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Faculty of Mathematics, Physics and Informatics  
Comenius University  
Bratislava



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prostredníctvom

Plánu obnovy a odolnosti SR v rámci  
projektu č. 09I03-03-V04-00137

# Európsky vesmír... od Gaie k Euclidovi

RNDr. Roman Nagy, PhD.









- Galaxie, galaxie a zase galaxie
- 
- Misia Gaia – Galaktická revolúcia
- 
- Štruktúra vzdialených galaktických kútov
- 
- Misia Eucid – prehliadka vzdialeneho vesmíru



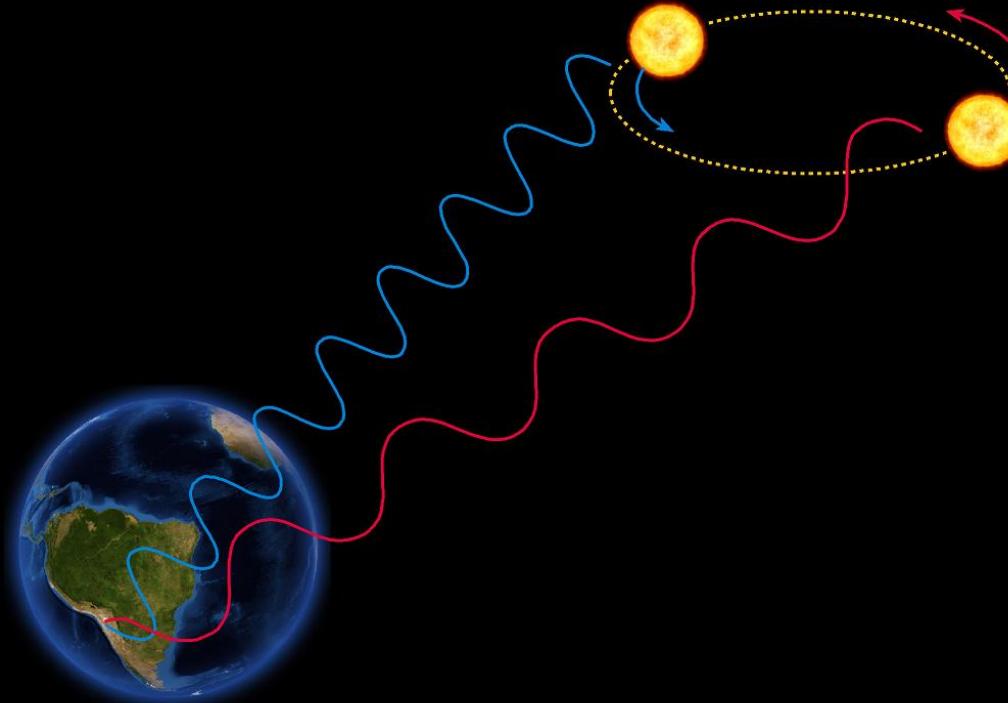
# The Great Debate

- 1917 - Heber Curtis – pozoroval nový v M31 – presadzoval myšlienku „ostrovného vesmíru“
- 1920 diskusia sa už zahustúje
- Curtis si všimol výrazný Dopplerov posun na M31... ale stále nie je nič isté



# The Great Debate

- 1917 - Heber C „ostrovného vě
- 1920 diskusia s
- Curtis si všimol isté



oval myšlienku

že stále nie je nič



# The Great Debate

- 1917 - Heber Curtis – pozoroval nový v M31 – presadzoval myšlienku „ostrovného vesmíru“
- 1920 diskusia sa už zahustúje
- Curtis si všimol výrazný Dopplerov posun na M31... ale stále nie je nič isté
- 1925 - Hubble – pozoroval Cepheidy v M31 – trefa do čierneho



# The Great

- 1917 - Heber  
„ostrovného“
- 1920 diskus
- Curtis si všimol isté
- 1925 - Hubble



al myšlienku  
ále nie je nič  
rneho

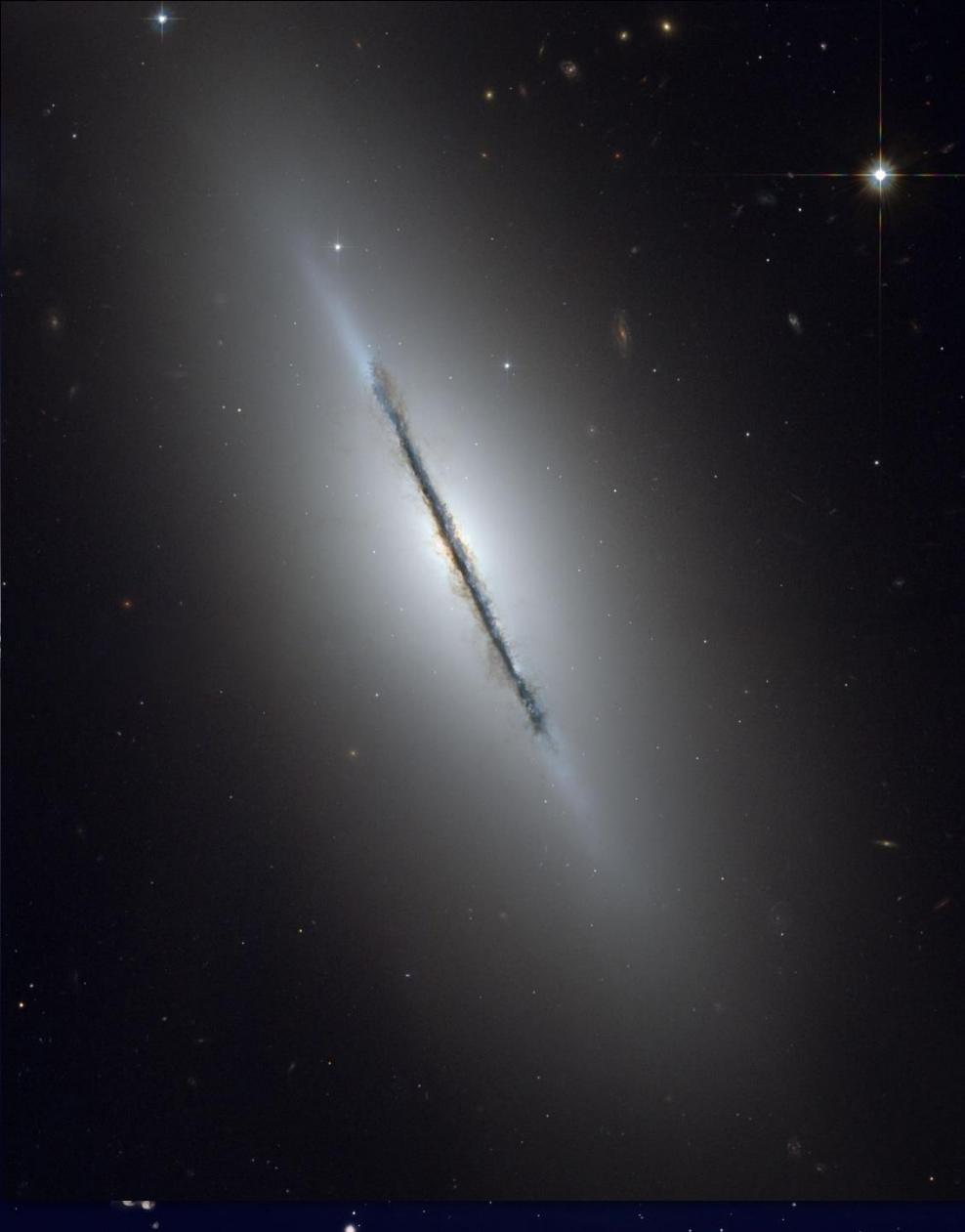
# Nie je galaxia ako galaxia

- Rozmer od 100iek svetelných rokov až po milióny svetelných rokov
- Hmotnosti =  $100\ 000\ 000\ 000\ 000 = 100\ \text{miliónov miliónov}$
- Svetlosť od 100 000 000 slnka do 1 000 000 000 slnka

# Nie je galaxia ako galaxia

ných rokov  
nov

Nie

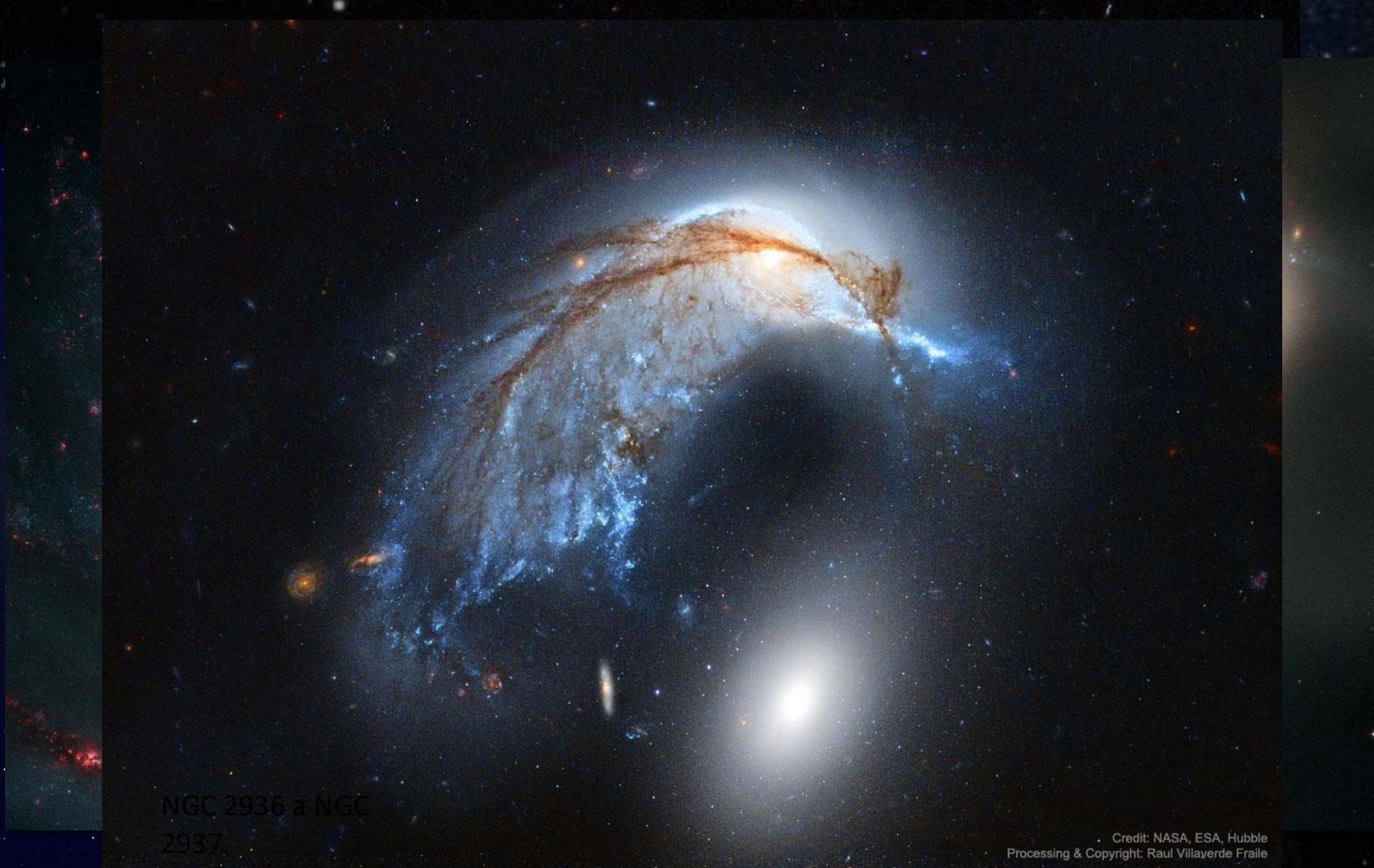


ných rokov  
nov

Nie







NGC 2936 a NGC  
2937

Credit: NASA, ESA, Hubble  
Processing & Copyright: Raul Villaverde Fraile



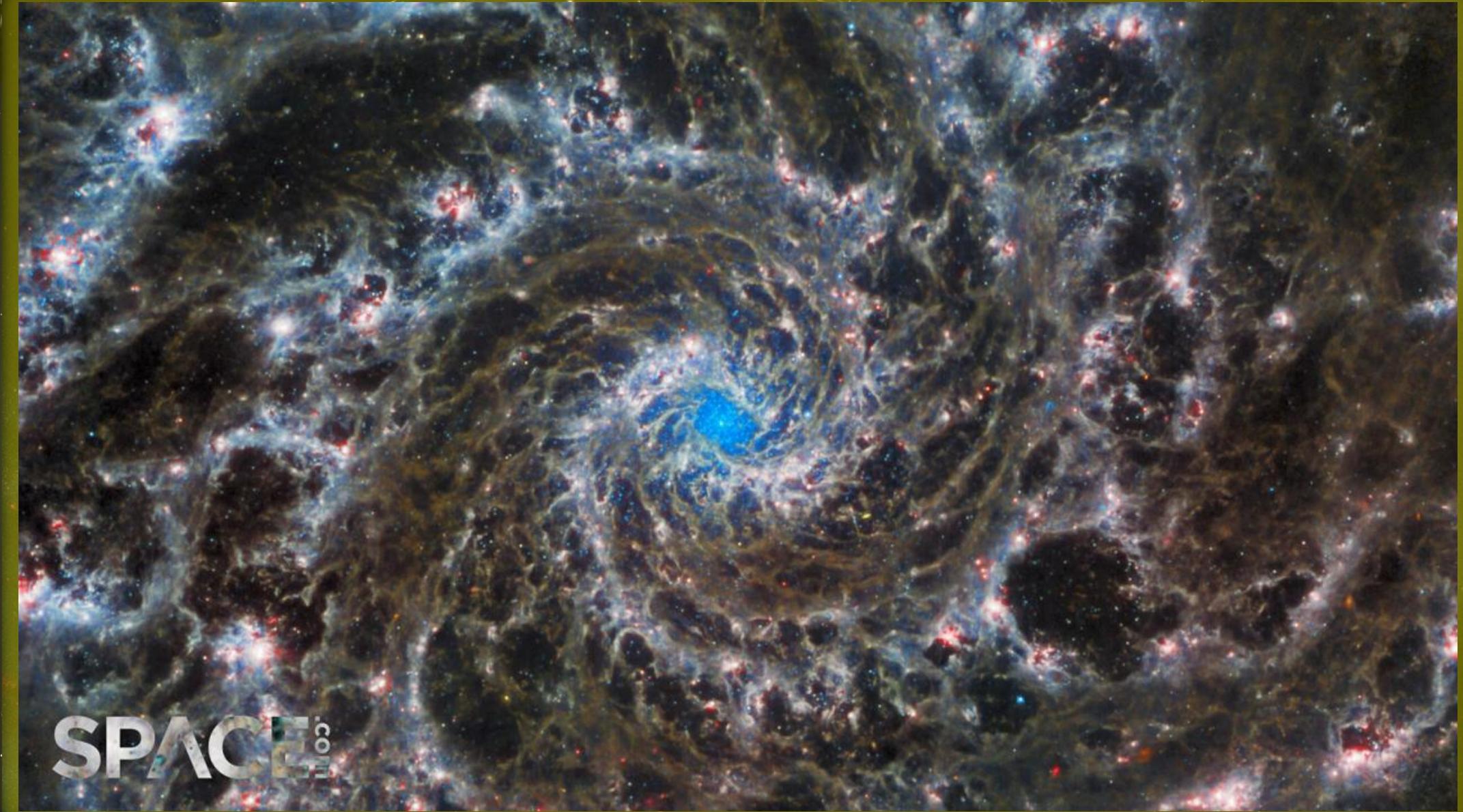
NGC 4038 a NGC 4039

Hubble  
Fraile



NGC 4038 a NGC 4039

Hubble  
Fraile



SPACE.com

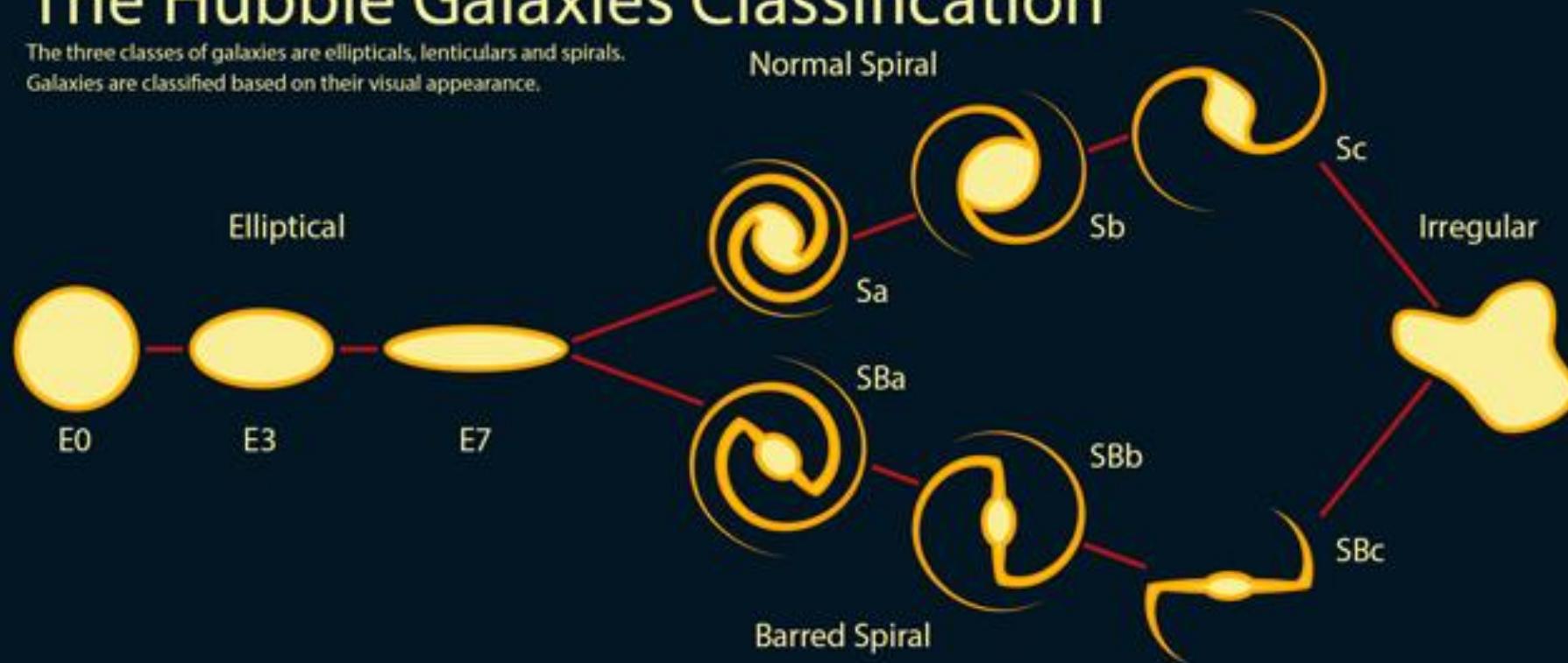
NGC 4038 a NGC 4039

Hubble  
Fraille

# Hubbleova klasifikácia galaxií

## The Hubble Galaxies Classification

The three classes of galaxies are ellipticals, lenticulars and spirals.  
Galaxies are classified based on their visual appearance.





