

A trail of Dark-Matter-free galaxies from a bullet-dwarf collision¹

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¹<https://www.nature.com/articles/s41586-022-04665-6>

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But first...

Why?



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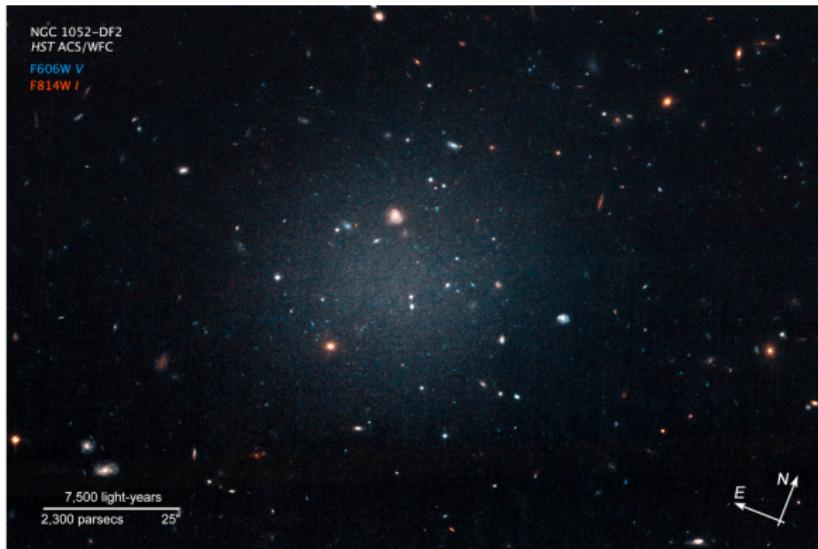
Why?

self interaction
cross-section
of Dark Matter



DF2 and DF4

DF2 and DF4 are Ultra-Diffuse Galaxies (UDG) \in NGC 1052 group



DF2 galaxy²

²<https://hubblesite.org/contents/media/images/2018/16/4139-Image.html>

DF2 and DF4

Unusual properties:

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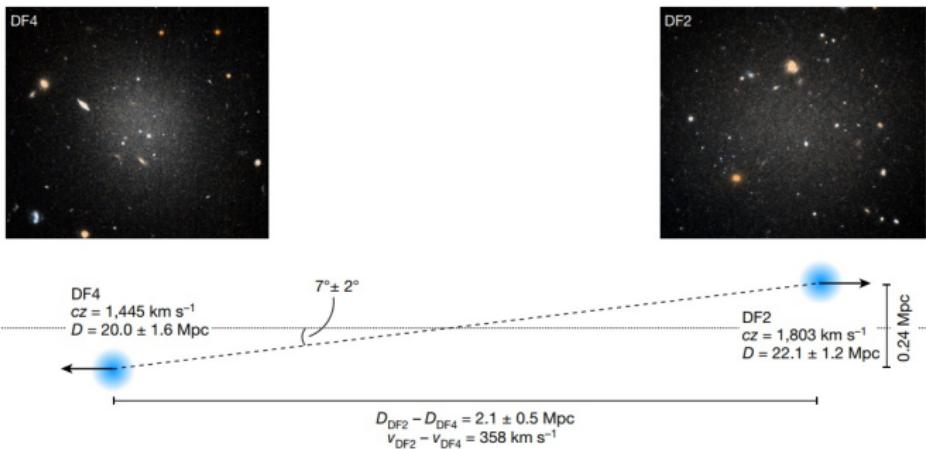
- low velocity dispersions
 \Rightarrow little or no Dark Matter (DM)

$$M \propto \sigma_v^k \quad k \simeq 3$$

$$M \geq \sum_i m_i$$

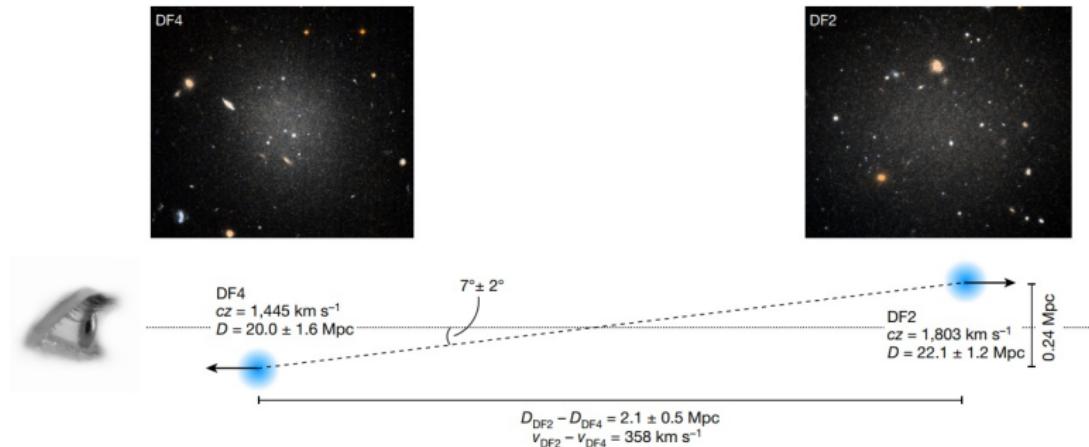
$$\Rightarrow \sigma_v^k \geq \sum_i m_i$$

