The decision to implement the WFIRST mission will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for information purposes only.

The WFIRST Coronagraph Instrument

# Photon Counting EMCCD Developments for the WFIRST Coronagraph

Patrick Morrissey, Camera Lead, JPL Flight Instrument Detectors and Camera Systems



Jet Propulsion Laboratory
California Institute of Technology

# WFIRST Coronagraph Camera Team

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# Outline

- Coronograph Overview
- Coronagraph Requirements
- Introduction to the EMCCD
- Radiation Test Program
- Simulations
- Technology Development Program
- Summary

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- WFIRST is the Wide Field Infrared Survey Telescope, a major new NASA observatory set to fly in the mid 20s. Its prime science mission is to study supernovae and gravitational (weak and micro) lensing
- WFIRST will also fly a Coronagraph Instrument designed to make direct images and spectra of planets around nearby stars
- The coronagraph is a *technology demonstration mission* that will showcase precision pointing, active wavefront control, and optical photon counting detectors in space for the first time.

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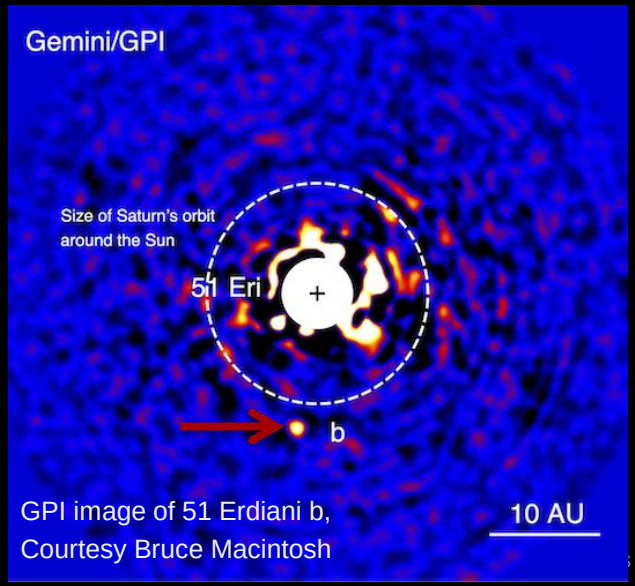
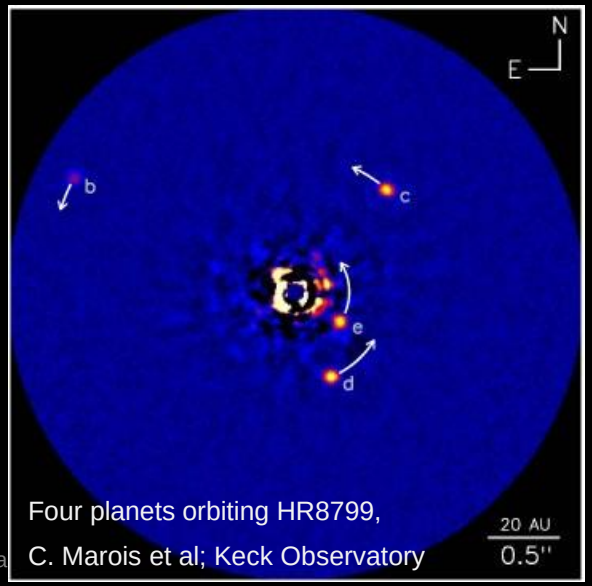
DARE MIGHTY THINGS



