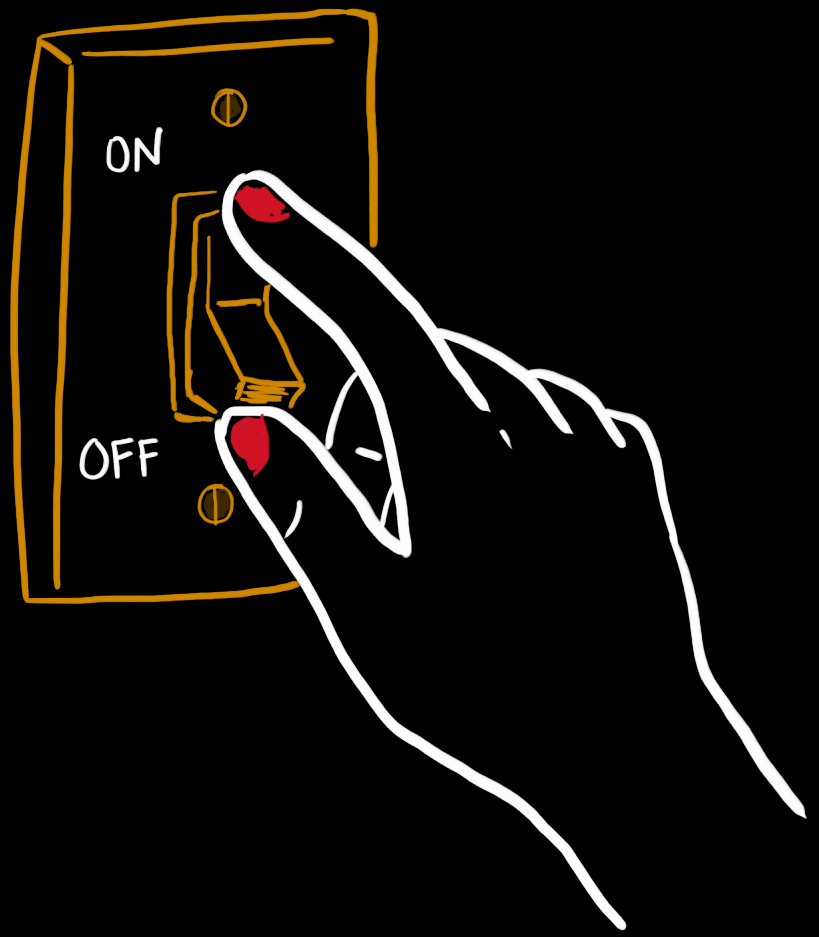
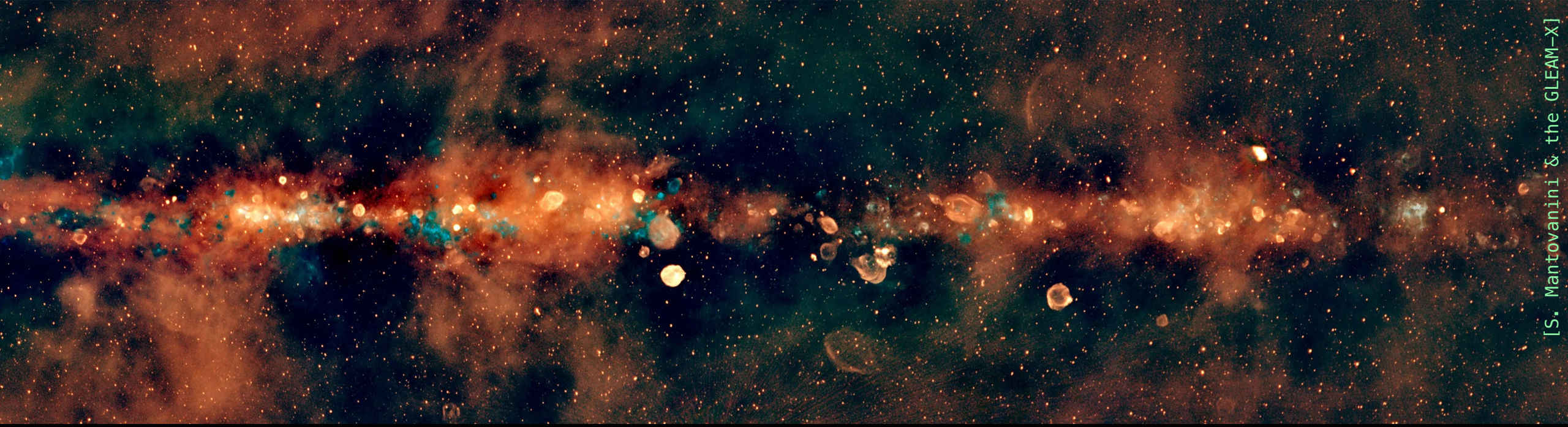

[Vera Rubin Observatory/LSST]

ALL THE DARK
WE CANNOT SEE

Dr. Milena Crnogorčević

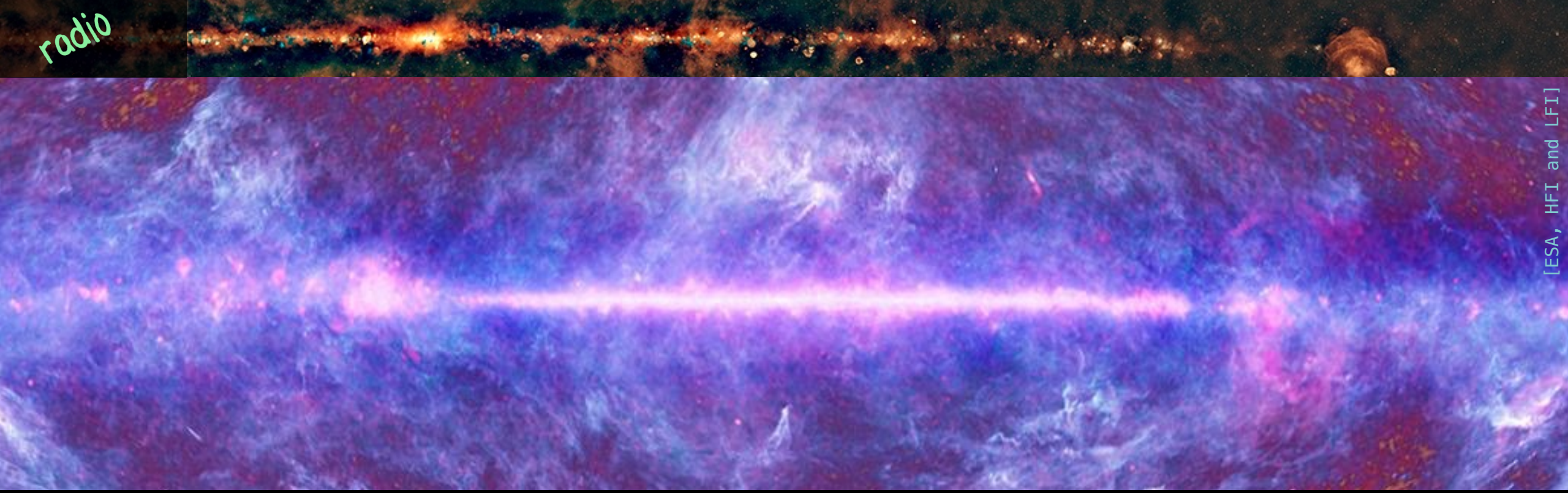
Let's take a look at our own backyard: Milky Way



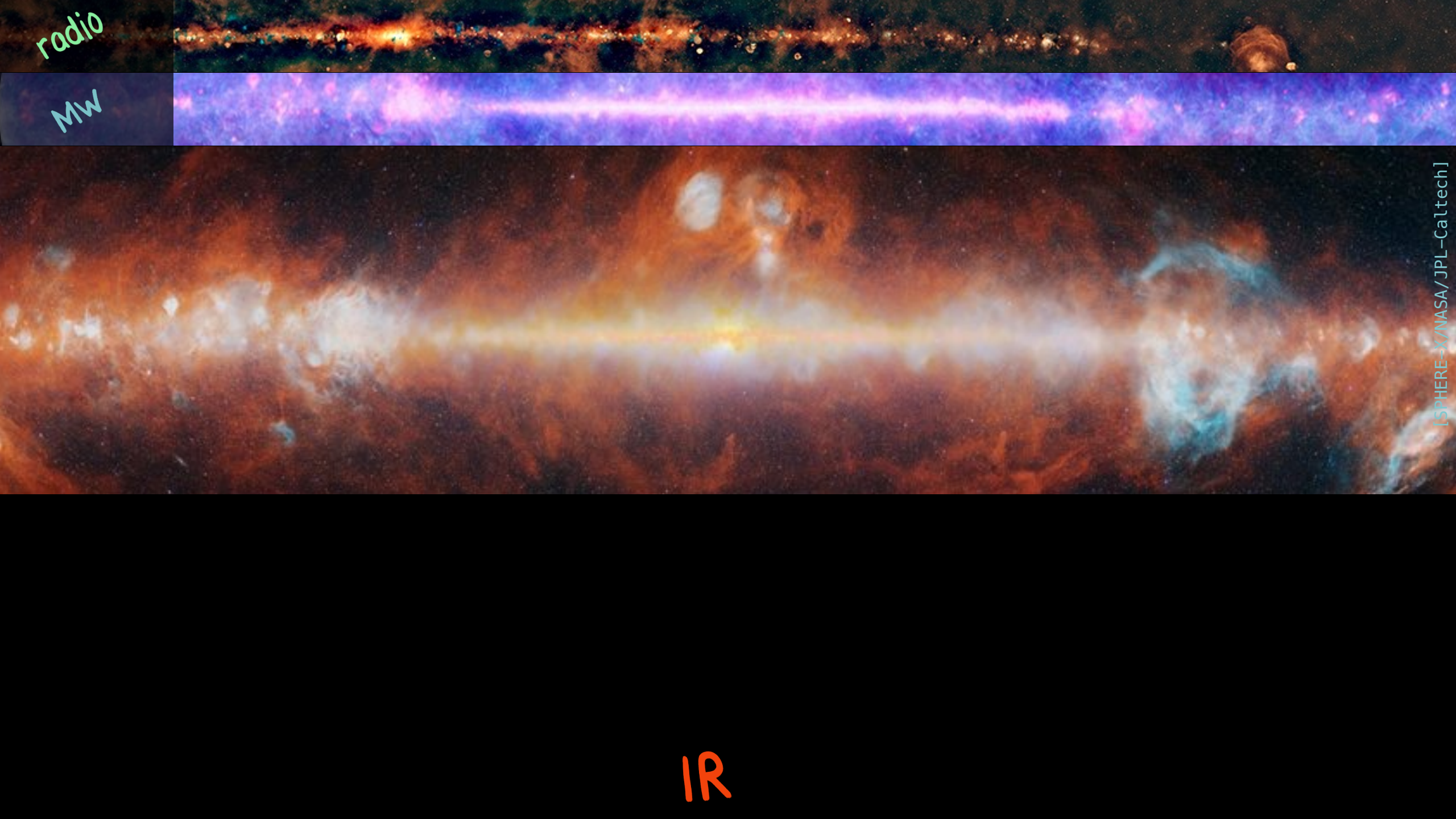


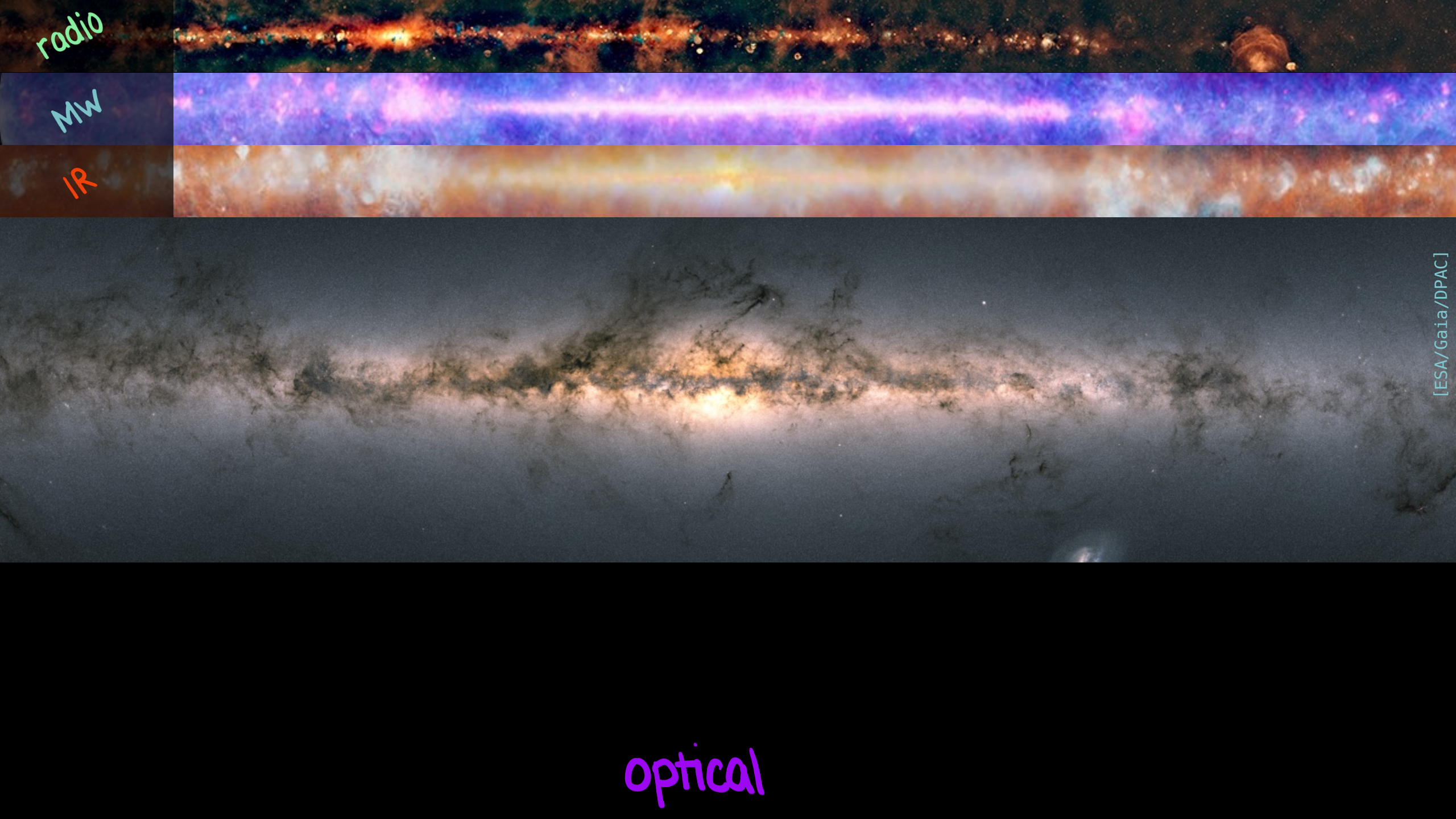
[S. Mantovanini & the GLEAM-X]

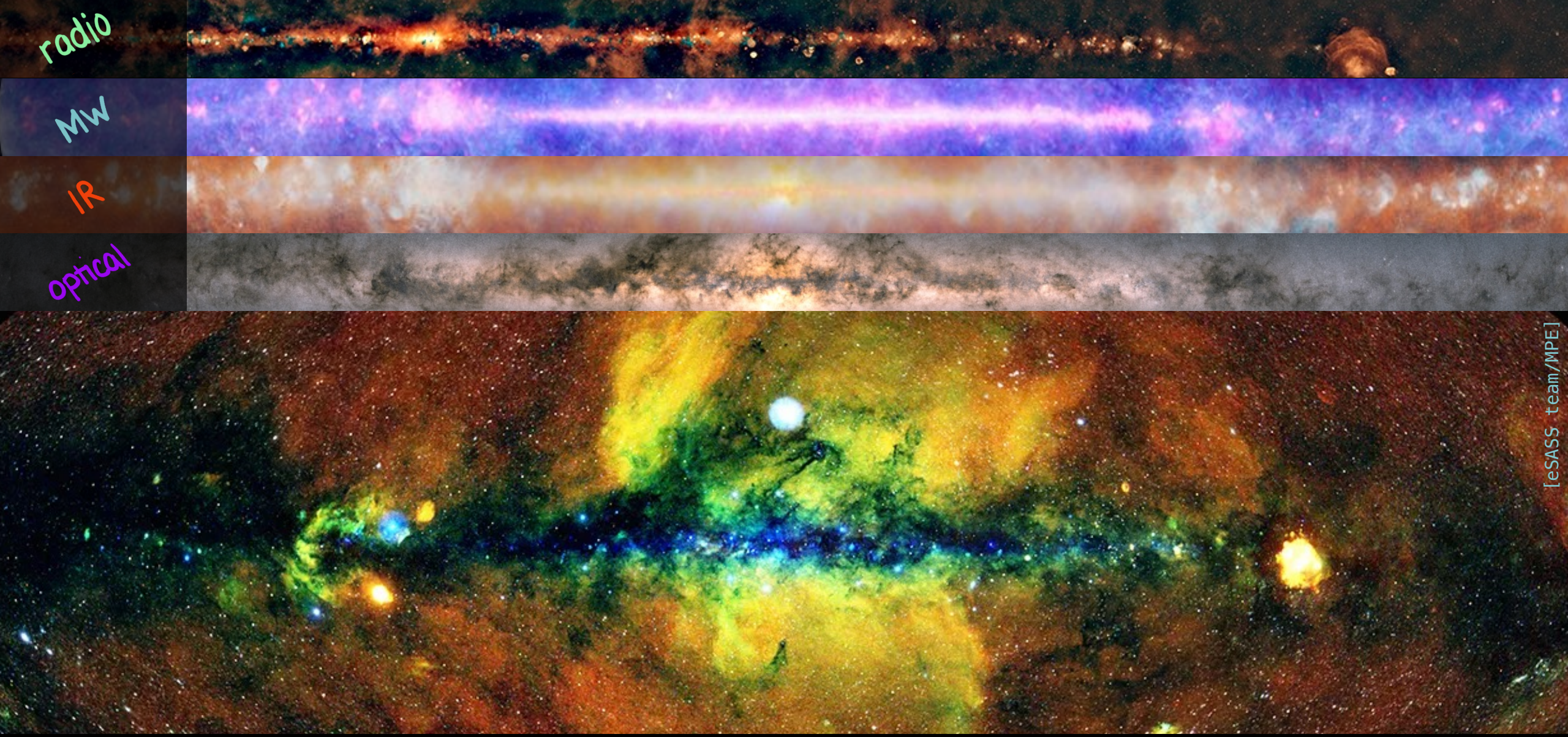
radio



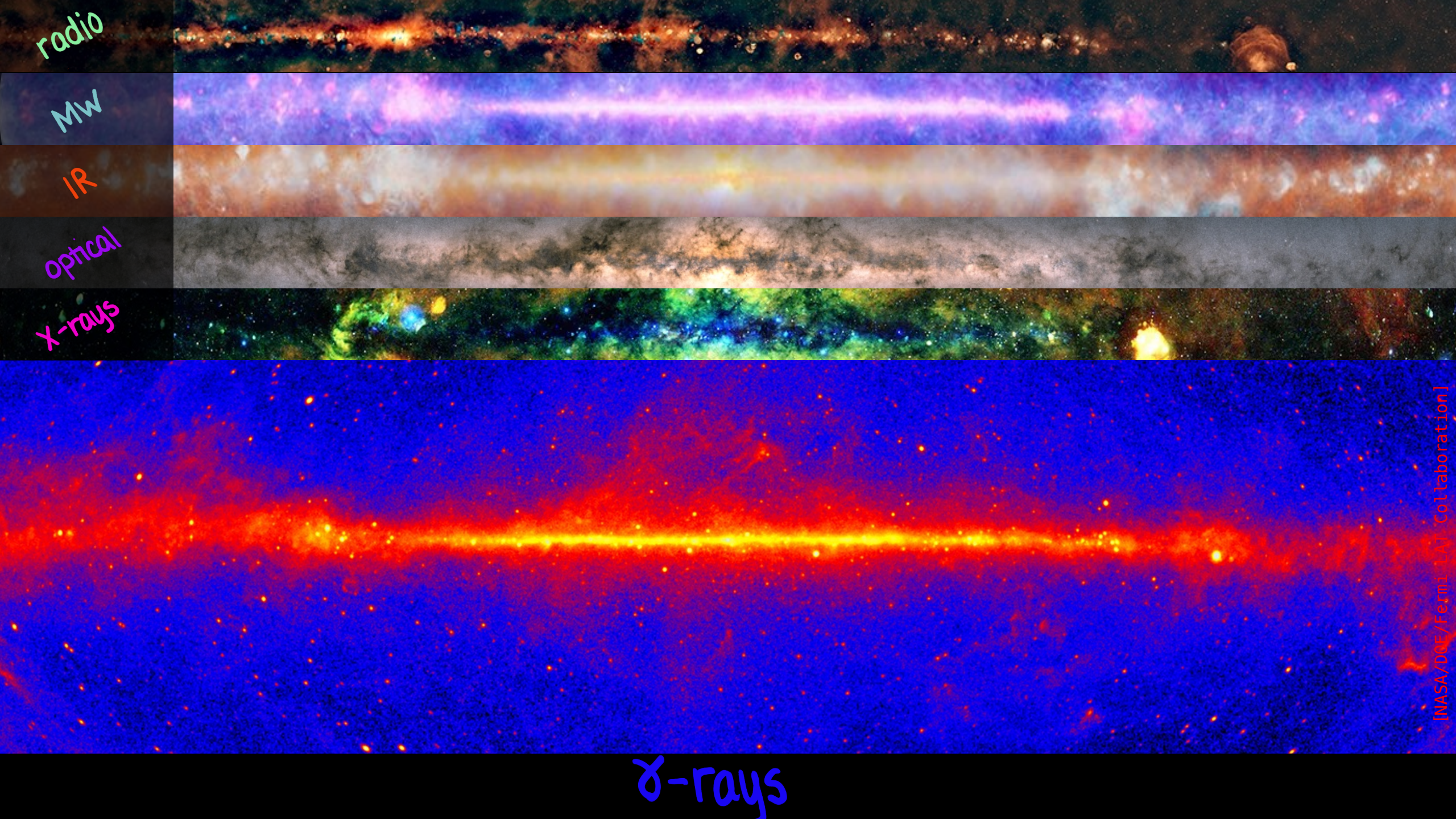
Mw

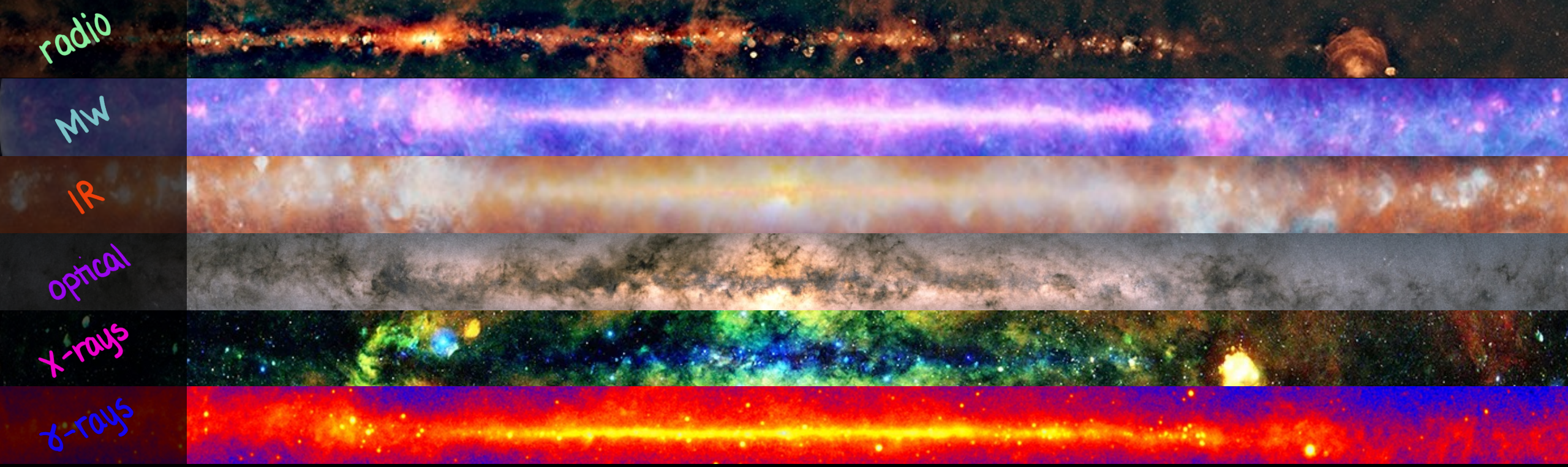

radio
MW
IR
[SPHERE-X/NASA/JPL-Caltech]


radio
MW
IR
[ESA/Gaia/DPAC]
optical



X-rays


radio
MW
IR
optical
X-rays
γ-rays
[NASA/DOE/Fermi LAT Collaboration]



HOW DO WE "SEE" GALAXIES?

