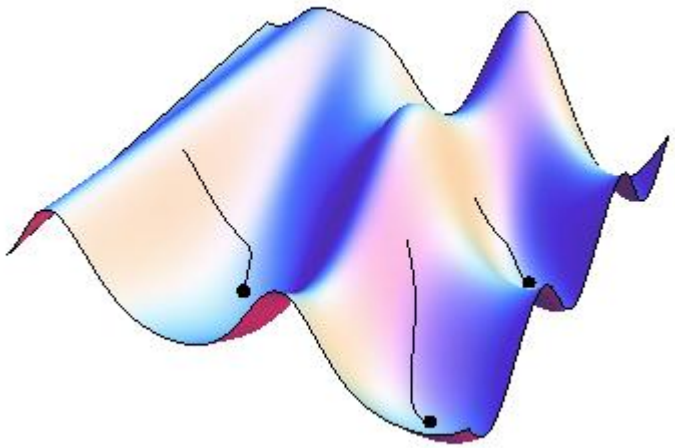
Real-time modeling of microlensing events



V. Bozza

University of Salerno, Italy

ARTEMIS

- **M. Dominik et al. have created ARTEMIS, a fully automatic system that …**
- **collects data from all telescopes;**
- **finds models for ordinary events;**
- **alerts in case of anomalous data points;**
- **now finds models for anomalous events too, thanks to RTModel !**
- **suggests a priority list for the observations.**

www.artemis-uk.org

Why Real-time modeling?

- **Every year more than 1000 microlensing events are discovered.**
- **Roughly 5% of these are anomalous**
  (binary source, binary lens, finite size of the source, parallax, orbital motion, …)

- **Roughly 0.5% may be explained by a planet.**
- **A huge amount of data to be analyzed.**
- **Immediate feedback from theoretical interpretation may help driving observations.**
- **Human bias may lead to wrong interpretations.**

Automatic Real Time Modeling: How?

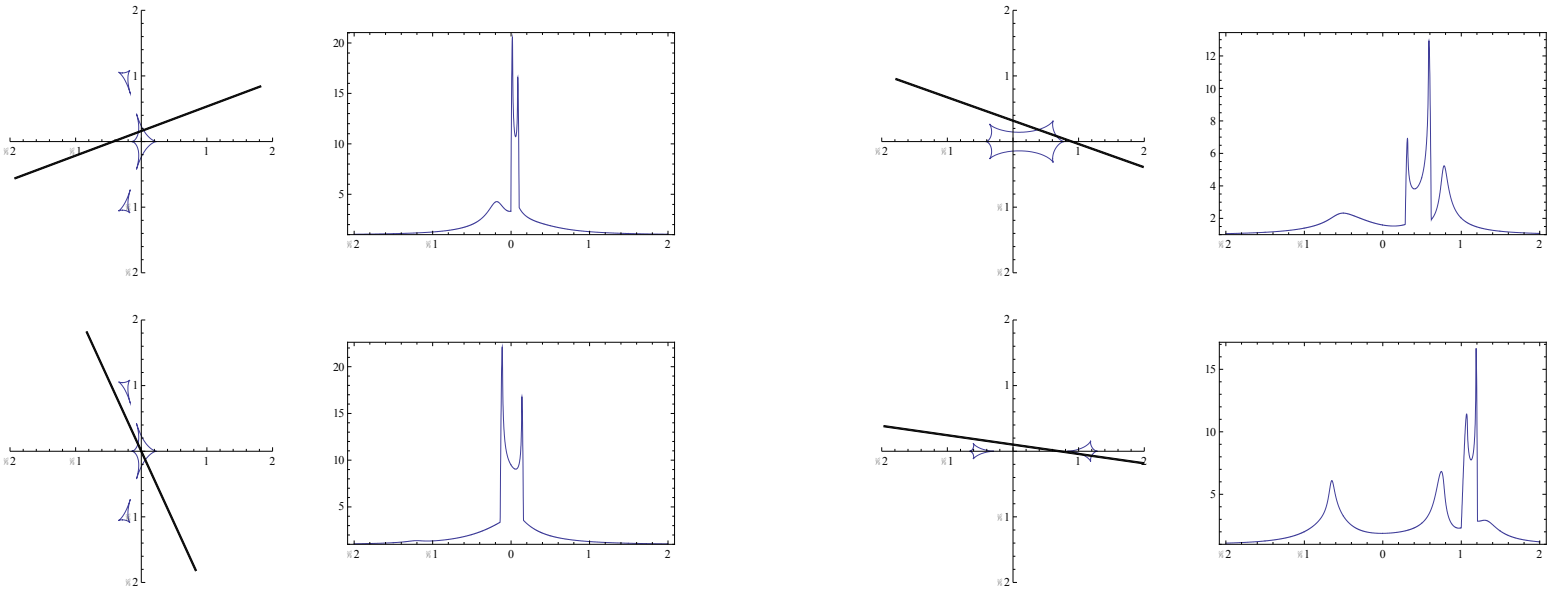
- **Need to select most interesting events automatically**
- **Need to collect data quickly**
- **Need to assess the quality of the datasets**
- **Need to set plausible initial conditions for fitting**
- **Need to be fast in computation**
- **Need to be accurate enough**
- **Need to explore the parameter space quickly**
- **Need to explore the parameter space exhaustively**
- **Need to select best models removing fake and duplicates**

RTModel structure

- **A master program calls subprograms for specific tasks:**
  - **Pick Event.exe: selects the next event to be modeled**
  - **Reader.exe: downloads and formats the data of the event to be analyzed**
  - **InitCond.exe: determines 236 possible initial conditions by matching the observed peaks to template light curves**
  - **MicroFit.exe: executes a downhill fit for a given initial condition (run once for each of the 236 initial conditions)**
  - **Model Selector.exe: selects the best models and removes duplicates**

Choice of initial conditions

- **Binary microlensing light curves can be classified depending on the nature of the peaks.**
- **Peaks can be due to fold crossing, cusp approach, fold approach (from the inside).**
- **We have used 40 classes of light curves in 2011**



