Census of Brown Dwarfs in Open Clusters & Young Associations

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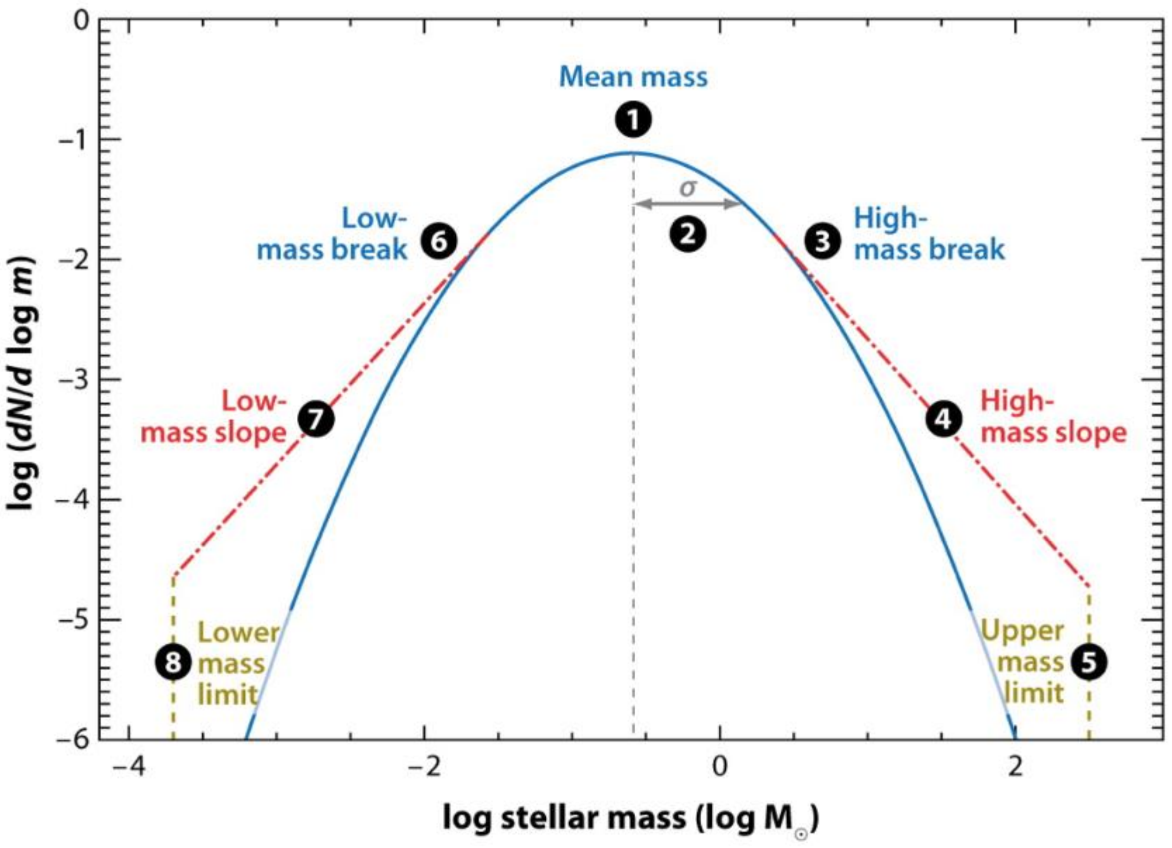
Brown dwarfs are a key piece of the star formation puzzle

The initial mass of a star determines its evolutionary path, but what dictates its initial mass?

Stars are fundamental components of our visible universe:

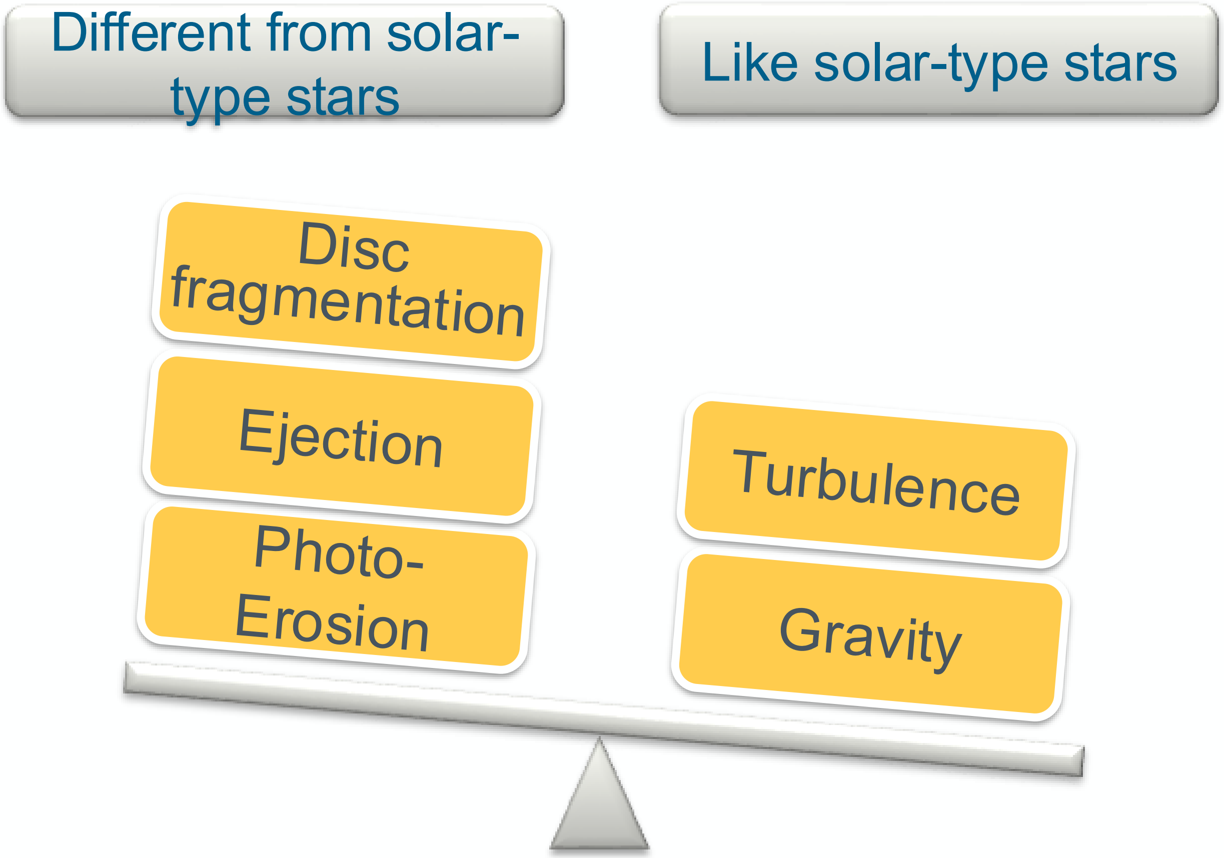
- Host planetary systems
- Building blocks of galaxies
- Source of chemical elements
- Progenitors of supernovae and black holes



