A Bayesian algorithm for real-time model selection in caustic-crossing events

Noé Kains (ESO)
Keith Horne, Paul Browne, Markus Hundertmark (St Andrews)
Arnaud Cassan (IAP)

How things work

- Follow-up teams select “promising” MOA/ OGLE events, higher cadence or/and better photometry (with e.g. lucky imaging)
- Challenge: new-generation surveys alert ~1700 events/ year
    - How to select best events to follow up?
    - How to model so many events, given the large amount of (human and computational) time required for each event

Microlensing Anomalies

- Following up the “right” anomalies is key
- No simple selection criterion
- Come in a huge variety of shapes and timescales (few hours - few days)
- No way of avoiding computationally intensive modelling

What do we want from modelling

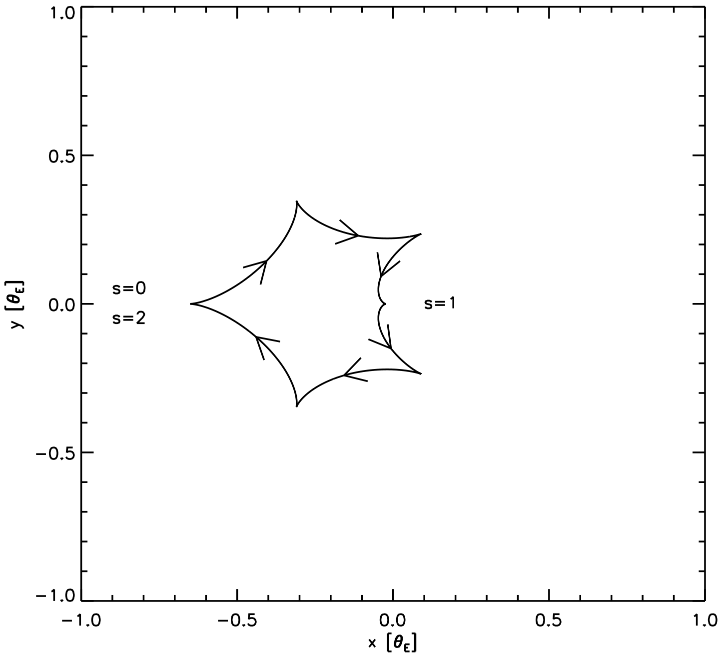
- 2 main purposes:
    - Real-time modelling → predictions of upcoming features, feed information back to telescopes for optimal target selection
    - Post-event modelling: be as thorough and systematic as possible (i.e. explore parameter space)

- Ideally, an algorithm that is good for both
- Several approaches amongst modellers (see talks by V. Bozza, C. Han)

Feature-based parameterisation

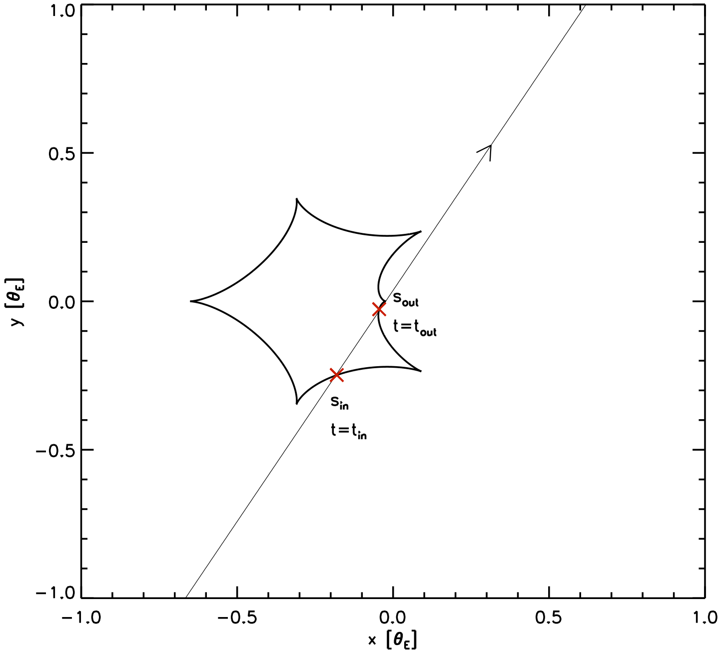
- Use parameters that are well constrained by data features
- Caustic-crossing events:
    - Re-parameterised binary-lens lightcurves (Cassan+ 2008, 2010 Kains+ 2009) + MCMC to conduct grid search and generate posterior maps with available data
    - Include as much prior information as possible without biasing modelling

Parameterisation of Cassan (2008)



