

# NSTX Diagnostic Ideas

July 21 and July 26, 2011

# Introduction/Organization

- One slide/five minutes per idea with brief discussion
- Agenda and presentations in DragNDrop Area:  
[http://nstx.pppl.gov/DragNDrop/Five\\_Year\\_Plans/2014\\_2018/diagnostic\\_brainstorming/meetings/2011\\_July/Day1\\_07\\_21\\_2011/](http://nstx.pppl.gov/DragNDrop/Five_Year_Plans/2014_2018/diagnostic_brainstorming/meetings/2011_July/Day1_07_21_2011/)
  - Overview by J. Menard
  - Idea presentations in one Powerpoint document
- Summarize at the end of presentations on both days

# Current Density/ $q$ Profile Measurements

## Real-Time MSE (rtMSE)

- Hardware/software upgrade to MSE-CIF system to provide magnetic field pitch angles in real time.
- Spatial(1-3 cm) and time(5 ms) resolution the same as the present MSE-CIF system.
- Combined with real time equilibrium reconstruction to provide q-profiles for current profile control using NBI.

# Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF)

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- Installation for first operation in upcoming run.
- Diagnostic neutral beam and laser.
- Measurements of magnetic field magnitude and pitch angle.
- Can operate during startup and for RF studies.
- $|B|$  can be used to reconstruct the total plasma pressure, use for MHD studies, and for fast ion pressure.
- With MSE-CIF system, determine radial electric fields of interest for transport.
- Time resolution  $\sim 5$  ms, spatial resolution 1–3 cm, 38 channels planned (fibers for 10 channels presently installed)



DNB in NSTX!

NOVA  
PHOTONICS

# Internal Magnetic Fluctuation Profile Measurement

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- Utilizes MSE-CIF system. Coherent magnetic pitch angle fluctuation measurement has 5–10 ms time interval with ~100 kHz frequency bandwidth, same 18 spatial channels as MSE.
- Capability presently installed - completed filter upgrade in 2010 - initial analysis underway.
- Simultaneously measure density fluctuation profile, and phase angle between density and magnetic field fluctuations.
- Can identify magnetic island locations, provide information for stability control.
- MHD studies, including seeking internal magnetic field fluctuation precursors to disruptions.

# Lithium Beam Zeeman Polarimetry on NSTX

A. Diallo

- Knowledge of the edge current density is crucial for the understanding of the local MHD and pedestal physics.
- Lithium beam polarimetry in combination with EFIT could provide such measurement. Characterization of the Zeeman triplet components of Lithium emission at 670 nm.
- Inline with the assessment of pedestal at up to 2.0 MA.
- Suited for industry/university.

# Coherent Imaging of the Magnetic Pitch Angle in the Edge Region

A. Diallo

- Knowledge of the edge current during the inter-ELM phase in the pedestal region is important for local MHD stability and pedestal physics.
- Measurement of the pitch from polarization characteristics of  $D_\alpha$  components of Stark splitting in the edge region.
- Target an imaging polarization interferometer approach for greater spatial resolution and throughput. The temporal resolution can be 5 ms.
- 2D imaging scheme will supplement the magnetic equilibrium solver, EFIT, for equilibrium reconstructions in the pedestal region.
- Will provide 2D snapshot of the pitch angle, which could be synchronized with ELM events for enhanced temporal resolution in the pedestal.
- Suited for industry/university.

