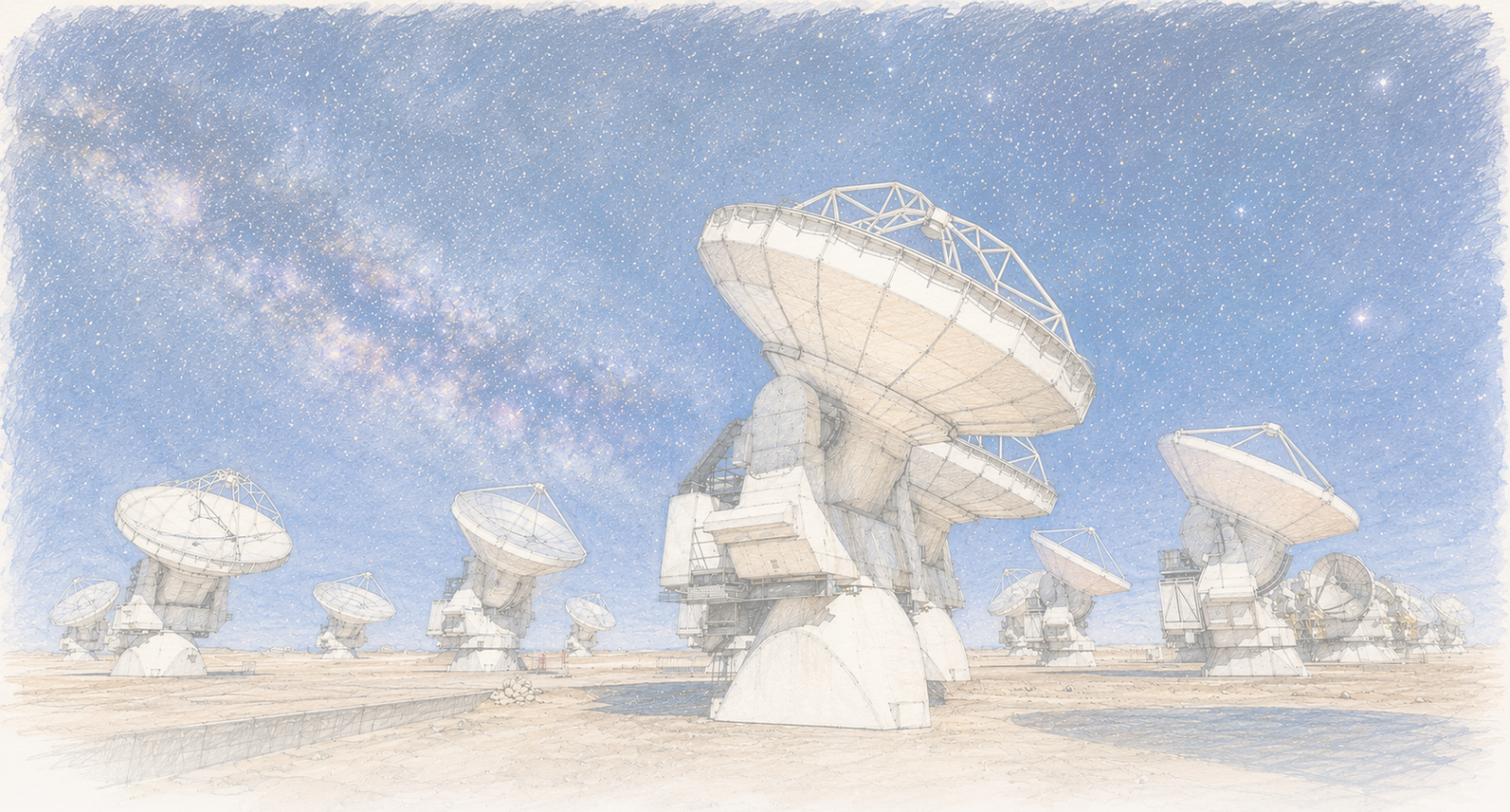




The CLEAN PAPER

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

Tauraro mai wutsiya 3I/ATLAS daga wani tauraro yana dauke da ruwan da ya samu a sanyi fiye da namu — karatun sinadarai na farko daga wani tsarin duniyoyi

