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Ultra-high resolution heterodyne spectroscopy for Venus atmospheric studies

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and IVOLGA team

Why

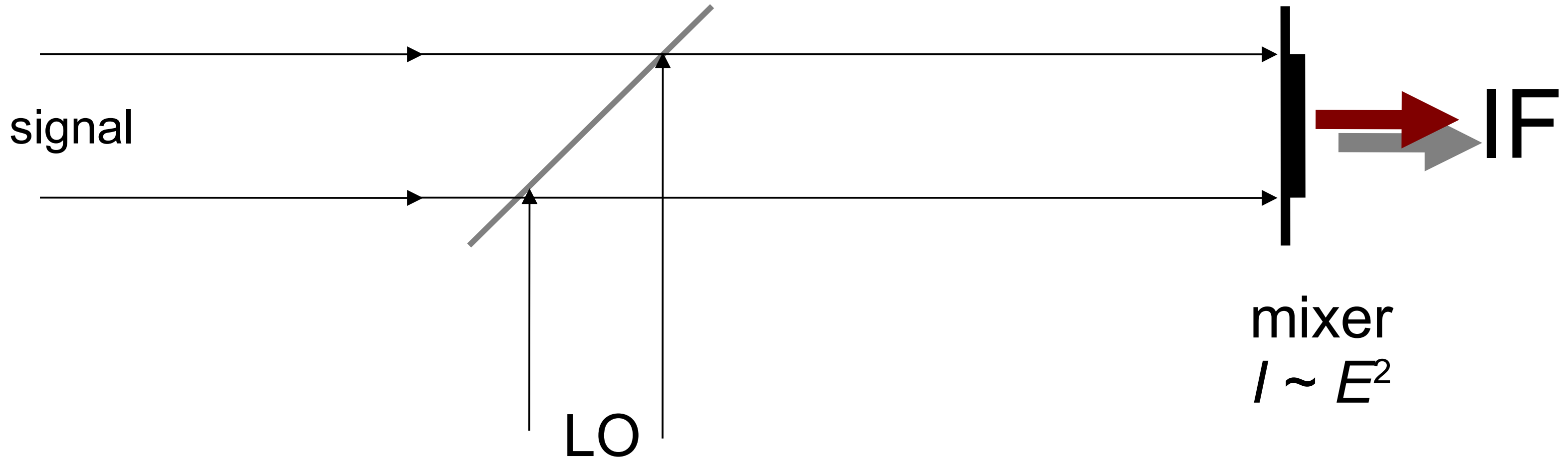
ultra-high resolution?

- Trace gas analysis
- Isotopic ratios
- Vertical profiling of pressure & temperature
- Doppler wind measurements

Etc...etc...etc...

Why heterodyne?

- Signal level decreases with channel bandwidth
- Noise level is invariant
- Heterodyning is the only method to provide acceptable S/N at ultra-high resolution



First paper on the optical heterodyning, 1956

Горелик 1956.pdf — r567e.pdf

1956 г. Июль *Т. LIX, вып. 3*

УСПЕХИ ФИЗИЧЕСКИХ НАУК

ГЕТЕРОДИНИРОВАНИЕ СВЕТА

С. И. Боровицкий и Г. С. Горелик

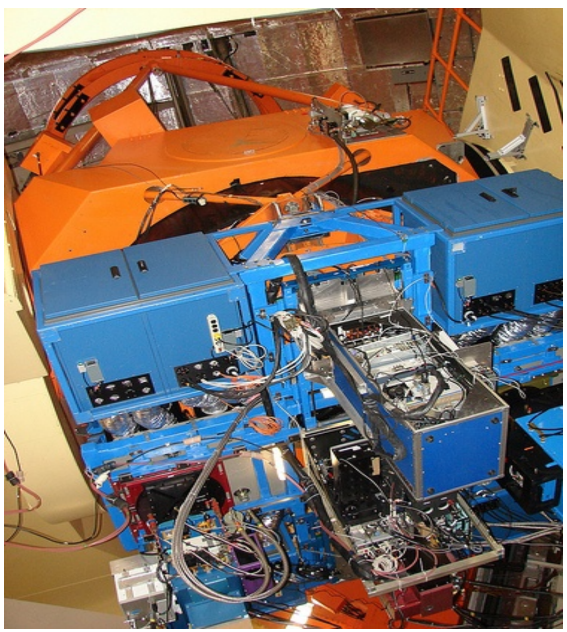
Недавно появилась статья Форрестера, Гудмундсена и Джонсона [1] с описанием опытов, в которых им удалось получить одно из явлений, которые могут быть описаны как интерференция двух некогерентных световых излучений. Американским исследователям удалось осуществить с помощью специально разработанного для этой цели фотоэлектрического преобразователя гетеродинирование, или, как они выражаются, смешение (mixing) двух оптических спектральных линий, разностная частота которых принадлежит к области сверхвысоких радиочастот.

