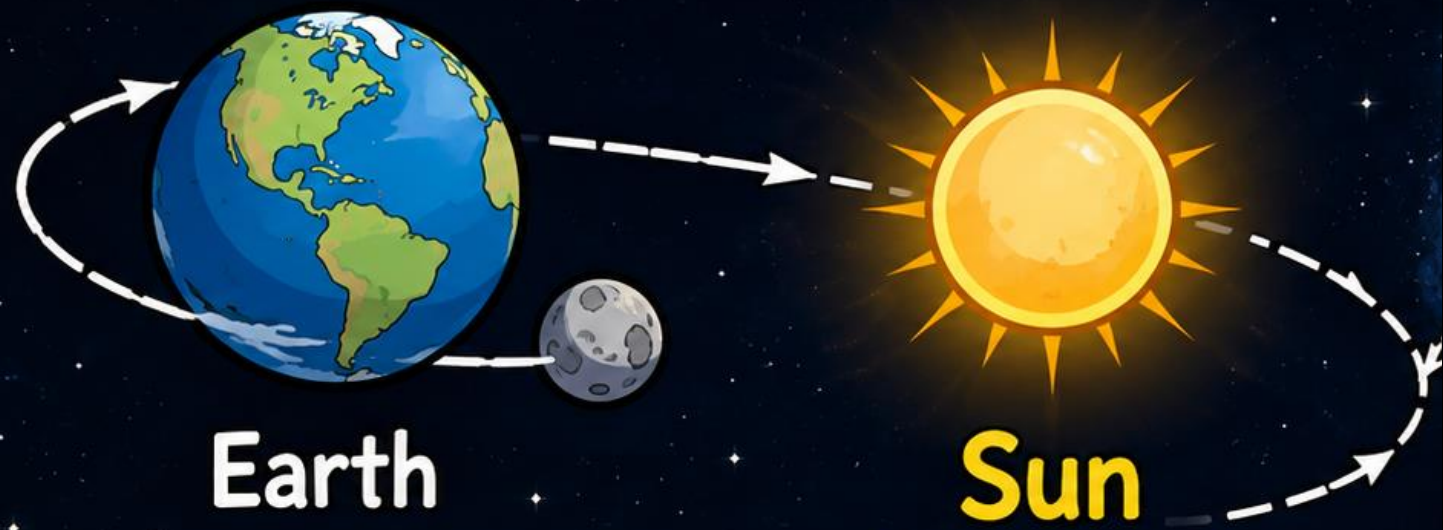


Dark Energy Bubble as Dynamical Dark Energy

Batia Friedman-Shaw

Matthew Johnson, Katherine Mack





Earth

Sun

8 Minutes



Earth



Sun

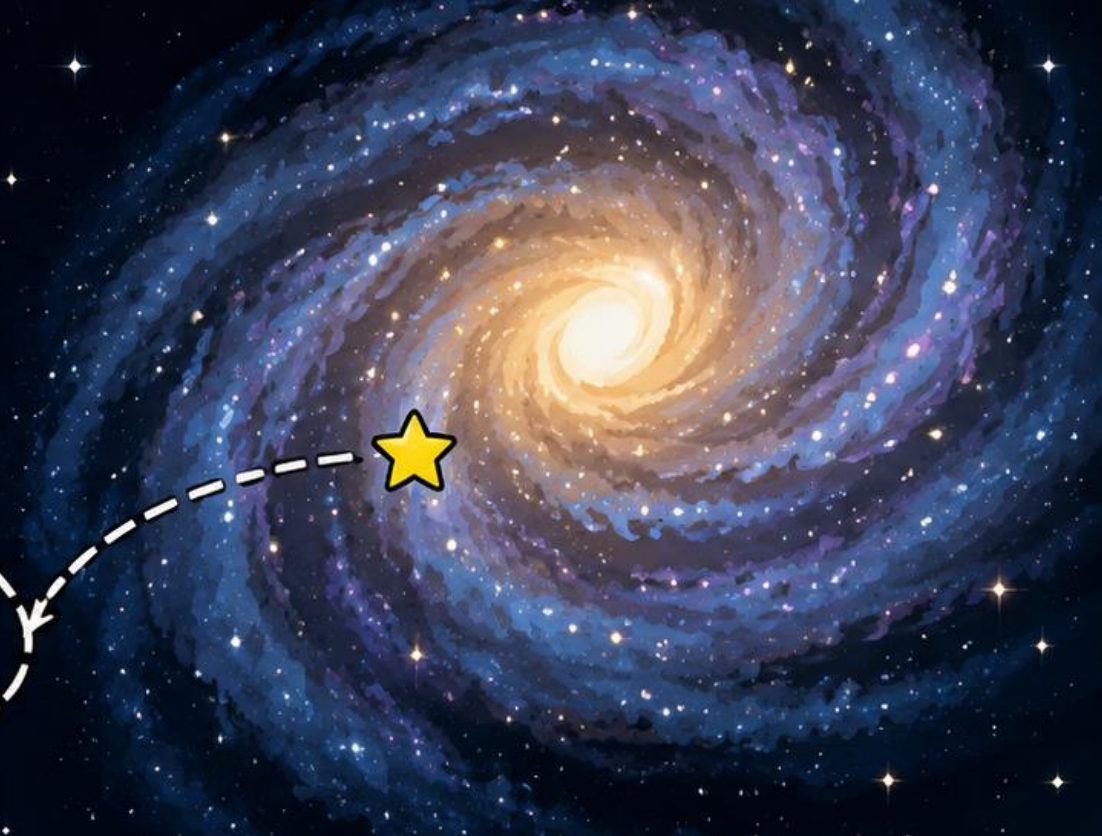
8 Minutes



Earth



Sun



Milky Way

8 Minutes

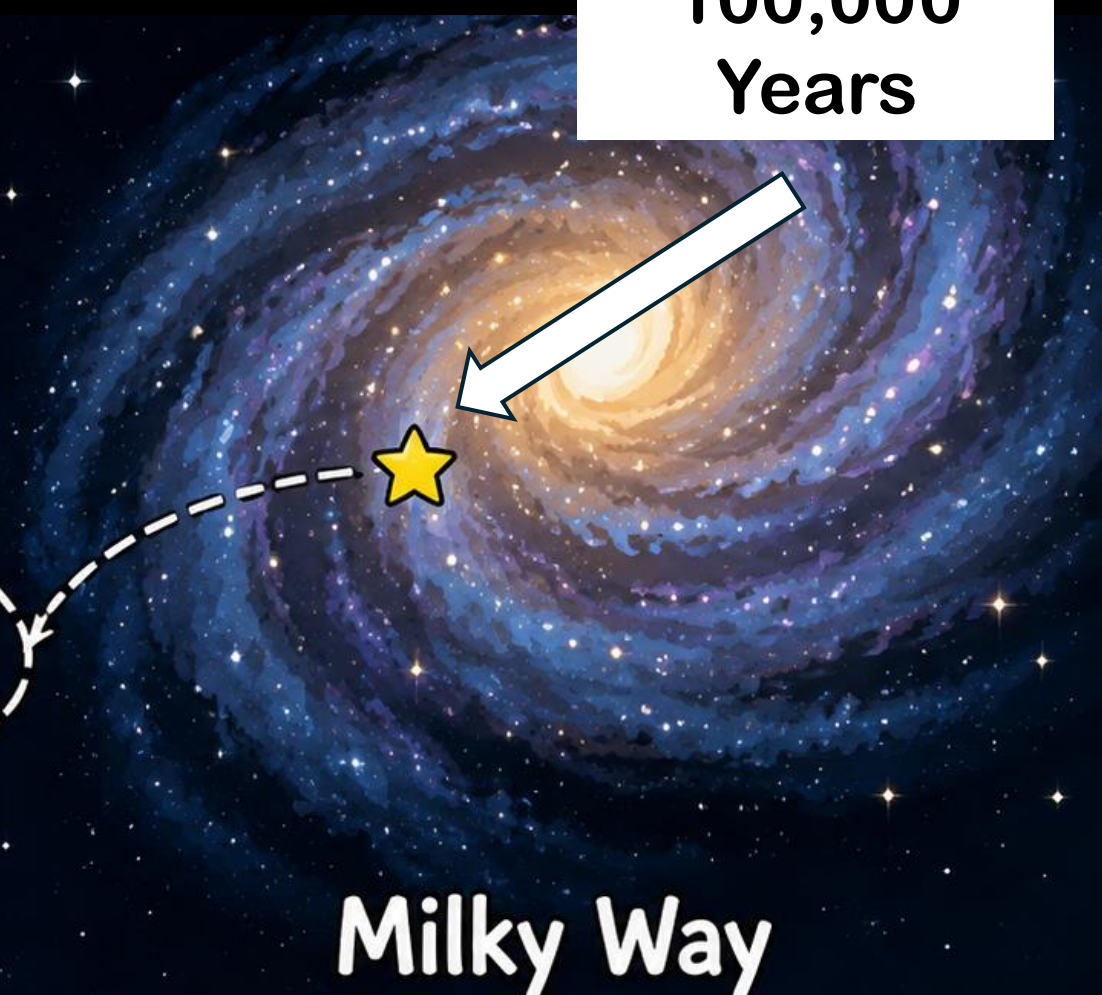
100,000
Years



Earth



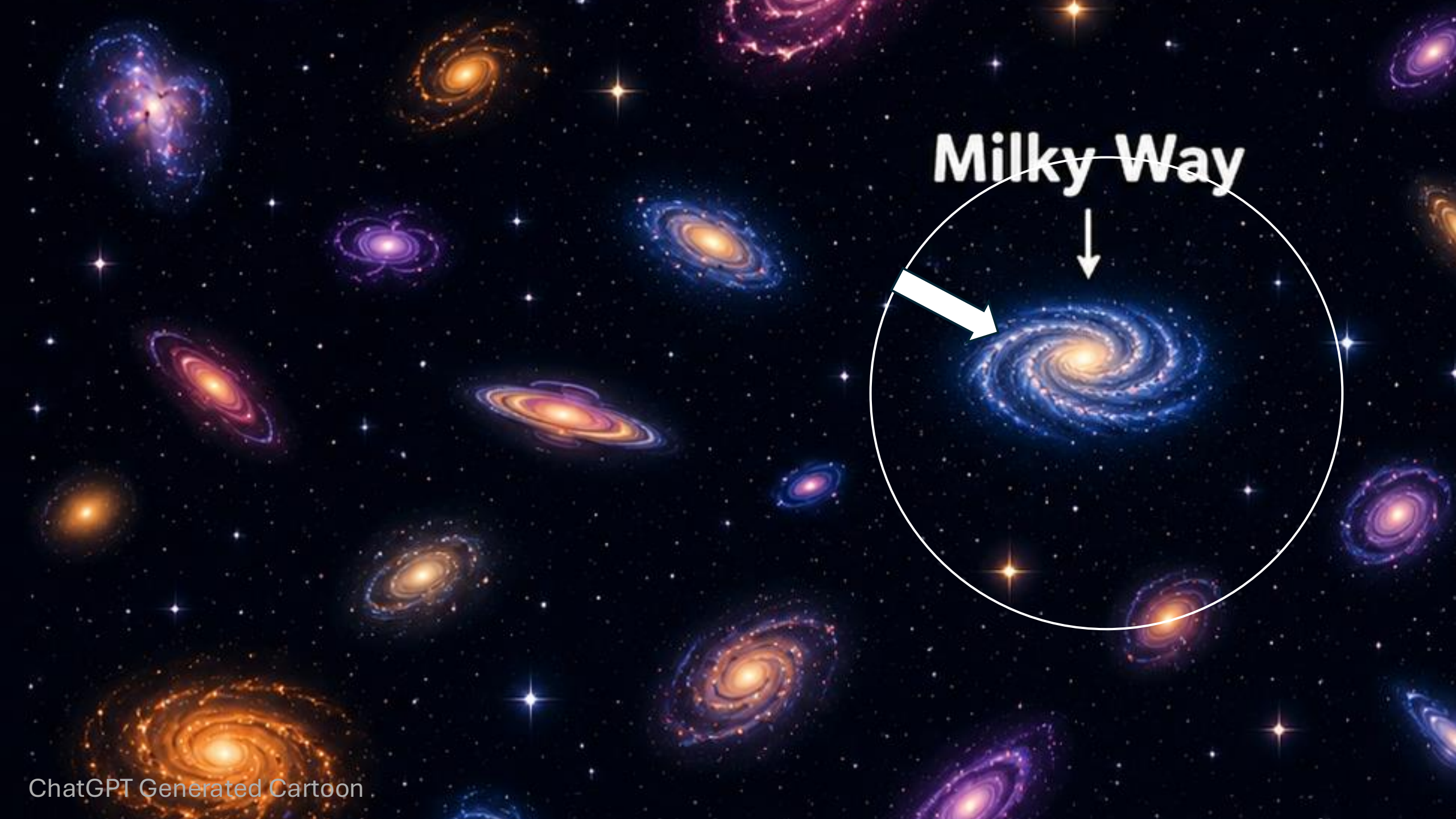
Sun



Milky Way

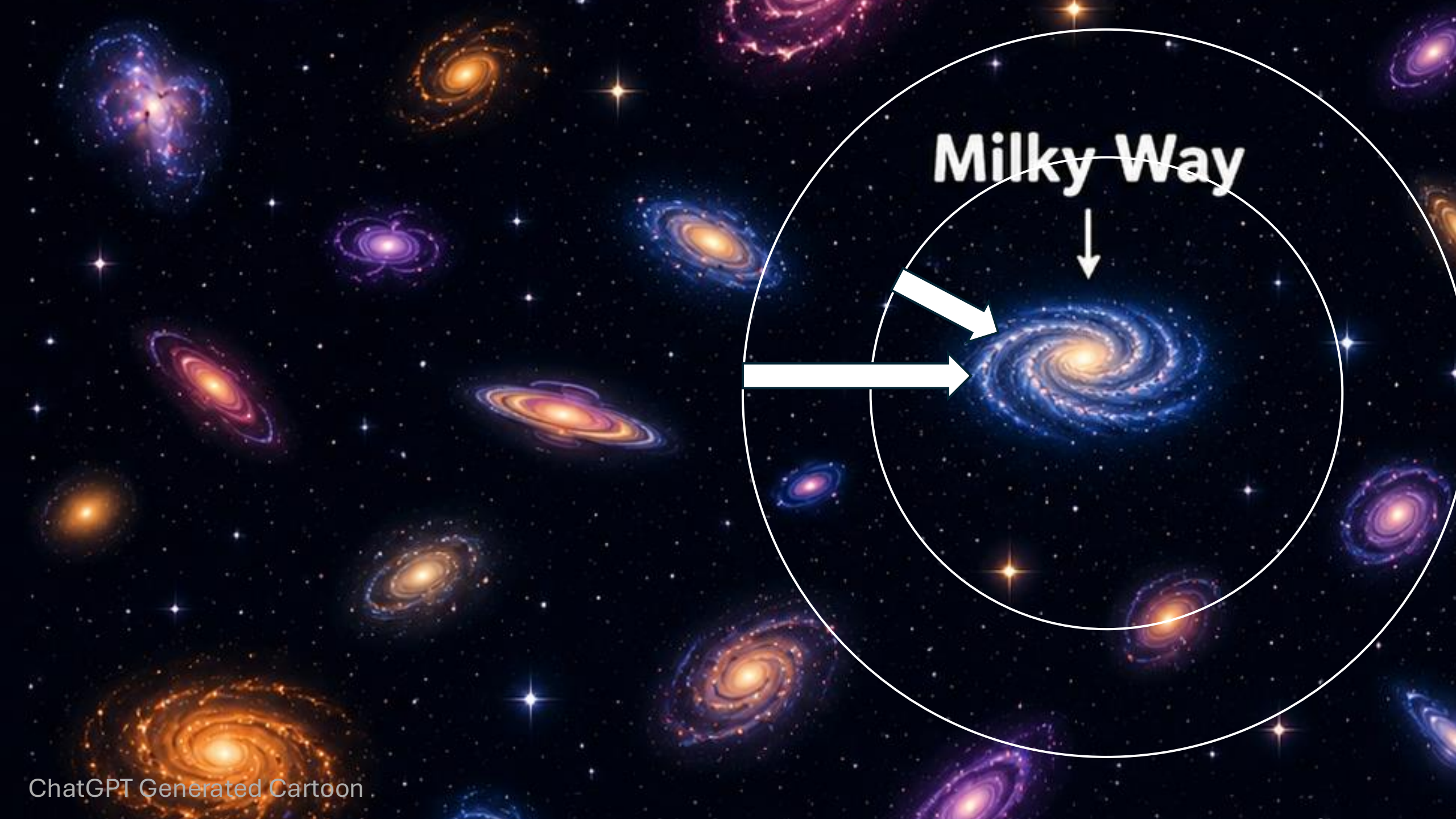
Milky Way



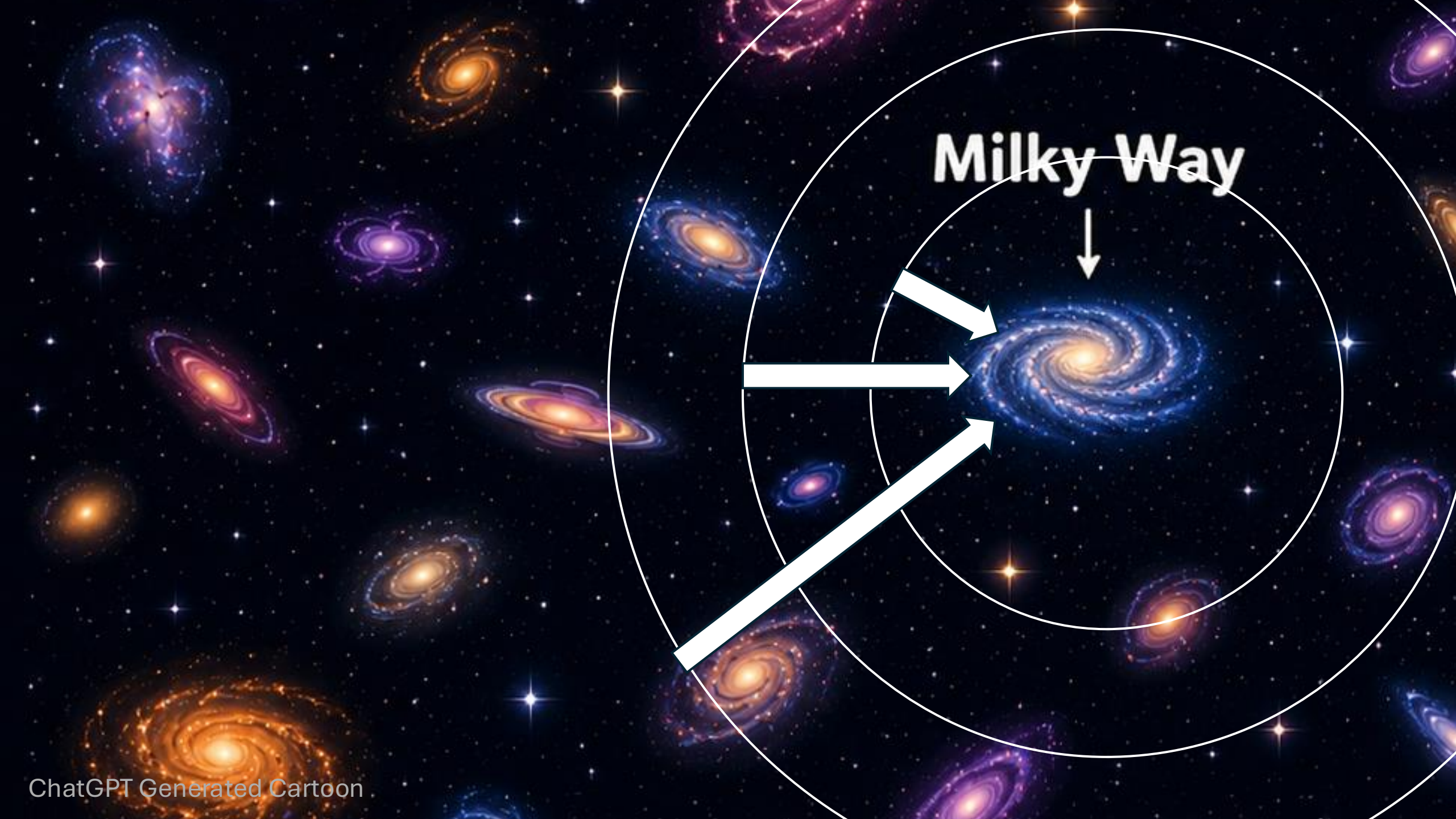


Milky Way





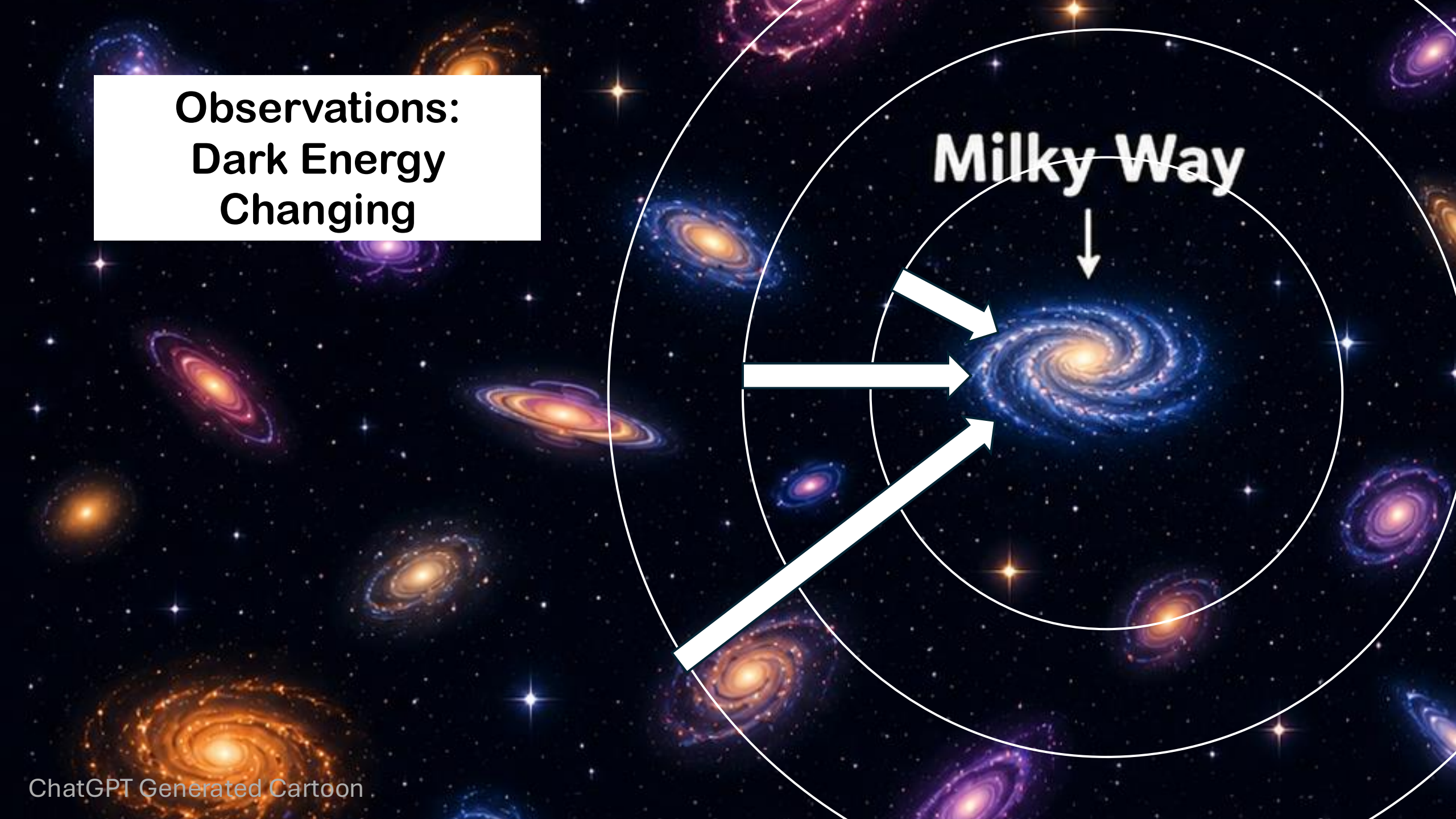
Milky Way



Milky Way

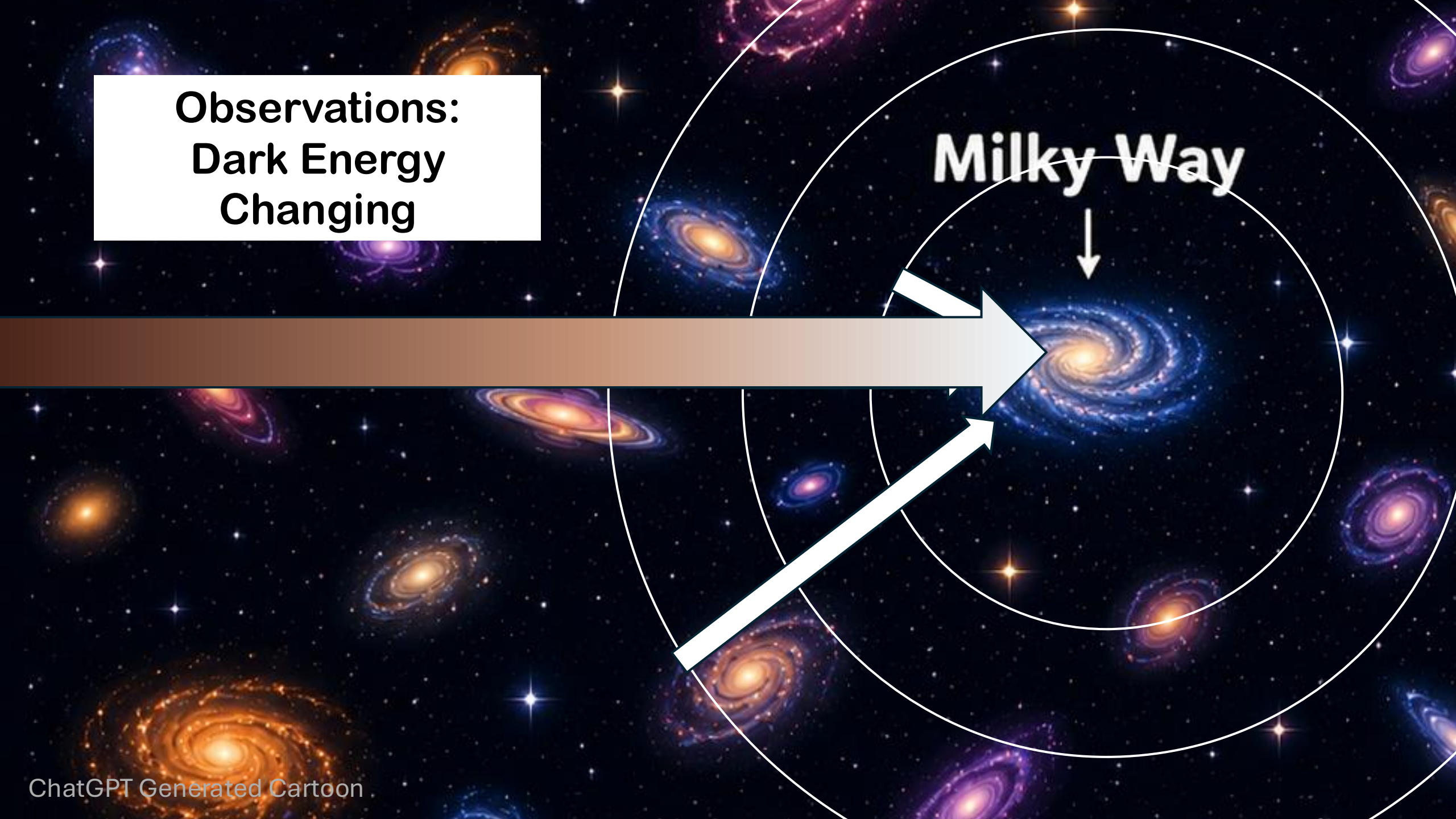
**Observations:
Dark Energy
Changing**

Milky Way



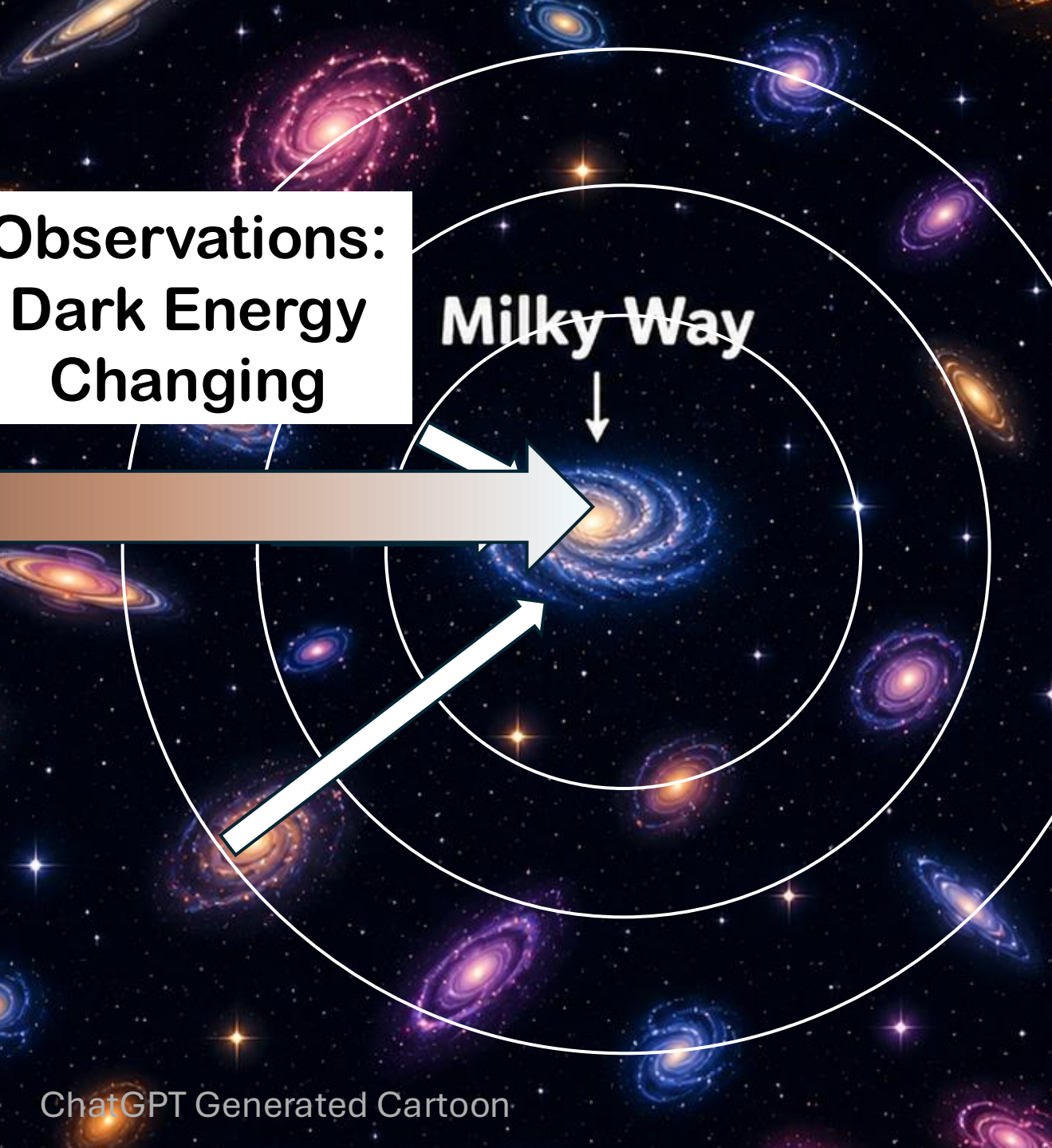
**Observations:
Dark Energy
Changing**

Milky Way



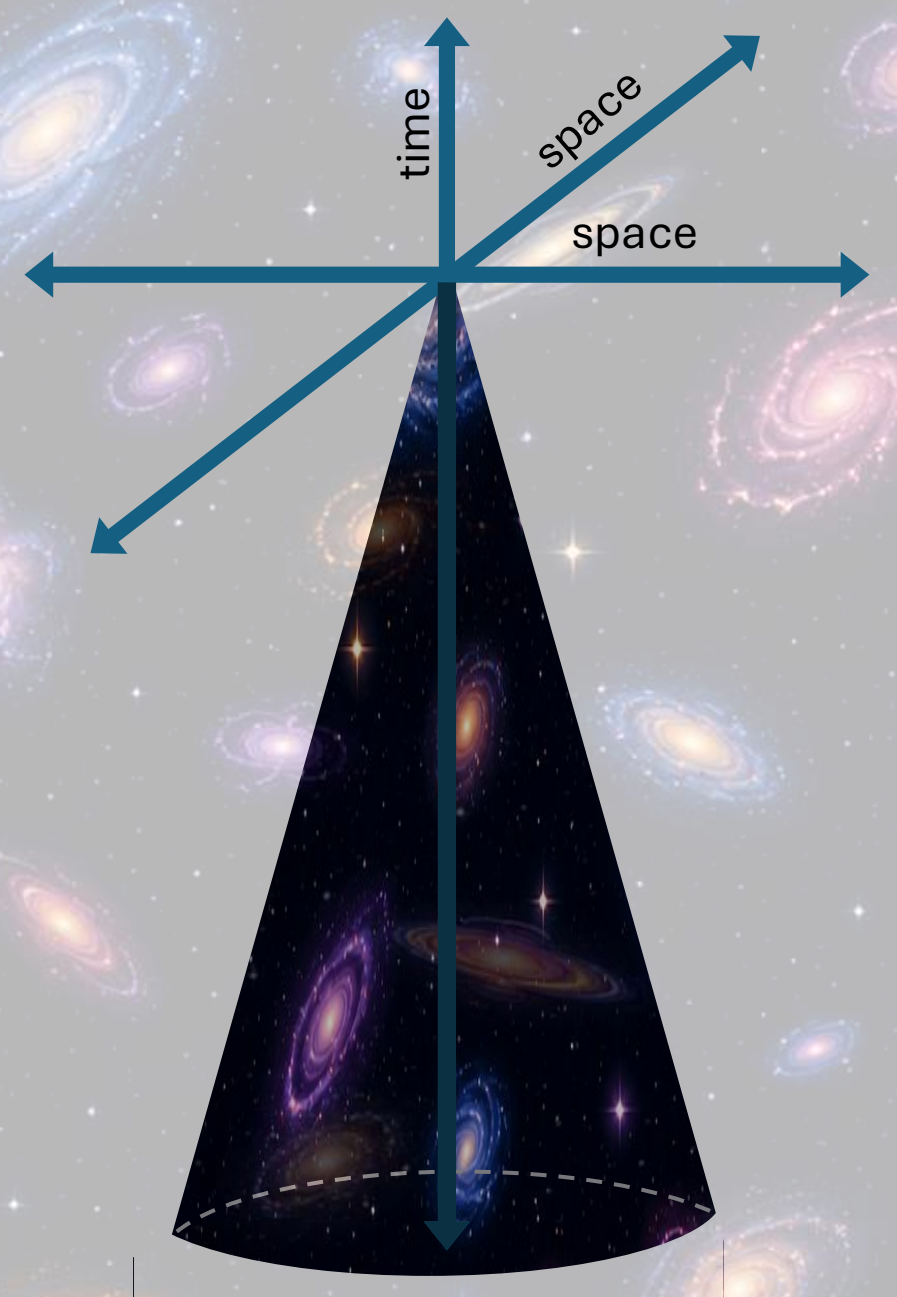
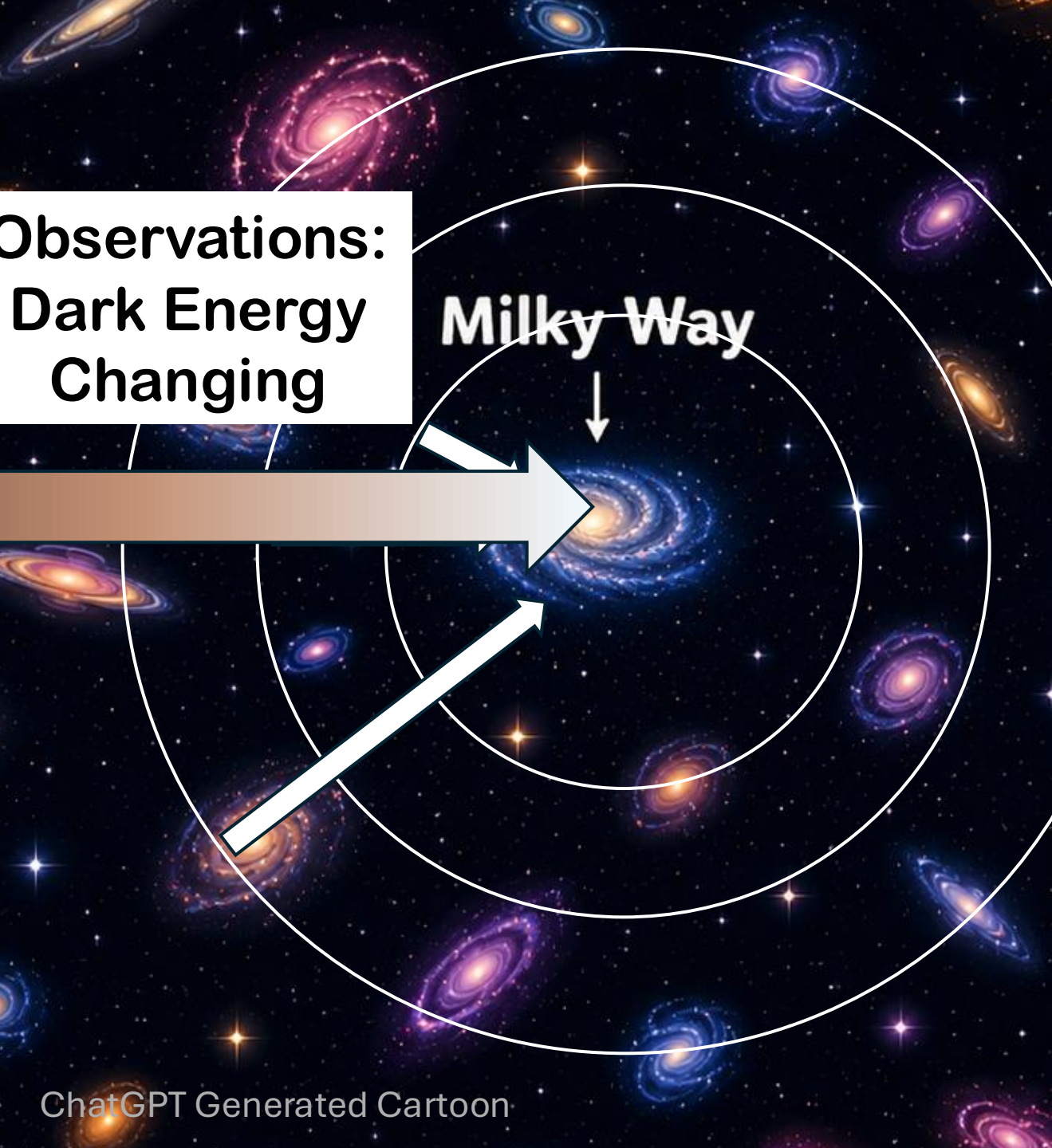
**Observations:
Dark Energy
Changing**

