Fusion Reactor Technology I
(459.760, 3 Credits)

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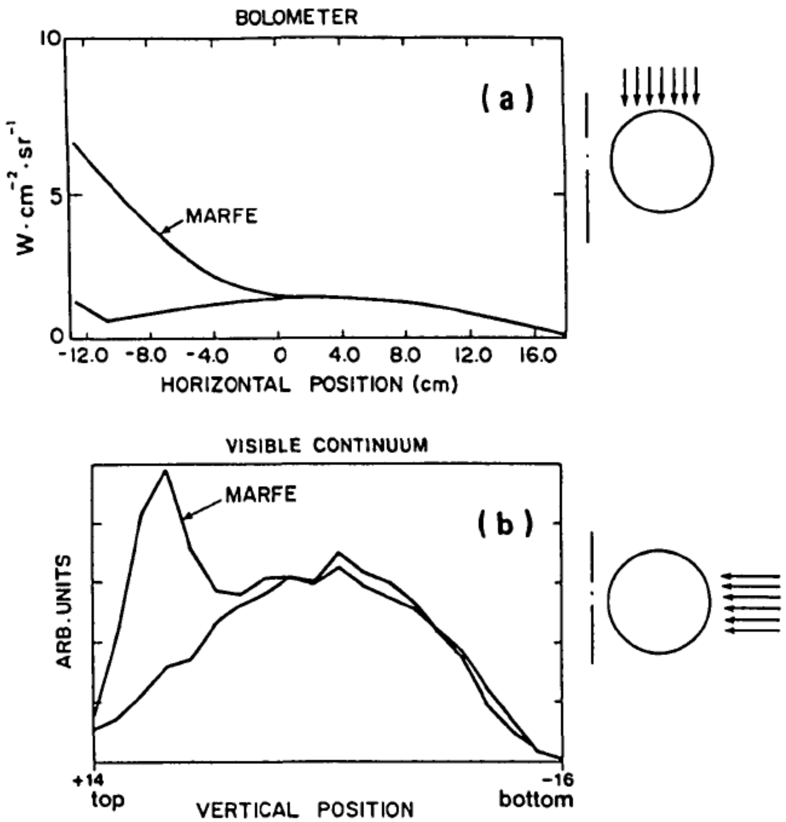
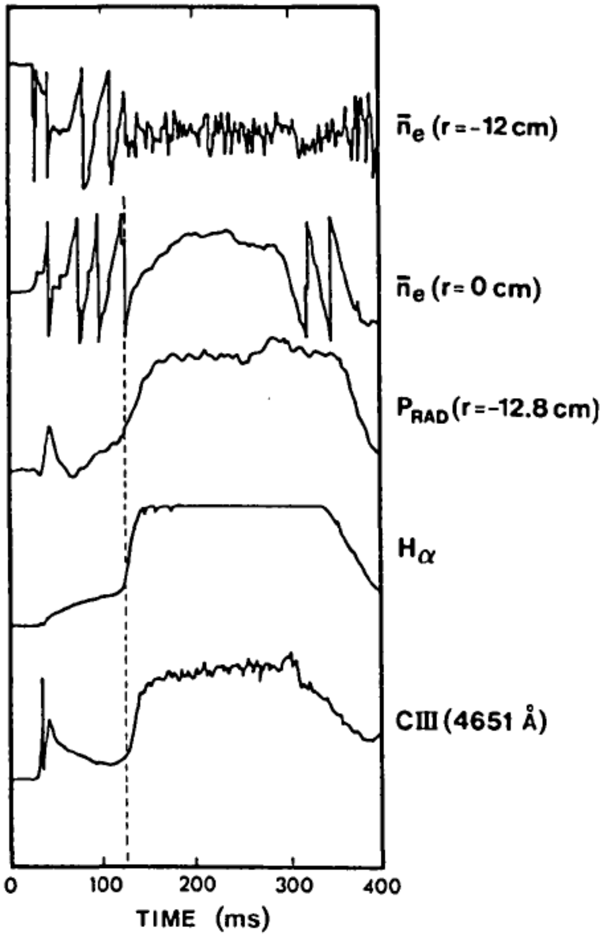
Contents