Locations on the caustic of caustic entry and exit

s_{in}, s_{out}



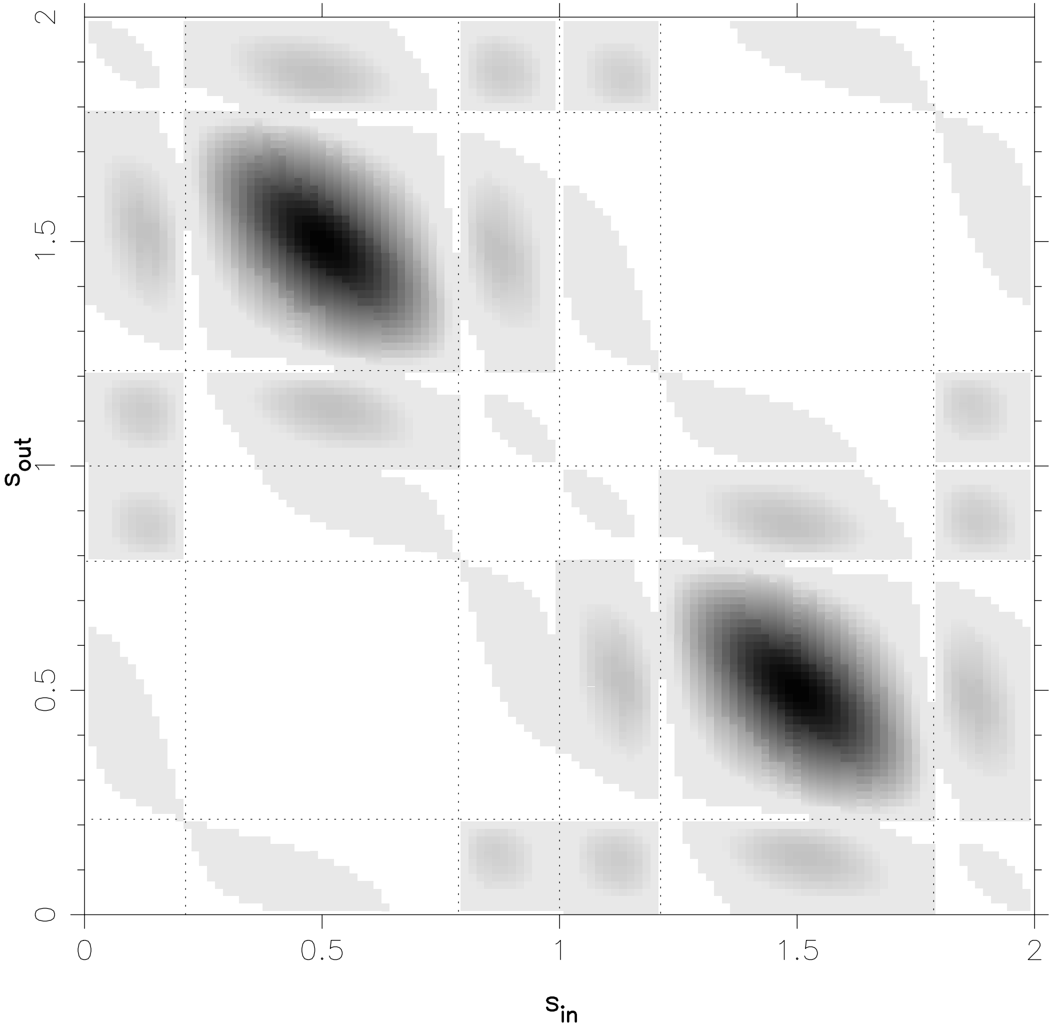
Times of caustic entry and exit

t_{in}, t_{out}

Duration of crossing Δt_c

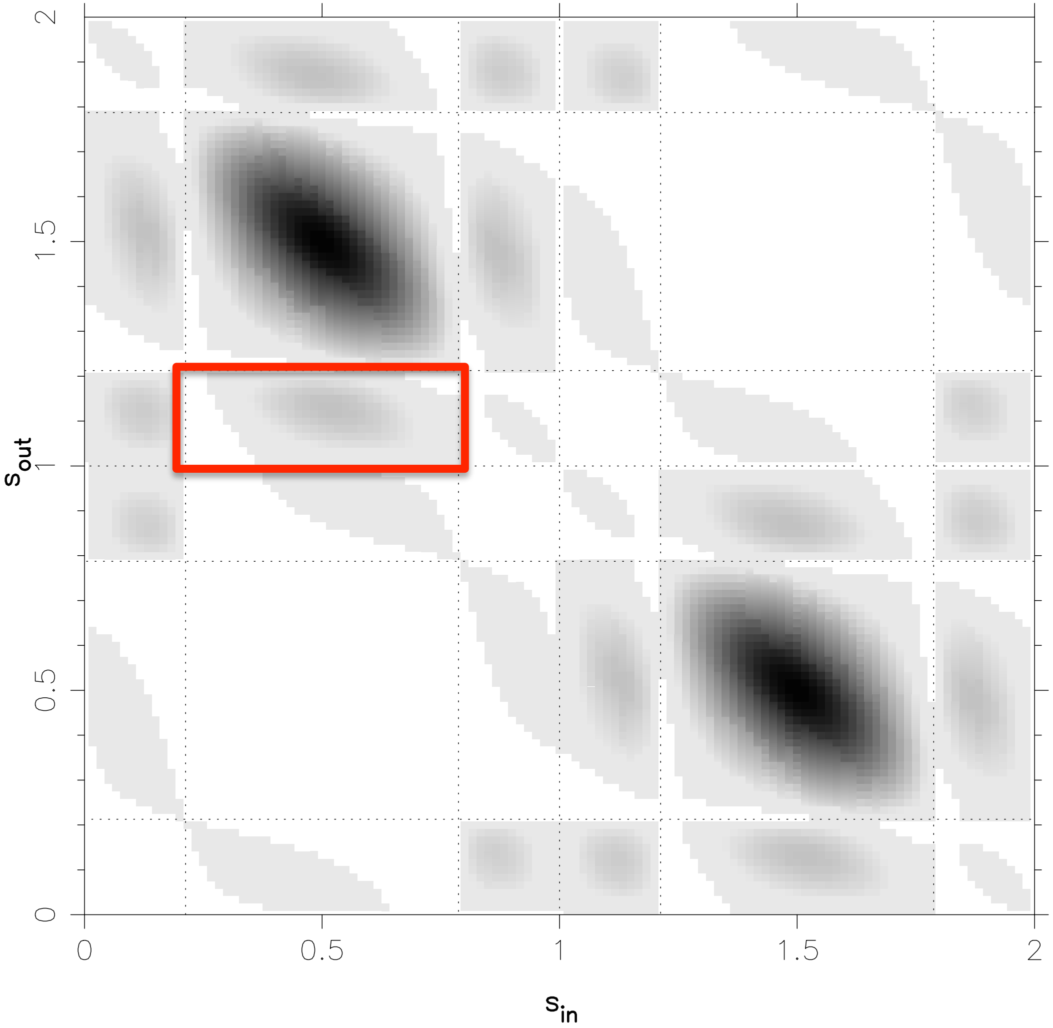
t_0, t_E, α, u_0, ρ_*(or t_*), d, q

→ t_{in}, t_{out}, s_{in}, s_{out}, Δt_c, d, q



