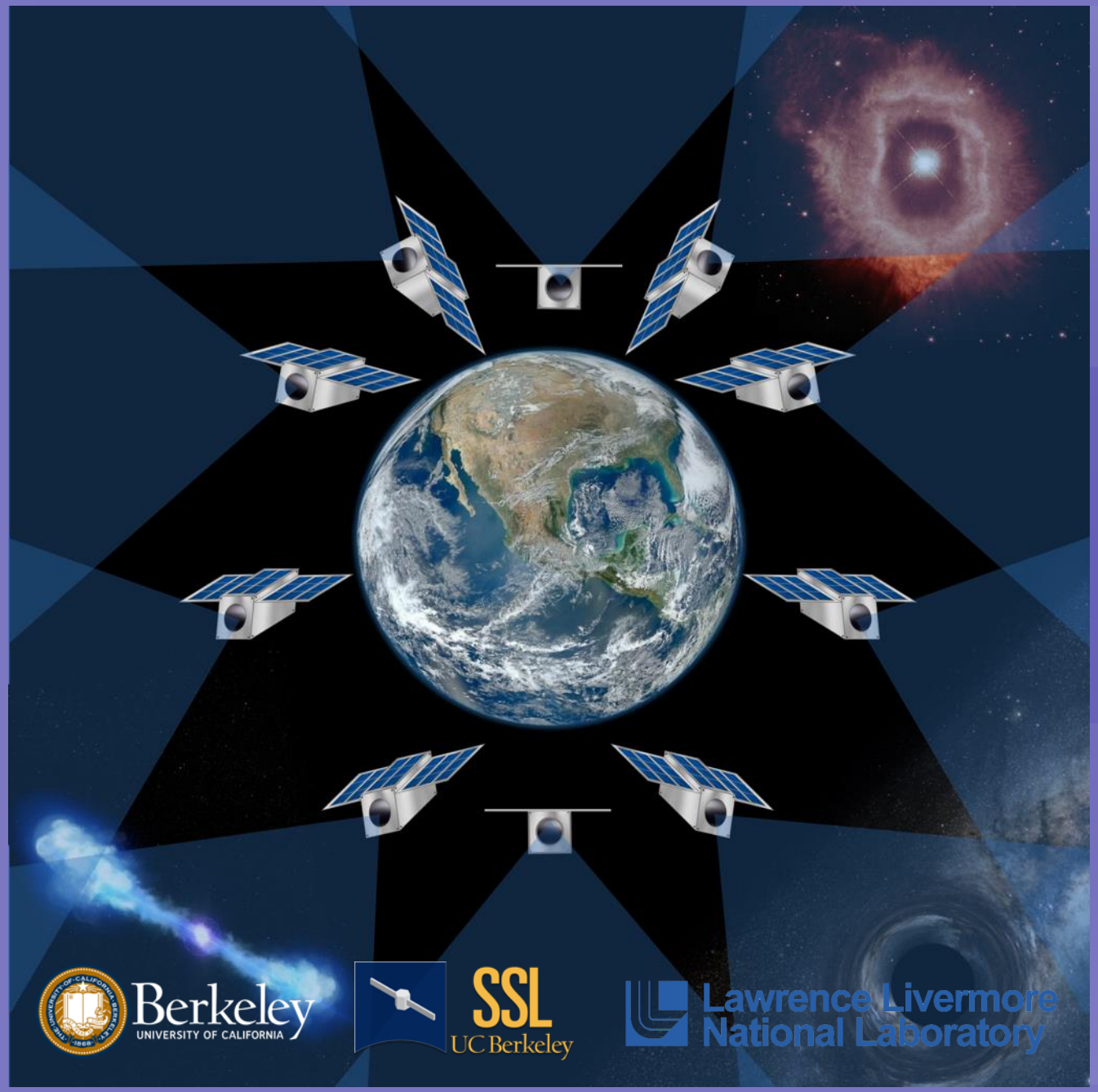


CuRIO

CubeSats for Rapid Infrared and Optical Surveys

Hannah Gulick

and the CuRIOS team

UC Berkeley+SSL: *Jessica Lu, Steve Beckwith, Josh Bloom, Tim Miller, Kodi Rider, Jeremy McCauley, Guy Nir, Ben Bressler*

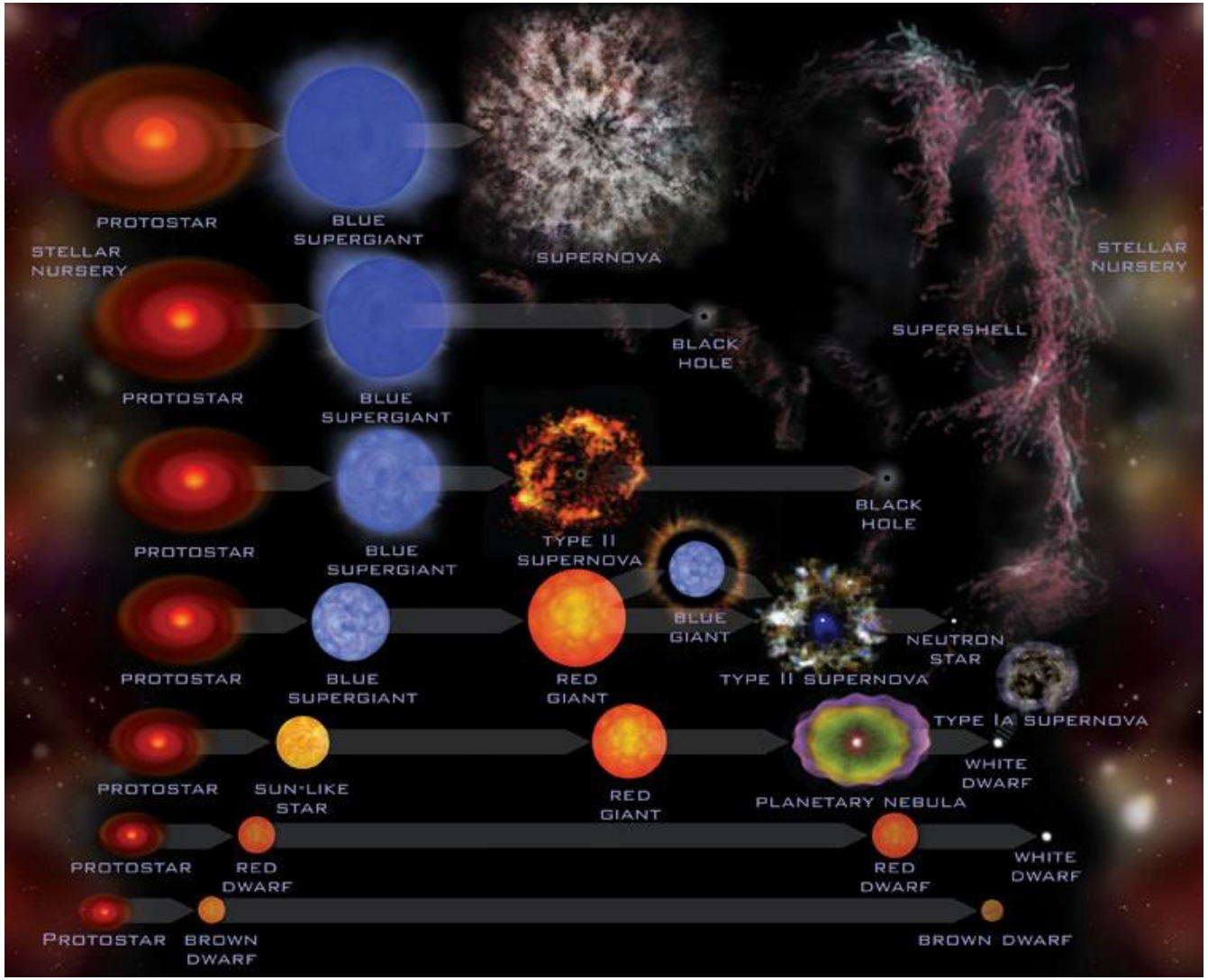
LLNL: *Frank Ravizza, John Ganino, Alex Pertica, Wim de Vries*

The Death and Afterlife of Stars

Scientific frontier: black holes and neutron stars

Open questions:

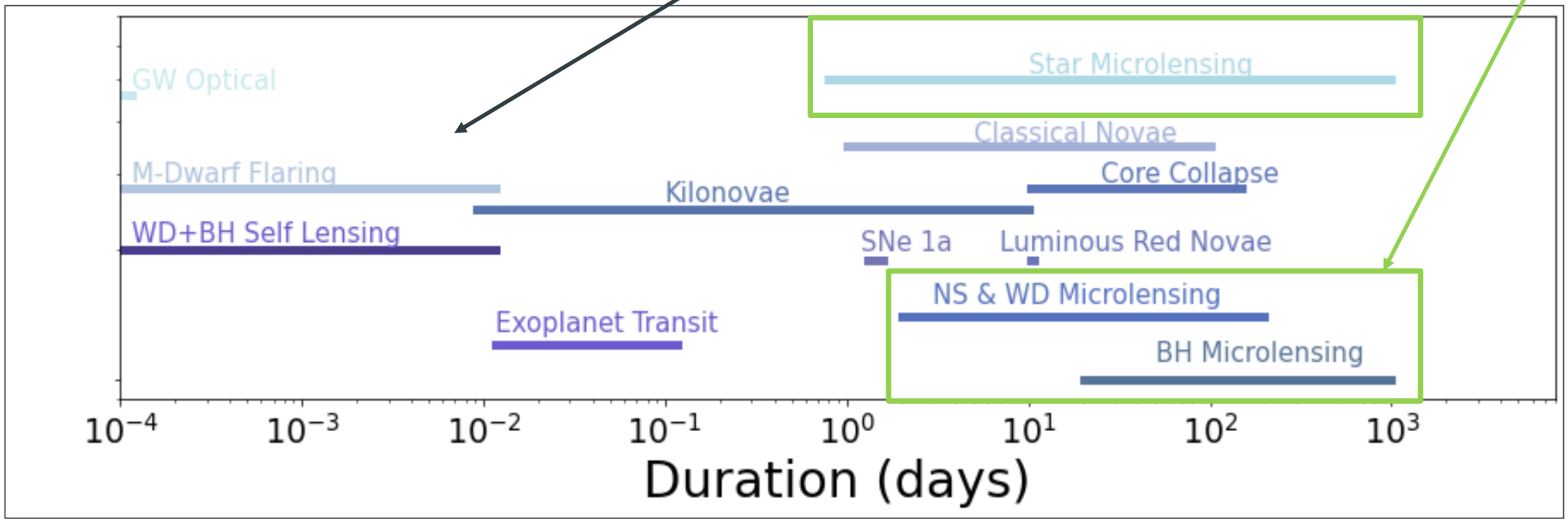
- Basic properties
- Origin
- Populations
- Evolution



The Death and Afterlife of Stars

Other science cases that will be observed by CuRIOS

Only 1 isolated stellar-mass black hole detected so far through astrometric microlensing: Lam et al. 2022, Sahu et al. 2022

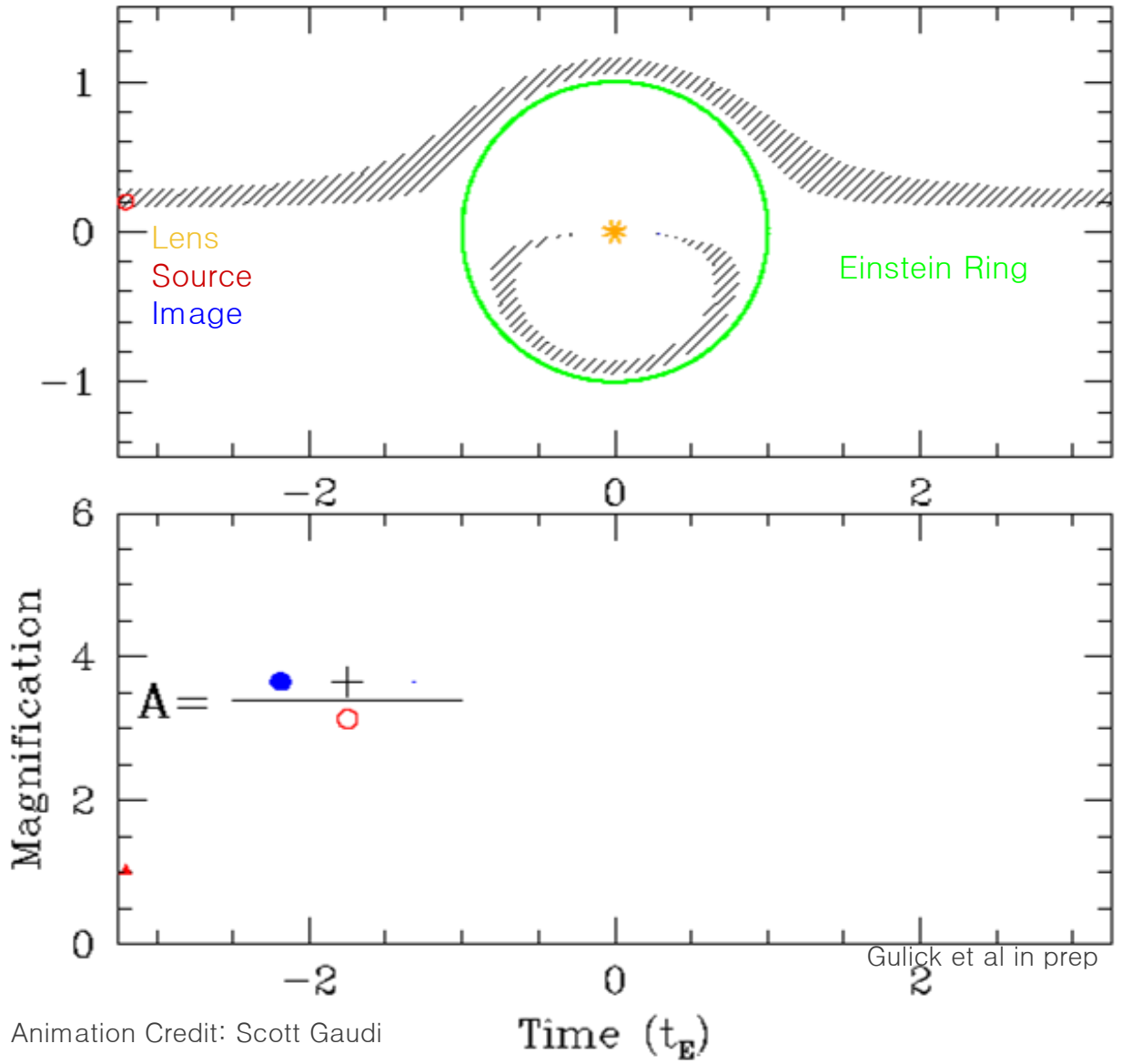


Gravitational Microlensing

As a black hole passes in front of a star it:

- Disrupts the star's image
- Magnifies the star's light

What do we see in a telescope?



