Hyperbolically twisted Alexander polynomials of knots

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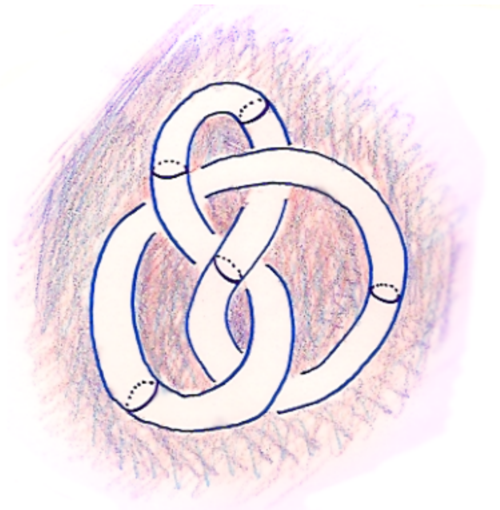
Setup:

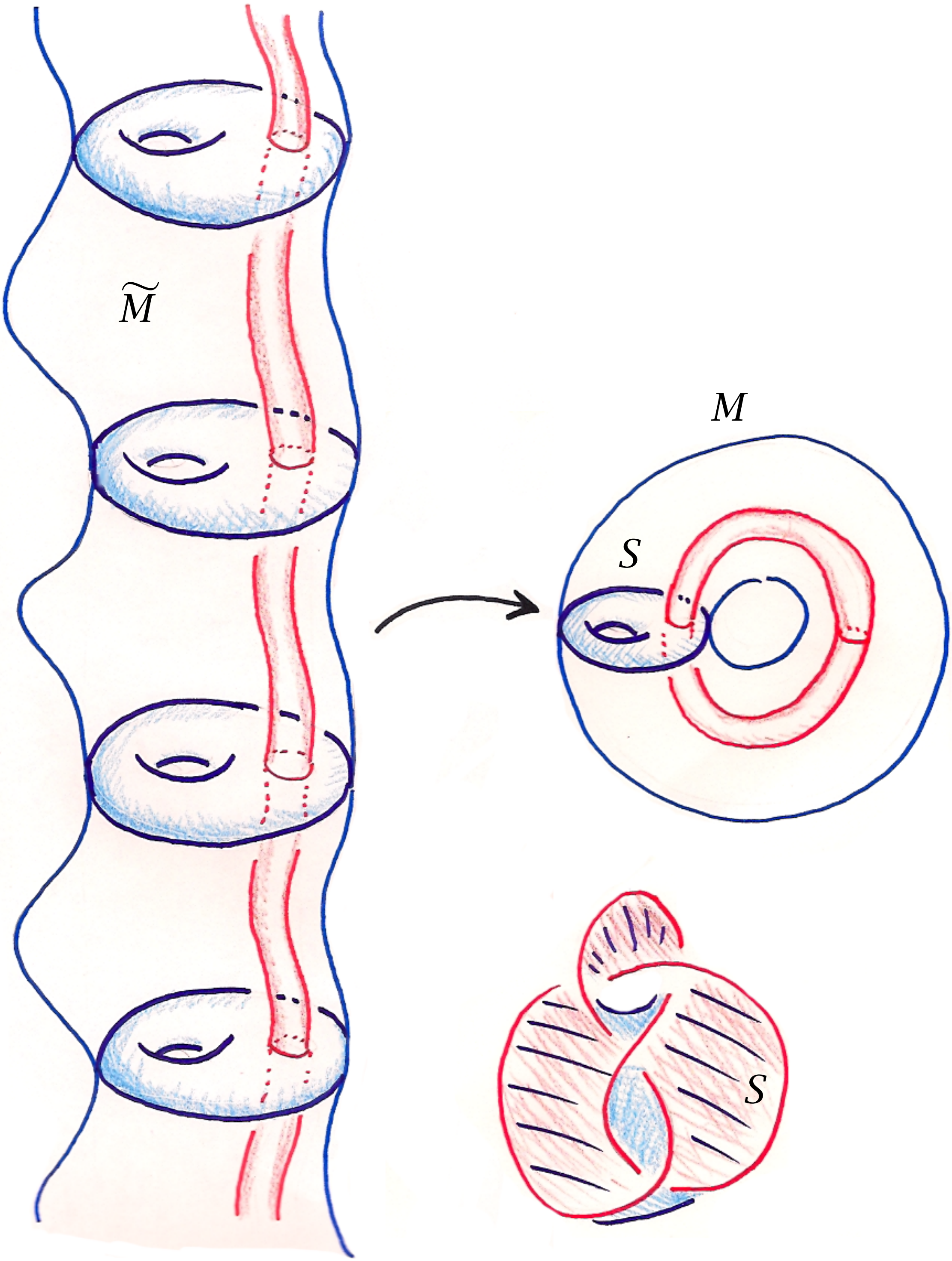
- Knot: $K = S^1 \hookrightarrow S^3$
- Exterior: $M = S^3 - \mathring{N}(K)$



