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# PLATO telescopes optical units: An update on working status

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**ABSTRACT**

PLATO (PLAnetary Transits and Oscillation of stars) is the ESA Medium size dedicated to exo-planets discovery and cataloguing, adopted in the framework of the Cosmic Vision 2015-2025. The PLATO launch is planned in 2026 and the mission will last at least 4 years in the Lagrangian point L2. The primary scientific goal of PLATO is to discover and characterize a large amount of exo-planets hosted by bright nearby stars. The PLATO strategy is to split the collecting area into 24(+2) identical 120 mm aperture diameter fully refractive cameras with partially overlapped Field of View delivering an overall instantaneous sky covered area of about >2100 square degrees. The opto-mechanical sub-system of each camera, namely Telescope Optical Unit (TOU), is basically composed by a 6 lenses fully refractive optical system, presenting one aspheric surface on the front lens, and by a mechanical structure made in AlBeMet. In this paper we will update on the current working status of the TOUs.

**Keywords:** PLATO, Exoplanets, Wide field telescope, Photometry

## 1. INTRODUCTION

Our knowledge of alien worlds changed dramatically from the earliest, ground based discoveries [1] to the current knowledge of the architectures [2] of the so-called exoplanets. While the measurements of their mass is largely due to spectroscopic observations from the ground, the vast majority of new systems have been obtained through photometric scrutiny of a large sample of stars, looking for transits [3] that occours when the line of sight of the observer to the monitored star is interested by the passing exoplanet. As this is a statistically inefficient process a large number of stars are to be continuously scrutinized. If one is looking for relatively nearby exoplanets around relatively bright stars, such that further observations from the ground or from other space based facilities would be effective, one needs, in order to cover a large enough number of potential targets, a very large Field of View, through a significant optical aperture with a reasonable pixel scale. For a 1m class facility this would requires impossible focal ratios such that segmentation of the telescope into numerous units are the basic ingredients of the M-sized mission PLATO [4,5,6,7].

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In PLATO 24 Telescope Optical Units are grouped into four groups with partially overlapping Field of View such to maximize the covered amount of targets, allowing for a significant fraction to convey high quality and accuracy photometric data. This is obtained through a wide field, refractive, intermediate pupil optical design [8] whose final layout has been maximized in order to assure exceptional performances after a nominal lifetime of 6 years with a possible extension to further 2, with an accurate selection of thermomechanical and rad-hardened optical elements [9,10].

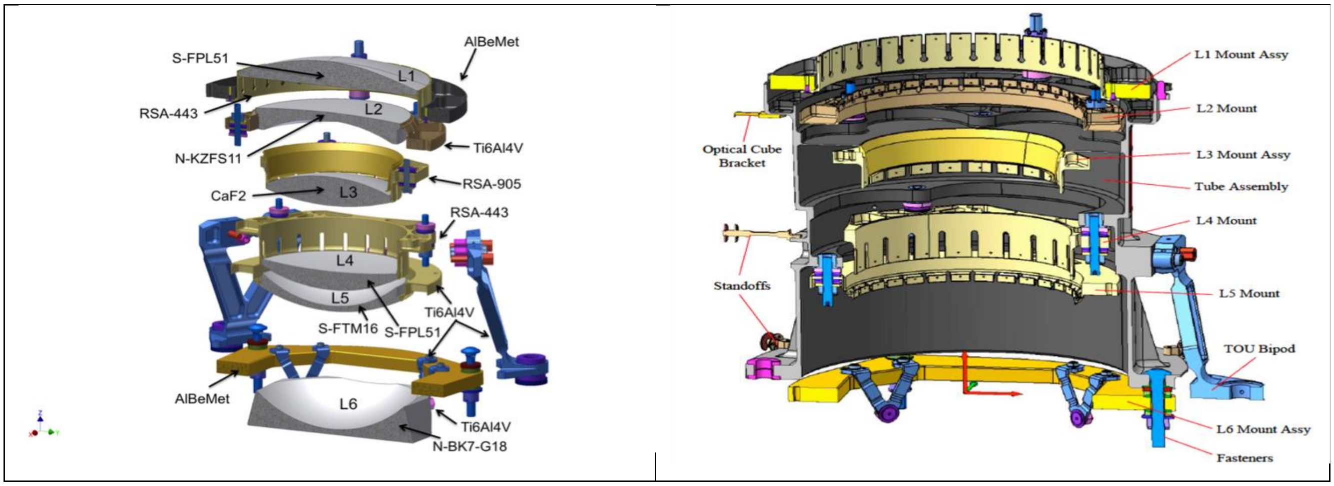



Figure 1 – *Left*: an exploded view of a PLATO's TOU with a focus on the materials used for the glasses, their mounts, and for the interface components. *Right:* Details of the mechanical structure with subcomponents highlighted.

