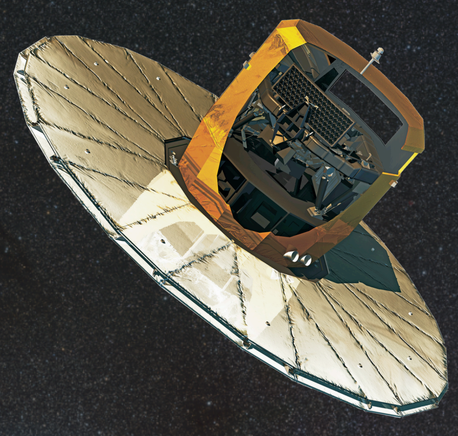
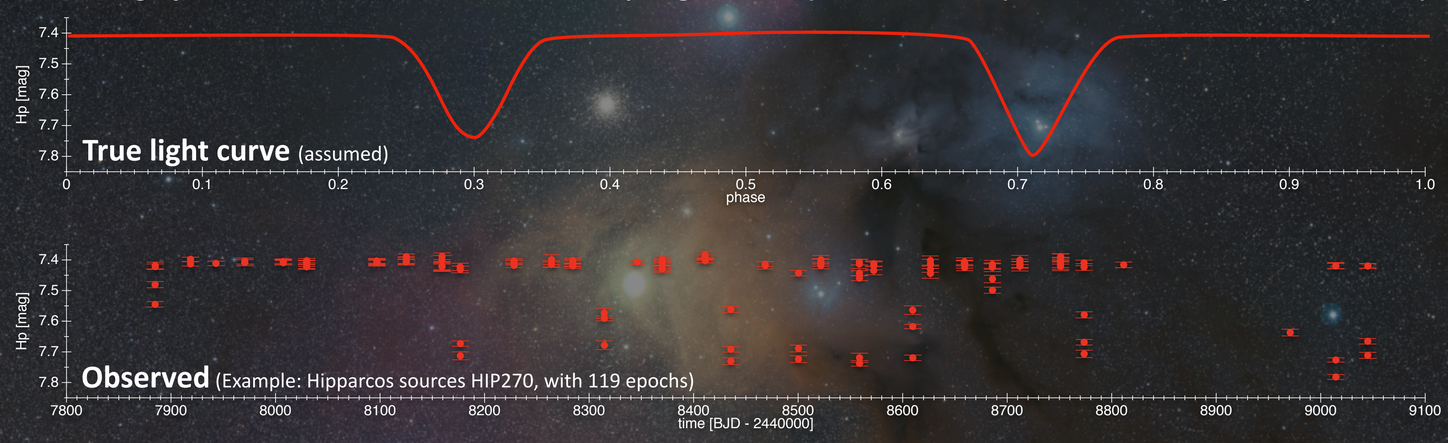
Automatic determination of eclipsing binary periods, geometric-model and quality ranking in Gaia data

B. Holl, N. Mowlavi, I. Lecoeur-Taibi, F. Barblan, L. Rimoldini, L. Eyer, on behalf of the CU7 Consortium
(Department of Astronomy, University of Geneva, Switzerland)



Observing periodic eclipsing binary signal

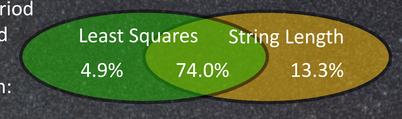
During 5yr Gaia observes ~0.5 - 5 million eclipsing binaries (Holl et al. 2013) with 45 to 300 epochs (70 mean).