‼ Review talk ‼ : María Rosa Zapatero Osorio (R): The substellar IMF

The Initial Mass Function, Bastian N, el al. 2010, AR, 48:339-89

The brown-dwarf regime



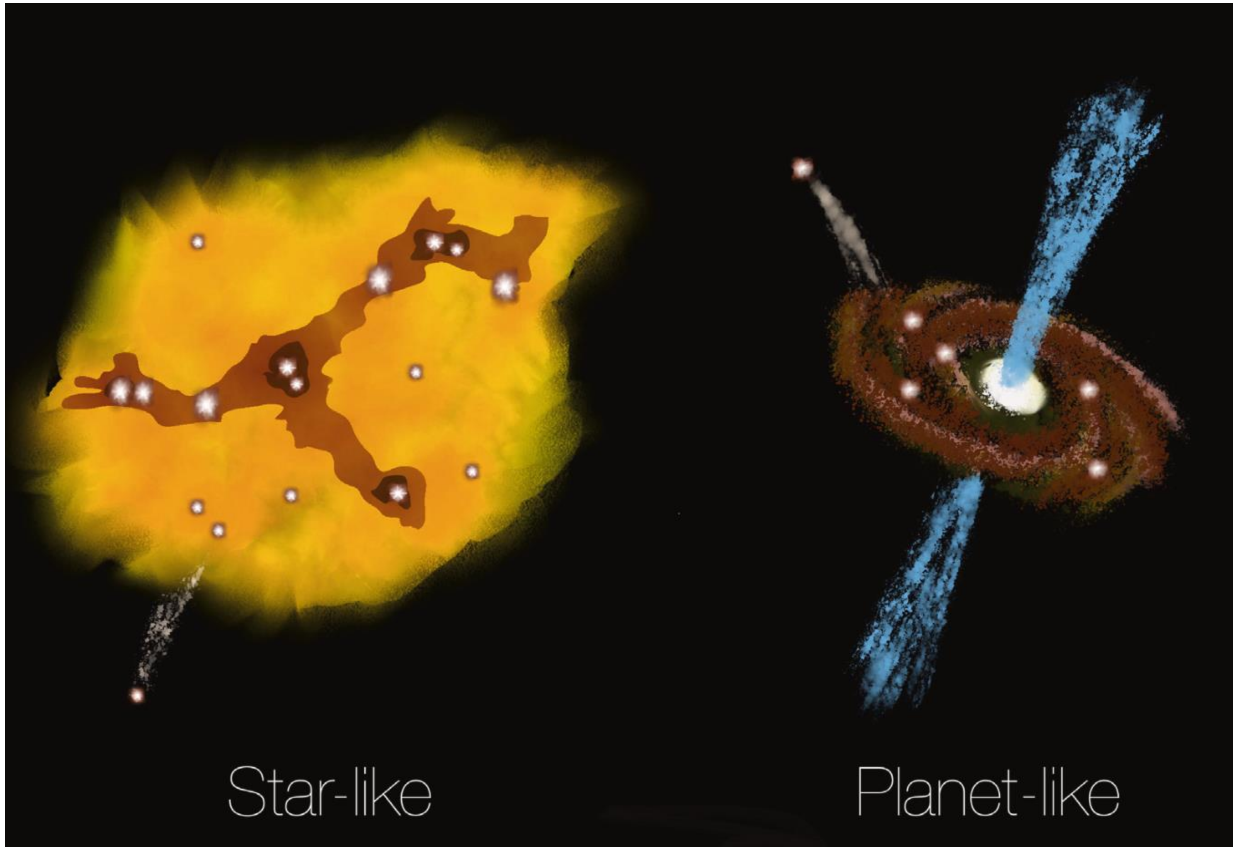
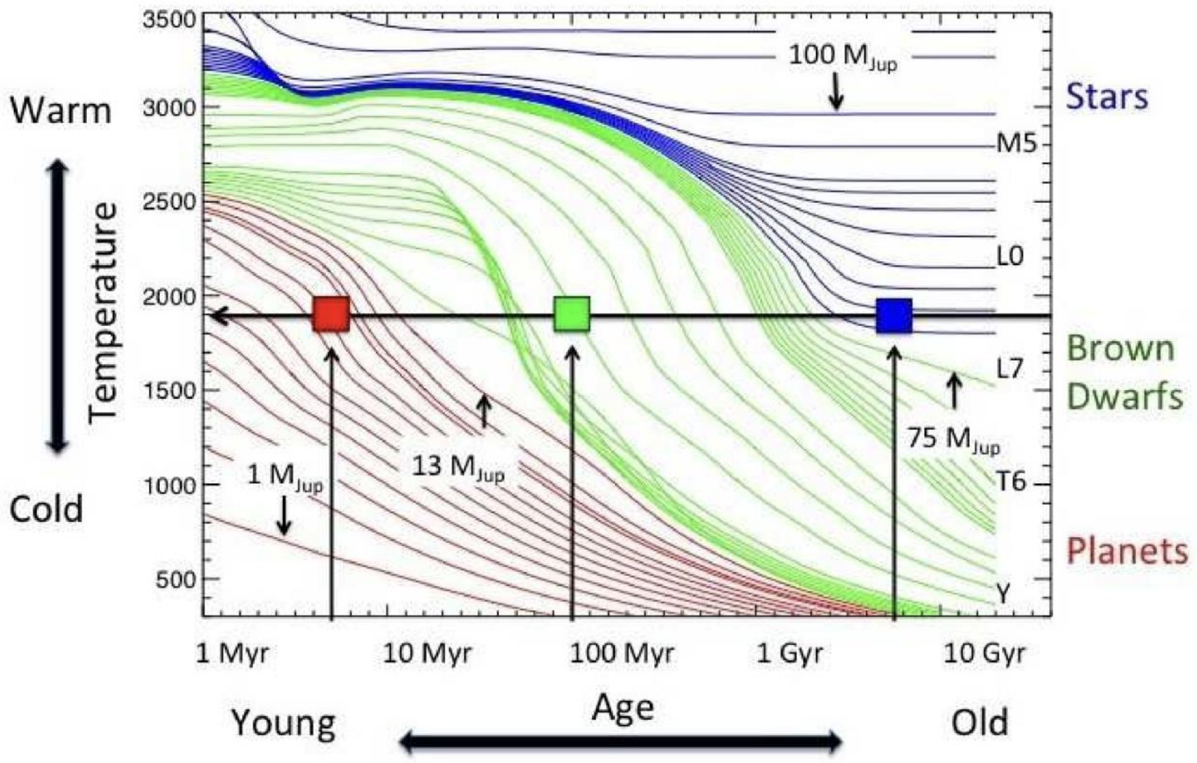


