Known Small Solar System Bodies in the HSC-SSP Data

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Small Solar System bodies (SSSBs)

The investigation of small Solar System bodies (SSSBs) is crucial for unraveling the dynamical and collisional evolution from the early solar nebula to the current Solar System. To enhance our understanding of the history of the Solar System, it is essential to comprehensively grasp the spatial distribution, size distribution, and surface properties of various types of SSSBs.
Therefore, it is highly required to increase the observational data of small SSSBs for the essential understanding of the collisional evolution of the Solar System. Observations with 8-10 m class large telescopes enable us to investigate the detailed properties of sub-km or smaller SSSBs.

Even if the observation is not dedicated to the SSSB survey, SSSBs can be found among many observed astronomical objects. Since SSSBs are moving objects, we need to construct an efficient method to extract and identify the SSSBs among a huge number of detected sources.

Discovered SSSBs
Asteroids/TNOs: **1,329548**
Comets: **4,602**
as of 2024-Jan-15
(from Minor Planet Center)

Hyper Suprime-Cam Subaru Strategic Program data

We use photometric (SRC) and imaging (CORR) data obtained with the **Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) survey** for the SSSB extraction. HSC covers a wide field of view of 1.8 deg^2 with 116 CCDs (104 CCDs are used for science imaging), and thousands of sources are detected in each CCD image for one exposure (Fig. 1, 2).

Photometric data (SRC) of sources detected with the HSC analysis pipeline, hscPipe[1,2] (version 8), for all frames obtained with **Wide survey in March 2014 - January 2020 (Public Data Release 3: PDR3)**[2,3] are stored in **PostgreSQL database.**

HSC-Wide detected source DB
(PostgreSQL version 11.10)
- ~2,000—5,000 sources/ccd
- 104 ccds/exposure
- ~100 exposures/night
- 278 nights

⇒ **total ~4.0 billion records !!!**

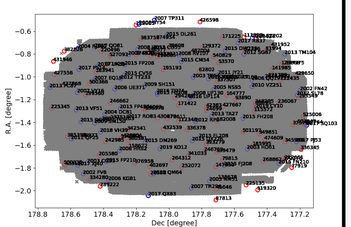


Fig.1 An example of asteroids expected to be observed with HSC for one exposure.
Red: numbered (155 objects)
Blue: unnumbered (113 objects)

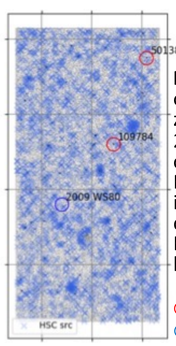


Fig. 2 An example of HSC CCD image, z-band, obstime = 2015-03-16T10:43, ccd = 58.
Blue crosses indicate sources detected with the HSC pipeline, hscPipe.
○ numbered
○ unnumbered

Extraction and identification method of SSSBs from HSC-SSP data (flowchart)

observed HSC data frame
(278 nights, ~21,000 exposures for Wide)

Input: visit, obstime

NASA JPL/Horizons
(astroquery.jplhorizons)

Horizons terminology[4]
r = heliocentric distance
delta = geocentric distance
elong = solar elongation angle
(flag = leading or trailing)
alpha = sun-target-observer angle

Objects with (ra, dec) fall within the HSC FOV at the observation

objname, pointing, visit, obstime, ccd, ra_obj, dec_obj, ra_rate, dec_rate, ra_3sigma, dec_3sigma, r, delta, vmag, elong(Flag), alpha

Photometric data (SRC) of detected sources for all CCD images (278 nights)

hscPipe terminology[1]
pointing = sequential # of date-obs
visit = exposure
parent = unique ID of parent source
deblend_nchild = # of child sources

pointing, visit, obstime, ccd, exptime, filter, id, coord_ra, coord_dec, parent, deblend_nchild, sdssshape_[xx|yy|xy], fluxmag0, fluxmag0err, circularApertureFlux(Sigma), psfFlux(Sigma)

HSC SSSB candidates
(~10,000 SSSBs/night)

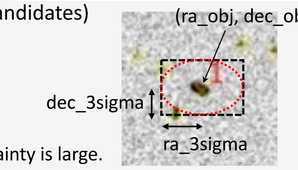
matching
(e.g., 150 sec for ~10000 candidates)

ccdsrc (PostgreSQL DB)
(~4.0 billion sources)

1 position

obstime = obstime AND
$(coord\_ra - ra\_obj)^2/ra\_3sigma^2 + (coord\_dec - dec\_obj)^2/dec\_3sigma^2 < 1$

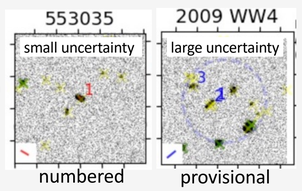
Several candidates may be selected when position uncertainty is large.