Milky Way



Observations:
Dark Energy
Changing

Milky Way

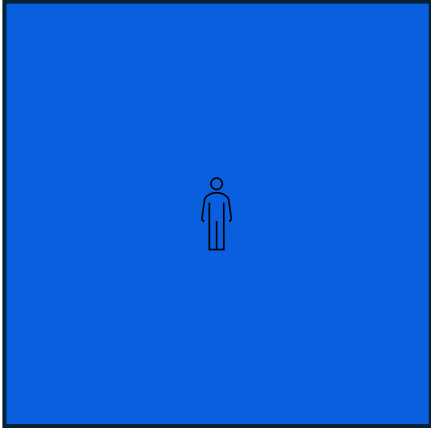


Time
Varying



Time

Time
Varying

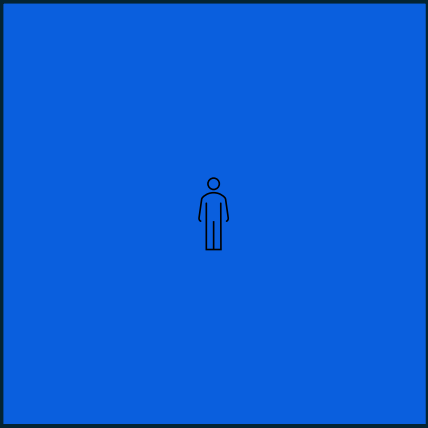


t_1

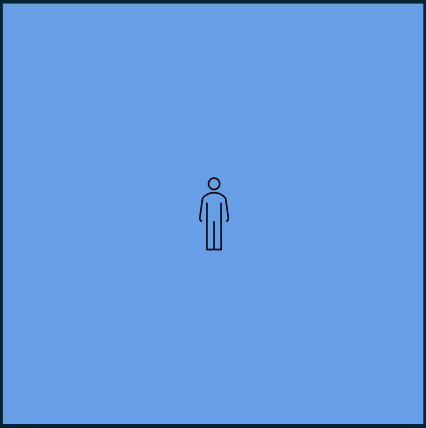
Time



Time
Varying



t_1

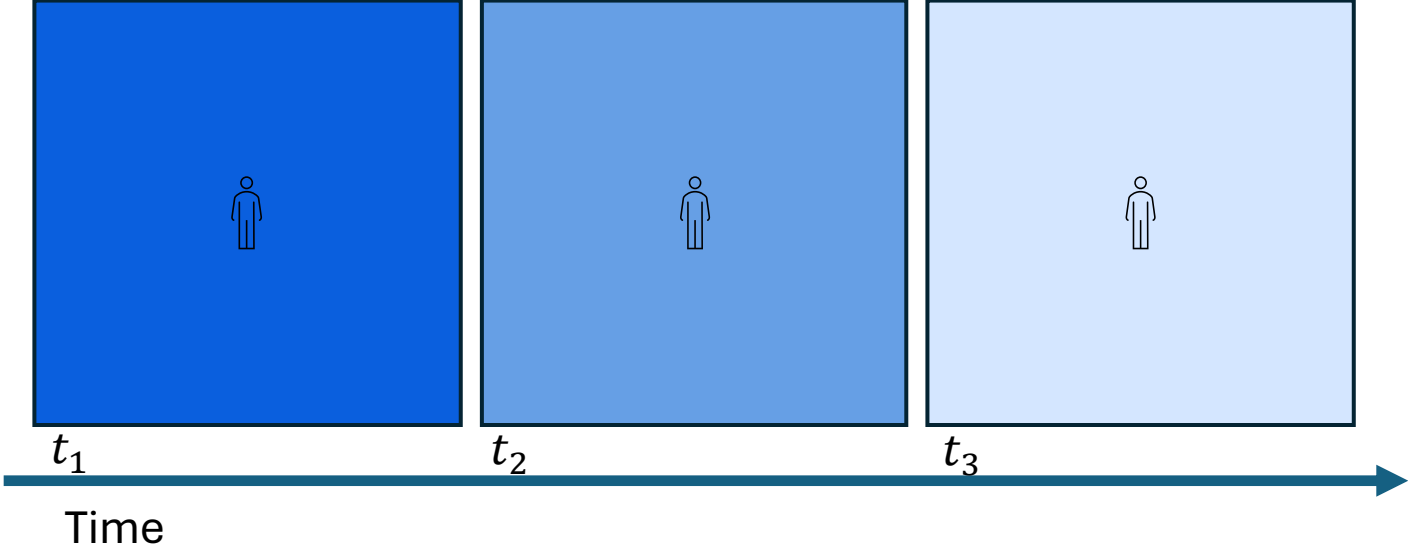


t_2

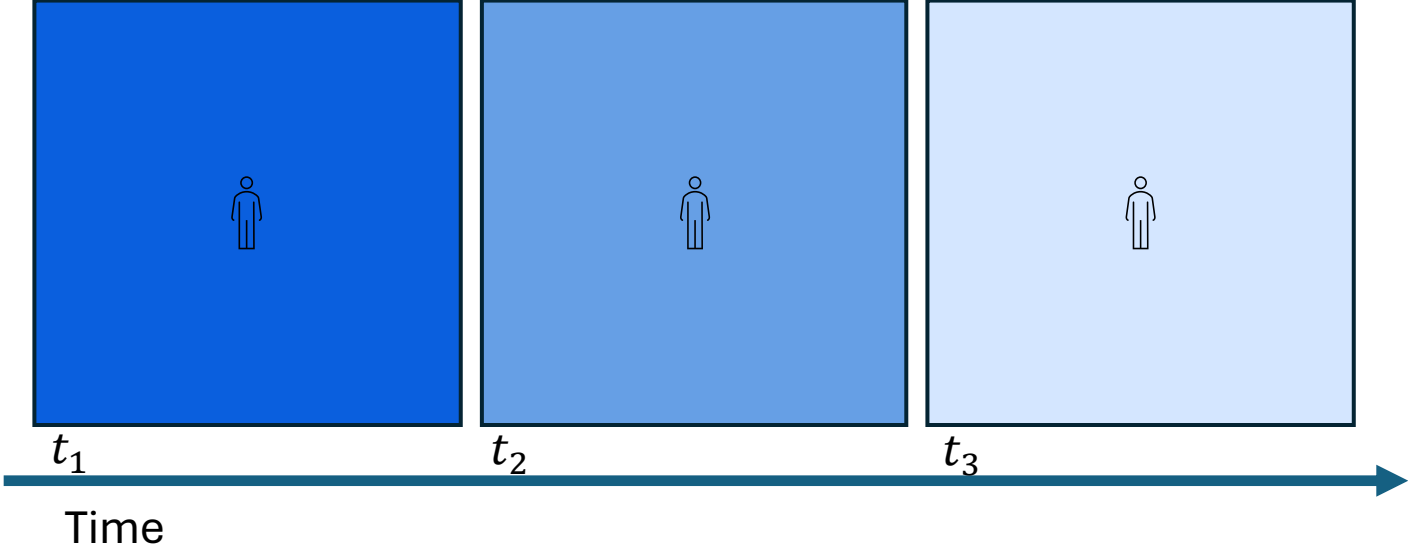
Time



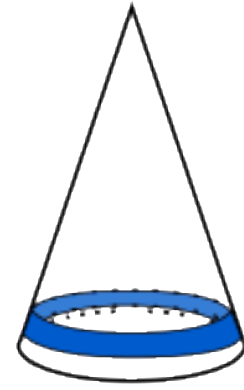
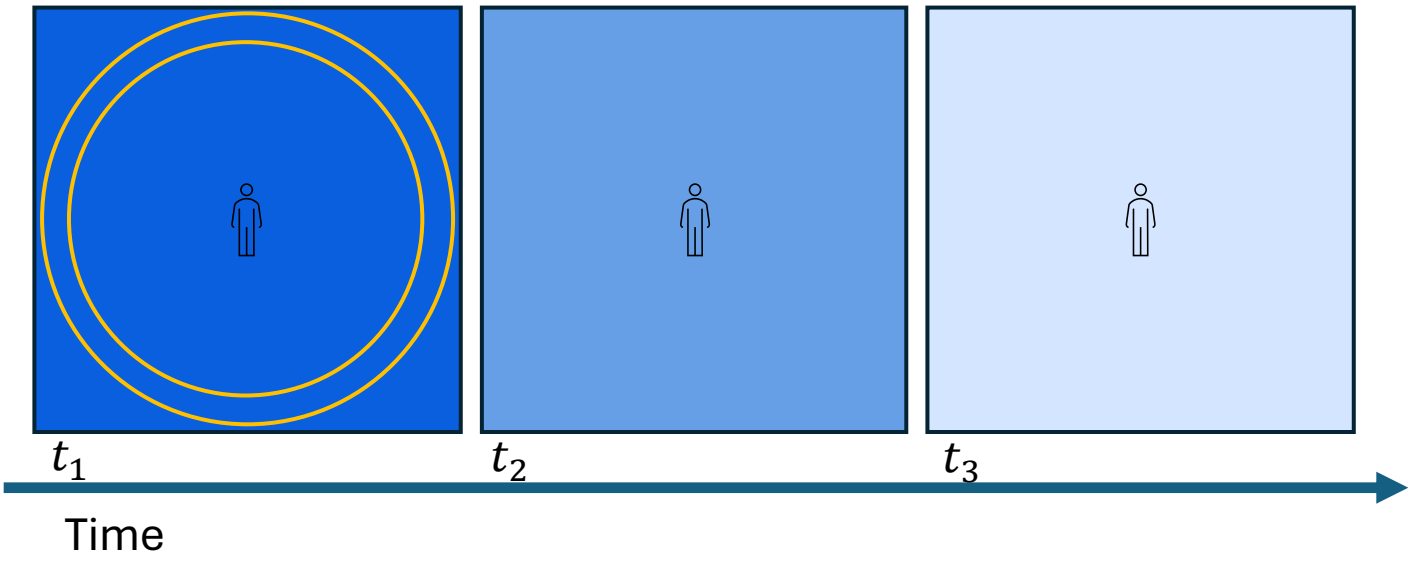
Time
Varying



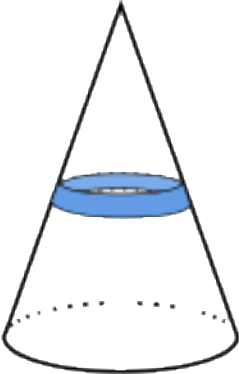
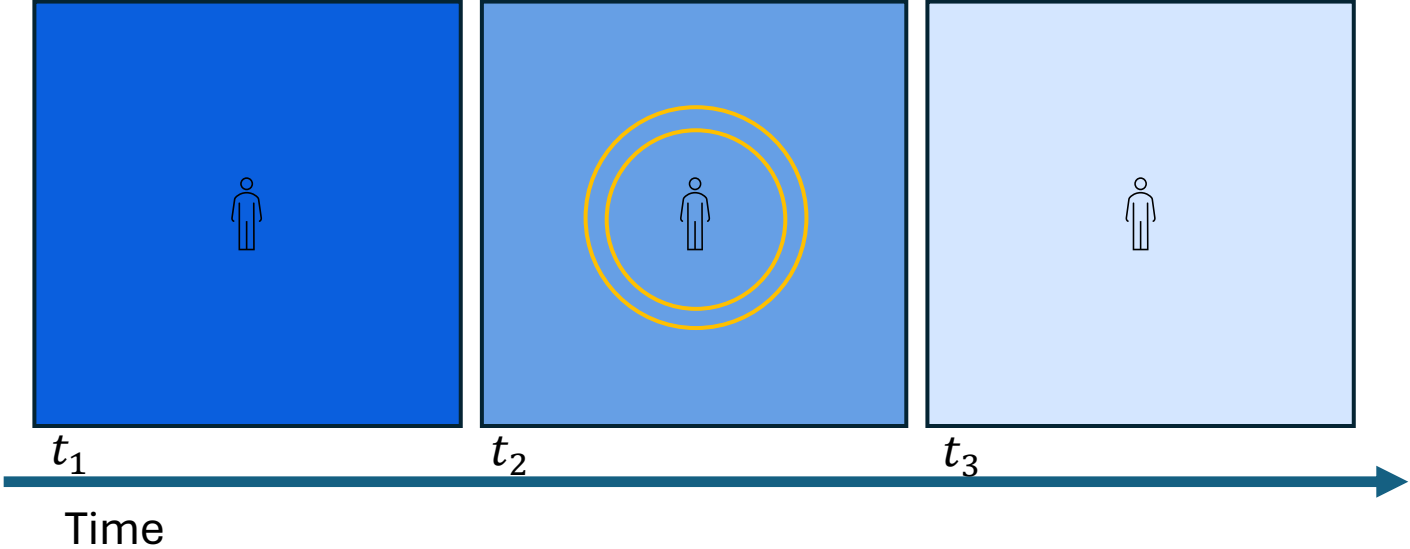
Time
Varying



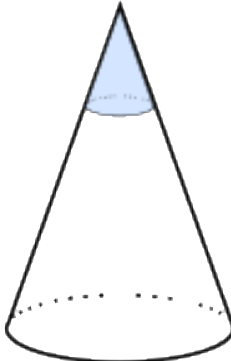
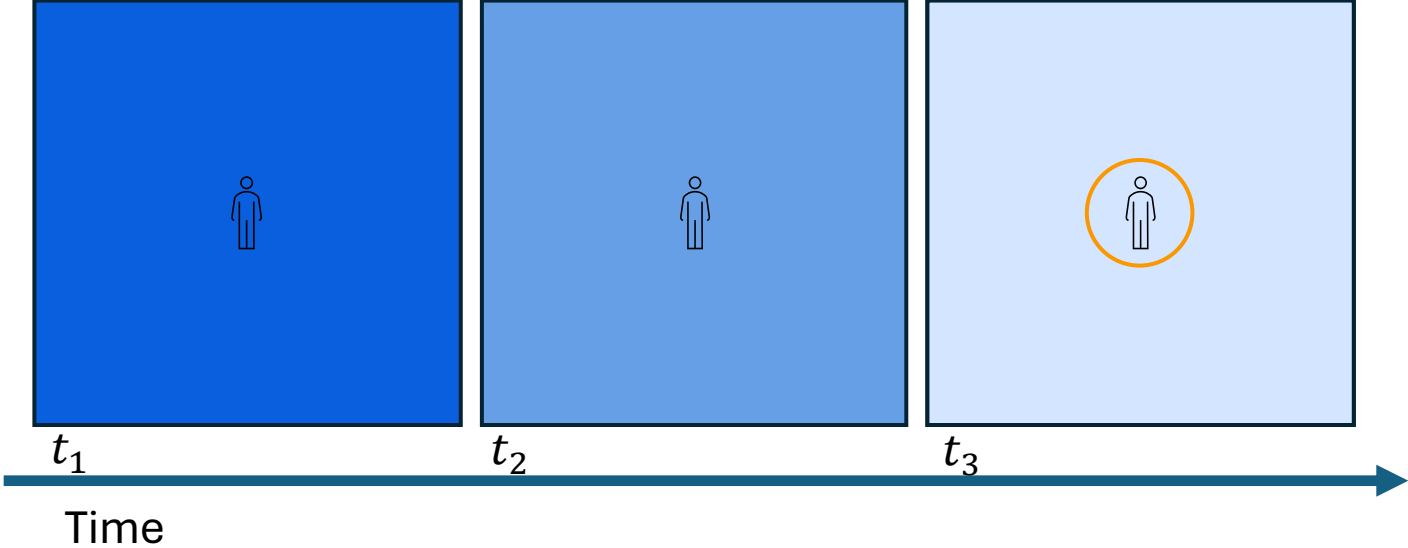
Time
Varying



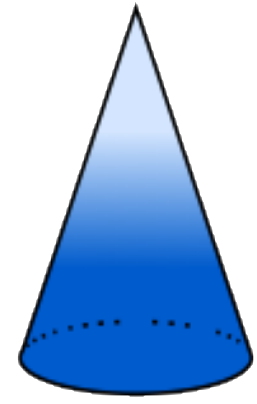
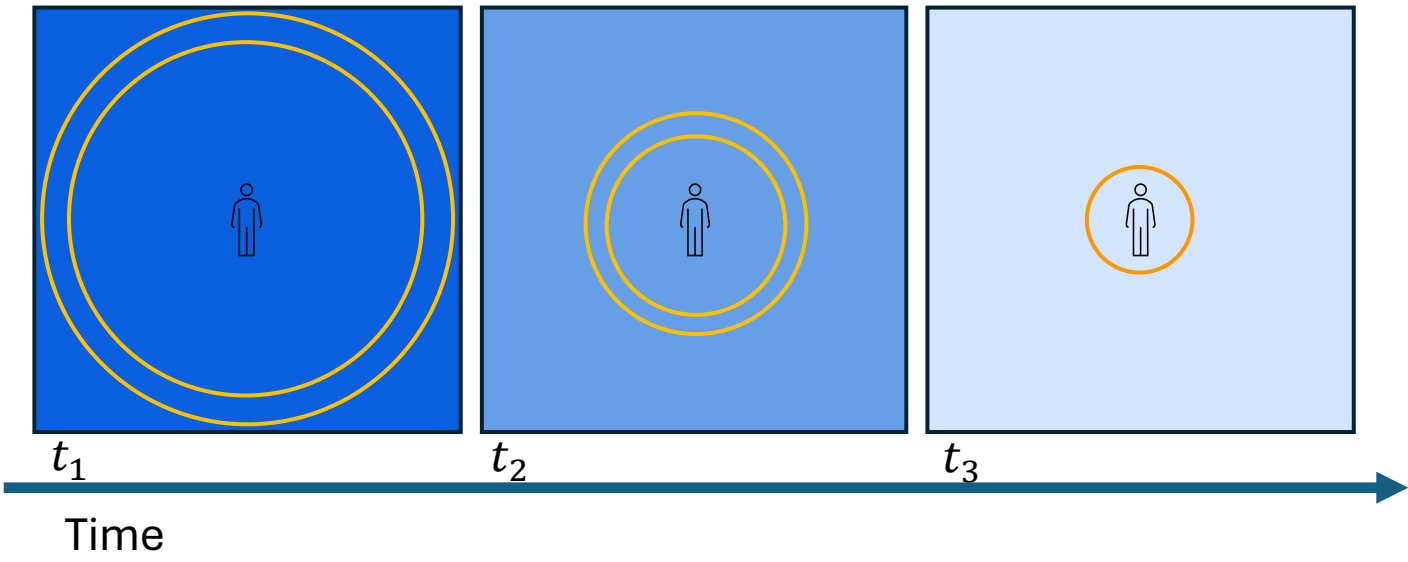
Time
Varying



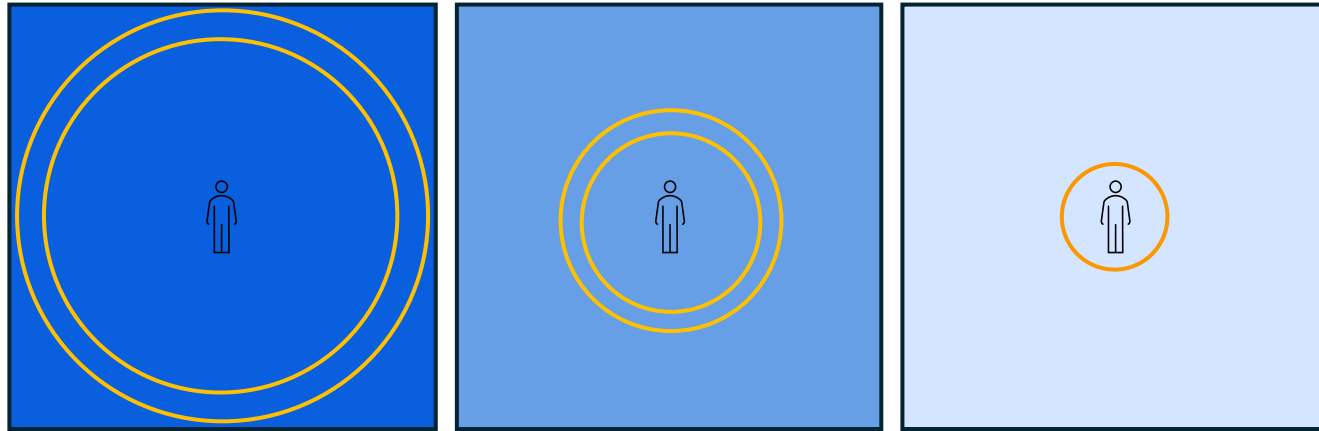
Time
Varying



Time
Varying



Time
Varying



t_1

t_2

t_3

Time

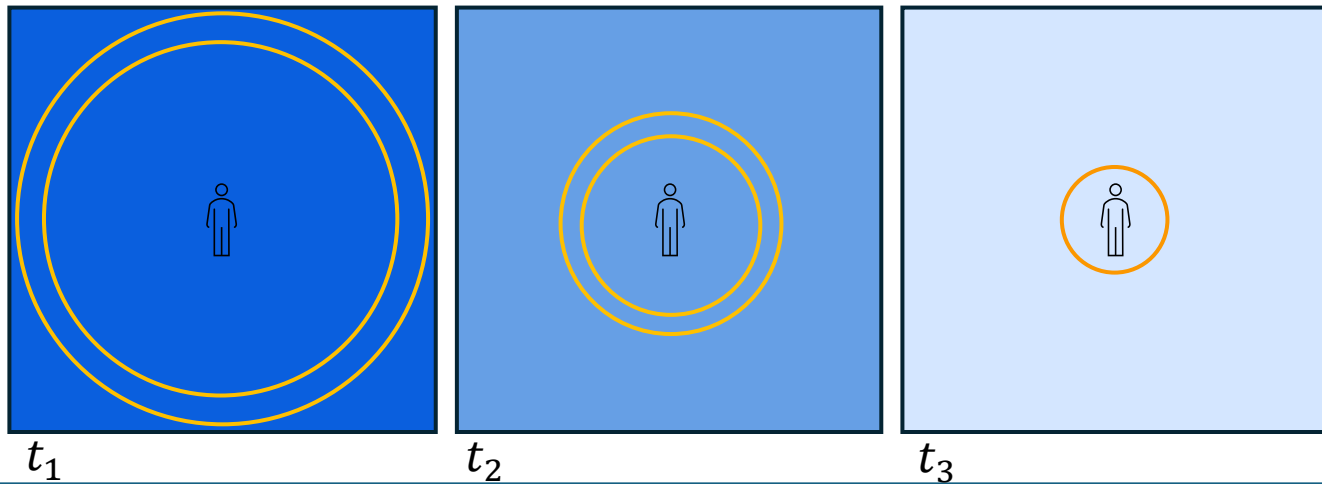


Space
Varying



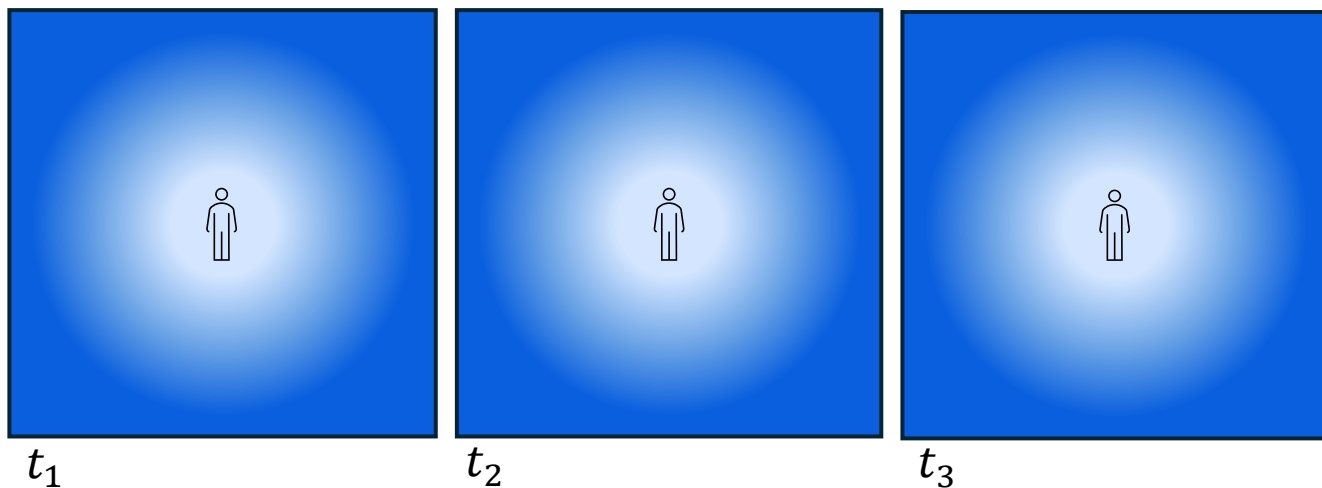
Time

Time
Varying

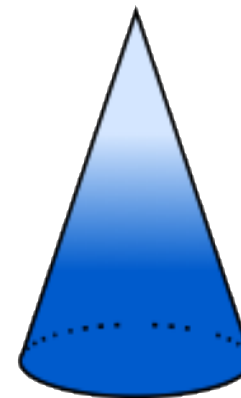


Time

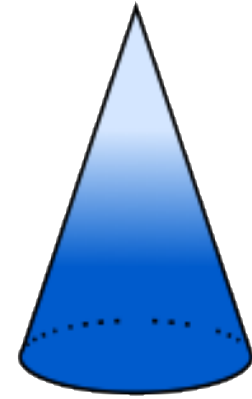
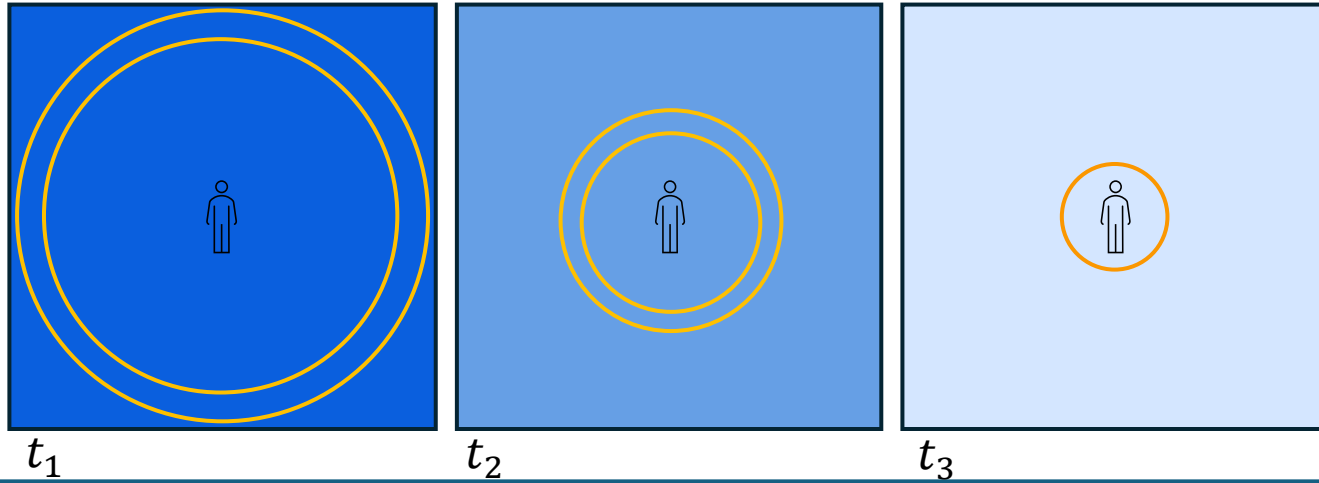
Space
Varying



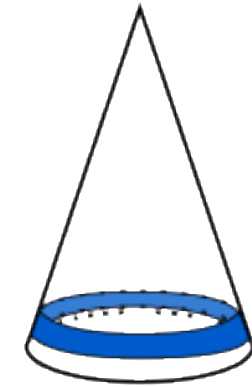
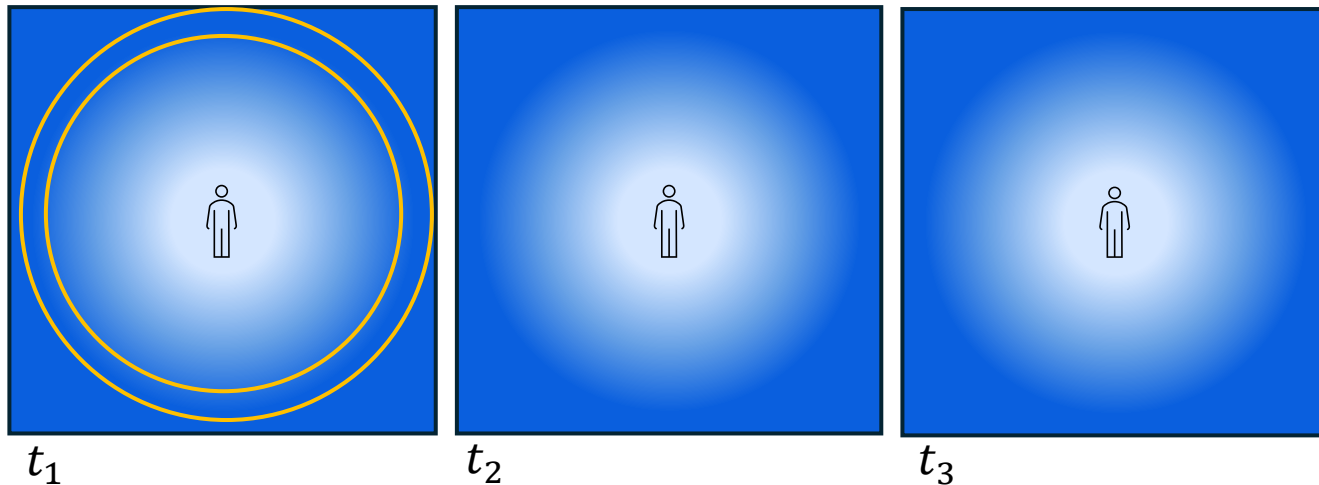
Time



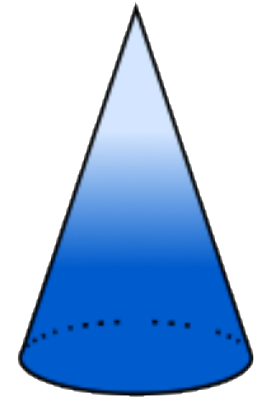
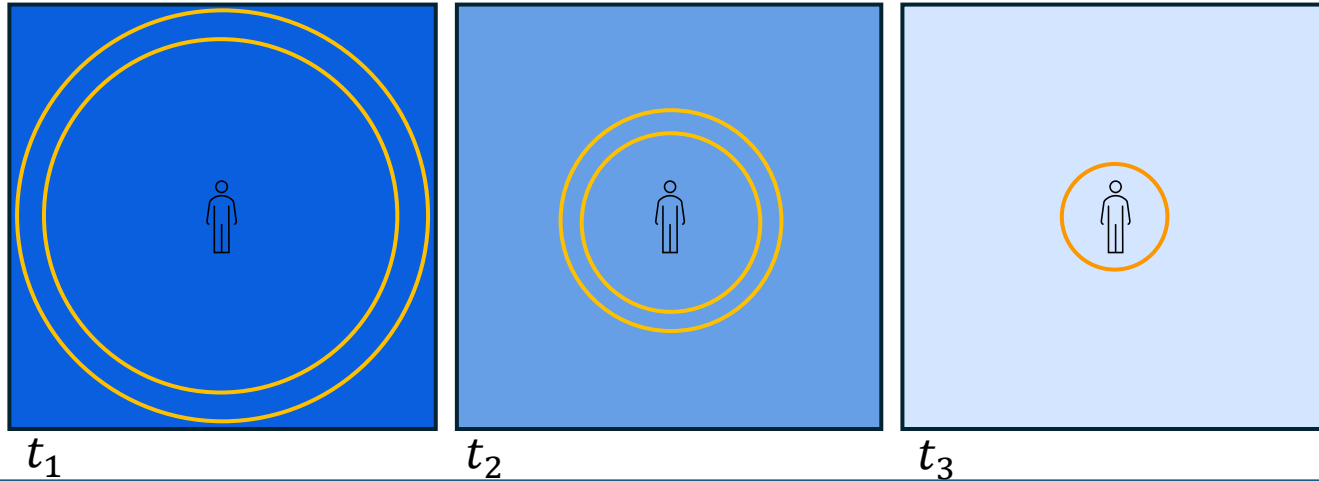
Time Varying



Space Varying

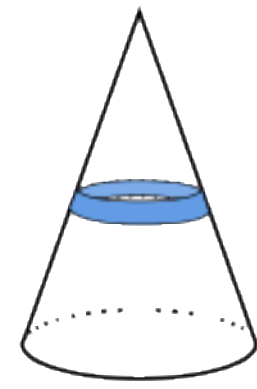
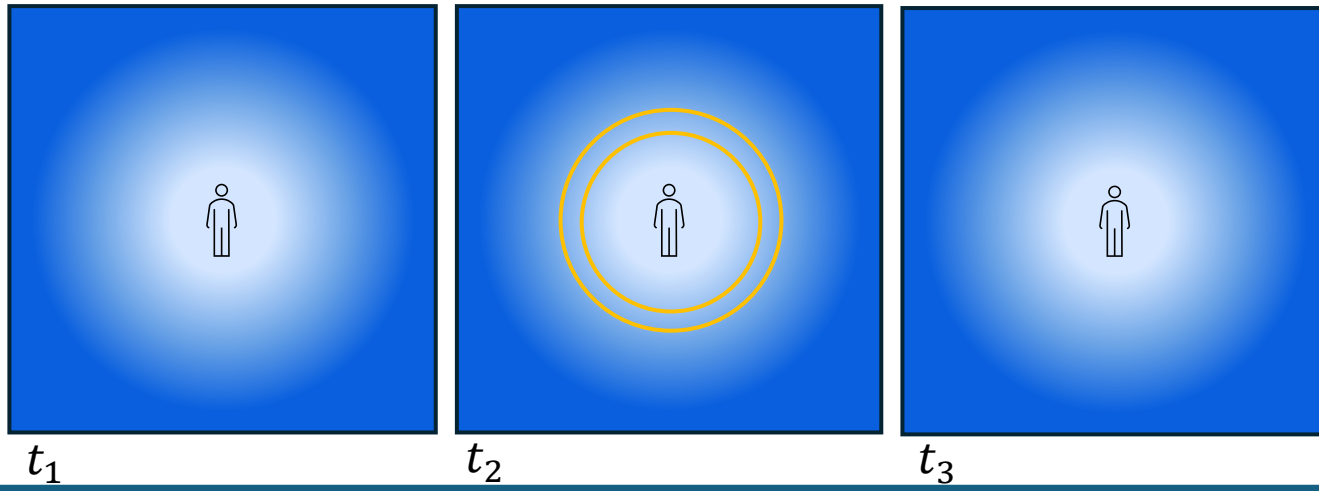


Time Varying



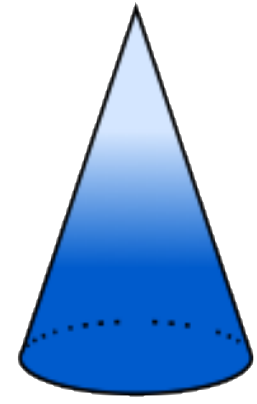
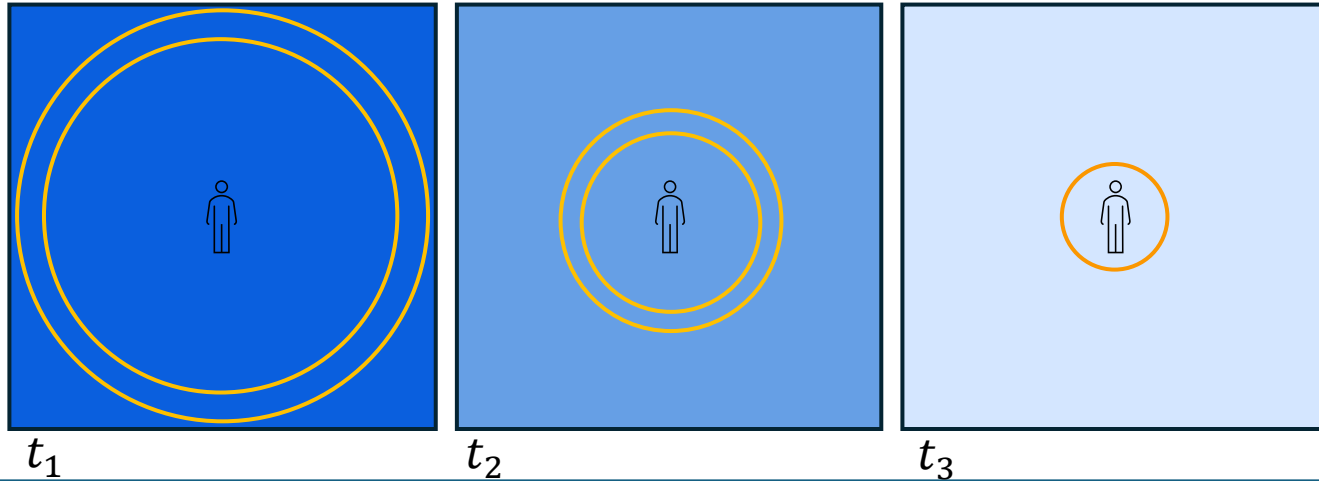
Time

