

Útikalauz a galaxisokhoz (nem csak stopposoknak!)

Világos Blanka

Lendület Csillagok nukleoszintézise kutatócsoport (CSFK)
Lendület Tejútrendszer kutatócsoport (ELTE GAO)

Atomoktól a csillagokig, 2023. 09. 28.



ELTE
EÖTVÖS LORÁND
TUDOMÁNYEGYETEM



Lendület
program





MICSODA A GALAXIS?

Háttér: Simon-Zsók Anett



M31, rajz: Kiss Péter

“A nagy vita”
(1920)



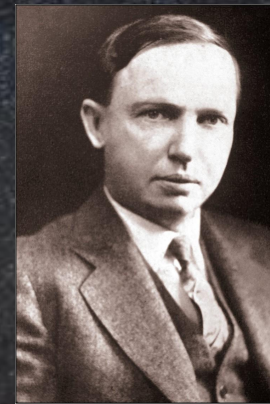
NASA/FUSE/
Lynette Cook

kicsi, közeli
porkorong

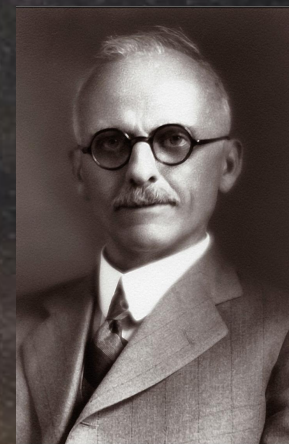


csillagok hatalmas,
távoli városa

M101, Bagi László



Harlow Shapley

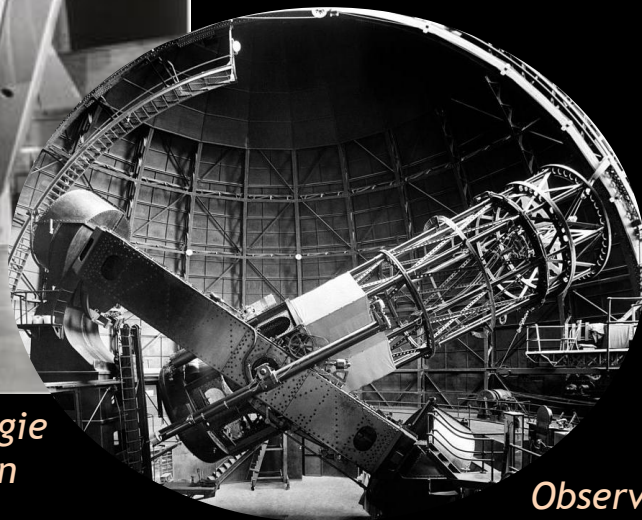


Heber Curtis

Edwin Hubble



*Mt. Wilson Archive, Carnegie
Institution of Washington*



*Observatories of the Carnegie Institution for Science
Collection, Huntington Library, San Marino, USA*

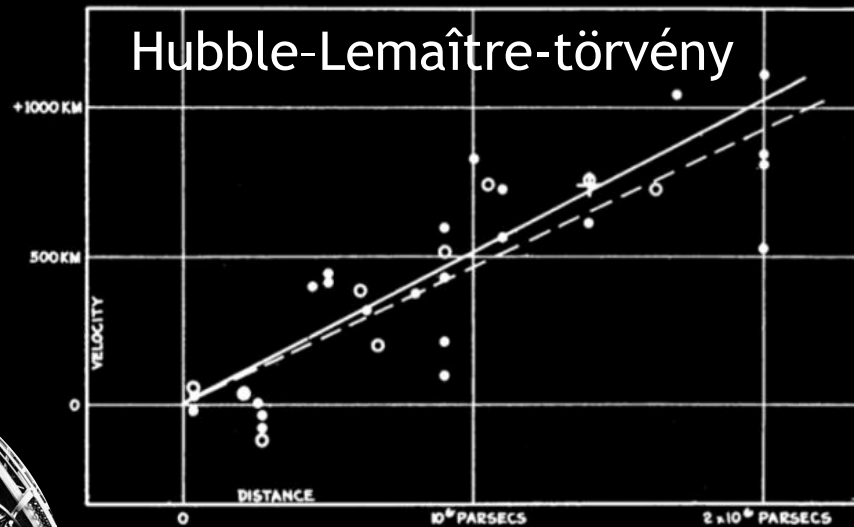
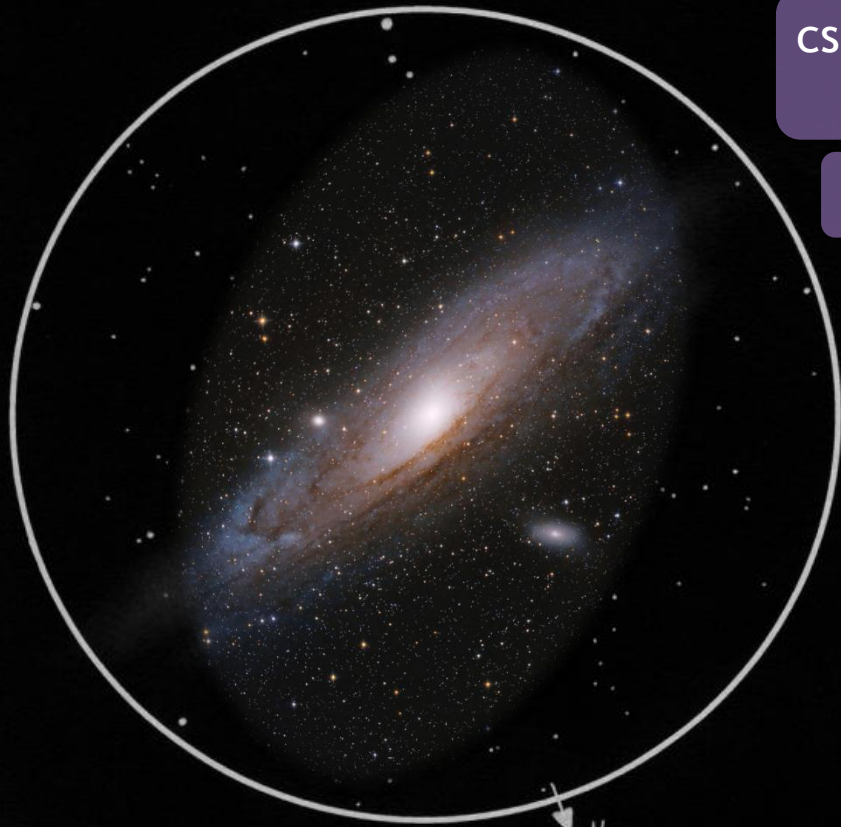


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Edwin Hubble publikációja



csillagok hatalmas,
távoli városa

De mekkora?



