THE HIGH-CADENCE, HIGH-TIME-RESOLUTION OBSERVATIONS AT ESO – HEADSTART FOR THE E-ELT INSTRUMENTATION

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Why is it needed?

- high speed physical processes, i.e. neutron stars, pulsars, stellar occultation
- events with limited duration and no possibility for repeated observations, i.e. lunar ocultations, TNO occultations, transits of exoplanets (for timing)
- extremely bright objects that would saturate at 8-10-meter class telescope but must be observed as calibrators of for lack of adequate instruments at smaller telescopes: i.e. flux or polarimetric standards, spectroscopic templates, the Moon (for eclipses, etc.)
- lucky imaging – fast imaging “to freeze” the seeing

HOW?

- using “off the shelf” infrared detectors because:
  - they are designed to read fast to avoid saturation from the sky emission
  - they are designed with low readout noise to accommodate splitting the integrations into many individual exposures
  - implementation: ISAAC, SofI, NaCo, HAWK-I, VISIR

- using “off the shelf” optical detectors/CCDs:
  - their large format allows to move the charge across the detector while integrating
  - implementation: FORS2

ISAAC (similar for SofI and HAWK-I)

- ***Fast photometry*** – for continuous monitoring and ***burst*** – for short high-speed observations
- saving individual DITs (as opposed to a number of averaged DITs for the traditional modes) to generate individual measurements, i.e. for characterization of the systematic effects; the ***minimum DIT is 3.2/12 msec***
- detector read-out mode (ReadResetRead) allows while restting / reading one pixel, to integrate with the rest of the detector; this reduces the readout time to microseconds; however, the integrations of individual pixels are shifted in phase
- hardware windowing – minimizes the volume of the data that meed to be transferred
- the charge is stored in the IRACE memory (256 / 512 Mb), so the transfer occurs only after the buffer is filled; for short observations this occurs only after the observations are completed
- no shopping, i.e. stare observations (even though ISAAC uses the ALADIN detector)

ISAAC Details

- Hardware windowing parameters:

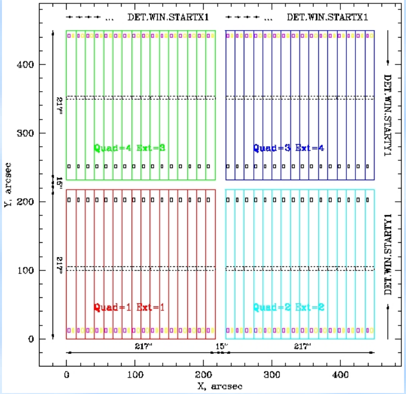
			Burst mode		FastJitter mode	
Window Size [pxs]	StartX=StartY [pxs]	Field of View ["]	min DIT [ms]	max NDIT	min DIT [ms]	max NDIT
32x32	497	4.7x4.7	3.2	16000	12	32000
64x64	481	9.5x9.5	6.4	15990	12	15990
128x128	449	19x19	14	3995	14	3995
256x256	385	38x38	37	995	37	995
512x512	257	75x75	106	245	106	245

- FastJitt Overheads (highly variable):

Window Size [pxs]	DIT [ms]	NDIT	N. Frames	Execution time [s]	Data cube Size [Mb]
32x32	12	1000	1000	18	4.1
32x32	12	2000	2000	30	8.2
32x32	12	3000	3000	41	12.3
32x32	12	4000	4000	54	16.4
32x32	12	5000	5000	66	20.5
32x32	12	6000	6000	77	24.6
32x32	12	7000	7000	89	28.7
32x32	12	8000	8000	102	32.8
32x32	12	9000	9000	113	36.9
32x32	12	10000	10000	126	41.0
32x32	12	11000	11000	137	45.0
32x32	12	13000	13000	162	53.3
32x32	12	14000	14000	174	57.4
32x32	12	15000	15000	187	61.5
32x32	12	16000	16000	198	65.6
32x32	12	20000	20000	246	82.0
32x32	12	32000	32000	388	131.1
64x64	12	16000	16000	199	262.2
128x128	14	4000	4000	114	262.2
256x256	37	1000	1000	37	262.2

HAWK-I Details

- Multi-detector grid (larger field of view – important for finding reference sources):



- FastPhot Overheads:

STARTX	NX	STARTY	NY	MINDIT, sec	NDIT	DIT sec	Integr. Time, sec	Exec. Time, sec
1	16×32= 512	1	16×2= 32	0.0044	1000	0.0044	4.4	4.4
1	32×32=1024	512	32×2= 64	0.0222	100	1.0	100	103
1	64×32=2048	1	64×2=128	0.0170	—-	—-	—-	—-
1	128×32=4096	810	200×2=400	0.3354	100	0.5	50	53
1	128×32=4096	810	200×2=400	0.3354	200	0.5	100	108
1	128×32=4096	512	16×2= 32	0.0331	100	1.0	100	102
1	128×32=4096	512	32×2= 64	0.0590	100	1.0	100	103
1	128×32=4096	512	64×2=128	0.1109	100	0.1109	100	13
1	128×32=4096	1	128×2=256	0.2145	100	1.0	100	103
1	128×32=4096	256	128×2=256	0.4219	100	1.0	100	103
1	128×32=4096	512	128×2=256	0.4219	200	0.4219	84	87
1	128×32=4096	512	128×2=256	0.4219	100	1.0	100	102
1	128×32=4096	768	128×2=256	0.4219	100	1.0	100	102
1	128×32–4096	1024	128×2–256	0.4219	100	1.0	100	102
1	128×32–4096	1280	128×2–256	0.4219	100	1.0	100	103
1	128×32=4096	1536	128×2=256	0.4219	100	1.0	100	102
1	128×32–4096	1792	128×2–256	0.4219	100	1.0	100	103
1	128×32=4096	1920	128×2=256	0.4219	100	1.0	100	103
1	128×32=4096	512	256×2=512	1.6876	100	1.0	100	103

NaCo Details

- every DIT is saved, the data are stored on the IRACE memory, fast readout (DCR-HD), microsecond timing accuracy
- offered in the following modes: basic imaging, including APP, SDI+, coronography, SAM in NGC (but no LGS)
- time saving from having only one header per NDIT frames, as opposed to one header per each DIT (= the case for NDIT=1); each fits file transfer and header merging "costs" 16-17 sec.
- "shift-and-add" post-processing can increase significantly the Strehl ratio
- hardware windowing:

Detector Setup	Window size	Min DIT	Max NDIT[12]	Frame Loss	Time Loss[13]
DCR/HD	1024×1026	0.35	126	20-22%	~16 s
DCR/HD	1024×1026	0.50	126	0	0
DCR/HD	512×514	0.109	508	0	0
DCR/HD	256×258	0.039	2027	0	0
DCR/HD	128×130	0.016	8049	0	0
DCR/HD	64×66	0.007	31711	0	0
Note DCR: minDIT (0.35sec) always loses frames. 0.5 sec does not. Efficient					

FORS2 Details

- exposing on a small fraction of the detector defined with the MOS slits on the extreme left side of the detector; the charges are moved to the right (the positive X-direction) while integrating; a full movement takes between 1 and 256 sec; the rate of charge movement is between 0.28 and 73 px/milisec
- in affect, the charges are stored on the detector (analogous to the IRACE for the infrared detectors); the detector is read after the charge movement is complete, i.e. once every 1 or 256 sec
- the time resolution depends on the seeing: for 1 arcsec seeing (scale 0.125 arcsec/px) it varies from 2.3 milisec to 0.56 sec depending on the charge transfer rate; having a reference star in the field/slit is critical
- imaging and spectroscopy (with the cross-dispersers) are available:

FORS2 cross disperser grisms for the HIT-S mode

Grism	$\lambda_{central}$ [Å]	λ_{range} [Å]	dispersion [Å/mm]/[Å/pixel]	$\lambda/\Delta\lambda$ at $\lambda_{central}$	filter
XGRIS_600B+92	4452	3300 - 6012	50/0.75	780	
XGRIS_300I+91	8575	6000 - 11000	108/1.62	660	OG590+32
XGRIS_300I+91	8575	5032 - (6600)	108/1.62	660	

Summery and Results

The high-time-resolution high-cadence observing modes are routinely used at the VLT and other ESO telescopes for solving a diverse set of scientific problems – from TNO and exoplanet transits/occultations to lucky imaging of stars and extragalactic objects.

We expect that these modes will be beneficial for the future extremely large telescopes, for the following reasons:

(1) to address specific scientific questions related to objects with fast variability,

(2) to observe unique events with limited observing windows, making the most of the photons than can be detected during the window, and

(3) to observe extremely bright calibration and template sources that would saturate the traditional “slow” modes.

Some examples of recent publications based on the “fast” modes are given bellow.

Examples of recent “fast” mode work:

- Caceres, Ivanov et al. 2009, A&A, 507, 481
- Richichi et al. 2010, A&A, 522, 65
- Caceres, Ivanov er al. 2011, A&A, 530, 5
- Richichi et al. 2011, A&A, 532, 101
- Richichi & Glindemann 2012, A&A, 538, 56
- Ortiz, ... Ivanov et al. 2012, Nature, 491, 566