# 2. DEVELOPMENT MODELS

26 flight models of the TOU will be part of the PLATO Payload: the 24 "Normal TOUs" (N-TOUs), as briefly described in § 1, and 2 "Fast TOUs" (F-TOUs). The latter are equivalent to the *Normal* ones but for the coating of the flat window, located at the base of the Baffle Assembly, which select a white bandpass (500-1000 nm) for the 24 N-TOUs, and a blue (505-700 nm)/red (665—1000 nm) bandpass for each of the 2 F-TOUs, respectively.

After material and processes quailifications, a number of breadboards, prototypes and models have been produced to qualify the thermomechanical properties, the integration and alignment procedures [11], and eventually the performance of the TOU. Achieving the capability of serial production and high cadence delivering of the 26 flight models and a number of flight spares, was a driver to all integration and testing procedures. Among the models developed and tested so far are:

- A number of BreadBoards of the Optical Mechanical Groups (OMGs)
- A Structural Thermal Model
- An Engineering Model
- 26 Mass Thermal Dummies

## 2.1 OMGs BreadBoards

BreadbBoards (**OMGs BB**) have been used for design qualification of the six Opto Mechanical Groups (cf. **Figure 1** *left)* and to validate the procedures used for their integration and alignment.

For each OMG, two identical BBs have been produced. Each OMG was assembled with a polished uncoated lens, and a mount of the same shape and material used for the flight model. Only exceptions were the use of a spherical lens for L1, in place of the aspherical one adopted for the nominal design, the use of a not rad-hard version for the L6 glass (SCHOTT N-BK7 instead of BK7-G18), and the use of Toolox 44 instead of AlBeMet for the flange of the OMG-1 and OMG-6; the Toolox flanges were designed in order to have structural modes at the same frequencies as the flight one and the same load at lenses and adhesive pads. I/Fs between each lens and its mount were all flight model-like.

Each OMG was assembled under the control of an optical centering equipment (a tailored version of the "OptiCentric®-Bonding5D" machine produced by *Trioptic* company, resulting from co-engineeering by *Leonardo* and *Trioptic* experts based on TOU needs), which allows the bonding of the lens in its mount with nulling tilts. Integration procedure of OMGs with Trioptic machine was fast, reliable, very accurate, and so successfully validated.