# Fusion Products/ Fast Ions

# Neutron Collimator

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- Beam current drive studies will be a key aspect of the initial NSTX-U program.
- Pending confinement and profile assumptions:
  - Fully non-inductive:  $0.7 < f_{\text{GW}} < 1.0$ ,  $900 \text{ kA} < I_p < 1100 \text{ kA}$
  - Highest sustained  $\beta_T$ :  $0.7 < f_{\text{GW}} < 1.0$ ,  $1000 \text{ kA} < I_p < 1300 \text{ kA}$
- These conditions would prove difficult for the present FIDA system.
  - Cases with NBCD most interesting for scenario physics might be poorly diagnosed w/ regard to fast ion dynamics?
- Desire a diagnostic that i) can provide useful data over a range of higher current and  $f_{\text{GW}}$  conditions, and iii) be easily compared to the outputs of codes like TRANSP + NUBEAM.
- Neutron collimator can be easily compared to NUBEAM calculations..
- Nice to have 3-4 chords, 5-20 msec time resolution is good enough for quiescent scenarios.
  - Should be faster than  $\tau_E$  or  $\tau_{\text{CR}}$ .
  - Faster time resolution would be nice for mode-induced loss dynamics, but may suffer for S/N.
- Should take representative Upgrade Scenarios and calculate the expected signals for various scenarios.
  - Determine if a “realistic” collimator design can discriminate against  $D_{\text{FI}}$ , different source tangency radii, various outer gaps.
  - Compare simulations to those of other fast ion diagnostics to determine the best tool for these scenarios.
  - If there are better solutions than a collimator, then great.
- Industry vs. University vs. PPPL: Any of the above.

## Fusion source profile measurement via charged DD fusion products (Boeglin(FIU), Darrow, Roquemore)

- Goal: Measure DD fusion rate profile to determine radial profile of full energy neutral beam ions
  - 3 MeV p, 1 MeV T & 0.8 MeV  $^3\text{He}$  from DD fusion unconfined in NSTX-U
  - measure flux of these over fan of collimated detectors at wall & invert fluxes to get emission profile  $Y_{\text{DD}}(R)$
  - Fusion rate nearly all due to beam-plasma reactions, so compute beam ion density  $n_{\text{NBI}}(R) = k Y_{\text{DD}}(R)/n_i(R)$
  - Strongly weighted to full energy beam ions by fusion cross section
- Resolution: 5-10 cm & 1-5 ms
- Supports NSTX-U research on:
  - Redistribution of NB-driven current
  - Fast ion redistribution & loss by Alfvénic & MHD modes
- Suitable for university collaboration: FIU now building prototype

# FIDA (& BES) Imaging

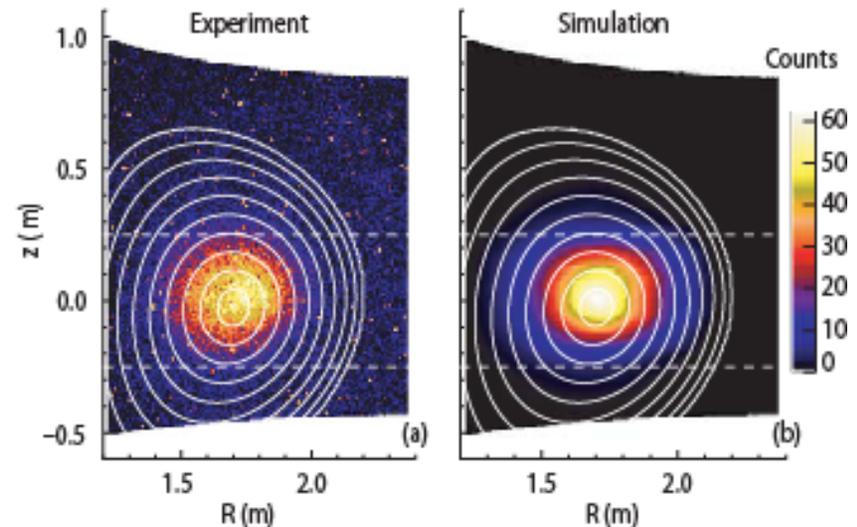
*Physics: Vertical & Radial profile of co-tangential fast ions (and of injected neutrals)*

Measured Quantity: Blue-shifted FIDA light (red-shifted BES light) obtained using bandpass filters & an imaging camera