Ta amfani da ALMA, masana taurari sun kayyade rabon hydrogen “mai nauyi” da na yau da kullum a ruwan 3I/ATLAS — abu na uku da aka sani daga tsakanin taurari — suka gano deuterium mai yawa: akalla kusan sau 40 na tekunan Duniya da sau 30 na tauraro mai wutsiya na Tsarin Rana. Wannan yana nuna ruwa da ya samu a yanayi mafi sanyi fiye da namu. Sakamakon iyaka ta kasa ce da aka samo a kaikaice (ba a gano ruwan kai tsaye ba), kuma bai ce kome game da rai ko fasaha ba — sinadarai da sanyi kawai.

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Antennar DV-59 tana gaba, yayin da anternonin ALMA da yawa suke kallon sararin dare mai hasken wata. Hoto: Alex Pérez / ALMA Observatory.

Alex Pérez / ALMA Observatory CC BY 4.0

Tauraro mai wutsiya daga wani tauraro, da sawun da ke cikin ruwansa

Wani lokaci wani abu da bai taɓa zama namu ba yakan ratsa Tsarin Rana. Ba dutse ne da ya face daga zoben asteroid ba, ba kuma tauraro mai wutsiya da ke dawowa daga gajimaren Oort a doguwar hanyarsa ba, sai wani abu a buɗaɗɗiyar hanyar hyperbola — wanda ya shigo daga sararin tsakanin taurari, zai zagaya Rana sau ɗaya, sannan ya tafi har abada. Yanzu mun ga guda uku. Na farko, ‘Oumuamua a 2017, ya kusan tafi kafin mutane su yarda da abin da yake. Na biyu, 2I/Borisov a 2019, tauraro mai wutsiya ne babu shakka. Na uku, wanda aka gano a Yuli 2025, shi ne 3I/ATLAS — kuma ya iso da coma mai aiki sosai da za a iya yin binciken sinadarai na gaske a kansa.

Ga abin da ya kamata a rike kafin hayaniya ta fara. Tauraro mai wutsiya daga wani tsarin taurari, a zahiri, gutsuren wani tsarin duniyoyi ne: kankara da kura da suka daskare a kusa da wani tauraro, wataƙila wani bugun nauyi ya jefa su waje tuntuɓi, suka yi yawo a cikin Galaxy, sannan suka zo kusa da Ranarmu har kankararsu ta fara tafasa a daidai wurin da maɗubin hangenmu za su iya gani. Wannan ita ce gaskiyar ban mamaki, kuma tana da ban mamaki sosai ba tare da ƙarin ado ba.

Amma ana kara mata ado. Abubuwan da suka fito daga tsakanin taurari suna jawo irin labaran da suke yin numfashi

da sauri — rage haske da tambayar *amma idan wani ne ya gina shi fa* — kuma 3I/ATLAS ya samu rabonsa. Amsar gaskiya ita ce mai sauƙi, kuma ita ce mafi ban sha'awa: tauraro mai wutsiya ne. Tambayar gaskiya ba ta taba zama ko wani ya gina shi ba. Tambayar da ta fi shiru ita ce — idan ka iya karanta sinadaran wani abu da aka gina kusa da wani tauraro, me zai gaya maka game da iyalin tauraron? Kuma ta yaya za ka karanta shi?

Abin karantawa a wannan karo shi ne ruwa. Ruwa yana da hydrogen biyu da oxygen ɗaya, amma karamin kaso na hydrogen ɗinsa *deuterium* ne — tagwaye mafi nauyi, wato atom na hydrogen na yau da kullum da ƙarin neutron ɗaya. Rabon hydrogen mai nauyi da hydrogen na yau da kullum a ruwa, wanda ake rubuta D/H, ba na bazata ba ne. Sinadarai suna tsara shi musamman bisa yadda wurin da ruwan ya fara samuwa yake da sanyi: idan wurin ya fi sanyi da natsuwa, deuterium mai yawa yake kullewa. Kuma domin tauraro mai wutsiya ainihin babban firiza ne — wanda zai iya ajiye kankararsa cikin sanyi tsawon biliyoyin shekaru — rabon D/H na ruwansa zai iya kiyaye sawun yanayin da ruwan ya samuwa.