# Od galaxie ku kopám galaxií

- Zwicky 1933 – pozorovanie kopu galaxií v súhvezdí Vlasy Bereniky (Coma cluster)
  - prvý odhad hmotnosti
- Počítal rýchlosť galaxií a využil Newtonov teorém ( $2 T = -U$ )
- Odhadol celkovú hmotnosť na základe svietivosti galaxií
  - druhý odhad hmotnosti



400x viac hmoty  
ako priamo pozorujeme

Rogelio Bernal Andreo  
[DeepSkyColors.com](http://DeepSkyColors.com)

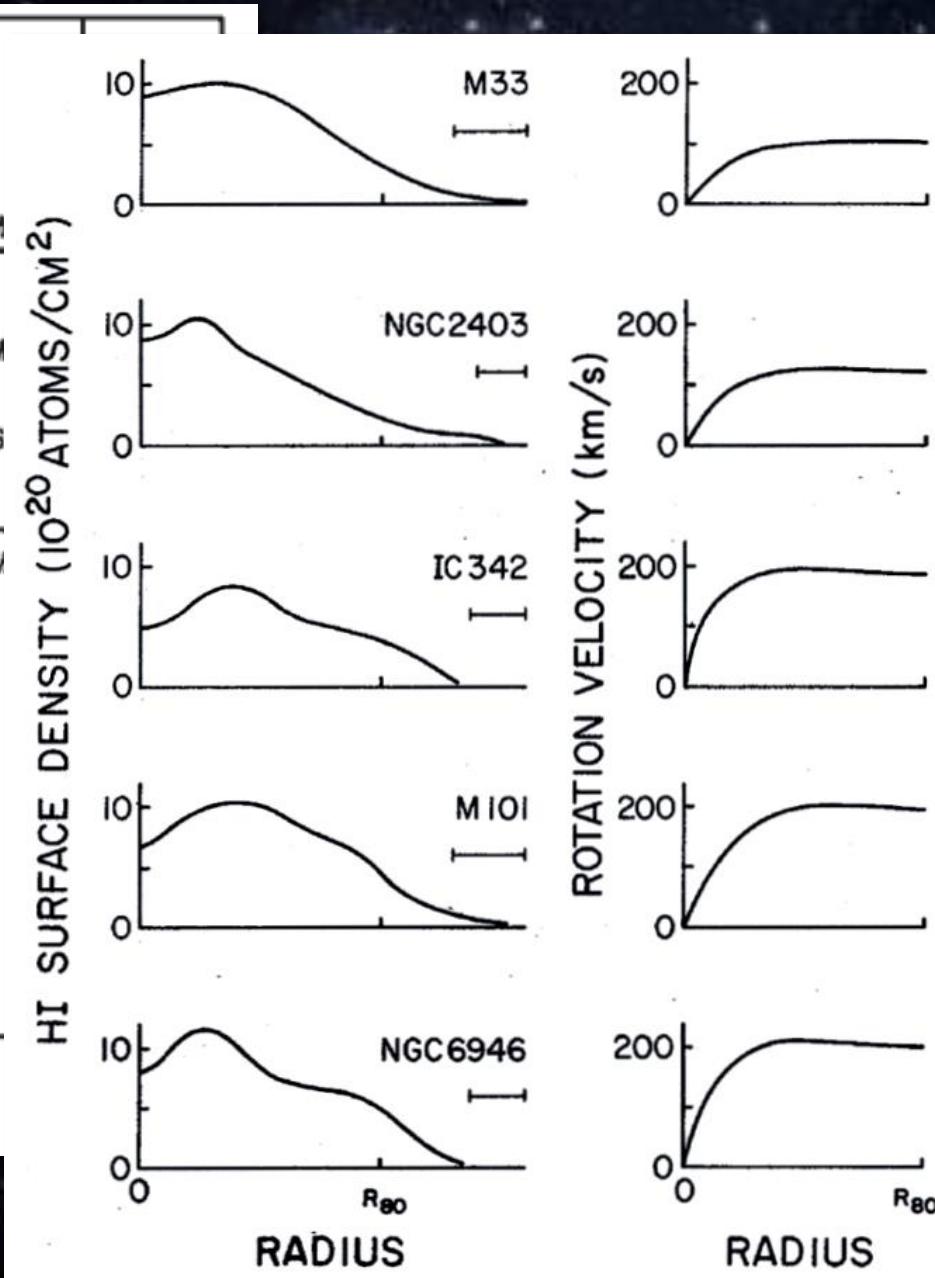
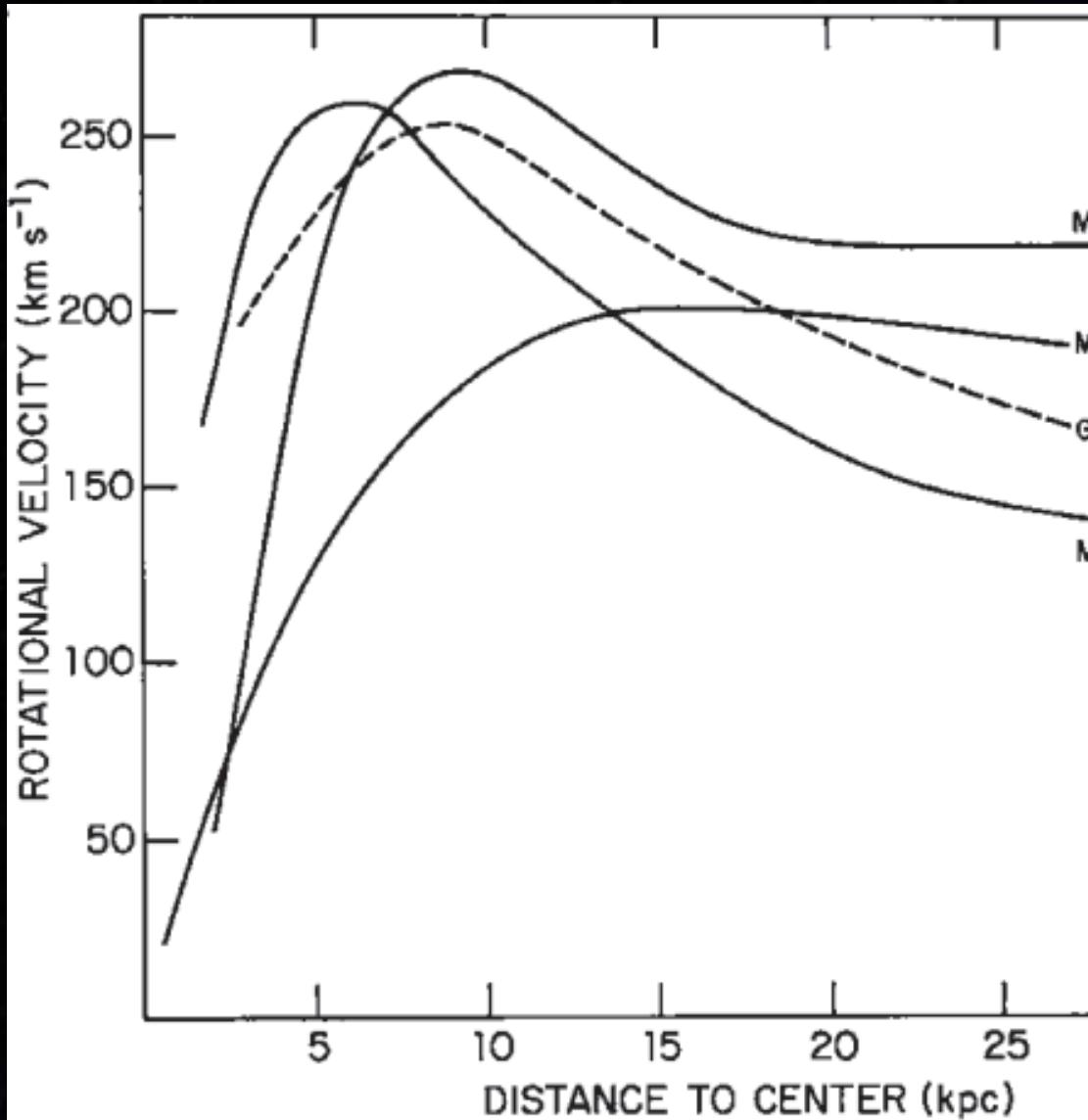
# 70te roky - nastal zlom

- Začína postupná konvergencia ku konceptu tmavej hmoty
- Nový druh pozorovaní
- Vera Rubin pozoruje rotačné krivky galaxií (funkčná závislosť obežnej rýchlosťi od radiálnej vzdialenosťi)

# Vera Rubin



Kitt Peak observatórium v Arizone, USA,  
ďalekohľad s priemerom 36 palcov



# Rotačná krivka





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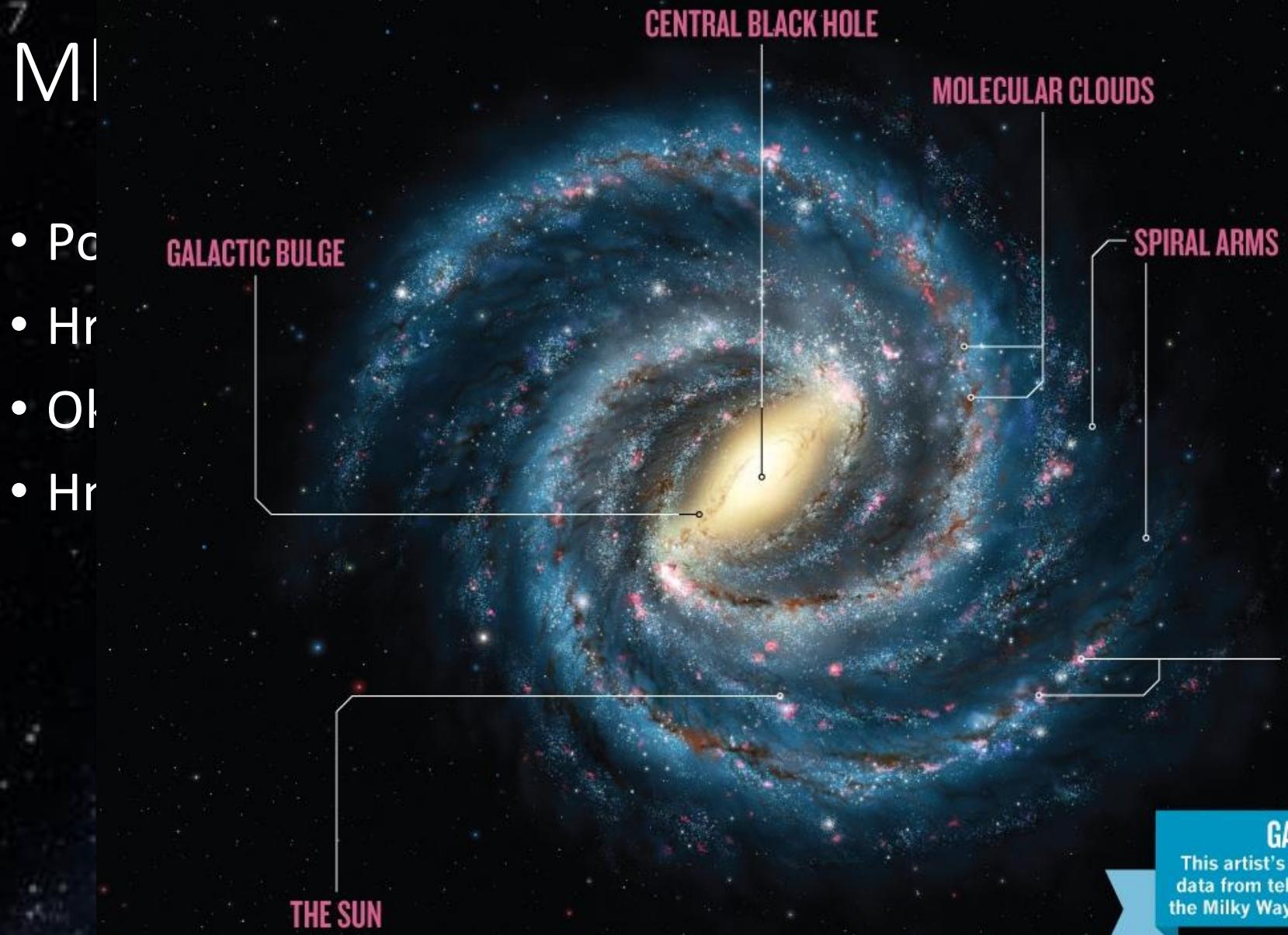
# Mliečna cesta – naša rodná galaxia



# Mliečna cesta – naša rodná galaxia

- Polomer disku 50 000 svetelných rokov
- Hrúbka disku je približne 1 000 svetelných rokov
- Okolo 400 miliárd hviezd
- Hmotnosť 1 bilión hmotností Slnka

M|



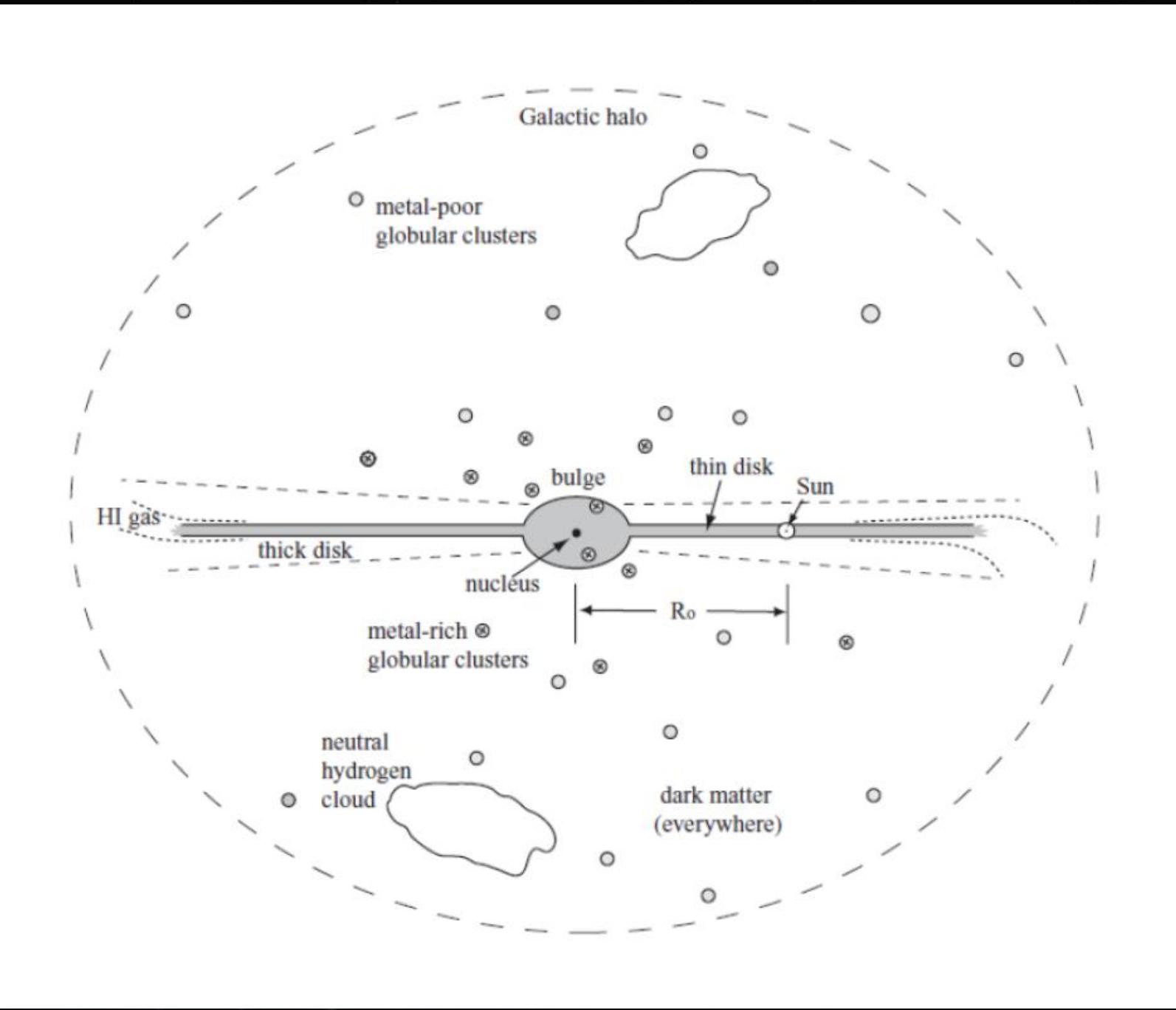
### GALACTIC PORTRAIT

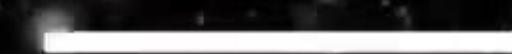
This artist's impression, based on the latest data from telescopes and simulations, shows the Milky Way viewed from outside the Galaxy.

