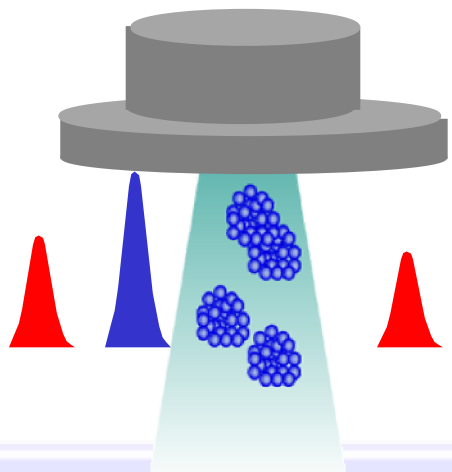
Characterization of Cluster/Monomer Ratio in Pulsed Supersonic Gas Jets



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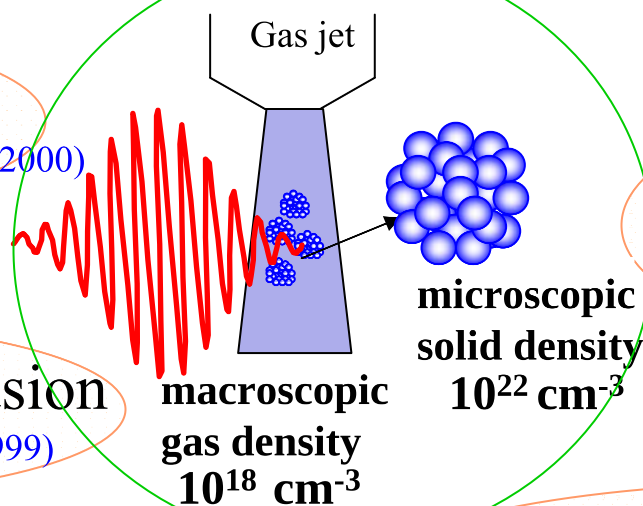
Dallas, TX, Nov. 20, 2008

Interaction of intense laser pulses with clusters has impacted several areas of laser-plasma science

- Efficient creation of hot plasma
  - T. Ditmire *et al*, PRL **75**, 3122 (1995)

- Pulsed X-rays
  - E. Parra *et al* PRE **62**, R5931 (2000)



- Optical harmonics
  - T.Donnelly *et al*, PRL **76**, 2472 (1996)
  - Tajima *et al*, Phys. Plasmas **6**, 3759(1999)

- Table-top nuclear fusion
  - T.Ditmire *et al*, Nature **398**, 492 (1999)

- Wakefield particle acceleration
  - Fukuda *et al*, Phys. Lett. A **363**, 130(2007)

- Plasma Waveguide
  - H. M. Milchberg *et al*, Phil. Trans. R. Soc. A **364**, 647(2006)

To interpret laser cluster experiments accurately, we must measure 3 key properties of the clustered gas target

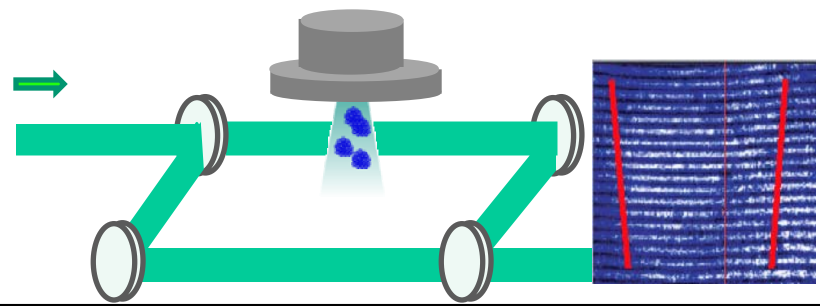
PROPERTY | MEASUREMENT

1) Total atomic density

$$N_{total} = N_{gas} + N_{\#} N_{cluster}$$

N_{gas} = number density of monomers
$N_{cluster}$ = number density of clusters
$N_{\#}$ = number of monomers per cluster

