SPHERE

(Spectro-Polarimetric High-contrast Exoplanet REsearch)
A Planet Finder Instrument for the VLT

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and numerous participants from 12 European institutes !

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SPHERE science objectives

- Directly **detect** photons from extrasolar giant planets
 - Explore the **mass-period** distribution (1-20 M_{jup} , 1-1000 years)
 - Survey an **extended number** of stars
 - First order **characterization** of the atmosphere (clouds, dust content, methane, water absorption, effective temperature, radius, dust polarization)
 - ➔ Understand the **planetary system origins**
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SPHERE science objectives

SPHERE main targets

- Target classes for wide exoplanet search (several hundreds objects)
 - ✓ Young nearby stars (5-50 Myr) down to $0.5 M_J$
 - ✓ Young active F-K stars (0.1 - 1 Gyr)
 - ✓ Late type stars
 - ✓ Known planetary systems (from other techniques)
 - ✓ Closest stars (< 6 pc)
- Selection of individual targets
 - ✓ Known (proto)planetary disks: physics, evolution, dynamics
 - ✓ Variety of selected high contrast targets: YSO gas environment, evolved stars

SPHERE expected achievements

- Clear EGP detection capability
 - ✓ <1 to few M_{Jup} depending on targets
 - ✓ Potential for new critical planet detection/characterization around nearest stars
- Wider view: orbital properties, statistics
 - ✓ Complementary period and spectral types wrt RV-transits
 - ✓ Wide target sample insight before future terrestrial planet search
- Physics of very low mass objects: atmosphere and internal structure properties, from BD to lower mass and cooler objects, comparison to refined models
- Planetary system evolution perspective
 - ✓ From Myr to Gyr planet properties
 - ✓ Planet multiplicity (inner-outer planets statistics and interactions)
 - ✓ From disk to planet formation, dynamics, and evolution

Operation strategy

- Survey of a few hundreds stars is desirable
 - ✓ Statistical approach needed (frequency)
 - ✓ More efficient use of instrument
- Follow-up observations for characterization
- A few hundred nights required over several years
(260 GTO nights already approved !)
- Additional survey to be discussed (250 nights as Public/Legacy Survey ?)
- Starting date 2010/11 is timely for planet studies

Scientific requirements

- High contrast detection capability
 - ✓ Gain up to 5 magnitudes in contrast as compared to current instrumentation (planet magnitude up to ~21-25)
 - ✓ Extreme AO (SR ~ 90% in H-band)
 - ✓ Coronagraphy (high dynamics at short separations: 0.1" - 3")
 - ✓ Differential detection (cancel residual halo)
 - ✓ Optimized for calibration accuracy
- Characterization (IRDIS)
 - ✓ Low resolution spectro-photometry ($R \sim 50-500$ in the range 0.96 - 2.32 microns)
- Integral Field Spectrograph (IFS)
 - ✓ Detection and spectral characterization with better perf.
- Differential polarimetry (ZIMPOL)
 - ✓ Detection and polarimetric characterization

Nasmyth focus

Environment: static bench, Nasmyth platform,
temperature and vibration control

Common Path

High frequency AO correction (41x41 act.)
High stability : image / pupil control
Refraction correction
Visible – NIR, FoV = 12.5''

NIR

Vis

AO sensing

SH-WFS in visible, 40x40
1.2 KHz, RON < 1e-

ZIMPOL

Dual imaging polarimetry
(direct imaging BB + NB)
Lyot coronagraph

Corono

Pupil apodisation
Focal masks: Lyot, 4-Q, APLC
IR-TT sensor for fine centering

0.95 – 1.35 μm $\lambda/2\text{D}$ @ 0.95 μm
Spectral resolution: $R_{\text{pix}} = 54$
FoV = 1.77''

IFS

IRDIS

0.9 – 2.3 μm ; $\lambda/2\text{D}$ @ 0.95 μm
Differential imaging: 2 wavelengths, $R \sim 30$, FoV = 12.5''
Long Slit spectro (grism), $R \sim 50/500$, differential polarization

Instrument modes

Science module	Modes	Motivation / specificities
IRDIS	Dual Band Imaging (DBI)	<ul style="list-style-type: none"> • Baseline planet detection capability • High contrast imaging • Complete NIR spectral range coverage, optimized for J and H • Wide simultaneous FoV (>11")
	Long slit spectroscopy	<ul style="list-style-type: none"> • Simultaneous low resolution Yto Ks spectrum • Medium resolution spectroscopy
	Classical imaging	<ul style="list-style-type: none"> • Complete set of wide and medium band filters • Wide FoV (>11")
	Dual Polarization imaging (DPI)	<ul style="list-style-type: none"> • Spectral complementarity with ZIMPOL • Larger simultaneous FoV (>3")
IFS	Imaging spectroscopy in Y to J	<ul style="list-style-type: none"> • Higher contrast performance goal • Internal multiplex advantage with more spectral channels than DBI, more robust to unexpected spectral features • Multiplex advantage when simultaneous with IRDIS
ZIMPOL	Very accurate relative polarimetry	<ul style="list-style-type: none"> • Detection of very faint reflected light (down to the level of inner planets)
	Classical imaging	<ul style="list-style-type: none"> • High Strehl, high angular resolution • Complete set of wide, medium and narrow band filters

