Introduction to Photometry

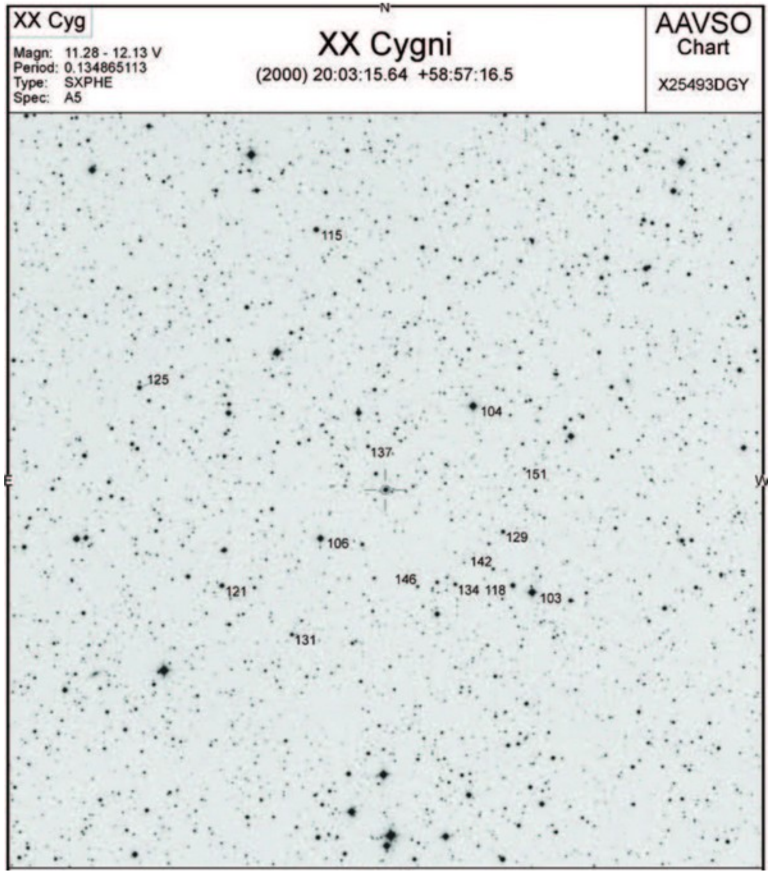
Martin Jelínek

MJ?

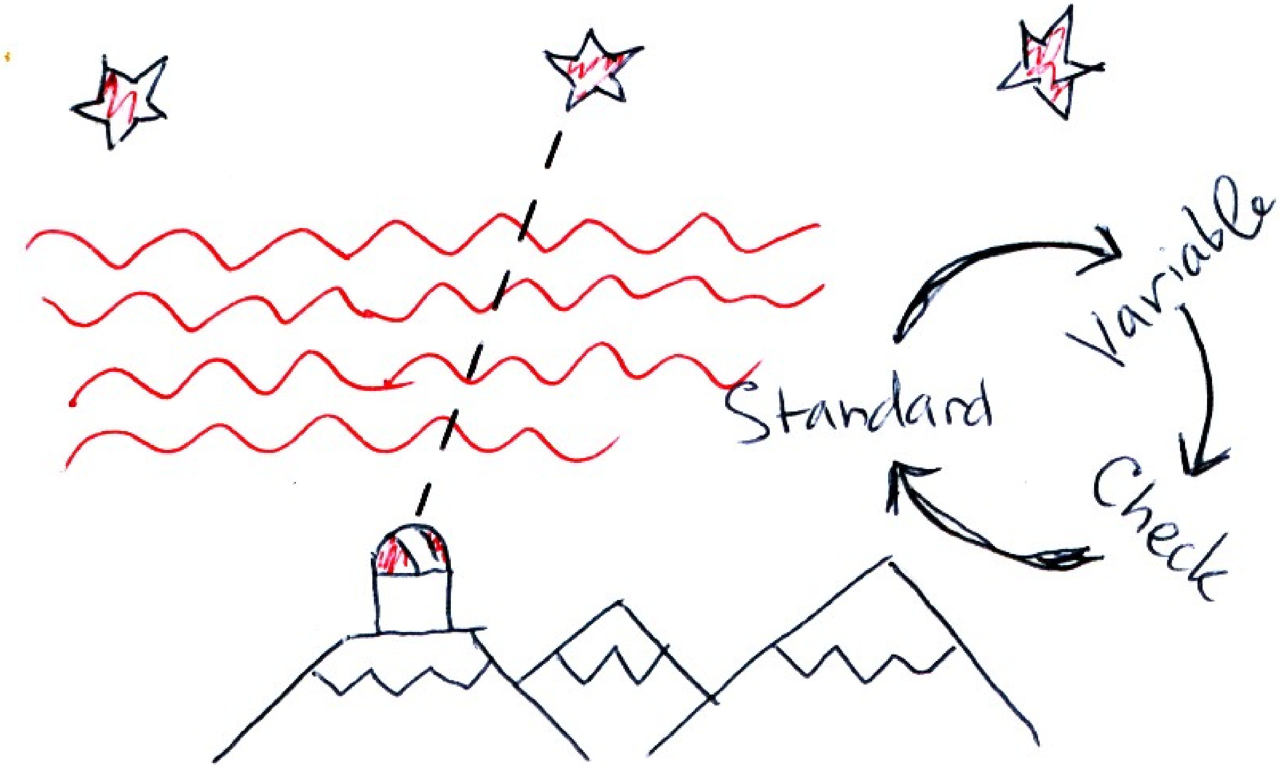
- Transient astronomer
- Robotic telescopes
- Prague + Granada
- Photometry
- Low res. spectroscopy

Why would we still use photometry?

