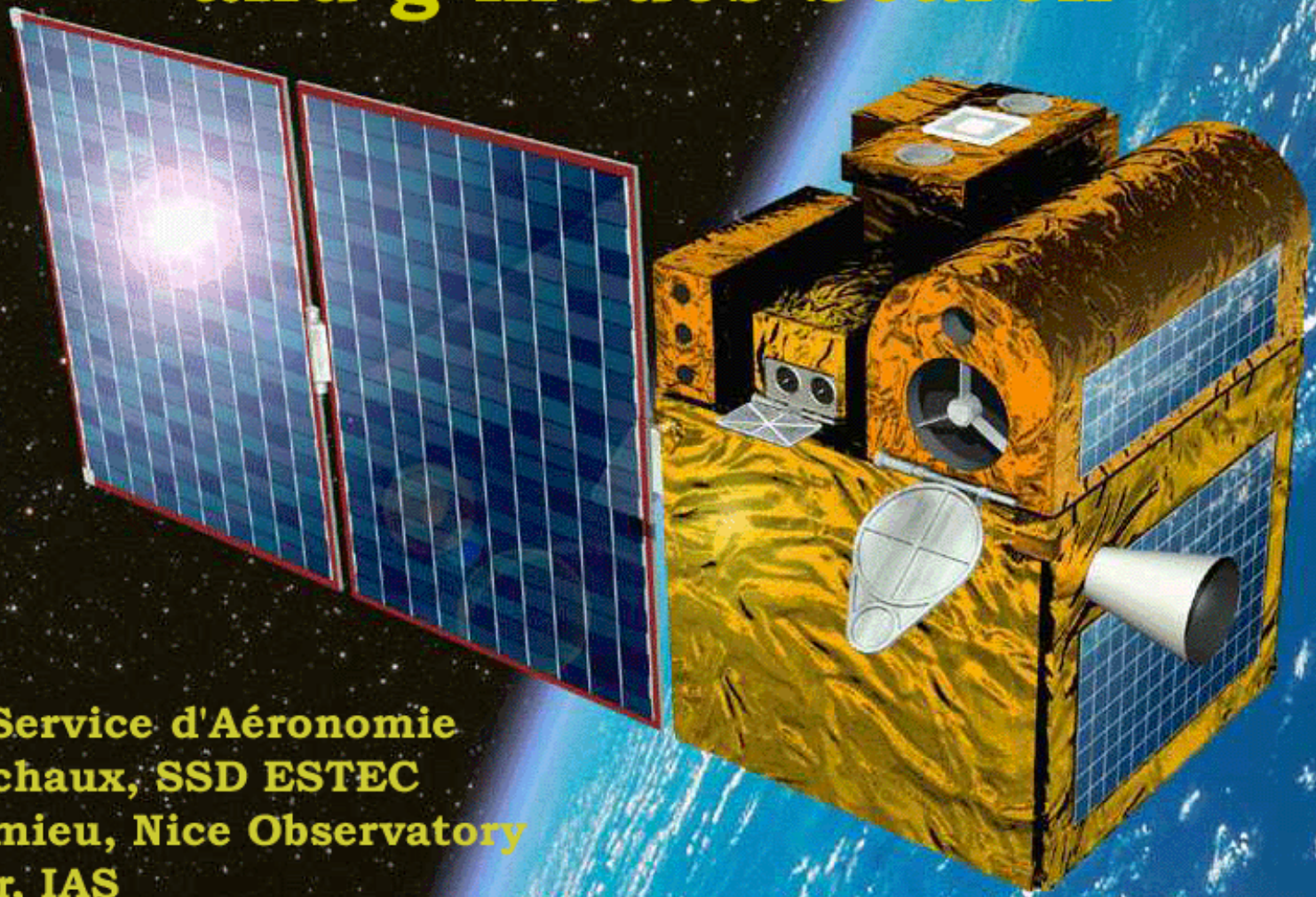
PICARD: Solar Diameter Measure and g-modes Search



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SOHO 10 – GONG 2000
Tenerife, October 2–6, 2000

PICARD Mission Facts

- Proposed January 98; selected October 98; Phase B 7/03/2000
- The CNES provides the microsatellite as a Line of Product bus (satellite 110 kg ; power 80 W; dimensions 60x60x80 cm^3):
  - Payload mass: up to 45 kg (no propulsion); power up to 48 W
  - Payload dimensions: 60x60x30 cm^3; Data rate: 1.6 Gbits/day
  - Pointing | normal (platform): ± 0.1°
scientific (active guiding using payload information): ± 0.01°
stellar calibration mode: ± 0.1°
stellar stability: 0.01°/s
bus pointing: > 90° in 10 mn (0.5°/s)
  - Datation: ± 0.5 s
  - Orbit restitution: ± 1 km
- Orbit and launch:
  - Launch expected before the end of 2003 (before solar minimum)
  - Nominal orbit: SSO 6h/18h 800 km 98° (➠ near continuity: oscillations)
dedicated DNEPR launcher (PICARD master payload)

