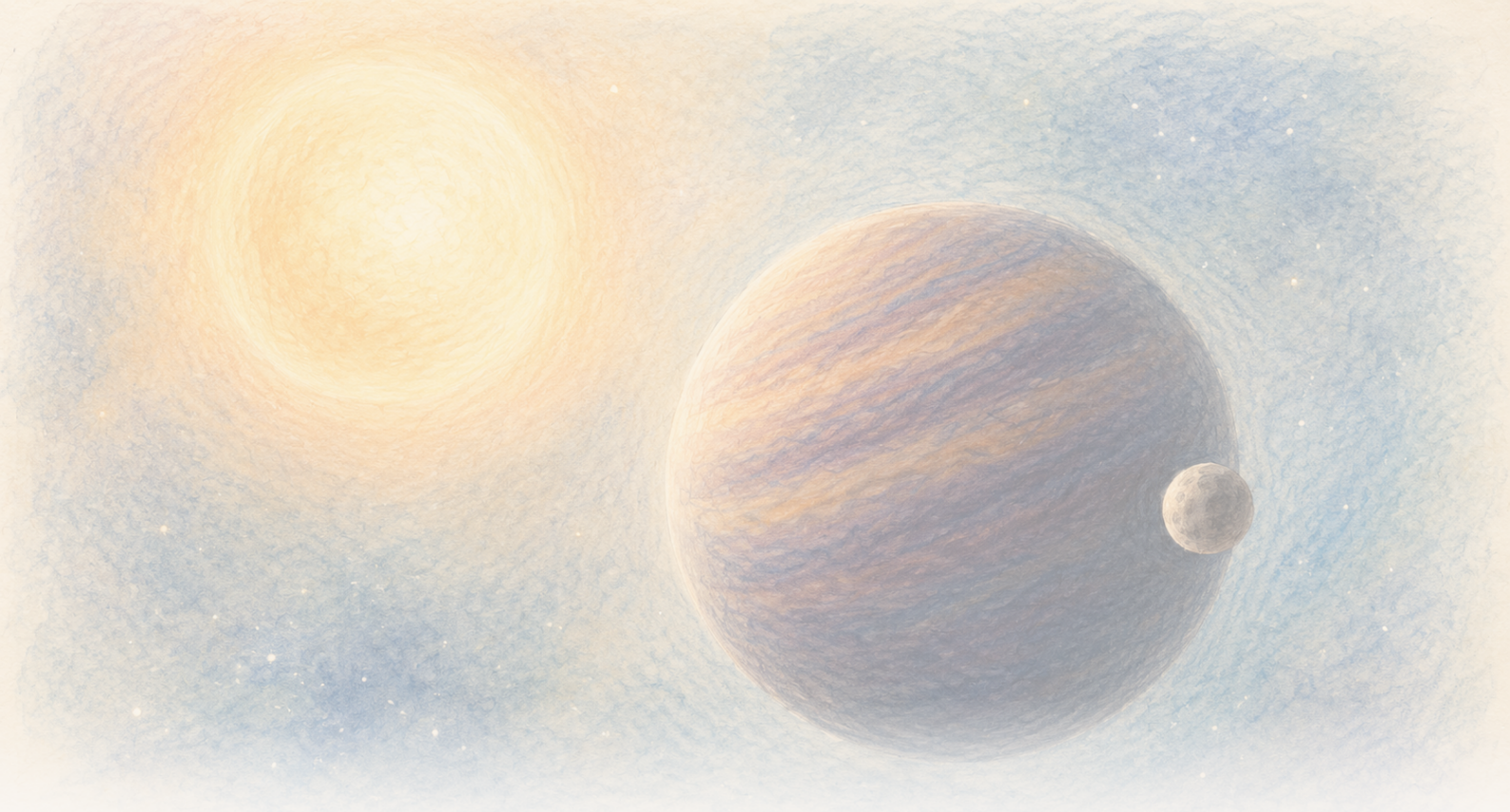




The CLEAN PAPER

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

Brown dwarf kan dà bí ẹni pé ó ní wobble ní gbogbo
ojó 171. Ayé kan tí a kò rí lè ní fa a, sùgbón data ẹi
gba possibility méjì láyè

High-quality spectrum 23 reveal strong periodic shift nínú motion CD-35 2722 B. Preferred model jẹ one eccentric companion pẹlú minimum mass near Jupiter's, sùgbón two-object model lè mimic same signal, slow brown-dwarf variability ẹi possible in principle, ọrò 'exomoon' kò sì ní settled boundary núbí.