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ASTRONOMICAL OBJECT

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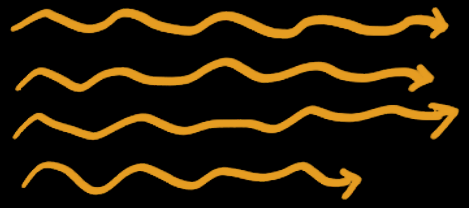
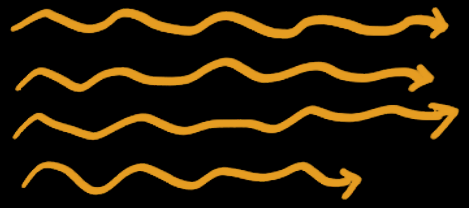


LIGHT TRAVELS TO US

HOW DO WE "SEE" GALAXIES?

ASTRONOMICAL OBJECT



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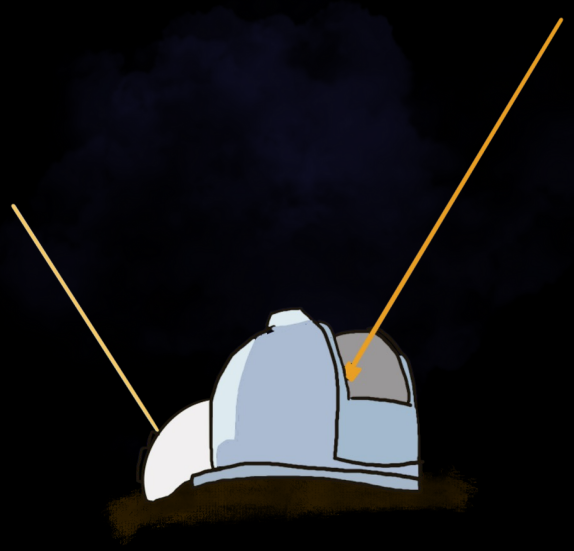

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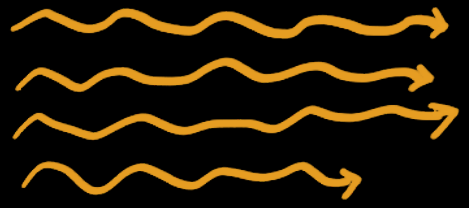

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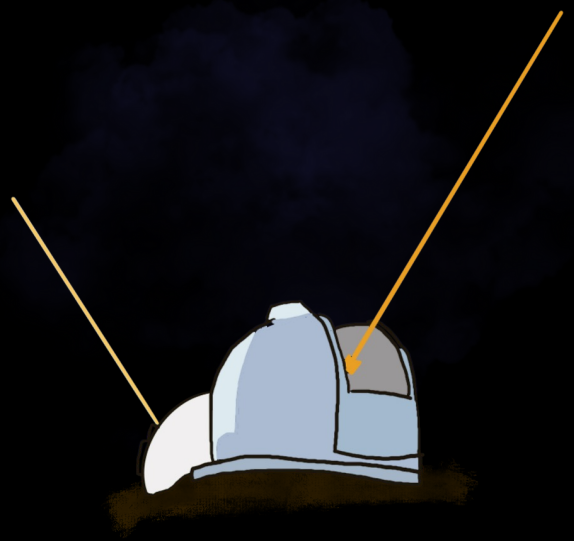
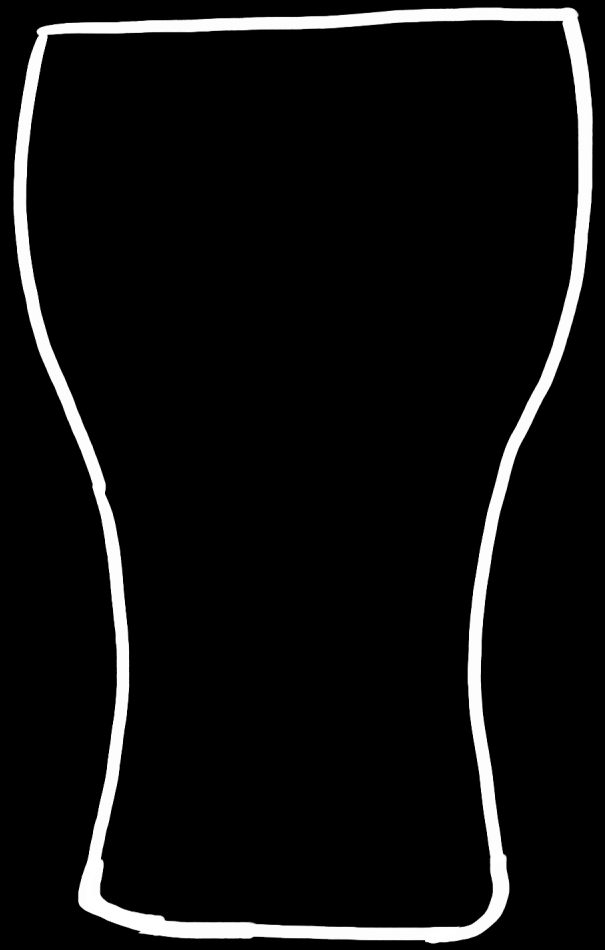


What is in our Pint of Universe?



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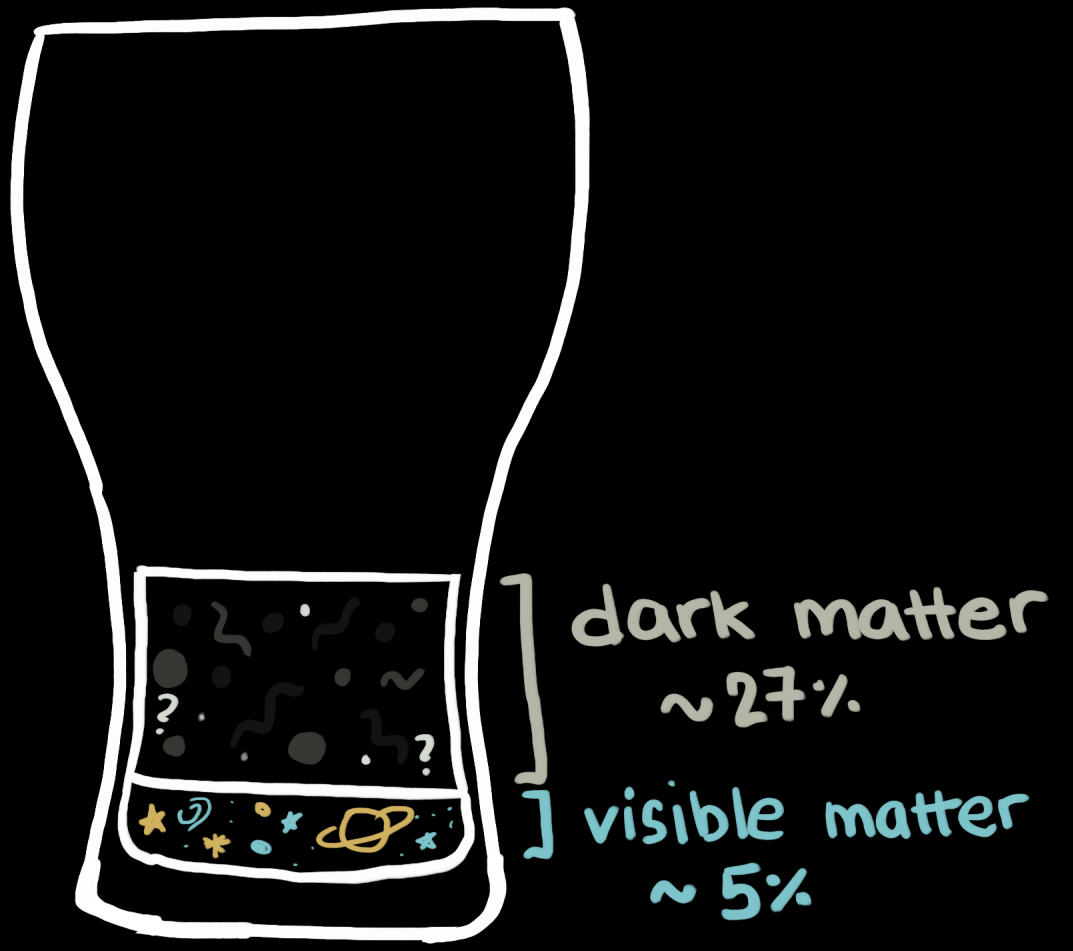


What is in our Pint of Universe?

DARK MATTER INTERACTS WEAKLY*

ASTRONOMICAL OBJECT

*IF it interacts…

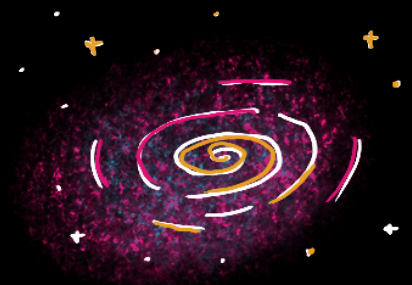
DARK MATTER INTERACTS WEAKLY*

ASTRONOMICAL OBJECT

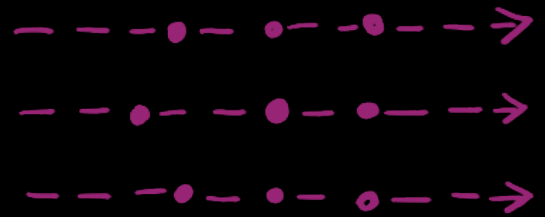
Dark matter travels to us

*IF it interacts...

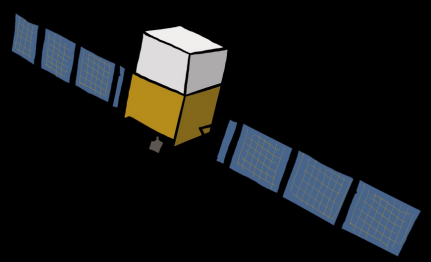
DARK MATTER INTERACTS WEAKLY*



ASTRONOMICAL OBJECT

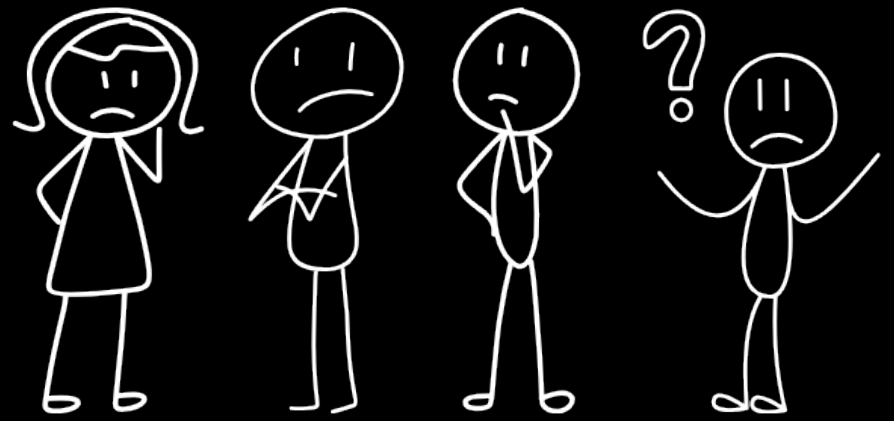


Dark matter travels to us



*IF it interacts…

How do we know dark matter is there?



Which photo was taken on a windy day?

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Images taken from Adobe Stock

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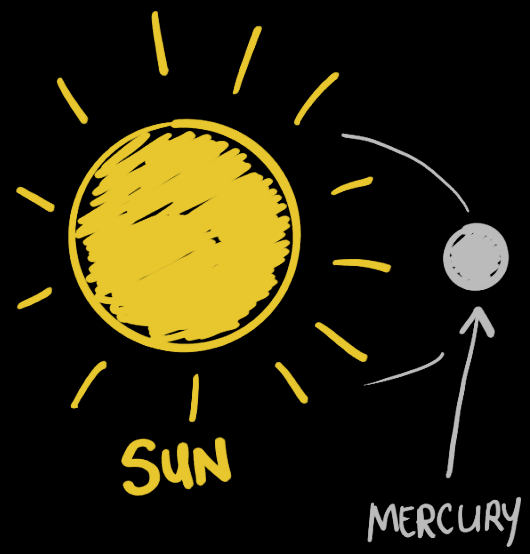
OUR SOLAR SYSTEM*

*not to scale...

OUR SOLAR SYSTEM*



*not to scale...

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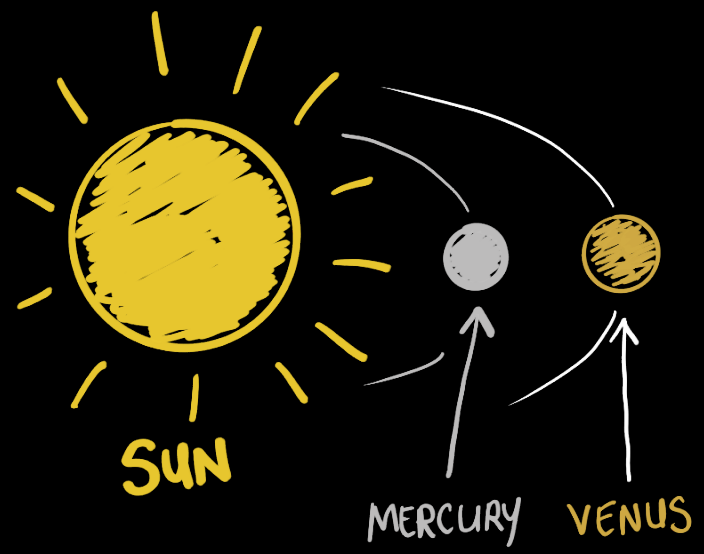

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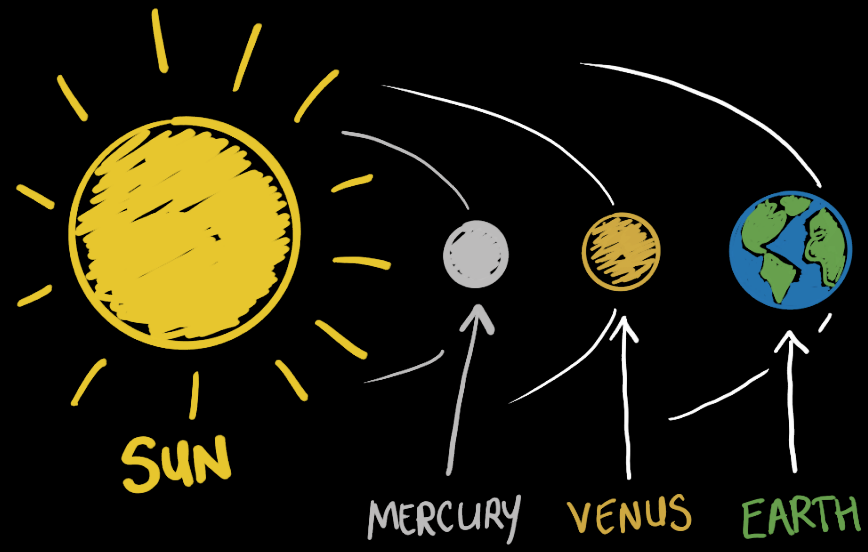

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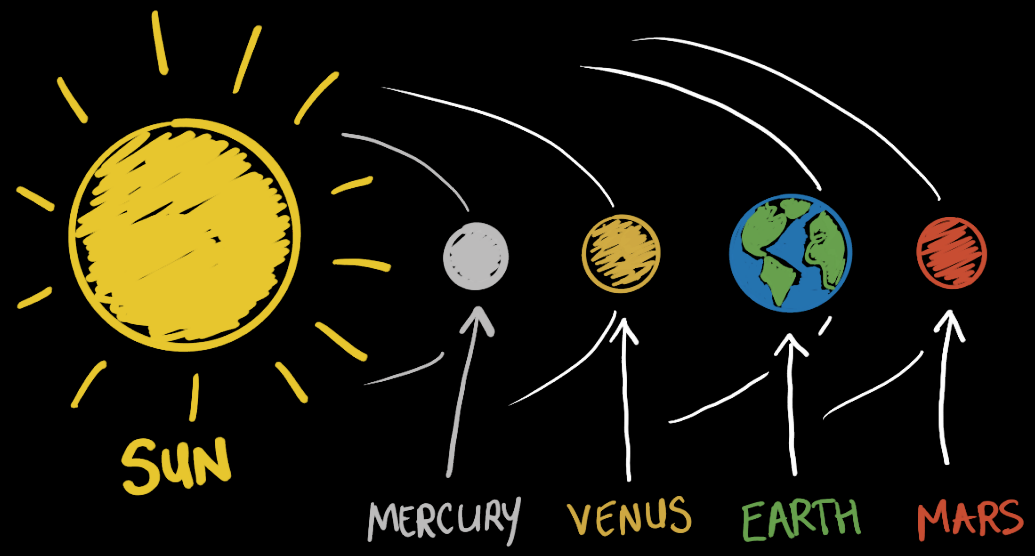

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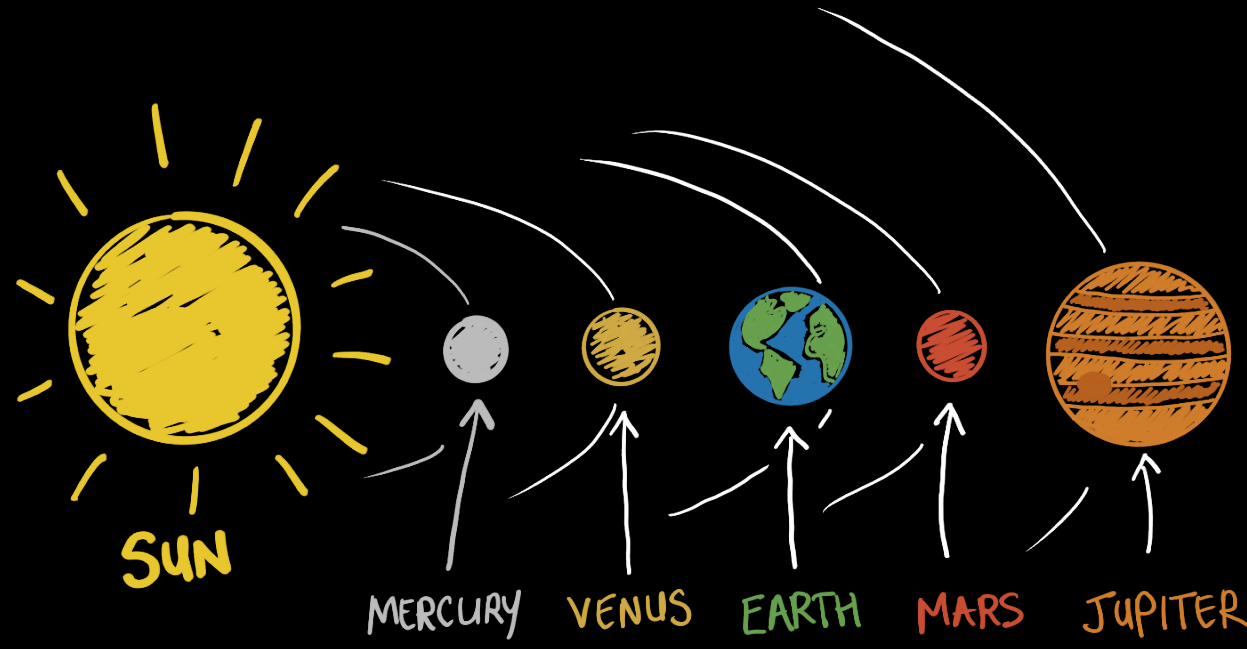

