

# EXACT: A Scintillation Detector-Equipped CubeSat for Timing Photon Arrival from Pulsars

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## Abstract

Experiment for **X**-ray **N**avigation, **C**haracterization and **T**iming (EXACT) is a 3U CubeSat mission whose primary goal is to accurately measure the time of arrival of hard X-ray (HXR) and soft  $\gamma$ -ray photons from pulsars to test and validate new techniques for clock synchronization (i.e. time-transfer) in Low Earth Orbit (LEO) in GPS/GNSS-denied conditions. The secondary mission of EXACT is to measure solar X-ray photon energies and arrival times to study electron acceleration in solar flares which are major drivers of space weather events. Analysis of the data gathered during EXACT's time in orbit will lead to a better understanding of how to precisely locate instruments without the use of GPS/GNSS and will contribute to our ability to understand and predict space weather events. EXACT is a UNP funded mission that is being designed and built as a collaboration between UMN, MSU, UCSC, and SwRI.

## Introduction

Global Navigation Satellite Systems (GNSS) is a term used to collectively describe satellite-based positioning and timing systems. The Global Positioning System (GPS), operated by the United States Department of Defense, is perhaps the most well-known and widely used GNSS. The accuracy of its position and timing solutions have revolutionized operations on Earth and in space alike. However, it is well documented that GPS has vulnerabilities which could be exploited to deny its use on orbit. As such, it is the practice of Positioning, Navigation, and Timing (PNT) system designers to design and field multi-sensor systems which are not reliant on a single sensor or system for operation. One way to do this is to utilize signals of opportunity (SOPs). SOPs are signals that were not conceived for PNT purposes but can be used opportunistically to generate a navigation or timing solution. EXACT's primary mission is to use X-ray emissions from pulsars as SOPs for clock synchronization (Figure 1).

