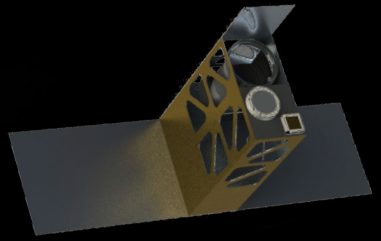
Tokyo Institute of Technology



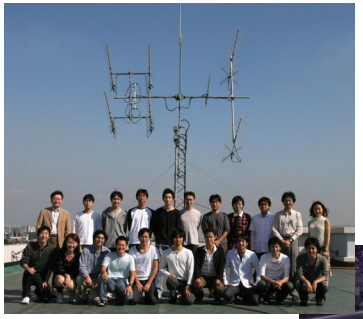
6U CubeSat for ultraviolet time-domain astronomy

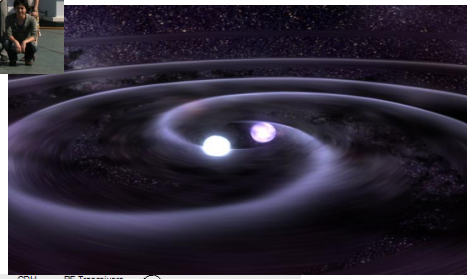
Yoichi YATSU Tokyo Tech

on behalf of Tokyo Tech Small Sat team

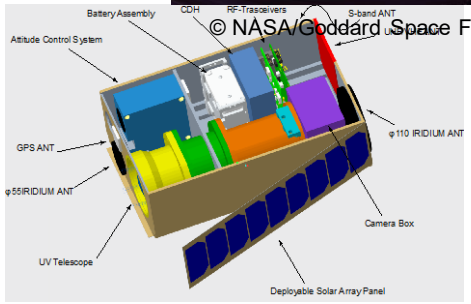
Outline

- Self introduction
- Scientific Motivation
- Mission design
- System design
- Status report

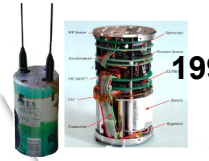




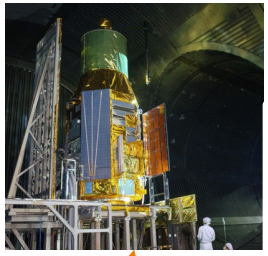
© NASA/Goddard Space Flight Center



Tokyo Tech smallsat projects



1999~ CAN Sats



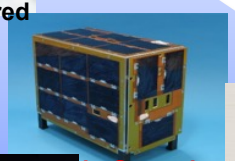
2016 ASTRO-H (JAXA's flagship X-ray satellite)

