Planet-finding with SIM

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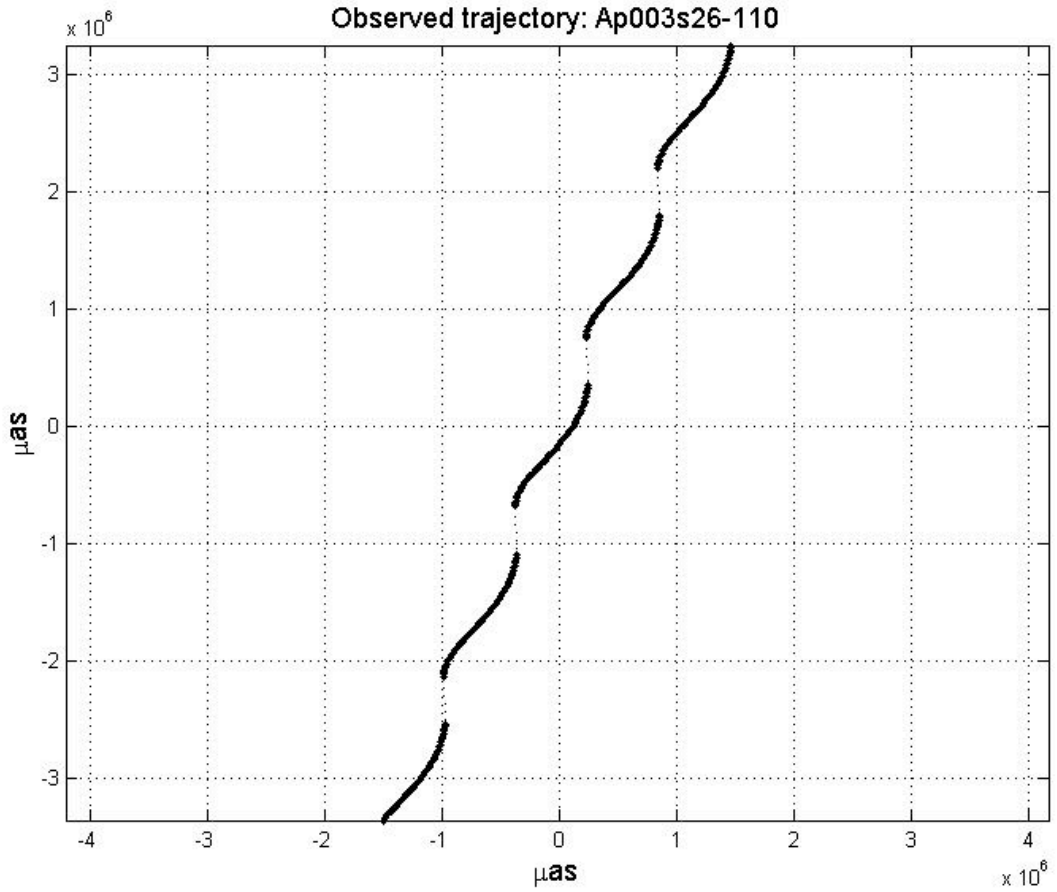
Analysis of MSC test case

- Ap003s26_110 astrometric-only data set
  - 0.9*solar mass star at 8.525 pc and ecliptic latitude of -9.3 degrees.
  - Three planets
  - Proper motion and parallax
  - Real observing schedule
    - The spacecraft ephemeris is for an Earth-trailing, Spitzer-like orbit
    - 250 2D observations
    - Includes annual solar exclusion gap
    - Otherwise, quasi-even sampling (within +/-5% of uniform), away from exclusion gap.
  - No noise

