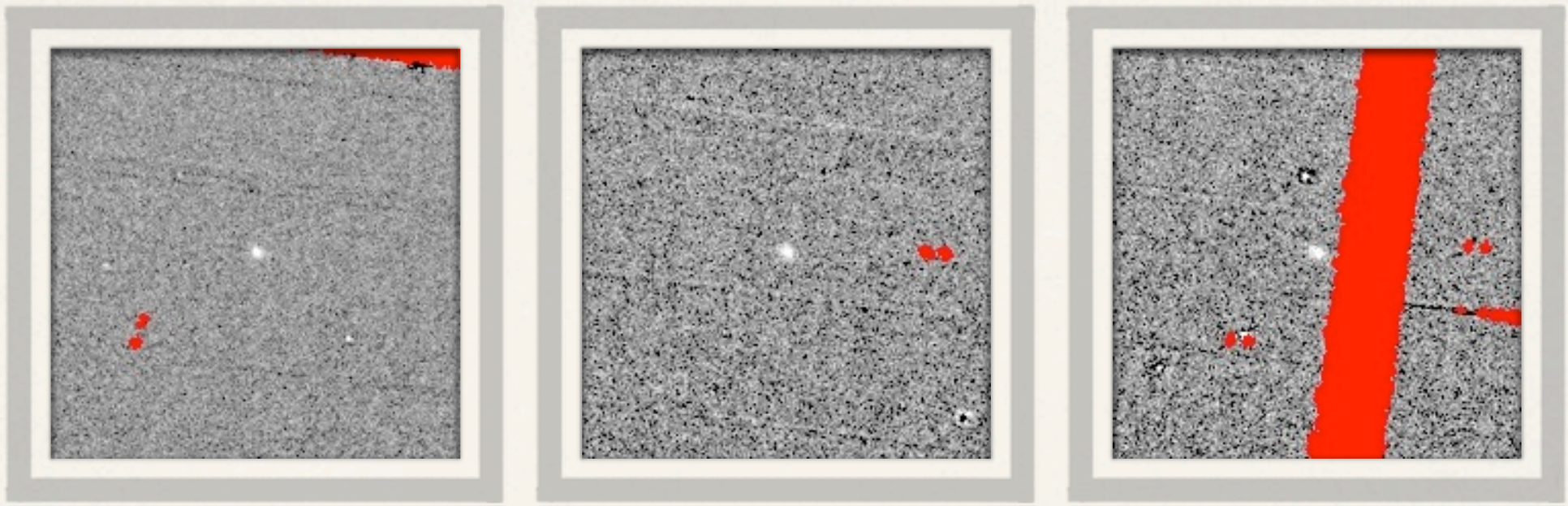


2012 UR138

The Pan-STARRS Moving Object Processing System

Larry Denneau

PS1 Seminar November 2, 2012

Acknowledgements

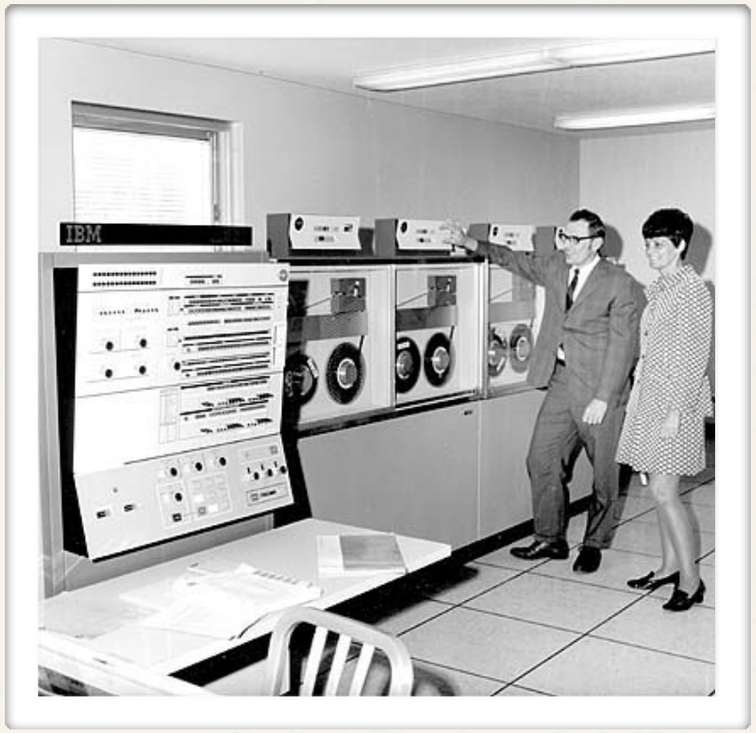
- IfA, Pan-STARRS Project
- AFRL, NASA NEOO
- PS1SC
- NAI
- JPL, OrbFit, CMU, LSSTC
- KP1

Outline

- What is MOPS?
- How MOPS works
- MOPS Tracklets
- PS1 MDRM Survey
- PS1 MOPS Processing
- Results
- Navigating MOPS Data
- Auxiliary products
- Data issues
- PSPS and MOPS
- More information

What is MOPS?

IPP Transient Detections



Observations + Orbits q, e, i etc.

99% PHOs d > 1 km
90% PHOs d > 300 m
90% everything else

What is MOPS?

- First funded PS science client, managed by Pan-STARRS project; continued development funded by Project and NEOO
- Stand-alone, unbiased dataset of detections and orbits; OK to be incomplete as long as we can measure it
- Highly useful as a simulation tool (PS1, LSST, ATLAS, TALCS)
- Operation verified by many simulations using synthetic solar system
- Originally designed for PS4
- Tracklet-centric (single-night processing) operation for PS1

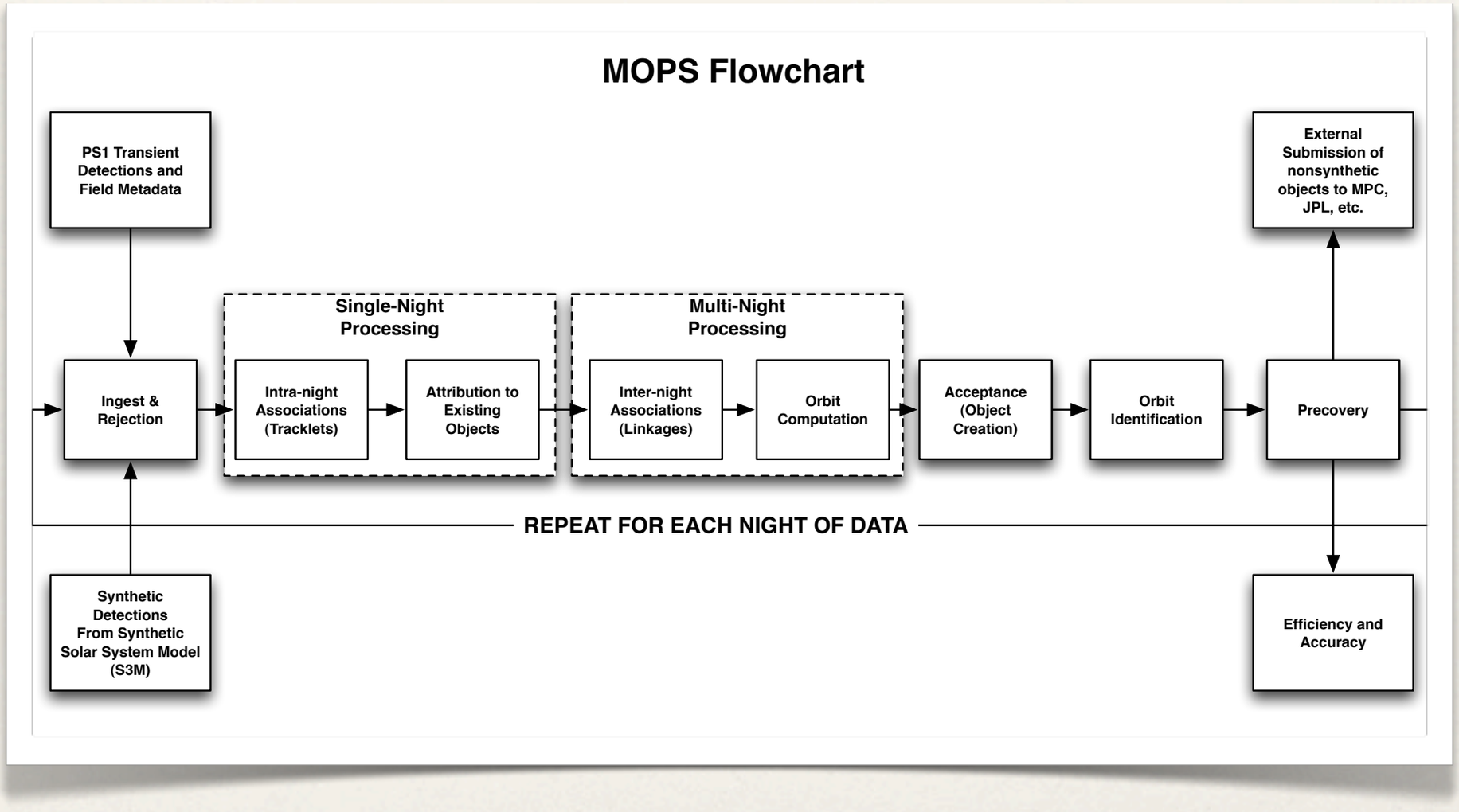
What is MOPS?

