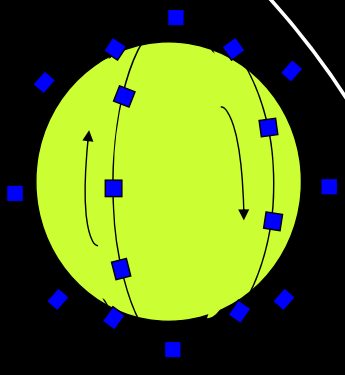
Introduction to PreMIC8 Workshop

- Constellation and Formation Flying Mission Design

Why Constellation is Required ?

LEO (500-800km alt.)
Almost all remote sensing sat.
- High spatial resolution 0.3m – 30m
- Time resolution is several - 40 days
- Several hundreds sats required for less than 1 hour time resolution



Constellation of many LEO satellites

GEO (36000km alt.)
Himawari and a few satellites.
- Low spatial resolution (18m – 2 km)
- Continuous monitoring possible
- High time resolution achieved by quick scanning (even 10 minutes)

Commercial Program of Constellations for Communication

Operator	Country	Band*/ orbit	Size**	Capacity	Lifetime	Target markets	Status
SES O3b mPOWER	U.K.	Ka-MEO	7-22	200+ Gbps per satellite	> 10 years	Trunking, backhaul, Enterprise, Civil Govt., Military, Mobility (primarily maritime)	Development (contracted)
SPACEX STARLINK	U.S.A.	Ku-LEO	Up to 4000	~20 Gbps per satellite	~5 years	Consumer broadband, Enterprise, Backhaul, Military, Commercial Aviation	Deployment
TELESAT	Canada	Ka-LEO	292	~40-50 Gbps per satellite	10 years	Backhaul, Enterprise, Civil Govt., Mobility, Military	Development (uncontracted)
amazon	U.S.A.	Ka-LEO	3236	NA	7 years	Consumer, Enterprise, Backhaul, Civil Govt., Mobility	Development
OneWeb	U.K.	Ku-LEO	648	~7.5 Gbps per satellite	7 years	Enterprise, backhaul, Civil Govt., Aero, Maritime, Military	Deployment
Viasat	U.S.A./ NED	Ka-LEO	288	~100 Gbps per satellite	N/A	Consumer, Enterprise, Civil Govt., Aero, Military	Planning (uncontracted)
AST	U.S.A./ PNG	LTE-LEO	243	N/A	N/A	Consumer/Enterprise (Mobile Network Operators)	Development (in-house)
MANGATA	U.S.A.	Ka-/V-MEO/HEO	up to 800	~75-100 Gbps per satellite	N/A	Backhaul, mobility, enterprise, IoT	Planning
Hongyun (CASIC)	China	Ka-LEO	156	<5 Gbps per satellite	N/A	Consumer, enterprise, backhaul, mobility, satnav, EO	Development
Hongyan (CASC)	China	Ka-/L-LEO	320-864	~10 Gbps per satellite	N/A	Consumer, backhaul, enterprise, IoT	Development
Galaxy Space	China	Q-/V-LEO	144-650	10 Gbps per satellite	N/A	Consumer, backhaul, enterprise, civil govt.	Planning

*User links **Current generation only

"Big GEO satellites" and "LEO constella-tion"

PNT (Position, Navigation and Time) is one of key data

Ref. Euroconsult, Satellites to be built & launched by 2(

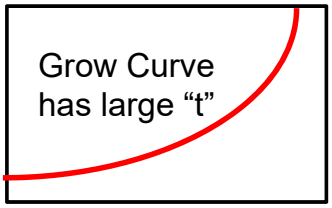
Merits of Constellations for various missions

- Earth observation
  - Improving "time resolution" (more frequent observation)
  - Resilience (robust against satellite damages/loss)
  - Quick data downlink by multiple satellite cross-links
- Communication
  - Connecting all over the world by multiple cross-links
  - Strong merits as to RF power requirement and latency
- Navigation (PNT:Positioning, Navigation and Time)
  - Received power can be stronger (may use in-house)
  - Quick convergence of precise positioning if many moving satellites can be seen from ground
- Quantity of developed satellites and iterations will be huge, then….

