Update on asteroseismology with Plato

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Outline

- Overview of the mission
- Photometric performances*
- Seismic performances*
- Seismic stellar characterisation*
- Conclusions

* 'expected' must be understood in the following ! ;-)

- M3 mission selected by ESA in February 2015
- Launch in 2025 by a Soyouz rocket, L2 orbit
- PI Heike Rauer (Germany) - PSM: Don Pollacco (UK)
- Currently in phase B2 (consolidated definition phase)
- Process for adoption November 2016

Scientific objectives of Plato

- Determine the bulk properties (mass, radius, mean density) of planets in a wide range of systems, including terrestrial planets in the habitable zone of solar-like stars.

  output : $> 100(goal : 400)$ *precisely characterized exoplanets including* $> 5(goal : 30)$ *(super-)Earths in the habitable zone of solar-like stars.*

- Evolution of planets and planet systems with age.
- Study the internal structure of stars and how it evolves with age.

(for details, see Rauer et al., 2014, the Yellow book 2016)

Reaching the scientific objectives: 3 techniques

- Detection of exoplanets by photometric transits : orbital parameters and R_p/R_*
- Confirmation by spectroscopic ground-based follow-up : M_p/M_*
- Precise M_*, R_*, and age by seismology of the host star

For host stars :

- 2% for the radius uncertainties
- 10 % for the mass uncertainties
- 10% uncertainties for the age for the reference star at magnitude 10

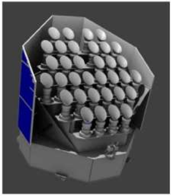
(Reference star : $1M_\odot, 1R_\odot, 6000\ K$)

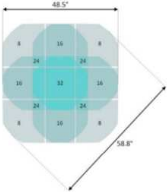
This translates into the following requirement:

$\sim 0.1 - 0.2\ \mu$Hz uncertainties for frequencies around ν_{max}

Payload

- 32 «normal» 12cm cameras, cadence 25 s, white light (500-1050 nm) , $8 < V < 16$, 1100 deg^2 (tot)
- 2 «fast» 12cm cameras, cadence 2.5 s, 2 colours, $4 \leq V \leq 8$, 550 deg^2 (tot)
- Field-of-View: $48.5^\circ \times 48.5^\circ$ (2250deg^2)

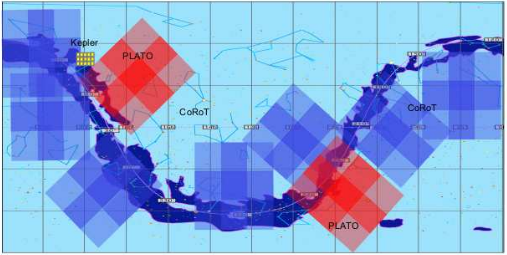




Samples of stars will be observed with different numbers of telescopes corresponding to different noise levels

Observing scenario

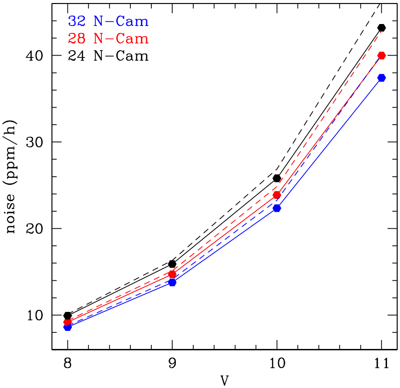
- 6.5 years after commissioning+ possibility of 2 year extension
- 2 long runs (3 years then 2 years) and a sky survey in a step-and-stare mode (2 to 5 months)
- rotation 90° around the line-of-sight every 3 months
- duty cycle about 95%



Random noise level as a function magnitude for 32, 28 and 24 cameras

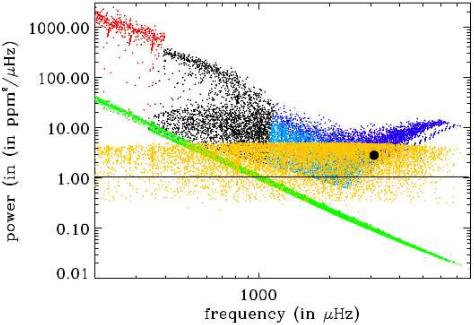
The requirement $\leq 0.1\ \mu$Hz frequency uncertainties translates into a random noise level ≤ 34 ppm/h in ASD for $V = 11$
(Kepler : photon noise 34 ppm/h for $V = 12$)