Transverse Interferometry



2) Average Cluster Radius

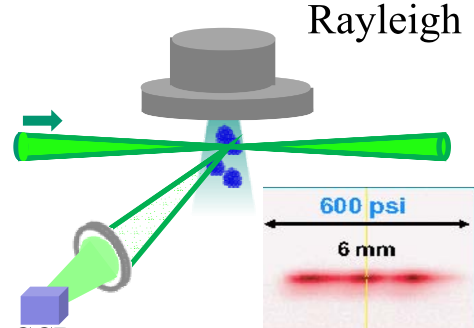
$$\Gamma^* = k \frac{(0.74d/\tan\alpha)^{0.85}}{T_0^{2.29}} P_0$$

$$N_{\#} = \begin{cases} 33(\Gamma^*/1000)^{2.35} \\ 100(\Gamma^*/1000)^{1.8} \end{cases}$$

O. F. Hagena, Rev. Sci. Instrum. **63**, 2374 (1992)

F. Dorchies *et al* PRA **68**, 023201 (2003)

Rayleigh Scatter



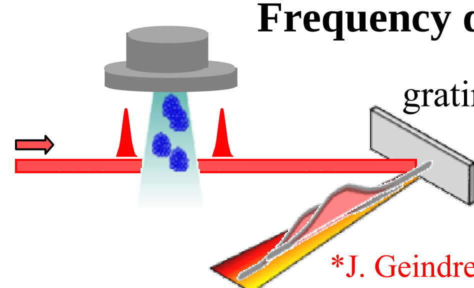
$$\frac{E_{sc}}{E_{in}} \propto \overline{r_c^6} N_{cluster}$$

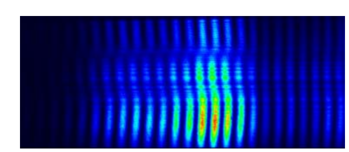
K.Y. Kim *et al*, **83**, 3210 APL (2003)

3) Cluster Mass Fraction

$$f_c = \frac{N_{\#} N_{cluster}}{N_{total}}$$

Frequency domain interferometer*

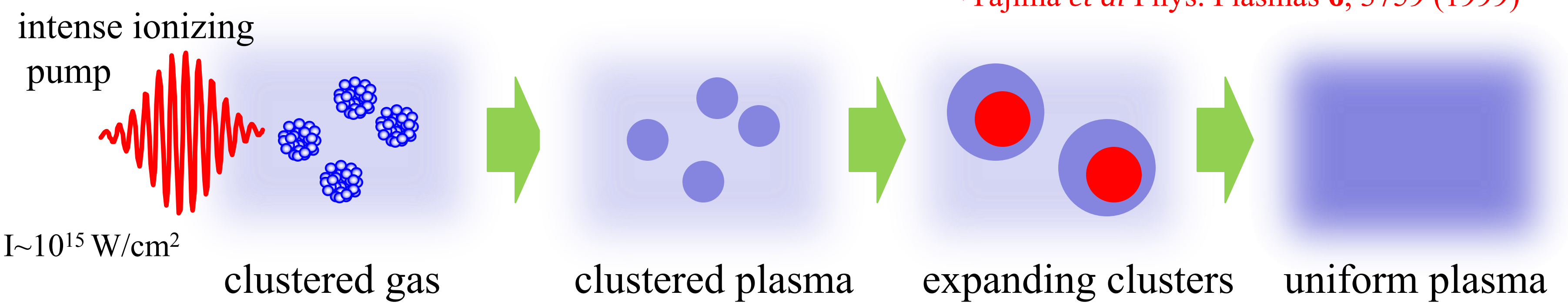




*J. Geindre *et al*, Opt. Lett. **19**, 1997(1994)
K. Y. Kim *et al*, PRL **90**, 023401 (2003)

The method of measuring cluster fraction f_c exploits the opposite signs of the contributions of monomers and clusters to the refractive index†

†Tajima *et al* Phys. Plasmas **6**, 3759 (1999)