banán: FreeSVG

Androméda átmérője: 46,56 kpc = 152 000 ly

Banán mérete: 20 cm = 6 attopc = 6×10^{-18} pc

10^{-22} = 0.000000000000000000000001-szerese

M31, Szántó Szabolcs





NASA, Hubble Űrtávcső

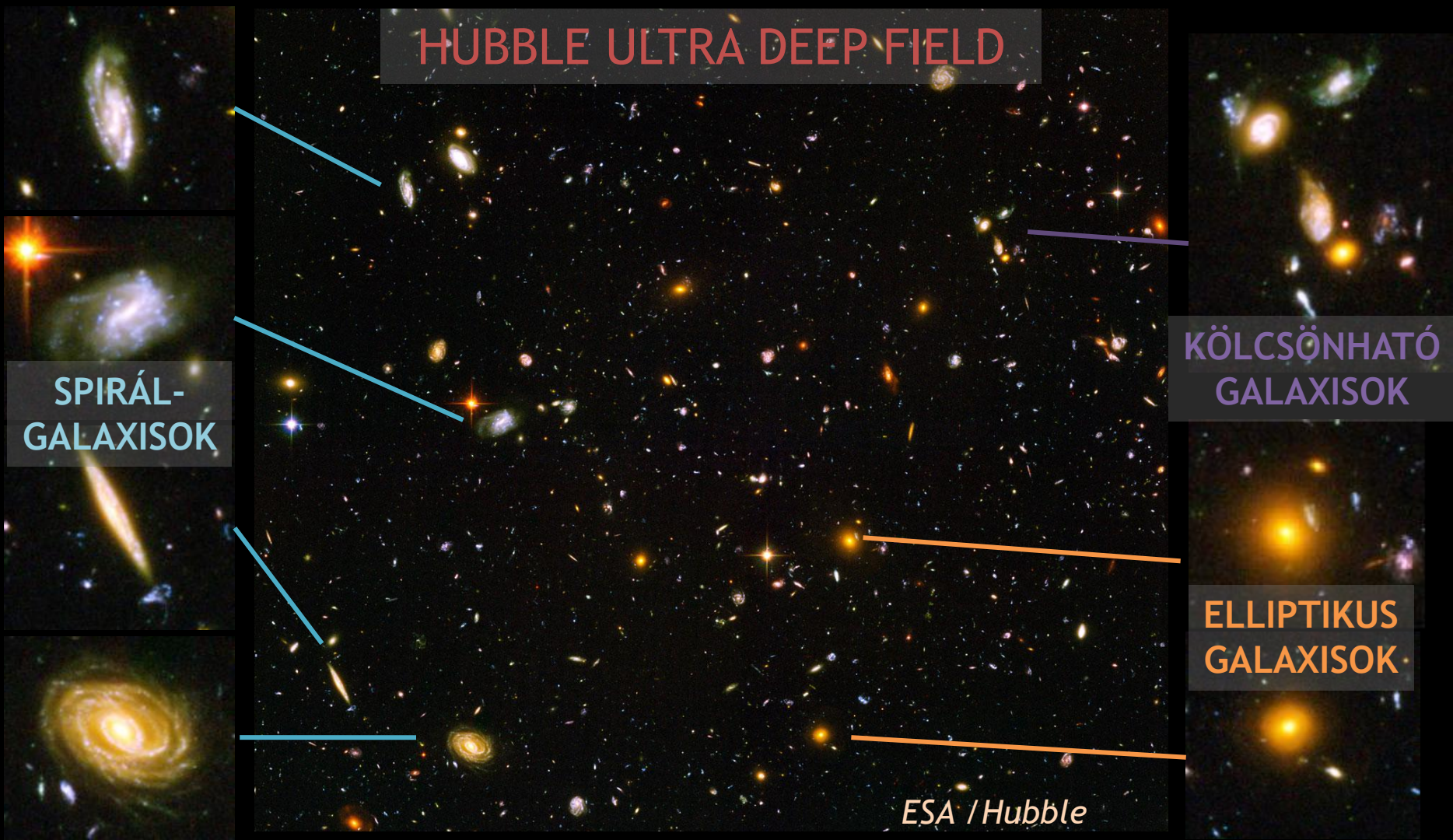
HUBBLE ULTRA DEEP FIELD

SPIRÁL-
GALAXISOK

KÖLCSÖNHATÓ
GALAXISOK

ELLIPTIKUS
GALAXISOK

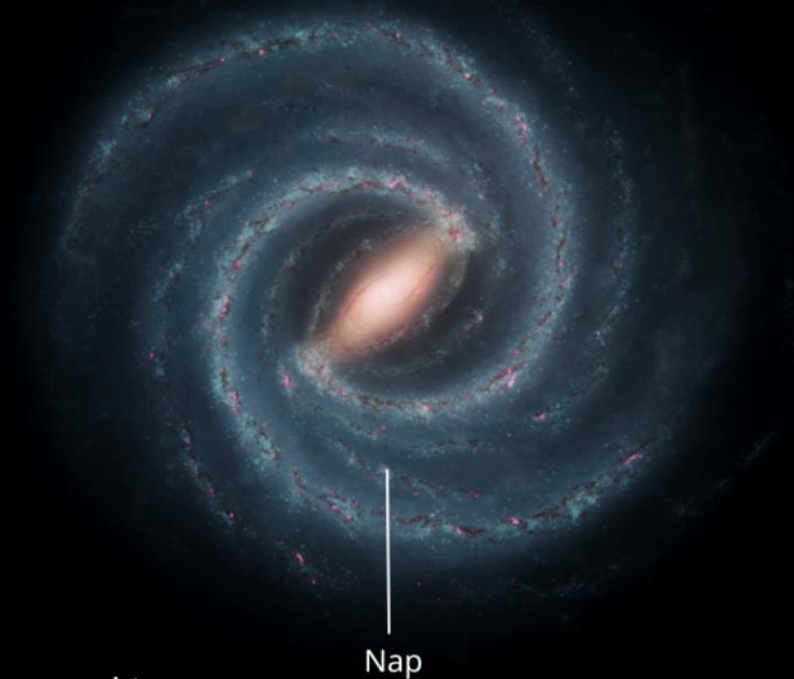
ESA / Hubble





Hadházi Csaba

→ A TEJÚTRENSZER SZERKEZETE



www.esa.int

Nap

Központi dudor

Gömbhalmazok

Korong

Csillagos haló

Nap

European Space Agency

NUKLEÁRIS ASZTROFIZIKA

avagy alkímia csillagászoknak

Periódusos rendszer

... csillagászoknak

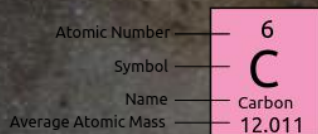
1 H Hydrogen 1.008																	2 He Helium 4.003	
3 Li Lithium 6.94	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948	
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.97	35 Br Bromine 79.904	36 Kr Krypton 83.798	
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium [97]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293	
55 Cs Cesium 132.905	56 Ba Barium 137.327	* 57 - 70	71 Lu Lutetium 174.967	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.997	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	** 89 - 102	103 Lr Lawrencium [262]	104 Rf Rutherfordium [267]	105 Db Dubnium [270]	106 Sg Seaborgium [269]	107 Bh Bohrium [270]	108 Hs Hassium [270]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [281]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [293]	118 Og Oganesson [294]
*Lanthanide series		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045			
**Actinide series		89 Ac Actinium [227]	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]			




Atomic Number — 6
 Symbol — C
 Name — Carbon
 Average Atomic Mass — 12.011

fémek —
 nem fémek —
 félfémek —

Periódusos rendszer

... csillagászoknak



fémek 
nem fémek 
félfémek 

*Lanthanide series

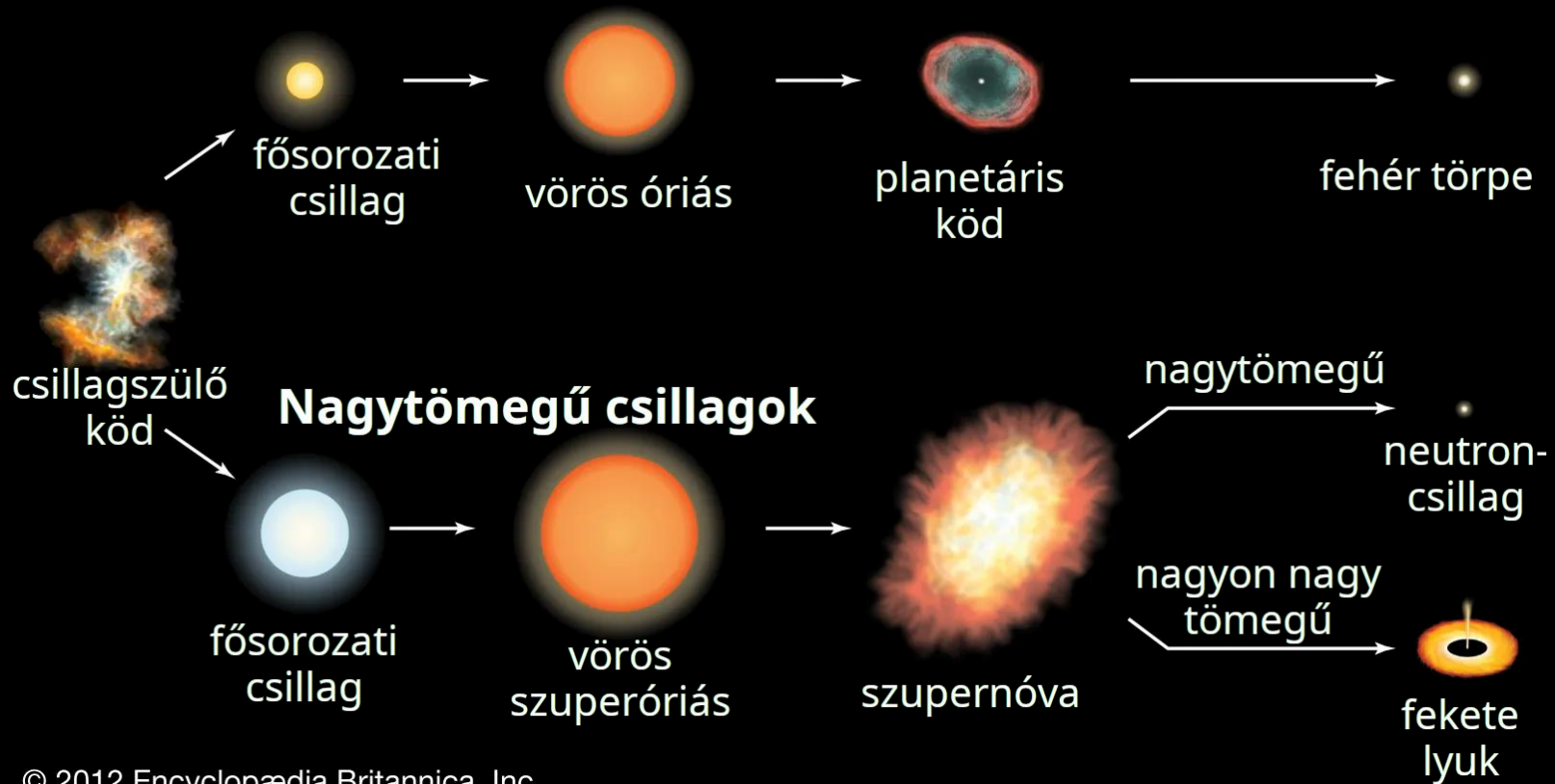
*Actinide series

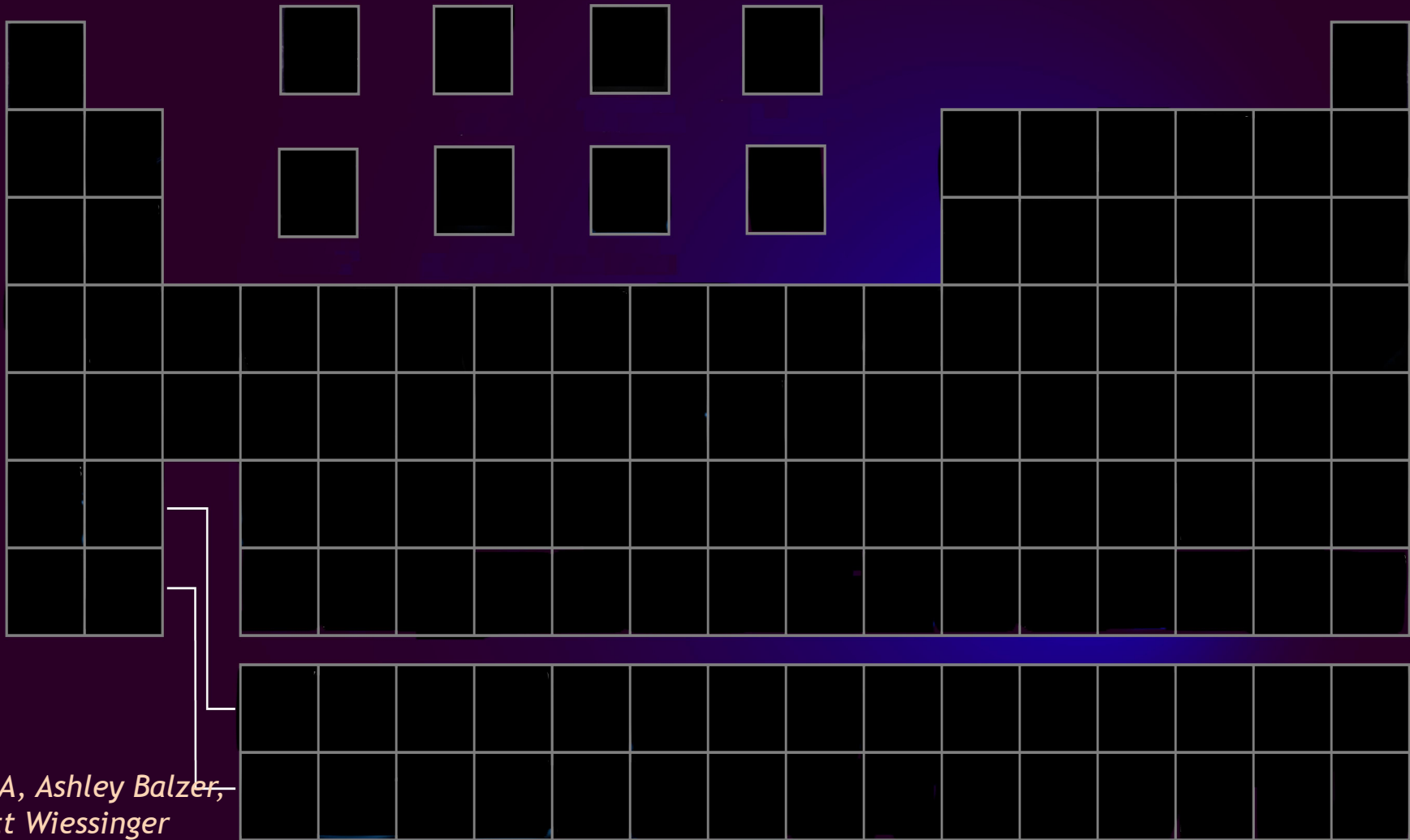




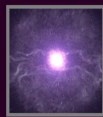
A csillagok életútja

Kis- és közepes tömegű csillagok (pl. Nap)

