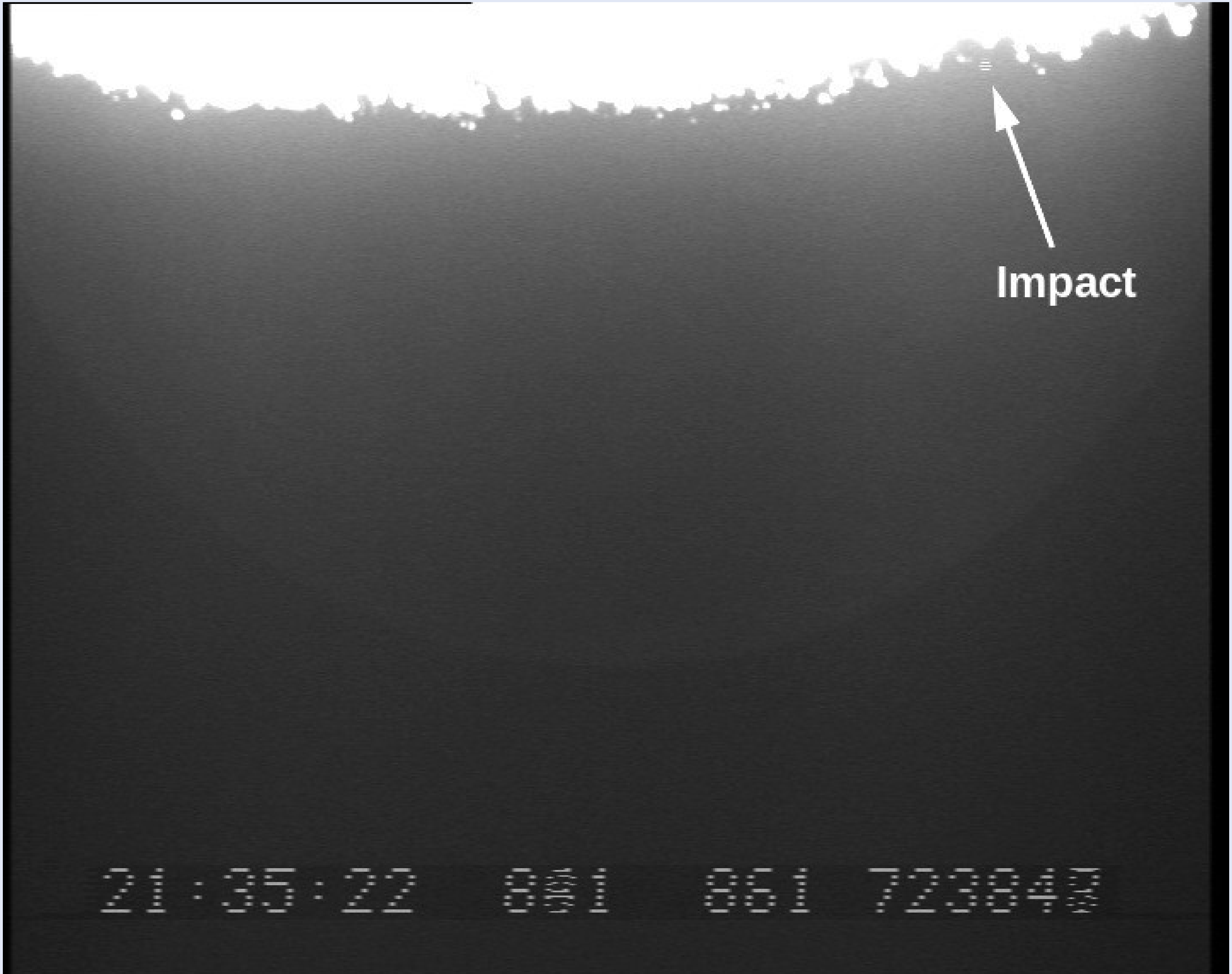
Photometry of an Impact-Produced Dust Cloud Near the Lunar Terminator

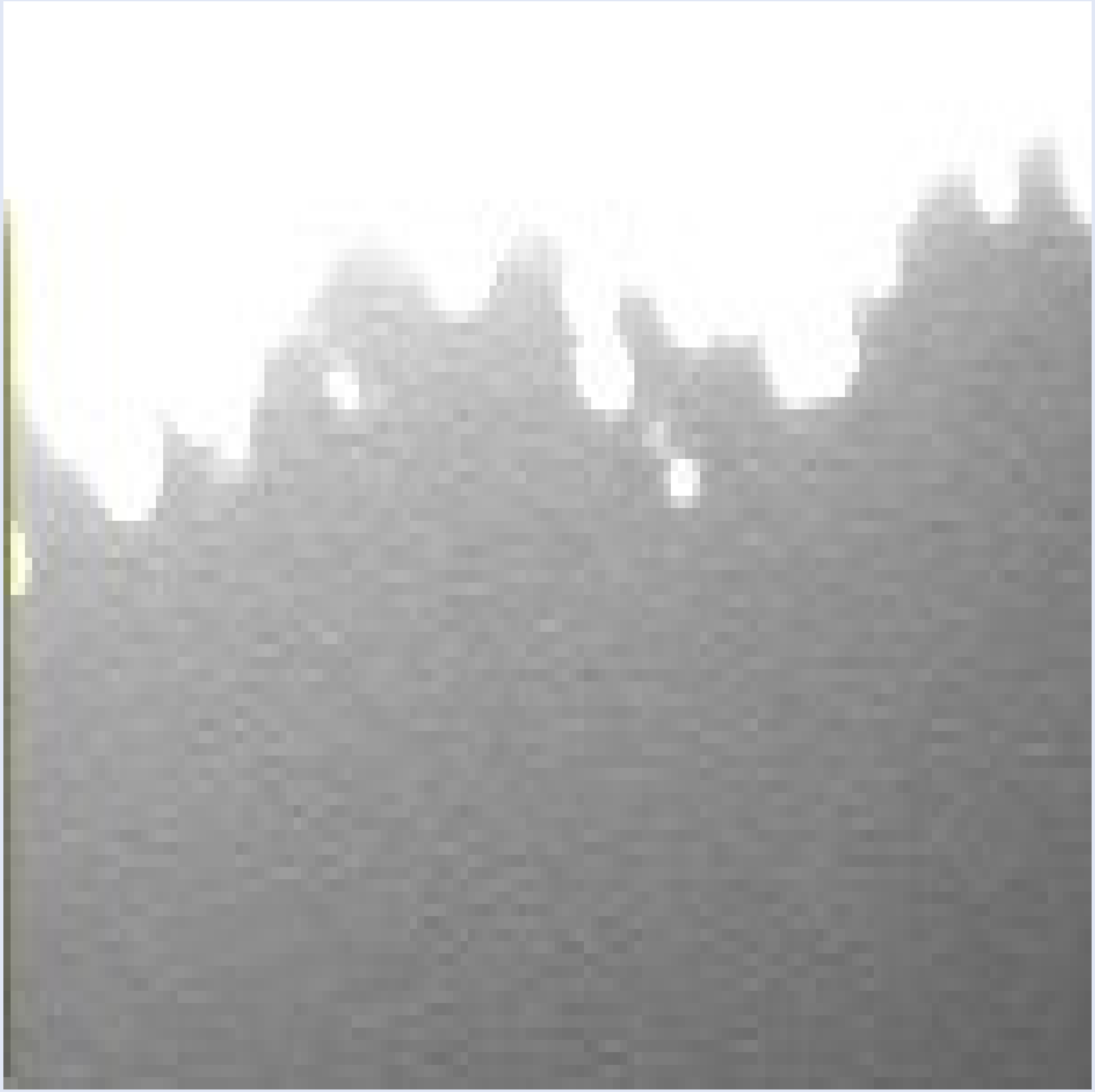
Yu.I. Velikodsky[1,2], A.O. Tereshchenko[1], A.A. Berezhnoy[3], M. Iten[4], R. Lena[5], S. Sposetti[6], E. Zubko[2,7]

