POET: Photometry for Orbits, Eclipses, and Transits

Joseph Harrington (UCF)
Thomas J. Loredo (Cornell)
and the UCF Exoplanets Group

Planetary Sciences Group
University of Central Florida
Orlando, Florida

Why Be So Careful?

- Reanalyses show problems of simple analyses
- Events often weak, <4σ, upper limits
- Most analyses have right eclipse depths
  - A few multimodal ones might change
- BUT, many error bars are likely wrong
  - Too low: bad, eliminate valid theory
  - Too high: also bad, accept invalid theory
- Reviewers (*US!*) should be pickier!
  - Many models, show posterior dist., show tests
  - Our papers discuss what to look for & why

UCF's POET Pipeline

- Many dozen eclipse and transit datasets
- Concern: Spitzer systematics >> eclipse signal
- Photometry for Orbits, Eclipses, and Transits
- Try all methods, evaluate analyses statistically
- Not scattershot! Ask *right* statistical questions
- Example: Select best aperture by SDNR, but select best ramp/intrapixel by BIC
  - If several analyses have similar BIC, solution encompasses them
- With up to 20 apertures and ~12 ramps, can do many dozens of analyses per eclipse

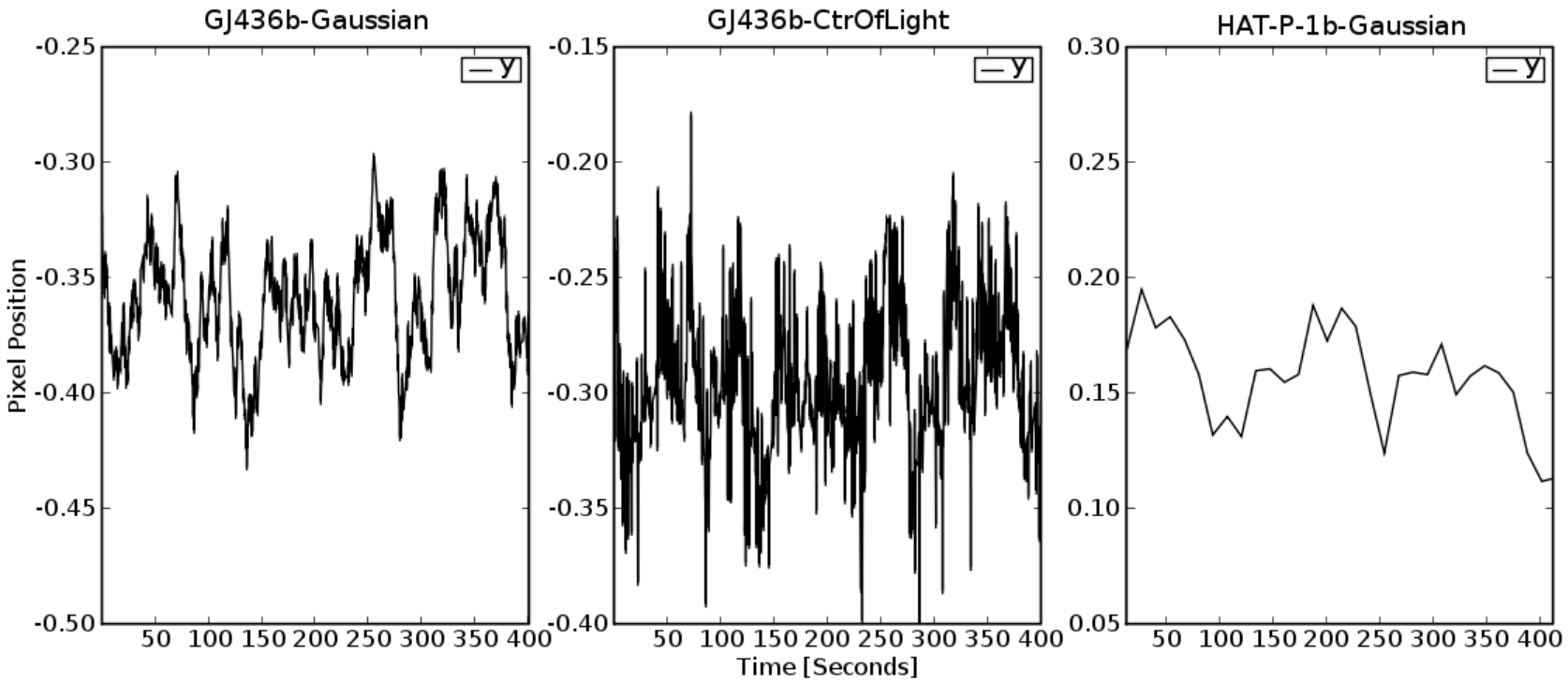
POET Photometry

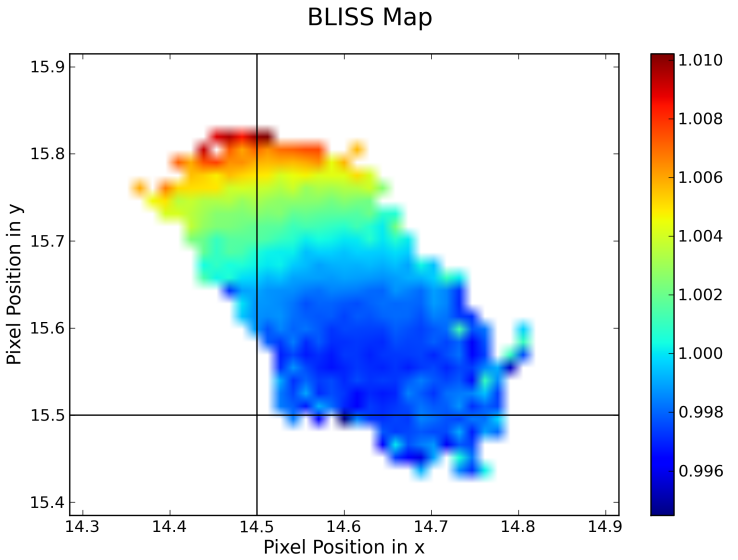
- Object-oriented design
  - Based on first 3 exoplanet analyses in 2004-5
- Event object allows joint fits among many datasets
- Code and settings data completely separate
  - Isolates human decisions, text files of parameters
  - Undergrads leading papers w/POET
- Motivated by HD 149026b debacle: bad stats→bad results!
- Bad pixels identified in time, groups of 64 frames, sigrej
- Precision centering (~0.01 pix)
- Interpolated aperture photometry (cures pixelation) w/errs
- Never discard a frame without a reason

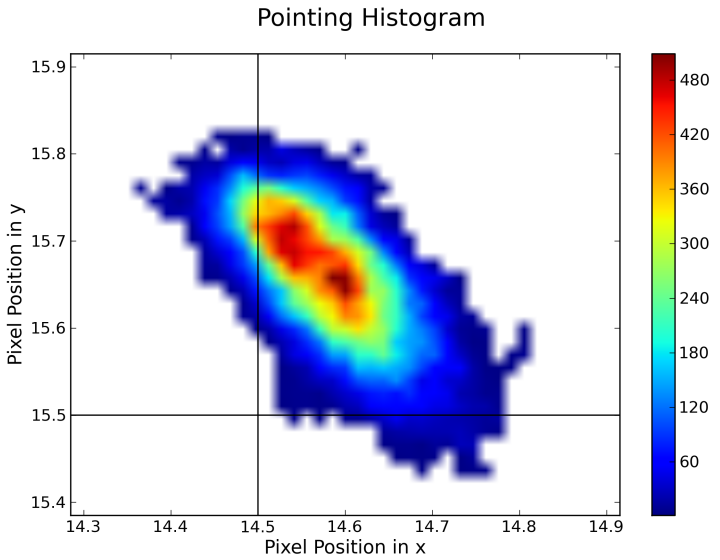
POET Event Modeling

- FIRE: Flux, Image, Ramp, Eclipse simultaneous fit