Contents

Non-linear Plasma Activity

- **MARFE (Multi-faceted Asymmetric Radiation From the Edge)**





B. Lipschultz et al, NF ***24*** *977 (1984)*

Non-linear Plasma Activity

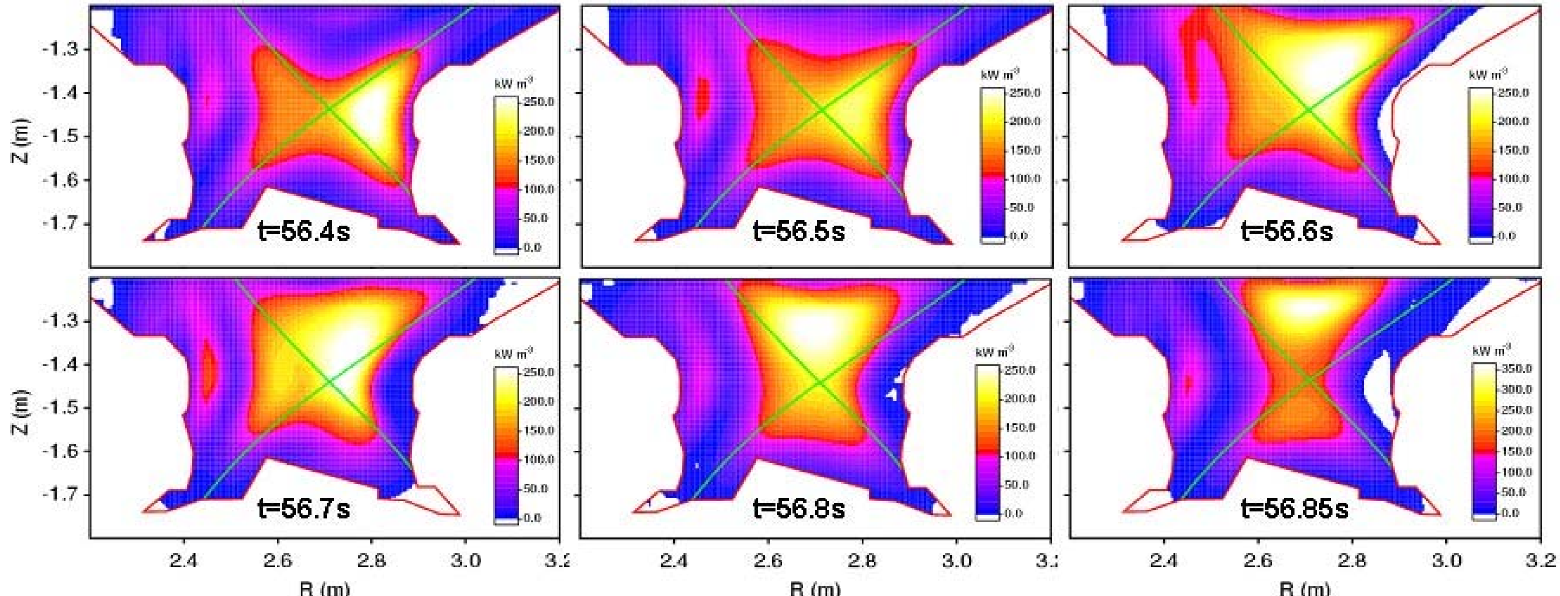
- **MARFE (Multi-faceted Asymmetric Radiation From the Edge)**

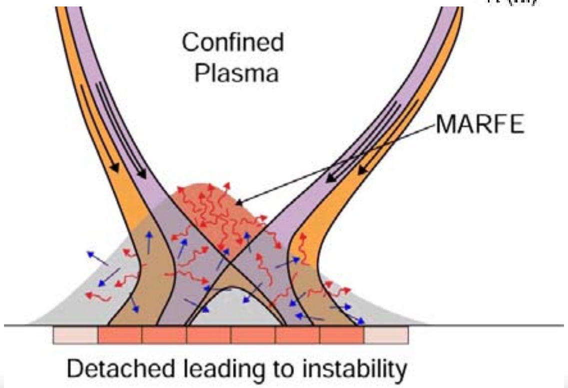
KSTAR

Shots selected by Dr. Y. M. Jeon (NFRI)

Non-linear Plasma Activity

- **MARFE (Multi-faceted Asymmetric Radiation From the Edge)**





Non-linear Plasma Activity

- **MARFE**

- First observed in medium- to high-density in ALCATOR-C discharges
  J. L. Terry et al, Bull. Am. Phys. Soc. **26** 886 (1981)
- Characterised by a toroidal ring of a dense moderately cold plasma, located at the periphery of a plasma column on its inner contour
- Edge impurity radiation is both in/out and up/down asymmetric, before and during a MARFE.
- Relatively small MARFE region emits a large fraction of the total radiated power.
- Easily observed due to its intense light radiation:
  High plasma density: ion density increased by a factor of up to ten
  comparable with the central
  density of the main plasma
  Low temperature: temperature dropped by 50% or so
  several eVs

