Small satellites for big science: the challenges of high-density design in the DLR Kompaktsatellit AsteroidFinder/SSB

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H. Michaelis, S. Mottola, M. Siemer, P. Spietz & the AsteroidFinder Team

DLR German Aerospace Center

AsteroidFinder Mission & Instrument presentations given at the COSPAR 2010

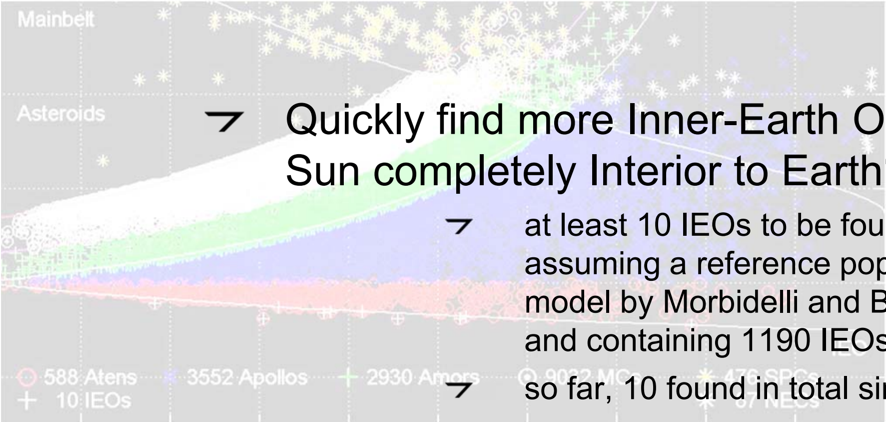
- on the AsteroidFinder science mission
  - Stefano Mottola et al. ***The DLR AsteroidFinder for NEO***
  - Symposium P, Session SW2, Nr. 17 (COSPAR-10 PSW2-0017-10)
  - Sunday, 18 July 2010, 18:00-18:30, Hall 4.1 / Jupiter

    (solicited talk)

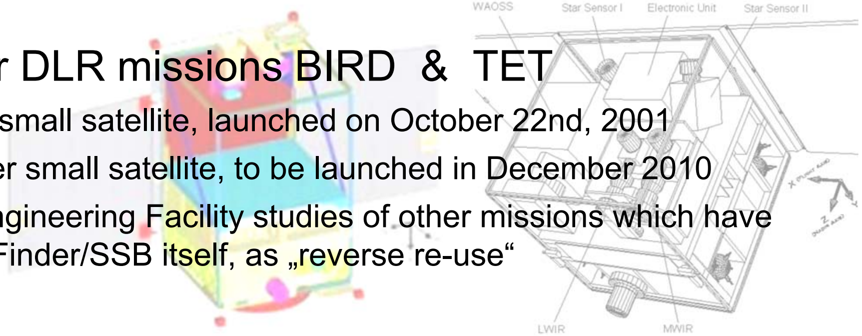
- on the AsteroidFinder Instrument payload (AFI)
  - Harald Michaelis et al. ***The AsteroidFinder Instrument***
  - Symposium P, Session SW2, Nr. 23 (COSPAR-10 PSW2-0023-10)
  - Tuesday, 20 July 2010, 16:00-17:30, Hall 3 / Poster Area; Tue-334

    (poster presentation)

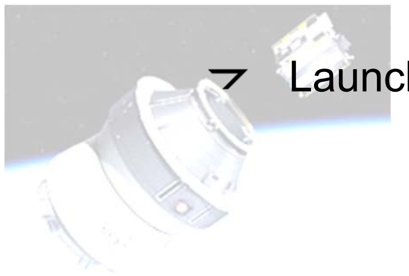
AsteroidFinder in basic requirements



- Quickly find more Inner-Earth Objects, i.e. small solar system bodies orbiting the Sun completely Interior to Earth‘s Orbit (IEO)
  - at least 10 IEOs to be found and tracked sufficiently to allow precise orbit determination, assuming a reference population equivalent to the long-term orbit evolution propagation model by Morbidelli and Bottke, simulated down to H = 23mag ⬄ Ø ~100m @ albedo 0.15, and containing 1190 IEOs and ~3300 Atens, of a total of 57649 objects
  - so far, 10 found in total since 1998, the first one lost again, and only 1 „deep“ IEO known



- Re-use as much as possible of the earlier DLR missions BIRD & TET
  - BIRD – *B*ispectral *I*nfra*R*ed *D*etection small satellite, launched on October 22nd, 2001
  - TET – Technology Experiments Carrier small satellite, to be launched in December 2010
  - take advantage of local Concurrent Engineering Facility studies of other missions which have their first iterations based on AsteroidFinder/SSB itself, as „reverse re-use“



- Launch „piggy-back“ in 2013
  - take into account all launch vehicles presently announced or available on the market
  - be ready for every flight opportunity: no self-generated technical restrictions
  - robust design in terms of mechanical ruggedness and operational flexibility

How to get your scientific satellite into space – Step 1: Decide…

Method (A) – or – Method (B)

(*Note*: not to scale)

ACCOUNTANT-GERNERAL'S WARNING: Taking decisions may irreversibly affect your financial health.

CP 4 in flight photographed by AeroCube-2, Apr.17 2007 – EnviSat model during ground maintenance, by abrev

Satellite Size Matters

Cubesat

- limited resources
- limited space
- limited mass
- no repeat pattern
- no LTAN control
- no altitude control

+ clearly defined design conditions
+ efficient solutions
+ up-to-date components and methods
+ changing coverage pattern
+ time-variable coverage
+ decay changes observing conditions

Envisat

stable observing conditions +
predictable coverage cycles +
set data-take schedule +
space-qualified hardware & methods +
proven solutions +
design-to-mission flexibility +

fuel-related risks & hazards -
substantial analysis effort -
payload reliance on bus services -
no intrinsic hard growth limit -
volumionus platform-box structure -
resource sharing between payloads -

Pros & Cons

Cubesat | **Envisat**

- limited resources
- limited space
- limited mass
- no repeat pattern
- no LTAN control
- no altitude control

what you can do

mission-related

what you want

stable observing conditions +
predictable coverage cycles +
set data-take schedule +
space-qualified hardware & methods +
proven solutions +
design-to-mission flexibility +

+ clearly defined design conditions
+ efficient solutions
+ up-to-date components and methods
+ changing coverage pattern
+ time-variable coverage
+ decay changes observing conditions

easy

development-related

risky

fuel-related risks & hazards -
substantial analysis effort -
payload reliance on bus services -
no intrinsic hard growth limit -
volumionus platform-box structure -
resource sharing between payloads -

$^{X}/_{Y} \cong$ efficiency

Satellite Size – Is there a best-of …?

from Cube:

- limited resources
- limited space
- limited mass
- no repeat pattern
- no LTAN control
- no altitude control

+ clearly defined design conditions
+ efficient solutions
+ up-to-date components and methods
+ changing coverage pattern
+ time-variable coverage
+ decay changes observing conditions

?

from Envisat:

stable observing conditions +
predictable coverage cycles +
set data-take schedule +
space-qualified hardware & methods +
proven solutions +
design-to-mission flexibility +

fuel-related risks & hazards -
substantial analysis effort -
payload reliance on bus services -
no intrinsic hard growth limit -
volumionus platform-box structure -
resource sharing between payloads -

„Small Satellites", the buzzword approach – or: How to Clash the Cultures

from Cube up:

± smart design-to-cost
± efficient hardware
± careful design
- no repeat pattern
- no LTAN control
- no altitude control

+ clearly defined design conditions
+ when new, efficient solutions
+ when needed, up-to-date design
+ orbit drift insensitivity
+ time-variable coverage
+ decay changes observing conditions

from Envisat down:

one full-scale instrument +
capable attitude control +
early mission analysis +
re-use of hardware & methods +
proven design concepts +
design-to-mission flexibility +

fuel-related risks & hazards -
substantial analysis effort ±
organic bus-payload integration ±
no intrinsic hard growth limit -
volumionus platform-box structure -
resource sharing between payloads -

?

„Small Satellites", *the* ~~buzzword~~ approach – or: How to ~~Clash the Cultures~~ Make It Work

work & think harder!

from Cube up:

question basic requirements!

