SEDM White Paper for Solar System Moving Objects

1. EXECUTIVE SUMMARY

Taking advantage of the large-scaled survey of ZTF and the high efficiency of the SEDM, a comprehensive program to monitor the transient phenomena of solar system moving objects (i.e., comets, Centaurs and asteroids) is proposed in tandem with a near-Earth asteroids (NEA) taxonomic survey. The triggering criteria are (1) limiting magnitude for the objects to be monitored is $m_v \sim 18.5$, and (2) $\Delta m > 1$ (for outbutsts). It is estimated that the outburst monitoring component will require on the order of 10 hours per month and the NEA component another 10 hours per month. The requested SEDM time for the moving objects program is therefore 20 hours per month.

2. SCIENCE CASE

2.1 Cometary outbursts

Comets are considered to be representative of the icy planetesimals formed in the accretion zone of the outer planets. Their chemical compositions and structures of the cometary nuclei are therefore diagnostic of the physical condition of the early solar system during planetary formation. On the average, 2-3 new comets coming from the distant Oort cloud will be discovered per year. Their light curves and time variation of their coma brightness are different from those of the short-period comets suggesting major dissimilarities in the relative abundances of the volatile ices on the surfaces and in the subsurface regions of the respective cometary nuclei. The dusty comas of both long-period comets from the Oort cloud and the short-period comets from the Kuiper belt share one important physical property. That is, they often exhibit sudden brightening by about one (or more) magnitude and hence outbursts in their corresponding outgassing activities. Examples are comet C/1995 O1 Hale-Bopp (Fernandez, 2002) and 15P/Finlay (Ishiguro et al., 2016) . Several mechanisms have been suggested to explain these puzzling phenomena including meteoroid impacts, rotational breakup and explosion of surface pockets of super-volatile materials. No systematic survey has been given to an in-depth analysis and comparison of the cometary outbursts because of the lack of comprehensive coverage as now made available by ZTF. Irrespective of the specific mechanisms, the ejected gas and dust carry key information on the original substance buried since the solar

system formation. For example, from a comparison of the various species in optical emission, e.g., C_2, C_3 and CN, we can explore the underlying taxonomical classification (A'Hearn et al., 1995). The proposed SEDM observation program will address this study probing the pristine composition of the cometary nuclei.

2.2 Centaur outbursts

Centaurs orbiting in the orbital space between the orbits of Jupiter and Neptune, respectively, are transitional objects between the KBOs and short-period comets. Their sizes are usually 10 times or more than that of a comet. In addition, some of them are active probably with thermal sublimation of CO_2 or CO ice as the driving mechanism. A number of them have also shown large outburst effects. These include 29P/Schwassmann-Wachmann 1, 2060 Chiron and 174P/Echeclus, just to name a few. Like the cometary bursts, the spectral signatures of the emitted gas will give us key information on the composition of the icy mixture inside these building blocks of the outer planets.

2.3 Close Earth-approaches by Near-Earth Asteroids (NEAs) and comets

The NEAs are high-value targets of wide-field surveys like Pan-STARRS and LSST because of their potential impact hazards to the Earth. By inference, their study should also be an important component of ZTF. Similar to SNe, the SEDs of NEAs are essential to their understanding and classification. A large fraction of the NEA population is sub-km in size. This means these small objects are accessible to SEDM observations only when they come close enough to the Earth. Our previous experience in the photometric measurements of NEAs using the One-meter telescope at Lulin indicated that we should expect 20-30 NEAs with $m_v \sim$ 18-19 per month. A spectroscopic NEA survey by the SEDM will fill an important knowledge gap.

The apparent brightness of a small comet would increase tremendously if it has close approach to the Earth. A case in point is comt 46P/Wirtanen that will reach a closest encounter distance of only 30 Earth-Moon distance (0.078 AU) on December 16, 2018. Its brightness might reach as much as $m_v \sim 4$. For this rare event, we would request the allocation of the SEDM time for a special spectroscopic campaign to map the coma structure of this Jupiter-family comet.

2.4 SED of interstellar objects

The discovery of the first interstellar asteroid, A/U1 'Oumuamua by Pan-STARRS has brought a lot of interest and excitement. It is expected that more stray objects of this type will be discovered in near future, with some possibly by ZTF. When this happens, it is requested that the SEDM be used for SED measurements if it is within the limiting magnitude of $m_v \sim 19$.

3. EXPECTED OUTCOME & PUBLICATION PLAN

We have started collecting and analyzing images taken of comets and Centaurs in the commission phase. Besides meeting abstracts and presentations, we expect to be able to submit a couple of early papers for publication before June, 2018. We are therefore well prepared to produce three sets of papers after the first six months of the ZTF project on the basis of the ToO data obtained. They are, respectively, (1) cometary outbursts; (2) Centaur outbursts; and (3) NEA SED survey. These studies will constitute the first comprehensive SED survey of solar system small objects in combination with ZTF and an in-built alert system.

4. Manpower available

The workload of the proposed ToO program will be shared by NCU, UMD and Caltech. The NCU group and the UMD group are both implementing data system to download ZTF images for analysis. Both groups have access to a number of telescopes and facilities for complementary and follow-up observations. The core team of W.-H. Ip, Rex Chang, and Zhongyi Lin (all NCU) and Mike Kelley and Dennis Bodewis (all UMD) will be supported by postdocs and graduate students in their institutions.

5. Trigger criteria

1. Cometary outbursts: $m_v < 18.5$ and $\Delta m > 1$.
2. Centaur outbursts: $m_v < 18.5$ and $\Delta m > 1$.
3. Asteroidal activity: $m_v < 18.5$ and $\Delta m > 1$.

From 1 to 3, one SEDM measurement at least (<u>total</u> exposure time ~ 20 min) consecutively for 5 nights if nothing special. For each case, a reference SED should be made 10 days after the outburst. An estimated event rates for 1-3 is about 5 per month. <u>The total time request is 10 hours/month.</u>

4. NEA SED: $m_v < 18.5$. An estimated event rate is 20 per month with <u>total</u>

exposure time = 30 min for each target. The total time request is 10 hours/month.

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