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 kan dà bí ẹni pé ó n wobble ní gbogbo ojú 171. Ayé kan tí a kò rí lè n fa a, sùgbón dátà si gba possibility méjì láyè

Àwọn onímò ìjìnlẹ̀ sánmà lè rí CD-35 2722 B gégé bí kókó of light tirẹ̀, yàtò sí iràwò tí ó n orbit. Ó jẹ brown dwarf, nínú mass regime lááárín giant pílánẹ̀tì àti iràwò: ní nìkan bí Jupiter mass 37, ó massive ju typical giant pílánẹ̀tì lọ sùgbọ̀n kì í ẹ̀ normal hydrogen-burning iràwò. Wọ̀n kò lè rí object kékére tí ó lè n orbit brown dwarf fúnra rẹ̀. Tí a bá confirm rẹ̀, innermost object yẹn yòò mú èyí di hierarchy àkókó tí a observe ti satellite kan yí larger substellar object ká, nígbà tí object nàà fúnra rẹ̀ tún n orbit iràwò kan.

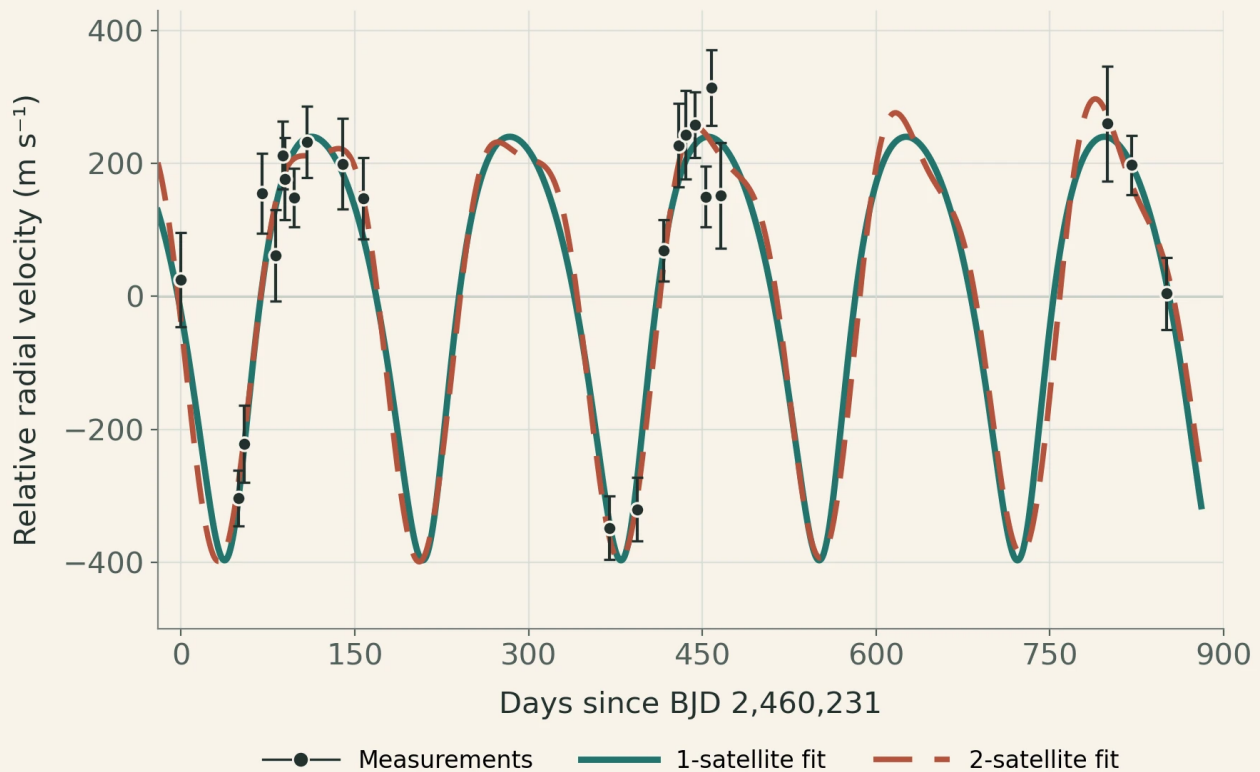
Ohun tí wọn rí dípò rè ní rhythm kan. Ní diẹ lára night, light brown dwarf shift diẹ bí ó ẹ ní rìn sí Earth. Ní night mǐràn, ó shift bí brown dwarf ẹ ní rìn kúrò lódò wa. Pattern nàà ní tún ara rè ẹ nńkan bí gbogbo **171 days**.

