FIRI/ESPRIT Exploratory SPace Radio Interferometric Telescope

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SAFARI
the Imaging Spectrometer on the SPICA space observatory;
revealing the origins of the universe,
from planets to galaxies.
This is the first opportunity Europe has for a FIR mission
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Netherlands Institute for Space Research
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ESPRIT – opening remarks

- In 2007 FIRI proposal – Emphasis on AGN, starbursts and galaxy evolution -> sensitivity
- In 2013 L2/L3 white paper – emphasis shifts to planet formation (disks) -> high spectral resolution

- For sensitivity SPICA is the way to go and this needs full European support!

- For spectral resolution a heterodyne interferometer and a passively cooled large single dish with heterodyne instruments are optimal
- Note that most targets within our Galaxy are to bright for SPICA

- file://localhost/Users/fph/Documents/ESPRIT.mpg

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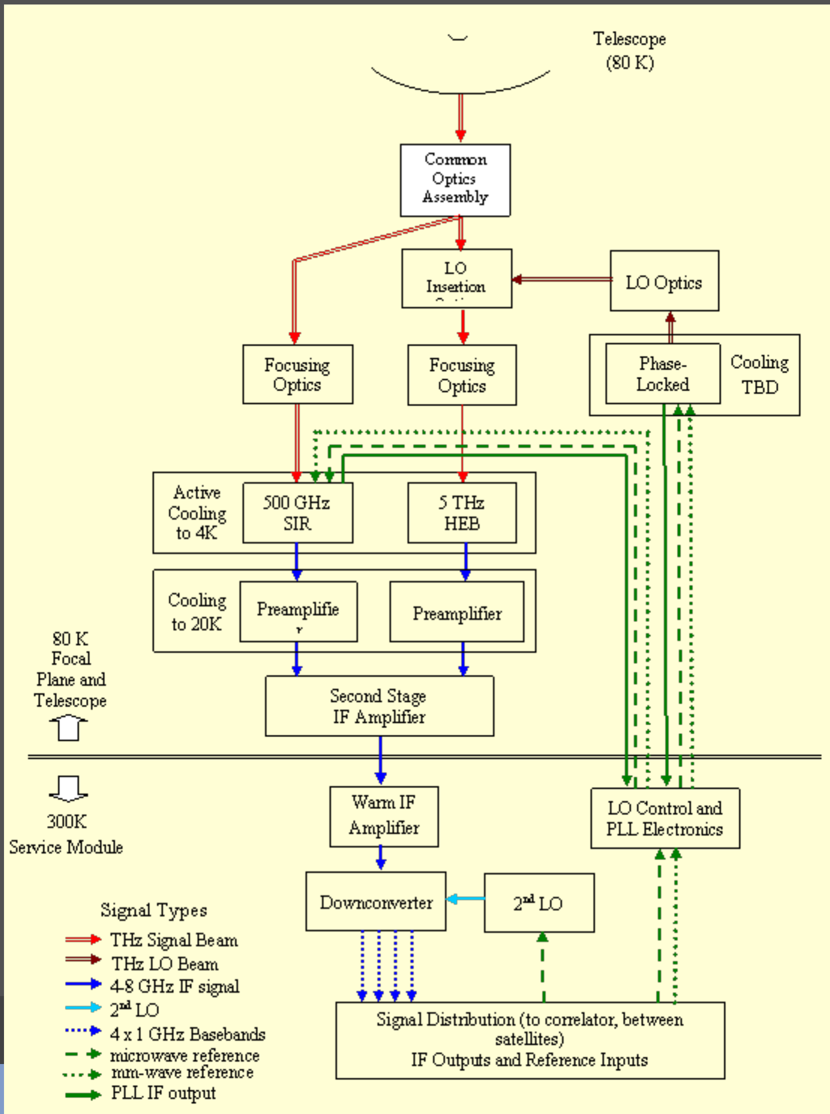
Heterodyne detection interferometry

Goal: down convert the sky signal to frequencies for which electronic amplification works

Requires:

1) very pure phase-locked Local Oscillator sources and very low-noise mixers
2) Limited a priori knowledge of positions needed and accurate a posteriori knowledge.
3) Suitable correlators
4) Elements need to move to fill UV plane