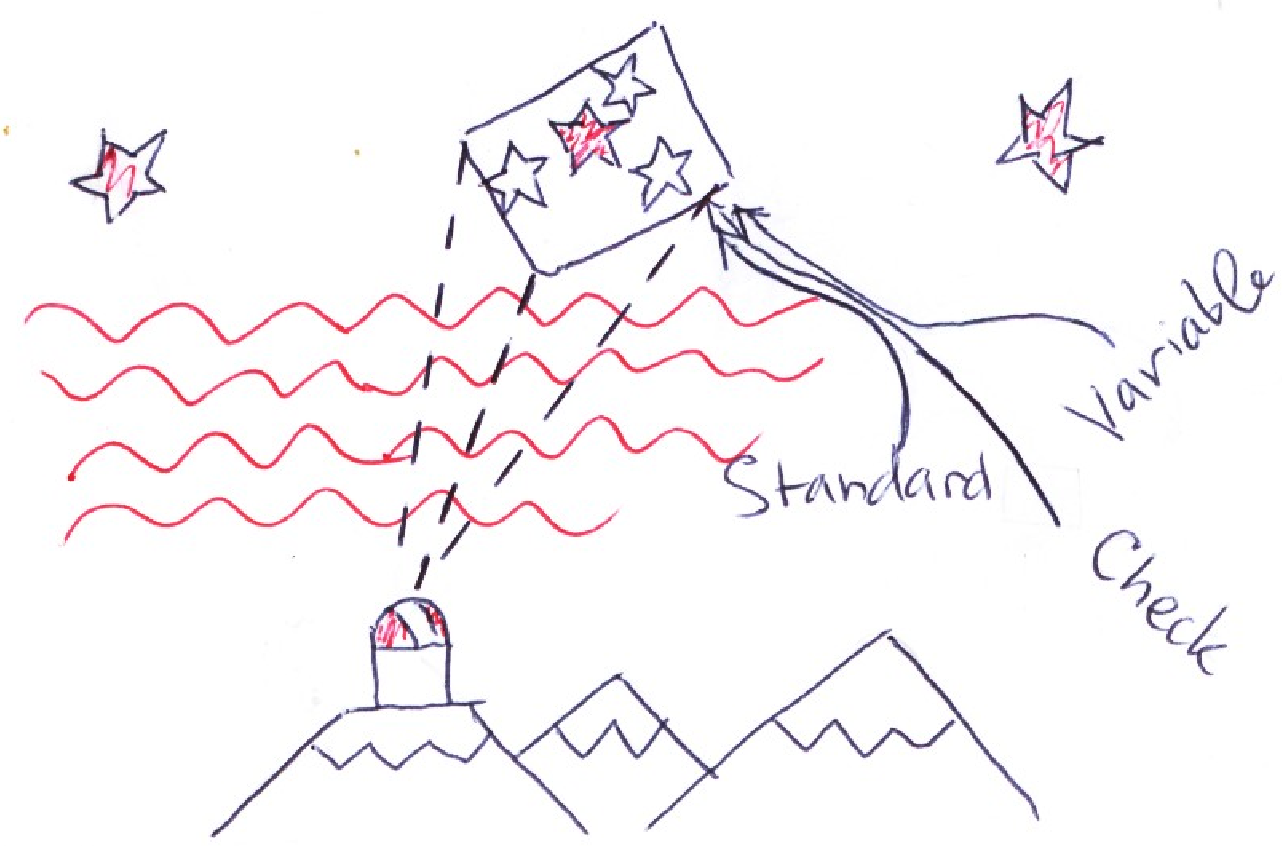
Ancient photometry



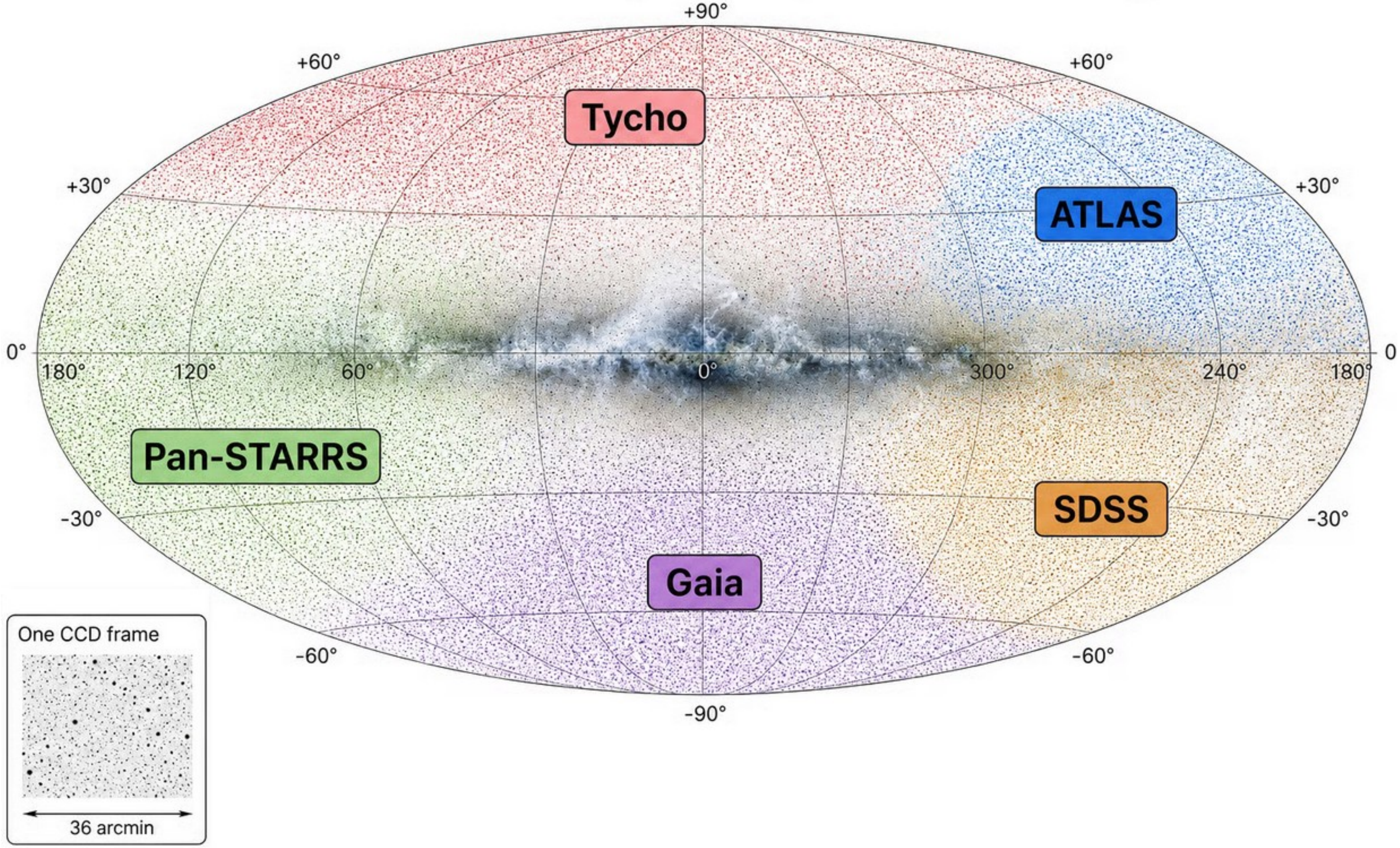
Photoelectric photometry era



CCD revolution



Photometric surveys



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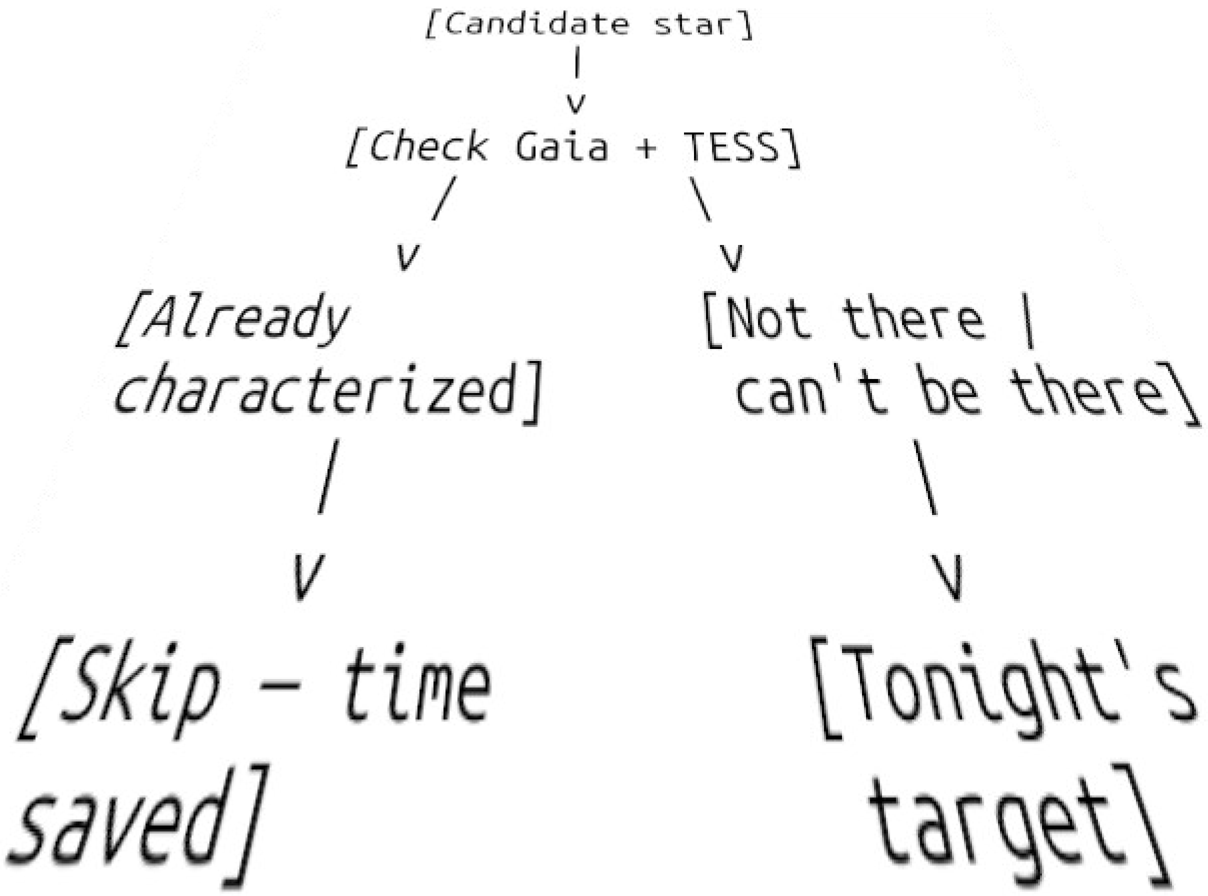
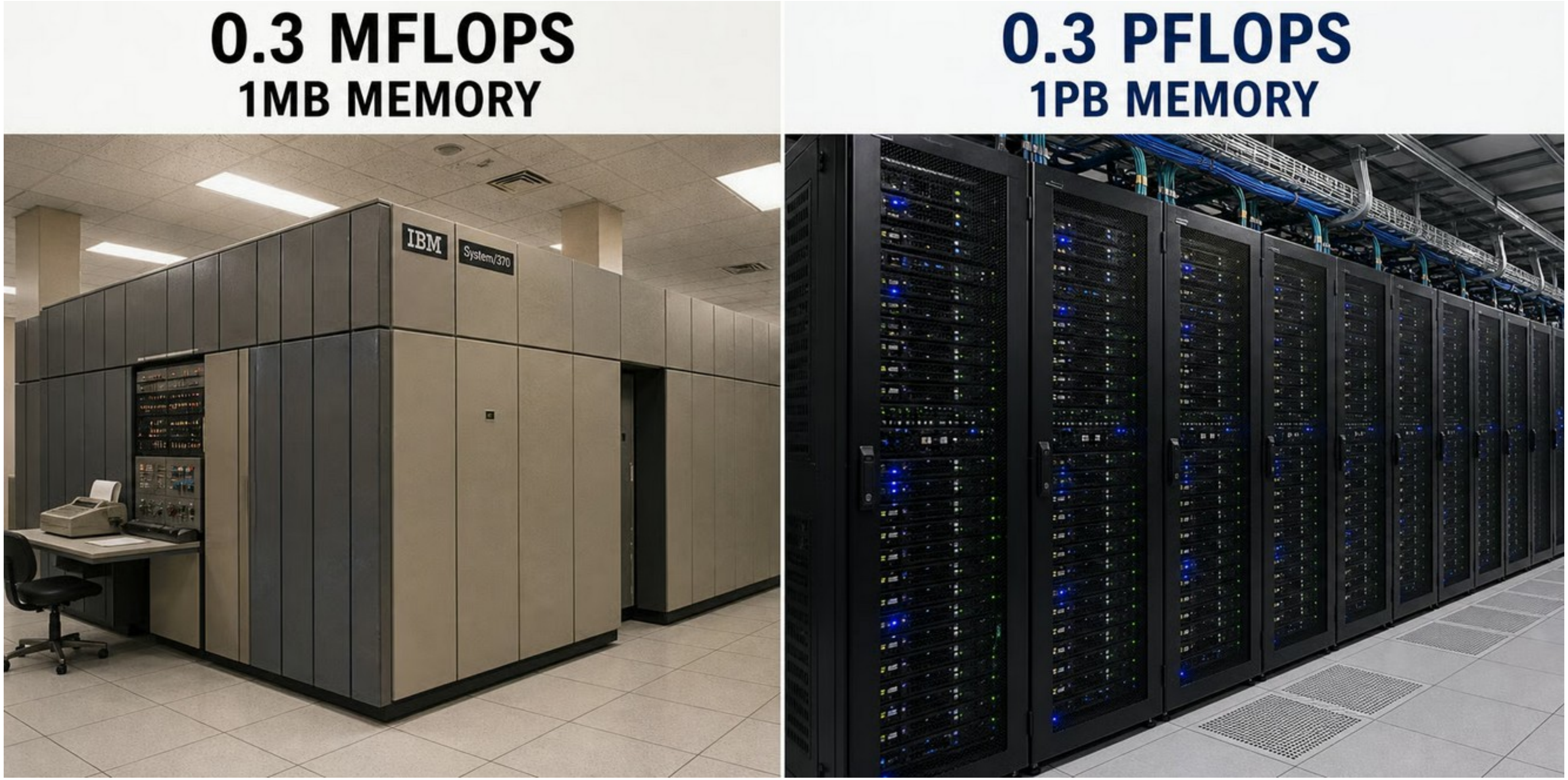


Volume and processing today



Flux measurement

Flux density = Energy / Time / Area / Frequency

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Magnitude Scale

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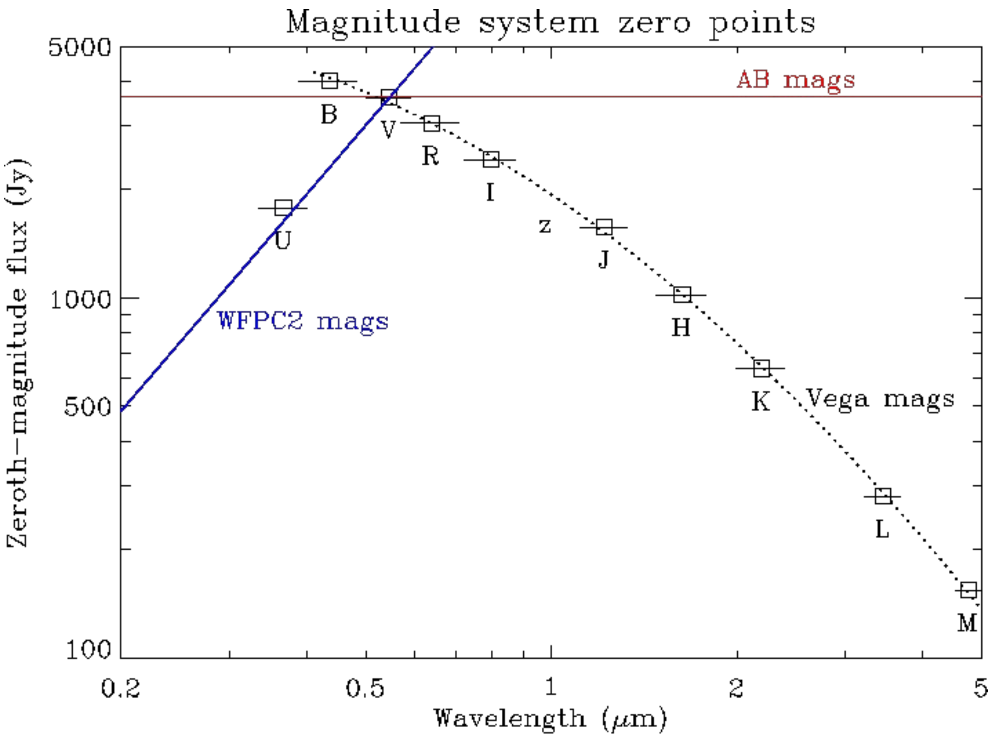

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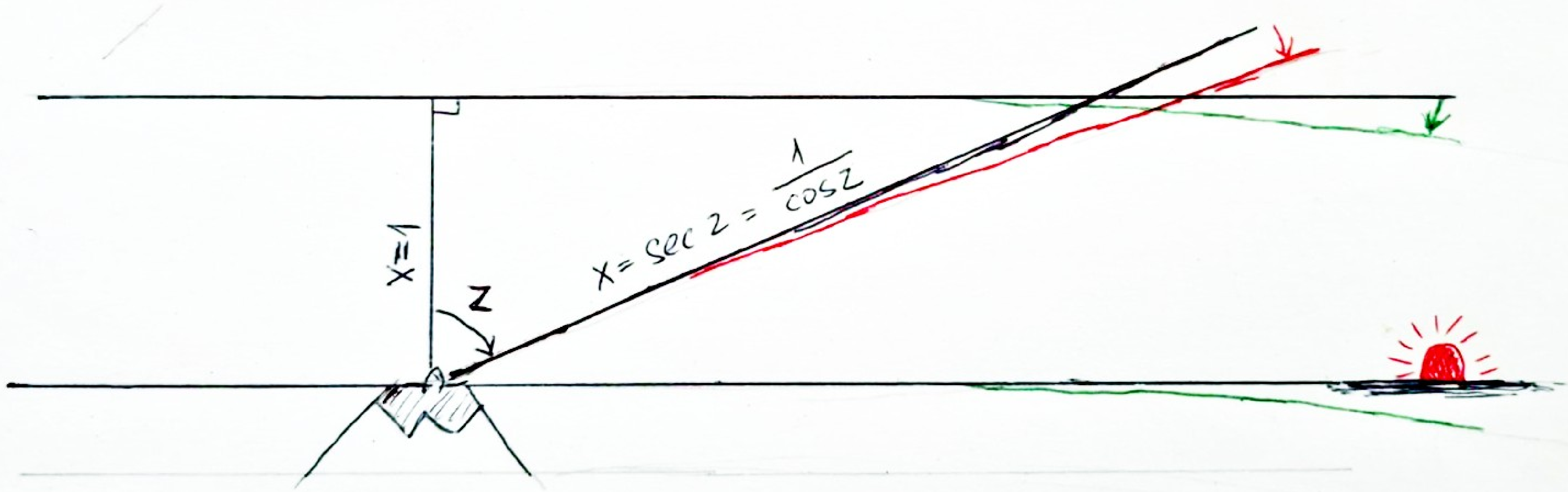

