

Milyen titkokat rejt a születő csillagok fényé?

Kóspál Ágnes

**MTA CSFK Konkoly Thege Miklós
Csillagászati Intézet**

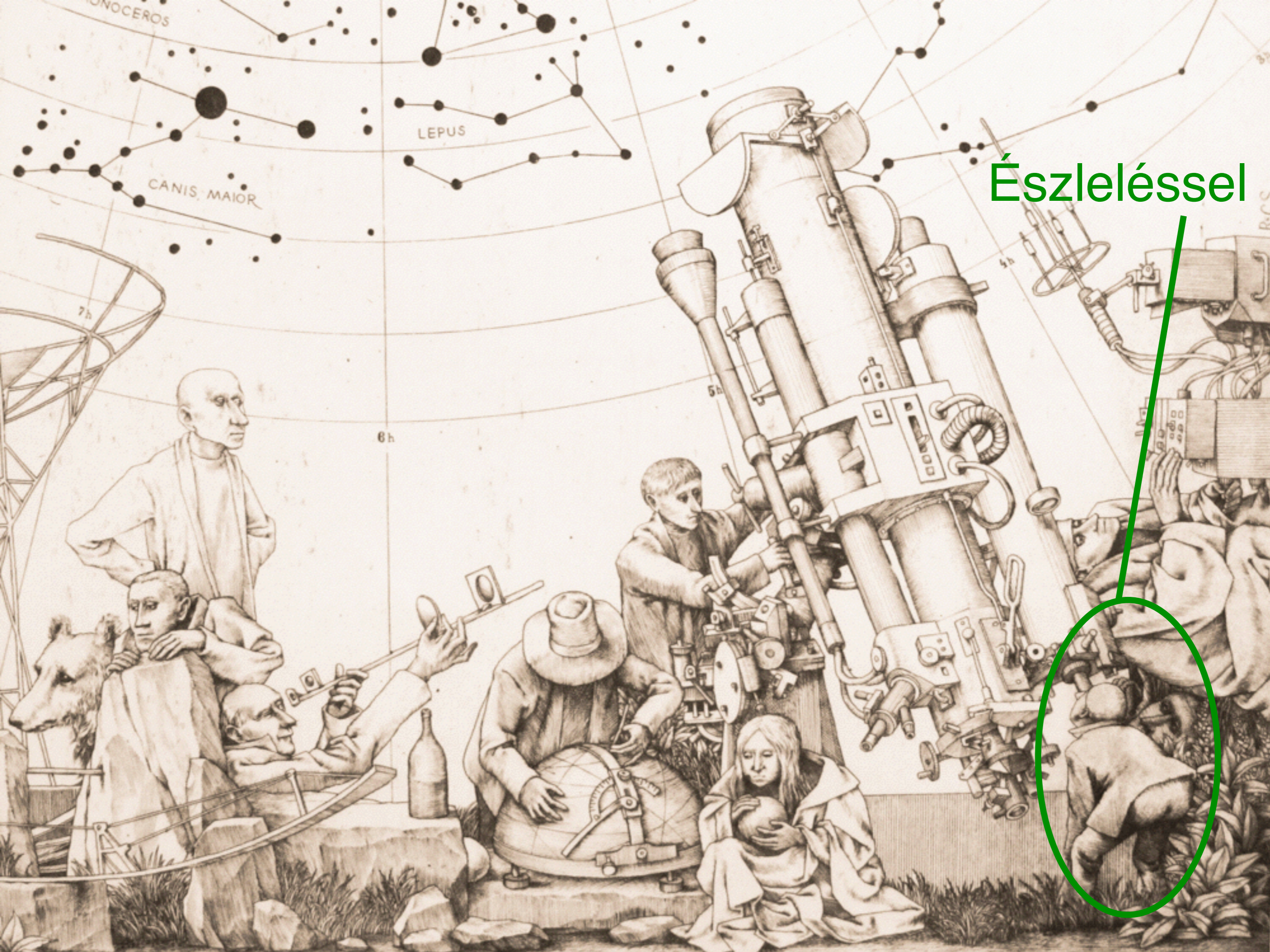


Az atomoktól a Csillagokig Előadássorozat, ELTE TTK

2016. március 31.

Mivel foglalkozik egy 21. századi csillagász?

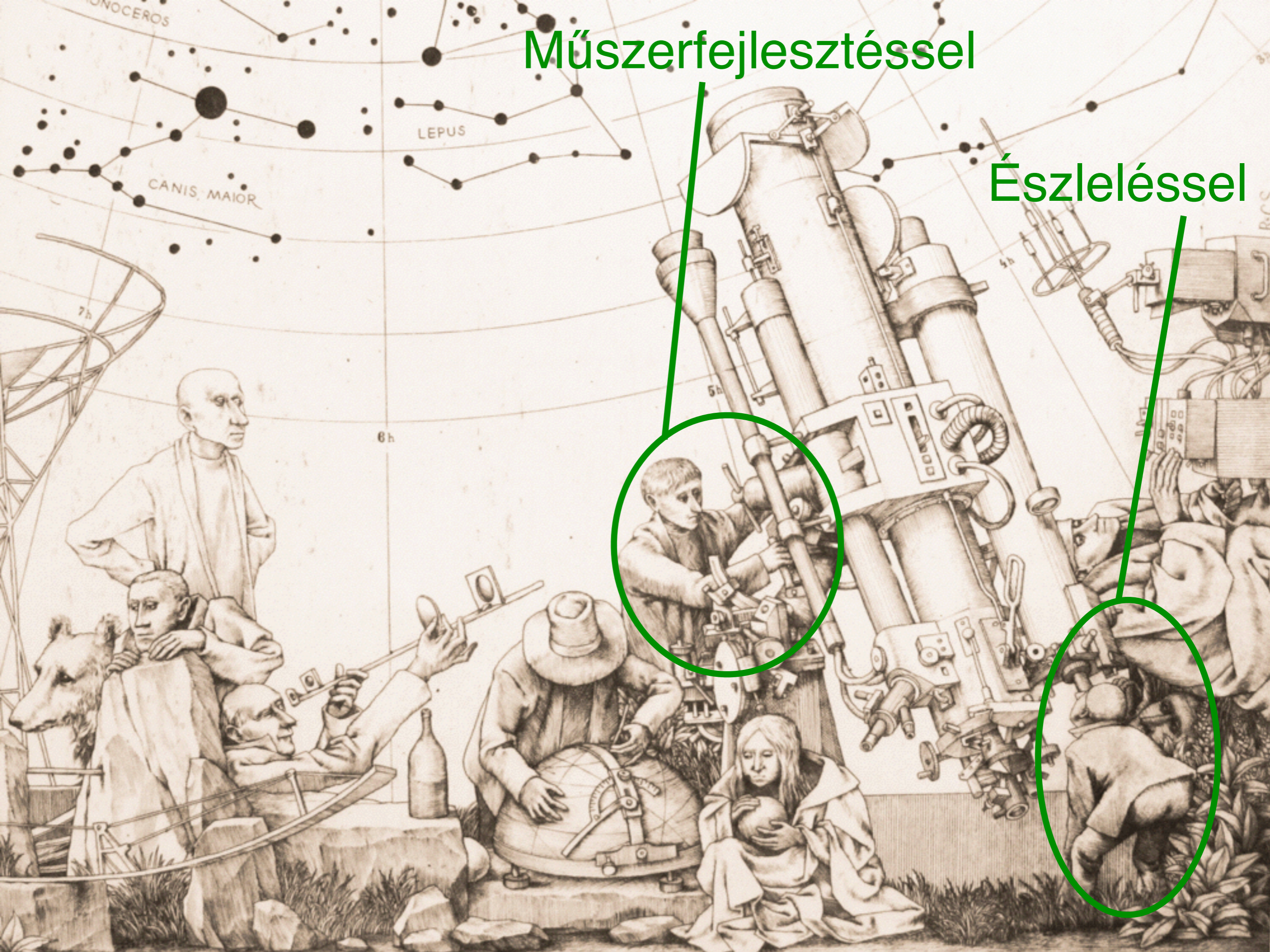




Észleléssel

Műszerfejlesztéssel

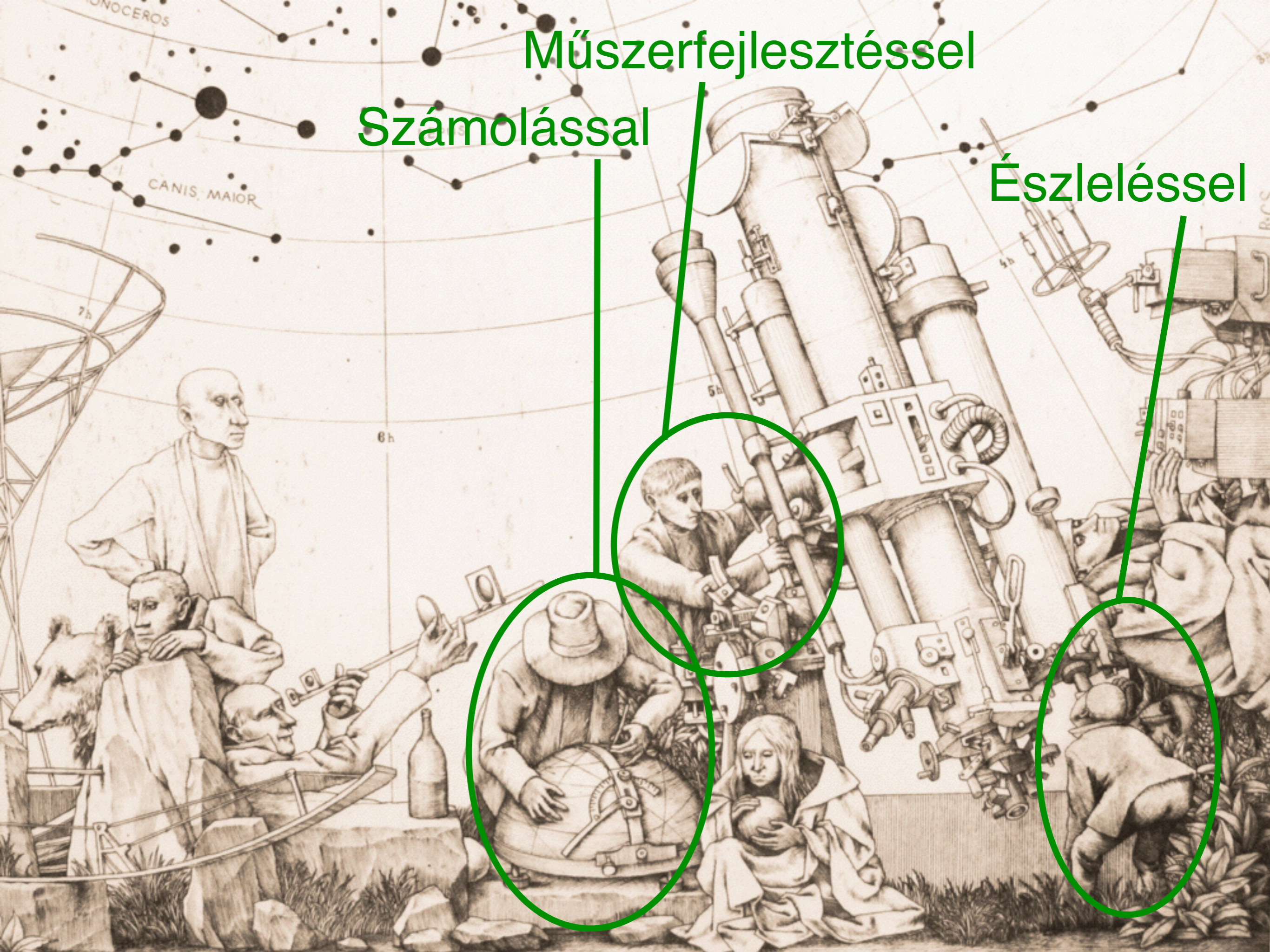
Észleléssel



Műszerfejlesztéssel

Számolással

Észleléssel

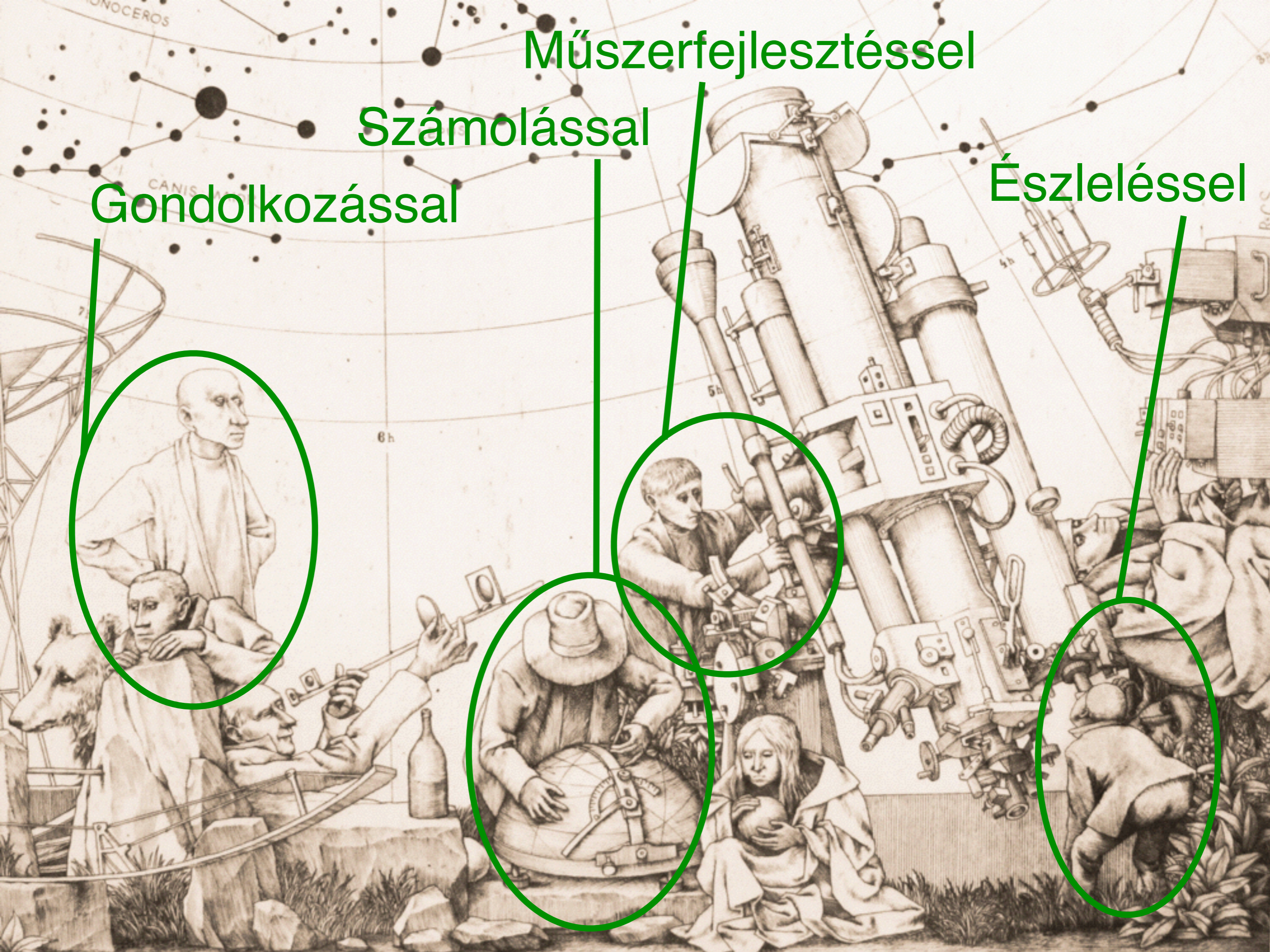


Műszerfejlesztéssel

Számolással

Gondolkozással

Észleléssel



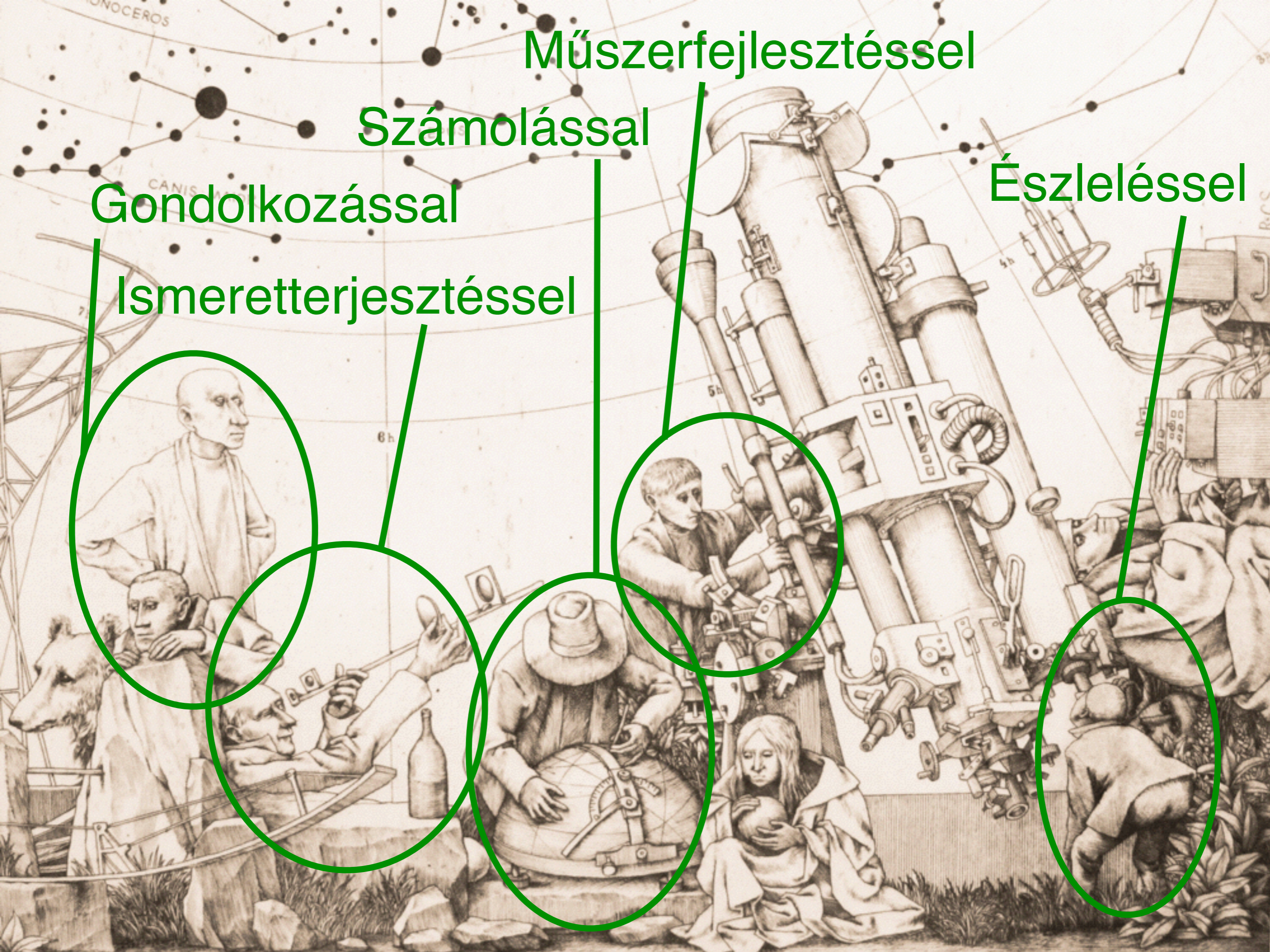
Műszerfejlesztéssel

Számolással

Észleléssel

Gondolkozással

Ismeretterjesztéssel



Műszerfejlesztéssel

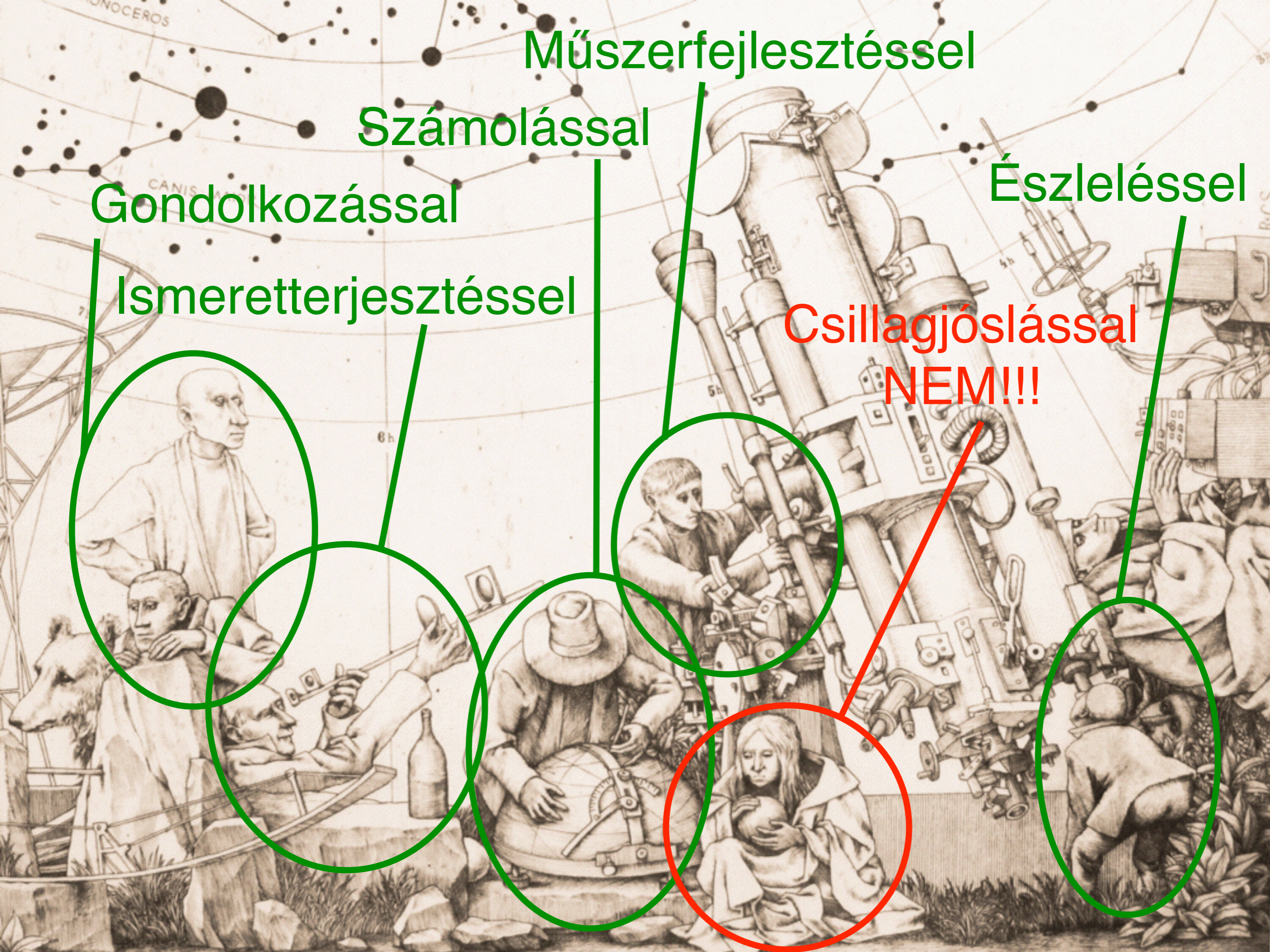
Számolással

Gondolkozással

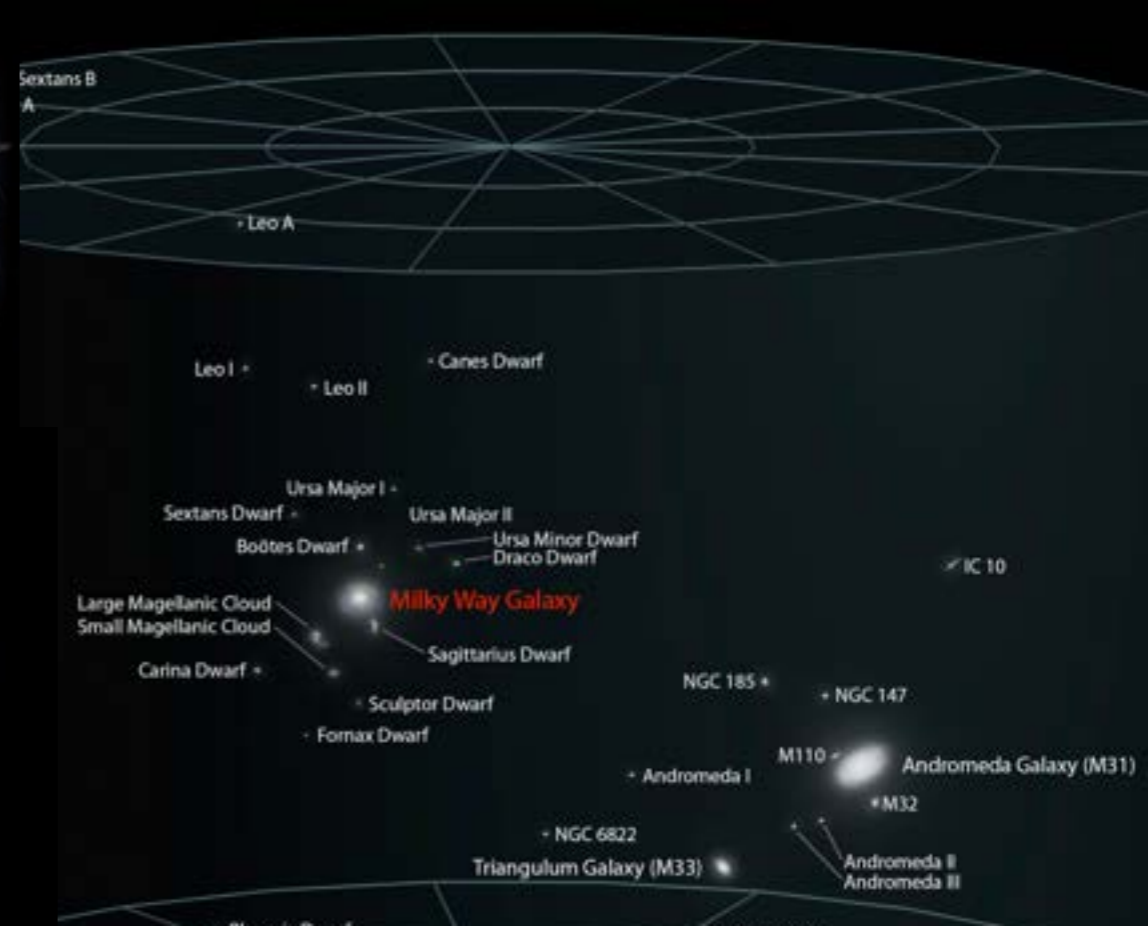
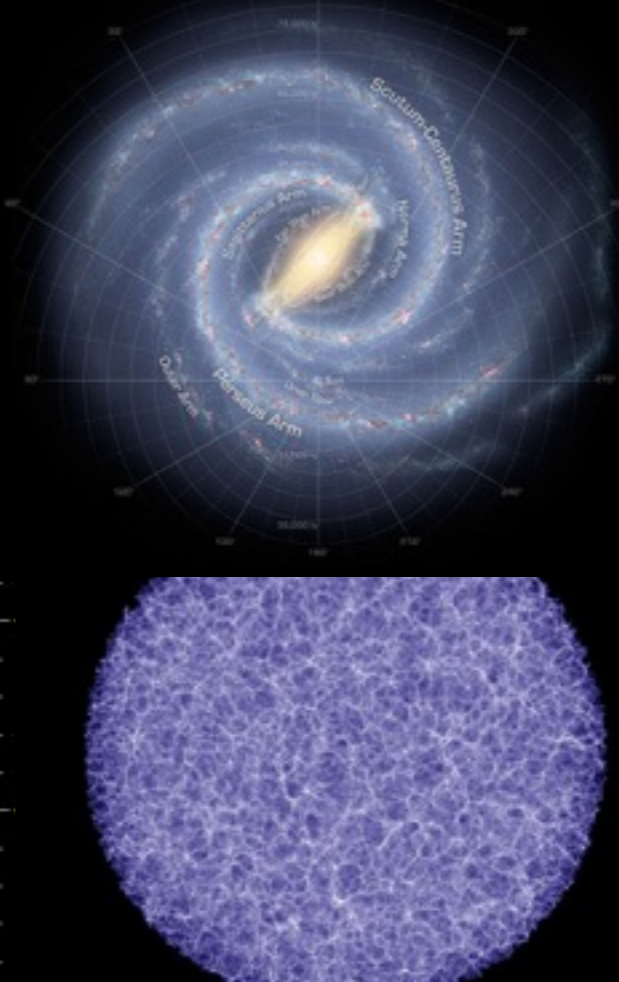
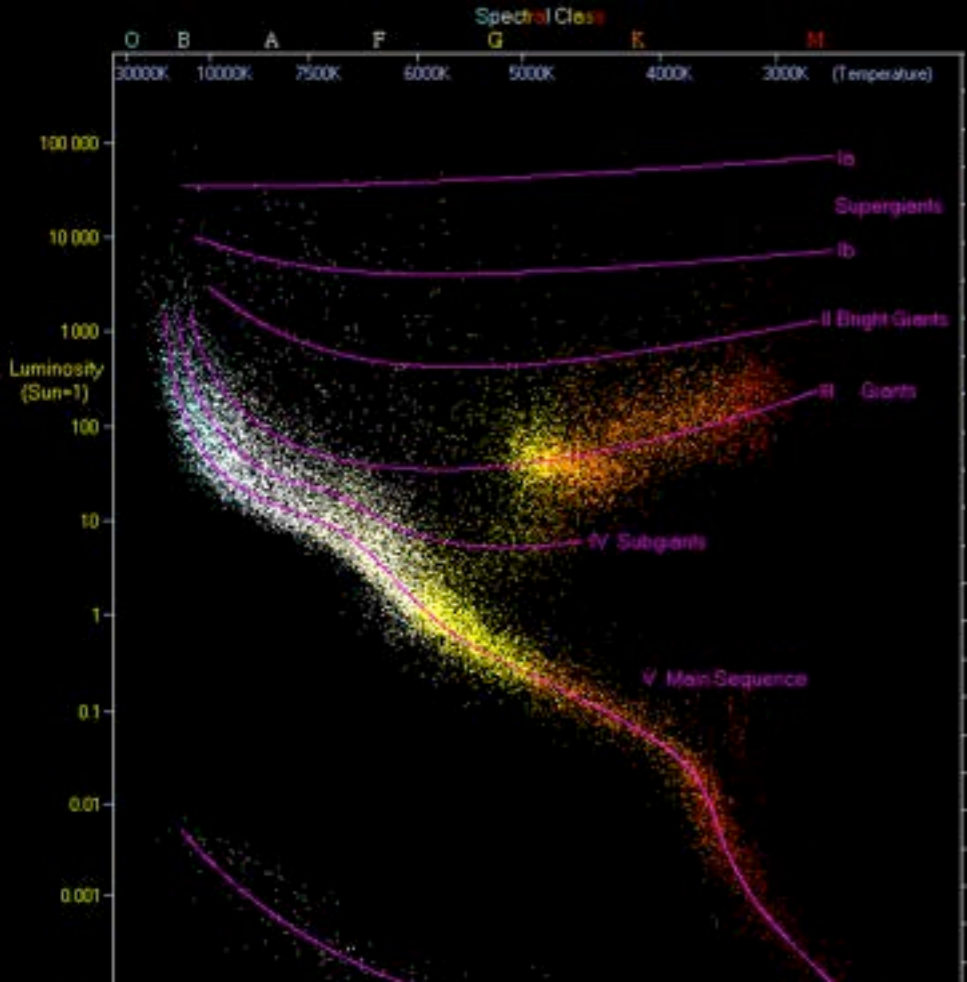
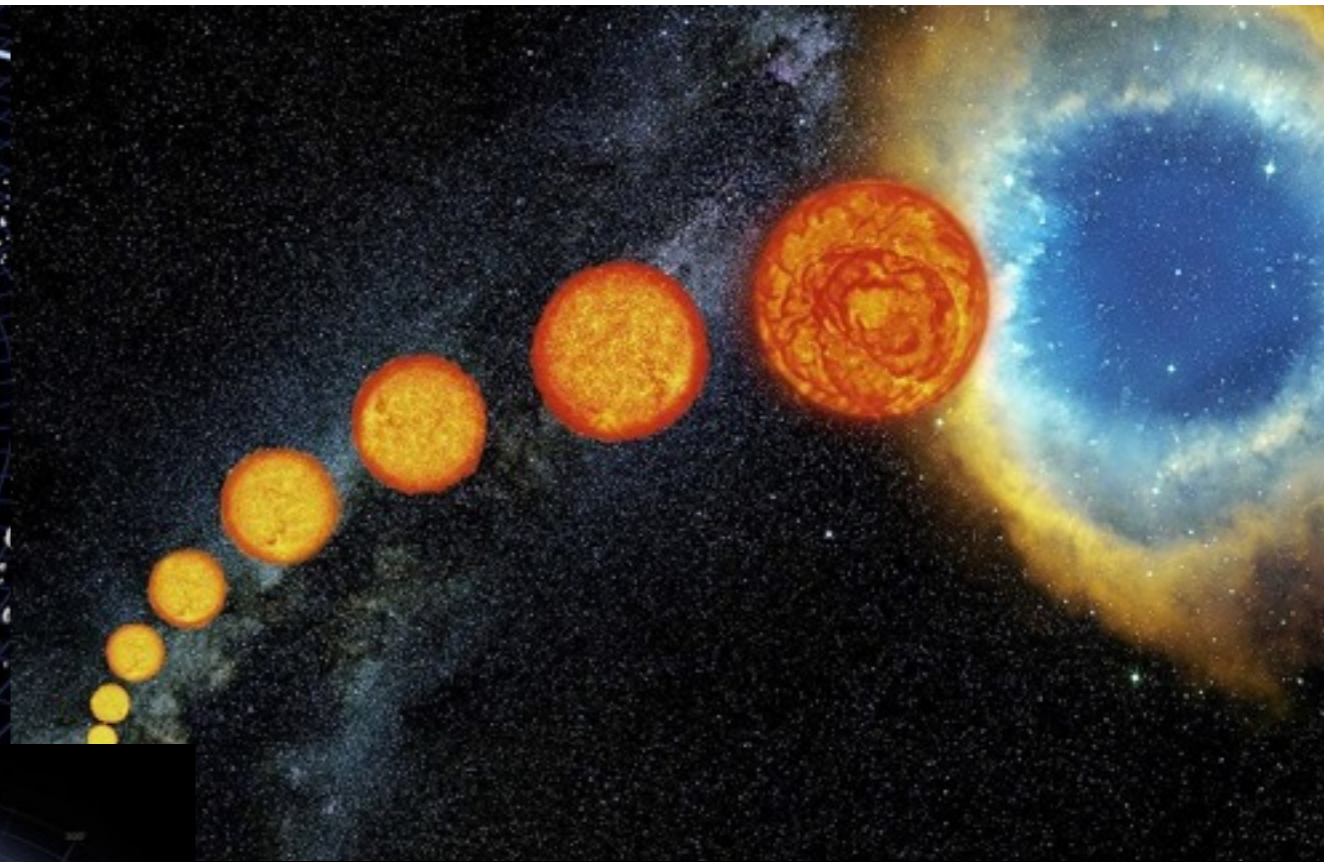
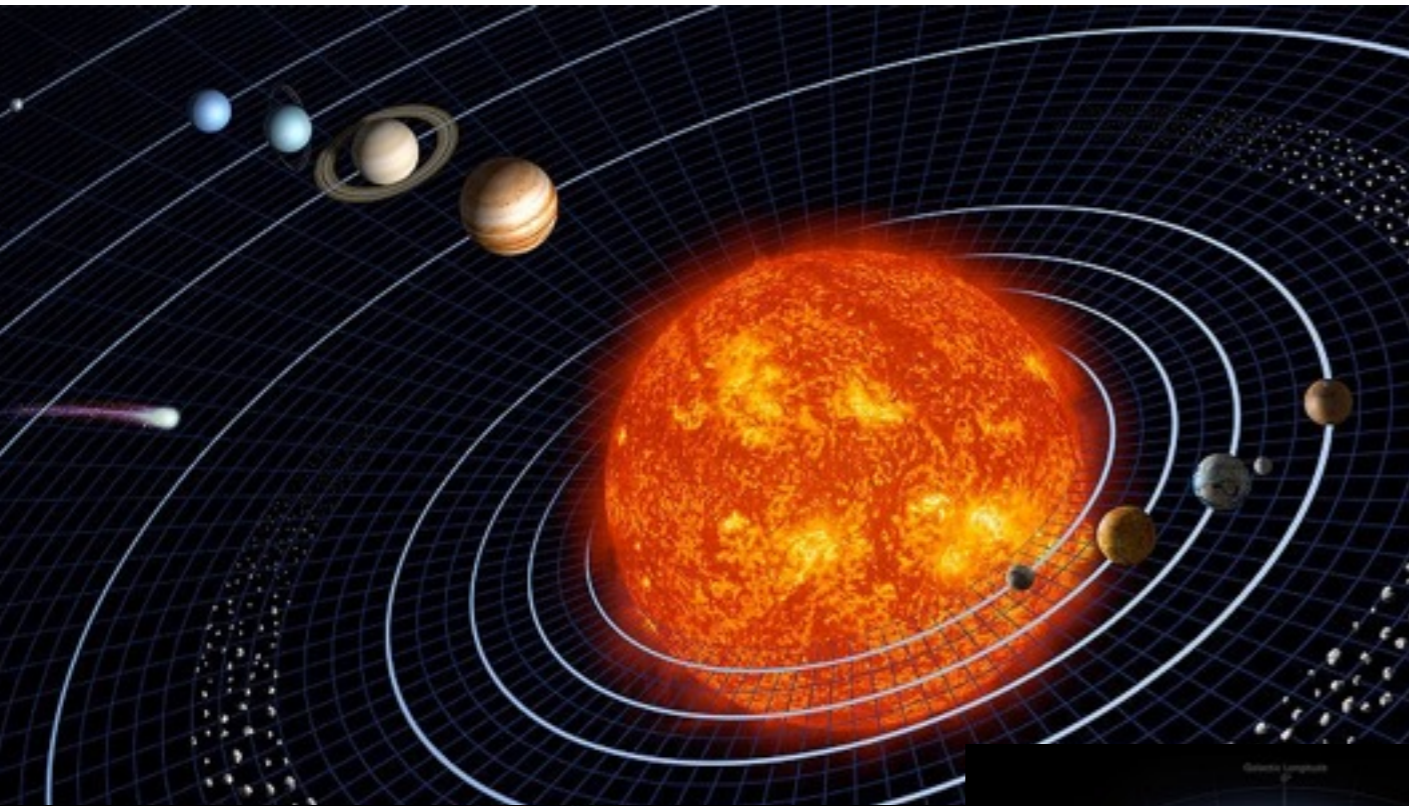
Észleléssel

