PHOTOFRAGMENT IMAGE PROCESSING via PATTERN RECOGNITION.

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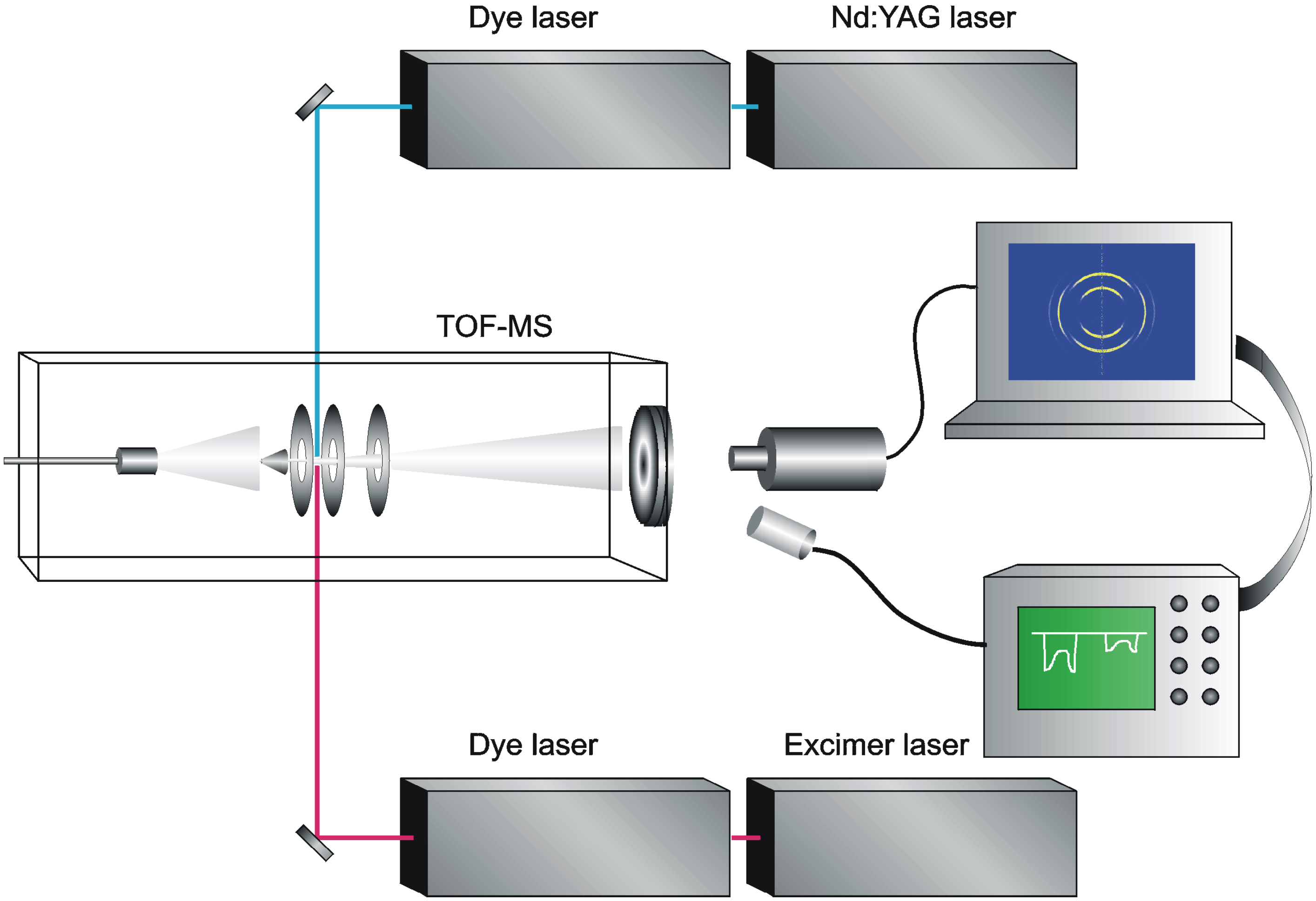
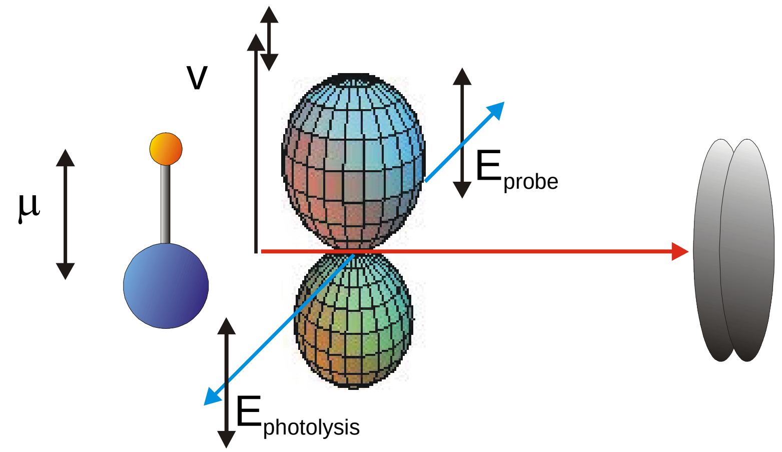
A Photofragment Imaging Setup