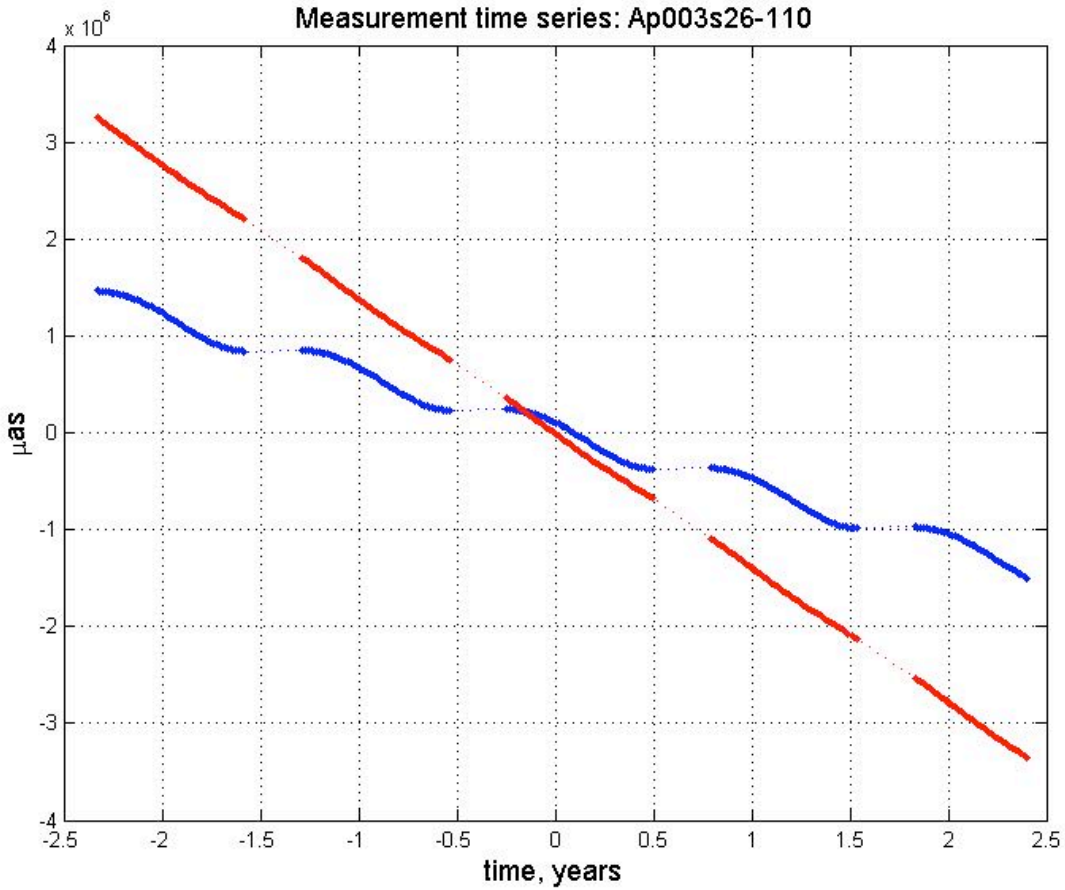
Brief overview of hierarchical approach

- Use the periodogram to detect and estimate the period of the planet with the strongest signal.
- Use the periodogram estimate as the initial guess for a non-linear least squares (NLLS) fit of the data to a model of a Keplerian orbit, proper motion and parallax (PMPX).
- Subtract the fitted model from the data to get the residual
- Apply the periodogram to the residual to detect and estimate the period of the planet with the next strongest signal.
- Use the fitted parameters of the previous planet fit together with the estimated period of the next planet to do a NLLS Keplerian orbit fit to 2 planets & PMPX. Note that the parameters for planet 1 as well as proper motion and parallax are updated during this fit.
- Repeat iteratively until the periodogram has no peaks that exceed the 1% false alarm probability threshold

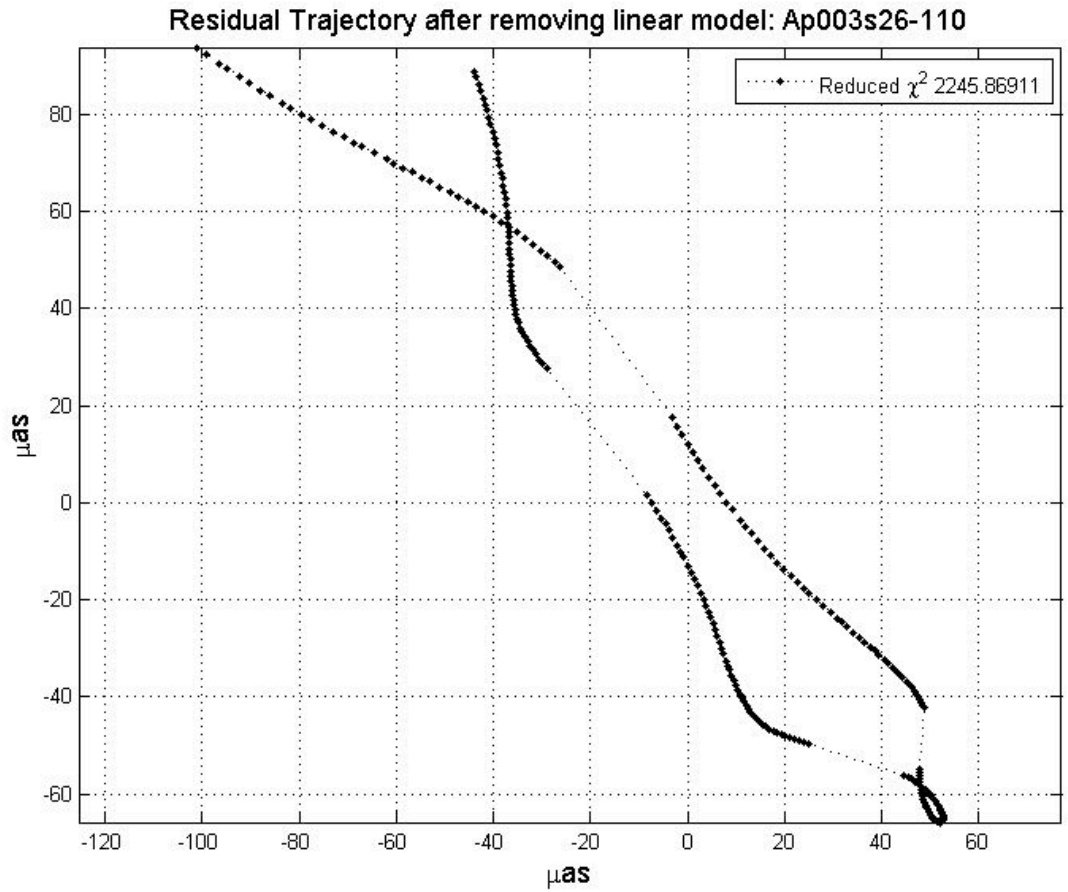
Stellar trajectory (from data)