Back-and-forth motion yẹn ni unseen companion lè fa: bí object méjì ẹ̀e ní orbit shared centre of mass, object kékeré ní yí larger òkan ká, sùgbọn larger òkan nàà ní ẹ̀e loop tó kéré púpọ̀. Tí rhythm yìí bá jẹ orbital, Nature iwé iwádílí tuntun kan gbé planetary-mass object kan kalẹ̀ gégẹ́ bí preferred explanation fún loop tí a measure yí CD-35 2722 B ká.

Ó jẹ possibility tó remarkable, kì í ẹ photo moon kan. High-quality observing night 23 reveal lágbára periodic àmì. Yíyí àmì yẹn padà sí world kan require àwòṣe, current dátà sì ẹ gba architecture ju ọkan lọ láyè. Wọn tún kò fully exclude slow change nínú brown dwarf fúnra rẹ.

One wobble, two nearly identical fits

23 radial-velocity measurements of the brown dwarf CD-35 B



Points and error bars are observations. Curves are model fits, not directly observed companions.

Black kókó àti àṣiṣe bar ni 23 nightly radial-velocity measurement. Solid àti dashed curve ni best-fitting ọkan-àti two-satellite àwòṣe. Near overlap wọn fi hàn idí tí dátà fi lè reveal periodic wobble láì tǐ determine architecture ètò; curve kankan kì í ṣe taara image companion.

