# Conversion from Classical to Robotic Astronomy: The Lowell Observatory 0.8-m Telescope

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# Telescope Site, Anderson Mesa, AZ

# Philosophical Approach

- Robotic mode is a new option, not a conversion
- Observing with no oversight during the night
  - No image display
  - Log files are only source of feedback
- Foundation of system is an automaton
- Modular and layered design
- Linux/Solaris platform
- No off-site network connectivity required

# Ground Rules and Other Constraints

- Zero impact allowed on classical observing
    - Reverse is not true, sadly
- Continue to support instrument changes
    - No longer common, thankfully
- Essentially no funding or institutional support
- Do no harm to people or equipment
- Minimal effort required for operational support

# System Overview

- One process per system
  - `move` – telescope interface layer
  - `roboccd` – camera operation
  - `cmdr` – observing queue
- Communication via IPC messages
  - Fast and tight communication
  - Simple program design
- Everything is modular and separate, TCP/IP layer can easily be added as a separate task.

# Telescope

- 0.8-m aperture, Anderson Mesa Station
- English-yoke equatorial mount
    - 60°N pointing limit, very stable but tracks poorly
- Closed-tube made of aluminum
    - Very strong temperature/focus relationship
- Digital stepper motors, RA/DEC and focus
- Ash dome
    - upper/lower shutter with narrow power pad
    - Bar code reader for absolute position knowledge

# Camera(s)

- PCCD (2001-2005)
  - Photometrics TH7883 CCD (384x576), 1.3"/pix
  - Thermoelectrically cooled: –43°C
  - 10-position filter wheel
- NASAcam (2007-present)
  - EEV 2k CCD, 0.45"/pixel
  - Leach Gen3 readout electronics
  - Cryotiger cooling: –112ºC
  - Two 10-position filter wheels