Mun san sawun tsarinmu da kyau: tekunan Duniya da nau'ikan taurarin wutsiya na Tsarin Rana suna taruwa cikin karamin zango. Abin da ba a taba kayyadewa ba shi ne wannan sawun a ruwan da ya samu a kusa da *wani tauraro*. Wannan shi ne abin da makalar ta yi niyyar karantawa a 3I/ATLAS.

Abin da marubutan suka yi

Sun nuna ALMA — babban jerin kwanon rediyo a hamadar Chile — zuwa 3I/ATLAS a 4 Nuwamba 2025, kwana shida bayan tauraron wutsiya ya zagaya Rana. Sun daidaita shi domin kama raunin hasken milimita na ƙwayoyin sinadarai uku a coma: ruwa na yau da kullum (H_2O), ruwa *mai nauyi* (HDO, inda hydrogen ɗaya deuterium ne), da methanol (CH_3OH).

Rabon D/H da suke nema, a aikace, rabon ruwa mai nauyi da ruwa na yau da kullum ne. Don haka suna buƙatar duka biyun. Sannan suka shigar da spectra cikin model na radiative transfer na iskar tauraro mai wutsiya da ke faɗaɗa (lambar da ake kira SUBLIME), suka daidaita shi da irin tsarin ƙididdigar da ake amfani da shi wajen gano abubuwan da ke cikin iskar duniyoyin wajen Tsarin Rana, domin fitar da zafin jiki, kwararar waje, da adadin kowane ƙwayar sinadari da tauraron yake samarwa.

Matsala ɗaya ce ke tsara duk abin da zai biyo baya: **ba su gano ruwan kai tsaye ba**. HDO da methanol sun bayyana; H_2O kansa ya kasance ƙarƙashin hayaniya. Ba don ruwa na yau da kullum ya yi kaɗan ba — ya fi nau'in mai nauyi yawa sosai. Bayyanar layi ba ta dogara da adadin ƙwayar sinadari kawai ba, har da yadda takamaiman layin yake da sauƙin gani, kuma abubuwa biyu sun yi wa layin ruwan cikas. Na farko shi ne sararin Duniya: layin H_2O da za su iya nufi (kusa da 183 GHz) yana daidai inda iskar Duniya mai ɗauke da ruwa take shan sigina da ƙarfi, don haka karanta ruwan tauraro mai wutsiya daga kasa a wurin kamar ganin kyandir ta cikin hazo ne — makalar ta ce waɗannan layukan ruwa masu karamin makamashi suna fama da shan iska sosai, yayin da layin ruwa mai nauyi (HDO) kusa da 241 GHz yake cikin taga mafi tsabta. Na biyu shi ne ji: hanyar ruwan ta fi hayaniya — kusan 500 mJy ga kowane beam, idan aka kwatanta da 21 na HDO — don haka ko sigina mai yawa zai iya boyewa a ƙarƙashinta. Tsakanin hazo da hayaniya, ruwan yau da kullum mai yawa ya kasance kasa da matakin ganowa, yayin da ruwa mai nauyi da ya fi ƙaranci, wanda aka kama a taga mai tsabta da shiru, ya bayyana. (Daga sararin samaniya, sama da iskar Duniya, ruwan yana da sauƙin gani: daga baya JWST ya gano ruwan tauraron a infrared bayan perihelion — don haka rashin ganowar ALMA ya shafi wannan layi ɗaya ta cikin iskar Duniya, ba rashin ruwa ba.) Saboda haka sai aka kimanta adadin ruwan yau da kullum *ta hanyar da ba kai tsaye ba* — musamman

