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/DragNDropNSTX_Meetings/Diagnostic_Ideas_Meetings/

  - 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)

- 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 ~5 ms, spatial resolution 1–3 cm, 38 channels planned (fibers for 10 channels presently installed)

NOVA PHOTONICS

Internal Magnetic Fluctuation Profile Measurement

- 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.

NOVA PHOTONICS

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_α 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

SPG

- Beam current drive studies will be a key aspect of the initial NSTX-U program.
- Pending confinement and profile assumptions:
  - Fully non-inductive: $0.7<f_{GW}<1.0$, $900\ kA < I_P < 1100\ kA$
  - Highest sustained β_T: $0.7<f_{GW}<1.0$, $1000\ kA < I_P < 1300\ kA$
- 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_{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 the τ_E or τ_{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_{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}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 $Y_{DD}(R)$
  - Fusion rate nearly all due to beam-plasma reactions, so compute beam ion density $n_{NBI}(R) = k\, Y_{DD}(R)/n_i(R)$
  - 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

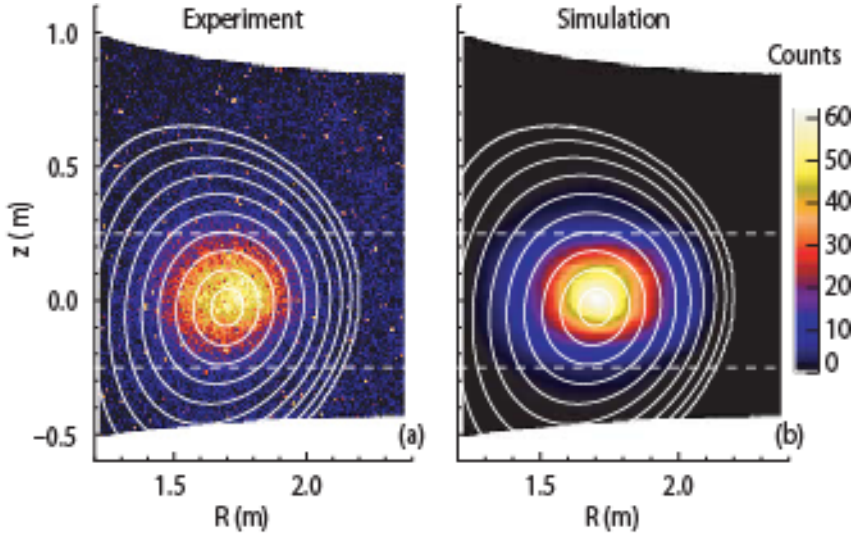
Physics: Vertical & Radial profile of co-tangential fast ions (and of injected neutrals)

