JRA 3

Fast Readout High Performance Optical Detectors for Astronomy

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JRA 3

- **Outline**
- Scientific motivation (HTRA, Imaging)
- Technological motivation
- The past, the JRA, and the future
- Teams
- Structure and organisation
- The workpackages
- Timelines, Milestones
- The first 18 months
- Relations to other I3 initiatives

JRA 3, Scientific Motivation

Observational astrophysics:
Locate sources in space (4 dimensions).
This includes precise timing.

The parameter space of photon detection
has expanded in many dimensions.

Time resolved astrophysics has not
participated in technological advancement

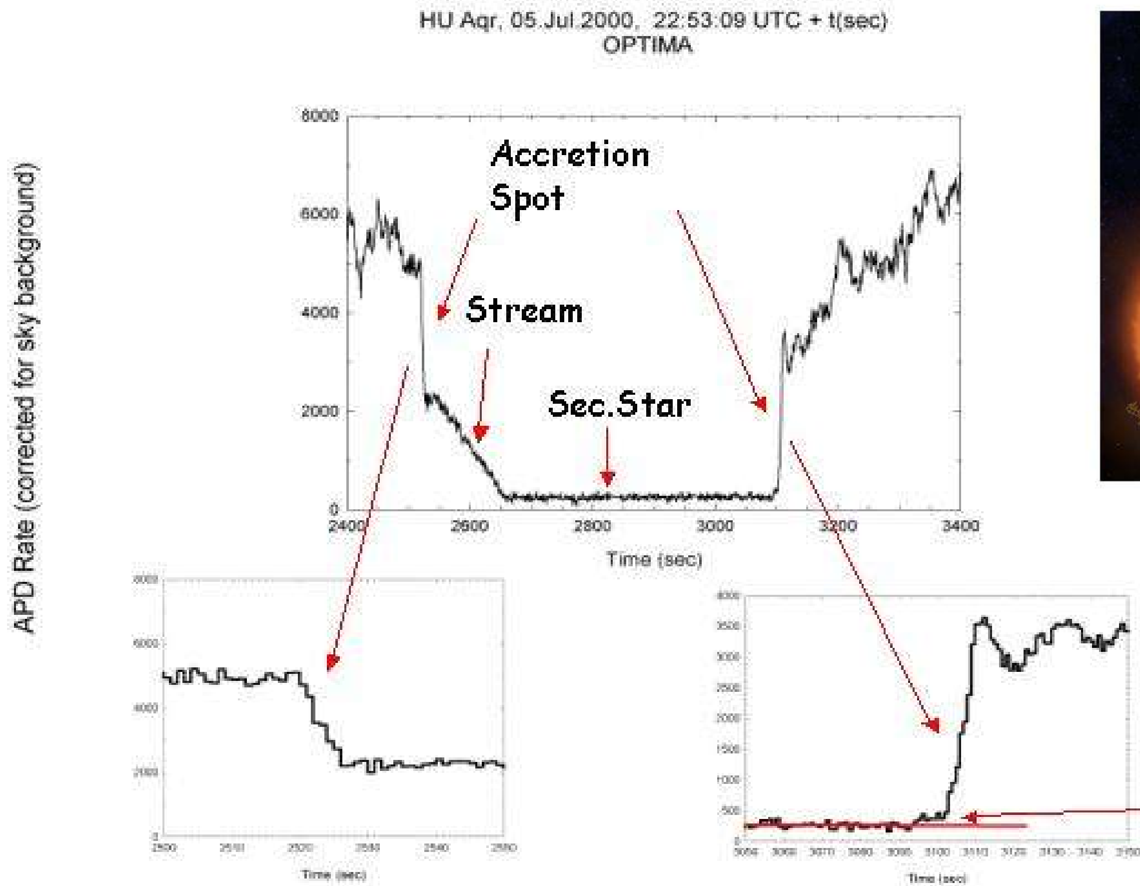
HTRA, Scientific Motivation

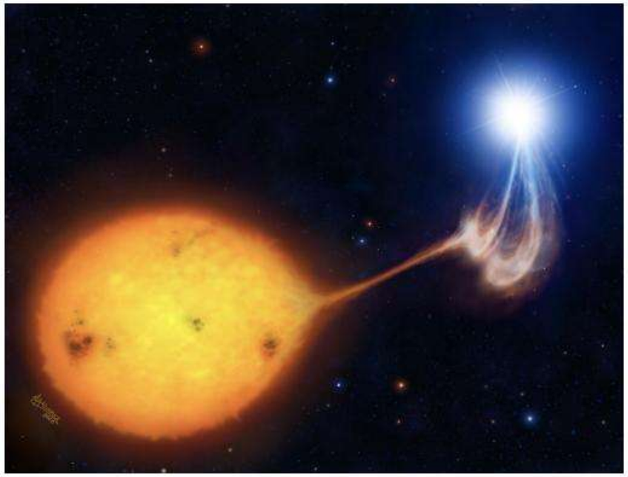
Prime role for high resolution in spatial dimension (Adaptive Optics, Interferometry).

