Stability of circumbinary planets: the role of binary properties and migration scenarios

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1 Observations and Formation of multi-planet systems

* Circumbinary planet (CBP) : planet orbiting both components of a binary star

* 17 CBPs observed around main-sequence binaries and 2 multi-planet systems: most of them found close to the binary star at a few binary separations a_B

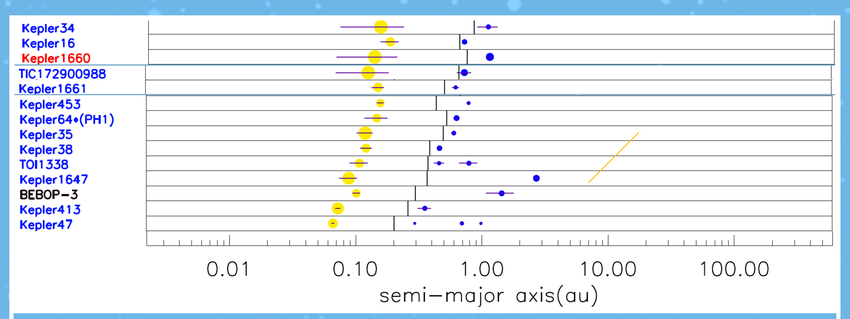


Fig.1 : List of CBPs orbiting main-sequence binaries (from [1])

* Question : Is the lack of planetary architectures with rocky CBPs due to observational biases or a dynamically hostile environment ?

* Circumbinary planets are unlikely to form in the inner part of the disk [2] → they may migrate inward from farther regions

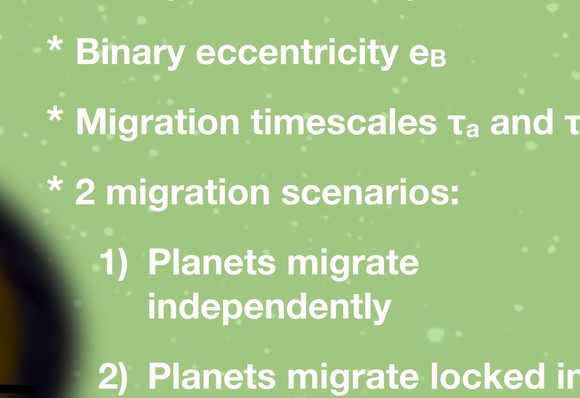
* Mean-motion resonance (MMR) : orbital periods of two bodies are locked in a ratio of small integers p:q

* MMRs help to halt planet migration and generate multi-planet systems [3]

2 N-body simulations of migrating CBPs

* 1200 N-body simulations with the C library REBOUND [4] :
  - Two migrating planets (10 $M_\odot$)
  - Simulation time : 1,000,000 years

120 combinations q_B / e_B / scenario
×
10 simulations with random initial orbital phases



Number of final architectures with ≥1 (Fig. 3) or 2 planets (Fig. 4) remaining

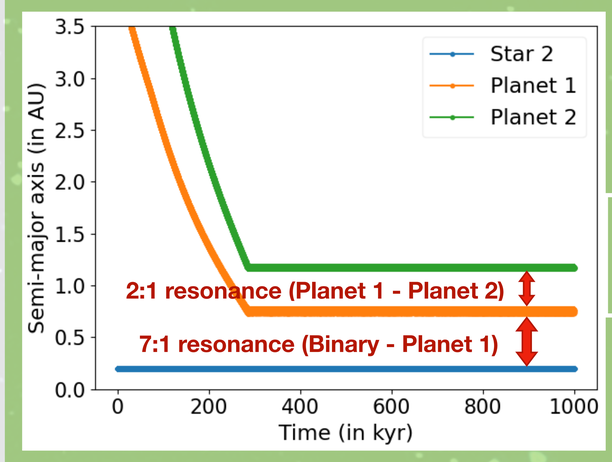
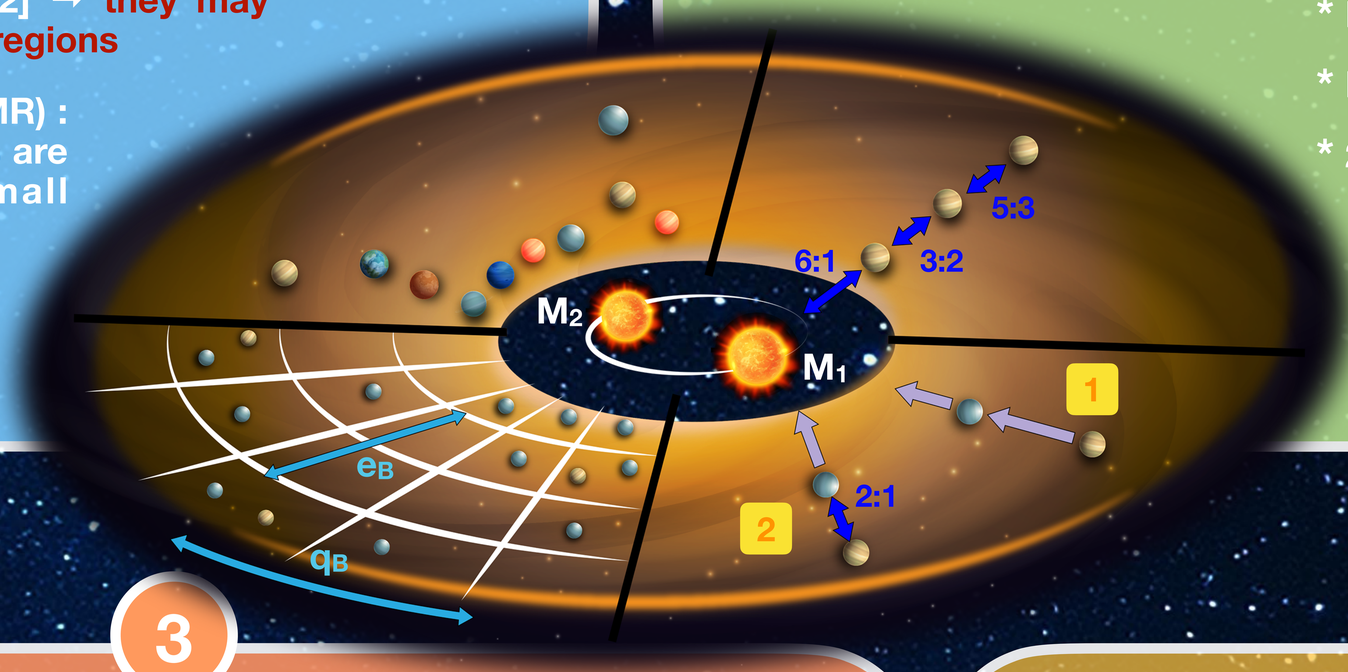


