Zwicky Transient Facility
Data System Review

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IPAC/Caltech (12/14/2015)

Why are we here?

- Review the design and functionality of the existing iPTF data system, which informs the functional requirements for ZTF.
- Examine the existing iPTF system performance.
- Discuss approach for resolving remaining design choices for ZTF.
- Show the schedule for deployment and readiness for ZTF first light.

PTF/iPTF: Evolutionary and Agile Development

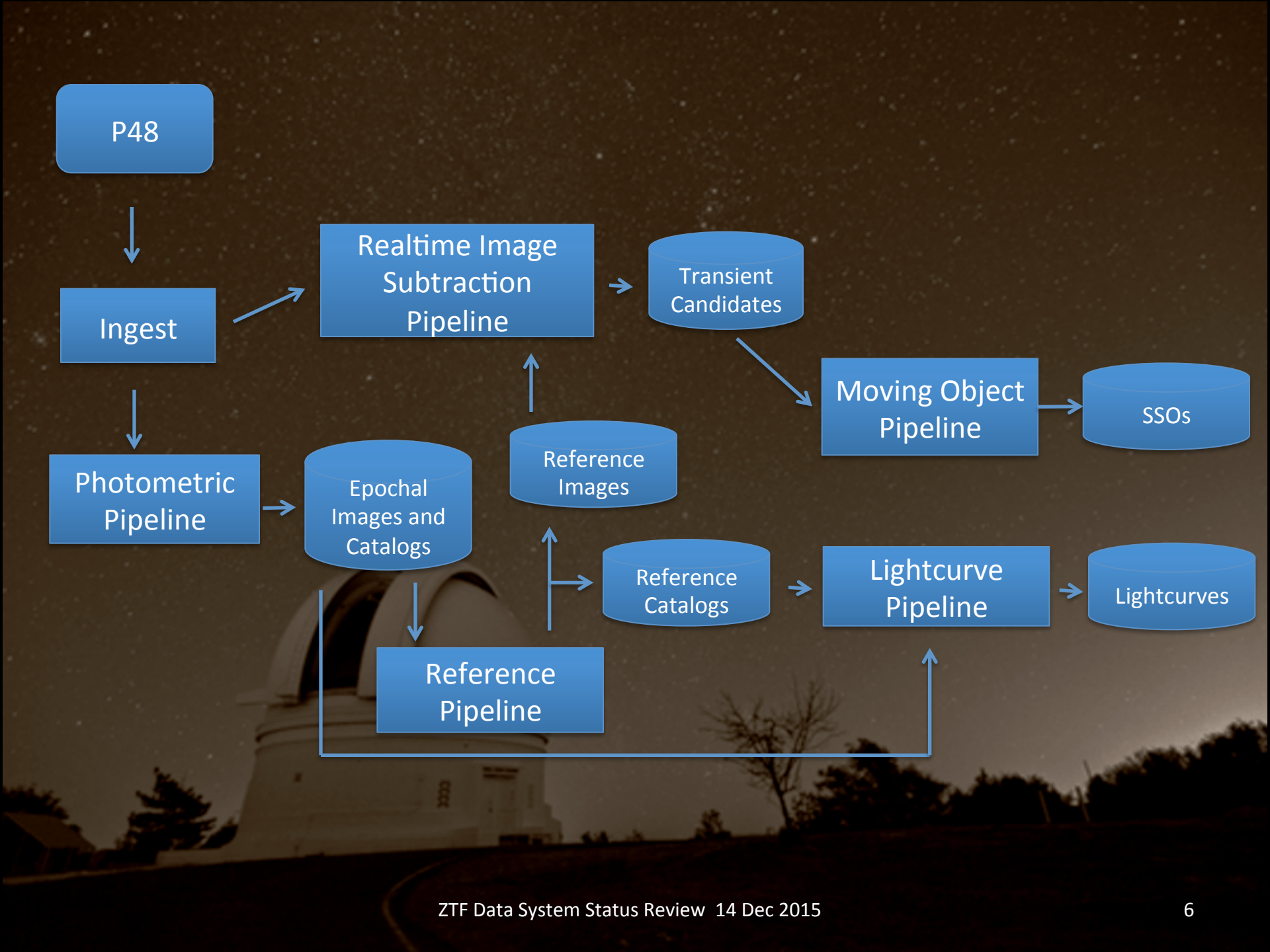
- PTF grew organically, with requirements being driven by a constantly evolving science program.
- Initial IPAC system grew as a concept to produce well-calibrated image products, to supplement the existing NERSC image subtraction and transient detection pipeline.
- System has evolved continuously over the past six years to add new capability: detection of solar system objects, light curve generation, deep coadds, etc.

Why is this relevant?

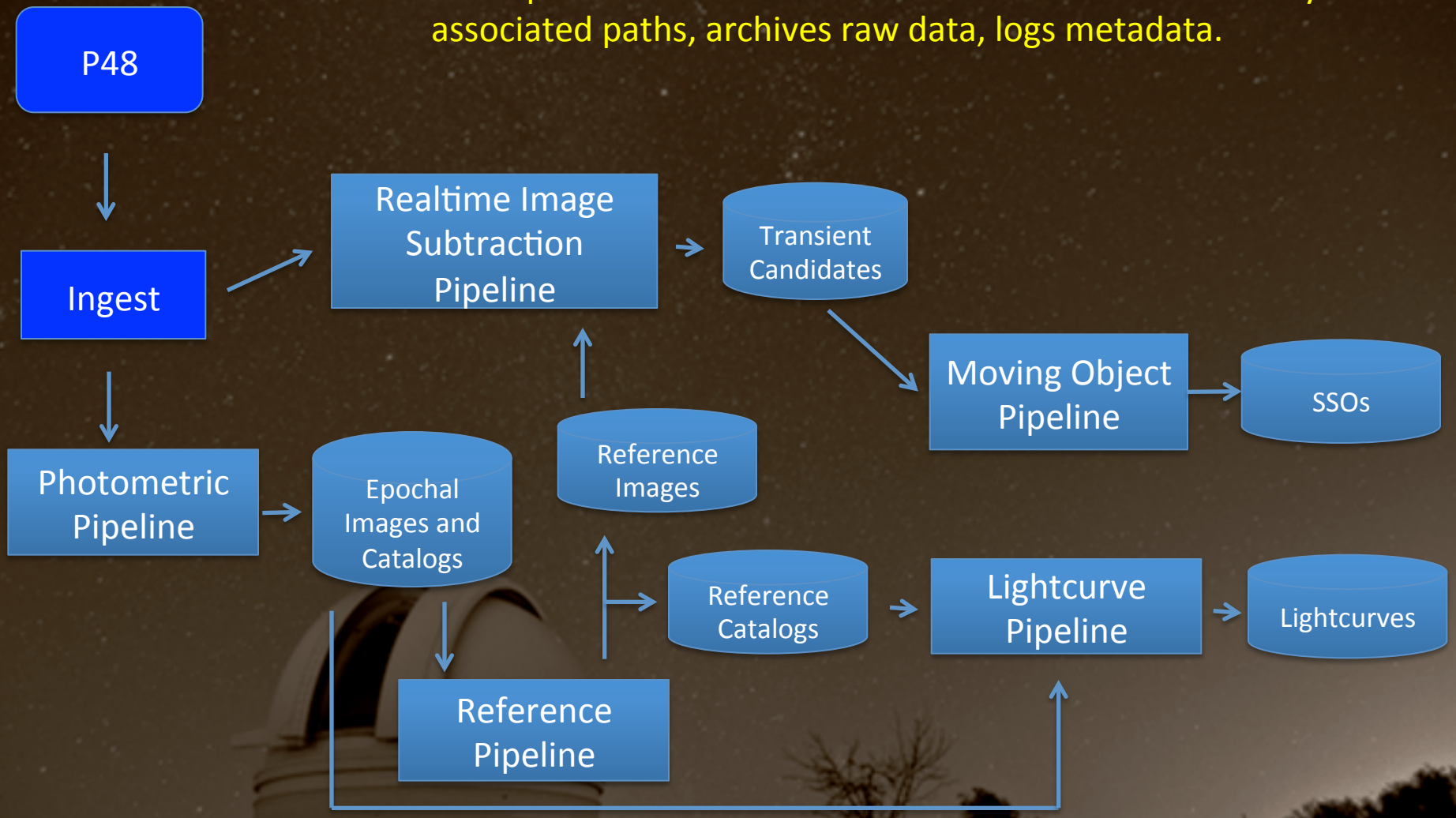
- ZTF has no formal requirements for the data system. As a result the ZTF project proposal was based on duplicating the capabilities of the existing PTF/iPTF data system, as it existed or was envisioned to exist at the time of the iPTF/ ZTF switchover.
- ZTF funding model used for the MSIP proposal was designed to be “low budget” in that it proposed to reuse the existing PTF software heritage.
- Significant new code development and new pipeline segments are outside the planned funding envelope and development horizon.
- Understanding iPTF is the model for the first year of ZTF.

Primary Pipeline Segments

- Data Ingest – receipt of data, initial logging of metadata.
- Realtime Data Processing – image subtraction, transient detection, machine vetting, and delivery of products to the treasures portal and science marshals.
- Solar System Pipeline - solar system object detection, tracklet construction.
- High Fidelity Daily Processing – nightly processing and recalibration for highest data quality images and source catalogs.
- Reference Image Pipeline – coaddition as input to other pipelines.
- Relative Photometry – periodic construction of coadded images, processing of catalogs to create high precision light curves.
- Data Archiving - storage of all raw data, processed data (images and extracted photometry), and an advanced data archive with data exploration tools enabling public and in-collaboration access.


P48
Ingest
Photometric Pipeline
Epochal Images and Catalogs
Realtime Image Subtraction Pipeline
Transient Candidates
Moving Object Pipeline
SSOs
Reference Images
Reference Catalogs
Lightcurve Pipeline
Lightcurves
Reference Pipeline

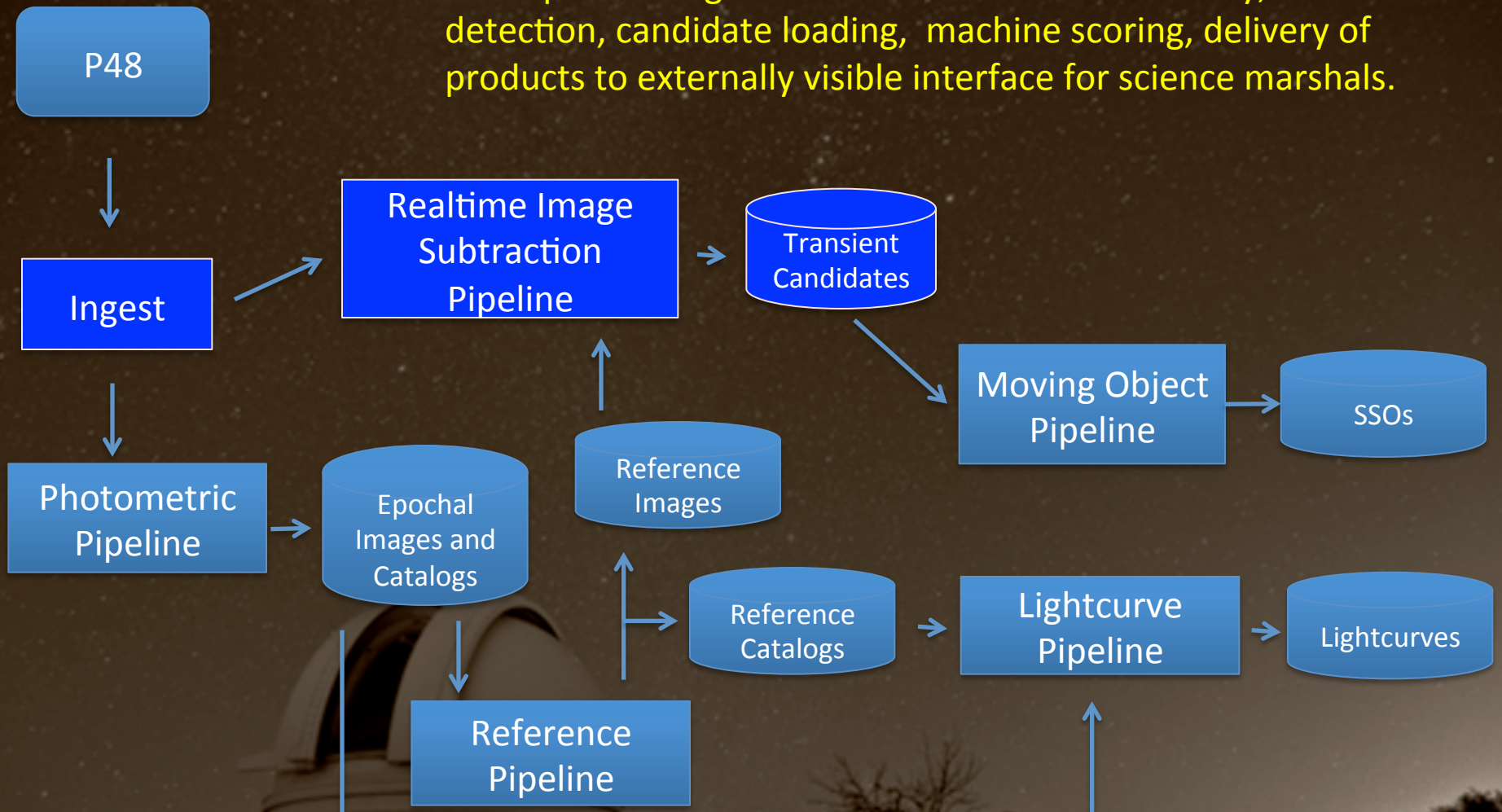
Description: receives data in realtime via microwave relay and associated paths, archives raw data, logs metadata.



