Spectroscopie haute résolution et mesures de fréquences

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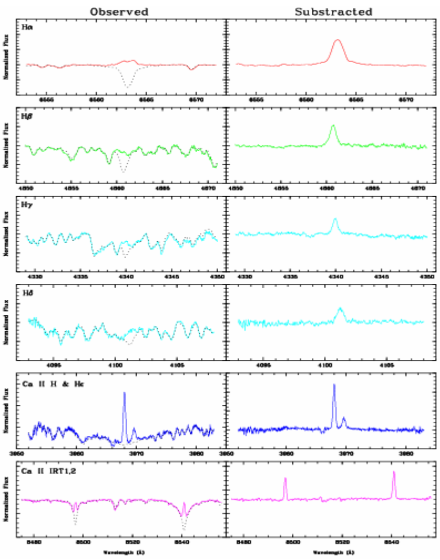
Exemples

Spectroscopic Analysis

- **Kinematics (U, V, W).**
  - Radial velocity (Vr)
- **Age** (LiI 6707.8Å).
- **Chromospheric activity**
  - CaII H&K to CaII IRT
- **Rotation** ($v$sen$i$).
  - Activity – rotación relation
- **Stellar parameters.**
  - T_{eff}, log g, ξ and **[Fe/H]**
- **Absolute and differential abudances.**
  - Chemical tagging



Chemical abundances

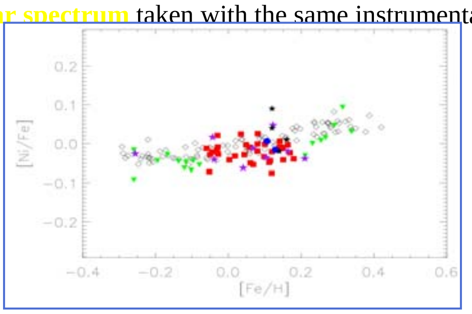
Fe, Na, Mg …..

Fe, Na, Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Co, and Ni

- **EW** method in a line-by-line basis with *ARES* code (Sousa et al. 2007).

- Line lists and atomic parameters from (Neves et al. 2009; González Hernández et al. 2010).

- Abundance analysis with *MOOG* (Sneden 1973) using our determined atmospheric parameters and a solar spectrum taken with the same instrumental configuration.



[Ni/Fe] vs [Fe/H]: open diamonds represent the thin disk data (González Hernández et al. 2010), black filled triangles represent Hyades cluster data (Paulson et al. 2003). Red points are our stars compatible with Hyades Fe abundance, and the green ones not compatible. BZ Cet and HD19902 Hyades cluster members are marked with blue circles. Purple starred points represent the giant stars. Black starred points are the candidates selected stars in De Silva et al. (2011), black circles are those selected in Pompéia et al. (2011).

Plan

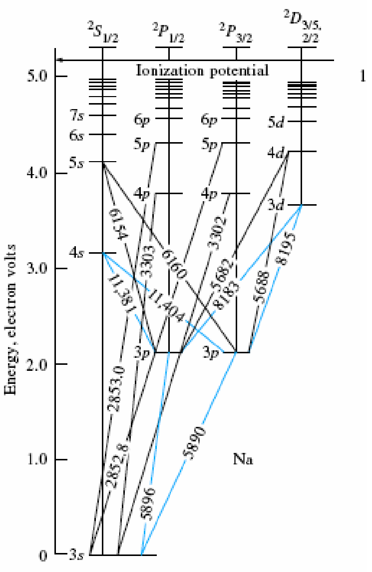
1. Spectroscopie haute résolution
2. Effets d'élargissements
3. Méthodes « Doppler-free »
   – 2 photon
   – Absorption saturée
4. Mesure de fréquence

- spectre de I_2
  - monochromateur
  - détection optogalvanique
  - lambda-mètre,
  - chaîne de fréquence
  - peigne de fréquence

