Trials and limits of automation: Experiences from the Zimmerwald well characterized and fully automated SLR-system

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20th International Workshop on Laser Ranging,
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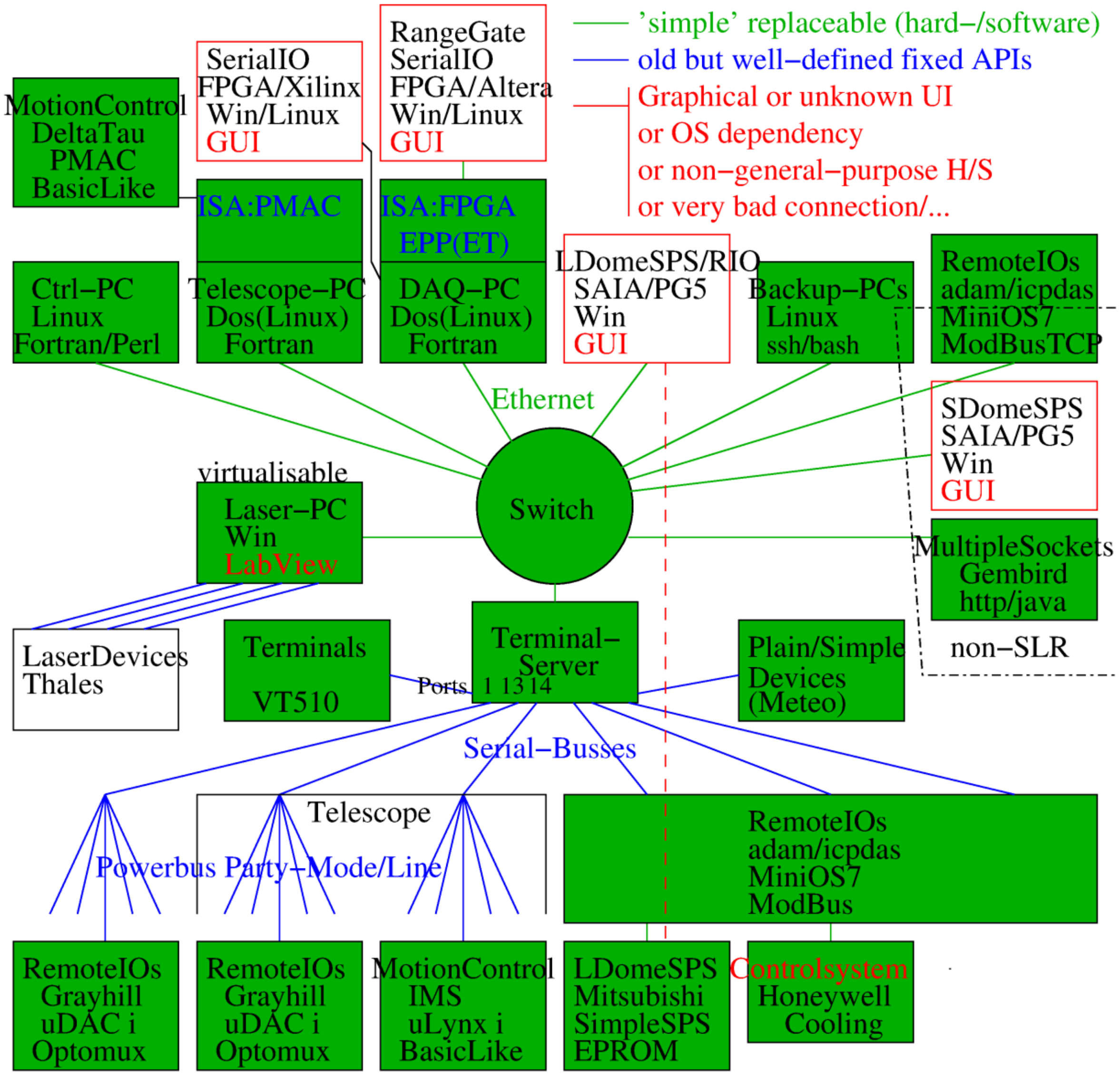
Hardware Communication Layout