2 shape

adaptive moments[5]: sdssshape_xx, sdsshape_yy, sdsshape_xy (indicator of source shape and size)

transverse velocity (ra_rate, dec_rate) * exptime



HSC-SSP known SSSB catalog

Columns (to be updated): object[number, name, provisional designation], obstime[isot, jd], ra_obj, dec_obj, ra_3sigma, dec_3sigma, azimuth, elevation, airmass, glxlon, glxlat, vmag, r, delta, elong, elongFlag, alpha, pointing, visit, ccd, exptime, filter, id, coord_ra, coord_dec, parent, deblend_nchild, sdssshape_xx, sdssshape_yy, sdssshape_xy, moving_angle, moving_length, magnitudes & errors (aperture photometry with radius = 20, 30, 40, 60 arcsec & psf photometry)

References: [1] Bosch+ 2018, PASJ, 70, 5; Bosch+ 2019, ADASS XXVIII, 521
[2] Aihara+ 2021, PASJ, 74, 247
[3] https://hsc-release.mtk.nao.ac.jp/doc/index.php/sample-page/pdr3/
[4] https://ssd.jpl.nasa.gov/horizons/
[5] https://www.sdss.org/dr12/algorithms/classify/#photo_adaptive
[6] Takata+ 2020, ASPC, 527, 717 (ADASS XXIX); Furusawa+ 2020, SPIE 11452, id. 1145226

HSC-SSP PDR3 SSSB catalog

Information of identified SSSBs are summarized for all 278 nights and made the preliminary **HSC-SSP PDR3 Wide SSSB catalog**. The catalog contains **~1,000,000** records for **>200,000** unique objects. The heliocentric distances of SSSBs when observed are shown in Fig. 3. Examples of NEA, Main-belt, Jupiter Trojan, and TNO are shown in Fig. 4.

# of obs >= 30: >120 objects # of obs > 1: ~160,000 objects
# of obs >= 20: ~1,800 objects # of obs = 1: ~60,000 objects
# of obs >= 10: ~22,500 objects

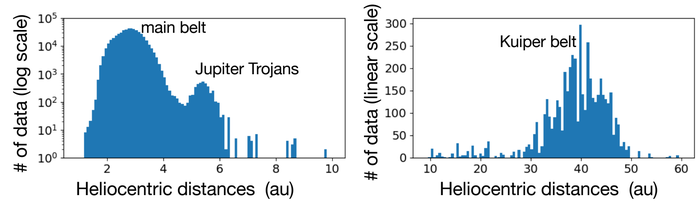


Fig. 3 Histogram of heliocentric distances of objects in the HSC SSSB catalog

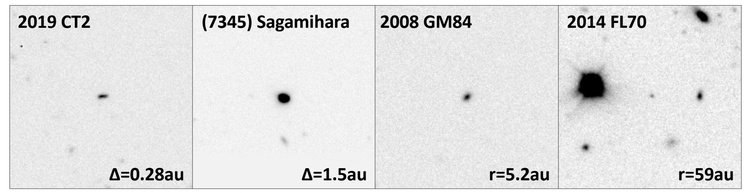


Fig. 4 Example objects of SSSBs in HSC-SSP PDR3 .

Summary and Future works

We used the SRC and CORR data in the **HSC-SSP PDR3 Wide** for the SSSB extraction. We first constructed the **PostgreSQL** database of SRC data of all detected sources **between March 2014 and January 2020.** We developed a system to effectively extract known SSSBs from the sources registered to the database. The information (coordinates, magnitudes, etc.) on known SSSBs is obtained using the orbital data provided by the Minor Planet Center (MPC) and the NASA JPL/Horizons web tools. As the first result, we identified **~1,000,000 events for >200,000 SSSBs** for 278 nights.

We are currently creating a catalog using the data of PDR3 Deep/Ultra Deep. In the next step, we will make a catalog of both known and newly discovered SSSBs using the final PDR data.

Our final goal of this project is to **develop a fast extraction and identification system for known and newly discovered SSSBs among the Subaru HSC data and keep updating the HSC SSSB catalog**, using a hyper-speed database management system and a large-scale parallel computing system[6].