CREATING THE COEFFICIENT OF VARIATION OF NORMALIZED LINK STRENGTH. THIS INDICATES THAT LARGE FOOD WEBS FOLLOWS QUALITATIVELY DIFFERENT RULES THAN SMALLER WEBS (16) AND SUGGESTS THAT EXTREME LINK STRENGTHS SHOULD BE RARER IN LARGE FOOD WEBS. FURTHER, WE FOUND A POWER LAW FOR THE SCALING OF FOOD-WEB STABILITY WITH SPECIES NUMBER AND CONNECTANCE AND IDENTIFIED TWO TOPOLOGICAL RULES GOVERNING FOOD-WEB STABILITY: FOR A GIVEN NUMBER OF SPECIES AND LINKS, FOOD-WEB STABILITY IS ENHANCED WHEN (i) SPECIES AT HIGH TROPHIC LEVELS FEED ON MULTIPLE PREY SPECIES AND (ii) SPECIES AT INTERMEDIATE TROPHIC LEVELS ARE FEED UPON BY MANY PREDATOR SPECIES. THIS PATTERN, WITH GENERALIST APICAL PREDATORS FEEDING UPON MULTIPLE INTERMEDIATE SPECIES FEEDING ON OTHER MULTIPLE INTERMEDIATE SPECIES, HAS MANY POTENTIAL FOR ADDRESSING A LARGE CLASS OF RELATED QUESTIONS.

**References and Notes**

20. Materials and methods are available as supporting material on Science Online.
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**Supporting Online Material**

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Materials and Methods

Figs. S1 and S2

Table S1

References

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**C3PO, an Endoribonuclease That Promotes RNAi by Facilitating RISC Activation**

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The catalytic engine of RNA interference (RNAi) is the RNA-induced silencing complex (RISC), wherein the endoribonuclease Argonaute and single-stranded small interfering RNA (siRNA) direct target mRNA cleavage. We reconstituted long double-stranded RNA- and duplex siRNA–initiated RISC activities with the use of recombinant *Drosophila* Dicer-2, R2D2, and Ago2 proteins. We used this core reconstitution system to purify an RNAi regulator that we term C3PO (component 3 promoter of RISC), a complex of the endoribonuclease Argonaute (Ago) to catalyze sequence-specific cleavage. We successfully reconstitute long dsRNA– and duplex siRNA–initiated RISC activities (Fig. 1A). The RISC activity was abolished when using catalytic mutant Ago2 (Fig. 1A), indicating that Ago2 was responsible for mRNA cleavage in this reconstituted system. However, recombinant Dicer-2–R2D2 and Ago2 generated lower RISC activities than did S2 extract (Fig. 1A), which suggests that additional factors are required to achieve maximal RISC activity. Therefore, we used this core reconstitution system to search for new RISC-enhancing factors. We found that mRNA stability treatment (HI, 37°C for 30 min) abolished the RISC activity in S2 extract (Fig. S2) and that addition of S2 extract greatly enhanced the RISC activity of recombinant Dicer-2–R2D2 and Ago2 (Fig. 1B). This indicates the existence of an RNAi activator. We named this factor C3PO (component 3 promoter of RISC) because this is the third component besides Dcr-2 and R2D2 that promotes RISC activity.

We used a seven-step chromatographic procedure to purify C3PO from S2 extract. At the final step, two proteins, ~27 kD and ~37 kD, showed close correlation with the RISC-enhancing activity (Fig. 1C). They were identified by mass spectrometry as the evolutionary conserved T. R2D2 and Ago2 proteins.

**References and Notes**

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without Translin. By contrast, the core RNAi components (i.e., Dcr-2, R2D2, and Ago2) remained at wild-type levels in trsn mutant lysate (Fig. 2A). Whereas siRNA-generating activity was slightly higher in the mutant lysate (Fig. S4), duplex siRNA-initiated RISC activity was at ~25% of wild-type level in trsn extract (Fig. 2B), and this defect was rescued by adding recombinant C3PO (Fig. 2C). Thus, C3PO is required for optimal RISC activity in vitro.

To determine whether C3PO is required for RNAi in vivo, we injected wild-type and trsn mutant embryos with *fushi tarazu* (*ftz*) siRNA or dsRNA that causes segmentation defects by silencing *ftz* expression (9). After injection with *ftz* siRNA, more than 80% of wild-type embryos displayed a severe segmentation phenotype, whereas a substantial portion of *trsn* mutant embryos showed mild or no phenotype (Fig. 2, D and E). A similar phenomenon was observed with *ftz* dsRNA injection (Fig. 2F). These experiments indicate that C3PO is required for efficient RNAi in vivo.

To distinguish whether C3PO enhances RISC assembly or activity, we compared the amount of RISC activity generated by recombinant Dcr-2–R2D2 and Ago2 with C3PO added before or after RISC assembly (fig. S3C). In both cases, C3PO could enhance the core RISC activity; however, the RISC-enhancing effect was greatly diminished when C3PO was added late to preassembled RISC (fig. S3D). Therefore, we conclude that C3PO primarily promotes RISC activation but also enhances RISC-mediated target cleavage. Consistent with the latter, C3PO modestly enhanced single-stranded siRNA-initiated RISC activity (Fig. S3E).