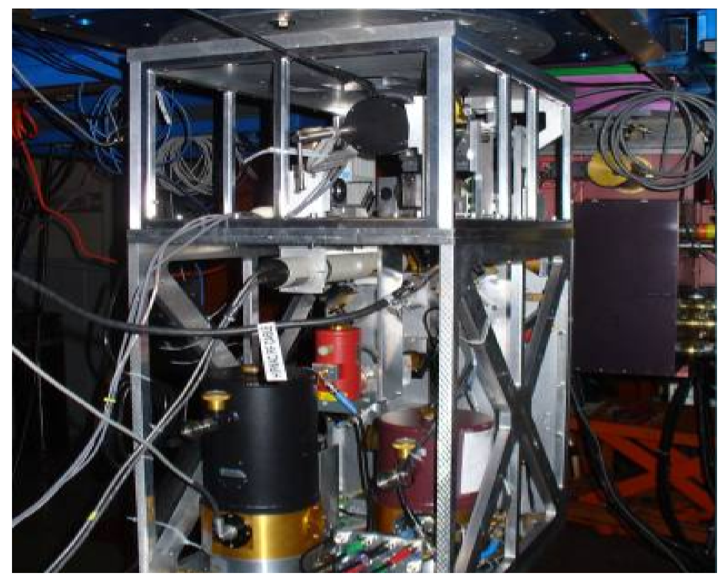
Spectral range

освоено в гетеродинной спектроскопии:

THIS@NASA IRTF (Sonnabend *et al.*)	9 – 12 μm	(QCL)
IRHS@NASA IRTF (Kostiuk et al.)	9.5 – 12 μm	(CO_2)
HIPWAC (Kostiuk et al.)	9.5 – 12 μm	(CO_2)

No heterodyne instruments at 1-6 μm yet!





Instruments operating in thermal IR are heavy and extremely fragile
Moving to shorter wavelength may be a solution
but decreases signal level by few orders. Solar occultations?