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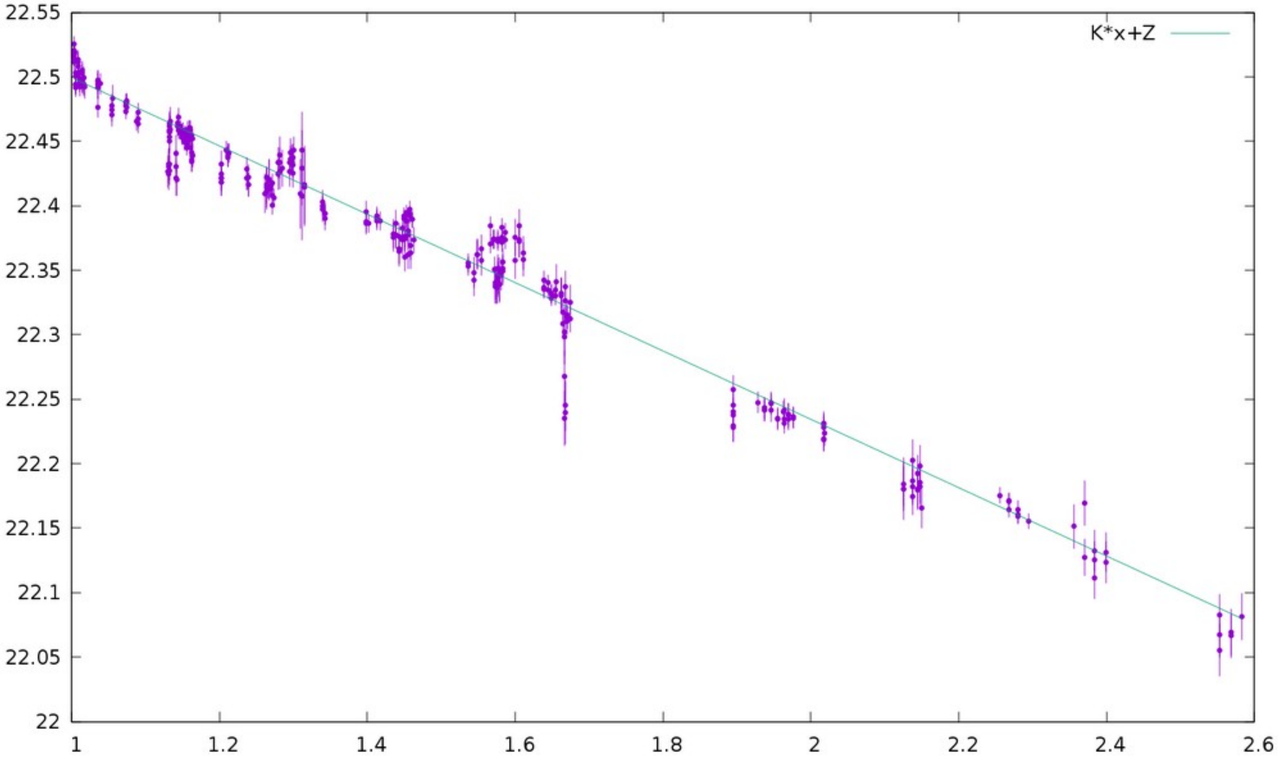

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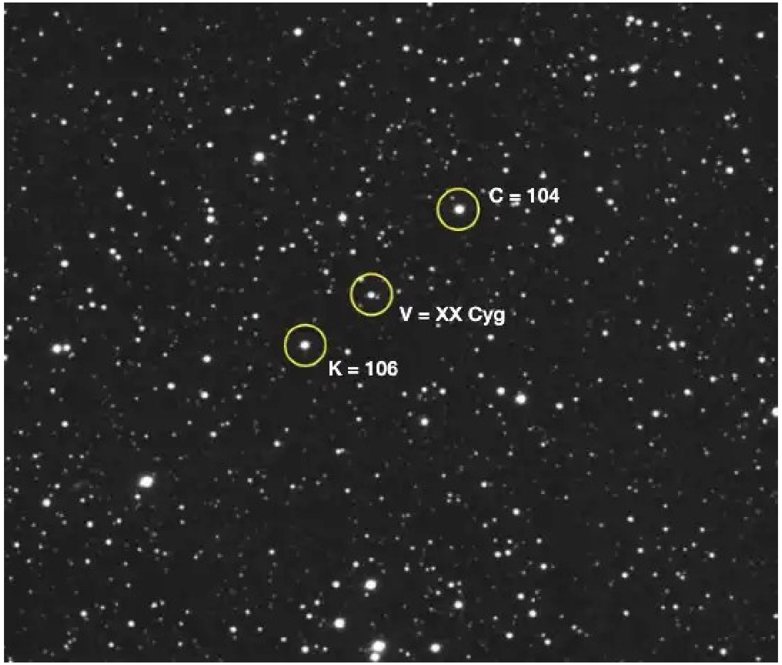

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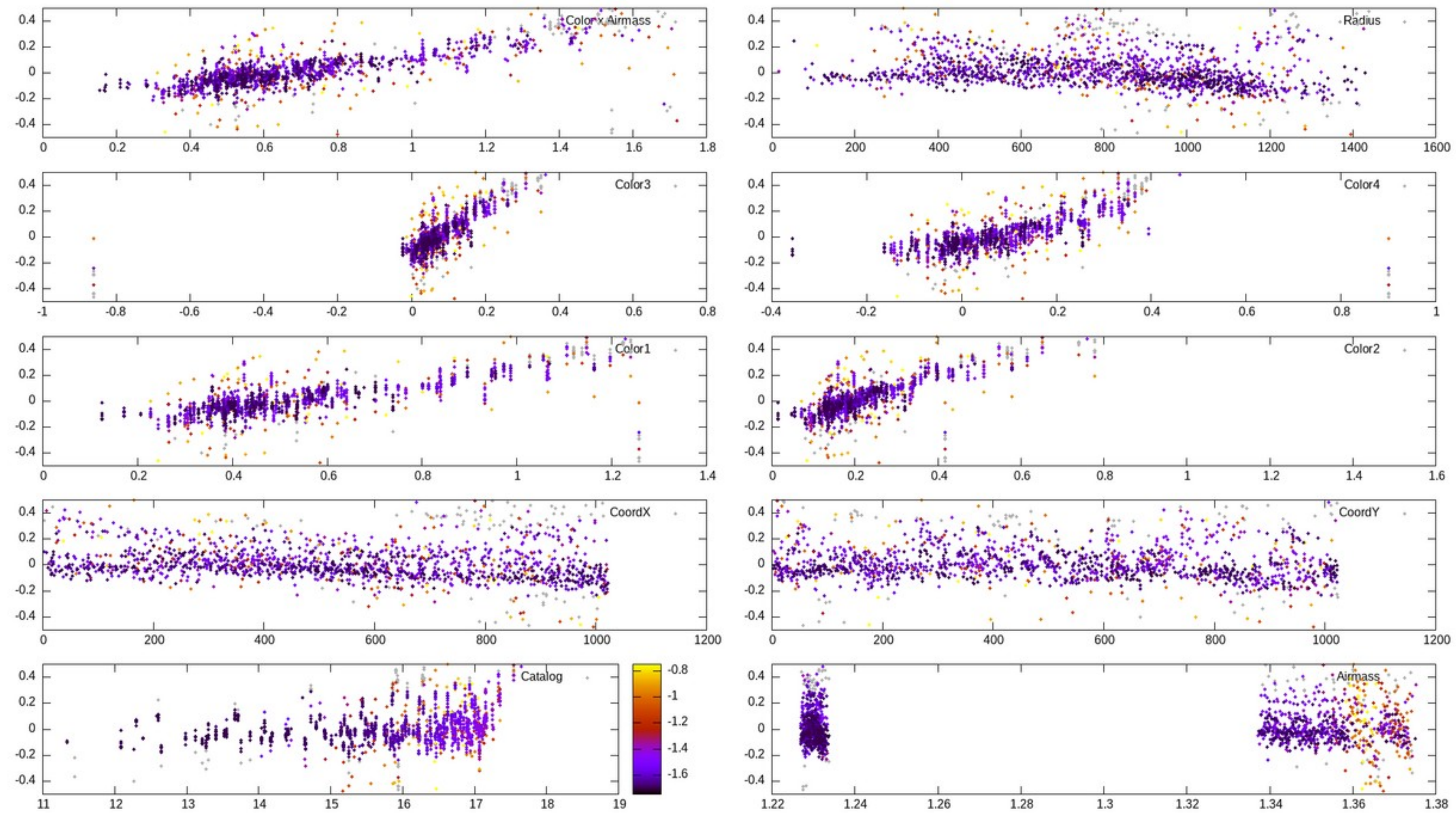

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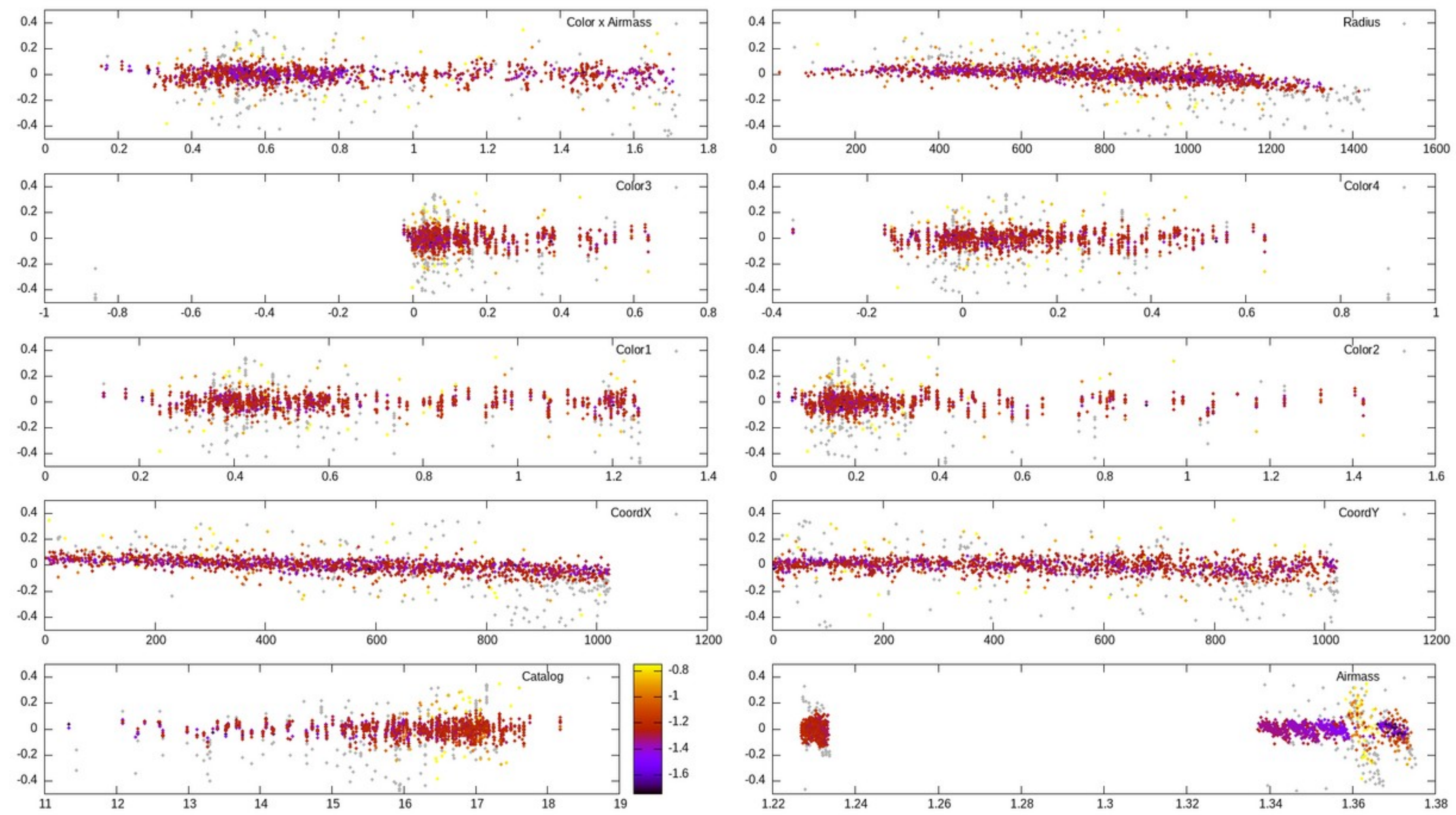