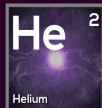
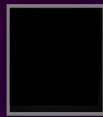




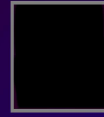
*NASA, Ashley Balzer,
Scott Wiessinger*



The big bang



Cosmic ray collisions



NASA, Ashley Balzer, Scott Wiessinger






H ¹ Hydrogen					He ² Helium						
Be ⁴ Beryllium					B ⁵ Boron						
Ca ²⁰ Calcium	Ti ²² Titanium	V ²³ Vanadium	Cr ²⁴ Chromium	Mn ²⁵ Manganese	Fe ²⁶ Iron	Co ²⁷ Cobalt	Ni ²⁸ Nickel	Cu ²⁹ Copper	Zn ³⁰ Zinc	S ¹⁶ Sulfur	Ar ¹⁸ Argon



Ia típusú szupernóvák

NASA/CXC/M. Weiss

NASA, Ashley Balzer,
Scott Wiessinger

H 1 Hydrogen			
Be 4 Beryllium			He 2 Helium
Na 11 Sodium	Mg 12 Magnesium	B 5 Boron	O 8 Oxygen
Al 13 Aluminum	Si 14 Silicon	P 15 Phosphorus	S 16 Sulfur
Cl 17 Chlorine	Ar 18 Argon	K 19 Potassium	Ca 20 Calcium
Sc 21 Scandium	Ti 22 Titanium	V 23 Vanadium	Cr 24 Chromium
Mn 25 Manganese	Fe 26 Iron	Co 27 Cobalt	Ni 28 Nickel
Cu 29 Copper	Zn 30 Zinc	Ga 31 Gallium	Ge 32 Germanium
As 33 Arsenic	Se 34 Selenium	Br 35 Bromine	Kr 36 Krypton
Rb 37 Rubidium			

Csillagszél



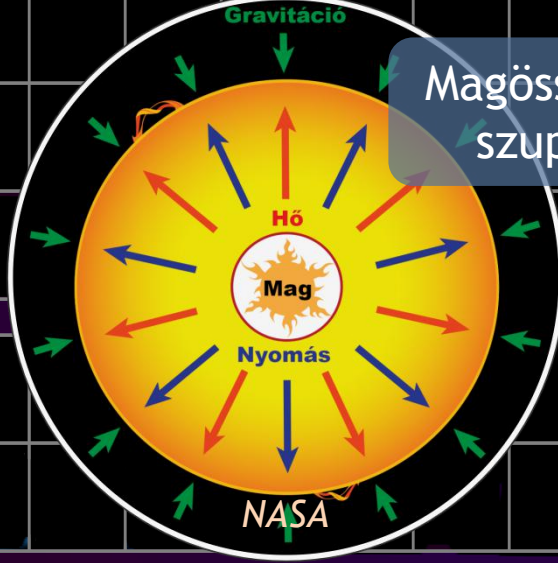
NASA/ESA

Gravitáció

Hő

Mag

Nyomás

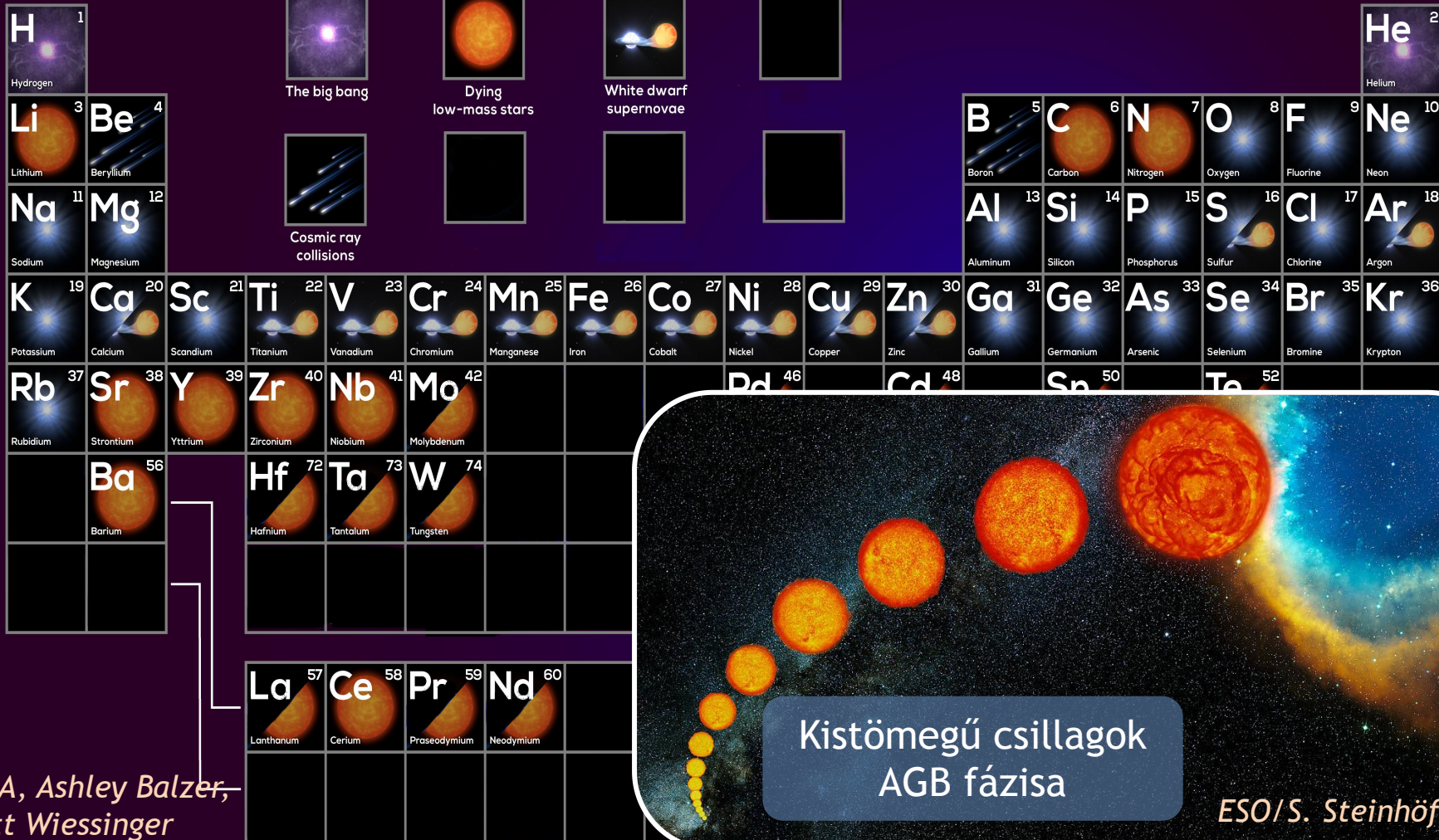


NASA

Magösszeomlásos szupernóvák



NASA/Hubble



The big bang

Dying low-mass stars

White dwarf supernovae

Cosmic ray collisions



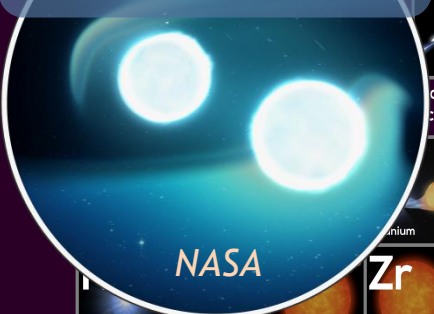
Kistömegű csillagok
AGB fázisa

ESO/S. Steinhöfel

NASA, Ashley Balzer,
Scott Wiessinger

H¹

Neutroncsillagok összeolvadása



The big bang



Dying low-mass stars



White dwarf supernovae



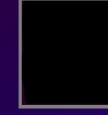
cosmic ray collisions



Dying high-mass stars



Merging neutron stars



He²

Helium

B ⁵ Boron	C ⁶ Carbon	N ⁷ Nitrogen	O ⁸ Oxygen	F ⁹ Fluorine	Ne ¹⁰ Neon
Al ¹³ Aluminum	Si ¹⁴ Silicon	P ¹⁵ Phosphorus	S ¹⁶ Sulfur	Cl ¹⁷ Chlorine	Ar ¹⁸ Argon

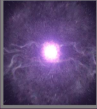
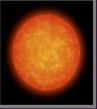

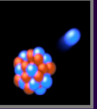


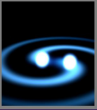

22 V Vanadium	23 Cr Chromium	24 Mn Manganese	25 Fe Iron	26 Co Cobalt	27 Ni Nickel	28 Cu Copper	29 Zn Zinc	30 Ga Gallium	31 Ge Germanium	32 As Arsenic	33 Se Selenium	34 Br Bromine	35 Kr Krypton	36
40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon	
55 Cs Cesium	56 Ba Barium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	

Mágneses-hidrodinamikai jet?



