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}].

Astronomy & Astrophysics manuscript no. aanda
December 18, 2023

Final project: Easy management of catalogues

Mary Verdugo

Universidad de La Serena

December 14th, 2023

ABSTRACT

Context. To learn about differents tools to manage data in astronomic context, in this work i put in practice the differents habilities adquire during the theory of the course

Aims. To make easier the future work that i going to do with the data for my master thesis, and in other areas, via **object oriented programming**

Methods. Using visual studio code, UML diagram, python, jupyter-notebook,

Results. Vibrational instability is found to be a common phenomenon at temperatures lower than the second He ionisation zone. The κ-mechanism is widespread under 'cool' conditions.

Key words. giant planet formation – κ-mechanism – stability of gas spheres

1. Introduction

In the context of the contents covered belong the course *Herramientas informaticas para la Astronomía*, the development of this project is grounded in the *object-oriented programming* principles, a topic introduced in the theoretically class and further explored independently to establish a foundation for future astrophysics works.

The area of extragalactic astronomy encompasses various subtopics, providing ideal scenarios to investigate the relationships between galaxies, their grouping, interactions, and associations with their environment. In particular, my master thesis focuses on studying galactic conformity within galaxy clusters. For this, we are going to use a huge simulation of 1 Gpc box, MultiDark Planck 2 (MDPL2) simulation that belongs to the series of MultiDark simulations with Planck cosmology.

Integrating these two ideas, the project designed to carry on this semester, search to make an easy management of the catalogues provided by the MDPL2 simulation. The principal aim is relate the different propiertes from the dark matter haloes (DM haloes) to link with the galactic two-halo conformity. The use of the MDPL2 is based in their size, pointing to have better stadistical results and confidence data, using the Planck Collaborations parameters. This produces a big technical problem which is the read of the data using normal-master-student hardware. There is the moment where the *object-oriented programming* take the main-stage like solution to moves on the catalogue without overchage the hardware. The principal idea is take the DM halo and convert in to an object, i.e. modular, reusable and easy to maintain.

The primary outcomes expected include the foundation for creating different objects in the future. Particularly, *UML diagrams* will be generated, focusing on the `read_file` class. In the future, through the use of inheritance, this class will be replicated to create sub-classes.

2. Selected tools

In this section the one-zone model of Baker (1966), 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.

Baker (1966) 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 1966). 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
$E_{\rm th}$	thermal energy of the zone

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

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

and the *local free-fall time*

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

Baker's K and σ_0 have the following form:

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

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

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

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

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:

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

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

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

For a physical discussion of the stability criteria see Baker (1966) or Cox (1980).

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

Table 1. Opacity sources.

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

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

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

$$\Gamma_1 > \frac{4}{3}\,. \tag{9}$$

Stability of the thermodynamical equilibrium demands

$$\chi_\rho > 0, \quad c_v > 0\,, \tag{10}$$

and

$$\chi_T > 0 \tag{11}$$

holds for a wide range of physical situations. With

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

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

$$\nabla_{\mathrm{ad}} = \frac{\Gamma_3 - 1}{\Gamma_1} \quad > \quad 0 \tag{14}$$

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:

$$3\Gamma_1 - 4 =: S_{\mathrm{dyn}} > \quad 0 \tag{15}$$

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

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

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, ∇_{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_{dyn}, S_{sec} and S_{vib}. See Fig. 2 for a picture of S_{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 (1966) 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.

Acknowledgements. Part of this work was supported by the German *Deutsche Forschungsgemeinschaft, DFG* project number Ts 17/2–1.

References

Baker, N. 1966, in Stellar Evolution, ed. R. F. Stein,& A. G. W. Cameron (Plenum, New York) 333
Balluch, M. 1988, A&A, 200, 58
Cox, J. P. 1980, Theory of Stellar Pulsation (Princeton University Press, Princeton) 165
Cox, A. N.,& Stewart, J. N. 1969, Academia Nauk, Scientific Information 15, 1
Mizuno H. 1980, Prog. Theor. Phys., 64, 544
Tscharnuter W. M. 1987, A&A, 188, 55
Terlevich, R. 1992, in ASP Conf. Ser. 31, Relationships between Active Galactic Nuclei and Starburst Galaxies, ed. A. V. Filippenko, 13
Yorke, H. W. 1980a, A&A, 86, 286
Zheng, W., Davidsen, A. F., Tytler, D. & Kriss, G. A. 1997, preprint