THz heterodyne interferometer



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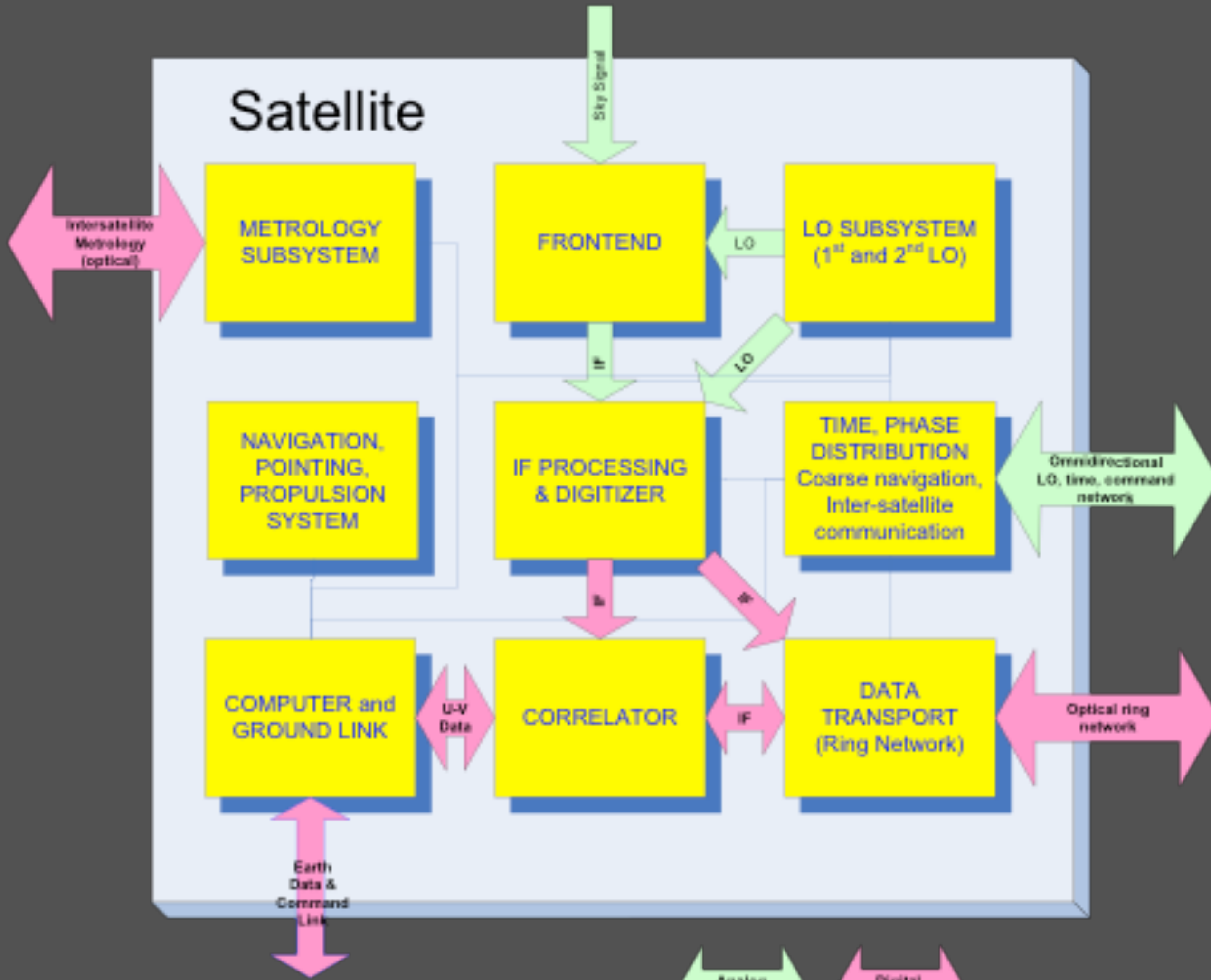
ESPRIT modular design



Critical items: detector technology 2008

- None of the current detectors are suitable for FIRI
- SPICA-SAFARI is currently driving the developments in Europe:
  - CEA – Saclay Si bolometers
  - MPE – Garching Photoconductors
  - SRON/Cardiff TES bolometers
  - SRON Kinetic Inductance Detectors
  - SRON/TU Delft – HEB mixers and Quantum Cascade Lasers

- While there are problems meeting the SPICA deadlines set by ESA, there is good hope that detectors will be available for FIRI, as long as investments can be done over several years