M|

- Pg
- Hr
- Ol
- Hr

GALACTIC





1 light-year

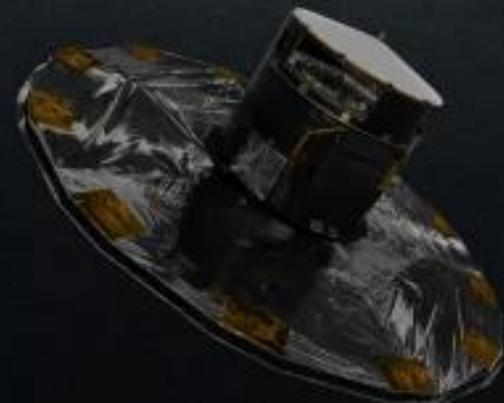


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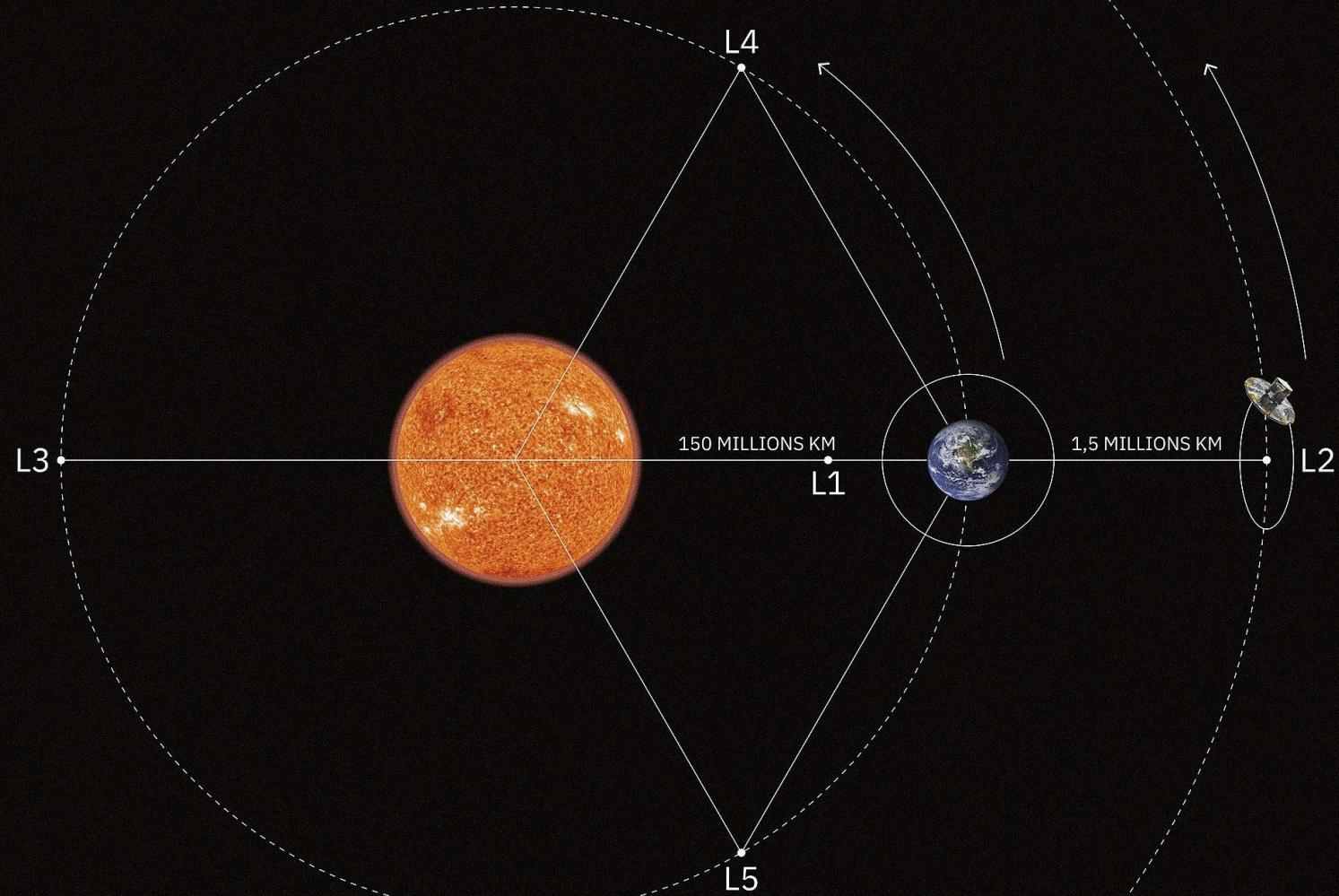
# Gaia – galaktická revolúcia





G

• D  
• N  
• A





# Gaia – Galaktická revolúcia

- December 2013 – 2019 (východiskový scenár)
- Misia ESA v L2
- Astrometrická, fotometrická a spektroskopická misia

poloha

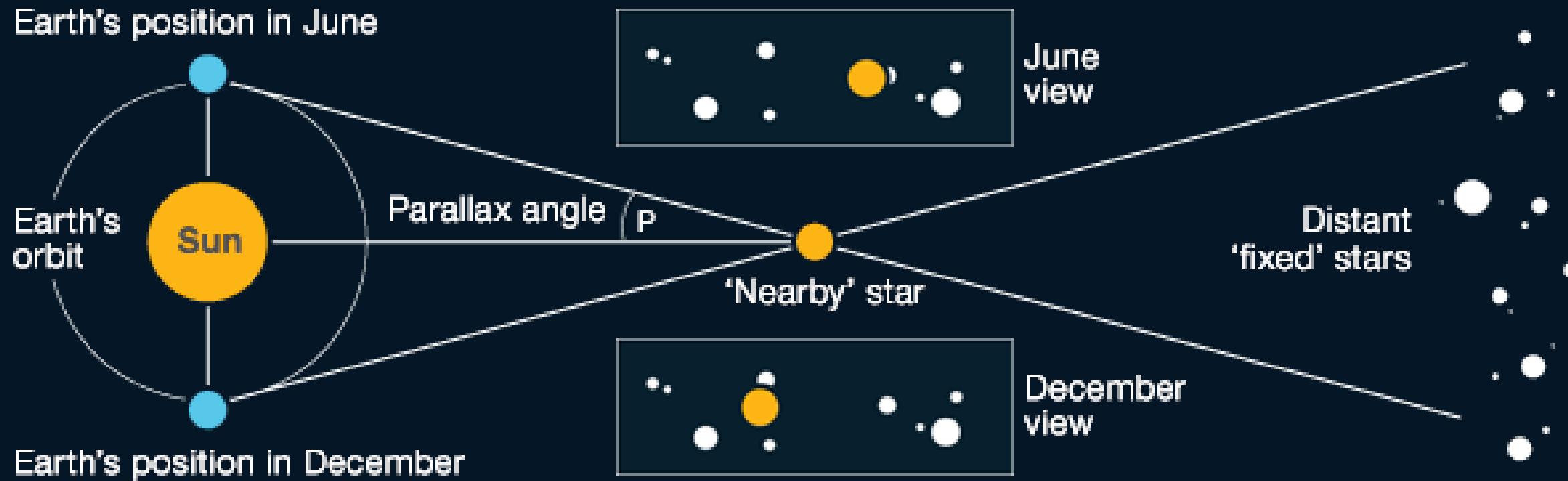
jasnosť

radiálna  
rýchlosť



# Gaia – Galaktická revolúcia

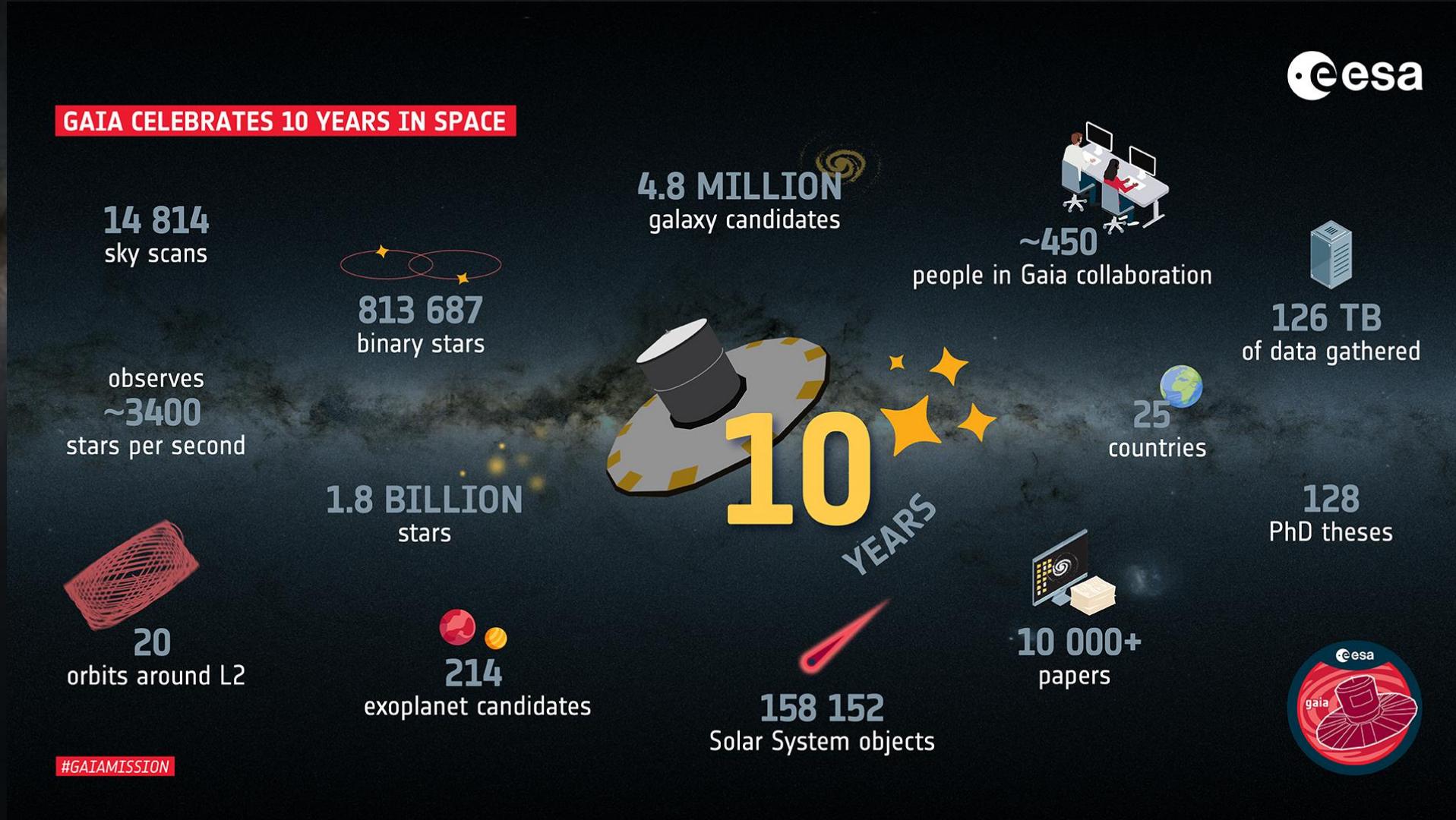
## Stellar parallax: Measuring the distance of stars







# Gaia – Galaktická revolúcia

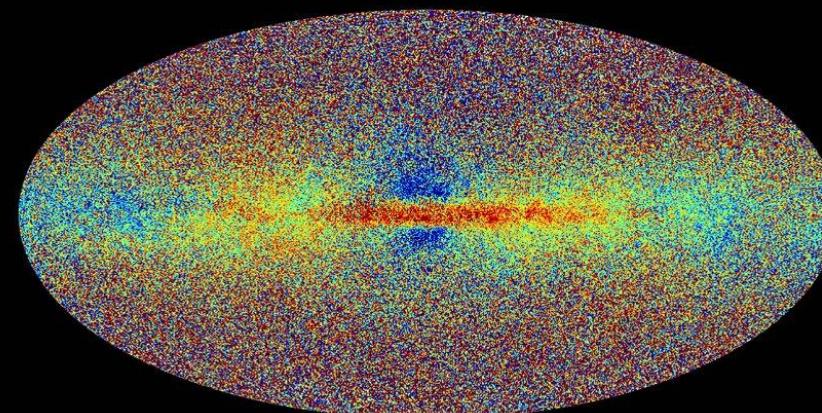
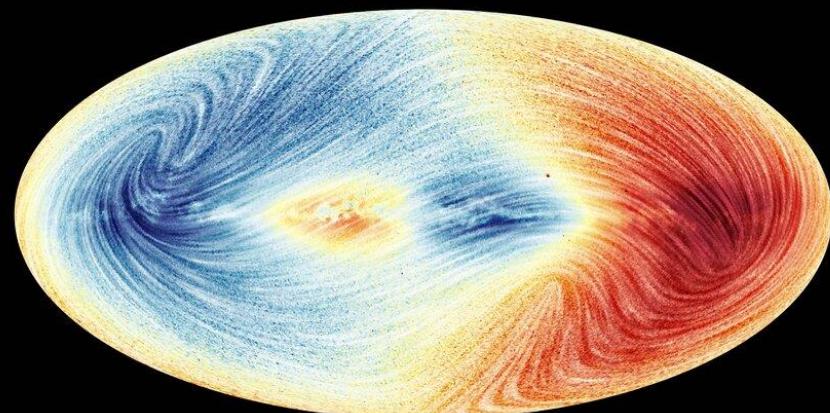
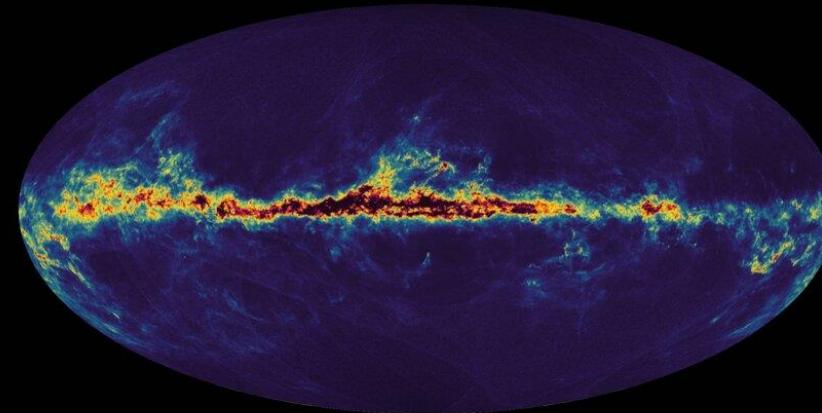
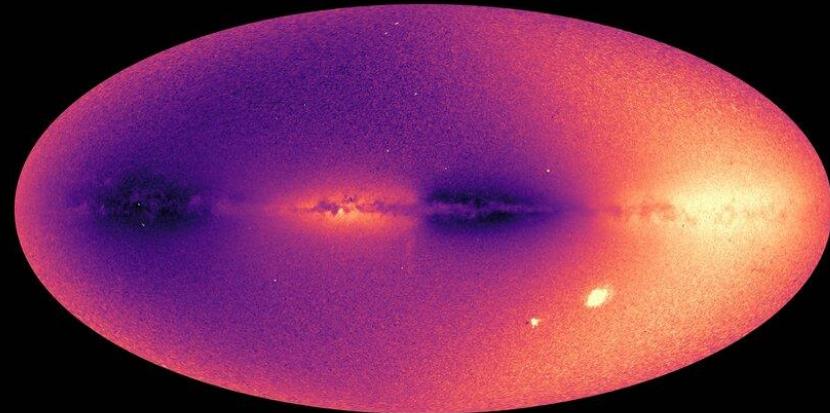


