THERMAL INSTABILITY AS A TOOL TO SEARCH TWO-PHASE REGIONS IN CENTERS OF GALAXIES

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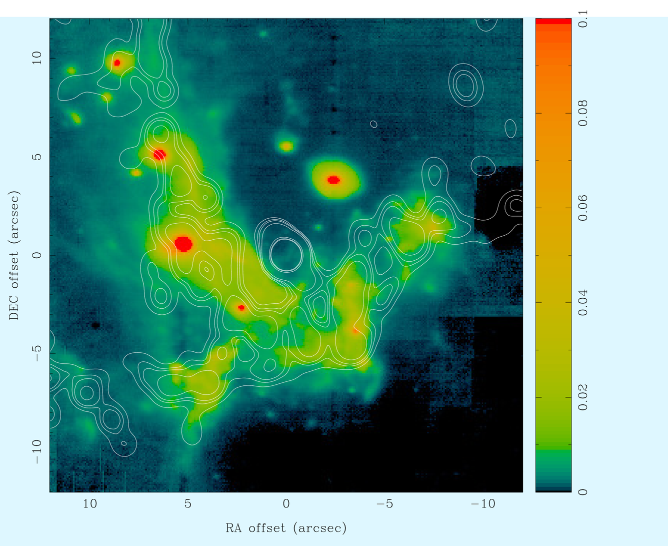
We explore the conditions for the thermal instability to operate in close centres of galaxies, where both the hot and cold media are known to coexist. The Cloudy photoionisation calculations are performed for different physical states of plasma. We consider Sgr A* minispiral region for which we have shown that for the highest luminosity state in the past, the two-phase medium could be created up to 1.4 pc from the centre. The clumpiness is thus induced in the high activity period, and the cooling/heating timescales are long enough to preserve the past multi-phase structure. Here, we explore the influence of additional mechanical heating by young stars, on the range of properties of two-phase medium. We also discuss our model in the context of ultracompact dwarf galaxy M60-UCD1 in Virgo Cluster.



Mini-spiral as a source of material for Sgr A* (**Kunneriath et al. 2012**)

The Case of Sgr A* Minispiral region

The circumnuclear region of Sgr A* contains a dense nuclear star cluster in addition to a reservoir of partially ionised cold clumps ($T \sim 10^4 K, n_e \sim 10^4 cm^{-3}$) in the mini-spiral surrounded by the hot ionized plasma ($T \sim 10^7 K, n_e \sim 30 cm^{-3}$). The two media appear to be in mutual contact and the pressure equilibrium can be established.

Różańska et al. (2014) considered the effect of thermal instability in supporting the scenario of **Czerny et al. (2013)** for the enhanced accretion of clouds during the past active period of Sgr A*. In this work, we extend the previous analysis to include the energy input of the nuclear stellar cluster by radiative heating and wind outflows.

We use Cloudy photoionisation code (**Ferland et al. 2013**) to set up a simplified model of the two-phase ISM in the GC, using photoionisation calculations with a proper treatment of all cooling and heating mechanisms operating in the region for three cases: i) radiative heating only by the accreting central black hole as in **Różańska et al. (2014)**, (ii) with additional radiative heating by the stellar cluster, and (iii) with additional mechanical heating by stellar winds.

