Nanosatellite Beacons for Space Weather Monitoring

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ESA 6th Round Table on MNT
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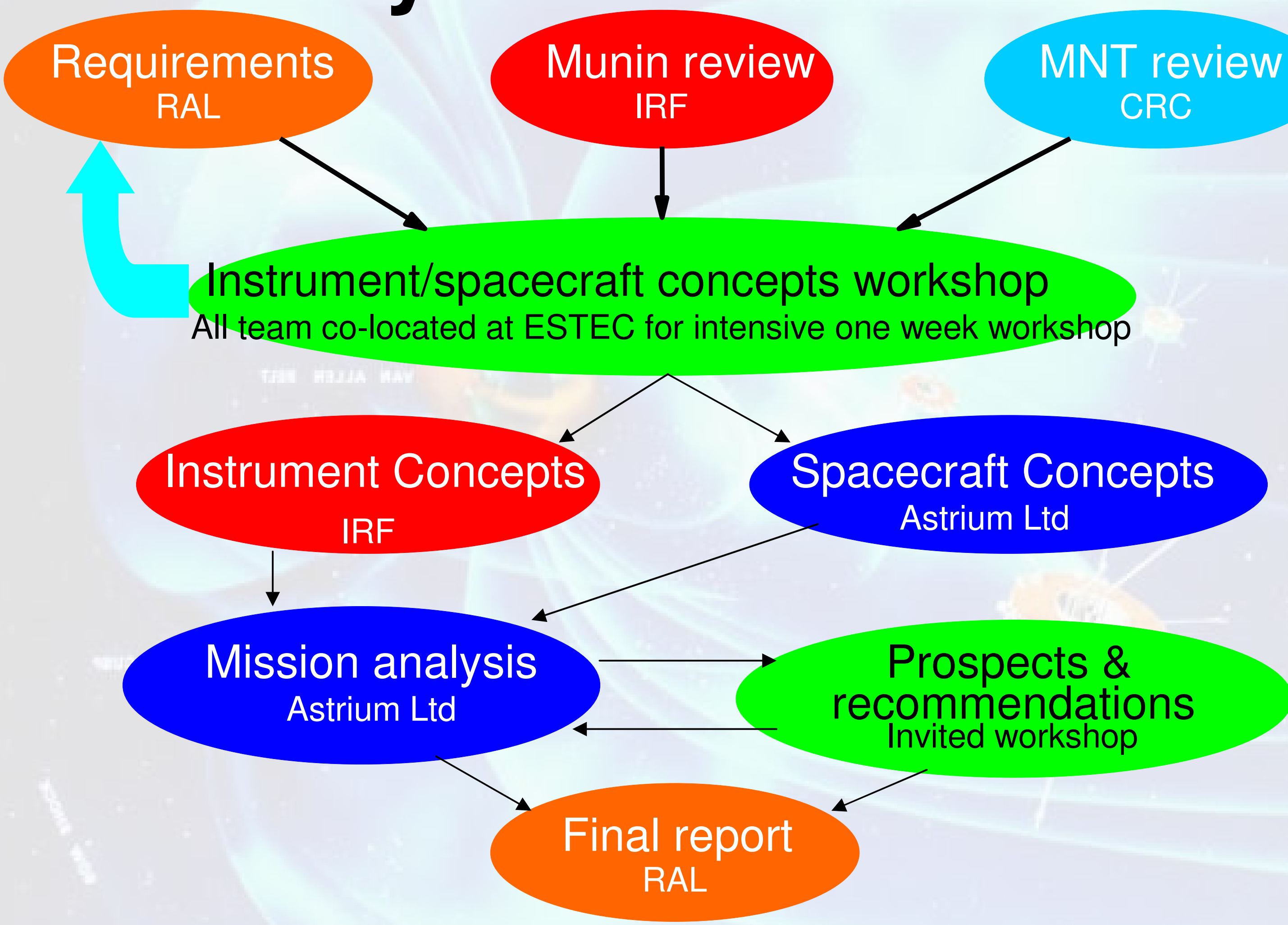
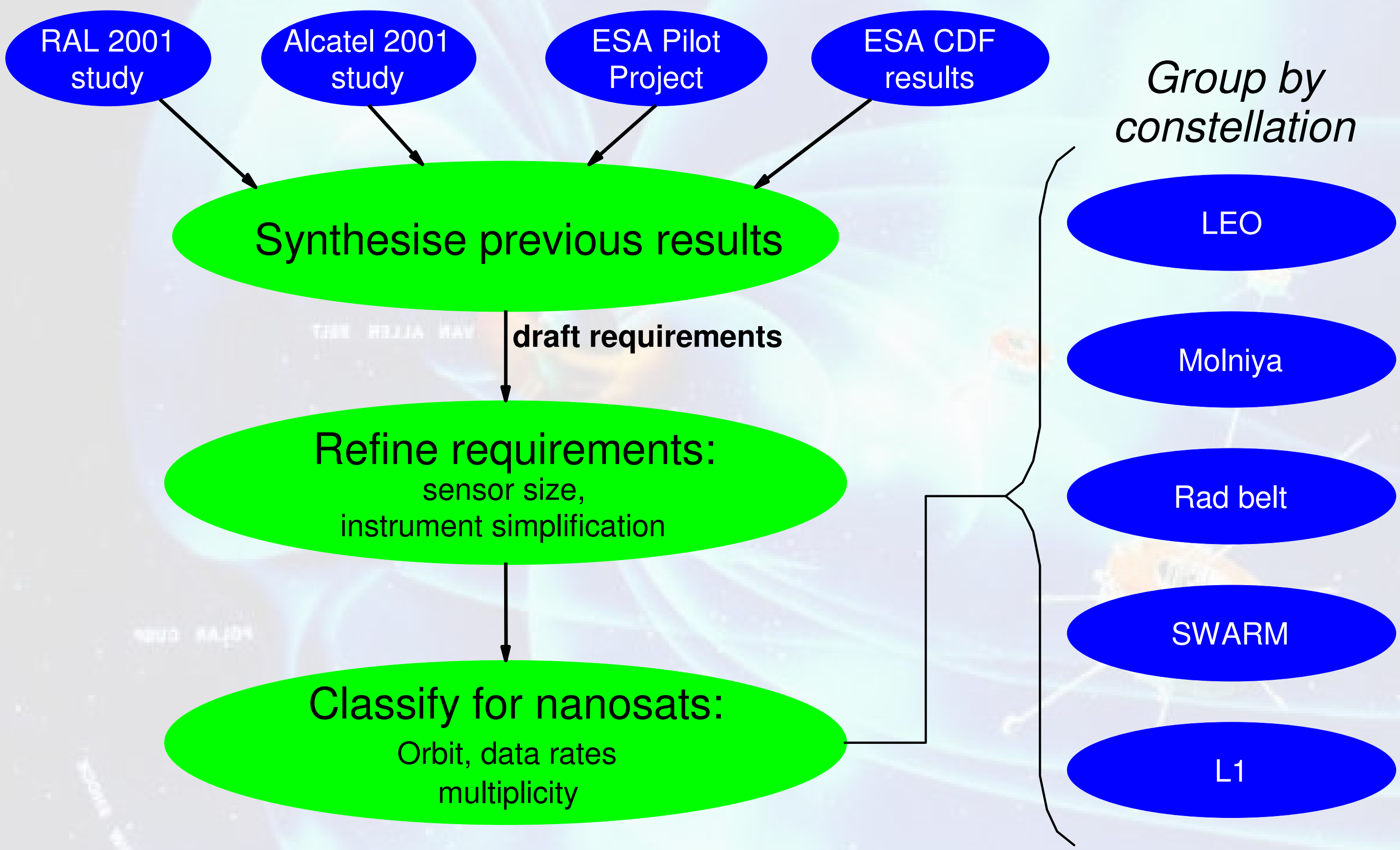
Study Rationale & Aims