Choice of initial conditions

- **We consider 6 possible matchings between observed and template light curves**
  (all combinations with 2 observed peaks and 3 top peaks in the template curve)

* **Finding peaks in an observed light curve is not trivial at all!**

- **We end up with 232 initial conditions.**
- **To these we add the 4 top models of the previous run.**

Summing up: 236 initial conditions

Modeling anomalous events

Calculation of light curves

- **Two methods: Inverse ray shooting vs Contour integration**
- **We have improved contour integration with a parabolic correction, full error control, optimal sampling and limb darkening *(Bozza, MNRAS 2010)***

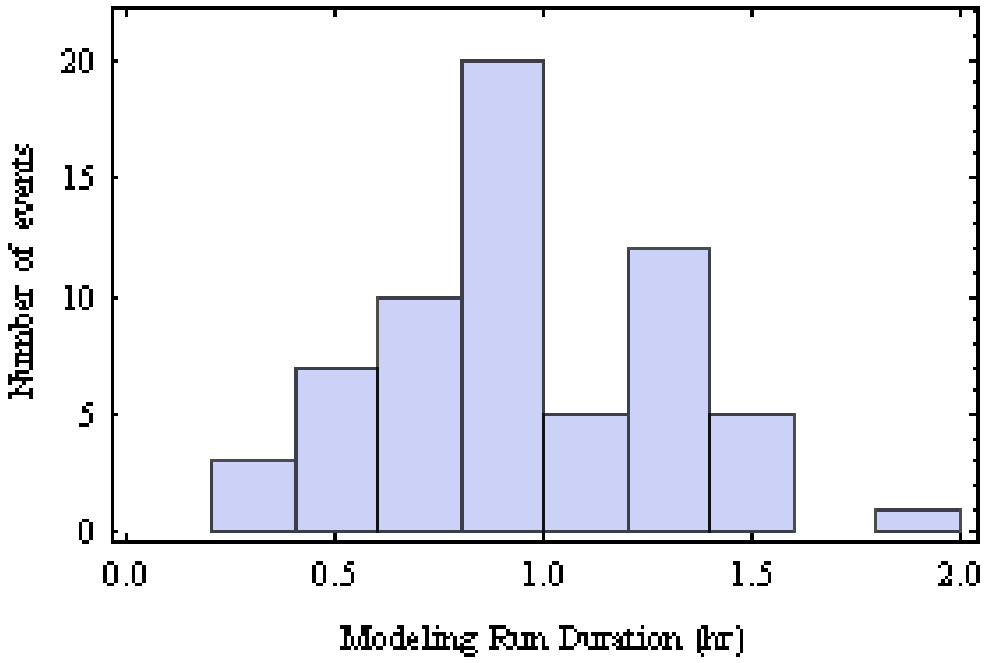
Finding best models

- **Two methods: Markov chain MonteCarlo vs Downhill algorithms**
- **We repetitively use Levenberg-Marquardt and expand our search by adding penalty functions to local minima whenever found.**

Maximum run duration is 3 hours

on a DELL 8-processor workstation

Modeling Run Duration



- **The average duration of a modeling run has been 1.1 h**

Results for 2011 season

- **The final version of RTModel was deployed on 20 May**
- **61 events were analyzed and classified as follows**
  - **False alerts: 15**
  - **Uncertain anomalies: 6**
  - **Poor quality data: 10**
  - **Single lens with parallax: 3**
  - **Single lens with finite source: 1**
  - **Binary events successfully modeled: 23**
  - **Modeling failed: 3**

Events successfully modeled

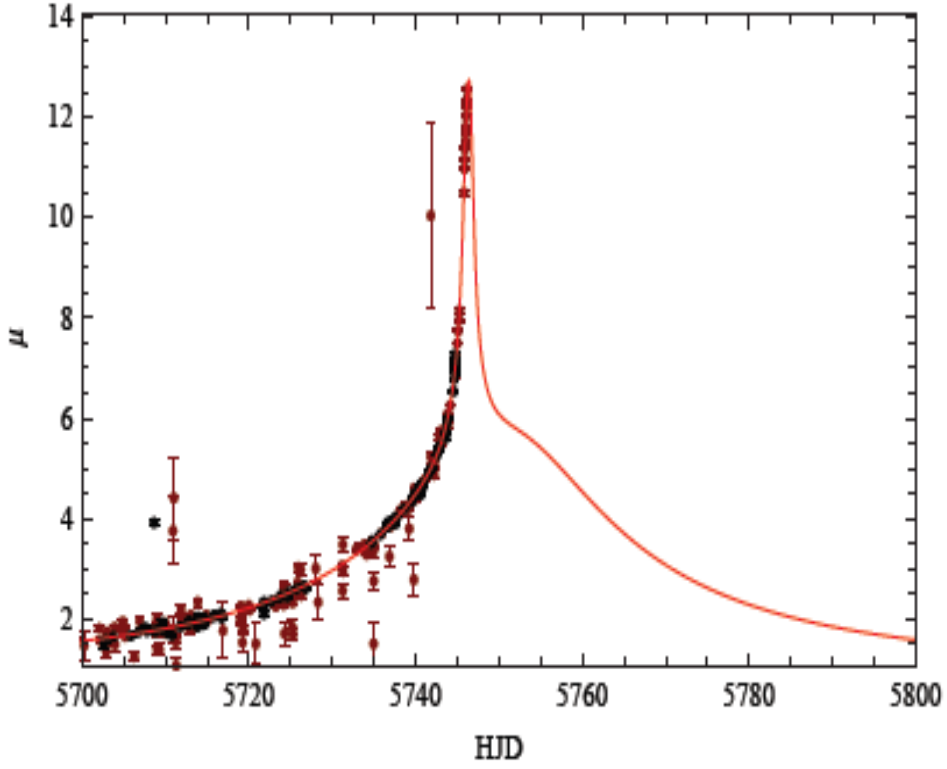
- **In 19 cases I have circulated the first reasonably correct model**