[1]National Aviation University, Kyiv, Ukraine
[2]Institute of Astronomy, V.N. Karazin Kharkiv University, Kharkiv, Ukraine
[3]Sternberg Astronomical Institute, Moscow State University, Moscow, Russia
[4]Garden Observatory, Gordola, Switzerland
[5]Geologic Lunar Research Group, Rome, Italy
[6]Gnosca Observatory, Gnosca, Switzerland
[7]School of Natural Sciences, Far Eastern Federal University, Vladivostok, Russia

First frame of the event ($t = 0$)



Impact flash



Duration: 0.36 s

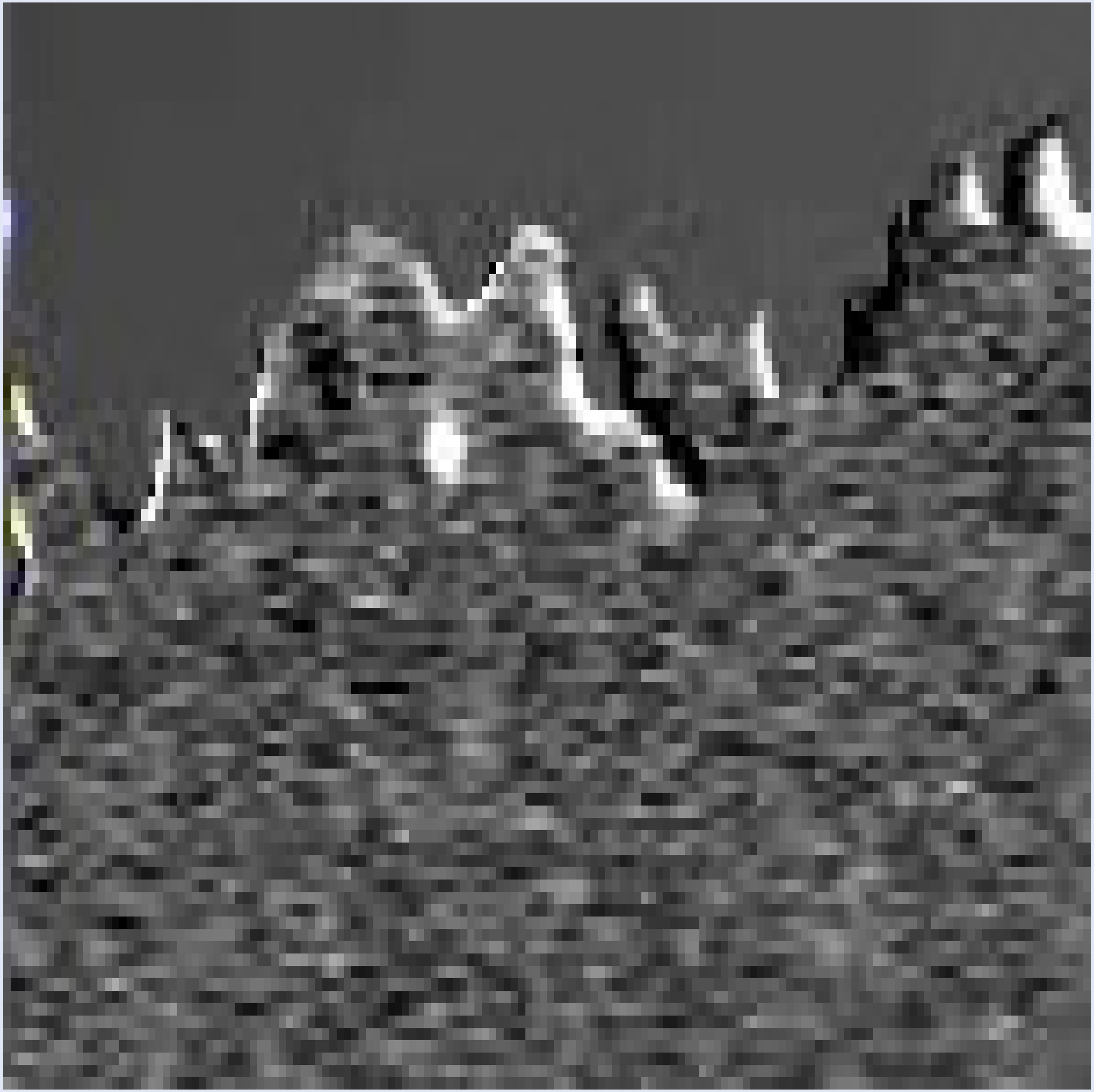
Speed: 0.04x

Impact time:
21h 35m 22.871s ± 0.010s UT,
February 26, 2015

Observer: Marco Iten (Gordola)

