MCMC algorithms at the service of exo-planets hunters

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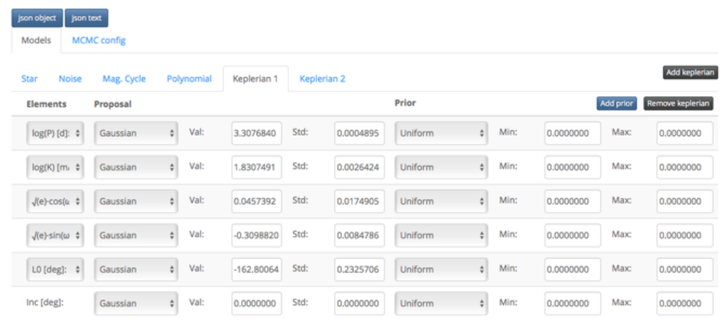
Abstract

Exo-planetary research is a fast growing science domain. More and more astronomical instruments are dedicated to exo-planet searches, collecting terabytes of data. In order to explore this huge amount of data sophisticated algorithms are necessary. The Markov Chain Monte Carlo is a family of algorithms very well suited for the exploration of the high dimensional space of parameters describing keplerian orbits. The Data & Analysis Center for Exoplanets (DACE) contains a database with thousands of radial velocities measurements and transit light curves amongst other observations. It also implements algorithms for treating, displaying, optimising and exploring this data. One of the recently developed algorithms for fitting keplerian orbits is the MCMC algorithm with two variations: the simple Metropolis-Hastings MCMC and its Change of Basis (CoB) version. The simple MHMCMC is very efficient for well constrained orbital parameters, the CoB works better for less constrained cases, such as when the orbits are not closed. The software was written in Java, whose object oriented structure allows for nice integration of several solutions into the same scheme and separation of the algorithm from the model. In this way, the DACE MCMC can be applied to any astrophysical model within DACE. The DACE MCMC is directly linked to the DACE database, so it can be launched on the data extracted from the DB on the DACE server or locally on the user computer. It can also be run on user private data. The software development is still ongoing and future features will include the incorporation of different models as well as the running of several Markov Chains in parallel with their solutions combined.

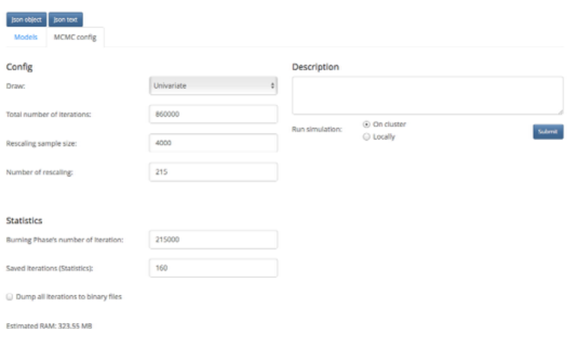
DACE

To explore an exo-planetary system parameters space with MCMC one needs the initial parameters. These are provided by the model construction in DACE, where the user has the access to all the system data and fitting algorithms.

MCMC parameters



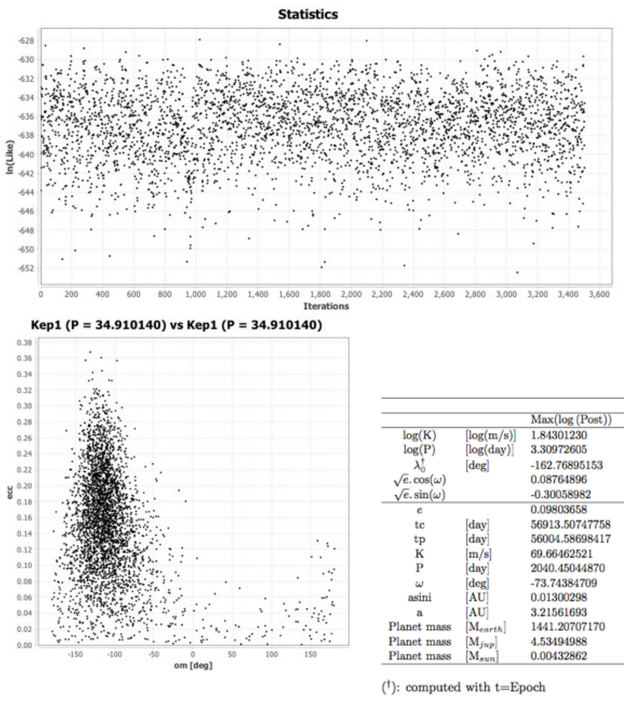
The fitted parameters are fed into the MCMC form, where user can adjust them, decide which parameters will evolve and define the prior distributions.