Physical Nature of the Problem

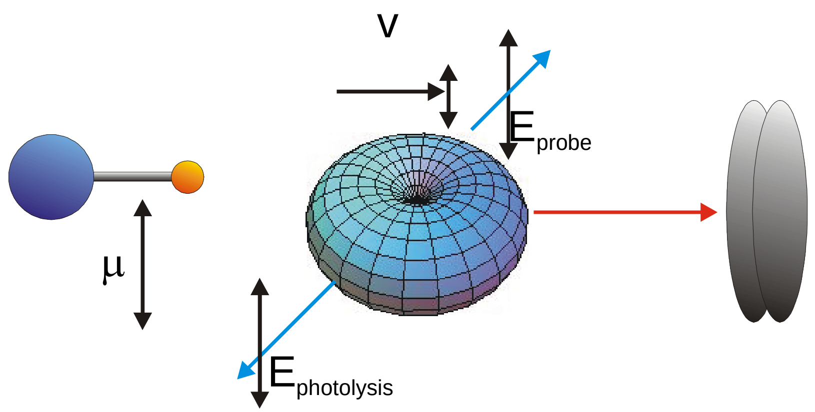
Particle distribution

$$I(r,\theta) = \frac{1}{2}\sum_{n,k} \frac{G(r - r_n, \gamma_n)}{r} \beta_{nk} P_k(\cos\theta)$$



Projection: Abel Transform

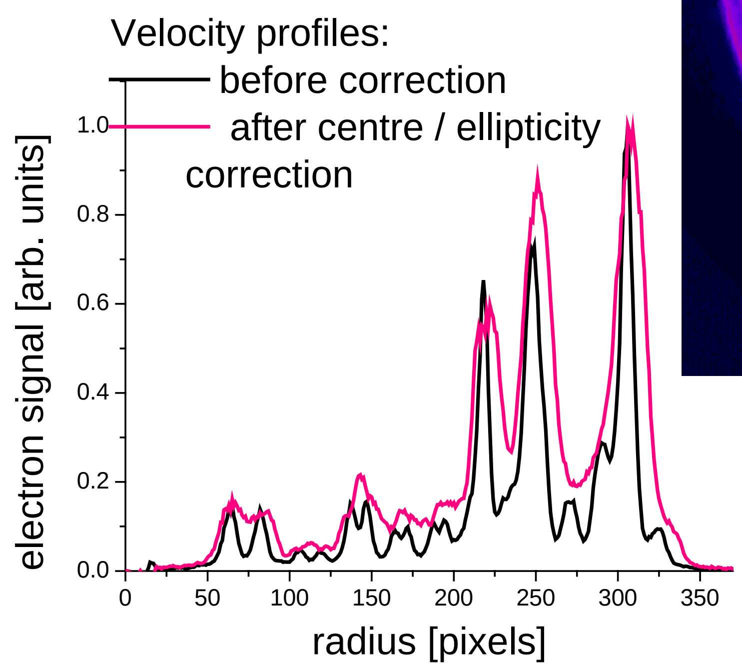
$$P(x,z) = 2\int_{|x|}^{\infty} \frac{rI(r,z)}{\sqrt{r^2 - x^2}} dr$$

