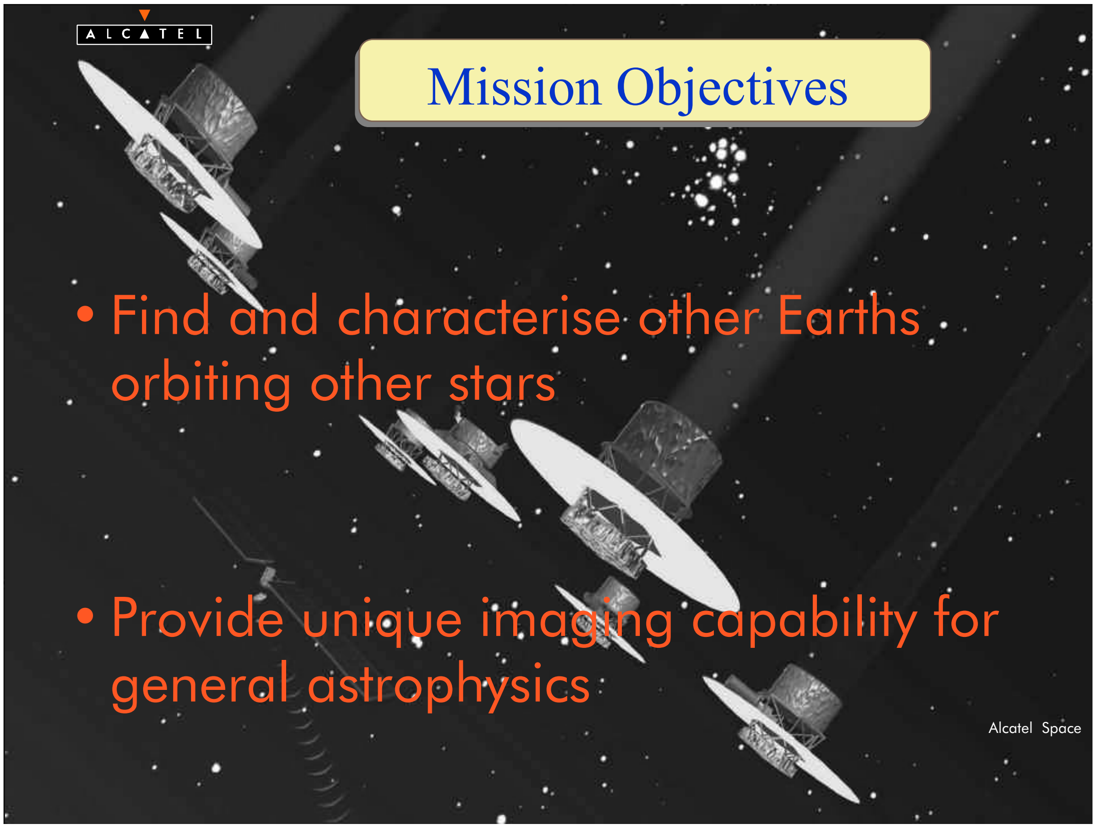
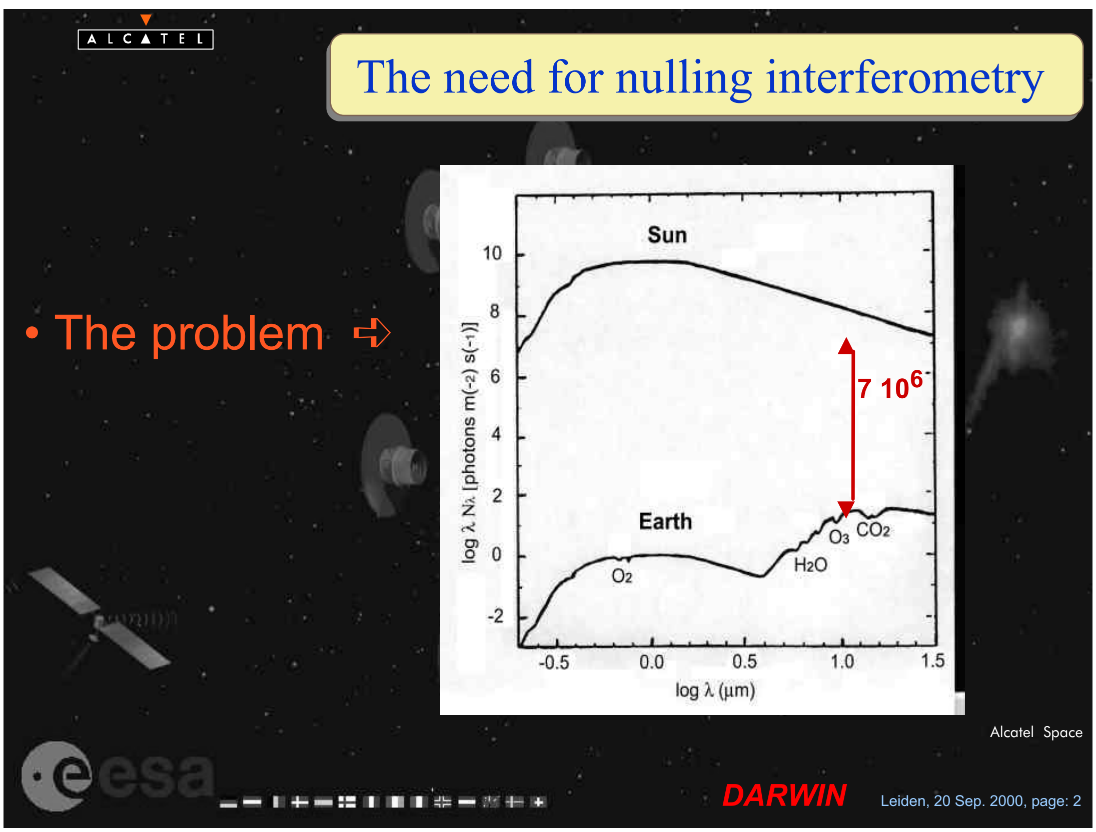
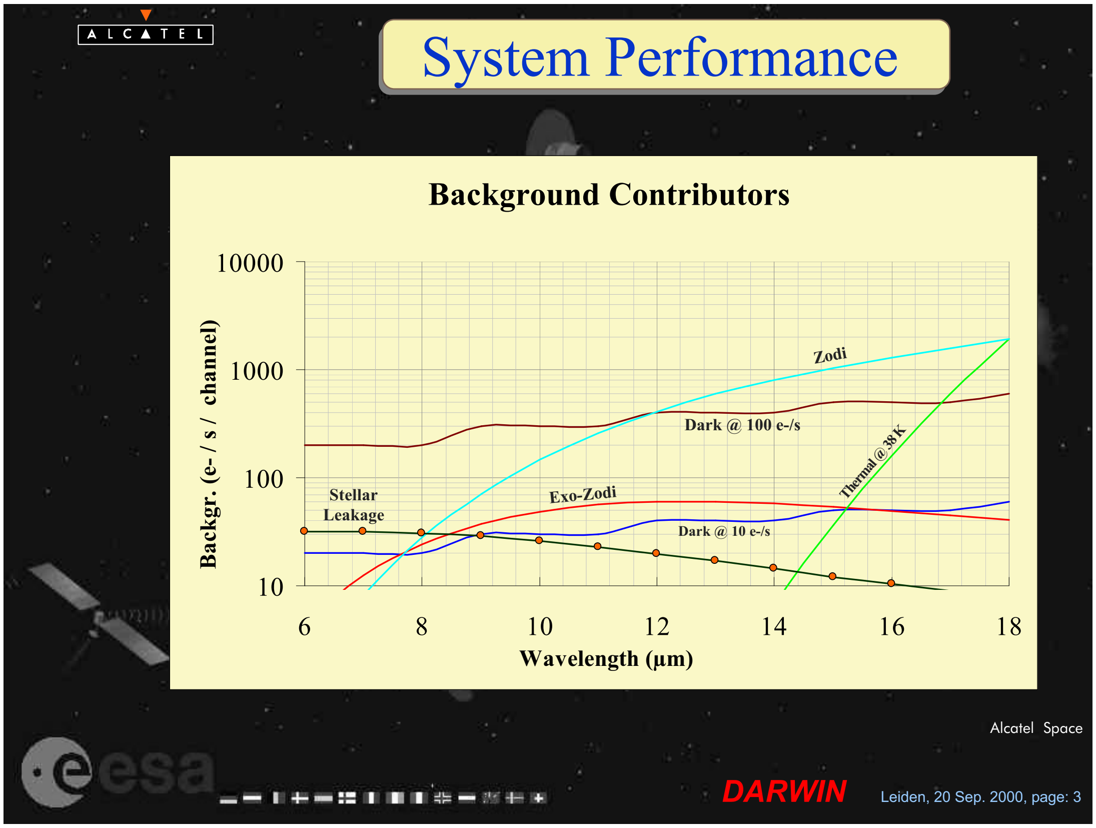
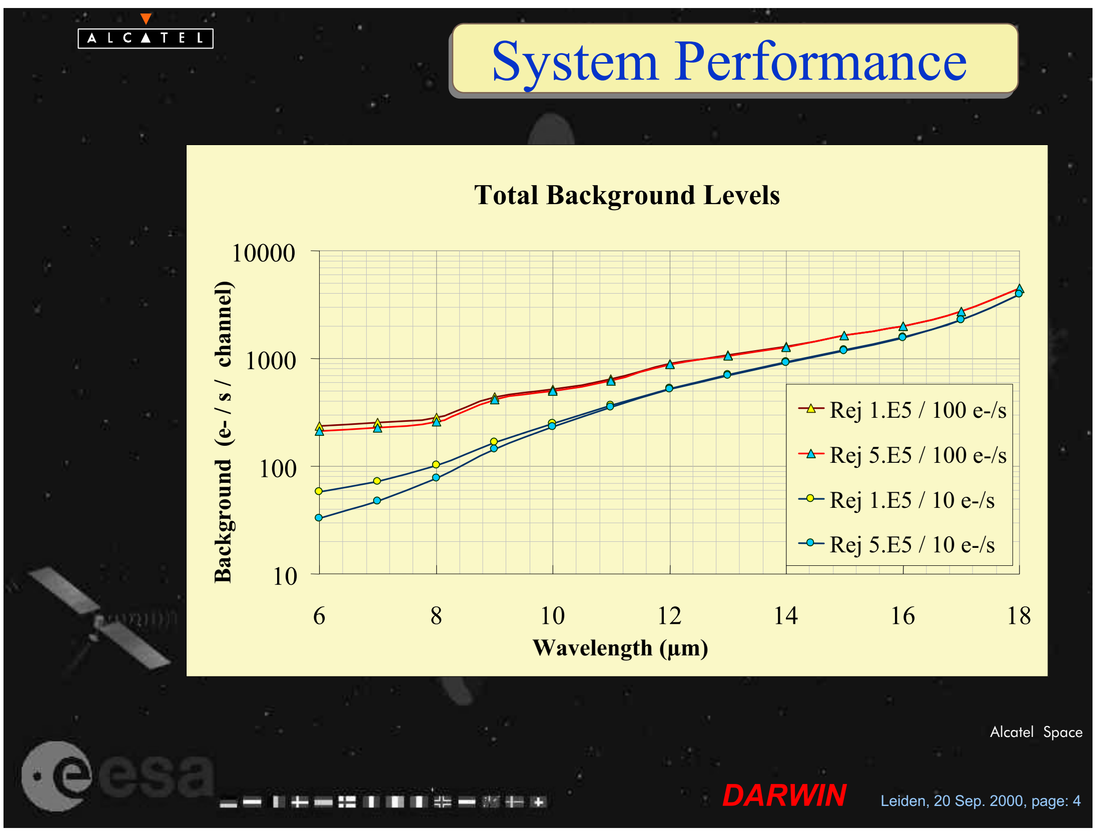
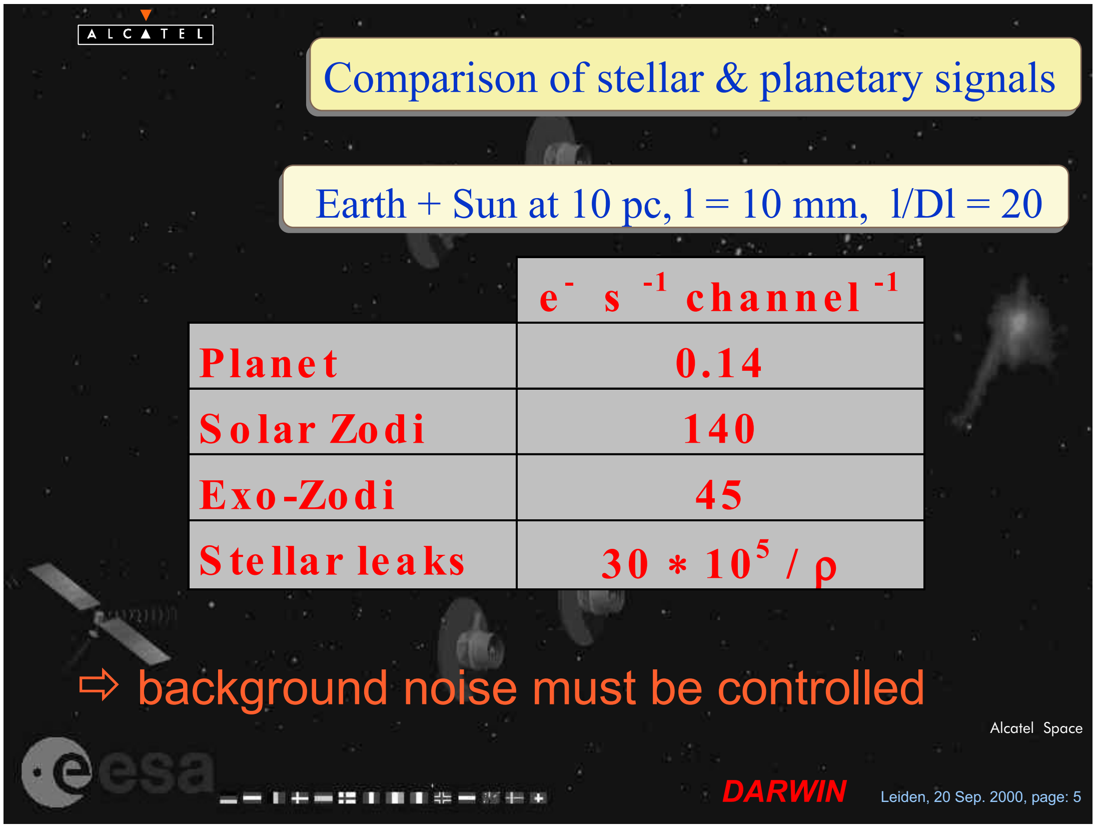