Merit of Large Number of Iterations

Compounding of R (value)

$$R = (1 + Y)^t$$



Y : Improvement at one iteration

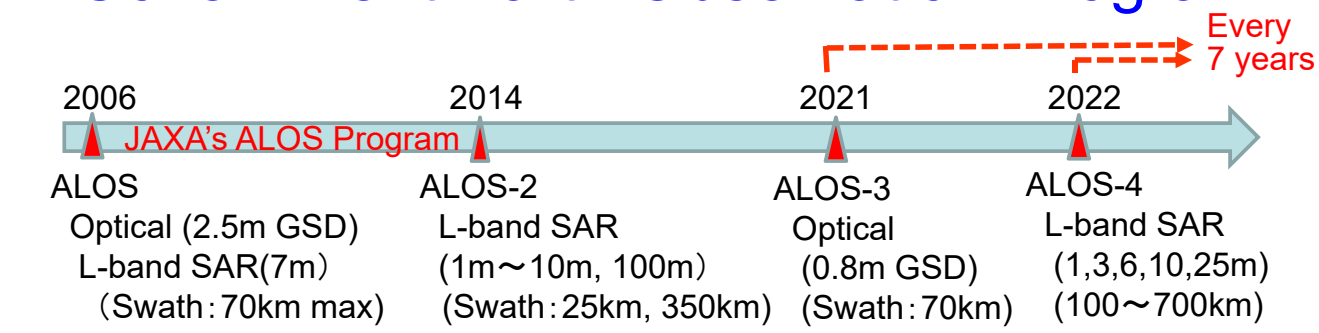
t : How many iteration you can take

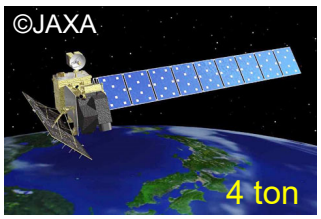
“If things are not failing, you are not innovating enough”
「失敗していないとすれば、イノベーションを起こしていないということだ」（イーロン・マスク）

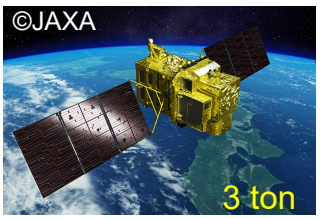
Design Issues in Constellation

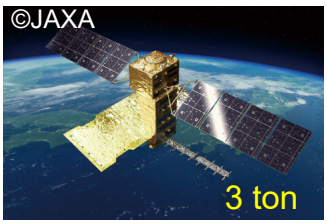
- Finding clear objective to use “constellation”
- Design of Revisit Interval
  - Mission will decide the required interval (1hr, 1day,---)
    - which decides the number of satellites and their orbital planes, heights, satellite phases (positions) in each orbit, etc…
  - Tradeoff of the number of satellites and total cost
- Consideration of latency of data-link
  - Mission will decide permissible latency
    - which decides the number and positions of ground stations
    - Option: GEO satellite link or inter-satellites cross link used ?
- Design of satellites themselves
  - Heterogeneous or Homogeneous ?
  - Additional design for cross-link or constellation operation

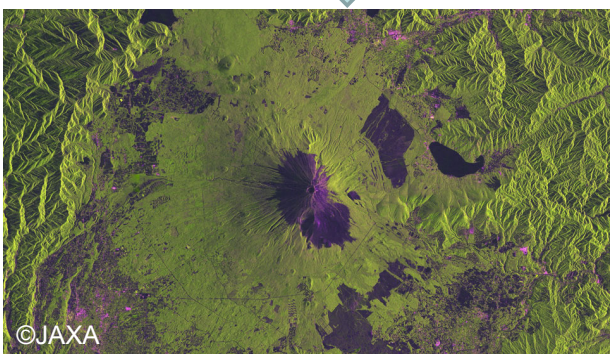
Government Earth Observation Program







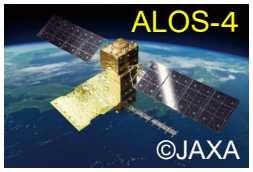




Other Ministries' Program
GOSAT Series: Greenhouse Gas
Himawari Series: Meteorological
GCOM: Water and particles
ASNARO-1: Optical (450kg,0.5m)
ASNARO-2: X-band SAR(570kg,1m)