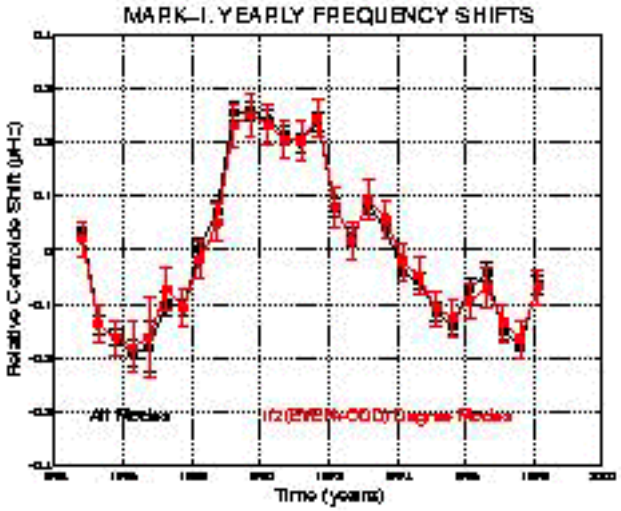
PICARD Scientific Objectives

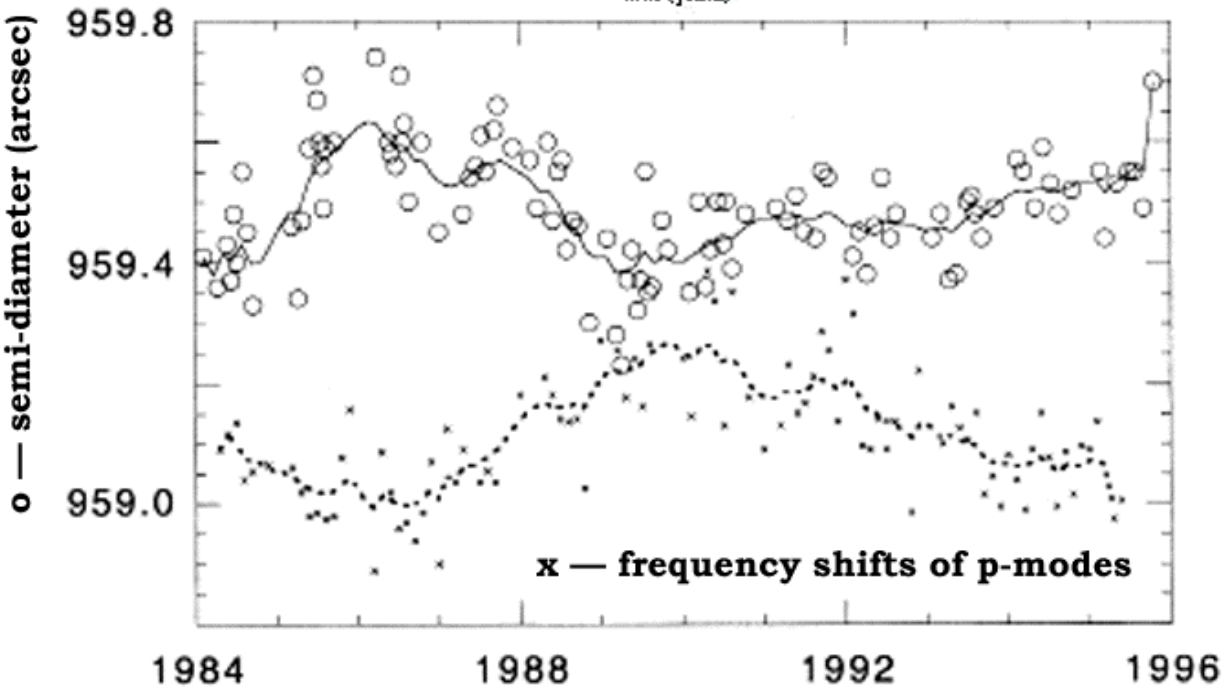
- Confirm diameter variations (and validate ground measurements and their accuracy)
- Establish relation diameter/global irradiance/differential rotation
- Study the variability (long and short terms) of the parameters
- In particular (limb advantage) observe low degree p-modes and, if their amplitude allows, detect g-modes
- Oblateness measure and solar shape to higher orders (dynamo and convection)
- Provide Space Weather – solar activity full Sun images with 1" resolution in magnetically sensitive lines (Lyman α) & continua (160 nm)

Diameter and p-modes variability

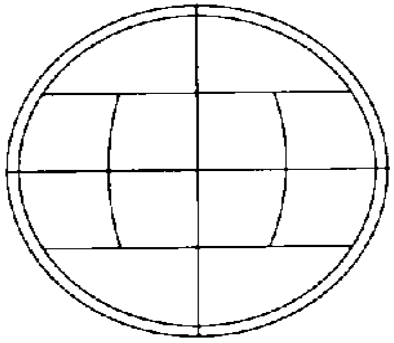
- The modes proper frequencies vary with the solar cycle (Jimenez et al., 1997, 1999).

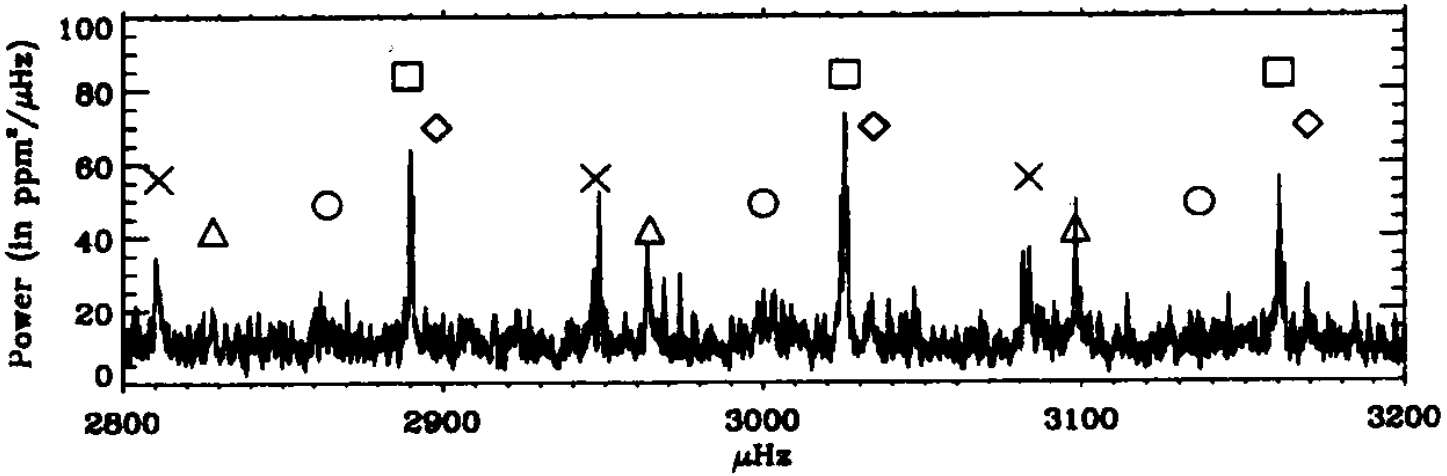
- A precise anti-correlation of these frequencies variations with the diameter measures of CERGA (Laclare et al., 1999) is observed.

