ion star. We now know of many pulsars in such binary systems, including several where both stars are neutron stars and one system where both are pulsars. Exquisite precision measurements allow detection of the precession of the orbit, the inward spiraling of the two stars, the gravitational redshift, and other phenomena predicted by the theory of general relativity, and confirm that theory to the 0.05% level.

Although we understand the precision of pulsars, we still do not understand the mechanism that produces the radio emission. And while it seems sensible that the rotation should gradually slow (typically the period has increased by 1 second since the extinction of the dinosaurs), we do not really understand the slowing-down mechanism either. Furthermore, some pulsars have "glitches"—the pulsar rotation speeding up suddenly—and a full explanation of that is still pending. Precision timing of a pulsar allows the detection of the wobble produced by planets orbiting it, and we know of two (or maybe three) pulsars with planets. Two or three is a difficult number to explain given that we know of around 2000 pulsars. You would expect none, but if we accept that our understanding is incomplete and that there must be a way of keeping or creating planets around pulsars, then surely there should be many more.

Astronomers working in the high-energy x-ray and gamma-ray wavebands have added to the interest by finding objects that look just like pulsars but are mostly "radio quiet." Pulsar magnetic fields are believed to be large (a million million times Earth's magnetic field), but some of the x-ray and gamma-ray pulsars, known as magnetars, have fields that are a thousand times larger still.

And so it has gone on, amazing result followed by jaw-dropping discovery. Although the field is 40 years old, it is showing no sign of settling down into middle age—quite the opposite. At the moment, we seem to be in a phase where we are discovering "peculiar pulsars." Unusual (or, more fairly, unexpected) types of pulsar or neutron star are coming to light, and we suspect we've seriously underestimated the number of neutron stars in the Galaxy. Now we have intermittent pulsars, which are quiet more than they pulse but still accurately maintain the pulse phase (*4*, *5*). We also have to revise our understanding of the supernovae explosions that create neutron stars.

Forty years is approximately a scientist's working lifetime, and those who joined this new field as graduate students or postdocs are now reaching retirement age. However, the community is young and vigorous, with excellent leadership, so will continue to thrive. The large radio telescopes that the community uses were almost all in existence when pulsars were discovered, although the receivers and the computing facilities used with those large telescopes have improved immensely. But if that much can be done with 50-year old telescopes, what will the new generation of telescopes like the Square Kilometer Array (*6*) and its precursors reveal?

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EVOLUTION

The Sharp End of Altruism

Simulations show that war drives the joint evolution of altruism and hostility to outsiders.

Holly Arrow

Which would you prefer: a society of selfish but tolerant freetraders, or a warrior society in which people help one another but are hostile to outsiders? If you value both altruism and tolerance, neither seems ideal. Societies of tolerant altruists, however, are exceedingly rare in the simulation presented by Choi and Bowles on page 636 of this issue (*1*). Instead, altruism flourishes only in the company of outgroup hostility (parochialism), with war as both the engine of this coevolutionary process and its legacy. For a compatriot, the parochial altruist who risks his life is a shining knight, whereas the outsider encounters the sharp end of this altruism.

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From an evolutionary perspective, altruism—acts that benefit others at a personal cost—is puzzling. Some influential theories that address this puzzle are kin altruism (*2*), the tendency to help blood relations; and reciprocal altruism (*3*), the tendency to help people who are likely to return the favor. Neither explains generosity to non-kin when costs are high and reciprocation unlikely. Heroism in warfare is an example. Explaining such extravagant altruism via indirect benefits to altruists and their kin has proved difficult. A growing body of work seeks instead to explain altruism with models that include selection on both individuals and groups.

In such "multilevel" models (*4*), the evolutionary outcome depends on the relative impact of competing pushes and pulls at individual and group levels. Individual selection pushes counterproductive behaviors like altruism out of the gene pool. Group selection exerts a contrary pull, favoring groups with many altruists over groups of more selfish folk. In most species, individual selection wins out. For humans living in small groups, however, a strong group selection pull is plausible. Evidence that intergroup violence killed a nontrivial proportion of our ancestors (*5*) has fueled interest in war as a force for robust group selection. War is a strong candidate because people kill each other based on group membership.

In Choi and Bowles' simulation, 20 small groups of agents interact over thousands of generations. Agents have two genes, each with two alleles. They are either tolerant (T) or parochial (P) and either altruistic (A) or not (N). Offspring inherit their parents' traits, with occasional random mutations. Altruists help fellow group members at a personal cost; non-

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altruists do not. Tolerant agents have lucrative exchanges with outsiders; parochial agents do not. A high proportion of parochials in groups restricts trading opportunities for all.