Assuming uniform distribution of source trajectories and source sizes, this is what a map of a joint prior on (sin, sout) looks like.

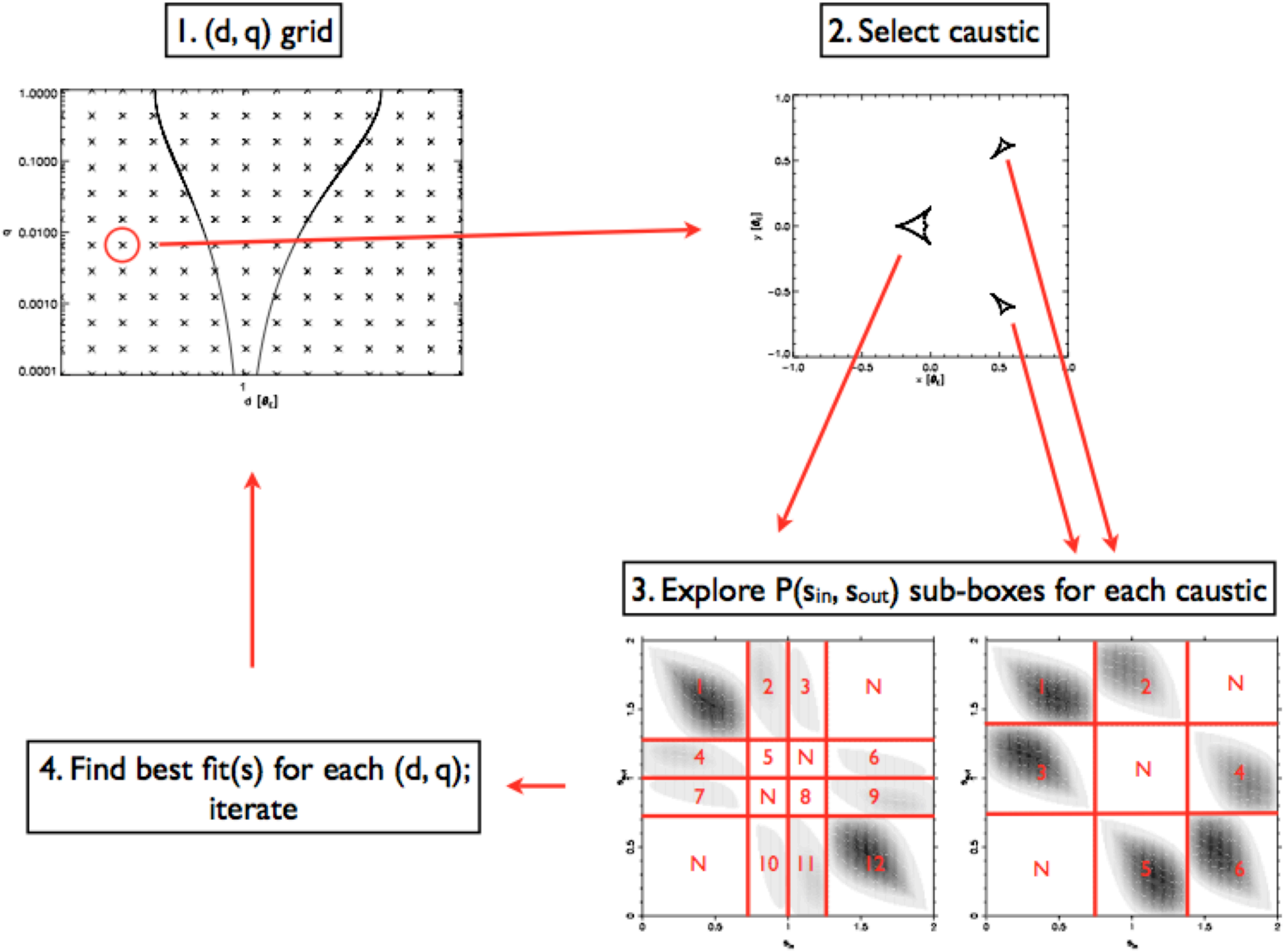
We can exploit the structure of these maps to devise a scheme for thorough parameter space exploration