58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	92 U Uranium	94 Pu Plutonium										

NASA
Scott W.
canva

H 1 Hydrogen	   				He 2 Helium															
Li 3 Lithium	Be 4 Beryllium	   				B 5 Boron C 6 Carbon N 7 Nitrogen O 8 Oxygen F 9 Fluorine Ne 10 Neon														
Na 11 Sodium	Mg 12 Magnesium					Al 13 Aluminum Si 14 Silicon P 15 Phosphorus S 16 Sulfur Cl 17 Chlorine Ar 18 Argon														
K 19 Potassium	Ca 20 Calcium	Sc 21 Scandium	Ti 22 Titanium	V 23 Vanadium	Cr 24 Chromium	Mn 25 Manganese	Fe 26 Iron	Co 27 Cobalt	Ni 28 Nickel	Cu 29 Copper	Zn 30 Zinc	Ga 31 Gallium	Ge 32 Germanium	As 33 Arsenic	Se 34 Selenium	Br 35 Bromine	Kr 36 Krypton			
Rb 37 Rubidium	Sr 38 Strontium	Y 39 Yttrium	Zr 40 Zirconium	Nb 41 Niobium	Mo 42 Molybdenum	Tc 43 Technetium	Ru 44 Ruthenium	Rh 45 Rhodium	Pd 46 Palladium	Ag 47 Silver	Cd 48 Cadmium	In 49 Indium	Sn 50 Tin	Sb 51 Antimony	Te 52 Tellurium	I 53 Iodine	Xe 54 Xenon			
Cs 55 Cesium	Ba 56 Barium					Hf 72 Hafnium	Ta 73 Tantalum	W 74 Tungsten	Re 75 Rhenium	Os 76 Osmium	Ir 77 Iridium	Pt 78 Platinum	Au 79 Gold	Hg 80 Mercury	Tl 81 Thallium	Pb 82 Lead	Bi 83 Bismuth	Po 84 Polonium	At 85 Astatine	Rn 86 Radon
Fr 87 Francium	Ra 88 Radium					Rf 104 Rutherfordium	Df 105 Dubnium	Sg 106 Seaborgium	Bh 107 Bohrium	Hs 108 Hassium	Mt 109 Meitnerium	Ds 110 Darmstadtium	Rg 111 Roentgenium	Cn 112 Copernicium	Nh 113 Nihonium	Fl 114 Flerovium	Mc 115 Moscovium	Lv 116 Livermorium	Ts 117 Tennessine	Og 118 Oganesson

La 57 Lanthanum	Ce 58 Cerium	Pr 59 Praseodymium	Nd 60 Neodymium	Pm 61 Promethium	Sm 62 Samarium	Eu 63 Europium	Gd 64 Gadolinium	Tb 65 Terbium	Dy 66 Dysprosium	Ho 67 Holmium	Er 68 Erbium	Tm 69 Thulium	Yb 70 Ytterbium	Lu 71 Lutetium
Ac 89 Actinium	Th 90 Thorium	Pa 91 Protactinium	U 92 Uranium	Np 93 Neptunium	Pu 94 Plutonium	Am 95 Americium	Cm 96 Curium	Bk 97 Berkelium	Cf 98 Californium	Es 99 Einsteinium	Fm 100 Fermium	Md 101 Mendelevium	No 102 Nobelium	Lr 103 Lawrencium

NASA, Ashley Balzer,
Scott Wiessinger

The background is a dark, grainy, and textured surface, likely representing a galaxy or nebula. It features a mix of dark brown, black, and grey tones, with several bright, reddish-pink spots scattered across the field. The overall appearance is that of a complex, multi-colored astronomical object.

MODELLEZZÜNK GALAXIST!



Gáz és por

Csillagok maradványai:
fehér törpék, neutroncsillagok,
fekete lyukak

Csillagok

(Sötét anyag)

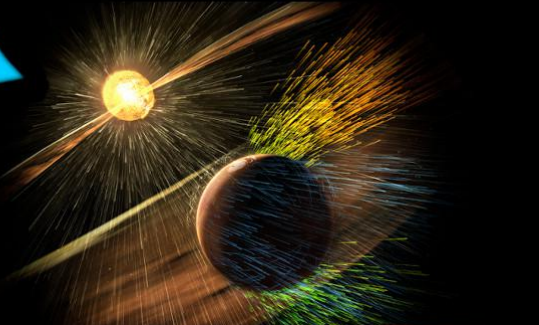
NASA, Hubble Űrtávcső



Csillagszülő felhők



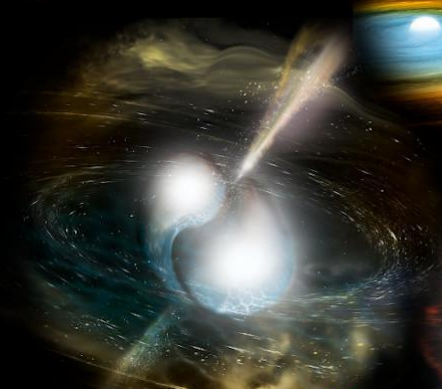
Csillagok



Csillagszél



Szupernóvák



**Neutroncsillag-
összeolvadások**

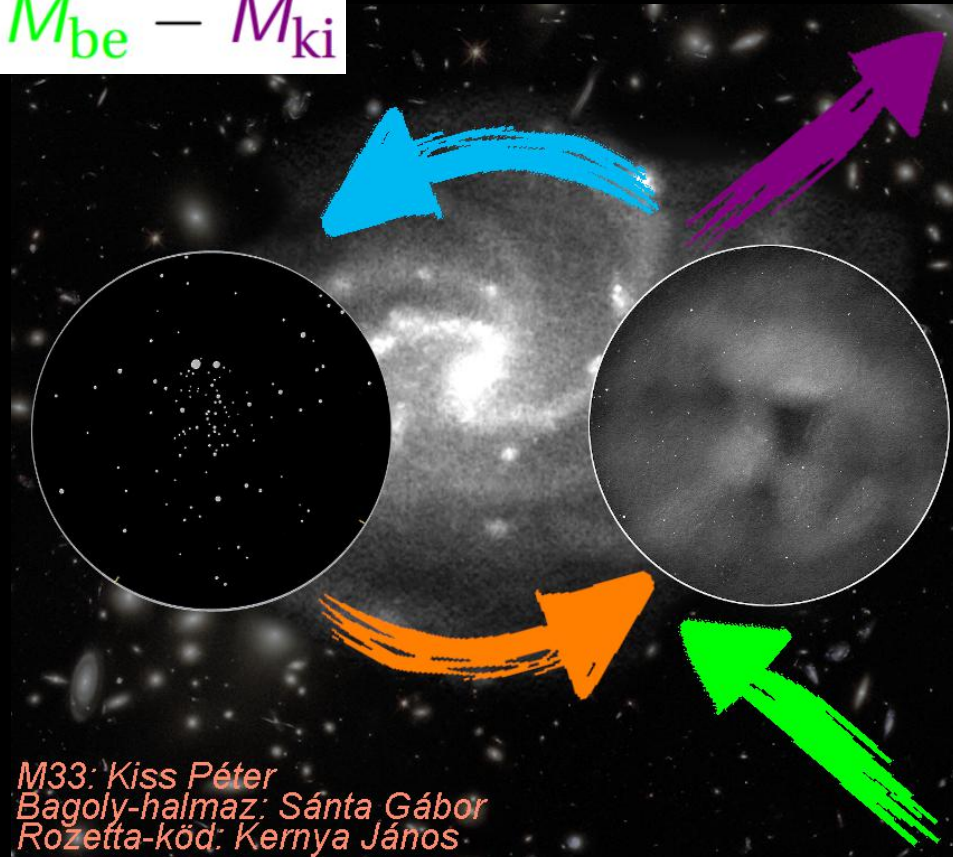


Csillagközi anyag

GALAKTIKUS
KÉMIAI
FEJLŐDÉS

A galaxis anyagának körforgása

$$\dot{M}_{\text{gáz}} = \dot{M}_{\text{termelt}} - \dot{M}_{*} + \dot{M}_{\text{be}} - \dot{M}_{\text{ki}}$$



M33: Kiss Péter
Bagoly-halmaz: Sánta Gábor
Rozeffa-köd: Kernya János

A galaxis anyagának körforgása

$$\dot{M}_{\text{gáz}} = \dot{M}_{\text{termelt}} - \dot{M}_{*} + \dot{M}_{\text{be}} - \dot{M}_{\text{ki}}$$

```
def __init__(self, mgal=1.0, print_off=False, halo_in_out_on=True, \
             m_outer_ini=-1.0, epsilon_sne_halo=0.0, nb_ccsne_per_m=0.01, \
             epsilon_sne_gal=-1, sfe_m_index=1.0, halo_out_index=1.0, \
             is_SF=True, sfe_m_dep=False, gal_out_index=1.0, f_halo_to_gal_out=-1, \
             DM_outflow_C17=False, m_cold_flow_tresh=-1, C17_eta_z_dep=True, \
             Grackle_on=False, f_t_ff=1.0, t_inflow=-1.0, t_ff_index=1.0, \
             max_half_life=1e14, min_half_life=1000, t_merge=-1.0, \
             substeps = [2, 3, 4, 6, 8, 12, 16, 24, 32, 48, 64, 96, 128, 192, 256, 384], \
             tolerance = 1e-5, min_val = 1e-20, print_param=False, \
             is_SF_t=np.array([]), outer_ini_f=np.array([]), ymgal_outer_ini=np.array([]), \
             sne_L_feedback=np.array([]), sfe_t=np.array([]), sfh_with_sfe=np.array([]), \
             dmo_ini=np.array([]), dmo_ini_t=np.array([]), exp_infall=np.array([]), tauup = [], \
             m_inflow_in=np.array([]), is_sub_array=np.array([]), **kwargs):
```

Not implemented yet

```
if len(sne_L_feedback) > 0:
```

```
    print('The sne_L_feedback option is currently not available.')
```

```
    print('Simulation aborted.')
```

```
    return
```

Announce the beginning of the simulation

```
if not print_off:
```

```
    print ('OMEGA+ run in progress..')
```

OMEGA+

M33: Kiss Péter
Bagoly-halmaz: Kiss Péter
Rožetta-kód: Kernya





**A TEJÚTRENDSZER
TÖRTÉNETÉNEK NYOMÁBAN**

Hogyan ismerhetjük meg a Tejútrendszer történetét?

Vegyünk egy időgépet!



FaseehUdeen

Hogyan ismerhetjük meg a Tejútrendszer történetét?

