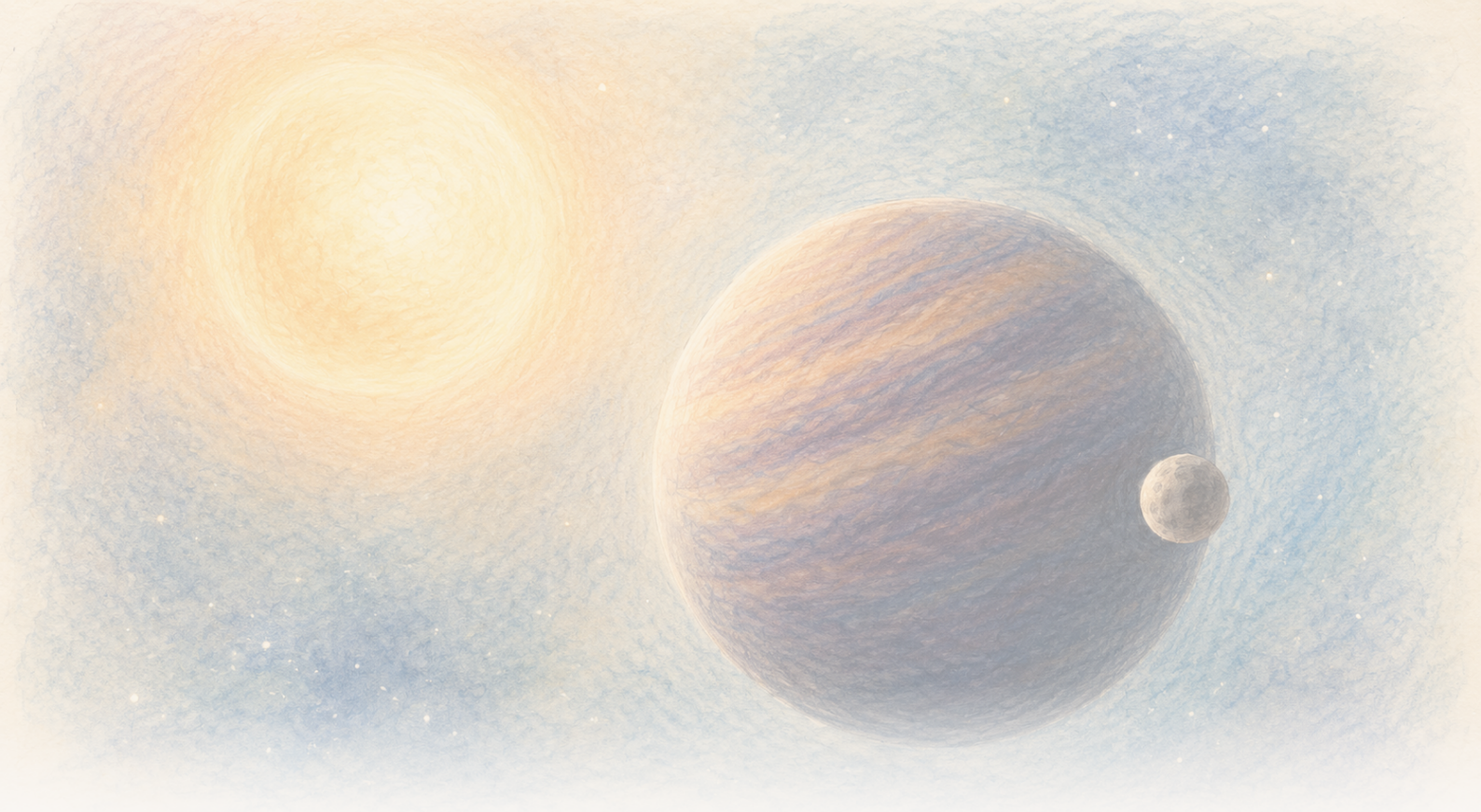


The Clean Paper

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Wani brown dwarf yana kamar yana karkarwa duk bayan kwanaki 171. Wata ɓoyayyiyar duniya na iya jan shi, amma bayanan har yanzu suna ba da damar tsarin biyu

High-quality spectra 23 sun nuna periodic shift mai karfi a motion na CD-35 2722 B. Model da ya fi dacewa da bayanan shi ne eccentric companion guda da minimum mass kusa da na Jupiter, amma model mai objects biyu zai iya kwaikwayon signal d'in, slow brown-dwarf variability har yanzu ba za a iya cire shi gaba d'aya a principle ba, kuma kalmar 'exomoon' ba ta da settled boundary a wannan yanayin.