Timing Requirements:
No specific req – rolled into realtime requirements.

Products: 185 MB/110 sec, 50GB/day, all image products.

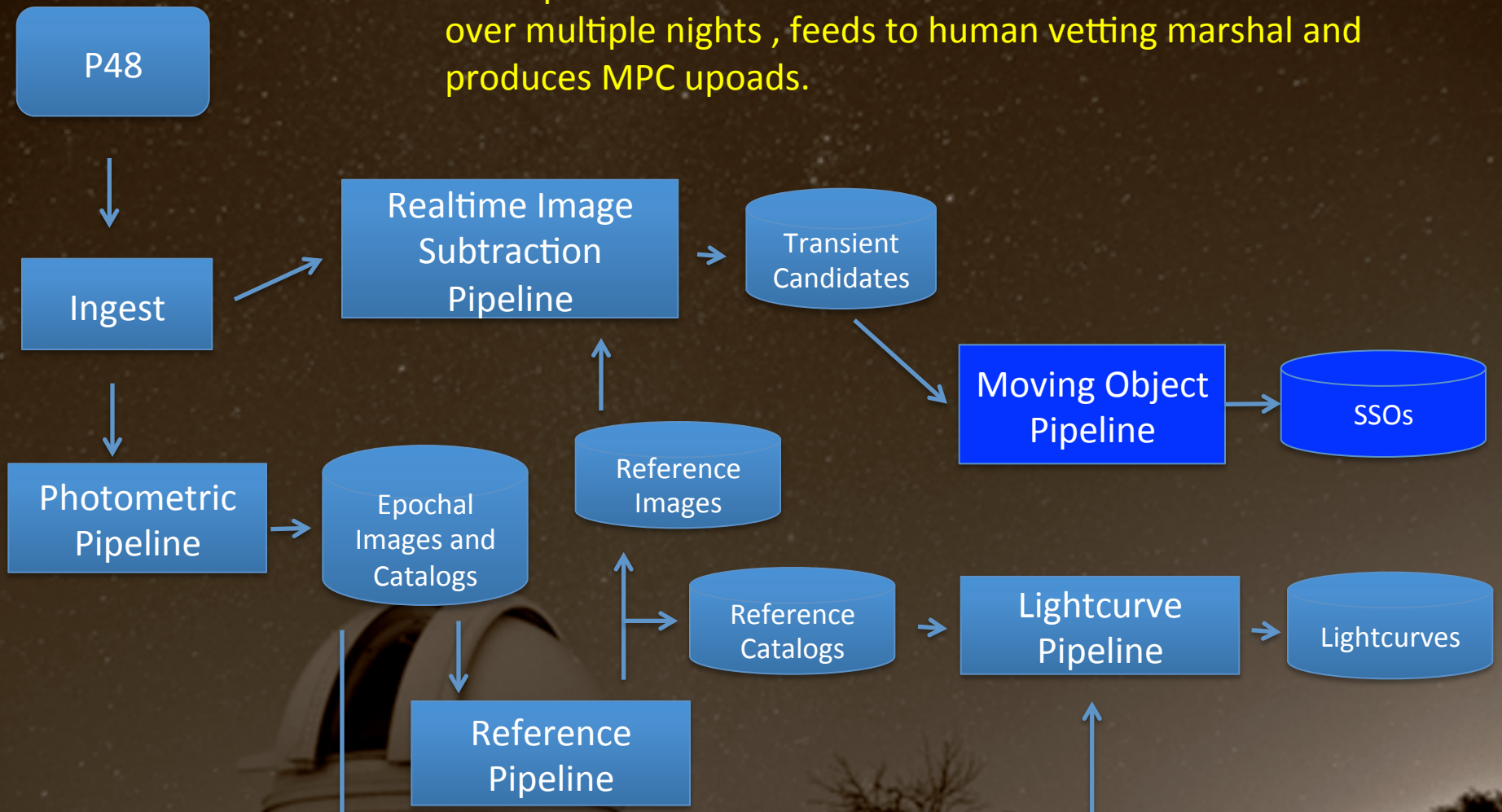
Description: image subtraction vs. reference library, transient detection, candidate loading, machine scoring, delivery of products to externally visible interface for science marshals.



Timing Requirements:
20 minutes from time of receipt at IPAC, 10 min stretch goal.

Products: 400 MB/110 sec, 100GB/day image products, 20e3 candidates/110 sec.

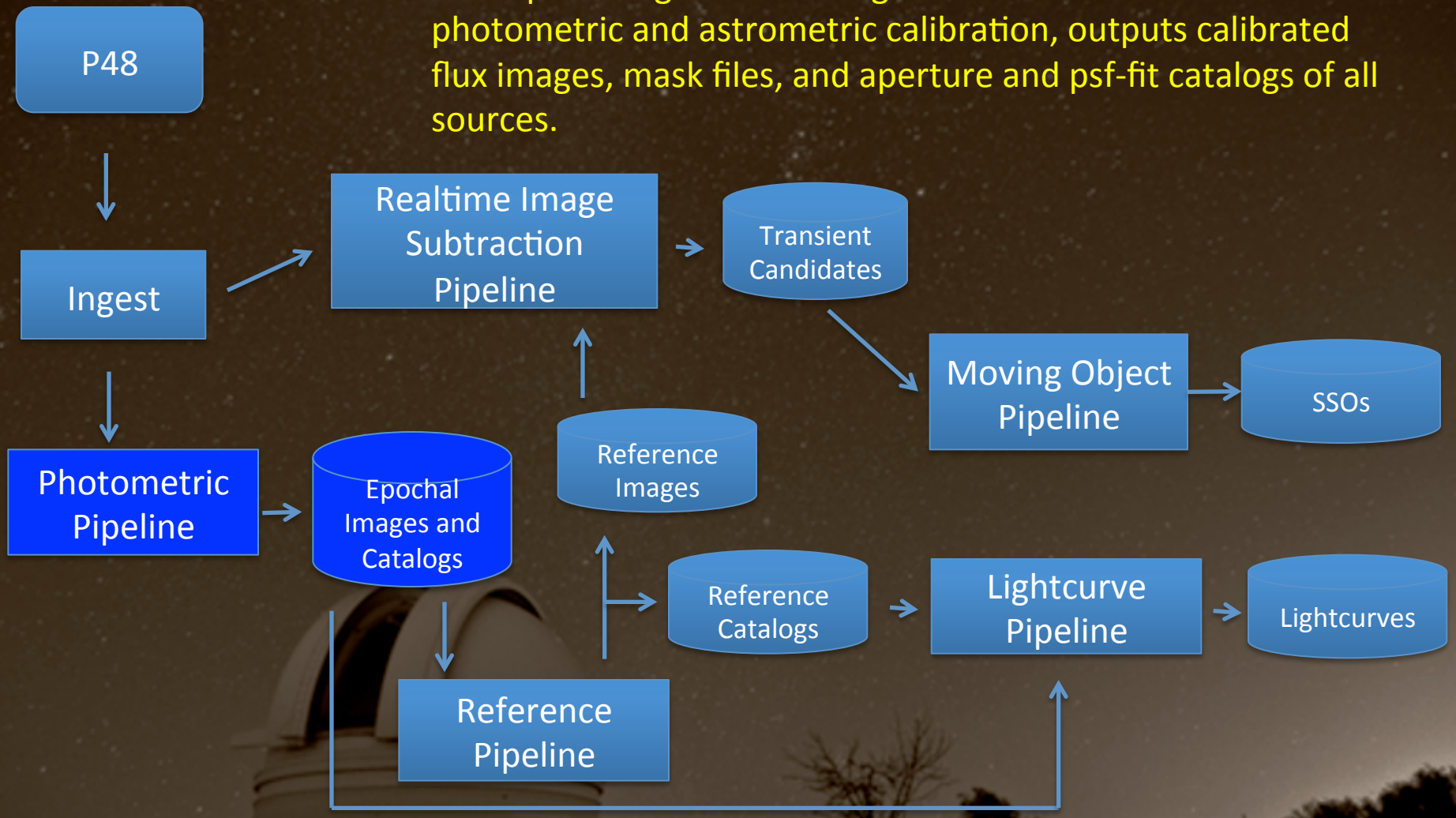
Description: assembles tracklets from transient candidates over multiple nights , feeds to human vetting marshal and produces MPC upoads.



Timing Requirements:
Runs every four hours, uses previous three nights.

Products: very small database and catalog files.

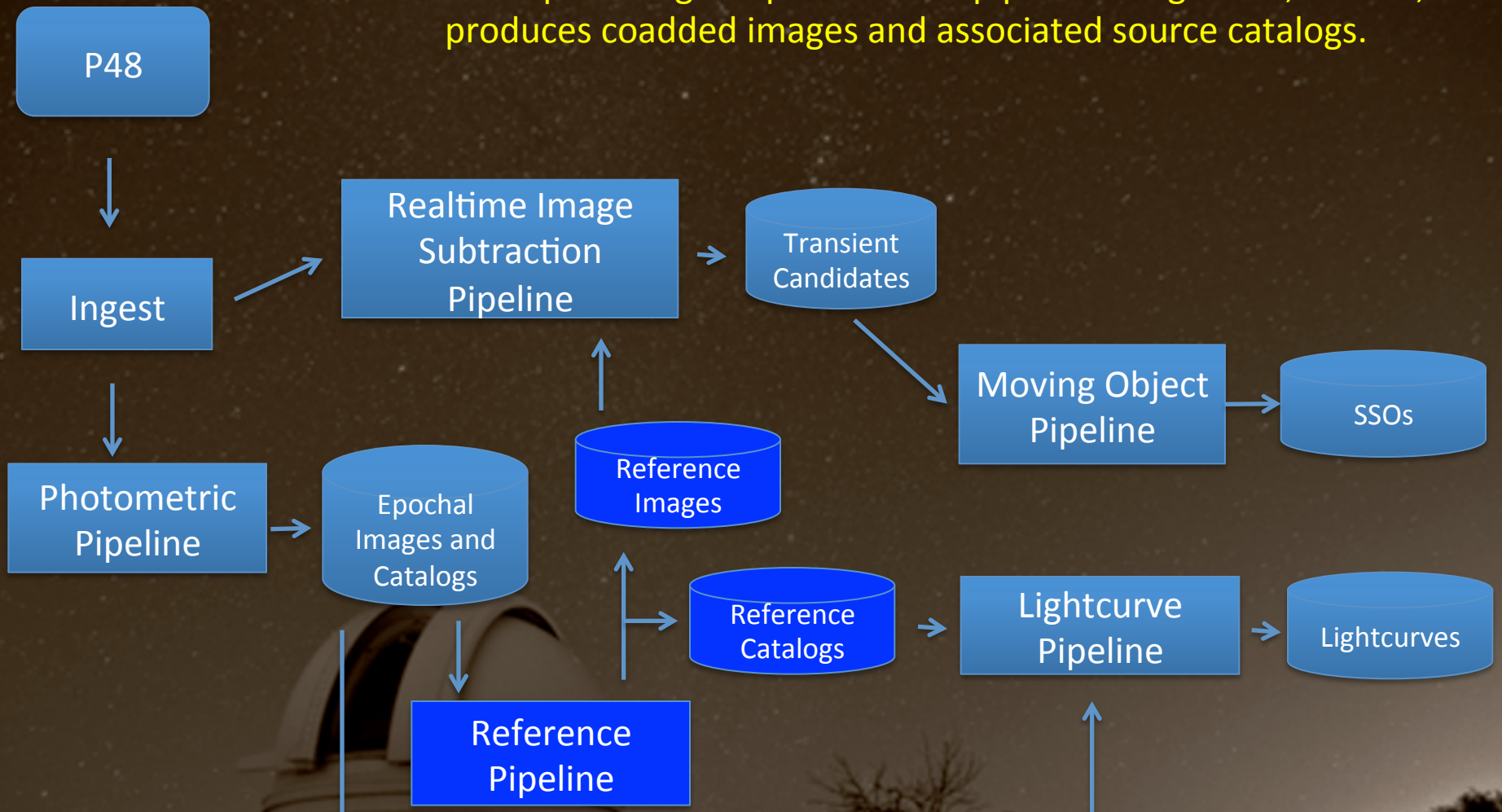
Description: ingests entire night's worth of data to derive photometric and astrometric calibration, outputs calibrated flux images, mask files, and aperture and psf-fit catalogs of all sources.



Timing Requirements:
Starts at end of night, must complete in 12 hours.

Products: 100GB/day image files, 20GB/day catalog files, no DB upload, but 10-30 million records per night to archive, 10B/yr.