Resolution: ~1 cm; ~ 5 ms; poor energy

Upgrade Goals: NBCD & Energetic Particles

Collaborator?: Yes



PPCF 51 (2009) 055001

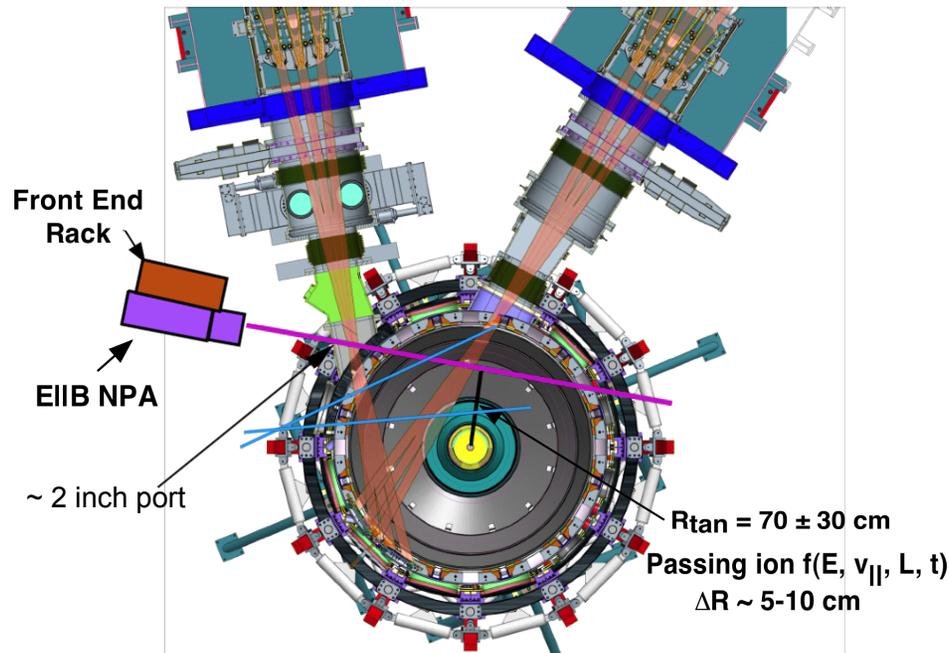
# NSTX-U diagnostic proposal: upgrade of ssNPA (M. Podestà, D. Darrow, W. Heidbrink, A. Bortolon)

- Goal: measure radial profile of escaping fast neutrals with improved spatial resolution
  - Complement NPA, FIDA, neutrons, sFLIP, ...
  - Good localization in pitch, energy-resolved spectra
    - TBD: focus on trapped or passing fraction -> viewing geometry ?
- Use *arrays* of diodes; combine both current and pulse-count modes for time + energy resolved measurements
  - Spatial resolution: 8 - 16 radial channels -> 10 - 5 cm
  - Time resolution: ~1 MHz (current mode),  $\geq 100$  Hz (pulse-height mode)
  - Energy resolution: ~10 keV (pulse-height mode @ 100Hz acq. rate)
- Supports NSTX-U research on
  - Redistribution of NB-driven current
  - Fast ion loss/redistribution by Alfvénic modes
  - RF interaction with fast ions
- Project is OK for external collaborations

