A celebration of wo

Jocelyn Bell Burnell ponders the achievements and status of women in astronomy, past, present and future.

Abstract

Women have made significant contributions to the development of astronomy as a science, yet their work has been restricted, unregarded and little recognized. Here I outline some significant careers and show how these talented and determined women overcame the restrictions on their lives to make their marks. Their solid achievements came at considerable cost and attracted little professional recognition. I then consider how far astronomy has progressed at the present day. There remain limited numbers of professional women astronomers; what still stops women choosing this career?

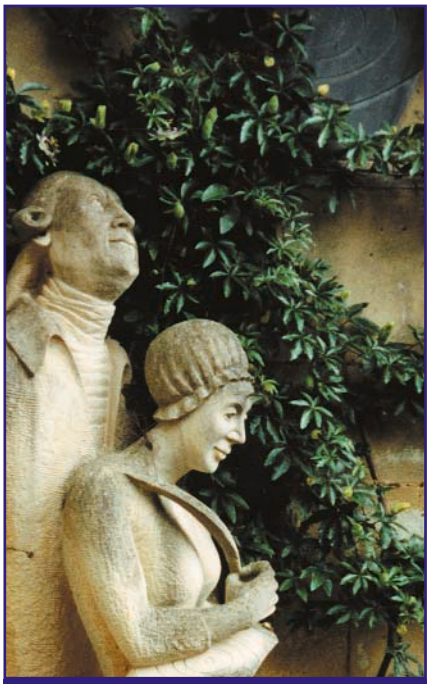
I come from the University of Bath and so I thought it appropriate to start with a Bath astronomer, Caroline Herschel. Caroline Herschel was born in 1750 into a large family in Germany. Her father was a military musician; her mother was a hausfrau who was mystified by intellectual interests and who could neither read nor write. Caroline's brothers all trained as musicians but she was refused an education because she was a girl. Her father advised her that she was unlikely to marry because she was neither handsome nor rich; her role was to be a housekeeper for one of her brothers. She became housekeeper to one of her elder brothers, Jacob. Jacob would not allow her to have French lessons but he would, however, allow her to go to needlework classes, provided all her efforts went into making clothes for him. A sister's function, after all, was to make life comfortable for her brothers. Another of her brothers, William (a name that will be familiar to you), moved to England and bought Caroline out of Jacob's service by paying for a maid to replace her. He brought Caroline to Bath, where he was based, to train as a singer. She was 22 at the time, with a nice soprano voice and she was prepared to perform as a soloist provided William was the conductor. She didn't have the confidence to work with anyone else. On coming to England she had to learn English, of course, but she also learnt arithmetic and bookkeeping. I have to say she was a serious-minded woman and found Bath social life and etiquette a little trying and irrelevant. She was physically very slight and looked frail but I think she was actually made of tough stuff.

William had been up to then earning his living as a musician. He conducted, he composed, he played various instruments and there was quite a lot of music on the Bath–Bristol circuit, then as now. But shortly after Caroline arrived, William started making his own telescopes and he became more and more hooked. Caroline regretted that every room in the house had become a workshop and that the lace ruffles were getting spattered with molten pitch. While making a seven-foot mirror, he worked continuously on it for 16 hours; Caroline fed him fork-fulls of food so that he wouldn't have to take his hands off the job. In 1781 in Bath, William discovered the planet Uranus and he was appointed Court Astronomer by George III. They then moved to Windsor to be nearer the court and had frequent distinguished visitors. What seems to have happened is that if the royals had visitors and didn't know what to do with them, they bundled them into a coach and took them round to the Herschels' place to see the telescopes. The Herschels' visitors' book reads like a *Debrett's* or *Who's Who* of late 18th-century society. If William was away, Caroline showed them the telescopes and it became very clear to everybody that Caroline understood the telescopes every bit as well as William and could deputize for him excellently.

William and Caroline developed a wonderful observing system that allowed one of them to remain dark-adapted while the other worked at a small table with a light and recorded the data. Typically, William worked at the telescope calling out the transits while Caroline sat at a small table within earshot equipped with a clock, pen and ink, record book and pointer showing the telescope's azimuth. As William called out the transit she noted the time for each one. They discovered variable stars, the ice caps on Mars, the heights of the mountains of the Moon. They made catalogues of thousands of stars, nebulae, clusters and even began to consider what they called "the structure of the heavens". They observed whenever the weather permitted and several times when other, weaker souls would have baled out. Caroline records when the Thames' flood water was lapping at the bottom of the garden and a night when the temperature dropped to 11 °F – the ink in the inkwell froze, and William's feet froze to the ground! Caroline was moved to protest, just slightly, on that occasion.

