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MODELING THE PROPAGATION OF SAGITTARIUS A*'S PAST ACTIVITY

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Abstract. The supermassive black hole Sgr A* has been active in the recent past and the echoes of its exceptionally luminous past outbursts are currently propagating through the Galactic center. The limited time baseline of the observations and missing information about the reflecting clouds are major limitations to the proper reconstruction of Sgr A*'s past lightcurve. In order to test several scenarios, we developed a simple model to derive the variations expected for the clouds' illumination as a function of the epoch and the duration of Sgr A*'s flares. Here, we present the results for a given set of parameters.

Keywords: Galactic center, diffuse X-rays, molecular clouds

1 Introduction

The supermassive black hole at the Galactic center, Sagittarius A*, is currently extremely faint but there are strong hints that it experienced a higher level of activity in the past (Ponti et al. 2013). In particular, its recent history can be reconstructed from the non-thermal emission emanating from the molecular clouds at the Galactic center. The hard X-ray radiation, presumably originating from Sgr A*, is indeed reflected through Compton scattering and photo-ionization, thereby creating an X-ray emission characterized by a hard continuum component and a strong Fe Kα line at 6.4 keV. The variation of this emission, induced by the propagation of the signal inside the central molecular zone (CMZ), has been detected from an increasing number of interstellar structures (Ponti et al. 2010; Terrier et al. 2010; Clavel et al. 2014a) and the detailed analysis of these variations has demonstrated that there were at least two short events now propagating through the inner regions of the Galaxy (Clavel et al. 2013). However, reconstructing the precise lightcurve of Sgr A* is very complex because the distribution of the clouds along the line of sight is barely known. In this work, we assume a given distribution for the CMZ and we investigate the timing properties of a single event propagating away from Sgr A*.

2 Simple model for the echo propagation

Modeling the propagation of an echo within the central molecular zone requires both a precise description of the matter distribution and detailed information about the incident radiation.

Matter distribution. So far, several models have been proposed to account for the 3D CMZ distribution, but there is no general consensus concerning the position and the internal structure of individual clouds. In our simulation, we decide to use a distribution of ellipsoidal and uniform-density clouds, which follows the twisted ring proposed by Molinari et al. (2011), as shown in Fig. 1.

Event propagation and illumination. We consider a single event originating at the position of Sgr A* and having a constant flux over 50 years. We show this event at different epochs in order to account for its propagation over time. At a given time, all the clouds illuminated by this event are along the same paraboloid, as first defined by Sunyaev & Churazov (1998) and represented in Fig. 1 (left). To determine the intensity of the Fe Kα emission line, projected onto the plane of the sky, we then integrate the illuminated material along the line of sight and follow Sunyaev & Churazov (1998, eq. 2) to derive the relative brightness of the illuminated structures (Fig. 1, right).

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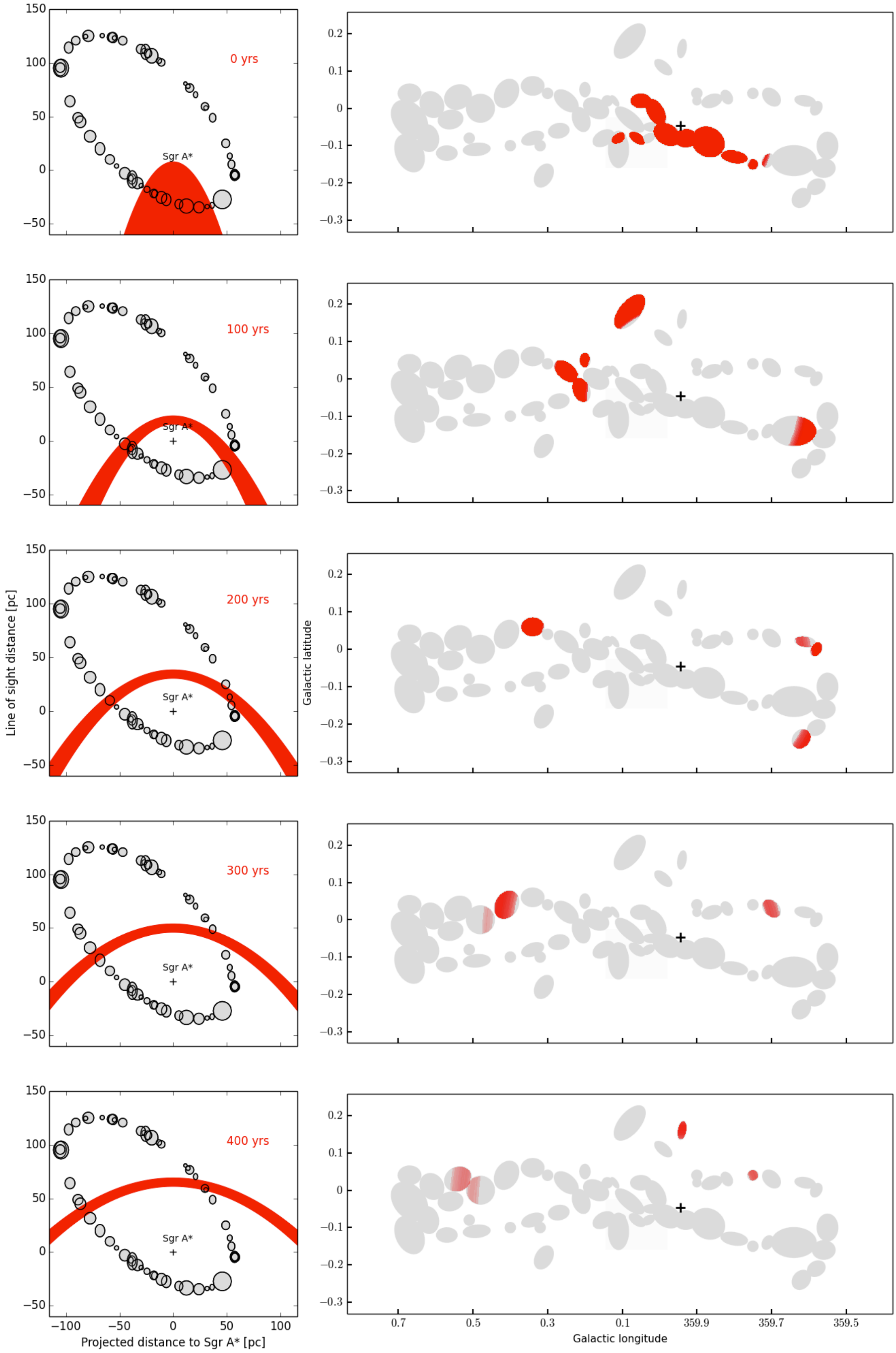