± smart design-to-cost
± efficient hardware
± careful design
- no repeat pattern
- no LTAN control
- no altitude control

+ clearly defined design conditions
+ when new, efficient solutions
+ when needed, up-to-date design
+ orbit drift insensitivity
+ time-variable coverage
+ decay changes observing conditions

payload & bus: work & think together!

√

from Envisat down:

one full-scale instrument +
capable attitude control +
early mission analysis +
re-use of hardware & methods +
proven design concepts +
design-to-mission flexibility +

fuel-related risks & hazards -
substantial analysis effort ±
organic bus-payload integration ±
no intrinsic hard growth limit -
volumionus platform-box structure -
resource sharing between payloads -

capitalize benefits!

enforce initial decisions!

Convergence Matters!

from Cube up:

work & think harder!

question basic requirements!

- **multi-scenario mission analysis in cycles**
- **multiple design options**

from Envisat down:

± **smart** design-**to-cost**

± **efficient** hardware

± **careful** design

\- no **repeat** pattern

\- no LTAN **control**

\- no altitude control

one full-scale instrument +

capable attitude control +

early mission **analysis** +

re-use of hardware & **methods** +

proven design concepts +

design-to-**mission flexibility** +

100³cm³

200 kg

300 W

\+ **clearly defined** design conditions

\+ when **new, efficient** solutions

\+ when needed, **up-to-date** design

\+ orbit **drift insensitivity**

\+ **time-variable** coverage

\+ decay **changes observing conditions**

fuel-related risks & hazards -

substantial analysis effort ±

organic bus-payload **integration** ±

no intrinsic hard **growth limit** -

volumionus **platform-box structure** -

resource sharing between payloads -

payload & bus: work & think together!

- **integrated tech-team**
- **one system-level design**

enforce initial decisions!

capitalize benefits!

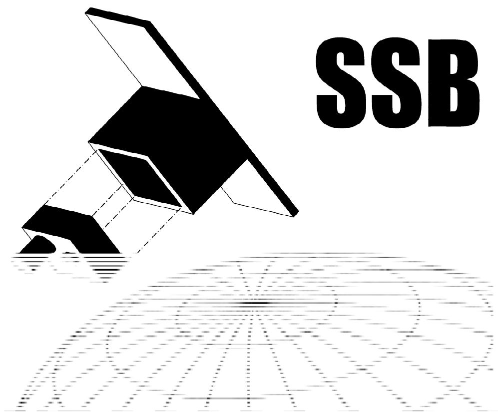
save fuel mass

redistribute gains made

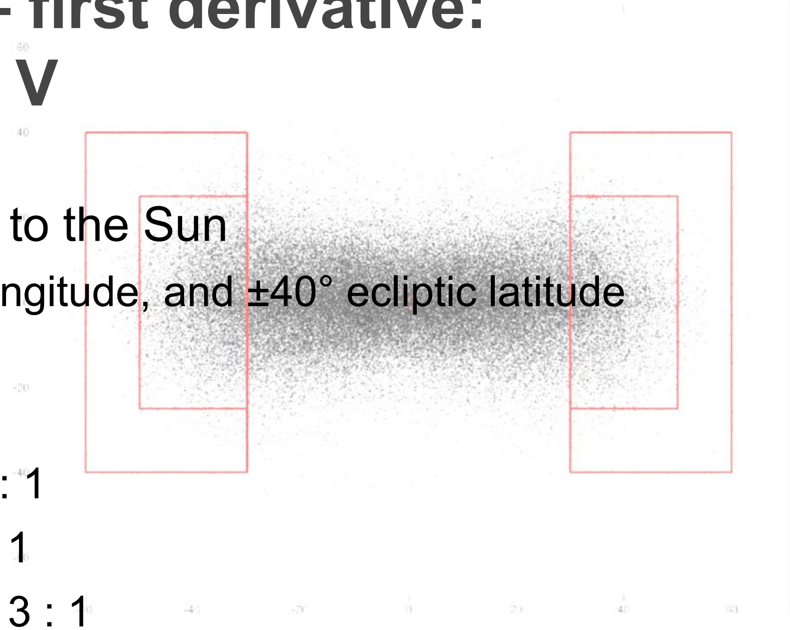
system-level margin management

„Kompaktsatellit“ programmatics

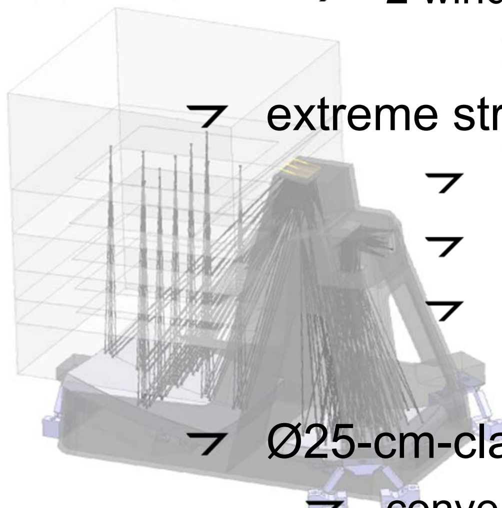
- the „Kompaktsatellit“ programme has been created for scientific payloads from within DLR
- „Kompaktsatellit“ spacecraft focus on one scientific mission and payload instrument
- The AsteroidFinder instrument has been selected following an internal competition, to become the first payload in the „Kompaktsatellit“ programme
- AsteroidFinder/SSB is the first satellite in a planned series of future satellites in the „Kompaktsatellit“ programme as part of the DLR research & development programmes



AsteroidFinder requirements – first derivative: Rough-Order mag +18.5 V

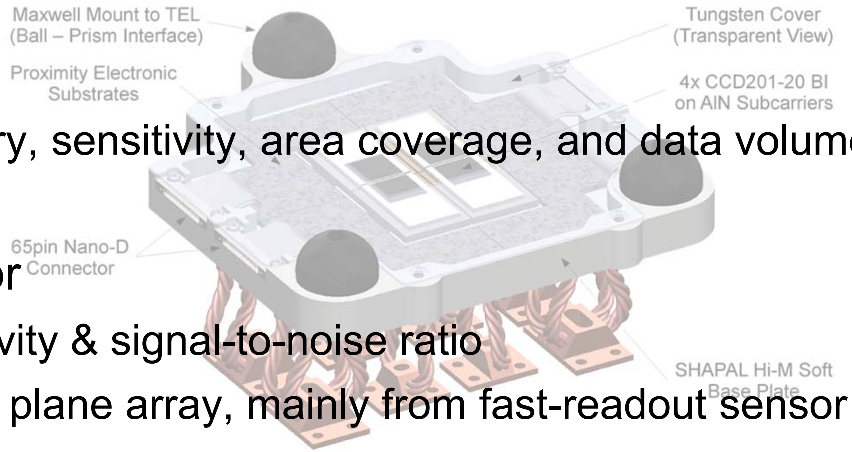


- Region of Interest (RoI) defined relative to the Sun
  - 2 windows at ± (≤30° to 60°) ecliptic longitude, and ±40° ecliptic latitude

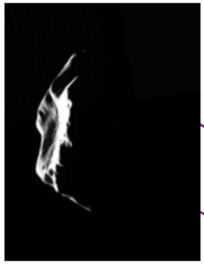


- extreme straylight suppression
  - Sun : asteroid ~ 10^{18} : 1
  - planet : asteroid ~ 10^{8} : 1
  - asteroid : background ~ 5 : 1 … 3 : 1

- Ø25-cm-class telescope
  - convergence of astrometry, sensitivity, area coverage, and data volume

