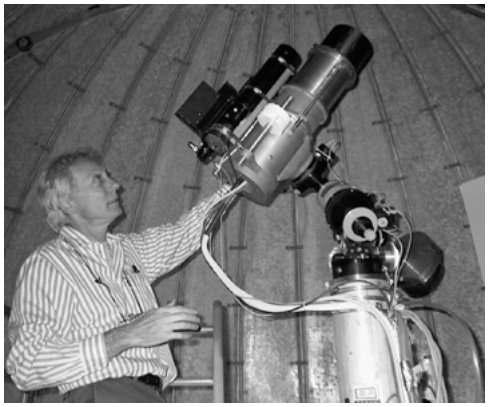
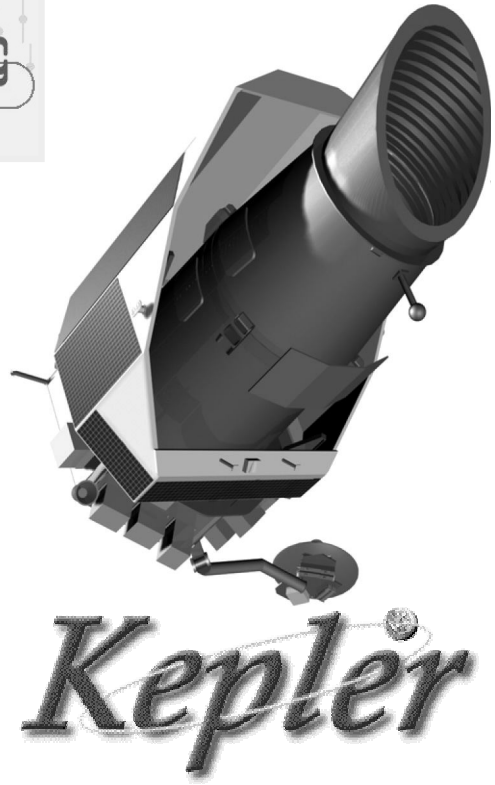
Transit Photometry at NASA Ames



Vulcan



Vulcan South

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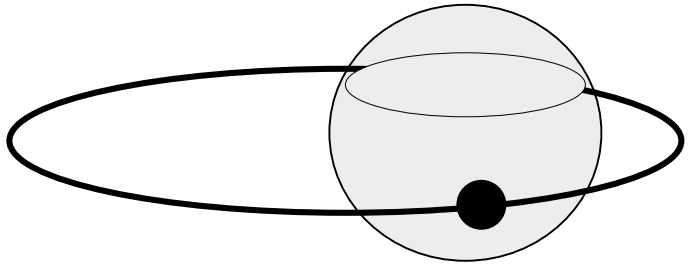
SETI Institute/
Ames-SST

Planet Detection with Transits

•Transit data give duration, depth (A_p/A_*), orbital period, and inclination



•Derive planet's **size** and **orbital radius** using stellar properties (mass, age, size)

•Derive planet's **mass** and **density** using radial velocity detection of the planet