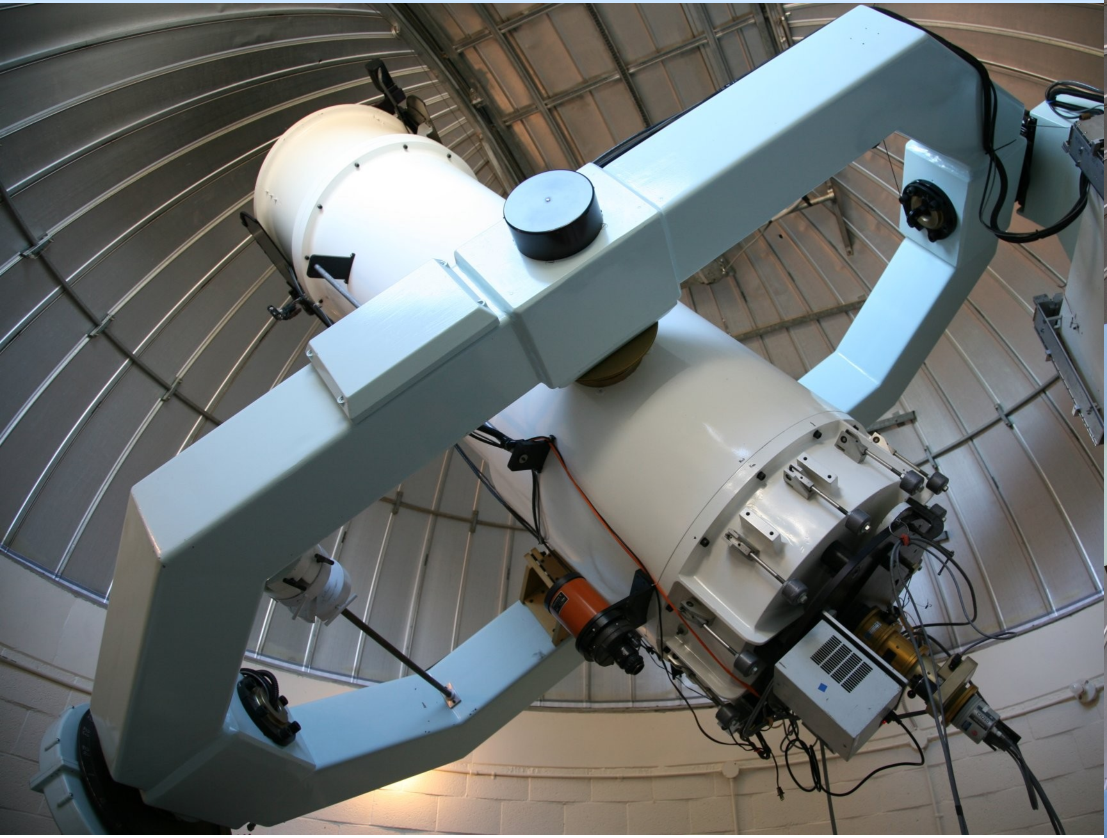
# Environmental Data

- Davis weather station with server/logger
- Color day-time webcam (90° FOV)
- B/W high-sensitivity night camera (90° FOV)
- Dome CCTV monitoring camera
- Boresight high-sensitivity camera (10x14° FOV)
- Tube, mirror, and dome air temperature

# Telescope and Instrument

2011

2001



# Interesting Lessons Learned

- How much real-time analysis?
  - Peak pixel: x, y, DN, FWHM, aperture flux
  - Sky background: mean, standard deviation
- How to focus?
  - Focus sweep, 1 second, total time needed 1 minute
  - No fitting, find best figure-of-merit (peak/flux)
- Timing control – LST is your friend
- No automated error recovery
  - Supervised recovery, only one failure allowed

# Interesting Lessons Learned, cont'd

- Good log files are critically important
  - Balance required between too much and too little
  - Use good search string markers for use with grep
  - Time-tag *everything*
  - *All* machines involved need good time, use ntp
- Standard star scheduling
  - Magic time when standard field at X=2.5
  - Work science data around standards

# Interesting Lessons Learned, cont'd

- Demand for this system is low at Lowell but interest is growing
  - Inertia, mysterious but consistent with most professional observatories I've worked at
  - Non full-time use excludes some projects
- Maintenance (non-observing) costs appear to be independent of classical/robotic usage
- Response time for responding to failures is slower than for classical observing → less “value” given to robotic time