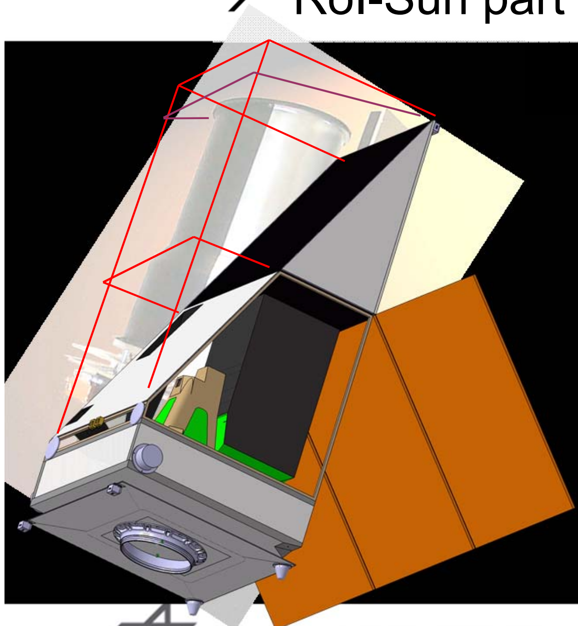


- passive cooling of the sensor
  - -80°C required for sensitivity & signal-to-noise ratio
  - ~3 W dissipation on focal plane array, mainly from fast-readout sensor itself



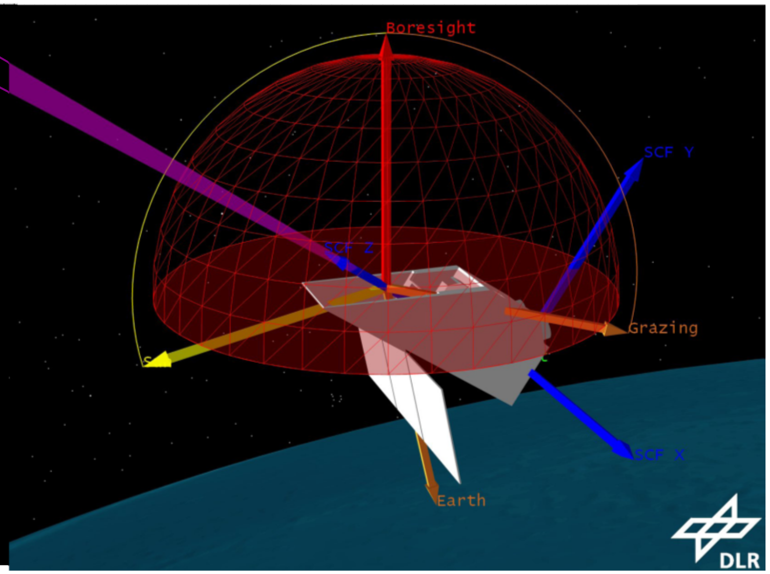
Geometry – Region of Interest vs Straylight
wedged in between constraints

- targets of observation are faint <u>*and*</u> close to the brightest source of all
- the second-brightest source covers almost half of the sky all the time
- *scattered* straylight from either source: observations beome impossible
- the whole satellite shape is defined by RoI-Earth-Sun geometry, only
- RoI-Sun part of geometry is LTAN-independent, but RoI-Earth is not



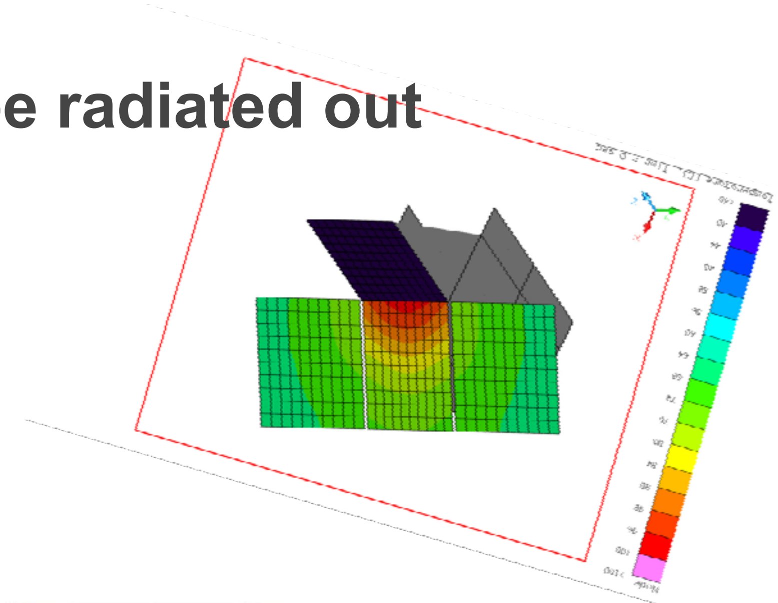
cost of constraint:

- >¼ of payload volume
- ~¾ of deployable baffle volume
- scientific yield reduced when moving away from dawn-dusk Sun-synchronous orbit

