

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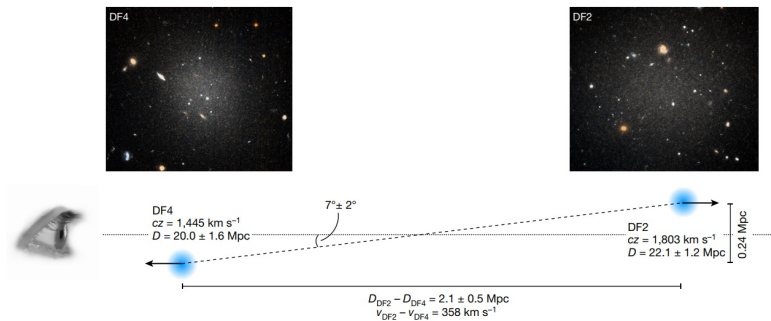
- low velocity dispersions
 \implies little or no Dark Matter (DM)

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

$$M \geq \sum_i m_i$$

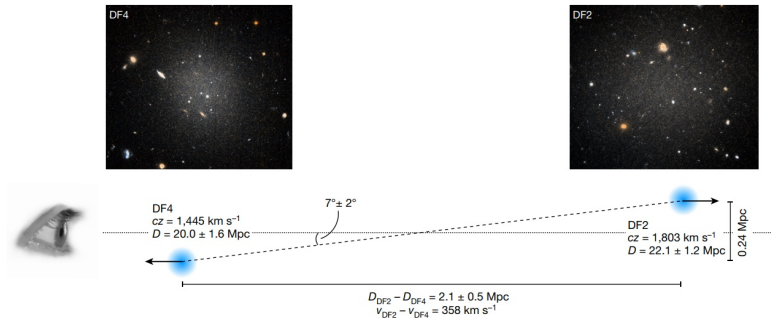
$$\implies \sigma_v^k \geq \sum_i m_i$$

Why a collisional formation



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

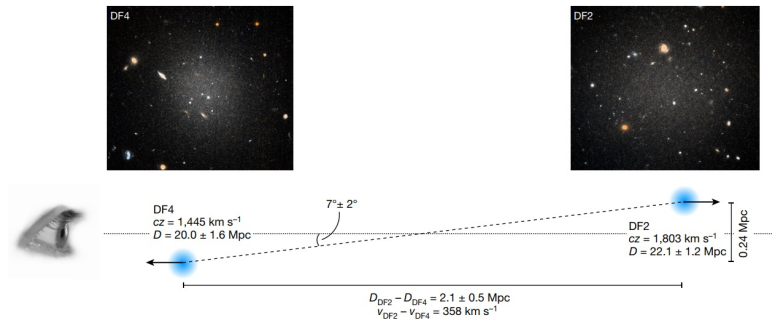
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The **joint** collisional formation is suggested by:

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

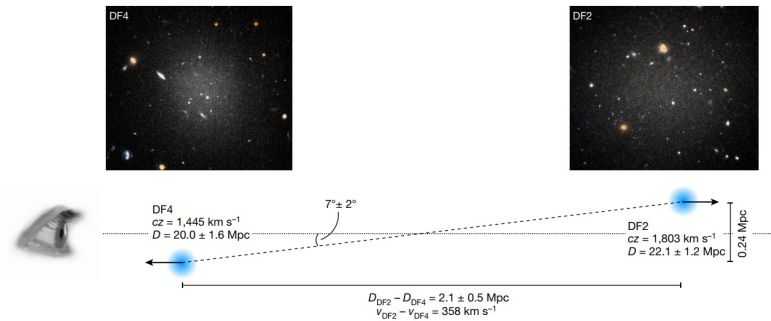
Why a collisional formation



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



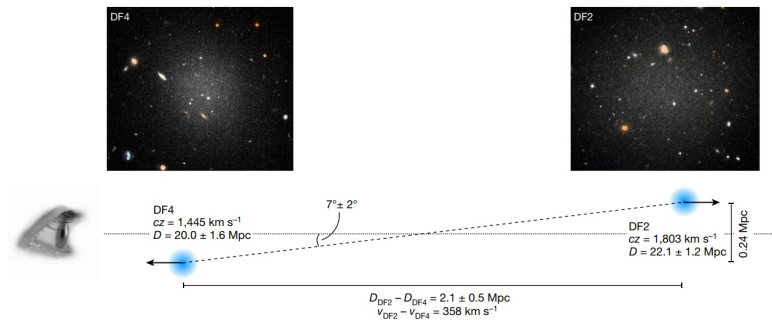
The joint **collisional** formation is implied by

- 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:

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

In the plane of the sky:

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

Details of the collision

★ Who?