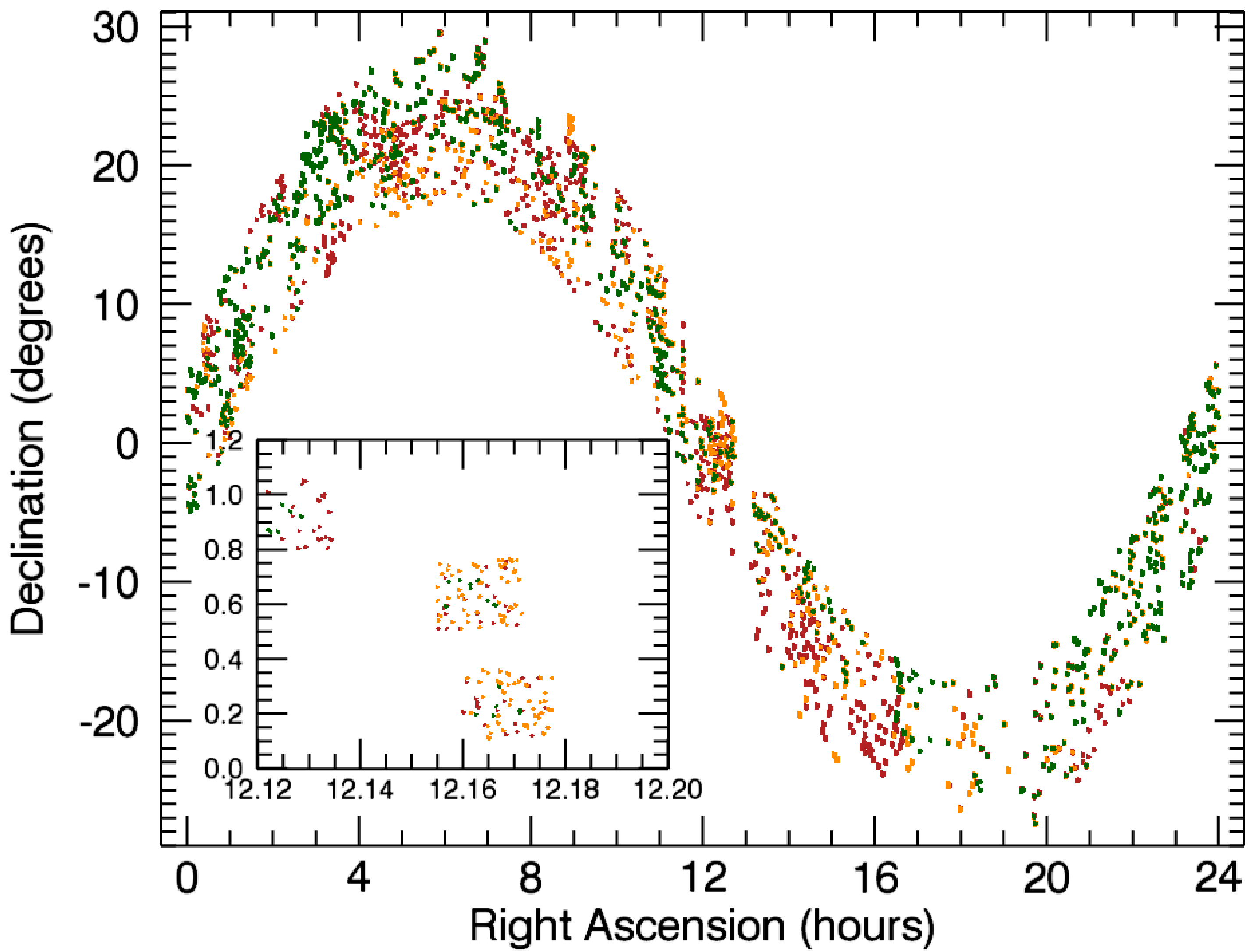
# Upgrades

- More flexible and general scheduling system
  - Development limited by funding opportunities
  - Ideal tool is a just-in time scheduler based on a fuzzy-logic based system.
- Off-axis guider
  - System completed after 10+ years of effort
  - Classical modes work now
  - Robotic modes require new control methodology

