A Review of MPGD Applications in Space Missions

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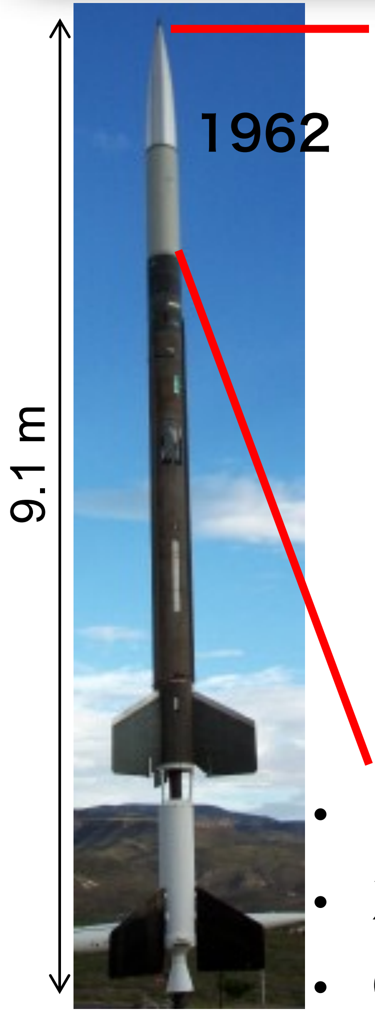
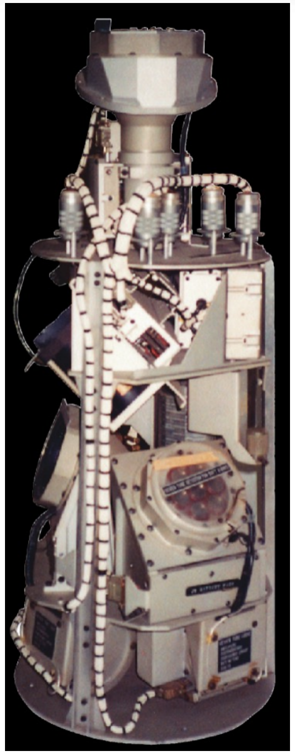
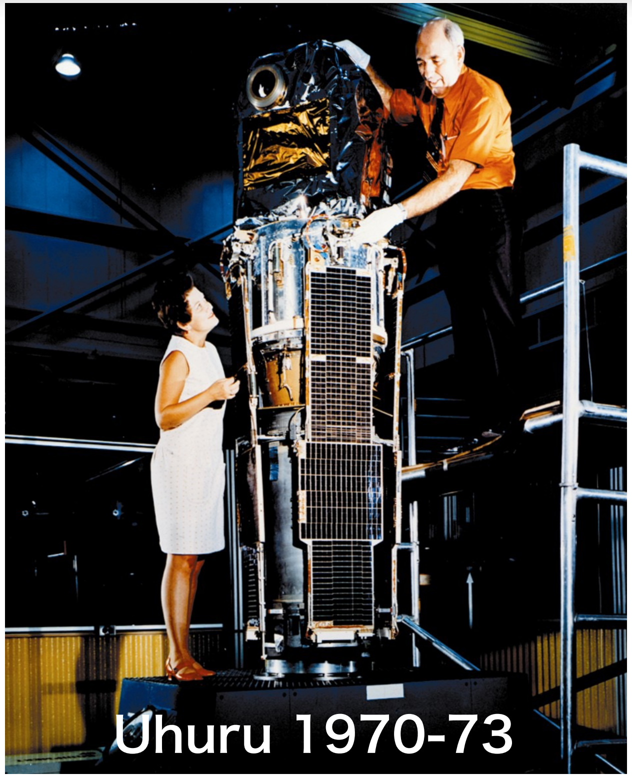
Outline

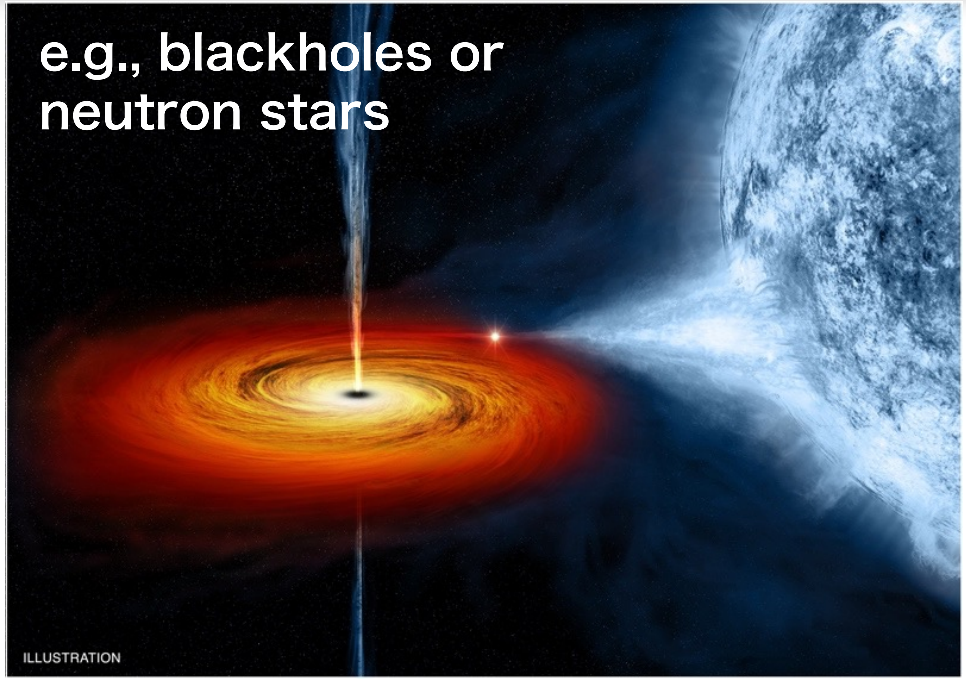
Cannot cover all proposed project,
but only projects which already flew or soon fly.

1.1 History of gas counters in space





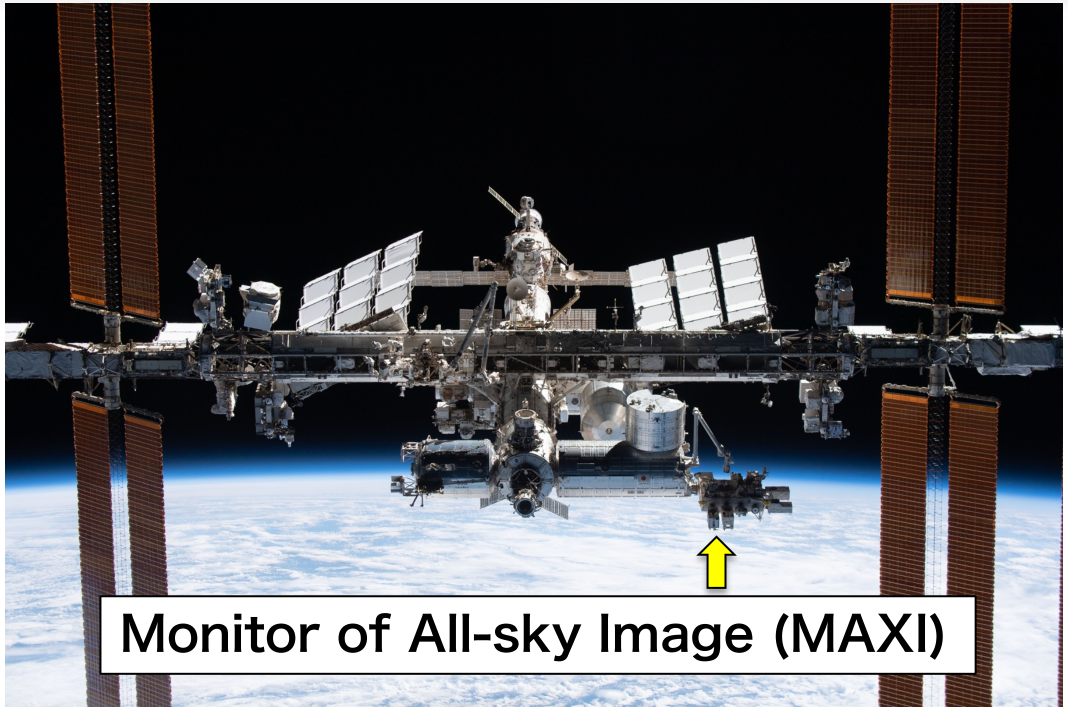


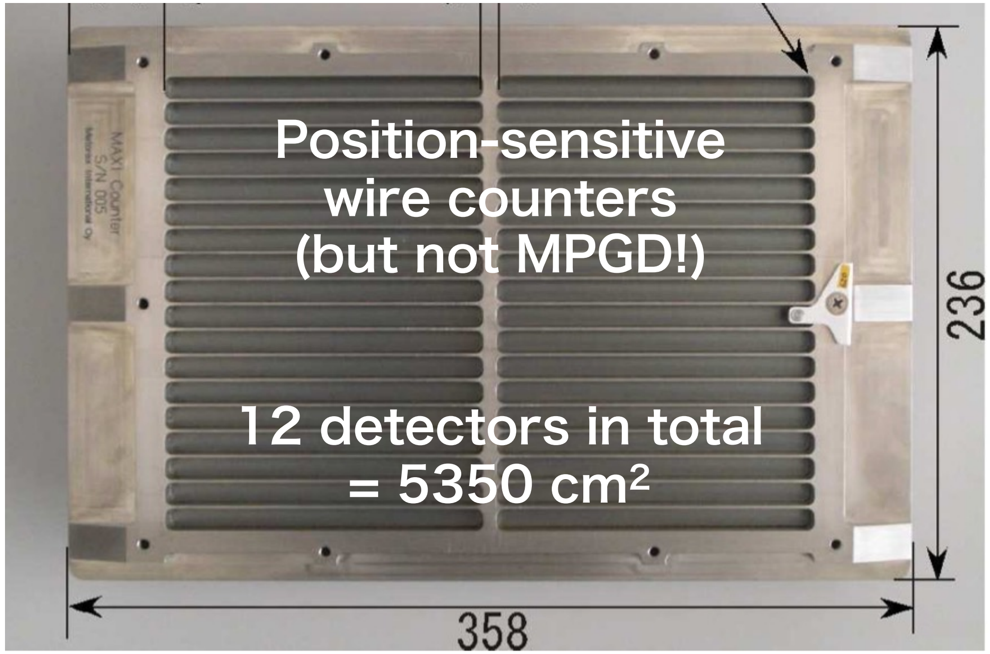


Blackhole or neutron star binary

- High-energy astrophysics is a new field began in 1962 with rocket obs.
- X-rays are blocked by atmosphere, only way to obs them is to go out into space.
- Geiger and/or proportional counters were often used in early phase.
- Until 1990s, gas detectors were the main instruments.
- High-energy astrophysics = observe high energy phenomena in BH and NS.

