The evolution of galaxy formation

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Abstract

Our history of understanding galaxy formation could be traced through the development of individual ideas. A cynic might be tempted to suggest that new catchphrases are developed at a faster rate than genuine progress is made.

The story so far

Galaxy formation is a complex subject, and the fundamental question “how do galaxies form?” is poorly defined. Galaxies do not “form” instantaneously, and there is no sharp dividing line between their creation and the evolution of their properties. Understanding how lumps of a specific size developed from simplicity to complexity is clearly a challenging endeavour. Different researchers approach this from a variety of directions, and the history of progress on this topic is replete with ideas that have temporarily captured the imagination of astrophysicists. This history can be followed through a series of the most important review (or review-like) articles, including Gamow (1948), Hoyle (1953), Sciama (1955), Eggen, Lyden-Bell & Sandage (1962), Layzer (1964), Peebles (1965), Doroshkevich, Zeldovich & Novikov (1967), Larson (1969), Harrison (1970), Peebles (1974), Jones (1976), Gott (1977), Rees (1978), Efstathiou & Silk (1983), Blumenthal et al. (1984), White (1995), Baugh (2006) and Benson (2010), as well as books by Longair (1998, 2008), Spinrad (2005) and Mo, Van den Bosch & White (2010).

However, instead of reviewing these reviews, I present a brief timeline for the development of the concepts underlying our current understanding of galaxy formation [1]. This is best told via pieces of what was once called “rhetorick” and in the modern age might be known as “catchphrases”, “sound-bites” or “spin” [2]. For each of these physical ideas, I have tried to identify the originator as well as when the idea caught on, as traced through the first paper found with the relevant phrase in the title or abstract [3]. These entries are arranged in chronological order of first appearance of each phrase, which in some cases may be a surprisingly long time after the concept was first described. No attempt has been made to measure how prevalent each idea has been, or to track its rise and fall [4]. Imperfect as it may be, this list provides an interesting history of ideas in this perplexing branch of astrophysics [5].
ORIGIN

Light
↓
Nebulae
↓
Spirals
↓
Island universes
↓
Galaxies
↓
Ellipticals
↓
Galactic vs. extragalactic nebulae
↓
Gravitational instability
↓
Primordial gas
↓
Tuning-fork diagram
↓
Early vs. Late types
↓
Dark matter
↓
Proto-galaxies
↓
Mass-to-light ratios
↓
Cloud fragmentation
↓
Violent relaxation
↓
Reionisation
↓
Thermal instability
↓
Radiative cooling
↓
Perturbation theory
↓
Hubble sequence
↓

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Lessons

What can we learn from this timeline by viewing it as a process? First, if we simply count ideas, and assume there is a bandwagon effect associated with each one, then the duration of each fad is approximately one year [7]. The corollary to this finding, and the advice for new researchers, is that one should jump quickly onto bandwagons before they pass. The second point is that not all of the concepts listed are entirely new, and it may even seem to the cynical reader that some apparently new suggestions are simply recycled from earlier ones, but with new names. This leads to another recommendation for those who wish to make an impact on galaxy formation – study what is already known, find something that has not been highlighted much before, and come up with a new name for it.

Sidelines

We end with a list of ideas that are at least a little off the mainstream of galaxy formation research. These are the “also-ran” or “dead-end” concepts, some of which seemed a bit outré in the first place, while others appeared promising briefly, but were ultimately seen to be merely a distraction [8]. Such ideas might include: primordial turbulence; continuous creation; cosmic explosions; mock gravity; isocurvature baryons; cosmic string wakes; textures; late time phase transitions; warm dark matter; self-interacting dark matter; cooling flows; hyper-extended perturbation theory; retarded galaxies in voids; jet-triggered star formation; fractal structure; plasma cosmology; MOND; MOG; primordial black holes; primordial magnetic fields; etc.

No doubt there will be many more such notions to come. Only time will tell whether any of them become part of the main narrative.

The future

Experts disagree on whether we are about to enter a golden “precision era” of galaxy formation or whether the subject is essentially over, with just the weather-prediction details left to fuss about. Although precise future directions are unknown, some general predictions are possible: (1) galaxy formation will not be completely “solved” in the near future; (2) ambitious multi-wavelength surveys will extend our empirical understanding of the high-z Universe; (3) there will continue to be phrases spun to describe new ideas; (4) some of these ideas will be old ideas, dressed up; (5) some ideas will be crazy, and will fall by the wayside; but (6) some ideas will genuinely progress the field, inspiring a new generation of galaxy fabricators.

Notes and references

[1] The boundaries are of course quite blurred between galaxy formation and the nearby topics of star formation, cluster physics and large-scale structure. The choice of how far to explore around these boundaries is necessarily quite subjective.

[2] Using analogies from the world’s of entertainment, the media and politics. The web 2.0 version would be “meme”.

[3] For tracking down the source of a phrase or idea, I have tried to simplify a complicated history by picking a single paper in most cases. There will undoubtedly be errors in this process, and I apologise for either getting the originator wrong, or missing an earlier example of the use of the phrase. The main aim of the “usage” column is to trace when the idea started to become popular in the literature, and to be definitive I focus on abstracts of papers in journals or conference proceedings, ignoring AAS abstracts or telescope proposals.

[4] One could study the longevity of each idea, and whether specific periods of time, scientists or journals have been more productive, etc. This is complicated by the fact that some phrases were originally coined with a slightly different meaning, e.g. “starburst” (the nucleus only), “quenching” (of radio emission) and “cold streams” (tidal debris). Tracking the citations is made more difficult as a result of the natural tendency of researchers to consider history to have started when they entered the field. Because of these complications I leave it to more serious historians of science to trace the detailed evolution of each idea. My colleague Dr. Frolop has already embarked on such a project.
[5] Other areas of astrophysics could surely be traced in a similar way; however, galaxy formation seems to have more than its fair share of these catchphrases, presumably because it is a complex subject, which has to be tackled from many different perspectives.

[6] This term is often used in popular-level presentations, but rarely in technical papers.

[7] Many ideas are current at the same time of course, so this estimate is really the new bandwagon rate. Catchphrases differ in their longevity; some taking a long time to be picked up in the literature after first being discussed, while others resonating instantly with other researchers.

[8] Although of course no idea ever dies entirely.

[9] This article made use of NASA’s Astrophysical Data System Bibliographic Services. I wish to acknowledge discussions with and advice from many colleagues, particularly those who refrained from simply pointing out which ideas had been theirs.

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