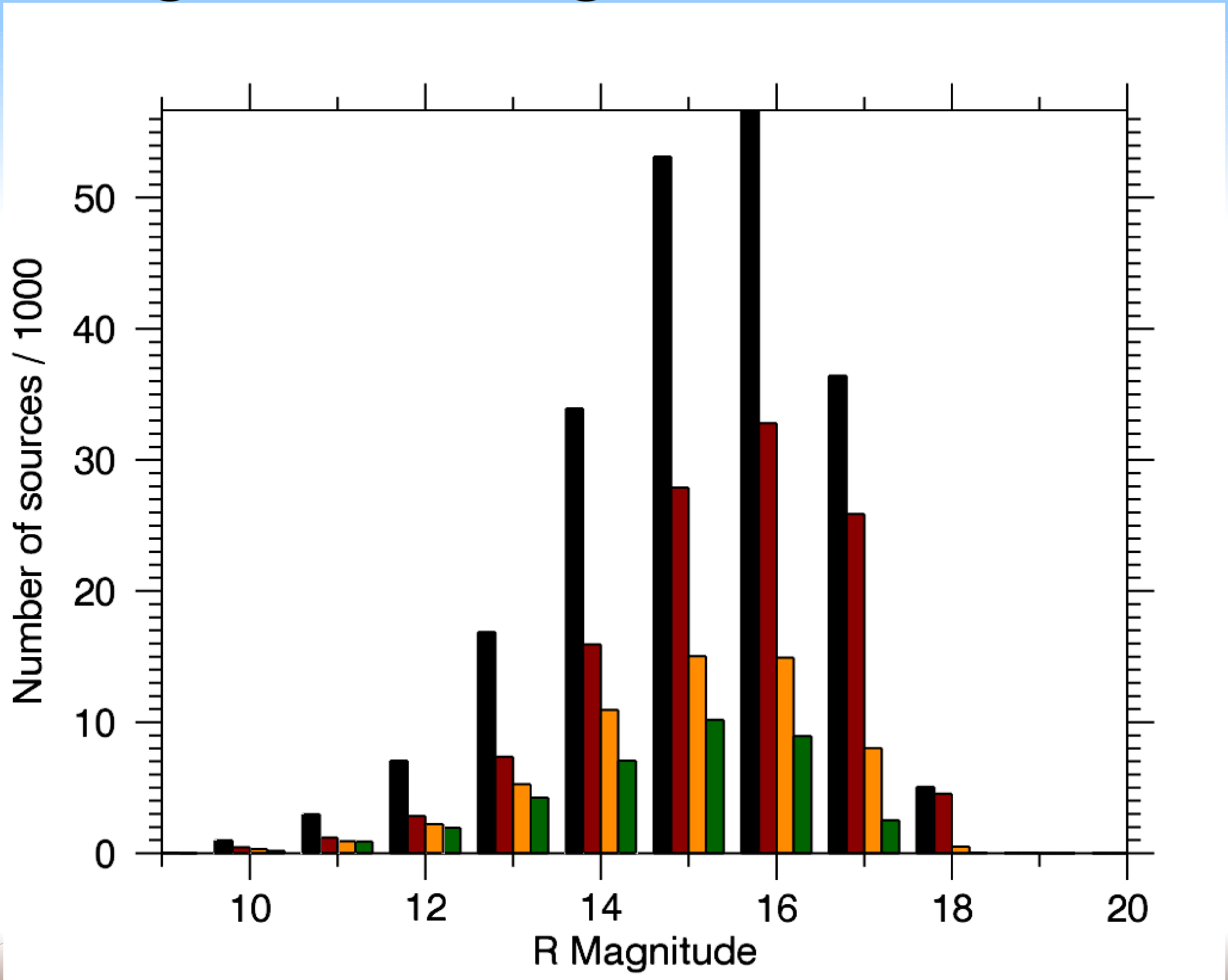
# Results

- Deep Ecliptic Survey
  - NOAO Survey Program to search for Kuiper Belt objects along the ecliptic
  - Search data using Mosaic camera at Cerro Tololo and Kitt Peak on the 4-m telescopes
  - Photometric zero-point calibration relegated to smaller facilities
  - Calibration observations began in 2001, completed in 2010, on robotic system
  - 213,272 sources calibrated in V and R; 54,472 sources measured on three or more nights.

