# Rapid Multi-Wavelength Correlated Variability with STROBE-X

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# What is "Rapid"?

- It depends (dramatically!) on who you ask …
- Typically from <1μs to ~1000s or longer (9+ orders of magnitude)
- Community/science-dependent; Detector/technology-dependent
  - Photon-counting technologies fastest options
  - "Staring" technologies (i.e. standard CCDs and IR arrays) usually slower, but may have similar ultimate sensitivity at speeds in the ~10 Hz range
- For purposes here, I will address >0.1 Hz (<10s)

# Rotation Powered Pulsars

**Early multi-wavelength work from radio to IR, optical, X-rays, $\gamma$-rays (Crab & other young RPP)**

**Primary science $\Rightarrow$ pulsar emission mechanisms**



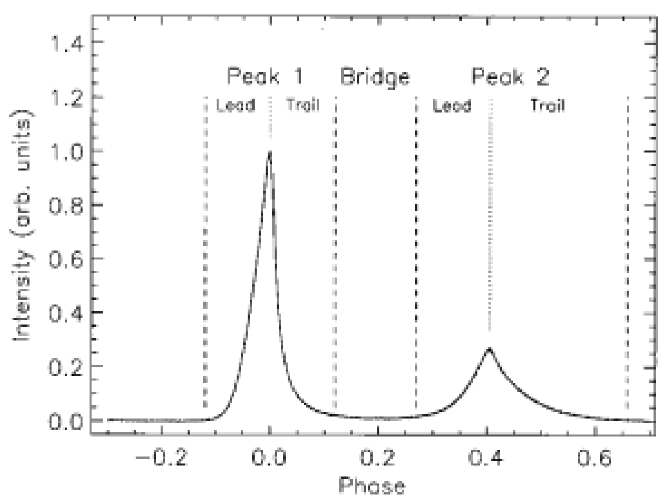



FIG. 1.—Pulse profile with phase conventions used in the analyses

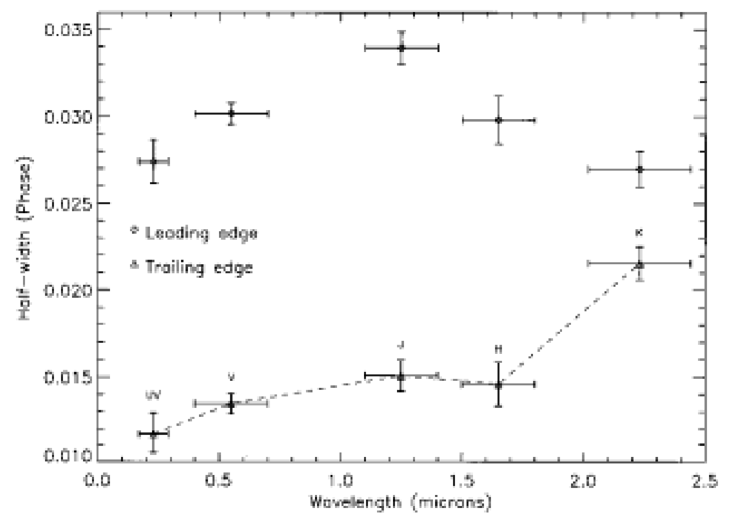
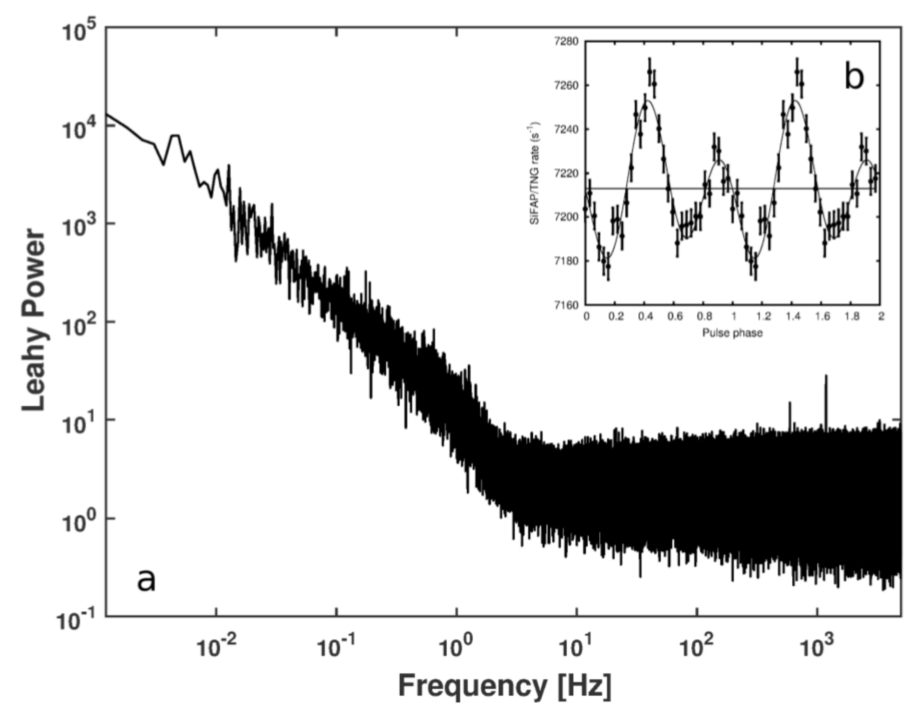



FIG. 2.—Peak half-width half-maximum vs. wavelength for Peak 1 leading and trailing edges.

# Rotation Powered Pulsars

**Recent (last week on arXiv) detection of (relatively bright) optical pulsations from transitional MSP J1023+0038 (Ambrosino et al., 2017)**



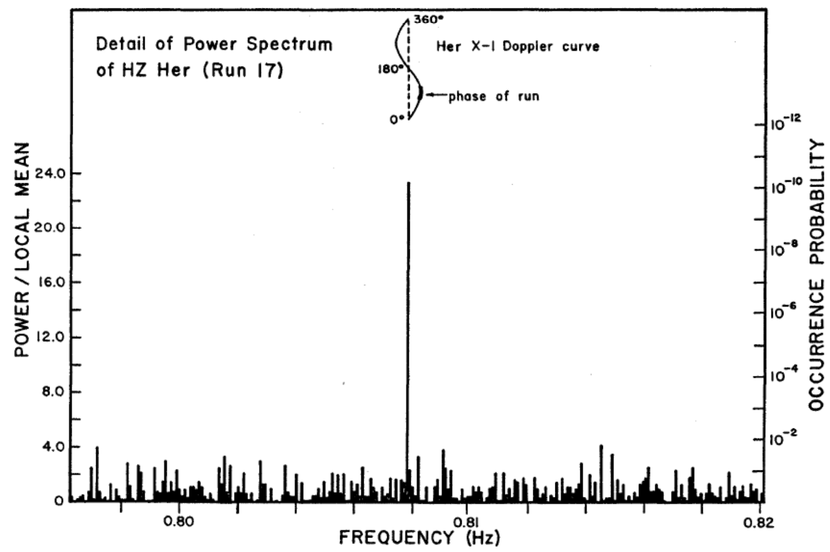

**Potential probe of the transitional magnetosphere**

**Maybe more optical pulsars out there?**

# Accreting Pulsars

Optical pulsations seen from Her X-1 45+ yrs ago

Frequency shifts vs X-ray pulsations (reprocessing on moving surfaces)




Middleditch et al., 1973

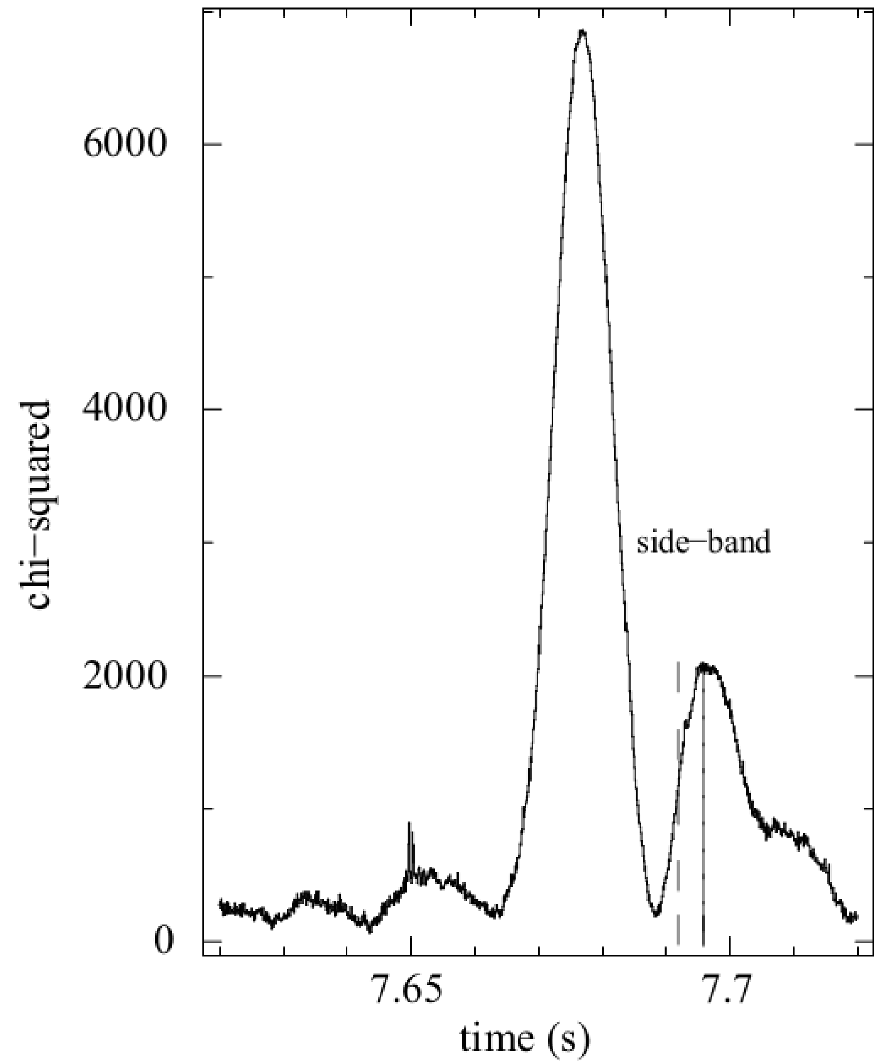
Notable orbital/super-orbital phase dependence $\Rightarrow$ multiple reprocessing sites