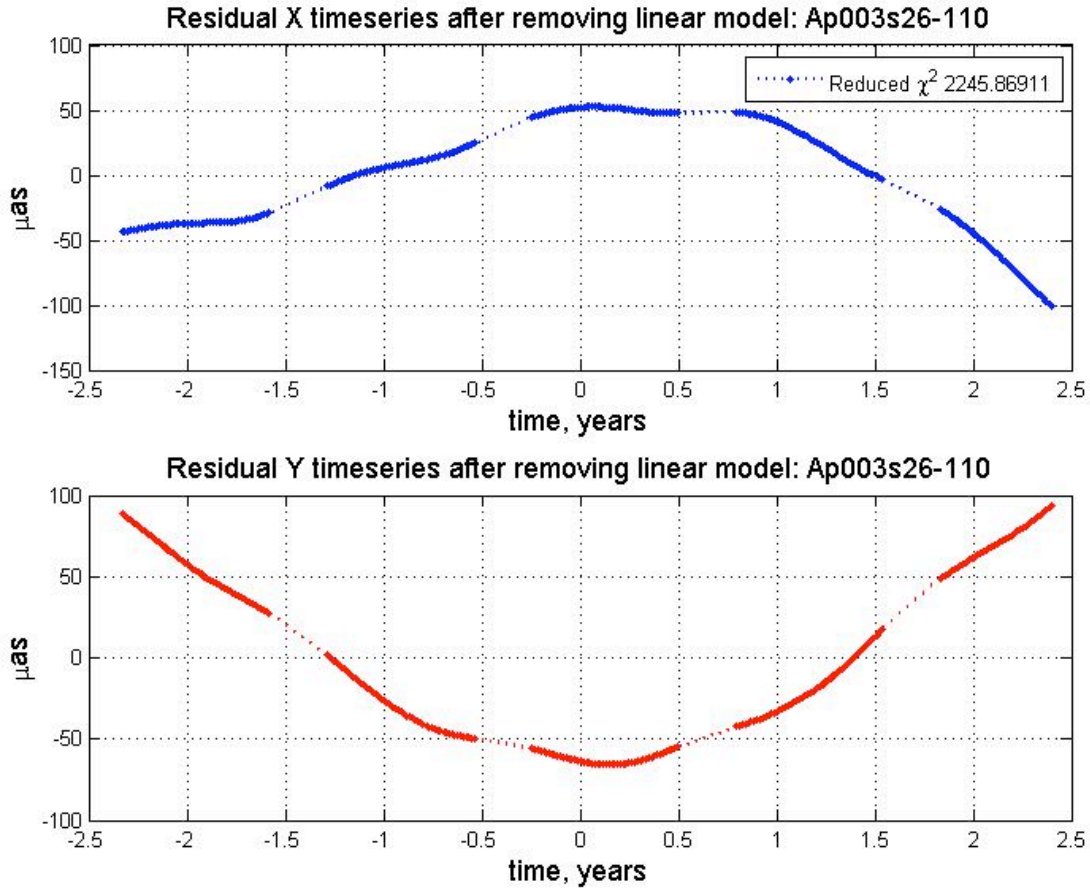
Time series of X and Y data



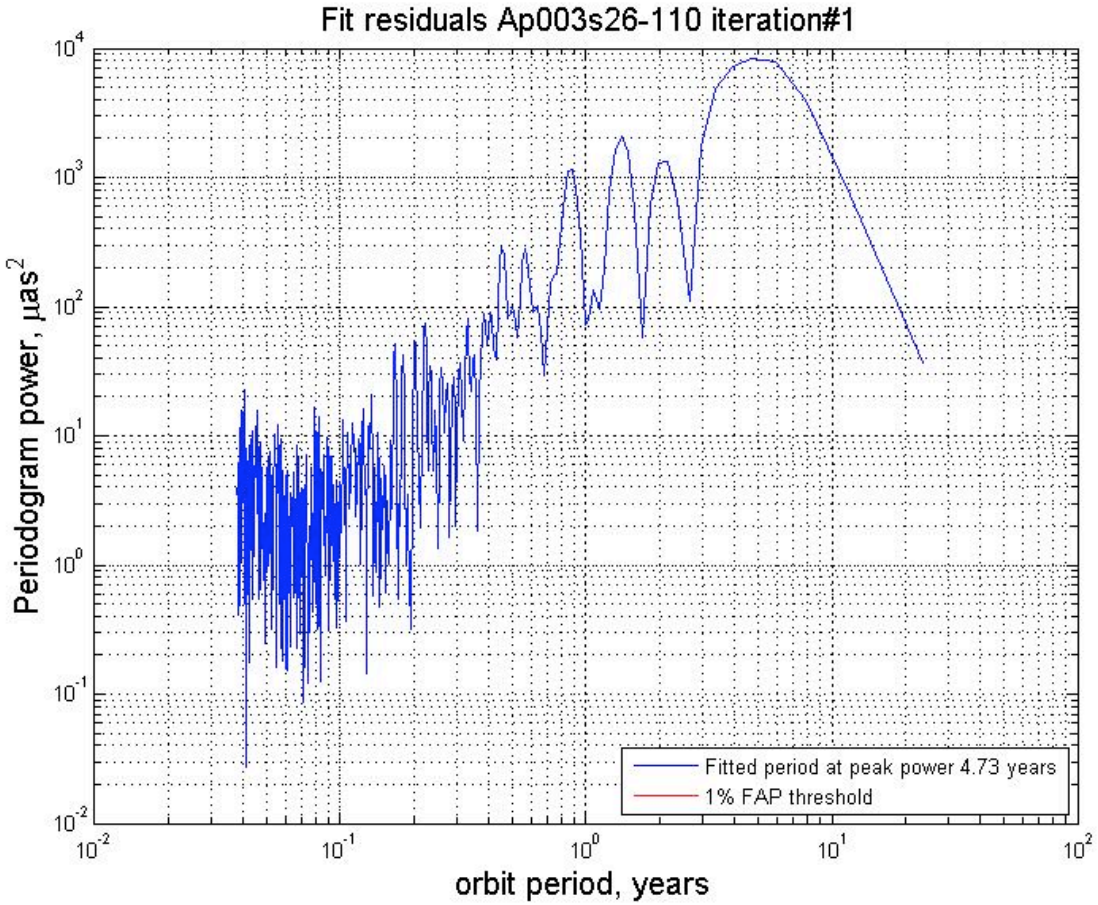
Residual trajectory after removing linear model for estimated