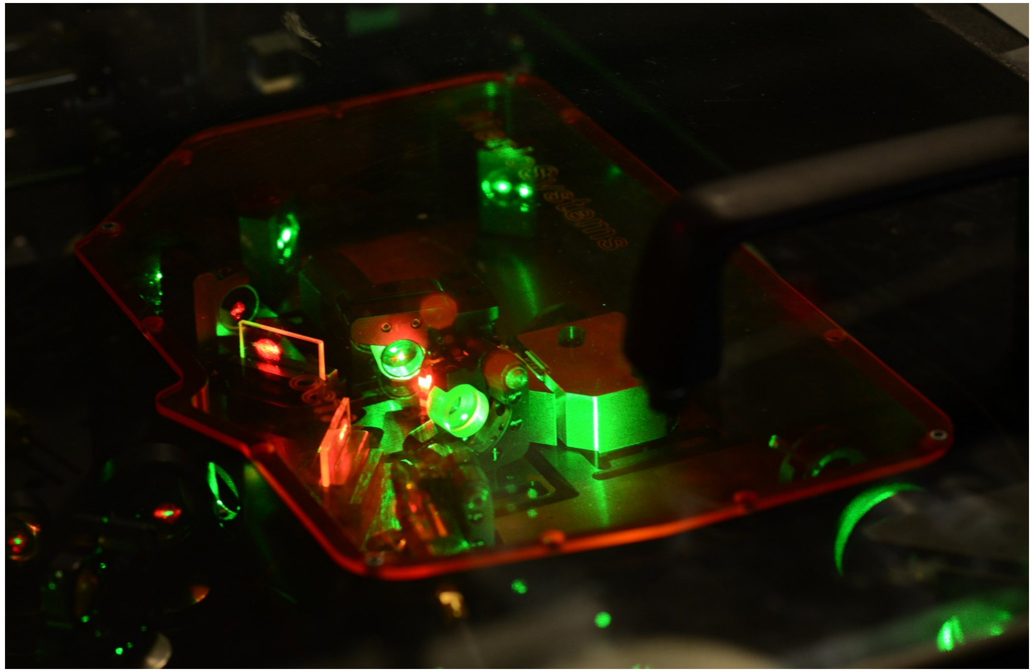
Lasercomb and Solartelescope

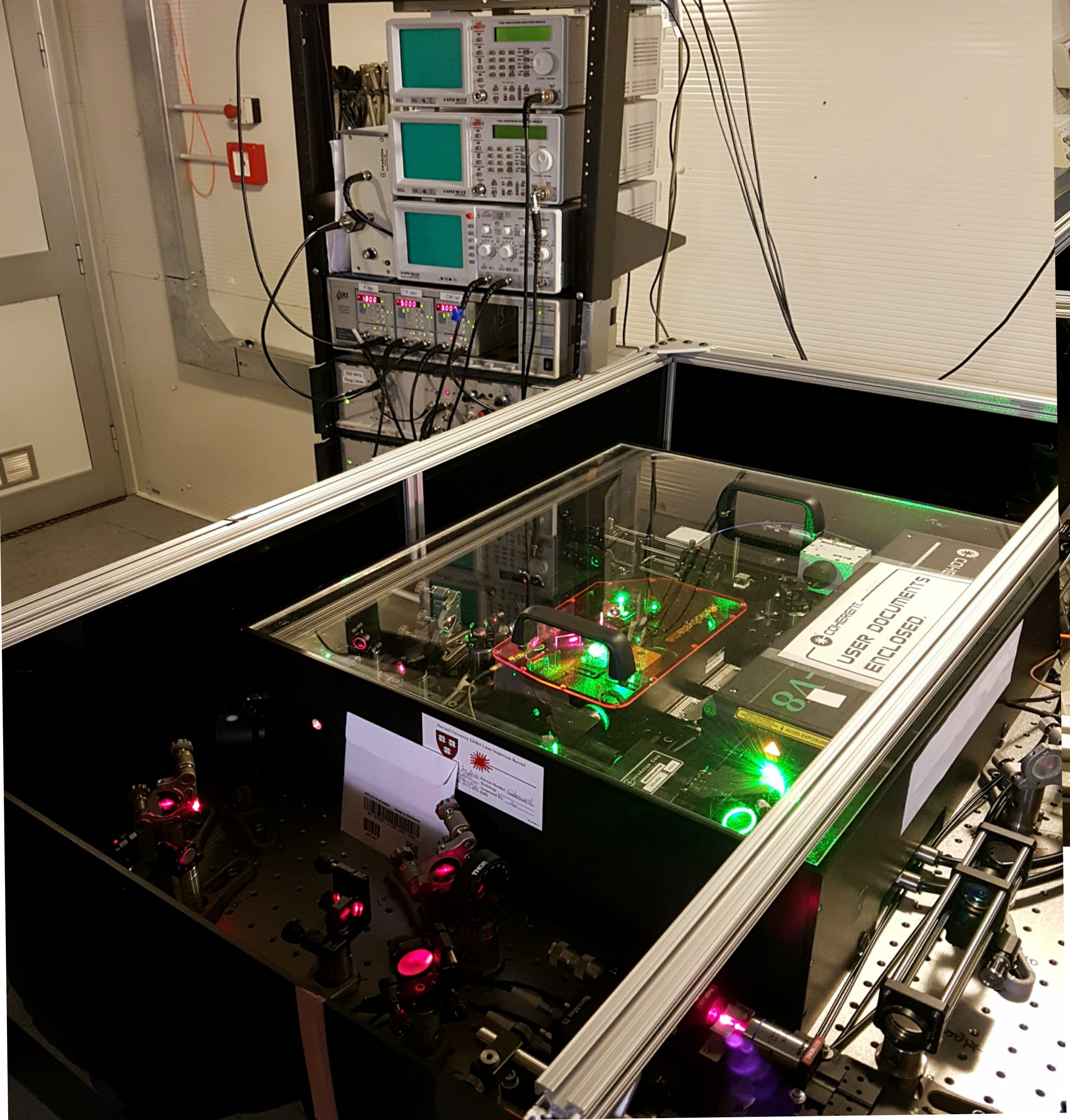
*Status of the LFC based calibrator, **Astro Comb***
*and of the **Low Cost Solar Telescope** at the TNG*

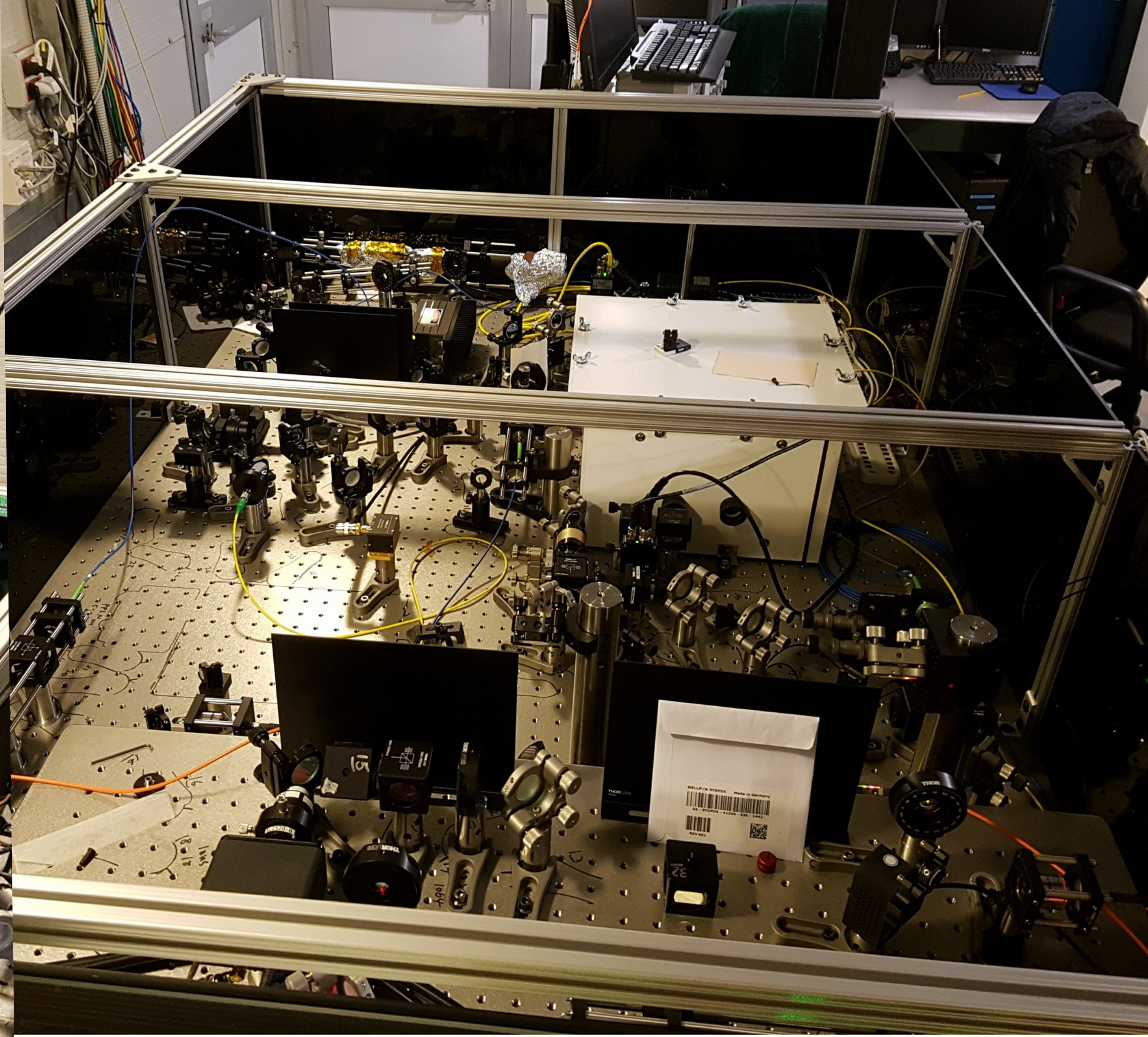


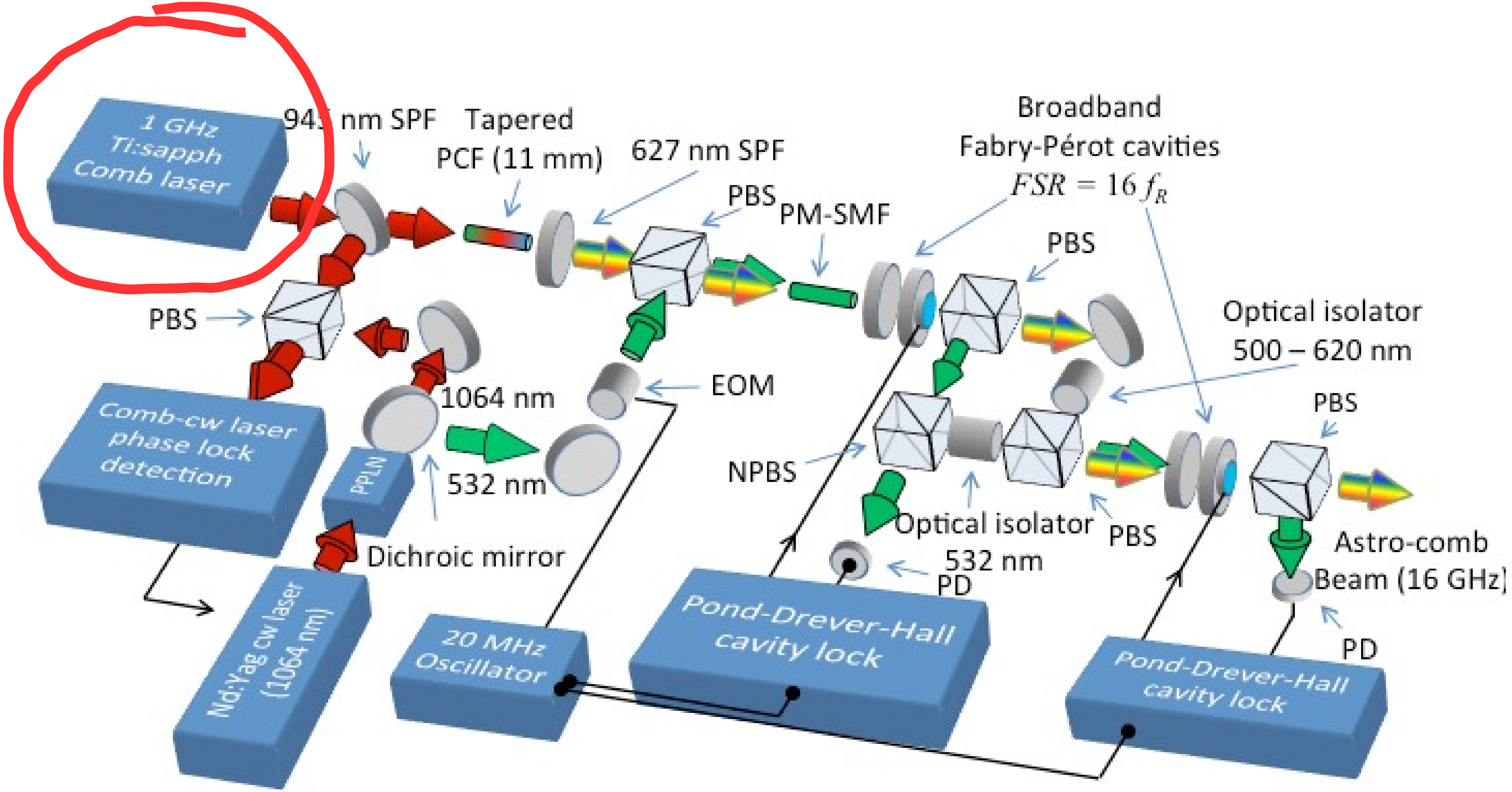
Leopoldo Martin and FGG-INAF staff
David F. Phillips and the CfA collaboration
Xavier Dumusque, GTO and solar group