High temporal resolution is an indirect way of achieving even higher spatial resolution.

d alpha = dx/D > dt c/D (causality)
nsec (Pulsars) ~ meters ~ femto-arcsec
10 sec (Blazars) ~ R(star) ~ 50 femto-arcsec

HTRA, Scientific Motivation





orbital velocity

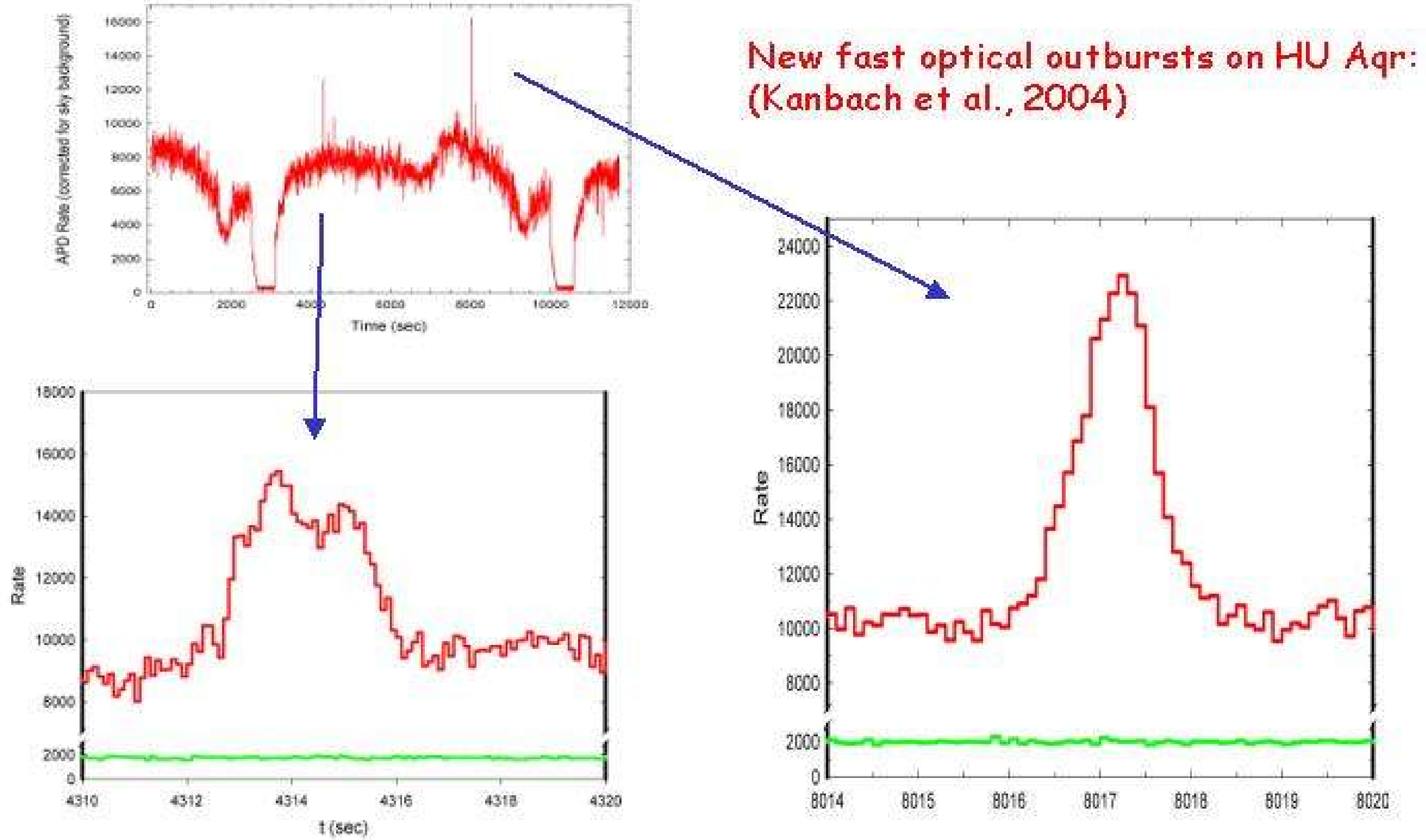
~200 km/s

dt ~ 6 sec = 1200 km

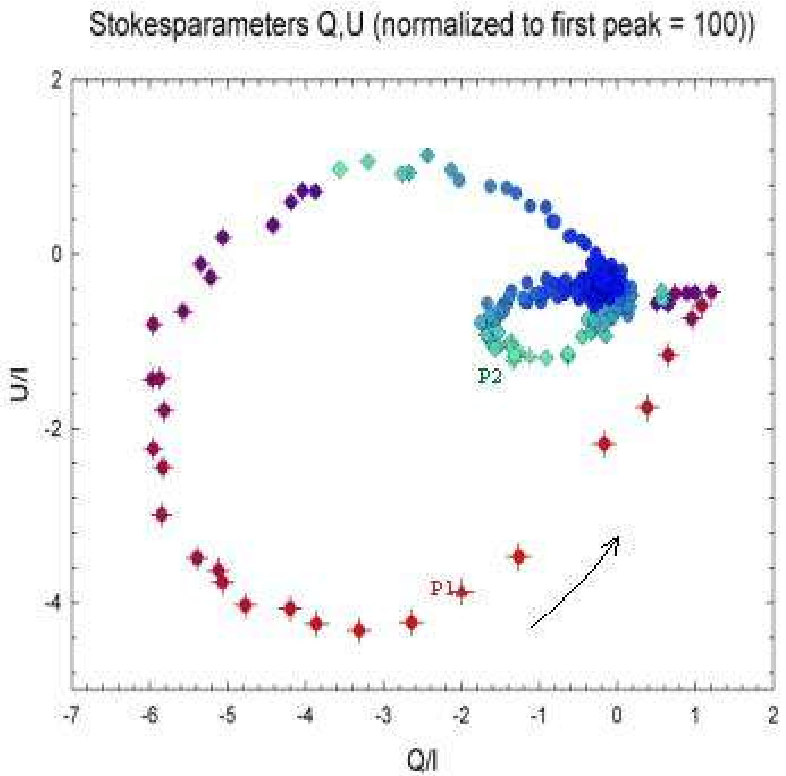
dt~ 7 sec = 1400 km

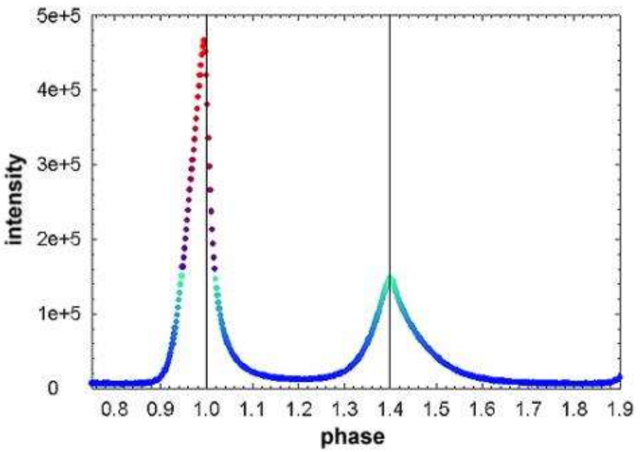
