# Recent progress of visible light nulling interferometry and first 1 million null result

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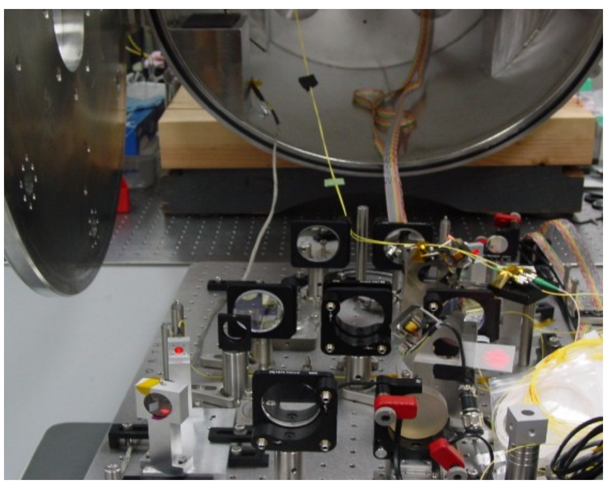
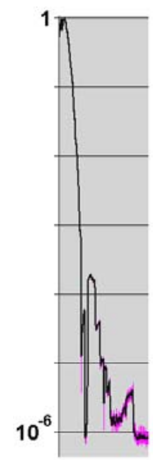
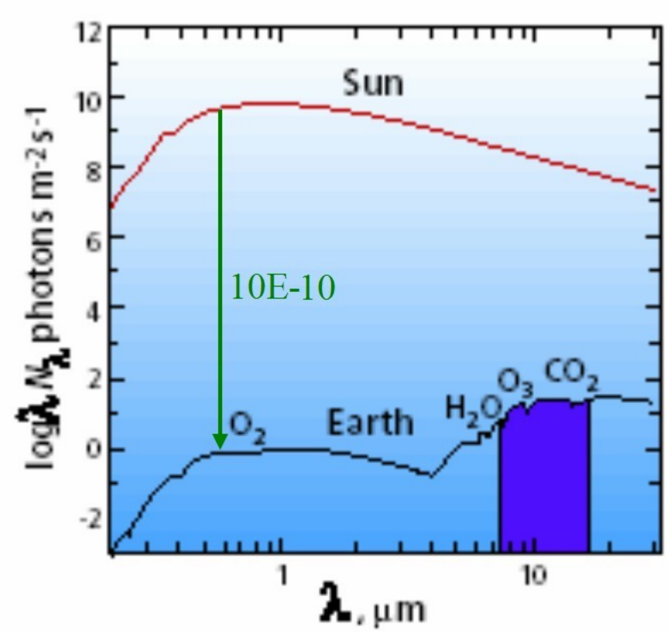


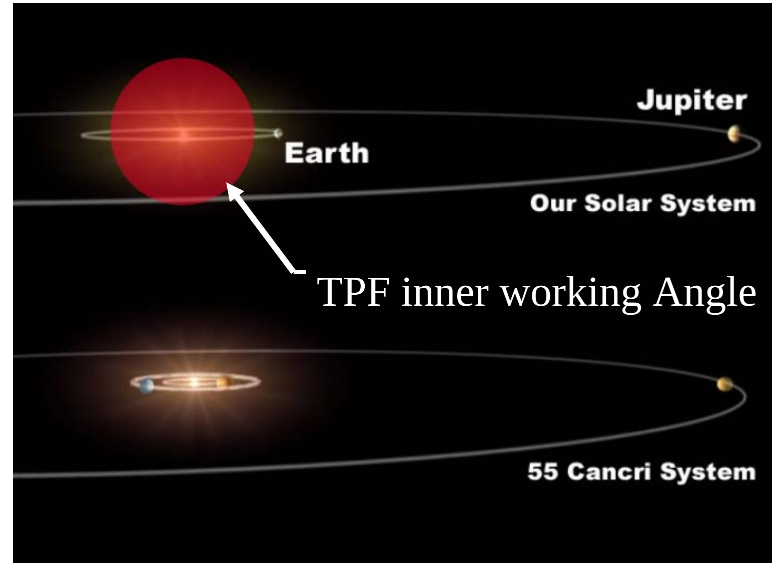


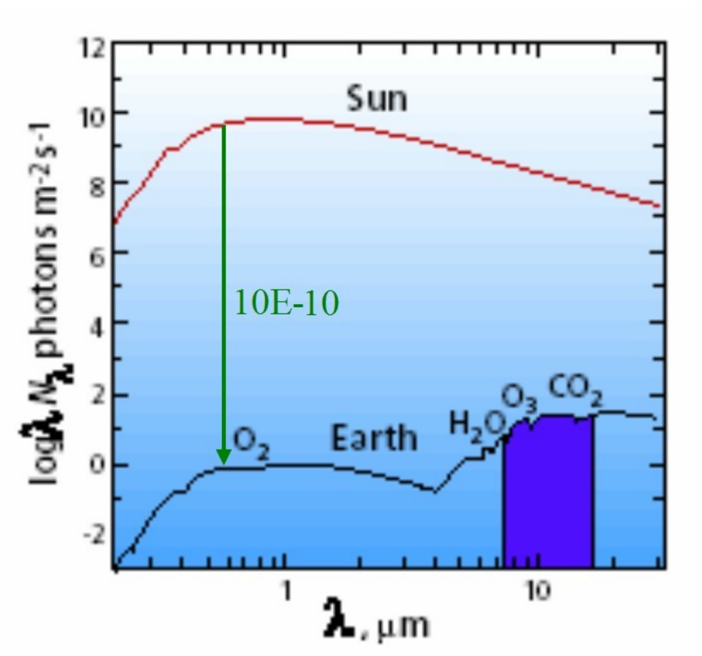




Keywords: extra solar planet detection, interferometry, nulling, null ratio, optical path stabilization