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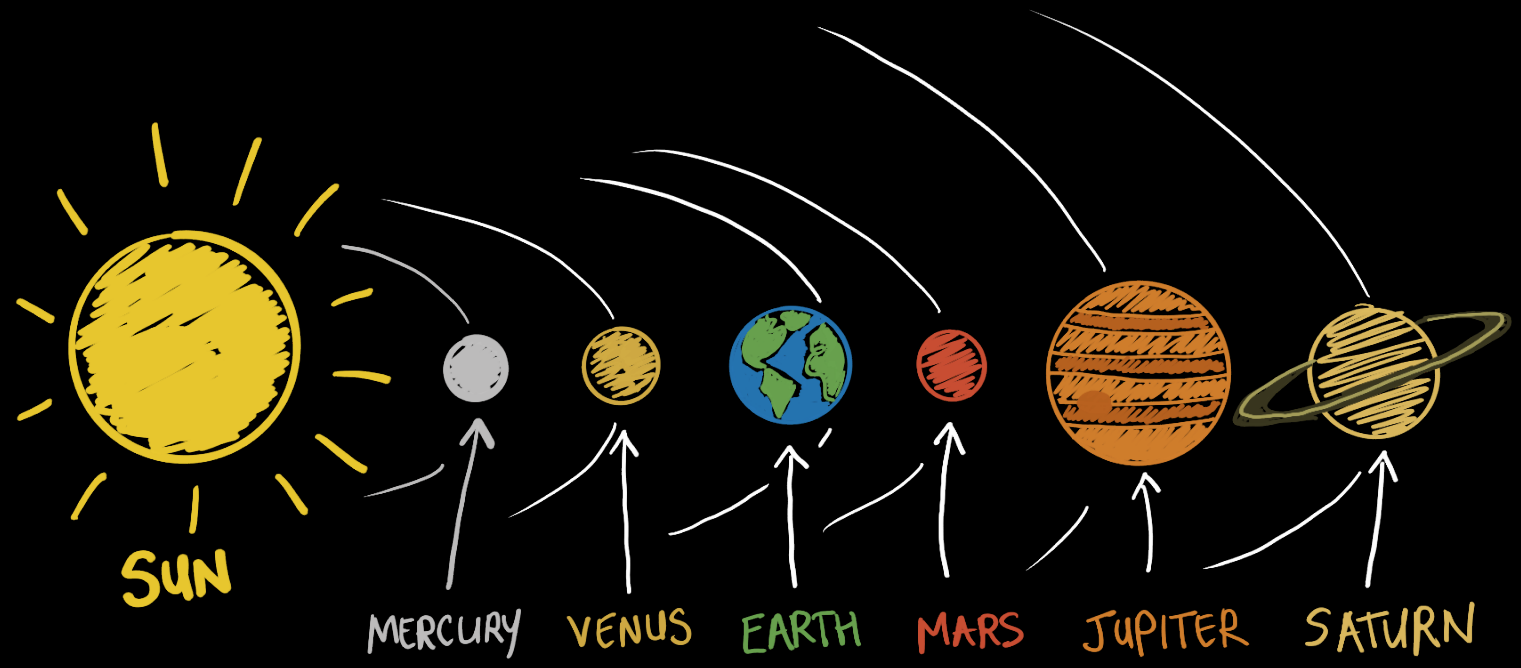

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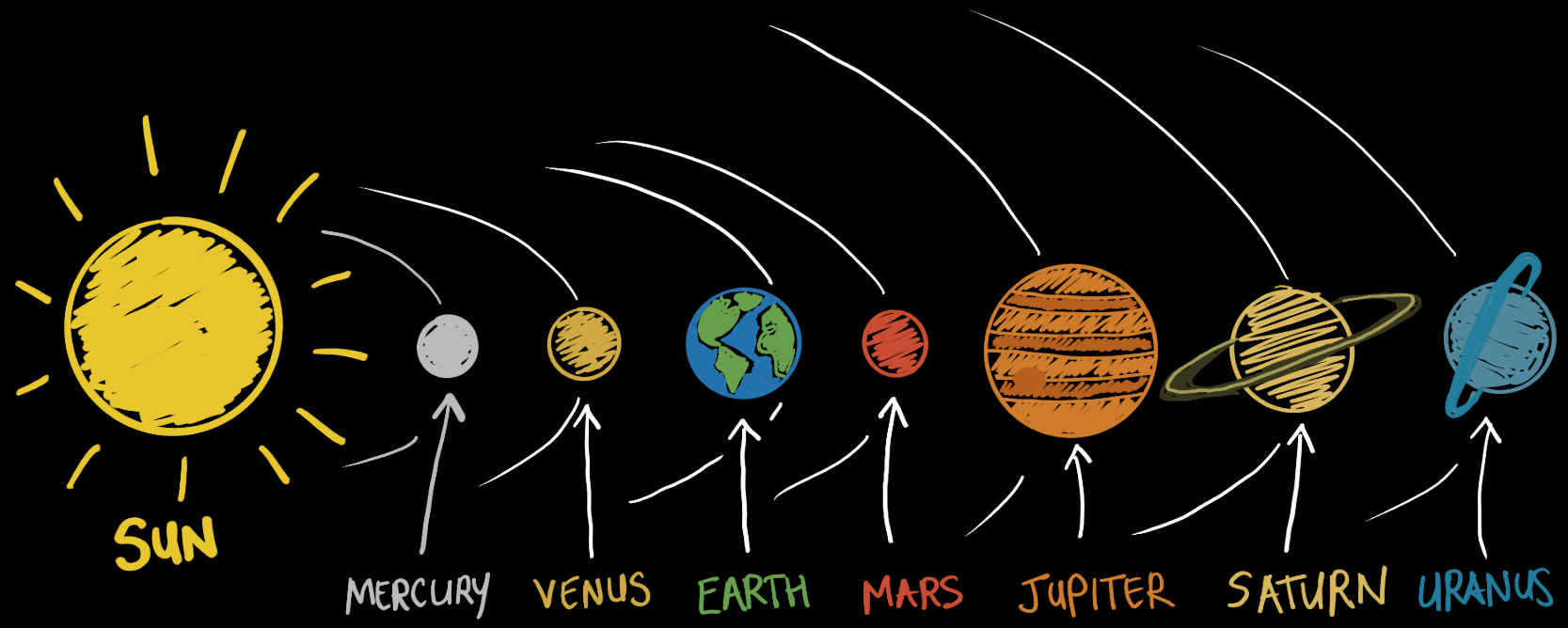

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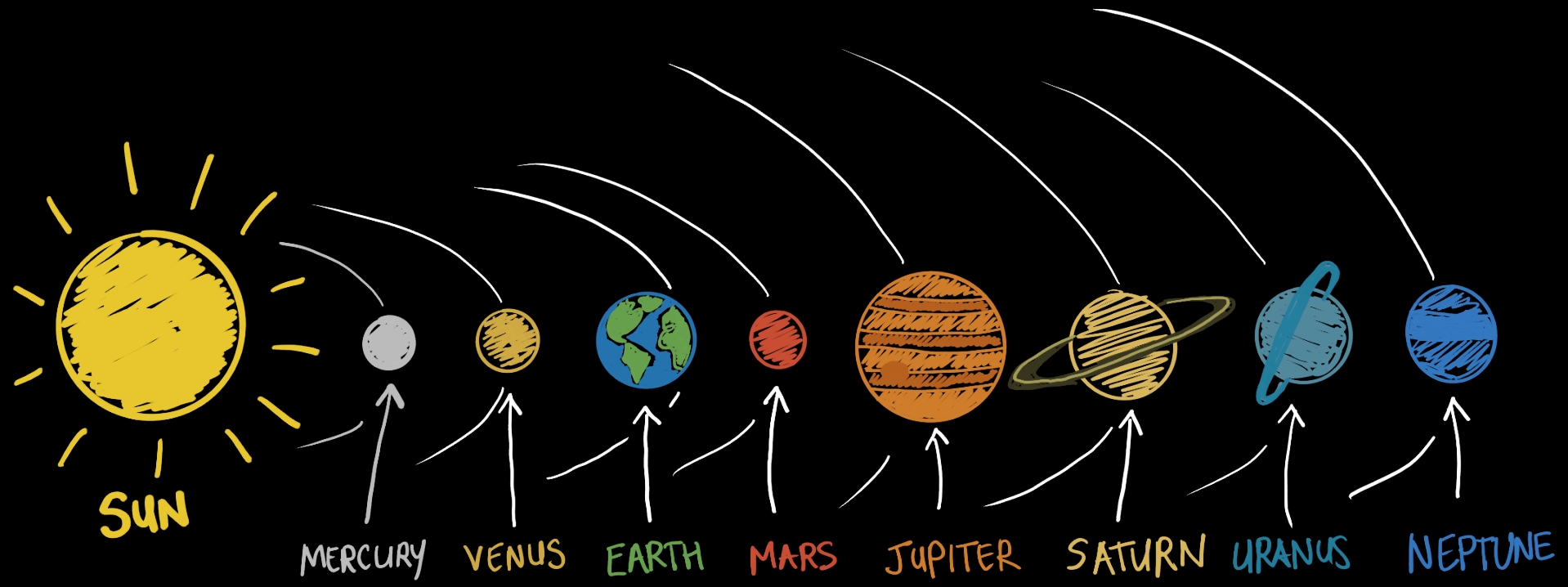

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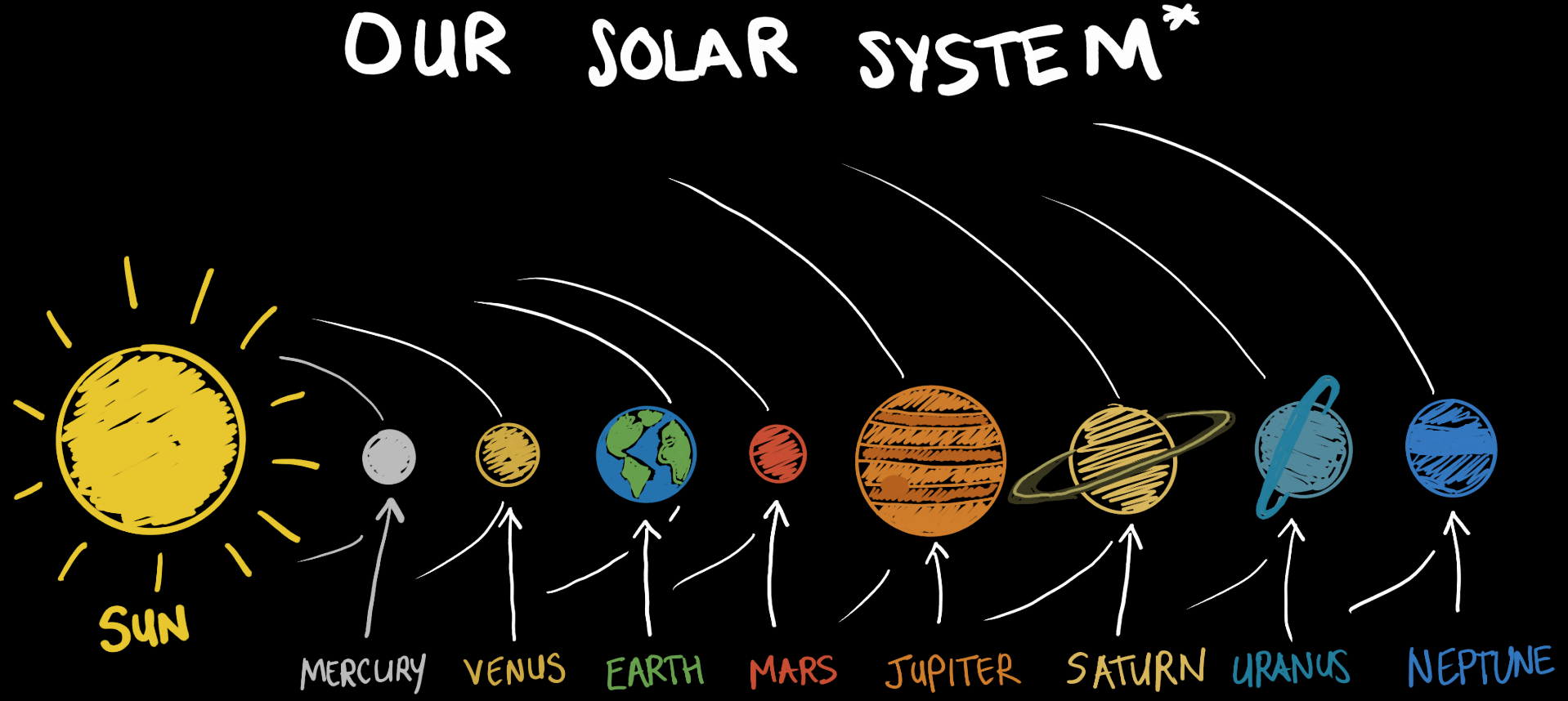
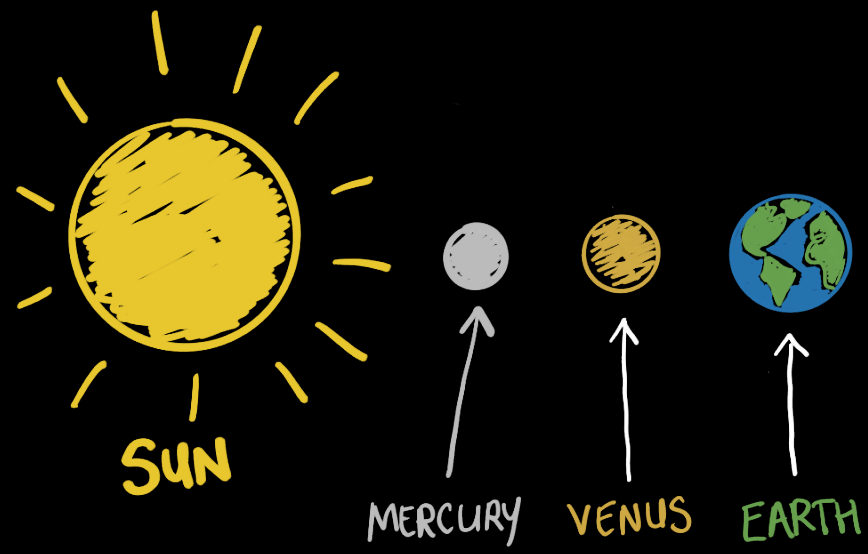


Which planet has the highest (orbital) speed?

*not to scale...

OUR SOLAR SYSTEM*



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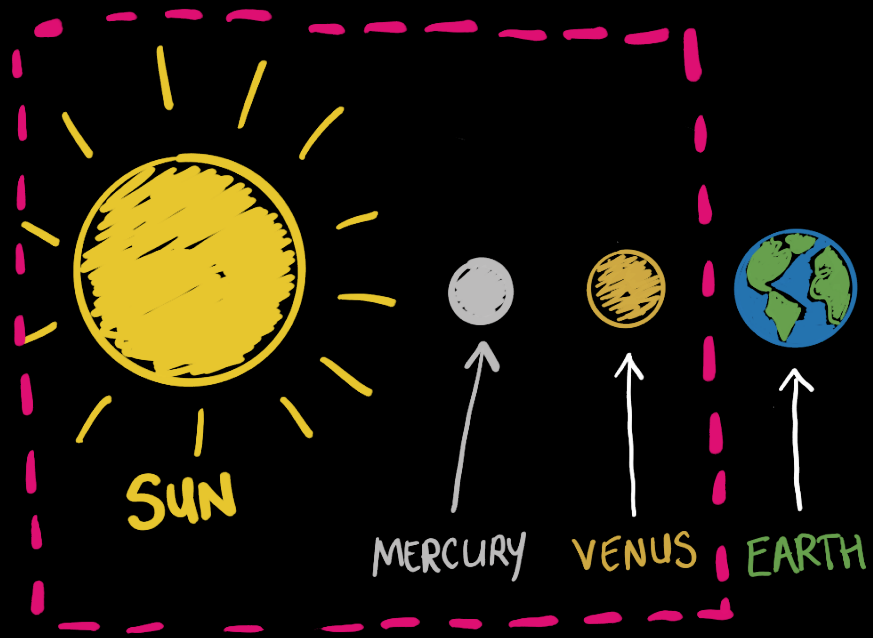
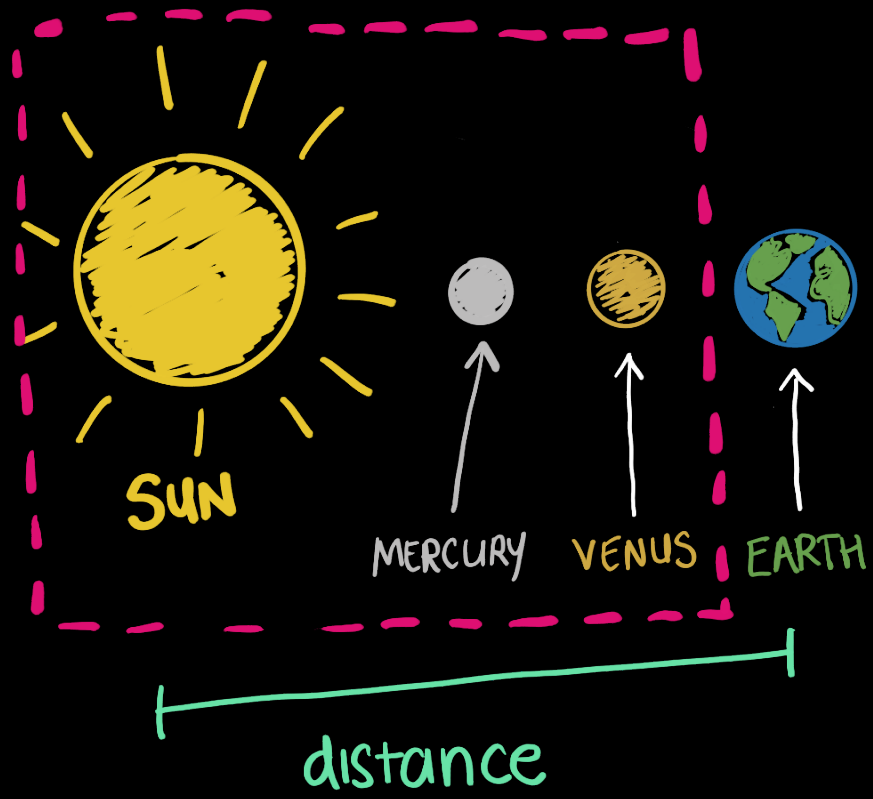
OUR SOLAR SYSTEM*



$$\text{ORBITAL SPEED} \sim \sqrt{\text{MASS ENCLOSED}}$$

*not to scale...

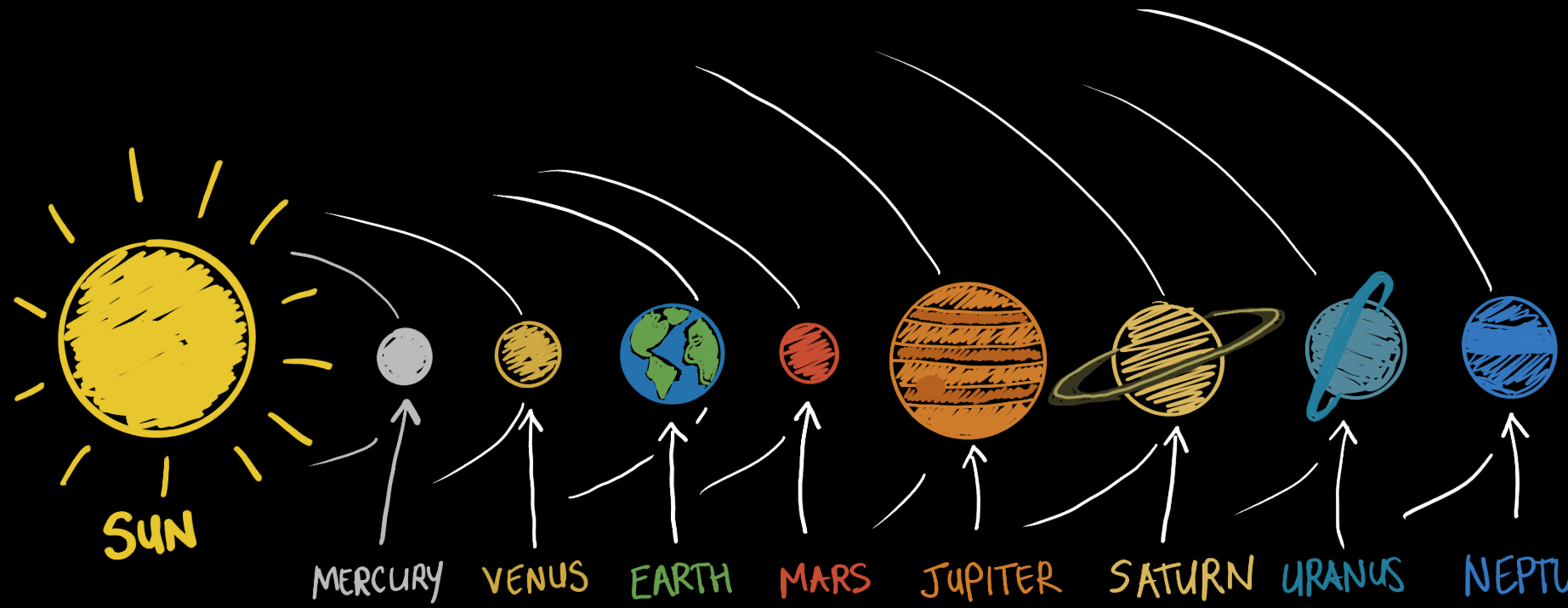
OUR SOLAR SYSTEM*



$$\text{ORBITAL SPEED} \sim \frac{\sqrt{\text{MASS ENCLOSED}}}{\text{DISTANCE}}$$

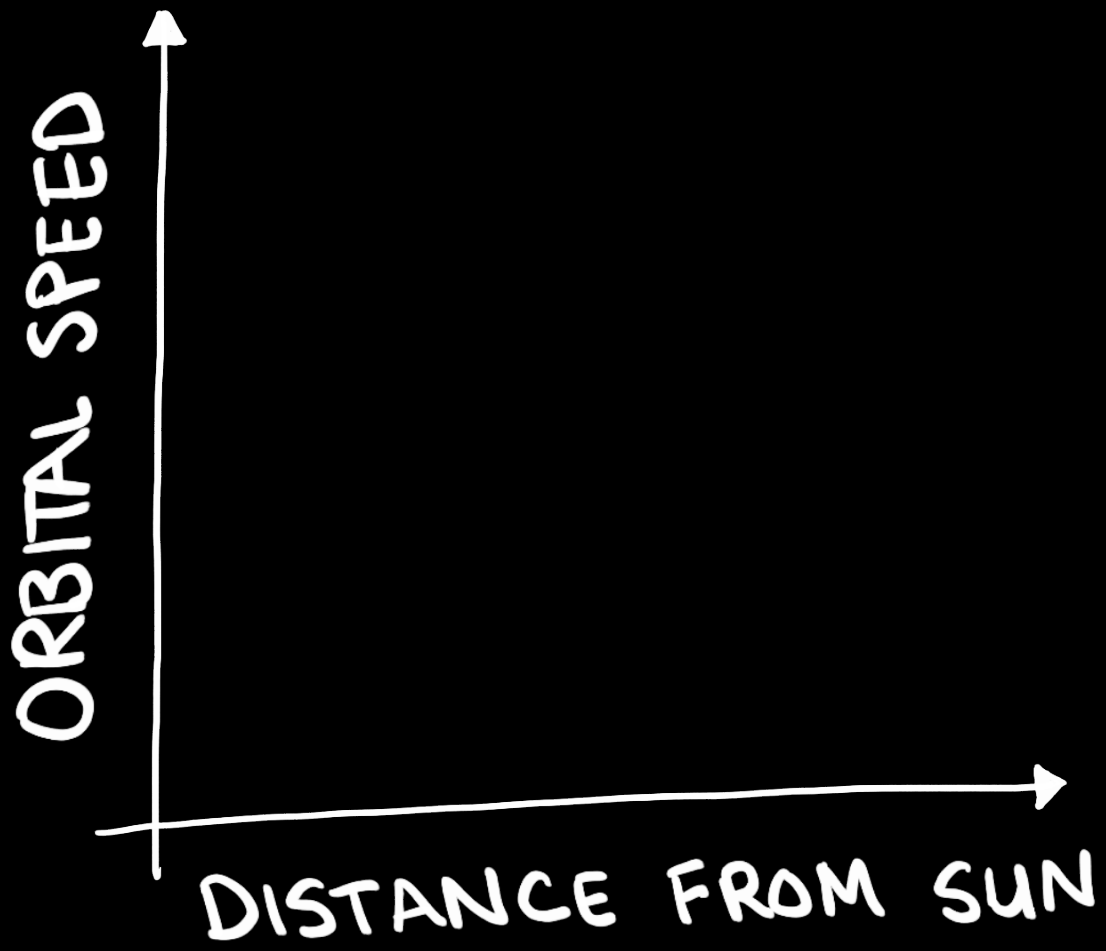
*not to scale...

