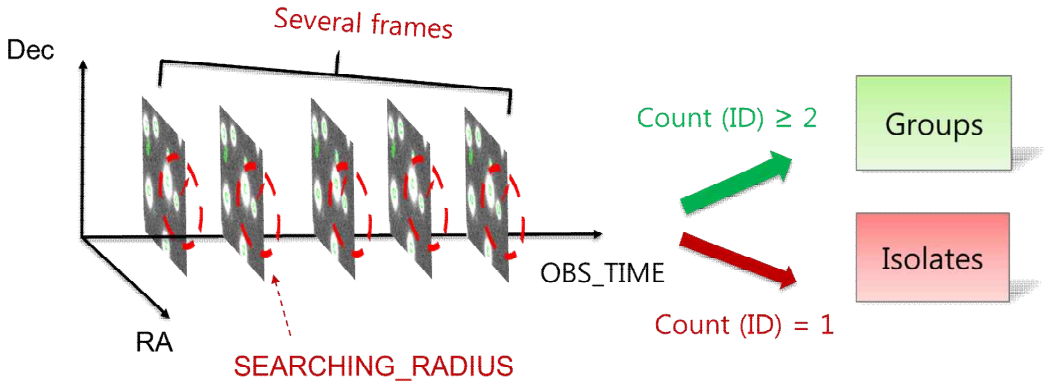
Multiple cores



➔ We confirm that FastBit indexing can help to accelerate data accesses and reduce the query response time.

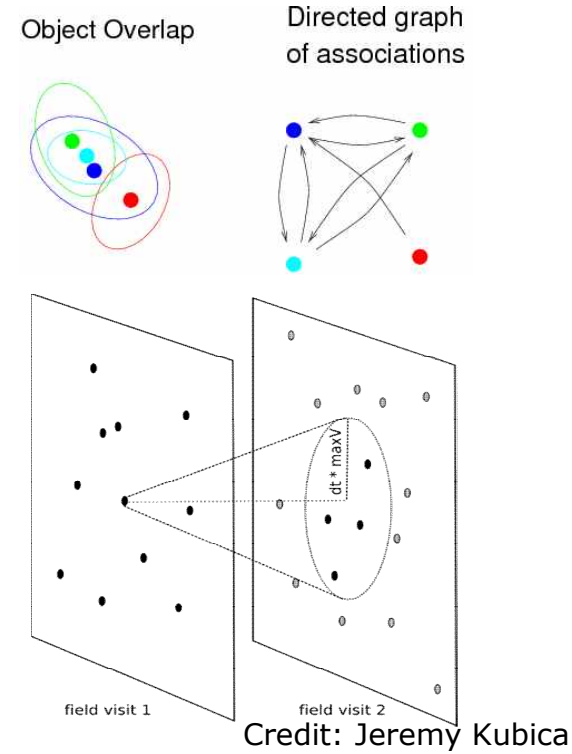
[Step 3] Exploring the temporal and spatial variability with DEEP-South Database!

- Construct light curves for repeated measurement of same star (**Groups**)
- Isolate those which appear only in one (or a few) frame catalogs (**Transients**).




```
>> ibis –d INDEXDB –q "select count(ID) where (MJD between
OBS_START and OBS_END) and (sqrt(power(RA-RA_REF, 2)
+power(DEC-DEC_REF, 2)) between 0 and SEARCHING_RADIUS)"
```

Simple cone search (current version)