- Main objective – consider potential roles for nanosats & MNT's to monitor space weather conditions within "Geospace".
  - Nanosats ideally suited as space weather beacons (***low mass instruments***, low data rates, high multiplicity reqd)
  - MNT's offer very low mass, power, volume
  - Combination of nanosats & MNT could allow innovative mission architecture solutions
- The study required space weather service with:
  - a minimum of 10 years continuous operations
  - deployment of spacecraft from 2010-2015.
  - inclusion of a nanosat replacement strategy

Study Flow Overview



Requirement Analysis



Requirement drivers and limits

- Driving requirement usually - real-time data reception.
  - major impact on communications & ground segment architectures
  - Relay constellations problematic for nanosats:
    - long link to MEO or GEO for nanosat antenna capability
    - no available European LEO relay constellation
  - Need crosslinks (LEO) or ground segment constellation (GTO)
- Some instruments too big for nanosats:
  - Optical measurements – if large systems (e.g. coronograph)
  - Plasma wave measurements – if large antenna needed
- Some instruments can be simplified
  - Low resolution ok for solar flare location
  - High flux detection ok for solar p^+, rad belt e^-, auroral e^-

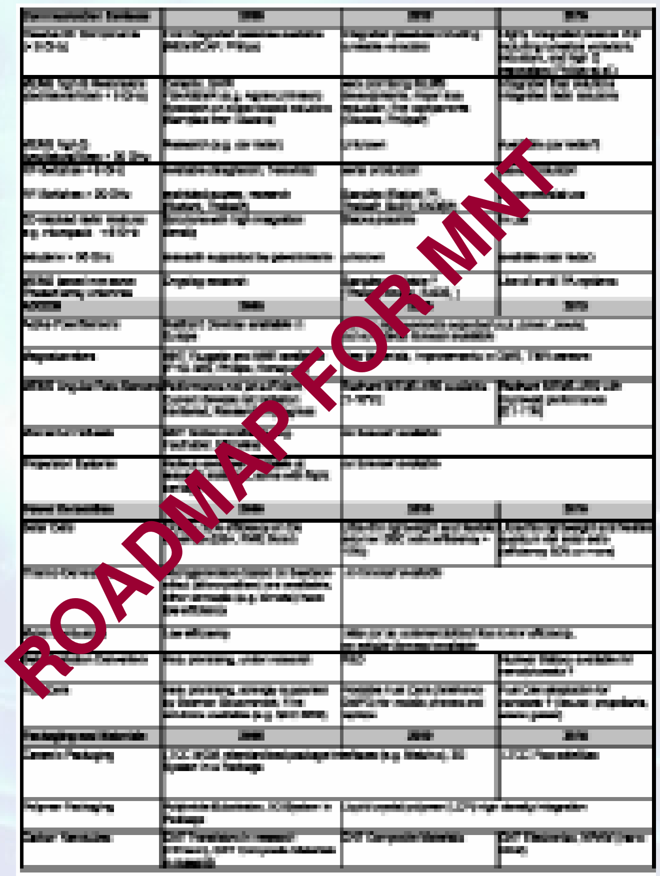
Nanosat experience

- IRF experience via Munin nanosat
- Europe’s first scientific nanosat!
  - 6 kg, 21 x 21 x 22 cm, 3 W nominal, 9 W peak
  - launched Nov 2000, lifetime 2.5 months
  - UHF comms (up and down)
- Made LEO Space Weather observations
  - energetic particles plus auroral imager
- Key lesson
  - On-board autonomy eliminates need routine command uplink & reduces impact of radiation

	Meas. range	Field of view	Time res. (s)	Look dir.	Mass (g)	Power (mW)
MEDUSA, ions and electrons	2 eV - 15 keV	10° x 360°	0.25	0°-180°	588	1000
DINA, ions and neutrals	20 - 2400 keV	5° x 30°,	0.25	0°& 90°	900	500
HiSCC, visible imager	320 x 249 pixels	50°	30-60	0°	100	300

Review of MNT status for Space

- MNT Roadmap produced
  - Focus on subsystem components
- Closest to market:
  - RF MEMS
  - AOCS & Propulsion (e.g. gyros)
- Critical Issues
  - Integration/Packaging/Materials
  - Qualification & Validation
- MNT instruments not reviewed
  - Much promise in this area
  - Drives design (e.g. accommodation)
  - needs further study!!