Figure from Palau et al. 2024: Sketch of the two main scenarios proposed for the formation of isolated BDs.

‼ Review article ‼ : Palau et al. 2024, *Observations of pre- and proto-brown dwarfs in nearby clouds: Paving the way to further constraining theories of brown dwarf formation*

The value of brown-dwarf census



- It anchors the low-mass IMF and informs planet vs. star formation channels
- Critical for understanding star formation y constraining low-mass boundary conditions
- "Counting" brown dwarfs (BDs) is hard because youth, mass, and luminosity are entangled
- What we learn about the low-mass IMF and planetary-mass objects depends on *membership*, *age*, and *models*
- Reference for atmospheric studies in exoplanets

‼ Review talk ‼ ZengHua Zhang (R): Spectral Classification of Brown Dwarfs Across the Full Metallicity Range

Why Open Clusters & Young Associations?

Technological advances offered optical, and then IR, wide-field detectors and larger telescopes

Study of the sub-stellar mass function in the Galactic field initially hampered by observational and theoretical uncertainties

‼ Review talk ‼ : Nicolas Lodieu (R): Discoveries in large-scale surveys

Young open clusters (~30-600 Myr) first extended the field to the substellar mass-function:

- Reliance on higher mass bona fide cluster members to estimate age, distance and metallicity

Young associations and star forming regions pushed the limits to the Jupiter-mass objects regime

- Brown dwarfs are brighter when they are young, making them easier to detect down to lower masses

Early Discoveries: right away, clusters mattered

Clusters provided the **context and leverage** to confirm and interpret the first brown dwarfs — not just isolated oddities, but part of a population.

E.g., Teide 1, the first confirmed brown dwarf in the Pleiades open cluster (Rebolo et al. 1995)