# Context of exo-planet detection

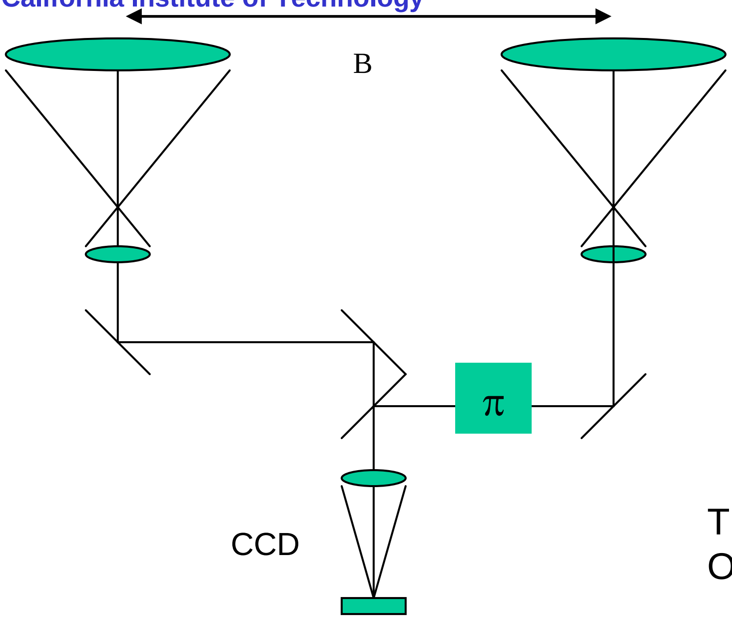
- The challenge is to observe a very faint planet near a bright star.
- The starlight needs to be cancelled. It is a contrast and resolution problem
- The Inner Working Angle is the angle inside which direct detection of a planet is not possible. IWA=N*$\lambda$/D where N depends on the coronograph type

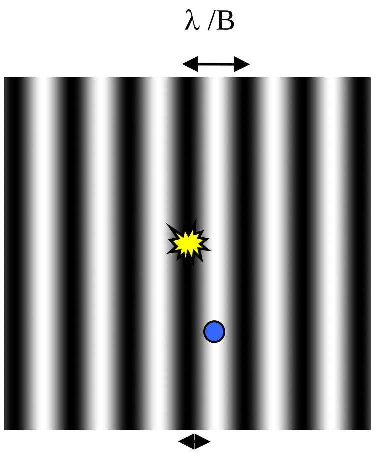


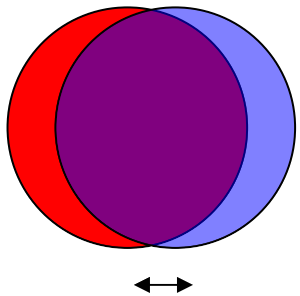

- In the visible the ratio planet/star is 10E-9 (Jup) to 10E-10 (Earth), in the infrared it is about 1000 times easier
- However the planet is brightest in visible
- a null of 10E-7 corresponds to a contrast of 10E-10 @ 1 airy spot ($\lambda$/D)
- Very large telescopes are not needed:
  - For an Earth @10pc D~1.5m
  - For a Jupiter @10pc D~0.3m only

# Planet Detection with a Nulling Interferometer




Transmission Pattern of Nuller
On the sky. (Star is at the center)




- With just one aperture the star forms an Airy disk image (of size 2.44λ/D )
- With 2 or more apertures the image is modulated by a fringe pattern of period λ/B where B is the baseline between the pupils
- The goal is to put the star on the null and the planet on the bright fringe

- A nulling interferometer can be either
  - An array or 2 or more telescopes forming a baseline B
  - Or a single aperture telescope with a mask of 2 or more apertures downstream

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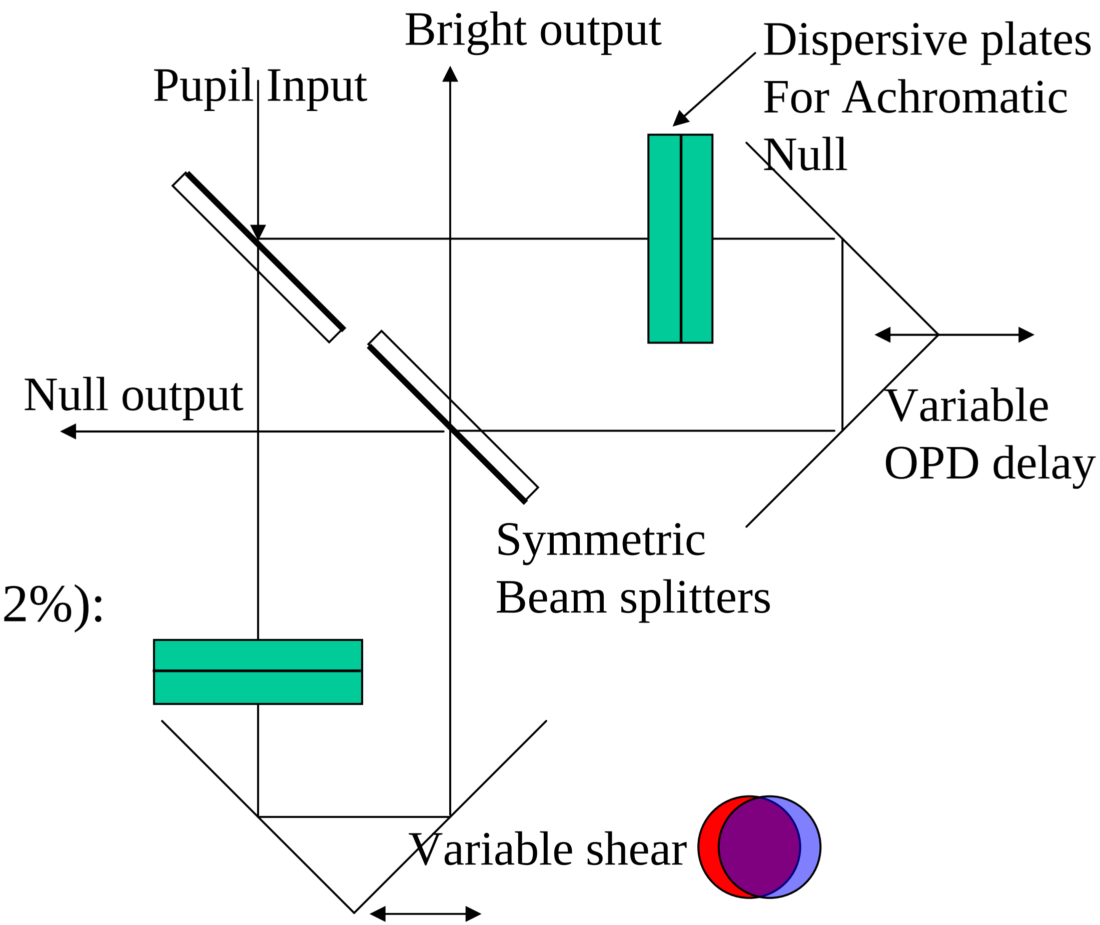
# Achromatic Nulling Interferometer

