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Star Mode – The improved operating regime of a Fusor

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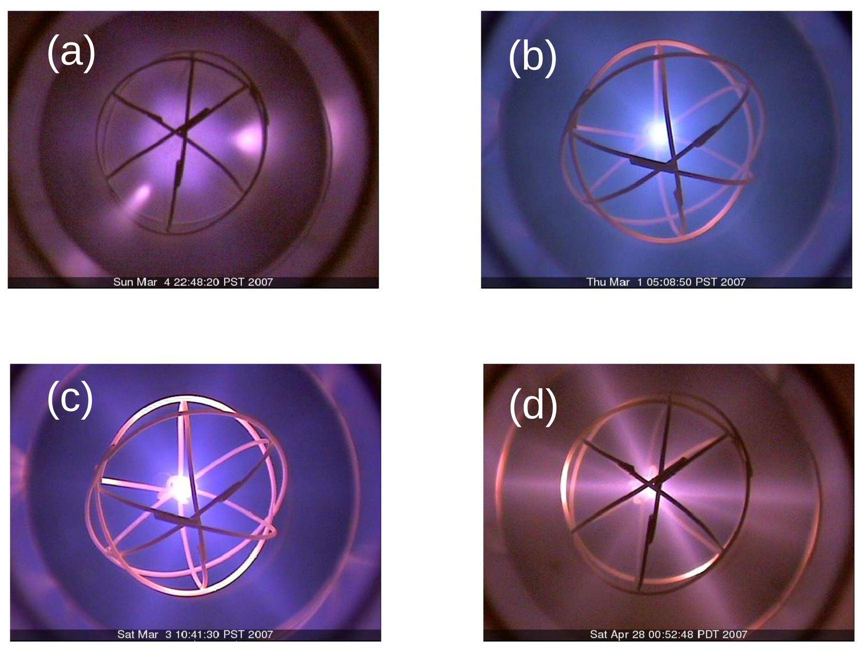
1 Summary

It was found in 1997, by G. H. Miley [1], that Fusors [2] can operate in a regime where the effective transparency of the accelerating grid is greatly enhanced over the value one would traditionally expect from considering the fraction of area taken up by the grid wires. This "Star Mode" reduces the heating of the grid wires and so should in principle allow smaller devices to be constructed. At present there is no complete explanation for this Star Mode. In this presentation we revisit some of the basic ideas and offer some new insights into the problem by considering the stability of the individual particle orbits

2 Experimental signatures



Figures reproduced from [3]

- Quasi-spherical DC electrostatic potential create by charged wire grid
- Gas filled chamber
- Glow discharge subsequently forms
- Characteristics depend on gas presure and voltage
- (a) Low voltage – High pressure
- (b) High voltage – High pressure
- (c) High voltage – Low pressure
- (d & e) **STAR MODE** – High voltage – Low pressure (~10kV and ~20mTorr)