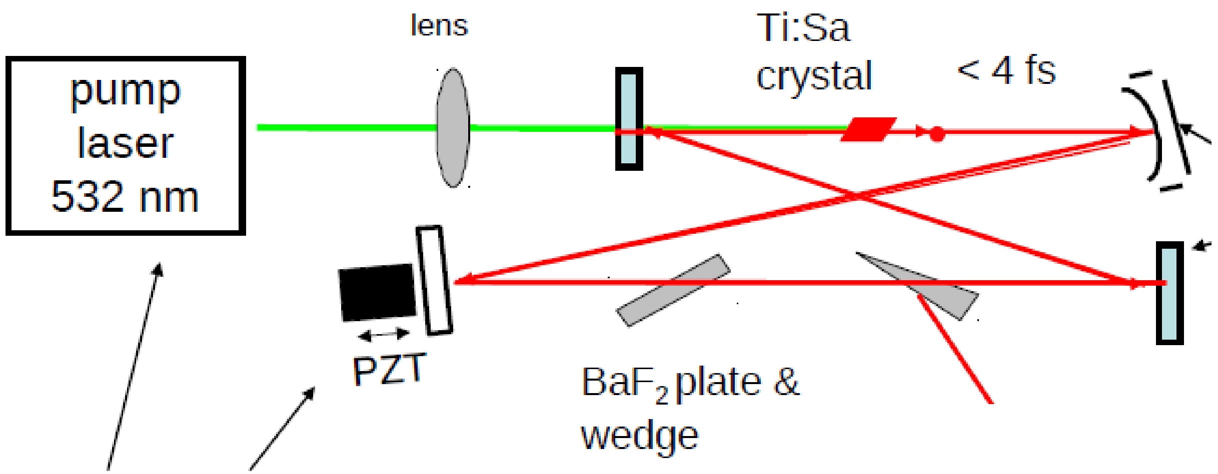
- Laser comb used in many fields: medicine, communications, chemistry, physics.
- Spanning the whole EM spectrum from UV to mid IR.
- Becomes astro comb with a few tricks and turns out to be a stable and precise reference system for precision radial velocities (PRV) measurements.
- Stability of 10^{-12} allows for ~1cm/s RV precision


COHERENT


COHERENT
USER DOCUMENTS ENCLOSED.

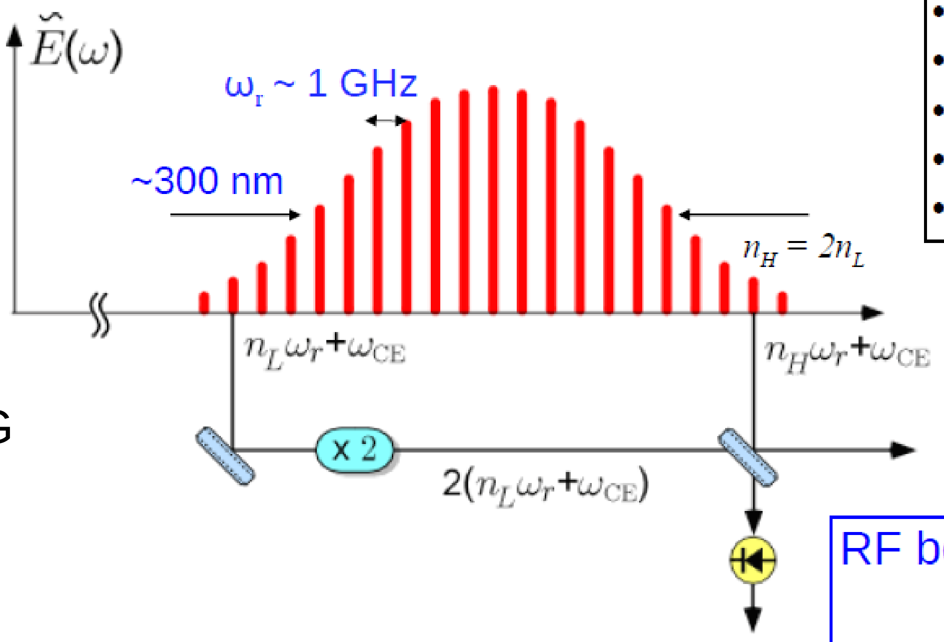



1 GHz
Ti:sapph
Comb laser
94_ nm SPF
Tapered
PCF (11 mm)
627 nm SPF
PBS
PM-SMF
Broadband
Fabry-Pérot cavities
$FSR = 16 f_R$
PBS
Optical isolator
500 – 620 nm
PBS
EOM
1064 nm
532 nm
Dichroic mirror
PPLN
Comb-cw laser
phase lock
detection
Nd:Yag cw laser
(1064 nm)
20 MHz
Oscillator
NPBS
Optical isolator
532 nm
PD
PBS
Astro-comb
Beam (16 GHz)
PD
Pond-Drever-Hall
cavity lock
Pond-Drever-Hall
cavity lock



- Stabilize ω_r => feedback to external cavity length
- Stabilize ω_{CE} => feedback to pump laser power

$\tau_{pulse} < 4$ fs



- 10^5 comb lines
- narrow lines (<kHz)
- coherent
- equally-spaced
- intense (10 μW/line)

OCTAVE SPANNING → SELF REFERENCING

Stability and accuracy of atomic clock

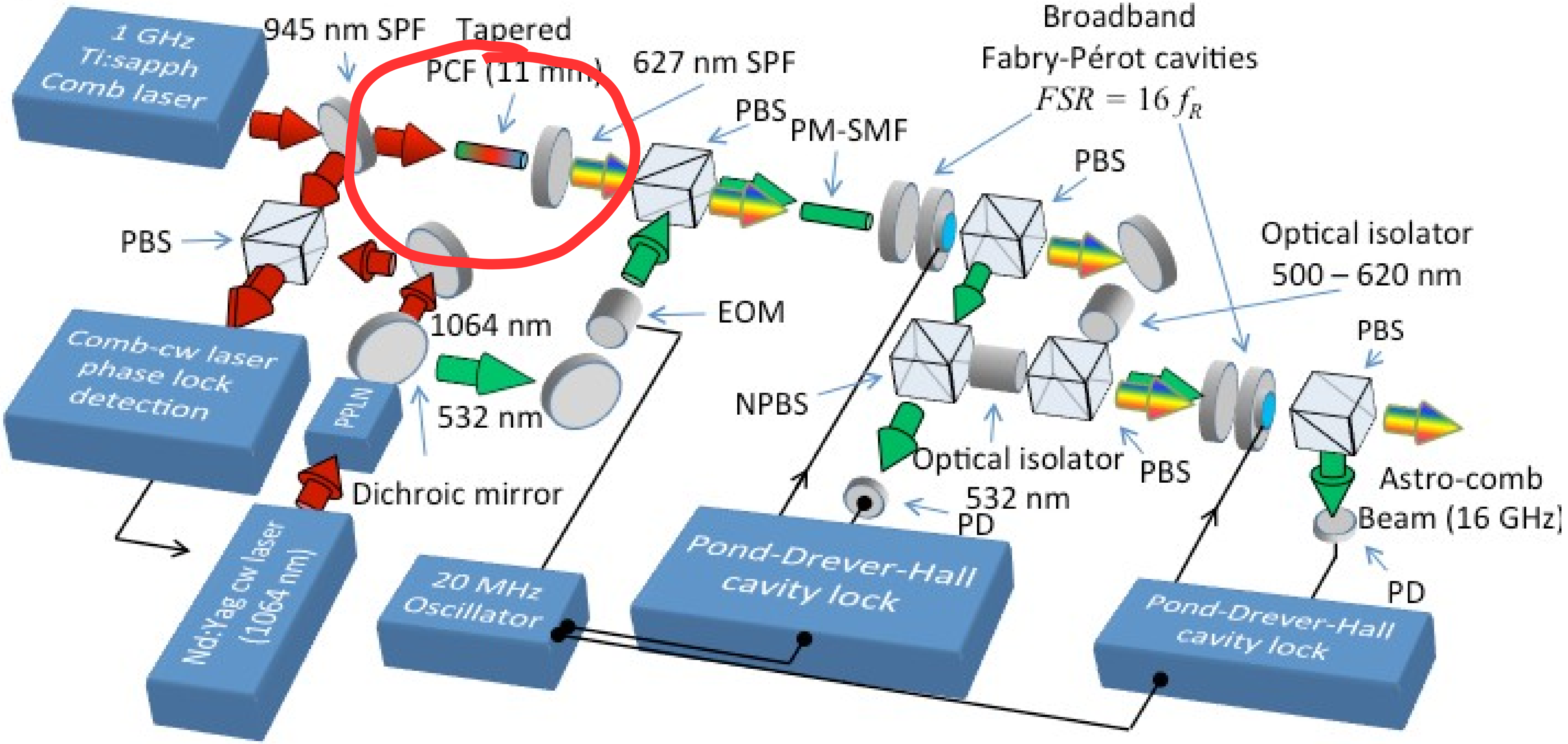
RF beat frequencies => lock ω_r & ω_{CE} to atomic clock

- 2 DoF : offset frequency = f_{ceo} and repetition rate= f_{rep} .
- Spanning 1 octave of frequency → self referencing.

- Every single frequency line is defined by:
    - $f_1 = f_{ceo} + n f_{rep}$
    - $2 f_1 = f_2 = f_{ceo} + 2 n f_{rep}$

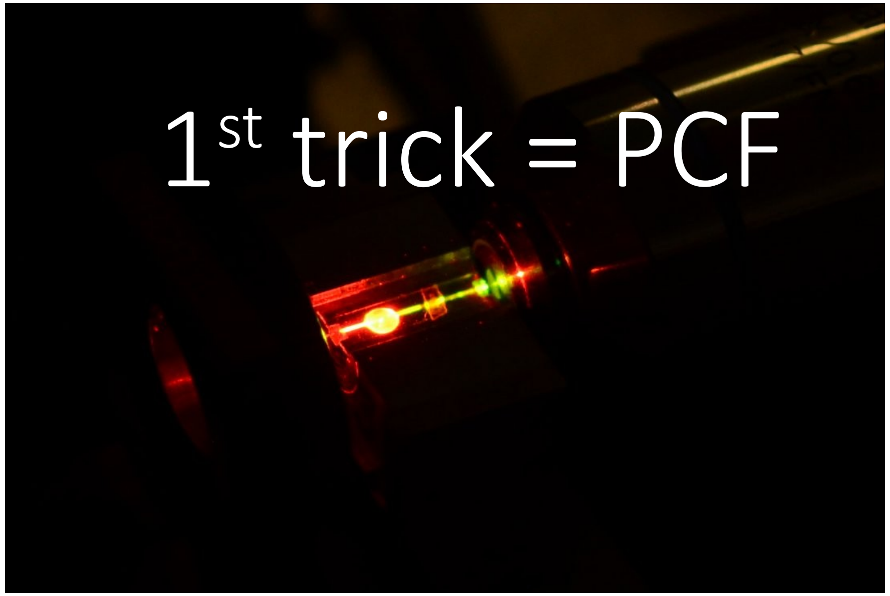
$$\boxed{2 f_1 - f_2} = 2 f_{ceo} + 2 n f_{rep} - f_{ceo} - 2 n f_{rep} \boxed{= f_{ceo}}$$