Day and night

Automated Devices

```
  1: 0ABSENKUNG    2: 0FLIPFLOPE    3: 0FLIPFLOPW    4: 0IN_HUMID     5: 0IN_TEMP
  6: 0PARKPOS      7: A0321_INIT    8: A0321_SYNC    9: A0322_INIT   10: A0322_SYNC
 11: ABSENKUNG    12: AZI_NULLPT   13: AZ_HEATER    14: AZ_HUMID     15: AZ_H_MON
 16: AZ_TEMP      17: A_MIRROR     18: BEAM_CAM     19: CABLE_TEMP   20: CAL_WINDOW
 21: CAMAC        22: CAMAC_PC     23: CAMAC_PWR    24: CAMTRIGEN    25: CCDZMDX
 26: CC_BEEPER    27: CFD_CONT     28: CHILL_COND   29: CHILL_FLOW   30: CHILL_TEMP
 31: CM_SHUTTER   32: CNTR_TEMP    33: CONST_FLZT   34: COOLING      35: COUNTER_01
 36: COUNTER_02   37: COUNTER_03   38: CP1_DRIVE    39: CP1_POWER    40: CP1_WHEEL
 41: CP2_DRIVE    42: CP2_POWER    43: CP2_WHEEL    44: CP3_DRIVE    45: CP3_POWER
 46: CP3_WHEEL    47: CP4_DRIVE    48: CP4_POWER    49: C_SHUTTER    50: DAY_TV
 51: DBS          52: DECIMATE     53: DELPHINUS    54: DETECTORS    55: DIVERGENCE
 56: DIV_OK       57: DIV_RST      58: DM_DRIVE     59: DOME         60: DOME_FAN
 61: DOME_LIGHT   62: DOME_NCLOS   63: DOME_SPOT    64: DOMW_NCLOS   65: FO_DELAY
 66: FO_PERCORR   67: FO_PERIOD    68: FP_GR        69: FREQ3_INIT   70: F_SHUTTER
 71: GPS_DIFF_B   72: HWI_NULLPT   73: LASER        74: LASER_GR     75: LASER_IR
 76: LRO_CORR     77: LSH_INH      78: LS_AIRTEMP   79: LS_CHILLER   80: LS_COOLTMP
 81: LS_DI_O      82: LS_LASTEMP   83: LS_MEDOX     84: LS_OSCTEMP   85: LS_WARN
 86: L_SHUTTER    87: L_SHUTT_GR   88: L_SIMUL      89: M2_FLUSH     90: MANCOR_X
 91: MANCOR_X0    92: MANCOR_Y     93: MANCOR_Y0    94: MAN_MODE     95: MASER1PS1
 96: MASER1PS2    97: MASERTEST    98: MASERV1BA    99: MASERV1IN   100: MASERV1PS
101: MASERV2BA   102: MASERV2IN   103: MASERV2PS   104: METEO_FAN   105: ML_DRIVE
106: MOTION_DET  107: NDFILT_GR   108: NDFILT_IR   109: ND_CALFILT  110: OBS_WINDOW
111: OUT_HUMID   112: OUT_PRESS   113: OUT_TEMP    114: P1_P2       115: PINHOLE
116: PWR_FAIL_1  117: PWR_FAIL_2  118: PWR_LABPC   119: R1_SHUTTER  120: R2_SHUTTER
121: R3_SHUTTER  122: RACK_TEMP   123: RADAR       124: RADAR_TEST  125: RAINSENSOR
126: RA_TUNE     127: RA_TUNE_OK  128: ROT_CONFL   129: ROT_SHUTC   130: ROT_SHUTE
131: ROT_SHUTL   132: ROT_SHUTON  133: ROT_SH_CL   134: ROT_SH_OP   135: ROT_SH_RST
136: RR_WINDOWS  137: R_GATE      138: R_SWITCH_1  139: R_SWITCH_2  140: SAT_RGTOFF
141: SEN_CLK_S   142: SI1100      143: STAN3_INIT  144: STAN_FREQ3  145: START_OK
146: STOP_DOME   147: SUN_ANGLE   148: SUN_COVER   149: SUN_C_STAT  150: TEL_BRAKES
151: TEL_LAMP    152: TEMP_FORK   153: TEMP_M1     154: TEMP_PFI    155: TEMP_TUBE
156: TILT_HOR    157: TILT_PWR    158: TILT_VER    159: TR_M_LOCK   160: TR_REMOTE
161: TR_STROBE   162: TUBE_FAN    163: TUBE_HEAT   164: V1_KEY      165: VND_GR_OK
166: VND_IR_OK   167: W_PRESS     168: ZIMDATAPC2  169: ZIMLAT
```

- **~165 Devices**
  - **Moving Devices:** Matching Lens, Divergence Optics
  - **On/Off Devices:** Laser Shutter, Tube Fan
  - **Read-only Devices:** Humidity Sensor, Maser In Voltages
- **Design Rules:**
  - MTBF: long lifetime,
  - less maintenance