2003~ CUTE-I

Still alive

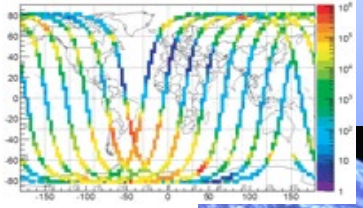
Re-entered

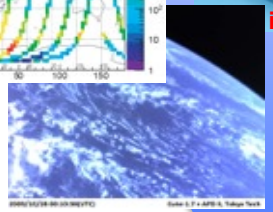
2006 Cute-1.7＋APD



2008~ Cute-1.7+APD II

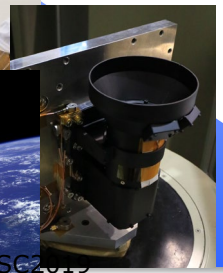
in Operation





2014~2015
TSUBAME

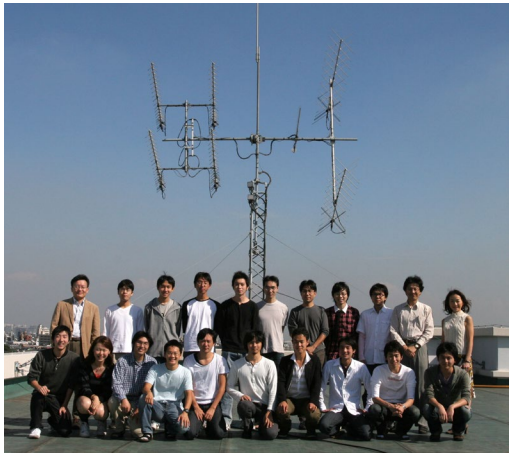
2019~
DLAS/RAPIS-1



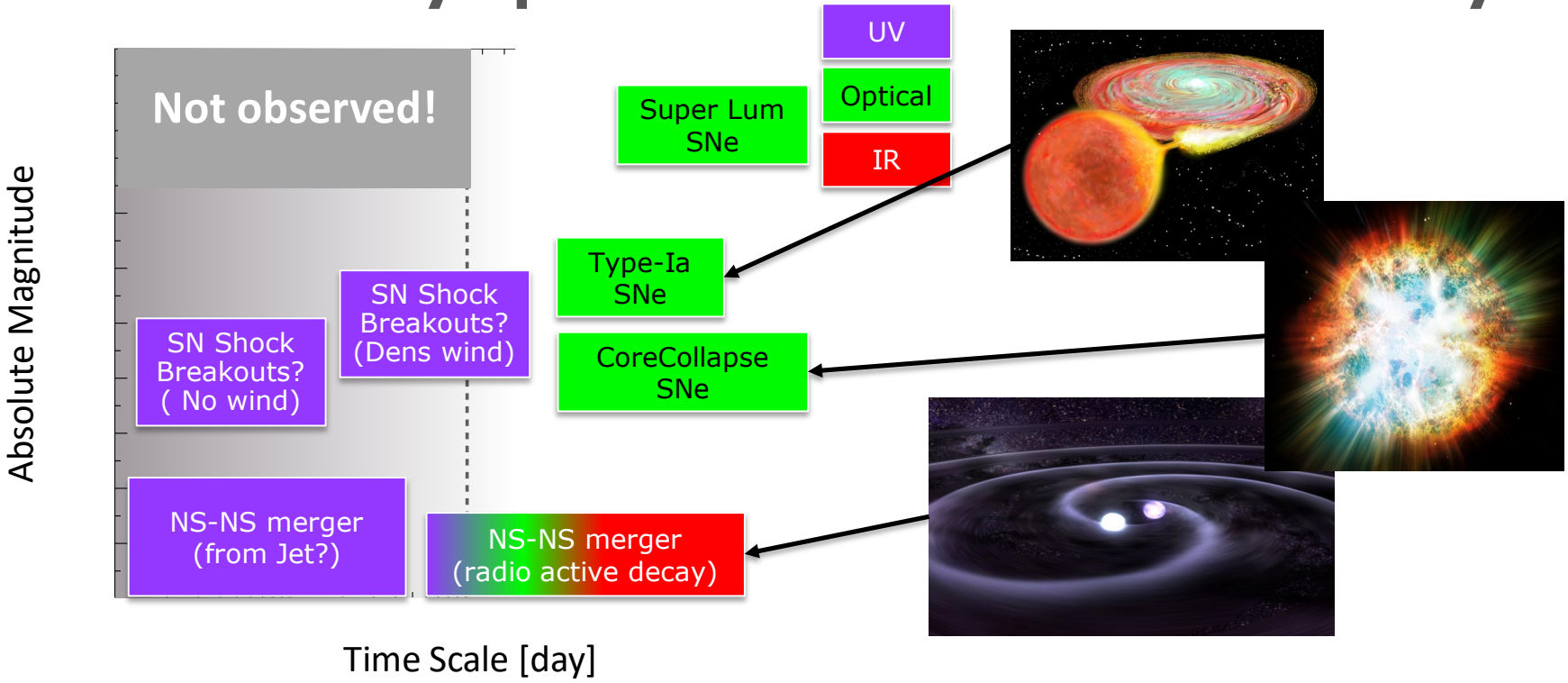
~15 graduate students

3 facalty staffs from

Dept of Engineering and Dept of Physics



New discovery space: Time-domain astronomy

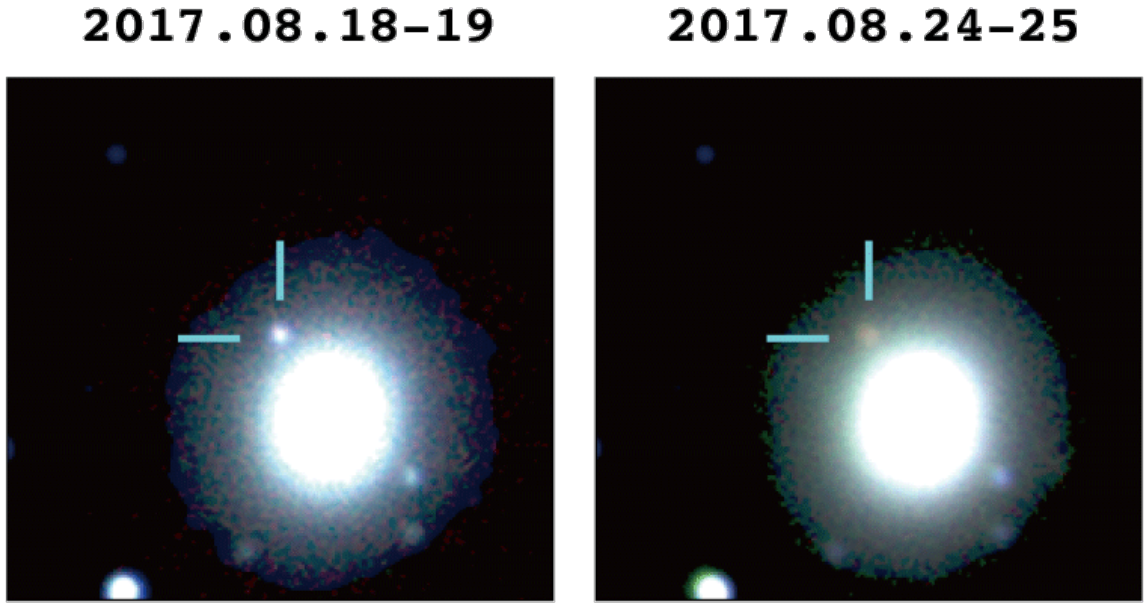


- A transient must be hotter in immediate after the explosion.
- UV is therefore ideal to investigate early phase behavior.

Main Target: Gravitational wavce sources

- The afterglow was BLUE in the very early phase!

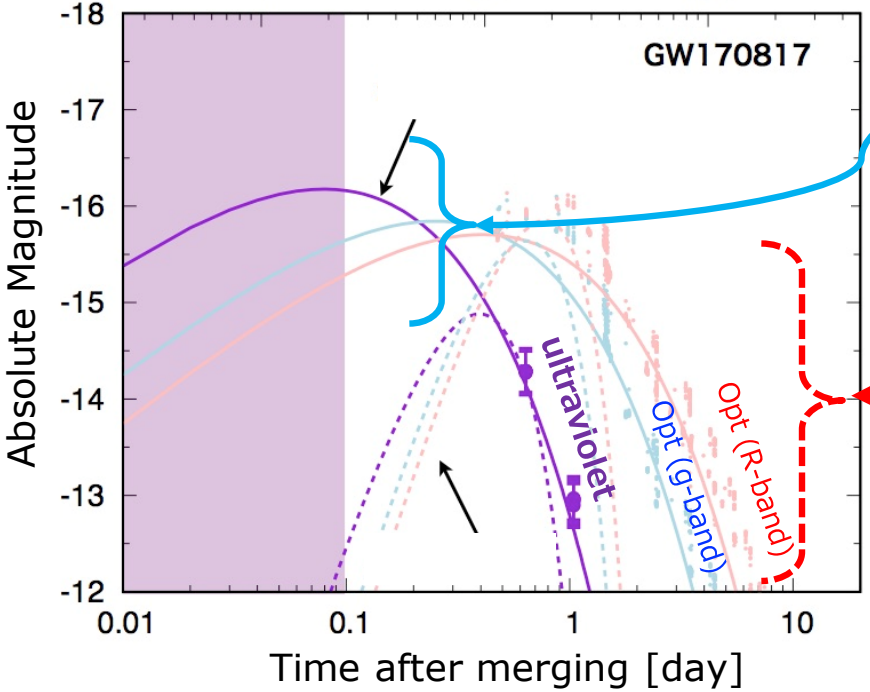
GW170817

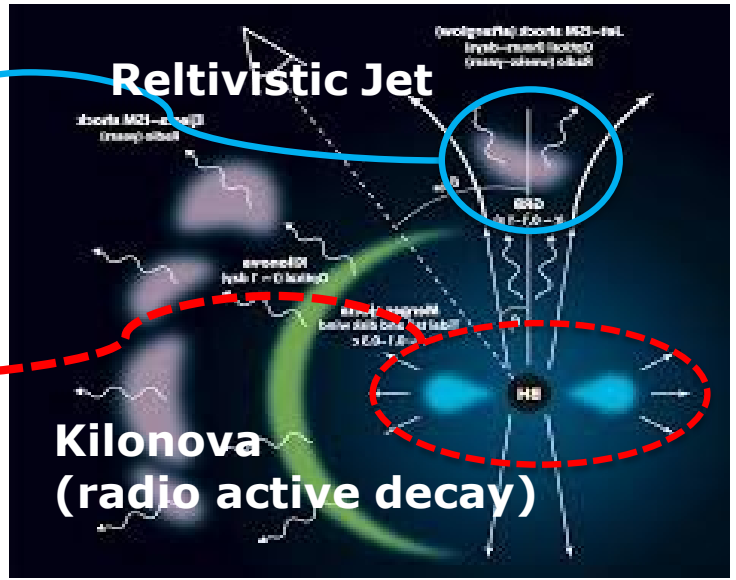


Utsumi+ 2017

We still do NOT know the mechanism/origin of this blue emission !!

Kilonova or relativistic Jet

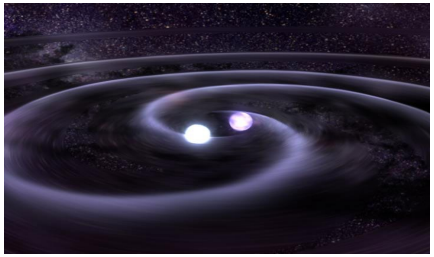




Metzger&Berger12

- Early phase observation within an hour after the merge
- In early phase, UV band is dominant

Possible Targets and Expected Event Rate



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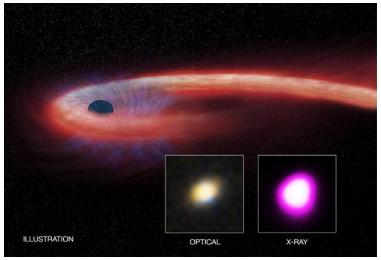
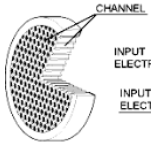


© CXC/M. Weiss

Target	Position uncertainty	Duration	Magnitude
GWs (NS-NS)	**~100 deg^2**	**0.5**~10 hr?	**20 mag@100 Mpc**
Shock Breakouts	Unpredictable	**~0.5 hr?**	**~3 yr^{-1} 100 deg^{-2}**
Tidal Disruption Events	Unpredictable	~a few weeks	**~2 yr^{-1} 100 deg^{-2}**