GPI image of 51 Erdiani b, Courtesy Bruce Macintosh

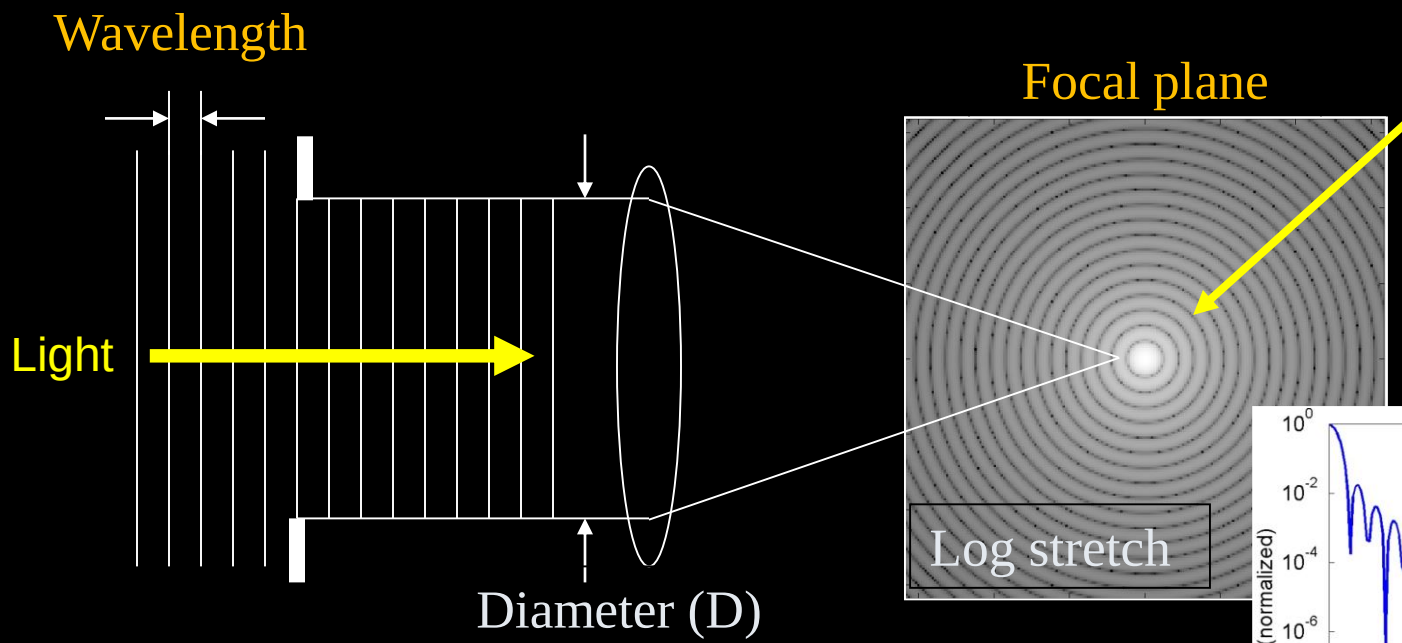


Four planets orbiting HR8799, C. Marois et al; Keck Observatory

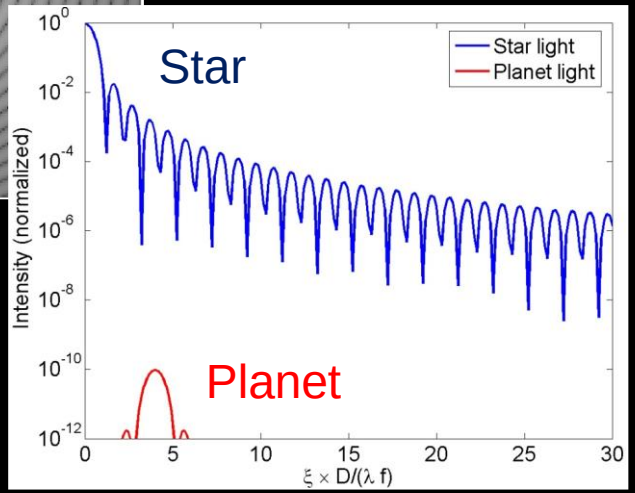
The exciting field of exoplanet discovery and characterization is successfully identifying many new planetary systems. Most are too far to be directly imaged. The few that have been directly imaged from the ground contain large, self-luminous planets.

The WFIRST CGI will demonstrate technology necessary to detect planets that are similar to the ones in our own solar system.

