

# Fenomenologia della materia oscura

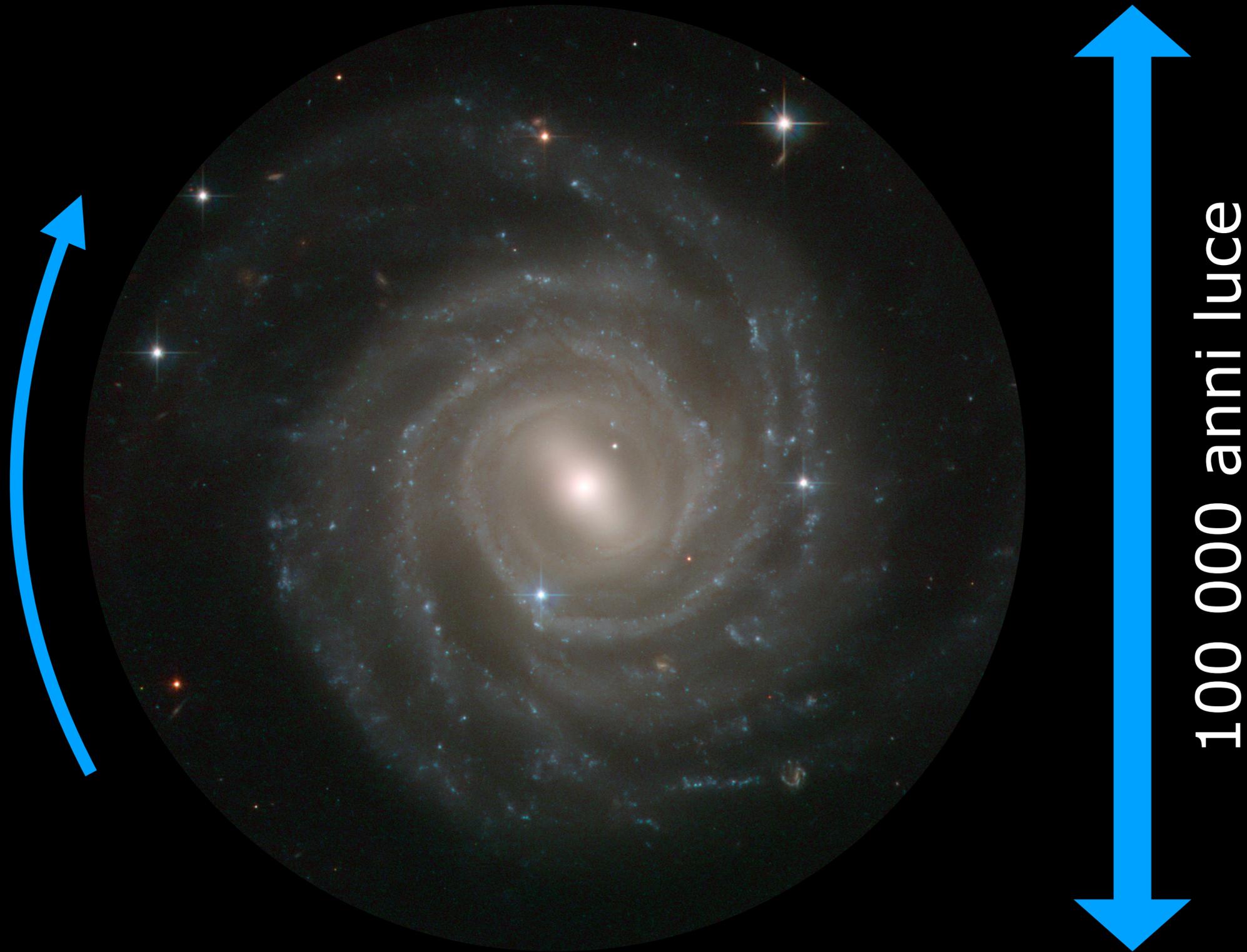
Paolo Serra



- Galassie
- Ammassi di galassie
- Struttura su larga scala dell'Universo
- Alcuni problemi irrisolti

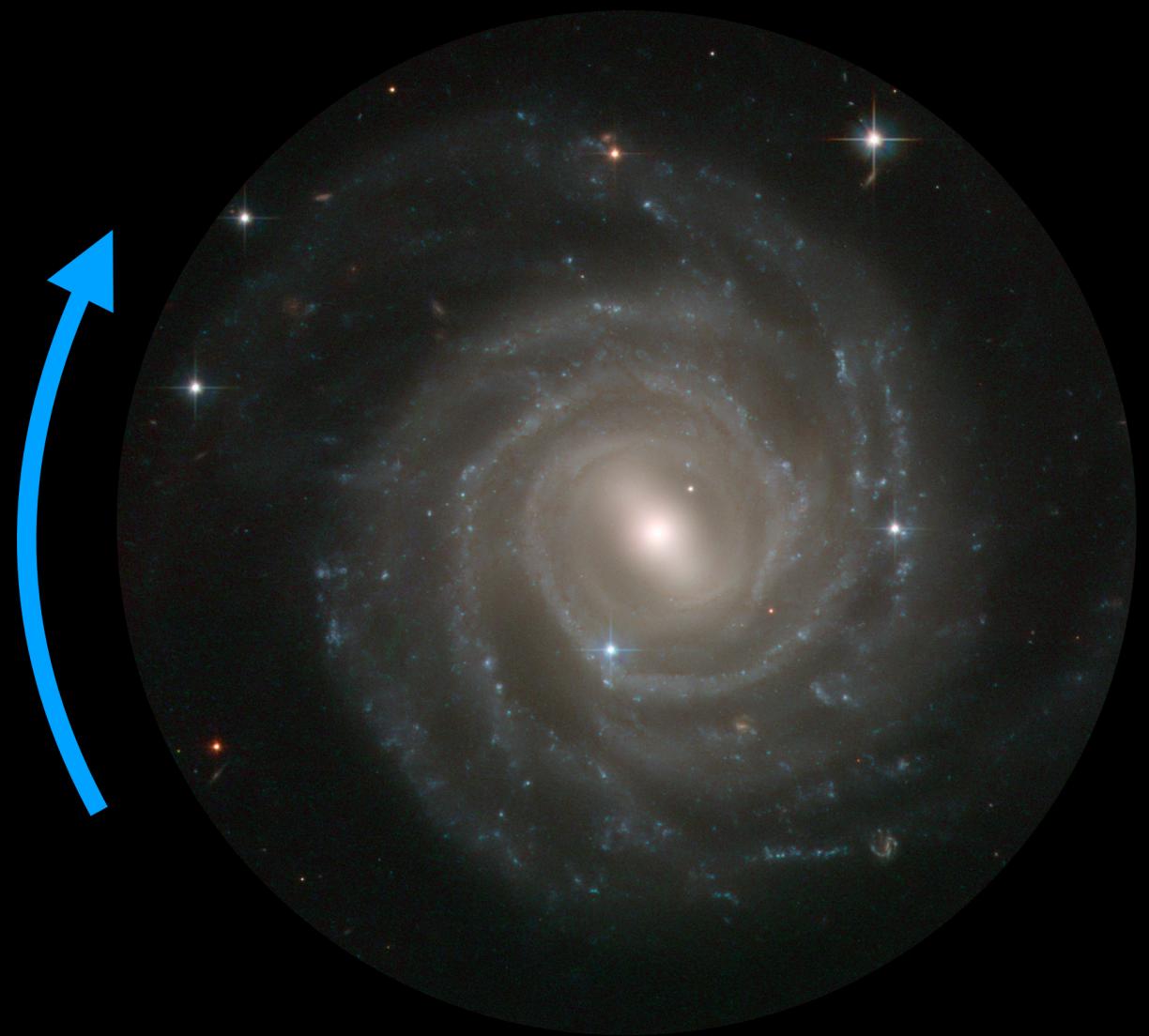
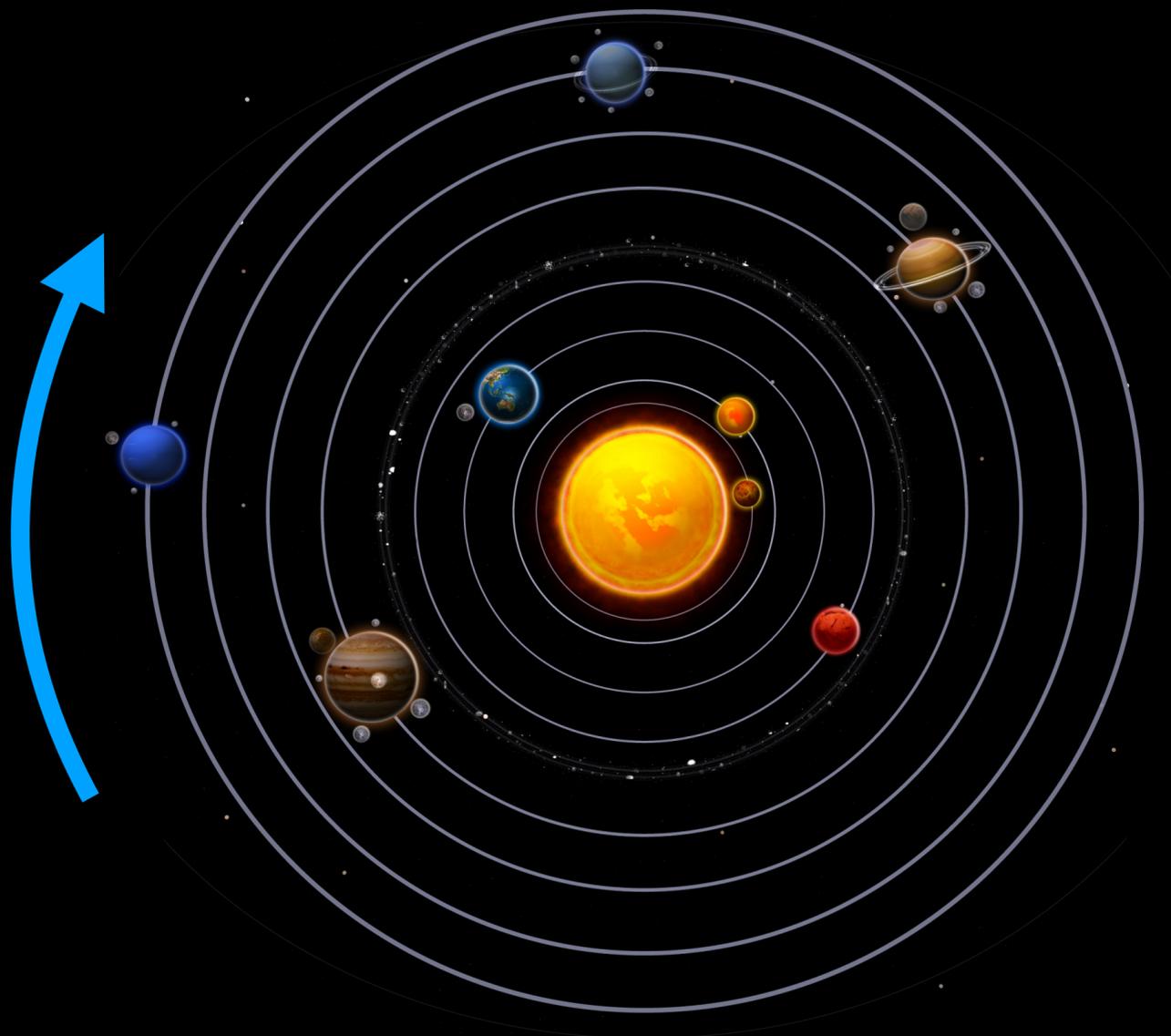


