The Zwicky Transient Facility (ZTF)

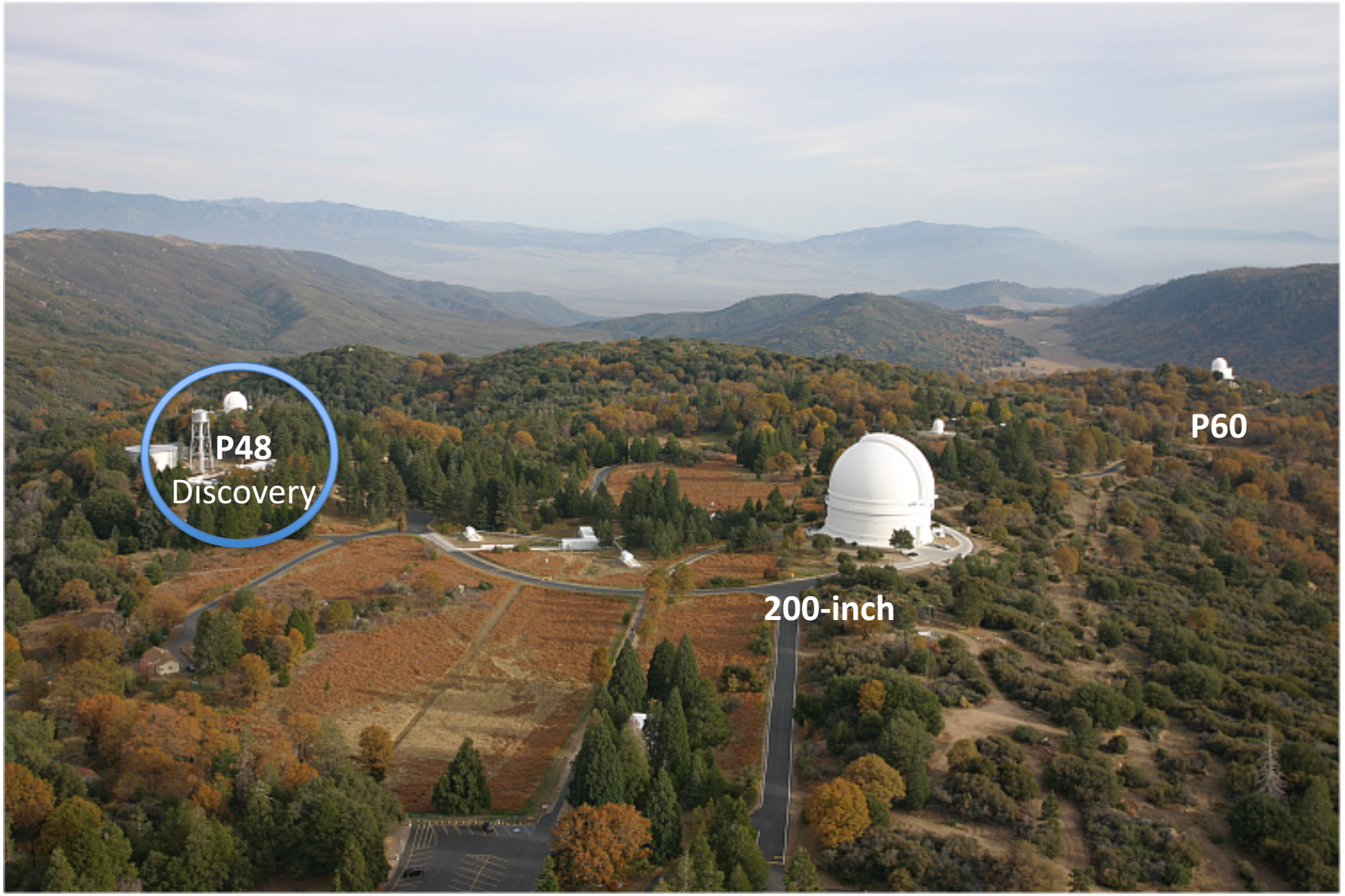
AAS Meeting, Grapevine, Texas

January 3, 2017

I. WELCOME BY SHRI KULKARNI

Era of Time Domain Astronomy (TDA)

- We are already in the era of TDA
  - CRTS, PTF, PS-1, ASAS-SN, ATLAS (and others)
  - Blanco (DEC) & Subaru (HSC)
  - MASTERS, Evryscope, Armada of Sophisticated Amateurs
- History of ZTF
  - Palomar Transient Factory (PTF; 2009-2012)
  - Intermediate PTF (2013-2016)
  - 2013: ZTF proposed for MSIP (& success!)
  - 2017: Three-year survey expected to start in ~November


P48
Discovery
P60
200-inch

Two views of ZTF

- ZTF as a stepping stone to LSST in the field of TDA (variability & transients)
  - “pre-cursor” survey(s)
  - introduce TDA methodology to the wider US community
  - use experience to guide development of tools
  - cf. LSST begins routine survey in 2022
- ZTF is a PI-led science project
  - Surveys address a broad range of both stellar & extragalactic astronomy
  - Initial surveys are now defined (more later)

ZTF: Public-private partnership

- Private
  - NCU-Taiwan, WIS-Israel, OKC-Sweden, DESY-Germany, UMd-College Park, UW-Milwaukee, UW-Seattle & Caltech
- Public (NSFI, MSIP grant)
  - Principal Investigator: S. R. Kulkarni
  - Project Scientist: Eric Bellm
  - Co-Is:
    - R. Dekany (Project Manager)
    - G. Helou (IPAC Data Center)
    - T. Prince (Galactic Plane, Solar System)
    - B. Penprase (EPO)

Resources, Data Center & CSAC

- Allocation of resources (P48)
  - 40% MSIP, 40% Partnership, 20% Caltech
- IPAC serves as the Data Center for all ZTF data
- Community Science Advisory Committee
  - Ridgway (Chair), Agueros, Boroson, Frail, Gehrels, Juric, Kollmeir, Pinsonneault, Shafter, Szkody
- Visit

  http://www.ptf.caltech.edu/page/ztf_msip

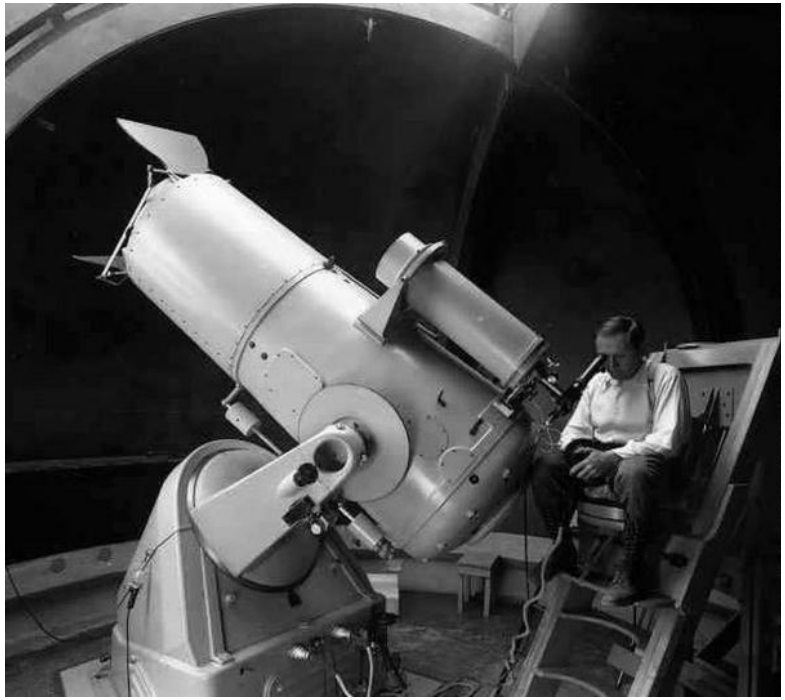
Zwicky Transient Facility

S. Kulkarni

PI

E. Bellm

Project Scientist



II. WELCOME BY STEPHEN RIDGWAY

The ZTF Community Science Advisory Committee	
Steve Ridgway (Chair)	Mario Juric
Marcel Agueros	Juna Kollmeier
Todd Boroson	Marc Pinsonneault
Dale Frail	Allen Shafter
Neil Gehrels	Paula Szkody

Today's Agenda and Schedule	
1:05	Stats, Status, and Schedule [Eric; 20 minutes + 10 minutes discussion]
1:35	Public Surveys [Shri: 25+10 minutes]
2:10	Planned Public Data Products [Eric; 10 + 15]
2:35	Concerns & Opportunities [Shri; 15 + 10]
3:00	Refreshments [30 minutes]
3:30	Open Discussion [Ridgway; 30 minutes]
4:00	Demonstration & Early Peek at ZTF Data Center [Eric; 20 minutes]
4:20	Optional: self-organized breakout discussions (meet ZTF team members to explore collaborations or understand opportunities) [all; remaining period]

http://www.ptf.caltech.edu/page/ztf_msip

III. ZTF STATS, STATUS, AND SCHEDULE: ERIC BELLM

The PTF survey family has three phases.

PTF *yesterday*

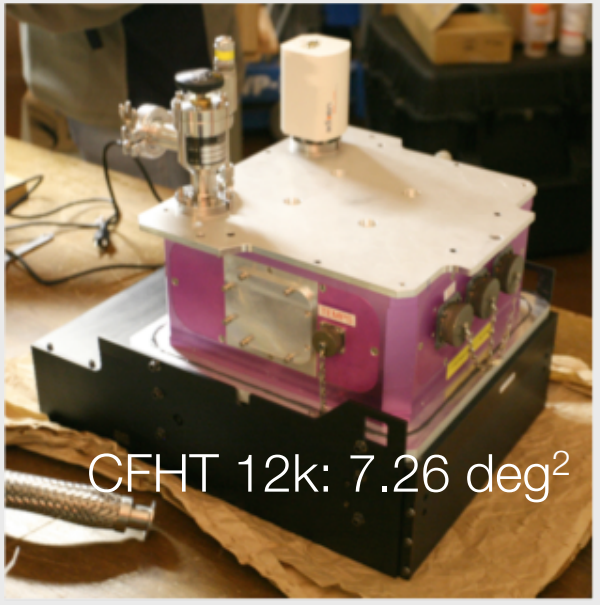
The Palomar Transient Factory (2009-2012)

General synoptic transient survey

iPTF *today*

Intermediate Palomar Transient Factory (2013-2017)

Focused mini-surveys



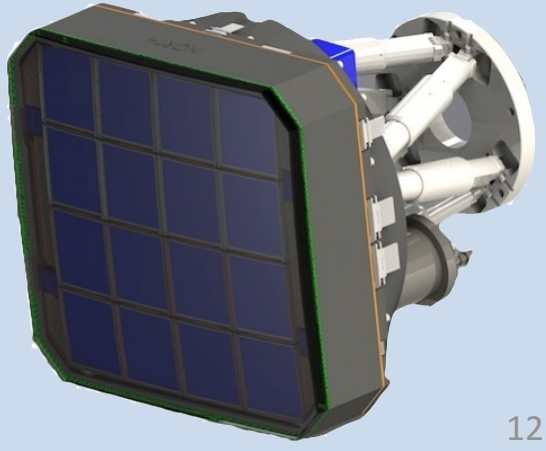
178+ papers, 6100+ citations

ZTF *tomorrow*

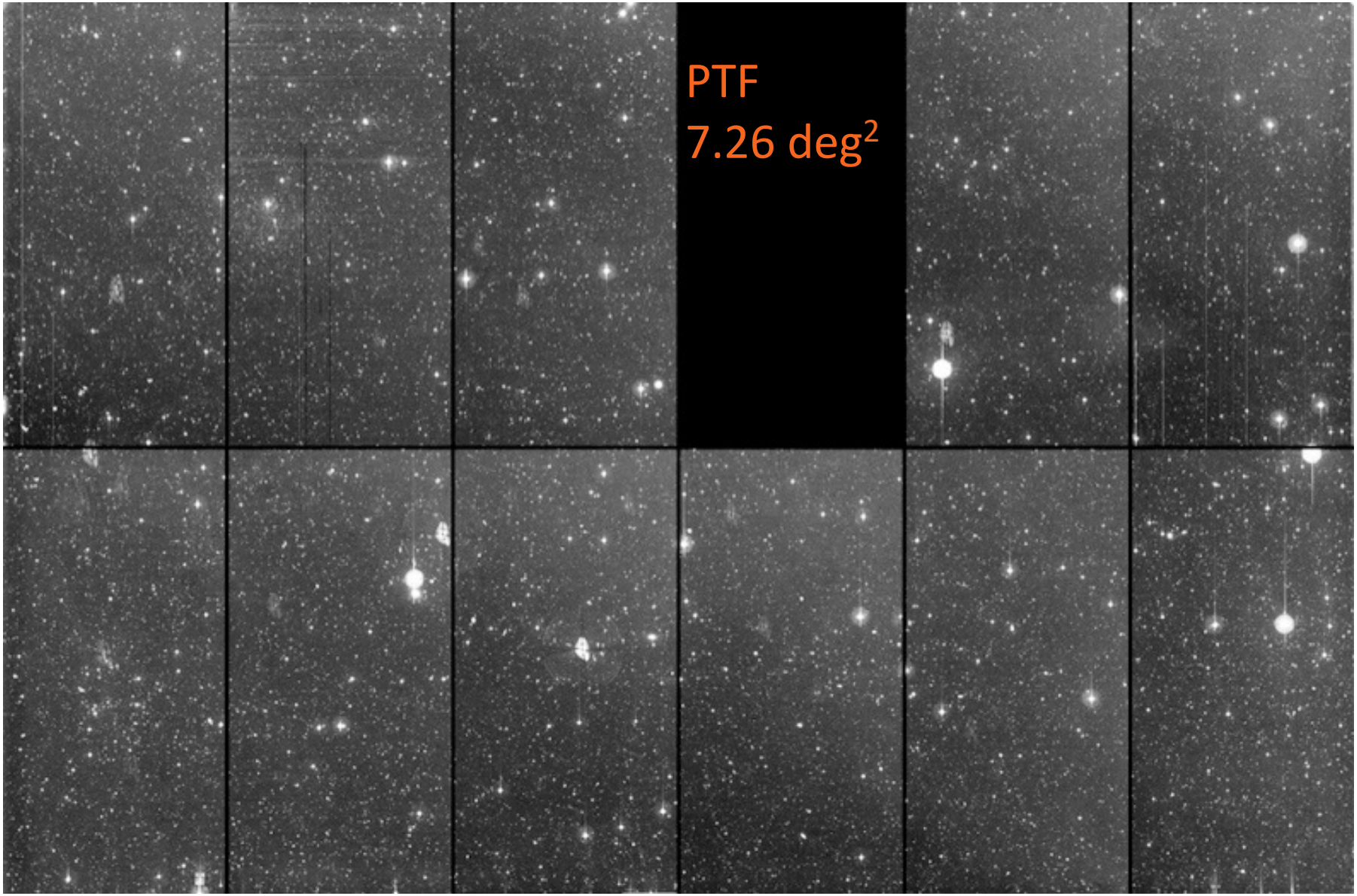
The Zwicky Transient Facility (2017-2020)

High-cadence, wide-area survey

new 47 deg² camera



ZTF's new camera will fill the P48 focal plane.



