# Unveiling free-floating binary planets with Gaia-NIR astrometry

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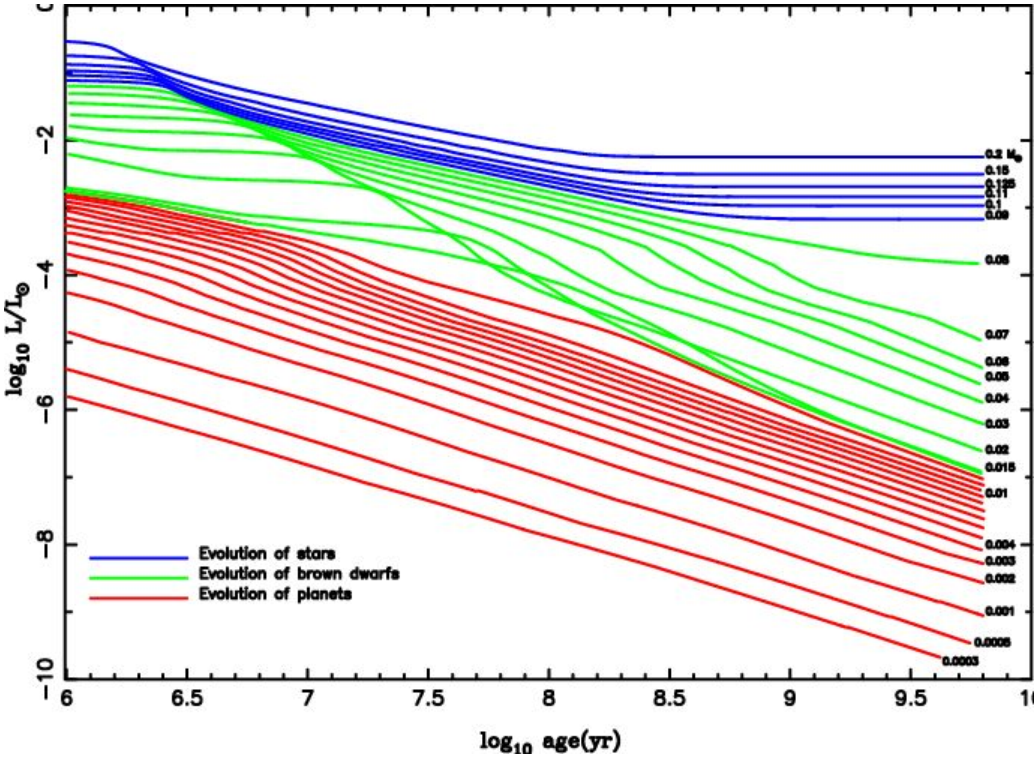
# Massive planets and brown dwarfs

- Exist both as companions to stars and as free-floating objects
- Becoming very faint and cool with age (no nuclear burning, but short-term lithium and deuterium)
- Direct detection in Gaia limited to more massive and/or younger objects due faintness in the optical

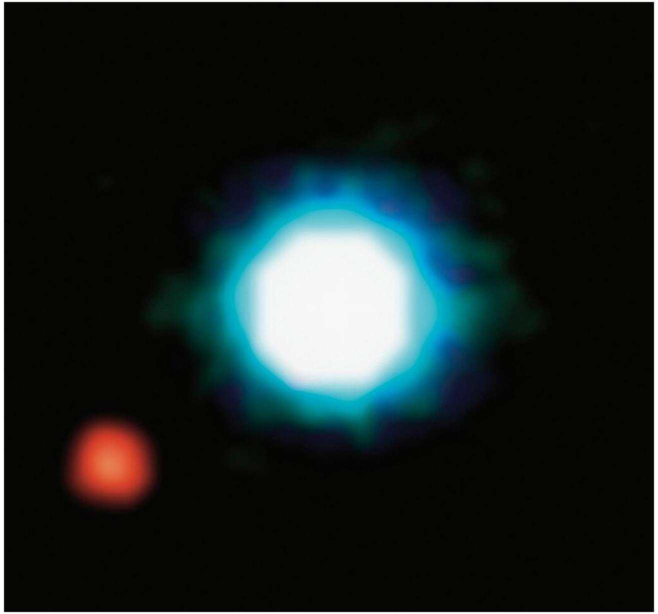



Burrows+1997

# Multiplicity

- Focus of this contribution is the multiplicity of substellar objects, down to free floating planets