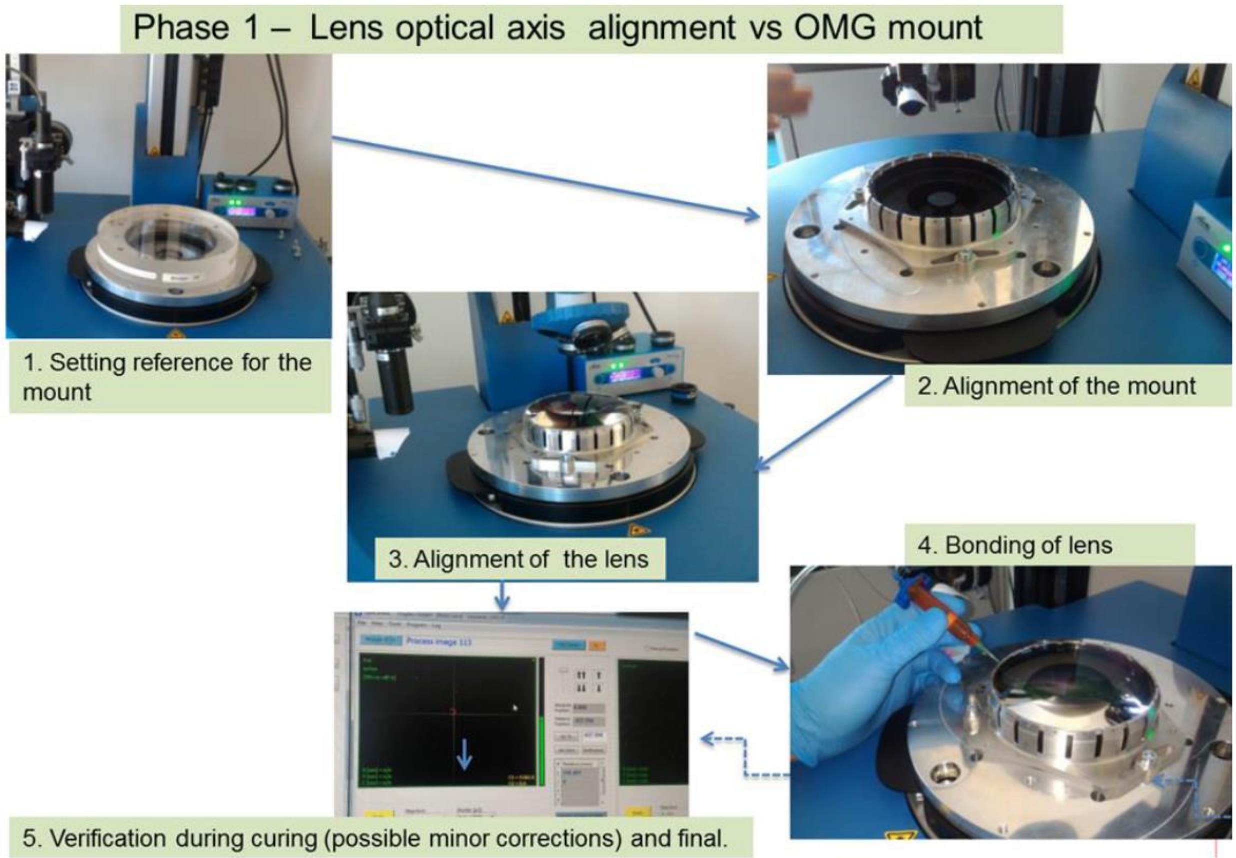



Figure 2 – Step-by-step the procedure of lens-mount assembly is described. The process occurs under control of an optical centering machine, a version of the "OptiCentric®-Bonding5D" machine produced by Trioptic company, tailored to TOU needs by Leonardo and Trioptic experts. The machine, purchased by Leonardo, was operated at HST srl (Prato, Italy) for the assembly of the OMG BBs, and of the STM and EM OMGs. The integration of the OMBs in the tube, and their alignment is operated under control of the same Trioptic machine, configured in "MultiLens® Alignment" mode.

All OMG BBs underwent then thermal cycles demonstrating that they can safely reach the required minimum temperature of -115 °C. One set of 6 OMGs (BB1) were qualified with random up to qualification level; and again with random up to failure level. The vibration test to failure showed margins of safety with respect to the design load ranging from 3.2 to 10.3, which were deemed comfortably sufficient to give the go-ahead for the STM H/W integration.

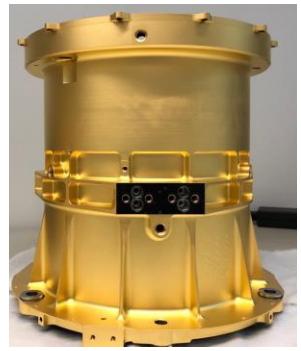
A second set of 6 OMGs (BB2) will be tested for shock to failure after the completion of the Camera STM campaign. The purpose will be to derive margin of safety of the OMG design for shock.

### 2.2 The STM model

The Structural Thermal Model (STM) of the TOU consists of a flight-like structure, made of a AlBeMet tube, black Nickel coated, and gold coated in the external part, in which a set of OMGs are integrated. The STM OMGs are like the one used for the OMG design qualification (cf. §2.1) but for OMG-1 and OMG-6 whose flanges are made in AlBeMet as in the nominal flight model design. While the Baffle Assembly of the STM was successfully tested for random with a dummy glass window, made in Suprasil quartz with same design of the flight model, but not optically polished (fine grinded only and inspected for cracks), the TOU STM as a whole was tested for random with the window replaced by an Al dummy with the same mass and barycenter. The TOU STM tests were carried out at University of Bern. To the purpose, a Focal Plane Assembly (FPA) dummy was assembled to the TOU STM. After TV cycles reaching -110 °C, the model was tested for random till qualification levels. A metrology characterization of the STM TOU, without the Baffle Assembly, was then carried out by Leonardo with the Trioptic machine, in order to have a reference configuration for the metrology run that is planned after the shock test at Camera level. The TOU STM was then delivered to CSL, in Liege, at the end of Sep 2020 for integration of the FPA STM and other STM CAM subsystems.