Size of the polar ‚hot' spot

HTRA, Scientific Motivation



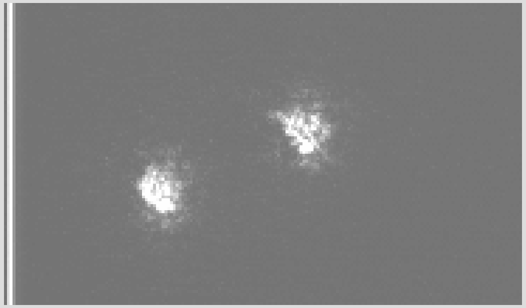
HTRA, Scientific Motivation





JRA3, Scientific Motivation

Overcome seeing limitations:



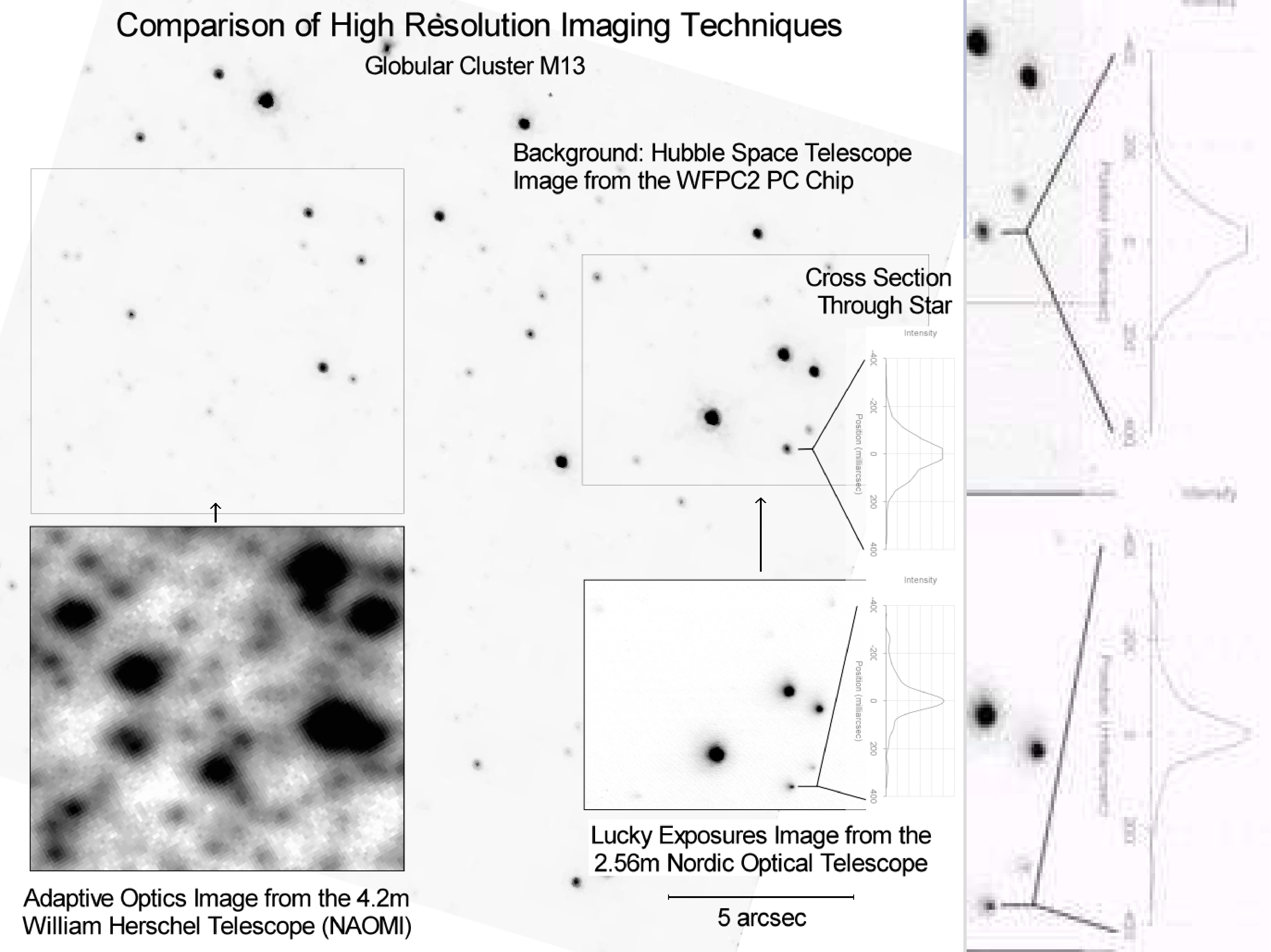
Seeing: variations on many scales.
Short (noise-free) exposures enable selective imaging and a post-recording selection of (close-to) diffraction limited images.
(LuckyCam @ NOT)