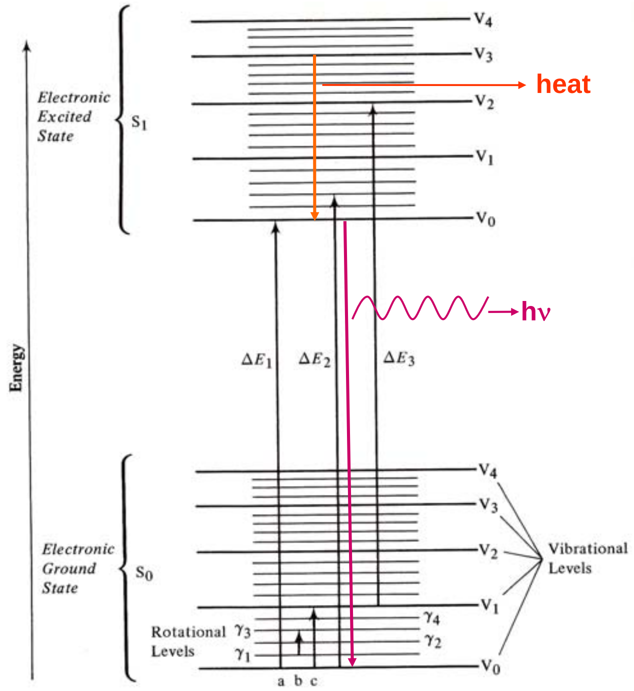
1. Spectroscopie haute résolution

- **Spectroscpie atomique**: peu de raies, typiquement energie élévées (visible, UV)
- bcp de données connues, aussi de l'astrophysique

- **Spectroscopie moléculaire**: melange de transitions electronique et ro-vibrationelle
- situation bcp plus complexe



(a)



Lowering of energy to the lowest vibrational and rotational level within the same electronic level

The remainder of the energy is the radiated, returning to the ground state

1. Spectroscopie haute résolution

- Å, nm, cm^{-1}, (kayser), MHz

- haute résolution temporelle – spectrale

  $\Delta\nu = (2\pi\tau)^{-1}$

$$\Delta\upsilon = \frac{1}{2\,\pi\tau}$$

largeur de raie naturelle

- principe d'incertitude de Heisenberg pour un paquet d'onde

  $\Delta x \cdot \Delta p_x \geq \hbar/2$ ou $\leftrightarrow$ $\Delta E \cdot \Delta t \geq \hbar$

2. Effets d'élargissement

(1) Dans un jet : temps de transit

(2) Agitation thermique : effet Doppler $\frac{\Delta \upsilon}{\upsilon} = 7.16 \times 10^{-7} \sqrt{\frac{T}{M}}$

(3) Modification de la durée de vie : collisions

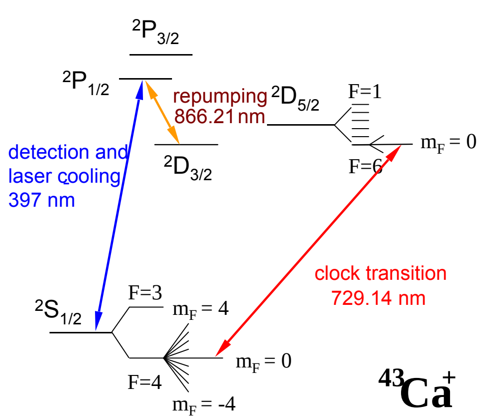
(4) Par un champ externe : Zeeman, Stark

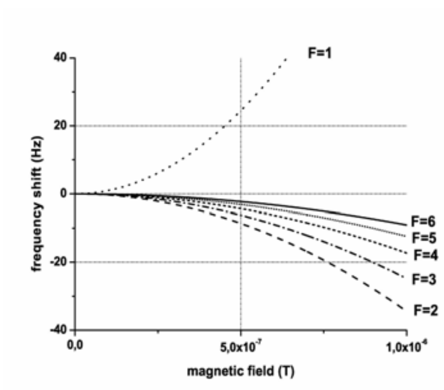
(5) Par saturation

(6) ...

Effets d'élargissement et de déplacement (broadening and shift)

Line broadening and shift





Effets systématiques - $^{43}Ca^{+}$

effet	*proportionnel à*	*condition*	*δf [Hz]*	*δf/f*
DC Stark * (corps noir)	$5.7+2.1\times\frac{1}{2}(3\cos^2\theta-1)$	1V/mm T=300K	**0.39±0.27**	**9.5(±6.5)x10^{-16}**
quadrupole shift	$-8.1\times10^{-7}\left(\frac{1}{2}\frac{\partial^2 V}{\partial x^2}\right)\Pi$	1V/mm sur 1mm (piège sphérique) **3 mesures**	**+/-0.1**	**+/- 2.5x10^{-16}**
AC Stark (dépl.lumineux)		0.75µW/mm^2 @ 729nm *et* 0.1µT	**±0.006**	**± 1.5x10^{-17}**
Doppler 2nd ordre	- ½ v^2/c^2	Doppler limit, <n>≈10	**-1x10^{-4}**	**-2.5x10^{-19}**
Zeeman linéaire			**0**	**0**
Zeeman quadr. *	-9.05 Hz/µT^2	(0.1±0.05 µT) stability	**-0.09±0.09**	**-2.2(±2.2)x10^{-16}**
TOTAL			**+0.3±0.4**	**(+7±10)x10^{-16}**