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



A dwarf galaxy ³

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

Details of the collision

★ Who?

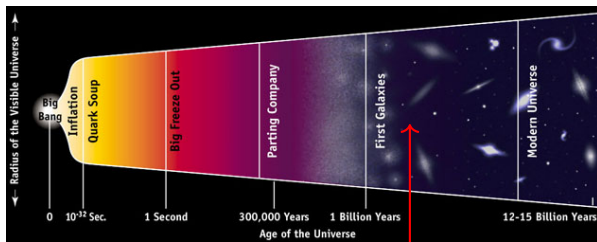
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When?

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

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



here

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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 (~ 300 km/s)

Details of the collision



Who were the progenitors?

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

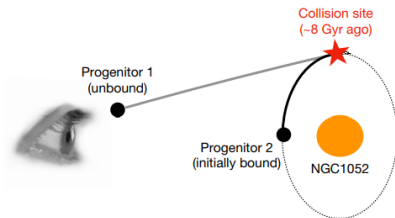


It is consistent with tidal distortions?

The two galaxies have almost identical tidal distortions

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

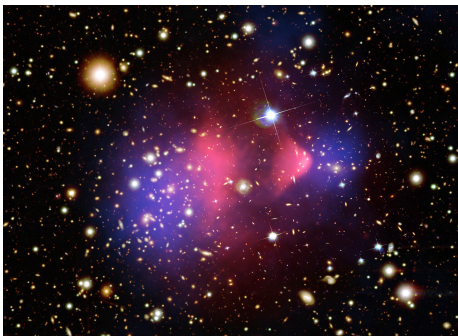
Details of the collision



What happened?

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

Details of the collision

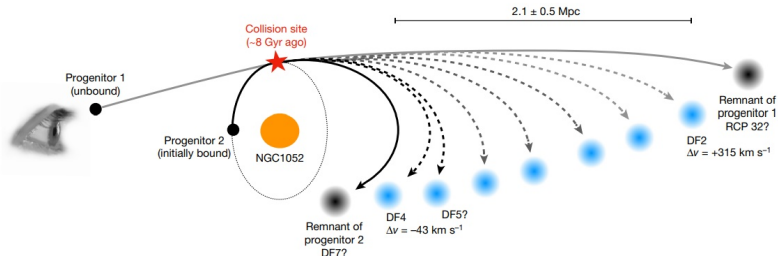


What happened?

- 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



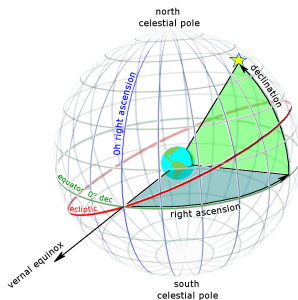
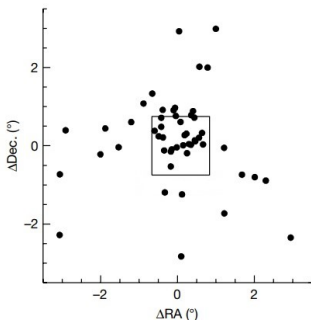
What happened?

- 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:

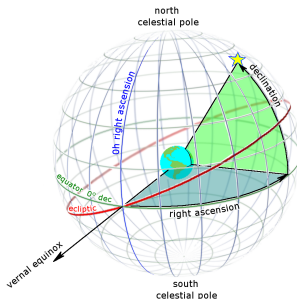
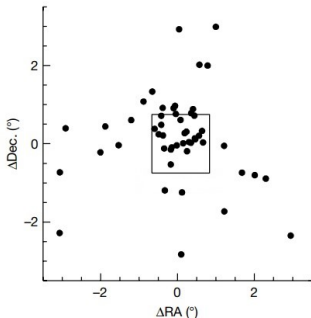
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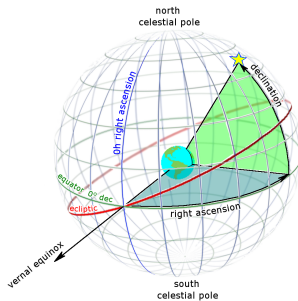
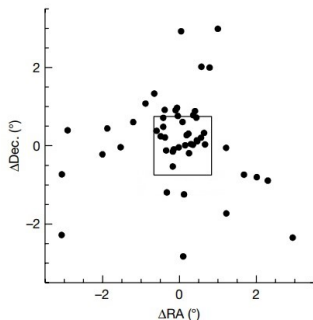