proper motion and parallax



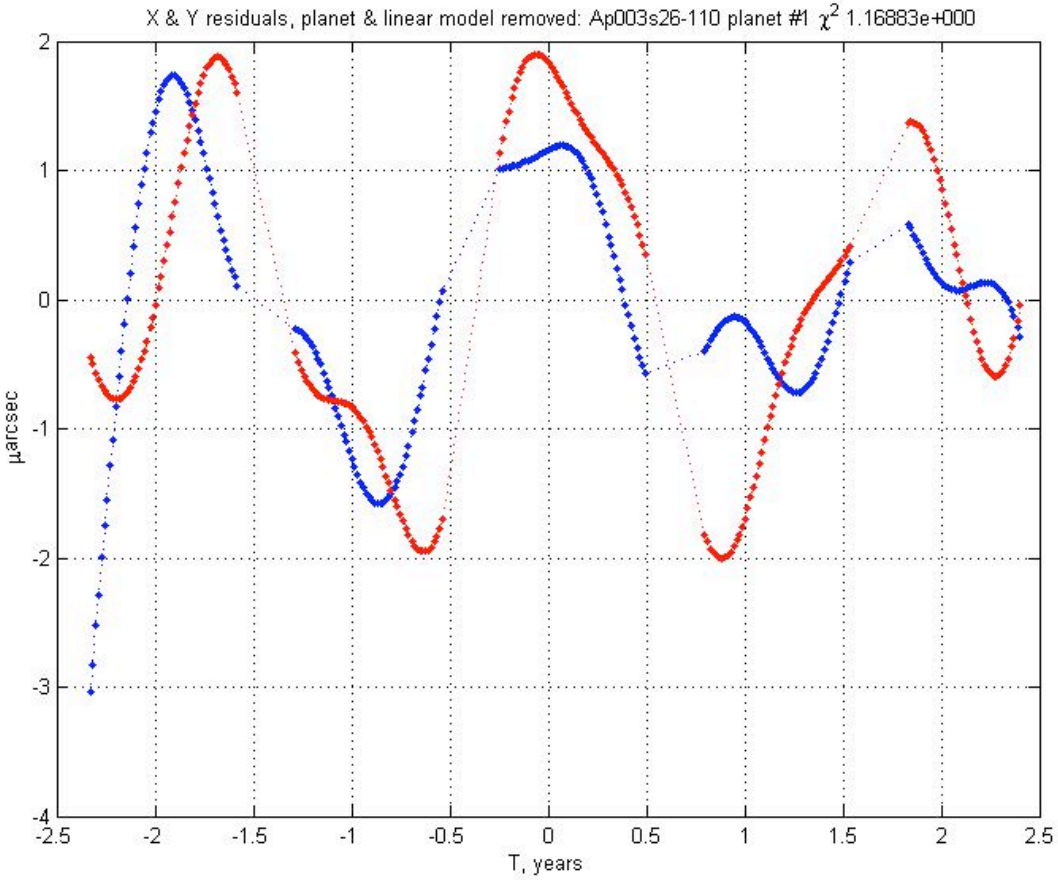
Time series of residuals after removing linear model for estimated proper motion and parallax