Written by Cinzia Vaglio · Cross-checked by Matteo · Edited by Michele Renda · Figures by Cinzia Vaglio, Laura Nesso and Nova Vela · AI-assisted, human-reviewed

Paper: *Planetary-mass exosatellite detected around the substellar companion of a star*, Kevin Hoy, Alice Zurlo, Pablo A. Pena R., Jana Kohler, Silvano Desidera, Raffaele Gratton, Cecilia Lazzoni, Simon Petrus, Florian Rodler, Jonathan Smoker, Valentina D'Orazi, Ilaria Carleo and Ilaria Giovannini, Nature 655, 865-869 (2026) · DOI: 10.1038/s41586-026-10751-w

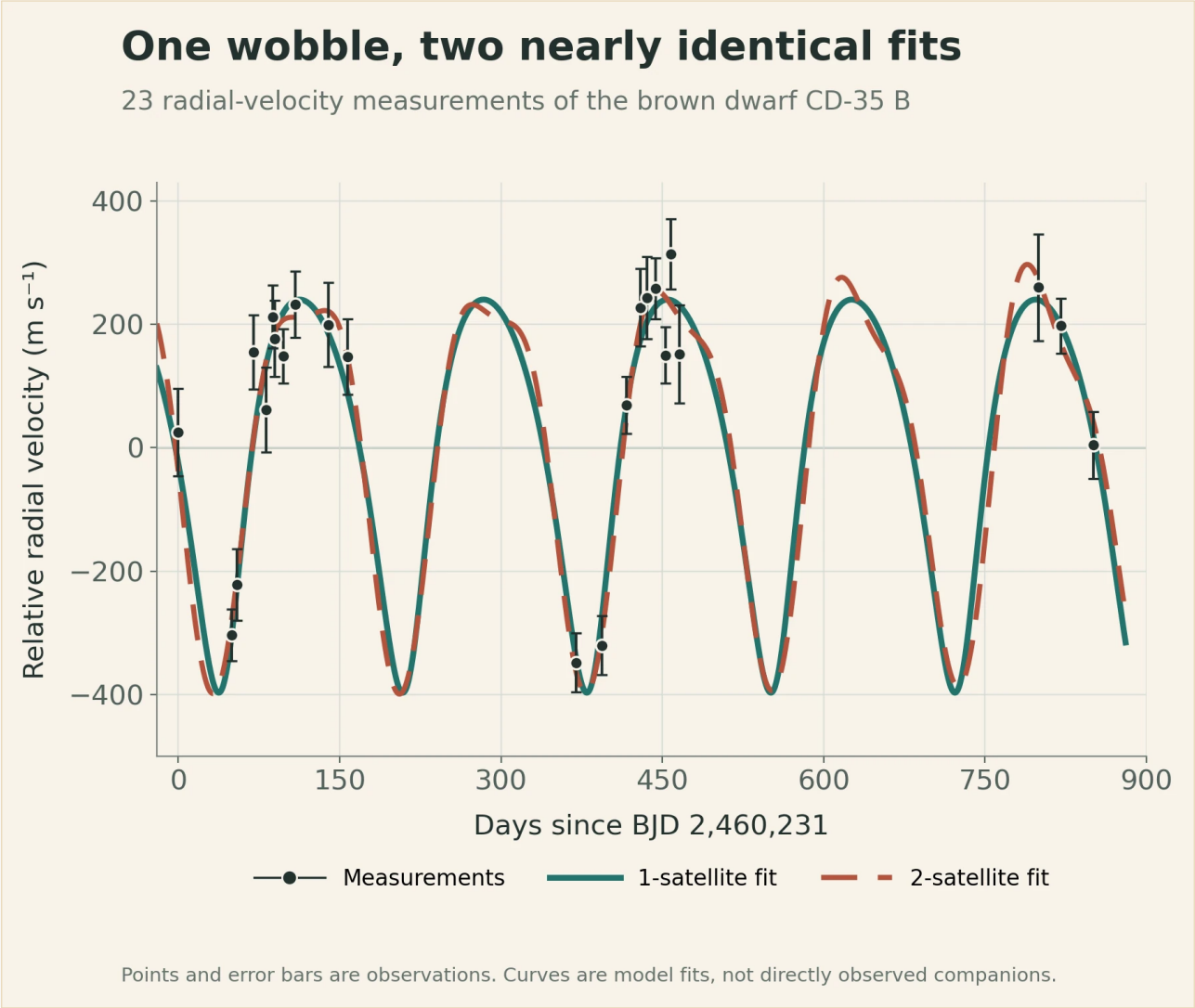
Brown dwarf ɗin nan yana nuna motsi mai maimaituwa duk kusan kwanaki 171. Wata duniyar da ba a gani ba na iya jan sa, amma bayanan har yanzu suna iya dacewa da abubuwa biyu

Masana taurari suna iya ganin CD-35 2722 B a matsayin haske daban da tauraron da yake kewaya. **Brown dwarf** ne: wani abu mai nauyi tsakanin manyan planets da stars. Nauyinsa kusan sau 37 na Jupiter ne, don haka ya fi giant planet na yau da kullum nauyi amma bai kai star da ke kunna hydrogen fusion ba. Abin da ba a iya gani kai tsaye shi ne ƙaramin object da wataƙila yake kewaya brown dwarf ɗin kansa. Idan aka tabbatar, zai zama tsarin matakai uku: star, brown dwarf da ke kewaya star ɗin, sannan satellite mai planetary mass da ke kewaya brown dwarf.

