Interaction of a Supersonic Radiatively Cooled Plasma Jet with a Background Ambient

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Protostellar Jets in Context
Rhodes, Greece
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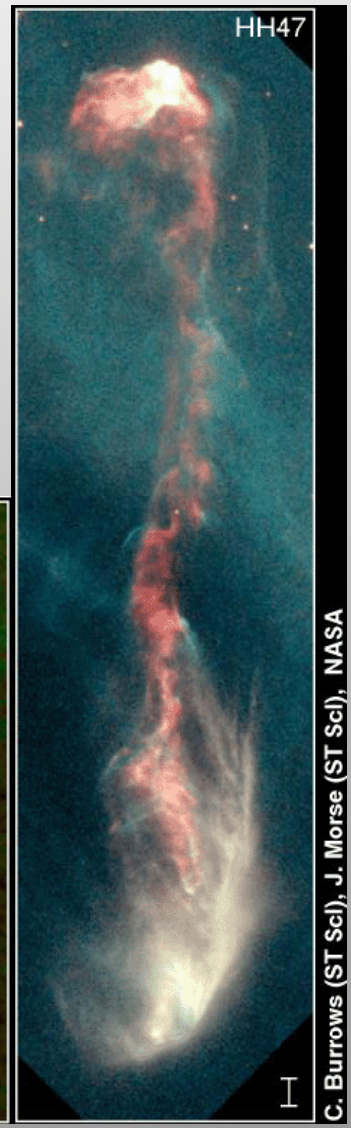
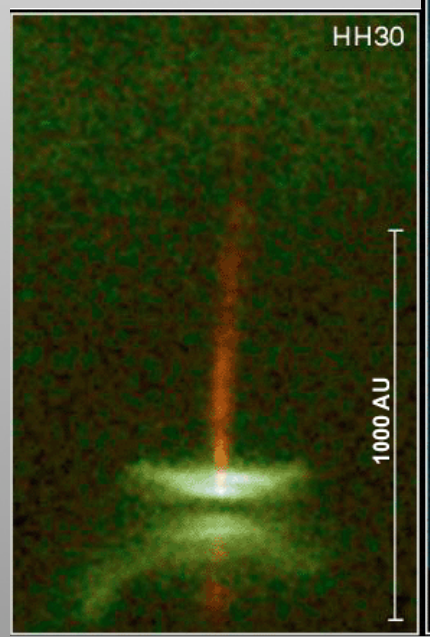
JeTseT

Jets from young stellar objects

- Experiments aim to reproduce particular features / regions of YSO jets, in particular:
- Dimensionless parameters and initial conditions need to be the *same* in both laboratory and space.





Outflow region (jet propagation, interaction, etc.)

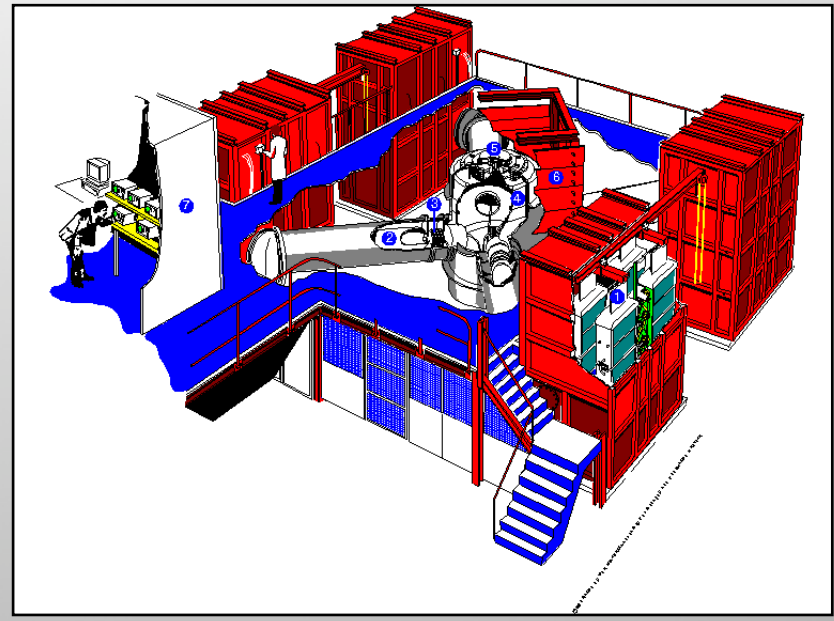
B-field less relevant?

Launching / Driving region (jet formation, launching)

B-fields dynamically significant?

Radial foil z-pinch

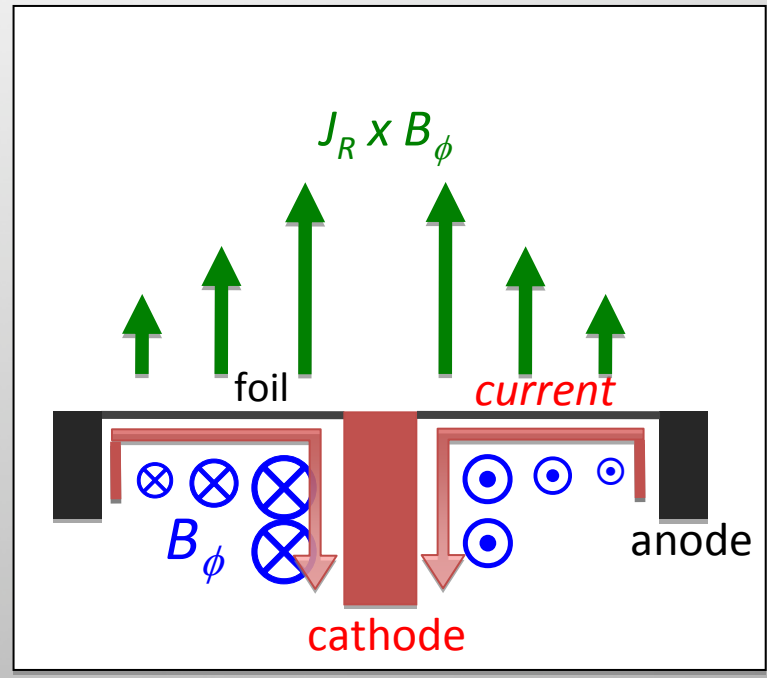
- 1 MA, 250 ns current from MAGPIE generator.
- Previous similar experiments have shown to be scalable to YSO jets:
  - Radial wire array
    (Lebedev et al., MNRAS 2005).
  - Conical wire array
    (Ampleford et al., PRL 2008).