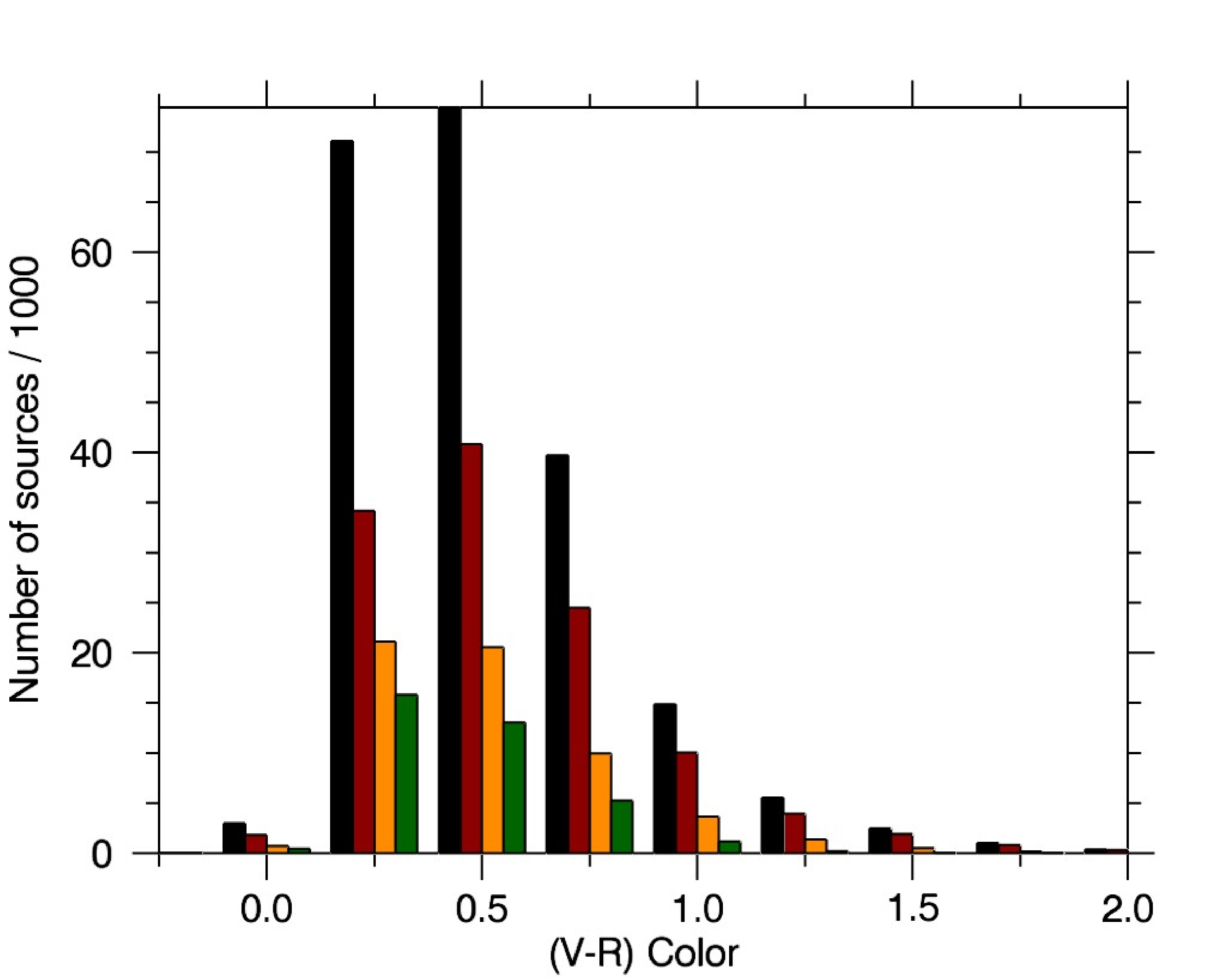
# Positions of Sources Observed



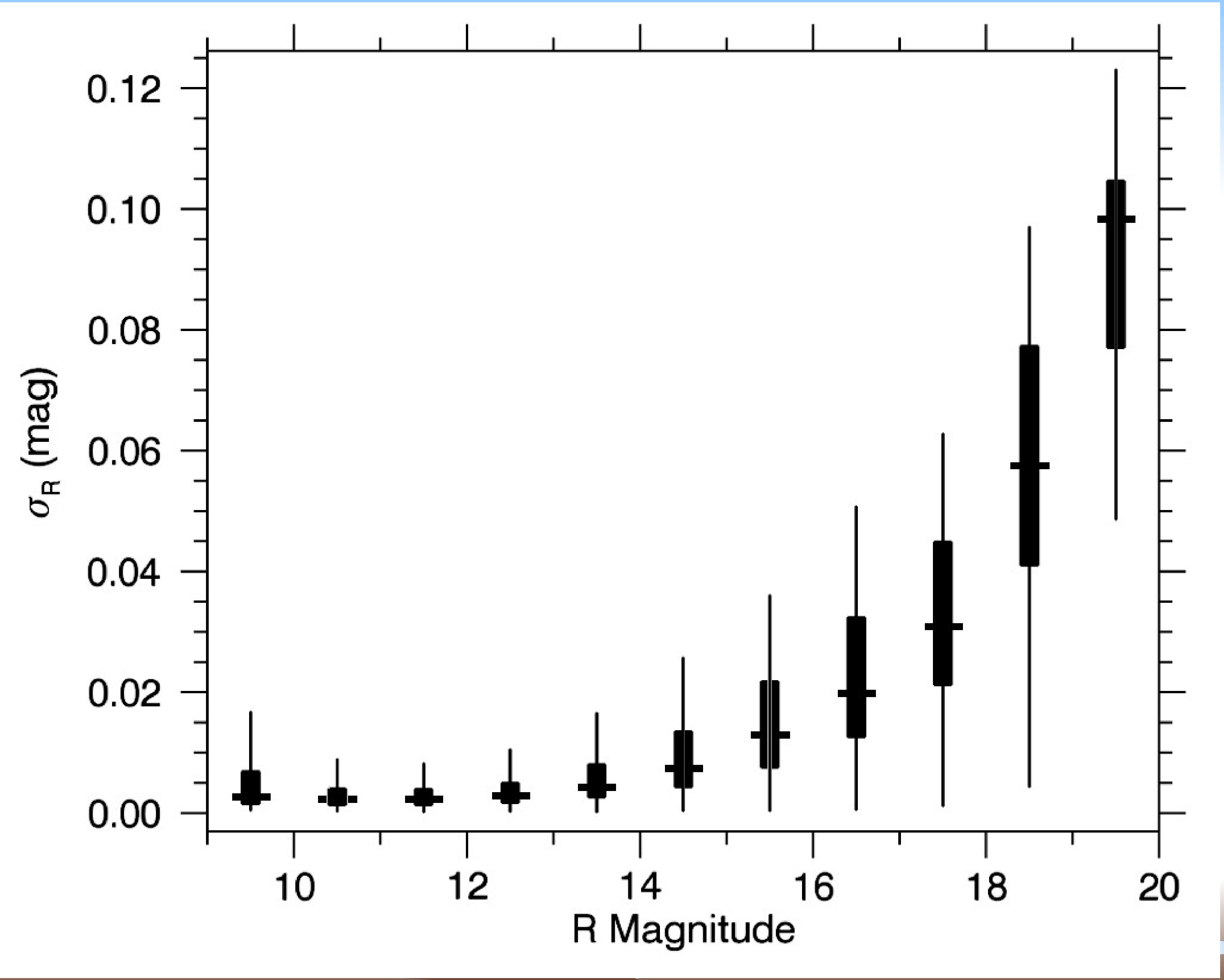
