The Coming Occultation Program in PMO

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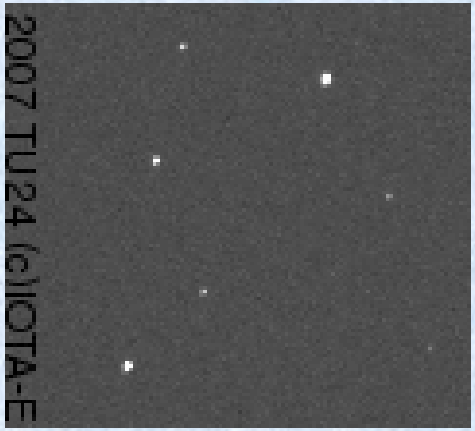
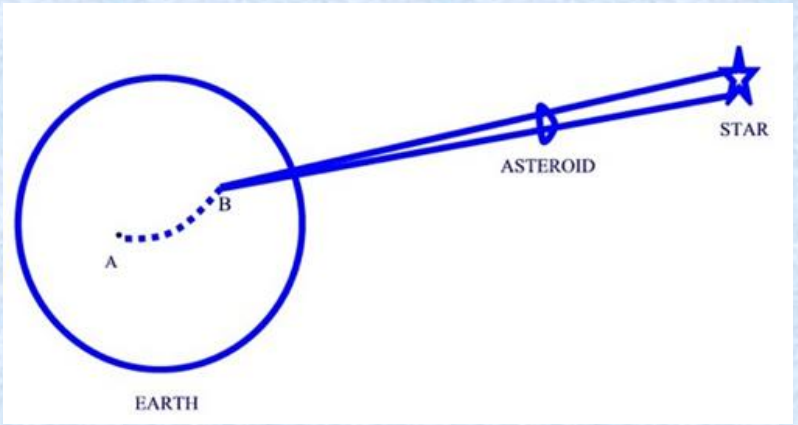
Outline

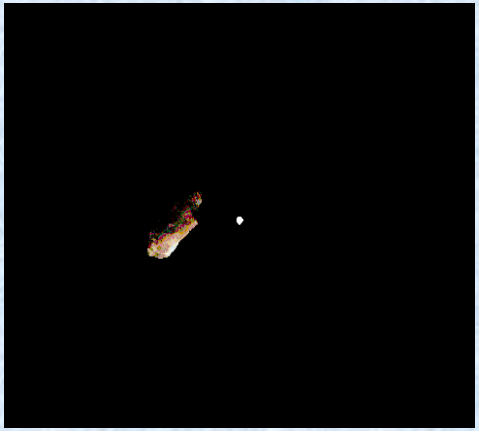
- Introduce the concept of the occultation
- Scientific significances of the occultation
- Main Observational targets
- Initial idea of the equipment design

Occultation

- Occultation is an event in which one object passes completely behind another object.
- In a stellar occultation, a star is briefly obscured by a solar system object.