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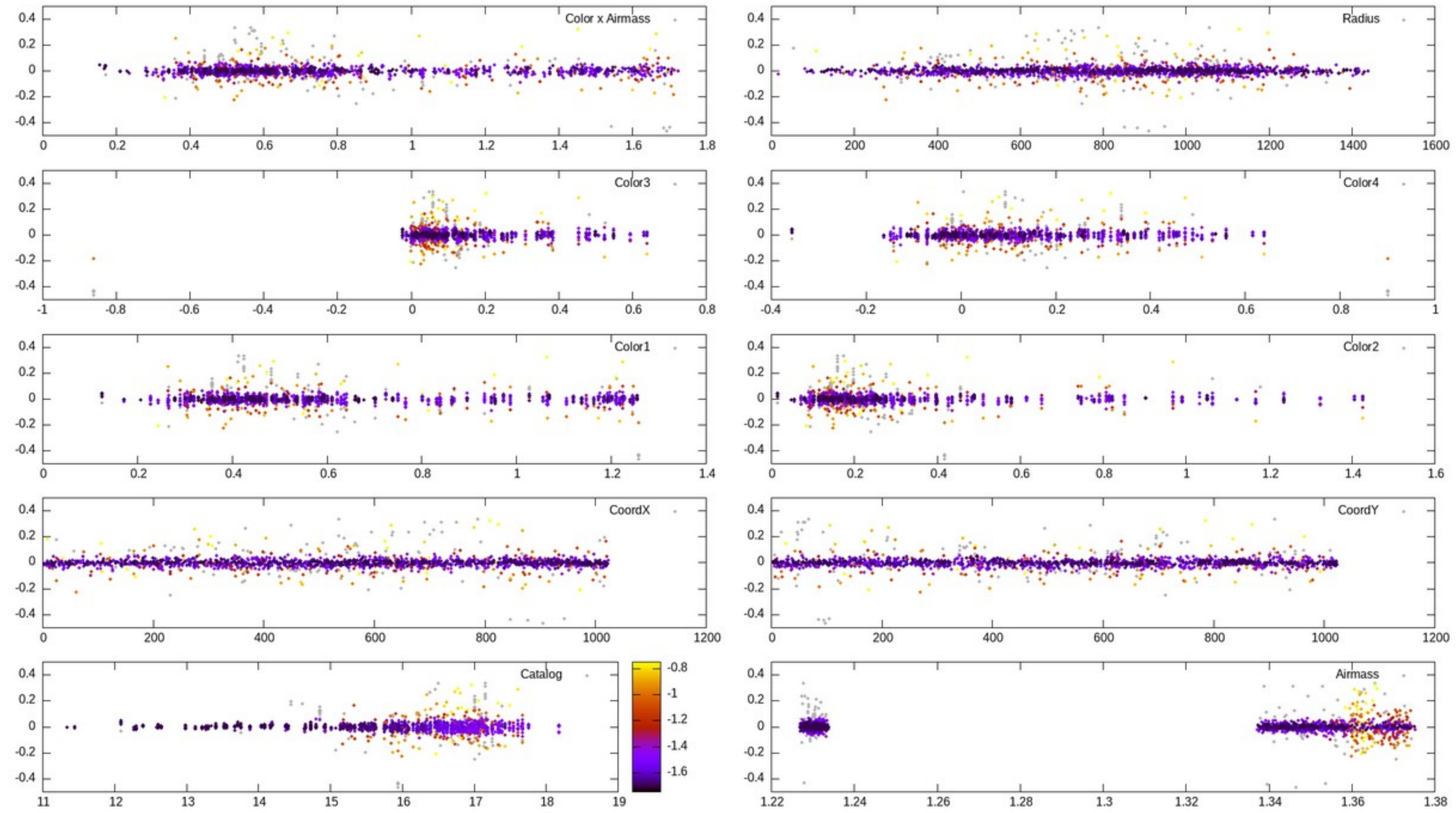

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Filter design evolution

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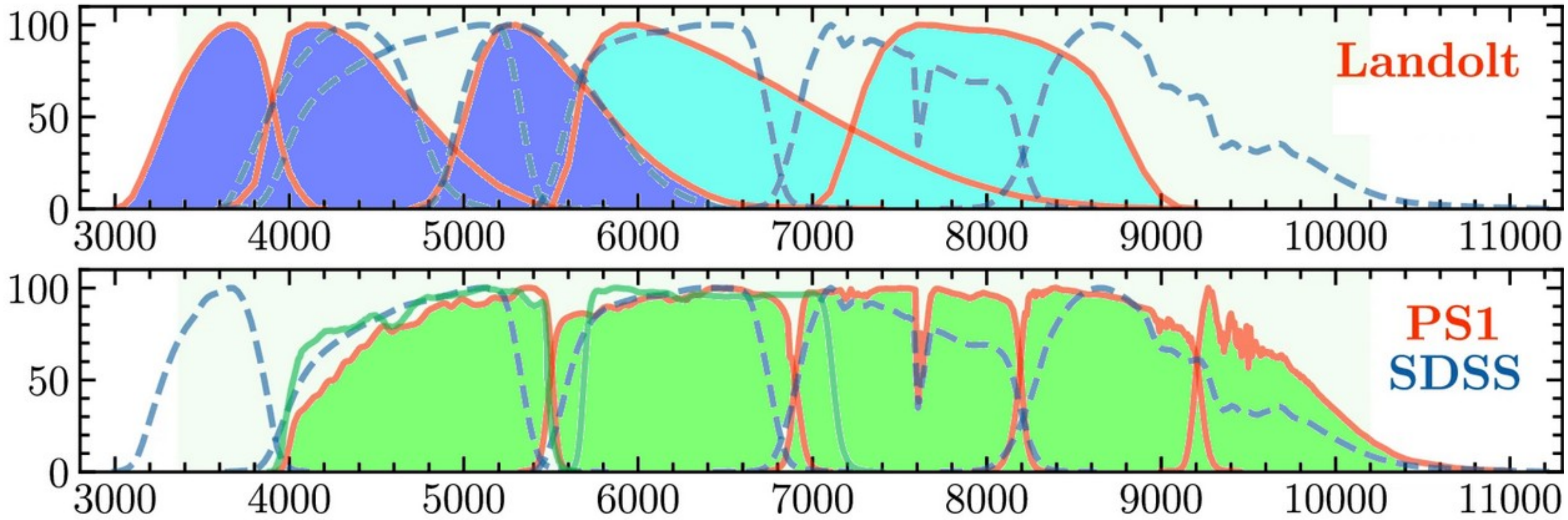
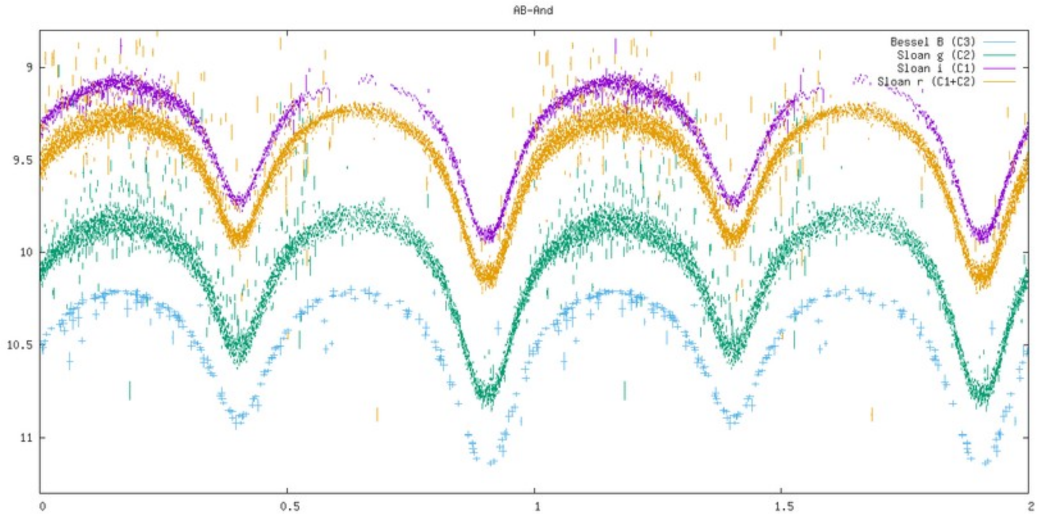
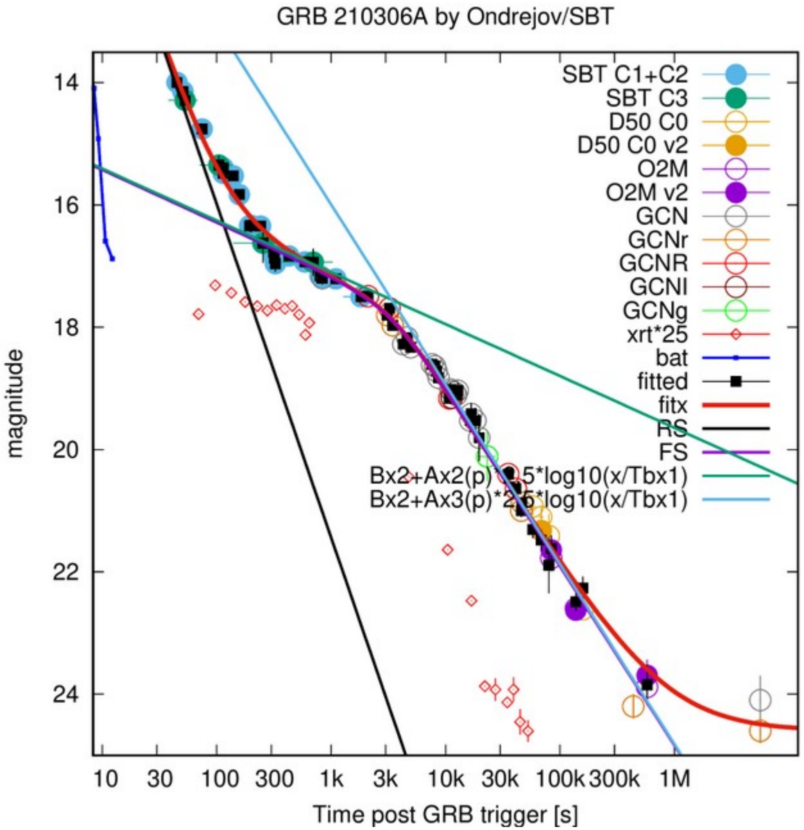
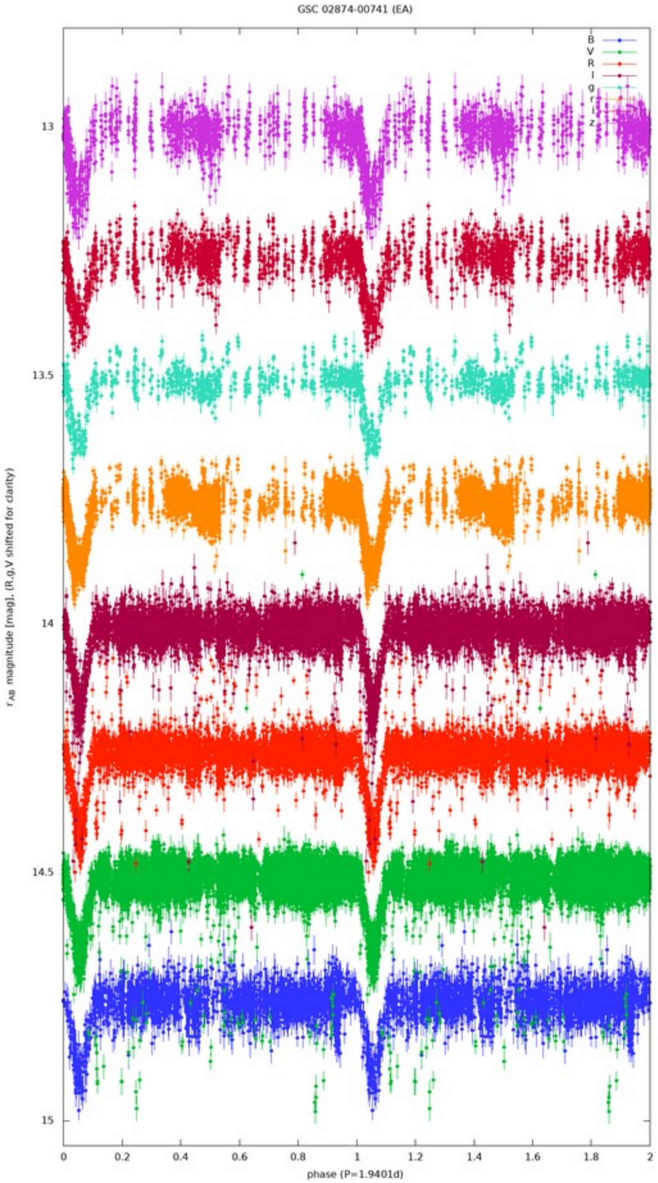