# Range of R magnitude covered



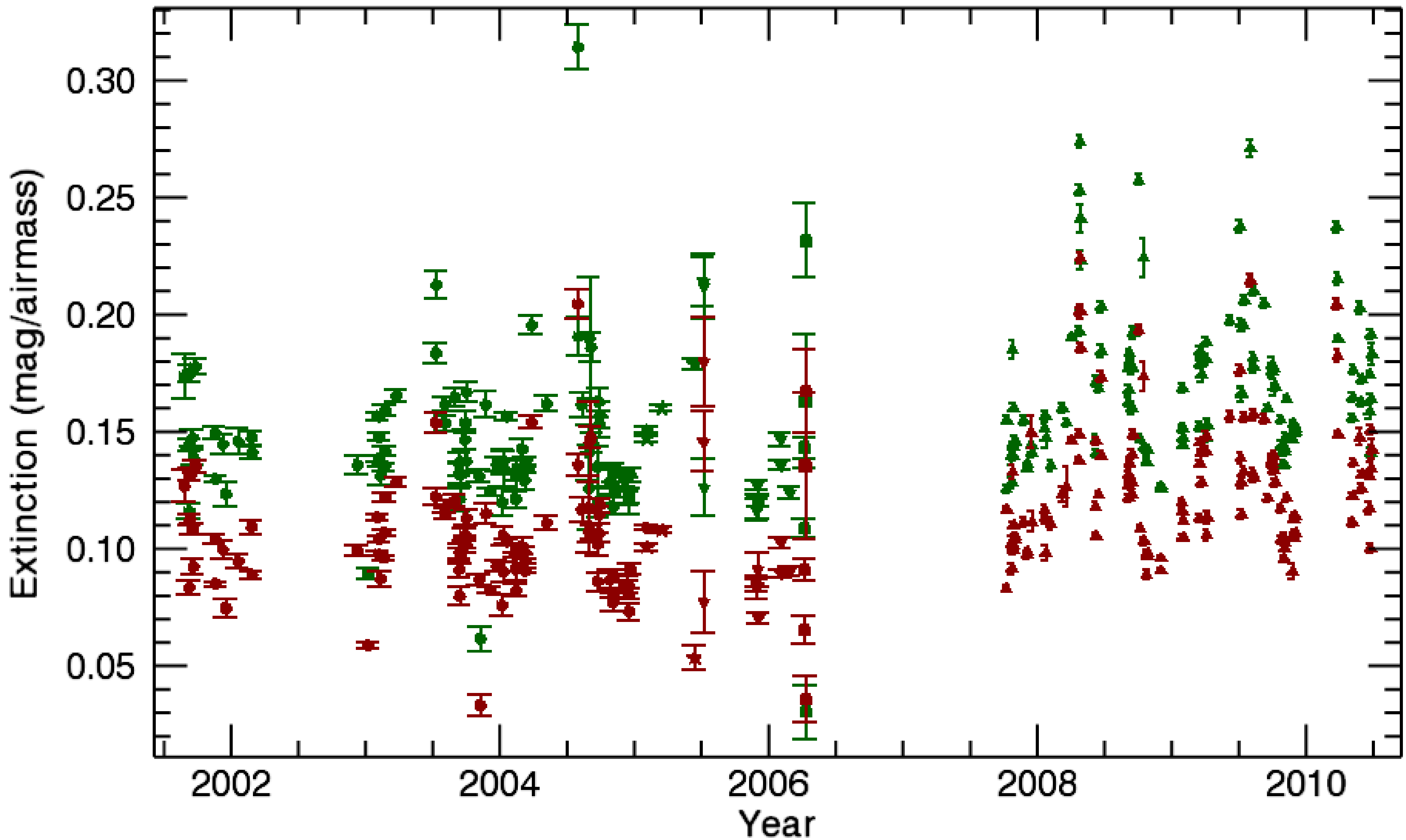
# Distribution of