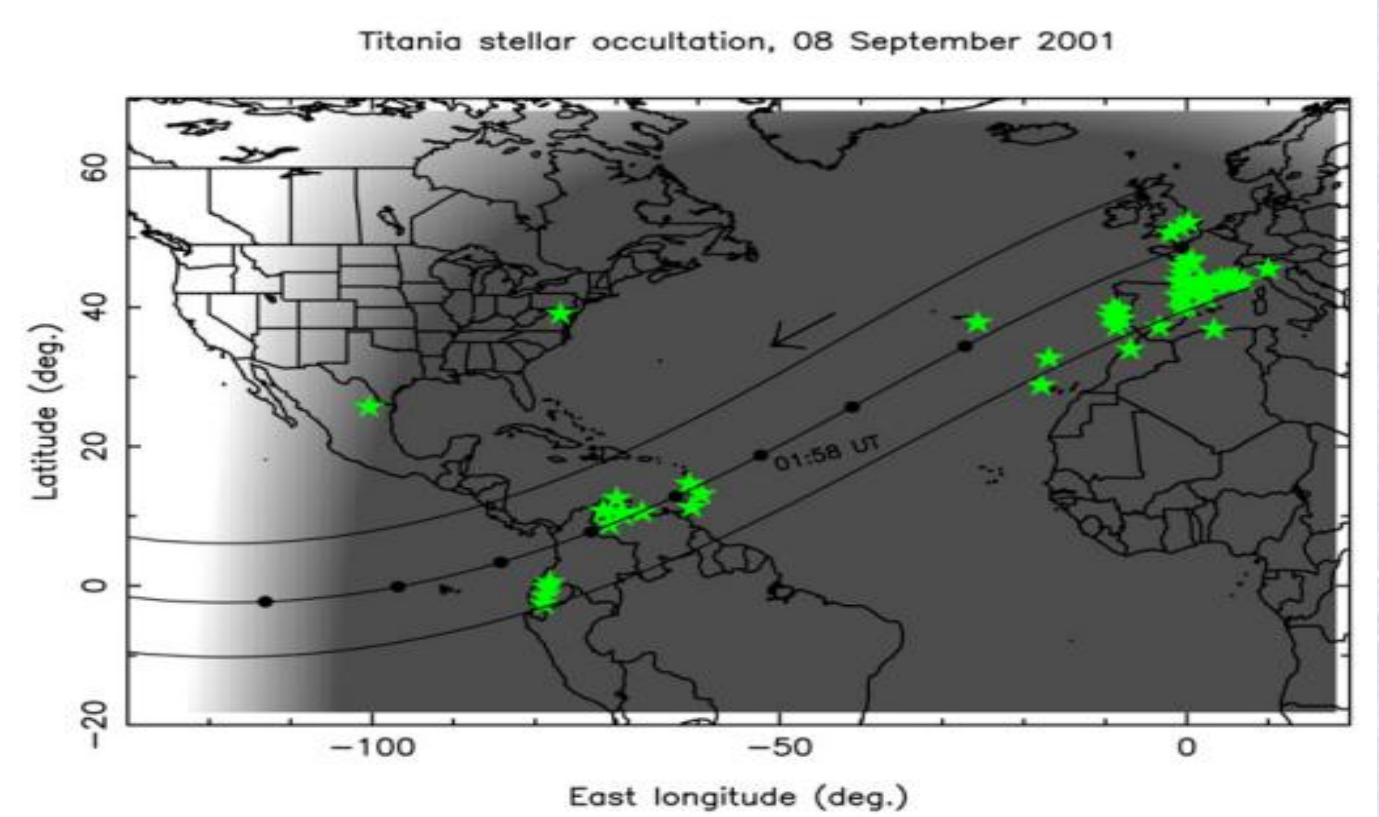






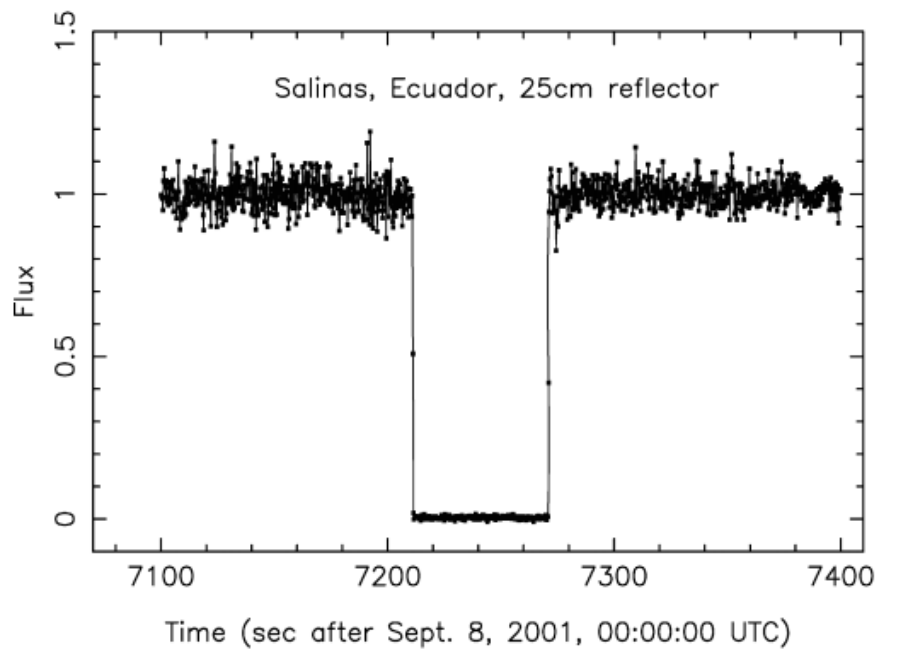
Titania Occulted Hipparcos star 106829(V=7.2mag)

