Zwicky Transient Facility (ZTF)

Science Capability Validation Plan

CIN #692

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# Revision History

|  |  |  |  |
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| 0.1 | 2017-08-07 | MG | Initial draft |
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| 0.2 | 2017-10-16 | MG | Experiment details added, updated schedule |

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# Introduction

## Purpose

This document summarizes the science capability validation plan for ZTF. It includes functional and performance requirements.

## Scope

Science capability validation determines that the ZTF system (from photons to bytes) is able to deliver the necessary data products to carry out the intended science programs defined by Caltech, the ZTF partnership, and the MSIP consortium.

## Acronyms and abbreviations

* DS – Data System (the data processing and archiving portion of the ZTF project)
* FITS – Flexible Image Transport System.
* FoV – Field of View
* GCN – Gamma-ray Coordination Network
* GUI – Graphical User Interface
* MTBF – Mean Time Between Failure
* OS – Observing System (the data acquisition portion of the ZTF project)
* PBS – Product Breakdown Structure
* TBD – To Be Determined.
* TBC – To Be Confirmed.
* TBR – To Be Revised.
* TCS – Telescope Control System.
* ToO – Target of Opportunity
* WaSP – Wafer-Scale camera for Prime, a large-format CCD camera for the Palomar 200” prime focus.
* ZTF – Zwicky Transient Facility.

## Definitions

In the requirements specifications, the following verbs are defined:

* **SHALL** – denotes a requirement that is mandatory whenever the criterion for conformance with the specification requires that there be no deviation. It implies obligation.
* **SHOULD** – denotes a guideline or recommendation whenever noncompliance with the specification is permissible. It expresses a contingent or conditional act or state, or a moral obligation.
* **WILL** – denotes a simple statement of fact.

## Related Documents

* ZTF Science Requirements Document
* ZTF Photometric Requirements Document
* ZTF Pipeline Needs v1.0

## Document Organization

The rest of this document defines the plan for validating the science capabilities of ZTF. It describes the observations and analyses that need to be performed prior to the start of Operations.

## Points of Contact

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# Background

The ZTF camera was installed on the Palomar 48-inch telescope on October 12, 2017. It will then undergo a period of engineering commissioning to determine and verify basic instrumental, telescope, and system performance. It is expected that handover to the science commissioning team will occur in early November 2017. Validation of the science capabilities of the instrument, telescope, and system will then proceed until December 31, 2017. Science Operations will commence on January 2, 2018.

The ZTF Experiments and Framework committee solicited a call for white papers to identify the high-level scientific goals for the partnership share (40%) of ZTF observing time. These form the basis for a defined science strategy that aims to meet most of the proposed science goals. The MSIP proposal similarly defines two surveys for the MSIP share (40%) of observing time that serve a number of overlapping (and complementary) science objectives with the partnership strategy. No specific programs have yet been identified for the remaining 20% of observing time (Caltech share) but it is expected that these will also have a set of similar science aims.

Though the stated science goals range from asteroid detection to EM followup of GW triggers, together they require a minimal set of science capabilities:

* A limiting magnitude of 20.5 at 5σ detection
* Photometric calibration accurate to 0.05 mag, 0.1 mag or 2% (depending on the proposal)
* Responding to a ToO with immediate repointing
* Multifilter sequences
* Exposure times from 30s to 300s

# PREREQUISITES

The following items shall be available prior to any capability validation activities:

* A flat-field illuminator
* A basic set of calibration products ­– flats, biases, masks, etc. – that can characterize the instrumental and telescope behavior (see Appendix 1)
* A pipeline that can generate a calibrated single epoch image from an observation
* A pipeline that can generate a difference image relative to some reference image
* A pipeline that can produce aperture photometry from an image
* A pipeline that can produce PSF photometry from an image
* A pipeline that can identify moving objects in an image
* The ability to schedule a set of observations (minimum 10) to be carried out in an automated fashion

The following items shall be available within the science validation period:

* An aspherical correction plate
* An automated filter exchanger (this is expected on a mid-November timeframe and so a single filter will be used on a given night prior to this date)
* The ability to schedule automated filter changes in an observing sequence (see above)
* A pipeline that can produce a transient alert in AVRO format
* A mechanism to distribute transient alerts in AVRO format to subscribed parties (this is only expected in early December but transient alerts will be retrievable from the archive prior to this date)
* A mechanism to select specific (predefined filtered) sets of transient alerts to receive (see above)

**NOTE:** The *i*-band filter is currently delayed (expected Q2 2018) and will not be available during commissioning.

# EXPERIMENTS

The following experiments have been proposed by members of the ZTF Project:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ID** | **Theme** | **Lead** | **Products** | **Observations** |
| SCV0 | Reference images | E. Bellm | Reference images | Available sky |
| SCV1 | Asteroids | C.-K. Chang | Asteroid lightcurves | 6-7 fields for 2 hrs |
| SCV2 | Astrometric | A. Ho | Check astrometric precision (req.: 0.1”, goal: 0.03”) | Field close to Moon, far from zenith, at high airmass (1.5 – 2.5), all filters |
| SCV3 | Atmospheric solution | M. Giomi, J. Nordin | Check of photometric calibration stability, feasibility of atmospheric solutions | 3 great circle seq / night (1hr), 15x / month (varying conditions) |
| SCV4 | COSMOS field | M. Rigault | Check of photometric accuracy, color dependency test of CCD response | COSMOS field (10 00 28.6, 02 12 21.0) in g and r  |
| SCV5 | Comets | D. Bodewits | Detection limit of comets, lightcurve of C/2016 R2 | 300 MSIP fields with known comets, 10 of C/2016 R2 over 4 wks in g and r |
| SCV6 | Kepler fields | M. Giomi, J. Nordin | Check of instrument, pipeline and alert distribution system | 4 pointings per night of K2 campaign 15 and 16 fields in g  |
| SCV7 | Nuclear transients | S. van Velzen | Estimate of astrometric accuracy in galactic nuclei | Stripe 82 (300 deg2) per night in g and r |
| SCV8 | Twilight survey | Q.-Z. Ye | Detection limits of moving objects in the twilight zone | 20 fields, 4x in 5 min cadence (20 min session) |
| SCV9 | Flexure | M. Giomi | Check intra-night stability of system with time and angle | 10x field with 30 min. cadence/10 nights |
| SCV10 | CCD linearity | R. Biswas | Characterization of CCD linearity | 50 exposures of field with exposure time between 1s and 10 min |
| SCV11 | Exposure time (shutter test) | D. Küsters | N/A | Proposed obs. not feasible |
| SCV12 | Sensitivity maps | A. van Sistine | Starflats | 100 exposures of hexagonal pattern at start/middle/end of commissioning in g and r |
| SCV13 | Neutrino ToO | L. Rauch, A. Franckowiak | Check of alert distribution system and ToO mode | 9 exposures of GCN alert field: 5x in 1hr, 2x next two nights |
| SCV14 | Tracking accuracy | M. Giomi | Check of tracking accuracy | Track a field through the night, repeat through commissioning |
| SCV15 | Streaks | Q.-Z. Ye | Streak detection algorithm | MSIP |
| SCV16 | Densest | T. Küpfer | Verify pipeline performance in densest regions | 2-3 hrs on densest region |
| SCV17 | FastCad | T. Küpfer | Verify detectability of ultracompact sources | 2-2.5 hrs on: SDSS J082239.54 +304857.2 and SDSS J065133.33 +284423.3 |
| SCV18 | M31 | T. Küpfer | Verify pipeline performance in M31 | Two exposures of M31/night in g/r |
| SCV19 | Star formation | T. Küpfer | Verify pipeline performance in highly obscured star forming regions | Orion and North America nebulae |
| SCV20 | Machine learning | A. Mahabal | Defect types, response maps for CCDs | Range of Galactic latitudes and airmasses, bright stars on tiles, ecliptic region, some clusters of galaxies |
| SCV21 | Coadding | P. Nugent | Demonstrate DESI depths | 200 exposures of specific fields |
| SCV100 | Survey cadence | E.Bellm | Verify survey cadence | MSIP |

## SCV0: Reference image construction (default)

In the absence of any specific program set for a night, images will be taken of the available sky to contribute towards the reference image stack.