Ismeretterjesztéssel

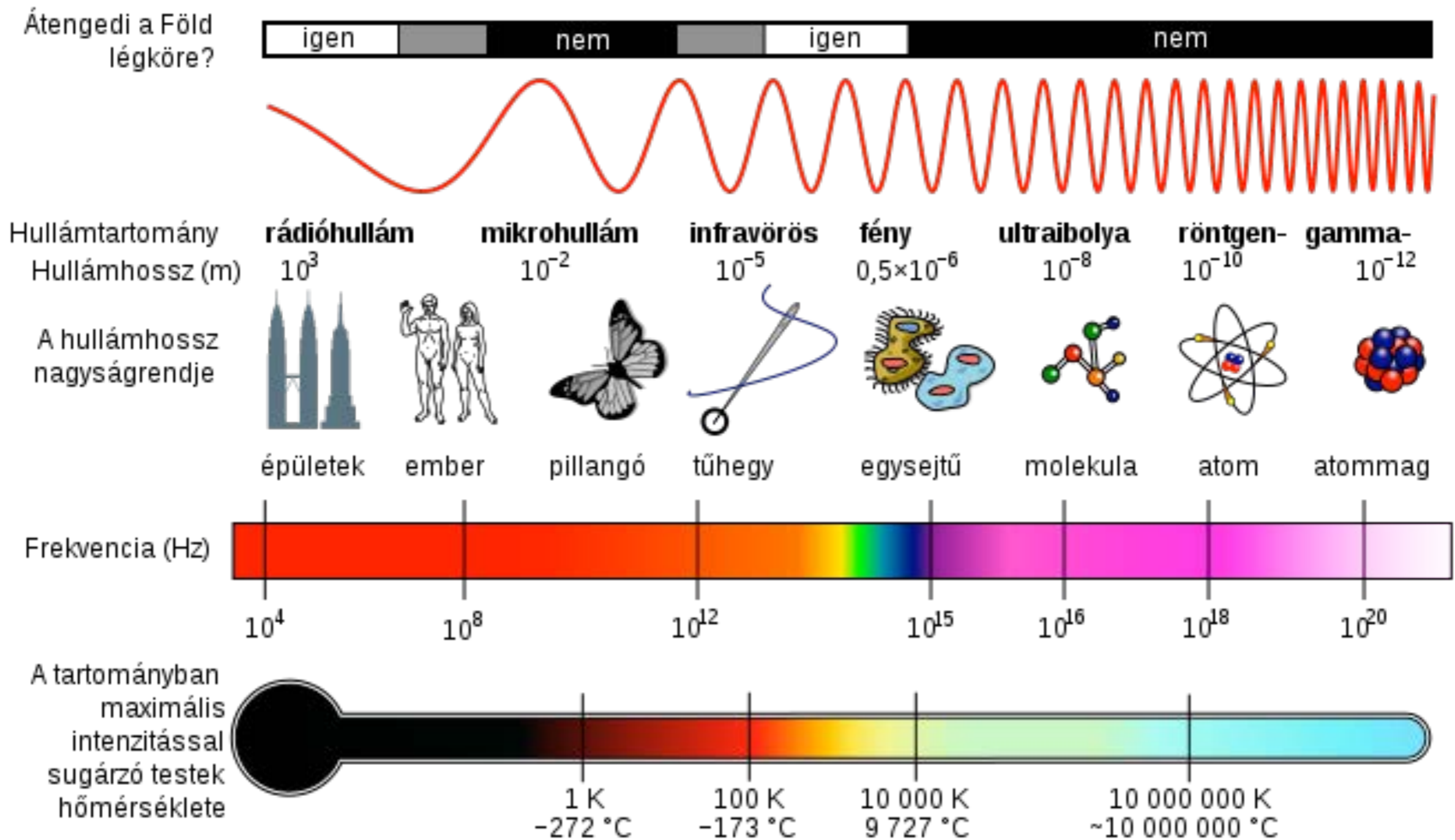
Csillagjóslassal
NEM!!!



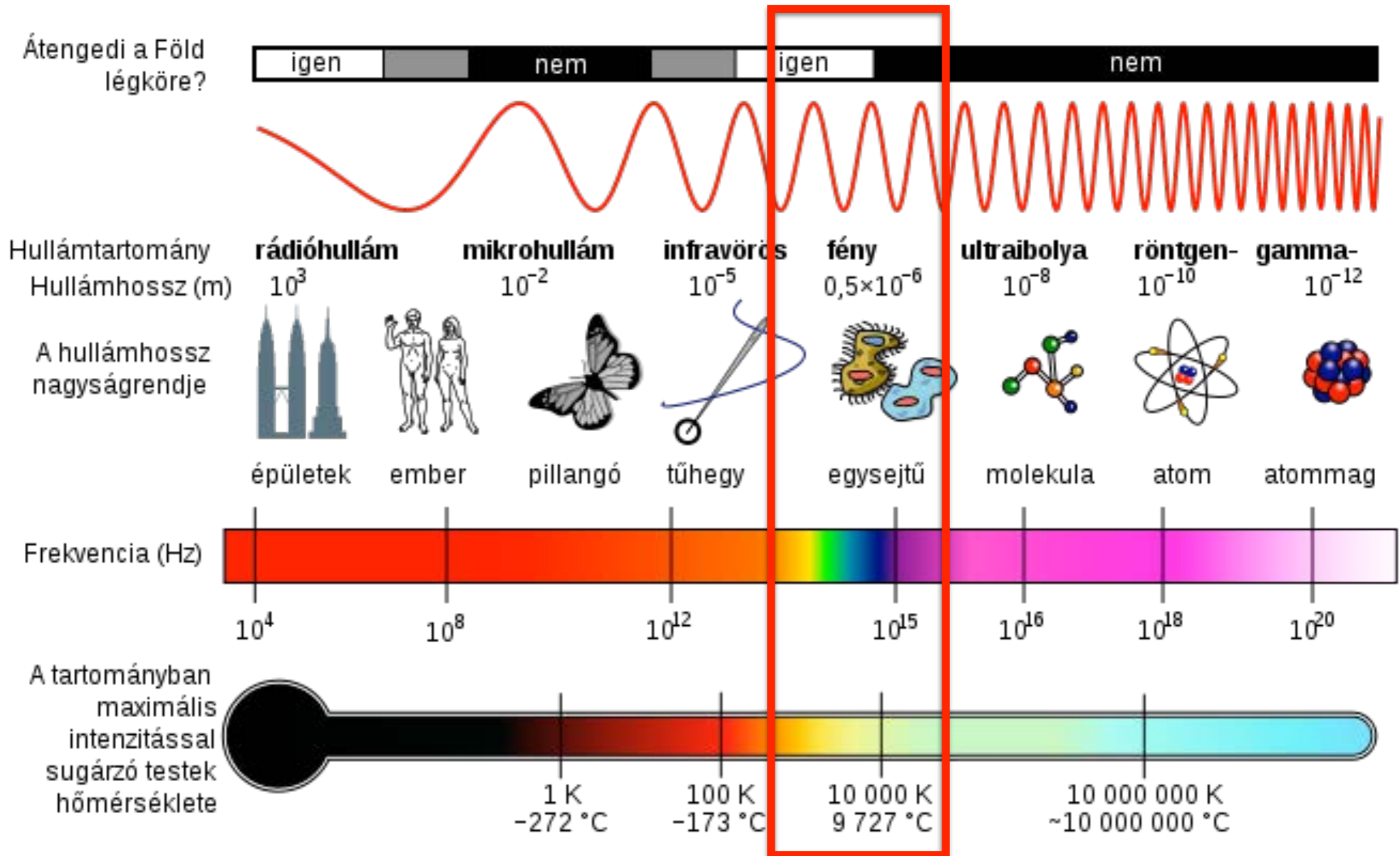
Hogyan működik az Univerzum?



Hogyan szerzünk erről információt?

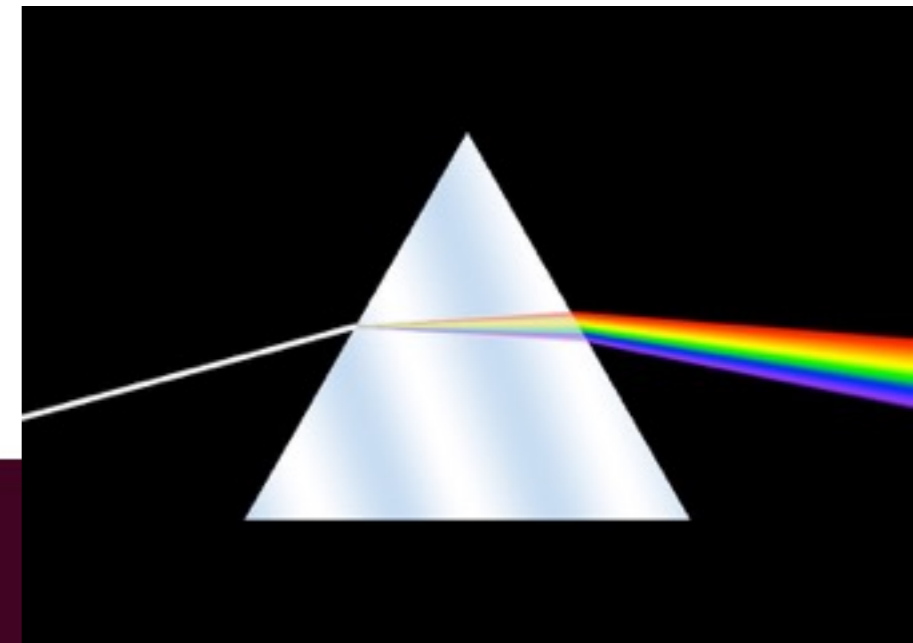
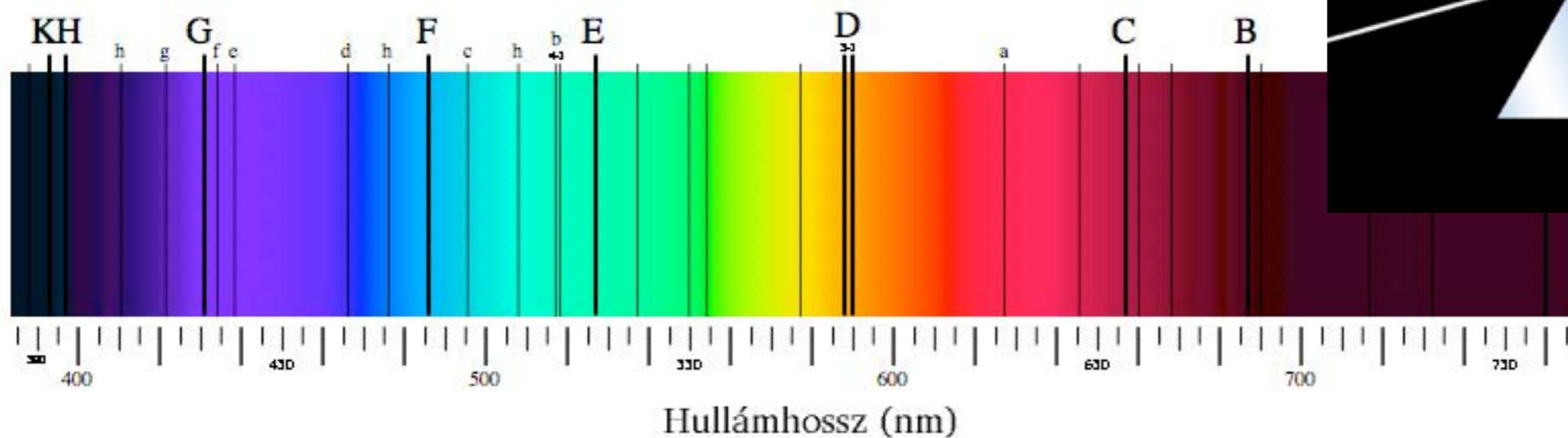


Hogyan szerzünk erről információt?



Hogyan szerzünk erről információt?

1814: Fraunhofer színeképvonalakat fedez fel a Nap spektrumában



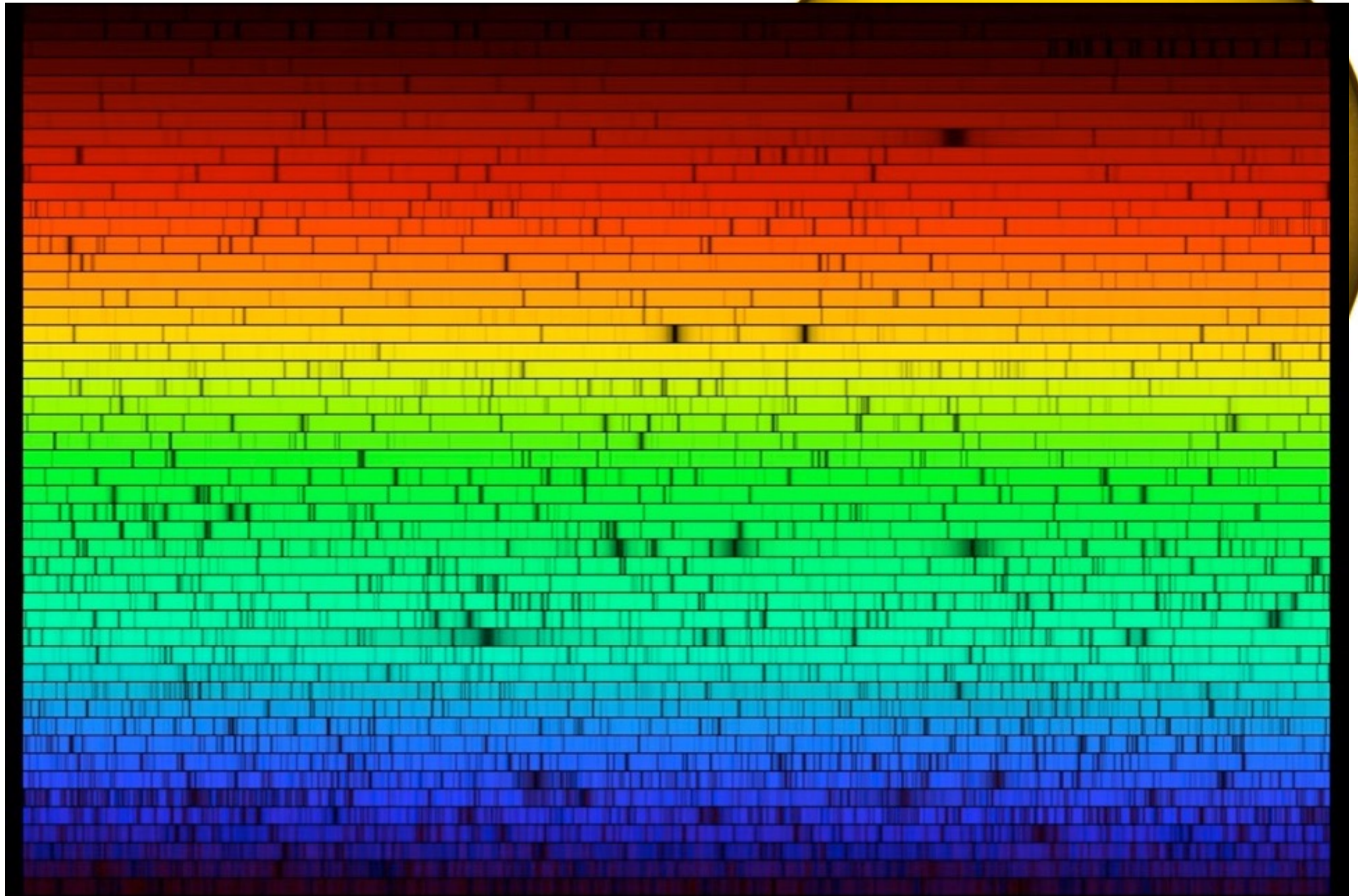
1859: Kirchhoff és Bunsen rájött, hogy a vonalakat a Napban lévő atomok (és ionok) elnyelése okozza

Kapcsolat van az égitestek **fizikai jellemzői** és a **spektrumuk** között: megszületett az **asztrofizika**

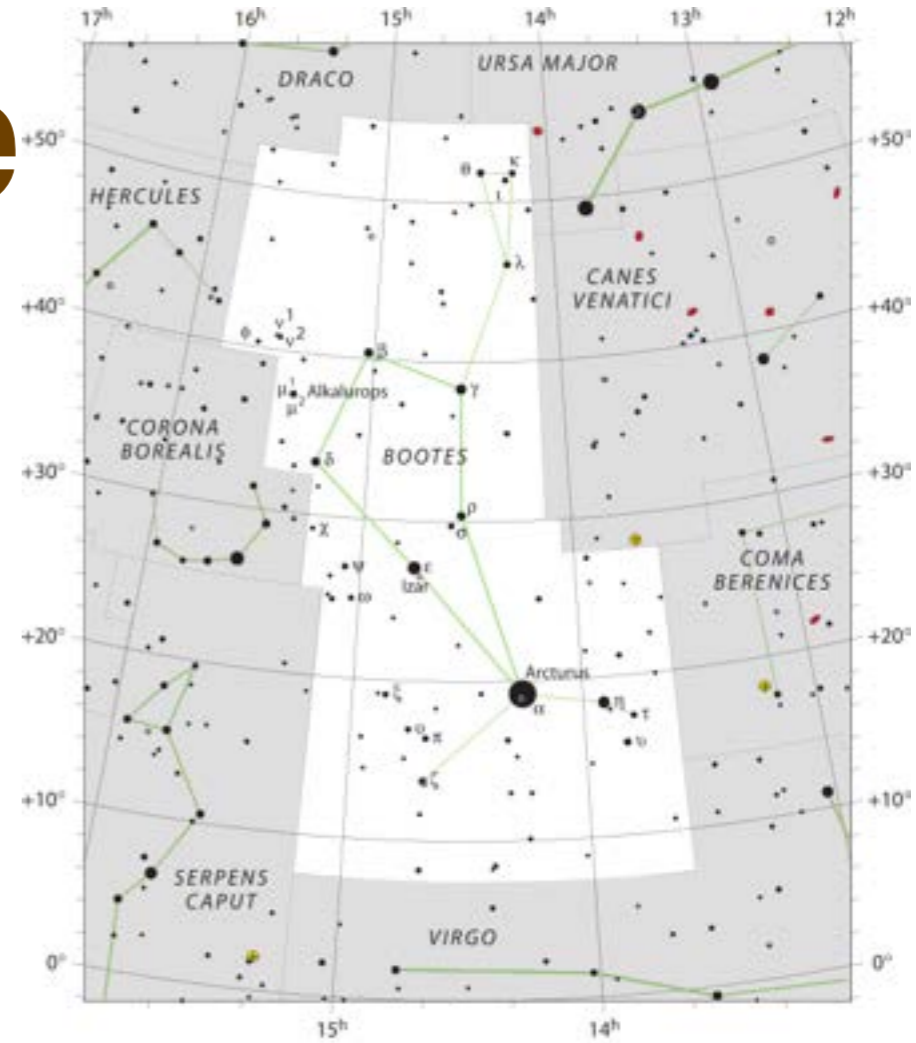
A Nap színeképe



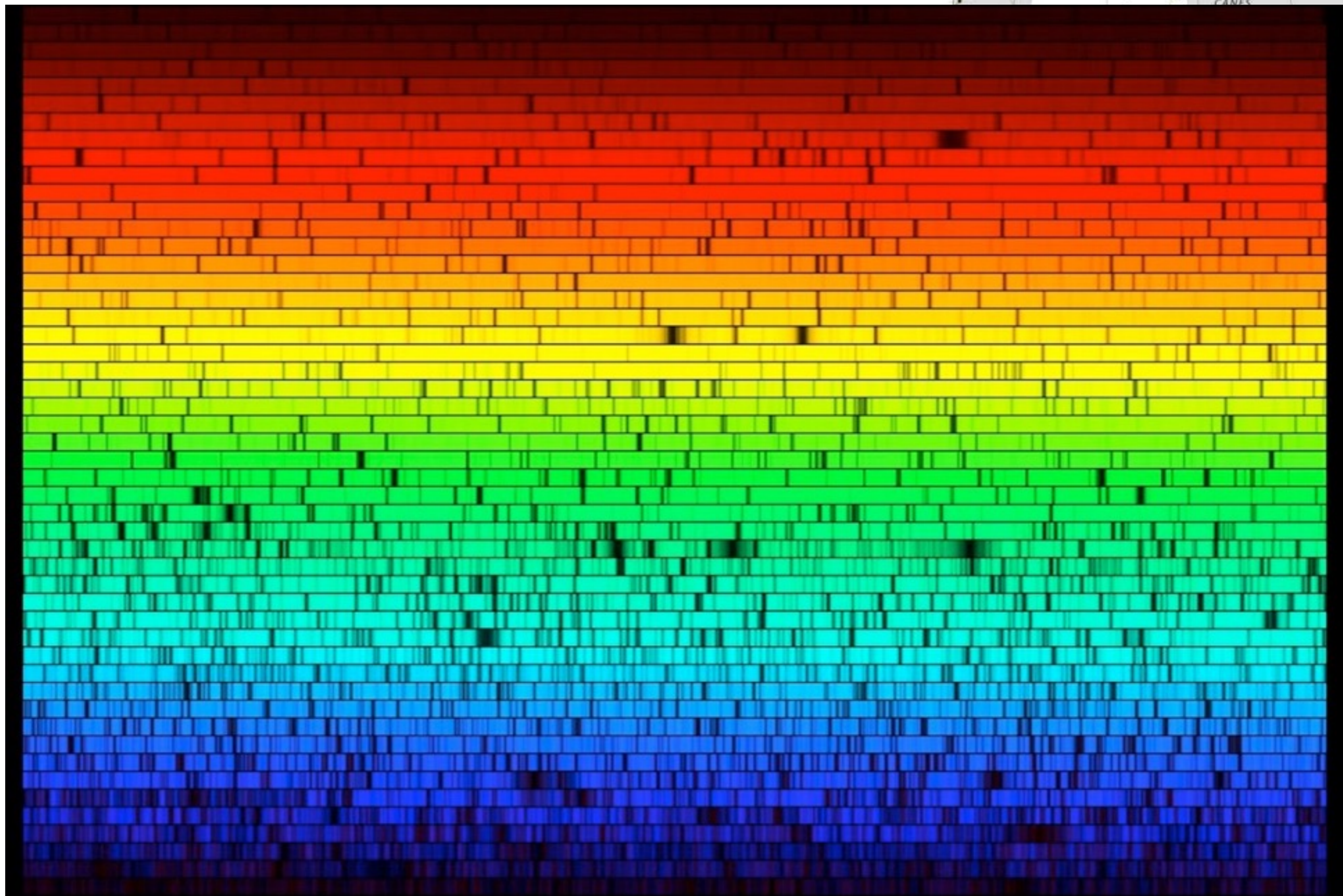
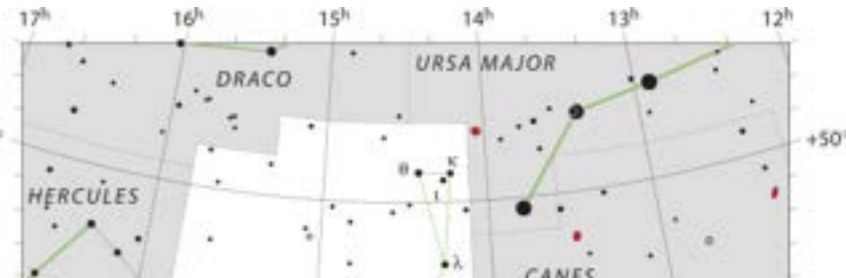
A Nap színeképe