Gulick et al in prep

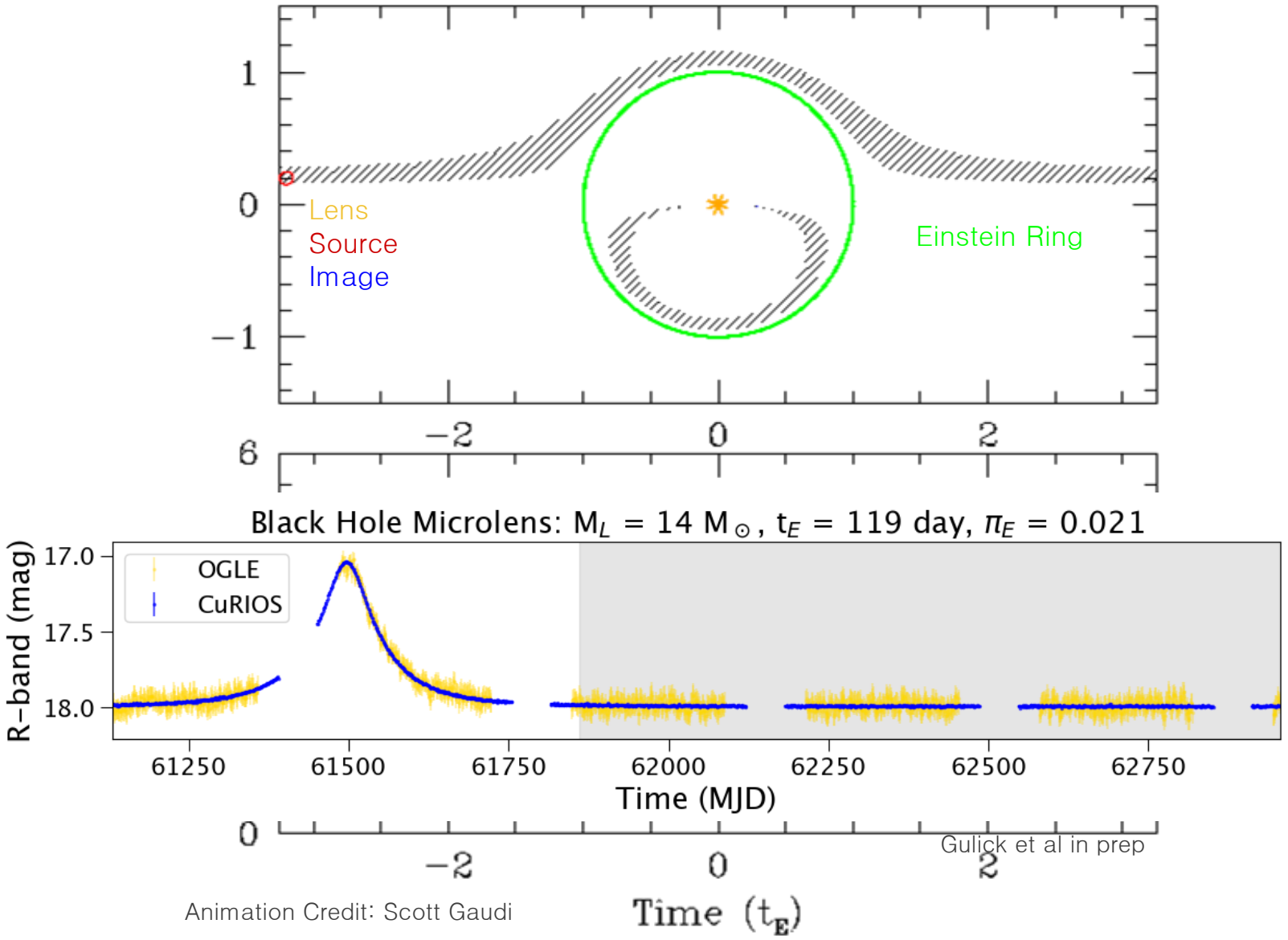
Animation Credit: Scott Gaudi

Gravitational Microlensing

As a black hole passes in front of a star it:

- Disrupts the star's image
- Magnifies the star's light

What do we see in a telescope?



Gulick et al in prep

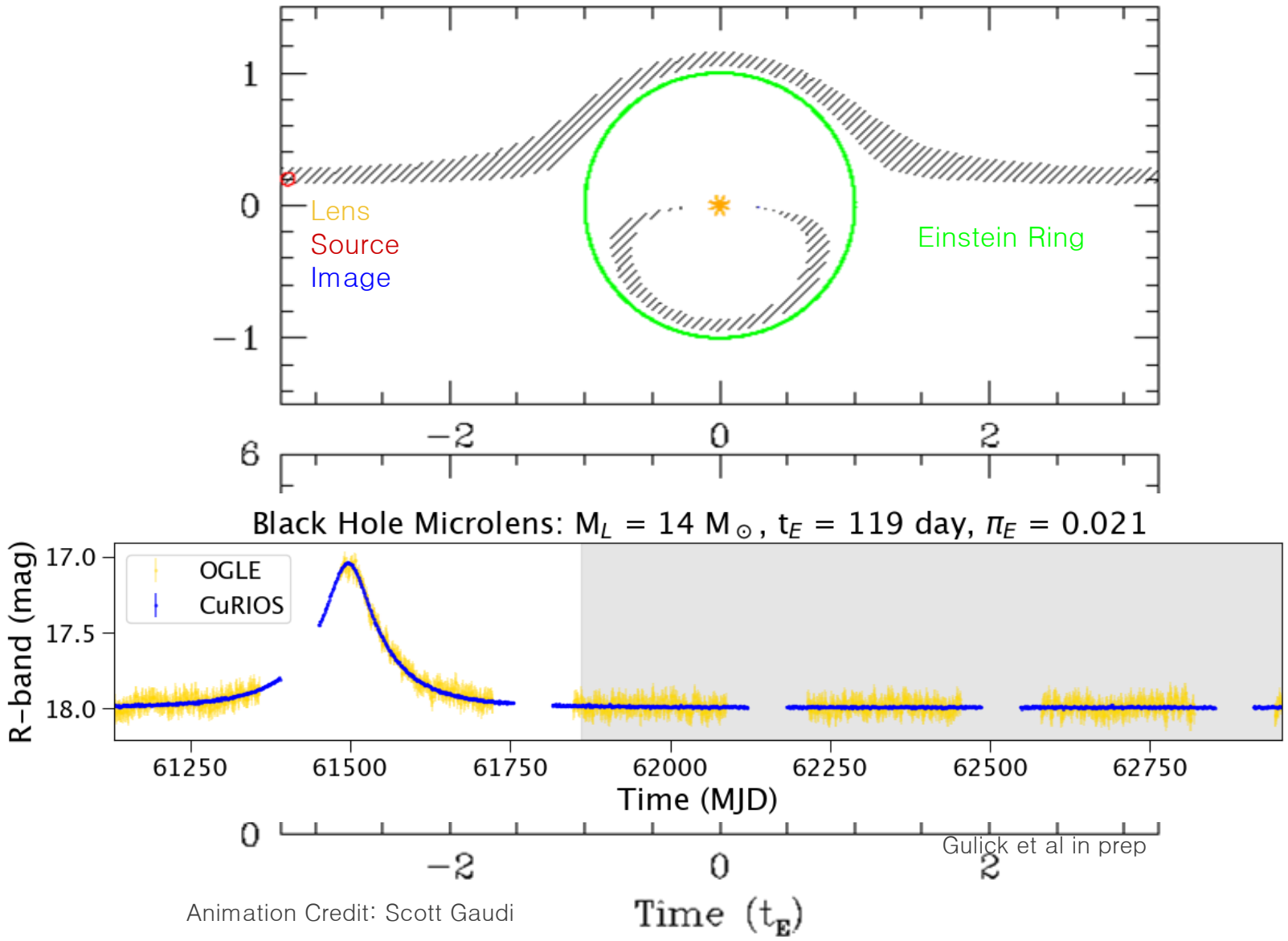
Animation Credit: Scott Gaudi

Gravitational Microlensing

Observational Challenges:

Microlensing is a transient phenomenon that occurs on timescales of ~1 to 1000 days.

1. Constant all-sky monitoring required to properly sample baseline
2. Necessary photometric precision not possible on the ground.