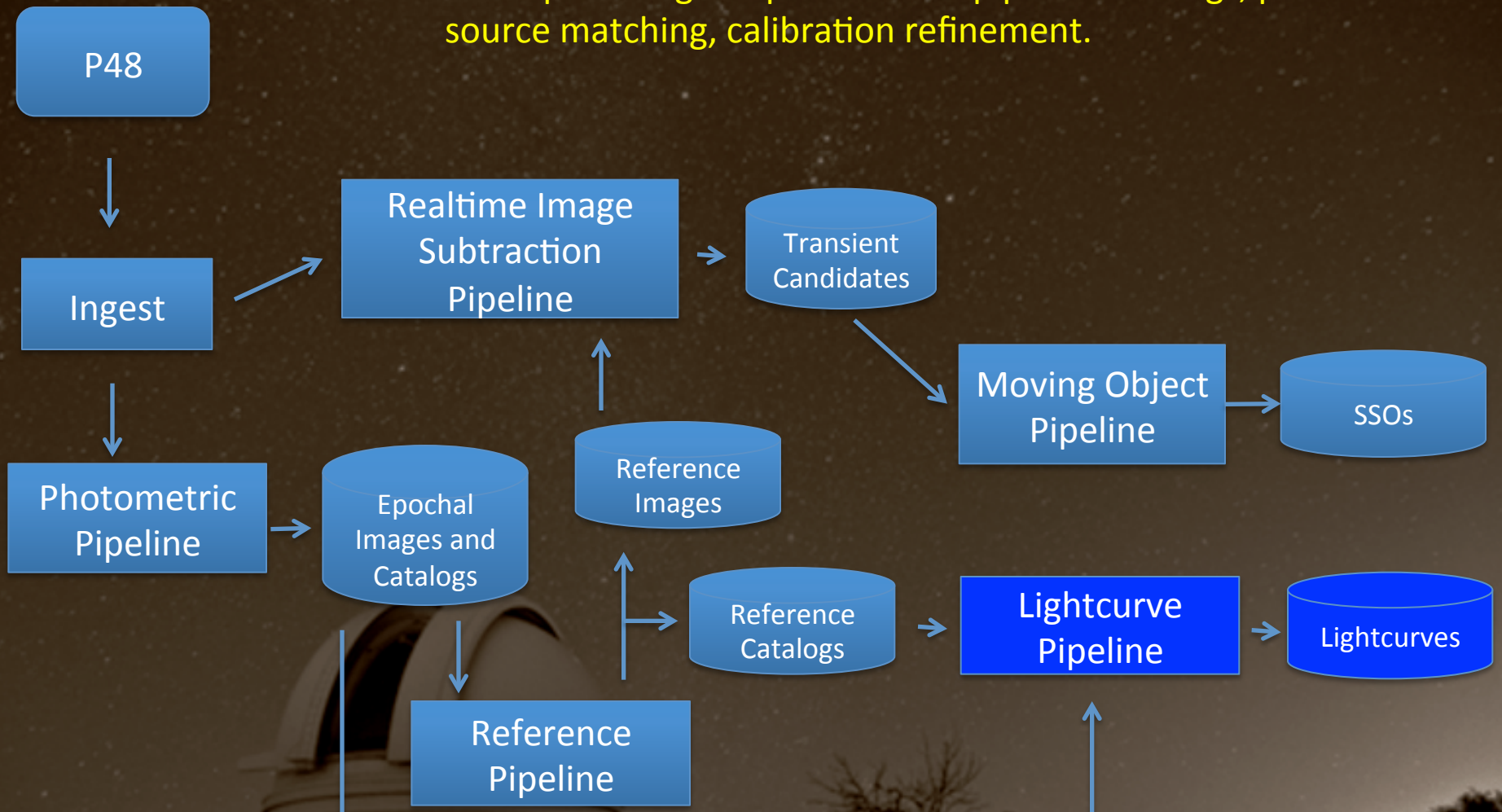
Description: ingests photometric pipeline image data, coadds, produces coadded images and associated source catalogs.



Timing Requirements: runs on-demand and infrequently, but must complete sky in less than 6 months.

Products: of order 300GBimage data for entire sky with current tiling scheme. 1B DB records.

Description: ingests photometric pipeline catalogs, performs source matching, calibration refinement.



Timing Requirements: source matching runs daily, relative photometry once a month.

Products: continuously accruing match files, 10-30M associations per night.

Archive and External Interfaces

- Primary image and catalog archive is through IRSA.
- GUI and API interfaces.
- IRSA receives nightly deliveries of image and catalog files, and sql load files for catalog data. Currently several hundred TB of file data, and 25B rows of catalog data.
- Process of transferring ownership and registering metadata typically incurs 1-3 day delay in appearance in archive.
- Realtime data is accessed via a specialized web server, containing API interfaces to query transient candidate tables, access image data.

PTF Software Architecture

- Mixture of community and in-house developed software, organized into “pipelines”, which are self-contained tasks.
- Pipelines are structured within PERL wrappers.
- Job control is managed through a central database.
- “Jobbers” running on pipeline drones poll the job control database for work.
- Heritage from previous IPAC missions.
- Pipelines work within local scratch disks, ship data upon completion to an intermediate shared disk pool called a “sandbox”.
- Archive process transfers sandboxed data to permanent archive storage.

PTF Operations Hardware

- Primary compute hardware consists of two banks of 12 drones each (24 total), running RHEL. Drones have 8/12 cores and 16/48GB of ram.
- One dedicated operations Sun/Solaris file server with Nexsan attached storage.
- One shared archive Sun/Solaris file server with Nexsan attached storage.
- Two dedicated operations DB servers. One primary and one user copy.
- One shared DB server for archive.
- Transfer computers.
- Operations web server.
- Various IPAC infrastructure (switches, firewall, etc).

Parallelization Quanta

- Massive parallelization is required for processing this sort of survey data.
- Parallelization is based on detector and spatial tiling on sky. This allows asynchronous processing.
- This is baked deep into the system architecture. Other surveys failed to use this approach, and crashed as a result.
- This improves image subtraction, light curve generation, etc, but is not conducive to absolute calibration.

PTF vs. ZTF Data Rates

- ZTF not only has more pixels, they come faster.
- ZTF focal plane has roughly 6.5x as many pixels as the functional PTF camera.
- However, the cadence has also increased from an achieved 110 second cadence with PTF to a planned 45 second cadence.
- Resulting change in data rate is a factor of 16.
- This is the single greatest challenge in adapting to ZTF.

Total Product Storage

- Note that the total storage requirement is different from nightly storage rate due to weather.
- Analysis of iPTF predicts 376 science exposures on average per night + 56 calibration exposures.
- Assume raw data is Rice compressed, processed images and masks gzipped or similar:
- Compressed Raw Data = 70TB/yr, compressed.
- Processed Image Data = 300TB/yr, compressed.

Need about 0.5PB/yr for minimum archive storage. Baseline funded operation is three years.

MSIP Proposed Architecture

- The data system portion of the MSIP proposal was based on a scaling of the existing PTF architecture.
- Existing PTF design was known to work.
- ZTF CCD readout quadrants (64 total) similar in size to a PTF CCD.
- ZTF system would replicate the PTF system into independent subunits based on detector, each of which has it's own servers and storage.
- Hardware requirements derived from direct scaling of existing system.
- This remains the fallback approach should we discover significant scaling problems – sharding by spatial sky and detector location.

Tractability Issues in Existing System

- Existing job management requires hands-on decisions regarding resource management. Non-optimal resource utilization, particularly CPU.
- Non-automated robustness to hardware failures, which are increasingly likely on a cluster this size.
- Difficulty in packaging new job types.
- Unnecessarily cumbersome deployment and configuration control for software and hardware.

Requirements & Capabilities

MSIP Proposal Requirements

- System is being designed to meet the operational requirements needed to make the NSF-mandated delivery schedule. This is commensurate with the supplied funding profile.

- Data ingest & Realtime Processing: 20 minute turnaround for scored transient candidates from receipt at IPAC.
- High-Fidelity Processing: up to 1000 science exposures completed within 12 hours
- Reference Image Processing: 40 thousand references in 6 months (full sky).
- Light Curves: new solutions on weekly timescales.

MSIP Proposal Requirements (2)

- All deliverables could be made with the iPTF system that will exist at the iPTF/ZTF handover, with the exception of the automated alerts. Additional capabilities are out of the funding and planning horizon through 2017.

- The existing PTF system is used heavily to run “ad hoc” jobs. These are primarily special or experimental processing to support in-collaboration science.

- The ZTF system will not preclude such jobs, but would require additional computing and personnel resources.

ZTF Data Systems Design

Steve Groom, Ben Rusholme,
Russ Laher, Jason Surace

outline

- Design approach
- PTF overview
- Evaluating PTF
- Major changes for ZTF
- ZTF design overview
- Status of subsystems

Design Approach for ZTF

- Overall idea has been to model ZTF after PTF
  - Extrapolate PTF system design to larger sizes and higher rates

- PTF data system is "working"
  - Data volume requirements are clear
  - Processing: pipeline algorithms implemented and working
  - Throughput is acceptable

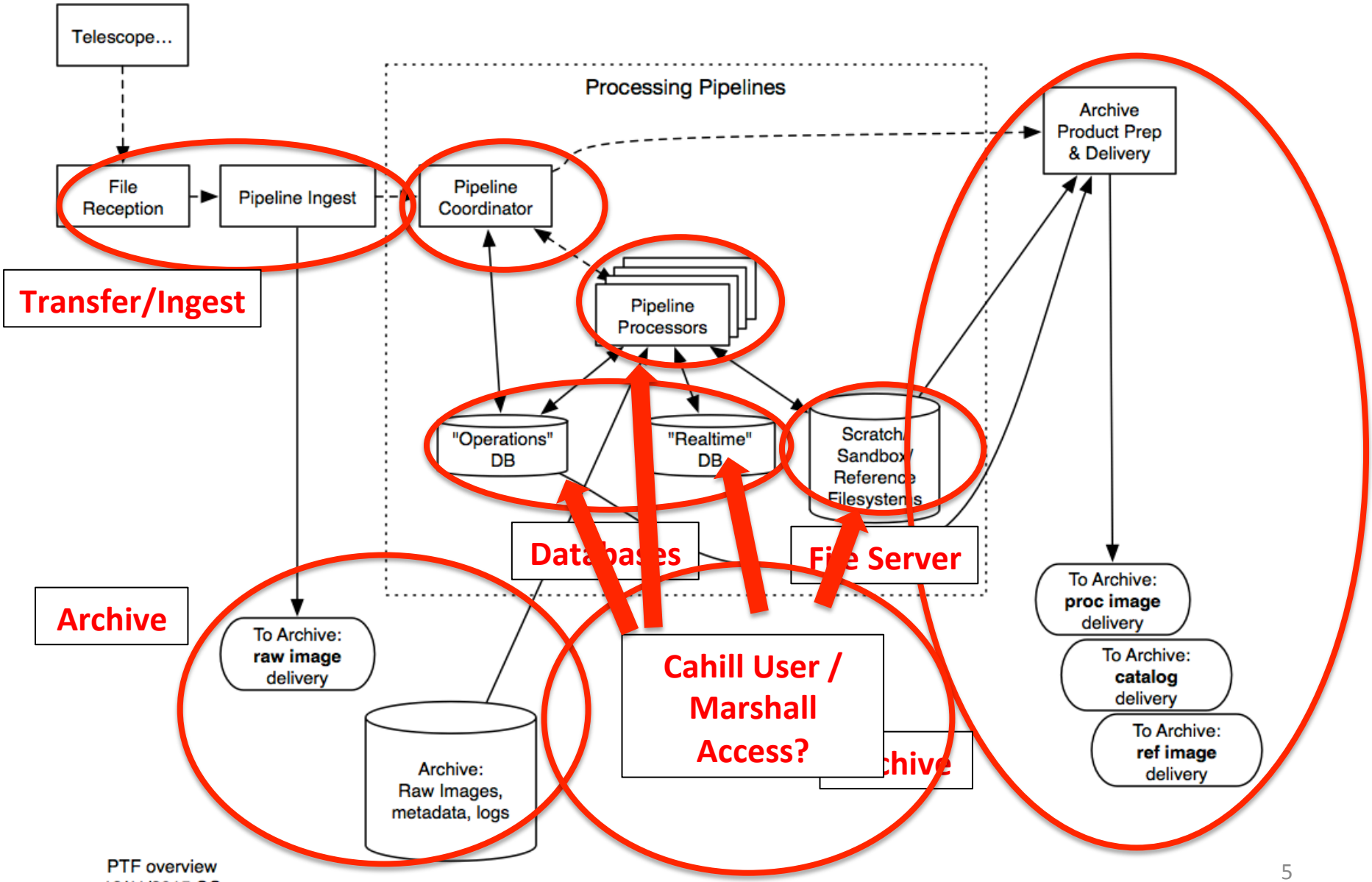
- HOWEVER: current system has not been carefully studied or tuned – overall behavior is not well understood
  - Data *movement* within the system not very clear
    - important since I/O is a major part of the picture, how to scale?
  - Database is a "black box"
    - PTF relies heavily on central DB, but we don't have a good sense of how well it is working
    - Can we scale "up" or "out"? Or ?
  - Much of PTF realtime data access (and the load that imposes on data systems) is unknown
    - Users/Marshalls tap directly into data system, with unmeasured impacts

Design Approach for ZTF (cont.)