Fig. 1: Variations induced at the Galactic center by the reflection of a single past event of Sgr A*, assuming all the molecular clouds are distributed along the twisted ring proposed by Molinari et al. (2011). **Left:** Propagation of a 50-year duration event (in red) inside the molecular material (in grey) for ten different periods (spanning from 0 to 900 years after the end of the event). View from the Galactic North Pole. **Right:** See next page.

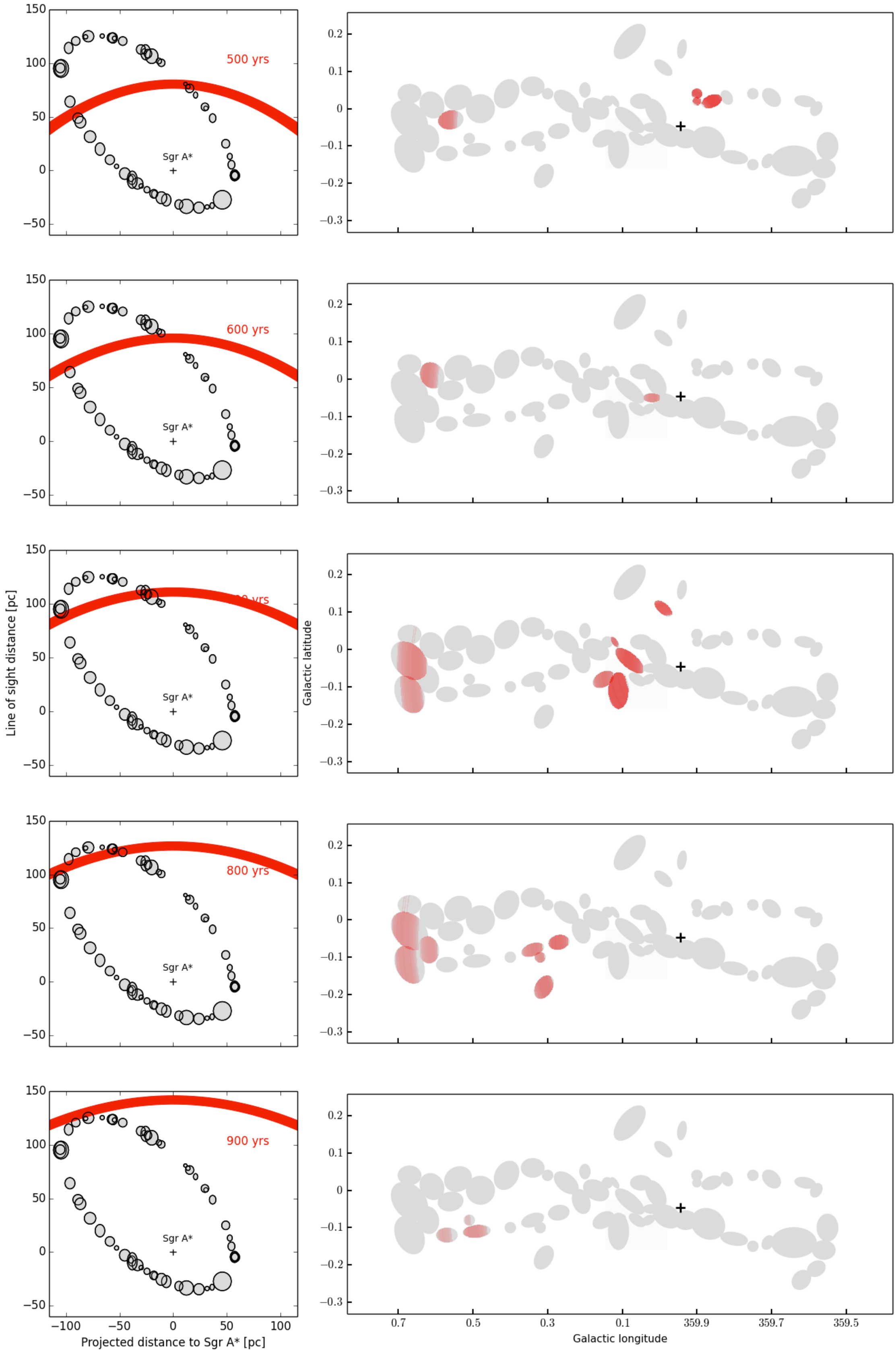

Fig. 1: (Continued). **Left:** See previous page. **Right:** Matter distribution projected onto the plane of the sky (in grey) and regions reflecting the past event at Sgr A⋆ (in red). The strength of the red color indicates the intensity of the Fe Kα fluorescence line emission. The cross indicates the position of Sgr A⋆.

Predicted variability. As shown in Fig. 1, the echo will take about a thousand years to propagate entirely through the chosen cloud distribution, and it will illuminate very few clouds at any given time. As the event propagates through the matter distribution, it illuminates clouds that are, on average, more distant from Sgr A*, so the reflected flux is globally decreasing with time. Within a single cloud, the echo is likely to propagate away from Sgr A*. However, the global variation pattern seen in the plane of the sky is impossible to predict if the distribution along the line of sight is unknown. Indeed, clouds at the same projected distance (e.g. $l \sim 0.1°$) can be illuminated after a short or a long delay, depending on whether they are in front or behind Sgr A*.

3 Comparison with the observations

An X-ray emission compatible with reflection is now observed from a large fraction of the CMZ. Furthermore, the regular X-ray monitoring of this region for the past fifteen years has allowed for detailed analyses of the spectral evolution of the molecular clouds. The main variations were detected from the dense molecular complexes. In particular, the systematic analysis performed on the Sgr A complex ($l \sim 0.1°$) with an unprecedented spatial resolution, highlighted two distinct time behaviors that can only be explained by two distinct events of a few-year-duration propagating in this region (Clavel et al. 