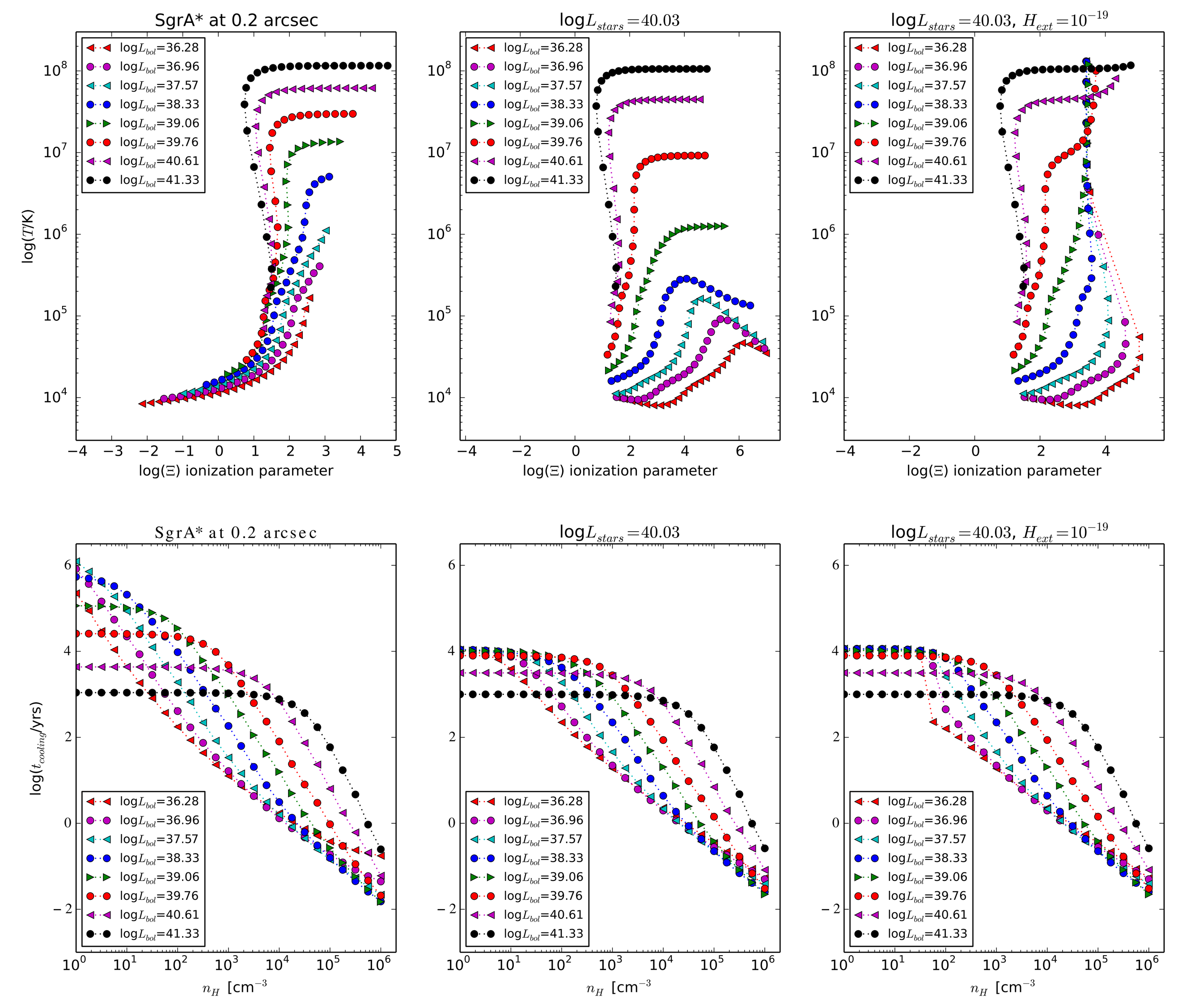


Figure 1: Instability curves i.e. log(T) versus log(Ξ) (top), and the dependence of cooling time on the cloud number density (bottom), for matter located at 0.2″ from the nucleus (0.008 pc). The comparison of three cases is shown: radiative heating only by Sgr A* (left), by Sgr A* and by the stellar cluster (middle), radiative heating by both, along with heating by stellar winds (right).

We consider a broad range of the possible bolometric luminosities of Sgr A* from **Moscibrodzka et al. (2012)** as described in **Różańska et al. (2014)**. The stellar light is given by the spectral template for stars of solar metal abundances and age 6 Myr from Starburst99 (**Leitherer et al. 1999**). Assuming a stellar mass input of $10^{-8} M_{\odot}$ yr^{-1} and wind velocity 1000 km s^{-1} at a distance of $0.2''$ from the nucleus (**Shcherbakov et al. 2010**), we calculate the volume heating by stars as $Q_{\star} = 1.0 \times 10^{-19}$erg s^{-1}cm^{-3} for the nuclear stellar cluster.

In Fig. 1 we see that addition of stellar light to the radiative heating results in a decrease of the temperature of the irradiated medium, especially for lower luminosities of Sgr A*. Since the central emission has the strong X-ray component, the addition of a blue light lowers the Inverse Compton temperature of the incident radiation. **Furthermore, the inclusion of the mechanical heating by the shocked stellar winds changes the picture dramatically. The matter of lower density heats up to the huge values of temperature without possibility to reach hot stable branch. Low density material must outflow from the region much more vigorously than at the present level of the Sgr A* activity (Quataert 2004).**

Two-phase medium around Sgr A*

For the Bondi accretion flow starting roughly at the capture radius, we computed density and gas pressure profiles around Sgr A*, for an outer temperature $T_{\rm e}^{\rm out} = 3.5$ keV and number density $n_{\rm e}^{\rm out} = 1$ cm^{-3}. The regions of instability are shown in Fig. 2 (left) in the form of strips. For all gas above the red contour, only hot phase can exist at a given luminosity while below the blue contour, only cold clouds can exist. **There are several distance ranges where two-phase medium can co-exist. For the two highest luminosities, the two-phase medium can be sustained up to 1.4 pc. The right panel of Fig. 2 shows possible size of clouds in the temperature - cooling time plane, which can be created when instability operates.**

Massive clouds created on the past Sgr A* activity may be visible at present.