Requirements & Instrument solutions

- 25 measurement requirements applicable to nanosats
  - Requirements are in various orbit groups (e.g. LEO etc)
  - An instrument solution was mapped to each requirement
- Instruments characterised in terms of attributes and miniaturisation trends:
  - Instrument type and heritage (if any)
  - Mass, power, dimensions, data rate
  - Likely evolution (2005, 2010, 2020)
- Instrument budgets fed into later mission analysis

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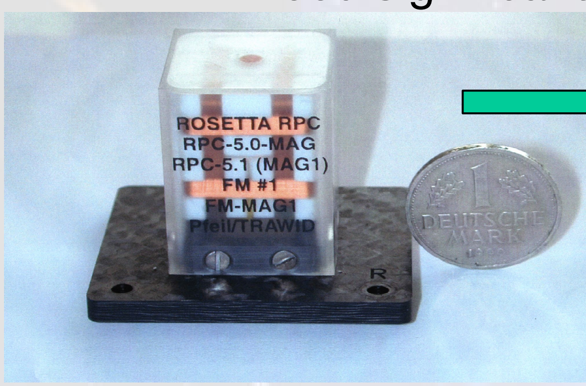
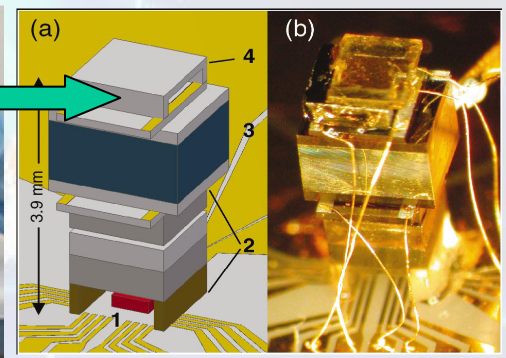
Instrument concepts/solutions

- Miniature solutions exist - e.g. space GPS (ionosphere sounding), dosimeter-on-chip, & Langmuir probes
- Others miniaturisable; e.g. magnetometers, particle detectors
- But - Limited miniaturisation with optical & some plasma devices
- Can we use intelligent techniques to ‘get around the physics’?
  - Fly many sensors on the surface of a spacecraft, e.g. magnetometry
  - Need significant development for space use!

