Absolute and Convective Two-Plasmon Decay Driven by Multiple Laser Beams



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Multibeam two-plasmon decay (TPD) depends on the number, orientation, and polarization of the beams; in general it requires 3-D analysis

- With increasing angle of incidence TPD convective gains increase and absolute thresholds decrease
- The location and magnitude of the spatial TPD gain and the onset of absolute instability is sensitive to the relative orientations and polarizations of the beams in 3-D
- The analysis presented here is linear; however, there is evidence that the absolute TPD it describes persists well into the nonlinear regime



The temporal growth rate for TPD is maximized on a hyperbola in *k* space



- The hyperbola lies in the plane of polarization
- Different points on the hyperbola correspond to decays occurring at different densities; larger wave vectors → smaller densities

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The single-beam convective spatial gain increases with angle of incidence



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- The *p*-polarized case is shown here; this is also true for the *s*-polarized case
- Consequence of longer effective scale length for oblique incidence
- For the same reason, the absolute threshold decreases at larger angles of incidence

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The nature of multibeam TPD is sensitive to the relative orientations and polarizations of the beams in 3-D



- On the left the two pump wave vectors and polarization vectors lie in the x-y plane; this can be treated as 2-D problem
- On the right, the two pump wave vectors lie in the x–z plane but the maximum gain is in the x–y plane; this requires 3-D analysis/simulation

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Larger angles between beams give rise to a new regime of small-*k* (potentially absolute) TPD



- At large angles the two "backward" branches of the hyperbolas nearly intersect, leading to enhanced gain
- This becomes the dominant form of the absolute instability



The origin in *k* space corresponds to the plasma wave turning point, allowing TPD to be absolute there

- In general, instabilities can only be convective in inhomogeneous plasmas*
- Near the turning point, however, there is a finite threshold for absolute instability**
- Enhanced multibeam convective gain near the origin in *k* space suggests the potential for absolute instability there

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^{*}M. N. Rosenbluth, Phys. Rev. Lett. <u>29</u>, 565 (1972).

^{**}C. S. Liu, M. N. Rosenbluth, and R. B. White, Phys. Rev. Lett. <u>31</u>, 697 (1973); A. Simon *et al.*, Phys. Fluids <u>26</u>, 3107 (1983).

For a single beam, the absolute TPD threshold* is lower than the Rosenbluth convective threshold

• The Simon threshold (adjusted for s-polarized oblique incidence) is

$$\eta \equiv rac{I_{14} L_{\mu}}{233 T_{keV} \cos heta} > 1$$

- The Rosenbluth convective gain is $G_R = \frac{2\pi\gamma_0^2}{\kappa' V_1 V_2} = \frac{I_{14}L_{\mu}}{53.6T_{keV}\cos\theta} \cong 4.35 \eta$
- The nominal convective threshold is $G_R > 2\pi$ or $\eta > \frac{2\pi}{4.35} \cong 1.44$
- Therefore, the absolute instability appears below the convective instability threshold; this, in general, remains true for multiple beams



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Fourier analysis of the time-dependent TPD equations results in a set of first-order linear equations

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Numerical integration of these equations gives spatial gain; divergent gain indicates absolute threshold



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The absolute threshold for TPD depends on the angle of incidence and polarization

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• As a result, the threshold is reduced by $\sim \cos^2 \theta$





For two *p*-polarized beams, the gain regions separate with increasing angle, reducing synergy



• For two s-polarized beams the separation is much smaller



For two *p*-polarized beams, an on-axis absolute mode with $k_v = 0$ has the lowest threshold at larger angles



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At larger angles, the on-axis mode is closer to the hyperbolas than the off-axis modes





 $\theta = 40^{\circ}$

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With more beams, the absolute TPD threshold for the on-axis mode is quite sensitive to the cone angle





The spectral signature of the absolute instability near $n_c/4$ is a sharp red-shifted feature that can be used for T_e measurements*



• Although the absolute instability is obtained from linear analysis, it can remain the most-intense TPD mode in the nonlinear regime, persisting throughout the pulse



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^{*}W. Seka et al., Phys. Rev. Lett. <u>112</u>, 145001 (2014).

Summary/Conclusions

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- With increasing angle of incidence TPD convective gains increase and absolute thresholds decrease
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