Gulick et al in prep

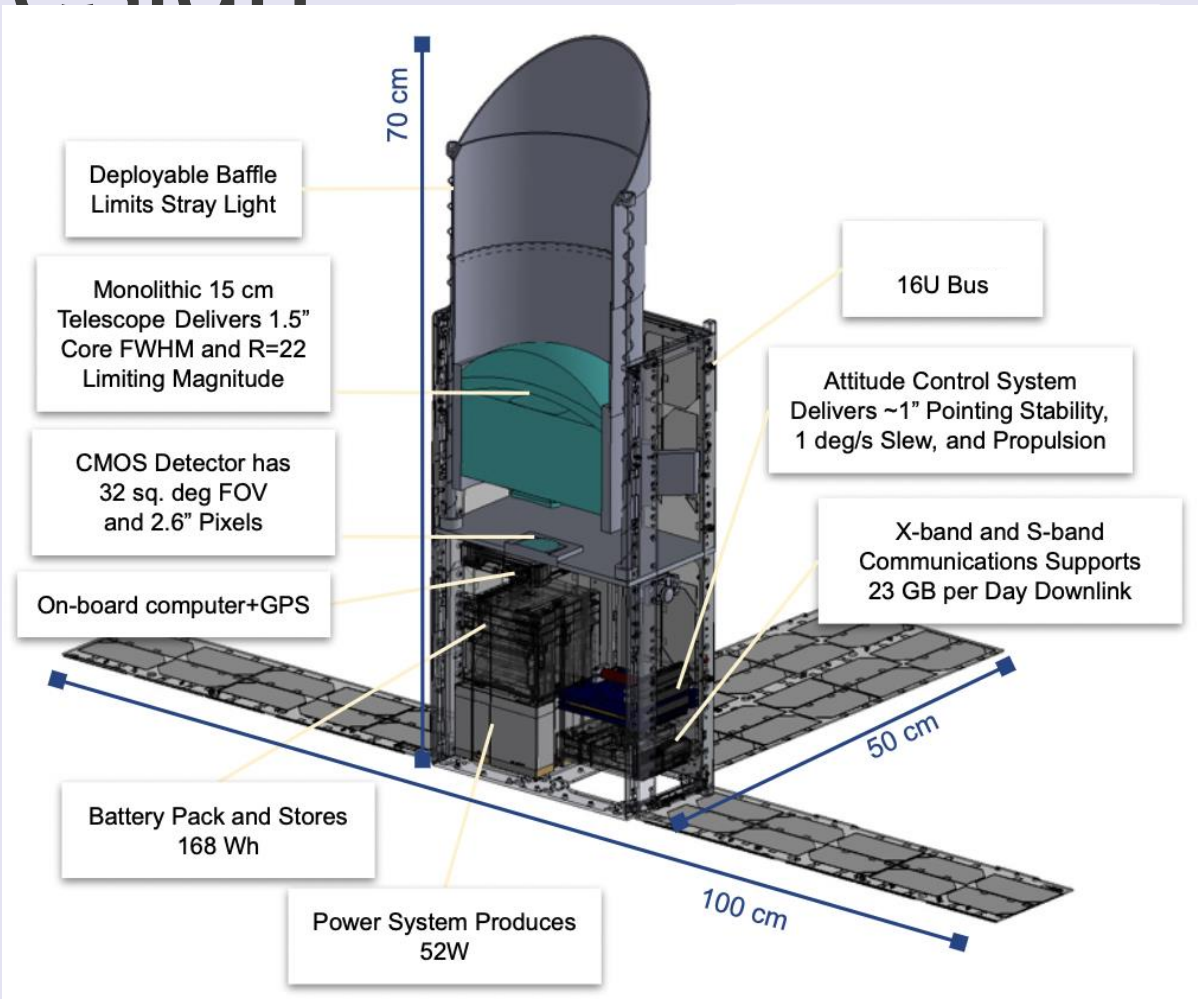
Animation Credit: Scott Gaudi

Solution: CuRIOS

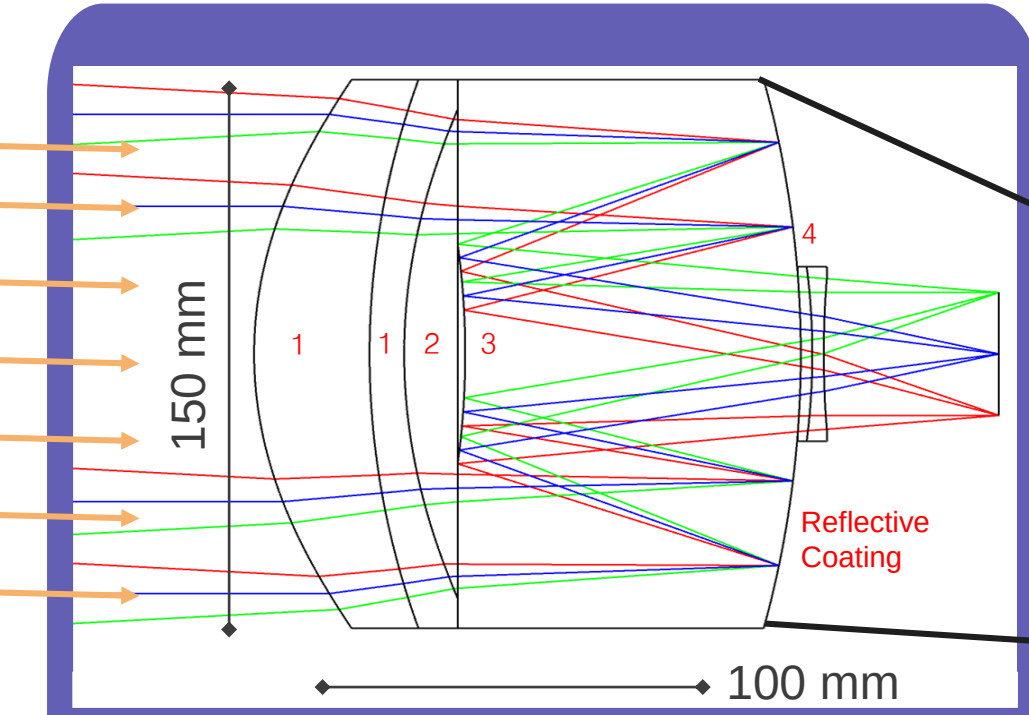
CuRIOS will employ a swarm of optical/near-IR CubeSats to provide all-sky all-the-time monitoring of star death and afterlife by observing transient phenomena originating from black holes and neutron stars.

CuRIOS Instrument Design

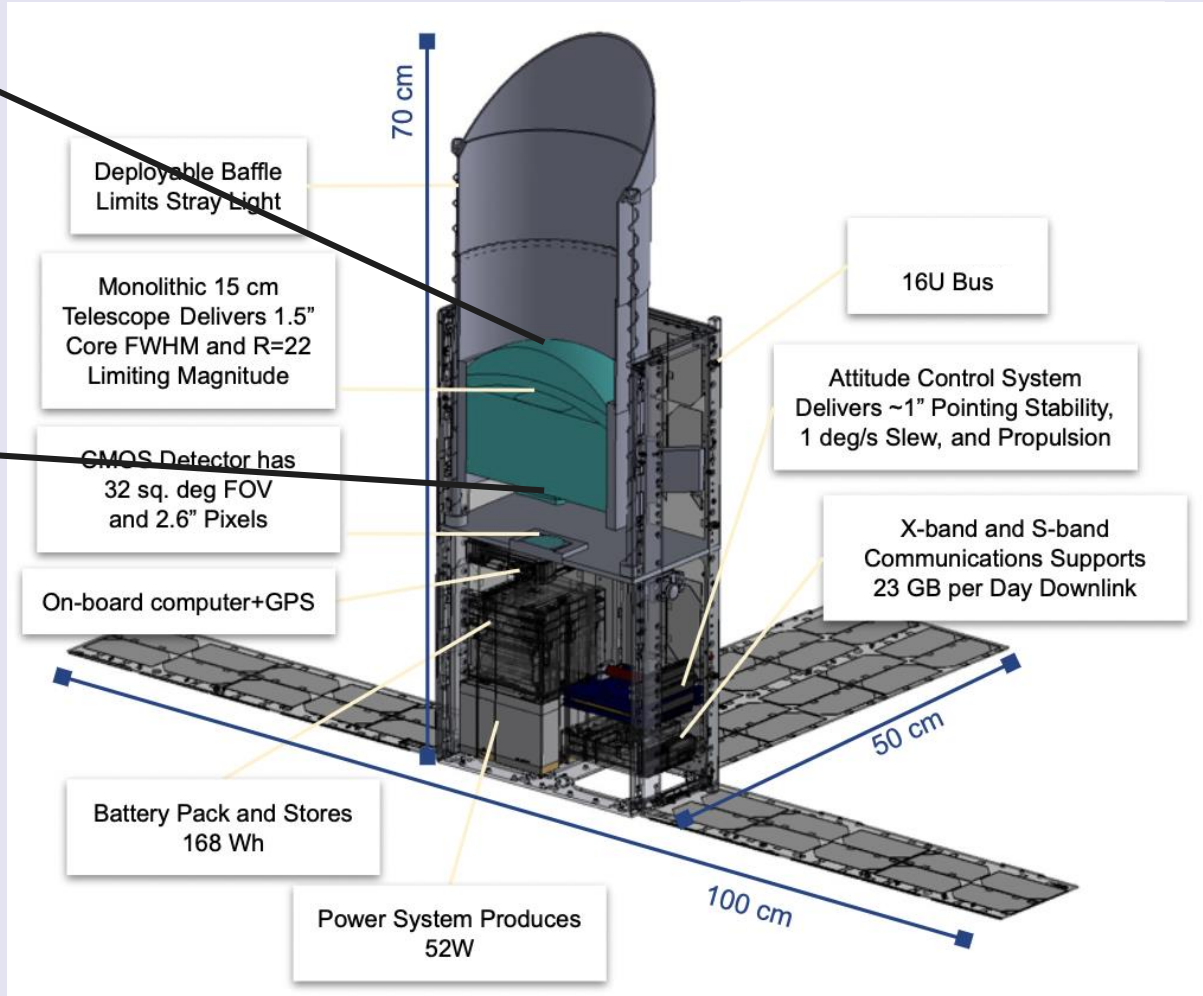
Aperture	15 cm
Bandpass	0.45 μm to 0.9 μm
Detector	61 MP CMOS
Duration	5 years
Sensitivity	R=21.7 mag @ SNR=10 In 15 min
Cadence (1 satellite)	30 sec exp → 15 min stack 90 min gaps 10 months per year
Orbit	LEO Sun-sync



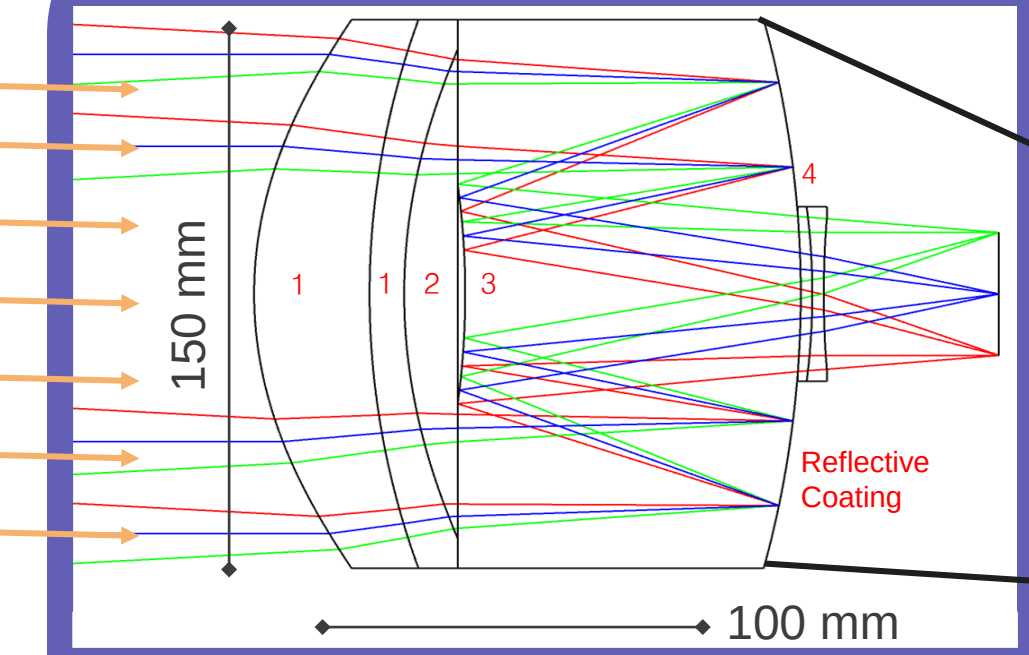
Monolithic Optic



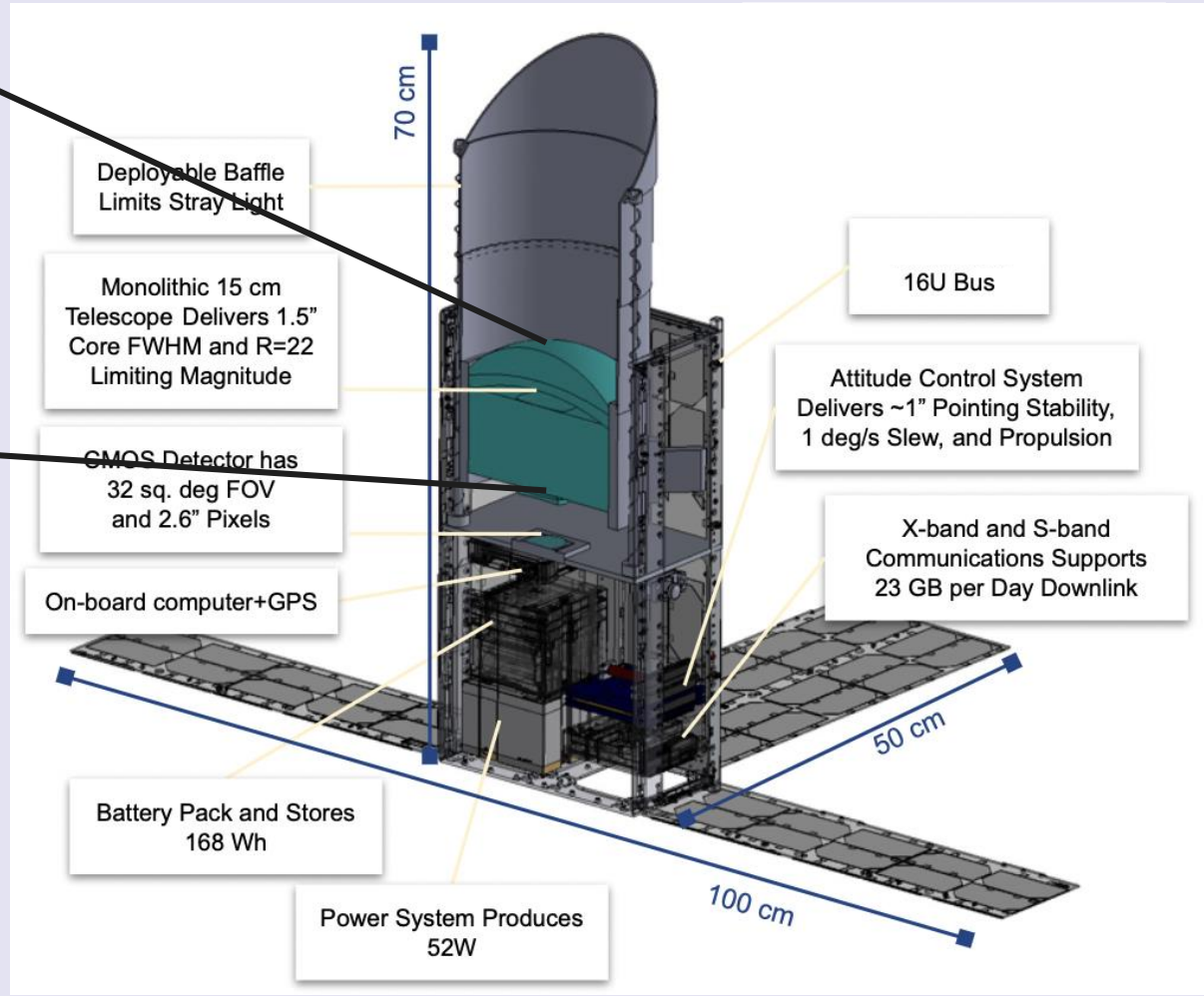
1. Transmissive doublet
2. Secondary lens
3. Main optic
4. Second transmissive doublet