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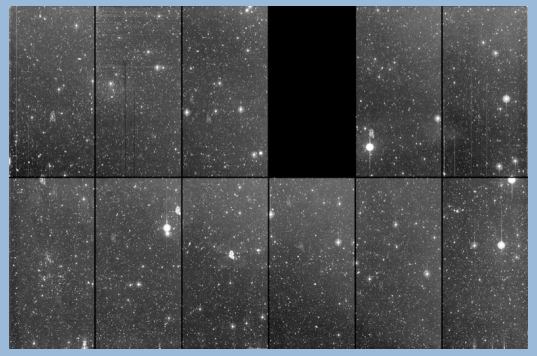
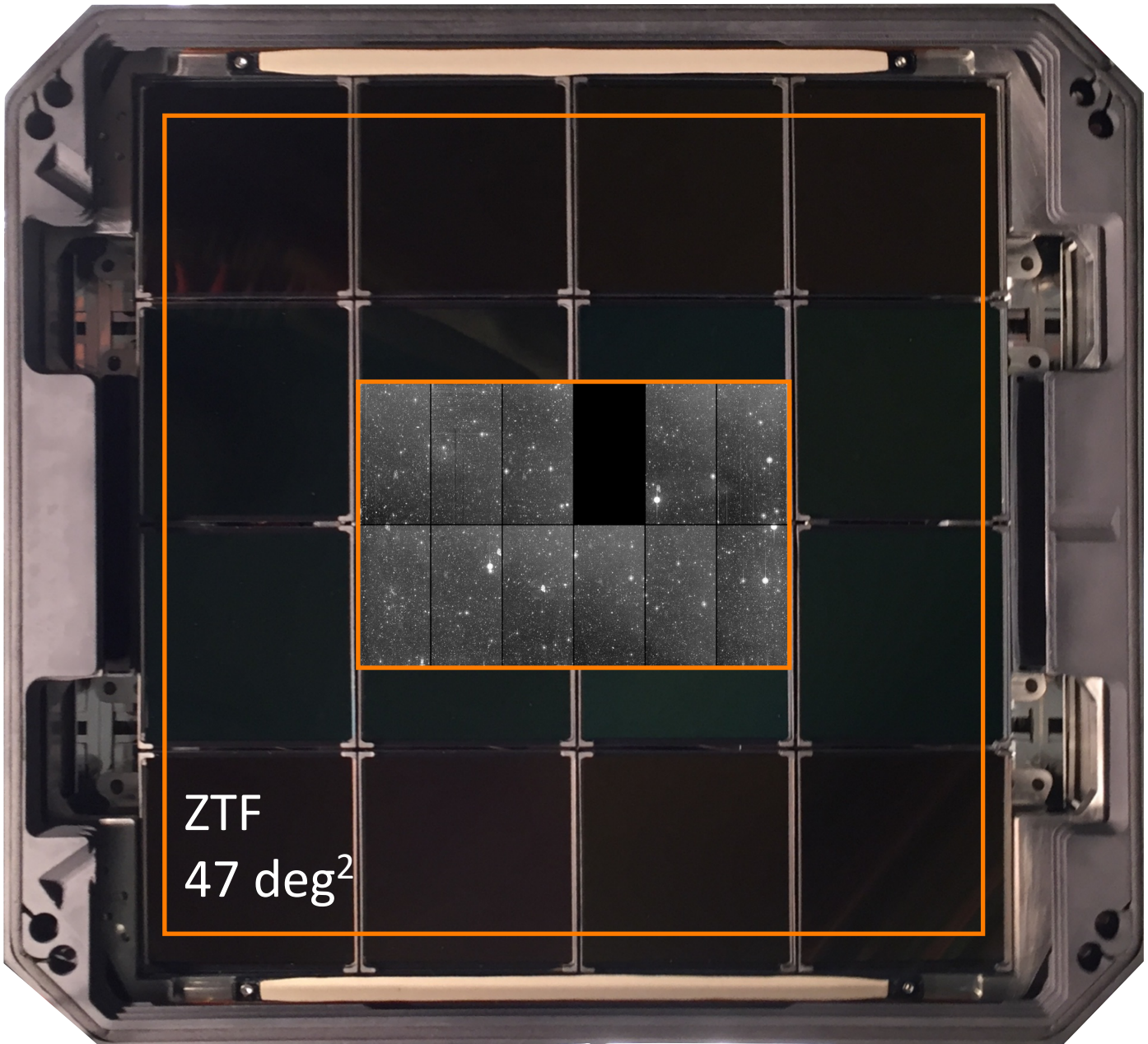
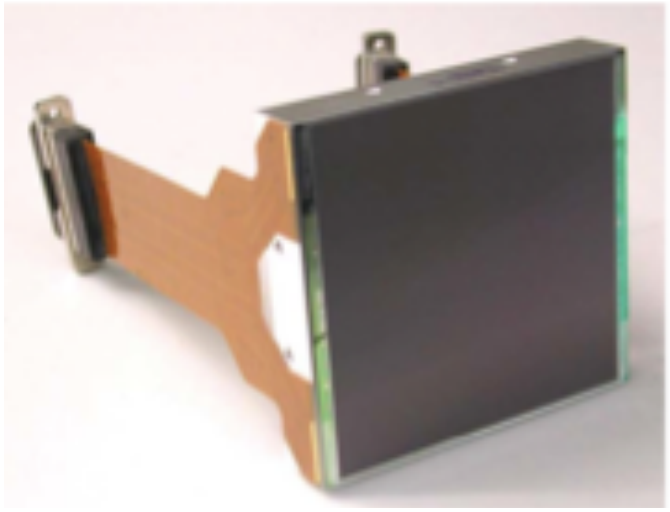


POSS plates
43.6 deg^2

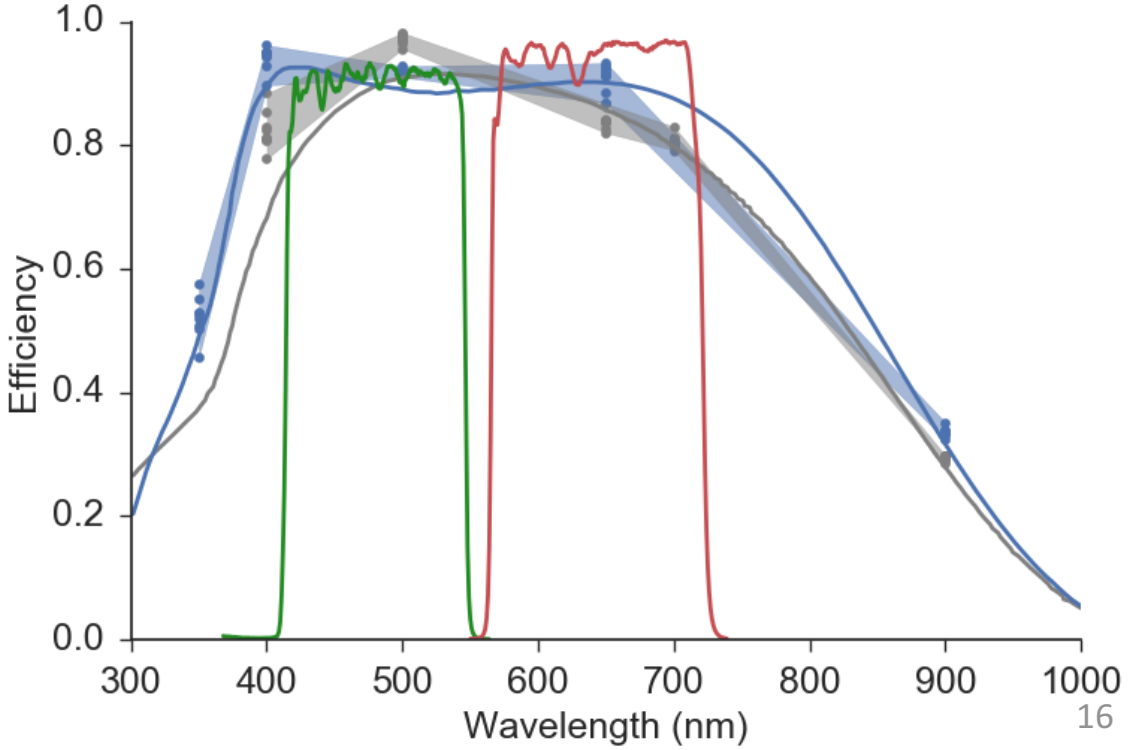
ZTF's new camera will fill the P48 focal plane.



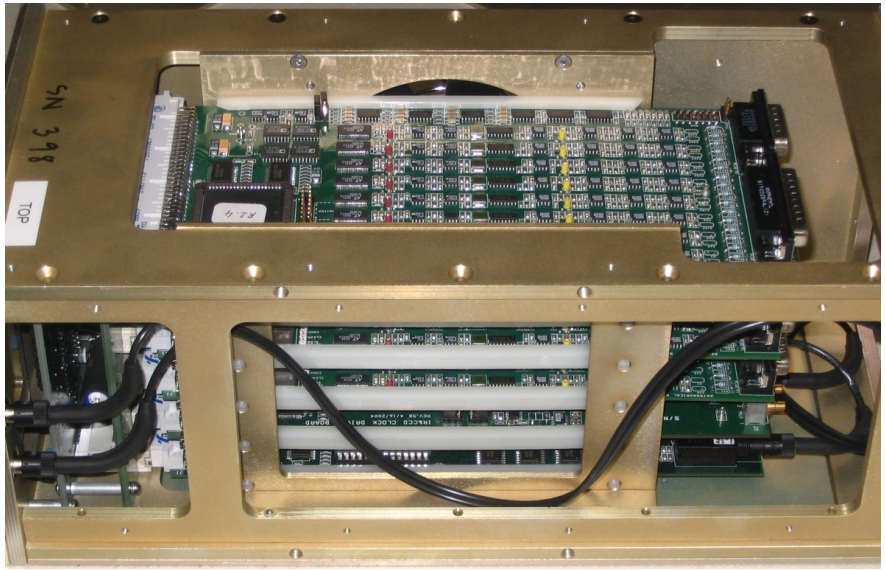
Affordable wafer-scale CCDs make ZTF possible.

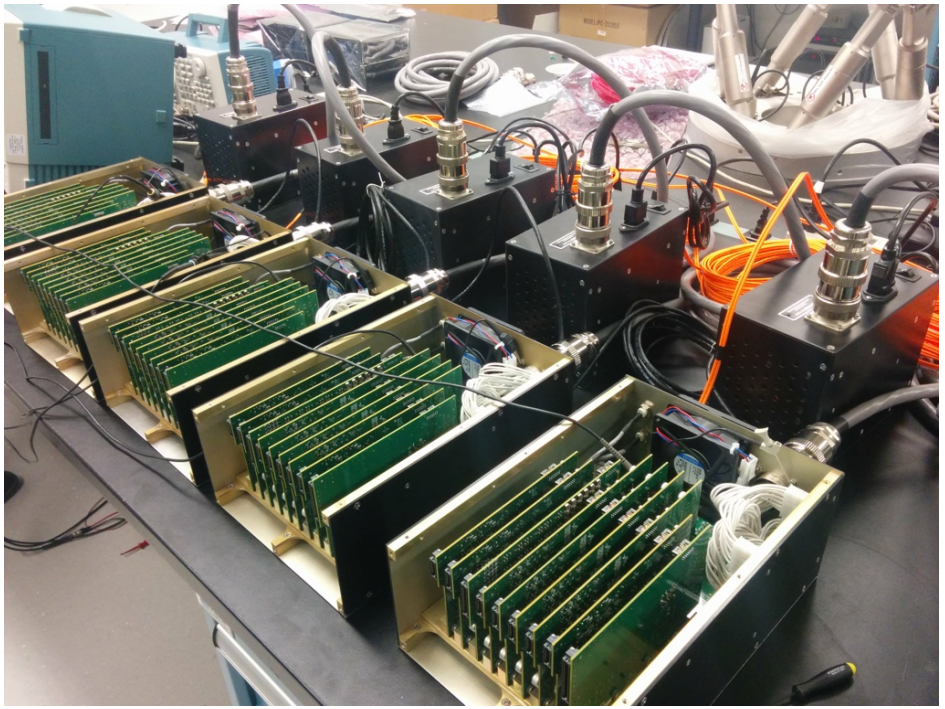


e2v	
dimension	9.2 x 9.2 cm
pixels	6.1k x 6.1k
pixel size	15 micron
pixel scale	1”/pixel
outputs	4



Moore's Law reduces overhead.