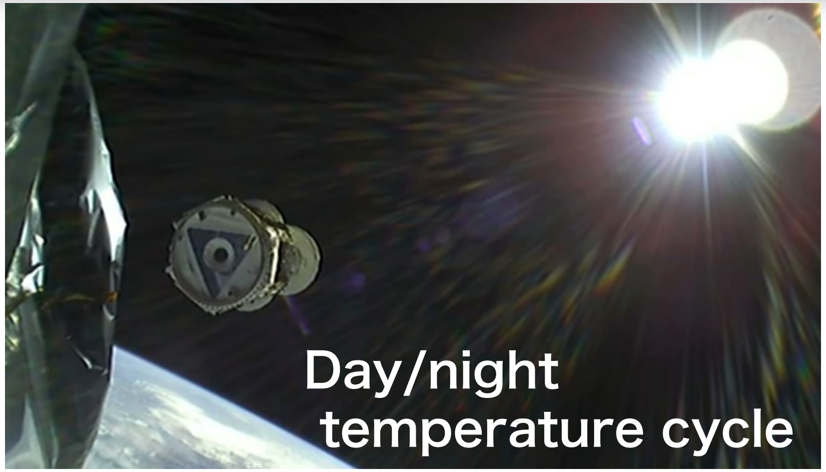
1.2 Why still gas counters?

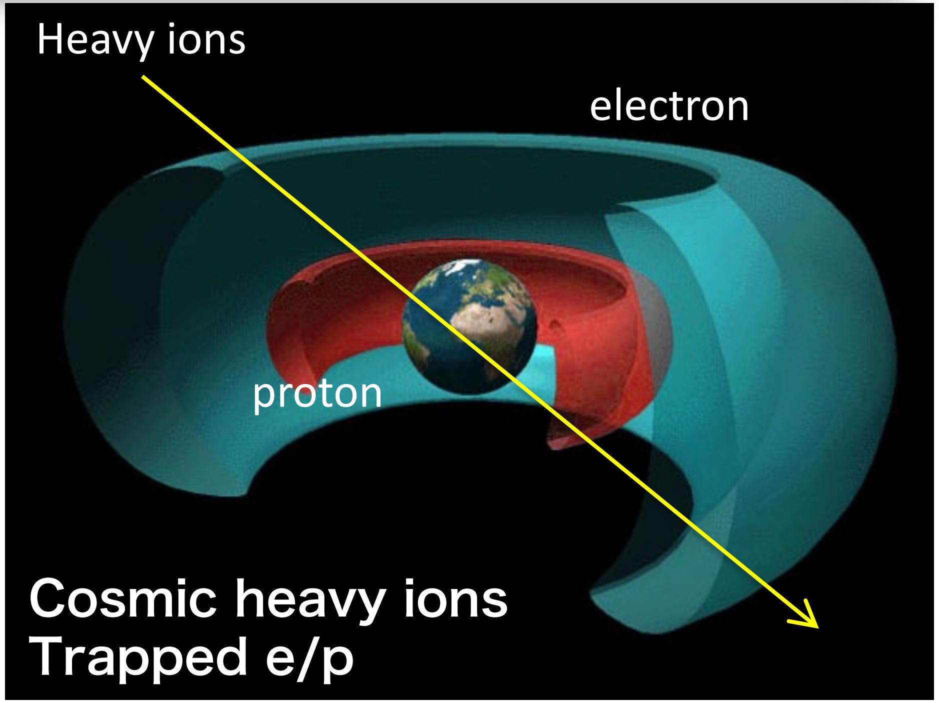




- RIKEN is running large gas detectors on ISS called MAXI with JAXA from 2009.
- Gas detector is easy to expand the effective volume. (Photons from obj. is quite less. << 1 cps/cm^2) Need large volume.
- Solid state or scintillation detector cannot swap gas counters. (ess expensive per volume).
- In addition, thanks to MPGDs, the range of application has enormously expanded.

1.3 How different from ground exp?





- Space experiments are different from ground exp.
  In a word, harsh conditions.
- Detectors are subject to strong vibration, acoustic, and shock during launch.
- Day/night thermal cycle are severe; breaking structures due to CTE difference.
- “Bake and vib well” your detector before launch.
- Total radiation dose is not so severe, but heavy ion injection should be care for gas detectors.
- Once launched, you cannot repair!! No upgrades can be made other than software.

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2. Astrophysics (space missions)
3. Astrophysics (suborbital missions)
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5. Realtime Space Dosimetry
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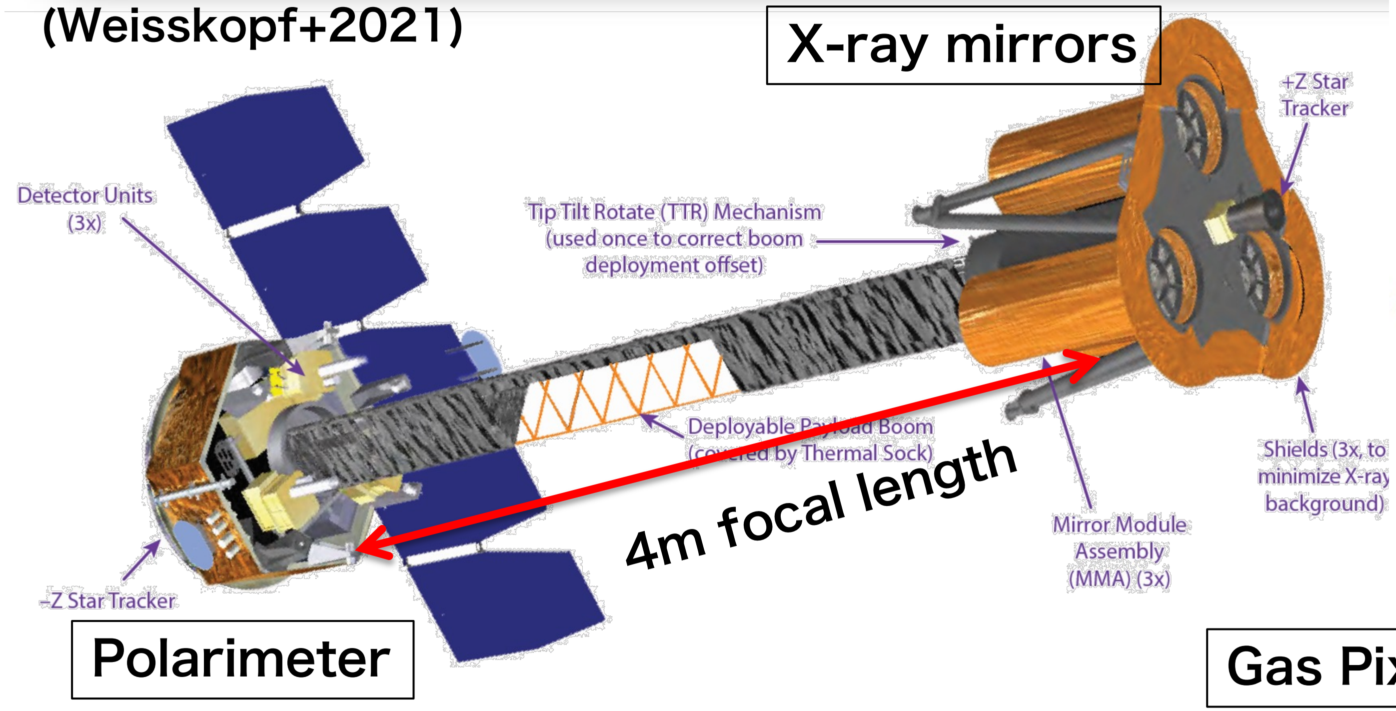
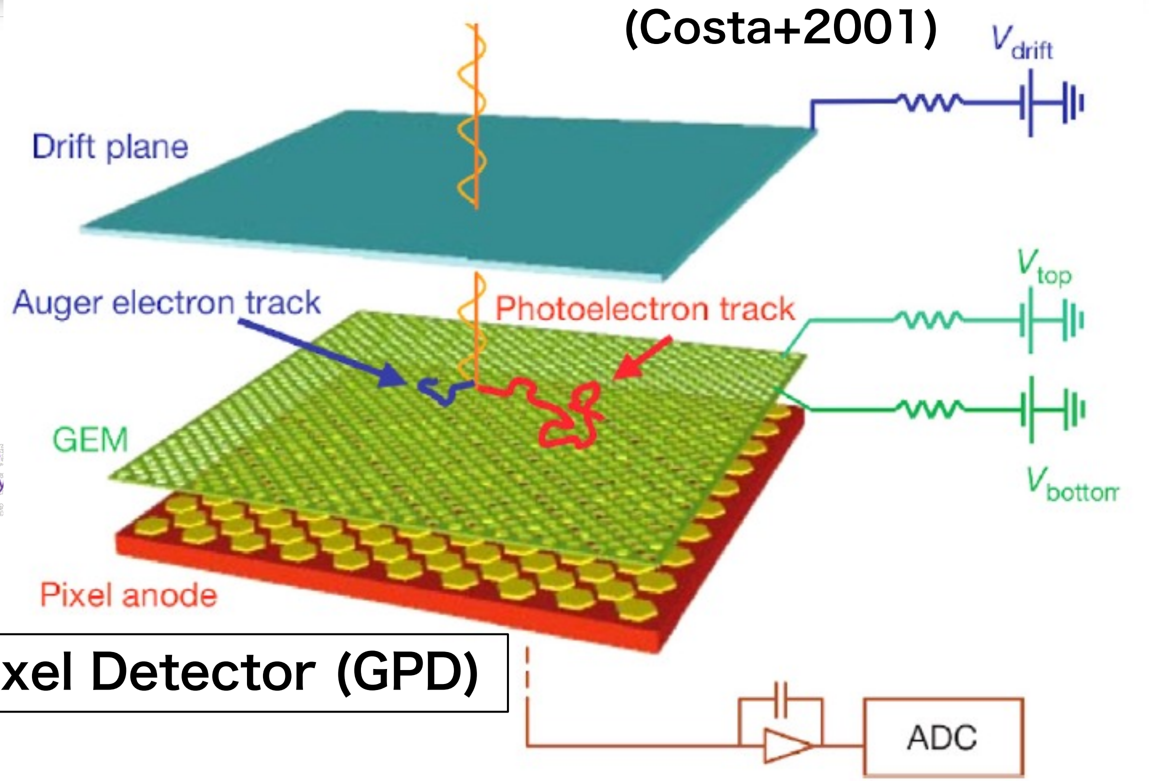
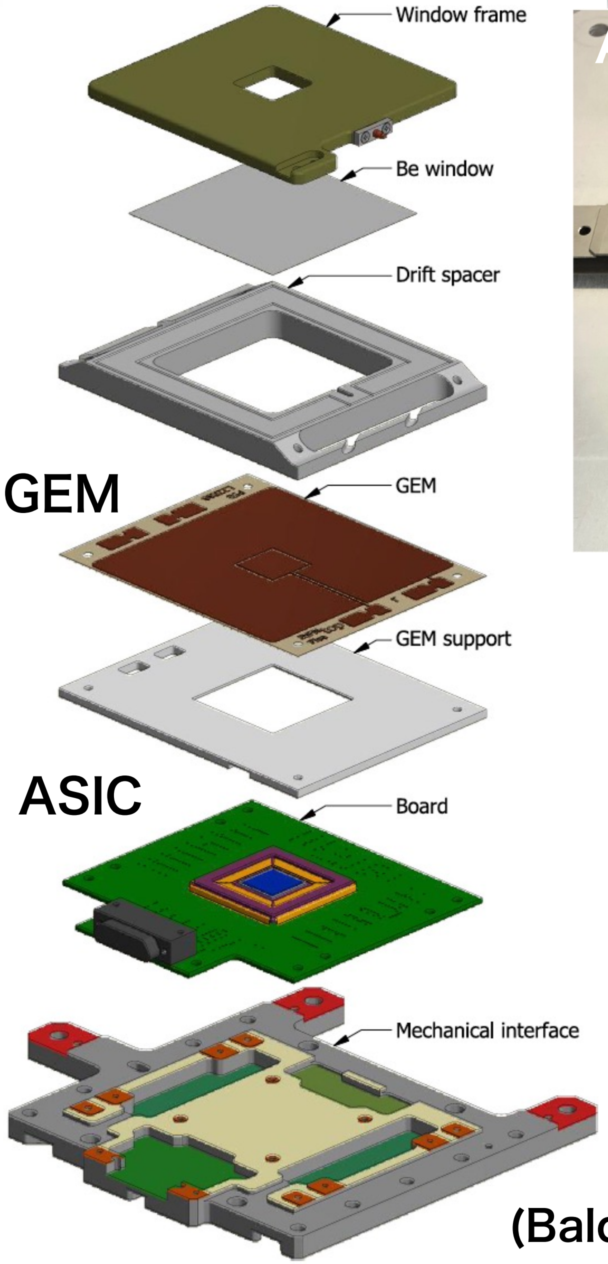
2.1 Imaging X-ray polarimeter (IXPE)