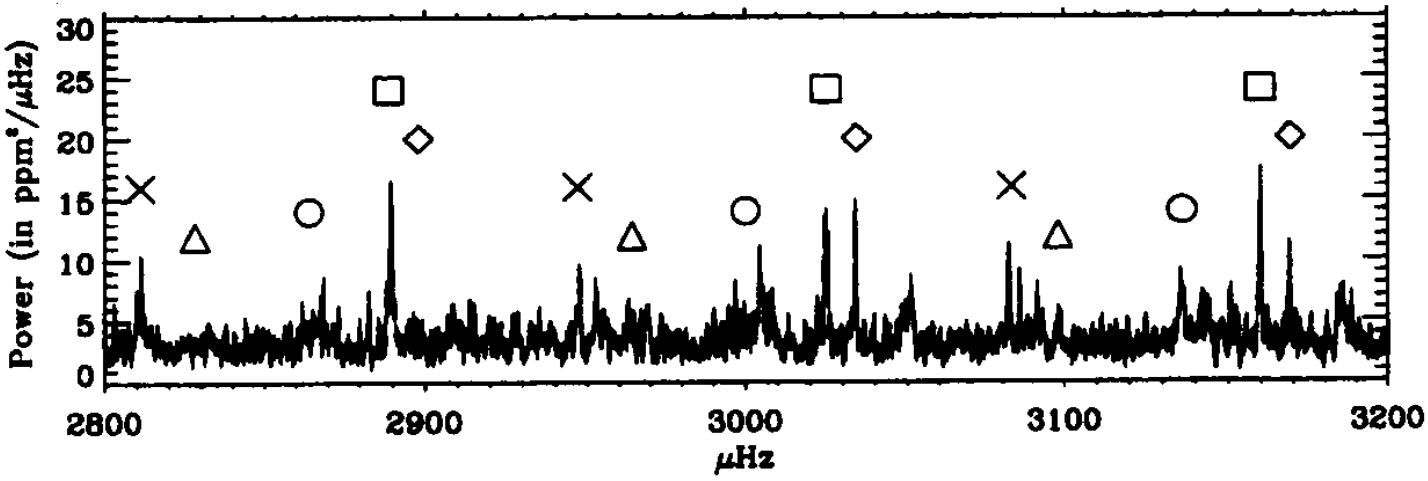




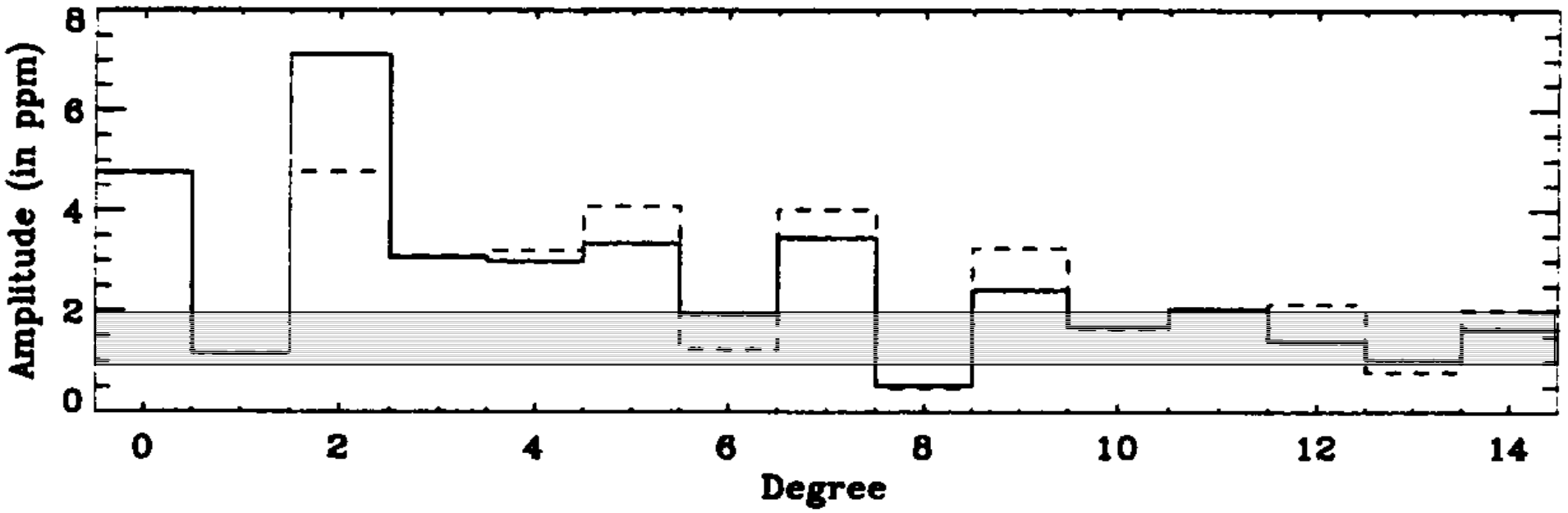
Why the limb? ➠ p-modes detected in the guiding signal of the LOI