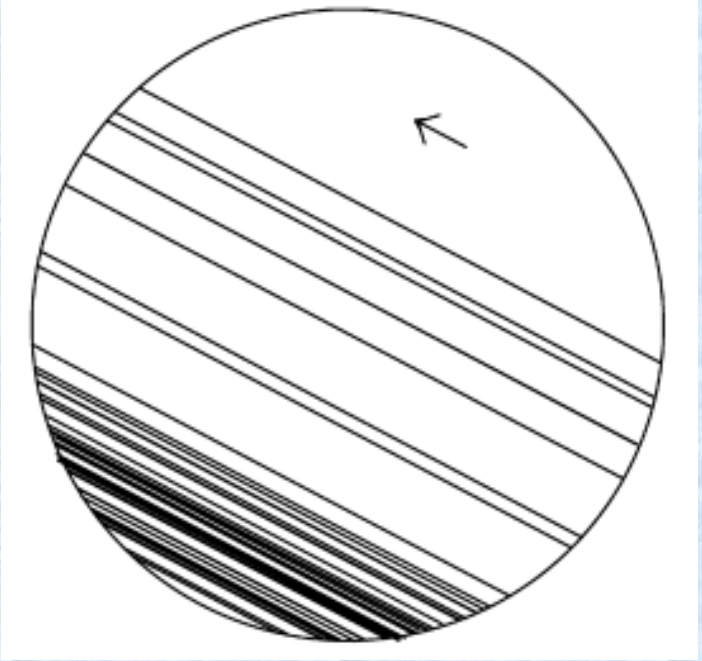
- Cited from T. Widemann, et al. Icarus, 2009, 199, 458



Observed Light Curve

- Maximum time duration is about 75s.





Results

- Stellar diameter: 0.51 $\pm$0.03mas,
- Titania's ephemeris offset

  ephemeris: DE405+GUST86 theory

  total offset: $\begin{cases} \Delta\alpha_T \cos(\delta_T) = -108 \pm 7 \text{ mas}, \\ \Delta\delta_T = -62 \pm 6 \text{ mas}. \end{cases} \quad \begin{cases} \alpha = 324.55817850° \pm [\Delta\alpha \cos(\delta) = 7.4 \text{ mas}], \\ \delta = -14.90997417° \pm [\Delta\delta = 5.7 \text{ mas}], \end{cases}$

  offset from DE405: $\begin{cases} \Delta\alpha_U \cos(\delta_U) = -100 \pm 25 \text{ mas}, \\ \Delta\delta_U = -85 \pm 25 \text{ mas}. \end{cases}$
- Titania's radius: $R_{T,\text{occ}} = 788.4 \pm 0.6 \text{ km}.$
- Constrain the atmosphere based on radius and light curve.

Scientific Significances

- Determine shapes and sizes of the SSOs, such as satellites, asteroids, and angular diameter of the occulted star.
- Atmosphere structure of some SSOs.
- Find the new SSOs with smaller scales.
- Obtain the positions of the SSOs with high precision.

Give the positional data to improve the ephemeris of the SSOs.

Correlations between Occultation and Ephemeris

- Prediction accuracy and observable success rate of the occultation rely on the precision of ephemeris precision.

- Positions with high precision can be obtained from the occultation observations and can be used to improve the ephemeris.