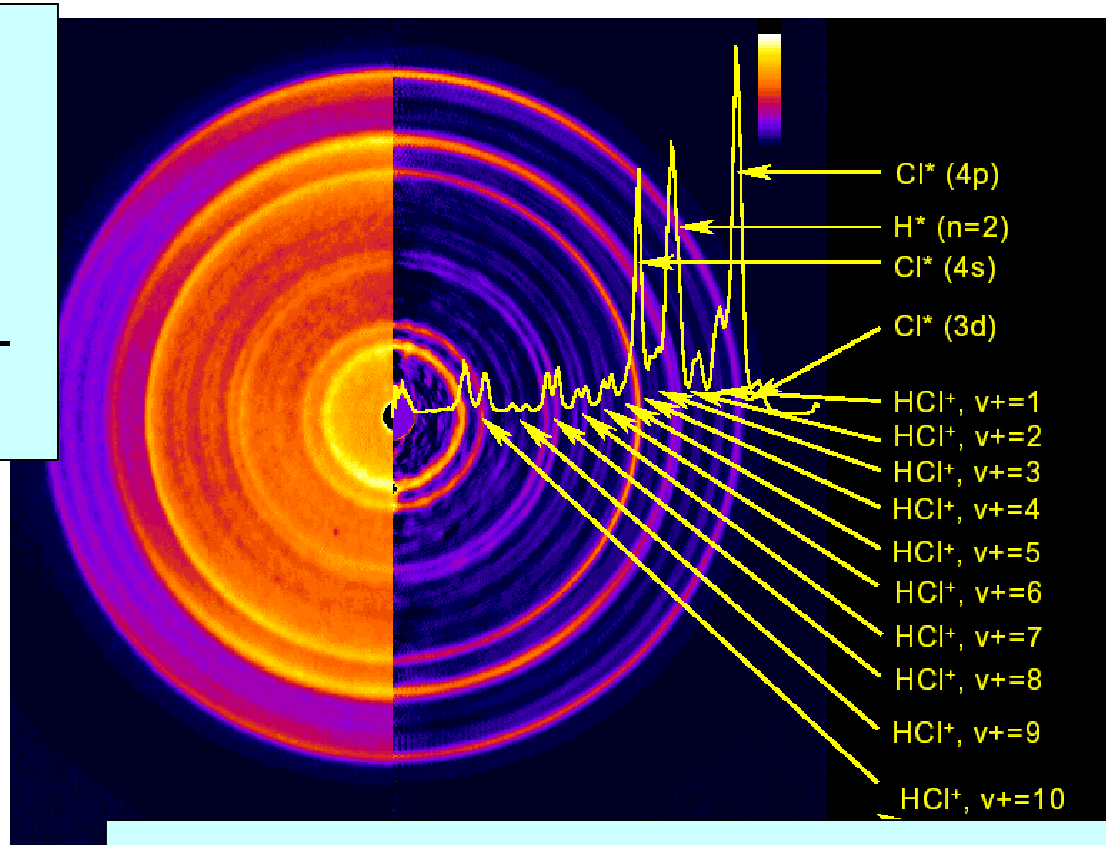


Also:
- Columb explosion;
- X-ray scattering;
- Fs photoelectron spectroscopy.

Issues in Photofragment Image Reconstruction

- Centre and ellipticity distortions;
- Multiple channels to resolve;
- Tedious line-by-line pixel-by-pixel processing.





Better:

- detect circles on the raw image (Part 1);
- use this info to reconstruct channel parameters (Part 2).

Part 1. Circle Detection: Variations on Hough Transform

Hough Transform (formulated via Radon Transform):