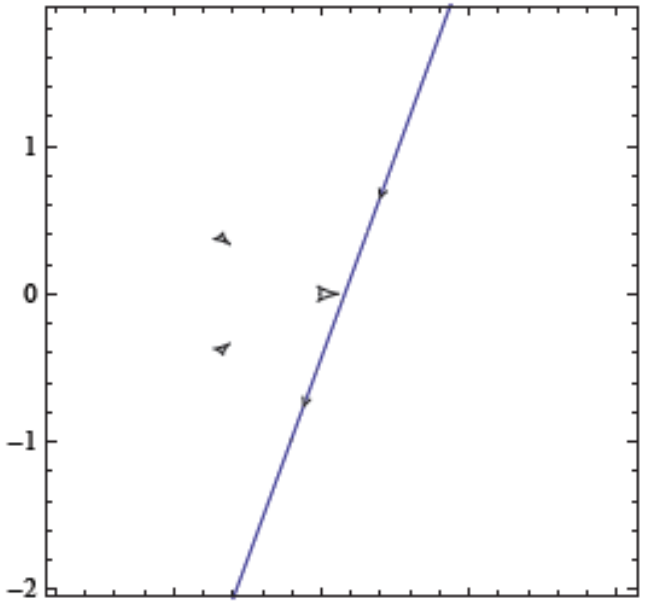
Event	Date of announce
MB11090	4/5
MB11149	20/5
MB11169	29/5
MB11201	2/6
OB110422/MB11171	4/6
OB110488/MB11232	26/6
MB11266	28/6
MB11278	2/7
OB110665/MB11276	4/7
OB110265/MB11197	4/7

Event	Date of announce
OB110420	24/7
MB11358	4/8
OB111192/MB11371	20/8
OB110307/MB110241	23/8
OB110979	30/8
OB110993	30/8
OB111087/MB11326	30/8
OB110417	15/9
OB111392	23/9

OB110265/MB11197

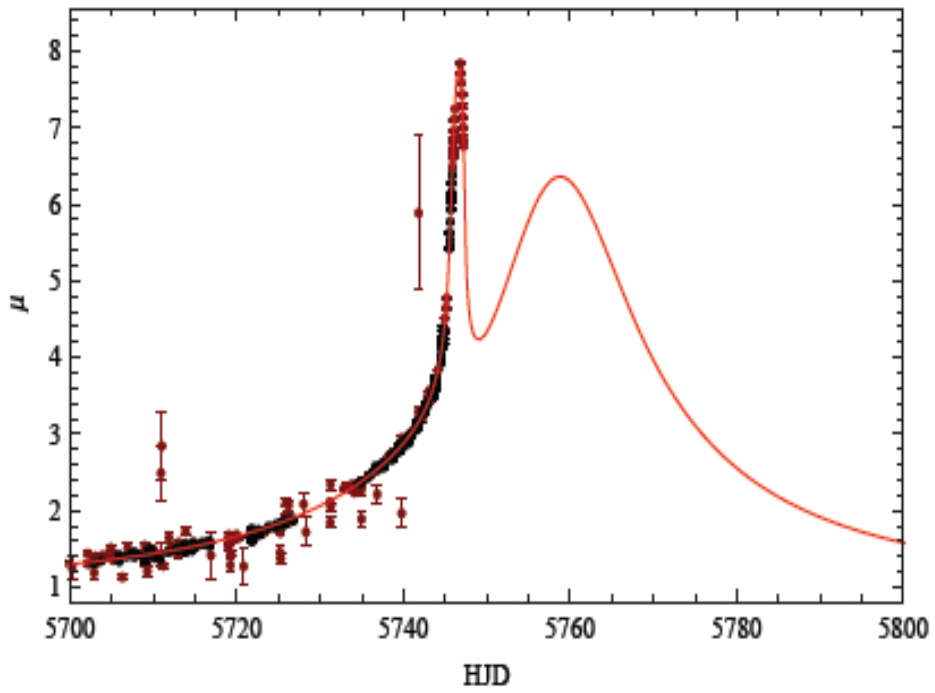
- **4/7 6:09 UTC: First e-mail calling a central cusp approach with close/wide degeneracy**