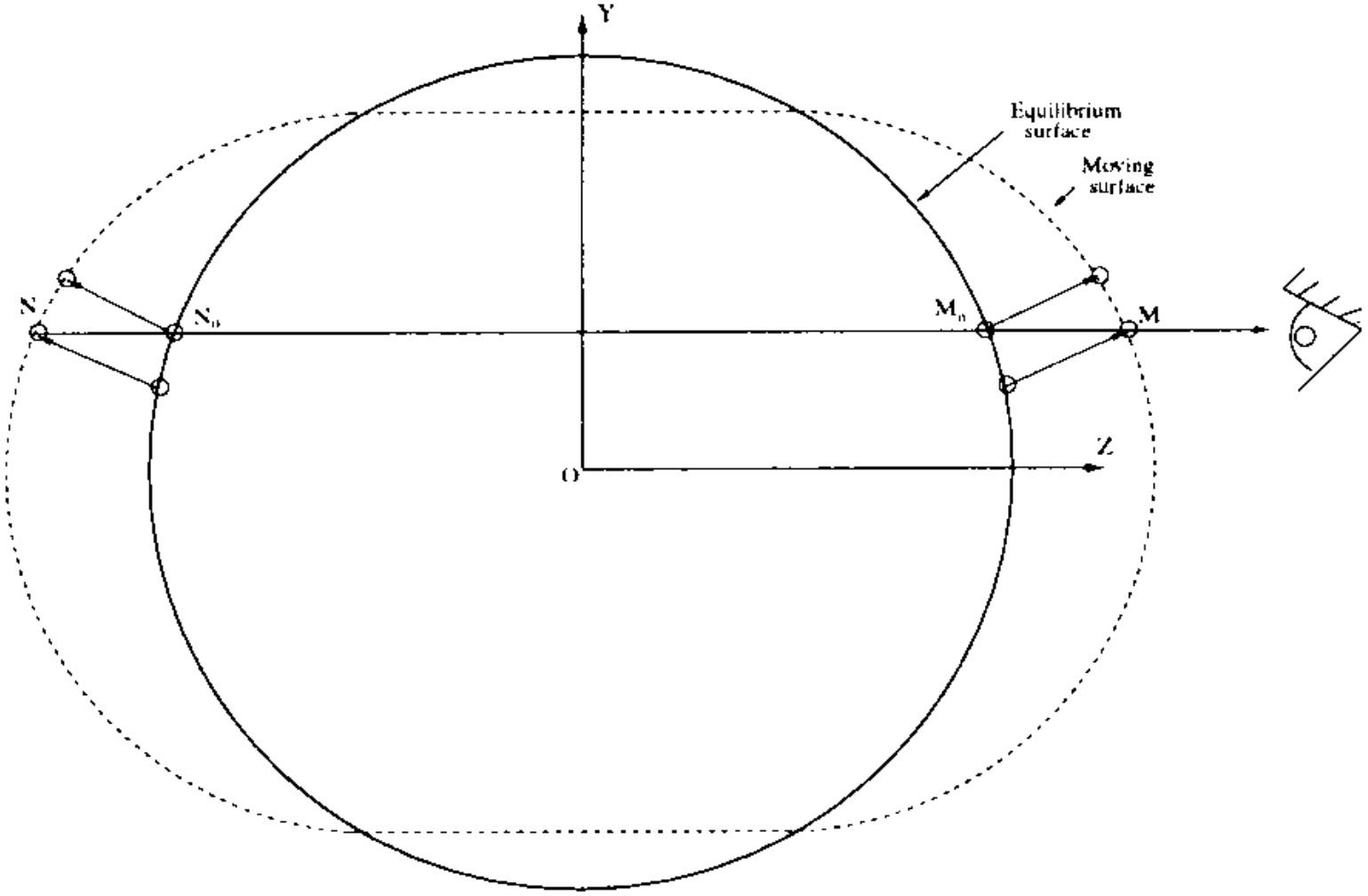
Visibilities on the solar limb



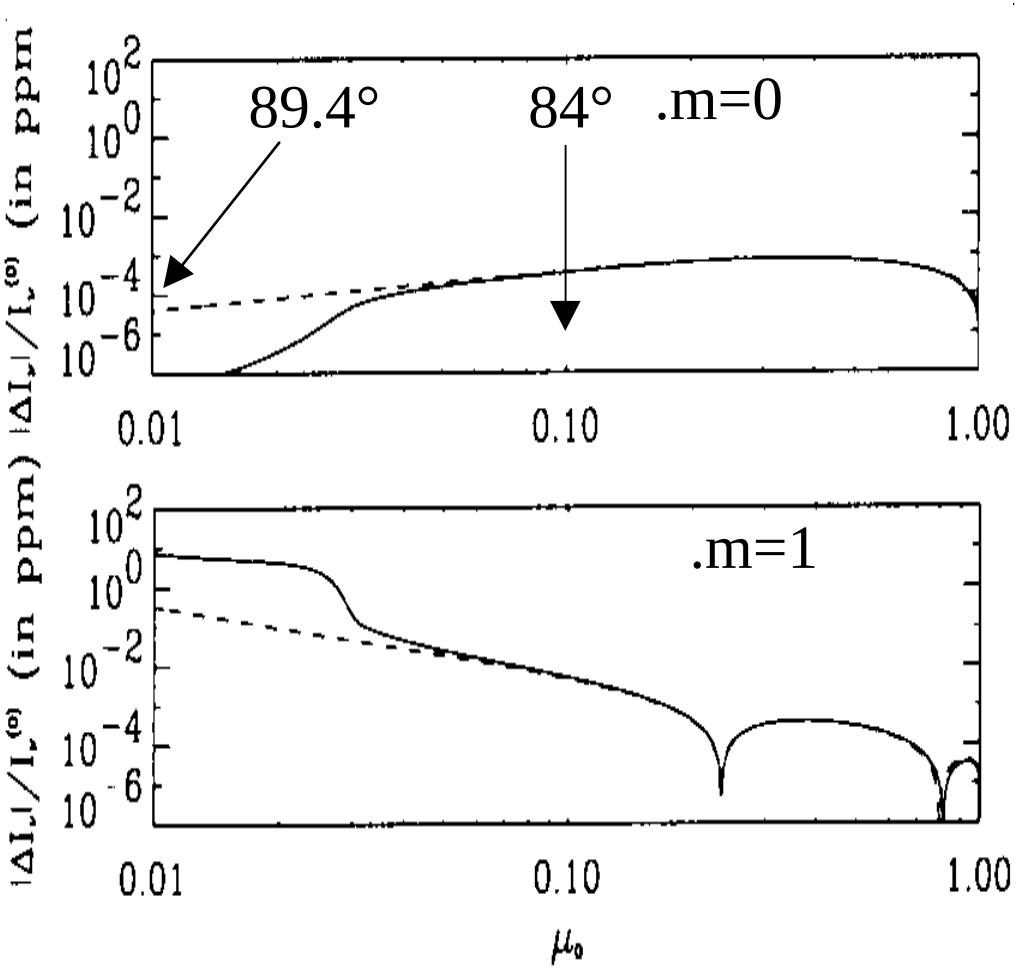
Without hypothesis, we would expect 1 to 2 ppm...

We observe an amplification of a **factor 5** on all the degrees visible in the LOI guiding pixels.

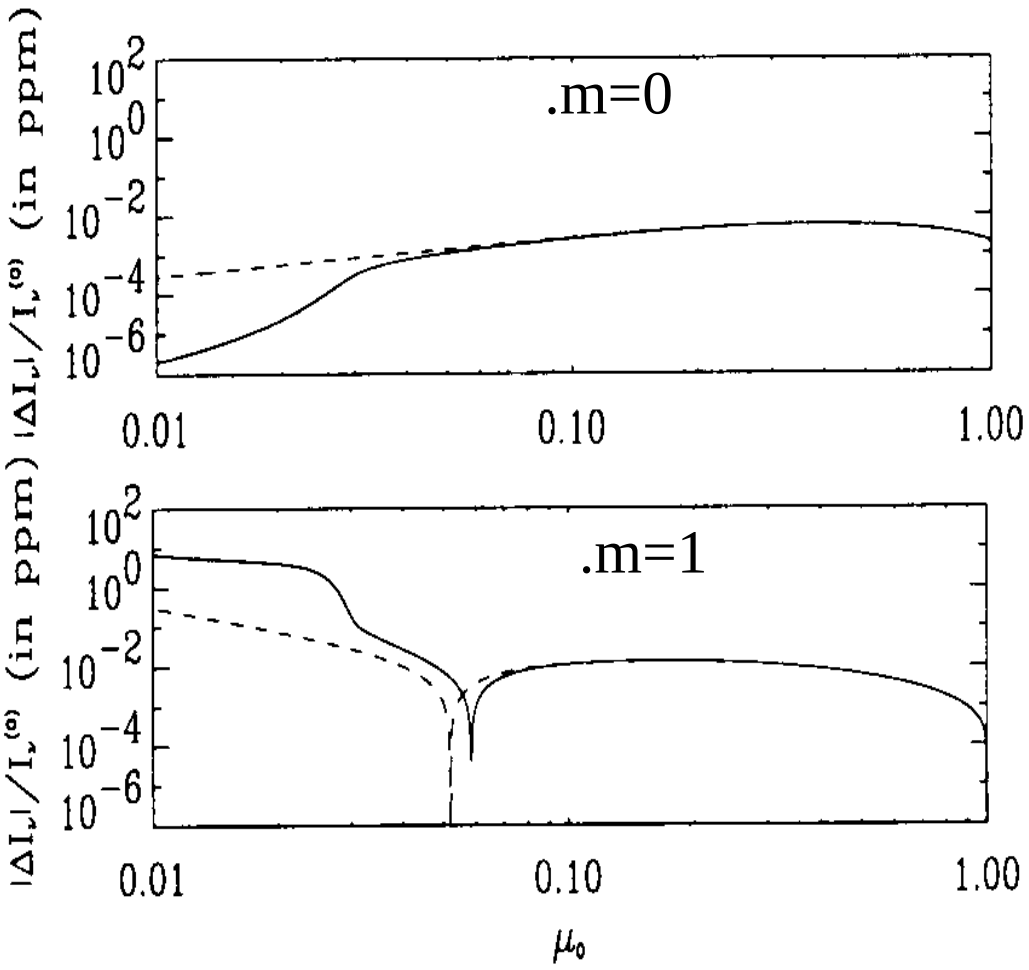
Effect of a deformation when integrating on the line-of-sight



Results (Toutain et al., 1999)