Space Varying

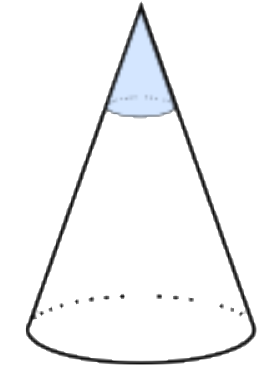
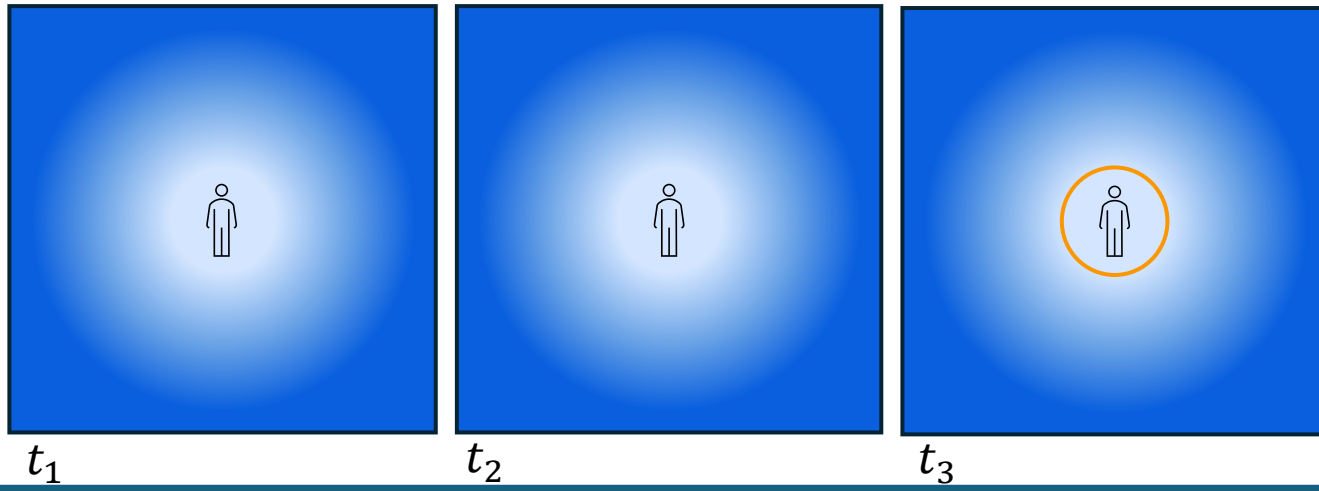


Time

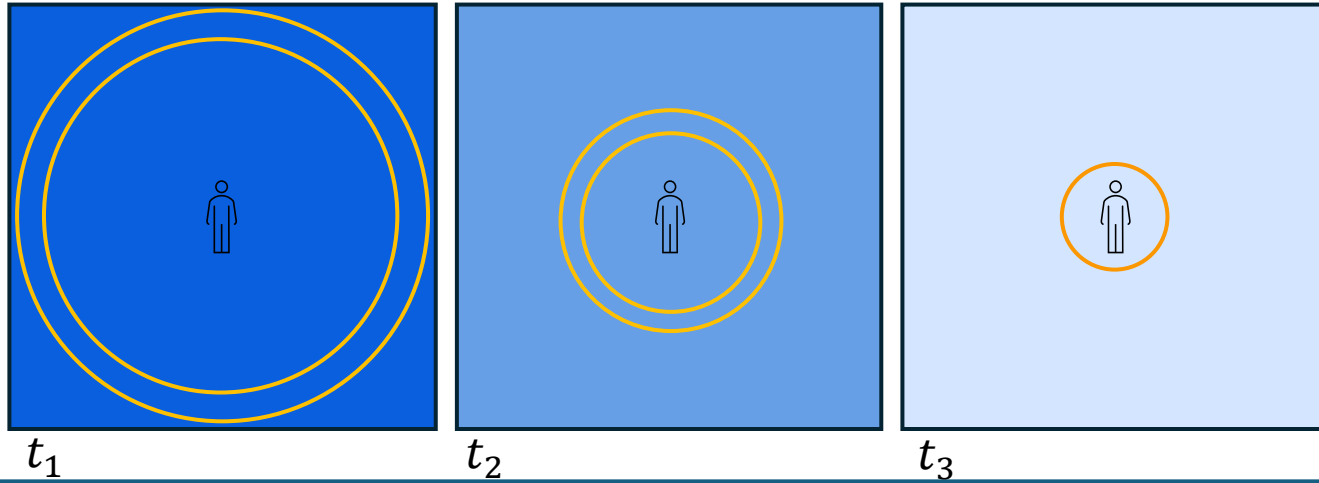
Time Varying



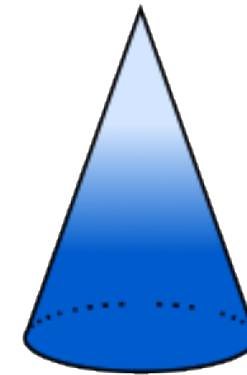
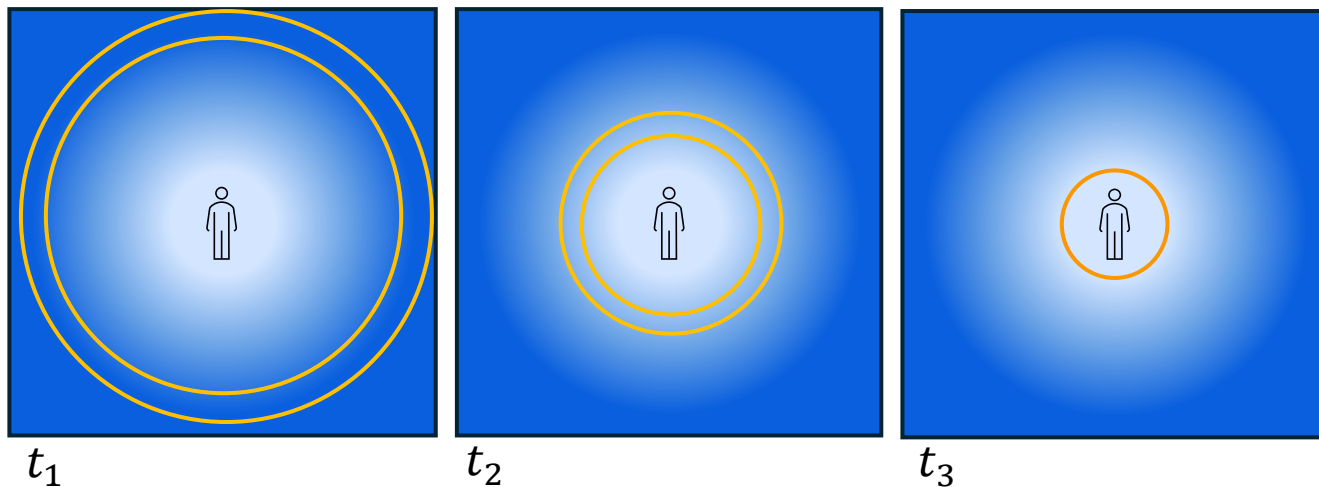
Space Varying



Time
Varying



Space
Varying





t_1

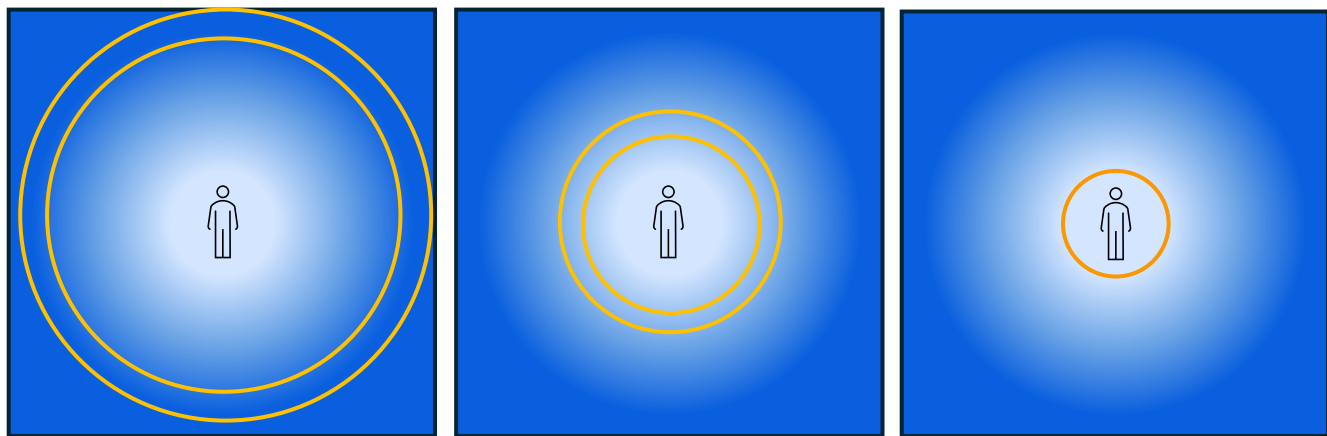
t_2

t_3

Time



Space
Varying

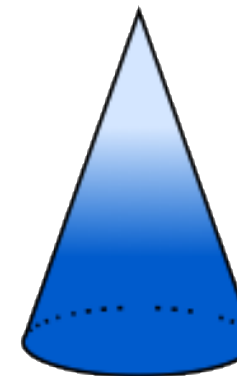


t_1

t_2

t_3

Time





t_1

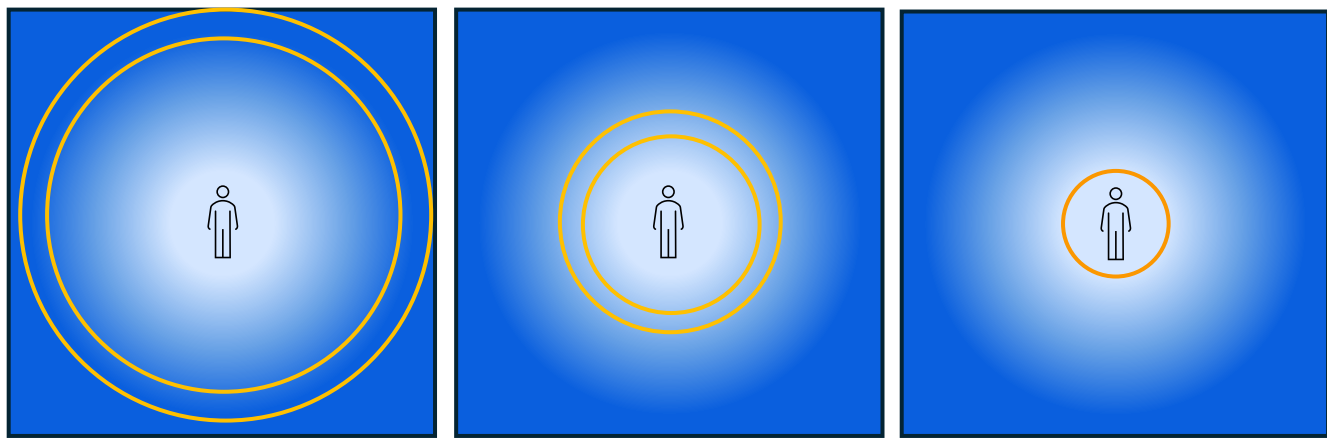
t_2

t_3

Time



Space
Varying



t_1

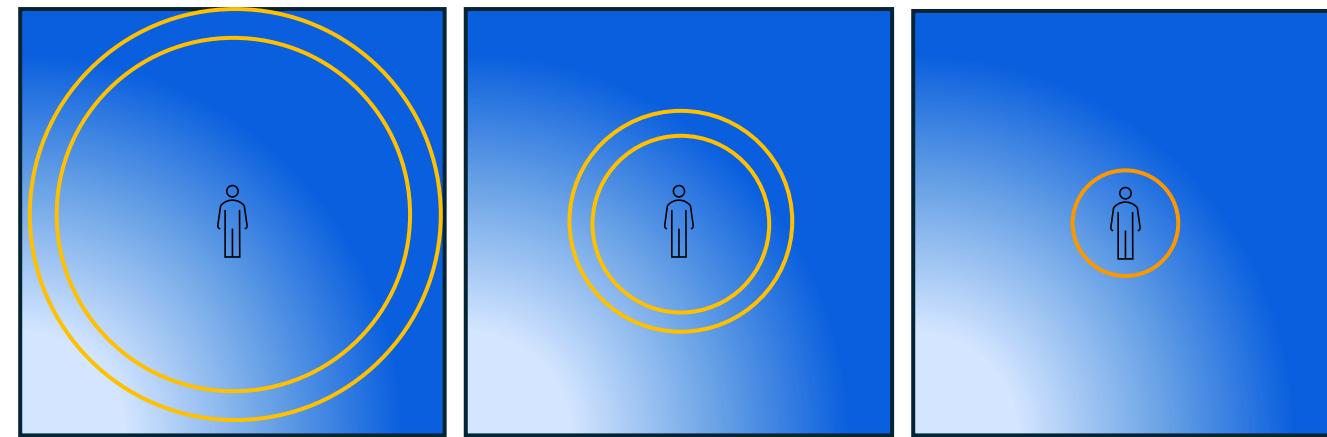
t_2

t_3

Time



Off
Centre



t_1

t_2

t_3

Time

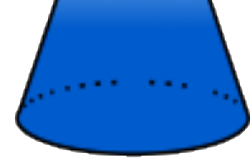


t_1

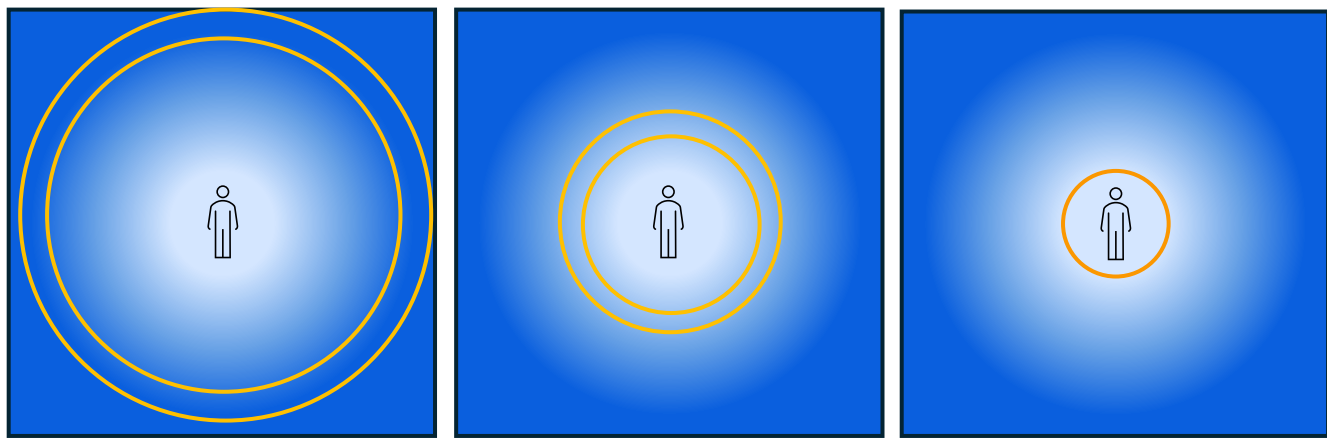
t_2

t_3

Time



Space
Varying

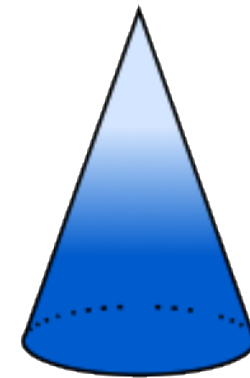


t_1

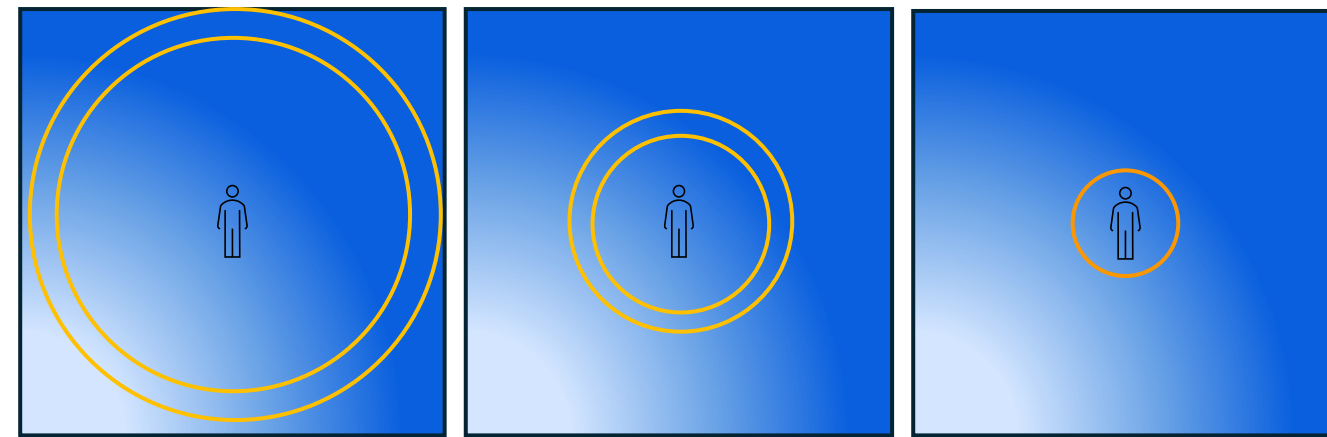
t_2

t_3

Time



Off
Centre

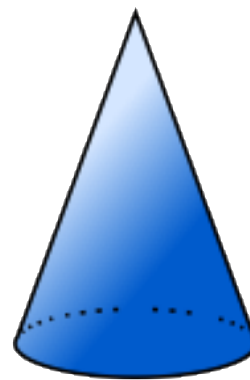


t_1

t_2

t_3

Time



Why would DE vary in space?

Why would DE vary in space?

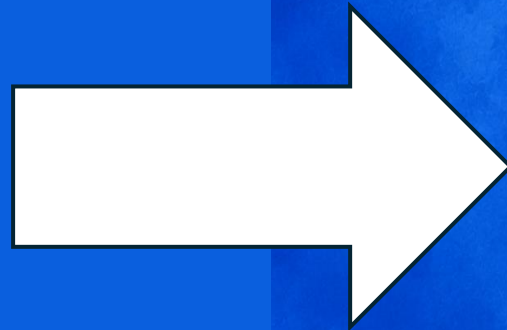
Cosmological Constant problem – Why our Λ ?

Λ

Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

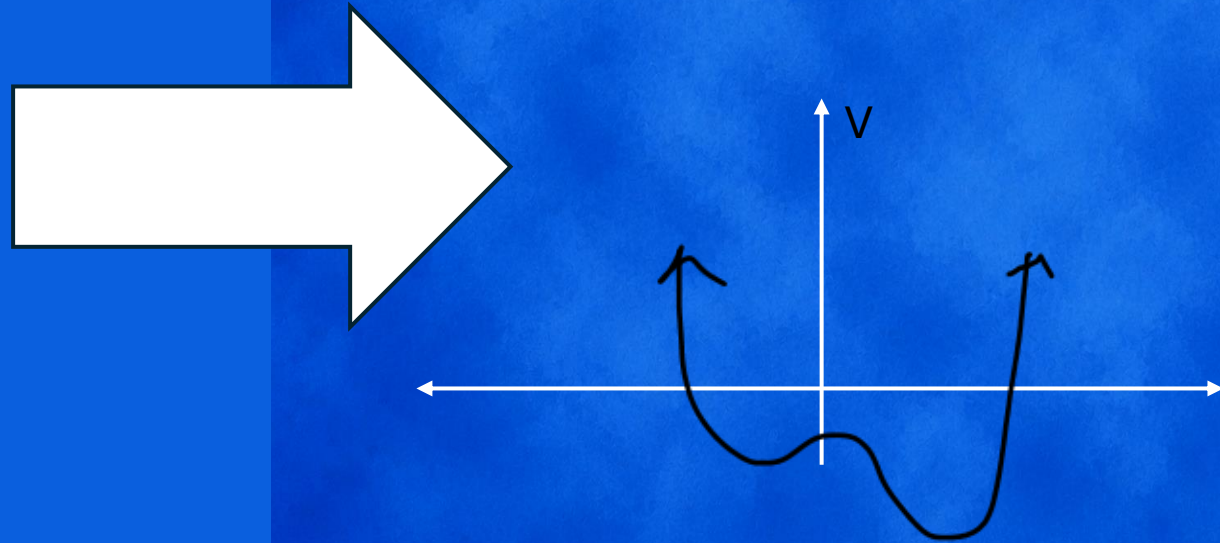
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

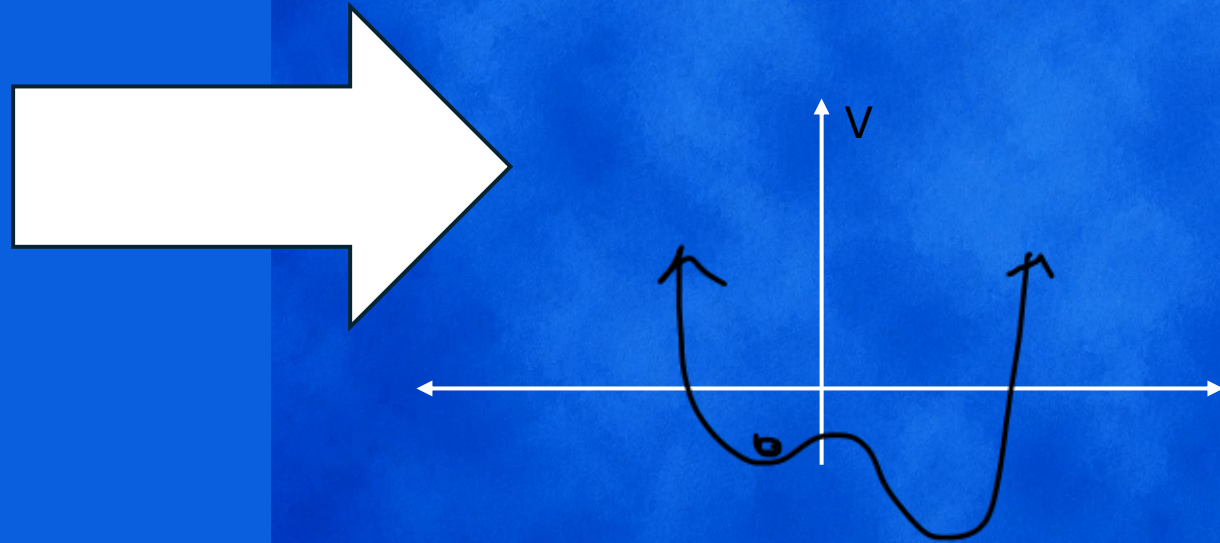
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

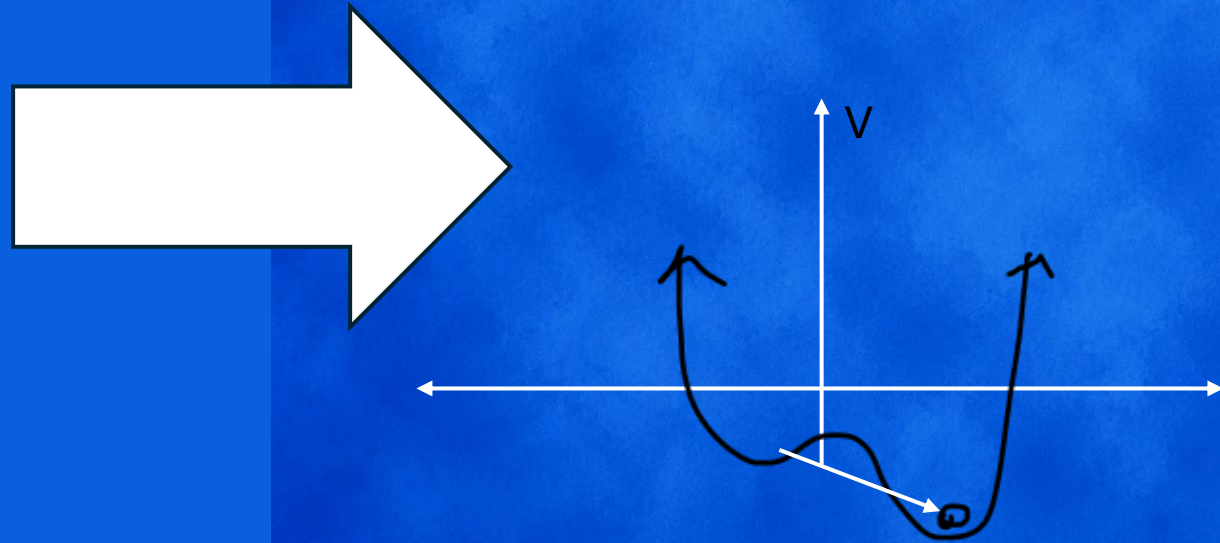
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

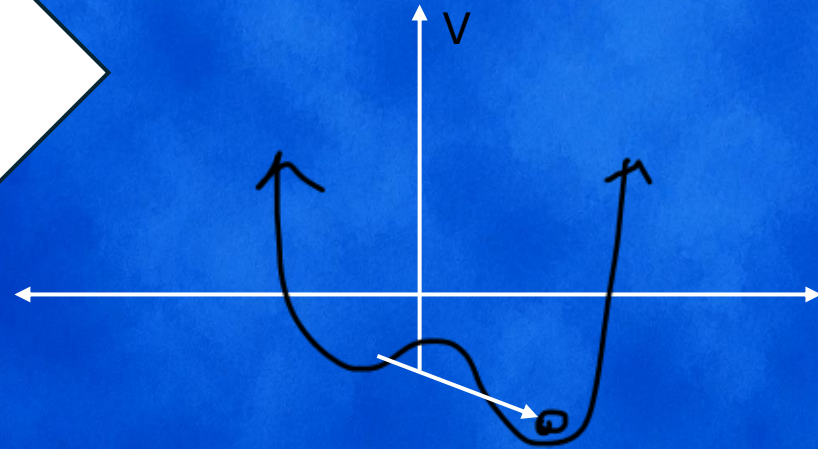
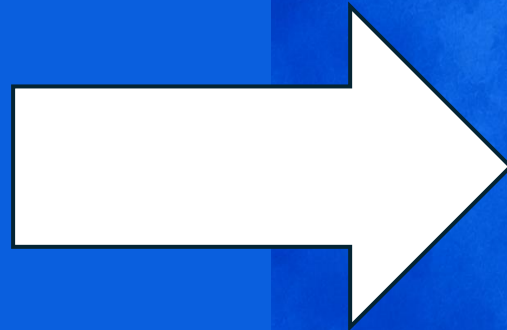
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

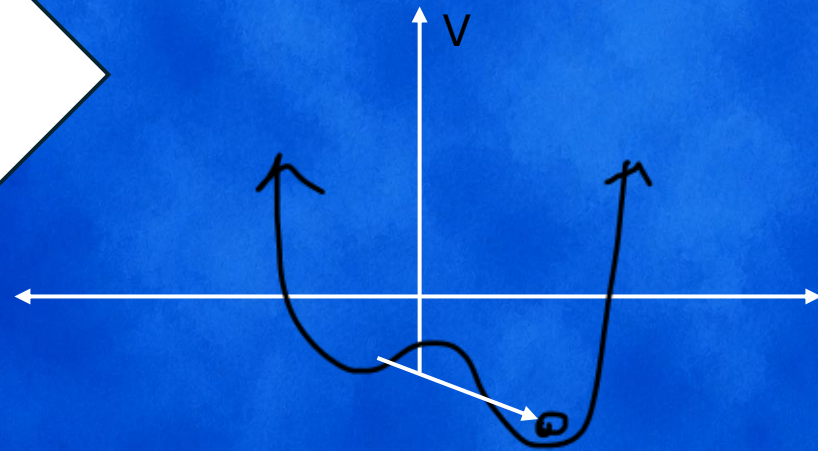
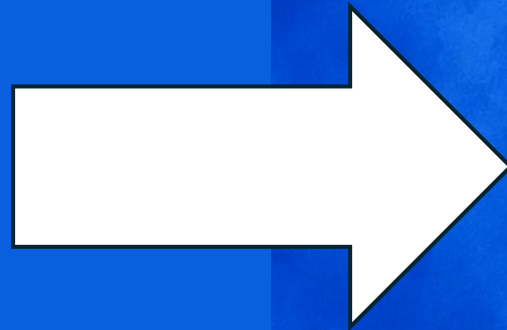
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

Λ

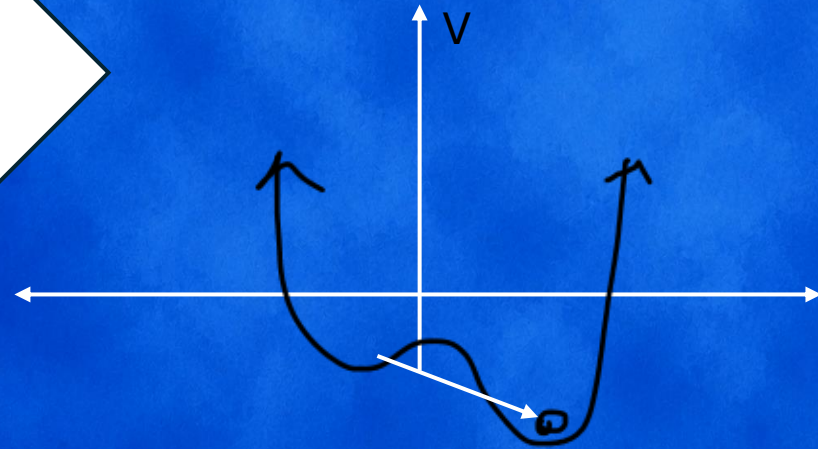
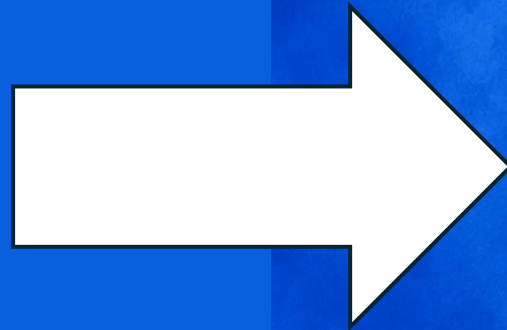


$$\frac{4}{3}\pi r^3 \rho$$

Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

Λ

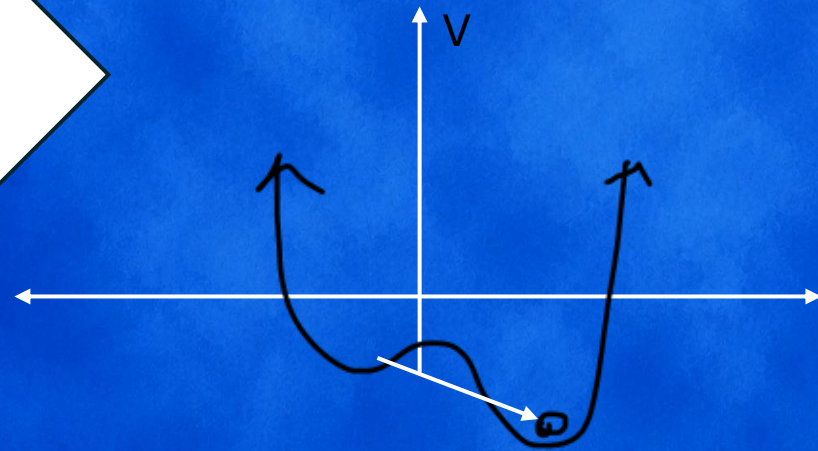
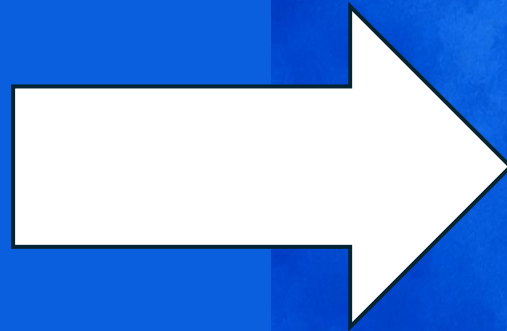


$$\frac{4}{3}\pi r^3 \rho$$

Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

Λ

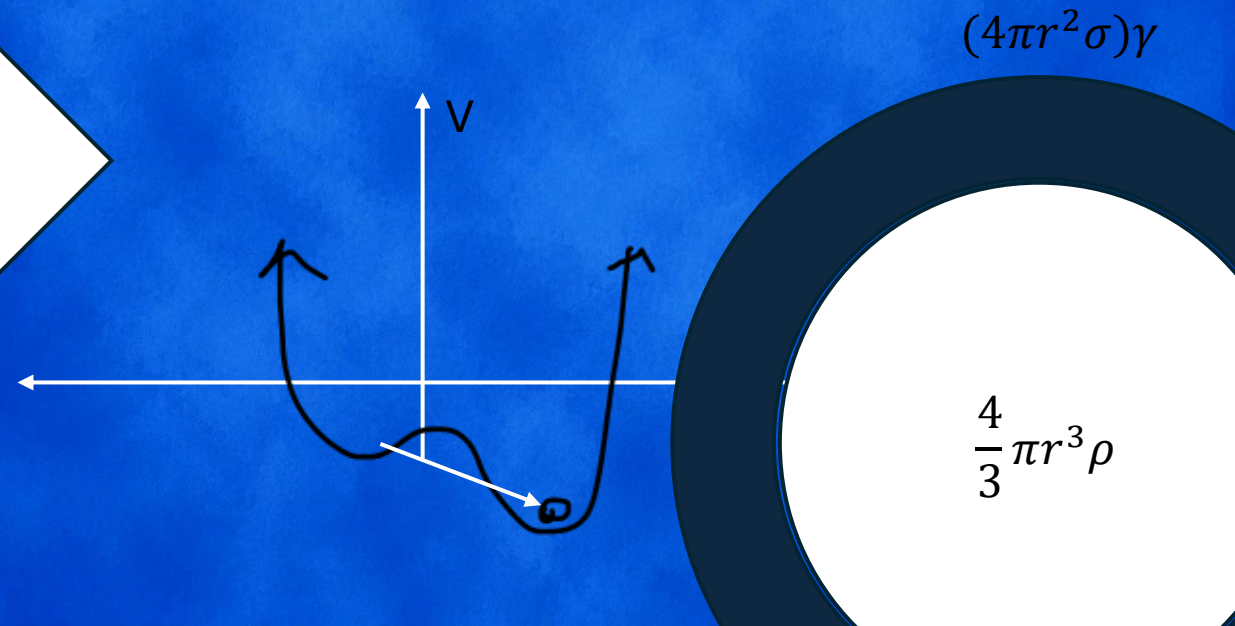
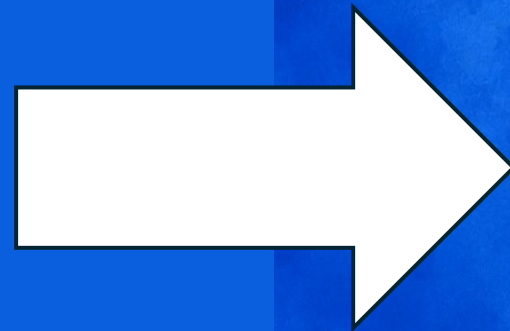


$$(4\pi r^2 \sigma) \gamma$$
$$\frac{4}{3} \pi r^3 \rho$$

Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

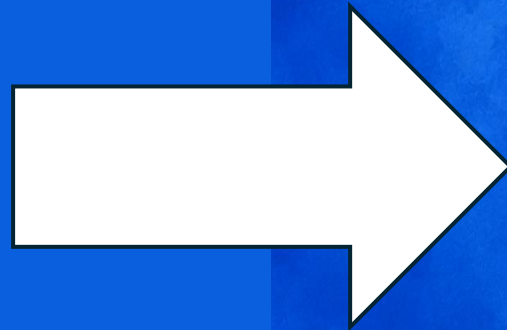
Λ



Why would DE vary in space?

Cosmological Constant problem – Why our Λ ?