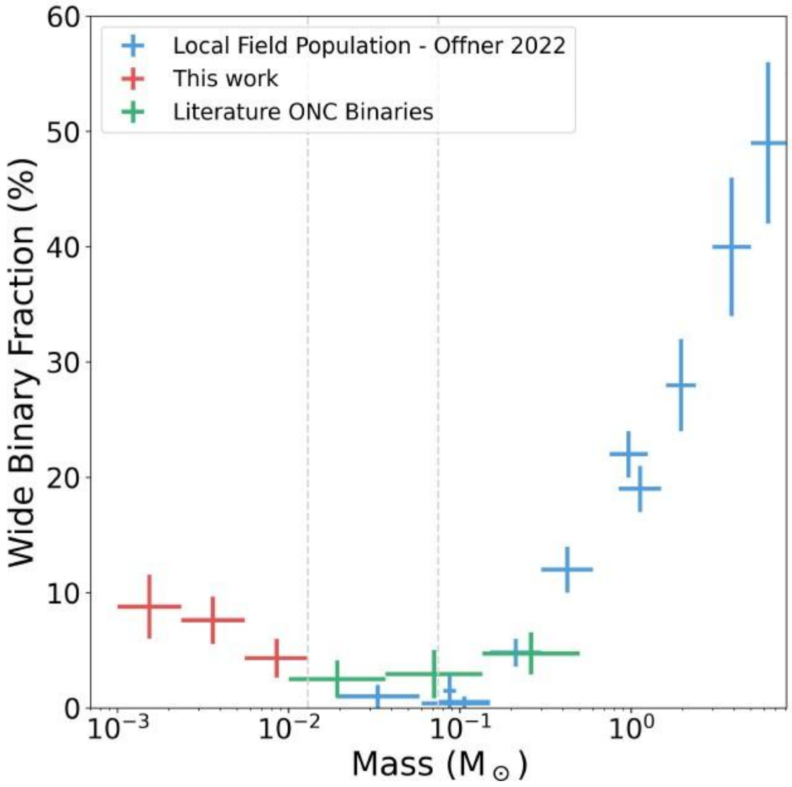
- Current results show the existence of BD pairs, BD-planets pairs, BD-BD pairs as companions of stars (direct imaging)
- No confirmed binary planets from transit surveys (close separation from the central star)
- Sparse detections from microlensing
- Pluto-Charon in the Solar System (mass ratio 0.12)



25 + 5 Mjup Chauvin+2004

# A turnover of multiplicity fraction in the planetary regime ?

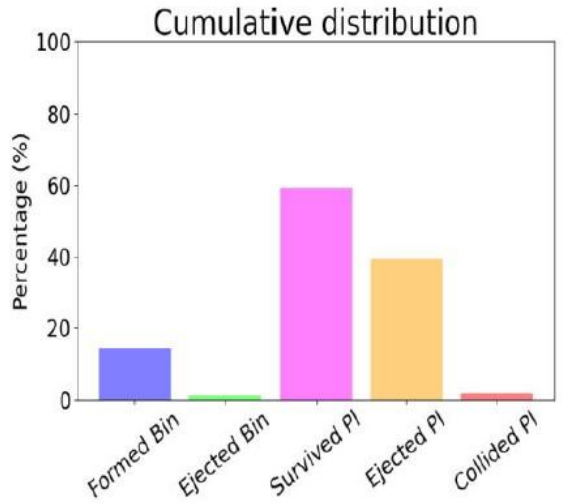
- Well known decrease of multiplicity fraction with mass of central objects in the stellar and substellar regime
- Unexpected **increase of multiplicity fraction** (visual companions, >100 au) **in the planetary regime** in Trapezium cluster (very young age and moderately high stellar density)
- Point to **specific mechanism(s) for the production of free-floating binary planets**