ÉSZLELÉSEK:

- Csillagok eloszlása, a galaxis struktúrái
- Csillagok mozgása
- Csillagok összetétele
- Gáz eloszlása
- Környező galaxisok mozgása
- Egyéb galaxisok megfigyelése

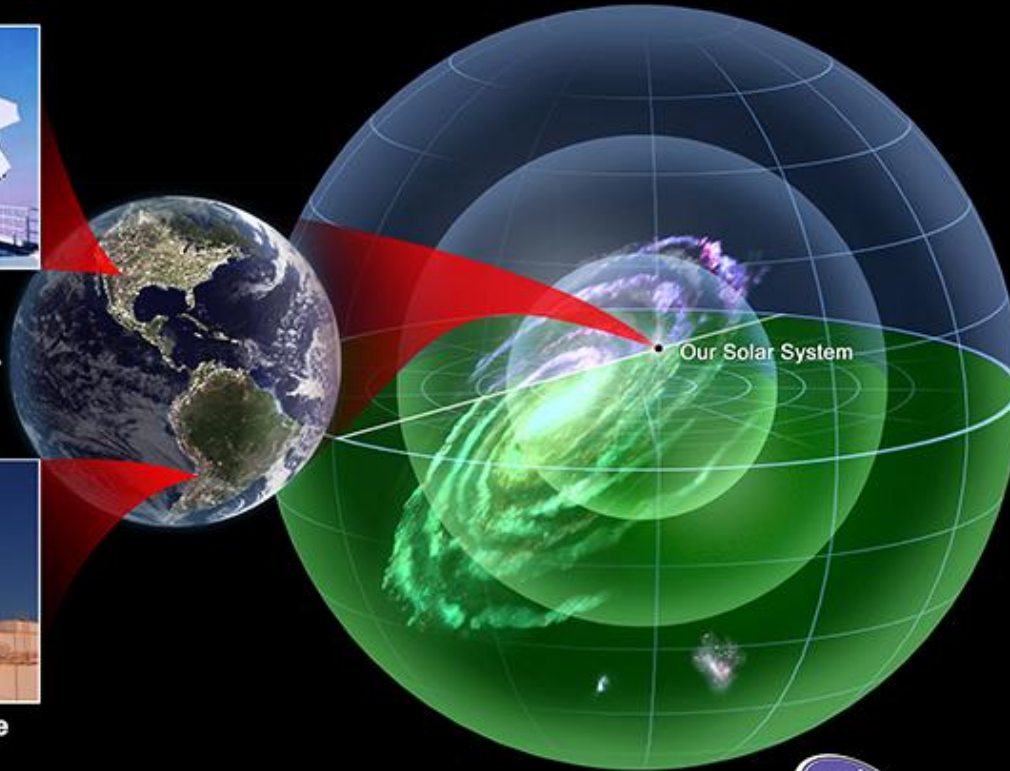
Az APOGEE égboltfelmérő program



Sloan Foundation
Telescope
New Mexico, U.S.A.

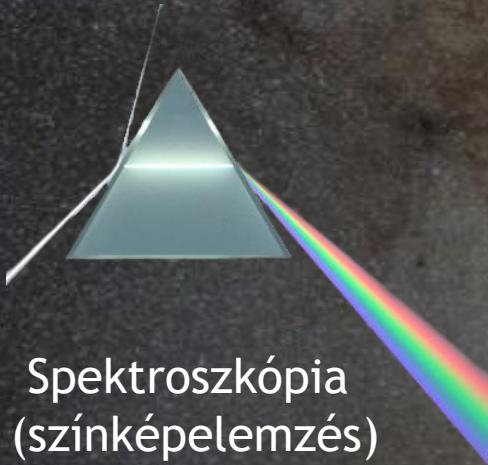


du Pont Telescope
Chile



A Tejútrendszer
homogén
kémiai térképe

Az APOGEE égboltfelmérő program

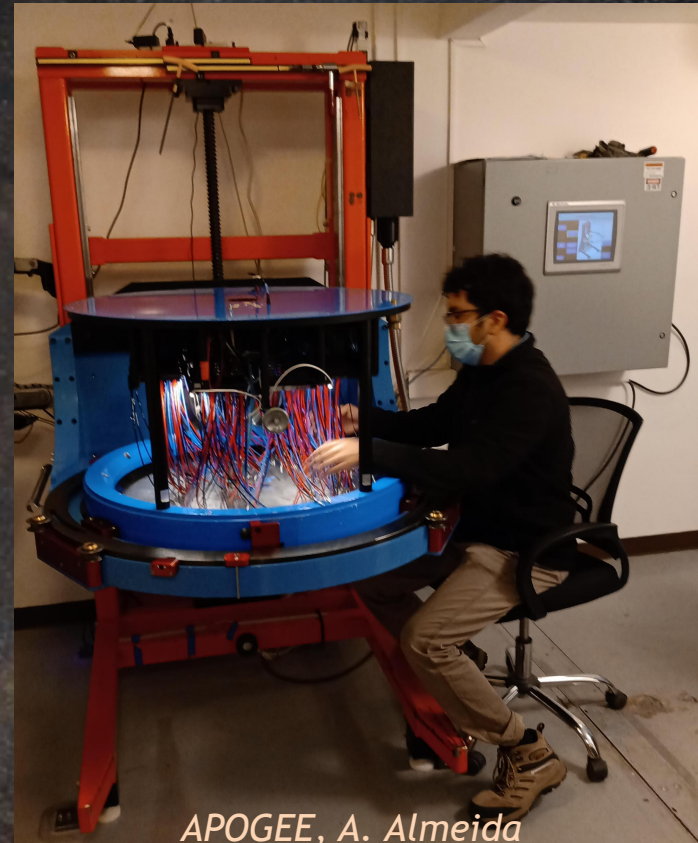


Spektroszkópia
(színképelemzés)