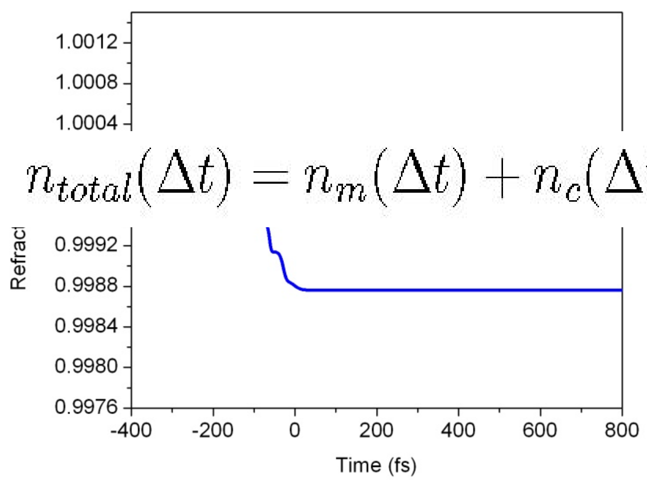


Monomer contribution

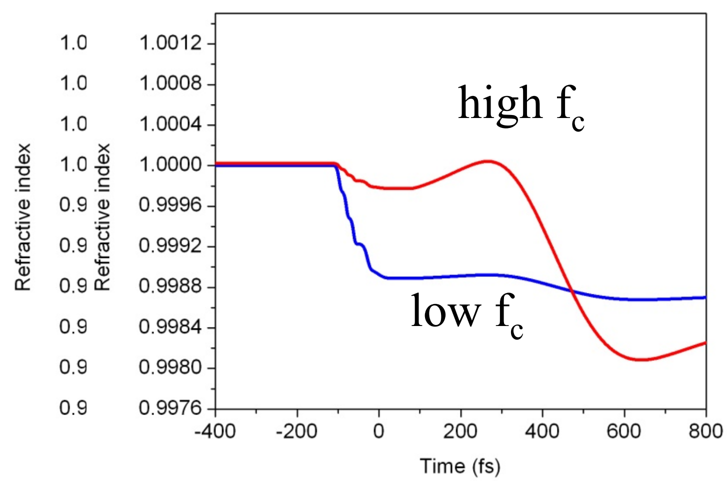
$$n_m = 1 - \frac{1}{2}\frac{\overline{Z}N_{gas}e^2}{\epsilon_0 m_e \omega^2}$$

Cluster contribution

$$n_c \approx 1 - \frac{1}{2}\mathrm{Re}\left(\frac{p\omega_p^2}{\omega^2 - \frac{1}{3}\omega_p^2 + i\nu\omega}\right), \text{ where } p = \frac{4\pi}{3}N_{cluster}a^3$$