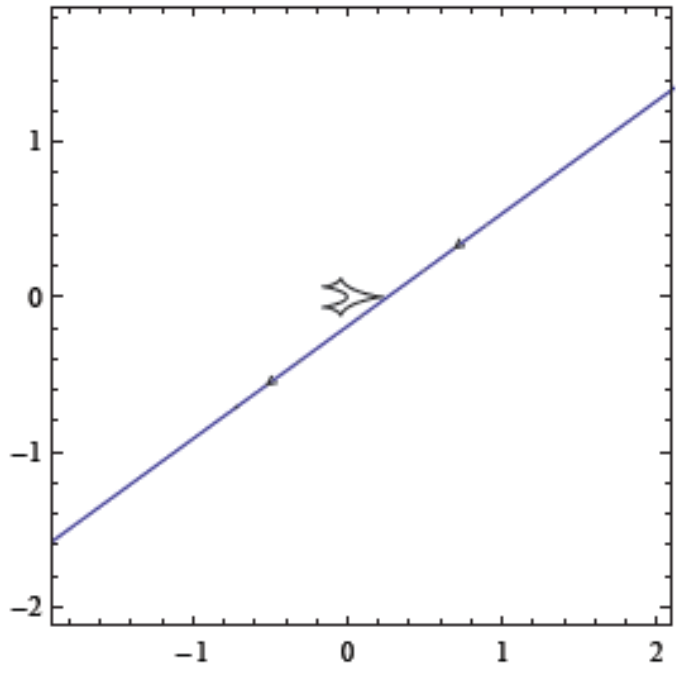




OB110265/MB11197

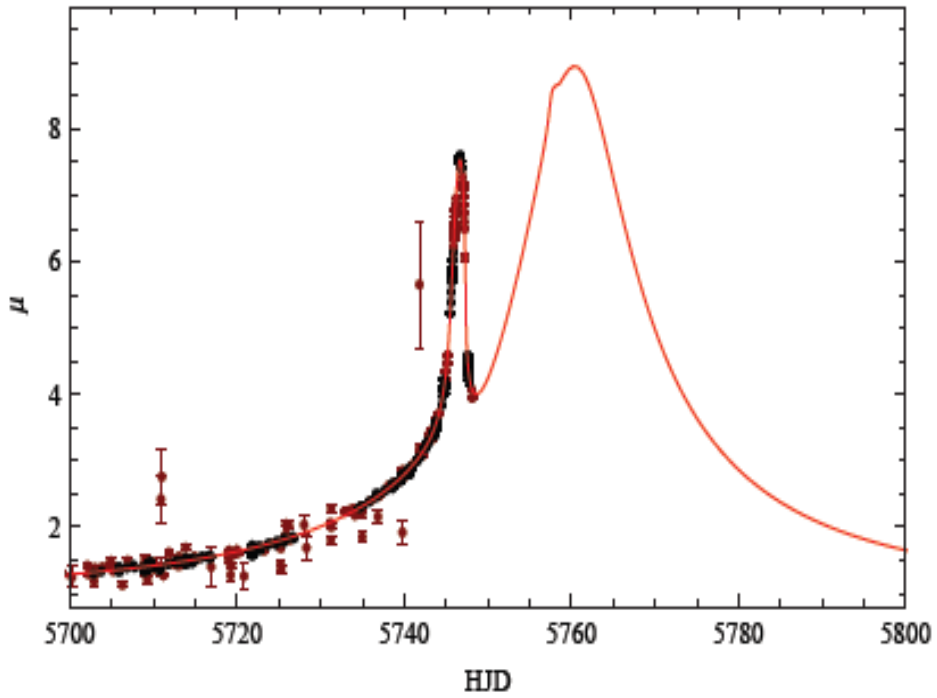
- **4/7 20:38 UTC: Cusp approach confirmed; model drifting toward intermediate topology**

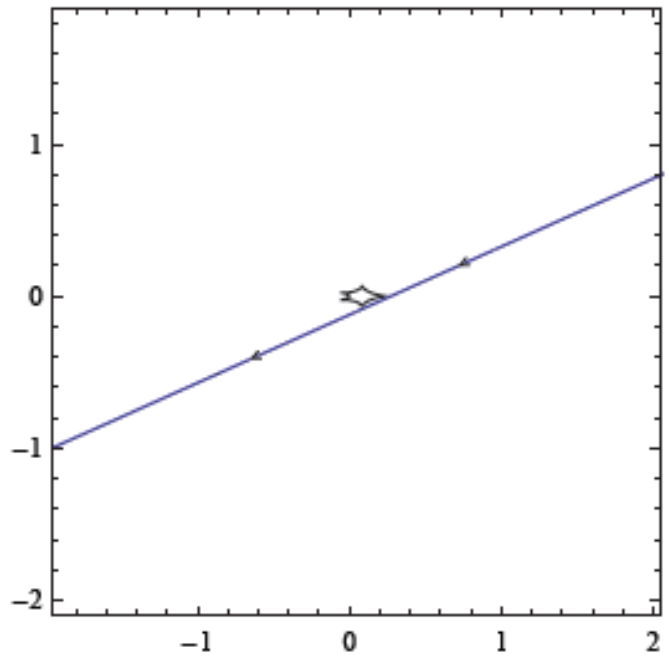




OB110265/MB11197

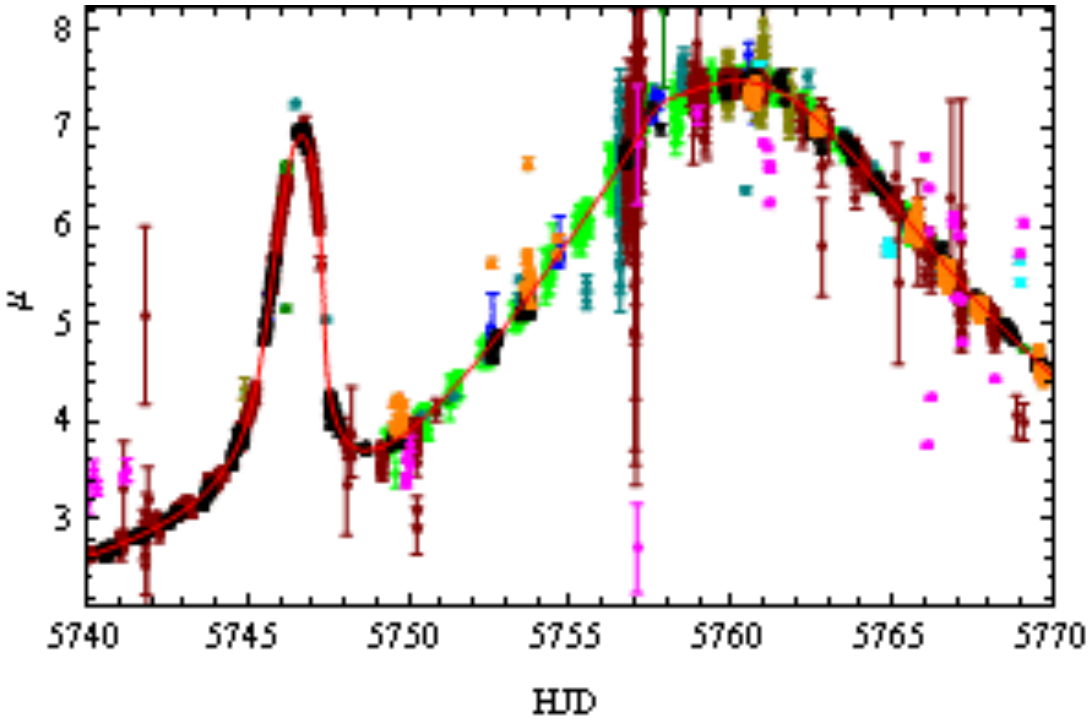
- **6/7 6:37 UTC: Final model basically defined**
- **6/7 11:45 UTC: Dave notices a possible second cusp approach**