ALCATEL
Mission Objectives
• Find and characterise other Earths orbiting other stars
• Provide unique imaging capability for general astrophysics
Alcatel Space

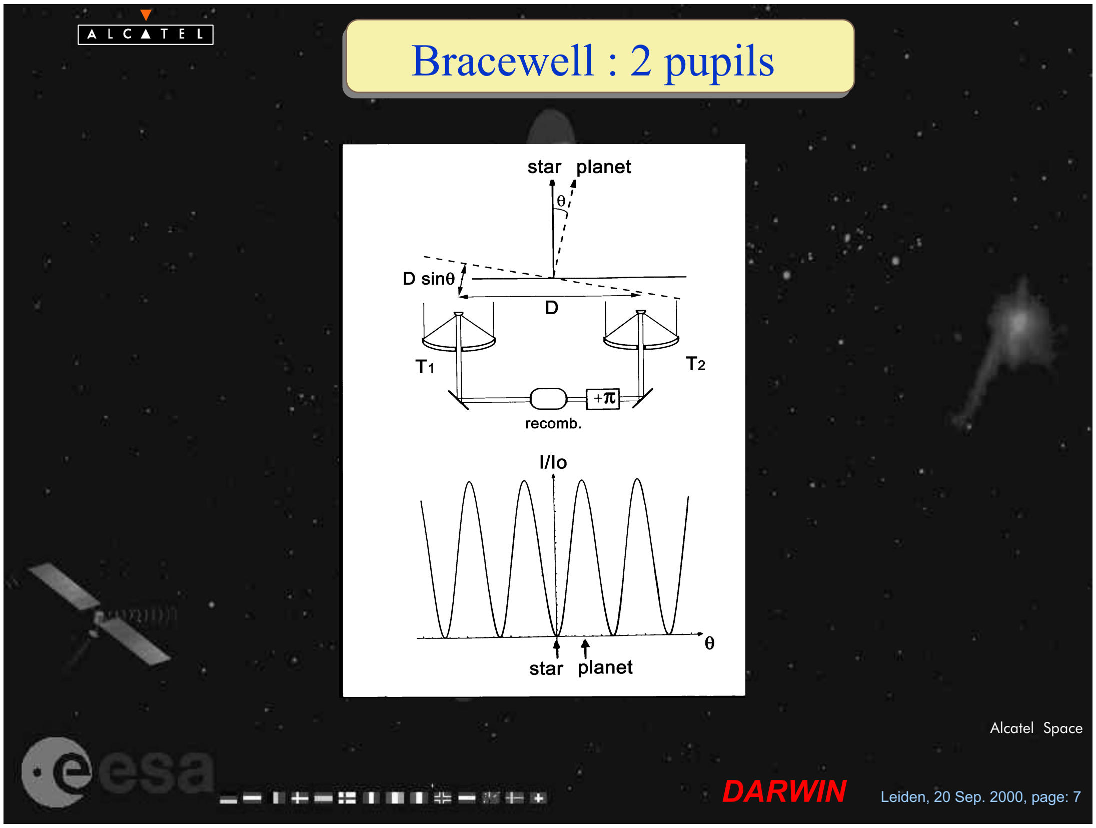

ALCATEL
The need for nulling interferometry
• The problem
Sun
Earth
7 10^6
O2
H2O
O3
CO2
log λ Nλ [photons m(-2) s(-1)]
log λ (μm)
10
8
6
4
2
0
-2
-0.5
0.0
0.5
1.0
1.5
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 2

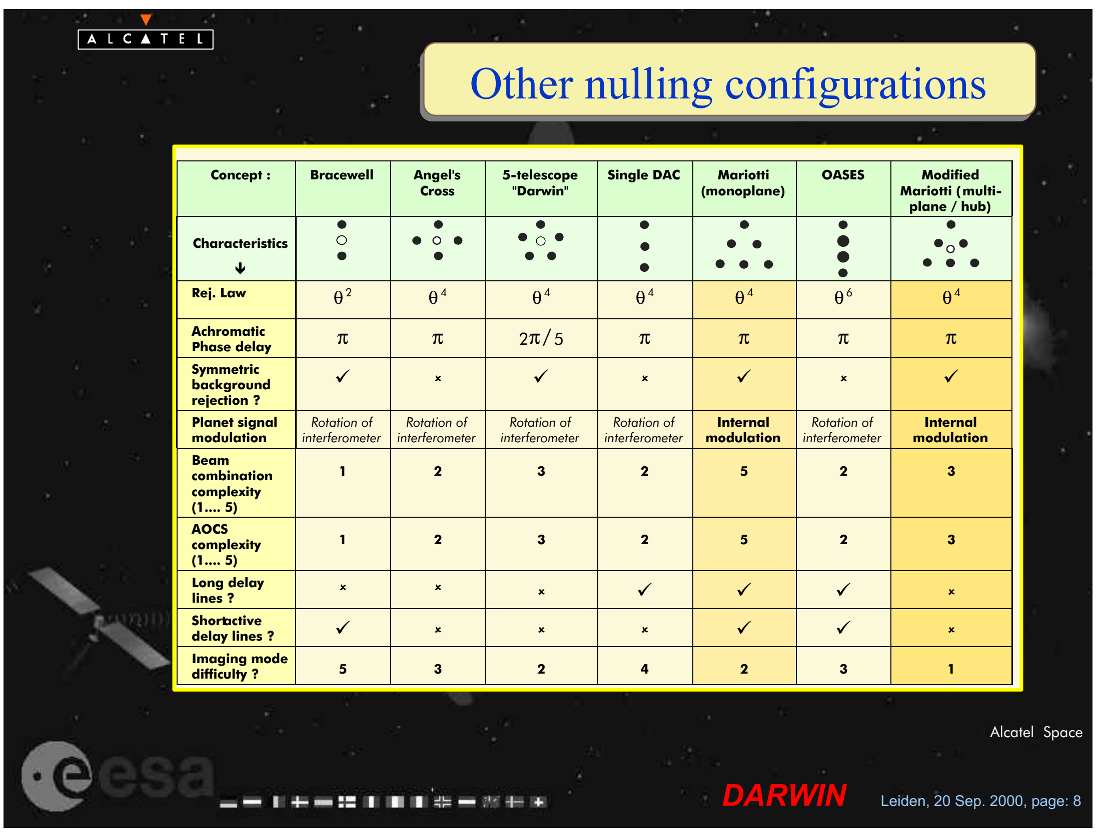

ALCATEL
System Performance
Background Contributors
10000
1000
100
10
Backgr. (e- / s / channel)
6
8
10
12
14
16
18
Wavelength (µm)
Zodi
Dark @ 100 e-/s
Thermal @ 38 K
Stellar
Leakage
Exo-Zodi
Dark @ 10 e-/s
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 3


ALCATEL
System Performance
Total Background Levels
10000
1000
100
10
Background (e- / s / channel)
6
8
10
12
14
16
18
Wavelength (µm)
Rej 1.E5 / 100 e-/s
Rej 5.E5 / 100 e-/s
Rej 1.E5 / 10 e-/s
Rej 5.E5 / 10 e-/s
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 4

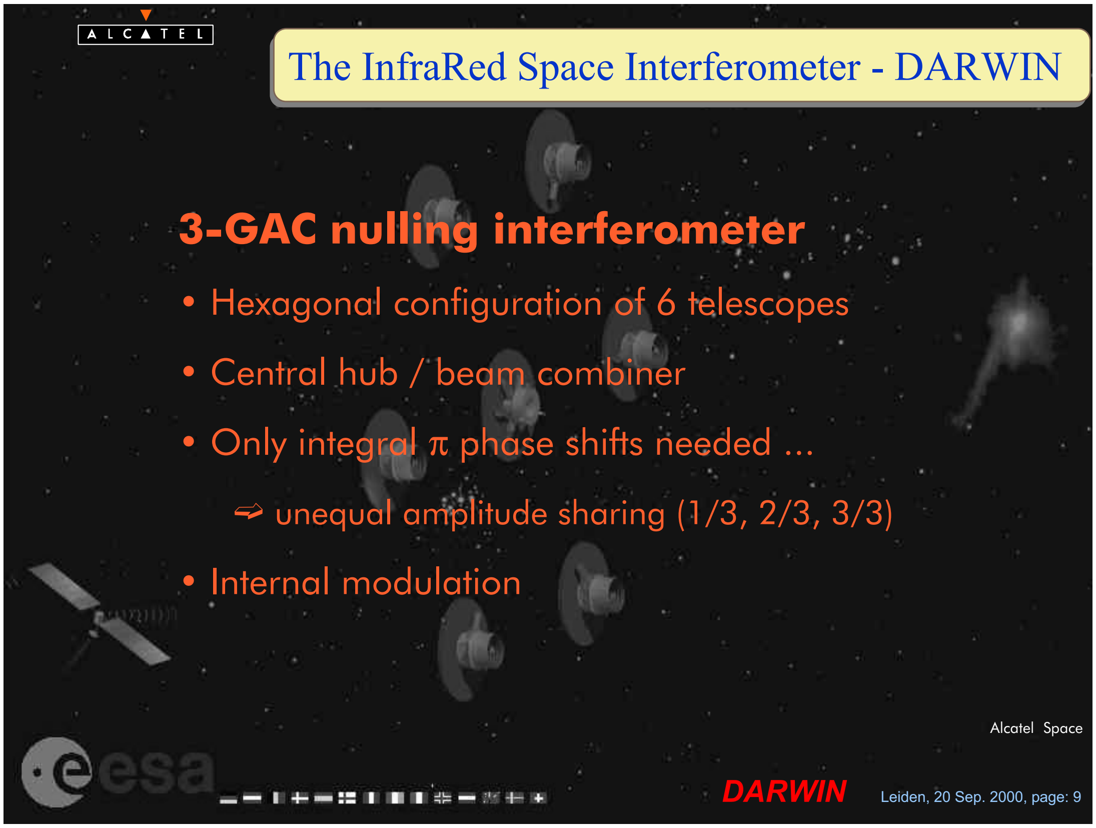

ALCATEL
Comparison of stellar & planetary signals
Earth + Sun at 10 pc, l = 10 mm, l/Dl = 20
$e^- \; s^{-1}$ channel$^{-1}$
Planet 0.14
Solar Zodi 140
Exo-Zodi 45
Stellar leaks $30 * 10^5 / \rho$
⇨ background noise must be controlled
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 5

