The CaNaPy RTC: towards pre-correction of the LGS beacon

RTC4AO 2023

CaNaPy RTC status Report / 06.11.2023

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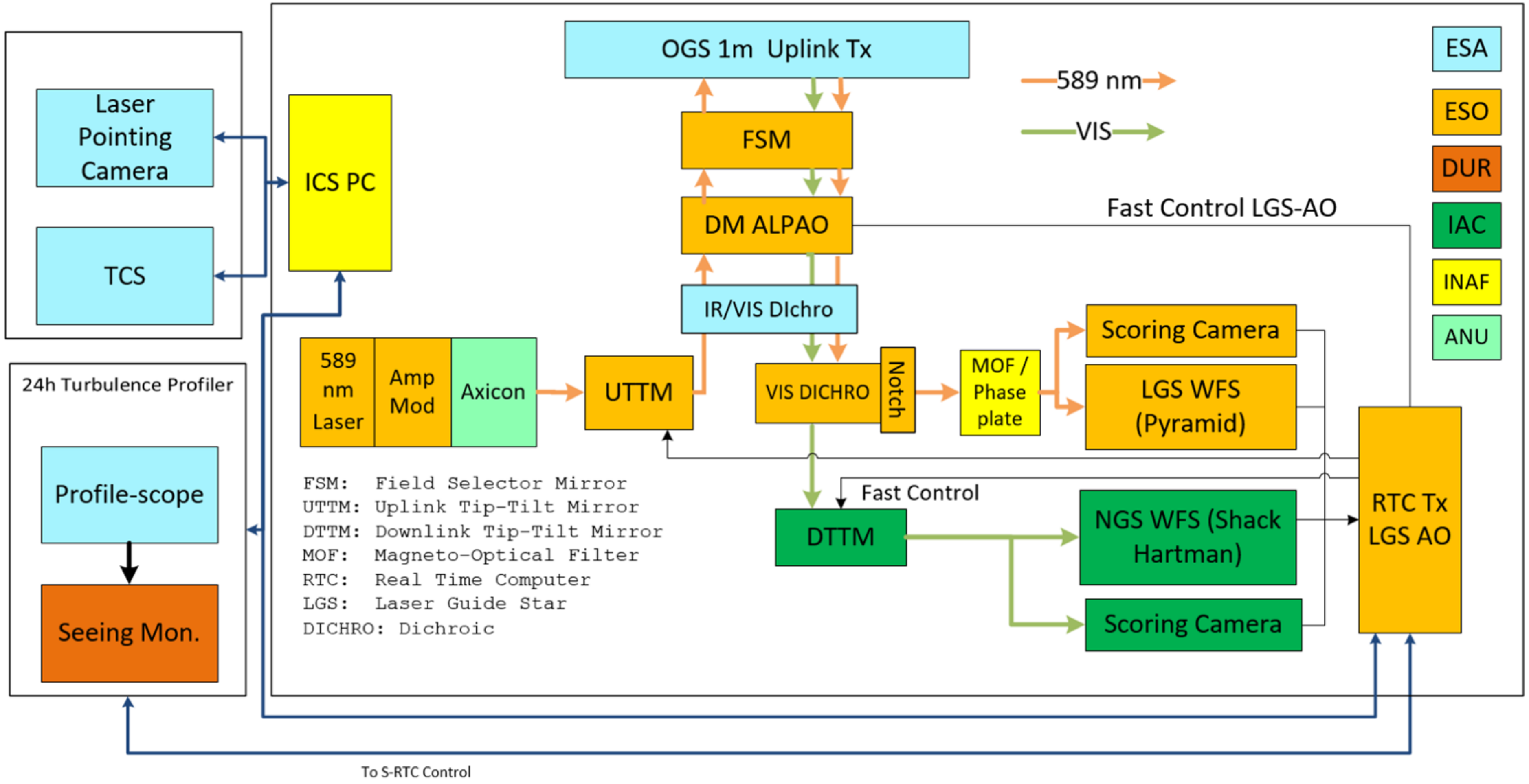
What is CaNaPy?

- Demonstrate and Optimize LGS uplink pre-compensation, for the smallest LGS size (implies pulsed/chopped laser)
- Close the LGS-AO loop with Pyramid WFS, in monostatic configuration
- Optimize for operation in the visible, demonstrate performance
- Have an experimental facility for advanced LGS-AO R&D experiments (agreement with ESA done)

- So far foreseen CaNaPy experiments within the collaboration with ESA:
  - Demonstrate operation and control also in non-favourable seeing conditions (including daytime)
  - Test the time delay method (Ragazzoni, 1999) for the measurements of tip-tilt from the LGS
  - Test the candle-light method to have and use the sodium profile and its centroid during operations
  - Evaluate the advantages of the uplink pre-compensation in monostatic mode, vs more standard bistatic LGS-AO configurations

CaNaPy Concept



Project: CaNaPy	Title: System Block Diagram	DBC	Version: 4.0	Date: 27th July 2021

CaNaPy AO System

- LGS AO system with one high order ALPAO 97 DM and one LGS uplink jitter mirror
- A monostatic launch, laser is launched from the main telescope
- The laser is chopped (pulsed) synchronously with the WFSs shutters to avoid blinding the cameras during the propagation
- LGS Pyramid WFS with 40x40 pixels per pupil (4x4 oversampling) for High Order control
  - Using the OCAM 2S at 2kHz

CaNaPy AO System

- NGS Shack-Hartmann with 12x12 sub-apertures for Low Order tip, tilt and focus
  - Using the OCAM 2K also at up to 2kHz
- ALPAO 97-15 DM, provides high order modal correction with up to ~90 modes
- Downlink TT mirror in front of the NGS SH-WFS only
- Uplink LGS Jitter Loop mirror to keep LGS pointing
- Each WFS has a "scoring" camera to look at the PSFs
  - LGS-WFS uses an EVT HB-1800-S, NGS-WFS uses a Hamamatsu ORCA