- Radial metallic foil (~μm thick)
  - Typically: 6 – 6.5um thick Aluminium foil.
  - Material can be easily changed.

Radial foil z-pinch

- As current increases:
  - Toroidal magnetic field increases below the foil ($B\phi$).
  - $B\phi$ is stronger close to cathode.
  - *JxB* force ablates plasma axially.



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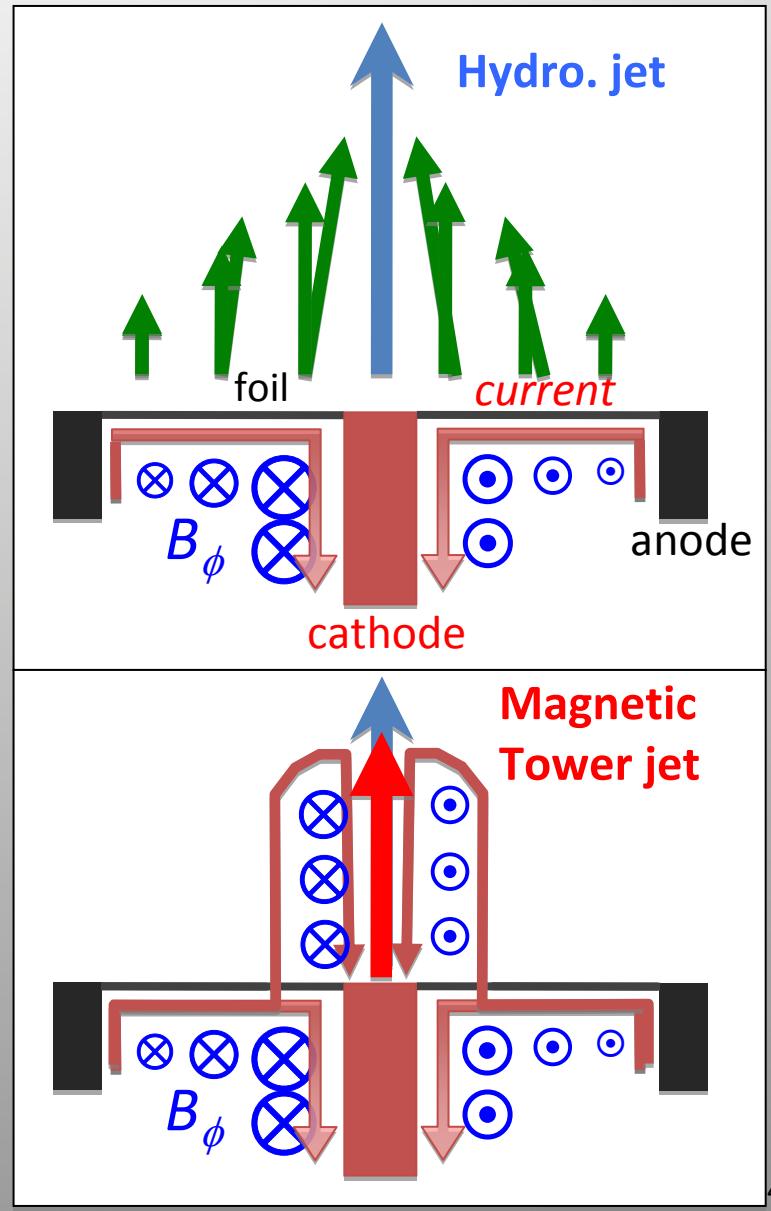
  - Plasma flow converges on axis
    - Hydrodynamic jet is formed
    - B-field is not dynamically relevant to drive the jet.
- As current keeps increasing:
  - Formation of magnetic tower jet.
  - Radial foil -> Episodic jets.