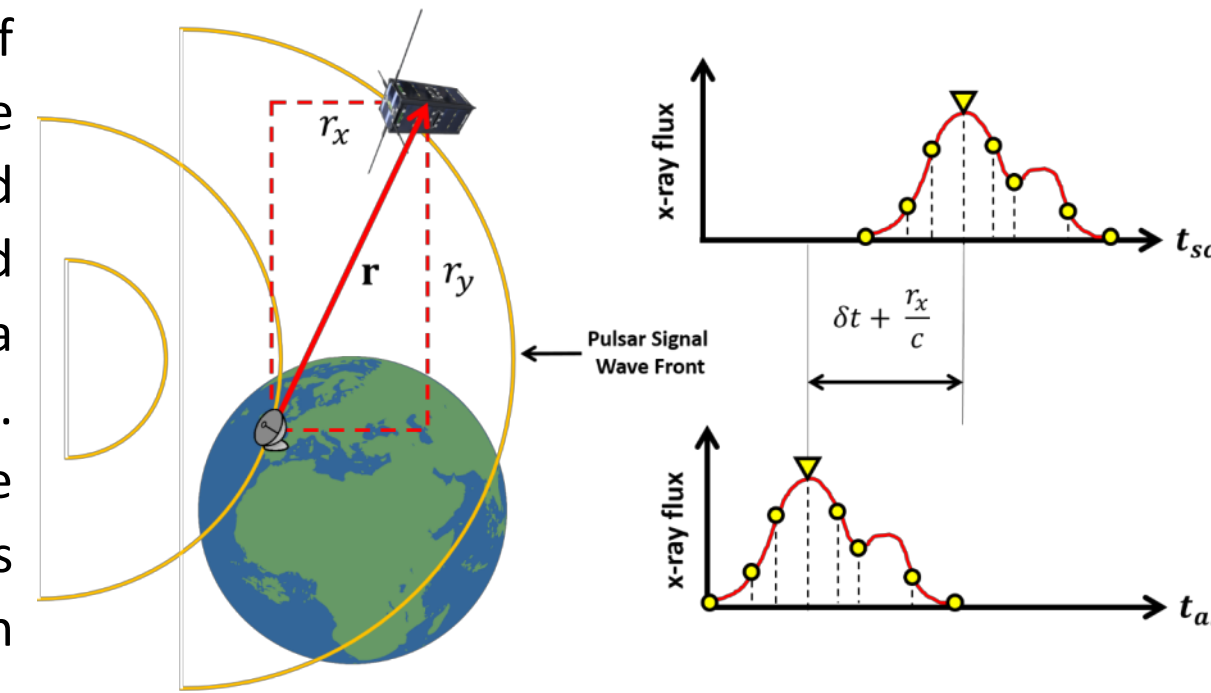


Figure 1: Using pulsar signal timing to calculate position

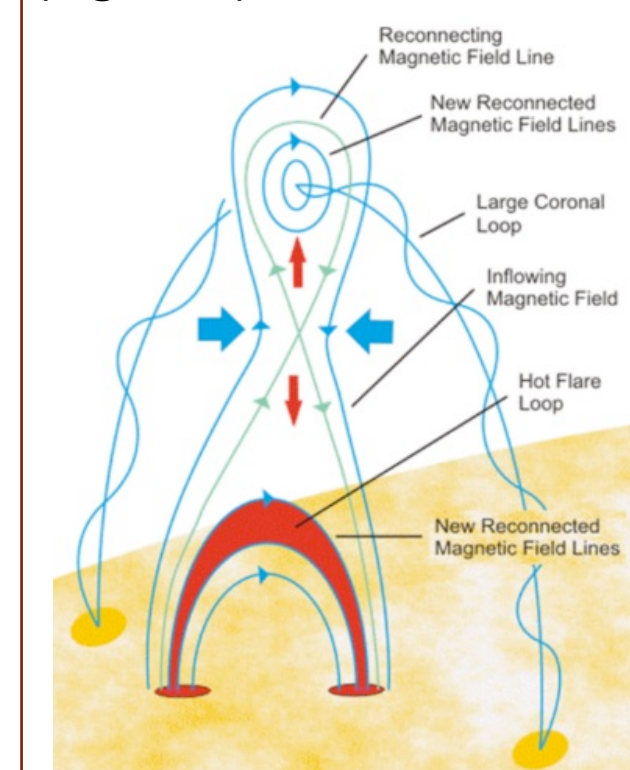


Figure 2: Diagram of a solar flare

The emphasis on precise timing for the primary mission of EXACT allows for the same instrument to study solar flares. Solar flares occur on the surface of the sun in regions with strong unstable magnetic fields (Figure 2). Coronal loops undergo a process called magnetic reconnection. As the magnetic flux tubes reconnect, electromagnetic radiation outbursts occur. This radiation or energy ejection results in an emission of X-rays caused by accelerated electrons colliding with ions. Coronal mass ejections impact the Earth and can cause solar storms, damaging or disrupting radio communications.

## Mission Requirements

Number	Min/Max	Requirement
MR-1	Min	EXACT shall measure the absolute time of arrival of photons to a 165 $\mu$ s accuracy.
	Max	EXACT shall measure the absolute time of arrival of photons to a 33 $\mu$ s accuracy.
MR-2	Min	EXACT shall produce a spectrum with a range of 5keV to 100keV with a resolution of 25% (as measured at 59keV) for 1 solar flare.
	Max	EXACT shall produce a spectrum with a range of 5keV to 100keV with a resolution of 15% (as measured at 59keV) for 100 solar flares
MR-3	Min	EXACT shall measure its position on orbit to a 1km accuracy using a "ground truth."

## Previous Work

The students that make up the University of Minnesota Small Satellite Team have previous experience with designing the SOCRATES CubeSat and the CITIES scintillator detector carried on SOCRATES. The design of the detector carried on EXACT is an expansion of CITIES, and much of the form of EXACT is based on that of SOCRATES. SOCRATES was deployed from the International Space Station on February 19<sup>th</sup>, 2020.