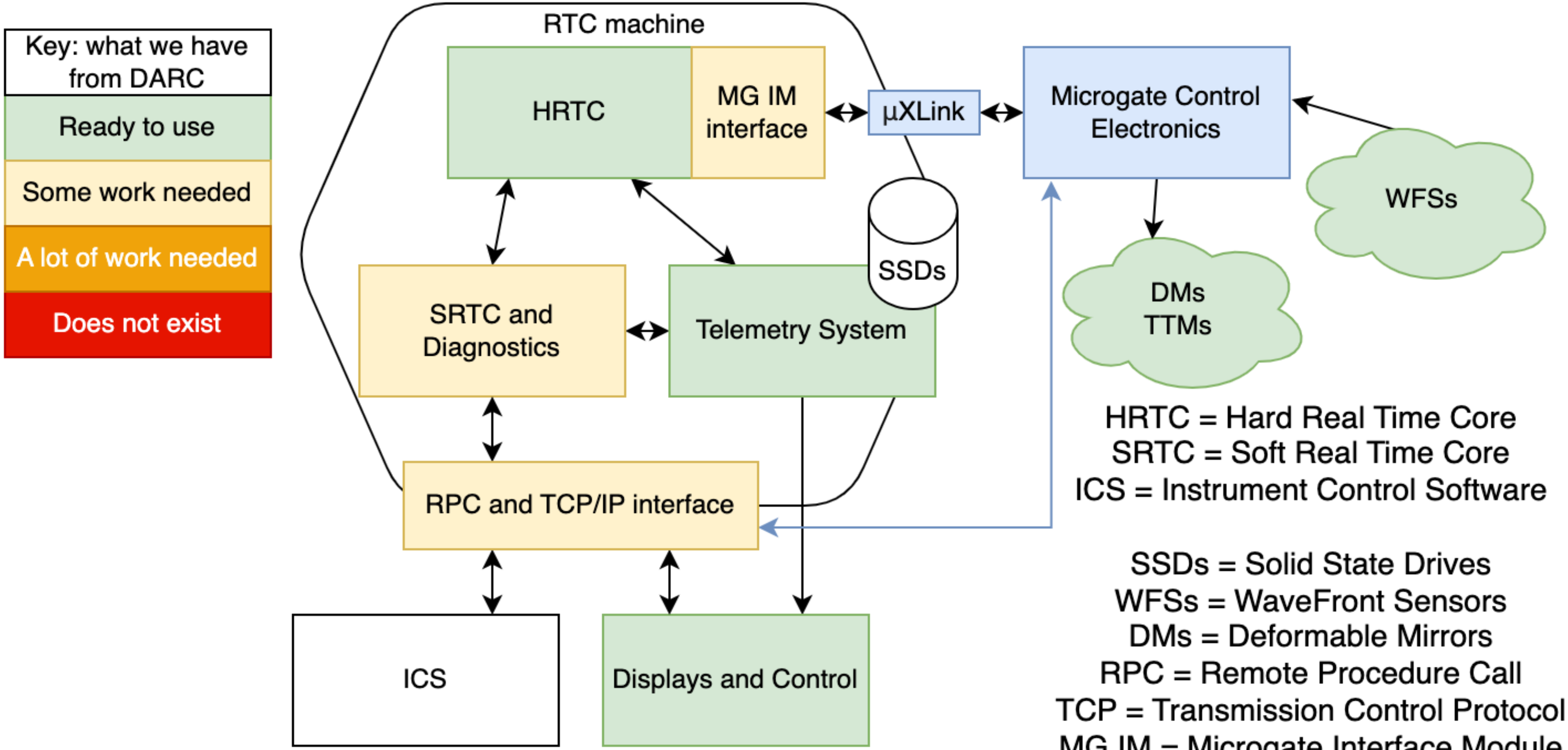
ALASCA upgrade with Microgate

- Converts CaNaPy into an optical feeder link experiment for Satellite communications
- Introduces an IR Tx and Rx path
  - The Rx path includes an IR Py-WFS using a CRED 2-lite, otherwise a clone of the LGS Py-WFS
- Upgrades the AO hardware interfaces to the RTC
  - Microgate hardware streams pixels directly into CPU memory
  - Actuator command are read directly from CPU memory and sent to the hardware
  - Reduces the load on the CPU to concentrate on AO reconstruction
- The IR WFS uses the satellite downlink as a guide star

CaNaPy RTC

- The RTC processing is done on a COTS Dell server running CentOS 7.5 (legacy due to kernel requirements for PCIe ALPAO interface)
- CaNaPy is a small-scale experimental AO system
- CaNaPy RTC sub-system developer, operator and maintainer: David Jenkins (ESO) with support from Microgate for hardware interfaces

