Polarimetry and spectral imaging of mature Jupiter and super-Earth SEE-COAST

Raphaël Galicher

Jean Schneider, A. Boccaletti, P. Baudoz,

G. Tinetti, D. Stam, R. Gratton, …
Outline

Why direct imaging ?
Why from space (SEE-COAST) ?
Which kinds of objects ?
Spectroscopy and polarimetry interest ?
What's detected by 1.5meter telescope ?
Which technology ?
Outline

Why direct imaging?

Why from space (SEE-COAST)?

Which kinds of objects?

Spectroscopy and polarimetry interest?

What's detected by 1.5 meter telescope?

Which technology?
How are you doing mate?

… not yet
Complementarity of techniques

From the extrasolar planets encyclopaedia

http://exoplanet.eu

Radial velocity
Transits
Microlensing
Timing
Direct imaging

log(Planet mass) (M_Jup)

log(Planet semi-major axis) (AU)

http://exoplanet.eu
Complementarity of techniques

From the extrasolar planets encyclopaedia

log(Planet mass) (Mjup)

log(Planet semi-major axis) (AU)

Gaia

Astrometry

Sim

Radial velocity

Transits

Microlensing

Timing

Direct imaging

http://exoplanet.eu
Complementarity of techniques

From the extrasolar planets encyclopaedia

Geometrical probability

Light curve quality

http://exoplanet.eu

Radial velocity
Transits
Microlensing
Timing
Direct imaging

log(Planet semi-major axis) (AU)

log(Planet mass) (MJup)
Larger telescopes
Dedicated instruments

Only the

http://exoplanet.eu
Complementarity of techniques

From the extrasolar planets encyclopaedia

http://exoplanet.eu

Radial velocity
Transits
Microlensing
Timing
Direct imaging

$\sim T^{2/3}$
Complementarity of techniques

From the extrasolar planets encyclopaedia

Radial velocity
Transits
Microlensing
Timing
Direct imaging

http://exoplanet.eu

log(Planet mass) (M\text{Jup})

log(Planet semi-major axis) (AU)

1e-5
1e-4
1e-3
1e-2
1e-1
1
1e1
1e2

0.01
0.1
1
10
100

didn't survive.
Complementarity of techniques

From the extrasolar planets encyclopaedia

Direct imaging

Transit

SPECTRA & POLARIZATION

The woman
Outline

Why direct imaging?

Why from space (SEE-COAST)?

Which kinds of objects?

Spectroscopy and polarimetry interest?

What's detected by 1.5 meter telescope?

Which technology?
Ground/space complementarity

We are here | Space-based


Ground-based
Ground/space complementarity


HST

We are here

Space-based

4m + OA Silla, CFH
8m + OA VLT, Keck, Gemini

Ground/space complementarity

We are here
Ground/space complementarity

We are here

Space-based


4m + OA
Silla, CFH
8m + OA
VLT, Keck, Gemini

8m + XAO
SPHERE / GPI / HICIAO
NIR : EGPs
young/massive/nearby

Ground/space complementarity
Ground/space complementarity

- **Space-based**
  - HST
  - 4m + OA Silla, CFH
  - 8m + OA VLT, Keck, Gemini
  - 8m + XAO SPHERE / GPI / HICIAO
  - 30/42m + XAO EPICS, PFI, etc. with ELTs

- **Ground-based**
  - Nir : EGPs intermediate
  - Old + Super-Earth?

- **We are here**
  - 1995-2000
  - 2010-2011
  - 2017-2020
  - >2025-30
Ground/space complementarity

Space-based

We are here

JWST

NIR + MIR:
Old EGPs

>2025-30

SPICA MIR:
Old EGPs

1995
2000
2010
2011
2017-2020

13/42m + XAO
EPICS, PFI, etc with ELTs
NIR: EGPs intermediate
Old + Super-Earth?

