Mission Statement & Overview

- **PIRANHA** will map the plane of the Milky Way in the near infrared, establishing the first **3D spatial motion map** of both stars and substellar objects.

- Dedicated to **Astrometry**, **Photometry**, and **Spectroscopy**

- **Launch in 2020**
  - Operation in **L2 orbit**
  - **6 years mission lifetime**
Outline

• **Science Objectives and Requirements**

• Telescope and Instrumentation

• Mission and Spacecraft

• Cost and Programmatics
Primary Science Objectives

„The determination of the stellar initial mass function (IMF) is one of the Holy Grails of astrophysics.“ (G. Chabrier, 2005)

- Determine the **low-mass end of the IMF**
- Test **competing theoretical concepts**
- Obtain reliable stellar parameters
  i.e. **luminosity, mass and age** → distance is the key
- Is there a **universal IMF**?
  (spatial & temporal variations, metallicity, field MF, star formation history)
- Are there **different modes of star formation**?
- How does the **environment** affect the
  **formation of low mass and substellar objects**?
Legacy Science

- Solve the isolated star formation paradigm
- Understand the impact of binarity
- Formation of spiral arms and the central bar
- Galactic dynamics
- Determining the age of clusters (AGB turn-off)
- Stellar streams (merged dwarf galaxies & globular clusters)

- Data obtained will complement and improve Gaia results
Multiwavelength Milky Way
(images mainly from GSFC/ADC)

- Radio Continuum (408 MHz, 74 cm)
- H I (21 cm, Dwingeloo)
- CO J=1 \rightarrow 0 (2.6 mm, CfA)
- Mid-Far Infrared (12-100 \mu m, IRAS)
- Near Infrared (1.25-3.5 \mu m, COBE)
- Optical (A. Mellinger Panorama)
- X-Ray (0.25 – 1.5 keV, ROSAT)
- Gamma Ray (> 100 MeV, EGRET)

Galactic Longitude

Slide courtesy of T. Dame
Near Infrared Passbands

Y (1.03 µm)
J (1.25 µm)
H (1.63 µm)
K (2.20 µm)
Color Magnitude Diagram

300,000 Objects in H & K bands

(Dawson, Scholz & Ray, 2011)
Vector Point Diagram

photometrically selected objects

(Dawson, Scholz & Ray, 2011)
Scientific Objectives

- Wide-field NIR astrometric space telescope
- measure astrometric parallaxes
- of all stars up to 1 kpc
- with an accuracy of 10 %
- measure radial velocities
- create 3D spatial motion map
- towards the visually obscured plane of the Milky Way
Scientific Requirements

Astrophysical Parameters
- Intrinsic Luminosity
- Mass
- Age
- Motion
- Distance
- Metallicity
- Cluster Membership
- Temperature

Observable Parameters
- Apparent Luminosity
- Proper Motion
- Radial Velocity
- Spectral Type
Scientific Requirements

- **SURVEY**
  - observe 360° of the Milky Way ±1° of the galactic plane

- **TELESCOPE & ASTROMETRY**
  - mag. coverage: 7 – 20 mag (K)
  - angular res.: 0.2 arcsec
  - astrometric acc.: 0.1 mas

- **PHOTOMETRY**
  - bands: Y, J, H, K
  - accuracy: 0.1 mag

- **SPECTROSCOPY**
  - range: 2.29 – 2.39 um
  - resolution: 20,000
Outline

- Science Objectives and Requirements
- **Telescope and Instrumentation**
- Mission and Spacecraft
- Cost and Programmatics
Telescope & Instrumentation

- **3.5 m Cassegrain Design**

- **Large Infrared Camera Assembly**
  - infrared imaging device
  - astrometry with acc.: 0.1 mas
  - photometry with res.: 0.1 mag

- **Digital Micromirror Device Multi-Object Spectograph**
  - radial velocity by multi-object spectroscopy
  - spectral range: 2.29 - 2.39 um
  - spectral res.: 21.300
Telescope

- prim. mirror: 3.5 m
- design: Ritchey-Chrétien Cassegrain
- angular resolution: 0.2 arcsec
- FOV: 0.35° x 0.31°
- structure: silicon carbide
- heritage: Herschel
Large Infrared Camera Array

- **64 Hawaii 2RG Teledyne Detectors**
  - 2048 x 2048 pixels (18 um)
  - 37 x 37 mm chipsize

- **4 NIR bandpass filters**
  - Y, J, H, K

- **FOVs**
  - 0.35° x 0.31° FPA
  - 0.25° x 0.06° filter

- **step & stare mode**
  - no TDI mode
LICA Schematics

- Data Collection Unit
- Data Processing Unit
- Instrument Control Unit
- Service Module