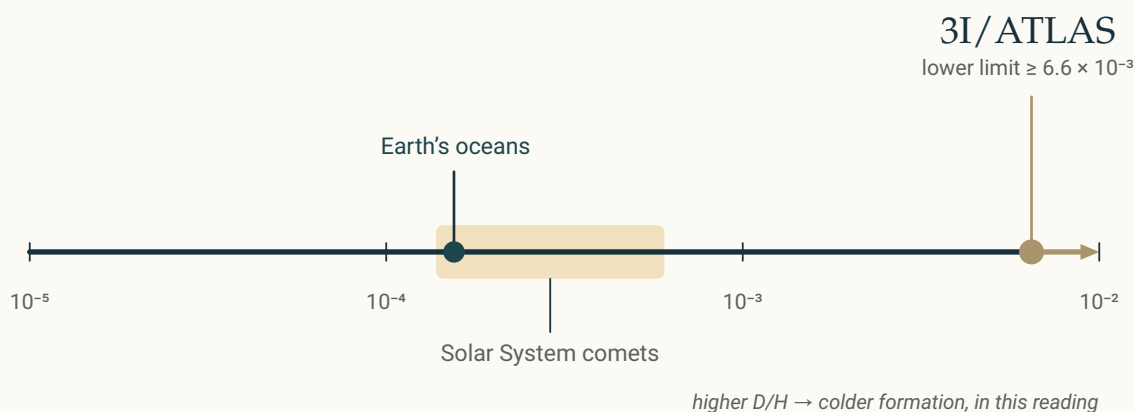
daga yadda layukan methanol suka motsa, wanda ya dogara da yawan karo tsakanin kwayoyin methanol da ruwa. Wannan ma'auni ne na gaske, amma ya dogara da model, kuma marubutan sun fadɓi haka a fili.

Abin da suka gano

- **Ruwa mai nauyi, amma ba a ga ruwa na yau da kullum ba.** An gano HDO da layukan methanol da dama a fili; ba a gano H_2O ba. Domin rabon D/H ya dogara da *iyaka ta sama* ga adadin samar da ruwa na yau da kullum — an ɗauke shi haka da gangan saboda layin ruwan ya kasance karkashin hayaniya — rabon deuterium ya fito a matsayin **iyaka ta kasa**, ba wata kima guda ba.
- **Yawan deuterium sosai.** A yanayinsu mai taka-tsantsan, rabon D/H na ruwa ya **fi** 6.6×10^{-3} — sama da kusan **sau 40** na tekunan Duniya, kuma sama da kusan **sau 30** na tauraro mai wutsiya na Tsarin Rana na yau da kullum. A kowace kimantawarsu biyu, 3I/ATLAS yana can saman duk ma'aunin D/H na ruwa da aka taɓa yi.
- **Watakila ba bazata ta wannan dare ɗaya ba ce.** Ma'aunin daga lokaci ɗaya ne, amma kallon farko na bayan ALMA da ke kusa bai nuna babban sauyi daga rana zuwa rana ba, kuma wani bincike mai zaman kansa na JWST na 3I/ATLAS da aka yi fiye da wata ɗaya bayan haka yana nuna irin wannan — ruwa mai deuterium da yawa.

Where 3I/ATLAS's water sits on the deuterium scale

Water D/H ratio — logarithmic scale



Matsayin ruwan 3I/ATLAS a ma'aunin deuterium: can sosai a gefen da ke da deuterium da yawa, sama da tekunan Duniya da duk taurarin wutsiya na Tsarin Rana (an nuna su a matsayin zango na kimantawa). Kibiyar tana nuna *iyaka ta kasa* — kimar gaskiya tana iya fi haka. Babban rabon D/H alama ce ta *yanayin samuwa mai sanyi*, ba adireshin asali ba.

Abin da wannan mai yiwuwa yake nufi

Babban rabon D/H a ruwa alama ce ta ruwan da ya daskare a wuri mai sanyi sosai (kasa da kusan 30 K) kuma zafi bai sake sarrafa shi sosai ba. Don haka fassara mafi tsafata ita ce ruwan 3I/ATLAS ya samu a yanayi *mai sanyi da natsuwa* fiye da ruwan taurarin wutsiya na Tsarin Ranarmu — saboda haka tsarin duniyoyin da ya fito ya gina kankararsa dabam da namu.

Marubutan sun yi taka-tsantsan da mataki na gaba, mu ma haka ya kamata. Akwai hanyoyi biyu na samun ruwa mai deuterium da yawa haka, kuma wannan ma'aunin ba zai iya raba su ba: ruwa zai iya *gado* yawan daga gajimaren sanyi da tsarin ya haifu a ciki, ko kuma a sa shi daga baya yayin samuwar tauraron wutsiya a faifan waje mai sanyi. Ko wace hanya ce, muhimmiyar matsayar tana nan — yanayin da ya tsara 3I/ATLAS ba shi ne wanda ya tsara taurarin wutsiyarmu ba — amma *dalilin* ya kasance bude.