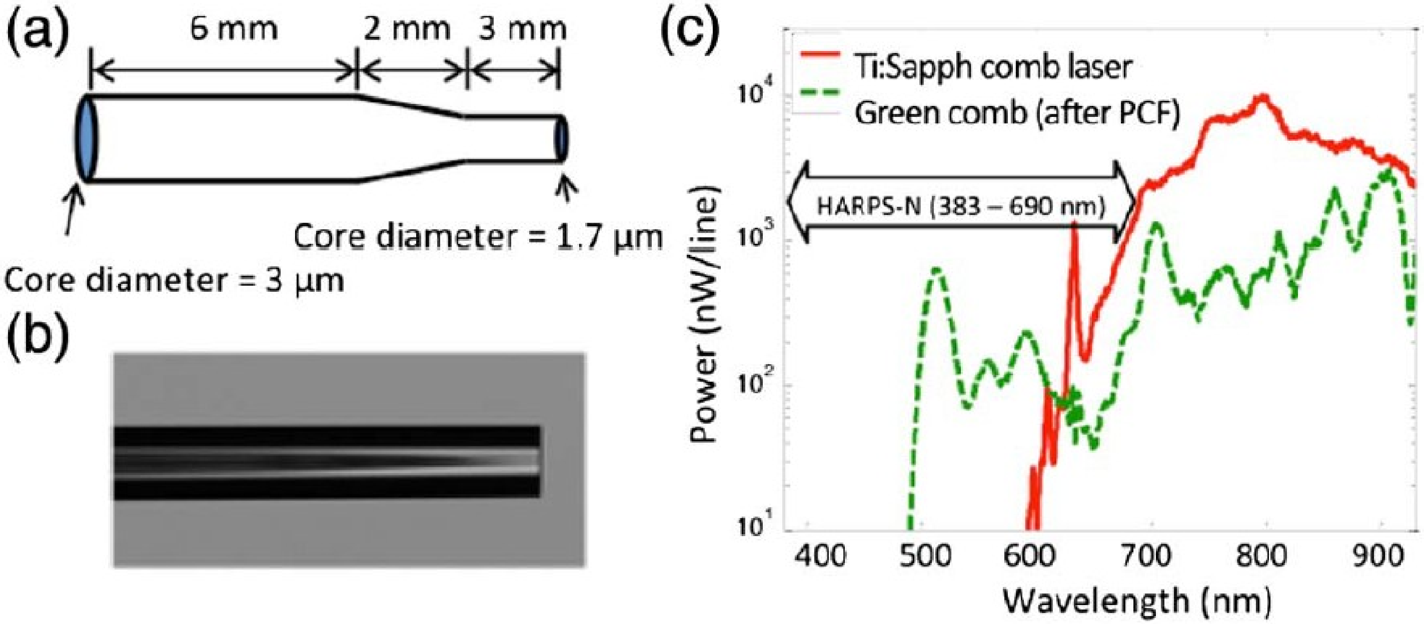
- To use it for HARPSN the problems are:
  1) the spectrograph observes in another bandwidth.
  2) the spectrograph does not resolve at 1 GHz.



1 GHz Ti:sapph Comb laser
945 nm SPF
Tapered PCF (11 mm)
627 nm SPF
PBS
PM-SMF
Broadband Fabry-Pérot cavities
$FSR = 16\ f_R$
PBS
PBS
Optical isolator 500 – 620 nm
EOM
1064 nm
532 nm
Comb-cw laser phase lock detection
PPLN
Dichroic mirror
NPBS
Optical isolator
532 nm
PBS
PD
PBS
Astro-comb Beam (16 GHz)
PD
Nd:Yag cw laser (1064 nm)
20 MHz Oscillator
Pond-Drever-Hall cavity lock
Pond-Drever-Hall cavity lock

1st trick = PCF





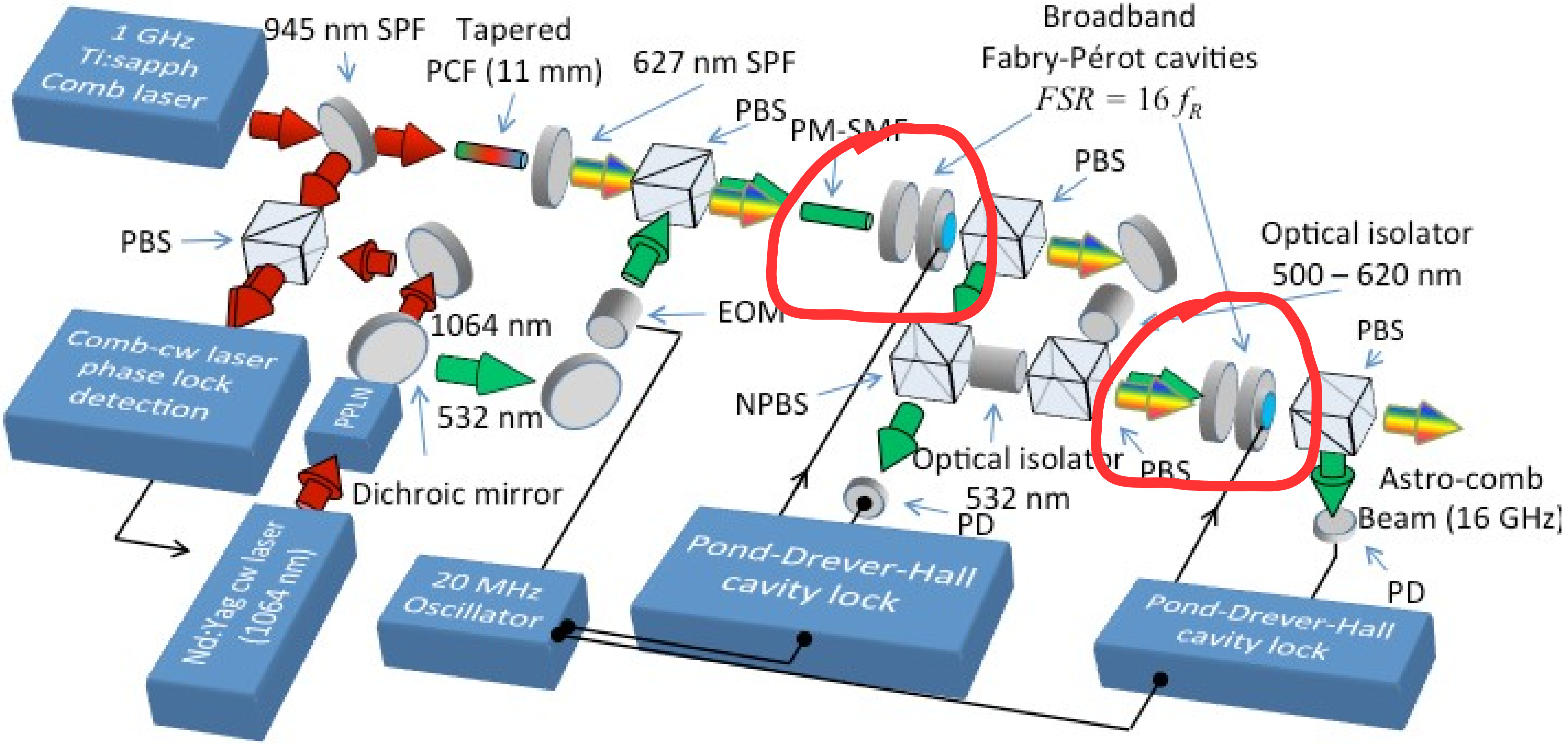
- Tapered Photonic Crystal Fiber = Move the light pulses to the visible band
- Adiabatic transfer through holed and tapered fiber
- Bandwidth is a compromise between intensity and temporal width of the source comb pulse
- Output = 120nm bw (500,620) nm
-

2^{nd} trick = FPC

Fabry Perot Cavity (AKA Filter Cavity) with stable FSR (free spectral range) locked to the laser frequency in Pound Drever Hall mode with EOM

Increase resolution from 1GHz to ~10GHz typical of astronomical spectrographs.

- 16GHz for our astro comb ; means to keep 1 of every 16 lines and suppress the others 15.
- 22dB per pass. Double cavity -44dB
- Suppress side bands because unresolved could shift lines