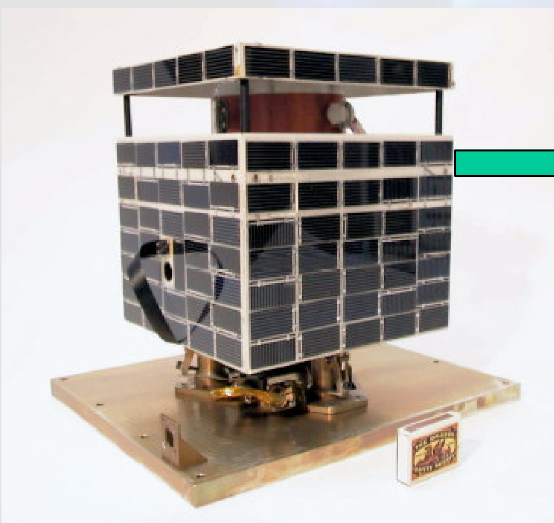


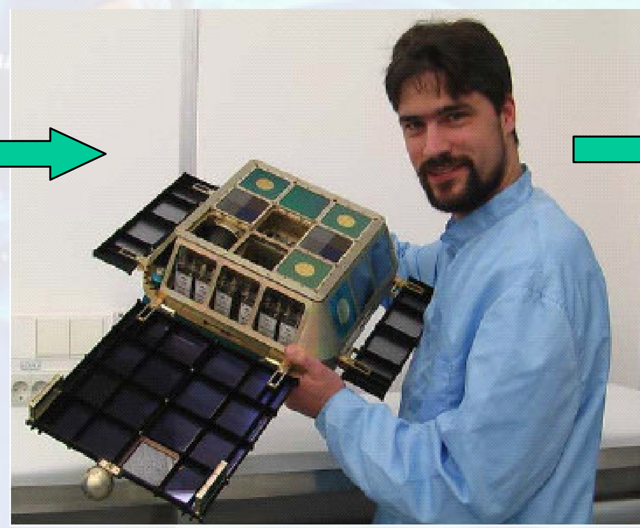


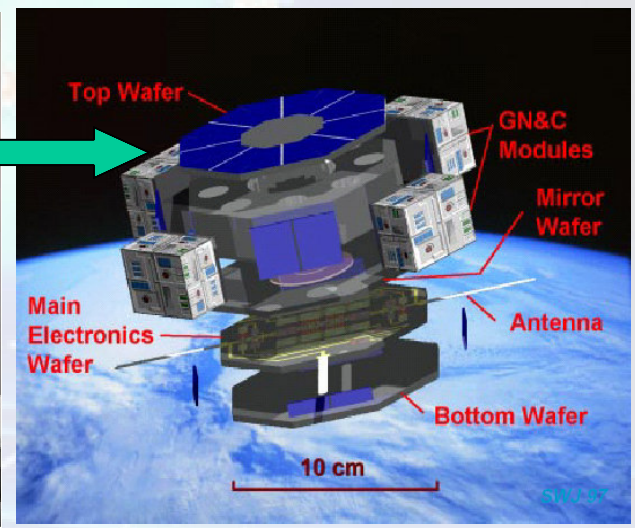
Magnetometer Trends for Space Weather:
Left - Rosetta’s MAG (launched 2002), Middle - Micro-link-1s MR (launch TBD), Right - DARPA sponsored Chipscale Atomic Magnetometer (2015-20?)

Spacecraft concepts/solutions

- Extensive review of nanosats (past, 2005, 2010, 2020)
- Analysis of mission & technology trends for nanosats
- Review fundamental limits/constraints of <10kg spacecraft







Nanosat Trends for Space Weather: IRF's Munin (launched 2000), AAC's Micro-link-1 (launch in 2009), Aerospace Corp's "Wafersat" (2015-20?)

Near term nanosat technology trends

Technology Area	Mission	Description
MEMS	PACE*	MEMS temperature sensors and course sun-sensors
	YAMSAT-1A*	MEMS spectrometer to measure the sunlight scattering spectrum from the atmosphere
Spacecraft deployment mechanism,	ST5	Assumed to be the deployment mechanism from launcher and other spacecraft
Electrodynamic tether for de-orbit	Cute 1.7*	Tether satellite disposal system.
Power	Delfi-C3*	Test-bed for thin film solar cells
	Hausat 1*	experimental solar panel deployment mechanism and Li-ion battery cells
	XI-V*	demonstration of newly developed CIGS (Cu(In,Ga)Se2) solar cells in space
Communications	Delfi-C3*	wireless on-board communication
	ST5	X-Band Transponder
AOCS	AASUSAT-II*	Active AOCS stabilization to detumble and actively control the satellite utilizing coils and momentum wheels.
	CP2v	three-axis attitude determination and control
	CP1*	Low cost sun sensor and experimental magnetorquer
	Can-X2*	Nanosatellite-sized reaction/momentum wheel for momentum bias three-axis stabilized attitude control
	Can-X2*	Custom-designed attitude determination system using a suite of coarse and fine sun sensors and a three-axis magnetometer
	Cute 1.7*	Demonstrate various attitude control algorithms, such as three-axis stabilization, detumbling, and spin-up, with three magnetic torquers placed orthogonal to each other. AOCS is three-axis gyrosensor, a three-axis magnetometer, a sun sensor and an earth sensor.
	ION*	demonstrate the use of an active magnetic attitude system.
	PACE*	momentum wheel, magnetic coils and sensors such as a three axis gyro, three axis magnetometer and course sun sensors. Existing cubesats do not employ 3 axis stabilisation due to power, mass and computation constraints.
	SEEDS*	test a 3 axis geomagnetic sensor and 3 axis gyros to measure satellite orientation
	ST5	Miniature magnetometer, Miniature spinning sun sensor, Magnetometer, deployment boom Nutation Damper,

