The Central Parsecs of the Galaxy
ASP Conference Series, Vol. 186, 1999
H. Falcke, A. Cotera, W.J. Duschl, F. Melia, M.J. Rieke, eds.

Discussion Session VIII: The Magnetic Field in the Galactic Center

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Abstract. This is an edited transcript of a discussion session about the magnetic field in the Galactic Center that took place during the Galactic Center conference "The Central Parsecs" in Tucson, Arizona, Sep. 7-11, 1998. The session was chaired by the moderator as indicated in the author list. The discussions were taped, transcribed, and finally edited by an editor who is listed as co-author. The contributions of the conference participants are preceded by their names and thus references to specific aspects and ideas of this discussion session must also include a reference to the respective speaker(s), e.g., in a footnote.

Discussion

Sofue: Before we go on I'd like to summarize the ways in which we can learn about the magnetic field at the Galactic Center. I think that people here would agree that we have several ways to do this: (1) the Zeeman effect in maser and radio recombination lines (summarized by Mark Wardle and Doug Roberts), (2) far infrared polarization of dust grains in molecular clouds (reported on by Giles Novak), and (3) radio synchrotron emission and polarization (as Cornelia Lang talked about). From Zeeman measurements, we can derive the magnetic field strength and orientation. Far infrared observations give us the orientation of the plane-of-sky component, but no information on the strength. And, finally, the radio component gives a lot of information: intensity, morphology, and linear polarization of synchrotron emission. Also, there is the rotation measure, which gives information on the line of sight magnetic field. But for the rotation measure, we need information on the thermal electron density, for which Anantha[ramaiah] gave us some idea. I think people have also reached some consensus about the strength of the magnetic field in the Galactic Center region from Zeeman splitting—we probably get a field strength of 1–10 mG, right?

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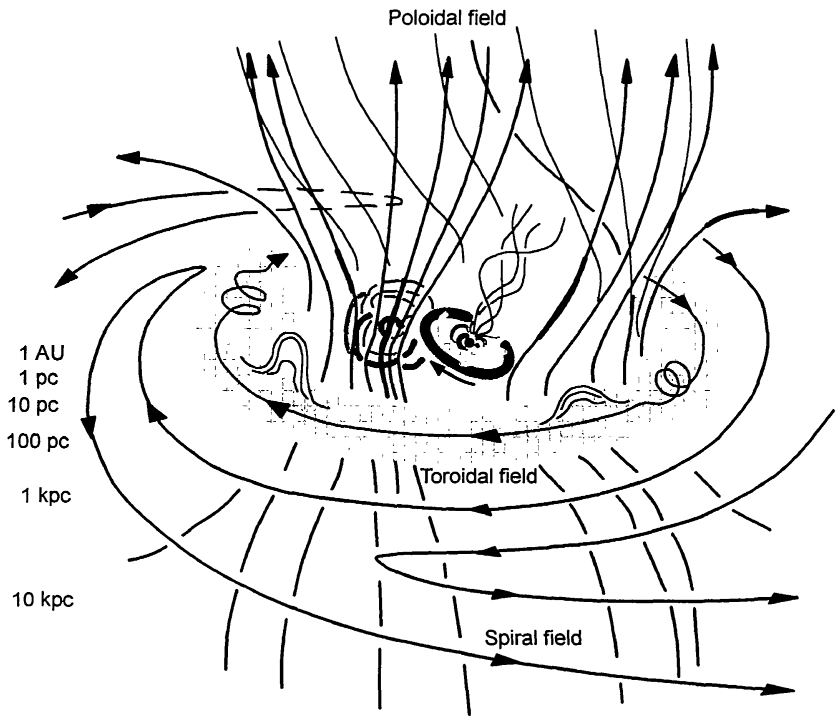

Figure 1. Sketch of the magnetic field configuration in the Galactic Center (from Y. Sofue; not to scale)

Roberts: 8 mG is the upper limit for the magnetic field strength from Zeeman splitting; 5 mG was the highest actual detection.

Sofue: What can you tell us about the direction of these detections?

Roberts: In all of the cases we have observed, the direction has been away from the observer, away from the Earth, except for the Northern Arm, in which case the orientation is towards us. There's one other measurement I didn't mention, but that is in the Southern Arm. There's another potential HI Zeeman detection which is also away from us, but that is a marginal result.