Gaia

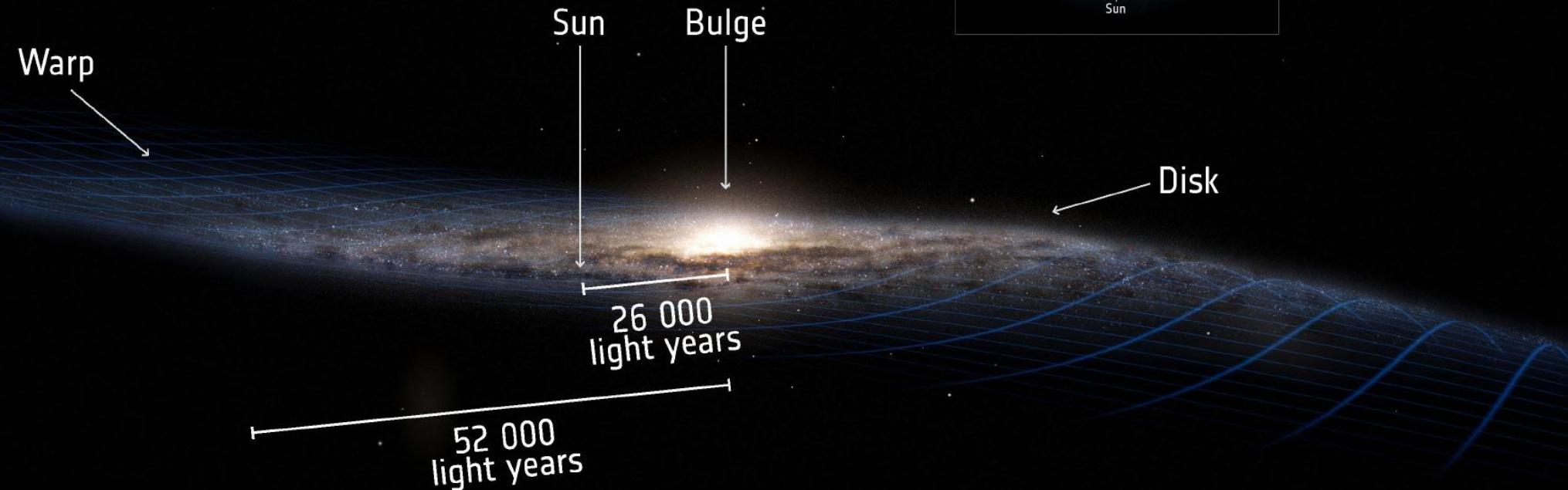
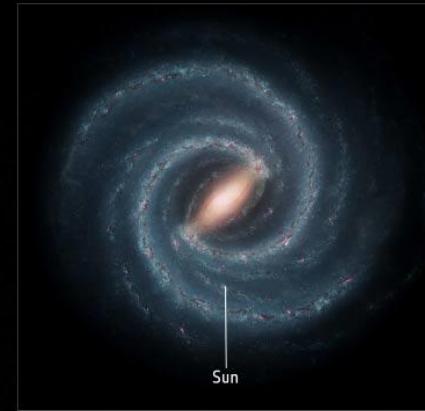


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atics, Physics and Informatics  
ty

## GAIA: EXPLORING THE MULTI-DIMENSIONAL MILKY WAY



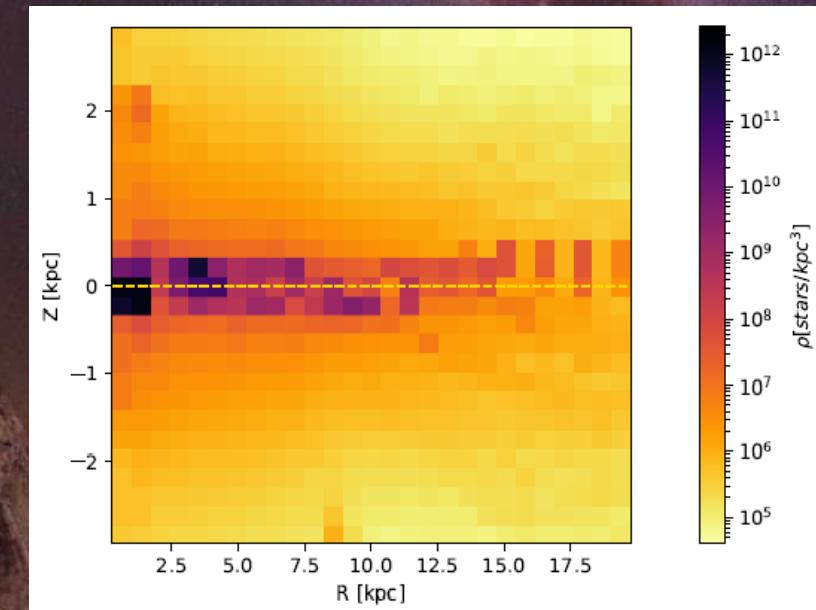
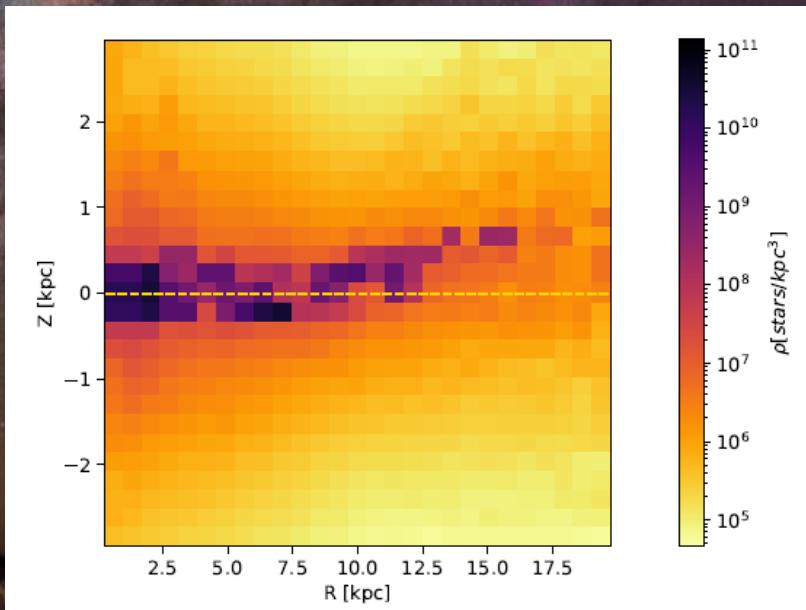
## THE MILKY WAY'S WARP





# Galaktické predmestia

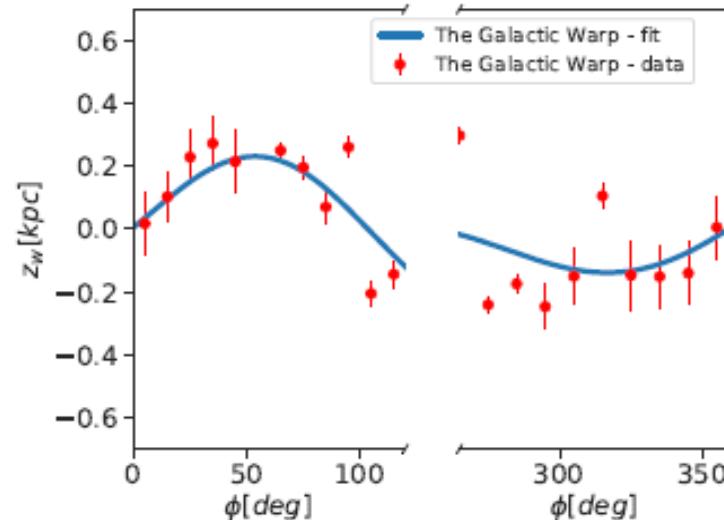
- Galaktický warp



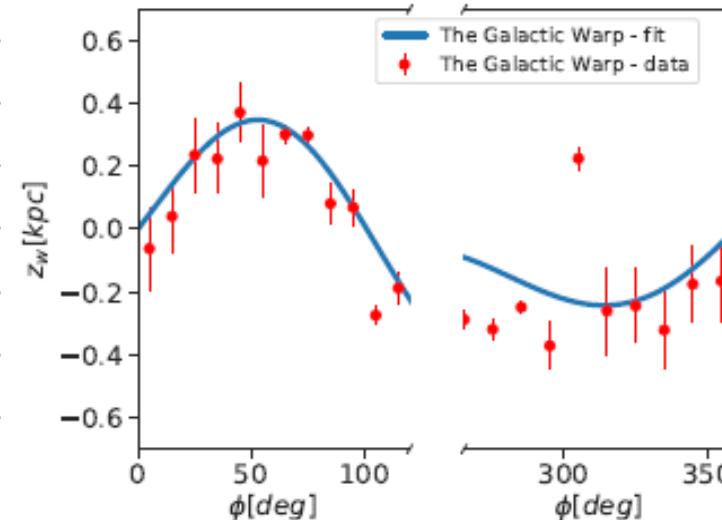


# Galaktické predmestia

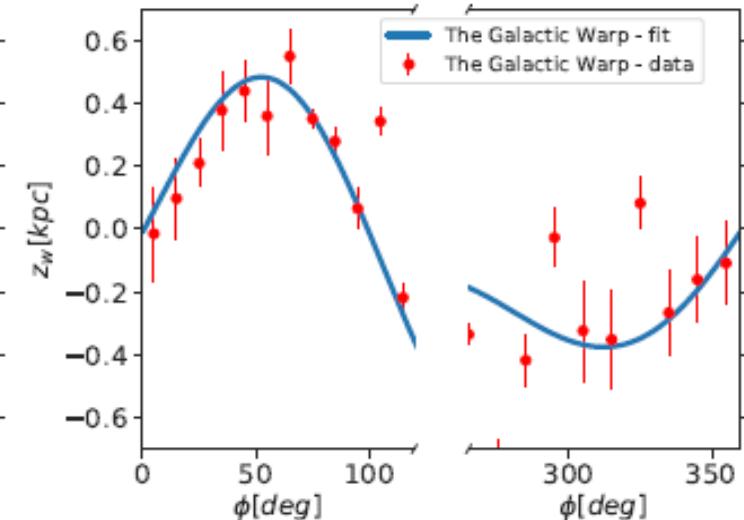
- Galaktický warp



(a)



(b)

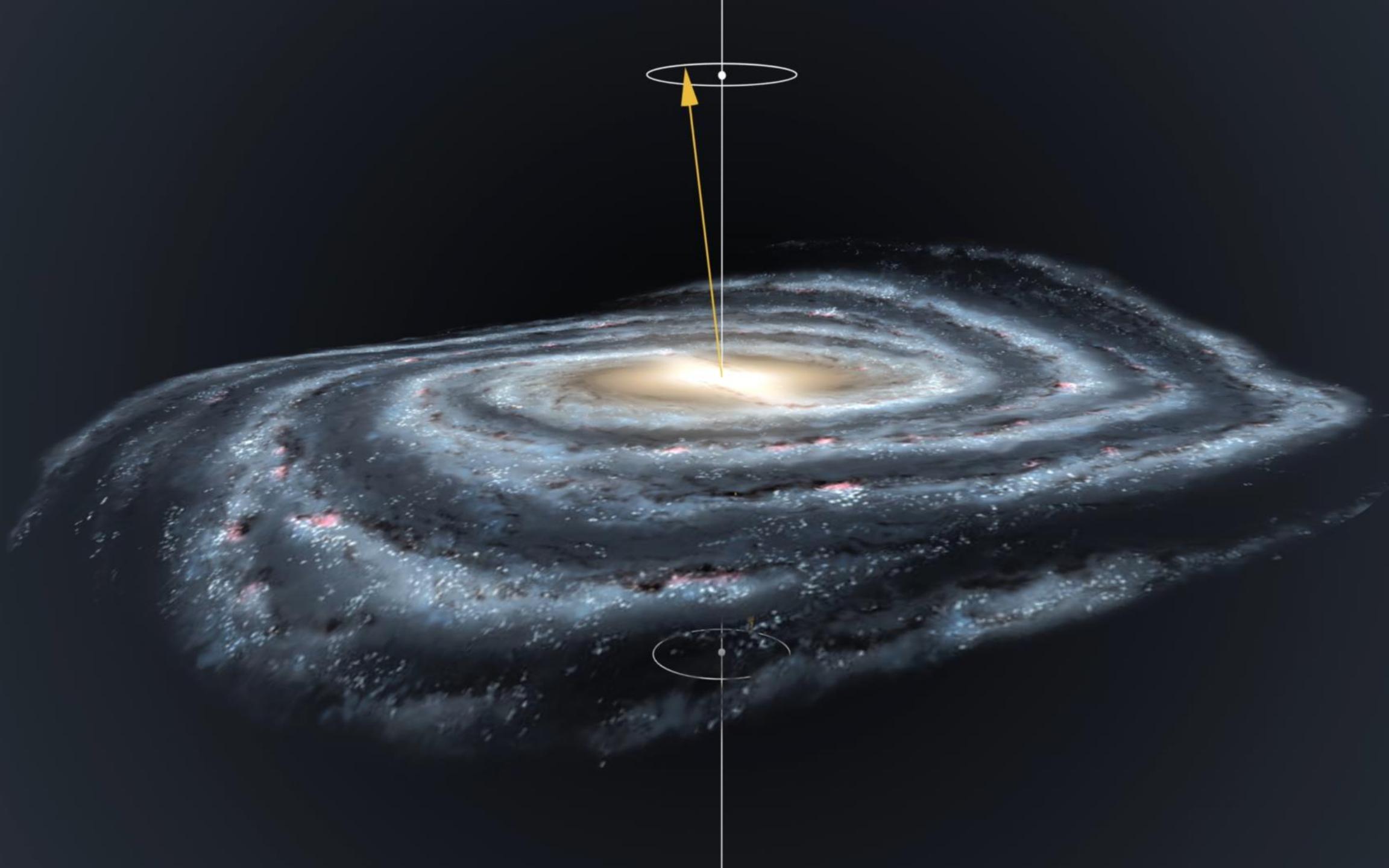


(c)



# Galactic suburbs

- Galactic warp





# Galaktické predmestia

- Galaktický warp
- Galaktický flare – zhrubnutie disku

$$\rho(R, z) = \rho_0(R) \times \exp(-R/h_r) \times \exp(-|z|/h_z)$$

- Zvyšovanie škálovaciej hrúbky ( $h_z$ ) disku so zvyšujúcou sa vzdialenosťou od stredu Galaxie
- Pozorované v plynných vodíkových aj hviezdnych populáciách



# Galaktické predmestia

- Galaktický warp – skútenie
- 
- Galaktický flare – zhrubnutie disku
- Hviezdne prúdy



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©Trevor Dobson



# Gaia a nedávne galaktické splynutie

- Známe galaktické splynutie Gaia-Sausage-Enceladus – 8 až 11 Gyr
- Gaia DR3 naznačujú nedávnu veľkú zrážku 3 Gyr
- Virgo Radial Merger