- C/C++/Fortran 95/Perl/Python/R (even LISP)
- UW Condor for task management
- Various orbit determination packages (JPL, OrbFit, OpenOrb, MPC)
- 32-cores, 2 GB/core, 200 GFLOPS
- 10TB MySQL DB
- Production cluster at IfA Manoa

How MOPS Works

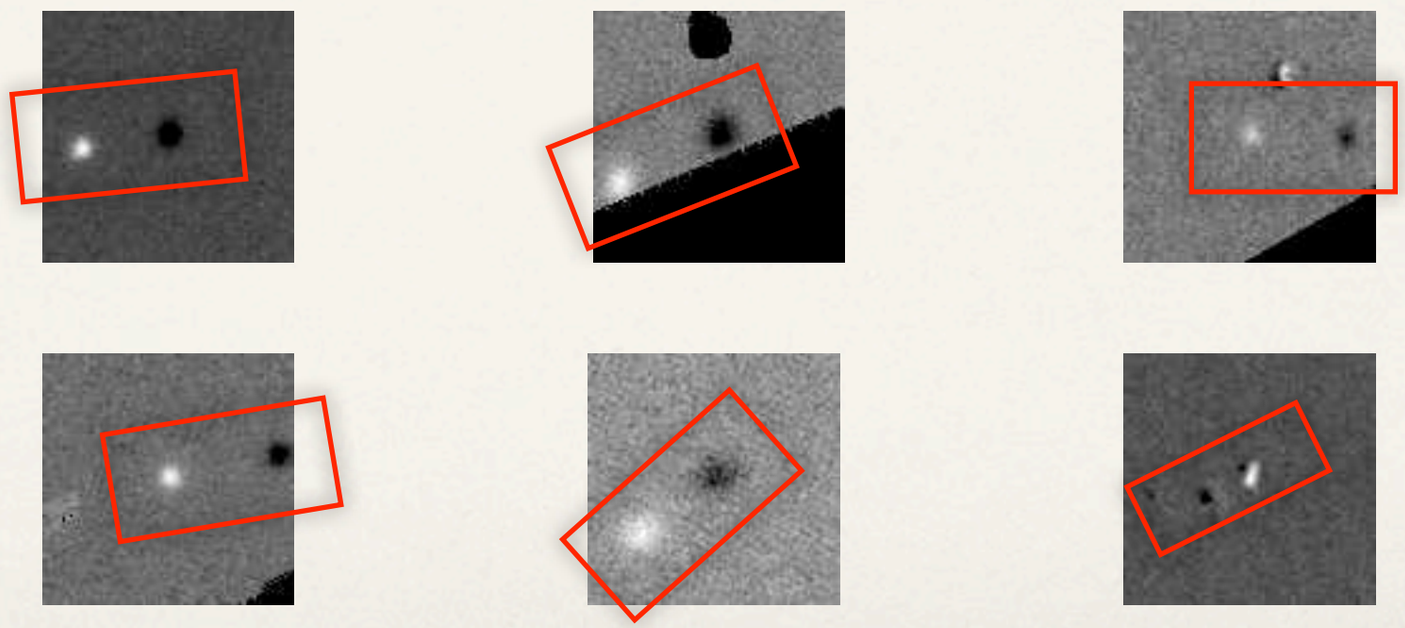
- Nightly processing of diff detection catalogs (warp-warp or warp-stack) from IPP
- Synthetics injected
- Tracklets created
- Derived objects/orbits where possible
- Attribution/precovery
- Instantaneous efficiency
- Export to PSPS, MPC, MOPS alert system
- MySQL database for all detections, tracklets and derived objects

How MOPS Works



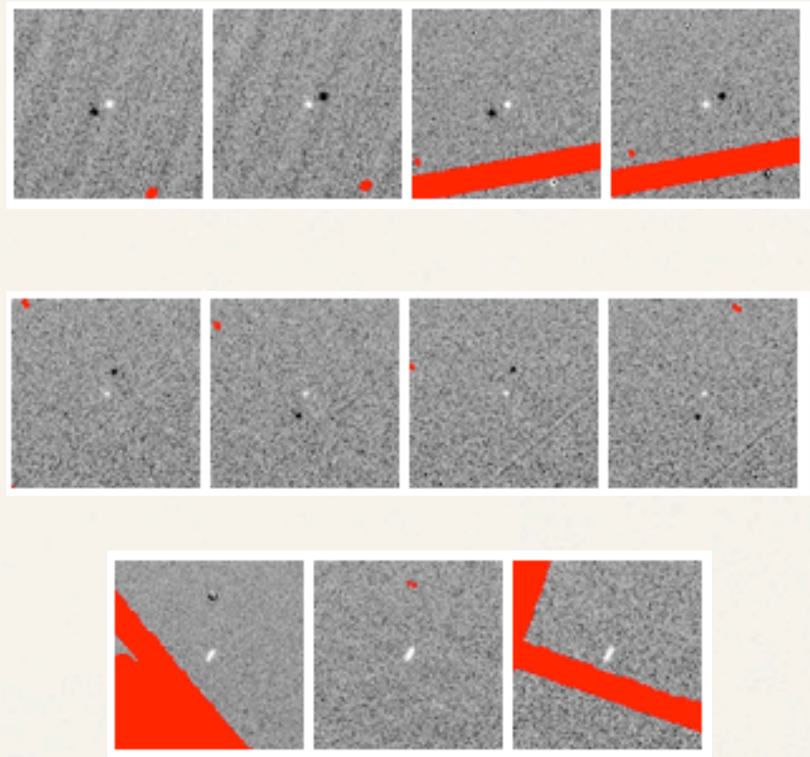
MOPS Tracklets

- Same-night associations that could be the same body
- Acquired in TTI pairs or “quads”
- 10-45 minutes between first and last observations



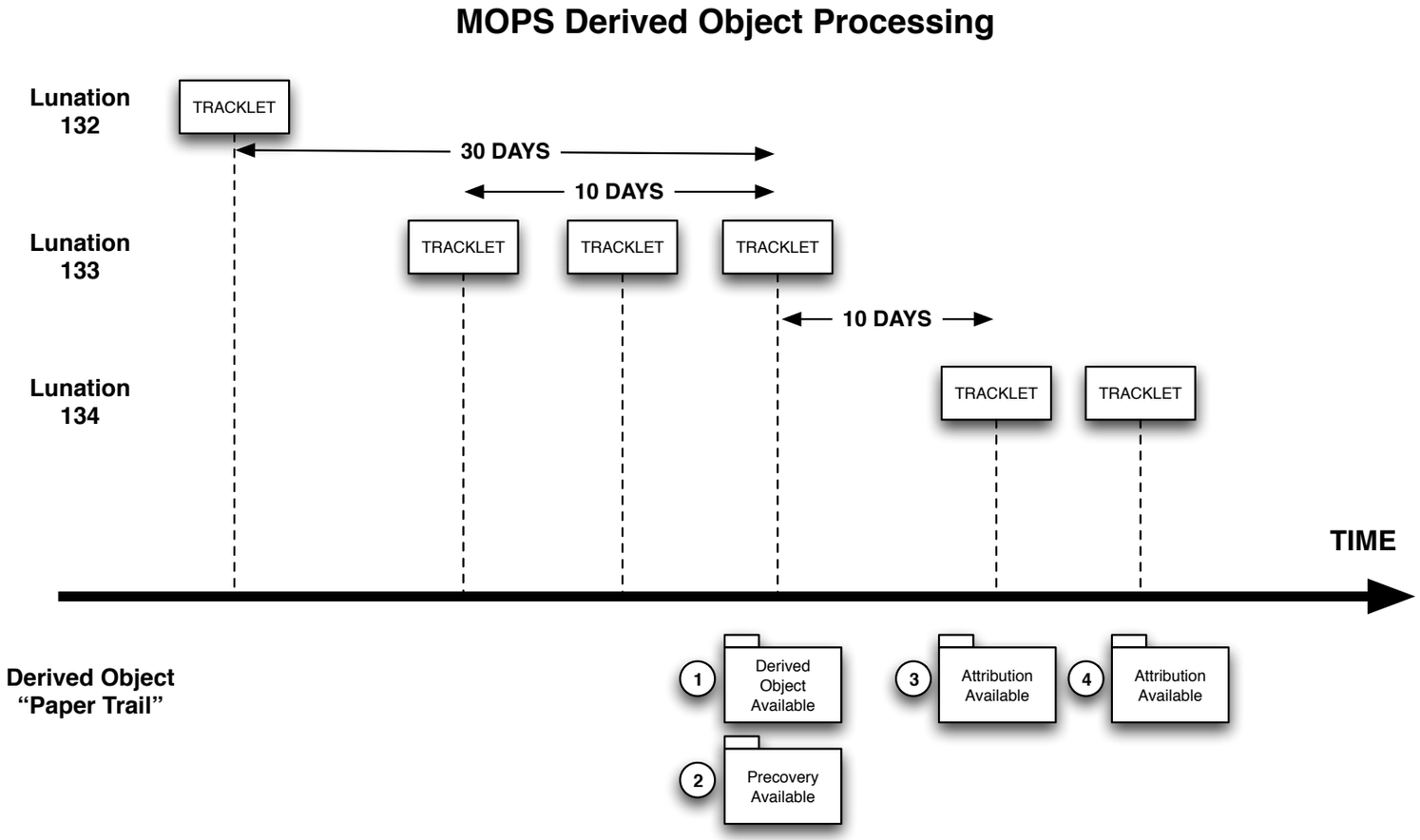
MOPS Tracklets

- Solar system observing occurs using back-to-back pairs called “quads”