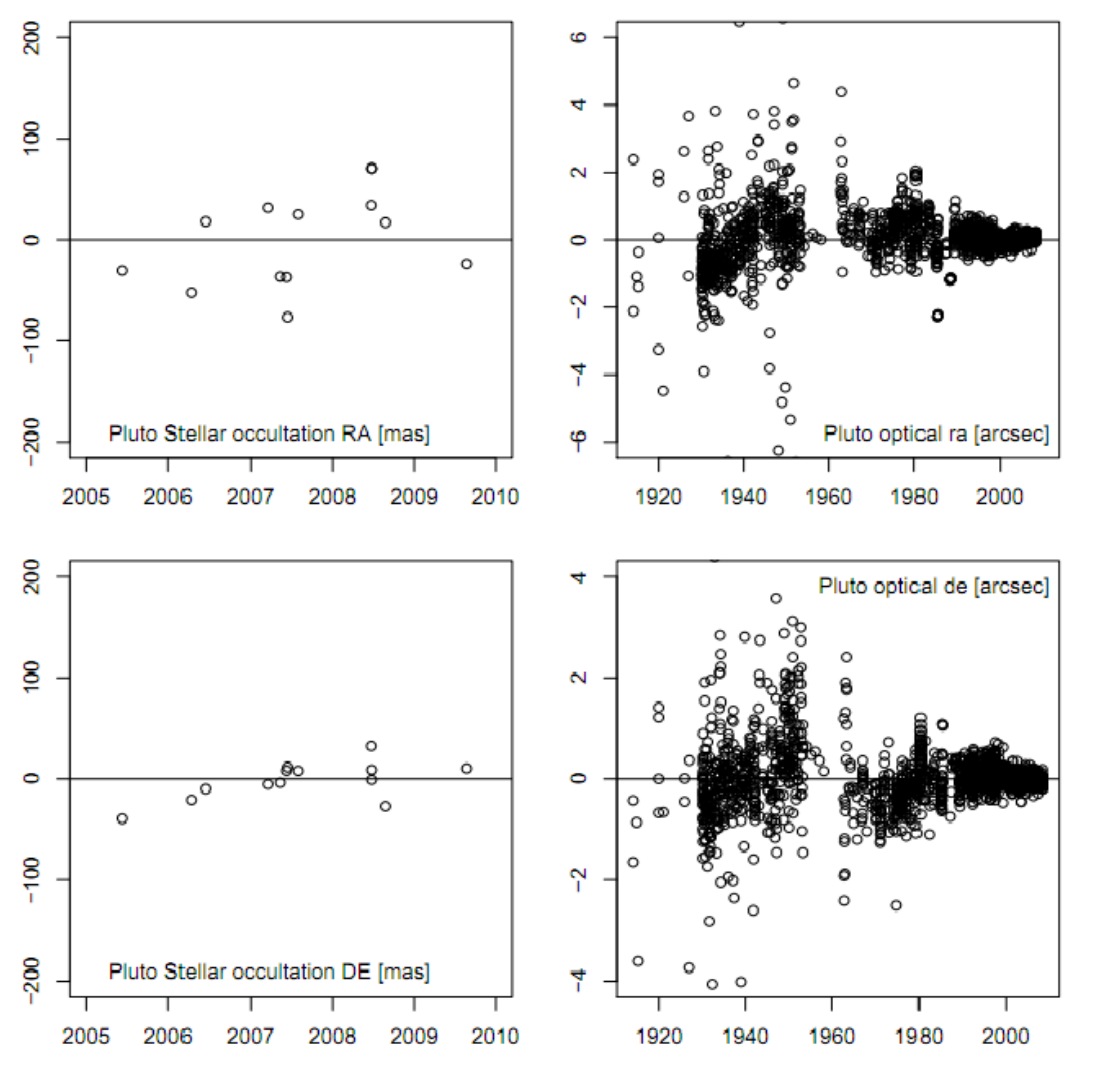
Occultation Data Set of DE405

CCD ASTROMETRY OF URANUS, NEPTUNE AND PLUTO						
Flagstaff - USNO	1995–1996	Ura, Nep	r.a., dec.	0".20	313	
Flagstaff - USNO	1995–1996	Plu	r.a., dec.	0".20	63	
Bordeaux	1995–1996	Plu	r.a., dec.	0".20	13	389
OCCULTATION TIMINGS						
Uranus rings	1977–1983	Ura	r.a., dec.	0".14	14	
Neptune disk	1968–1985	Nep	r.a., dec.	0".27	18	32

(Cited from the specification of DE405)