Instrument: 125-mm refractor / Watec 902H2 Ultimate videocam

Impact-produced dust cloud



Duration: 40 s

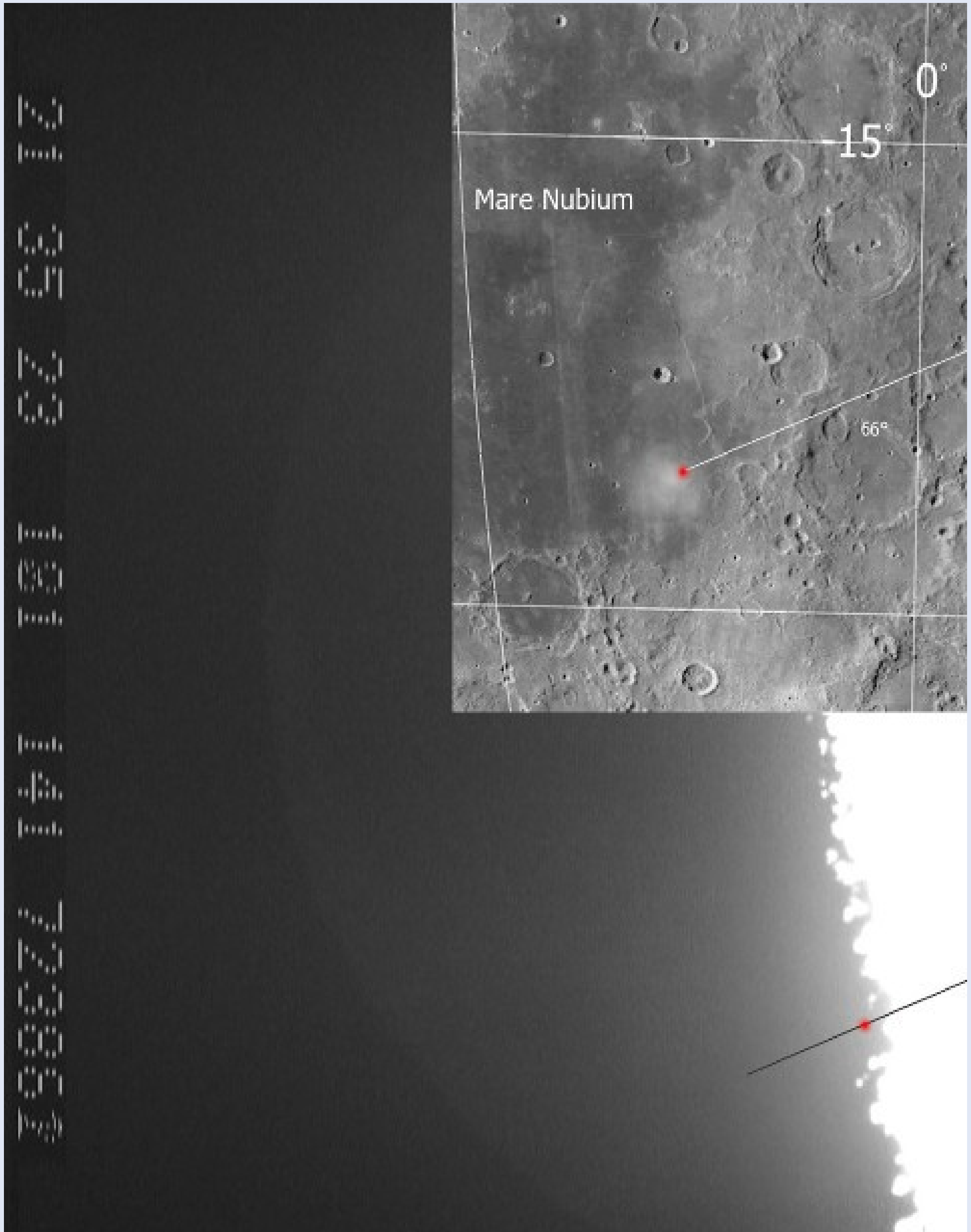
Speed: 4x

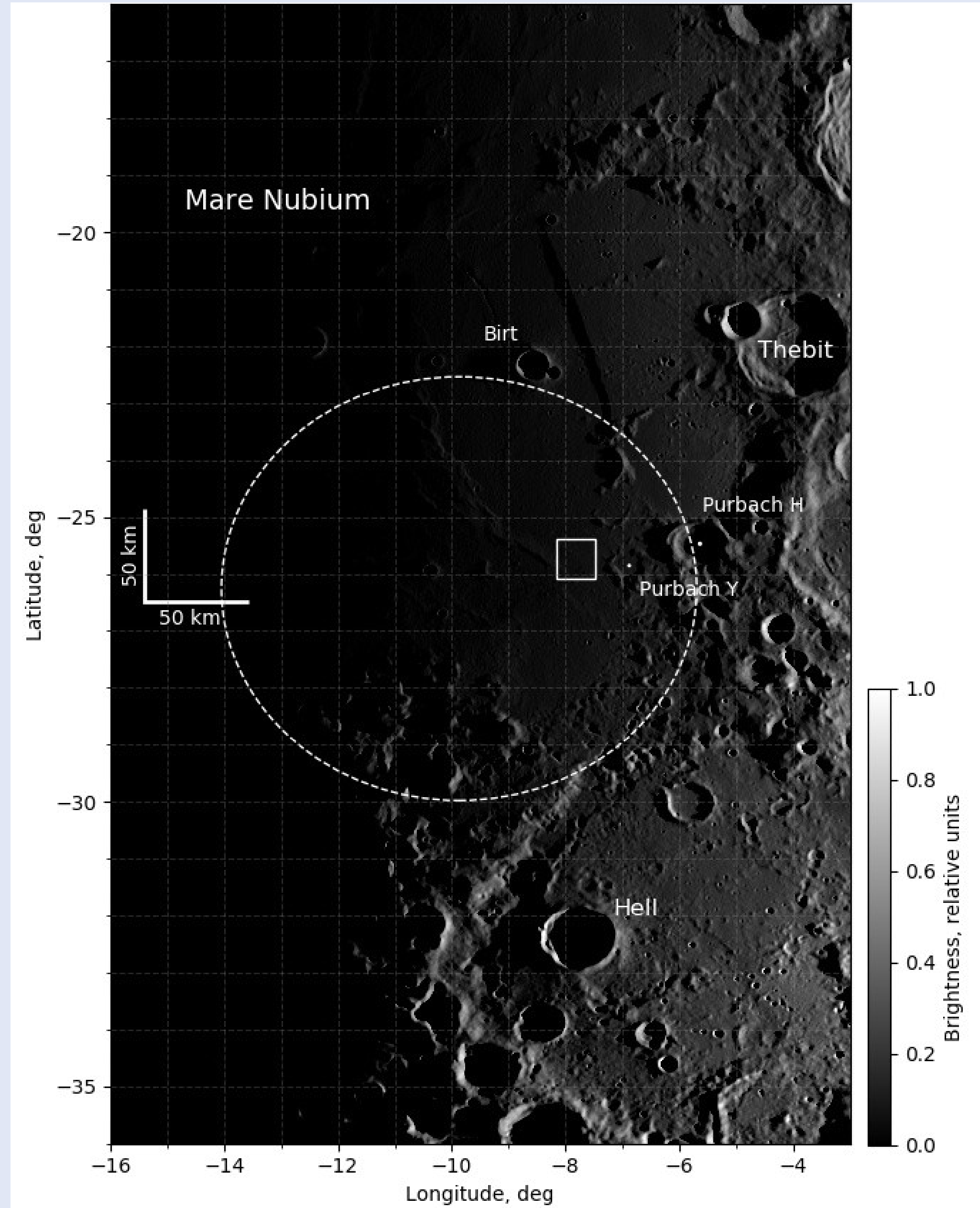
Impact time:
$21^h 35^m 22.871^s \pm 0.010^s$ UT,
February 26, 2015

Observer: Marco Iten (Gordola)