# Diffraction



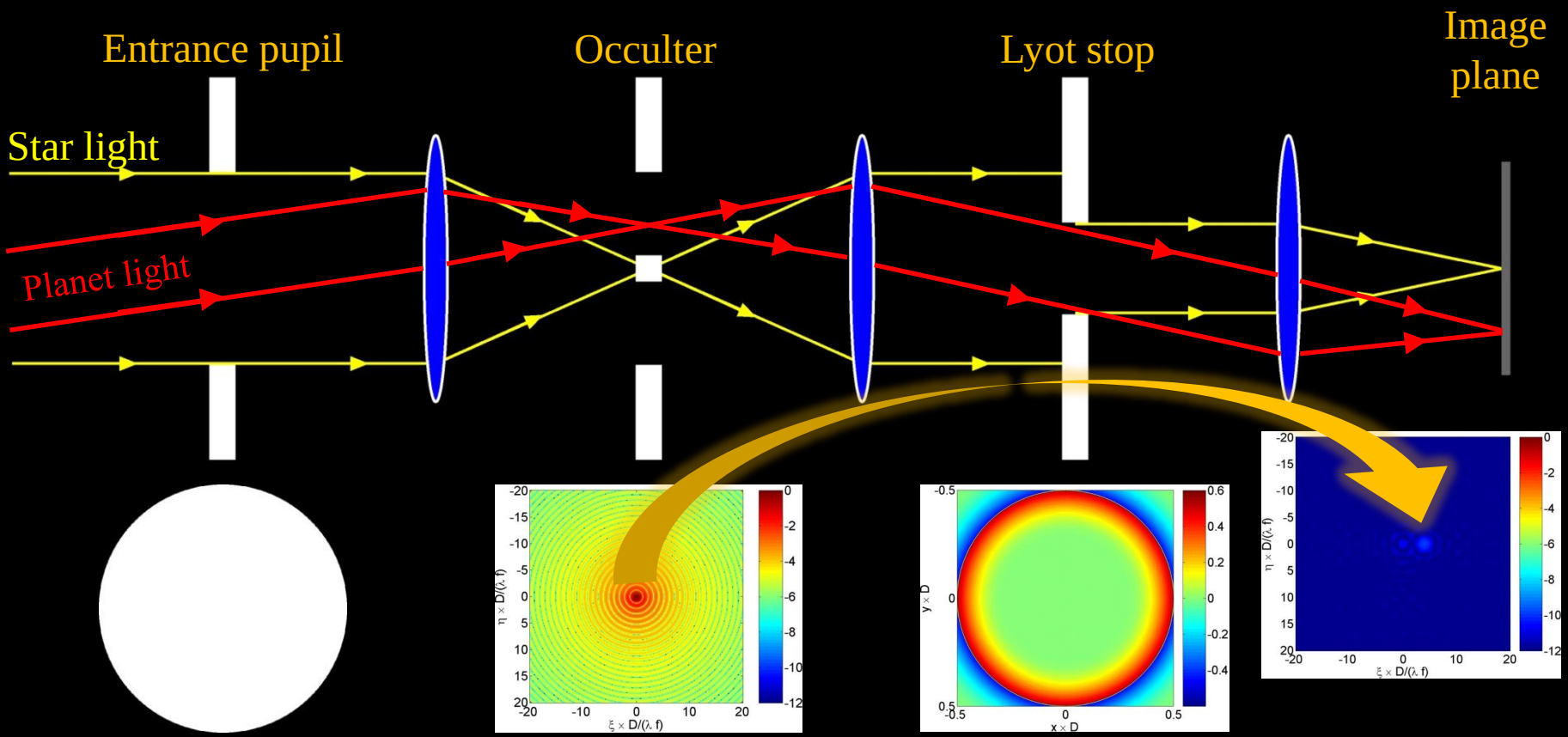

**The planet is hidden in here, and would be over a million times dimmer)**




Diffraction is a big problem for direct exoplanet detection.