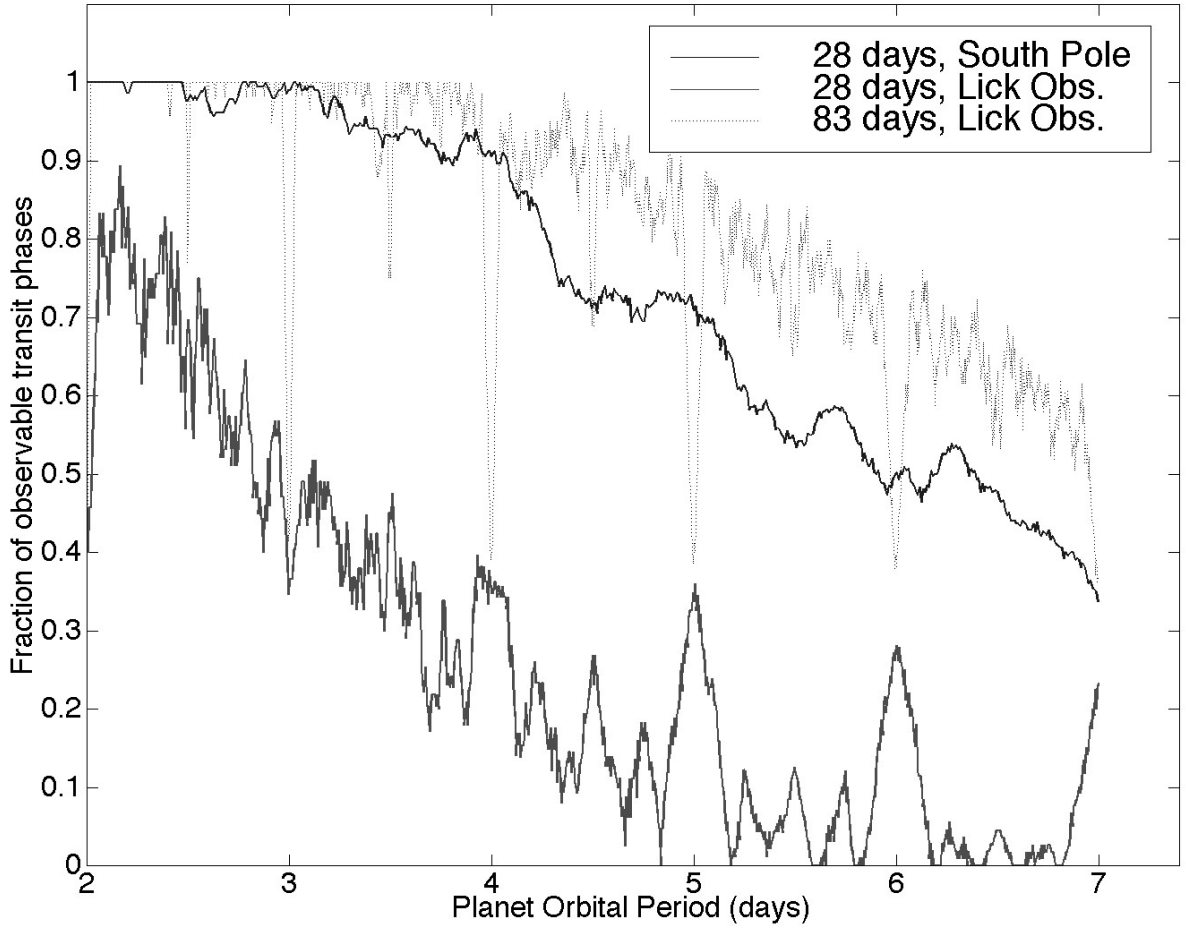
Transit Properties

- Probability of transit is R_*/R_{orb}
  - ~10% for close-in planets
  - ~1/2% for Earth orbit
- Brightness change during transit is A_*/A_p
  - ~1/100 for Jupiter - Sun system
  - ~1/12000 for Earth - Sun system
- Duration and frequency depend on orbital parameters and star size
  - ~3 hours for close-in planets (period = 3 days)
  - ~16 hours for Earth orbit (period = 1 year)