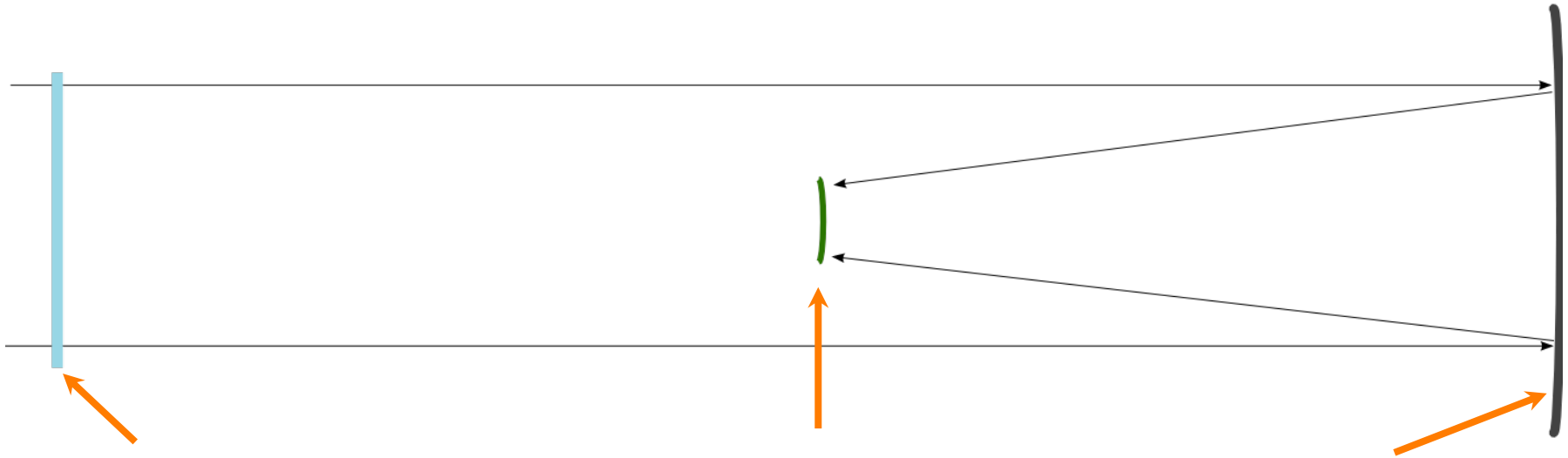




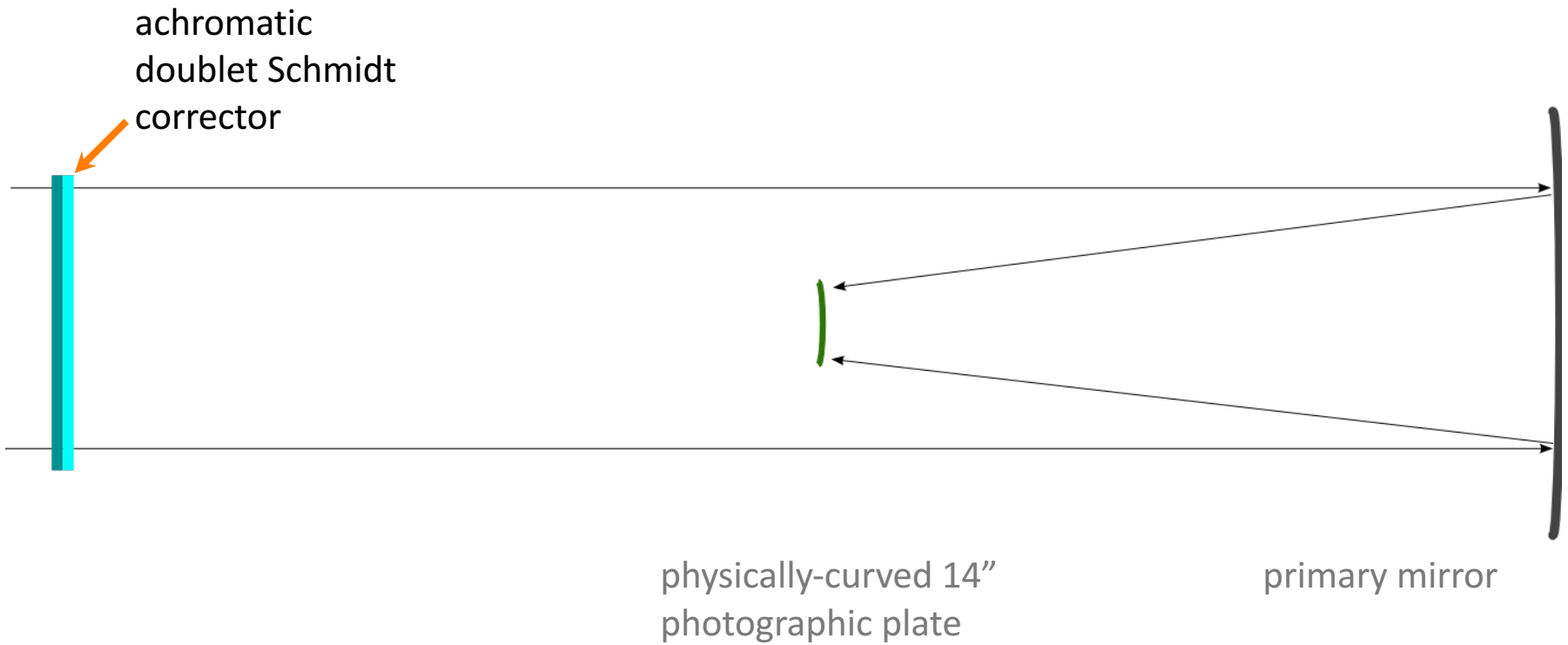
PTF
2000-era Leach Gen-II controller
36 second readout of 96 Mpx

ZTF
modern STA Archon controller
10 second readout of 576 Mpx

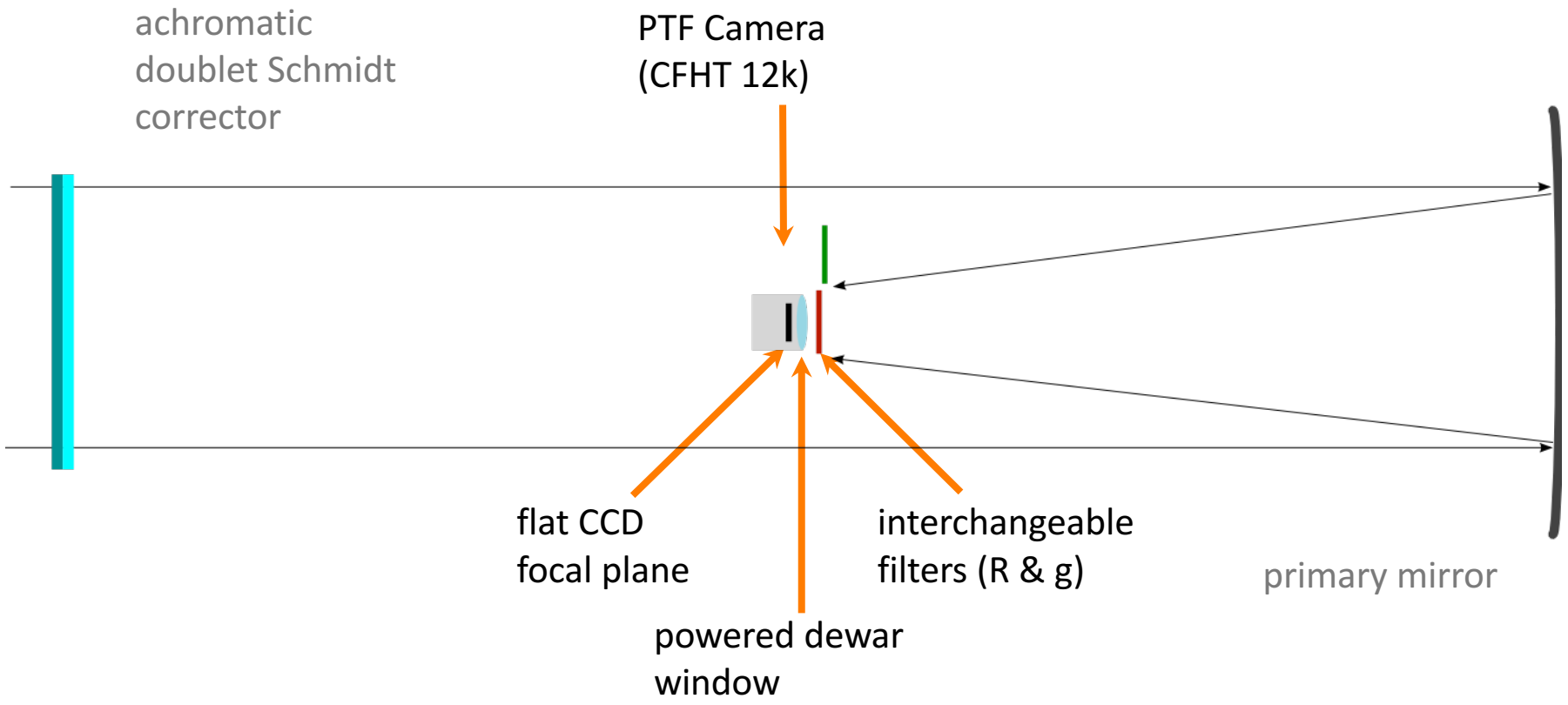
P48 used a basic Schmidt configuration for the first Palomar Sky Survey.



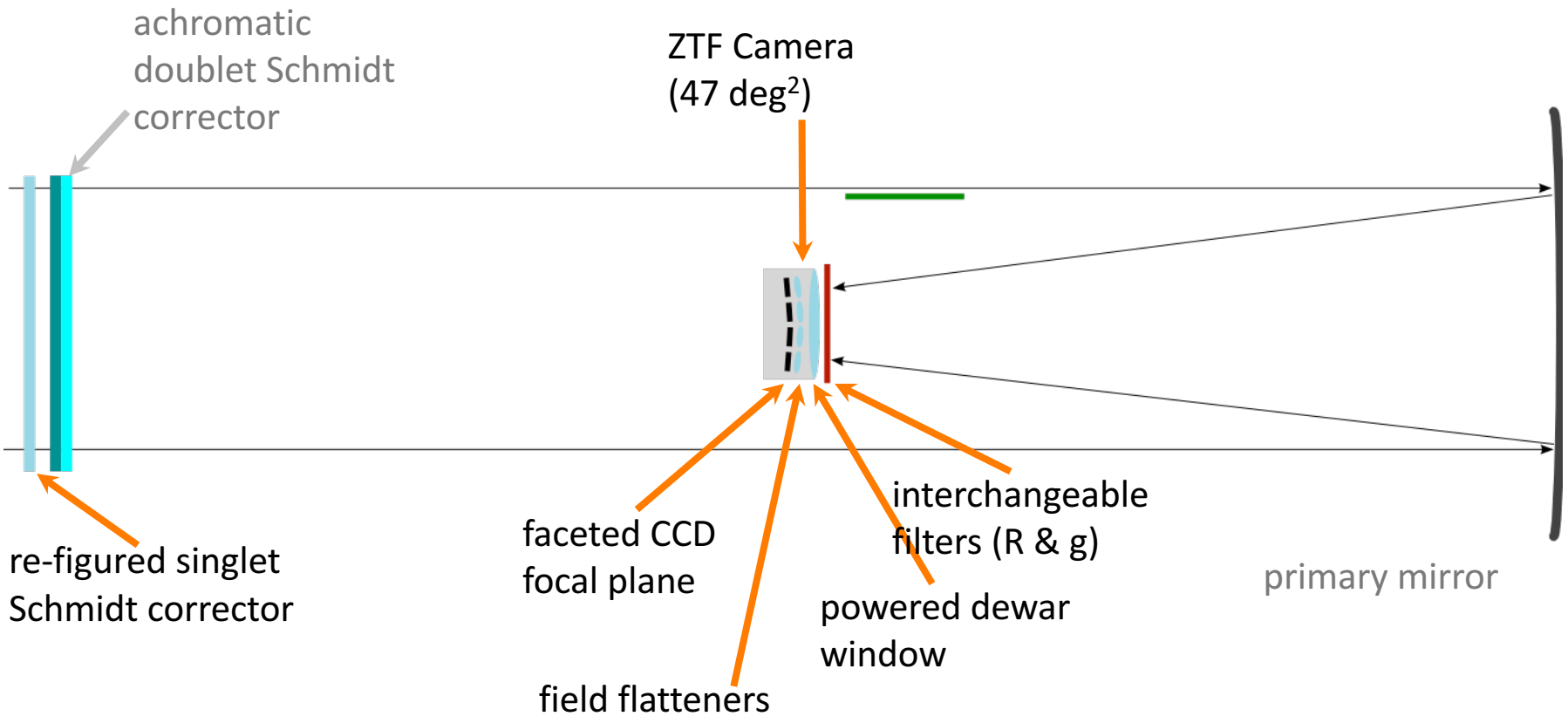
The second Sky Survey added a doublet corrector.



PTF replaced the plates with a CCD camera.

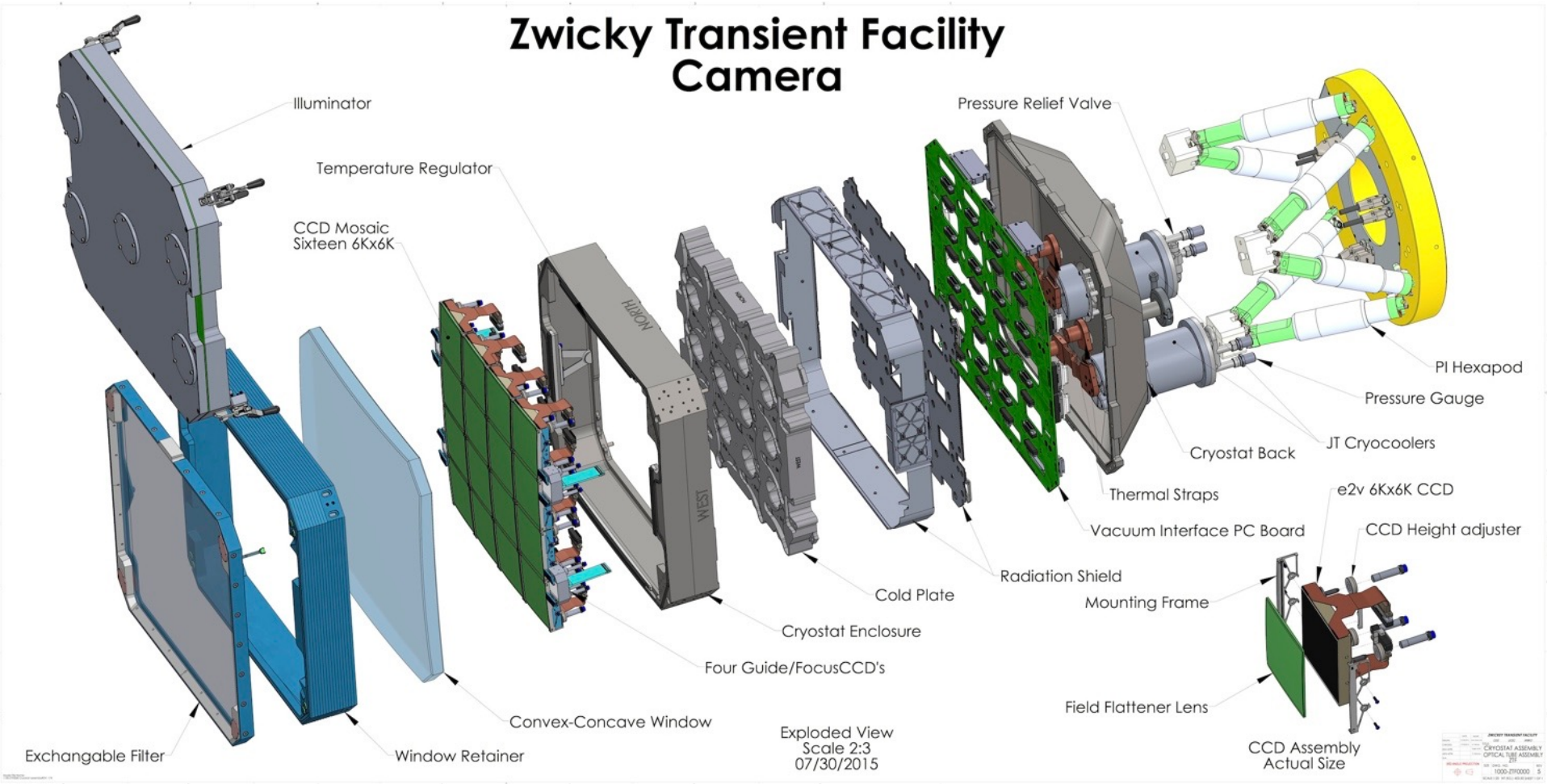


New optics enable ZTF's unprecedented field of view.



camera & filter optics fabricated;
corrector plate in production

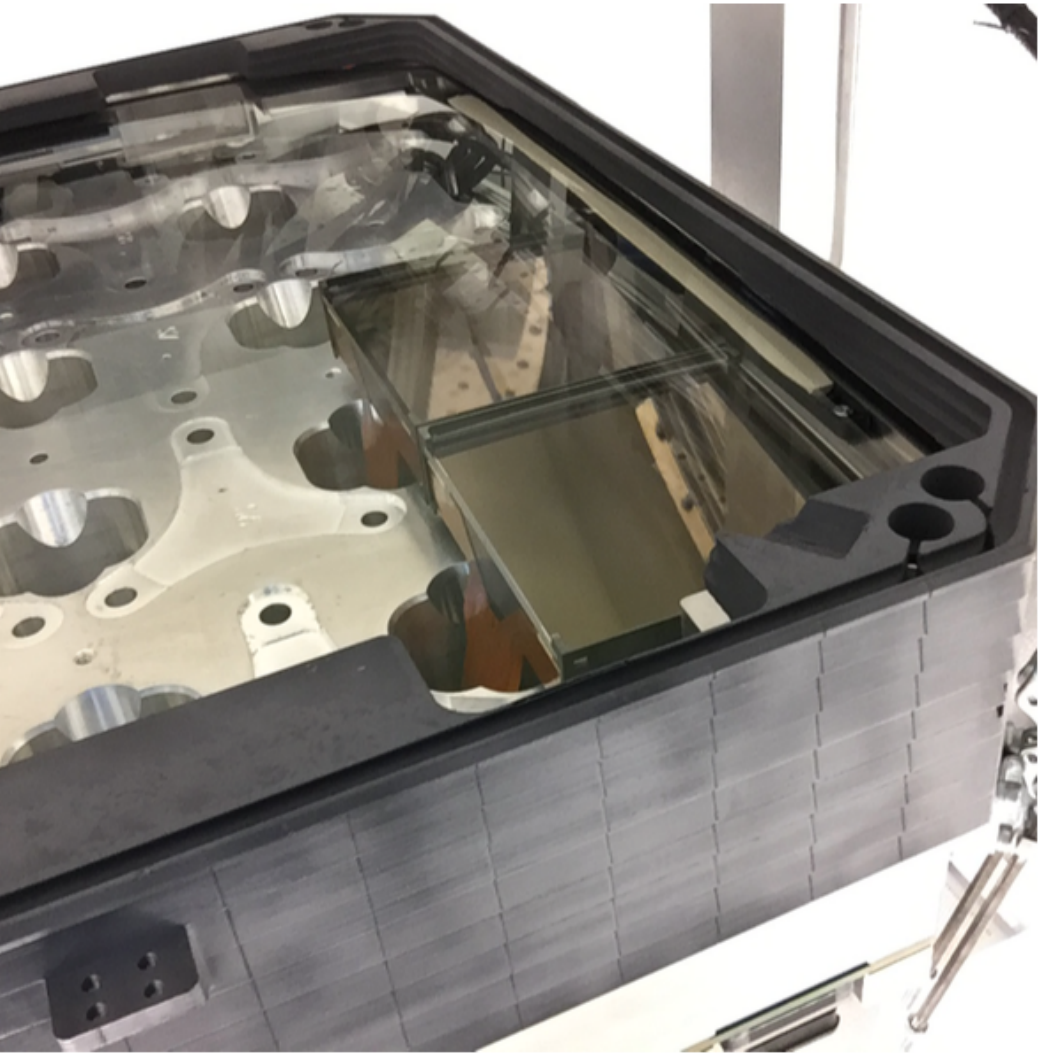
The ZTF cryostat is compact.