- Challenge for design approach:
  - requirements-driven design difficult to do since we are missing important details about and won't have a complete set of requirements
  - Extrapolation difficult since we don't have a good sense of what will scale easily and what won't – don't know where stress points are in existing system

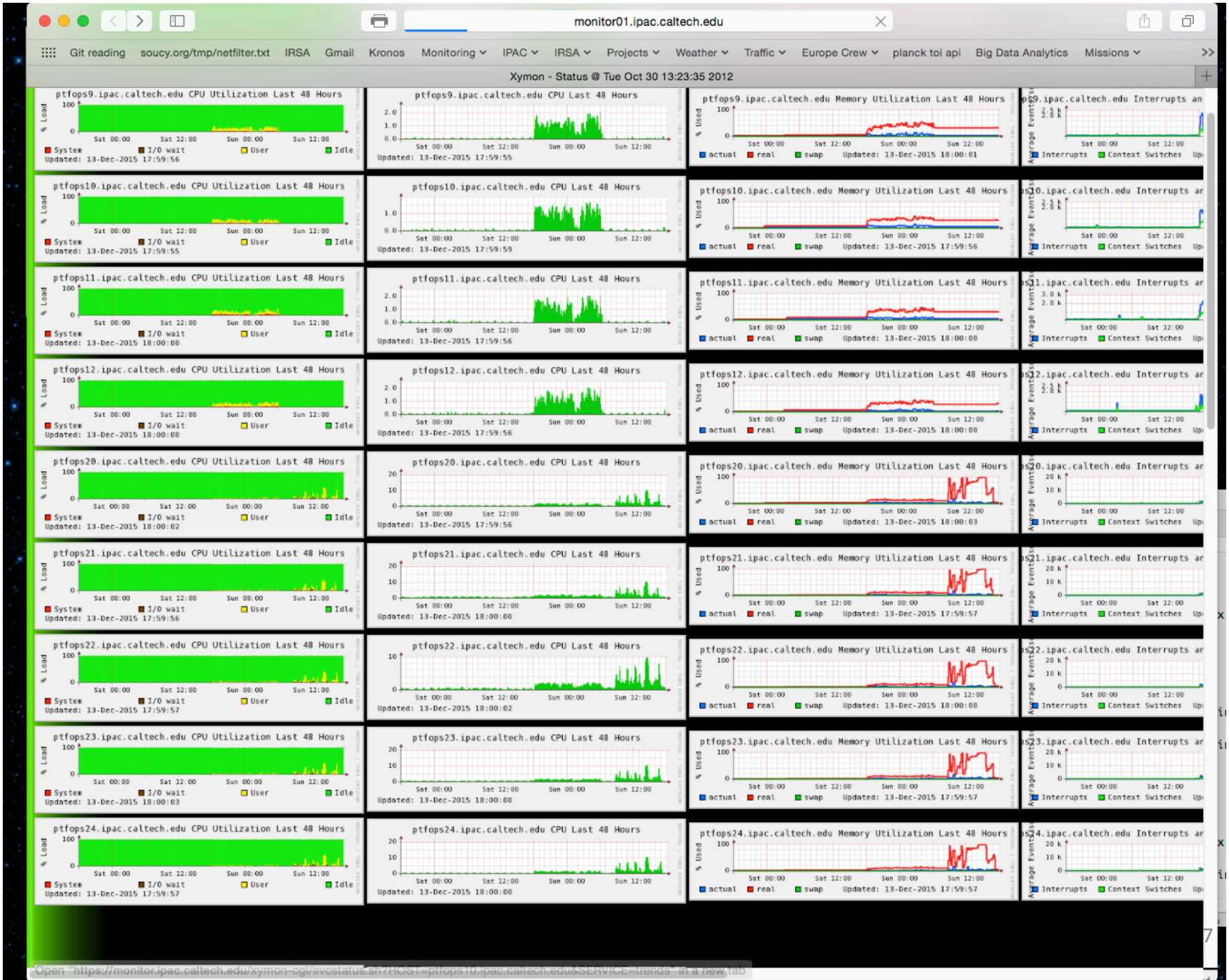
- **Result: a hybrid approach**
  - Review subsystems, assess scalability and efficiency
  - Extrapolate from PTF with some adjustments
  - Prototype and check progress against expectations

Data Flow Overview - PTF



Analyzing the current system

- Instrumenting the current system to review
  - Utilization: how hard is it working?
    - vs. capacity
    - vs. time
  - Activity: what is it doing and when?
  - Bottlenecks
    - What/where are current limitations
    - Impacts on scalability
  - Efficiency: how effectively are we utilizing what we already have?
- Identifying key areas requiring attention, and insights influencing overall design and operations
- Observations influence technology choices and guiding additional work to be done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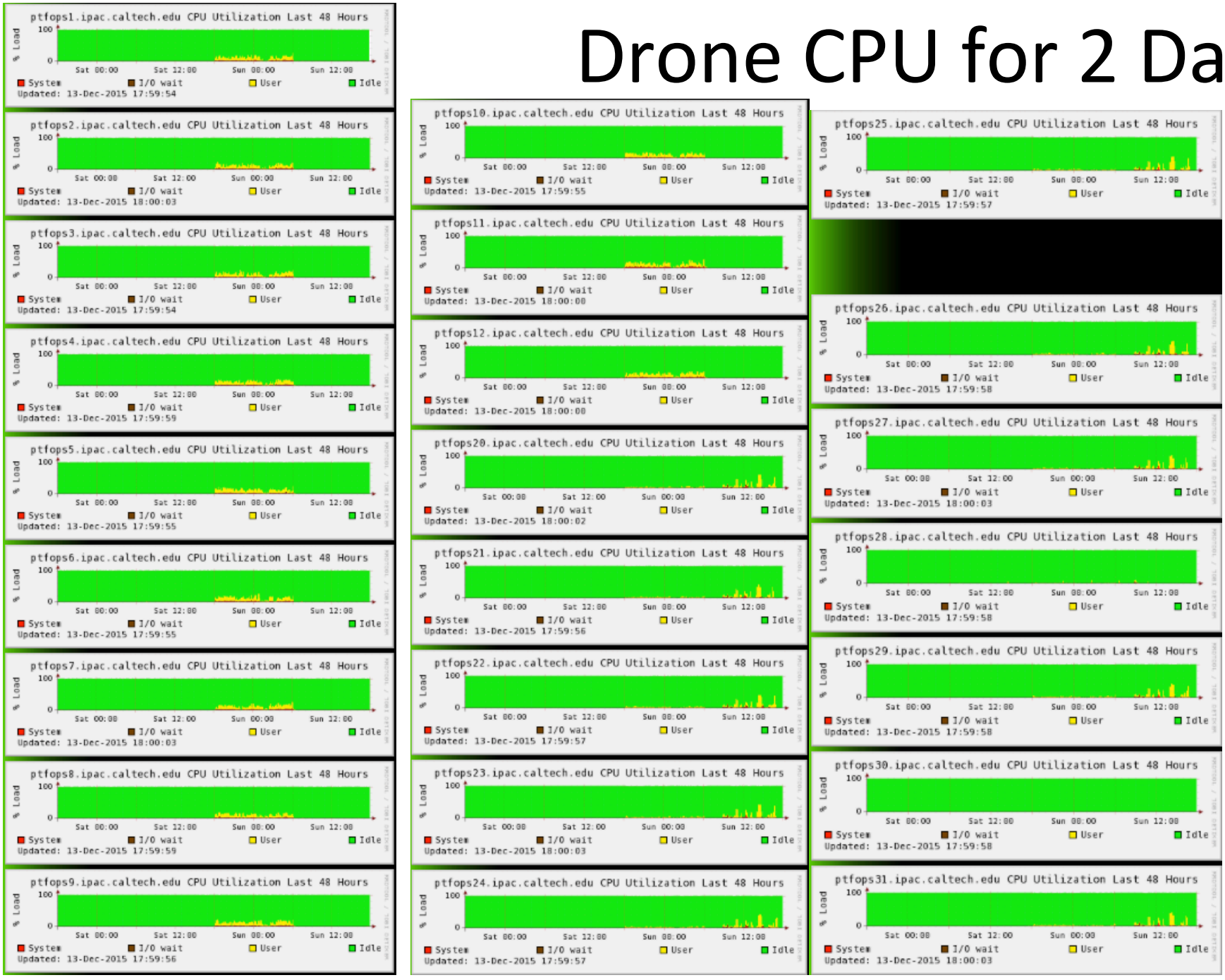
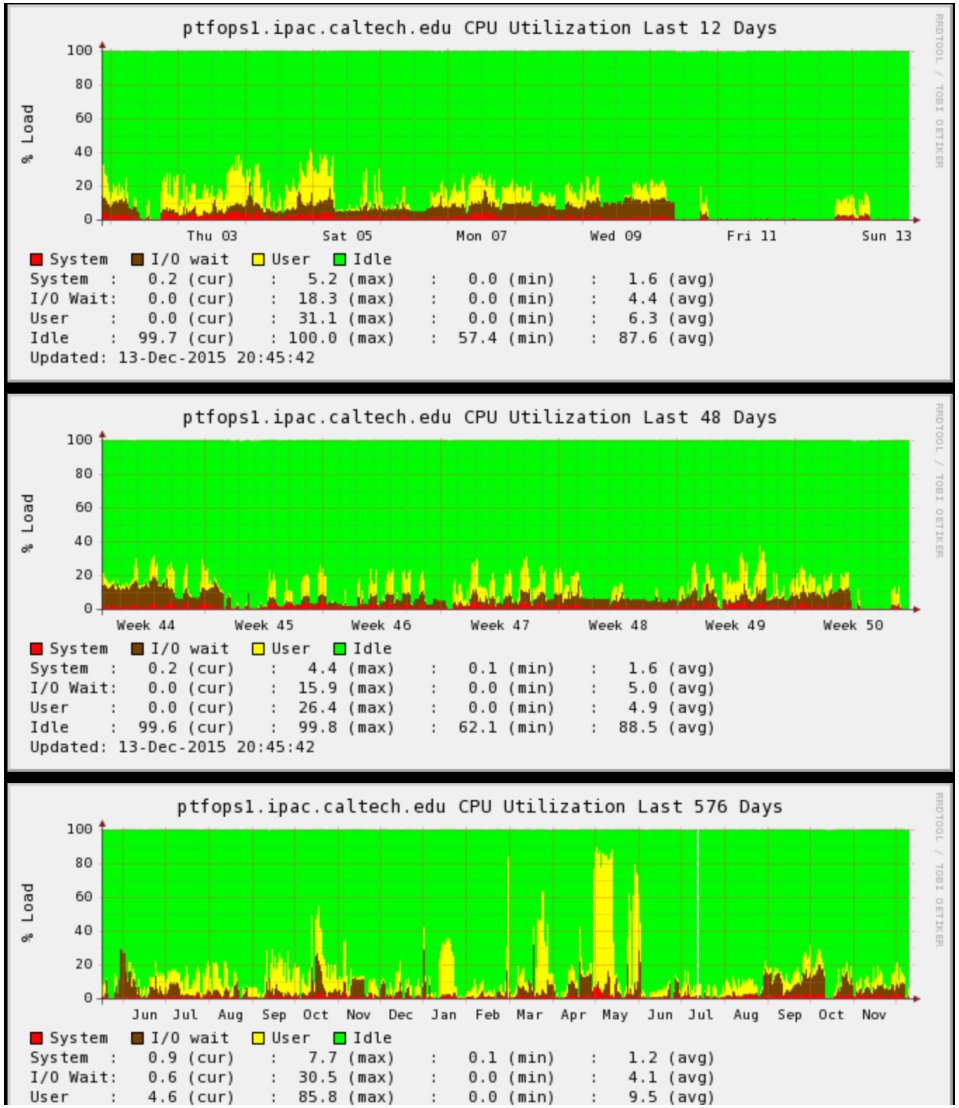
Drone CPU for 2 Days

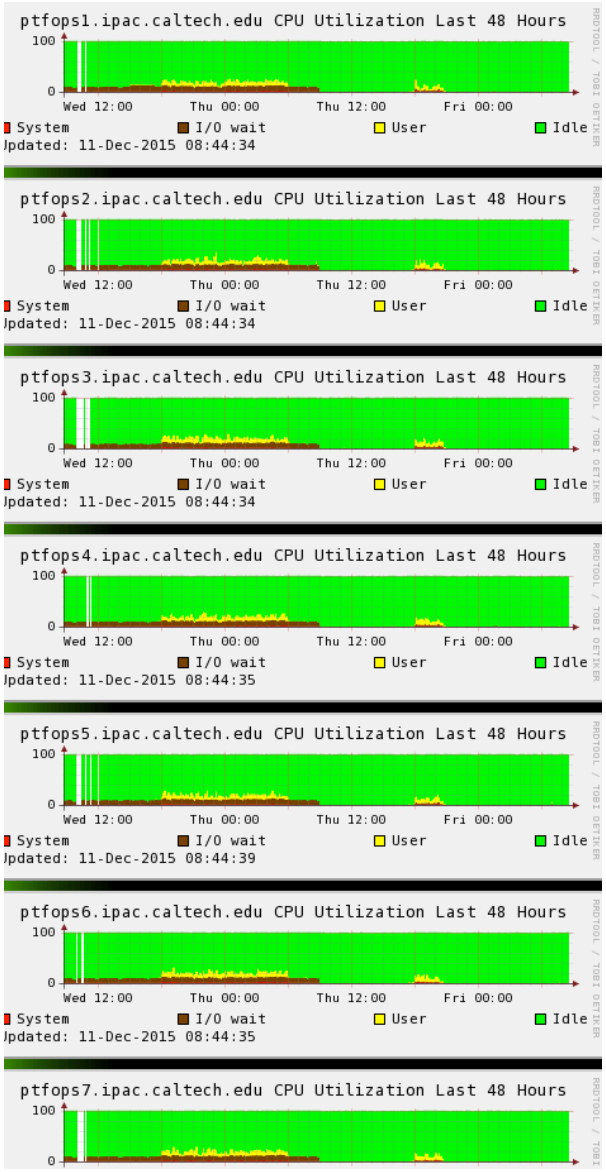


CPU history for one drone

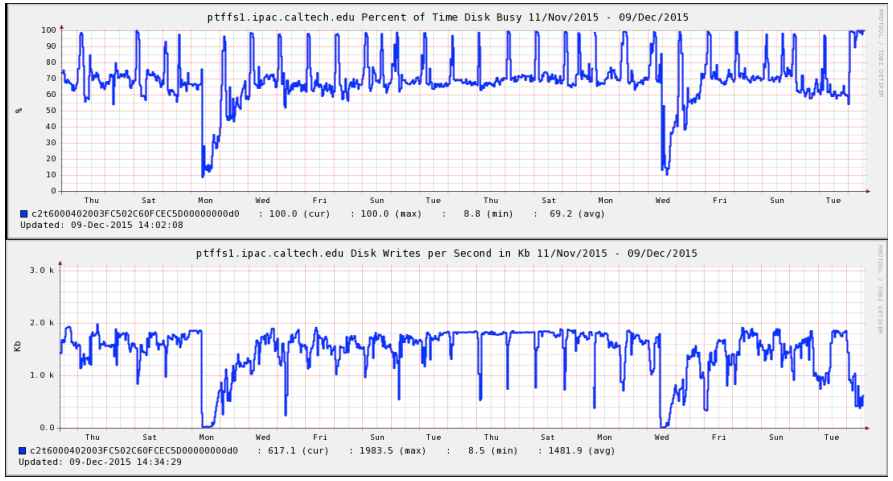
- Long term trends show high I/O overheads, low overall utilization
- Cause of overhead?
- Impact on scalability?