1 GHz Ti:sapph Comb laser
945 nm SPF
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627 nm SPF
PBS
PM-SMF
Broadband Fabry-Pérot cavities
$FSR = 16\,f_R$
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Comb-cw laser phase lock detection
1064 nm
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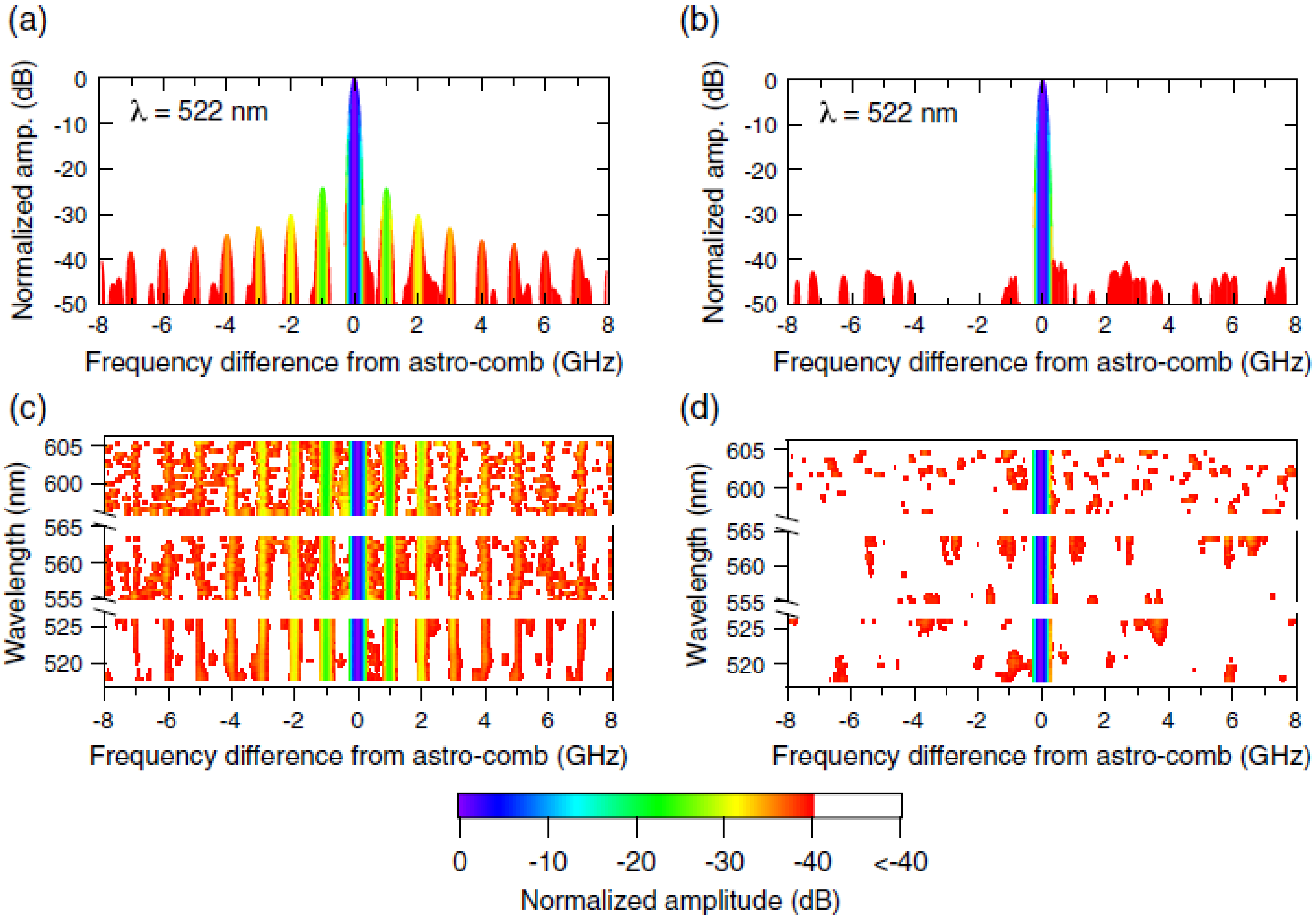
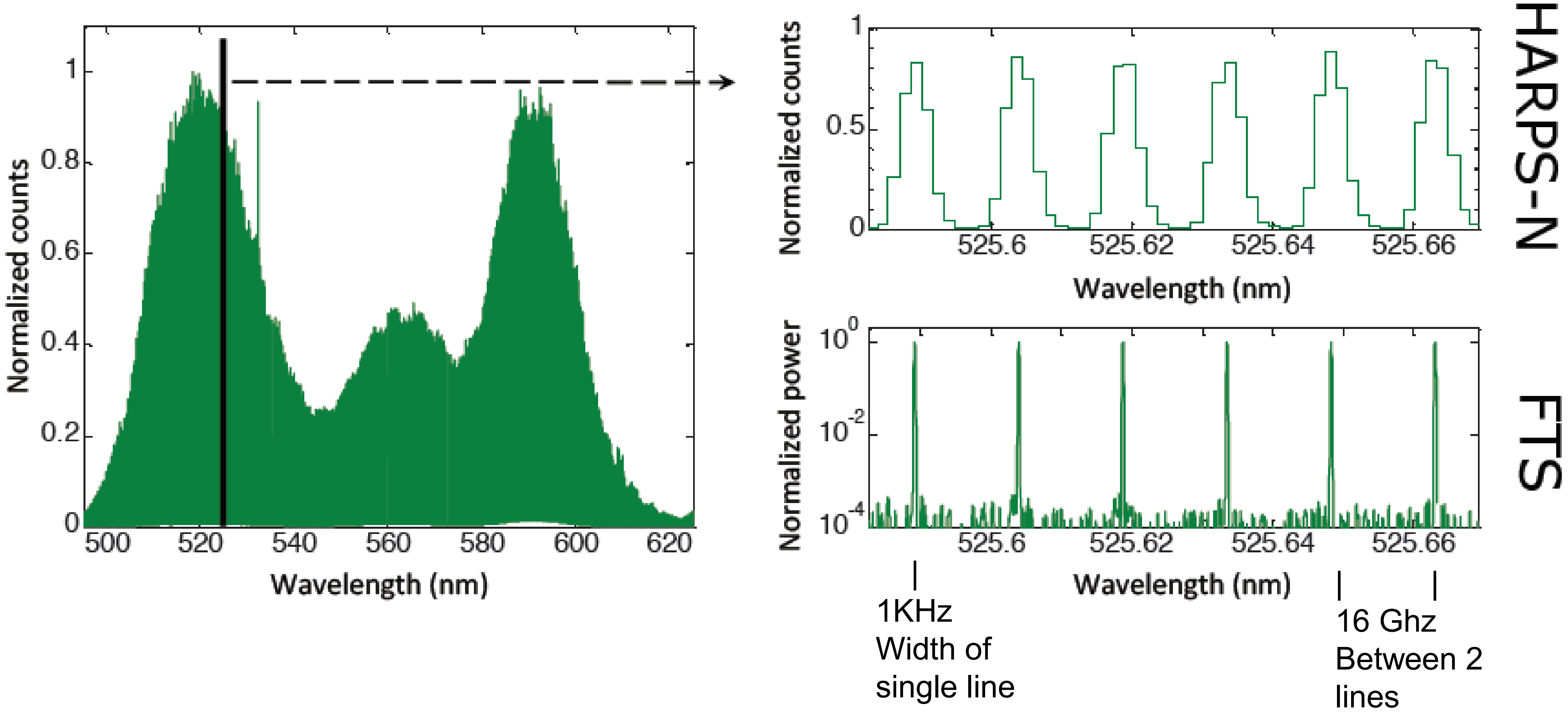
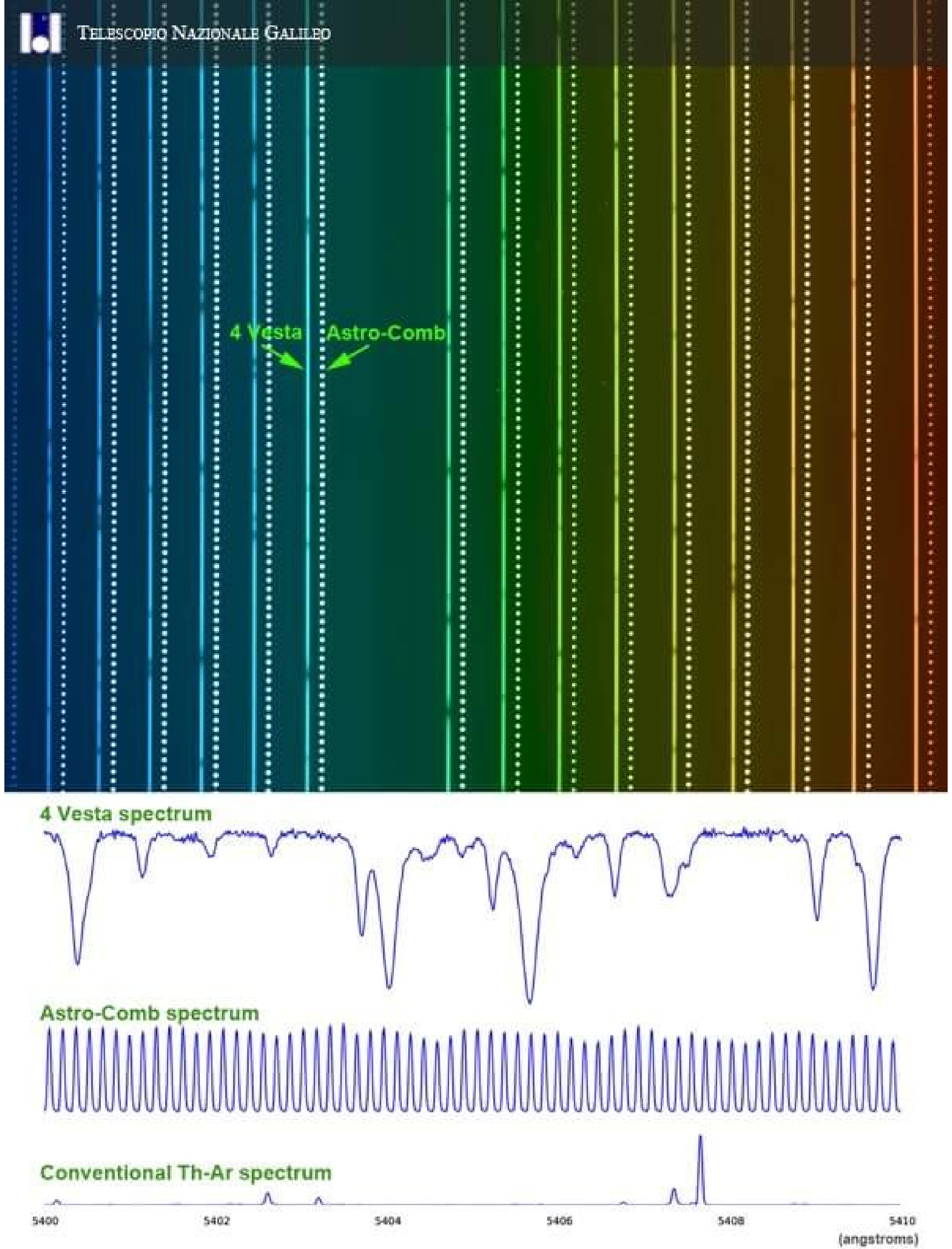
Astro-comb Beam (16 GHz)
PD
Nd:Yag cw laser (1064 nm)
20 MHz Oscillator
Pond-Drever-Hall cavity lock
Pond-Drever-Hall cavity lock
PD

FPC : fundamental to suppress side bands to -40db → double FPC

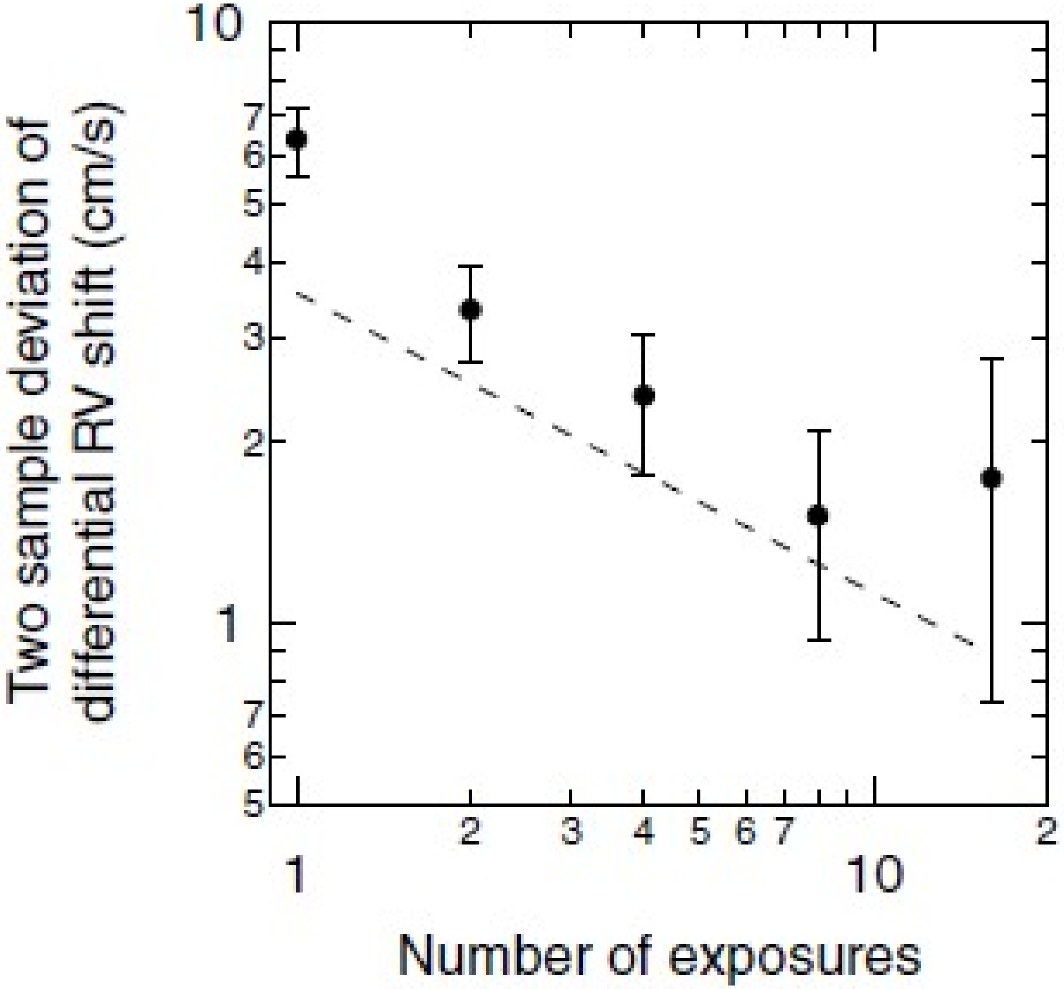


Comb Calibration Spectrum





Telescopio Nazionale Galileo
4 Vesta
Astro-Comb
4 Vesta spectrum
Astro-Comb spectrum
Conventional Th-Ar spectrum
5400
5402
5404
5406
5408
5410
(angstroms)



Two sample deviation of differential RV shift (cm/s)
10
7
6
5
4
3
2
1
7
6
5
1
2
3
4
5
6
7
10
2
Number of exposures

A few problems

1)No turn key system: we (Leo) are working on it;
2)Short bandwidth;
3)Still an experiment/demonstrator → it works but not routinely;
4)PCF degradation → needs replacement;

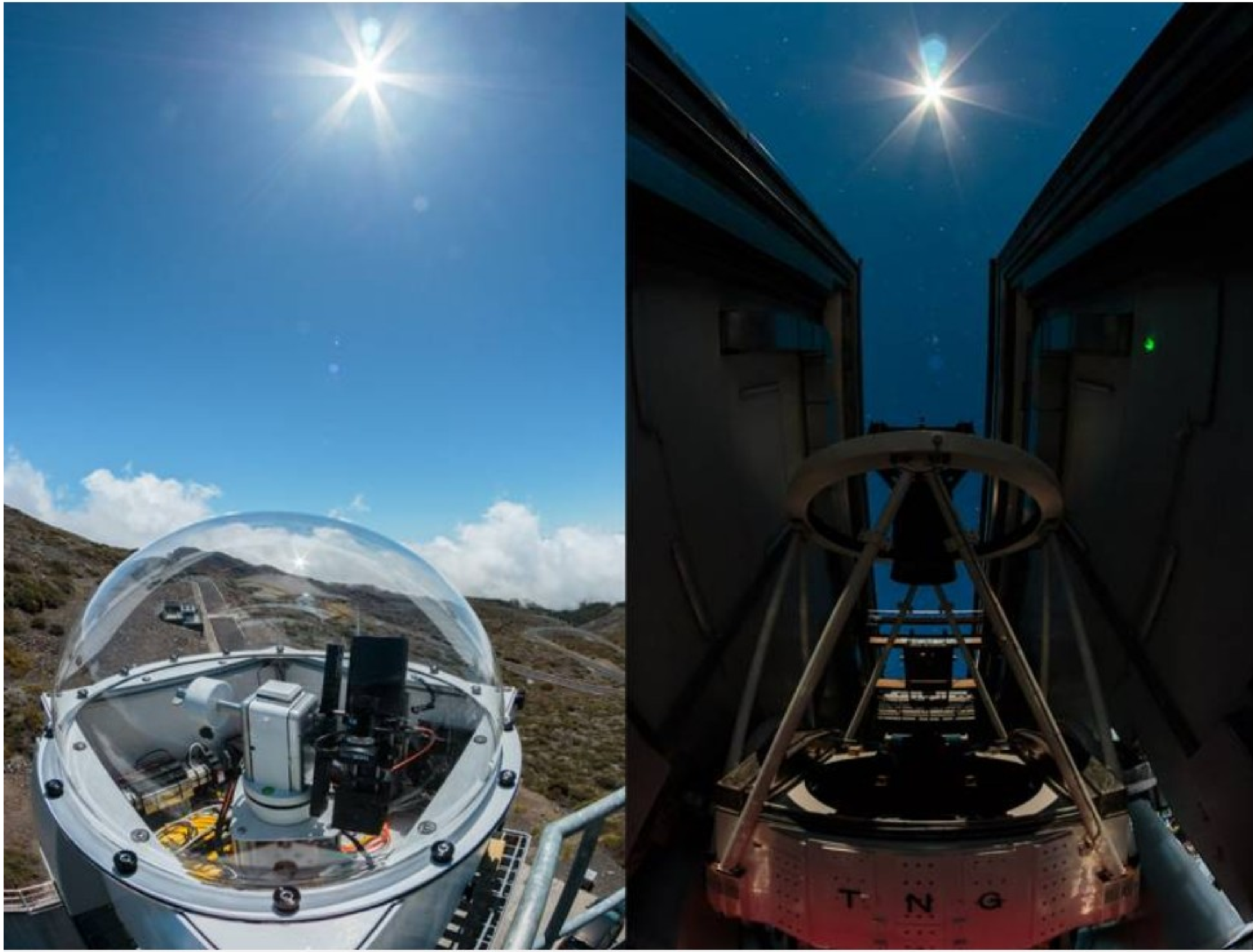
(1+2+3+4) → planned test in April 2017 with Laser Quantum (Taccor);