In 1787 the King gave Caroline an annual salary as well as William being Court Astronomer. We believe this is the first occasion that a woman was so paid. Occasionally William was away and in these circumstances Caroline observed on her own using a telescope William had given her – I think a wide-field telescope. With this telescope she found eight comets and computed their orbits. She also found several star clusters and a number of new nebulae. She knew the constellations so well that anything strange like a comet stood out instantly to her. She became known throughout Europe as an astronomer in her own right. Typically, over breakfast after a night's observing, she would ask William questions and that way taught herself spherical trigonometry and logarithms. During the day, after these working breakfasts, she wrote up her observations, calculated stellar positions, prepared catalogues for publication, ran the house and perhaps got some sleep – then repeated it all the next night.

When William married, Caroline no longer had to keep house for him and she got a little more life of her own, but I think she was still very focused on William and astronomy. When William died she was lost. He had been



1: A statue of William and Caroline Herschel in the garden of the refurbished Herschel house in Bath. (Bob Mizon)

men in astronomy

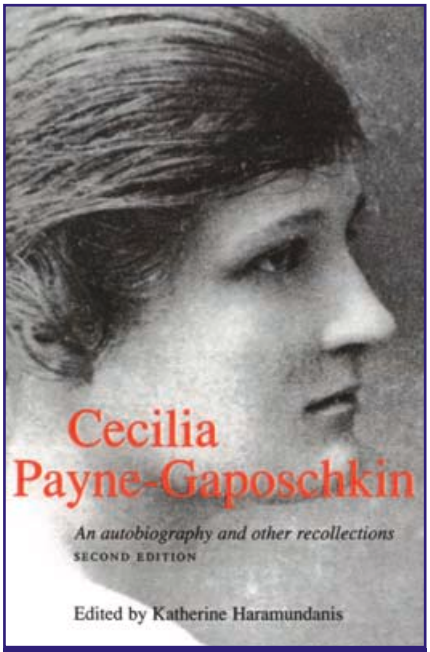
2: Portrait of Caroline Herschel.

her lifeline: he had rescued her and given her a life. Whenever anybody attempted to praise her, she reflected the praise back to William. She was very self-effacing, apparently without personal ambition and she underestimated her own abilities. I wonder if this was because that was the only way she could be a lady, as defined by society, and still do science. I suspect she was caught between her abilities and achievements and the prevailing social attitudes that defined women as unaccredited assistants.

Ultimately she gained credit. In 1828 the Royal Astronomical Society gave her a Gold Medal, but that was the first award she ever had, at the age of 78. At age 85, the RAS made her an honorary member. A few years later the Royal Irish Academy made her a member, and on her 96th birthday she got a Gold Medal from the King of Prussia. She died the following year. I have enormous respect for her, not just because of her Bath connection, and I am sorry she had to play out her life as an unaccredited assistant for so much of it.

A revolutionary without a post

Cecilia Payne-Gaposchkin is another lady for whom I have very great respect. I'd like to tell you just a little bit about her life. She was born in 1900 near Oxford. Her father had been an Oxford don who resigned his fellowship in order to marry; he was aged 56 by the time she was born. She went to St Paul's School where her music teacher was Gustav Holst, who was so impressed with her abilities that he tried to persuade her to become a professional musician. I believe she played the violin particularly well. However, she wanted to do science so she said no to music, but then had to fight quite



3: Cecilia Payne-Gaposchkin pictured on the cover of her autobiography.

hard to get a science education at school. She went to Newnham College, Cambridge to read biology, and this must have been about 1918, maybe 1919.