Constellation Required for Disaster Prevention and Mitigation (P&M)

- Satellite performance required for Disaster (P&M)
  - The first information on disaster areas should be delivered at least before 12 hours
    - To find out where to send rescue teams
  - After that, periodically the information of the specific areas should be delivered with interval of 3-6 hours
    - To monitor the area after disastor
  - All weather, 24 hours information is important

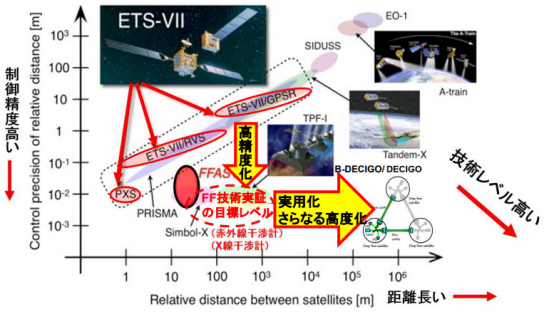


- SAR satellites with large swath (200km) would be attractive, but only one satellite (such as ALOS-4 alone) is not enough to obtain high responsiveness and time resolution (<12 hours)
- Constellation is needed to obtain frequent observations
  - "finding out" can be done by government sat + small sat constellation
  - "monitoring" can be done by buying small sat constellation

“Formation Flying (FF)”

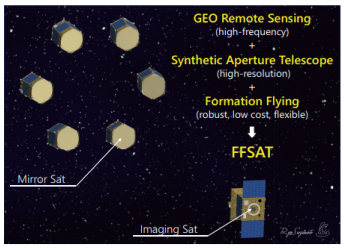
Formation Flying (FF) of spacecraft:

- Technology for coordinated control of multiple spacecraft flying near to each other
- May realize high level astronomical / Earth observation missions that would not be possible with a single spacecraft
- Suitable for micro/nano/pico-satellites as their capability as one satellite is limited but want tc realize high level mission.