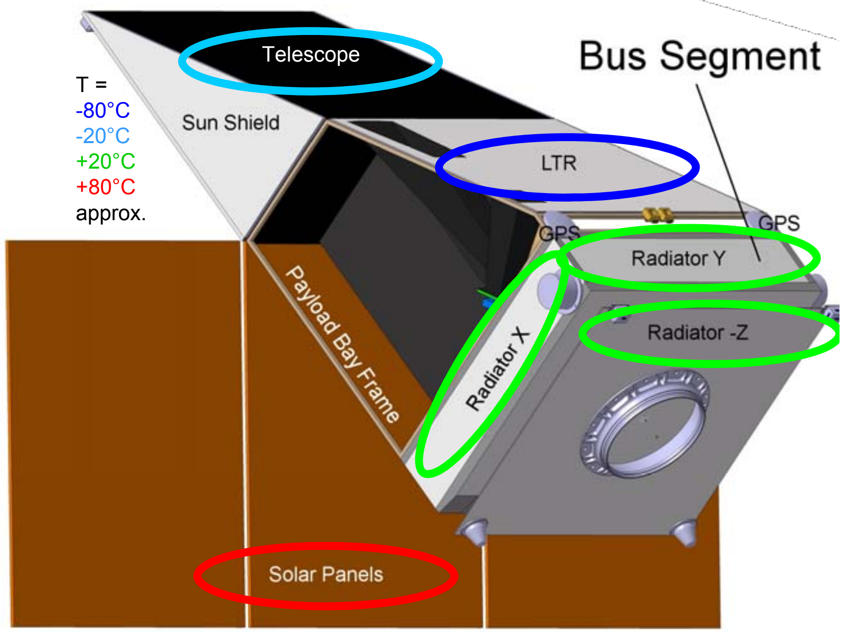


Power – what goes in… must be radiated out

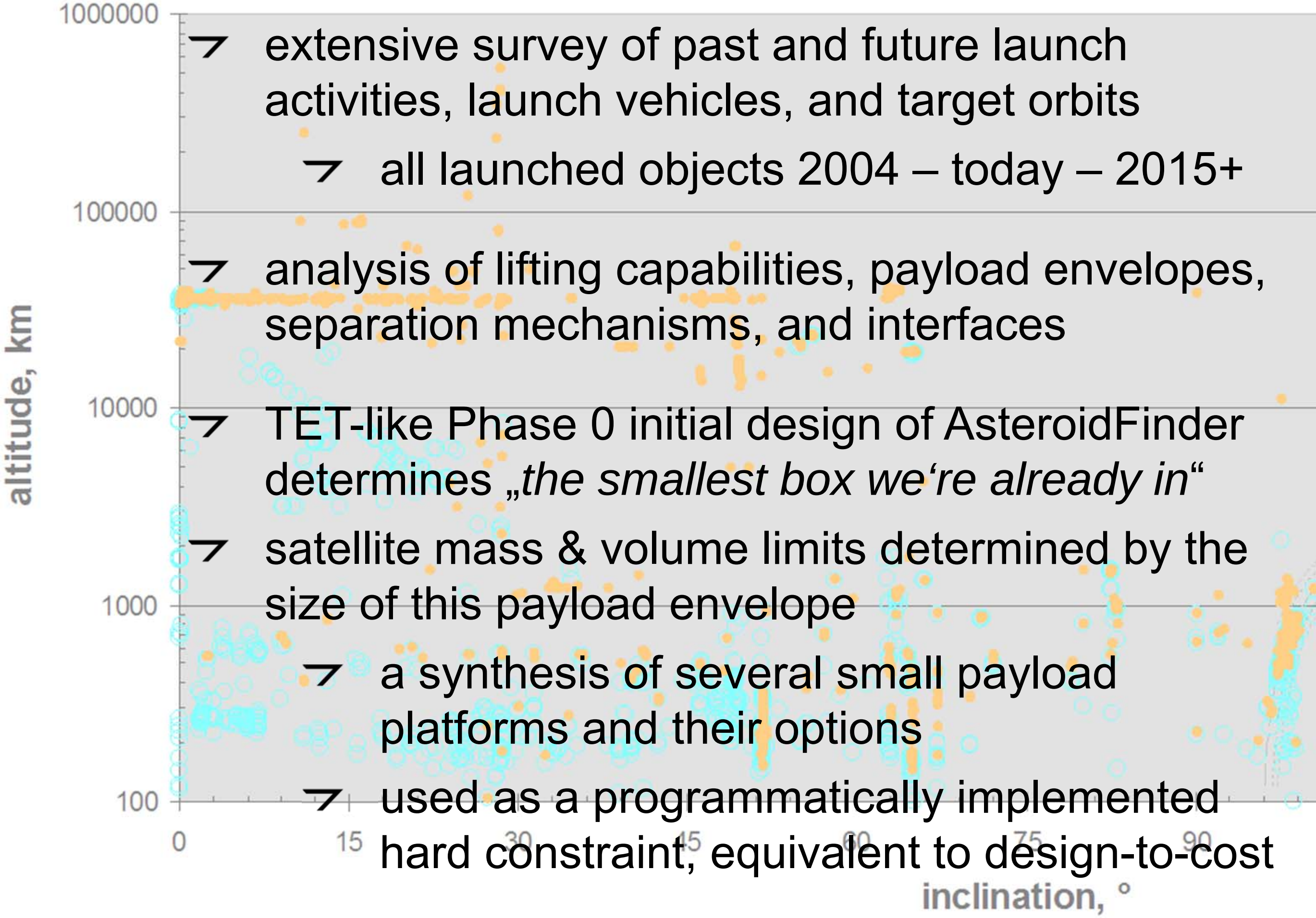
- 24/7 IEO survey observations
- operational satellite, not tech-dem
- 720 images & slews / day
- significant on-board processing



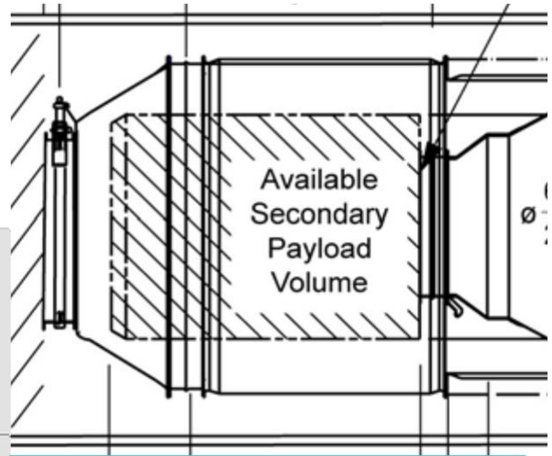
- ~275 W constant power consumption
- maximum solar panel area available in stowed & deployed configuration
- ‚hot' solar panels very close to the ‚cool' telescope bay at upper hinge
- ‚cold' radiator well protected, but some leakage inevitable
- majority of satellite surface collects energy and/or radiates dissipation
- *energy flow ⇔ lower-limit satellite size*



„piggy-back“ – optimized stowaway

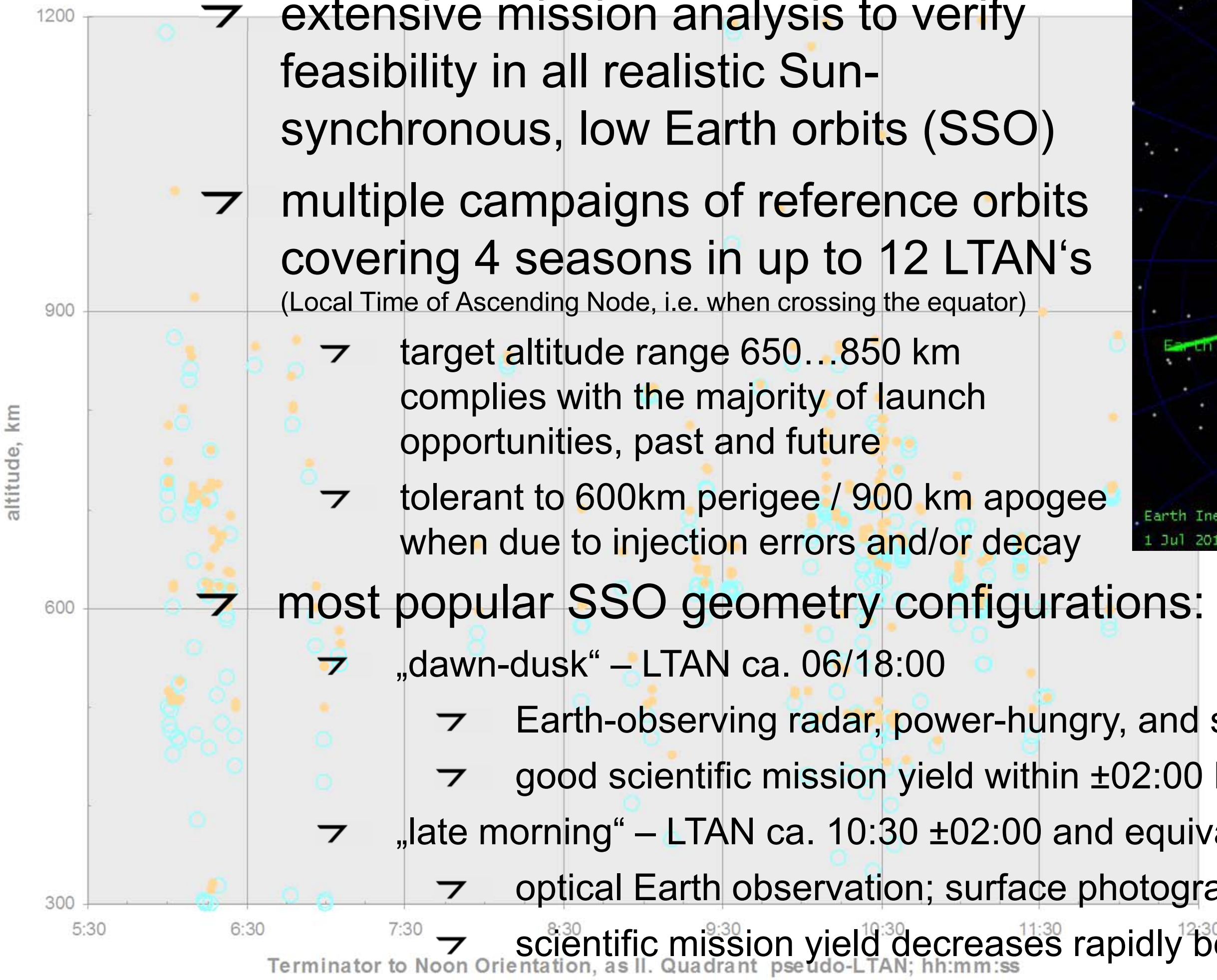


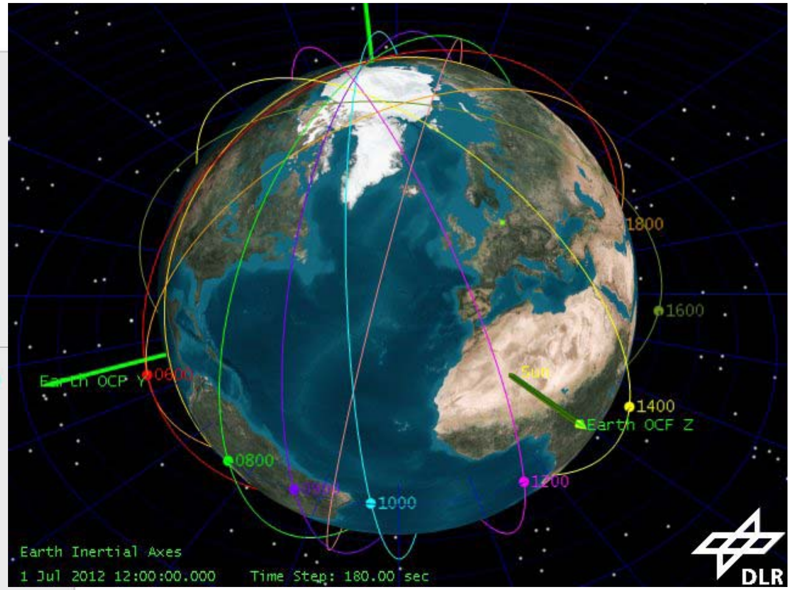
- extensive survey of past and future launch activities, launch vehicles, and target orbits
  - all launched objects 2004 – today – 2015+
- analysis of lifting capabilities, payload envelopes, separation mechanisms, and interfaces
- TET-like Phase 0 initial design of AsteroidFinder determines *„the smallest box we‘re already in“*
- satellite mass & volume limits determined by the size of this payload envelope
  - a synthesis of several small payload platforms and their options
  - used as a programmatically implemented hard constraint, equivalent to design-to-cost



