Characterization of the DIMS system based on astronomical meteor techniques for macroscopic dark matter search

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Nuclearites are strange quark matter conglomerates that are hypothesized as possible candidates of macroscopic dark matter. Impacting with the Earth's atmosphere, they should generate meteor-like events but with different signatures in their altitude, speed and motion direction.

The **DIMS** (Dark matter and Interstellar Meteoroid Study) experiment was born in 2017 aiming to search for fast-moving objects by observing the sky with wide-field and **high-sensitivity CMOS cameras** [1].

In this contribution, we give a preliminary report on the characterization of the DIMS system designed for macroscopic dark matter search.

Nuclearites dynamics in the Earth's atmosphere

We generalized the model by De Rujula and Glashow [2] by considering a nuclearite with an arbitrary velocity v. The **visual magnitude** is given by:

$$\mathcal{M} = 0.80 - 1.67\log_{10}\left(\frac{M}{1\text{ g}}\right) + 5\log_{10}\left(\frac{h}{10\text{ km}}\right) - 7.5\log_{10}\left(\frac{v}{250\text{ km s}^{-1}}\right)$$

and the **maximum height of light emission is**:

$$\frac{h_{max}}{1\text{ km}} = 3.3\left[\ln\left(\frac{M}{1\text{ g}}\right) + 3\ln\left(\frac{v}{250\text{ km s}^{-1}}\right)\right] + 38.79$$

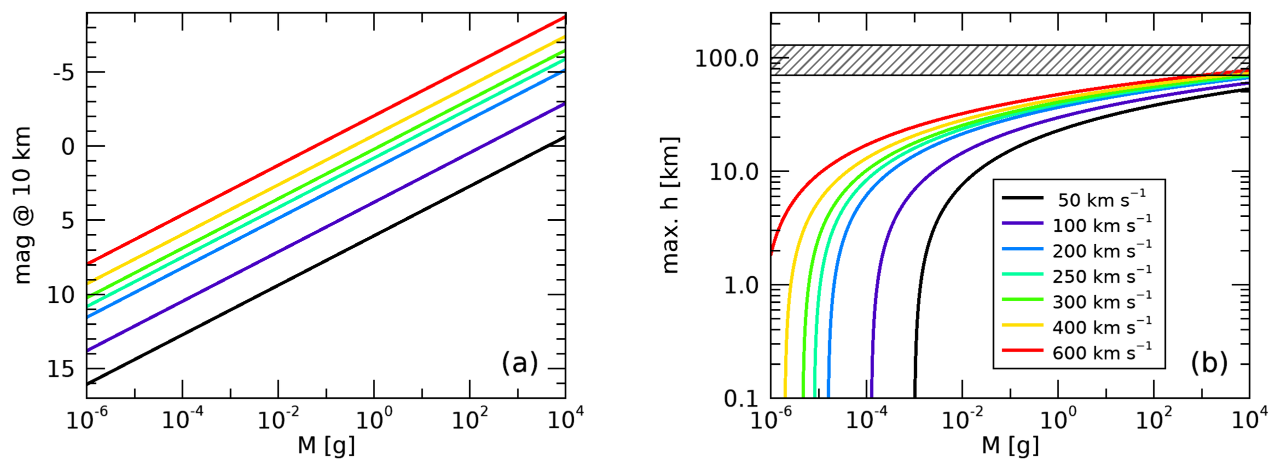
The nuclearite dynamics is greatly affected by its speed in the Earth's atmosphere, which might be up to 550 km s^{-1} (figure, panel a). In all cases, light emission occurs at **heights always lower than meteors** (panel b).

