30 MHz ICRH for DIII-D

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ICRH is an effective means of core heating magnetically confined plasmas

- **Using the fast wave in the ion cyclotron range of frequencies, with the absorption mechanism being ion cyclotron damping is a well-established method of core heating in tokamaks**
  - Successful in PLT, ASDEX, TFTR, JET, Alcator C, C-mod, TEXTOR, DIII-D (Dec. 19-21, 1990, shots 70750 – 70800), Tore Supra, AUG, . . . (partial list)
  - Highest fusion Q in JET in a steady-state was with ICRH (Start, et al.)
  - Only form of heating in C-mod
- **No upper density limit (unlike ECH, LH)**
- **Essentially only heating technique that can interact with the fusing ions under some circumstances**

We have a good deal of legacy equipment applicable to 30 MHz ICRH

- **Two 30-120 MHz transmitters (identical to IPP-Garching units that are used at 30 MHz on AUG), capable of providing up to 2 MW at 30 MHz each, mothballed since 2012**
- **Transmission line components used in the FWCD program, plus a large amount of line from Archimedes in storage at DIII-D**
- **Two antennas (0 deg, 180 deg) that were optimized for 60-120 MHz operation but should be usable at some level for 30 MHz**
  - Transmission line entirely intact on 0 deg
  - Sections removed between Mezz 2 and DIII-D on 180 deg (in storage)

Effective heating scenarios at wide range of toroidal fields

Ion damping mechanisms for 30 MHz FWs:

- **H fundamental minority and/or 2nd harmonic D at R where B_T=1.97 T**
  - Note the coincidence with location where 110 GHz EC power is absorbed at 2nd harmonic of electrons
  - Transition from H fundamental to 2nd harmonic D was studied on PLT by Hammett (thesis, 1985)
- **Absorption on injected beam ions at 3rd harmonic D at B_T=1.31 T**
  - Tested in TEXTOR
- **Absorption on injected beam ions at 4th harmonic at B_T= 1 T (same as former 60 MHz at 2 T, stronger)**

What exactly would we propose to do?

- **First stage: use one transmitter on 0 deg antenna**
  - Ought to be able to couple ~1 MW or more, depending on loading
  - Note on first day with 285-300 antenna (at 32 MHz) we reached that level in Dec. 1990
- **Could use both transmitters on one antenna to repeat and extend C-mod experiment on inner/outer power ratio effect on impurity source**
- **A later phase could use both 0 deg and 180 deg antennas with a load-resilient setup such as used on AUG**
- **For applications at high power, probably at some point need new antennas optimized for low frequency**
  - Could consider advanced antennas (comb-lines?)

Technical challenges for application of ICRH on DIII-D

- **Rf-specific impurities**
  - But central ICRH is used on AUG, JET to 'chase' metals from the core as we use ECH here
  - The metal ring campaign would have been a great opportunity to pin down far-field sheath metallic impurity sources
- **Adequate loading to couple high power in H-mode**
  - Reasons to think that despite low loading, we may be able to successfully deal with it at this low frequency
- **Obtaining enough load resilience to deal with ELMs**
  - Several ways to cope with this (mostly pioneered here)

Summary: ICRH at 30 MHz for DIII-D

- **ICRH is a useful tool for heating the core of tokamak plasmas that has no upper density limit, can be used over a wide range of fields and plasma conditions**
- **We have 4 MW of transmitter capability at DIII-D at 30 MHz, never exercised up to now (at that frequency)**
- **ICRH can generate higher energy ions than can be injected with NBI**
- **ICRH on DIII-D could be tested at modest cost (< 100 K$ for 1 MW test), expanded to more power at a cost on the order of 1-2 M$ (new antennas)**
- **After C-mod, no ICRH in US; ICRH is major part of the day-1 heating complement on ITER**
  - Possibly interest in collaboration from ASIPP, who also use ICRH