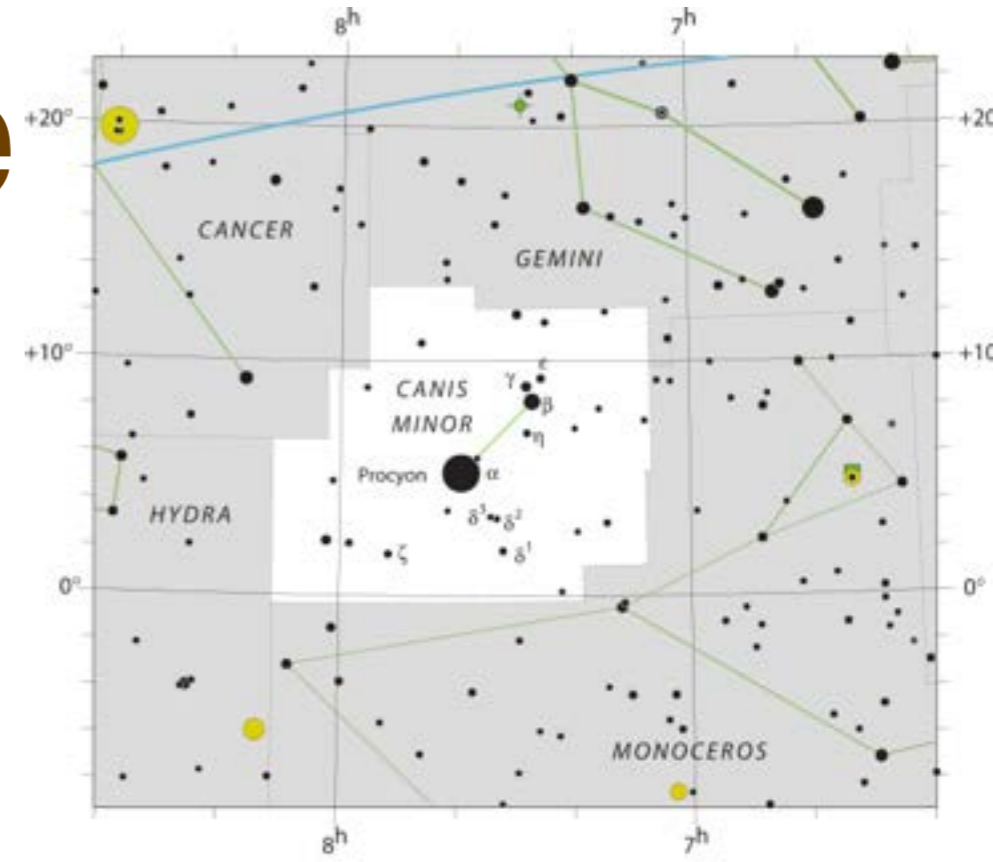
Az Arcturus színeképe



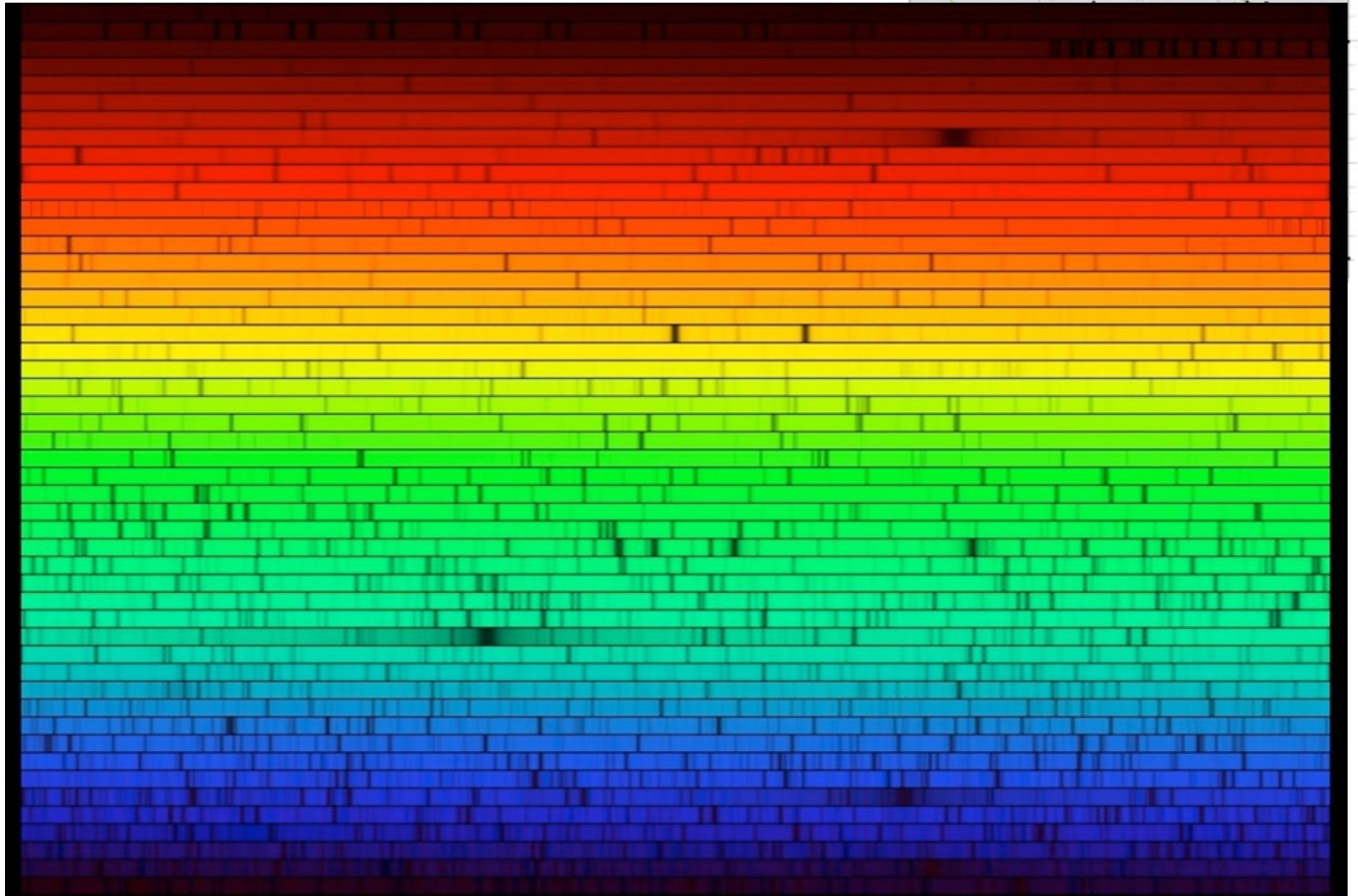
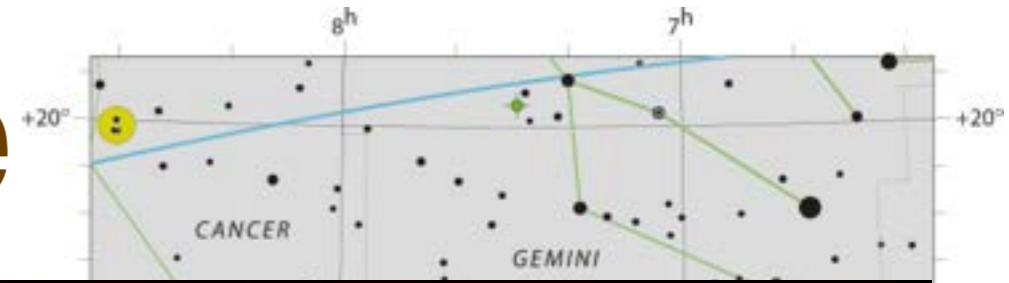
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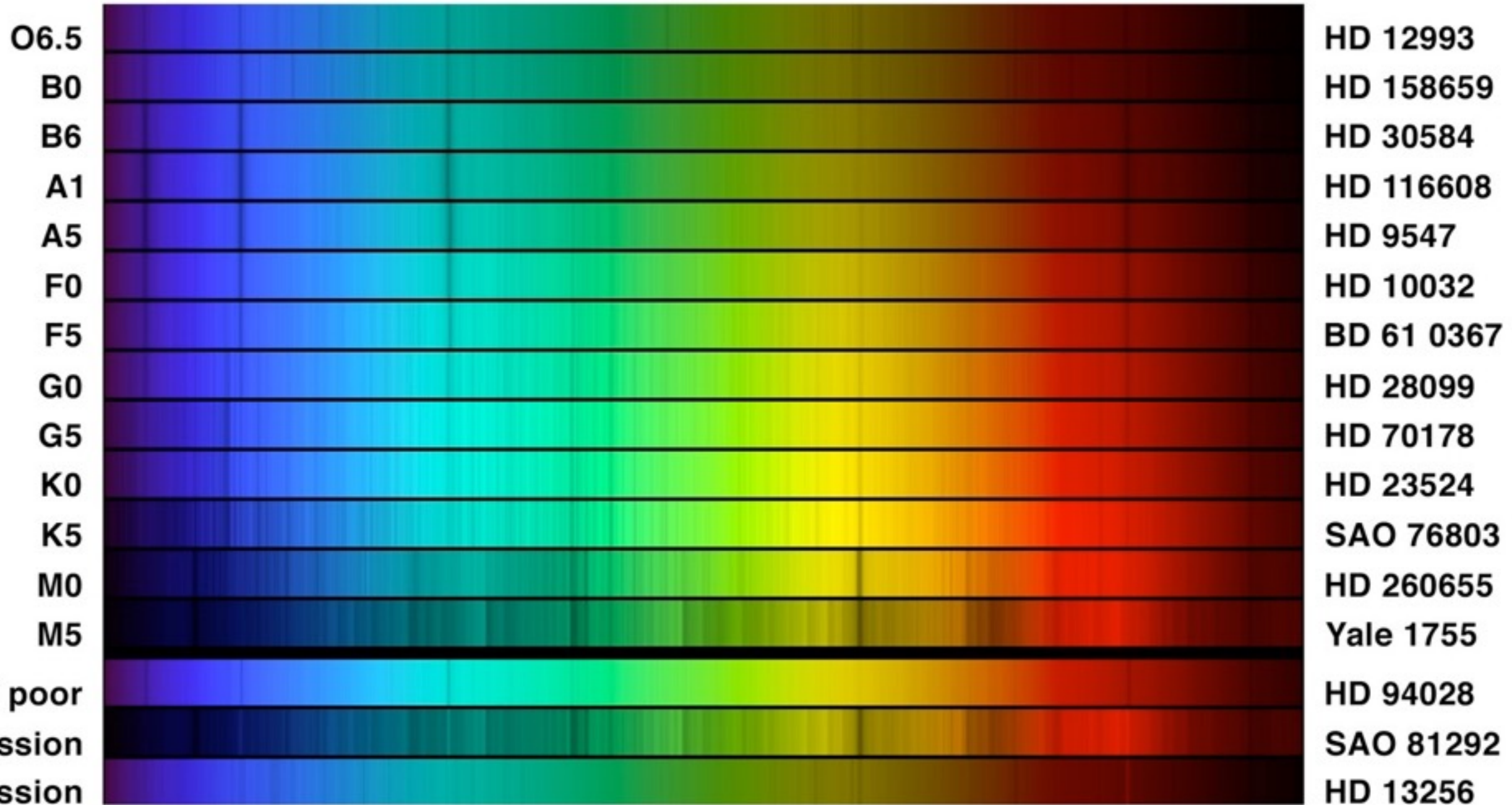
A Procyon színeképe



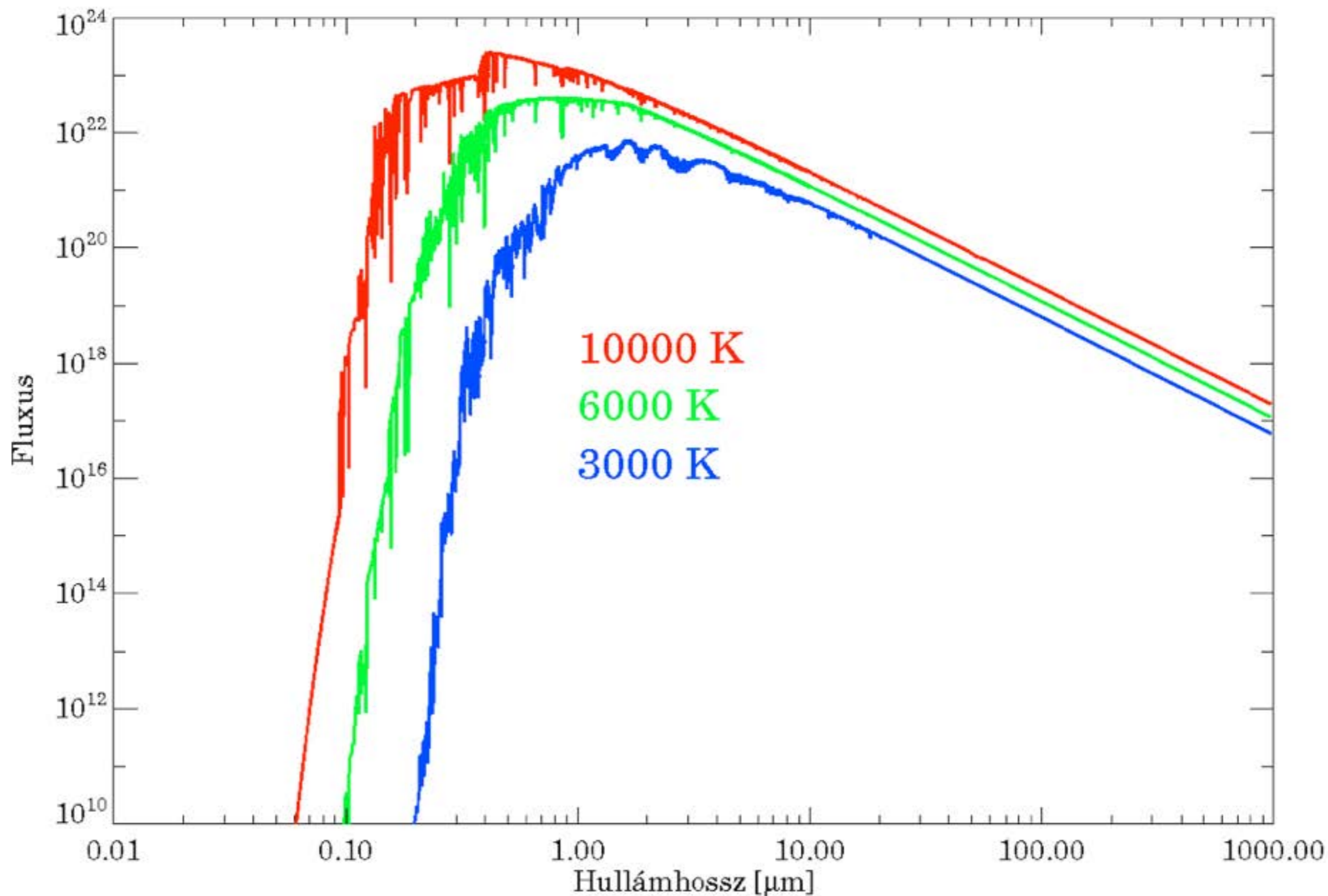
A Procyon színeképe



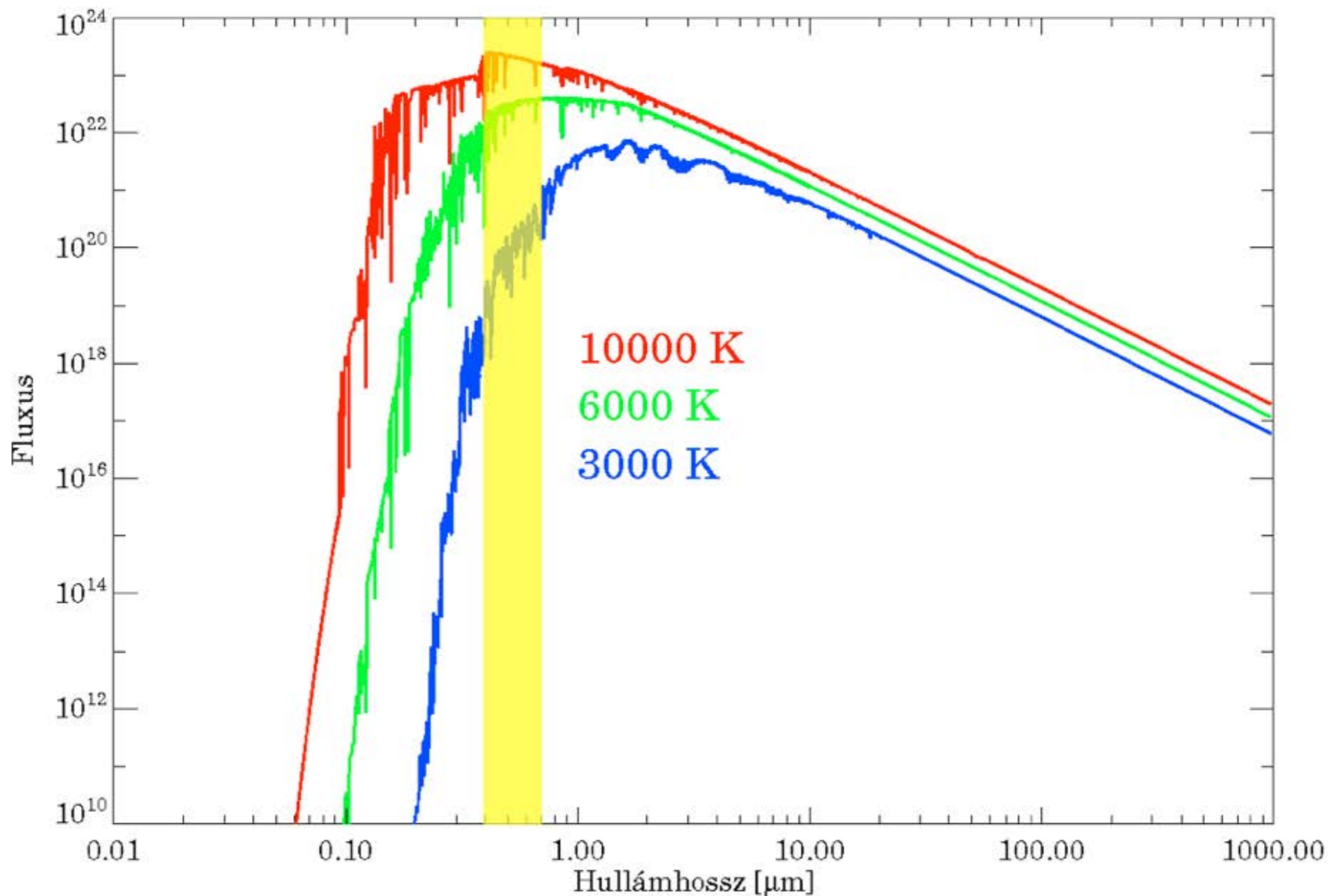
Színeképosztályozás



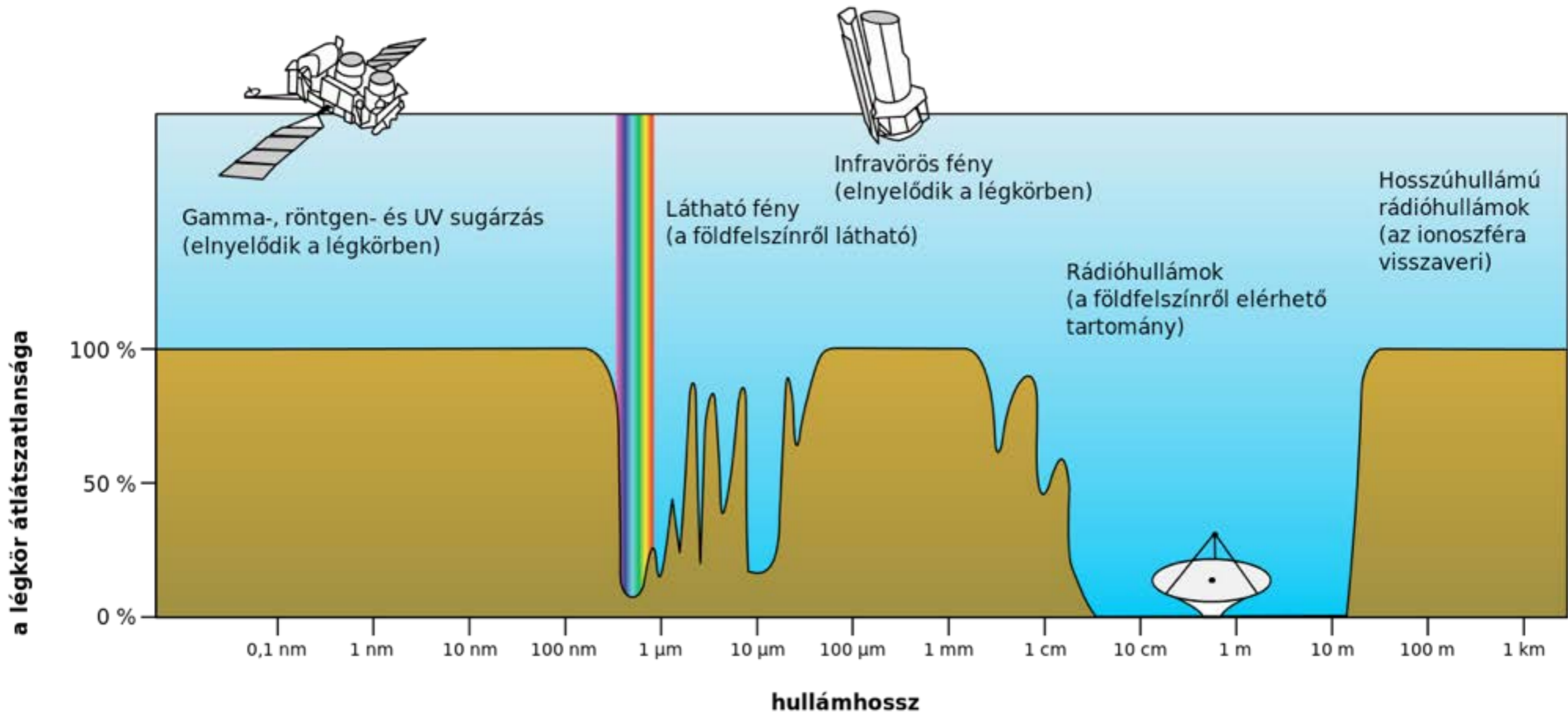
Csillagszínképek



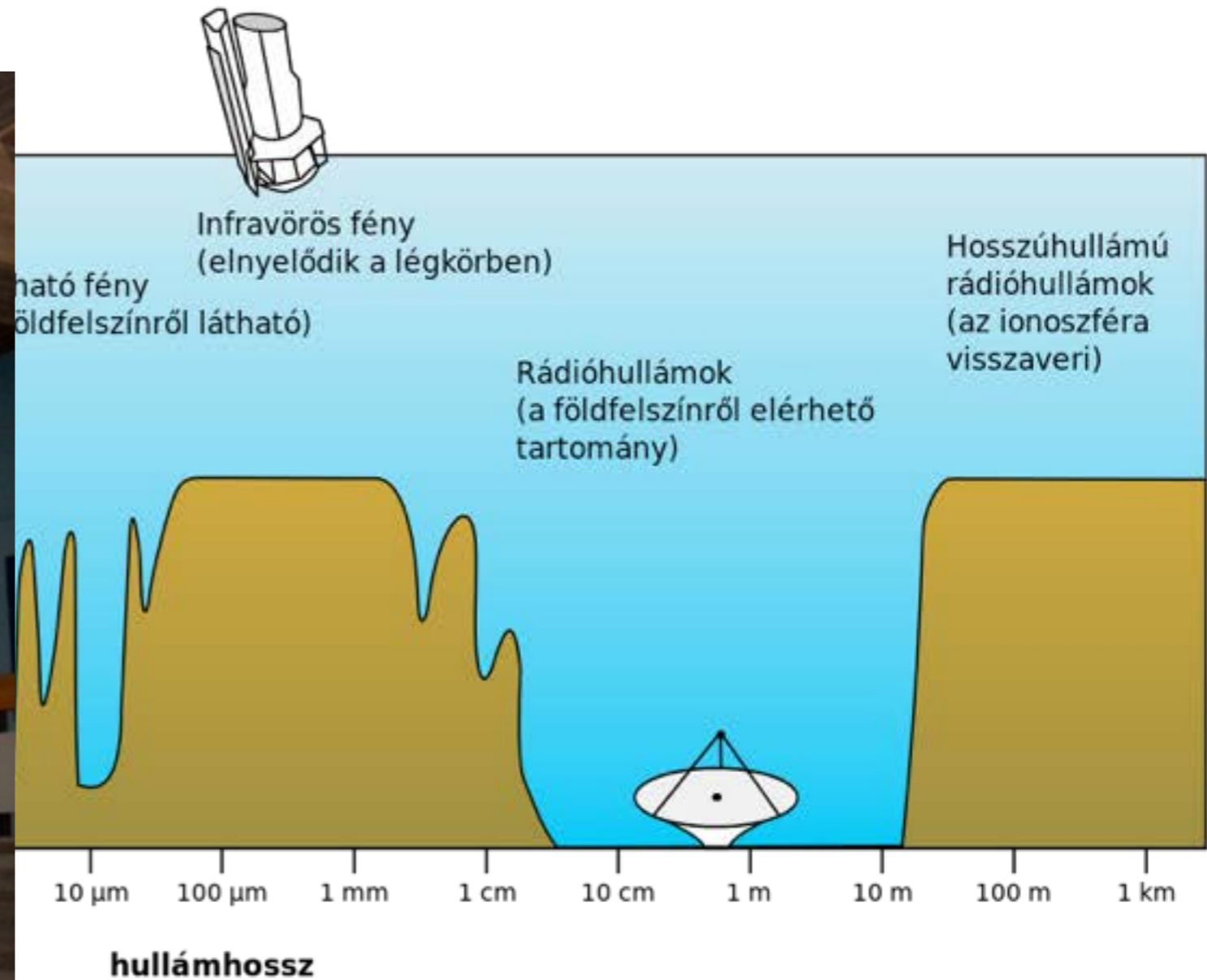
Csillagszíneképek



A földi légkör átteresztése



A földi légkör áteresztése



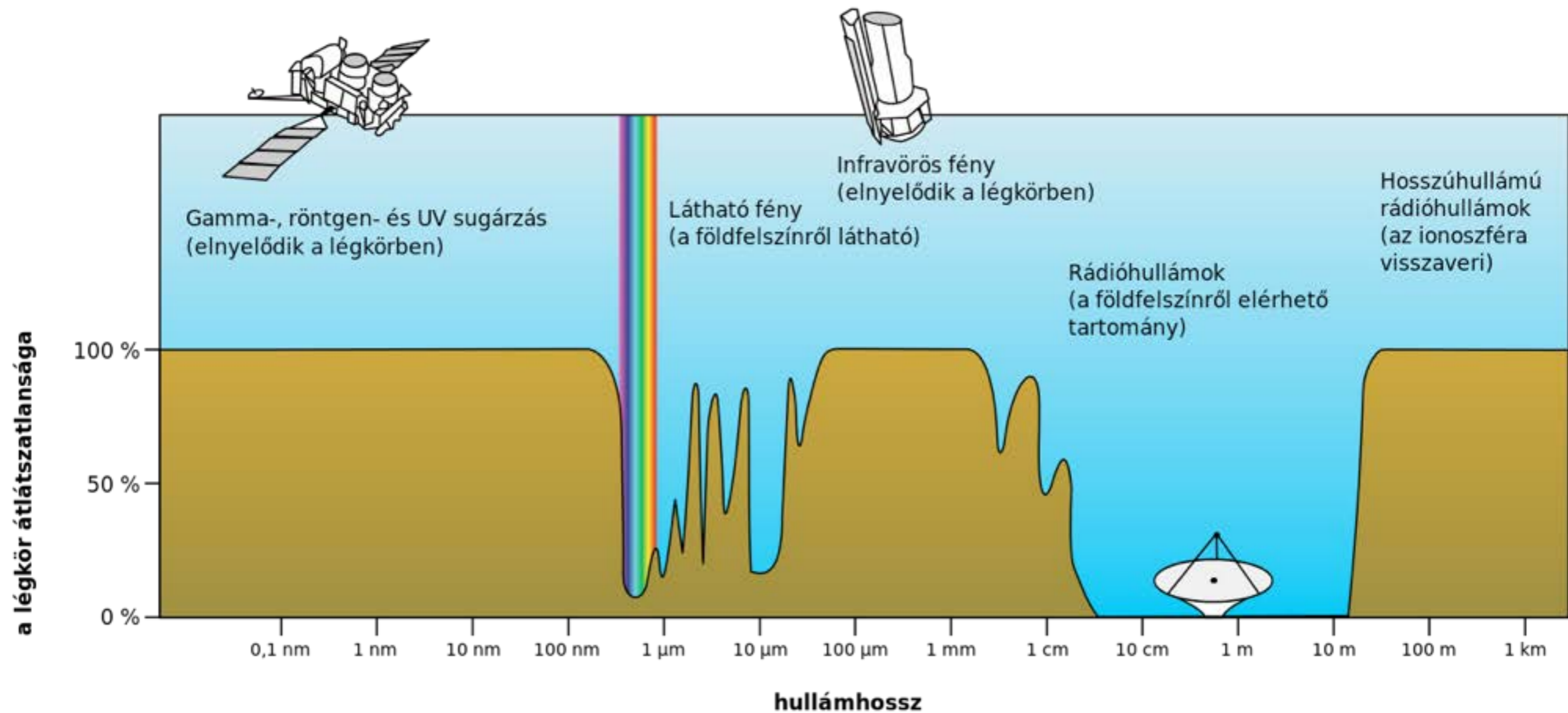
A földi légkör áteresztése



A földi légkör átteresztése



Infravörös sugárzás

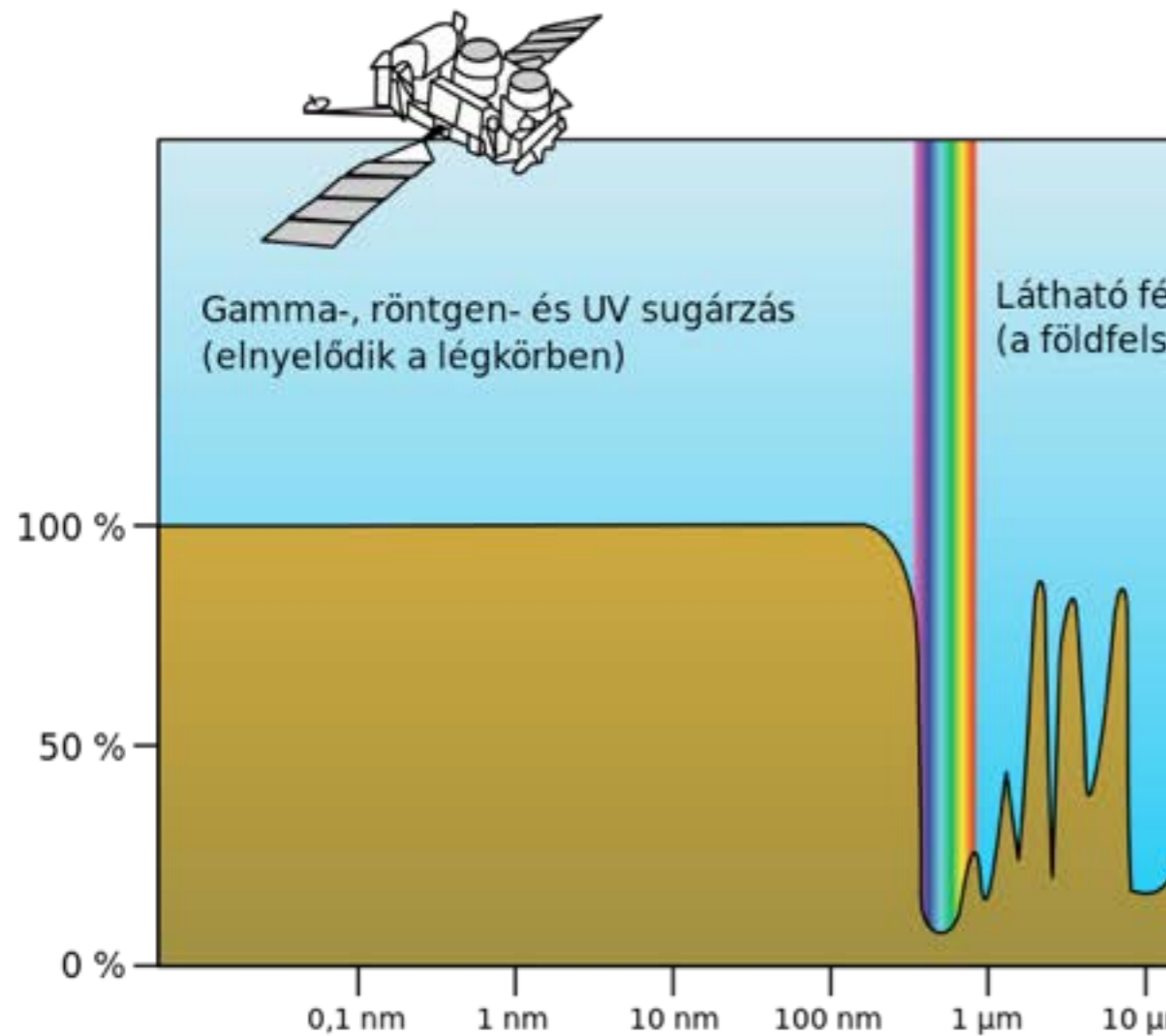


Infravörös sugárzás

Sir William Herschel
(1738-1822)