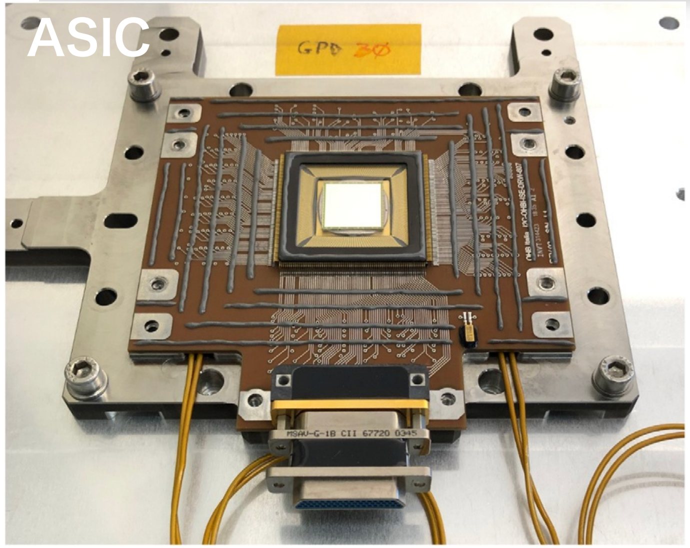


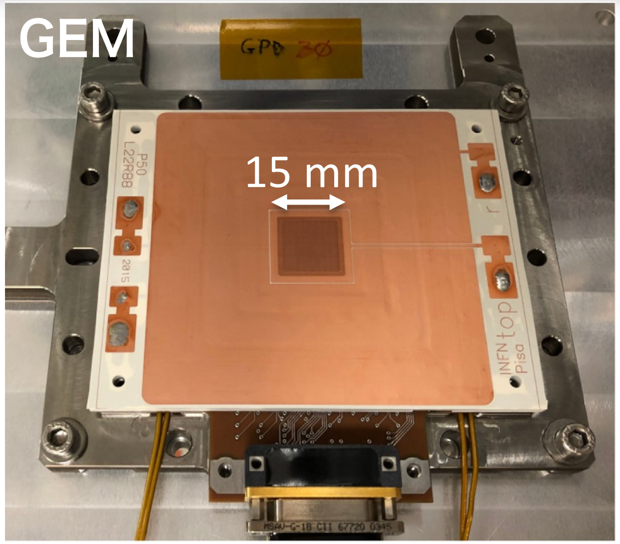


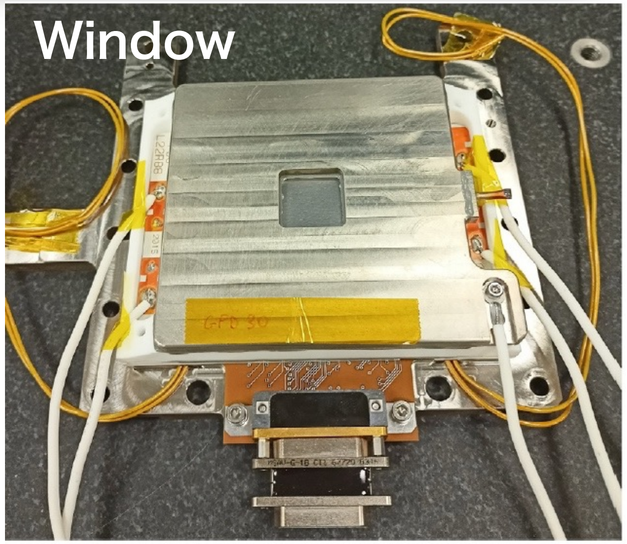
- NASA's small explorer approved in 2017 and was launched on 9 December 2021.
- Worlds first high sensitivity X-ray polarimetry mission.
- Polarimeter was developed by INFN/Pisa (Bellazzini+) and RIKEN provided fine-pitch GEM.
- The emission direction of photoelectrons ~ polarization direction.
- GPD measures tracks with a fine pixel detector.