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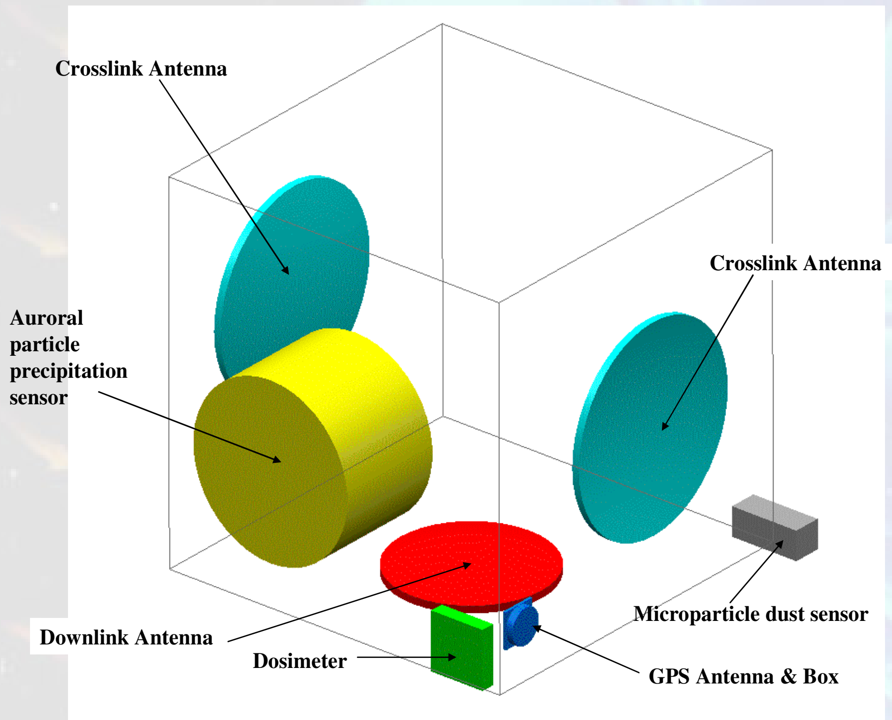
Mission & systems analysis approach

- 6 different mission classes analysed!
- Strawman mission concepts developed
- 2010 timeframe selected as baseline
- 10 year period for service provision
- Focus on overall mission design:
  - 10yr measurement & data provision robustness
  - Launch, transfer, deployment, mission geometry & coverage analysis, operations, constellation robustness, replacement…….