- **BIRD**
  - 550 · 620 · 647 of 600 · 600 · 800 mm³
  - 92 of 100 kg
  - defined by Kosmos-3M, actually flew with PSLV
- **TET**
  - 546 · 639 · 821 of 550 · 650 · 880 mm³
  - 120 of 120 kg
  - defined by „BIRD+-P/L‘s“, to fly with Soyuz-Fregat
- **AsteroidFinder/SSB**, Ph. 0 - ΔA
  - 550 · 650 · 880 mm³
  - 112…135 of 120 kg
  - defined by TET
- **AsteroidFinder/SSB**, Ph. ΔA & B
  - 800 · 800 · 1000 mm³
  - 160 ±20 of 180 kg
  - defined by launch vehicles

„piggy-back“ – wherever you end up

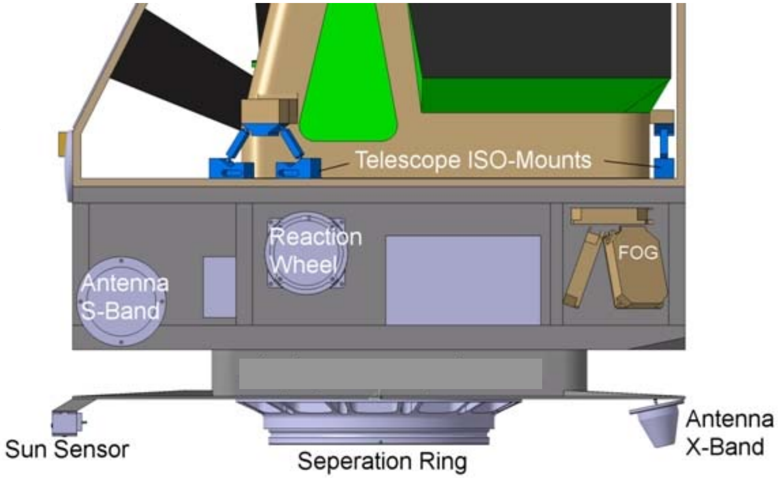


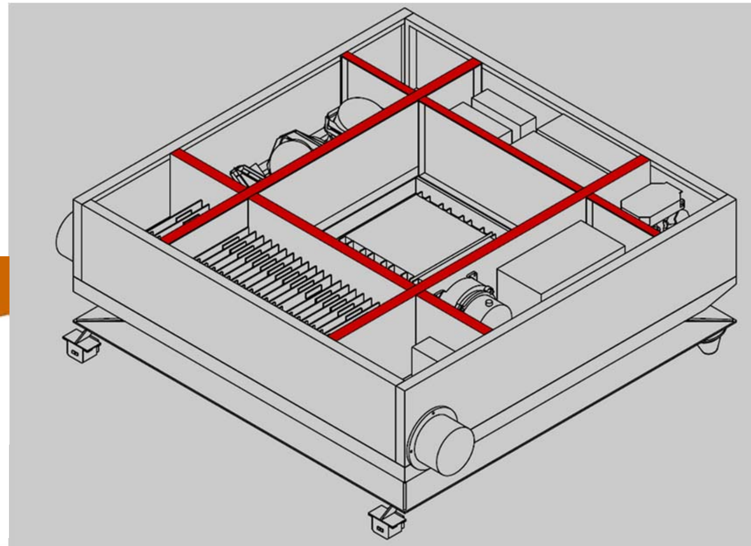


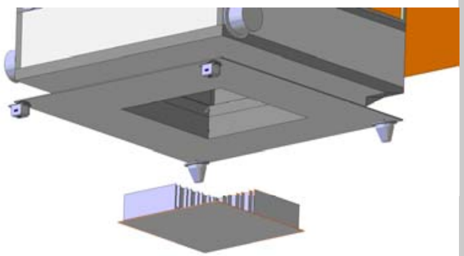
- extensive mission analysis to verify feasibility in all realistic Sun-synchronous, low Earth orbits (SSO)
- multiple campaigns of reference orbits covering 4 seasons in up to 12 LTAN‘s
  (Local Time of Ascending Node, i.e. when crossing the equator)
  - target altitude range 650…850 km complies with the majority of launch opportunities, past and future
  - tolerant to 600km perigee / 900 km apogee when due to injection errors and/or decay
- most popular SSO geometry configurations:
  - „dawn-dusk“ – LTAN ca. 06/18:00
    - Earth-observing radar, power-hungry, and solar science primary payloads
    - good scientific mission yield within ±02:00 LTAN, acceptable within ~±03:00
  - „late morning“ – LTAN ca. 10:30 ±02:00 and equivalents
    - optical Earth observation; surface photography, weather and atmosphere
    - scientific mission yield decreases rapidly beyond 09:00-LTAN-like geometry

In the Box – /SSB internal accommodation

- easy access to all units
- all bus & many payload units in one box
- avionics on Eurocards & backplanes
- extremely high volume utilization
- massive Al structure provides:
  - mechanical load handling
  - thermal conduction
  - thermal inertia
  - radiation shielding
  - Σ : *lighter than dedicated subsystems!*
- battery removable,
- separation mechanism exchangeable
- eases integration & reduces launch delay and launcher change impact







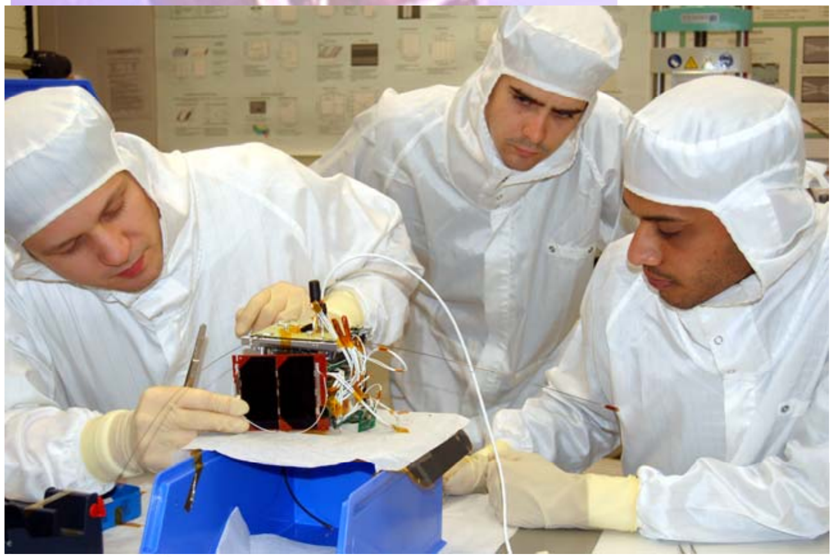
Out of the Box

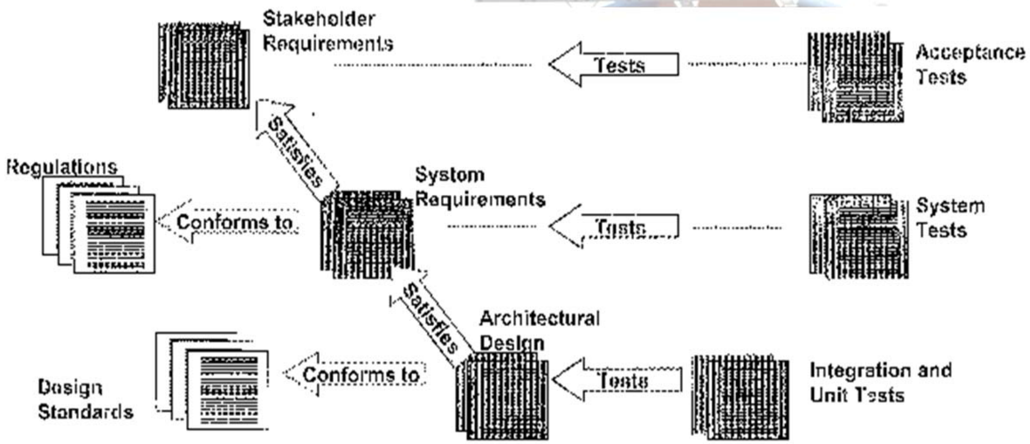
Cubesat Style

- small team
- intense cross-training
- immediate communication
- single-site design, production, testing