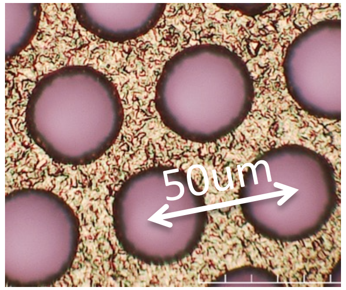
2.2 Polarimeter fabrication

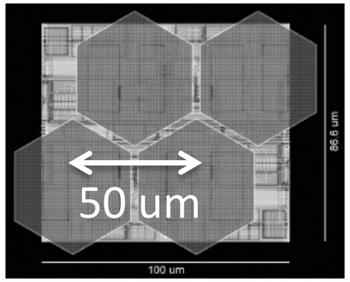








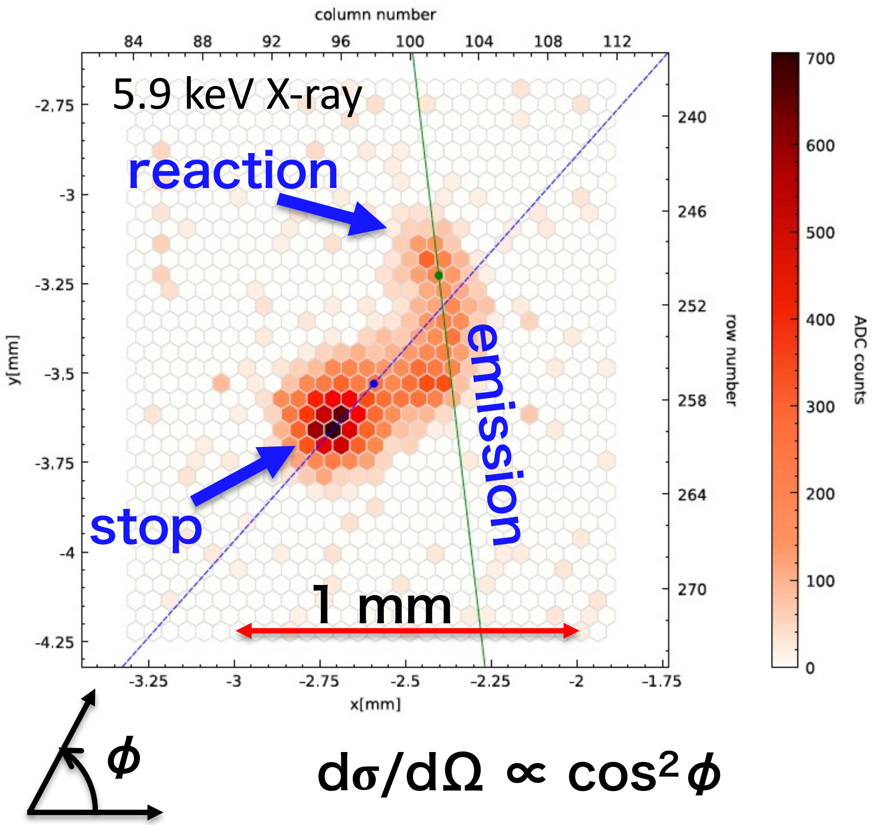




(Baldini+2021)

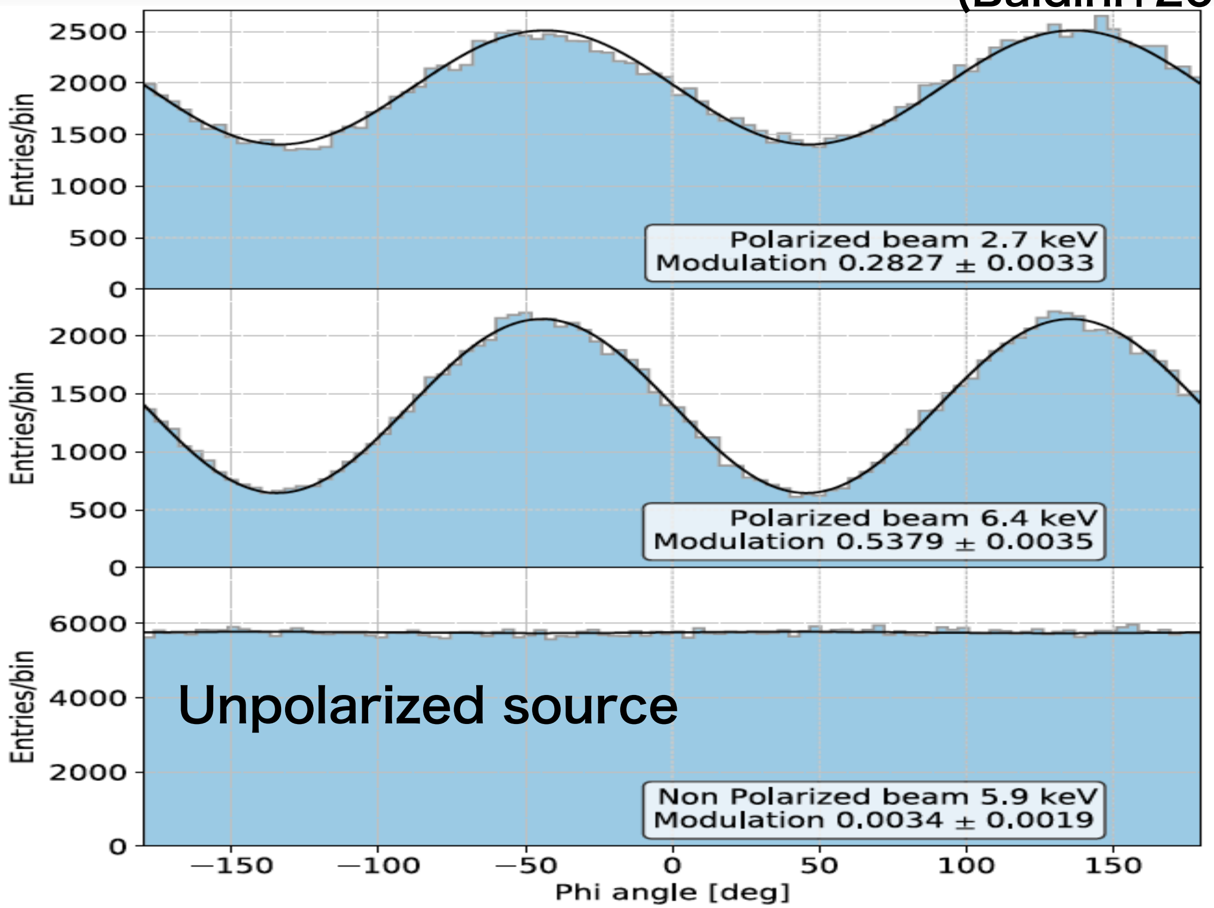
- Fine-pitch GEM P: 50um, D:30um, T:50um LCP substrate
  - Drilled with a laser etching (Tamagawa+2009)
- Readout ASIC P: 50 um, 300 x 352 pix (Bellazzini+2004)
- 10 mm drift, 15 mm x 15 mm effective area
- Gas: 0.8 bar pure DME
- Gain~200 at dV_{GEM}=470V
- Energy range: 2-8 keV

2.3 Polarimeter performance



$d\sigma/d\Omega \propto \cos^2\phi$

(Baldini+2021)

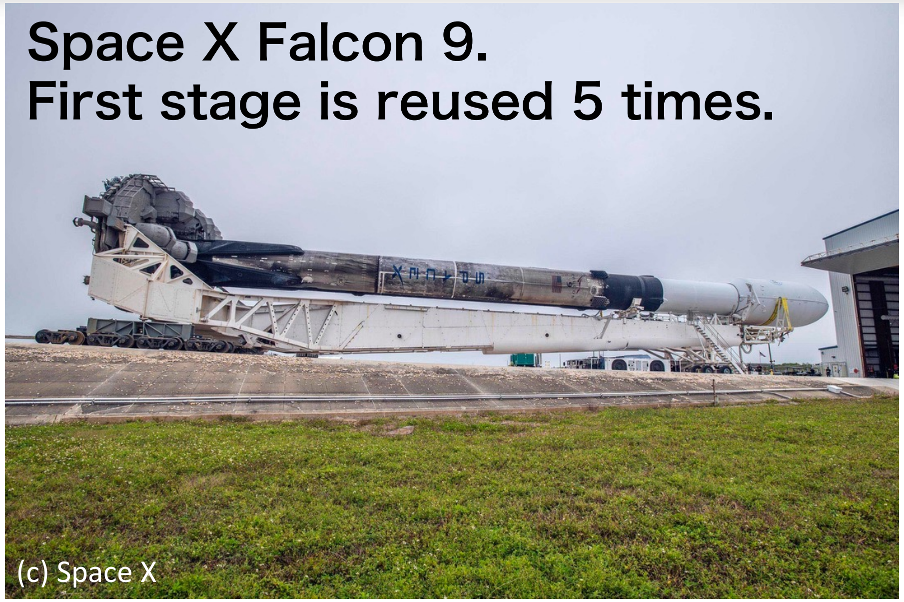


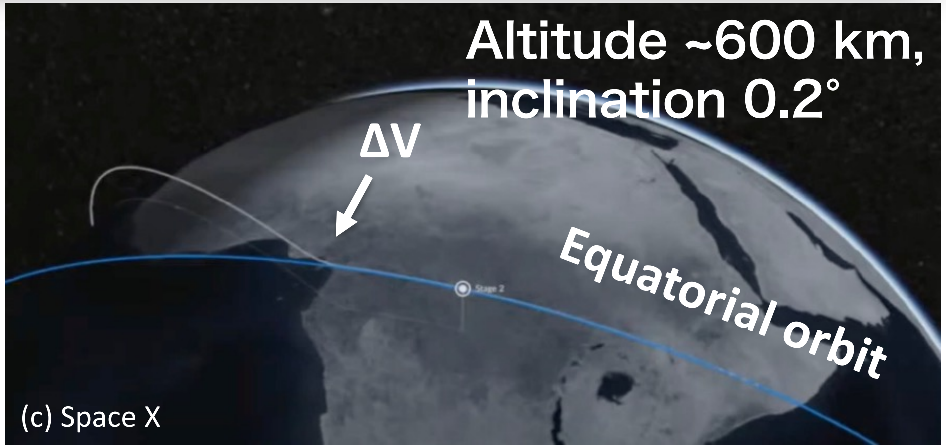
- Gas pixel detector met our requirements.
- High sensitivity X-ray polarimetry was difficult to realize, but strongly desired for 50 years.
- Finally, we done.

Never been accomplished without MPGD!