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

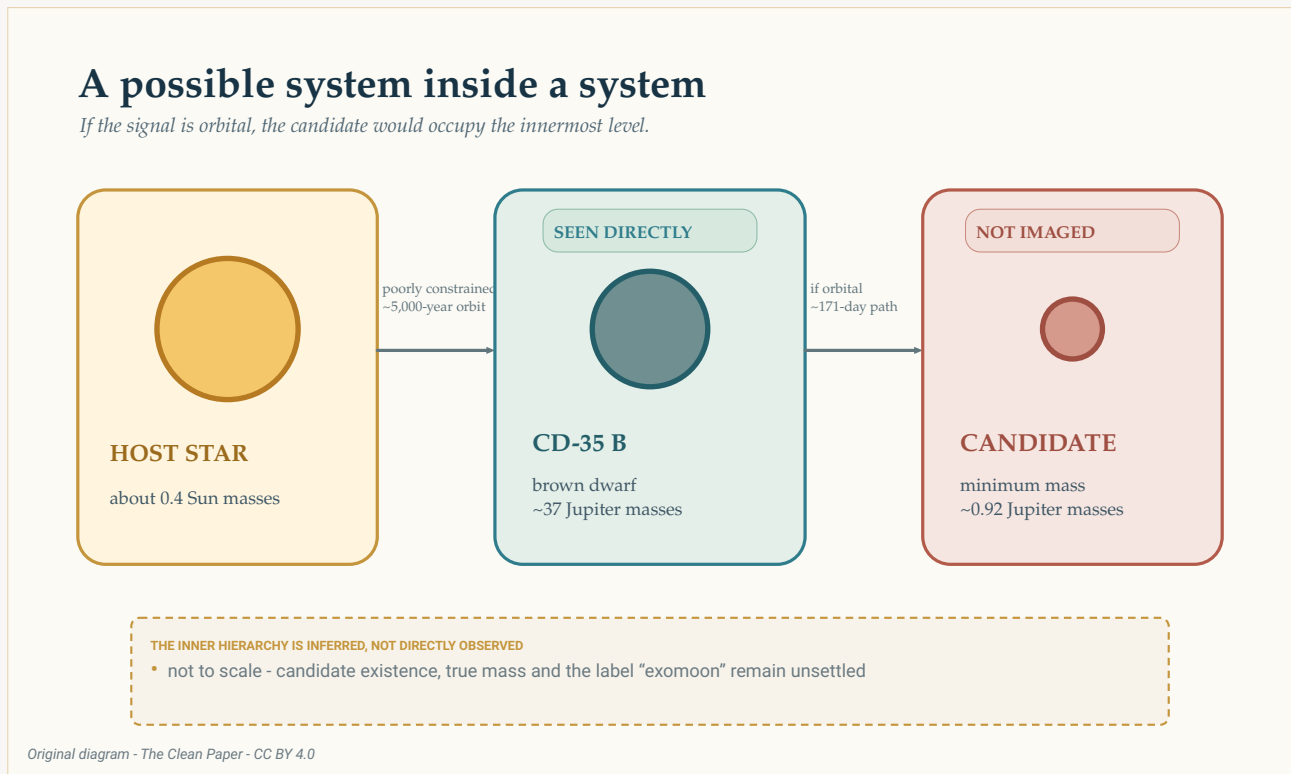
System kan nínú ètò

CD-35 2722 B jẹ **brown dwarf**: object kan láàárín familiar category. Ó massive ju typical giant pílánẹ̀tì lọ, ṣùgbón mass rẹ kò tó látí shine bí normal hydrogen-burning iràwọ̀. ìwé iwádíí lo estimated mass nńkan bí **Jupiter 37**.

Brown dwarf nàà jẹ discovered ní taara imaging, iye telescope resolved light rẹ yàtò sí ti host iràwọ̀. Ó hàn nńkan bí 2.8 arcseconds kùrò lódò iràwọ̀ lórí sky. Wide orbit tó connect pair nàà poorly known, ṣùgbón current ìṣírò àfojúsùn daba highly stretched path tó gba nńkan bí **5,000 years**.

Tí periodic àmì bá jẹ orbital, inferred architecture yòò fi candidate nàà sí ipele jinlẹ sí i: iràwọ̀ kan tí brown dwarf

ní orbit, pèlú planetary-mass companion tí ó ní orbit brown dwarf yẹn.



Tí àmì bá jẹ orbital, candidate yóò gba innermost ìpele nínú ẹẹ́ ẹẹ́ hierarchy yìí. Brown dwarf nìkan nì a tí rí tààrà. Outer orbit yí iràwò ká poorly constrained, nígbà tí approximately 171-day inner path jẹ inferred láti measured wobble brown dwarf. Size àti ijìnnà kì í ẹẹ́ to scale.

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Possible hierarchy yìí rọ̀rùn láti draw. Physical reality àti vocabulary rẹ̀ kò tì settle. Ẹ́ planetary-mass body tí ó ní orbit brown dwarf yẹ́ kí a pè ní moon, pílánẹ̀tì tàbí satellite nìkan? Àwọn astronomer kò ní accepted òfin tó settle ibèèrè nàà. Nítorí nàà ìwé ìwádìí lo broader word **exosatellite**.

Bí 23 night ẹ́ di wobble

ẹgbẹ́ nàà observe CD-35 2722 B (wo NASA Eyes on Exoplanets entry) pèlú CRIRES+, high-resolution spectrograph lórí European Southern Observatory's Very Large Telescope. Láàárín October 2023 àti February 2026, wọn gba 26 observing epoch. Ọ̀kan ní àmì tó kéré ju, méjì tí a gba nínú bad weather jẹ rejected, wọn sì repeat wọn, tó fi **23 high-quality nights** sílẹ̀.

Spectrograph ní tan light sí detailed àpẹẹrẹ́ line. Nígbà tí orísun bá ní rìn sí Earth tàbí kúrò lódò rẹ́, line wònyí shift díẹ̀. Repeated measurement tí line-of-sight motion yìí nì a ní pè ní **radial velocity**. Wọn kò fi hidden body hàn. Wọn fi bí observed body ẹ́ lè ní move lábẹ́ unseen pull hàn.

Strongest periodicity nínú measurement wà sunmọ́ 170 days. Ó kọ́já **0.1% false-alarm-probability threshold** ìwádìí. Threshold yẹn bèèrè bí ariwo ẹ́ máa, lábẹ́ assumption ìdánwò, produce periodogram peak tó lágbára bá yí

ní igba mélòò. Kì í ẹ̀ probability 99.9% pé satellite wà, kò sì sọ ohunkóhun fúnra rẹ̀ nípa bóyá companion kan tàbí méjì ní.

Kí ní radial-velocity signal lè establish?

Radial velocity yí repeated shift nínú spectral line padà sí measurement motion sí observer àti kúrò lódò observer. Repeating àpẹ̀rẹ̀ lè jẹ́ fit pẹ̀lú equation orbit, tó jẹ́ kí olùwádíí infer period, ìwọ̀n measured wobble àti minimum companion mass.

Şùgbọ̀n ọ̀nà kò photograph companion tààrà. Stellar tàbí substellar atmosphere tún lè shift spectral line, observing schedule lè create misleading rhythm, yàtò orbital arrangement sì lè imitate ara wọ̀n. àmì nàà, physical explanation rẹ̀ àti orúkọ tí a fún inferred object jẹ́ separate ìbèèrè.