Envisat Style

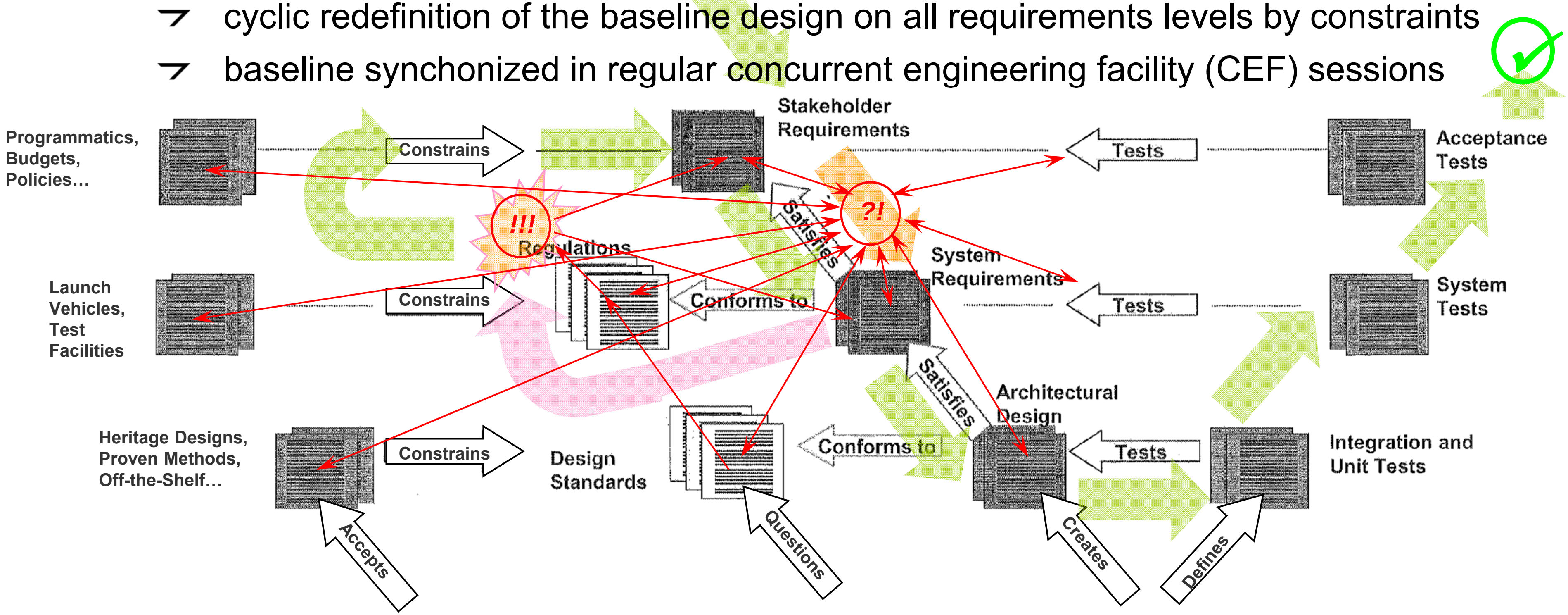
- large team
- highly specialized
- hierarchical communication
- many partners, distant sites, procedures