# Accreting Pulsars

**LMXB 4U1626-67**

**Shows optical pulsations, QPOs, flares**

**Optical pulses also show sideband due to orbital modulation (?)**



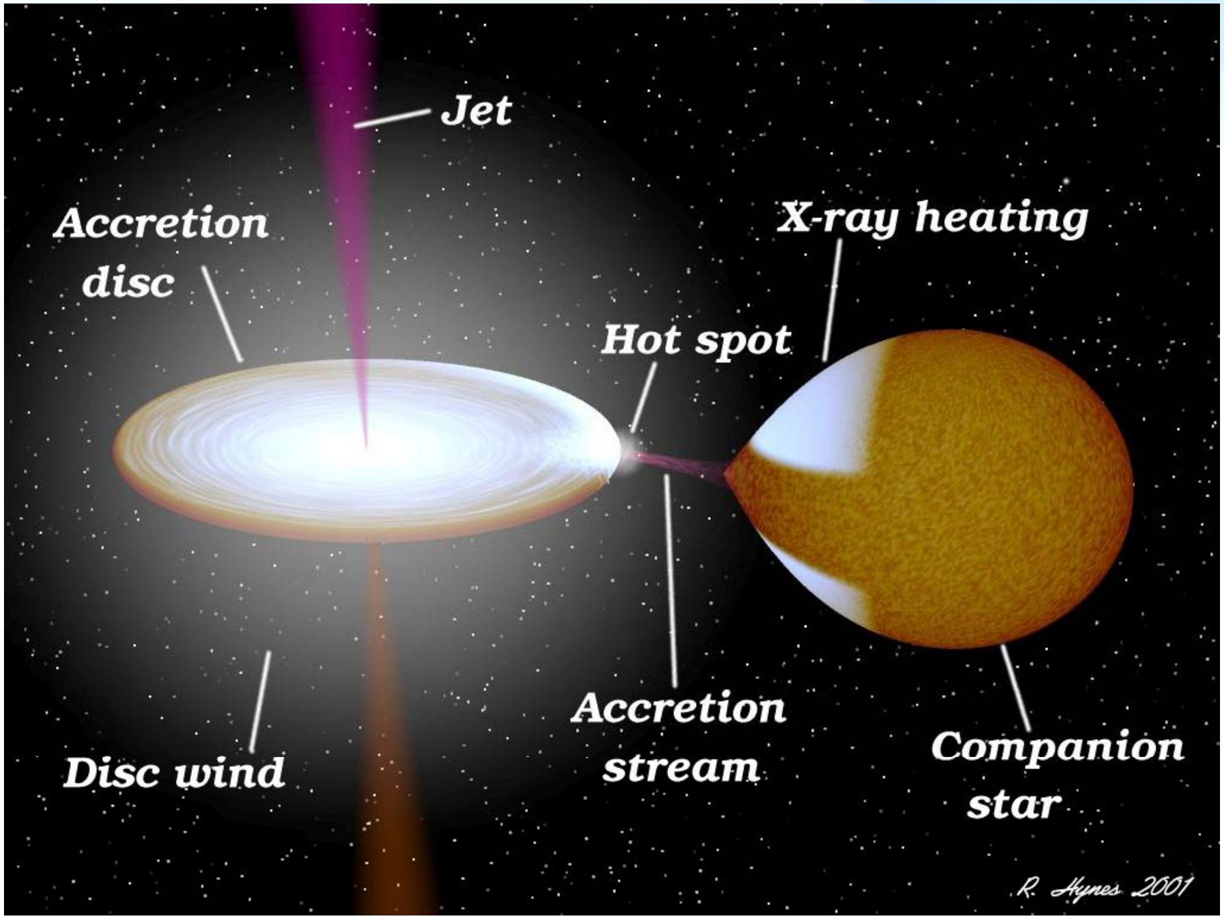

Raman et al., 2016

# X-ray/Optical Reprocessing

Major player in the Accreting Pulsars

Also seen in bursters, Z sources, etc.

Optical reverb can distinguish between near/far X-ray reverb sites

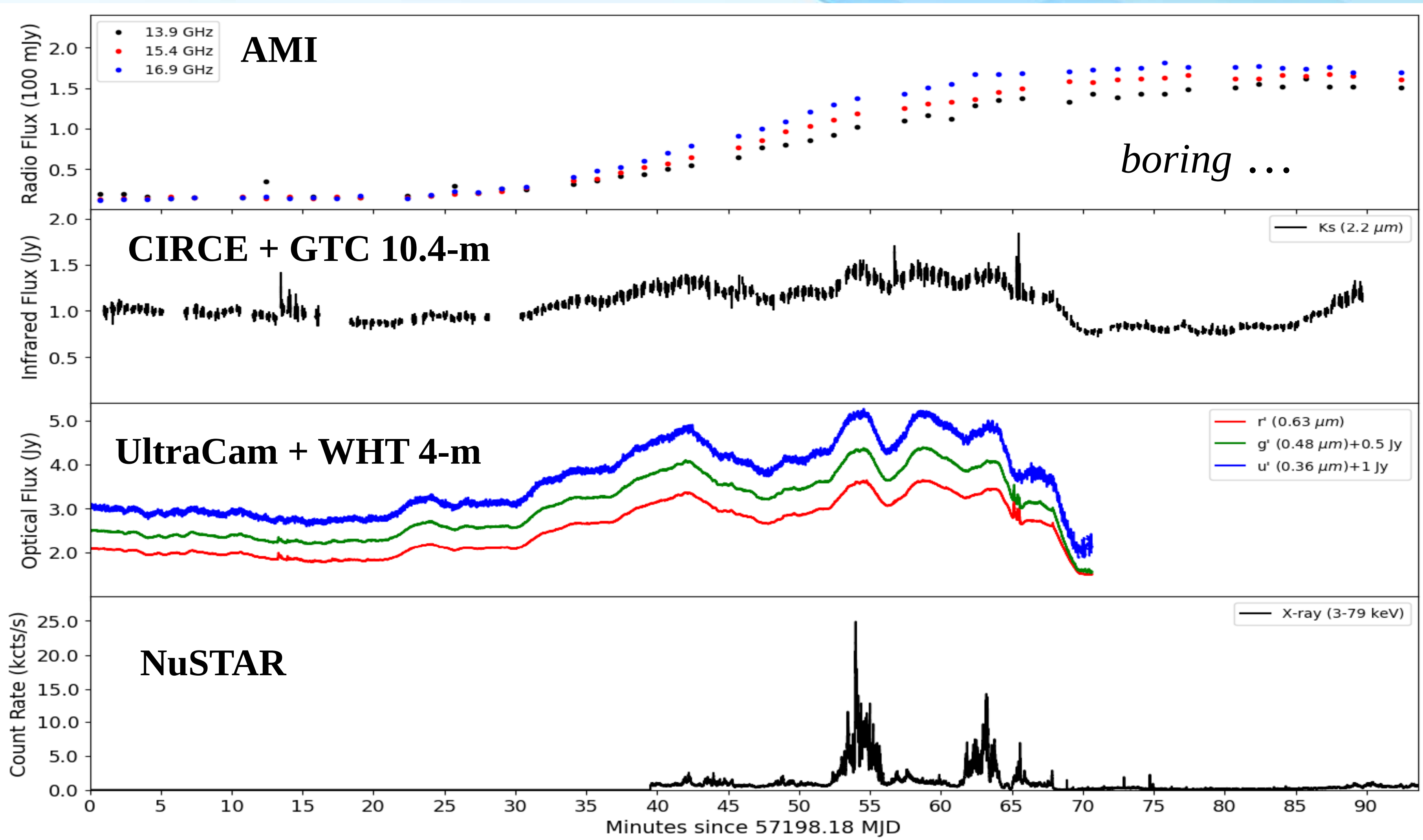


# Relativistic Jets

- Lots of sources show a HUGE variety behaviors
- Flares (from <1s to $10^4$ s)
- QPOs
- Reprocessing of jet flux
- Spectral lines
- Polarization
- Recent example V404 Cyg