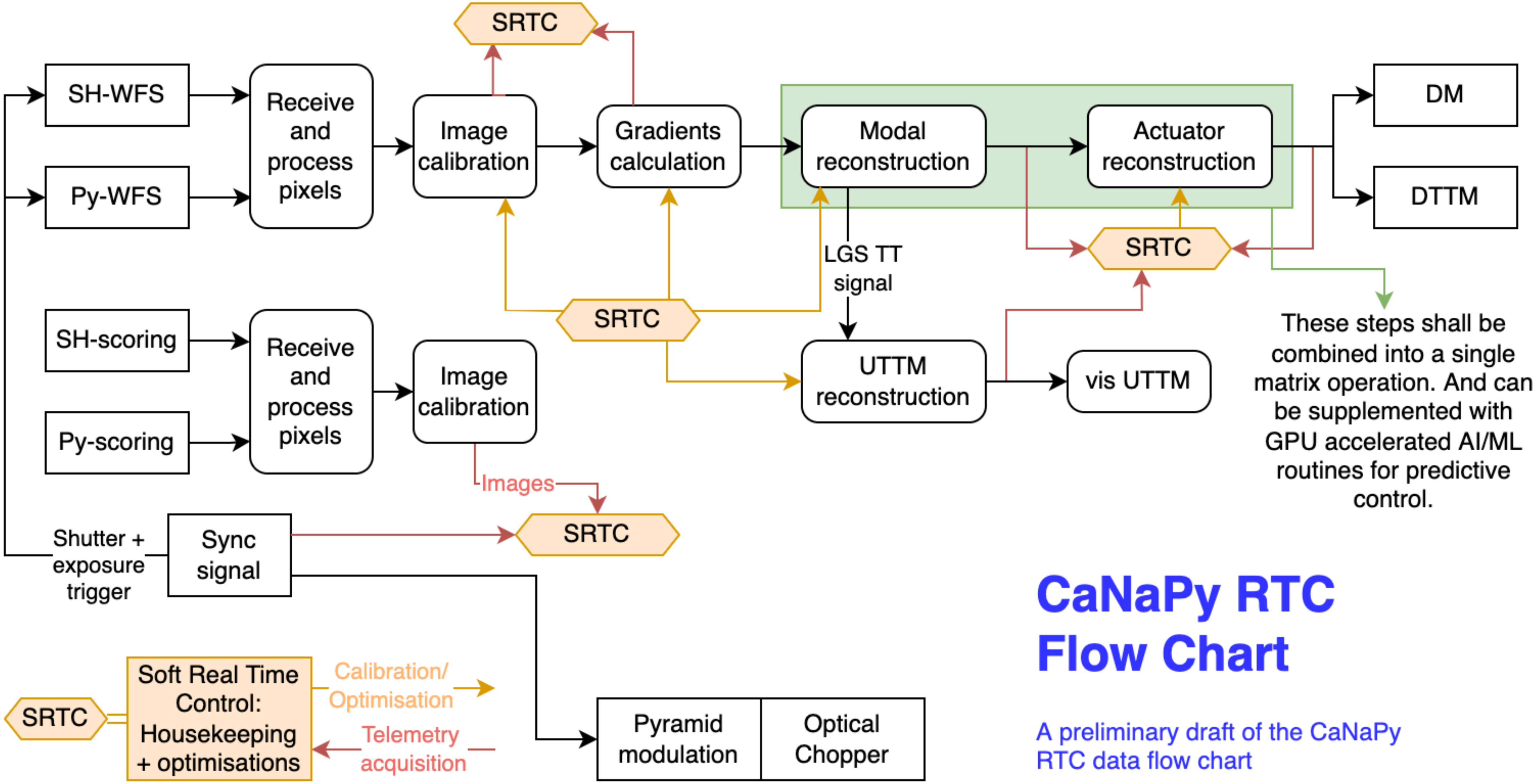
CaNaPy RTC Status



HRTC = Hard Real Time Core
SRTC = Soft Real Time Core
ICS = Instrument Control Software

SSDs = Solid State Drives
WFSs = WaveFront Sensors
DMs = Deformable Mirrors
RPC = Remote Procedure Call
TCP = Transmission Control Protocol
MG IM = Microgate Interface Module

CaNaPy RTC Flow Chart



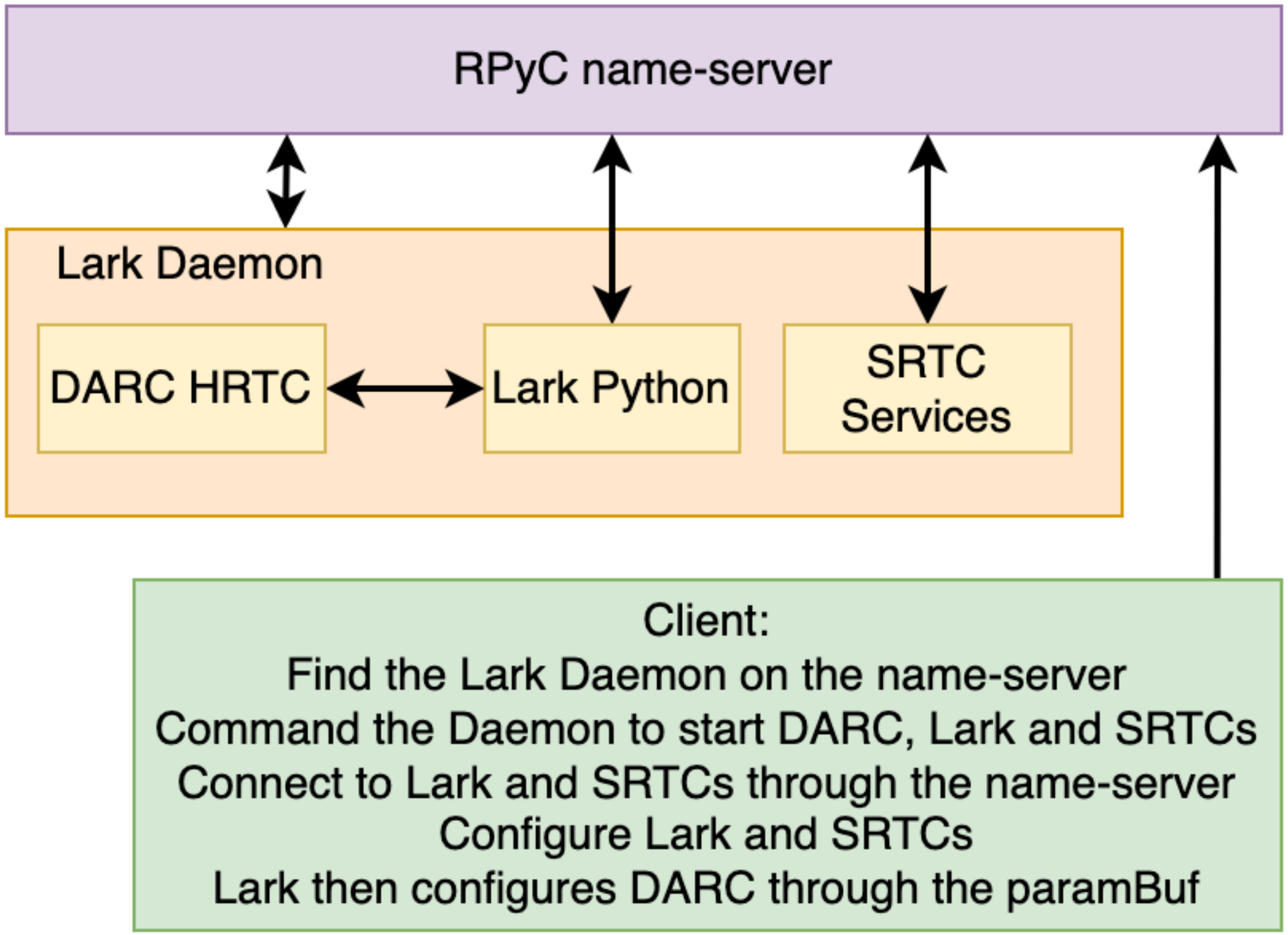
CaNaPy RTC Flow Chart

A preliminary draft of the CaNaPy RTC data flow chart

Software Architecture

- HRTC uses DARC c code
  - DARC is multithreaded C with shared memory parameter buffer and circular buffers for telemetry
  - ”Horizontal” multi-threading, each thread processes a portion of pixels through to the partial actuators
  - For CaNaPy only a single thread is needed, small problem size
  - New camera and mirror libraries to interface with the Microgate hardware
- HRTC control and SRTC uses Lark, pure Python and Python C-Extensions
  - Python code can apply parameters to the HRTC through the shared memory parameter buffer
  - It can read telemetry from the circular buffers
  - Custom Python C-extensions use the DARC shared libraries directly
  - Only implements the required functionality
- Systemd services are used to launch the DARC core (with root privileges) and to launch Python RPyC services for control and SRTC (with user privileges)
  - All process are run in the background, Python services spawn new processes
  - Uses RPyC, zeromq, and shared memory for communication