Problems

- shot noise

- LO stability

- low angular aperture

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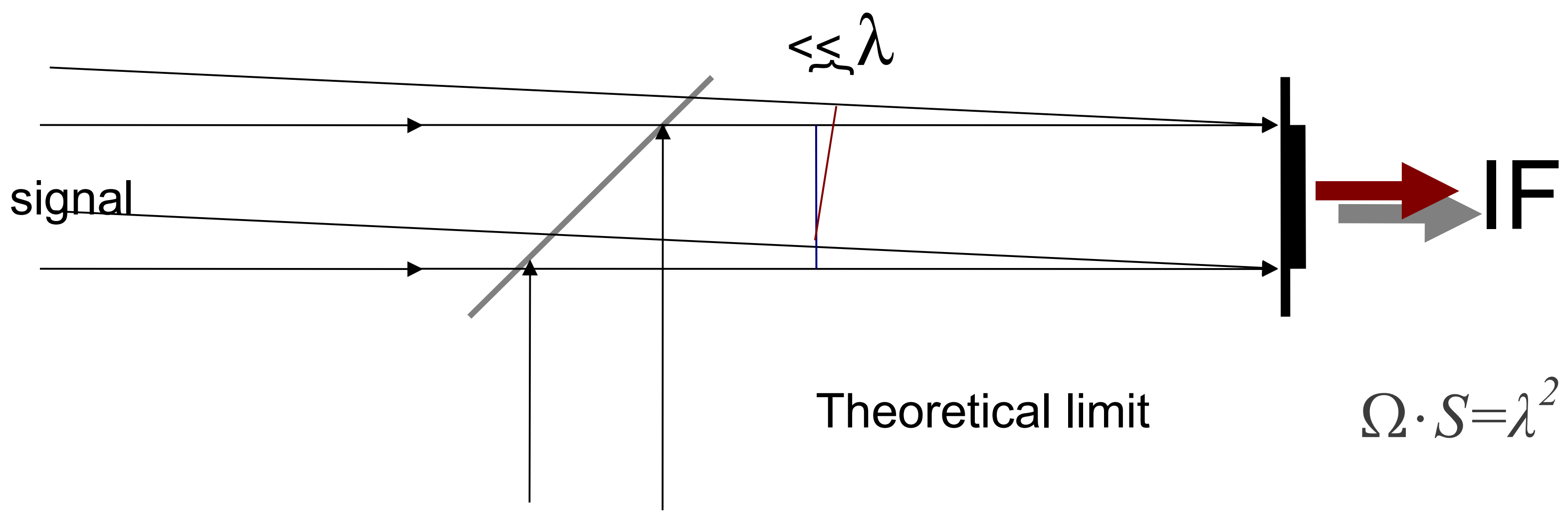
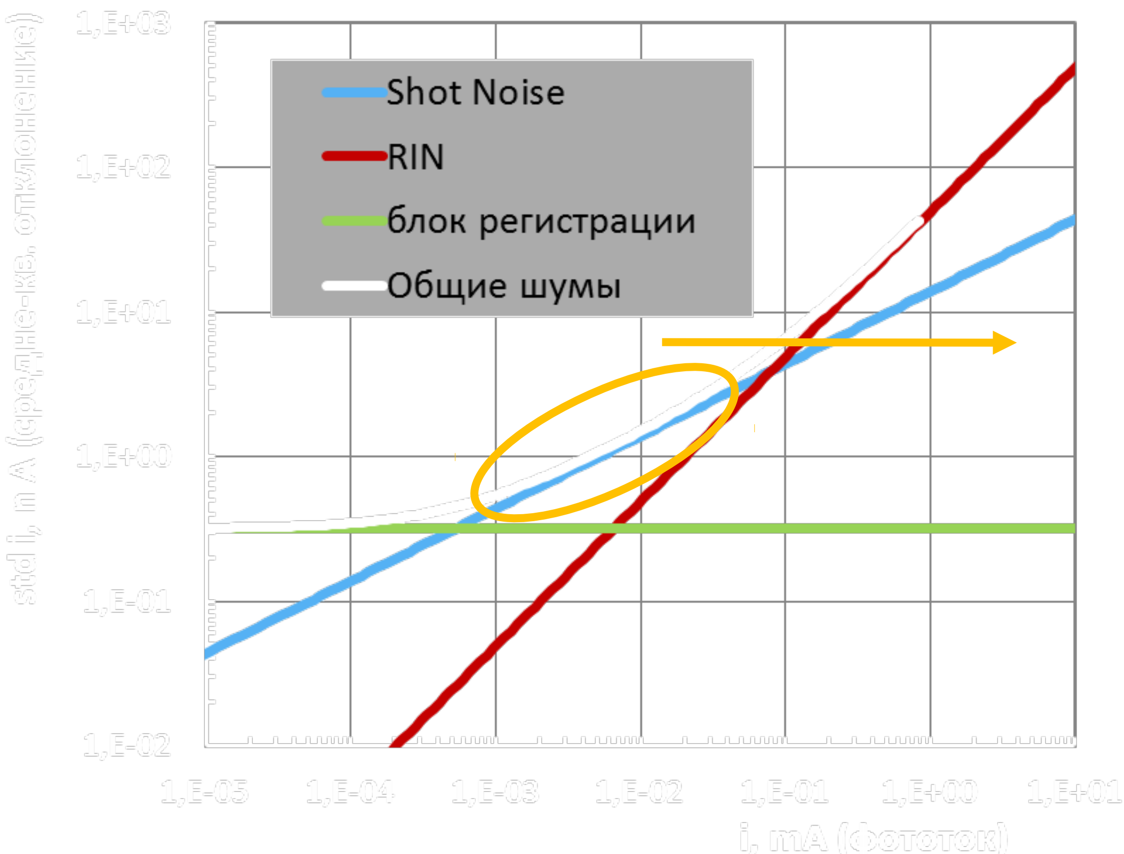


Noise estimate:

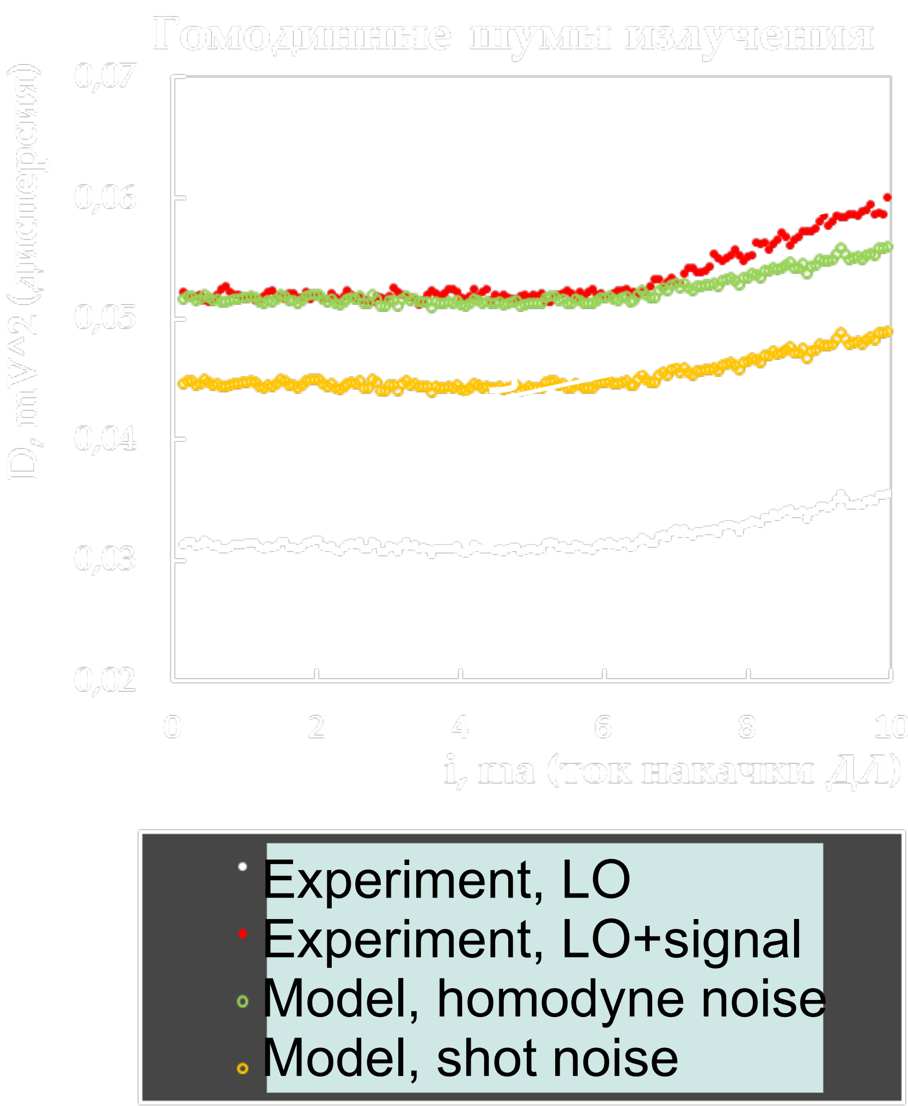
Noise vs photocurrent



There is an optimal area where shot noise dominates
Corresponding LO power ~ 2-20 μW

Homodyne noise detected:

First detection of beating between close component of the broadband signal [Forreter *1961*]