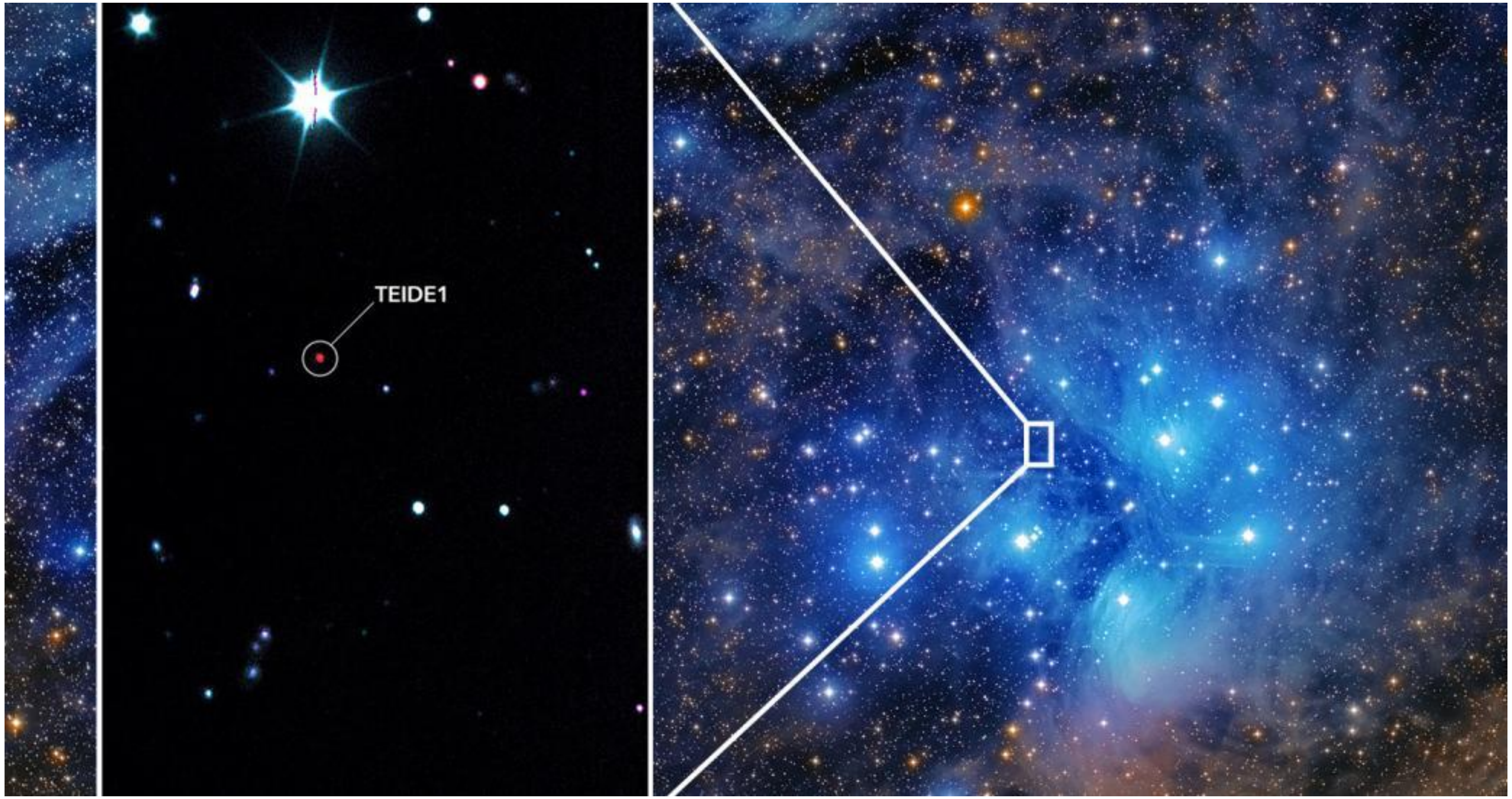
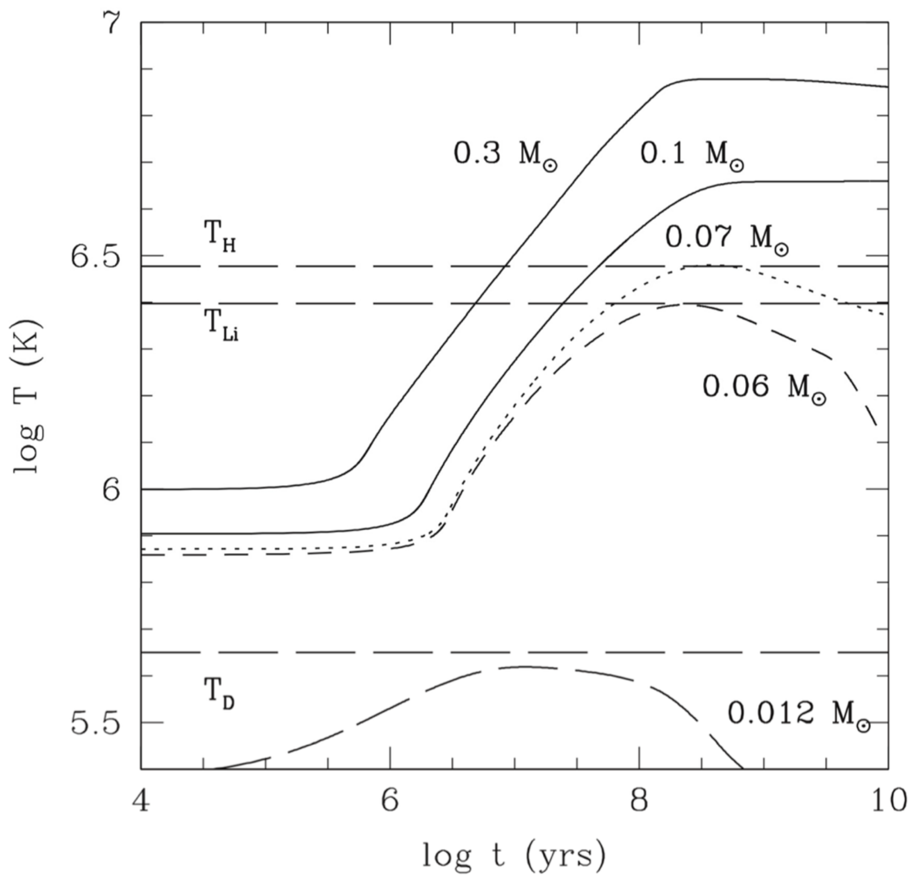


Image of the Teide 1 brown dwarf (Credit: Gran Telescopio Canarias) located in the Open Cluster of the Pleiades (Credit: Daniel López /Alfred Rosenberg, IAC)

‼ Review talk ‼ Rafael Rebolo (R): Discovery of Brown Dwarfs

Down to planetary masses

- **Ongoing frontier:** searches continue for the lowest-mass brown dwarfs and the bottom of the Initial Mass Function (IMF)
- **Deeper observations → lower masses:** new surveys consistently reveal fainter, cooler objects approaching just a few Jupiter masses
- **Perhaps no fusion:** these planetary-mass objects have a mass below the limiting mass for thermonuclear fusion of deuterium



Central temperature of stars, brown dwarfs and "planetary-mass objects" as a function of age. Credits: Caballero 2018, based on Charbrier & Baraffe 2000

‼ Review article ‼ : Cabellero 2018, Geosciences 2018, 8, 362

How we build a brown dwarf census in a cluster

Select Cluster
Young, nearby, well-studied at higher masses

Identify candidates
Deep optical / IR photometry, Colour & Magnitude diagrams

Remove contaminants
Proper motions, extinction corrections, galaxies

Confirm youth and membership
Spectroscopy (low gravity features, lithium test, accretion signatures), kinematics, disks

Assess completeness
Membership distribution, extinction, sensitivity of observations, crowding

Brown dwarfs in open clusters and associations

- Several hundreds of brown dwarfs have been found in open clusters and associations in the past 30 years

‼ Review article ‼ : Bejar & Martín et al. 2019, updated 2025, Handbook of Exoplanets, *Brown Dwarfs and Free-Floating Planets in Young Stellar Clusters*

Pleiades
σ Orionis
Upper Scorpius
Praesepe
Hyades
Trapezium
Taurus
IC 348
NGC 1333
Chamaeleon I
ρ Ophiuchus
α Persei
NGC2024
Lupus
...

