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How we can recognize strcutures in the universe?

Clusters, groups and substructures

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ABSTRACT

Aims. Recognize the different methods to study the strcutures in the universe that are gravitationally bound or in intereaction, i.e. galaxy clusters and their substructures, galaxy groups, galaxy groups like substructures of clusters or substructures per se
Methods.
Results.

1. Introduction

It is always a problem to define the limits of the things, above all in astronomy. In particular, the area of the extendends objects is impossible to know how many stars belongs to a star cluster or a galaxy in a gravitational way, due to the instrumental limitations. The study of the membership of galaxy groups and clusters is a chaotic task in order to define spatially the limits of the structure.

In 1961, Zwicky et al. (1961) produce one of the first catalogs of galaxy clusters, based in overdensities over the photometrics measures of differents regions of the sky. After, Abell (1958) did a similar study of the same sky, using the criteria Abell applied for the identification of clusters refer to an overdensity of galaxies within a specified solid angle. This, includes the redshift measurement, but at the epoch was imposible to take images at $z \leq 0.02$ giving the dimensions of a photoplate ($\approx 6^o \times 6^o$) and the angular size of the clusters. For higher redshifts ($z \geq 0.2$), the sensivite and the hardware of the telescopes were not enough (Schneider (2006)).

Later, Helou et al. (1979) made observations in H_{21cm} to different structures (clusters and groups of galaxies) and when the cloud of H_{21cm} was the same, the strcuture was the same. In Zhao et al. (1990) they used the *maximum likelihood method* to identify galaxies for the same structure via similar redshift. In two cases was important the spatial distribution in the plane of the sky of the structure to limit the center of the overdensity. In particular this introduce the *foreground and background* galaxies like contamination to the sample. One of the most emblematics cases was the *Stephan quintent's* defined by Hickson (1982) like a compact group, ignoring the redshift and this was result in that one of the galaxies was a foreground galaxy, before and spectroscopic analysis (Hickson et al. (1992)).

Today, the membership of the structures still be a problem to the extragalactic astronomers. In particular for the less luminous galaxies and the outskirts of the structures. In this essay the principal aim is unterstand why and how we can do a good classification of the members of galaxy clusters.

2. Different methods

2.1. Abell criteria

2.2.

2.3. Use of the photo-z

In this section the one-zone model of **?**, originally used to study the Cepheïd pulsation mechanism, will be briefly reviewed. The resulting stability criteria will be rewritten in terms of local state variables, local timescales and constitutive relations.

? investigates the stability of thin layers in self-gravitating, spherical gas clouds with the following properties:

– hydrostatic equilibrium,
– thermal equilibrium,
– energy transport by grey radiation diffusion.

For the one-zone-model Baker obtains necessary conditions for dynamical, secular and vibrational (or pulsational) stability (Eqs. (34a, b, c) in Baker **?**). Using Baker's notation:

M_r	mass internal to the radius r
m	mass of the zone
r_0	unperturbed zone radius
ρ_0	unperturbed density in the zone
T_0	unperturbed temperature in the zone
L_{r0}	unperturbed luminosity
E_{th}	thermal energy of the zone

and with the definitions of the *local cooling time* (see Fig. 1)

$$\tau_{\mathrm{co}} = \frac{E_{\mathrm{th}}}{L_{r0}}\,, \tag{1}$$

and the *local free-fall time*

$$\tau_{\mathrm{ff}} = \sqrt{\frac{3\pi}{32G}\frac{4\pi r_0^3}{3M_{\mathrm{r}}}}\,, \tag{2}$$

Baker's K and σ_0 have the following form:

$$\sigma_0 = \frac{\pi}{\sqrt{8}}\frac{1}{\tau_{\mathrm{ff}}} \tag{3}$$

$$K = \frac{\sqrt{32}}{\pi}\frac{1}{\delta}\frac{\tau_{\mathrm{ff}}}{\tau_{\mathrm{co}}}\,; \tag{4}$$

