Dark matter and the spiral structure of NGC 2915

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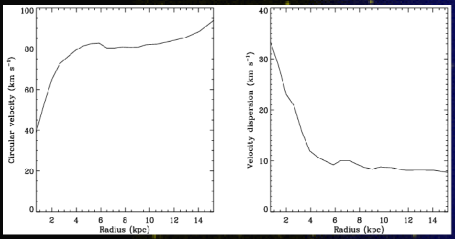
Abstract

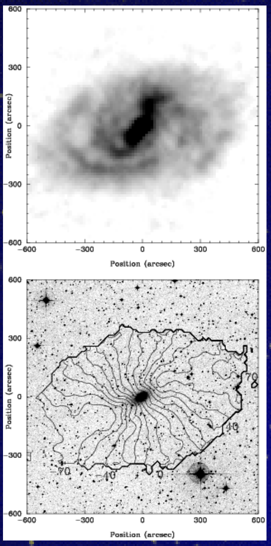
NGC 2915 is a blue compact dwarf galaxy embedded in an extended, low surface brightness HI disk with a bar and two-armed spiral structure. Common mechanisms are unable to explain those patterns and disk dark matter or a rotating triaxial dark halo were proposed as alternatives. Hydrodynamical simulations were run for each case and compared to observations using customized column density and kinematic constraints. The spiral structure can be accounted for both by an unseen bar or triaxial halo. However, the large bar mass or halo pattern frequency required make it unlikely that the spiral is driven by a non-axisymmetric halo. In particular, the spin parameter lambda is much higher than predicted by current CDM structure formation scenarios. Massive disk models show that when the gas surface density is scaled up by a factor about 10, the disk develops a spiral structure matching the observed one in perturbed density and velocity. This suggests that the disk of NGC 2915 contains much more mass than is visible, tightly linked to the neutral hydrogen. A classic (quasi-)spherical halo is nevertheless still required, as increasing the disk mass further to fit the circular velocity curve would make the disk violently unstable.

Observational properties

NGC 2915 is a BCD galaxy at a distance *D=5.3±1.6* Mpc. Radio observations show an HI disk extending to 22 radial length scales in the *B* band. This hydrogen disk exhibits a grand design *m=2* spiral pattern, as can be seen on the figure to the right showing the total HI map and velocity field from the naturally weighted cube of Meurer et al. (1996). The high surface brightness core of NGC 2915, blue and lumpy, is entirely contained within one beam width. The circular velocity and velocity dispersion profiles are shown below.

Bureau et al. (1999) measured the bar pattern speed of NGC 2915 using the Tremaine-Weinberg method (1984) and found 8.0±2.4 km/s/kpc.





What is the origin of the spiral structure ?

It can be due either to:

- a tidal excitation by an "external" perturber (which either a triaxial halo or a bar);
- a global gravitational instability of the disk (e.g. SWING), requiring that this latter be actually much more massive than observed.

We entertain both possibilities by means of simple numerical simulations

Hydrodynamic code

- It is a 2D grid-based polar mesh hydrocode (with staggered mesh and artificial viscosity, see Stone & Norman 1992).
- Fast advection algorithm aimed at getting rid of the mean azimuthal motion, thus relieving the Courant constraint (see Masset 2000).
- Analytical perturbing potential and disk self-gravity.

Constraints from observations

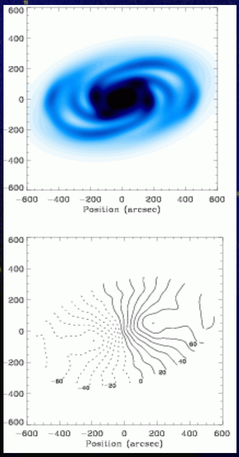
One has to account simultaneously for:

- The pitch angle of the spiral arms
- The arm-interarm contrast
- The perturbed velocity field (streaming motions associated with the spiral and bar)

Massive disks models

We scaled the observed gaseous disk surface density by a uniform constant *C*.
A spherical analytical halo is still added (whose mass decreases with *C*) in order to reproduce the observed rotation curve.
The Fourier components of the potential with $m>6$ are filtered out in order to prevent the onset of medium to small scale gravitational instabilities, and so that only the large scale dynamics is reproduced.
Low-level noise is added to the initial conditions in order to allow for the growth of the unstable modes.

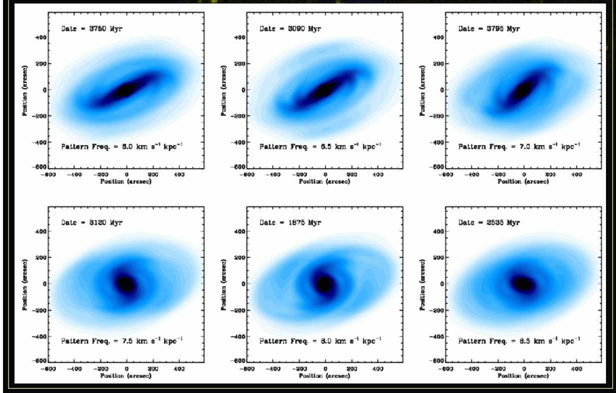
We find that by scaling-up the observed surface density by a factor ~10, we get a grand-design spiral structure which resembles the one of NGC 2915, as shown on the figure below.



Externally forced disks models

Varying either the bar mass or the halo triaxiality, and the pattern speed, we find that a perturber which excites a spiral response resembling most the observed one must have:
* a pattern frequency 6.5-8.0 km/s/kpc;
* a perturbing strength given either by:
  - a 5-7.10^9 solar masses bar
  - a halo triaxiality: *b/a* ~ 0.83 to 0.88 (*c/a* is unconstrained.)

The figure below shows the disk surface density response to a perturbing bar with different pattern speeds.



Conclusions

The mass required for a forcing bar, or the pattern speed required for a forcing triaxial halo, are both unlikely: the observed stellar mass is about one order of magnitude inferior to the bar mass required, while a triaxial halo would rotate too fast (high spin parameter lambda).

The massive disk runs show that one can closely reproduce the spiral response and associated velocity field, assuming that the disk contains a large fraction (90%) of unseen gaseous material that has a similar sound speed (i.e. velocity dispersion) as the HI. A halo is still required, with a mass comparable to that of the disk at the outer disk radius.

References

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Credits: the background image is a montage of NGC 2915 in the optical (yellow) and in the HI (blue), due to G. Meurer, and reproduced with his kind authorization.