Case study: CPU I/O wait



- Why are drones showing so much time spent as “I/O wait”?
- What is causing certain some filesystems to be so heavily loaded?



%busy

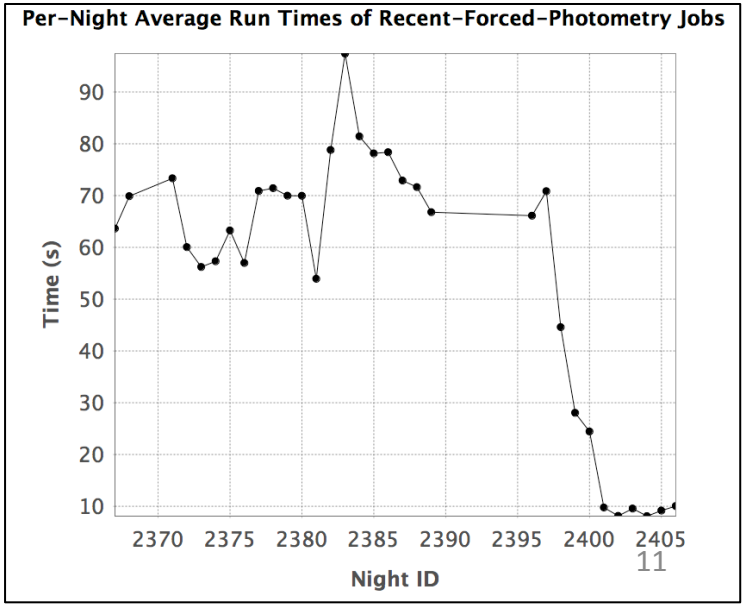
Write MB/sec

Case study: CPU I/O wait

- The find: excessive logging, combined with expensive NFS option, overloading server

- The result:
  - Python now loads 10x faster
  - RPF job runtimes
    - before: 70s
    - after: 10s

- Scalability predictions depend on understanding what the system is doing under the hood.



Observations

Resource utilization and operations practices

- Reduce I/O footprint of processing?
- localize I/O where possible
- explicit synchronization creating server spikes
- more parallelization and use of async processing to fill drone idle time, increase throughput
- software issues: logging, file locking
- background load due to server backups, RAID scrubs

High reliance on central services

- localize intermediate I/O
- single database used for everything, including job scheduling
- localize software installs

Technical performance bottlenecks

- underutilization of 10Gbit network
- excessive TCP retransmits
- server disk performance

Data Organization effects on I/O patterns

- segregate user areas from key data areas to isolate activity
- take data volatility into account, adjust caching and backup parameters
- mixing of permanent and temporary disk areas

Community Practices

- open access to key shared resources is not accounted for

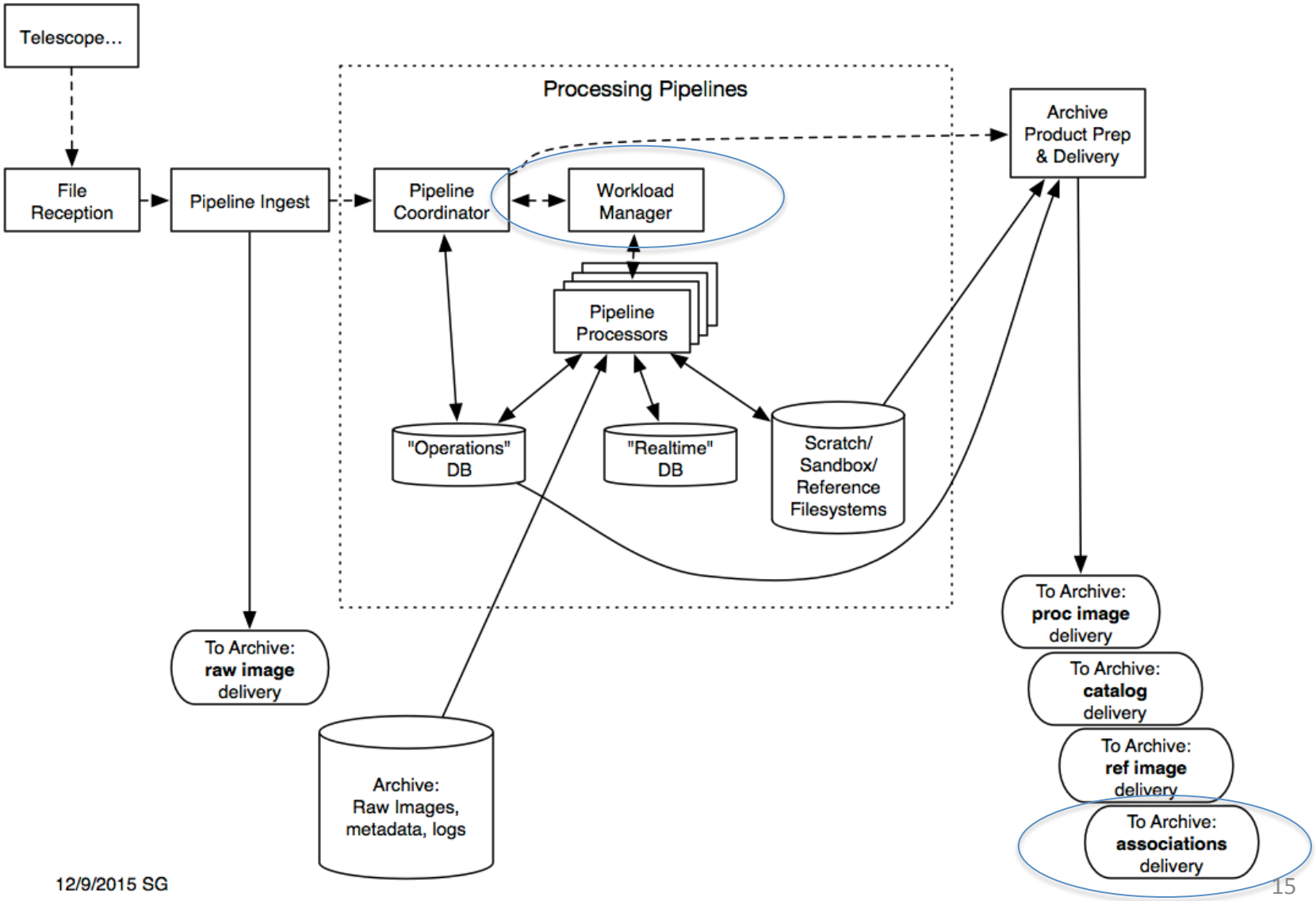
Significant changes for ZTF

- Dynamic job scheduling, use of open-source workload manger
- Careful organization of data layouts
- Tuning of software, and changes to reduce unnecessary data movement
- Basic scale-out approach for fileservers
- Database still TBD

Dynamic workload management

- Static job scheduling limits scalability
- Homegrown scheduler hard to tune
- Shift to dynamic job scheduling can improve utilization, help level resource spikes
- Open source solutions provide practical alternative
- Currently prototyping using SLURM
- More detailed illustration later

Data Flow Overview - ZTF



Subsystem status summaries

Subsystem: Transfer/Ingest

- Existing server needs simple upgrade
- Review & confirm network data rates
- Add 2nd network interface to separate internal & external traffic
- Should be OK

Subsystem: Raw Archive

- Raw data is ingested directly to archive disks
- No separate copy kept for pipeline access
- Pipeline processes read data from archive as needed
- Add interfaces based on drone scaling

Subsystem: Pipeline Coordinator

- Tracks frame completion status
- Submits processing tasks via Workload Manager

- Workload manager functionality to be split out
- Prototyping in progress

Subsystem: Workload Manager

- Manages work queue, dispatching jobs to worker nodes
- Implements priorities, enforces inter-job dependencies
- Implements tuning parameters e.g. number of running jobs per node

- Improved CPU: dynamic scheduling for better processor utilization, dynamic priority adjustment, flexible scheduling
- Improved I/O: Better load leveling helps reduce server spikes

- Prototyping in progress – discussion later

Subsystem: Processing nodes ("drones")

- Initial purchase being used for testing and prototype
- Developing prototype to test node scalability using dynamic scheduler
- Testing installation and management software

Subsystem: Databases

- Need to better understand load patterns here
- Updated server and storage hardware
- Same PostgreSQL software
- Probably need to partition data somehow across multiple servers
  - spatial? (sharding by sky region)
  - By data type? E.g. “operations” vs “realtime” db’s
- May need to restrict user access, or implement replication to support live users

Subsystem: Fileservers

- Solaris servers stable, but 10gbit enet performance has been disappointing
- Closely examining server activity
- Examining data organization, remapping content based on activity
- Should be easy to scale by spreading data across multiple servers
- Prototyping ZFS-on-Linux solution

Subsystem: networking

- Look at dividing drones into multiple networks, or other technique to utilize multiple NIC's at server
- Instrumentation of server network usage for further analysis

Archiving of processed products

- Keeping existing model
- Need to work out handoff of associations data

Access to data and processing resources by Cahill users/marshalls

- **Topic for discussion**

Summary

- Proceeding with examination of subsystems
- Applying tuning to PTF as issues identified
- Prototyping workload manager and new drone configurations
- Database organization will be key in scaling/ sizing approach
- Improving flexibility to deal with unexpected usage patterns

New ZTF Hardware/SLURM

Ben Rusholme

ZTF Data Systems Review

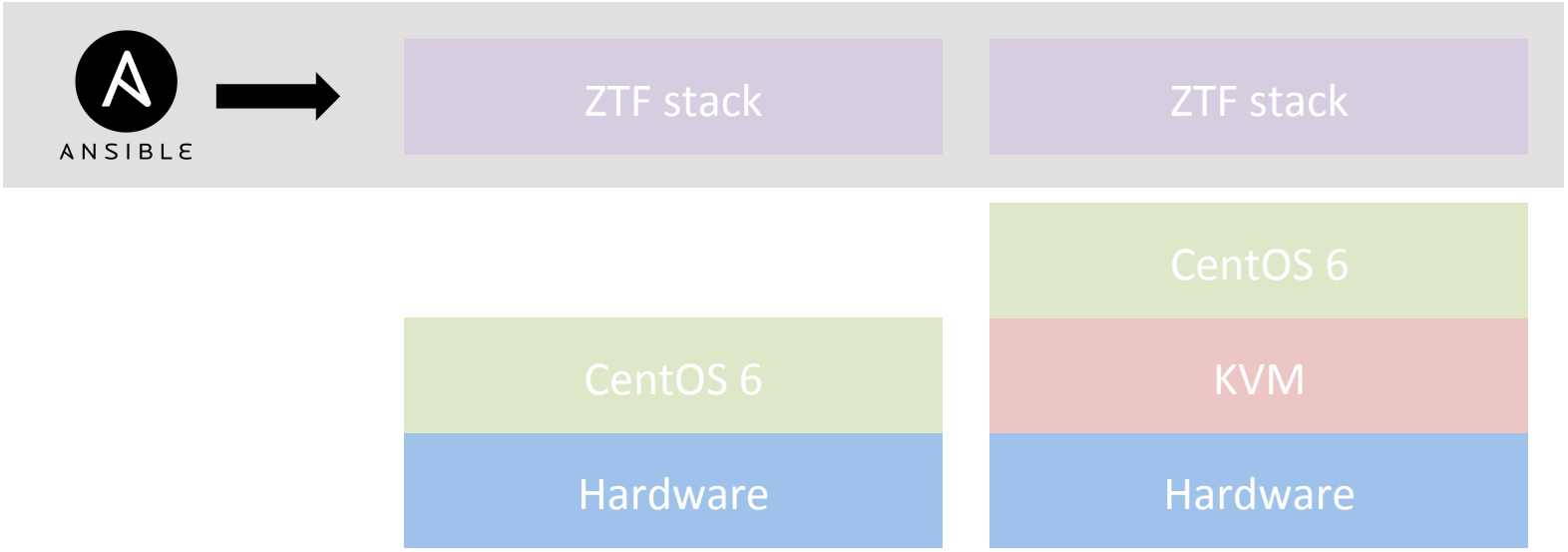
14th December 2015

Status

- 32 nodes delivered, racked, burnt-in
- Currently testing subset of 5
- CentOS 6
- Evaluating both Bare Metal & KVM
- Selected SLURM as job/resource manager
  - Throughput
  - cGroup isolation
  - Flexibility of srun intra-job
  - No MOAB scheduler license required