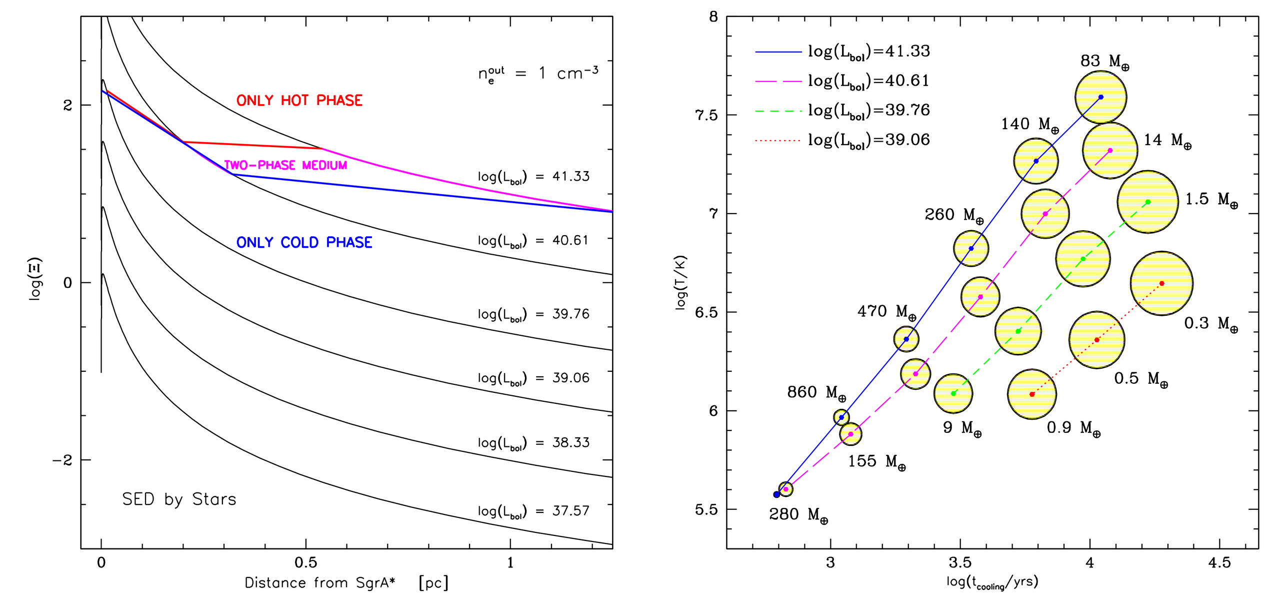


Figure 2: Instability strips for the different luminosity states in case of Bondi accretion flow onto Sgr A* for outer temperature $T_{\rm e}^{\rm out} = 3.5$ keV and outer number density $n_{\rm e}^{\rm out} = 1$ cm^{-3} (left). The different size of clouds along the instability branch in temperature versus cooling time plane for different luminosity states (right). The cloud radius represents the Field length (**Field 1965**). Masses of clouds are given in the units of Earth mass $M_{\oplus}$.

Ultracompact dwarf galaxy M60-UCD1 in Virgo Cluster

We follow the same analysis for the ultracompact galaxy M60-UCD1, recently discovered in Virgo Cluster (**Strader et al. 2013**). With a dynamical mass of $2.0 \times 10^8 {\rm M}_{\odot}$ but a half-light radius of only ~ 24 pc, it is the densest galaxy known in the local universe. Visual and X-ray luminosities were measured to be $L_{\rm V} = 4.1 \times 10^7 {\rm L}_{\odot}$ and $L_{\rm X} = 1.3 \times 10^{38}$ erg/s respectively. The stellar kinematic method was used to estimate the central black hole mass on: ${\rm M}_{\rm BH} = 2.1^{+1.4}_{-0.7} \times 10^7 {\rm M}_{\odot}$ (**Seth et al. 2014**). Since the accretion pattern of the source is unknown, we adopt the same luminosity states as for Sgr A*, normalizing continua to achieve the same value of X-ray luminosity in the range of 2-10 keV. **Therefore, the stability curve displays instability only for the luminosity state with the highest amount of X-ray photons (Fig. 3 top panels). Besides this effect, we see that, when only irradiation by central source is taken into account, the instability is located close to the nucleus. At the half-light radius of M60-UCD1, the radiation is already geometrically diluted, and thermal instability does not operate.**