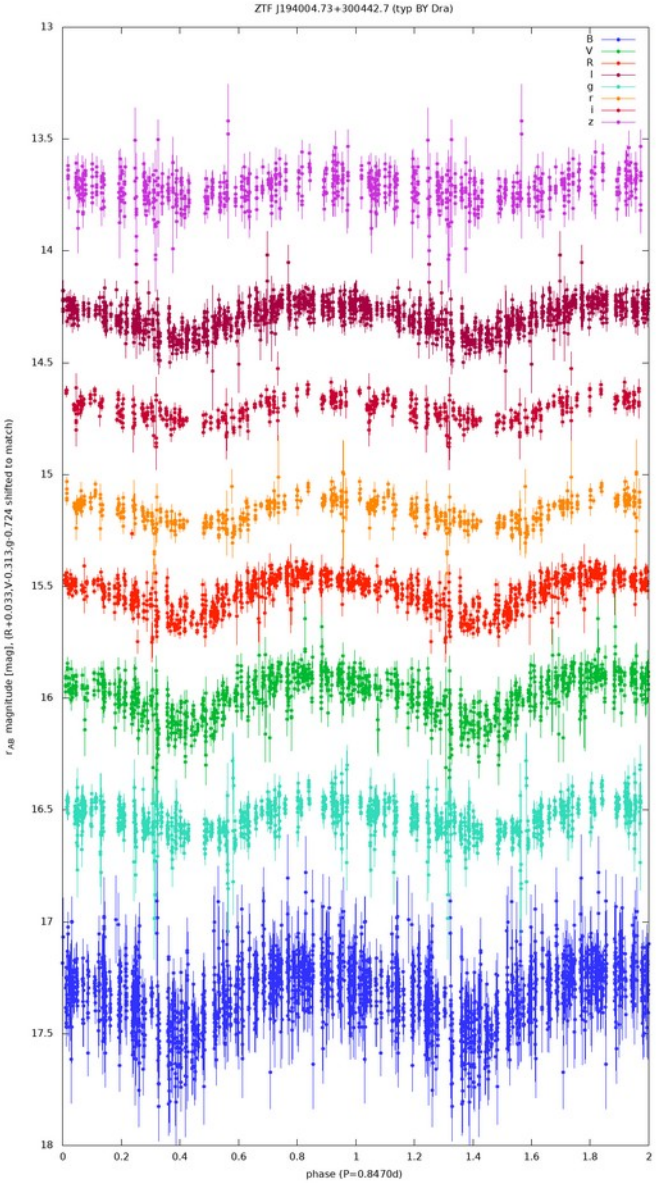
- Modern ugrizy etc.
  - Sloan / Gunn
- Narrow-band filters
- Special systems
  - JHK(-LMN...), ubvy, ...

Lightcurves






GSC 02874-00741 (EA)
B
V
R
I
g
r
i
z
rAB magnitude [mag], (R,g,V shifted for clarity)
phase (P=1.9401d)


ZTF J194004.73+300442.7 (typ BY Dra)
B
V
R
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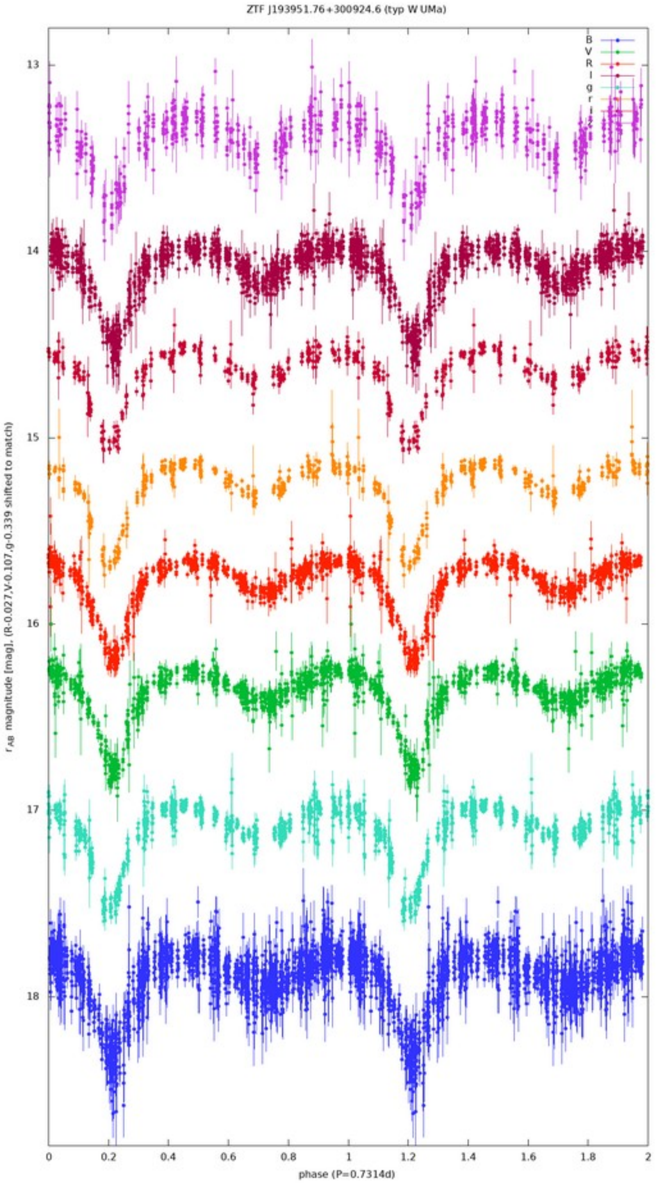
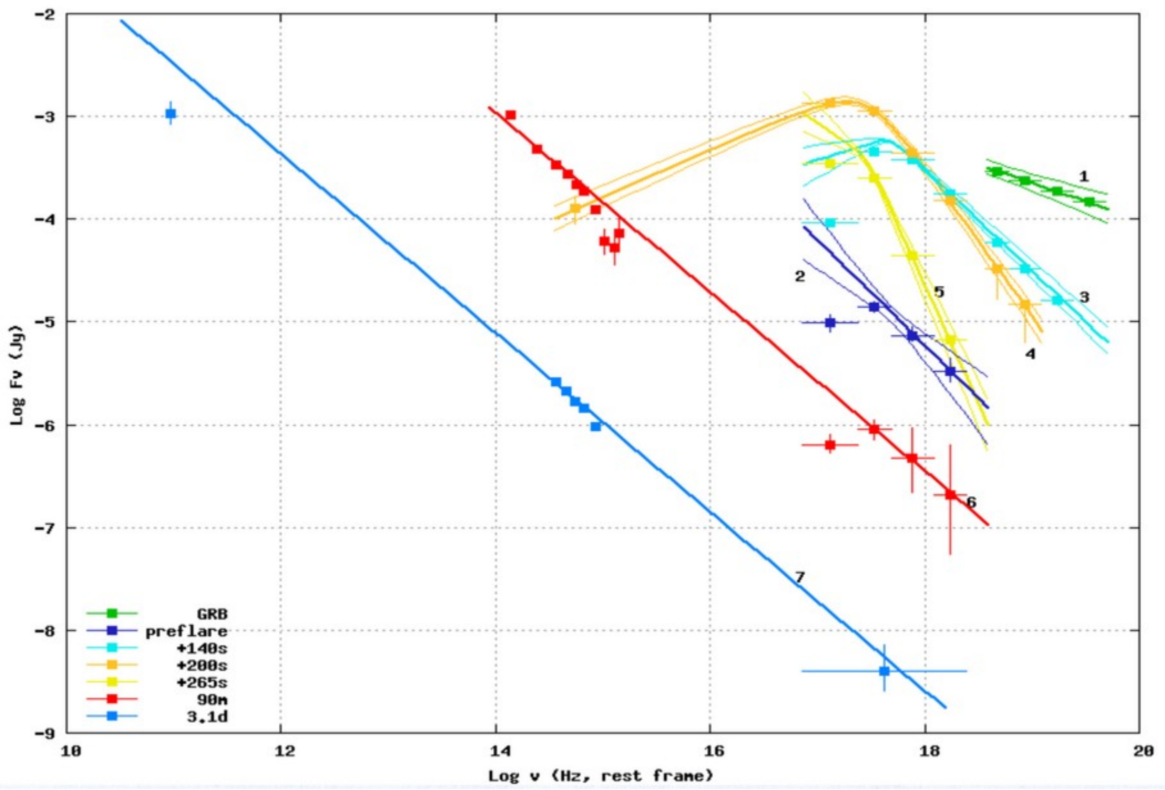
rAB magnitude [mag], (R+0.033,V-0.313,g-0.724 shifted to match)
phase (P=0.8470d)


ZTF J193951.76+300924.6 (typ W UMa)
B
V
R
I
g
r
i
z
rAB magnitude [mag], (R-0.027,V-0.107,g-0.339 shifted to match)
phase (P=0.7314d)

Spectral Energy Distribution

- We can take (quasi) simultaneous measurements in many filters
- compute flux in Jy, show how the emission is distributed among different channels

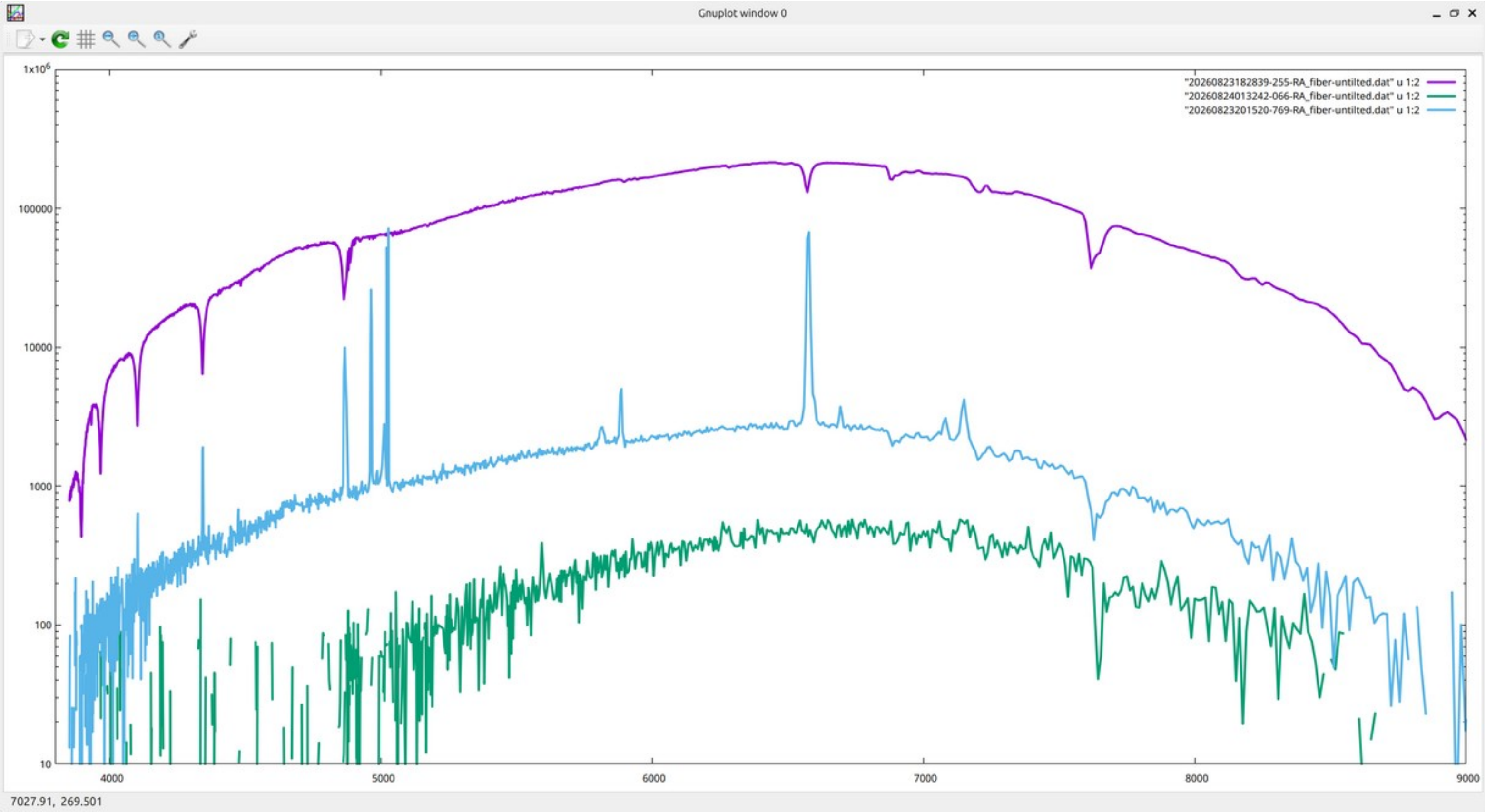


What SEDs can tell you

- Effective temperature
- Surface gravity (luminosity class)
- Metallicity
- Interstellar reddening

- BTW: 4 numbers, this is why 5 filters!