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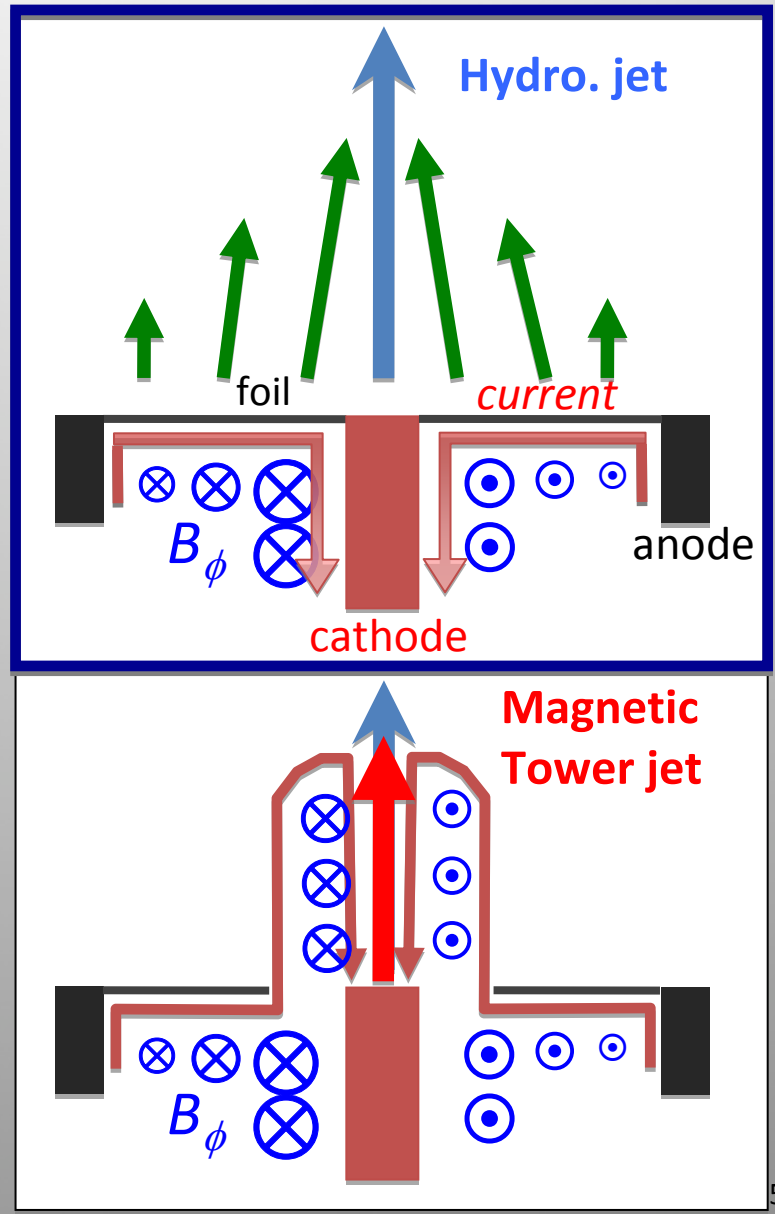
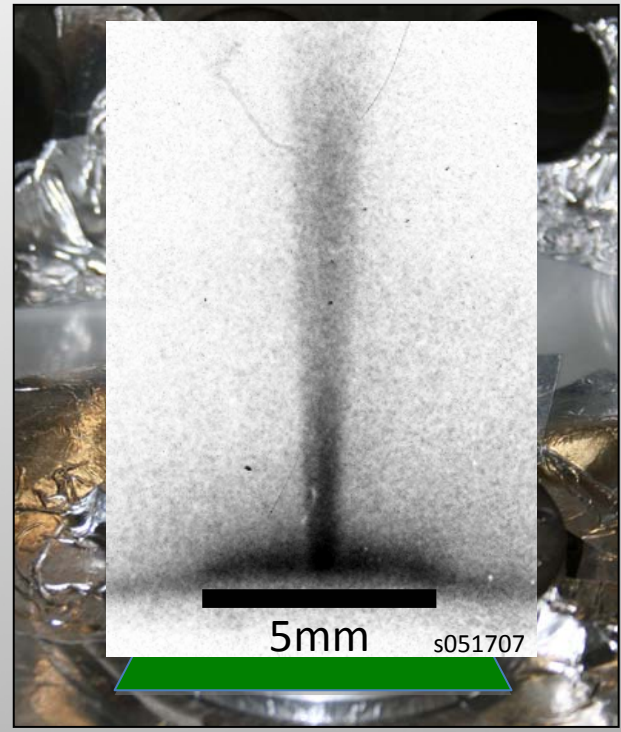
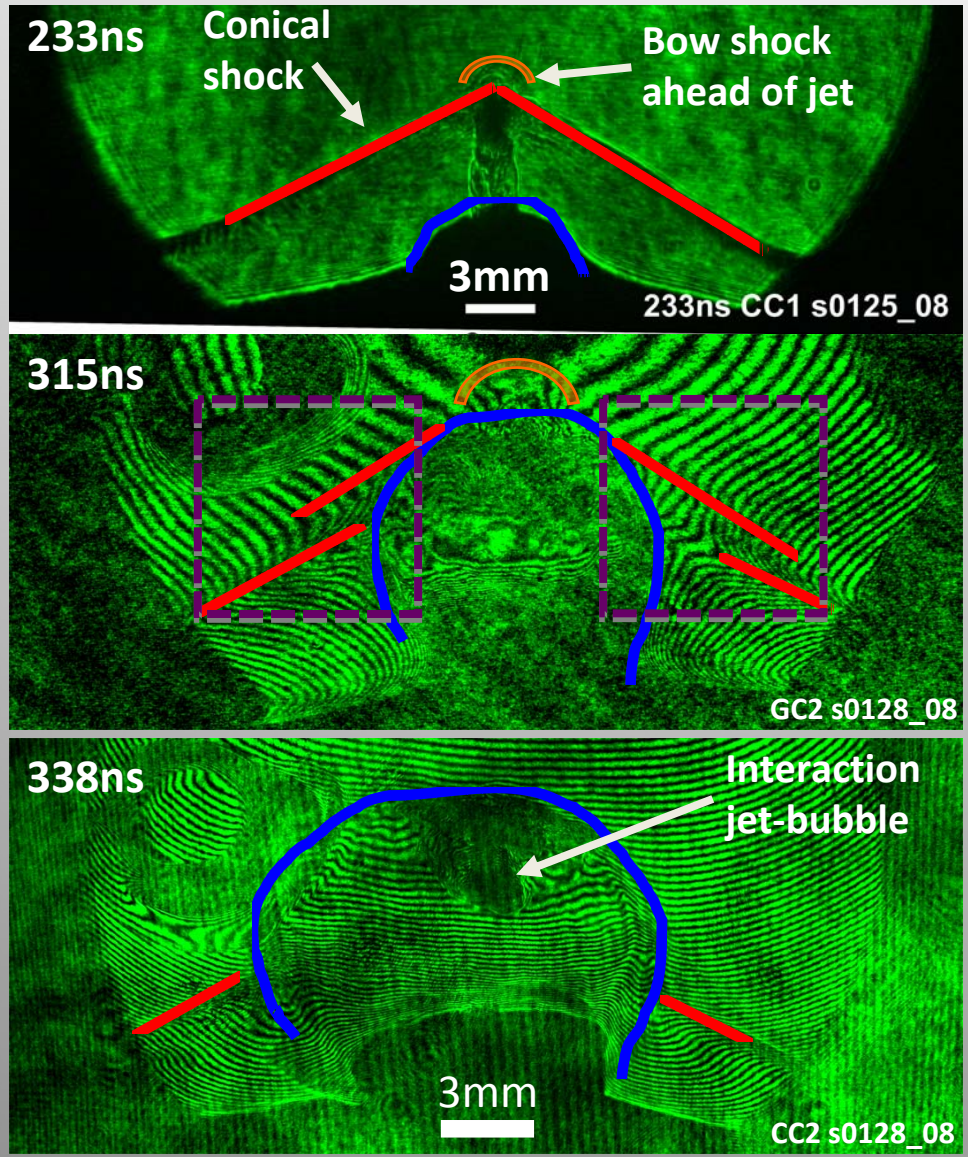