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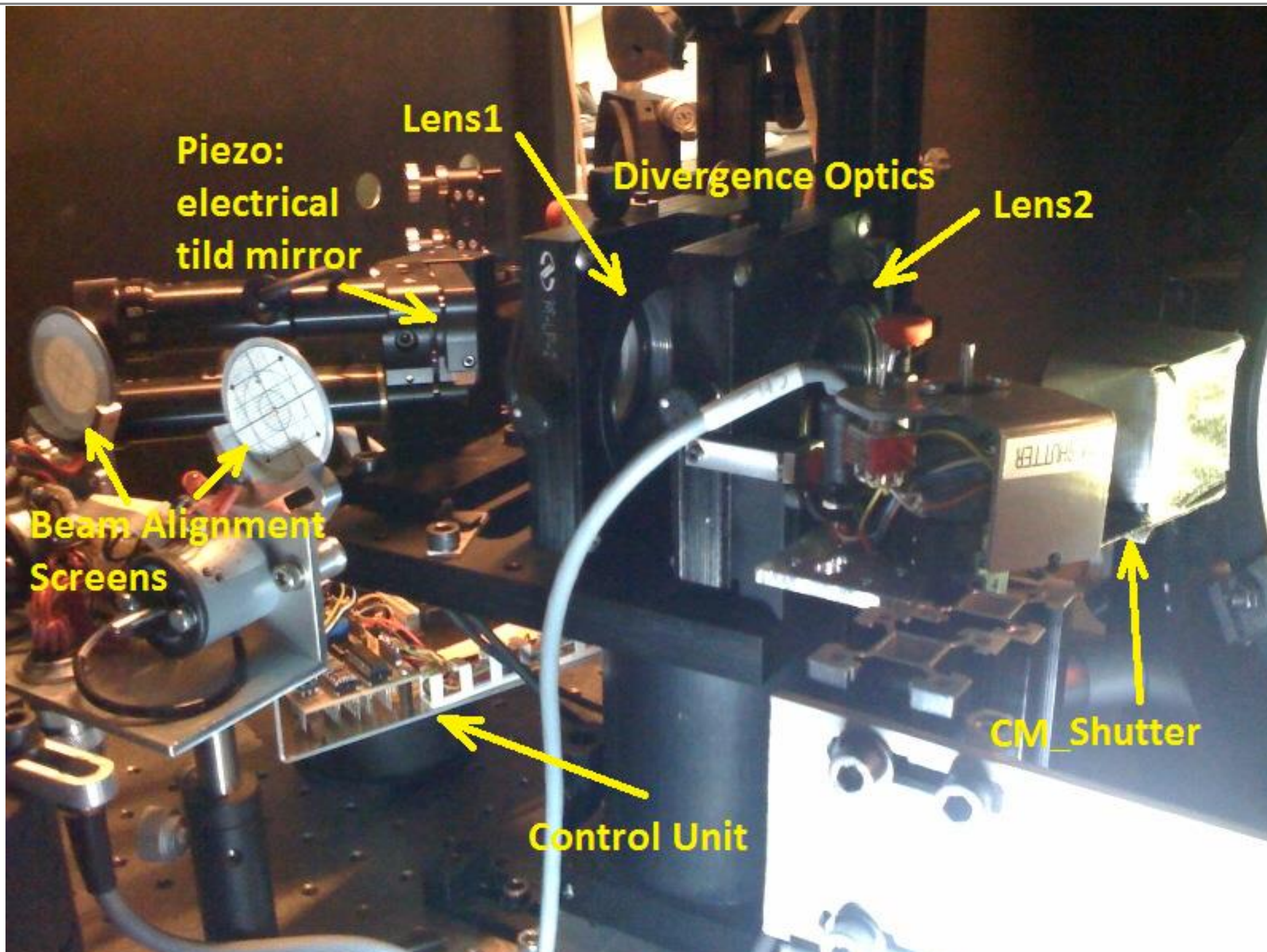
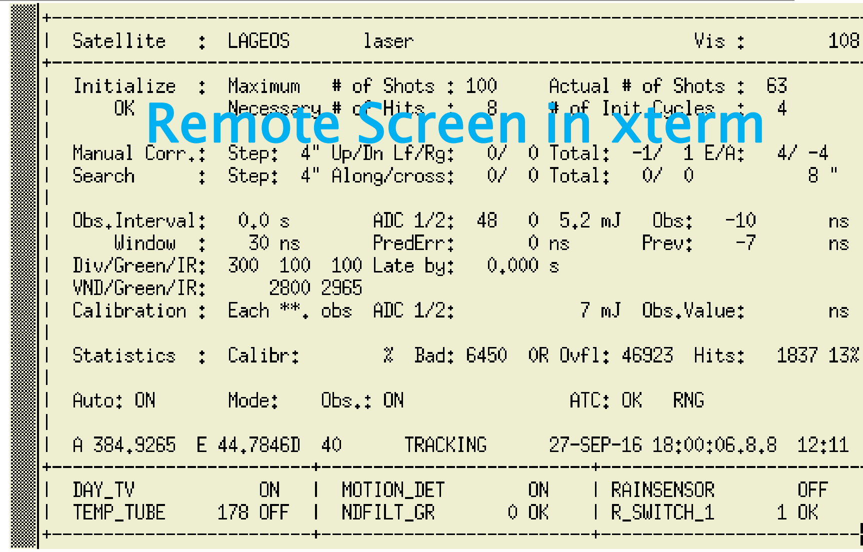
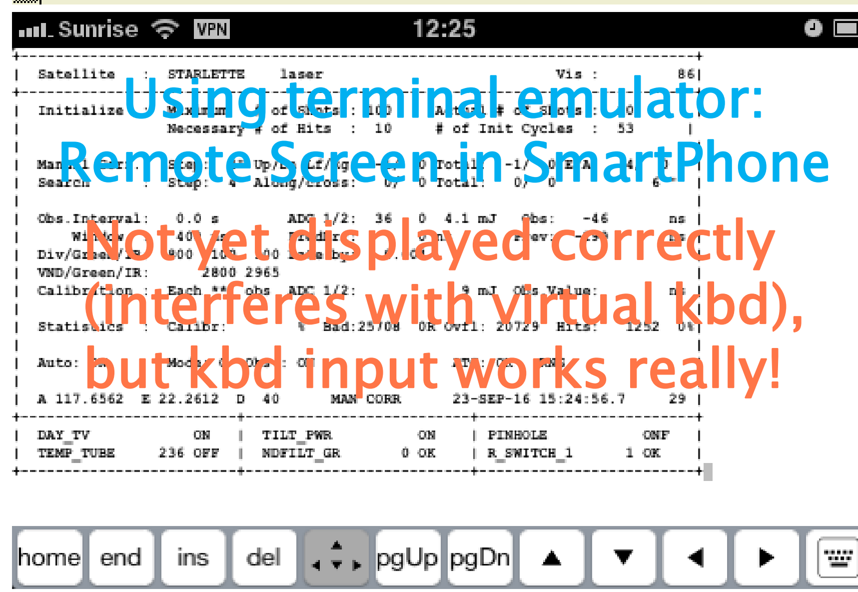
Example: Some Devices…



Software Maintenance

- **Linux is your friend here**
- **Philosophies**
  - Upgrading old, in order to maintain automation
  - Writing new, which automates new things, e.g. Envisat data processing
- **~300.000 lines Fortran77 source code, under revision control, some «minor» not**
- **Design Rules:**
  - less maintenance, use (**IX) standard interfaces
  - simple expansible
- **BTW: Use host- and usernames carefully…**





Software Porting

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Motivation:

- Old code has less bugs!
- development very bad under DOS

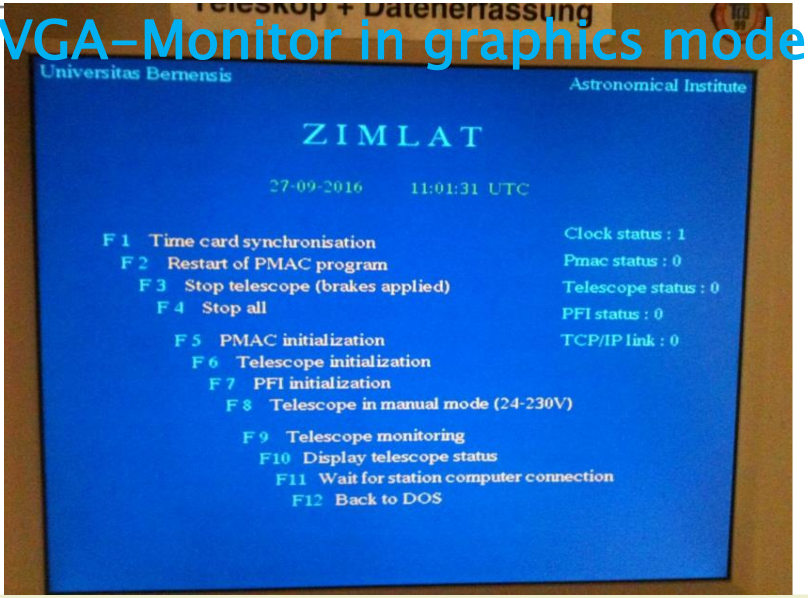
Software interfaces:

- text terminal/keyboard-based,
- TCP/IP network, only one X11 application (pgplot) for residuals,
- byte code protocols (e.g. Modbus) network

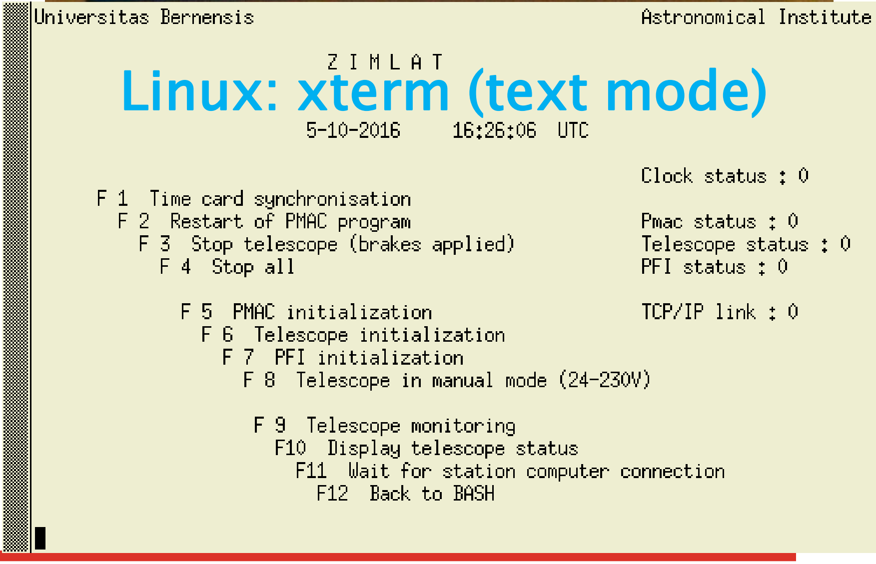
Hardware interfaces:

- EPP, ISA
- Video graphics: If uses only text: API adapted to use ncurses calls

DOS: VGA-Monitor in graphics mode



Linux: xterm (text mode)



PC Hardware Maintenance and Porting

Idea: hardware redundancy, no complete new system, replace single components only

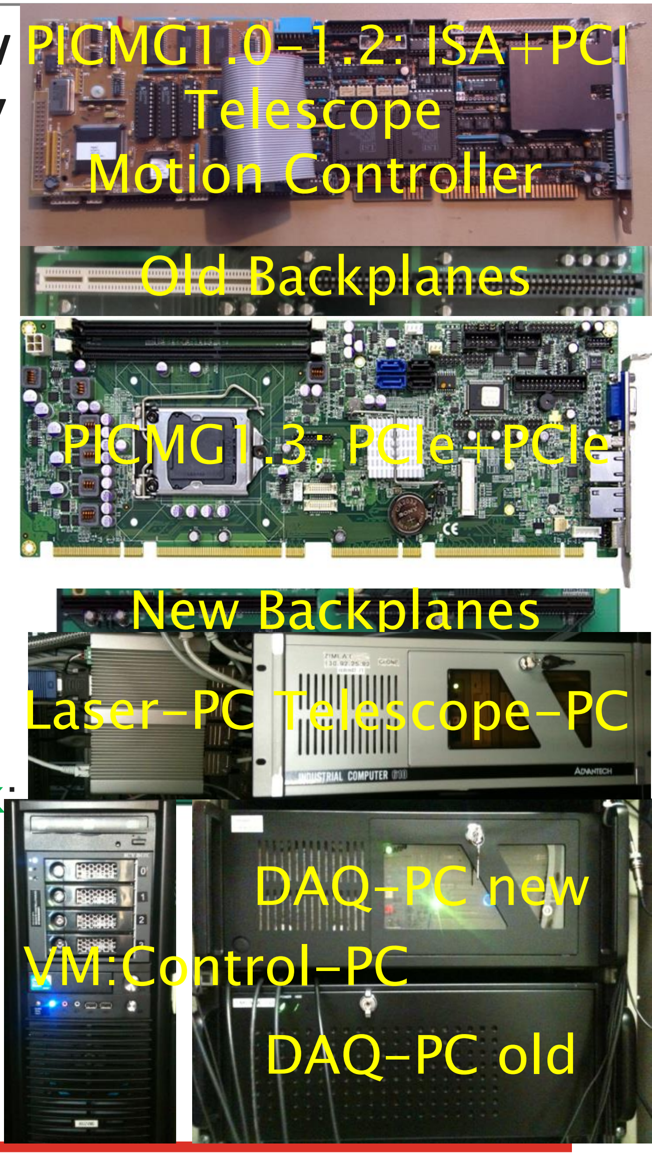
PCs Maintenance (copying):

- Station Control: made a virtual machine
- DAQ: almost cloned, lacks a print card
- Telescope: cloned
- Laser: program copied onto new PC and OS (Windows)

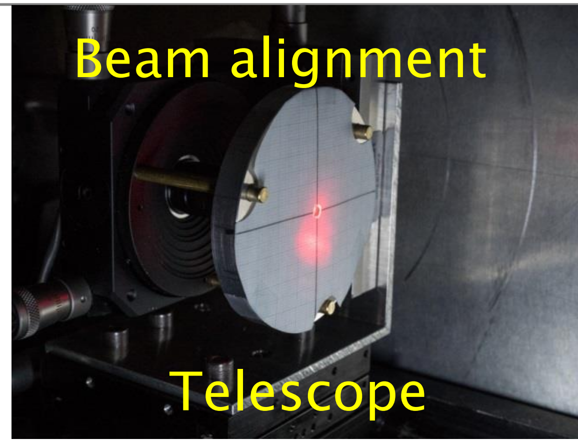
Porting DOS to Linux

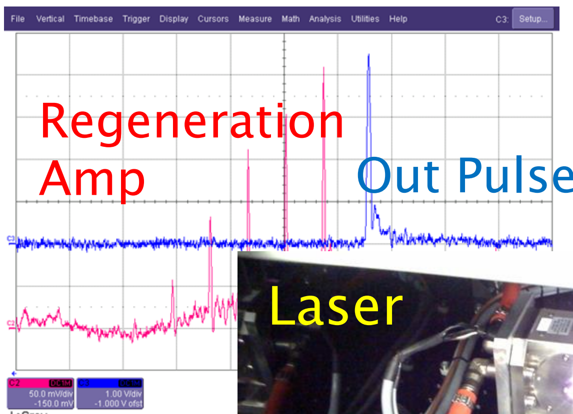
- ISA port/memory mapped access seem to work: first time as user root, or Linux driver
- last interesting tests in real environment come up… difficult: timing restrictions if any