Homodyne noise $D_{HOM} = i^2 \frac{BR^2}{2\Delta w}$

Shot noise $D_{SN} = ieBR^2$

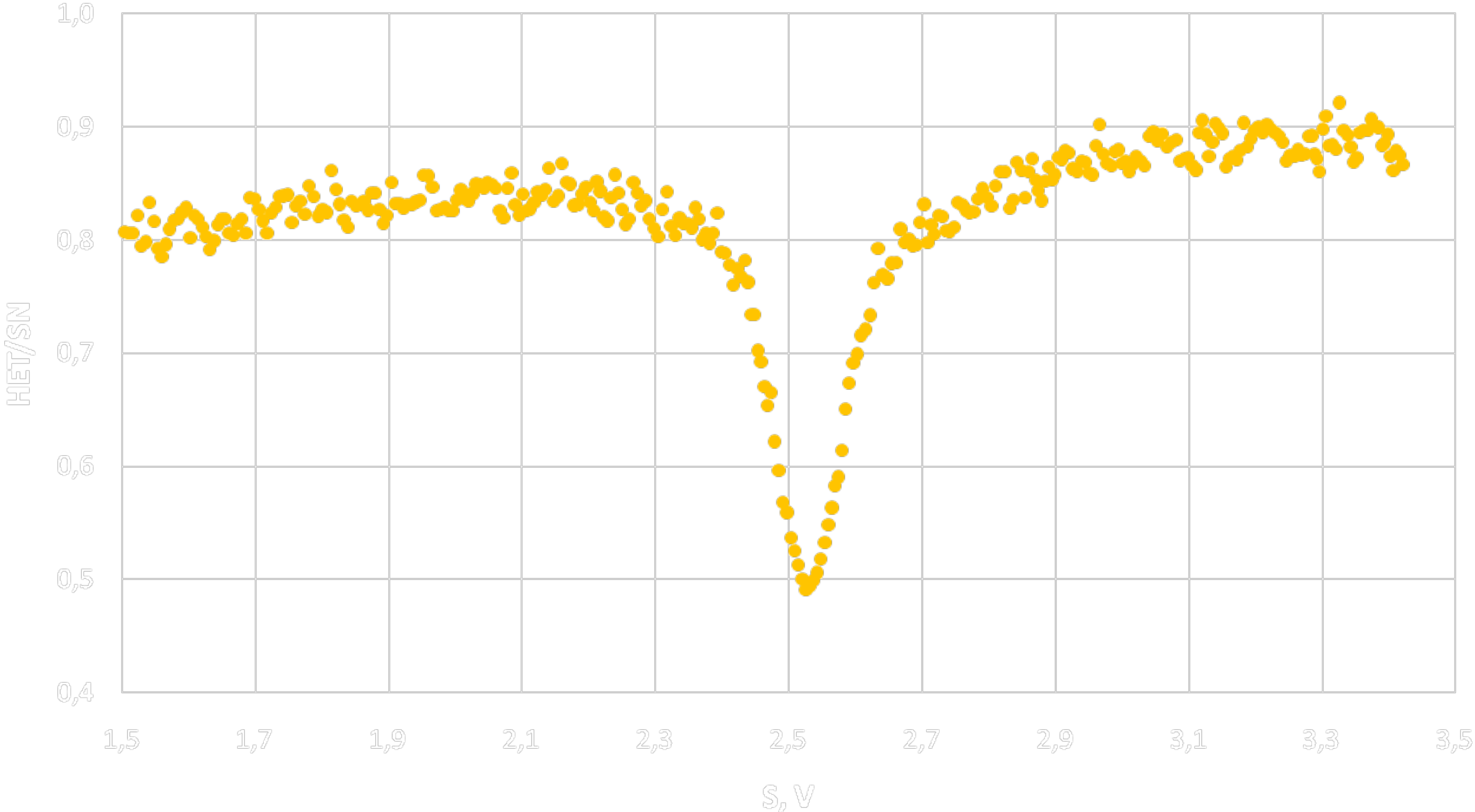
Δw - FWHM

$$\frac{D_{HOM}}{D_{SN}} \sim \frac{e}{G}$$

G – radiance spectral power

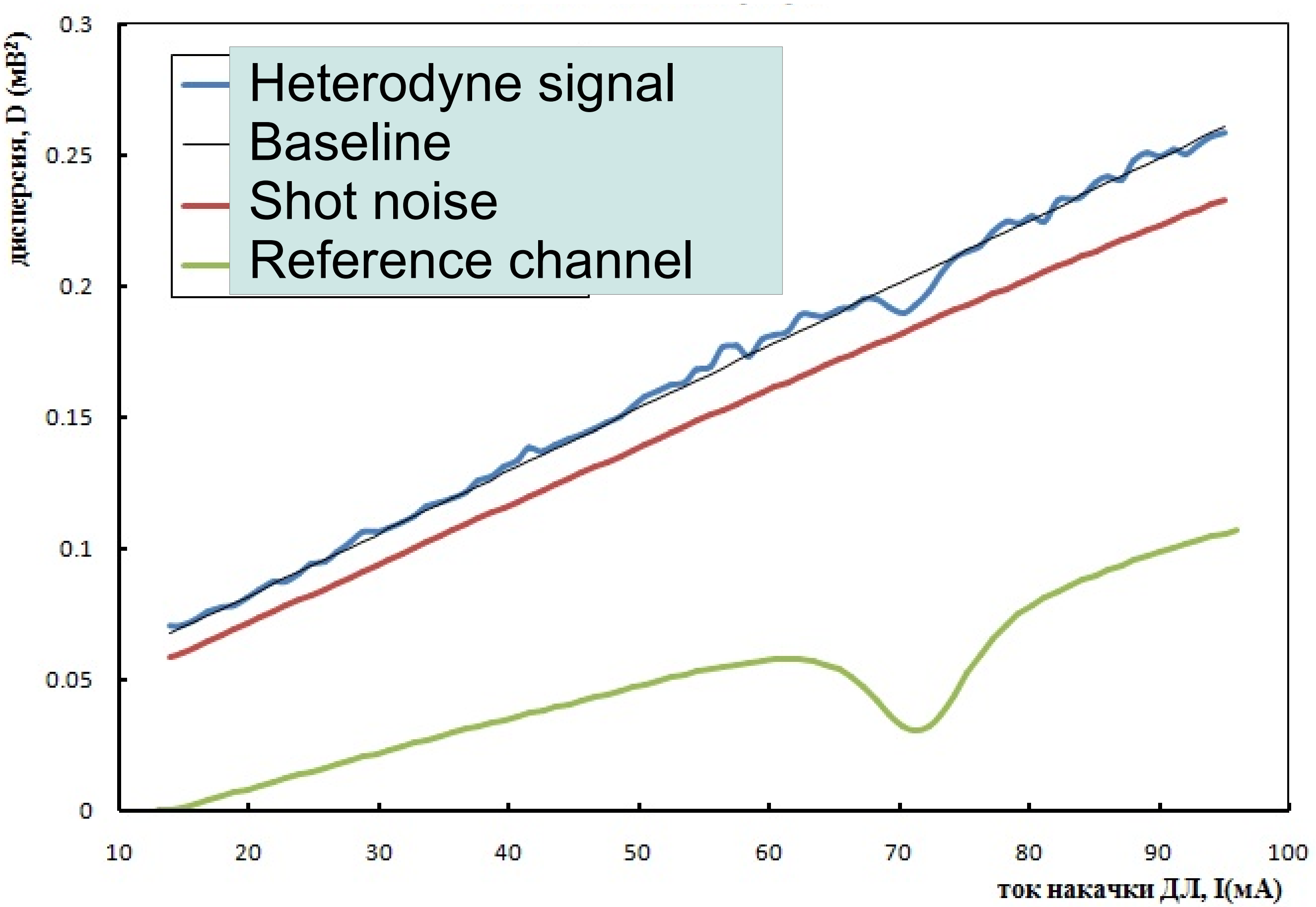
Homodyne nose needs to be accounted for while detecting weak signals