Lark Concept

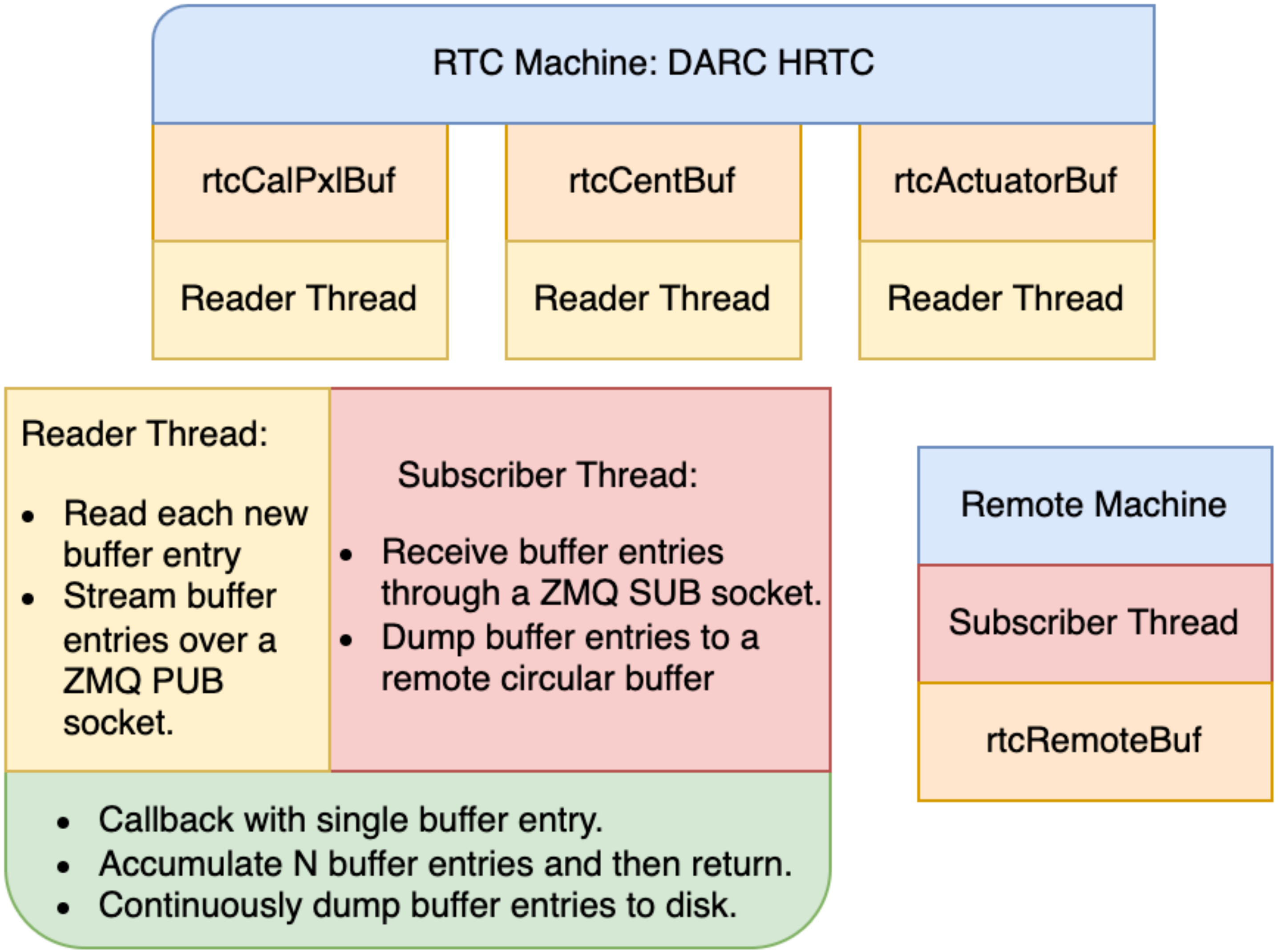


Modes:

- A mode is a collection of DARCs/Larks and Services that are launched together.
- Used for configuring an observing mode
- These can be launched by a client by processing the mode configuration and command the Daemon to start the processes

Lark Telemetry System

- Each telemetry buffer has a reader thread implemented in the Python C extension
- The reader transfer telemetry as needed
- Saving to disk has been implemented in a novel way
    - Empty .cfits or .npy files are created on disk by Python code
    - Files are queued up to ensure continuous operation
    - Memory regions are mmap'd by the C extension with the correct offsets
    - Data is copied directly to the file region
    - The .cfits extension is used to distinguish files with little endiannes



SRTC Services and Plugins

- Background processes for calibration and optimisation functions and loops
- Each function or loop is implemented as a Plugin
- Plugins are registered to a SRTC Service
- Uses runtime introspection to display functionality in a GUI

SRTC Service:

- Can register Plugins
- Holds parameters for all Plugins
- Initialises and Configures Plugins
- Execute Plugins
- Access Results
- Report Plugin Status
- Interface for Displays

- Not only for Soft Real Time Processes
- Can also be used to implement general background process functionality.
- e.g. for OCAM iPort Daemon and command sending

SRTC Plugin:

A python class that implements methods to run specific tasks:

- Configure: to update parameters
- Init: first time setup
- Setup: setup per run
- Acquire: get data
- Execute: main functionality
- Check: verify resilts
- Finalise: cleanup and store result
- Apply: optional send new data to RTC
- Result: return the last result

High Level:

- run: calls the above functions in order with option for calling Apply
- start: run every N seconds in a python thread, Setup is called once at beginning
- stop: cancel the thread

The Background Tasks for CaNaPy - SRTC

Each WFS
- OCAM frame-rate, exposure time, gain
- OCAM image calibrations, dark, flat, background
- WFS-DM misalignments
- NCPA
- WFS-modes matrix