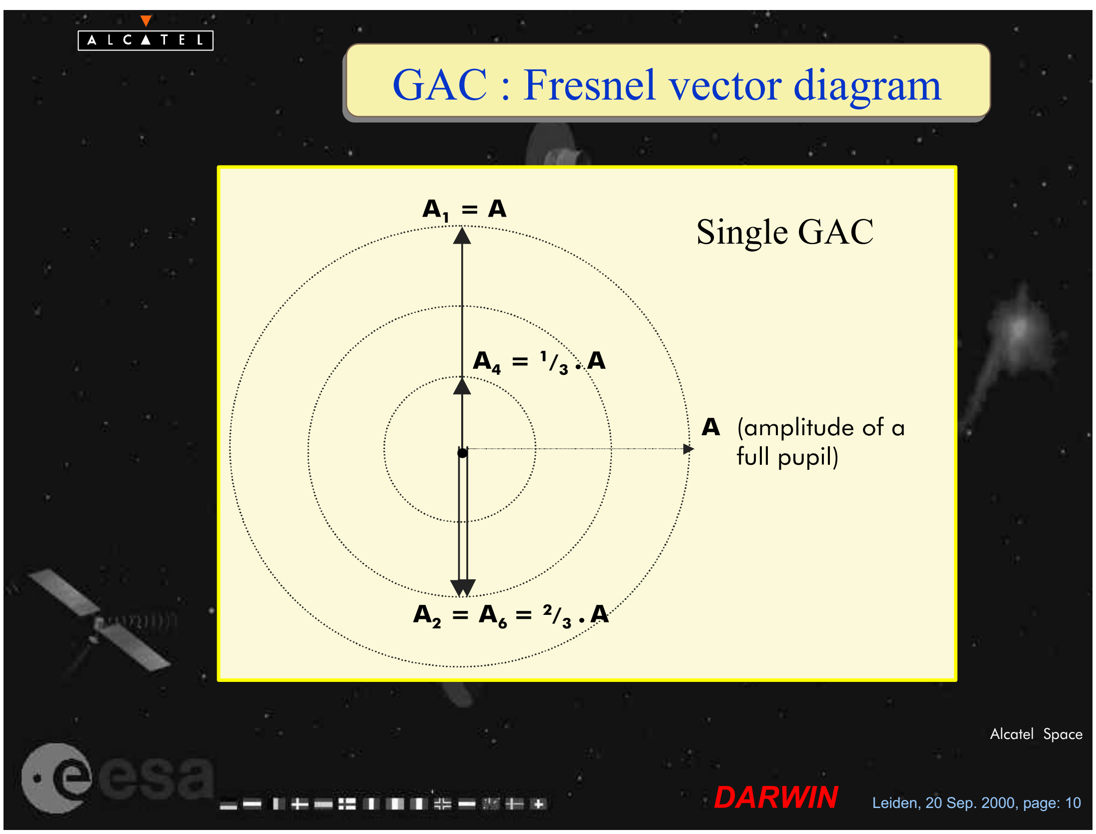

ALCATEL
But, how do you get the null ???
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 6

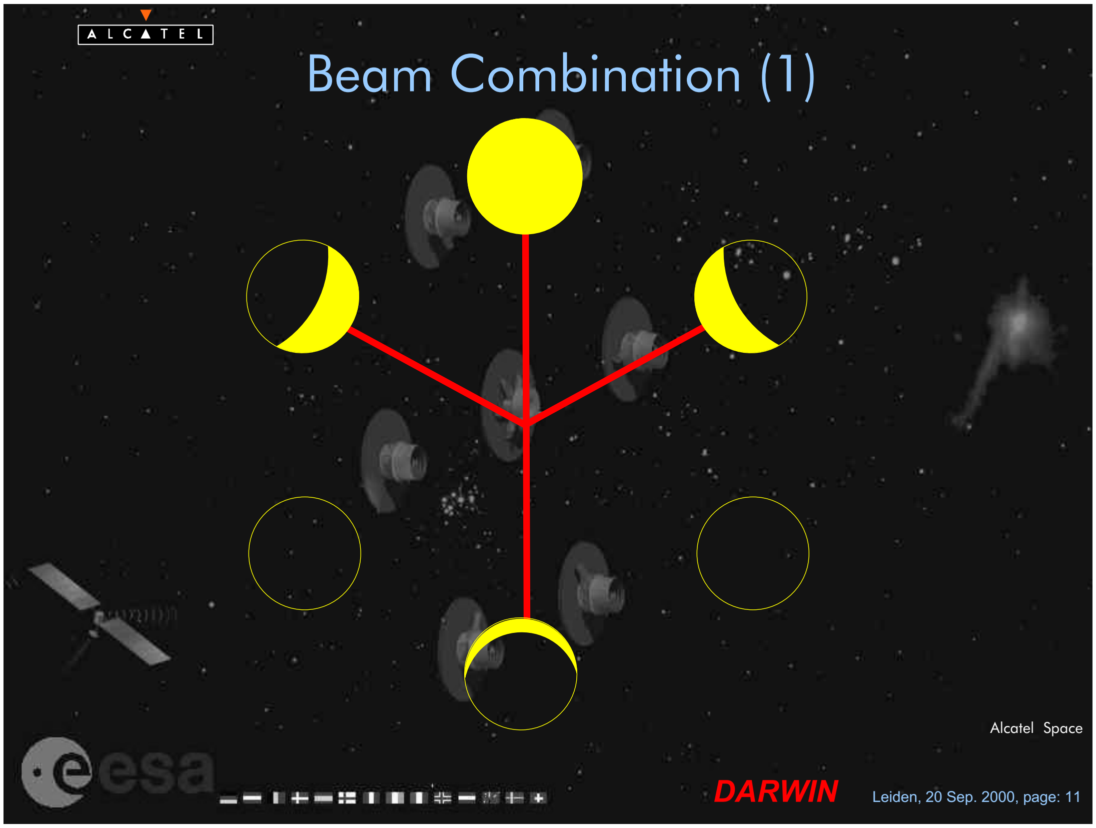


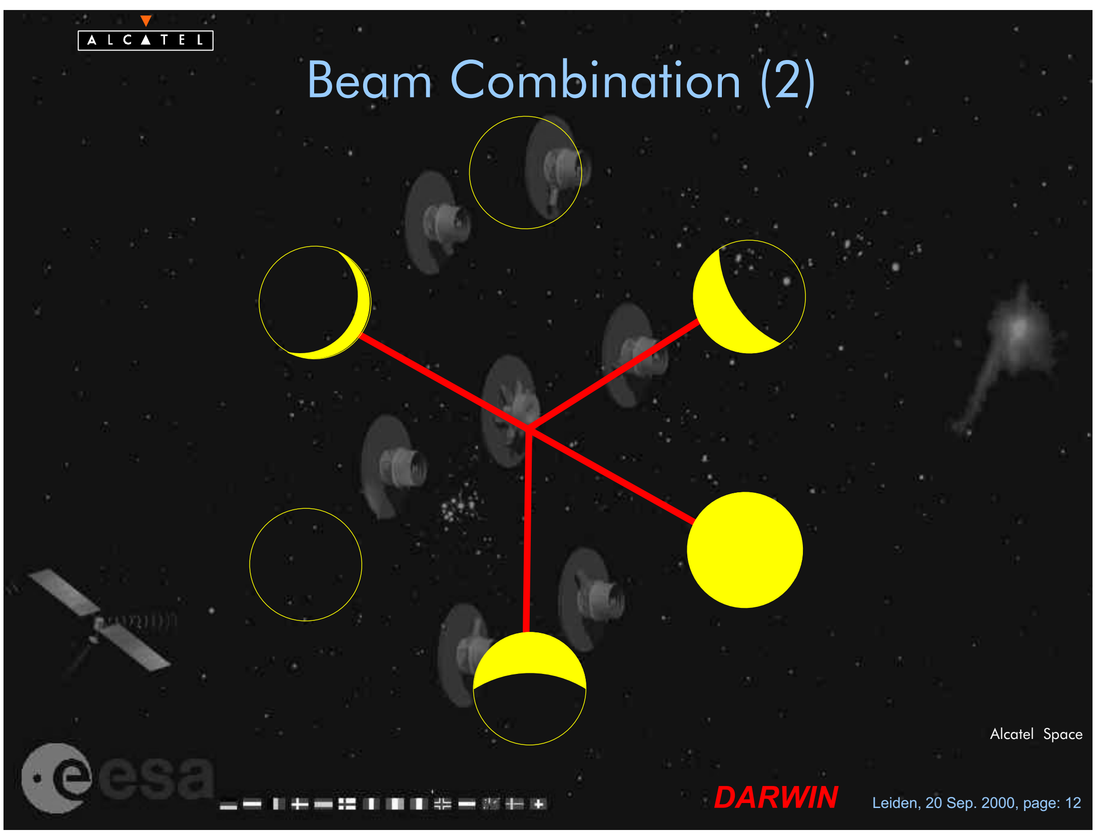



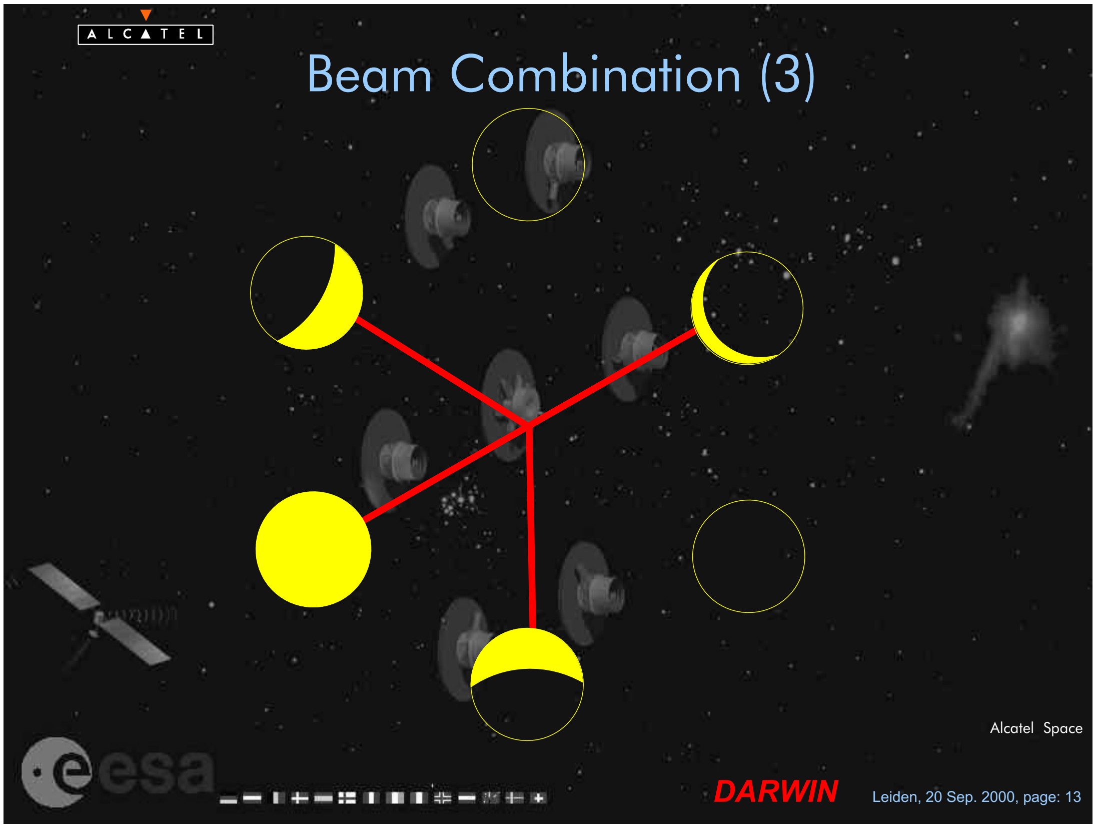

| Concept : | Bracewell | Angel's Cross | 5-telescope "Darwin" | Single DAC | Mariotti (monoplane) | OASES | Modified Mariotti (multi-plane / hub) |
|---|---|---|---|---|---|---|---|
| Characteristics ↓ | ● ○ ● | ● ● ○ ● ● | ● ● ○ ● ● ● | ● ● ● | ● ● ● ● ● ● | ● ● ● ● ● | ● ● ○ ● ● ● ● |
| Rej. Law | $\theta^2$ | $\theta^4$ | $\theta^4$ | $\theta^4$ | $\theta^4$ | $\theta^6$ | $\theta^4$ |
| Achromatic Phase delay | $\pi$ | $\pi$ | $2\pi/5$ | $\pi$ | $\pi$ | $\pi$ | $\pi$ |
| Symmetric background rejection ? | ✓ | × | ✓ | × | ✓ | × | ✓ |
| Planet signal modulation | *Rotation of interferometer* | *Rotation of interferometer* | *Rotation of interferometer* | *Rotation of interferometer* | **Internal modulation** | *Rotation of interferometer* | **Internal modulation** |
| Beam combination complexity (1.... 5) | 1 | 2 | 3 | 2 | 5 | 2 | 3 |
| AOCS complexity (1.... 5) | 1 | 2 | 3 | 2 | 5 | 2 | 3 |
| Long delay lines ? | × | × | × | ✓ | ✓ | ✓ | × |
| Short active delay lines ? | ✓ | × | × | × | ✓ | ✓ | × |
| Imaging mode difficulty ? | 5 | 3 | 2 | 4 | 2 | 3 | 1 |