a légkör átlátszatlansága



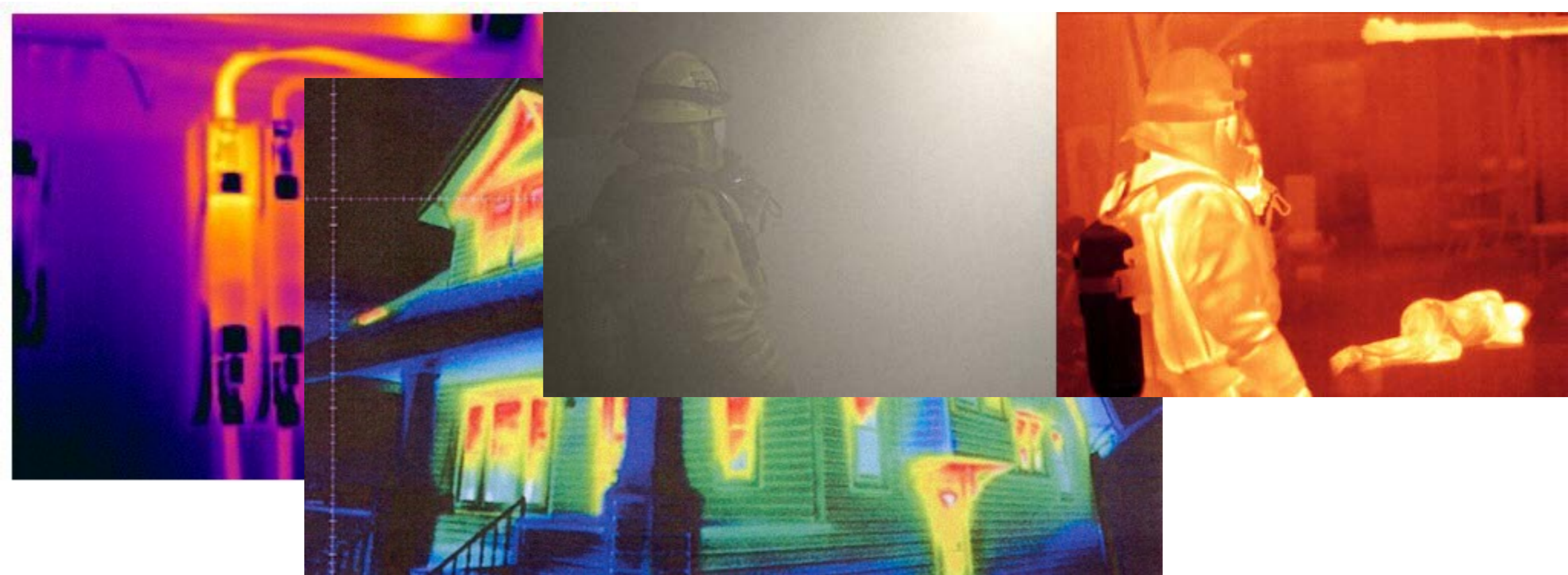
A világ infravörösben



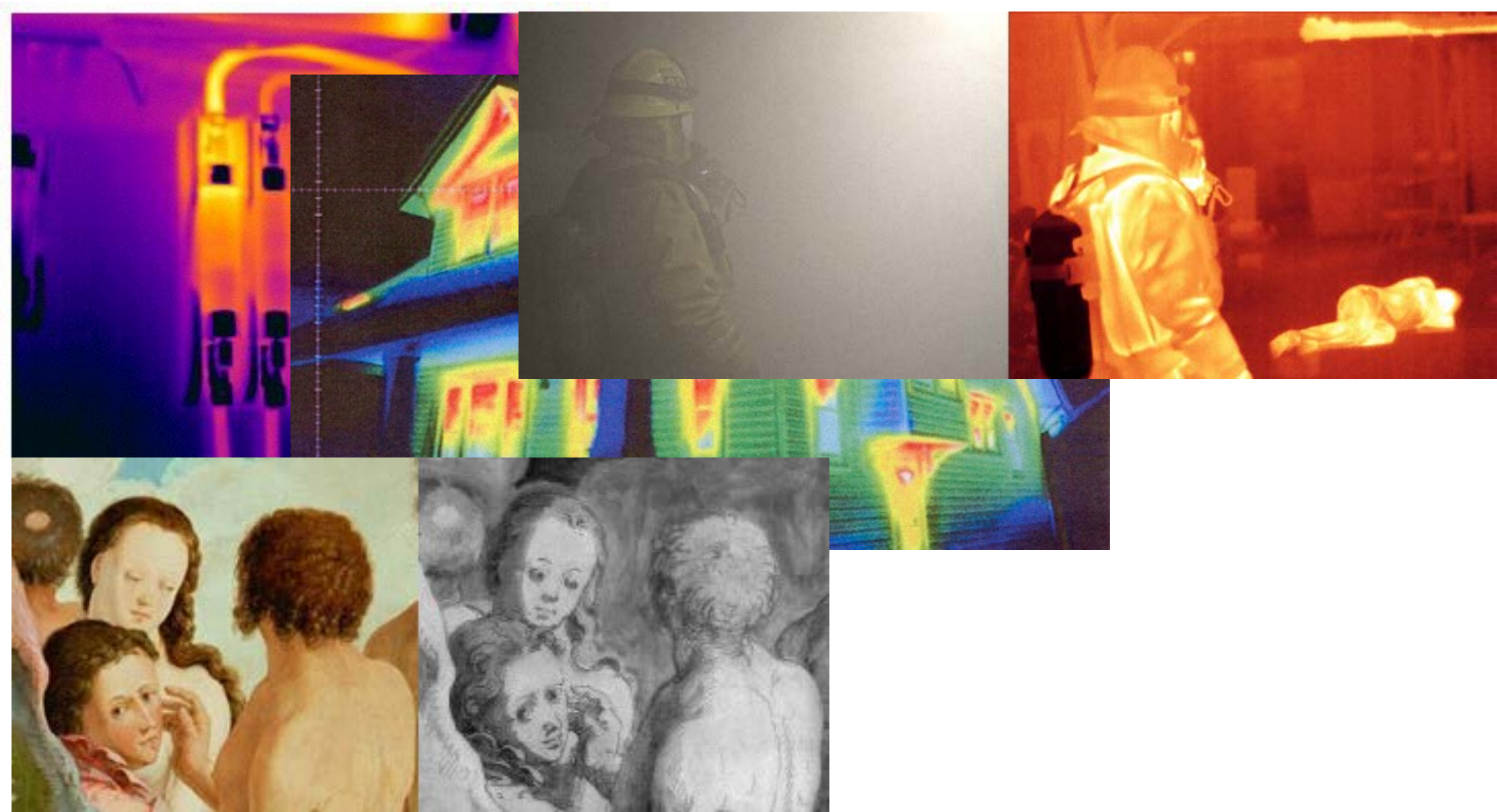
A világ infravörösben



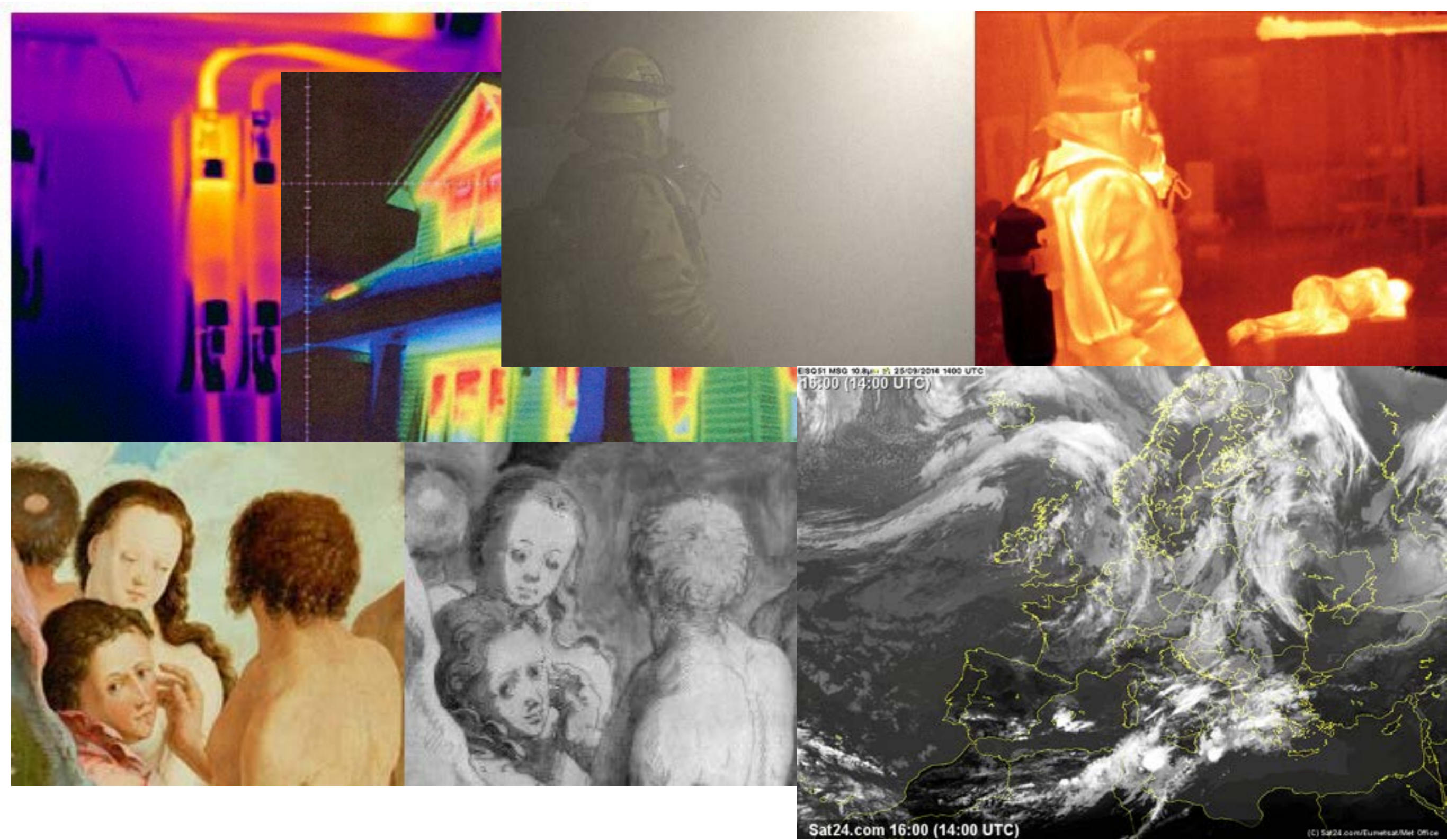
A világ infravörösben



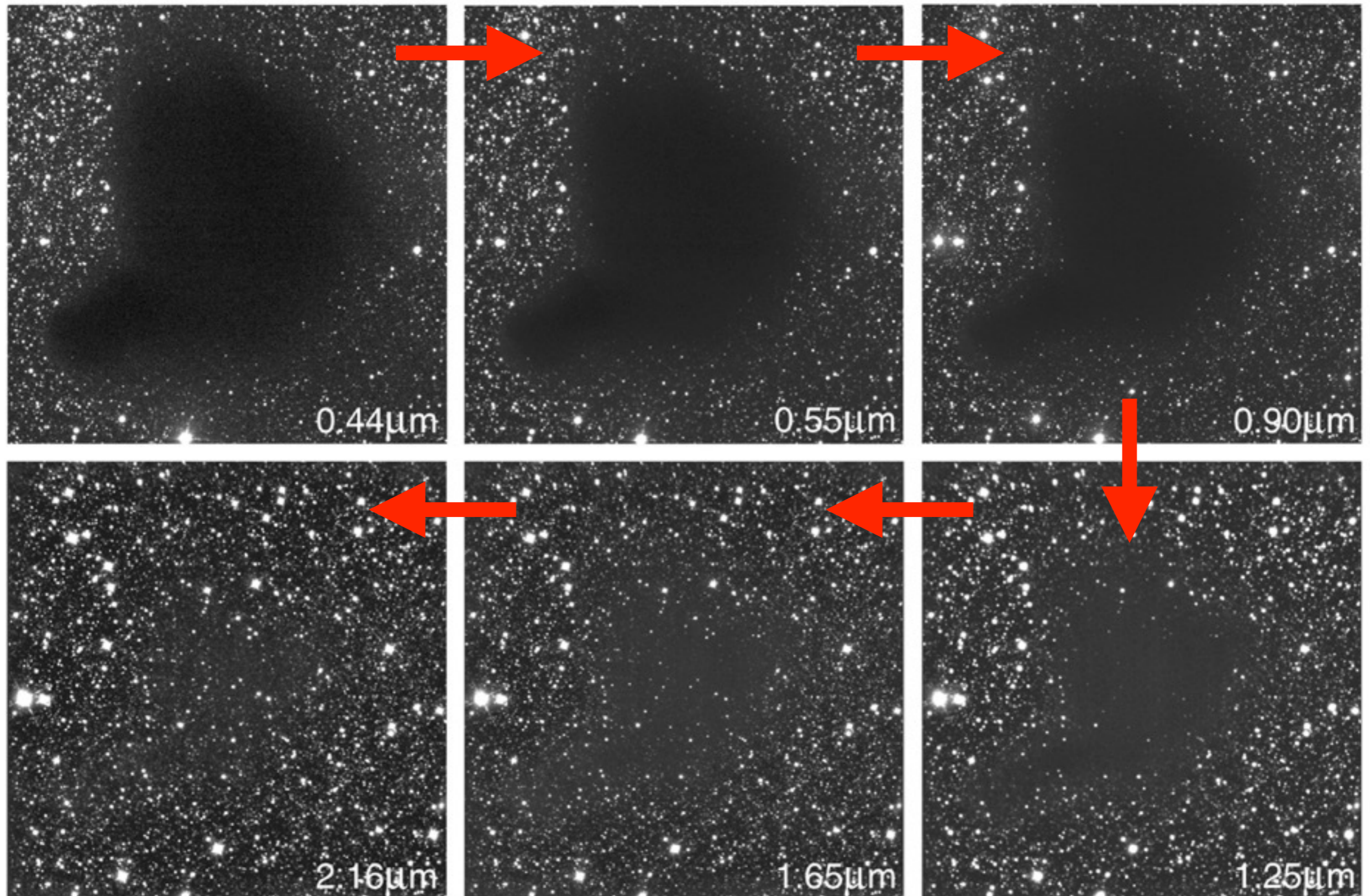
A világ infravörösben



A világ infravörösben

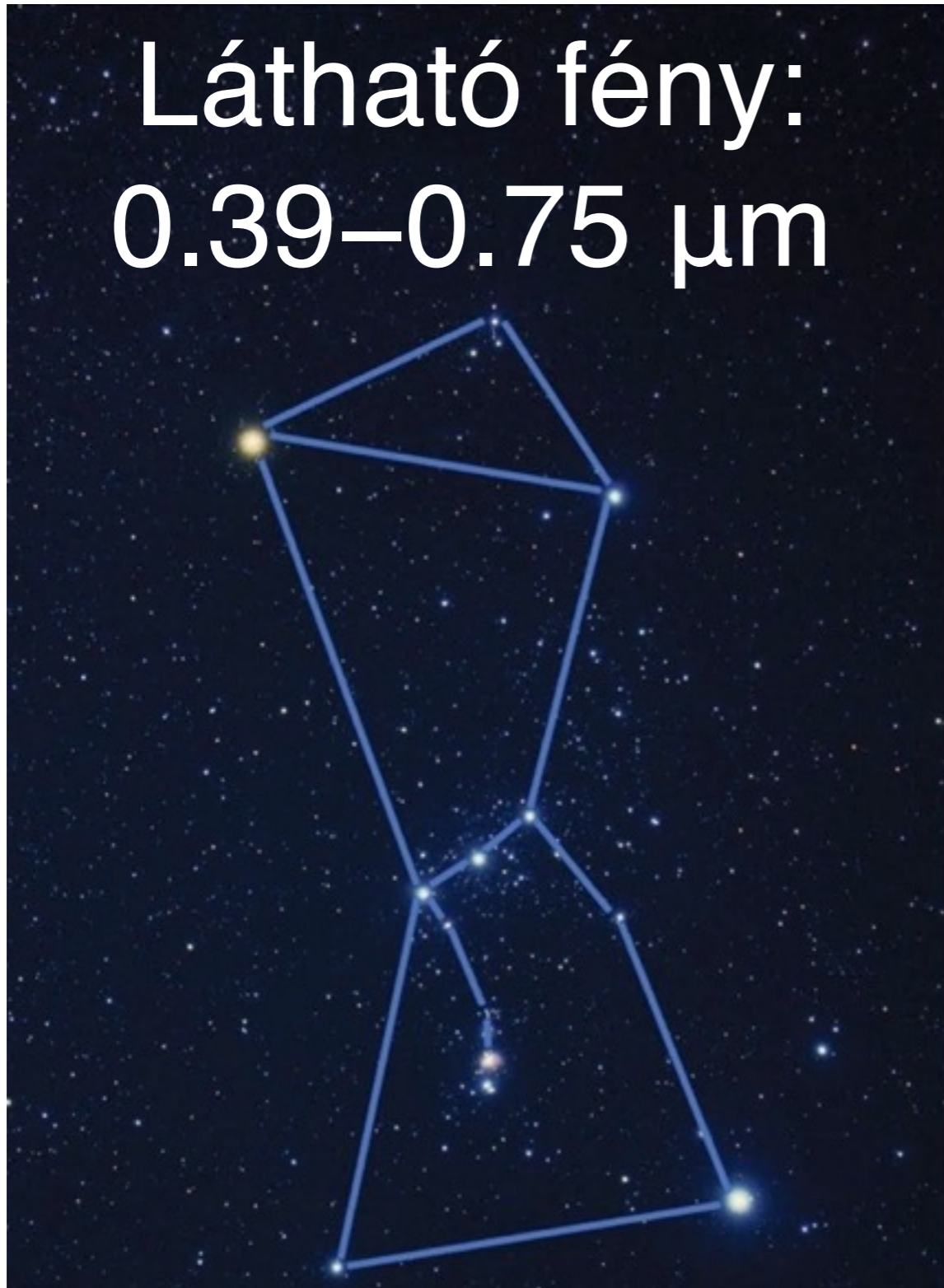


Az univerzum infravörösben



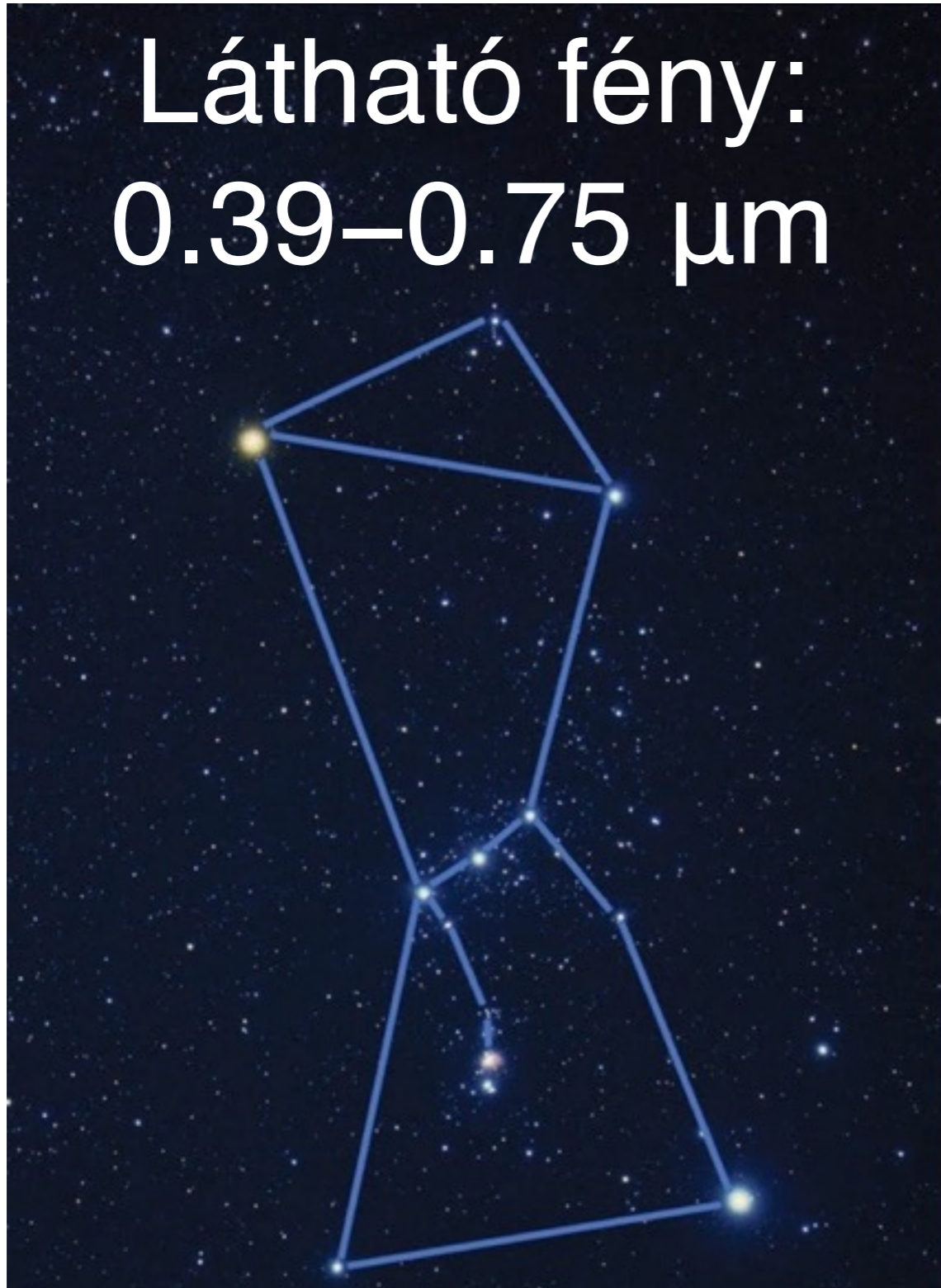
Az univerzum infravörösben

Látható fény:
0.39–0.75 μm

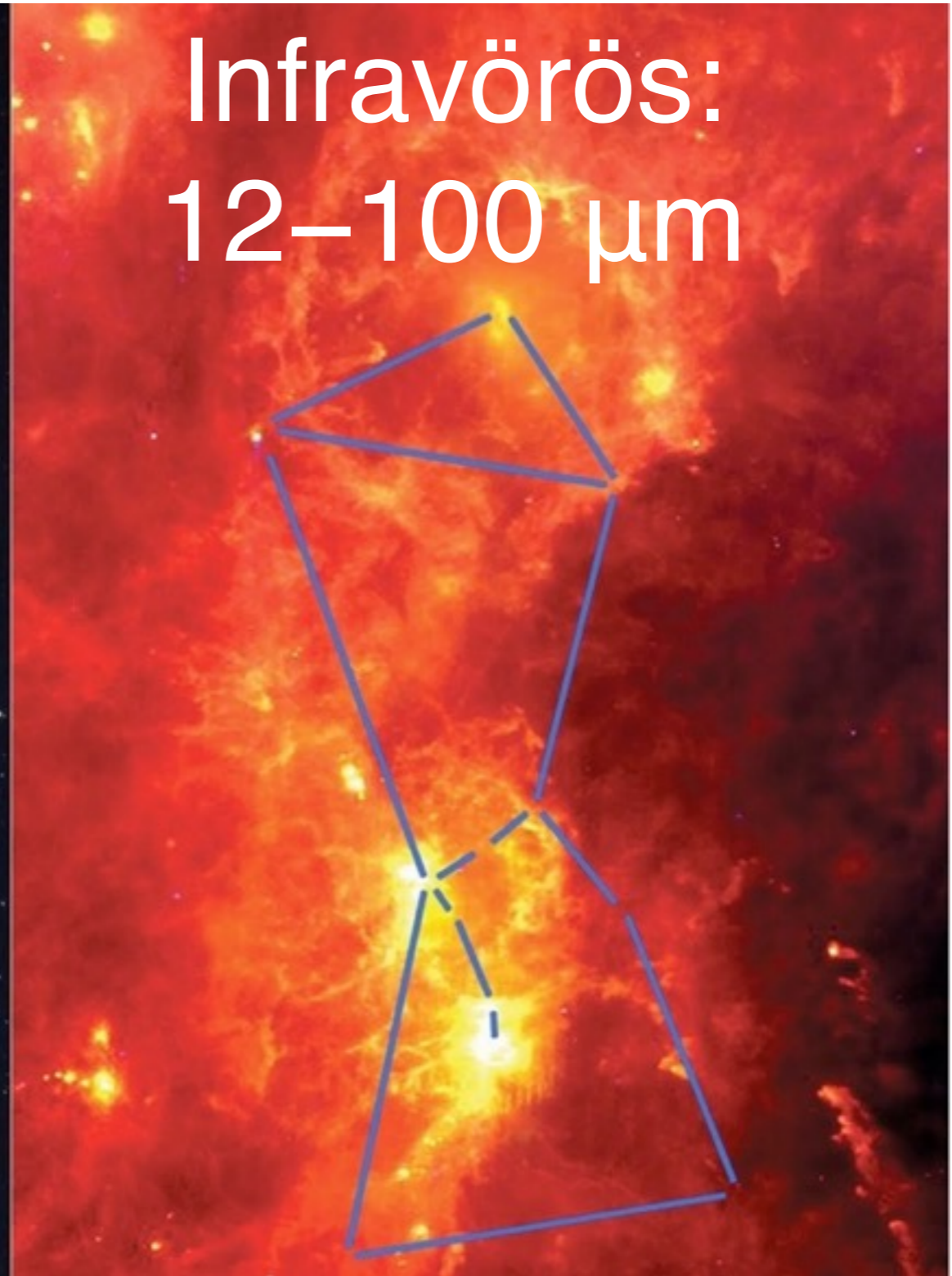


Az univerzum infravörösben

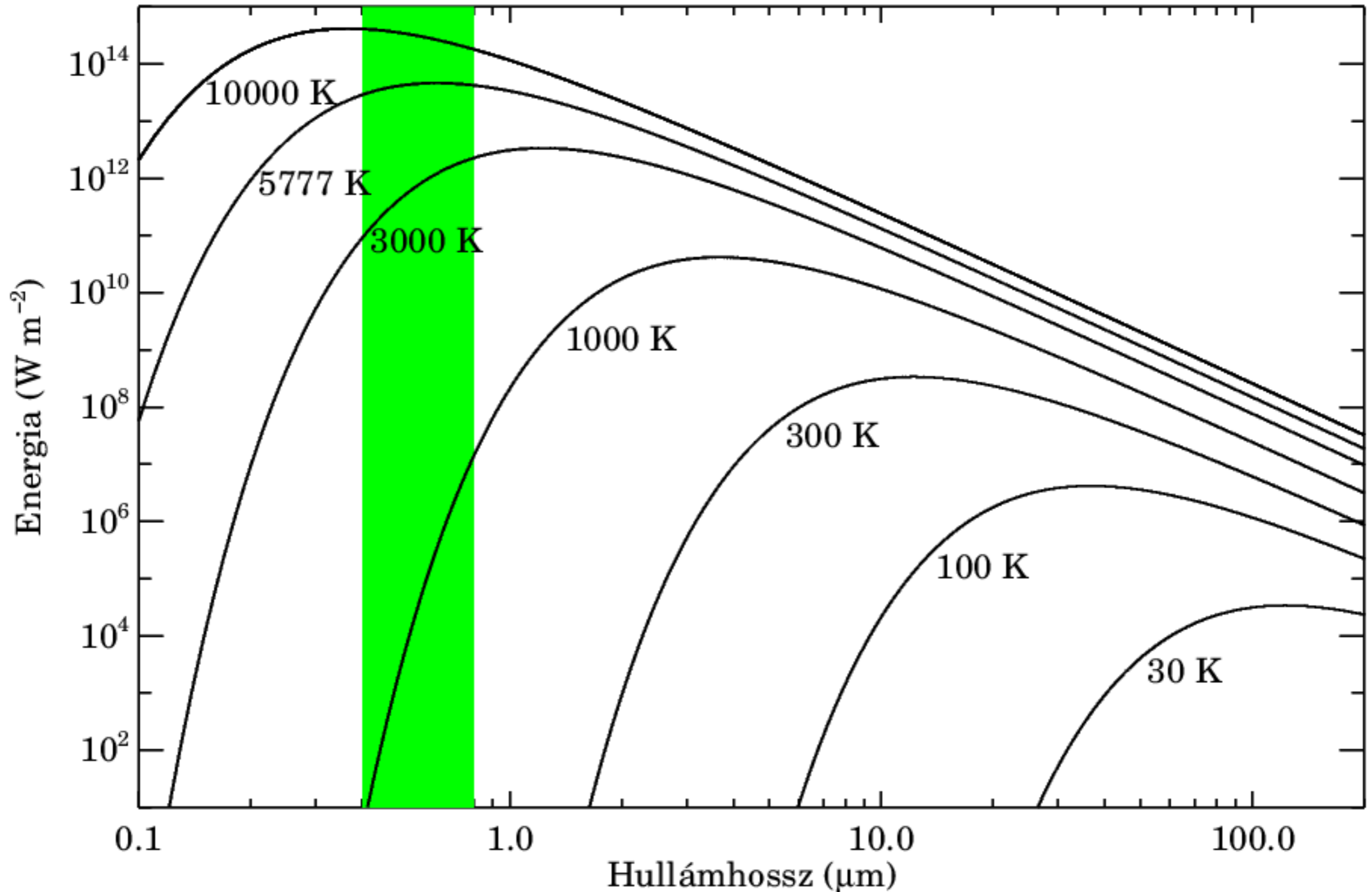
Látható fény:
0.39–0.75 μm



Infravörös:
12–100 μm



Hőmérsékleti sugárzás



Észak-Amerika köd



Ophiuchus



Cygnus X



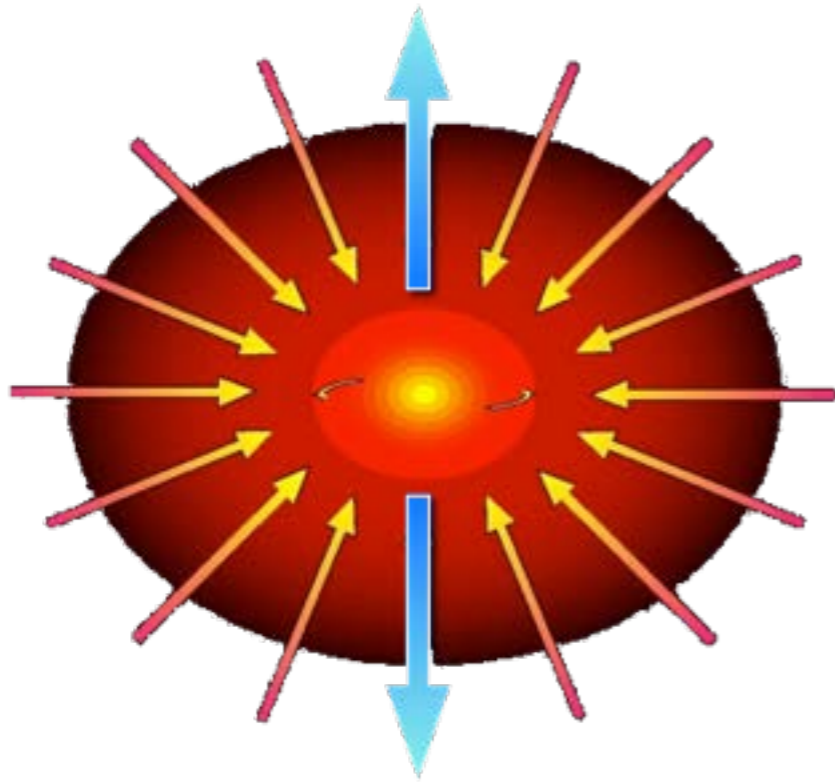
herchel

Carina köd

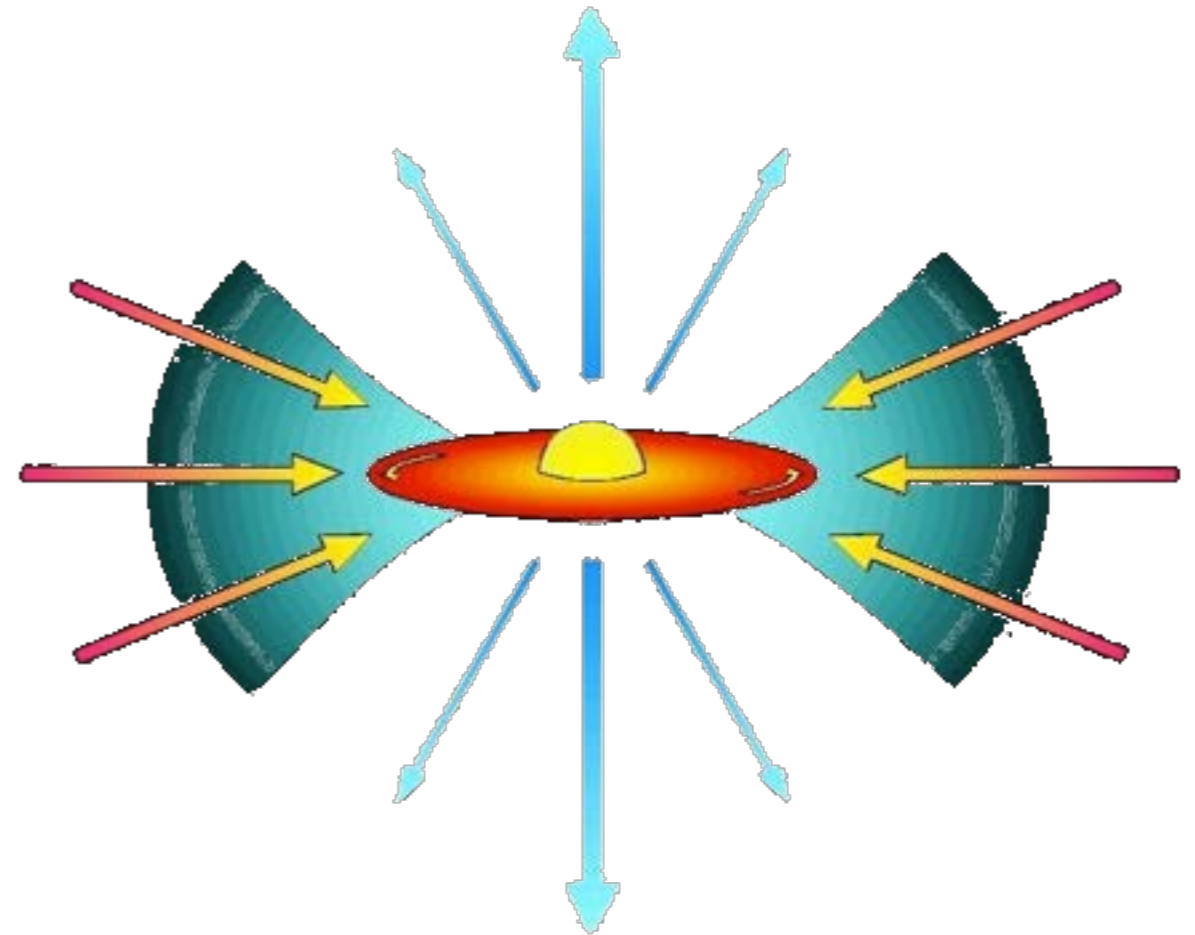


herschel

Csillagkeletkezés



0. osztály
10 000 év
10 000 CsE
10–300 K

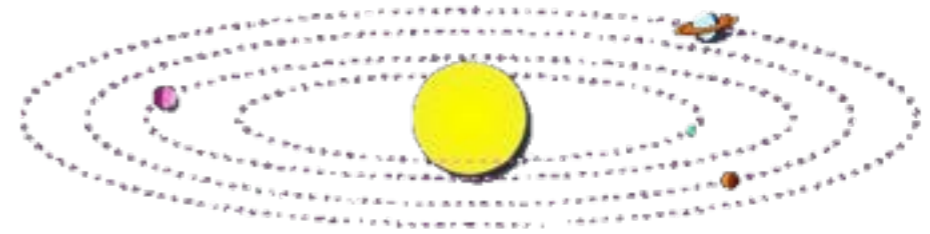


1. osztály
100 000 – 1 millió év
1000 CsE
100–3000 K