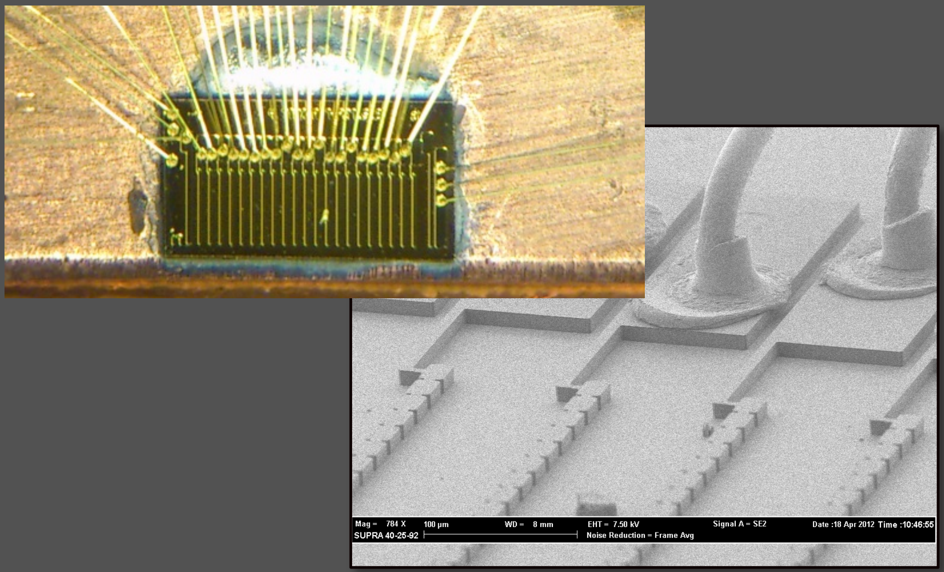
LO sources

- **First attempt**
  - First QCL phase locking required lots of cooling power because the device was quite warm
  - The beam of the QCL was not optimized for coupling its radiation with the HEBM
  - The QCL was not tunable

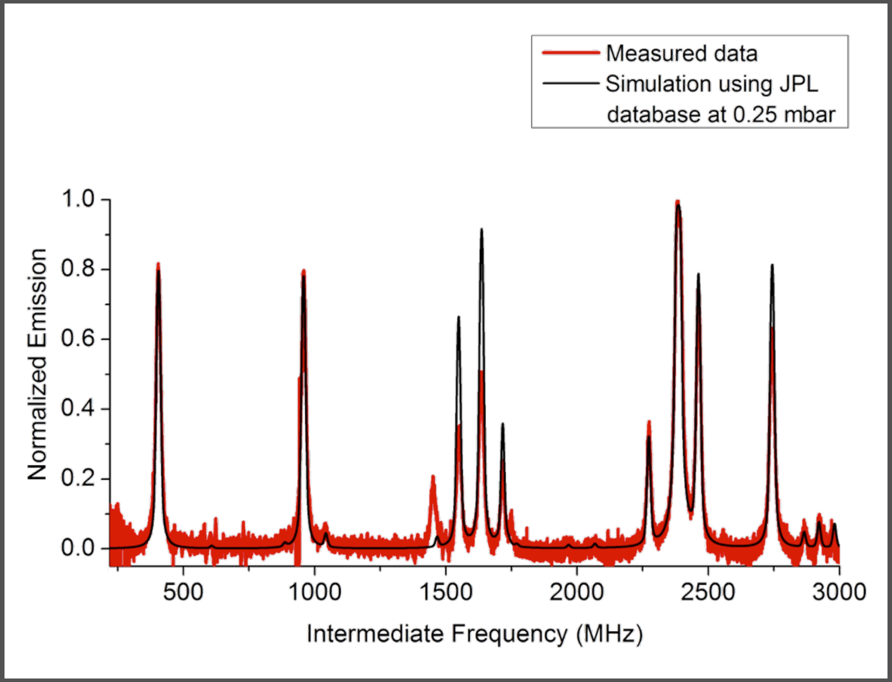
- **State-of-the-art**
  - QCL phase locking is not simple, but is doable now: Hayton et al ApL 103, 051115, 2013
  - Beam properties are well understood and under control by design
  - Tunability of QCLs have been achieved over short wavelength ranges. Cascading QCLs is always an option for wide wavelength coverage

LO sources

- QCL has been improved enormously since 2005: single spot beam, exact target frequency, DC consuming power (<1 W), and operating temperature (40-70 K)
- QCL phase locking using only room temperature electronics, Hayton et al APL (2013)