Abin da aka gani kai tsaye ba satellite ba ne, sai **motsi mai maimaituwa**. A wasu darare, spectral lines na brown dwarf suna ɗan matsawa ta hanyar da ta nuna yana zuwa wajen Duniya; a wasu kuma suna nuna yana tafiya nesa da mu. Wannan yanayin yana maimaituwa kusan duk **kwanaki 171**.

Companion da ba a gani ba zai iya haifar da irin wannan motsi. Idan objects biyu suna kewaya centre of mass ɗinsu, ƙaramin object yana yin babbar kewayawa, amma babban ma yana yin ƙaramar kewayawa. Idan wannan maimaituwar ta samo asali daga orbit, sabuwar takarda a *Nature* ta gabatar da object guda mai planetary mass a matsayin bayanin da ya fi dacewa da wobble da aka auna a CD-35 2722 B.

Wannan yiwuwar tana da ban sha’awa sosai, amma ba hoton moon ba ne. Dararen lura masu inganci guda 23 ne suka nuna periodic signal mai ƙarfi. Don a fassara wannan signal a matsayin sabuwar duniya, dole ne a yi amfani da model, kuma bayanan da ake da su yanzu suna iya dacewa da tsarin companion guda ɗaya ko biyu. Haka kuma ba a kawar gaba ɗaya da yiwuwar cewa brown dwarf ɗin kansa yana sauyawa a hankali ba.



Bakaken points da error bars su ne radial-velocity measurements na darare 23. Solid da dashed curves suna nuna mafi kyawun fits na model mai satellite guda ɗaya da na satellites biyu. Kusancin curves ɗin yana nuna dalilin da bayanan za su iya gano periodic wobble amma har yanzu ba su tantance tsarin da ya haifar da shi ba; babu ɗaya daga curves ɗin da yake hoton companion kai tsaye.

Original chart — The Clean Paper; data from Hoy et al., Nature (2026), Figure 1 source workbook CC BY 4.0