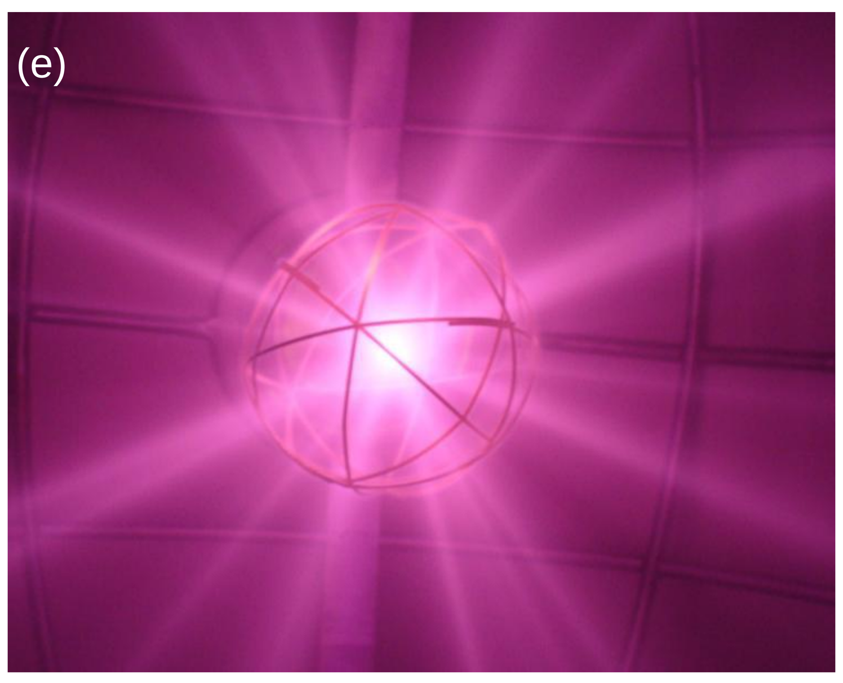


Figure reproduced from [4]

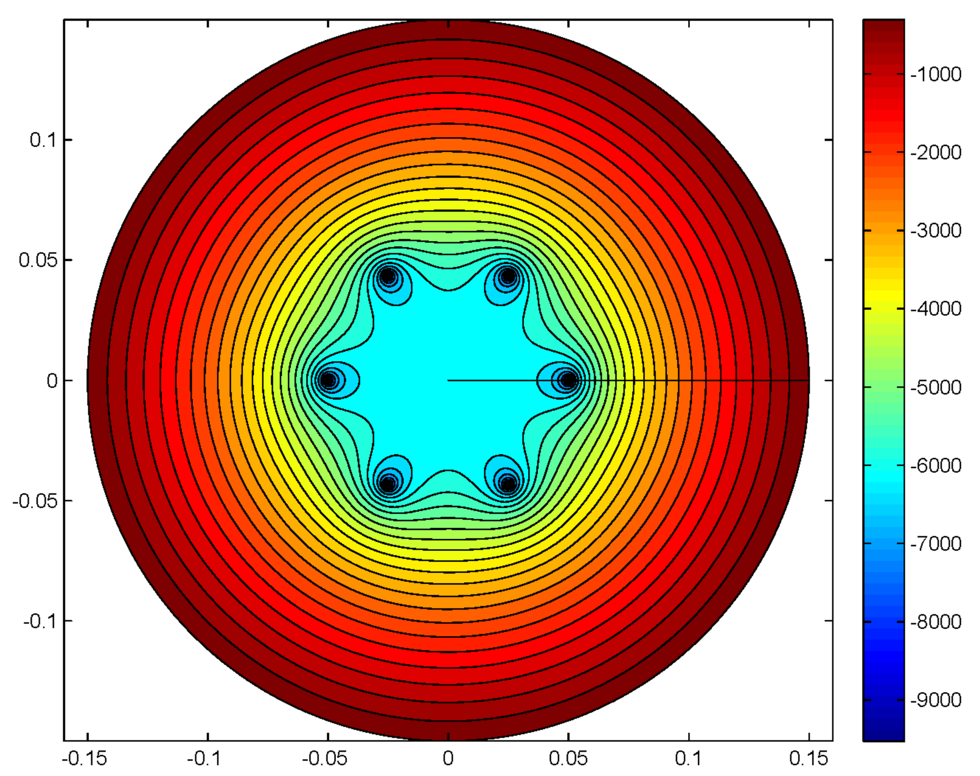
STAR MODE - Claimed

- Longer particle lifetime and less heating of the grid
- Better radial particle focussing and higher fusion reaction rate
- Existence of mode due to shape of vacuum potential