Instrument: 125-mm refractor / Watec 902H2 Ultimate videocam

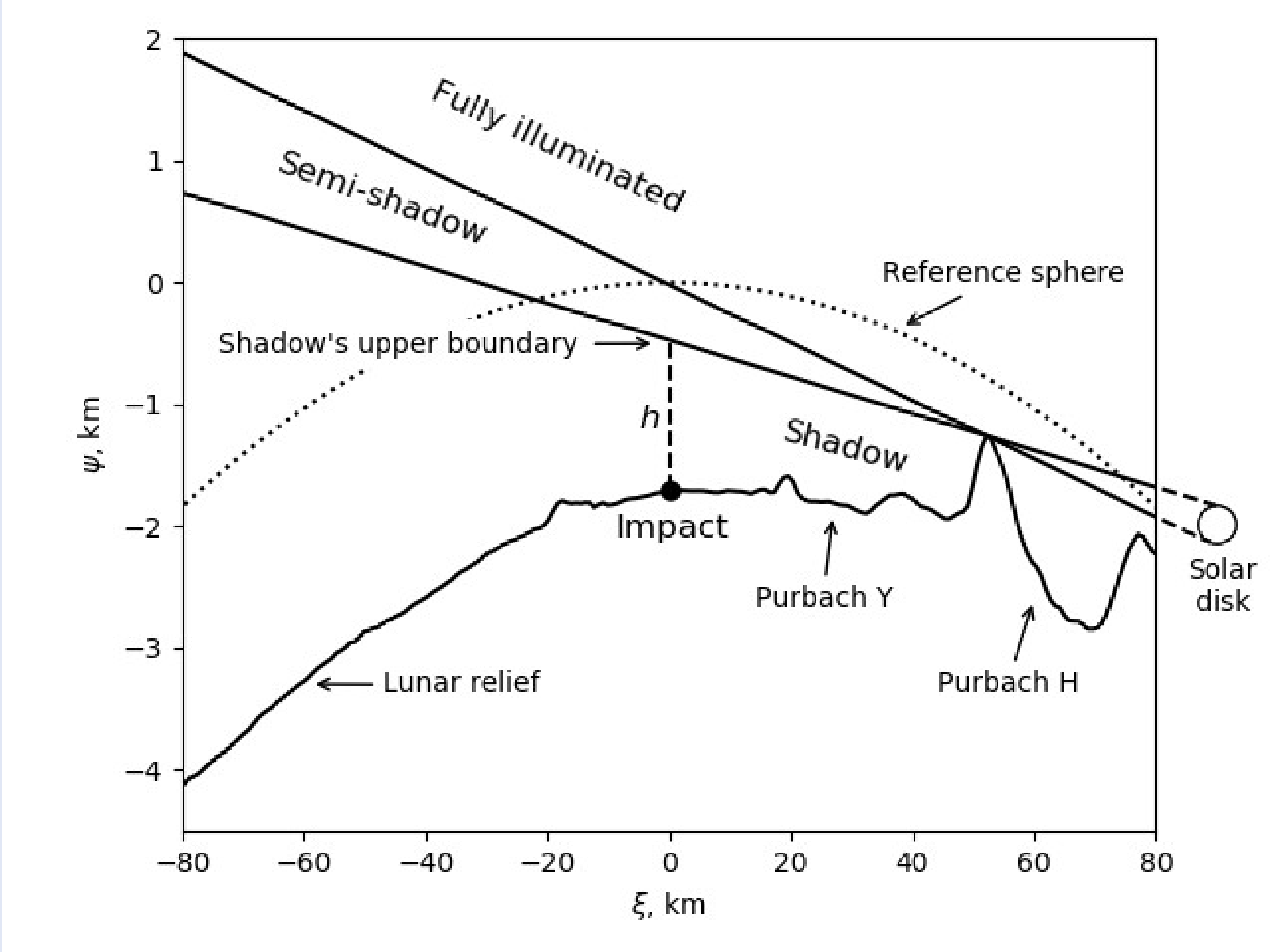
Selenographic coordinates





25.73°±0.35° S, 7.82°±0.33° W

The geometry of shadow formation

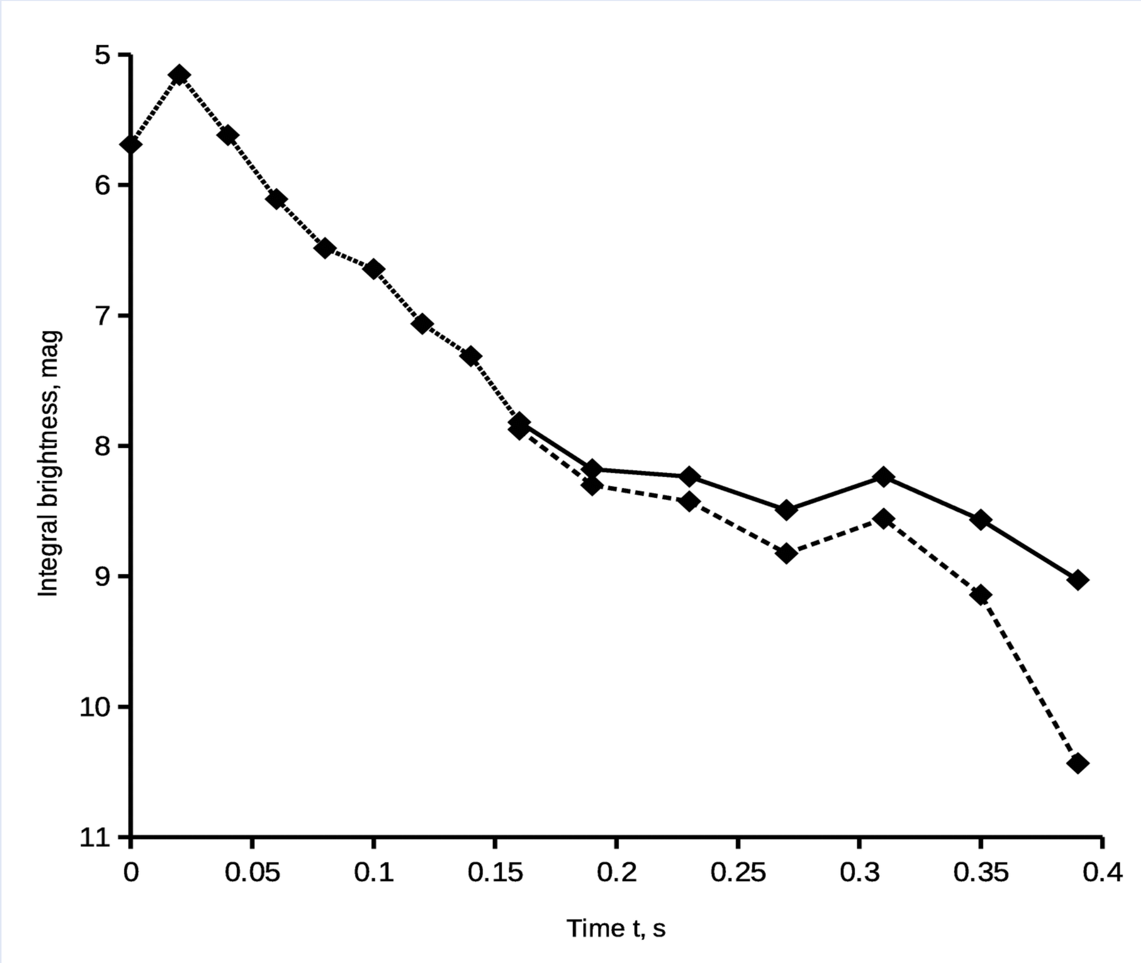


ξ, ψ are coordinates in the plane passing through the impact point, Moon’s and Sun’s centers;

Reference sphere is a selenocentric sphere of radius 1737.4 km;

$h = 1.0 \pm 0.5$ km is the height of shadow’s upper boundary.

Photometry of the flash



Impact velocity: 12-27 km/s

Mass of the impactor: 2-24 kg

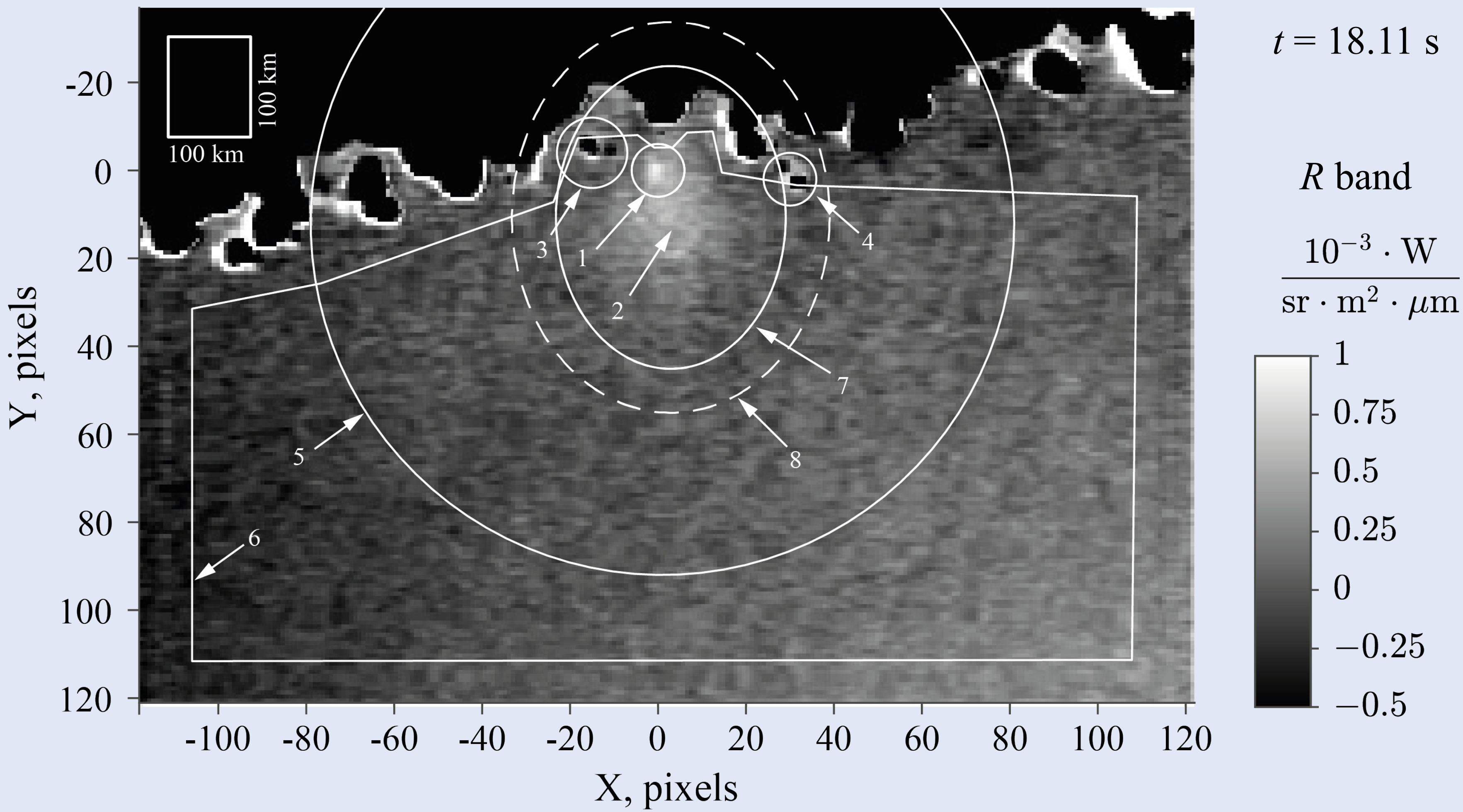
Radius of the impactor: 6-15 cm

Diameter of crater: 8-13 m

Light curve of the flash in the *R* band.