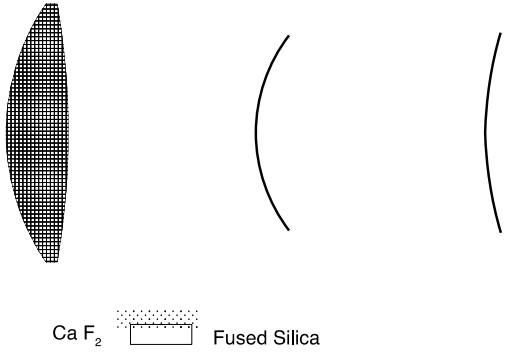
- FoV > 100 deg2
- Limiting mag > 20 mag
- Detection alert => within 1 hour

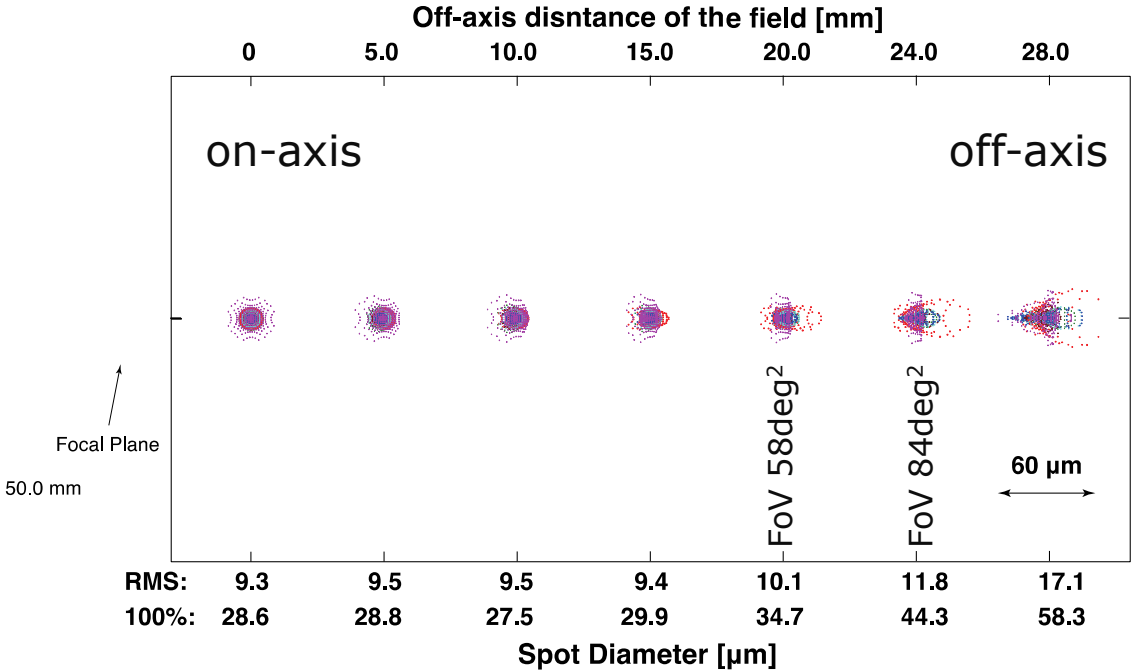
How to overcome the size limit?

BUS	Telescope	throughput	Detector	FoV	Cost
 GALEX（NASA）	D=50cm	T~3%	 MCP QE~10%	 1deg²	$100M

- Utilizing new technologies (JPL's delta-doping detector/AR coarting)
- [Sensitivity]×[FoV] will be almost the same with GALEX

Ray diagram & Spot diagram

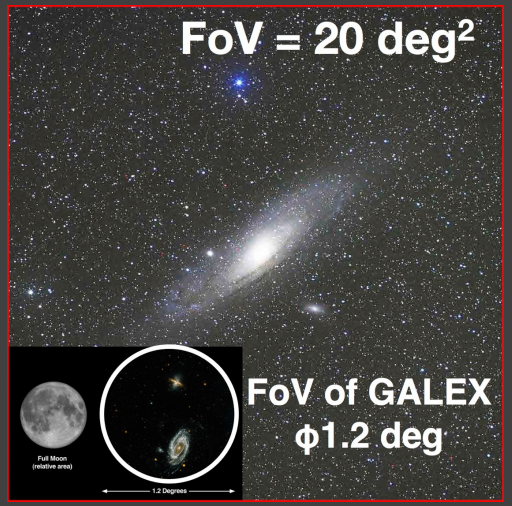




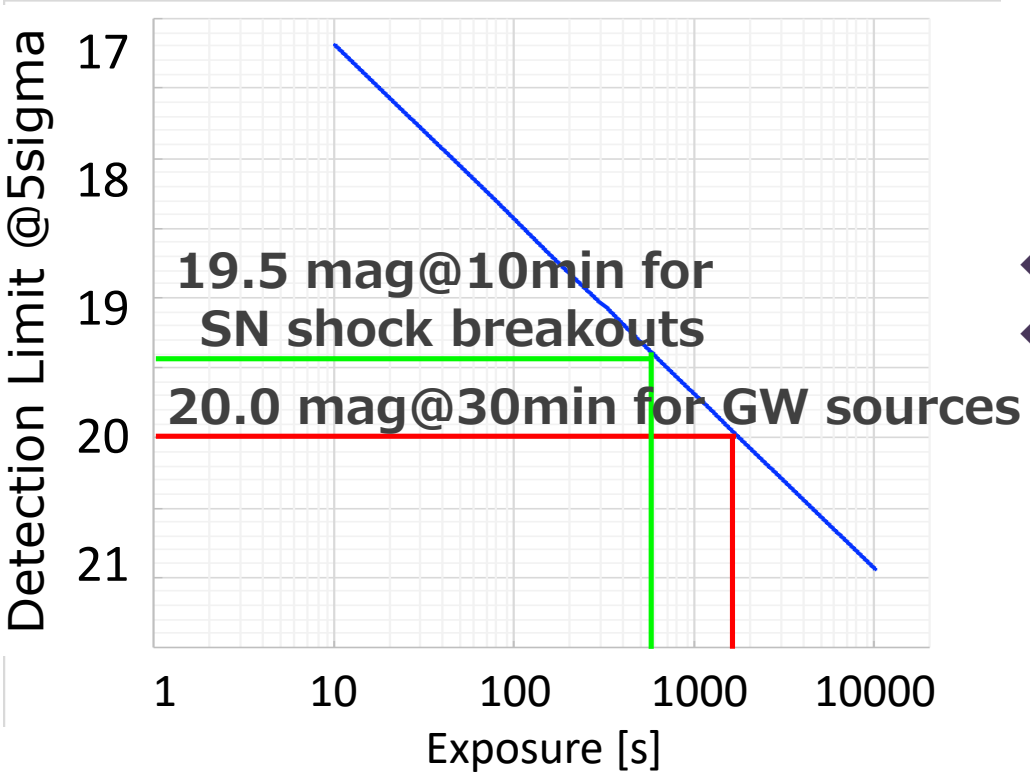
- The image circle ≥ ø48mm, FoV ≥ 84 deg^2
- But the focal length is quite sensitive ~ a few tens of um/°C.