$$n_{total}(\Delta t) = n_m(\Delta t) + n_c(\Delta t)$$

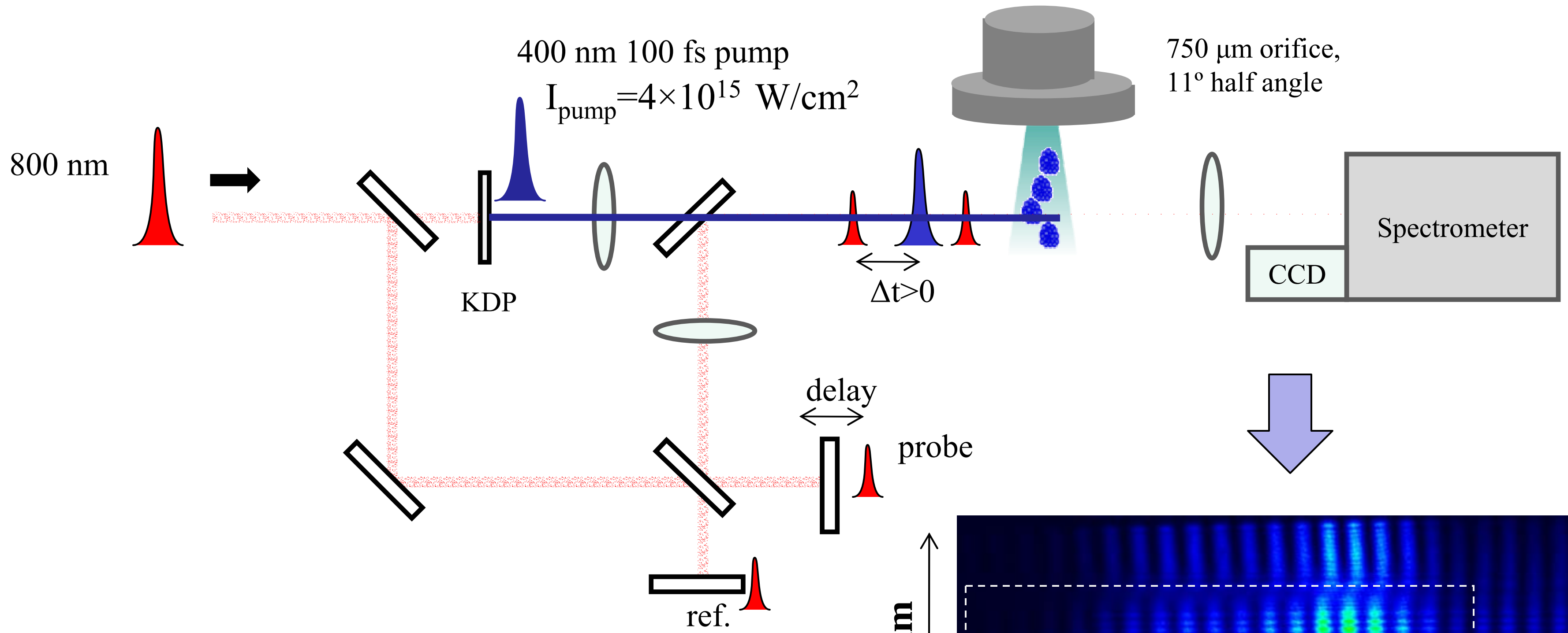


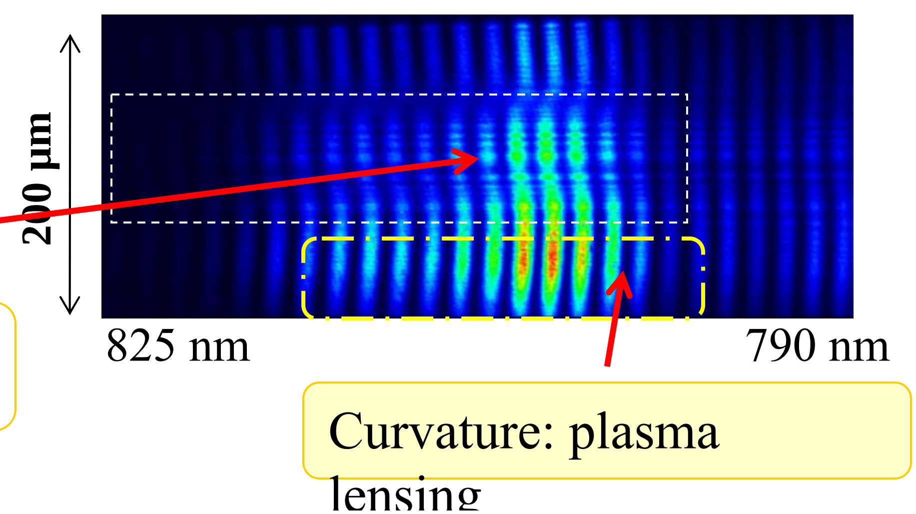
Calculated by Mikhail Tushentsov with hydro-model

$I_{pump}=4\times10^{15}$ W/cm^2

We measured time-resolved refractive index n(Δt) of an ionized clustered gas using fs-frequency domain interferometry*

*J. Geindre *et al*, Opt. Lett. **19**, 1997(1994)
K. Y. Kim *et al*, PRL **90**, 023401 (2003)