**Capabilities validated:** Reference images

**Deliverables:** A minimum of 12 images in each filter at each pointing on the survey grids

**Contact person:** E. Bellm

## SCV1: Streaking asteroids

6-7 fields near the opposition point along the ecliptic plane are observed in either filter for 2 hours with a 5 minute cadence. Light curves for asteroids are generated by Z-MODE.

**Capabilities validated:** Moving object pipeline, short cadence observations for light curves

**Deliverables:** 24 images of 6-7 fields, asteroid lightcurves

**Contact person:** C.-K. Chang

## SCV2: Astrometric accuracy and precision

A set of fields are observed in both filters in non-optimal conditions – close to the moon, far from zenith, at high airmass (between 1.5 and 2.5) – to test that the astrometric solution derived during engineering commissioning is accurate to 0.1” as required (to 0.03” desired).

**Capabilities validated:** Astrometric solution in different observing conditions

**Deliverables:** Images of fields in non-optimal conditions

**Contact person:** A. Ho

## SCV3: Atmospheric solution test

Pairs of consecutive exposures (separated by a ~3˚ offset in azimuth) are taken along a great circle at altitude angles of, say, 24˚, 30˚, 42˚, 90˚, 127˚, 145˚, or 154˚ in one filter and then repeated in the other filter. 3 sequences should be taken during a night and the pattern repeated 15 times a month.

**Capabilities validated:** Photometric calibration and atmospheric solutions in different observing conditions

**Deliverables**: Images of fields for a range of airmass, moon phases, and atmospheric conditions

**Contact person:** M.Giomi, J. Nordin

## SCV4: Observations of COSMOS field

Exposures of the COSMOS field (10 00 28.6, 02 12 21.0) are observed in both filters.

**Capabilities validated:** Photometric calibration, color dependencies of CCDs

**Deliverables**: Images of field

**Contact person:** M. Rigault

## SCV5: Observation of comets

300 exposures in both filters of MSIP survey fields known to contain comets, equally distributed along ecliptic longitude (+/- 20 deg from ecliptic plane). 10 observations of comet C/2016 R2 over 4 weeks.

**Capabilities validated**: Detection efficiency and photometric stability of comets and other extended objects

**Deliverables**: Lightcurve of C/2016 R2

**Contact person**: D. Bodewits

## SCV6: Observation of Kepler fields

4 exposures in both filters of Kepler (K2) campaign 15 and 16 fields each night.

**Capabilities validated**: Photometric stability of ZTF vs. PanStarrs

**Deliverables:** Images of K2 campaign 15 and 16 fields

**Contact person:** M.Giomi

## SCV7: Nuclear transients

Exposures of SDSS Stripe 82 (20h 24m < RA < 04h 08m, -2˚ < Dec < 2˚) in both filters every night for at least a week.

**Capabilities validated:** Detection efficiency and astrometric accuracy in galaxy nuclei

**Deliverables:** Images of fields, histogram with offsets of difference image detection and host galaxy position

**Contact person**: S. van Velzen

## SCV8: Twilight survey

4 exposures in r of 20 random fields within region 40˚-60˚ from the Sun and within +/- 20˚ from the ecliptic plane with 5-min cadence (4 separate sessions).

**Capabilities validated:** Observations in the twilight zone

**Deliverables**: Moving objects in twilight zone

**Contact person**: Q.-Z. Ye

## SCV9: Flexure and calibration stability

10 exposures of a field with a 30 minute cadence on 10 nights.

**Capabilities validated:** Intra-night system stability with time and angle

**Deliverables:** Images of field

**Contact person:** M. Giomi

## SCV10: CCD linearity test

50 consecutive exposures of a field in at least one filter with scrambled exposure times between 1s and the maximum allowed by tracking constaints.

**Capabilities validated:** CCD/pipeline linearity vs. exposure times/counts

**Deliverables:** Linear range of CCD and pipeline

**Contact person**: R. Biswas

## SCV11: Effective exposure time test (DEPRECATED)

This experiment is not feasible since it requires sequences of exposures separated by rotations of the telescope around its optical axis, a mode of operation which is not supported.