2.4 Launch and operations

Final check at
Ball Aerospace

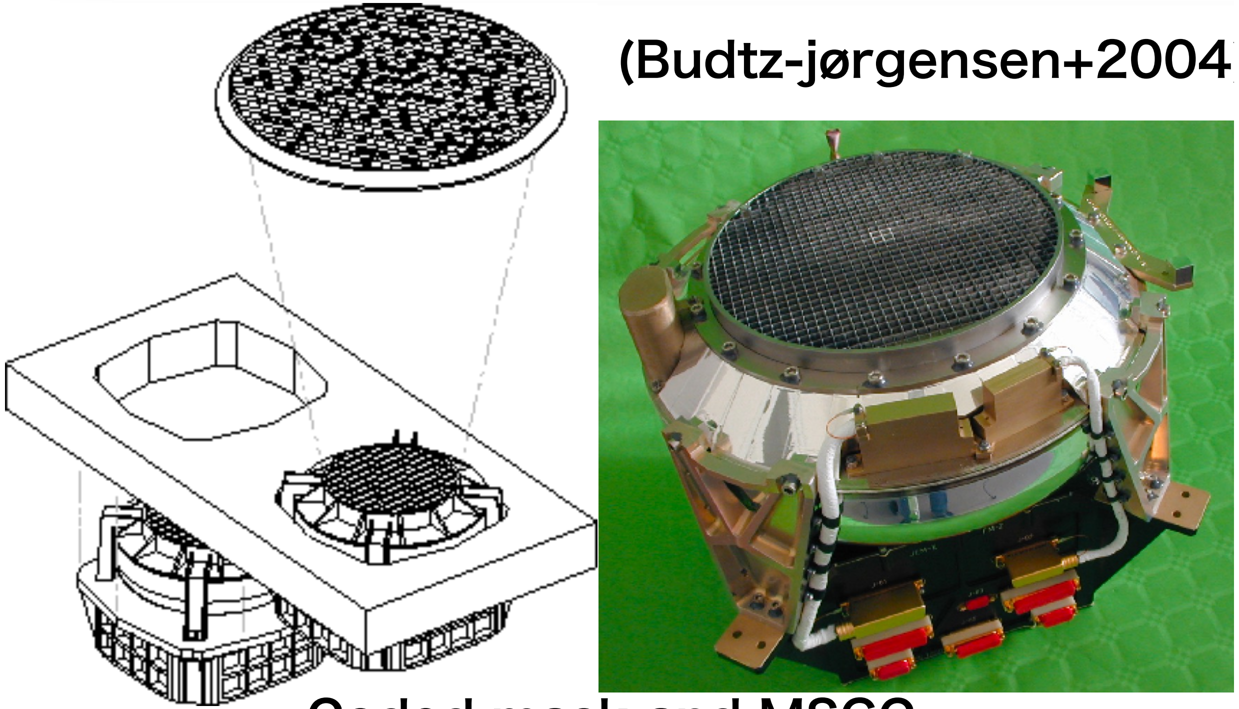




- 2 Nature, 2 Science and more preparing.
- 2 yrs nominal, and more if sat fine.

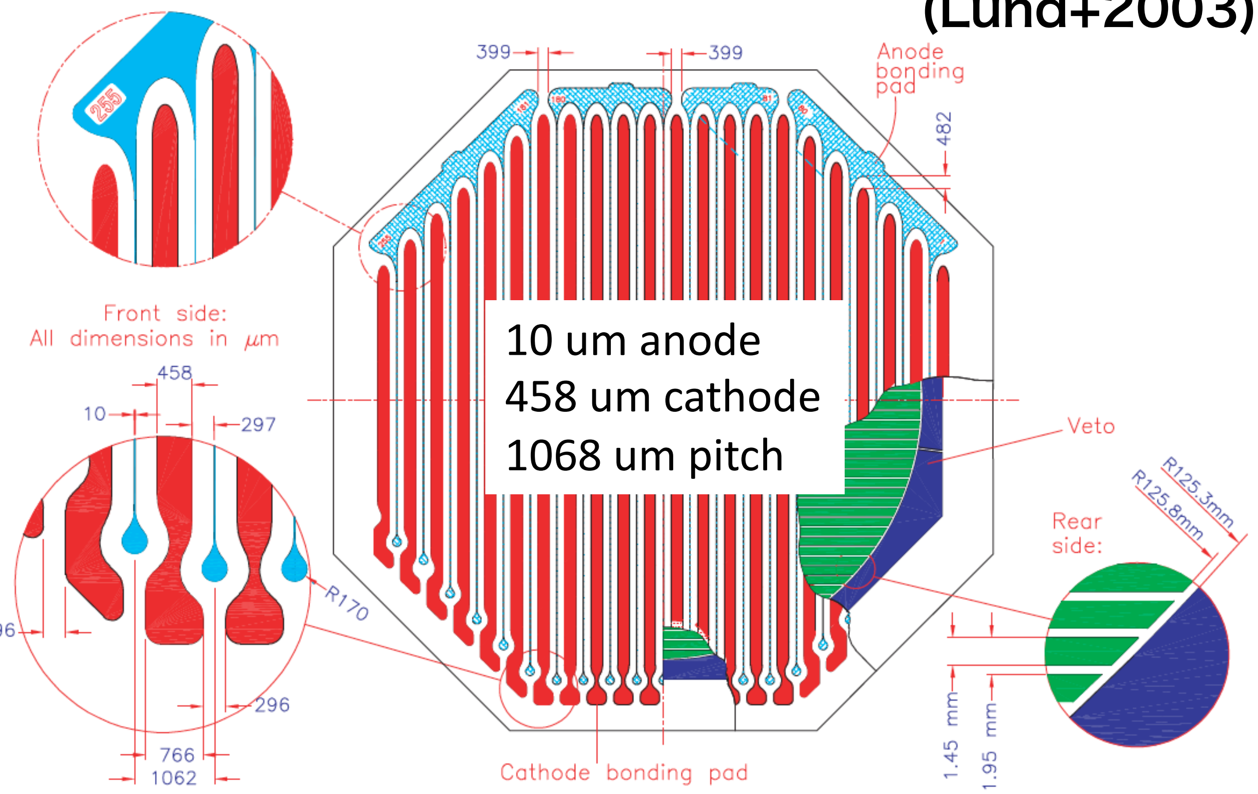
2.5 INTEGRAL JEM-X

(Budtz-jørgensen+2004)



Coded mask and MSGC

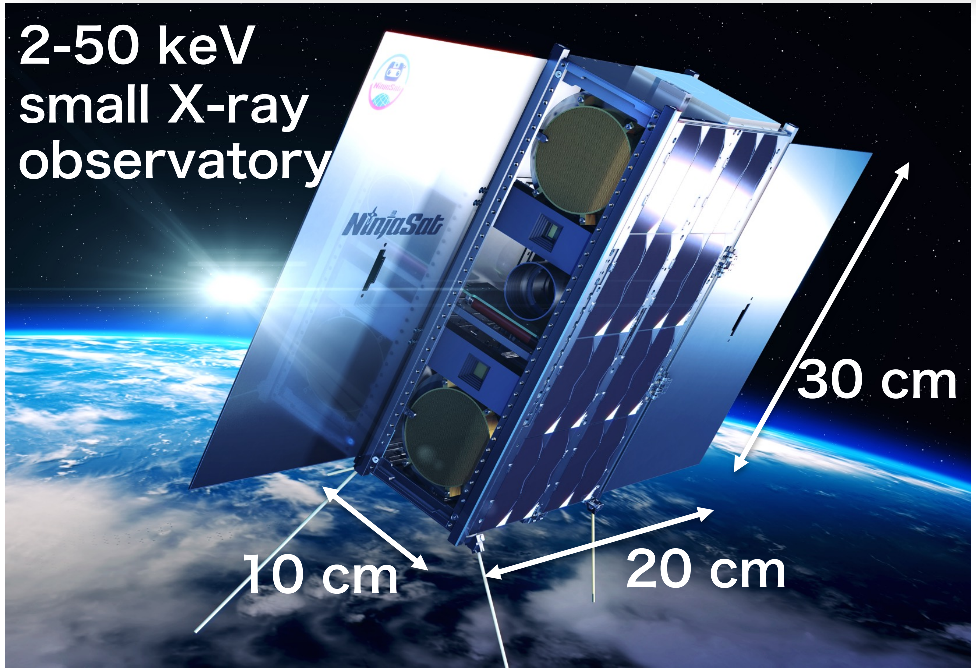
(Lund+2003)

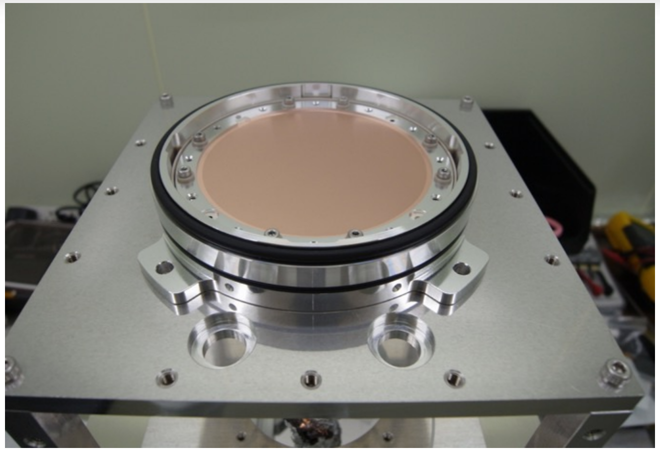


- X-ray monitor onboard INTEGRAL gamma-ray satellite (ESA) (2000~).
- An excellent method for achieving a large A_{eff} and high positional resolution.
- Gas: Xe+CH_4(10%), 1.5 bar, Gain~1500 => 500 in orbit (breakdown by heavy ions)

This is the pioneering work with MPGD in space missions.