Saboda haka wannan shi ne karo na farko da aka karanta sawun samuwar ruwa daga kayan wani tsarin duniyoyi, aka kuma ga bai dace da namu ba.

Abin da wannan *bai tabbatar ba*

- **Bai ce kome ba** game da rai, fasaha, ko niyya. Babu wani “abu” da aka gina; “daga tsakanin taurari” yana bayyana hanya, ba tarihin kirƙira ba. Ma'aunin sinadaran ruwa ne.
- **Ba** kayyadadden kimar D/H ba ne. *Iyaka ta kasa* ce, kuma ba a gano ruwan da ake magana kai tsaye ba — an kimanta yawansa daga motsin wata kwayar sinadari, methanol, bisa zaton ruwa ne babban abin da methanol yake karo da shi.
- **Bai bayyana** inda aka haifi 3I/ATLAS ba. Ba za a iya gano tauraron asali da tabbaci ba, kuma babban rabon D/H alamar *yanayi* ne, ba adireshe ba.
- **Bai warware** dalilin yawan deuterium ba. “Gado daga gajimaren haihuwa mai sanyi” da “samun shi yayin gina faifan” duka sun dace da bayanai; makalar ba ta zaɓi daya ba.
- Abu **guda ɗaya** ne, wanda aka auna a lokaci **ɗaya**. Goyon bayan yana karfafa, amma ba dogon tarihin ma'auni ba ne.

Yaya karfin shaidar yake?

Abubuwa biyu ya kamata a auna dabam: alkiblar sakamakon da kuma ainihin adadin.

- **Alkiblar tana da karfi.** Cewa ruwan 3I/ATLAS yana da deuterium sosai wata iyaka ta kasa ce mai taka-tsantsan, tana sama da duk taurarin wutsiya na Tsarin Rana, kuma wani binciken JWST mai zaman kansa yana goyon bayanta. Wannan fangaren ba mai rauni ba ne.
- **Adadin ya dogara da jerin model.** Domin ba a gano H₂O ba, adadin ruwa — da rabon D/H — ya jingina da kimanta ruwa ta motsin methanol. Wannan yana dauka cewa ruwa ne babban abokin karo a coma (mai yiwuwa ne kusa da perihelion, amma ba za a kawar da gudummawar CO₂ ba) kuma yana amfani da kimantattun kimar karo da marubutan suka yarda ba a kayyade su sosai ba. Sun bayyana duk wannan kuma da gangan suka ba da

sakamakon a matsayin iyaka, ba cikakken ma'auni ba.

- **Fassarar tana da dalili amma ba ita kadai ba ce.** Sanyi shi ne bayanin da ya fi dacewa da babban D/H; ko an gaji sanyi ko an sa shi daga baya ba a warware ba, kuma ba a iya gano tsarin asali.

A takaice: cewa ruwan ya samu cikin sanyi yana kan tushe mai karfi; ainihin yawan sanyi da ainihin dalilin suna buɗe da gaskiya.

Me ya sa yake da muhimmanci

Tsawon shekaru da dama, tambayar inda ruwan Duniya ya fito — da abin da ke tsara sawun deuterium na ruwa a tsarin duniyoyi masu tasowa — an amsa ta ne da ma'auni daga cikin Tsarin Ranarmu kawai. Wannan ne karo na farko da aka fadada taswirar zuwa kayan da tabbas suka samuwa a kusa da wani tauraro.

Amsar ba “ko’ina kamar gida ne” ba ce. Akasin haka: wani tsarin zai iya shimfiɗa kankararsa a yanayi mai sanyi har ya bar sawun da taurarin wutsiyarmu ba su taɓa ɗauka ba. Wannan karamar, takamaiman shaida ce ga wani babban abu mai shiru — sinadarai da tarihin daskararrun abubuwan da ke gina duniyoyi na iya bambanta daga tauraro zuwa tauraro. Kuma ba jirgin sararin samaniya da aka aika ya ketare shekarun haske ne ya kawo ta ba, sai kama gutsuren wani tsarin yayin da ya ratsa kusa, a karanta ruwansa kafin ya tafi.