A different theoretical model for macros interaction in the atmosphere [3] predicts much higher visual magnitudes:

$$\mathcal{M} = 39.66 - 5\log_{10}\left(\frac{M}{1\text{ g}}\right) + 5\log_{10}\left(\frac{h}{10\text{ km}}\right) - 5\log_{10}\left(\frac{\rho_N}{\rho}\right) + \frac{1}{\ln 10}\left(\frac{h}{1\text{ km}}\right)$$

$$\begin{cases} M = 1\ g \\ h = 10\ km \\ \rho = \rho_N \\ v = 250\ km\ s^{-1} \end{cases}$$

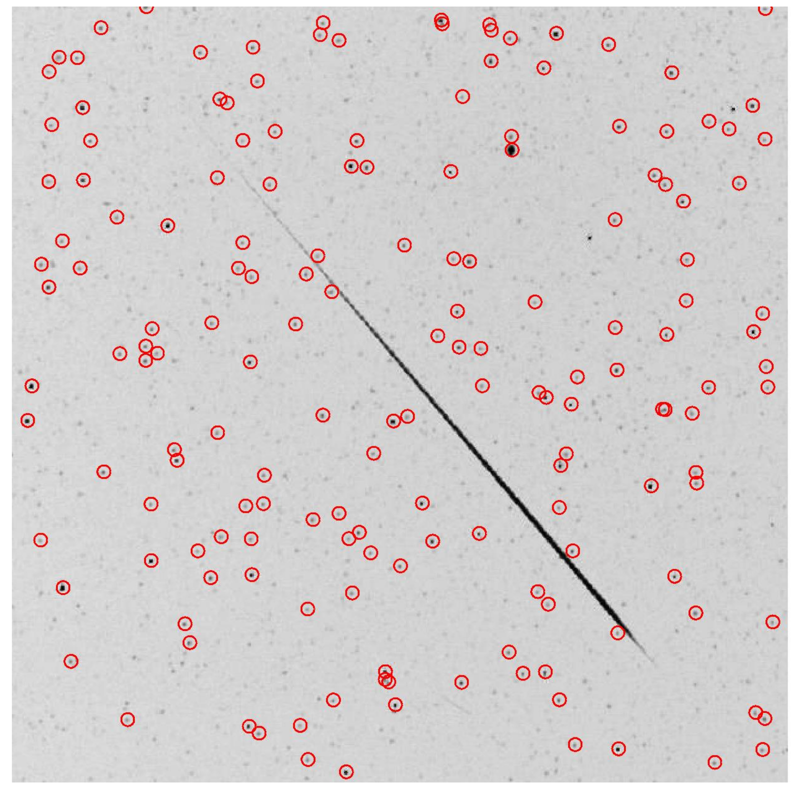
$$\rightarrow \Delta\mathcal{M} = +43$$



Astrometric and photometric calibration

DIMS cameras are equipped with an **high-efficiency CMOS sensor**. We derived the calibration of the instrument by means of astrometric and photometric techniques applied to imaged stars in the FoV.

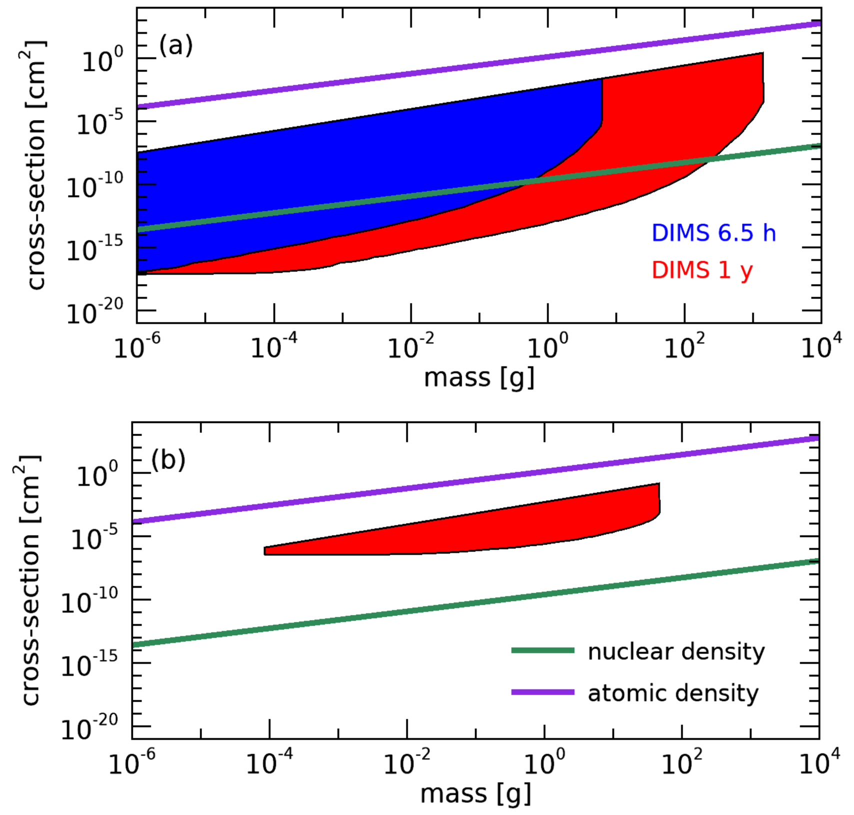
Stars are **automatically identified and correlated** with entries on the Hipparcos-Tycho catalogue. A portion of the FoV with the meteor trail and identified stars is presented in figure. We can identify about 900 stars per image up to magnitude +8, and achieve a sub-pixel positioning precision. Our sensor have a **wide bandpass** (300-1000 nm) and we calibrate measured intensities against Hipparcos magnitude of stars.