106 deg² (JPL CMOS)

84 deg² (PSF < 1 pixel)



Expected Performance



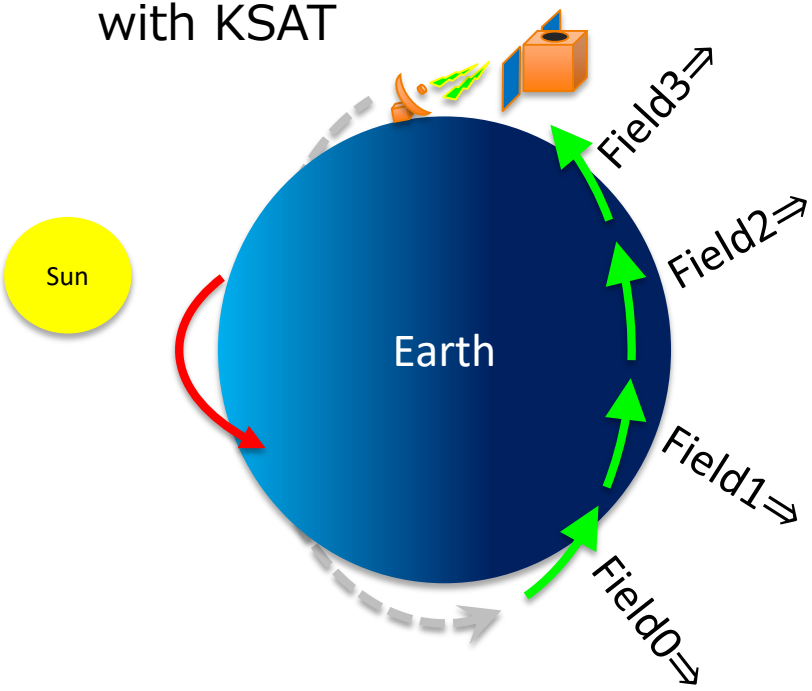
- We need 1800 s exposure
- Detection limit of 20mag@5σ

Data rate

- Raw image data:
  - 4k x 4x 16bit x 1/3(zipped) = 10.7 MByte/image
  - Number of Images
    - 3 image x 4 field x 15 orbit = 180 images/day
    - (180 s combined image x 3 + 1 min MNV for 1 field)
  - **Image data: 180 x 10.7 MByte ~ 1.8 GByte/day**
- Photometric data:
  - Stellar density <20 mag ~ 183 star/deg^2
  - Stellar number (100deg^2) ~20000 objects/image
  - [20000 stars] x [180 images] x 180s/60s = 1.08x10^7 records
  - Bit depth
    - Flux 16bit, Flux error 16 bit
    - Coordinate（R.A. 24bit, Dec 24bit, X 16 bit, Y 16 bit）
  - Frame Header
    - Timestamp（32bit/frame）
    - Attitutde （Quatanion 16bitx4 ）bit
  - **Photometric data = 152.2 MByte/day**
- **Data Rate ~ 2GByte /day**

Observation Strategy

TLM downlink
with KSAT



Charging
in Dayside

Observing
in Nightside

FoV : 100 deg^2

Survey area : 100 deg^2 x4

Limitting mag :

19.5 mag /orbit

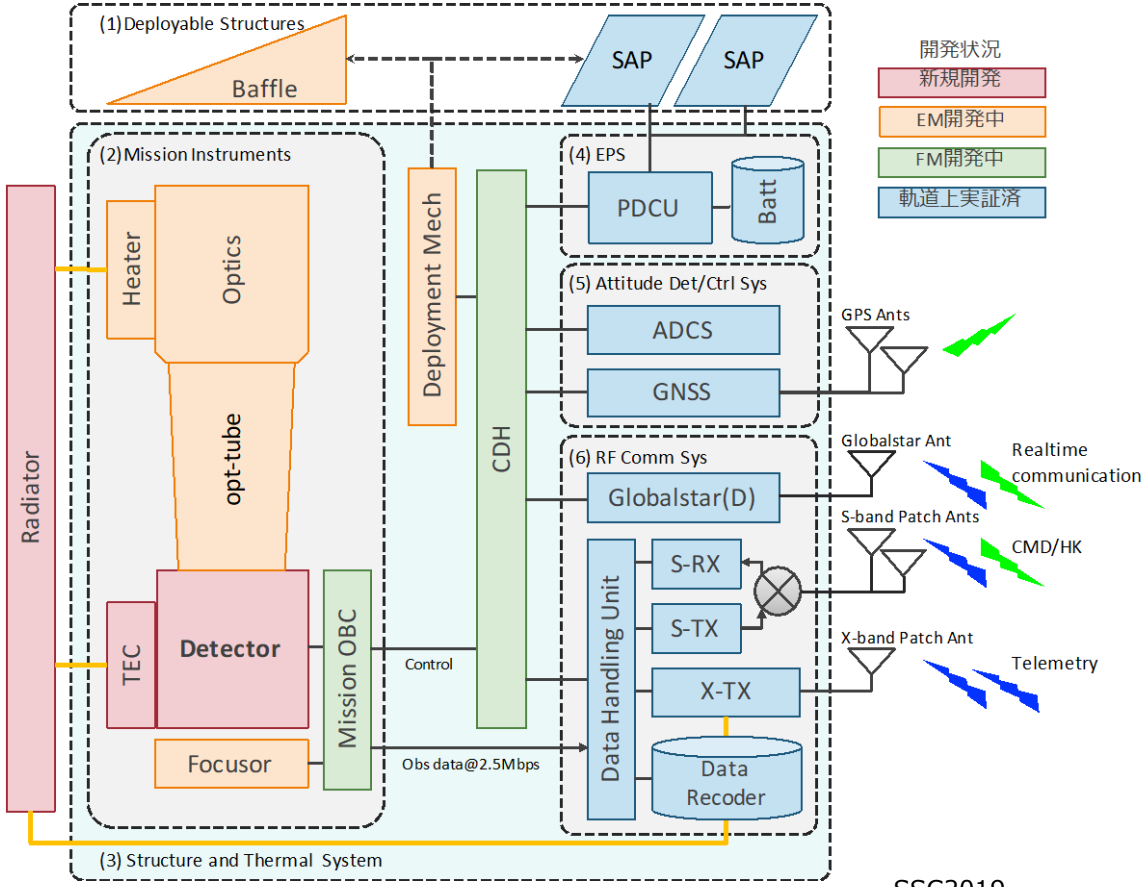
20.5 mag /day

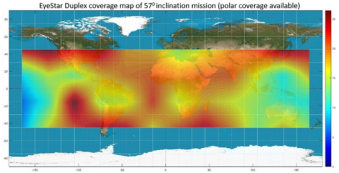
We will observe the same field for 3 weeks

⇒ 6800 deg^2 /yr

- >20 core-collapese SNe
- 0.4~16 GW/yr

System block Diagram (Shopping list)

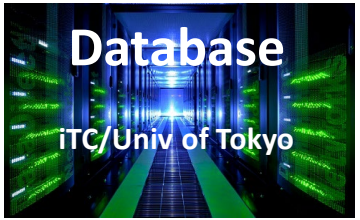




Globalstar (Alert)

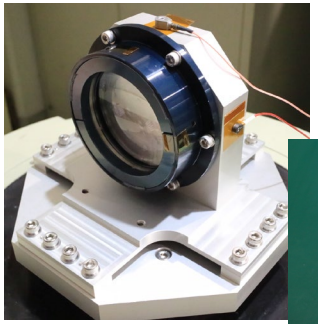
KSAT(TLM)

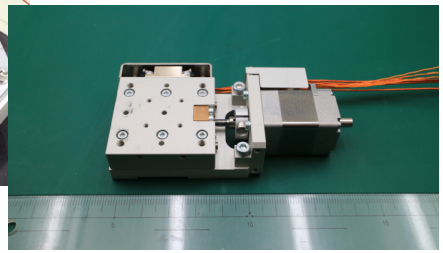
S-band station (CMD/HK)