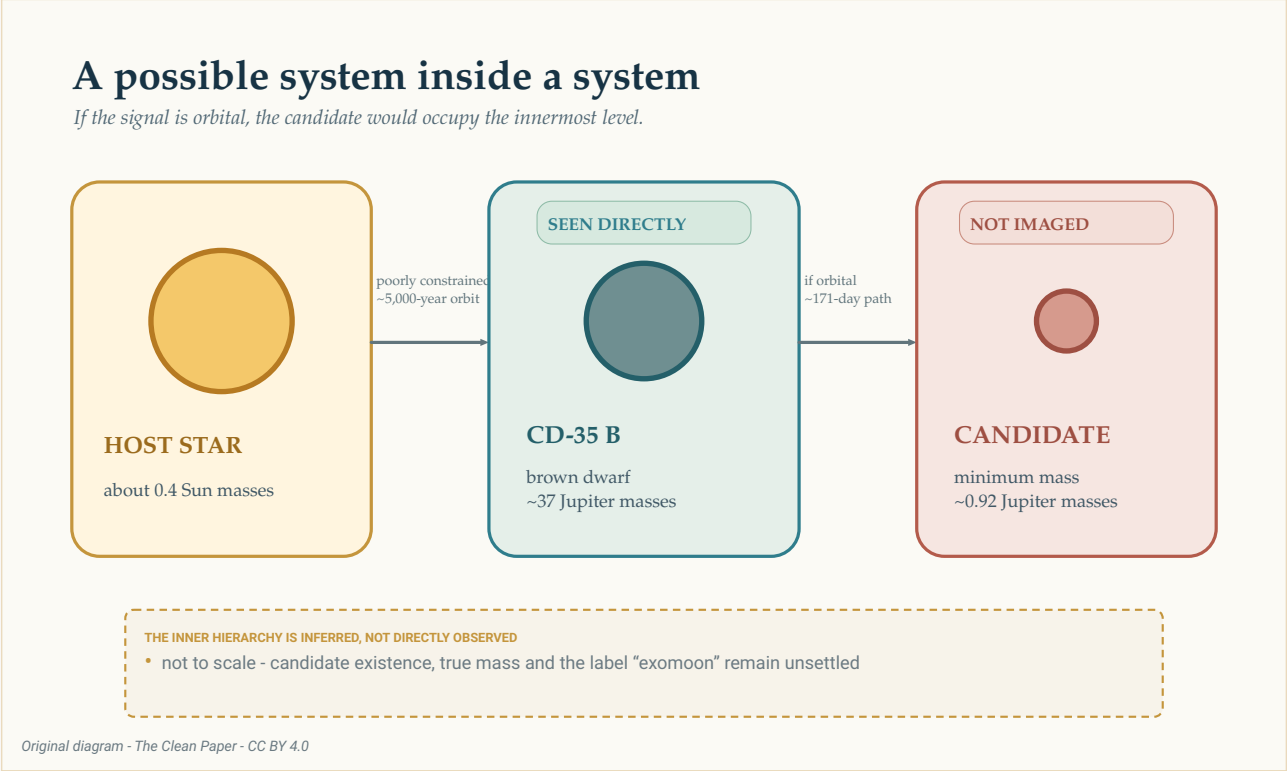
Tsari a cikin wani tsari

CD-35 2722 B **brown dwarf** ne, wato object da yake tsakanin categories da muka saba. Ya fi giant planet na yau da kullum nauyi, amma bai kai nauyin da zai sa ya haskaka kamar hydrogen-burning star ba. Takardar ta yi amfani da estimated mass na kusan **Jupiters 37**.

An gano brown dwarf ɗin ta direct imaging: telescopes sun iya raba haskensa da na host star. A sararin sama yana bayyana kusan 2.8 arcseconds daga star ɗin. Ba a san wide orbit ɗinsu sosai ba, amma estimates na yanzu suna nuna hanya mai tsawo sosai wadda kewayarta na iya ɗaukar kusan **shekaru 5,000**.

Idan periodic signal ɗin orbital ne, candidate ɗin zai kasance mataki mafi ciki: star a waje, brown dwarf yana

kewaya shi, sannan planetary-mass companion yana kewaya brown dwarf.



Idan signal ɗin orbital ne, candidate ɗin zai kasance a mataki mafi ciki na wannan yiwuwar hierarchy. Brown dwarf kaɗai aka gani kai tsaye. Outer orbit ɗinsa da star ba a san shi sosai ba, yayin da inner orbit na kusan kwanaki 171 aka infer daga wobble da aka auna a brown dwarf. Girma da nisa ba su kan scale ba.

Zana wannan hierarchy abu ne mai sauƙi; tabbatar da ainihin tsarin da kuma sunan da ya dace da object ɗin ya fi wahala. Shin body mai planetary mass da ke kewaya brown dwarf **moon** ne, **planet** ne, ko kuma kawai **satellite**? Babu accepted rule guda ɗaya da masana taurari suka amince da shi domin warware wannan tambaya. Saboda haka takardar ta yi amfani da kalmar da ta fi faɗi: **exosatellite**.

Yadda darare 23 suka ba da wobble

Kungiyar ta lura da CD-35 2722 B — akwai kuma shafinsa a NASA Eyes on Exoplanets — da CRIRES+, high-resolution spectrograph na Very Large Telescope na European Southern Observatory. Tsakanin Oktoba 2023 da Fabrairu 2026, sun yi observing epochs 26. Ɗaya bai ba da signal isasshe ba, biyu kuma da aka ɗauka cikin mummunan yanayi an ƙi su sannan aka maimaita. Hakan ya bar **darare 23 masu inganci**.

Spectrograph yana warware haske zuwa jerin spectral lines masu cikakken bayani. Idan source yana motsawa zuwa Duniya ko nesa da ita, lines ɗin suna matsawa kaɗan. Idan aka maimaita irin wannan ma'auni, ana samun **radial velocities**. Wannan ba ya nuna hidden companion kai tsaye; yana nuna yadda object da muke gani zai iya motsawa saboda jan wani object da ba mu gani ba.

Periodic signal mafi ƙarfi yana kusa da kwanaki 170. Ya wuce **0.1% false-alarm-probability threshold** da binciken ya sa. Wannan threshold yana tambayar sau nawa noise, bisa assumptions na test, zai iya samar da periodogram peak mai ƙarfi kamar wannan ko fiye. Ba yana nufin akwai 99.9% probability cewa satellite ya wanzu ba, kuma shi kaɗai ba ya gaya mana ko companion ɗaya ne ko biyu.

> **Me radial-velocity signal zai iya tabbatarwa?**
>
> Radial velocity tana juya canjin spectral lines da ake maimaitawa zuwa ma'aunin motsi zuwa wajen observer ko nesa da shi. Idan pattern ya maimaitu, ana iya fit shi da equations na orbit domin a infer period, girman wobble da minimum mass na companion.
> Amma hanyar ba ta ɗaukar hoton companion kai tsaye. Atmosphere na star ko brown dwarf na iya sauya spectral lines, jadawalin observations na iya haifar da rhythms na ƙarya, kuma orbital arrangements daban-daban na iya kwaikwayon juna. Don haka signal, bayaninsa na physics da sunan object ɗin da aka infer tambayoyi ne daban-daban.