Expected macros constraints by DIMS experiment

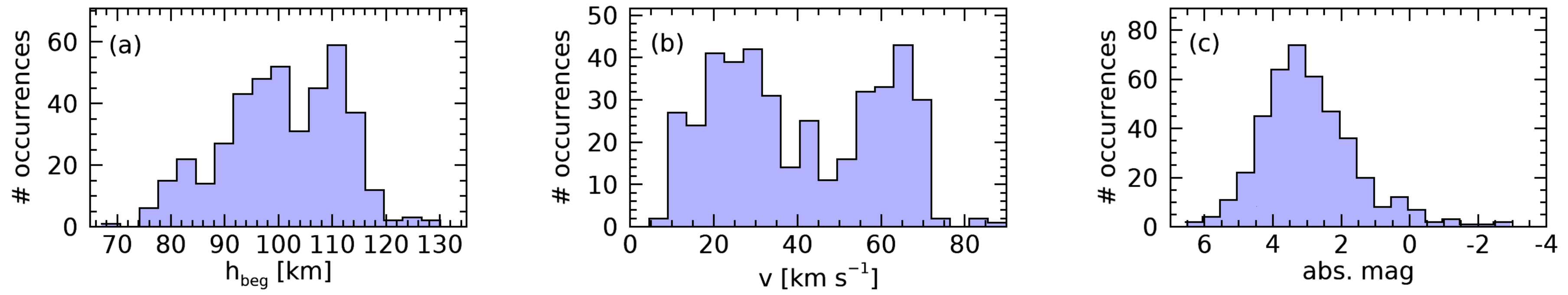
We analyzed about **400 meteors** captured during the 1st September 2019 observational session, with two cameras (N1 and N2) installed at the Telescop Array site (Utah, USA) at a 17 km distance.

None of the analyzed event shows indisputable features indicating non-meteor origin. This allows us to give expected constrains on **macro's mass and cross-section** [4]. These limits are different according to the considered model and are presented in figure (panel a for model [2], b for [3]). The blue area refers to the region excluded by this dataset, and the red area is the 1-year projection with 10% duty cycle.



Conclusions

- We reviewed two theoretical models for the interaction of macro's in the Earth atmosphere.
- We derived the calibration of DIMS sensor by astronomical techniques applied to observed stars in the FoV. We deduced a **limiting absolute magnitude for meteors of about +6** (see figure, panel c).
- **None of the analyzed events shows a clear non-meteor origin**. We gave expected macros constraints from these first results.



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References

[1] Kajino et al., 36th ICRC Proc. (2019); [2] De Rujula & Glashow, Nature (1984); [3] Sidhu et al., JCAP (2019); [4] Sidhu et al. PhRD (2019)

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