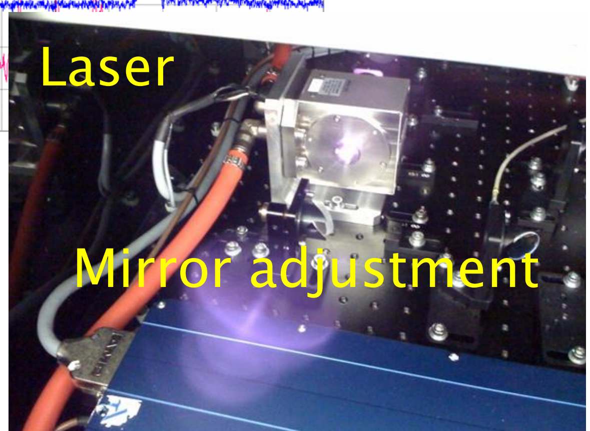
Btw: Mixed experiences with new (all-in-one) SPS



Limits of Automation

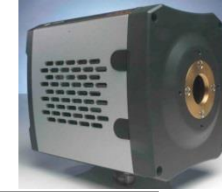




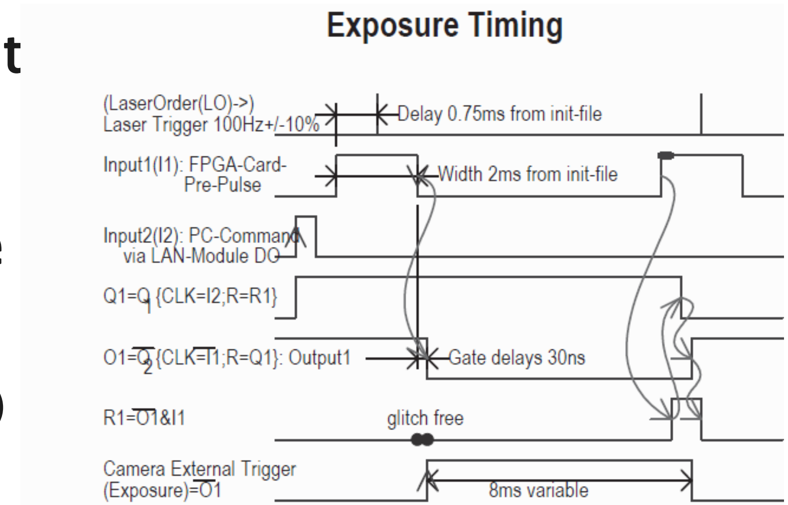


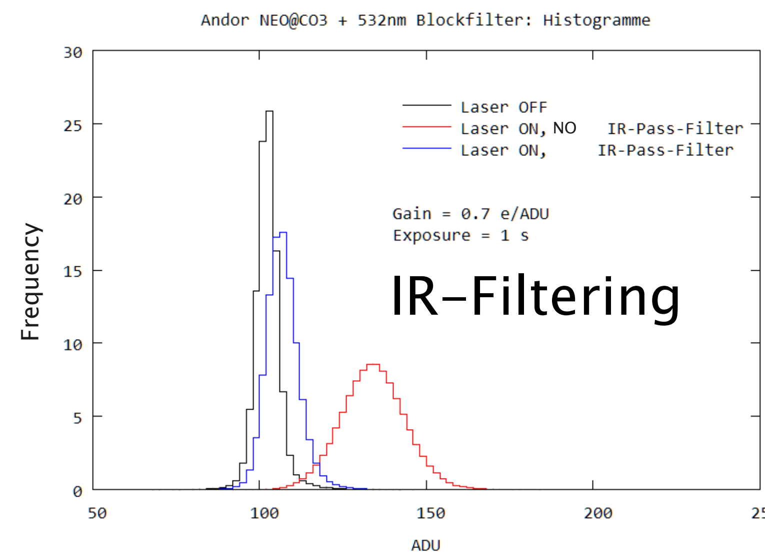
- **frequent**
  - optics cleaning
  - replacing: fans, power supplies, batteries
- **rare**
  - receive path: Fabry-Pérot adjustment
  - Maser frequency drift correction

Night Tracking Camera



- Like in the earlier days of SLR: Point to HEO sat., between laser pulses take a photo, evaluate photo: find HEO sat., calculate deviation, move telescope directly to sat. position
- Digital Camera Neo sCMOS (Andor) evaluated: should fit purpose
- Exposure Timing works
- Light shade pipe required
- laser light filtering: Additional filter for IR too seems to solve
- Implementing Software of image processing continues…
- analogue technique was so easy…





Safety of Low Energy Tracking

… should be fully automated and should be fully secure

- Targets: ISS (ELT: 0.1mJ), Sentinel-3A, …
- for standard tracking: Why do we need so much energy at all? RegenOut 0.4mJ@532nm and 100Hz enough for all LEOs incl. Lageos (see also other publications…)
- currently, everything depends on the satellite name only
  - one software problem should not affect safety!:
  - second software variable from second data channel required? (like Go/NoGo-Flag)
- Energy measurement in real-time: Ulbricht Sphere + Photo Diode: less precision compared to thermal sensor: to be checked again
- divergence control seems to be reliable
measurements continue when at 8mJ again