*A modified Mach-Zender to provide $\pi$ achromatic null*

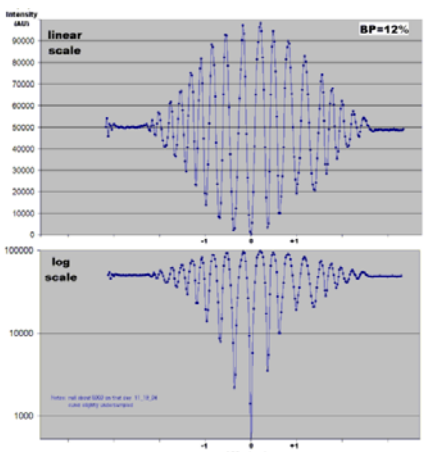
- Single pupil input
- Symmetric design
- Preserves pupil orientation and polarization
- Pupil shear adjustable– variable null baseline
- Dielectric plates provide achromatic null




Typical OPD scan (BP=12%):

Lin

Log

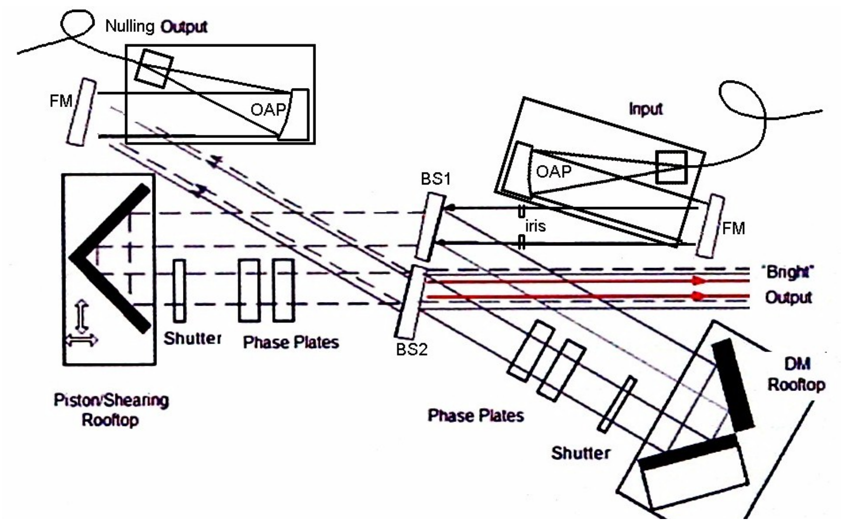


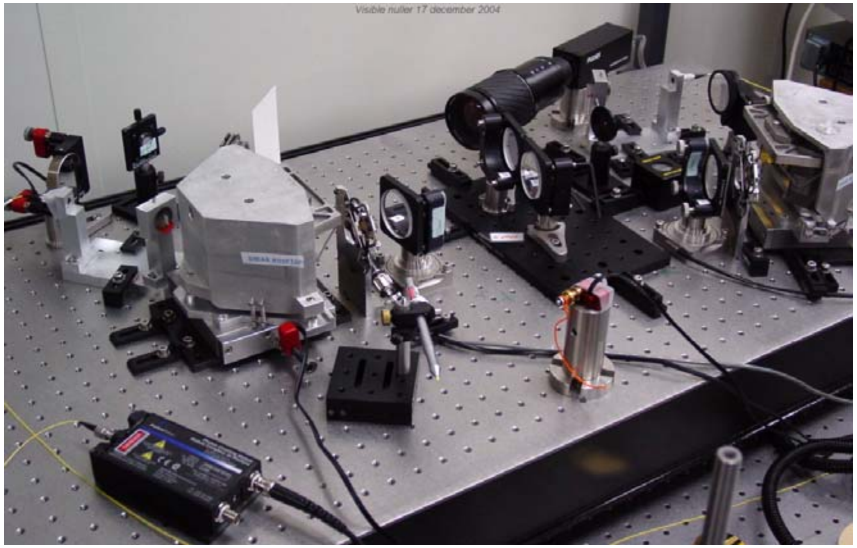

$$I_{monochr} = \frac{Io}{2}[1 - V\cos(kx)] =\sim \frac{Io}{2}\left[\varepsilon + (kx)^2/2\right]$$

$V=1-\varepsilon\ ,\ \varepsilon\sim 0\ ,\ x\sim 0$

# Experimental implementation and setup photo

**Older setup** (used between RSI research years* until Dec04):
**-rooftops arms ie 2 mirrors/arm** (rooftop to decouple OPD/shear DOF)