Kafin a yanke hukuncin orbital, sampling ɗin ya cancanci kulawa. Radial-velocity measurements huɗu masu ƙasa musamman suna da tasiri mai yawa a pattern ɗin. Sun zo a pairs biyu cikin yanayin lura da aka bayyana a matsayin mai kyau, kuma lokacin da marubutan suka maimaita analysis suna cire point ɗaya bayan ɗaya, babu point guda da ya ƙirƙiri signal shi kaɗai. Duk da haka, observations ɗin sun rufe wani ɓangare ne kawai na orbital phases. Darare 23 da suka bazu sama da shekaru biyu ba su daidai da continuous coverage ba.

Marubutan sun kuma gwada yiwuwar artefact na rabin shekara. Kuskure a gyaran motsin Duniya ko instrument profile na iya samar da annual signal na ƙarya wanda sampling ya sauya shi zuwa rabin shekarar Duniya, wato **kwanaki 182.5**. Preferred period ɗin su **kwanaki 171.11** ne, da uncertainty +0.53/-0.36 day; sun bayyana cewa wannan yana kusan standard deviations 20 daga 182.5 days. Haka kuma ba su gano correlation da motsin Duniya, seeing, atmospheric water vapour ko instrument properties da suka gwada ba. Waɗannan controls suna ƙarfafa orbital explanation har ya cancanci a yi model, amma ba su gano companion ɗin kai tsaye ba.

Mafi sauƙin orbital model: companion guda ɗaya

A model da aka fi so, object guda yana yin eccentric — wato ɗan elongated — orbit a kusa da brown dwarf duk kwanaki 171.11. Eccentricity ɗin ya kai kusan **0.27**, semi-major axis kuma kusan **0.200 astronomical units**, kusan kashi ɗaya cikin biyar na matsakaicin nisan Duniya da Rana.

Wobble da aka auna yana da amplitude kusan **318 metres per second**. Daga wannan, model ɗin ya ba companion **minimum mass** kusan **0.92 Jupiter masses**.

Kalmar *minimum* tana da muhimmanci. Radial velocity tana auna ne kawai ɓangaren orbital motion da yake zuwa gare mu ko nesa da mu. Idan ana kallon orbit ɗin edge-on, babban ɓangaren motsin yana bayyana a wannan direction. Idan ana kallonsa more face-on, yawancin motsin yana ketare sararin sama maimakon zuwa da daga gare mu; a wannan yanayin companion mai nauyi fiye da 0.92 Jupiter masses zai iya haifar da wobble iri ɗaya.

Masana taurari suna rubuta wannan da **m sin(i)**: mass da aka ninka da sine na inclination `i`, wato viewing angle na orbit. Bayanai suna takaita wannan product ne, ba true mass kai tsaye ba. Saboda haka 0.92 Jupiter masses lower

bound ne, ba ainihin mass da aka auna ba.

> **Me ya sa viewing angle yake ɓoye mass?**
>
> Ka yi tunanin circular track da kake kallo daga gefe. Mai gudu yana zuwa gare ka sannan ya koma nesa, don haka wannan component na motsi yana da sauƙin gani. Idan ka kalli track ɗin daga sama, mai gudu zai fi motsi a faɗin gani, ba zuwa gare ka ko nesa da kai ba.
> Radial velocity tana ganin component na farko ne kawai. Factor `sin(i)` yana bayyana nawa daga orbital motion ɗin yake kan line of sight ɗinmu. Har sai an san inclination `i`, mass da aka infer zai kasance minimum ne kawai.

Marubutan sun kuma gwada ko wannan orbit zai iya kasancewa stable na dogon lokaci. Numerical tests ɗin su sun nuna one-companion model gabaɗaya stable ne. Wannan yana sa shi wani physically plausible interpretation na signal, amma ba second detection ba ne.