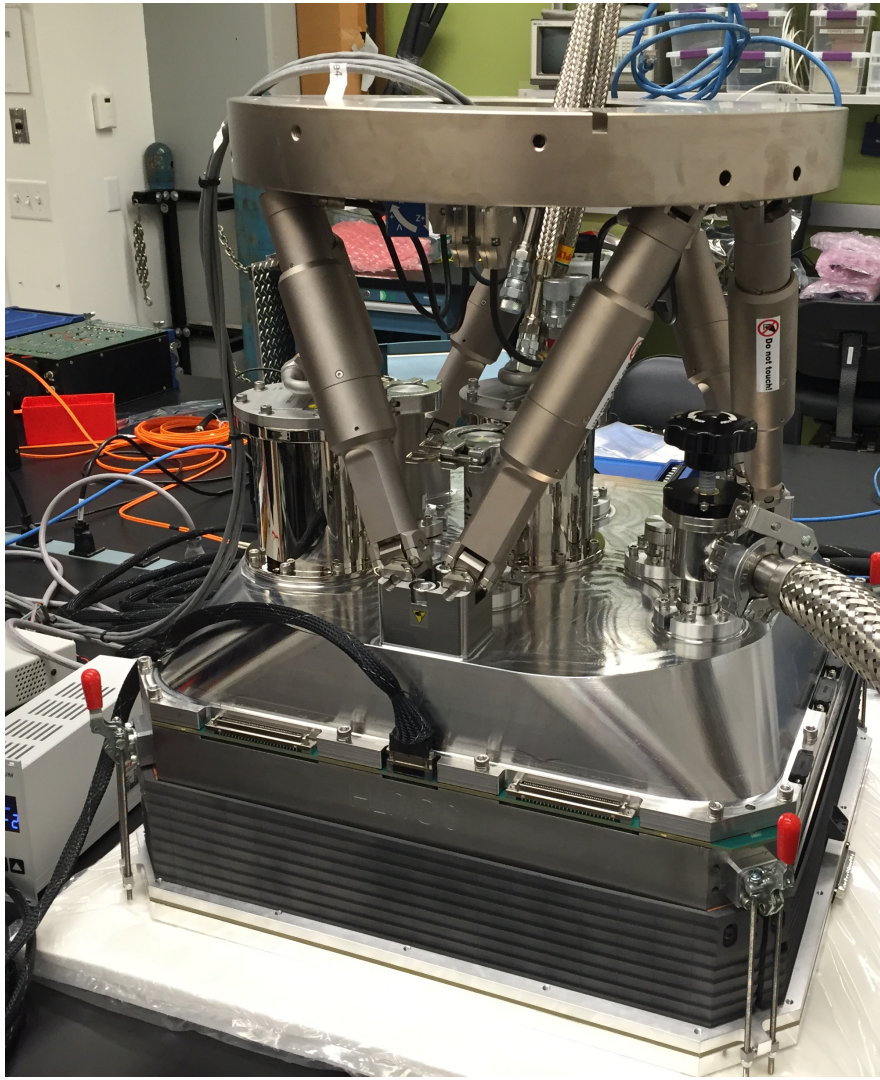


CCDs loaded,
full system testing in progress

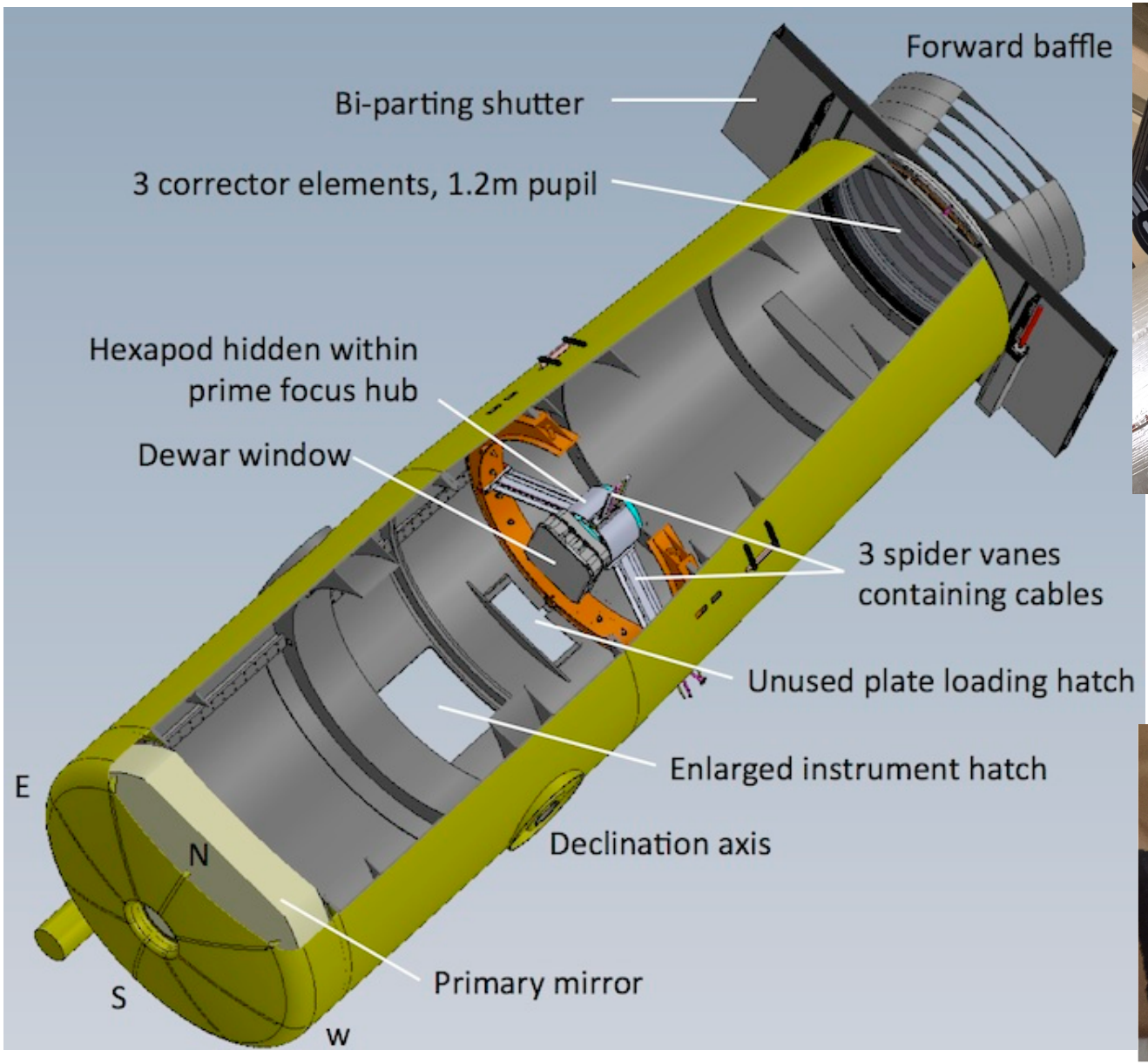
conceptual design: LBNL
detailed design: Caltech

CCD installation is complete and testing is in progress.

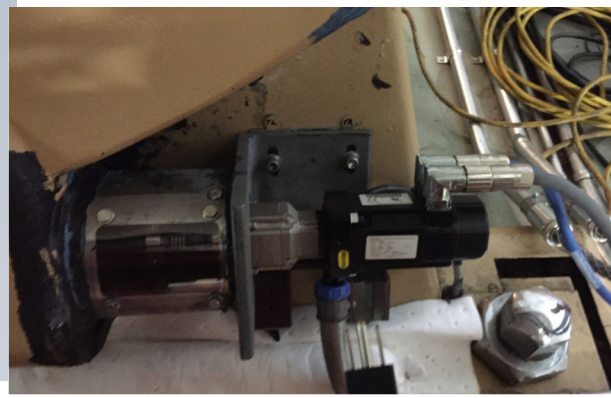




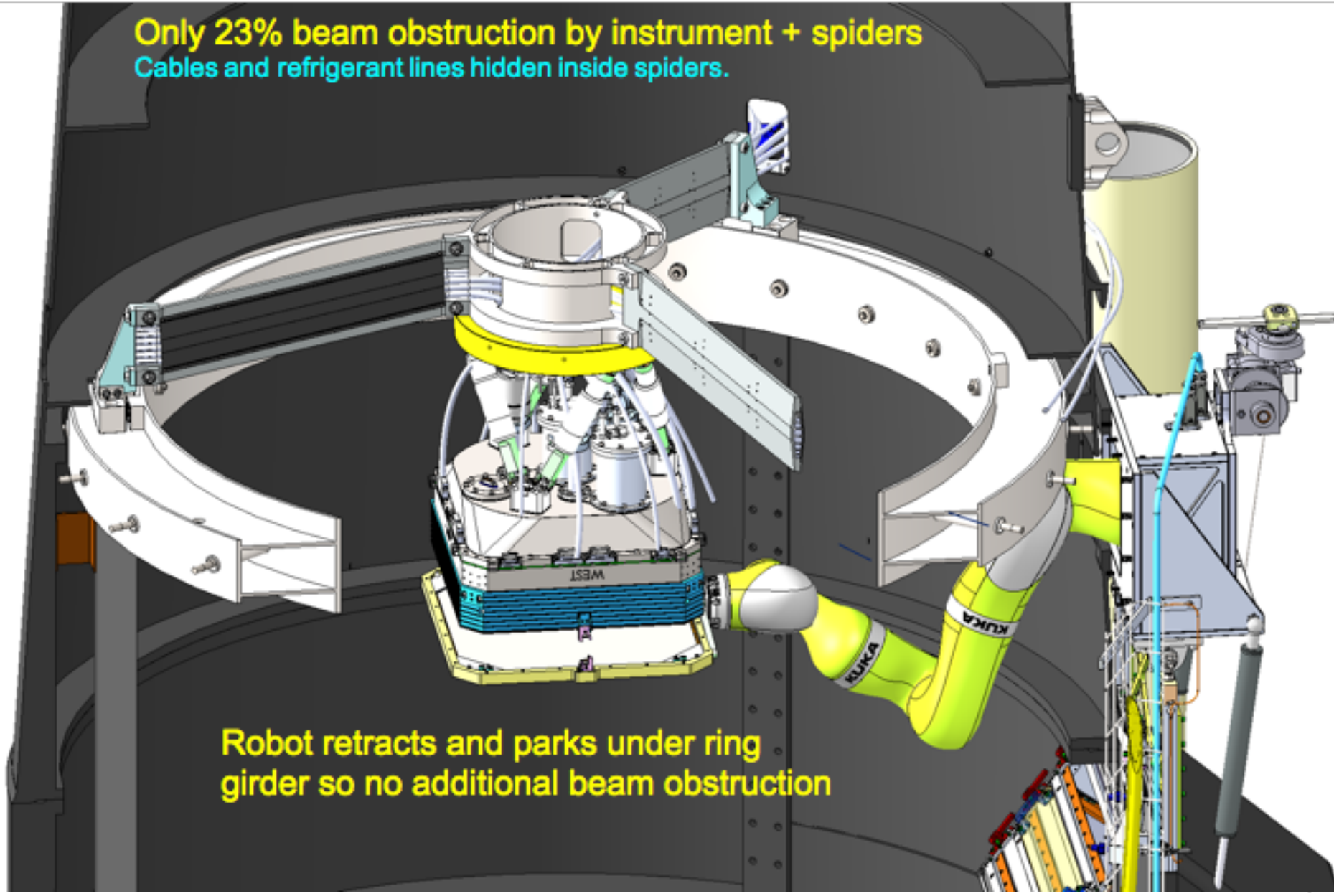
P48 upgrades will ensure robust operation.



new Bonn shutter mounted on P48; new drive motors



ZTF will use a commercial robotic arm to exchange filters.



ZTF will survey an order of magnitude faster than PTF.