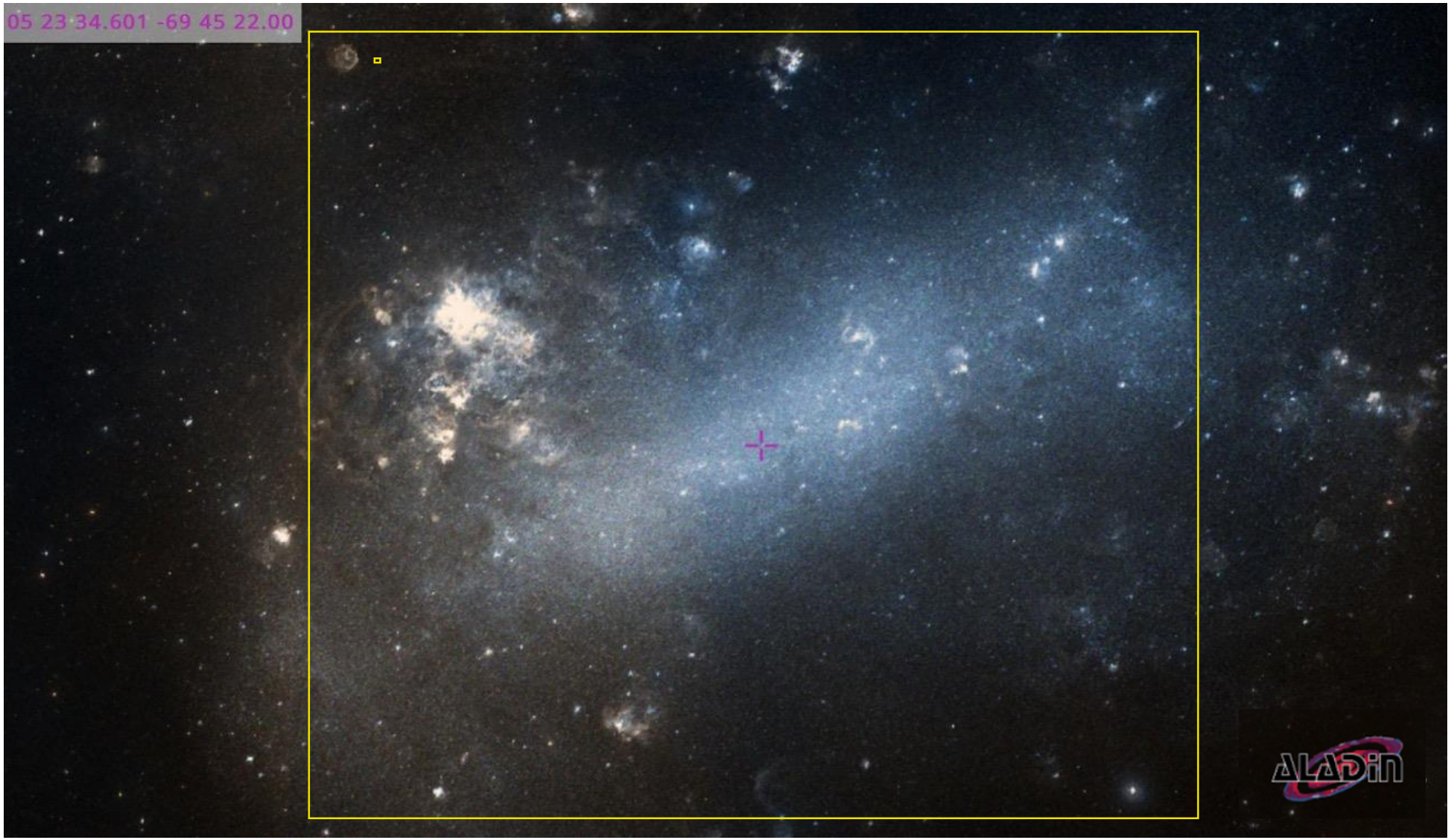
Monolithic Optic



FOV	6.9 deg by 4.6 deg	
Resolution	1.5” center	<3.0” edge
Plate scale	2.6”/pixel	

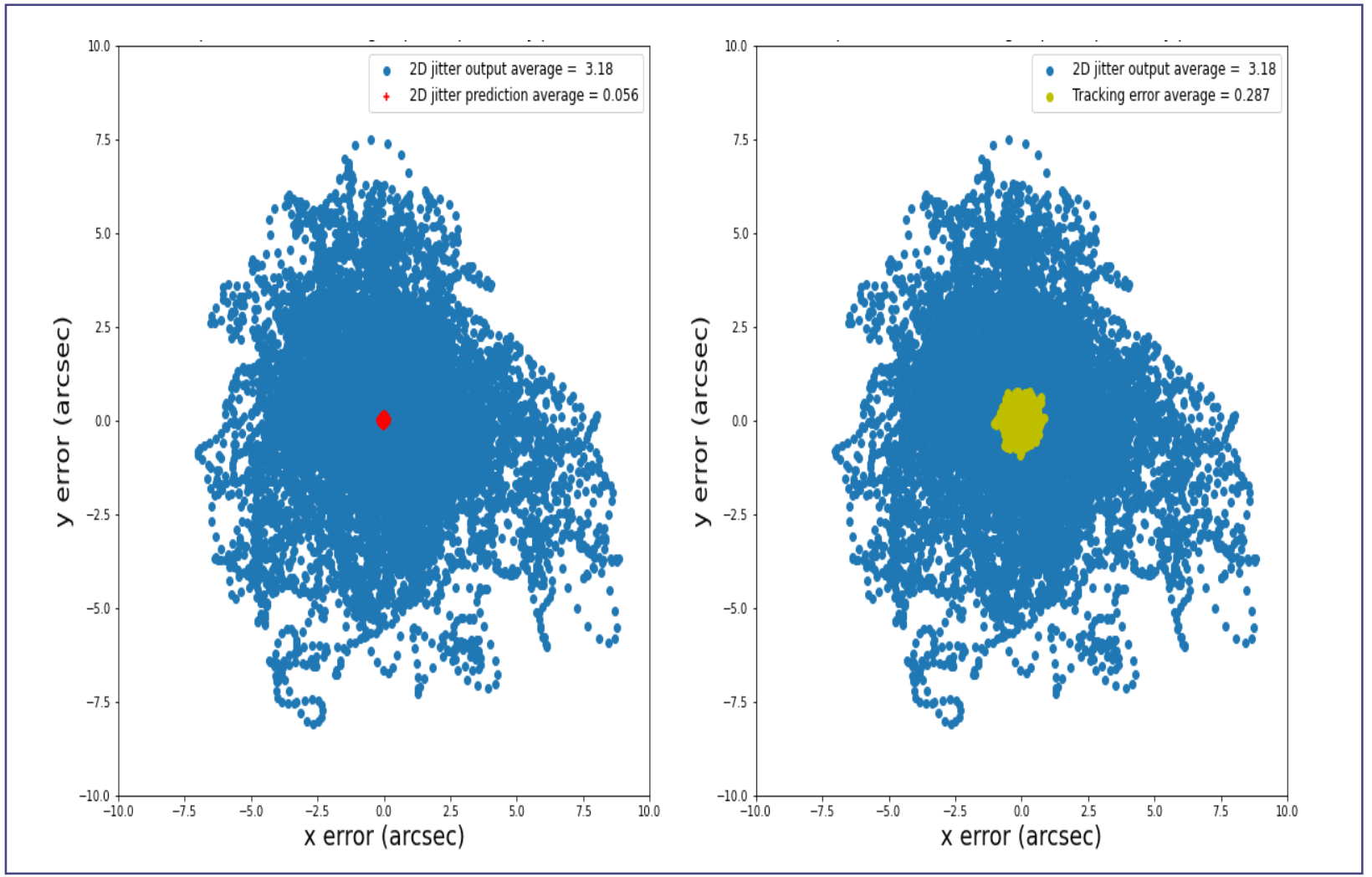


CuRIOS FOV



Pointing and Stability

- CuRIOS requirement: < 1” over exposure (30 s)
- Previous CubeSats achieved down to ~1.6”
- Using payload as additional star tracker: ~ 0.3” RMS jitter
  - This is an active area of research.



Data Downloading

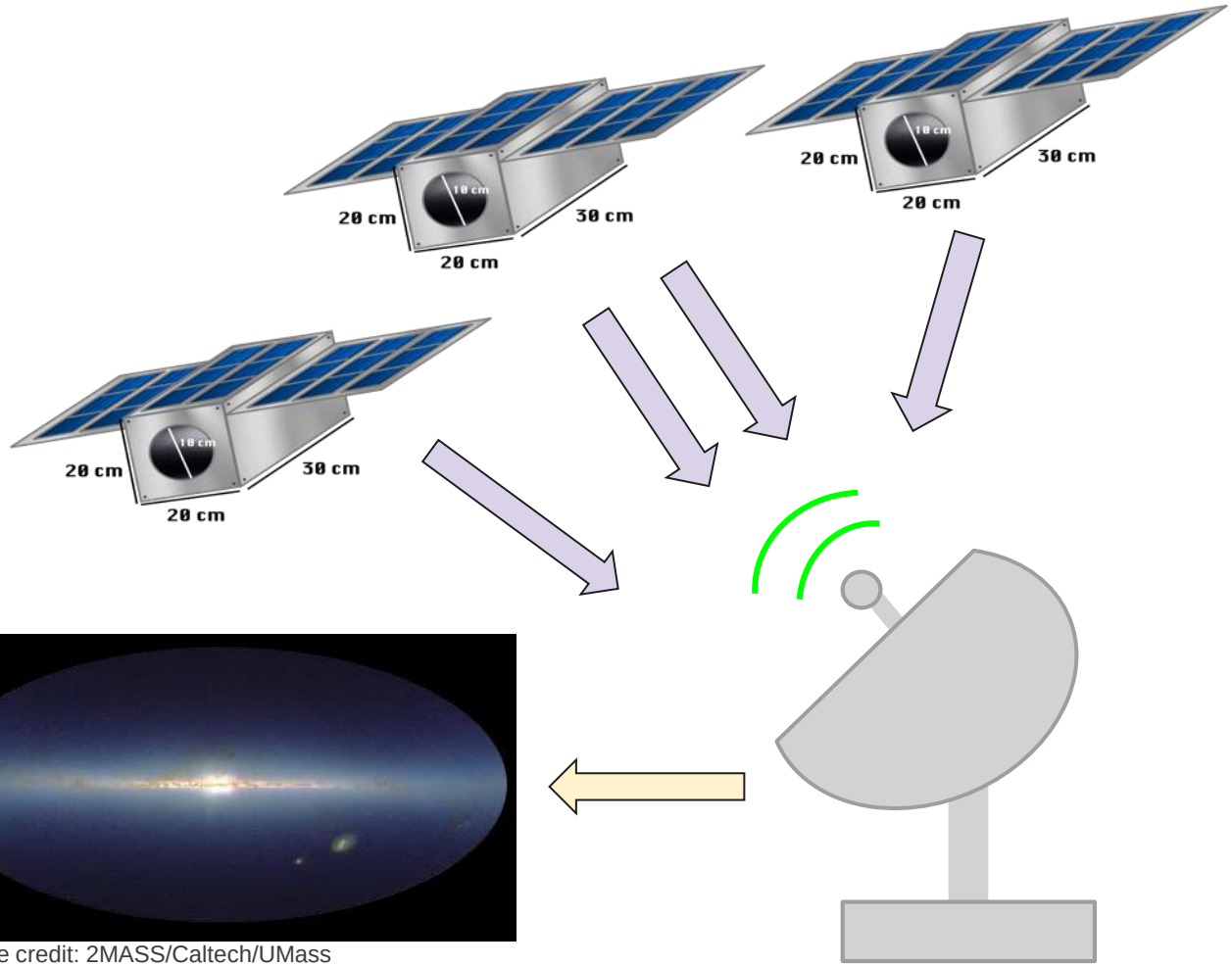


Image credit: 2MASS/Caltech/UMass

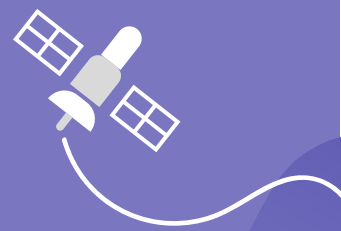
All-sky surveys produce a lot of data

- Likely 1 Gbit/s for 300 sats

Even with onboard processing

Addressing with orbit selection, upgrading stations, etc.

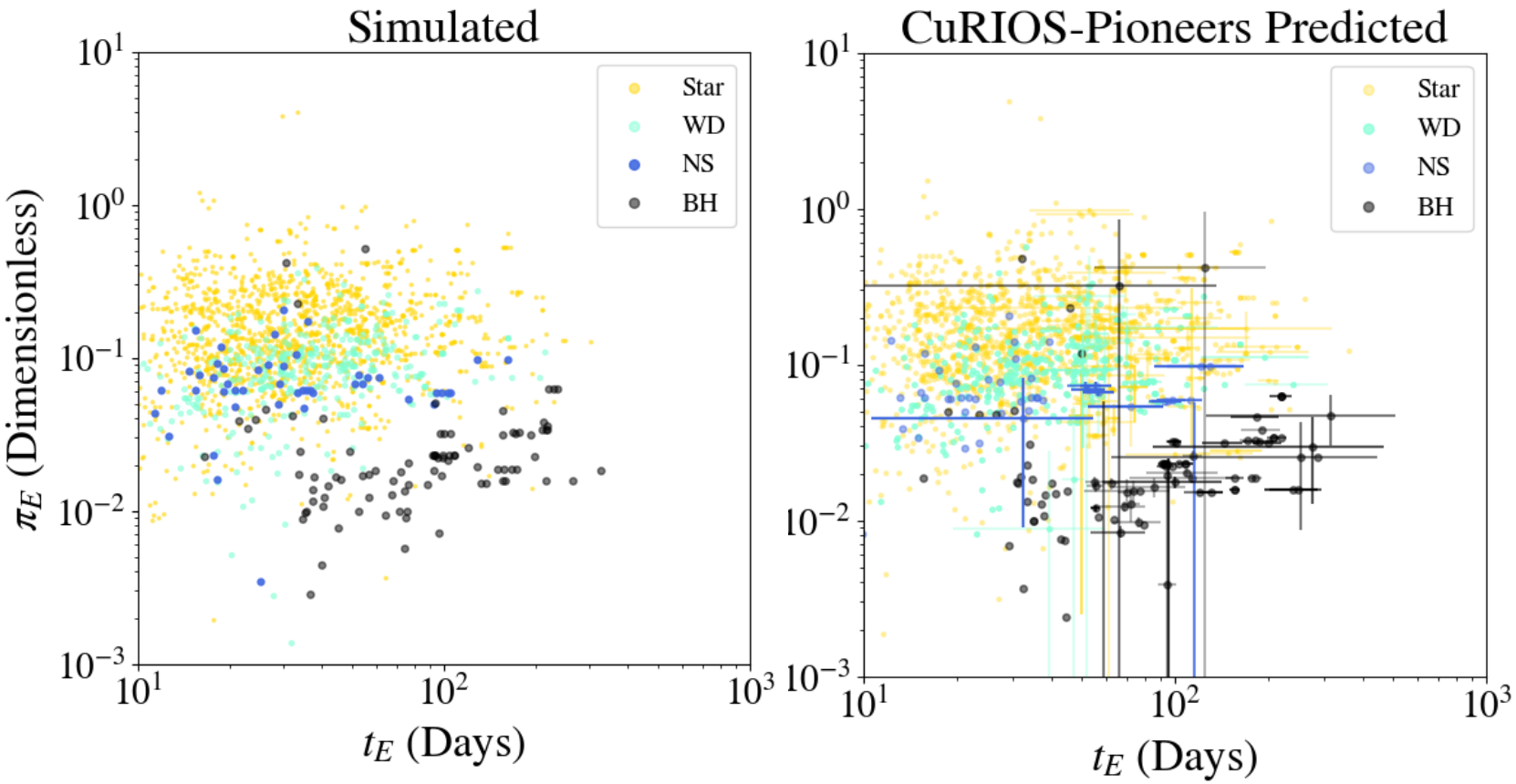
Options?