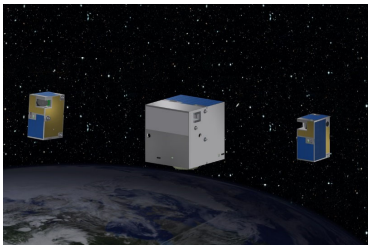
Earth Observation

Synthetic Aperture Telescope FFSAT

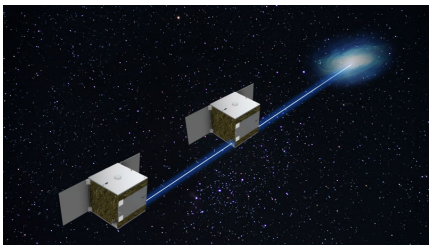


Astronomy, Astrophysics

Infrared Interferometer SEIRIOS

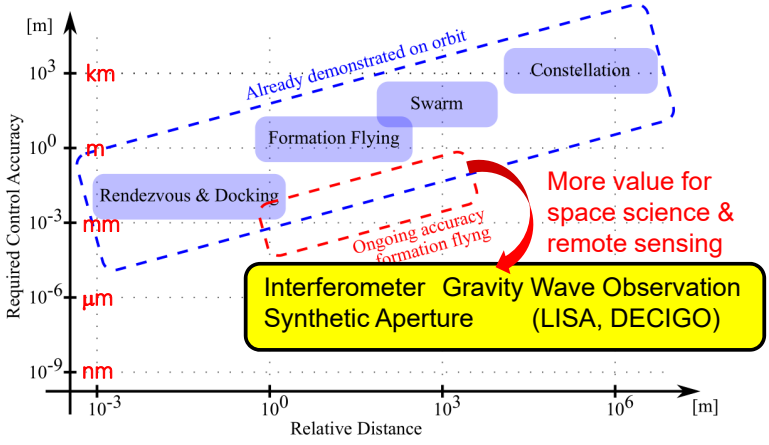


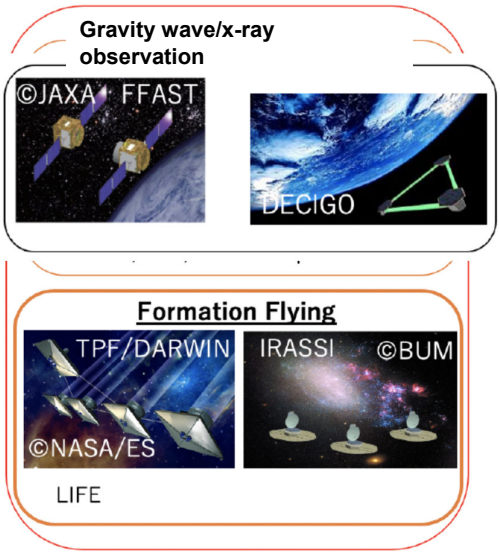
X-ray Telescope MIXIM-SF



Various Accuracy Levels of FF Missions

- The relative position control accuracy of cm～m was achieved in 2014 by CanX-4&5 (1U, with inter S/C distance of about 100 m).
- mm-class FF missions are ongoing (e.g., PROBA-3).
- **Higher accuracy (μm - mm) will make interferometer or synthetic aperture missions possible**
- **Low accuracy (cm - m level) formation flying still have some useful missions**