$$f(\xi, p) = \iint_D F(x, y)\delta[p - C(x, y\;\xi)]dxdy$$

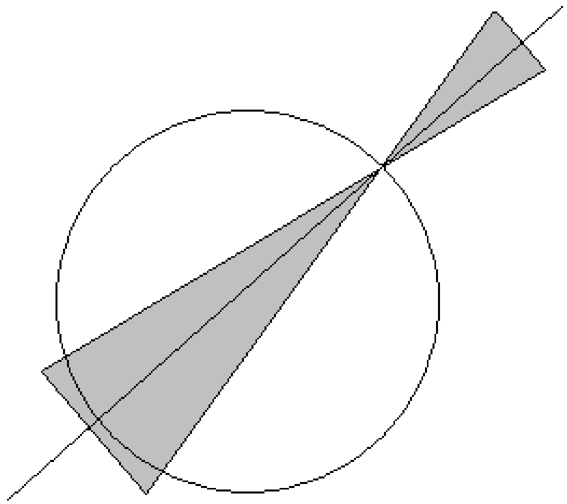
Example: C: $y=x^2$

$$p = y - \xi_1 x^2 - \xi_2 x,$$

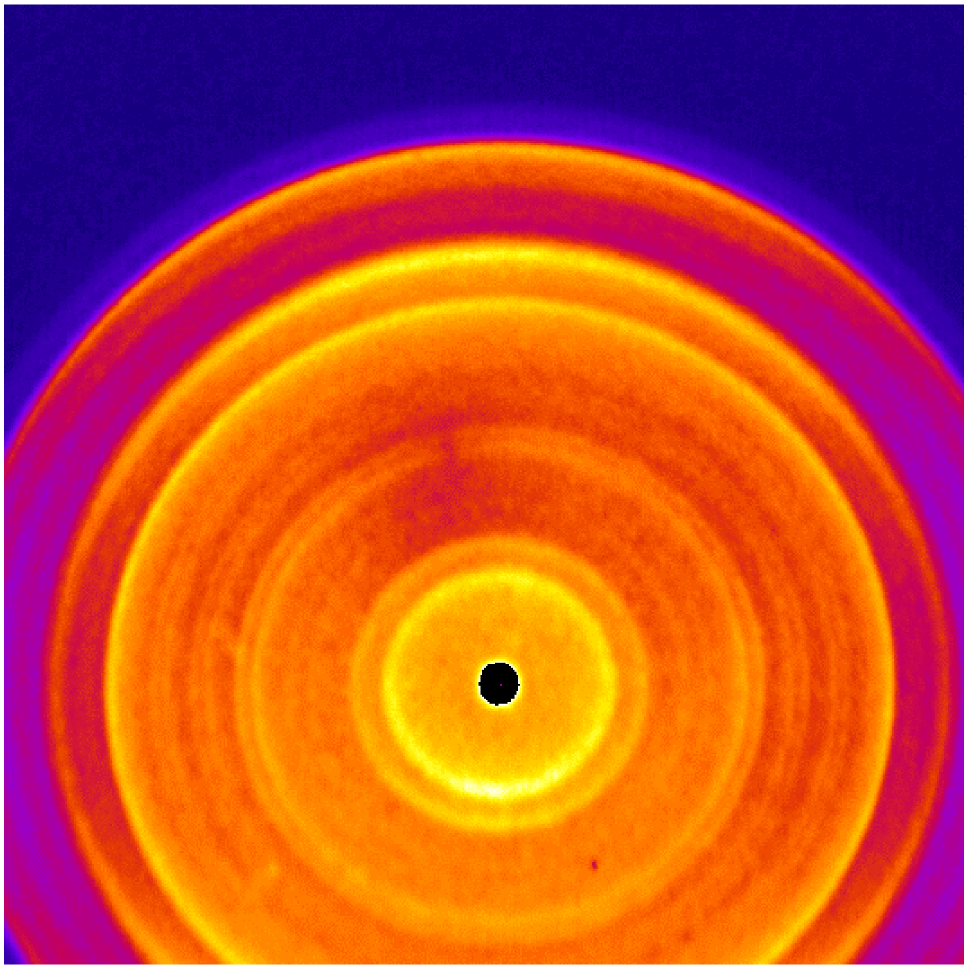
f will be concentrated at $p=0$, $\xi_1 = 1$, $\xi_2 = 0$.

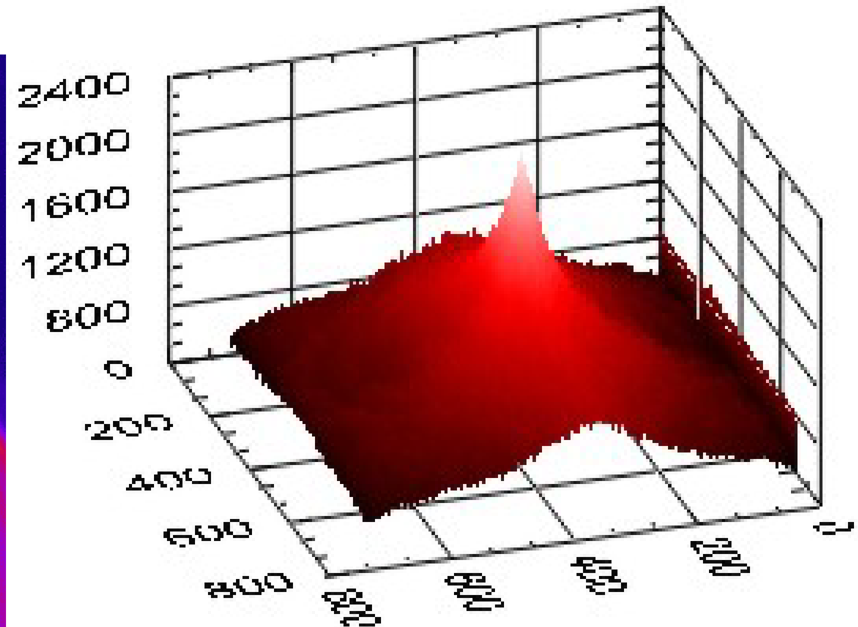
- *Enhance edges*
- *Accumulate edge normals*
  $\rightarrow$ *get the centre*