Jet-Ambient interaction

- Radial foil (no gas):
  - Hydro. jet observed from early times
- Gas ambient:
  - Neutral gas injected before the start of the current (~5 ms).
  - Gas fills the region above the foil.
  - Typically **Argon** (but also Xe, He).
  - N ~ 10^{17}-10^{18} cm^{-3}



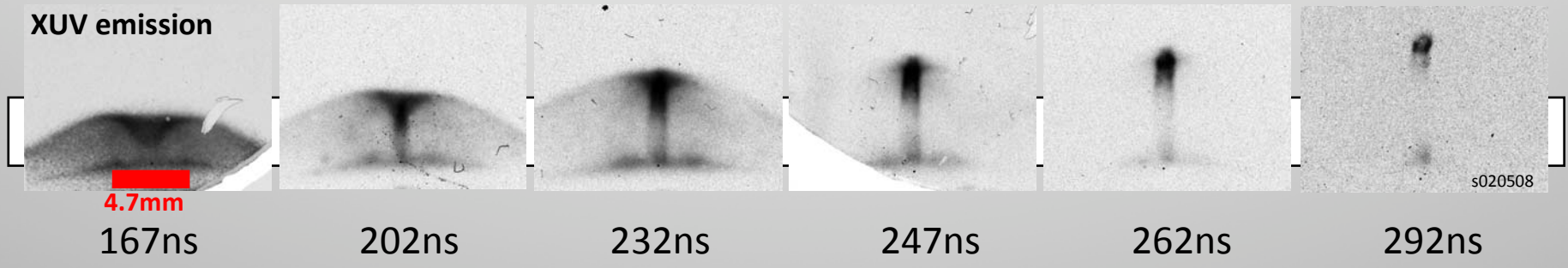
Foil with argon gas background



- **6.5um Al foil, 3.1mm cathode**
- Several new features observed:
- Conical shock
- Bow shock ahead of jet
- Conical shock separates into 2 oblique shocks?
- Episodic magnetic towers (Vz~300 km/s) overtake these shock features.

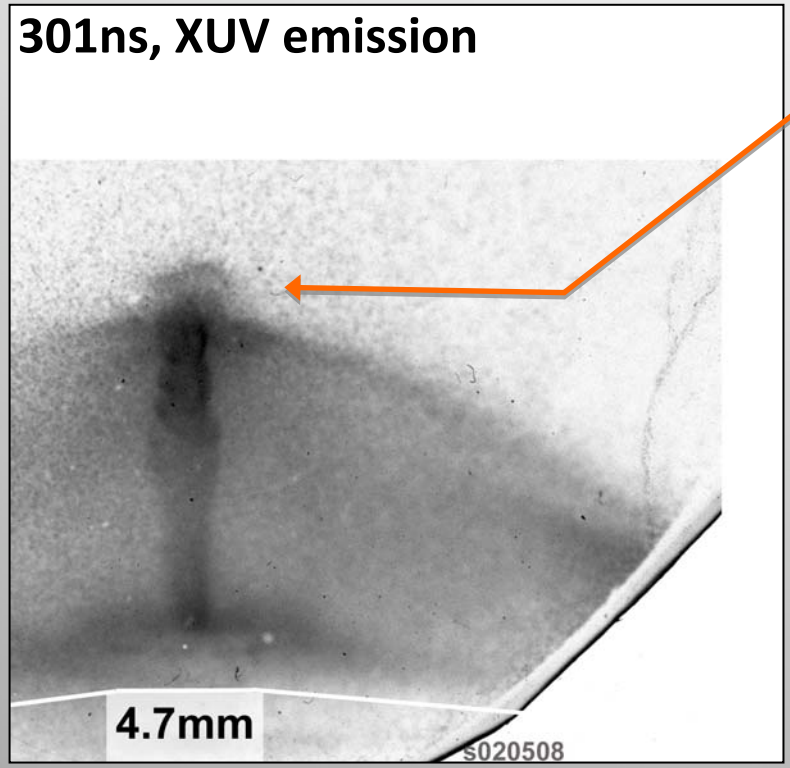
Conical shock formation

- Formation of episodic magnetic towers are “delayed” by increasing the diameter of the central cathode.