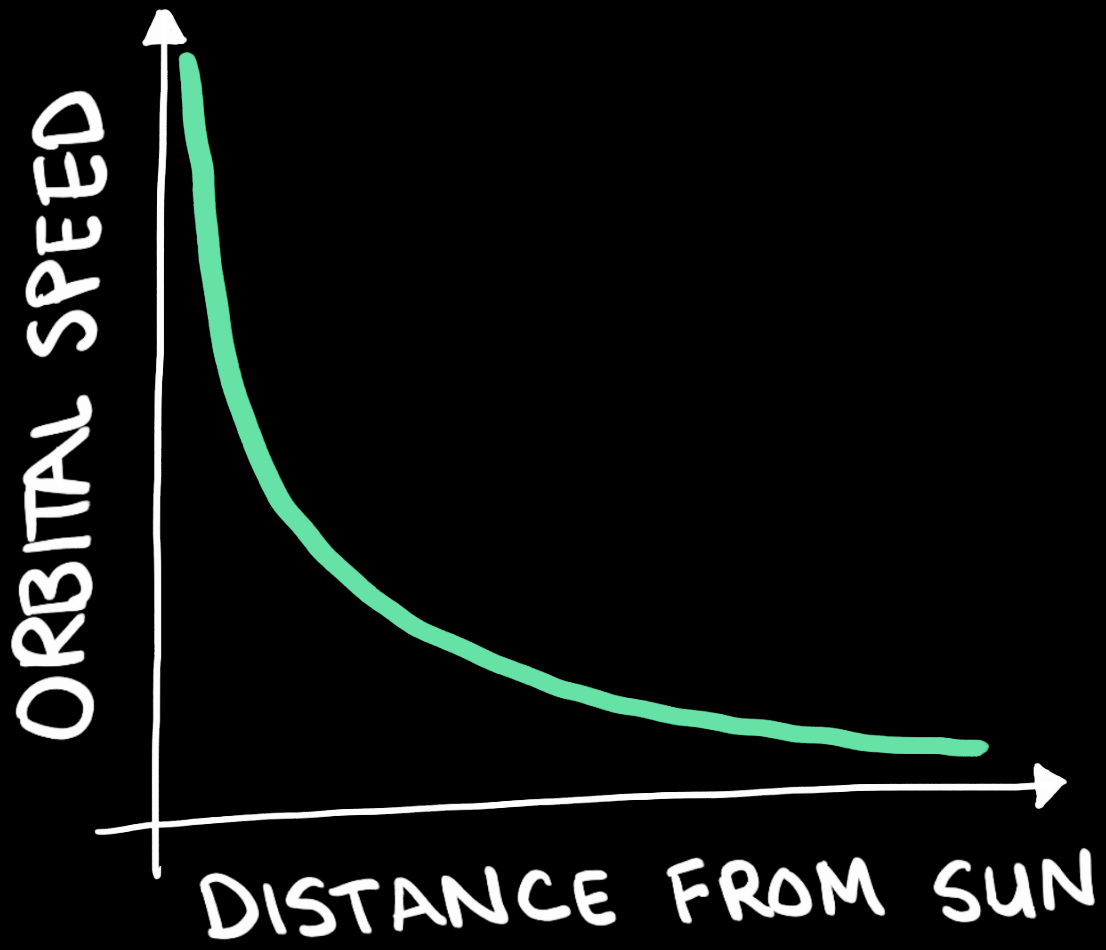
OUR SOLAR SYSTEM*

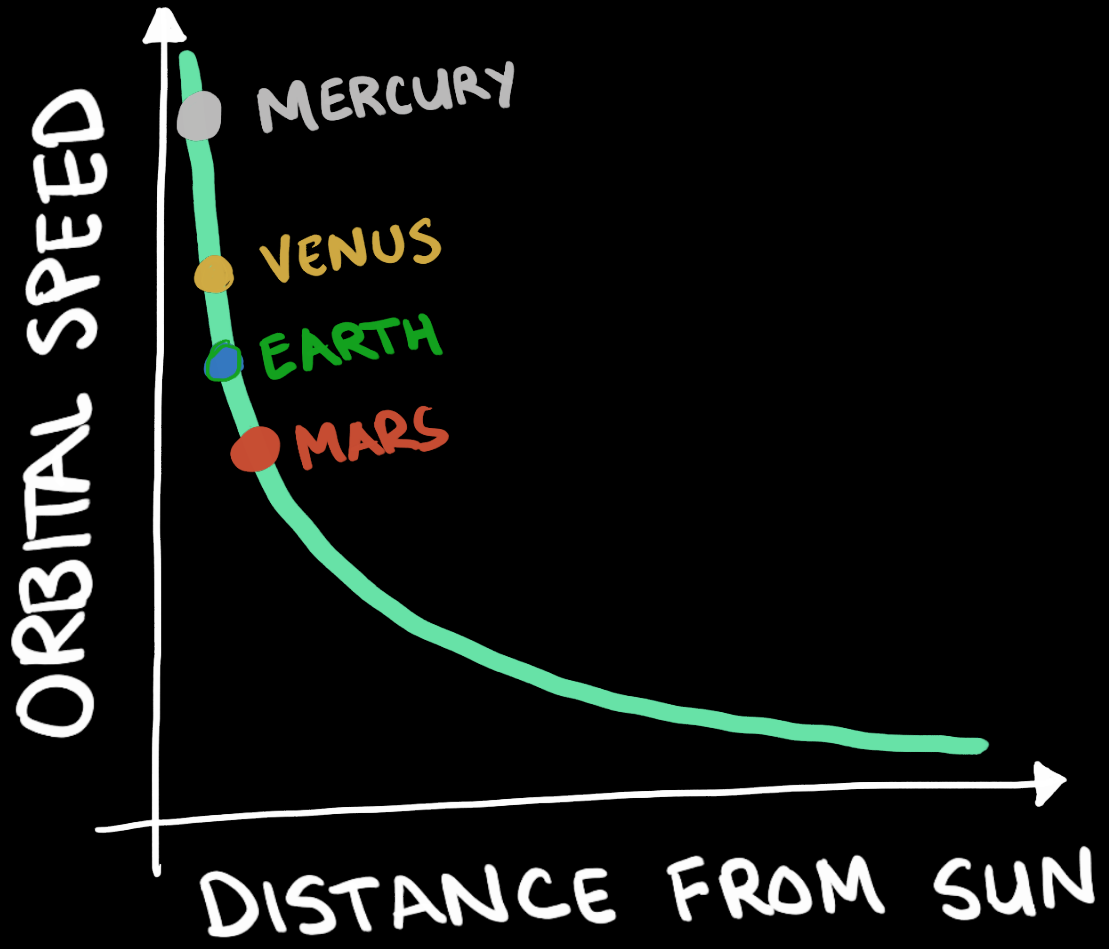


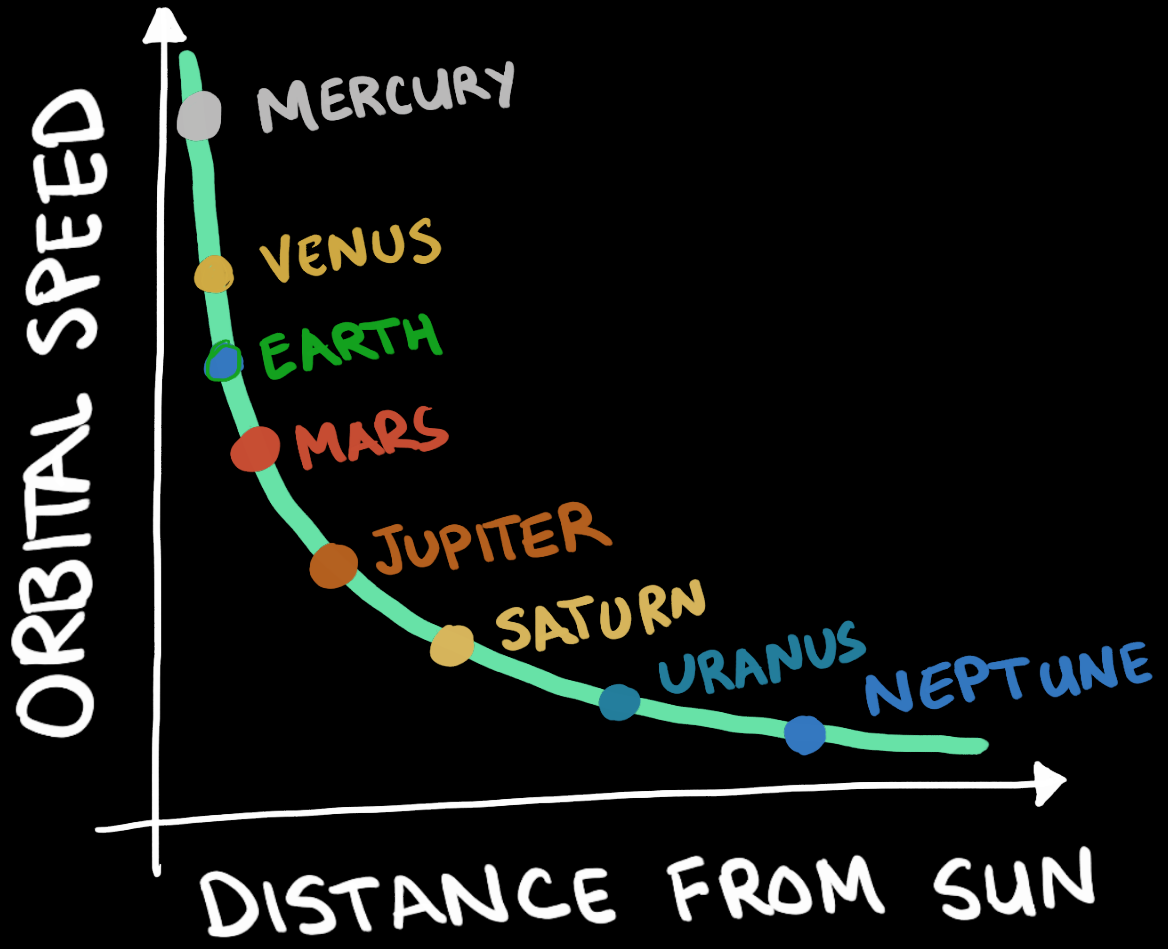
FAST → SLOW

*not to scale...

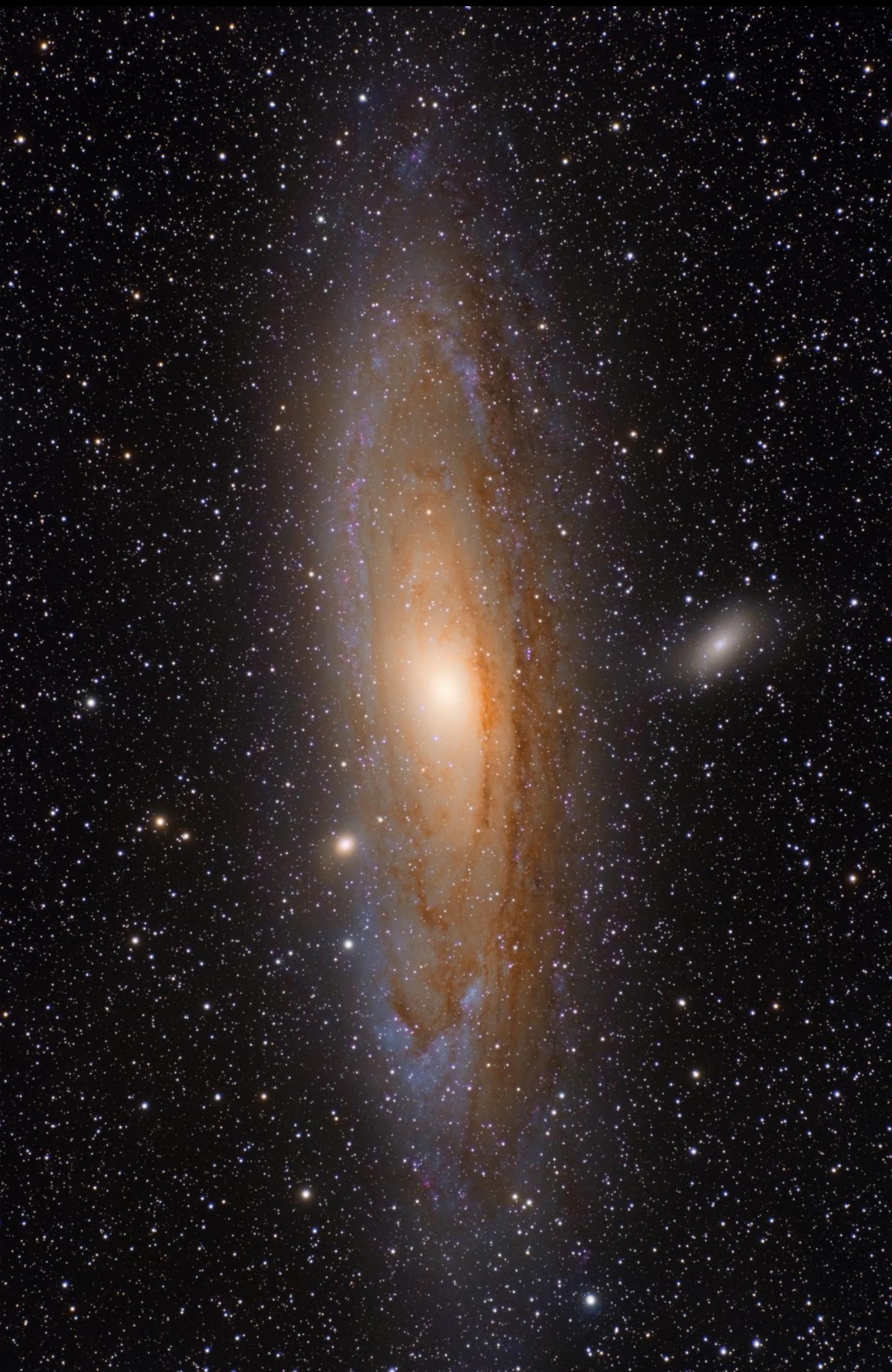

ORBITAL SPEED
DISTANCE FROM SUN

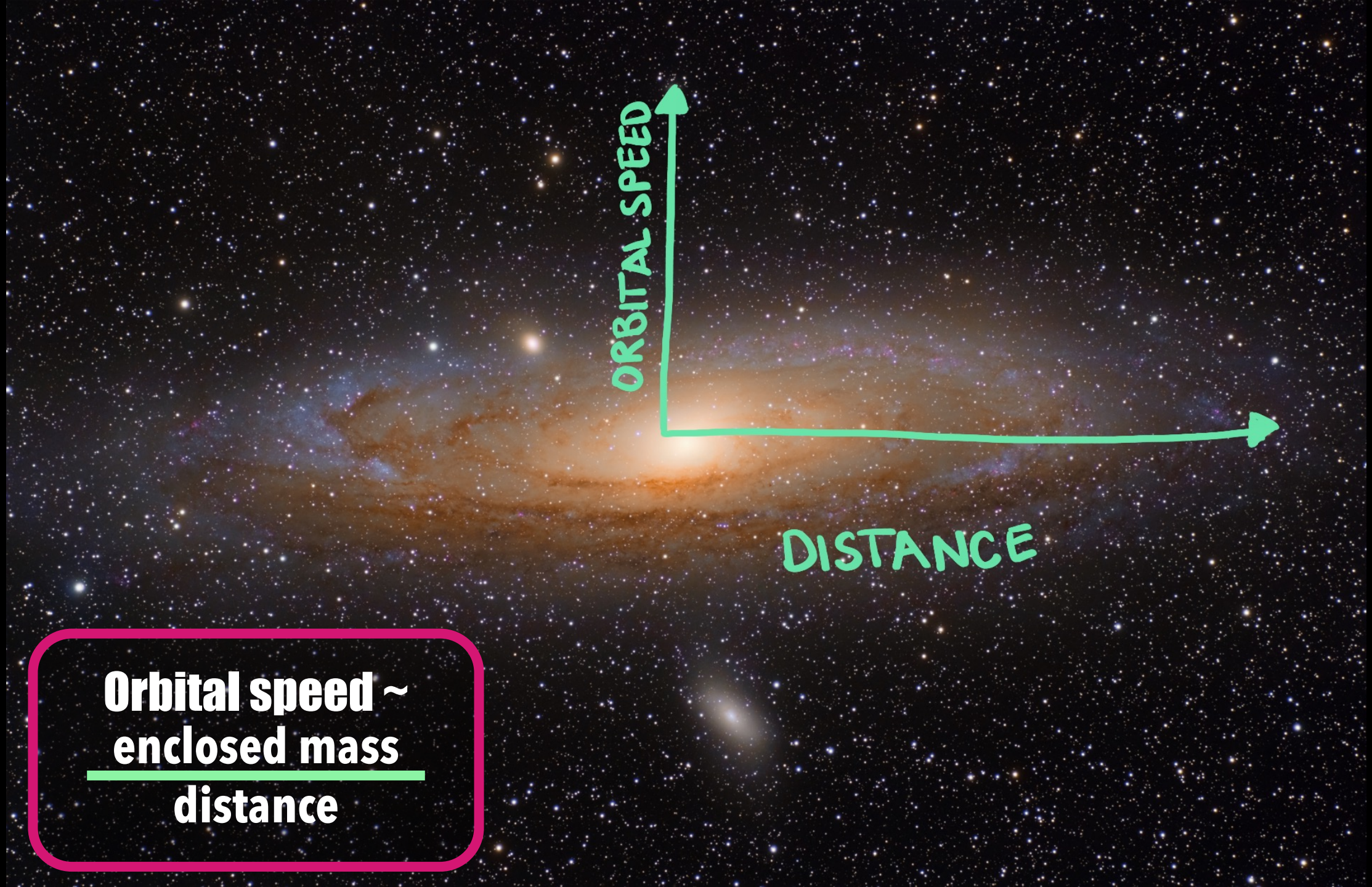

ORBITAL SPEED
DISTANCE FROM SUN


ORBITAL SPEED
MERCURY
VENUS
EARTH
MARS
DISTANCE FROM SUN


ORBITAL SPEED
MERCURY
VENUS
EARTH
MARS
JUPITER
SATURN
URANUS
NEPTUNE
DISTANCE FROM SUN

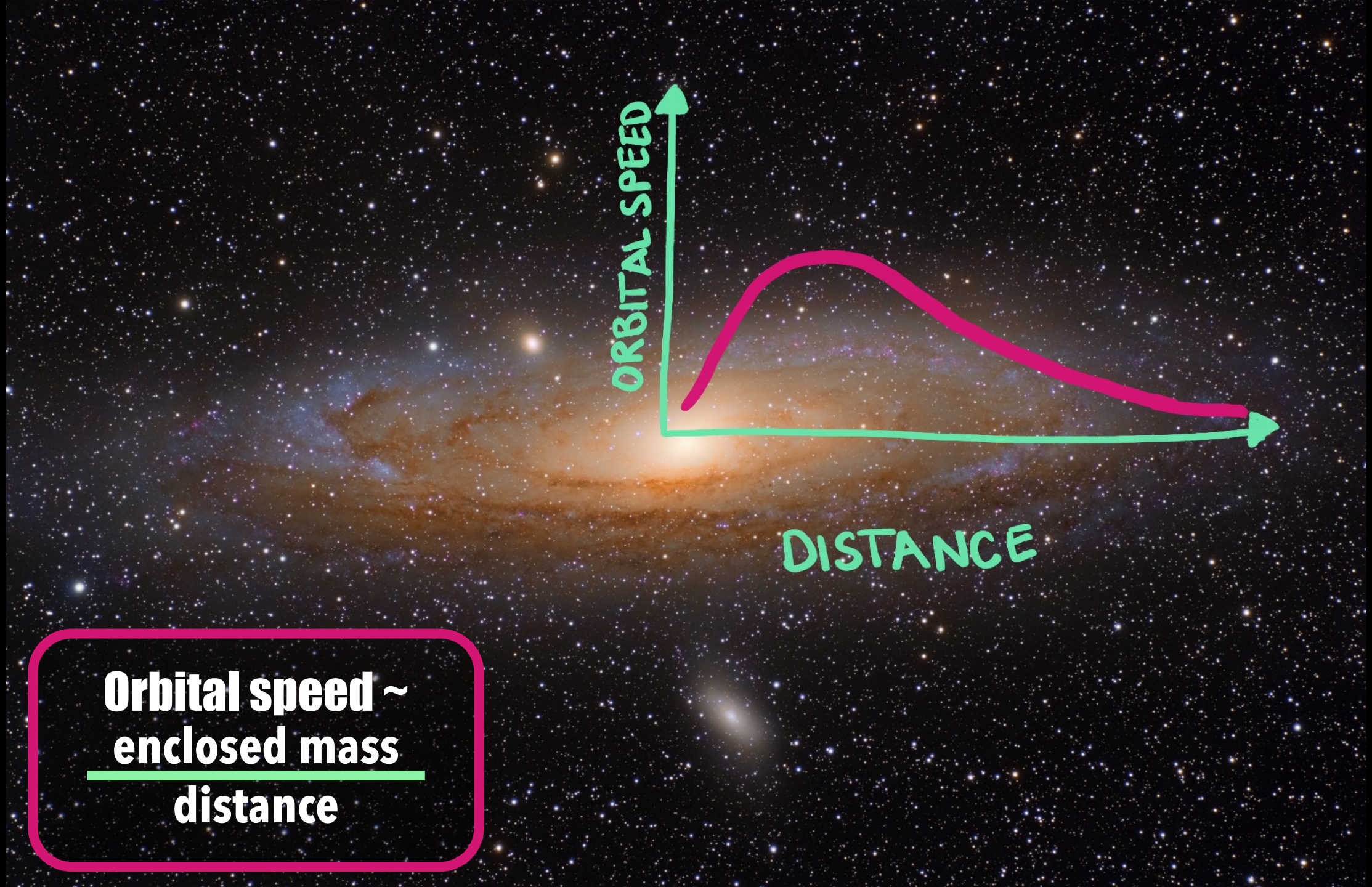
[image credit: Brody Wesner]





$$\text{Orbital speed} \sim \frac{\text{enclosed mass}}{\text{distance}}$$

[image credit: Brody Wesner]