Why a collisional formation



The **joint** collisional formation is suggested by:

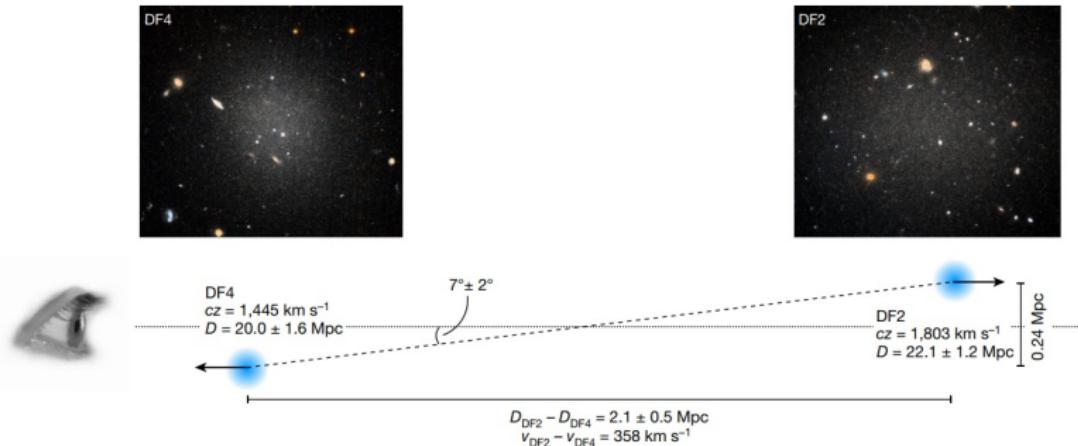
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The **joint** collisional formation is suggested by:

- Many unusual properties in common are unlikely to be a coincidence

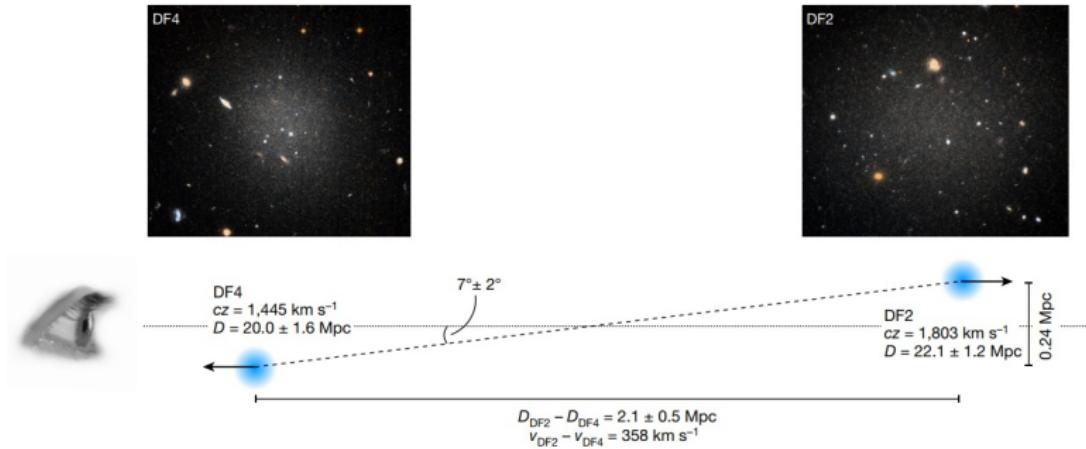
Why a collisional formation



The **joint** collisional formation is suggested by:

- Many unusual properties in common are unlikely to be a coincidence
- DF2 and DF4 close to each other at the time of their formation