# V404 Cyg Rapid Multi-Wavelength

**Y. Dallilar, SSE, et al., 2017, *Science* (accepted)**



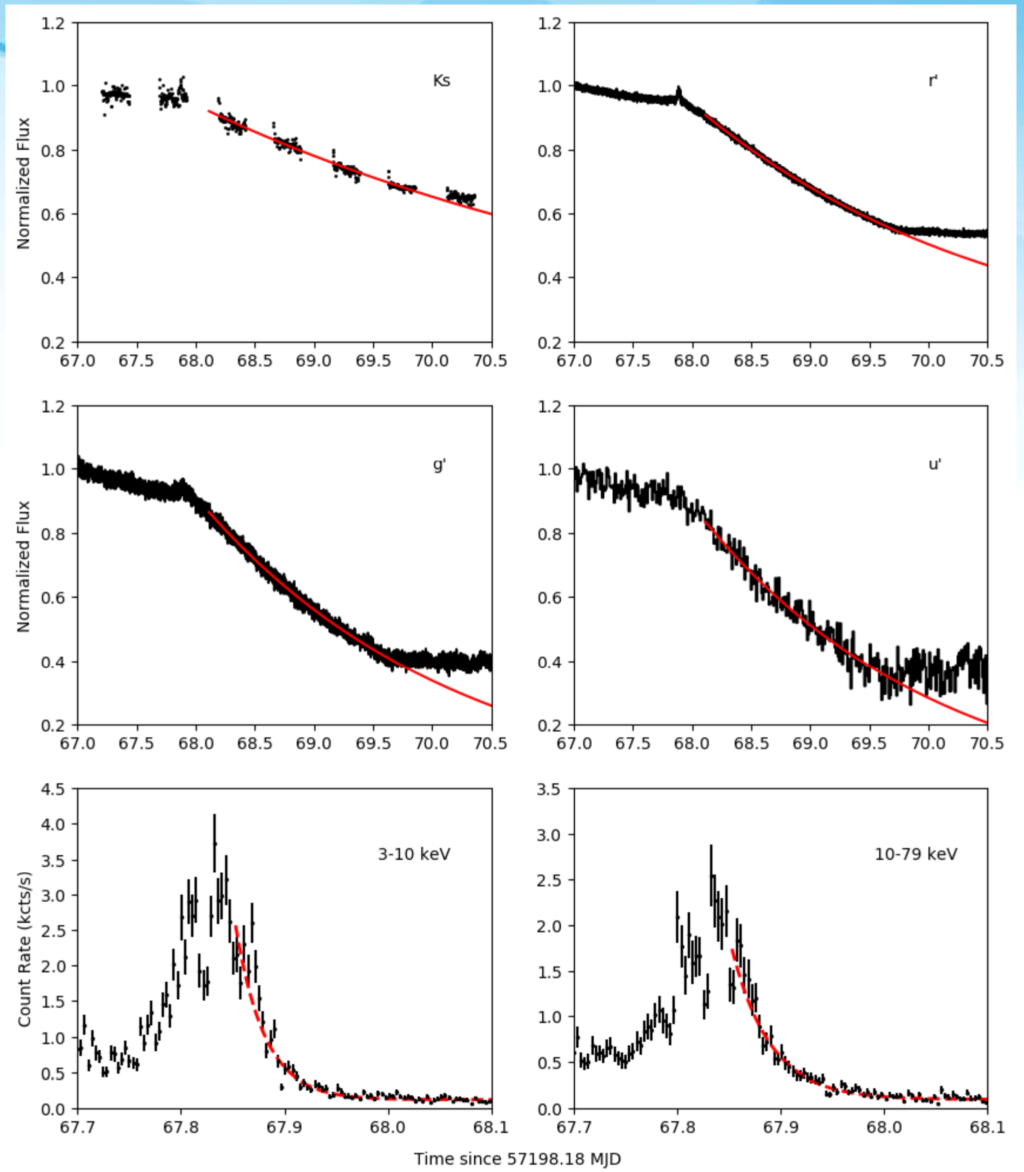
# V404 Cyg – “Big Dip”