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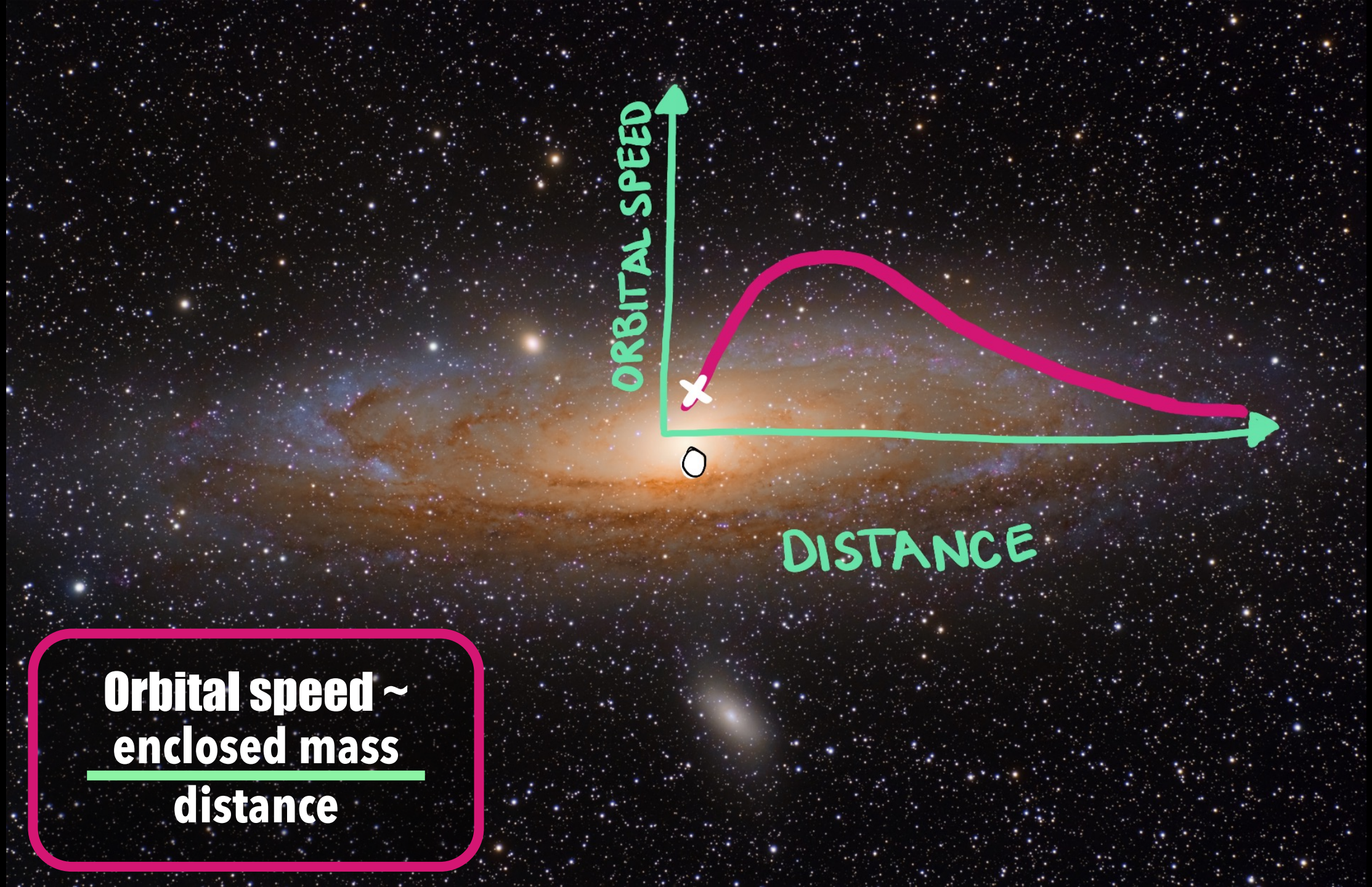

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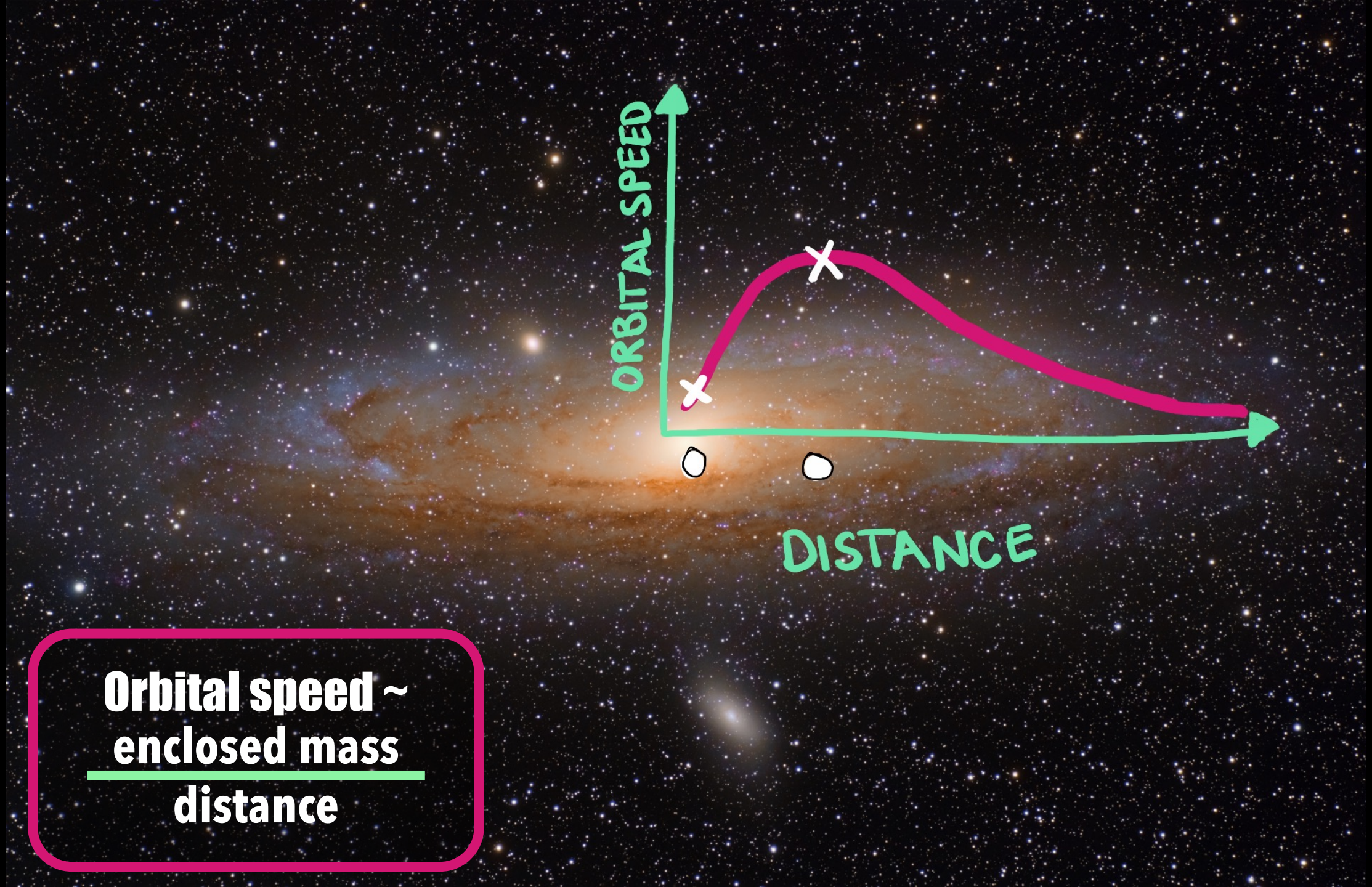

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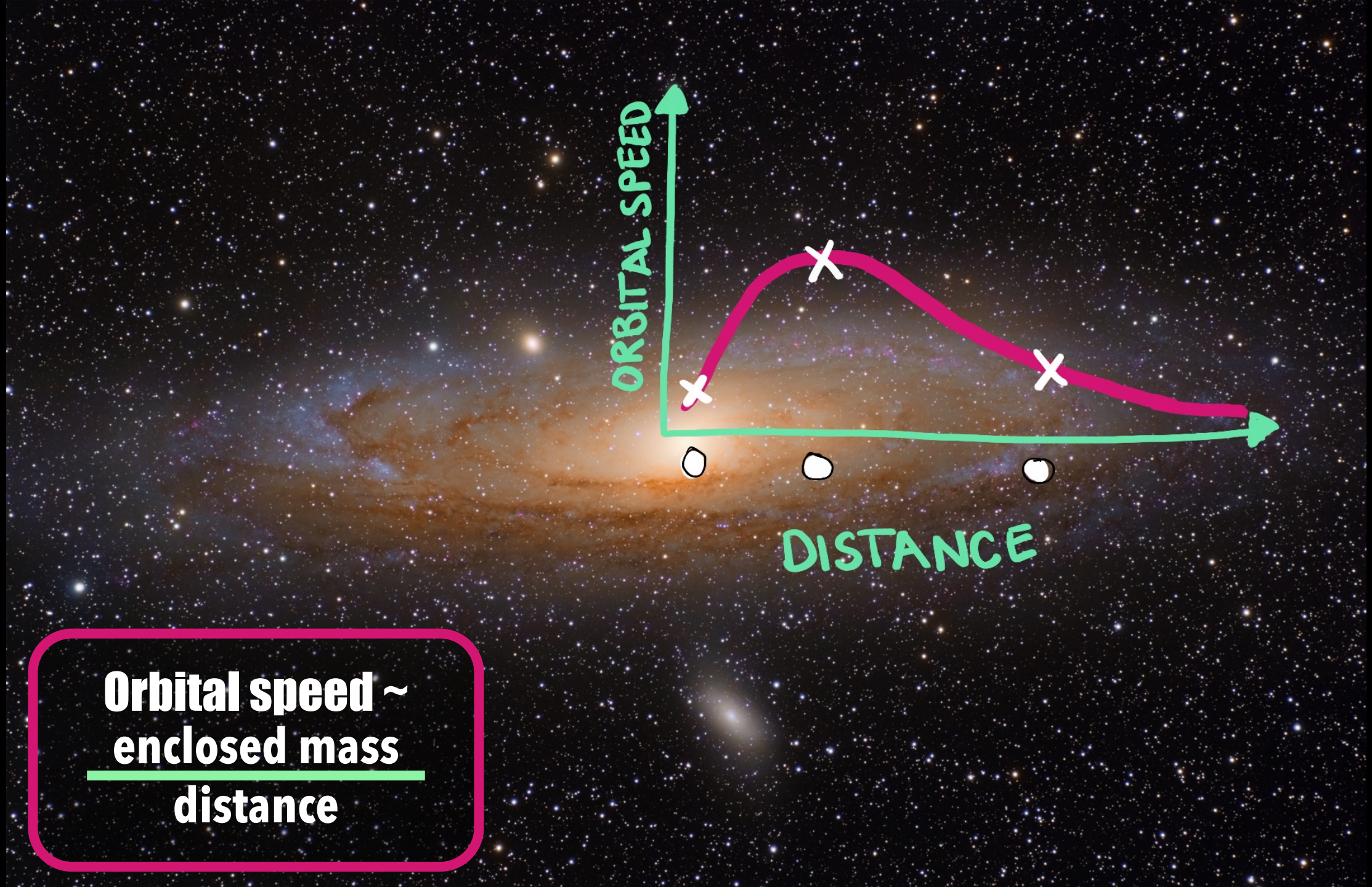

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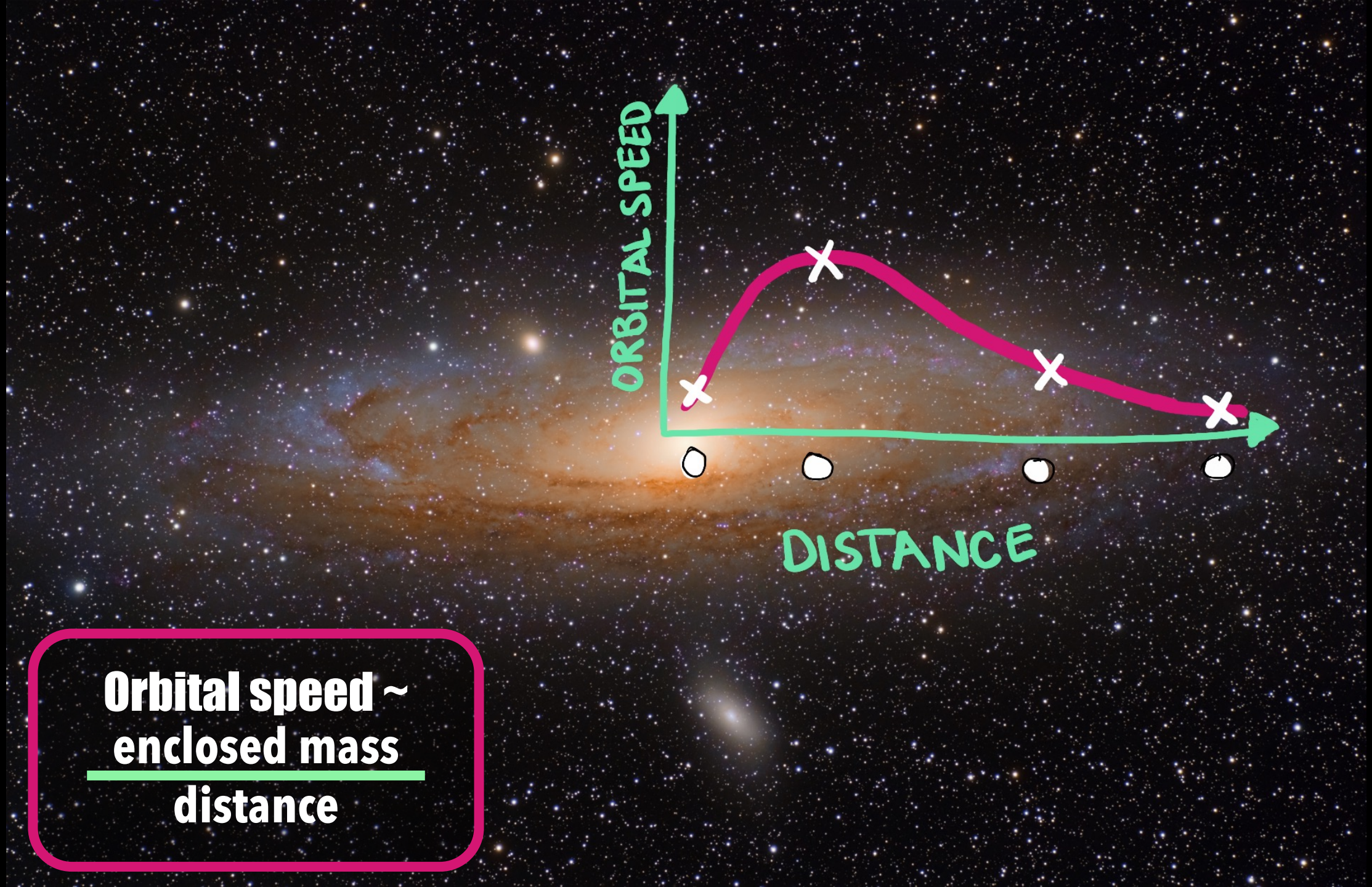

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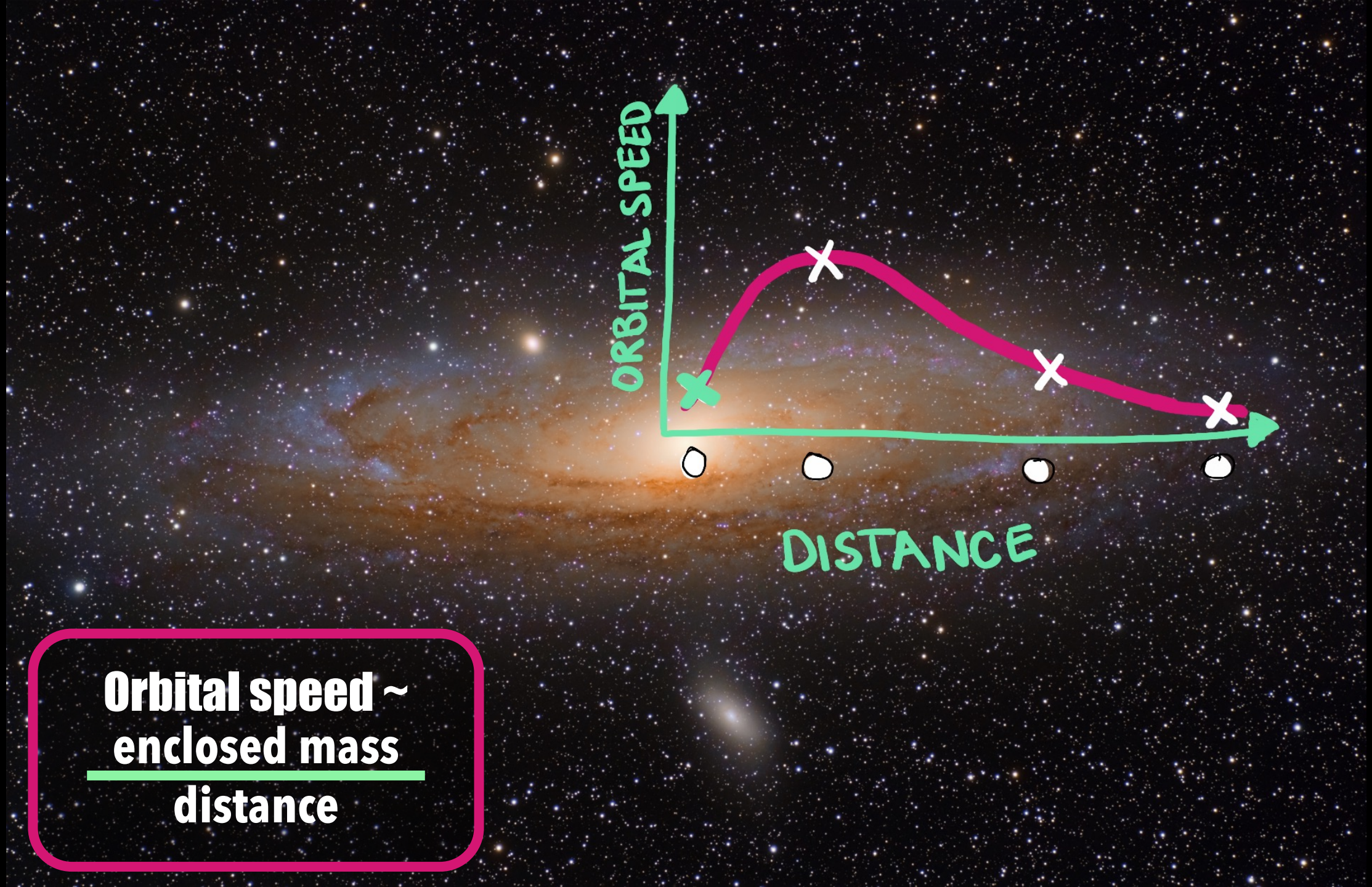