4.7 THz QCL array with 7 GHz in difference, MIT



Gas cell measurement using HEB-QCL at 4.7 THz (OI line)

Mixers

2014

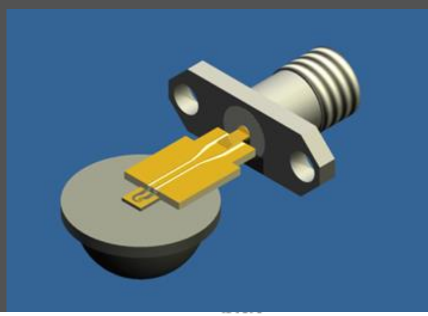
- HEB mixers are optimized for sensitivity. They are more than twice as sensitive as the HIFI mixers and at THz frequencies they can be operated near the quantum limit (e.g Delorme et al. ISSTT 2011)
- Control of the LO power improves the stability by over an order of magnitude compared with HIFI
- Array technology has been studied within EU-Radionet and the Russian/NL TeraDec consortium
- GREAT instrument on SOFIA carries a HEBM array

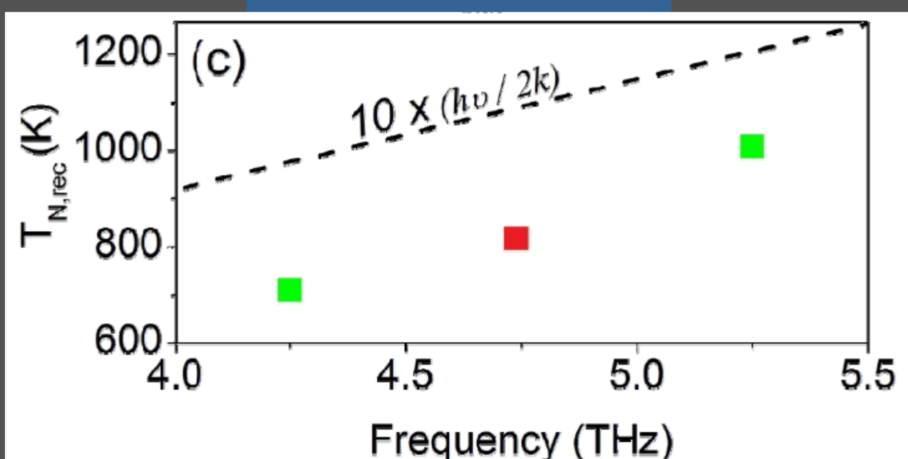
- Measurements are planned with a NASA balloon carrying the Univ of Arizona STO-2 instrument (single pixel HEBM/QCL)

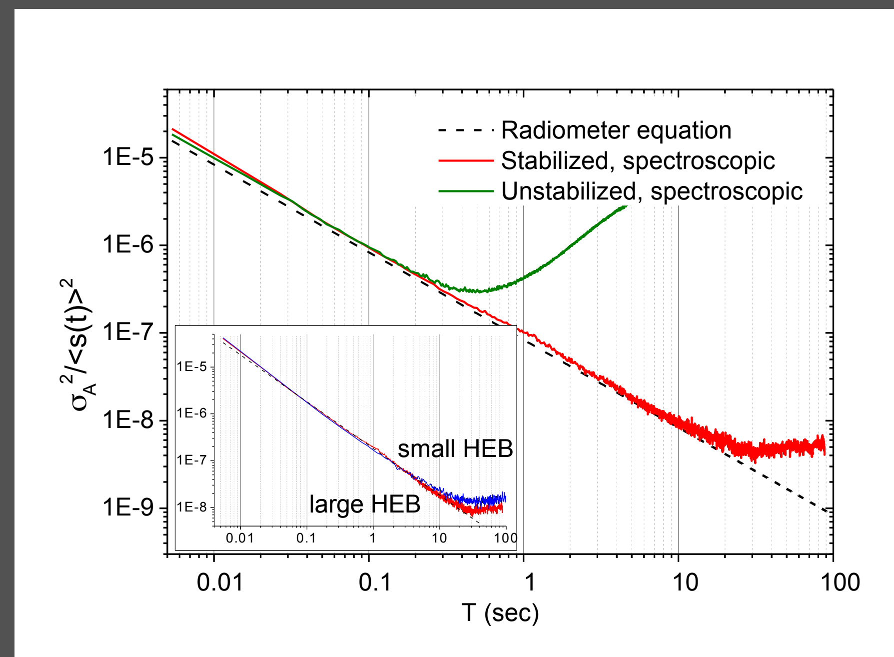
- Proposals have been written for GUSSTO (will be resubmitted) and for the ESA-CAS joint satellite with HEBM array technology/ QCL