Csillagkeletkezés



2. osztály
1–10 millió év
100 CsE
100–5000 K



3. osztály
10 millió – 1 milliárd év
100 CsE
100–5000 K

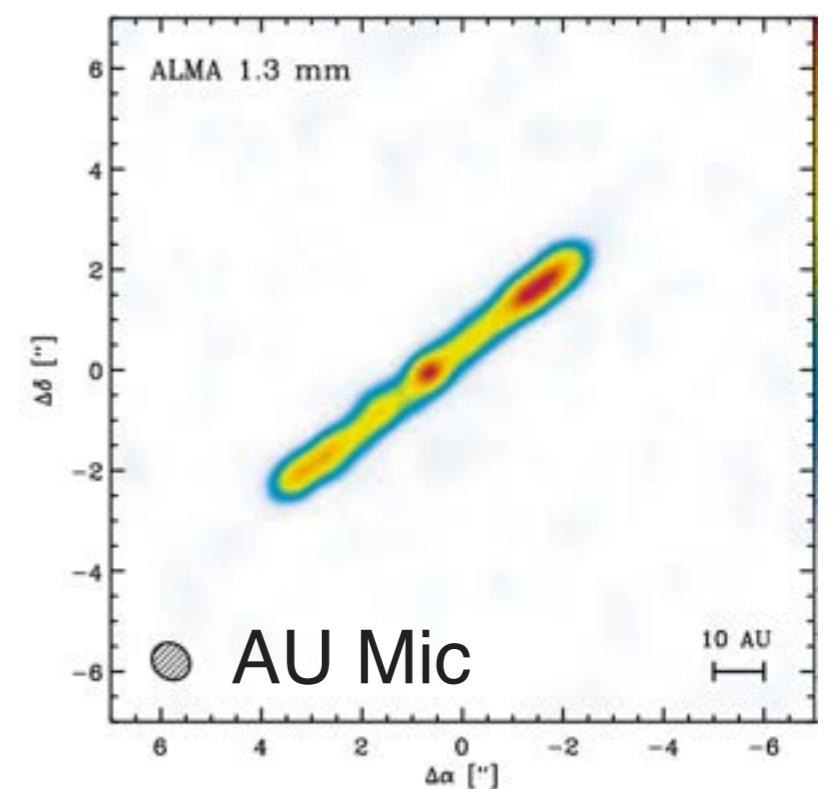
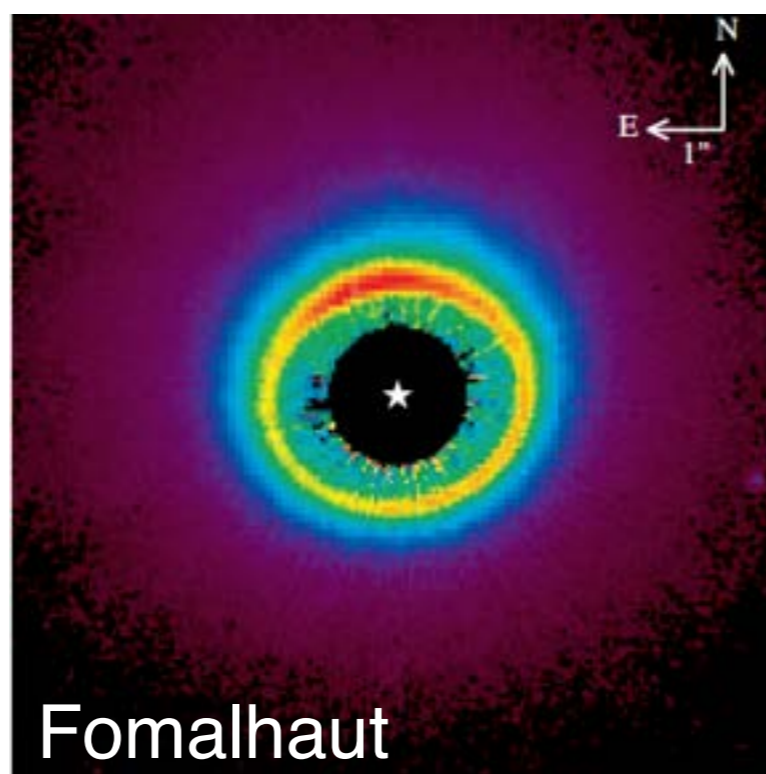
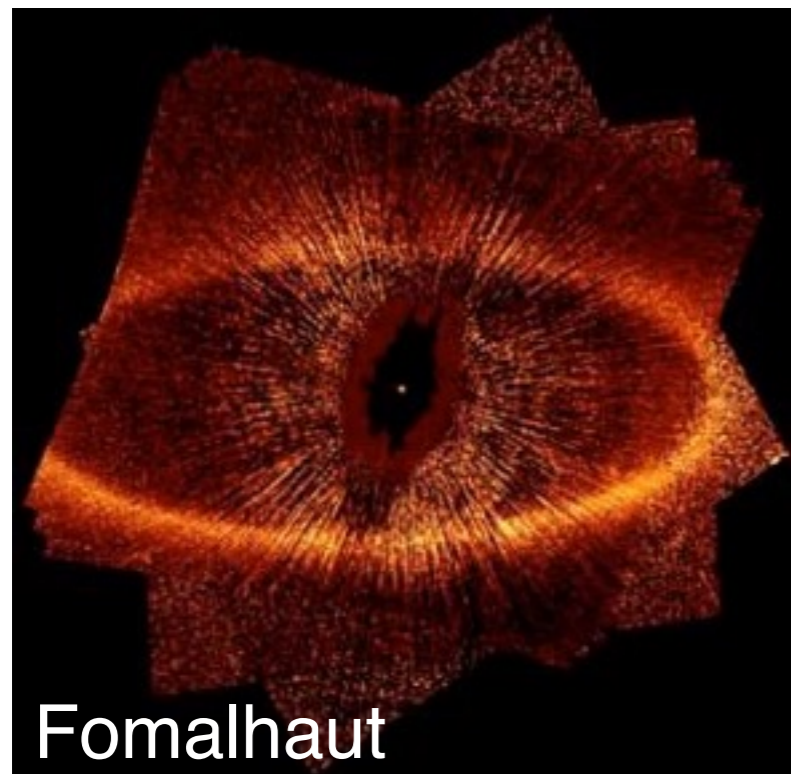
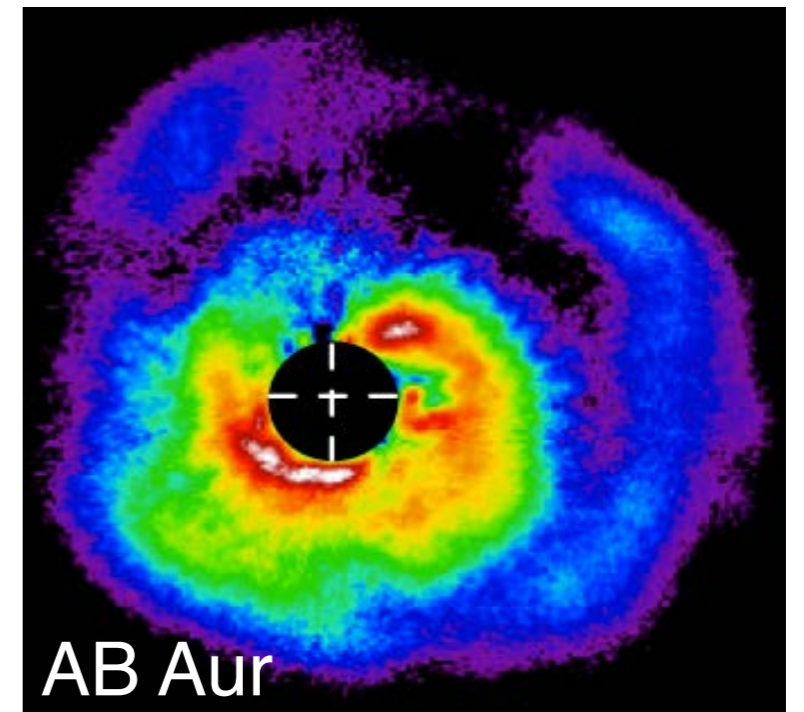
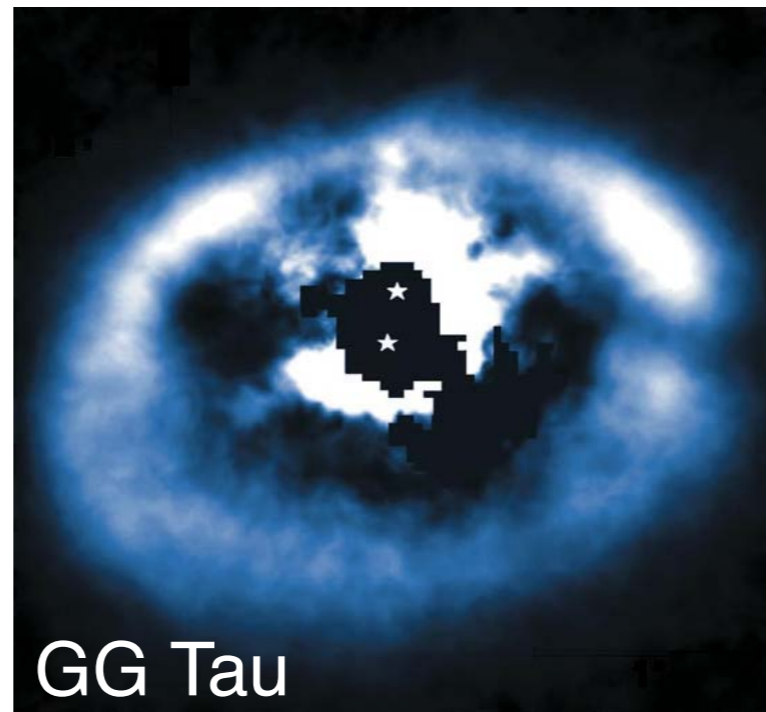
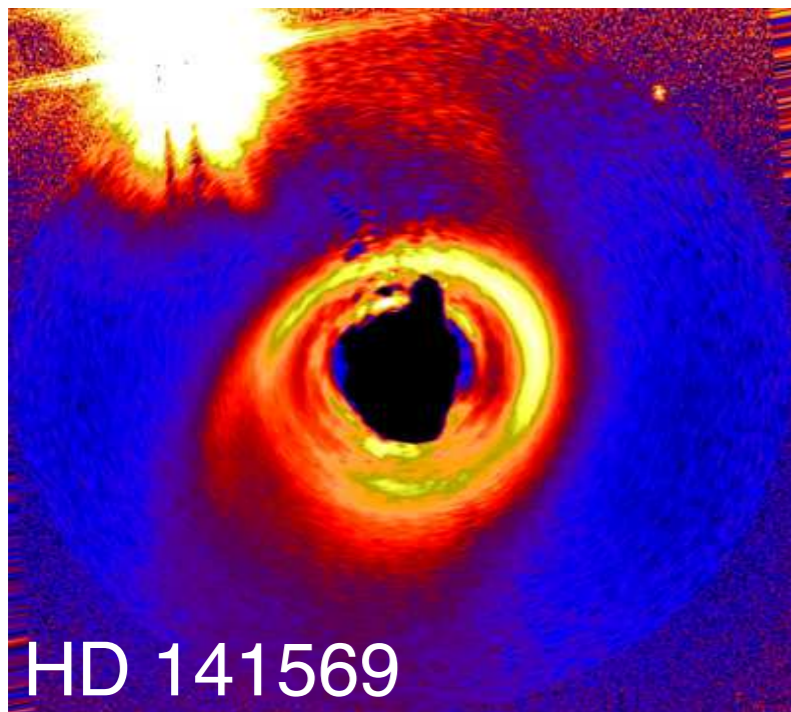
Csillagkörűli korongok

Ahogy a művész elképzeli:

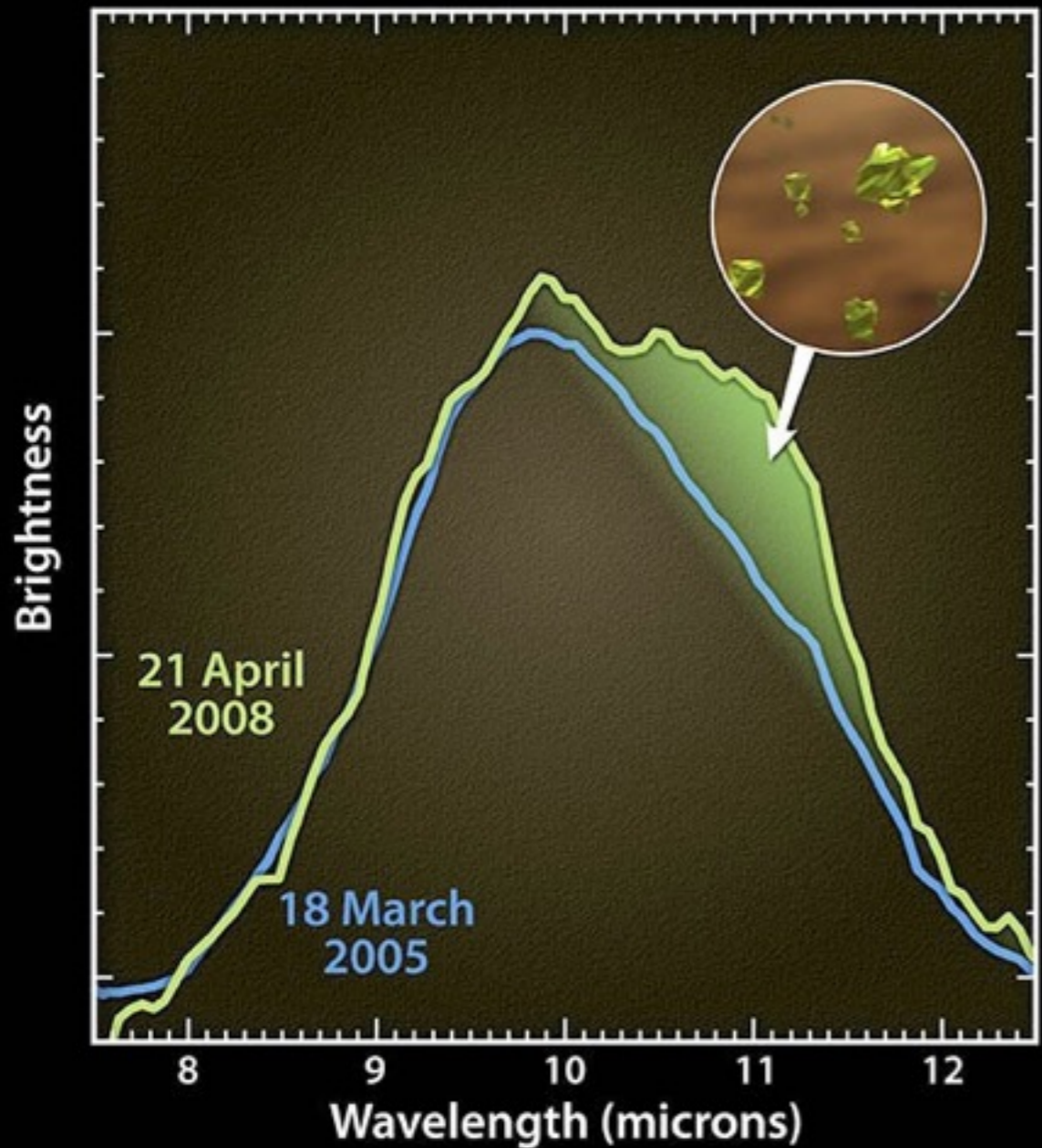


Csillagkörüli korongok

Ahogyan a csillagászok látják:

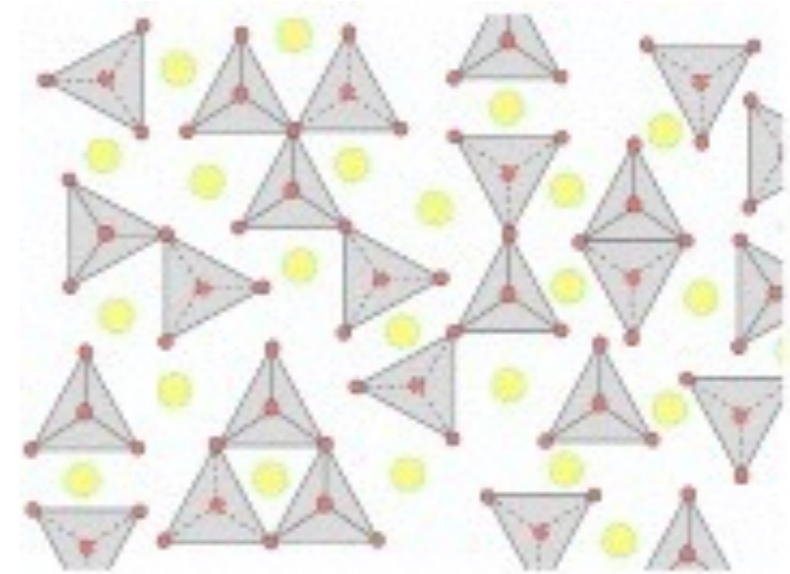


Kristályos szilikátok

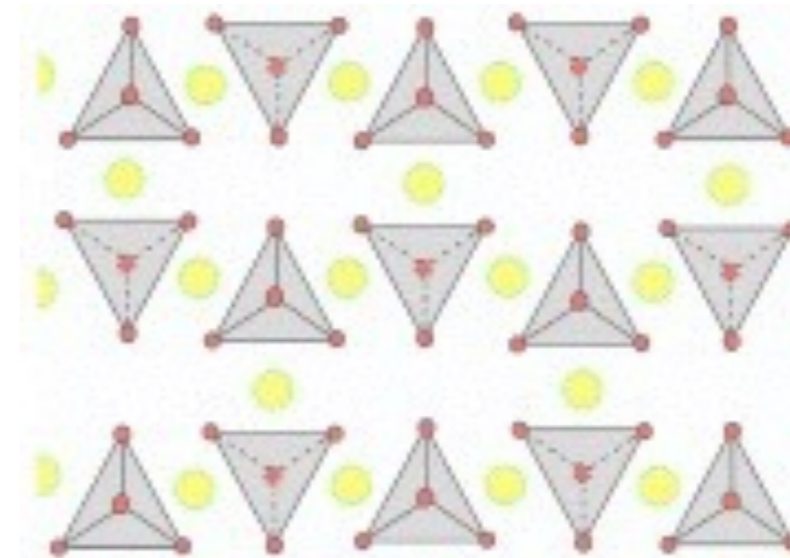


Crystal Formation in the Disk of an Erupting Star
Spitzer Space Telescope • IRS

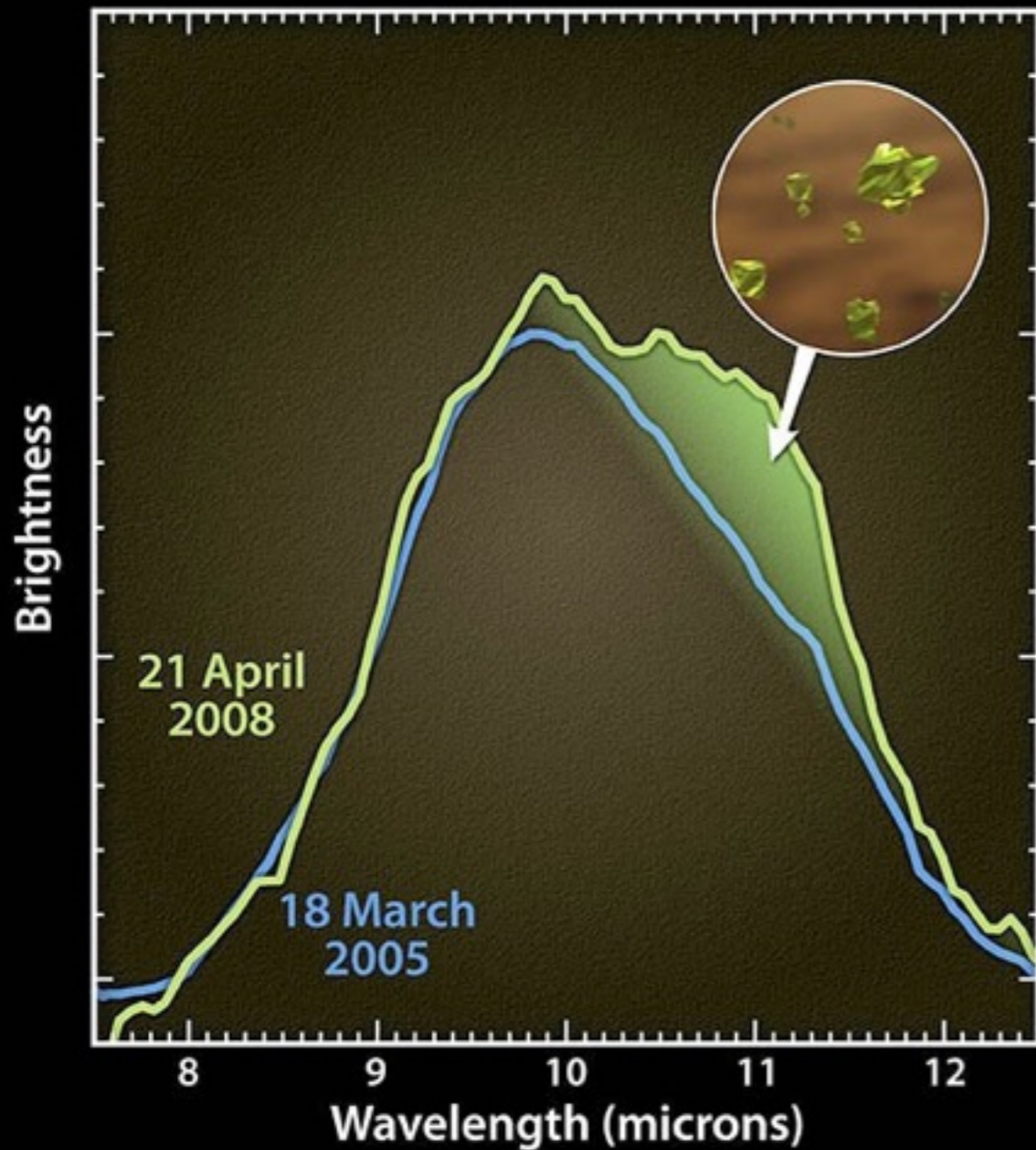
Amorf



Kristályos

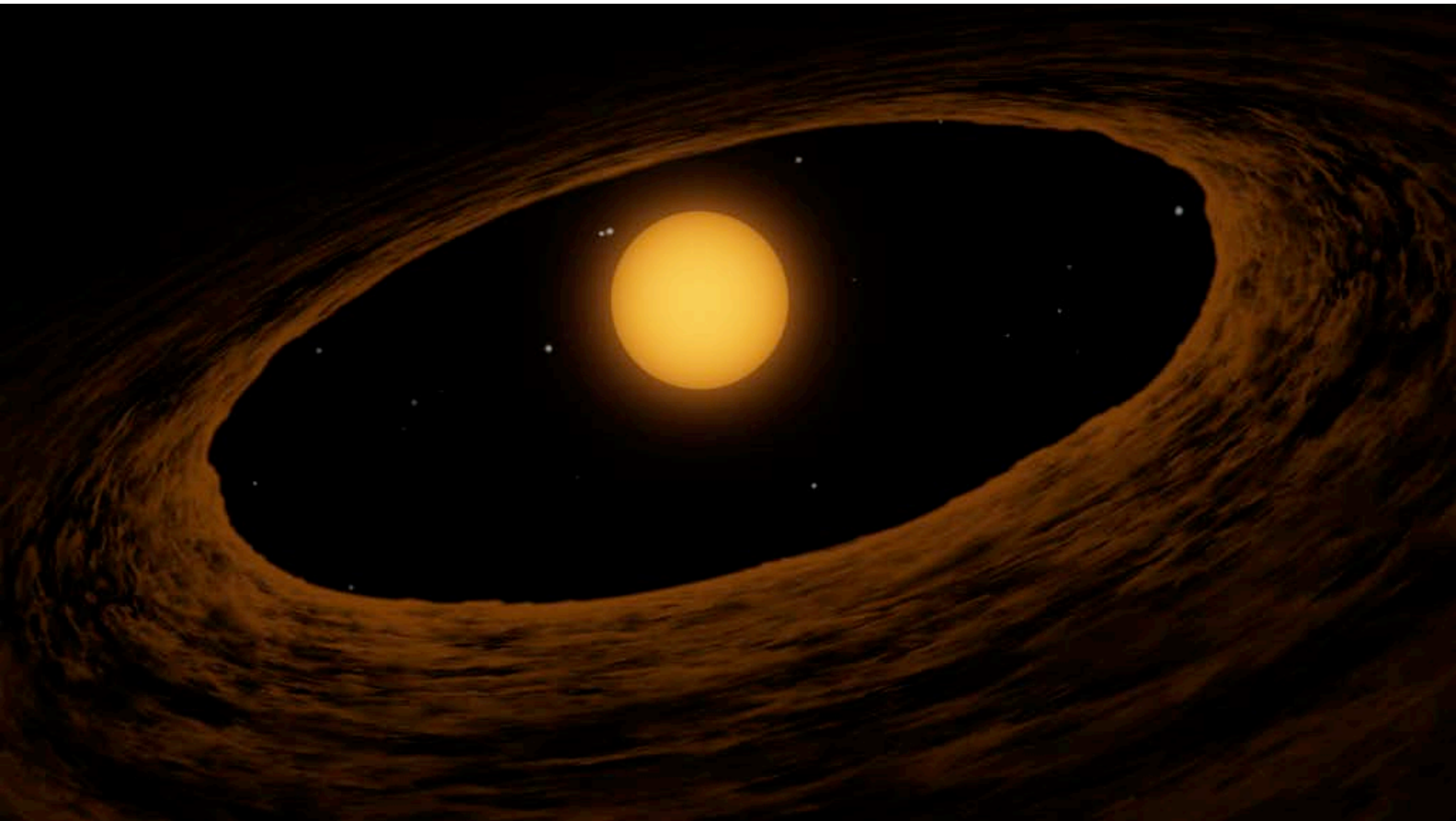


Kristályos szilikátok

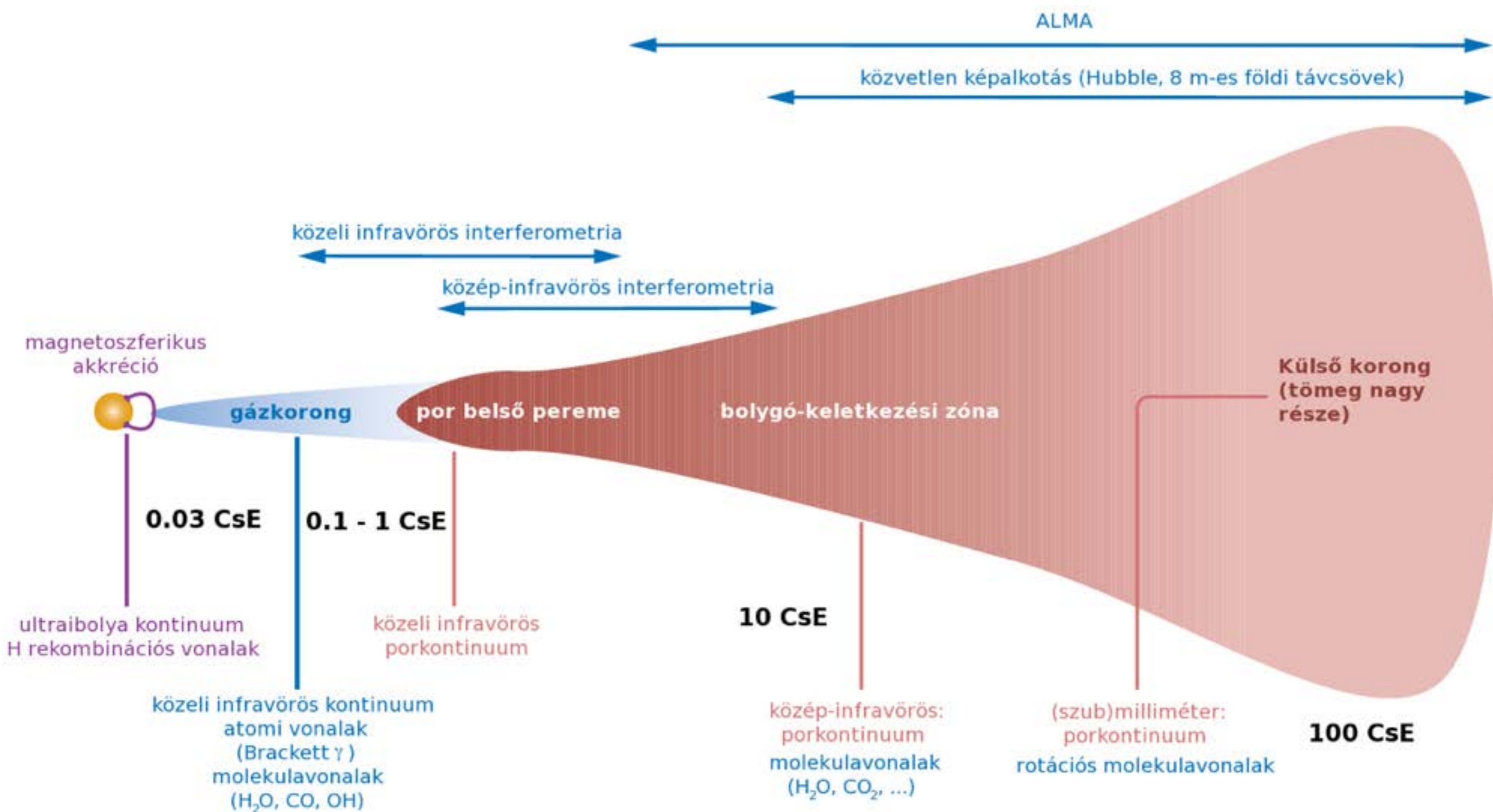


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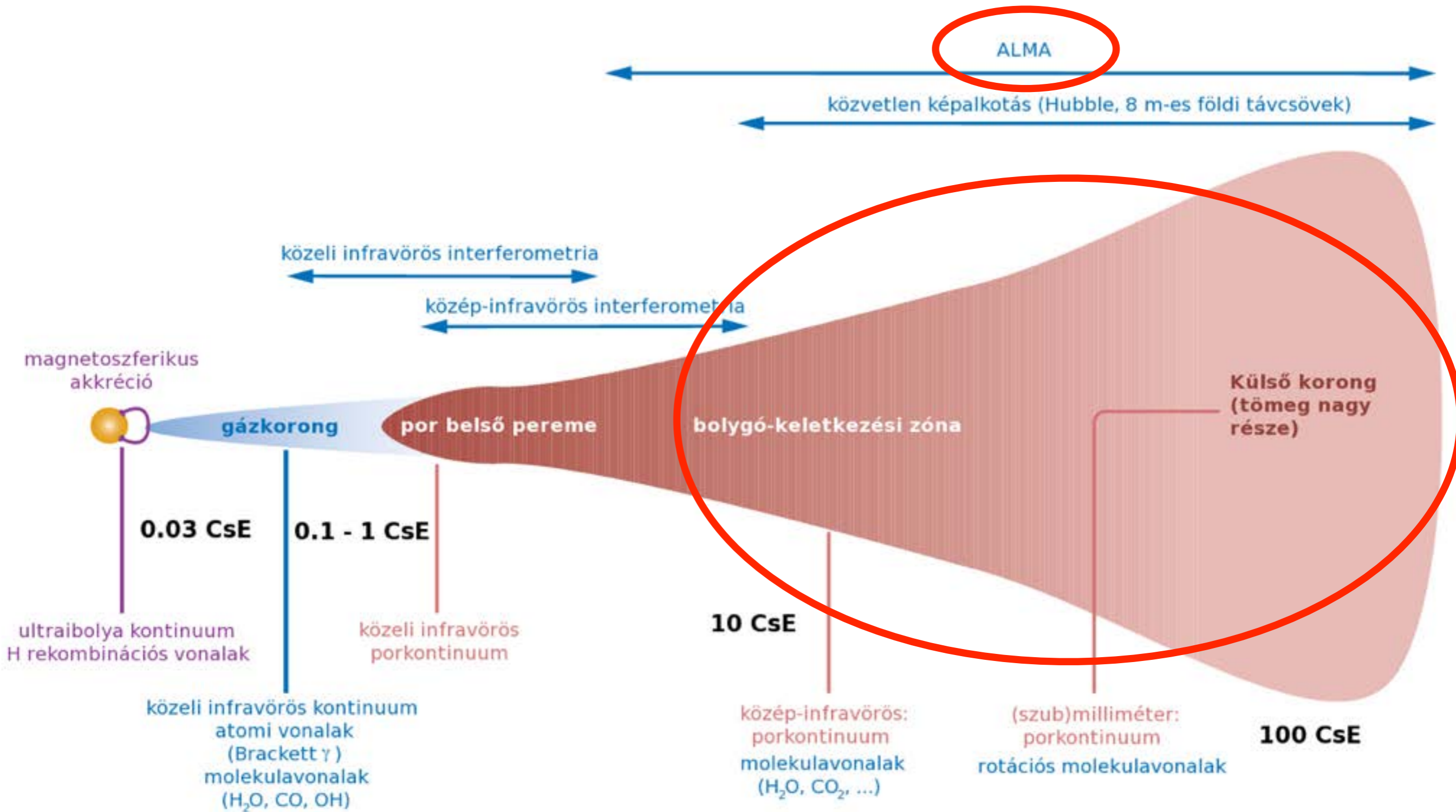
Kristályosodás a korongban