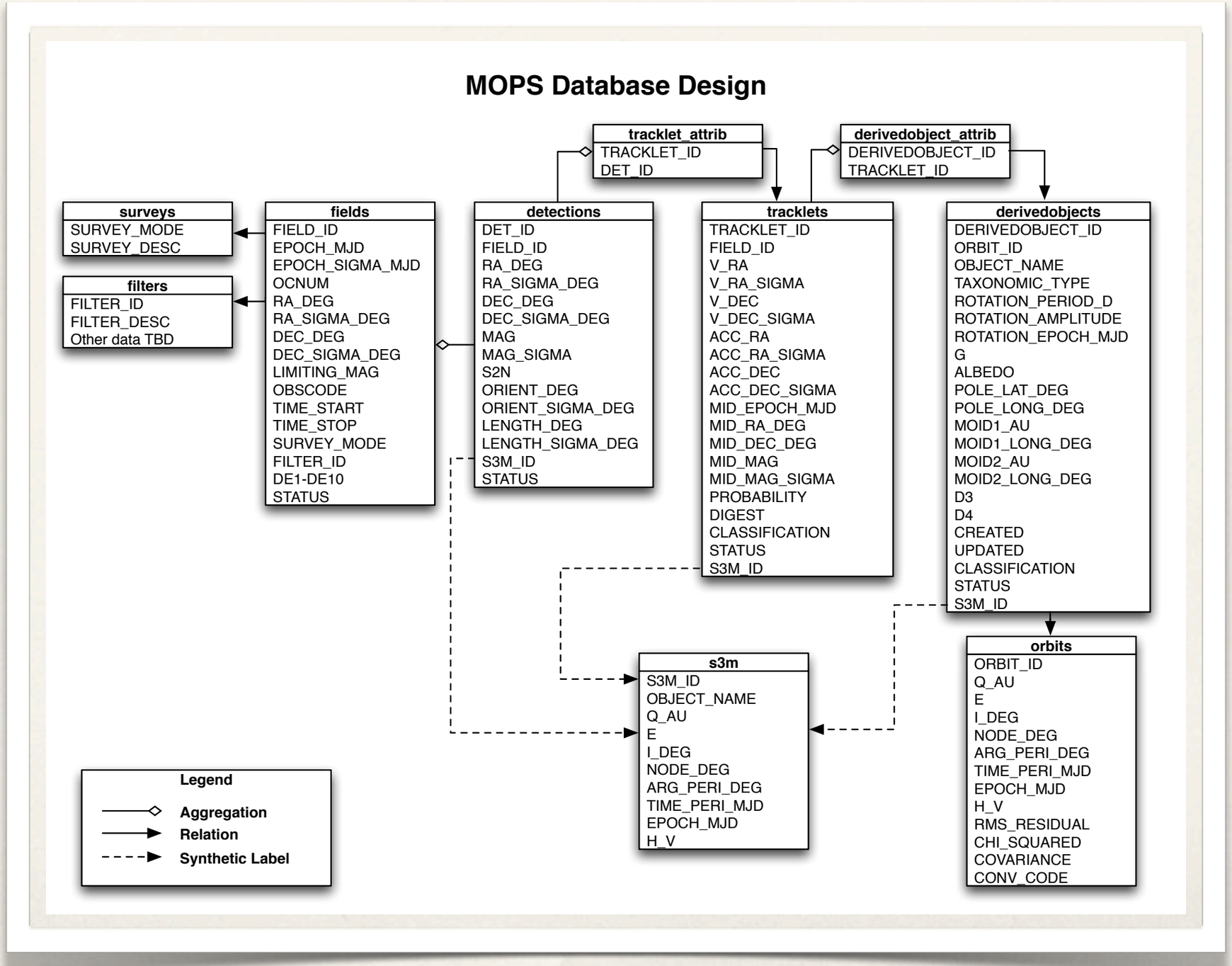


- Most pair tracklets are false
- Most slow-moving quad tracklets are true

How MOPS Works



How MOPS Works



PS1 Survey

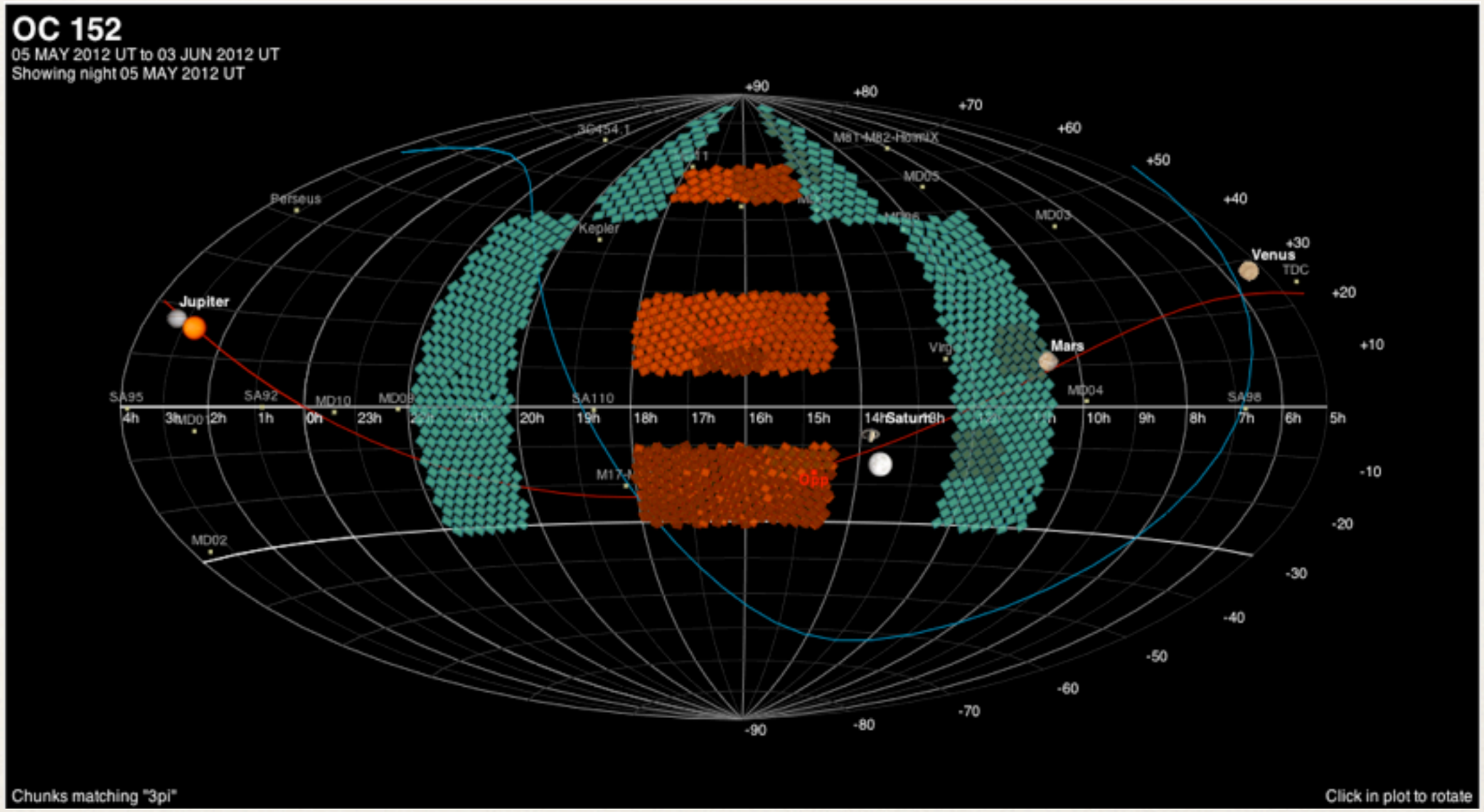
- 3π — single pairs or back-to-back pairs in two filters ("quads"), matched to solar colors (*g*=43 sec, *r*=40 sec, *i*=45 sec), 56%
- Medium Deep — 8x240 sec
- Solar System — w-band quads at opposition or small solar elongation "sweetspots"
- STS — very difficult, but one NEO found
- M31 not useable for MOPS