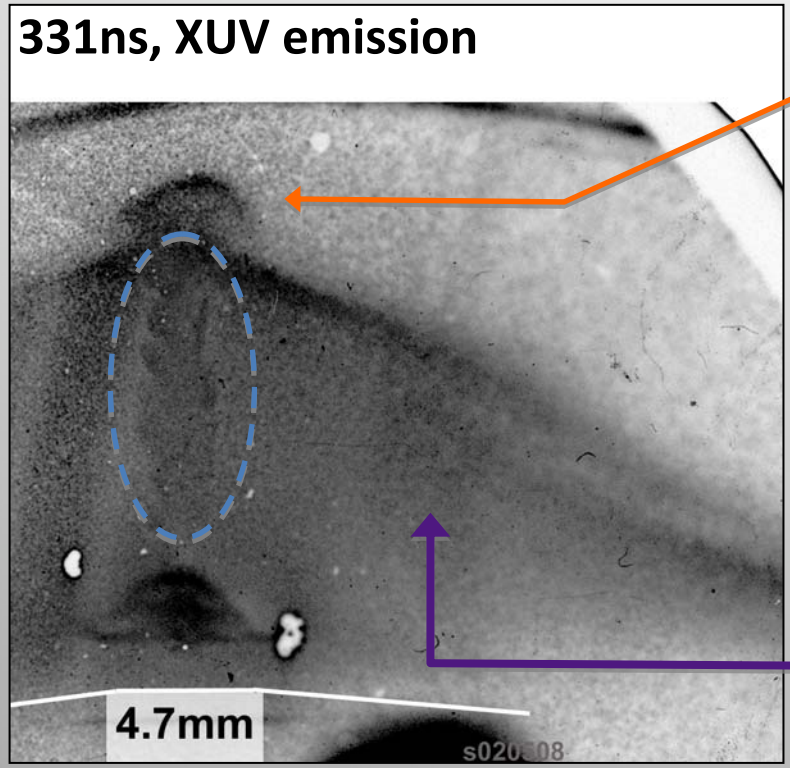
- Ablation of plasma from the foil converges on axis, forming the hydrodynamical jet (Vz ~ 55 - 65 km/s)
- Interaction of the jet with the gas background forms the conical shock (half-angle ~ 60˚).
- Tip of the jet shows higher emission. Plasma is swept and compressed.

Detailed shock dynamics



- Bow-shock starts forming at the tip of the jet.
- Spherical front with Vz~80-100 km/s

Detailed shock dynamics



- Bow-shock starts forming at the tip of the jet.
- Spherical front with Vz~80-100 km/s
- Instabilities in the jet?
- Separate shock structures from the initial conical shock.

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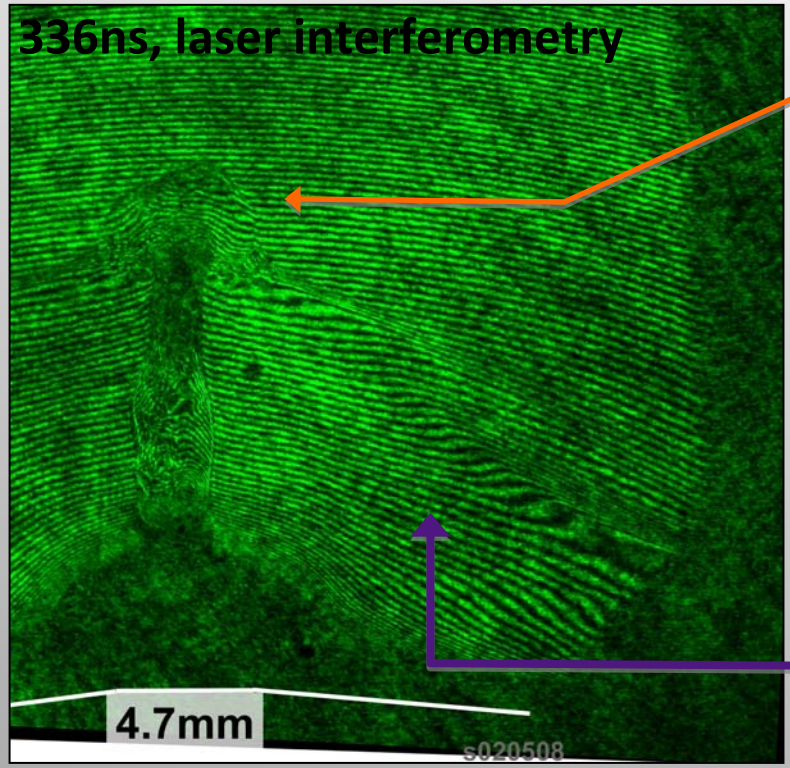