2.6 NinjaSat: a CubeSat astro mission





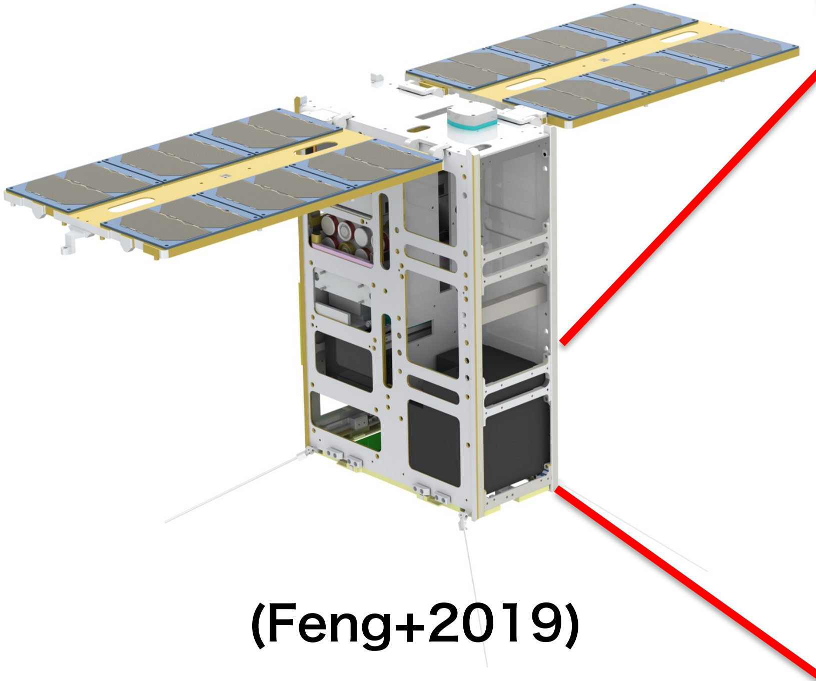
LCP GEM P: 140um,
D: 70um, T: 100um
Gas 1.2 atm
Xe75%+Ar24%+DME1%

Flight detector

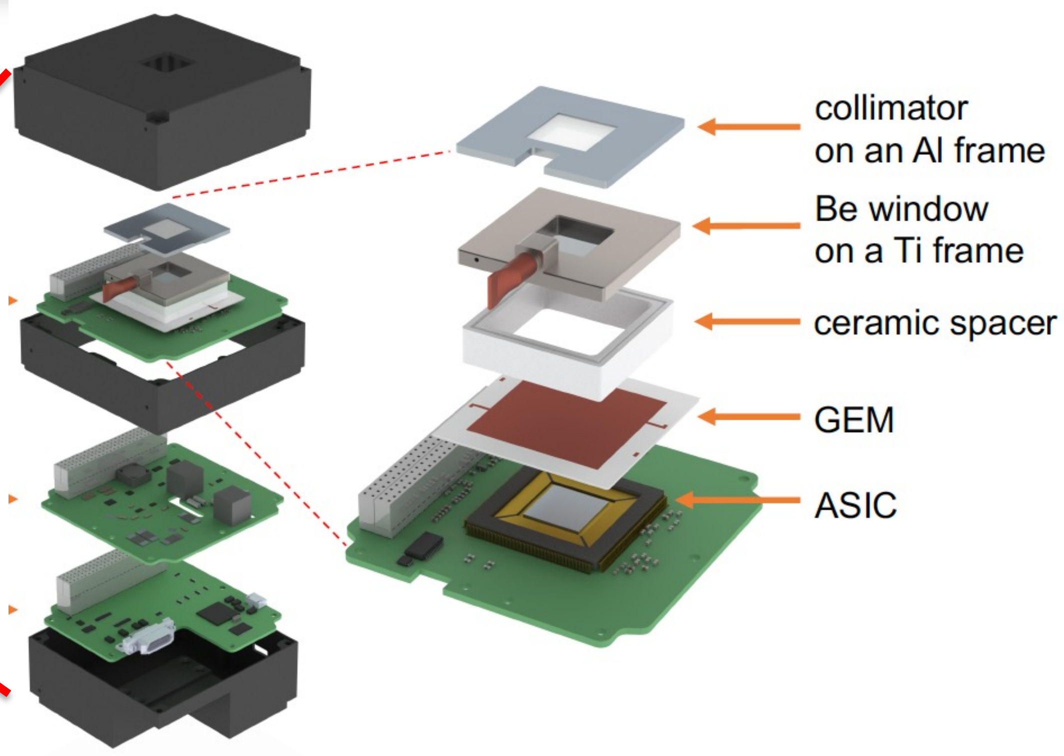
- NinjaSat is a small X-ray observatory procured by RIKEN and launched in October 2023.
- Gas counter is the only way to achieve large effective areas with the limited resources of nano-satellites (CubeSat).
- With MPGD, more flexible design than wire counters maximize effective area.
- Nano-satellite does scientific observations when powered with MPGD!

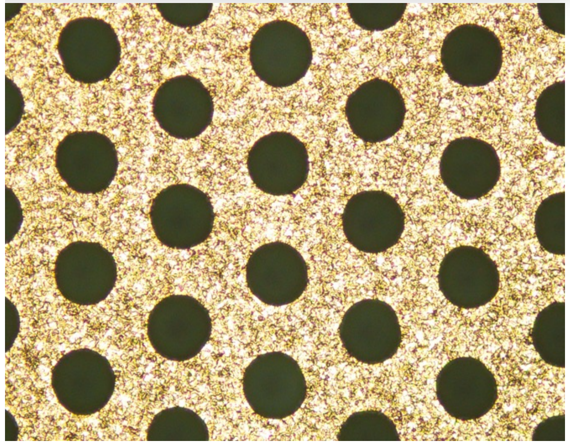
See posters by Takeda & Ota!

2.7 Polar Light: a CubeSat astro mission



(Feng+2019)





LCP thick-foil GEM
P: 100um, D: 50um,
T: 100um
ASIC 50um hexagonal
Gas 0.8 bar pure DME

- PolarLight is a CubeSat polarimetry mission launched on October 29, 2018.
- The precursor mission of IXPE. Carried same ASIC and thick-foil GEM provided from Japanese Company SciEnergy.
- Gas detectors require very small resource on satellites: suite to CubeSat missions.
- Good observations can be made even with small satellites with MPGD!

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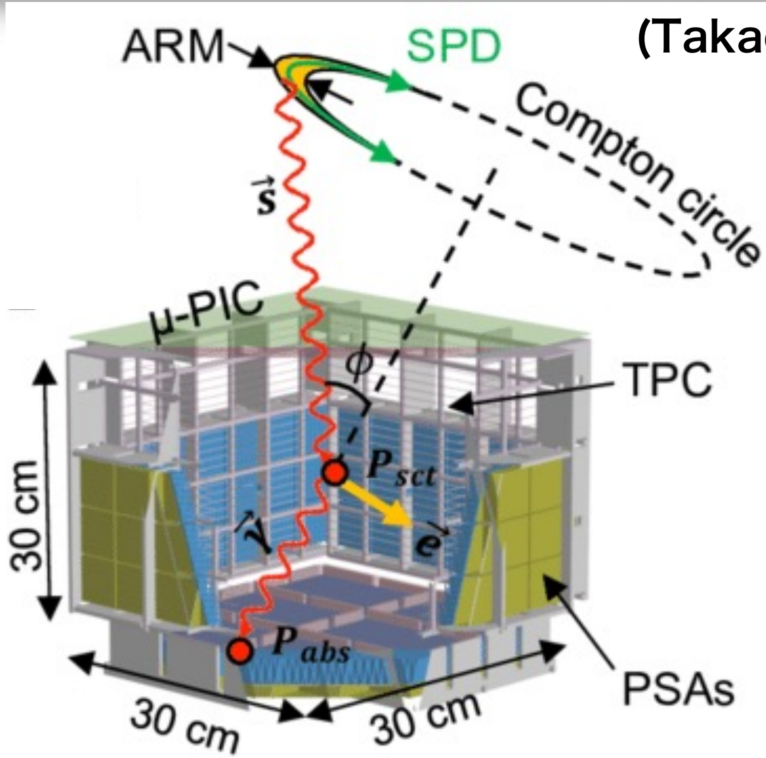
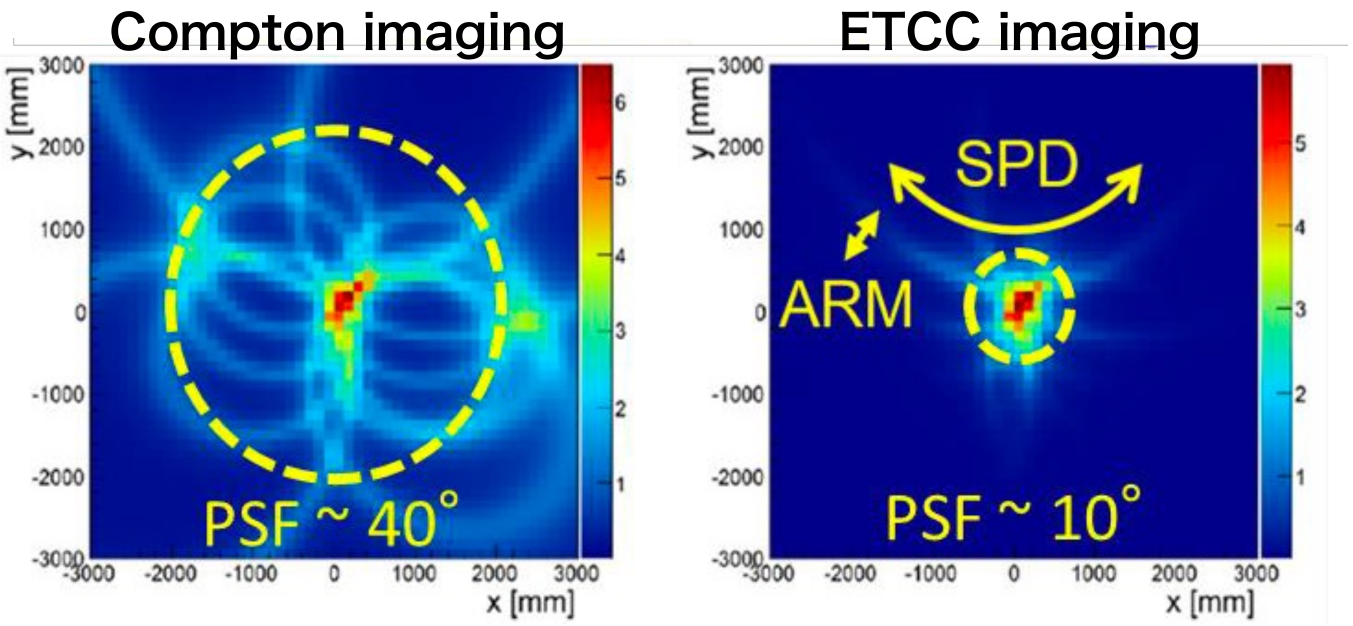
3.1 Compton gamma-ray detector