A basic and fundamental invariant of K its *Alexander polynomial* (1923):

$$\Delta_K(t) = \Delta_M(t) \in \mathbb{Z}[t, t^{-1}]$$

Universal cyclic cover: corresponds to the kernel of the unique epimorphism $\pi_1(M) \to \mathbb{Z}$.



$A_M = H_1(\widetilde{M};\mathbb{Q})$ is a module over $\Lambda = \mathbb{Q}[t^{\pm 1}]$, where $\langle t \rangle$ is the covering group.

As Λ is a PID,

$$A_M = \prod_{k=0}^{n} \Lambda \Big/ \big(p_k(t)\big)$$

Define

$$\Delta_M(t) = \prod_{k=0}^{n} p_k(t) \in \mathbb{Q}[t, t^{-1}]$$

Figure-8 knot:

$$\Delta_M = t - 3 + t^{-1}$$

Genus:

$$\begin{aligned} g &= \min\big(\text{genus of } S \text{ with } \partial S = K\big) \\ &= \min\big(\text{genus of } S \text{ gen. } H_2(M, \partial M; \mathbb{Z})\big) \end{aligned}$$

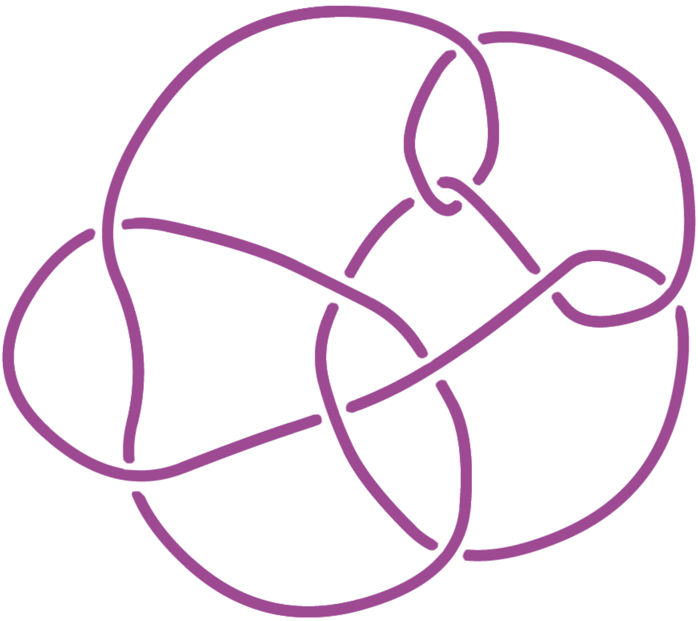
Fundamental fact:

$$2g \geq \deg(\Delta_M)$$

Proof: Note $\deg(\Delta_M) = \dim_{\mathbb{Q}}(A_M)$. As A_M is generated by $H_1(S; \mathbb{Q}) \cong \mathbb{Q}^{2g}$, the inequality follows.

$\Delta(t)$ determines g for all alternating knots and all fibered knots.

Kinoshita-Terasaka knot: $\Delta(t) = 1$ but $g = 2$.



Idea: Improve Δ_M by looking at $H_1(\widetilde{M}; V_\rho)$ for the system of local coefficients coming from a representation $\alpha\colon \pi_1(M) \to \mathrm{GL}(V)$. [Lin 1990; Wada 1994,...]

Twisted Alexander polynomial: $\tau_{M,\alpha} \in \mathbb{F}[t^{\pm 1}]$

Technically, it's best to define $\tau_{M,\alpha}$ as a torsion, a la Reidemeister/Milnor/Turaev.