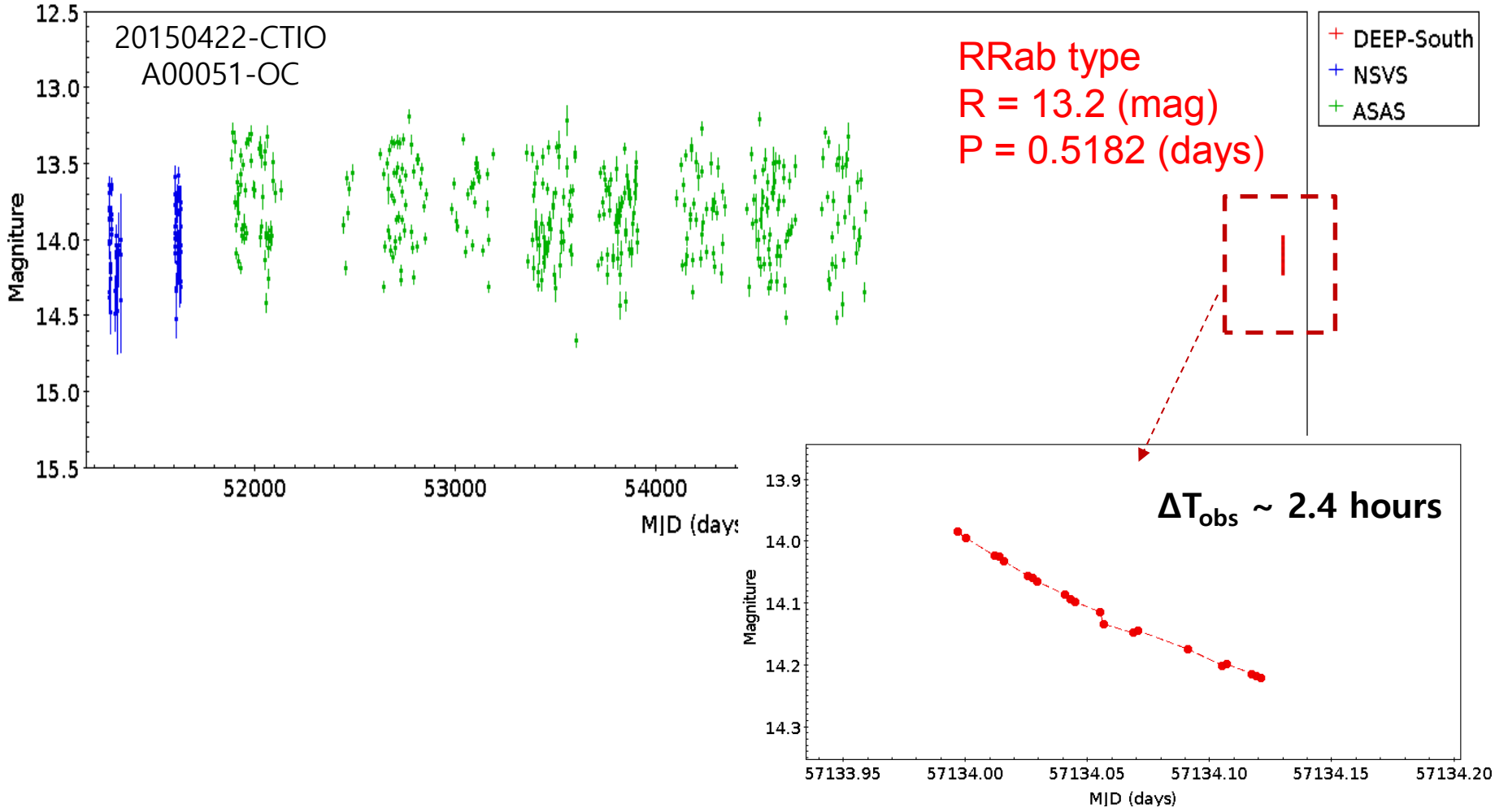


Credit: Jeremy Kubica

Advanced cross-matching/FindTracklets (Planned version)