Matsalar da ta rage: companions biyu ma za su iya kwaikwayon guda ɗaya

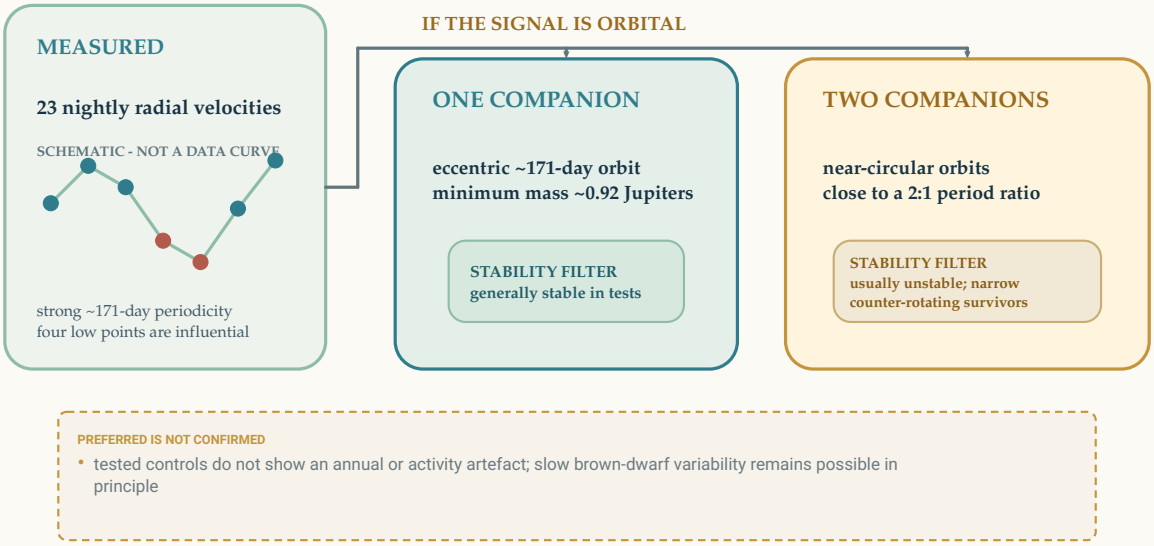
Eccentric radial-velocity signal yana da sanannen ambiguity. A wasu yanayi, objects biyu a kusan circular orbits, inda period na ɗaya ya kusan ninka na ɗayan, za su iya haɗa signals ɗinsu su yi kama da object guda a eccentric orbit.

Wannan matsala ta bayyana a nan. Two-companion model ma zai iya fit measurements ɗin yanzu, da outer signal kusa da kwanaki 171 da inner signal mai shorter period. Saboda observing times ba su rufe kowane phase daidai ba, inner signal yana da aliases da dama. Dogayen gaps tsakanin darare 23 suna sa trial periods daban-daban su iya ƙidaya adadin unseen cycles daban amma har yanzu su dace da points iri ɗaya. Saboda haka candidate periods kusa da kwanaki 14, 70, 88 da 115 ba detections huɗu masu zaman kansu ba ne; alternative fits ne ga shorter signal guda ɗaya da aka sample mara kyau.

Marubutan sun ƙi window na kwanaki 13 zuwa 17 saboda ba ta ware convincing period guda ba: solutions da yawa ƙasa da kusan kwanaki 20 suna iya sake samar da low-cadence measurements, abin da ya sa window ɗin ya fi kama da sampling artefact. Daga sauran windows, solution kusan kwanaki 88 ya fi na 70 da 115 fit, amma ba da ƙarfi har takardar ta ce an san second period ba. A best-fit table, minimum masses kusan 0.87 Jupiter masses ne ga outer object da 0.22 ga inner object. Waɗannan lambobi suna bayyana model da ba a fi so ba; ba measurements na confirmed worlds biyu ba ne.

One measured rhythm, more than one orbital model

The dynamics favour one object; they do not add another observation.



Original diagram - The Clean Paper - CC BY 4.0

Idan signal na kusan kwanaki 171 orbital ne, broad radial-velocity pattern iri ɗaya na iya fit da eccentric companion guda ɗaya ko near-circular companions biyu da periods kusan 2:1. Stability tests sun fi goyon bayan one-object interpretation, amma ba su mai da model ya zama direct image ko kawar da duk yiwuwar slow brown-dwarf variability ba.

Stability calculations sun ƙara bambanta models ɗin. Yawancin two-companion arrangements da aka gwada sun fitar da object guda daga system cikin few hundred simulated years. Configurations da suka tsira sun kasance a wani narrow, unusual region inda orbits kusan suna plane ɗaya amma suna tafiya directions masu sabani. Host star ma ya ƙara wasu unstable regions.

Wannan dalili ne na fifita eccentric companion guda ɗaya a kan two-companion systems da aka gwada. Amma ba hujjar cewa nature dole ta zaɓi simplest model ba ce. Stability tana tace interpretations **bayan** an auna radial velocities; ba ta ƙara sabon observed point ga curve ba.

Ta yaya eccentric orbit guda zai yi kama da circular orbits biyu?

Perfect circular orbit yana ba da simple repeating radial-velocity wave. Eccentric orbit yana ƙara distortions. Circular orbits biyu da periods ɗinsu kusan 2:1 za su iya haɗuwa ta yadda signal ɗaya ya ba da babban rhythm, ɗayan kuma ya samar da distortion mai kama da na eccentric orbit.