**Capabilities validated: -**

**Deliverables: -**

**Contact person:** D. Küsters

## SCV12: Sensitivity maps

100 consecutive exposures in both filters of a field with pointing offsets in a hexagonal pattern between successive images.

**Capabilities validated:** Relative sensitivity of CCD pixels

**Deliverables:** Images of field, characterization of large scale sensitivity variation of the CCDs

**Contact person:** A. van Sistine

## SCV13: Test trigger for neutrino Target of Opportunity search

9 exposures of a GCN alert in same filter with an initial cadence of 12 minutes for the first hour and then 2 images each on successive nights.

**Capabilities validated:** ToO scheduling

**Deliverables:** Images of field

**Contact person:** L. Rauch

## SCV14: Tracking accuracy

Consecutive exposures of a field without repointing until the target field disappears from images.

**Capabilities validated:** Accuracy of tracking

**Deliverables:** Images of field

**Contact person:** M. Giomi

## SCV15: Streaking asteroids

Exposures of MSIP fields within 20˚ from the ecliptic and 10 exposures of field #444584 within a 2 hour time span in r filter between November 12 and 18, 2017.

**Capabilities validated:** Detection of streaking asteroids

**Deliverables:** Streaking asteroids

**Contact person:** Q.-Z. Ye

## SCV16: High cadence observations in the densest Plane regions

Consecutive exposures in g filter of the densest region visible for 2 – 3 hours.

**Capabilities validated:** Pipeline performance in the densest Galactic Plane regions

**Deliverables**: Images of field and light curves

**Contact person:** T. Küpfer

## SCV17: High cadence observations

Consecutive exposures in g filter for 2 – 2.5 hours of SDSS J082239.54+304857.2 and SDSS J065133.33+284423.3.

**Capabilities validated:** Photometric precision in high-cadence observations

**Deliverables:** Images, lightcurves and periodogram of sources

**Contact person**: T. Küpfer

## SCV18: Regular monitoring of M31

2 exposures in at least a single filter of M31 each night.

**Capabilities validated:** Photometric and astrometry accuracy for M31

**Deliverables:** Images of field and source lightcurves

**Contact person**: T. Küpfer

## SCV19: High cadence observations of star forming regions

Consecutive exposures in r filter of the Orion and North American nebulae until no longer visible (the latter will need to scheduled early since it is only visible in the beginning of the night in science validation).

**Capabilities validated:** Photometric and astrometry accuracy in highly obscured star forming regions.

**Deliverables:** Images of field and source lightcurves

**Contact person:** T. Küpfer

## SCV20: Training set for machine learning

Exposures in both filters of: different object densities using Galactic latitude as a proxy, bright stars on different CCDs and quadrants, areas within the ecliptic (higher density of asteroids), range of airmasses, and covering some clusters of galaxies. These can be met within other experiments.

**Capabilities validated:** Dynamic range, uniformity, and lack of defects in each CCD

**Deliverables:** Identified defect types and response maps for CCDs

**Contact person:** A. Mahabal

## SCV21: Slews (TBC)

Perform a set of observations to simulate LIGO follow-up with large slews.

**Capabilities validated:** Telescope slew and pointing

**Deliverables:** -

**Contact person:** TBD

## SCV22: Alert generation and verification (TBC)

Generate a set of transient alerts from difference images, pick areas also simultaneously covered by CRTS, ATLAS, or Pan-Starrs.