Example open clusters: The Pleiades

Nearest rich open cluster: ~1,000+ members, distance = 134 pc, age = 100–140 Myr (LDB method), solar metallicity

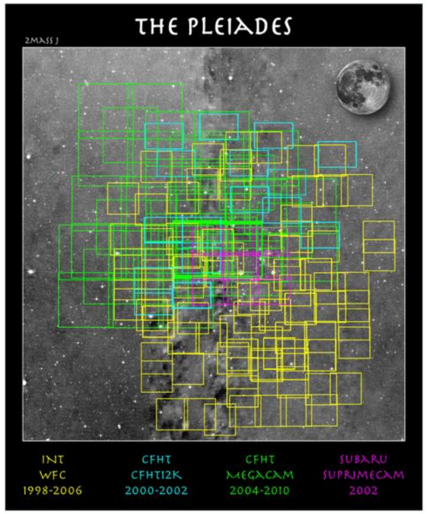
Historical significance: visible since antiquity; target of the *first systematic brown dwarf searches*

Key discoveries:

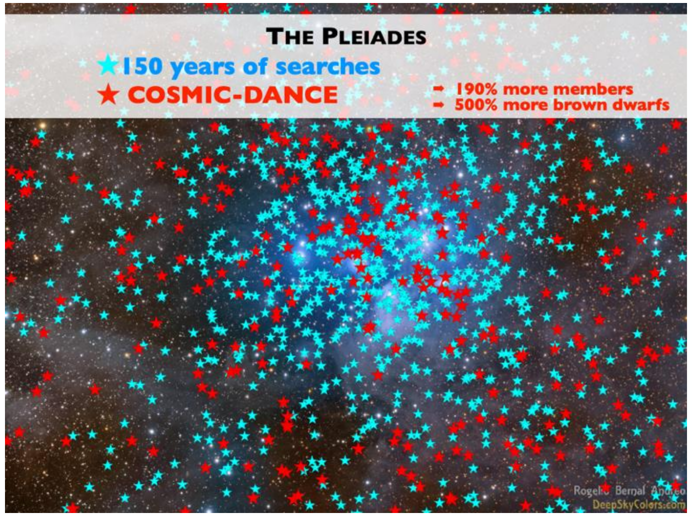
- 1995: *Teide 1* → first unambiguous brown dwarf in a cluster *(Rebolo et al. 1995)*
- 1996: *Teide 1* & *Calar 3* confirmed by lithium test; *PPL 15* found retaining lithium (later a spectroscopic binary) *(Rebolo et al. 1996, Basri et al. 1996)*

Impact: Pleiades became a benchmark for brown dwarf studies

- Numerous surveys identified members across the full substellar regime (M6–late L, 0.075–0.008 M⊙) *(e.g., Bouy et al. 2015, Olivares et al. 2018a)*
- Discovery of faint candidates with T spectral types → possible **isolated planetary-mass objects** *(e.g., Zapatero Osorio 2018)*
- **Today**: Gaia improving the census for members inside and beyond the tidal radius *(e.g., Lodieu et al 2019a, Alfonso & García-Varela 2023, Žerjal et al. 2024)*

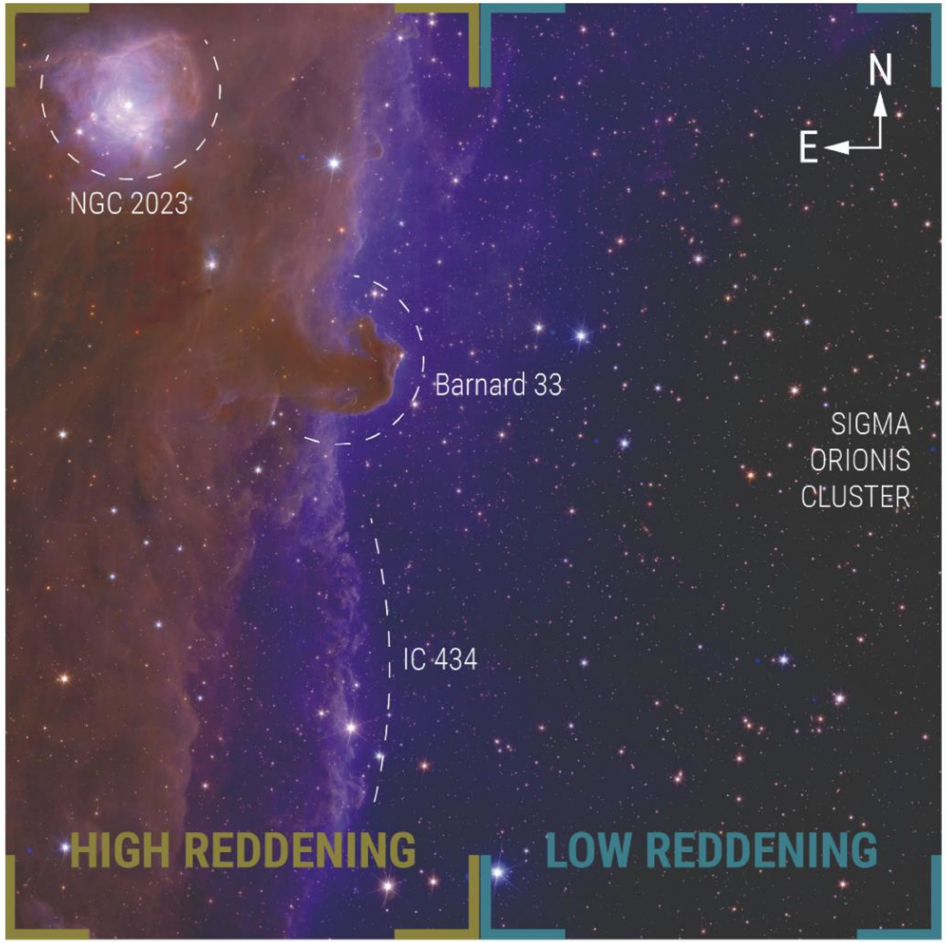


Credits: J. Bouvier



Credits: H. Bouy

Example star forming regions: σ Orionis



Euclid multi-colour mosaic (Credit: Martín et al. 2025)