At this time, just post-World War I, Eddington was setting up an eclipse expedition to the island of Principe to attempt to verify some of Einstein's theory of relativity. It was also the time when Rutherford and Bohr, and Einstein and Heisenberg were coming into the frame. Eddington, however, was responsible for a huge change in Cecilia Payne's life. After the eclipse expedition, he gave a public talk in Trinity Great Hall and she got a ticket for it. It is interesting to note what Cecilia says about that talk by Eddington. This is her description of that occasion:

"The great hall was crowded. The speaker was a slender dark young man. He gave an outline of the theory of relativity in popular language that none could do better than he. He described the Lorentz–Fitzgerald contraction, the Michelson–Morley experiment and its consequences. He led up to the shift of the stellar images near the Sun as predicted by Einstein and described his verification of the prediction. The result was a complete transformation of my world-picture … When I returned to my room I found I could write down the lecture, word for word … For three nights I did not sleep. The upshot was … I was done with biology, dedicated to the physical sciences for ever."

She didn't ask, she informed the Cambridge authorities that she was switching to natural sciences. And it was an exciting time. Rutherford was a lecturer; Bohr occasionally visited and lectured in an incomprehensible accent! Chadwick – all these great names were her lecturers.

She decided not only that she was keen on astronomy but that she wanted to do postgraduate work in astronomy. She consulted Eddington, who advised her not to stay in England. He told her to go to the States, so she went to Harvard to work on stellar spectra. This was at the time that atomic theory was being developed – and she helped develop it through providing astronomical data. She also got involved in an interesting bit of history. Her work as a PhD student suggested that hydrogen was a million times more abundant in the stars than it was on Earth. Shapley, the director of the Harvard Observatory where she was working, and Henry Norris Russell both said this was clearly impossible. She heard them and when she published this result she said the abundance was probably inaccurate. But actually she was right. Subsequently Russell recognized that there is lots of hydrogen in the universe but, regrettably, he did not acknowledge her work when he published that conclusion.

Why didn't she argue her case with him? Well, she was just 25. She had been to a girls' school and a women's college at Cambridge. She was the first-ever PhD student in astronomy at Harvard and of course the first female one. She was in a foreign country. She was the lone woman scientist in the place. There were several women computers but they were paid to classify spectra, not to be scientists. I judge it took all her persistence and assertiveness just to be there. She probably had none left over to argue. She had very little experience of working with men and they with women, and she probably didn't know how hard to push to be believed; maybe she'd never have been believed anyway. So she, in a sense, backed away from her own conclusion. But she was right and she continued to be at the forefront of all sorts of things – an amazing woman.

Cecilia lived almost 80 years, the first 80 years of the 1900s. Just think of the changes there were in that period. Besides Rutherford, Bohr, Einstein and Heisenberg, whom I've already mentioned, understanding of the nature of the nebulae – that they were external galaxies – came in the 1920s; understanding about the energy sources in stars came by the 1930s; and recognition that there was an interstellar medium in the late 1930s. Then came the expansion of the universe, the 3 K radiation, followed by all the things that spun out of the Second World War: radio astronomy, satellite-based astronomy, the opening up of the electro-magnetic spectrum and the growth of high-energy astrophysics.

She saw many revolutions in the subject and she was in the midst of several of them. She was frequently right up at the front helping the revolution along and she was totally unfazed by the pace of change. She was active in research using satellite data until her death in her 80th year. She never moved back to England. She stayed in Massachusetts where she married a Russian émigré, Sergei Gaposchkin, and they had several children. For many years she was paid out of the observatory's equipment budget. She didn't have a proper post. And by my judgement she's never had the recognition she deserves. And now there's a little rhyme:

Twinkle, twinkle little star,
I do not wonder what you are,
For by spectroscopic ken,
I know that you are hydrogen!

And we heard it first from Cecilia Payne-Gaposchkin!