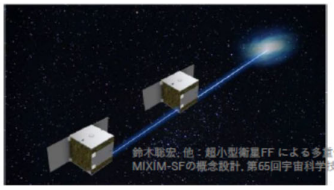


Example of Scientific Missions Using Two Satellites Straight Line Formation

"Straight Line Formation" Missions

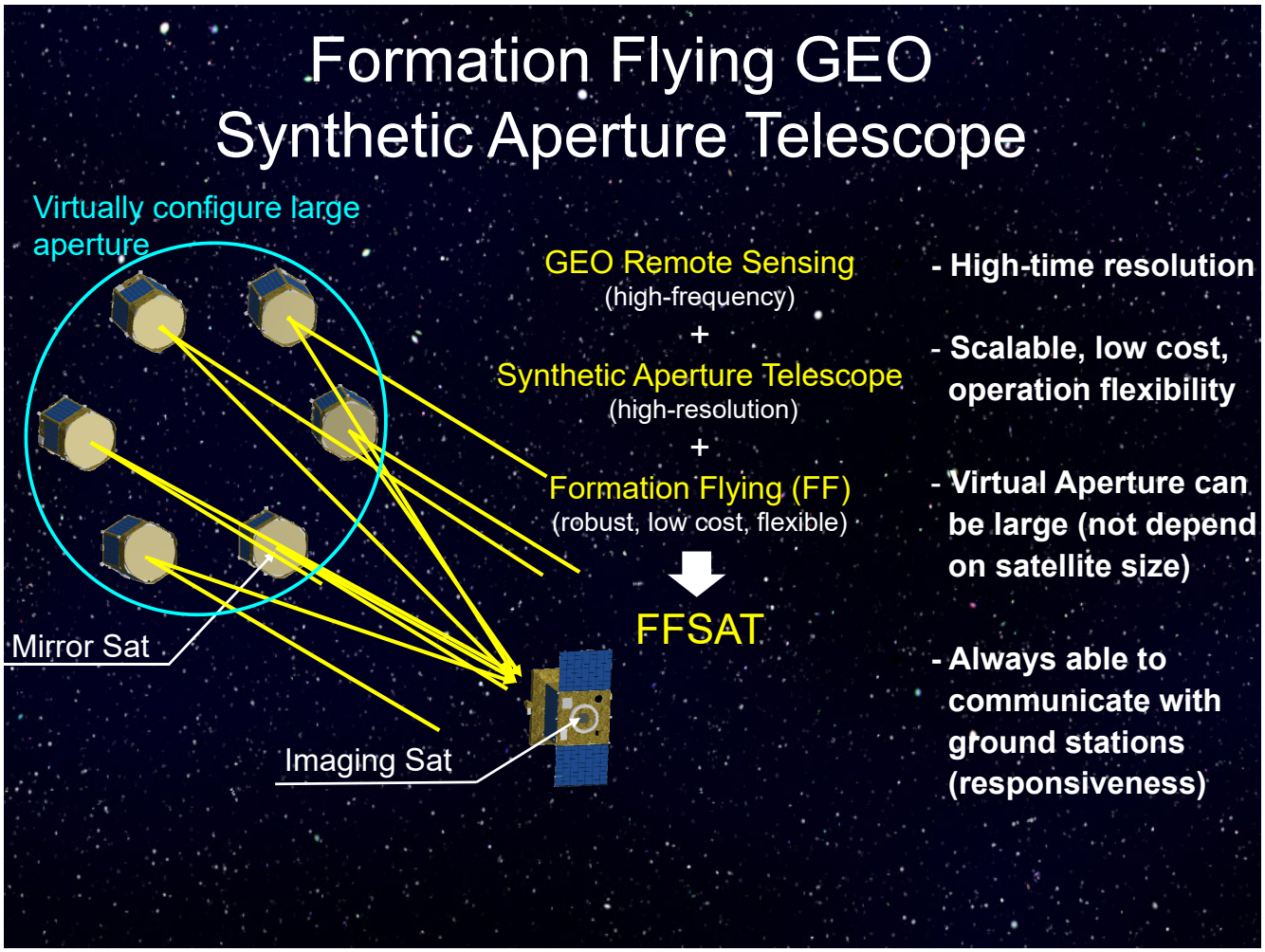
- **Starshade Mission**
  - New exoplanet observation method
  - The light of a star is blocked by an occulter satellite
  - Exoplanet around the star can be observed by a telescope satellite directly
  - Example of Earth orbit starshede missions: mDOT, Euryops
- **X-ray telescope/interferometer**
  - Target: High energy (= high temperature) objects such as black holes
  - Due to the property of X-rays, it is necessary to make the telescope longer in order to obtain higher resolution

  → Formation flying is needed!
  - Example of Earth orbit X-ray missions: VTXO (telescope), MIXIM (interferometer)



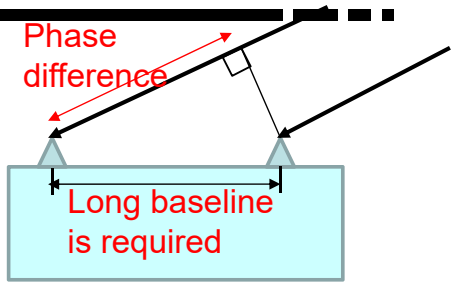
How to keep the straight line formation and
how to change from one to another line direction for multiple targets ?

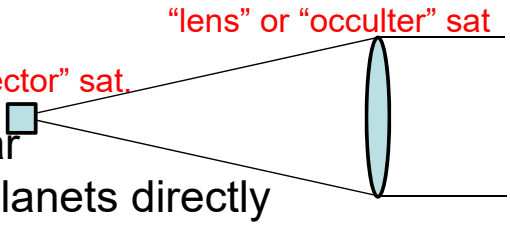
Formation Flying GEO Synthetic Aperture Telescope



Usages of Formation Flying

- Interferometric observation
  - Accurate estimation of direction of incoming light / RF
    - Improving resolution
- Realizing long focal length
  - X-ray telescope
  - "Starshade" to occult main star light to observe surrounding planets directly
- Synthetic Aperture Telescope
  - Virtually realize large aperture telescope by using multiple "mirror satellites"
- Simultaneous observations at many points
  - Particles, magnetic field, gravity, electric potential, …..