Ground-based

4m + OA
Silla, CFH

8m + OA
VLT, Keck, Gemini

8m + XAO
SPHERE / GPI / HICIAO
NIR: EGPs young/massive/nearby
Ground/space complementarity

**Space-based**

- **1995**: HST
- **2000**: 8m + OA (Silla, CFH)
- **2010**: 8m + OA (VLT, Keck, Gemini)
- **2011**: 8m + XAO (SPHERE / GPI / HICIAO)
- **2017-2020**: 30/42m + XAO (EPICS, PFI, etc. with ELTs)
- **>2025-30**: Darwin/TPF-I (MIR: Earth), TPF-C (Vis: Earth)

**Ground-based**

- **We are here**
- **1995**: Old EGPs
- **2000**: Old EGPs
- **2010**: NIR + MIR: Old EGPs
- **2011**: Old + Super-Earth?
- **2017-2020**: NIR: EGPs intermediate
- **>2025-30**: Old + Super-Earth?
Ground/space complementarity

Space-based

Opportunity for space projects

Visible light

Old giants & super-Earths

Ground-based

We are here


HST

JWST

NIR + MIR: Old EGPs

4m + OA Silla, CFH

VLT, Keck, Gemini

8m + OA

8m + XAO SPHERE / GPI / HICIAO NIR: EGPs young/massive/nearby

30/42m + XAO EPICS, PFI, etc with ELTs NIR: EGPs intermediate Old + Super-Earth?

Darwin/TPF-I

MIR: Earth

TPF-C

Vis: Earth

Ground/space complementarity

8m + XAO SPHERE / GPI / HICIAO NIR: EGPs young/massive/nearby

30/42m + XAO EPICS, PFI, etc with ELTs NIR: EGPs intermediate Old + Super-Earth?
Ground/space complementarity

We are here

Space-based

SPICA
MIR:
Old EGPs

JWST
NIR + MIR:
Old EGPs

SEE
Super Earth Explorer

SEE COAST
Vis/NIR
Old Jupiter + Super Earth

Darwin/TPF-I
MIR: Earth
TPF-C
Vis: Earth

1995
2000
2010
2011
2017-2020
>2025-30

Ground

4m + OA
Silla, CFH

8m + OA
VLT, Keck, Gemini

8m + XAO
SPHERE / GPI / HICIAO
NIR : EGPs
young/massive/nearby

30/42m + XAO
EPICS, PFI, etc with ELTs
NIR : EGPs intermediate
Old + Super-Earth ?

Rockwell

Ground-based

HST
Outline

Why direct imaging ?
Why from space (SEE-COAST) ?
Which kinds of objects ?
Spectroscopy and polarimetry interest ?
What's detected by 1.5meter telescope ?
Which technology ?
See-Coast will characterize:

**What's expected:**

**Mature Jupiter** (~5Gyr)

**Super Earth** → **Brighter**
- Atmosphere, climate variations, habitable

**Exo-zodiacal disk**

**And unexpected objects!**

Stay open-minded (cf. hot Jupiter in 1995)

23 octobre 2009
Raphaël Galicher
Outline

Why direct imaging?
Why from space (SEE-COAST)?
Which kinds of objects?

Spectroscopy and polarimetry interest?
What's detected by 1.5 meter telescope?
Which technology?
Spectroscopy: chemical composition

Giant planets
- Jupiter 1 AU
- Jupiter 2 AU
- Jupiter 4 AU
- Earth 1 AU, 1 atm

Solid planets
Polarimetry: physical informations

Clouds / albedo

Jupiter-like planet - Stam et al. 2005

Spectrum

Polarization
Outline

Why direct imaging ?
Why from space (SEE-COAST) ?
Which kinds of objects ?
Spectroscopy and polarimetry interest ?
What's detected by 1.5meter telescope ?
Which technology ?
How many detections?

Nearby stars (<20pc)

- Planet-star separation (arcsec)
- Planet-star contrast (V band)

- $10^{-4}$
- $10^{-5}$
- $10^{-6}$
- $10^{-7}$
- $10^{-8}$
- $10^{-9}$
- $10^{-10}$
- $10^{-11}$

Gratton et al.
How many detections?

Nearby stars (<20pc)

![Graph showing planet-star contrast vs. separation for different wavelengths and detection methods.](image)

- Nearby stars (<20pc)
- Planet-star separation (arcsec)
- Planet-star contrast (V band)

- 1.5 m space coronographs
- λ=600nm
- λ=1.2μm

Gratton et al.
How many detections?

Nearby stars (<20pc)

- Planet-star separation (arcsec)
- Planet-star contrast (V band)

Gratton et al.