Occultation Data Set of INPOP10a

Saturn Cassini				
ra [mas]	31	2004-2007	1.5 ± 4	0.7 ± 4
de [mas]	31	2004-2007	7.0 ± 7	6.5 ± 7
range [m]	31	2004-2007	0.5 ± 22	0.0 ± 17
Saturn VLBI Cassini				
ra [mas]	10	2004-2009	0.3 ± 0.7	0.0 ± 0.6
de [mas]	10	2004-2009	-1.2 ± 2.0	0.1 ± 0.4
Saturn Optical				
ra [mas]	7824	1914-2008	-16 ± 305	-16 ± 305
de [mas]	7799	1914-2008	-7 ± 276	-9 ± 276
Uranus flybys				
ra [mas]	1	1986	-90	-30
de [mas]	1	1986	-36	-7
range [km]	1		1139	0.080
Uranus Optical				
ra [mas]	4145	1914-2008	-44 ± 278	-27 ± 290
de [mas]	4130	1914-2008	-38 ± 339	-11 ± 338
Neptune flybys				
ra [mas]	1	1989	-88	-11
de [mas]	1	1989	-48	-10
range [km]	1		2305	0.004
Neptune Optical				
ra [mas]	4340	1914-2008	-32 ± 282	2 ± 281
de [mas]	4320	1914-2008	-36 ± 335	
Pluto occultation				
ra [mas]	13	2005-2009	-6 ± 46	-1 ± 47
de [mas]	13	2005-2009	16 ± 30	-2 ± 19
Pluto Optical				
ra [mas]	2449	1914-2008	353 ± 926	38 ± 629
de [mas]	2463	1914-2008	-22 ± 524	17 ± 536



Positional Residuals of Pluto in INPOP10a

Main Targets of this Program

Occulting Objects (Ephemeris Objects)

- Outer planet (Jupiter, Saturn, Uranus, Neptune, Pluto) systems.
- Some asteroids with sizes larger than 100km (total number: 430(220/210)).
- If sizes and shapes of these objects are preliminarily given, positions of mass center can be given by the observed chords.
- If not, sizes and positions are determined at the same time.

Occulted Objects

- Stars with visual magnitude less than 12mag,
- Number ~ 2,500,000 in tycho-2 catalogue.

Number of the events

- Time interval: 2013-2017.
- Predictions are computed by the software OCCULT 4.0 developed by David Herald.
- For stars in Tycho-2 catalogue occulted by the outer planet systems, the total number is about 350.
- For stars occulted by the asteroids with size larger than 100km, the total number is about 6000.

Ephemeris Precision and Prediction Accuracy

Recent Status

- Positional precision of outer planet systems ~ 100mas (INPOP, DE)
- Precision of asteroid positions ~ 500mas (Bowell's Asteroid Orbit Database)
- Precision of stellar positions (V<12mag) ~ 100mas

After Gaia

- Large size(>600mas?) objects, such as a few main planets and large satellites will not be observed by Gaia. But these objects can easily be observed.
- Positional precision of solar system objects with small sizes will be about 1 mas and increased over time.
- Precision of stellar positions (6<V<12mag) ~0.2mas in the coming 20 years.

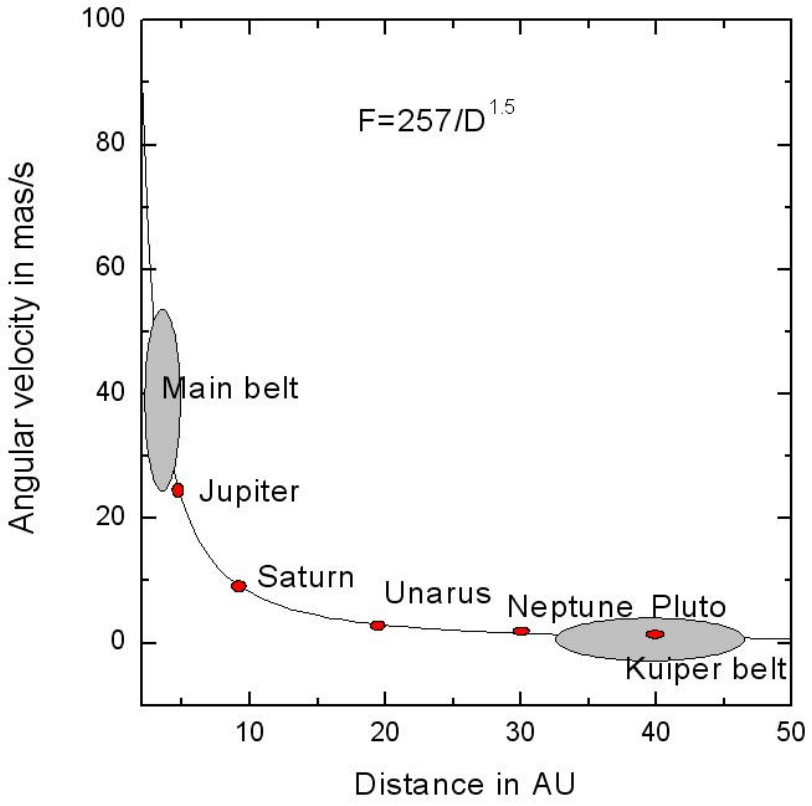
- Then, for smaller SSOs, prediction accuracy will be improved by a factor ~ 100 than ever before. (Cited from T. tanga & M.Delbo, 2007, A&A, 474, 1015)