Estimated Returnables: BH Microlensing

BH event cuts:

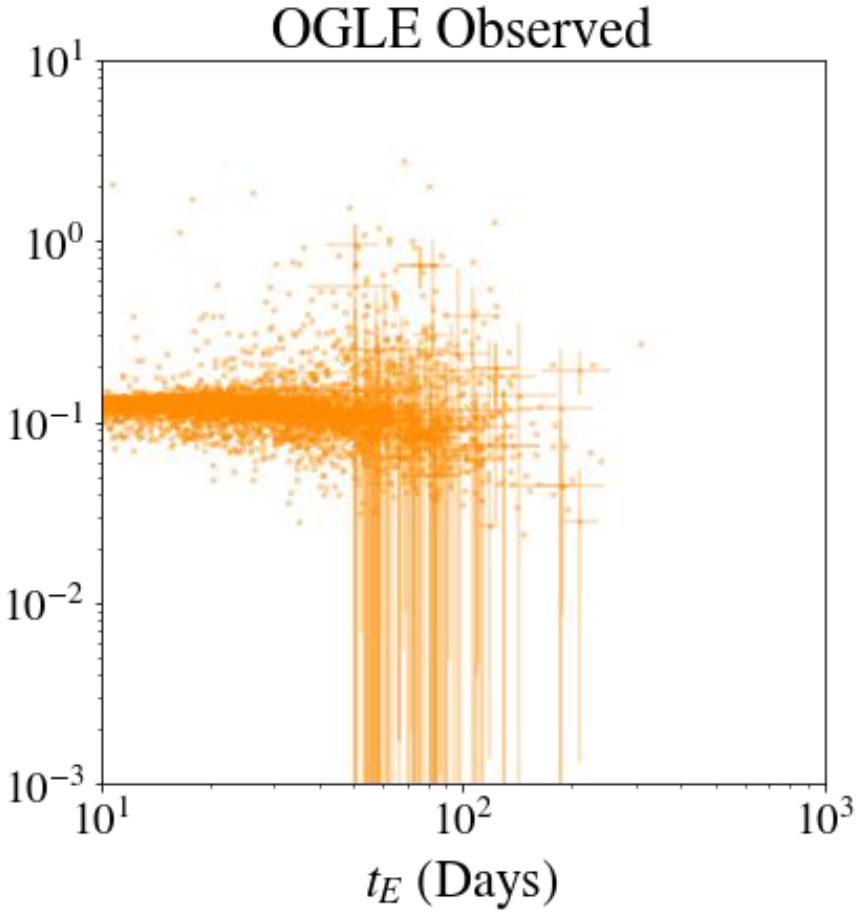
- Amplification magnitude, duration (> 2orbits), source magnitude

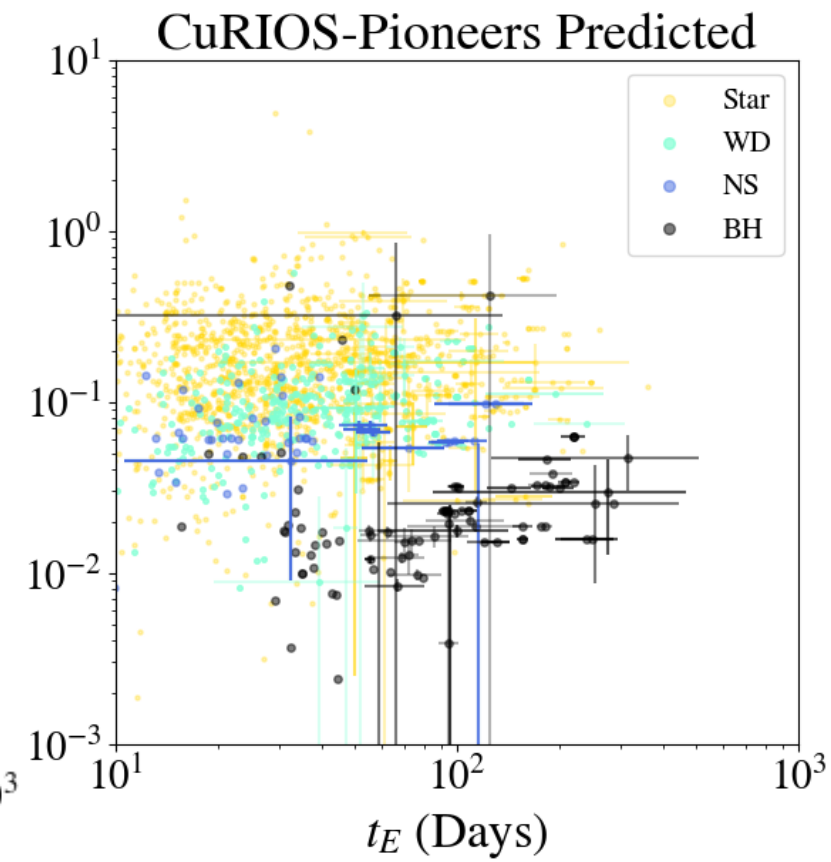


Estimated Returnables: BH Microlensing

BH event cuts:

- Amplification magnitude, duration (> 2orbits), source magnitude





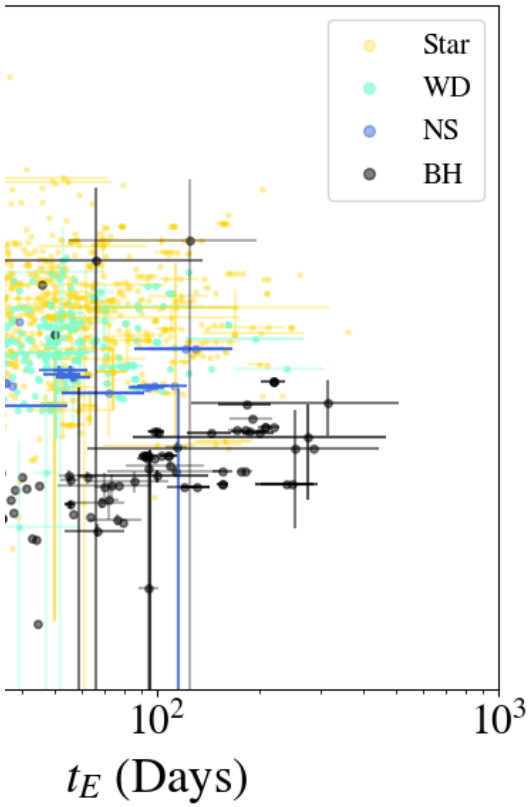
Berkeley UNIVERSITY OF CALIFORNIA

SSL UC Berkeley

Estimated Returnables: BH Microle

OGLE Observed

CuRIOS-Pioneers Predicted



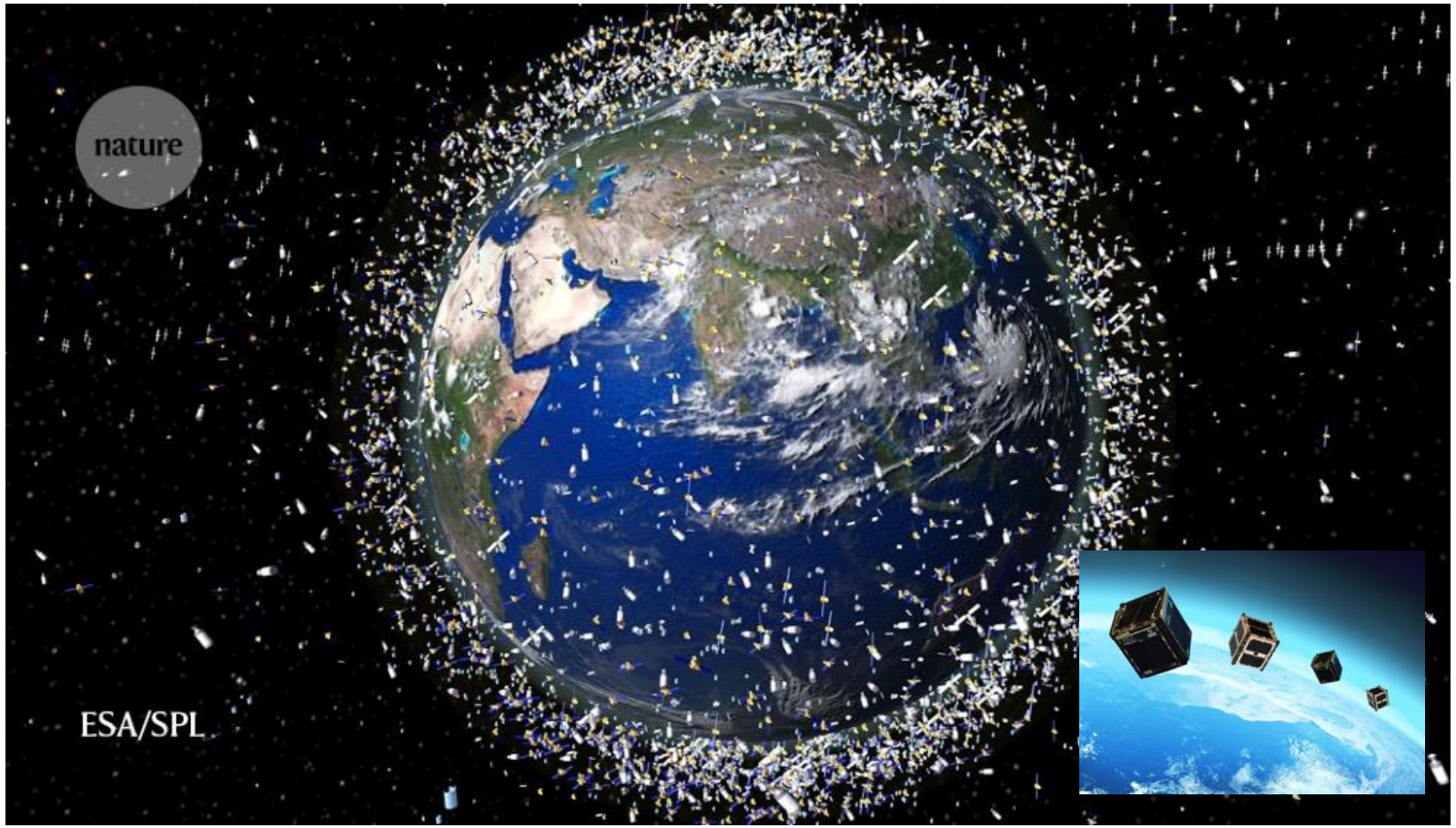
Averaging over the field:

~50 black hole events / year / CuRIOS FOV in the GC!

BH event cuts:

- Amplificatio
  duration (> 2
  source magn

Why now?