Why a collisional formation



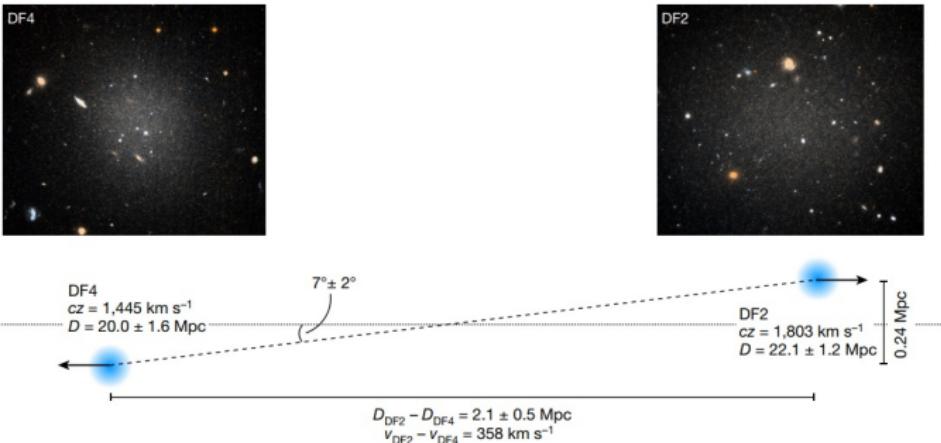
The joint **collisional** formation is implied by

- their present-day radial velocities

$$v_{DF2} - v_{DF4} = 358 \text{ km/s} \sim 3\sigma_{NGC1052}$$

→ consistent with their line-of-sight distances

Why a collisional formation



The joint **collisional** formation is implied by

- 3D locations
Along the line of sight:

$$D_{\text{DF2}} - D_{\text{DF4}} = (2.1 \pm 0.5) \text{ Mpc} \sim 5R_{\text{NGC1052}}$$

In the plane of the sky:

$$y_{\text{DF2}} - y_{\text{DF4}} = 0.24 \text{ Mpc}$$

Details of the collision

★ Who?

Gas-rich dwarf galaxies, i.e a few billion stars



A dwarf galaxy³

³<https://esahubble.org/wordbank/dwarf-galaxy/>

Details of the collision

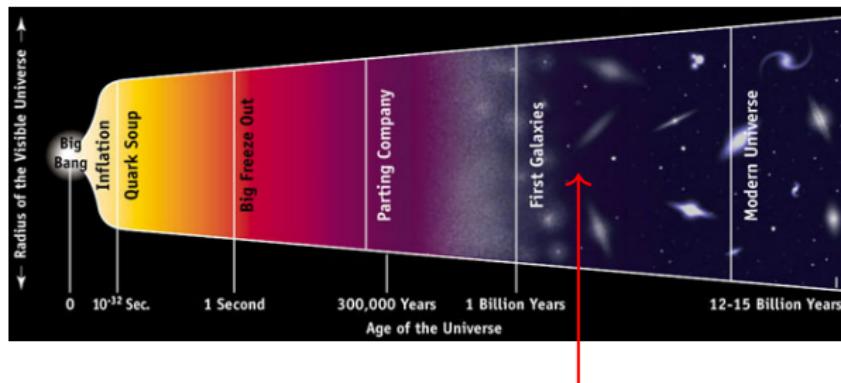
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⌚ When?

Around 8 billion years ago (at least 6 Gyr).

- inferred assuming a post-collision velocity $\langle v \rangle \sim 350 \text{ km/s}$.
- consistent with the age of the globular clusters of DF2



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Near the central galaxy NGC 1052

- \sim halfway between DF2 and DF4 in projection
- its deep potential well is conducive to high-speed interactions

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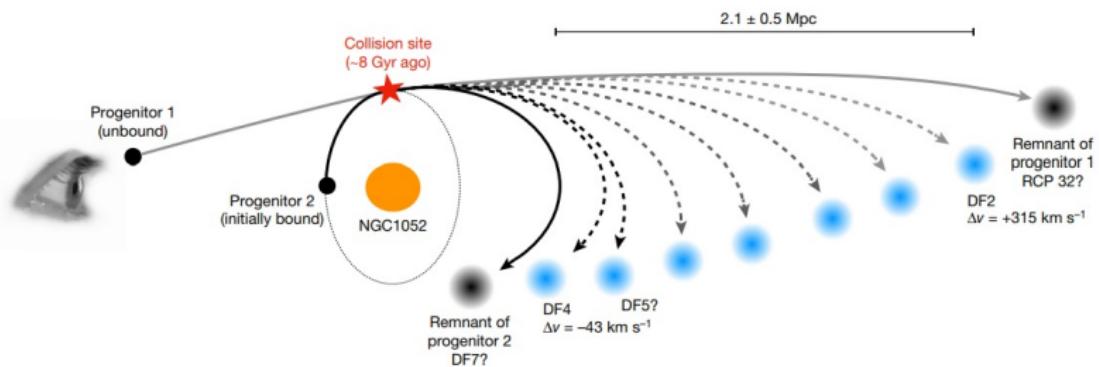
↗ How?