Galassie



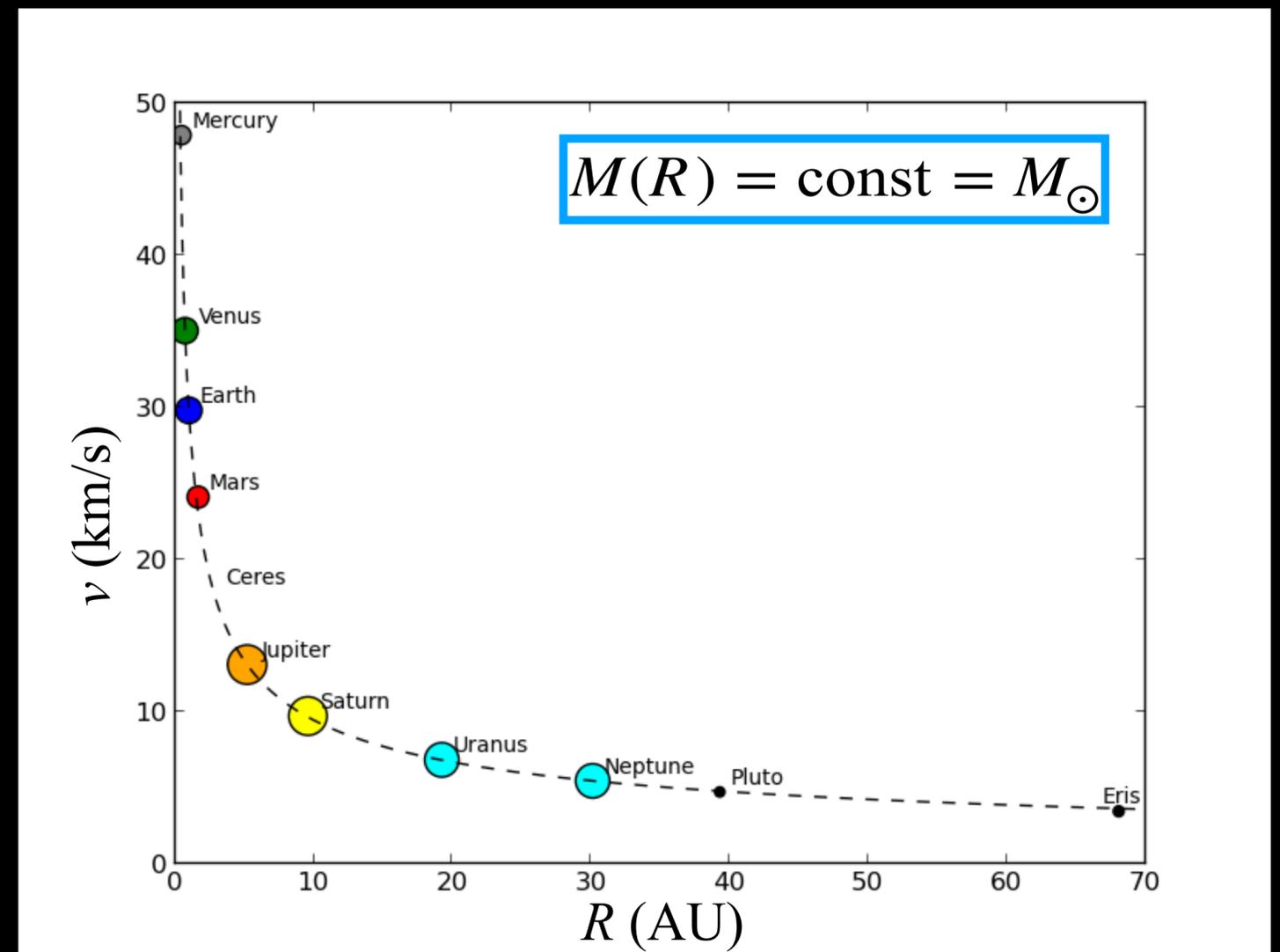
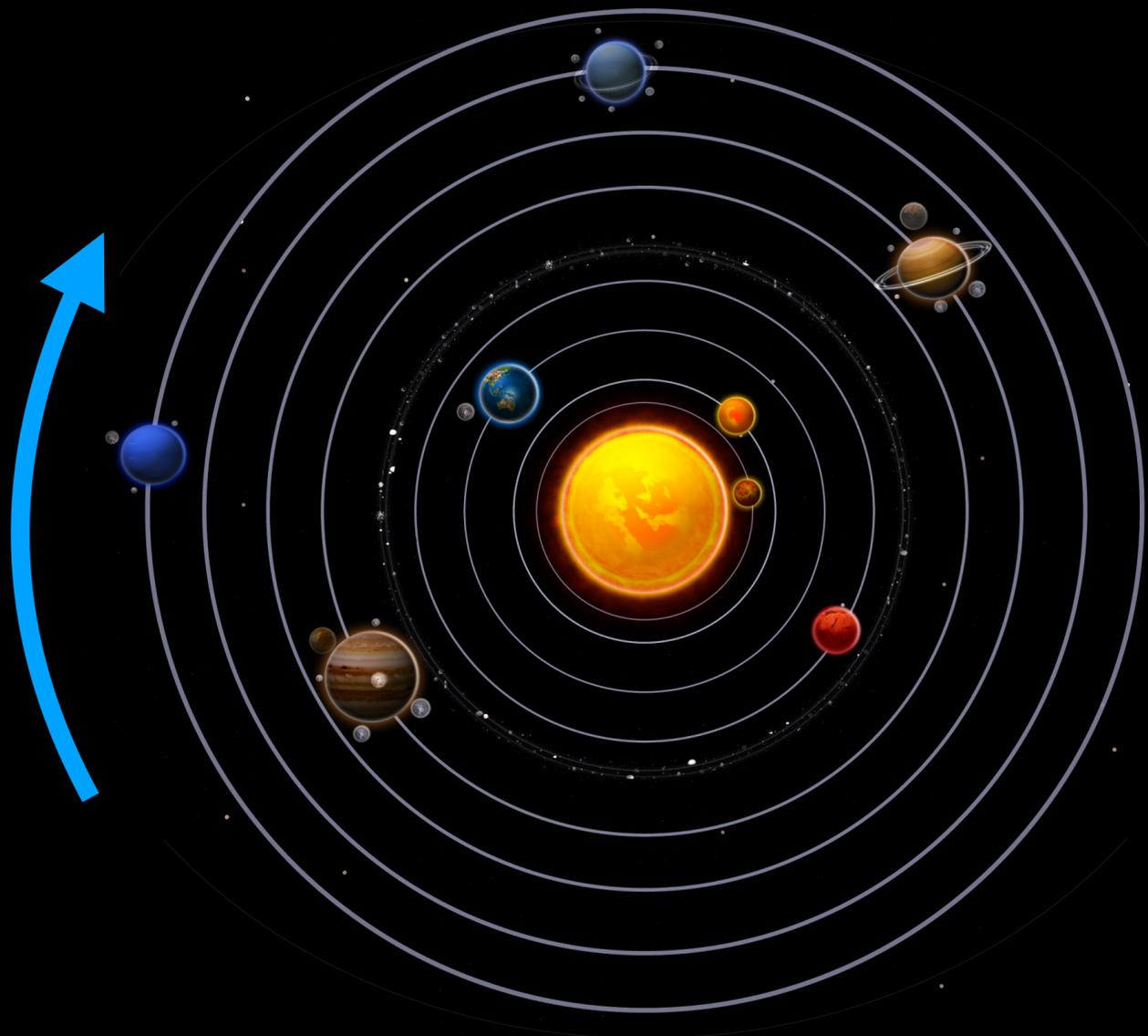
100 000 anni luce

$$v(R) = \sqrt{\frac{GM(R)}{R}}$$



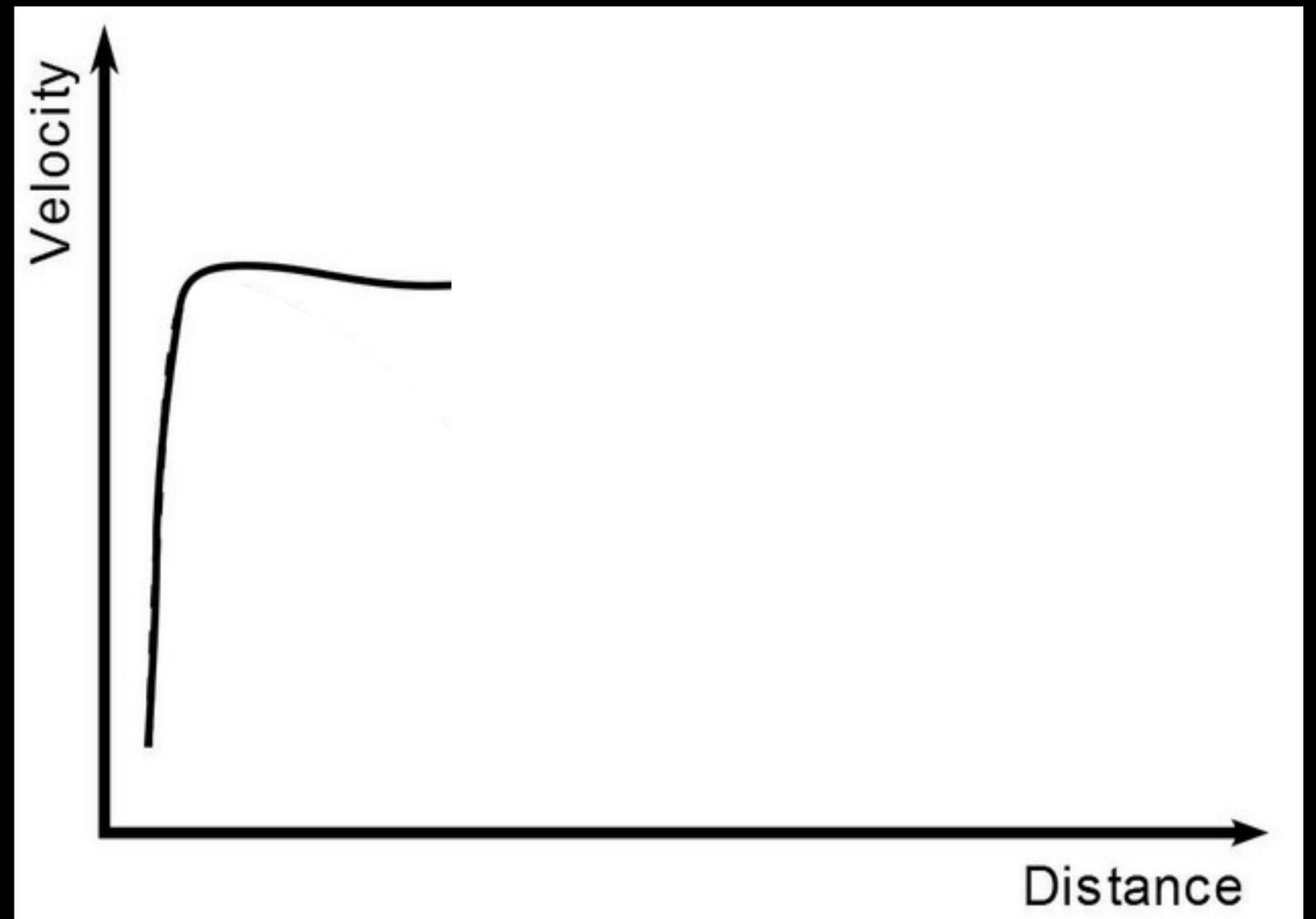
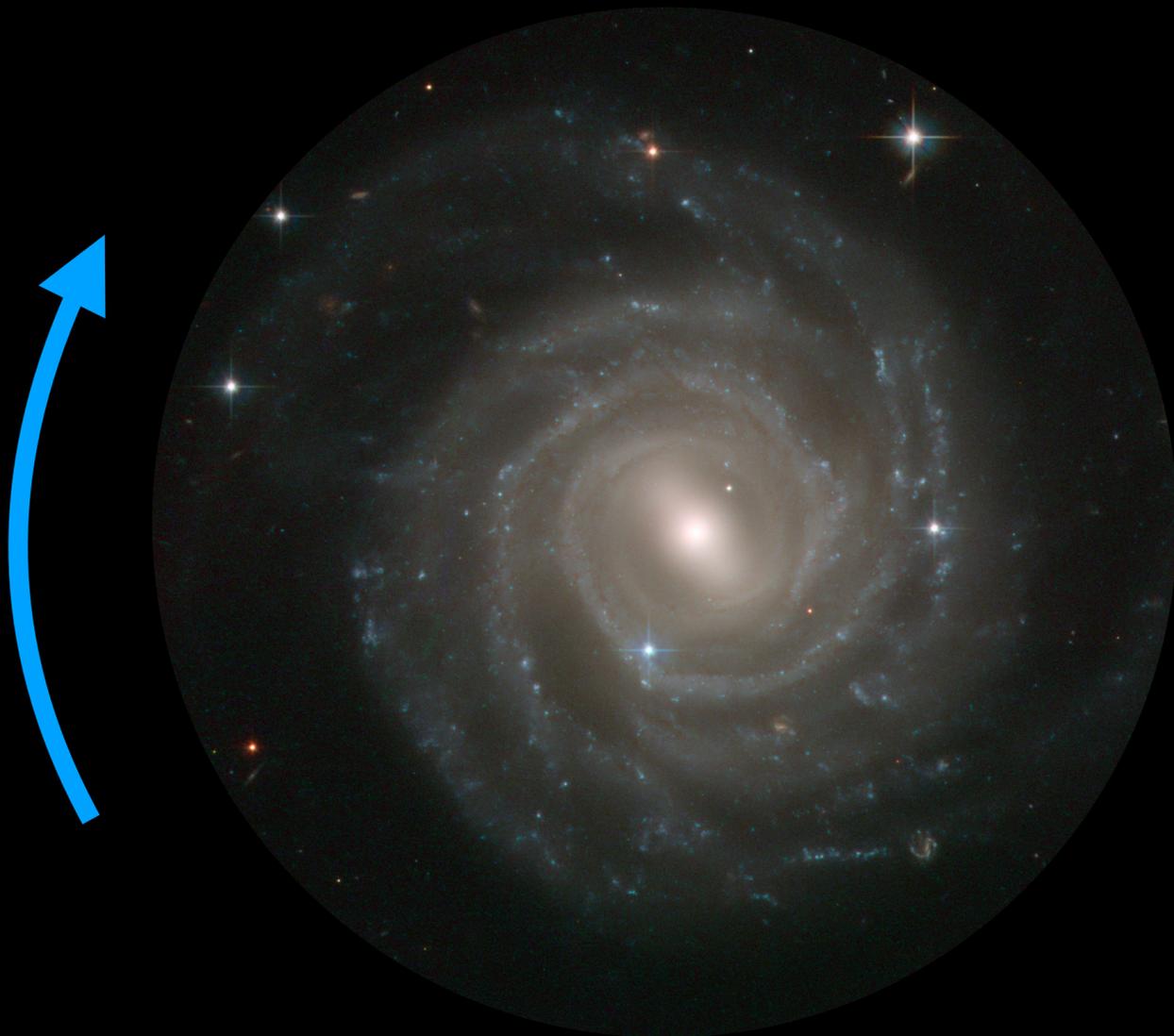
# Un sistema semplice: curva di rotazione Kepleriana