Pearson+2023, Nat

# Theoretical explanations for binary planets

- Direct formation as free-floating pairs (Portegies Zwart+2023)
- Core accretion or gravitational instability + close encounters with tidal dissipation (Ochiai+2014; Lazzoni+2024)
- After stellar fly-by with a planetary system (Wang+2023)
- Peeble accretion (Konjin+2023)



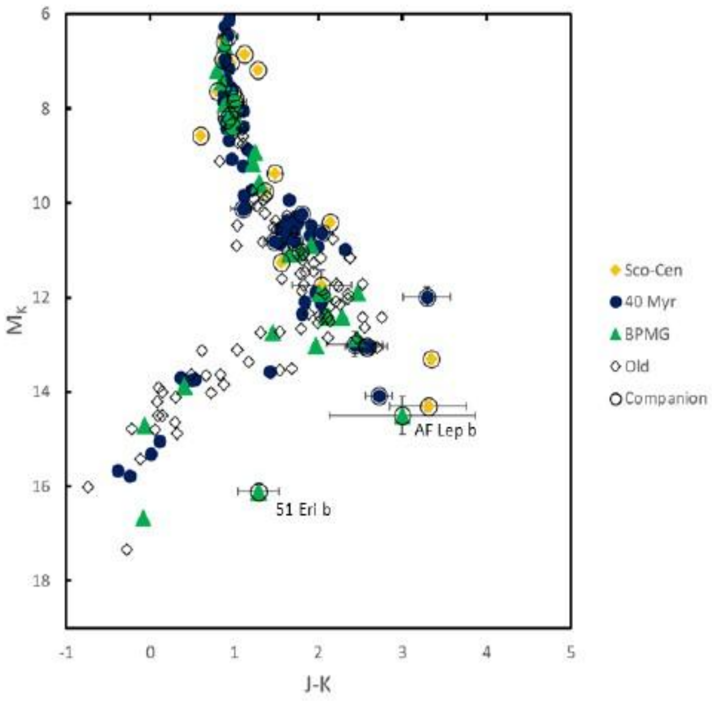

Lazzoni et al. MNRAS 2024

**Key observables to disentangle**: frequency vs separation (exploring closer separation); frequency vs age; environment (clusters vs sparse associations and field); frequency of binary planets bound to stars

**Most of these diagnostics can be studies by Gaia-NIR**

# The role of Gaia-NIR: direct detections

- Increase of sensitivity to less massive and/or older substellar objects when moving to NIR
- Magnitude limit approx K=22: detection limits (direct detection) fully into planetary regime (free-floating objects or very wide companions) at close distances and young ages




Gratton+, A&A, submitted

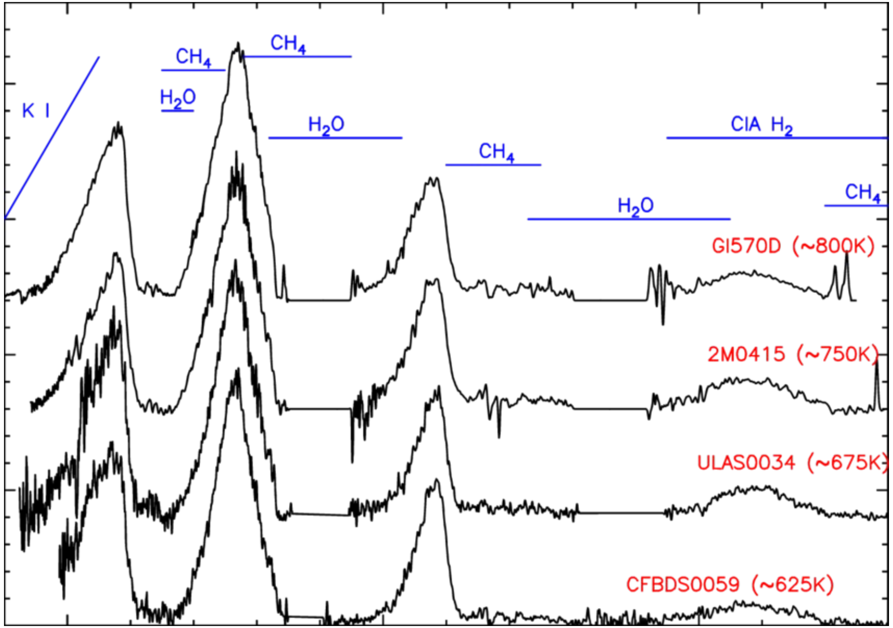
# The role of Gaia-NIR: direct detections