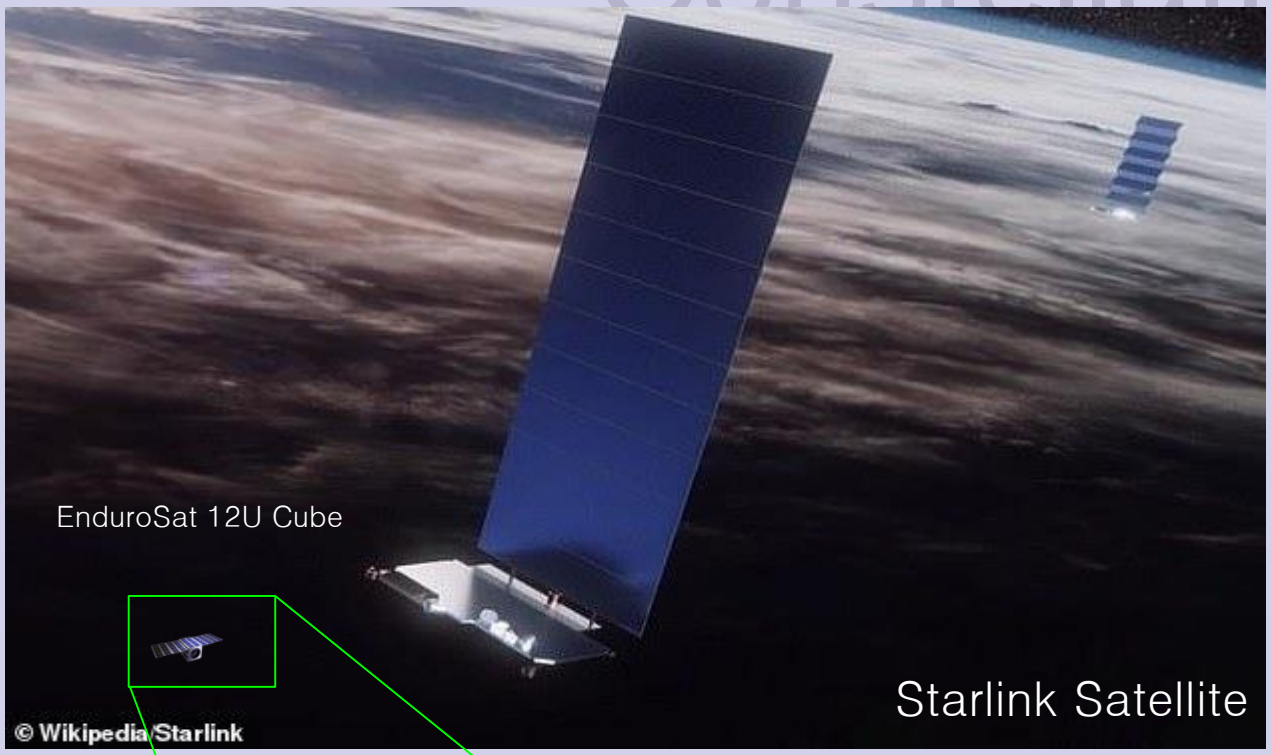


Commercial industry rapidly occupied:

- Planet Labs, Doves
- SpaceX, Starlink
- Iridium, NEXT

Early constellations show the need for measures to minimize contamination (developing alongside constellation technology).

Managing Constellations

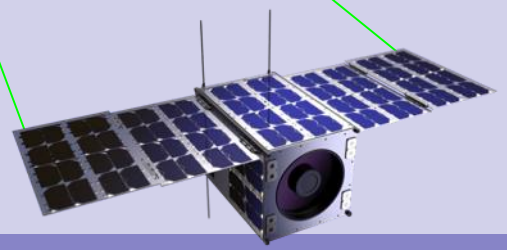


Major concerns:

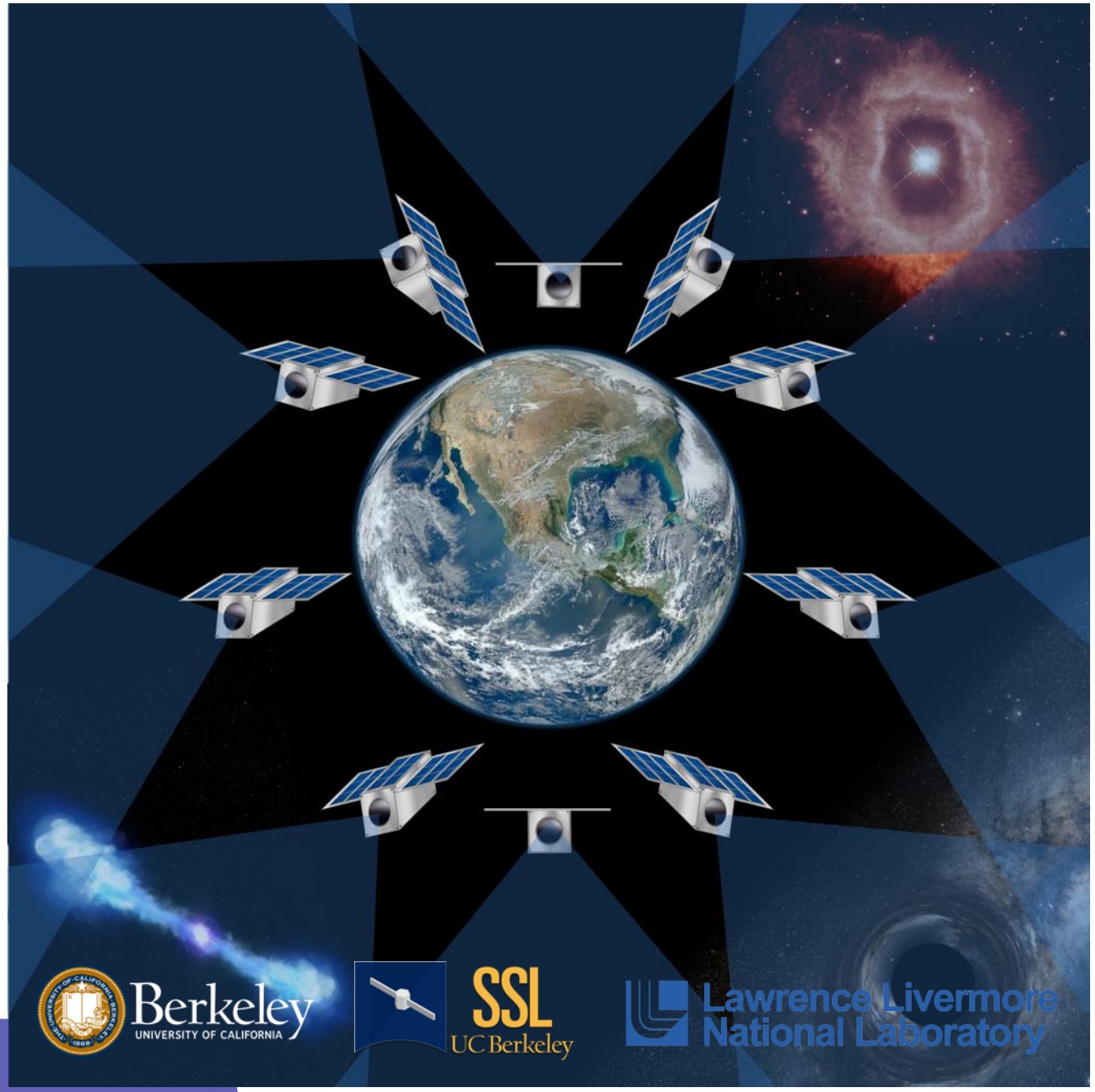
- Visibility
- Overcrowding

Active design work:

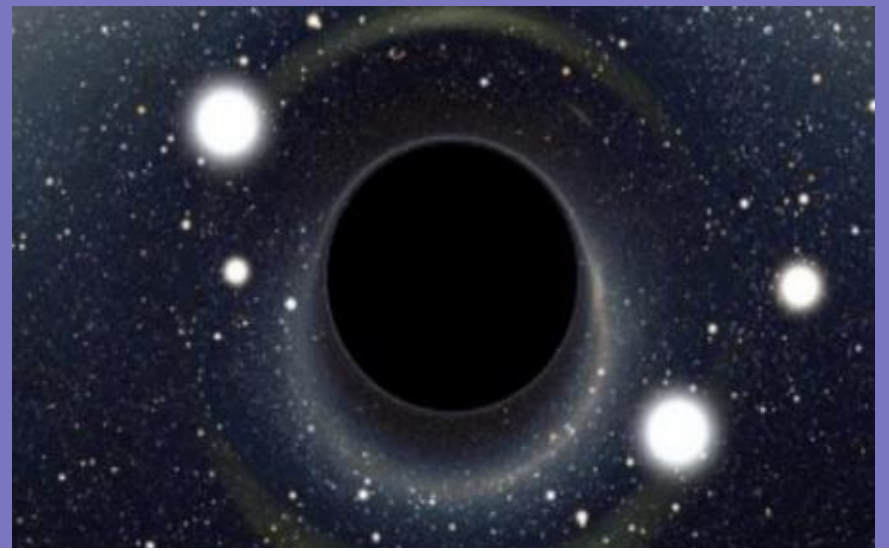
- Baffling
- Orbit design
- Propulsion

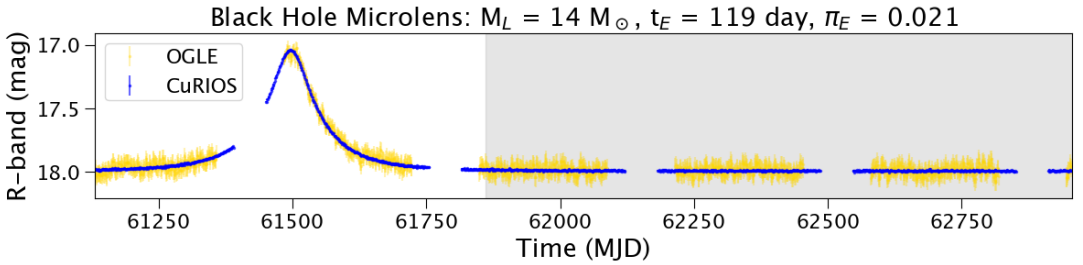


16U CubeSat is a factor of ~100 smaller (1% the size of Starlink with solar panels)



Thank you!
Questions?





Extras

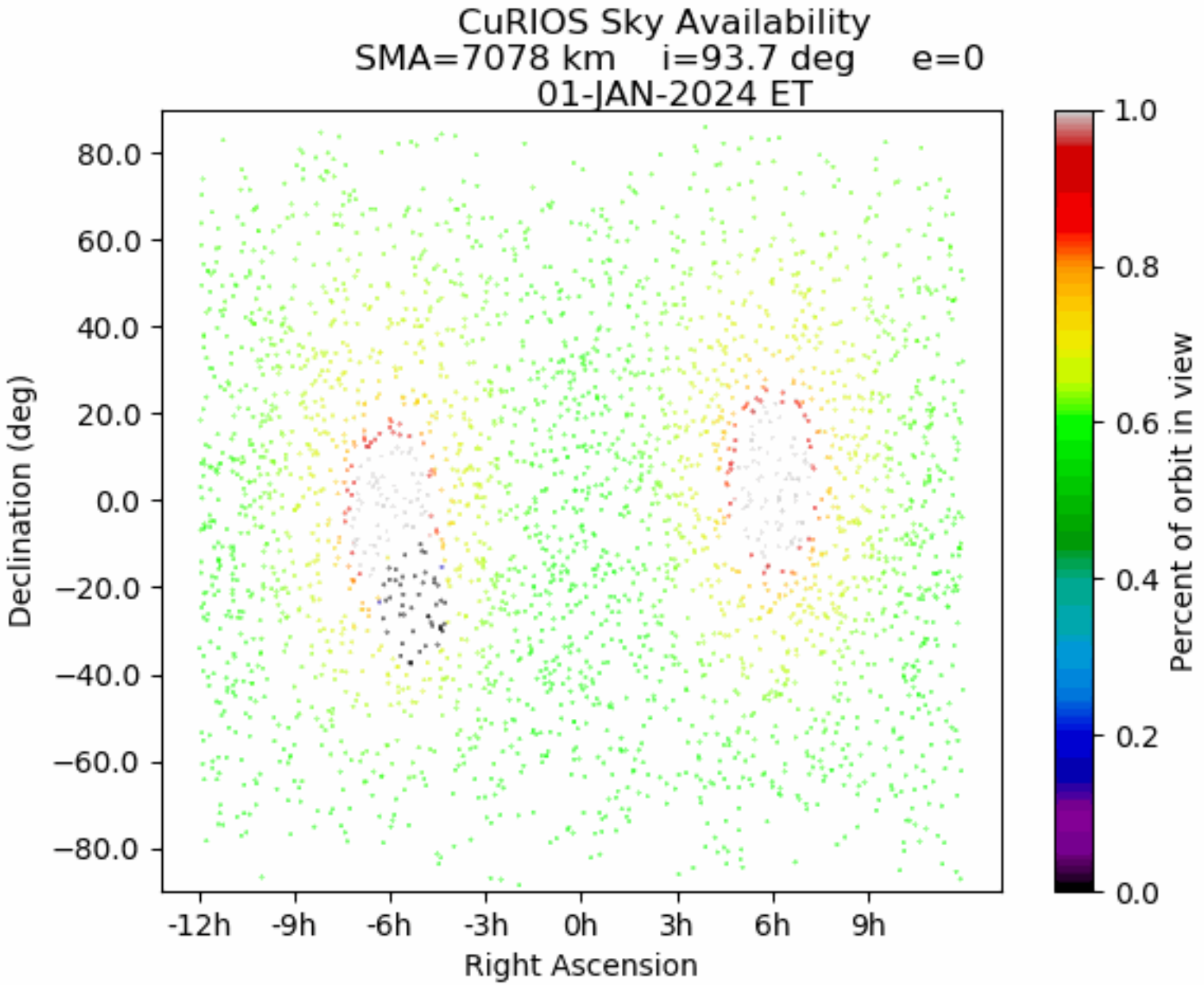
CuRIOS Orbit

Needs: fast downlink speed (closer to Earth), long time on source (higher orbit), and frequent launches

