Supplemental to Temporal Simultons in Optical Parametric Oscillators

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OPO Cavity Design.—The OPO cavity consists of a 1.2 m long bowtie resonator shown in Fig.1(c). Cavity length adjustments are made by mounting the input coupler (M1) on a piezo stage (Newport NPM140). The input coupler is a dielectric mirror coated for high transmission ($T > 96\%$) around the 1040 nm pump and high reflectivity ($R > 99\%$) for signal wavelengths from 1758 nm to 2315 nm. Two concave gold mirrors (M2, M3) with $R > 98\%$ and a radius of curvature of 38 mm focus the pump and signal to a $1/e^2$ beam radius of 10 μm and 14 μm respectively, and the separation of M2 and M3 is chosen to minimize the sensitivity of the signal waist with respect to mirror alignment. The output coupler (M4) is a dielectric mirror coated for broadband transmission ($T = 65\%$) from 1400 nm to 2600 nm. Fig.S.1(solid line) shows the net reflection coefficient of the dielectric mirrors, which is well described by a constant ($R(\Omega) = 35\%$) from 1758 nm to 2315 nm. The net group delay dispersion of the dielectric mirrors is shown in Fig.S.1(dotted line), with the net phase deviation of the cavity well approximated by

$$\Delta\phi(\Omega) = \sum_{m=2}^{5} \frac{\phi_m}{m!}\Omega^m,$$

where the ϕ_m are given in Table I.

TABLE I: Phase deviations due to higher order dispersion of the cavity mirrors

ϕ_2	25 fs^2
ϕ_3	76 fs^3
ϕ_4	-13020 fs^4
ϕ_5	983328 fs^5

In addition to the linear loss of the cavity, spatial gain narrowing in the OPA contributes a power dependent loss by scattering power from the resonant TEM$_{00}$ mode into higher order spatial modes. The Guoy phase accumulated by these higher order modes shifts their resonances and timings from that of the TEM$_{00}$ mode, and the power scattered into these modes radiates out of the cavity. While a full spatio-temporal treatment of the OPO is beyond the scope of this work, we can account for this nonlinear loss to first order by considering the spatial gain narrowing due to an undepleted near-field pump. Under these conditions, the signal at the output of an OPA of length L is given by [28]

$$A_\omega(L,r) = A_\omega(0,r)\exp\left(\gamma_0 L \exp\left(-\frac{r^2}{w_{2\omega}^2}\right)\right)$$

where γ_0 is the small signal gain coefficient, $w_{2\omega}$ is the pump waist, and w_ω is the waist of the signal. The effective feedback coefficient of the cavity is given by the projection of the signal onto the amplified TEM$_{00}$ cavity mode

$$R(\gamma_0) = R(0)\frac{\int dr \exp\left(\gamma_0 L \exp\left(-\frac{r^2}{w_{2\omega}^2}\right)\right)\exp\left(\frac{-r^2}{w_\omega^2}\right)}{\exp(\gamma_0 L)\int dr \exp\frac{-2r^2}{w_\omega^2}}.$$

Here the gain coefficient is $\gamma_0 = \gamma_{th}\sqrt{p}$ where p is the times above threshold and $\gamma_{th}L = -\ln\left(\sqrt{R(0)}\right)$. While these corrections do not change the spectral features and regimes of operation seen in Fig.2(e-f), they are necessary to capture the observed threshold and slope efficiency of the OPO (Fig.2(a)). Deviations between simulation and experiment in Fig.2(a) for large pump powers are likely due to spatially varying saturation effects, and will be the subject of future publications.

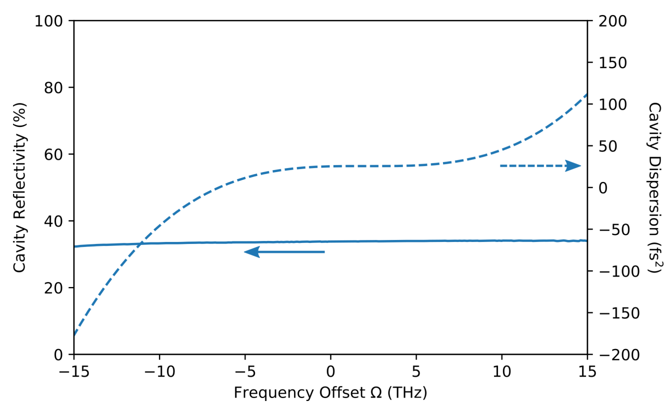

Fig.S. 1: (Solid Line) The net reflection coefficient of the passive cavity optics and (Dotted Line) the associated group delay dispersion.

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