Low resolution spectroscopy (FLORES)



Observing plan for this workshop

- Identify a few bright recent supernovae
- Observe lightcurves with D50
- Try and obtain a spectrum with FLORES
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Contributions

- Understand advantages and limits of photometry and low resolution spectroscopy
- Understand supernovae

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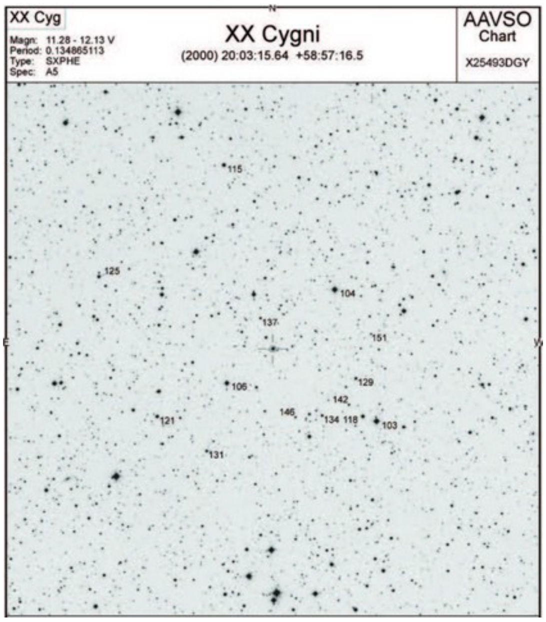
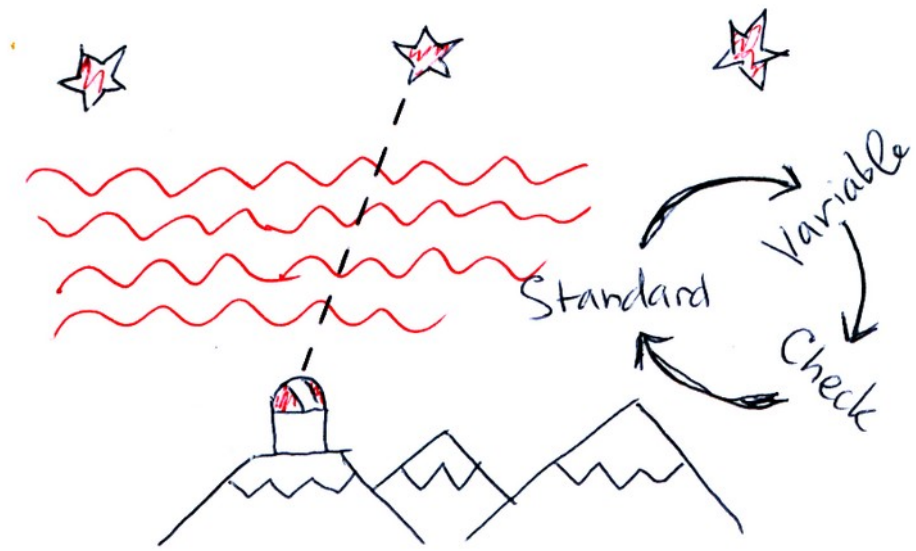


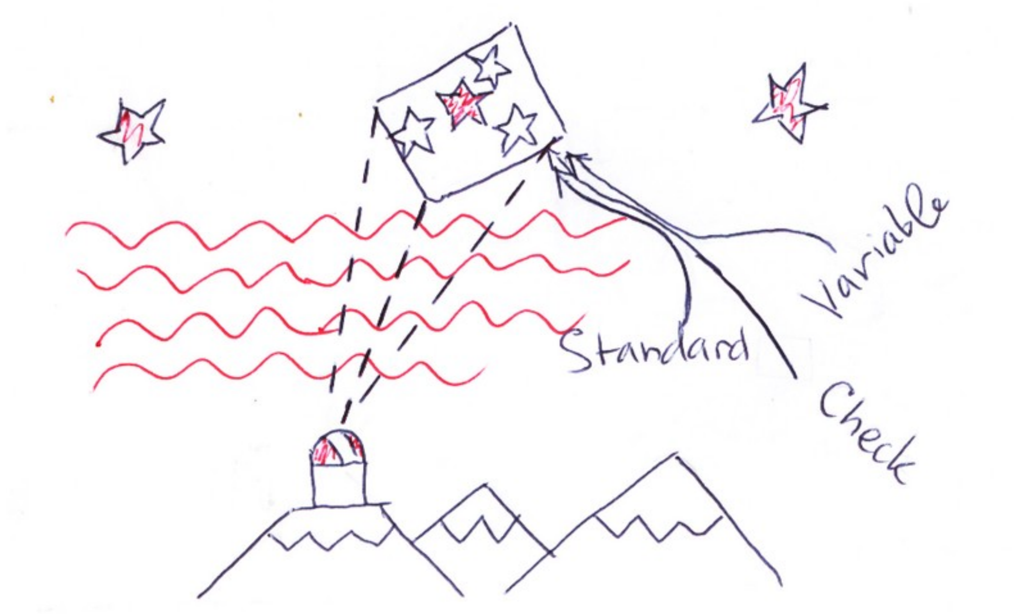
- Hipparchus, ~2nd century BC: six classes, brightest to just-visible — a catalog, not a measurement. Purpose: practical (navigation, calendars), not precision science
- Centuries later: visual variable-star observers (Argelander's step method) get more ambitious — estimate a target as a fraction of the way between two charted comparison stars of known magnitude
- Result: trained eye + a good chart → ~0.1 mag precision, no instrument required
- The pattern that starts here and never lets up all workshop: people have always over-engineered ways to squeeze more precision out of "how bright is that dot"
- Bridge line into slide 5: then someone put a photomultiplier tube where the eyeball used to be...

Photoelectric photometry era



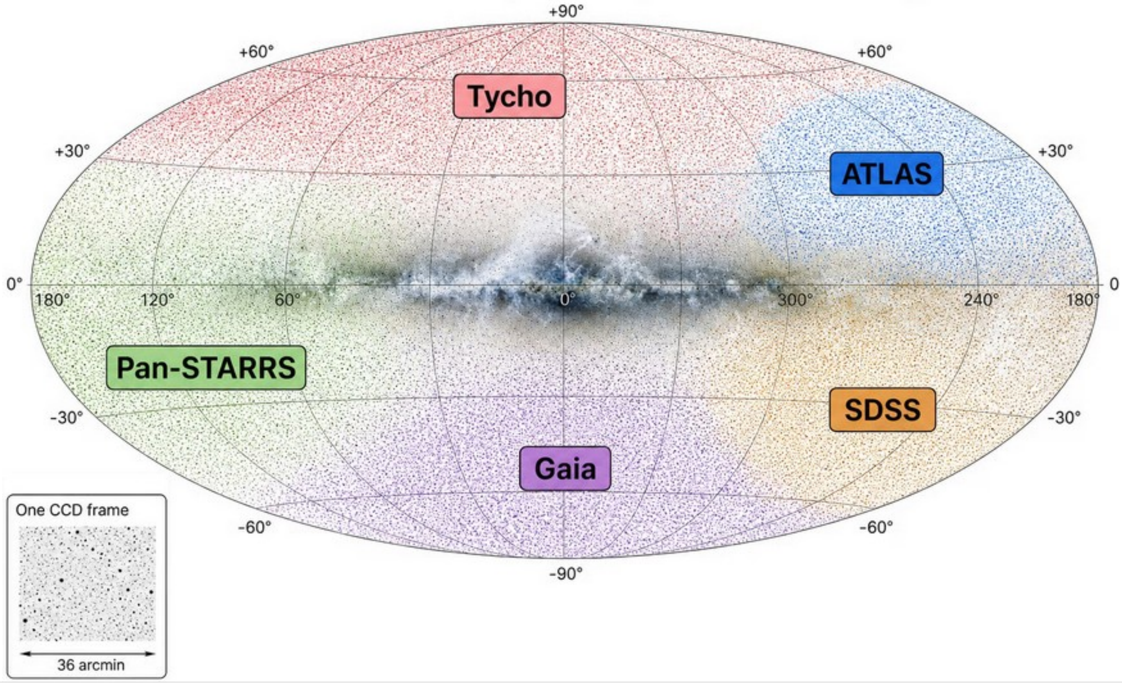
- One true enemy: the atmosphere — extinction, changing transparency, changing effective wavelength
- PMT are UV sensitive, (almost) blind to IR
- One star at a time → the whole night's strategy is what matters in overcoming the atmosphere: standards at multiple airmasses, variable/comparison/check cycling
- get a good number or know immediately it’s not
- Few data points: every number matters
- Consequence: Forbes effect, nightly-solved extinction coefficients, filter transformations — taken far more seriously than today, worked to real rigor
- less rigorous today? Two reasons, only the first is a little embarrassing: (1) it's "finished science" now, nobody publishes by refining a 60-year-old extinction correction; (2) we gave up UV for IR

CCD revolution



- revolution not *better detector* but *simultaneity*: target, comparison, check, and everything else in the field, captured at once, same atmosphere, same airmass
- in simplest case just shoot at the same place
- still! - the atmosphere isn't defeated - absolute calibration across nights/sites is a thing
- tradeoff? – volume, need for storage and computing
- Harmanec?: 2000 can I work with 1–2 million measurements from one night? his eyes popped out
- PMT and CCD photometry are different sports
- Then vs. now: pile-up corrections gone (CCDs integrate charge, don't photon-count, so PMT dead-time correction isn't a thing anymore); seasonal transformations mostly ignored (rigor didn't survive the transition); instrument stability is a different problem (flat-fielding/linearity replace PMT drift)
- What stayed: the fundamentals — still turning photons into magnitudes, still fighting for consistency — but what "precision" means moved; mmag-level

Photometric surveys

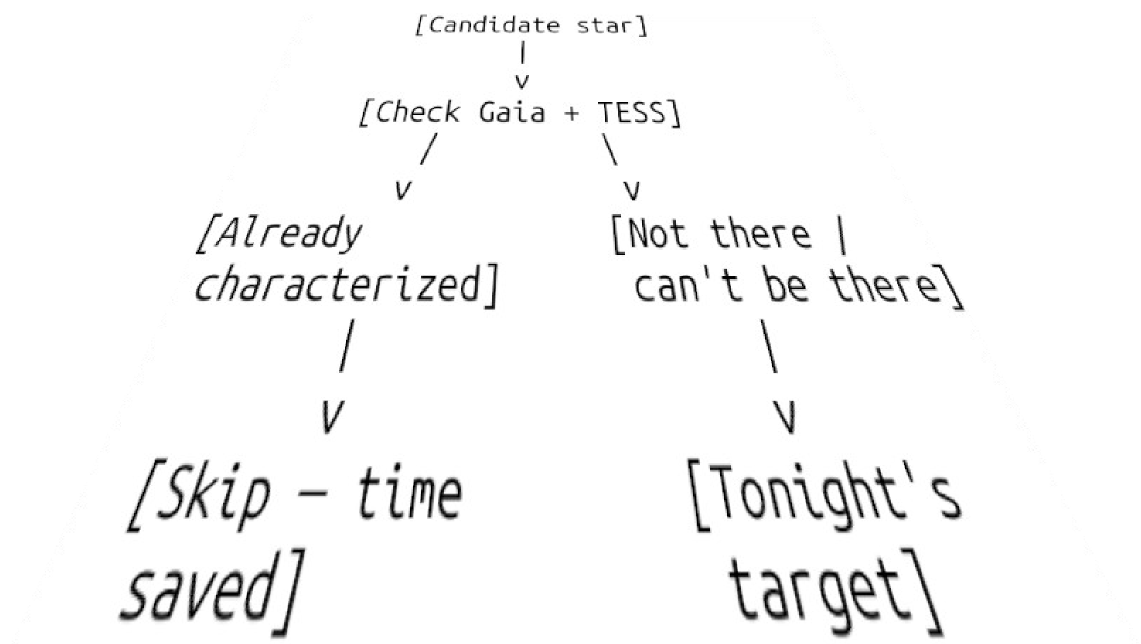


- Not "thousands of stars per frame" anymore: the whole sky, repeatedly, automatically

