PIXE 2017: PocketSpacecraft.com Integrated eXploration Environment

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6th Interplanetary CubeSat Workshop
iCubeSat 2017

Cambridge, United Kingdom
30th May 2017
goal
send spacecraft to orbit and/or land on the surface of every body in the solar system over the next 25 19 years
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>10 > ~ 5000km radius
>100 > ~ 100 km radius
>10,000 > ~ 20 km radius
>1,000,000 > ~ 0.5km radius in asteroid belt alone
**pocket spacecraft**
a spacecraft that an individual can afford to buy, launch and operate with little or no technical expertise

**personal space age**
the era of exploration of space by private individuals for science, general interest and profit

Graphics courtesy: JA / PocketSpacecraft.com
KickSat proof of concept mission

- Crowd sourced funding via 315 Kickstarter backers
  - 67 @ $25
  - 67 @ $75
  - 88 @ $300
  - 26 @ $1000
  - 0 @ $5000
  - 1 @ $10000
- 104+1 s/c -> ELaNa 5 launch April 2014
Pocket Spacecraft
TF-SLR Scout prototype v0.4

Solar cell
CIGS or Spectrolab TASC

SoC lapped to <50μm
TI CC430F5137IRGZ die

Printed passives (RCL)
e.g. Cabot CCI-300 ink

Antenna bustle/actuator
NiTi memory metal

Custom graphics
Laser marked

Graphics courtesy: JA / PocketSpacecraft.com
Spacecraft-on-Demand
Manufacturing mg to g scale spacecraft in space for science, exploration & entertainment

Traditional Mars Orbiter-Rover Mission

Spacecraft-on-Demand Mars Orbiter-Rover Mission (Virtual Node Names)

Funding:
- Centre for EO Instrumentation
- Santander
- Tsinghua University

Graphics: A. Taylor, Caltech – NASA / JPL, IA / PocketSpacecraft.com, N. Gabbani

NOT TO SCALE

F1 Earth
C1
C2
C3

T2

~24 light minutes

Mars

~$2000 million

F2

C1
C2
C3

vC4a
vS1a

vC4b
vS2a

vC4c
vS1b

vC5
vS2b

va1

$1 million
• Rad-hard open source Spacecraft on Chip (SpoC) IP core
  – Bit-serial, optimised for very low power (ASIC: <0.1-10 mW)
  – Variable size memory efficient micro architecture (1-128 bit)
  – Parametrically defined processing, storage, communication, general purpose input/output and sensor (e.g. pH, temperature) capabilities

• Process independent
  – Compatible with GaAs, SOI, thin-film & more
  – Suitable for ASIC, FPGA, MEMS, solar cell and thin-film substrate integration + SMD
  – Apply to existing devices / surfaces with focused ion beam or materials printer

• TRL3 (FPGA), TRL9 (ASIC) in 2017
• Very thin (<20 μm) low mass (<100 mg) TF-SLR lander designed for direct insertion from orbit by Interplanetary CubeSat Mothership

• Up to 200 mW @ 1.67 AU from solar cells backed by thin film energy storage

• Integrated processing, storage, communications and sensors (humidity, pressure and temperature)

• Can return data to traditional orbiters, deployment device, or each other using custom or CCSDS compatible UHF and S-band

• Robust, disposable, customisable

• Designed for COSPAR Class IVc planetary protection processes
Planetary protection
TF-SLR properties

• Common
  – A/m ratio: <10-20 g/m²
  – Substrates: 20 nm-50 μm polyimide, CP1, etc.
  – Power: 100 mW (10% of 80 mm Ø) – 100 W @ 1 AU (90% of 640 mm Ø) / 3.7 W @ 5.2 AU
  – Processor: 0.1 – 20 MHz COTS or custom rad hard
  – RAM: 0.1 – 4KB
  – Non-volatile: 0.1 – 64 KB (+up to 128 GB)
  – Radio: 0.01 – 10 W UHF/VHF/S-band, 0.1–1200 bps
  – Actuators: burn wires, magnetorquer, memory metal puller, microfluidics, reflectivity control device

• Custom
  – Expandable, inflatable and deployable structures
  – Printed or bonded instruments/sensors (e.g. dust, gyroscope, imager, Laingmuir probe, magnetometer, temperature, strain gauge, sun sensor, etc.)
Navigation & communications

SE607HBA - Onsala
3370272.092, 712125.596, 5349990.054
57.39875746, 11.93098904, 41.356
Delay compensation: OFF

DE604HBA - Potsdam-Bornim
3796380.254, 877613.809, 5032712.272
52.43785922, 13.01648194, 75.843
Delay compensation: OFF

DE603HBA - Tautenburg
3940296.126, 816722.532, 4932394.152
50.97939457, 11.71012829, 376.426
Delay compensation: OFF