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# Galaxy



9.8 billion years ago  
1.3 billion years before collision

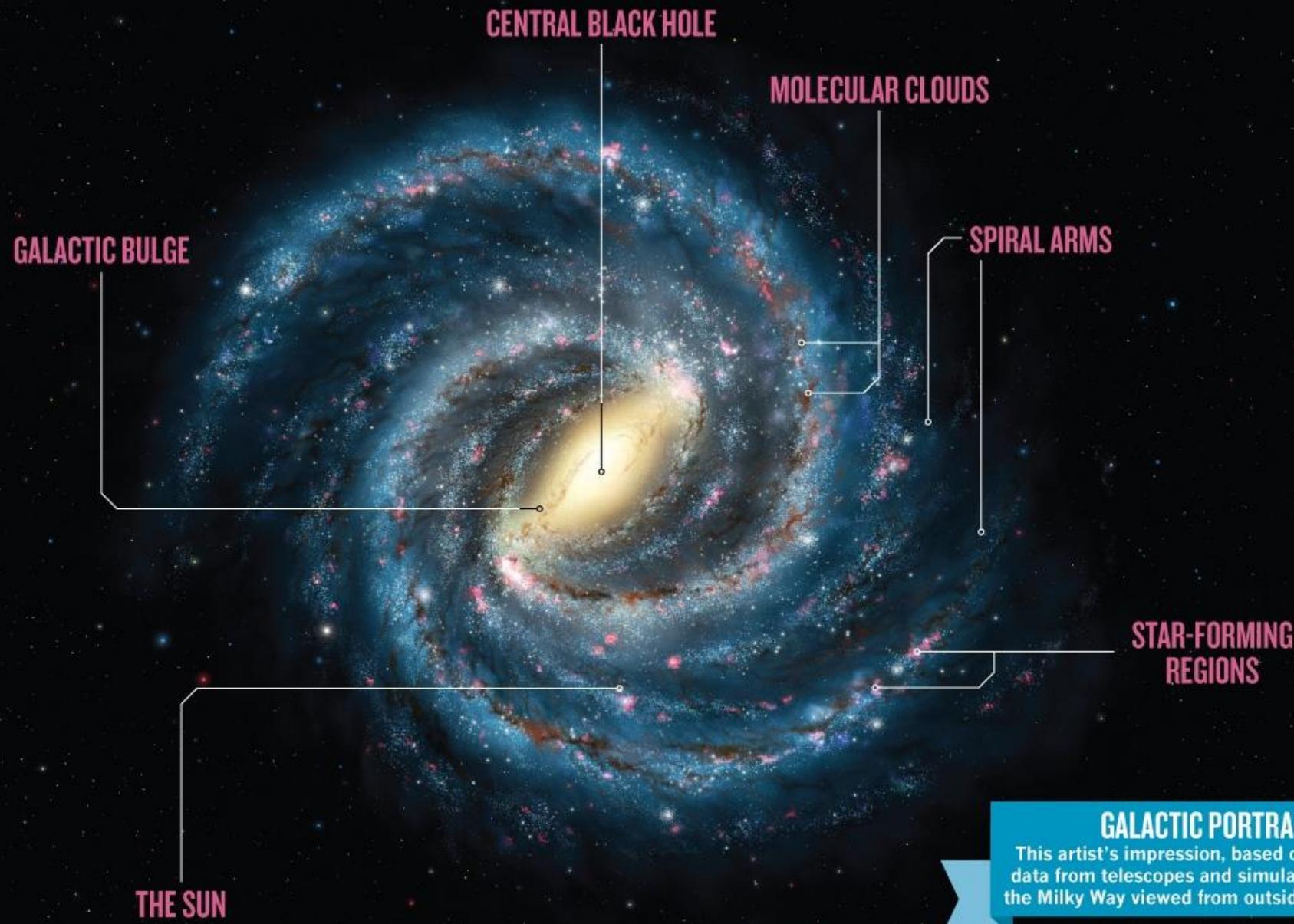
- Zn
- Ga
- Vi



# Galaktická priečka

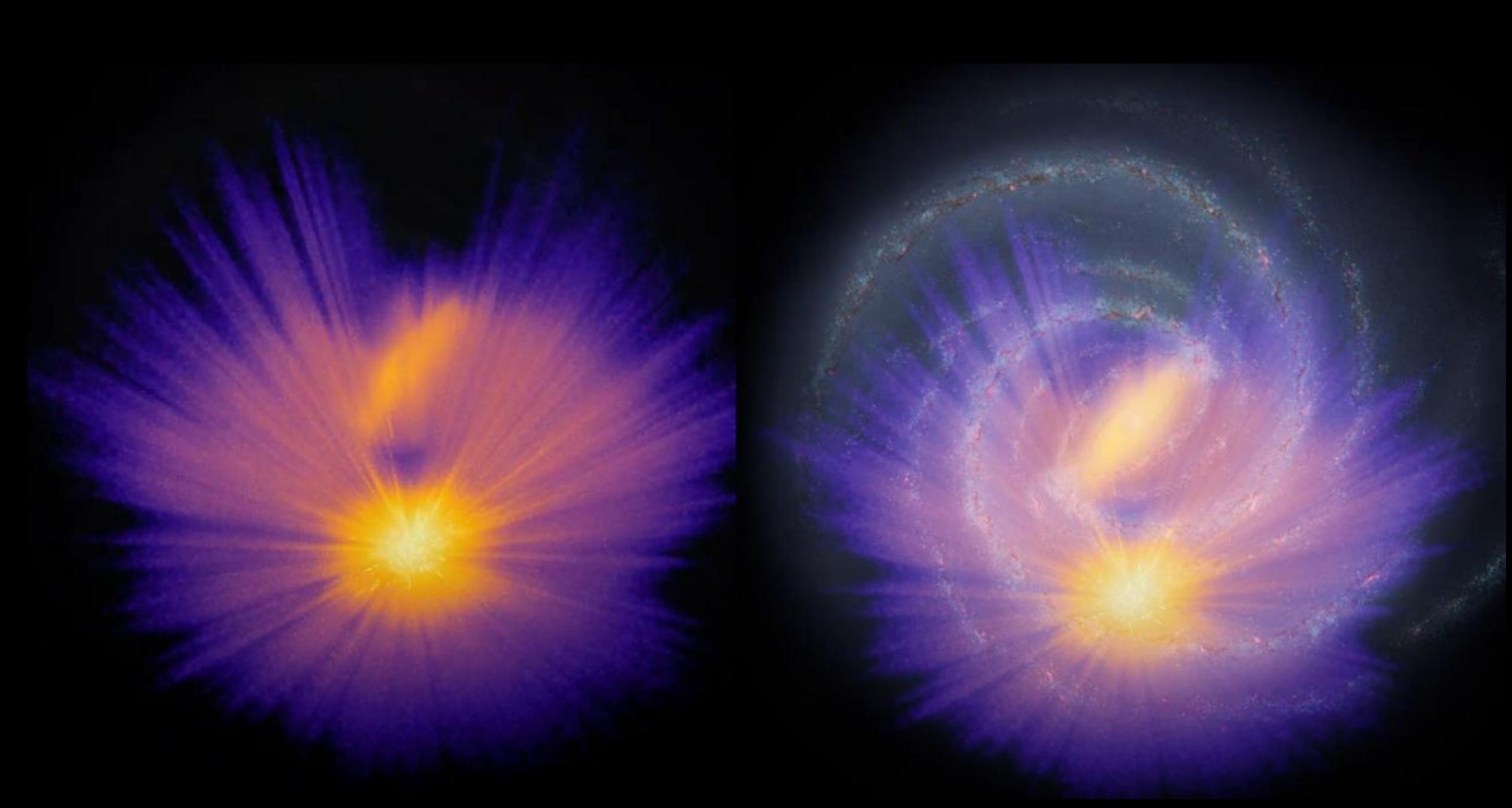


G



### GALACTIC PORTRAIT

This artist's impression, based on the latest data from telescopes and simulations, shows the Milky Way viewed from outside the Galaxy.



	SAP	SM1	SM2	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	BP	RP	RVS1	RVS2	RVS3
VPU1	3.15	3.15	3.18	3.16	3.17	3.17	3.20	3.17	3.15	3.16	3.17	3.15	3.16	3.17			
VPU2	3.13	3.13	3.15		3.19	3.15	3.14		3.13		3.15						
VPU3		3.13	3.14		3.16	3.15	3.11		3.12		3.14		3.11				
VPU4	3.07	3.11				3.07					3.08			3.14	3.11	3.08	
VPU5	3.14	3.13	3.11	3.13		3.11	3.09	3.11			3.10		3.12	3.11	3.16	3.15	3.15
VPU6	3.09	3.13			3.09					3.12				3.15	3.15	3.14	
VPU7	3.10	3.16	3.10	3.12	3.14	3.16	3.13	3.16	3.14	3.13	3.13	3.14	3.16	3.18	3.16	3.17	

Science TM FALSE

VPU1 MODE PRO\_SER

VPU2 MODE PRO\_SER

VPU3 MODE PRO\_SER

VPU4 MODE PRO\_SER

VPU5 MODE PRO\_SER

VPU6 MODE PRO\_SER

VPU7 MODE PRO\_SER

Goodbye Gaia – March 25



# Euclid – Extragalaktická revolúcia

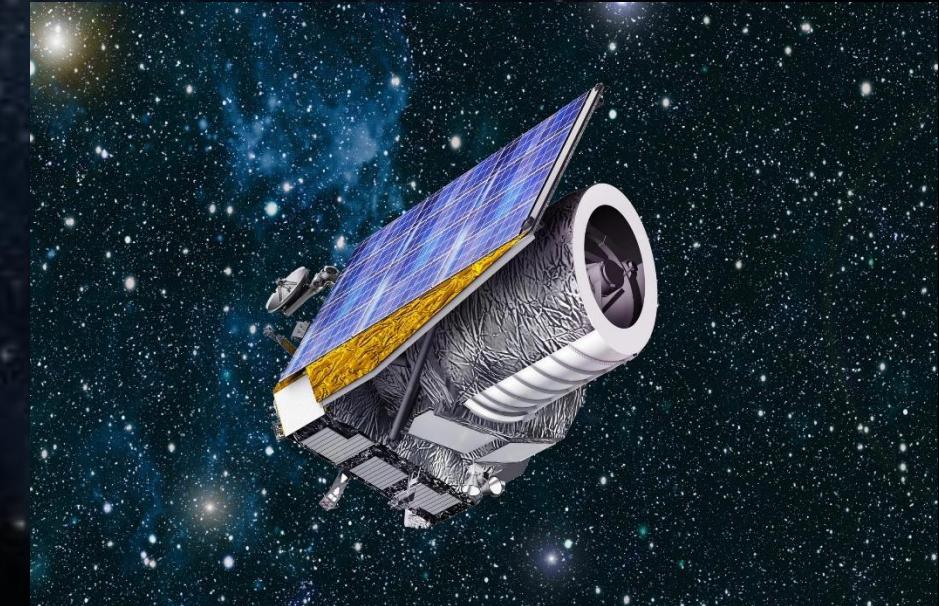


# Euclid – Prieskum hlbokého vesmíru

- 2023, prvé údaje 2025
- Misia ESA v L2
- 600 Mpx fotoaparát, 0,5 stupňa x 0,5 stupňa
- Priemer 1,2 m v optickom a blízkom IR
- 
- Fotometrické a spektroskopické

jasnosť

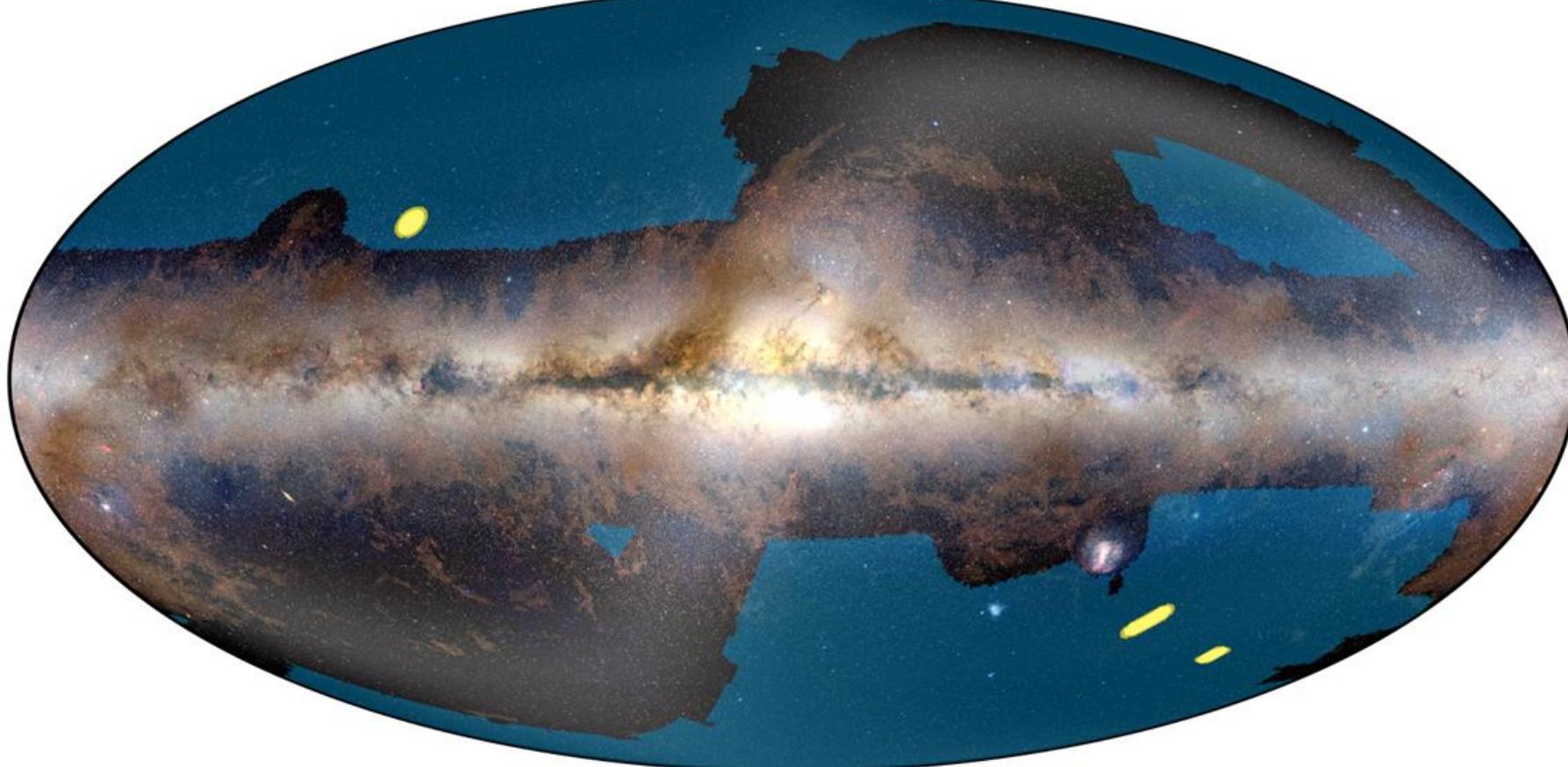
radiálna  
rýchlosť





Eu

- 2024
- Millions
- 600
- Primary
- Deep
- Fornax



#### The Euclid Wide Survey and the Euclid Deep Survey

■ Euclid Wide Survey :  $13,345 \text{ deg}^2$  in 6 years, avoiding the galactic plane (stars, dust) and the ecliptic plane (zodiacal light)

■ Euclid Deep Fields : North= $20 \text{ deg}^2$  (top left), Fornax= $10 \text{ deg}^2$  (bottom right), South= $23 \text{ deg}^2$  [+ extended coverage]

⇒ The Euclid survey focuses on the two galactic caps to explore the extragalactic sky (total coverage =  $2200 \text{ deg}^2/\text{year}$ ) Background: Euclid Consortium / Planck Collaboration / A. Mellinger



jasnosi



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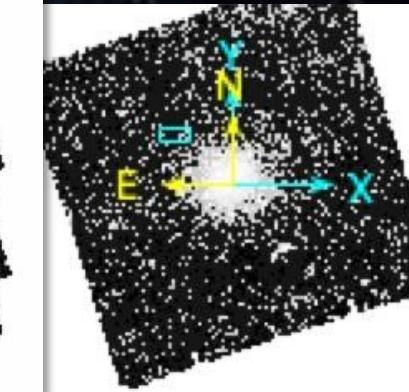
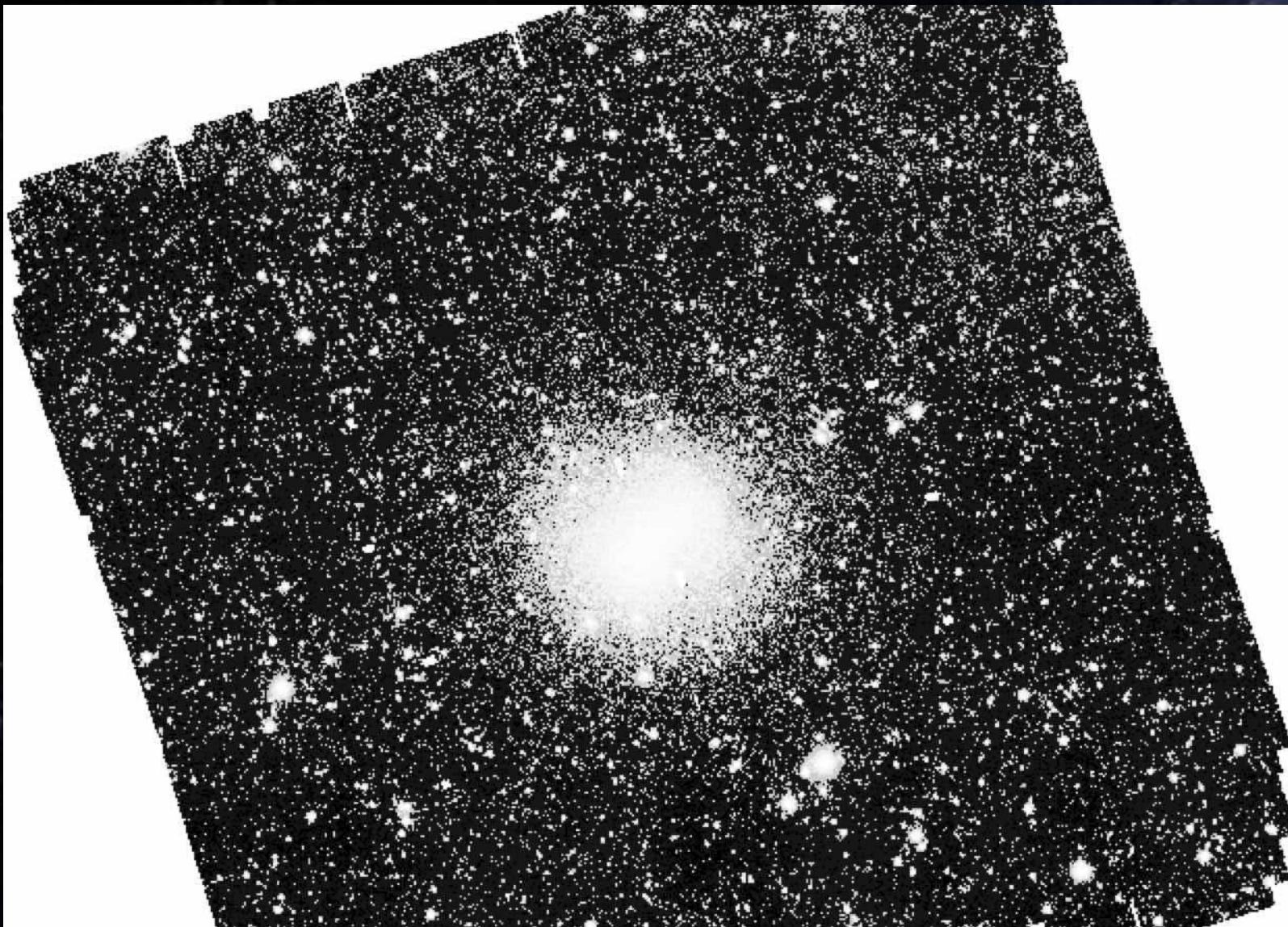