PS1 Survey Allocation

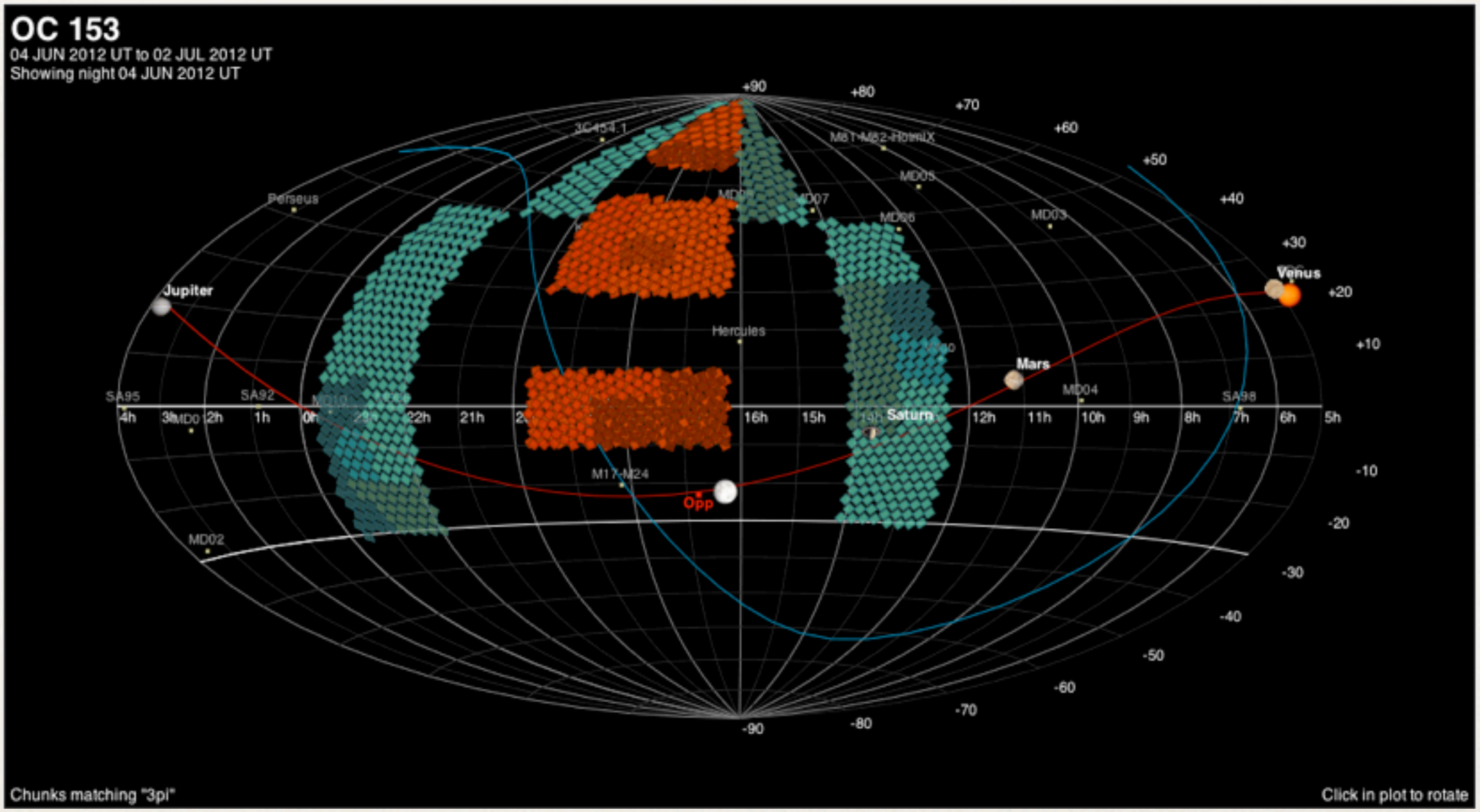
3π	56%
MD	25%
SS	5% (11%)
Rest	14% (8%)

Solar system time increased to 11% as of Nov 2012

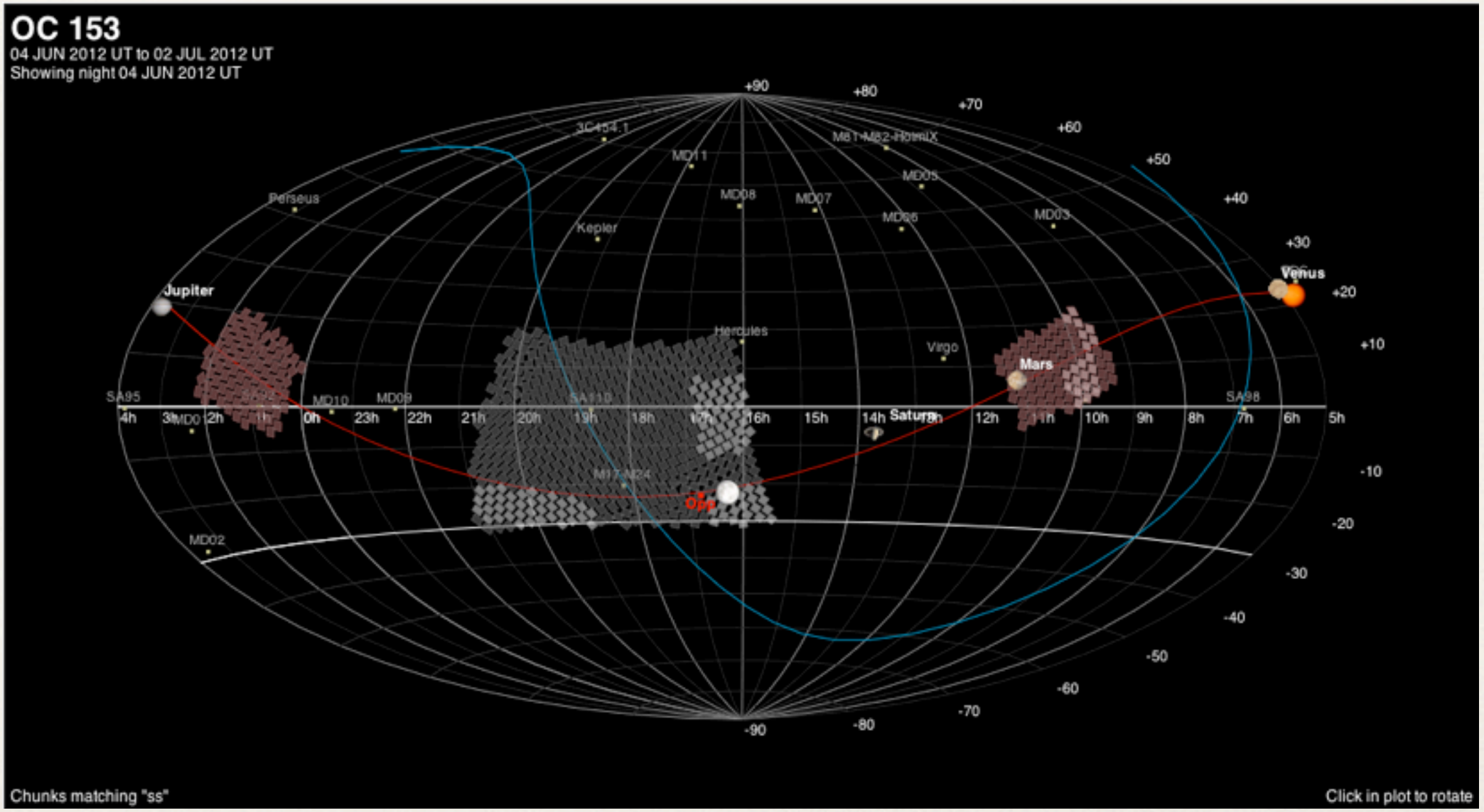
PS1 MDRM Survey — 3π



PS1 MDRM Survey — 3π



PS1 MDRM Survey — SS



MOPS S3M

- Realistic flux-limited synthetic solar system model
- 14M objects
  - main belt, NEO, Trojans
  - comets, Centaurs, scattered disc, Kuiper belt
  - impactors, hyperbolics
- S3M provides live efficiency of pipeline operations
- Grid model verifies phase space coverage

PS1 MOPS Processing

- Tracklet-centric processing (SYNTH, TRACKLET, KNOWN)
- Reviewed by humans, screened for NEO candidates and comets
  - NEOs => NEOCP
  - Comets => internal followup (usually)
  - Known numbered and multiopp asteroids assigned by KNOWN_SERVER
- Objects discovered from 3PI, SS, MD chunks