Table 1: Percentage of women IAU members by country

national member	no. of members	% of total	% women
Macedonia	1	0.01	100.00
Romania	37	0.41	37.84
Argentina	106	1.17	34.91
Philippines*	3	0.03	33.33
Bulgaria	50	0.55	30.00
Georgia	17	0.19	29.41
France	633	6.96	25.91
Lithuania	16	0.18	25.00
Peru*	4	0.04	25.00
Serbia & Montenegro	24	0.26	25.00
Uruguay	4	0.04	25.00
Venezuela	13	0.14	23.08
Portugal	35	0.38	22.86
Italy	443	4.87	20.77
Brazil	143	1.57	20.28
Hungary	45	0.49	20.00
Ukraine	162	1.78	19.14
Mexico	91	1	17.58
Spain	245	2.69	17.55
Russian Federation	377	4.14	17.51
Estonia	23	0.25	17.39
Tajikistan*	6	0.07	16.67
Croatia	13	0.14	15.38
Ireland	35	0.38	14.29
Malaysia*	7	0.08	14.29
Belgium	110	1.21	13.64
Greece	105	1.15	13.33
Latvia	15	0.16	13.33
Finland	54	0.59	12.96
Total national members	**9027**	**99.22**	**12.82**
Slovakia	32	0.35	12.50
Sweden	108	1.19	12.04
Denmark	59	0.65	11.86
Austria	34	0.37	11.76
Indonesia	17	0.19	11.76
Turkey	51	0.56	11.76
China (Nanjing)	291	3.2	11.68
China (Taipei)	28	0.31	10.71
New Zealand	28	0.31	10.71
Egypt	57	0.63	10.53
USA	2457	27.01	10.34
Poland	128	1.41	10.16
Australia	217	2.39	10.14
UK	582	6.4	10.14
South Africa	53	0.58	9.43
Norway	22	0.24	9.09
Netherlands	178	1.96	8.99
Chile	56	0.62	8.93
Canada	197	2.17	8.63
Czech Republic	74	0.81	8.11
Armenia	25	0.27	8.00
Germany	492	5.41	6.50
Korea	67	0.74	5.97
India	224	2.46	5.80
Switzerland	89	0.98	5.62
Israel	64	0.7	4.69
Japan	504	5.54	3.97
Algeria	4	0.04	0.00
Cuba*	5	0.05	0.00
Iceland	4	0.04	0.00
Iran	24	0.26	0.00
Morocco*	7	0.08	0.00
Nigeria	4	0.04	0.00
Saudi Arabia	12	0.13	0.00
Uzbekistan*	11	0.12	0.00
Vatican City	5	0.05	0.00
Bolivia*	–	–	–

*interim status

IAU information as at 15 December 2003, taken from http://www.iau.org/organization/member/mship_statist.html.

The other Gold Medallist

The Royal Astronomical Society has been handing out Gold Medals for 180 years, including the one to Caroline Herschel in 1828. How many Gold Medals do you think we have awarded to women in total in those 180 years? Two? Four? Ten? It's a lot isn't it? It is two! There have been 224 Gold Medals and two of them have gone to women: Caroline Herschel in 1828 and Vera Rubin in 1996. That's 160-odd years between the two, and none since 1996.

Vera Rubin didn't have it too easy either. She wanted to go to Princeton to study – she's American – but they didn't accept women. In fact they wouldn't even send her a prospectus because she was a woman. She was the first woman to gain time on Palomar Observatory in her own right, in 1965. I think Margaret Burbidge might have been there before, but she got it in her husband Geoff's name. Vera is noted for two particular pieces of work concerning velocities of galaxies. She did a lot of the very important observational work on the way galaxies rotate that established that there

simply had to be some sort of dark matter providing the extra gravitational attraction – invisible material but undoubtedly there. You could not explain the rotation of these galaxies without a lot of extra invisible gravity, if I can put it that way. She also, along with Ken Ford, found evidence for the peculiar motions of the local group, although this work was somewhat disputed to begin with. It didn't meet with universal acceptance but it is now recognized as being right and providing important information on motions of galaxies.

Vera is distinguished among women of her generation by bringing up four children all of whom went on to do PhDs in science and are active scientists. I also recognize her because of what she has done for the career development of young astronomers and how she has been a representative and a role model for women in astronomy.

Now I have somewhat criticized the RAS for the lack of Gold Medals awarded to women, but I also have to say that the RAS has a lot of good practices that I think we should recognize. As long as I've been around, the RAS has always had a fair number of women on its Council, and rather a higher proportion than you find on many physical sciences bodies. Some of you will be acutely aware that if you've been organizing a national astronomy meeting or a specialist discussion meeting, or something like that for the RAS, and have sent in a provisional programme, sometimes it is bounced back to you with the comment that there aren't enough women as chairs or speakers in your beautifully crafted programme. Where we fund meetings, we do watch what is euphemistically called "gender balance", but actually it's still "gender imbalance". We try to ensure that women get some exposure, not overdoing it, but ensuring women get proper recognition. There's an active RAS committee concerned with women in astronomy and geophysics. But there's still something we don't do. We're quite good about making women associates, we're quite good about awarding the named lectureships to women, but will we give a medal to a woman? The last time we awarded a medal to a woman was Vera Rubin in 1996. It reminds me of a big university I used to work at that regularly gave women honorary masters degrees and gave the men honorary doctorates. Or the system that used to pertain in the nation's honours system where women got the MBEs and men got the OBEs and CBEs. We're perpetrating something like that here, folks, and I'm not comfortable with it.