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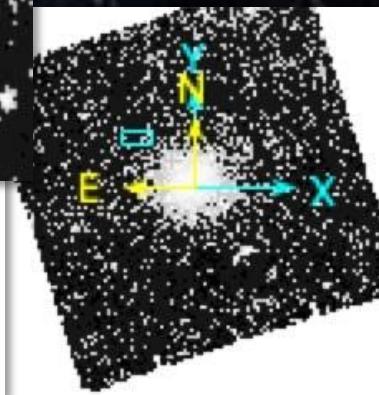
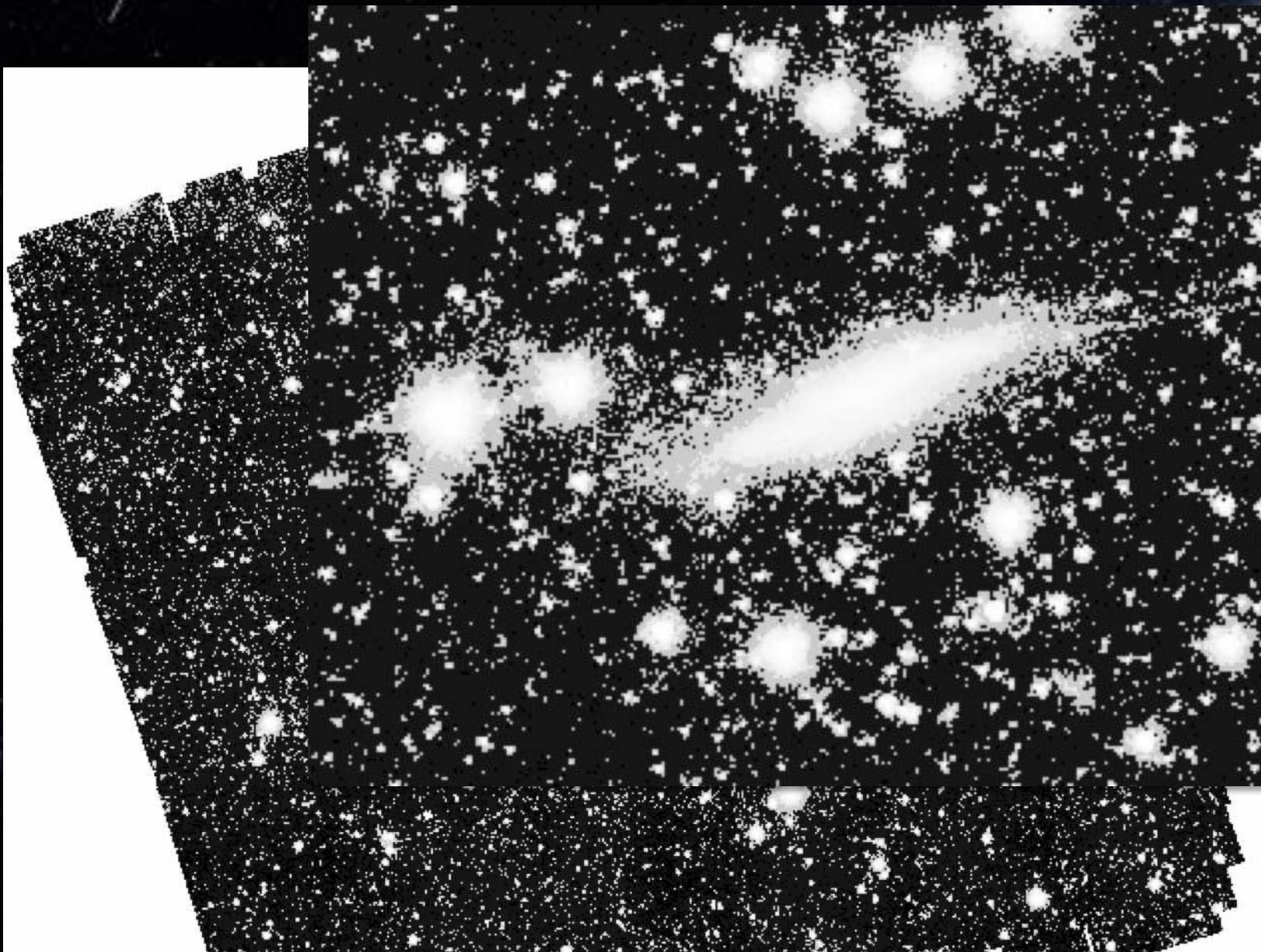


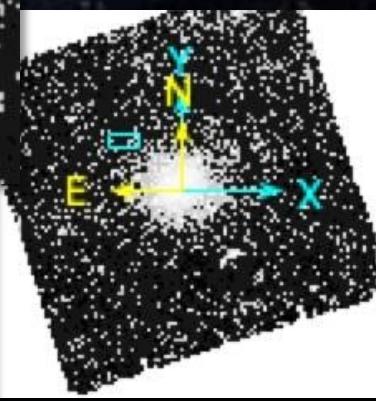
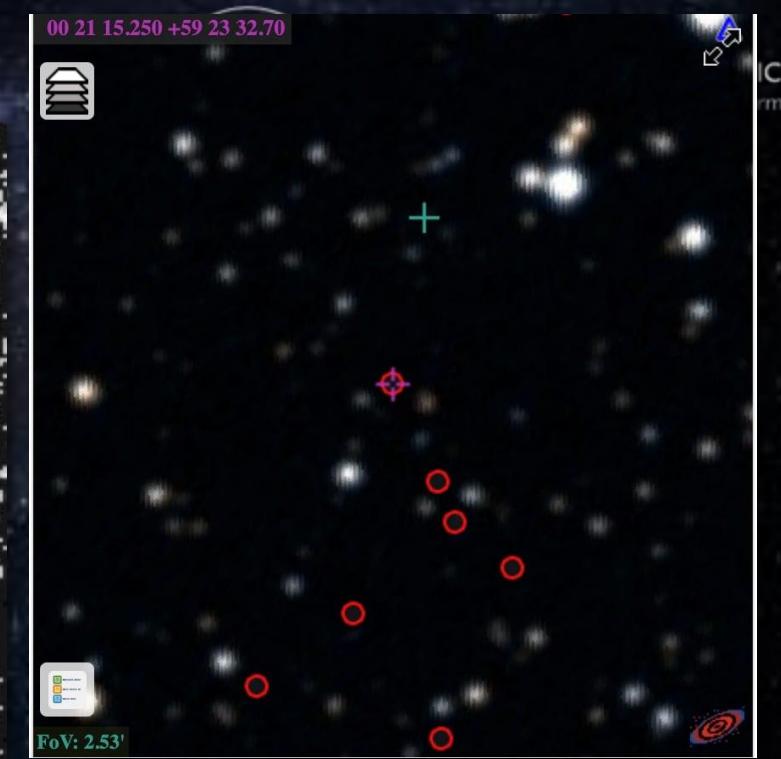
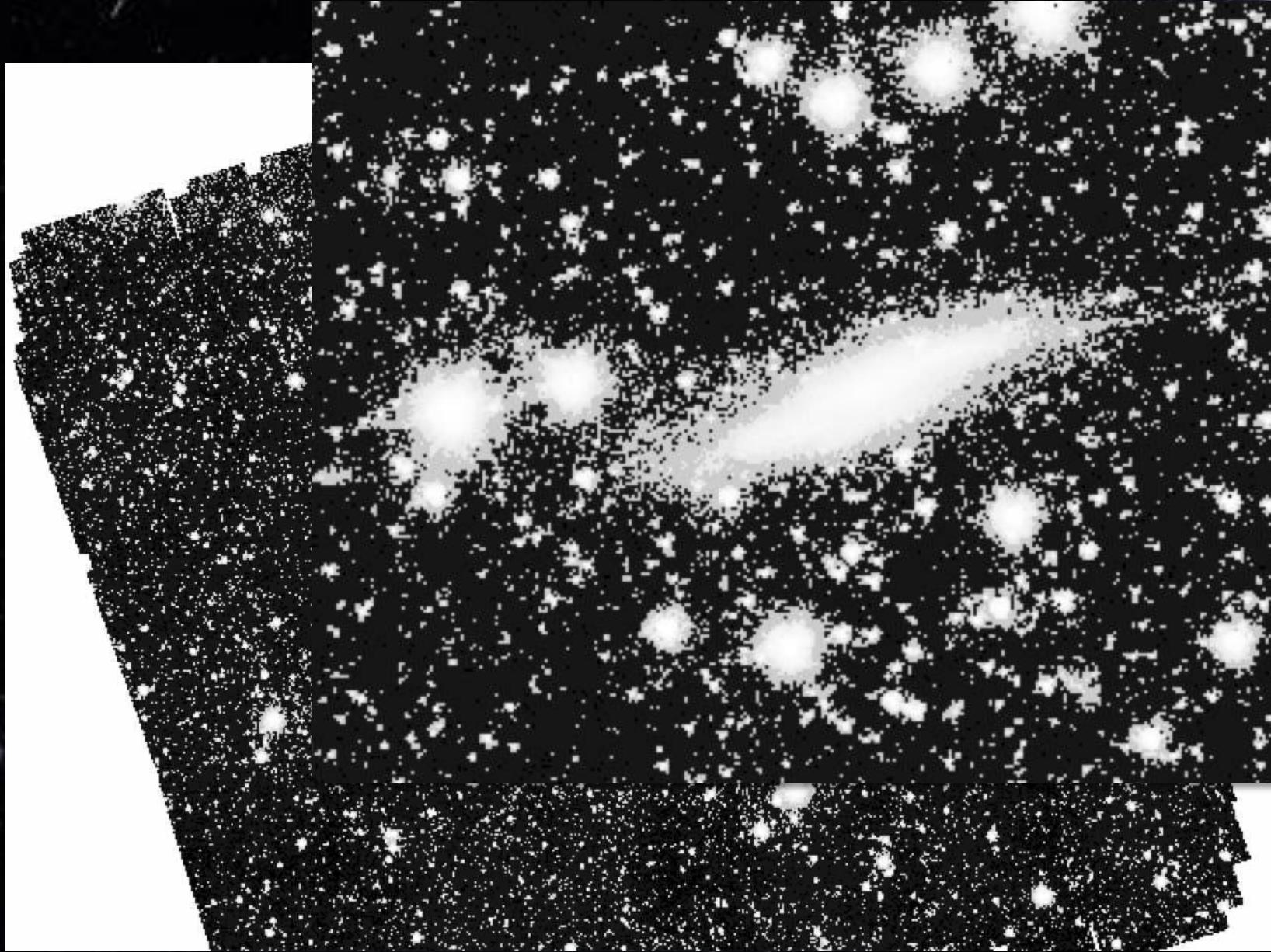
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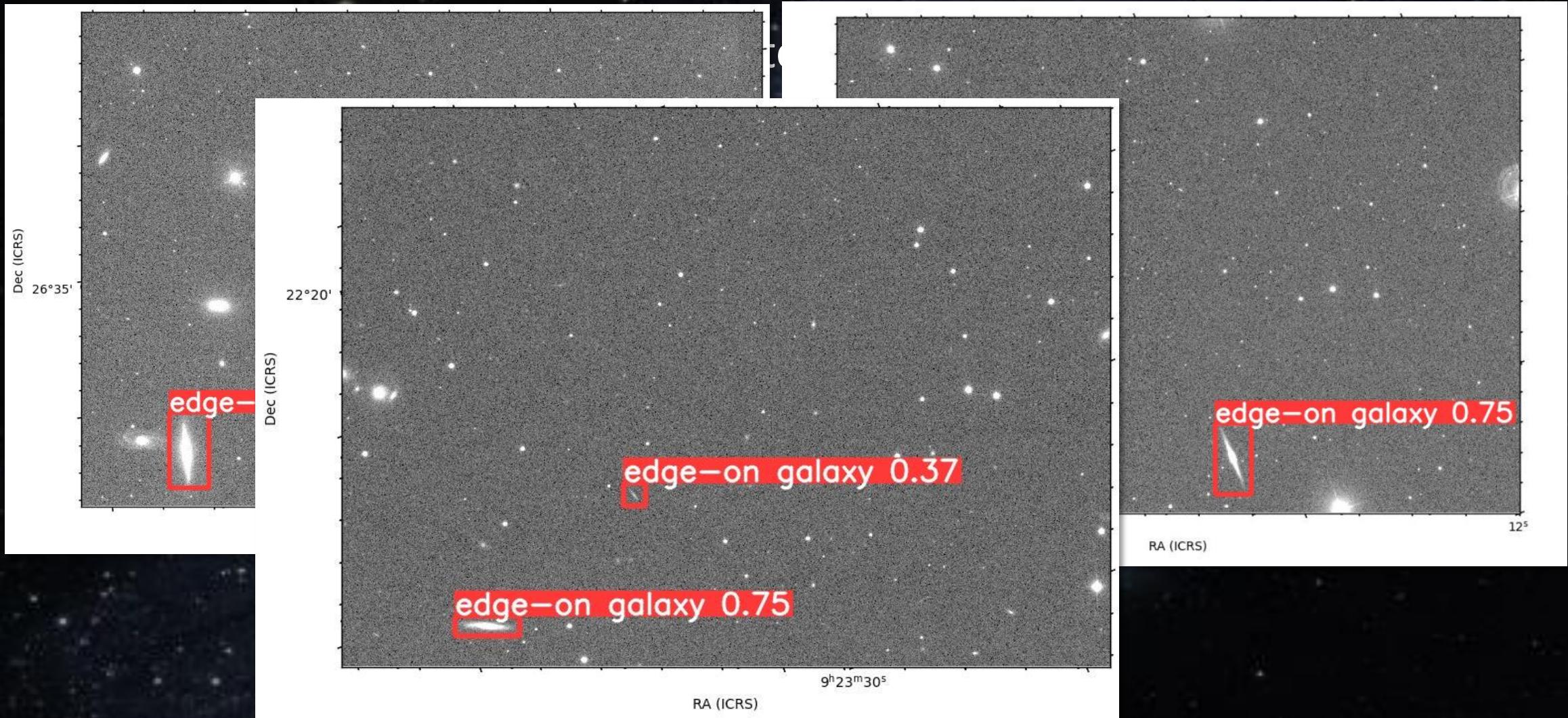


# Galaktický warp a iné galaxie

- Čas na umelú inteligenciu... Metódy ML na detekciu galaktického skútenia
- UCL London (Žofia Chrobáková), TUKE Košice (Vierka, Peťo), Univerzita Komenského Bratislava
- SDSS DR7 - 15 000 galaxií ... Predvoj pre Euclid