# Installation of the E||B Neutral Particle Analyzer (NPA) with a Fixed Sightline on NSTX-U

**New 2<sup>nd</sup> NBI**  
( $R_{TAN}=110, 120, 130\text{cm}$ )

**Present NBI**  
( $R_{TAN} = 50, 60, 70\text{cm}$ )



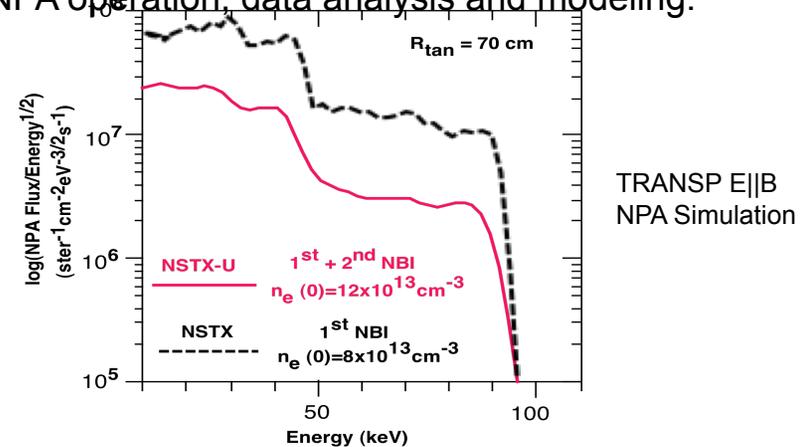
- $E_{max}/E_{min} = 30$  with 35 energy channels simultaneously for both H and D.

- Energetic ion spectrum,  $f(E, v_{||}, L, t)$ , is core-localized to sightline intersection with 1<sup>st</sup> NBI.

- $E_D = 1-300 \text{ keV}$ ,  $E_H = 1-600 \text{ keV}$ ,  $\Delta E/E \sim 2-5\%$ ,  $v_{||}/v \sim 0.8 \pm 0.1$ ,  $\Delta L \sim 20 \text{ cm}$ ,  $\Delta t \sim 0.1 \text{ ms}$ .

- High resolution  $f(E, v_{||}, L, t)$  for NBI-driven  $I_p$  scenarios including MHD/\*AE effects thereon.

- Prime opportunity for university collaboration on NPA operation, data analysis and modeling.



- NSTX-U E||B NPA key redeployment elements:
  - 1) Remove massive scanning mechanism and install NPA on a small fixed pedestal.
  - 2) Reuse all existing support equipment (CAMAC, electronics, cabling, pumps, etc.).

# Thomson Scattering (not incl. divertor TS)

# rtMPTS

*B.P. LeBlanc after discussion with S.P. Gerhardt and S.A. Sabbagh*

- rtEFIT does not have internal constraints at present
  - Only magnetics...magnetic flux and fields, loop voltages
- rtMPTS can provide internal constraints
  - $p_e$  isobaric (à la EFIT02) or  $T_e$  isotherm (à la LRDFIT04, EFITXX)
  - Constrain magnetic axis location
  - Can help constrain outer gap
  - Useful to estimate resistivity for current profile control
- Resolution:
  - 2 Nd:YAG lasers → 16.7msec; 11ms with a 3<sup>rd</sup> laser
  - 10 to 20 radial channels distributed on both sides of magnetic axis
- Scheme and latency
  - Use existing buffered outputs, do initial-guess  $T_e$  and  $n_e$  calculations
    - Iterative fit steps might be possible
  - 0.4ms intrinsic latency, plus computation time → 1ms after laser pulse

Innocent bystanders: A. Diallo, J. Dong, and H. Schneider

## Edge Thomson Scattering System

A. Diallo

- Dedicated edge system at the region of near optimal flux expansion (20 cm below midplane)
- Increasing spatial resolution in the pedestal region (sub-mm). Further constraining the EFIT equilibrium reconstruction.
- Support the pedestal physics studies and turbulence codes.
- Suited for industry/university.

# Neutral Density Measurements

# Neutral density measurements for H-mode, ion power balance, fueling, particle balance, lithium studies

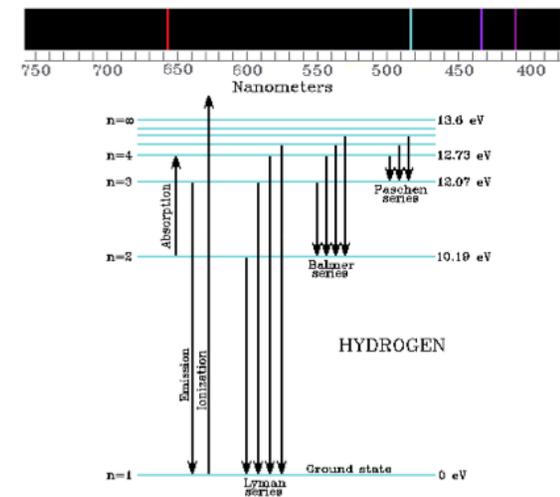
## Laser-induced ionization (LII) diagnostic for 1D core, pedestal and edge neutral profiles