High-velocity collision ($\sim 300 \text{ km/s}$)

Details of the collision

Who were the progenitors?

- progenitor 1, unbound
 \Rightarrow DF2 took its property
- progenitor 2, on a bound orbit (satellite of NGC 1052)
 \Rightarrow DF4 took its property



Details of the collision

Who were the progenitors?

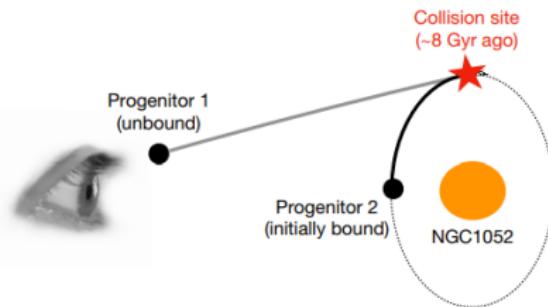
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It is consistent with tidal distortions?

The two galaxies have almost identical tidal distortions

→ agrees with the galaxies being at the same distance from NGC 1052 when they were formed

Details of the collision



What happened?

- Progenitor 1 arrived in the vicinity of progenitor 2 with high-speed

Details of the collision

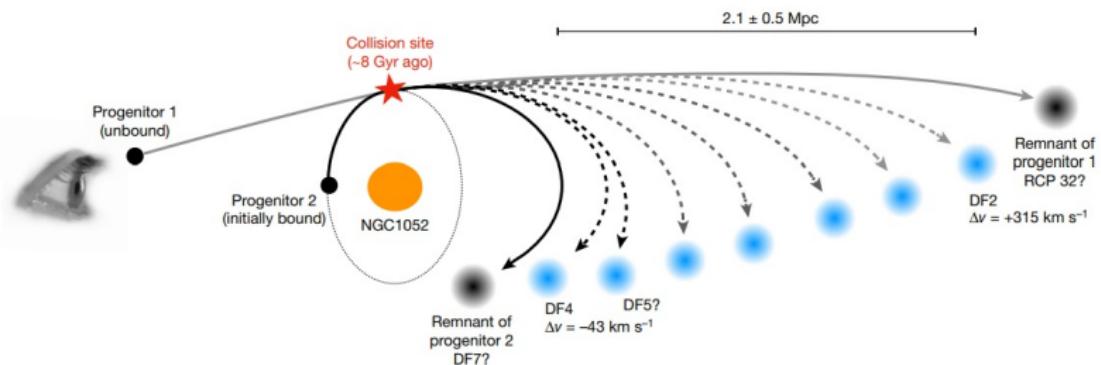


What happened?

- Progenitor 1 arrived in the vicinity of progenitor 2 with high-speed
- The gas was separated from the collisionless DM and pre-existing stars³

³<https://apod.nasa.gov/apod/ap060824.html>

Details of the collision



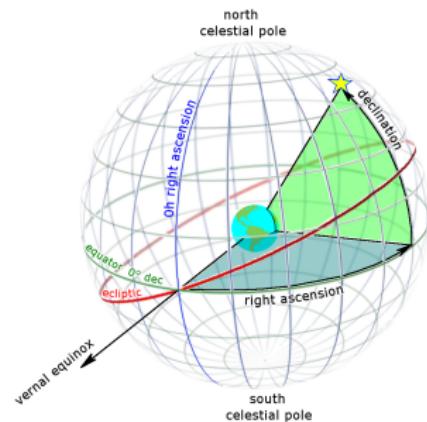
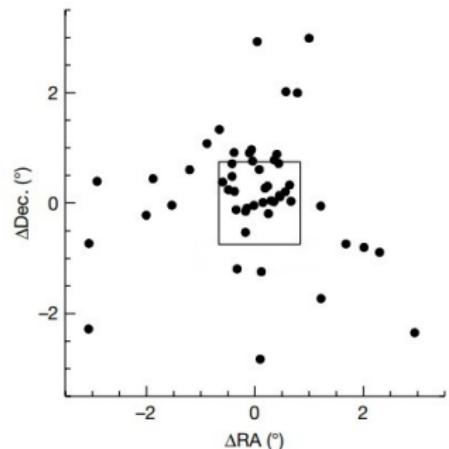
What happened?

- Progenitor 1 arrived in the vicinity of progenitor 2 with high-speed
- The gas was separated from the collisionless DM and pre-existing stars
- New galaxies were formed together with massive clumps.