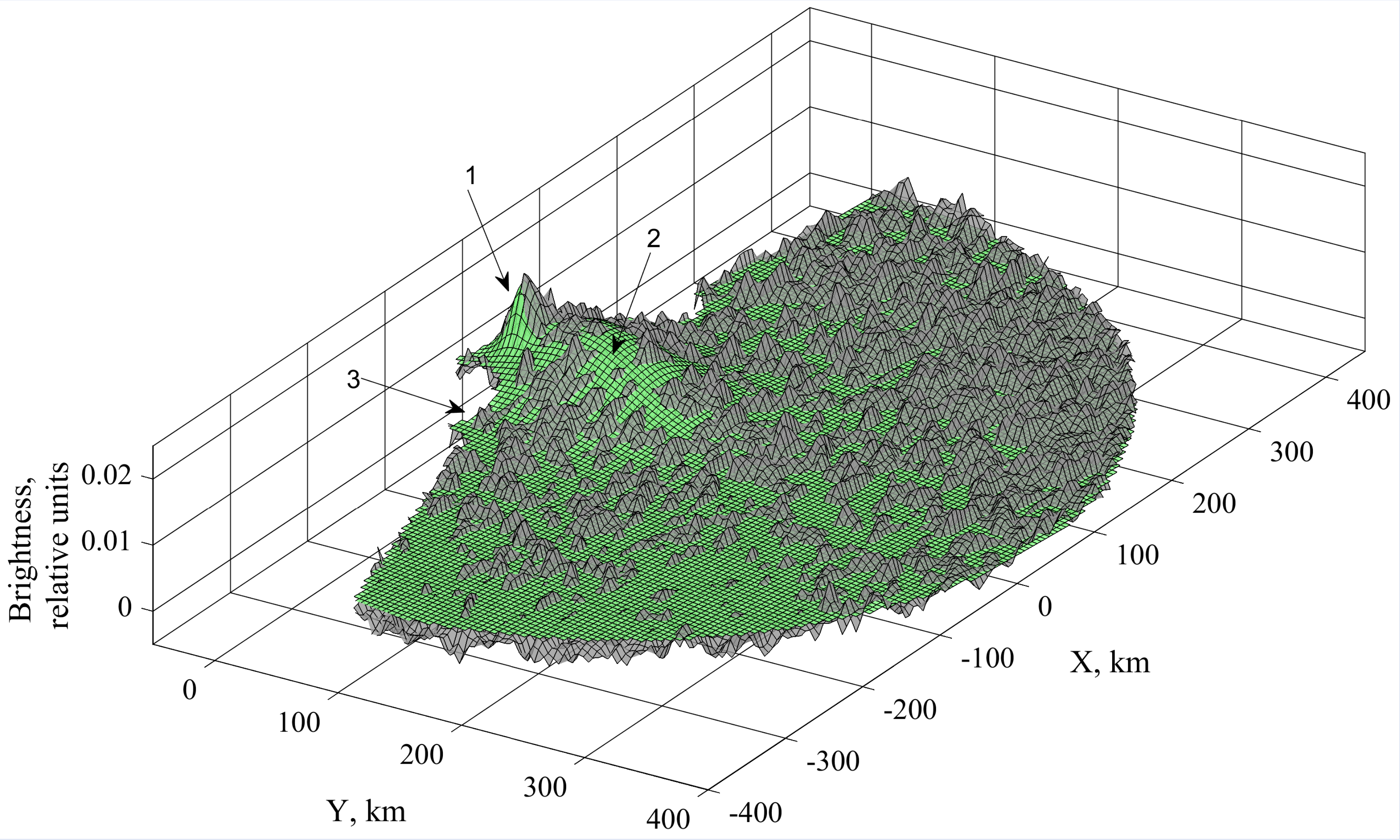
Dashed line is the flash brightness corrected for the dust cloud brightness

Photometry of the dust clouds



1 – small cloud,
2 – large cloud,
3, *4* – isolated lunar features,
5 – area of the phenomenon,
6 – background area,
7 – elliptical area for the large cloud fit,
8 – ring area for the linear trend calculation.