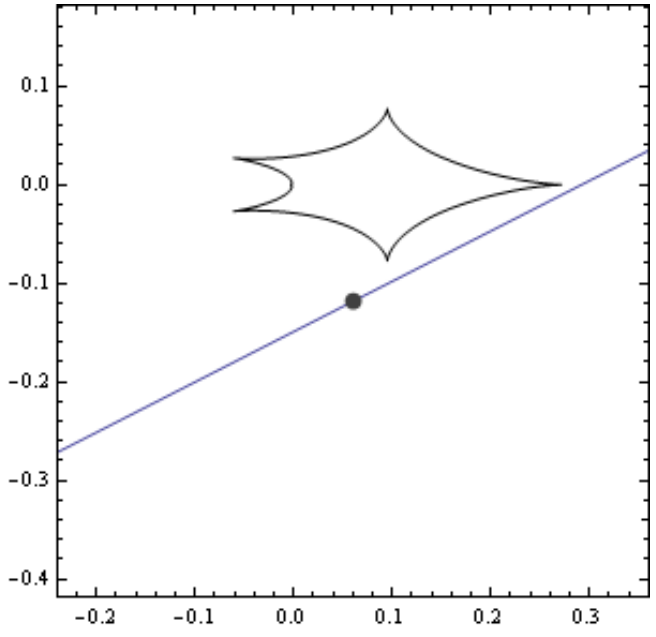




OB110265/MB11197

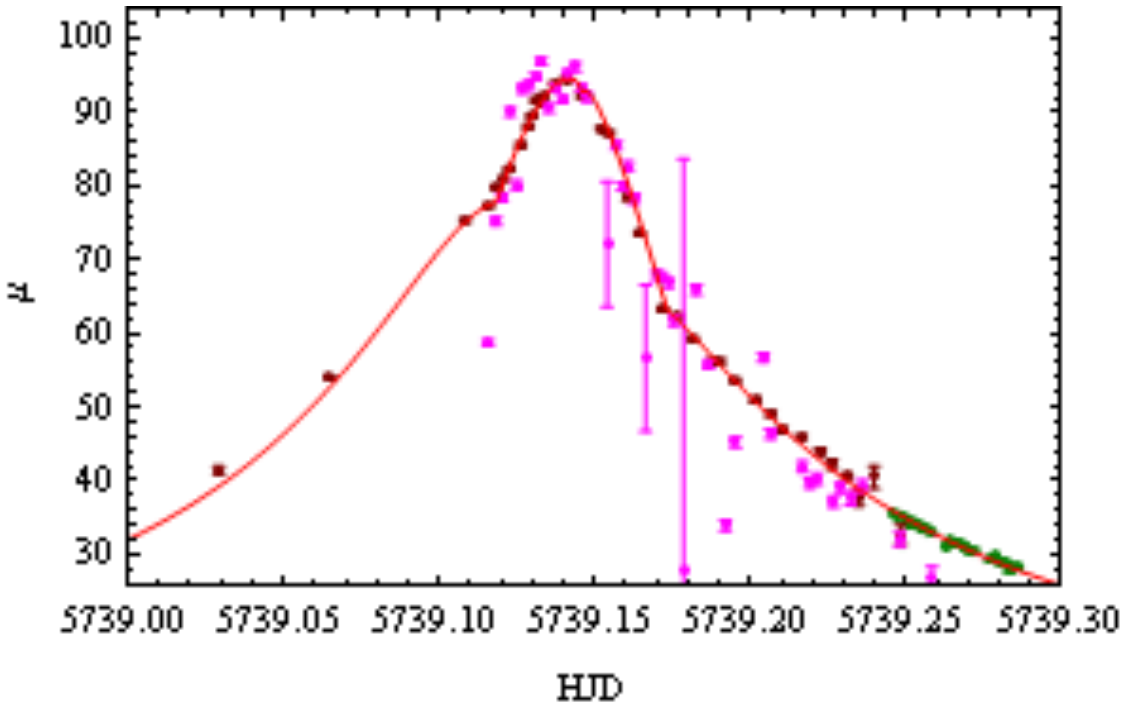
- **Data fully confirm the preliminary model found in real time.**