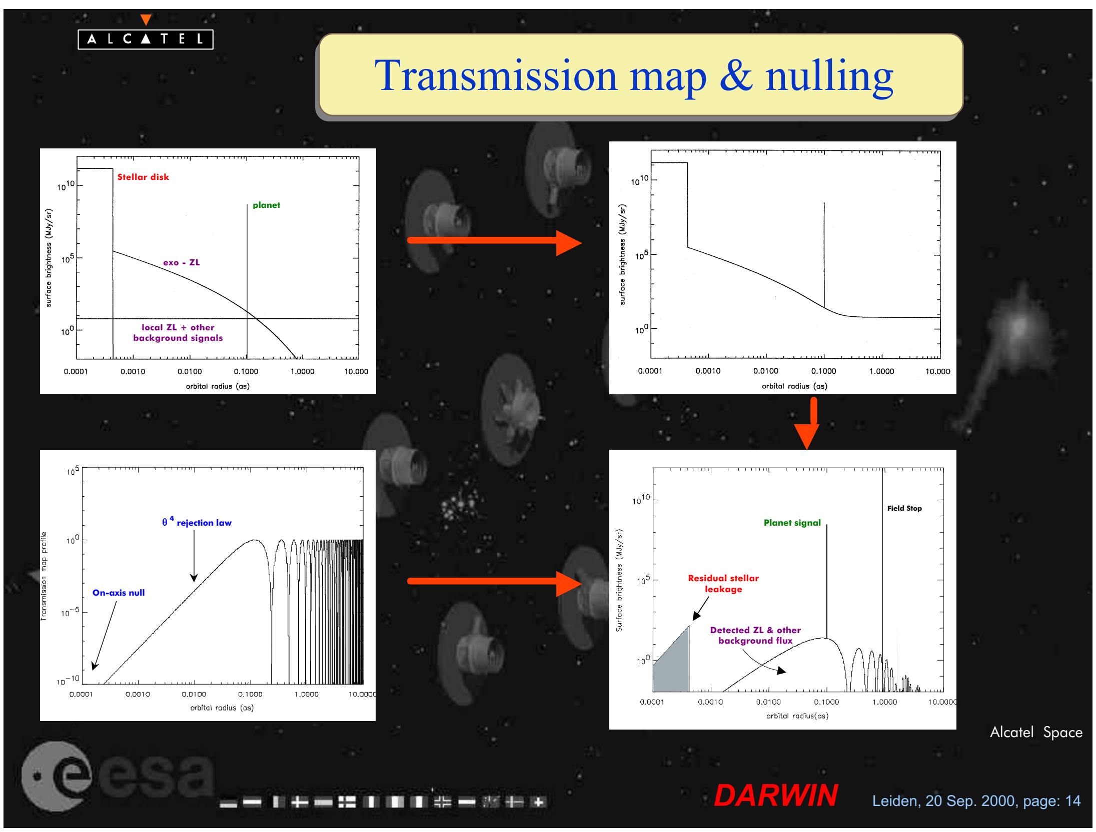

ALCATEL
The InfraRed Space Interferometer - DARWIN
3-GAC nulling interferometer
• Hexagonal configuration of 6 telescopes
• Central hub / beam combiner
• Only integral π phase shifts needed ...
⇨ unequal amplitude sharing (1/3, 2/3, 3/3)
• Internal modulation
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 9

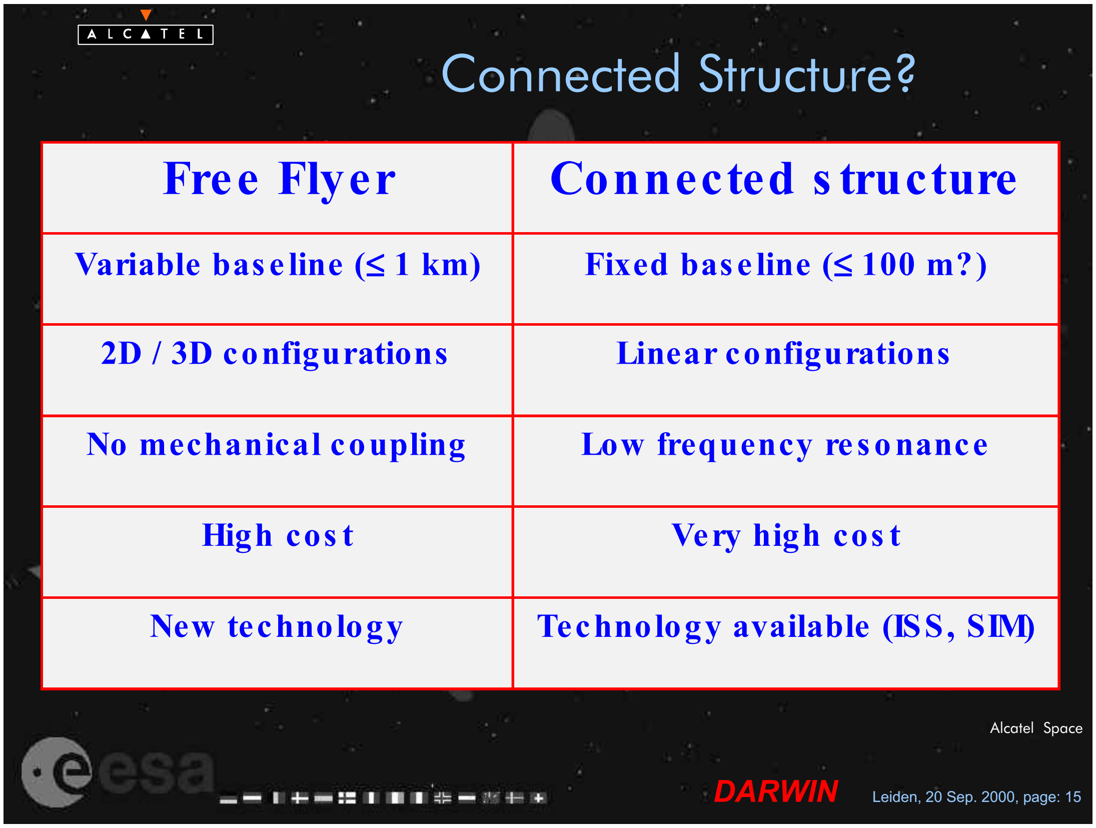

ALCATEL
GAC : Fresnel vector diagram
A1 = A
Single GAC
A4 = 1/3 . A
A (amplitude of a full pupil)
A2 = A6 = 2/3 . A
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 10

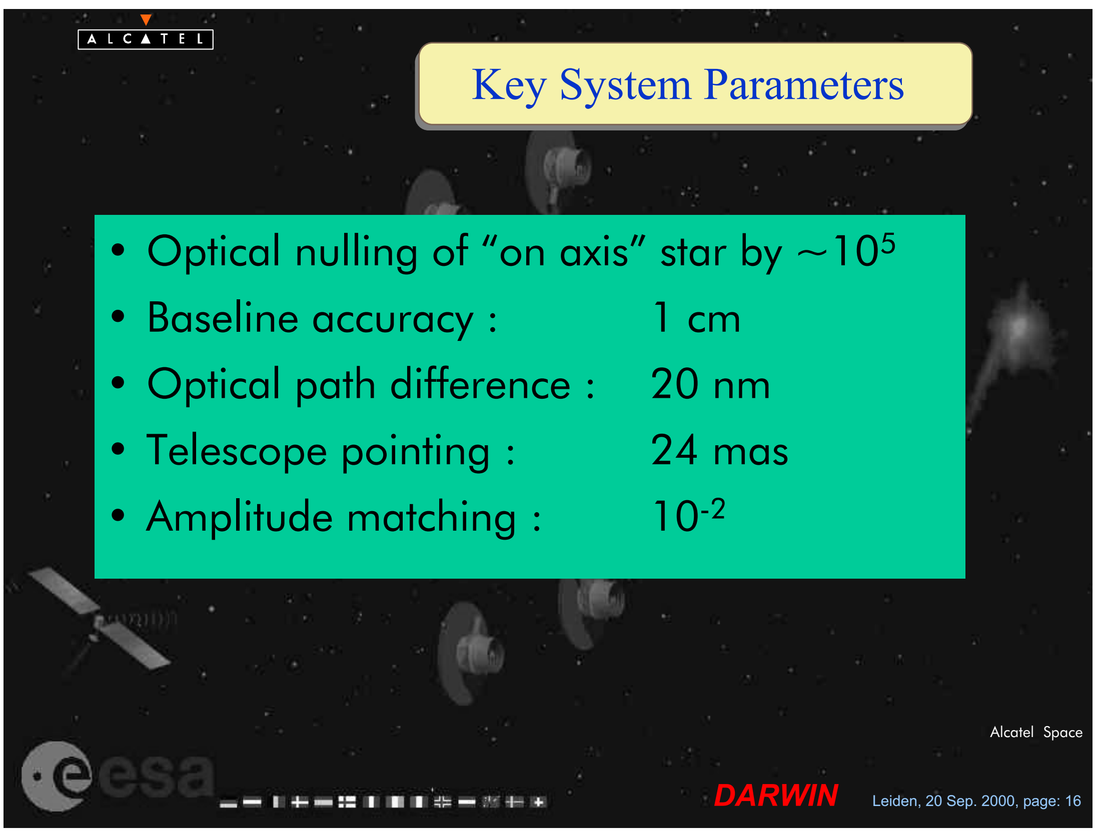

ALCATEL
Beam Combination (1)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 11

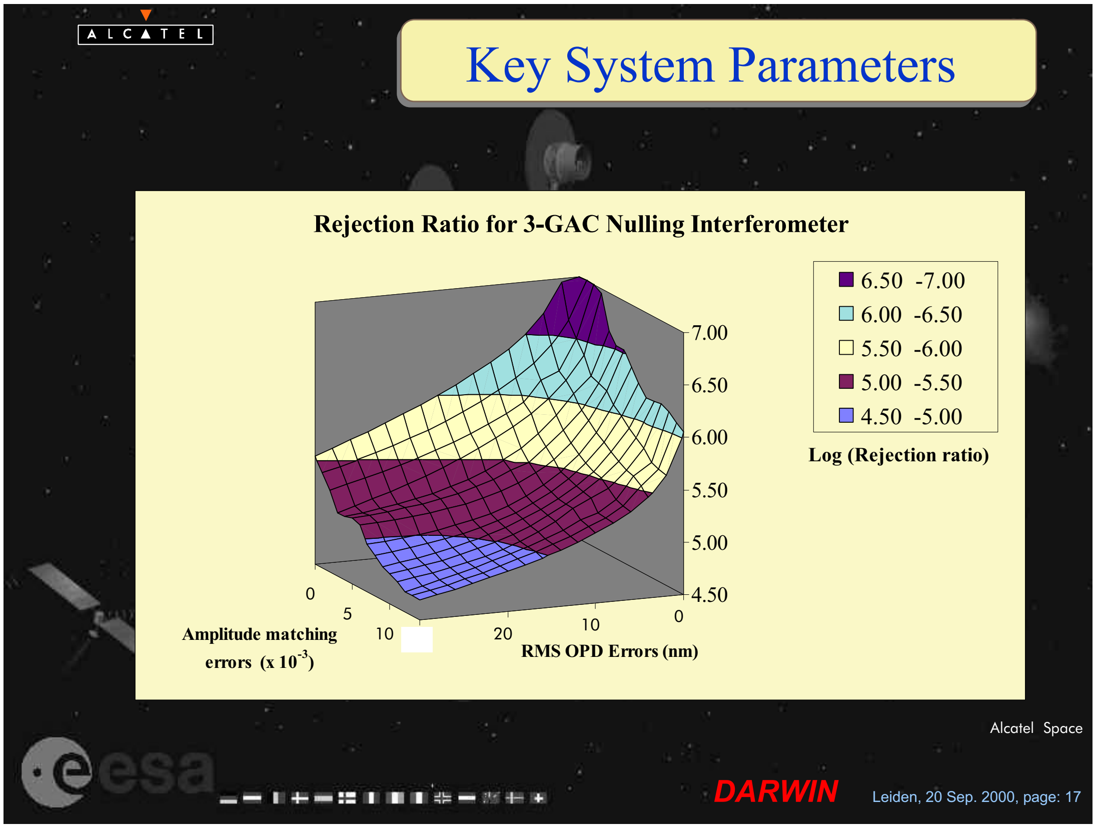

ALCATEL
Beam Combination (2)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 12