Profile fitting



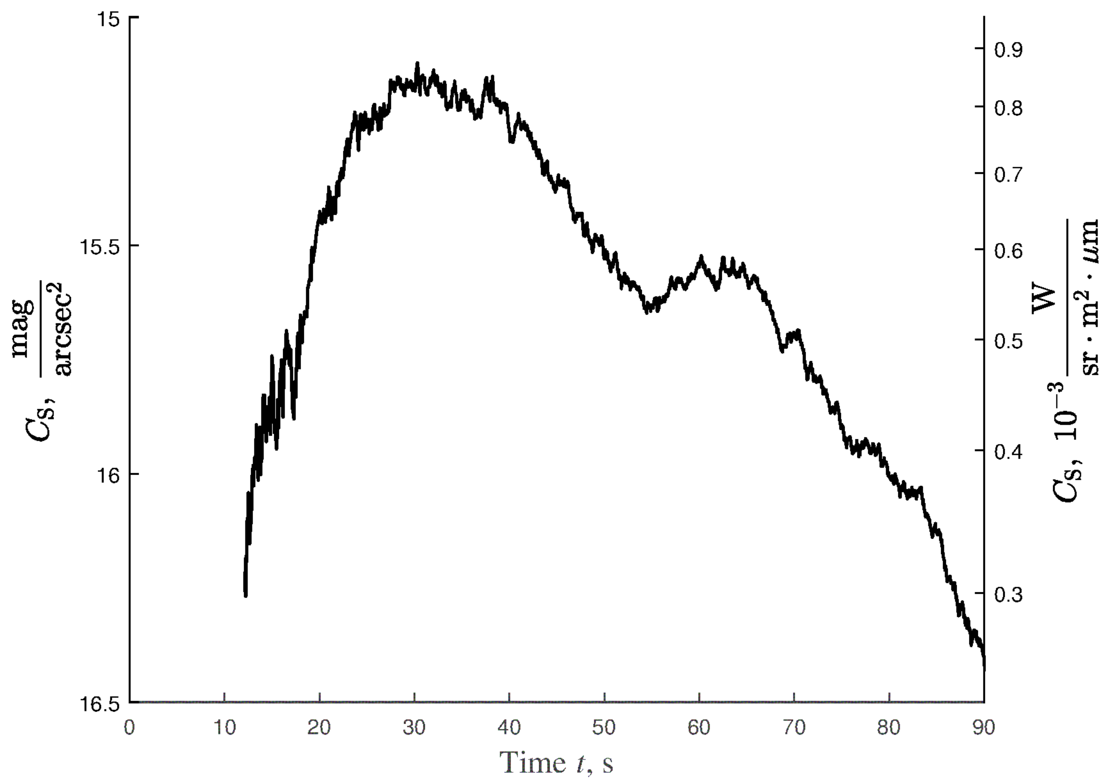
Small cloud *1*

$$B(x, y) = C_S \exp\left(-\frac{x^2 + y^2}{2\sigma_S^2}\right)$$

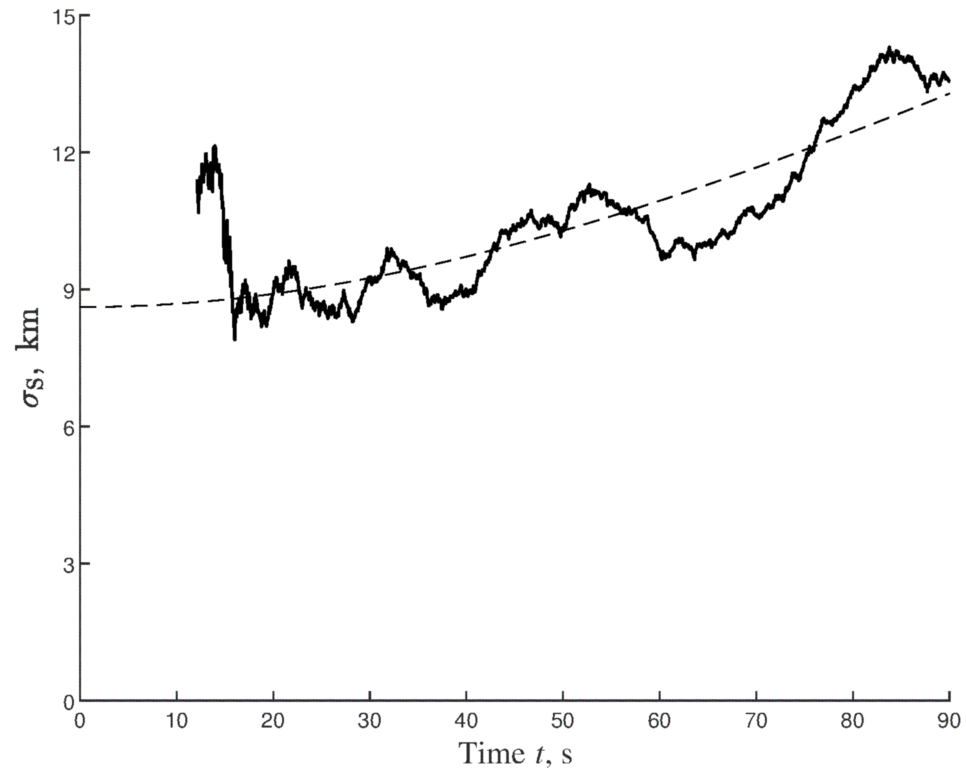
Large cloud *2*

$$B(x, y) = C_L \exp\left(-\frac{(x - x_L)^2}{2\sigma_{Lx}^2} - \frac{(y - y_L)^2}{2\sigma_{Ly}^2}\right)$$