1.5 m space coronographs

Warm Jupiters
Cold Jupiters
Neptunes
Rocky planets

fed her.
How many detections?

Nearby stars (<20pc)

- Planet-star separation (arcsec)
- Planet-star contrast (V band)

- Nearby stars (<20pc)
- Planet-star separation (arcsec)
- Planet-star contrast (V band)

Gratton et al.

At $\lambda = 1.2 \mu m$

1.5 m space coronographs

Warm Jupiters
Cold Jupiters
Neptunes
Rocky planets

Gratton et al.
How many detections?

Nearby stars (<20pc)

1) 1e-10 contrast
2) Small inner working angle
Outline

Why direct imaging ?
Why from space (SEE-COAST) ?
Which kinds of objects ?
Spectroscopy and polarimetry interest ?
What's detected by 1.5meter telescope ?
Which technology ?
SEE-Coast: proposed to Cosmic Vision

Hyperbolic secondary mirror 4,85m long
Parabolic primary mirror

Parameter Value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance pupil diameter</td>
<td>$D &gt; 1.5m$</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>0.4 to 1.2 $\mu m$</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>$R &gt; 40$</td>
</tr>
<tr>
<td>Contrast (after speckle subtraction) @ 2 $\lambda / D$</td>
<td>$&lt; 10^{-9}$</td>
</tr>
<tr>
<td>Contrast (after speckle subtraction) @ 4 $\lambda / D$</td>
<td>$&lt; 10^{-10}$</td>
</tr>
<tr>
<td>Orbit for 6 months visibility, high thermal stability</td>
<td>L2 Lagrangian</td>
</tr>
</tbody>
</table>

Submitted in 2007 to ESA Cosmic Vision
SEE-Coast: proposed to Cosmic Vision

1) Coronagraph
2) Wavefront control (a few nm rms from science image)
3) Differential imaging
4) Integral field spectrometer/polarimeter

Hyperbolic secondary mirror 4.85m long

Orbit for 6 months visibility, high thermal stability
L2 Lagrangian

Submitted in 2007 to ESA Cosmic Vision

Parabolic primary mirror

Two folding mirrors

Focal plane

restaurant,
Achromatic coronagraph

Laboratory planet
Contrast : $6.7 \times 10^{-9}$
at $4.5\lambda/D$

$\Delta \lambda/\lambda = 20\%$
Visible light

Baudouz et al. 2007, 08
Wavefront sensor in the science image

Speckle nulling in a limited FOV with a DM (JPL)
Wavefront sensor in the science image

Self-coherent camera (SCC)

Galicher et al. 2008, 2009

Remember Marion Mas' talk

23 octobre 2009

Raphaël Galicher
Integral Field Spectrometer
+ Self-coherent camera

Aberrations = function of $\lambda$ (Fresnel propagation)

Classical IFS
strongly limited

One solution:
SCC-IFS

Field of view position
Summary

- Direct imaging: **unexplored domain of parameter space**
- Space telescope: **visible light**

- See-coast requires: **1e-10 contrast** and **small IWA** (2\(\lambda/D\))

- **Spectrometry**
  - low resolution **spectra** of **young/old Jupiter** (<20pc, 8-10 AU)
  - **colors** of **super-Earths** (<10pc, 4-5 AU)
  - low resolution **spectra** of **self-luminous planets** (NIR)

- **Polarimetry**: more physical informations

- See-coast next steps:
  - refine **optical design** and **derive science cases**
  - technology with **coronagraphy, wavefront control, differential imaging**
  - **Cosmic vision proposal in late 2010**
Thank you for your attention

If you want to participate in this project, please contact:

- Raphaël Galicher, raphael.galicher 'at' obspm.fr
- Jean Schneider, jean.schneider 'at' obspm.fr

23 octobre 2009
Raphaël Galicher
Self-coherent camera + four quadrant phase mask coronagraph
A woman goes to the restaurant and orders a seabird. She eats it and says: « Urgh, I ate my husband! »
Why?

Because: the couple and their friends aircrashed on a desert island. Only the man didn't survive. The woman was starving but nothing to eat except seabirds. Her friends fed her. At the restaurant, the seabird did not taste as on the island...