- Developed at Ioffe Institute in the 90-s (Nuclear Fusion 35, 1385 (1995))
- Feasibility study for NSTX by Dr. S. Tolstyakov in 2001
  - Collaboration with Globus-M
- Based on spectroscopic measurements of upper level population depletion using laser photoionization ( $P_{laser} \sim \text{MW/cm}^2$ )

$$E = A_{ij} n_j n_0$$

- May be possible to use for pilot measurements
  - present MPTS system
  - proposed divertor Thomson system

## Electron Energy Levels in Hydrogen



Sensitivity  $n_0 > 10^{14} \text{ m}^{-3}$

# Measurements of $n_D$ using a Two-Photon Laser-Induced Fluorescence in the Edge Plasma

A. Diallo

- Measure the radial profile of the neutral density  $n_D$  near the separatrix.
- Possibly determine the core fueling rate.
- Doppler-free two-photon excitation in Lyman $\beta$  and observation of the fluorescence of Balmer  $\alpha$ . [Voslamber and Seidel RSI 1999].  
Requires two counter-propagating laser beams to eliminate the linear Doppler broadening.  
Scheme is being implemented at DIII-D [Brooks APS 2010]
- Support the pedestal physics studies by providing information on the effects of neutral.
- Suited for industry/university.

# Electron Density Measurements

# FIReTIP-II for NSTX Up-grade

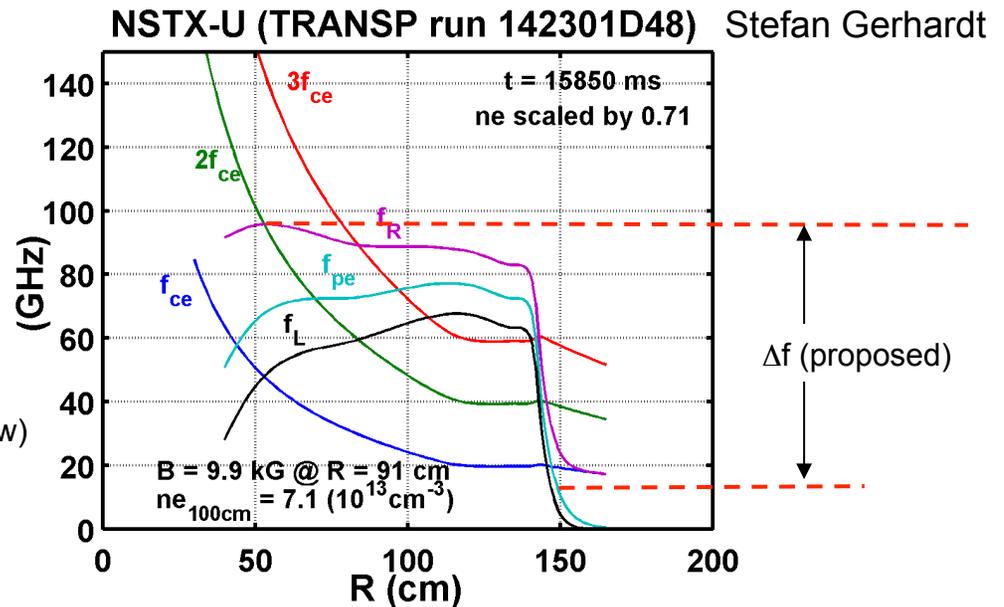
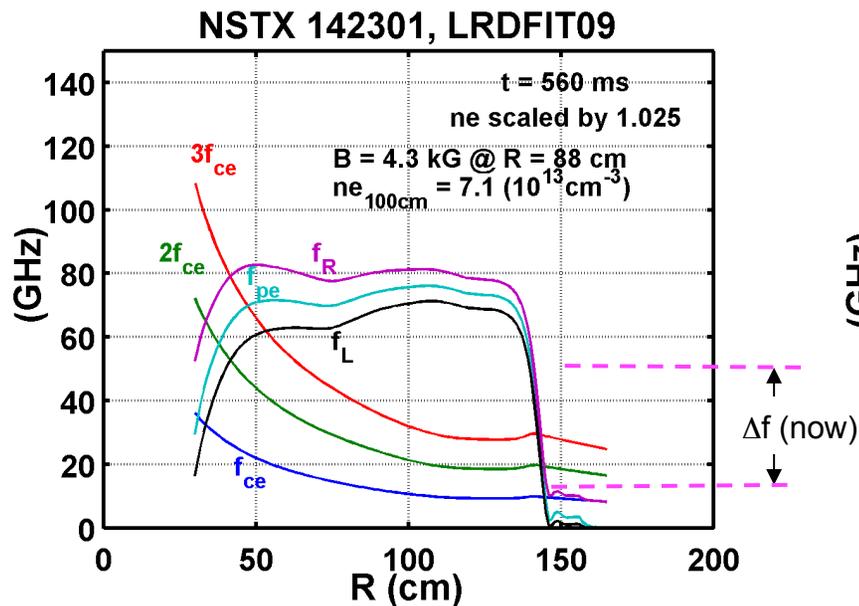
- ▶ Rearrange of FIR lasers and beam paths : launching (Bay-K → Bay-L & K),
- ▶ Improve signal level and resolution by (a) humidity control (40% → < 5% for up-grade, ~20% achieved in 2011), (b) two color system (edge channel), (c) new detector technology
  - Provide real time electron density data for feedback control
  - Absolute measurement of density for Thomson scattering calibration
  - Density fluctuation measurement for T&T /MHD(\*AE, EPH-mode, ELM etc) studies
  - Accurate edge density by two-color system for boundary/SOL study