* utilisation de $^2S_{1/2}$, F=4, m_F=0 → $^2D_{5/2}$, F=6, m_F=0

Broadening and shifts - *experimental constraints* -

$\Delta\nu_{nat}/\nu \approx 3\cdot 10^{-16}$

to reach a 1-Hz linewidth at 411 THz ($\Delta\nu/\nu = 2.4\cdot10^{-15}$)

ion at the Doppler limit, <n>≈10	*2nd order Doppler*
magnetic field < (0.1 ± 0.05 µT)	*quadratic Zeeman, AC Stark*
residual electric field <1V/mm	*DC Stark*
electric field gradient <1V/mm over 1 mm (spherical trap)	*quadrupole moment*
3 optical axes (orthogonal)	*measure of the quadrupole moment*
T= 300K	*DC Stark (black-body radiation)*
P<0.75µW/mm^2 @ 729nm	*AC Stark (light shift)*

B

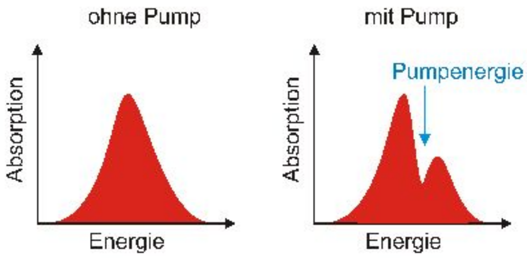
3. Méthodes sans effet Doppler

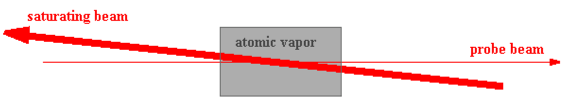
Techniques non-linéaires

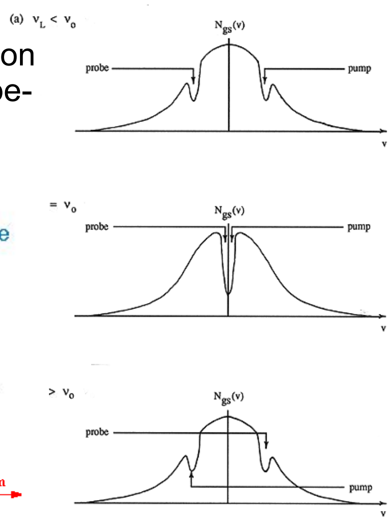
- Absorption saturée
- Spectroscopie à 2 photons
- ...

Absorption saturée

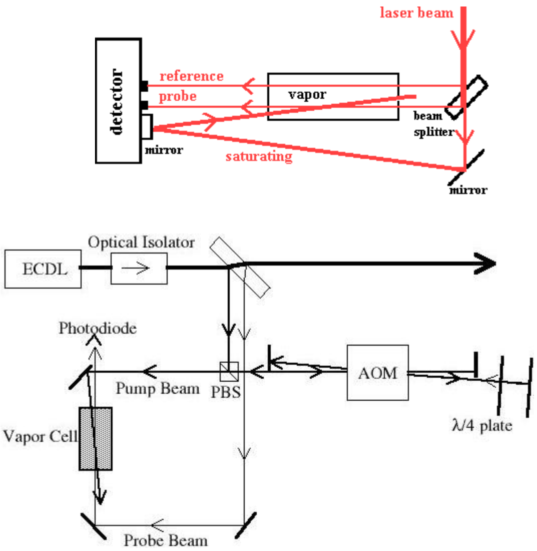
- Techniques « Doppler-free » par « spectral hole-burning » modification de la courbe de gain (faiscau pompe-faisceau sonde)