# Galaktický warp a iné galaxie





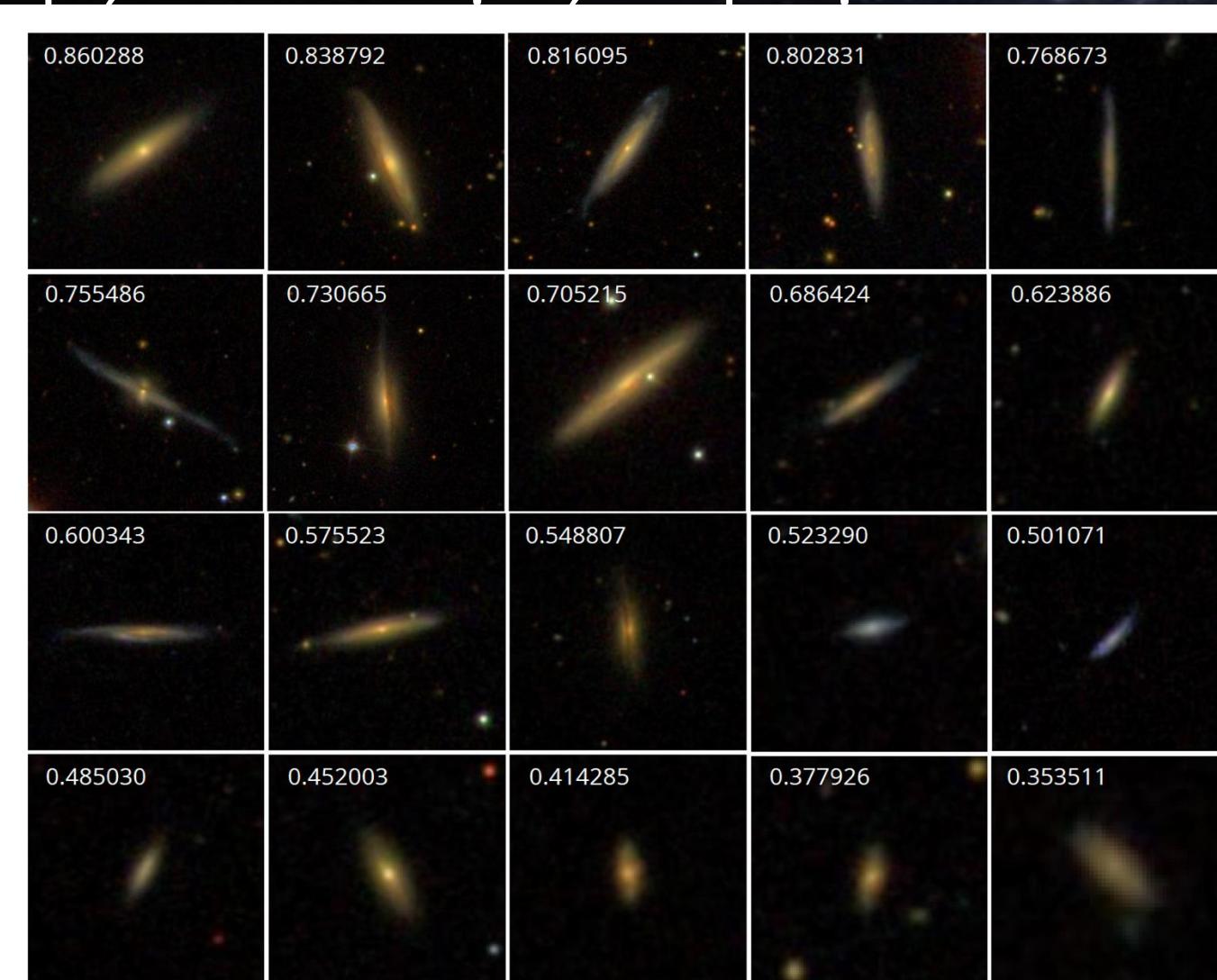
# Galaktický warp a iné galaxie

- Čas na umelú inteligenciu... Metódy ML na detekciu galaktického skútenia
- UCL London (Žofia Chrobáková), TUKE Košice (Vierka, Peťo), Univerzita Komenského Bratislava
- SDSS DR7 - 15 000 galaxií ... Predvoj pre Euclid
- YOLOv5



# Galaktické katalogy

- Čas na učebnici - galaktické katalogy
- UCL London, Univerzita v Londýne, eto),
- SDSS DR12
- YOLOv5





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# Galakti

0.860288 0.838792 0.816095 0.802831 0.768673

Publications of the Astronomical Society of the Pacific, 137:034101 (16pp), 2025 March

<https://doi.org/10.1088/1538-3873/adbcd6>

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## Deep Learning-based Detection and Segmentation of Edge-on and Highly Inclined Galaxies

Ž. Chrobáková<sup>1</sup> , V. Krešňáková<sup>2</sup> , R. Nagy<sup>3</sup> , J. Gazdová<sup>2</sup> , and P. Butka<sup>2</sup> 

<sup>1</sup> Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK

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*Received 2024 November 19; revised 2025 February 21; accepted 2025 March 5; published 2025 March 21*

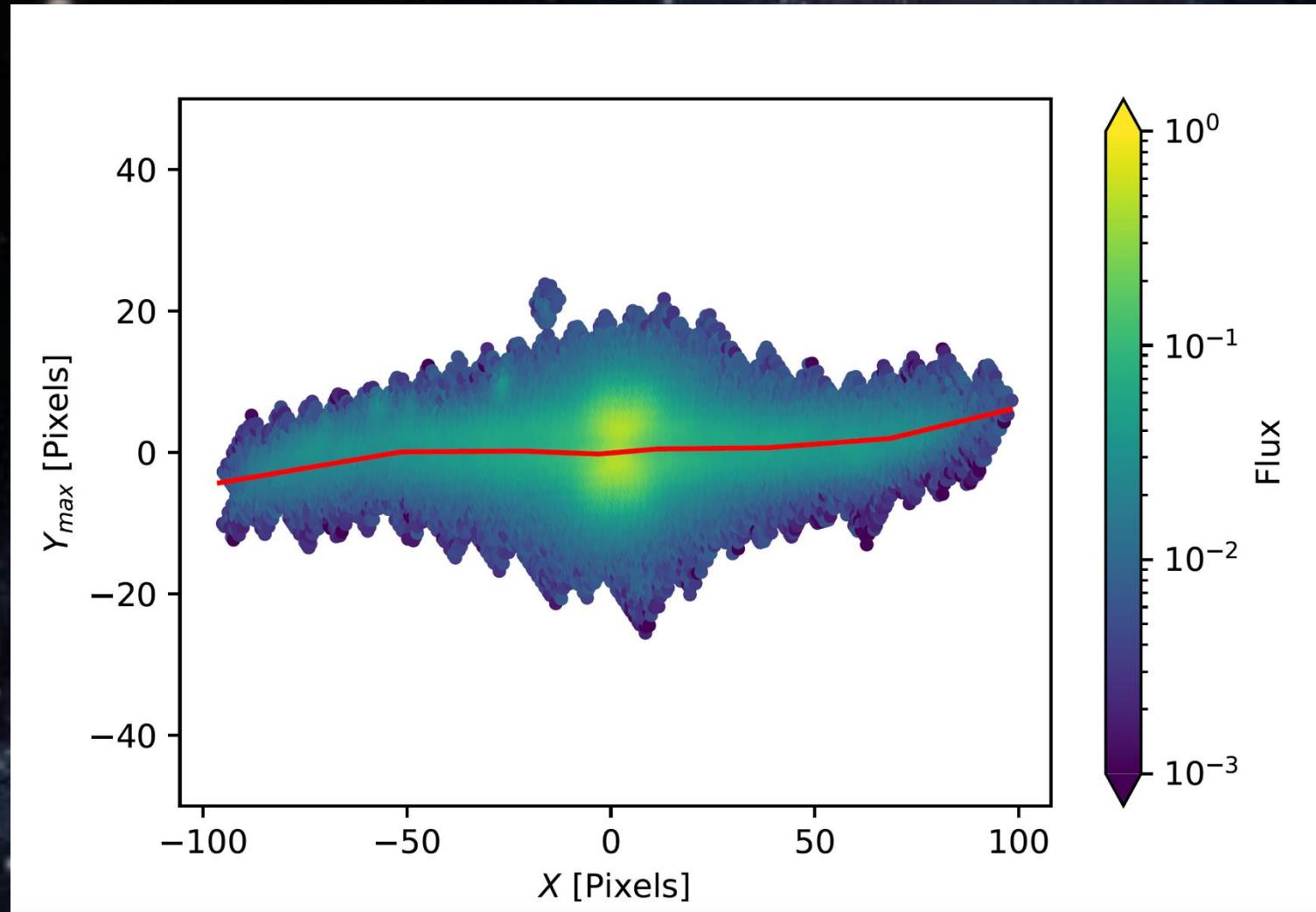
0.485030 0.452003 0.414285 0.377926 0.353511