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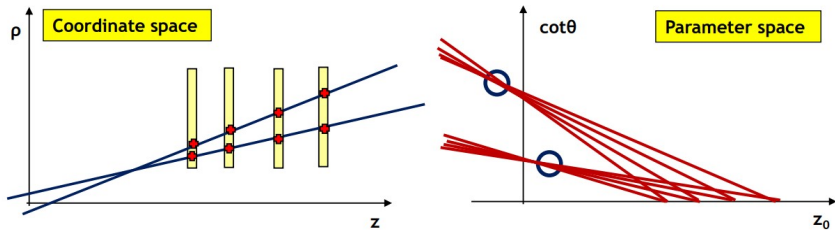
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⇒ Hough transform



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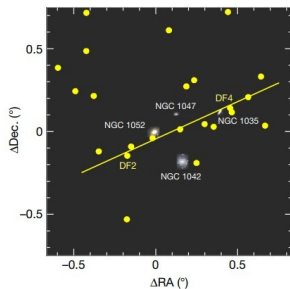
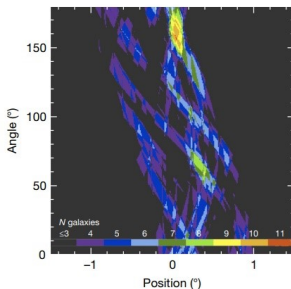
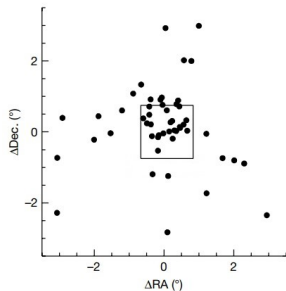
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A trail of DM-free objects

Peak with 11 galaxies in a line:

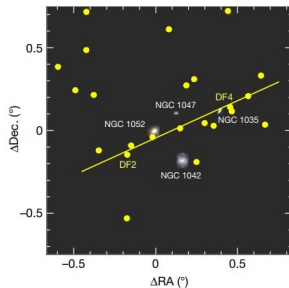
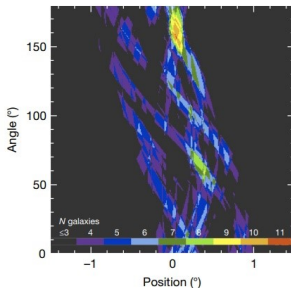
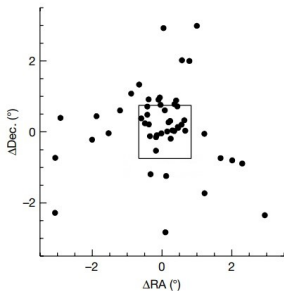
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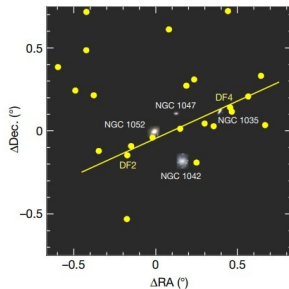
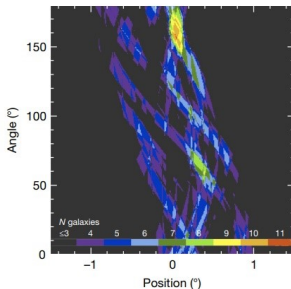
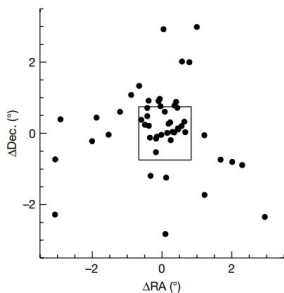