| Association | Age (Myr) | Mean dist (pc) | Mass@K=22 (Mjup) (Baraffe models) |
|---|---|---|---|
| beta Pic MG | 21 | 47 | 2 |
| Tuc-Hor | 37 | 49 | 3 |
| AB Dor | 137 | 51 | 6 |
| Sco-Cen | 5-15 | 140 | 2 |
| Taurus | 1 | 140 | 0.5 |
| old field | 5000 | 10 | 24 |
| old field | 5000 | 100 | 45 |

- Detection down to few Mjup in nearby young associations
- Limited astrometric accuracy at the magnitude limit of the instrument

# Caveat: peculiar SED of T and Y type objects

- Peculiar SED of T and Y type objects driven by molecular bands
- Any impact for Gaia-NIR performances with respect to more regular M or L type spectra ?




0.9-2.3 µm spectra
Delorme+, 2008

# The role of Gaia-NIR: astrometry

- Application of a sample of free floating substellar objects in nearby associations  (165 objects; Gratton et al., submitted)
- The associations have large spread in distances (several tens of pc). Using mean distances from Gratton+ submitted
- Small system masses → longer orbital periods for same a with respect to stars
- Considering  P=1000 d as reference case in the following
- Need consolidated error budget of astrometric accuracy vs magnitude and dedicated simulations but detectability is well in the planetary regime for reasonable assumptions

# The role of Gaia-NIR: astrometry

| Association | Age (Myr) | Mean dist (pc) | Kmag (40 Mjup) | 1 Mjup companion @1000d | Kmag (10 Mjup) | 1 Mjup companion @1000d |
|---|---|---|---|---|---|---|
| beta Pic MG | 21 | 47 | 11.5 | 353 µas | 15 | 911 µas |
| Tuc-Hor | 37 | 49 | 12.6 | 339 µas | 16.5 | 874 µas |
| AB Dor | 137 | 51 | 14.0 | 326 µas | 18.8 | 840 µas |
| Sco-Cen | 5-15 | 140 | 13.7 | 119 µas | 16.6 | 306 µas |
| Taurus | 1 | 140 | 12.5 | 119 µas | 14.3 | 306 µas |
| old field | 5000 | 10 | 18.0 | 1660 µas | >22 | NA |

- to be compared with realistic error budget but the amplitudes are definitely promising for detections

# A special case: WISE J225540.75-311842.0

- Free floating substellar object
- Distance 14 pc
- Kmag = 17.42
- 99% membership probability for beta Pic MG (age 21 Myr)
- mass 3.5 Mjup (the less massive object known in the beta Pic MG, slightly less massive than 51 Eri b)

- P=1000 d
- a=0.29 au
- companions/satellite mass 17 Mearth (1 Mneptune) (mass/ratio 0.015)
- astrometric amplitude 320 μas
- should be within Gaia-NIR capabilities

# Conclusions and Perspectives

- Relevant role expected for Gaia-NIR for free-floating planets (or very wide companions) and brown dwarfs

- Completeness in detections (new detections + kinematic parameters allowing evaluations of groups membership and derivations of other properties); take care of peculiar SED

- Good sensitivity for companions/satellites around free-floating planets from the astrometric monitoring
- Down to few tens of Earth masses for the most favourable cases.

- Interested to contribute to the science case