Sampling yẹ́ kí a fi attention sí ẹ́áájú orbital answer. Four especially low radial-velocity measurement ru weight tó substantial nínú àpẹ̀rẹ̀. Wọ̀n ẹ̀lẹ̀ ní pair méjì, lábẹ̀ reported good condition, kò sì sí single kókó kan tó create àmì nígbà tí ònkòwé repeat ítúpalẹ̀ lẹ́yìn removing kókó kan ní gbogbo igba. Síbẹ̀, apá orbital phase nìkan ní a àpẹ̀rẹ̀. Night 23 spread kọ́já ju méjì years lọ kí í ẹ̀ kan nàà as continuous coverage.

Àwọ̀n ònkòwé tún idánwò ẹ́ẹ̀ ẹ̀ half-year artefact. Imperfect correction fún Earth's changing motion tàbí instrument profile lè create false annual àmì tí sampling alias sí half Earth year, tàbí **182.5 days**. Preferred period wọ̀n jẹ́ **171.11 days**, pẹ̀lú uncertainty +0.53/-0.36 days; ònkòwé rọ̀yìn pé èyí wà nìkan bí 20 standard deviation kúrò ní 182.5 days. Wọ̀n tún rọ̀yìn no correlation pẹ̀lú Earth's changing motion, seeing, atmospheric water vapour tàbí instrument property tí wọ̀n examine. Àwọ̀n yí jẹ́ important control. Wọ̀n mú orbital explanation compelling tó láti àwòşẹ̀, şùgbọ̀n wọ̀n kò identify object nàà fúnra wọ̀n.

Orbital answer tó simplest: companion kan

Nínú preferred àwòşẹ̀, object kan tẹ̀lé eccentric, tàbí somewhat stretched, orbit yí brown dwarf ká ní gbogbo 171.11 days. Fitted orbit ní eccentricity nìkan bí **0.27** àti semi-major axis nìkan bí **0.200 astronomical units** — roughly ọ̀kan fifth ti average Earth-Sun ijìnnà.

Measured wobble ní amplitude nìkan bí **318 metres per second**. Láti motion yẹ̀n, àwòşẹ̀ fún companion ní minimum mass nìkan bí **0.92 times Jupiter's mass**.

Ọ̀rọ̀ *minimum* ẹ̀ pàtàkì. Radial velocity measure nìkan apá orbital motion directed sí wa àti kúrò lódò wa. Tí orbit bá viewed edge-on, ọ̀pọ̀ motion rẹ̀ hàn légbẹ́ line yẹ̀n. Tí a bá viewed rẹ̀ sí i face-on, much motion kọ́já sky dípò, companion tó massive sí i yóò sì needed láti produce kan nàà measured wobble.

Astronomer kọ̀ ẹ̀sì gégé bí **$m \sin(i)$** : mass multiplied pẹ̀lú sine ti unknown inclination orbit, tàbí viewing angle. dátà constrain product yẹ̀n, kì í ẹ̀ true mass fúnra rẹ̀. Nítorí nàà nìkan bí 0.92 Jupiter masses jẹ́ lower bound, kì í ẹ̀ measurement exact mass object.

Kí ló dé tí viewing angle fi hide mass?

Foju runner kan lóri circular track tí o ní wo láti side. Runner náà repeatedly ní rìn sí ọ àti kúrò lódò rẹ, nítorí náà component motion yẹn rọrùn láti measure. Báyyí wo kan náà track láti oke. Runner ní rìn mostly across view rẹ, ó sì fẹrẹẹ má rìn sí ọ tàbí kúrò lódò rẹ.

Radial velocity rí component àkókó nìkan. Mathematical factor $\sin(i)$ sàpèjúwe iye orbital motion tó kókó légbẹẹ line of sight wa. Títí inclination i yóò fi mò, inferred mass sì jẹ minimum.

Lẹyìn náà àwọn ònṣẹwé beèrè bóyá orbit yíì lè persist dípò kí ó quickly destroy ara rẹ. Numerical idánwò wọn rí one-companion àwòṣe generally stable. Èyí mú un di physically ṣeé gbà interpretation àmì. Kò constitute second detection.