Mixers

- HEBM with high sensitivity from 1-5 THz (450K @1.4 THz; 800 K @4.7THz, a few times QN)
- Improve the HEB receiver stability by controling LO amplitude
- HEBM array on SOFIA and to be developed for STO2 and GUSSTO







- Allan time > 30 sec at 16 MHz

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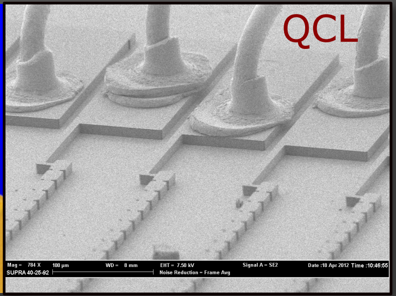
Flying heterodyne receivers (SRON – Delft)

Participation in NASA Stratospheric TeraHertz Observatory STO-2 (from Antarctica), single pixel at 4.7 THz (2016)

STO-2 is a proof-concept to support a resubmitted proposal of NASA-GUSSTO mission: 4x4 array at 4.7 THz

QCL will be operated in a stirling cooler



Critical items: Phase calibration & fringe stopping

2008

- The far-IR is a place where the whole sky shows structure at all angular scales
- Phase calibration needs stable point sources which are rare in the sky – dedicated study needed to define the exact reuirements for phase calibration
- Signals from far-away sources will be weak – How can we find the fringe and how can we stay on the fringe? – dedicated study will be needed to define the observing strategy – one option could be to use mid-IR point sources in the field
- Internal to the system very stringent (order 1 micron) metrology will be needed

Phase calibration

- Herschel provides incredibly good (better than 2%) absolute photometric calibration
- However, this is only for a limited set of sources with known size (and be aware that asteroids are variable) and thus not easily a phase calibrator is found in (or close to) the field of view
- No dedicated studies have been performed to find the precise characteristics of phase calibrators for ESPRIT

- What is the ALMA experience at the highest frequencies?

Critical items: Volume and Mass

2008

- Stacking several (>2) space craft into one fairing is currently limited by volume (SPIRIT)
- Larger collecting area (3.5m dishes) will increase the speed of detection, but will increase the size of the sun-shields and the total mass -> lightweighting necessary
- Using 6 space craft as in ESPRIT needs similar lightweighting for dishes but since ESPRIT is mainly electronics miniaturisation is a necessity, e.g LO’s should be tiny, correlator small (e.g. FFTS), use of FPGA’s etc.

Volume and Mass

- The Planck satellite is almost 2000 kg, (with a mirror of 1.5m) and a diameter and height of 4.2m
- Decrease height: secondary off-axis on a boom that should have a set-and-forget mechanism
- Lightweight the mirrors
- Decrease energy consumption, by miniaturizing electronics

- In the white paper for L2/L3 these exact parameters were to come from a CDF study (Concurrent Design Facility). No new data available

Critical items: Formation flying

2008

- To fill the UV-plane the space craft need to be able to define base-lines upto 1 km – formation flying is a must
- ESPRIT study uses FEEPs as devices for acceleration and deceleration
  - Pro's: very small and efficient in "fuel"
  - Cons: very power hungry and not very good tuneable in acceleration speed
- Darwin studies use cold gas devices – applicability to FIRI not assessed
- SPECS uses a tethered design
  - Pro's: very fast and efficient
  - Cons: for more than three space craft on a line design is complicated

Propulsion

- FEEPs are not considered anymore
- Electric propulsion has been tested by SMART-1: Hall effect thruster with 0.068 N for 5000 hours (80 kg Xenon)
- GAIA: 12 cold gas thrusters with thrust between 1 and 500 microNewton, 500 million cycles over a life time of 20,000 hours. Two tanks of 28.5 kg N_2 at 310 bar
- Lisa PathFinder also tests laser optics besides colloidal micro thrusters