Project Boundary

- Provisioning/networking handled by ISG
- Project-specific configuration via Ansible
- Developed using Vagrant & Github

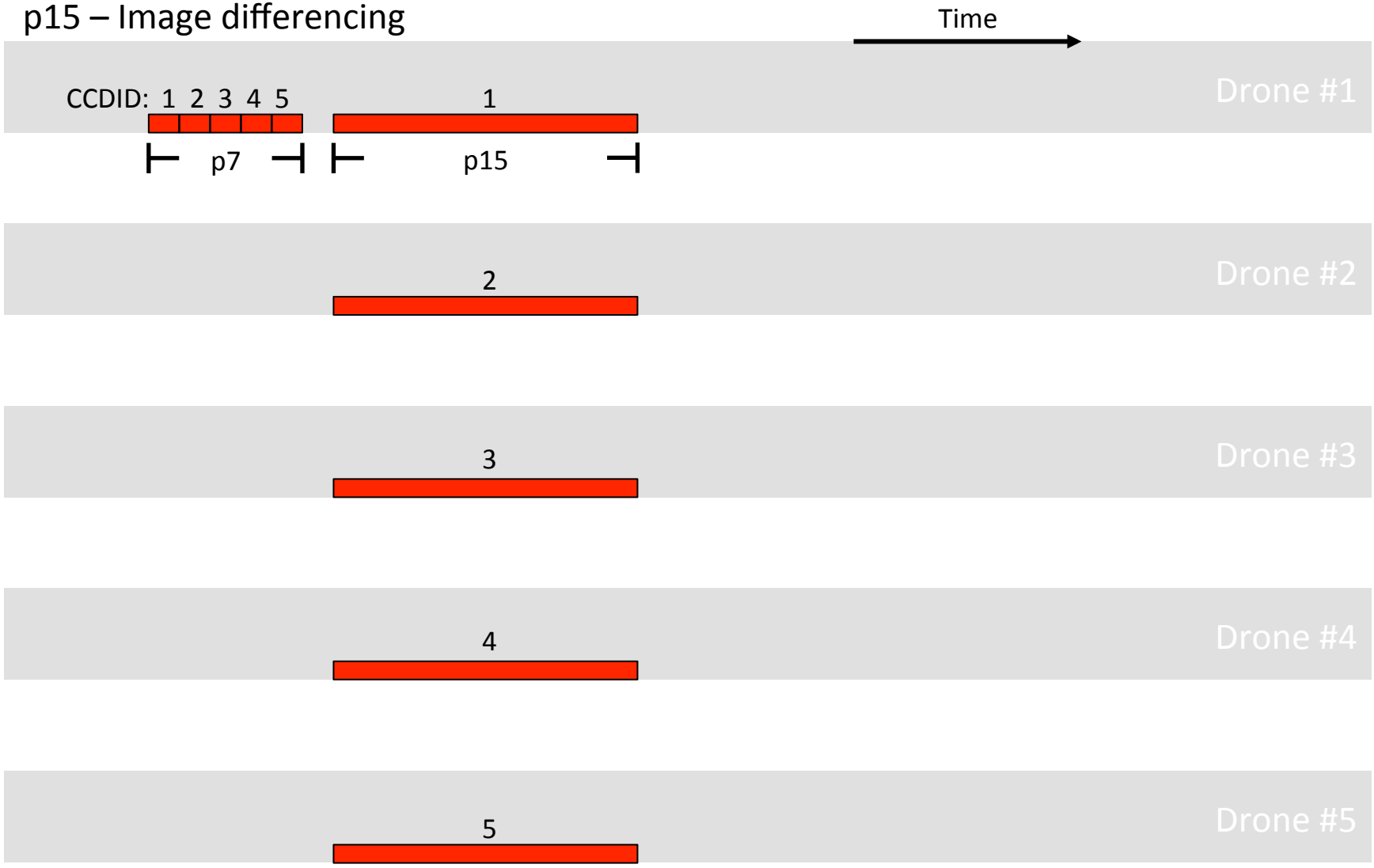


Using SLURM

- Breaking PTF mapping of CCDID to drone#
- Advantages:
  - Location agnostic code
  - Hand-off scheduling, dependencies, node-cleanup
  - Bypass node failures
  - Flexibility in allocating resources (to achieve latency)
  - Reorganize to:
    - Maximize data locality
    - Minimize NFS transfers

PTF Nightly Pipeline

p7 – Ingest (split into CCDS, astrometric correction)
p15 – Image differencing



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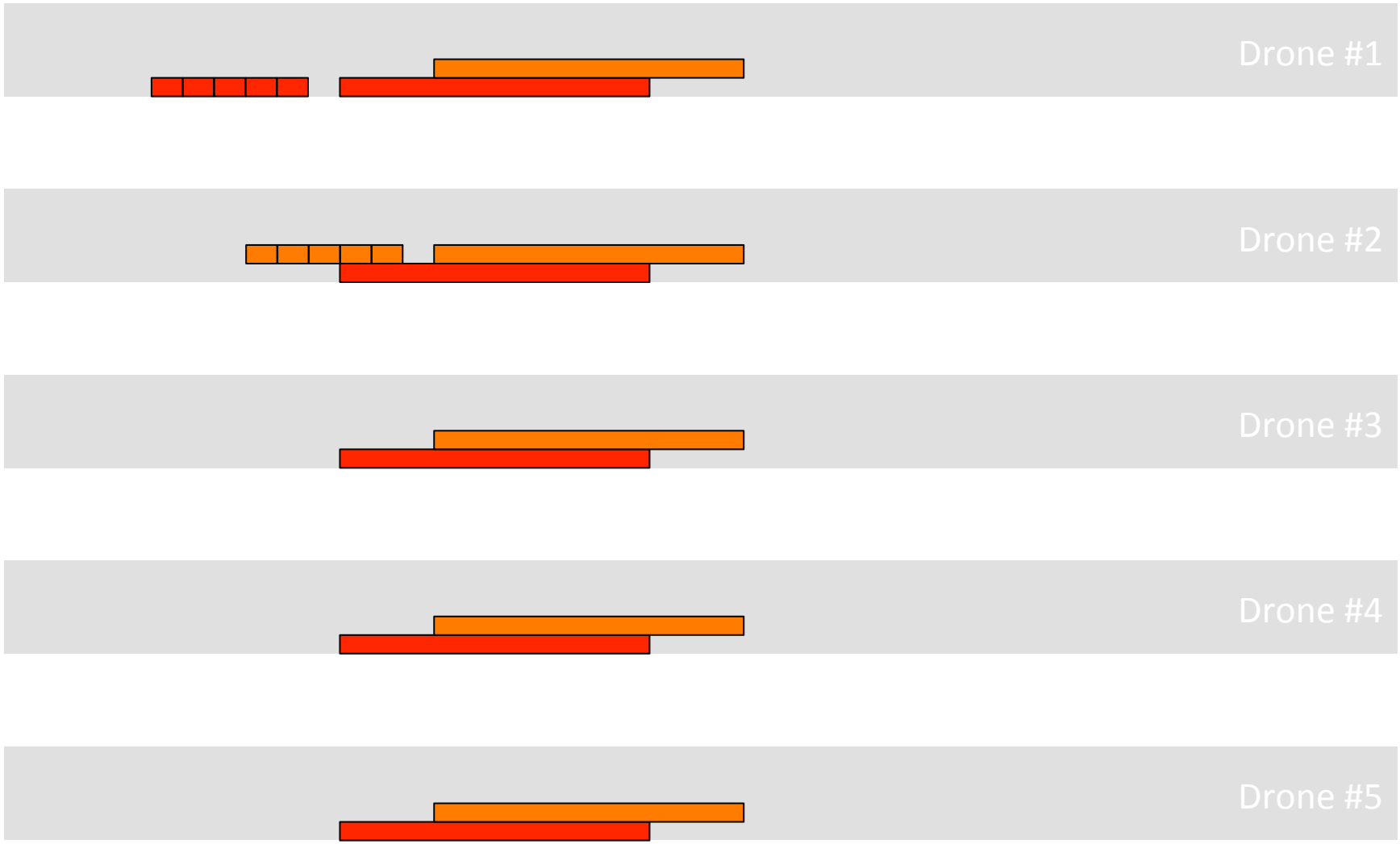

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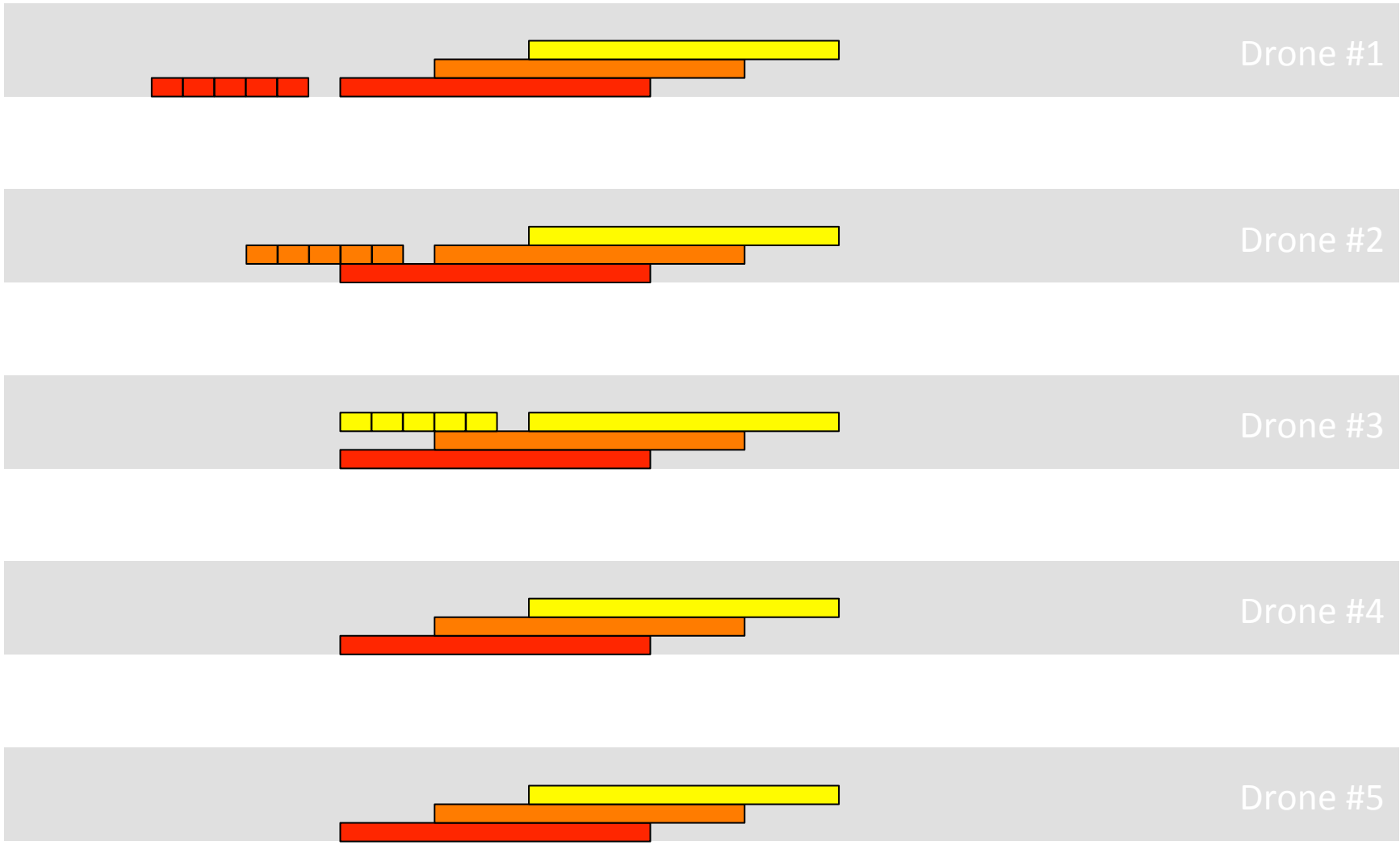