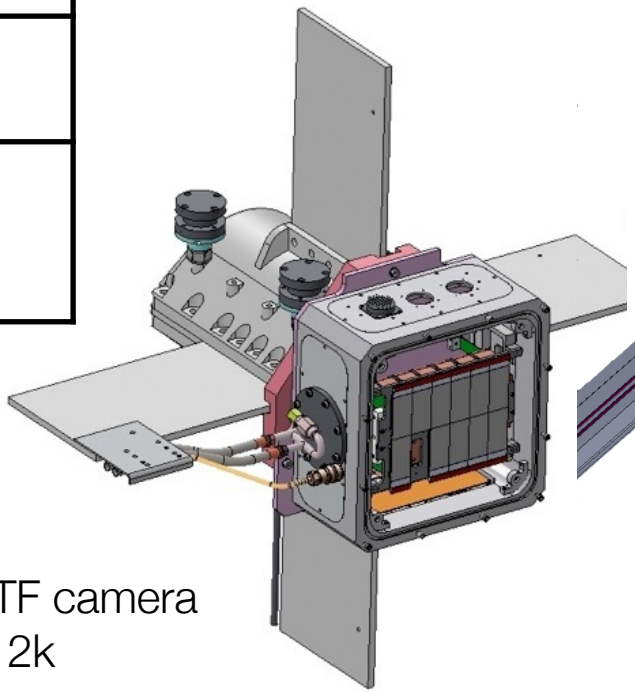
	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	15.0x
Relative Volumetric Survey Rate	1x	12.3x

3750 deg^2/hour

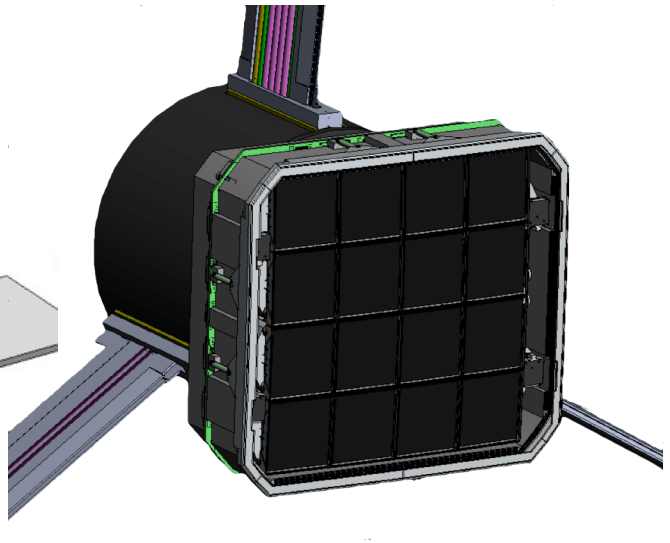
⇒ 3π survey in 8 hours

>250 observations/field/year

for uniform survey

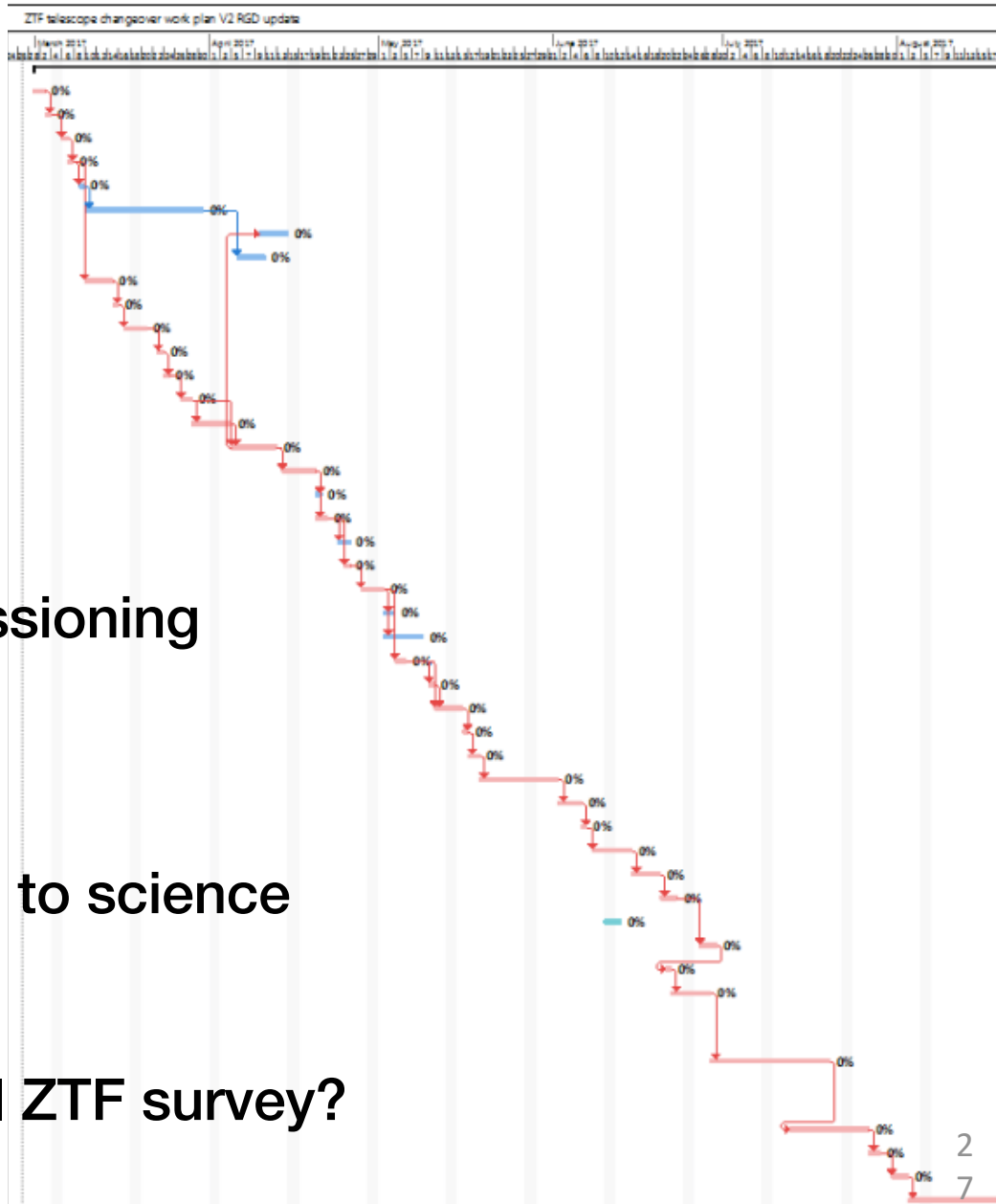


Existing PTF camera
MOSAIC 12k



New ZTF camera:
16 6k x 6k e2v CCDs

ZTF goes on sky in 2017.



March 1, 2017: iPTF decommissioning

~July 20: estimated first light

~Sept. 15: estimated transition to science commissioning

~Nov. 1, 2017: beginning of full ZTF survey?

The Amazing ZTF Development Team

Observing System - Caltech

- Roger Smith – Observing System Lead
  Richard Dekany – Project Manager
  Eric Bellm – Project Scientist
  Justin Belicki – Electronics
  John Cromer – Instrument Software
  Alex Delacroix – Cryo & FPA Mechanical
  Gina Duggan – FPA Metrology
  Michael Feeney – Cryo & P48 Mechanical
  David Hale – Camera & Filter Exchanger Software
  Steve Kaye – VIB & Detector Testing
  Thomas Kupfer – Ops Planning
  Peter Mao – Detector Test Automation
  Jennifer Milburn – Autoguider Software
  Patrick Murphy – Electronics & Cryo
  Reston Nash – Exchanger Mechanical
  Michael Porter – Filter Exchanger Lead
  Dan Reiley – Optics Lead
  Reed Riddle – Software Lead
  James Wincentsen – ZTF Documentation

  Jeff Zolkower – P48 Chief Engineer
  Bruce Baker – P48 Supervisor
  Tom Barlow – P48 Operations
  John Henning – P48 TCS
  Dan McKenna – P48 Telescope Engineering
  Victor Tapia – P48 Engineering
  Richard Walters – P48 Operations

Observing System - DESY

- Klaus Reif – Shutter Lead
  Philipp Mueller – Systems Engineering
  Martin Polder - Mechanical

Data System

- Frank Masci – Data System Lead
  Ron Beck – Pipeline Operations
  Lee Bennett – Systems Engineering
  Imel David – IPAC Manager
  Steve Groom – Archive Architect
  George Helou – IPAC Director
  Ed Jackson – Database Mngt
  Russ Laher – Pipeline Infrastructure; Ingest; Test
  Ben Rusholme – Data xfre; Pipeline; Config. Mngt
  David Shupe – Source Matching; Astrometry
  Jason Surace – Image Simulation; Data Analysis
  Lin Yan – Marshal Planning & Summer School

Education and Public Outreach

- Andy Boden – E/PO Lead and HPWREN
  Bryan Penprase – Undergraduate Education

Shri Kulkarni, Principal Investigator & Eric Bellm, Project Scientist

IV. ZTF PUBLIC SURVEYS: S. KULKARNI

MSIP Survey

- Celestial Cinematography (CC)
  - cover large fraction of night sky every 3 nights (15 kilo deg^2)
  - g & R separated by ~ 1 hour
- Galactic Plane Sweep (GPS)
  - g & R every night, +/- 6^o along the Galactic equator
- At the end of first 12 months of routine survey (~early 2019):
  - By this time data from commissioning and early survey will be available to the community
  - Performance of image differencing and Galactic Plane photometry will be better understood
- Review the status of TDA field, devise new surveys, consult CSAC & ZTF Board and put in effect new surveys

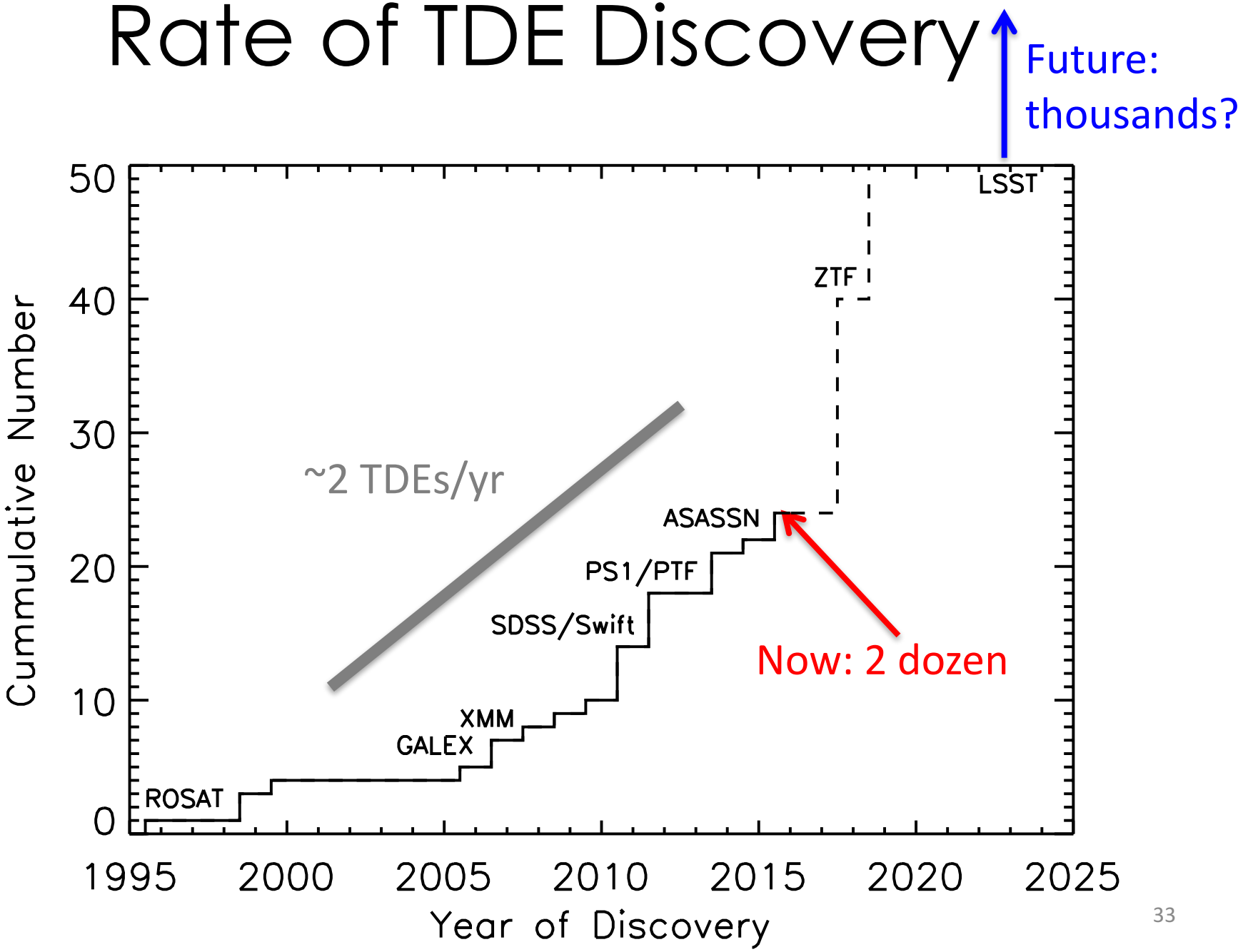
Celestial Cinematography: Exemplars

- Local Volume Supernova Survey
- A complete census of Tidal Disruption Events
- Low redshift Super-luminous supernovae (& star formation history)
- Merger events in the local Universe
- Precision Type Ia cosmology for $z<0.12$
  - Largest errors at lowest redshift!

Suvi Gezari
(University of Maryland)

TDE SCIENCE WITH ZTF MSIP

Rate of TDE Discovery



ZTF is a Game Changer for TDE Science

- ZTF will be the first survey to provide a **statistical** sample of TDEs

- This sample of 20 TDEs per year will enable:
  - studies of rates as a function of host galaxy properties and redshift
  - well-sampled light curves (on the rise to peak) to be used to probe black hole masses in normal (inactive) galaxies
  - The search for rare events like TDEs around IMBHs, spinning SMBHs, binary SMBHs, recoiling SMBHs

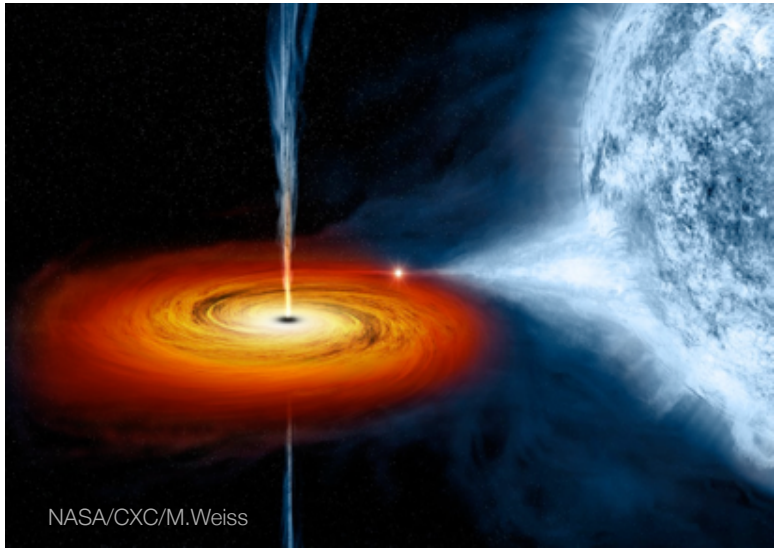
*With a systematic study of nuclear transients, **expect** to detect **unexpected** phenomena associated with SMBHs!*

Thomas Kupfer
(Caltech)