Each ‘sub-box’ corresponds to the source entering and exiting the caustic on a different caustic fold

By exploring each sub-box, we can ensure all possible caustic-crossing trajectories are explored for a given caustic

This allows us to conduct a grid search in the (d, q) plane

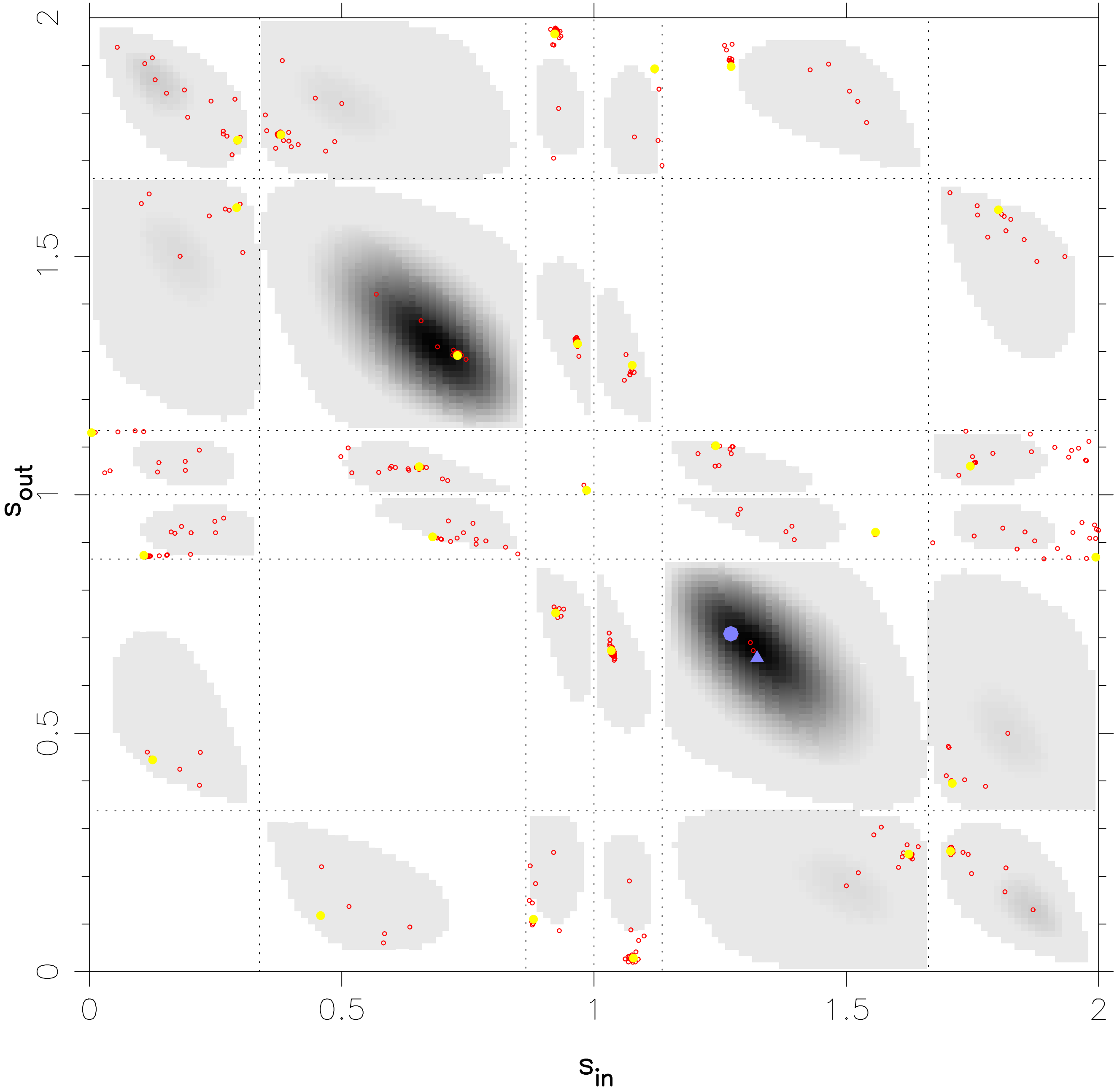


1. (d, q) grid

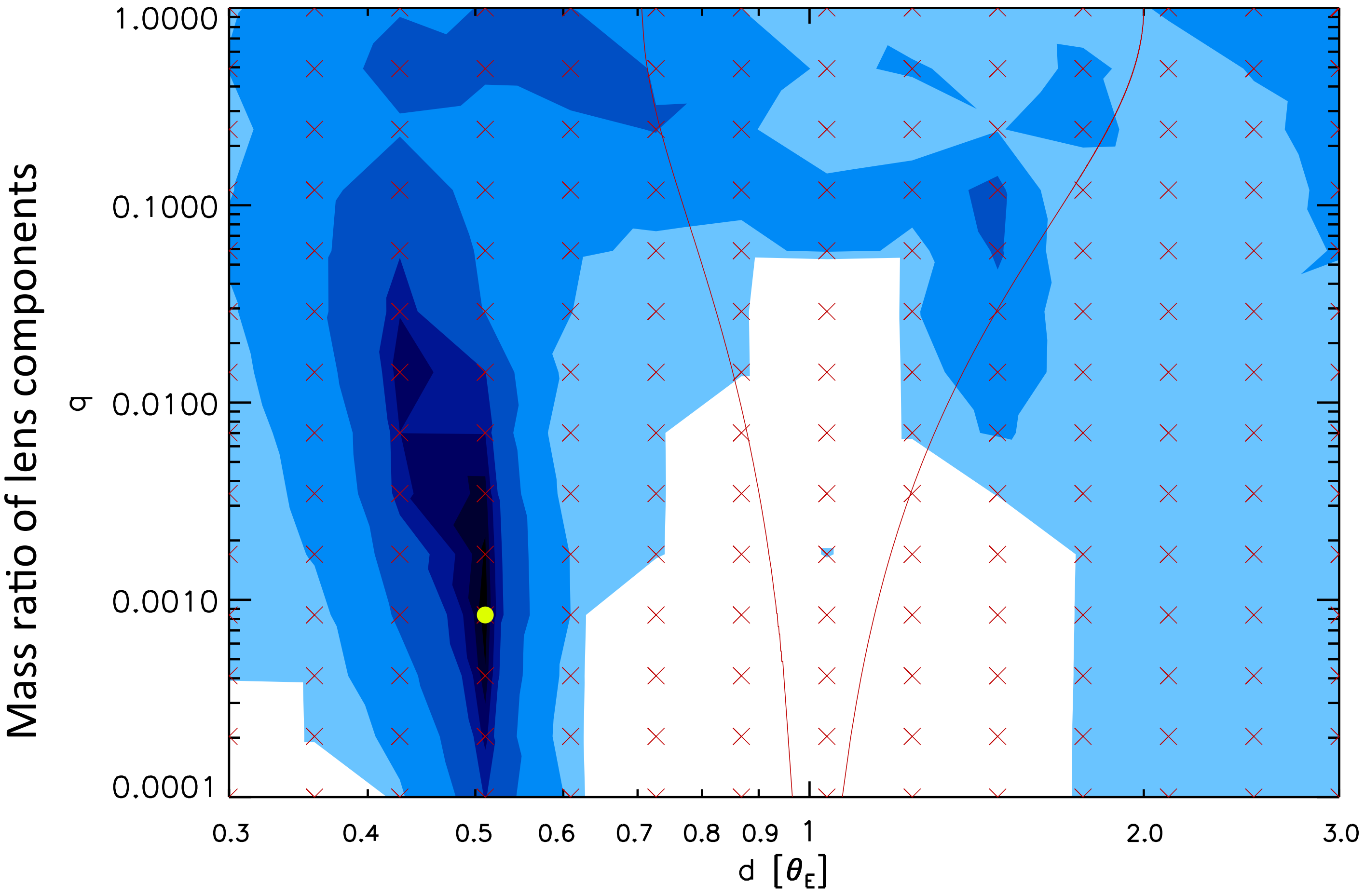
2. Select caustic

3. Explore $P(s_{in}, s_{out})$ sub-boxes for each caustic

4. Find best fit(s) for each (d, q); iterate