Pyr-WFS
- Modulation rate and magnitude
- Modulation and exposure synchronisation
- Pyramid quadrant detector offset
- DM + UTTM interaction matrix
- DM + UTTM control matrix

SH-WFS
- SH sub-aperture positions
- Centroiding, thresholds, correlation
- DM + DTTM interaction matrix
- DM + DTTM control matrix

Telemetry needed
- Decimated WFS images
- Pyramid flux values (add quadrants)
- SH subaperture and image flux
- Wavefront gradients
- Wavefront modes
- Actuator values

Scoring cameras
- OCAM frame-rate, exposure time, gain
- OCAM image calibrations, dark, flat, background
- Image stacking?
- Image processing, FWHM, SR, centroid

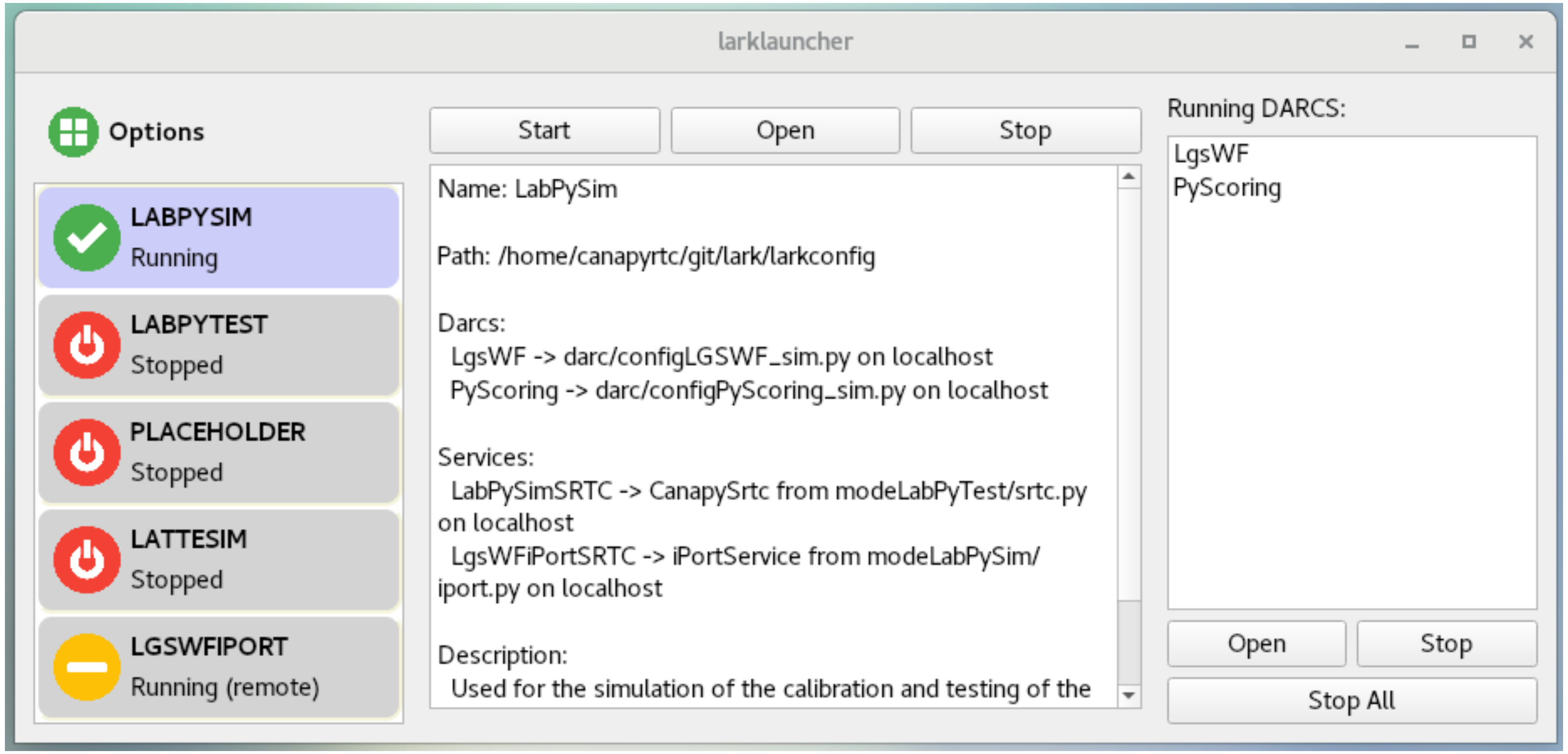
DM, UTTM, DTTM
- Modes-DM control matrix
- Actuator scaling, clipping