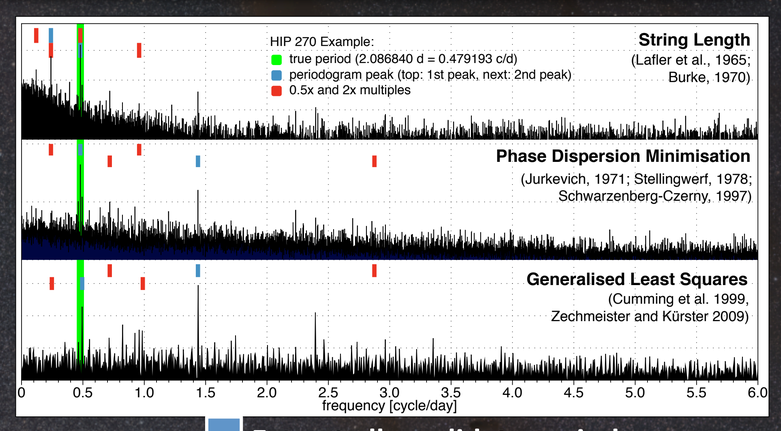


Period recovery from such sparsely sampled data

Identify candidate periods
Period search with various methods

- **An ensemble of period search methods is used to identify candidate periods** to cover the wide variety of geometric light curve shapes.
- **From each periodogram we extract several highest peaks and frequently occurring fractions of them** (like 1/2 and 2).
- Example on a subset of 588 Hipparcos eclipsing binaries: for 92.2% of them, the correct period is contained in the set of 8 candidate periods composed of the 2 highest peaks and their doubled period using Generalised Least Squares and String Length:





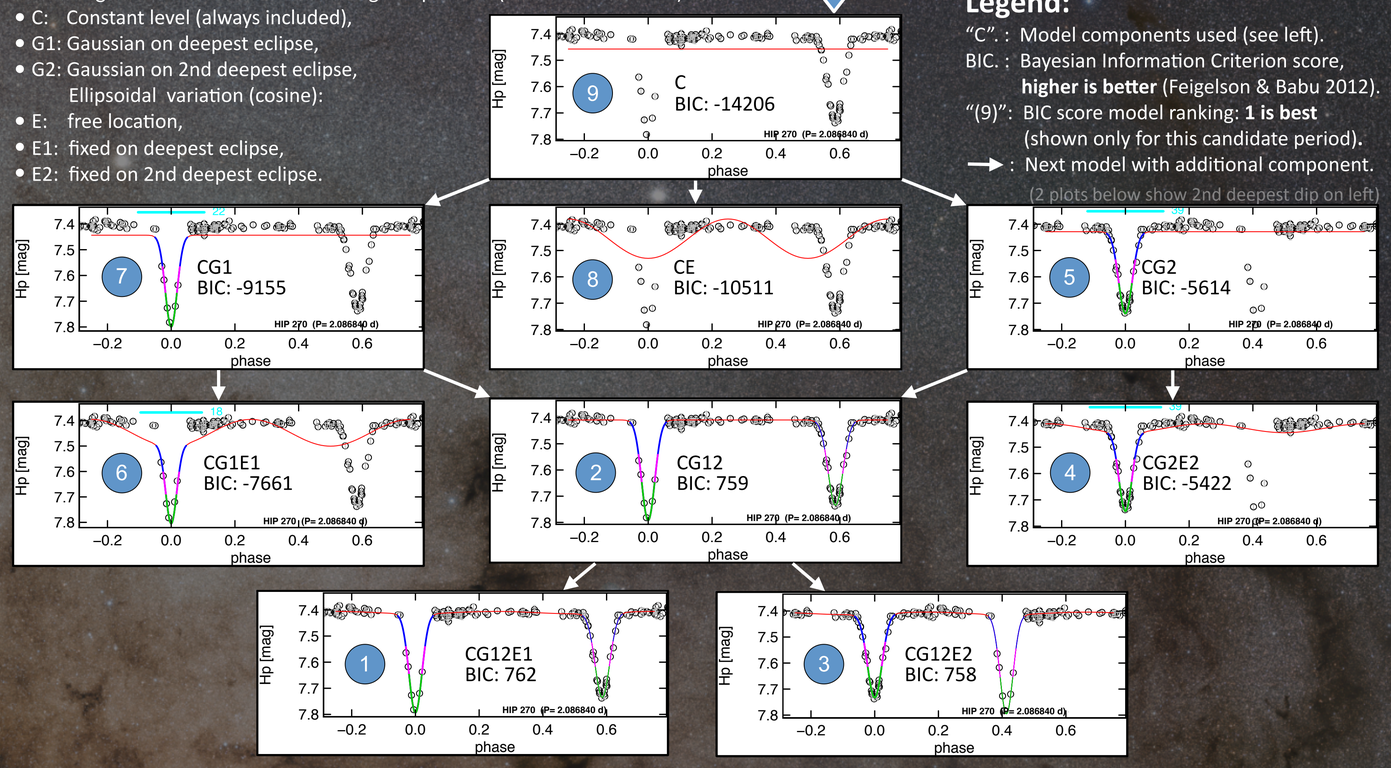
Extract all candidate periods from all periodograms (18 above).