Λ

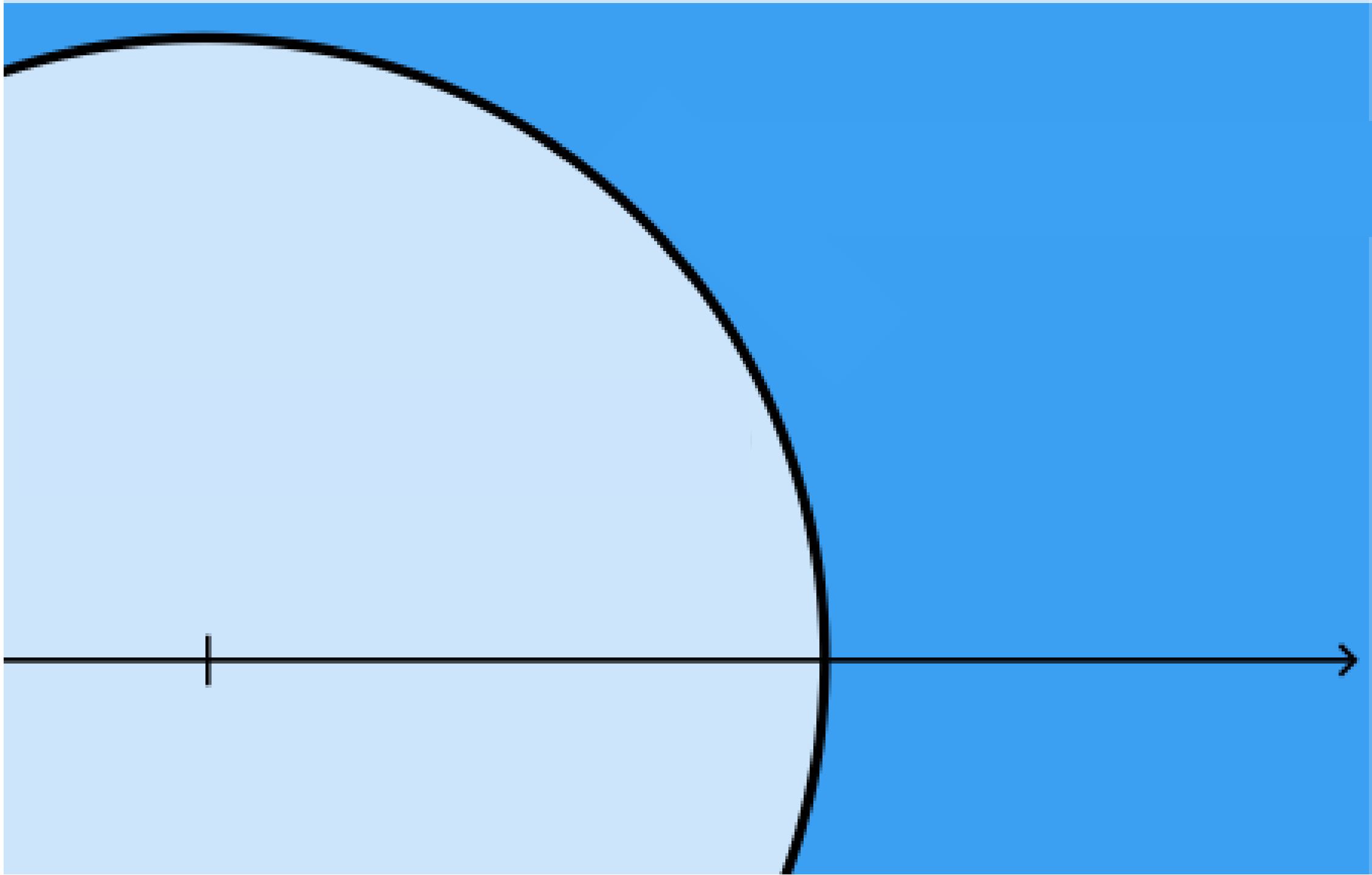


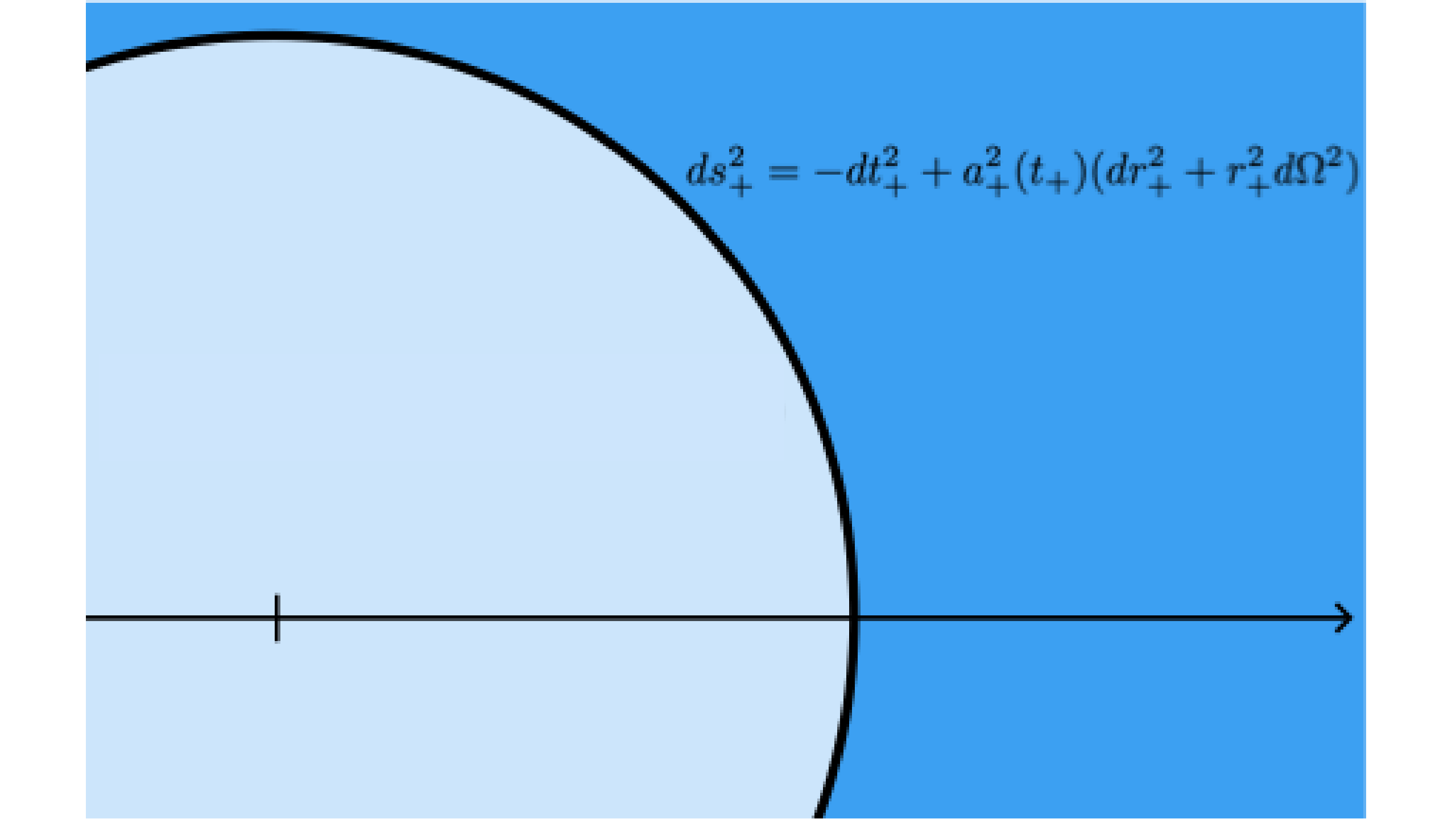
$$(4\pi r^2 \sigma) \gamma$$

v



$$\frac{4}{3} \pi r^3 \rho$$




$$ds_+^2 = -dt_+^2 + a_+^2(t_+)(dr_+^2 + r_+^2 d\Omega^2)$$


$$ds_+^2 = -dt_+^2 + a_+^2(t_+)(dr_+^2 + r_+^2 d\Omega^2)$$

$$ds_-^2 = -dt_-^2 + a_-^2(t_-)(dr_-^2 + r_-^2 d\Omega^2)$$

$$ds_+^2 = -dt_+^2 + a_+^2(t_+)(dr_+^2 + r_+^2 d\Omega^2)$$

$$ds_-^2 = -dt_-^2 + a_-^2(t_-)(dr_-^2 + r_-^2 d\Omega^2)$$

$$a_-(t_-)r_-$$

$$a_+(t_+)r_+$$

$$ds_+^2 = -dt_+^2 + a_+^2(t_+)(dr_+^2 + r_+^2 d\Omega^2)$$

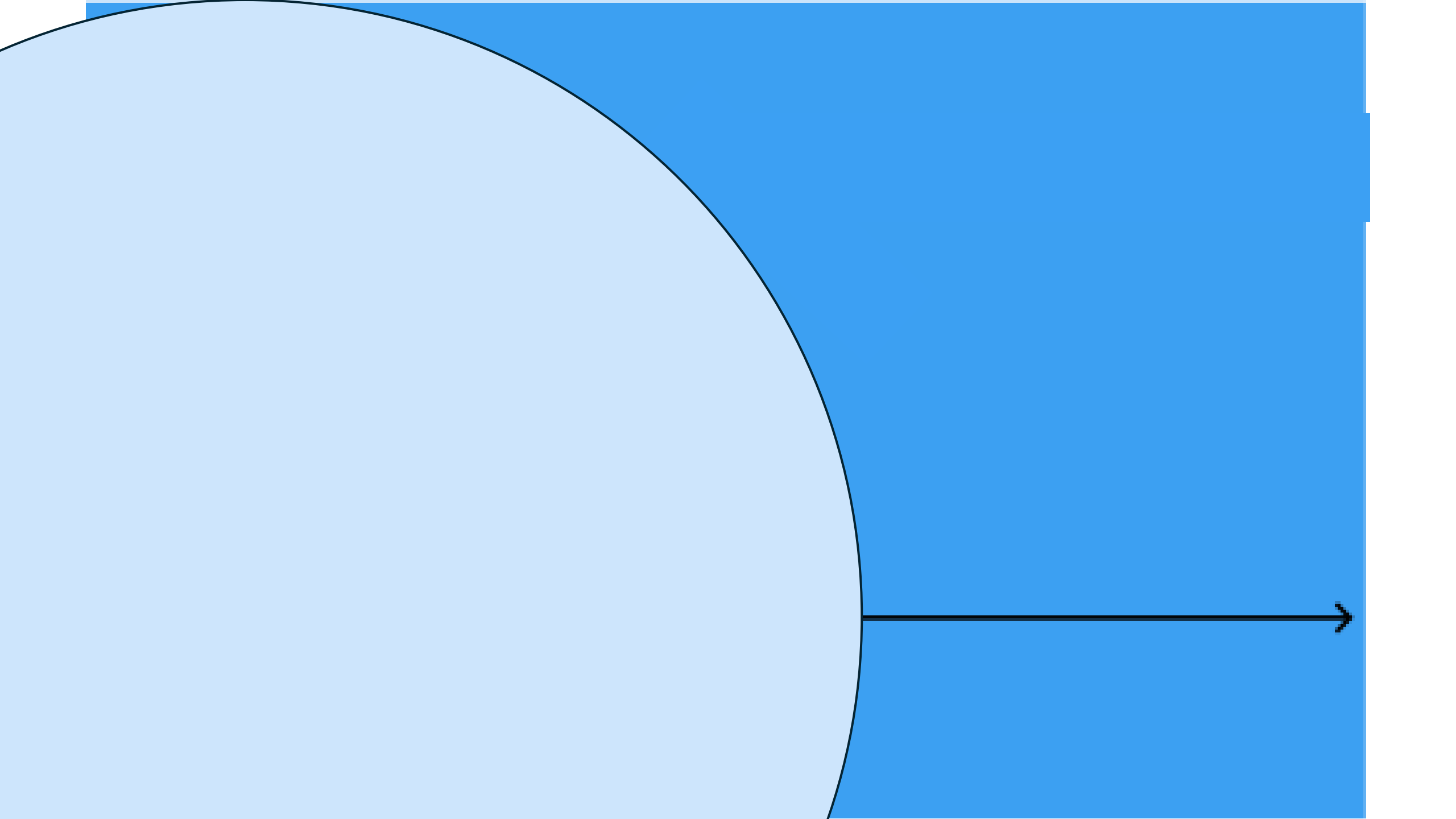
$$ds_-^2 = -dt_-^2 + a_-^2(t_-)(dr_-^2 + r_-^2 d\Omega^2)$$

$$a_-(t_-)r_-$$

$$a_+(t_+)r_+$$

Junction (gluing) Condition

$$a_-(t_-^0)r_-^b = a_+(t_+^0)r_+^b$$



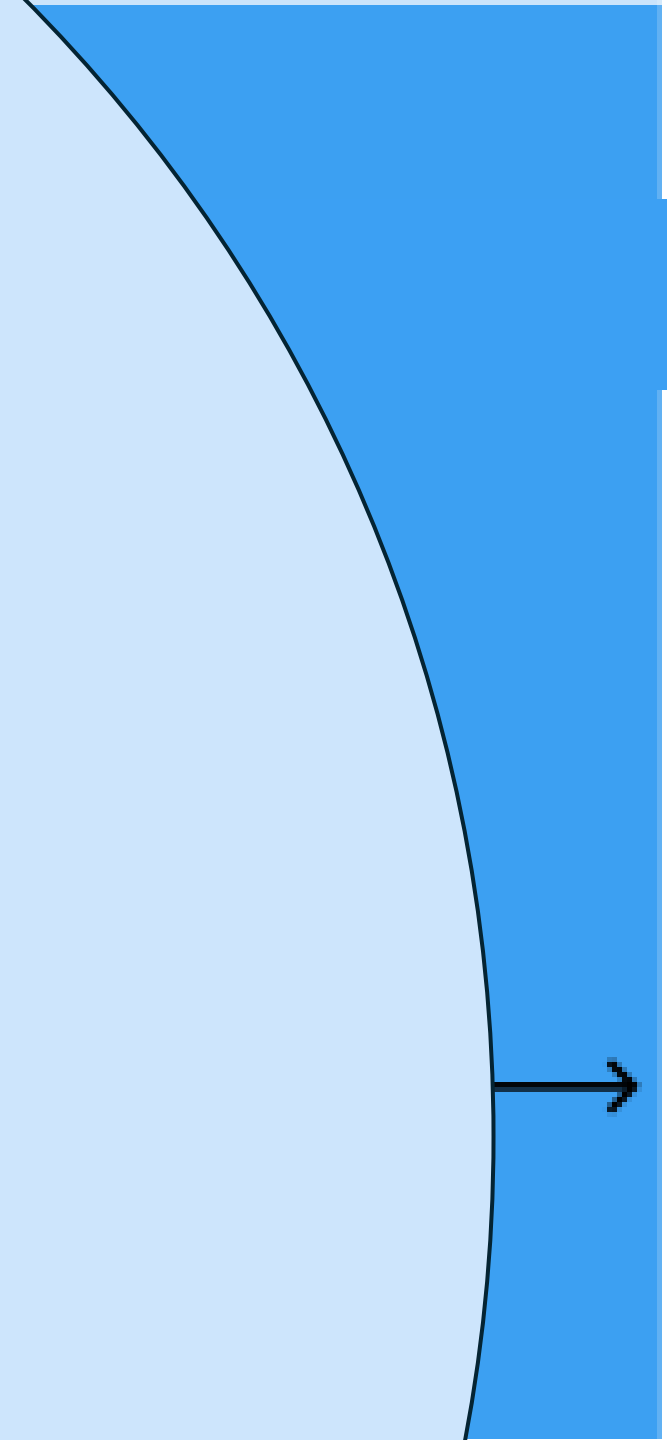
Junction (gluing)
Conditions =>
Bubble Grows!



Junction (gluing)
Conditions \Rightarrow
Bubble Grows!



Junction (gluing)
Conditions =>
Bubble Grows!
Quickly!



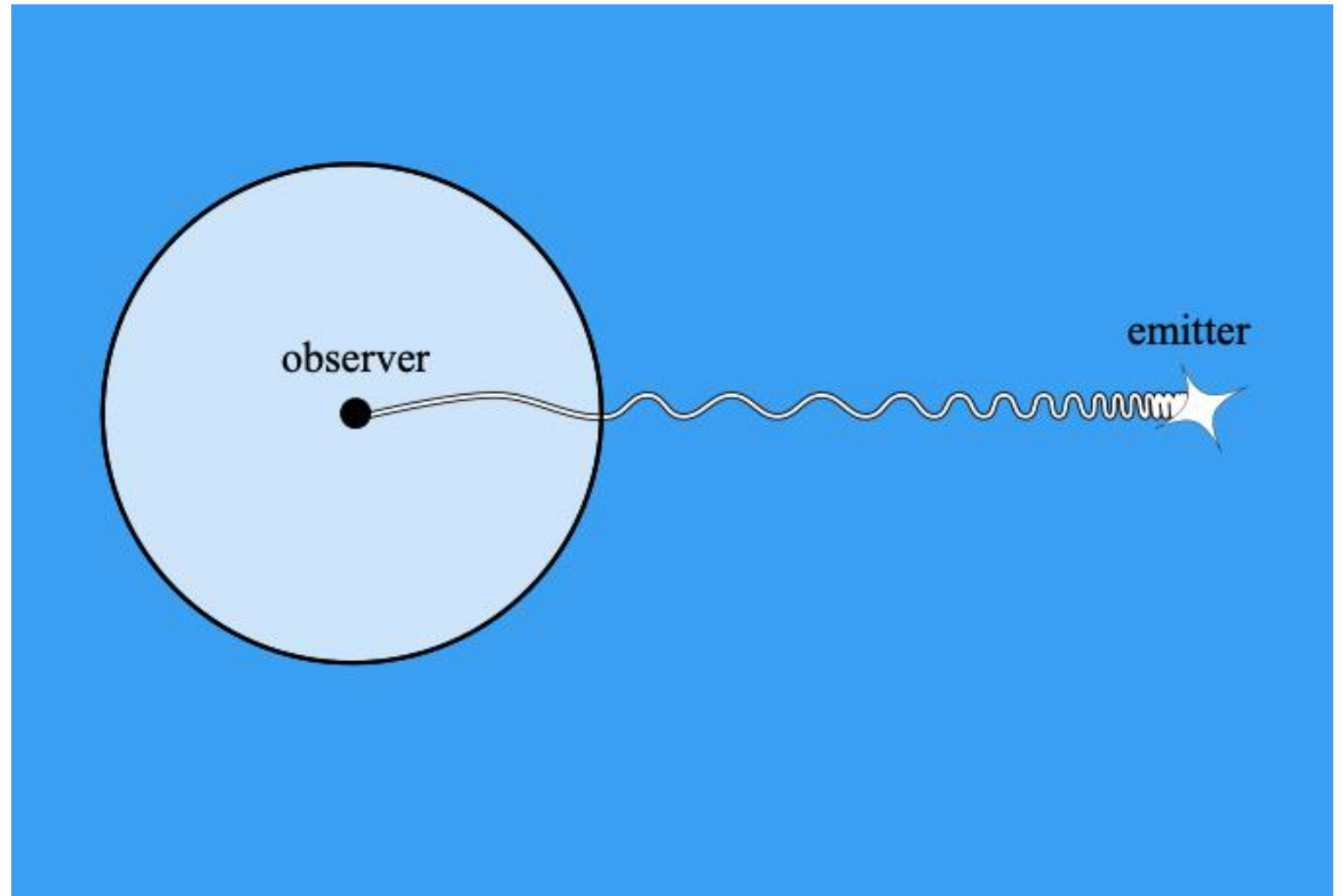
Junction (gluing)
Conditions =>
Bubble Grows!
Quickly!

Junction (gluing)
Conditions =>
Bubble Grows!
Quickly!

Bubble Properties

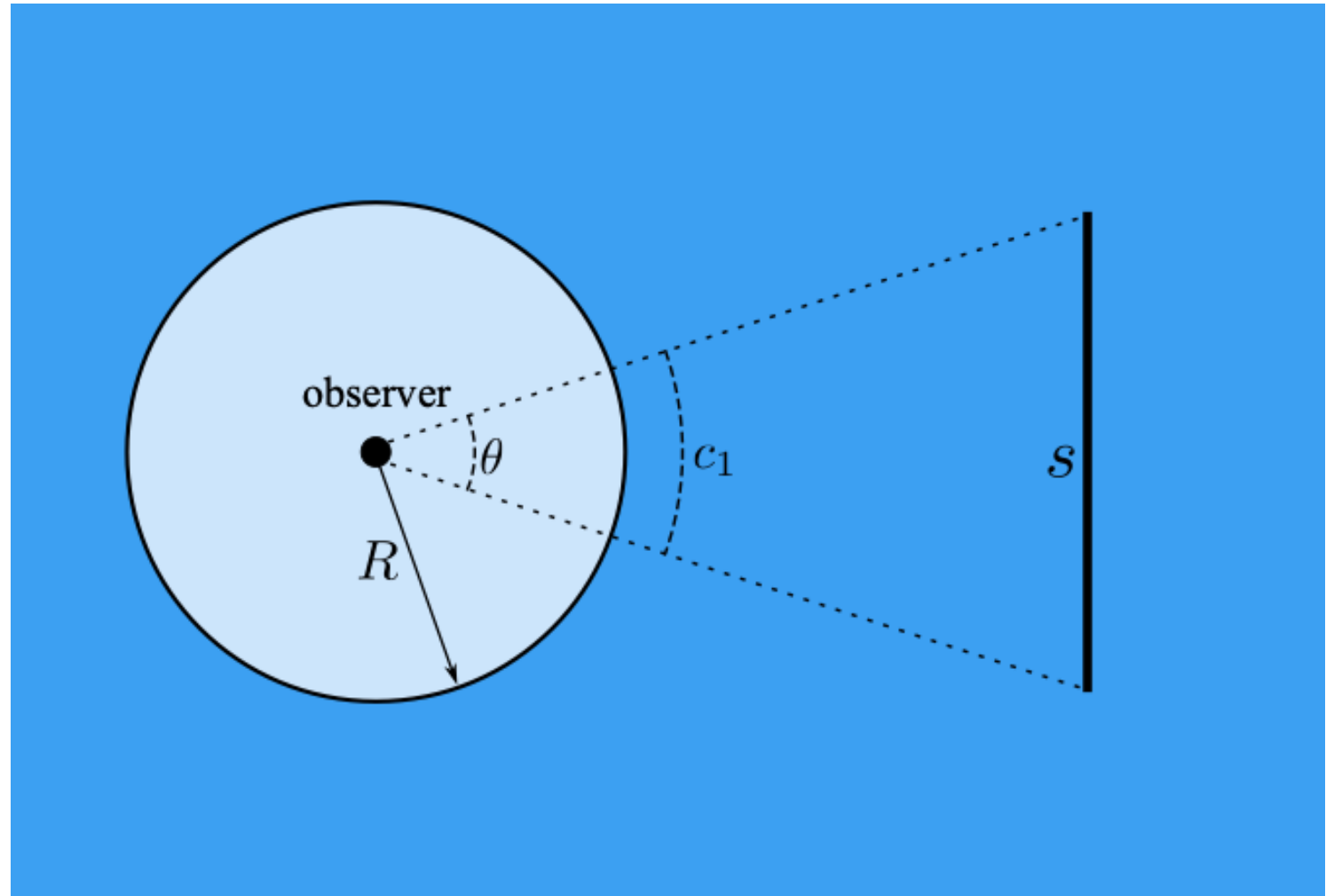
Bubble Properties

- Redshifts



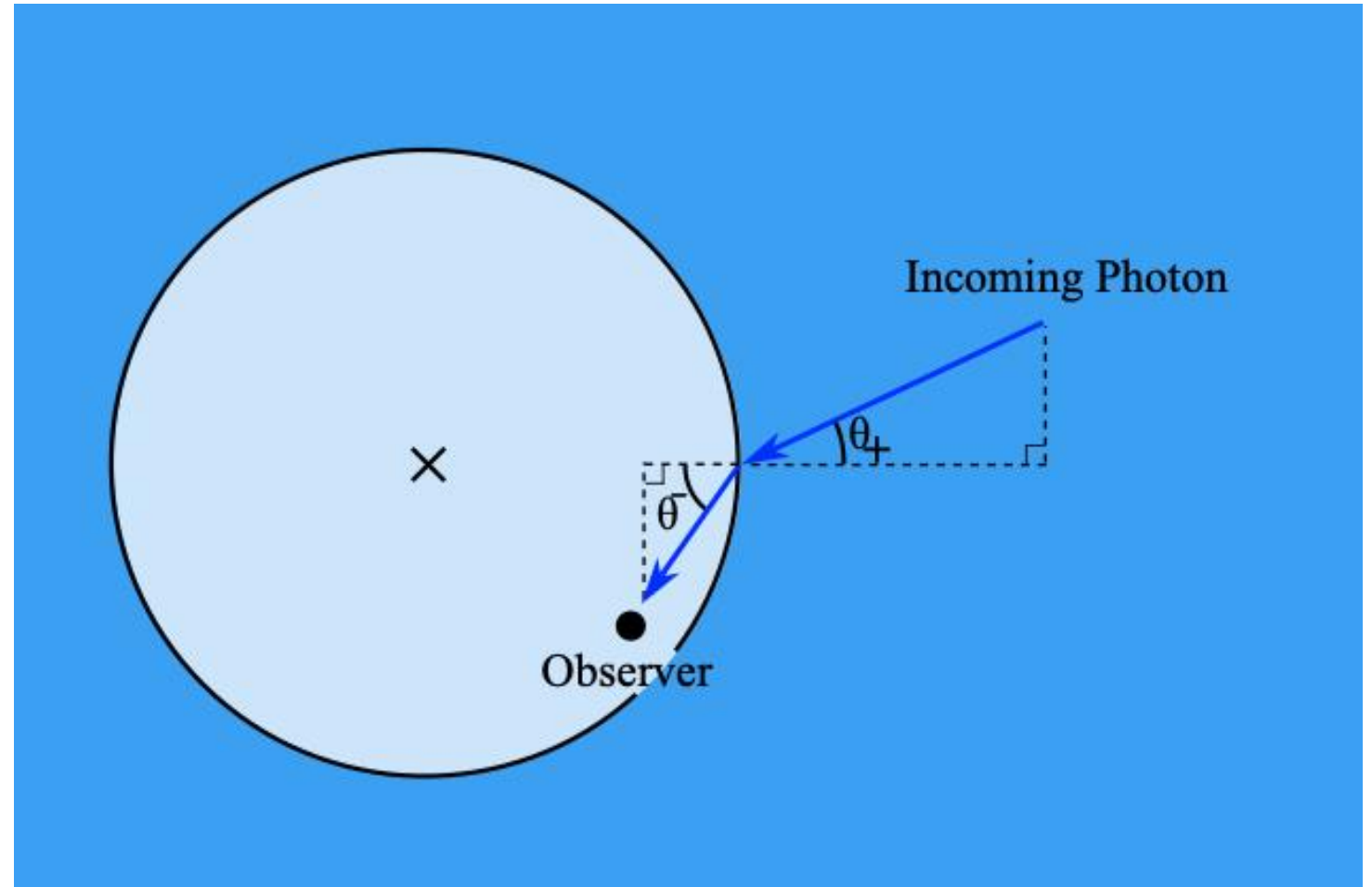
Bubble Properties

- Redshifts
- Distance relationships,
Hubble Parameter



Bubble Properties

- Redshifts
- Distance relationships,
Hubble Parameter
- Photon Deflection
(~Snell's law)

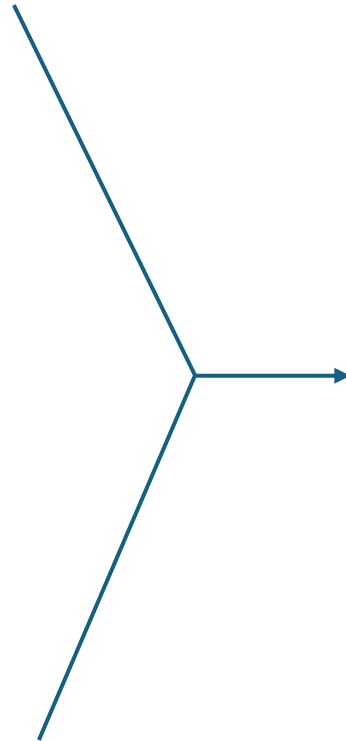


Bubble Properties

- Redshifts
- Distance relationships,
Hubble Parameter
- Photon Deflection
(~Snell's law)

Bubble Properties

- Redshifts
- Distance relationships,
Hubble Parameter
- Photon Deflection
(~Snell's law)



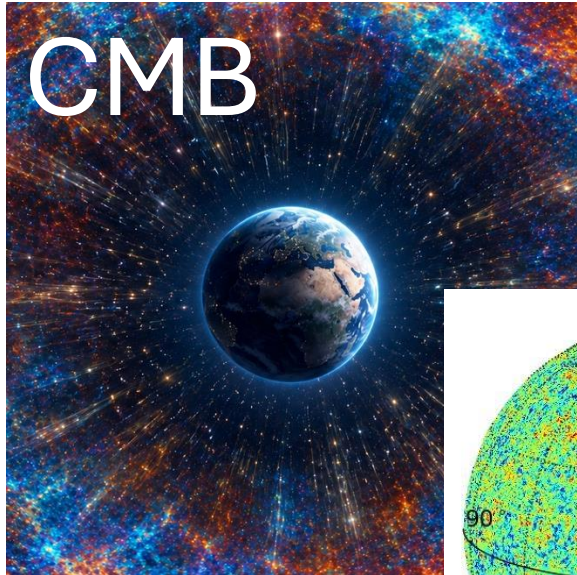
Observations

Observations



ChatGPT Generated

Observations



ChatGPT Generated

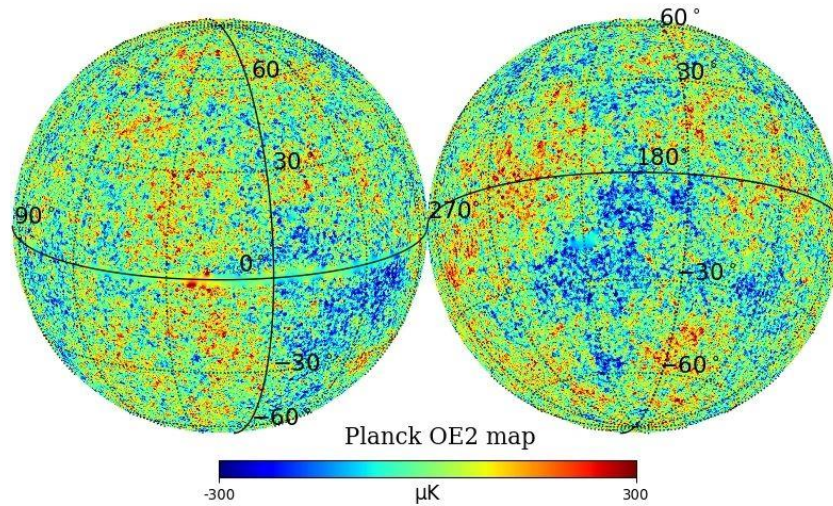
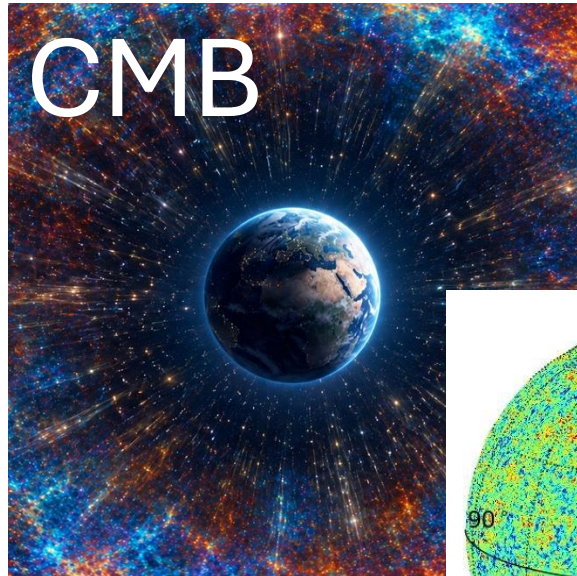


Image Credit: Pablo Fosalba

Observations



ChatGPT Generated

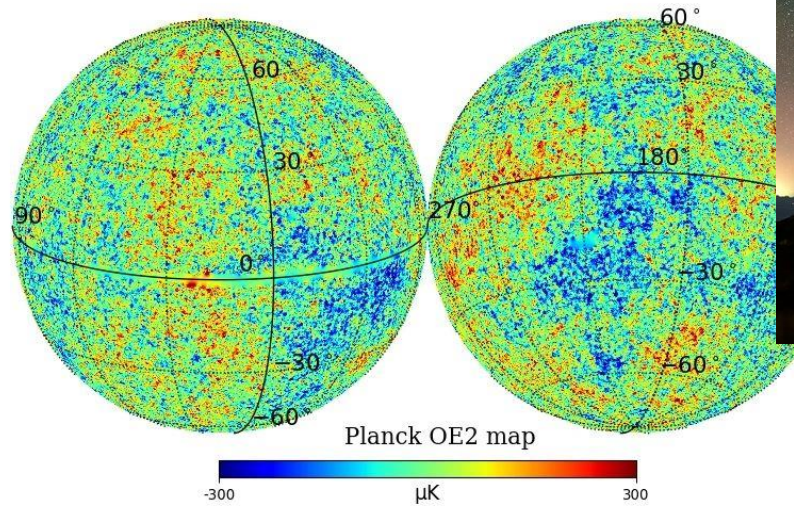
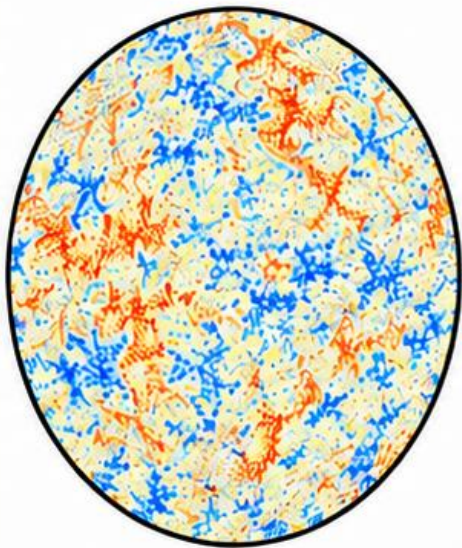