- Bigger telescopes help
- Coronagraphs suppress the diffraction

# The Lyot Coronagraph



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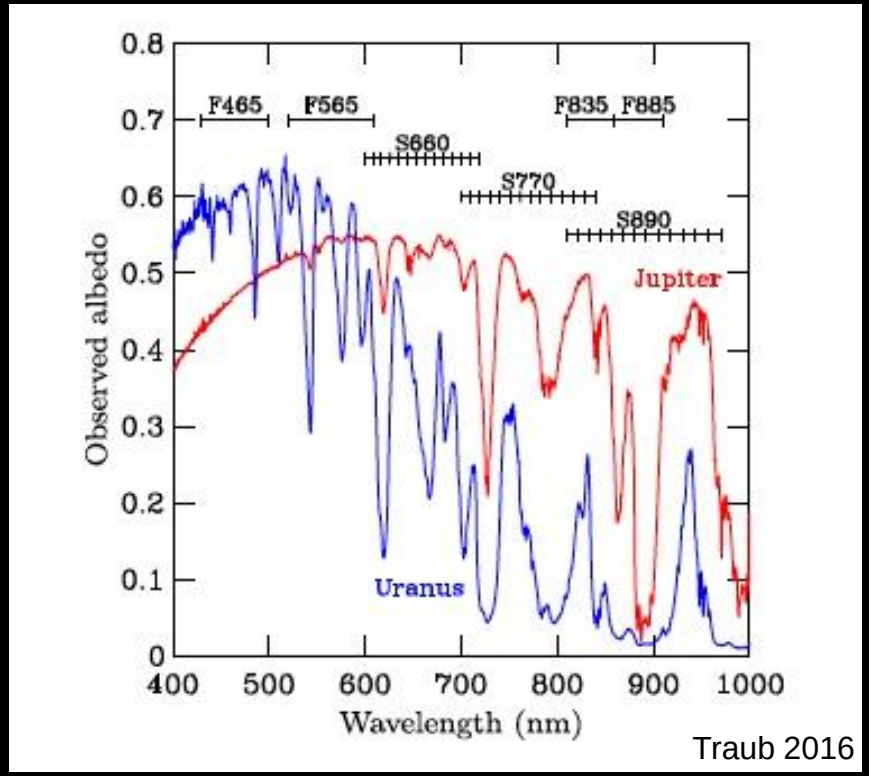
# Requirements

- ✓ Optical/red sensitivity to detect spectral features of interest
- ✓ Extremely low noise to enable faint detection
- ✓ Large format to enable integral field spectroscopy
- ✓ Wide dynamic range to accommodate coronagraph operations
- Rad-hard – detector meets needs, but further development is in progress to improve margin.




Traub 2016

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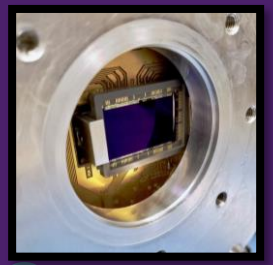
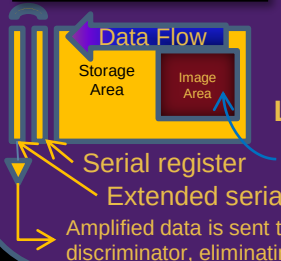
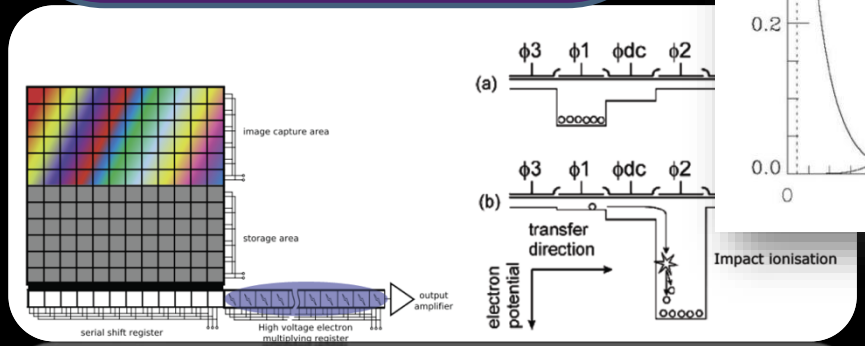
## Teledyne-e2v L3 Technology