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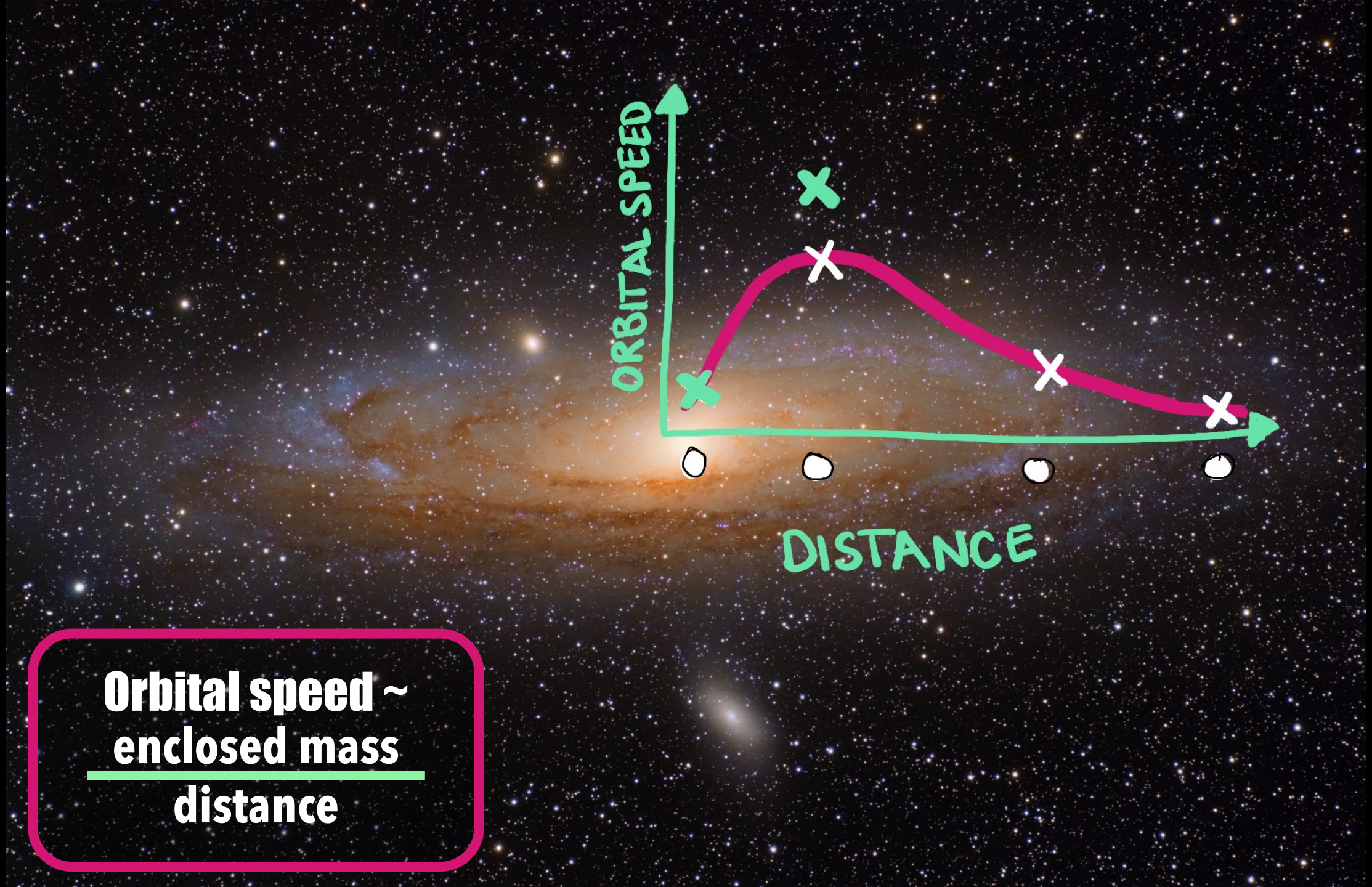

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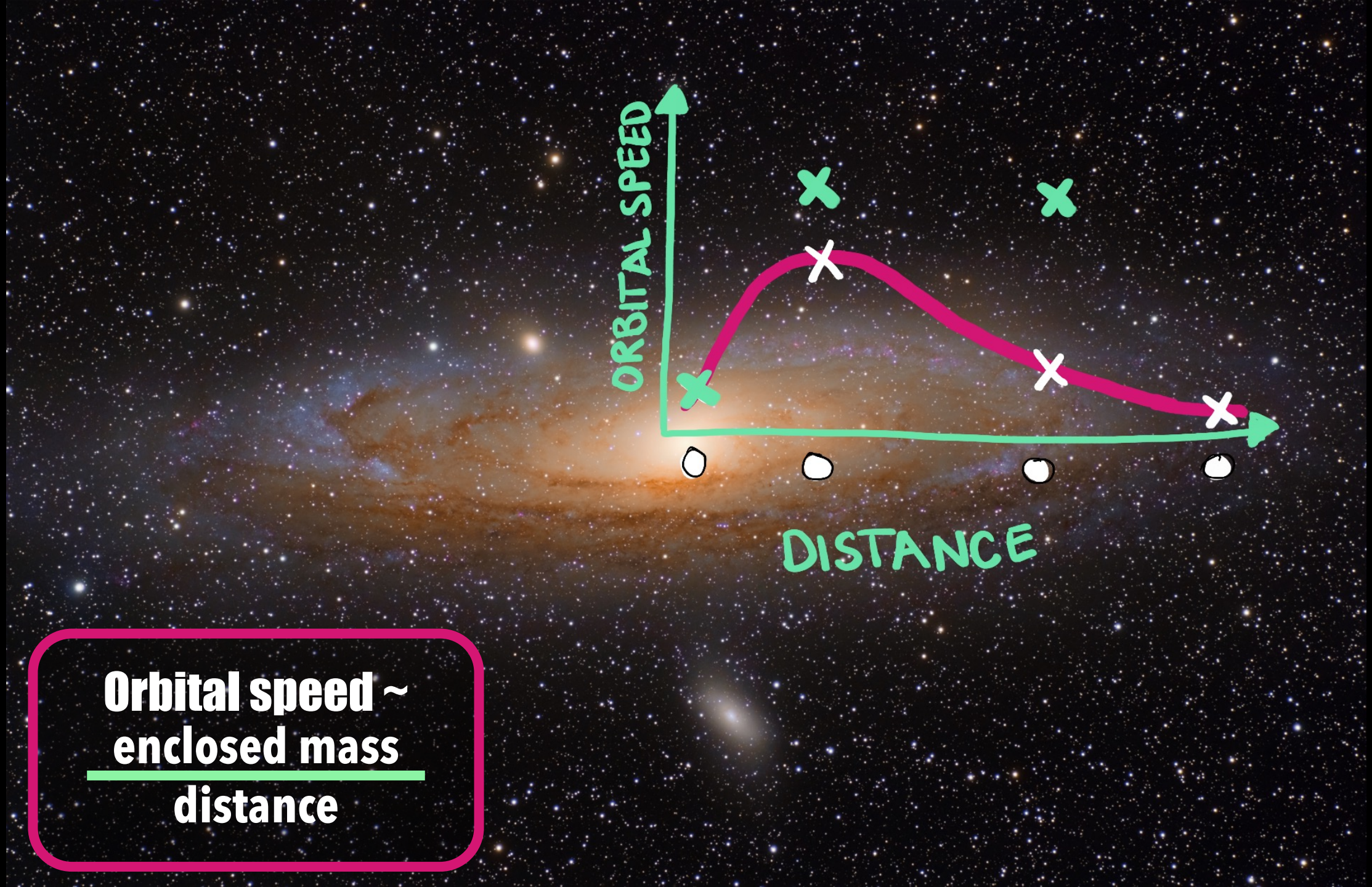

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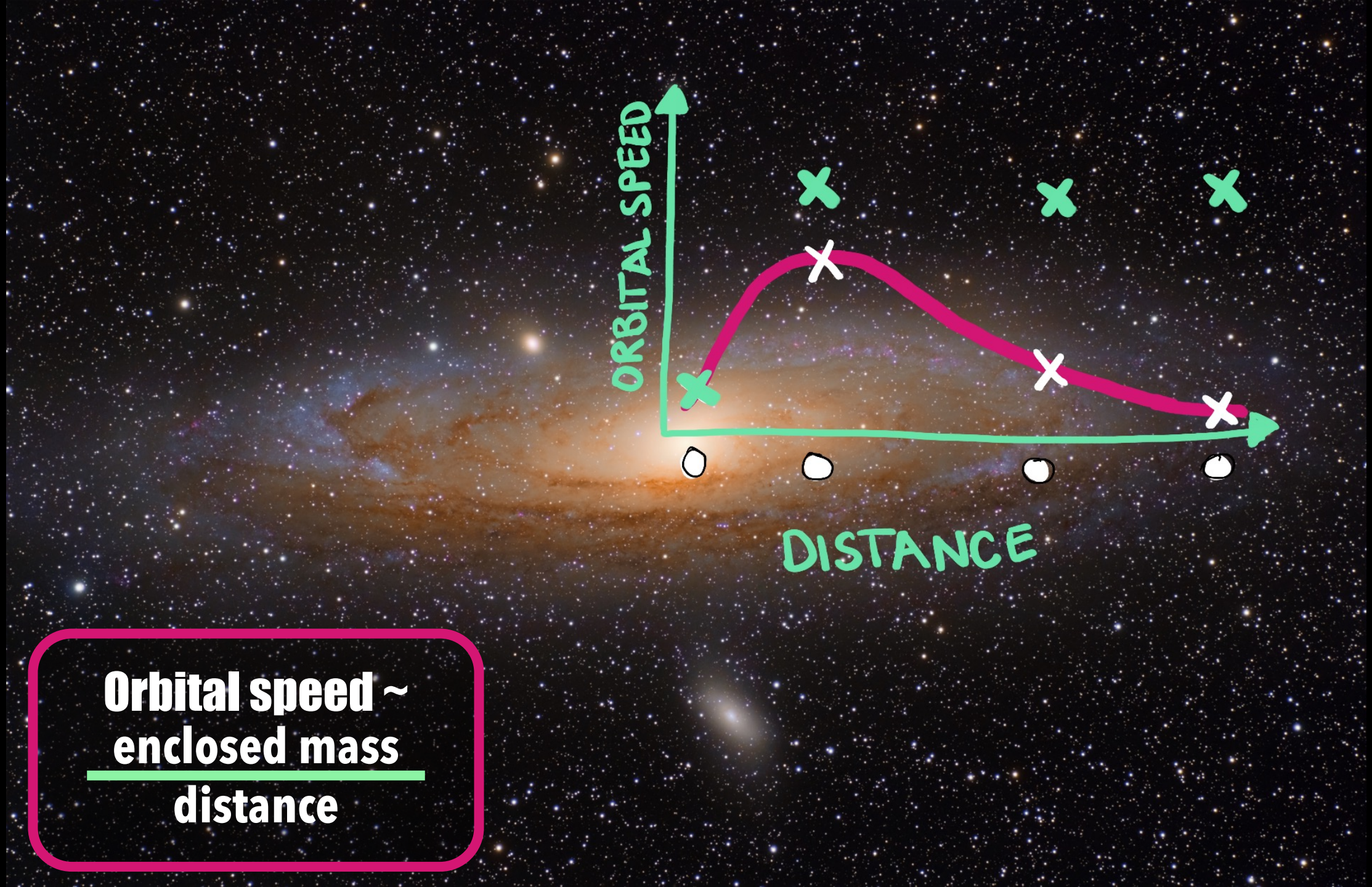
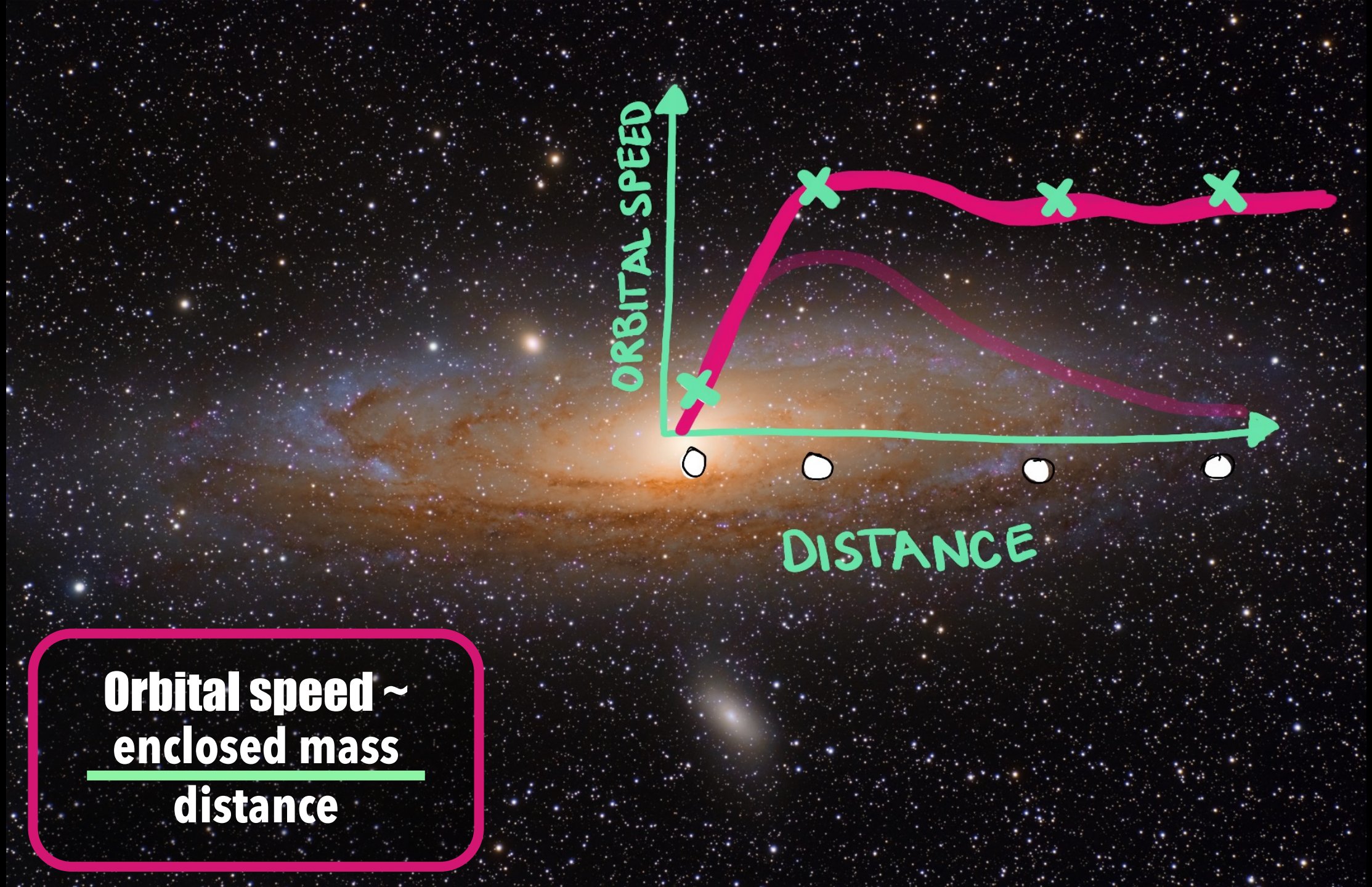


Orbital speed ~ $\frac{\text{enclosed mass}}{\text{distance}}$

[image credit: Brody Wesner]



Orbital speed ~ $\frac{\text{enclosed mass}}{\text{distance}}$

[image credit: Brody Wesner]

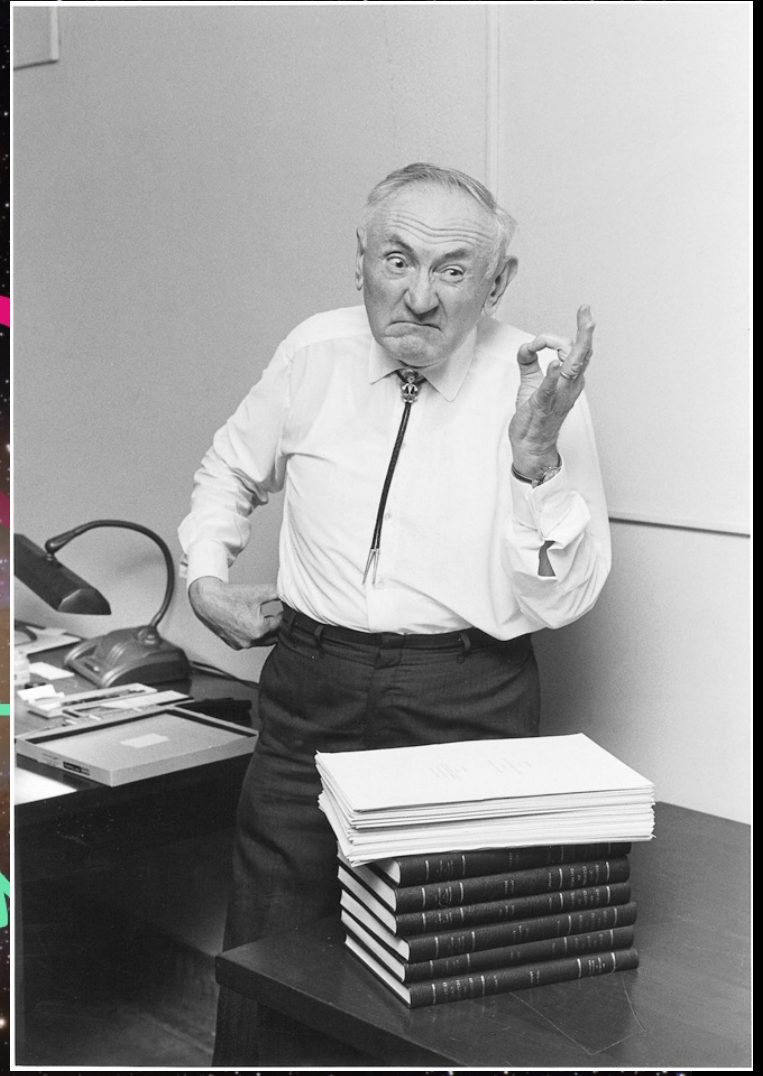
There must be more enclosed mass than what we can observe…

⚠ DARK MATTER

[image credit: Brody Wesner]

There must be more enclosed mass than what we can observe…

⚠ **DARK MATTER**



Fritz Zwicky (1933)

[image credit: Brody Wesner] [Caltech Archives]

There must be more enclosed mass than what we can observe…

⚠ DARK MATTER

Vera Rubin (1970)

Fritz Zwicky (1933)

[image credit: Brody Wesner] [Caltech Archives] [Carnegie Institution of Washington, via Associated Press]

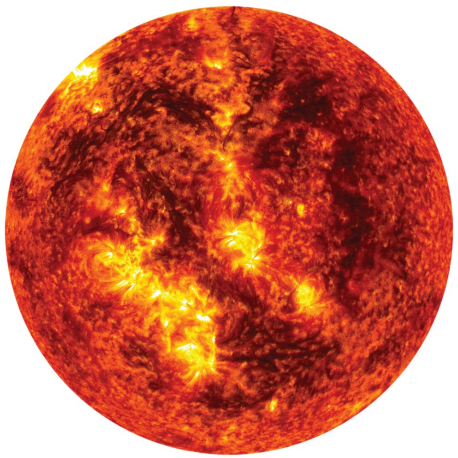
For the curious: more observational evidences since, including gravitational lensing, imprints in cosmic microwave background light, large scale structure

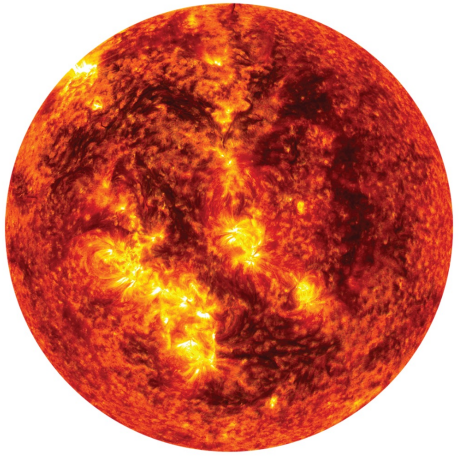
Vera Rubin (1970)

Fritz Zwicky (1933)

[image credit: Brody Wesner] [Caltech Archives] [Carnegie Institution of Washington, via Associated Press]

What is dark matter made of?