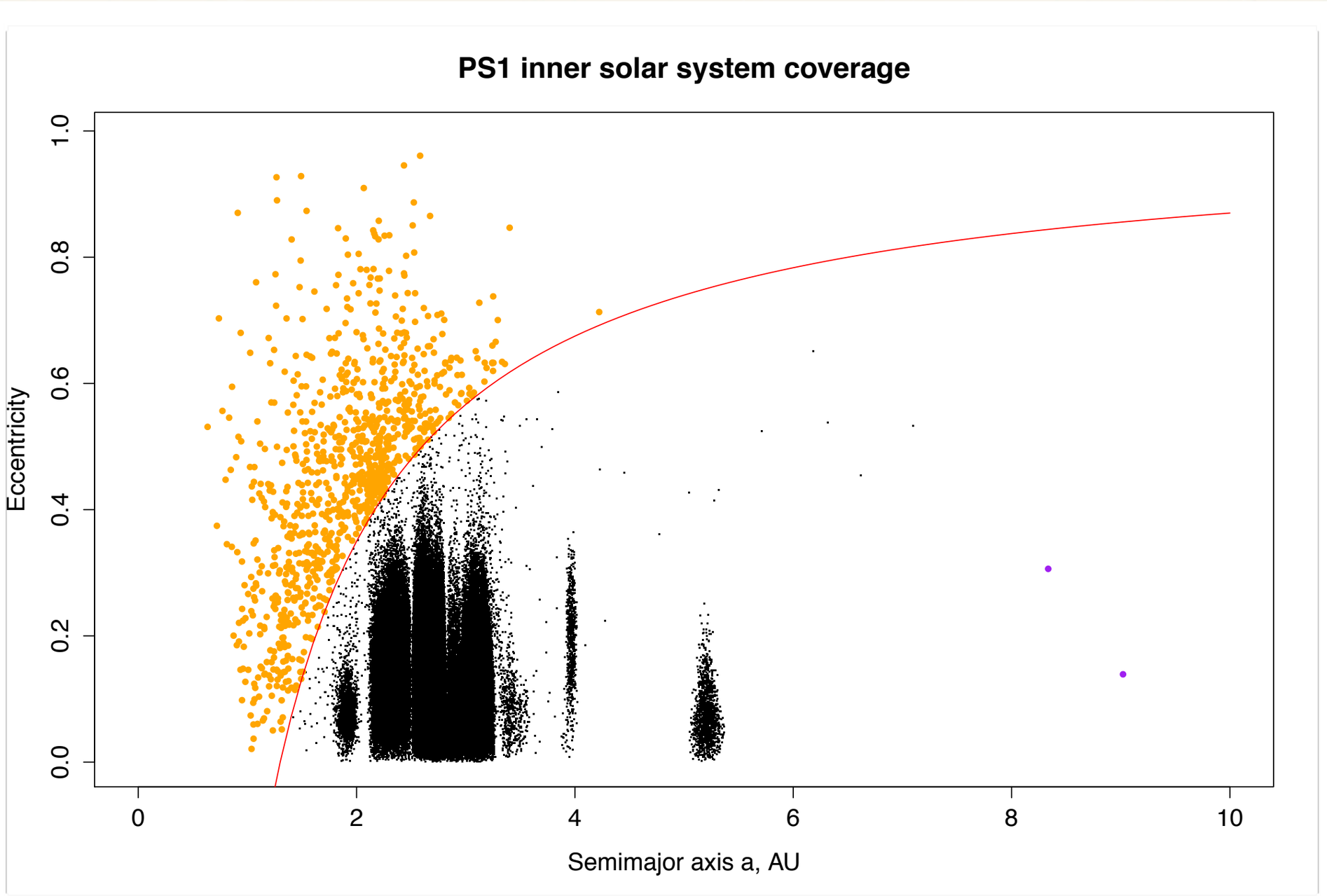
PS1 MOPS Processing

- Inner solar system only, $a < 5.5$ AU
  - warp-warp image diffs lose slow-moving objects
  - KP2 has its own pipeline
- Derived objects processing postponed until end of PS1 mission

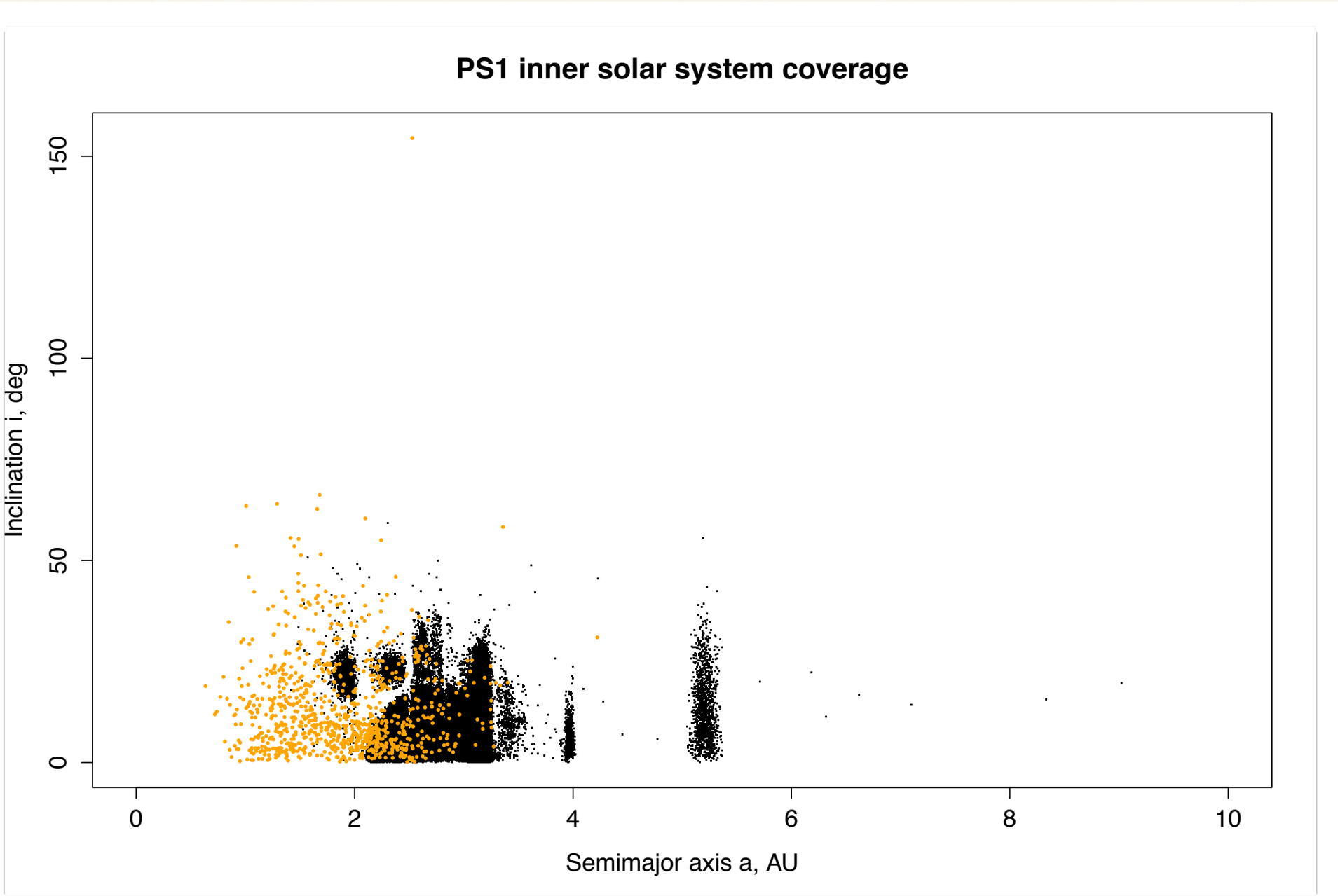
PS1 MOPS Results (Oct 2012)

- Over 3,000,000 observations of 280,000 asteroids submitted observations to MPC (~10,000/night)
- 20,000 MBAs discovered
- 400+ NEOs (~30/month)
- 20+ comets, 2 MBCs
- C/2011 L4
- Astrometry is excellent, < 0.15” (from KNOWN_SERVER residuals)