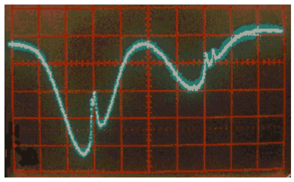




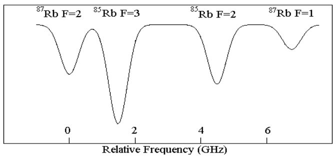


Absorption saturée

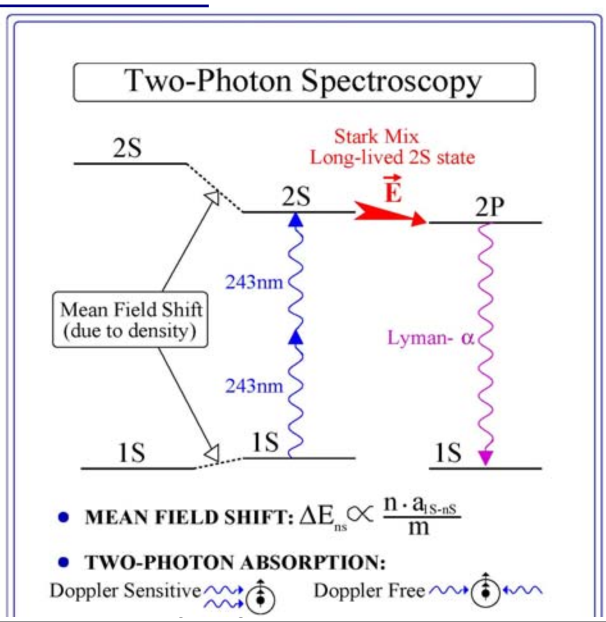




$5S_{1/2}$ to $5P_{3/2}$ transitions in ^{85}Rb and ^{87}Rb, the hyperfine structure is resolved.



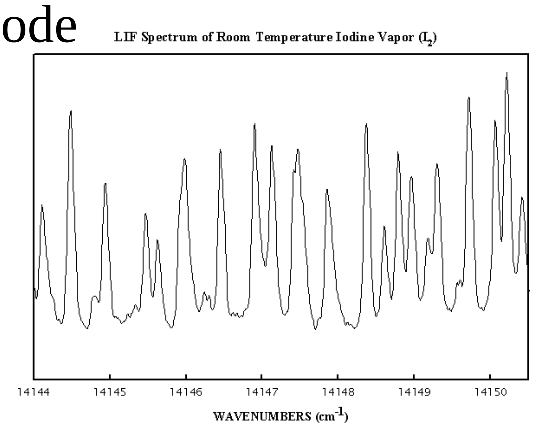
2 photons spectroscopie



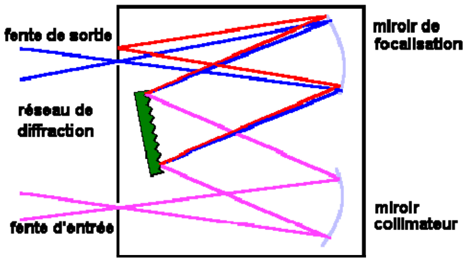
Mesures de fréquence

Mesure de fréquence

- spectre de l'iode

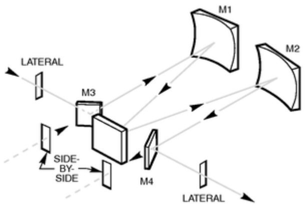


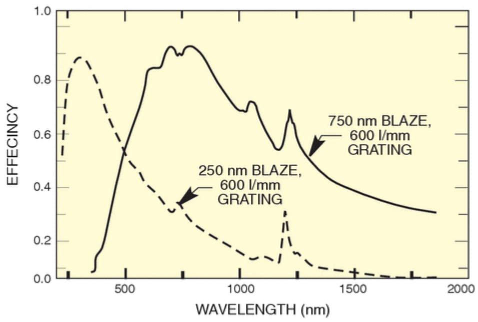
Mesure de fréquence



- Monochromateur

resolution 1nm





Mesure de fréquence - λ-mètre

- Ratio inverse du nombre des franges d'interférences
- Précision 10^{-5} à 10^{-8}