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

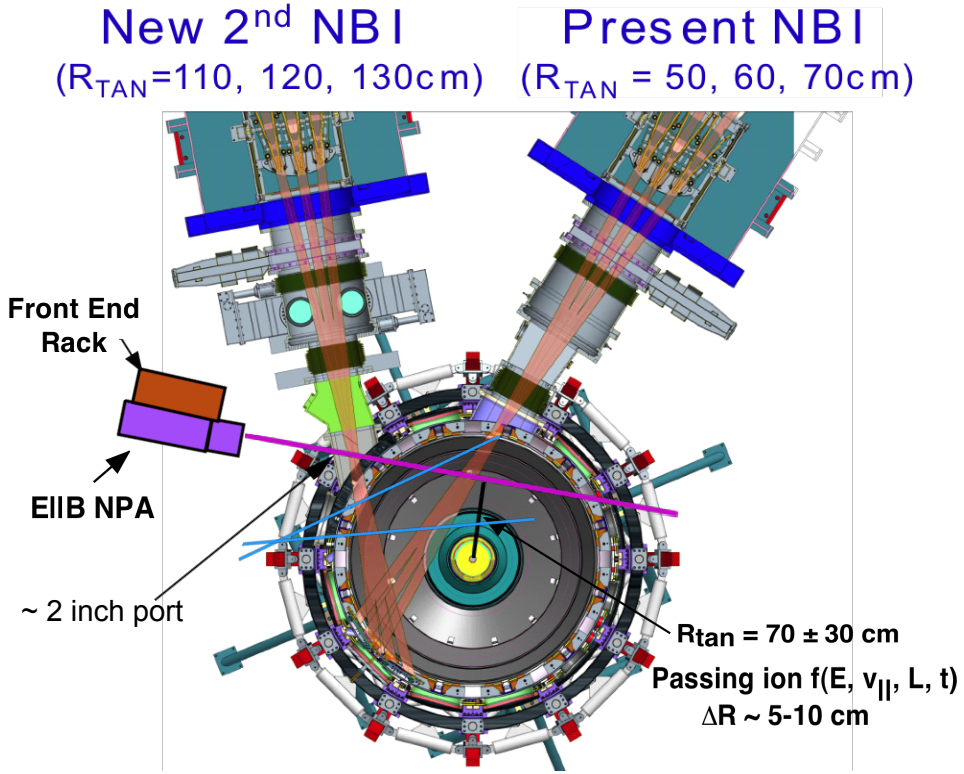


PPCF 51 (2009) 055001

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), ≥ 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



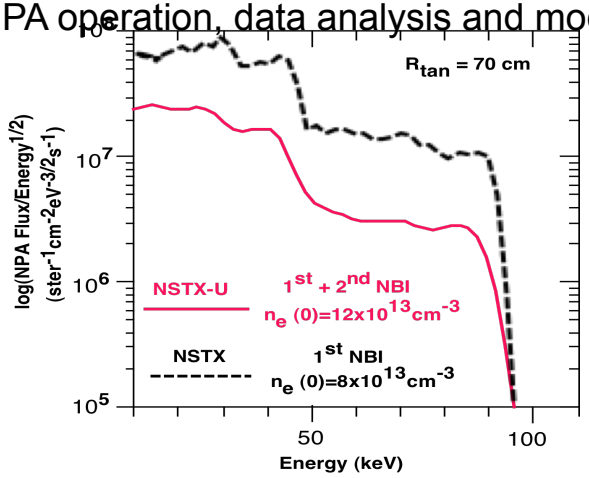
- E_{max}/E_{min} = 30 with 35 energy channels simultaneously for both H and D.

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

- E_D = 1–300 keV, E_H = 1-600 keV, $\Delta E/E$ ~ 2-5%, $v_{||}/v$ ~ 0.8 ± 0.1, ΔL ~ 20 cm, Δt ~ 0.1 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.



TRANSP E||B NPA Simulation

- 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 constrains
  - 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 3rd 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.

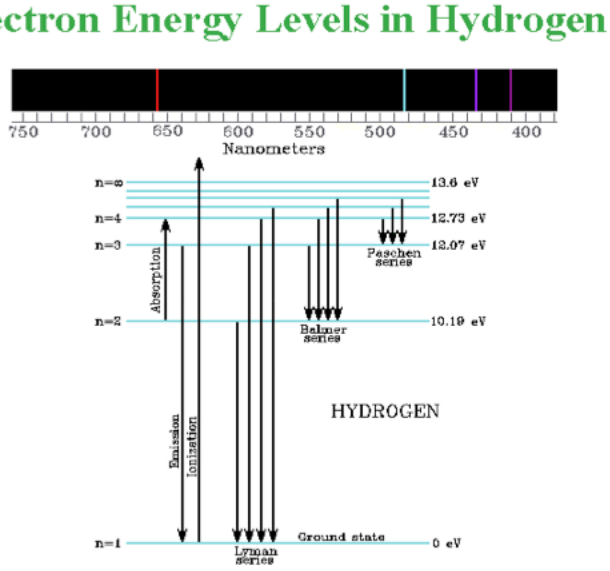
Neutral Density Measurements

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} ~ 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



Sensitivity $n_0 > 10^{14}$ 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 Lymanβ and observation of the fluorescence of Balmer α. [Voslamber and Seidel RSI 1999].
  - Requires two counter-propagating laser beams to eliminate the linear Doppler broadening.
  - Scheme is being implemented at DIIID [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 ~50 cm), one outboard channel (R_T ~120 cm), one edge channel (R_T ~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 2nd 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