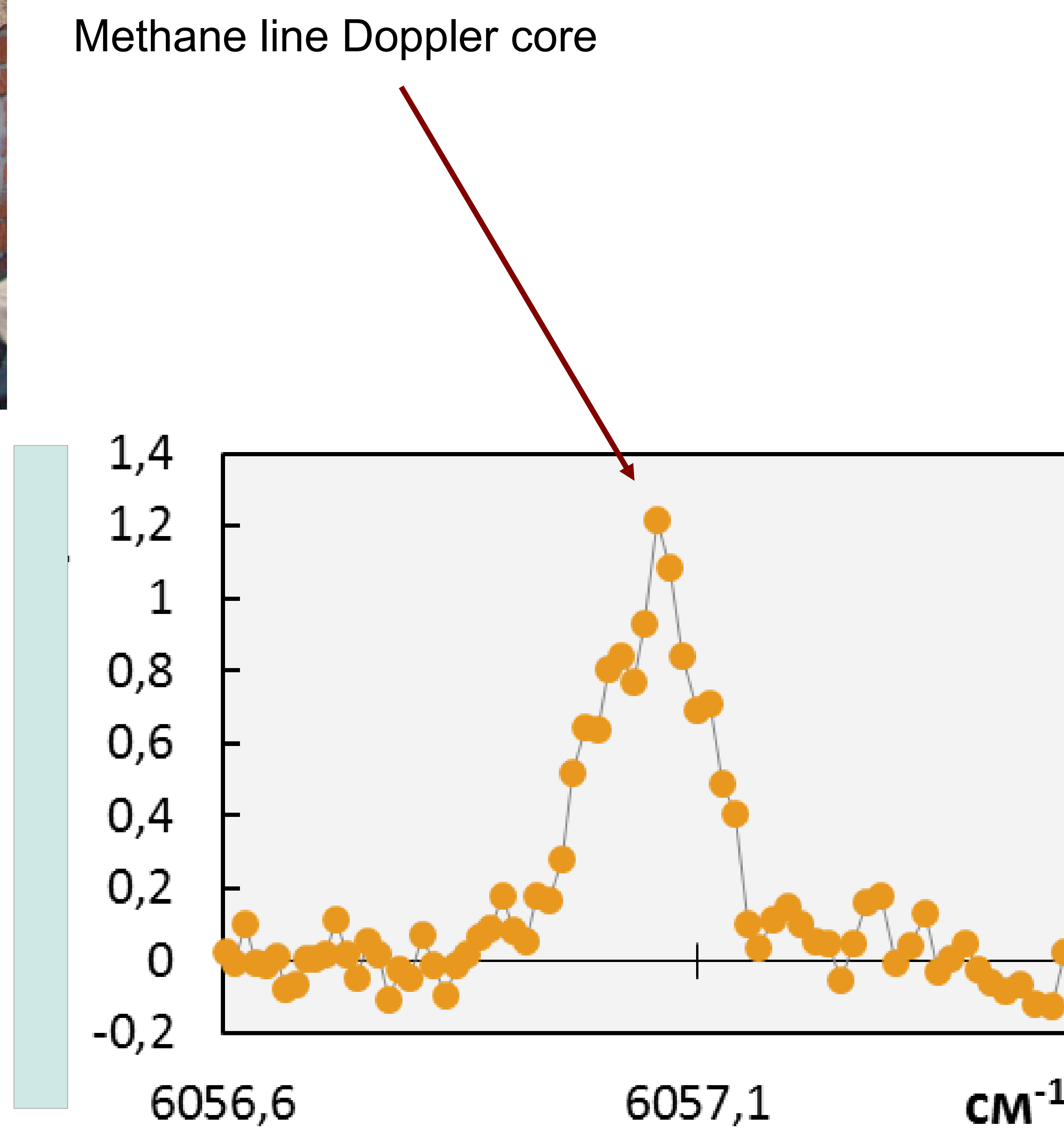
H_2O absorption line



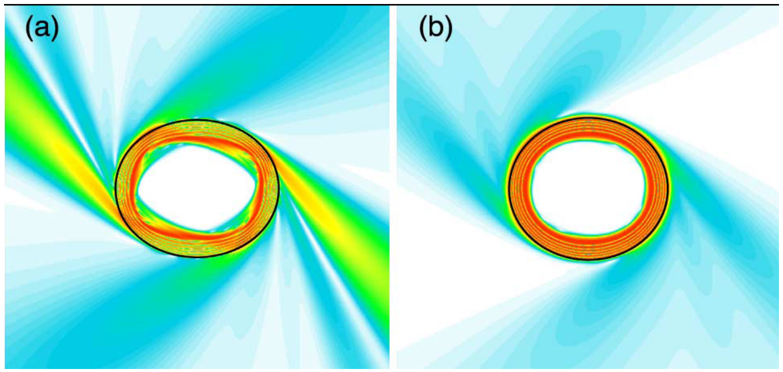
T=28.6 0C
v=7182.15588 см-1

CH_4 absorption in the atmosphere