Excursion: Frequency Stability for ELT

- SLR Zimmerwald is phase locked to the Maser since 9.8.2016, 15:20 UTC
- Maser frequency drift is corrected manually: 1PPS Difference of GPS to the Maser is at the measurement precision of the GPS-receiver (res30ns/acc165ns)
- METAS (Time and Frequency Lab, located 8 km from station) checks for optical link between its Caesium fountain and station

Safety for European Laser Time Transfer (ELT)

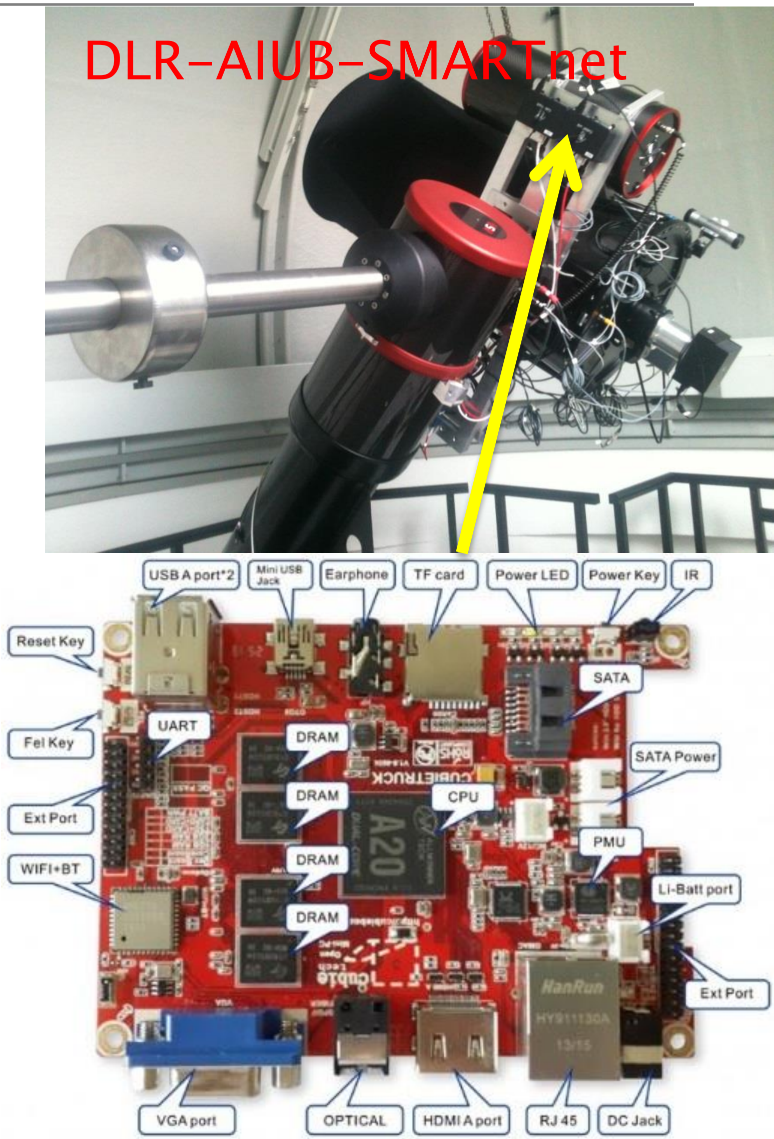
Paper: "..ELT and Laser Safety for the ISS", U. Schreiber et al., 2013
Some checks for our system specific implementation:

- **Easy to program: For ISS, switch CM_SHUTTER (located after energy measurement) ON (to open) if laser energy is less than...**
- **Mains Power Off/On Scenario and UPS (to be checked again):**
  - Control-PCs have UPS, UPS can work contrary to safety
  - laser power supply and chiller have no UPS,
  - Shutters should be closed by gravity (currently by springs)
- **Micro switches at Divergence Optics: seems to be a good idea**
- **Amplifier gain reduction:**
  - Delay between Amp pumping and laser pulse + polarizer attenuator might work
  - Switching off Post-Amps: Amps not at thermal operating point: For fully automated operation, have to be back in stable operation condition after ISS passage: switching off Amps might be a bad idea

New Systems

Idea: New technology: Carbon-Fibre-Tube: high stiffness, cheaper

- Used for Space Debris, not yet for SLR, ok, equatorial mount is bad for SLR …
- other motion controller: completely new, first version software, some minor source code imported from old system
- Camera readout “PCs”: low power SBCs at telescope axis: Cubietruck, no mechanics (less maintenance): no active cooling/fan, flash/SSD memory, a lot of similar boards available: to be evaluated
- Satellite pointing at arc sec precision, development affected already others
- For SLR some is missing: e.g. Sun avoidance and timing precision!