V-R in Catalog



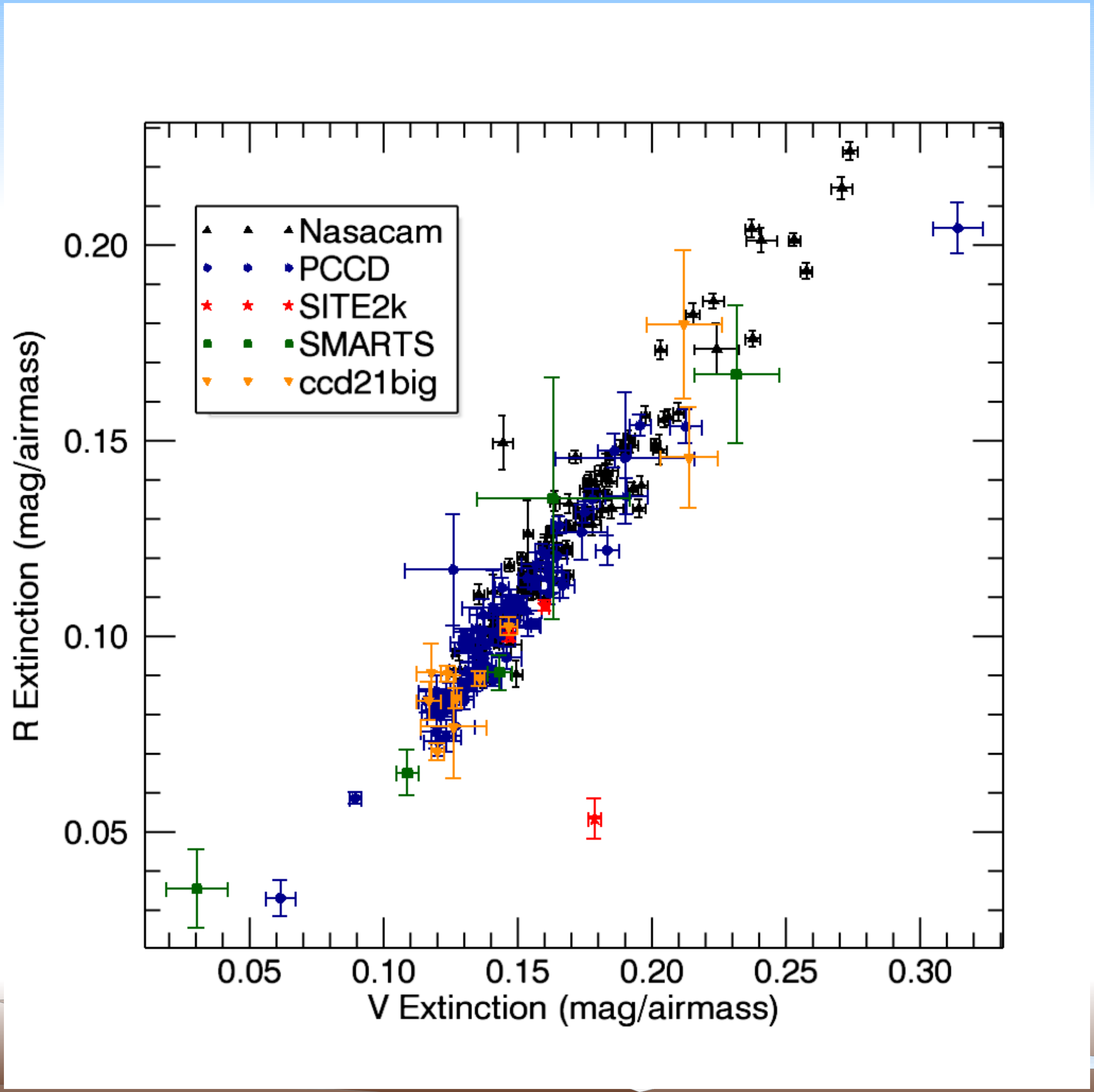
# Distribution of Uncertainties in Catalog