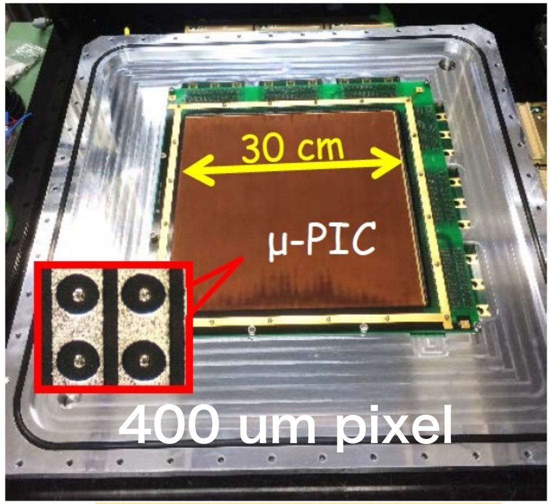
(Takada, Tanimori +2017)

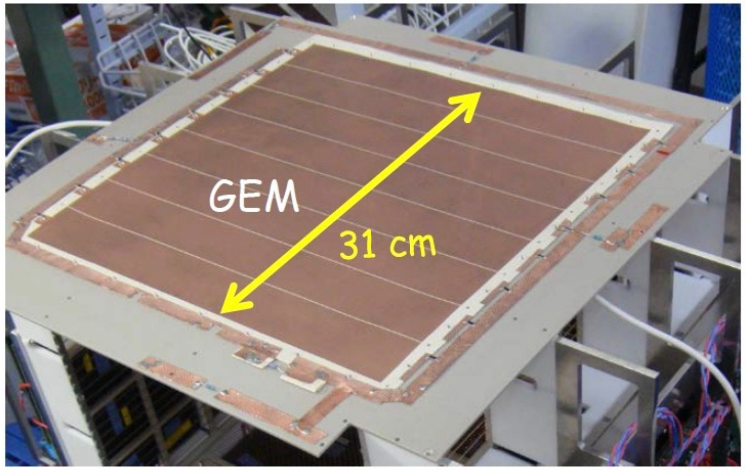


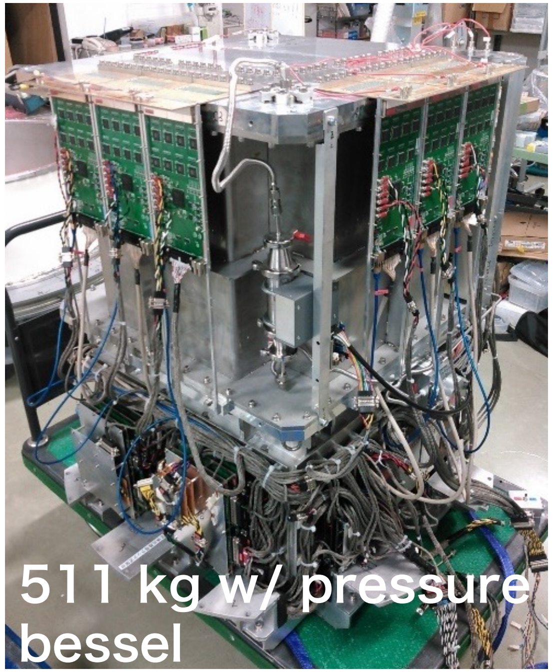
- SMILE: Balloon born gamma-ray observatory
- Open gamma-ray astronomy: detect nuclear gamma-lines from supernovae etc.
- This is the only mission that can track electrons and solve Compton kinematics.
- With the current technology, this cannot be achieved with semiconductors; using MPGD is the only solution.

3.2 SMILE2+ and future

(Takada+2017)







uPIC 400 um pixel
Thick-foil LCP GEM P: 140um, D:70um, T: 100um
Gas 2 atm
Ar 95% + CF_4 3% + iC_4H_{10} 2%

- SMILE2+ successfully detect gamma-ray excess from the galactic center (Takada+2022).
- Upgrade and the next fly scheduled in Australia in 2026.

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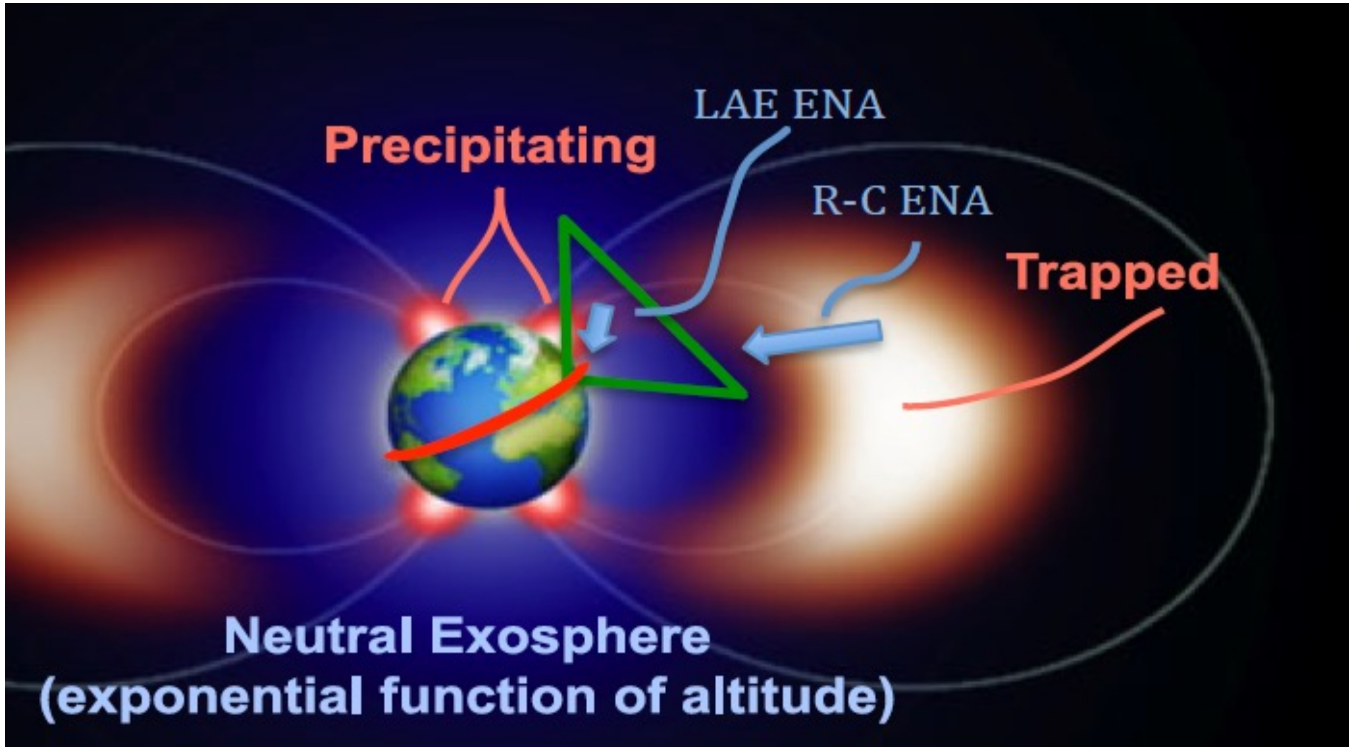
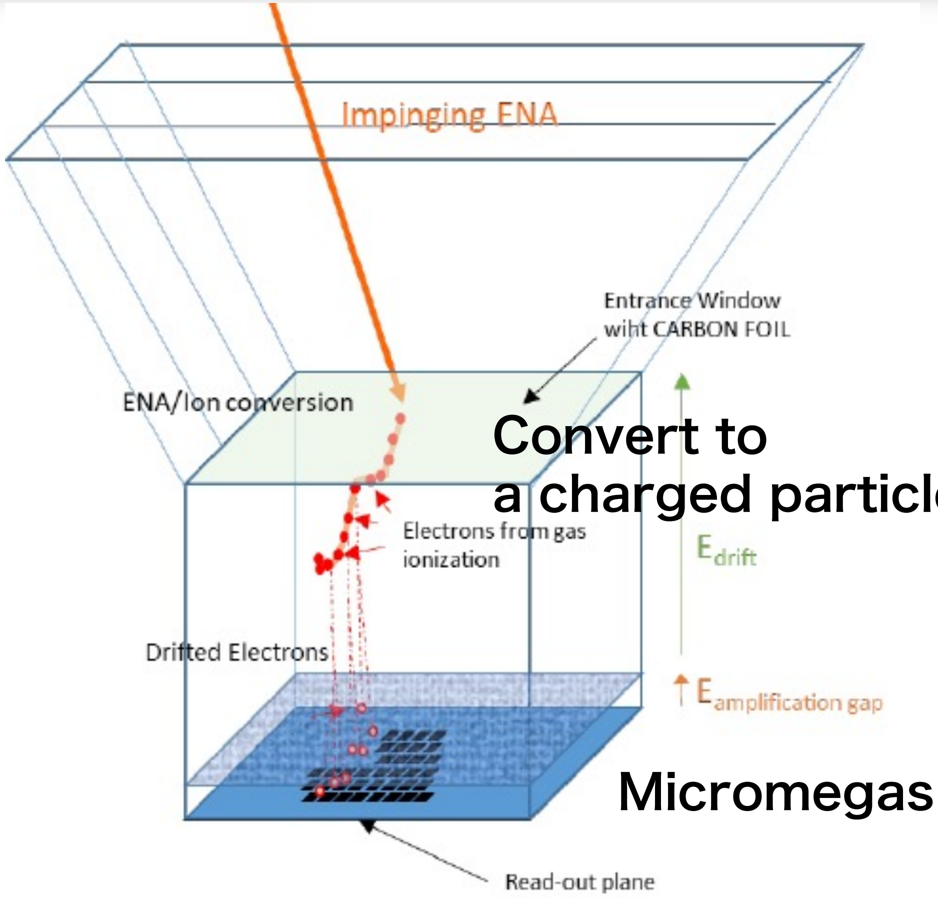
4 SWEATERS

Space WEAther Ena Radiation Sensor





Convert to a charged particle

Micromegas (?)