$$v(R) = \sqrt{\frac{GM(R)}{R}}$$

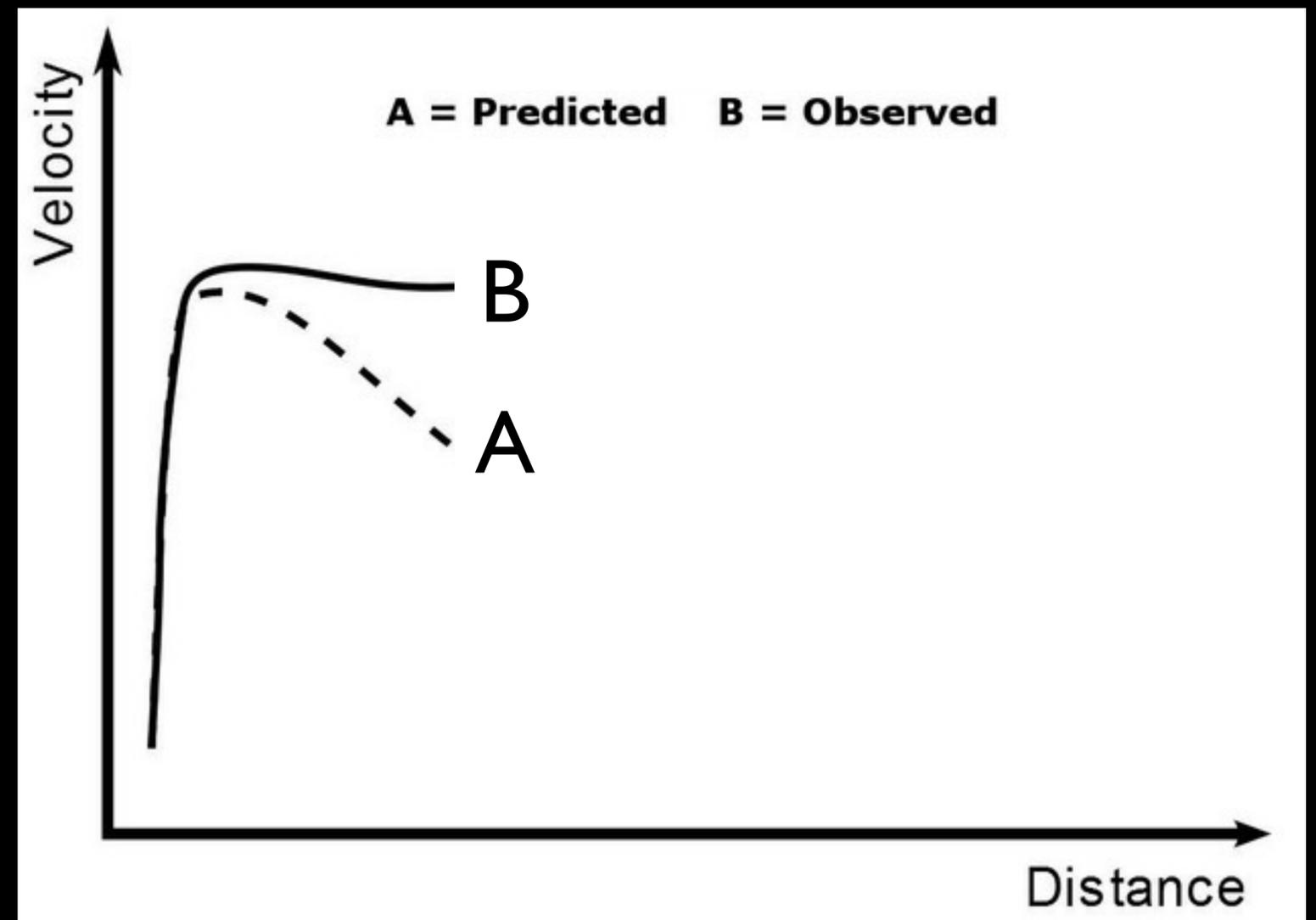
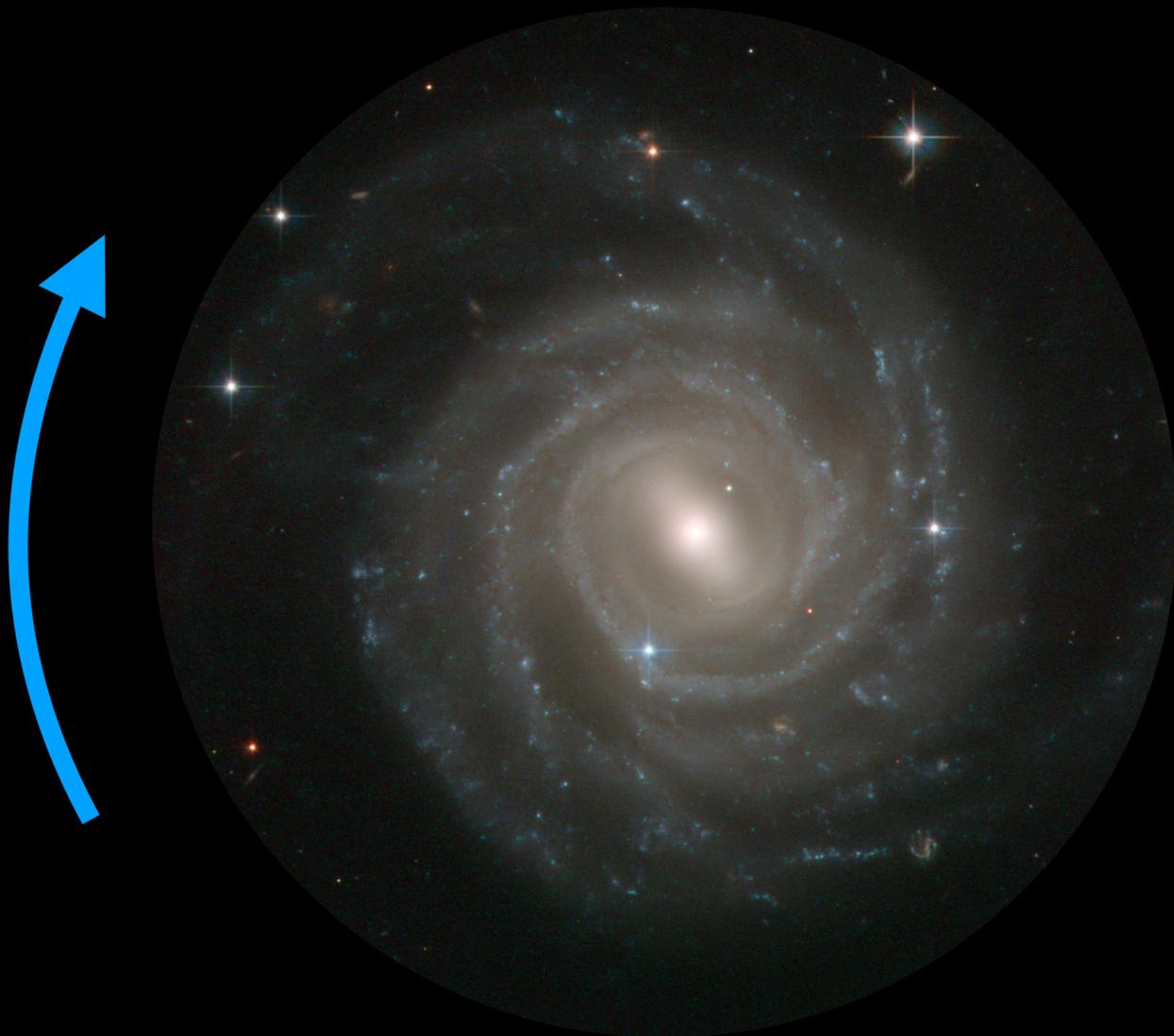