- Observing time 2 years
- reference star
- Target photon noise + random noise from the instrument + residual noise after correction for systematic errors quadratically added in ASD



Noise level for a long run from a simulated star population
from Besançon model (Robin, 2014)

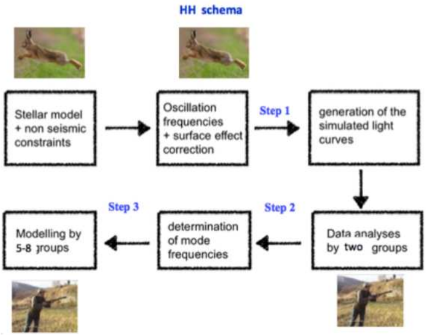
- Maximum mode height noise
  - deep blue $M < 1.1 M_{\odot}$ MS
  - light blue $M > 1.1 M_{\odot}$ MS
  - black : subgiants
  - red : giants
- + Plato photon noise (28 telescopes)
- + residual noise after correction for systematic errors in PSD
- + 'stellar noise ' (granulation)(green dots)



A noise level of $\leq$ 34 ppm/h in ASD for $V = 11 \longrightarrow \leq 0.1$ μHz frequency uncertainties $\longrightarrow$ 10% age uncertainty for the reference star at $V = 10$.

Estimations by means of Hare and hound exercises (WP120)

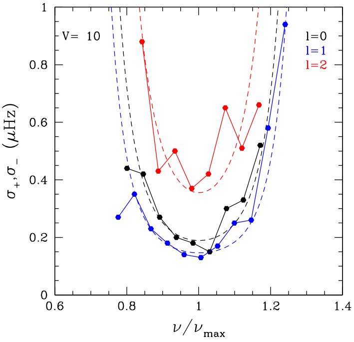
- Input model:
  $1.12 M_\odot, 1.20 R_\odot, T_{eff} = 6130K$
  $age = 3.44$ Gyr $(Xc = 0.30)$
- simulated light curves : $V = 8$ to 11
  Stochastically excited oscillating signal + stellar granulation + Plato background noise
  2 years, 32 cameras
  (R. Samadi)



Estimations by means of HH exercises:
Step 1: blind data analyses by 2 groups

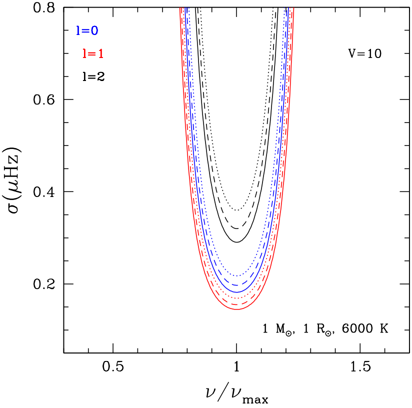
- Good accuracy ($\leq 0.1\mu$ Hz) : comparison between estimated frequencies by Birm's group and exact frequencies and between estimated frequencies by Birm's group and O. Benomar

- Frequency uncertainties for the $V = 10$ case
  - dots : from data analyses by T. Campante and Birm's group
  - dashed lines : computed with Libbrecht (1992)'s formula



The reference star $1.M_{\odot}, 1.R_{\odot}, T_{eff} = 6000K$

- 32 tel : solid line
- 28 tel : dashed line
- 24 tel : dotted line

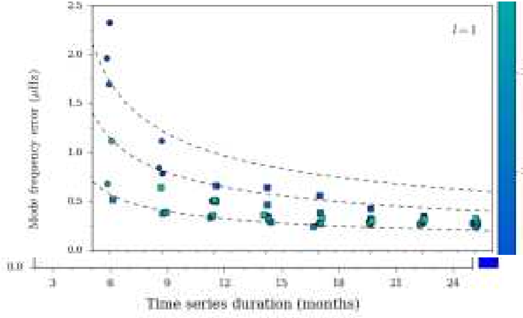


Uncertainties are close to 0.1 μ Hz for several frequencies around ν_{max} for a G0V star

Reaching 0.1μHz with time
Simulated light curve for $V = 10.5$ analysed by 3n month periods