2014b). Thanks to a large survey, we are now extending this analysis to the entire CMZ (Soldi et al. 2014). We confirm the general decrease detected towards Sgr B ($l \sim 0.7°$) and report, for the first time, a decreasing trend from Sgr C ($l \sim 359.6°$). The variations observed in these two complexes are consistent with the reflection of short events, such as those detected in Sgr A.

Inputs from our model. Assuming that the matter distribution proposed by Molinari et al. (2011) is correct, at least three events are needed to account for the illumination of the bright molecular complexes. A recent event (less than 50 years) would explain one of the time behaviors detected in Sgr A, an earlier one (about 150 years) would account for the Sgr C emission and an even older one (about 700 years) would be responsible for both Sgr B and the second time behavior seen in Sgr A. Furthermore, the echo propagation away from Sgr A* is observed in several clouds of the Sgr A complex. However, a more precise comparison is not straightforward, mainly for two reasons. First, the fine details of the observed cloud lightcurves are partly due to the clouds' internal structure, which is poorly known and has not been modeled here. Second, the observations of the CMZ cover less than fifteen years, which means that the positional displacement of the wavefront in the data is smaller than the width of the event parabola in our simulation. Nevertheless, it seems difficult to reproduce with our simulation the rapidly decreasing trend we observe, since the event should continuously illuminate new clouds as it propagates away from Sgr A*.

4 Conclusions

The model we developed to better understand the timing properties of Sgr A*'s echoes at the Galactic center allows us to derive general properties about the illumination variations. However, the individual cloud comparison is highly dependent on the distribution chosen for the central molecular zone and is therefore not yet conclusive. Thus, to fully reconstruct Sgr A*'s past activity, a better 3D gas model and further observations will be needed in order to constrain both the individual cloud structures and the timing properties of the echoes.

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