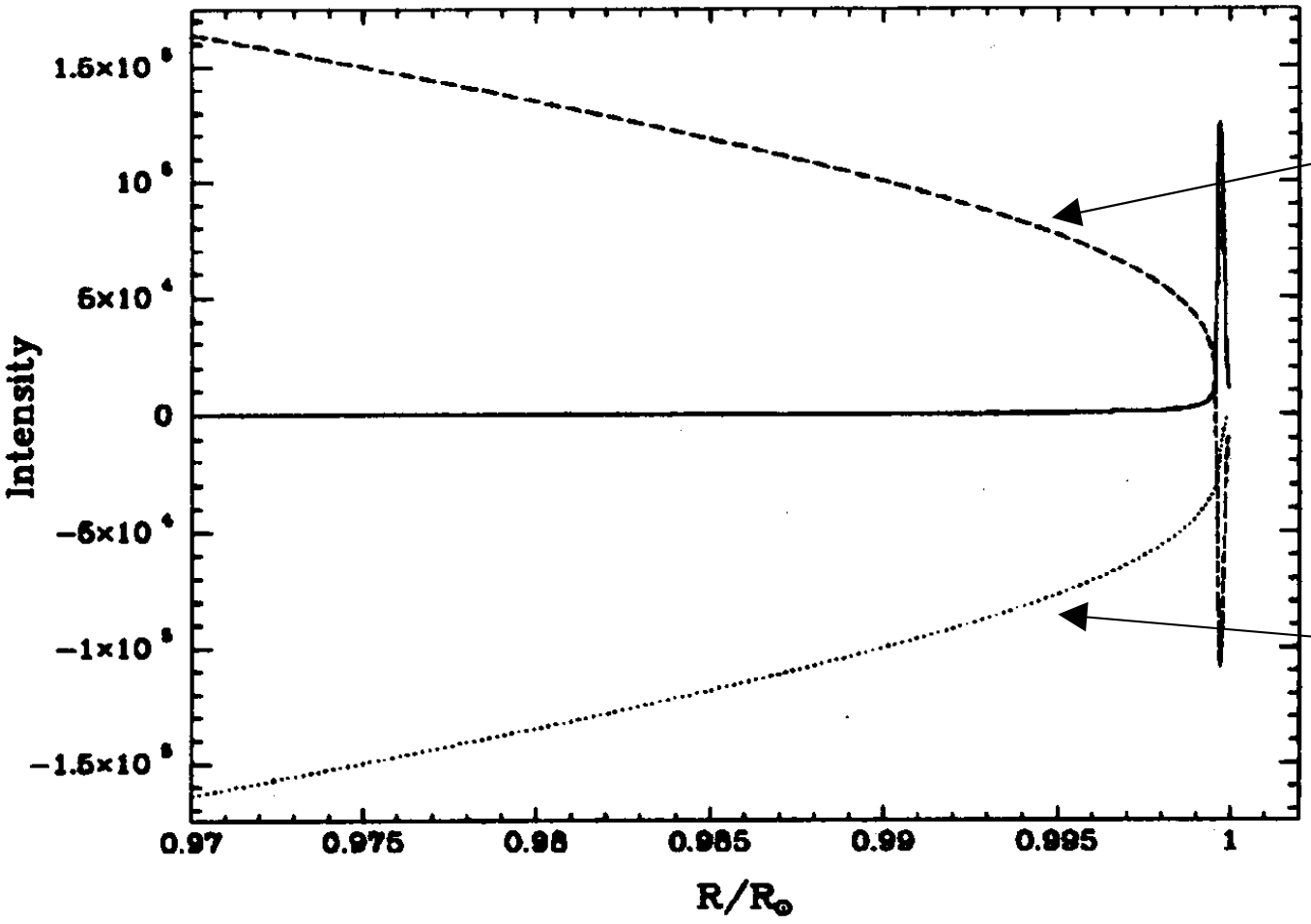


g-mode l=1 with 1mm/s



p-mode l=1 with 1mm/s

Similar approach, but different presentation (Toner et al., 1999)

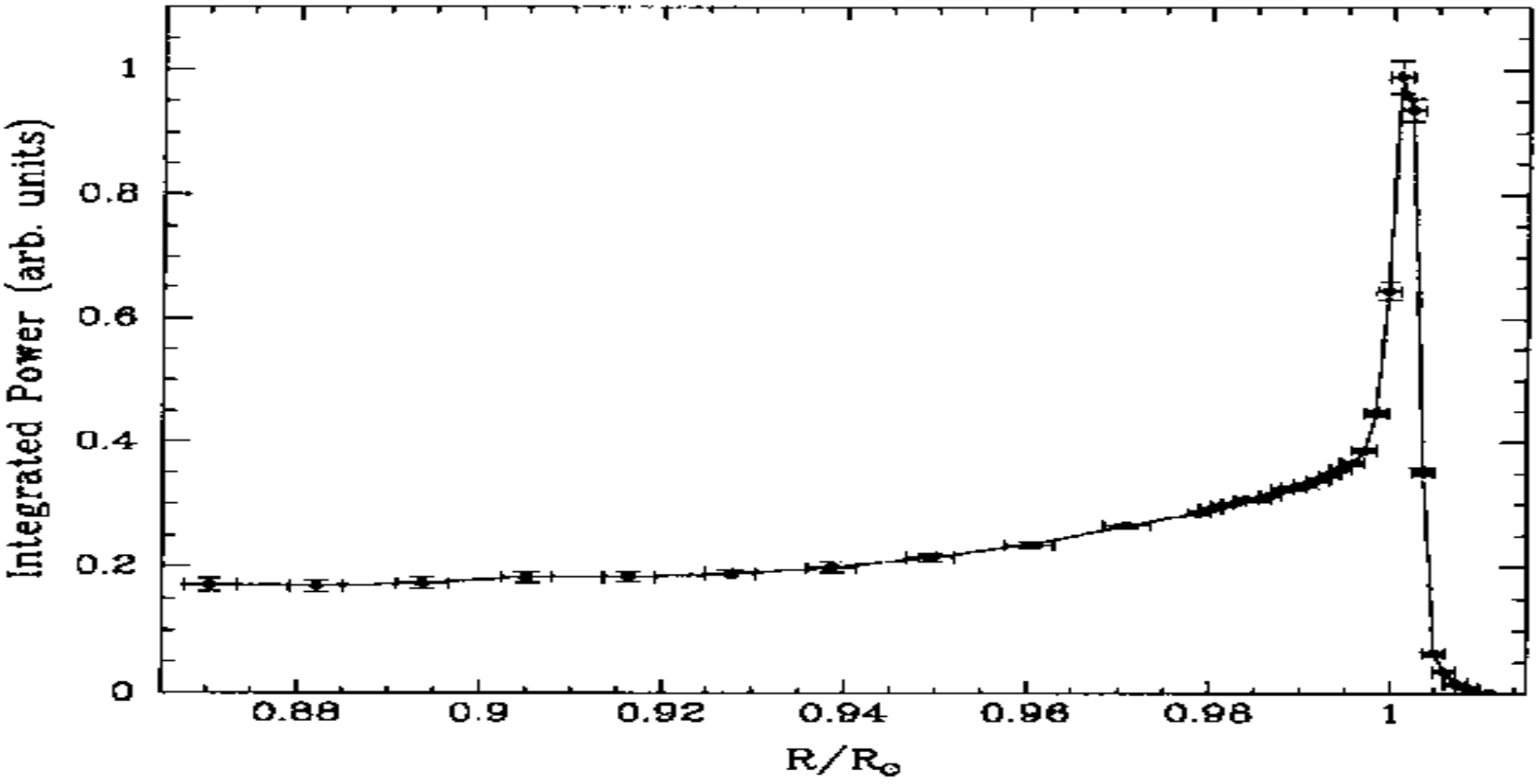


Effect of the temperature fluctuation

The difference...