-Choice of various sources (laser 638nm, filtered white light, etc)
-fiber input and output (using OAPs for achromaticity)
-in each arm: disp plates and shutters
-many 'picomotors' to move mirrors, piezzo in 1 arm to vary OPD
-matched Beam Splitters, all angles 14-15deg AOI, high symmetry
-detection with various photodetectors, or APD for weak white light

*Rotational Shearing Interferometer: Serabyn Appl Opt vol38,no34 1999

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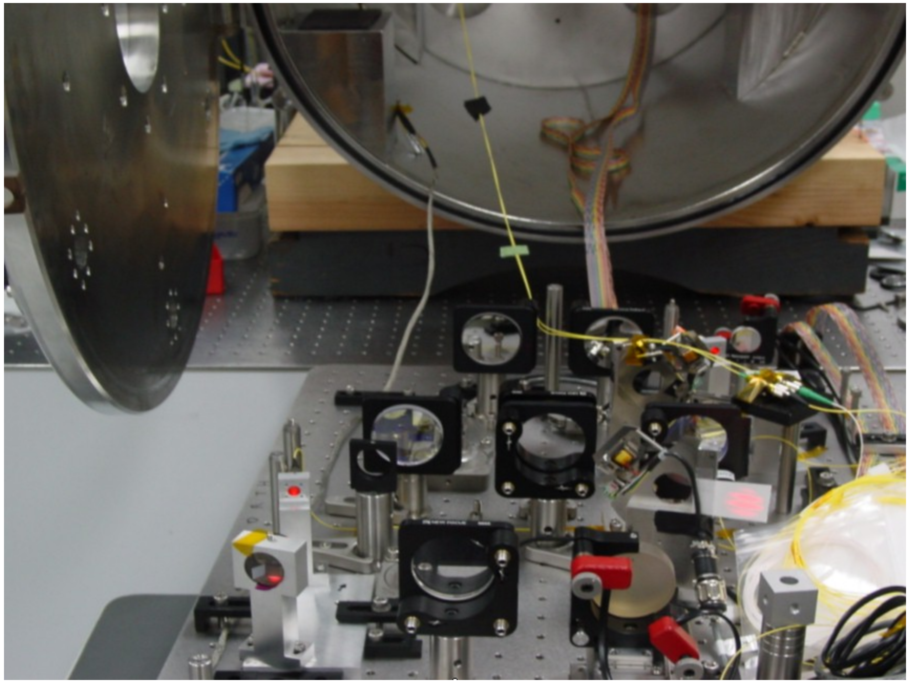
# Experimental implementation and setup photo

⇒ Need to adapt a DM in one arm, with low AOI, for upcoming projects
Layout modification needed: **from 2 (rooftop) to 3 mirrors (W shape)**
Will not change of the principle of nulling

**=>Newer setup** (mar05-sept05+):
**-3 mirror nuller with W arms**
**-vacuum tank capability**

-picomotors in and out of nuller
-longer OPD (~20inch/arm now)
-more isolation from ground
-better subnm OPD stability
-less heat devices near nuller
-many experimental fixes
-more automated control/software



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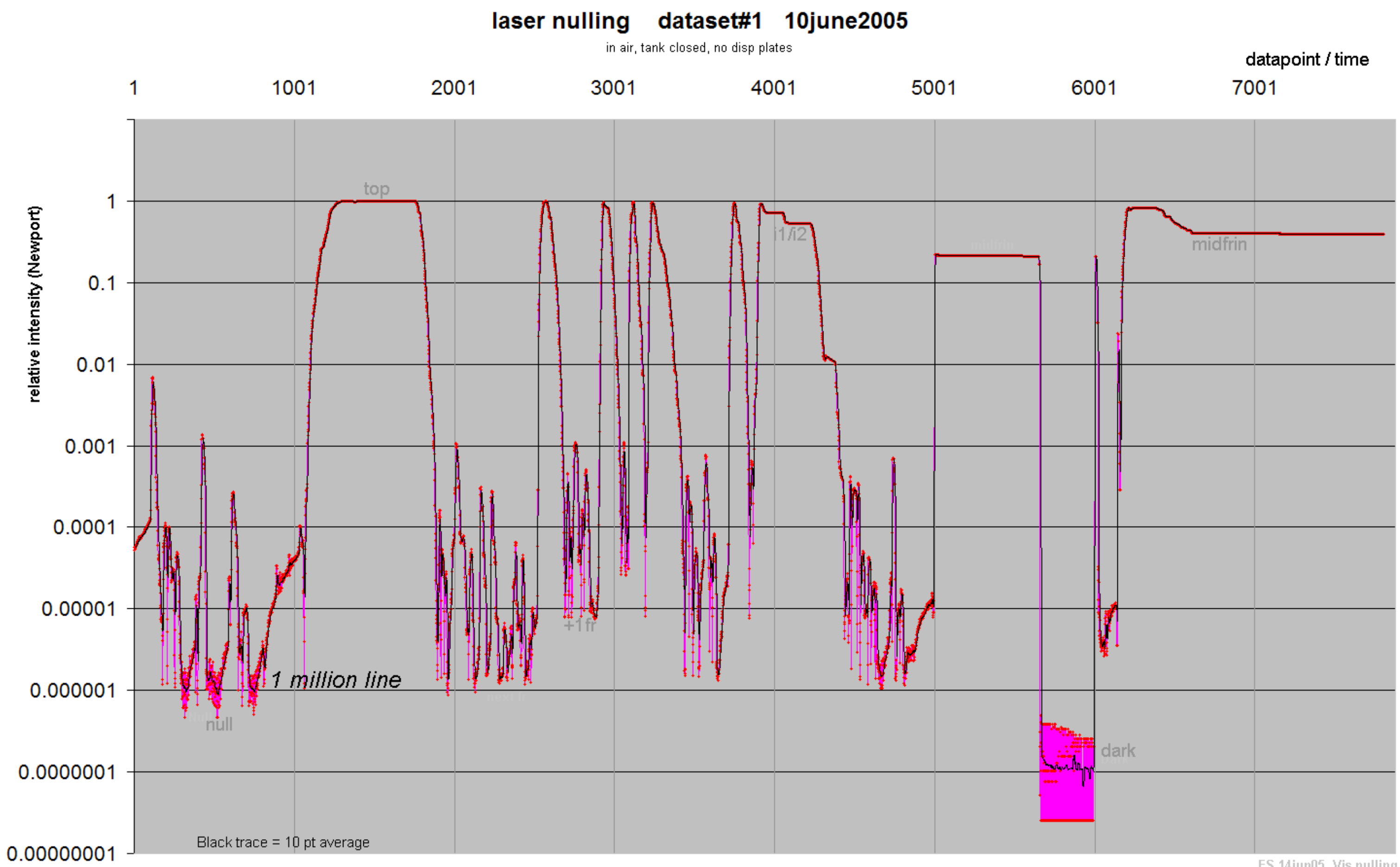
# First Million* null
## laser λ=633nm , in air, manual