Image Credit: Pablo Fosalba

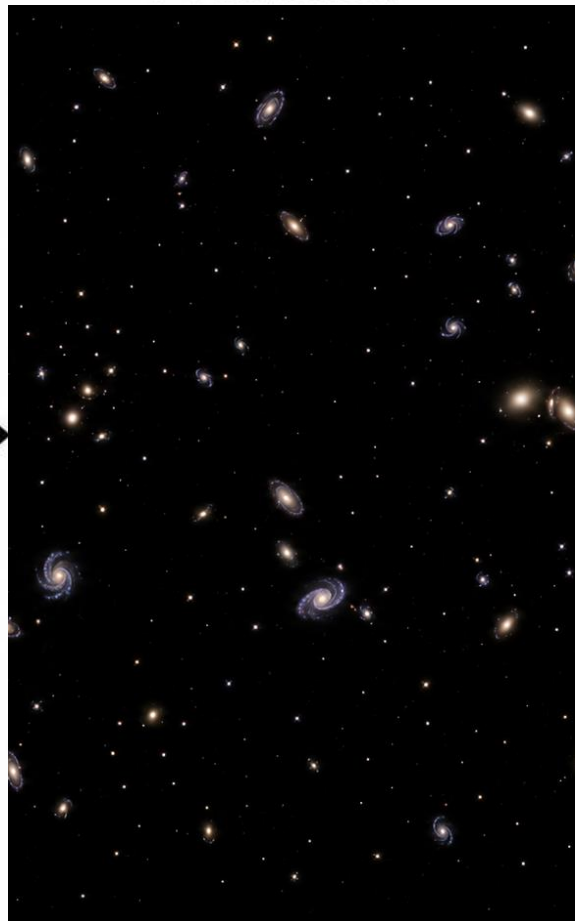


Image Credit: DESI Collaboration

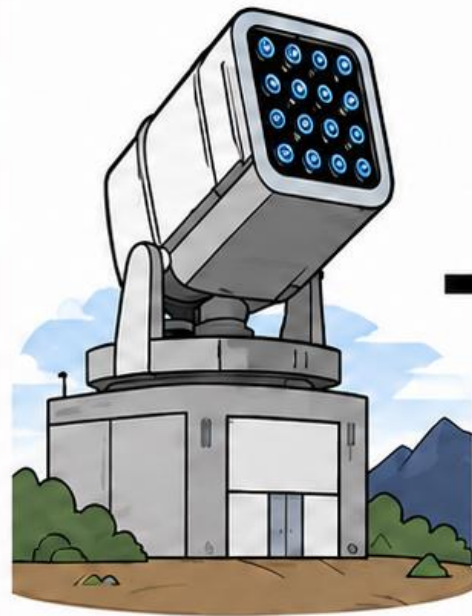
CMB



Predicted

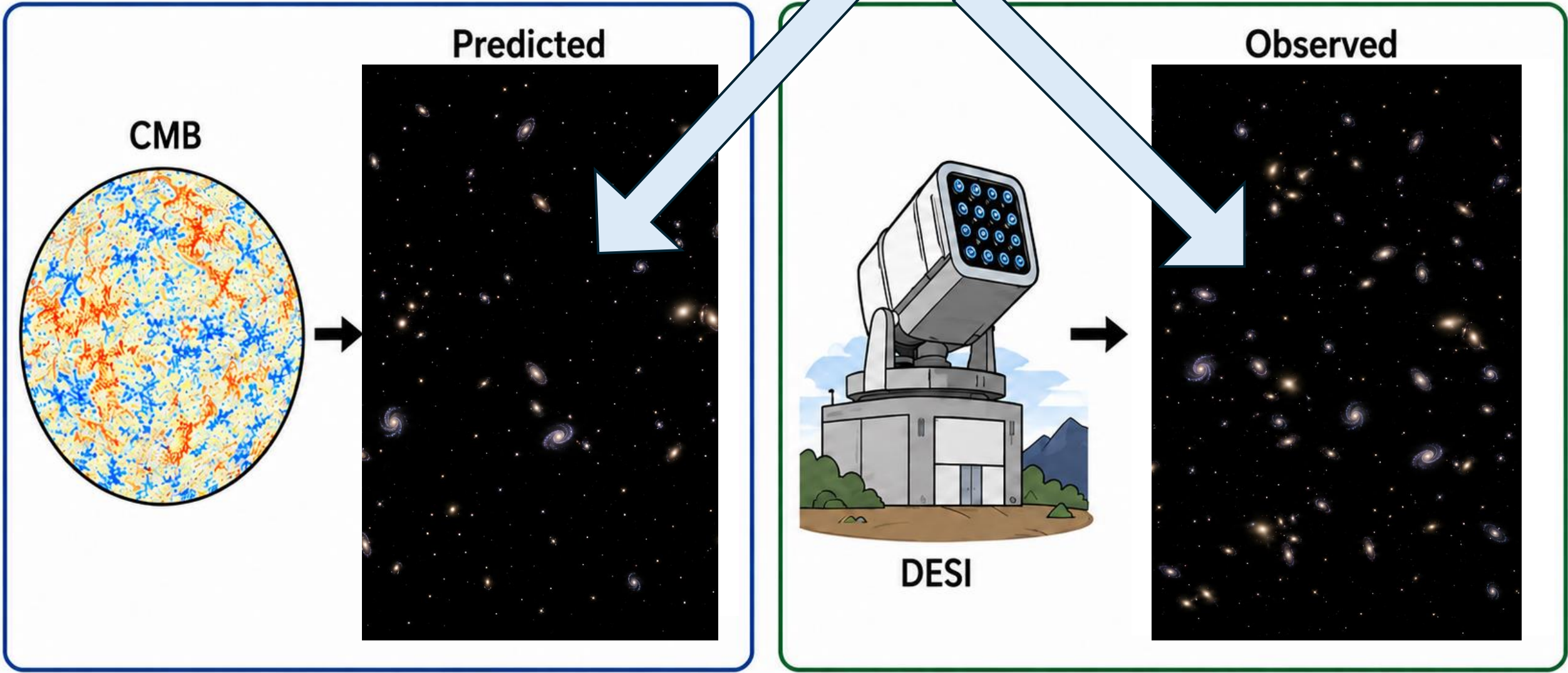


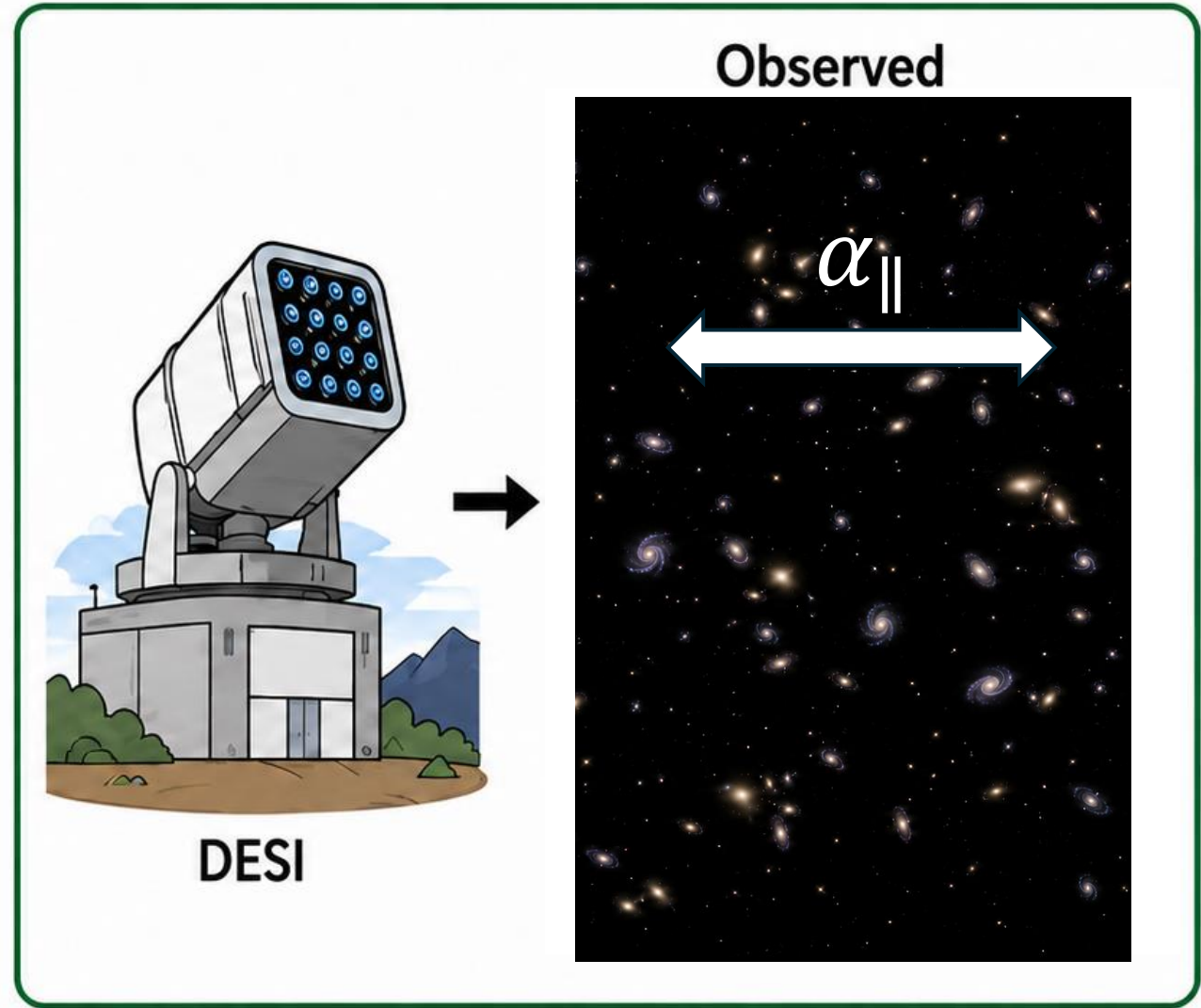
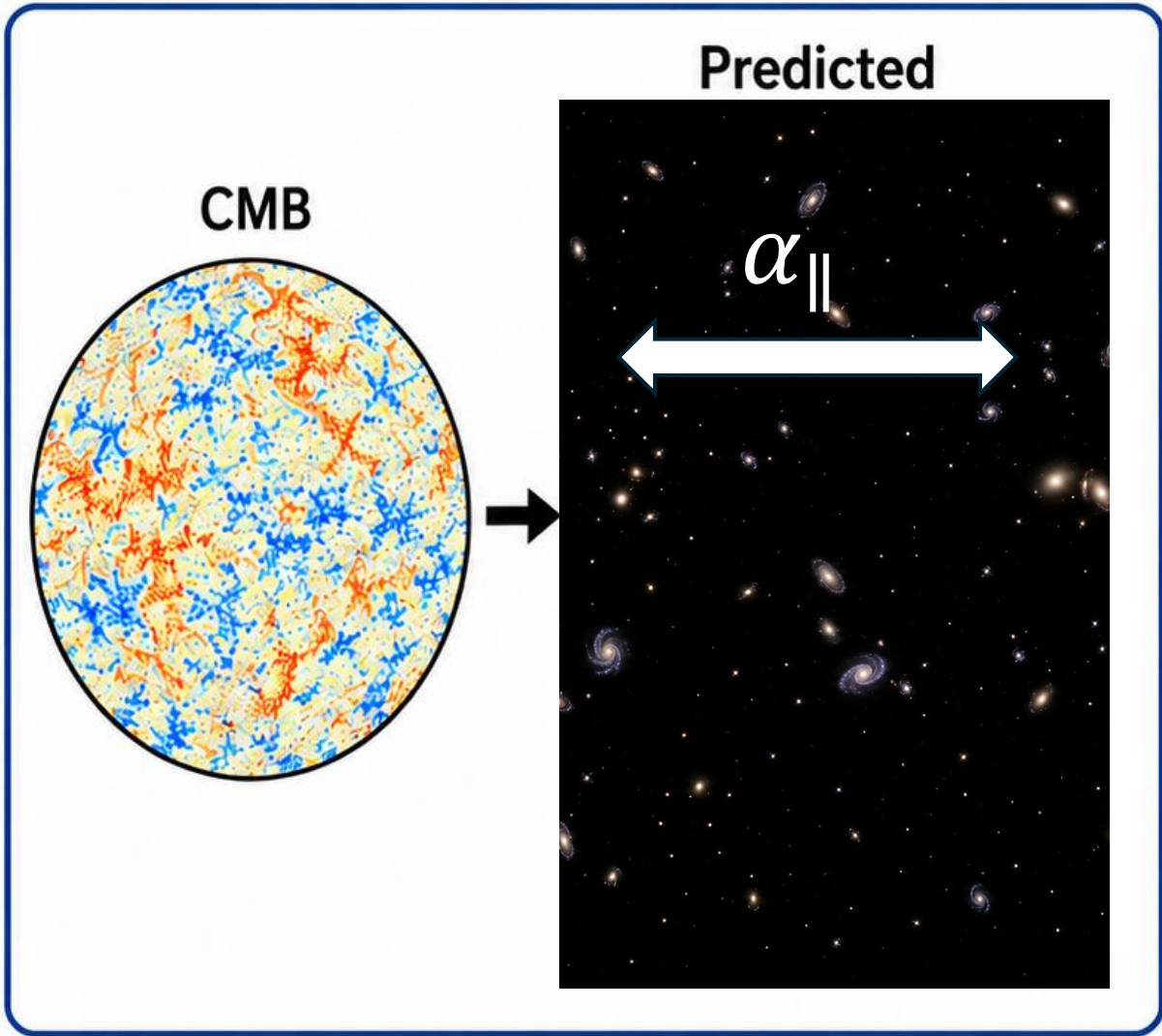
Observed

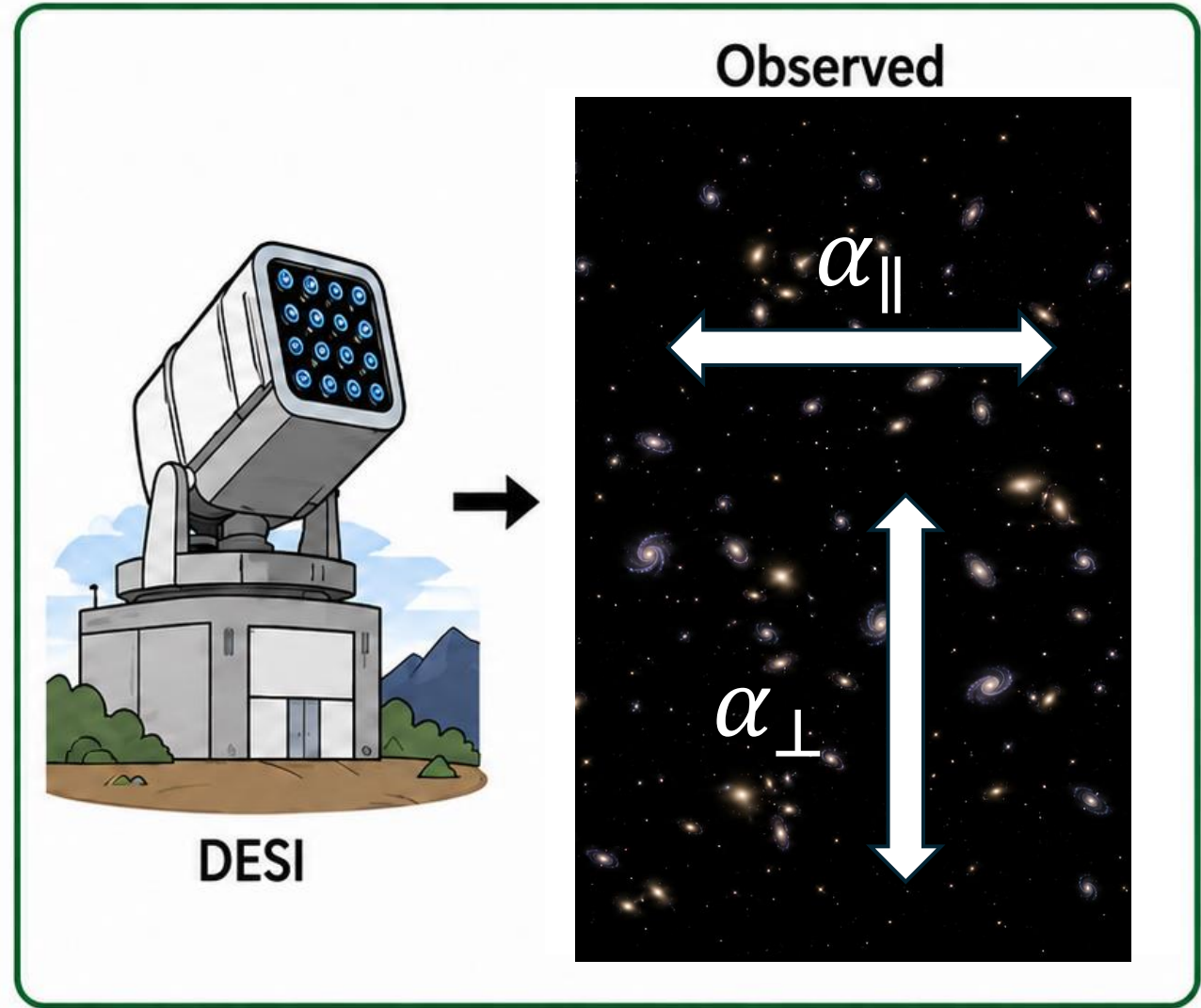
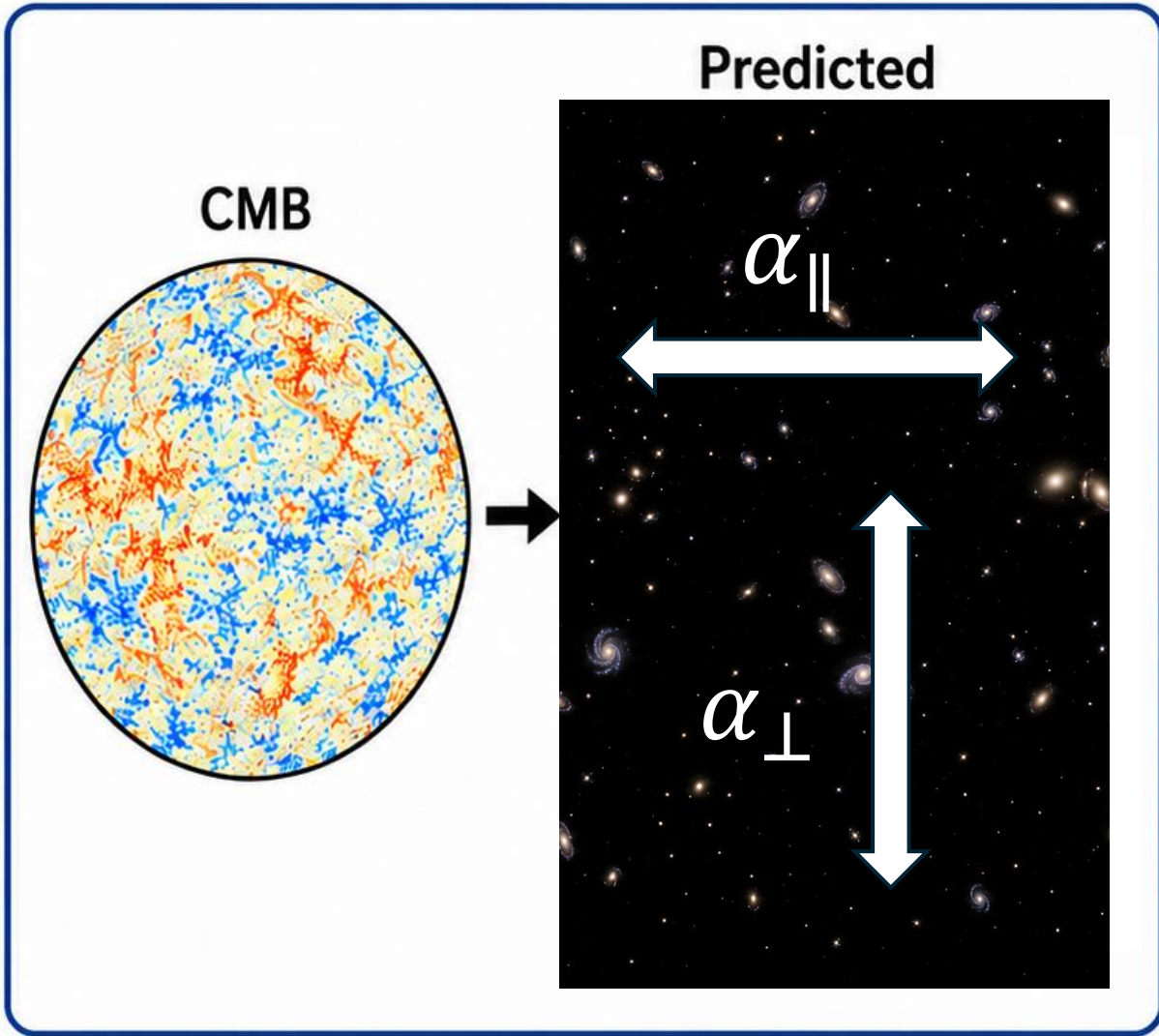


DESI

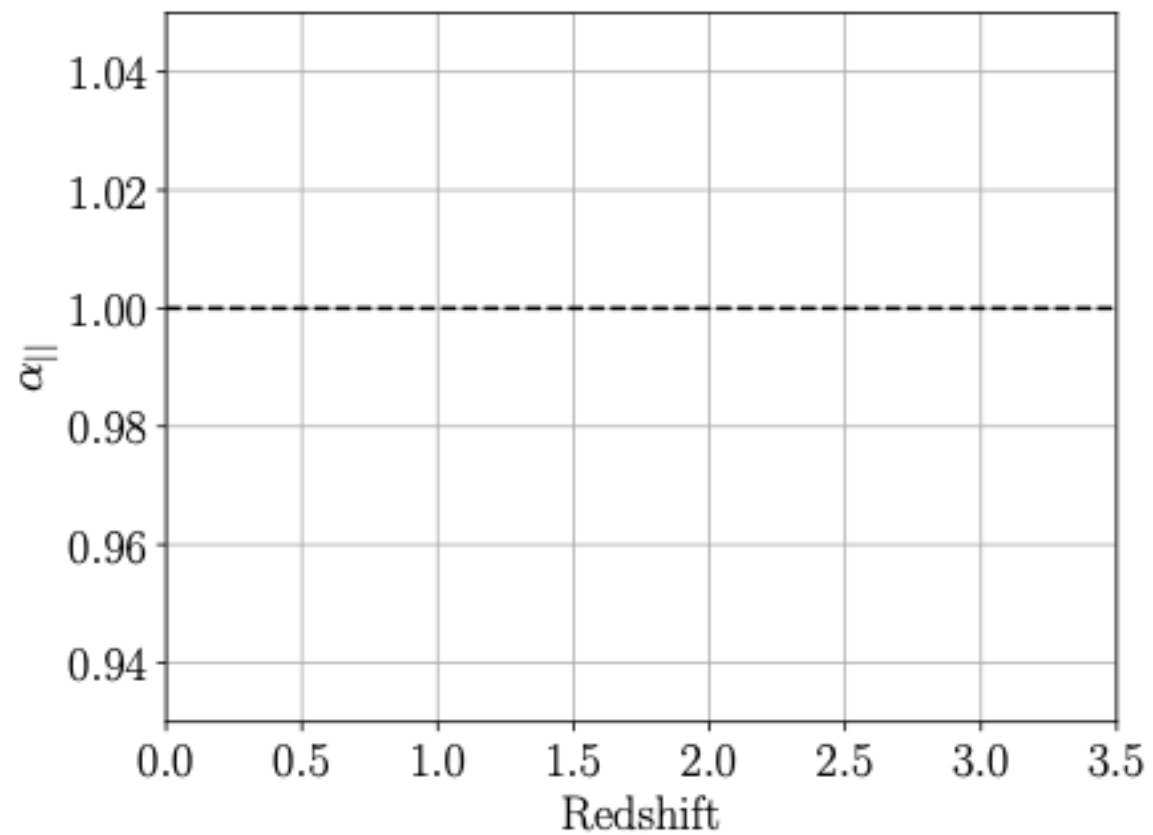
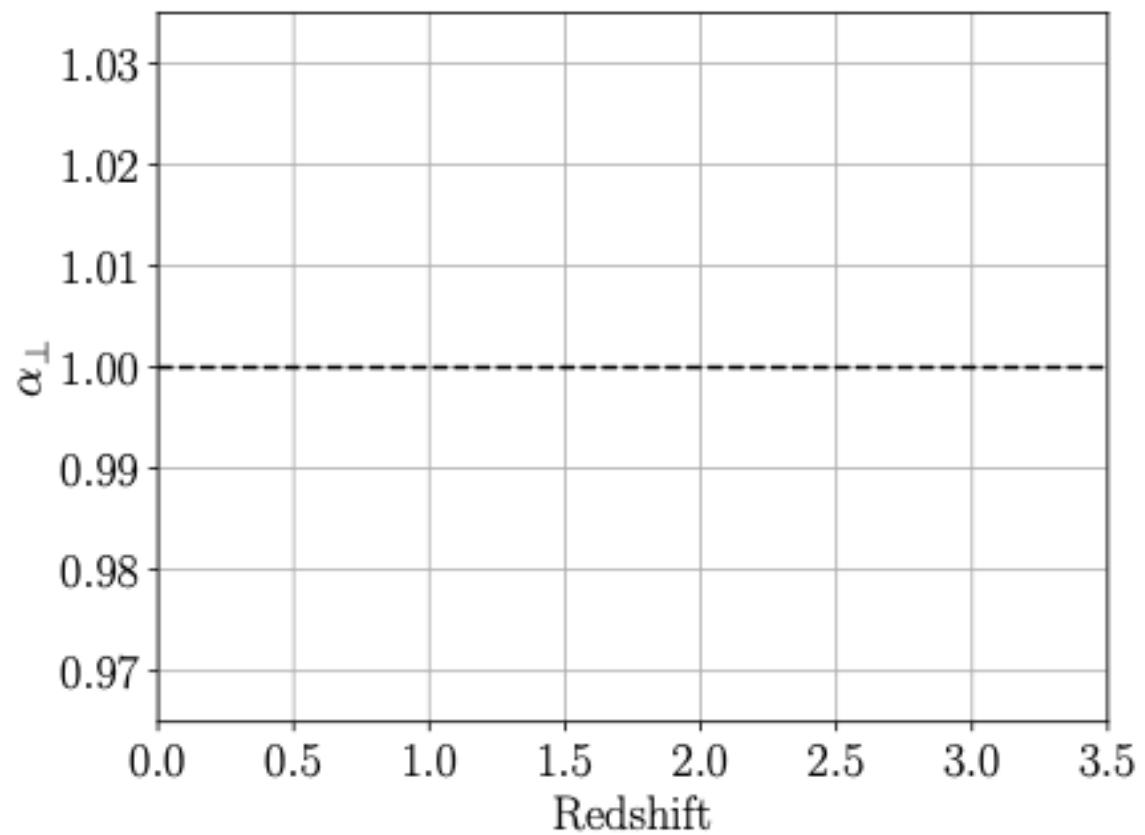




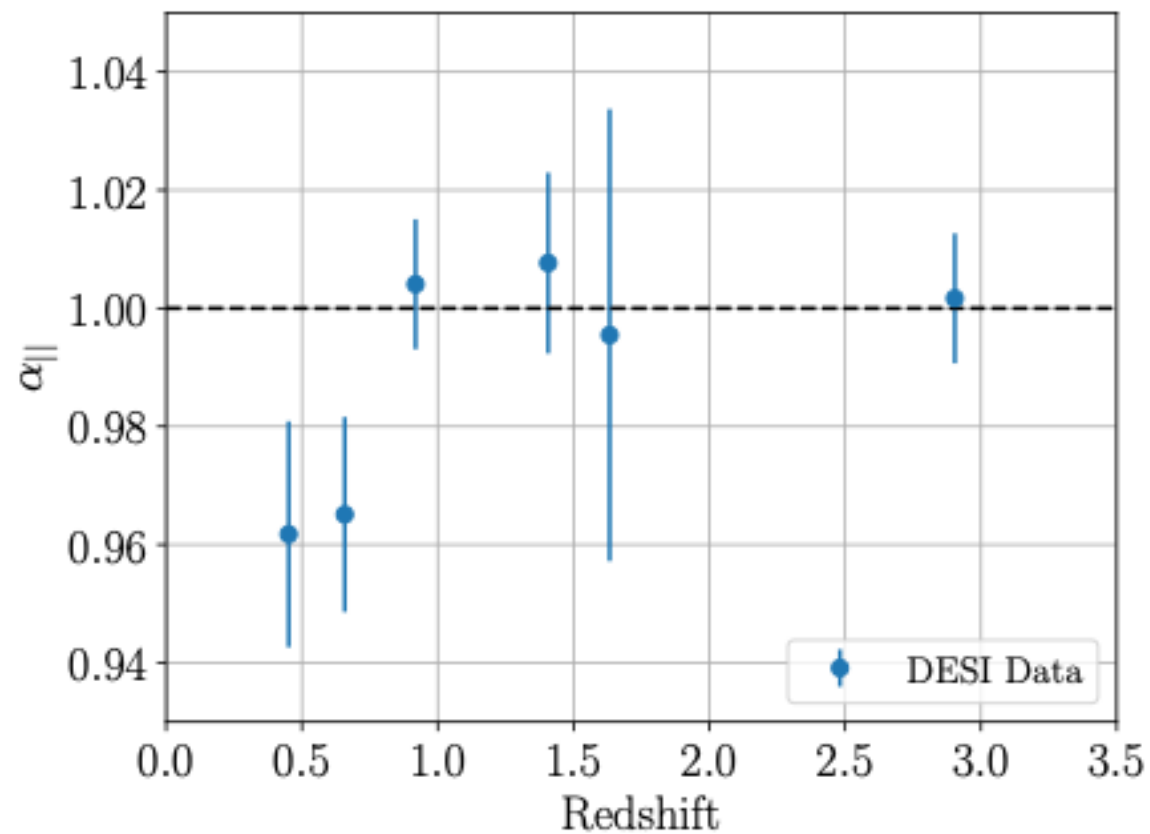
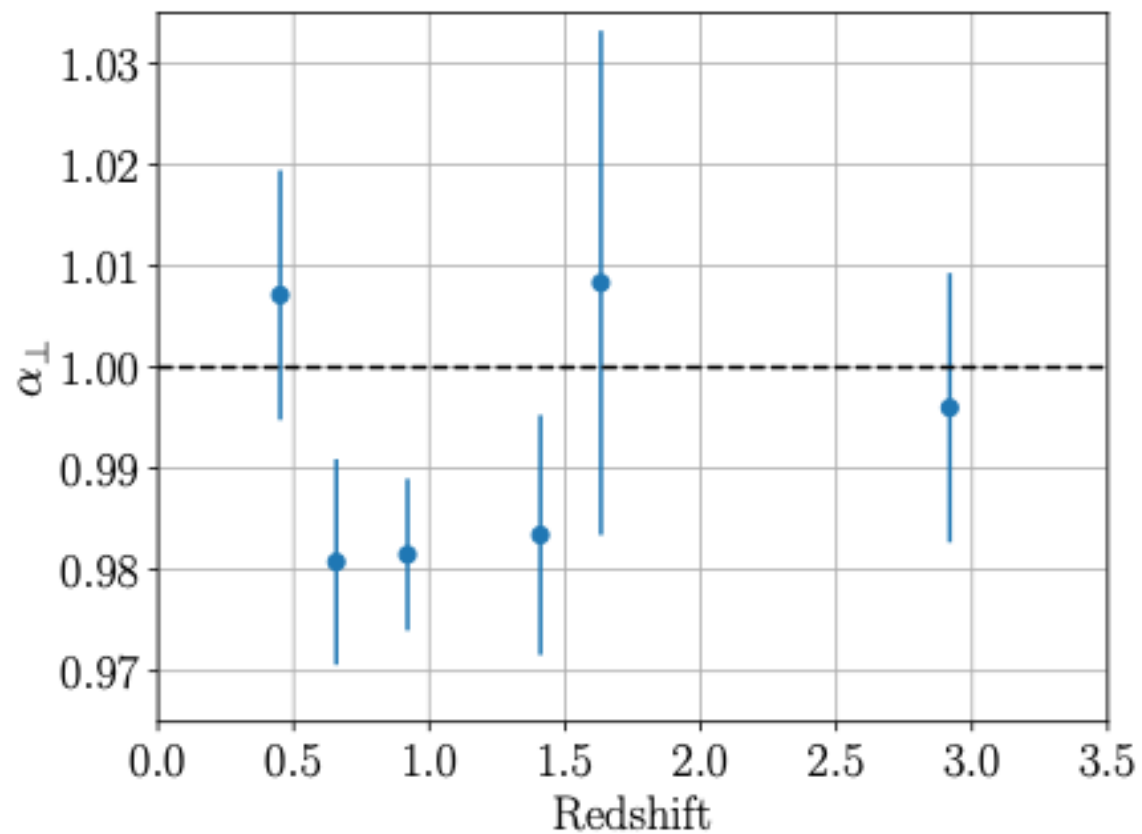




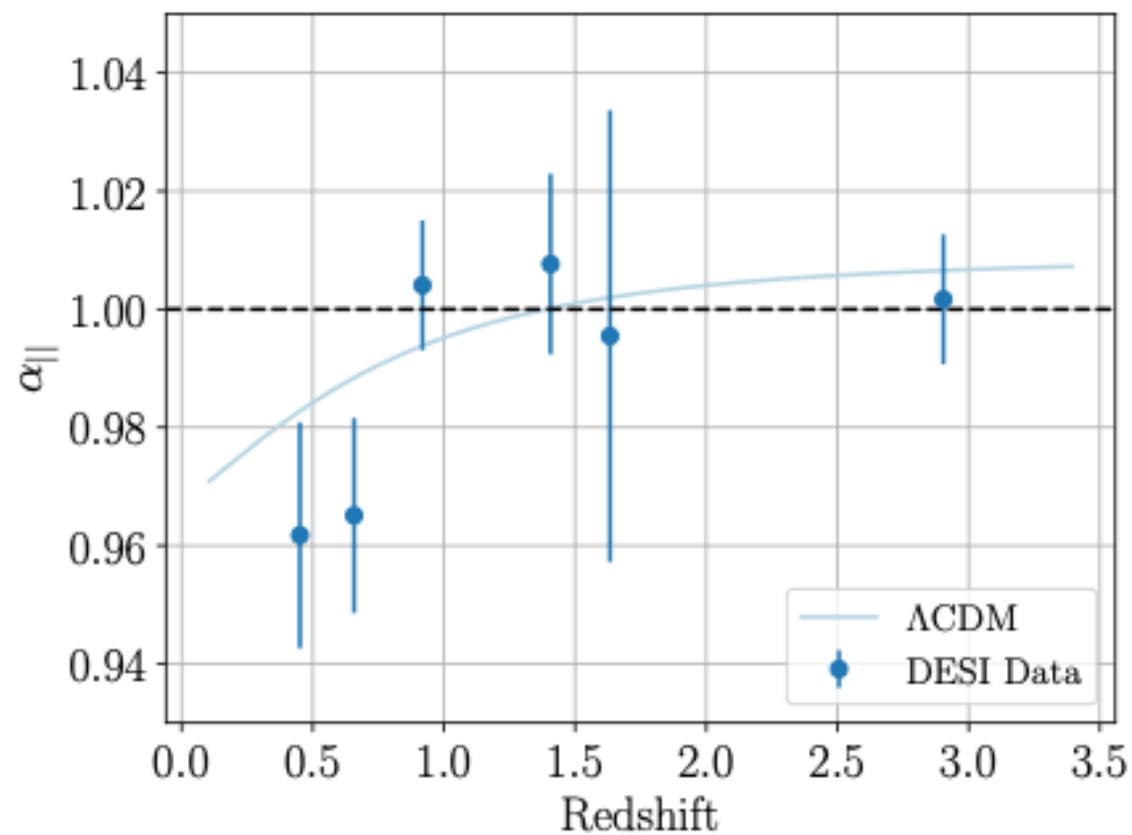
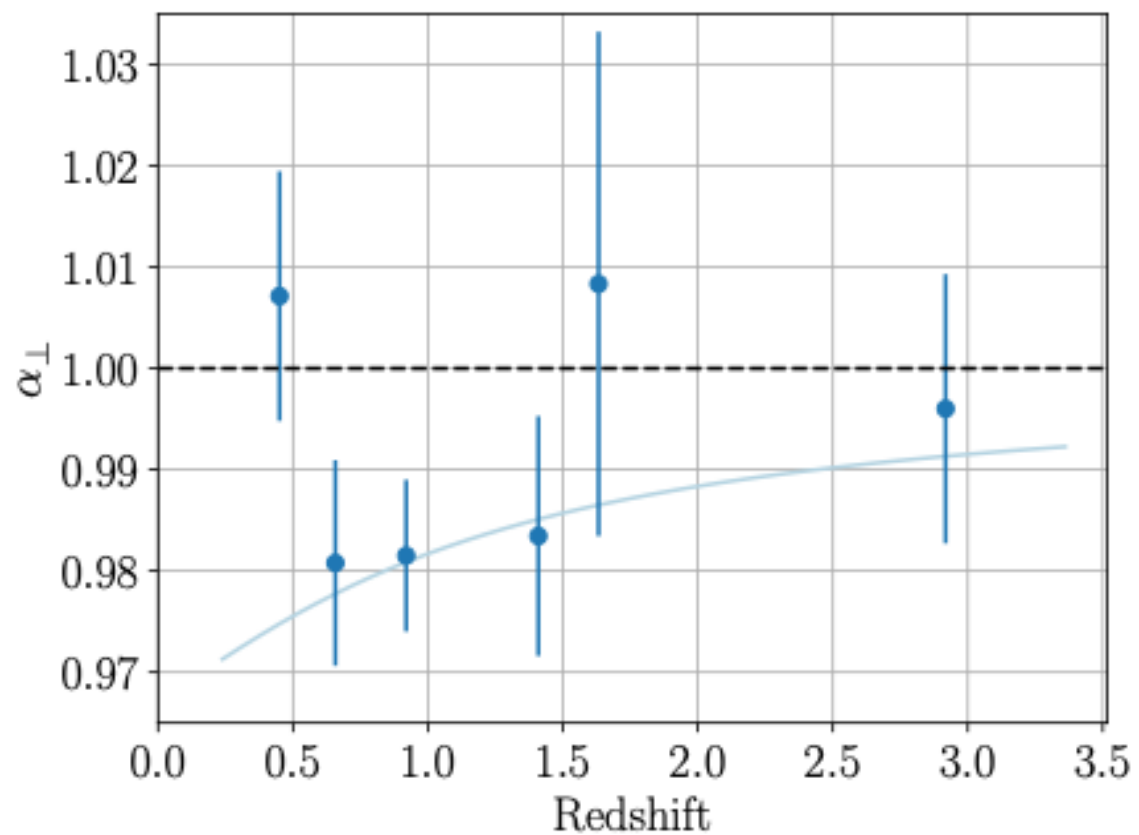
DESI Observations



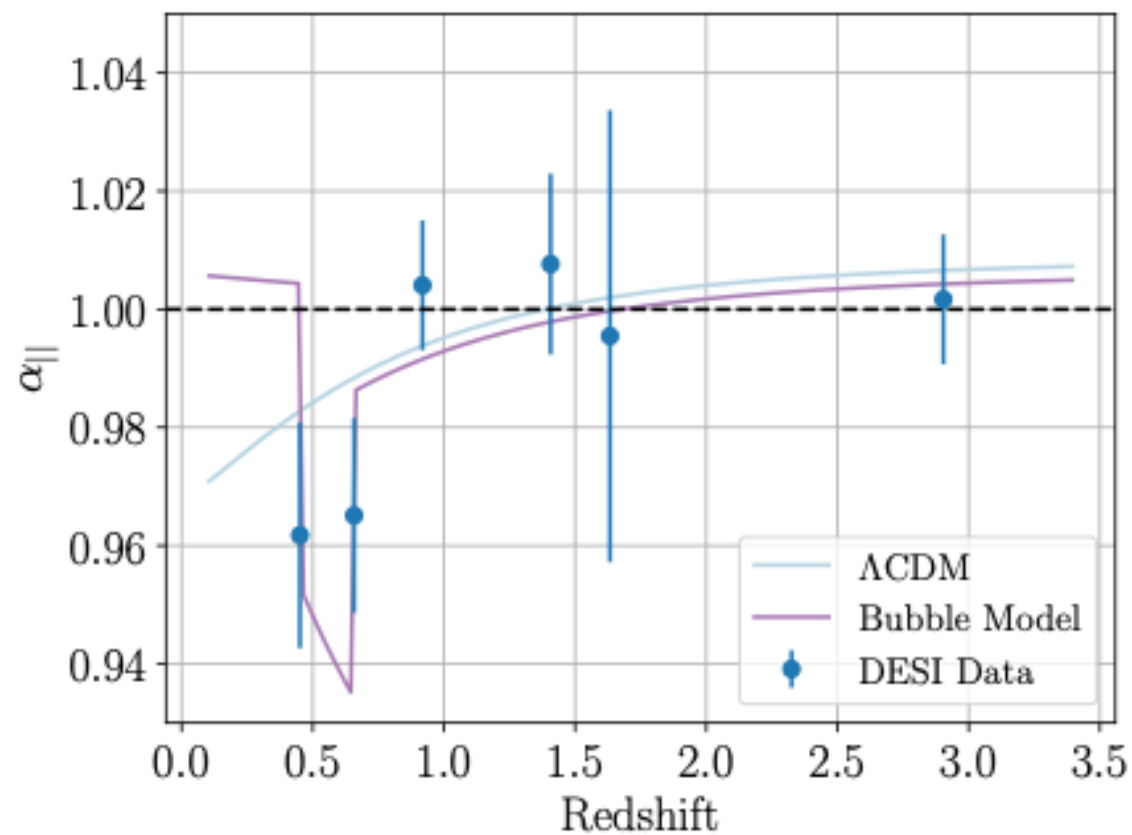
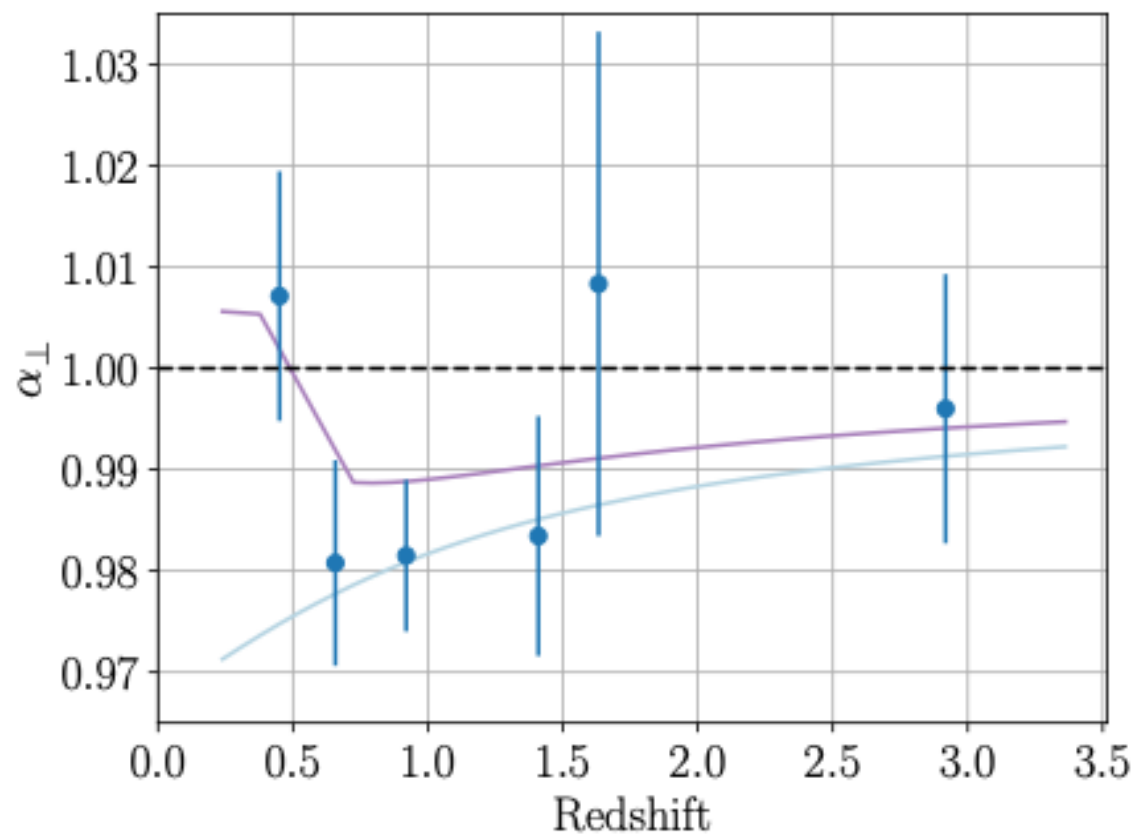
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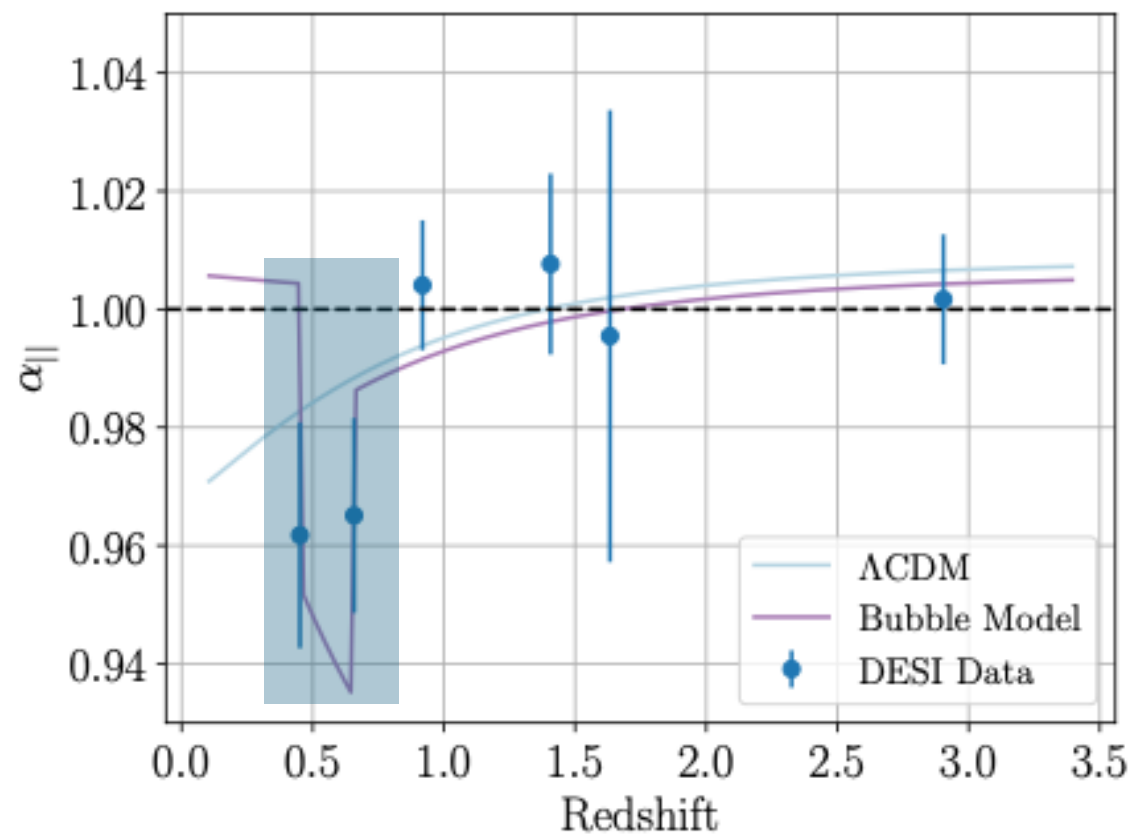
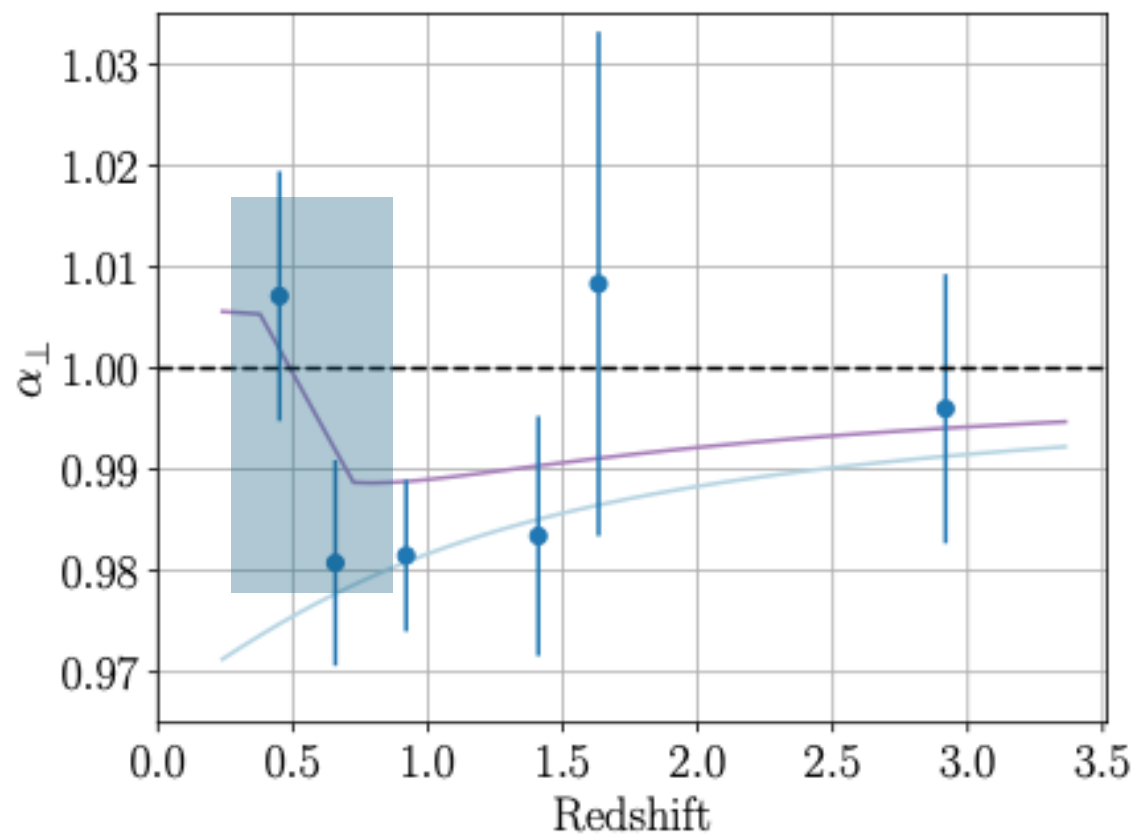
DESI Observations