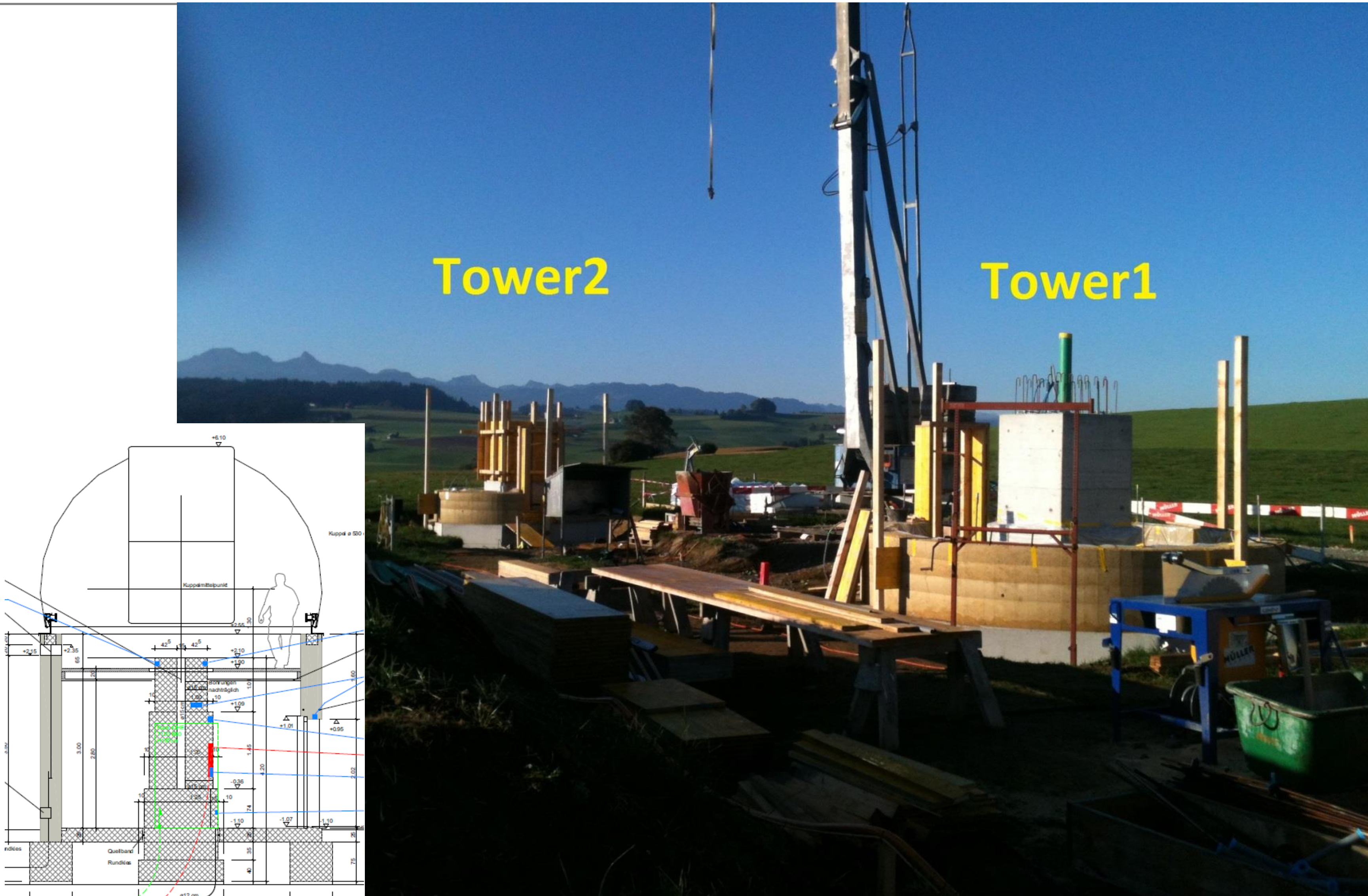


Conclusion

- **Think carefully about what you're going to implement, for both hardware and software!**
- **A lot of work to do…**

Thank you very much for your attention!