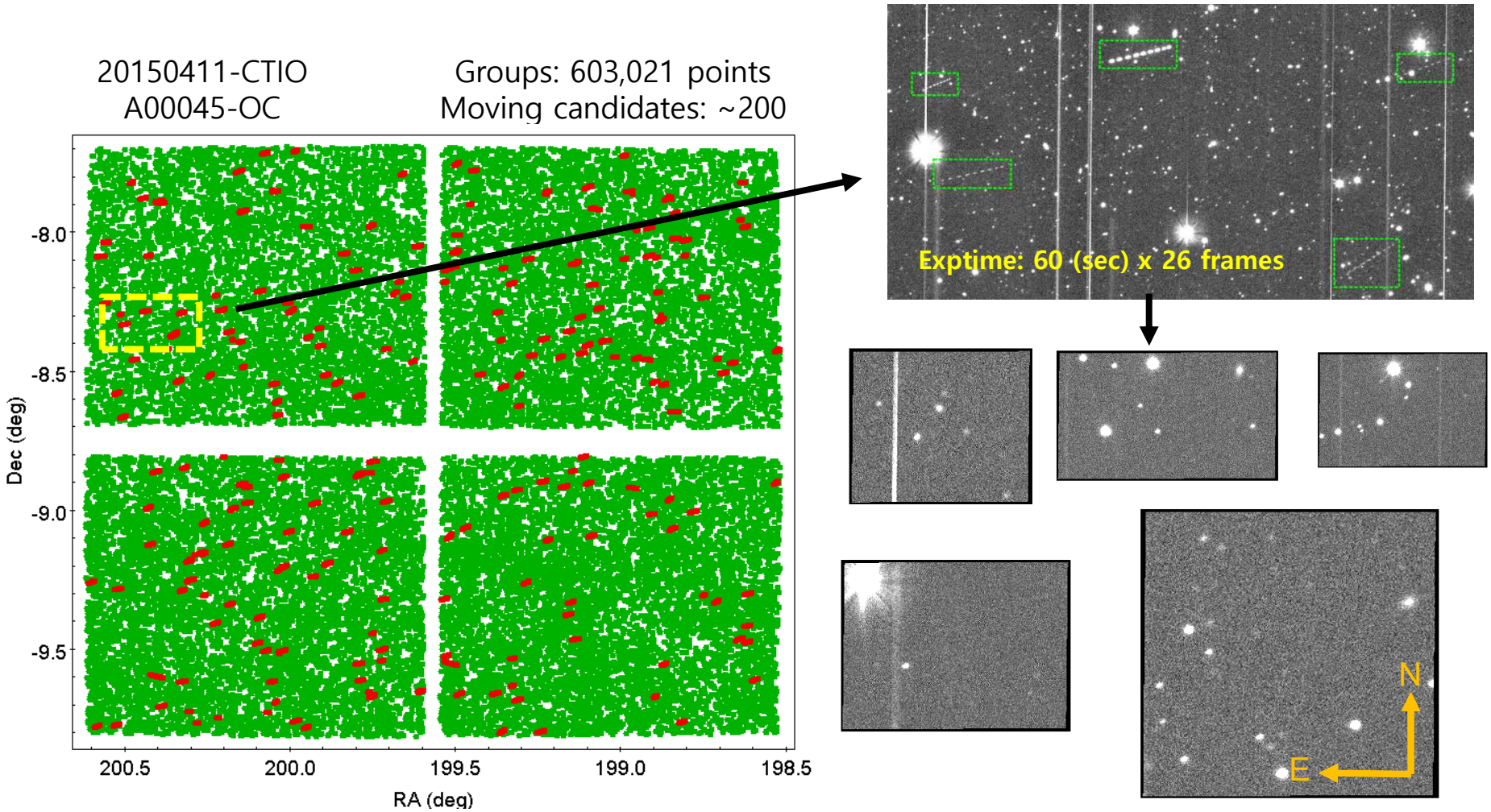
Light curve of known variable

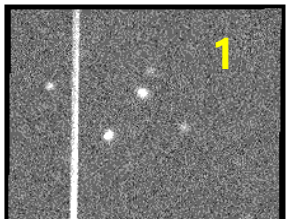
- AAVSO (American Association of Variable Star Observers) catalog: Checking Variable Stars!
- Listed variable stars are too bright to compare with our observations ☹.

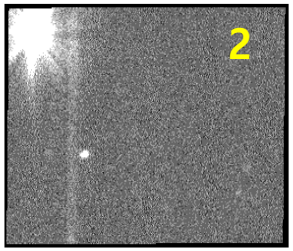


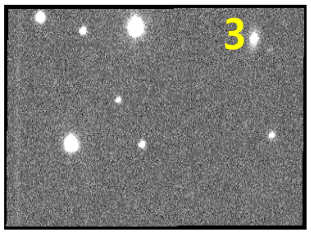
HSSEL chart & moving objects

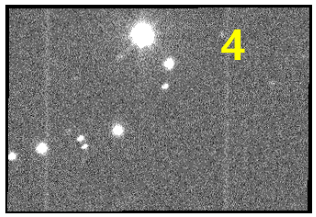
- Use of the HSSEL (High-signal single event list) chart helps to identify bright moving objects in images.
- False positives with high S/N are still a problem.