Formation flying: Horizon 2020 work program

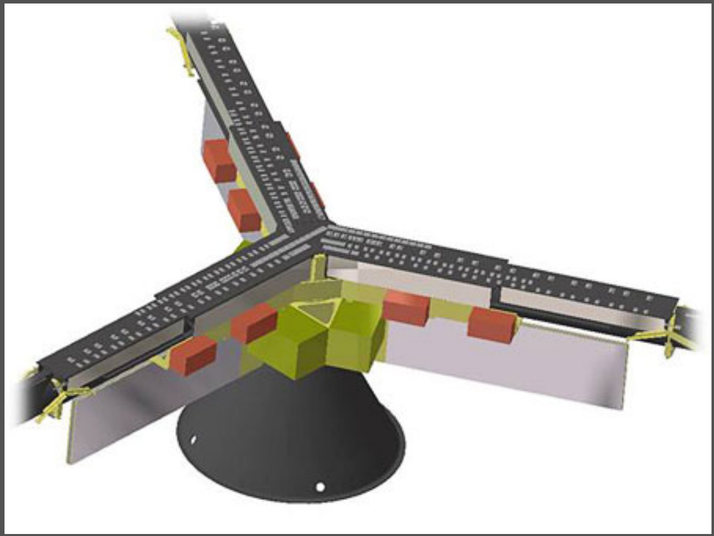
- EO-3-2015: Technology developments for competitive imaging from space

Specific challenge: Observation concepts based on fractionated sensors (e.g. telescope arrays) have revolutionised astronomy, and **their observation potential from space (swarm missions, satellite constellations) has yet to be realised**. This represents a departure from an approach of many different sensors residing on one satellite, in favour of many smaller single-sensor missions. It remains to be established for which areas of Earth observation (land monitoring, atmospheric measurements, water quality, maritime surveillance, emergency management, security, etc.) this approach might be particularly effective, be it in performance, risk management and cost effectiveness. Equally, it needs to be understood which technologies would be needed to allow a network/constellation to act as one instrument. Specific requirements for the sensors may also be needed to allow benefit to be taken of such mission concepts

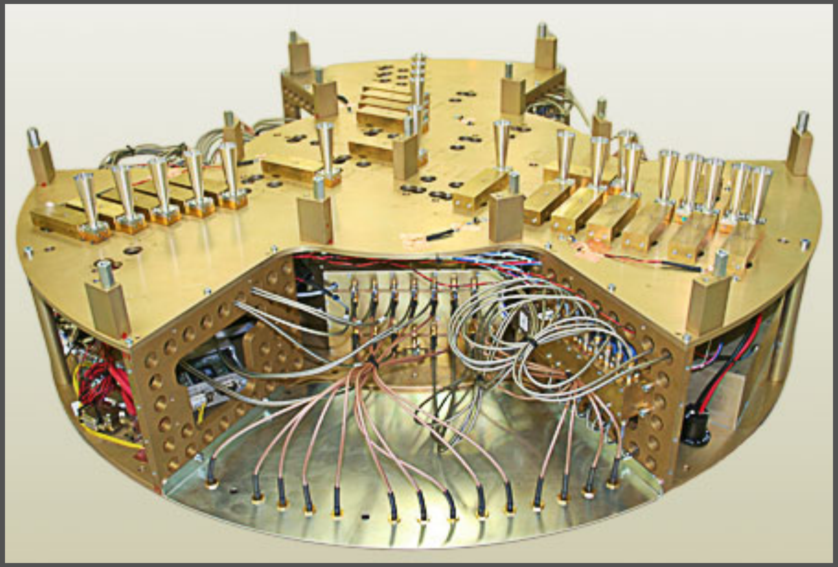
Horizon 2020 work program (cont.)

Scope: Research should be undertaken to review the emerging fractionated observation system concepts. **The required technology challenges as regards interfacing, synchronisation, formation flying, precision thrusting and pointing, communication within the constellation or with ground stations are to be identified.** Potential benefits to be obtained (e.g. monitoring performance, risk mitigation, cost effectiveness, responsiveness) are to be examined in light of observation needs in different earth observation domains. Observation needs should be validated with the respective user communities to be fit for purpose in terms of scientific and commercial applications. Constellations of instruments might be of the same instrument type, or include a variety of different instruments and related data fusion approaches. **Demands for data transfers and communication should be examined in light of current developments of high-speed in-space communication methodologies**. The results obtained should enable mission designers and implementers to decide what missions should be initiated for which application areas, and the requirements for communications support