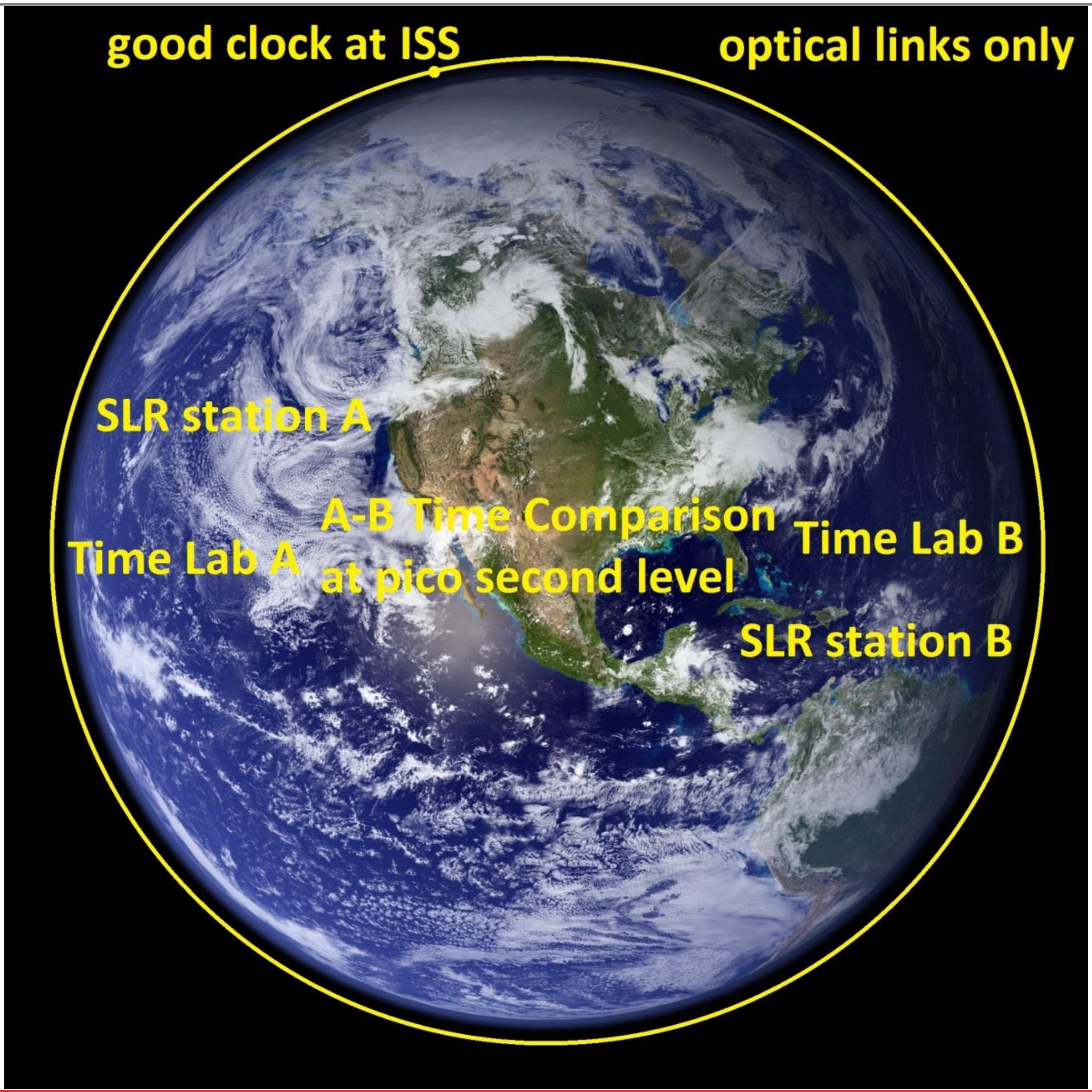
Two new Towers for new Telescopes



Backup

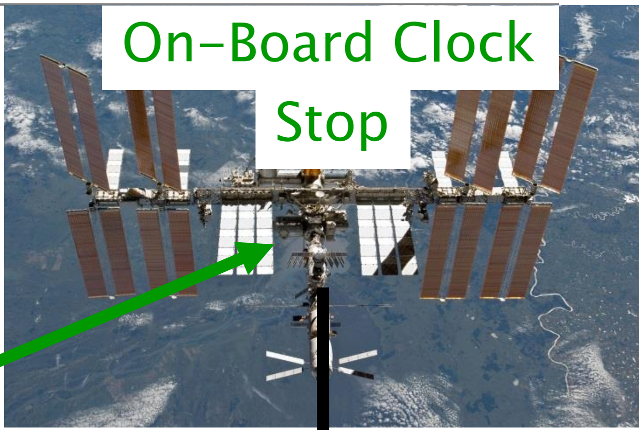
- ZIMLAT-Telescope used for
  - Geodesy (SLR) and
  - Imaging (Space Debris)
  - Hybrid design is difficult: optical compromise
- ELT: Event-Timing: Dassault-Elements required?
  We don’t want to buy such expensive devices…

Time Transfer Principle



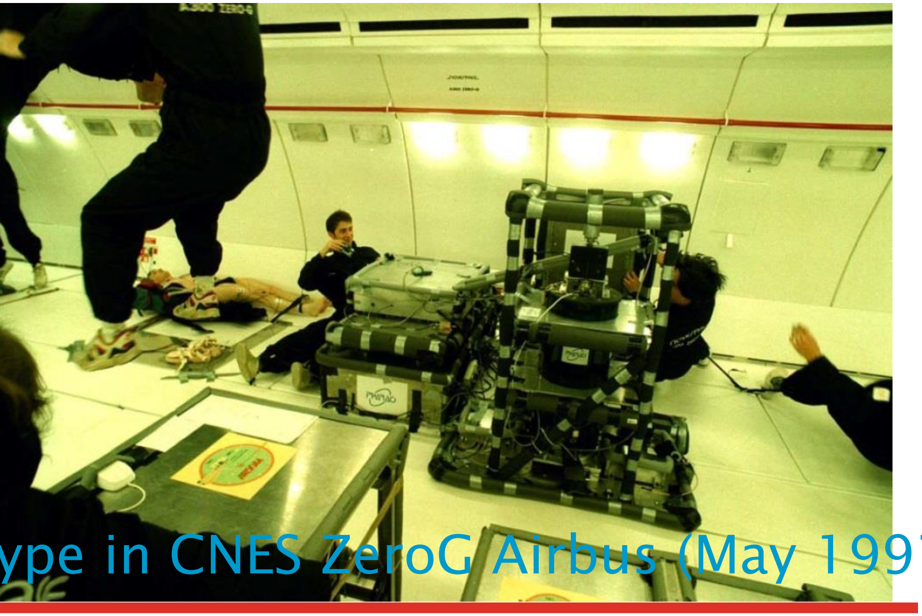
Time–Transfer Principle (2)

- Purpose: Clock comparison by Time–tagging on space and ground
- SLR in parallel
- Satellite site cannot be changed easily



Excursion: The used Clock in Space

- **ACES (Atomic Clock Ensemble in Space)**
  - cold atoms in microgravity
  - Combination of cold Caesium clock and H-Maser:
  - test of PHARAO frequency stability $10^{-13} x \tau^{-1/2}$ and accuracy $3x10^{-16}$
  - test of SHM frequency stability $2.1x10^{-15}$ @ 1000 s
- **Applications in Fundamental Physics**
  - gravitational red-shift
  - drift in fine structure constant
  - anisotropy of light



Pharao prototype in CNES ZeroG Airbus (May 1997)

Time Transfer Predecessors: simple clocks

- **T2L2: Operated by France, OCA and CNES**
  - On-board Clock (USO) no longer State-of-the-Art
  - At end of lifetime
  - Since years precision evaluation: Allan-Variance: about 1ps: optical transfer much better than RF ones
  - Data on request (see http://www.geoazur.fr/t2l2/en/data/v4/ Ground to Space section: 1 Triple data files tar-ball/ 1 day)
  - A lot of published papers
- **LRO: Lunar Reconnaissance Orbiter (NASA), spacecraft around the moon (mission ended)**
  - Requires enough energy, good weather conditions and schedule
  - Precision data NASA proprietary?

ELT: European Laser Time Transfer uses ACES

- **ELT difficulties:**
  - Operated by ESA via NASA via ISS-operators,
  - ACES launch scheduled for 2016,
  - Not yet operating,
  - ISS operated -2020?
- **Successor project of T2L2, in principal similar, new:**
  - improved detector-retro-package, ready for launch, pre-flight experiments and papers well-known
  - The best On-board Clock ever: ACES
  - ESA requirement: Ground-Data-Infrastructure ready before Hardware launch
- **SLR-Stations**
  - locked to Maser: Time comparisons can be made

ELT objectives (a copy from an ELT workshop..)

- **Clock Comparisons and Time Transfer**
  - Space-to-ground comparisons of clocks reaching a TDEV of 4 ps between 300 s and 10^4s of integration time, better than 7 ps on the long-term
  - common view comparisons below 6 ps per ISS pass
  - Non-common view comparisons below 6 ps after 2000 s of dead time
  - Space-to-ground and ground-to-ground synchronization of clocks
- **Laser Ranging**
  - Laser ranging performance at the centimetre level per single shot (50 ps one-way)
  - Comparison of ranging techniques: one-way optical ranging, two-way optical ranging, microwave ranging
  - Analysis of atmosphere propagation delays