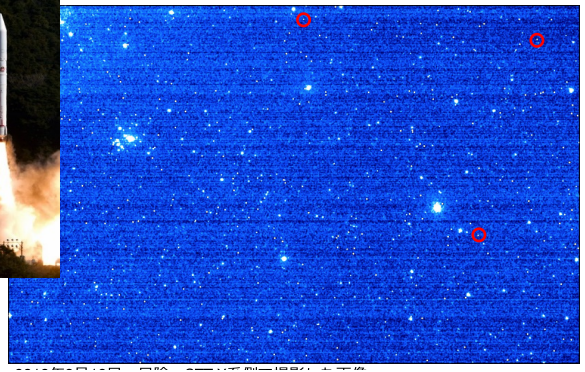
Development status

- Mission components
  - Optical tube passed the V-test
  - Focusing mechanism





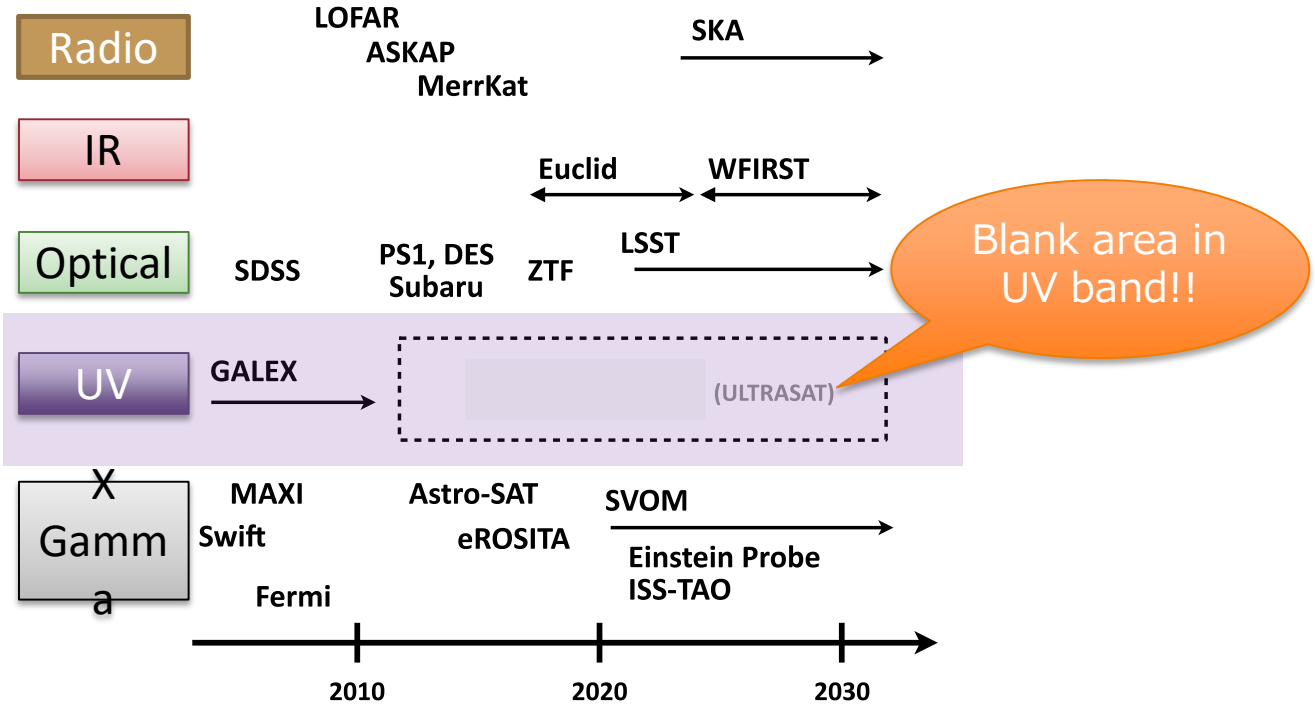
- OBC・Flight Software
  - Demonstration of Astrometry software
  - on RAPIS-1/DLAS
- Bus system
  - I will enjoy shopping this week.



Summary

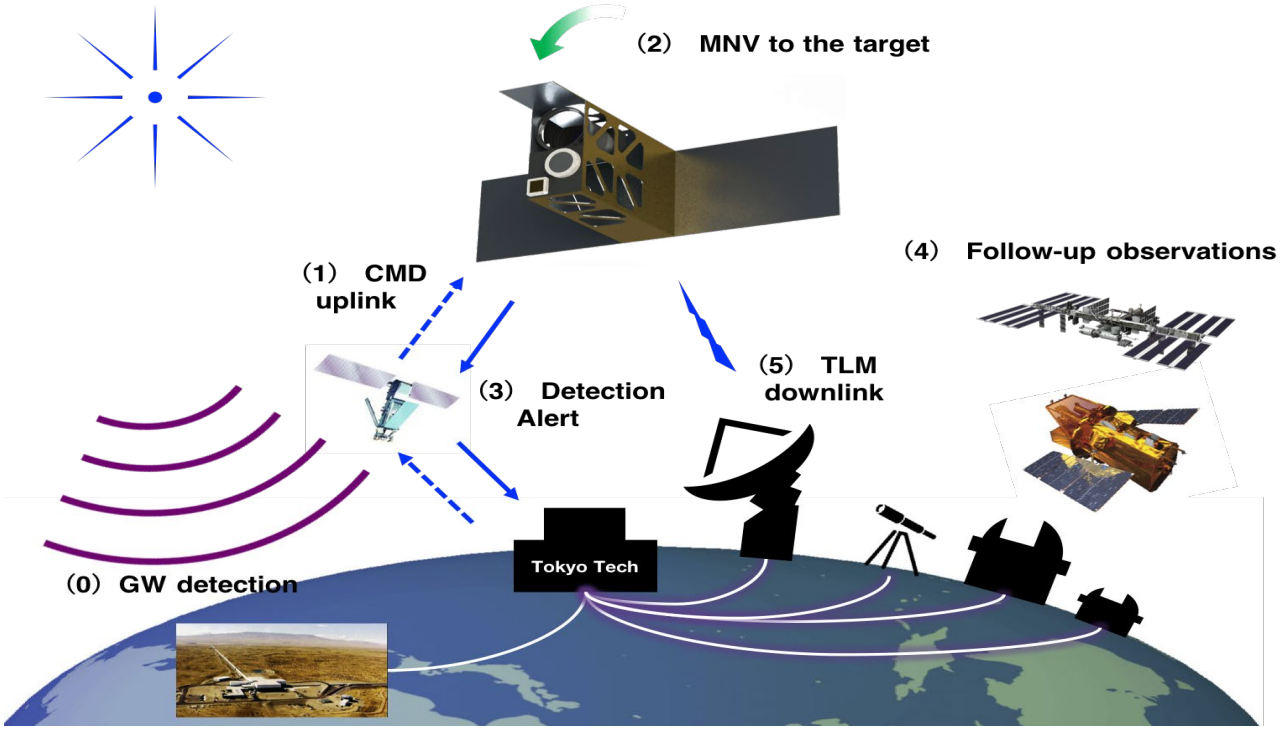
- We proposed a wide-field UV survey satellite for Time-domain astronomy.
- FoV ~ 100 deg2, Sensitivity ~ 20 mag(AB)
- We finished conceptual design and moved to BBM phase.
- This satellite will be launched around 2023.