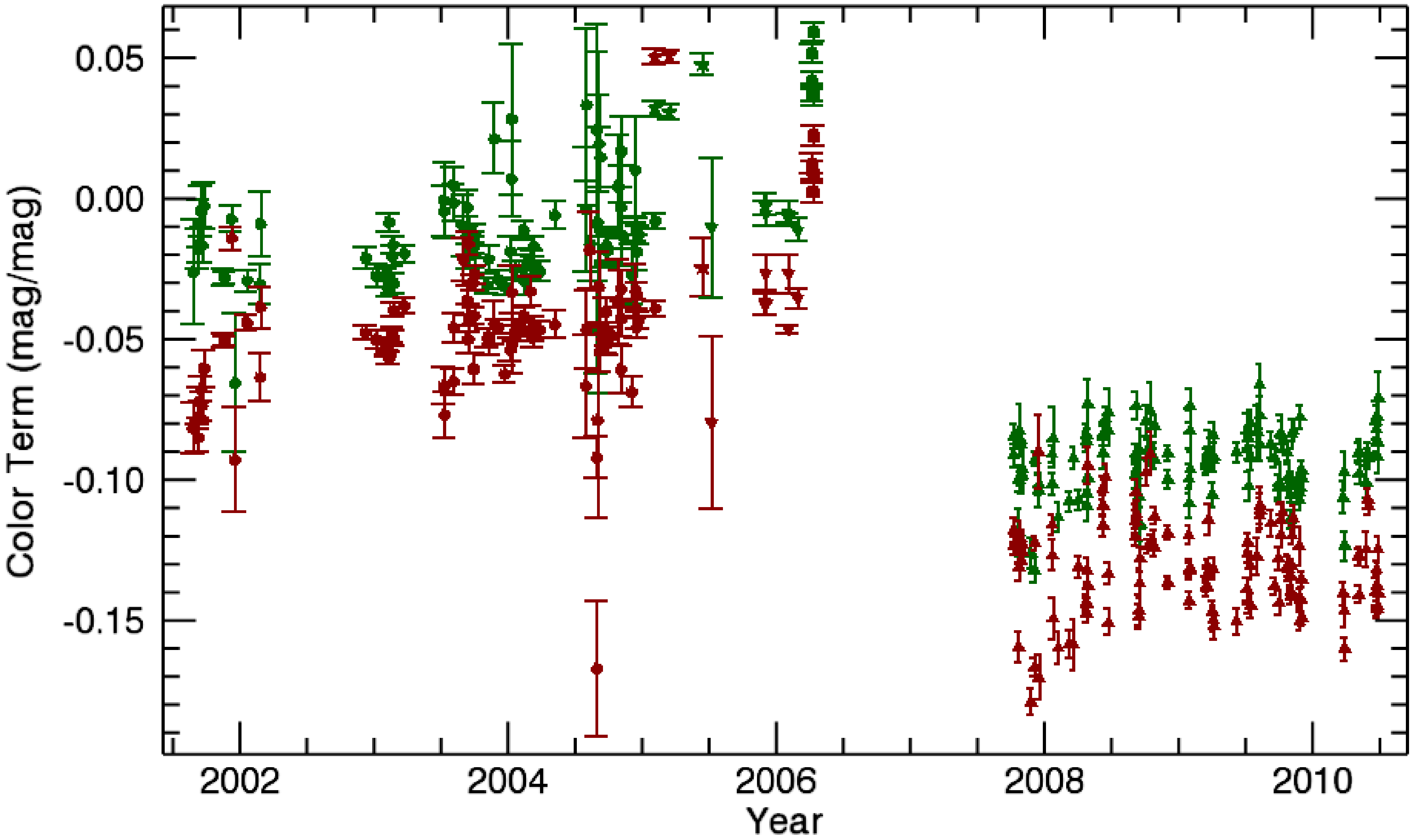
# Extinction History



# V and R extinction comparison



# Color term history



# Zero-point history