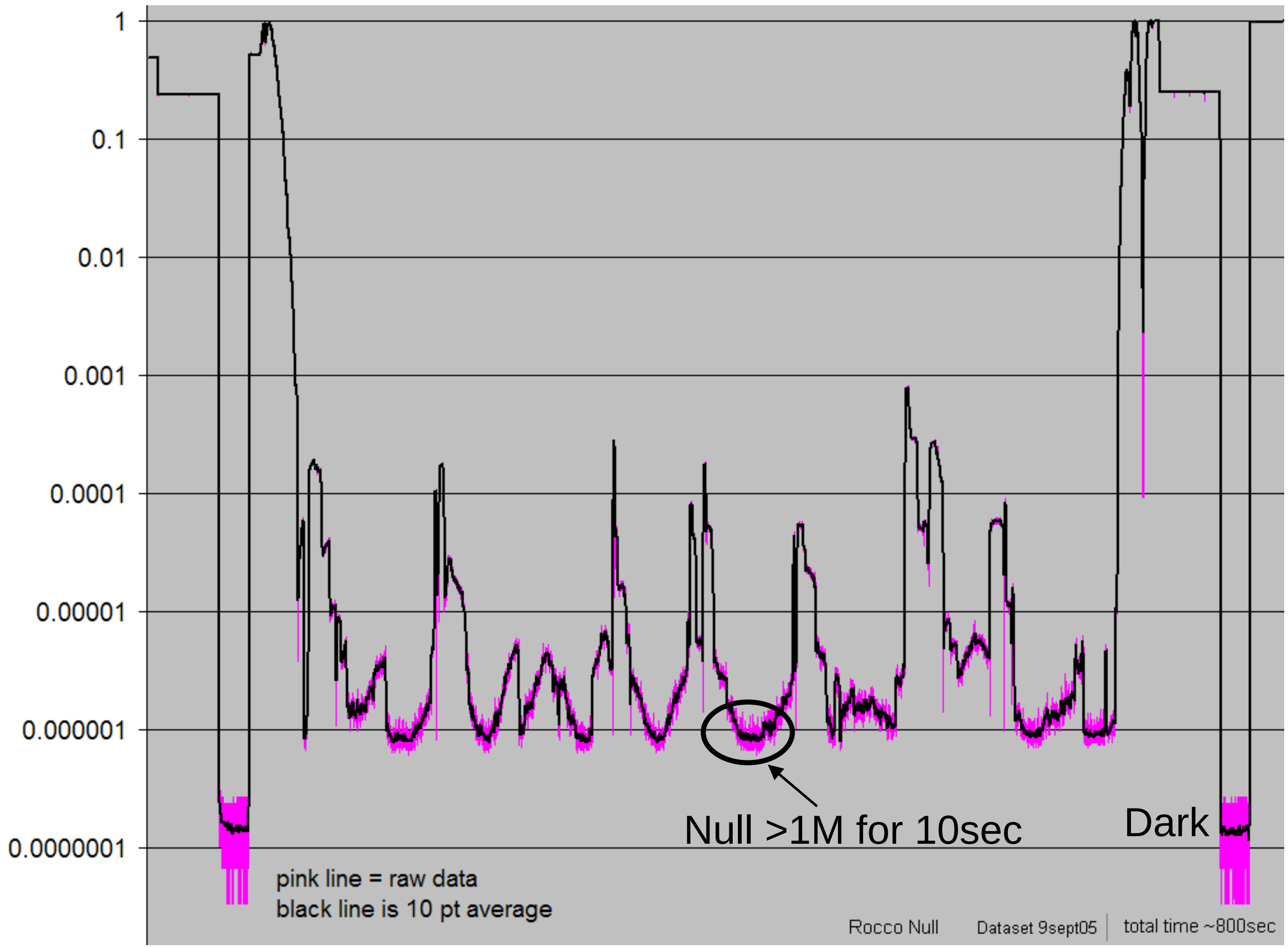



**Other parameters: raw data (corrected improve 1.1x), no shear, 20mm diam beams, rate=25Hz, detection=Newport powermeter, zero OPD 'surfed manually'**