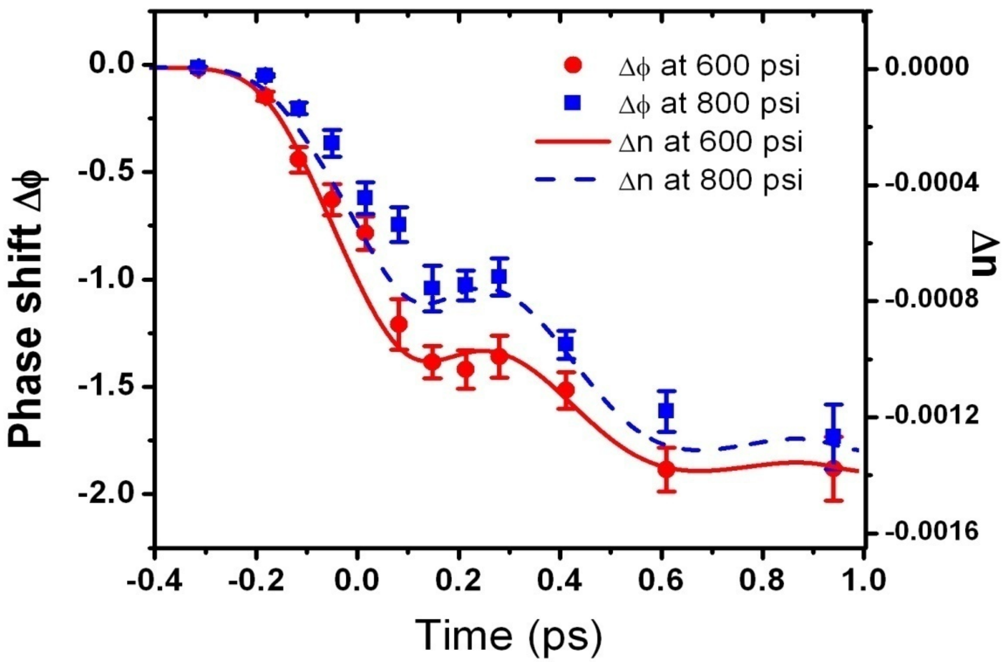




$$\Delta\varphi = \frac{2\pi}{\lambda}(\overline{n}-1)L$$

We observed monomer and plasma contribution in different time scale and fit it using an adiabatic expanding nanoplasma model*

*Mikhail Tushentsov, Alex Arefiev, Boris Breizman



measured phase shift and fit of the refractive index

f_c =0.20±0.05 at 600 psi
f_c =0.30±0.05 at 800 psi

This method is self-referencing. It doesn't rely on the interaction length or N_{total} measurement.

	600 psi	800 psi
N_{total}	10^{18} cm^{-3}	10^{18} cm^{-3}
$\bar{r}$	5.7 nm	6.1 nm
f_c	0.20	0.30

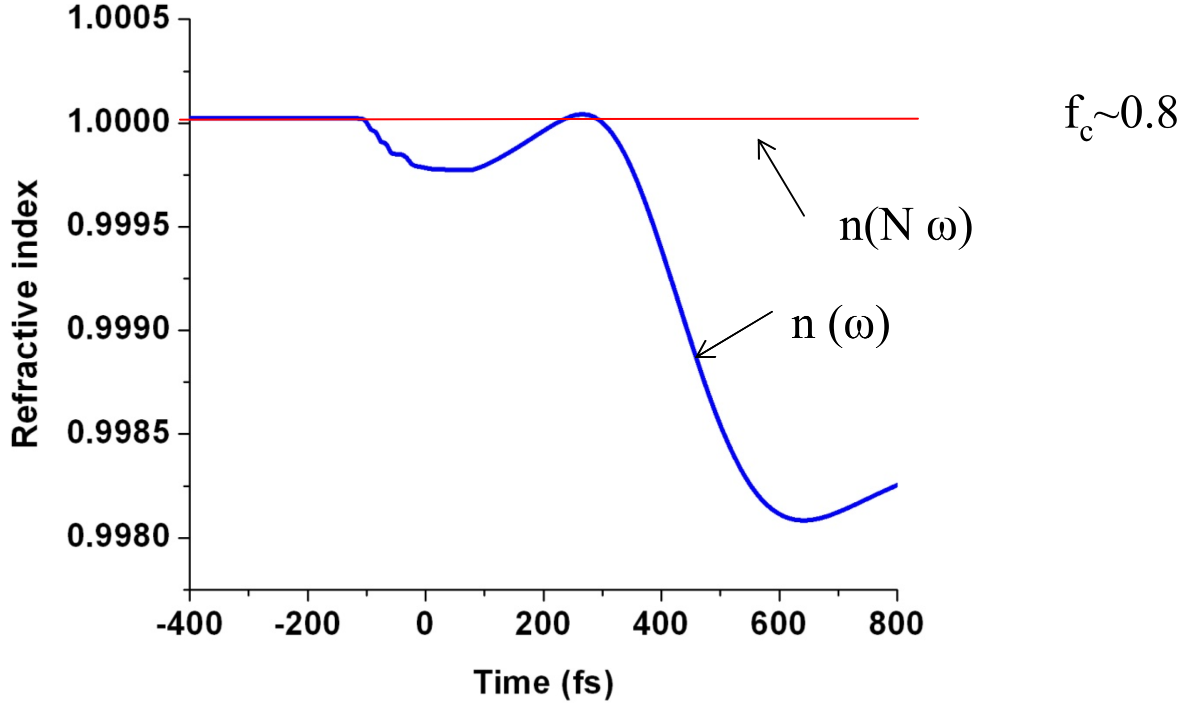
Recent simulations* shows $f_c < 0.5$ for typical cluster jets. Low cluster faction (f~0.2) † and high cluster fraction (f ~ 1.0)‡ were implied in other experiments with nominal identical gas jets.