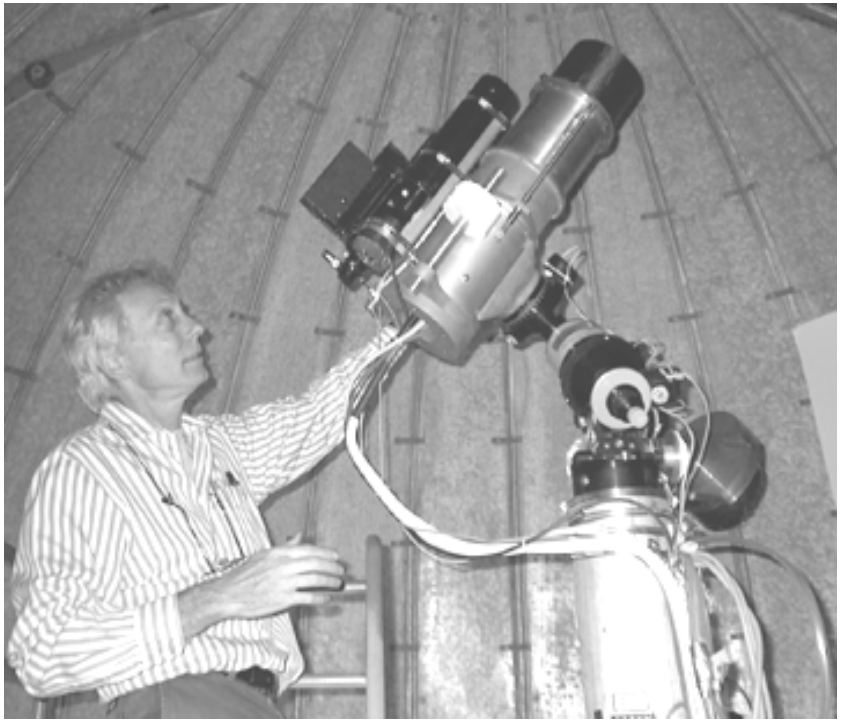
Ground-based Searches

- Limited observing time (day-night cycle, seasonal visibility of stars) makes short-period planets the most accessible targets for multiple-transit detection.
- Atmospheric variations limit the detectable brightness change to ~0.1%, thereby limiting the minimum detectable planet size.

Three-transit Phase Coverage



Vulcan Camera Project



Vulcan Camera-III uses a 300mm F.L. *f*/2.8 Canon lens & 4k x 4k Kodak CCD for a 7º x 7º field-of-view

- Began operation 1997
- Monitors ~6000 stars per field
  - 2-3 months per field
  - 3 minute sampling rate
  - 6-14 hours per night
- 4 fields observed
  - Cygnus: 3 seasons, 105 nights
  - Cygnus-II: 1 season, 30 nights
  - Perseus: 2 seasons, 60 nights
  - Auriga: 3 seasons, 60 nights

Vulcan Camera Results

- **32** candidates with ≤ 3% “transits” were observed with spectroscopy
  - **10** where RV orbit matches photometric orbit:
    - **4** stellar binaries with grazing eclipses
    - **2** eclipsing binaries in triple star systems
    - **4** M-dwarf companions
  - **1** background binary
  - **7** evolved stars with stellar mass companions
  - **13** early spectral types => stellar companions
  - **1** unresolved candidate with large $V \sin i$

Vulcan-South Project

- South Pole has advantages for transit searches:
  - Long winter night offers much better multi-transit phase coverage
  - Stars move at constant airmass
    - Flux changes ~10-20% due to extinction at temperate sites
    - Time-scale of extinction changes ~ transit duration
  - Low sky background, low scintillation
  - Galactic plane high in sky
- Deployment scheduled for Dec 2003

- Uses a network of amateur astronomers to target individual stars
- Multiple-sites offer excellent phase coverage, allowing for detection of longer period planets
- Known exoplanets can be targeted on an ongoing basis
- Excellent growth potential without overhead of building a new observatory

Kepler

Space based photometer is the best option:

- Heliocentric orbit offers continuous viewing of one star-field for 4 years
- Precision is sufficient to see Earth analogs
- Currently the only technology available to determine the frequency of Earth-like planets in the habitable zones of Solar-like stars
- Discover planets smaller than the Earth in short-period orbits or around small stars