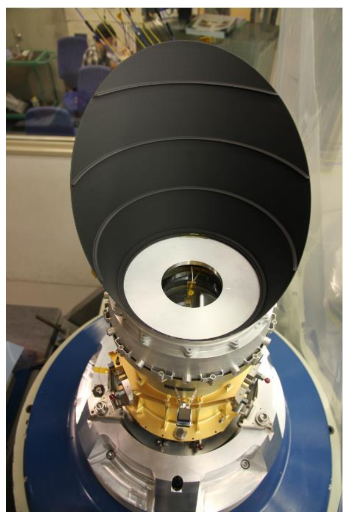
*STM OMGs(1-6)*

*STM BA*



*STM tube*

*FPA dummy*



*Integrated STM @Univ. of Bern*

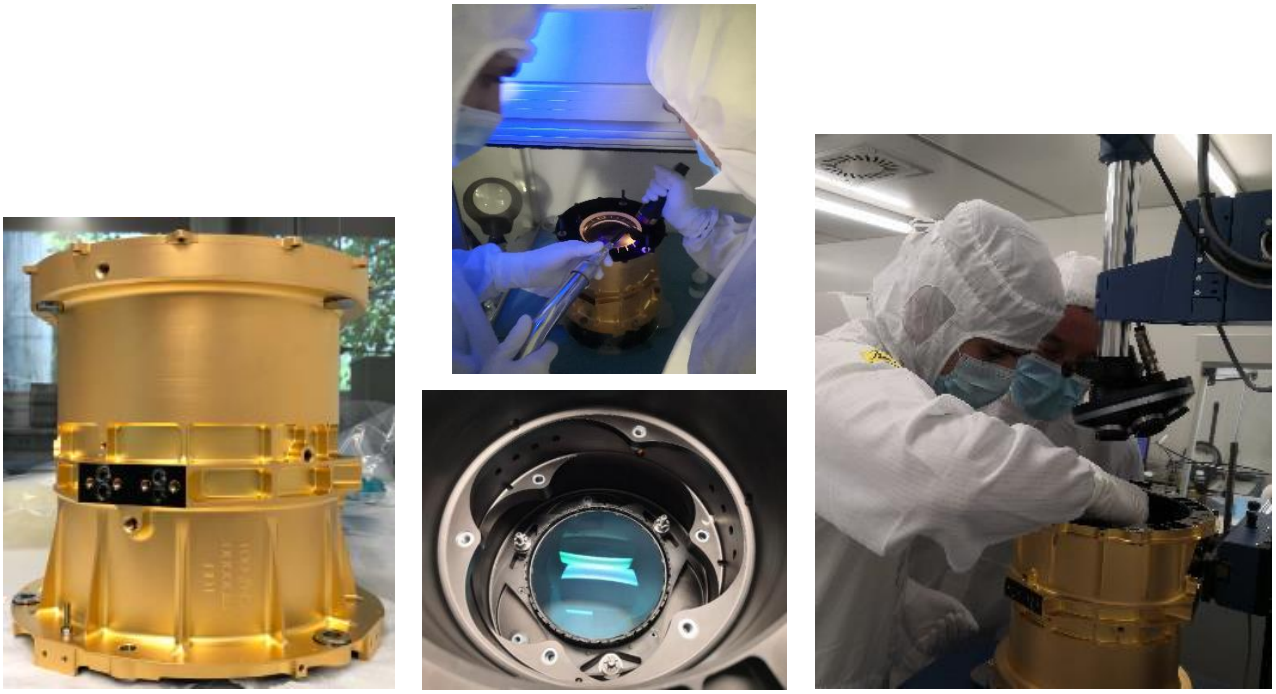
*TOU STM under metrology at Leonardo /HST*

Figure 3 - TOU STM integrated, tested and successfully qualified at University of Bern. STM OMGs assembled and qualified by Leonardo; Baffle Assembly designed, manufactured and tested by Thales Alenia Space, Italy and Leonardo. FPA dummy provided by INTA.