Wide-field Surveys for Time-domain



- A Wide-field telescope is required in UV band
- That should be launched in early 2020's

Mission Sequence



Detection Alert must be transferred within 30 min after the detection

Mission Requirements

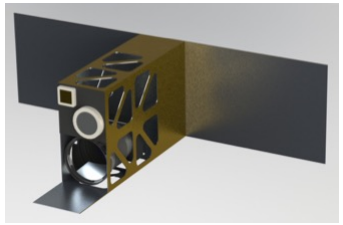
Parameter	Value	Target
Wavelength	near UV (< 300 nm)	SNe, GWs
FoV	100 deg^2	GWs
Survey Area	400 deg^2	SNe
Sensitivity (ABmag)	19 mag/orbit 20 mag/hr	SNe GWs
Survey Cadence	< 1 hr	SNe
Data link frequency	within 1 hr after observation	SNe, GWs

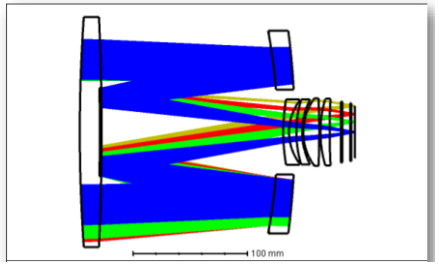
S.R. Kulkarni@Caltech (Science advisor) said

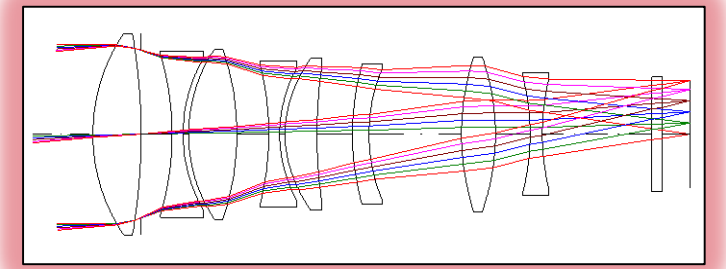
”All of tha raw data should be transferrred if you do not want to launch a useless satellite like a toy"

Optical design

- Cassegrain vs Refractor (assuming the same diameters)



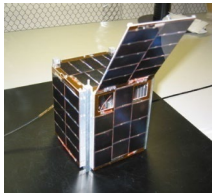




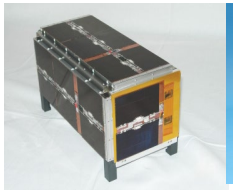
Target	Cassegrain	Refractor
Tube Length	**Short**	Long
Focal length	**Long**	**Short (= Wide FoV)**
Throughput Ratio	~50 %	**~90%**
Structure	Complicated	**Simple**
Cost	High	**Low**
Limiting magnitude	**Shallower**	**Deeper**

Refractor seems better for Cubesat and the sensitivity is also sfficitnt!!

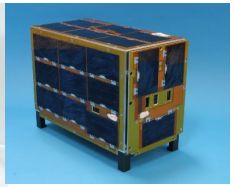
Which platform should be use??



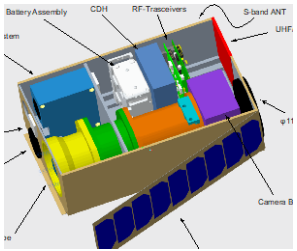
-I

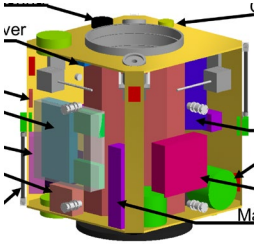


'05 Cute-1.7



'08 Cute-1.7 II





'14 TSUBAME

Type	Cubesat			50 kg class
Size	1 U	2~3 U	6 U	Custom
Cost	**$ 0.1M**	**$0.2 M**	**0.5 M**	2M~5M
Dev.Time	**2 yr**	**3 yr**	**3 yr**	5 yr
Launc Opp.	**Frequent**	**Frequent**	**Frequent**	Not Frequent
Difficulty	**difficult**	**difficult**	**may be difficult**	kind of hell
Telesope	Too small for	Φ50 mm	**Φ80 mm**	**Φ200 mm**
Sensitivity	-	15 mag	**20 mag**	**21.5 mag**

- We chose to go to space with 6U cubesat for the early realization.

開発スケジュール

革新1号打ち上げ　革新2号打ち上げ?　ひばり フライト?

月	2019 11	12	1	2	3	2020 4	5	6	7	8	9	10	11	12	1	2	3	2021 4	5	6	7	8	9	10	11	12	1	2	3	2022 4	5	6	7	8	9	10	11	12	1	2	3	2023 4	5	6	7	8	9	10	11	12	1	2	3
システム イベント										△PDR								△CDR												△Shipping								△Launch																
	Phase-B											Phase-C						Phase D																				Flight OP																
	基本設計											詳細設計						FM製造						地上試験・デバッグ														初期運用						ミッション運用											
EPS						△EM Btt発注,納品					△FM SAP発注							△FM発注	△納品																																								
CDH	回路設計・要素試作										△pFM回路設計							△FM製造																																								
Com						△FM発注	△納品																																																	
STR	EM熱・構造設計										△EM製造				△EM試験			△FM製造																																						
ADCS						△エミュレータ発注					シミュレーション							△FM発注	△納品																																							
Software	△概念設計										CMD/HK処理系					姿勢系		運用シーケンス																																									
CMOS@JPL	△CMOS試作					△CMOS完成																																																	
DAQ	CMOS・DAQ予備設計														FM設計・製造																																							
光学系		FM硝材製造					FM製造								地上性能評価			FM単体試験		△引き渡し																																			
熱・構造系	熱設計・温度制御装置設計							FM製造																																														

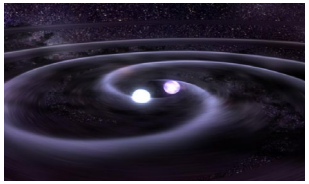
- 実機開発は2021年内に完了
- 以降ソフトウェア・地上処理系開発に専念

開発コスト見積もり

Sub System	Component	Price(kyen)	Number	Sub Total	EM納品状況	Status
EPS	EPS/BMS	2,000	1	2,000	有	既成品
	太陽電池セル	40	100	4,000	一部有	既成品・革新2号で実証
Comm	S-Rx	1,500	1	1,500	有	ほどよしで実証済
	S-Tx	1,800	1	1,800	有	ほどよしで実証済
	X-Tx	4,000	1	4,000	未	ほどよしで実証済
	Globalstar(Duplex)	1,200	1	1,200	買わない	既成品・革新2号で実証
CDH	DHU	800	1	800	有	既成品・革新2号で実証
	DRU	1,500	1	1,500	有	既成品・革新2号で実証
	OBC Board	1,000	1	1,000	有	革新2号で実証
ADCS	XACT	20,000	1	20,000	買わない	ASTERIAで実証済み
	XACT Simulator	1,000	1	1,000	購入予定	ASTERIAで実証済み
	GNSS	50	1	50	有	既成品・革新1号で実証済み
STR	6U bus + 熱計装	10,000	1	10,000	製造予定	機械環境試験含む
Mission	Optics	10,000	1	10,000	有	若手Aにて EMまで製造
	Detector/Driver	20,000	1	20,000	有	若手Aにて BBMまで製造
	TEC System	10,000	1	10,000	製造予定	若手Aにて BBMまで製造
	Focusor	1,000	1	1,000	有	若手Aにて EMまで製造
	Mission OBC	1,000	1	1,000	有	革新2号で実証
Comm cost	KSAT	24	24	576	-	2年運用を見込む
	KSAT	9	4,380	**39,420**	-	1日6pass 2.25GByte/day
	Globalstar(Duplex)	360	24	8,640	-	1回700Byte 144秒に1回送受信
	S-band uplink/down	3,000	2	6,000	-	メンテナンス等コスト計上
Data Storage	Storage/DataBase	400	2	800	-	東大・会津大と協力
Operation	Automation Software	8,000	1	8,000	-	速報系, TLM系, 処理パイプライン
合計				154,286		29.6