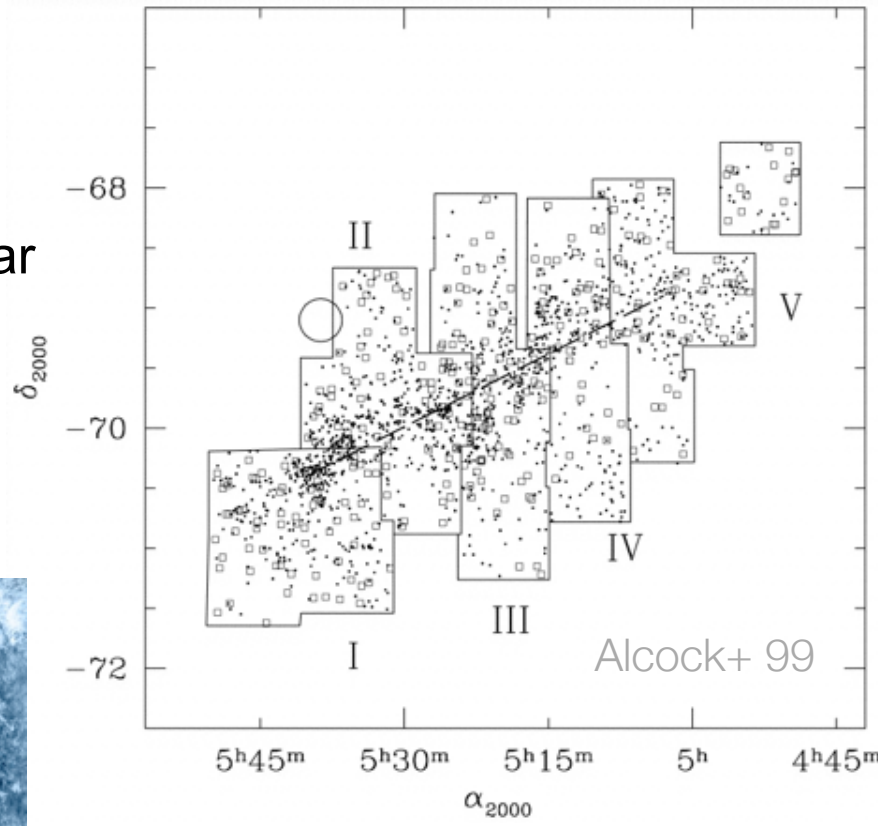
GALACTIC PLANE SURVEY

Variability studies in the Galaxy opens new science

Understand accretion in Young Stellar Objects



Find rare compact binaries

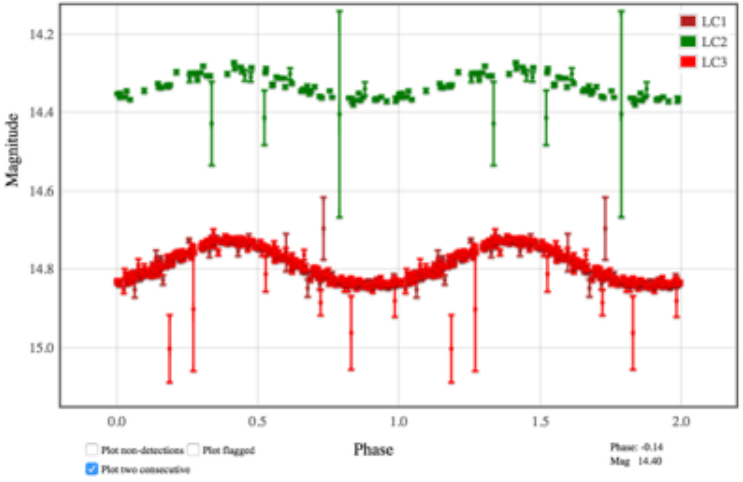


Trace Galactic Structure with Pulsating Variables

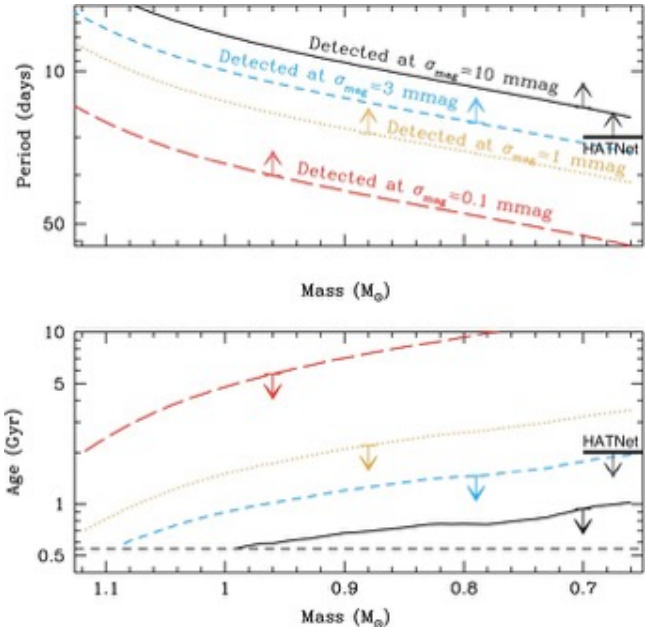
plus: gyrochronology, microlensing, M dwarf flares, rare stellar variables...

Variables in the Galactic Plane

- Galactic Plane generates more attention (e.g. PanSTARRS, Gaia, EGAPS)
  - However, time domain variability data in the Galactic Plane limited
- For the first time, ZTF will provide about >150 in g+r per year in the Plane
- This will allow to discover a large number of periodic/aperiodic variable objects with periods of hours up to months/years e.g.
  - Census of variable stars in the Galaxy (binary evolution)
  - Gyrochronoloy: Rotation periods of stars
  - Long period variables (e.g. Cepheids)
- g+r will allow for to search for color dependent variability (e.g. reflection effect)



Reflection effect binary star

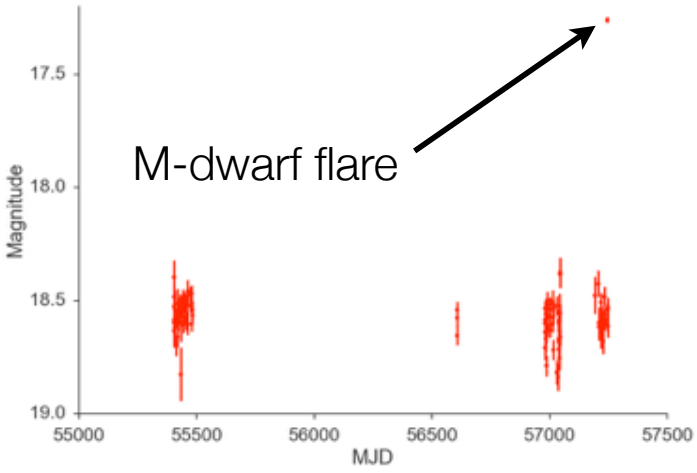


Gyrochronology:

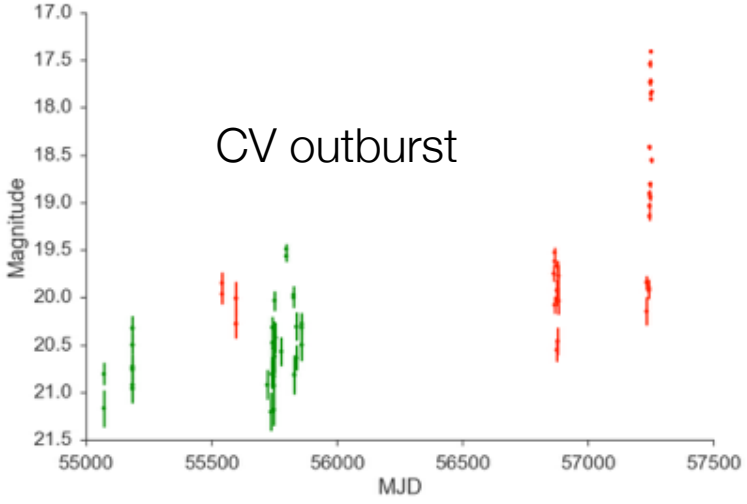
ZTF period measurements of < 1.5 Gyr dwarfs will refine period/age relationships in clusters, test theories of disk migration dynamics

Transients in the Galactic Plane

- Typical Galactic transients are dwarf novae, flaring stars
  - last for hours - days
- With a nightly g+r survey in the Galactic Plane we will be able to detect every individual transient in the Plane
  - Possibility to find rare events, e.g. stellar mergers, Galactic Novae, common envelope events
  - g+r allows for immediate identification by colors
    - dwarf novae, flaring stars are blue
    - stellar mergers, common envelope events are red



Flare star discovered by iPTF



Dwarf novae discovered by iPTF

V. ZTF PUBLIC DATA PRODUCTS: E. BELLM

MSIP funding provides access to PTF, iPTF, & ZTF data.

Raw and processed images

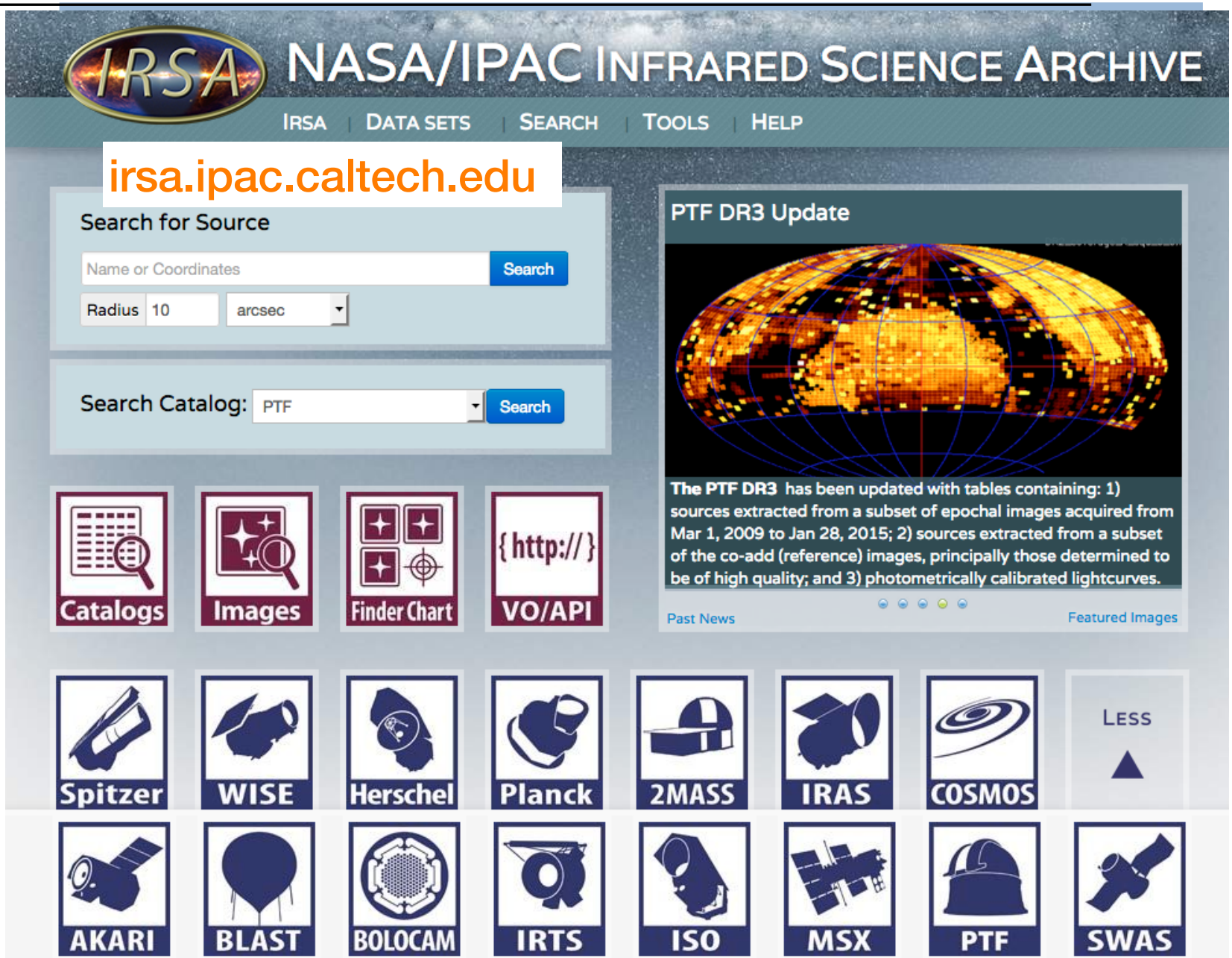
PSF and aperture catalogs

Relative-photometry-corrected lightcurves from catalogs

Image difference alerts from public surveys

Summer schools

IRSA provides access to PTF, iPTF, and ZTF data.



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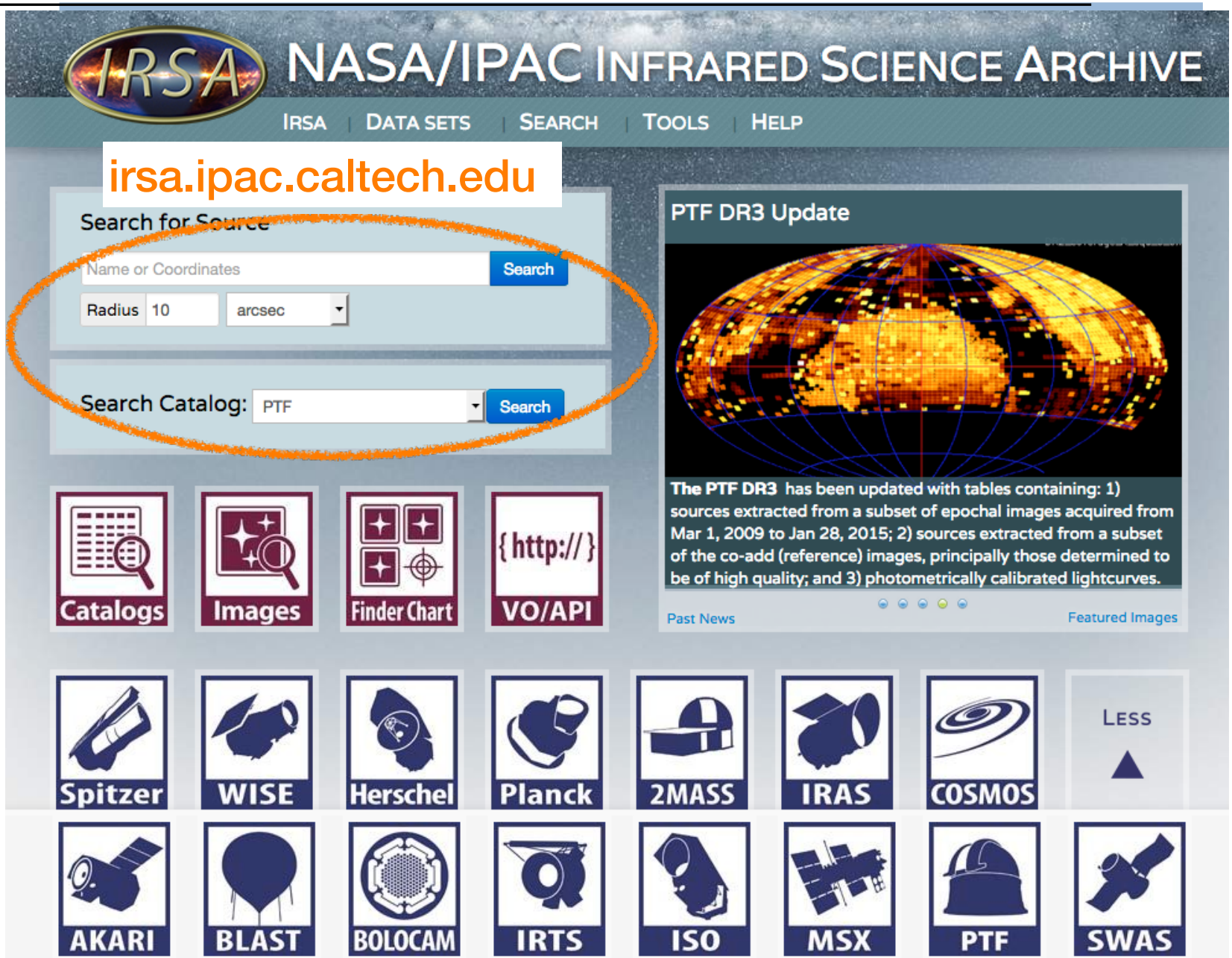