Correlation



- Anders Emmerich writes that Omnisys will start with a demonstration of a 16 (TBC) element system at 183 GHz, with > 1 GHz bandwidth in the cross correlator back-end.
- Demonstrator study for a 20 element 50 GHz frontends microwave limbsounder



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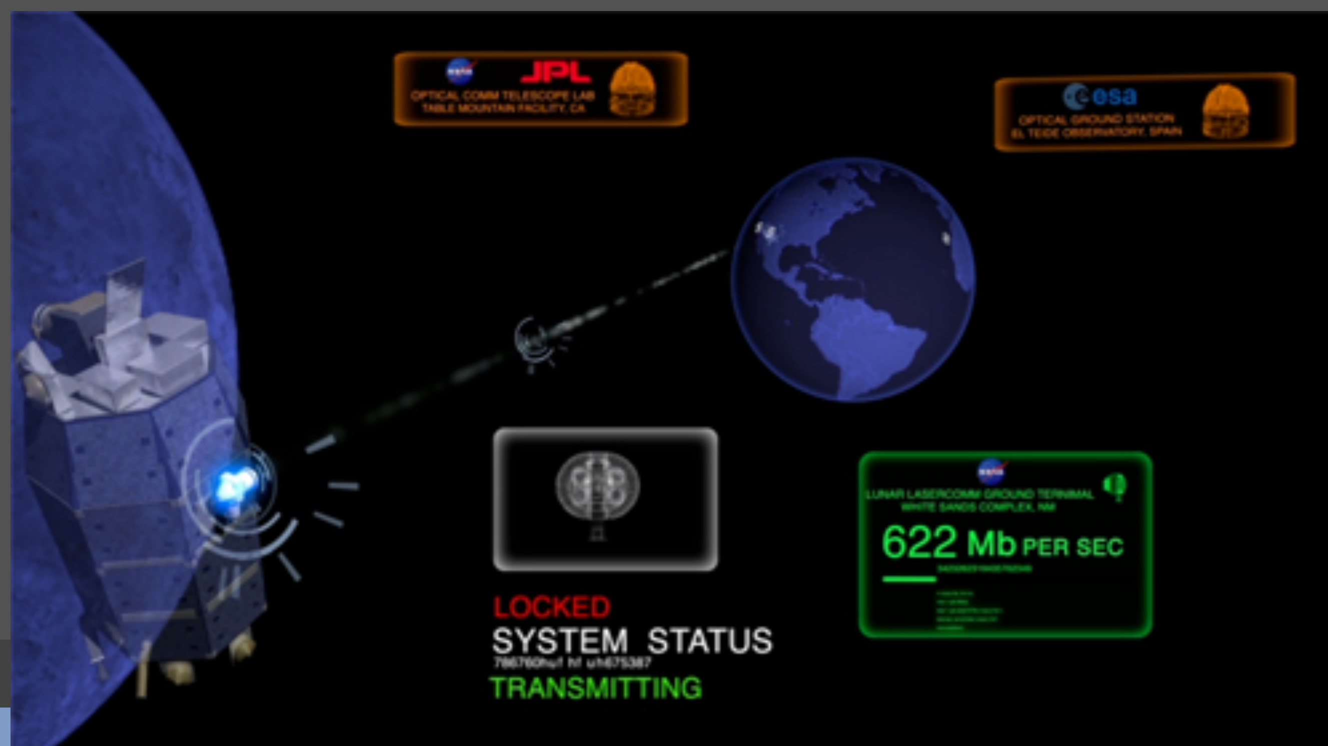
Laser links

- NASA LADEE satellite uses laser for satellite – ground connection: 622 Mb/s over distance Moon-Earth



Correlation – DARIS and OLFAR

- Ultra low radio frequency (0,3-30 MHz) studies impossible from below the atmosphere -> go to space

- Correlation concepts were studied (Rajan et al. 2013 Proceedings of the Aerospace Conf, Big Sky) :
- Distributed FX was most optimal for data handling and correlation, however the choice depends heavily on frequency and hardware

- For ESPRIT the frequency distributed hybrid XF variant in a ring topology still seems to be the right choice

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Conclusion

- There has been a lot of progress in the last 6 years in many vital areas, and there will be in the coming years
  - Mixers,
  - LOs
  - Correlators
  - Thrusters
  - Formation flying
- There is no dedicated plan for the missing parts, but this may fit into Horizon2020 after the FISICA program has ended