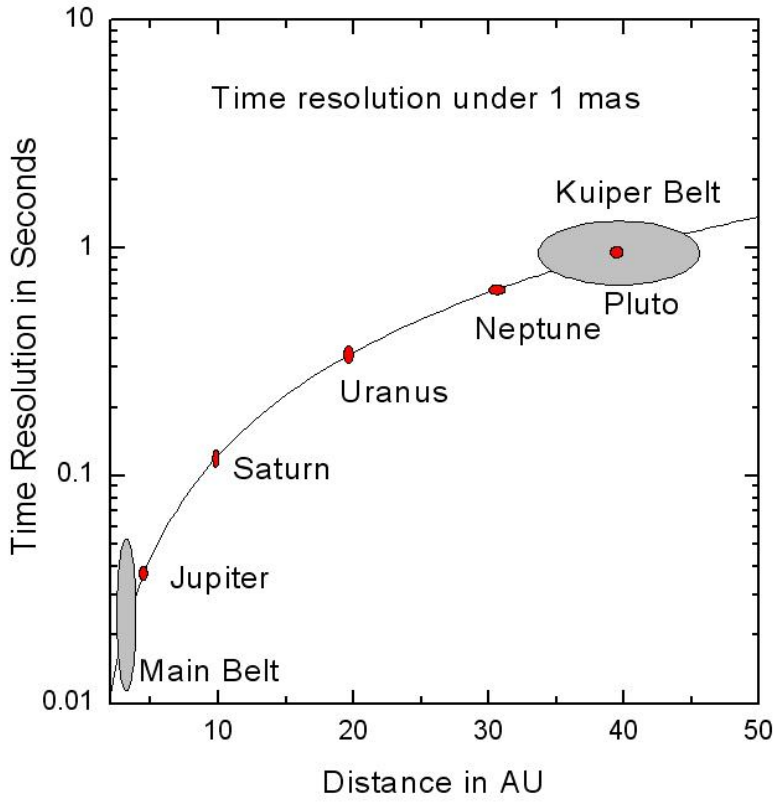
Constraints of Observational Precision

- The first constraint is the positional precision of the occulted star.
- Another constraint is the time resolution of the observational equipment.

- We will consider the time resolution under the situation of the precision of 1 mas.

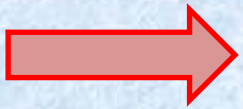
Time Resolution with Distance





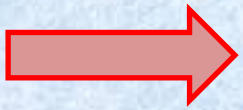
Technical Requirements

- Time resolution from 0.03s to 1s



minimum integration time of CCD
less than 0.03s
maximum fps of CCD larger than 30

- Timing accuracy better than 0.001s
- Occulted stars with magnitude less than 12mag



limiting magnitude of optical system
larger than 15mag

- Portable

Initial Idea of the Equipment Design

- Telescope
  portable, 12-14 inch. For example, Meade LX200 series.
- Camera
  low-end products:
  Video, FLI MicroLine ML 01050
  High-end products:
  PI ProEM+,
  Hamamatsu ImagEM
  Andor IXon3 Ultra 897
- Timer
  GPS receiver: latitude, longitude, altitude, time, frequency output
- Data acquisition
  laptops or computer with mini case

Back Illuminated CCD
Pixels 512×512
High Frame rate > 35
High quantum efficiency >90%
Low read noise
But high Price

Preliminary Plan

- Supported by NSFC, in next year,

  2-3 portable occultation observation systems will be developed.

  Occultation events of the main targets will be predicted in detail and observation plan for the future 3 years will be planned.

  Also,

  models and data pipeline will be built.

Thank you for your attention!