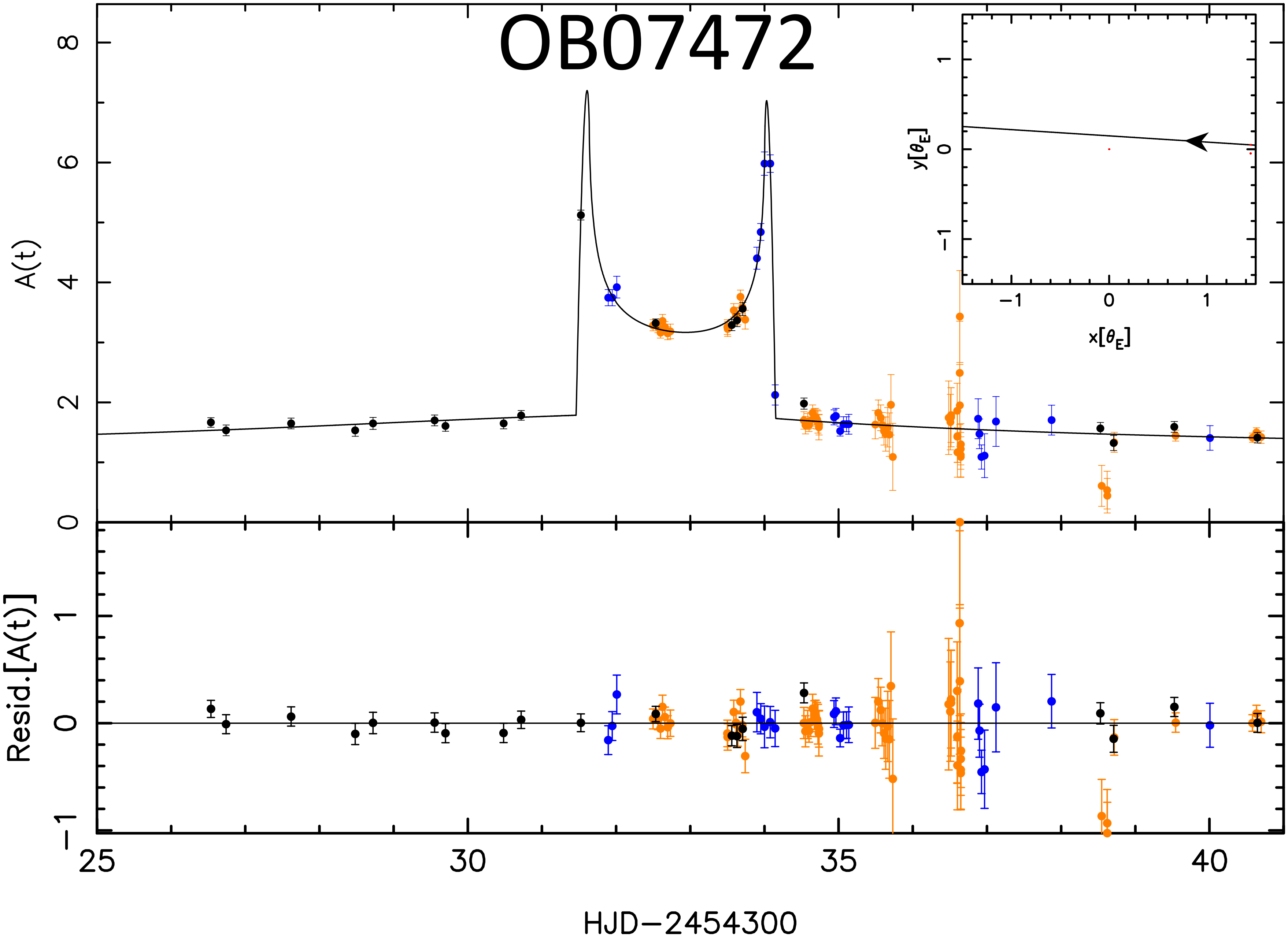

0
0.5
1
1.5
2
s_in
0
0.5
1
1.5
2
s_out

…end up with a "posterior map" of whichever badness-of-fit statistic we choose. E.g. chi2 map:



Separation between lens components (e.g. planetary orbit)