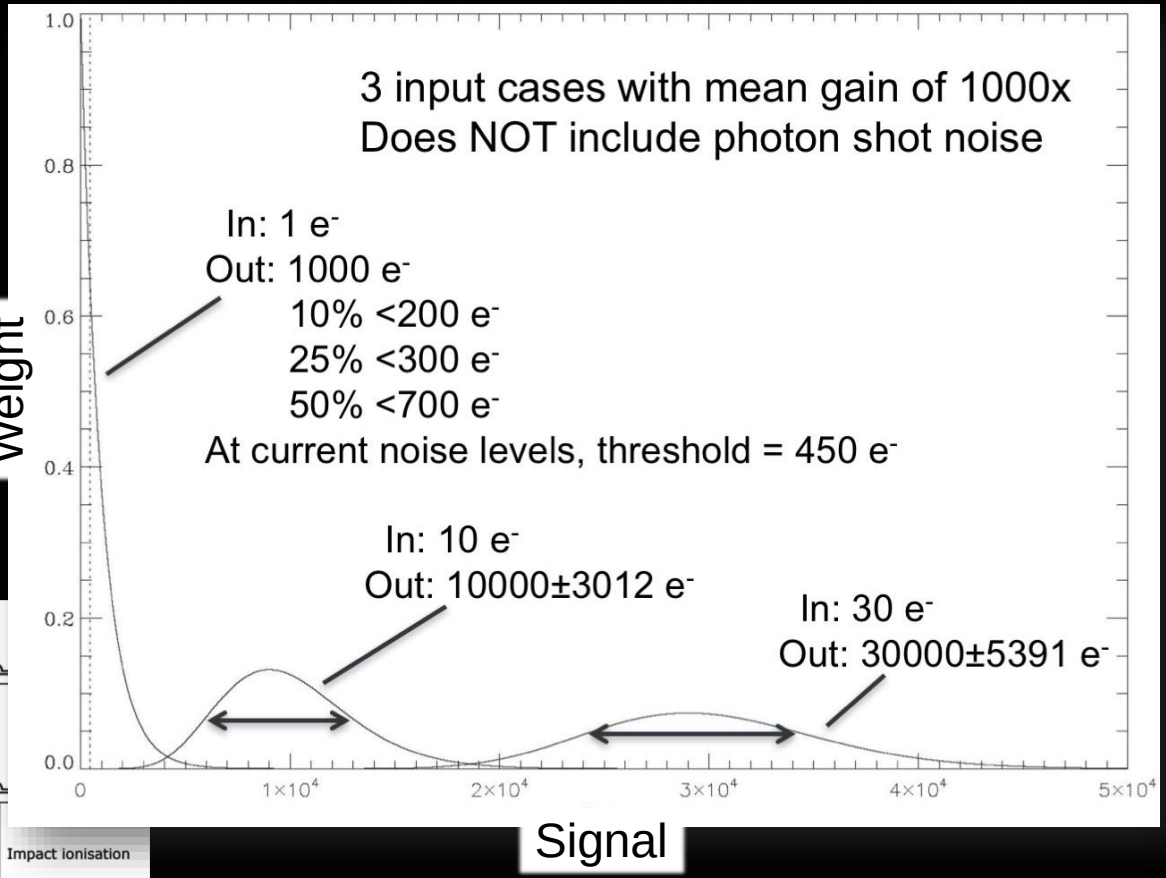


A **Low Light Level (L3) extended serial register** operating at elevated voltage (~50V) amplifies signals well above the level of the read noise, enabling high QE CCD imaging and **zero read noise** photon counting.




**L3 functional diagram**




The “gain” is the weighted mean of the signal

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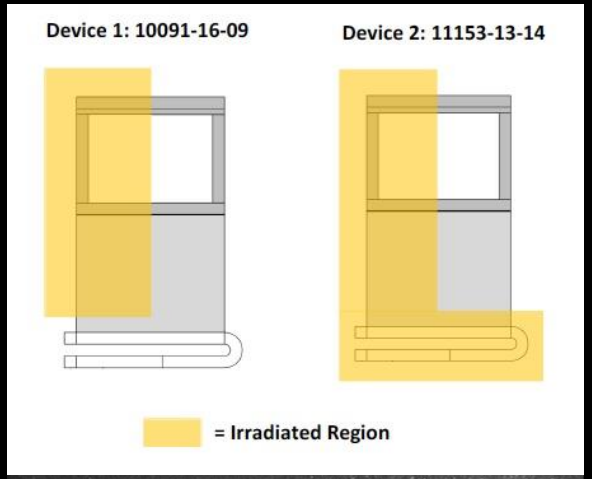
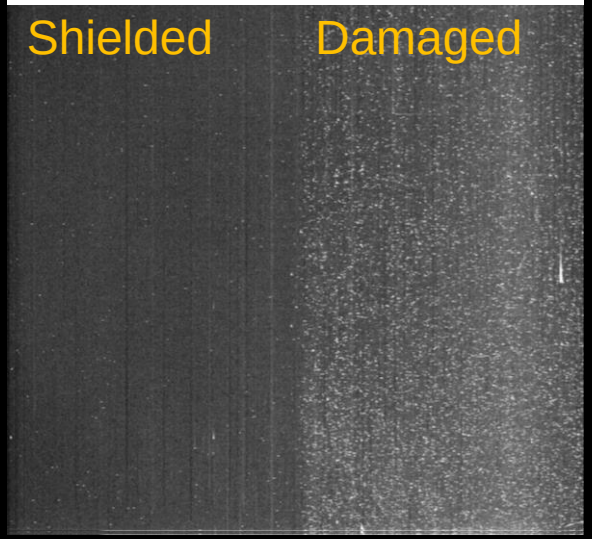
# The WFIRST Radiation Test Program