Sofue: It is extremely important to see if the magnetic field is toroidal or poloidal in the circumnuclear region.

Roberts: If it was a toroidal field, we expect to see a sign reversal across the symmetric structure, and so far we have not detected that.

Sofue: Probably we can then agree that the magnetic field strength in some clouds is as high as 1–10 mG.

Yusef-Zadeh: We may have a potential to measure the total field by doing Faraday rotation towards these masers, i.e. by converting the linear polarization of these masers into a field strength. This is something that has been done for W44 and W28.

Roberts: What are the results that are found using this method?

Goss: We got very messy results in W28 that we could not interpret with the linear polarization. Some of the problem was the lack of angular resolution, and it ended up being completely ambiguous.

Sofue: Now they've given me the strength of the magnetic field, we can make some comparisons between the equipartition magnetic fields and the interstellar medium: ionized gas, cosmic ray energy density, and molecular gas. On size scales of 10–100 pc,the magnetic field dominates. But, of course, the gravity must dominate everything close in near the black hole. From the question about the energy ratio between the magnetic field and the gas, we learned that the gas farther out may be dominated by the magnetic field.

Cotera: Actually, I had a general question. It does not seem like there is any systematic magnetic field: there appears to be a large-scale magnetic field, but when you start getting closer and closer to the center, the magnetic field seems to be very tangled. So I'm wondering how, if you have tangled magnetic fields everywhere, does that affect star formation? Do we have the situation that Doug was talking about, where you have to have massive clumps already to overcome magnetic pressure along field lines? If the magnetic field is tangled, do you still have a magnetic field pressure to overcome?

Unknown: It makes it more difficult, because you can't have free fall, and if it's even more tangled, the ability to collapse is even worse.

Unknown: I've got a follow-up question. If a field is really poloidal as the filaments seem to suggest, and if they really originate from this sort of H II/molecular cloud interaction, why do we only see them in the Northern hemisphere? Take the Northern Thread for example. There is an H II/molecular gas complex there, the filament seems to only extend in one direction away from this complex, to positive latitudes, and not the other, right?

Lang: But we do see something [in the other direction]. If you look closely at the λ20 cm image, you see hints of parallel features arising at negative latitudes, too. However, they are just faint hints of filaments. But, if you actually look at the whole length of the Northern Thread, it extends over 50 parsecs, and there is a 10 pc spur of the filament that is on the other side of the Arched Filaments [at negative latitudes]. And there is also the Snake filament, located at negative latitudes.

Roberts: I have a follow-up question to that: I was just asking Giles if at the position where the Northern Thread intersects the Arched Filaments, is there any disturbance in the orientation of the plane of sky vectors?

Novak: It appears to follow the Arched Filaments over its entire length.

Sofue: What about the field strength in the Arched Filaments?

Novak: Well, Mark Morris estimated a field strength of 8 mG based on using the Chandrasekhar and Fermi method, but you can easily get into problems when you use that method. You have conflicts of superposition along the line of sight in the clumps, so I think that it is, as Doug said, very difficult to derive a field strength here.

Yusef-Zadeh: I guess I should say that, if you look at all the magnetic field measurements of thermal gas, you really don't see any poloidal magnetic field. Everything seems to be azimuthal. That is the field inside of the [molecular] clouds, isn't it? And there is nothing poloidal about it.

Figer: Why should the magnetic field inside of a cloud match the magnetic field in the Galactic Center, with the cloud rotating, and presumably getting ripped apart?

Yusef-Zadeh: Right. I agree, there is no strong evidence for poloidal magnetic fields in the molecular gas. The only evidence we have are the magnetized filaments, that appear to trace field lines perpendicular to the plane of the Galaxy. So I think it's important to find more evidence for this poloidal field.

Figer: There's evidence for a poloidal field, and no evidence against it. Because in every case where it's azimuthal, it's *inside* a cloud.

Yusef-Zadeh: Yeah, the thing is that everybody talks about it, and we came up with it, the suggestion that there is a poloidal magnetic field pervasive throughout the Galactic Center, but it is surprising that you do not find any evidence for it. [Laughter]

Sofue: I'm confused, but that's okay. Here is a sketch (Fig. 1) of the different scales of the magnetic field in the Galactic Center, and its strength and orientation. As Cornelia [Lang] suggested in her discussion today, there may be a transition at the position of the new filament, and from the dust polarization that Giles [Novak] talked about, there is a suggestion that the magnetic field near the center (i.e. the circumnuclear disk) is toroidal.