Among the four possible combinations of traits, TN is the most profitable. These self-interested traders profit both from contact with outsiders and from the donations made by altruists. The most costly combination is PA. These generous warriors make donations and also risk their lives to protect noncombatants and conquer new territory for the group's offspring. Individual selection favors the T and N alleles over the P and A alleles. Victory in war favors groups with more PA types over those with fewer. The other two trait combinations are PN bullies, who are both hostile and selfish, and TA philanthropists, who both trade and donate to others.

In each generation, groups are randomly paired. What happens next depends on the proportions of tolerant types and warriors in the paired groups. If two highly tolerant groups are paired, tolerant members reap the benefits of trade. If the proportion of tolerant types drops below a strong majority in either group, however, the likelihood of peaceful trade plummets. Instead, the groups have either an unproductive standoff or a war. If both groups have the same numbers of warriors, a standoff results. War becomes increasingly likely the greater the imbalance of power, and wars end in a victory or a draw. Some proportion of warriors are killed regardless of outcome. In a victory, however, many civilians on the losing side are also killed, and offspring from a postwar baby boom among the victors migrate into the conquered territory.

The societies that evolve are stable in two conditions: when either selfish traders (TN) or generous warriors (PA) are the dominant type. A few PN bullies and even fewer TA philanthropists can coexist within trader or warrior regimes. The trading regime is peaceful. Standoffs and wars are more common in the warrior regime, but even infrequent war—10 to 20% of encounters—can maintain high levels of parochial altruism. Similar findings for the impact of intermittent war on the evolution of heroism (*6*) suggest that war need not be "constant" to act as a powerful selective force.

The convergence of altruism and parochialism in Choi and Bowles' simulation is consistent with links between the two found in behavioral studies. Selfish choices in social dilemma experiments, for example, diminish markedly when the game is embedded in an intergroup context (*7*). The boost in altruism caused by awareness of an outgroup is also more marked among women than men (*8*), consistent with war exerting stronger selective pressure on males as warriors. Interestingly, altruism levels for women, although relatively unaffected by intergroup hostility, were still high. It appears that the relative importance of alternative evolutionary pathways to altruism may differ for men and women.

A full accounting of such pathways must include cultural evolution. In other work, Bowles and colleagues show how norms can support altruism by promoting conformity (*9*). In the current simulation, warrior-rich groups enforce a trading ban. However, this norm is predetermined. An obvious extension would be to allow norms to evolve. Can pro-trade norms outcompete more isolationist parochial norms? Do norms that punish cowards naturally coevolve with war and altruism?

The simulation findings suggest that one legacy of war is an inherent tension between tolerance and altruism. Cross-cultural studies, however, provide grounds for optimism. In one study, people from 15 small-scale societies played a donation game (*10*). Average generosity correlated with the amount of market exchange and economic cooperation typical in the society. By adding mutable norms to the simulation, the potential viability of societies of tolerant altruists could be further explored.

A better understanding of how our impulses to give, to trade, and to attack outsiders are intertwined should help in the quest to promote pro-social behavior while keeping the sharp end of altruism sheathed.

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ATMOSPHERE

Call Off the Quest

Myles R. Allen and David J. Frame

Knowledge of the long-term response of Earth's climate to a doubling of atmospheric carbon doixide may be less useful for policy-makers than commonly assumed.

Over the past 30 years, the climate research community has made valiant efforts to answer the "climate sensitivity" question: What is the long-term equilibrium warming response to a doubling of atmospheric carbon dioxide? Earlier this year, the Intergovernmental Panel on Climate Change (*1*) concluded that this sensitivity is likely to be in the range of 2° to 4.5°C, with a 1-in-3 chance that it is outside that range. The lower bound of 2°C is slightly higher than the 1.6°C proposed in the 1970s (*2*); progress on the upper bound has been minimal.

On page 629 of this issue, Roe and Baker (*3*) explain why. The fundamental problem is that the properties of the climate system that we can observe now do not distinguish between a climate sensitivity, S, of 4°C and $S > 6$°C. In a sense, this should be obvious: Once the world has warmed by 4°C, conditions will be so different from anything we can observe today (and still more different from the last ice age) that it is inherently hard to say when the warming will stop. Roe and Baker formalize the problem by showing how a symmetric constraint on the strength of the feedback parameter f (which determines how much energy is radiated to space per degree of surface warming) gives a strongly asymmetric constraint on S. The reason is simple: As f approaches 1, S approaches infinity. Roe and Baker illustrate the point with the information provided by recent analyses of observed climate change, atmospheric feedbacks, and "perturbed physics" experiments in which uncertain parameters are varied in climate models.

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The Sharp End of Altruism

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