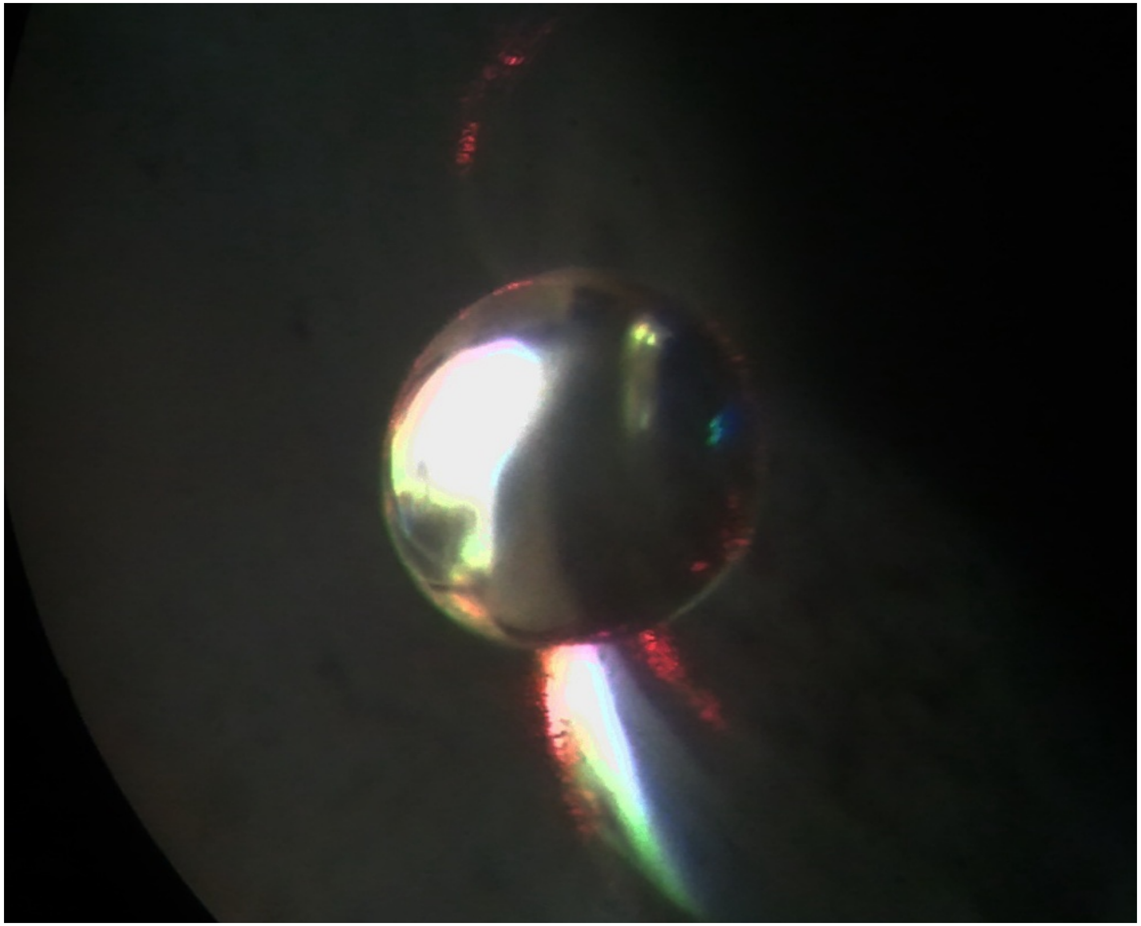

Methane line Doppler core
1,4
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
6056,6
6057,1
см-1