# Curva di rotazione galattica

$$v(R) = \sqrt{\frac{GM(R)}{R}}$$

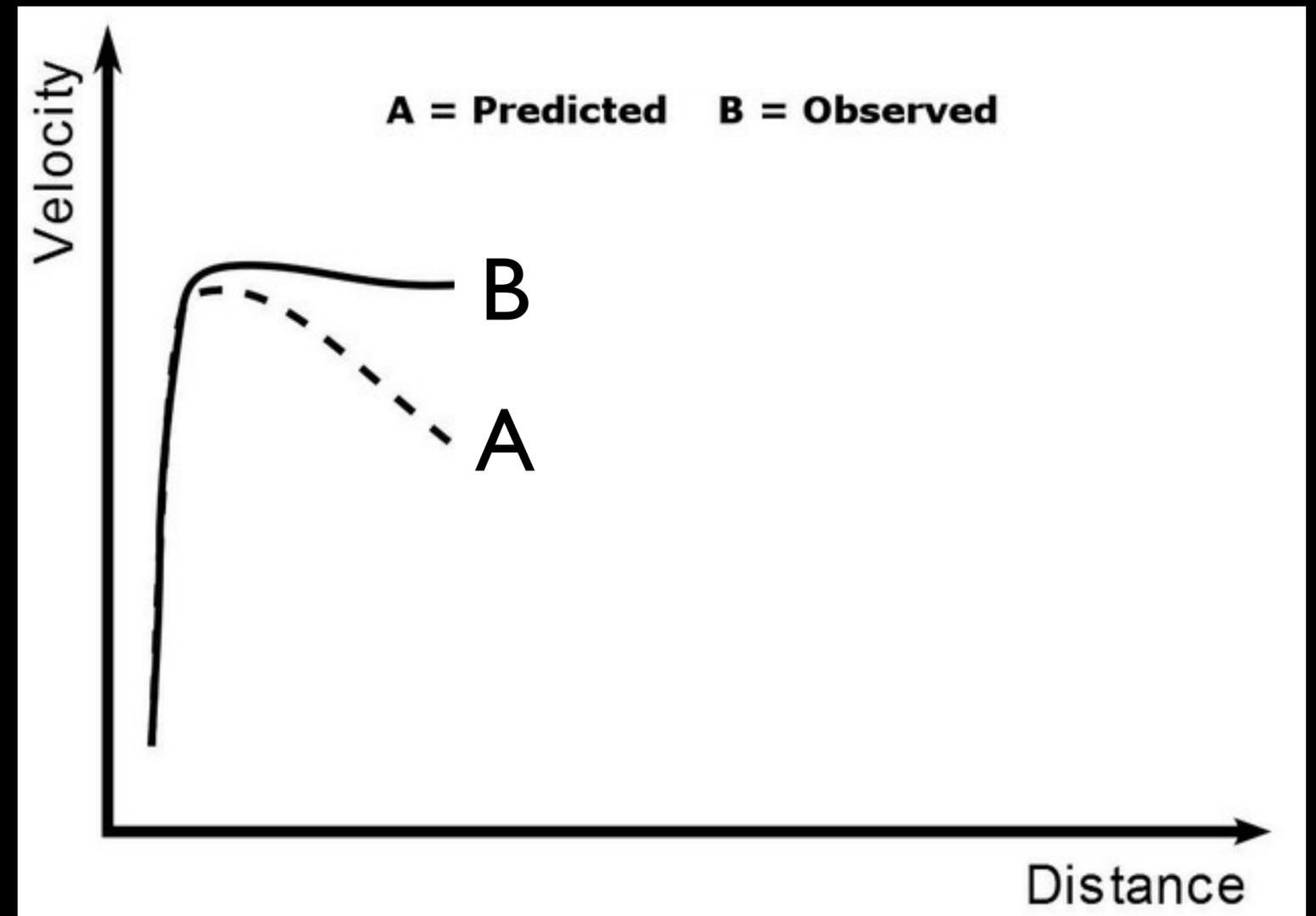
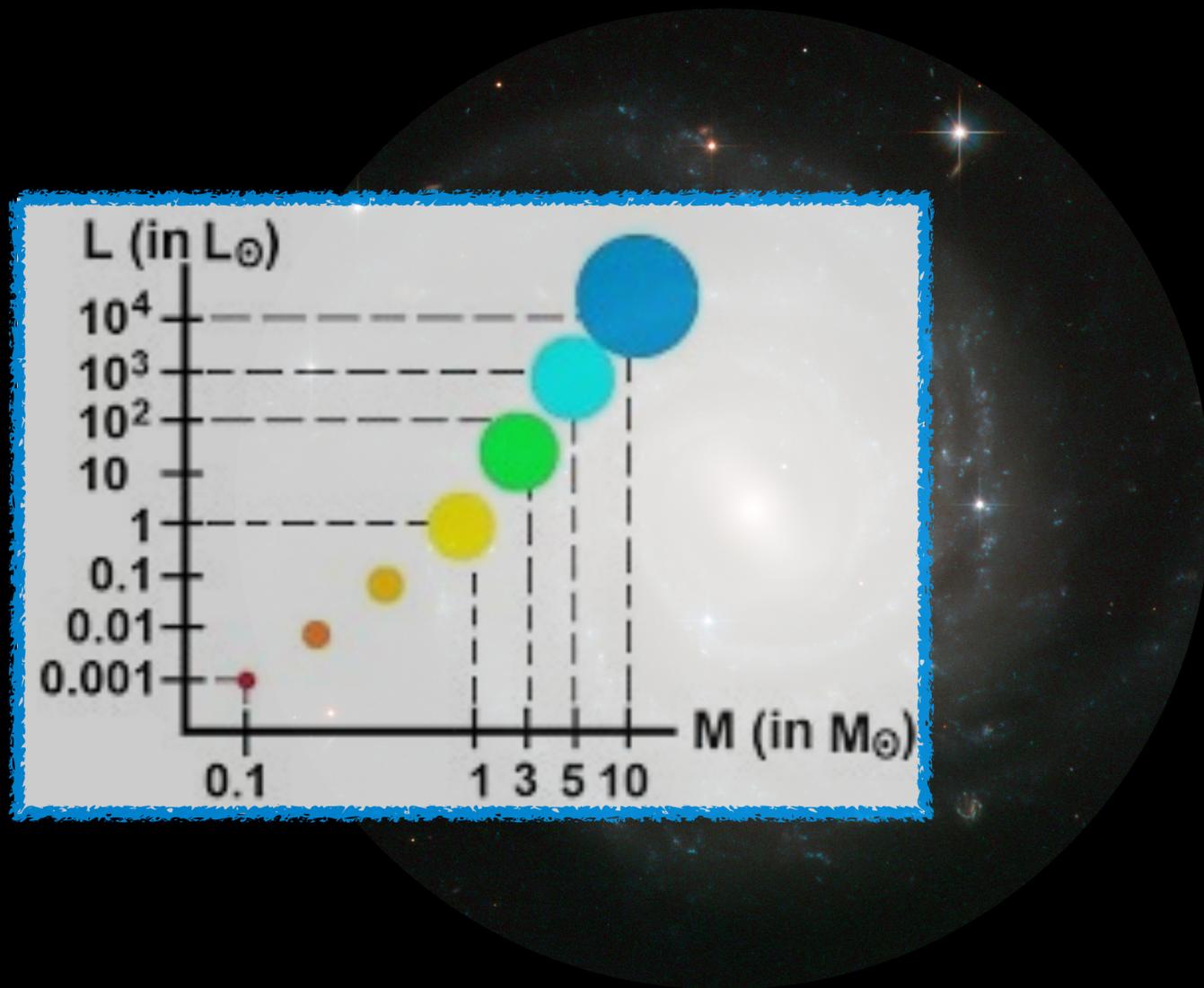


$$v_{\text{pred}}(R) = \sqrt{\frac{GM_{\text{pred}}(R)}{R}} < v_{\text{obs}}(R)$$



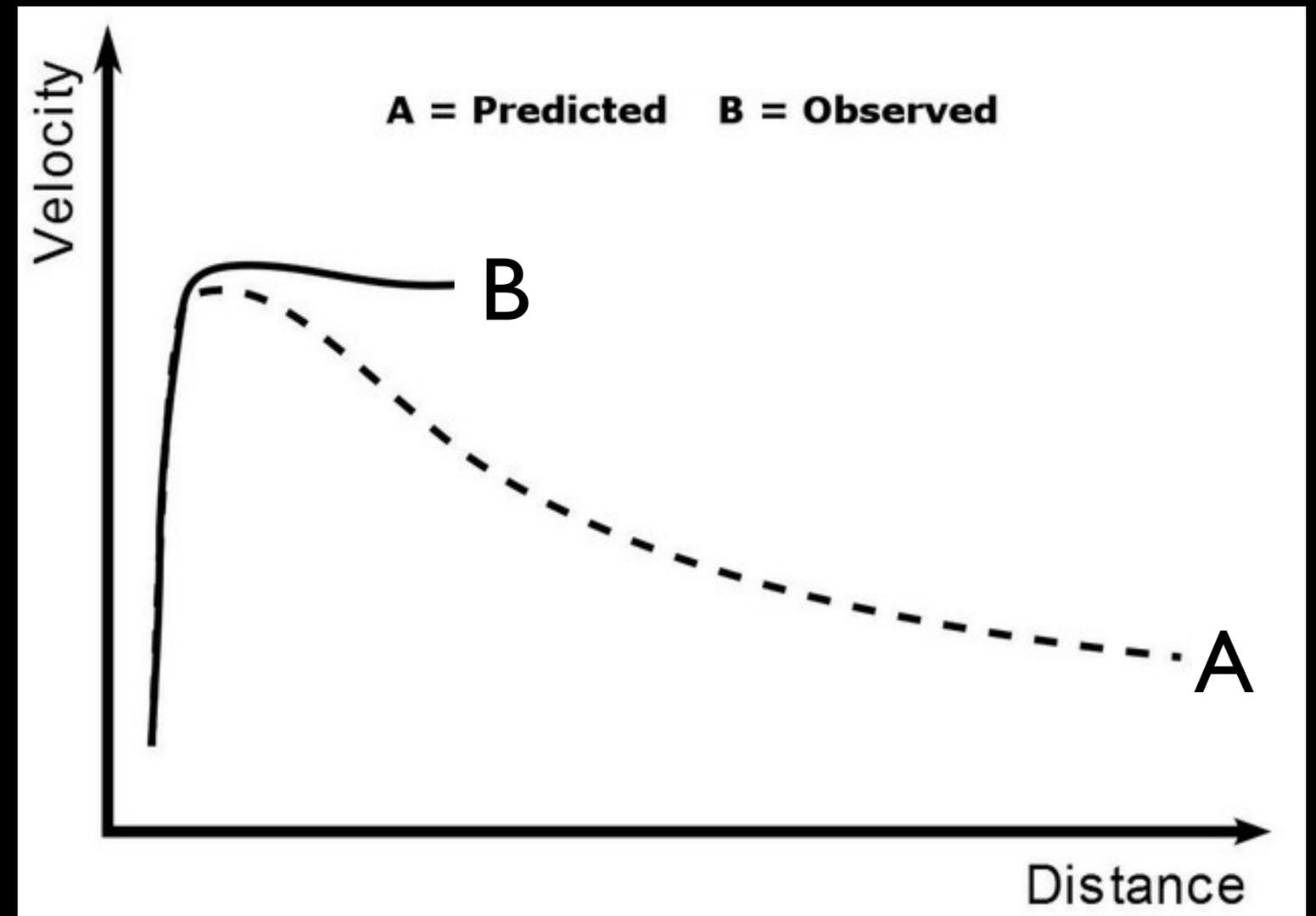
# Massa mancante o predizione sbagliata?

$$v_{\text{pred}}(R) = \sqrt{\frac{GM_{\text{pred}}(R)}{R}} < v_{\text{obs}}(R) ; \quad M_{\text{pred}}(R) = \gamma L(R)$$