### 2.3 The EM model

The TOU EM is equivalent to a N-TOU FM but for the use of a not rad-hard version for the L6 glass (SCHOTT N-BK7 instead of BK7-G18), and the passband coating of the window that needs to be qualified before using it on the flight models. The TOU EM, instrumental to build the CAM EM, is used to validate the optical functionalities. It will be used to study the optical performance variations in isothermal conditions at ambient and operative temperatures and when a thermal gradient is applied. The model will use for the first time the complex GSE that was designed to test the TOU performances in operative conditions (low temperature in TV), after having assembled it at ambient temperature.

During the manufacturing of the EM AlBeMet tube, the black Nickel coating as well as the gold coating processes were further refined under the supervision of the team at University of Bern. The tube was then delivered to Leonardo in Italy, when, after a metrology run, was TV cycled and assembled with the OMGs by means of the optical centering Trioptic machine usend in “MultiLens® Alignment” mode. The integration and alignment procedure was first tested by using a tube mock-up made in Al, provided by University of Bern,  and one set of OMG BB. Under control of the optical centering Trioptic machine, the OMGs were reciprocally aligned on barrel, by nulling XY and setting Z. With proper shims selection after Zemax simulation, the TOU EM was aligned and focused well within the specifications.



*TOU EM tube at Univ. Of Bern* *TOU EM duriing integration at Leonardo*

**Figure 4 – TOU EM model, used to test the optical performance.**

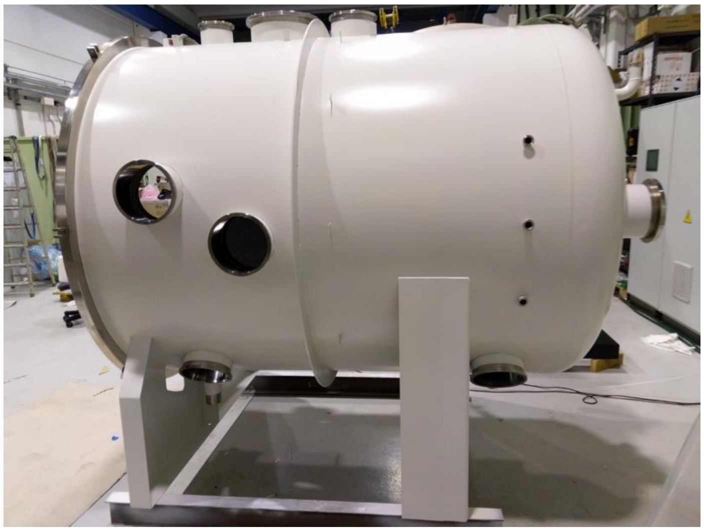
The tube TOU EM and each OMG were iteratively controlled and cleaned, if needed, under laminar flow bench ISO 5, then the TOU was positioned on the automatic centering machine. All alignment operations on TOU EM have been performed in ISO 6 (although the reference environment is ISO 7).The operation carried out up to date with EM allows to to state that the planned alignment and focusing procedure, hardware & jigs  (centering machine, BET, optics protections…) have been successfully verified. Some lessons have been learned,  debugging and improvement in knowledge/confidence using the centering equipment and  the special customized HW/SW. Also improvement areas have been identified (tooling and procedures) for the  FM serial production of TOUs

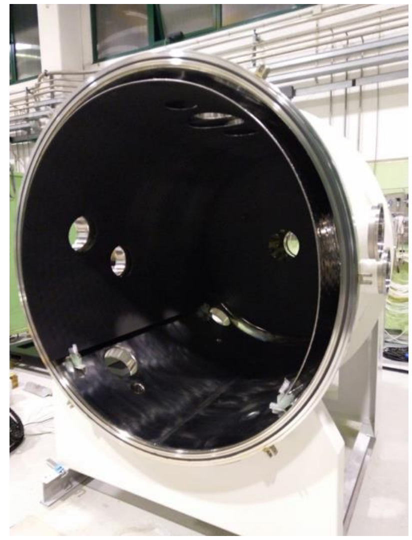
Next relevant phase is the EM test campaign, that will be conducted at ambient and operative temperatures. The main steps are:

- Alignment with the OGSE, followed by transmittance measurement at ambient temperature
- Cool down till operative temperature in isothermal conditions (spatial uniformity within 10°C), followed by performance measurements.
- Cool down till operative temperature with longitudinal gradient application (TBC value), followed by performance measurements
- Warm up at ambient temperature, then inspection,  test report, and TRB.