Reconstruction and control
- Gains
- Noise covariance matrices

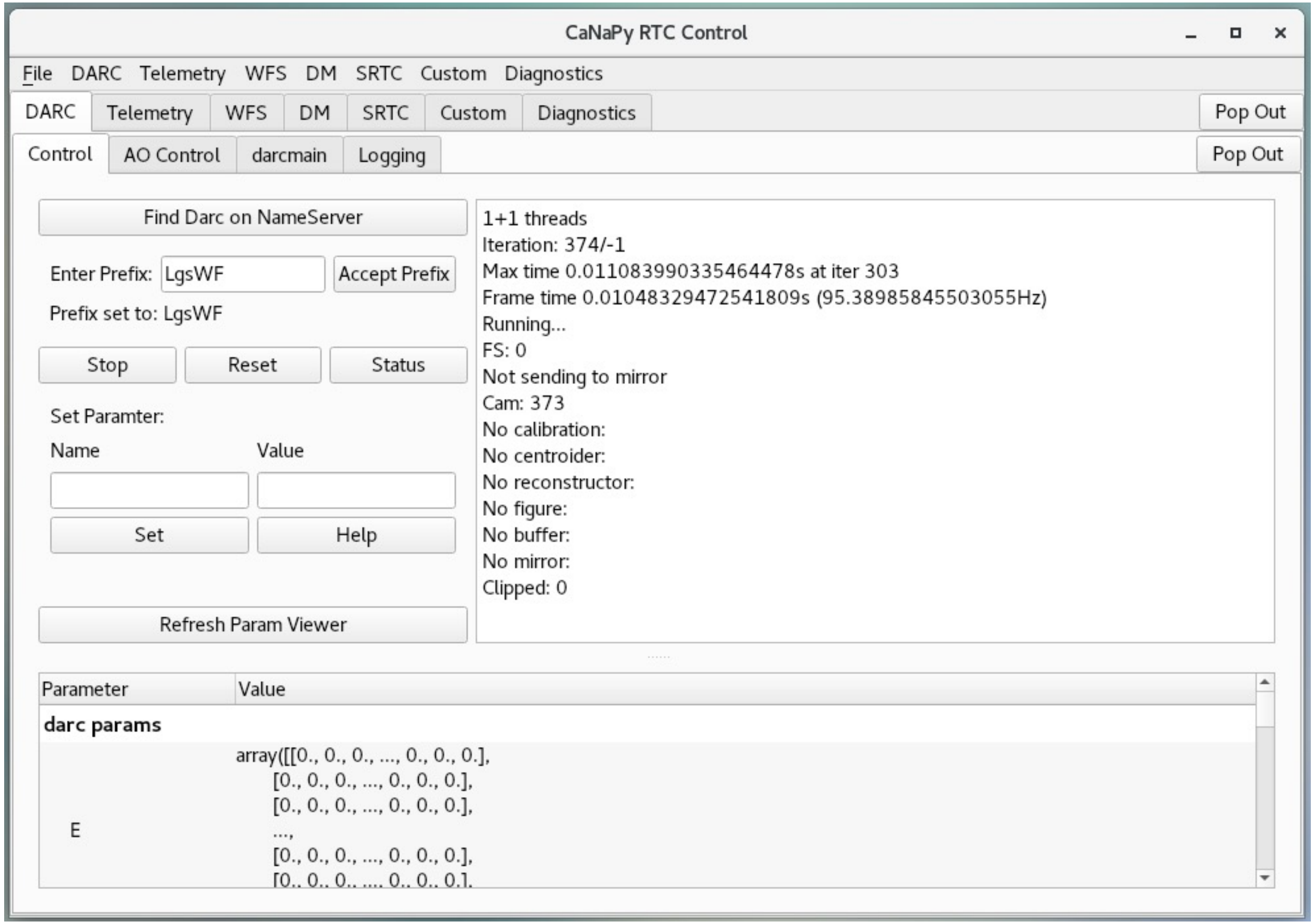
Key
- Continuously updated based on telemetry
- Calibrated once and used on every frame
- Telemetry needed for calibrations on every frame
- Telemetry used for visualisation only

Lark Launcher

- It finds modes in the config directory and loads the information
- Each mode has 3 basic commands, start, open and stop
- Open is used to open a mode specific display
- The running DARCS are displayed, and the basic Lark Plot GUI can be opened for each
- The options menu allows selecting a config directory and to reset the Lark Daemon to kill all running processes and start fresh



Lark Custom Displays



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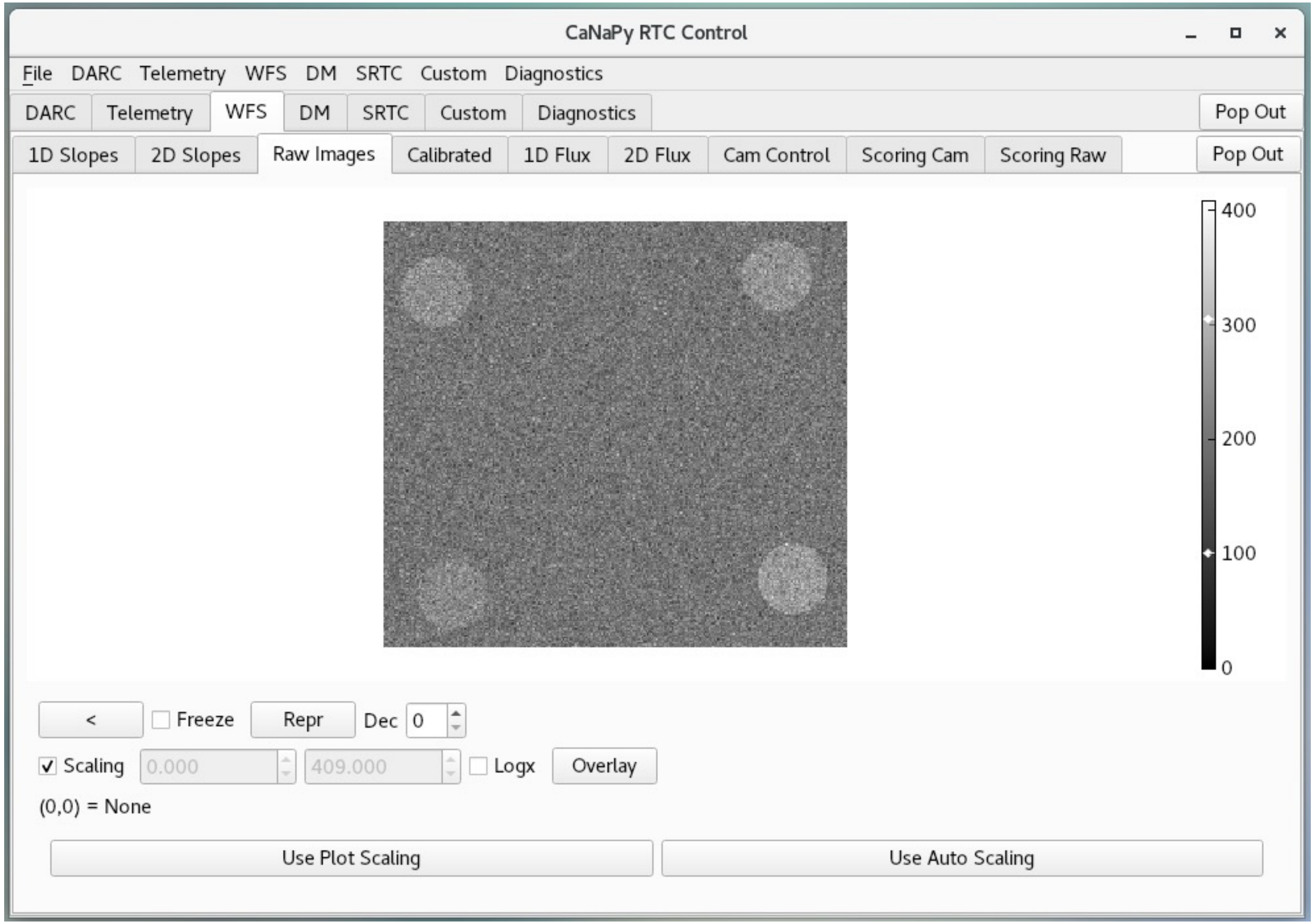