- The camera team has characterized the low flux sensitivity of radiation-damaged EMCCDs operating in photon counting mode.
  - The low noise performance of the EMCCD provides a performance advantage over almost any other type of detector.
- We have engaged the Centre for Electronic Imaging, Open University (UK) to help with testing and evaluation.
  - Commercial EMCCDs have been irradiated by protons to a 5 year flight-like dose.
  - Separate cold and warm irradiations (cold is worse)
  - We are operating radiation damaged EMCCDs in our lab at JPL using a commercial controller.
- The commercial EMCCD is radiation sensitive (as are all CCDs) but has margin on the technology requirements of the coronagraph.
  - We have contracted Teledyne-e2v to develop several variants of the commercial EMCCD that will be more robust to radiation, will address the effect of cosmic ray tails generated in the gain register, and will reduce latency for the LOWFS application.
  - **We are evaluating the LOWFS-optimized devices in the lab now, and expect to receive and test the science variants in the fall of 2018.**

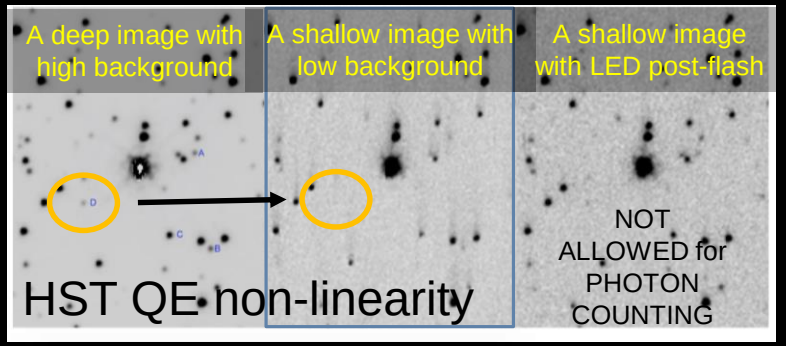


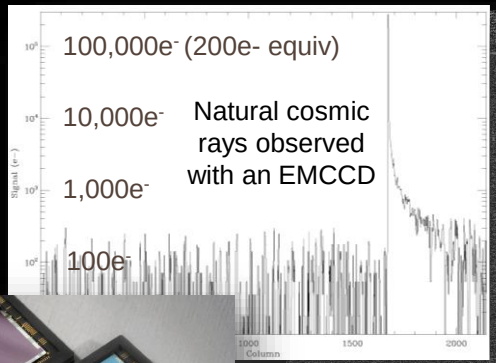
# Effects of Radiation Relevant to Photon Counting EMCCD

There are four main areas we are addressing to prepare for our flight application:

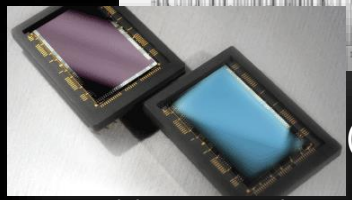
1. **Radiation Damage:** All CCDs are sensitive to radiation to varying degrees. Radiation damage causes hot pixels and also degrades charge transfer efficiency, introducing a QE non-linearity at very low fluxes (such as are required for exoplanet astronomy)
2. **Cosmic Ray Contamination:** Bright cosmic detections will occur at ~**300x** the typical ground rate at L2 orbit. Cosmic rays saturate in the gain register and leave a long tail.
3. **Readout noise: H**igh speeds that minimize CIC also require high gain for optimal efficiency, exacerbating cosmic ray tails
4. **Packaging:** The commercial EMCCD package must be adapted for a flight application and meet requirements (flatness).