Scientific Motivation, part II

Wavefront distortions are not corrected.
Frames badly affected by those distortions are ignored.

All frames are recorded. Post-imaging cuts in data-cube for any desired combination of depth and resolution.

AO is not cheap.
Selective imaging will eventually involve very little extra cost.


Comparison of High Resolution Imaging Techniques
Globular Cluster M13
Background: Hubble Space Telescope Image from the WFPC2 PC Chip
Cross Section Through Star
Intensity
Position (milliarcsec)
-400
-200
0
200
400
Intensity
Position (milliarcsec)
-400
-200
0
200
400
Lucky Exposures Image from the 2.56m Nordic Optical Telescope
5 arcsec
Adaptive Optics Image from the 4.2m William Herschel Telescope (NAOMI)

Scientific Motivation, part II

Selective imaging compares favorably with other high resolution approaches.

HST – NOT : Similar apertures and resolution.

High resolution not continuously, but very high efficiency (30%) has been reached.

Can be applied to imaging, spectroscopy, etc.
Co-add equivalent to classical techniques.

Ultimate goal: All 2-4m astronomy this way?

Technical Motivation

Detectors with high QE (CCDs) replaced other detectors with better temporal resolution.

Can modern detectors combine high QE, low noise and high temporal resolution?

The large parameter space (10 ns - 10 s), different fields, etc. may require different detector technologies.

Identify best solutions, promote development

Technical Motivation

Exploit synergies in electronics, and software.

Many other applications in astrophysics and elsewhere.

European industries play an important role in detector development, and may play the leading role in fast readout detectors in the near future (European added value).

The past, the JRA, and the future

Several team in Europe study HTRA.
Most concentrated on one technique,
and develop everything
(detector, read-out electronics,
camera head, software, instruments)
independently.

Eg. TRIFFID, UltraCam, OPTIMA,
LuckyCam.

The past, the JRA, and the future

Synergies in combining teams:
Experience with different detectors,
and experience in all components.

Common strategies in detector development,
common interfaces (electronics, sw, tests),
common test procedures.

Collective cooperation with European industry.

The past, the JRA, and the future

Maximizing efficiencies of detectors within “their“ optimum corners of parameter space.

Common interfaces of camera heads

Common software tools

Blueprints for HTRA instrumentation

The teams

ATC, Edinburgh, A. Vick
ESO, Garching, D. Baade
IoA, Cambridge, C.Mackay
LSW, Heidelberg, S. Wagner
MPA, Garching, H. Spruit
MPE, Garching, G. Kanbach
NOTSA, Copenhagen, J. Andersen
NUI, Galway, A. Shearer
U Sheffield, V. Dhillon
U Warwick, T. Marsh

Structure and Organisation

Management

Infrastructure	Detectors
Electronics	L3CCD
Camera Head	PN Sensors
Software	APD Arrays
Testbed, Instrument Design	

Structure and Organisation

Organized in eight workpackages
Lead and deputy

Usually involvement from several teams
in definition phase (~12 months).
Duration depending on progress.

Several meetings in year 1
KO: March 14-17, JM2 July 2004, ...
WP restructuring after definition

Work-packages

- 8 Workpackages

- WP1 Management (S. Wagner, H. Spruit)
- WP2 L3CCDs HTRA (V. Dhillon)
- WP3 PN Sensors (G. Kanbach)
- WP4 APD Arrays (A. Shearer)
- WP5 Electronics (C. Mackay)
- WP6 Software (J. Andersen)
- WP7 Camera Head (A. Vick)
- WP8 Testbed (S. Wagner)