Properties: Distance: ~400 pc, Age: 2–4 Myr, Low extinction, solar metallicity

Why Important:

- Very young, nearby, low extinction → ideal for substellar searches
- First photometric brown dwarfs discovered in 1999 (Béjar et al. 1999)
- Rich stellar population revealed by ROSAT (Walter et al. 1997)

Scientific Impact:

- Spectroscopic follow-up defined substellar sequence M6–L6 (Zapatero Osorio et al. 2000, 2002a,b, 2017; Damian et al. 2023)
- Brown dwarfs mass range: **0.075–0.006 M⊙**, spanning stellar limit → planetary regime
- First confirmed **isolated planetary-mass objects** in a cluster (Zapatero Osorio et al. 2000)

Today: a unique laboratory where **25 $M_{\odot}$ massive stars** coexist with **6 M_{Jup} objects**

Nearby young moving groups

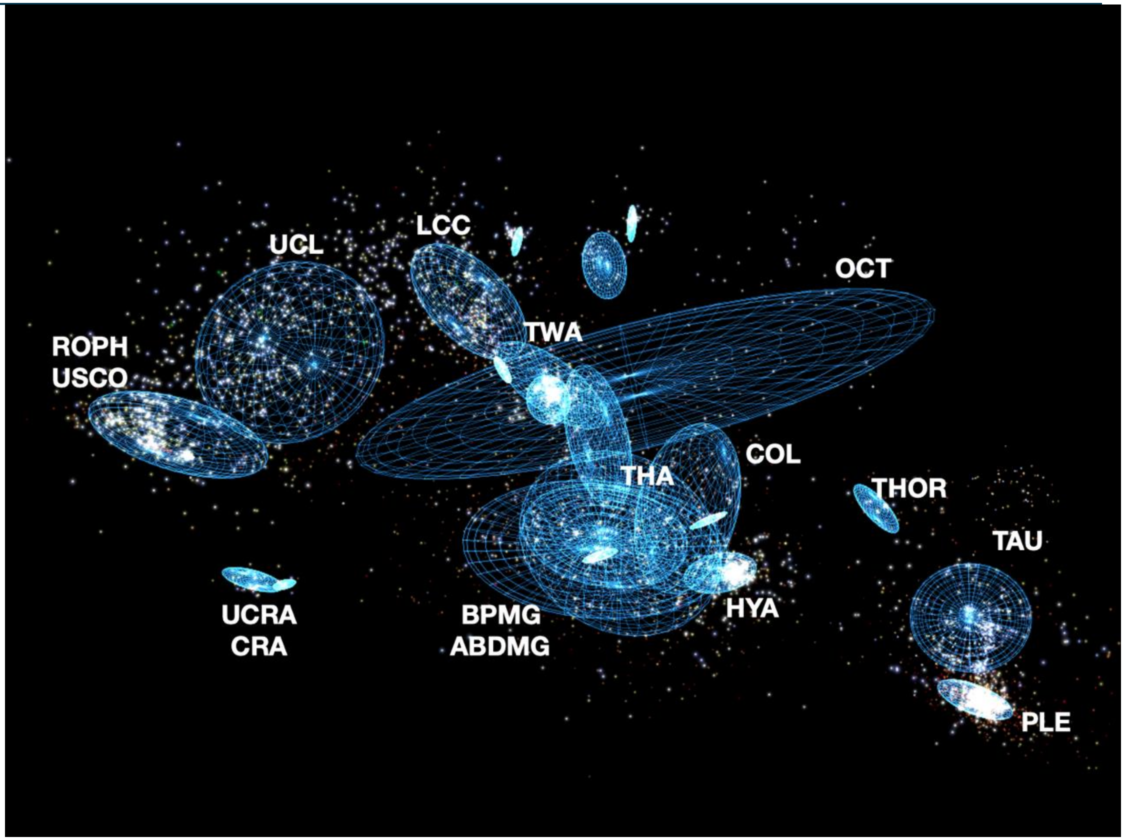
Nearby associations: >20 known groups within 150 pc, co-moving, similar ages, densely populated

Why Important:

- Rich in low-mass stars, brown dwarfs, and free-floating planetary-mass objects (<13 MJup) (e.g., Faherty *et al* 2016)
- Include key groups: Tucana-Horologium, TW Hydra, β Pictoris, AB Doradus
- Contain objects from several solar masses down to a few Jupiter masses, plus stars with planetary-mass companions (e.g., Gagné *et al* 2018)

Scientific opportunities:

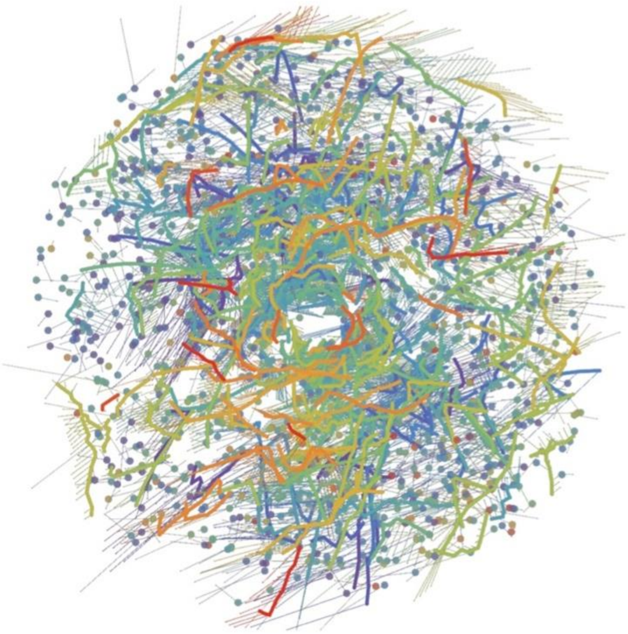
- Study mass function, kinematics, spatial distribution across ages: ~1–2 Myr, 30–50 Myr, 100–700 Myr
- Results with Gaia: some nearby moving groups may be fragments of dissolving open clusters *(Gagné et al 2021)*