*Boldarev *et al* Rev. Sci. Instrum. **77**, 083112 (2006)
† F. Dorchies *et al.*, PRA **68**, 023201 (2003)
‡ K.Y. Kim *et al*, PRL **90**, 023401 (2003)

HHG can be phase matched to very high orders (n>100), at high ionization levels (Z>>1) and high intensity ($I>10^{15}$ W/cm^2) in a clustered plasma with f_c~0.8

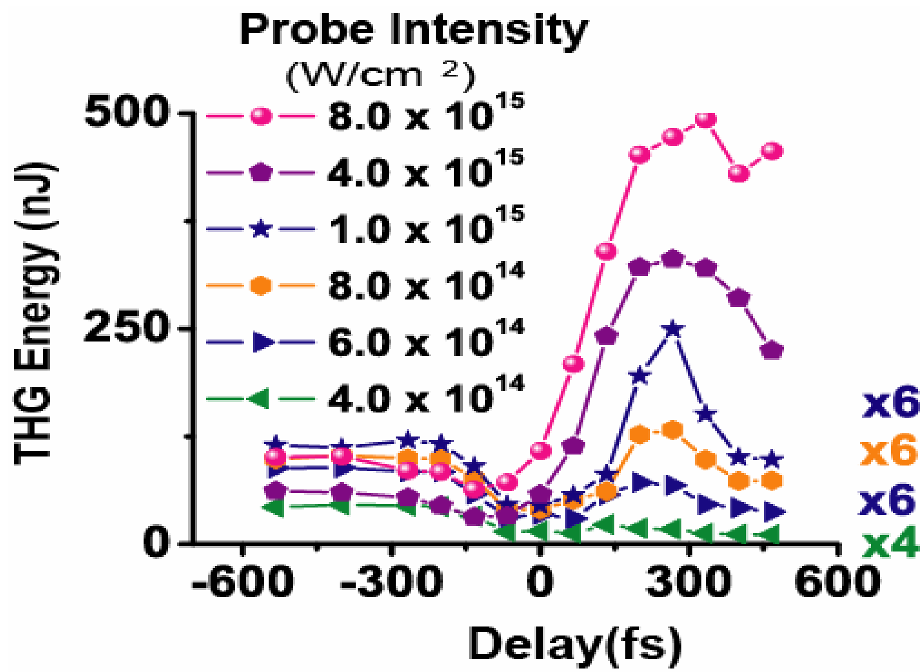
Tajima *et al*, Phys. Plasmas **6**, 3759 (1999)
Tisch et al, PRA 62, 041802R (2000)

$$\Delta k = \frac{N\omega}{c}[n_{jet}(N\omega) - N_{jet}(\omega)]$$



Phase-matching method based on corrugated wave-guide are limited to lower intensity $I < 10^{15}$ W/cm^2 and lower plasma density ($n_e<10^{17}$ cm^{-3})

As preliminary evidence of phase-matched HHG, we observed enhanced THG near the Mie resonance of the expanding clusters



Enhancement :

- Transient improvement of phase matching
- Resonant enhancement of $\chi^{(3)}$

B. Shim *et al* PRL **98**, 123902 (2007)

Conclusions

- The cluster/monomer ratio in pulsed supersonic gas jets was characterized by frequency domain interferometer.

- The cluster mass fraction varies widely in nominally identical cluster jets (0.1–1.0).

- The clustered plasma is a promising target for phase-matched HHG.

Supported by
NSF Grant No. PHY-0114336
DOE Grant No. DE-FG03-96ER40954

B. Shim *et al* PRL **98**, 123902 (2007)