- Decrease of frequency uncertainties in $1/\sqrt{time}$
- After, two years, the uncertainty level already reaches the specification for several frequencies around ν_{max}
- Step-and-stare duration : 2-5 months

credit: M. Lund and Birm's group

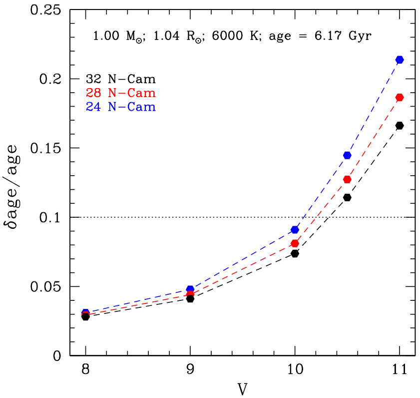


Age uncertainty as a function of the number of cameras

Assumptions

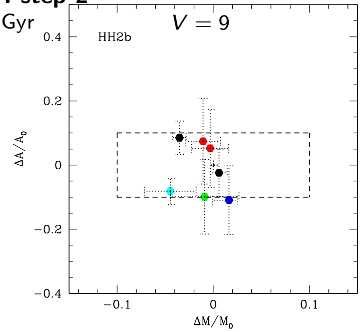
- $r_{02}(\nu_{max}) = c_0 \; age \; M^{3.4} + c_1$
  units: age (Gyr), M ($M_\odot$)
- Age uncertainty is computed as
  $\delta age = \left(\delta r_{02} - c_1\right)/(c_0 \; M^{3.4})$
- Observing time : 2 years
- δr_{02} from $\delta\nu_{l=0,1,2}$ at (ν_{max}) (assumed uncorrelated errors)
- Specification easily fulfilled at $V = 10$ but
- only statistical errors due to $\delta\nu$, assumed exact Teff, mass and radius and the physics of the input model

Reference star



With systematic errors into account: HH step 2

Model : $1.12M_{\odot}, 1.20R_{\odot}, T_{eff} = 6130K, 3.44$ Gyr



Relative uncertainties ($V = 10, 10.5$)

- for the mass : 0.8 – 2.5%
- for the age : 25 – 27%

For Plato requirements:

- Reference star ($\sim$ 6.3 Gyr), $\Delta A/A \sim$ [12-15]%.
- Kepler data for host stars (4 yrs) : $(\Delta A/A)_{stat} \sim 14$ % + several % (systematics)

  (Davis et al; 2015 & V. Silva et al. 2015)

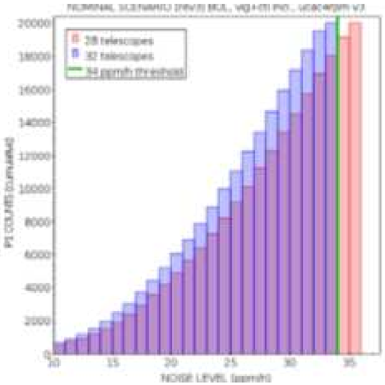
modellers:S. Deheuvels, V. Silva Aguirre, J. Christensen-Dalsgaard, O. Creevey, Y. Lebreton, I. Roxburgh, A. Mazumdar, K. Verma,

Corrections for systematics errors needed to reach the required 10% age uncertainty for the reference star at mag 10

Stellar count for P1 sample: (F5-K7) dwarfs and subgiants

Cumulative histogram for the number of stars with the noise level

- Total number of stars with ≤ 34 ppm/h, 20 000 stars for 32 N-Cam, 15 000 for 28 N-Cam
- A large number of stars with $\ll 34$ ppm/h
- > 5000 stars with $\Delta A/A \sim 10\%$, $\Delta R/R \sim 2\%, \Delta M/M < 10\%$ but many more with only slightly degraded seismic charaterization
- A large number of stars with ≤ 36 ppm/h noise ≥ 34 ppm/h will also be seismically characterized



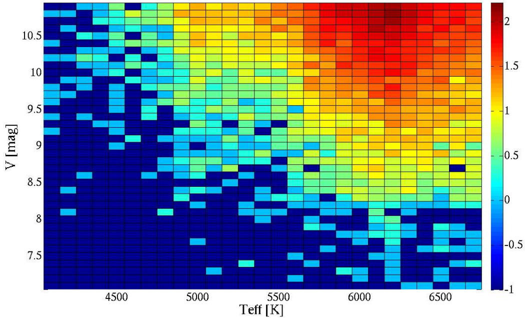
The full seismic potential of Plato not yet quantified !