**Broadband “Decay”**

**Seen in all bands exc. radio**

**Simultaneous start**

**Decay timescale varies with energy**



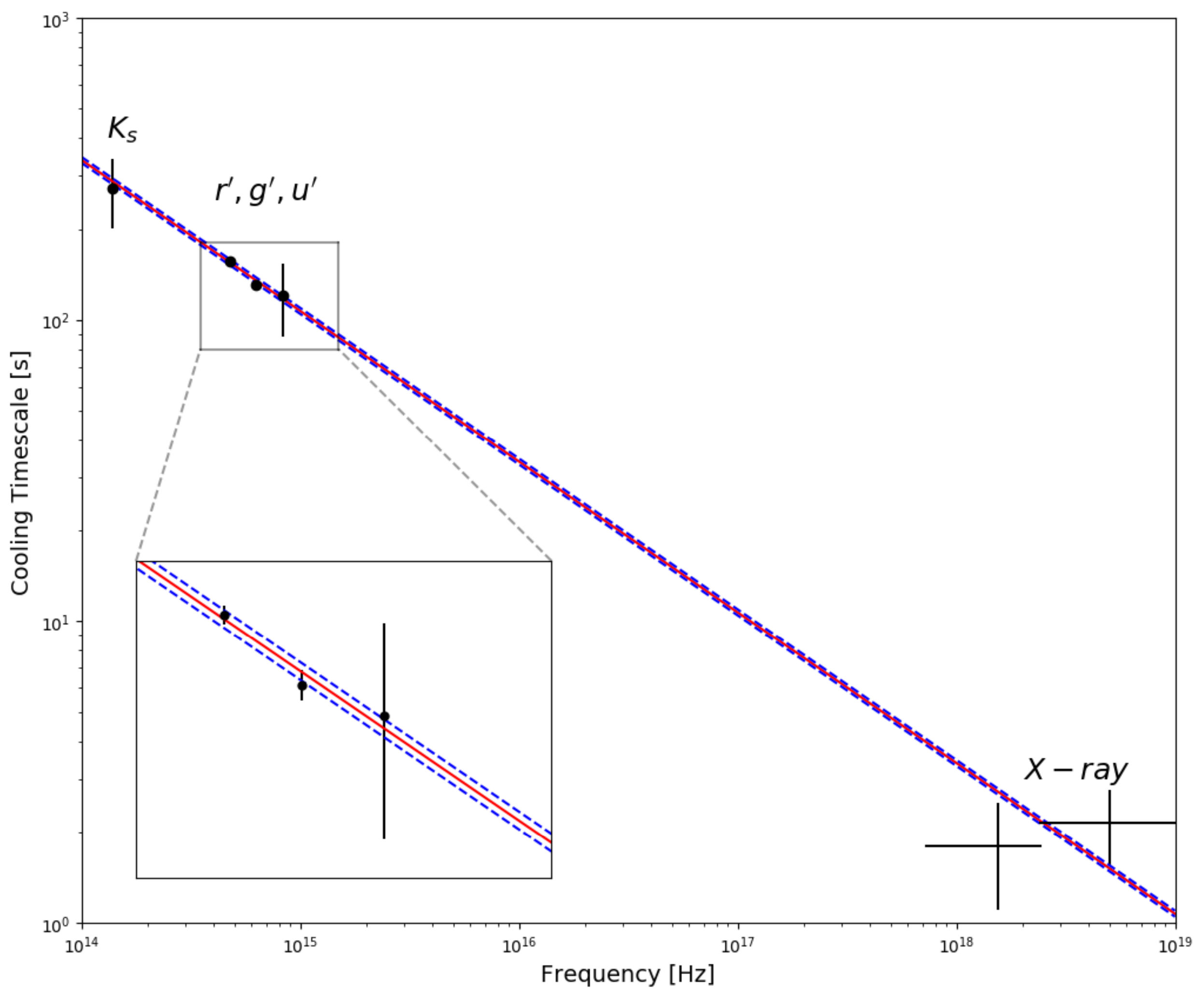
# Synchrotron Cooling

$\tau \sim \upsilon^{\alpha}$

**$\alpha$= -0.49 ±0.03**

**Matches synchrotron cooling ($\alpha$= -0.5)**

**B = 461 ± 12 G**



# *What is it?*

**A cloud of relativistic electrons in a magnetized blob, dominated by synchrotron cooling from IR to X-rays**

**No evidence of expansion**

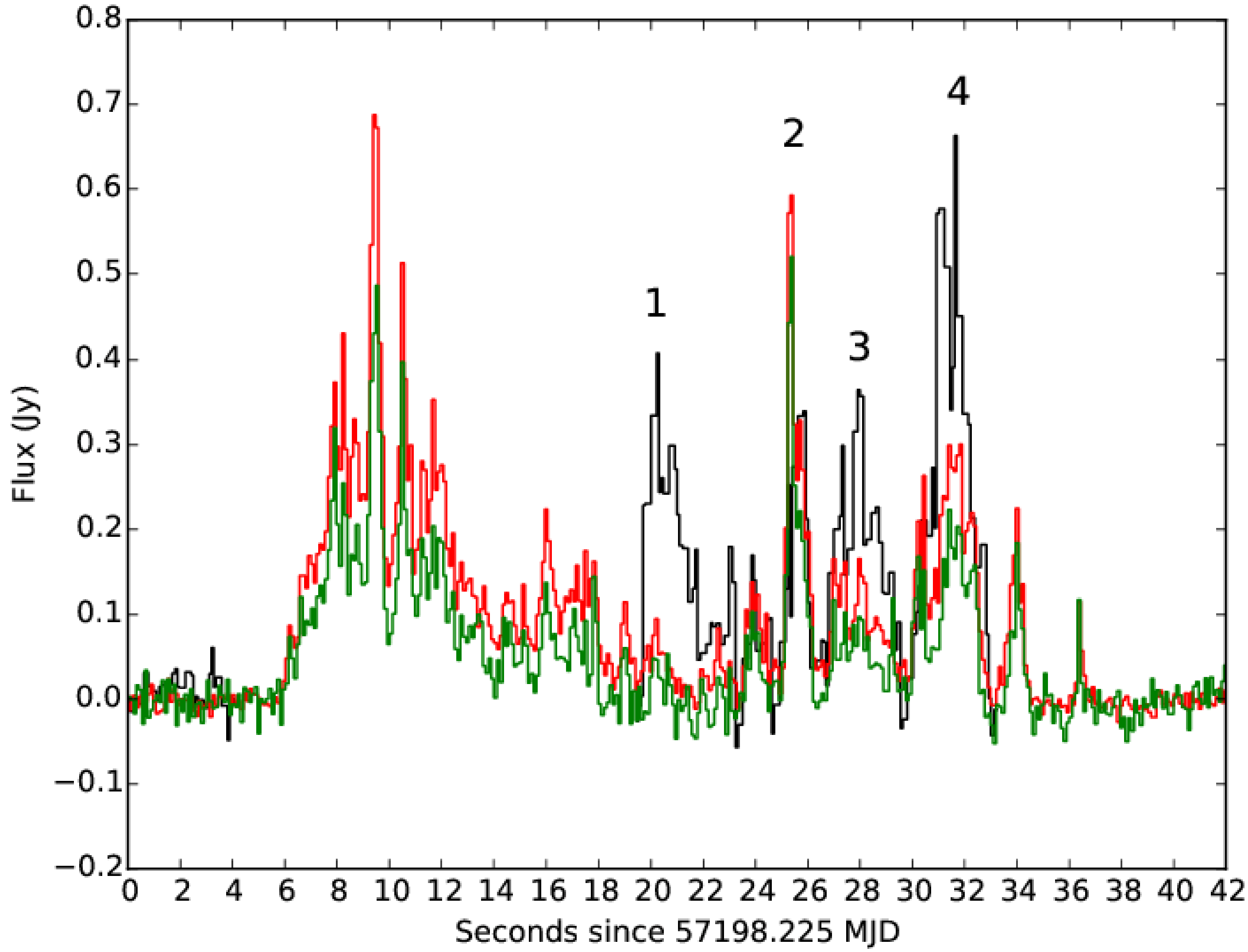
- Same apparent B-field for >200s
- Adiabatic expansion would change cooling timescale

**Long duration of the overall event (hours) ⇒ Quasi-steady**

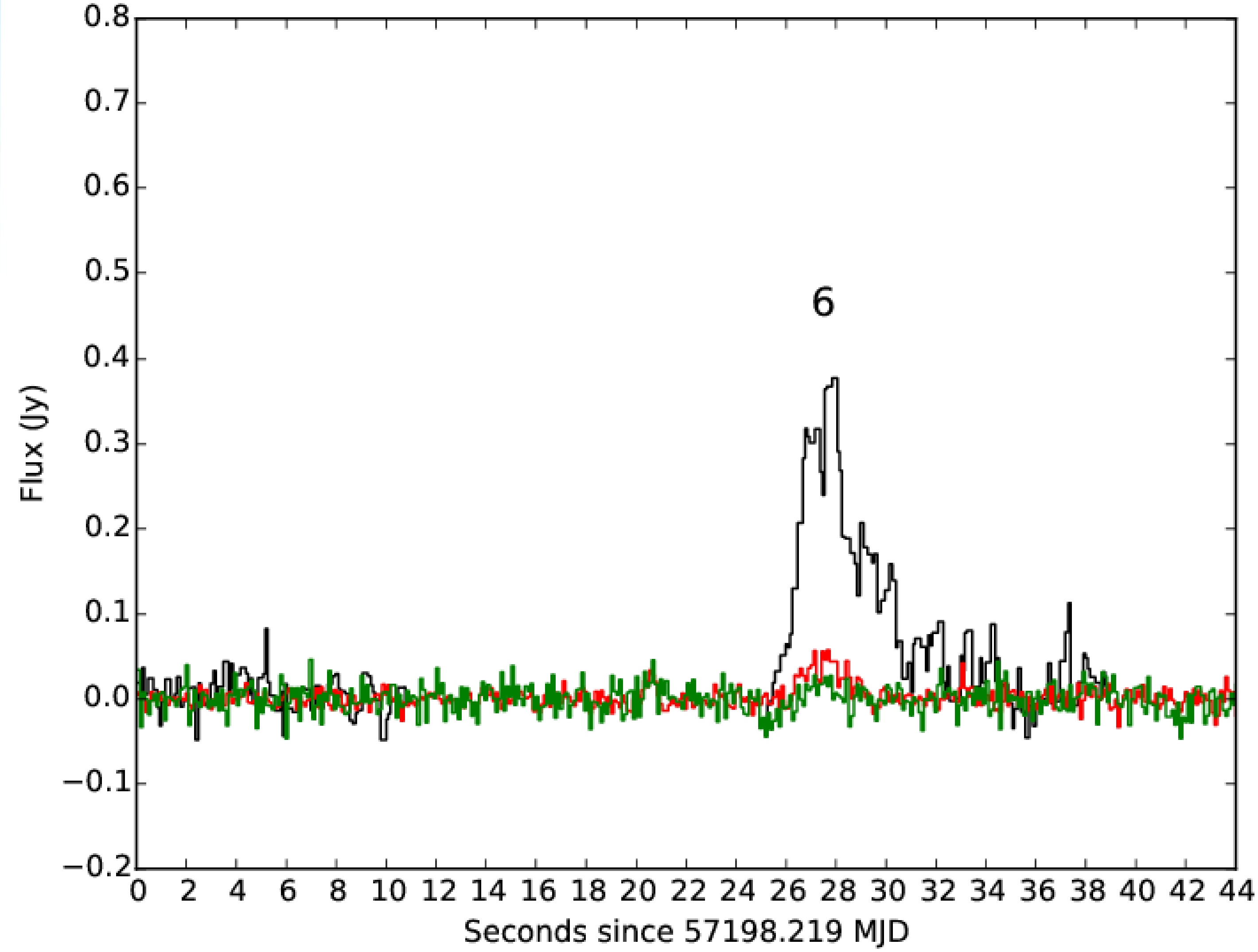
So … a quasi-stationary cloud of high-E e- around a black hole during a jet-producing episode