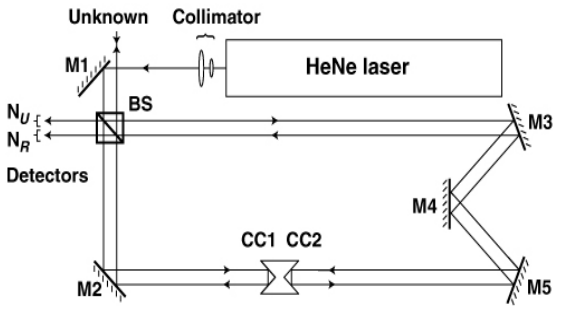
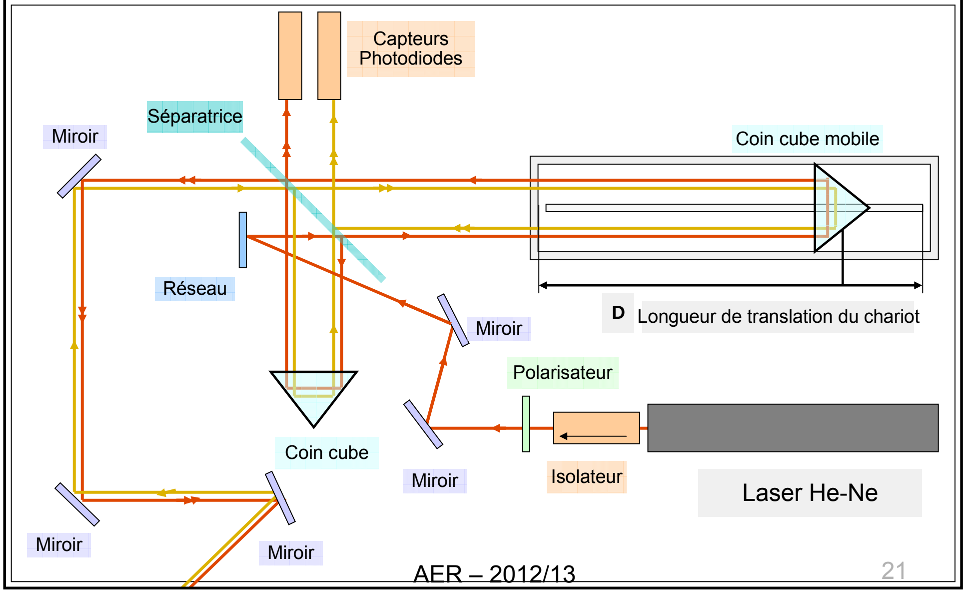


Schéma d'ensemble du Lambda mètre.



Mesure de fréquence – chaîne de fréquence

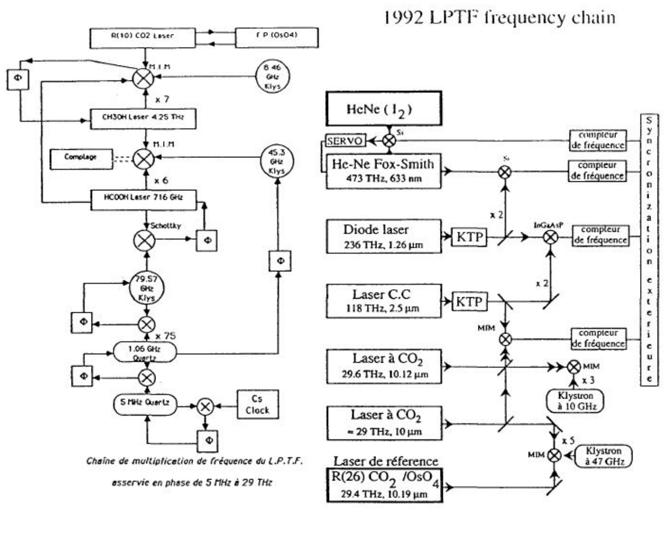
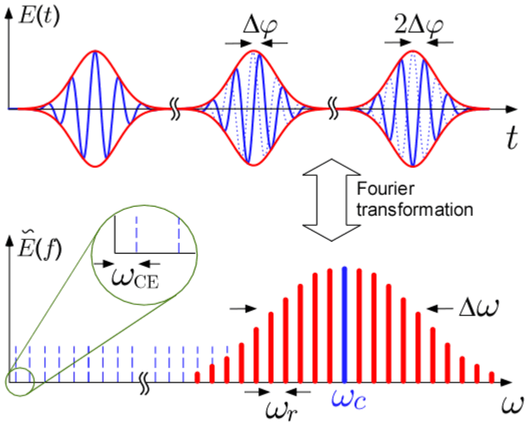


Figure 2 : chaîne de fréquences reliant l'horloge à césium vers 9 GHz à la région spectrale de 10 µm [2].