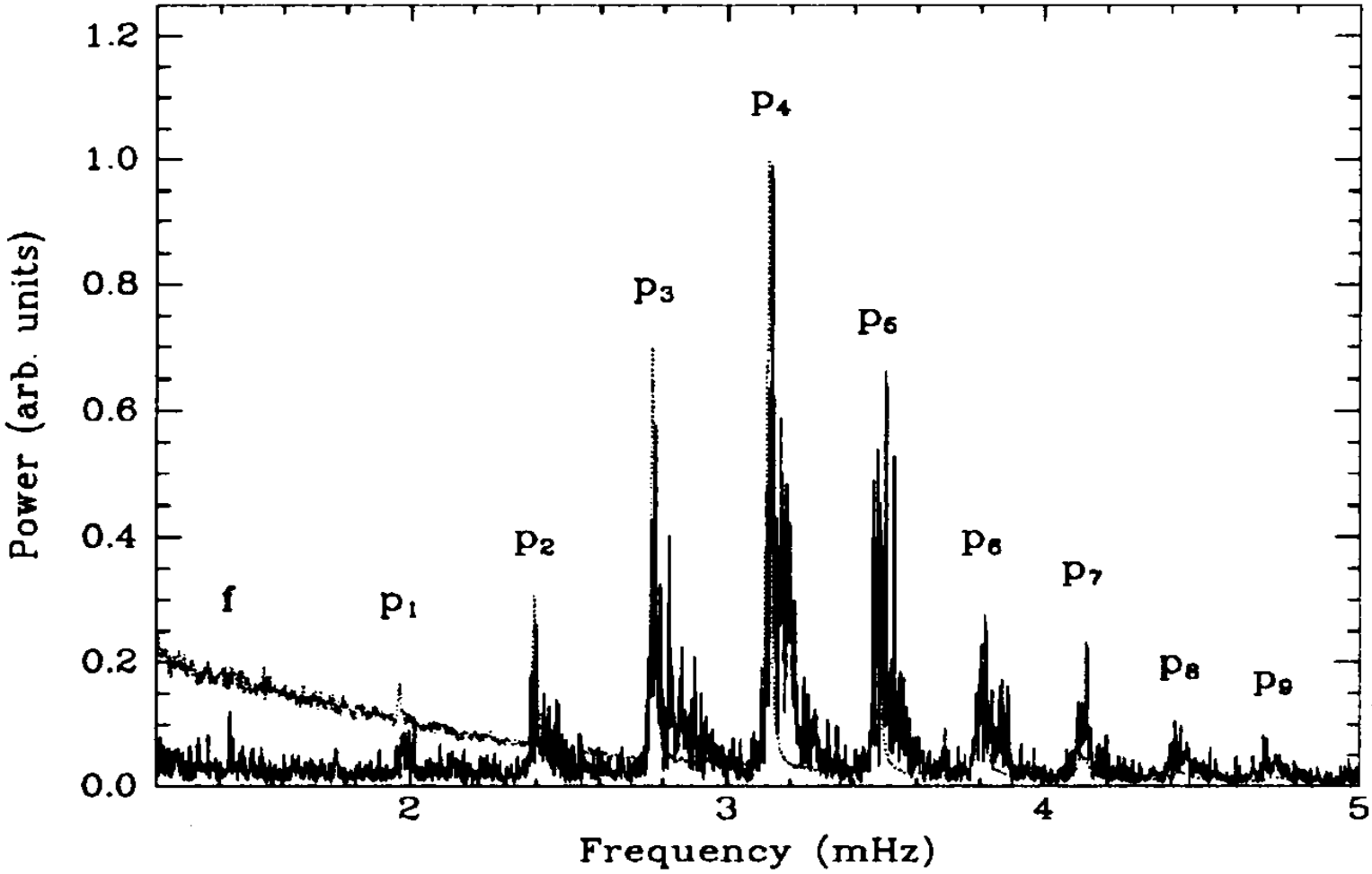
Effect of the density fluctuation

Limb advantage: factor 5



Integrated energy of p-modes from 1500 to 5000 µHz as a function of the center to limb distance

Limb advantage: on the peaks too



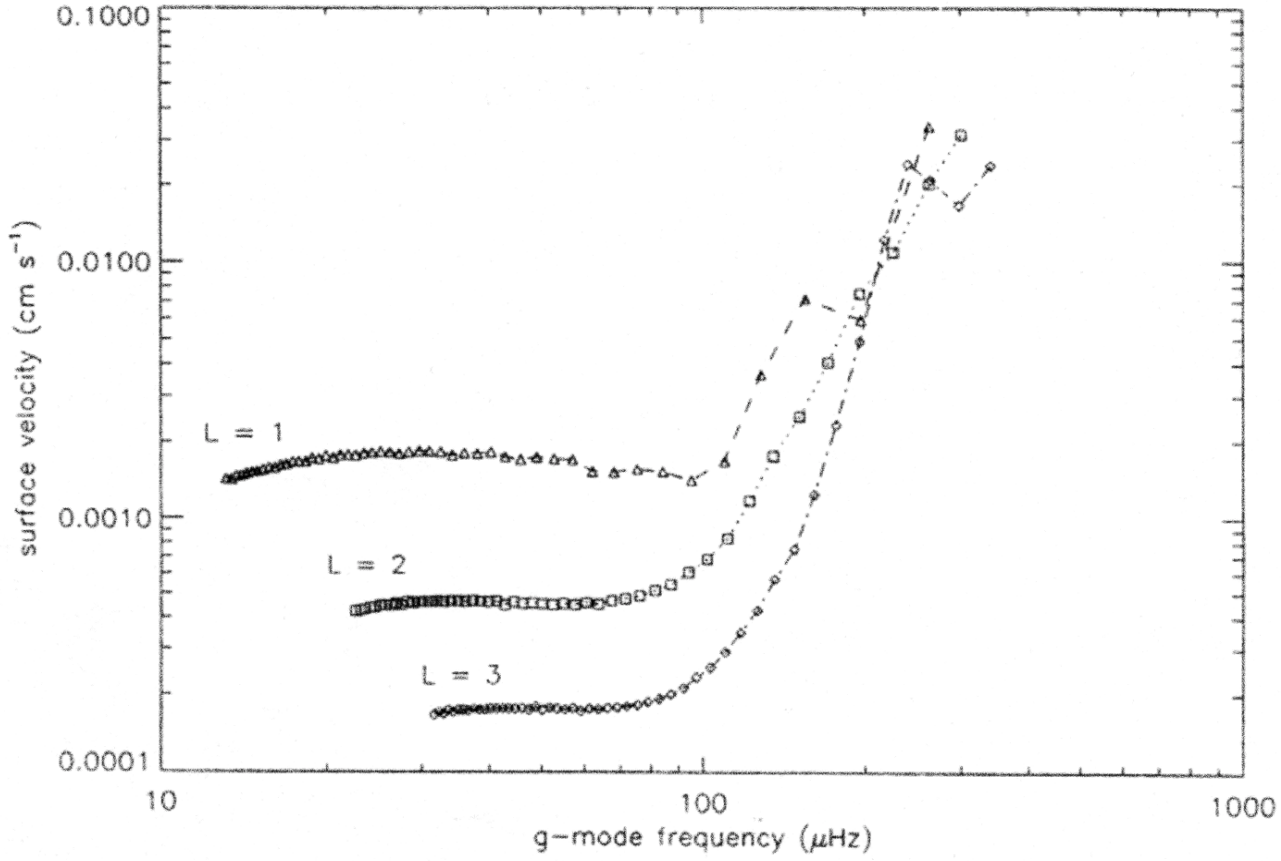
Note the appearance of the f and p1 modes at low frequencies and slimmer higher peaks in general when observing the limb.