STAR MODE - Questions

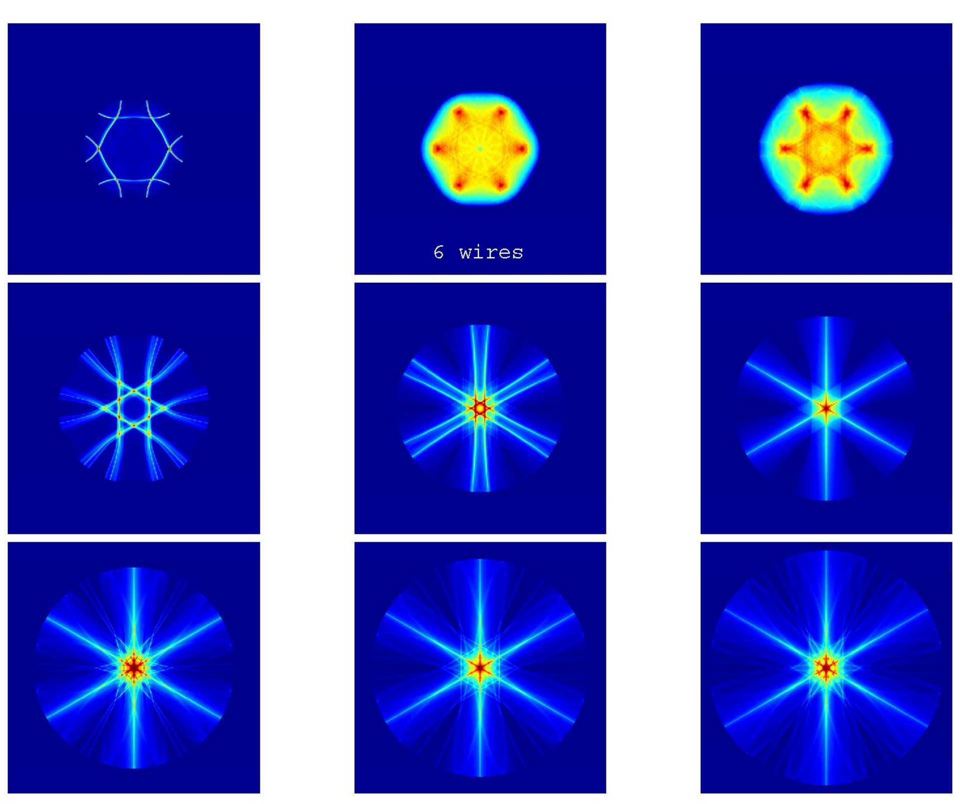
- What causes the transition to star mode when varying voltage and gas pressure?
- Why is the plasma shielding effect apparently so small?

3 Single particle modelling in 2D



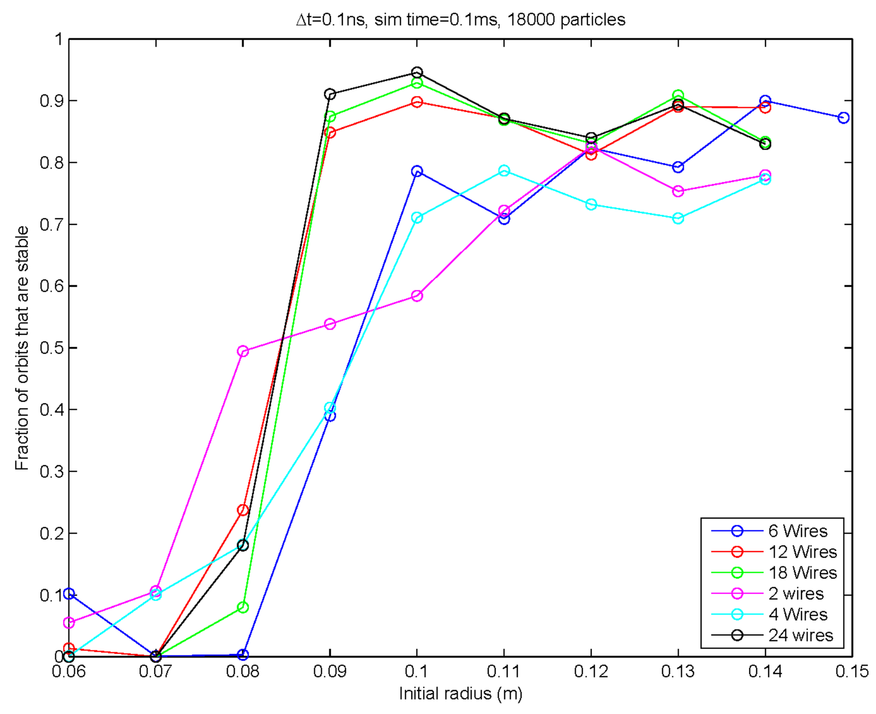
Potential:

- Formally one should solve $\nabla^2 V = 0$ with $V = 0$ at outer boundary and $V = V_w$ on circular wire surface
- If wire radius much smaller than distance between them we can instead solve $\nabla^2 V = 1/4\pi n \sum q\delta(\boldsymbol{r} - \boldsymbol{r}_w)$ with $V = 0$ boundary condition only (can use method of images or greens function method)
- Potential is symmetric to a large degree and only very close to the wires are the perturbations noticeable
- Along radial lines passing through the centre of the gaps in the wires the potential "ripples" appear to act to push particles towards the wires, not focus.



Particle orbits – Visual:

- Symplectic leap frog scheme solves Newton's equations – good for long timescale orbital motion
- Particles initialised with zero velocity uniformly in angle at a given initial radius
- If particle hits the wire or outer boundary kill it
- Time integrated density of particle trajectories - Top left to bottom right increasing initial particle radius.
- **Transition into apparent star like pattern** – seems to contradict repelling feature of the potential at gap

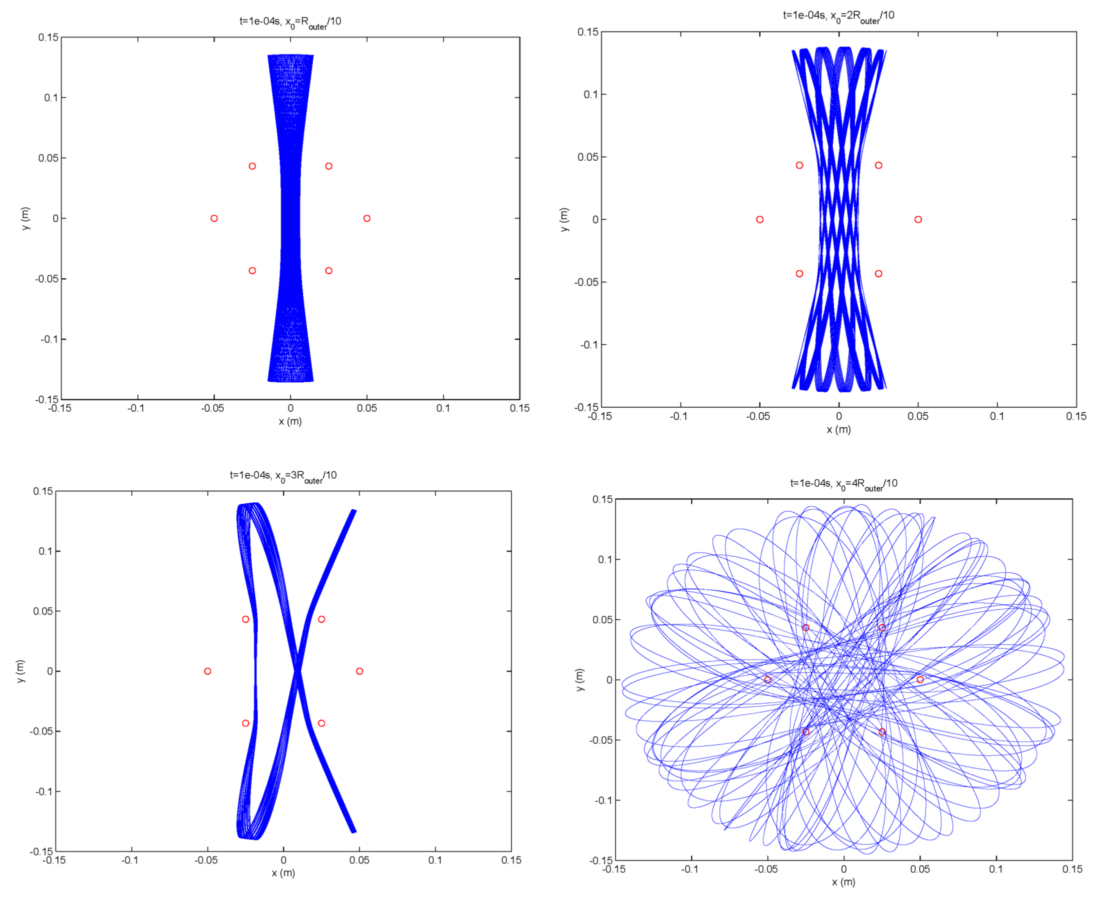


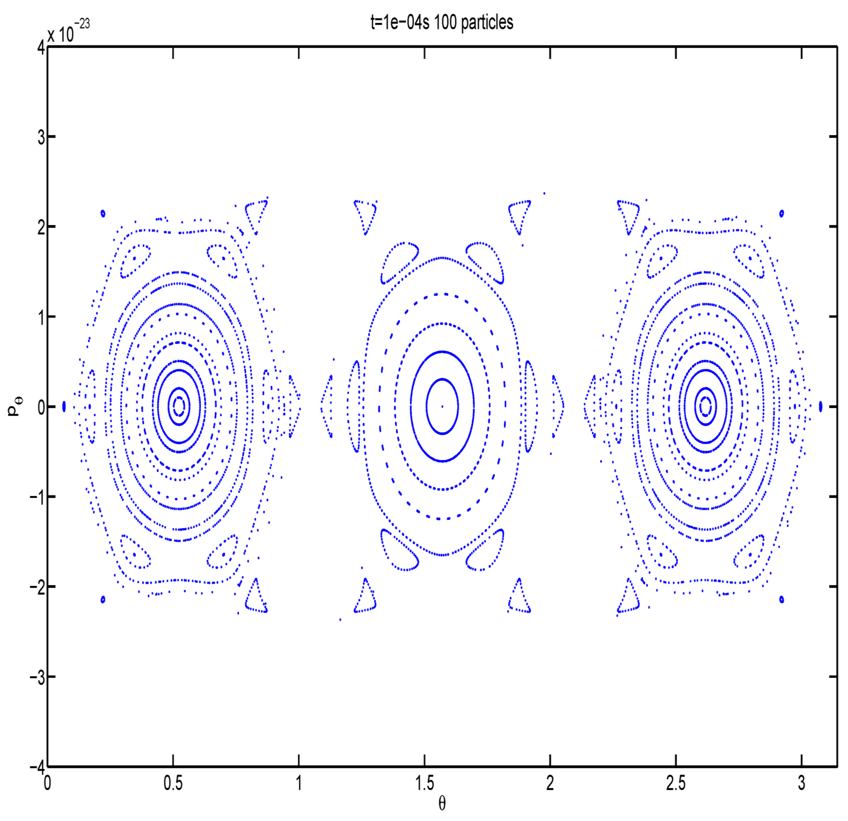
Particle orbits – Quantitative:

- After 1ms particle collisions with wires essentially stop
- Look what fraction are still remaining
- **Particle orbits are surprisingly stable (don't hit the wires) for a large range of initial radii**
- **Sharp transition between stable and unstable orbits for wire number >4**