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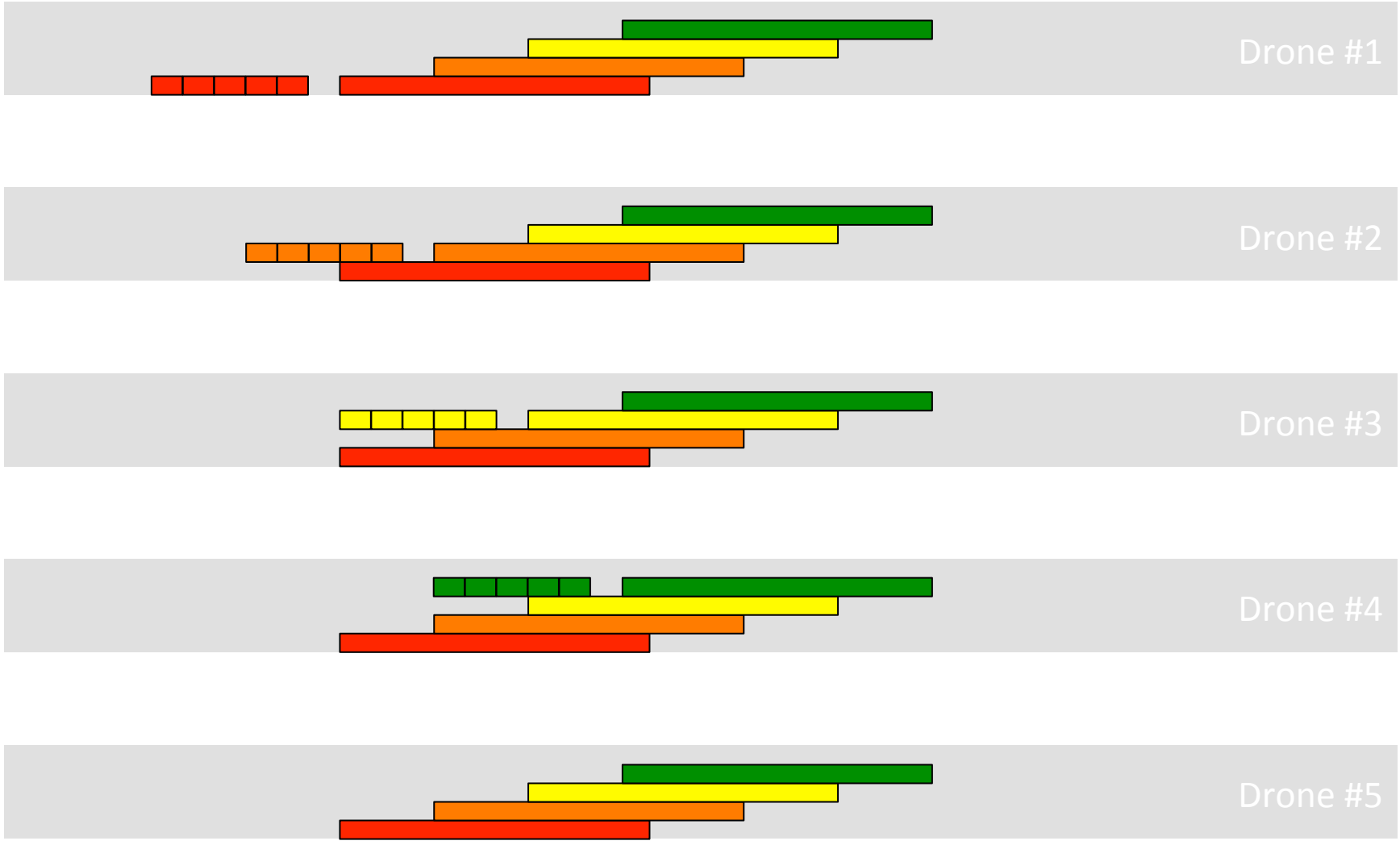

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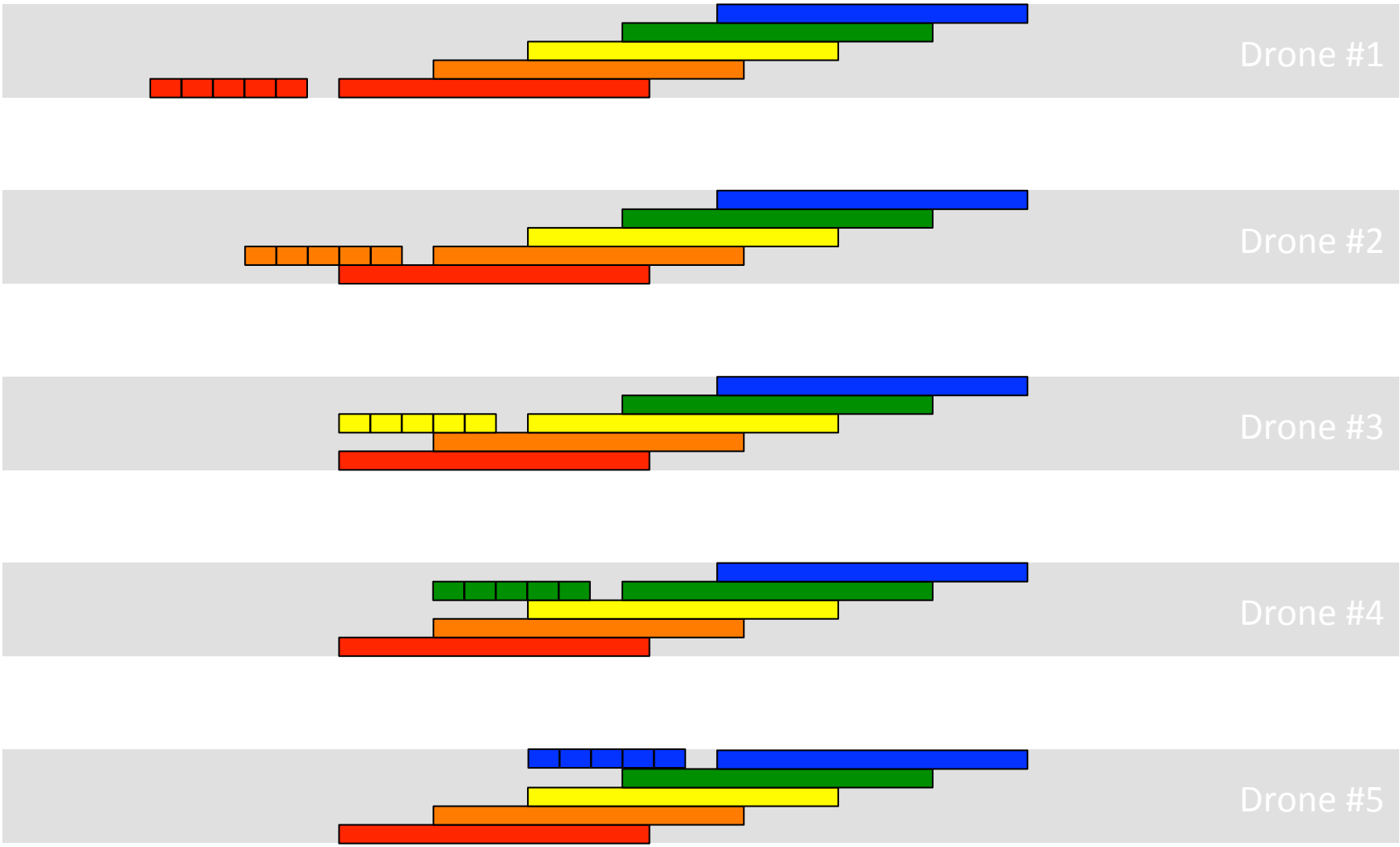

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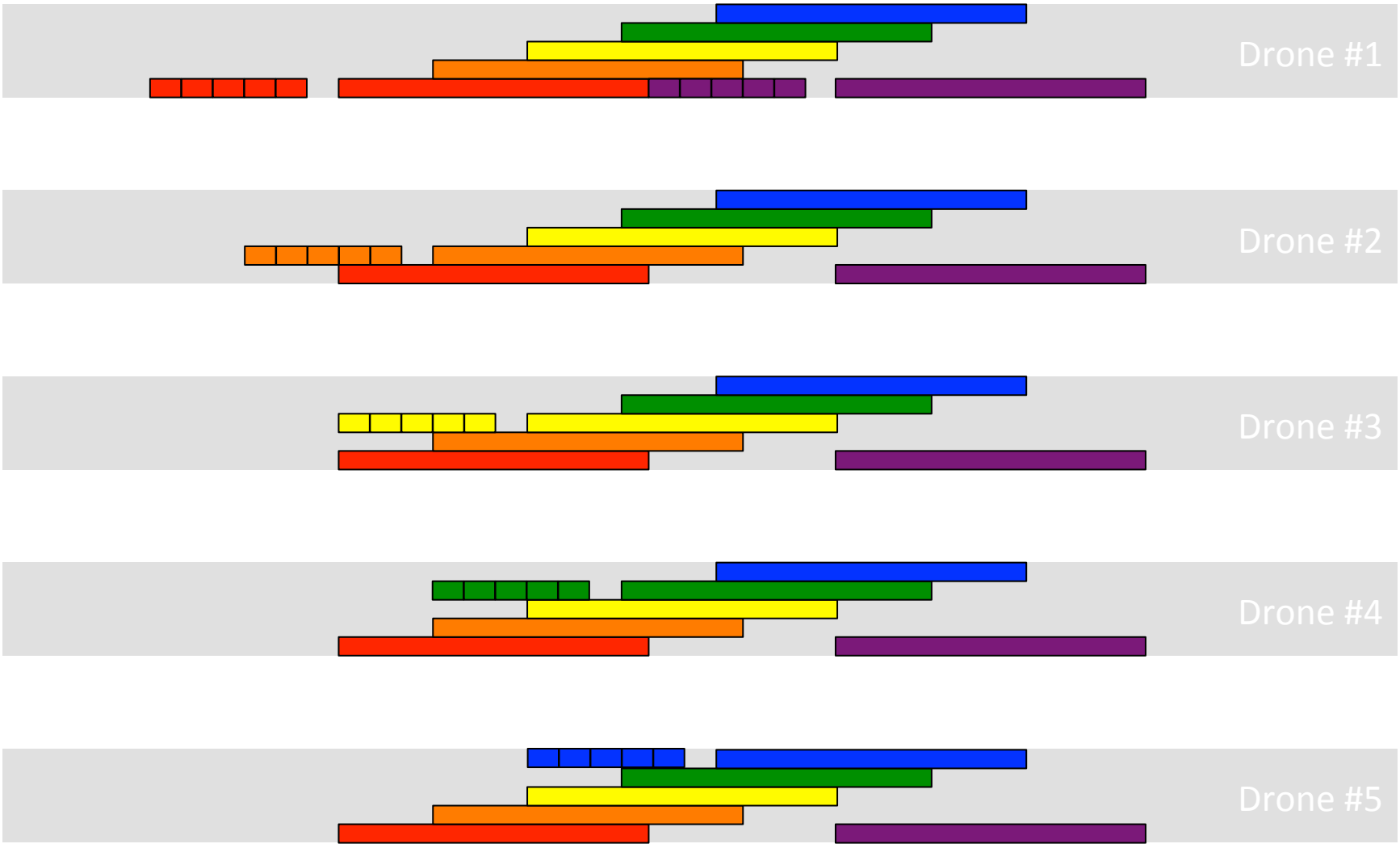
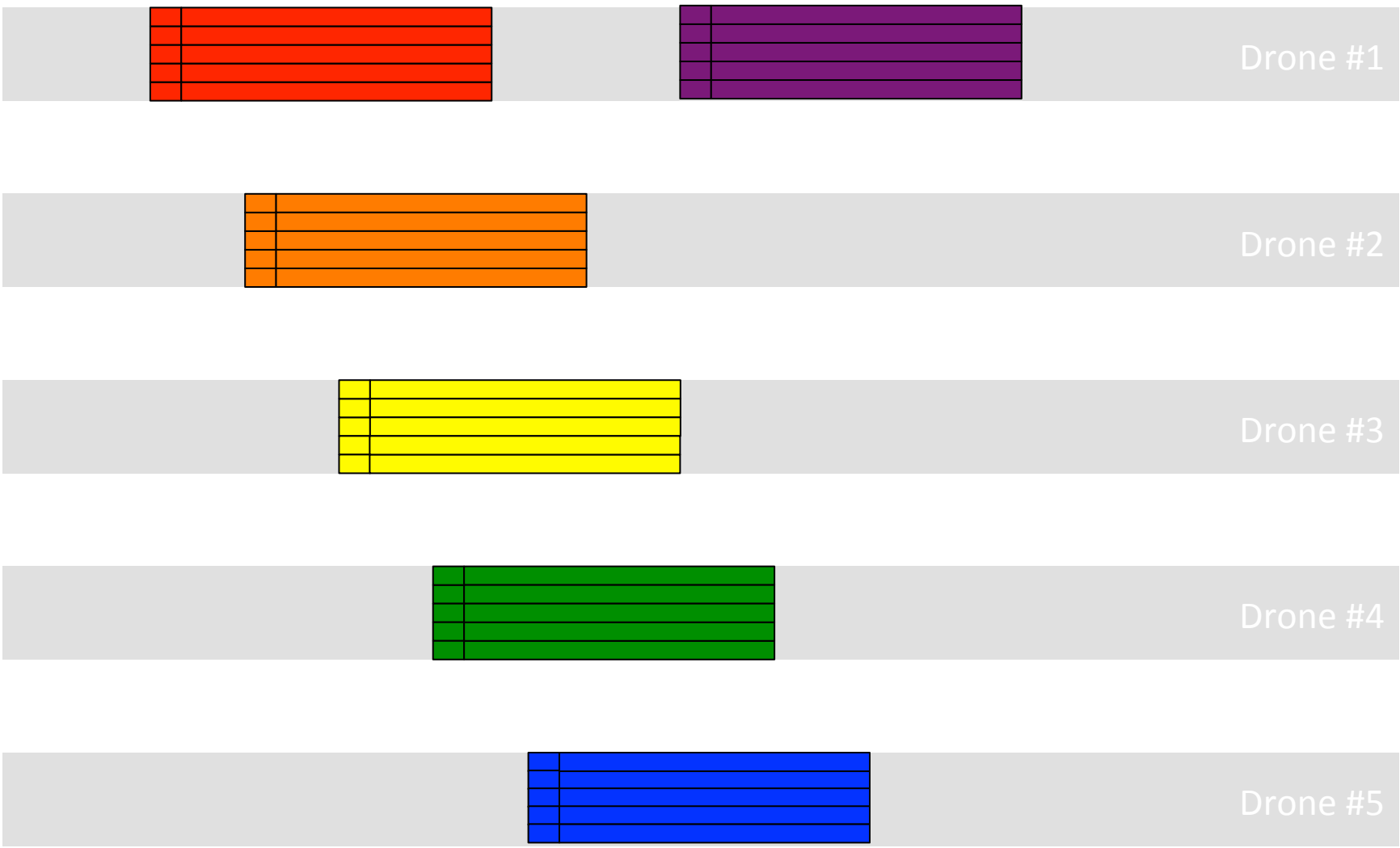
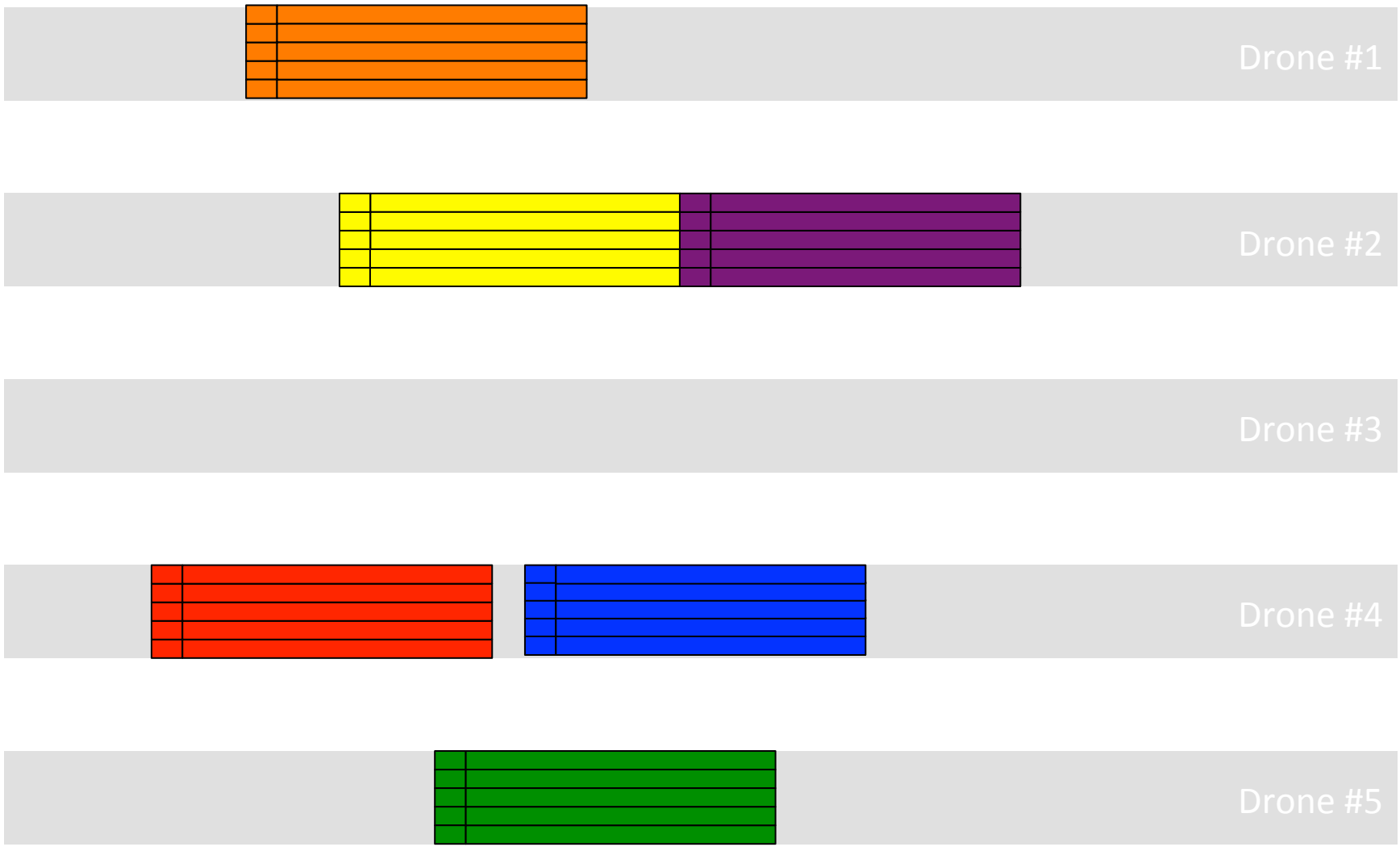