Distribution of stars from a simulated star population for a long run
Number of stars as a function Teff and V

- computed from a simulated stellar population with the Besancon model (A. Robin 2014) adapted for one PLATO long run
- restricted to K7- F5 (4000 - 6800 K) domain for dwarfs and subdwarfs

- HH and the reference stars $\in$ orange-red part
- In the Kepler field, $>$ 2063 stars $\in V = [8 - 11]$ range

Credit (T. Morel, 2014, PLATO-WP122)



(log unit; -1 means no stars within the bin)

Samples of target stars with the current baseline observing strategy

- P1:$\geq$ 15,000 (20 000) dwarfs and subgiants, spectral type F5-K7, $8 \leq mag \leq 11$, noise $\leq$ 34 ppm/h, LOP
- P2: $\geq$ 1,000 dwarfs and subgiants, spectral type F5-K7, $V \leq 8.2$, noise $\leq 34ppm/h$, (300 stars with 2 colours), 2.5s.
- P3: $\geq 3,000$ as in P1 for step-and-stare (SOP) (300 stars with 2 colours), 2.5s.
- P4: $> 10,000$ M dwarfs $V \leq 16$ (including 5000 in LOP), 25s.
- P5: $\geq$ 245,000 dwarfs and subgiants,spectral type F5-K7, $V \leq 13$, 25s for 9000 stars.

- Compared to Kepler data, the observing time PLATO for the long run 1/2 and 3/4 shorter but seismology will be possible for a much larger number of stars, particularly bright stars.
- The scientific preparation with a full study of the seismis potential of the PLATO has not started yet (will after adoption november 2016).
- Sofar WP120 focused on most accurate characterisation of solar-like low mass host stars
- Among what will also turn up after adoption: - characterisation of host stars with less precise/accurate requirements

  - seismology of stars not hosting planets with a whole range of precision/accuracy

  - solar-like oscillating red giants, seismology of F5-K7 stars in clusters, eclipsing binaries
- Complementary science : All types of variability

The Plato Science Management currently includes over 500 researchers from 14 ESA Member States, as well as an Associate Member state, and 7 other nations across Europe, North America, and South America

To become a consortium member, a way is to participate to PLATO scientific preparation and be part of one WP

- WP110 Exoplanet science
- WP120 Stellar science (core programme)
- WP130 PIC Input catalogue
- WP140 Follow up
- WP150 Complementary Science

To know more :

- Plato Science Management (PSM) : http://www2.warwick.ac.uk/fac/sci/physics/research/astro/plato-science
- Stellar science WP120 webpage : https://www.ias.u-psud.fr/PLATO_STESCI/PLATO_STESCI_OBJ.html

END

Spare slides

- Frequency uncertainty (Libbrecht 1992)
  For a given mode with frequency ν, the uncertainty σ_ν is given by

$$\sigma_\nu^2 = f(\beta_\nu)\ \frac{\Gamma_\nu}{4\pi T_{obs}} \quad (1)$$

  - width of the mode Γ_ν
  - observation duration T_{obs}
  - signal-to-noise ratio ($snr_\nu = 1/\beta_\nu$),
  -

$$f(\beta_\nu) = (1+\beta_\nu)^{1/2}\ \left((1+\beta_\nu)^{1/2}\ + \beta_\nu^{1/2}\right)^3$$

- The averaged level of the signal to noise ratio as computed in a power spectrum as as

$$snr = \frac{H}{B} \quad (2)$$

where H is the height of the mode and B is the background

The background noise is composed of several components: the target photon noise, the instrumental noise and the granulation noise : $B = B_V + B_{inst} + B_{gran}$The background noise for target photon noise and the instrumental noise (after correction) is taken for PLATO current measurements.The background noise for the granulation is computed according to Kallinger et al (2014) based on Kepler data.