Modified HT:
reducing dimensionality
of parameter space



It Works





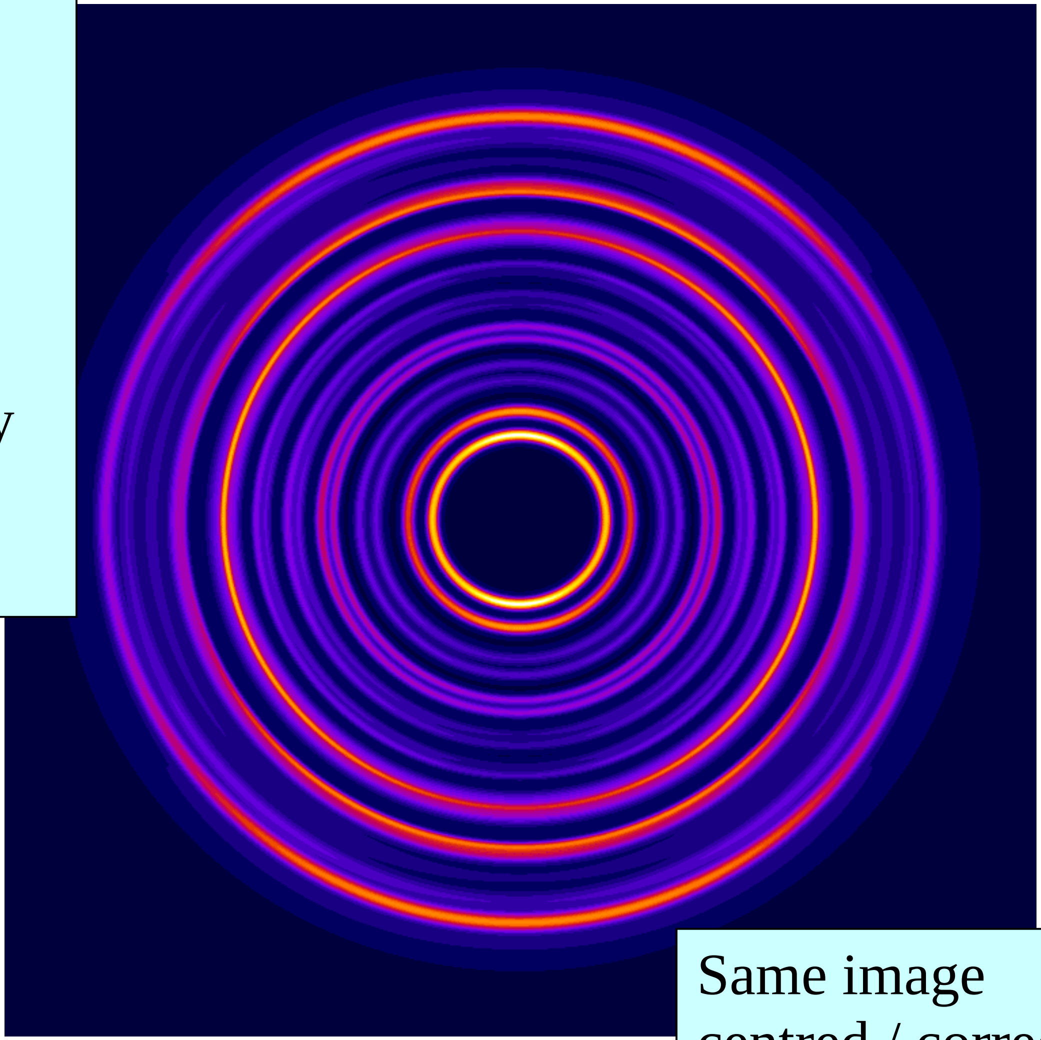
Centre found even when only a part of the image is present.

Centre Fine-Tuning and Ellipticity Correction

Sharpen the radial profile

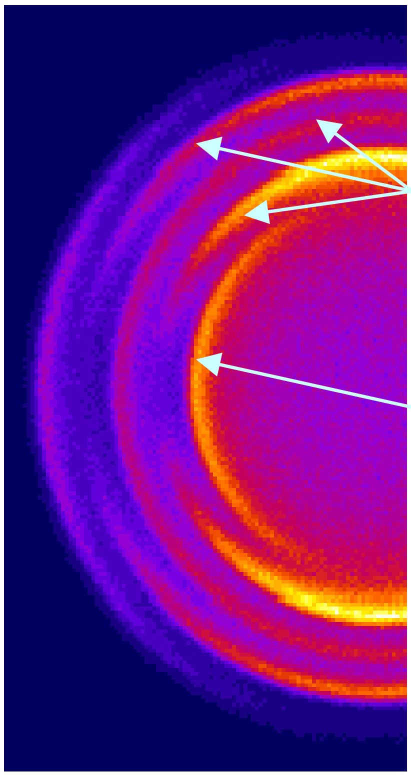
$$R(r) \equiv \int_{2\pi} P_{enhanced}(r,\theta)\,d\theta$$