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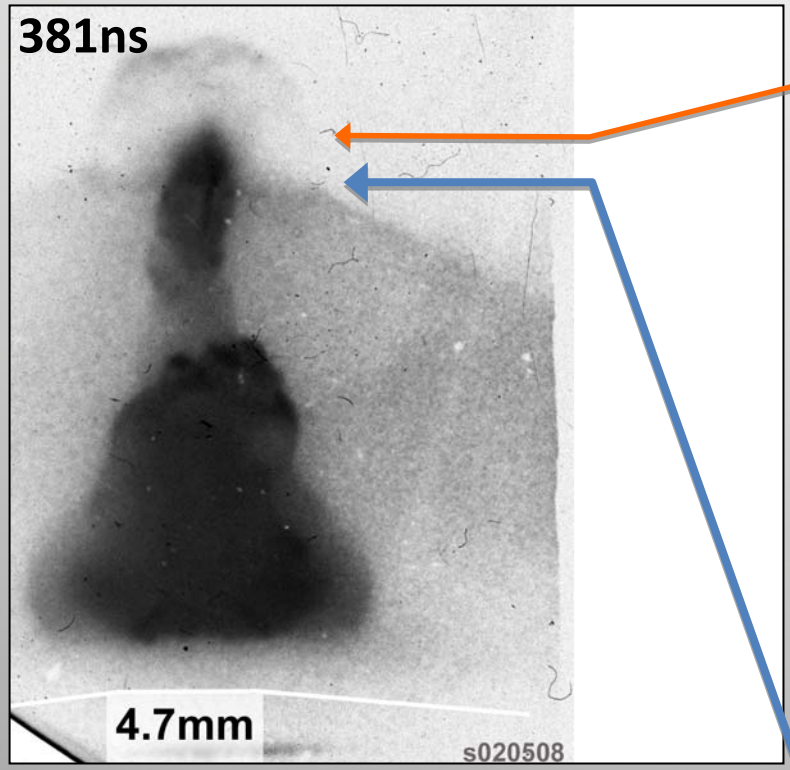
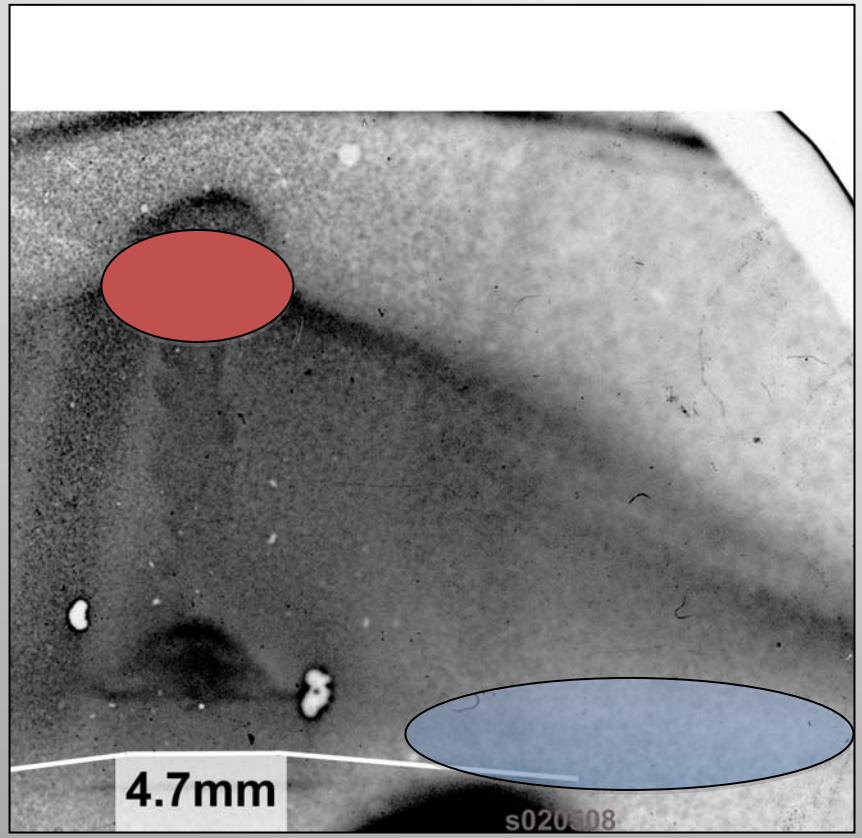


Radiation from the tip of the hydro. jet driving this shock?

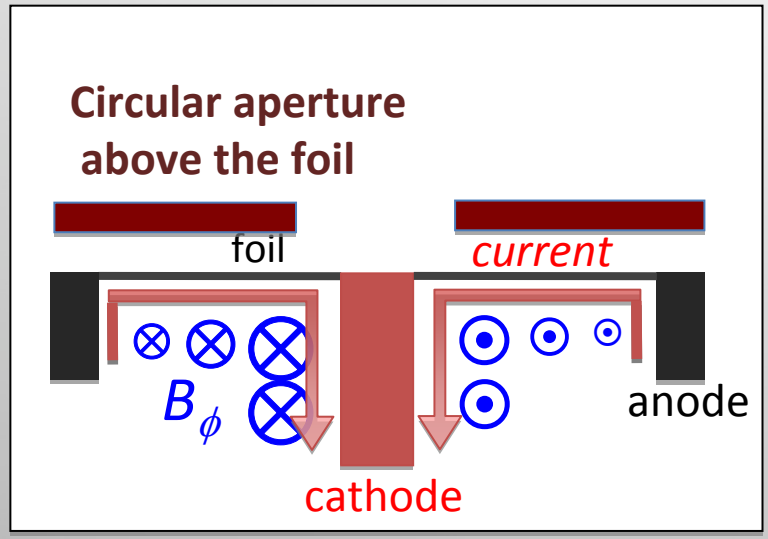
- Bow-shock starts forming at the tip of the jet.
- Spherical front with Vz~80-100 km/s
- Instabilities in the jet?
- Separate shock structures from the initial conical shock.
- Contact boundary from interaction of bow shock and conical shock.

Separate shocks



- Separate contributions to the conical shock formation:
  - Shock from the tip of the jet
  - Shock from plasma ablated from the foil (extends to larger radius)
- These dynamics can be modified.