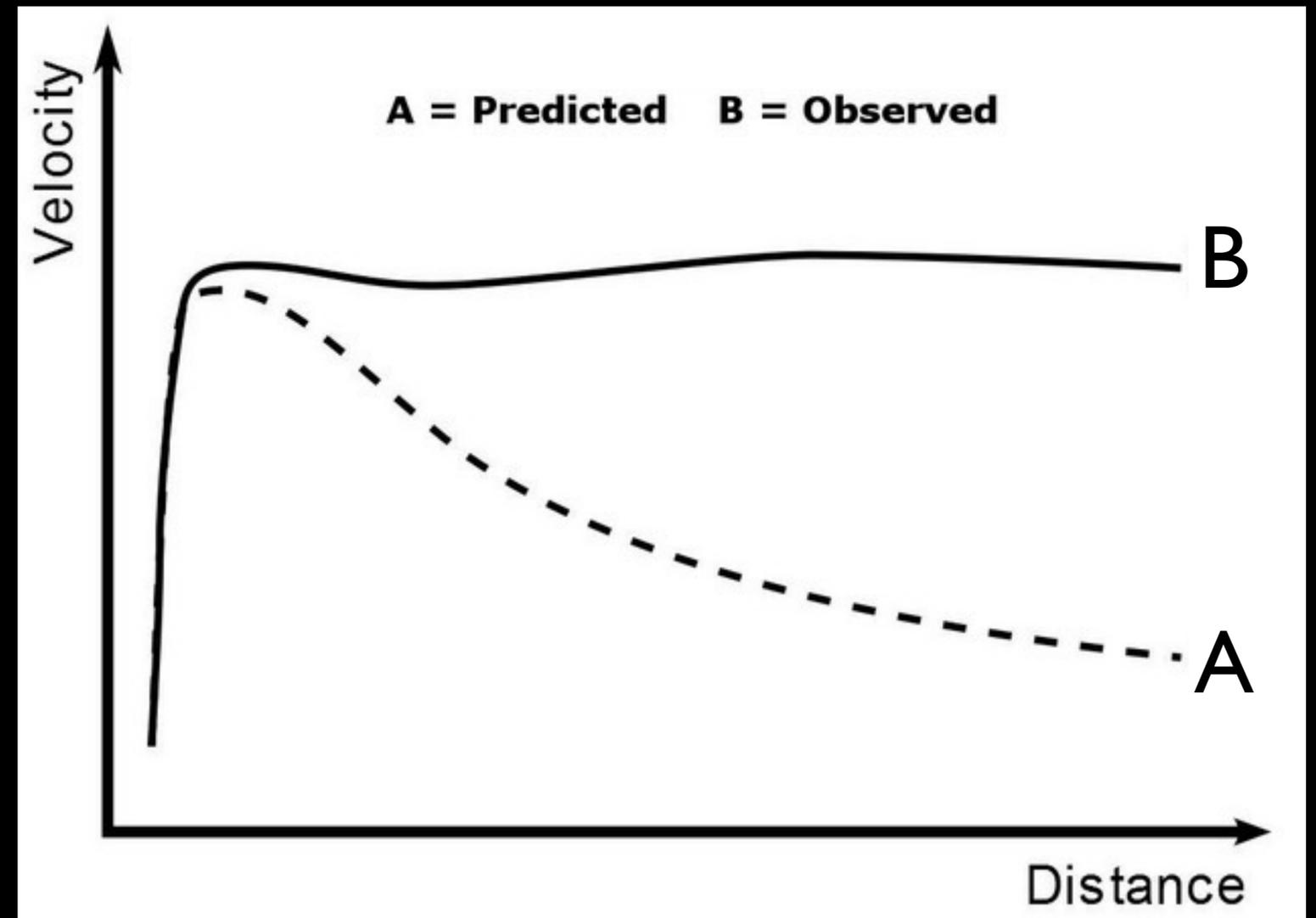
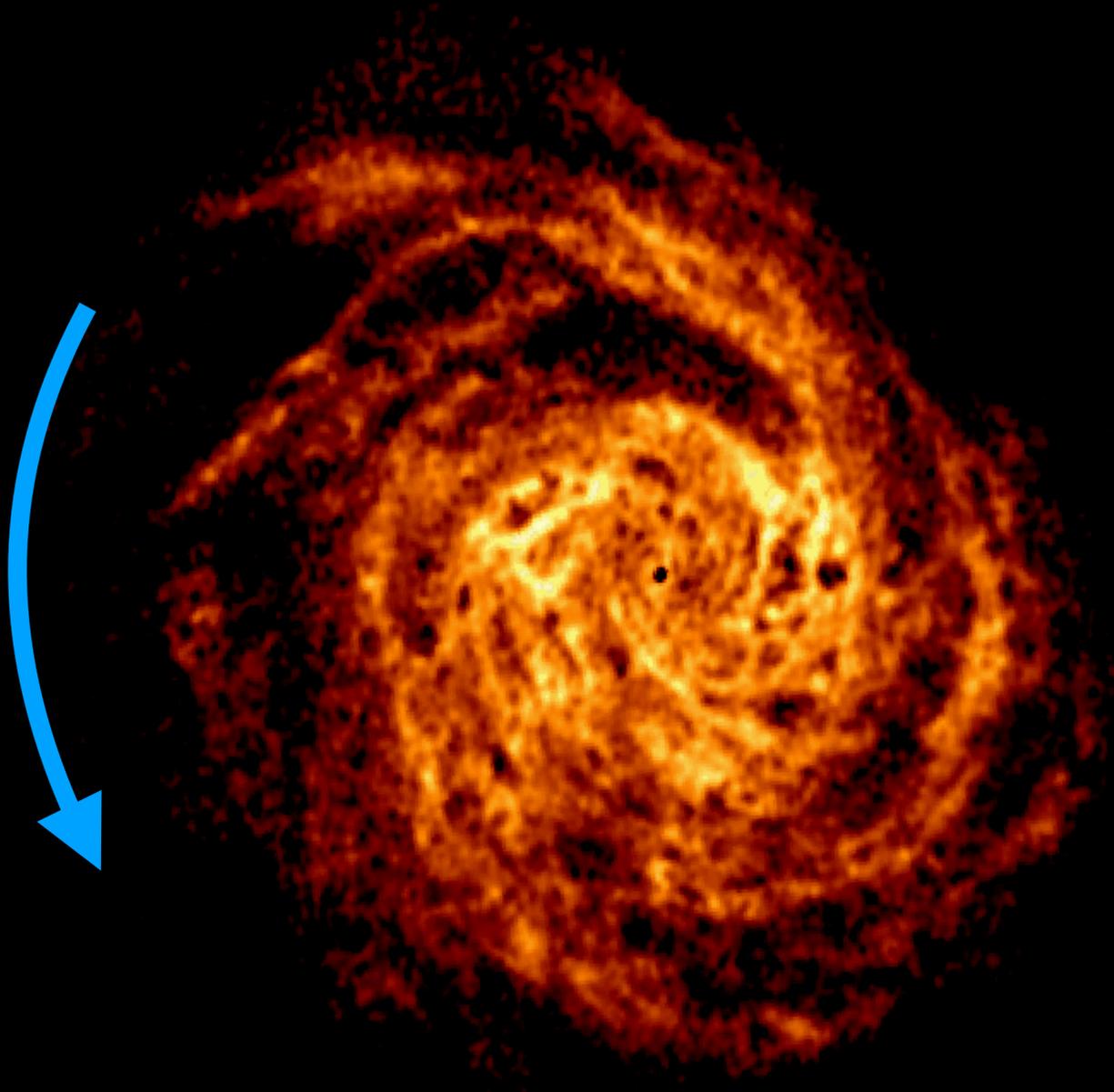
# Oltre il limite visibile delle galassie: curve Kepleriane