## Instrumentation

The instrument on EXACT that will detect X-ray emissions from pulsars and solar flares is a spectrometer comprised of four Cesium Bromide (CsBr) scintillation crystals, each with their own Silicon photomultiplier (SiPM) eMorpho board, and one all-in-one solid-state X-ray detector in the center of the detector face. Per the mission requirements, this instrument will detect X-ray photons with energies between 5-100 keV with a resolution of 25% or better and a timing accuracy of 165 microseconds or less. The use of scintillation crystals is ideal to meet those requirements because of the simplicity and high timing precision of scintillation in this energy range. The form of the crystals maximizes the detection area of the spectrometer while minimizing its size and power footprints (~0.5U and <5 watts). Windowing material of varying thickness will cover the crystals to prevent high count rate events from overwhelming the system. The inclusion of a solid-state X-ray detector allows for more precise observations of soft X-ray emissions, or X-ray photons with energies around 5-10 keV.

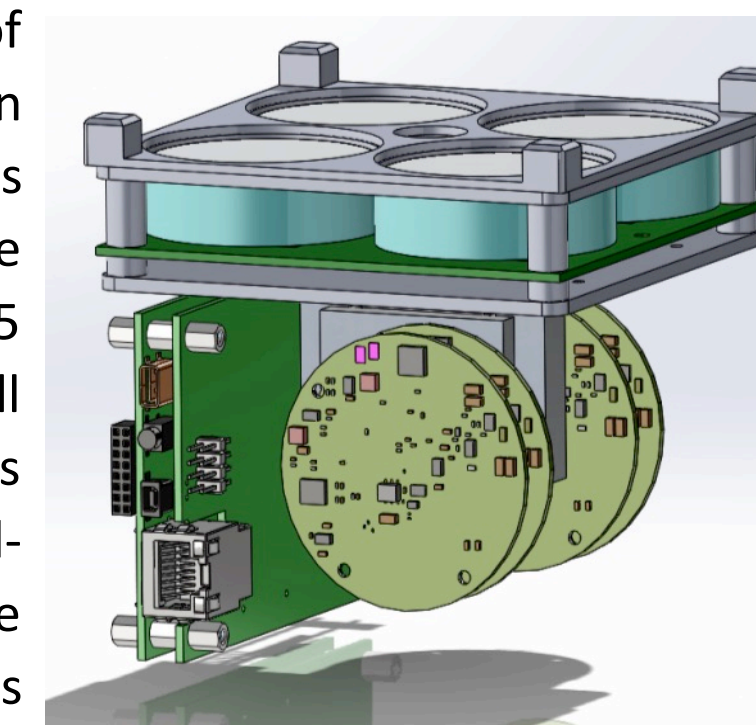


Figure 3: 3D model of the scintillator detector on EXACT

## CubeSat Design

The form of the EXACT CubeSat (Figure 4) is very similar to that of its predecessor, SOCRATES. EXACT, like SOCRATES, will be a 3U CubeSat, where 1U is the volume of a 10 cm cube. EXACT will be machined out of aluminum that is electrically grounded to minimize electrical noise throughout the system. One notable design change on EXACT is that the exterior solar panels will be hinged just below the detector housing rather than at the base of the CubeSat. Other components that make up EXACT are a battery that will power the system using the solar panels, several magnetorquers that allow the attitude of the CubeSat to be controlled, a radio to send data back to towers on Earth, and a microcontroller flight computer programmed to run the system. All these components are stacked inside the CubeSat in a way that allows for thermal control and stability in the various environments EXACT will experience.