**⇒ the (jet-launching) corona (!!??!!)**

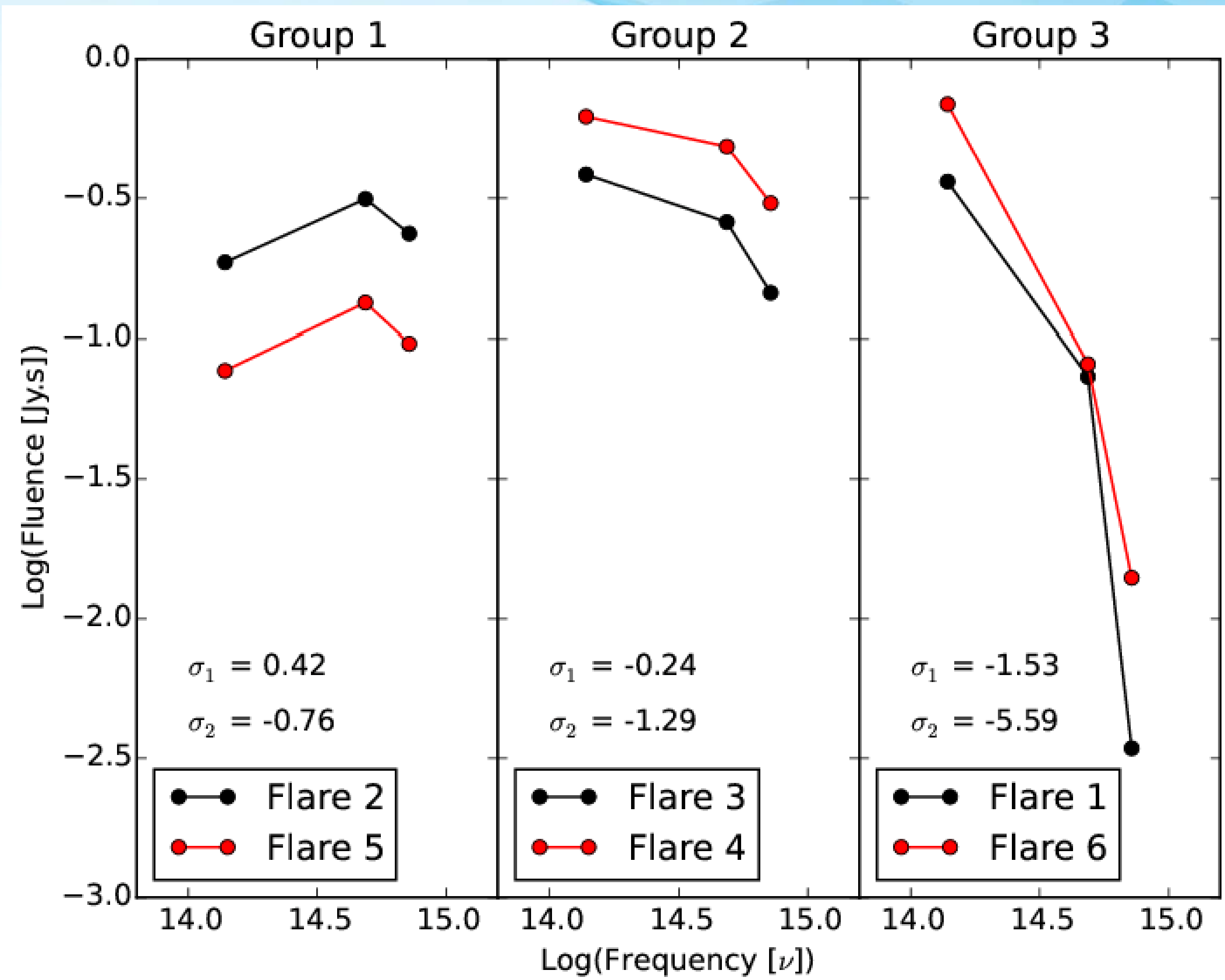
# Fast Optical/IR flares



# Fast Optical/IR flares



# Fast Optical/IR flares



# *What do the fast flares tell us?*

- $T_b > 10^7$ K $\Rightarrow$ non-thermal (as Gandhi et al. 2016 surmise)
- SEDs vary wildly:
    - "Peaked"
    - "Optically thin"
    - "Cutoff $e^-$ distribution"
- SEDs change quickly
    - Only seconds separate flares of different SED
- SEDs soften only slightly over flare time
    - Cooling seems ~adiabatic
    - Probably jet-like plasmoids (??)
    - **More to come …**

# Rapid Multi-Wavelength Correlated Variability with STROBE-X

Scientific drivers are strong: probing accretion structure, magnetosphere geometry, relativistic jet launching

Optical/IR MUCH more informative than radio

Previous impact – a mixed bag

Why?

Optical/IR resources often not available when needed … (= we're doing it wrong!)

# What resources do we need?

Telescopes (How big?)

- Can see lots of these things with 1-m class in optical
- Good S/N with 2-m to 4-m class
- Bigger often better … (but better is the enemy of good enough)

Instruments: Fast, low-noise, high QE

- But not many pixels needed (3-5 “pixels”)

Coordination

- Need access to telescopes (at the right time)
- Need the right instruments on them (at the right time)

# Things are improving …

## Telescopes

Lots more time available on 4-m class

Queue scheduling of large telescopes with rapidly-selectable instruments

## Instrument technologies

Frame Transfer CCDs & Fast IR arrays to ~kHz

APDs: Vis/IR photon-counting with good QE (~80%)

Fast polarimeters too

## Coordination

Queue-scheduling and TOOs more common now

SmartNET (http://www.isdc.unige.ch/smartnet/)

# PolyOculus: A Different Approach

- **Low-cost quasi-dedicated optical/NIR timing/spectroscopy**

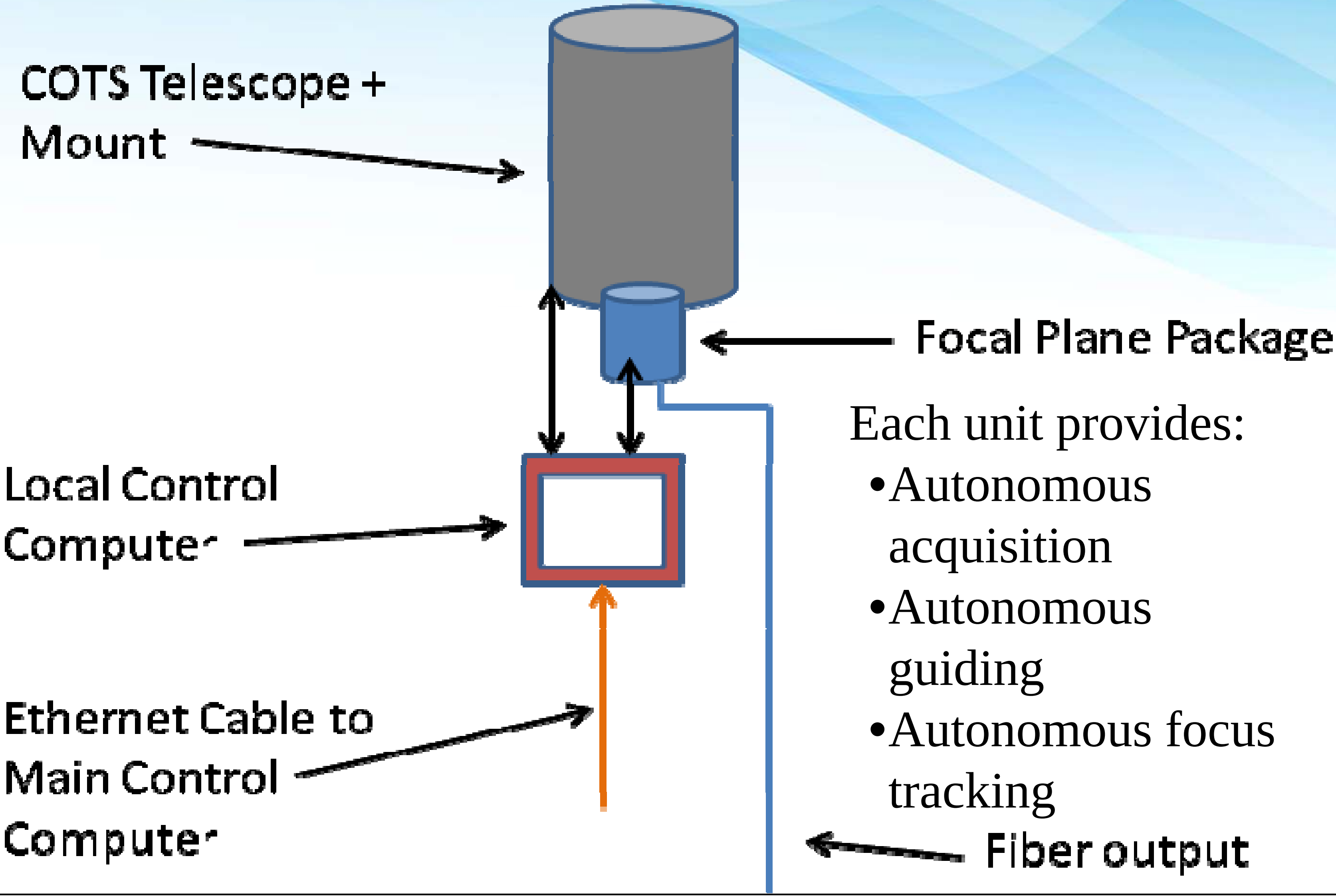
- **Recent evolution in key COTS technologies:**
  - **Low-cost telescopes with <1-arcsec guided tracking**
  - **Low-cost, small-package PCs (<$200 for Jetson)**
  - **Low-cost high-performance fast CCDs for A&G**

- **Use optical fibers and photonic technology to combine the light, and "synthesize" larger apertures**