$$v(R) = \sqrt{\frac{GM(R)}{R}}$$



# Oltre il limite visibile della galassie: osservazioni radio

$$v(R) = \sqrt{\frac{GM(R)}{R}}$$



Ammassi di galassie

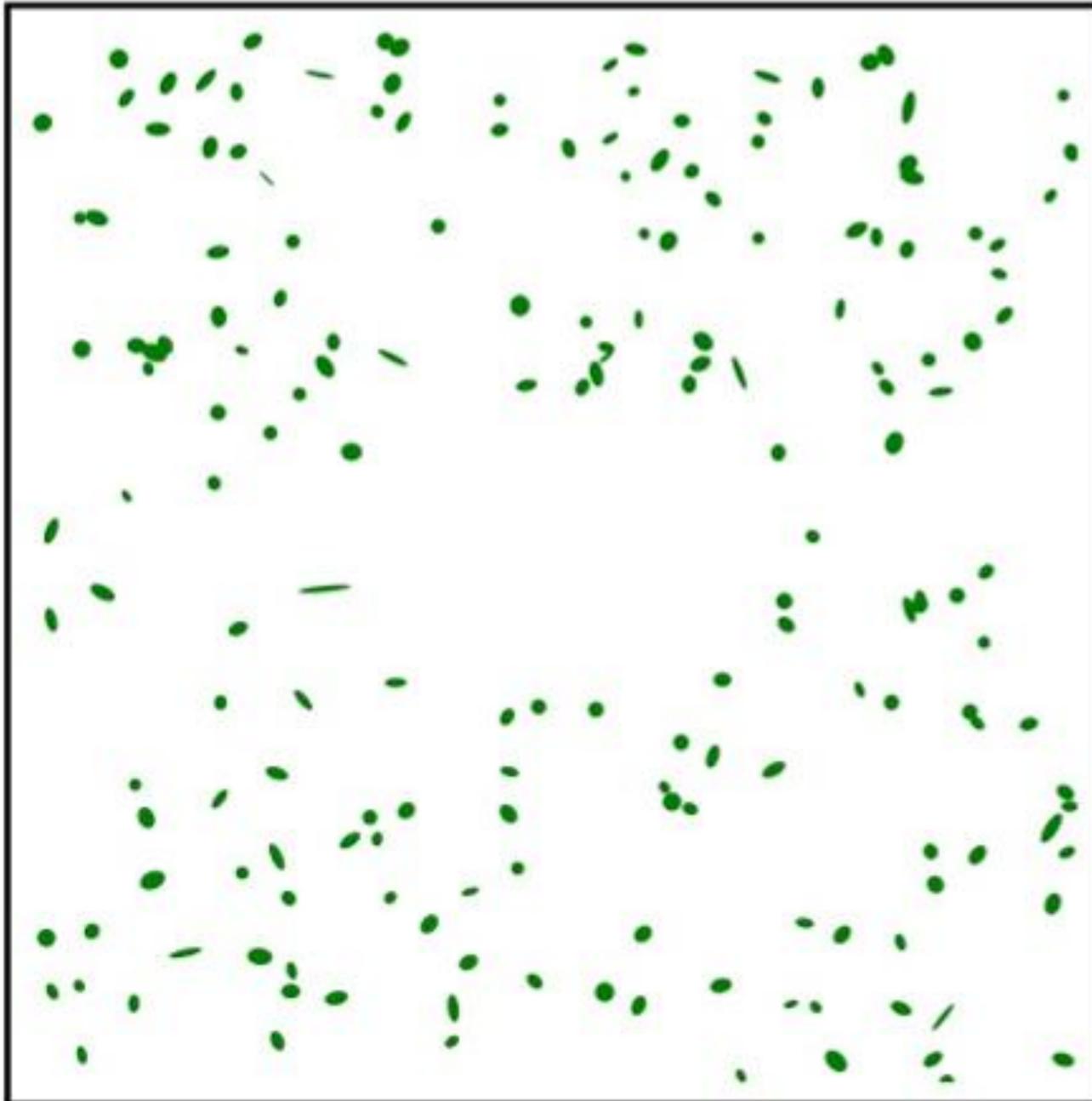
# Ammassi di galassie



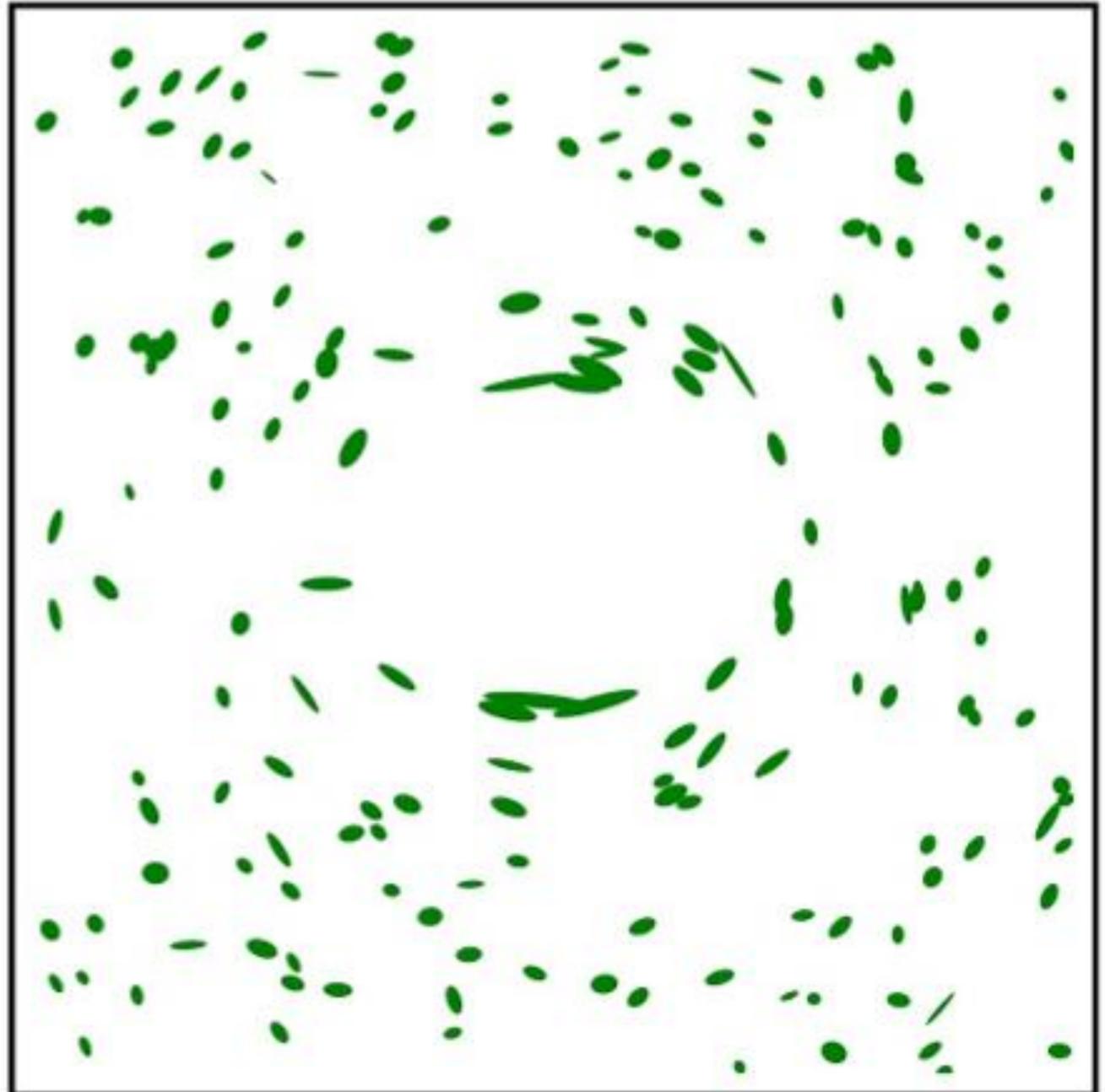
10 milioni di anni luce

# Lenti gravitazionali

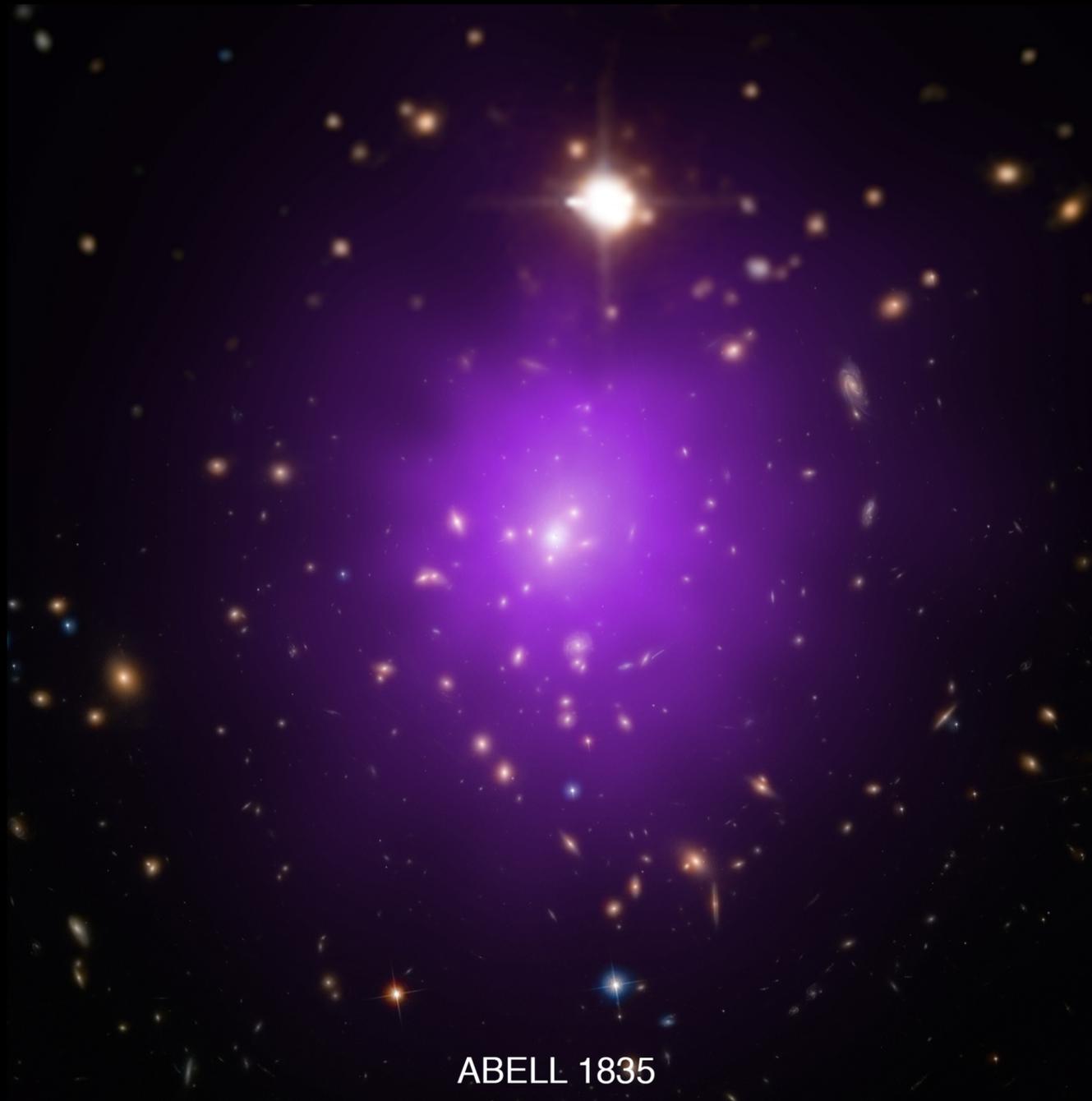
**Unlensed**



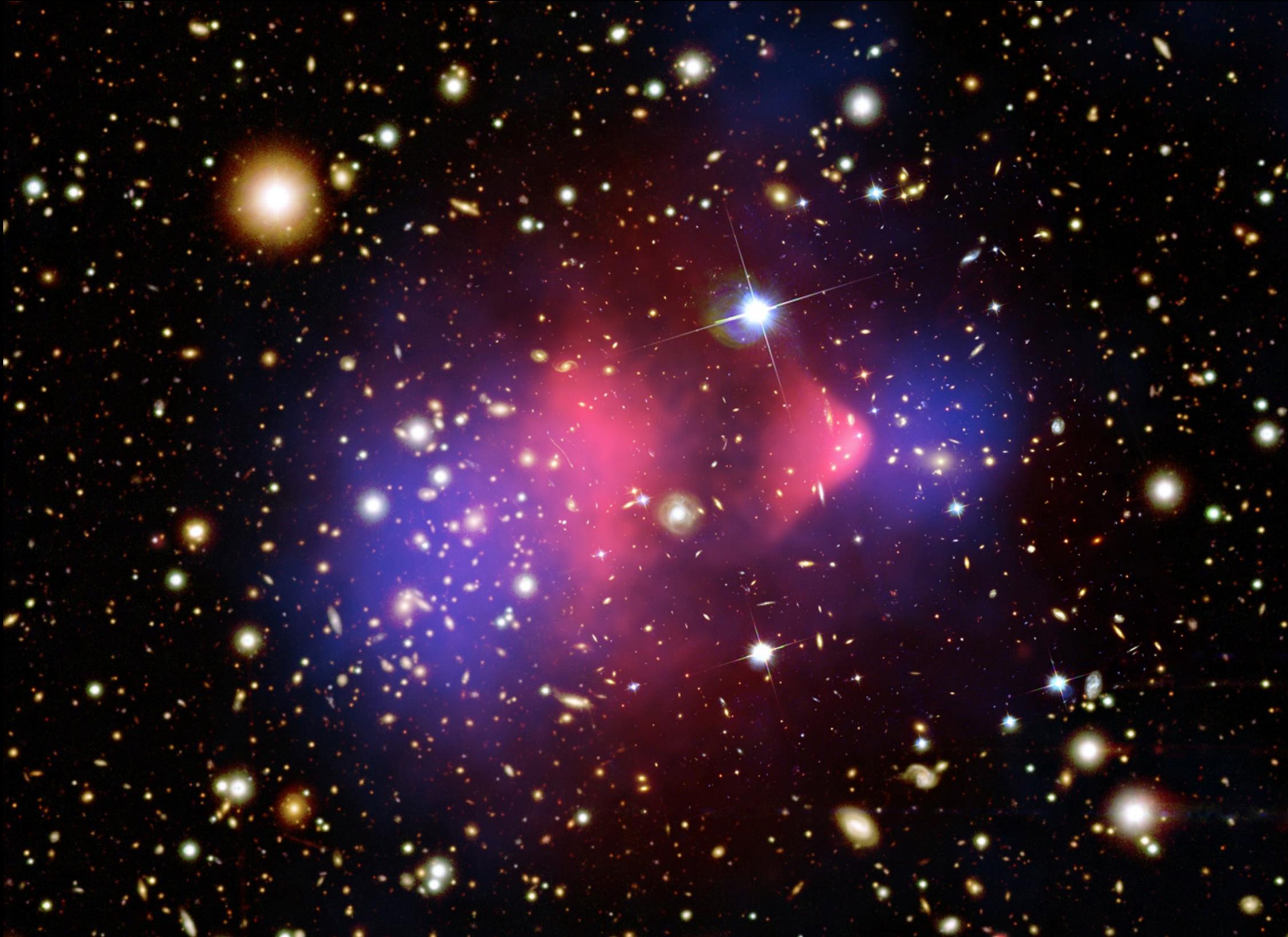
**Lensed**



# Gas caldo o materia oscura?



*Bullet cluster: separazione gas caldo / materia oscura*

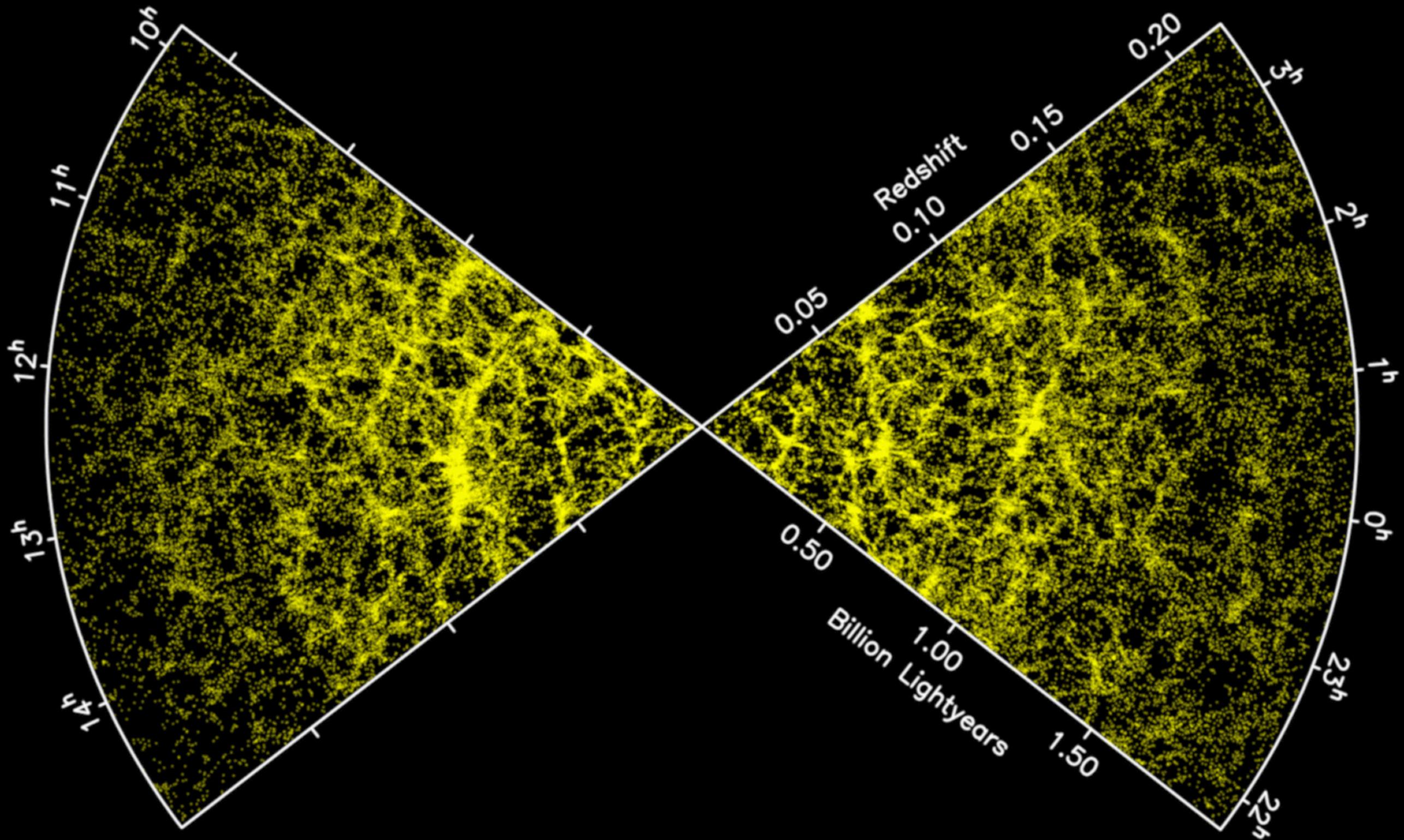


# Lezione dalle galassie e dagli ammassi

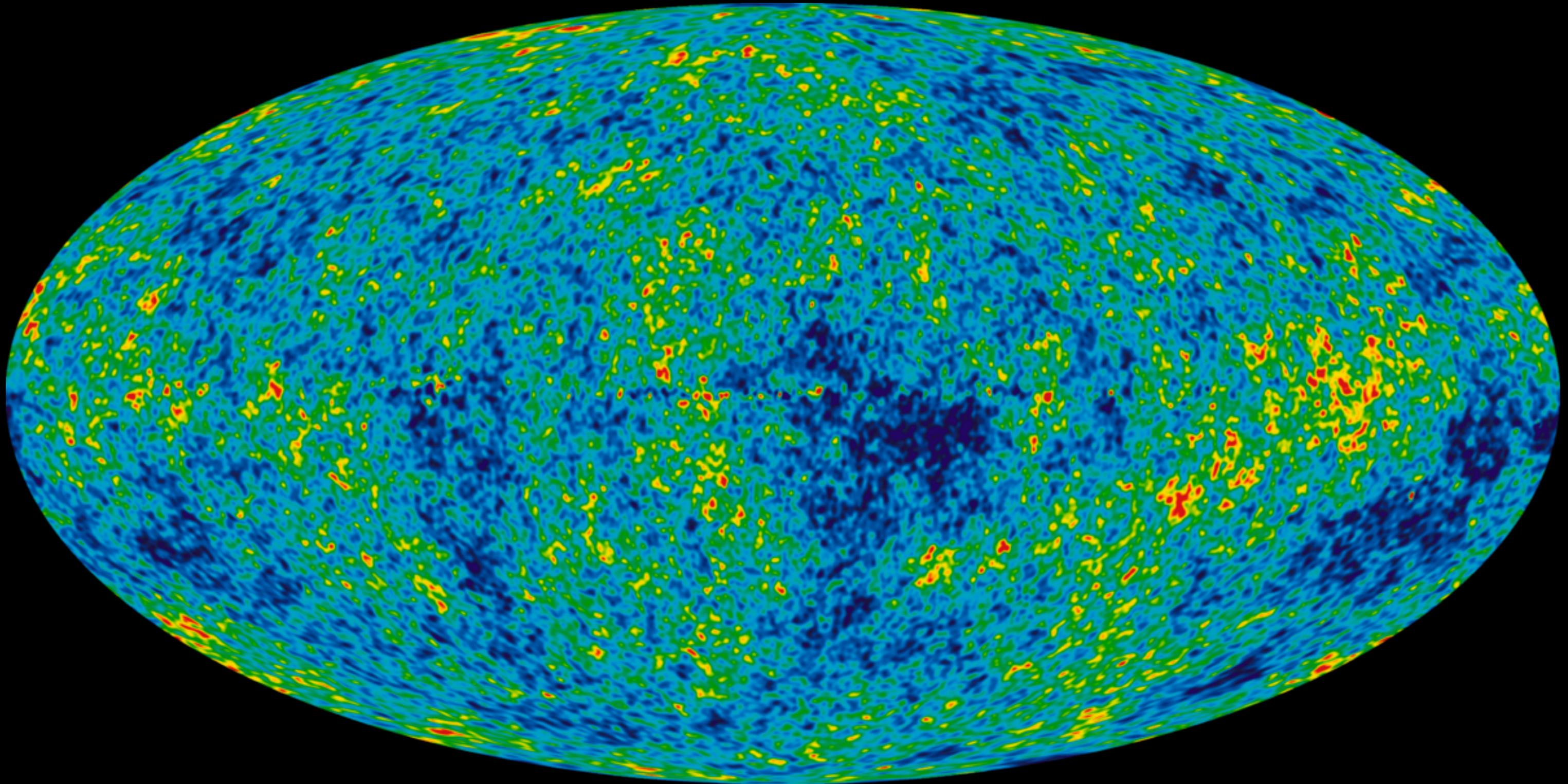
La massa stimata in base alle leggi della gravità  