5)Hard to pass on Know How for maintenance/availability

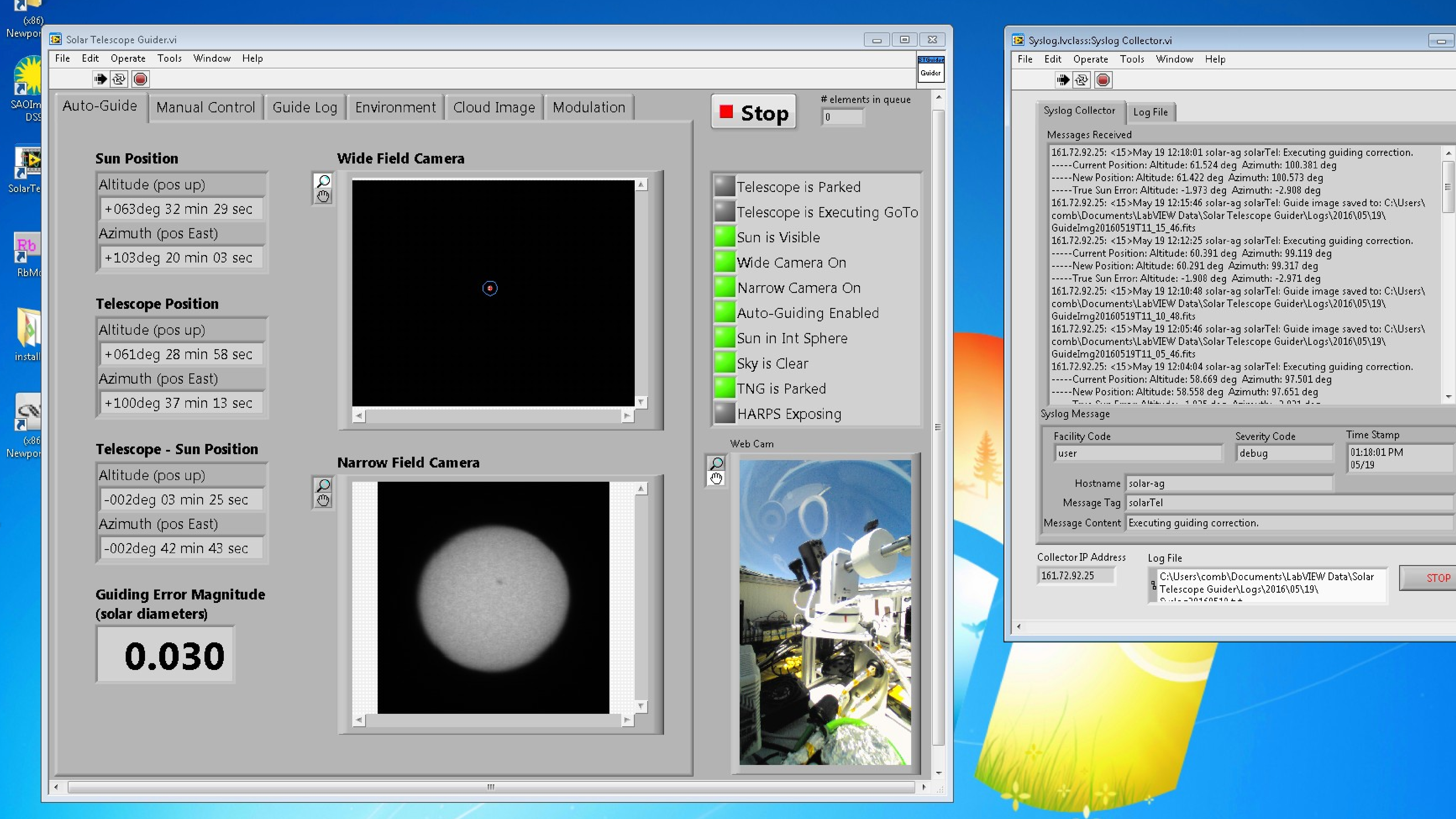
LCST = Low Cost Solar Telescope

- Purpose? Demonstrate that HARPSN + ASTROCOMB have enough precision to detect effect of Venus over the Sun's COM RV <10cm/sOperating at the TNG since July2015
- 3” lens f=200mm feeding 2” int sphere mounted on a commercial AZ mount inside a 60cm water proof dome hanging outside of the TNG dome, facing south.
- The sphere scrambles the image of the Sun and evenly illuminates a 35m long fiber of 300um that goes to HARPSN CU → give us a hi-res spectra of an unresolved star.
- Off the shelf → 10k Euros
- Completely autonomous. Starts feeding light to HARPSN from 10am ends at to 6pm or at TNG startup.
- Achieved 30cm/s daily sensitivity

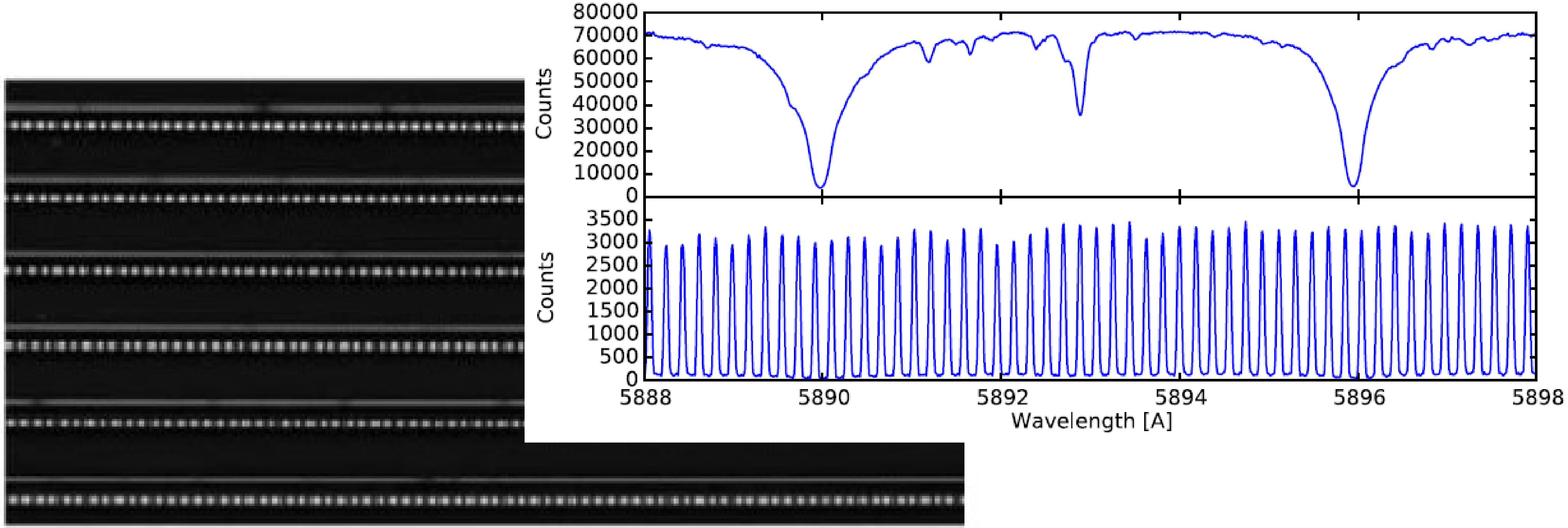
Unexpected Results!



El telescopio apunta de día y de noche al Sol. | DA

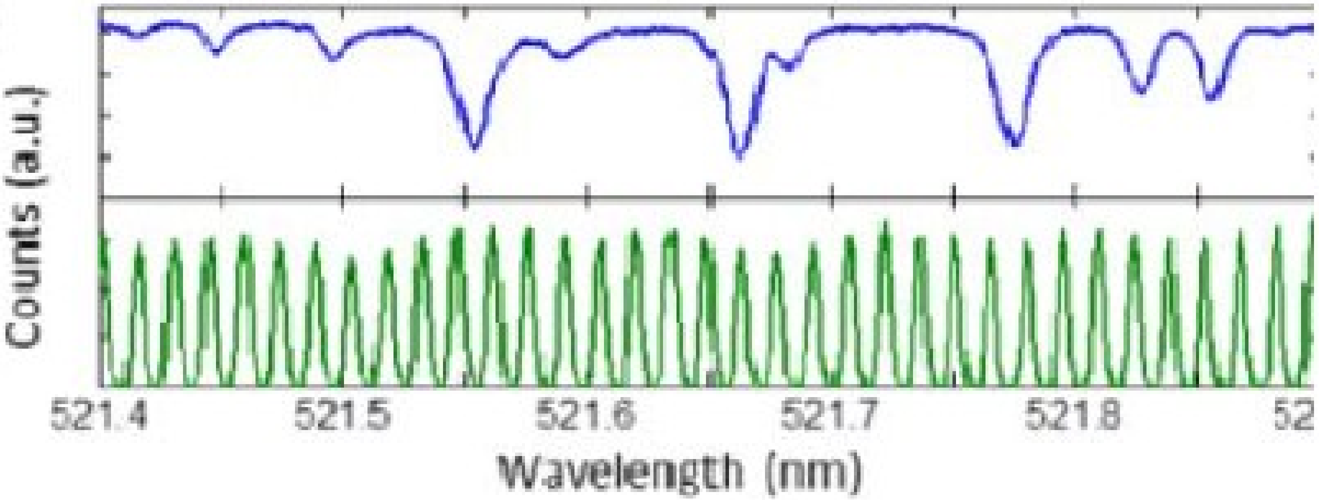

Solar Telescope Guider.vi
File Edit Operate Tools Window Help
Auto-Guide
Manual Control
Guide Log
Environment
Cloud Image
Modulation
Stop
elements in queue
0
Sun Position
Altitude (pos up)
+063deg 32 min 29 sec
Azimuth (pos East)
+103deg 20 min 03 sec
Telescope Position
Altitude (pos up)
+061deg 28 min 58 sec
Azimuth (pos East)
+100deg 37 min 13 sec
Telescope - Sun Position
Altitude (pos up)
-002deg 03 min 25 sec
Azimuth (pos East)
-002deg 42 min 43 sec
Guiding Error Magnitude (solar diameters)
0.030
Wide Field Camera
Narrow Field Camera
Telescope is Parked
Telescope is Executing GoTo
Sun is Visible
Wide Camera On
Narrow Camera On
Auto-Guiding Enabled
Sun in Int Sphere
Sky is Clear
TNG is Parked
HARPS Exposing
Web Cam
Syslog.lvclass:Syslog Collector.vi
File Edit Operate Tools Window Help
Syslog Collector
Log File
Messages Received
161.72.92.25: <15>May 19 12:18:01 solar-ag solarTel: Executing guiding correction.
-----Current Position: Altitude: 61.524 deg Azimuth: 100.381 deg
-----New Position: Altitude: 61.422 deg Azimuth: 100.573 deg
-----True Sun Error: Altitude: -1.973 deg Azimuth: -2.908 deg
161.72.92.25: <15>May 19 12:15:46 solar-ag solarTel: Guide image saved to: C:\Users\comb\Documents\LabVIEW Data\Solar Telescope Guider\Logs\2016\05\19\GuideImg20160519T11_15_46.fits
161.72.92.25: <15>May 19 12:12:25 solar-ag solarTel: Executing guiding correction.
-----Current Position: Altitude: 60.391 deg Azimuth: 99.119 deg
-----New Position: Altitude: 60.291 deg Azimuth: 99.317 deg
-----True Sun Error: Altitude: -1.908 deg Azimuth: -2.971 deg
161.72.92.25: <15>May 19 12:10:48 solar-ag solarTel: Guide image saved to: C:\Users\comb\Documents\LabVIEW Data\Solar Telescope Guider\Logs\2016\05\19\GuideImg20160519T11_10_48.fits
161.72.92.25: <15>May 19 12:05:46 solar-ag solarTel: Guide image saved to: C:\Users\comb\Documents\LabVIEW Data\Solar Telescope Guider\Logs\2016\05\19\GuideImg20160519T11_05_46.fits
161.72.92.25: <15>May 19 12:04:04 solar-ag solarTel: Executing guiding correction.
-----Current Position: Altitude: 58.669 deg Azimuth: 97.501 deg
-----New Position: Altitude: 58.558 deg Azimuth: 97.651 deg
Syslog Message
Facility Code
user
Severity Code
debug
Time Stamp
01:18:01 PM
05/19
Hostname
solar-ag
Message Tag
solarTel
Message Content
Executing guiding correction.
Collector IP Address
161.72.92.25
Log File
C:\Users\comb\Documents\LabVIEW Data\Solar Telescope Guider\Logs\2016\05\19\
STOP