Evaluating geometric models
2-Gaussian modelling of candidate periods

Fit each candidate period with 9 hierarchical models

containing a combination of the following components (Mowlavi et al. 2017):

- C: Constant level (always included),
- G1: Gaussian on deepest eclipse,
- G2: Gaussian on 2nd deepest eclipse,
  Ellipsoidal variation (cosine):
- E: free location,
- E1: fixed on deepest eclipse,
- E2: fixed on 2nd deepest eclipse.



Legend:
"C". : Model components used (see left).
BIC. : Bayesian Information Criterion score, **higher is better** (Feigelson & Babu 2012).
"(9)": BIC score model ranking: **1 is best** (shown only for this candidate period).
→ : Next model with additional component.
(2 plots below show 2nd deepest dip on left)

Quality ranking
Bayesian Information Criterion and other measures of goodness of fit

- **The BIC score allows us to directly compare all models of all candidate periods for a source.**
  Quality is initially ranked (circled numbers above) based on the Bayesian Information Criterion score (BIC), which has the advantage that it penalises model complexity, hence a more complex model will surpass the score of a simpler model if it is significantly better at fitting the data.
- **Correct period was found for HIP270 example** taking the best BIC scoring model (1 above) from *all* models of *all* candidate periods (i.e., 162 = 9 models for each of 18 candidate periods).
- Current investigations are concentrating on resolving model degeneracies (see below) and use of additional goodness of fit parameters like von Neumann (1941, 1942) to boost the number of correctly recovered periods. Tests on Hipparcos data show that automatic period recovery for up to 90% of the eclipsing binaries could be reachable.

Choosing from (partial) degenerate models

Add knowledge
Apply priors to model selection

Add more information
Break degeneracies using constraining data

- Some of the geometric models above are geometrically degenerate, e.g., the ellipsoidal component of a C+G1+E1 can mimic a second Gaussian component in a C+G1+G2 model for a smooth contact system light curve.
  In such a case we can favour the 2-Gaussian geometric model as it allows us to derive the eccentricity of the system (and might be in general closer to a physical interpretation of the system).
- **Gaia uniquely measures in the photometric, spectroscopic and astrometric domain, see figure.**
  Detectable signals in multiple domains provide additional constraints, e.g.:
- Binary systems in which 2 stars have different effective temperatures and/or composition will exhibit different colours during the eclipses, which can be detected in Gaia's blue and red spectral bands. This can break a period versus double period degeneracy if the eclipses are similarly deep or not well sampled.
- Radial velocity time series or astrometric binary fits for the brighter Gaia stars will give strong independent constraints on the orbital period of binary systems.

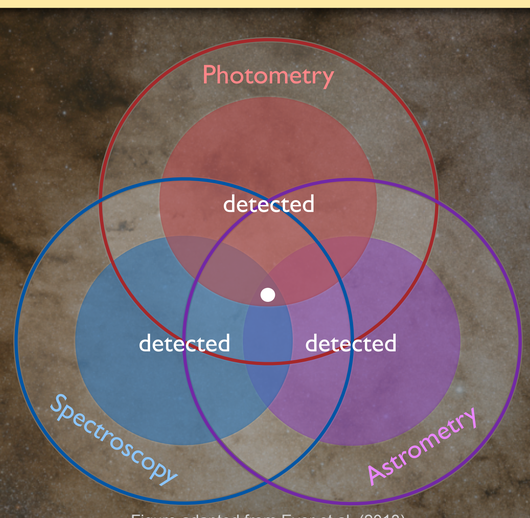


Figure adapted from Eyer et al. (2013)

Final strategy will be published in Holl et al. (in prep.)

Contact: Berry.Holl@unige.ch