民間運用局利用（2年）+ 安全マージン30%込で2億円以下
GALEXの1/100

- Scientific Motivation
- Mission design
- System design
- Summary



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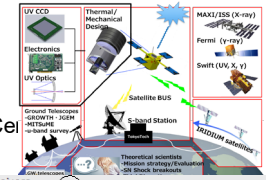
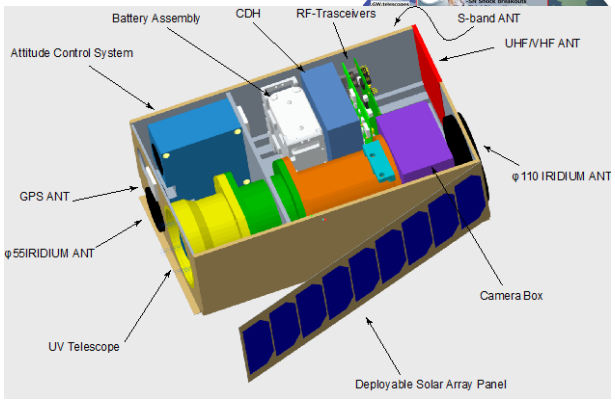
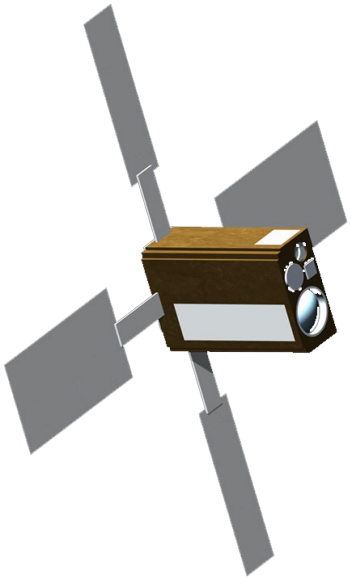
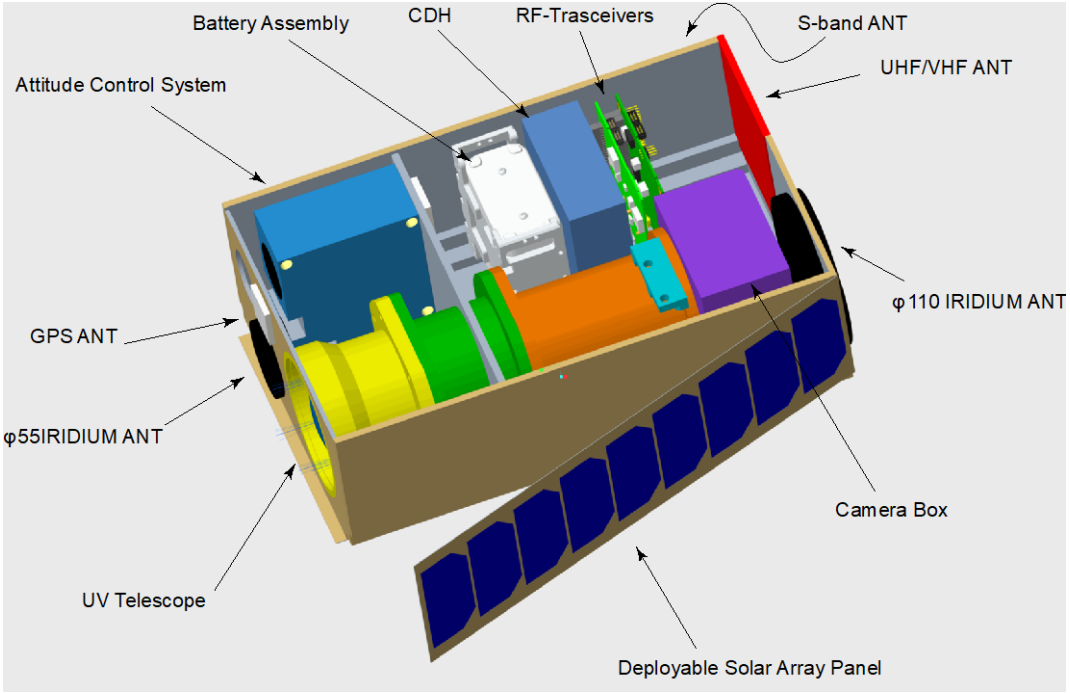




Structure





Cooling system for the detector must be considered.

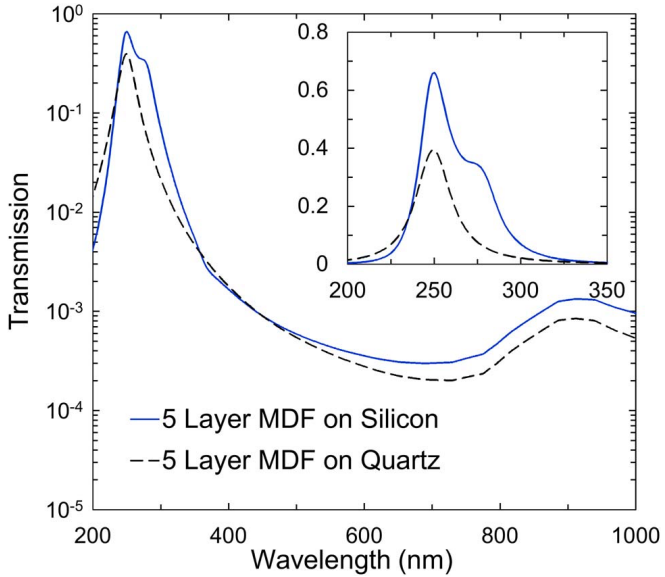
Summary

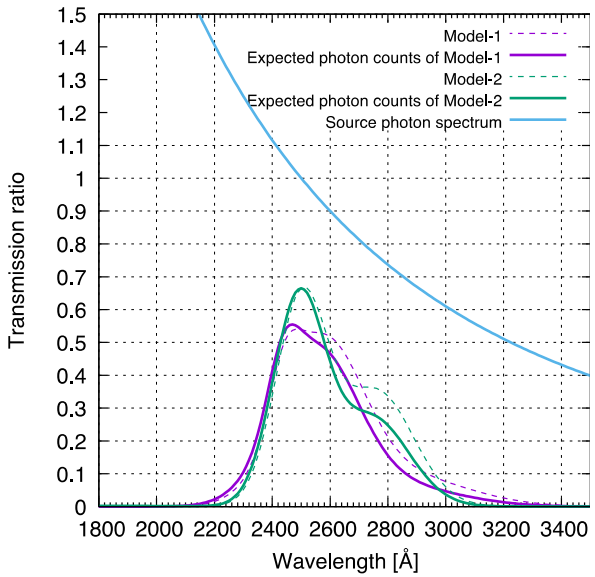
- A 6U cubesat for wide-field UV survey is proposed.
- Possible targets are
  - GW counterparts
  - SN Shock breakouts, Tidal disruption Events, Type-Ia SNe, Stellar flares etc
- Goal
  - covering LIGO's observable range(NS-NS merger)
  - ~ 3 shock breakouts/yr
  - ~ 2 TDE/yr
- Status
  - Conceptual Design, optical system design…almost Done
  - Launch will be 2021~2022
  - Demonstration of Attitude Sensors (will be launched in 2018)

Comments & Suggestions are welcom.