A csillagkörüli anyag vizsgálata



A csillagkörüli anyag vizsgálata



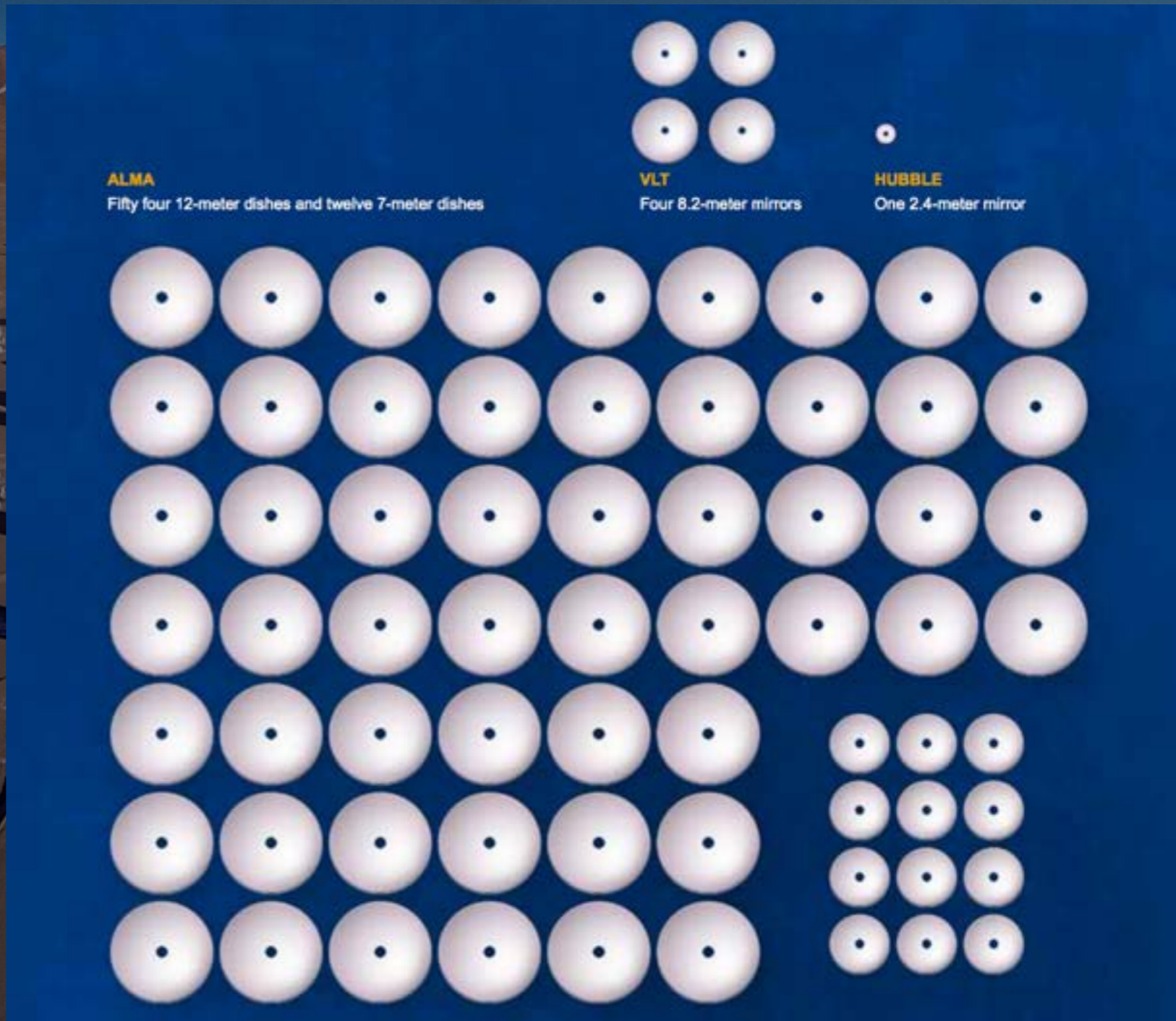
ALMA

Atacama Large Millimeter/submillimeter Array



ALMA

- 54 darab 12 méteres és 12 darab 7 méteres antenna
- Teljes fénygyűjtő felület: 6600 négyzetméter



ALMA

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- Teljes fénygyűjtő felület: 6600 négyzetméter
- Helyszín: Chile, Atacama sivatag, 5050 méter tengerszint feletti magasságban
- 0,3–3,6 milliméteres hullámhosszú sugárzást mér



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- Antennák felülete tökéletes parabola ($< 20 \mu\text{m}$)



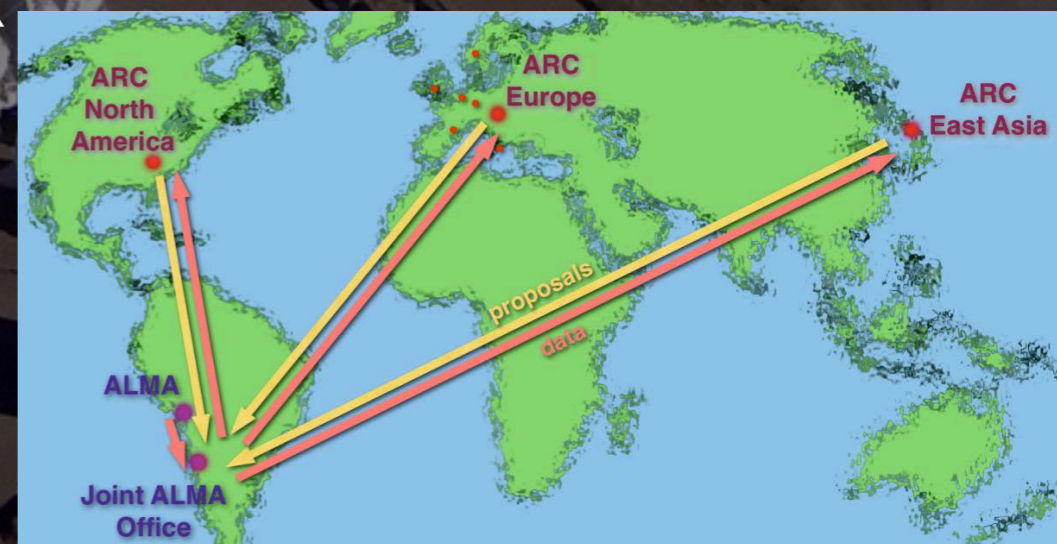
ALMA

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- Térbeli felbontás: 0.006" (golflabda 1500 km-ről)



ALMA

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- Teljes fénygyűjtő felület: 6600 négyzetméter
- Helyszín: Chile, Atacama sivatag, 5050 méter tengerszint feletti magasságban
- 0,4–3,1 milliméteres hullámhosszú sugárzást mér
- Antennák felülete tökéletes parabola ($< 20 \mu\text{m}$)
- Térbeli felbontás: $0.006''$ (golflabda 1500 km-ről)
- Építési költsége: 1 milliárd EUR (globális összefogás)



Az ALMA korrelátor



Az ALMA korrelátor

- A világ egyik legnagyobb szuperszámítógépe
- 134 millió processzor
- 17 peta-FLOP sebesség (17000000000000000 művelet másodpercenként)
- Antennákról másodpercenként 1 gigabyte adat érkezik
- 700 terabyte adatot kell tárolni évente
- Tipikus asztali számítógép vagy laptop
- 1–4 processzor
- 2–8 giga-FLOP sebesség (8000000000 művelet másodpercenként)
- Másodpercenként 1–10 megabyte adat az internetről
- 500 gigás – 1 terás tárolókapacitás

Az ALMA korrelátor

- A világ egyik legerősebb szuperszámítógépe **10 milliószor gyorsabb** egy közepes asztali számítógép vagy laptop
- 134 millió processzor, minden egységben 1–4 processzor
- 17 peta-FLOP sebesség (17000000000000000 művelet másodpercenként)
- 2–8 giga-FLOP sebesség (8000000000 művelet másodpercenként)
- Antennákról másodpercenként 1 gigabyte adat érkezik
- Másodpercenként 1–10 megabyte adat az internetről
- 700 terabyte adatot kell tárolni évente
- 500 gigás – 4 terás tárolókapacitás

Az ALMA energiafogyasztása

- Energiaigény: 4,2 MW
- Éves energiafogyasztás: 36,8 GWh (kisebb város teljes fogyasztása)
- Üzemanyag: LPB (cseppfolyós propán-bután)
- Éves üzemanyag-fogyasztás: 17,3 millió liter (7 darab olimpiai úszómedencét töltené ki)
- Éves költség: 10 millió dollár



ALMA Radio Telescope

Sitio de operaciones
del conjunto de ALMA

CBI/QUIET

ALMA transzporterek



ALMA transzporterek



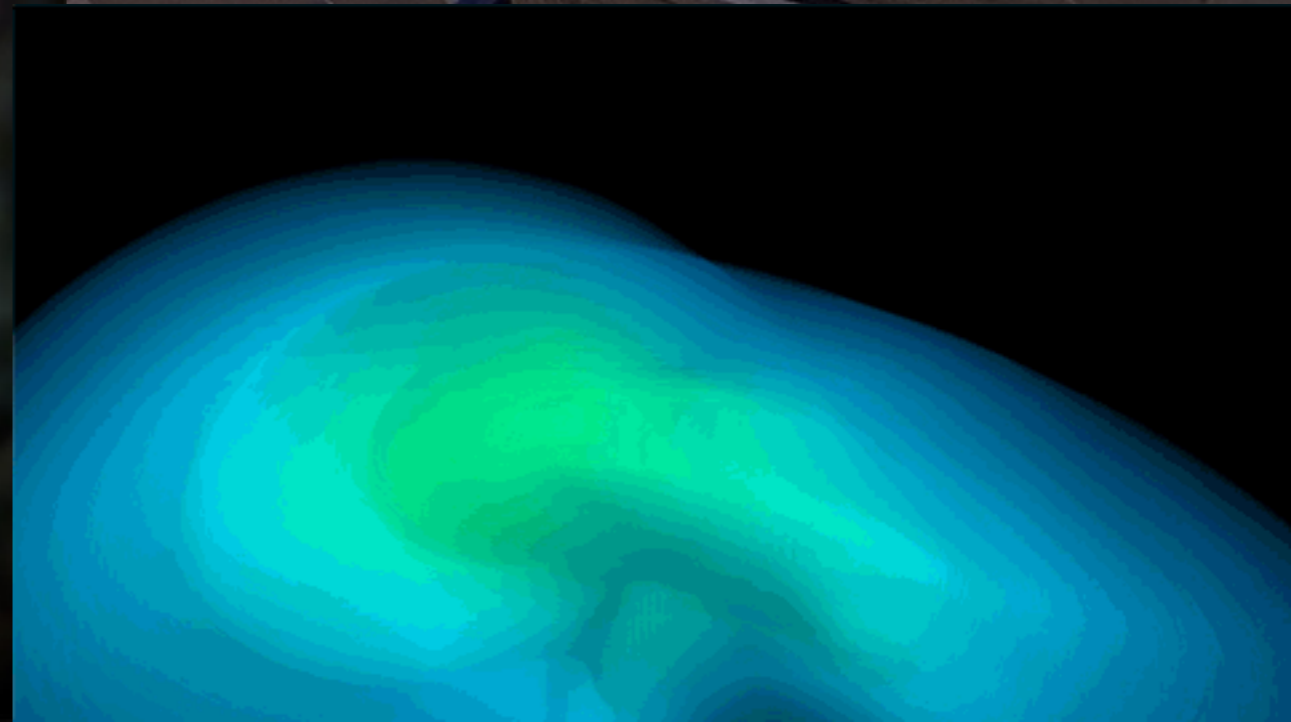
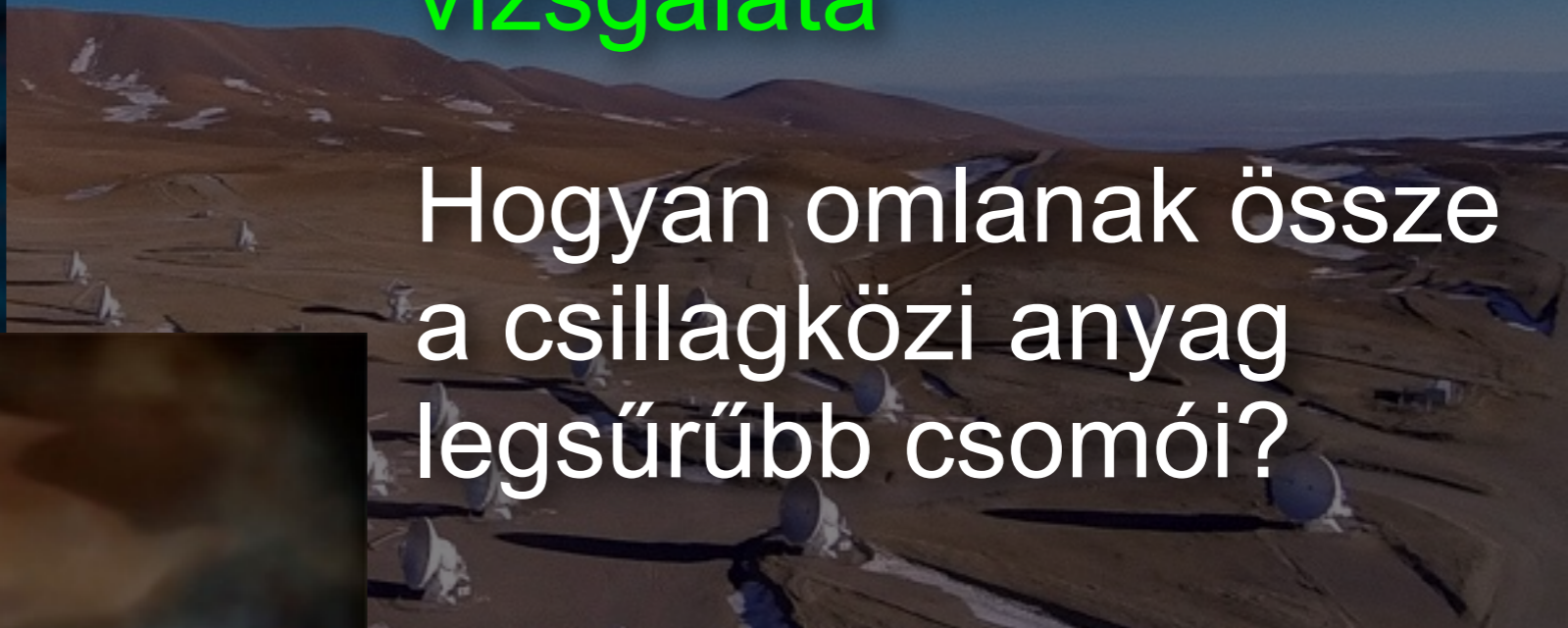
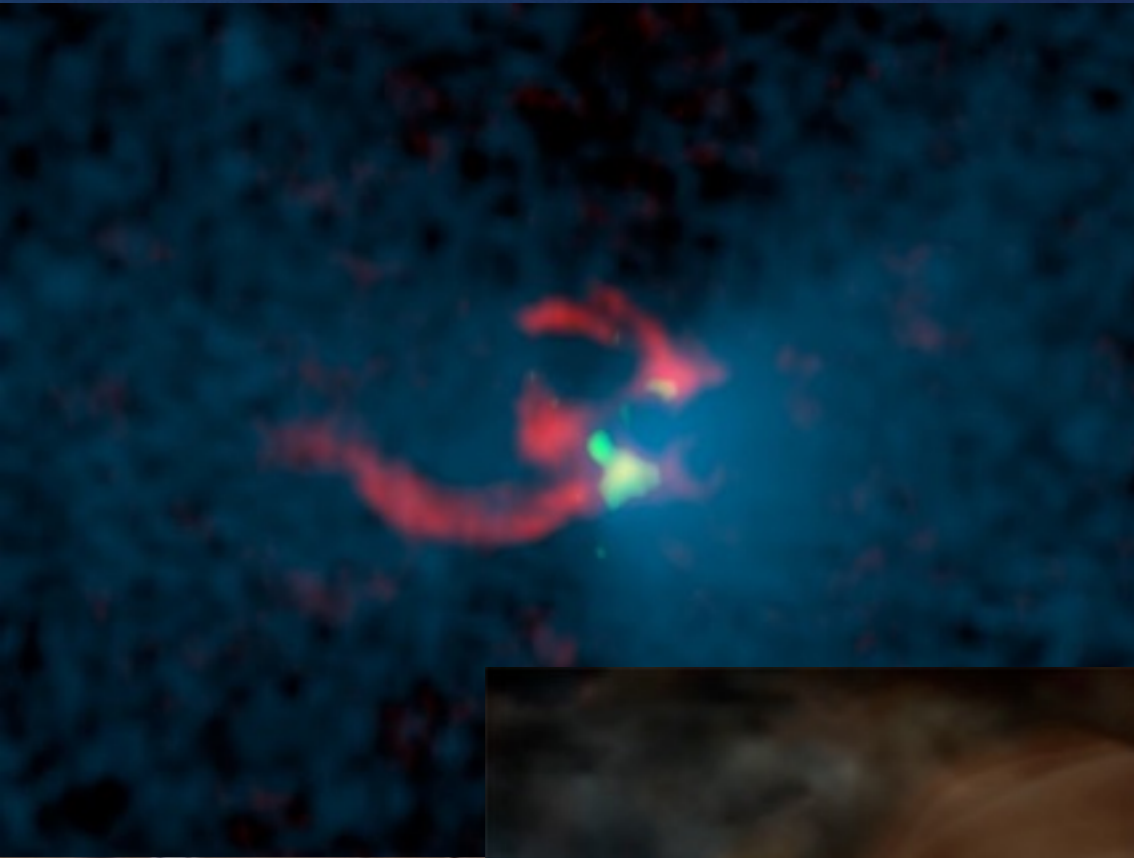
ALMA transzporterek



Korong-kutatás ALMA-val

A csillagkeletkezés
legkoraibb fázisainak
vizsgálata

Hogyan omlanak össze
a csillagközi anyag
legsűrűbb csomói?



Korong-kutatás ALMA-val

Közeli kettősök vizsgálata

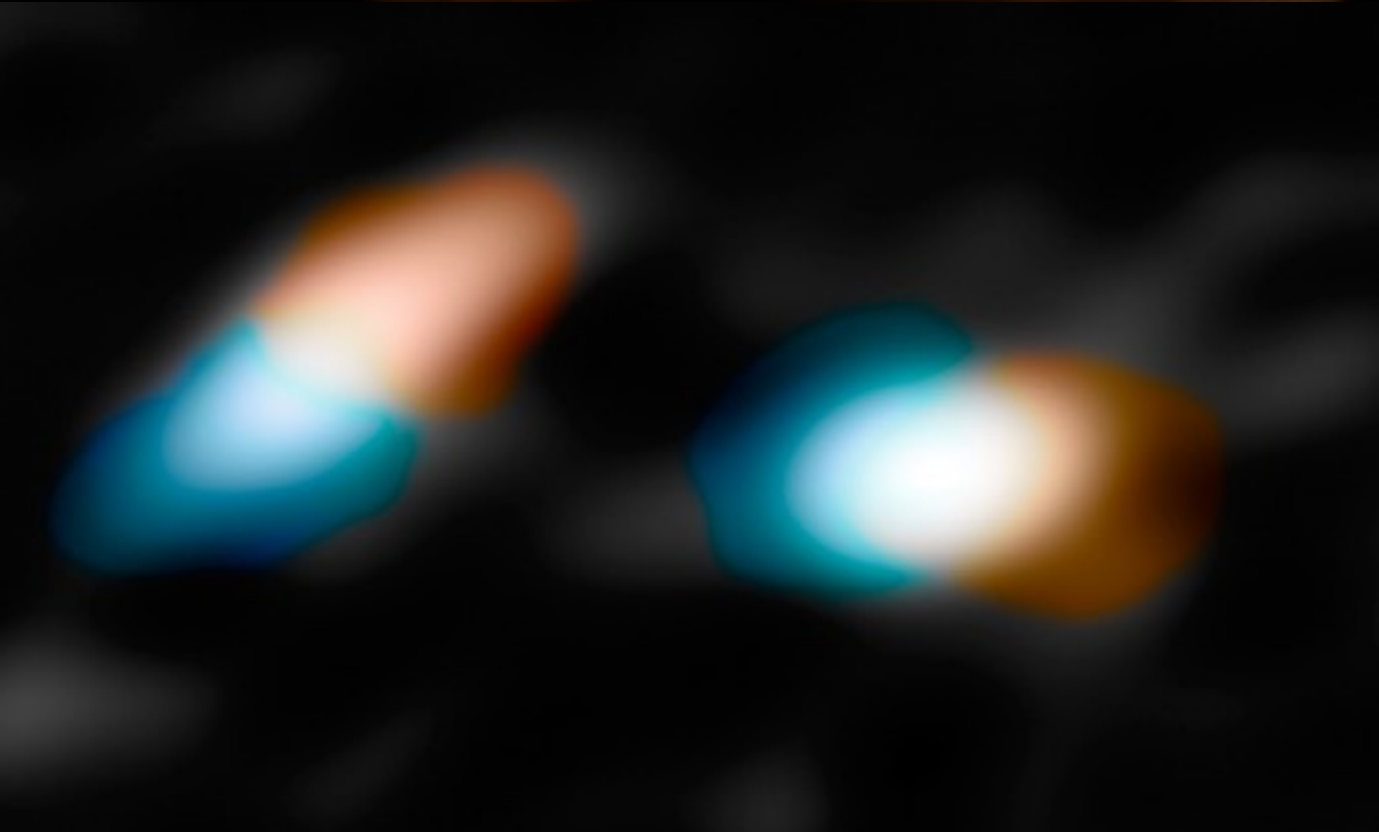
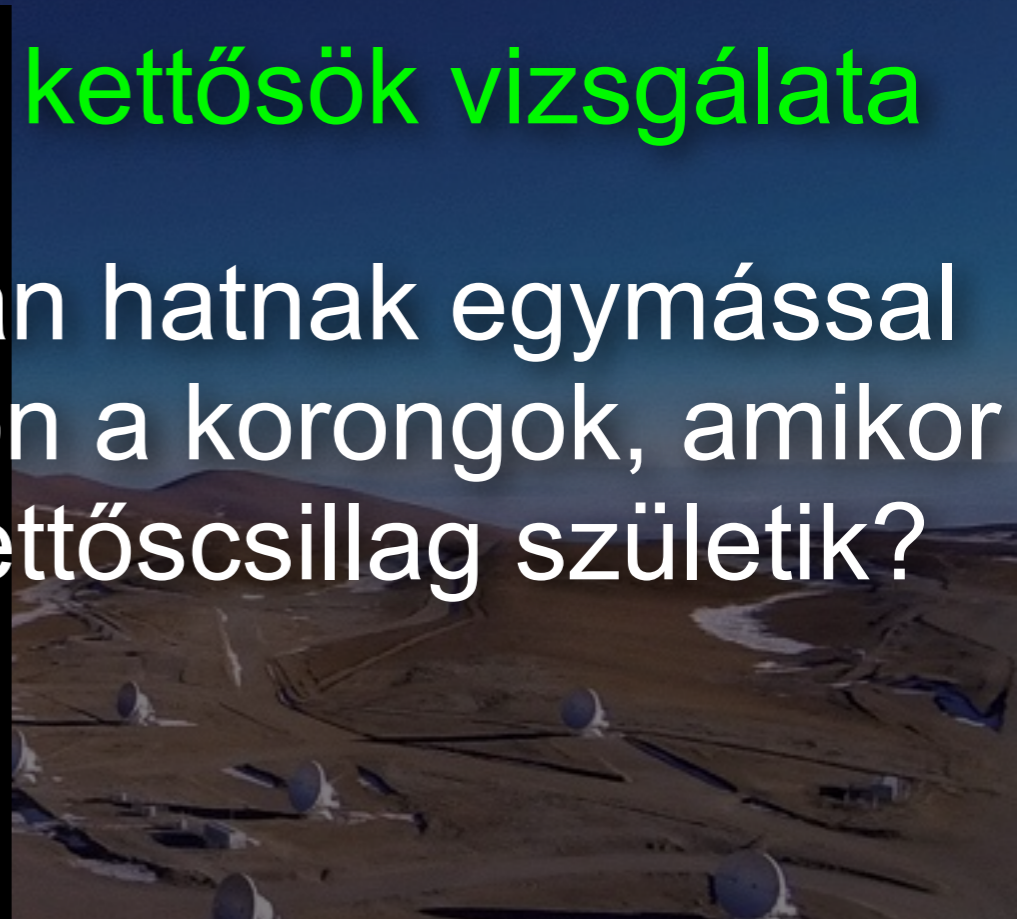
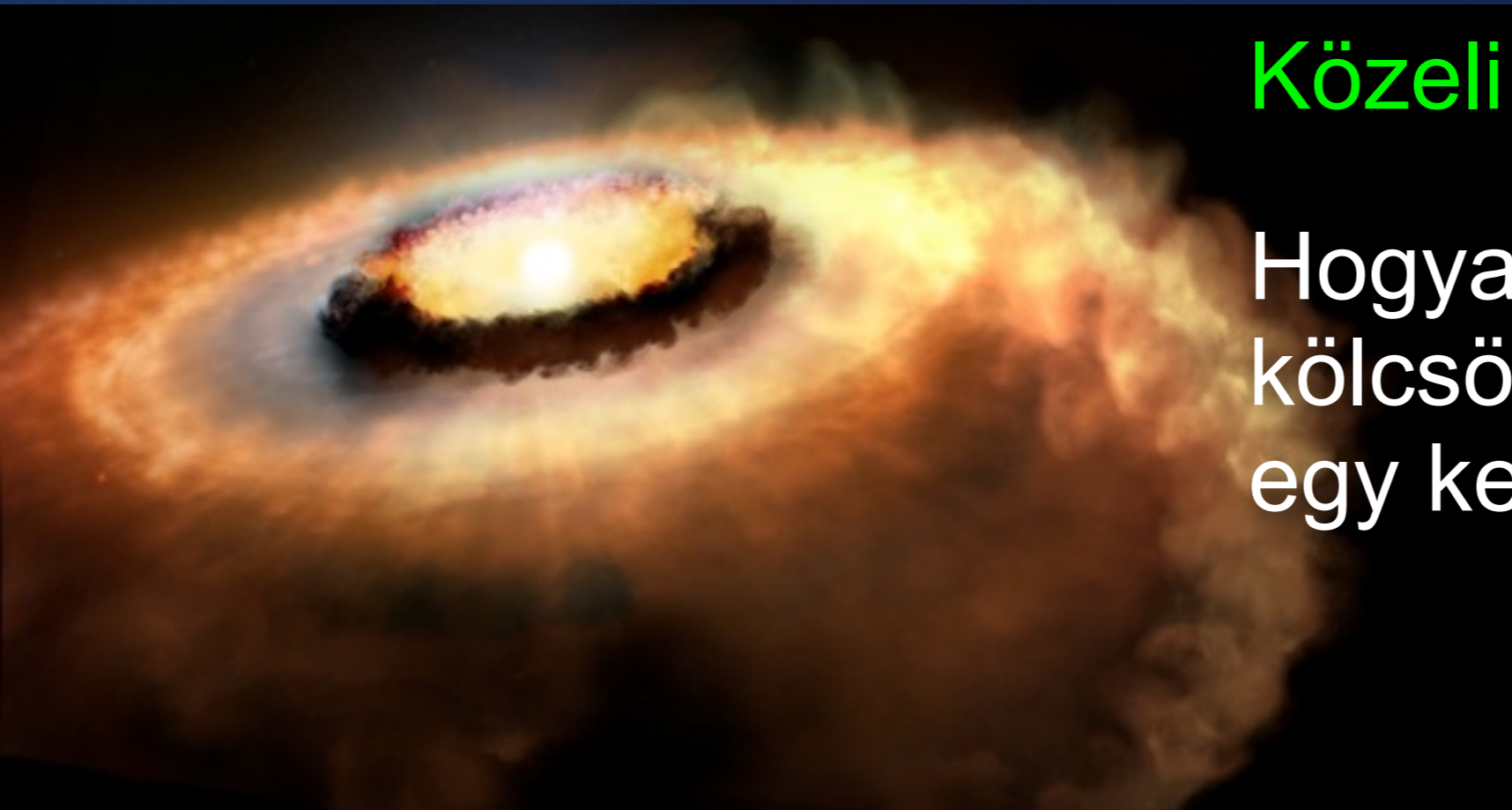
Hogyan hatnak egymással kölcsön a korongok, amikor egy kettőscsillag születik?