PS1 MOPS Results



PS1 MOPS Results

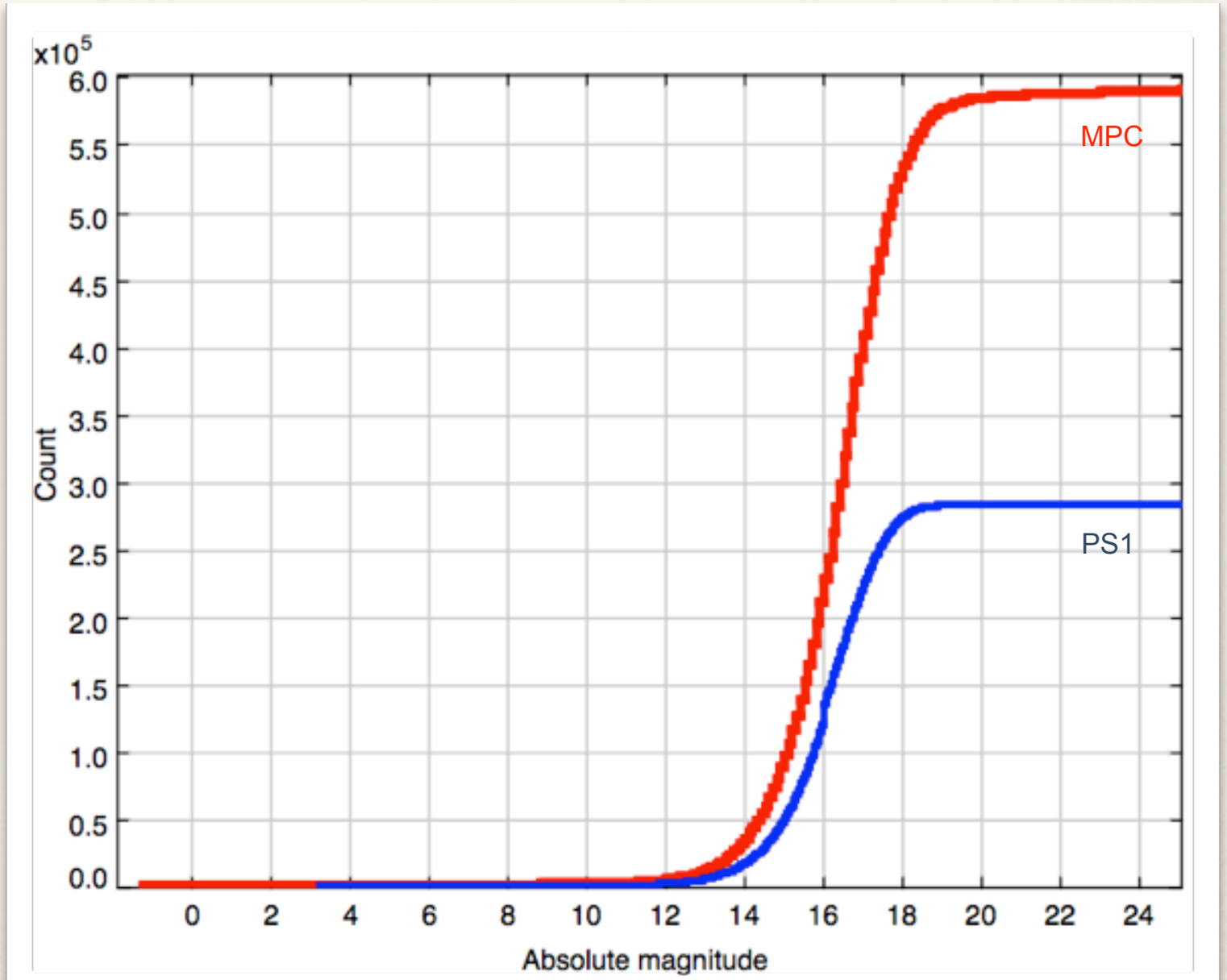


PS1 MOPS Results

Cumulative H distribution of PS1 vs MPC asteroids

PS1: 280,000

MPC: ~600,000



Navigating MOPS Data

- Most access is via MySQL or MOPS web interfaces, **psmops_ps1_mdrm137** and **mdrm152**

- Czaring pages for NEOs/comets

- http://mopshq1.ifa.hawaii.edu

MOPS Solar System Processing

psmops_ps1_mdrm152

TJD 6232

THU 01 NOV 2012 UT
OC 158

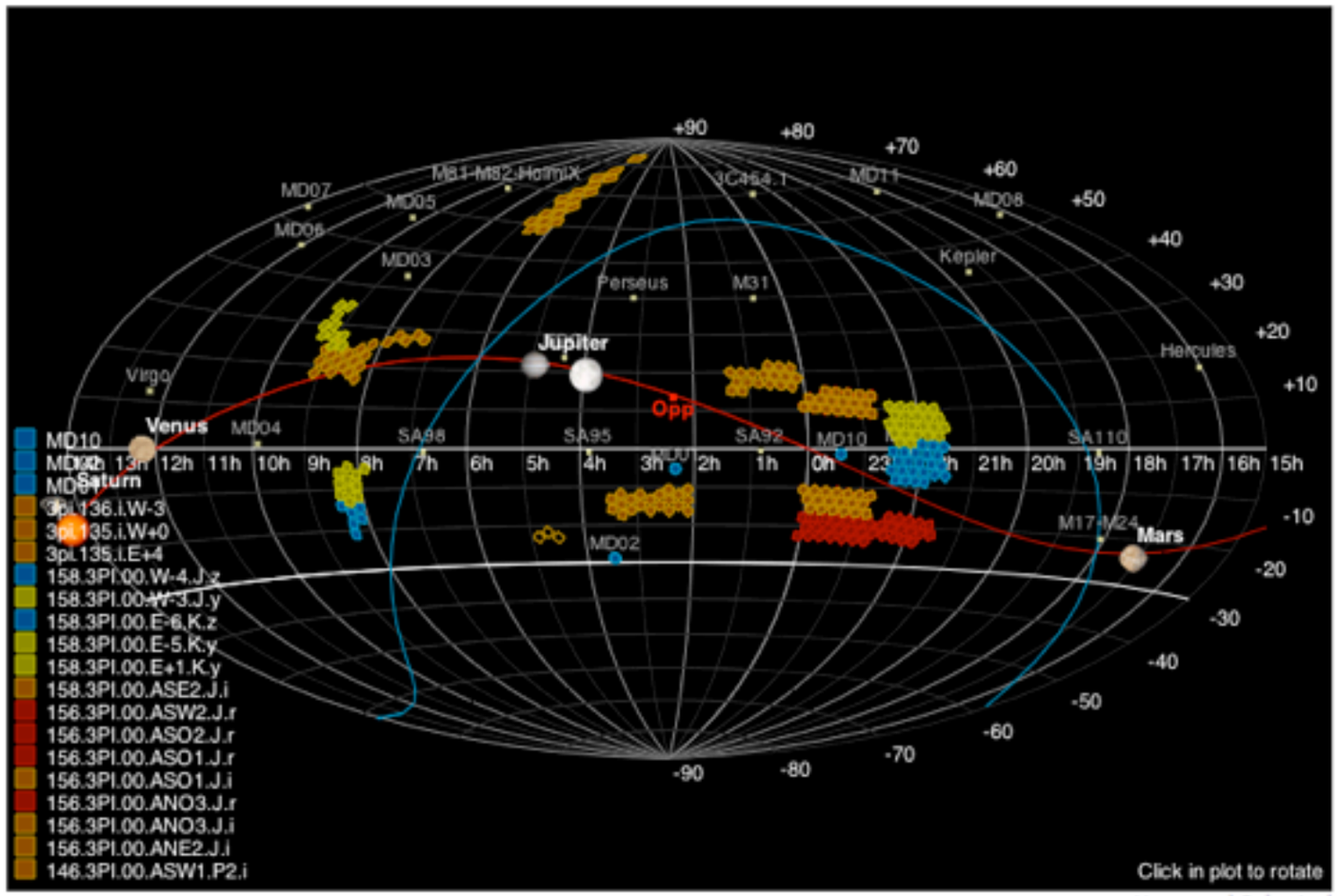
All Chunks By Observation Time

Chunk Name	Obs Time (UT)	Last Processing Status	Num Exposures
158.3Pl.00.W-3.J.y	04:30 UT	POSTTRACKLET	46
158.3Pl.00.W-4.J.z	05:05 UT	POSTTRACKLET	46
156.3Pl.00.ANO3.J.r	05:42 UT	POSTTRACKLET	36
156.3Pl.00.ASW2.J.r	06:18 UT	POSTTRACKLET	34
156.3Pl.00.ASO2.J.r	06:48 UT	POSTTRACKLET	38
156.3Pl.00.ASO1.J.r	07:24 UT	POSTTRACKLET	38
156.3Pl.00.ASO1.J.i	08:00 UT	POSTTRACKLET	38
156.3Pl.00.ANO3.J.i	08:40 UT	POSTTRACKLET	36
MD10	09:17 UT	POSTTRACKLET	8
156.3Pl.00.ANE2.J.i	09:54 UT	POSTTRACKLET	36
146.3Pl.00.ASW1.P2.i	10:31 UT	POSTTRACKLET	42
MD02	11:16 UT	POSTTRACKLET	8
MD01	11:53 UT	POSTTRACKLET	8
3pi.135.i.W+0	12:30 UT	POSTTRACKLET	36
3pi.136.i.W-3	13:09 UT	POSTTRACKLET	10
158.3Pl.00.ASE2.J.i	13:24 UT	INGESTED	6
3pi.135.i.E+4	14:22 UT	POSTTRACKLET	36
158.3Pl.00.E-6.K.z	15:01 UT	POSTTRACKLET	12
158.3Pl.00.E-5.K.y	15:12 UT	POSTTRACKLET	22
158.3Pl.00.E+1.K.y	15:31 UT	POSTTRACKLET	20