- Imaging of ENA (Energetic Neutral Atoms) for Space Weather.
- Neutral atoms not affected by geomagnetic fields. Good probe to survey particle env.
- Need fine spatial resolution, wide energy range (especially lower energy).
- MPGD is a good candidate. Does anybody know or related to this project?

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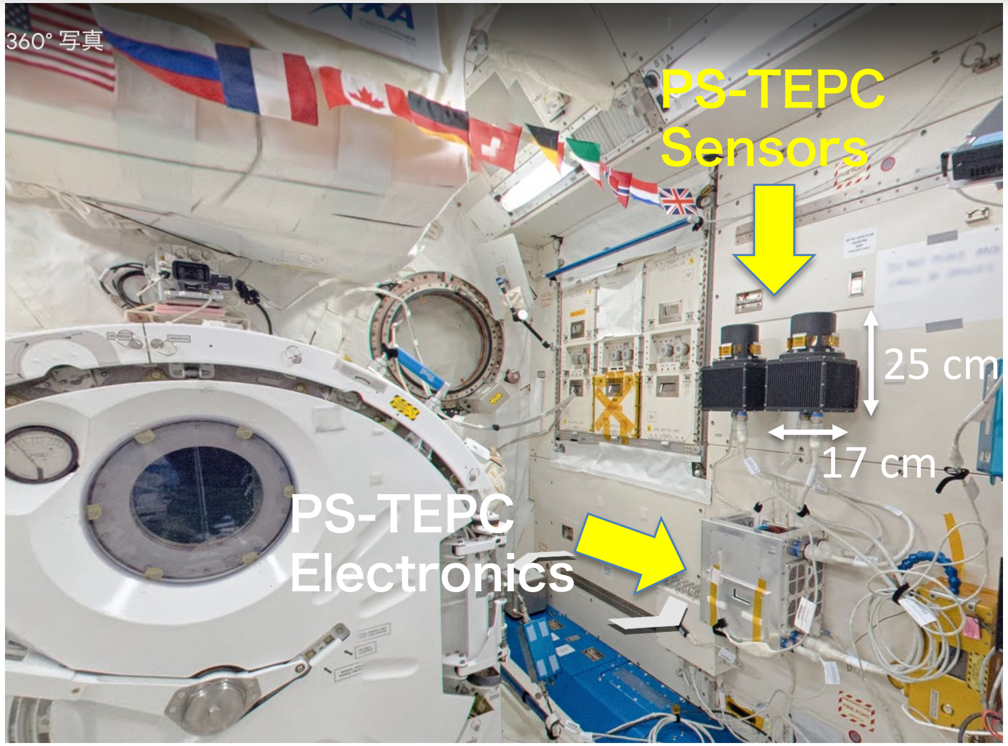
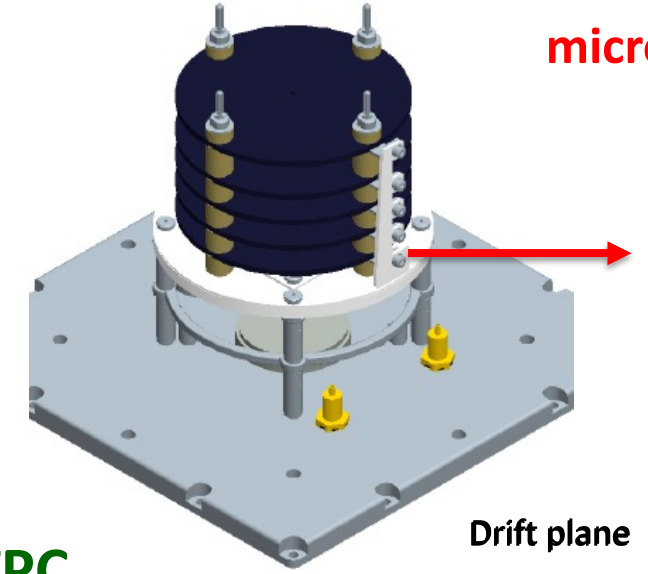
5.1 Realtime Space Dosimetry



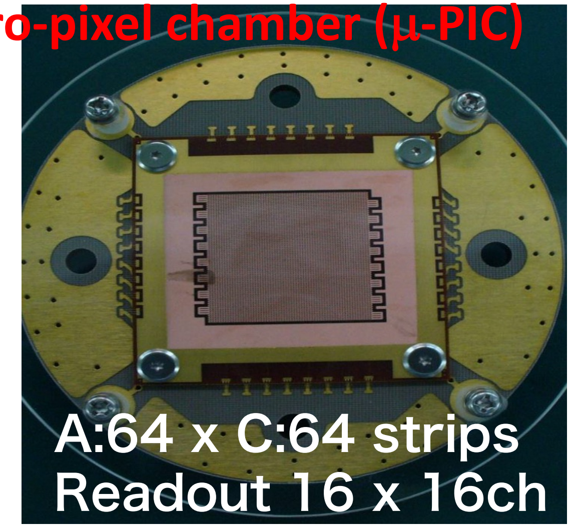
- Radiation exposure control is crucial for current/future human exploration in space.
- Precise and real-time LET monitor (dosimetry) is mandatory.
- The detector is preferably tissue-equivalent, gas: (CH_4 64.4% +CO_2 32.4% +N_2: 3.2%)
- position-sensitive tissue-equivalent proportional chamber (PS-TEPC)

5.2 PS-TEPC and moon exploration

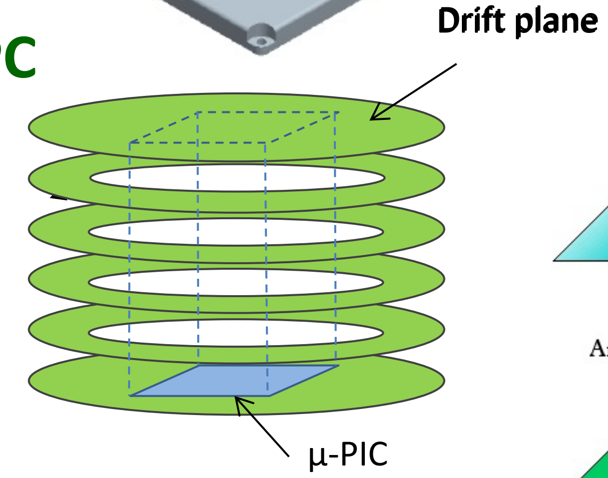
(Kishimoto+2018)



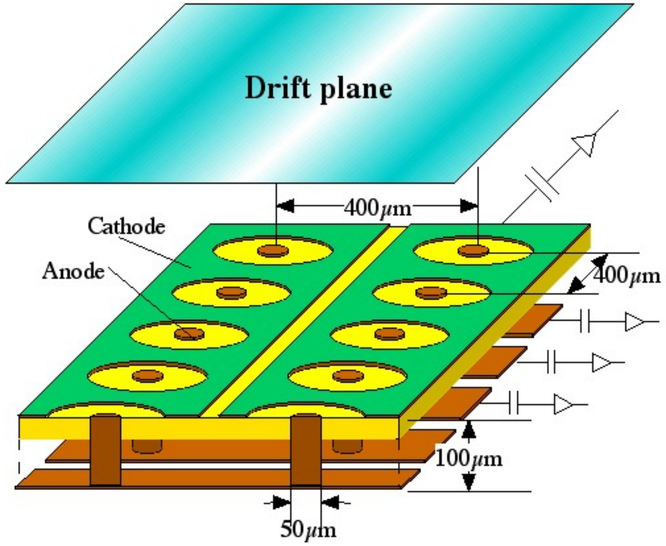
Time projection chamber using micro-pixel chamber (μ-PIC)



TPC



Fiducial volume
2.6×2.6×5.0 cm³



- Not integrated, but event by event.
- Spatial resolution, species.
- Tissue-equiv gases and plastics
- MPGD can play an important role.
- Planned to be installed on the Moon Gateway after 2027.

6.1 Summarized

Mission	Field	MPGD	Year
IXPE	X-ray polarimetry	Fine-pitch GEM	2021-
INTEGRAL/JEM-X	X-ray astrophysics	MSGC	2000-
NinjaSat	X-ray astrophysics	Thick-foil GEM	2023-
PolarLight	X-ray polarimetry	Thick-foil GEM	2018-
SMILE2+/3	Gamma astrophysics	uPIC/Thick-foil GEM	2018, 2026
SWEATERS	Space weather	Micromegas	202?-
PS-TEPC	Space dosimetry	uPIC	2016, 2027-

New MPGD such as GridPlix are expected to be join for space born missions.

6.2 Conclusion

- Space or sub-orbital missions which use MPGD were reviewed.
- Many astronomer consider gas detectors to be a generation old device, but I emphasize that gas detectors have some outstanding advantages not found in semiconductor detectors and other devices.
- With MPGD, the disadvantages of gas detectors have been greatly reduced; rather, the advantages have become more apparent.
- MPGD gave new life to space gas detectors. So far, excellent detectors have been launched in space and will continue to launch many in the future.

Thank all those who have been or are involved in the development of MPGD.