- ▶ Focusing one inboard channel ( $R_T \sim 50$  cm), one outboard channel ( $R_T \sim 120$  cm), one edge channel ( $R_T \sim 145$  cm) with 4 MHz bandwidth will support many NSTX Upgrade research plans;
  - density feedback control for current ramp-up and flat-top (scenario-2014)
  - turbulence understanding and ST confinement trends (T&T-2018)
  - pedestal structure understanding (boundary-2011)
  - measure \*AE activity by 2<sup>nd</sup> NBI-compare to existing NBI (energetic particle-2015)
  - comparing diverter gas injection to mid-plane gas injection/assess density assimilation (ITER-2012)
  - accurate density measurement (especially for edge) is critical for pedestal transport and ELM mitigation, can be incorporated for ITER and ST-FNSF
- ▶ FIReTIP-II will be collaboration with plasma diagnostics group of UC Davis

# “Simple” Interferometer For Operations and Density Feedback Control

- A highly reliable single chord interferometer could be useful for:
  - Physics operations: Provide basic information when MPTS is unavailable (deliberately or not), to facilitate basic operations.
  - Plasma control: Provide basic density feedback at the beginning of each discharge, to improve the pulse-to-pulse reliability.
    - Help avoid dangerously underdense plasmas.
  - Physics analysis:
    - Provide an ever-present check on the MPTS density calibration.
    - If in vertical view, could complement the horizontal MPTS view. For very downward shifted plasmas.
- Use of present interferometers for this purpose is constantly in planning...
- System requirements could be modest: 1-10 kHz, single chord.
- PPPL/Industry/University?: Many institutions in the U.S. have the capability to construct and run such an instrument.
  - But would any be interested in taking on such scope?
  - Operations support may be less relevant than physics data for collaborator proposals?