Fitting parameters. Small cloud

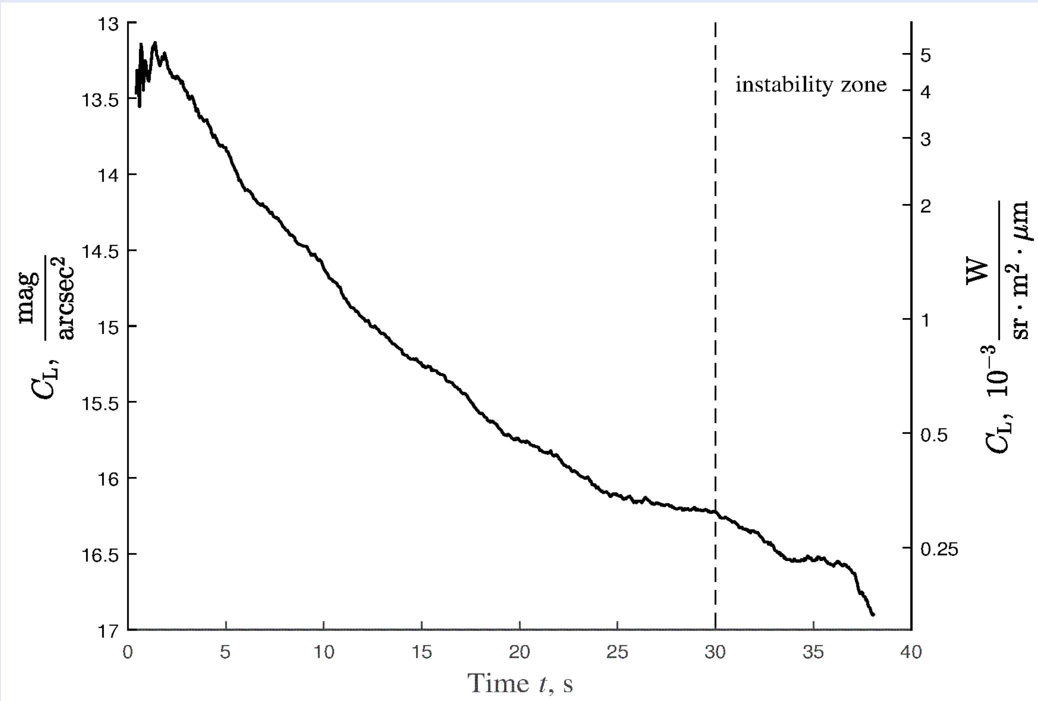


Surface brightness
of the cloud's center

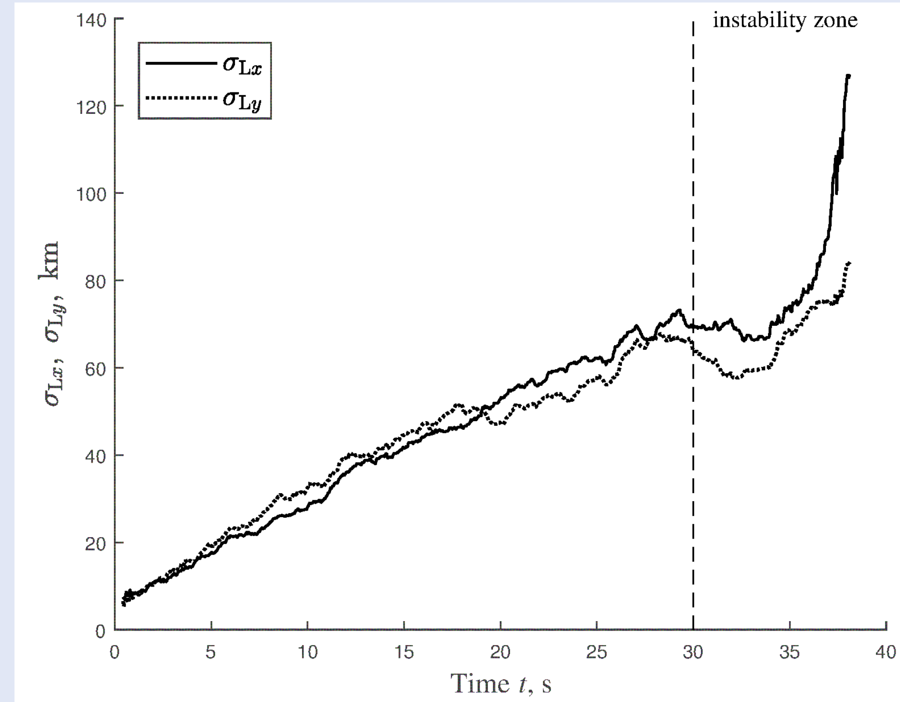


Root-mean-square radius
of the cloud

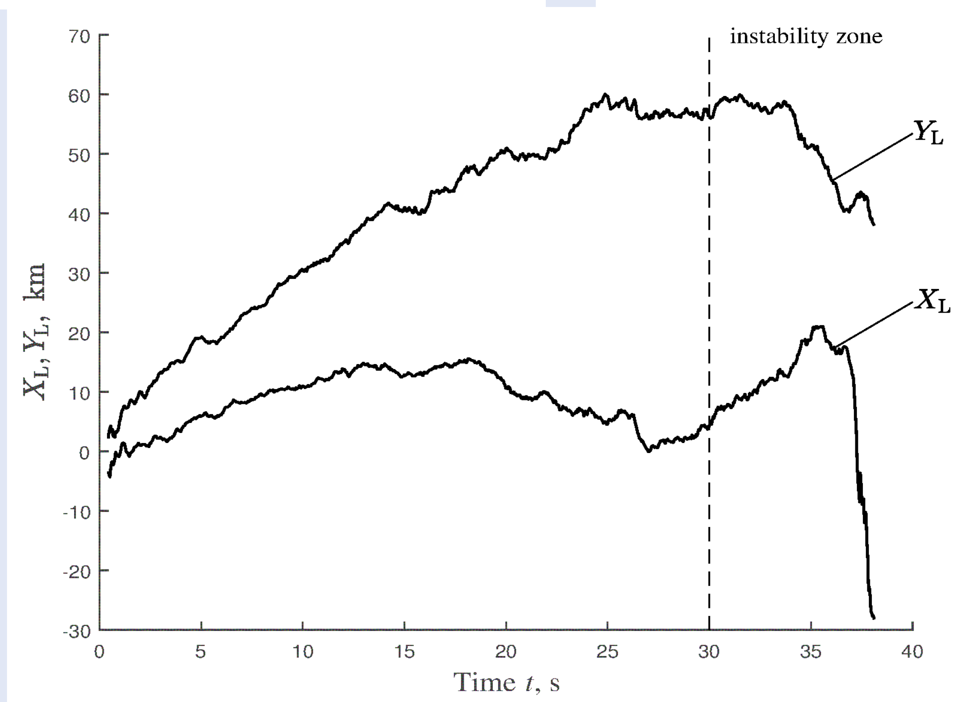
Fitting parameters. Large cloud



Surface brightness of the cloud's center

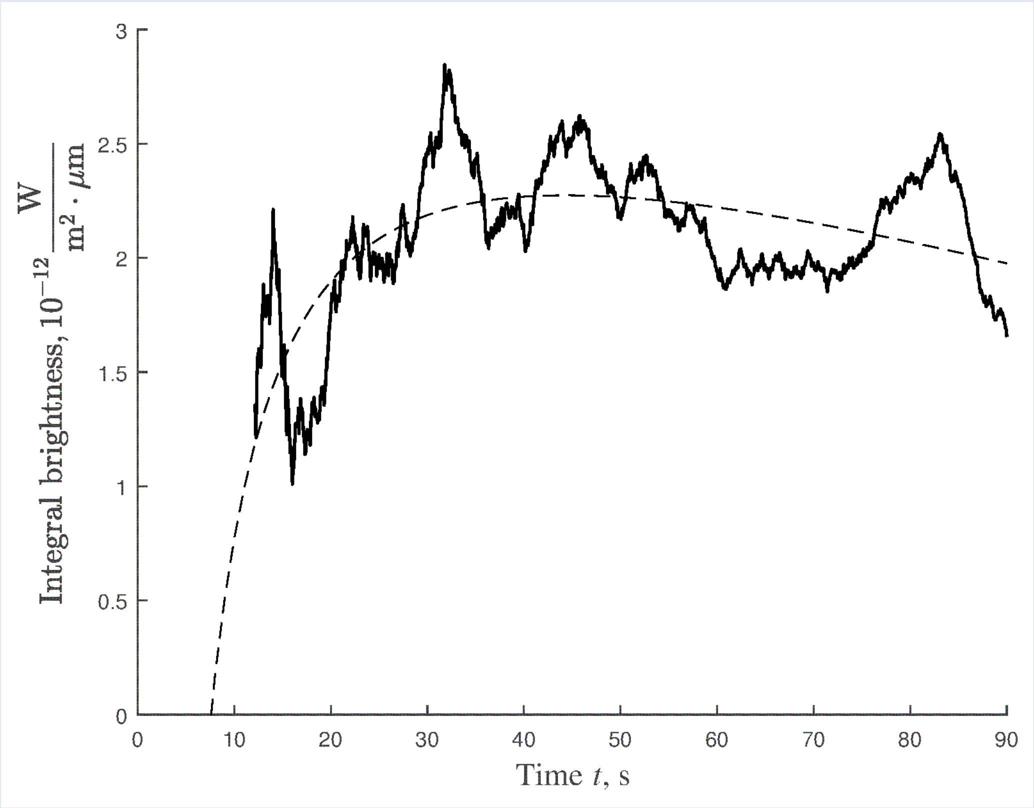


Root-mean-square semi-axes of the cloud

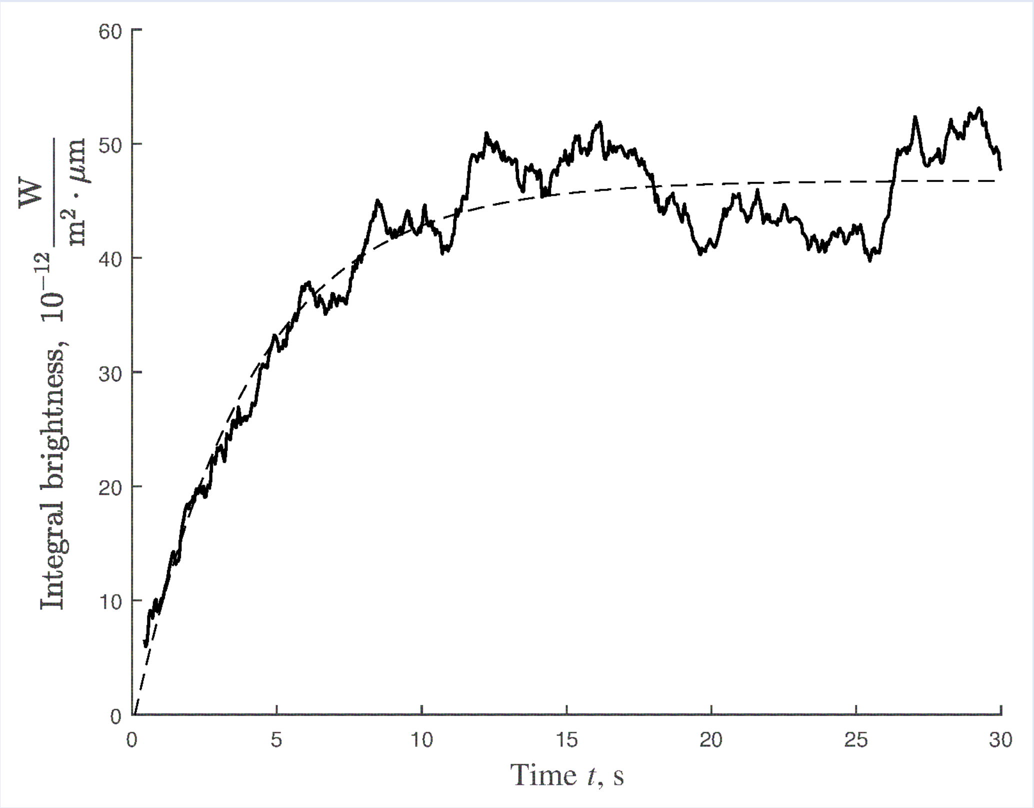


Coordinates of the cloud's center

Integral light curves (R band)