(b)

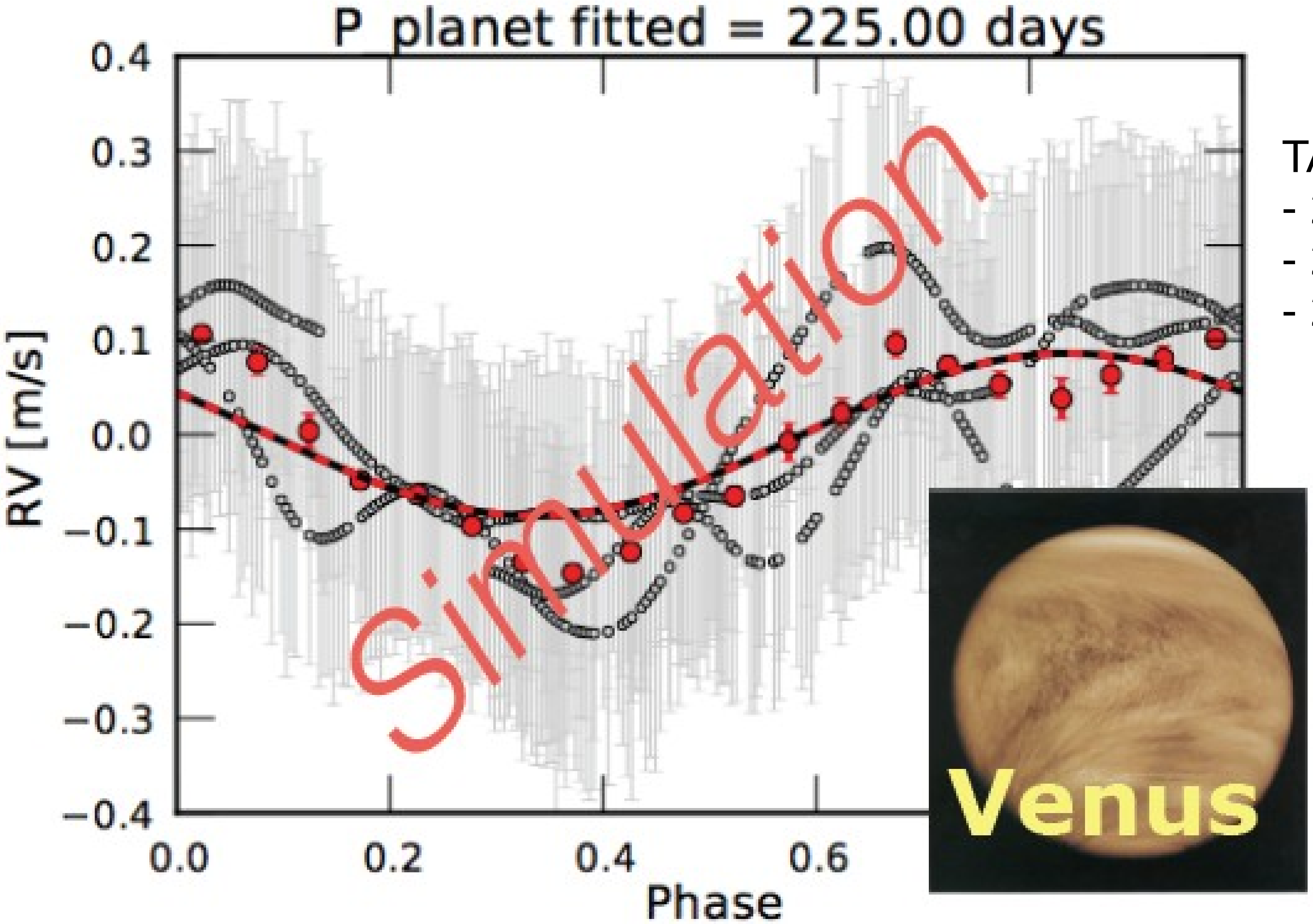


80000
70000
60000
50000
40000
30000
20000
10000
0
Counts
3500
3000
2500
2000
1500
1000
500
0
Counts
5888
5890
5892
5894
5896
5898
Wavelength [A]

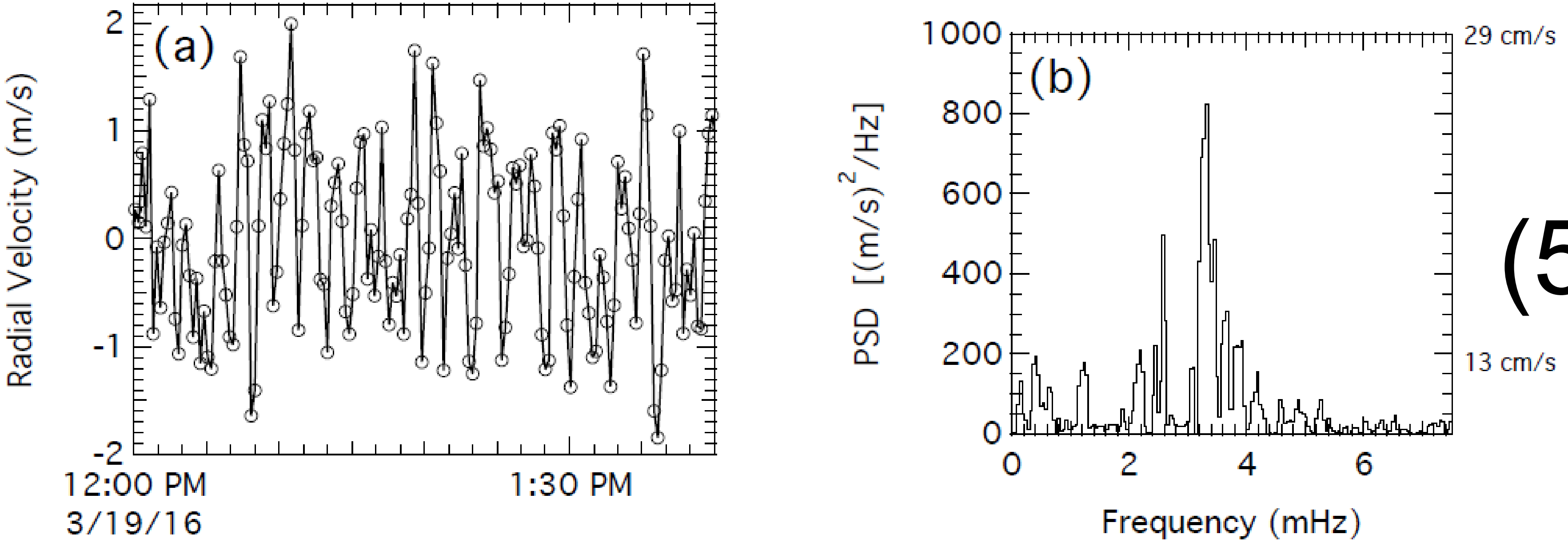
(c)



Counts (a.u.)
521.4
521.5
521.6
521.7
521.8
52
Wavelength (nm)

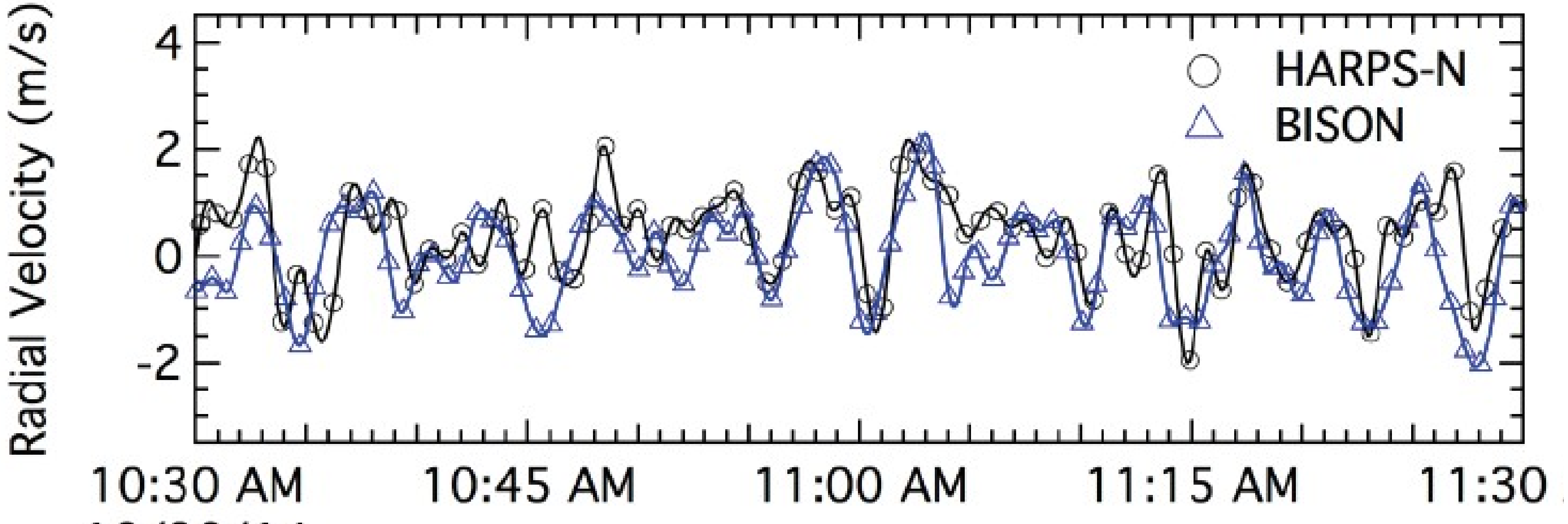


TARGET is:
- 2h obs/day
- 200 days/year
- 2 years

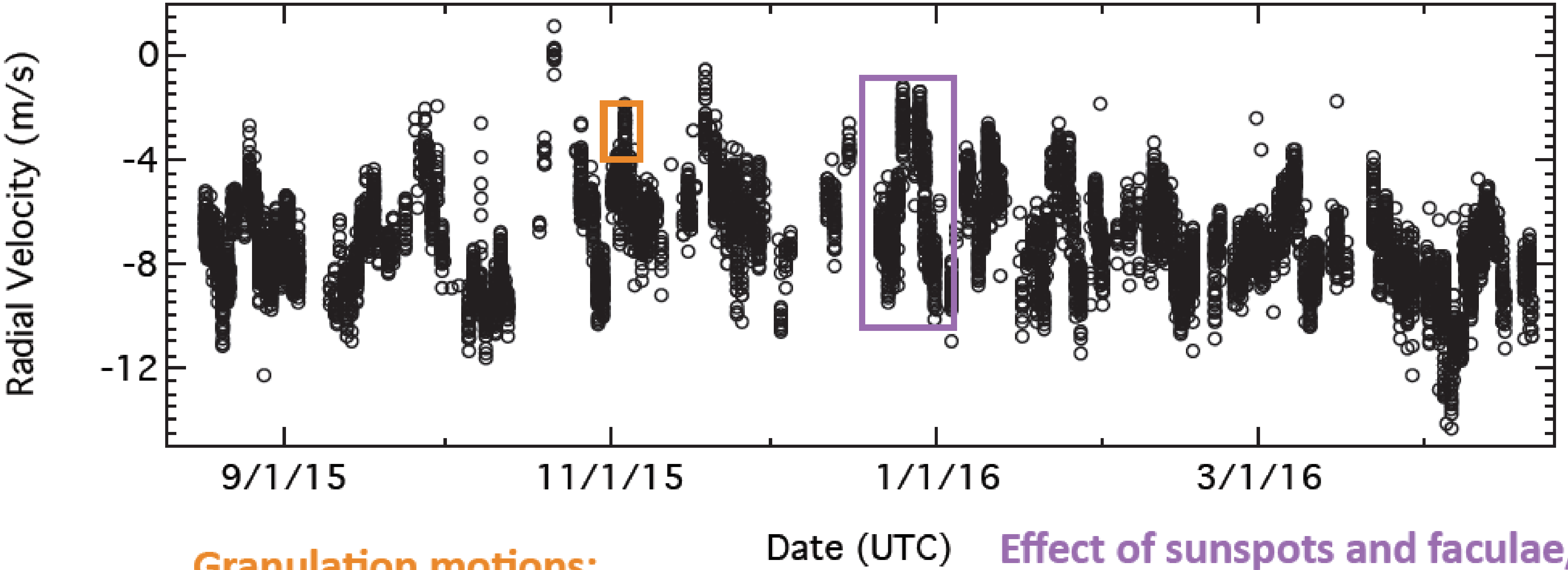


P-mode
(5min=3.3mHz)