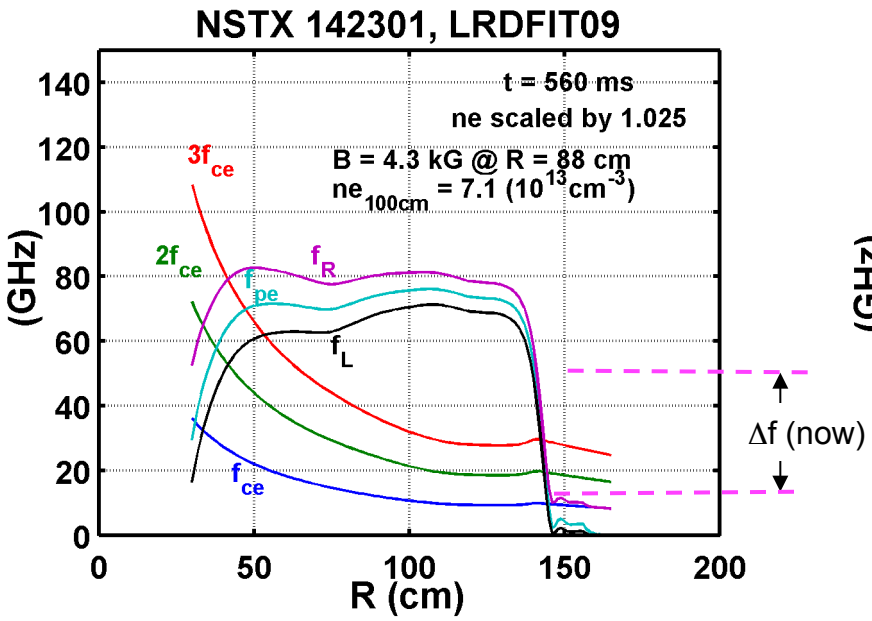
► FIReTIP-II will be collaboration with plasma diagnostics group of UC Davis

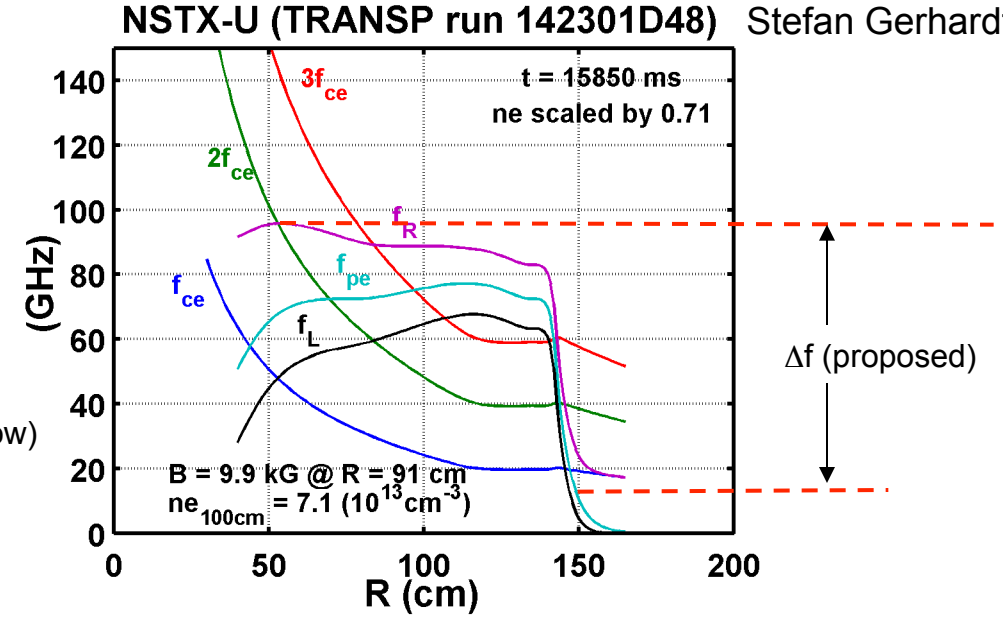
"Simple" Interferometer For Operations and Density Feedback Control

- 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?

SPG

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

- **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 (~5μs) 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 210μm fibers
  - Spatial resolution: ~20 radial channels, ≤1 cm resolution
  - Measurements in the range 135 cm < R < 155 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

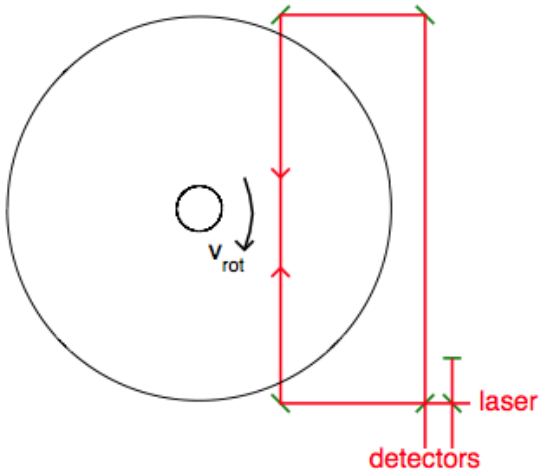
Gerrit J. Kramer

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

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

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
- LiII (548.6nm) and CIII (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.