Awkward answer: companion méjì lè fara wé ọkan

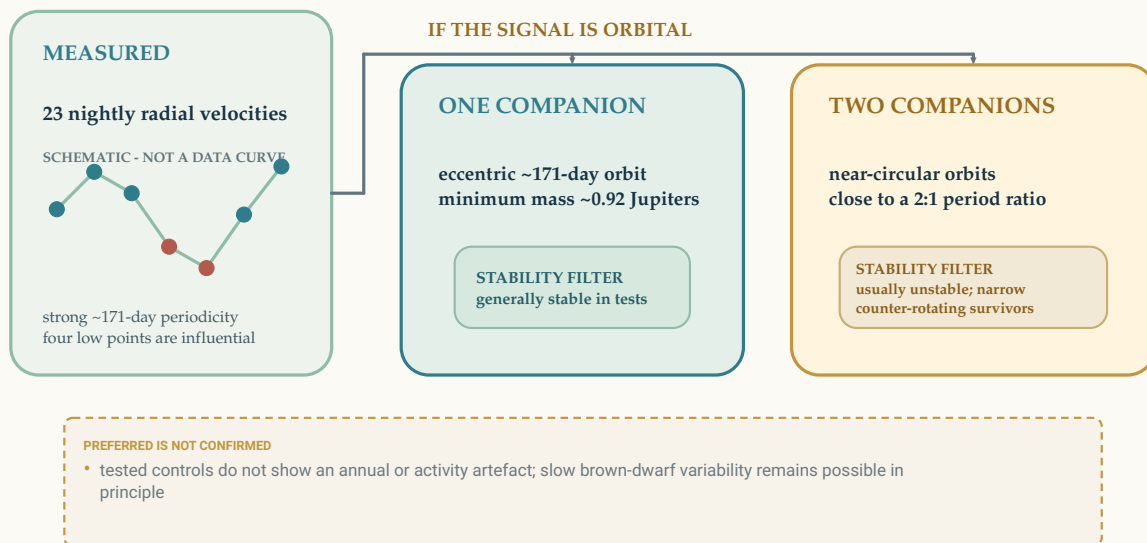
Eccentric radial-velocity àmì ní ambiguity tí a mò. Lábẹ diẹ lára condition, object méjì nínú nearly circular orbit, pèlú ọkan tí period rẹ roughly twice ti omí, lè produce combined àpẹrẹ tó resembles object kan nínú stretched orbit.

Ambiguity yẹn farahàn nìbí. Two-companion àwòṣe lè fit current measurement pèlú outer àmì near 171 days àti shorter-period inner àmì. Nítorí observing àkókò kò àpẹrẹ every phase evenly, shorter àmì ní several alias. Nítorí 23 selected nights fi long gap sílẹ, yàtò idánwò period lè count yàtò number unseen cycle láàárín visit, tí wọn sì sì align pèlú kan náà measurement. Candidate period near 14, 70, 88 àti 115 days nítorí náà jẹ alternative fit sí ọkan poorly sampled shorter àmì, kì í ṣe four independently detected rhythm.

Àwọn ònṣẹwé reject poorly constrained 13-to-17-day window. Nínú region yẹn, fit kò isolate ọkan convincing period: many closely spaced solution below nìkan bí 20 days lè reproduce low-cadence measurement, tí ó mú whole window likely sampling artefact. Láàárín remaining window, approximately 88-day solution fit better ju roughly 70- àti 115-day alternative, ṣùgbón kì í ṣe enough fún ìwé ìwádíí láti claim known second period. Nínú tabulated best fit, outer object's minimum mass jẹ nìkan bí 0.87 Jupiter masses, inner object's nìkan bí 0.22 Jupiter masses. Nǹbà wònyí describe disfavoured àwòṣe; kì í ṣe measurement of méjì established worlds.

One measured rhythm, more than one orbital model

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



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Tí approximately 171-day àmì bá jẹ orbital, kan náà broad radial-velocity àpẹẹrẹ lẹ jẹ represented nípasẹ ọkan eccentric companion tàbí méjì near-circular companion close sí two-to-one period ratio. Stability idánwò favor one-object interpretation, sùgbón kò yí àwòṣe sí image, kò sì ọfin out every form of slow brown-dwarf variability.

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Stability calculation sharpen ifiwéra. Most tested two-companion arrangement expelled ọkan object nínú few hundred simulated years. Surviving configuration occupied narrow, unusual region níbi tí orbit close sí kan náà plane sùgbón move opposite itọsọna. Host iràwọ introduce further unstable region.