Short Cadence Exposures



Extracted Radial Velocities



Granulation motions:
timescale of few min up to ~20h,
RV amplitude: ~40 cm/s

Effect of sunspots and faculae/plage:
modulated by the Sun's rotation (25 days),
RV amplitude: 100-700 cm/s

Problems

- Center of Mass Radial Velocities dominated by stellar activity RV variations
- Granulation/supergranulation/flares/spots/plages/mag.activity

Solutions

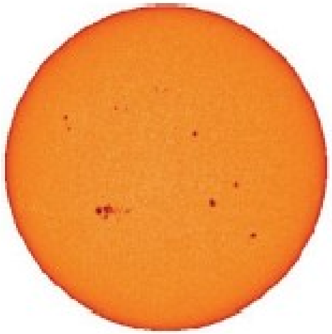
SORCE program and satellites (SDO) to know what is going on and find model to fit our data.

- Use S-index CaII H and K line as tracer for magnetic activity
- Use FF' to model total flux (Aigrin)
- Identify new proxies for activity-induced RV variations to disentangle planet orbits from stellar activity in RV observations of Sun-like stars

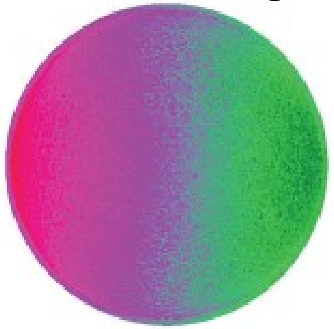
SDO Images

Magnetic Field

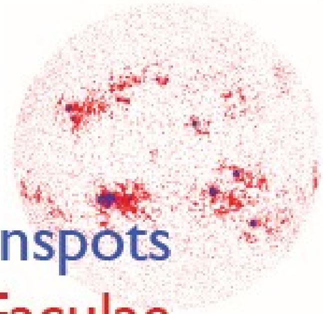
Continuum Intensity



Line-of-Sight Velocity

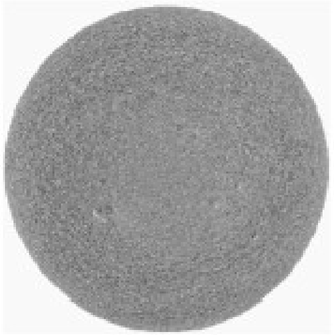


Thresholded Image

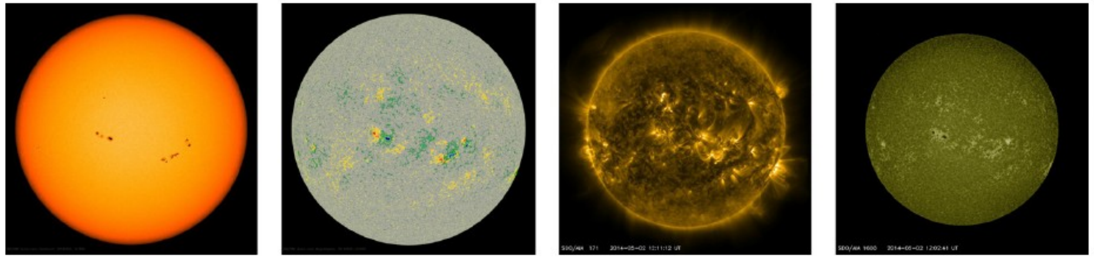


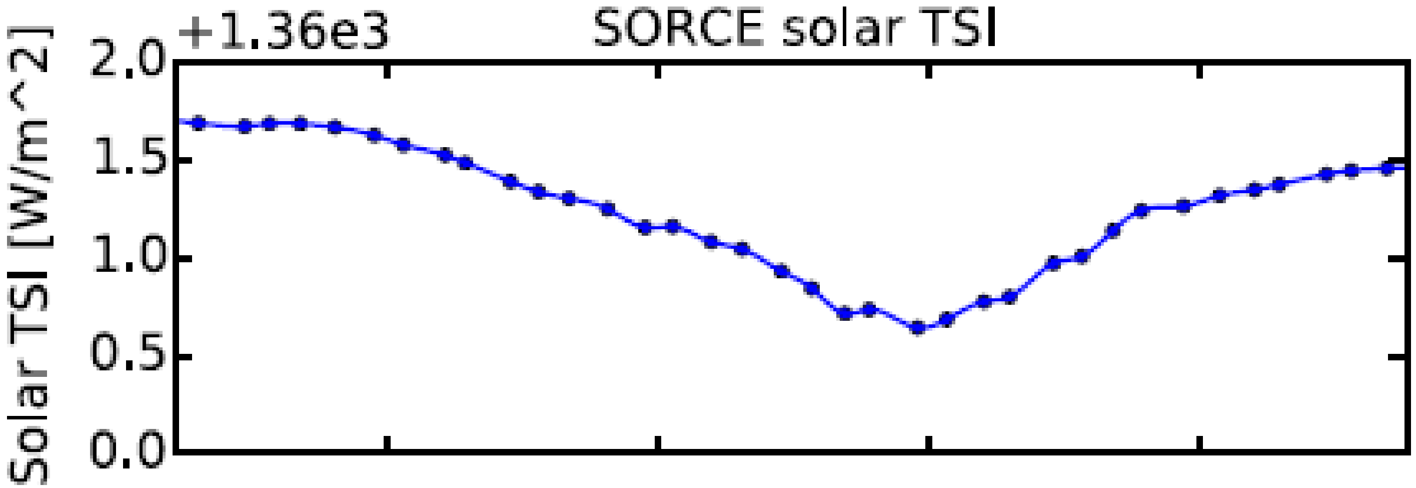
We use these images of the Sun to reconstruct the RV variations caused by the Sun's magnetic activity.

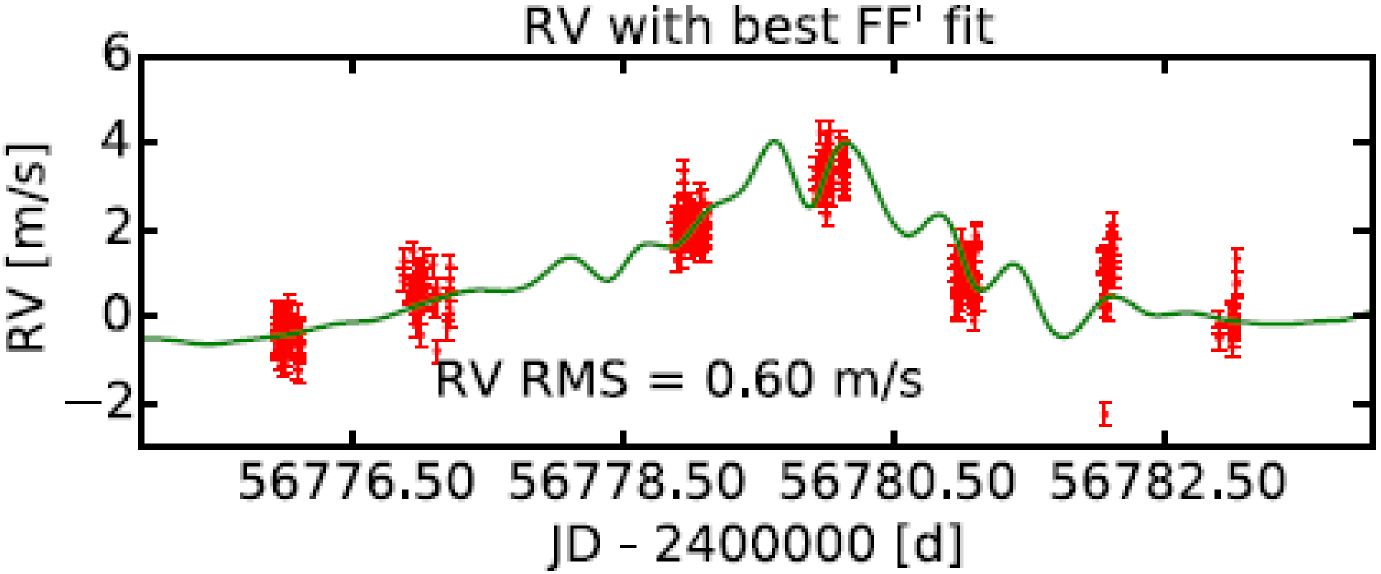
Line-of-sight velocity (Solar Rotation Removed)



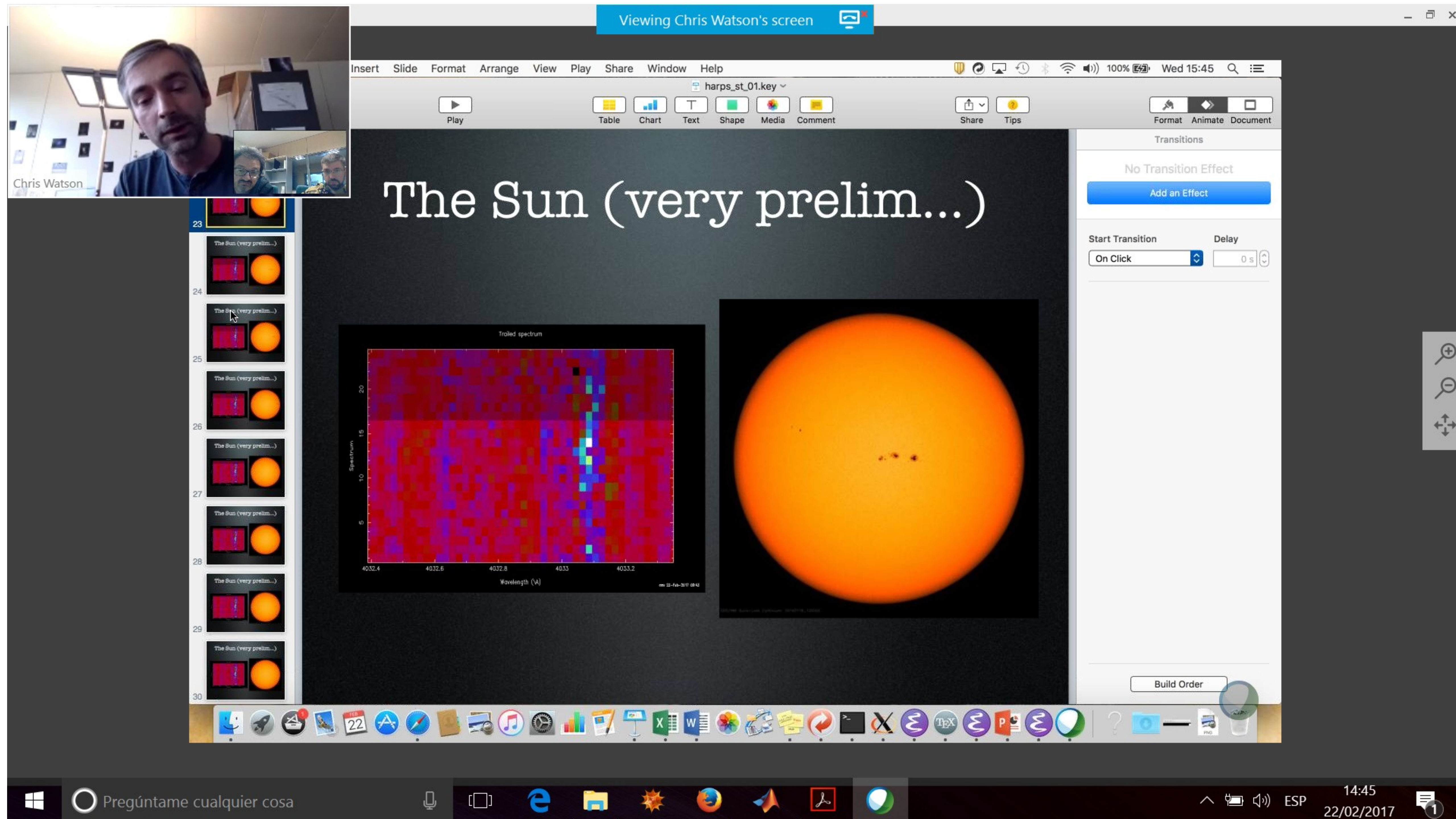
R. Haywood et al MNRAS ***457****, 3637 (2016).*