- **Cost per square meter drops by ~10 compared to standard telescopes**

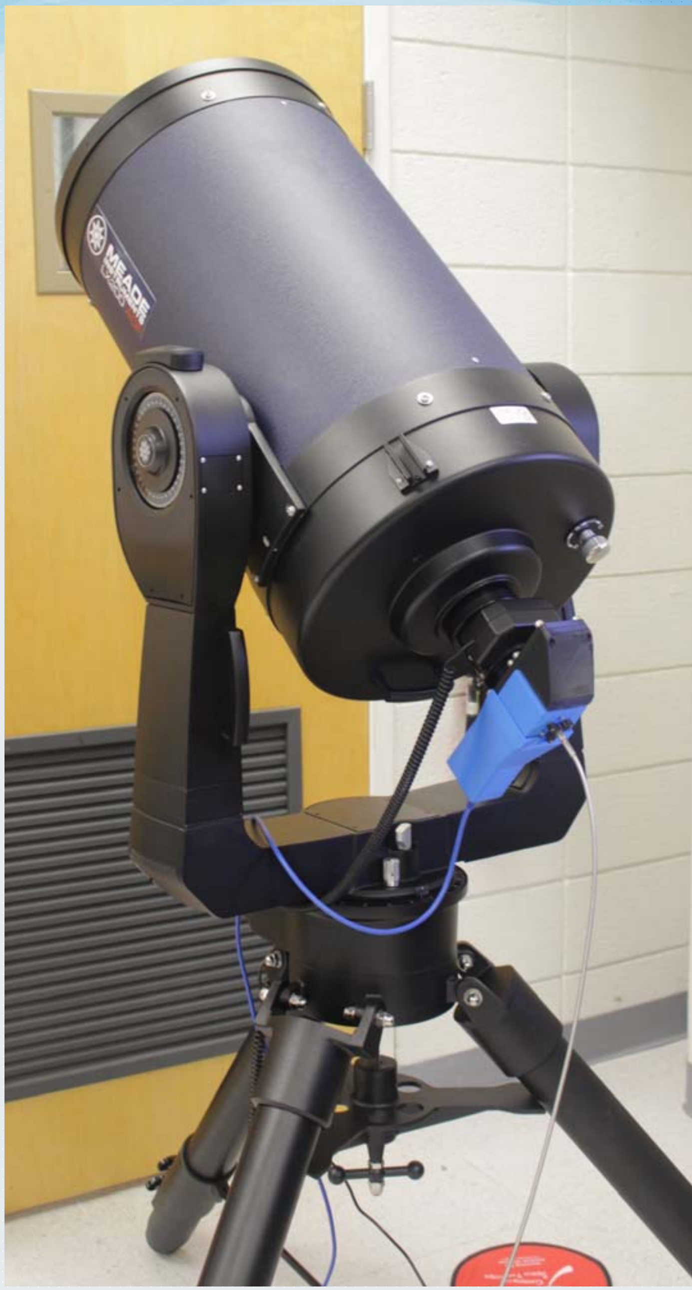
- **Dynamically re-configurable from single large aperture, to multiple autonomously-pointing/observing small apertures**

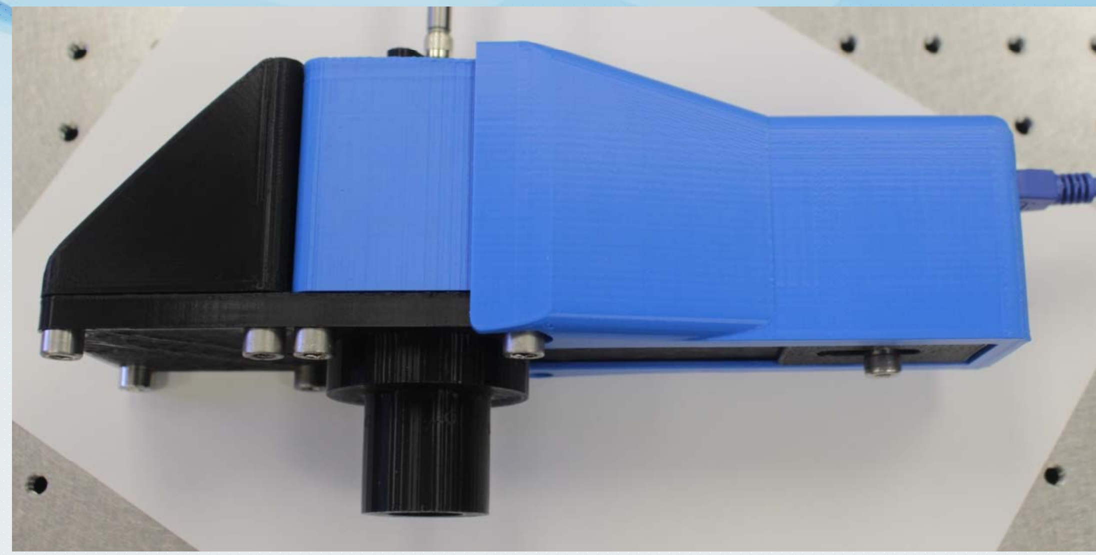
# PolyOculus Basic Unit

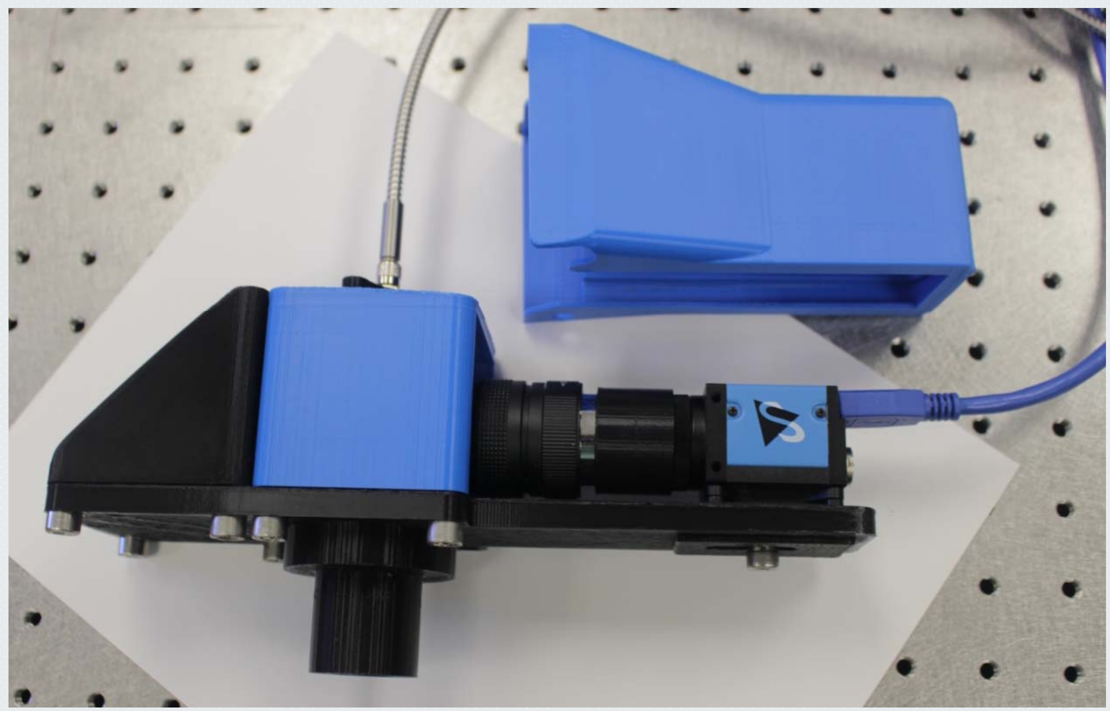



Each unit provides:
- Autonomous acquisition
- Autonomous guiding
- Autonomous focus tracking