Fig. 1. Adiabatic exponent Γ_1. Γ_1 is plotted as a function of lg internal energy [erg g^{-1}] and lg density [g cm^{-3}].

where $E_{\rm th} \approx m(P_0/\rho_0)$ has been used and

$$\begin{aligned}\delta &= -\left(\frac{\partial \ln \rho}{\partial \ln T}\right)_P \\ e &= mc^2\end{aligned} \qquad (5)$$

is a thermodynamical quantity which is of order 1 and equal to 1 for nonreacting mixtures of classical perfect gases. The physical meaning of σ_0 and K is clearly visible in the equations above. σ_0 represents a frequency of the order one per free-fall time. K is proportional to the ratio of the free-fall time and the cooling time. Substituting into Baker's criteria, using thermodynamic identities and definitions of thermodynamic quantities,

$$\Gamma_1 = \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_S, \ \chi_\rho = \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_T, \ \kappa_P = \left(\frac{\partial \ln \kappa}{\partial \ln P}\right)_T$$

$$\nabla_{\rm ad} = \left(\frac{\partial \ln T}{\partial \ln P}\right)_S, \ \chi_T = \left(\frac{\partial \ln P}{\partial \ln T}\right)_\rho, \ \kappa_T = \left(\frac{\partial \ln \kappa}{\partial \ln T}\right)_T$$

one obtains, after some pages of algebra, the conditions for *stability* given below:

$$\frac{\pi^2}{8}\frac{1}{\tau_{\rm ff}^2}(3\Gamma_1 - 4) \quad > \quad 0 \qquad (6)$$

$$\frac{\pi^2}{\tau_{\rm co}\tau_{\rm ff}^2}\Gamma_1\nabla_{\rm ad}\left[\frac{1-3/4\chi_\rho}{\chi_T}(\kappa_T - 4) + \kappa_P + 1\right] \quad > \quad 0 \qquad (7)$$

$$\frac{\pi^2}{4}\frac{3}{\tau_{\rm co}\tau_{\rm ff}^2}\Gamma_1^2\nabla_{\rm ad}\left[4\nabla_{\rm ad} - (\nabla_{\rm ad}\kappa_T + \kappa_P) - \frac{4}{3\Gamma_1}\right] \quad > \quad 0 \qquad (8)$$

For a physical discussion of the stability criteria see **?** or **?**.

We observe that these criteria for dynamical, secular and vibrational stability, respectively, can be factorized into

1. a factor containing local timescales only,
2. a factor containing only constitutive relations and their derivatives.

The first factors, depending on only timescales, are positive by definition. The signs of the left hand sides of the inequalities (6), (7) and (8) therefore depend exclusively on the second factors containing the constitutive relations. Since they depend only on state variables, the stability criteria themselves are *functions of the thermodynamic state in the local zone*. The one-zone stability can therefore be determined from a simple equation of state, given for example, as a function of density and temperature. Once the microphysics, i.e. the thermodynamics and opacities (see Table 1), are specified (in practice by specifying a chemical composition) the one-zone stability can be inferred if the thermodynamic state is specified. The zone – or in other words the layer – will be stable or unstable in whatever object it is imbedded as long as it satisfies the one-zone-model assumptions. Only the specific growth rates (depending upon the time scales) will be different for layers in different objects.

We will now write down the sign (and therefore stability) determining parts of the left-hand sides of the inequalities (6), (7) and (8) and thereby obtain *stability equations of state*.

The sign determining part of inequality (6) is $3\Gamma_1 - 4$ and it reduces to the criterion for dynamical stability

$$\Gamma_1 > \frac{4}{3}\,. \qquad (9)$$

Table 1. Opacity sources.

Source	$T/[\rm K]$
Yorke 1979, Yorke 1980a	$\leq 1700^{\rm a}$
Krügel 1971	$1700 \leq T \leq 5000$
Cox & Stewart 1969	$5000 \leq$

Fig. 2. Vibrational stability equation of state $S_{\rm vib}(\lg e, \lg \rho)$. > 0 means vibrational stability.