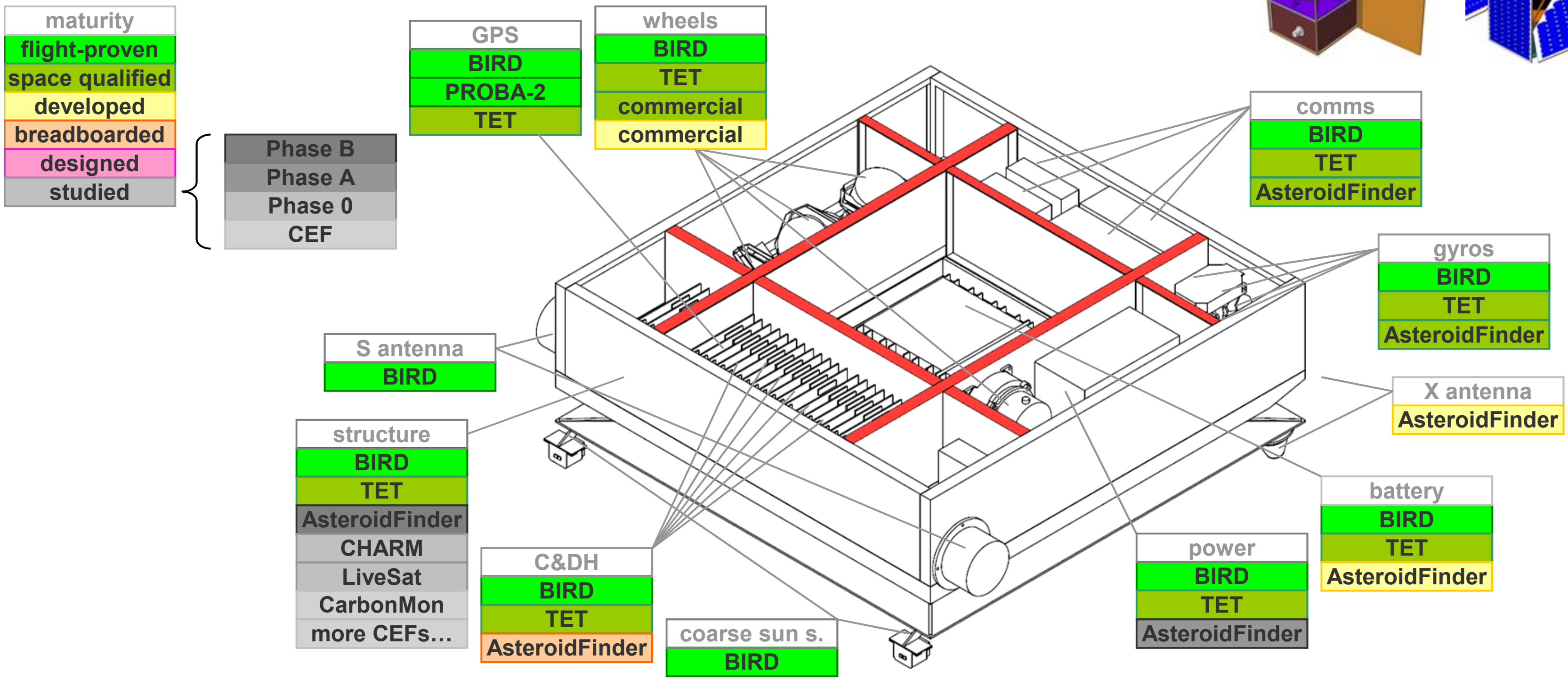


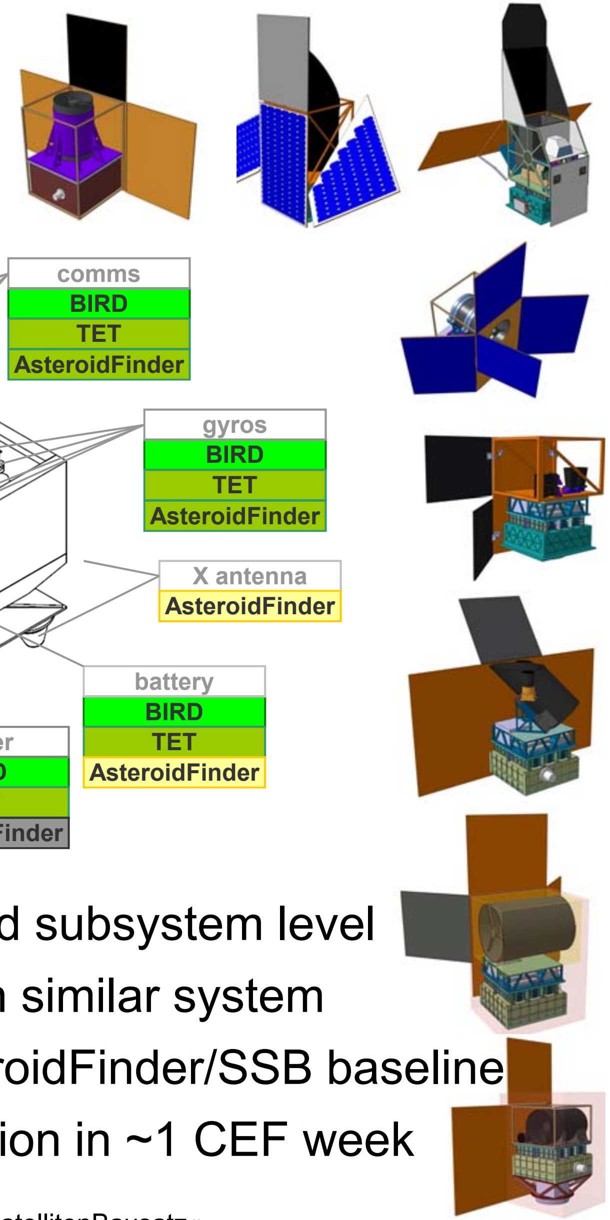
Synthesis

- design environment outlined by external as well as self-imposed constraints
- iterative evolution of the design solution towards full utilization of the design space
- strict application of structured requirements engineering within each iteration
- continuous budgeting of all resources using well-defined margin philosophy
- cyclic redefinition of the baseline design on all requirements levels by constraints
- baseline synchronized in regular concurrent engineering facility (CEF) sessions



/SSB – Standard Satellite Bus *kit*





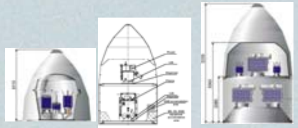
- the /SSB kit – a menu of options on unit level and subsystem level
- options of dissimilar maturity can be combined in similar system
- 1st iteration in parallel CEF studies: current AsteroidFinder/SSB baseline
- evolution of a payload-requirements-driven solution in ~1 CEF week

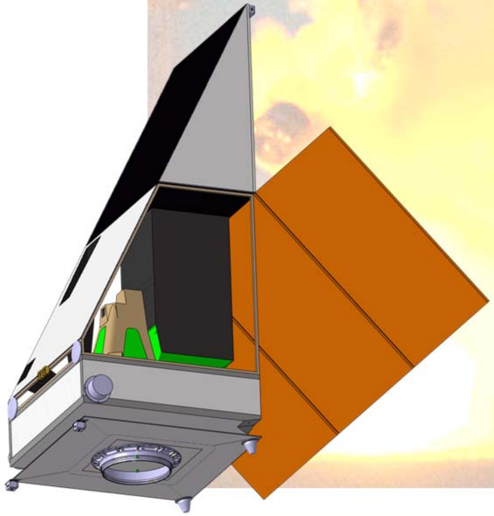
/SSB in German: »/StandardSatellitenBus« as well as »/StandardSatellitenBausatz«

Tech Progress & What a Difference the Way makes…

Spacecraft C	– 1996…2006 : 2007…2013 –	*Spacecraft A*
14.5 mag @ SNR 1000:1	limiting magnitude @ SNR	18.5 mag @ SNR 3:1
2°.7 · 3°.05	Field of View	(2°)²
Ø27 cm	telescope aperture	22.8 · 23.0 cm² , ƒ/3.4
590 cm² (off-axis afocal)	telescope collecting area	474 cm² (Cook TMA)
4 CCDs 2048², (13.5μm)² pixel	focal plane array	4 EMCCDs 1024², (13μm)² pixel
2.32‘‘/pixel	plate scale / IFOV	3.5‘‘/pixel
-40°C	sensor operating temperature	-80°C
16‘‘	pointing stability	100‘‘
0‘‘.5 (0‘‘.15 rms)	payload-augmented stability	7‘‘.5 /s (3σ)
4 .. 5 / year	fields visited	720 / day
2 GBit (EOL)	on-board storage	256 GBit (redundant)
1.5 Gbit/day	data transmission rate	224 Gbit/day
626 kg	satellite mass	180 kg
300 kg	payload mass	30 kg
4.10 m tall, Ø1.984 m	spacecraft size (launch)	1.00 m tall, □ (0.8 m)²
900 km, i = 90°	orbital altitude & inclination	650…850 km, i ~ 98°
2 ½ years	design lifetime	2 years

… To Scale

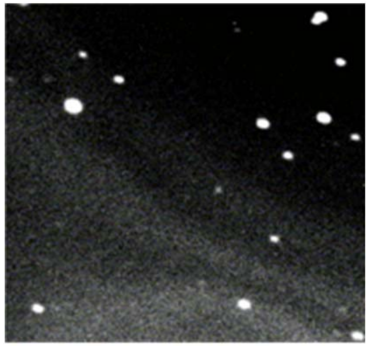




+++ BREAKING NEWS +++ EMCCD go-ahead given during COSPAR 2010 +++ BREAKING NEWS +++

Questions?

Asteroid 101: The Devil is in the Details



(99942) Apophis

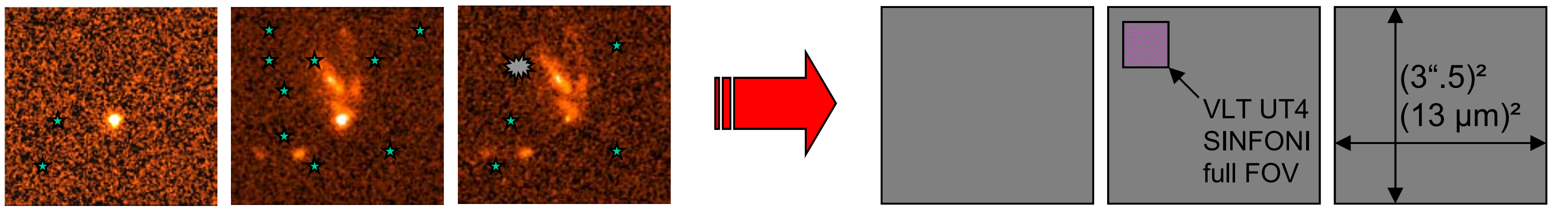
…named after the Ancient Egyptian Uncreator who dwells in the eternal darkness of the underworld. A close Earth flyby on Fri 13 Apr 2029 below geostationary altitude will gravity-assist Apophis for anything between a ~0.1 AU miss and a dead centre Earth impact on 13 Apr 2036, at 2.2E-5 estimated probability. Apophis spends most of its time inside the Earth’s orbit.