More DM-free objects born in the collision?

The spatial distribution of galaxies around DF2 and DF4 was studied in order to find:

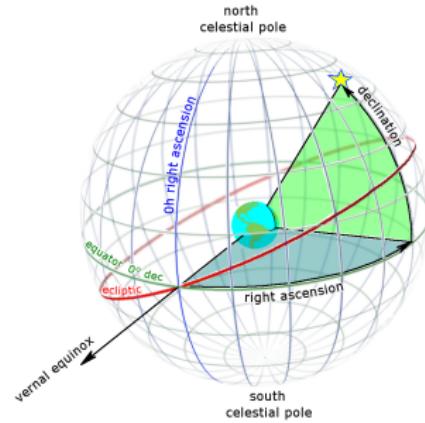
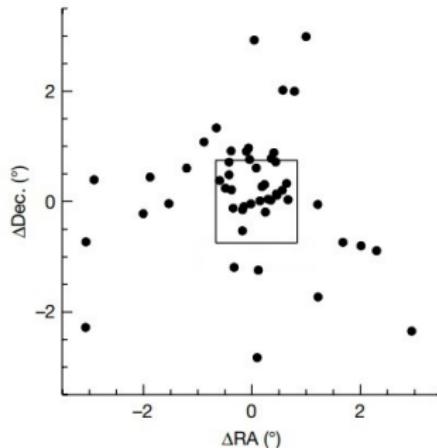
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- 2 DM-dominant objects, remnants of the two progenitors, predicted by the bullet dwarf event

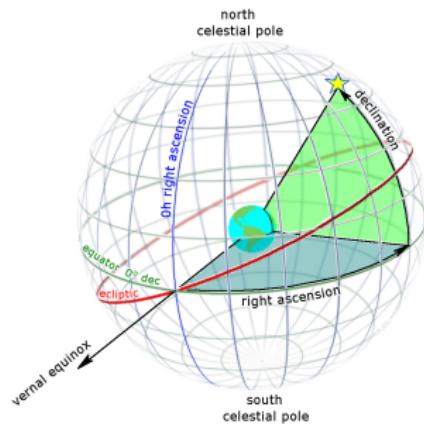
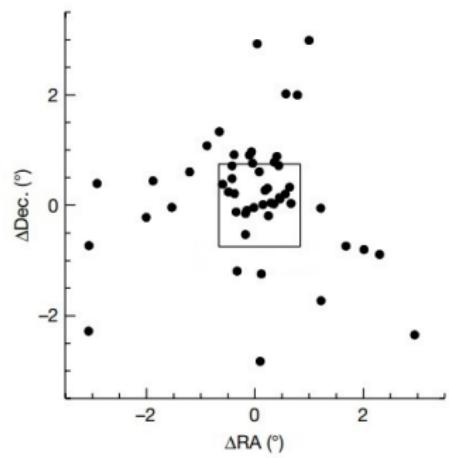


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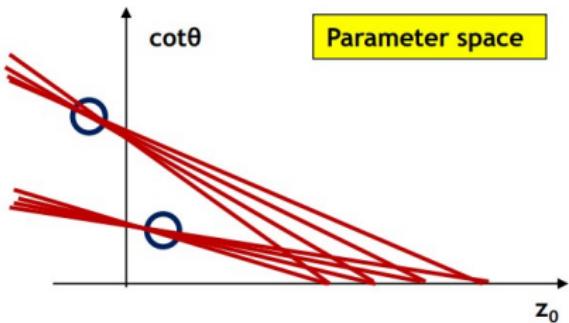
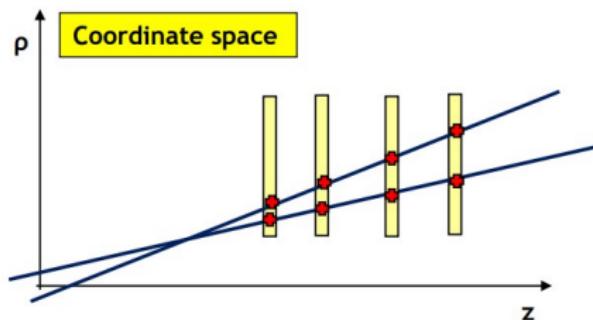
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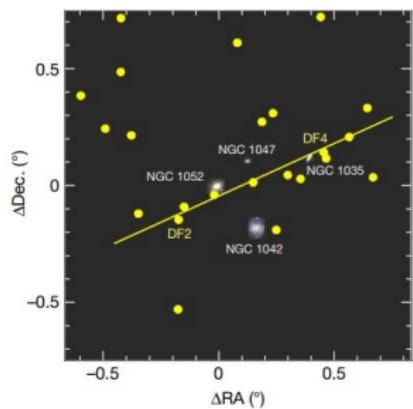
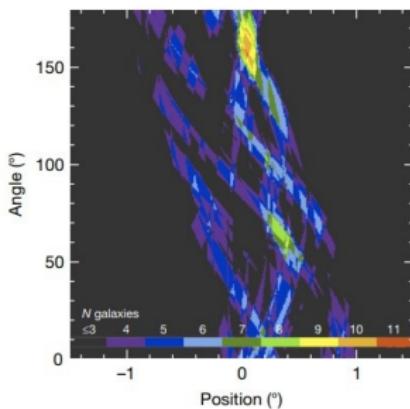
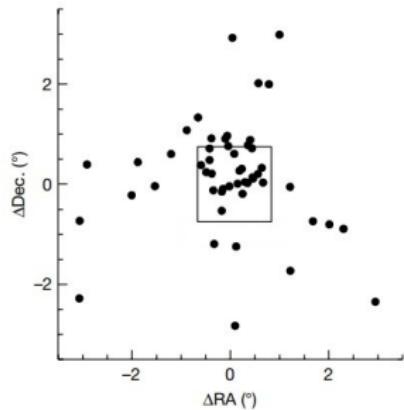
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A trail of DM-free objects