$\rightarrow$ maximise high-frequency components of *R(r)*



Same image centred / corrected

Part 2. Parameter Reconstruction



$$P(x,z)_m = P^{res} + P^{offres}$$

$$P^{offres}(x,z)_m \approx \sum_{n>m,k} \beta_{nk} P_k\left(\frac{r_m}{r_n}\cos\theta\right) \frac{\sqrt{r_n^2 - r_m^2\cos^2\theta}}{r_n\sqrt{r_n^2 - r_m^2}} \frac{\gamma_n(\theta_n)}{\gamma_n}$$

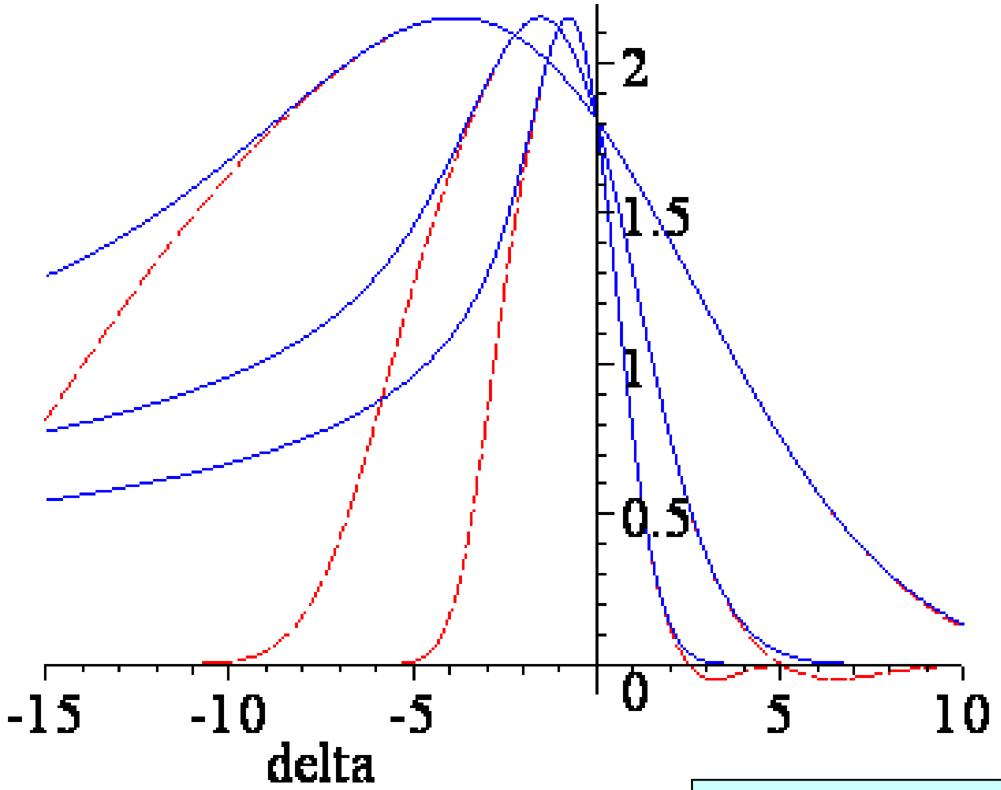
$$P^{res}(x,z)_m \approx \cos\theta \sum_k \beta_{mk} P_k(\cos\theta) I(\delta,\theta)\Big|_{\delta=0}$$

$$\approx \frac{0.60814}{\sqrt{\gamma_m r_m}} \sum_k \beta_{mk} P_k(\cos\theta)$$

Have an analytical expression for the raw image

Resonant Contribution – "Raw " Peak Shape

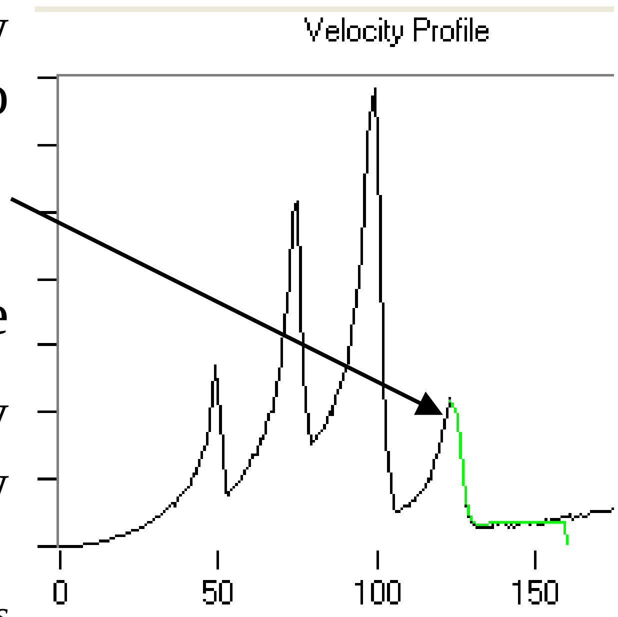
$$I(\delta,\theta)=\frac{\sqrt{\gamma_m(\theta)}}{\gamma_m 2^{3/4}\sqrt{\pi x_m}}\exp\left(-\frac{\delta^2}{2\gamma_m^2(\theta)}\right)\int_0^\infty \frac{dy}{\sqrt{y}}e^{-y^2}\exp\left(-\frac{\delta\sqrt{2}}{\gamma_m(\theta)}y\right)$$