The user can define the type of the MCMC to use: univariate or the Change of Basis. She/He can also fix the number of iterations, the size of the rescaling sample, how long the burning phase should take and the frequency of saving the iterations data.
Then the user can decide if s/he prefers to launch the MCMC directly on the cluster or locally on his own computer.

MCMC results

The results are presented as graphs and tables. Here you can see some examples like the evolution of the likelihood, the histogram of the period log, the correlation between the eccentricity and the omega and a table describing results for one of the keplerians.



Planet b

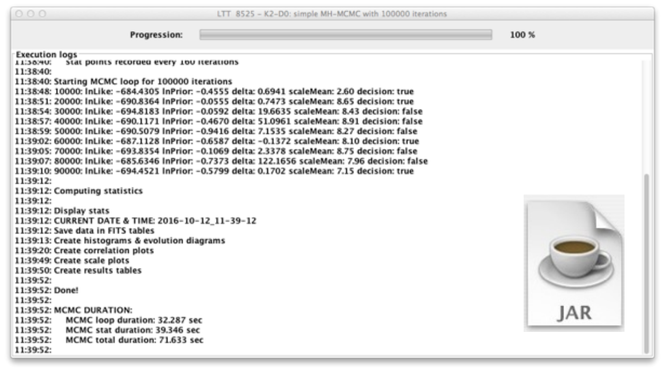
		Max(log (Post))	MED	MOD	COI 99%	RMS
log(K)	[log(m/s)]	1.84301230	1.84230631	$1.84210907^{+0.002874}_{-0.002366}$	[1.835571 , 1.849119]	0.00260900
log(P)	[log(day)]	3.30972605	3.30996235	$3.30990702^{+0.001337}_{-0.001163}$	[3.307016 , 3.313372]	0.00125165
$\lambda^{\dagger}_0$	[deg]	-162.76895153	-162.63628463	$-162.63320500^{+0.218787}_{-0.224026}$	[-163.306788 , -162.028212]	0.23181776
$\sqrt{e}.\cos(\omega)$		0.08764896	0.08989873	$0.08897600^{+0.013604}_{-0.013604}$	[0.051357 , 0.131123]	0.01505222
$\sqrt{e}.\sin(\omega)$		-0.30058982	-0.29318651	$-0.29323689^{+0.007197}_{-0.006493}$	[-0.310793 , -0.272415]	0.00716401
e		0.09803658	0.09422340	$0.09412102^{+0.003520}_{-0.003316}$	[0.085424 , 0.103490]	0.00349037
tc	[day]	56913.50747758	56913.65470340	$56913.71121736^{+6.648630}_{-7.162593}$	[56894.975558 , 56933.310501]	7.05487695
tp	[day]	56004.58698417	56008.82234884	$56008.54409962^{+15.747358}_{-14.870771}$	[55969.242462 , 56052.502057]	15.66546027
K	[m/s]	69.66462521	69.55146988	$69.52797901^{+0.453498}_{-0.386167}$	[68.481088 , 70.651156]	0.41794402
P	[day]	2040.45044870	2041.56096119	$2041.35546455^{+6.259035}_{-5.511722}$	[2027.755498 , 2057.651000]	5.88542583
ω	[deg]	-73.74384709	-72.98106964	$-73.29567069^{+3.281460}_{-2.444232}$	[-80.303101 , -64.745294]	2.92865875
asini	[AU]	0.01300298	0.01299334	$0.01299015^{+0.000112}_{-0.000101}$	[0.012740 , 0.013278]	0.00010655
a	[AU]	3.21561693	3.15244655	$3.15087523^{+0.052921}_{-0.051484}$	[3.014966 , 3.291317]	0.05262626
Planet mass	[M_{earth}]	1441.20707170	1372.21611241	$1371.41690844^{+46.524881}_{-44.158339}$	[1256.535288 , 1495.870608]	46.60814155
Planet mass	[M_{jup}]	4.53494988	4.31786064	$4.31534584^{+0.147655}_{-0.140838}$	[3.953856 , 4.706956]	0.14665872
Planet mass	[M_{sun}]	0.00432862	0.00412141	$0.00411901^{+0.000141}_{-0.000134}$	[0.003774 , 0.004493]	0.00013999

(†): computed with t=Epoch

JSON form + data

The MCMC input parameters are passed to MCMC application through the JSON form, together with the exo-planetary system data in one zip package.

MCMC execution



To execute the configured MCMC, user has only to launch the MCMC application by executing a jar file.

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