Èyí jẹ reason láti prefer ọkan eccentric companion ju tested two-companion ètò. Kì í ẹ proof pé nature yan simpler àwòṣe. Stability filter ẹẹ ẹ interpretation lẹyin radial velocity measurement; kò add observed kókó mǐràn sí curve.

Báwo ni eccentric orbit kan ẹ lẹ dà bí circular orbit méjì?

Perfect circular orbit produce simple repeating radial-velocity wave. Eccentric orbit add distortion sí wave yẹn. Two circular orbit pẹlú period near two-to-one ratio lẹ combine kí àmì kan supply pàtàkì rhythm, omí sì supply similar distortion.

Èyí jẹ **orbital degeneracy**: yàtò physical ètò produce similar measurement. More observation ní àkókò níbi tí àwòṣe predict yàtò velocity lẹ break tie. Dynamics idánwò help nípa asking bóyá proposed ètò kọ̀ọkan lẹ survive, sùgbón kò lẹ replace observation yẹn.

Sé rhythm lè wá láti brown dwarf fúnra rẹ?

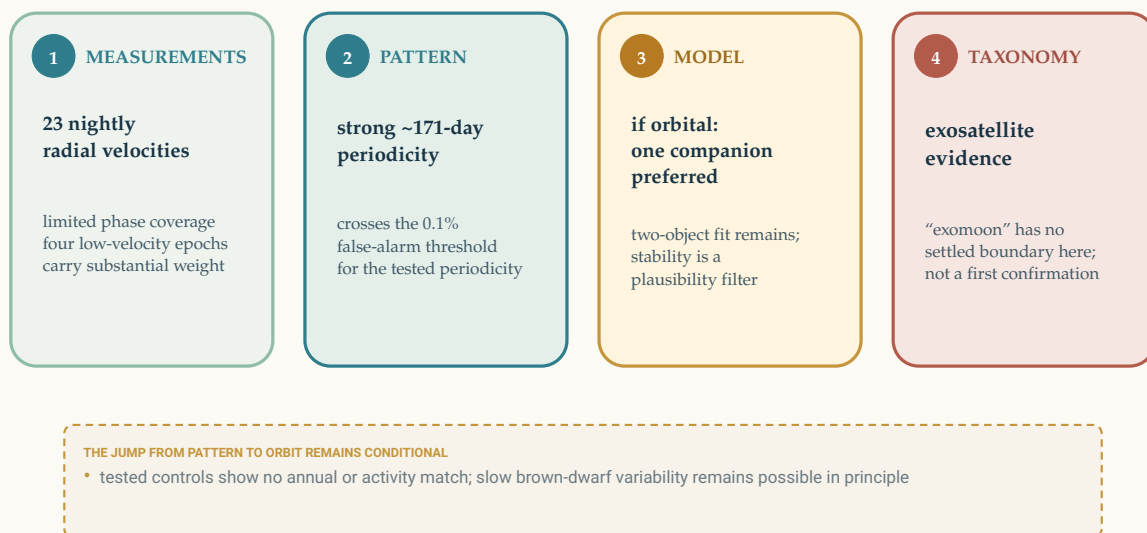
Brown dwarf kì í ẹ̀se silent ìdánwò mass. Atmosphere rẹ̀ rotate, form cloud, ó sì lè ní magnetic activity. Changing ojú àpẹ̀rẹ̀ lè reshape spectral line, kí ó sì imitate motion.

Estimated maximum rotation period CD-35 2722 B jẹ̀ nńkan bí **0.65 days**, kúkúrí púpò ju 171 days lọ. ẹ̀gbẹ̀ kò recover lágbára short rotation àmì, tàbí convincing cloud- tàbí granulation-like àmì, nínú activity àwòṣe tí wọn ìdánwò. Wọn tún examine annual sampling àti instrumental quantity láì rí match sí 171-day rhythm.

Check wònyí narrow alternative, ẹ̀gbẹ̀n ìwé ìwádíí kò claim pé gbogbo intrinsic variability ti eliminated. Long-timescale magnetic activity tàbí atmospheric circulation nínú brown dwarf kò lè òfin out in principle. Remaining possibility yẹn yẹ kí ó wà légbẹ̀ orbital àwòṣe, kì í ẹ̀se kí a hide léyìn wọn.

Four levels of evidence, not one confirmation

Each level answers a different question.



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ẹ̀rí n' gòkè kọ́já ipele tó yàtò: 23 nightly radial velocity pẹ̀lú limited phase coverage, lágbára approximately 171-day periodicity, preferred one-companion àwòṣe tí àmì bá jẹ̀ orbital, àti níkẹ́yìn unsettled "exomoon" label. Ladder náà ya measurement, statistical àpẹ̀rẹ̀, physical interpretation àti taxonomy sọtò; kì í ẹ̀se confirmation arrow.