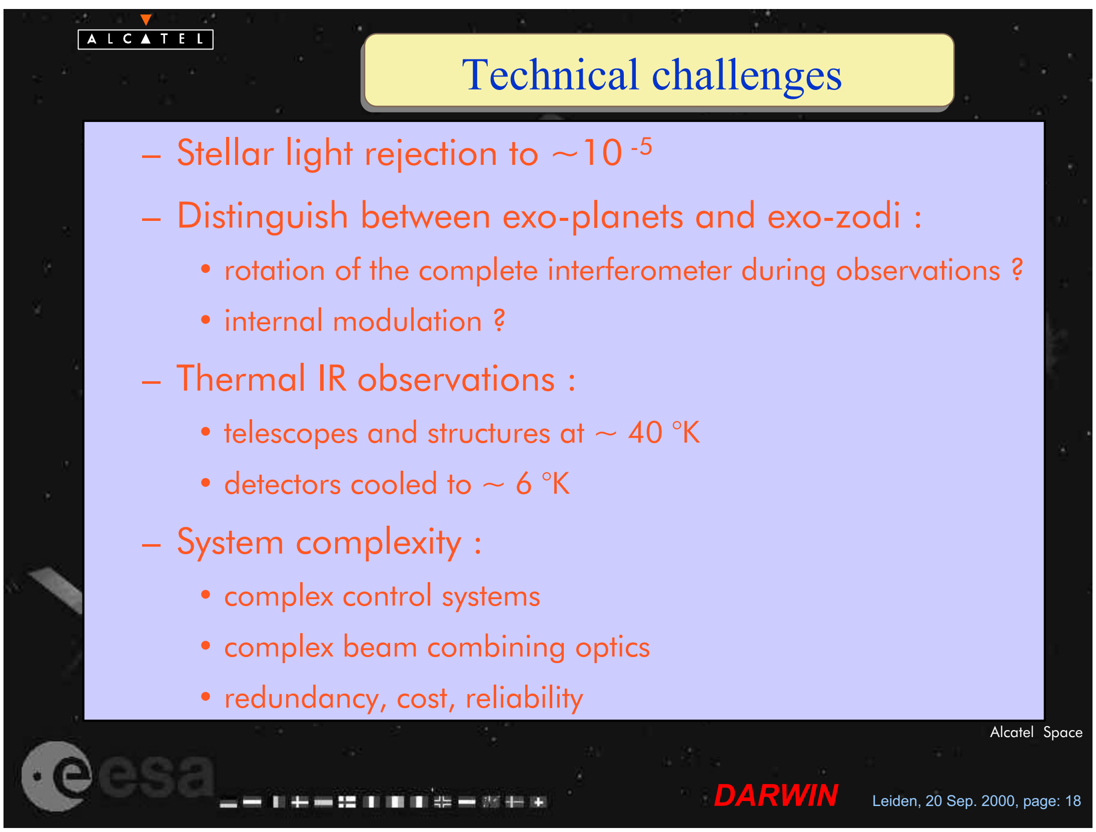

ALCATEL
Beam Combination (3)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 13

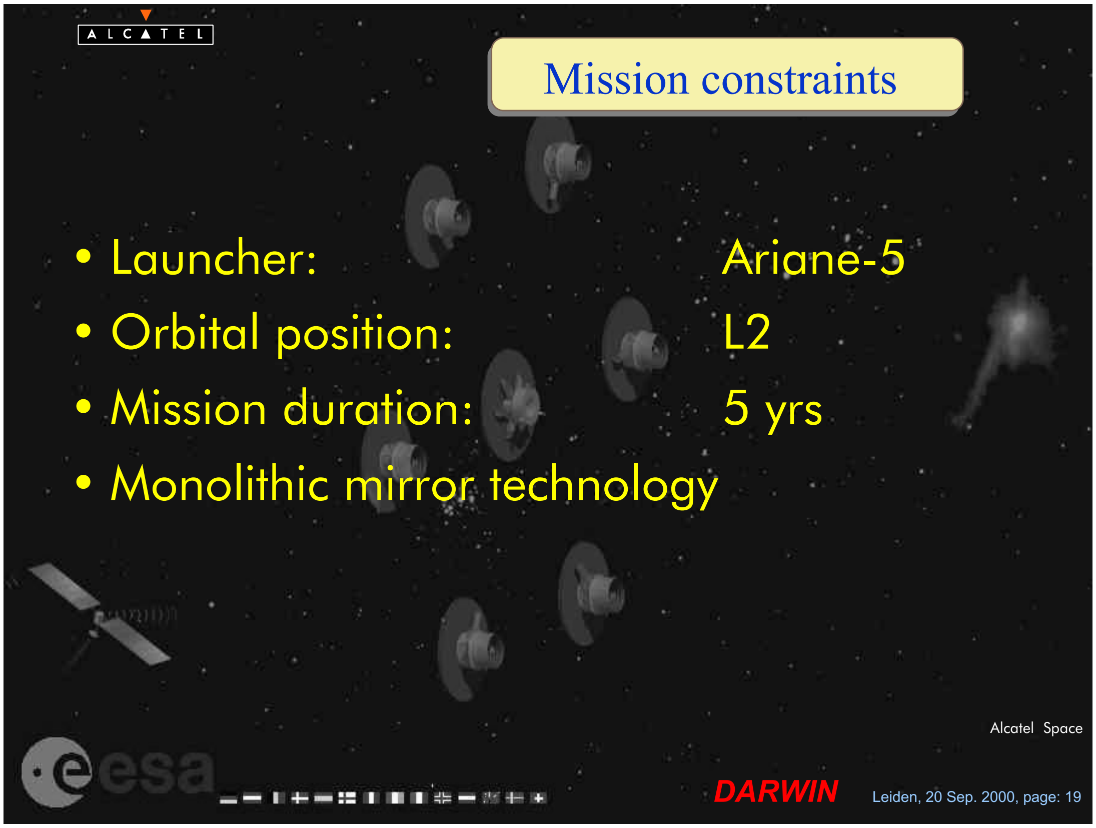

ALCATEL
Transmission map & nulling
surface brightness (MJy/sr)
Stellar disk
planet
exo - ZL
local ZL + other background signals
orbital radius (as)
Transmission map profile
θ 4 rejection law
On-axis null
orbital radius (as)
Field Stop
Planet signal
Residual stellar leakage
Detected ZL & other background flux
Surface brightness (MJy/sr)
orbital radius(as)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 14


ALCATEL
Connected Structure?
Free Flyer
Connected structure
Variable baseline (≤ 1 km)
Fixed baseline (≤ 100 m?)
2D / 3D configurations
Linear configurations
No mechanical coupling
Low frequency resonance
High cost
Very high cost
New technology
Technology available (ISS, SIM)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 15

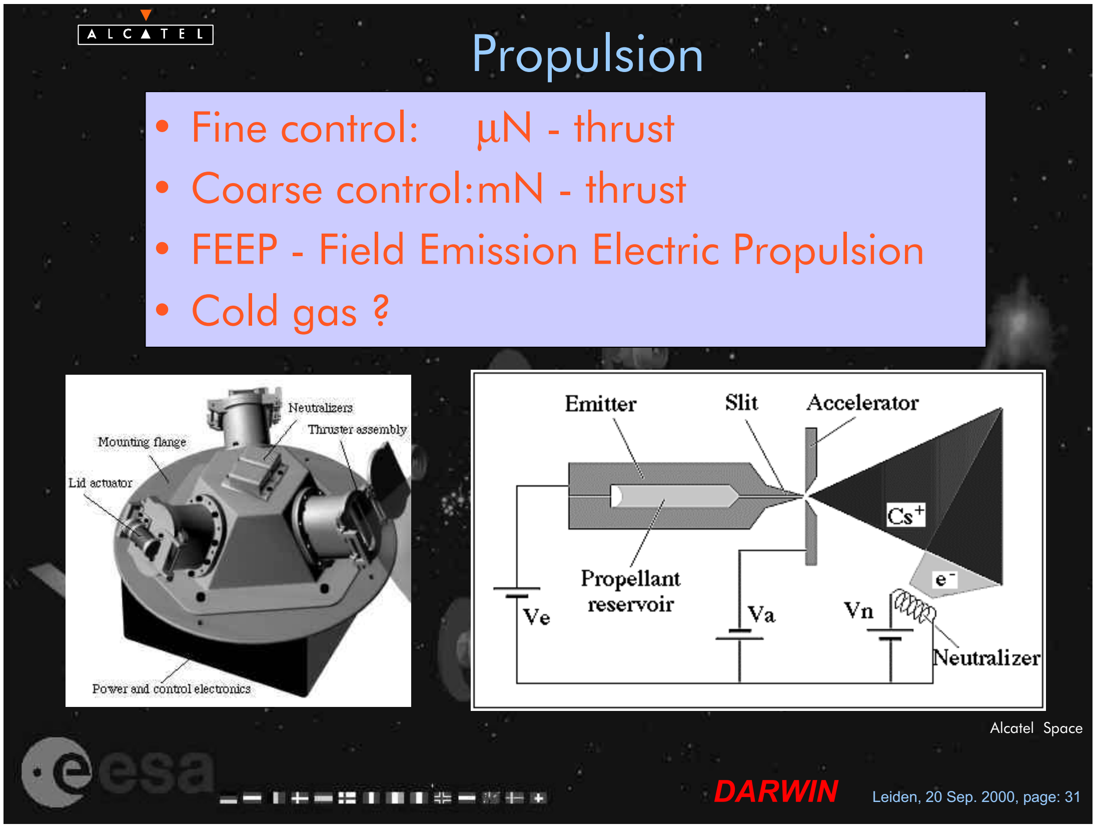

ALCATEL
Key System Parameters
• Optical nulling of "on axis" star by ~10^5
• Baseline accuracy : 1 cm
• Optical path difference : 20 nm
• Telescope pointing : 24 mas
• Amplitude matching : 10^-2
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 16

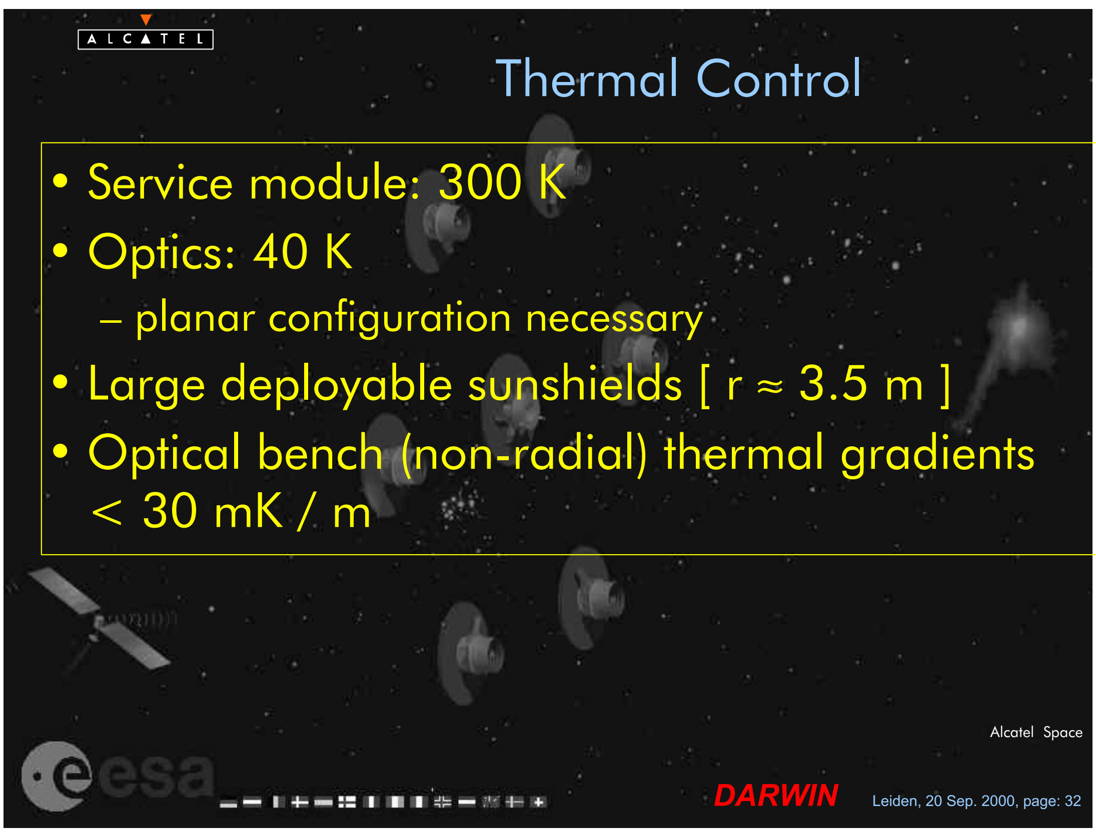

ALCATEL
Key System Parameters
Rejection Ratio for 3-GAC Nulling Interferometer
6.50 -7.00
6.00 -6.50
5.50 -6.00
5.00 -5.50
4.50 -5.00
Log (Rejection ratio)
7.00
6.50
6.00
5.50
5.00
4.50
0
5
10
Amplitude matching errors (x 10-3)
20
10
0
RMS OPD Errors (nm)
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 17