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# Profile reflectometry: Increased magnetic field combined with frequency upgrade provides access to new physics in NSTX-U



See: [http://w3.pppl.gov/~sgerhard/NSTXU\\_FBT\\_Rev0.pdf](http://w3.pppl.gov/~sgerhard/NSTXU_FBT_Rev0.pdf)

- **New physics:**

- detailed **particle transport** studies via gas modulation – includes SOL/edge/outer core
- the **effect of stochastic fields** on the edge/SOL profile
- investigation of the role of lithium, snowflake divertor, cryo-pumping, etc. in governing **particle transport and density control** in edge/SOL of NSTX-U
- investigation of simultaneous O & X-mode data provides an **additional constraint on EFIT**
- study of the spatial extent and effect of the **EHO** on edge density profile
- high temporal ( $\sim 5\mu\text{s}$ ) measurement of edge density profile evolution during **L-H transition/ELMS**

# Ion Temperature/Rotation Velocity Measurements

# NSTX-U diagnostic proposal: upgrade of ERD

(M. Podestà, R. E. Bell)

- Goal: upgrade Edge Rotation Diagnostic to improve spatial and temporal resolution
  - Complement CHERS/pCHERS with passive measurements
    - Measured lines: C III and He II
  - Keep basic configuration: toroidal + poloidal views
- Modify existing fiber holders; add 210 $\mu$ m fibers
  - Spatial resolution: ~20 radial channels,  $\leq 1$  cm resolution
  - Measurements in the range  $135 \text{ cm} < R < 155 \text{ cm}$
  - Time resolution: ~1 kHz (x10 with respect to present system)
  - Need new CCD camera
- Supports NSTX-U research on
  - Routine measurement of edge features, electric field
  - RF ion heating at the edge
- Project is more suitable for PPPL
  - Fiber holders for CHERS/pCHERS/RTV/FIDA must be re-designed
  - Analysis software already exists

# Measurement of bulk plasma flows with an interferometric technique

Gerrit J. Kramer

- The speed of light in a medium depends on the velocity of the medium:

$$v_{\text{light}} = 1/R (c \pm v_{\text{medium}} (R^2 - 1) / R) \quad (R: \text{index of refraction})$$

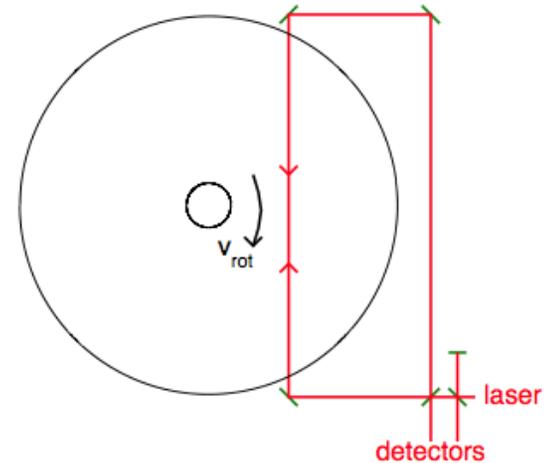
experimentally verified by: H. Fitzeau, Ann. de Chim. et de Phys. 57 (1859) p. 885

P. Zeeman KNAW, Proceedings, 17 I, 1914, Amsterdam, (1914) p. 445

- We can use this effect to measure the plasma rotation in NSTX

- Let light (or microwaves) pass through the plasma at the same line of sight in both co- and counter to the rotation and measure the phase difference between the signals

- This will give a measure of the line-integrated plasma velocity projected on the sight line but it is weighted to the tangency radius



- The (line integrated) density should also be measured to get index of refraction
- With this technique rotation measurements can be made that are independent from (diagnostic) NBI injection
- This project is suitable for university collaboration

## 2D Flow imaging in the Divertor

A. Diallo

- Large parallel flows have been predicted using UEDGE simulation.  
A.Y Pigarov, Memo 2005
- LII (548.6nm) and CIV (465 nm) are targeted for Doppler spectroscopy measurements in the divertor enabling larger radial coverage.
- Target a polarization interferometer scheme for greater spatial resolution and superior throughput. The temporal resolution can be 5 ms.
- 2D imaging scheme will generate a map of the “hurricane” type flows in the divertor, which can be compared to theory/simulation.
- Suited for industry/university.