Hawaii 2RG + SIDECAR

Spacewire interface to SVM
LICA Heritage

- **Detectors:** HST WFC3, JWST NirCam, WISE
- **ASICs:** JWST NirCam
- **Electronics:** JWST NirCam
- **Thermal Control:** Standard Equipment

LICA References

- **Filters:** Dune
- **FPA Structure:** Dune
Digital Multimirror Device
Multi-Object Spectrograph

- **2.56 million mirrors** to obtain spectra of up to **3200 stars** in one integration
- **Individual stars** are picked from data sets provided by LICA
DMDMOS Layout

Detector
Pix 2  λ = 1 Å
Pix 1  λ = 1 Å

Bandpass filter

Reflective grating
R = 21 300

Collimating mirror

Collimating mirror

DMDs

Incoming light

Foreoptics

not to scale
DMDMOS Detector Assembly

- 4 Hawaii 2RG
- same electronics as LICA
- 3200 spectra in parallel
DMDMOS Schematics

- **DMD Control Unit**
  - DMDCU (x 1)
  - Spectrograph (x 4)

- **Detector Assembly**
  - Hawaii 2RG (x 4)
  - SIDECAR (x 4)
  - DCU (x 2)
  - DPU (x 1)

- **Light**
  - From Detector Assembly to DMDCU
  - From DMDCU to ICU

- **Spacewire interface to SVM**
  - From ICU to Spacewire interface to SVM
DMDMOS Heritage

- **Detectors**: HST WFC3, JWST NirCam, WISE
- **ASICs**: JWST NirCam
- **Electronics**: JWST NirCam
- **Thermal Control**: Standard Eq. (see critical technology)

DMDMOS References

- **DMD**: RITMOS
- **Optical Design**: RITMOS
Observation Strategy

- **PIRANHA** will observe $2^\circ \times 360^\circ$ of the galactic plane (Project for Infrared Astrometry and High Accuracy)

- **A step & stare scanning mode will move stars** over 4 filters on LICA (Large Infrared Camera Array) and onto the DMDMOS (Digital Micromirror Device MOS)

- **Total area is divided into 4 parts**

- **Data is released in 4 sets**

- **6 years needed for total coverage**
begin of observations
covering 1° x 180° once after 6 months
> start second scan
1° x 180° coverage after 1.5 years observation
1° x 360° coverage after 3 years observation
expanding to $2^\circ \times 180^\circ$ after 4.5 years
full coverage achieved after 6 years observation
Dither Pattern

1. field integration
2. dithering
3. field integration
4. dithering
5. field integration

dither pattern according to layout of DMD
total time per field
13 min.

field integration is 200 s

integration of spectra 200 s

2x

field integration 200 s

dither & stab. 60 s

field integration 200 s

dither & stab. 60 s

field integration 200 s

spectra 60 s
Outline

- Science Objectives and Requirements
- Telescope and Instrumentation
- **Mission and Spacecraft**
- Cost and Programmatics
Mission Requirements

• **Survey Requirements**
  - perform a *survey of the galactic* plane 2° x 360°
  - observe every frame at least 3x with $\Delta t = 6$ months

**Pointing Requirements**
- Absolute Pointing Error: $< 200 \text{ mas}$ (DMD mirror size)
- Relative Pointing Error: $< 50 \text{ mas}$ (astrometric positions)

• **Thermal Requirements**
- mirror & payload: 100 K
- service module: 300 K

• **Telemetry Requirements**
- data rate: 800 Gbits / day
Orbit & Launcher

• **Orbit Selection**
  - L2 HALO orbit
  - thermally stable environment
  - constant solar aspect angle for whole survey

• **Launcher Selection**
  - Ariane 5 ECA
  - launch from Korou, French Guiana
  - required due to mass > 3 tons dimensions & orbit selection

enough space available to carry another team's mission !!!
Spacecraft Design

- Attitude & Orbit Control System
- Structure
- Thermal Control System
- Power Budget
- Onboard Data Handling
- Telecommunications
Attitude & Orbit Control System

• **Control Principle**
  - 3-axis stabilization

• **Requirements**
  - Absolute pointing error \( \text{APE} < 200 \text{ mas} \)
  - Relative pointing error \( \text{RPE} < 50 \text{ mas} \)

• **Sensors**
  - Star trackers
  - Gyros
  - Sun sensors
  - FGS (included in LICA FPA)