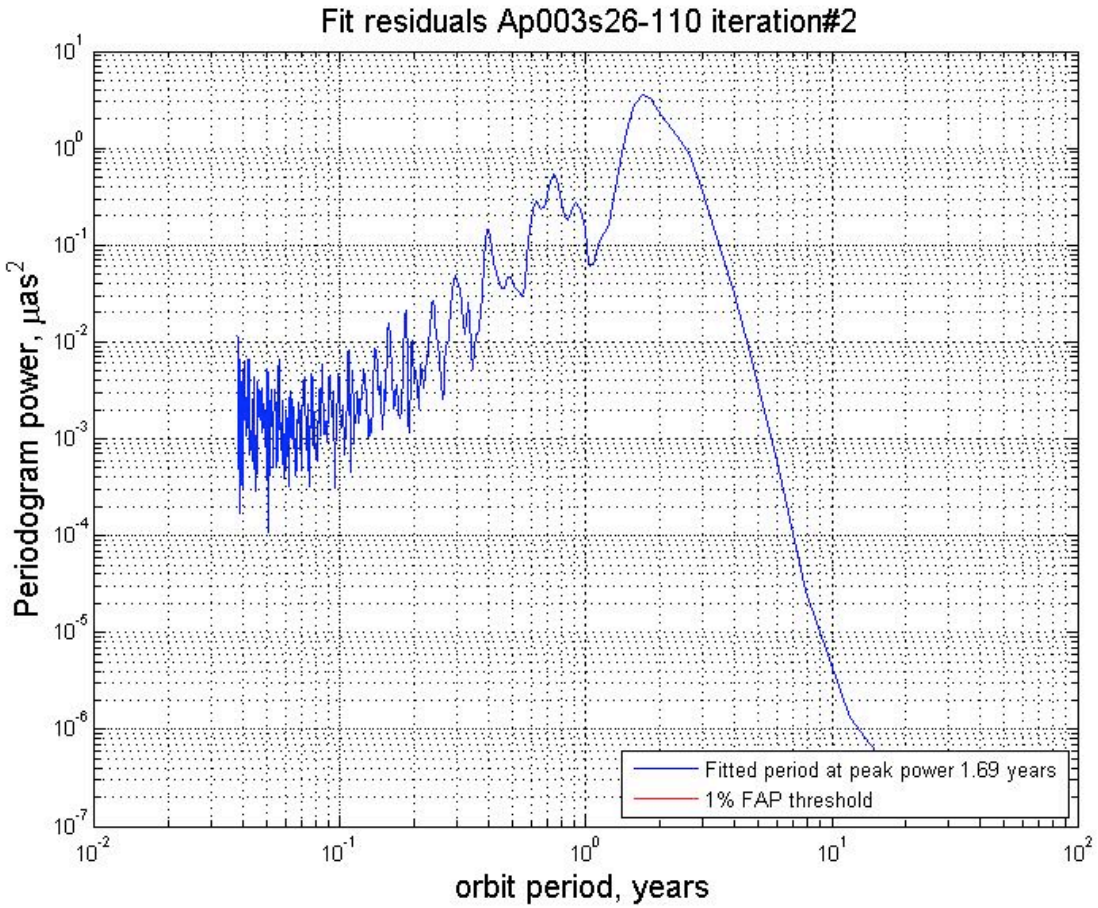
Joint periodogram of residual after removing linear model of proper motion and parallax