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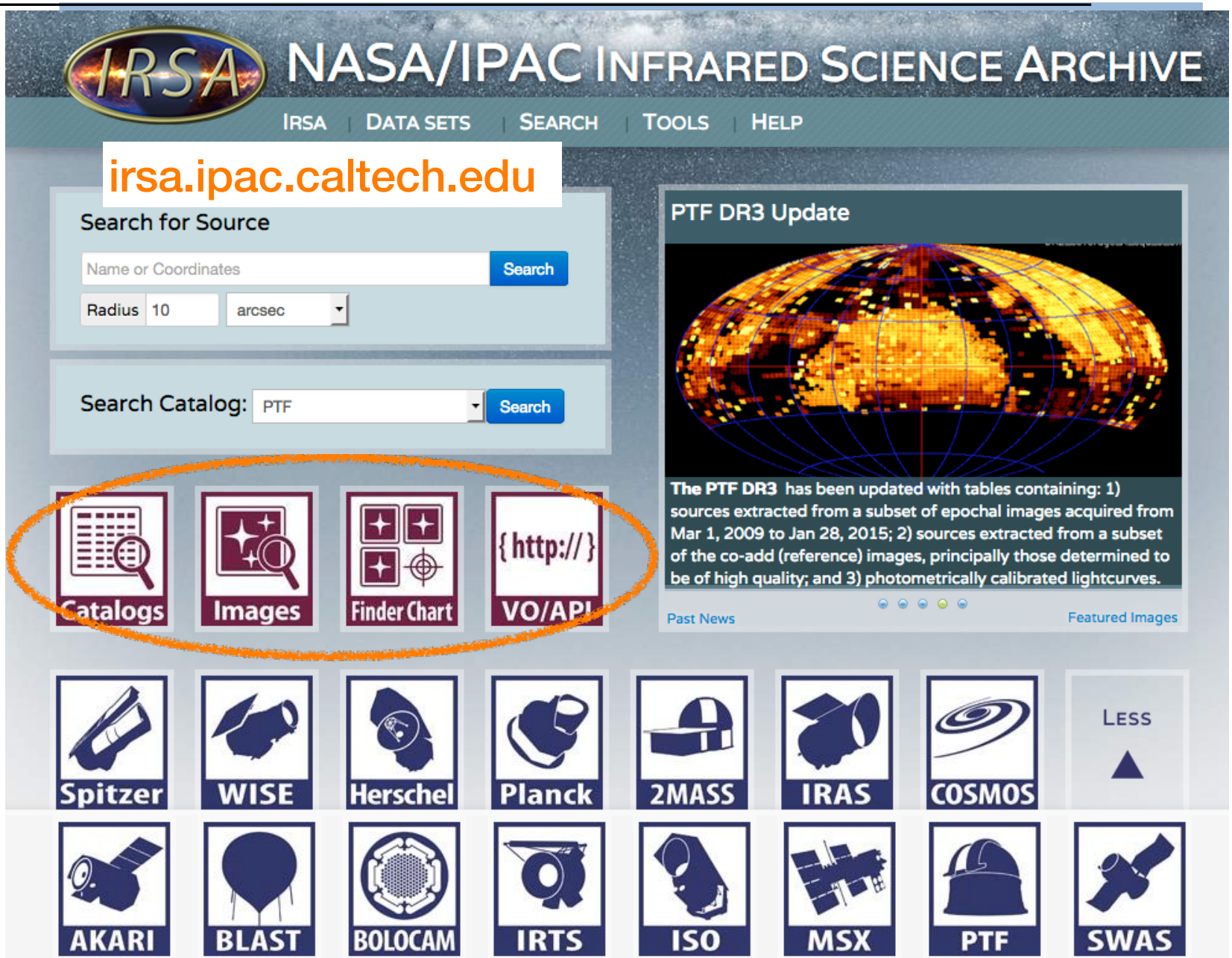

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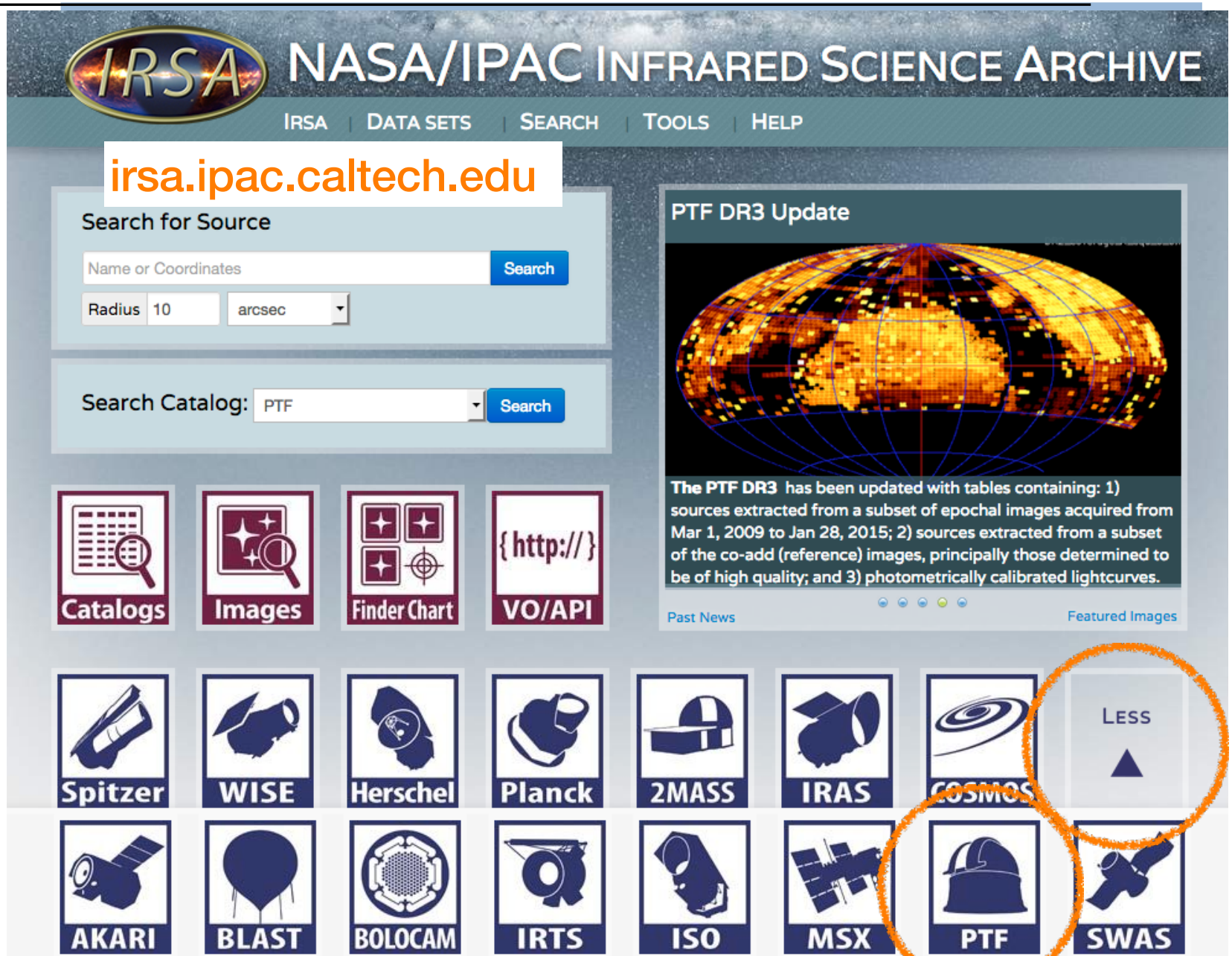
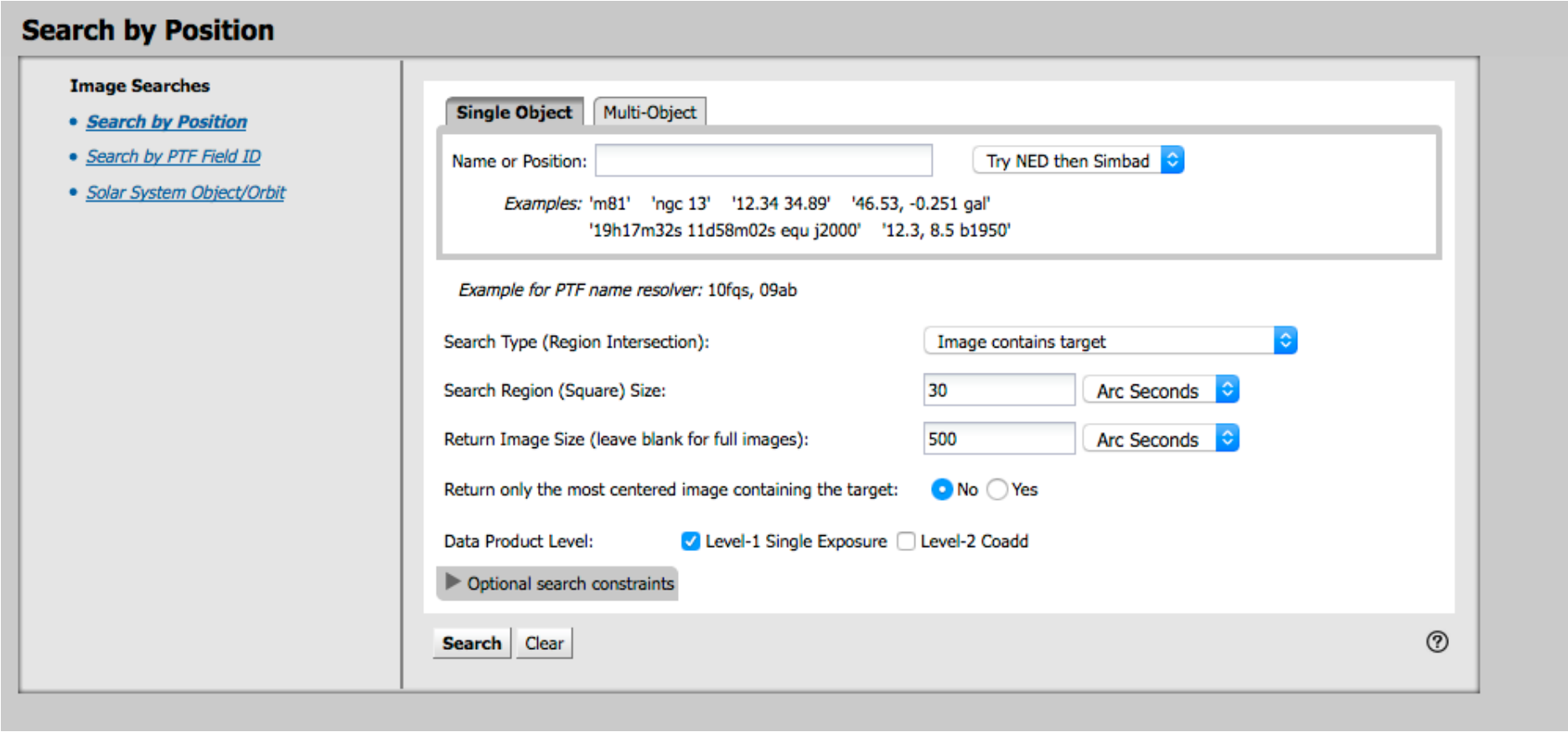


The image search service enables direct access to processed images and epochal catalogs.

irsa.ipac.caltech.edu/applications/ptf/



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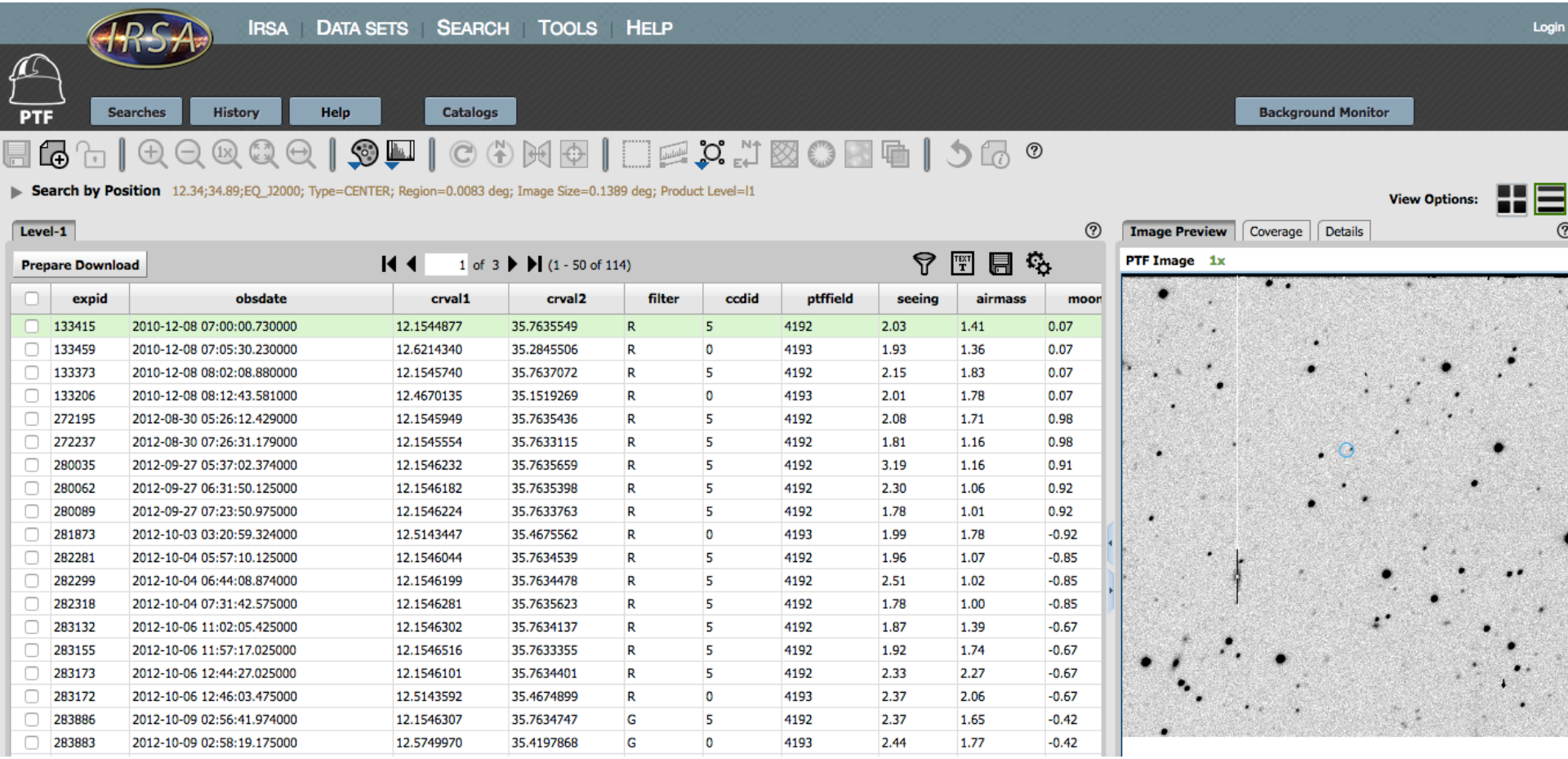


expid	obsdate	crval1	crval2	filter	ccdid	ptffield	seeing	airmass	moon
133415	2010-12-08 07:00:00.730000	12.1544877	35.7635549	R	5	4192	2.03	1.41	0.07
133459	2010-12-08 07:05:30.230000	12.6214340	35.2845506	R	0	4193	1.93	1.36	0.07
133373	2010-12-08 08:02:08.880000	12.1545740	35.7637072	R	5	4192	2.15	1.83	0.07
133206	2010-12-08 08:12:43.581000	12.4670135	35.1519269	R	0	4193	2.01	1.78	0.07
272195	2012-08-30 05:26:12.429000	12.1545949	35.7635436	R	5	4192	2.08	1.71	0.98
272237	2012-08-30 07:26:31.179000	12.1545554	35.7633115	R	5	4192	1.81	1.16	0.98
280035	2012-09-27 05:37:02.374000	12.1546232	35.7635659	R	5	4192	3.19	1.16	0.91
280062	2012-09-27 06:31:50.125000	12.1546182	35.7635398	R	5	4192	2.30	1.06	0.92
280089	2012-09-27 07:23:50.975000	12.1546224	35.7633763	R	5	4192	1.78	1.01	0.92
281873	2012-10-03 03:20:59.324000	12.5143447	35.4675562	R	0	4193	1.99	1.78	-0.92
282281	2012-10-04 05:57:10.125000	12.1546044	35.7634539	R	5	4192	1.96	1.07	-0.85
282299	2012-10-04 06:44:08.874000	12.1546199	35.7634478	R	5	4192	2.51	1.02	-0.85
282318	2012-10-04 07:31:42.575000	12.1546281	35.7635623	R	5	4192	1.78	1.00	-0.85
283132	2012-10-06 11:02:05.425000	12.1546302	35.7634137	R	5	4192	1.87	1.39	-0.67
283155	2012-10-06 11:57:17.025000	12.1546516	35.7633355	R	5	4192	1.92	1.74	-0.67
283173	2012-10-06 12:44:27.025000	12.1546101	35.7634401	R	5	4192	2.33	2.27	-0.67
283172	2012-10-06 12:46:03.475000	12.5143592	35.4674899	R	0	4193	2.37	2.06	-0.67
283886	2012-10-09 02:56:41.974000	12.1546307	35.7634747	G	5	4192	2.37	1.65	-0.42
283883	2012-10-09 02:58:19.175000	12.5749970	35.4197868	G	0	4193	2.44	1.77	-0.42