• **Actuators**
  - Magnetic Bearing Reaction wheels: Rockwell Collins
  - Thrusters hydrazine: EADS Astrium
Attitude & Orbit Control System

• **Operation Modes**
  - Safe mode (without payload): sun sensors, gyros, thrusters
  - Slew mode: Star trackers, gyros & reaction wheels
  - Orbital Control mode: Star trackers, gyros, thrusters
  - Science mode: FGS, reaction wheels

• **Pointing Performance**
  - Star trackers not selected for science mode
  - FGS achieves accuracy of 10 mas

• **Propulsion**
  - Thrusters: hydrazine monopropellant, Isp = 200 s
  - Orbital control and momentum dumping
Structure

**CFRP**
(Carbon fibre reinforced polymer)
Honeycomb structure for inner part of SVM, Sunshield, Baffle

**SiC**
(Silicon Carbide)
Mirrors, Optical bench and bipods

**Aluminum**
Outer part of SVM

Structure Total Mass: 1.46 tons
Thermal Control System

- **Passive Cooling**
  - Multi-Layer Insulation
    - Back of sun shield
    - SVM, PLM, Baffle
- **Temperatures**
  - Payload Module: 100 K
  - Service Module: 300 K
- **SiC mirror** required to couple primary mirror and instrument temperature
- **Instruments warm up electronics located in SVM**
Power

- **Solar Arrays**
  - Maximum power required: 1364 W
  - Gallium Arsenide, Eff.: 28%
  - Solar Array Area: 6.3 sqm

- **Launch Phase**
  - Li-Ion battery
  - sized for 2 hours of autonomy during initial sun acquisition
  - DOD: 0.6
  - Discharge eff.: 0.9

- **PCDU**
  - 28 V regulated
  - distributes up to 1500 W
## Power Budget

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<tr>
<th>Power budget</th>
<th>Science Mode [W]</th>
<th>Safe mode [W]</th>
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<tr>
<td>Payload</td>
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<td>AOCS</td>
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<td>OBC</td>
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<tr>
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<td><strong>Total with margin</strong></td>
<td><strong>1364</strong></td>
<td><strong>647.2</strong></td>
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Onboard Data Handling

- Storage capacity required: **3 x 800 Gbits** (3 days w/o downlink)
- Onboard computer OBC: **Leon3 processor**
- Data storage: **NAND flash memory**
- Communication
  - OBC to Spacecraft units via MIL-STD-1553 bus
  - OBC to mass memory and instruments via SpaceWire
Link Budget

- Requirements
  - data rate: \textbf{800 Gbits / day}
- 0.4 m high-gain antenna: \textbf{K-band}
- SC Antenna diameter: \textbf{0.4 m}
- Transmitter power: \textbf{35 W}

- Ground Antenna diameter: \textbf{35 m}
  (Cebreros/Malargue)
- Sending duration: \textbf{4h / day}
- Housekeeping elements performed via 2 low-gain antenna in X-Band
# Mass Budget

<table>
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<tr>
<th>System</th>
<th>Mass (kg)</th>
<th>Mass(%)</th>
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<tr>
<td>AOCS</td>
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<td>EPS</td>
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<td>TCS</td>
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<td>Margin (20%)</td>
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<td><strong>Total with margin</strong></td>
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Outline

• Science Objectives and Requirements

• Telescope and Instrumentation

• Mission and Spacecraft

• **Cost and Programmatics**
Costs Estimates

- Cost estimation based on a mass-based model
- **6 years mission lifetime**
- Total cost = **1.16 billion Euro**
Mission Schedule

Launch as early as 2020

Possible delay during phase B2/C/D
- DMDs qualification
- Number of Detectors
- Mirror: manufacturing, polishing and testing

Mission Analysis, Needs Identified
Feasibility
Preliminary Definition
Detailed Definition
Production, Ground Qualification, Testing
Utilization
Disposal
Risk Assessment

• **3.5 m Primary Mirror** for good optical performance
  – 2.0 m with impact on coverage / mission timeline

• **>68 Teledyne Hawaii-2RG** to be manufactured and delivered
  – impact: reduced FOV / coverage / mission timeline

• **Texas Instruments DMD** to be developed as specified and to be operated at 100K
  – impact: reduced number of spectra
  – temperature: development needed to reach 100 K
Risk Assessment

- **MBMRW** to achieve required APE and RPE
  - impact: inability to do spectroscopy
  - cold gas alternative not feasible
    due to amount of propellant required

- **Deep Space Network not yet upgraded to K-band**
  - impact: delay in mission schedule

- **FGS in LICA FPA**
  - impact: delay in mission schedule