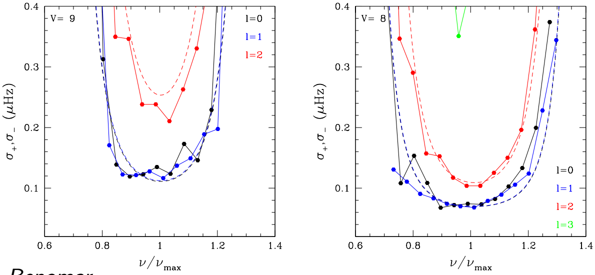
$$signal = V_1 \; H_{max} \; e^{-(\nu-\nu_{max})^2/(\Gamma^2/(4\log(2)))}$$

- $$\Gamma = 0.66 \; \nu_{max}^{0.88}$$
- $$H_{max} = 2\frac{A_{max}^2}{(\pi\gamma)}$$
  (one-sided power density spectrum)
- $$\gamma = \gamma_0 + \alpha\left(\frac{T_{eff}}{T_{eff,\odot}}\right)^s$$
  Appourchaux et al (2012), table 2, at maximum mode height with $T_{eff,\odot} = 5777K, \gamma_0 = 0.20; \alpha = 0.97; s = 13$
- A_{max} from a scaling relation for the oscillation maximum from Corsaro et al (2013, MNRAS 430, 2313-2326)

Expectation for bright stars

HH2a: $1.182 M_\odot, 1.335 R_\odot, T_{eff} = 5954K$

$V = 9$ $V = 8$



Credit : O. Benomar

The 0.1μHz requirement is more or less satisfied depending on the type of stars

The scientific community will be able to participate in the PLATO mission as:

- Member of the PMC
- Member of the GOP Team
- Community scientist in the Science Working Team (SWT)
- Guest observer

In addition, the science community will be able to access all science products available in the PLATO Science Archive, after any proprietary period has expired.

- Guest observer programme: Members of the scientific community may participate in the PLATO mission by becoming GOs selected by ESA through calls for proposals.

  GO programmes can contain targets that are part of the PIC, but not of the prime sample. For targets in common with the PIC, access to the associated Level-0 and Level-1 data will be granted with the condition that the observations are exclusively used in relation with the science objectives of the proposal. Exploitation for complementary science of non-public PIC target data will only be carried out through approved GO programmes.

Data delivery

From the SMP :
The release of PLATO data products will be based on the following scheme.

- End of first quarter of observations : delivery of Level-0 and Level-1 products by the SOC to the PMC
- then 6 months will be required for Level-1 data validation (and updating of the pipeline)
- then for the following quarters, 3 months will be needed.
- The public release of Level-0, Level-1 and Level-2 products for each observation quarter will be made one year after the end of each Level-1 product validation period.

Three months has been taken here as the data processing unit because it corresponds to the time duration between the 90° rotations of the spacecraft.

Data Policy

Planet candidates not followed-up by RV within the mission lifetime will become part of PLATO 2.0 legacy science (Section 4.9) and will provide a wealth of interesting targets for future RV measurements within the community.

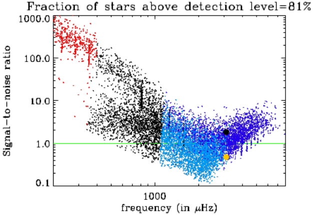


Figure : *Normal cameras. Signal-to-noise ratio as a function of frequency for solar-like stars (Deep blue, $M < 1.1M$; light blue $M > 1.1M$), subgiants (black dots) and red giants (red dots). The green line indicates the signal-to-noise ratio of 1 required for getting the mass, radius of the stars. The black and orange dot represent the signal-to-noise ratio for the reference star at 6000 K at $V = 8.5$ and $V = 11$, respectively.*

For a signal-to-ratio of 1 and 3, the frequency uncertainty is 0.16 μHz, 0.09 μHz, respectively. According to the age of stars