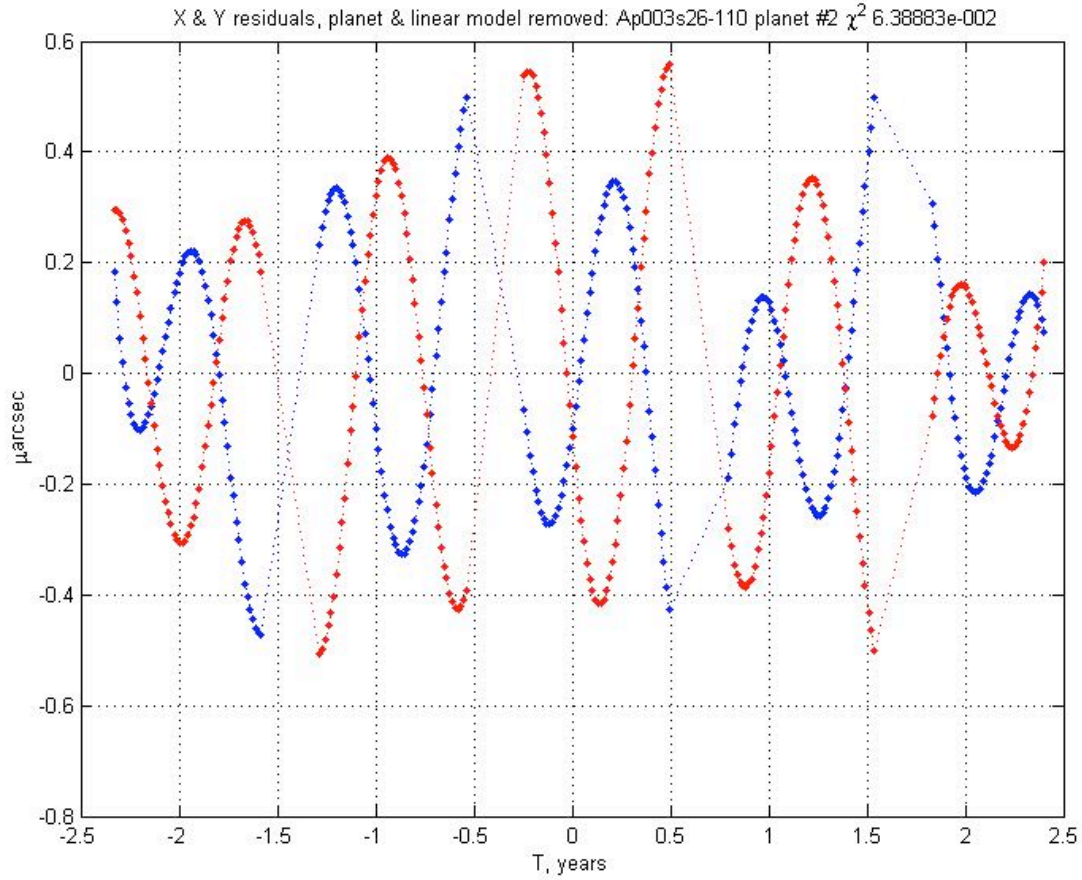
Residual after one-planet fit with period guess from periodogram



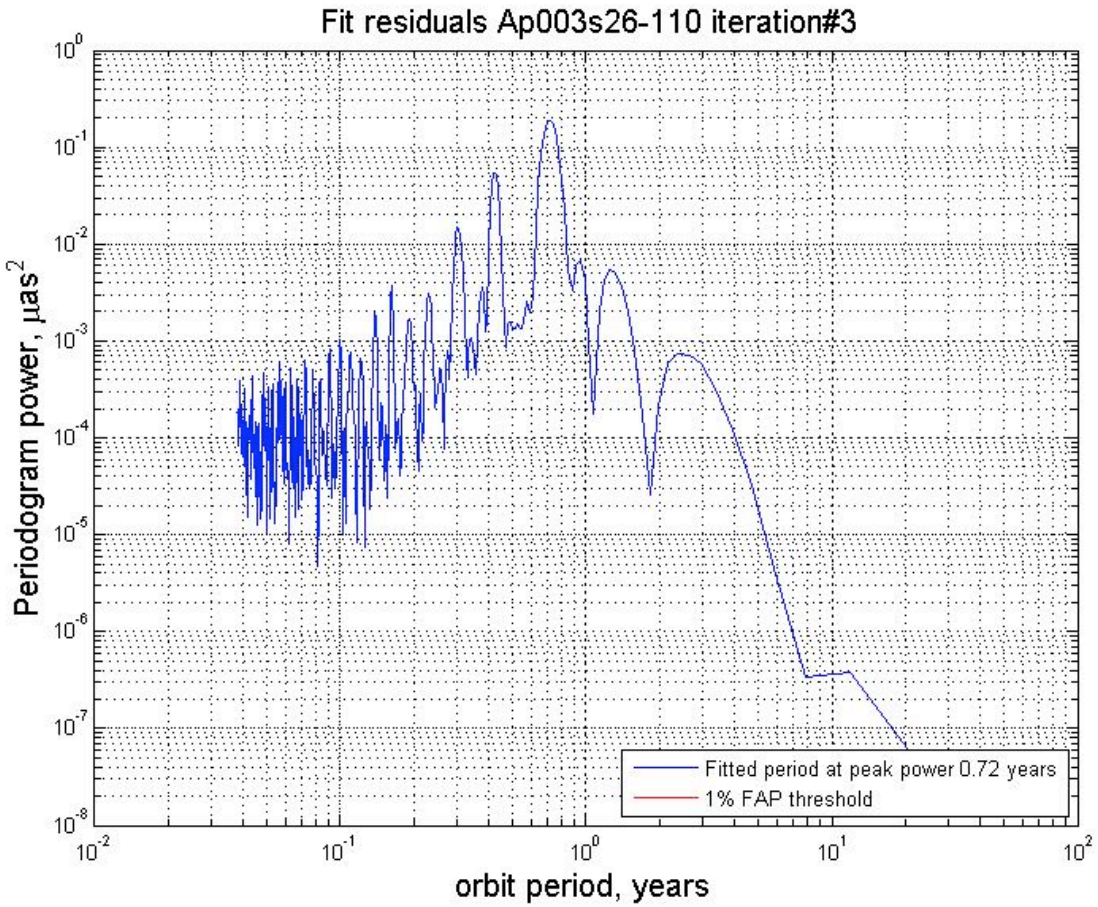
Joint periodogram of residual from one-planet fit