Genus bound: When α is irreducible and non-trivial:

$$2g - 1 \geq \frac{1}{\dim V} \deg(\tau_{M,\alpha}) \qquad (\star)$$

Proof:

$$\begin{aligned} \deg(\tau_{M,\alpha}) &= \dim H_1(\widetilde{M}; V_\alpha) \\ &\leq \dim H_1(S; V_\alpha) = (\dim V) \cdot \left| \chi(S) \right| \end{aligned}$$

Thm (Friedl-Vidussi) *If* $2g - 1 = \frac{1}{\dim V} \deg(\tau_{M,\alpha})$ *and* $\tau_{M,\alpha}$ *is monic for all* α*, then* M *is fibered.*

If $\pi_1(M)$ *is RFRS, then there exists some* α *where* $(\star)$ *is sharp.*

The above results hinge on work of Agol.

Thm (Wise) *If* M *is hyperbolic, then* $\pi_1(M)$ *is virtually special, hence RFRS.*

Assumption: M is hyperbolic, i.e.

$$\mathring{M} = \mathbb{H}^3 \big/ \Gamma \quad \text{for a lattice } \Gamma \leq \mathrm{Isom}^+ \mathbb{H}^3$$

Thus have a faithful representation

$$\alpha\colon\ \pi_1(M) \to \mathrm{SL}_2\mathbb{C} \leq \mathrm{GL}(V) \quad \text{where } V = \mathbb{C}^2.$$

Hyperbolic Alexander polynomial:

$$\tau_M(t) \in \mathbb{C}[t^{\pm 1}] \quad \text{coming from } H_1(\widetilde{M}; V_\alpha).$$

Examples:

- Figure-8: $\tau_M = t - 4 + t^{-1}$
- Kinoshita-Terasaka:

$$\begin{aligned}\tau_M \approx\, &(4.417926 + 0.376029i)(t^3 + t^{-3})\\ &- (22.941644 + 4.845091i)(t^2 + t^{-2})\\ &+ (61.964430 + 24.097441i)(t + t^{-1})\\ &- (-82.695420 + 43.485388i)\end{aligned}$$

Basic Properties:

- τ_M is an unambiguous element of $\mathbb{C}[t^{\pm 1}]$ with $\tau_M(t) = \tau_M(t^{-1})$.
- The coefficients of τ_M lie in $\mathbb{Q}\big(\operatorname{tr}(\Gamma)\big)$ and are often algebraic integers.
- $\tau_M(\zeta) \neq 0$ for any root of unity ζ.
- $\tau_{\overline{M}} = \overline{\tau_M(t)}$
- M amphichiral $\Rightarrow \tau_M(t) \in \mathbb{R}[t^{\pm 1}]$.
- Genus bound:

$$4g - 2 \geq \deg \tau_M(t)$$

  For the KT knot, $g = 2$ and $\deg \tau_M(t) = 3$ so this is sharp, unlike with Δ_M.

Knots by the numbers:

313,231	number of prime knots with at most 15 crossings. [HTW 98]
22	number which are non-hyperbolic.
8,834	number where $2g > \deg(\Delta_M)$.
7,972	number of non-fibered knots where Δ_M is monic.

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7,972	number of non-fibered knots where Δ_M is monic.
0	number where $4g - 2 > \deg(\tau_M)$.
0	number of non-fibered knots where τ_M is monic.

Conj. *τ_M determines the genus and fibering for any hyperbolic knot in S^3.*

Computing τ_M: Approximate $\pi_1(M) \to \mathrm{SL}_2\mathbb{C}$ to 250 digits by solving the gluing equations associated to some ideal triangulation of M to high precision.

Genus and fibering for most of these knots was previously unknown; Haken-style normal surface algorithms are impractical in this range, various tricks were used.

The conjecture is not even known for 2-bridge knots, even though the plain Δ_M works.

Can consider other reps to $SL_2\mathbb{C}$, understand how $\tau_{M,\alpha}$ varies as you move around the character variety:

Example: $m037$, $X_0 = \mathbb{C} \setminus \{-2, 0, 2\}$

$$\tau_{X_0}(t) = \frac{(u+2)^4}{16u^2}\left(t + t^{-1}\right) + \frac{(u+2)(u^4 + 4u^3 - 8u^2 + 16u + 16)}{8(u-2)u^2}$$