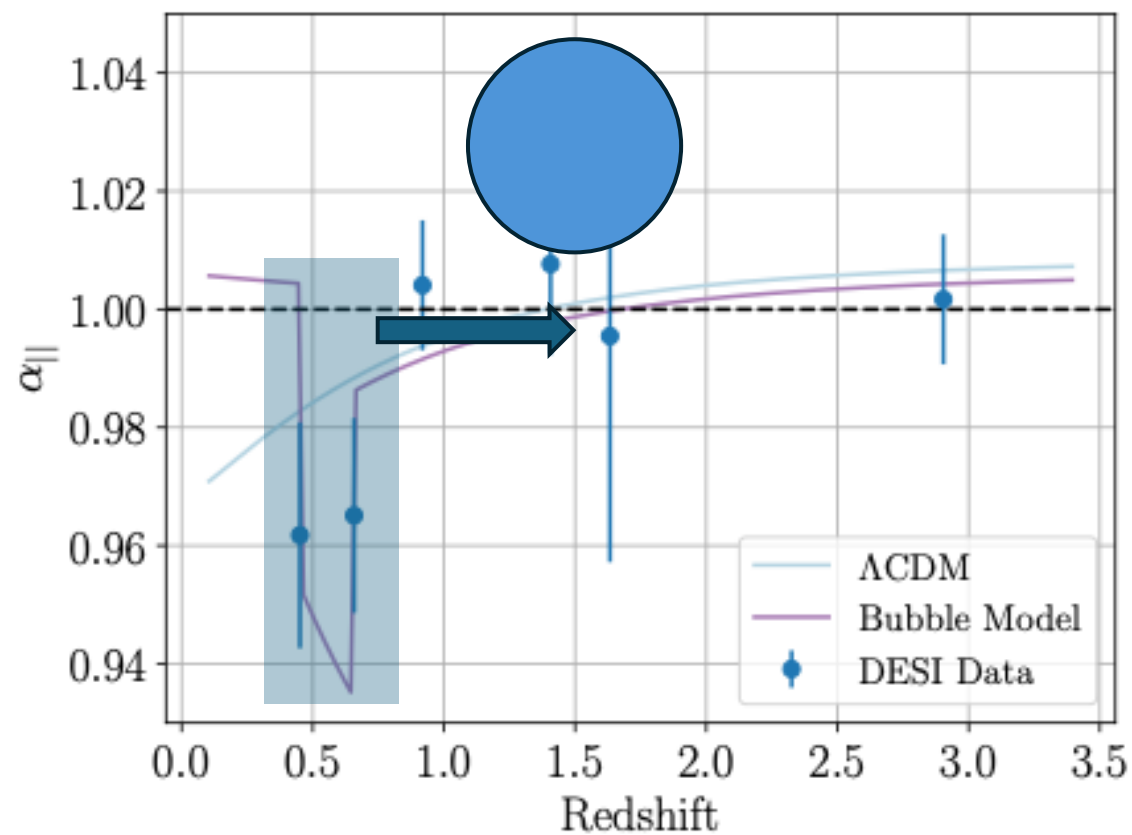
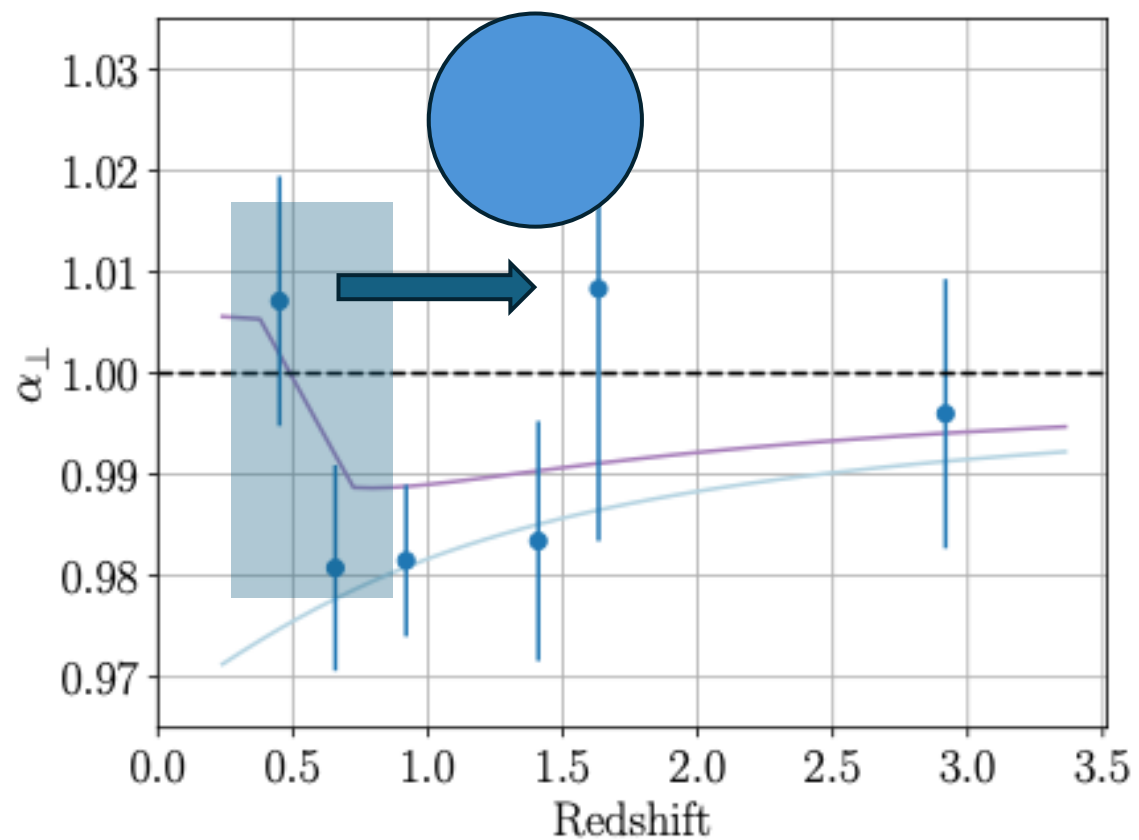
DESI Observations



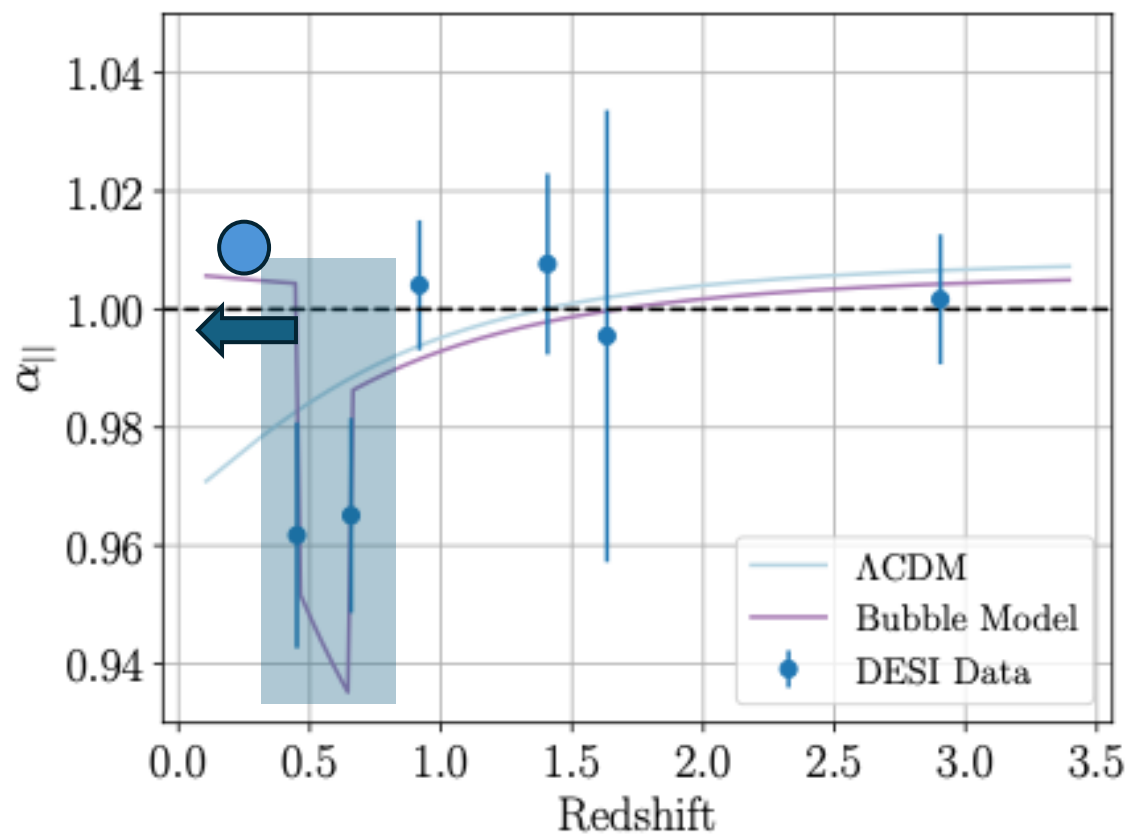
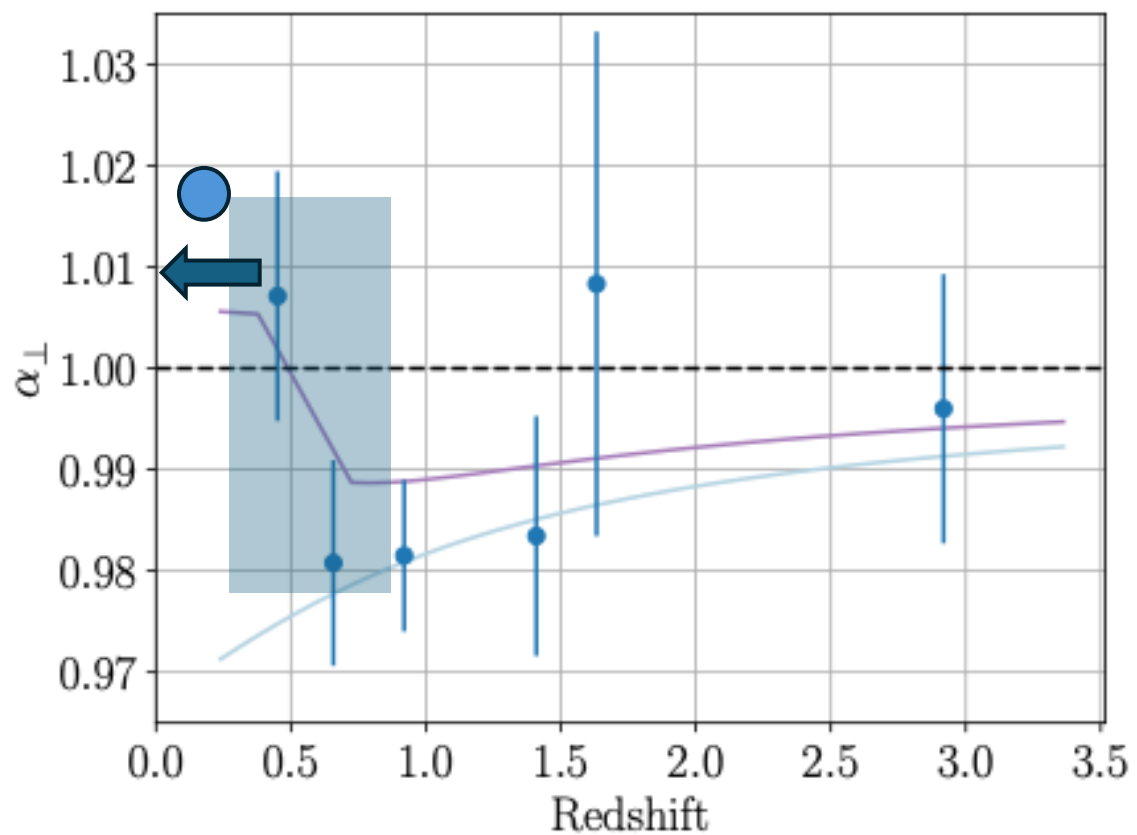
DESI Observations



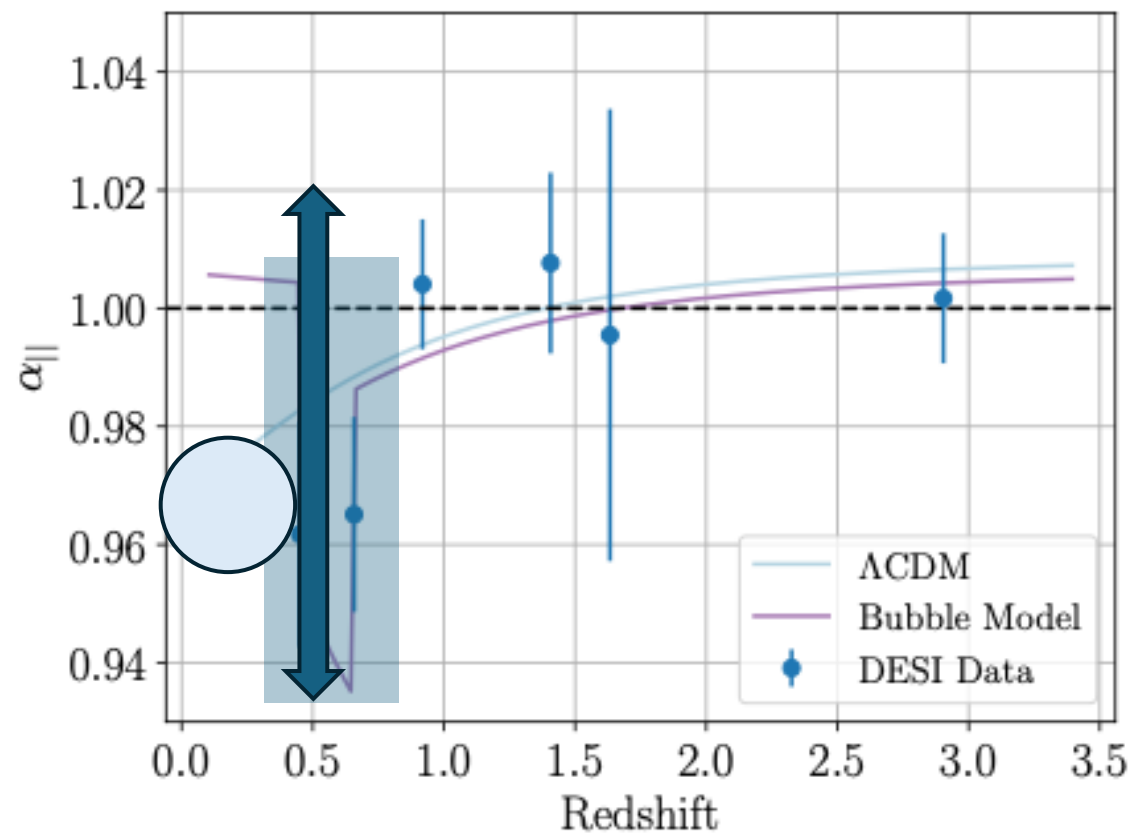
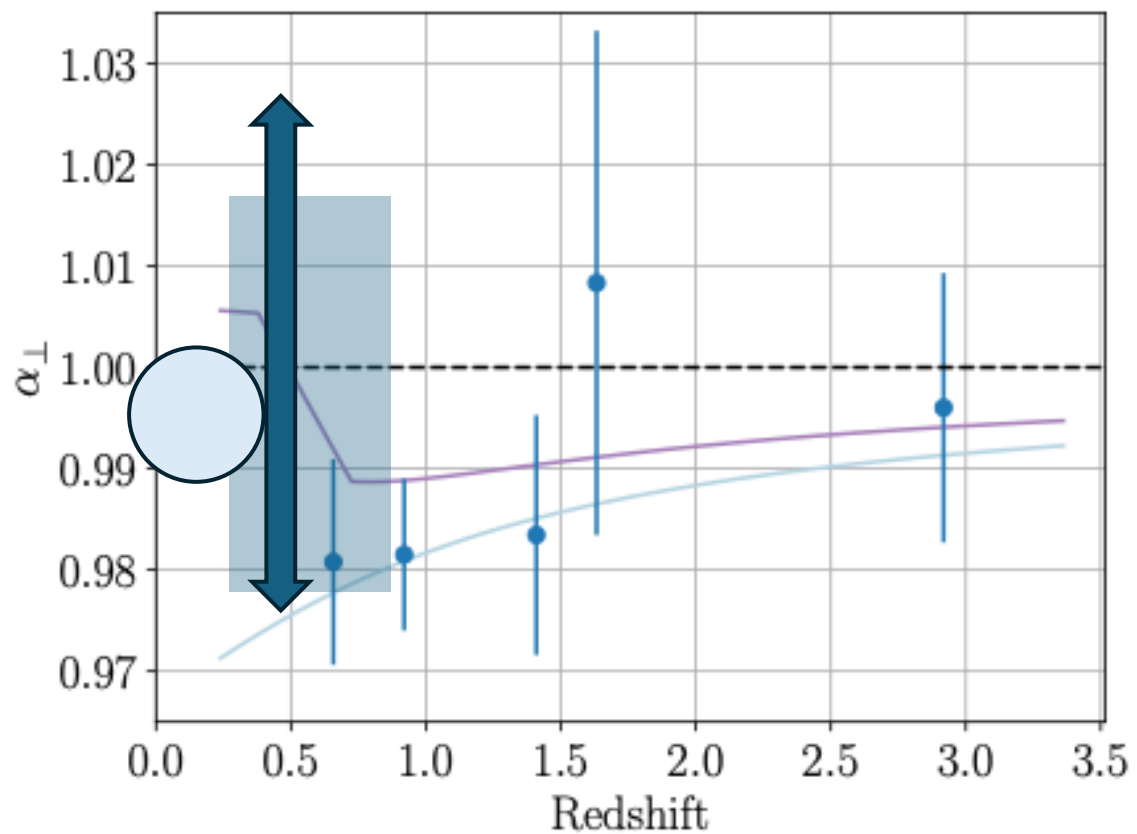
DESI Observations



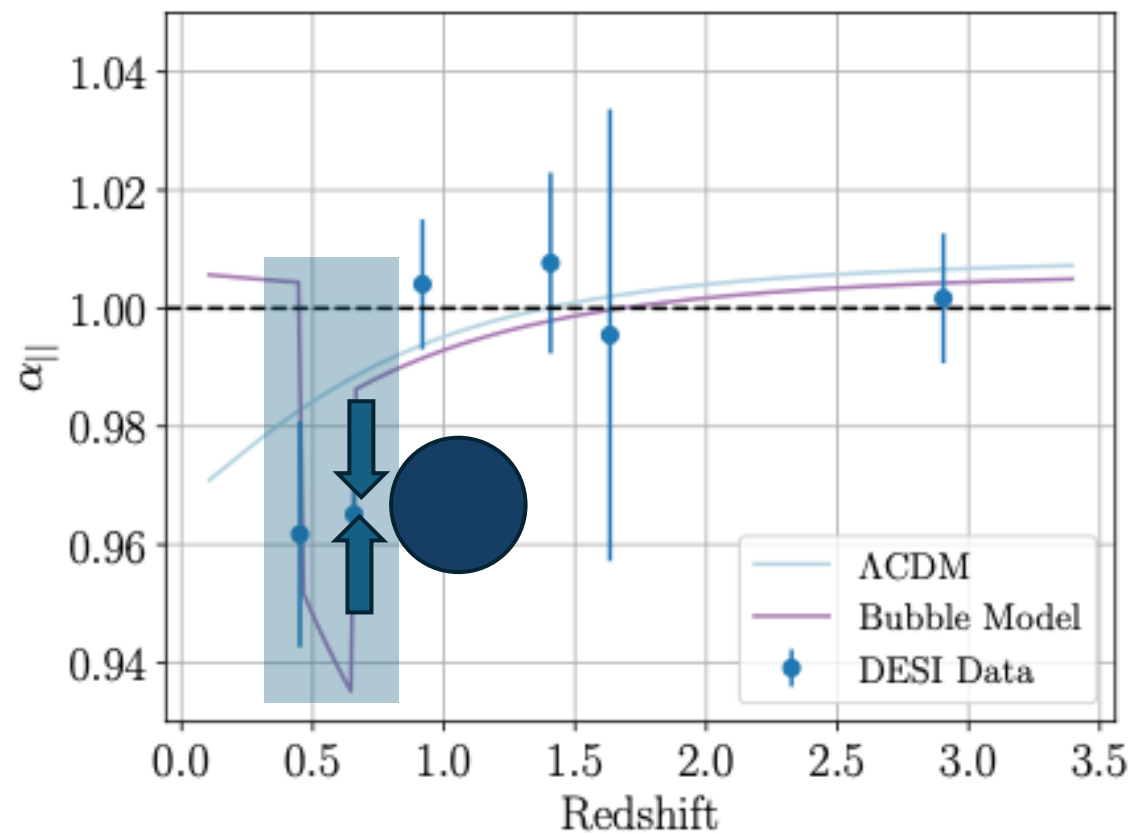
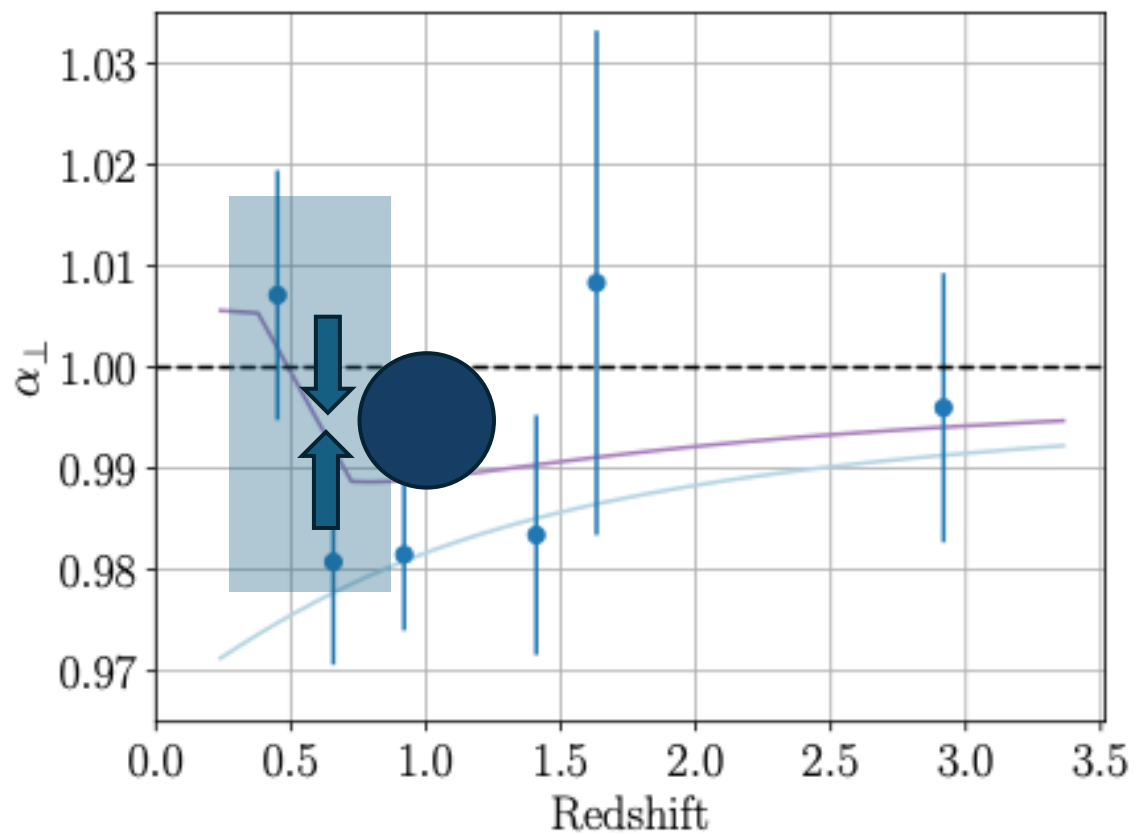
DESI Observations



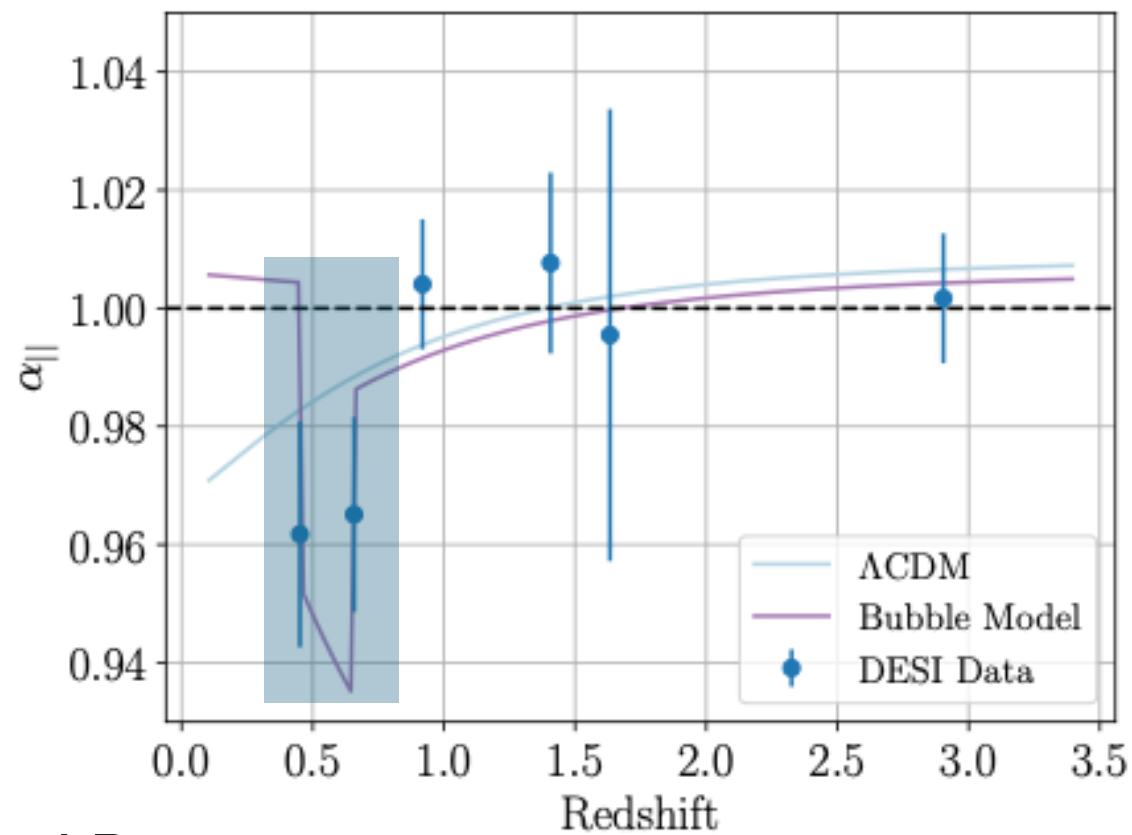
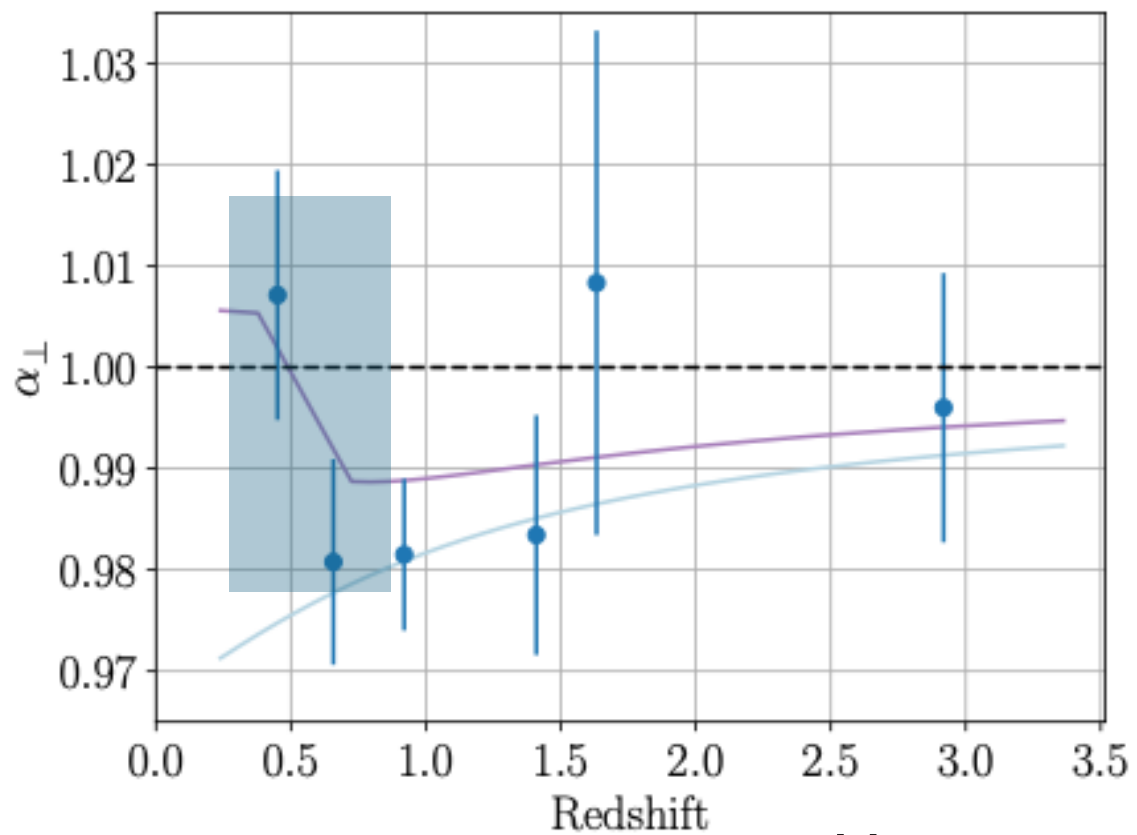
DESI Observations



DESI Observations



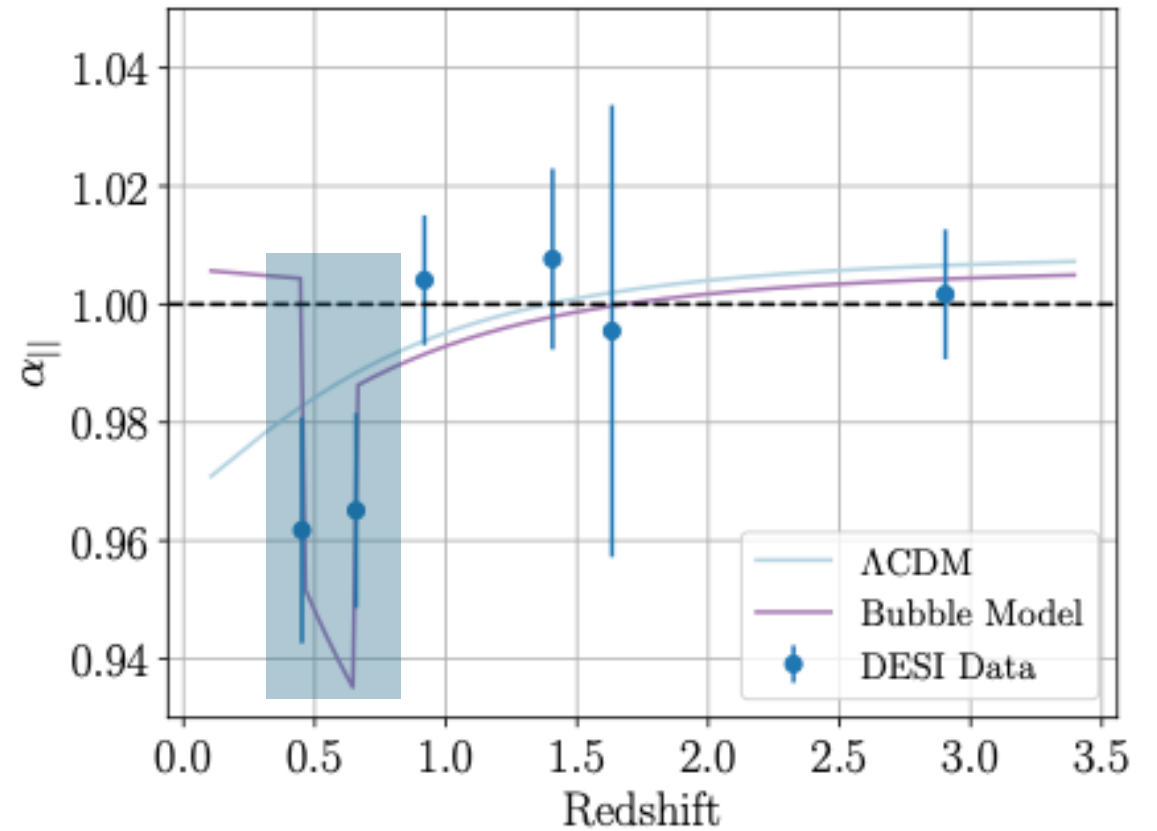
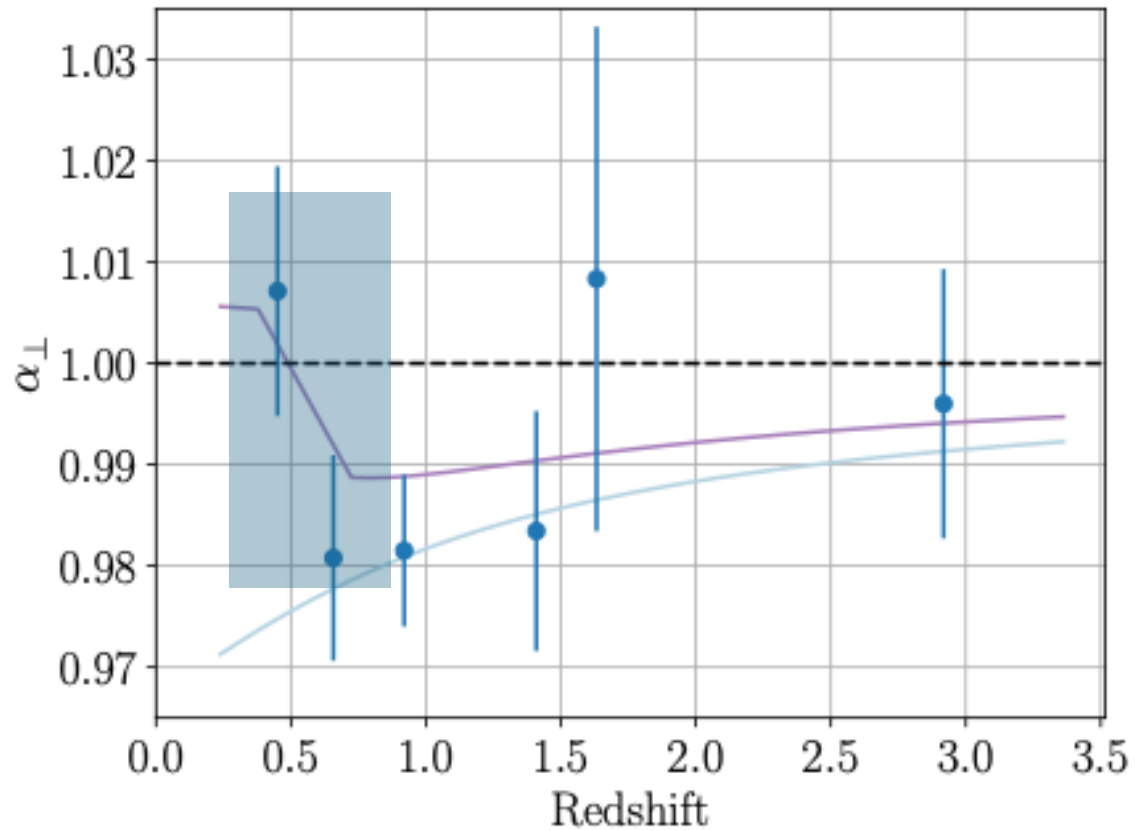
DESI Observations