Expand and fit the slope
→ get r and γ

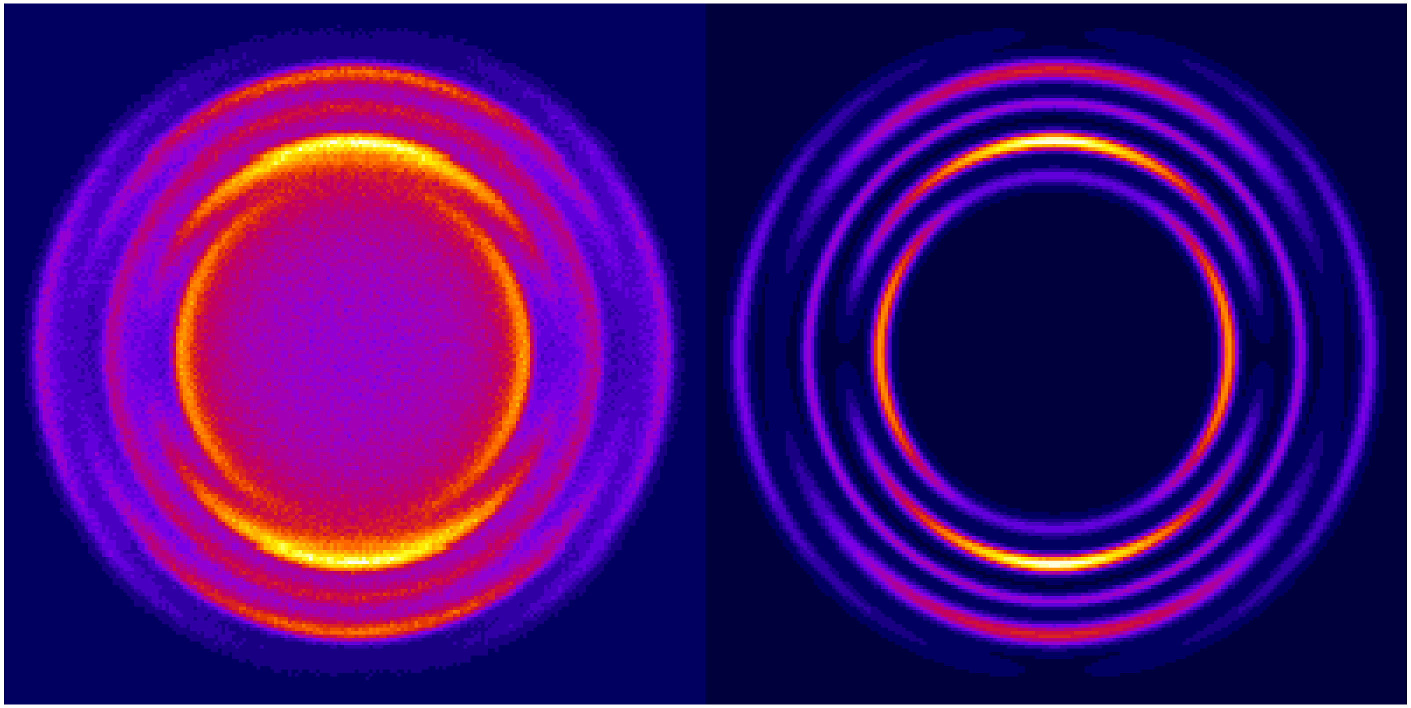
Reconstruction Strategy

1. For the outermost peak on the raw velocity profile, fit the outer slope to $I(\delta, \pi/2)$ and get position and width.



2. Set $\beta_{mk} = \beta_k^{raw}(r_m)\frac{\sqrt{r_m \gamma_m}}{0.60814}$, where $\beta_k^{raw}(r)$ are spatial anisotropy parameters calculated on the raw image.
3. For all inner rings, subtract P^{offres} from pixel intensities. In the immediate proximity to current ring, use P^{res} with the radial envelope of $I(\delta, \pi/2)$.
4. Repeat for all rings.