OB070472, first analysed with no priors in Kains+ 2009, also Kains+ in preparation

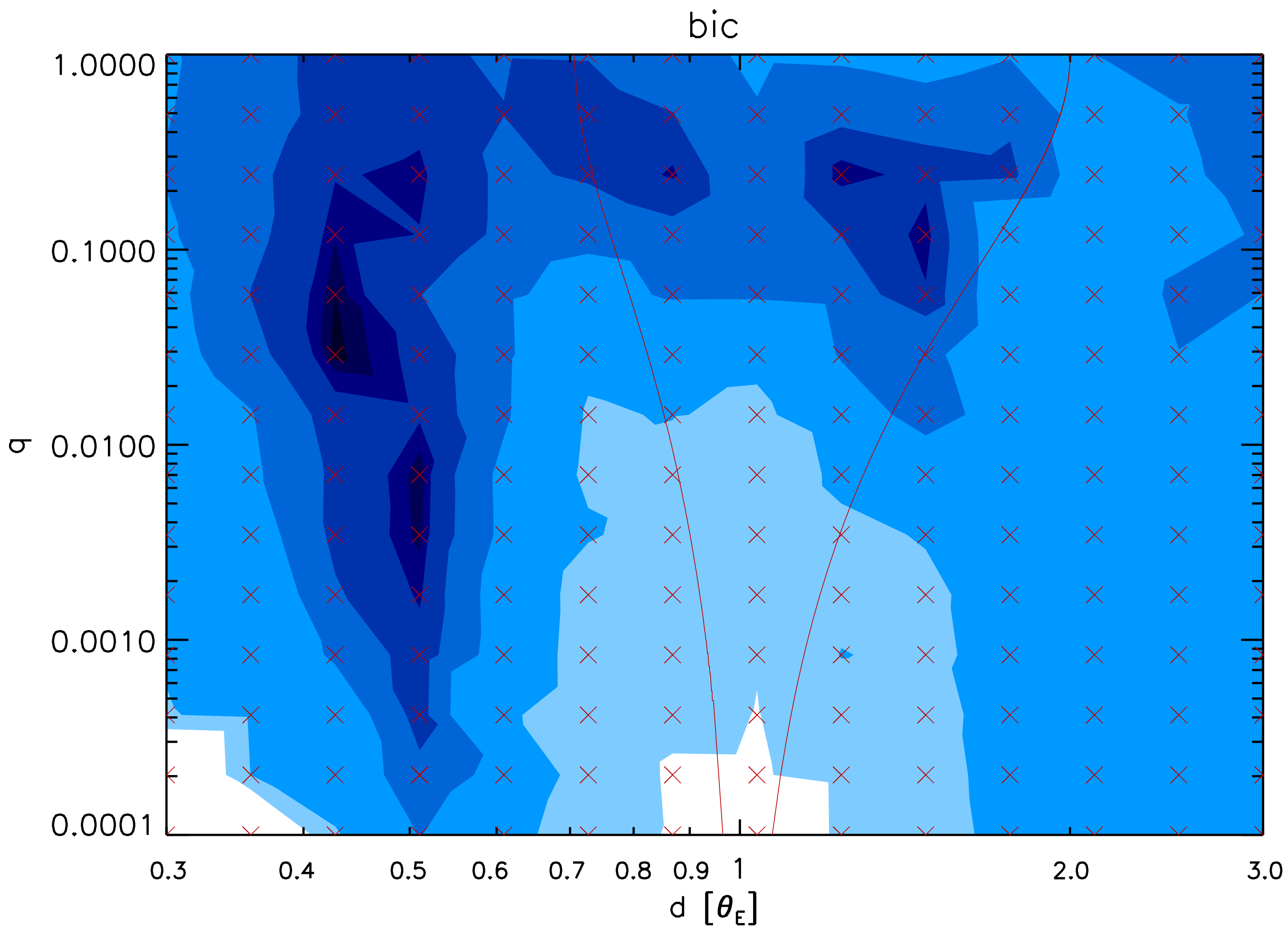

OB07472
A(t)
0
2
4
6
8
y[θ_E]
x[θ_E]
−1
0
1
Resid.[A(t)]
25
30
35
40
HJD−2454300

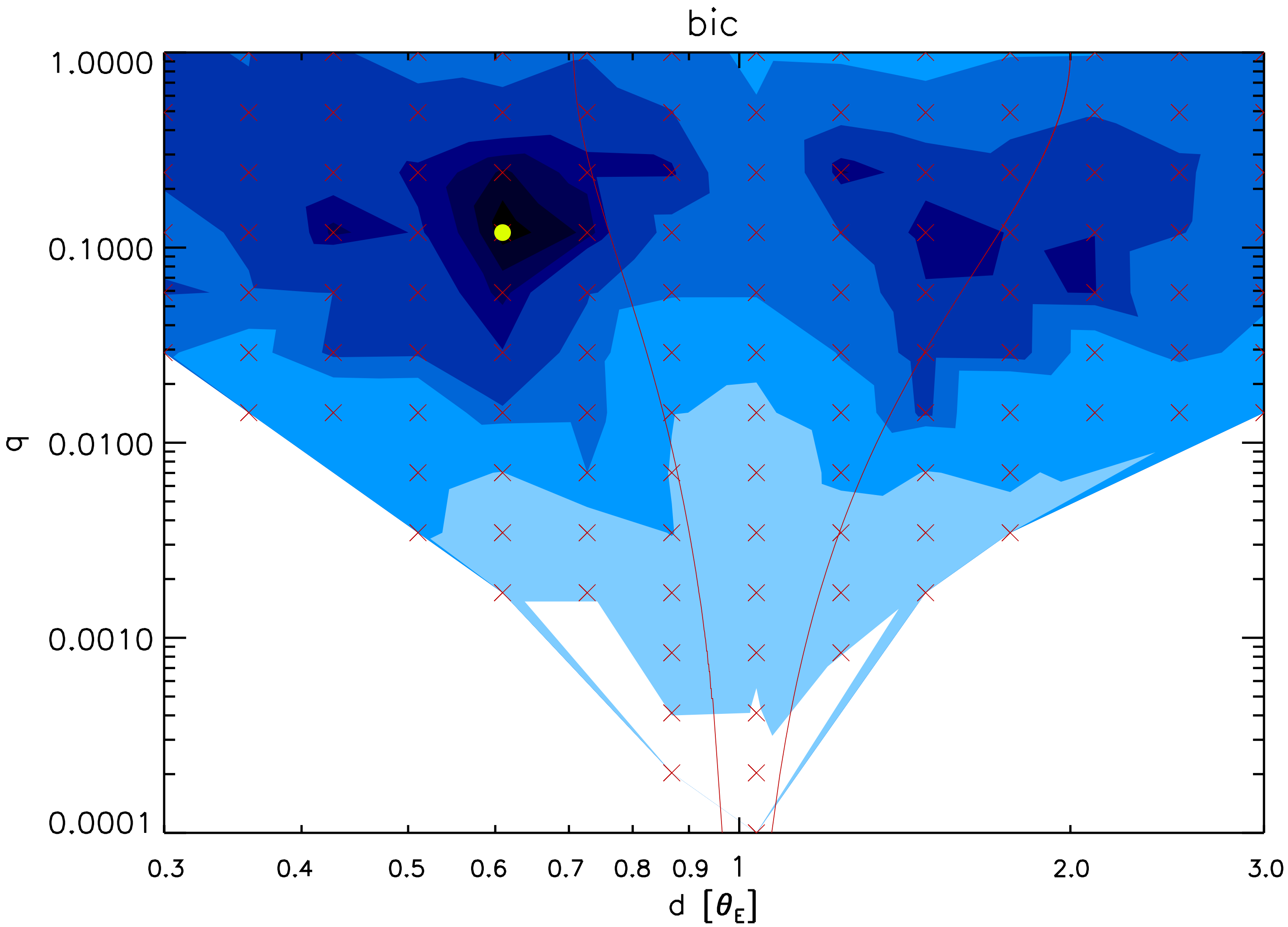
A robust statistic

- Kains+ (2009): best-χ^2 model for OB07472 has extreme t_E (~4000 days)
- χ^2 not necessarily the best estimator of true parameters
    - Need for a more reliable badness-of-fit statistic?
    - Include priors
- Some alternatives:
    - Maximum a-posteriori (MAP): Maximise $\chi^2 - 2*\ln(\text{prior})$
    - MAP + volume: take into account parameter space volume
    - Bayesian Information Criterion (BIC): takes into account number of parameters and data points

Choosing priors

- Free to choose prior from any suitable source
- E.g. a prior of timescales could come from a distribution of past observed events or a model distribution (e.g. Wood & Mao 2005)
- We used a joint prior on tE and ρ_* obtained from a Besançon model simulation (Robin+ 2003)


bic
1.0000
0.1000
0.0100
0.0010
0.0001
q
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2.0
3.0
d [θ_E]



$$BIC = X^2 - 2\ \ln(\text{Prior}) + N_{\text{eff}} * \ln(N_D)$$

Kains+ in preparation

Conclusions

- Neat way of ensuring the parameter space is explored completely
- Systematic and (nearly) automatic analysis of events
- Improved badness-of-fit statistic allows us to locate more robust best-fit minimum
- Drawbacks: limited to caustic-crossing events for now
- Could extend the parametrisation to include non-crossing caustic approaches etc.