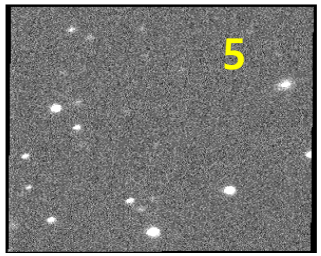




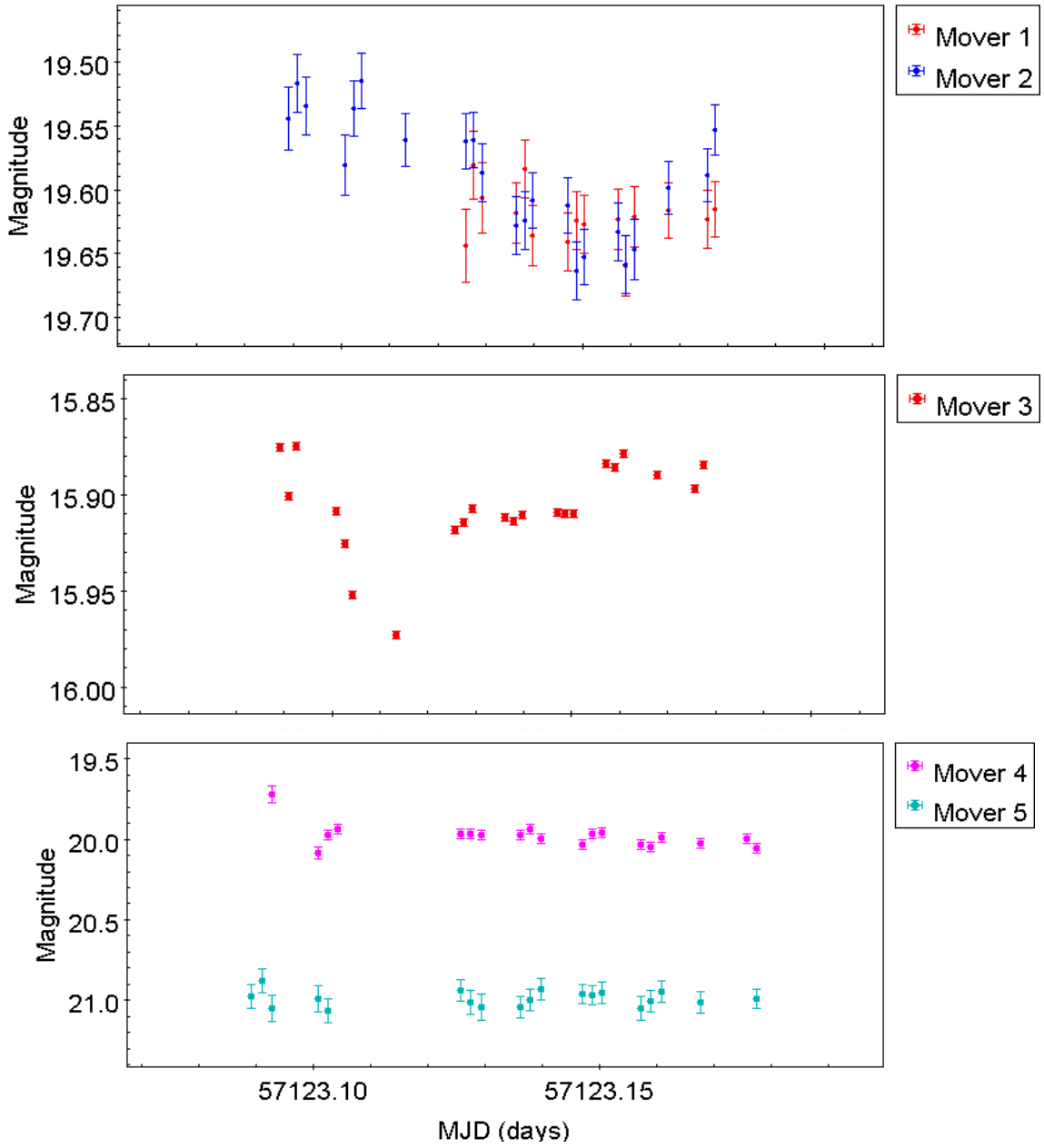




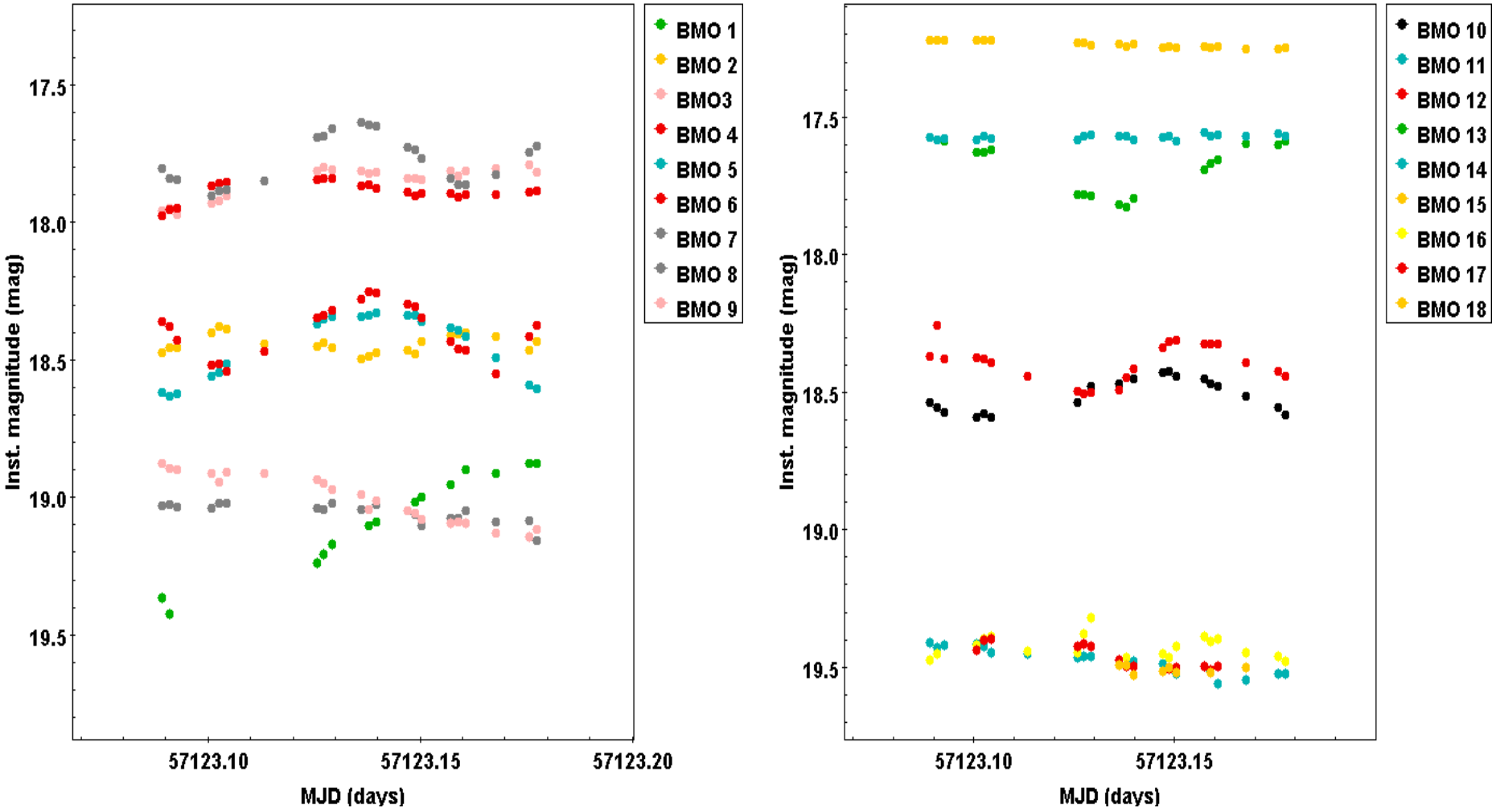




Sample light curves



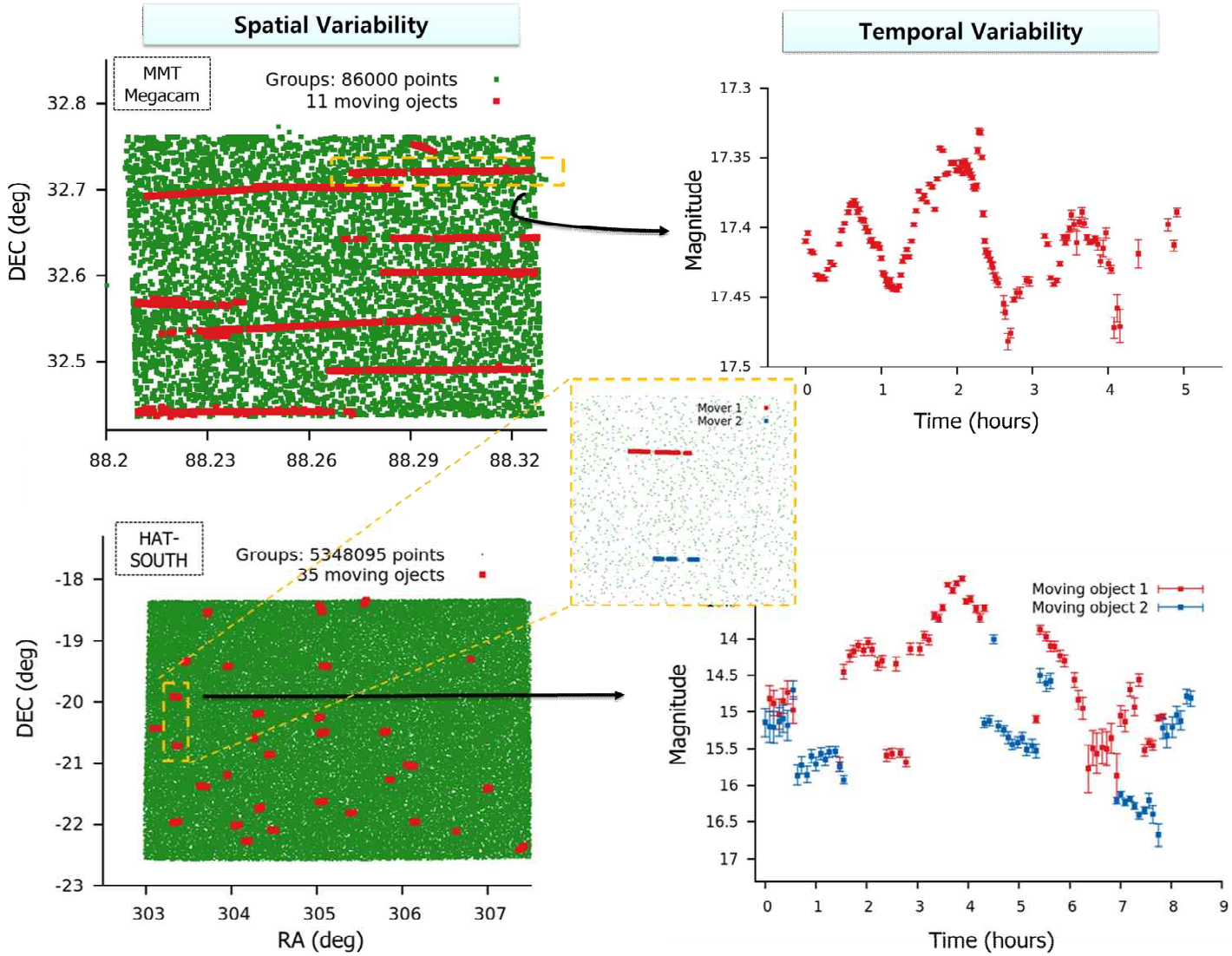
Sample light curves of bright moving objects



➔ We confirm that a large fraction of moving objects show their variable nature!

HSSEL chart (continue.)

- Spatial and temporal variability of trailed detections in a cleaned sample for MMT Megacam (Top) data and HAT-South (Bottom) data sets.



Summary and Planned works

- We develop an automatic reduction/photometry pipeline: SExtractor-based detection+ Multi-aperture measurement +FastBit indexing (Chang et al. in preparation).

- We achieve relatively fast and stable production of frame and lightcurve catalogs for all point sources. Our approach can make the DEEP-South image database useful in finding new variable sources. **The many lives of data!**

- Plan 1: Optimization of multi-aperture photometry pipeline for moving objects, including photometric calibrations of field-overlap regions (with a longer time span).

- Plan 2: Testing a new type of database which supports a spatio-temporal data types (Dr. Shin, M.-S. @ KASI).

- Plan 3: Defining and cataloging moving objects in DEEP-South. DEEP-South Asteroids Factory! (Yi, Han @ Yonsei & DS team).