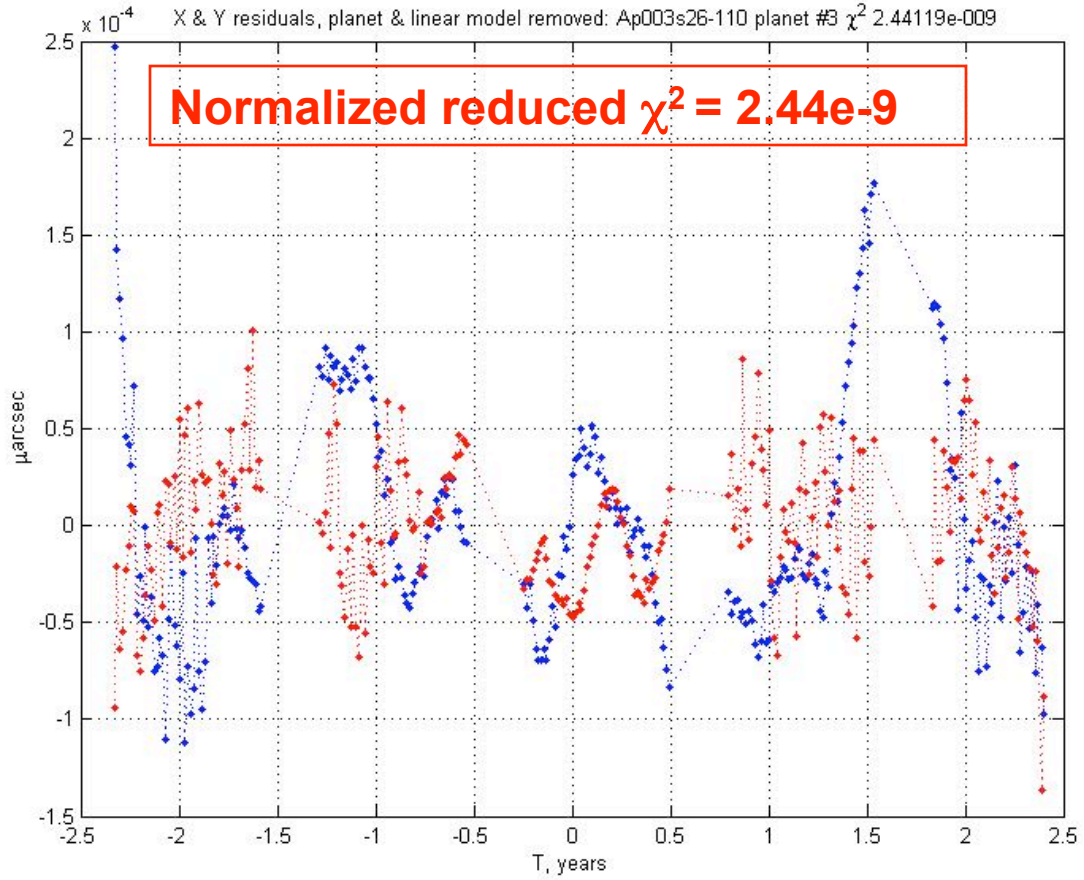
Residual after two-planet fit with 2nd planet period guess from periodogram