Tycho - first real all-sky precision reference catalog;
Pan-STARRS - continuous wide-field multi-band survey, watching for anything that changes
Gaia - ~1.8 billion sources, resurveyed dozens of times over the mission
SDSS - deep multi-band imaging that literally defined the ugriz filter system we meet on slide 20
ATLAS - built to hunt asteroids, produces forced-photometry light curves for huge numbers of stars as a side effect

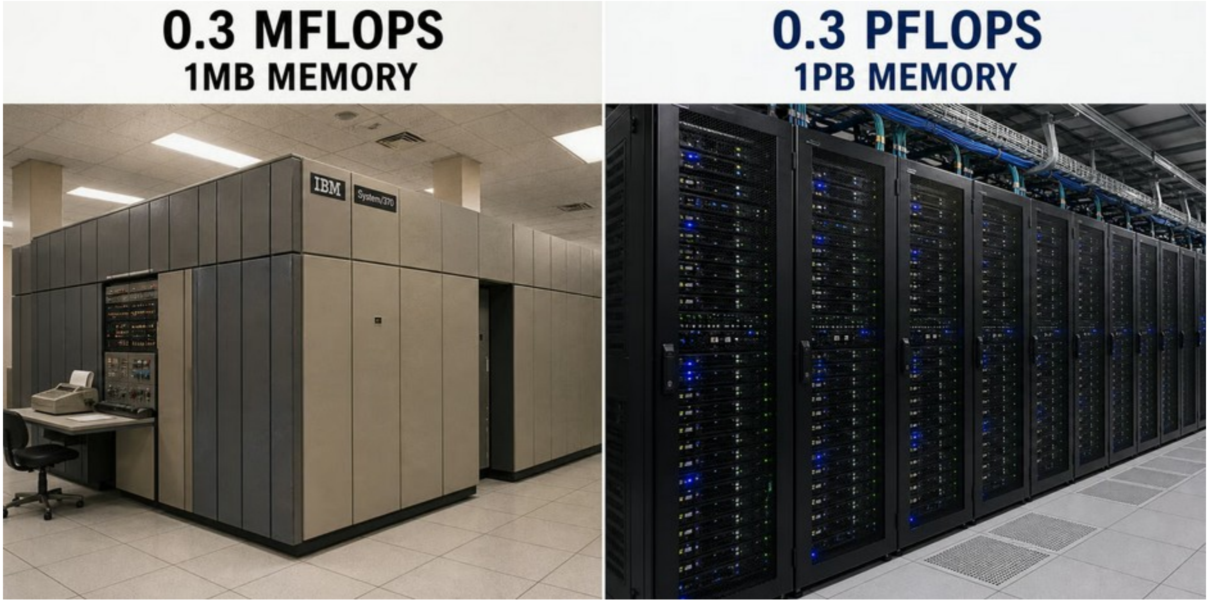
- The real point isn't the star count, it's that the atmosphere-fighting problem from slides 5 and 6 has, for almost any star you can point a telescope at, already been solved. By someone else. In advance.
- Bridge into slide 8: you don't start from zero anymore, you start from a catalog

Gaia + TESS changed everything



- Old instinct: point the telescope, start collecting, discover the basics from scratch — period, amplitude, timing all unknown going in
- New instinct: check existing survey data *before* opening the dome
  - Gaia — already flagged as variable? rough classification? approximate amplitude?
  - TESS - the exoplanet-hunting satellite that stares at huge patches of sky for weeks at a time - already observed this target in a sector? public light curve available? can you already read off a period?
- Only then do you plan your own observation - right cadence, right exposure time, timed around when the interesting behavior actually happens, instead of hoping to catch it blind
- Direct, concrete payoff: this is literally the method used in Workshop Planning (slide 26) to pick this workshop's targets - not a hypothetical, a preview of something they'll do themselves
- Continuity: this is slide 7's "you start from a catalog

Volume and processing today



- Today's surveys fight the *same* atmosphere with actual industrial compute - parallel processing, terabytes per night
- Not a new fight - same one, just with real horsepower behind it now
- This compute is *why* slide 7's "already solved by someone else, in advance" is even possible - calibration and cross-matching solved simultaneously across millions/billions of stars, sophisticated pipelines, not one scientist's Fortran code
- Forward callback: this is the same idea behind Calibration's "modern approach" (slide 15 — fit many catalog stars simultaneously to complex models), just at the scale of one observing run instead of an entire survey

So this was the „mundane“ version, lets dig deeper!

Flux measurement

Flux density = Energy / Time / Area / Frequency

1 Jy = 10^{-26} W/m^2/Hz

- What we mundanely feel as „Brightness“ is in physical terms a quantity called Flux density
- ENERGY PER TIME PER AREA PER FREQUENCY INTERVAL, technically two times density
- You must be by now accustomed that radiation’s natural coordinate is frequency, even though in photometry we usually work with wavelength, so the integrations are against our usual natural thinking.
- Standard unit is Jansky 10^-26 W/m2/Hz

- convert this to number of photons? No problem: each photon is hv energy,

Magnitude Scale

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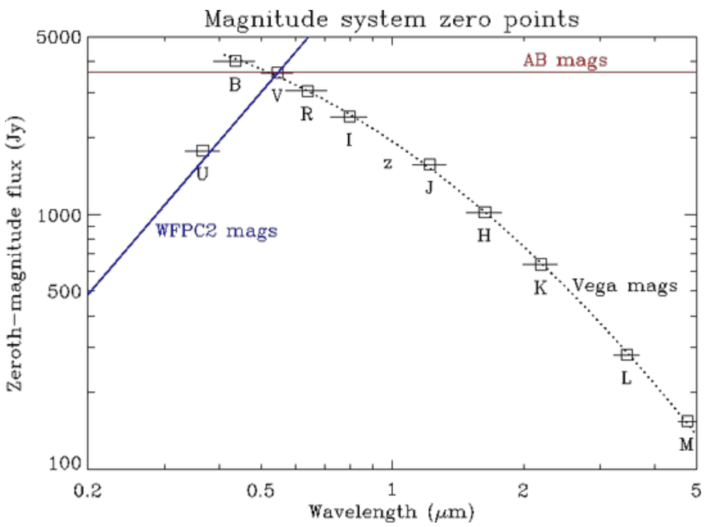

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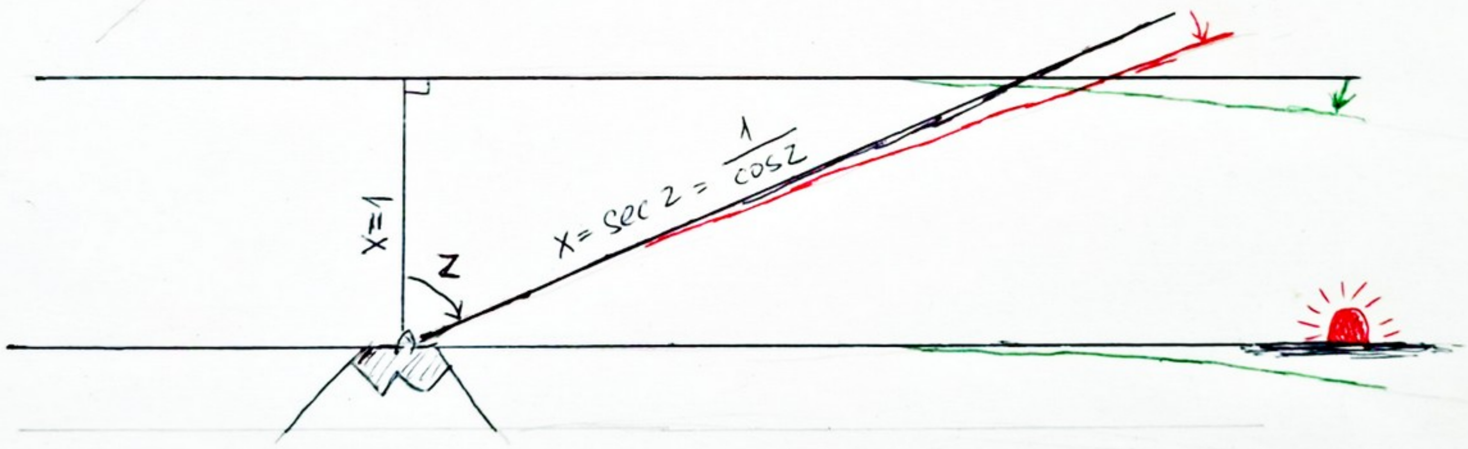

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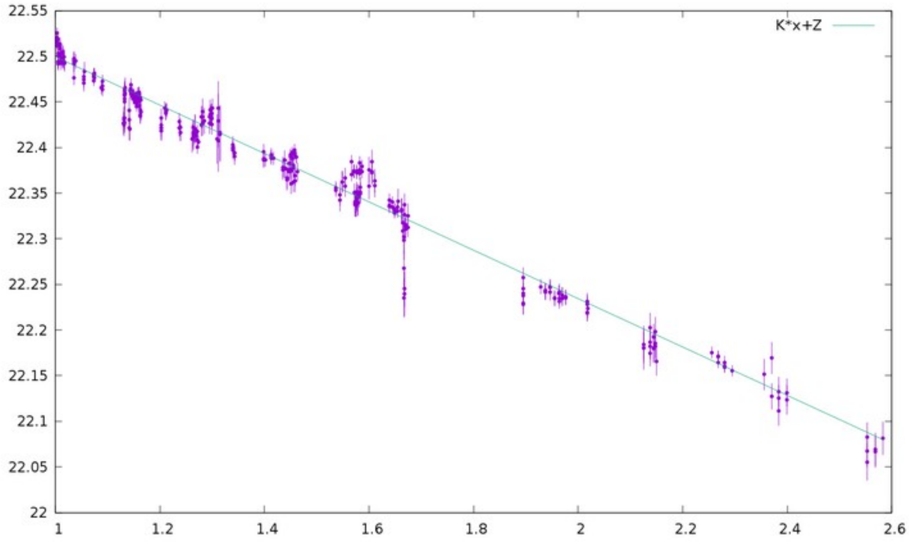

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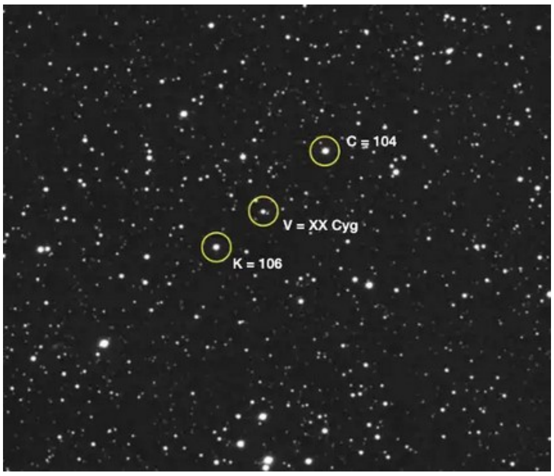

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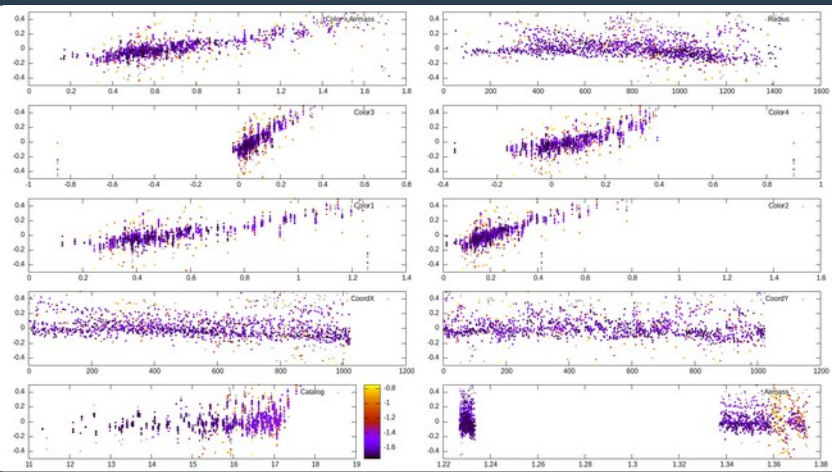