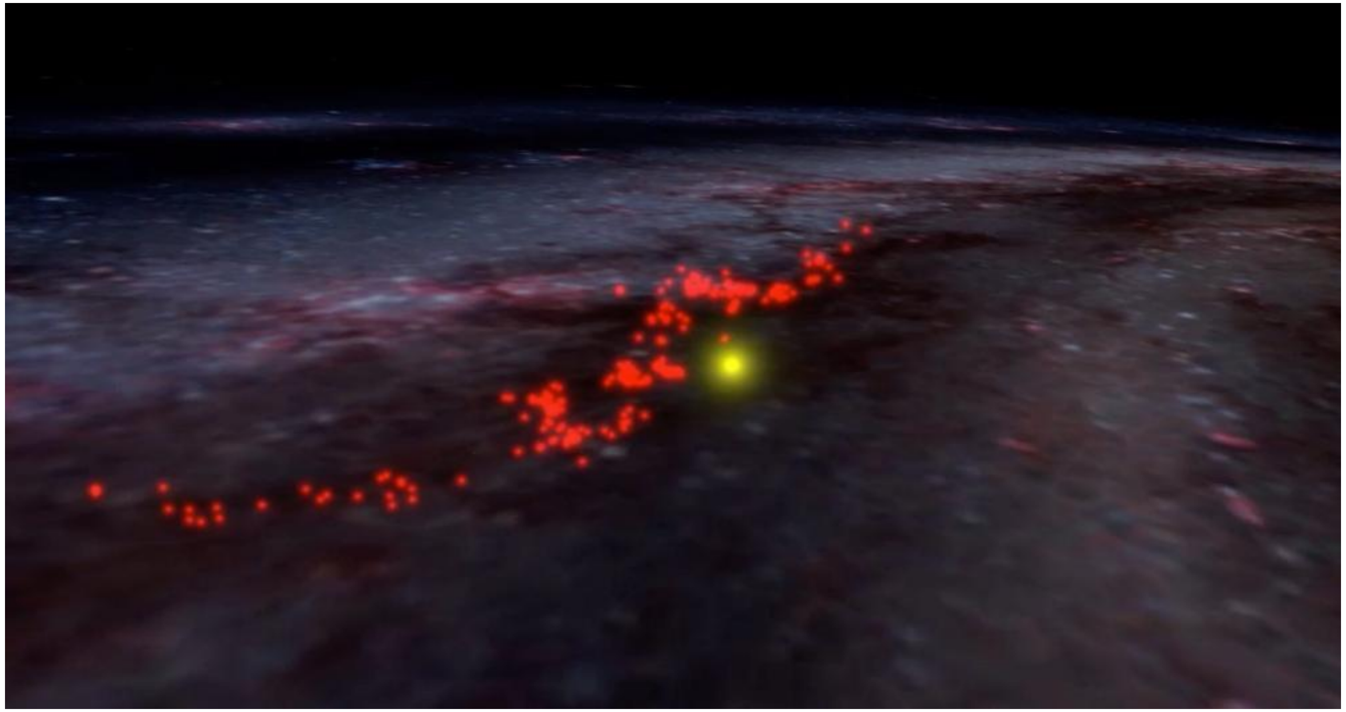
An image of the 150 pc area around the Sun highlighting the locations of star forming regions and nearby moving groups. Credits: Faherty et al. 2020

Data revolution in clusters: Gaia

Gaia is showing that star-forming regions, clusters, and associations are interconnected on truly vast scales, reframing how star formation is driven throughout the Milky Way



Stellar siblings often remain in long, string-like structures rather than dispersing quickly after formation
Credit: M. Kounkel & K. Covey (2019)

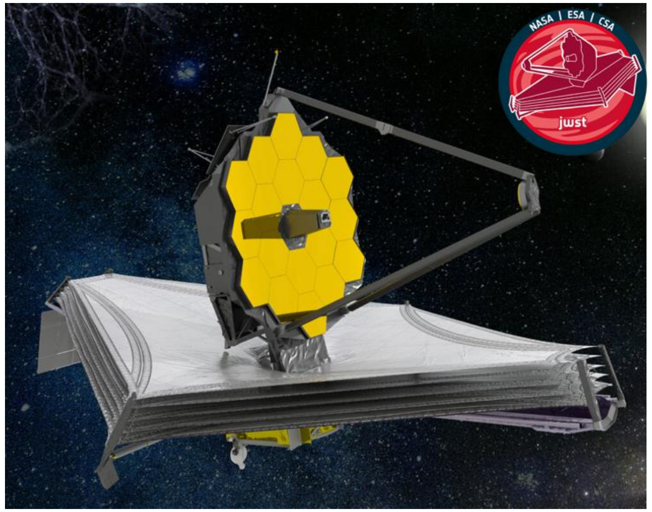


Radcliffe Wave: a narrow and coherent 2.7-kiloparsec arrangement of dense gas in the solar neighbourhood that comprises the majority of nearby star-forming regions
Credit: Alves et al. 2020, A. Goodman/WorldWide Telescope

Current Frontiers

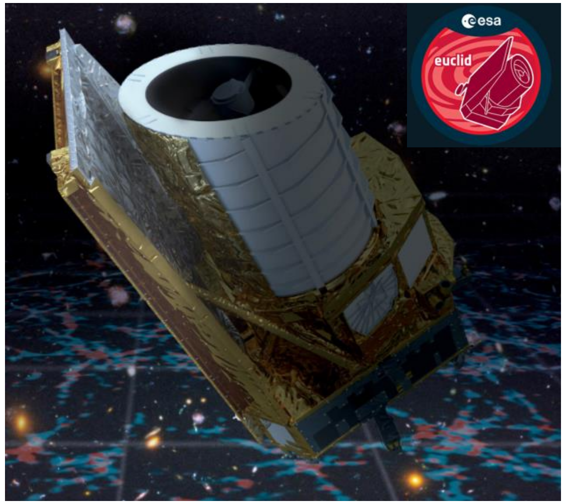
- Pushing observational limits – detection of the lowest mass brown dwarf
- High-precision astrometry – better membership confirmation, proper motions, and parallaxes
- Link to large-scale structures and star formation in our Galaxy - How cloud-scale density, turbulence, and dynamics affect brown dwarf formation
- Spectroscopic characterization – confirmation of youth, spectral sequences, understanding atmospheres of young, least massive objects
- Completeness and low-mass end of the initial mass function
- Synergy with exoplanet studies – planet formation and physics of cold atmospheres