DE602HBA - Unterweilenbach/Garching
4152568.416, 828788.802, 4754361.926
50.97934787, 11.71126745, 378.840
Delay compensation: OFF

CS002LBA - Superterp
3826577.462, 461022.624, 5064922.526
52.91511897, 6.66983284, 49.350
Delay compensation: ON

DE605HBA - Jülich
4095681.407, 458255.004, 4926467.940
52.91511897, 6.66983284, 49.350
Delay compensation: OFF

DE601HBA - Effelsberg
4034101.901, 487012.401, 4908230.210
50.52260468, 6.88365595, 356.993
Delay compensation: OFF

UK608HBA - Chilbolton
4006462.280, -100376.948, 4943716.600
51.14354266, -1.43445876, 177.05
Delay compensation: OFF

FR606HBA - Nançay
4324017.054, 165545.160, 4670271.072
47.37552429, 2.19250034, 182.091
Delay compensation: OFF

PS-DC44A - Bristol

AMS-IX - Amsterdam

Graphics courtesy: ASTRON, JA, LuxSpace, STFC
Interplanetary CubeSats

• Sizes from 0.5U → 6U
  – Interplanetary CubeSat Motherships (PocketSpacecraft.com)
  – INSPIRE (NASA/JPL)
  – MarCO (NASA/JPL)

• Lots more on the way from ESA, NASA and private companies (>100 million)

• Complete spacecraft: TRL8, path to TRL9 in 2017/2018

• Large toolbox of individual compatible subsystems including avionics, power, solar arrays, propulsion, etc., at TRL9

http://www.kiss.caltech.edu/study/smallsat/KISS-SmallSat-FinalReport.pdf

Image Credit: NASA-JPL/Caltech, Keck Institute for Space Studies
Interplanetary CubeSat Mothership

- 0.5U CubeSat to dispense >100 TF-SLRs
- Generic TF-SLR Dispenser
  
  ![Diagram]

  Tuna can       Foot flush       Top plate flush
  10-100mm TF-SLR stack = up to 2000 TF-SLR/U

- 3x Z+ mounted up to 100 W O888 deployable TWIST solar array arrays
- Parametric structure with shielding
- CubeSat Kit compatible subsystems with novel drop in upgrades

Graphics courtesy: JA / PocketSpacecraft.com
Interplanetary CubeSat Mothership

- Built for deep space
  Whipple shields, >5 mm Al, etc.
- Extensive test program
- Inexpensive ($10s K)
- Multiple flight spares

• Redundant systems
  – Thin film avionics, minimal mass penalty
  – Distributed processing and interconnects
  – Multiple communication systems (U/V/S)
  – Over actuated
    e.g. reaction wheels, deployment systems
What do you want to fly?

Control experiments?  Inflatable?  Deployable?

First heliogyro on orbit?  <<10 g/m² sails?

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Acknowledgements

>4000 private individuals in >45 countries

and many others
michael@PocketSpacecraft.com

“It’s hard to imagine [TF-SLRs] will be capable enough, but that’s exactly what people said about CubeSats”

Therese Moretto Jorgensen, Program Director, National Science Foundation

Nature 508, 300-301 (17 April 2014)

7th Interplanetary CubeSat Workshop
Paris, France
29-30 May 2018

iCubeSat 2018, the seventh Interplanetary CubeSat Workshop, will address the opportunities, technical challenges, and practicalities of space exploration with CubeSats. The workshop will provide a unique environment for open practical collaboration between academic researchers, industry professionals, policy makers and students developing this new and rapidly growing field.

Talks on astrodynamics, attitude control and determination systems, citizen science, citizen space exploration, communications, landers, launch opportunities, open source approaches, outreach, payloads, policy, power systems, propulsion, reentry systems, rideshares, science missions, software, standardization, structures, systems engineering and other related topics are all welcome.

The workshop will be held on or near the campuses of l’Observatoire de Paris and École Normale Supérieure de Paris Sciences et Lettres in central Paris, France.

Abstracts due 1st April 2018 via iCubeSat.org

www.iCubeSat.org

Graphics: B.Bishop, JA / iCubeSat.org, NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI)
• PocketRTG radioisotope thermoelectric generator
  – One to six <0.5 g Americium 241 (preferred), Plutonium 238 or Strontium 90 pellets
  – Up to 50mW electrical output for decades
  – <50 x 50 x 50 mm, <500 g
  – Configurable with direct or decoupled electrical and thermal payload interfaces
  – Repackaging as RHU with substantial mass/volume savings viable
• Safety
  – designed to relevant ESA/NASA standards
  – penetrator mission concept parameters within design limits
  – potential for light touch regulation due to minimal fuel mass
• TRL4 (\(^{241}\)Am) 2016, path to TRL9 TBD (?2018/19)