Observation modes

Mode	Use	Sub system			Mode switches		
		IRDIS	IFS	ZIM POL	Pupil or image de - rotation	CP Polar. plates	AO / ZIMPOL beam split
NIR survey	Large survey <i>Hundreds of targets</i>	H band DBI	Y-J		Pupil	Out	100 / 0
ZIMPOL alone	Reflected light detection and HAR imaging <i>Selected targets</i>			Vis, any filter	None or field	In	~20/80 or dichro (tbd)
IRDIS alone	Complete spectral characterization, full FOV imaging <i>Selected targets</i>	Y-Ks, any mode			Pupil or field	Out (In for DPI tbc)	100 / 0
NIR survey +ZIMPOL (TBC)							
	survey						

Optical design

Mechanical implementation

AO system

➤ High angular resolution

- ✓ Clean PSF out to $\sim 0.8''$ at $1.6 \mu\text{m}$
 - 41×41 act. DM (CILAS, contract JRA1)
 - Fast Tip-Tilt correction (jitter residuals $< 3 \text{ mas rms}$)
 - Kalman filtering (system vibrations) + focal plane filtering
- ✓ Calibration issues (critical part of the system)
 - Strong impact on instrument design
 - Phase diversity will be used

➤ High sensitivity

- ✓ Optimal correction up to $V \sim 10$
 - Visible range ($0.45 - 0.95 \mu\text{m}$) WFS + low noise CCD (L3 CCD)
 - $> 1.2 \text{ kHz}$ WFS frame rate + optimal WFS measurements (WCoG)

➤ High stability

- ✓ Slow Tip-Tilt correction (image position on coronagraph $< 0.5 \text{ mas}$)
- ✓ Pupil stability ($< 0.2 \%$ of full-pupil diameter)

Coronagraphs

- Classical Lyot coronagraph
 - ✓ Proven concept, existing on sky, no substrate
 - ✓ Limited to external regions ($> 0.5''$)
- 4Q phase mask γ , J, H (see Boccaletti's poster)
 - ✓ Well studied, existing in NACO
 - ✓ Allow to explore inner regions (down to λ/D)
 - ✓ On-going R&D (achromatisation, throughput improvements)
- Apodized pupil Lyot
 - ✓ Optimized for γ , J, H
- Other concepts (modular design)
 - ✓ New ideas (very active research field !)

Prototype validation

IRDIS dual beam imager

- ✓ Spectral range: 950-2320 nm (Y to Ks Band)
- ✓ Image sampling: 12.25 mas ($\lambda/2D$ at 950 nm)
- ✓ Direct & Dual imaging FOV: 11" x 12.5"
- ✓ Dual Polarization Imaging mode (DPI):
 - ✓ same filters as DI, 3" FOV, goal: 6" x 12.5"
- ✓ Spectroscopy mode: FOV 12.5" along-slit, slit width : 3 to 12 px,
 - ✓ $R > 50$, Y to Ks simultaneously
 - ✓ $R \sim 500$, 950-1800 nm (simultaneously if possible)
- ✓ Image Quality: static aberrations < 45 nm
- ✓ Differential Image Quality: Δ WFE < 10 nm
- ✓ Flat Field accuracy for all Imaging modes : < $2 \cdot 10^{-3}$ (goal 10^{-3})

NIR spectral features

Condensed, 5 MJup, 10 Myr

IRDIS

IRDIS Opto-mechanical implementation inside the Cryostat

3D view of mechanical implementation with common filters before beam splitter

IRDIS

Static WFE Budget

Used for the End-to-End instrument model
Total static WFE = 45 nm rms

IRDIS dual beam imager

Integral Field Spectrograph

- ✓ IFU scheme: BIGRE, Hexagonal-C
- ✓ Wavelength range: 0.95-1.35 μm
- ✓ Spectral resolution: 54 (2 pixels), 0.0106 $\mu\text{m}/\text{pixel}$
- ✓ Spaxels: 145^2 , 12.25 milliarcsec/pixel
- ✓ FOV: square, 1.77 arcsec side
- ✓ Cross Talk: $<10^{-3}$

Complete scheme of the SPHERE - IFS

BIGRE lab tests

Cross Talk:
a few 10^{-4}

Combined use and advantages of IRDIS/DBI and IFS

- DBI in H + IFS in Y-J
- Simultaneous information of main NIR spectral features
- Complementary FoV
- Deeper insight in inner part with IFS
- False alarm reduction

ZIMPOL

- Visible light (600 to 900 nm)
- Polarimetric precision better than 10^{-5}
 - ✓ Ferro-electric polarization modulator (1 kHz)
 - ✓ Synchronous demodulating CCD
- 3" x 3" FOV on detector
 - ✓ Access to a field of radius 4" by tip-tilt

Talk by Franco Joos

ZIMPOL

ZIMPOL

- ZIMPOL observing α Cen A
 - ✓ The planet size corresponds to Jupiter
 - ✓ 50% polarization, assuming a phase angle of 80deg

Zurich Imaging Polarimeter (ZIMPOL)

Project schedule

- May 2003: Start of the 2 phase A studies (MPIA, LAOG)
- Dec. 2004: Phase A reviews by ESO
- Apr. 2005: Merging of the 2 teams
- March 2006: Kick-off
- March 2007: Preliminary Optical Design Review
- September 2007: Preliminary Design Review
- September 2008: Final Design Review
- September 2010: Preliminary Acceptance
- Early 2011: First light !

SPHERE DM

CILAS deformable mirror to be delivered in July 2007!