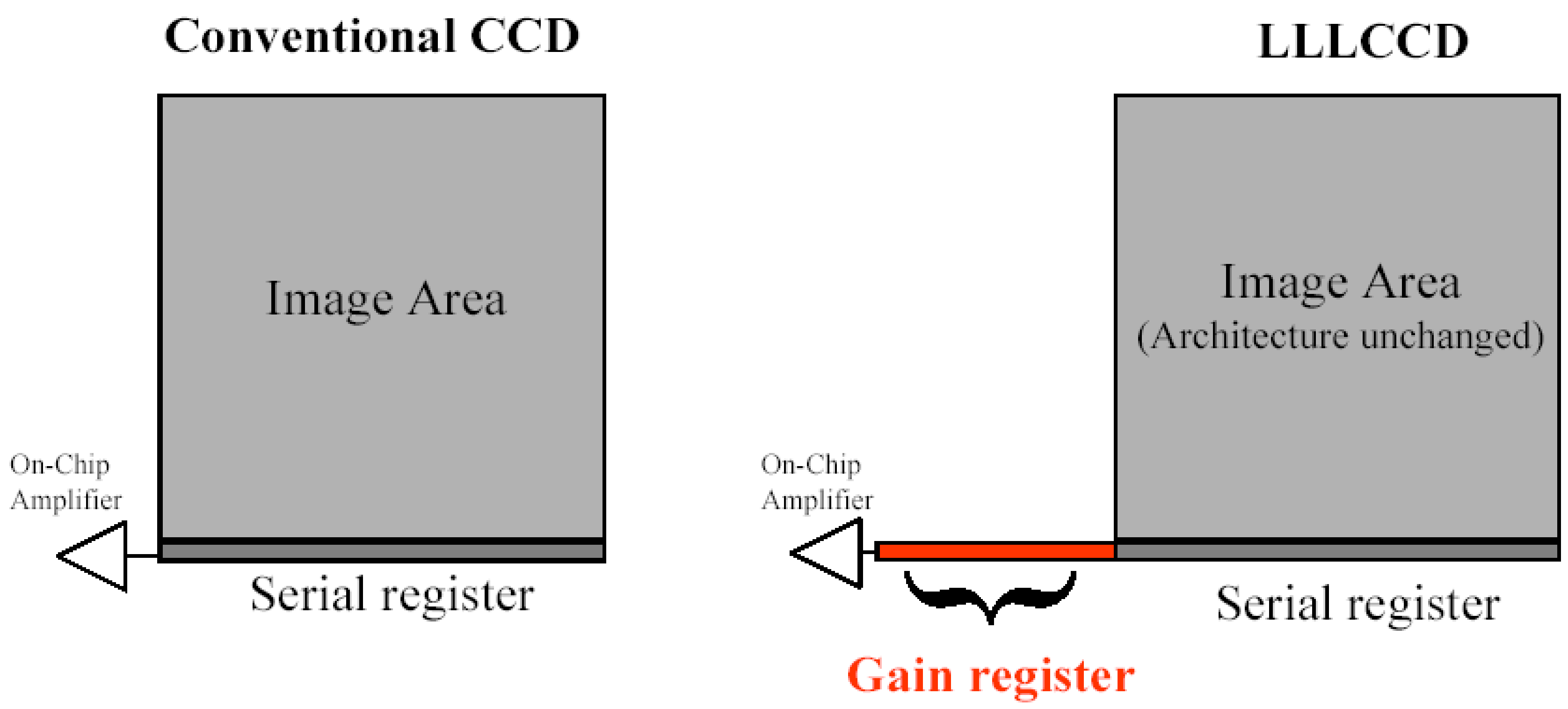
WP1: Management

- Coord: S. Wagner, LSW (H. Spruit, MPA)
- Home page
  (pw protected, open section soon)
- www.lsw.uni-heidelberg.de/projects/tra/jra.html

- Tasks:
- Coordination between other WPs
- Oversight timelines, milestones, resources
- Meetings, reports, deliverables (quality ctrl)
- Coordination with JRA2 and N3

WP2: LLL (L3)-CCDs

LLLCCD Gain Register Architecture



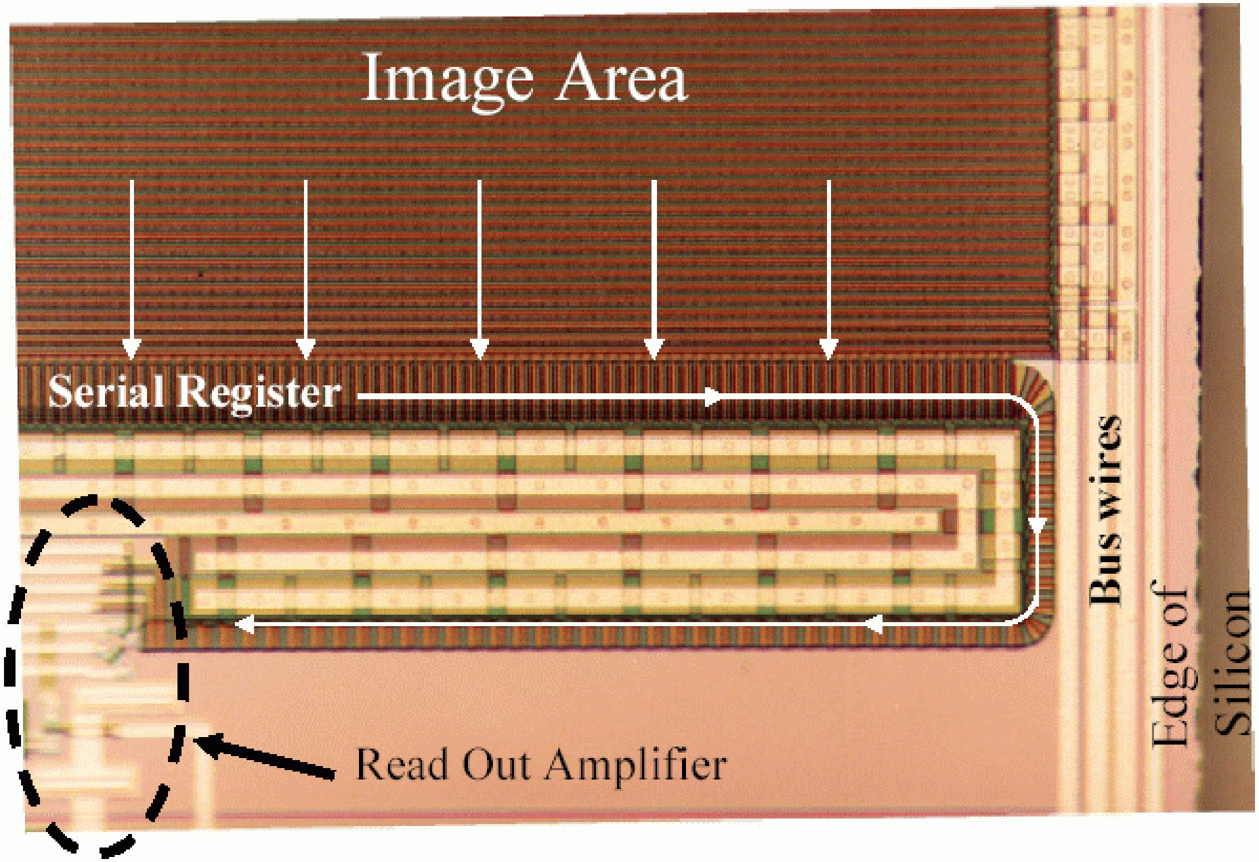
The Gain Register can be added to any existing design