→ a csillagok összetétele



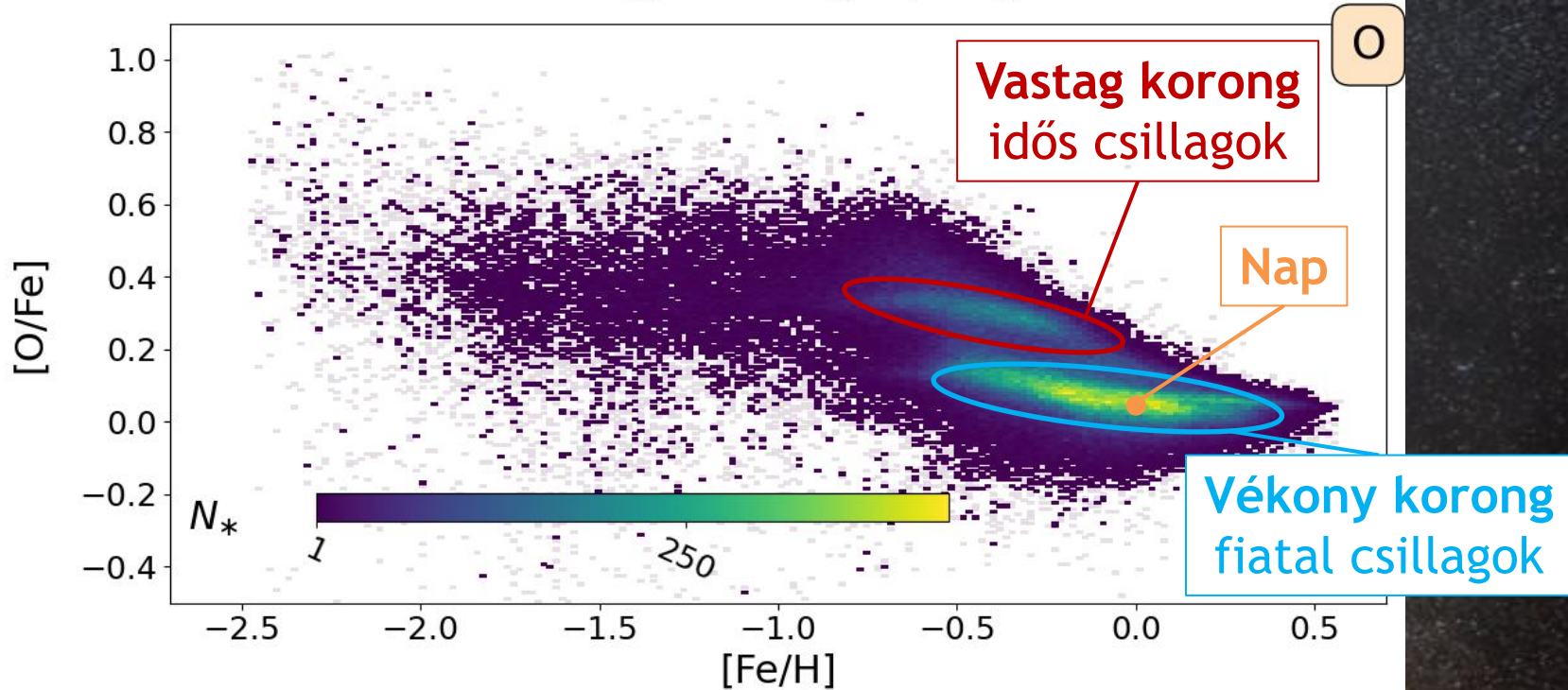
APOGEE



APOGEE, A. Almeida

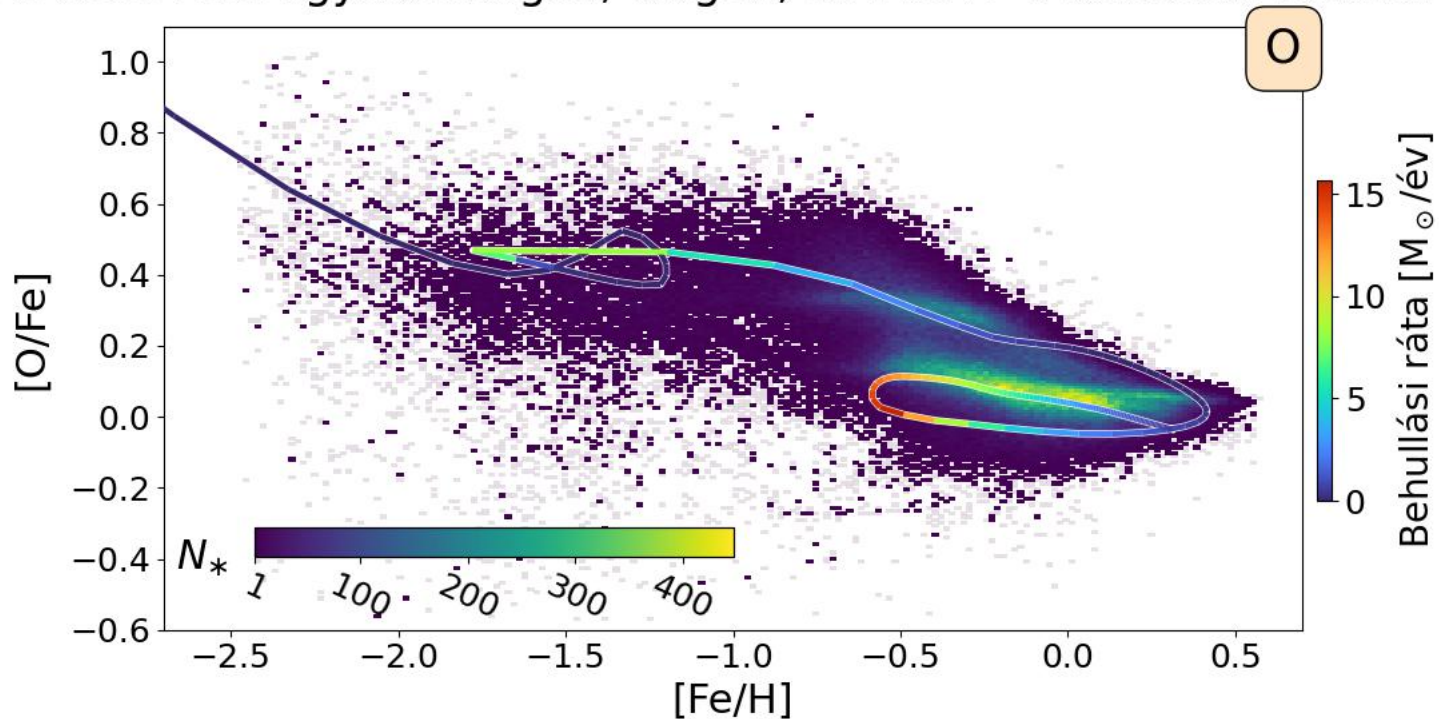
Kémiai kettősség

APOGEE elemgyakoriságok, oxigén



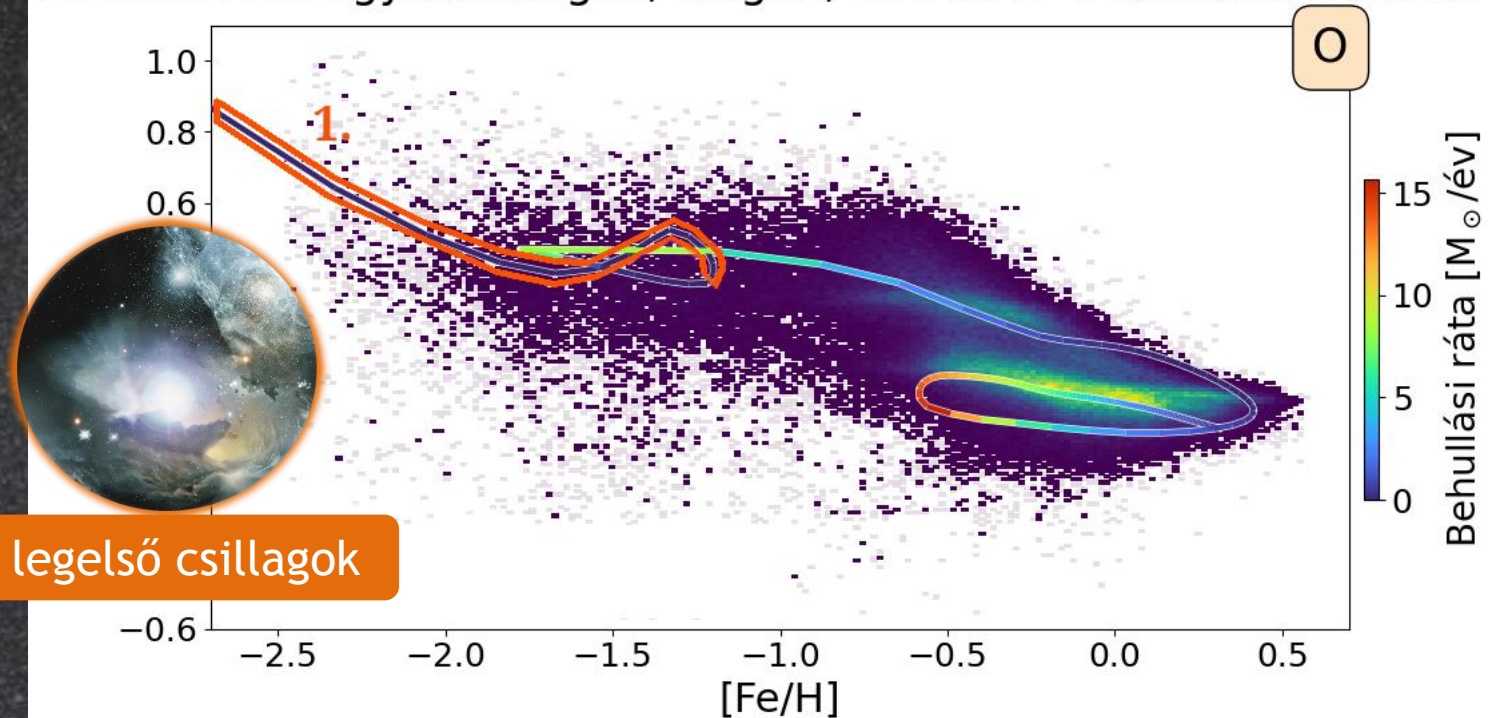
A Tejútrendszer kialakulásának folyamata

APOGEE elemgyakoriságok, oxigén; OMEGA+ a behullási rátával



A Tejútrendszer kialakulásának folyamata

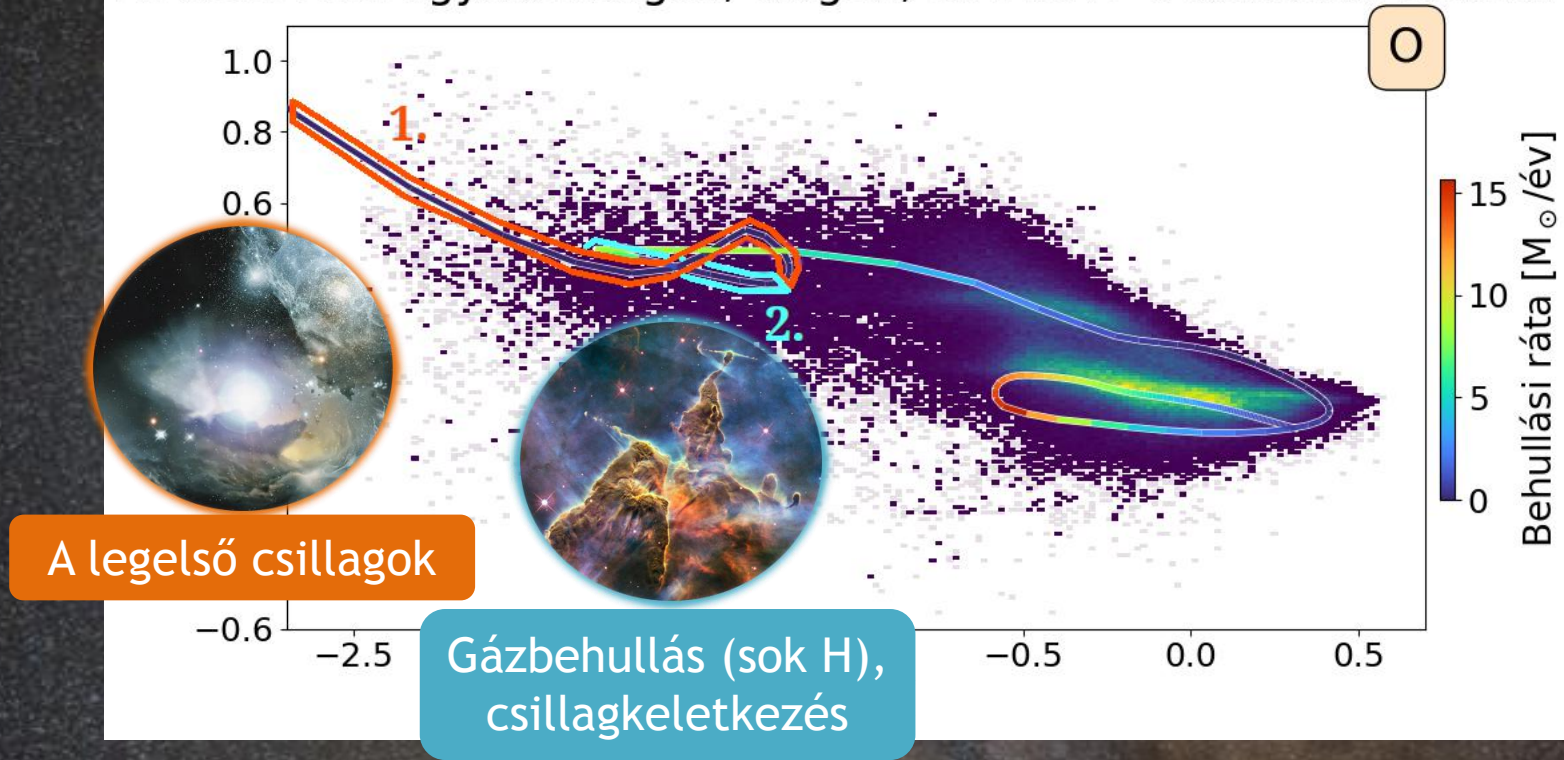
APOGEE elemgyakoriságok, oxigén; OMEGA+ a behullási rátával