Standard Model of Elementary Particles

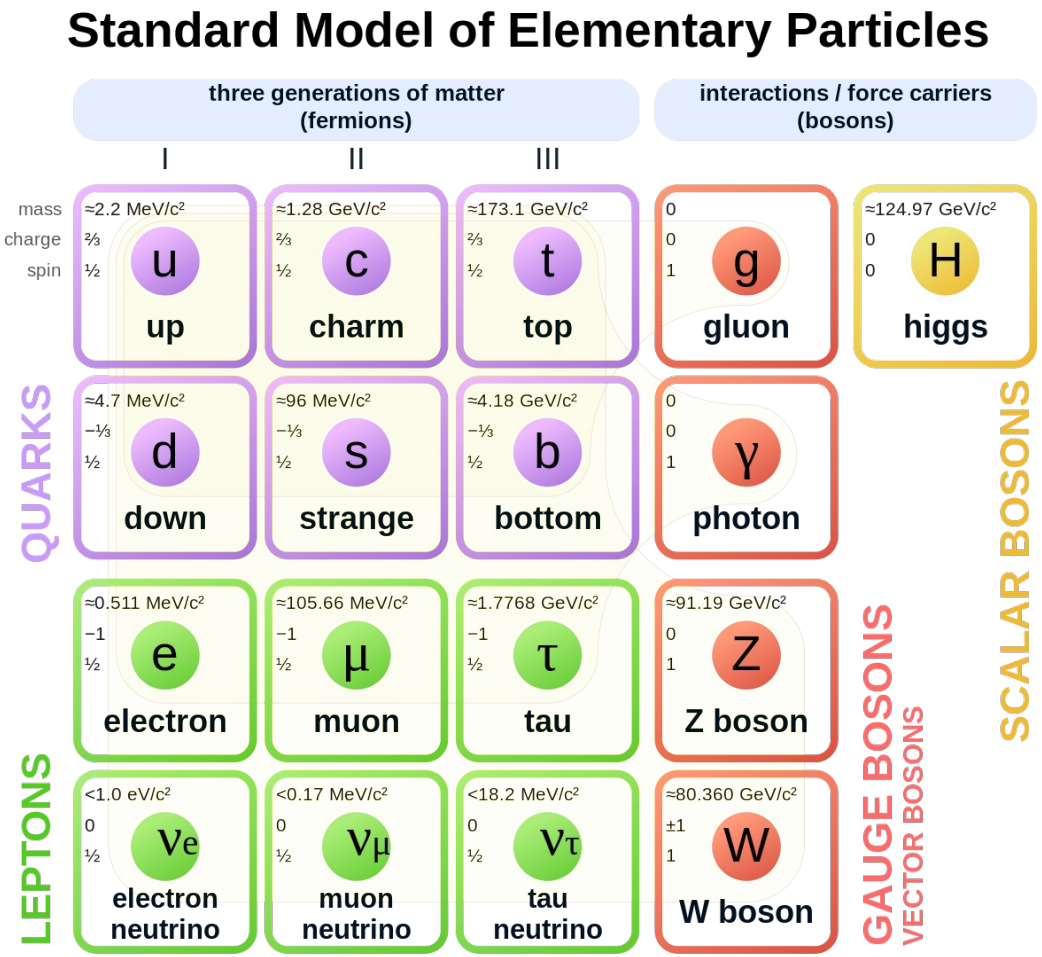
	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
mass	≈2.2 MeV/c²	≈1.28 GeV/c²	≈173.1 GeV/c²	0	≈124.97 GeV/c²
charge	⅔	⅔	⅔	0	0
spin	½	½	½	1	0
	u up	c charm	t top	g gluon	H higgs
QUARKS	≈4.7 MeV/c²	≈96 MeV/c²	≈4.18 GeV/c²	0	
	−⅓	−⅓	−⅓	0	
	½	½	½	1	
	d down	s strange	b bottom	γ photon	
	≈0.511 MeV/c²	≈105.66 MeV/c²	≈1.7768 GeV/c²	≈91.19 GeV/c²	
	−1	−1	−1	0	
	½	½	½	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²	≈80.360 GeV/c²	
	0	0	0	±1	
	½	½	½	1	
	νe electron neutrino	νμ muon neutrino	ντ tau neutrino	W W boson	

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

Dark matter:

1. neutral
2. stable
3. cold (think: heavy)



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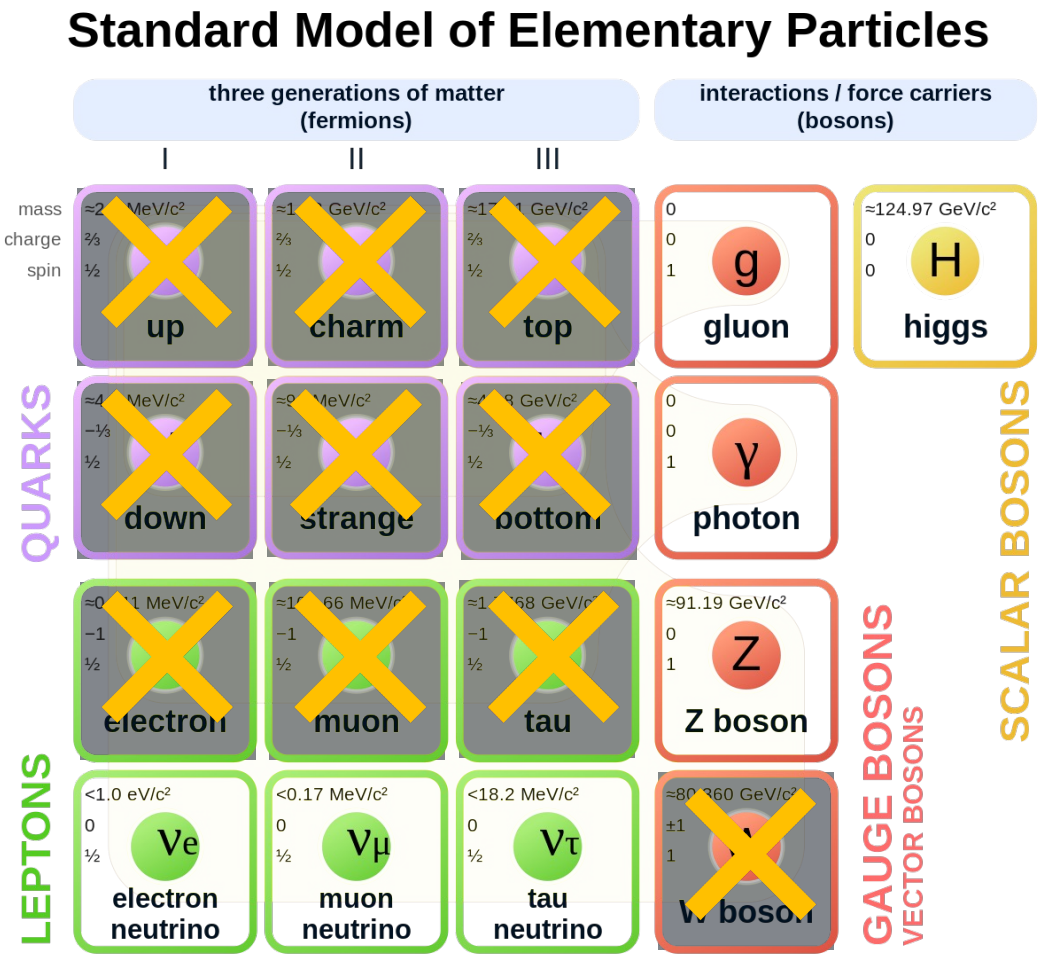

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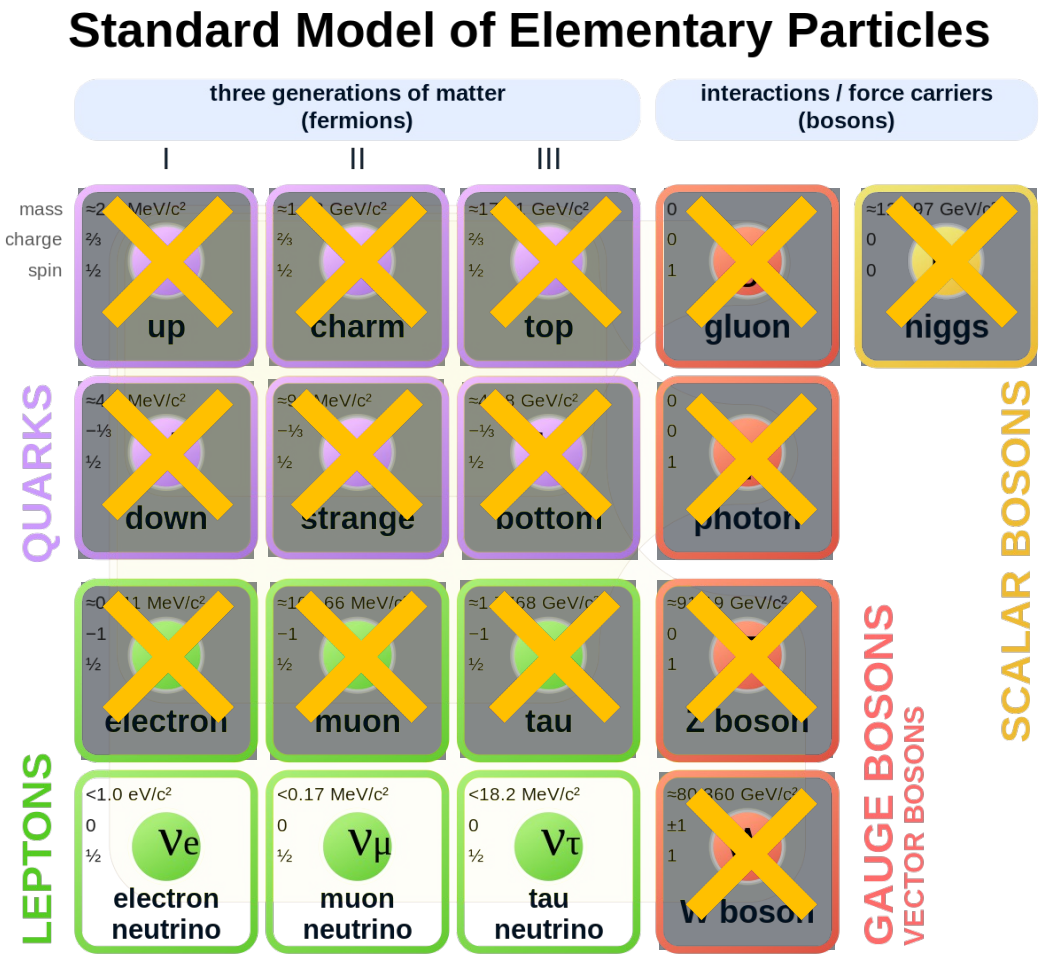

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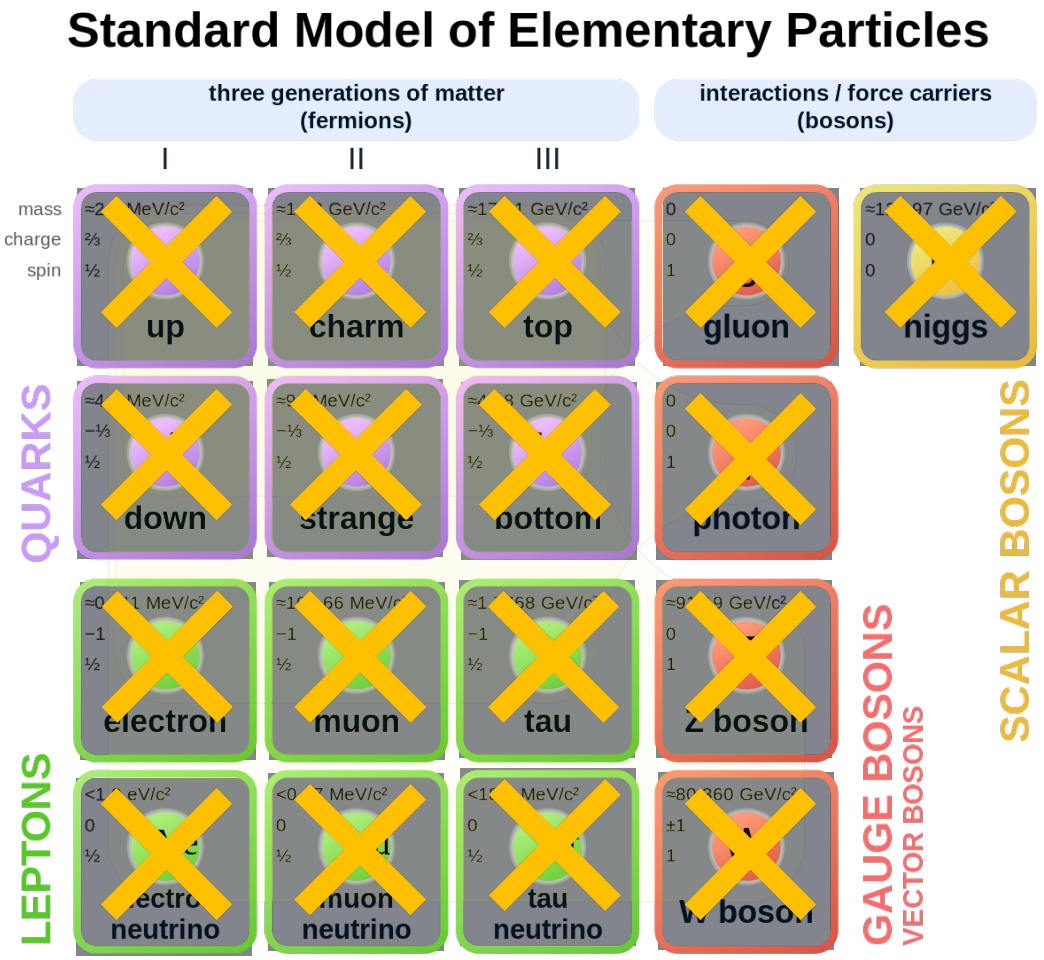


We don’t know what dark matter is made of.

Showing 1–17 of 17 results

1. arXiv:2605.15192 [pdf, ps, other] astro-ph.CO hep-ph hep-th

   Isocurvature-Free QCD Axion Dark Matter from Inflaton-Driven Early QCD: the Necessity of Inflationary Plateaus

   Authors: Katherine Freese, Evangelos I. Sfakianakis, Barmak Shams Es Haghi

   Submitted 14 May, 2026; **originally announced** May 2026.

   Comments: 9 pages, 2 figures

2. arXiv:2605.14887 [pdf, ps, other] astro-ph.SR

   Self-Interacting Dark Matter in Brown Dwarfs

   Authors: A. Pérez-Garrido

   Submitted 14 May, 2026; **originally announced** May 2026.

   Comments: 20 pages, 7 figures

3. arXiv:2605.14715 [pdf, ps, other] hep-ph

   Perspective of inert quartet in the context of perturbativity and dark matter phenomenology

   Authors: Pram Milan P. Robin, Priyotosh Bandyopadhyay

   Submitted 14 May, 2026; **originally announced** May 2026.

   Comments: 33 pages, 15 figures and 2 tables

   Report number: IITH-PH-0001/26

4. arXiv:2605.14528 [pdf, ps, other] gr-qc hep-th

   Quasinormal modes of massless scalar and electromagnetic perturbations for Euler Heisenberg black holes surrounded by perfect fluid dark matter

   Authors: Chengfu Feng, Sheng-Yuan Li, Xufen Zhang, Ming Zhang, De-Cheng Zou, Rui-Hong Yue

   Submitted 14 May, 2026; **originally announced** May 2026.

5. arXiv:2605.14447 [pdf, ps, other] nucl-th hep-ph hep-th

   Bayesian analysis of density profile of light dark matter elucidating the properties of dark matter admixed neutron stars in the presence of hyperons

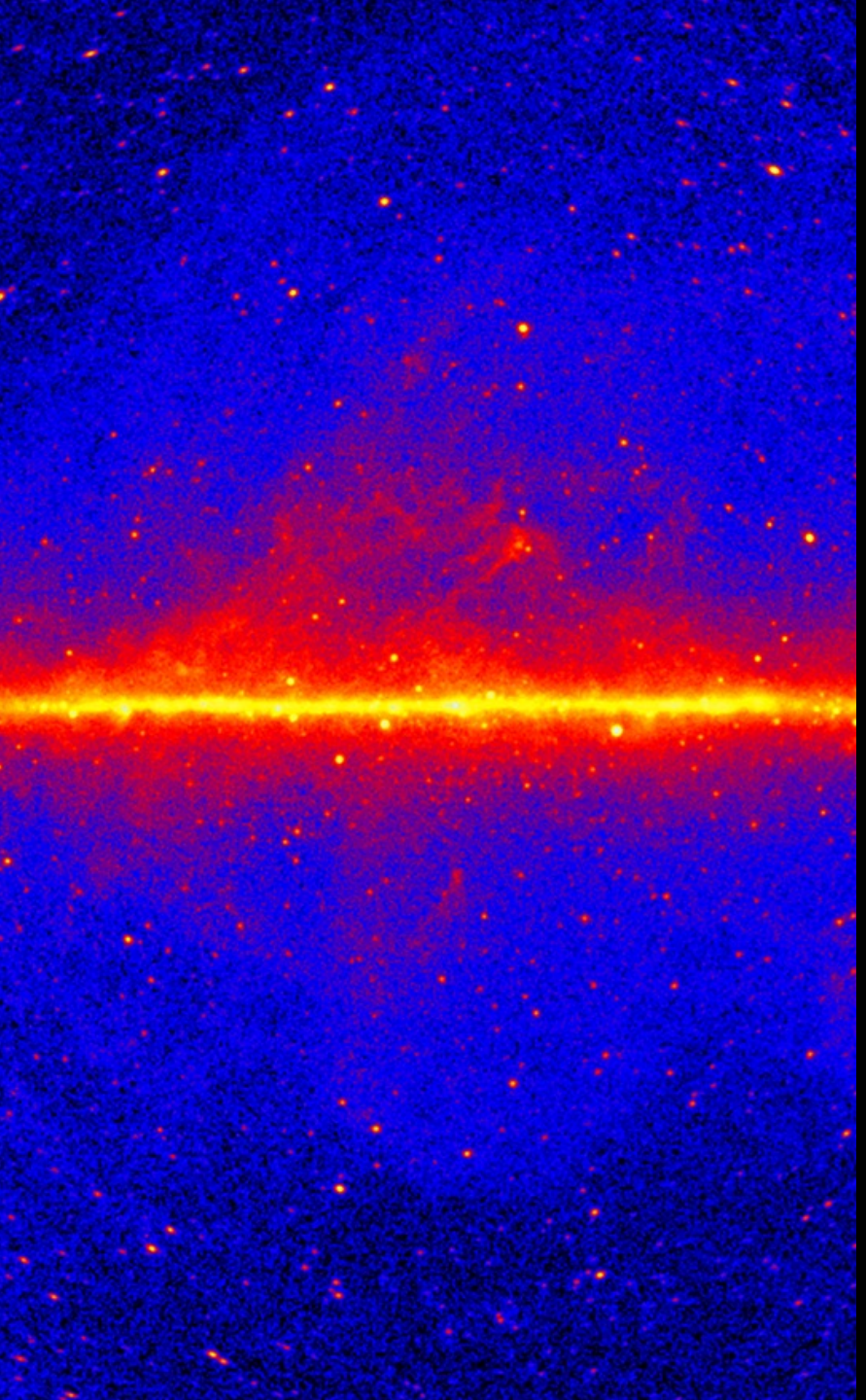
   Authors: Debashree Sen, Atanu Guha, Chang Ho Hyun

   Submitted 14 May, 2026; **originally announced** May 2026.

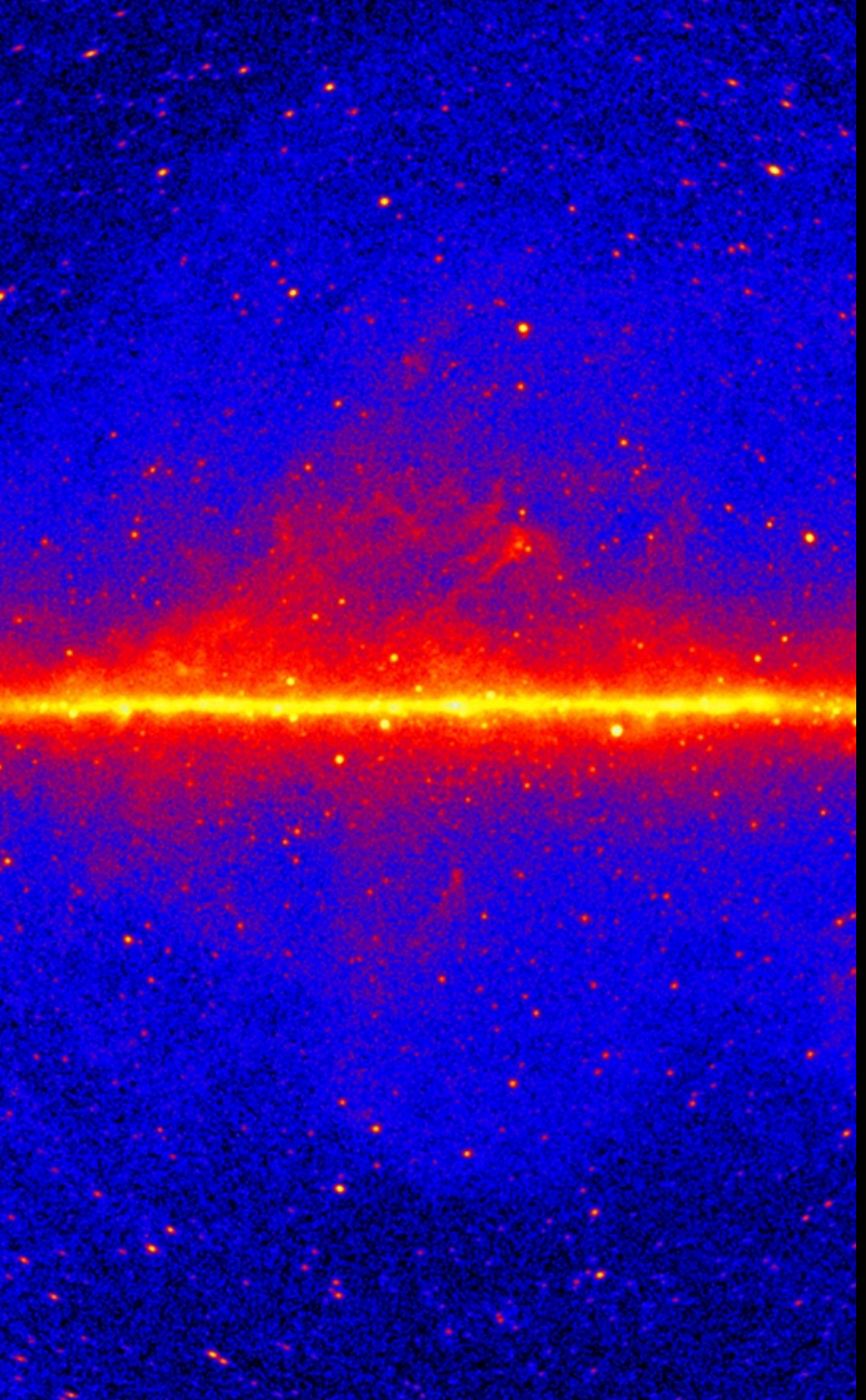
   Comments: 22 pages, 9 figures

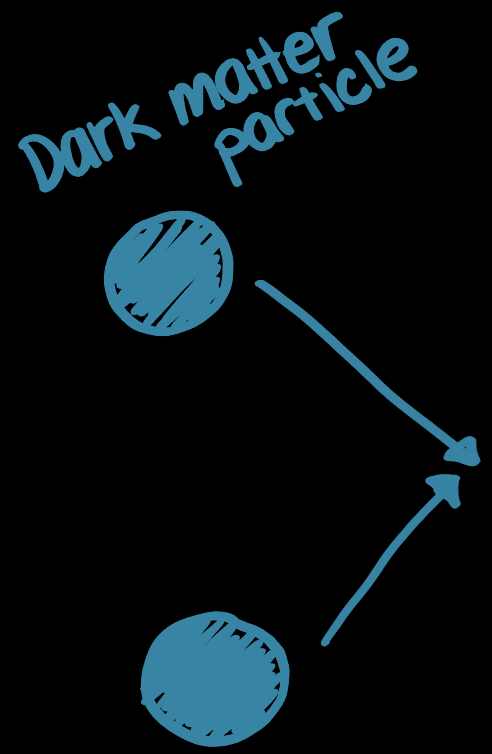
6. arXiv:2601.07670 [pdf, ps, other] astro-ph.CO gr-qc hep-ph