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Sé ó jẹ exomoon?

Nínú Solar System, moon ní orbit pílánẹ̀tì. CD-35 2722 B jẹ̀ brown dwarf, true mass inferred companion kò sì tì mò. Familiar name bèrẹ̀ sí í nira nígbà tí object kan wà sunmọ planet-brown-dwarf ààlà, omíu sì sunmọ

moon-planet ààlà.

ìwé ìwádíí kò claim first confirmed exomoon. Ó sọ pé kò sí exomoon tí a ti confidently detect, ó present èrí fún planetary-mass **exosatellite**, ó sì pe ètò nàà ní step sí uncontroversial detection. Discussion şeé şe novelty rẹ bẹrẹ conditionally: tí àmì bá fi èrí múlẹ legitimate.

Caution yẹn kò mú èsì di empty. Measuring radial velocity tààrà láti faint brown dwarf companion nira. Tí continued observation bá preserve àmì, ètò yóò fi hàn pé planet-search ọ̀nà lẹ reach down òmíràn ìpele celestial hierarchy.

Another observing season lẹ şe ju adding kókó lọ. One- àti two-companion àwòşe predict yàtò velocity ní particular future àkókò. Measurement tó fill missing orbital phase lẹ ìdánwò bóyá 171-day rhythm persist, dín kù influence four low kókó, kí competing curve diverge.

Fún bá'yí, honest image kì í şe tuntun moon hanging lẹgbẹẹ brown dwarf. Ó jẹ spectrum, repeated night lẹyìn night, tí ó ru small periodic shift. Ayé kan lẹ wà nínú rhythm yẹn. Achievement nàà ni learning how much lẹ be inferred láti it láì pretend pé inference ti complete.

Àkótán mímọ

Àwọn astronomer measure radial velocity ti taara imaged brown dwarf CD-35 2722 B ní 23 high-quality nights láàárín October 2023 àti February 2026. Spectral line rẹ fi hàn lágbára periodic shift near 171 days. Preferred orbital àwòşe ní ọ̀kan eccentric companion pẹ̀lú minimum mass near 0.92 Jupiter masses, şùgbọ̀n true mass unknown nítorí orbital inclination unknown. Two near-circular companion lẹ mimic kan nàà broad àmì, bí most tested two-object configuration tilẹ dynamically unstable. Four low-velocity epoch influential, orbital phase coverage sì limited: observation àpẹẹrẹ selected part ti şeé şe 171-day cycle dípò tracing continuously nípasẹ every phase. ìdánwò kò identify rotation, annual sampling, weather tàbí examined instrument property gẹgẹ bí orísun, şùgbọ̀n long-timescale brown-dwarf variability kò lẹ ọ̀fin out in principle. Unseen object kò taara imaged, one-object àwòşe preferred dípò confirmed, kò sì sí settled ọ̀fin pé planetary-mass body tí ó ní orbit brown dwarf jẹ exomoon.

àyèwò láìsí àsọdùn

Ohun tí a observe: 23 nightly radial-velocity measurement ti CD-35 2722 B ní lágbára approximately 171-day periodicity. Brown dwarf fúnra rẹ taara imaged; proposed companion kò.

Ohun tí àwọn ònkòwé prefer: Tí àmì bá jẹ orbital, ọ̀kan eccentric companion pẹ̀lú minimum mass near Jupiter's mass fún simplest dynamically şeé gbà interpretation ti current dátà.

Ohun tí şì şí: Two companion lẹ fit radial velocity, bí tested ètò tilẹ usually unstable; long-timescale brown-dwarf variability kò excluded in principle; unknown viewing angle sì fi true companion mass undetermined.

Ohun tí ìwé ìwádíí kò establish: First confirmed exomoon, taara seen satellite, exactly ọ̀kan orbiting object, true mass 0.92 Jupiter masses, tàbí probability 99.9% pé preferred physical àwòşe correct.

Ohun tí yòò mú ìgbẹ̀kẹ̀lẹ̀ pọ̀: Continued radial-velocity measurement tó cover sí i orbital phase, ìdánwò bóyá 171-day àmì persist, àti àpẹẹrẹ àkókò níbi tí ọ̀kan- àti two-companion àwòṣe make yàtò prediction.

Àwọn orísun

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