Chaos-based entrance device allows to overcome aperture limit



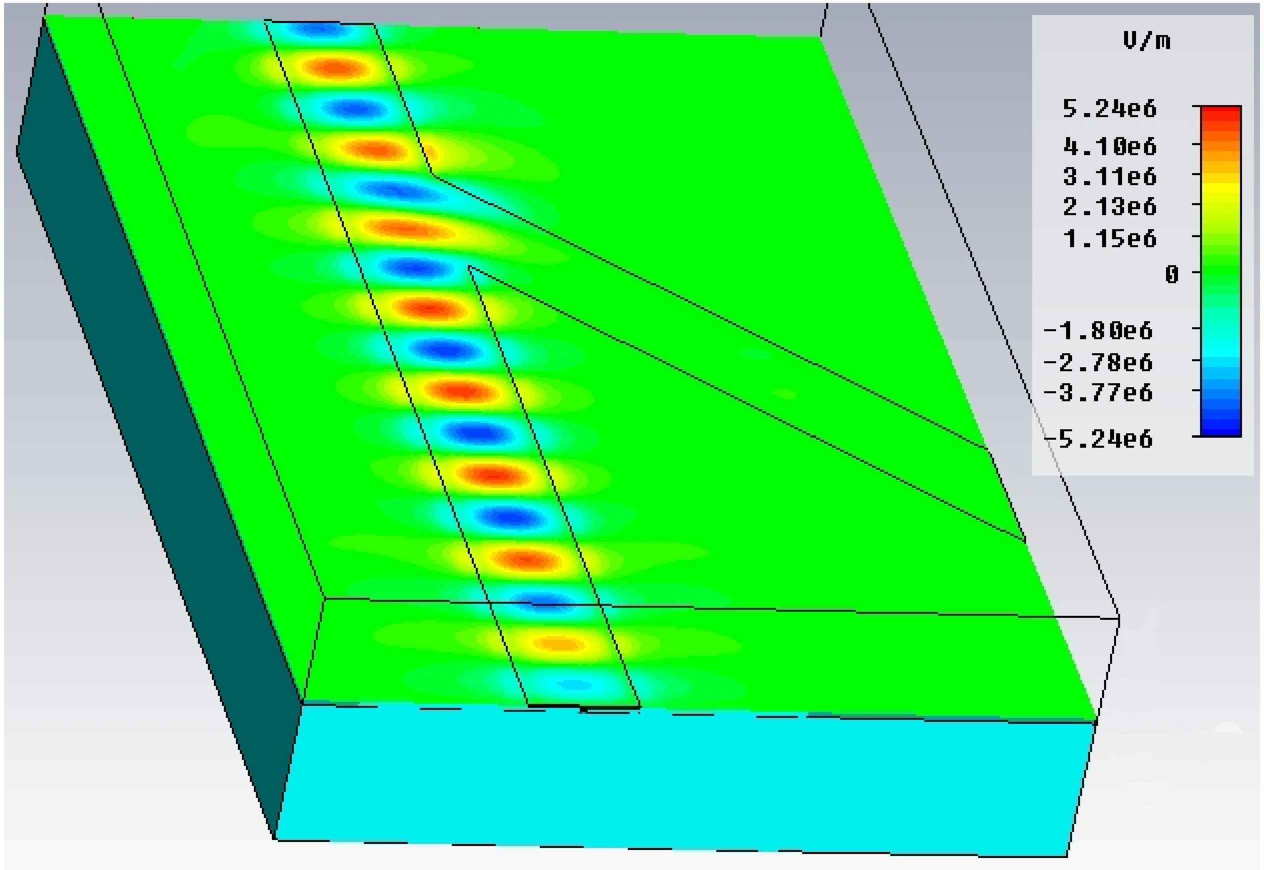
S. Lacey et al. 2003

Spheroidal resonator is capable to radiate within 30°. Connection of a resonator with a single mode fiber is provided by their tight approaching near the area of fiber deformation



First model of a non-spherical WGM resonator. Diameter ~0.4 mm

Integral optical chip may replace single mode fiber optics in the mid-infrared



Conclusion

An orbiter-based ultra high resolution heterodyne spectrometers in NIR and MIR spectral ranges are highly demanded in Venus atmospehric studies. Current state of research and technologies allows to plan such instruments for the closest Venus mission

Thank you!