A few years ago the International Astronomical Union had a look at its statistics of memberships in countries with more than 50 members. I list the country, the number of members it has and the percentage that is female, and they are listed in order of female percentage (see table 1, data from the *IAU Bulletin*). The UK is not only not very near the top, it's also well below the average. This is a little sad. I have to say that in this country, IAU membership tends to be restricted to those who have tenured posts and so it does reflect the more senior levels, but "could do better" I think is the appropriate comment.

4: Vera Rubin, circa 1970.

Let There Always Be Light: Searching for Dark Matter

For this we go out on dark nights,
searching for the dimmest stars, for signs of unseen things,
to weigh us down, to stop the universe from rushing on and on
into its own beyond, til it exhausts itself
and lies down cold its last star going out.

What ever they turn out to be,
let there be swarms of them, enough for immortality.
Always a star where we can warm ourselves.
Let there be enough to bring it back from its own edges,
to bring us all so close we ignite the bright spark of resurrection.

Rebecca Elson

5: Rebecca Elson and, above, one of her poems.

Physics and poetry

Another astronomer that I want to name for you who I think a number of you may have known is Rebecca Elson. She was Canadian originally and she died in Cambridge in 1999 at a very young age (you'll find her obituary in *A&G* **41** 2.38). She went to Smith College, Massachusetts, which is a women's college, where she was converted to astronomy. After a science degree at Smith she recognized that she needed more physics before doing a PhD in astronomy and went to do an MSc in physics at the University of British Columbia. She almost didn't make it. It was a predominantly male body, unsupportive, and she said "often going in to class felt like walking into the men's bathroom by mistake". She didn't do well there, partly because I think she felt so uncomfortable, but she did get her MSc and she came to do a PhD in Cambridge, England.

Becky was much happier there. She did a PhD on globular clusters, spending time observing in Australia. She then moved to Princeton and, once again, she nearly gave up. She tactfully described it as a mismatch between her needs and the place, but she found it fairly hostile. She was at the Institute for Advanced Studies there. I have to say, still on the theme of bathrooms, that I spent time in Princeton University's Physics Department and the women's bathrooms in that department were remarkable. They were the men's bathrooms with only the name on the outside of the door changed! What a brilliant way to make women feel honoured and welcome members of your department.

While Becky was at Princeton she started writing poetry and that was her lifeline. Her poetry is wonderful. Becky Elson moved to Harvard where life was quite a bit easier, then came back to Cambridge for about the last 10 years of her life. She died very early of cancer, having latterly worked quite a lot on the Magellanic Clouds, on stellar populations and star clusters. But it may be that her poetry lasts even longer than her science; I think there is a power to it.

"Why can't a woman be more like a man?" wondered Professor Higgins in *My Fair Lady*, and I think he is not the only one, certainly among the academic community. Well, the first women into a subject area have to be like the men; they don't survive otherwise. They have to be, indeed, even better than the men to survive, I judge. The first few women into our field were, I think, exceptionally able. In the next phase

women are made more assertive, braver, better at putting their heads above the parapet. There have been, in recent years, programmes that offer women special training: mentoring, role models, helping them to make themselves more assertive and promote themselves. This is known in the game as the "women as deficit" model. There are things that women lack, so the story goes, so these initiatives are to make them fit in better to the existing culture in science. It's not working terribly well. It's making a bit of difference but, despite this, there's a loss of people from our field. We know we train more PhDs and postdocs than can continue in the field. But a higher proportion of women than men leave science, engineering and technology, at every stage. At every hurdle, there is a higher proportion of men than women in our field. It's also true that the women seem to progress more slowly than the men. They tend to get left behind. Why might this be? Some of these are hoary old explanations: lack of childcare facilities or the "two body" problem, or it's the cultural conditioning that a lot of us got at school, or maybe the playing field's not level. These are all probably true at some level. But maybe it's the wrong game. Maybe the science game that we play is not actually attractive to a lot of women.