The workhorses of the next decade

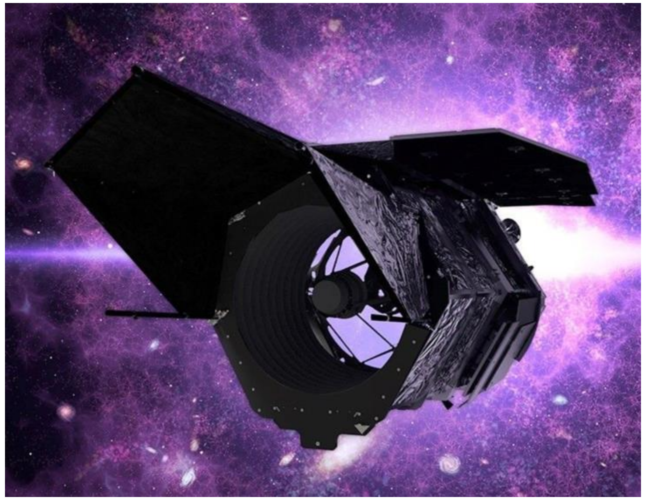


JWST

Gaia



Euclid



Planned: Roman

And ground-based facilities, e.g.:

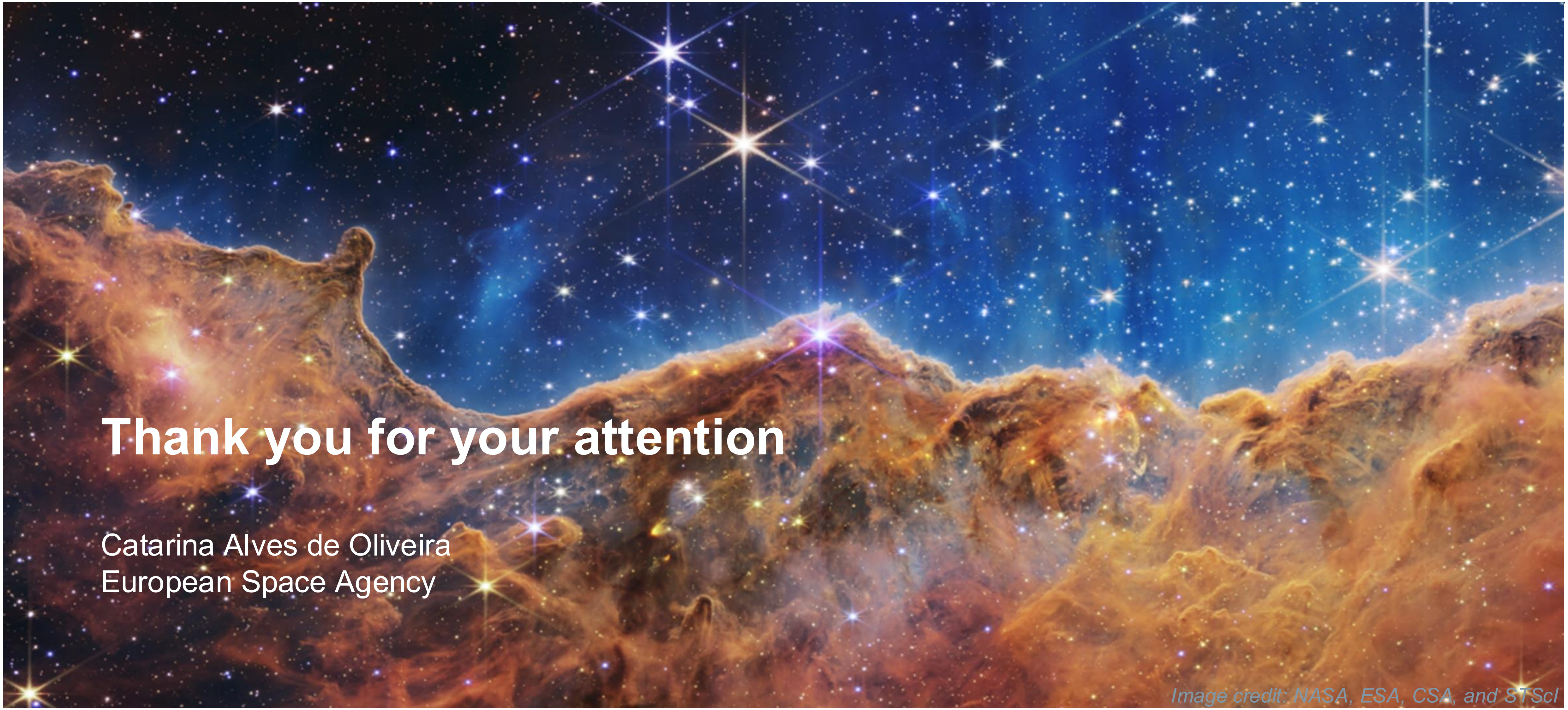
- Vera C. Rubin Observatory
- ELT European Southern Observatory

‼ Review talks ‼

Koraljka Muzic (R): Young Brown Dwarfs in the JWST era

Eduardo Martín (R): Brown dwarfs with the Euclid space mission

Matthew Da Furio (R): Brown dwarfs with Nancy Roman Space telescope



Thank you for your attention

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Image credit: NASA, ESA, CSA, and STScI