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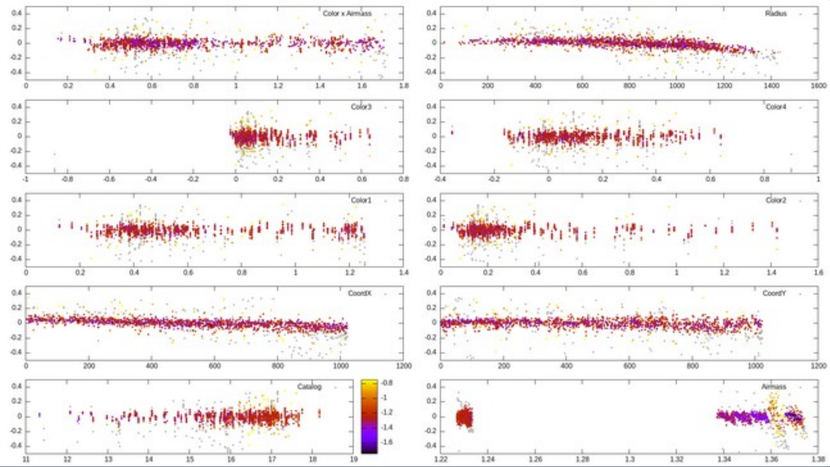

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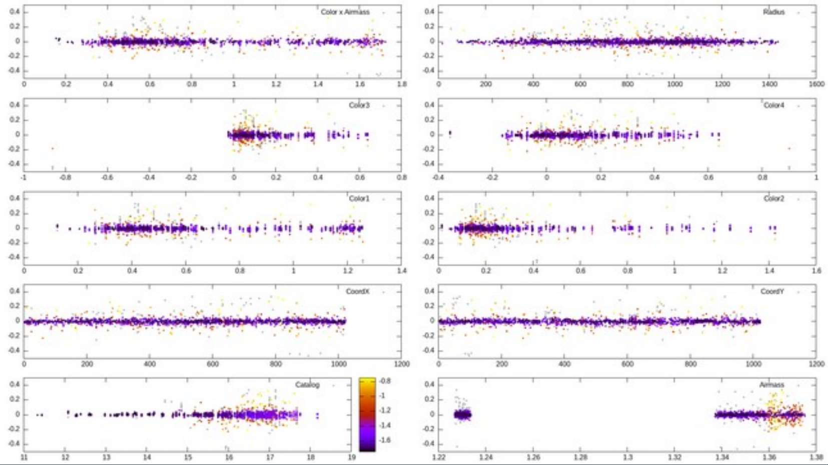

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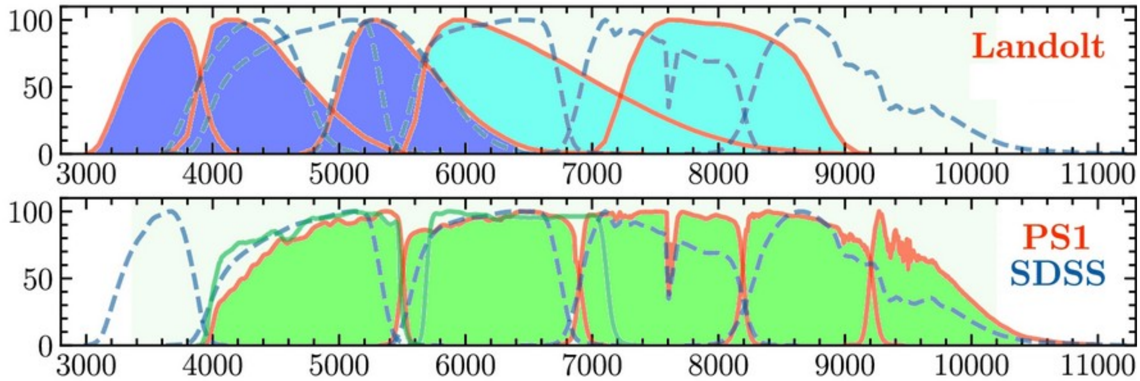

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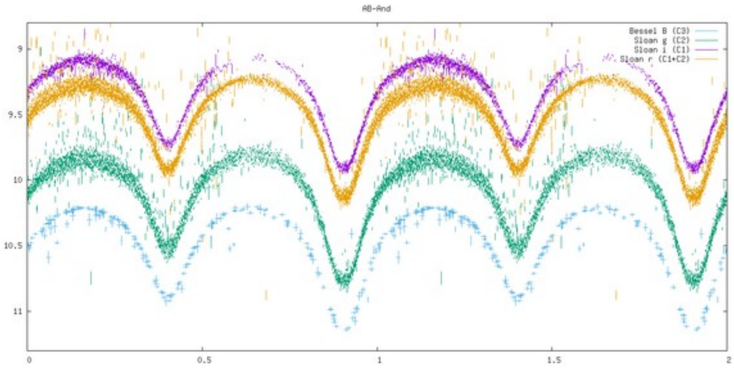

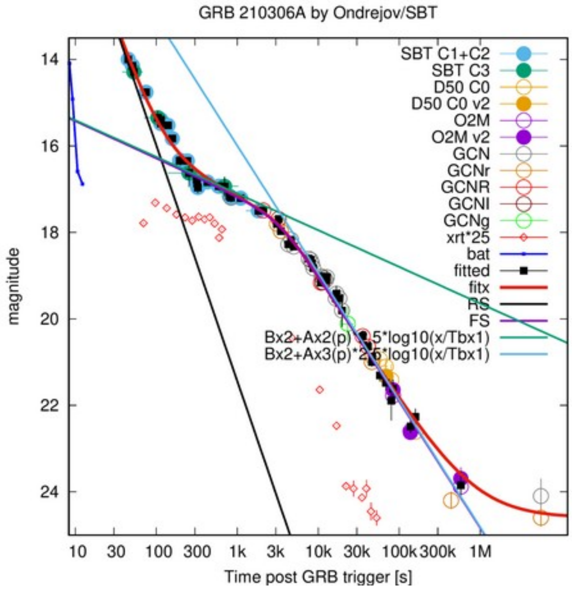

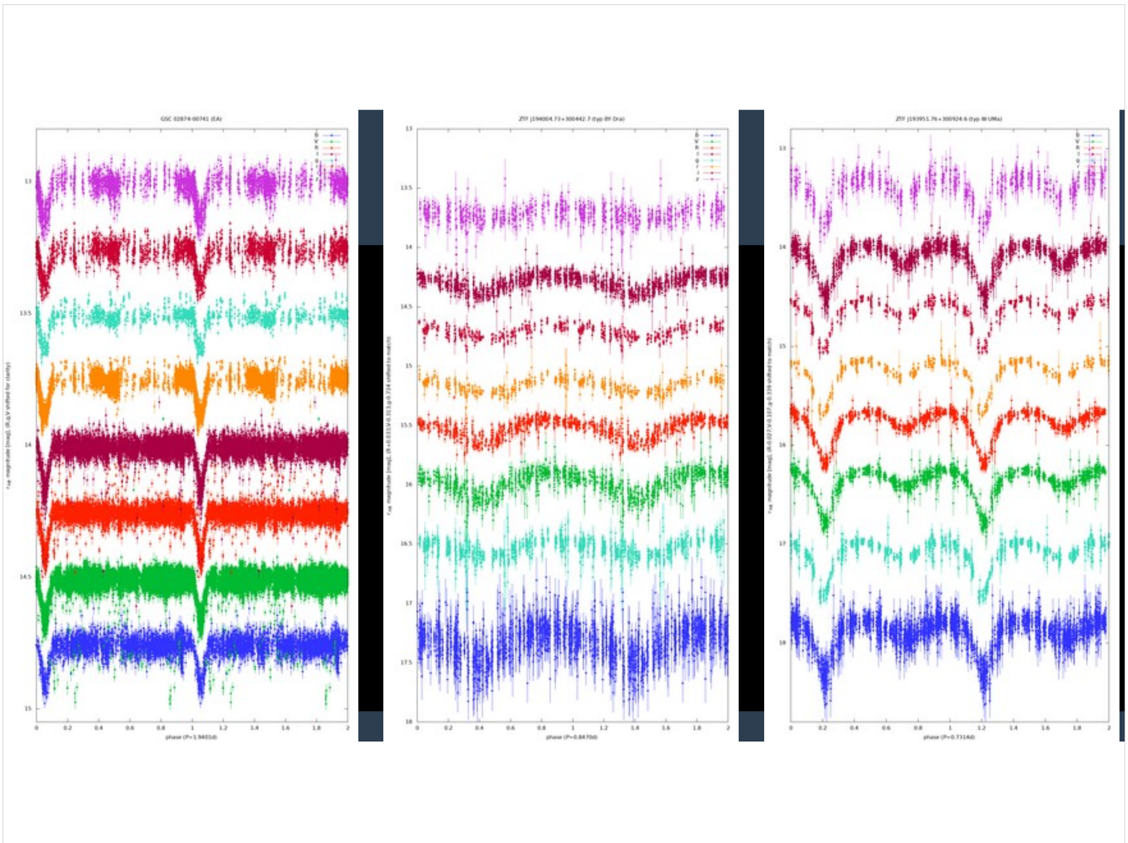
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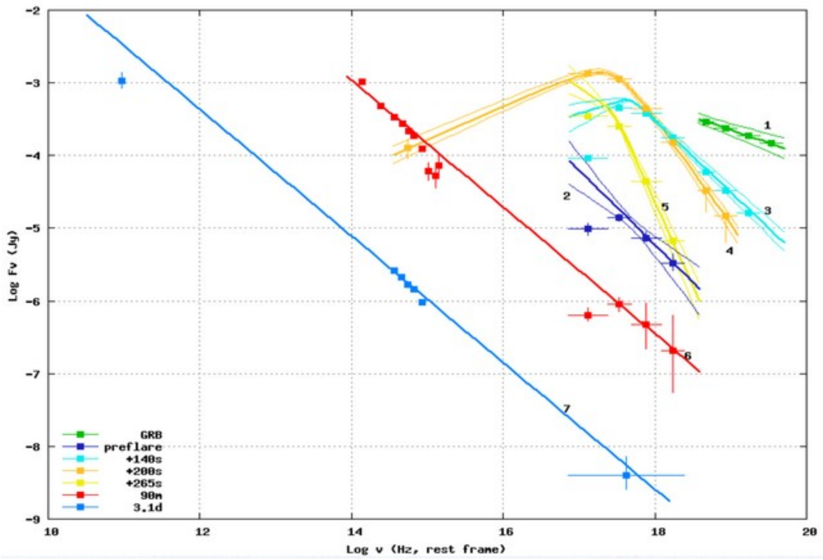

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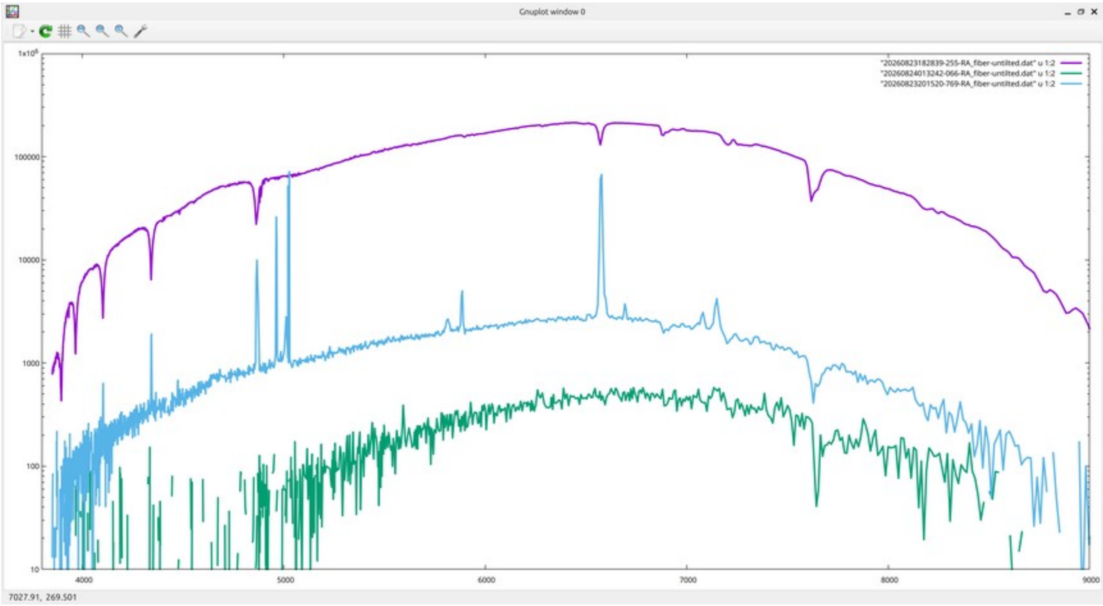

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