Small cloud



Large cloud

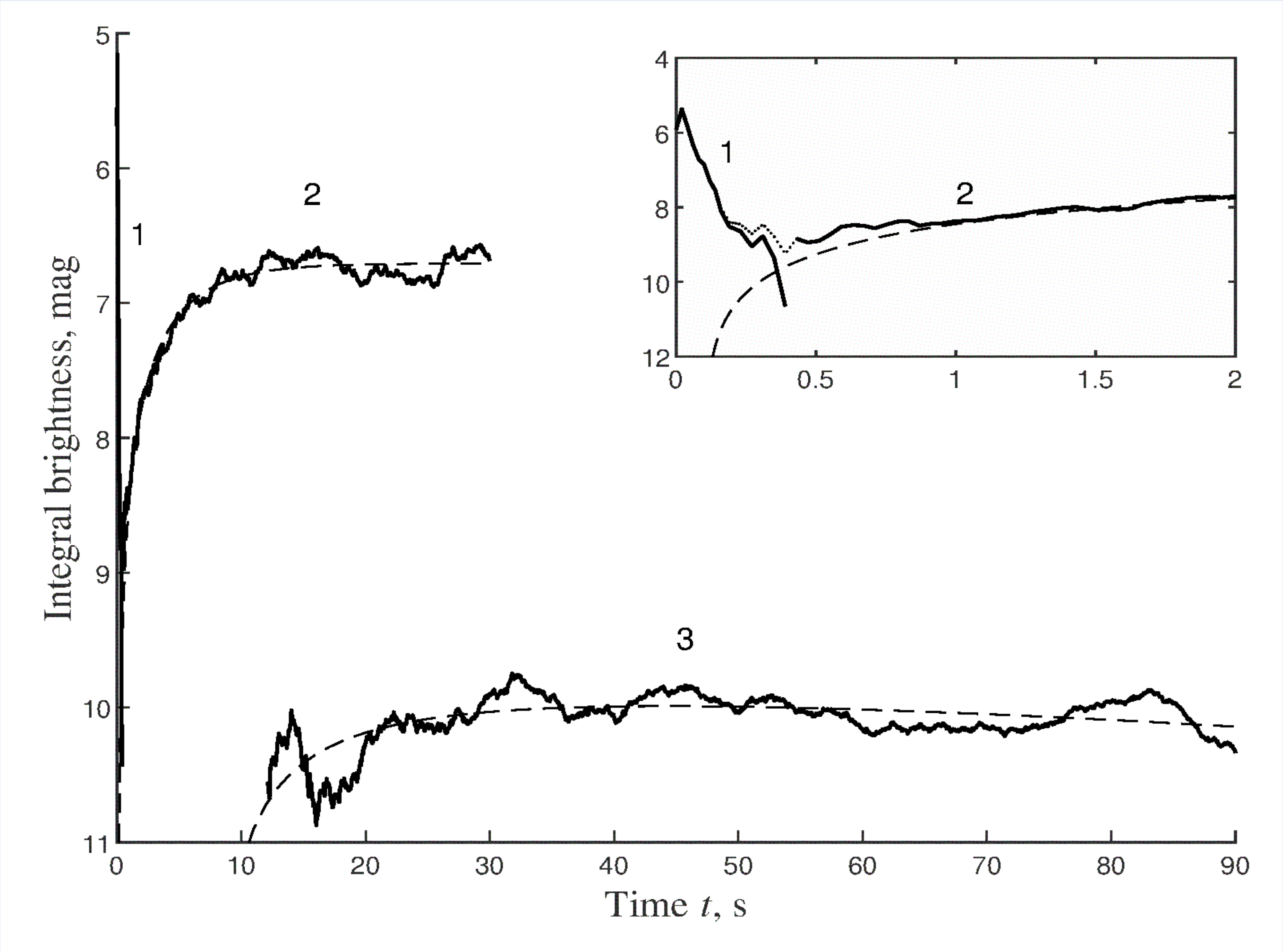
Zero brightness: $t_0 = 7.6 \pm 2.7$ s

Maximal brightness: $t_{max} = 44 \pm 8$ s

Zero brightness: $t_0 = 0.10 \pm 0.13$ s

Maximal brightness: $t_{max} > 10$ s

Integral light curves (*R* band)



1 – thermal flash

2 – large cloud

3 – small cloud

Velocities

Small cloud

The cloud expands approximately isotropically around the impact point with a root-mean-squared velocity of about **0.1 km/s**.

Large cloud

The cloud moves horizontally with a velocity of about **3 km/s** and expands approximately isotropically with a root-mean-squared velocity of about **3 km/s**. Fastest particles in the cloud move with a velocity of about **9 km/s**.

LADEE / LDEX

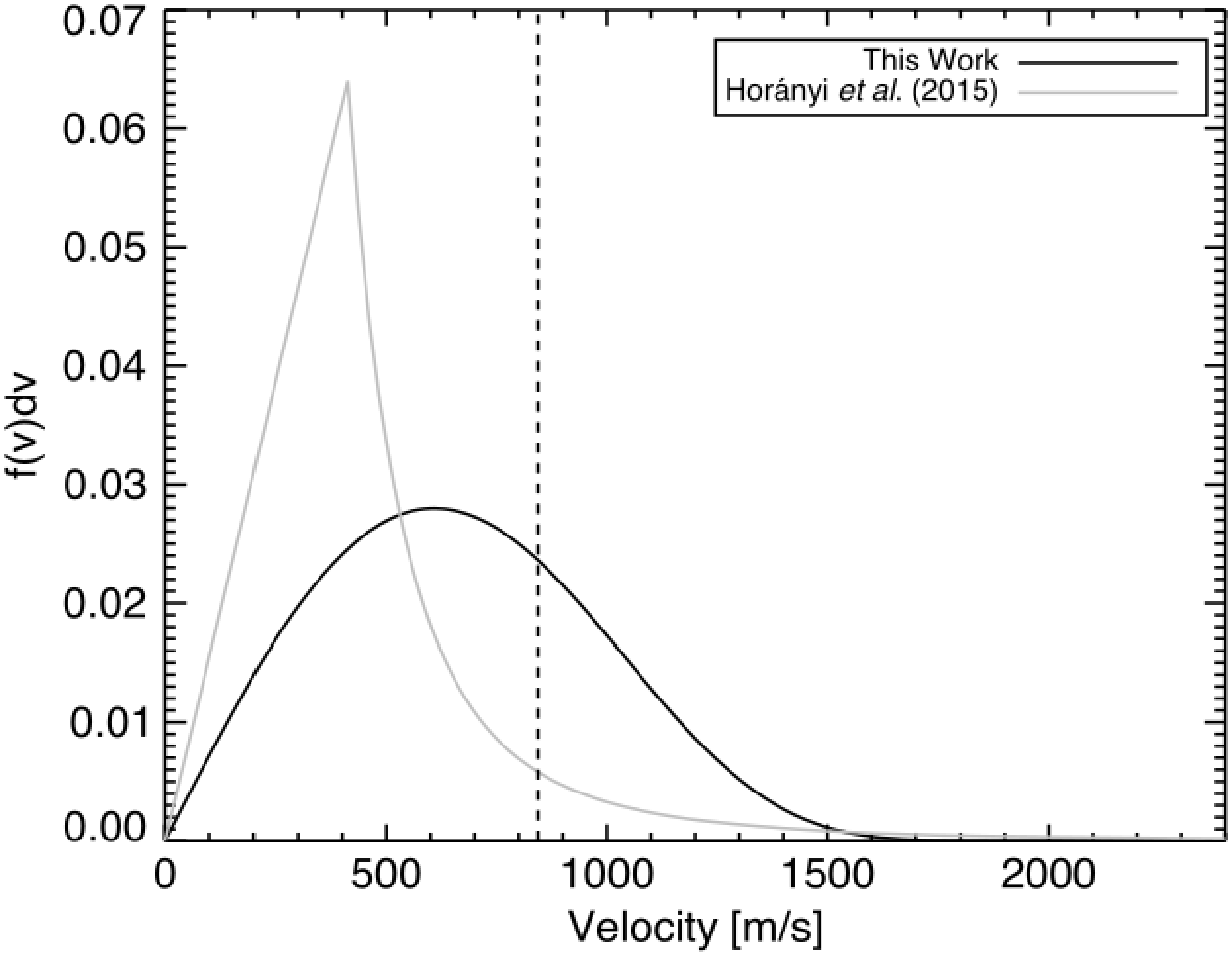


Figure 2. The velocity distribution function from equation (1) (black) along with the previously derived distribution (grey) from *Horányi et al.* [2015, Methods]. The vertical dashed line indicates the velocity to reach the highest altitude visited by LDEX of 250 km. For velocities $\gtrsim$840 m/s, the distribution function derived in this work is an extrapolation.

Szalay, J. R., and M. Horányi (2016). Lunar meteoritic gardening rate derived from in situ LADEE/LDEX measurements, *Geophys. Res. Lett., 43*, 4893–4898.

Impact modeling

1. *Nemtchinov, I.V., Shuvalov, V.V., Artemieva, N.A., Kosarev, I.B., Trubetskaya, I.A.* (1999). Expansion, radiation and condensation of vapor cloud, created by high-velocity impact onto a target in vacuum, International Journal of Impact Engineering 23, 651–662.

2. *Nemtchinov, I.V., Shuvalov, V.V., Artemieva, N.A., Kosarev, I.B., Popel, S.I.*, (2002). Transient atmosphere generated by large meteoroid impacts onto an atmosphereless cosmic body: gasdynamic and physical processes, International Journal of Impact Engineering 27, 521–534.

Conclusions

1. A unique impact flash near the lunar terminator accompanying by appearance of exospheric dust clouds was detected in the first time. A possibility of imaging the impact-produced dust clouds on the Moon using Earth-based observations is proved.

2. Impact-produced dust ejecta are divided into two classes with different kinematic properties: the large fast cloud (~3 km/s) and the small slow cloud (~0.1 km/s).

3. Further observations are required for detailed studies of impact-produced dust clouds in the lunar exosphere. Theoretical modeling of mass, size, and velocity distributions of dust particles excavated to the lunar exosphere upon detected impact is planned.