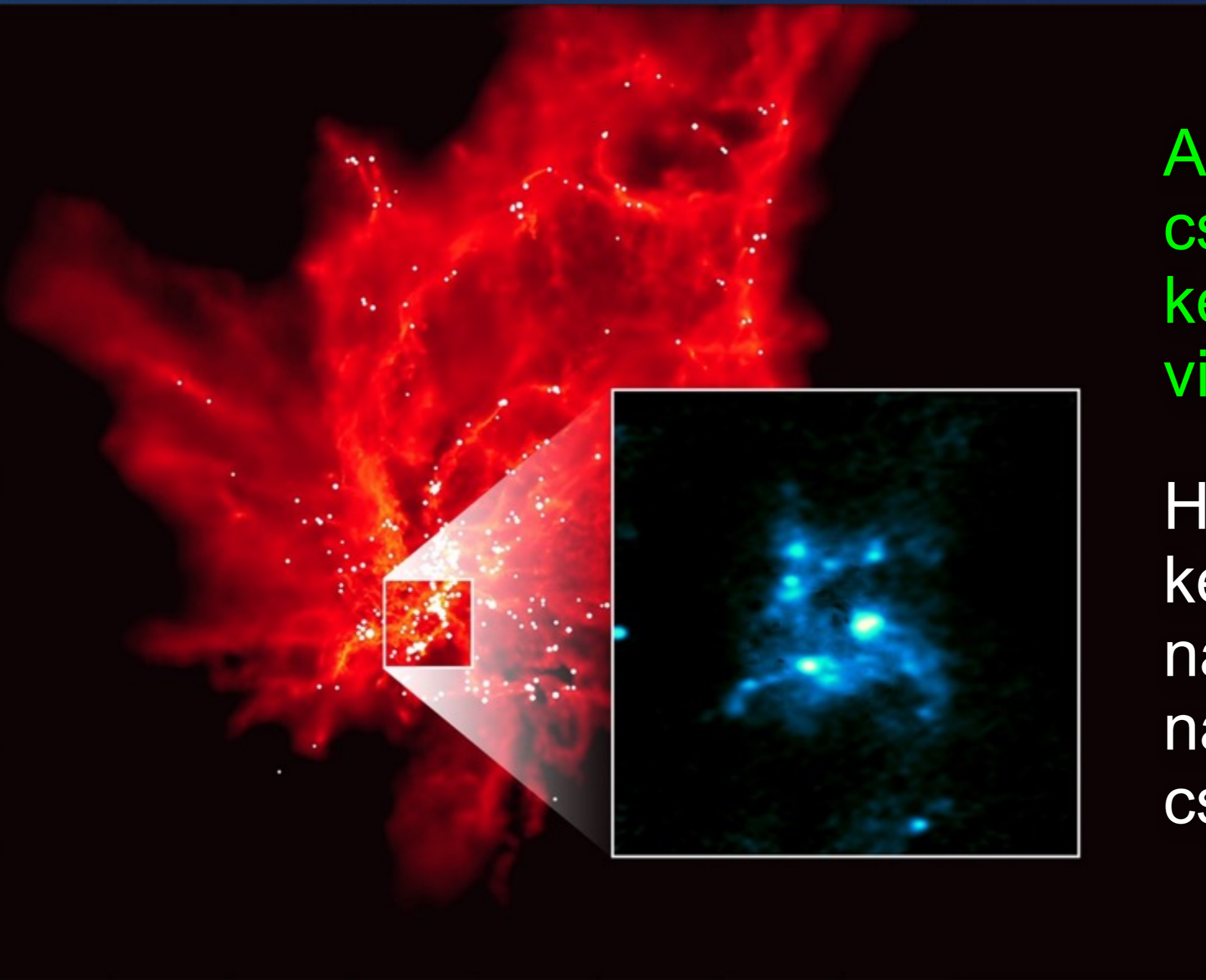
Korong-kutatás ALMA-val

Közeli kettősök vizsgálata

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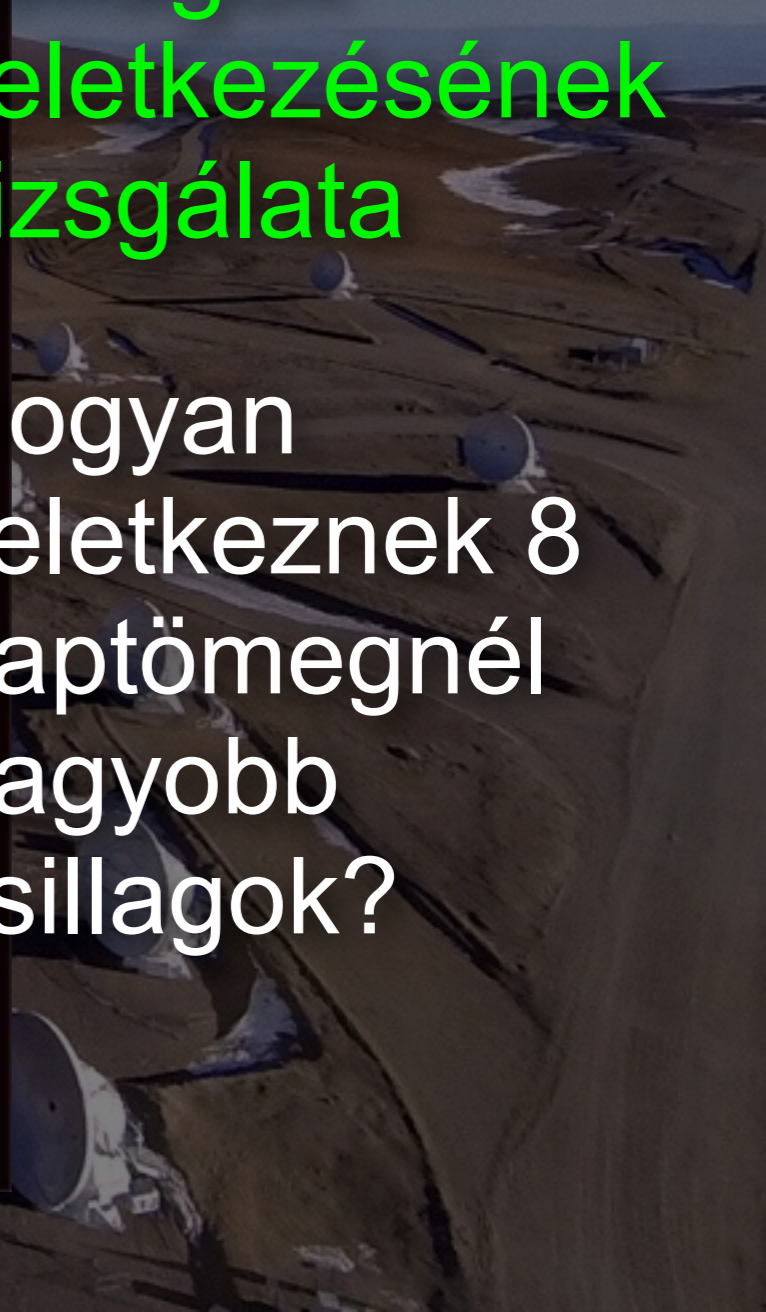


Korong-kutatás ALMA-val



A nagytömegű
csillagok
keletkezésének
vizsgálata

Hogyan
keletkeznek 8
naptömegnél
nagyobb
csillagok?



Korong-kutatás ALMA-val

Korongok barna törpék körül

Kialakulhatnak-e Föld-típusú bolygók barna törpék körül?

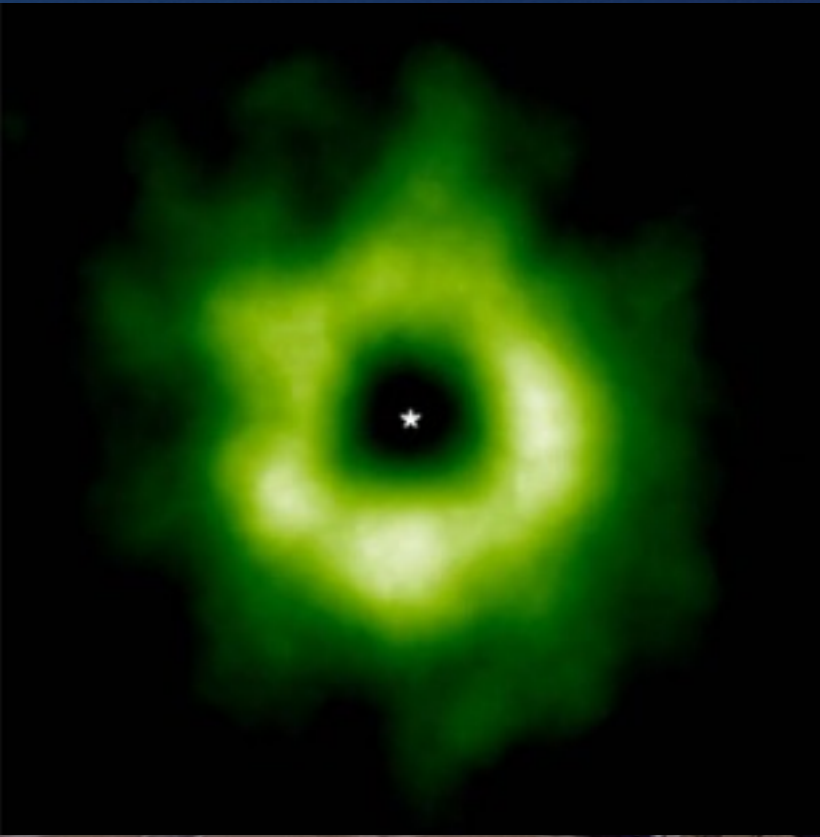


Korong-kutatás ALMA-val

Asztrokémia

Milyen molekulák
találhatók a csillagkörüli
anyagban?

CO, OH, CO₂, CH₄,
NH₃, N₂H⁺, HCO⁺, CN,
CS, SO, HNCO, HCN,
HC₃N, H₂CO, CH₃OH,
CH₃CN, ...

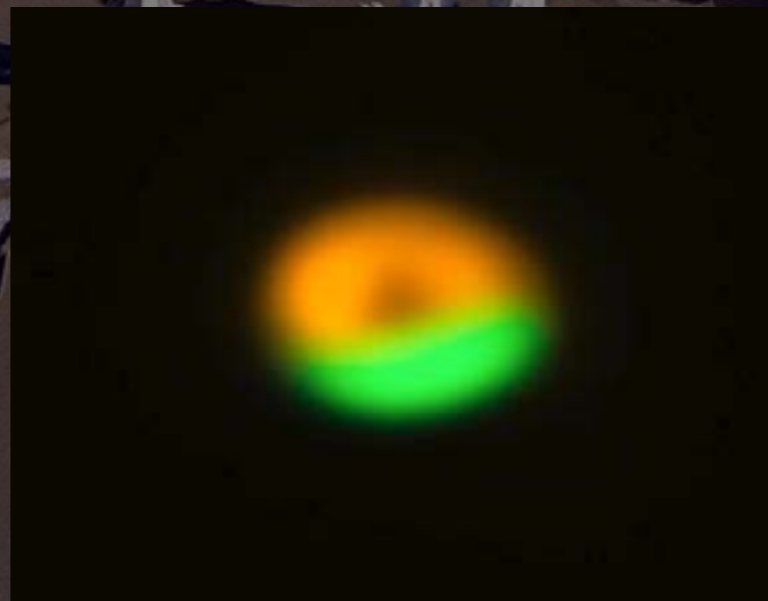
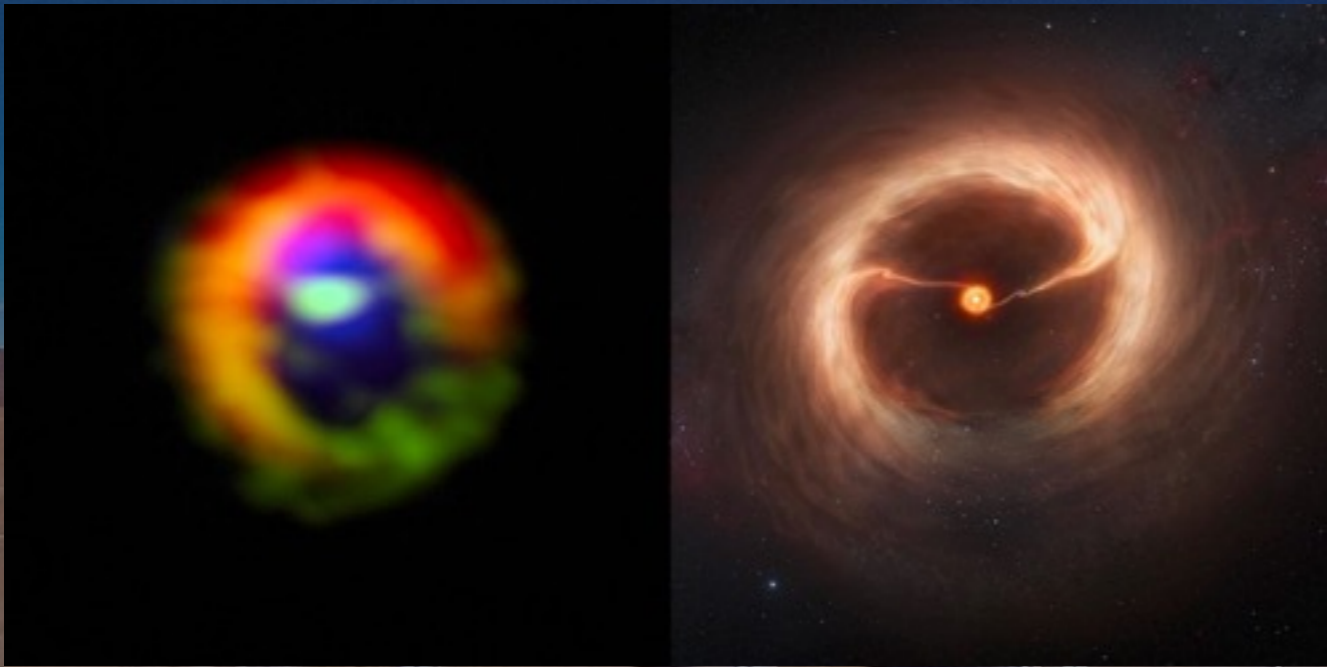


Korong-kutatás ALMA-val

A korongok részletes szerkezete

Mi az aszimmetriák oka?

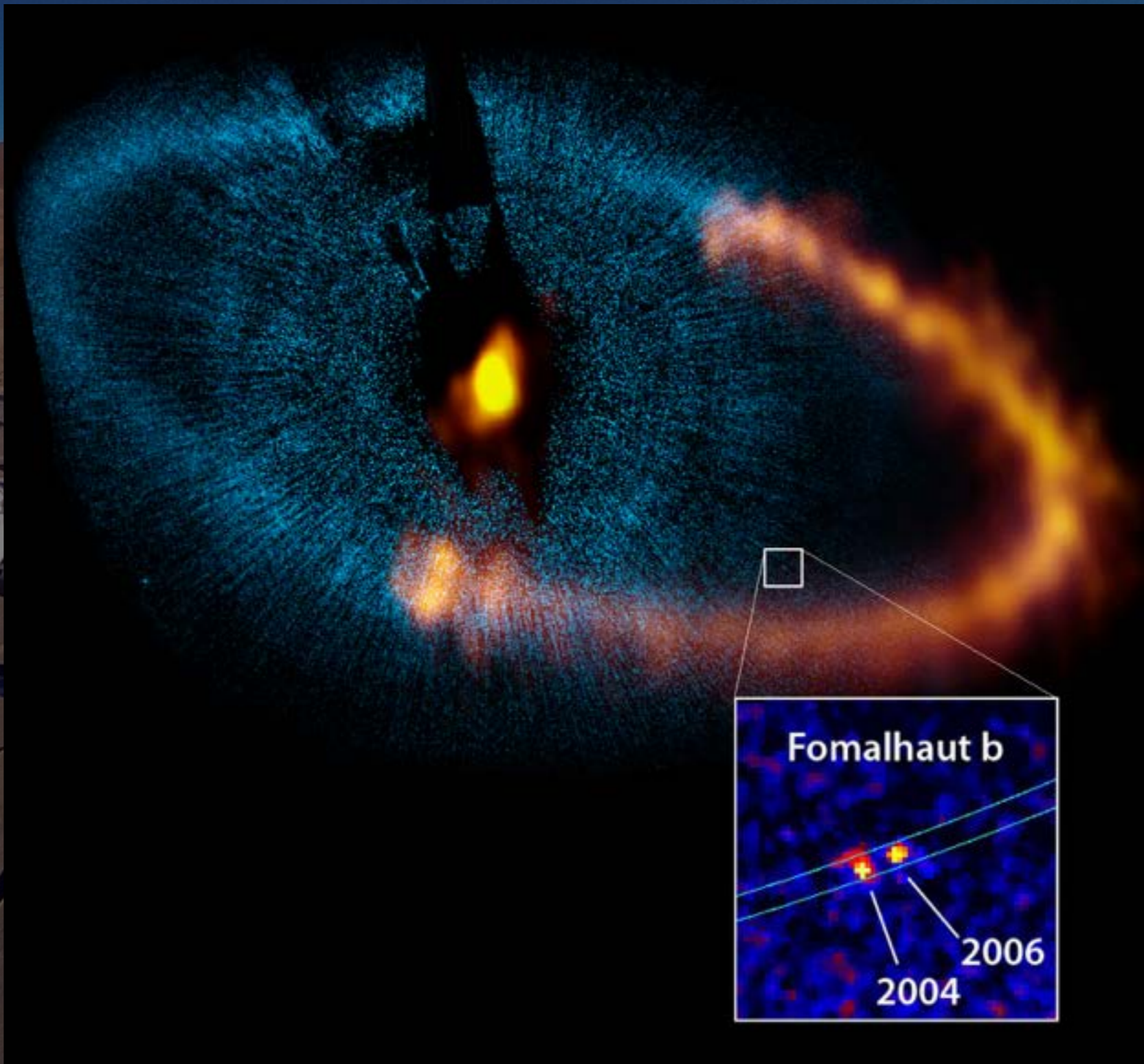
Bolygók, örvények a korongban?



Korong-kutatás ALMA-val

Korongok és bolygók kapcsolata

Hogyan hatnak
kölcson az
exobolygók a
csillagkörüli
porral?

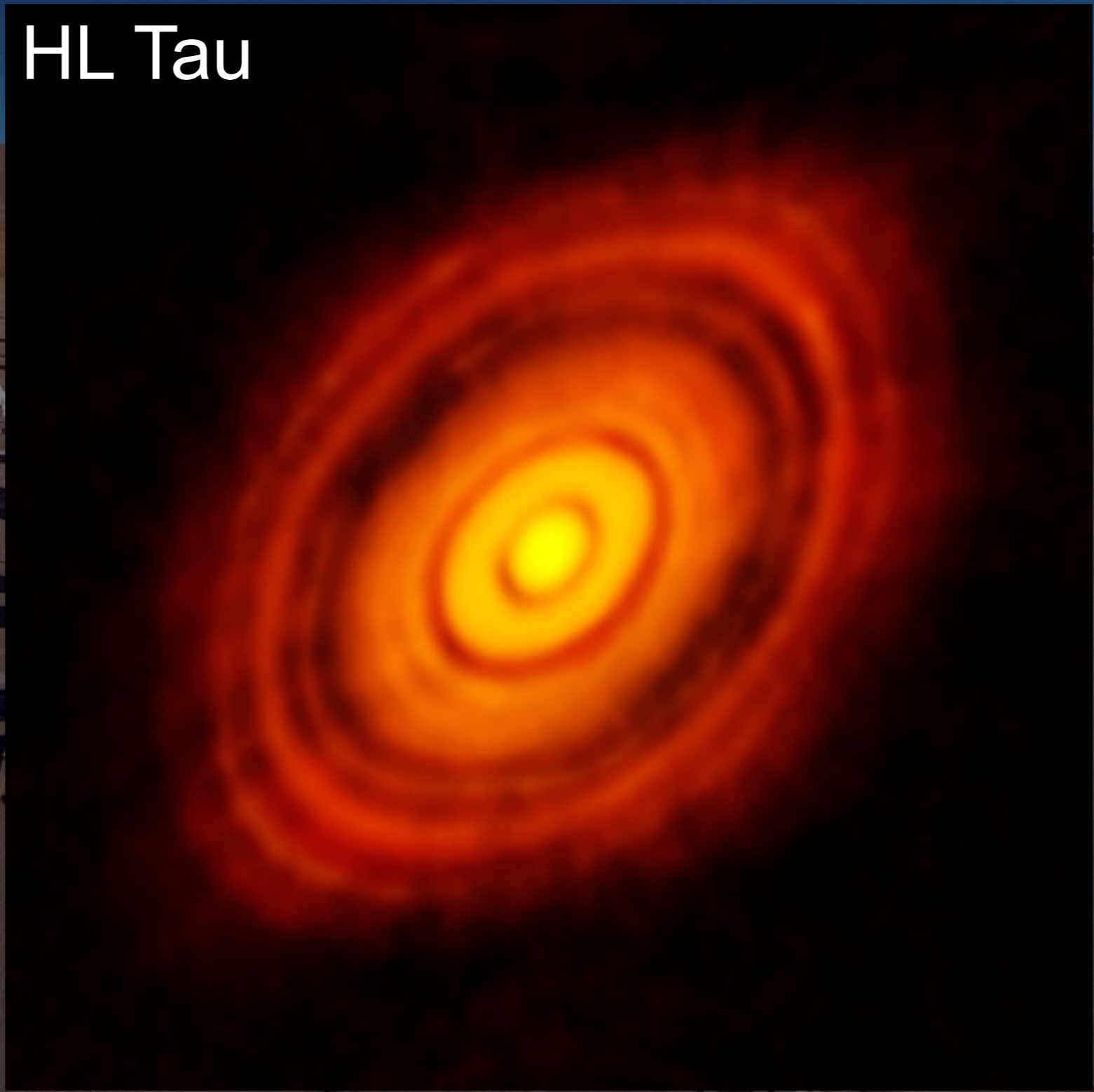


Korong-kutatás ALMA-val

Korongok és bolygók kapcsolata

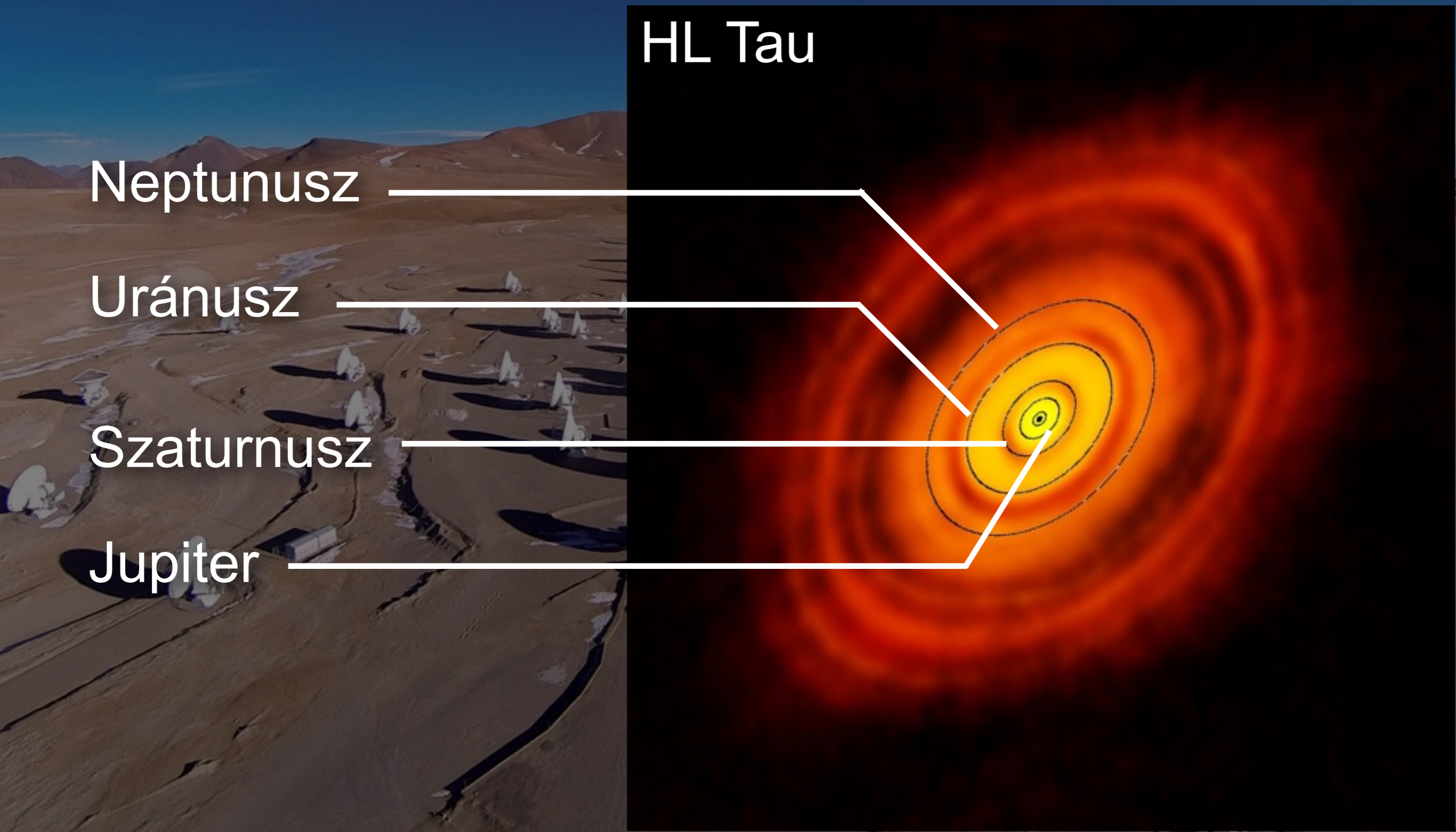


HL Tau



Korong-kutatás ALMA-val

Korongok és bolygók kapcsolata



HL Tau

Neptunusz

Uránusz

Szaturnusz

Jupiter

Korong-kutatás ALMA-val

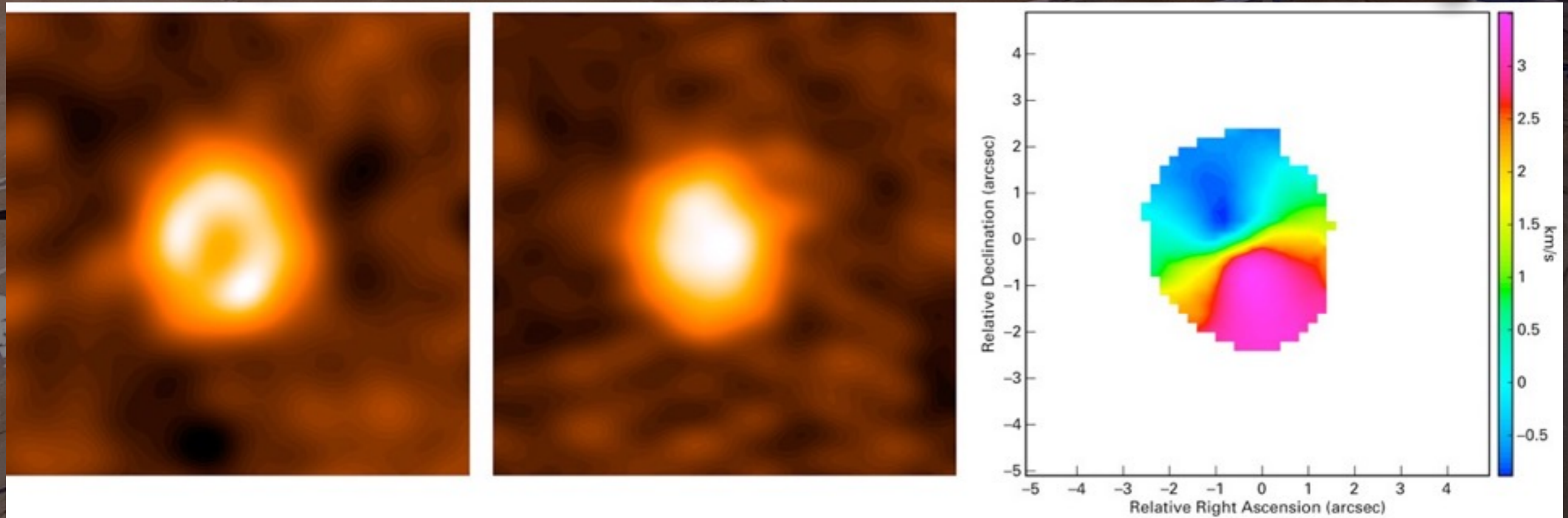
A korongok eltűnése

Hogyan tűnik el a korong por- és gázanyaga?

Por

Gáz

Gáz sebessége



Egyik legelső tudományos ALMA-mérés

Pályázatunk 11-szeres túljelentkezés mellett nyert

Folyó ALMA projektjeink

The screenshot displays the ALMA Project Tracker interface. At the top, there's a navigation bar with 'ALMA Project Tracker', 'User Manual', 'Alma Portal', and 'Log out'. Below this is a table listing 13 projects. The selected project, 2013.1.00870.S, is highlighted in blue. Below the table, the detailed view for this project is shown, including a tree view of entities, a description of the science goals, a technical note, a project status history table, and a project execution summary with progress bars.

Project Code	PI UserId	Executives	Project Name	State	Time C	Time of Creation	Timed Out	Project UID
2013.1.01376.S	jofltsso	EU	The HD 95086 planetary system: from discovery to structure	Reviewed		2013-12-05 14:59:51		uid://AD01/X113/X5e6
2013.1.01246.S	kospal	EU	Transport processes in the unique young eruptive system EX Lup	Reviewed		2013-12-05 14:00:19		uid://AD01/X112/X2c6
2013.1.01166.S	micheltus	CL	Towards an evolutionary sequence of molecular gas in young debris dis	InProgress		2013-12-05 13:10:47		uid://AD01/X112/X186
2013.1.00870.S	kospal	EU	Tracing the accretion history of pre-main sequence stars through the en	InProgress		2013-12-05 08:37:27		uid://AD01/X10e/X9d3
2013.1.00366.S	mhughes	NA	A 3-Dimensional View of Protoplanetary Disk Turbulence	InProgress		2013-12-04 16:37:35		uid://AD01/X10f/X267
2013.1.00088.S	mdunham	NA	The Mass Accretion Reservoir Surrounding a Variably Accreting Young	InProgress		2013-12-02 15:16:30		uid://AD01/X10a/Xc9
2012.1.00987.S	kospal	EU	Gas evolution in circumstellar disks: exploration of new gas-containing d	Reviewed		2012-07-12 13:50:18		uid://AD01/Xa0/X1990
2012.1.00863.S	kospal	EU	Dark shadows in T Tauri disks: ALMA interprets disk variability	Reviewed		2012-07-12 11:44:18		uid://AD01/Xa0/X157b

2013.1.00870.S - Tracing the accretion history of pre-main sequence stars through the envelope dynamics of FUors

Entity Status

- 2013.1.00870.S InProgress
 - Proposal
 - ObsUnitSet PartiallyObserved
 - SG OUS (V346_Nor_Band_6) PartiallyObserved
 - Group OUS PartiallyObserved
 - Member OUS (V346_Nor) Ready
 - V346_Nor_a_06_TE PartiallyObserved
 - Member OUS (V346_Nor) PipelineProcessing
 - V346_Nor_a_06_7M FullyObserved

The science goals are well presented, and As nicely summarized in the proposal, the brightening observed by FUors are thought to be related to episodic events of accretion. The observations will help in investigation the outburst/instability hypothesis. On the other hand, the panel had some concerns that it would be difficult to model an accreting envelope because the structure of the envelope is quite complicated.