By Run ID

Run 379 updated 2012-11-01 09:03:32 HST			
Chunk Name	**Type**	**Status**	**Footprints**
158.3Pl.00.E+1.K.y	PAIR	POSTTRACKLET	10
158.3Pl.00.E-5.K.y	PAIR	POSTTRACKLET	11
158.3Pl.00.E-6.K.z	PAIR	POSTTRACKLET	6
3pi.135.i.E+4	PAIR	POSTTRACKLET	18

Run 378 updated 2012-11-01 05:42:17 HST			
Chunk Name	**Type**	**Status**	**Footprints**
156.3Pl.00.ANO3.J.i 156.3Pl.00.ANO3.J.r	QUAD	POSTTRACKLET	18
156.3Pl.00.ASO1.J.i 156.3Pl.00.ASO1.J.r	QUAD	POSTTRACKLET	19
MD01	MD	POSTTRACKLET	1
MD02	MD	POSTTRACKLET	1
MD10	MD	POSTTRACKLET	1



Hammer | Spherical

TJD 6231
WED 31 OCT 2012 UT
OC 158

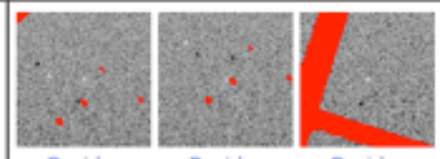
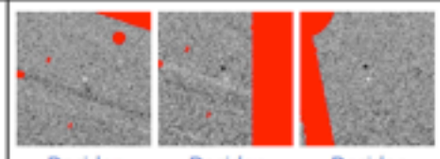
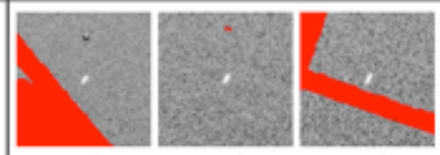
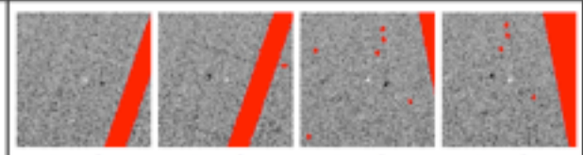
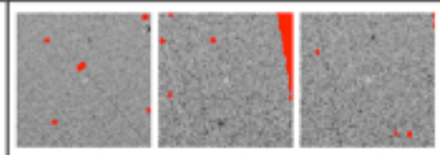
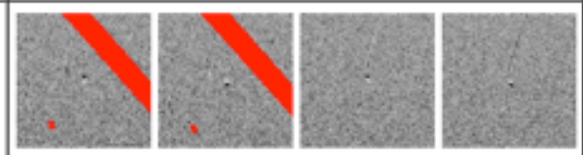
TJD 6233
FRI 02 NOV 2012 UT
OC 158

psmops_ps1_mdrm152

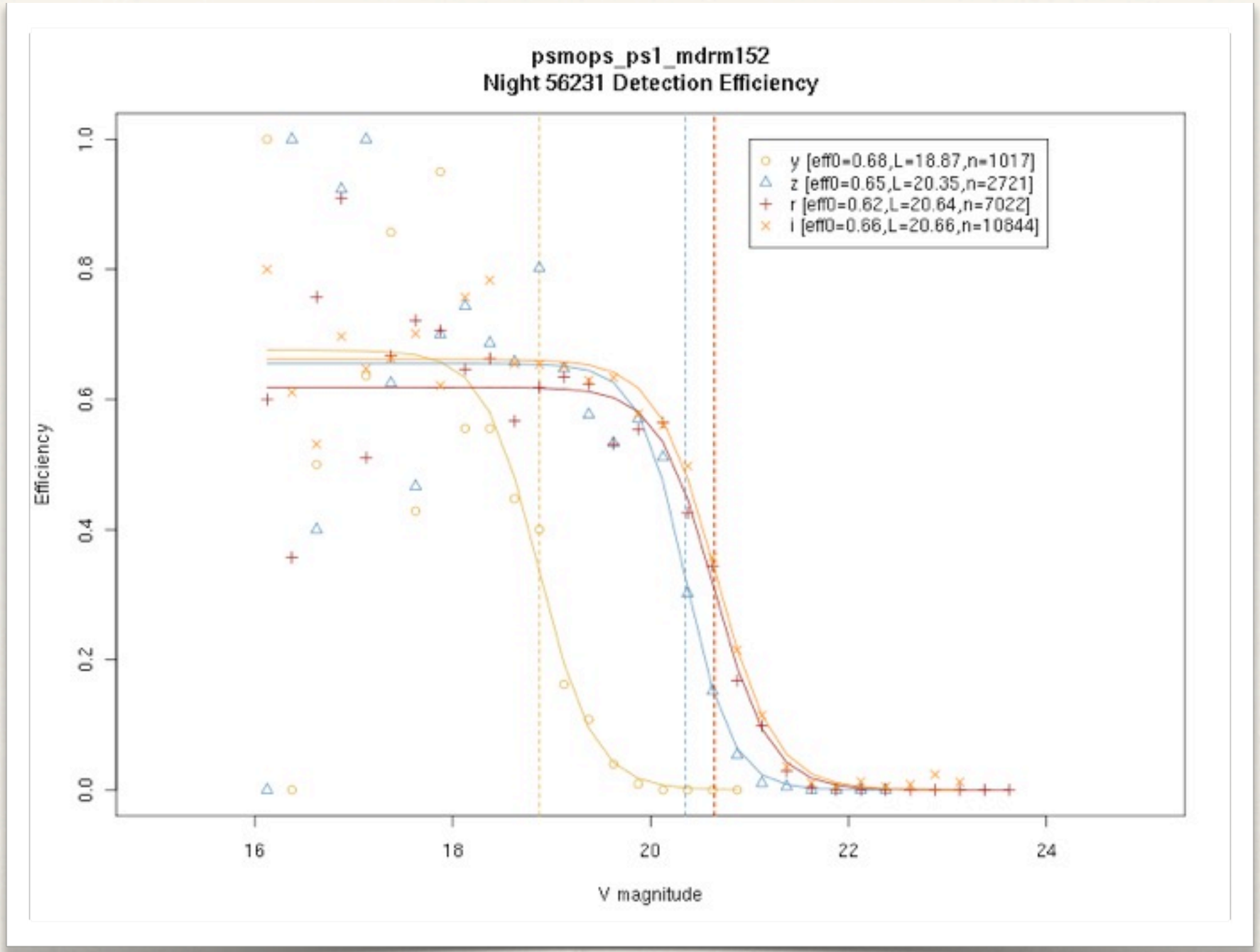
Comet Candidates (Submitted Objects)