***In this presentation we consider only *average* (typically 10pt @ 25Hz) values, not 'transcients'**

# Newer Million+* null plot

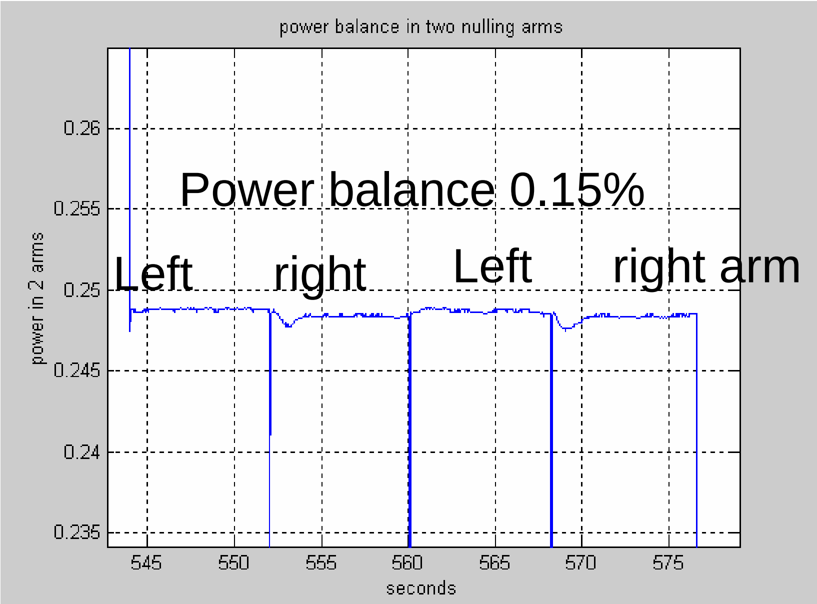
## laser , λ=633nm , in air, semi automated

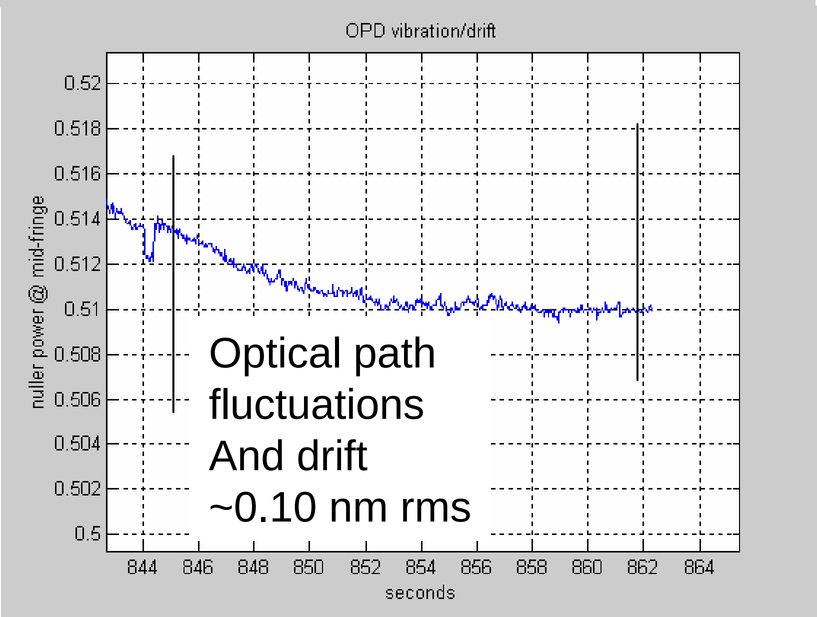



**⇒ 1M line easily crossed. Here about 1.2M* raw null, 1.4M* dark corrected null**

***In this presentation we consider only *average* (typically 10pt @25Hz) values, not 'transcients'**

# **Diagnosis**
# of the 1.2M null




Many many factors can degrade a null.
Two are easy to access:
-midfringe analysis/PSD => **OPD noise**
-i1/i2/i1 light trace => **power unbalance**

- 0.15% imbalance limits null to 2.8e-7
- 0.1 nm rms opd limits null to 2.5e-7
  - Sum of amplitude and phase errors => ~5e-7 versus 7e-7 measured.
- Possibly both amplitude and OPD stability to improve by 3~5x when chamber is pumped
- Current experiment could get 1~2e-7 nulls ( 1~2e10/airy spot)
- Third factor to fight could be polarization/angles

# Limits of our current 1M null

***what to improve to get to 2M…***

(all other reasons solved)

**1-OPD noise** from combination of reasons

-ground borne path: use efficient isolators

-acoustic: need of vacuum (but drifts seen in all vac sessions)

**2-powermatching:** Power balance I1/I2 needs to be at 1% for 10K null (easy) and 0.1% level for 1M null (harder)

-technique of mitigation of Airy spot positions on fiber core

-recent investigation of thin wire occultator

**3-possibly angular/alignment/polarization** issues:

-may need to align the AOI's of optics (15deg) to arcminutes

-attention to coatings, wedge values, wedge clocking, etc

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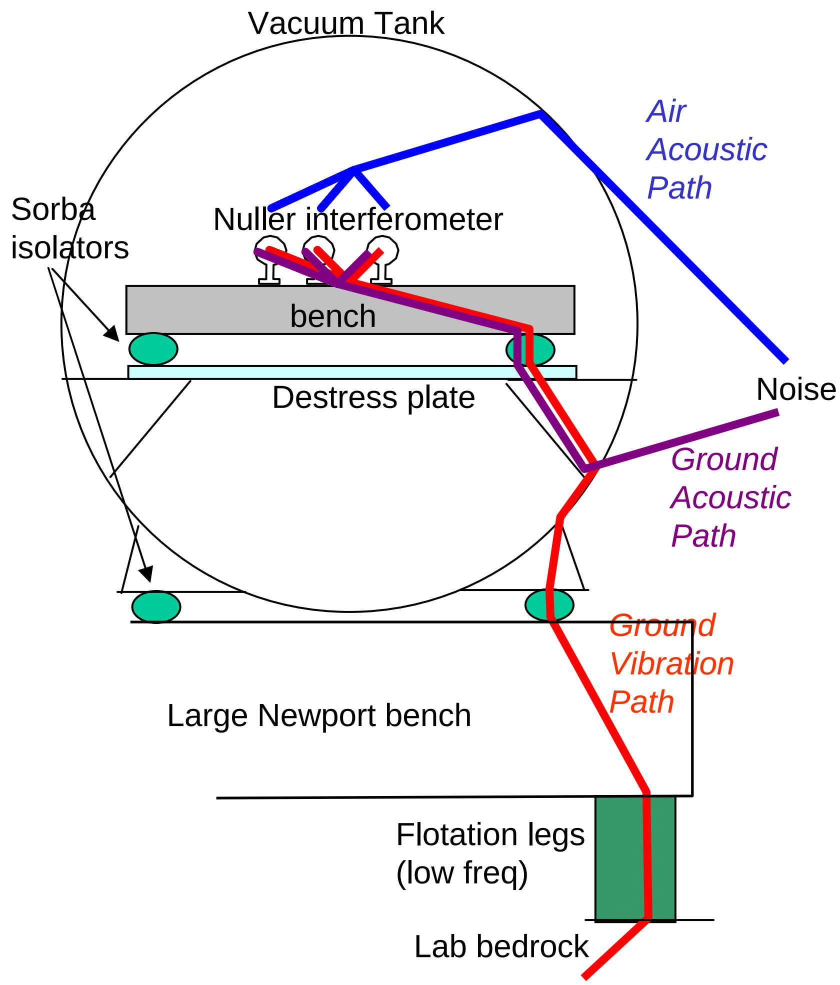
# Environmental conditions