Non-linear Plasma Activity

- **MARFE**

- Thermal-radiation instability observed in the

at high densities near the density limit:

Temperature decreases (due to radiation of

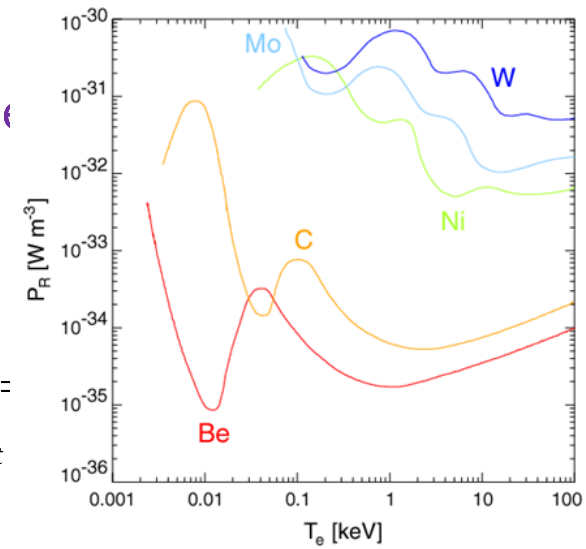
→ radiation increases

$$P_{line} = n_{19}\bar{n}_{19}^{*} A / \hat{T}_e^{\alpha} \quad (\alpha > 0)$$

↑ density of radiating elements

P_{br} =

P_{cyc}^{net}



The emissivity of most of the important impurities (mainly carbon from the wall materials) reach maxima at temperature in the range of 10 – 200 eV.

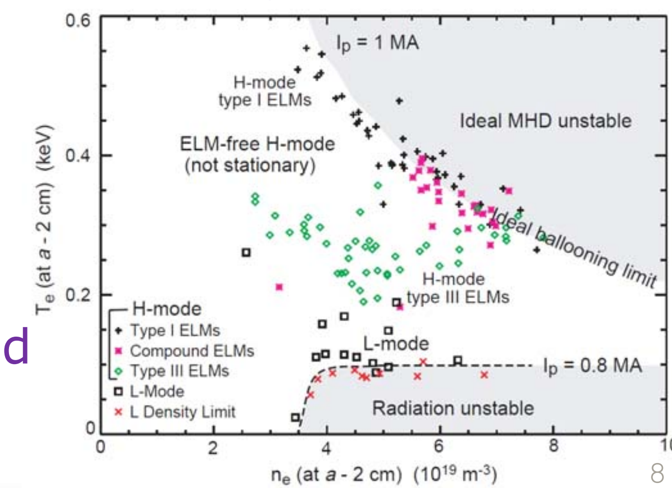
→ temperature continuously decreases

→ plasma pressure along the magnetic field increases plasma density

→ radiation further enhanced

→ a region of cold plasma (MARFE) formed

→ (sometimes) L-mode disruption



Non-linear Plasma Activity

- **MARFE**

- Edge plasma ‘compresses’ MARFE cold plasma (plasma flows into the MARFE, increasing the density) along magnetic field lines to maintain pressure balance and feeds the energy for the subsequent re-radiation: radiative condensation
- MARFE forms on closed flux surfaces inside the main plasma on a poloidal location where the temperature has a minimum: in a cylindrical limiter tokamak at the high-field side near the inner wall and in a divertor tokamak near the X-point.
- Outcome: not always the loss of H-mode confinement

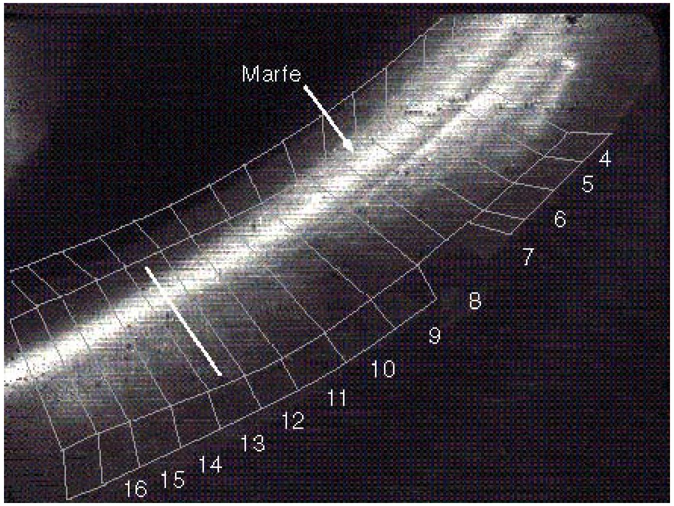
Non-linear Plasma Activity

- **MARFE: measurements**

- Discovered by the observation of an increased localized impurity emission from the MARFE edge by bolometry and visible spectroscopy
- Also detected by the bremsstrahlung from the high-density core of the MARFE in ASDEX Upgrade.