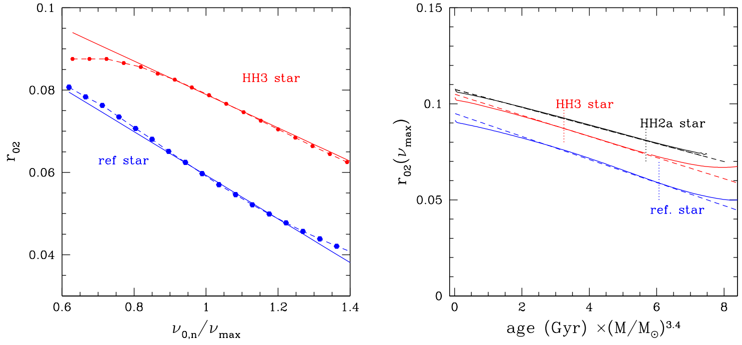
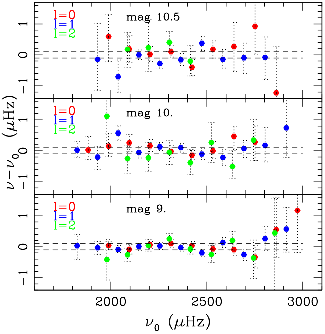

0.1
0.08
0.06
0.04
0.6
0.8
1
1.2
1.4
r_{02}
$\nu_{0,n}/\nu_{max}$
HH3 star
ref star
0.15
0.1
0.05
0
0
2
4
6
8
$r_{02}(\nu_{max})$
age (Gyr) $\times(M/M_\odot)^{3.4}$
HH3 star
HH2a star
ref. star

Table 5-1 PLATO 2.0 Instrument characteristics in comparison to *Kepler* and CoRoT

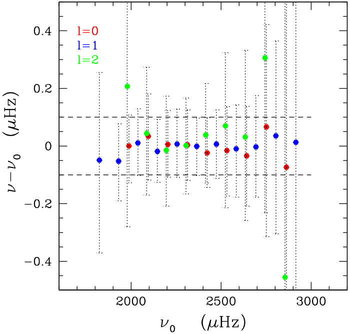
	PLATO 2.0	*Kepler*	CoRoT	Ref.
Magnitude range	- normal cameras: **$8 \le m_V \le 16$ mag** - fast cameras: **4-8 mag**	**$7 \le K_p \le 17$ mag**	- Exoplanet channel: **$11.5 < m_V < 16$ mag** - Asteroseismology channel: **$5.4 < m_V < 9.2$ mag**	1, 2, 3
Aperture size	- **32×12cm** normal cameras - **2×12cm** fast cameras	**99 cm**	**27 cm**	1, 2, 3
FoV	**2232 deg^2 total** (48.5°x48.5°) - normal cameras: ~1100 deg^2 - fast cameras: ~550 deg^2	**105 deg^2** 16° diameter	**2.7°×1.5°** (2.7°×3.05° until 03/2009)	1, 2, 3
CCDs	- normal cameras: 4 CCD per camera 4519×4510px, 18 μm square, full frame, 15 arcsec/px - fast cameras: 4519x2255px, 18 μm square, frame transfer	42 CCDs 1024×2200px	2 CCDs 2048x4096px (4 CCDs until 03/2009)	1, 2, 3
Time sampling of data points (readout cadence)	- normal cameras: **25 sec** (~22 sec exp. time) - fast cameras: **2.5 sec** (~2.3 sec exp. time)	- LC windows: **1766 sec** - SC windows: **59 sec**	- Exoplanet channel: **512 sec** (normal) **32 sec** (optional) - Asteroseismology channel: **32 sec**	1, 2, 3
Spectral range	- 500-1000 nm (normal cameras) - one broad band for each fast telescope	**423-897 nm**	**400-900 nm**	1, 2, 3
No. of target fields	Step-and-stare and 1-2 long pointings	**1**	**26**	3, 5
Observing period per target field	**20 days – 3 years**	**4 years**	**20 - 150 days**	1, 2, 9
No. of dwarf target stars per pointing	**~150,000***	**170,000**	- Exoplanet channel: **~6,000** (~12,000 until 03/2009) - Asteroseismology channel: **5** (10 until 03/2009)	1, 2, 3
Total no. of target stars over mission	**>1,000,000***	**170,000**	- Exoplanet channel: **~170,000** - Asteroseismology channel: **~150**	2, 3, 5
No. of bright targets ≤11 mag	**~85,000 stars total***	**~6,000 stars**	**~370**	2, 4, 5
No. of dwarf star asteroseismology	**~85,000 stars total***	**>512 stars**	**~150**	2, 3, 4, 5

Estimations by means of HH exercises:

Step 1: blind data analyses by 2 groups



Comparison between estimated frequencies by Birm's group and exact frequencies



Comparison between estimated frequencies by Birm's group and O. Benomar.

good accuracy