**Capabilities validated:** Alert generation

**Deliverables:** Completeness limits for alert detection

**Contact person:** TBD

## SCV100: Survey cadence

Test the Operations schedule for a night. This will reflect the nominal survey cadence:

|  |  |  |  |
| --- | --- | --- | --- |
| **Program** | **Area** | **Filters** | **Frequency** |
| Partnership | 1600 deg2 | g | 3 / night |
| Partnership | 6700 deg2 | i | every 4 days |
| MSIP | 15000 deg2 | gr | every 3 days |
| MSIP | Galactic plane | gr | 1 / night |
| Caltech | TBD | TBD | TBD |

**Capabilities validated:** Survey cadence

**Deliverables:** A set of images following survey cadence.

**Contact person:** E. Bellm

# SCHEDULING

There are 50 potential nights in the science capability validation phase (excluding December 24 and 25). Assuming an average night length of 10 hours between evening and morning astronomical twilight and 30% lost time owing to bad weather, etc., this gives ~330 hours of available observing time. Science experiments need to be prioritized and observations scheduled accordingly.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Experiment** | **Number of nights** | **Observations per night** | **Cadence** | **Total time (assuming 30s exposures)** |
| SCV1 | 1 | 24 x 6/7 | 5m | 2h |
| SCV2 | Unspecified | Unspecified | Unspecified | - |
| SCV3 | 30 | 3 x ~30 | 3h / night | 30h |
| SCV4 |  | 1 x 2 | - | ? |
| SCV5 | 110 | 300 x 21 | -4d | 6m |
| SCV6 |  | 4 x 2 | - | ? |
| SCV7 | 7+ | x 2 | - | ? |
| SCV8 | 4 | 5 x 4 | 5m | 1.25h |
| SCV9 | 10 | 10 | 30m | 1h |
| SCV10 | 1 | 50 | - | 30m |
| SCV11 | - | - | - | - |
| SCV12 | 1 | 100 x 2 | - | 2h |
| SCV13 | 3 | 5 + 2 + 2 | 12m, 1d | 5m |
| SCV14 | 1 | Unspecified | - | ? |
| SCV15 | 1 | 10 | 12m | 5m |
| SCV16 | 1 | 240 – 360 | - | 3h |
| SCV17 | 2 | 240 - 300 | - | 5h |
| SCV18 | 60 | 2 x 2 | - | 2h |
| SCV19 | 2 |  | - | ? |
| SCV20 | Unspecified | Unspecified | Unspecified | - |
| **Total** |  |  |  | ~47h |

The current plan to devote the first week of science validation time to SCV0 to ensure that the observing system is stable and start building up reference images – this will also be the default program when nothing else is scheduled. High priority individual fields, particularly those that may be unavailable later in the validation period, such as the North American nebula, will then be taken, along with monitored fields. Experiments requiring difference imaging will be scheduled later to ensure that the appropriate pipeline elements are in place to support these. The final week of science validation will be devoted to SCV100 which tests the default Operations mode.

Experiments SCV1, SCV16, SCV17, and SCV19 will require the list-mode scheduler.

# ISSUE TRACKING

An issue tracking system shall be used during the capability validation phase to track bugs, feature requests, etc., identified in validation analyses. A weekly meeting will be held to review the status of open issues and prioritize their resolution.

# APPENDIX 1: Basic calibration products

The IPAC pipeline requires the following products prior to any processing (from ZTF Pipeline Needs v1.0):

* A continuous set of >~ 100 zero-exposure bias frames for:
	+ Bias image calibration maps
	+ Read noise estimates for every readout channel
* A continuous set of >~100 exposures of the flatfield screen in all filters for:
	+ Relative pixel-to-pixel responsivity calibration maps
* A series of >~ 100 exposures where the overall illumination on the focal plane is varied across the full usable dynamic range for:
	+ Electronic gain esimates for each readout channel
* Repeated exposures of a field containing non-saturating calibrator sources spread across all readout channels with stepped exposure times for:
	+ Characterization of the level of non-linearity per readout channel
* Pointed observations at/close to zenith of several different moderately dense fields containing mostly stars and minimal background variation in all filters for:
	+ Prior optical-distortion map for imaged focal plane extent
	+ Low spatial frequency responsivity maps (star flats)
* 10 to 20 repeated exposures within sky survey with three targets at high galactic latitude and three at low galactic latitude in all filters for:
	+ Test coadds

**ACTION**: A prioritization of this is required.

Additionally the following products are needed for further characterization:

* Dithered pointings on several bright stars of different flux in all filters with each star falling in each of the readout channels for:
	+ Ghost maps
* Dither pointing around bright sources of different flux including the Moon for
	+ Characterization of scattered light