Strawman Missions Summary

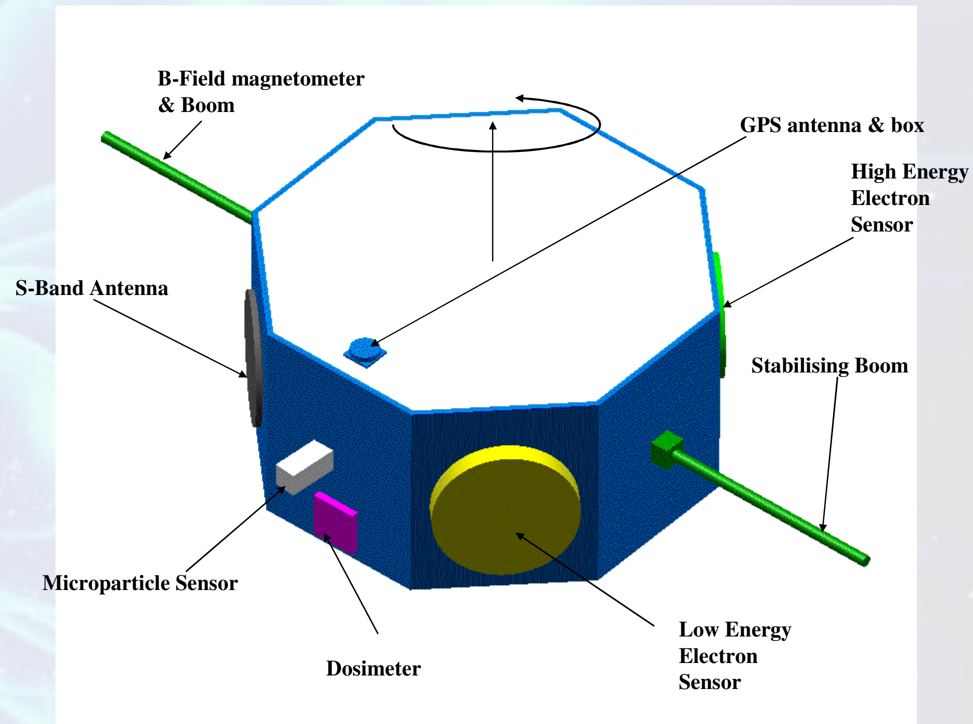
Constellation	Payload	Min no of satellites
LEO non-midnight (in-situ)	Auroral Particle Sensor, Dosimeter, GPS Antenna, Microparticle Dust Sensor	20
LEO dawn-dusk (in-situ)		12
LEO solar observing 1	UV Flux monitor	3
LEO solar observing 2	EUV Imager	3
LEO solar observing 3	X-ray/EUV Flux monitor	3
Molniya	Auroral Imager	3
GTO	Magnetometer, 1-10keV electron detector, 10-100keV high energy electron detector, Dosimeter, GPS Antenna, Microparticle Dust, Sensor	64
SWARM	Magnetometer	60
L1	Particle sensor (Solar wind bulk velocity & density) Magnetometer (Heliospheric magnetic field) Particle sensor (Heliospheric 2-100MeV & >100 MeV ions) Particle sensor (Heliospheric 2-20MeV electrons)	1

Conceptual LEO Ionospheric & GTO nanosats



Ionospheric LEO conceptual nanosat

25.7cm side length
26W max power
Payload 0.2kg, 1W



GTO conceptual nanosat

side length (across flats) 36cm, height 18cm
26W max power
Payload 1.7kg, 3W

Conclusions

- Nanosats can be useful low-cost component of future space weather service
  - Still need larger spacecraft for larger payloads (e.g. Coronagraphs)
- Space Weather nanosats can be further enabled by:
  - MNT (need to qualify for space) & Miniature instrumentation
  - Autonomy in space & on ground to simplify operations
  - On-board processing to compress data & reduce data rates
- Space weather nanosats <u>MUST</u> be highly reliable
- Clear need to prioritise/simplify requirements for nanosats
- Low-cost demo constellation encouraged to validate:
  - enabling technologies
  - reliability modelling for nanosats (GTO mission harshest)
  - Low cost multiple manufacture techniques

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Status

- Technical Notes were completed in early 2007
- Relevant work has since fed into ESA MNT Dossier
- Final Report to be completed by Nov 2007

Additional work in this area

- Detailed spacecraft design not possible within ESA study
- MSc Thesis projects with Cranfield University set-up to investigate this further
  - LEO space weather constellation (2005)
  - GTO space weather constellation (2007)
- Allows more in-depth nanosat design for a particular mission
- 'Real-life' project for student