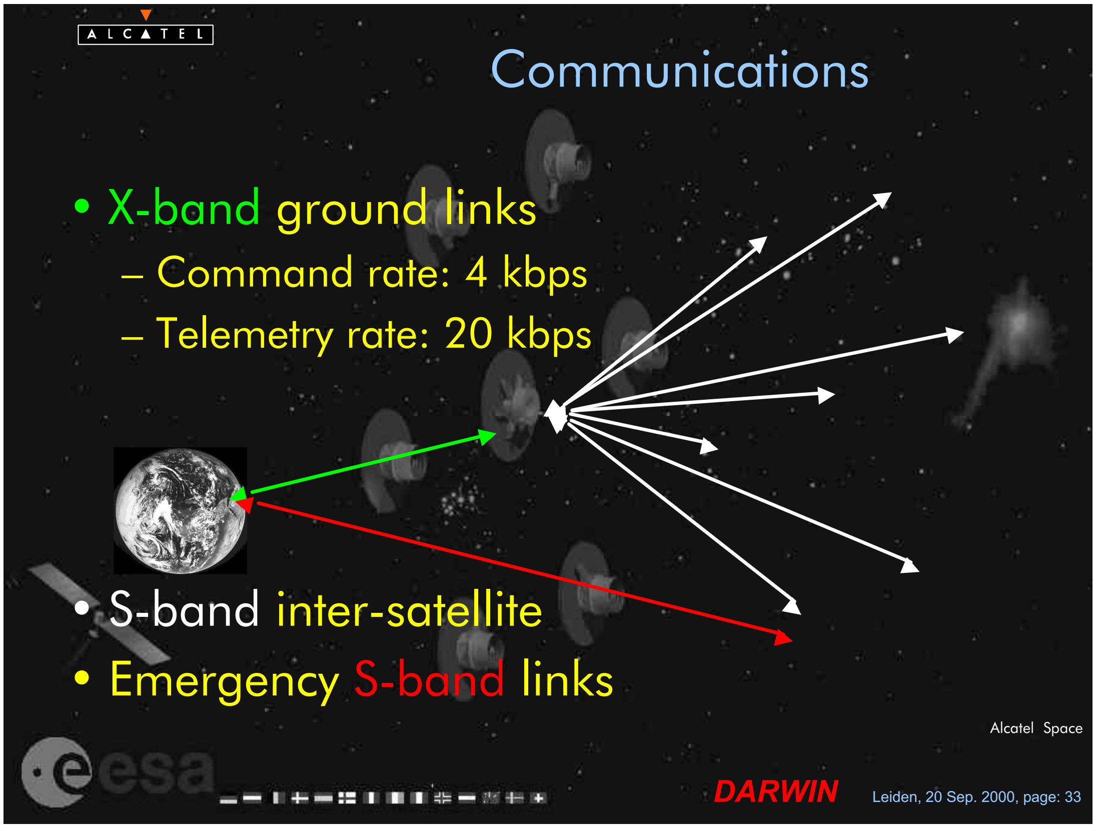

ALCATEL
Technical challenges
– Stellar light rejection to ~10 -5
– Distinguish between exo-planets and exo-zodi :
• rotation of the complete interferometer during observations ?
• internal modulation ?
– Thermal IR observations :
• telescopes and structures at ~ 40 °K
• detectors cooled to ~ 6 °K
– System complexity :
• complex control systems
• complex beam combining optics
• redundancy, cost, reliability
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 18

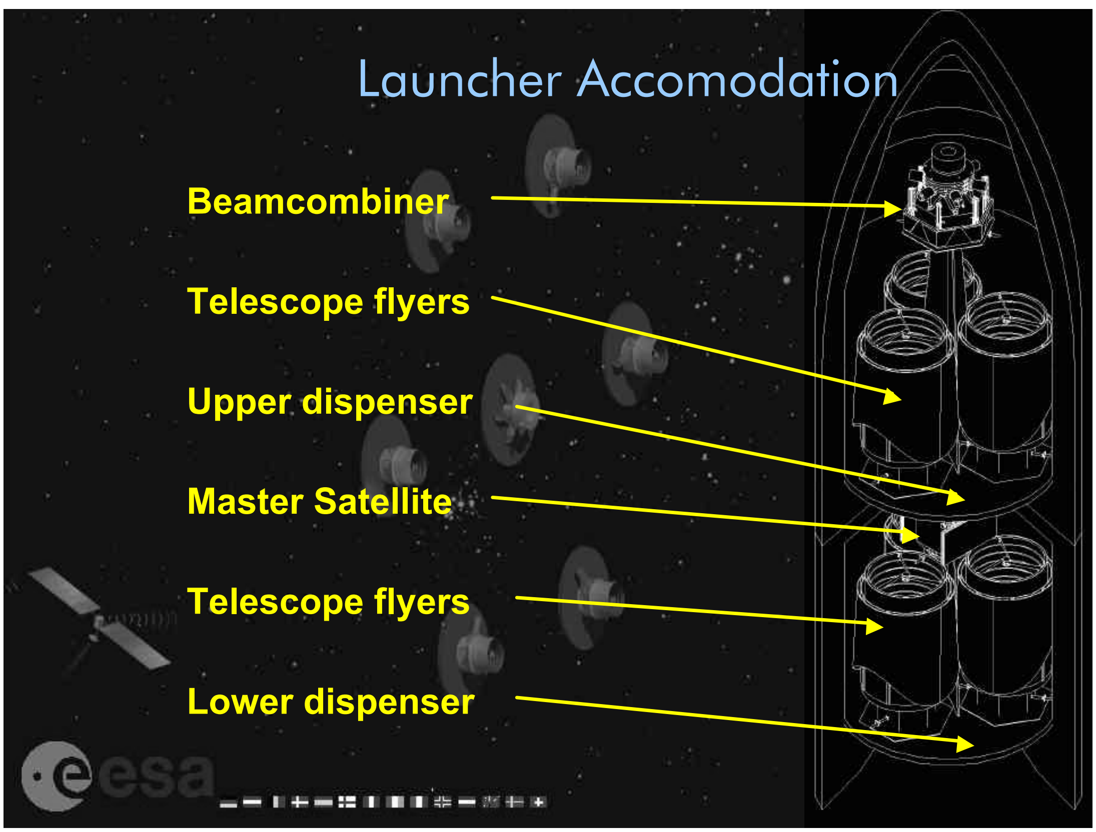

ALCATEL
Mission constraints
• Launcher: Ariane-5
• Orbital position: L2
• Mission duration: 5 yrs
• Monolithic mirror technology
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 19

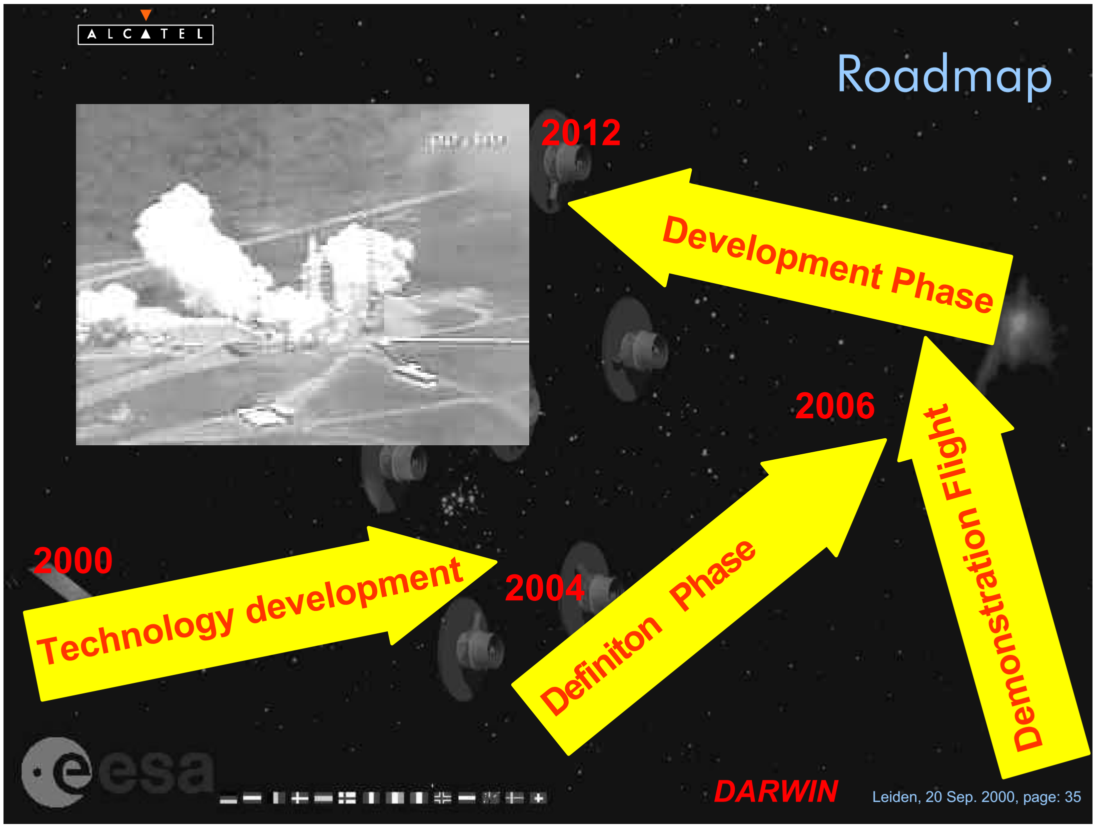

ALCATEL
Telescope Flyers
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 20

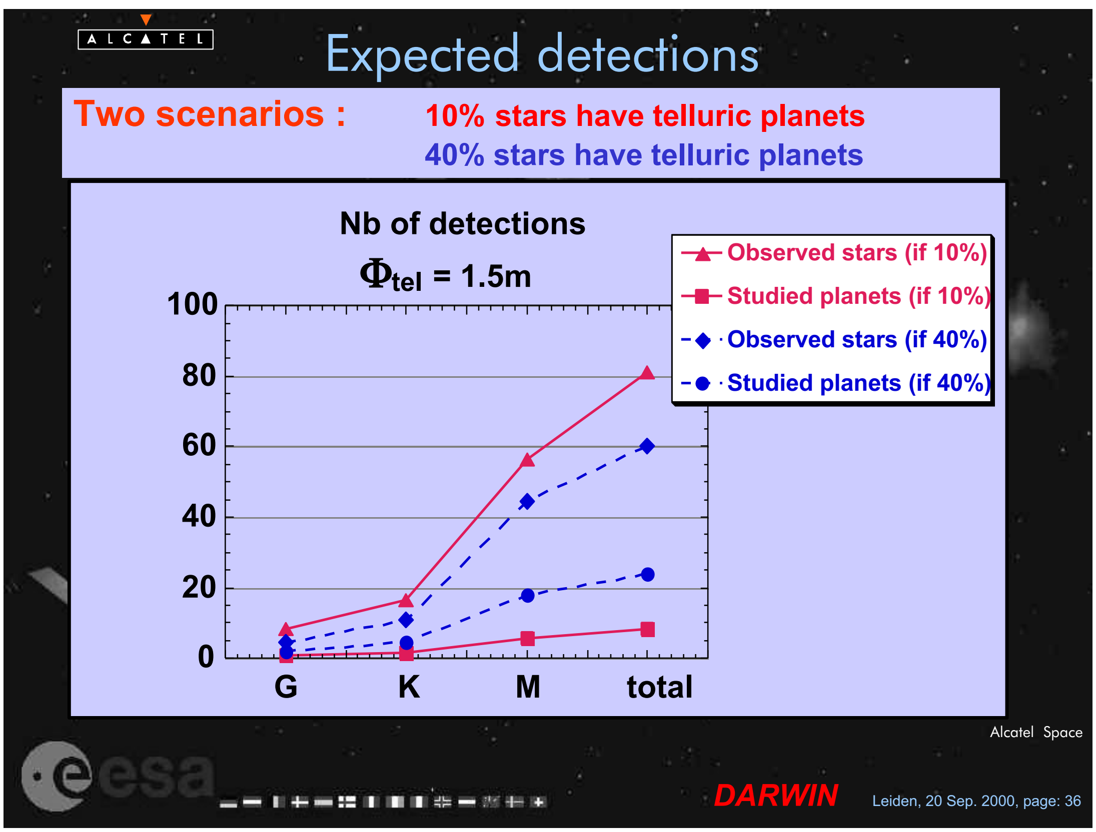

ALCATEL
Propulsion
• Fine control: µN - thrust
• Coarse control:mN - thrust
• FEEP - Field Emission Electric Propulsion
• Cold gas ?
Neutralizers
Thruster assembly
Mounting flange
Lid actuator
Power and control electronics
Emitter
Slit
Accelerator
Cs+
Propellant
reservoir
e-
Ve
Va
Vn
Neutralizer
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 31