Separate shocks



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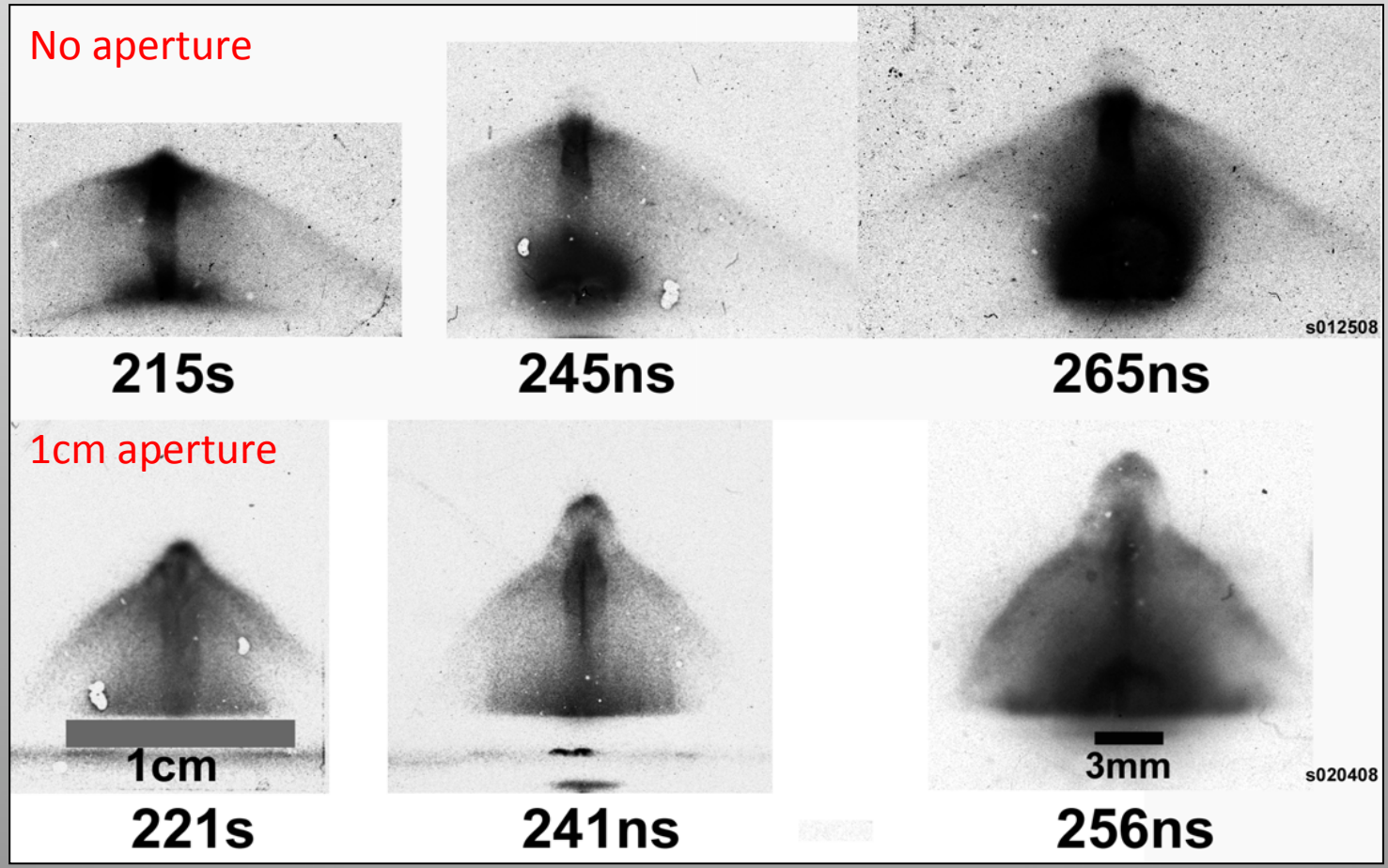
  - Shock from the tip of the jet
  - Shock from plasma ablated from the foil (extends to larger radius)

- These dynamics can be modified.

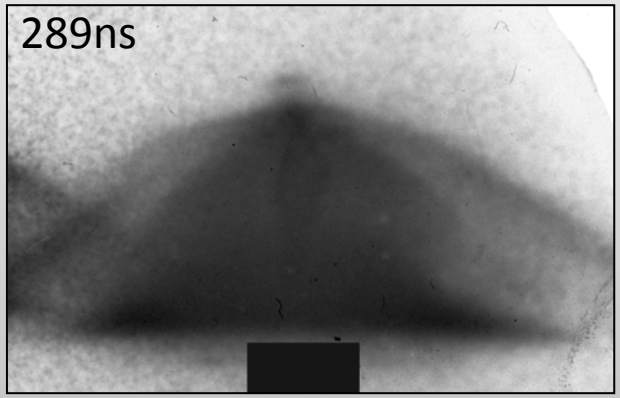
Separate shocks

- Angle of the conical shock is modified.
- No separate shocks are observed.

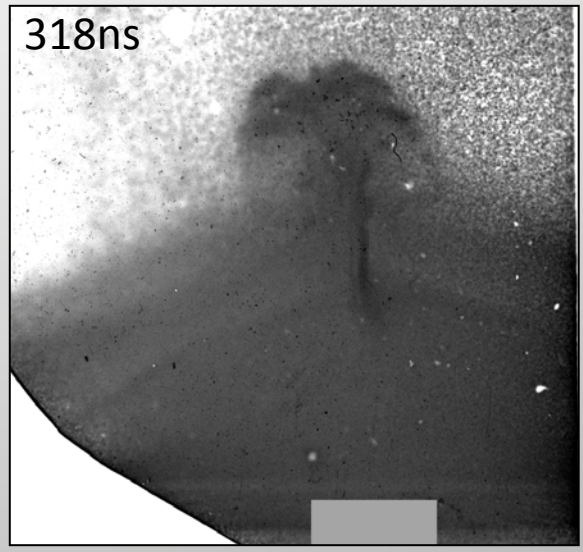


Changing initial conditions

- Same shock features are observed in different configurations:

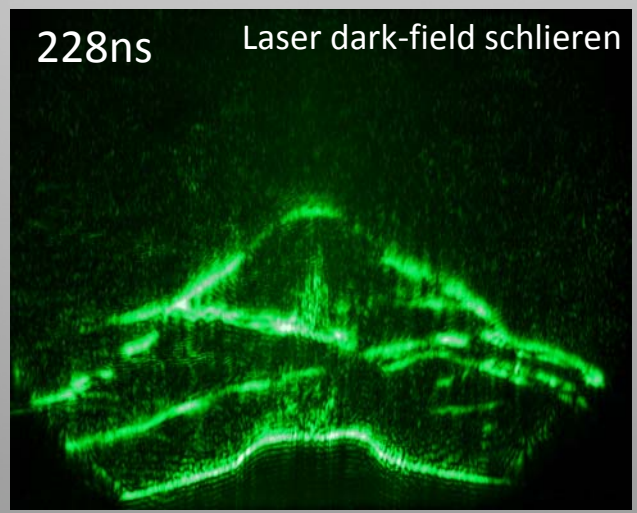


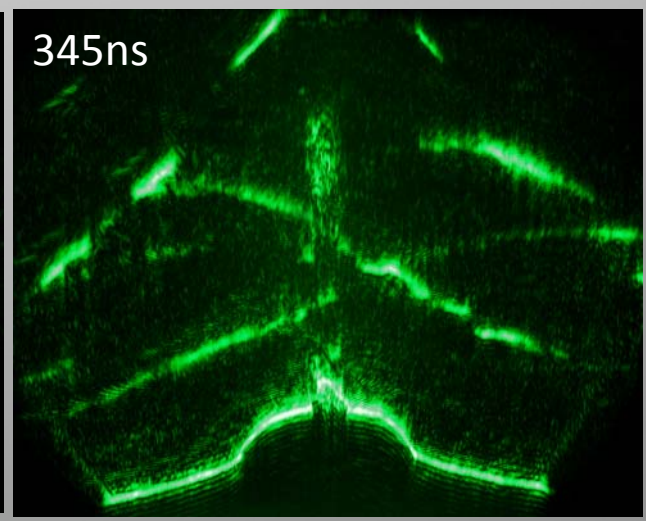
Copper foil (7um) + Argon gas



Tantalum foil (4.5um) + Argon gas

… and also more "puzzling" effects:



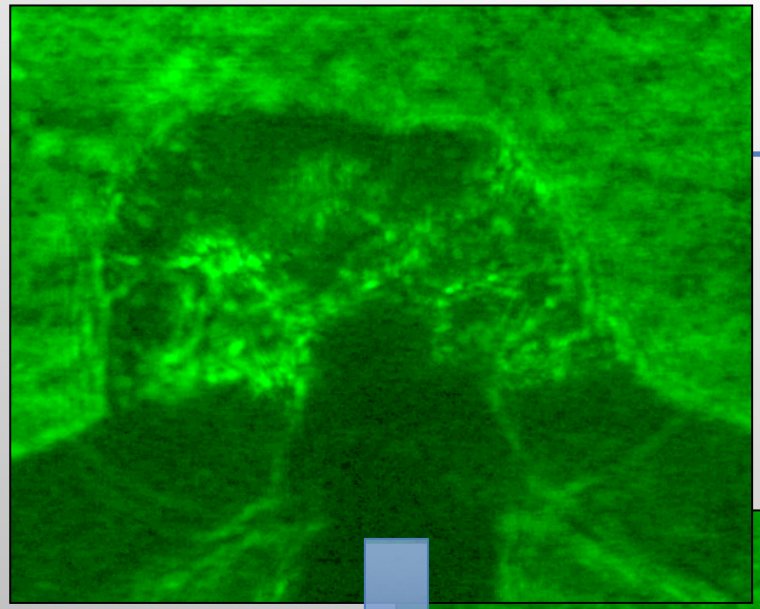


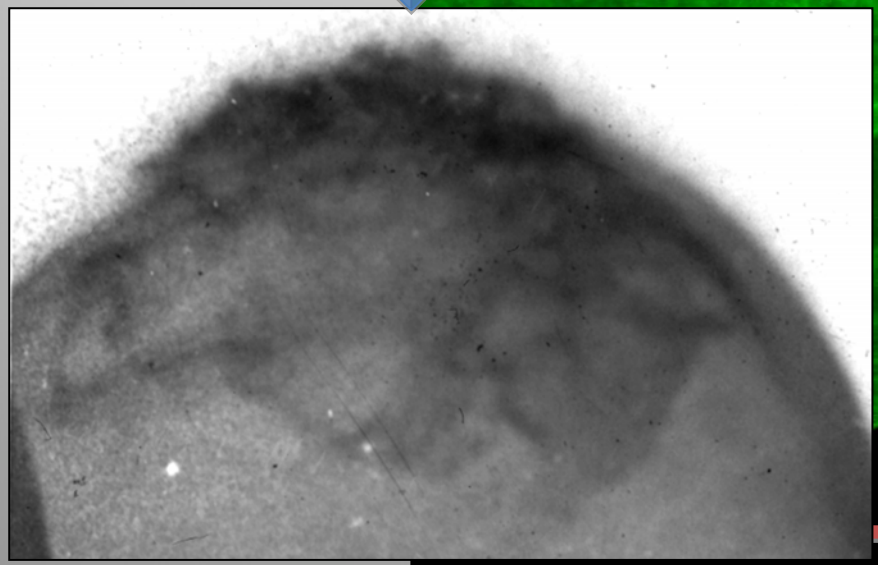
Aluminium foil (6.5um)
+
Helium gas

Conclusions

- A radial foil shows both hydrodynamical and magnetically driven jets in the same experiment.
- The conditions of the ambient medium where the jets propagate can be modified by adding a neutral gas.
- Dynamics of the interaction of the hydrodynamical jet lead to the formation of different shock structures.
- Further analysis will provide parameters of the conditions of these shocks together with astrophysical implications.

17





Thank you ☺