(1)




(2,3)

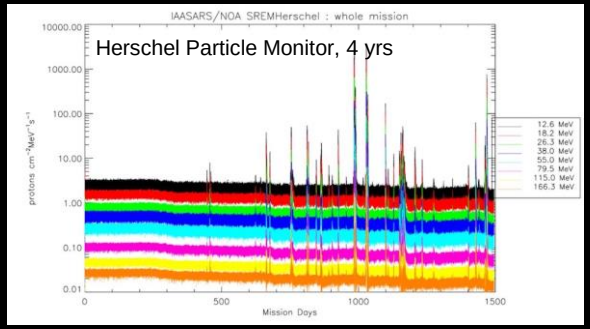


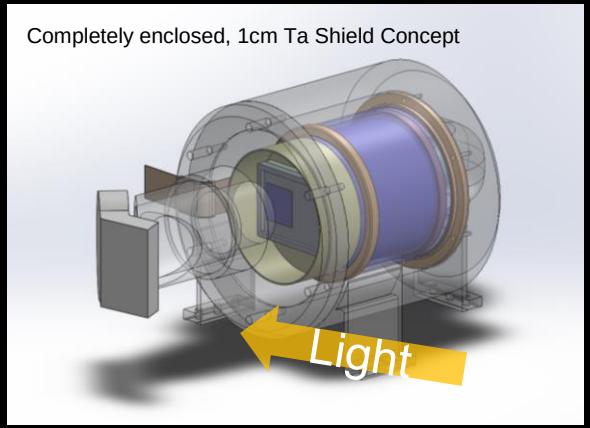
(4)

Commercial EMCCD package

# Camera Environment and Radiation Shield

- Radiation at L2 is comprised of episodic solar flares and a continuous flux of galactic cosmic ray protons.
  - Solar flares do most of the damage, but are shieldable
  - Galactic Cosmic rays are very energetic (~1 GeV) and are not shieldable.  They are primarily an observational nuisance.
- We have developed a fully enclosed shield assembly to protect the EMCCD as much as possible.
  - Radiation test levels (~2.5x10$^{9}$ p-cm$^{-2}$ 10 MeV equiv) were developed assuming this type of shield
  - Baseline material is Tantalum
  - Effects of secondary particles, particularly from GCR, are being investigated



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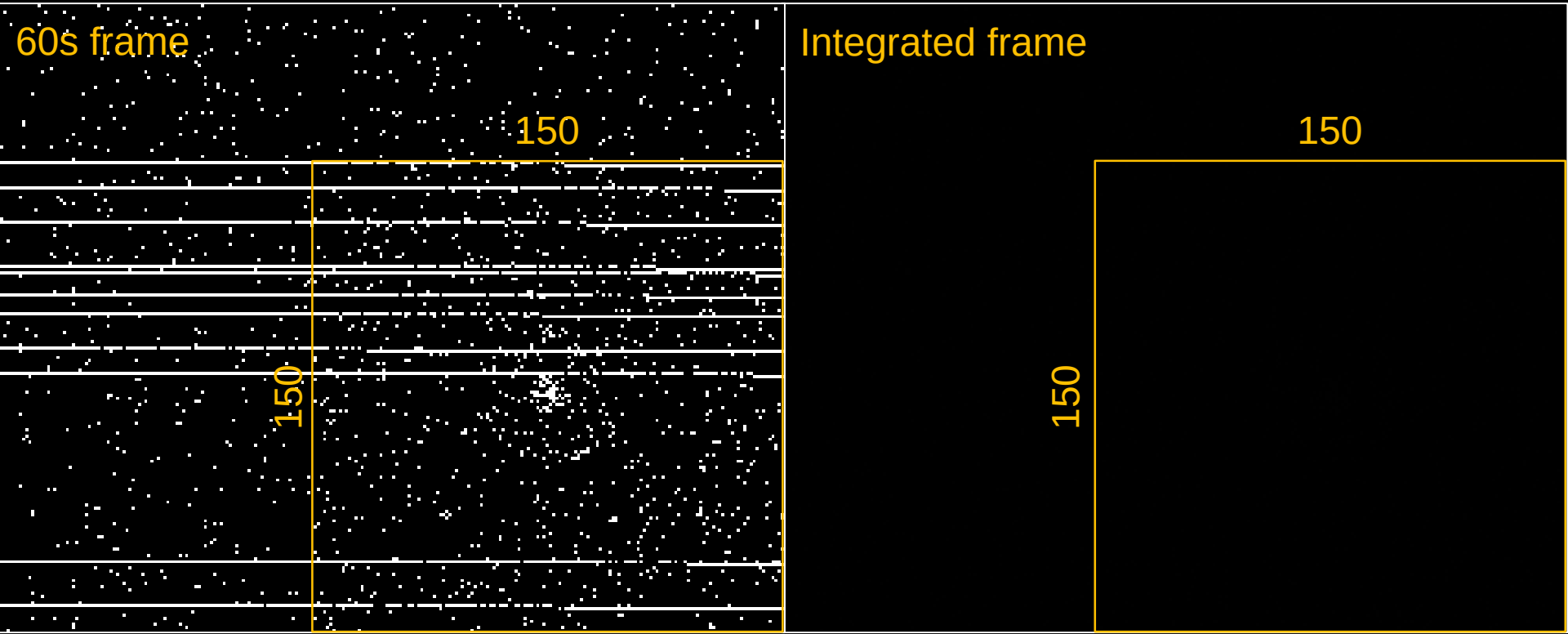
# Photon Counting Simulation: Direct Imager, 4000x, 24hrs, 60s frames