The temperature in the MAFRE centre can drop below 1 eV so that the plasma recombines by three-body recombination.

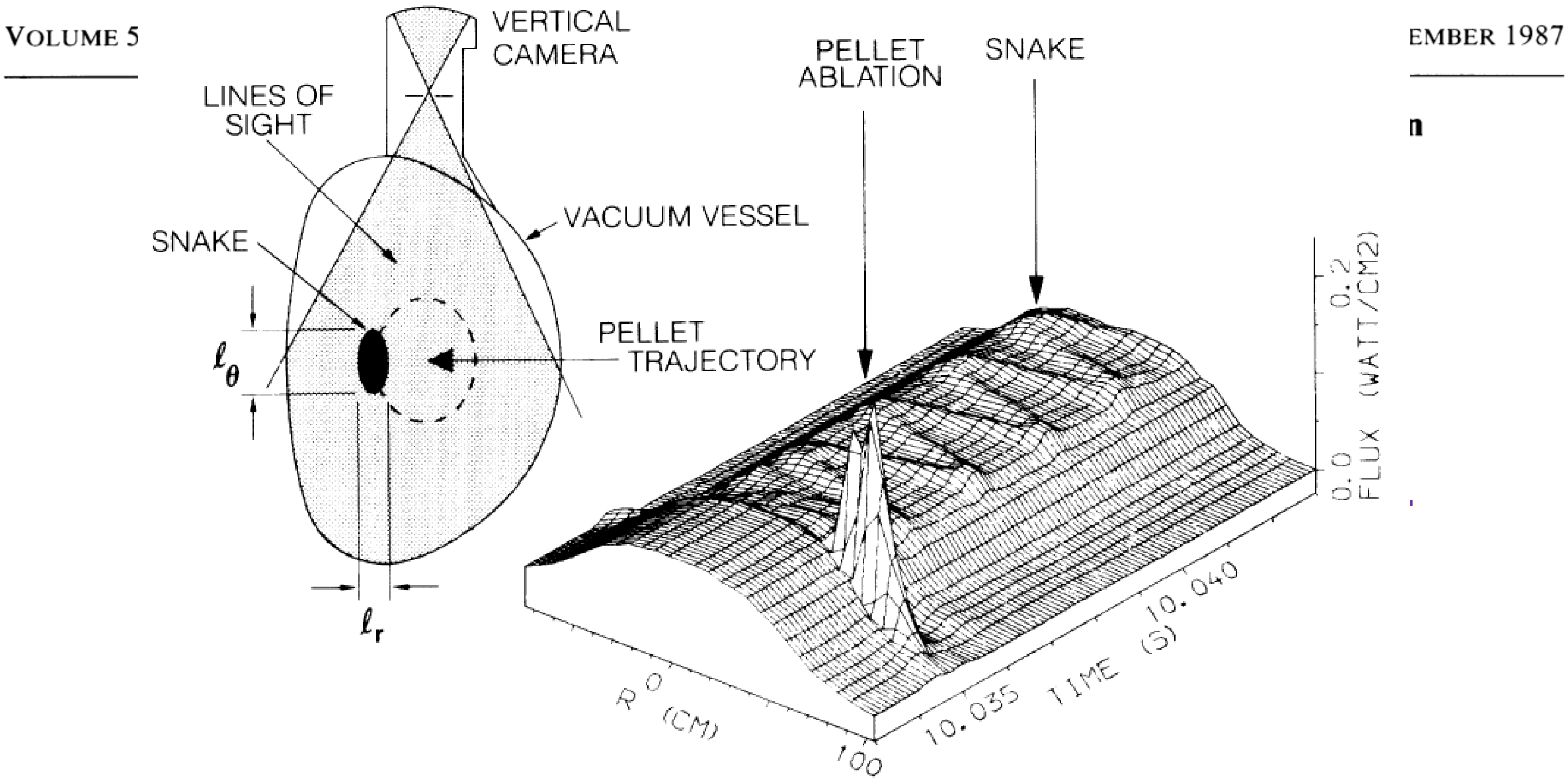
The three-body recombination in MARFE was detected by the characteristic Balmer spectrum near the series limit.