Peak with 11 galaxies in a line:

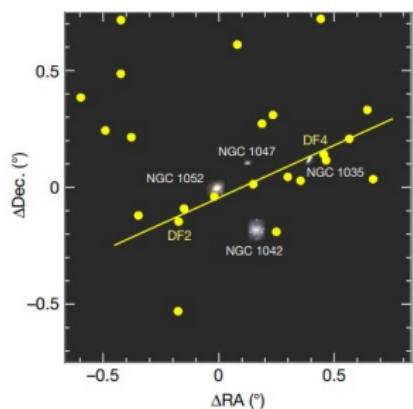
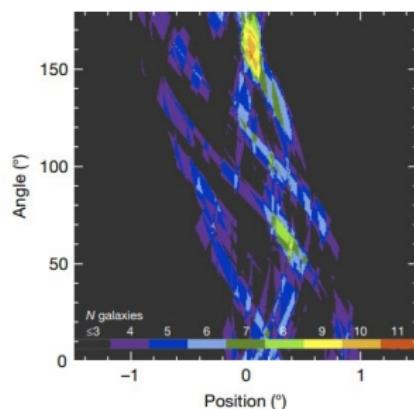
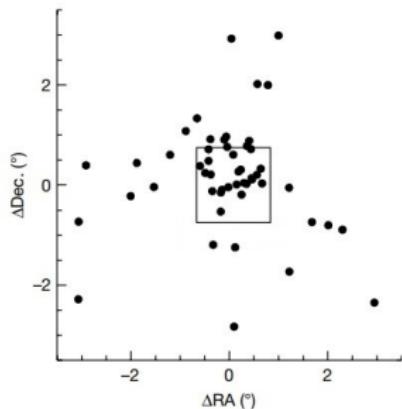
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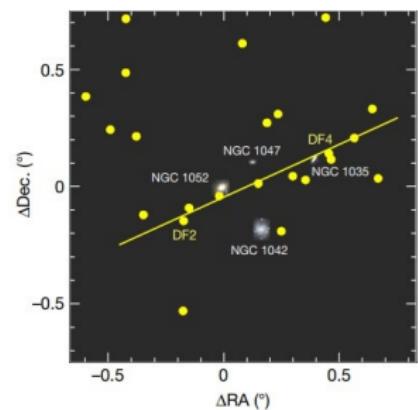
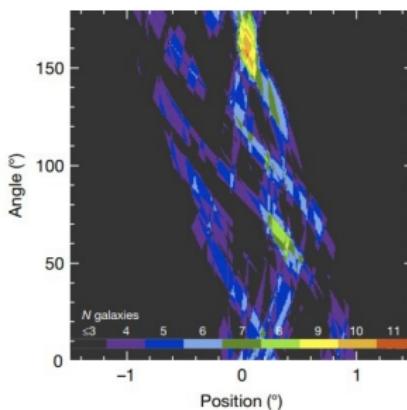
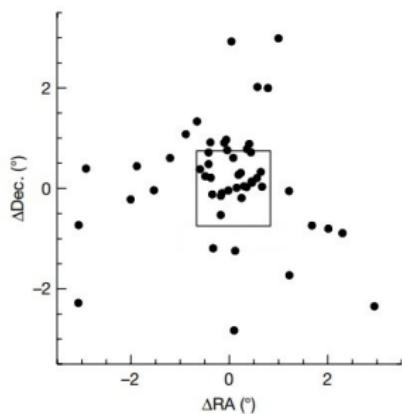