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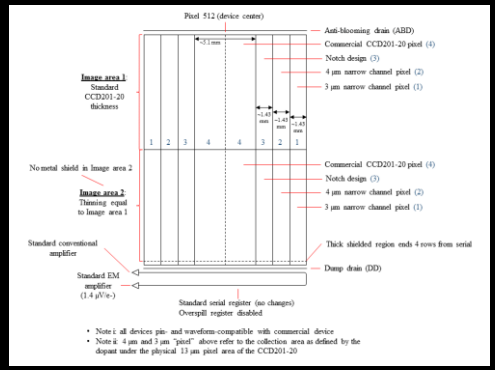
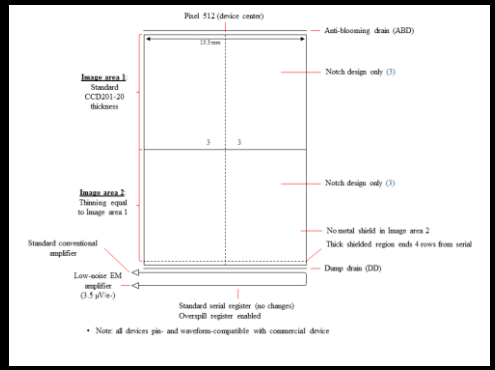
# Technology Development at Teledyne-e2v

- We have a program in place with Teledyne-e2v to produce radiation-hardened EMCCD detectors for flight that are based on the CCD201.
  - Type A (Wavefront sensor test):
    - Removes store shield
  - CCD301:
    - Removes store shield
    - Implements several different column widths to minimize transfer effects due to trap damage
  - CCD302:
    - Removes store shield
    - Implements a single “notch channel” design in the image area
    - Adds an overspill feature to the gain register
    - Implements a new 3T output stage to reduce noise with higher output loads
- Devices without store were received in January
- CCD301/CCD302 are anticipated in October.

Wafer Probe








# Summary

- The WFIRST Coronagraph Instrument is a technology demonstration that is planned to advance the state-of-the-art for future large missions to directly image habitable planets.
- The commercial EMCCD detector meets the requirements of the technology demonstration, although radiation effects are a factor.
- A program is underway at Teledyne-e2v to improve the radiation hardness of the EMCCD for flight applications. The program is designed to improve margins and to push detection limits to fainter levels.
- Be sure to see related presentations by:
  - Michael Bottom, “Smartphone scene generator for efficient characterization of visible imaging detectors”, 10709-107
  - Effinger, “WFIRST coronagraph detector trap modeling results and improvements”, 10709-44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