At the 100K-1M level ambiant noise/vibrations must be reduced such as Air Conditioning, computer fans, vac pumps, even conversations and street traffic…

-AAP can be removed with silence and 100% with vaccum

-GAP can be suppressed a lot (not 100%) with sorba isolators

-GVP can be reduced by floating the table and operating on evenings/weekends

Turbulence varies OPD slowly: remove heat devices and pump vacuum

Diagnosis tools: Midfringe/PSD analysis, fringe-o-phone (to diagnose local opto/mec instabilities and resonances)

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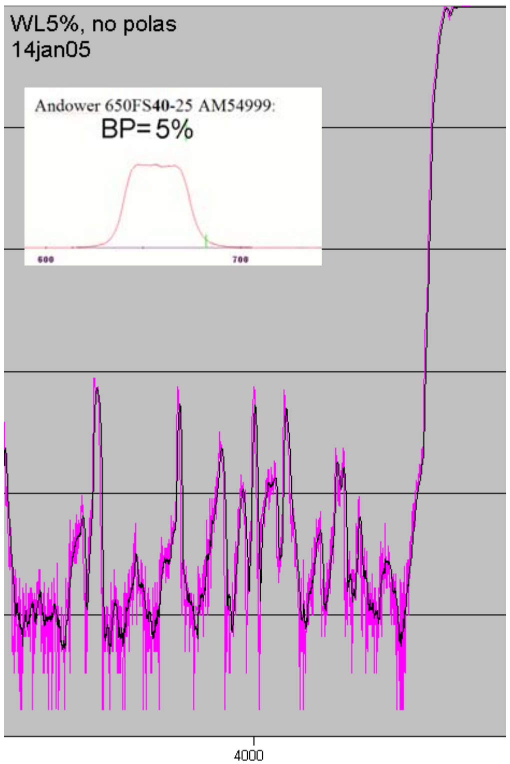
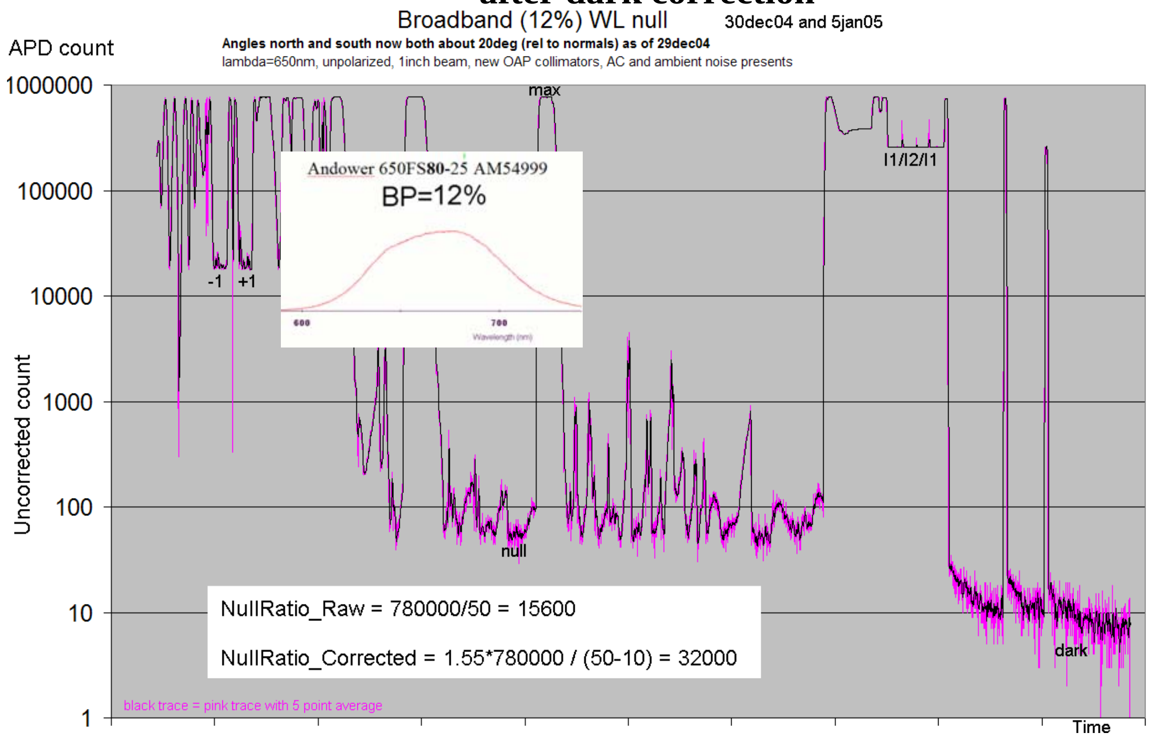
# Broadband null plots