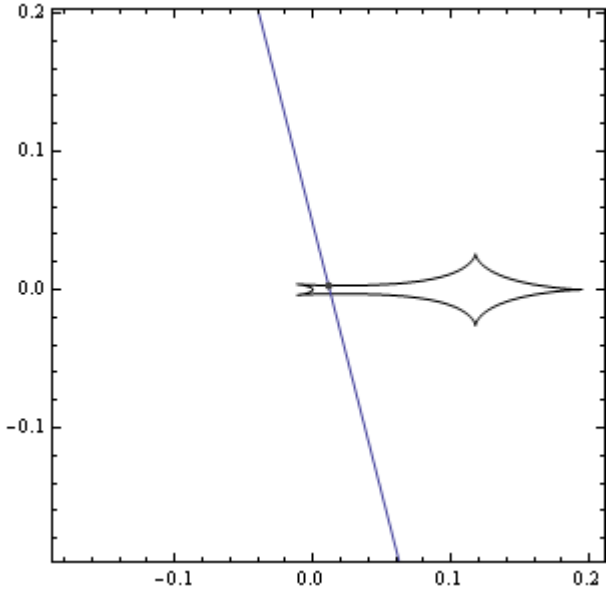




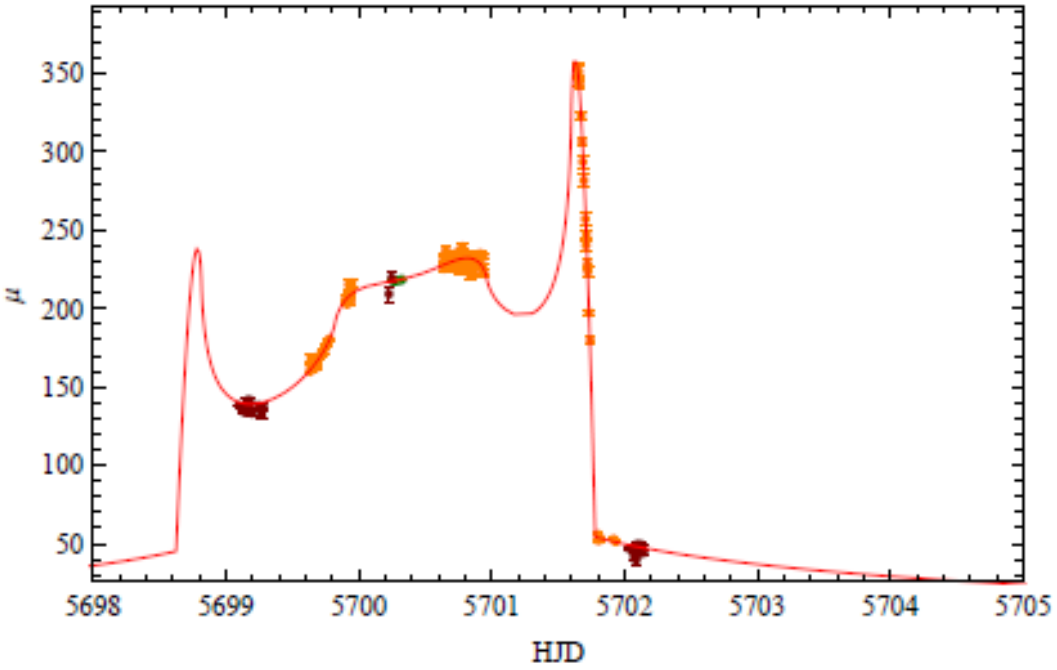
MB11262

- **First model by Dave.**
- **Caustic crossing variant found a few hours later by RTModel turned out to be correct.**





MB11149


350
300
250
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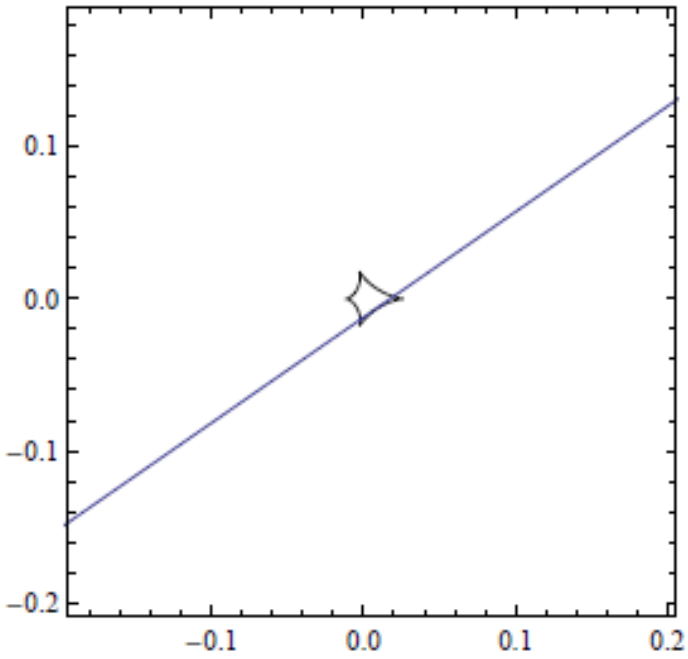
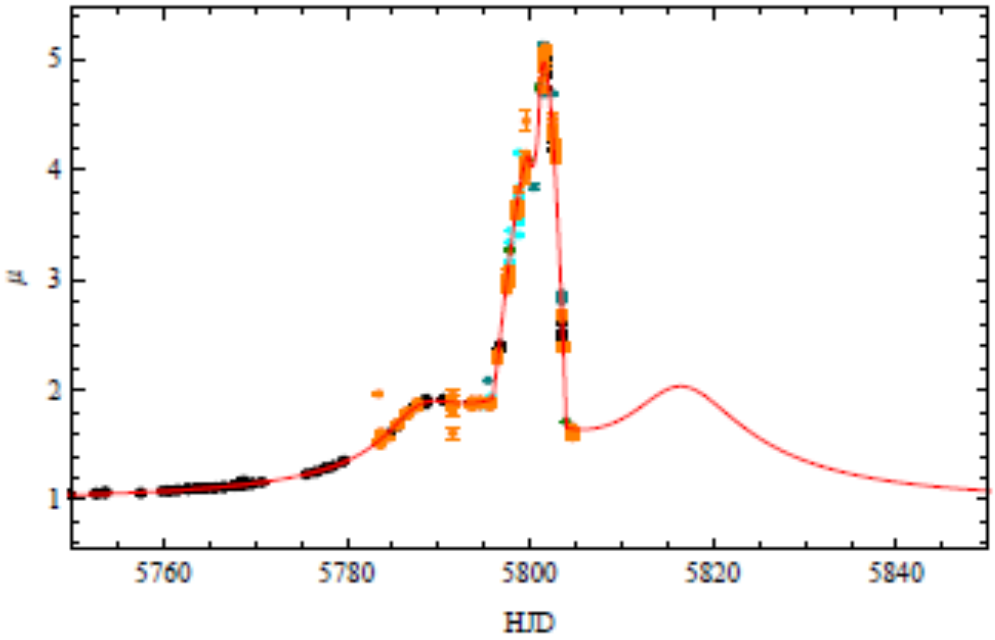
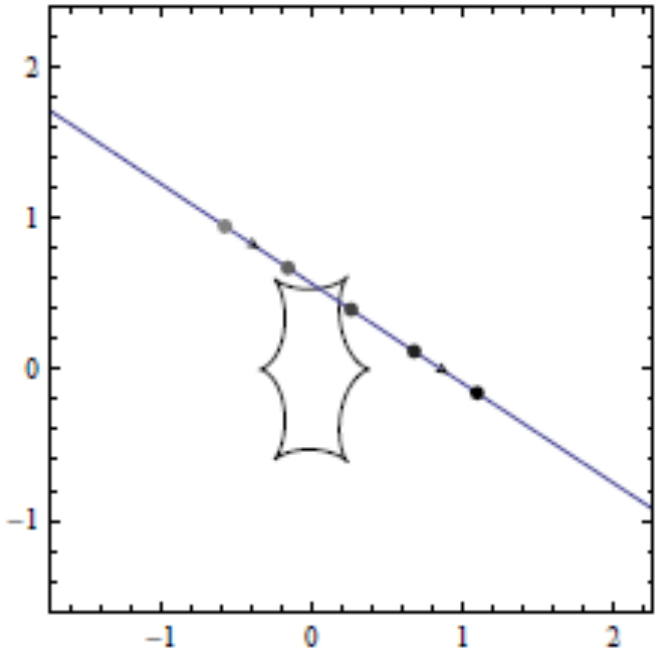
150
100
50
μ
5698
5699
5700
5701
5702
5703
5704
5705
HJD