Limb: conclusion

- We expect a factor 5 of amplification when observing at the limb, due to the fluctuations of the optical density.
- This might be sufficient to detect the g-modes.
- Even without any g-modes to detect, the contribution of the low degree and low frequency (500-1000 μHz) p-modes brings in important information to constrain the models in the solar core.

g-modes amplitudes

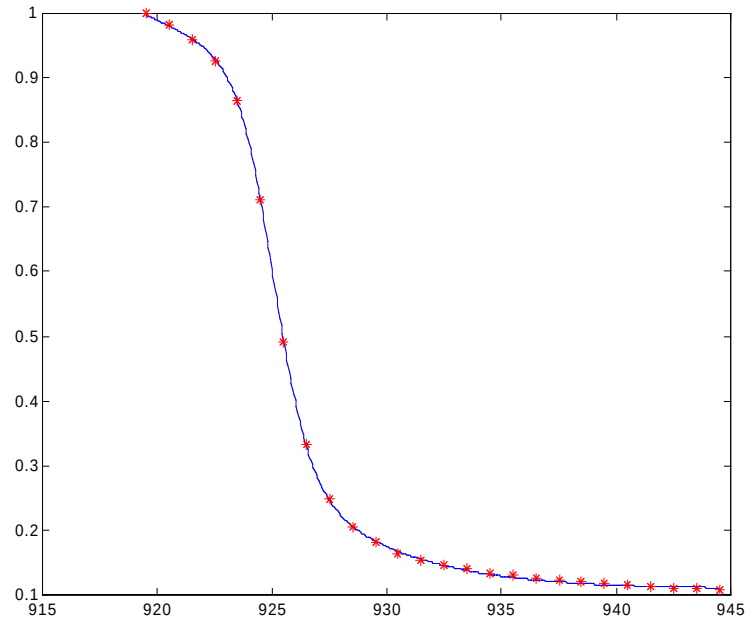
They could appear preferentially in the frequency band 200–350 μHz (Kumar et al., 1996)



Amplitude expected is still fairly low: 0.1–0.4 mm/s

Amplitude falls off strongly with increasing *l* (high-*l* modes unlikely)

Precision on the Diameter Measure



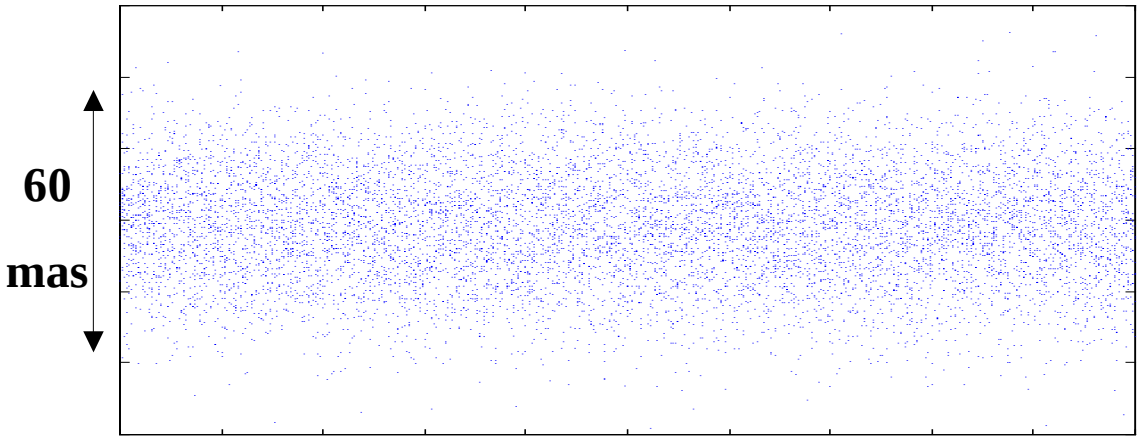
* Inflexion point measurement:

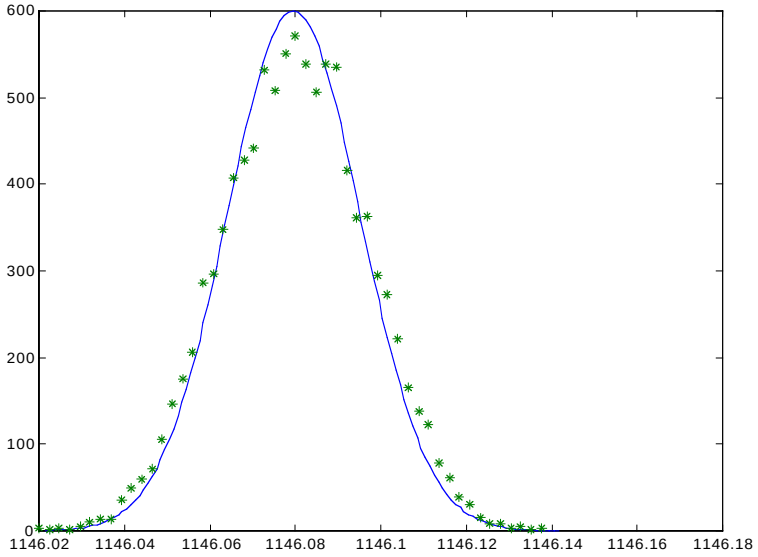
$$I(x) = a_1 + a_3 \cdot \left(1 + \left(1 + e^{a_4 \cdot (x - a_2)}\right)^{a_5}\right) \cdot \left(1 + \left(1 + e^{a_6 \cdot (x - a_2)}\right)^{a_7}\right)$$

* Precision on one realisation: σ ~ **10 mas**

* Precision on 100 measures: σ ~ **1 mas**

  on 1000 limb measures: σ ~ **0.3 mas**





g-modes limit with PICARD

- g-modes < 3 mm/s (GOLF)
- Objective: 0.3 mm/s or better (0.1 mm/s -> Kumar et al., 1996)
- Mode of one hour period: amplitude 0,2 m
- Application of the limb enhancement factor: 0,2 x 5 = 1 m
- In term of arcsec: $1.4\ 10^{-6}$

- If we suppose an instantaneous measure of 0.3 mas every 3 minutes we have:

  $\sqrt{20 \times 24 \times 365 \times 2} \sim 590$ of noise reduction after two years

  $0.3/590 \Rightarrow 0.5\ 10^{-6}$ i.e. a theoretical limit of ~ 0.1 mm/s

and PICARD mission is extensible to 6 years...