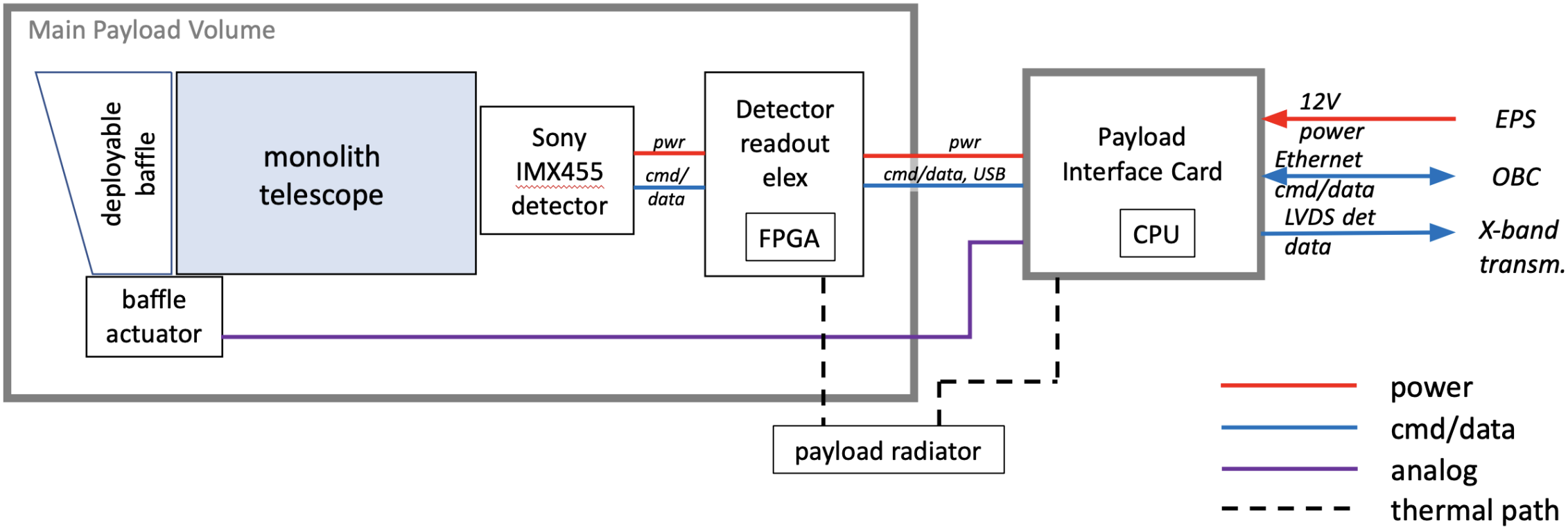
Best balance:

- Sun Synchronous (SSO), LEO
(~500 km, 90 minute orbit)

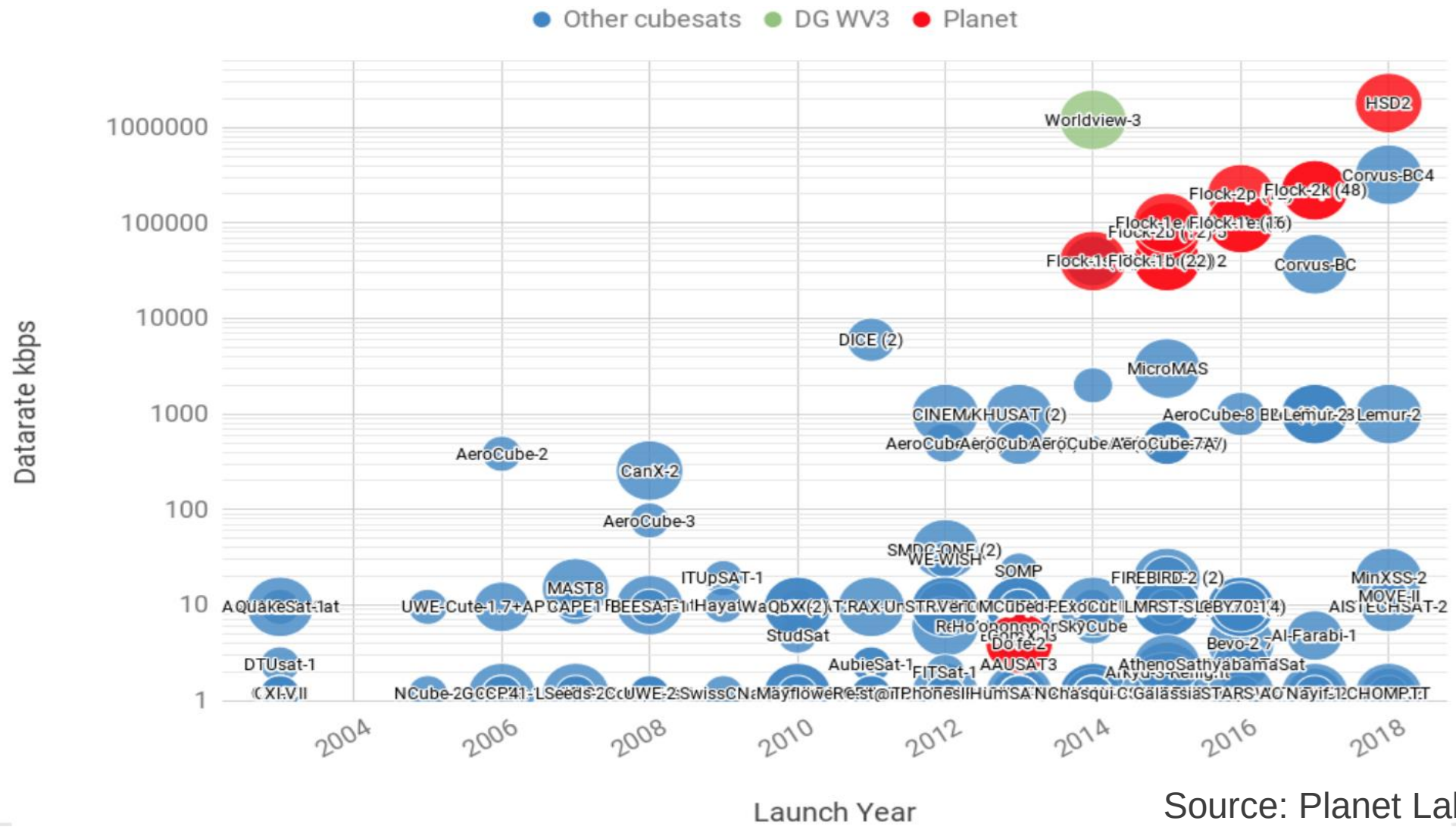
“String of Pearls” for constellation (in progress)



Block Diagram



Data Downloading Current Rates

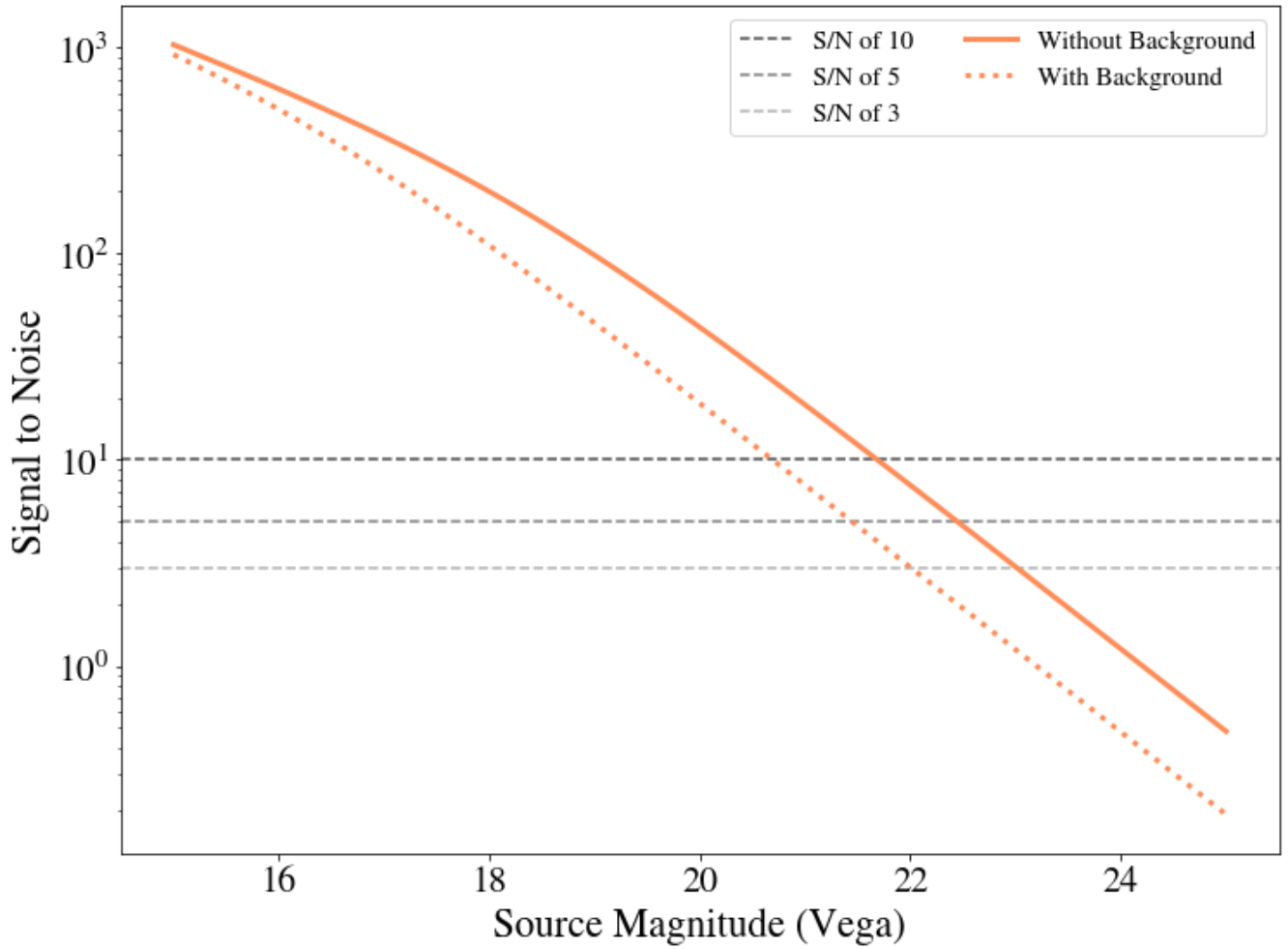


Source: Planet Labs

SNR Performance

Signal-to-noise:

- R-band
- 15 min exposure (composed of 60 frames)
- Background Components:
  - Zodiacal/sky
  - Earthshine
  - Instrumental radiance
  - Mean flux from neighboring stars

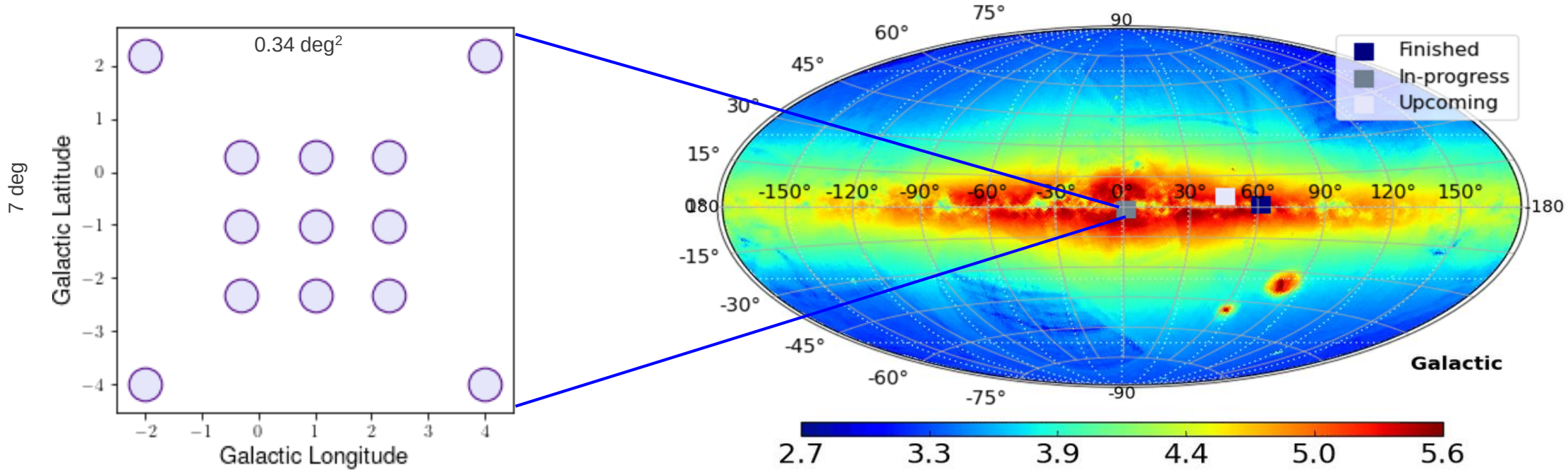


BH Simulations

Population **Sy**nthesis for **C**ompact-object **L**ensing **E**vents (PopSyCLE):