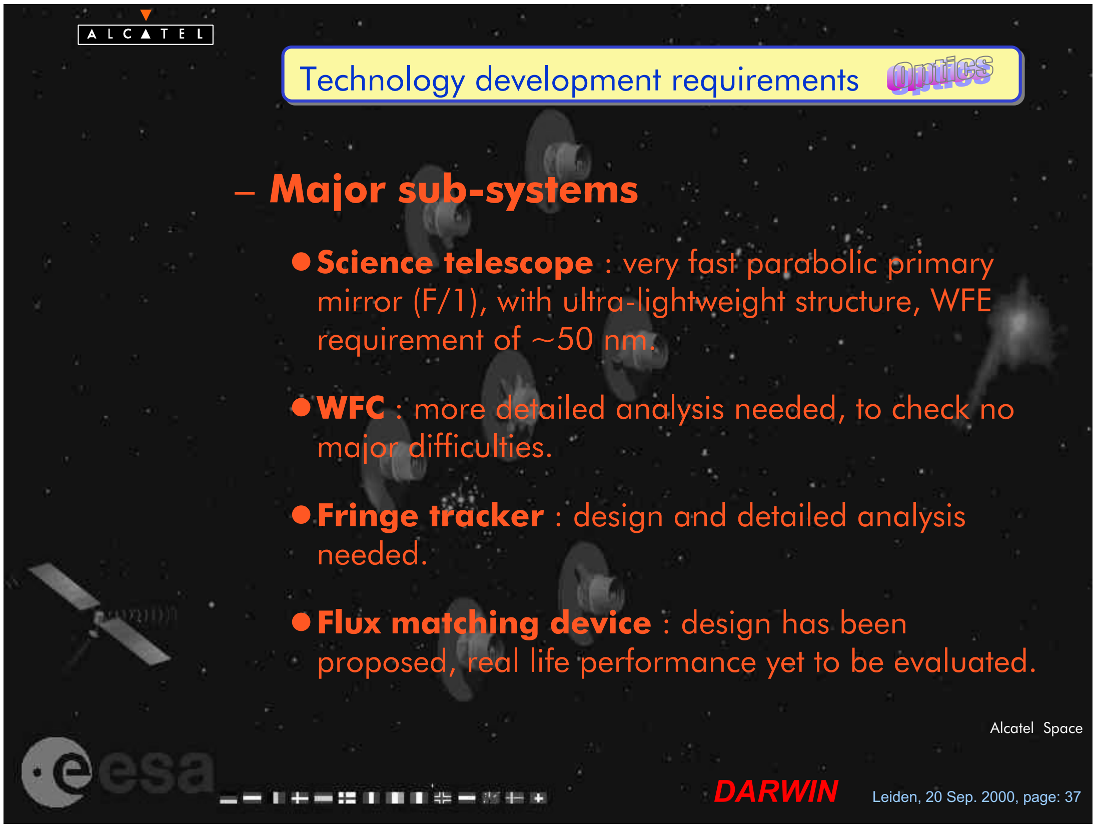

ALCATEL
Thermal Control
• Service module: 300 K
• Optics: 40 K
– planar configuration necessary
• Large deployable sunshields [ r ≈ 3.5 m ]
• Optical bench (non-radial) thermal gradients
< 30 mK / m
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 32

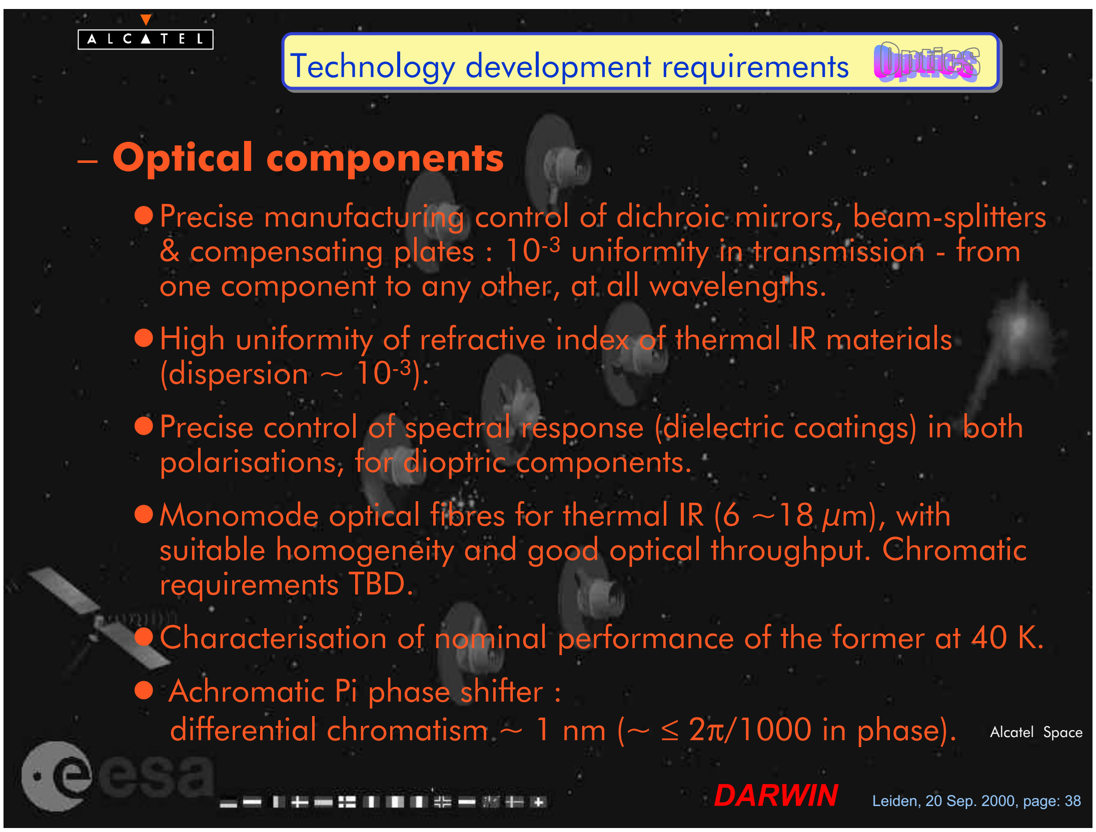

ALCATEL
Communications
• X-band ground links
– Command rate: 4 kbps
– Telemetry rate: 20 kbps
• S-band inter-satellite
• Emergency S-band links
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 33

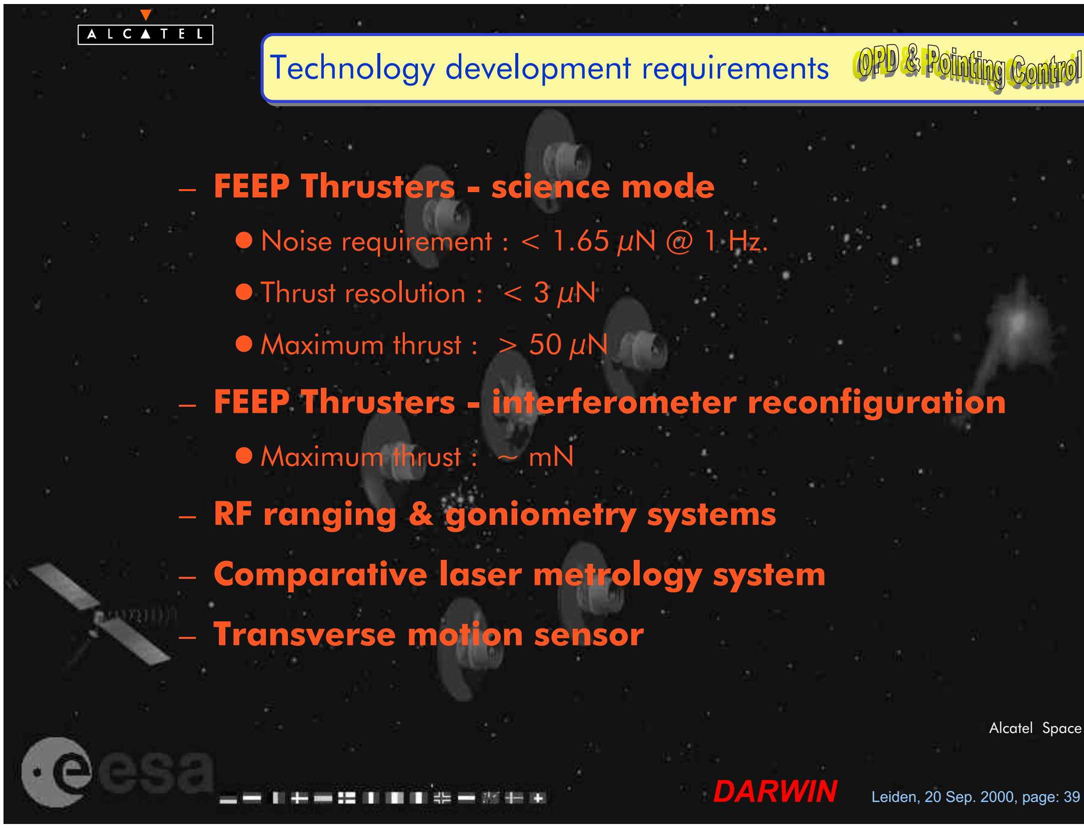

Launcher Accomodation
Beamcombiner
Telescope flyers
Upper dispenser
Master Satellite
Telescope flyers
Lower dispenser
esa

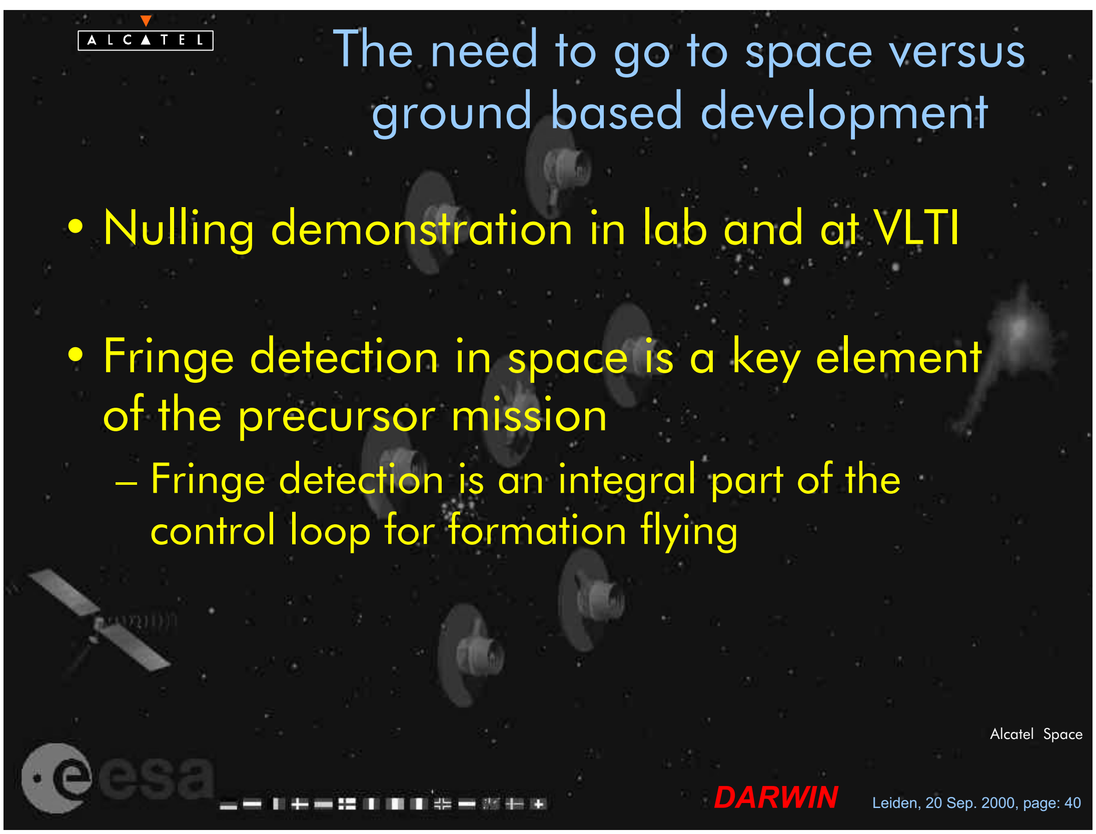

ALCATEL
Roadmap
2012
Development Phase
2006
Demonstration Flight
2000
Technology development
2004
Definiton Phase
esa
DARWIN
Leiden, 20 Sep. 2000, page: 35