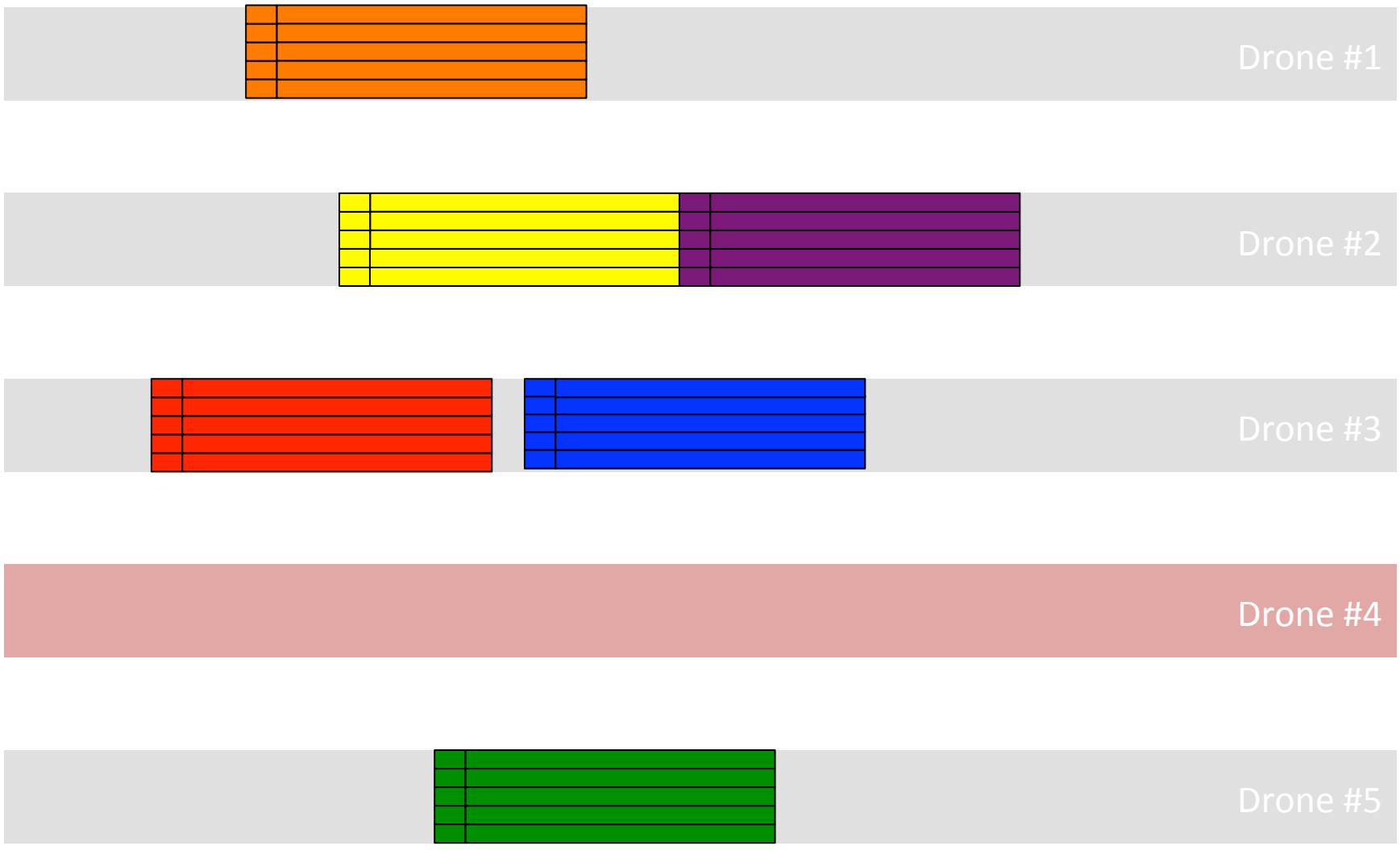
ZTF Proposed Layout



ZTF Proposed Layout



ZTF Proposed Layout



Performance Testing

p7, on PTF 2nd level hardware (8 cores), single test night

- October: 10 CCDs serial: 494s
  1 CCD: 47s
  8 CCDs parallel: 50s

- December: 10 CCDs serial: 154s
  8 CCDs parallel: 15.2s

Deployment Schedule Deliverables

Jason Surace

IPAC/Caltech

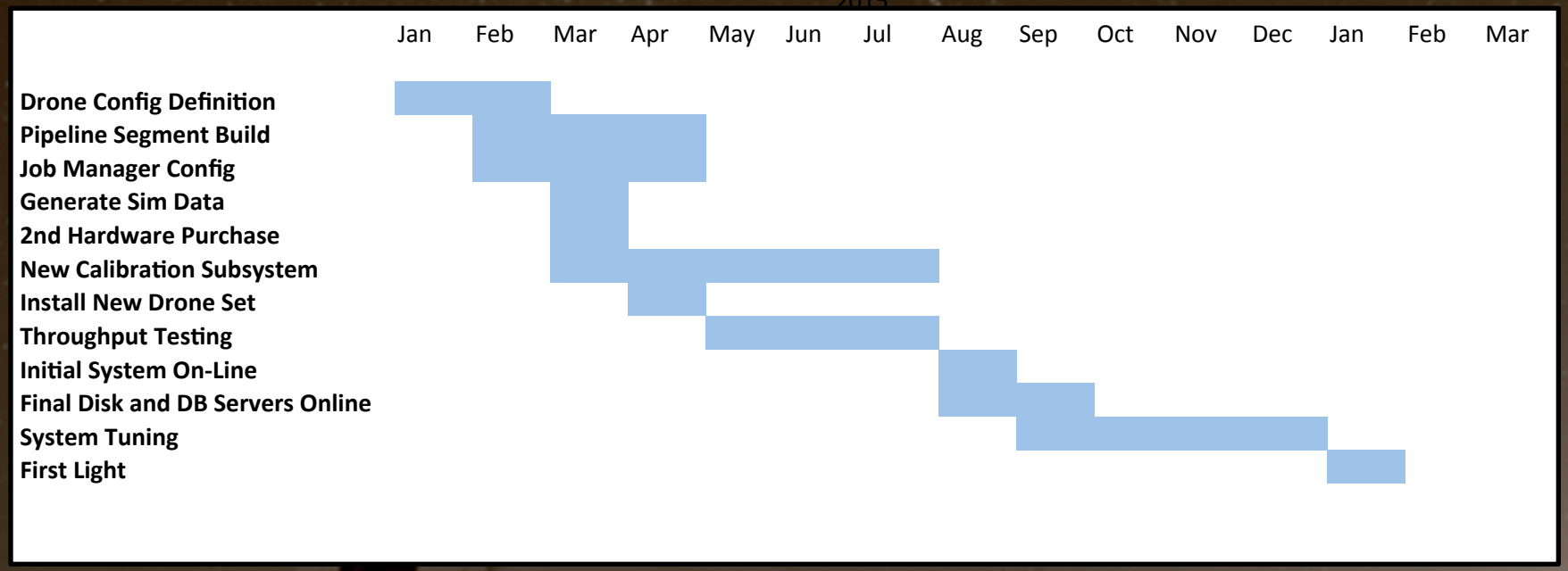
NSF-MSIP Deliverables

Year 1 (8/15) – first public data release of PTF image and catalog file data (epochal and coadded) over entire sky.
Year 2 (8/16) – release of light curve interface, as well as rolling release of iPTF image and catalog data.
Year 3 (first light + 1 yr) – release of ZTF references, catalogs, and light curves.
Year 4 – release of transient alerts and switch to semester-wise release of all other products.
Year 5 – same as year 4, but include near-realtime release of transient candidates.

Phased Hardware/Software Deployment

- Partially decoupling the software and hardware deployment to allow them to be developed in parallel.
- Initial purchase included 32 drones as well as network switches.
- Drones are currently online as a mixture of VMs and bare metal units for testing purposes.
- A temporary file and database server have been deployed to enable pipeline functionality.
- Currently testing the software deployment/build/ maintenance system, as well as the job management system.
- Under “smarter architecture” considering tradeoffs between drones and server capabilities. Will conclude this exercise in time for end of Q1 CY2016 purchases.

Deployment Schedule Overview



Deployment Schedule
Key Dates

- Hardware Procurement
  - 2/17 final decisions on content
  - 3/01 place orders
  - 3/21 – 4/22 installation and set-up

- Throughput testing – 3 phases across the summer
  - 6/6, 7/19, 8/23 (TBD)

- Full system available: 9/8
  - We do not plan to slip this schedule if first light is delayed