WP2: LLL (L3)-CCDs

- HTRA:
- Small array
- Photon counting
- Drift mode applications

- Imaging:
- Large array
- High speed
- Multiple ro

Photomicrograph of a corner of an EEV CCD.

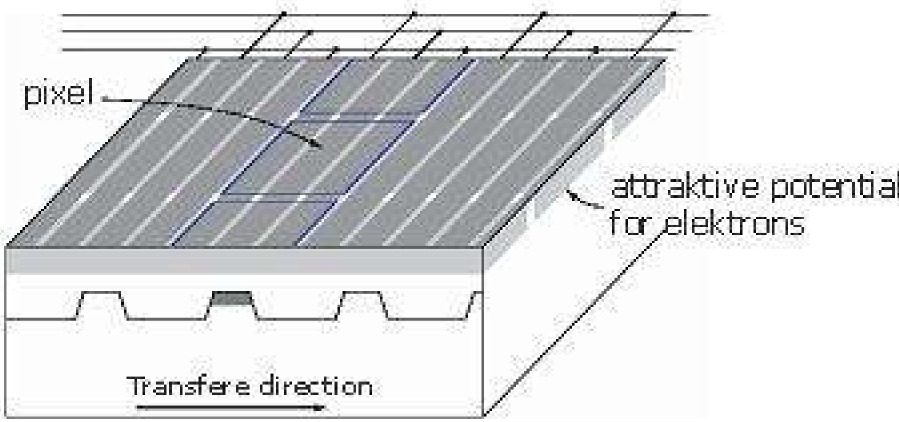


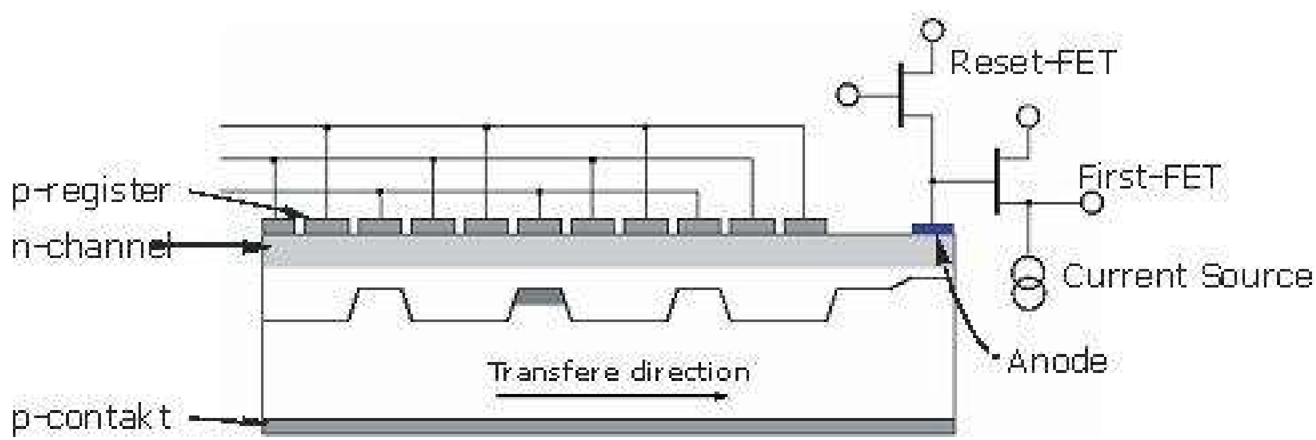
WP3: PN Sensors

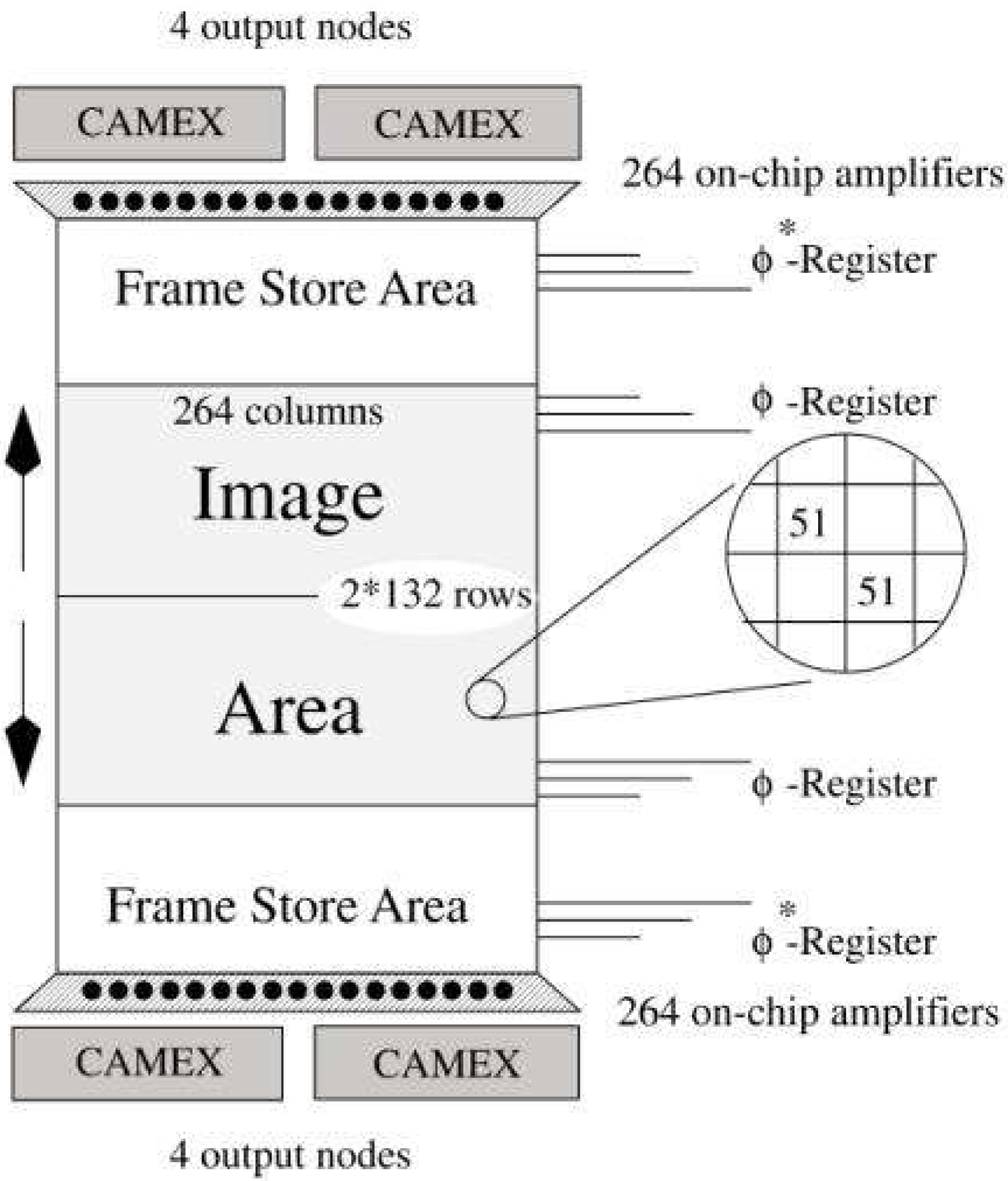
- PN Sensors:
- Extensively tested in X-ray Astronomy
- PN camera onboard XMM
- Applications in optical and NIR bands
- Silicon detectors, operated in full depletion
- High QE up to 1.2 micron, where silicon becomes transparent (bridging opt-IR gap)
- Little fringing
- Large pixels
- 1 amplifier/row, hence fast readout
- Synergies: AO applications?

Principle of the pnCCD

- Fully depleted, 3-phase CCD
- Cooled to -90° C
- High radiation hardness
- Backside illuminated
- Ultra-thin entrance window
- Small detector capacitance ~30 fF
  > small noise (3 e^-)
- Fast readout