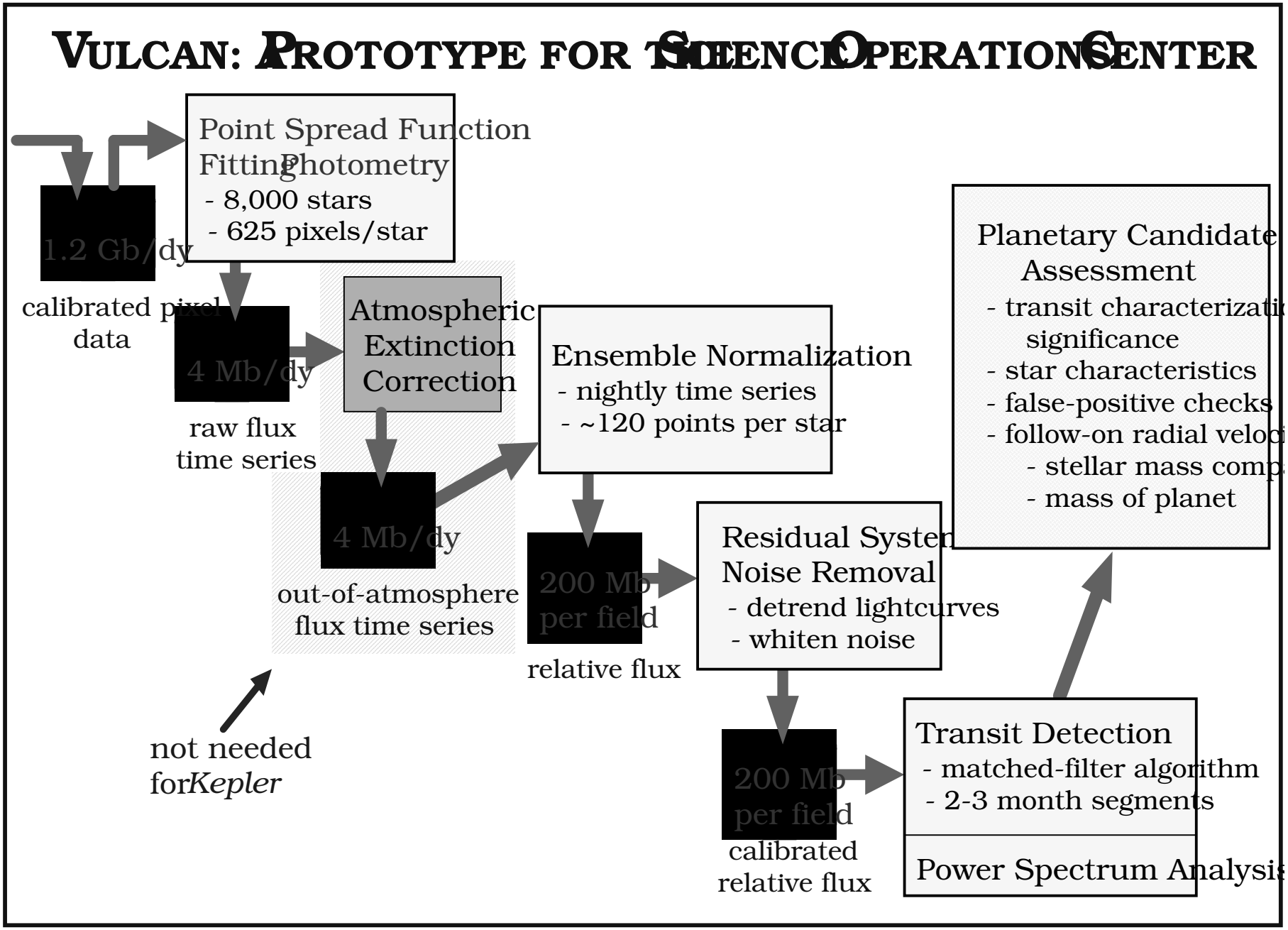
Kepler

- Wide-field (105 deg^2) Schmidt telescope to monitor 100,000 stars continuously for 4 years
- Expected results:
  - 50 planets if most stars have 1 R_{Earth} planets
  - 185 planets if most have 1.3 R_{Earth} planets
  - 870 giant planets with period <1 week from reflected light modulation (35 showing transits)
  - 135 inner-orbit giant planets and 30 outer-orbit giant planets from transits