A legelső csillagok

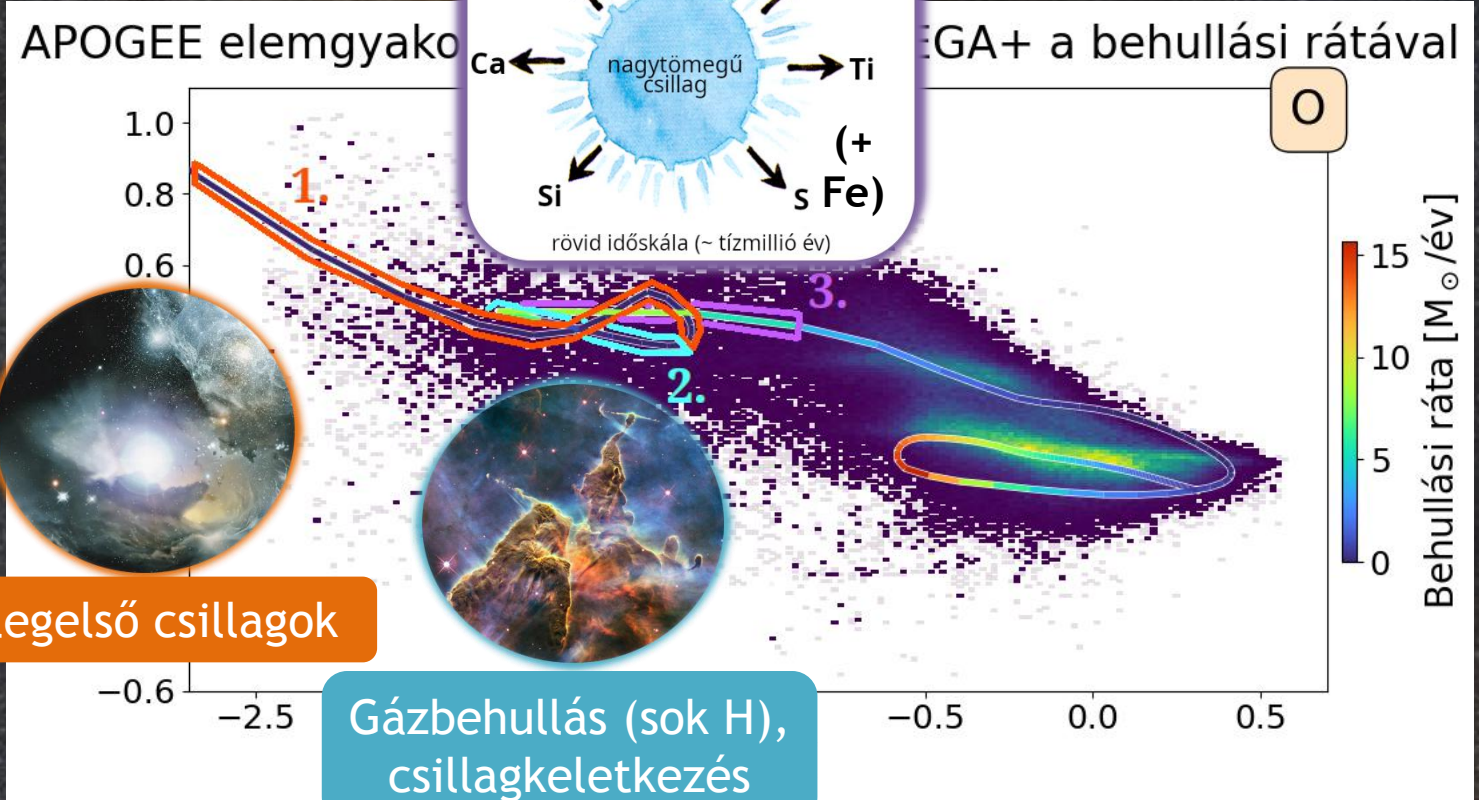
A Tejútrendszer kialakulásának folyamata

APOGEE elemgyakoriságok, oxigén; OMEGA+ a behullási rátával



NASA/ESA/ESO/Wolfram
Freudling et al. (STECF)

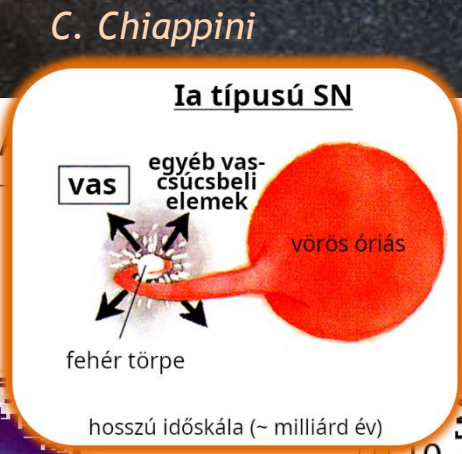
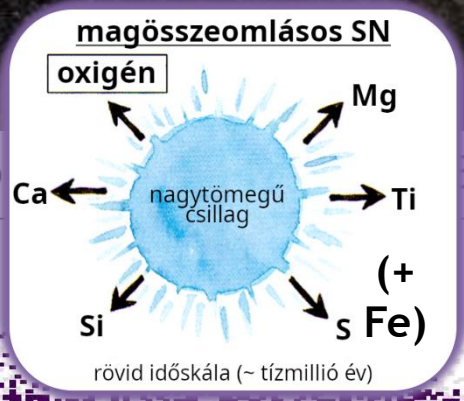
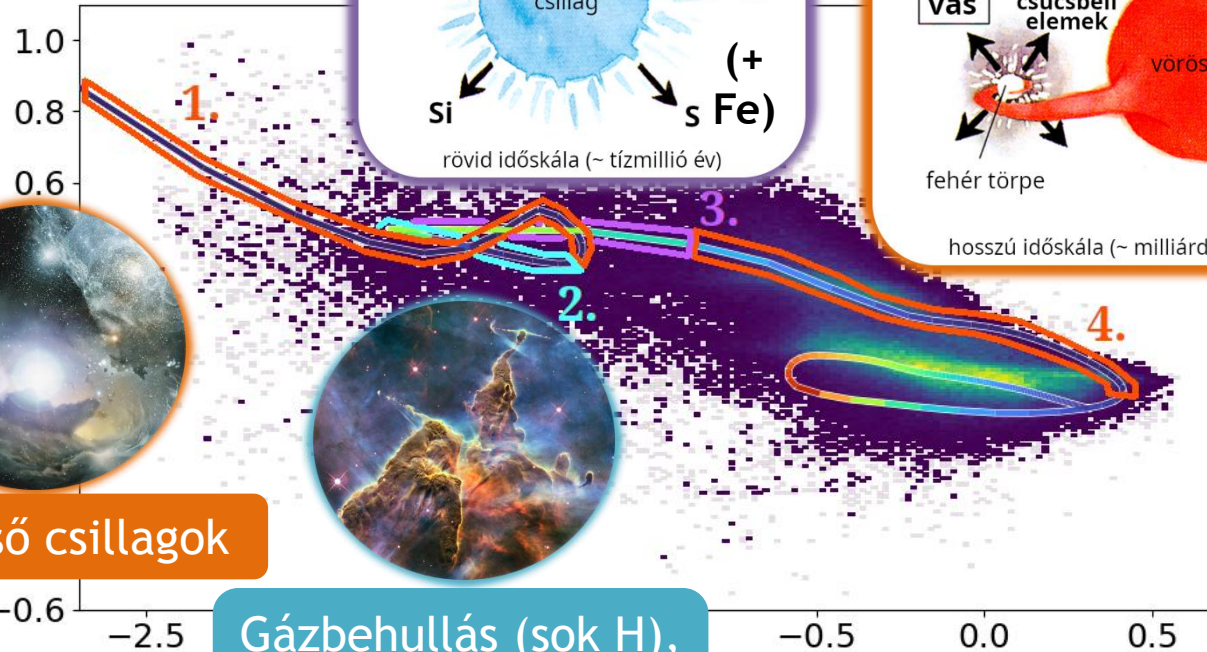
NASA, ESA, M. Livio and the
Hubble 20th Anniversary Team



A legelső csillagok

Gázbehullás (sok H), csillagkeletkezés

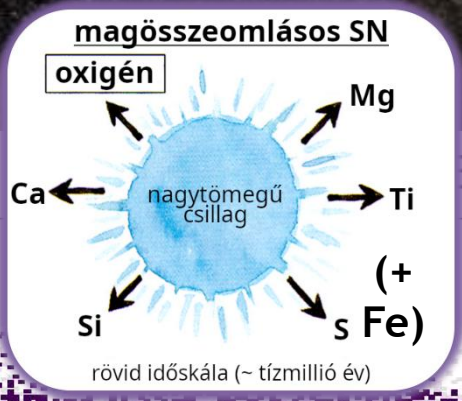
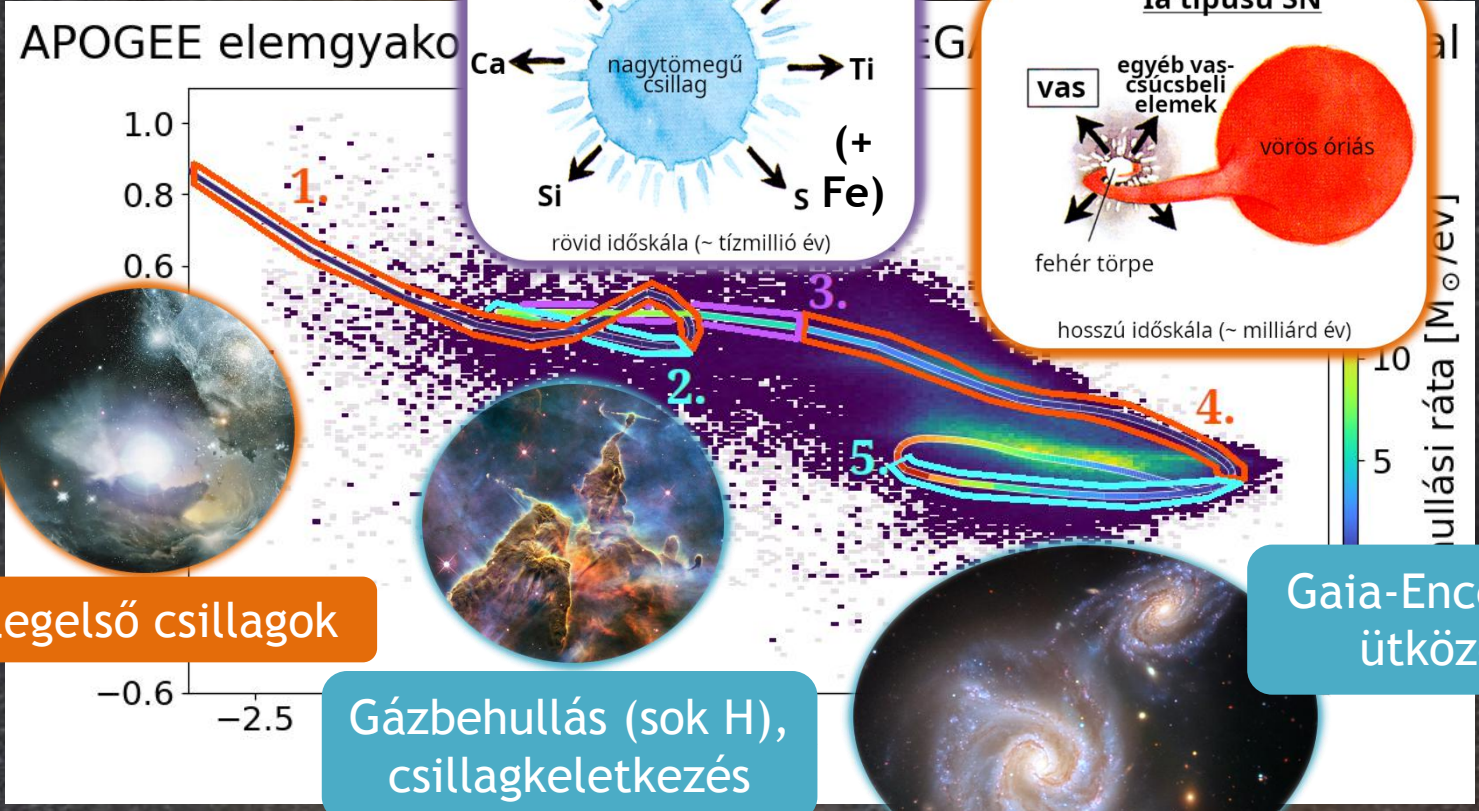
APOGEE elemgyako



A legelső csillagok

Gázbehullás (sok H), csillagkeletkezés

C. Chiappini



A legelső csillagok

Gázbehullás (sok H), csillagkeletkezés

Gaia-Enceladus ütközés?