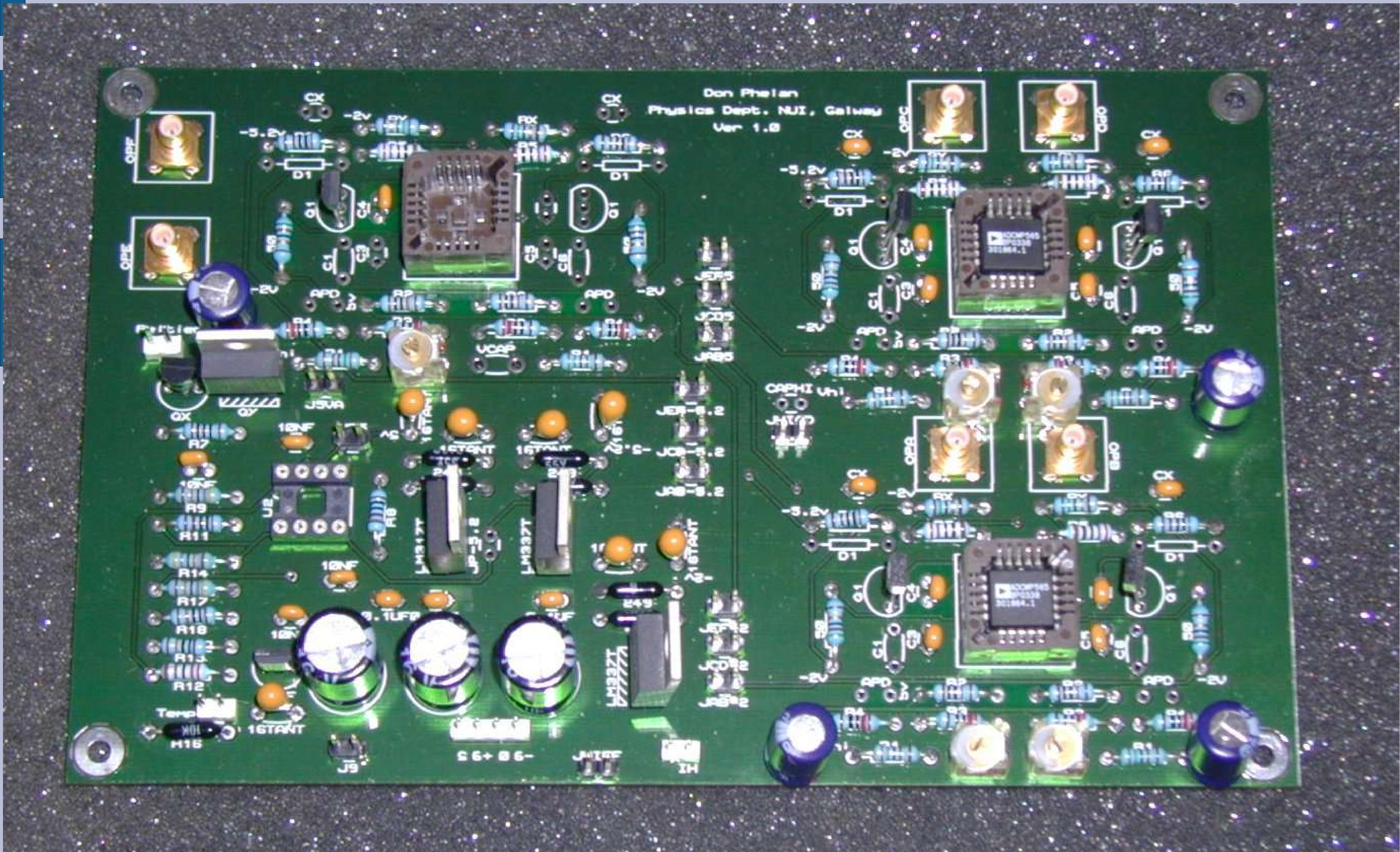





4 output nodes
CAMEX
CAMEX
264 on-chip amplifiers
ϕ* -Register
Frame Store Area
ϕ -Register
264 columns
Image
2*132 rows
Area
51
51
ϕ -Register
Frame Store Area
ϕ* -Register
264 on-chip amplifiers
CAMEX
CAMEX
4 output nodes

WP4: APD arrays

- APDs probe (sub-)microsec regime
- Operational goals for HTRA: 100 ns
- Novel approaches to established technology
- Problems: stability, modularity, efficiency
- Stability:
  Improvements in fabrication and testing
- Modularity:
  Mounting APDs in small arrays (common base) of ~ 25 pixels (linear, quadratic)
- Efficiency: Feeding microlens-arrays/fibers


Don Phelan
Physics Dept. NUI, Galway
Ver 1.0

WP5: Electronics, Controller

- L3CCDs/PN CCDs are operated in principle in the same way as classical CCDs.
- Controller requirements similar, adapted to very high frame-rates/pixel rates
- Absolute timing with very high reliability.
- Demonstrate feasibility of “HTRA - upgrade“ with standard controllers (e.g. SDSU).
- Development of multiple port controllers for L3CCDs.
- Development of common CCD/PNCCD electronics.

WP6: Common Software

- SW operating detectors in WP5/WP7
- WP6: SW downstream of amplifier/ADU
- Data Flow Management
  kHz framerates require fast/efficient pre-processing/analysis and archiving
- Fast Imaging:
  preselection, quick-look, processing.
  Ultimate aim: Fast mode on any CCD op'n.
- HTRA:
  preprocessing, timing, quick-look

WP7: Camera Heads

- Camera (hardware) - detector – controller
- Front-end-electronics optimized for MHz-frame-rates.
- Common design elements for different controllers and different detectors.
- Which elements could serve all detectors?
- Ultimate goal (beyond JRA):
  Camera that can host different detectors
  Camera that hosts different detectors in parallel.

WP8: Instrument Testbed

- Design and construct testbed which allows identical tests for different lab-setups to characterize different systems in homogeneous way (possibly beyond JRA)
- Design and construct testbed for realistic tests (on the sky) of different camera concepts (involving common, simple analysers) – proof of concept.
- Design studies of HTRA instrumentation, optimized for 2-4m/8m class telescopes.

Timelines, Milestones

- Detectors: Definition Phase (12 monhs):

- Identify optimum parts of parameter space for each detector
- Compare controller concepts
- Explore synergies (electronics, SW)
- Define Interfaces
- Consider novel ideas:
  e.g. deep depletion for L3CCDs,
  amplification (gain register) in PN Sensors
- Restructuring Work-packages

The first 18 (21?) months

Deliverables:

WP2: Test Report L3CCD
WP3: Preliminary design Report PN Sensors
WP5: Fast timing controller(s) L3CCD
WP7: Prototype Camera Head

Milestones:

PDR, CDR for technologies and controllers, procurement and integration L3CCD, test setup PN Sensor, APD Array Design

Relations to other I3 activities

JRA 2: Fast detectors for AO;
Related goal but very specific application with specific goals; detector technology may ultimately be similar.

Contacts (common meeting), contacts to industry (contracts?),
contacts on WP level to avoid duplication

N3 (WP3): HTRA

Access Program: Instrumentation

etc...