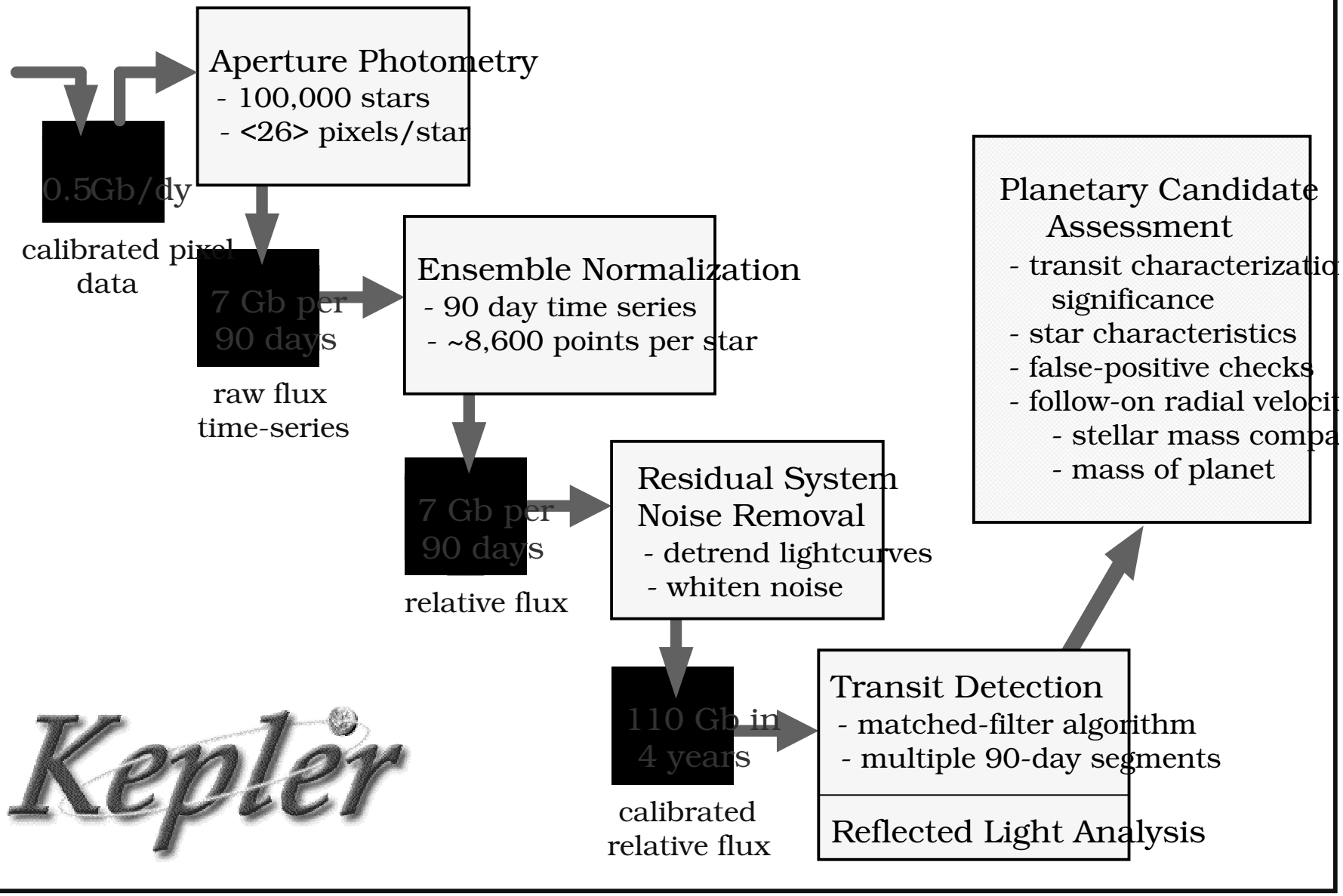
Transit Data Processing

- Image calibration (bias, thermal, gain correction)
- Measure star brightness on each image
  - Aperture photometry (with pixel weighting)
  - Point-spread-function fitting photometry
  - Difference-image photometry
- Ensemble normalization to remove systematic errors
- Noise ‘whitening’ and transit detection
  - Decorrelating lightcurves
  - Matched-filter detector