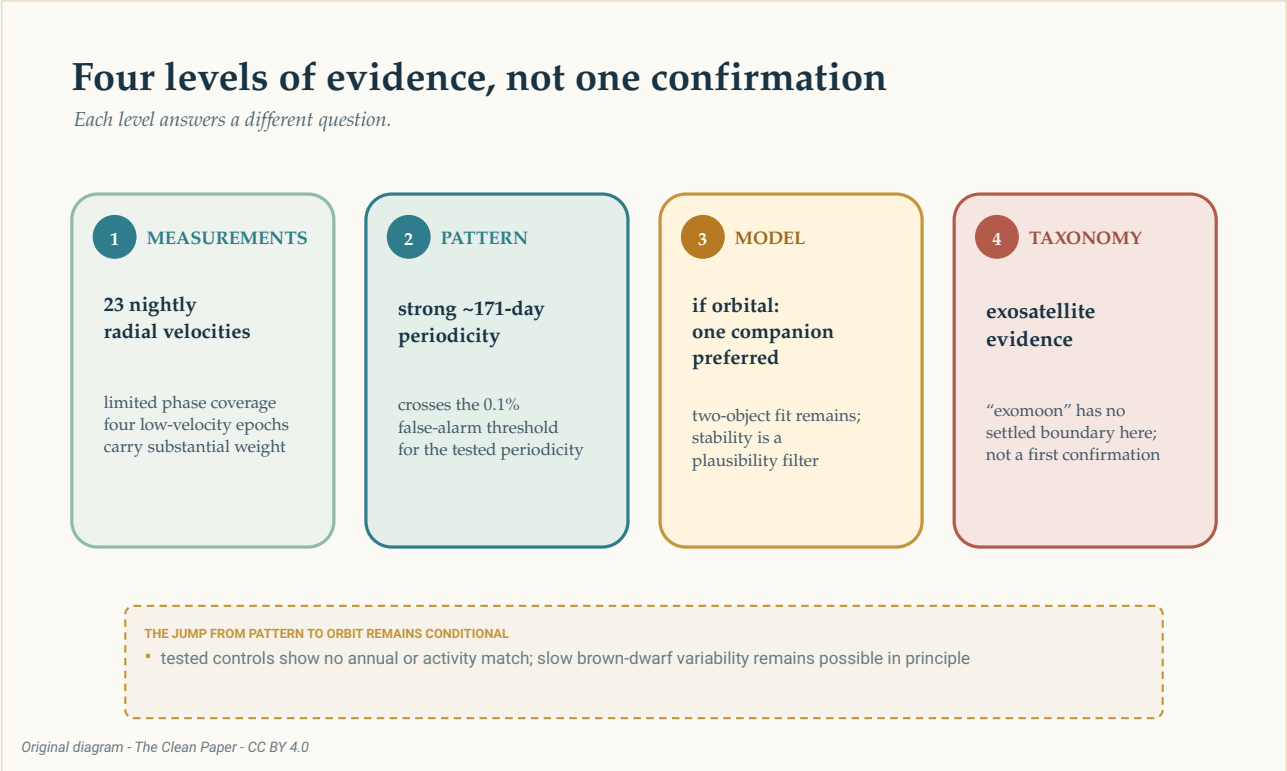
Wannan **orbital degeneracy** ne: physical systems daban na iya samar da measurements masu kama. Ƙarin observations a lokutan da models suke hasashen velocities daban za su iya raba su. Dynamics tests suna taimakawa wajen tambayar ko proposed system zai iya dawwama, amma ba su maye gurbin sabon observation ba.

Shin brown dwarf ɗin kansa zai iya haifar da rhythm ɗin?

Brown dwarf ba silent test mass ba ne. Atmosphere ɗinsa yana juyawa, yana samar da clouds, kuma zai iya nuna magnetic activity. Sauyin surface patterns na iya canza siffar spectral lines su yi kama da radial-velocity motion.

Estimated maximum rotation period na CD-35 2722 B kusan **kwanaki 0.65** ne, ƙasa sosai da kwanaki 171. Kungiyar ba ta gano strong short-period rotation signal ko convincing cloud- ko granulation-like signal a activity models da ta gwada ba. Ta kuma binciki annual sampling da instrument quantities ba tare da wani match ga 171-day rhythm ba.

Waɗannan checks suna rage yiwuwar alternatives, amma takardar ba ta ce an kawar da duk intrinsic variability ba. Long-timescale magnetic activity ko atmospheric circulation a brown dwarf har yanzu ba za a iya rule out in principle ba. Ya dace wannan yiwuwar ta kasance a fili tare da orbital models.



Shaidar tana hawa matakai daban-daban: radial-velocity measurements na darare 23 da limited phase coverage; periodicity mai ƙarfi na kusan kwanaki 171; preferred one-companion model idan signal orbital ne; sannan tambayar ko ya dace a kira object ɗin “exomoon”. Wannan ladder yana ware observation, statistical pattern, physical interpretation da taxonomy; ba jerin matakan confirmation ba ne.