• SDSS DR

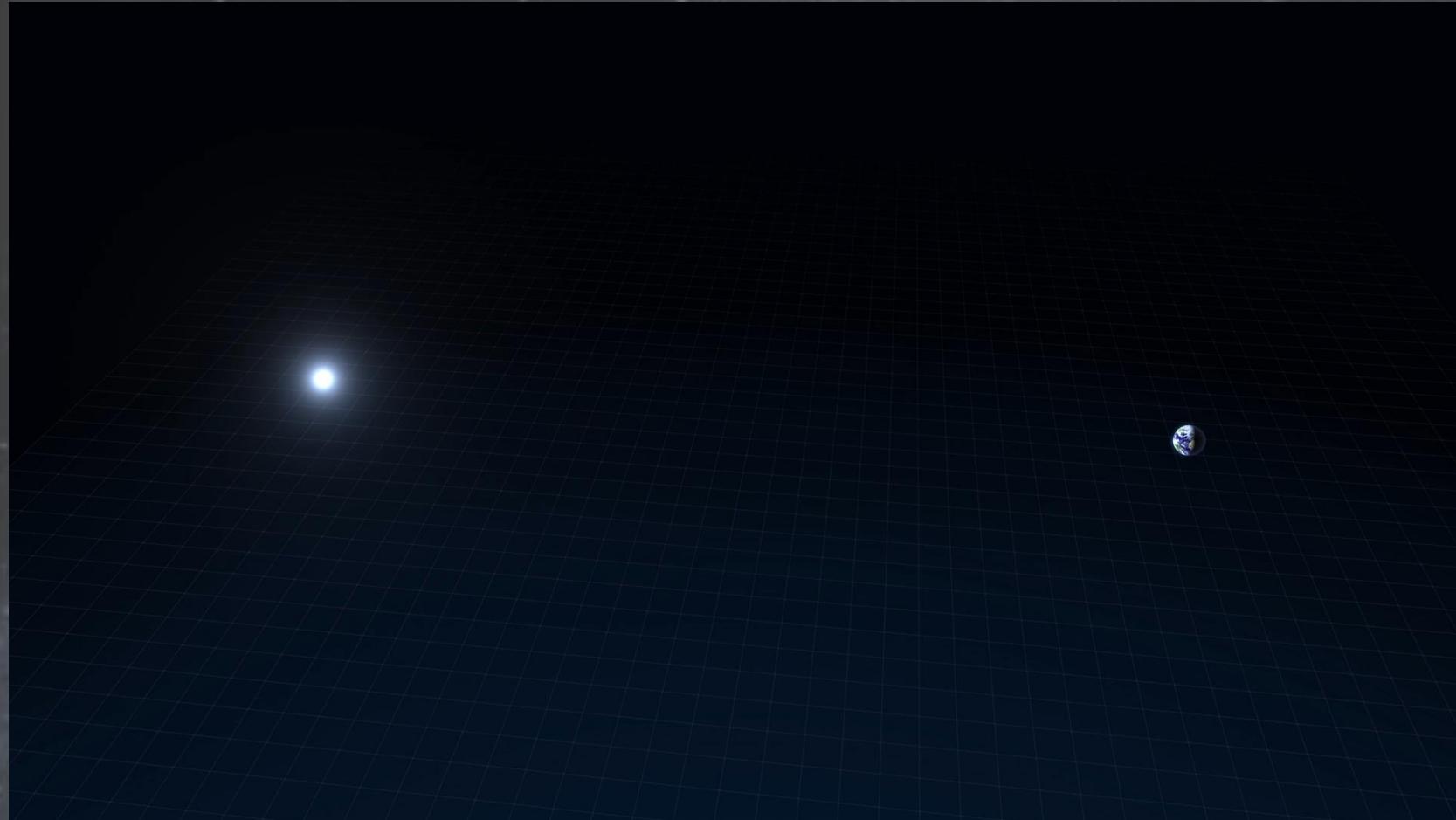
• YOLOv5

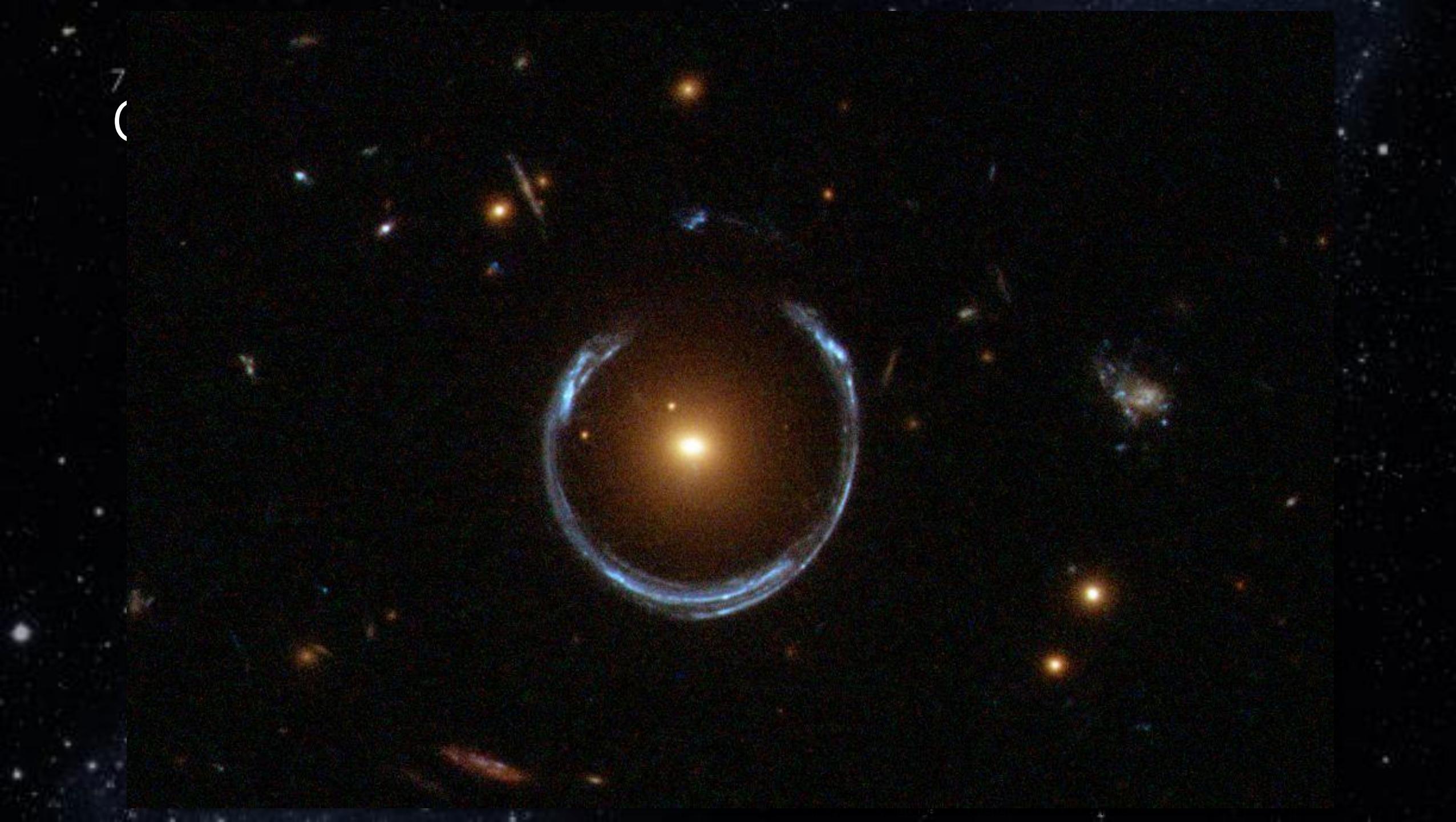


# Extragalactic warps using AI



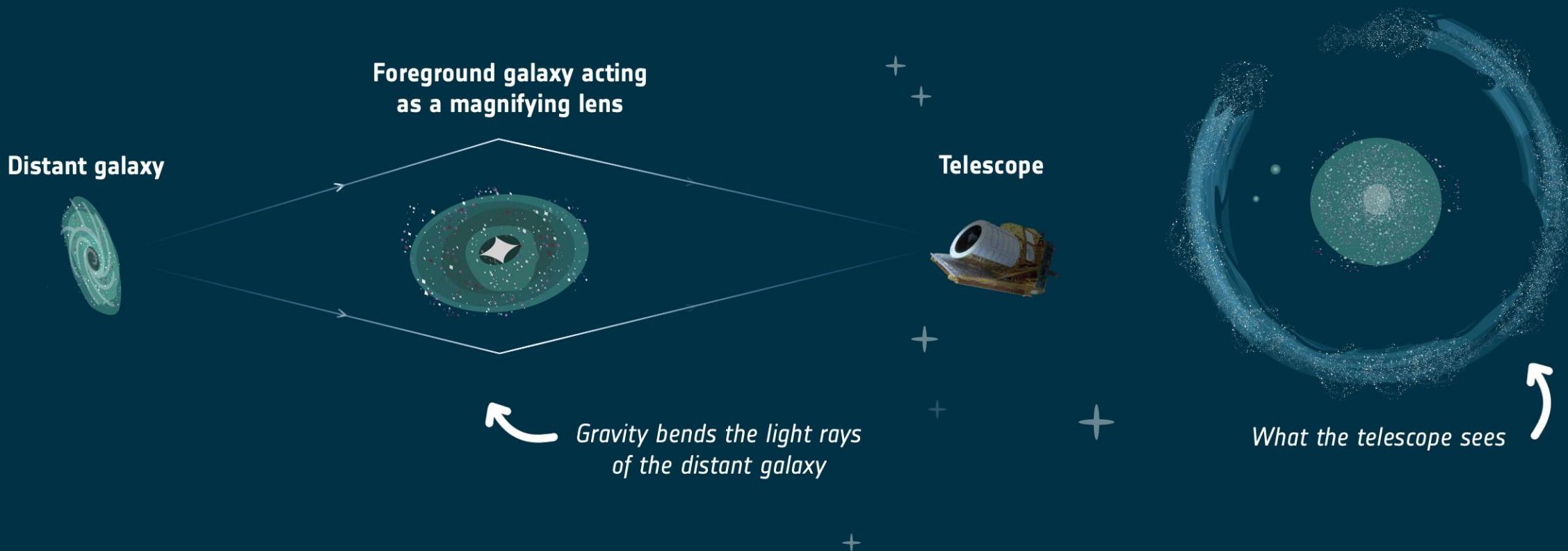
# Gravitačné šošovky





## EINSTEIN RING – EXPLAINED

When we observe a distant galaxy with our telescope, its light may encounter another galaxy on its way to us. The foreground galaxy acts like a magnifying lens, bending the travelling light rays due to its gravity. This is called gravitational lensing. If the background galaxy, the lensing galaxy, and the telescope are perfectly aligned, the image appears as a ring – called an Einstein ring.



RX J0911+0551

WGD J0405-3308

HS 0810+2554

EINS

When we  
way to us  
its gravity  
telescope

sa

Distant g



PS J1606-2333

WFI 2033-4723

SDSS J1330+1810

RX J0911+0551

WGD J0405-3308

HS 0810+2554

EINS

When we  
way to us  
its gravity  
telescope

sa



Distant g



PS J1606-2333

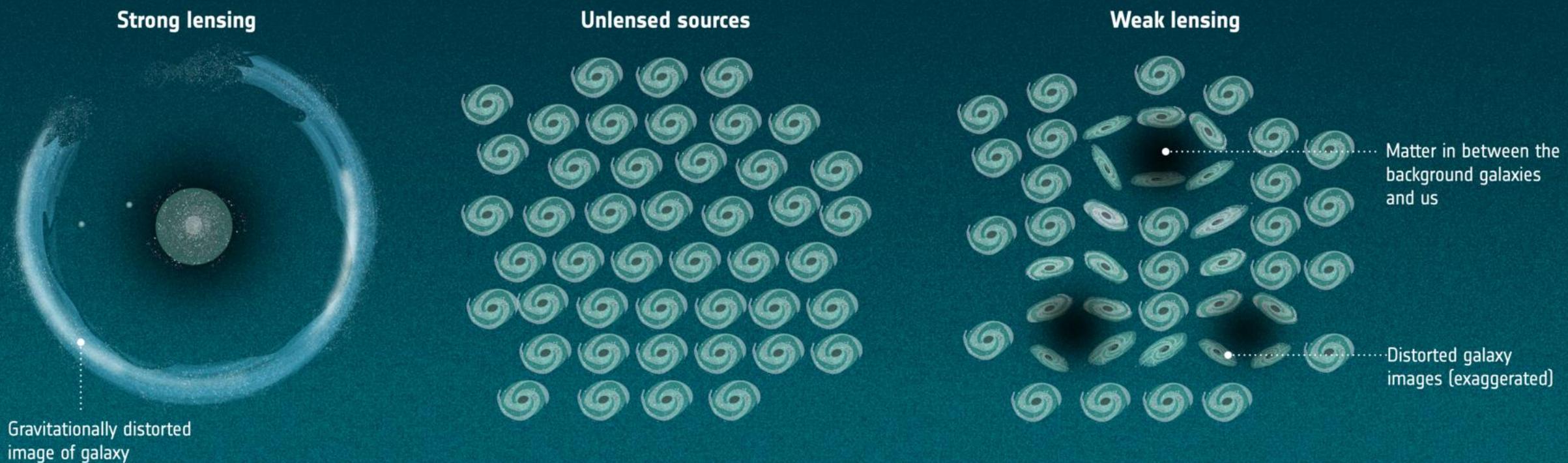
WFI 2033-4723

SDSS J1330+1810

## WHAT EUCLID WILL MEASURE: WEAK LENSING

A concentration of matter along the line of sight can act like a magnifying glass, bending and distorting light from galaxies and clusters behind it. This effect is called gravitational lensing. Scientists distinguish between strong gravitational lensing, when the distortions are very apparent, like in the case of Einstein rings, arcs, and multiple images, and weak gravitational lensing, when the distortions of background sources are much smaller. In this case, distortions (of a few percent) can only be detected by analysing large numbers of sources in a statistical way.

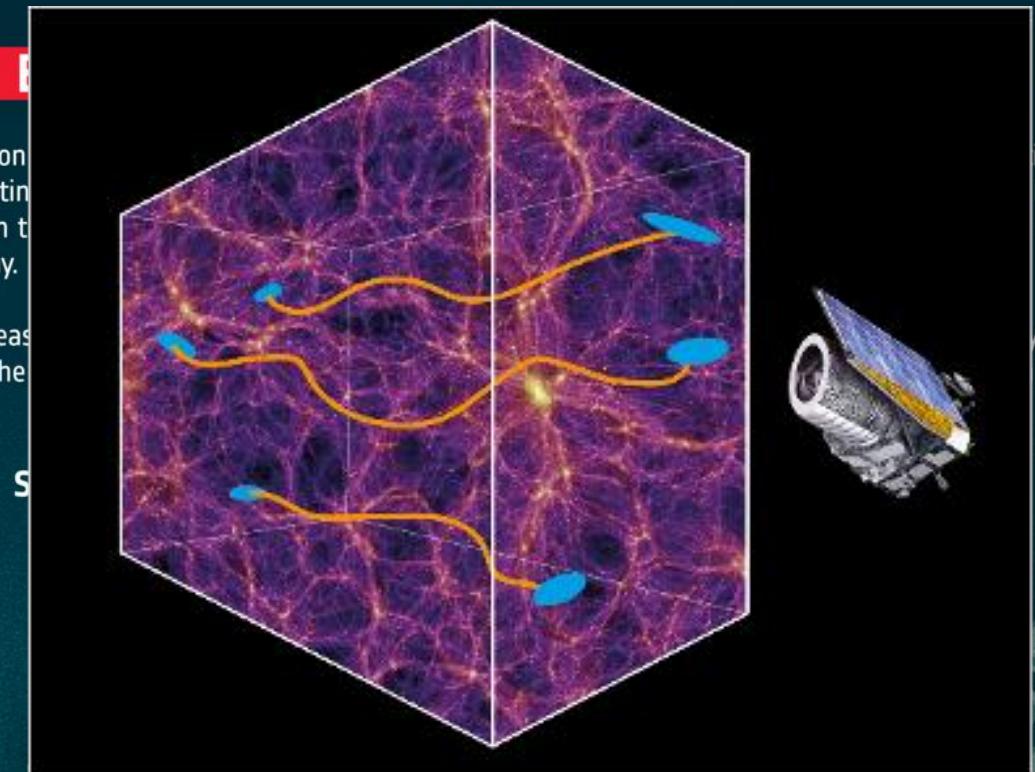
Euclid will measure the distorted shapes of billions of galaxies over 10 billion years of cosmic history, providing a 3D view of the dark matter distribution in our Universe. The map of the distribution of galaxies over cosmic time will also teach us about dark energy, which affects the spatial evolution of the large-scale structure.



## WHAT IS

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The map of the

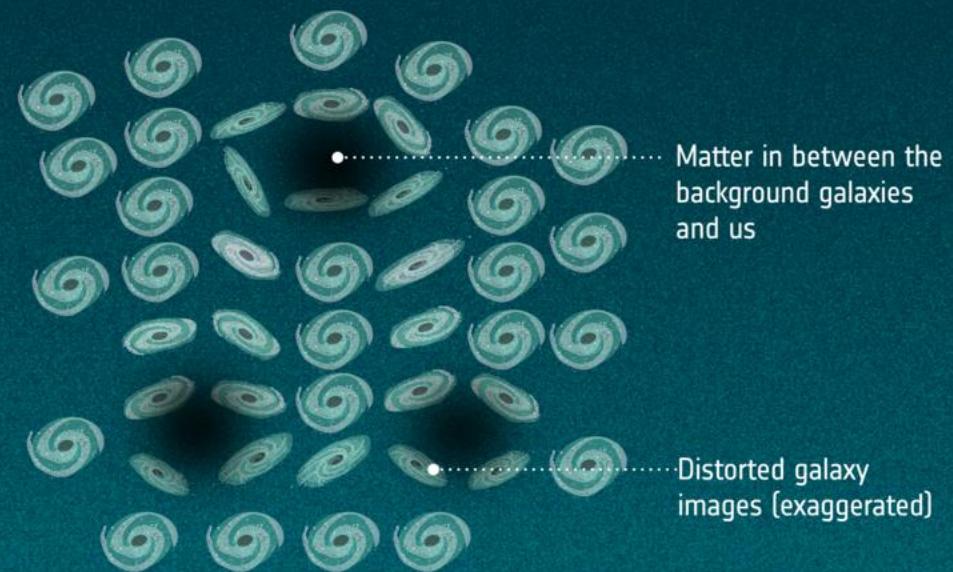


Gravitationally distorted  
image of galaxy

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### Weak lensing



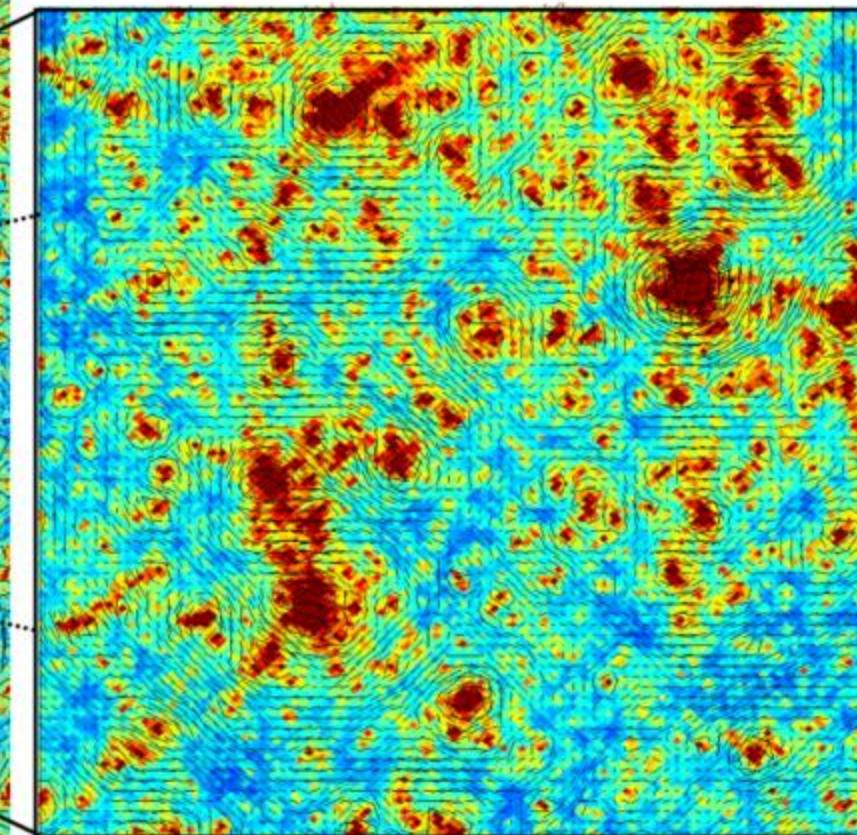
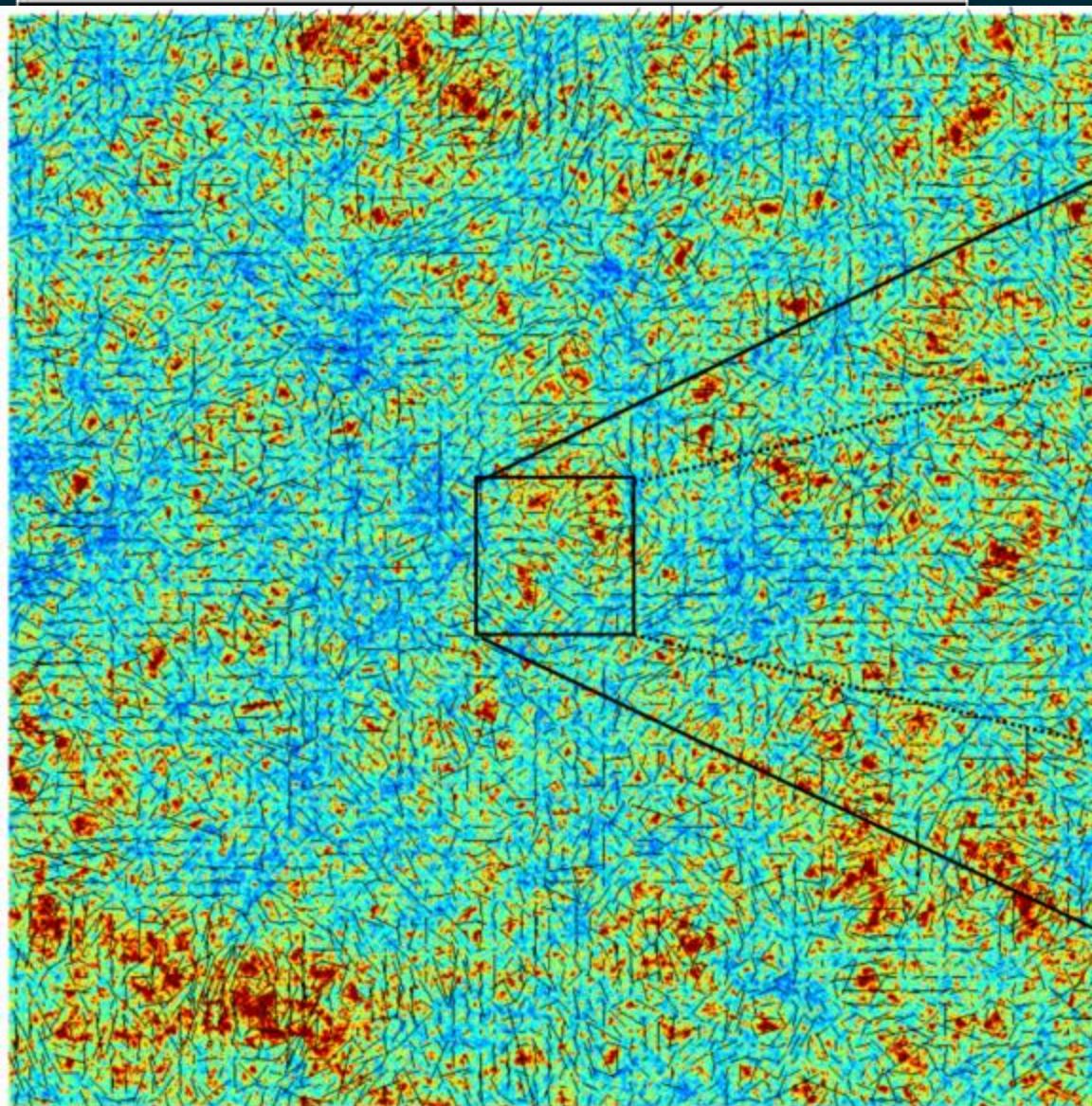
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Gravitationally  
image of galax



Euclid Collaboration: Castander et al. 2024

in between the  
and galaxies

and galaxy  
(exaggerated)



Funded by the  
European Union  
NextGenerationEU

Financované EÚ NextGenerationEU  
prostredníctvom  
Plánu obnovy a odolnosti SR v rámci  
projektu č. 09I03-03-V04-00137



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