- BLISS intrapixel mapper (Stevenson *et al.* 2012a)
- Large selection of analytical ramp models
- Markov-chain Monte Carlo phase-space exploration
- Tests: convergence, red noise, unimodality,...
- All selections based on end-to-end fit results
- SDNR selects apertures – can't use BIC on diff. data
- BIC selects systematic models with statistical rigor
- Detailed methods descriptions in papers

Pixel-Phase Effect







MCMC Checklist

- Find the minimum with a minimizer
  - Rescale errors after 1st good fit, Spitzer's are high
- Assess errors & correlations with MCMC
  - DO NOT report peak/median of each parameter distribution as best value!
  - If MCMC *ever* finds better χ^2, reminimize from there and restart MCMC
  - Gelman-Rubin test for MCMC convergence
  - Inspect histograms and correlation plots
- Differential-Evolution MC is MUCH BETTER!
- Red noise: RMS vs. bin size, wavelets, adj. err.

Boring but Important: BS vs. MCMC

- MCMC: How likely is theory given the data?
- BS: Compared to the best fit, where does the truth lie, given the model? truth:data as data:BS
- BS is subtle!
- There are several BSs (using the right one?)
- Short section in Press et al. inadequate
  - Does not discuss assumptions, limitations, interpretation (many adjustments needed)
- Read Efron & Tibshirani (1993 book) to do right
- Or just do MCMC, which is what you want

Spitzer Analysis Checklist

- Just because model fits does not mean it's right
- Eclipses require 10^{-4} accuracy!
- Worry about 2^{nd}- & 3^{rd}-order effects
- Observe 3 hours before, 2 after (or $2t$+1 hr)
- Try many apertures, centering methods
- Use subpixel photometry
- Try many intrapixel and ramp functions
- Run variations in all reasonable combinations
- Use SDNR, BIC, AIC to choose best, report ties
- Atmos: Report $T(p)$ and contribution functions