*U. Wenzel et al, Plasma Phys. Control. Fusion **44** L57 (2002)*

Non-linear Plasma Activity

- **Snakes**



Contour plot showing the snake-like perturbation of soft X-ray emission (by vertical cameras) following the injection of a deuterium pellet

Non-linear Plasma Activity

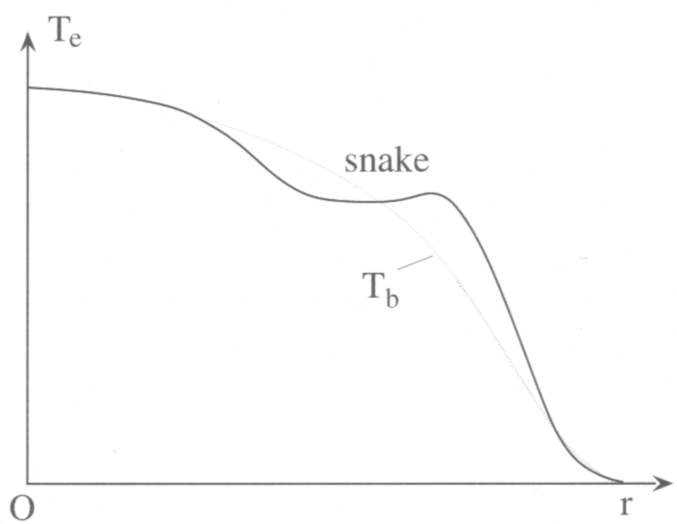
- **Snakes**

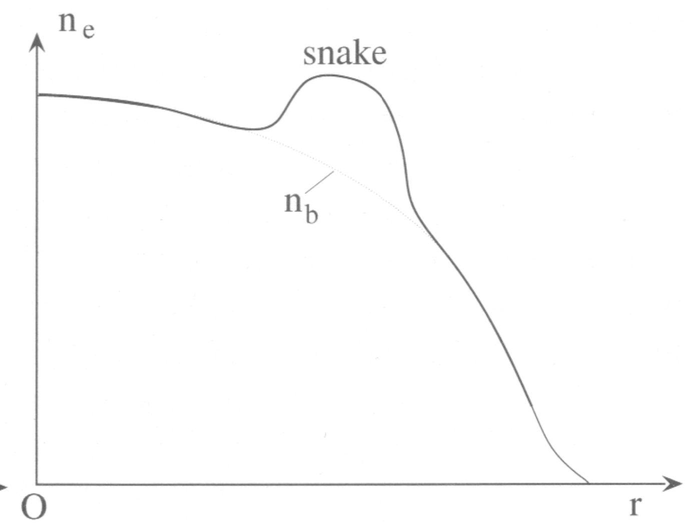
- First observed in JET: a rope-like filament observed in the soft-X-ray emission following the injection of a D_2 pellet
- A relatively cool, high density structure with typical poloidal and radial dimensions of $l_\theta \sim 25$ cm and $l_r \sim 17$ cm that forms on the $q = 1$ surface and which rotates about the minor axis
- While $q = 1$ is the preferred value, similar structures can occur on the $q = 3/2$ surface.
- Surviving for ~ 2 s regardless of frequent disturbances from sawtooth oscillations
- Pellet penetration needs to be inside the $q = 1$ surface to form the snakes.

Non-linear Plasma Activity

- **Snakes**

- Density and temperature of a typical snake:
  Δn = 3x10^{19} m^{-3}, n_b = 6x10^{19} m^{-3}, ΔT_e = -140 eV, T_b = 1200 eV
  (b : background values)
  total number of particles in the snake ~ 1% of the pellet particles
- Following an initial large drop attributed to the energy required to ionize the pellet atoms, T_e within the snake quickly rises to within 10% or so of the ambient plasma temperature.





Non-linear Plasma Activity

- **Snakes**

- Cool deuterium atoms supplied are swept outwards by the radial plasma motion until reaching a cool channel, C of the $q = 1$ surface (bottom of the sawtooth oscillation), where if the collapse phase of the sawtooth oscillation has just occurred.
- Ionization of the deuterium atoms as they cross C absorbs considerable energy and results in the large temperature drop. Equilibrium will require a nearly constant pressure and therefore initially, when C is relatively cool, it will become appreciable denser than its surroundings.
- Further progress to a fully developed snake depends on the transport of more particles into C and the maintenance of a temperature depression.

Non-linear Plasma Activity

- **Snakes: application to diagnostics**

- Acting as a sort of probe for studying of the position of the q = 1 surface during a sawtooth cycle
- Angular velocity of the snake about the minor axis providing a diagnostic of ion temperature, radial electric field (E_r)

$$E_r = v_\phi B_\theta - v_\theta B_\phi + p_i' / e n_e$$