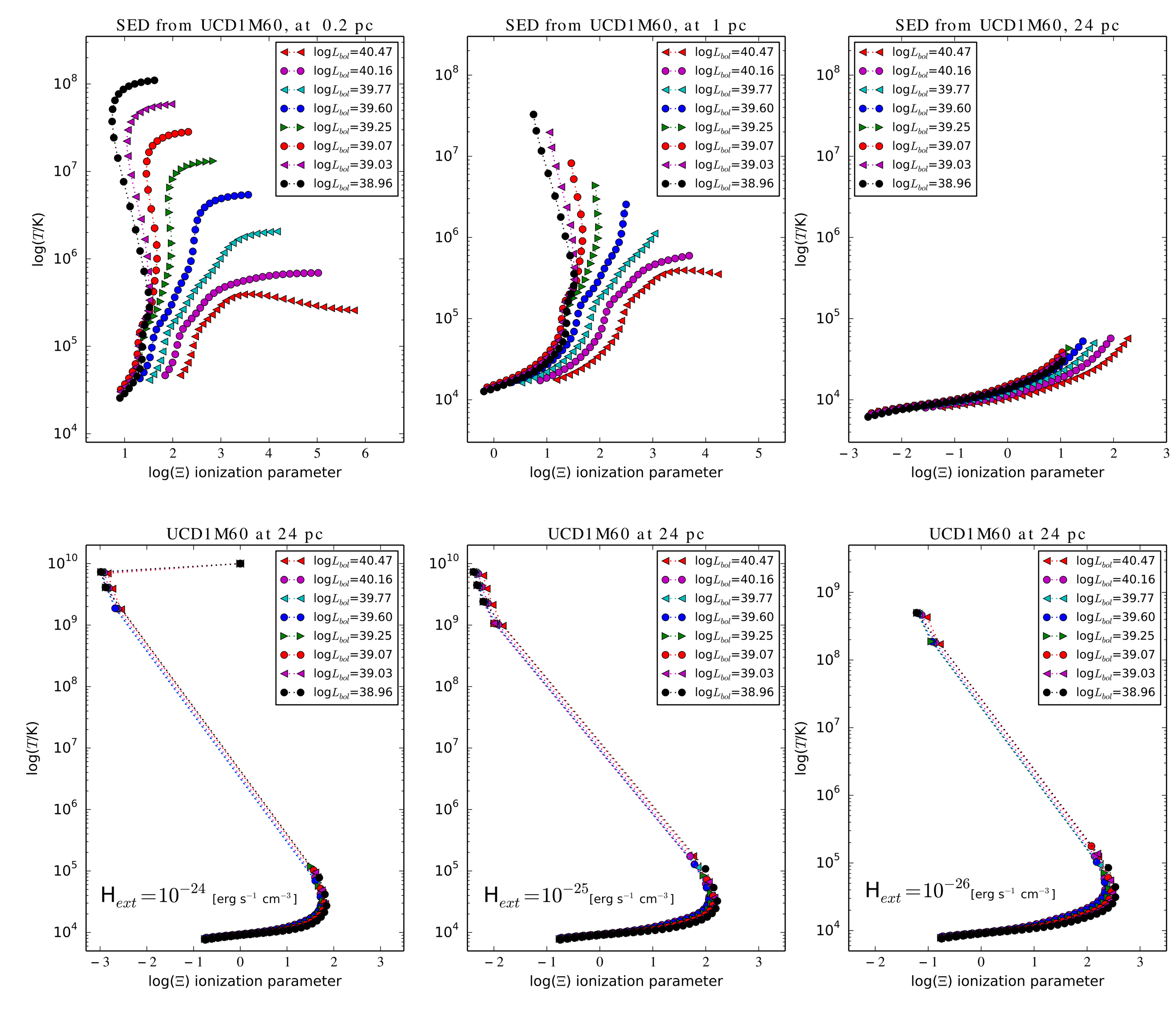


Figure 3: Instability curves at three distances from the M60-UCD1 nucleus: 0.2, 1, and 24 pc (top panels). The bottom panels represent the influence of mechanical heating on the gas stability at 24 pc, for three values of volume energy input: H$_{ext} = 10^{-24}$, 10^{-25}, and 10^{-26} erg s^{-1} cm^{-3} respectively.

Lower panels of Fig. 3 display the influence of mechanical heating on the gas located at 24 pc from the nucleus of M60-UCD1. The value of this heating is appropriate for 10 Gyr stars of solar abundances. Irradiation by the central source is fully taken into account. **Mechanical heating acts as an additional energy input and heats up the gas with relatively low density to enormous temperatures. Such gas never reaches the stable hot branch of Compton temperature ($\sim 10^8 K$), obtained in photoionisation calculations. Hot gas is probably constantly outflowing from the nucleus.**

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