A last step will be the characterisation of the best focus positions at ambient and cold (cf. P. Royer et al. paper [11] at this SPIE). The TOU test campaign will be completed by mid April 2021.

Built for the TOU EM test campaign, but functional to the serial production of TOU, a PLATO dedicated area in Leonardo has been organized. It will host a PLATO dedicated Thermo Vacuum chamber that is going in operation during December 2020. The TOU will be moved inside the TV chamber by a gimbal, while the detector assembly, outside the chamber, is controlled with an exapode.





*New Vacuum Chamber «CRIOTEC CTV-3» dedicated to PLATO in Leonardo (Italy)*

*Gimbal for moving the TOU in the TV chamber (made for Leonardo by SYMETRIE in France)*

*Hexapode for moving the Detector Assembly (made for Leonardo by SYMETRIE in France)*

**Figure 5 – Some of the GSE dedicated to TOU in Leonardo.**

### 2.4 The TOU MTDs

26 thermal-structural dummies (MTDs) representative in terms of mass properties, stiffness and thermo-elastic behaviour of the whole camera are required for the integration on the satellite STM for the satellite structural thermal qualification. The MTDs do not use lenses. The MTD tubes have been manufactured under responsibility of University of Bern, who provided also to their assembly with the MTD Baffle Assemblies provided by Thales Alenia Space-Italy under coordination of Leonardo and INAF. The TOU MTDs will be used to produce the CAM MTDs.


*26 MTDs assembled at University of Bern*

*6 MTDs in a transport container*

*4 transport containers ready to leave Bern*

Figure 6 – 26 TOU MTDs. These will be integrated with other Camera subsystems to build the CAM MTDS, that will be used on the satellite STM for the thermo-structural qualification of the satellite.

## 3. TOWARD THE FLIGHT MODELS

With a PLATO launch planned for the end of 2026, the TOU FM production is next. We plan to deliver two P-FMs (former QMs) in the last quarter of 2021; these models will be used as spares. The remaining 26 FMs will be delivered in sequence from early 2022 to early 2024.

To match this schedule, the procurement of the LLI has already started. Glasses for all the lenses have already been secured by Leonardo for the 2 P-FMs and for 8 FMs, so that lens manufacturing is in progress, and a first set of lenses is expected for the end of March 2021. Contemporary, procurement of raw material for the TOU structure of an equivalent numbers of models has been done by University of Bern. 10x Raw AlBeMet blocks are available @ RIGO, and manufacturing has been released for structures of 2 P-FMs and 4 FMs. L1-L6 mounts are expected to be ready for coating in February 2021, while 48x L6 bipods have already been sent to Acktar for coating.

## 4. CONCLUSION

PLATO is an example of a space-based cooperative telescope with several built-in innovations. The TOU itself is built with a rather large Field of View making use of aspheric optics built on non conventional glasses optimized for long duration in space. The partial overlap and the addition of two fast units makes the instrument able to cover a huge amount of targets in a large domain of the temporal power spectrum with the aim of providing unique data for both asteroseismology and the discovery and accurate transit determination of planetary systems potentially around nearby and bright stars that could provide in future the seeds for further detailed exploration from the ground or from space. Both the aperture and the focal plane reaches equivalent surfaces of the order of one square meter, making the observatory among the one with the largest possible *etendue*.

This is being accomplished through a sort of small mass series production of optomechanical elements, their characterization, alignment and testing prior to launch and operations. The on-board processing and the large data handling required is another kind of challenge linked with wide field, high temporal cadence, survey, that is going to change the way data are being treated and disseminated in the astronomical world of the near future. We hope that this status report highlight the technical, organizational, logistic and industrial challenges (currently in spite of the difficulties because of the pandemic restrictions) behind the achievement of such a kind of activity.

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