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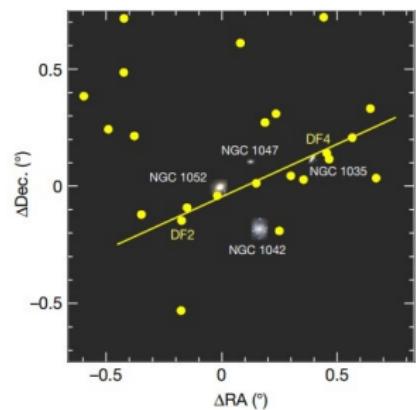
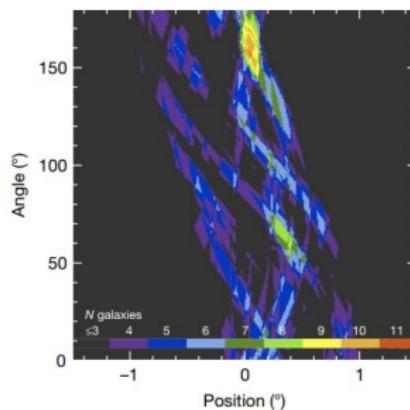
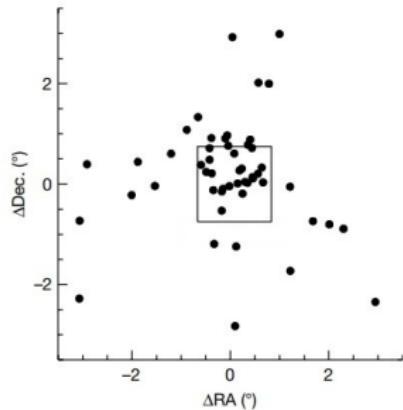
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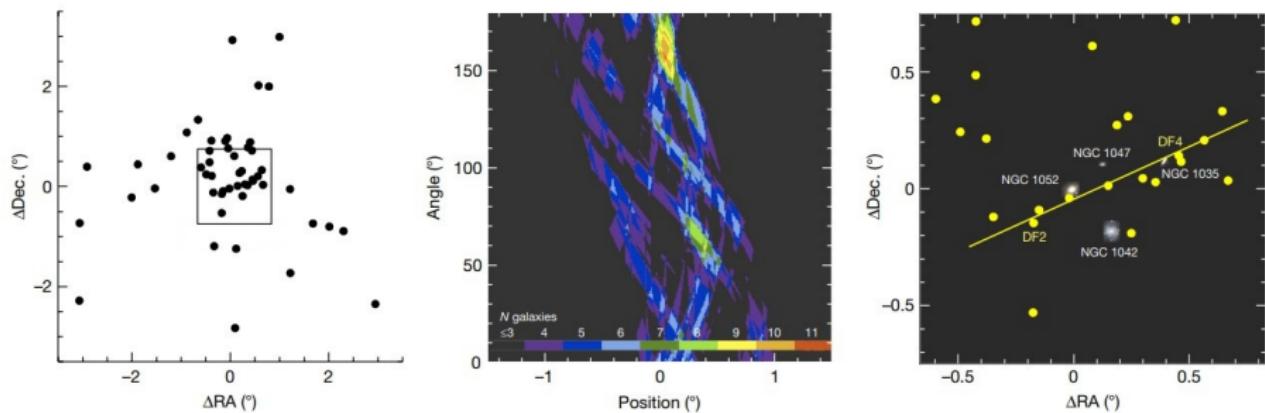
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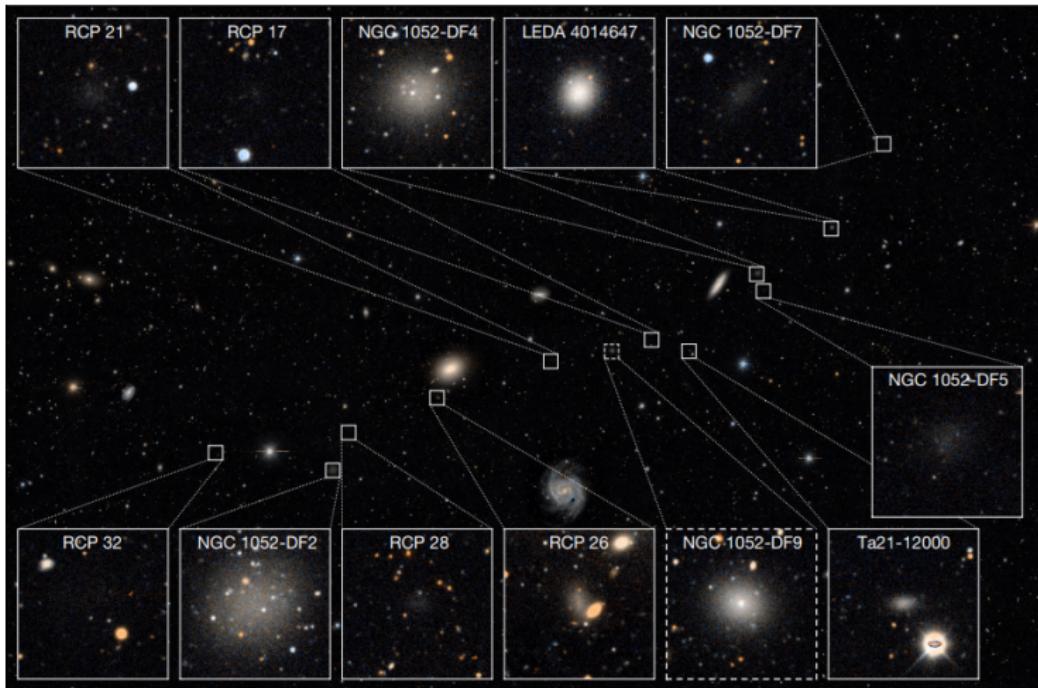
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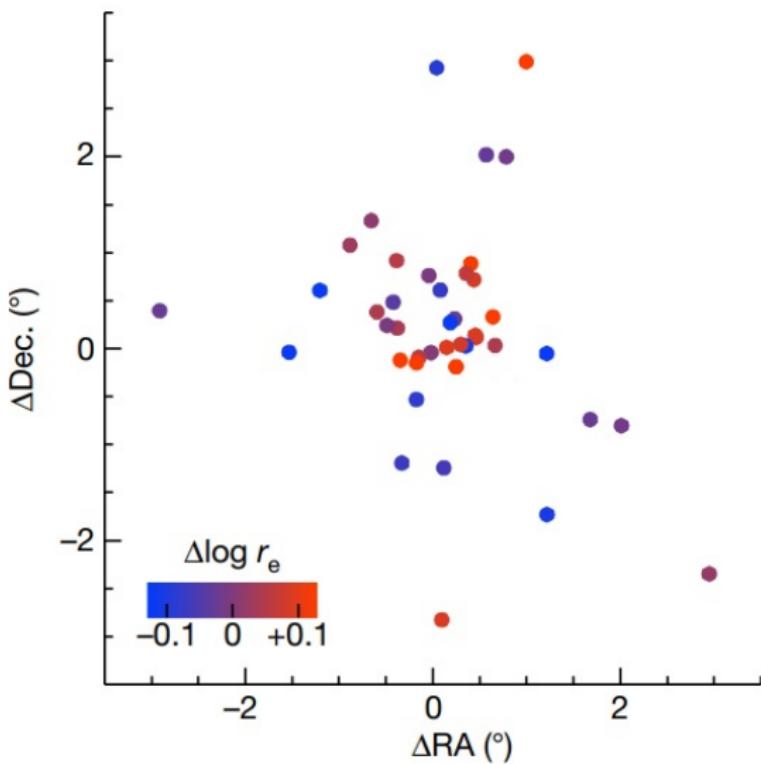
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\Rightarrow 7–11 galaxies in the structure

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- Deeper comprehension of bullet-dwarf collisional events to get a constraint to the self-interaction cross section of DM
 ⇒ need of other similar events

Conclusions

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A **trail of DM-free galaxies with joint collisional formation** roughly more than 2 Mpc apart and angled $7^\circ \pm 2^\circ$ from the line of sight has been identified

Your questions



References

- [1] Pieter van Dokkum et al. “A trail of dark-matter-free galaxies from a bullet-dwarf collision”. In: *Nature* 605.7910 (2022), pp. 435–439.
- [2] Yotam Cohen et al. “The Dragonfly Nearby Galaxies Survey. V. HST/ACS Observations of 23 Low Surface Brightness Objects in the Fields of NGC 1052, NGC 1084, M96, and NGC 4258”. In: *The Astrophysical Journal* 868.2 (2018), p. 96.
- [3] Zili Shen, Pieter van Dokkum, and Shany Danieli. “A complex luminosity function for the anomalous globular clusters in NGC 1052-DF2 and NGC 1052-DF4”. In: *The Astrophysical Journal* 909.2 (2021), p. 179.