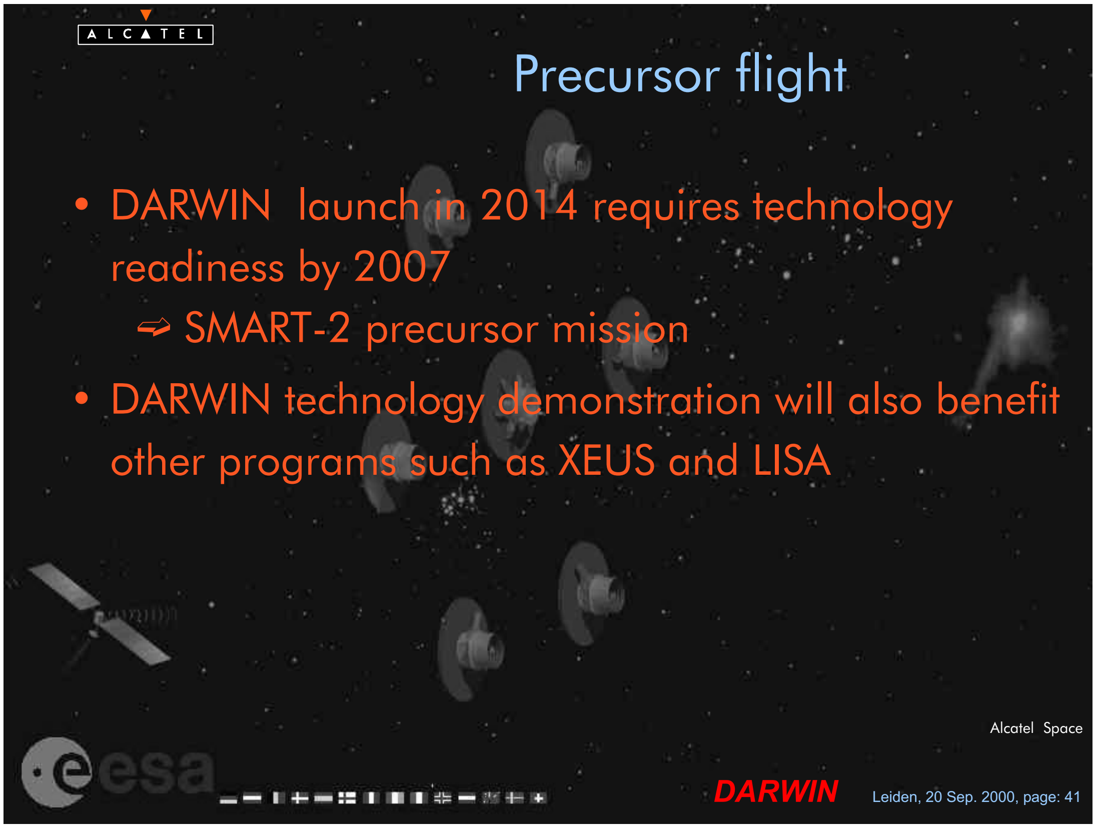

ALCATEL
Expected detections
Two scenarios :
10% stars have telluric planets
40% stars have telluric planets
Nb of detections
Φtel = 1.5m
Observed stars (if 10%)
Studied planets (if 10%)
Observed stars (if 40%)
Studied planets (if 40%)
100
80
60
40
20
0
G
K
M
total
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 36

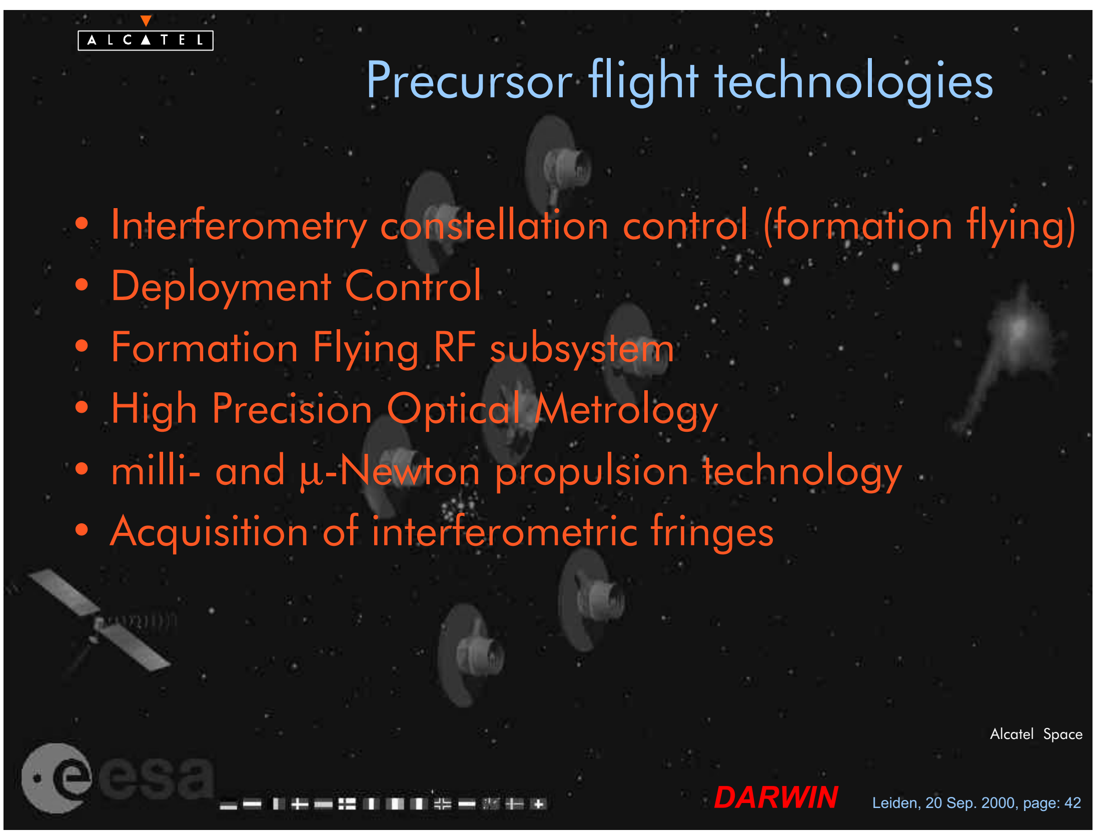

ALCATEL
Technology development requirements
Optics
– Major sub-systems
● Science telescope : very fast parabolic primary mirror (F/1), with ultra-lightweight structure, WFE requirement of ~50 nm.
● WFC : more detailed analysis needed, to check no major difficulties.
● Fringe tracker : design and detailed analysis needed.
● Flux matching device : design has been proposed, real life performance yet to be evaluated.
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 37


ALCATEL
Technology development requirements
Optics
– Optical components
● Precise manufacturing control of dichroic mirrors, beam-splitters & compensating plates : 10-3 uniformity in transmission - from one component to any other, at all wavelengths.
● High uniformity of refractive index of thermal IR materials (dispersion ~ 10-3).
● Precise control of spectral response (dielectric coatings) in both polarisations, for dioptric components.
● Monomode optical fibres for thermal IR (6 ~18 µm), with suitable homogeneity and good optical throughput. Chromatic requirements TBD.
● Characterisation of nominal performance of the former at 40 K.
● Achromatic Pi phase shifter : differential chromatism ~ 1 nm (~ ≤ 2π/1000 in phase).
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 38

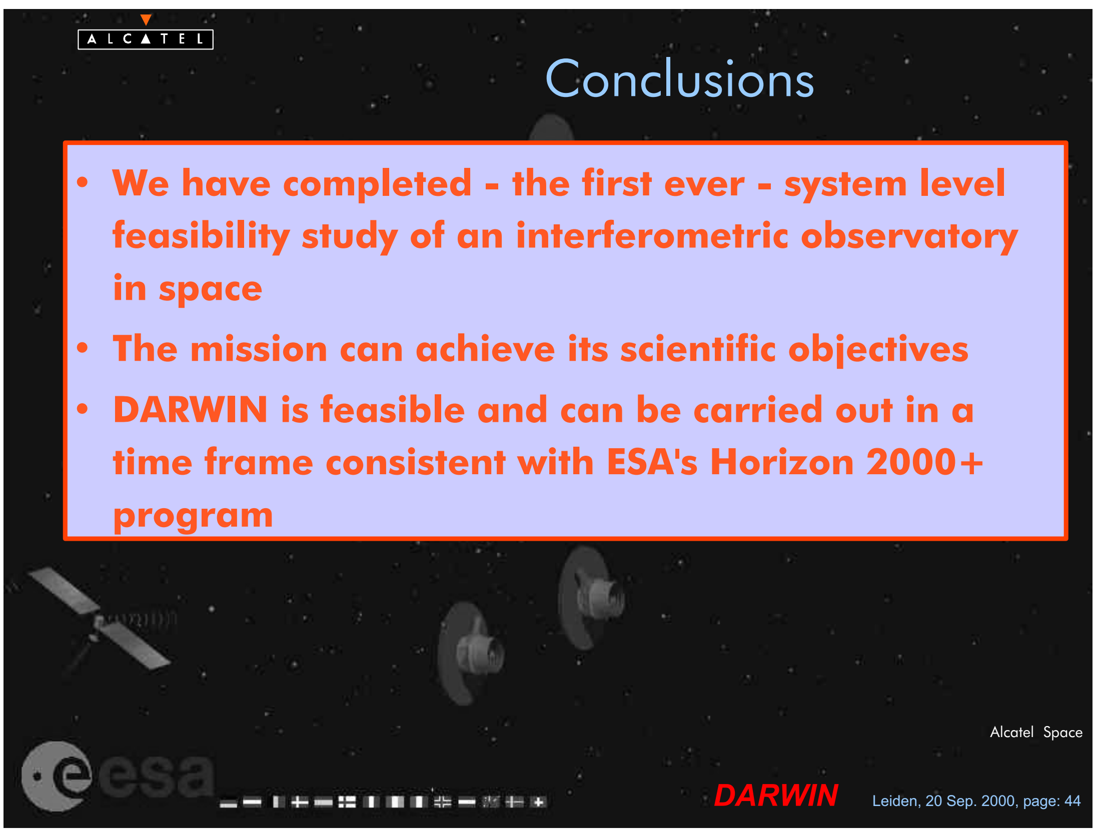

ALCATEL
Technology development requirements
OPD & Pointing Control
– FEEP Thrusters - science mode
● Noise requirement : < 1.65 μN @ 1 Hz.
● Thrust resolution : < 3 μN
● Maximum thrust : > 50 μN
– FEEP Thrusters - interferometer reconfiguration
● Maximum thrust : ~ mN
– RF ranging & goniometry systems
– Comparative laser metrology system
– Transverse motion sensor
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 39


ALCATEL
The need to go to space versus ground based development
• Nulling demonstration in lab and at VLTI
• Fringe detection in space is a key element of the precursor mission
– Fringe detection is an integral part of the control loop for formation flying
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 40


ALCATEL
Precursor flight
• DARWIN launch in 2014 requires technology readiness by 2007
⇨ SMART-2 precursor mission
• DARWIN technology demonstration will also benefit other programs such as XEUS and LISA
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 41


ALCATEL
Precursor flight technologies
• Interferometry constellation control (formation flying)
• Deployment Control
• Formation Flying RF subsystem
• High Precision Optical Metrology
• milli- and µ-Newton propulsion technology
• Acquisition of interferometric fringes
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 42


ALCATEL
International collaboration
Close co-operation exists at the scientific level between ESA and NASA on DARWIN and TPF
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 43


ALCATEL
Conclusions
• We have completed - the first ever - system level feasibility study of an interferometric observatory in space
• The mission can achieve its scientific objectives
• DARWIN is feasible and can be carried out in a time frame consistent with ESA's Horizon 2000+ program
Alcatel Space
esa
DARWIN
Leiden, 20 Sep. 2000, page: 44

This page was intentionally left blank