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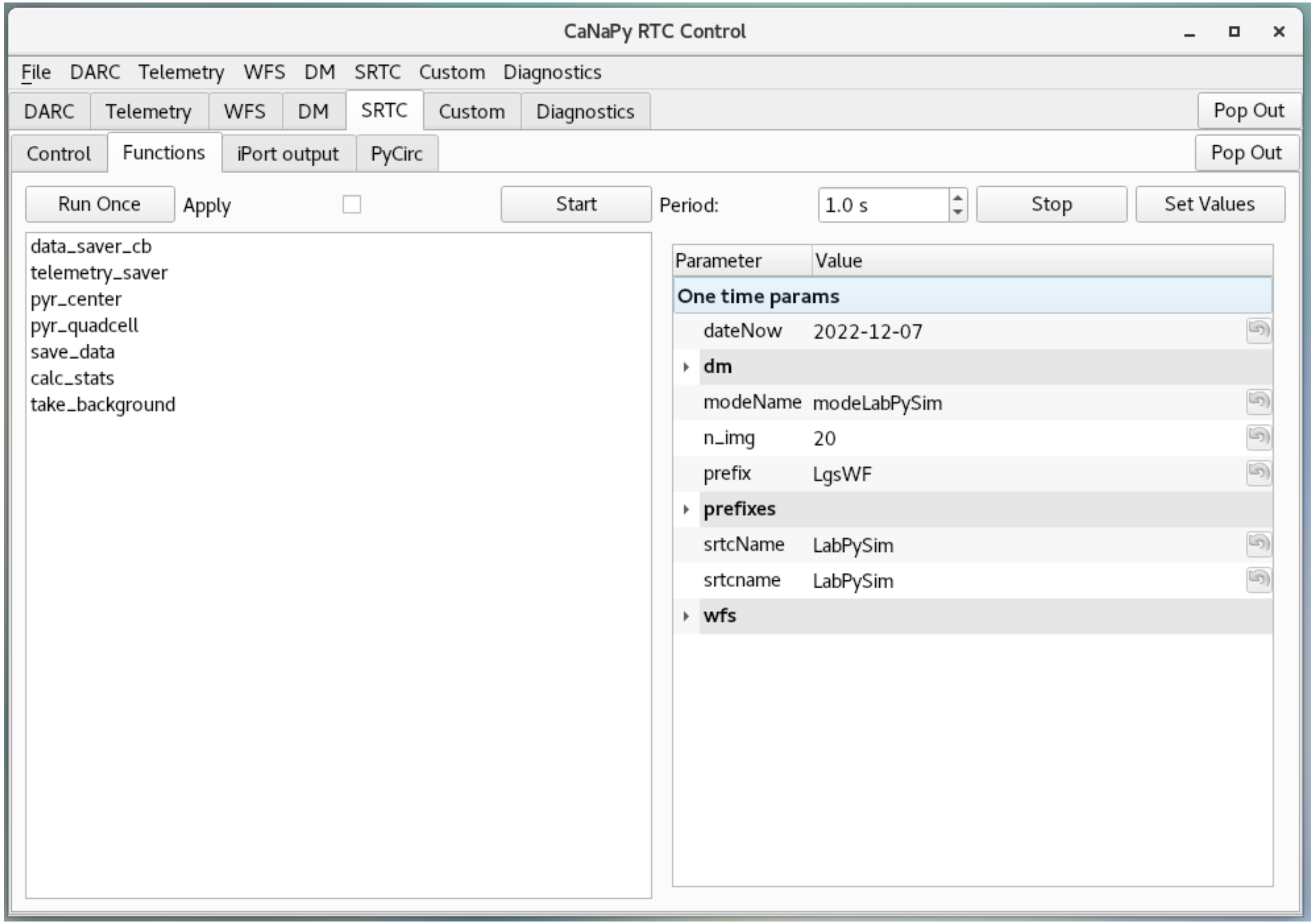