probability that the peak arose by chance: 3%

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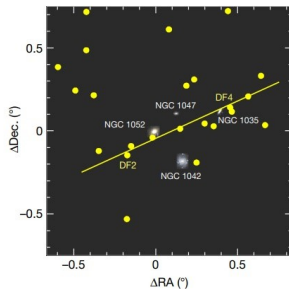
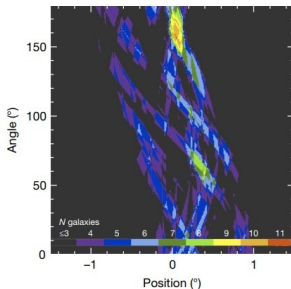
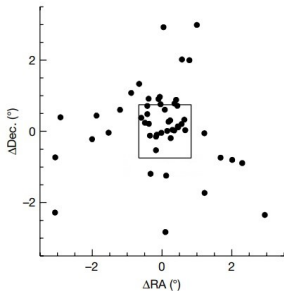
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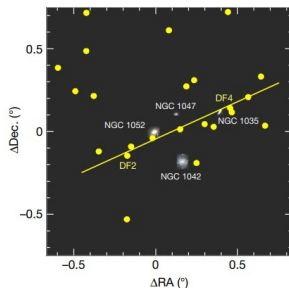
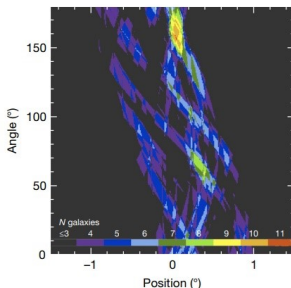
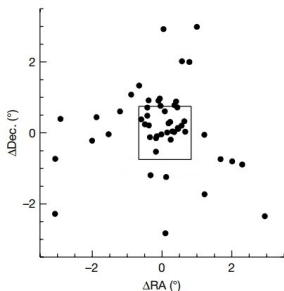
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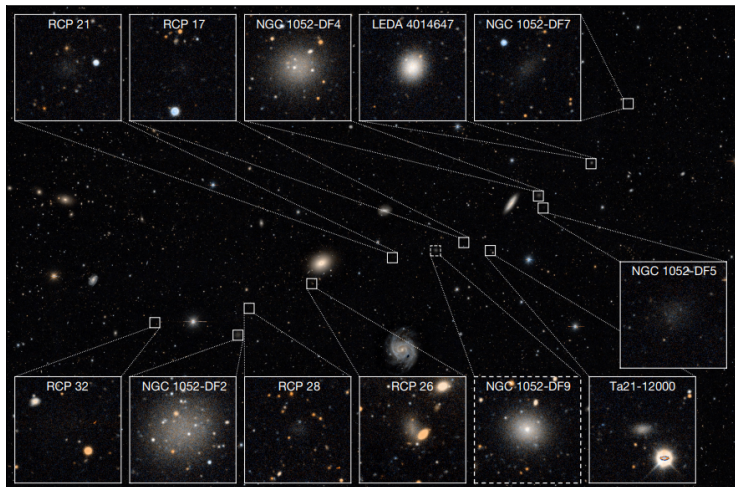
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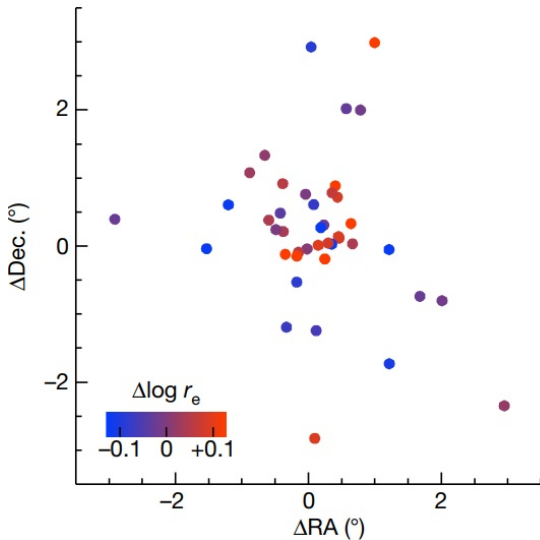
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\Rightarrow 7–11 galaxies in the structure

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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.