Takaitaccen bayani

3I/ATLAS shi ne abu na uku da aka sani daga tsakanin taurari kuma tauraro mai wutsiya mai aiki na biyu — gutsuren wani tsarin duniyoyi da ke ratsa namu sau ɗaya. Ta amfani da ALMA kusa da lokacin kusantarsa da Rana, masana taurari sun gano ruwa mai nauyi (HDO) da methanol a coma amma ba ruwan yau da kullum ba, sannan suka kimanta rabon deuterium da hydrogen a ruwan. Sun gano deuterium mai yawa — iyaka ta kasa sama da 6.6×10^{-3} , kusan sau 40 na tekunan Duniya da sau 30 na tauraro mai wutsiya na Tsarin Rana — wanda yake nuna ruwan da ya samu a yanayi mafi sanyi da karancin sake sarrafa shi fiye da taurarin wutsiyar Tsarin Rana. Adadin iyaka ta kasa ce da aka samu a kaikaice ta model, ba ma'auni kai tsaye ba, kuma ba zai iya faɗin ko an gaji yawan daga gajimaren haihuwa mai sanyi ko an sa shi daga baya a faifai mai sanyi ba, ko inda tauraron ya fito. Duk da haka, shi ne karatu na farko na wannan sawun sinadarai na ruwa daga wani tauraro — kuma sawun bai dace da namu ba.

Binciken ba tare da karin gishiri ba

Abin da makalar ta nuna: Daga kallon ALMA na tauraro mai wutsiya daga tsakanin taurari 3I/ATLAS kusa da perihelion, iyaka ta kasa ta rabon D/H na ruwansa ta $>6.6 \times 10^{-3}$ (yanayin taka-tsantsan) — kusan $40\times$ na tekunan Duniya da $30\times$ na tauraro mai wutsiya na Tsarin Rana — wanda yake nuna ruwa da ya samu a yanayi mafi sanyi da karancin sarrafa zafi fiye da taurarin wutsiyar Tsarin Rana. Wani binciken JWST mai zaman kansa ya yarda da alkiblar.

Abin da mai yiwuwa ne amma ba a tabbatar ba: Cewa yawan deuterium an gaje shi kai tsaye daga gajimaren sanyi kafin samuwar tauraro, maimakon a sa shi yayin samuwar tauraron wutsiya a faifan protoplanet mai sanyi. Duka sun dace; bayanana ba su bambanta su ba.

Abin da ba ta nuna ba: Kome game da rai, fasaha, ko asalin da aka kera; kayyadadden kimar D/H (iyaka ta kasa ce); ko wane tauraro ne asali ko inda yake; takamaiman dalilin babban D/H; ko cewa wannan sakamako na lokaci daya ba zai shafi sauyin coma ba.

Manyan iyakoki: Ba a gano H_2O kai tsaye ba, don haka an kimanta adadin ruwa — da rabon D/H — daga motsin methanol a kaikaice, bisa zaton ruwa ne babban abokin karo da kuma amfani da kimantattun kimar karo da marubutan suka ce ba a kayyade su sosai ba; sakamakon iyaka ce ta lokaci daya da ta dogara da model; ba a iya gano tsarin asali.

Yaya karfin amincewar mai karatu na yau da kullum ya kamata ya kasance? Babbar amincewa cewa ruwan 3I/ATLAS yana da deuterium sosai kuma ya samu a sanyi fiye da taurarin wutsiyarmu, kuma wannan ba ya cewa kome game da halittun sararin samaniya. Matsakaicin amincewa ga ainihin yawan, wanda iyaka ta kasa ce da ta dogara da model. Karamar amincewa ga takamaiman dalili da wurin haihuwa, waɗanda har yanzu buɗe suke. Matsayin da ya dace: mamaki mai natsuwa ga sakon sinadarai daga wani tsarin tauraro — ba asiri ba, kuma ba jirgin sararin samaniya ba.

Majiyoyi

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<https://doi.org/10.1038/s41550-026-02850-5>

arXiv 2603.07026

<https://arxiv.org/abs/2603.07026>

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<https://almascience.nrao.edu/aq/>