Unconstrained Parameters

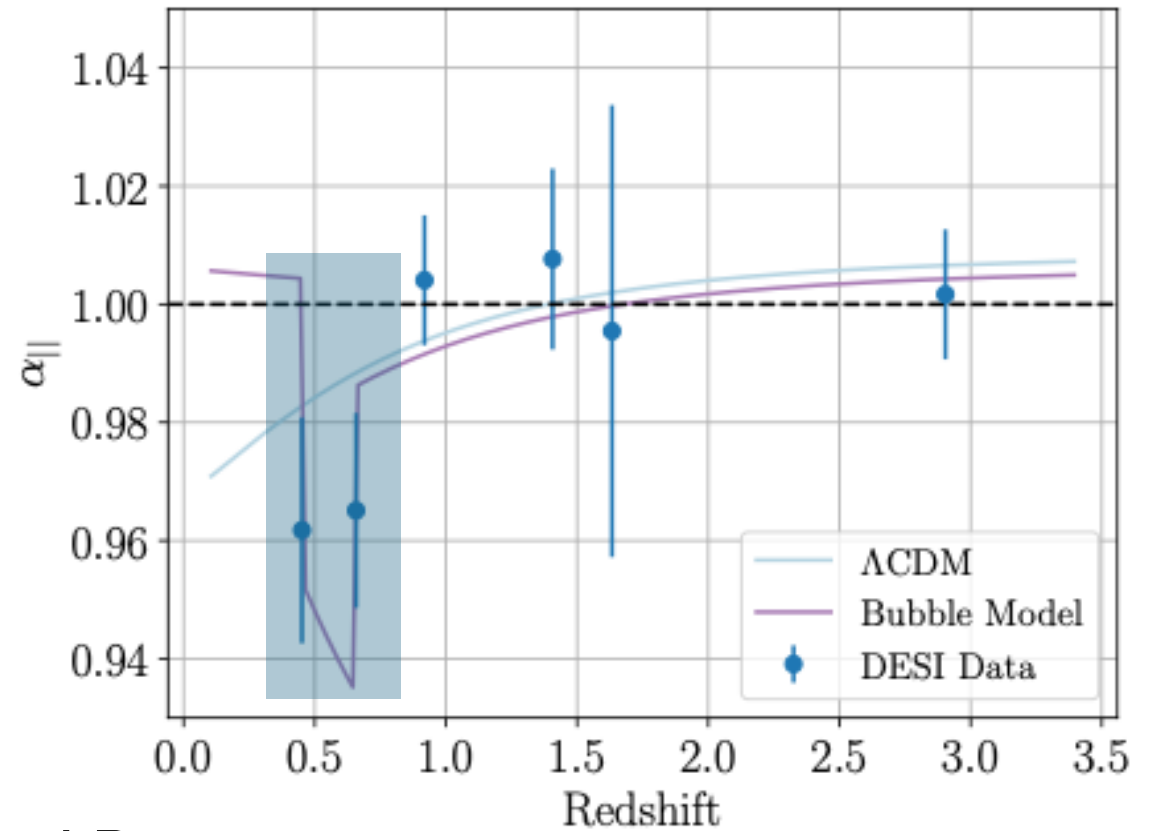
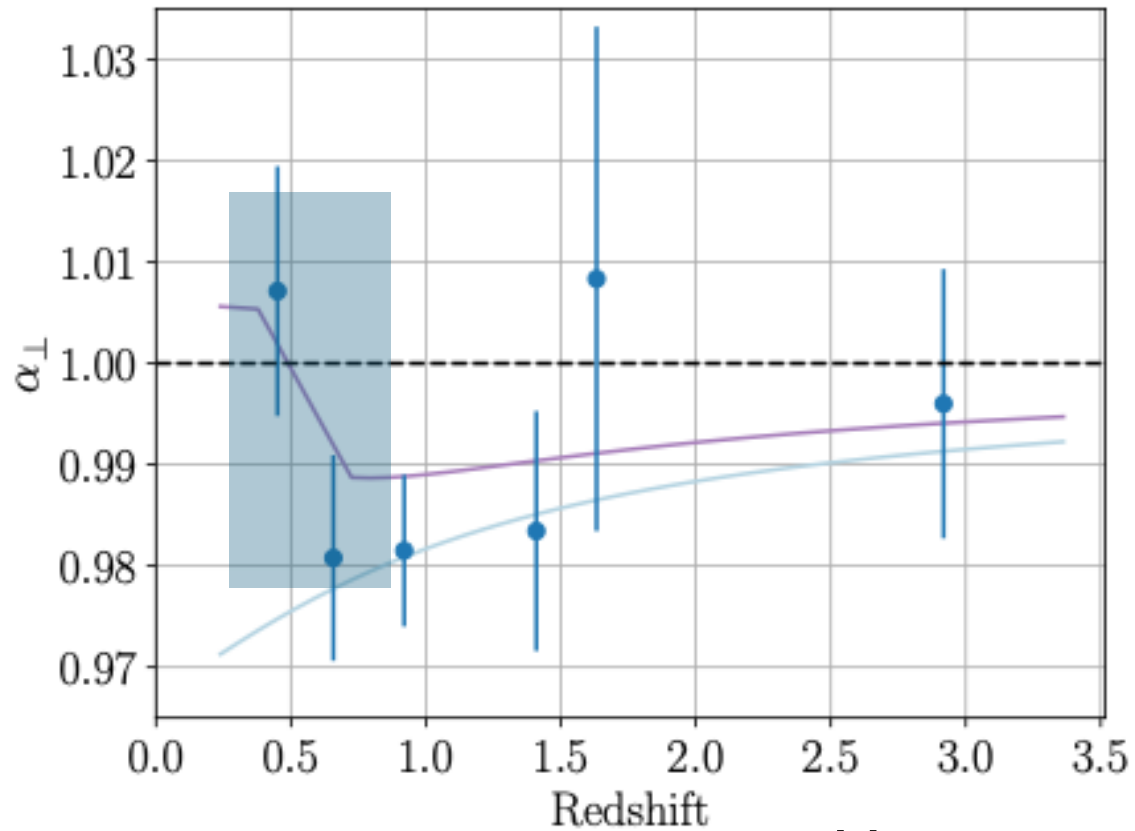
DESI Observations

10% less DE inside Bubble
Nucleated at Redshift 1.4



DESI Observations

10% less DE inside Bubble
Nucleated at Redshift 1.4



Unconstrained Parameters:
Use CMB

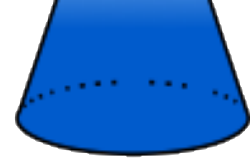


t_1

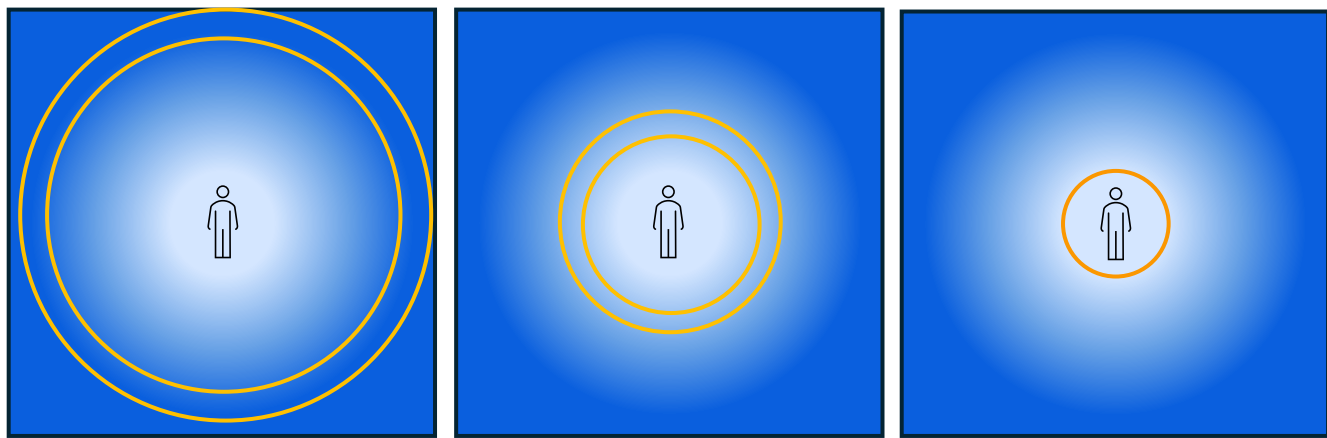
t_2

t_3

Time



Space
Varying

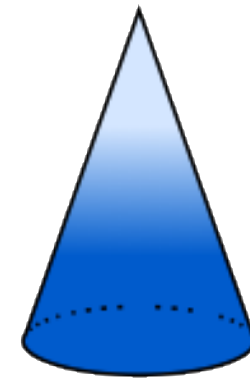


t_1

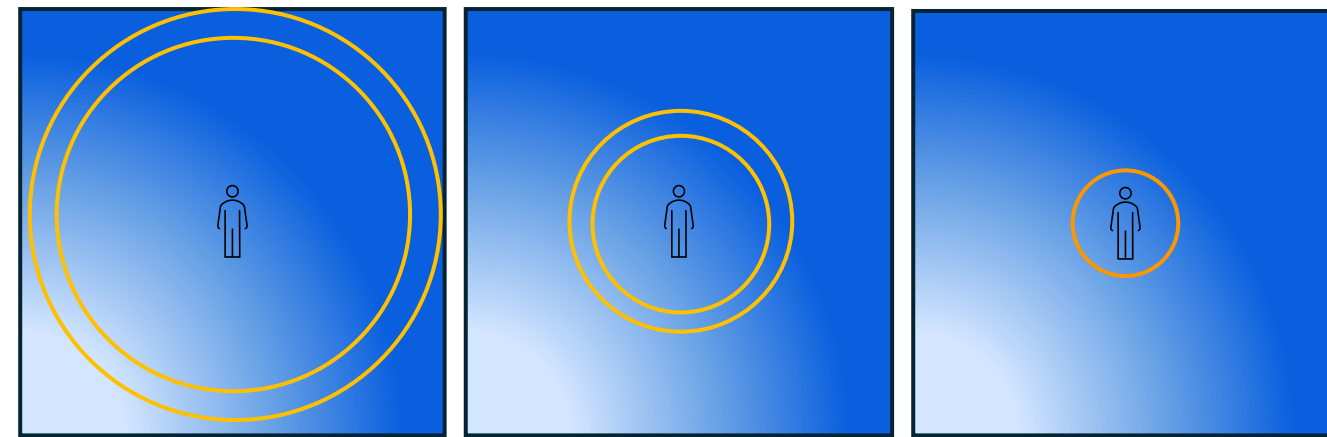
t_2

t_3

Time



Off
Centre

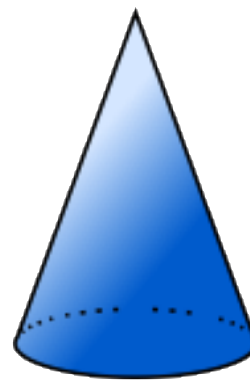


t_1

t_2

t_3

Time





t_1

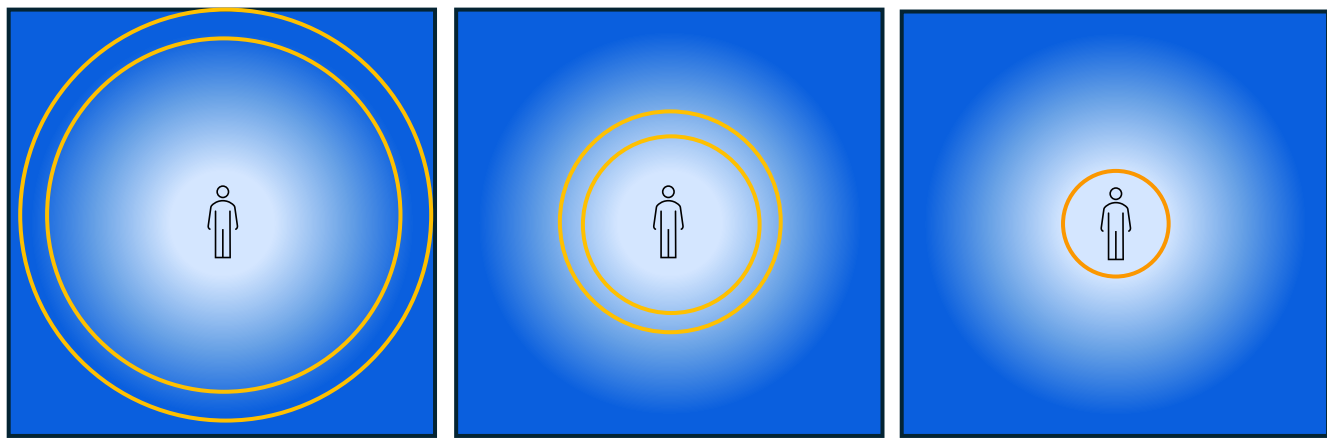
t_2

t_3

Time



Space
Varying



t_1

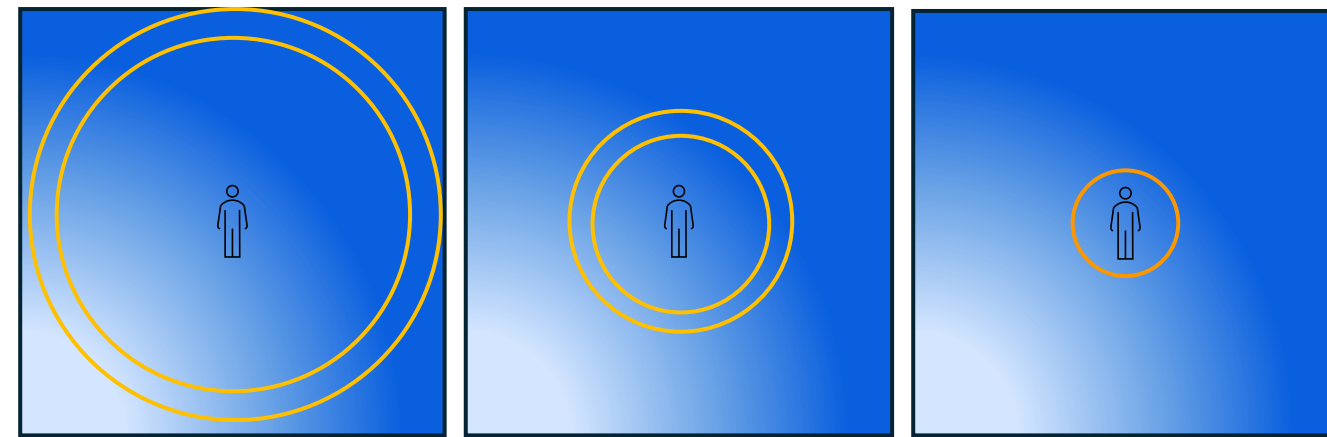
t_2

t_3

Time



Off
Centre

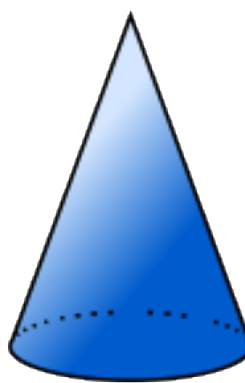


t_1

t_2

t_3

Time



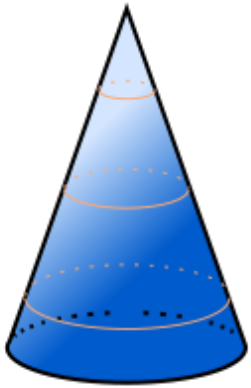
CMB Constraints

CMB Constraints

Off Centre:

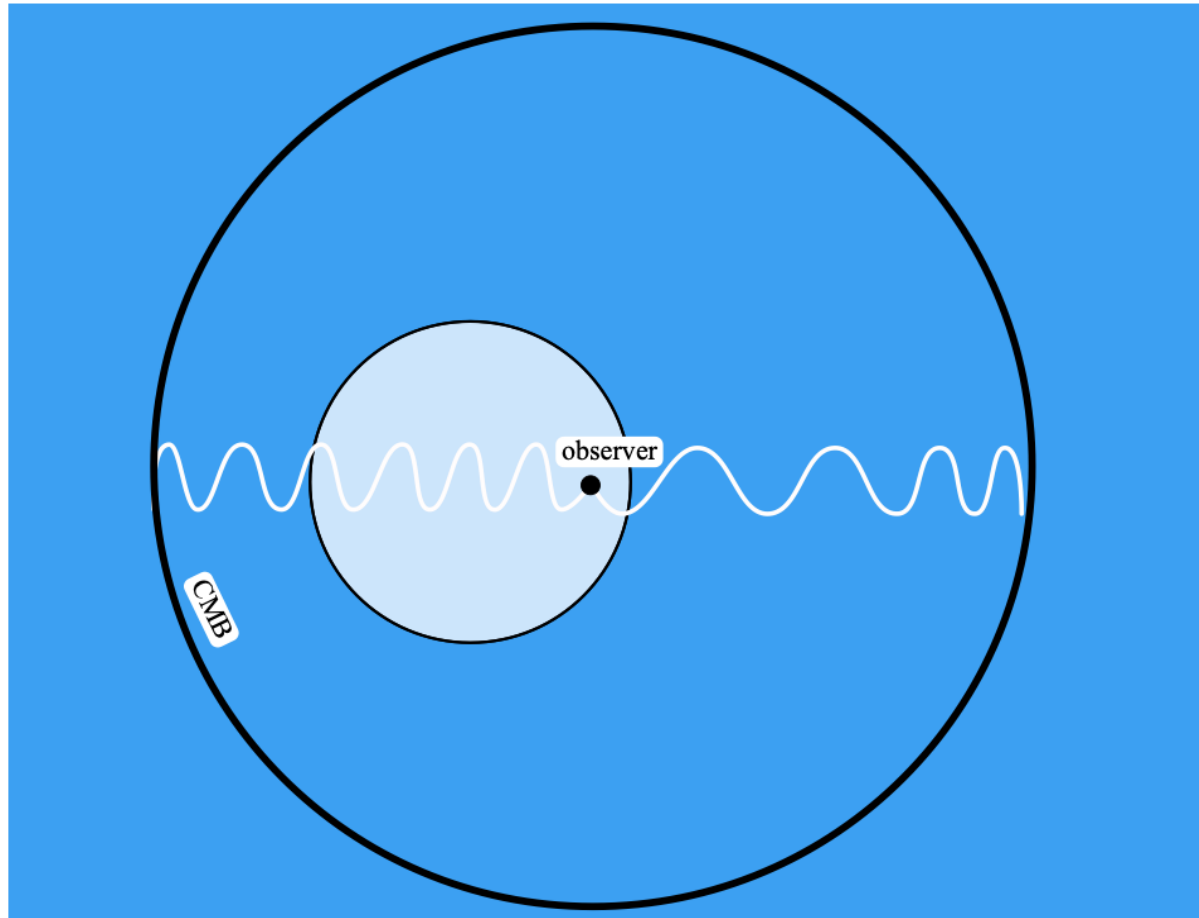
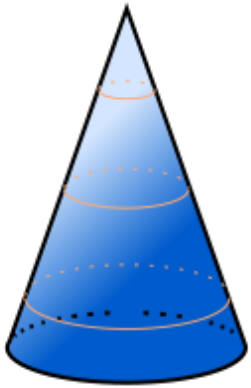
CMB Constraints

Off Centre:



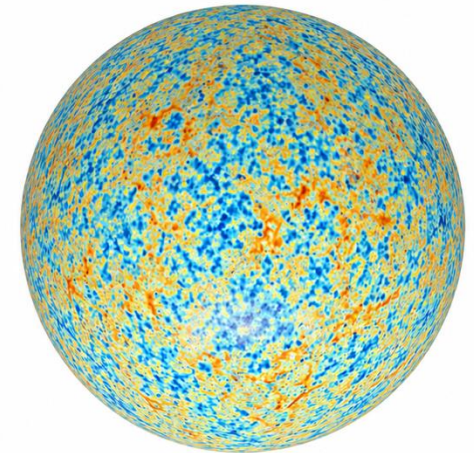
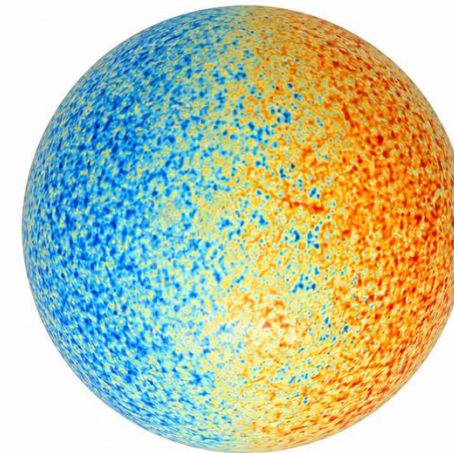
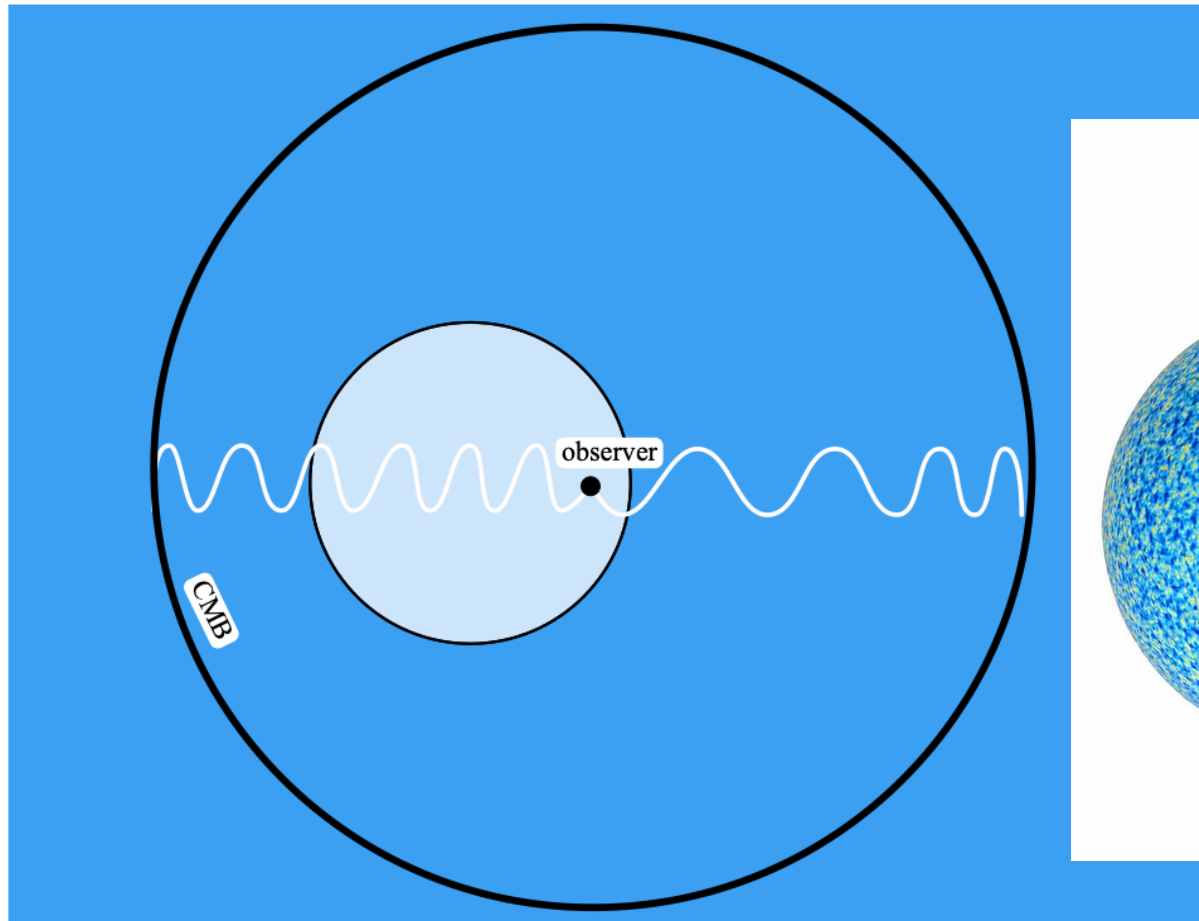
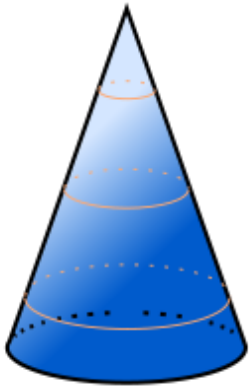
CMB Constraints

Off Centre:



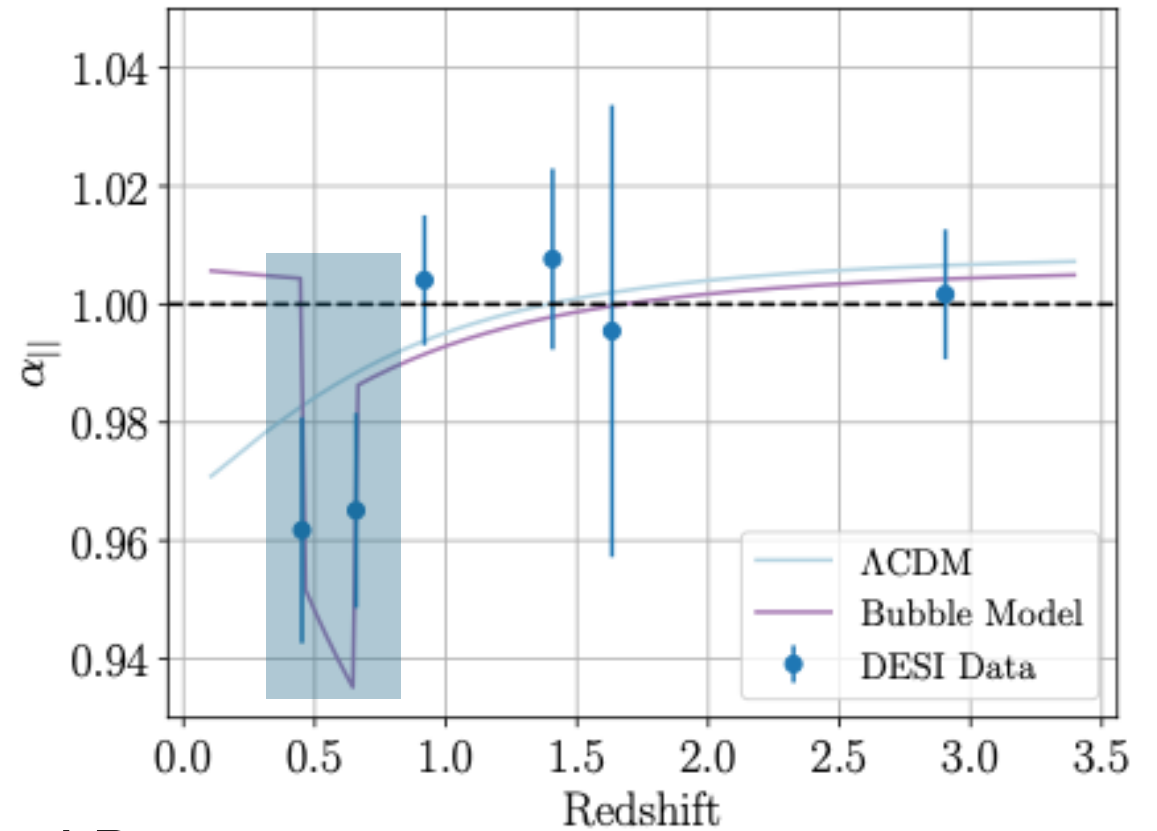
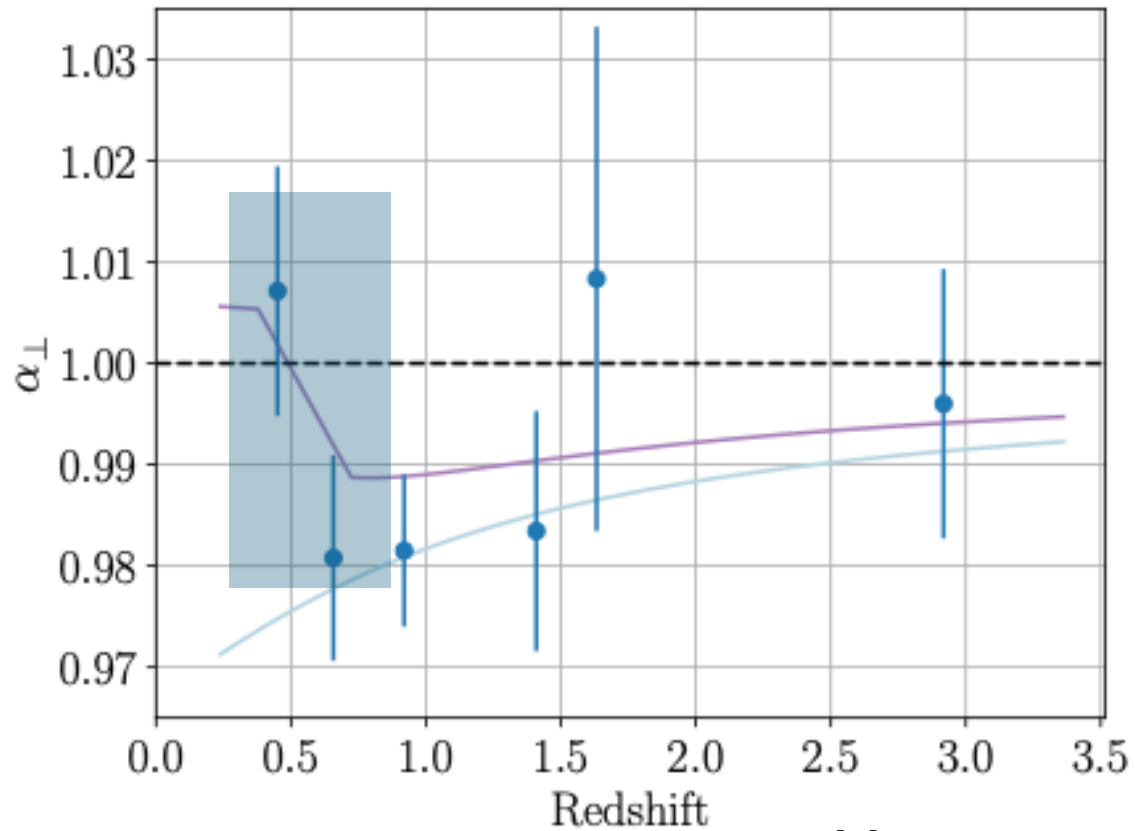
CMB Constraints

Off Centre:



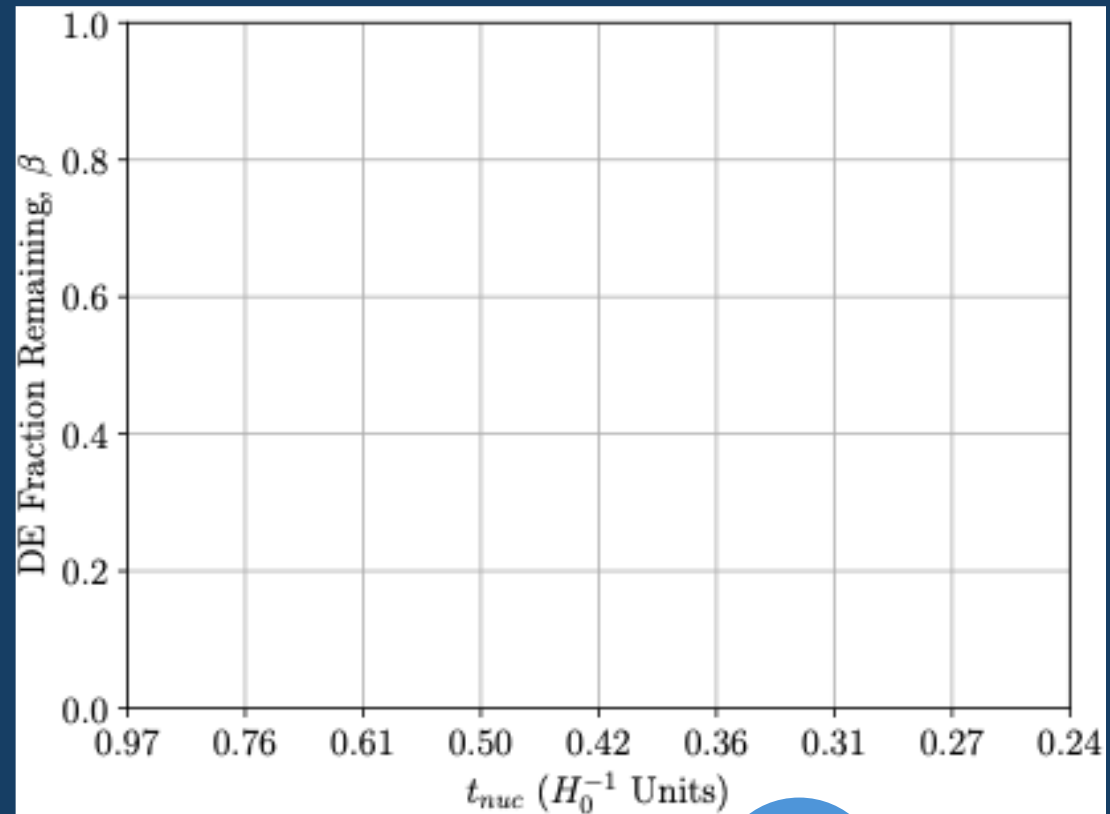
DESI Observations

10% less DE inside Bubble
Nucleated at Redshift 1.4



Unconstrained Parameters:
Use CMB

CMB Constraints

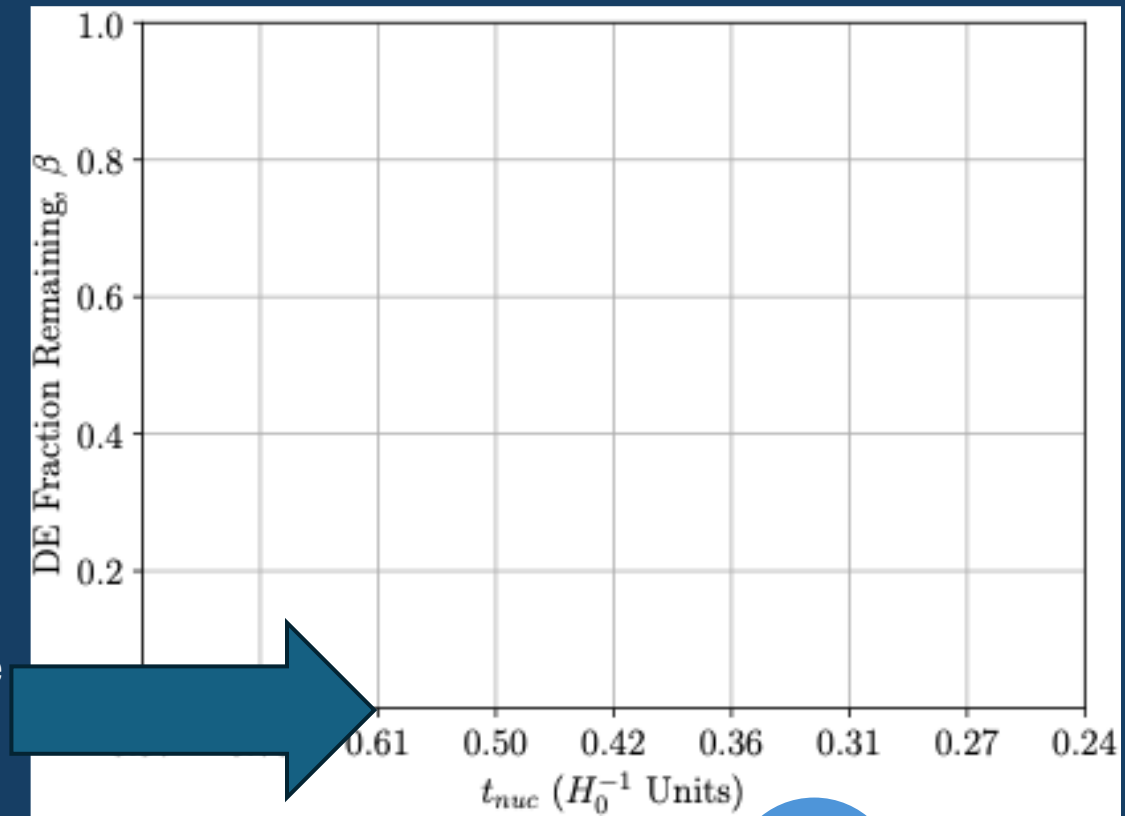


Small 

 Large

CMB Constraints

○ Empty, DE-free bubble



Small ○

Large ○

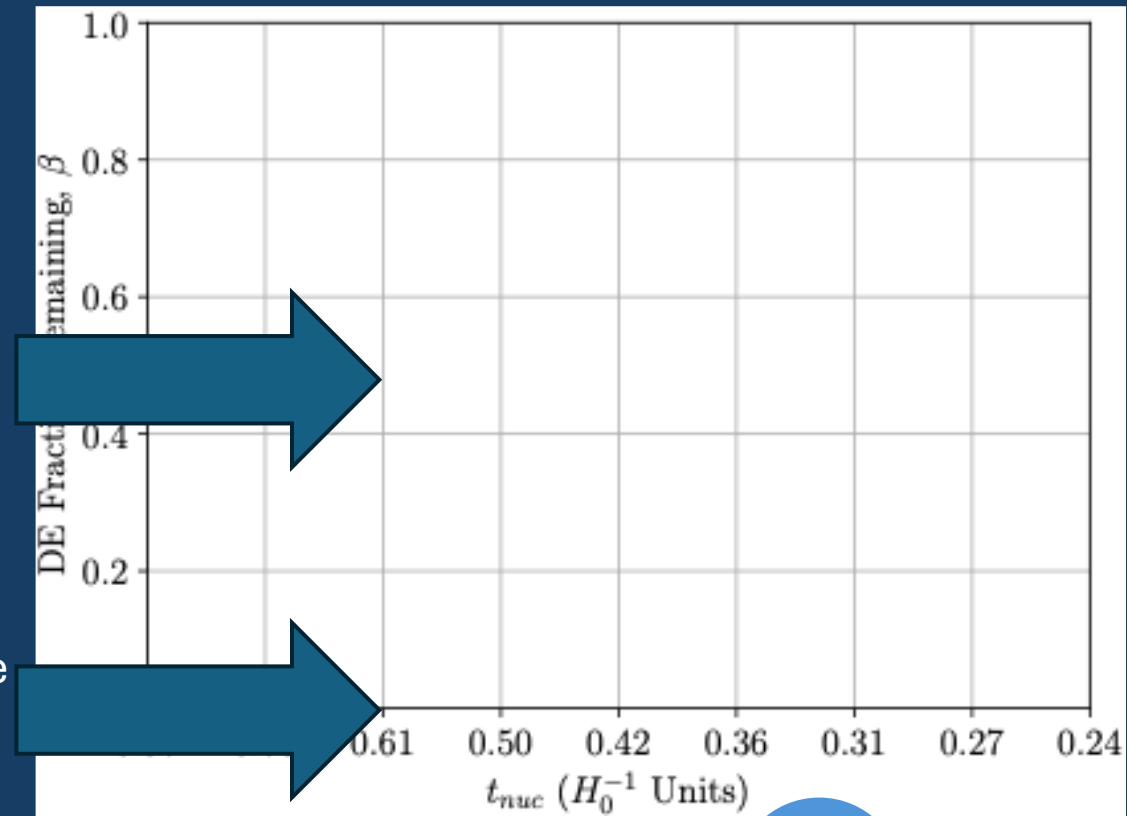
CMB Constraints



Half DE as outside



Empty, DE-free bubble



Small 

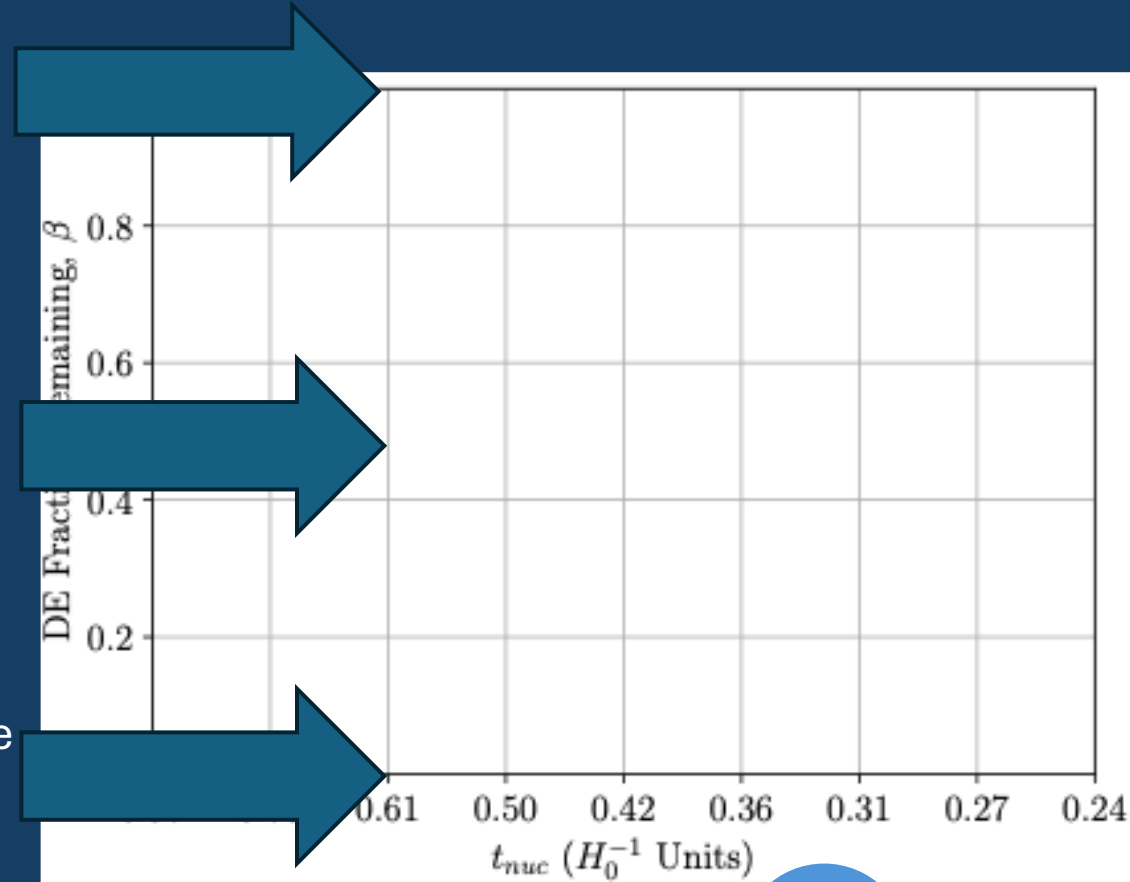
 Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

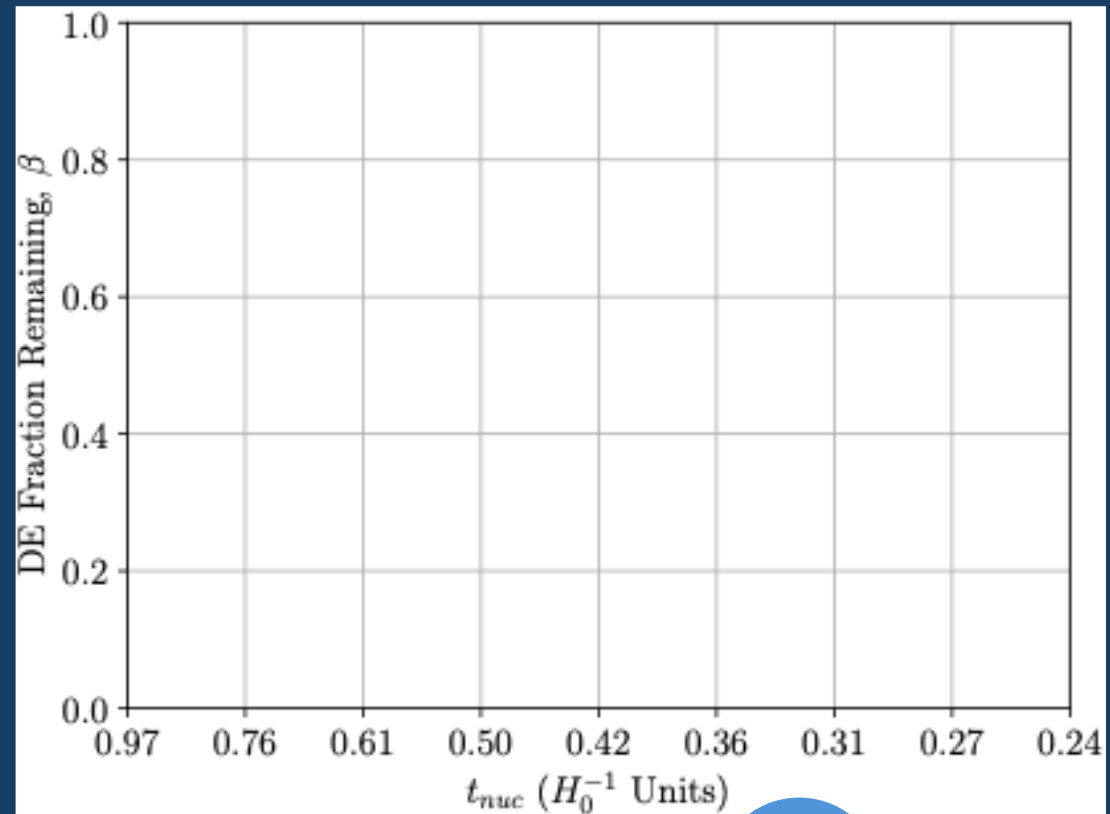
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

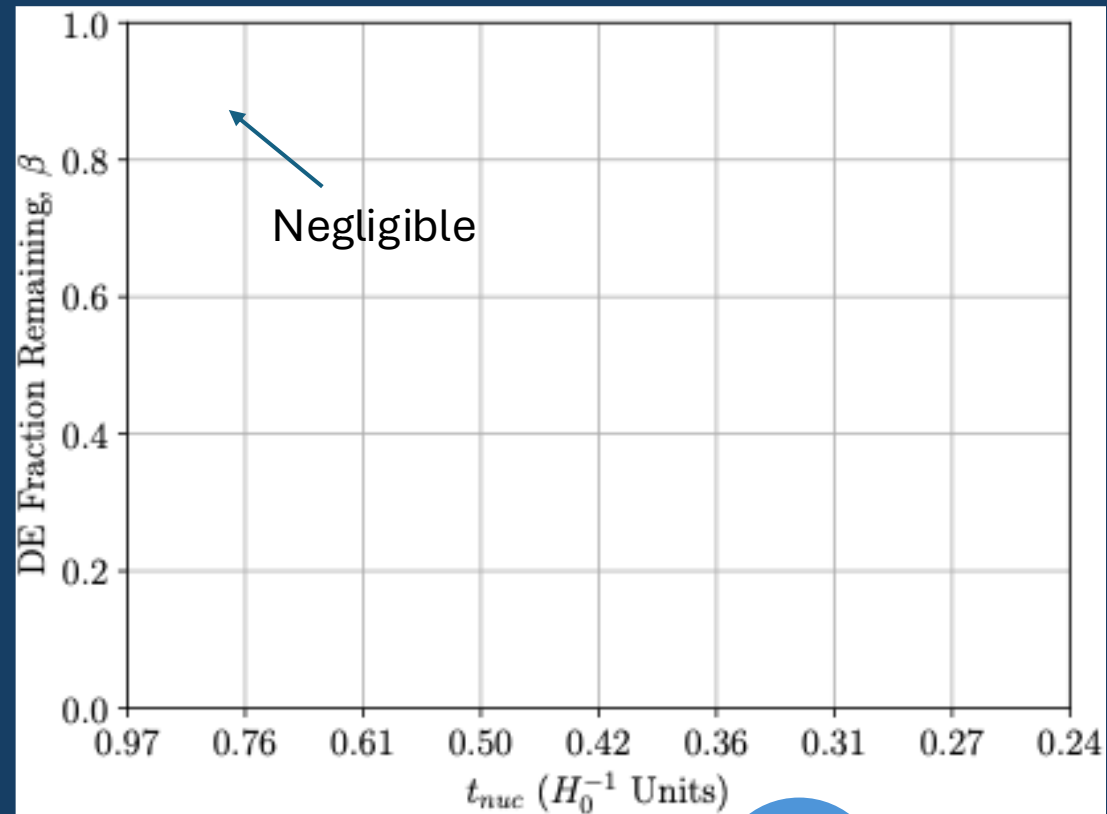
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

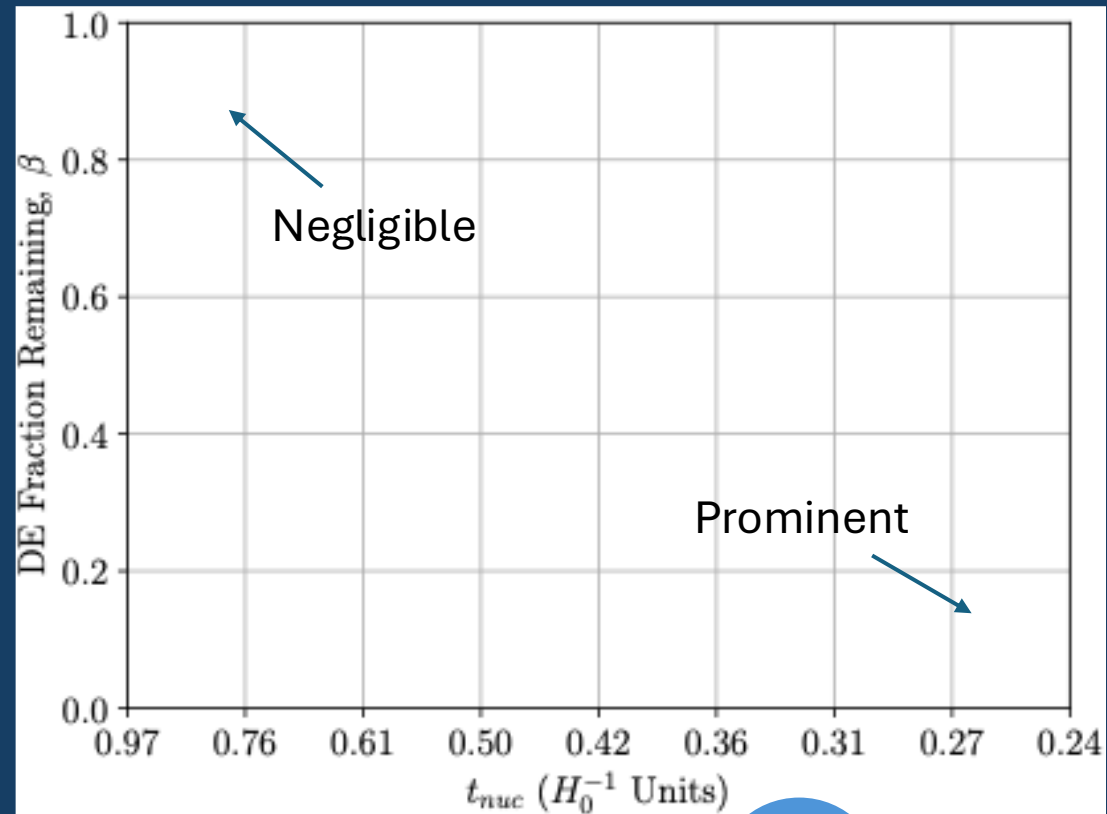
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

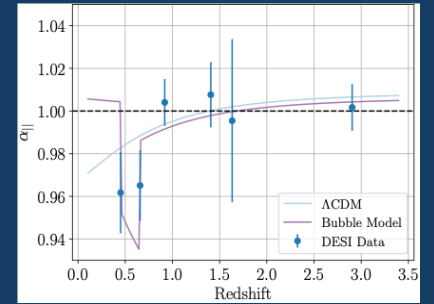
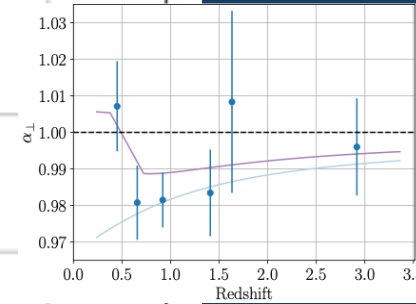
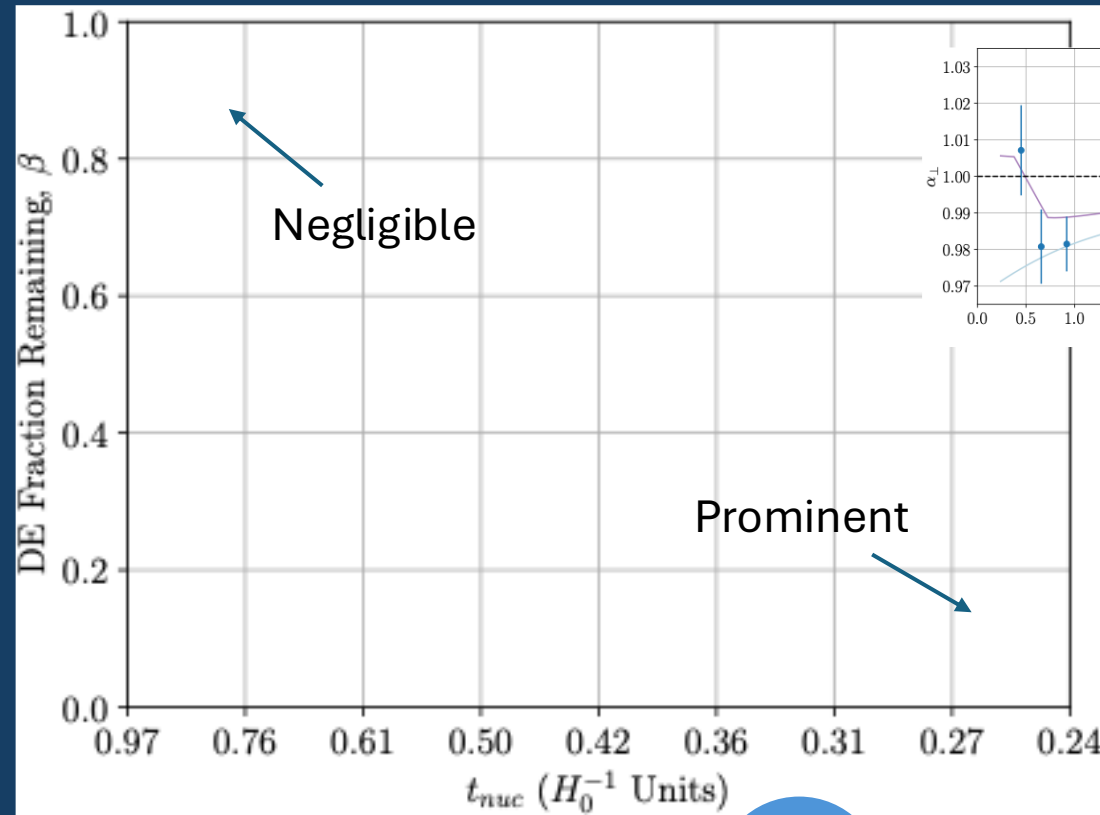
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

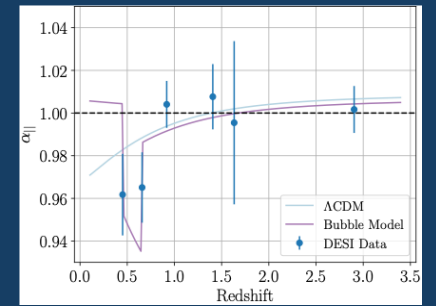
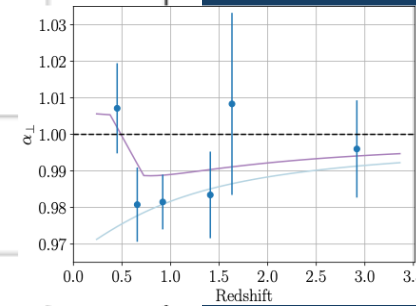
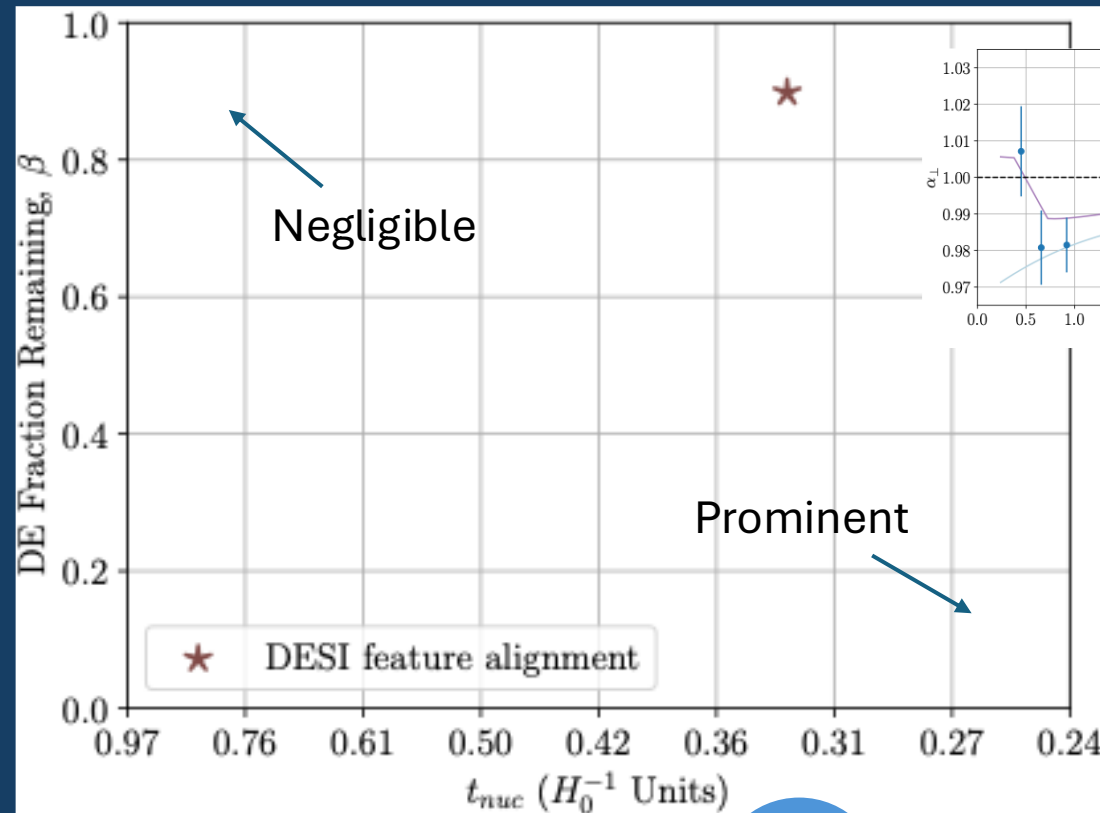
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

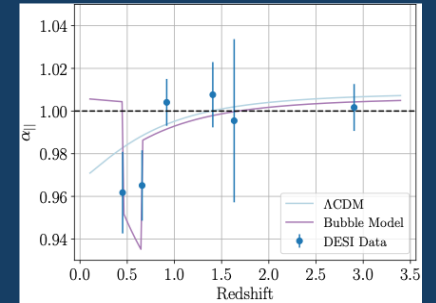
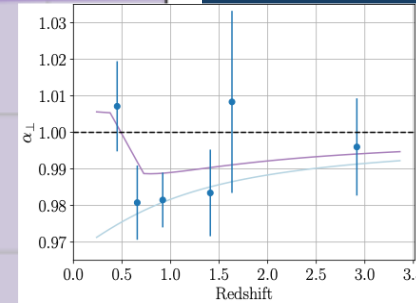
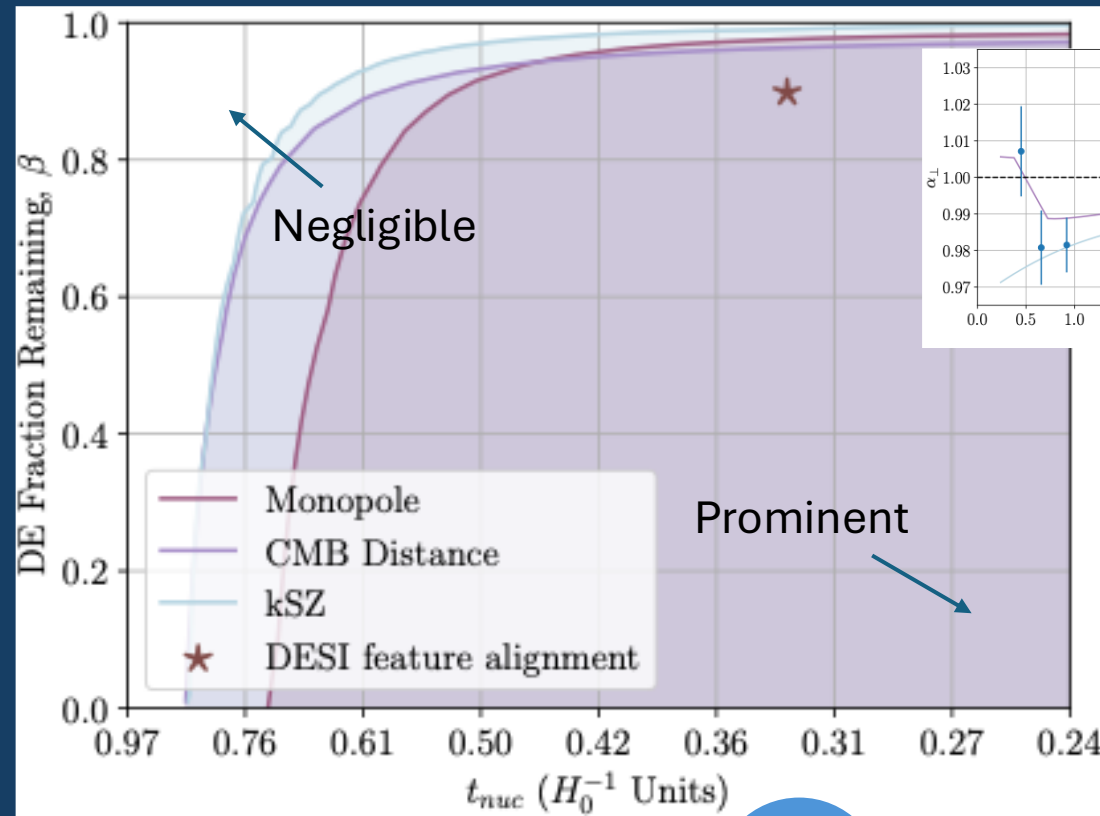
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

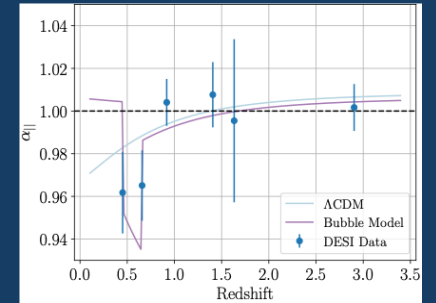
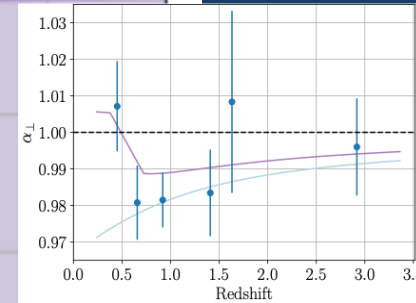
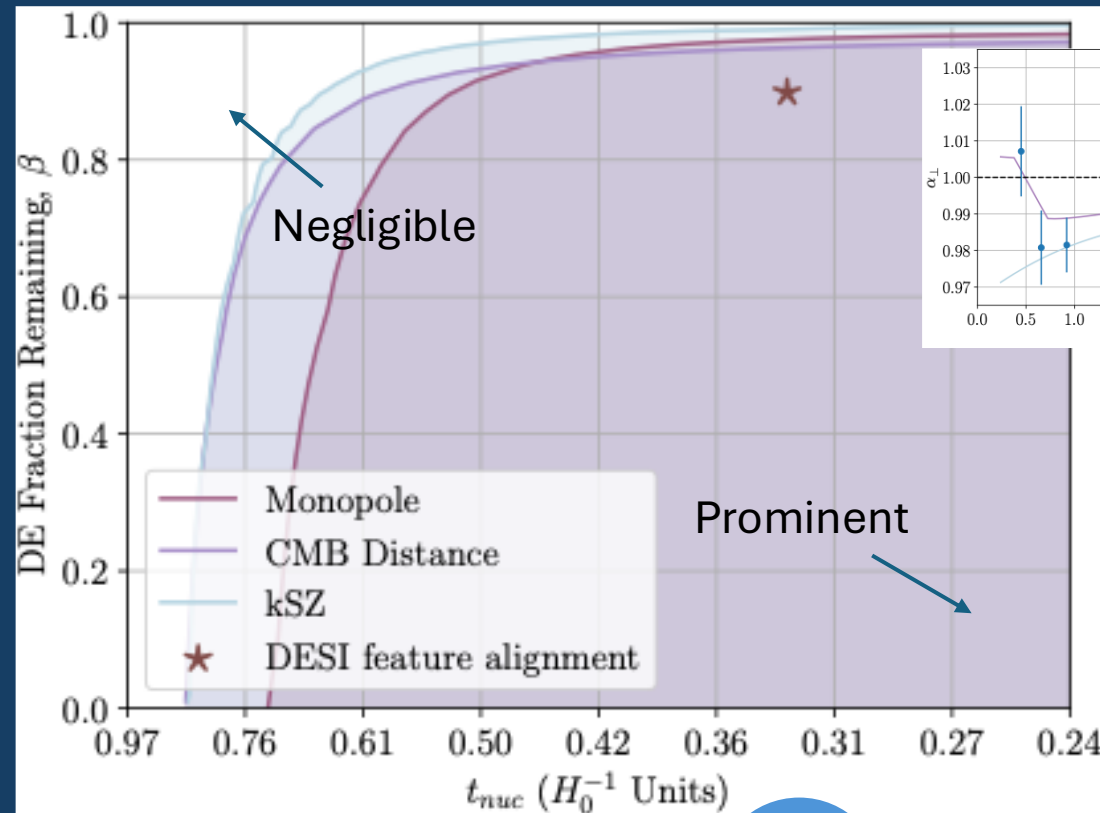
● Large

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

● Large

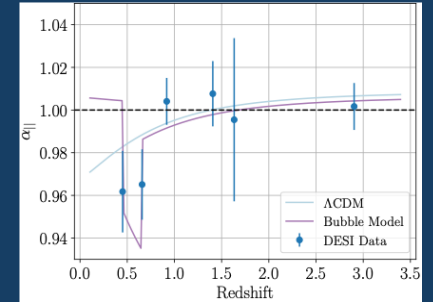
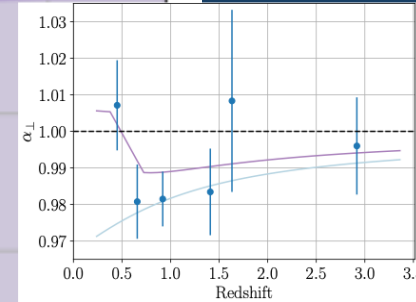
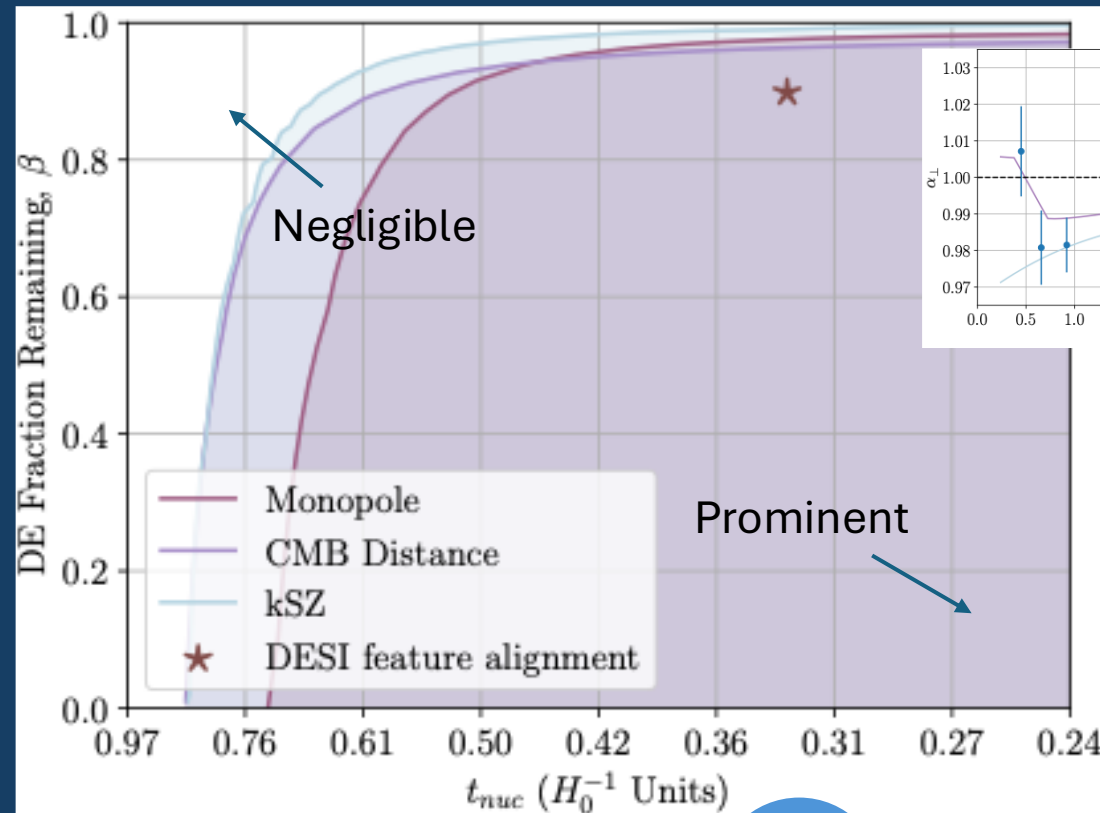
Upshot:

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

● Large

Upshot:

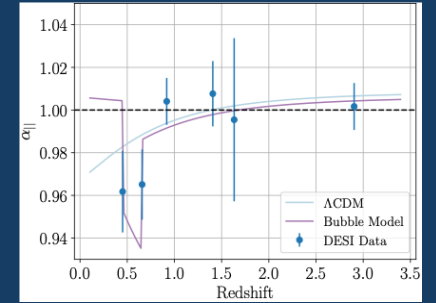
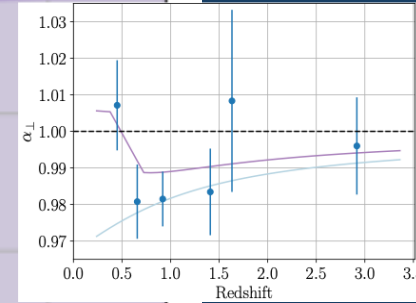
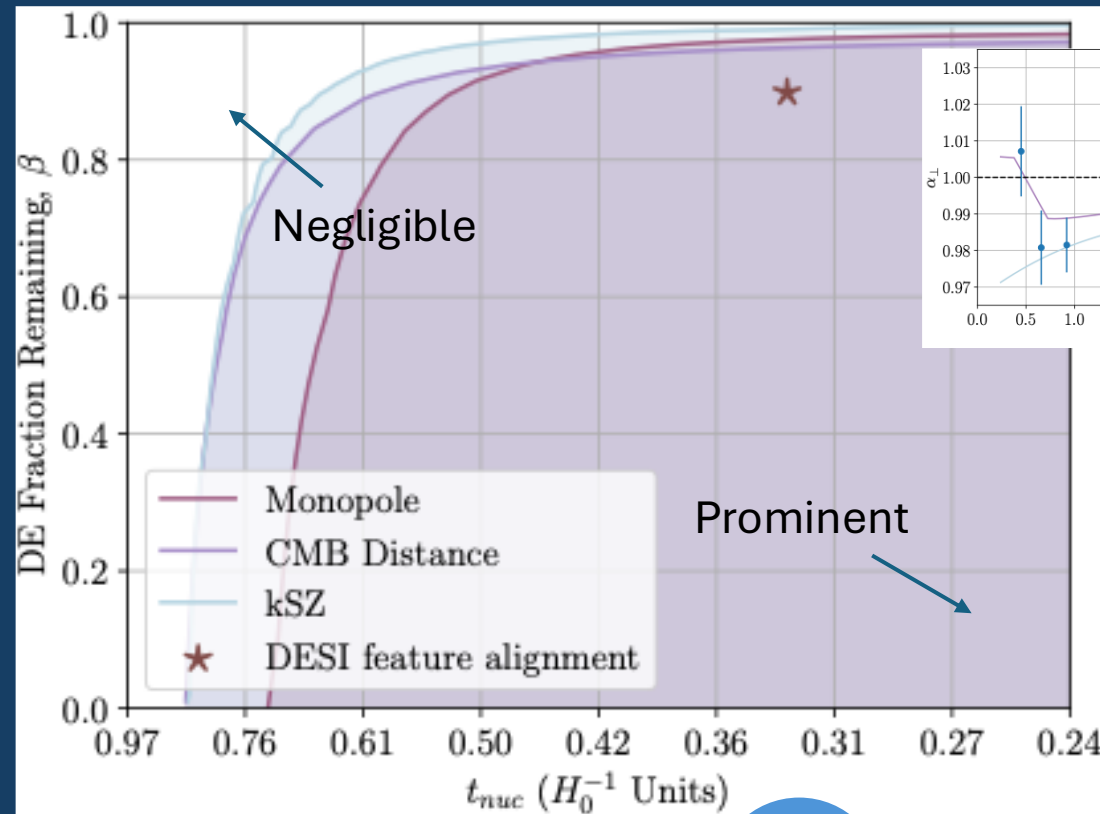
- Toy Model Ruled Out

CMB Constraints

○ Equal to Background

● Half DE as outside

○ Empty, DE-free bubble



Small ○

● Large

Upshot:

- Toy Model Ruled Out
- We understand DE with space varying component better



Upshot:

- Toy Model Ruled Out
- We understand DE with space varying component better



Next Steps: a more realistic Bubble

Upshot:

- Toy Model Ruled Out
- We understand DE with space varying component better



Next Steps: a more realistic Bubble

- Matter dynamics

Upshot:

- Toy Model Ruled Out
- We understand DE with space varying component better



Next Steps: a more realistic Bubble

- Matter dynamics
- Smooth Transition
at Wall

Upshot:

- Toy Model Ruled Out
- We understand DE
with space varying
component better



Thank You!