Hint: (99942) + ✂ ⍰+ ↱ ↴ ➔ ‘666’ + 42 ;-)

Asteroid 101: Space is not Unlimited

- stars and nebulae form a distant diffuse background at any resolution ("Billions and Billions")
- interplanetary dust forms a local background that moves around the Sun (Zodiacal light, Lunar L4/5 dust clouds)
- the corona forms a variable background centered on the Sun, even beyond the area out to 32 solar radii covered by SOHO LASCO C-3

On camera, at any given pixel scale,…

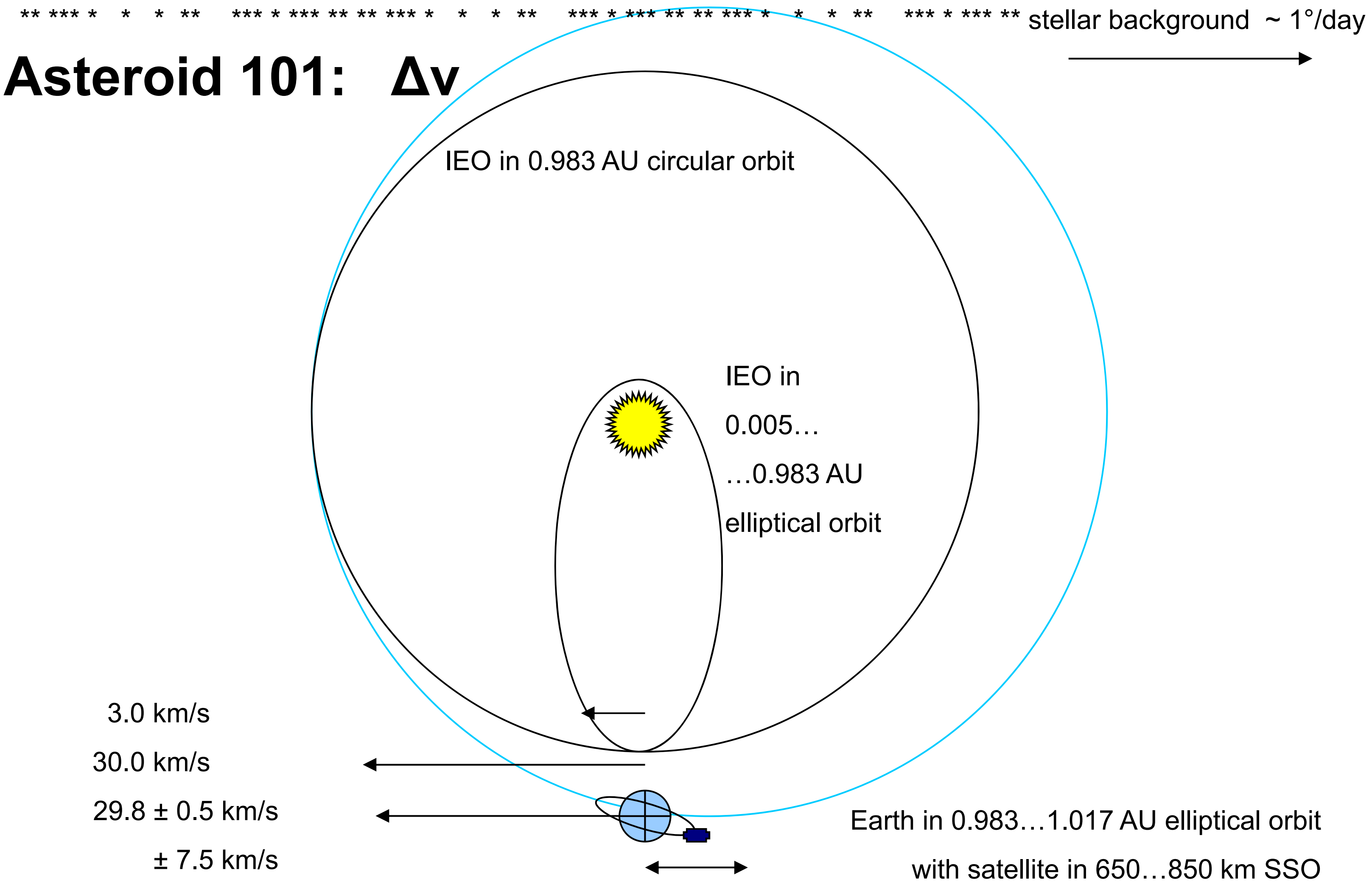


…diffuse background, stellar background, or a passing asteroid may…   …*READ EXACTLY THE SAME*

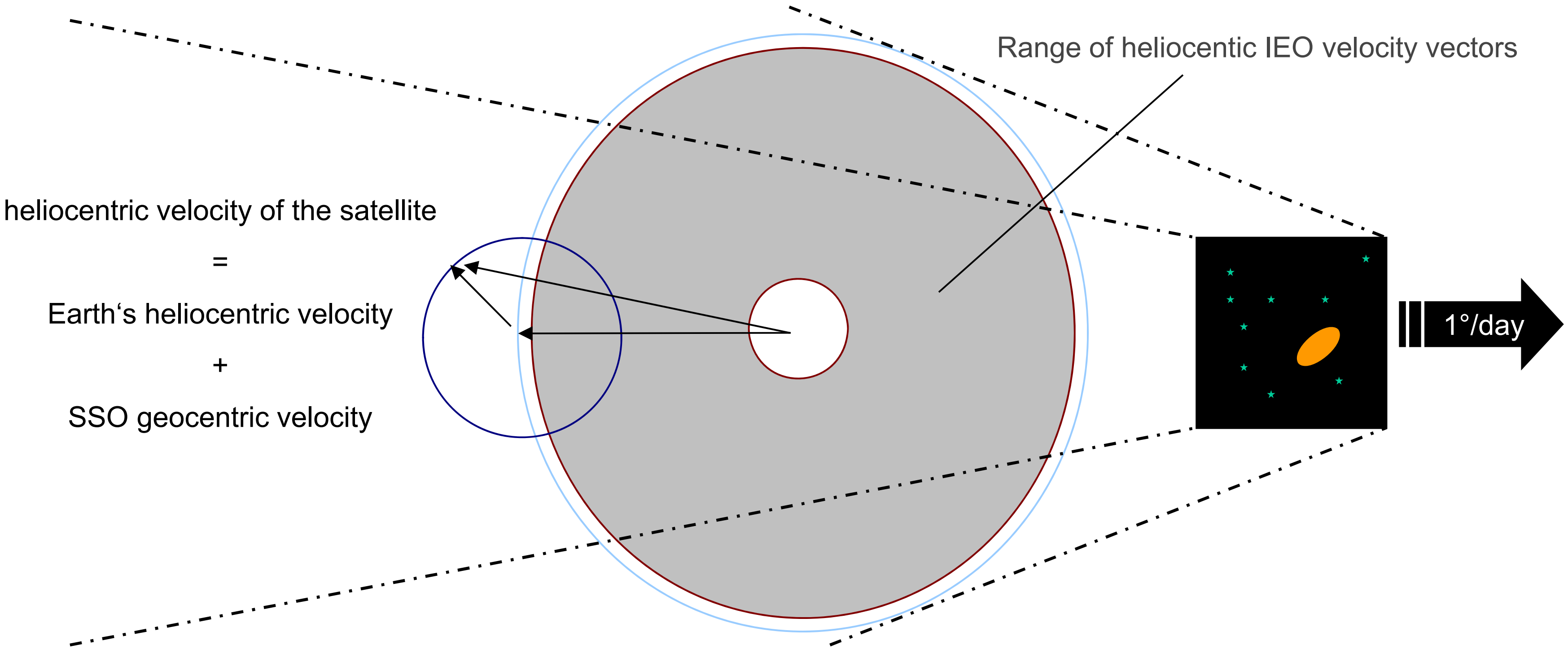
background image: GRB990123 by HST STIS, cropped to (3".2)² FOV, 0".05 detector pixel, 0".025 drizzled —— Difference Feb'99-Feb'00 – Feb'99 – Mar'99

HST FOC in hi-res mode: (3".6)² full FOV – VLT UT4 SINFONI in hi-res mode: (0".8)² full FOV

Asteroid 101: Δv



Asteroid 101: Δv projected



- Zero relative velocities and angular rates are possible, with a few to a few hundred arcseconds/minute being typical
- Impossible to catch all at any time

Asteroid 101: IEOs, NEOs, Mitigation
FAQ resources

- Gerhard Hahn, DLR EARN asteroid database: http://earn.dlr.de/nea/ *(provides population graph in slide #2)*
- IAU: Minor Planet Center – Lists and Plots: Minor Planets: http://cfa-www.harvard.edu/iau/lists/MPLists.html
- NEODyS Near Earth Objects Dynamic Site: http://newton.dm.unipi.it/cgi-bin/neodys/neoibo
- Don Yeomans, NASA NEO Program – Current Impact Risks: http://neo.jpl.nasa.gov/risk/
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