Tests Results



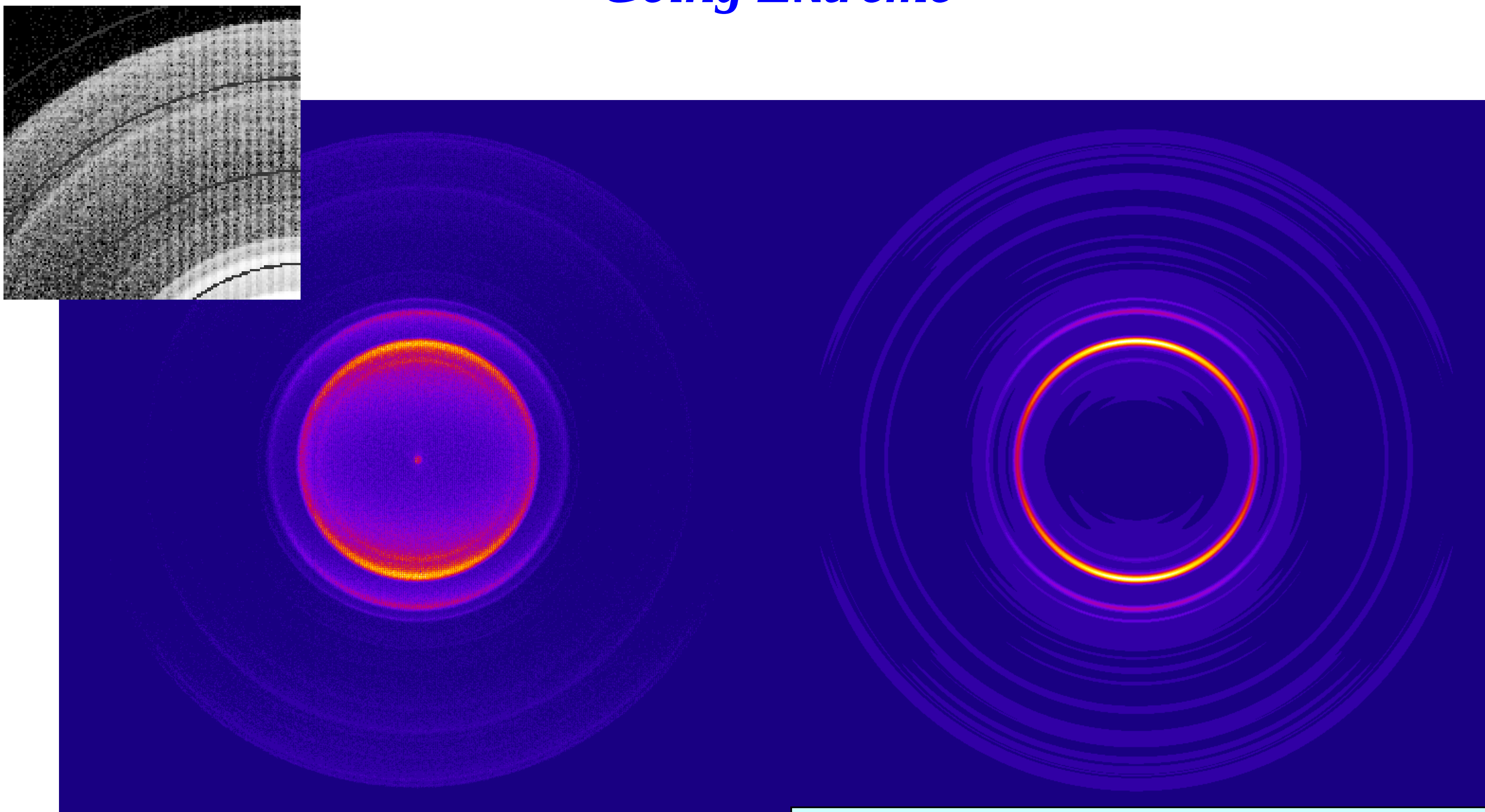
Average error in image parameters.

	Δr, pxl	$\Delta \beta_2$	$\Delta \gamma$, pxl	Δ ring intensity[1]
Present algorithm	0.14	0.076	0.14	0.0113
Onion peeling	1.10	0.057	0.25	0.0127

[1]where the total image intensity is 1.

Good agreement!

Going Extreme



- NO^+ image (from Dr. Parker)
- striped background
- multiple densely spaced rings
- high dynamic range

Conclusions

- The problem of centring, geometry correction and peak identification on a raw photofragment image solved using pattern recognition techniques;

- A novel semi-analytical method for reconstruction of ring intensity, width, and spatial anisotropy parameters from the *raw* image;

- The tandem HT-centring + Fourier Transform developed here provides an unprecedented precision in particle velocities and is recommended for use with any inversion technique.

Acknowledgements

Loock group

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Ring Resolution - Error in Spatial Anisotropy Parameters