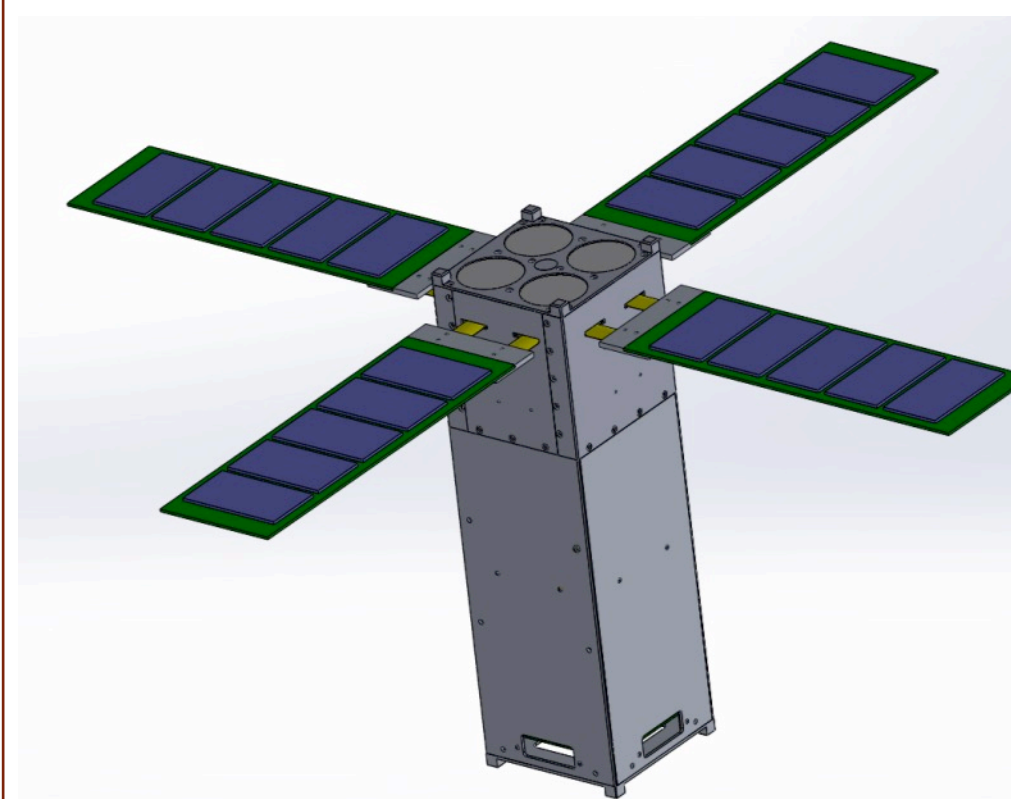


Figure 4: 3D model of the EXACT CubeSat

## Conclusions and Future Work

Below is a table of estimated dates for milestones for EXACT. Due to restrictions on lab work and production as a result of the COVID-19 pandemic, it is likely that these dates will be pushed back. After launch, EXACT will be in a Low Earth Orbit (LEO) for around a year before de-orbiting and burning up in the atmosphere. In that time, the data collected from EXACT will further University of Minnesota research on navigation and timing systems in GPS/GNSS-denied conditions and the mechanisms of solar flares and the space weather events they create on Earth.

Date	Event	Details
September 2020	Flat Sat	A goal the UMN student team has set for themselves is to have a flat sat, or a connection of all components of the CubeSat aside from the structure, done by the end of Summer 2020. This will ensure that all component interfaces match up.
January 2021	CDR	The Critical Design Review (CDR) will finalize the design of all components and systems within EXACT.
May 2021	FSR	The Flight Selection Review (FSR) will evaluate the design and model of EXACT and allow the mission to proceed to orbit if it is selected from several other CubeSat missions.
June 2022	Launch	If EXACT is selected during the FSR, it will likely be launched in the second half of 2022. This date is subject to change.

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## References

EXACT Requirements Verification – Kyle Houser, Jenna Burgett  
The Science of EXACT – Trevor Knuth  
Solar Flare Diagram – Gordon Holman and NASA  
EXACT 3D Model – Adrian Neoh

## UMN Student Sub-System Leads

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