To further dissect the role of C3PO in RISC activation, we examined the stepwise process of RISC assembly by native siRNA gel-shift assay. As previously described (6, 9, 13), three siRNA-protein (siRNP) complexes—B, RISC loading complex (RLC), and RISC—were formed in wild-type ovary extract. RLC contains Dcr-2–R2D2 and siRNA, whose formation precedes and is required for RISC assembly (6, 13). Neither RLC nor RISC could form in dcr-2 mutant extract, whereas only RISC was absent in ago2 mutant extract (Fig. 3A). By contrast, all three siRNP complexes could form in trsn mutant extract, but the amount of RISC was much less than that in wild-type extract (Fig. 3A). These results suggest that C3PO facilitates the transition from RLC to active RISC.

The central step of RISC activation is the unwinding of duplex siRNA and loading of the guide strand onto Ago2. Thus, we measured the efficiency of RISC assembly by means of the siRNA-unwinding assay (14). In the reconstitution system, recombinant C3PO enhanced the siRNA-unwinding activity of Dcr-2–R2D2 and Ago2 (Fig. S5A). Conversely, the efficiency of siRNA unwinding was lower in trsn mutant extract than in wild-type control extract (Fig. S5B). Both results indicate that C3PO promotes siRNA unwinding and RISC activation.
To study the relative contribution of different RISC activation mechanisms, we supplemented S2H extract, which displayed no siRNA-unwinding activity due to Ago2 inactivation (figs. S2 and S6B), with recombinant wild-type or catalytic mutant Ago2. Only wild-type, but not mutant, Ago2 could effectively rescue siRNA unwinding in S2H extract (fig. S6C). This result, together with previous studies (15–17), strongly supports the idea that the catalytic activity of Ago2 is indispensable for siRNA unwinding and RISC activation.

In the “slicer” model, Ago2 cleaves the passenger strand of siRNA into 9- and 12-nt fragments that simply melt away because of low binding energy, leaving the guide strand behind to form an active RISC with Ago2. By passenger strand cleavage assay (15, 17), we observed that both 9- and 12-nt fragments displayed a longer half-life in trsn mutant extract than in wild-type extract (Fig. 3, B to E, and fig. S7). Moreover, addition of C3PO complex, but not Translin, resulted in rapid degradation of the 9-nt fragment in the reconstituted system (fig. S8A). Together, these findings suggest that C3PO promotes RISC activation by removing siRNA passenger strand cleavage products.

In further support of this idea, recombinant C3PO displayed potent RNase activity toward single-stranded siRNA but showed little or no activity toward double-stranded siRNA or single-stranded DNA (Fig. 4A and fig. S8, B and C). The RNase activity of C3PO is Mg2+-dependent and could be blocked by EDTA, but not by EGTA (Fig. 4B). In addition, C3PO acts as an endonuclease, because it could degrade circular as well as linear RNA (Fig. 4C). Moreover, the endogenous C3PO complex closely correlated with the RISC-enhancing activity as well as a single-stranded RNAse activity after sequential chromatography (Fig. 4D and fig. S8D).

Neither subunit of C3PO shows similarity to any known RNase by bioinformatics and structural analyses (18). To identify the catalytic sites of C3PO, we performed a multisequence alignment of Translin and Trax and observed three acidic residues (Glu123, Glu126, and Asp204) of Trax to perform a multisequence alignment of Translin and Ago2 only wild-type, but not mutant, Ago2 activity due to Ago2 inactivation (figs. S2 and S6C). This result, together with previous studies (15–17), strongly supports the idea that the catalytic activity of Ago2 is indispensable for siRNA unwinding and RISC activation.

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Effects of Antibiotics and a Proto-Oncogene Homolog on Destruction of Protein Translocator SecY

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Protein secretion occurs via the translationally controlled SecY complex. LaZ hybrid proteins have long been used to study translocation in Escherichia coli. Some LaZ hybrids were thought to block secretion by physically jamming the Sec complex, leading to cell death. We found that jammed Sec complexes caused the degradation of essential translocator components by the protease FtsH. Increasing the amounts or the stability of the membrane protein YccA, a known inhibitor of FtsH, counteracted this destruction. Antibiotics that inhibit translation elongation also jammed the translocator and caused the degradation of translocator components, which may contribute to their effectiveness. Intriguingly, YccA is a functional homolog of the proto-oncogene product Bax Inhibitor-1, which may share a similar mechanism of action in regulating apoptosis upon prolonged secretion stress.

Protein translocation is a fundamental process that is essential for the delivery of most extracytoplasmic proteins to their final destination. This process is mediated by an evolutionarily conserved heterotrimeric membrane protein complex called the Sec61 complex (Sec61p in yeast and the Sec complex (SecY, -E, and -G) in prokaryotes) (1). In Escherichia coli, two pathways target proteins to the Sec complex (2): the posttranslational Sec pathway, which targets most outer membrane (OM) and periplasmic proteins (3), and the cotranslational pathway, which is used primarily by inner membrane (IM) proteins, where the ribosome-nascent chain complex is targeted to the Sec complex by the signal recognition particle (SRP) (4). In both cases, proteins are initially directed to the SecY translocator via an amino-terminal signal sequence (5). Because under noninducing conditions, strains carrying this fusion exhibit a Lac+ phenotype after induction with lactose, we used this system to study the effects of Dynasore on the Sec translocase.

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References and Notes
20. Abbreviations for amino acid residues: A, Ala; C, Cys; D, Asp; E, Glu; F, Phe; G, Gly; H, His; I, Ile; L, Leu; M, Met; N, Asn; P, Pro; Q, Gln; R, Arg; S, Ser; T, Thr; V, Val; W, Trp; Y, Tyr.
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