Technical note: this line setup (in particular, 13CO and 12CO 2-1) results in higher T_{sys} than normal due to fall off in the Band 6 IF below 5.5 GHz (see ALMA technical handbook ver 1.1 Dec 13, 2013 section 3.2.3). It is not clear that the OT handles this increased rms noise or not. If proposal proceeds to phase 2 the PI should carefully weigh the benefits of including 12CO (resulting in higher T_{sys} for all three CO isotopes) vs adjusting the request to possible not include 12CO (or alternatively, 13CO, though that appears to be of higher importance to this project) and improved noise performance.

Project status history	Timestamp
Phase1Submitted	Thu, 05 Dec 2013 08:37:28 GMT
Reviewed	Wed, 09 Apr 2014 15:13:00 GMT
Phase2Submitted	Mon, 02 Jun 2014 14:26:12 GMT
Ready	Mon, 02 Jun 2014 15:28:17 GMT
InProgress	Fri, 06 Jun 2014 03:10:22 GMT

Project execution summary

- Seconds observed: 56% 18334 of 32734 [s]
- # Member OUSs started: 50% 1 of 2
- # Member OUSs finished: 50% 1 of 2
- # OUSs delivered: 0% 0 of 4
- # SBs Fully Observed: 50% 1 of 2

Folyó ALMA projektjeink

The screenshot shows the ALMA Project Tracker interface. At the top, there's a navigation bar with 'asa.alma.cl/protrack/'. Below it, a table lists 13 projects. The project '2013.1.00870.S' is highlighted in blue. A red arrow points from the text 'Hogyan tűnik el a gáz a korongokból?' to this project. Below the table, the detailed view for project 2013.1.00870.S is shown, including a tree view of entities, a description, a project status history table, and a project execution summary.

Project Code	PI UserId	Executives	Project Name	State	Time C	Time of Creation	Timed Out	Project UID
2013.1.01376.S	jofltsso	EU	The HD 95086 planetary system: from discovery to structure	Reviewed		2013-12-05 14:59:51		uid://AD01/X113/X5e6
2013.1.01246.S	kospal	EU	Transport processes in the unique young eruptive system EX Lup	Reviewed		2013-12-05 14:00:19		uid://AD01/X112/
2013.1.01166.S	micheltus	CL	Towards an evolutionary sequence of molecular gas in young debris disks	Reviewed		2013-12-05 14:00:19		uid://AD01/X112/
2013.1.00870.S	kospal	EU	Tracing the accretion history of pre-main sequence stars through the envelope dynamics of FUors	InProgress		2013-12-05 08:37:27		uid://AD01/X10e/
2013.1.00366.S	mhughes	NA	A 3-Dimensional View of Protoplanetary Disk Turbulence	InProgress		2013-12-04 16:37:35		uid://AD01/X10f/
2013.1.00088.S	mdunham	NA	The Mass Accretion Reservoir Surrounding a Variably Accreting Young Star	InProgress		2013-12-02 15:16:30		uid://AD01/X10a/
2012.1.00987.S	kospal	EU	Gas evolution in circumstellar disks: exploration of new gas-containing disks	Reviewed		2012-07-12 13:50:18		uid://AD01/Xe0/
2012.1.00863.S	kospal	EU	Dark shadows in T Tauri disks: ALMA interprets disk variability	Reviewed				

2013.1.00870.S - Tracing the accretion history of pre-main sequence stars through the envelope dynamics of FUors

Entity | Status

- 2013.1.00870.S | InProgress
- Proposal | InProgress
- ObsUnitSet | PartiallyObserved
 - SG OUS (V346_Nor_Band_6) | PartiallyObserved
 - Group OUS | PartiallyObserved
 - Member OUS (V346_Nor) | Ready
 - V346_Nor_a_06_TE | PartiallyObserved
 - Member OUS (V346_Nor) | PipelineProcessing
 - V346_Nor_a_06_7M | FullyObserved

The science goals are well presented, and As nice as the brightening observed by FUors are thought to be of accretion. The observations will help in investigating the structure of the accreting envelope because the structure of the envelope is thought to be important for the accretion process.

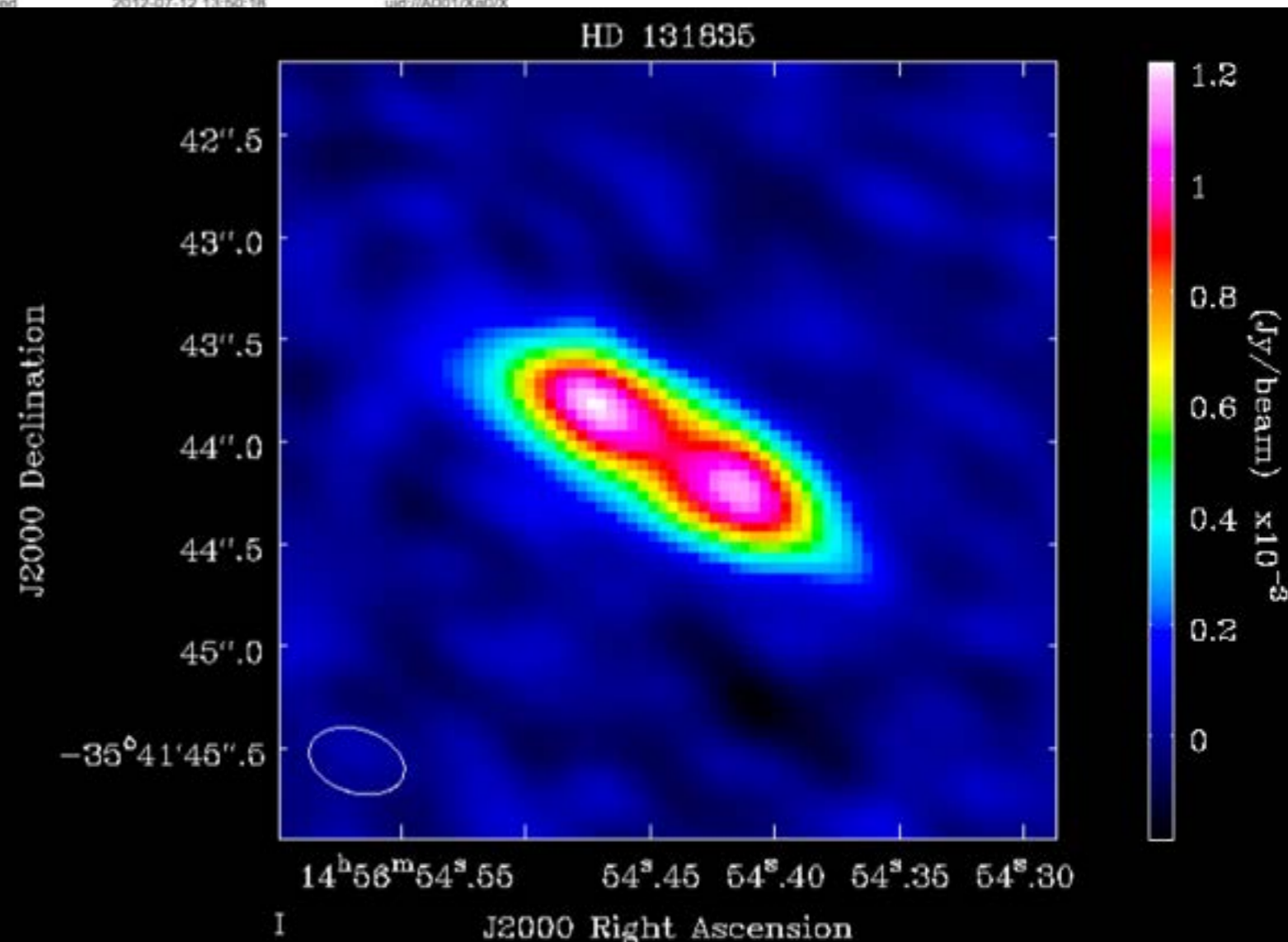
Technical note: this line setup (in particular, 13CO) is thought to fall off in the Band 6 IF below 5.5 GHz (see ALMA Band 6 IF not. If proposal proceeds to phase 2 the PI should carefully weigh the benefits of including 12CO and adjusting the request to possible not include 12CO importance to this project) and improved noise performance.

Project status history	Timestamp
Phase1Submitted	Thu, 05 Dec 2013 08:37:27
Reviewed	Wed, 09 Apr 2014 15:16:30
Phase2Submitted	Mon, 02 Jun 2014 14:21:00
Ready	Mon, 02 Jun 2014 15:21:00
InProgress	Fri, 06 Jun 2014 03:10:00

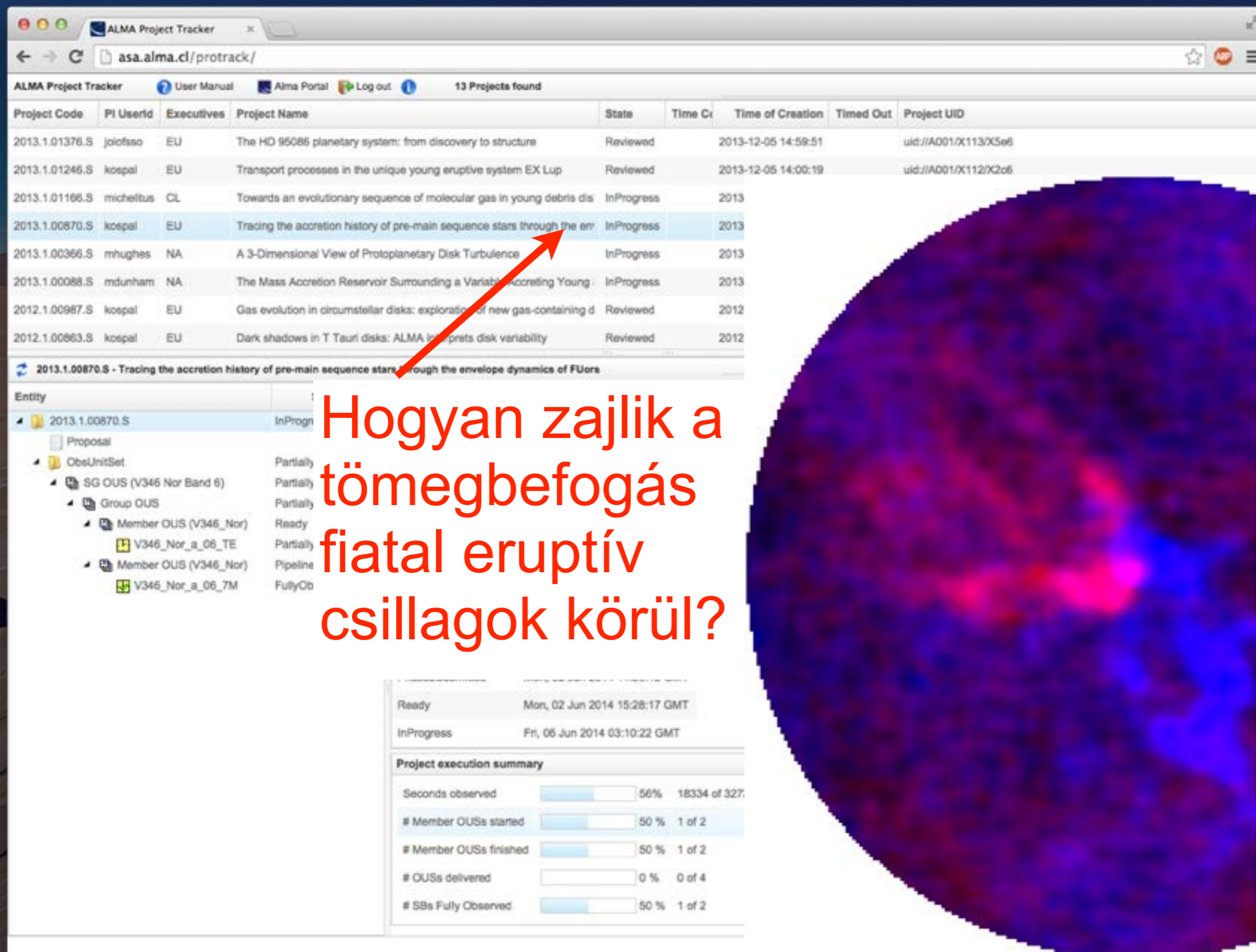
Project execution summary

- Seconds observed:
- # Member OUSs started:
- # Member OUSs finished:
- # OUSs delivered:
- # SBs Fully Observed:

Hogyan tűnik el a gáz a korongokból?



Folyó ALMA projektjeink



The screenshot shows the ALMA Project Tracker interface. At the top, there's a navigation bar with 'User Manual', 'Alma Portal', and 'Log out'. Below that, a table lists 13 projects. The project '2013.1.00870.S' is highlighted in blue, and a red arrow points to it from the text below. Below the table, the detailed view for this project is shown, including a tree view of the project structure and a 'Project execution summary' section.

Project Code	PI UserId	Executives	Project Name	State	Time C	Time of Creation	Timed Out	Project UID
2013.1.01376.S	joloisso	EU	The HD 95086 planetary system: from discovery to structure	Reviewed		2013-12-05 14:59:51		uid://AD01/X113/X5e6
2013.1.01246.S	kospal	EU	Transport processes in the unique young eruptive system EX Lup	Reviewed		2013-12-05 14:00:19		uid://AD01/X112/X2c6
2013.1.01166.S	micheltus	CL	Towards an evolutionary sequence of molecular gas in young debris dis	InProgress		2013		
2013.1.00870.S	kospal	EU	Tracing the accretion history of pre-main sequence stars through the en	InProgress		2013		
2013.1.00366.S	mhughes	NA	A 3-Dimensional View of Protoplanetary Disk Turbulence	InProgress		2013		
2013.1.00088.S	mdunham	NA	The Mass Accretion Reservoir Surrounding a Variable Accreting Young	InProgress		2013		
2012.1.00987.S	kospal	EU	Gas evolution in circumstellar disks: exploration of new gas-containing d	Reviewed		2012		
2012.1.00863.S	kospal	EU	Dark shadows in T Tauri disks: ALMA interprets disk variability	Reviewed		2012		

2013.1.00870.S - Tracing the accretion history of pre-main sequence stars through the envelope dynamics of FUors

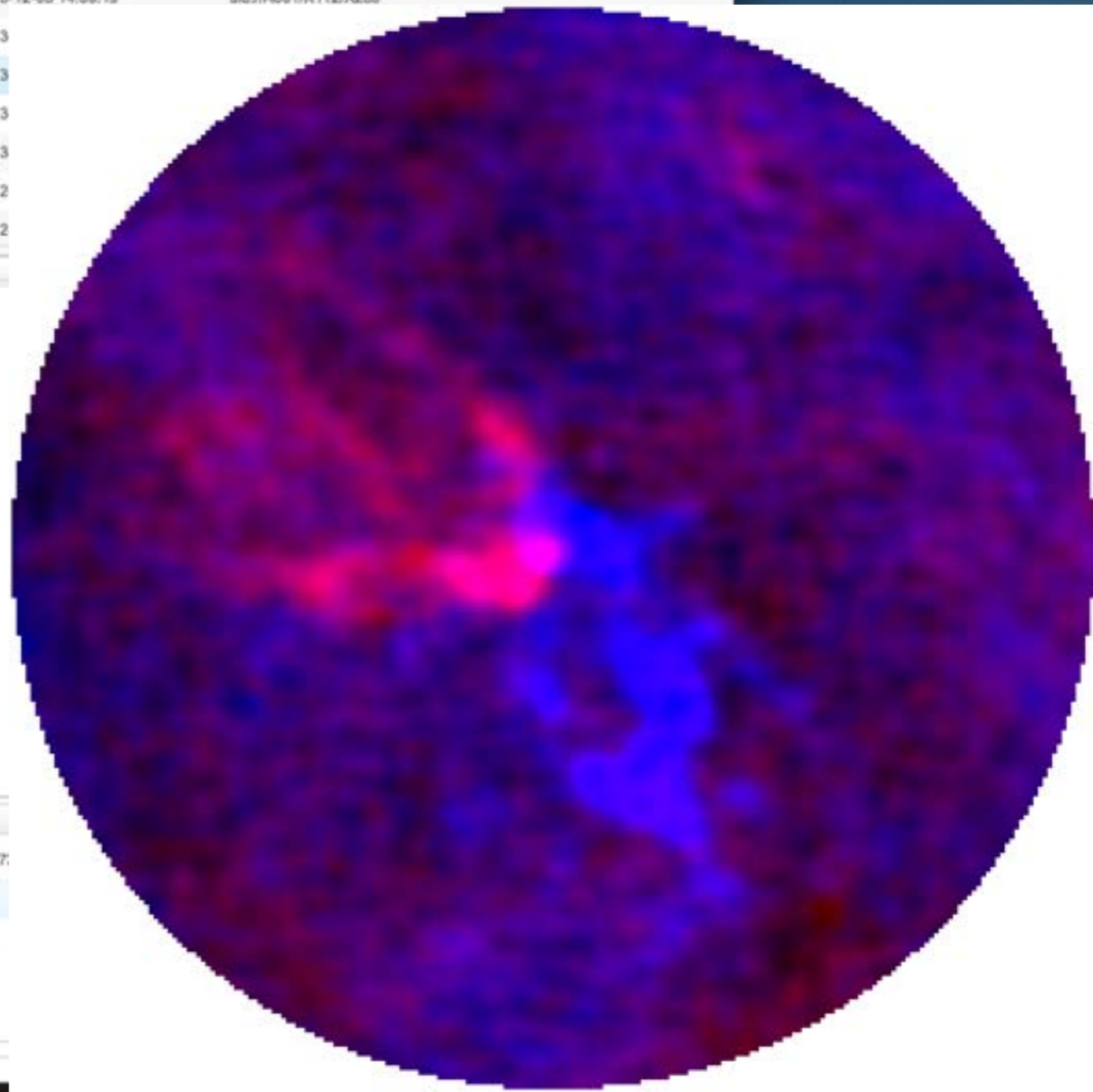
Entity

- 2013.1.00870.S (InProgn)
- Proposal
- ObsUnitSet
 - SG OUS (V346 Nor Band 6) (Partially)
 - Group OUS (Partially)
 - Member OUS (V346_Nor) (Ready)
 - V346_Nor_a_06_TE (Partially)
 - Member OUS (V346_Nor) (Pipeline)
 - V346_Nor_a_06_7M (FullyOb)

Project execution summary

Ready	Mon, 02 Jun 2014 15:28:17 GMT
InProgress	Fri, 06 Jun 2014 03:10:22 GMT
Seconds observed	56% 18334 of 327
# Member OUSs started	50% 1 of 2
# Member OUSs finished	50% 1 of 2
# OUSs delivered	0% 0 of 4
# SBs Fully Observed	50% 1 of 2

Hogyan zajlik a tömegbefogás fiatal eruptív csillagok körül?



Folyó ALMA projektjeink

ALMA Project Tracker

asa.alma.cl/protrack/

13 Projects found

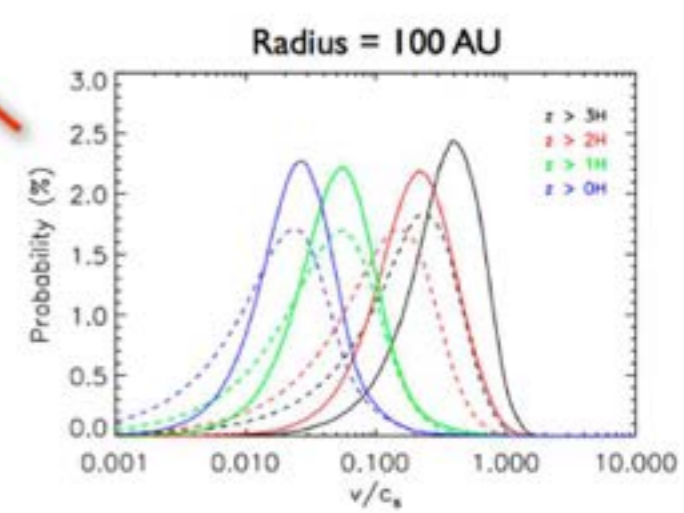
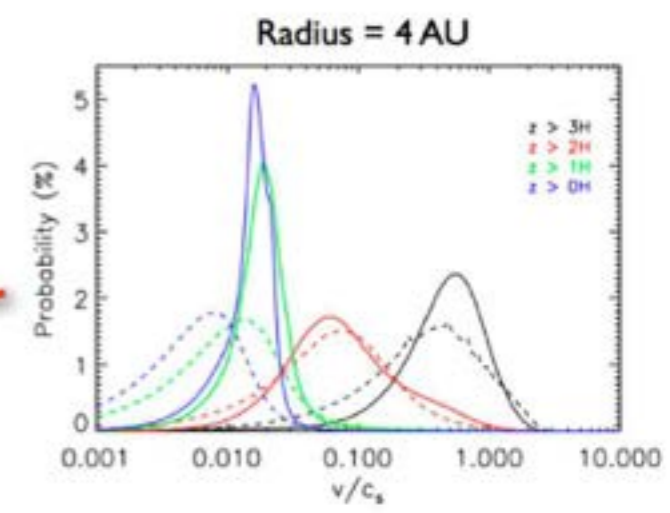
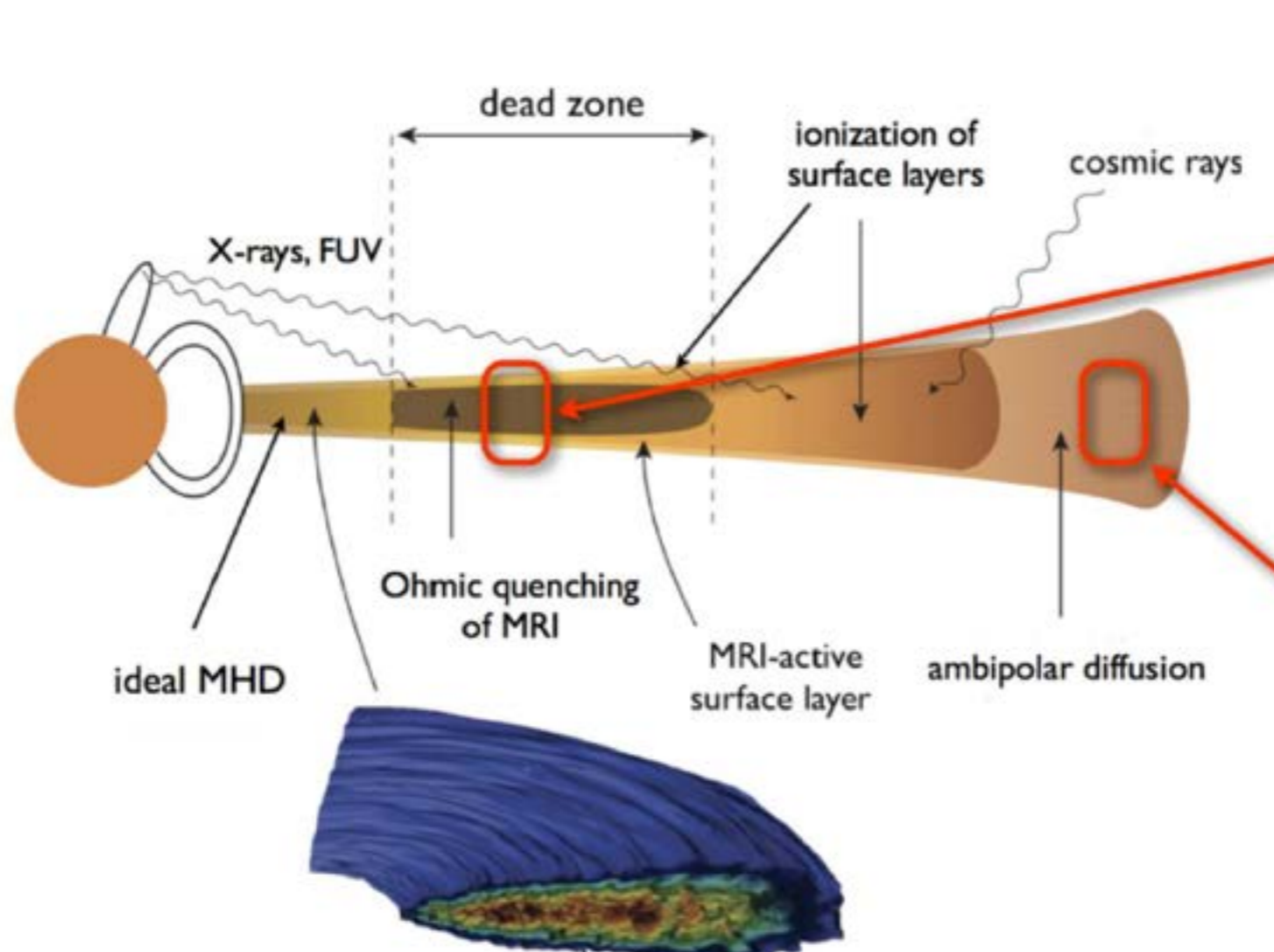
Project Code	PI UserId	Executives	Project Name	State	Time C	Time of Creation	Timed Out	Project UID
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2013.1.01246.S	kospal	EU	Transport processes in the unique young eruptive system EX Lup	Reviewed		2013-12-05 14:00:19		uid://AD01/X112/X2c6
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2013.1.00366.S	mhughes	NA	A 3-Dimensional View of Protoplanetary Disk Turbulence	InProgress				
2013.1.00088.S	mdunham	NA	The Mass Accretion Reservoir Surrounding a Variably Accreting Young	InProgress				
2012.1.00987.S	kospal	EU	Gas evolution in circumstellar disks: exploration of new gas-containing d	Reviewed				
2012.1.00863.S	kospal	EU	Dark shadow					

Turbulencia vizsgálata 3D-ben

2013.1.00870.S - Tracing the accretion history of pre-m

Entity

- 2013.1.00870.S InPro
- Proposal
- ObsUnitSet
- SG OUS (V346_Nor_Band_6)
- Group OUS
 - Member OUS (V346_Nor)
 - V346_Nor_a_06_TE
 - Member OUS (V346_Nor)
 - V346_Nor_a_06_7M



Folyó ALMA projektjeink

ALMA Project Tracker

asa.alma.cl/protrack/

13 Projects found

Project Code	PI UserId	Executives	Project Name	State	Time Cr	Time of Cr
2013.1.01376.S	joloisso	EU	The HD 95086 planetary system: from discovery to structure	Reviewed		2013-12-05 14
2013.1.01246.S	kospal	EU	Transport processes in the unique young eruptive system EX Lup	Reviewed		2013-12-05 11
2013.1.01166.S	micheltus	CL	Towards an evolutionary sequence of molecular gas in young debris dis	InProgress		2013-12-05 11
2013.1.00870.S	kospal	EU	Tracing the accretion history of pre-main sequence stars through the en	InProgress		2013-12-05 08
2013.1.00366.S	mhughes	NA	A 3-Dimensional View of Protoplanetary Disk Turbulence	InProgress		2013-12-04 16
2013.1.00088.S	mdunham	NA	The Mass Accretion Reservoir Surrounding a Rapidly Accreting Young	InProgress		2013-12-02 15
2012.1.00987.S	kospal	EU	Gas evolution in circumstellar disks: exploration of new gas-containing d	Reviewed		2012-07-12 13
2012.1.00863.S	kospal	EU	Dark shadows in T Tauri disks: ALMA interprets disk variability	Reviewed		2012-07-12 11

2013.1.00870.S - Tracing the accretion history of pre-main sequence stars through the envelope dynamics of FUors

Entity

Entity	Status
2013.1.00870.S	InProgress
Proposal	
ObsUnitSet	PartiallyObserved
SG OUS (V346_Nor_Band_6)	PartiallyObserved
Group OUS	PartiallyObserved
Member OUS (V346_Nor)	Ready
V346_Nor_a_06_TE	PartiallyObserved
Member OUS (V346_Nor)	PipelineProcessing
V346_Nor_a_06_7M	FullyObserved

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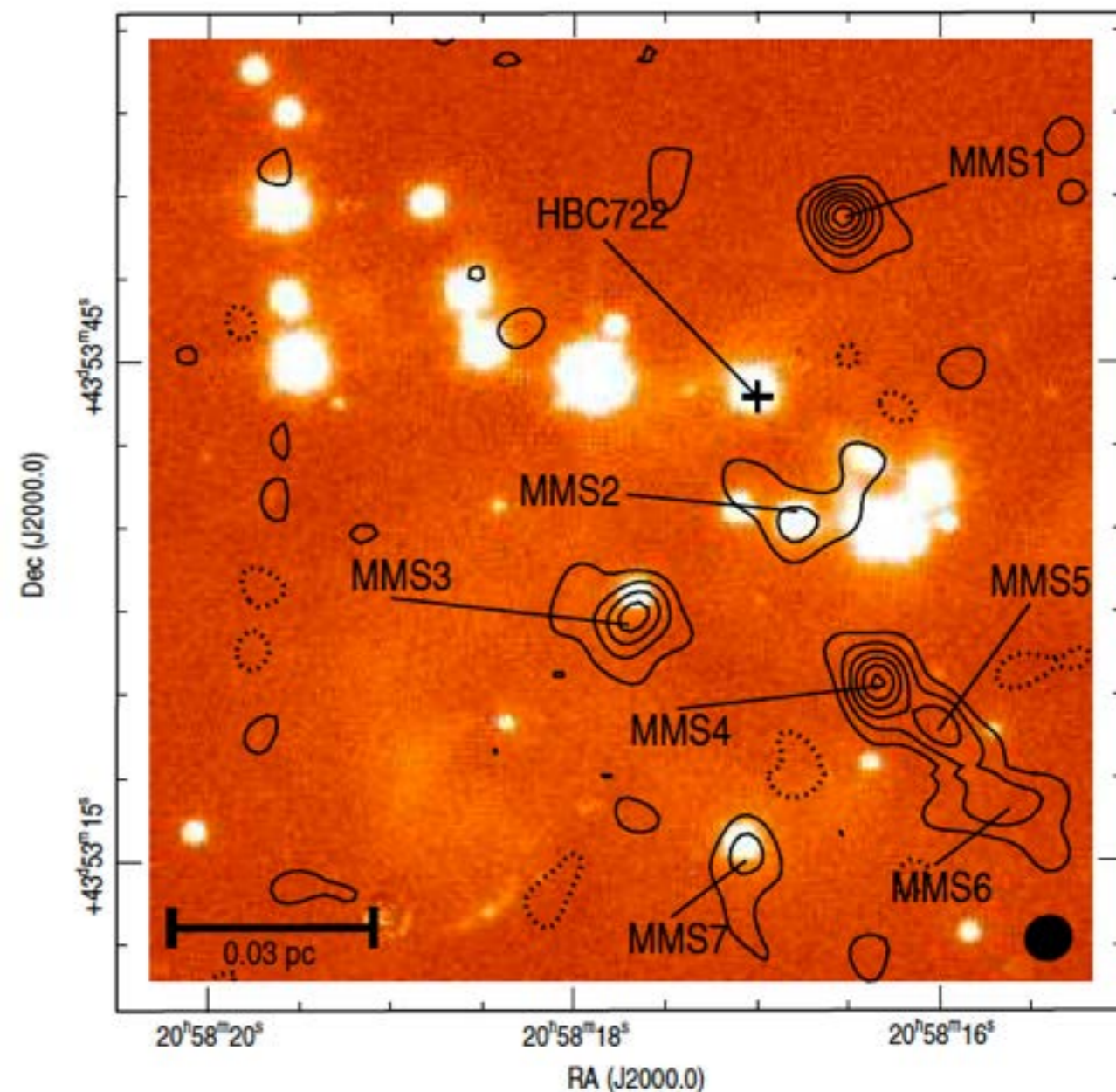
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# Member OUSs finished	50%	1 of 2
# OUSs delivered	0%	0 of 4
# SBs Fully Observed	50%	1 of 2

Hol raktározzák az anyagot a fiatal eruptív csillagok?



Tudomány az ALMÁ-val

- Kozmológia
- Nagy vöröseltolódású galaxisok
- Közeli galaxisok
- Csillagközi anyag
- Csillagfejlődés
- Szupernóvák
- Naprendszerbeli objektumok
- Nap

www.almaobservatory.org



www.eso.org