Stability of the thermodynamical equilibrium demands

$$\chi_\rho > 0, \quad c_v > 0\,, \qquad (10)$$

and

$$\chi_T > 0 \qquad (11)$$

holds for a wide range of physical situations. With

$$\Gamma_3 - 1 = \frac{P}{\rho T}\frac{\chi_T}{c_v} \quad > \quad 0 \qquad (12)$$

$$\Gamma_1 = \chi_\rho + \chi_T(\Gamma_3 - 1) \quad > \quad 0 \qquad (13)$$

$$\nabla_{\rm ad} = \frac{\Gamma_3 - 1}{\Gamma_1} \quad > \quad 0 \qquad (14)$$

we find the sign determining terms in inequalities (7) and (8) respectively and obtain the following form of the criteria for dynamical, secular and vibrational *stability*, respectively:

$$3\Gamma_1 - 4 =: S_{\rm dyn} > \quad 0 \qquad (15)$$

$$\frac{1-3/4\chi_\rho}{\chi_T}(\kappa_T - 4) + \kappa_P + 1 =: S_{\rm sec} > \quad 0 \qquad (16)$$

$$4\nabla_{\rm ad} - (\nabla_{\rm ad}\kappa_T + \kappa_P) - \frac{4}{3\Gamma_1} =: S_{\rm vib} > \quad 0\,. \qquad (17)$$

The constitutive relations are to be evaluated for the unperturbed thermodynamic state (say (ρ_0, T_0)) of the zone. We see that the one-zone stability of the layer depends only on the constitutive relations Γ_1, $\nabla_{\rm ad}$, χ_T, χ_ρ, κ_P, κ_T. These depend only on the unperturbed thermodynamical state of the layer. Therefore the above relations define the one-zone-stability equations of state $S_{\rm dyn}$, $S_{\rm sec}$ and $S_{\rm vib}$. See Fig. 2 for a picture of $S_{\rm vib}$. Regions of secular instability are listed in Table 1.

3. Conclusions

1. The conditions for the stability of static, radiative layers in gas spheres, as described by Baker's (**?**) standard one-zone model, can be expressed as stability equations of state. These stability equations of state depend only on the local thermodynamic state of the layer.
2. If the constitutive relations – equations of state and Rosseland mean opacities – are specified, the stability equations of state can be evaluated without specifying properties of the layer.

3. For solar composition gas the κ-mechanism is working in the regions of the ice and dust features in the opacities, the H_2 dissociation and the combined H, first He ionization zone, as indicated by vibrational instability. These regions of instability are much larger in extent and degree of instability than the second He ionization zone that drives the Cepheïd pulsations.

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References

Schneider, P. 2006, Extragalactic Astronomy and Cosmology, by Peter Schneider. Berlin: Springer, 2006.

Hickson, P. 1982, ApJ, 255, 382. doi:10.1086/159838

Hickson, P., Mendes de Oliveira, C., Huchra, J. P., et al. 1992, ApJ, 399, 353. doi:10.1086/171932

Farid, D., Aung, H., Nagai, D., et al. 2023, Astronomy and Computing, 45, 100743. doi:10.1016/j.ascom.2023.100743

Zhao, J.-L., Pan, R.-S., Huang, S.-N., et al. 1990, Acta Astrophysica Sinica, 10, 315

Abell, G. O., Corwin, H. G., & Olowin, R. P. 1989, ApJS, 70, 1. doi:10.1086/191333

Peebles, P. J. E. 1980, Large-Scale Structure of the Universe by Phillip James Edwin Peebles. Princeton University Press, 1980. ISBN: 978-0-691-08240-0

Helou, G., Salpeter, E. E., & Krumm, N. 1979, ApJ, 228, L1. doi:10.1086/182890

Sunyaev, R. A. & Zeldovich, Y. B. 1972, Comments on Astrophysics and Space Physics, 4, 173

Zwicky, F., Herzog, E., Wild, P., et al. 1961, Pasadena: California Institute of Technology (CIT), |c1961

Abell, G. O. 1958, ApJS, 3, 211. doi:10.1086/190036