We can still modify the system design at this moment

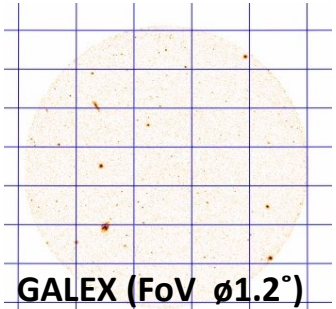
spectral photon density



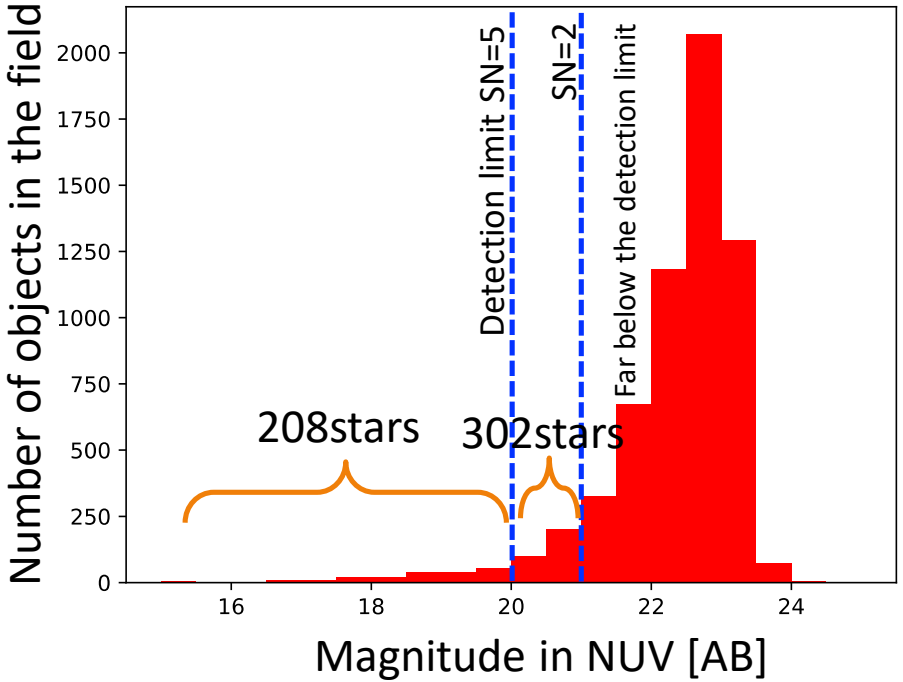


Centroid λ	2500 Å
Reference λ	2288 Å
	2389 Å
	2444 Å
	2507 Å
	2606 Å
	2765 Å
Diameter	80 mm
focal length	≥ 267 mm
Tube length	< 300 mm

Stellar surface density in NUV



Mag_{AB}	Number
15~20	**208**
20~21	**302**
21~22	998
22~23	3256
23~24	1374
NA	524
Total	6662



Stellar Surface density: 451個 deg^{-2} @ direction of Virgo cluster

Allowed congestion facotr: 3000 star/Mpixel

For the pixel sizse of 12 um => Focal length ≥ 267 mm

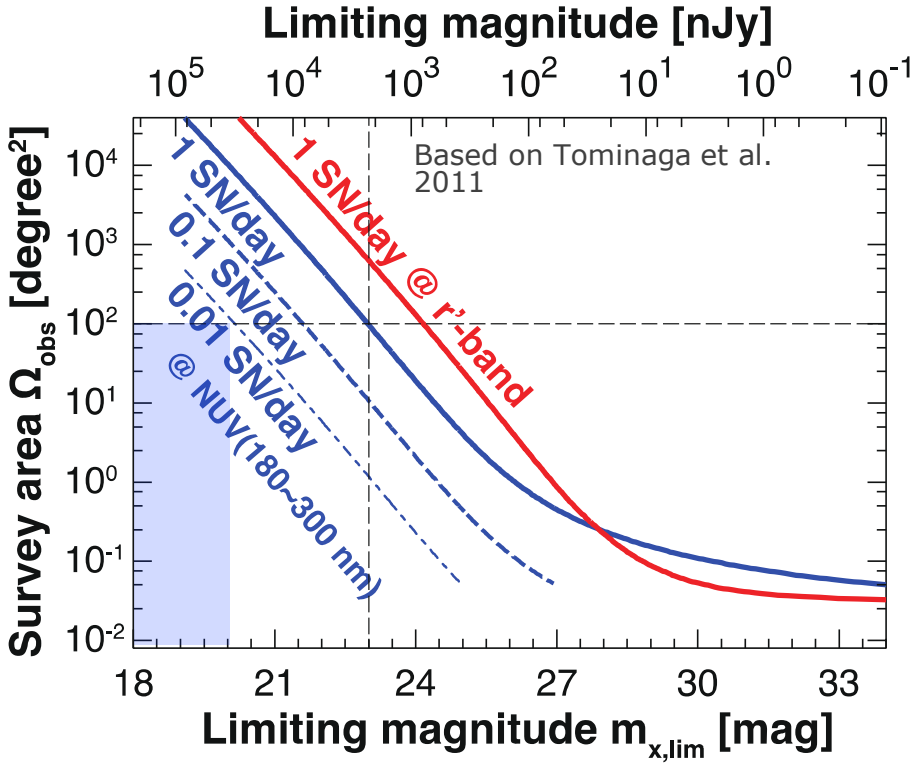
Summary: UV emission from NS mergers

by M. Tanaka

Timescale

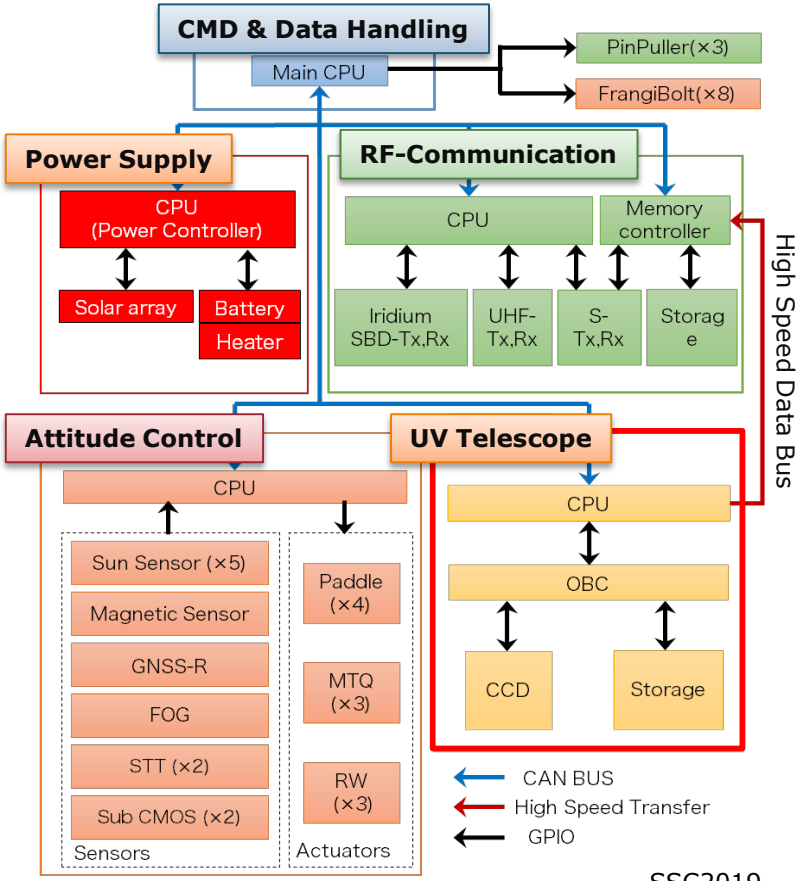
bari: 22.5 mag -100 deg^2 in 1 hr $\Rightarrow M \sim 0.03\, M_\odot$

Event rate of Shock Breakouts



more than 3 events/year

System Block Diagram



- System design is based on the experiences in TSUBAME project

- Controlled by CDH
- 2 kind of Data BUS
- Redundant design