It's becoming increasingly a concern of mine that the climate in which we work in our departments, in our institutions, is not attractive to a lot of women. I want to commend particularly – and want you to take up – a programme that the Institute of Physics has recently instituted, called "Site Visits" (some details can be found at http://diversity.iop.org/academia/index.html). What happens is that an enlightened department or head of department will invite a group put together by the Institute of Physics to visit their department and take a look at how it functions, and advise them on whether or not it's women-friendly and how it could be more so. It's a programme that has only started very recently and there is not a lot to point to in the way of outcomes yet. I think it's an excellent idea – it's one of the few things I see that I think might produce a climate-change and encourage more women to stay in the field and might improve the gender balance around us all.

It's very hard to explain what is wrong with the climate and I am really at quite a loss at this point. There are lots of horrendous things one can point to. All of us who have been in the field have a collection of horror stories, yet I don't want to maintain that my male colleagues are being deliberately malevolent. I think at worst it is lack or thought, or lack of enlightenment. The snag is that as time passes, these are no longer excuses. It feels a bit like it would feel if one was left-handed in an aggressively right-handed society. You can operate, you can function, but it's not quite natural and it costs more. I have a couple of illustrations, one very close to home, the other slightly further way.

The Institute of Physics has a dining club where I think quite a lot of business is done. On one occasion, three or four years ago, I was invited to be their after-dinner speaker. But I was invited to be their after-dinner speaker on their Ladies Night. What does that say about their perception of the normal membership if they have a Ladies Night? They have now changed it to a Guest Night. This is what we must consider progress! And just two or three years ago, as I started as Dean at the University of Bath, the Head of the Medical Sciences Department came to me and said, and I swear this is true, that he was very concerned for the future of medicine now that more than 50% of the undergraduate population was female. Year 2000 and people say things like that! I hope that wouldn't happen in astronomy, but you do wonder. You laugh these things off; you have to, there's no other way to handle it, but at what cost ultimately?

Now I want to go back to Caroline Herschel, and finish this address with her, just as I started. I want to tell you a little story from the RAS and show you another poem. At one point there was a joint project between the RAS and the National Portrait Gallery here in London to run a series of lectures about famous astronomers using, mainly, pictures of those famous astronomers held by the Gallery. I was on Council at the time and there was at least one other woman – I think it was Yvonne Elsworth. Yvonne asked very tactfully, as the list of famous astronomers was being drawn up, if we could have a woman on the list. Council chewed on that one for a bit and after some talk said yes, we could do a talk on Caroline Herschel. Great. Fast forward a month to the next Council Meeting. No, it's not possible to do a talk about Caroline Herschel because this is the only picture we have of her and she's not attractive enough! I was gob-smacked. Yvonne recovered her wits quickest I think of all of us and finally persuaded Council that attractiveness and scientific ability were not linked. And there was a talk about Caroline. She's not terribly attractive, I admit, but does it matter?

Hang on to this idea about the attractiveness of Caroline Herschel. I'm going to finish with a poem – not quite all of it – by Adrienne Rich, an American feminist author. It was written following a visit to a planetarium and it's called *Planetarium: Thinking of Caroline Herschel (1750–1848), Astronomer, Sister of William; and Others*. It was written in 1968, the year the discovery of pulsars was announced. Thank you for your interest. ●

Planetarium: Thinking of Caroline Herschel (1750–1848), Astronomer, Sister of William; and Others

A woman in the shape of a monster
a monster in the shape of a woman
the skies are full of them

a woman 'in the snow
among the Clocks and instruments
or measuring the ground with poles'

in her 98 years to discover
8 comets

She whom the moon ruled
like us
levitating into the night sky
riding the polished lenses

Galaxies of women, there
doing penance for impetuousness
ribs chilled

in those spaces of the mind

...

Heartbeat of the pulsar
heart sweating through my body

The radio impulse
pouring in from Taurus

I am bombarded yet I stand

I have been standing all my life in the
direct path of a battery of signals
the most accurately transmitted most
untranslatable language in the universe
I am a galactic cloud so deep so involuted that a light wave could take 15
years to travel through me And has
taken I am an instrument in the shape
of a woman trying to translate pulsations
into images for the relief of the body
and the reconstruction of the mind.

Adrienne Rich

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