**Filtered white light (λ=650nm), in air, two polarizers, 1 disp plate (glass type) per arm**

## BP=5%
## ~ 120000:1 null
**after dark correction**

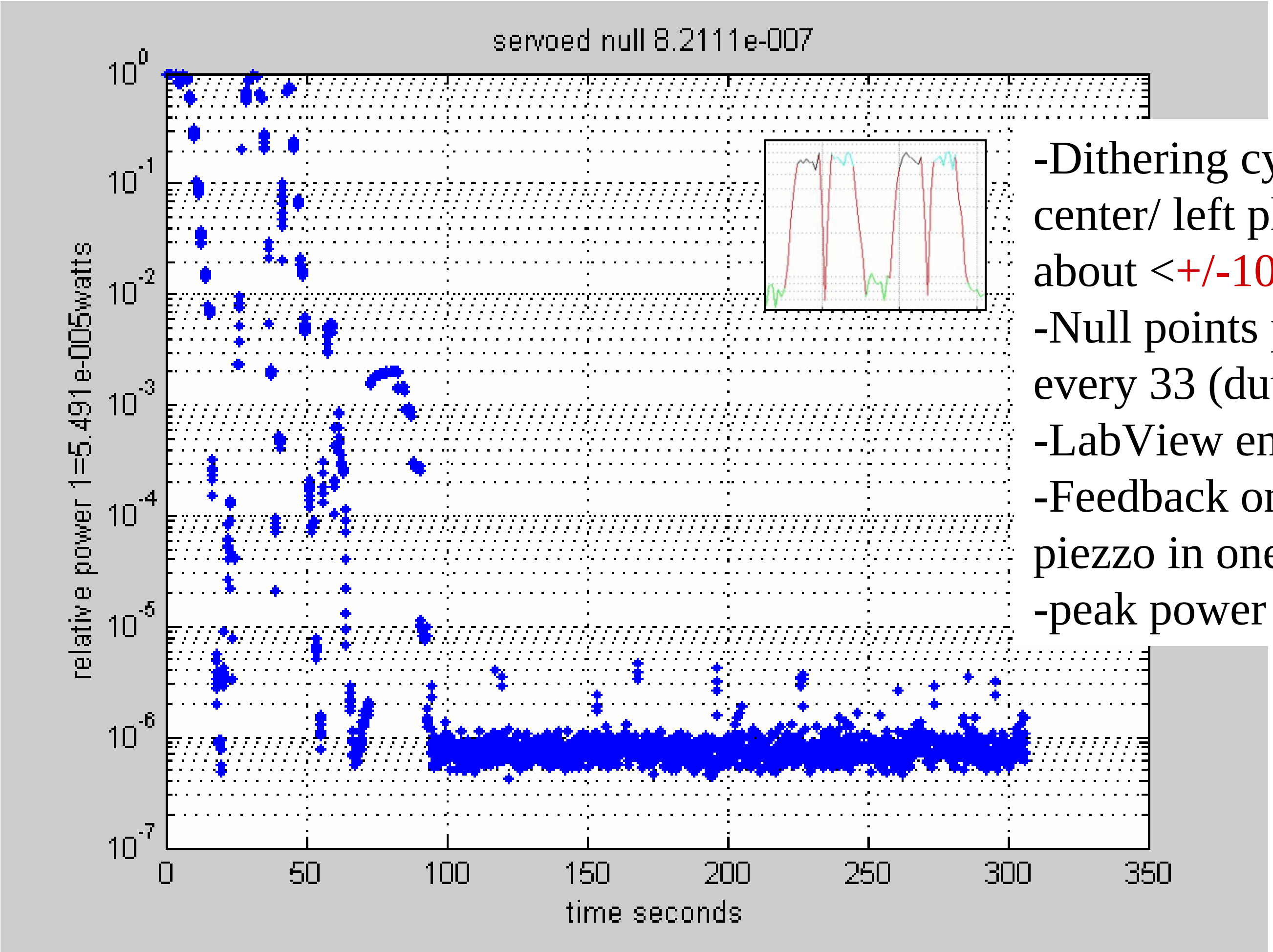
## BP=12%
## ~ 32000:1 null
**after dark correction**




**These 2 results using the 'Old' setup**

# Latest result: a 1M servo laser null




- Dithering cycle with right/ center/ left plateaux and span about <+/-10nm, rate~1Hz
- Null points plotted: 8 out of every 33 (duty cycle 25%)
- LabView environment
- Feedback on opd piston piezzo in one arm
- peak power 55uW

**Average null ratio is 8.2e-7 ie 1.2M**, over ~200s, after dark correction
Data obtained by R. Samuele and S. Fregoso on Sept 23rd, 2005

# Conclusion and future Work

Using a modified Mach Zender interferometer as our nuller tesbed we have developed technologies and reached deep nulls needed for future NASA missions such as TPF, or PICTURE (an upcoming sounding rocket experiment):

**-laser light (633nm): 1Million:1 null (average) or a little better**
**-broadband white light 120K:1 @ BP=5% and 32K:1 @ BP=12%**
**-Latest news: recently obtained 1M:1 servo null (laser)**
**-All this *without* pumping vacuum yet!**

We are only 10x away from TPF's goal of 10E-7. Using a combination of a fiber array and deformable mirror a null of 10E-7 would correspond to a contrast of 10E-10 ($\Delta$mag=25) at 1 Airy spot

Future plans:
-progress on deep laser nulling (goal of 2M soon, then eventually 10M)
-parallel effort on broadband (WL) nulling up to 20% (goal of 1M@5% soon)
-introduce certain parameters and devices for upcoming experiments such as shear, DM modulation, fiber array filtering, downstream addition of calibration system, more remote control, more end to end system

# Conclusion and future Work

Mettre  equa cos avec phi et esp

Mettre graph des 3 nulls

Dessin spider

Faire repete