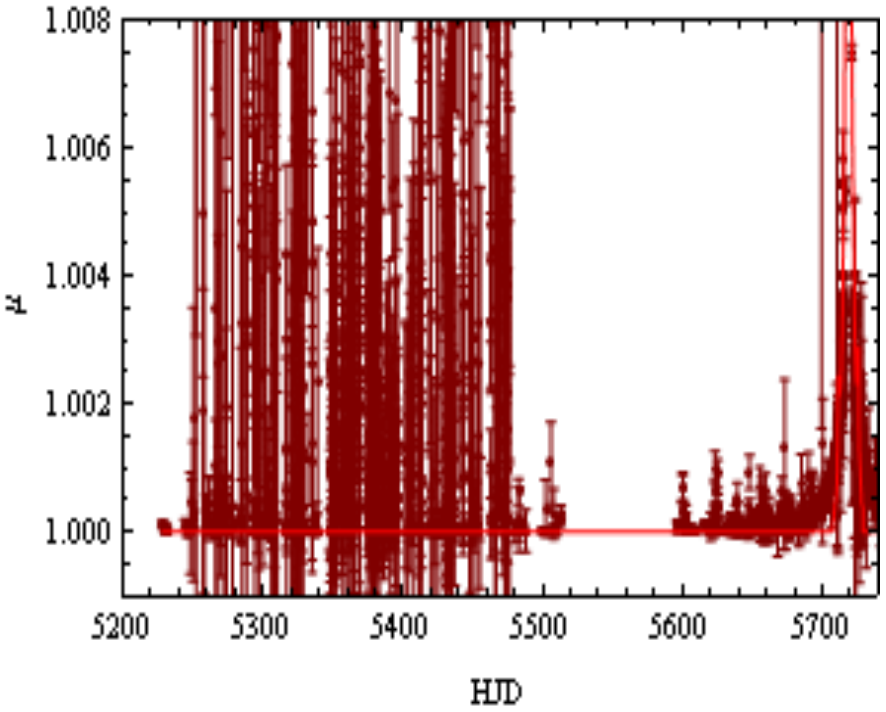

0.1
0.0
−0.1
−0.2
−0.1
0.0
0.1
0.2

OB110993



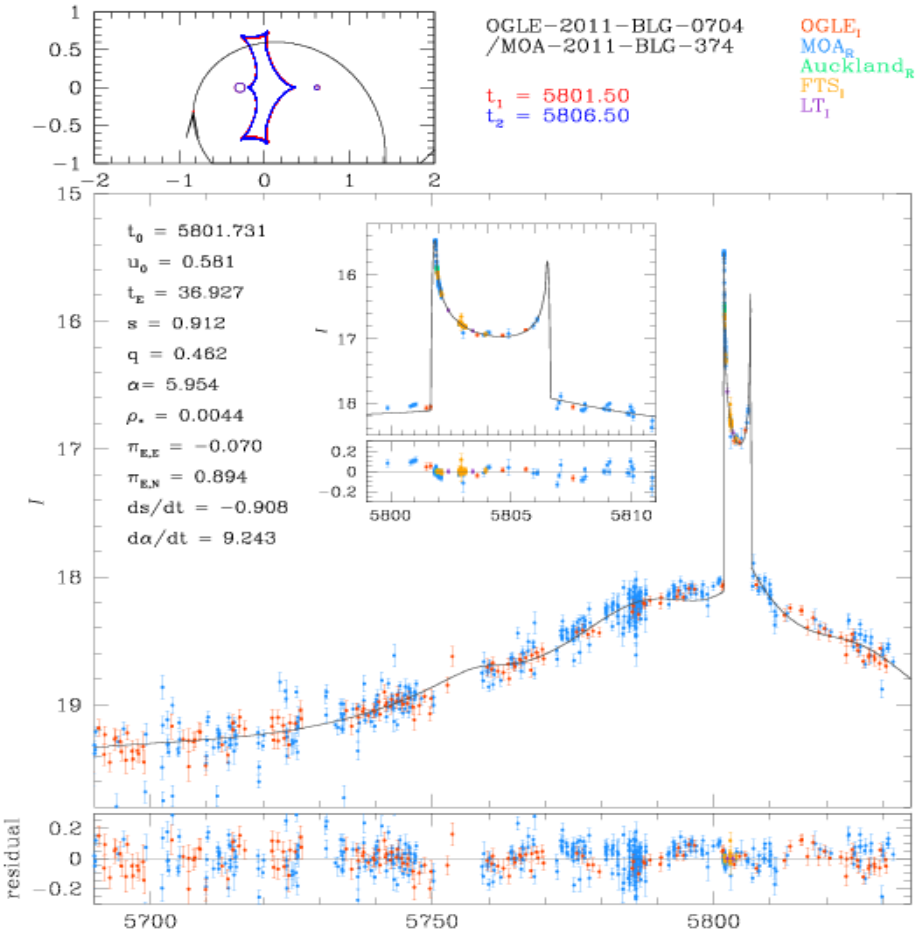


Failed models



- **MB110210: MOA baseline changed from previous year to 2011.**

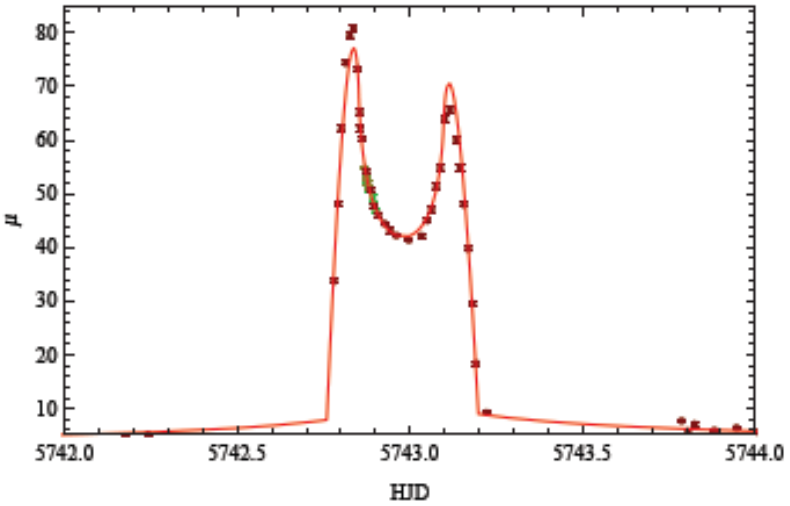
- **OB110704: Weird event Orbital motion? Variable source?**

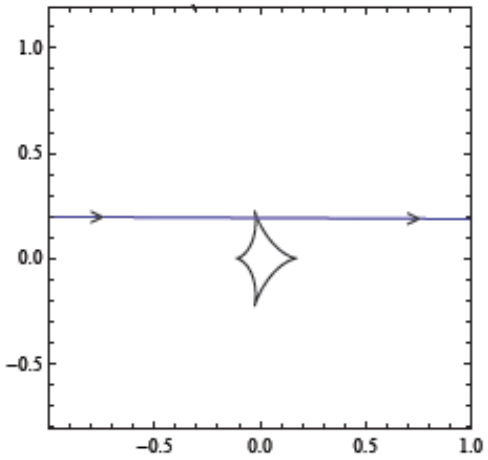


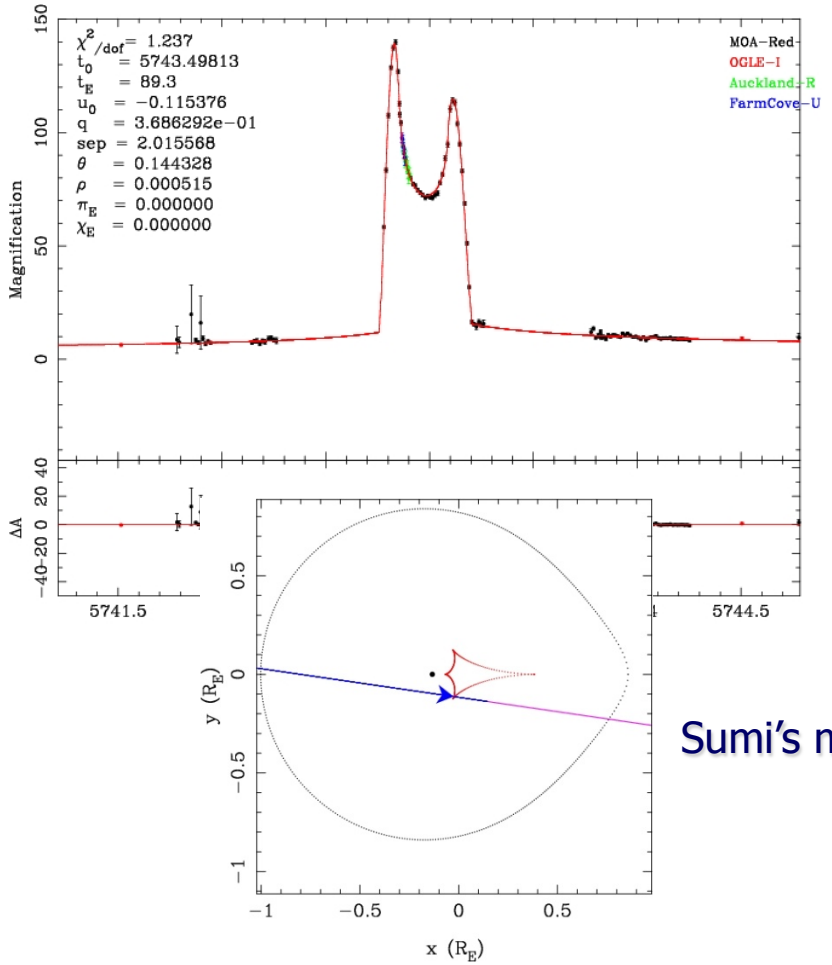
Taken from Han's webpage

Failed models

- **MB110275: very short binary anomaly. Model trapped by daily gaps.**







Sumi's model

Conclusions

- **Automatic modeling is a mandatory step in order to deal with large amounts of events.**
- **RTModel executes a model search in the whole parameter space in less than 2 hours.**
- **All steps are perfomed in a completely automatic way without human intervention: key is starting from templates and match the peaks**
- **Failures may occur with large gaps in the data.**
- **New in 2012!**
  - Alternative fits with parallax and/or binary source.
  - More initial conditions and more fail-safe algorithm.
  - Dedicated web page in ARTEMIS