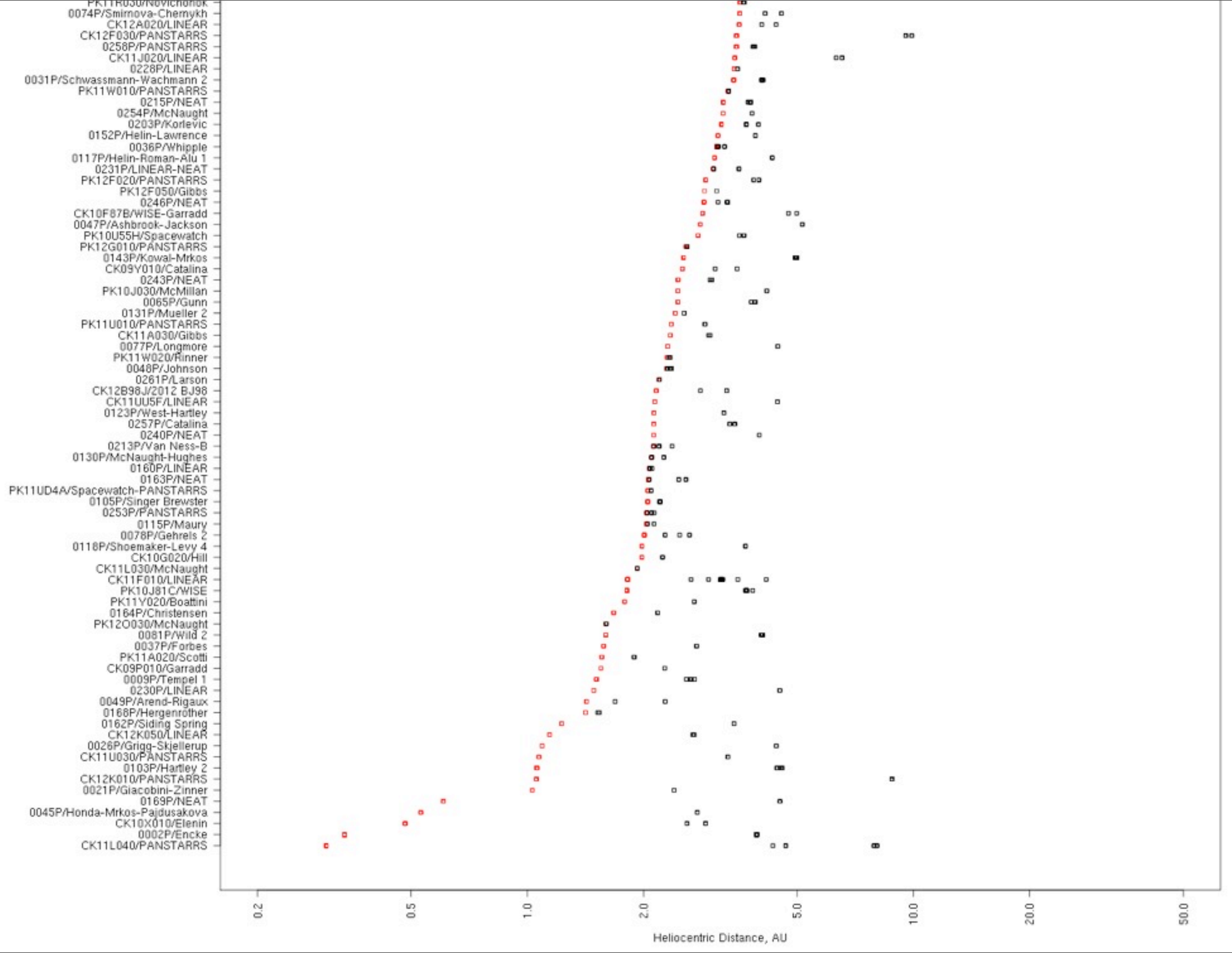
MOPS Night Number 56231 (TJD 6232)
2012-10-31T00:00:00.0Z to 2012-11-01T00:00:00.0Z

Showing 1 through 250 of 371.
First | Next 250 | Last

Tracklet ID	Score Sort	Position	V_{tot} (deg/day) Sort	Pos Ang (deg) Sort	Known As	Known q Sort	GCR (arcsec) Sort	Probability Sort	Digest	Stamps
8974151 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.18 Stamp Info	156.3PI.00.ASO1.J.i α: 349.839205 δ: -11.193932 23h19m21.41s -11d11'38.16" S Elong: 126.94 Ecl β: -5.70	0.202	162.1	N/A	N/A	0.11"	1.00	19	 Decider [3.18] Decider [2.45] Decider [1.29]
8977917 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.17 Stamp Info	156.3PI.00.ANO3.J.i α: 352.302409 δ: 9.915789 23h29m12.58s 9d54'56.84" S Elong: 136.65 Ecl β: +12.82	0.111	-165.3	N/A	N/A	0.10"	0.98	3	 Decider [1.35] Decider [3.17] Decider [1.36]
8976055 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.02 Stamp Info	156.3PI.00.ASO1.J.i α: 357.266483 δ: -14.323963 23h49m03.96s -14d19'26.27" S Elong: 130.38 Ecl β: -12.09	1.690	148.3	N/A	N/A	0.09"	0.85	100	 Decider [2.89] Decider [3.02] Decider [3.00]
8977655 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 4 ffuzz: 3.01 Stamp Info	156.3PI.00.ANO3.J.i α: 2.726264 δ: 11.685122 0h10m54.30s 11d41'06.44" S Elong: 145.54 Ecl β: +10.22	0.164	-101.9	N/A	N/A	0.11"	1.00	4	 Decider [3.01] Decider [1.28] Decider [1.26] Decider [1.92]
8978882 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 2.96 Stamp Info	156.3PI.00.ANO3.J.i α: 355.047412 δ: 16.548331 23h40m11.38s 16d32'53.99" S Elong: 139.84 Ecl β: +16.38	0.375	173.4	N/A	N/A	0.09"	0.99	22	 Decider [1.13] Decider [1.69] Decider [2.96]
8975392 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 4 ffuzz: 2.95 Stamp Info	156.3PI.00.ASO1.J.i α: 350.479670 δ: -12.218195 23h21m55.12s -12d13'05.50" S Elong: 127.39 Ecl β: -8.39	0.033	11.1	N/A	N/A	0.09"	0.99	3	 Decider [2.95] Decider [1.18] Decider [2.10] Decider N/A
8977504	nfuzz: 4	156.3PI.00.ANO3.J.i α: 356.405024 δ: 12.198036								

MOPS Web Interface




PK11R030/Novichonok
0074P/Smirnova-Chernykh
CK12A020/LINEAR
CK12F030/PANSTARRS
0258P/PANSTARRS
CK11J020/LINEAR
0228P/LINEAR
0031P/Schwassmann-Wachmann 2
PK11W010/PANSTARRS
0215P/NEAT
0254P/McNaught
0203P/Korlevic
0152P/Helin-Lawrence
0036P/Whipple
0117P/Helin-Roman-Alu 1
0231P/LINEAR-NEAT
PK12F020/PANSTARRS
PK12F050/Gibbs
0246P/NEAT
CK10F87B/WISE-Garradd
0047P/Ashbrook-Jackson
PK10U55H/Spacewatch
PK12G010/PANSTARRS
0143P/Kowal-Mrkos
CK09Y010/Catalina
0243P/NEAT
PK10J030/McMillan
0065P/Gunn
0131P/Mueller 2
PK11U010/PANSTARRS
CK11A030/Gibbs
0077P/Longmore
PK11W020/Rinner
0048P/Johnson
0261P/Larson
CK12B98J/2012 BJ98
CK11UU5F/LINEAR
0123P/West-Hartley
0257P/Catalina
0240P/NEAT
0213P/Van Ness-B
0130P/McNaught-Hughes
0160P/LINEAR
0163P/NEAT
PK11UD4A/Spacewatch-PANSTARRS
0105P/Singer Brewster
0253P/PANSTARRS
0115P/Maury
0078P/Gehrels 2
0118P/Shoemaker-Levy 4
CK10G020/Hill
CK11L030/McNaught
CK11F010/LINEAR
PK10J81C/WISE
PK11Y020/Boattini
0164P/Christensen
PK12O030/McNaught
0081P/Wild 2
0037P/Forbes
PK11A020/Scotti
CK09P010/Garradd
0009P/Tempel 1
0230P/LINEAR
0049P/Arend-Rigaux
0166P/Hergenrother
0162P/Siding Spring
CK12K050/LINEAR
0026P/Grigg-Skjellerup
CK11U030/PANSTARRS
0103P/Hartley 2
CK12K010/PANSTARRS
0021P/Giacobini-Zinner
0169P/NEAT
0045P/Honda-Mrkos-Pajdusakova
CK10X010/Elenin
0002P/Encke
CK11L040/PANSTARRS
0.2
0.5
1.0
2.0
5.0
10.0
20.0
50.0
Heliocentric Distance, AU

MOPS Auxiliary Products

- KNOWN_SERVER output
  - astrometric and photometric residuals of known asteroids
  - numbered and multi-opposition asteroids only
- MPC catalog integration
  - orbits and for single-night tracklets

MOPS Auxiliary Products

- Alert system
  - When interesting pipeline event occurs (e.g. NEO candidate, unusual light curve, extended source)
  - rules can be written by PS1SC scientists
  - IVOA VOEvents format
  - Various deployment methods (email, Twitter currently)

MOPS Data Issues

- Fill factor, gaps, burns, ghosts
- Visual verification using postage stamps is essential for new objects; still, some artifacts are very real-looking
- Magnitude calibration (ubercal, w-band issues)
- Diff sensitivity (S/N loss, stationary/slow-moving objects)
- Highly correlated false detections/tracklets
- Galactic plane is difficult
- No single MOPS database yet, probably not until end of PS1SC mission

MOPS Improvements

- Calibrated photometry (Schlafly et al.)
- Increased sensitivity to smaller/more distant object in 3π and SS from static sky subtraction
- Tighter coupling with MPC catalog
- Higher-fidelity efficiency measures for population studies
- Consolidated dataset
- Full MOPS derived object processing (late 2013)

PSPS

- Contains replicated versions of production MOPS databases
- SQL or SQL+PSPS interface only, no MOPS web interface or command-line tools
- Postage stamps not available yet

More Information

- KP1 co-leads Richard Wainscoat (IfA) and Alan Fitzsimmons (QUB)
- KP2 lead Matt Holman (CfA)
- MOPS web page at http://mopshq1.ifa.hawaii.edu (internal only)
- PS1SC MOPS wiki at http://ps1sc.ifa.hawaii.edu/PS1wiki/index.php/MOPS
- MOPS paper (Denneau et al., soon to be submitted)