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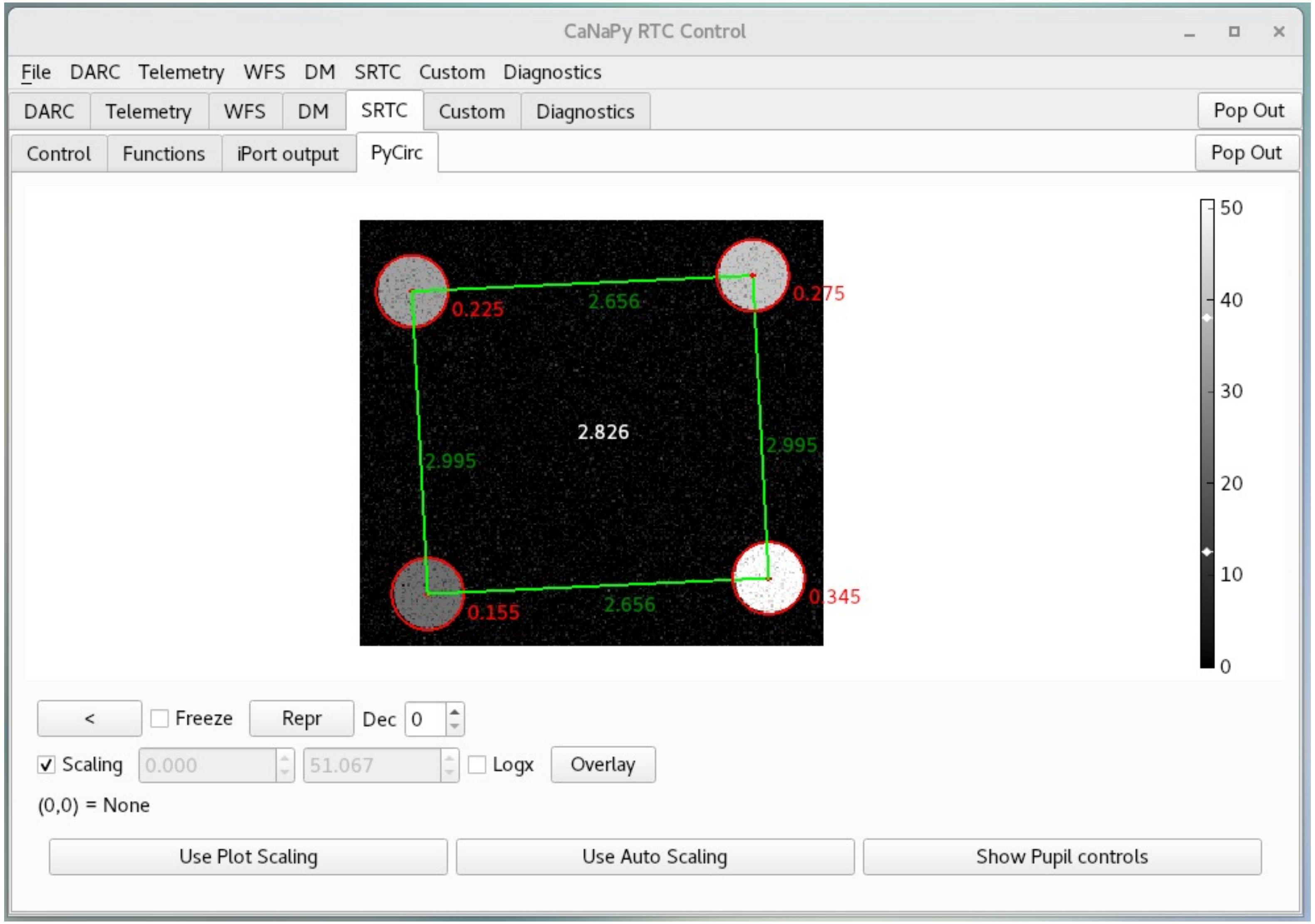
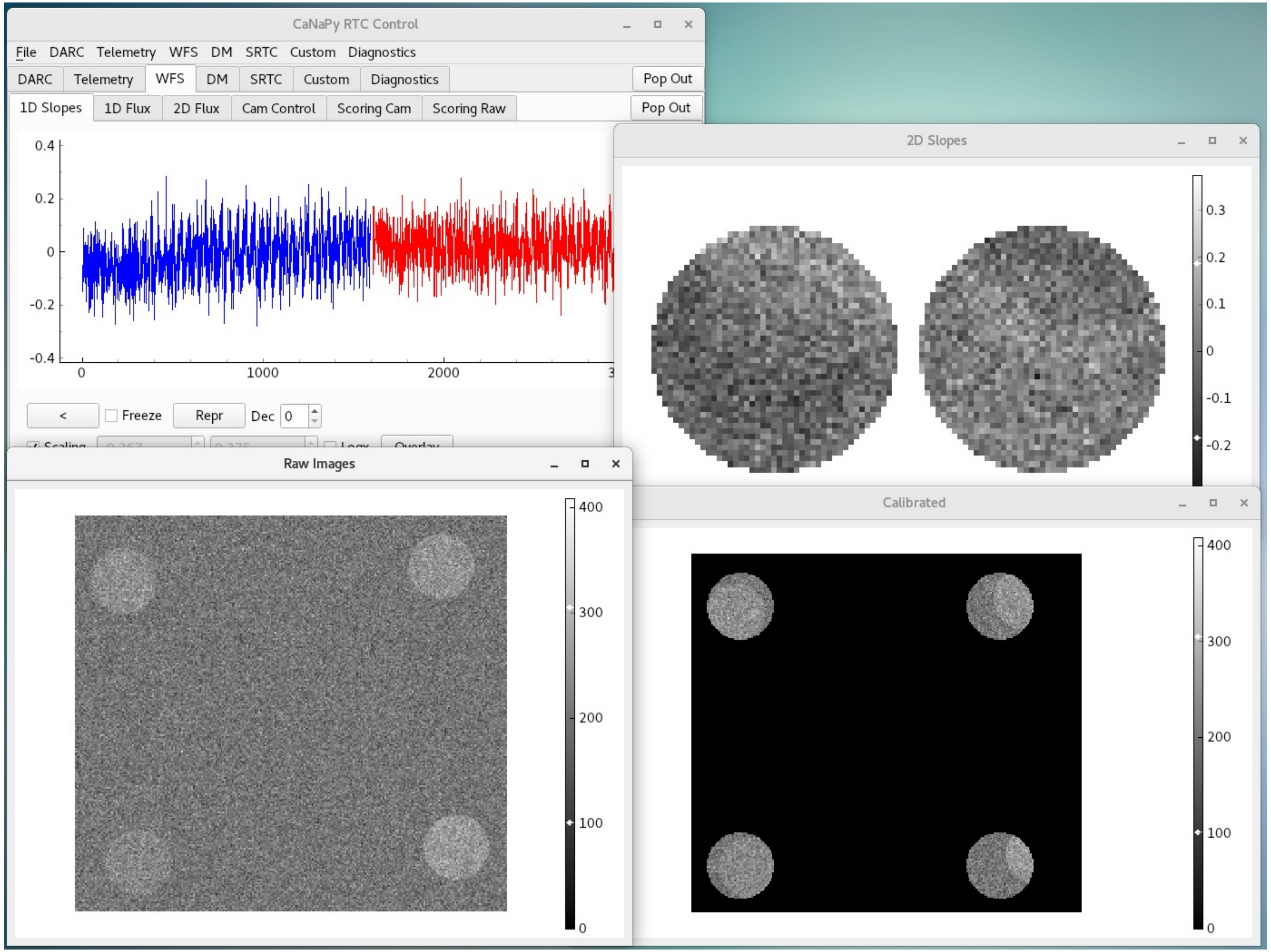


Displaying Multiple Plots



Current Status of CaNaPy

- Assembled and tested in laboratory conditions in engineering mode
  - Closed loop operation achieved with the Pyramid WFS and the ALPAO DM using a telescope simulator installed in the lab
- Currently being installed at the OGS on Tenerife
- September/October commissioning run delayed (Tenerife forest fires)
- Phase A commissioning planned for November 18-26, 2023
- Initial plan is to commission the NGS SH-WFS and the Laser uplink
- LGS Py-WFS closed loop planned for Spring 2024
- RTC development and testing will continue alongside the commissioning of CaNaPy/ALASCA

Questions?

- *CaNaPy is a test facility also for future further experiments with the community and with ESA*
- *CaNaPy is coordinated by ESO and carried out jointly with AO expert groups from three ESO member states: Durham University (UK), INAF (OAA and OAR - Italy), IAC (ES); and in synergy with ESA, within the frame of the ESO-ESA collaboration and implementation agreements.*