VULCAN: PROTOTYPE FOR THE SCIENCE OPERATIONS CENTER



Data Processing at the Science Operations Center

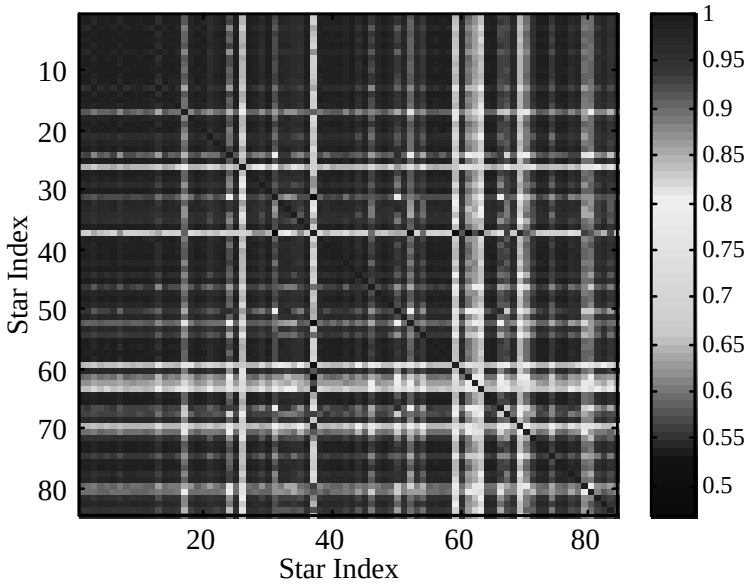


Transit Data Mining?

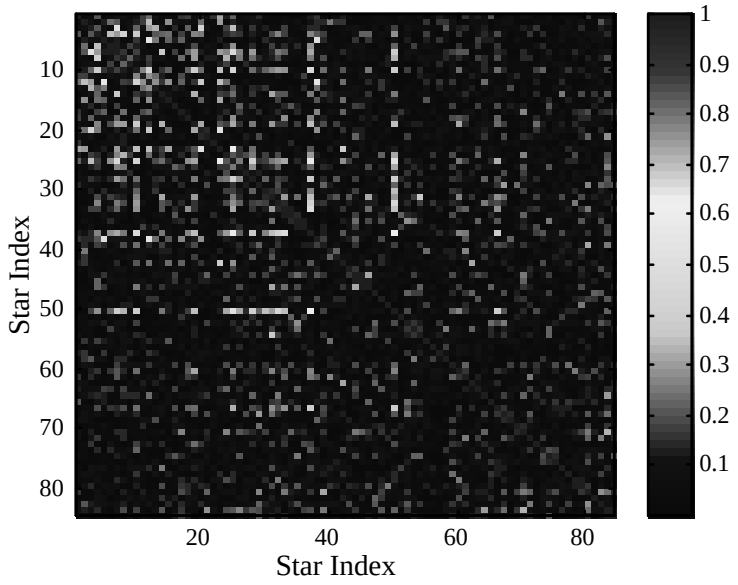
- Long-term precise monitoring of stars
- Transient events (flares, solar system bodies)
- Stellar variability/noise characterization
- Astrometry (stellar position changes)
- Eclipsing binaries
  - Planet detection through eclipse timing
  - Transit searches
- Planet properties
  - Reflected light modulation (albedo)
  - Moons or rings

Residual System Noise Removal

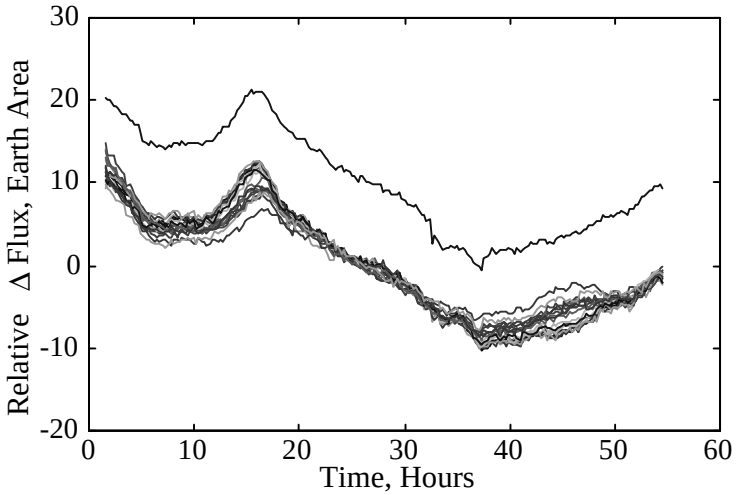
Flux Correlations



Corrected Flux Correlations



Raw Flux



Corrected Relative Flux