Fig.2 : Time evolution of the semi-major axes of two migrating CBPs and the outer component of a binary star.

Parameter space:

* Binary mass-ratio q_B
* Binary eccentricity e_B
* Migration timescales τ_a and τ_e
* 2 migration scenarios:
  1) Planets migrate independently
  2) Planets migrate locked in MMR



3 Results and Stability maps

* In both migration scenarios, most of (q_B / e_B) combinations lead to the survival of at least one planet (Fig.3)

* Innermost planet locked in MMR with the binary (potential CBP location in addition to the disk inner edge)

* Majority of (q_B / e_B) combinations against multiple planets, except for several regions of interest (Fig.4)

* Migration scenario 1 : similar stability map as Fig.4, but less stable and without the stable region at e_B = 0.4-0.5 → MMR between planets during the migration help for generating multi-planet systems

* Migration timescales τ_a and τ_e depend on disk and planet parameters → Fig.3 and Fig.4 obtained with only one disk profile

* High disk density and low disk aspect ratio favor stability of multi-planet systems

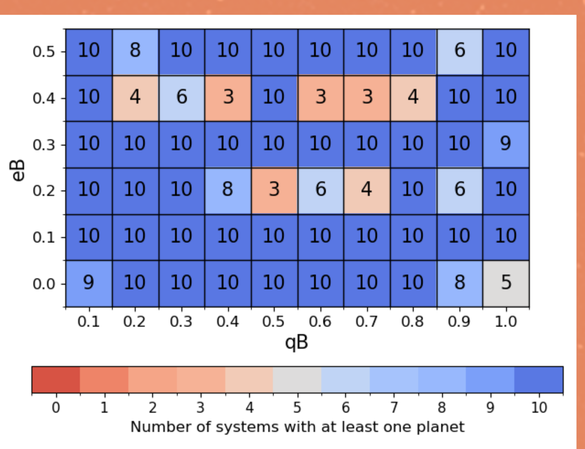


Fig.3 : Stability map (q_B - e_B) for systems with at least one planet remaining for the migration scenario 2.

Case favoring planet stability

Case favoring planet instability

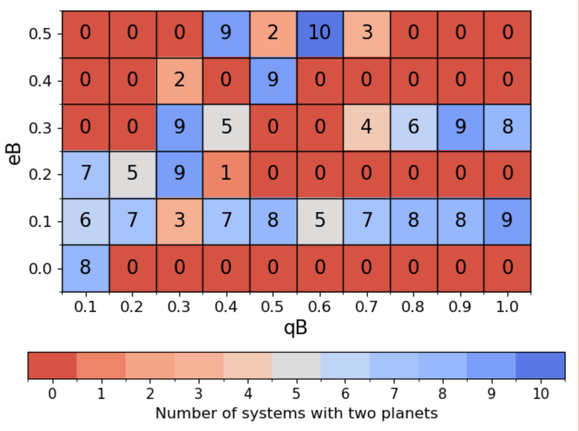


Fig.4 : Stability map (q_B - e_B) for systems with two planets remaining for the migration scenario 2.

4 Discussion

* Ejections mainly due to high values in eccentricity leading to close encounters between bodies → Binary-Planet MMR is the main source of increase in eccentricity and likely ejections of CBPs

* Low-mass planets migrate at higher values in τ_a → higher likelihood to form multi-planet systems

* Limitations:
  - No inner edge or eccentric inner region
  - Focus only on the migration phase

  → Likely variations in survival rates

Perspectives

* These preliminary results show the importance of binary parameters for the stability of CBPs

* These could serve for future observational campaigns (e.g. ESPRESSO, SOPHIE, TESS, Gaia)

[1]: Thebault P. ,Bonanni D., 2025, A&A,700, A106

[2]: Moriwaki K., Nakagawa Y., 2004, ApJ, 609, 1065

[3]: Weidenschilling S. J., Davis D. R., 1985, Icarus, 62, 16

[4]: Rein H., Liu S. F., 2012, A&A, 537, A128

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