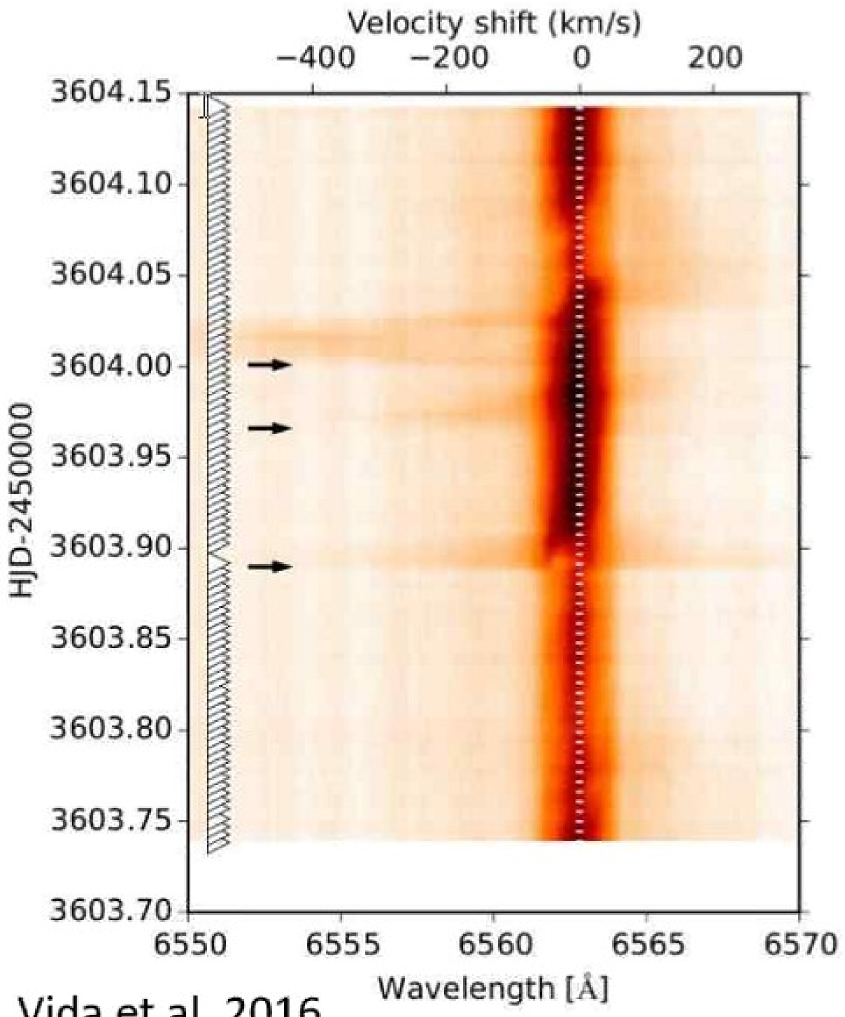




$$\Delta \mathrm{RV} = a \times FF' + b \times F^2,$$


Viewing Chris Watson's screen
Chris Watson
Insert Slide Format Arrange View Play Share Window Help
100% Wed 15:45
harps_st_01.key
Play
Table Chart Text Shape Media Comment
Share Tips
Format Animate Document
The Sun (very prelim...)
Trailed spectrum
Spectrum
20
15
10
5
4032.4
4032.6
4032.8
4033
4033.2
Wavelength (\A)
Transitions
No Transition Effect
Add an Effect
Start Transition
Delay
On Click
0 s
Build Order
23
24
25
26
27
28
29
30
Pregúntame cualquier cosa
ESP
14:45
22/02/2017

Hunting for CME

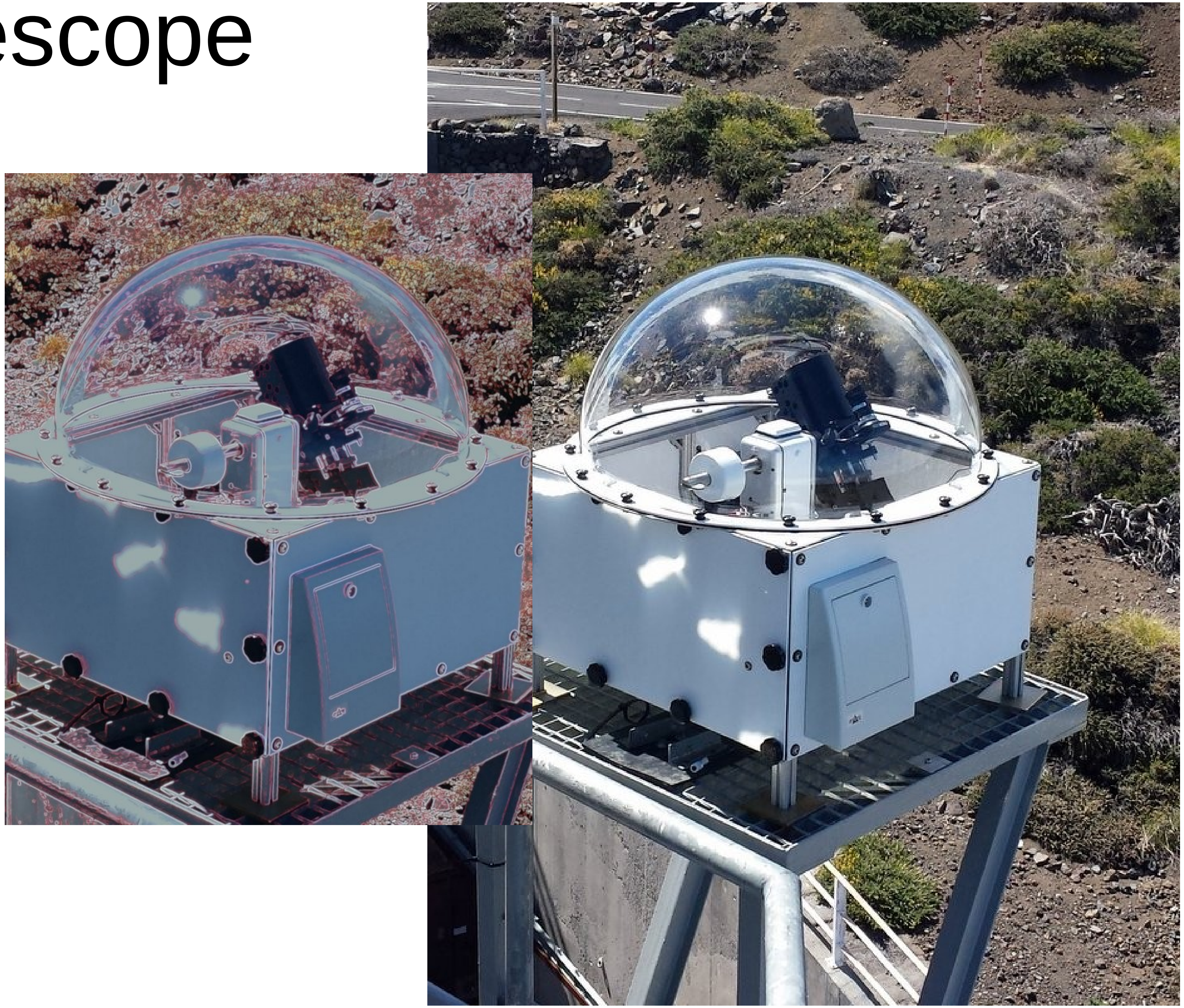


Vida et al. 2016

- We have run campaigns on young clusters with ESO telescopes (PI Leitzinger), Nordic Optical Telescope (PI Korhonen) and also used archival data of active stars (PI Vida)
- We detect CMEs, but much less than we would expect
- Here an example of a CME event in M dwarf V374 Peg is shown. Predicted CME rate for this star is 15-60 per day. We see one in 10 hours.

VIS-NIR Solar Telescope

- LCST Extended to NIR for GIANO
- *(R.Claudi, E.Pace, L.Gallorini, G.Micela, A.Lanza...)*
- Same opto-mechanical setup → 2 fibers to feed HARPS-N and GIANO-B
- Wavelength range?
- 0.4 ↔ 1.7 or 0.4 ↔ 2.5
- (pmma Absorption, modal noise, fiber cost, etc.)

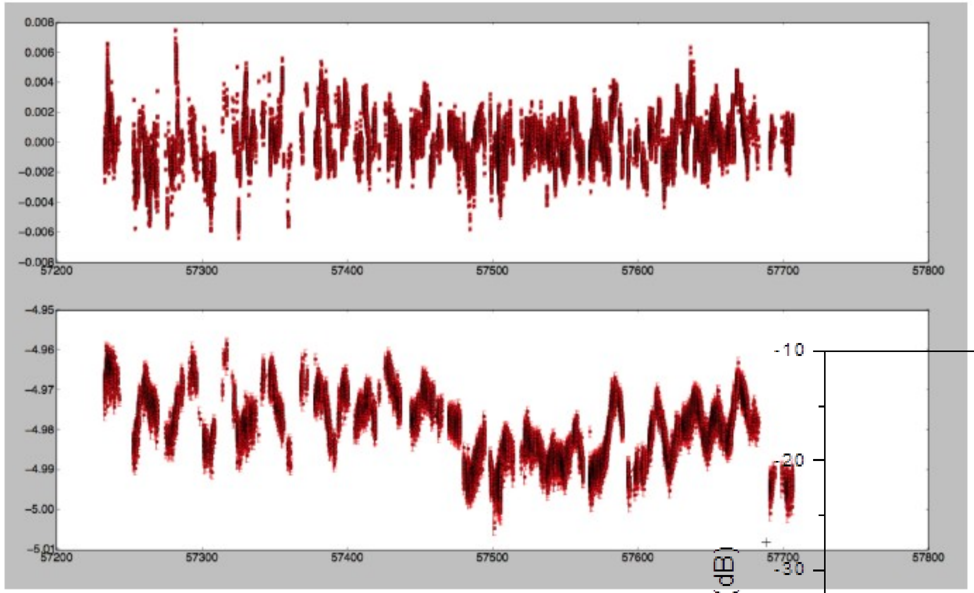


Conclusions

- Astro laser frequency comb – stable and accurate reference calibrator for PRV measurements
- Needs much improvements (=$$) to be turnkey system
- Planned Test with different source comb (Laser Quantum TACCOR demo laser).

- LCST interesting simple experiment that could produce top level science (detect Venus, astro-seismology, CME)
- Extend modeling of activity to disentangle doppler effects
- Be ready for the extended output to GIANO-B

THANKS !



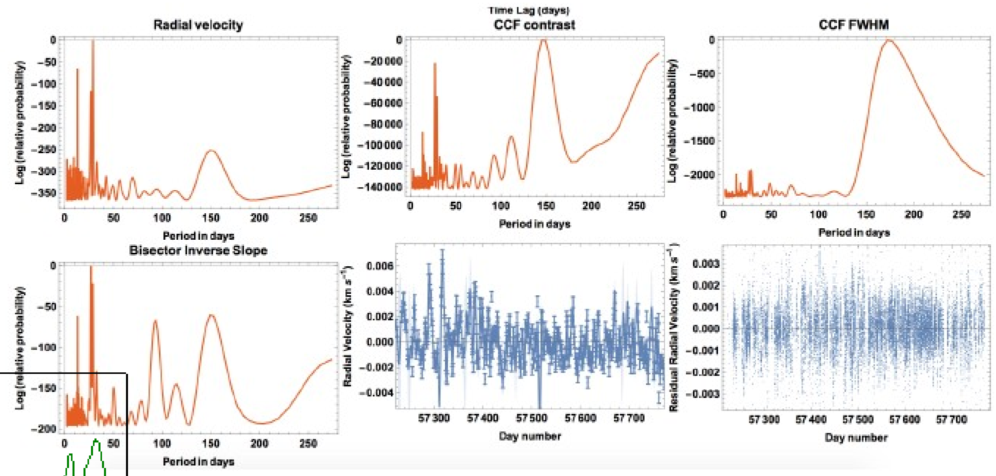


Figure 7: Snapshot continued