Starting with PTF DR3 and continuing with ZTF, IRSA is providing a lightcurve query service.

see http://www.ptf.caltech.edu/page/lcdb

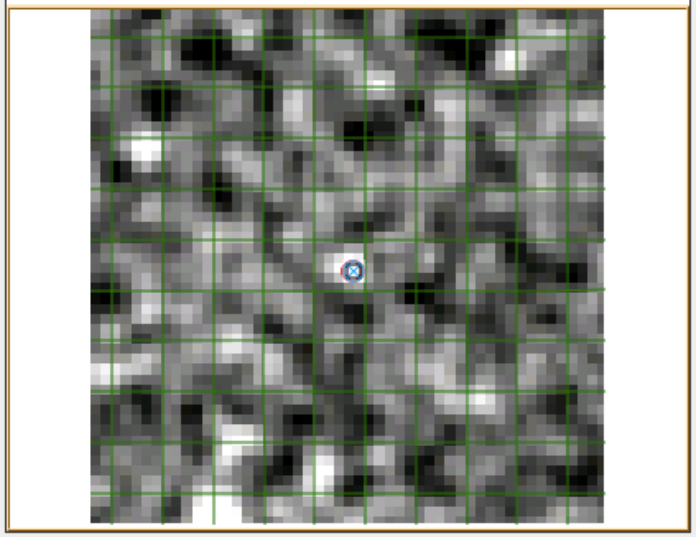
Starting with PTF DR3 and continuing with ZTF, IRSA is providing a lightcurve query service.

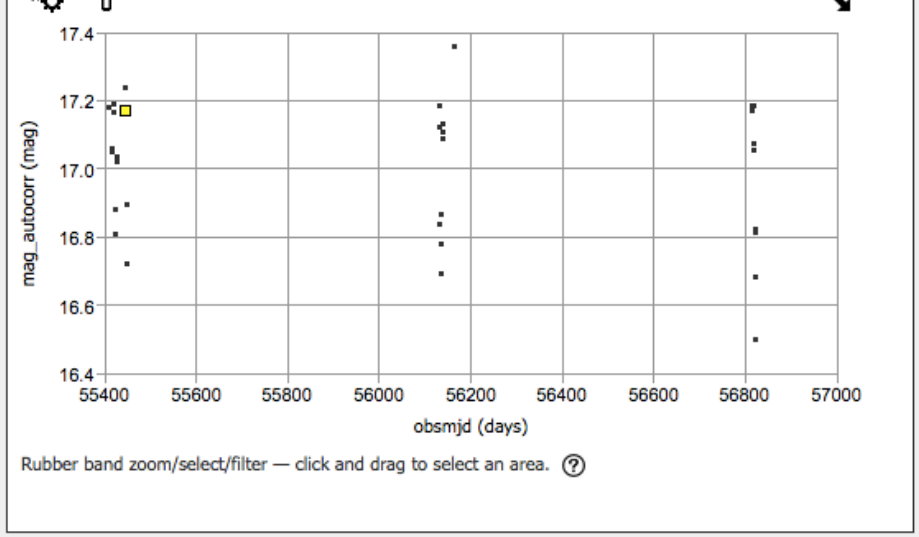
Catalog Search Result for PTF Lightcurve Table

Object/Coordinate	Source	Type	Glon	Glat	Equatorial J2000
312.333629 -1.078686	Coordinate		46.34431	-26.51339	20h 49m 20.07s -01d 04m 43.3s

Cone Search Constraints: No **33 sources found.**

Coverage 6.2x





Result IPAC Table | Column Key | To Periodogram

1 of 1 (1 - 33 of 33)

obsmjd (days)	mag_autocorr (mag)	magerr_auto (mag)	oid	ra (degrees)	dec (degrees)	clon	clat	
55443.199827200	17.172	0.028	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
55443.155617200	17.236	0.028	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
56820.421957200	16.498	0.028	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
56820.389757200	16.823	0.030	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
56816.435537200	17.187	0.031	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
56816.406667200	17.170	0.030	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2
56818.454537200	17.075	0.025	26832000000900	312.3336470	-1.0786560	20h49m20.08s	-01d04m43.16s	2

The lightcurve database can be queried by API.

```
In [1]: from astroquery.irsa import Irsa
   ...: from astropy.coordinates import SkyCoord
   ...: import astropy.units as u
   ...:
   ...: Irsa.query_region(coordinates=SkyCoord('08:22:17.19 +21:37:38.1',
   ...:         unit=(u.hourangle,u.deg)),catalog='ptf_lightcurves',radius=1.5*u.arcsec)
   ...:
Out[1]:
<Table masked=True length=10>
      obsmjd          mag_autocorr        magerr_auto     ...       angle          id
       days              mag                mag          ...        deg
     float64           float64            float64        ...      float64       object
----------------- ----------------- ------------------- ... ----------------- ------
55591.424737200003              19.503 0.17199999999999999 ... 12.741400000000001      0
55591.298507200001 19.109000000000002               0.218 ... 12.741400000000001      1
55591.406387199997 19.437999999999999 0.17100000000000001 ... 12.741400000000001      2
55591.253597199997 18.591999999999999                0.16 ... 12.741400000000001      3
55591.268347199999 18.687000000000001                0.16 ... 12.741400000000001      4
55591.220597200001 18.309999999999999               0.159 ... 12.741400000000001      5
55591.234247200002 18.414999999999999               0.159 ... 12.741400000000001      6
     55591.4401172 19.574000000000002 0.17699999999999999 ... 12.741400000000001      7
     55591.2227872 18.303000000000001 0.16600000000000001 ... 32.199841999999997      8
55591.267257200001 18.574000000000002 0.16700000000000001 ... 32.199841999999997      9
```

thanks to @keatonb!

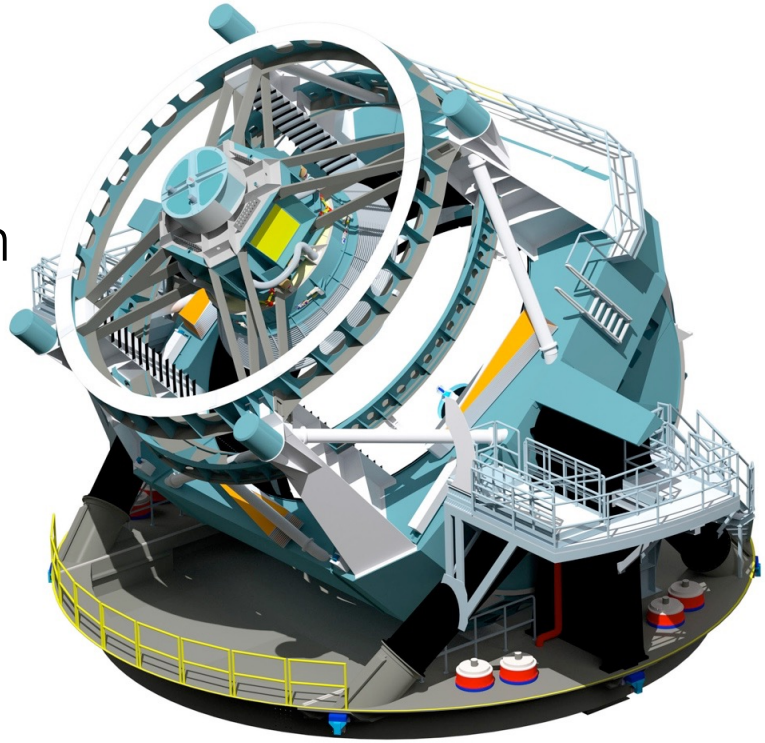
Public survey alerts are intended to emulate LSST's.

PTF: 4 x 10^4 events/night
ZTF: 3 x 10^5 events/night
LSST: 2 x 10^6 events/night

VOEvent stream with cutouts, cone search history, metrics: will emulate ls.st/dpdd as far as possible

will feed to prototype brokers
e.g., ZTF→ANTARES→LCOGT

other useful interfaces are envisioned but not yet funded



MSIP funding provides access to PTF, iPTF, & ZTF data.

2015: Complete PTF archive released (PTF DR2)
see http://www.ptf.caltech.edu/page/data_access
September 1, 2016: Initial release of iPTF data (PTF DR3)
December 1, 2016: lightcurve interface released

2017: ZTF first light & commissioning
March 1: iPTF decommissioning
~July 20: estimated first light
~Sept. 15: estimated transition to science commissioning.
formal survey starts ~November

What was stated in 2014 proposal:
2018: All-sky reference building for public surveys.
End of year: First ZTF data release (images, catalogs, lightcurves).
2019: Photometric alerts from public surveys; regular catalog releases.
2020: Transient alerts from public surveys. Final data releases.
We intend to do better! See next slide.

There are several prerequisites for image difference alerts.

reference image building

new Real/Bogus system to filter junk

requires time to bootstrap real transient detections with new camera

performance will depend strongly on characteristics of new camera and image subtraction pipelines!

building alert production service that can handle actual number of candidates coming through Real/Bogus

Accepted MSIP schedule had:

photometric alerts beginning in second full survey year.

image differencing alerts start of third full survey year.

We intend to accelerate the image differencing alerts into the first survey year but cannot guarantee a schedule until we see the actual behavior of the camera on-sky. Stream needs to be reliable!

Yearly ZTF summer schools introduce young researchers to time-domain methods.

CONCERNS & OPPORTUNITIES: S. KULKARNI

TDA: A Rapidly Evolving Field

- The landscape has changed since September 2013 (when we submitted phase I for MSIP)
- Now: Quality Image differencing, ML filtering is routine
- Progress in methodology (PTFIDE, ZOGY, other surveys) have lead to increased expectations for any TDA survey (including ZTF)

Data processing at IPAC

- All data (partnership, MSIP, Caltech) will be processed identically at IPAC
- We are not serving raw nor processed data outside IPAC (other than the scheduled releases)
- We are serving a number of products to all parties (but which have different proprietary restrictions)
  - Photometric products (goal: next day)
  - Image differencing alerts (goal: same night)
  - Light Curves (leisurely and released end of semester)

Overview of Data processing (Transients)

- PRELIMINARY (not including MOPS, TOO)
- Layer 1: Stream of candidates, estimated $3x10^5$/night (estimated) cadenced at 10 min (goal)
- Layer 2 (characterizing, filtering):
  - Star-galaxy separation
  - Contextual filters (spatial: catalogs)
  - Temporal filters
- Event flux is now reduced
  - Maintain history of events (-30 days/photometry & stamps)
  - Pass tagged events + history to user groups who will update their Marshal(s)
- Problem: Layer 2 is not yet fully specified
- Solution: Study and specify the scope (and then estimate resources needed)

UNFUNDED BUT NEEDED TOOLS & FACILITIES

RealBogus

- RealBogus
  - Needs to be trained (collect data, identify real transients, train, implement, verify)
  - Needs to be re-trained if pipeline is changed
  - Sustained manpower is needed for all these activities throughout the project
- Problem: Does our base operation cover this level of sustained manpower?
- Solution: Figure out the scope and then seek additional funding if needed

Light Curves for GP Survey(s)

- Image differencing (PTFIDE) produces reliable light curves in crowded regions
- Problem: MSIP mandate for producing GP light curves, but design assumed DAOphot (PSF) photometry rather than image differencing
- Current situation in iPTF
  - Unable to routinely produce reliable light curves for Galactic Plane, especially dense regions (astrometry)
  - As a result limited science productivity in the iPTF era
- What is needed?
  - Needs an industrial strength pipeline & machinery
  - Image differencing light curve data base
  - Need manpower to verify the quality of light curves from dense regions
- Solution:
  - UW perhaps may be interested in database
  - Review IPAC load (transients, GP) & find funds

Photometric Alerts

- Great value for Galactic science in issuing photometric alerts
  - Can potentially invigorate CV science
- Input Catalog Service can add value to ZTF
  - e.g. states of X-ray binaries, FU Ori
  - cf. ASAS-SN CV patrol

➢ Issue dedicated VOEvent stream

- Need funding (optimistic of a philanthropic gift)

Co-addition

- TDA on co-added images was not included in the original vision for PTF, iPTF or ZTF. However, there are big gains for a variety of projects by processing “co-adds” (over a night, over a week)
- This is not a technical problem
- It is a funding problem

Tools (urgently) needed by TDA users

- After data are delivered the most basic tool is a "Marshal" to aggregate all data for one's collections of transients
  - Major TDA groups have this tool (e.g. SNEX, DECAM)
  - Other efforts aimed at open source tools are under away
- "Broker" services
  - Filtering of events upstream (so that user receives optimally filtered event streams)
  - Work in progress (e.g. ANTARES at NOAO/UA)

Facilitating Followup by community

- A joint ZTF-LCO workshop (summer/TBD) to bring together developers and interested users (both neophyte, novice and experts)
- Get ready for follow up!
  - ~November 2017, start of surveys
  - 2018A:
    - Work out kinks in reference image build up
    - Priority to reference imaging
    - Train RealBogus to yield reliably candidates (low false positive)
    - Slow stream of alerts (no promises)
  - 2018B, 2019A: CC & GP survey
    - Expect routine operations
    - Good semester for vigorous follow up
    - Reminder: deadline for NOAO is March & September

Keep abreast

- The primary point for status, data access, white papers & performance is the ZTF website
  - http://www.ptf.caltech.edu/ztf

- Feel free to talk to Eric or Shri or members of the CSAC

Keep abreast

- The primary point for status, data access, white papers & performance is the ZTF website
- CSAC members:
  - * (rotating after AAS), ◆: (after commissioning)

The ZTF Community Science Advisory Committee	
Steve Ridgway (Chair)	Mario Juric
Marcel Agueros ◆	Juna Kollmeier
Todd Boroson	Marc Pinsonneault
Dale Frail *	Allen Shafter *
Neil Gehrels ◆	Paula Szkody ◆

http://www.ptf.caltech.edu/page/ztf_msip