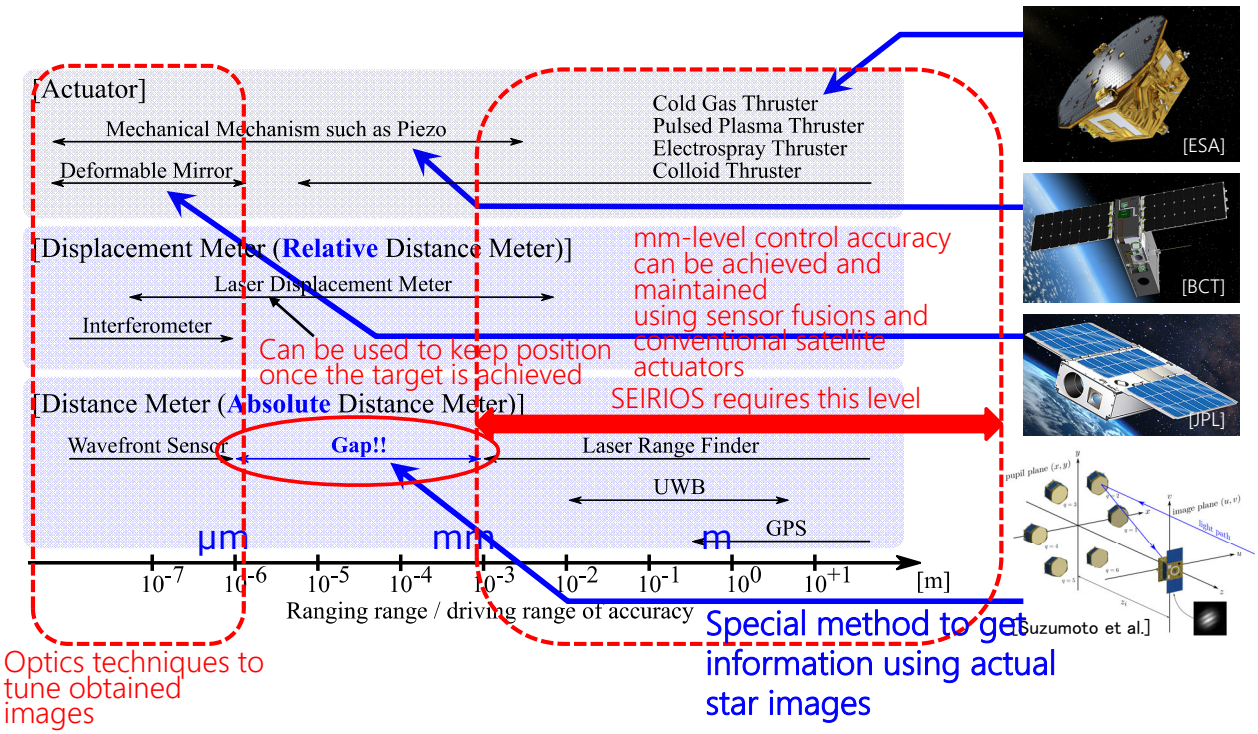


Design Issues in Formation Flying

- Find clear objective to use "Formation Flying"
- Define mission requirements
  - accuracy, observation duration, aperture size, ….
  - satellite quantity, position distributions, sensors, ……
- Define shape and accuracy of formation
  - planer formation, straight line formation, curt-wheel, ….
  - required position/attitude accuracy, change direction, ….
- How to realize/keep the required formation
  - how to estimate/control relative position and attitude with required accuracy (sometimes, *mm* – μm accuracy required)
  - how to change the direction of formation
  - how to keep the orbits of satellites with minimum ΔV
- Usual design of satellites

Example: Various Sensors/actuators for FF

- How to combine them to realize high accuracy? -



At "Pre-Mic 8" in Istanbul…..

- We will provide a mini-lecture (workshop) on how to design constellation or formation flying missions
  - assuming certain missions
    - constellation of Earth observation satellites (TBD)
    - formation flying of interferometric observation (TBD)

- Join us at UNISEC-GLOBAL Meeting in Turkey to be held in this October !