Shin exomoon ne?

A Solar System, moon yana kewaya planet. CD-35 2722 B brown dwarf ne, kuma true mass na companion da aka infer har yanzu ba a sani ba. Sunayen da muka saba suna fara rikicewa idan object ɗaya yana kusa da iyakar planet/brown-dwarf, ɗayan kuma kusa da iyakar moon/planet.

Takardar ba ta yi ikirarin cewa wannan shi ne first confirmed exomoon ba. Ta ce har yanzu ba a samu exomoon da aka gano da babban tabbaci ba, sannan ta gabatar da shaida ga wani planetary-mass **exosatellite** kuma ta kira system ɗin wani mataki zuwa detection da ba zai jawo gardama ba. Discussion ɗin novelty ma yana da sharadi: **idan signal ɗin ya tabbata**.

Wannan taka-tsantsan ba ya sa sakamakon ya zama mara amfani. Auna radial velocity kai tsaye daga faint brown dwarf companion abu ne mai wahala. Idan observations na gaba suka ci gaba da tabbatar da signal, system ɗin zai nuna cewa methods na neman planets za su iya sauka zuwa wani mataki na hierarchy na sammai.

Wani observing season zai iya yin fiye da ƙara points kawai. One- da two-companion models suna hasashen velocities daban a wasu future times. Measurements da suka cike missing orbital phases za su iya gwada ko 171-day rhythm yana ci gaba, su rage tasirin low points huɗu, kuma su sa competing curves su rabu sosai.

A yanzu, hoton da ya fi gaskiya ba sabon moon da ke rataye kusa da brown dwarf ba ne. Shi ne spectrum da aka maimaita dare bayan dare, wanda ke ɗauke da ƙaramin periodic shift. Watakila akwai wata duniya a cikin wannan rhythm. Babban abin da binciken ya cim ma shi ne nuna yawan abin da za a iya infer daga signal ɗin ba tare da a yi kamar inference ɗin ya riga ya zama confirmation ba.

Takaitaccen bayani

Masana taurari sun auna radial velocity na directly imaged brown dwarf CD-35 2722 B a darare 23 masu inganci tsakanin Oktoba 2023 da Fabrairu 2026. Spectral lines ɗinsa suna nuna periodic shift mai ƙarfi kusa da kwanaki 171. Preferred orbital model yana da eccentric companion guda ɗaya da minimum mass kusan 0.92 Jupiter masses, amma true mass ba a sani ba saboda orbital inclination ba a sani ba. Near-circular companions biyu za su iya kwaikwayon broad signal iri ɗaya, ko da yake yawancin tested two-object configurations ba su stable ba. Low-velocity epochs huɗu suna da tasiri, kuma orbital phase coverage har yanzu iyakantacce ne. Tests ba su nuna rotation, annual sampling, weather ko instrument properties da aka bincika su ne tushen signal ba, amma long-timescale brown-dwarf variability ba a kawar gaba ɗaya ba. Ba a direct image companion ɗin ba; one-object model an fi so ne, ba a tabbatar da shi ba; kuma babu settled rule da ke cewa body mai planetary mass da ke kewaya brown dwarf dole a kira shi exomoon.

Bincike ba tare da ƙarin gishiri ba

Abin da aka lura: Radial-velocity measurements na darare 23 na CD-35 2722 B suna ɗauke da periodicity mai ƙarfi na kusan kwanaki 171. Brown dwarf kansa an direct image shi; proposed companion ba a gani kai tsaye ba.

Abin da marubutan suka fi fifita: Idan signal orbital ne, eccentric companion guda ɗaya mai minimum mass kusa da Jupiter mass yana ba da simplest dynamically plausible interpretation na bayanan yanzu.

Abin da har yanzu yake buɗe: Companions biyu ma za su iya fit radial velocities, ko da yake yawancin tested systems ba su stable ba; long-timescale brown-dwarf variability ba a kawar in principle ba; kuma unknown viewing angle ya bar true mass na companion ba a tantance ba.

Abin da takardar ba ta tabbatar ba: First confirmed exomoon; directly seen satellite; tabbataccen orbiting object guda ɗaya; true mass na 0.92 Jupiter masses; ko 99.9% probability cewa preferred physical model daidai ne.

Abin da zai ƙara amincewa: Ƙarin radial-velocity measurements da za su rufe ƙarin orbital phases, su gwada ko 171-day signal yana ci gaba, kuma su auna a lokutan da one- da two-companion models ke yin hasashe daban-daban.

Majiyoyi

Hoy et al., Planetary-mass exosatellite detected around the substellar companion of a star, Nature 655, 865-869 (2026)
`https://doi.org/10.1038/s41586-026-10751-w`

Hoy et al., reduced data and analysis code for Nature_Hoy-2026
`https://github.com/kevinmhoy/Nature_Hoy-2026`