Unknown: I have a question: does that say that the circumnuclear disk has had to be turned around several times to turn on the magnetic field?

Novak: I don't know if it is several times, but it has to turn a little bit at least, because if one relies on differential rotation ... I guess you would have to calculate how extreme the differential rotation is. Can Mark Wardle comment on this?

Wardle: If you stretch the cloud out first before it gets in there, then you pull the magnetic field along too, and then wrap it around once. I'm thinking about the Northern Arm where you have the magnetic field running along that, for example. Our model, the Wardle and Königl model, which is essentially an accretion disk model, is assuming very different initial conditions.

Sanders: This is based on very recent work, about twenty minutes ago ... and probably the numbers should be checked again. I want to make a remark on the problems of star formation in the presence of a very strong gravitational field—that is, very near the black hole, very near the point mass. So, it would be star formation within a few tenths of a parsec from Sgr A*. And basically, these are very general arguments, which you could find in Spitzer's first book. For a collapse, if a magnetic field is not is going to prevent collapse, the gravitational potential energy has to be greater than the magnetic field energy. That means, roughly, that $\frac{GM^2}{R} > B^2R^3$, which gives you a limit on the mass, M $> \frac{BR^2}{\sqrt{G}}$. And you can use this similar relationship between mass, density, and radius [$M \propto \rho R^3$] to eliminate the radius. And what you find is that you can get gravitational collapse in the presence of a magnetic field, as long as the mass of this spherically collapsing clump is greater than a critical value, which is given roughly by $\frac{B^3}{\rho^2}$. Now I went through some numbers, and if you have a magnetic field of 1 mG, let's say, normal interstellar conditions with a density of 10 cm^{-3}, then this critical mass is about 10^6 $M_\odot$.

Wardle: A magnetic field of 1 mG in normal interstellar conditions corresponds to much higher densities than that, about 10^4 or 10^6 cm^{-3}.

Sanders: I'm just trying this out as sort of a numerical example. Certainly if you increase the density then you get into less trouble.

Sofue: So you have no chance to make a star?

Sanders: No chance to make stars unless you can get rid of the magnetic field by experienced techniques people talk about, but these are on the long-term, long time scales. In the Galactic Center, though, if you want star formation to start near the black hole, you have to exceed the Roche limit. And the Roche limit, as we heard yesterday, is something like 10^{10} cm^{-3}. That gives you a critical mass for a magnetic field of 1 mG of 10^{-12} $M_\odot$. So in other words, as long as the densities are high enough anyway to satisfy the Roche limits, magnetic fields should be no problem for star formation near the black hole. Now there's one caveat here, and that is, if you start with the 1 mG magnetic field, and you also compress it in a shock—up to maybe 1–10 G—then you have a problem. But you need fields in excess of 1 G to really hurt star formation, if the density exceeds the Roche limit.

Unknown: If you now use the argument that you made yesterday, with an estimated density of 10^6, then you are just right in the middle where you want to be.

Sanders: That's good to hear. I suspect actually, angular momentum might be more of a problem for star formation than magnetic fields. Because you have these streams of gas going by the black hole, you might expect a lot of shear and a lot of turbulence, a lot of vorticity. I haven't worked it out, but that could be a more serious problem.

Wardle: The magnetic fields will usually kill that, if you hang on to them long enough.

Sofue: As for the future, clearly more MHD simulations should be made, and include instabilities like the one Bob Sanders was just talking about. I must also mention that we need to get more observations of the magnetic fields near to the accretion disk.

Coker: I believe it was Geoff Bower in his talk, who said that the polarization is very small in the radio for Sgr A*, which suggests that at least very close to the black hole, the field is very tangled. Especially if it is synchrotron emission, it has to be tangled, because otherwise it had to be polarized, so there is a little bit of an argument that on a small scale you have a very tangled field, while only on the large scale you have an ordered field.

Zhao: That limit is still having problems, because of large rotation measures.

Bower: In the case of the millimeter data, though, we don't have a problem with large rotation measures. The rotation measures there are 10^7 rad m^{-2} and the fractional polarization is one plus or minus one, which is quite small and indicative of a tangled field.

Sofue: I think that today's discussion is now closed.

Session IX

What Would the Galactic Center Look Like from 1 Mpc?