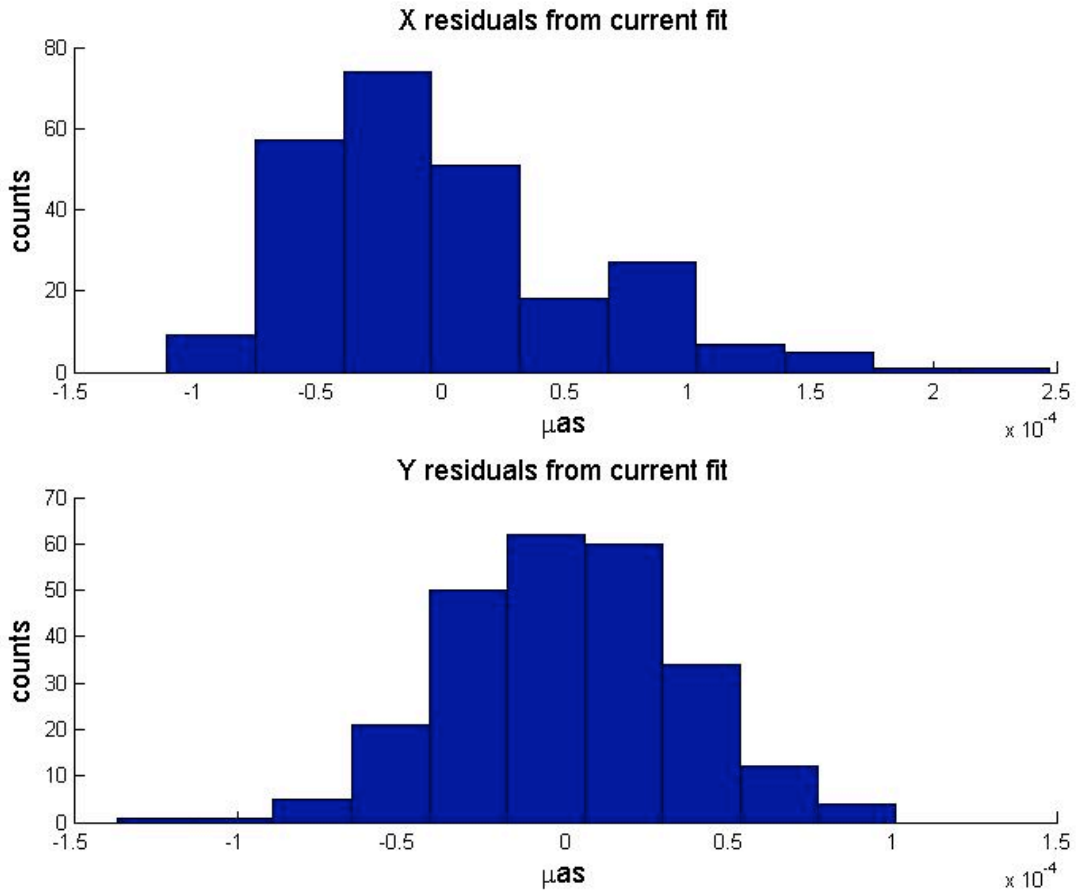
Joint periodogram of residual from two-planet fit



Residual after three-planet fit with 3rd planet period guess from periodogram



Histogram of residuals



Final three-planet fit

- Iteration #3: Joint periodogram detected period = 0.7167 years
- parallax estimate = 117.3 mas, distance = 8.525 pc
- Normalized reduced chi-squared for the simultaneous 3-planet fit is: $2*10^{-9}$
- Typical residuals are on the order of $5*10^{-5}$ uas, comparable to machine precision

Details of final three-planet fit

Planet number	1	2	3
Period (yrs)	8.114	1.782	0.718
Mass (units of M_{Earth})	102.80	4.17	1.74
Astrometric signature (uas)	156.888	2.313	0.528
Semimajor axis (AU)	3.90	1.42	0.77
Eccentricity	0.0872	0.1416	0.0201
Inclination, deg	70.92	70.48	68.03

Summary

- The hierarchical approach works well with multiple-planet systems
- We have extended the method to joint astrometric/RV fits.
- We have also analyzed cases with synthetic measurement noise.

Multiple planets caveat

- Multiple-planet systems are impossible to disentangle, if the periods are too closely spaced.
  - Frequency spacing of df < 1/T is problematic, where T is the mission duration.
  - For T = 5 years, this includes Jupiter/Saturn systems.
- BUT: RV data with a longer (15 to 20 year) time baseline helps.
- For systems with two or more long-period orbits, often the best that can be done is to model out the long-period planets without accurately solving their orbits, allowing the orbits of short period planets to be well-fitted.