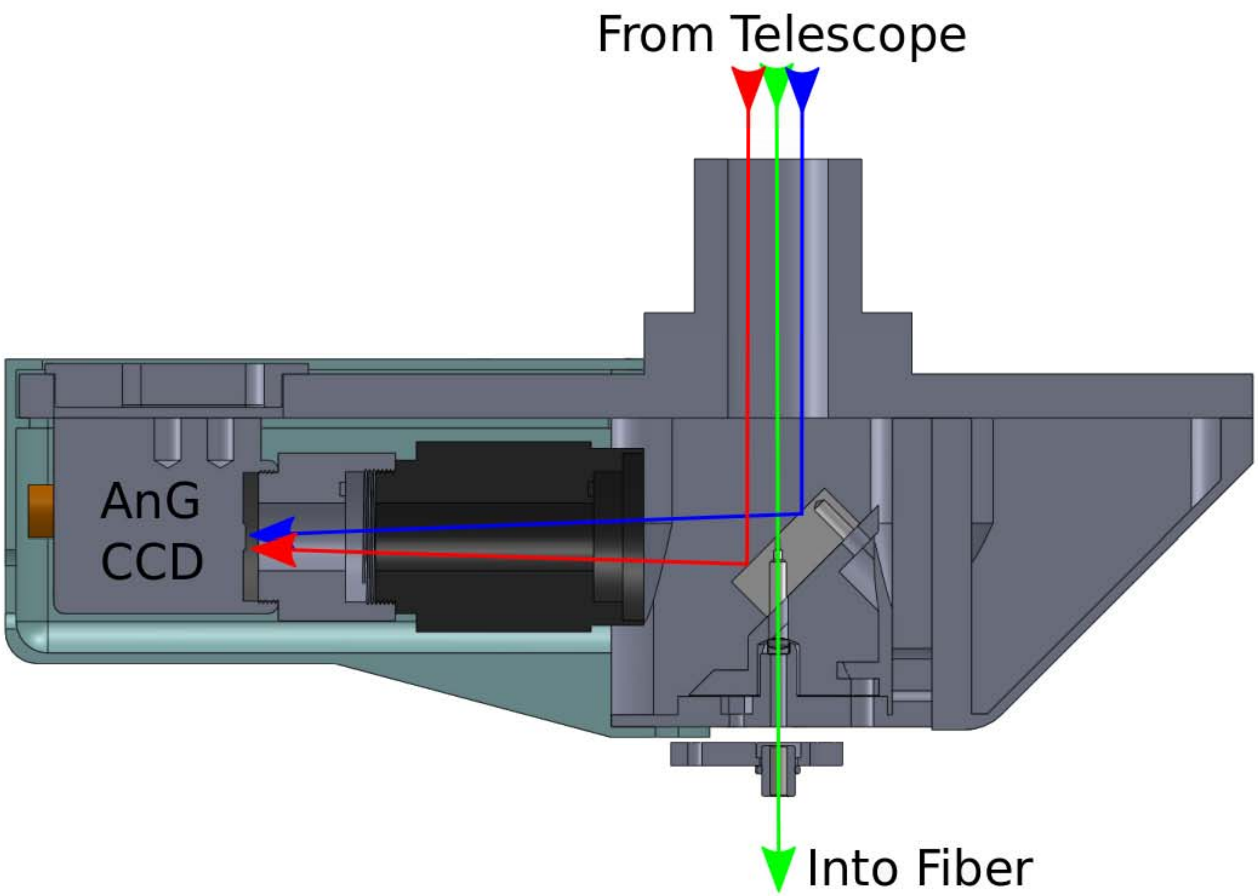
# PolyOculus Robotic Telescopes



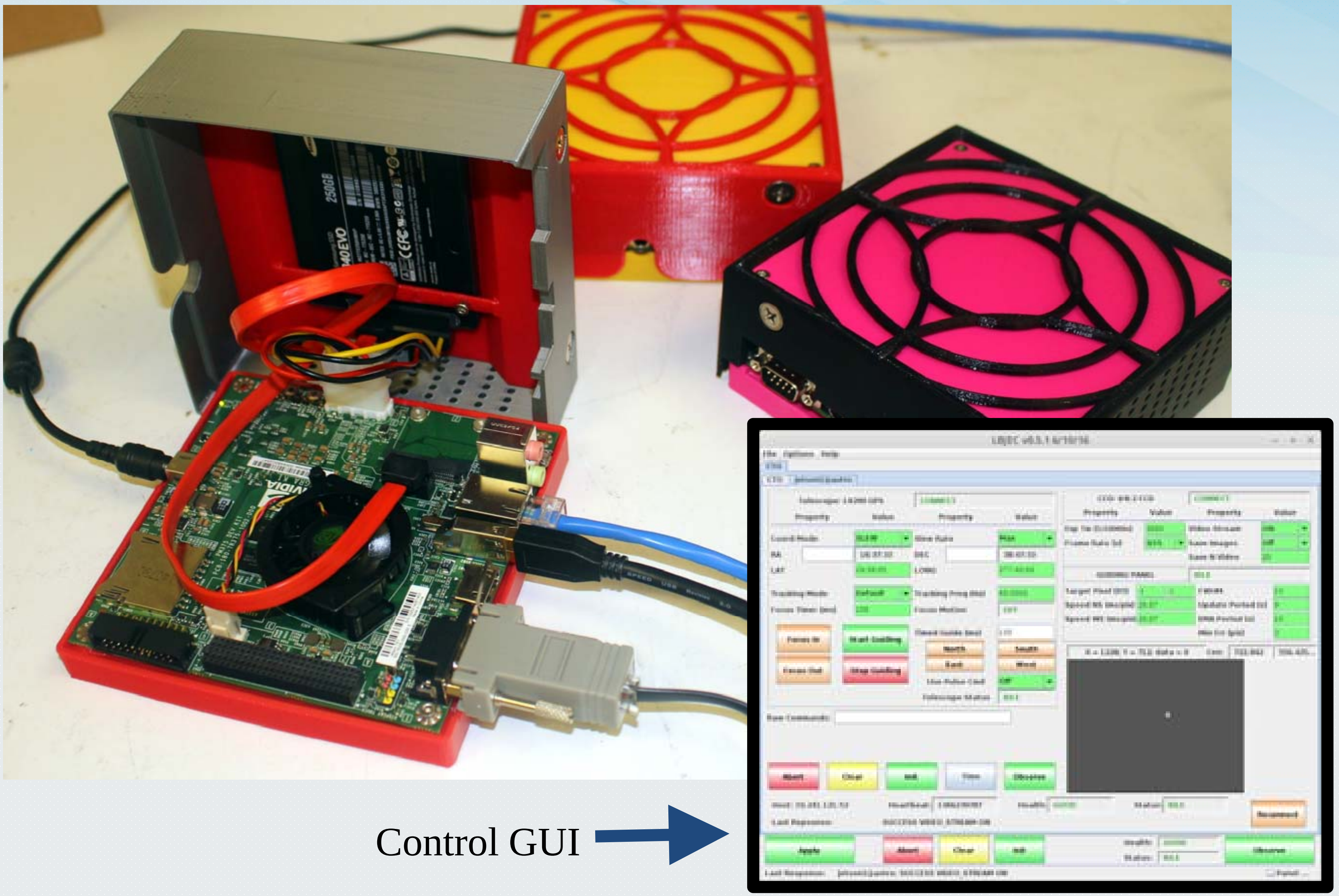




# Acquisition and Guiding

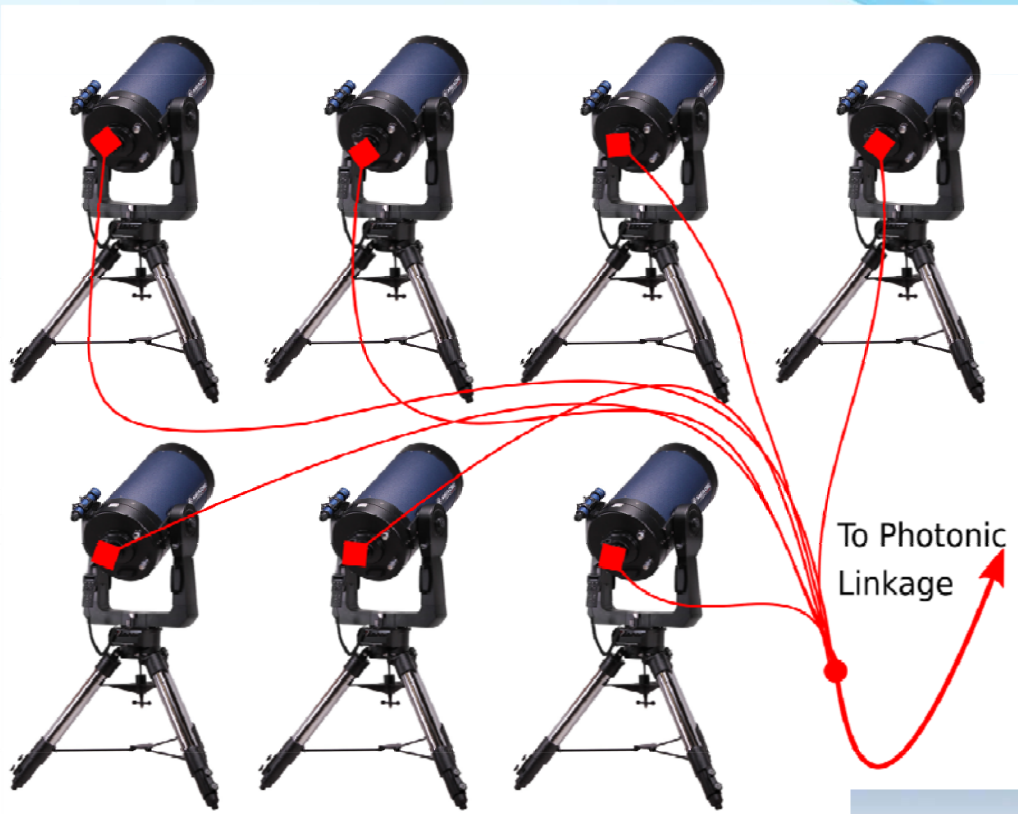


# Jetson Computers

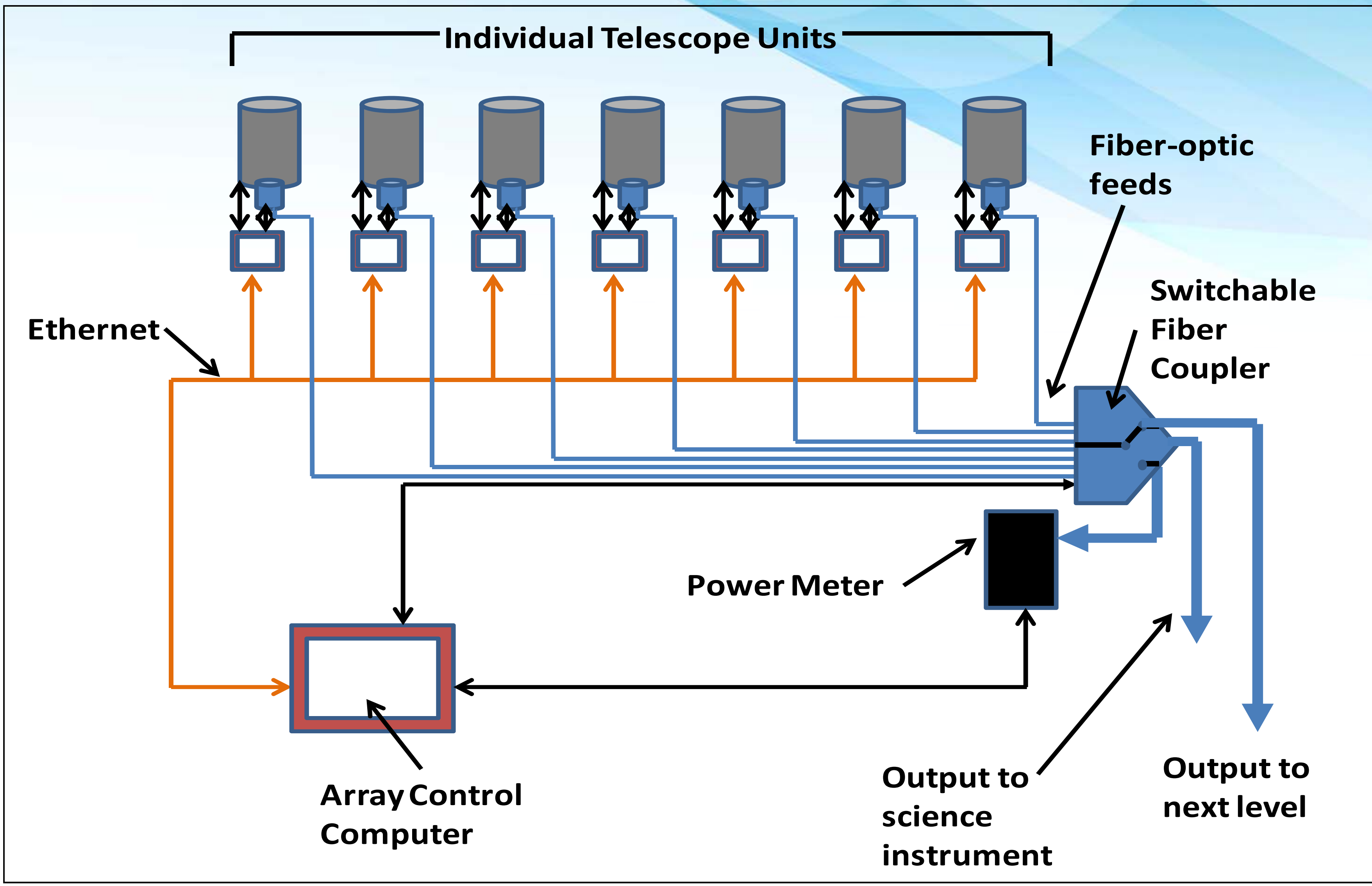


Control GUI

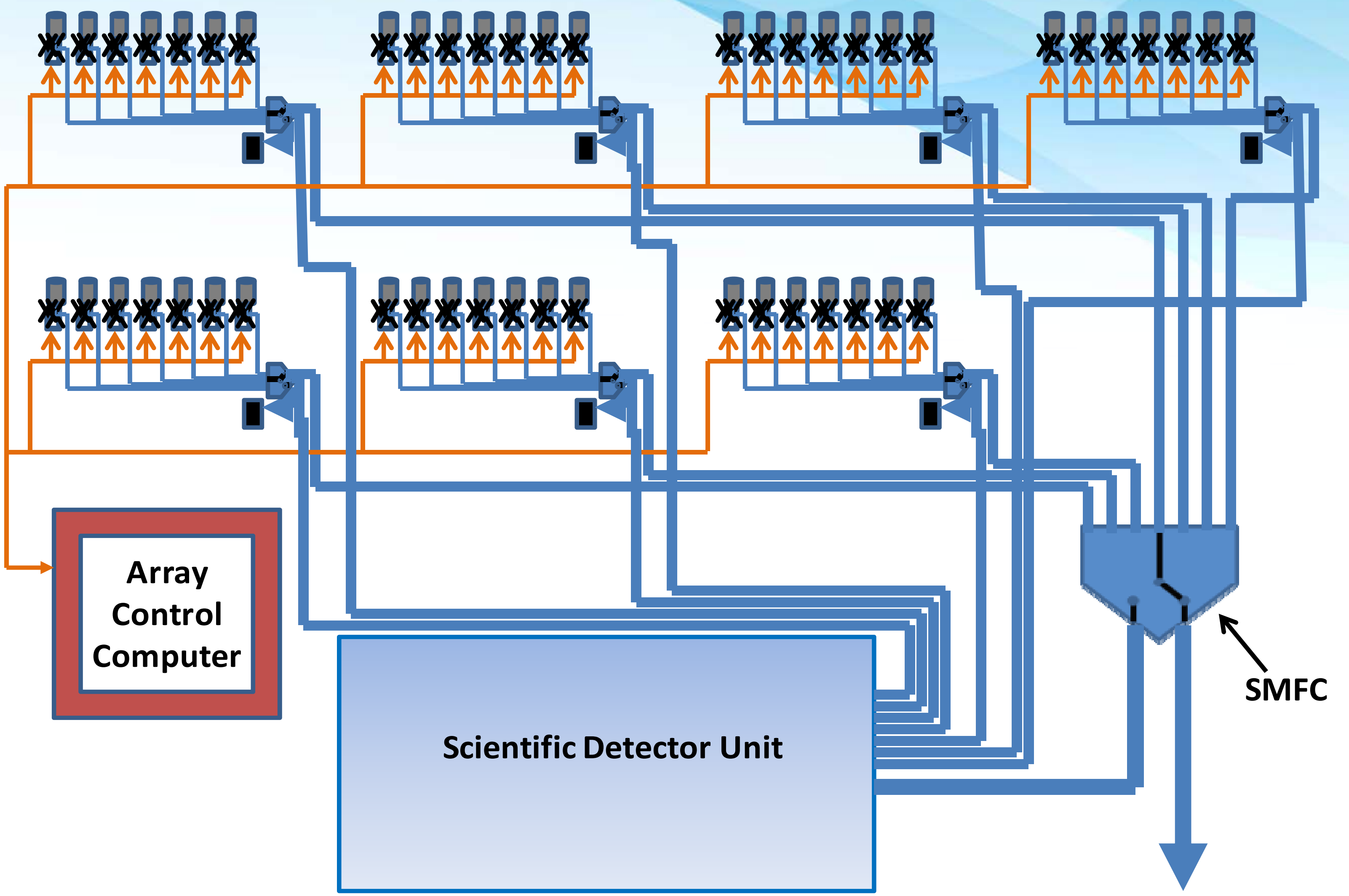
# PolyOculus – Photonic "Lightbucket" Telescope Arrays




# PolyOculus – Basic "7-Pack" Unit



# PolyOculus – “Level 2” Unit



# PolyOculus Cost Comparison

| Telescope | Cost | Cost/(sq. m) |
|---|---|---|
| Std 1-m | $750K-$1M | $1M - $1.3M |
| Std 2.5-m | $6M-$10M | $1M - $1.5M |
| Std 4-m | $20M | $1.5M |
| Keck 10-m | ~$100M (current $) | $1.3M |
| TMT 30-m | $1000M (facility) | $1.3M |
| PolyOculus Level-1 | $150K | $0.2M |
| PolyOculus Level-2 | $800K | $0.16M |
| PolyOculus 17-m | $28M | $0.1M |
| PolyOculus 42-m | $157M | $0.1M |

# PolyOculus & Strobe-X

**PolyOculus can be coupled to low-cost APDs (target, comparison stars, sky bkgd) or spectrographs**

**Cost per square meter drops by ~10x compared to standard telescopes**

**Dedicated low-cost facility – always available; Single-site ~$1M total cost**

**Multiple sites could provide excellent (~75%) overlap with Strobe-X for total cost ~$5M; During "off-time" (>50% per site) can do LSST follow-up spectroscopy**