Field selections in the Galactic center and Galactic plane

Interpolate across 49 deg^2 field to estimate total detections



Arenou et al. 2017

Detector Testing

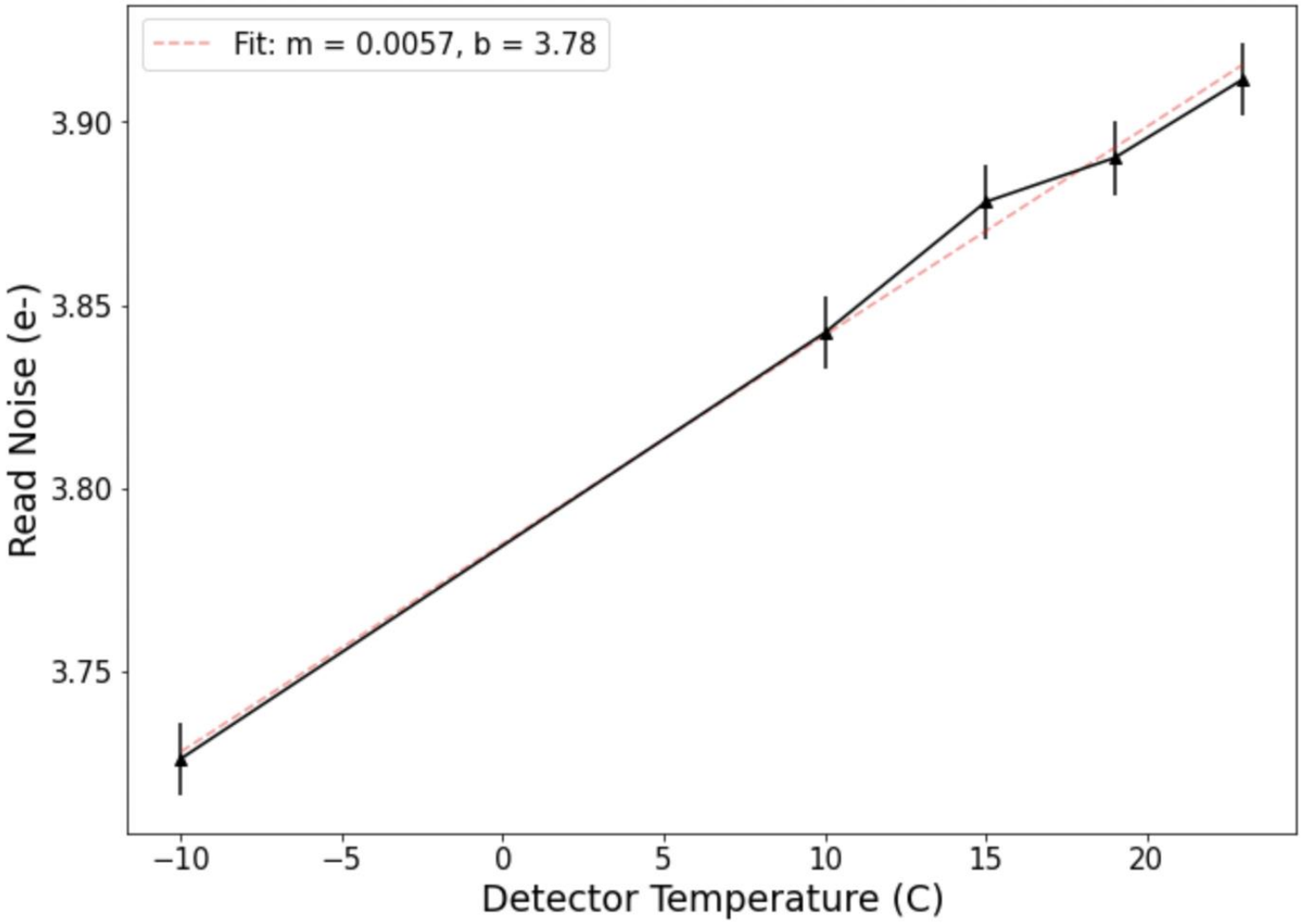
Low gain read noise

Read noise ~3.7 to 3.9 e-

Manufacturer reported:
down to 3.7 e-

Decreases with temperature as:

$m = 5.7 \times 10^{-3}$ e-/C
b = 3.78 e-



Detector Testing

Dark Current versus time and temperature

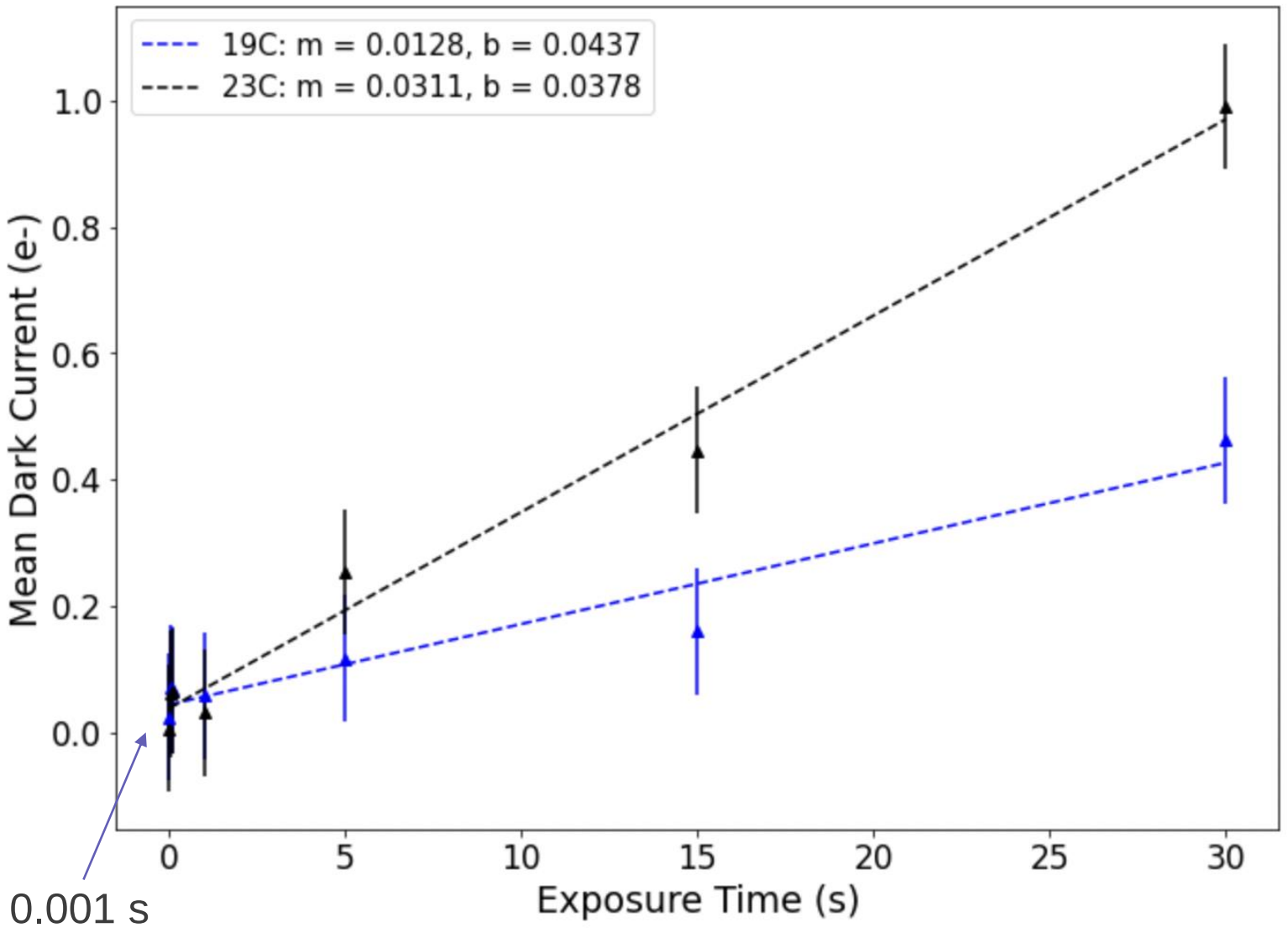
*** full temp profile in progress*

Very low dark current:

19 C	0.0128 e-/s
23 C	0.0311 e-/s

Manufacturer reported:

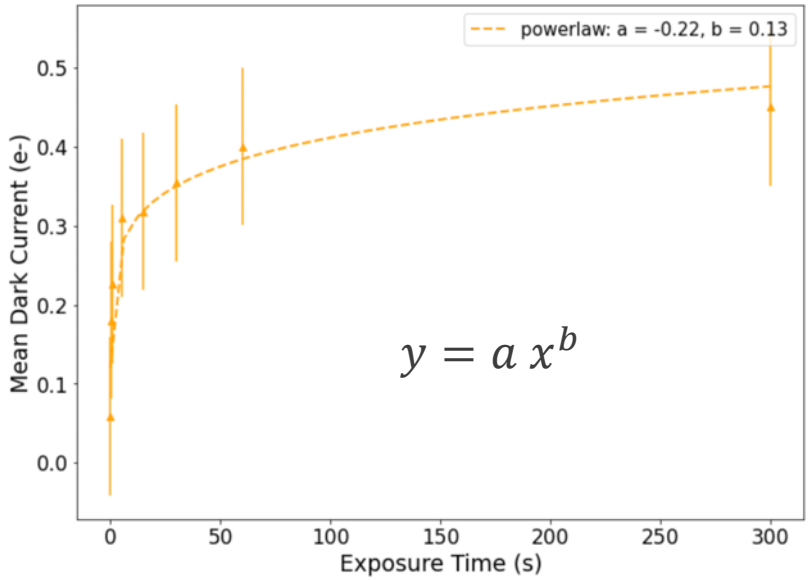
0 C	0.014 e-/s



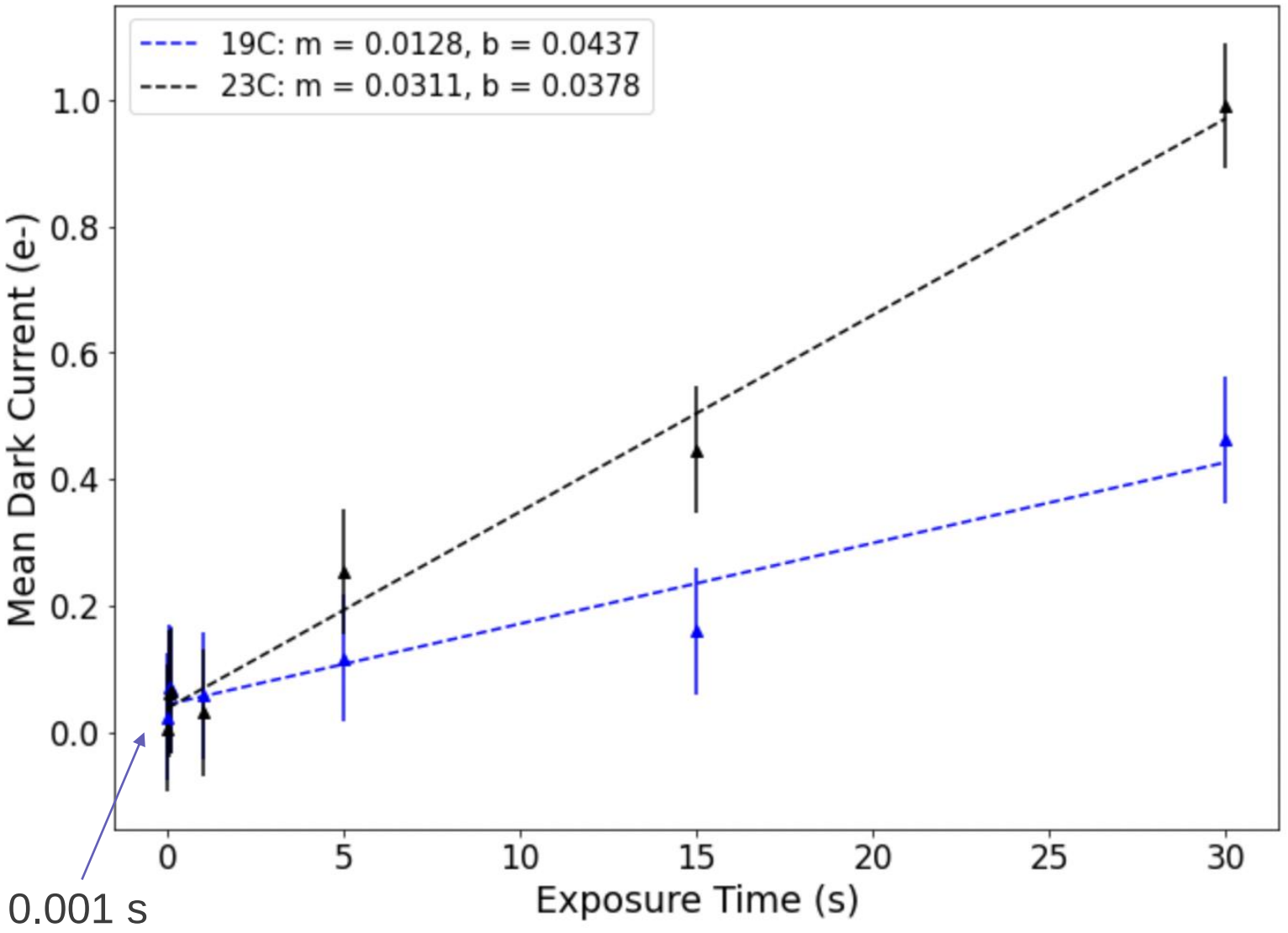
Detector Testing

Dark Current versus time and temperature

Non-linear profile below detector temp < 0C and exposure < 1s



$$y = a\,x^{b}$$



Detector: Sony IMX 455

Detector	Sony IMX455
Resolution (pix)	9568 x 6380 (61 MP)
Pixel Size (μm)	3.76
Max Frame Rate	3.9 Fps (16bit)
Shutter	Rolling
Read noise (e)	1
Full well capacity (ke)	51
Dark current (e/p/s)	*0.014 @ 0C
Cooling	Fan or water or heatsink
QE	*See Figure 1 (the best I could find so far)
Digitization	11, 12, 14, 16
Exposure Range (s)	90e-6 to 12
Dimensions (mm)	70x60x65