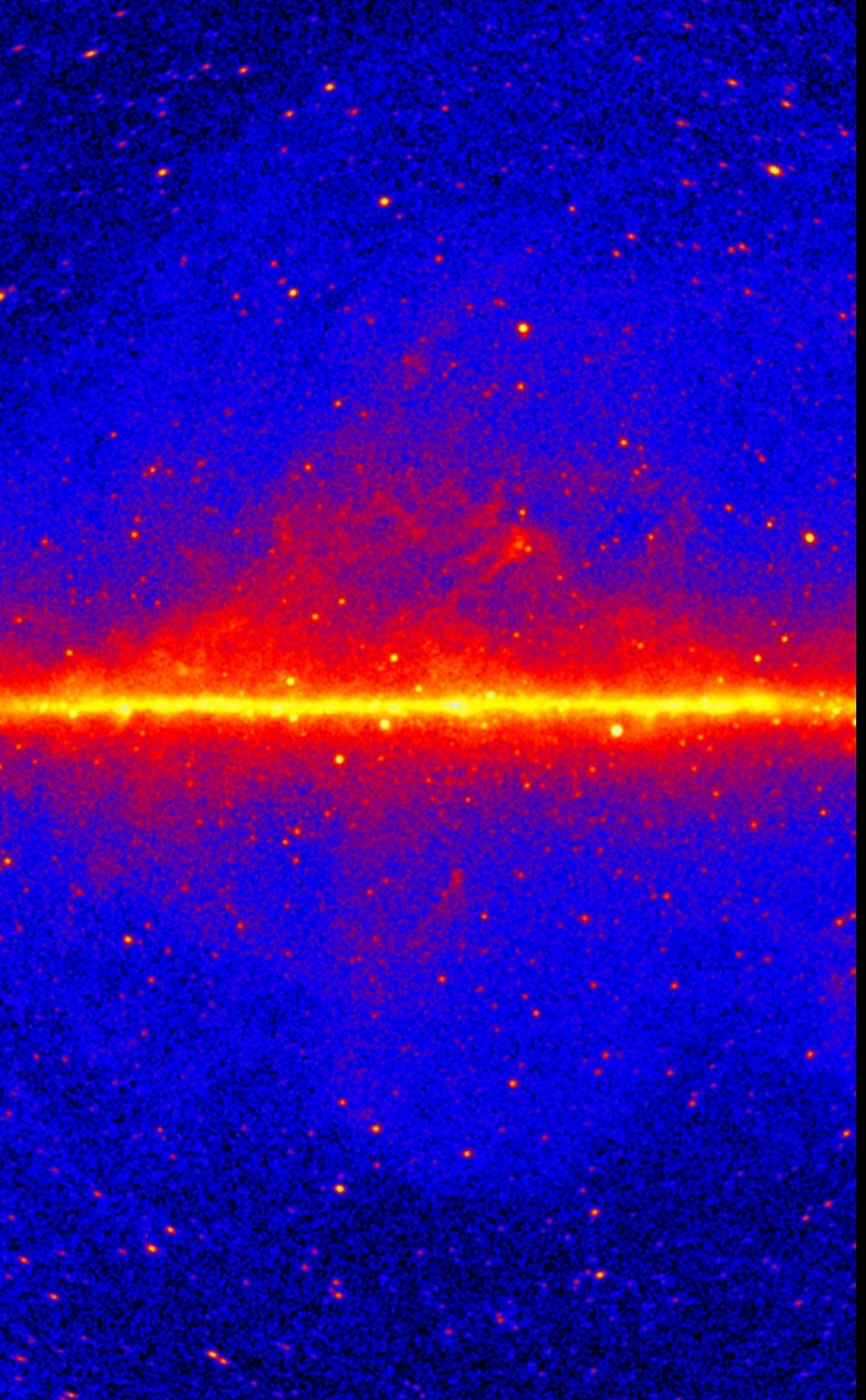
   Tachyonic gravitational dark matter production after inflation

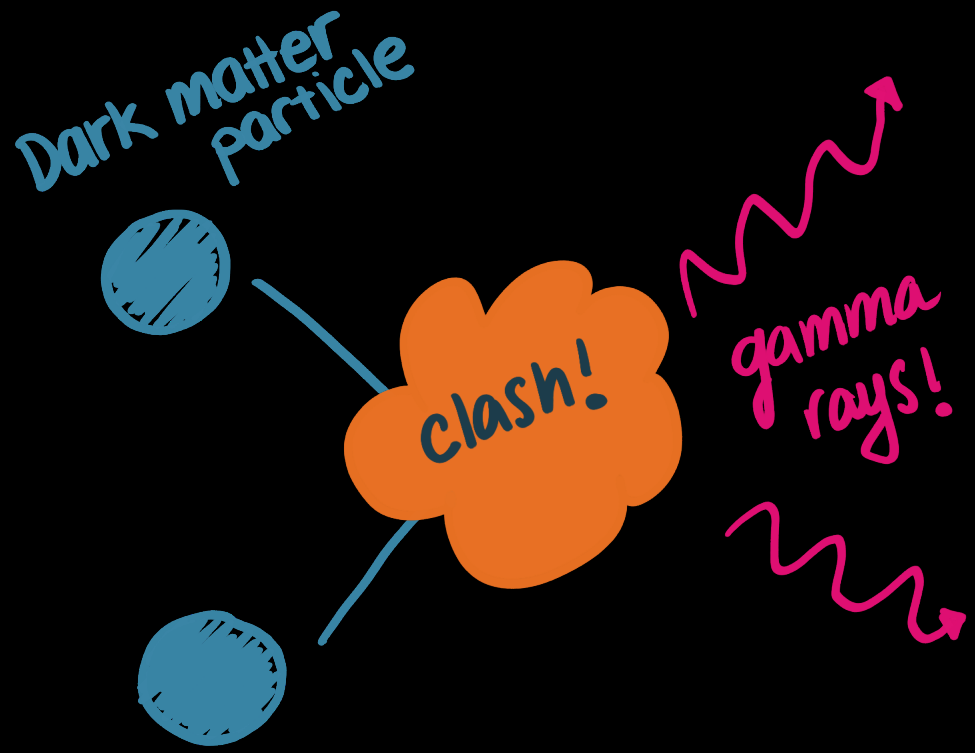


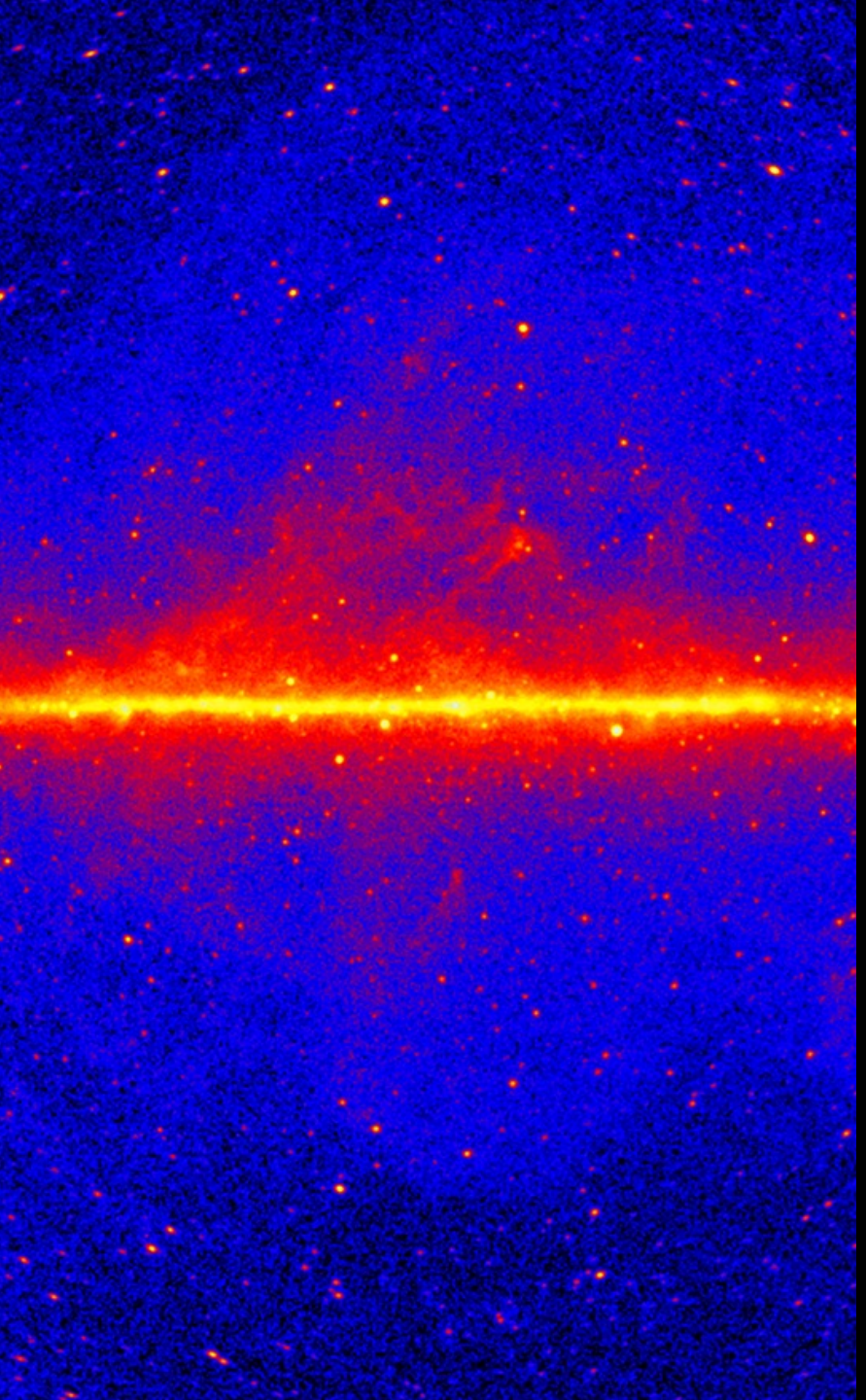
Dark matter particle

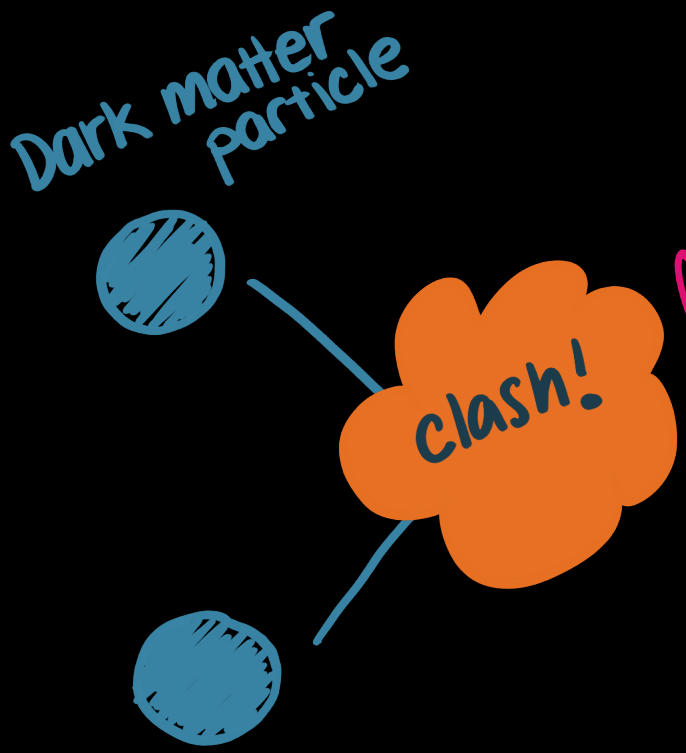



Dark matter particle




Dark matter particle
clash!
gamma rays!

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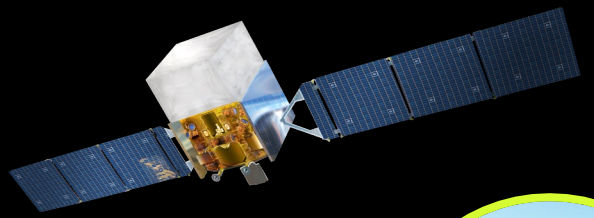

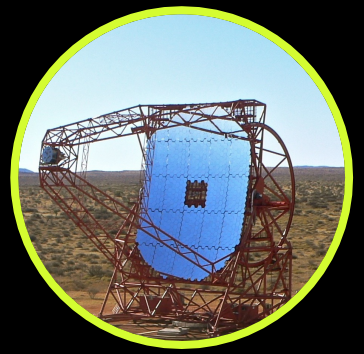

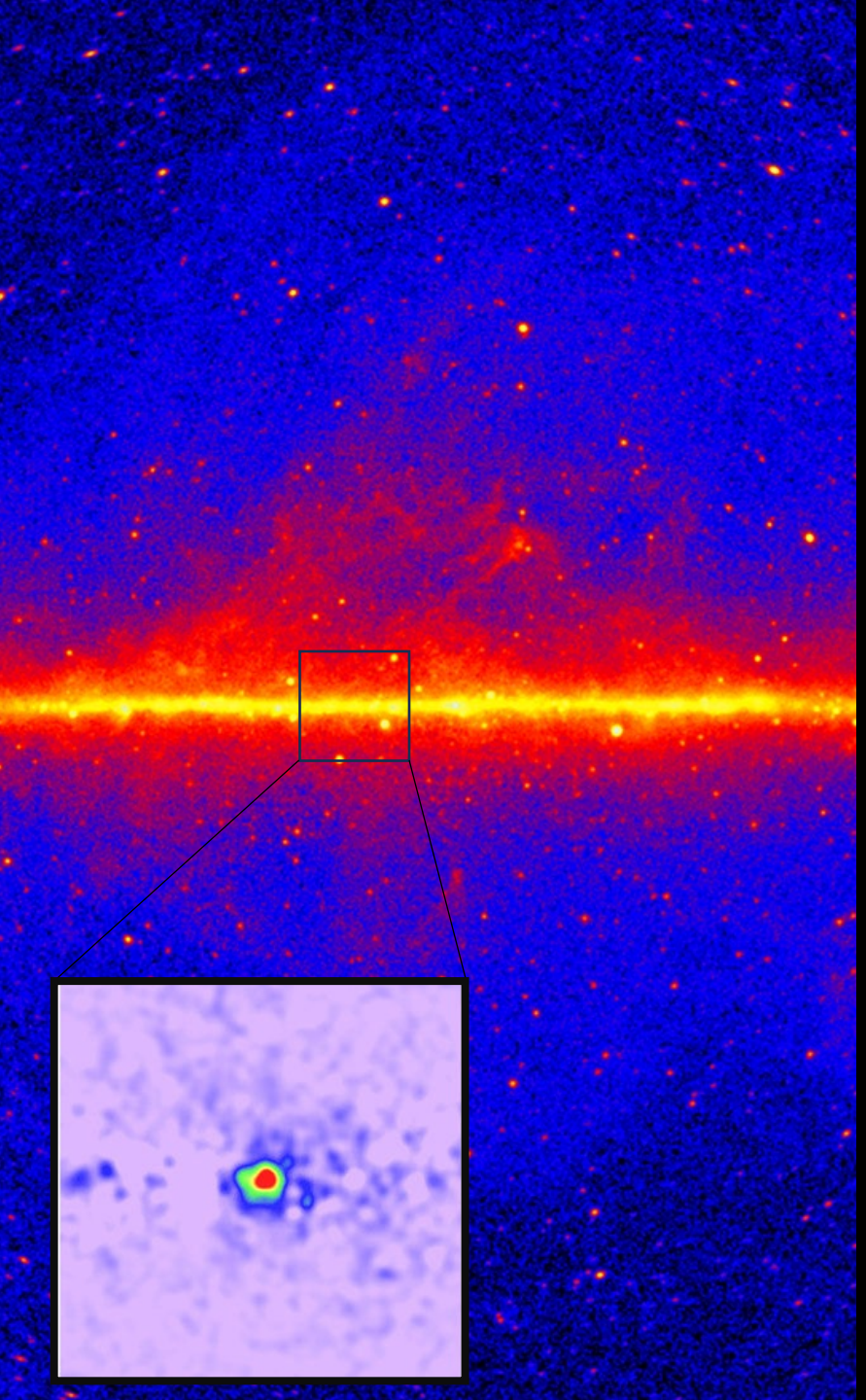

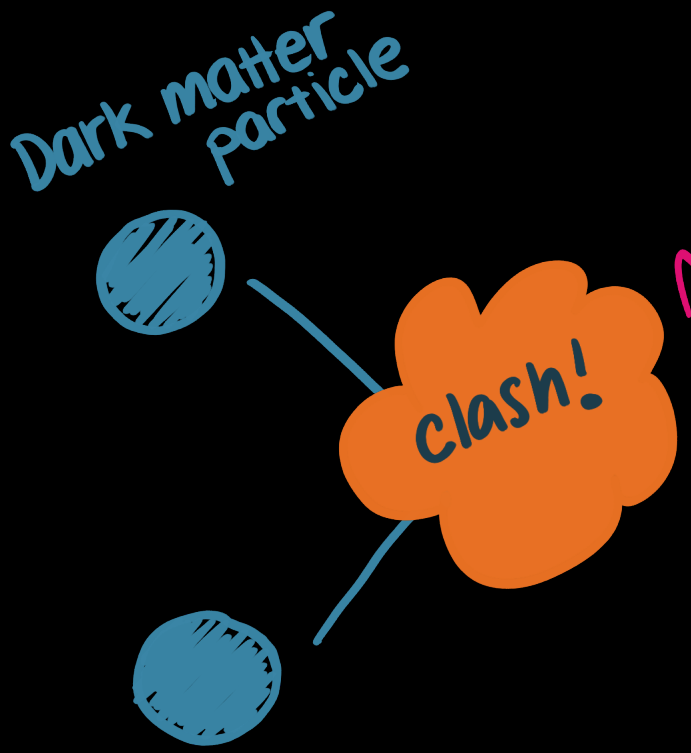
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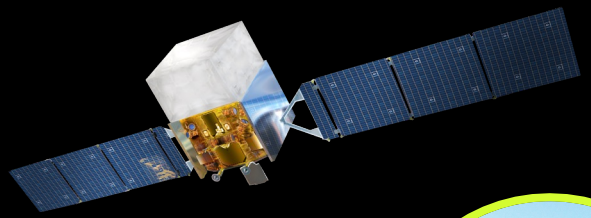

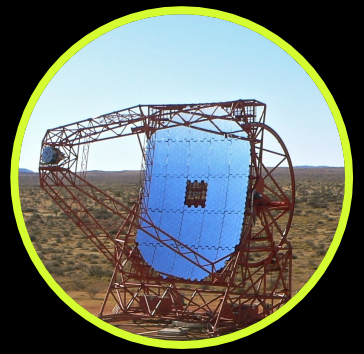

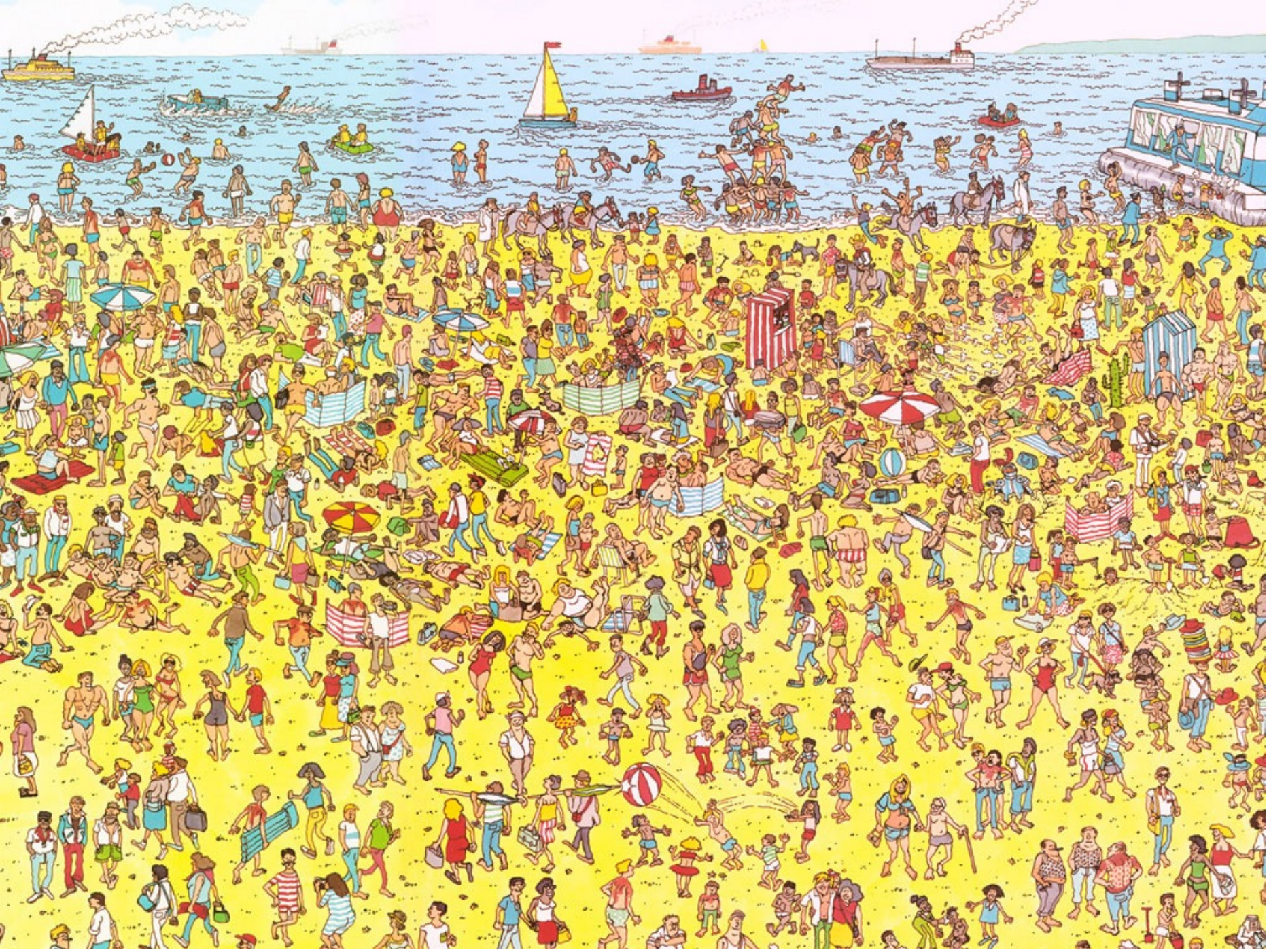

Caveats

…We don't know what Waldo **looks like**.

…Instead of **a beach**, we search **the whole Universe**.

…Waldo is **invisible** to our eyes (even with the fanciest visual aids).

milena.crnogorcevic@fysik.su.se

ALL THE DARK WE CANNOT SEE