Figure 3 : chaîne de fréquences reliant la région spectrale de 10 µm à la fréquence visible [4]

Peigne de fréquence

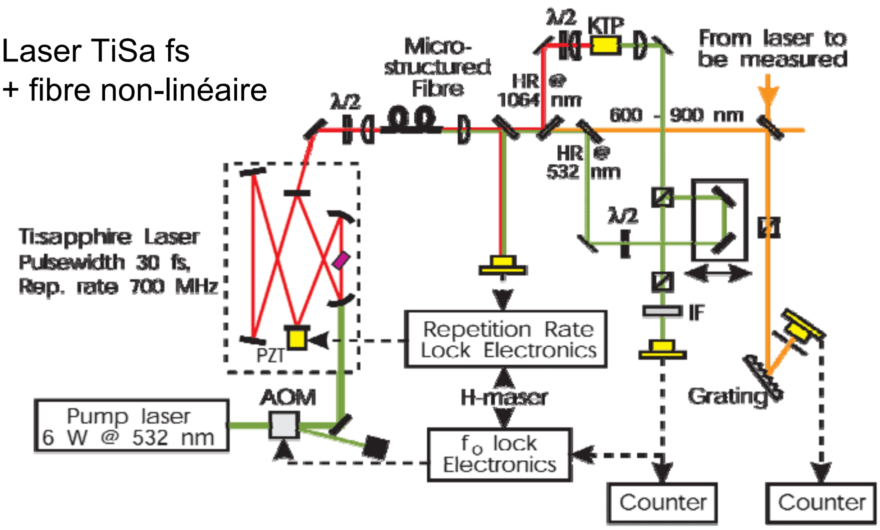
Laser TiSa fs
+ fibre non-linéaire



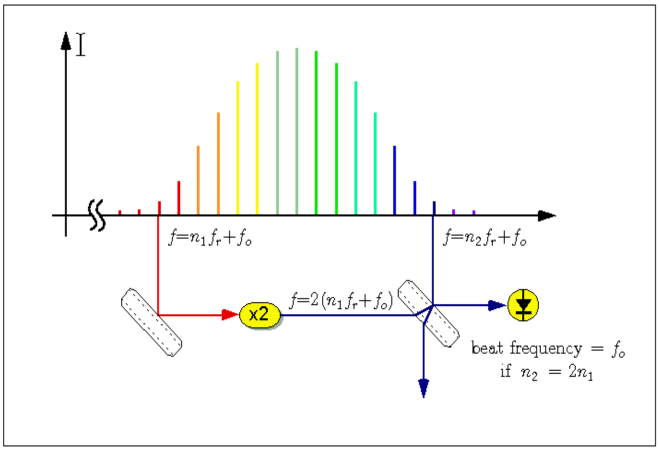
Three consecutive pulses of the pulse train emitted by a mode locked laser and the corresponding spectrum. The pulse-to-pulse phase shift results in a offset frequency CE = /T because the optical carrier wave at C moves with the phase velocity while the envelope moves with the group velocity.

Peigne de fréquence

Laser TiSa fs
+ fibre non-linéaire



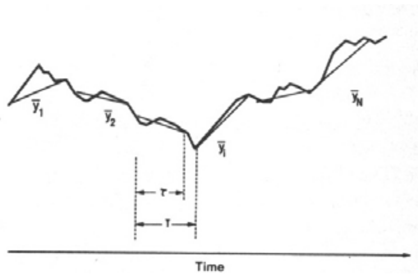
Peigne de fréquence - *autoreférencement*



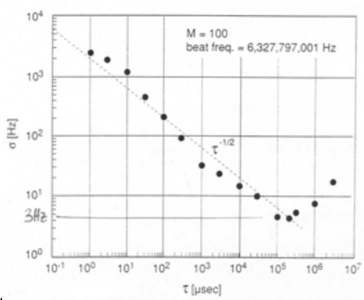
Th.Udem, R.Holzwarth, and T.W.Hänsch, Nature 416, 233 (2002)

Time domain (Allen variance)

Integration of measurementdata over different times τ



$$\sigma_y^2(\tau) = \frac{1}{2}\langle(\bar{y}_2 - \bar{y}_1)^2\rangle$$



Here: maximal stability of 3 Hz at integrating time of 0.2 sec.