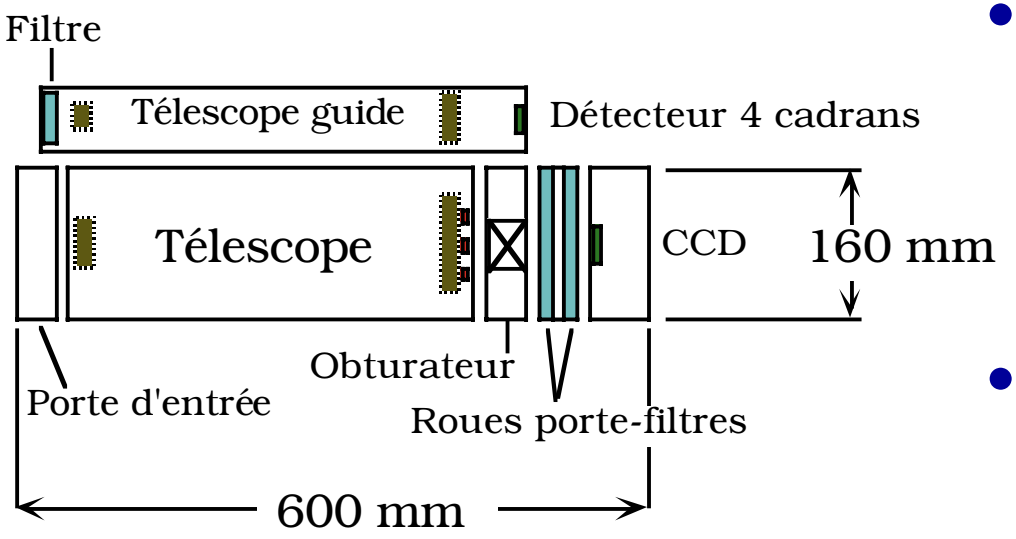
PICARD Measurements

- Diameter at 230 nm (SODISM)
- Diameter at 548 nm
  ➠ link with & validation of ground measurements
- Lyman Alpha images of the solar disk ➠ Ionosphere
- 160 nm images of the solar disk ➠ magnetic activity
- Differential rotation

- The solar constant - global irradiance (SOVAP)

- The integrated solar UV flux at 230 nm (PREMOS)
  ➠ ozone & photometric calibration of the CCD
  and in selected UV and visible bands (311, 402 and 548 nm)

SODISM/PICARD Concept

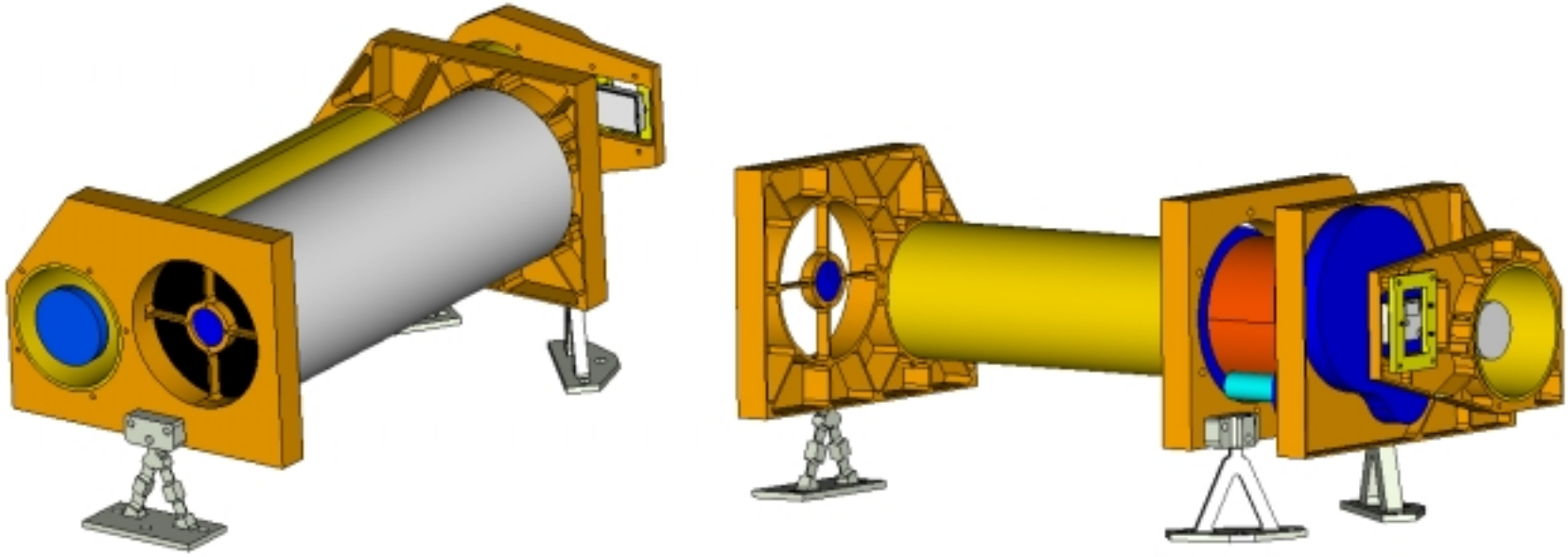


4 observing modes and
2 calibration ones

UV Nominal Mode	230 nm Δ8nm
Visible	548 nm Δ8nm
Magnetic Activity	160 nm Δ8nm
Prominences and Activity	Lyman α Δ8nm
Flat Field CCD	"Diffusion"
Stellar Field Imaging Δf	"Empty"

- **Sound optical concept**
  - active telescope Ø120 mm (3piezos controlled by a guiding telescope)
  - large 2048x2048 CCD (thinned & back illuminated)
  - two filter-wheels behind a shutter
- **"Best" choice of wavelengths**
  - 230 nm "neat" UV continuum (limited limb-darkening; flat continuum)
  - Visible, 548 nm for ground validation
  - Activity monitoring at 160 nm & Lyα
- **Mechanical stability**
  - Carbon-carbon low dilatation structure allowing ± 0.5° control
  - SiC mirrors: no aging of coatings and high conductivity
- **Absolute dimensional calibration**
  - HIPPARCOS star field calibration absolute ≤ 1 mas; relative << 1 mas

Mechanical Design of SODISM/PICARD



Mechanical structure of the SODISM/PICARD telescope (350 mm between the primary and secondary mirror and 150 mm between the primary and the CCD surface: total length without cover of 550 mm). Note the 3 Invar plates linked together with the 550 mm long carbon-carbon (shown in light brown) tube of Ø100 mm. The primary mirror is mounted on 3 piezoelectrics driven by a guiding telescope directly placed inside the C-C tube. The CCD (cooled to –40°C), is decoupled of the Invar plate by a Cordiérite support.

Scientific Data Flow

DNEPR launcher, 6:00–18:00, 800 km, 98°

No (or short) eclipses – full Sun orbit

DATA	Repetition rate	Production (in 90 mn)	Compression	Total
Continuum 230 nm - Limb Mode (*)	3 min	128560 x 16 x 30 = 60 Mbits	2 (ND)	30 Mbits
Continuum 230 nm - Full Image	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Visible 538 nm - Limb Mode (*)	3 min	128560 x 16 x 30 = 60 Mbits	2 (ND)	30 Mbits
Visible 538 nm - Full Image	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Continuum 160 nm (T. min.)	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
Lyman alpha, 121.6 nm	45 min	2048x2048 x 16 x 2 = 128 Mbits	20	6.4 Mbits
TOTAL per 24 hours (including 20% overhead)				1.6 Gbits

(*): 40 pixels wide area around the solar limb (1/10) — 22 pixels only (9/10)
(ND): Non-Destructive compression for precise diameter measurement