(curve di rotazione, dispersione di velocità, lenti gravitazionali)  
è maggiore  
della massa stimata in base alla luce

# Struttura su larga scala dell'Universo

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# Formazione della ragnatela cosmica: condizioni iniziali



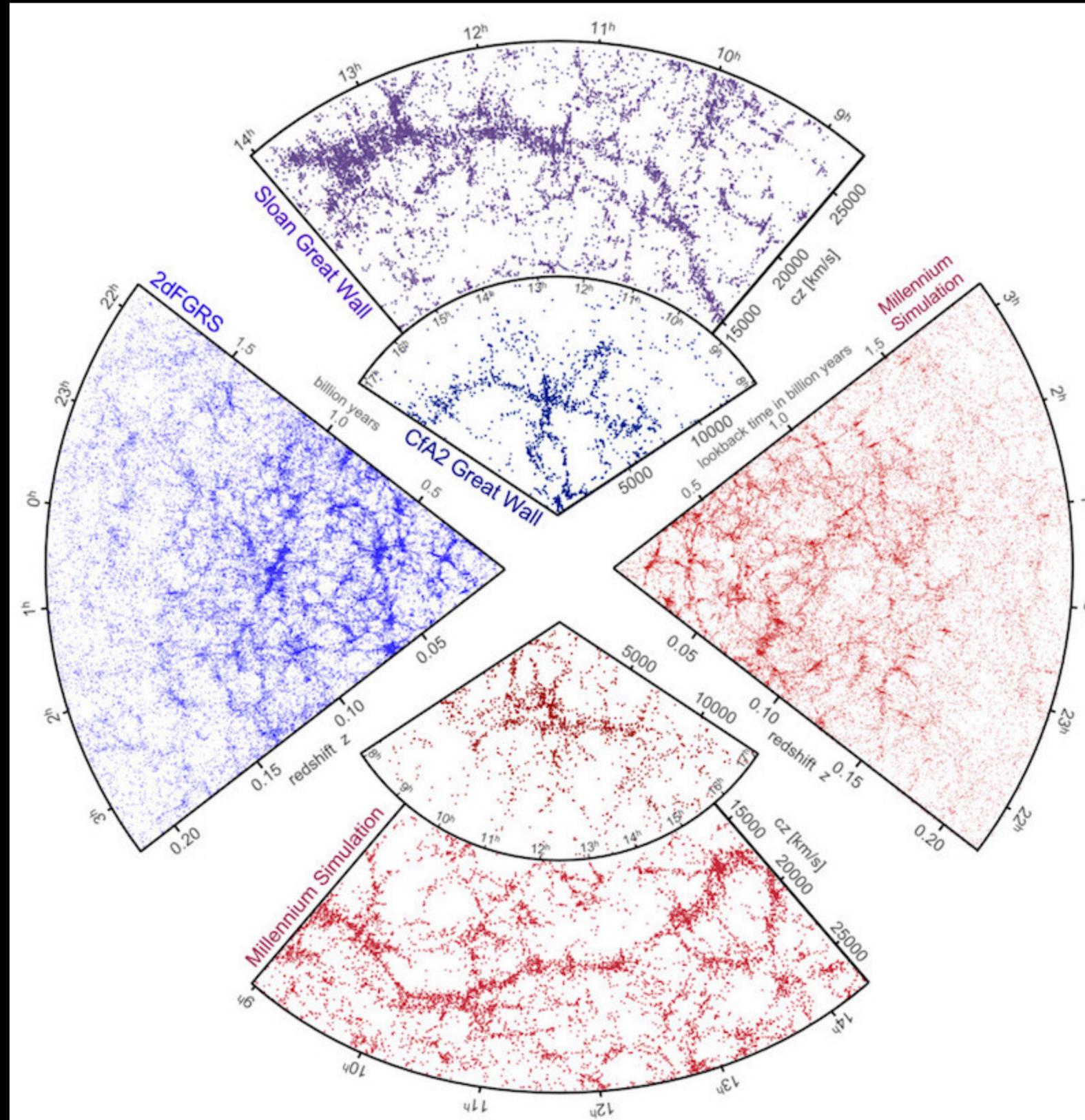
# Formazione della ragnatela cosmica (materia oscura)



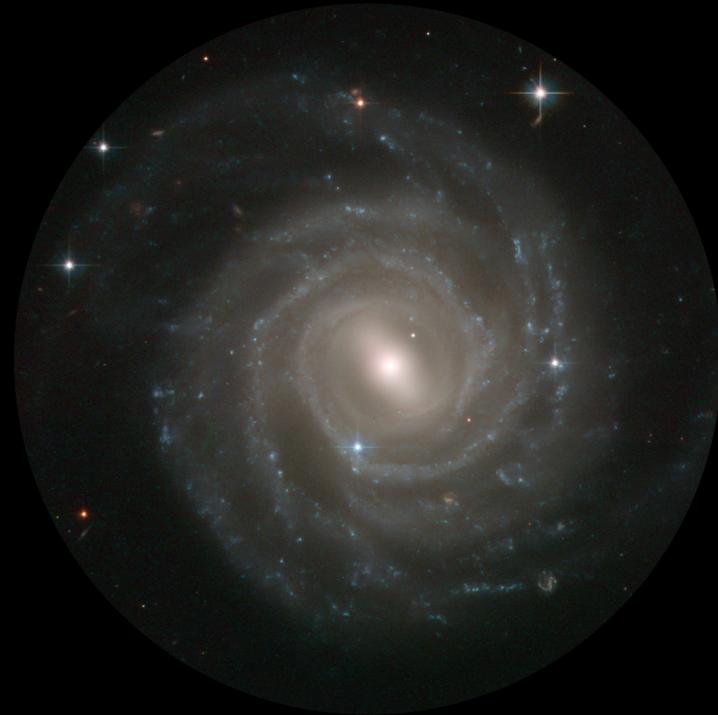
1 miliardo di anni luce

A vertical blue double-headed arrow is positioned to the right of the dark blue rectangle, indicating a scale of 1 billion light years.

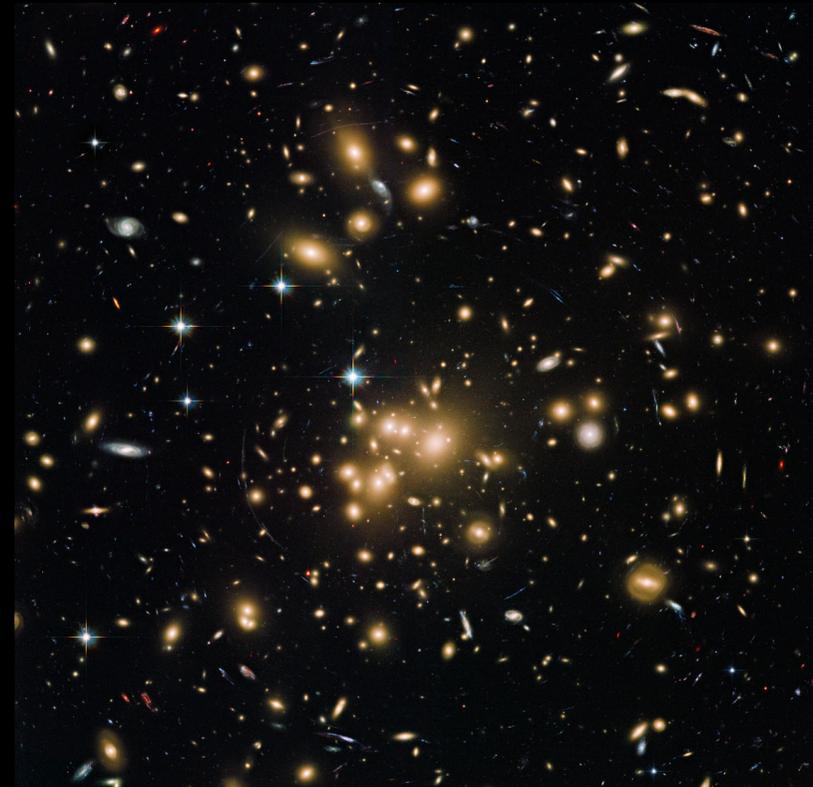
# Il successo su larga scala della materia oscura