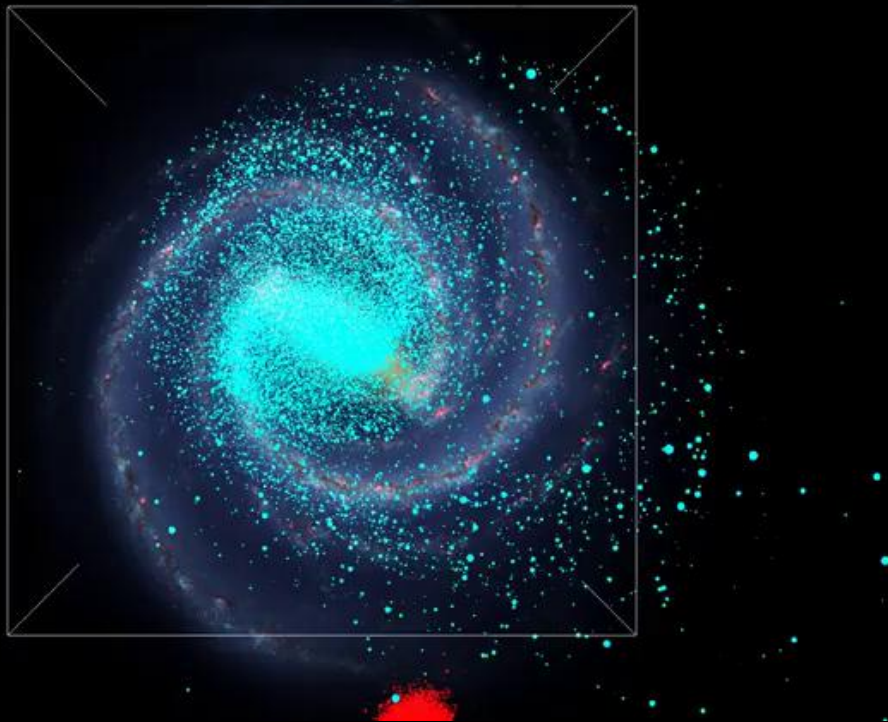
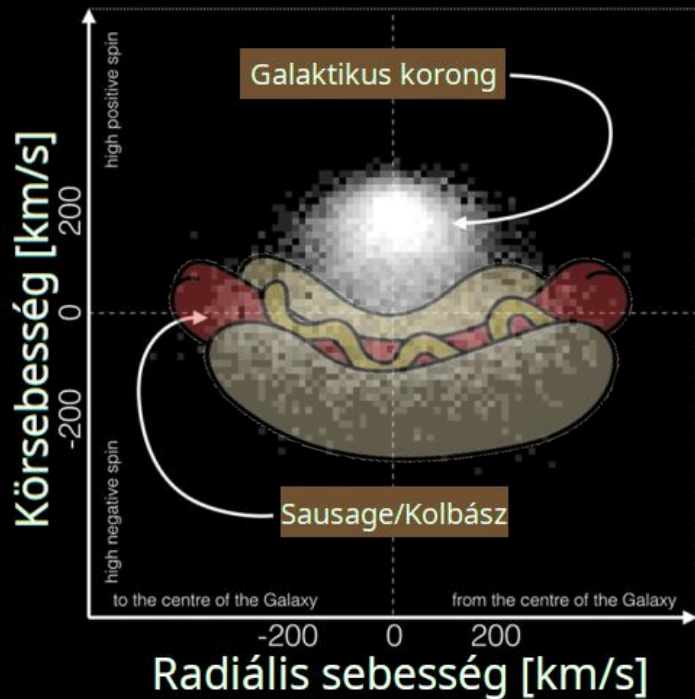
NASA/ESA/ESO/Wolfram Freudling et al. (STECF)

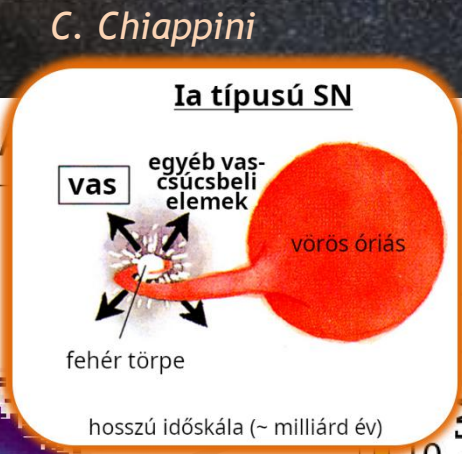
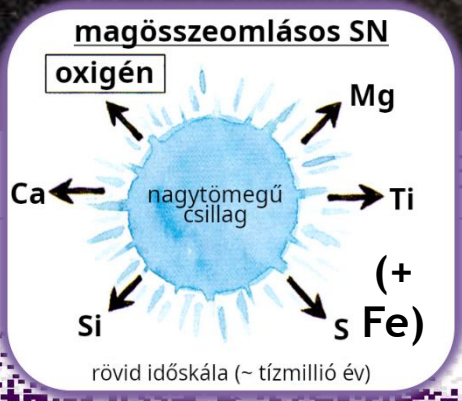
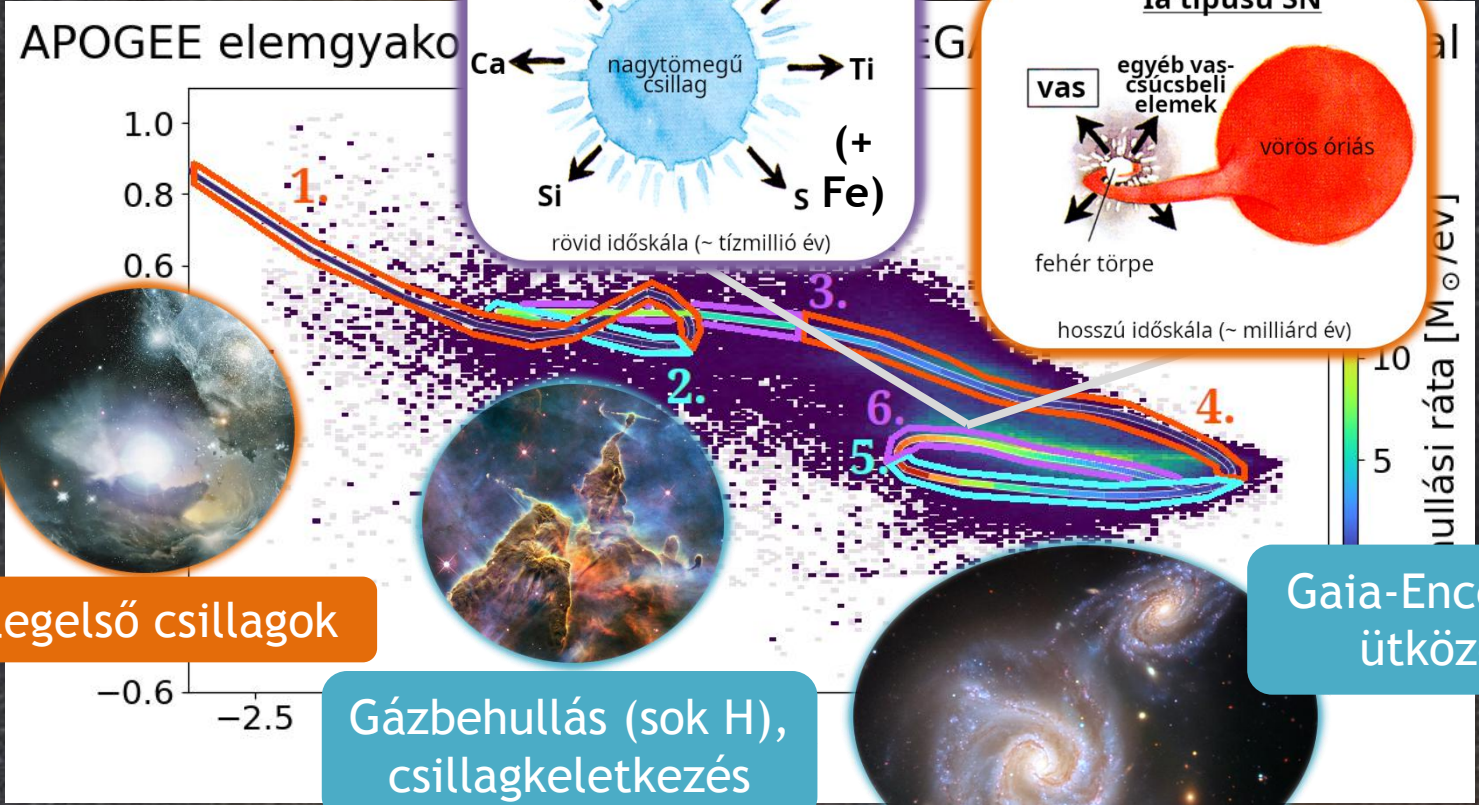
NASA, ESA, M. Livio and the Hubble 20th Anniversary Team

V. Belokurov, ESO/Juan Carlos Muñoz

Gaia-Enceladus

7 millió csillag mozgása (Gaia)





A legelső csillagok

Gázbehullás (sok H), csillagkeletkezés

Gaia-Enceladus ütközés?

Galaxis a garázsban - a recept

- Gravitáció
- Gáz, por
- → csillagok!
- Sötét anyag



Galaxis a garázsban - a recept

- Gravitáció
- Gáz, por
- → csillagok!
- Sötét anyag
- Fúzió!



**NE PRÓBÁLD
KI OTTHON!**