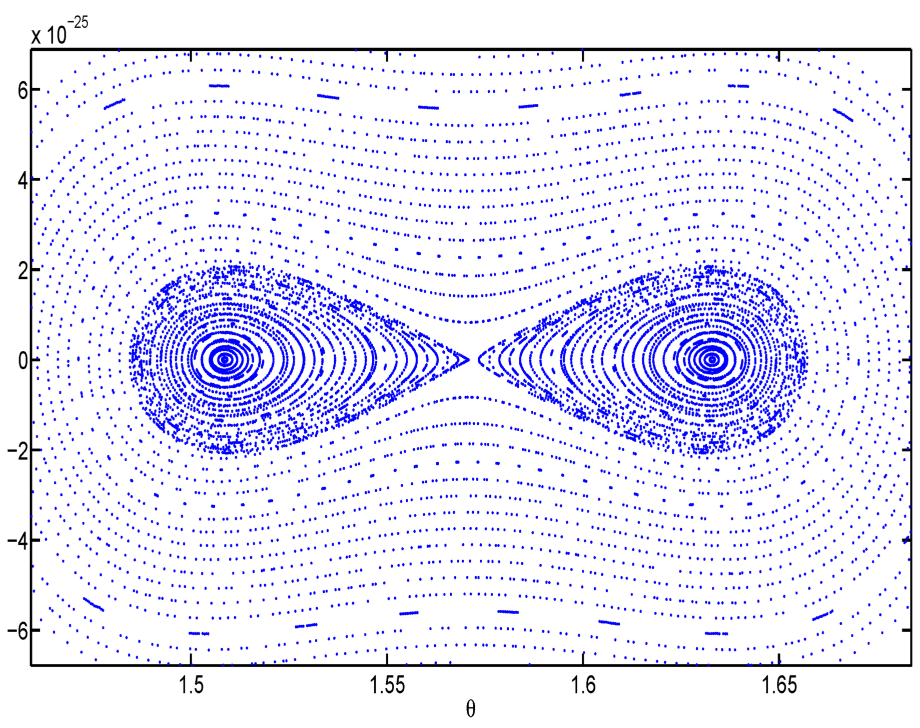
Dynamical systems perspective:

- 1 particle simulation - Top left to bottom right increasing initial x position for fixed y
- Stable bands in which particle oscillates about the axis. This band changes character and eventually ends in chaos
- Poincaré plots – Find the outer turning point for the particles ($\dot{r} = 0$) and plot the (θ, p_θ) values (100 particles)





- Phase space islands show existence of stable orbits for large initial radii
- Destabilising nature of the potential ripples can only be seen for more inwardly initialised particles where it is more pronounced. **Localised instability** of the orbits manifests as a figure of 8 surrounded by islands of stability



- Expansion of equation of motion about $x = 0$ to understand stability of orbits (all variables normalised to outer radius)

$$V = \frac{q}{4\pi n}[\ln A - \ln B]$$

$$A = r_w^{2n} - 2(rr_w)^n \cos n\theta + r^{2n}$$

$$B = 1 - 2(rr_w)^n \cos n\theta + (rr_w)^{2n}$$

$$m\ddot{x} = \frac{q^2 n|y|^n r_w^n}{2\pi|y|^2}\left\{\left(\frac{1}{A_0} - \frac{1}{B_0}\right)x - \frac{n^2}{|y|^2}\left[\left(\frac{1}{A_0} - \frac{1}{B_0}\right) - 6|y|^n r_w^n\left(\frac{1}{A_0^2} - \frac{1}{B_0^2}\right)\right]x^3\right\}$$

- Destabilising linear term, but **nonlinearity** is **stabilising** as long as the particles start far enough away from the wires – **suggests why sharp transition exists**
- For wires positioned too close to the boundary **nonlinearity always destabilising** so no star mode should form

4 Interpretation and Next steps

- The existence of a sharp transition in initial radius (R_{trans}) from stable to unstable orbits produces a natural length scale $R_{trans} - R_{wire}$
- If the ionisation mean free path is larger than this then an initially unstable particle orbit will quickly find its way onto a stable path after its initial impact with the wire, forming part of the star.
- This would explain the appearance of star mode at low gas pressures
- Need to understand the role that voltage plays – it doesn't appear to affect potential shape
- Addressing the plasma self fields – simple Debye length arguments suggest complete shielding of the vacuum field, yet we see interesting features and produce neutrons!

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