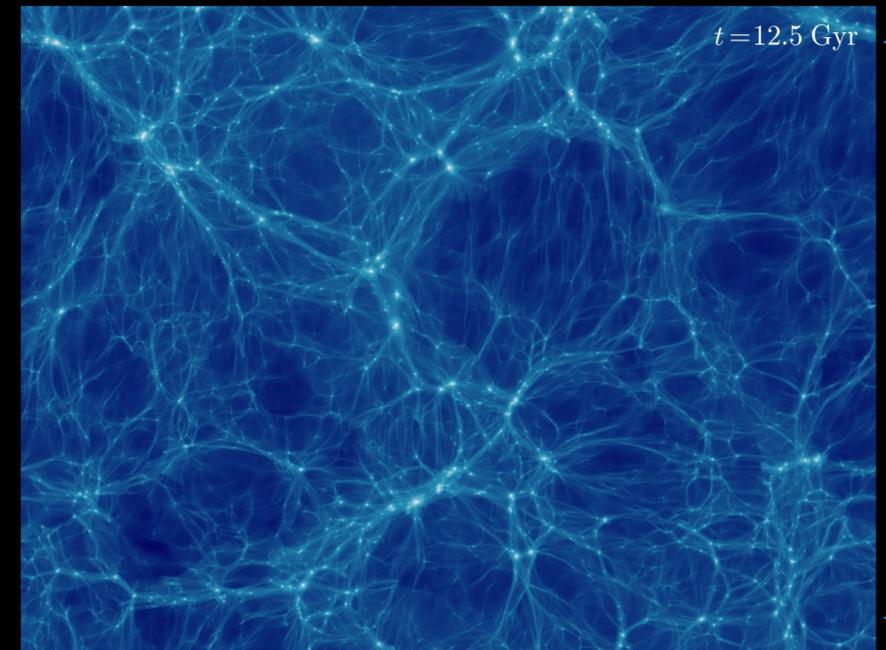
# Materia oscura su diverse scale



100 000 anni luce



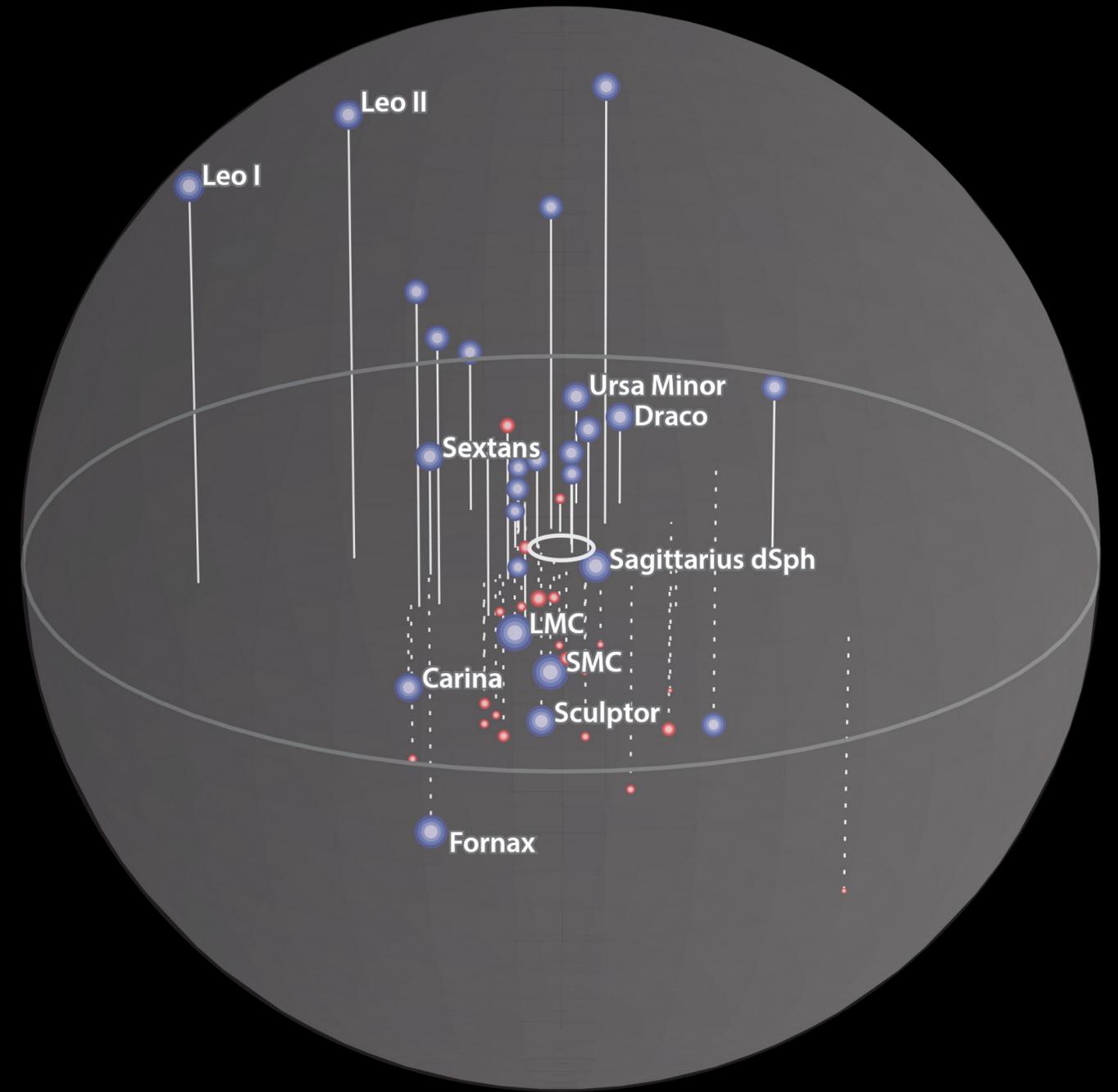
10 milioni di anni luce



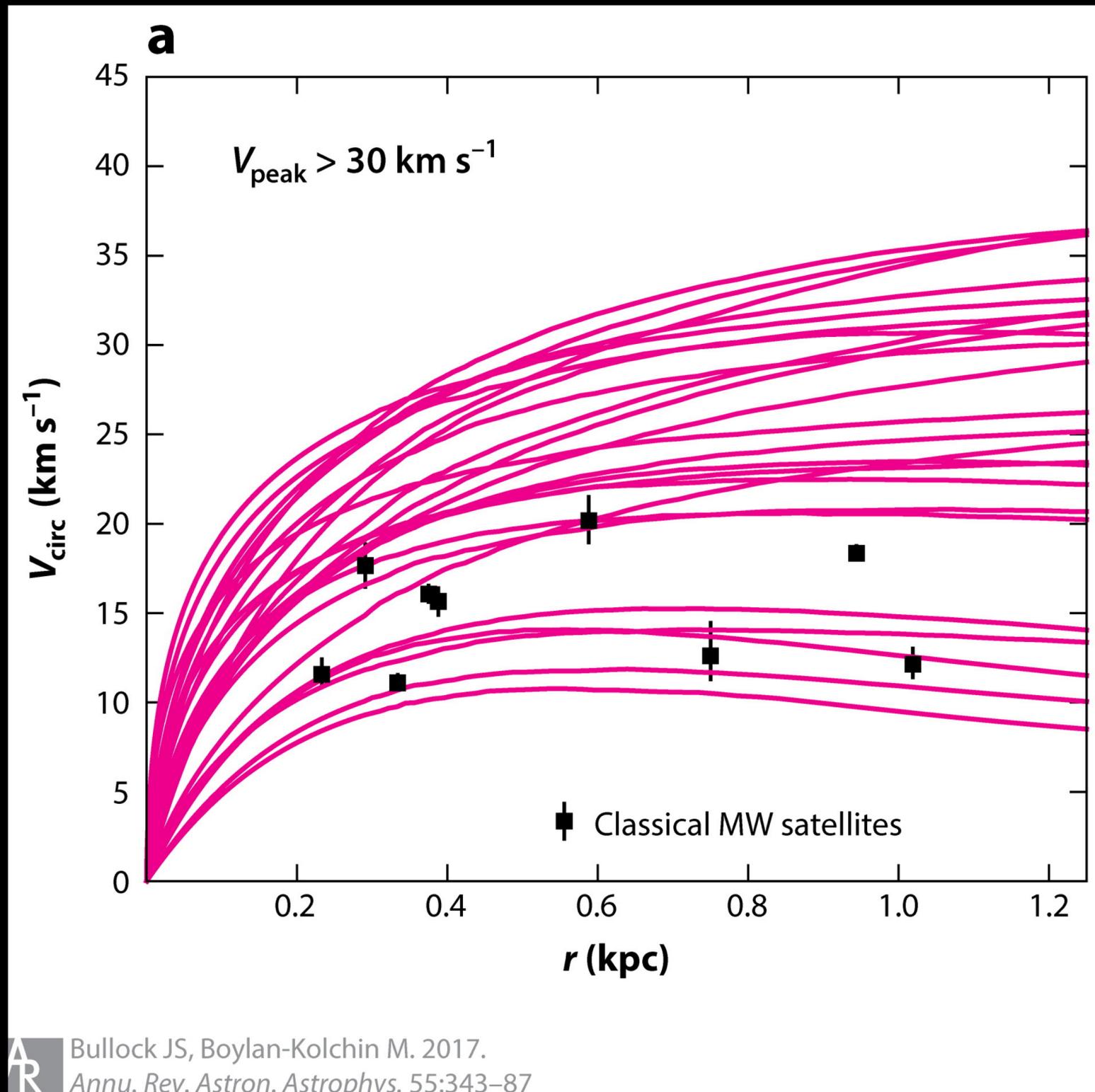
1 miliardo di anni luce

Alcuni problemi irrisolti

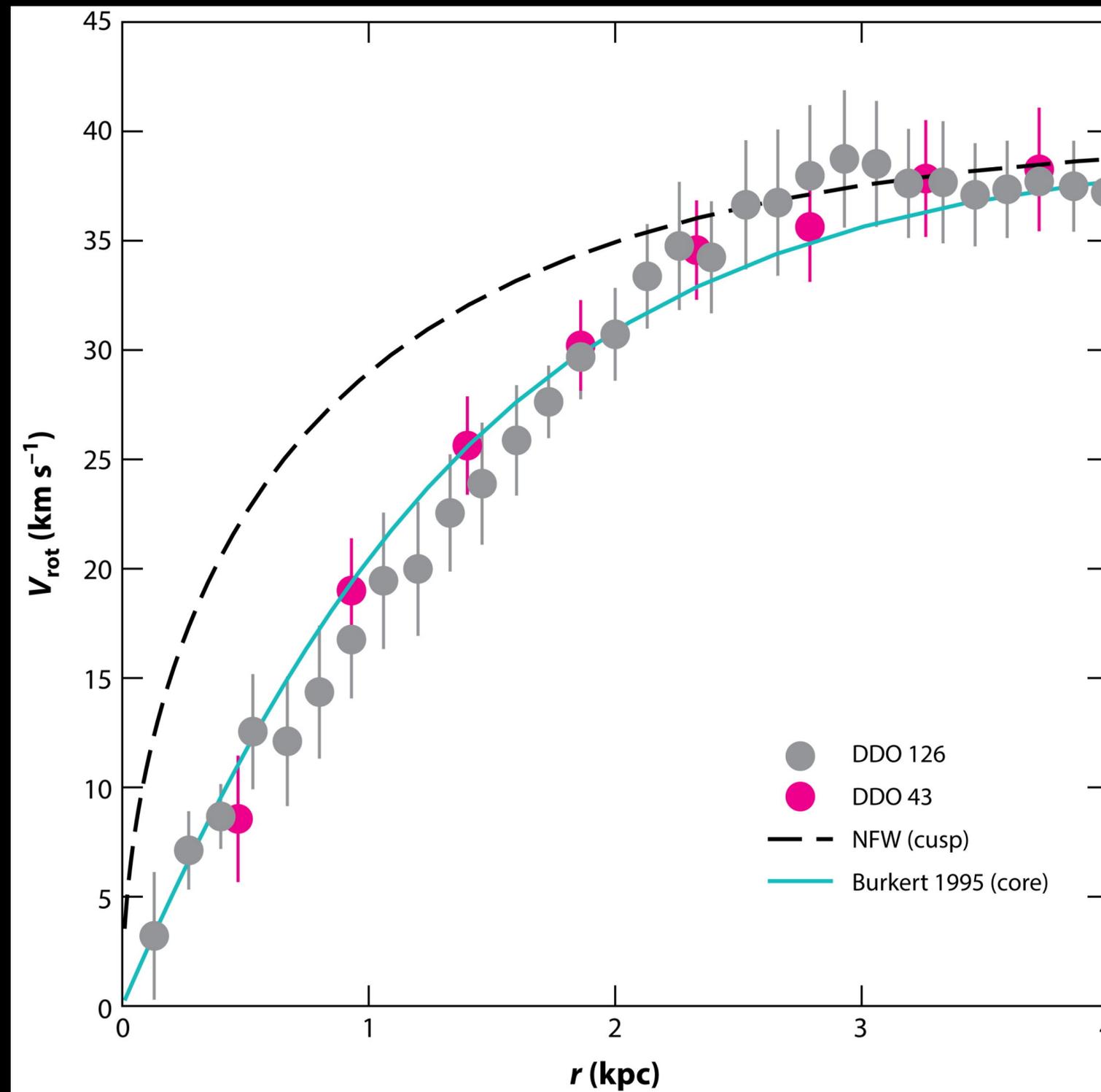
# I satelliti mancanti



# Densità centrale delle galassie satellite



# Profili di densità delle galassie nane



La massa stimata in base alle leggi della gravità è maggiore della massa stimata in base alla luce visibile

Una materia oscura composta di particelle debolmente interagenti spiega sia queste osservazioni sia la forma della struttura su larga scala dell'Universo

Le discrepanze con le osservazioni sono probabilmente risolvibili migliorando la nostra comprensione del processo di formazione delle galassie

- Zwicky (1937)
- Rubin & Ford (1970)
- Ostriker & Peebles (1973)
- Einasto et al. (1974)
- Ostriker, Peebles & Yahil (1974)
- Bosma (1978)
- Peebles (1982, 1984)
- Davis et al. (1985)
- Bullock & Boylan-Kolchin (2017)
- De Swart, Bertone & van Dongen (2017)