WEBVTT

1
00:00:05.009 --> 00:00:12.240
dong su: Okay, let's let's get going with the second lecture with Tracy slot here from MIT, and

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00:00:13.290 --> 00:00:24.540
dong su: She has been actually lecturing quite frequently at SSI. In the past few years and it's actually great to remind her back again this year to of course on various

3
00:00:25.350 --> 00:00:36.810
dong su: subjects related to talk matter. And of course, this on this year is the actual subject. She directly kind of expert on on the indirect commander searches Tracy take

4
00:00:38.250 --> 00:00:39.750
Tracy Slatyer: Thanks very much for the introduction.

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00:00:39.870 --> 00:00:41.910
Tracy Slatyer: And thanks very much for inviting me. I'm

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00:00:41.940 --> 00:00:50.160
Tracy Slatyer: Very happy to be here. Well, I'm very happy to be talking to you all. It's always fun to be able to go to SSI and plus in that are hopefully in future years.

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00:00:50.790 --> 00:00:55.410
Tracy Slatyer: So I was asked to talk to you about indirect experimental searches for dark matter.

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00:00:55.920 --> 00:01:05.640
Tracy Slatyer: So what do we mean by indirect detection. I'm going to define it broadly to be that we're looking either for the Standard Model particles that are produced from Doc metaphysics.

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00:01:05.850 --> 00:01:14.400
Tracy Slatyer: Or we're looking for the secondary effects of those Standard Model particles. So, I will not include the for today and tomorrow in this category.

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00:01:15.000 --> 00:01:22.830

Tracy Slatyer: Stuff like looking for doc meta soap interactions. Well, that's another really interesting or look that's another really interesting topic.

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00:01:23.280 --> 00:01:26.850
Tracy Slatyer: That I'm yeah I'm happy to say a little bit about if people would like

12
00:01:27.720 --> 00:01:37.710
Tracy Slatyer: So what can you do with indirect detection. So the kinds of processes that were imagining a typically cases way either dogmatic particles collide with each other, generating standard models.

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00:01:38.040 --> 00:01:48.030
Tracy Slatyer: Or perhaps were dogmatic is just not perfectly stable and can decay into standard model particles over the age of the universe that second process is something that

14
00:01:49.080 --> 00:01:55.020
Tracy Slatyer: It's can be very difficult to probe by methods of an indirect detection, because the up if

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00:01:55.380 --> 00:02:02.220
Tracy Slatyer: We're talking about something with a lifetime longer than the age of the universe, the operative word responsible for probably needs to be pretty suppressed.

16
00:02:02.490 --> 00:02:14.310
Tracy Slatyer: But as we'll see, we can constrain documented decaying with lifetimes, even you know 10 or more orders of magnitude longer than the age of the universe. So we can, we are very sensitive to the stability and lifetime.

17
00:02:14.970 --> 00:02:20.520
Tracy Slatyer: Of dogmatic into more relic models, which I believe you just heard about him. Professor Tate's lecture.

18
00:02:20.940 --> 00:02:26.910
Tracy Slatyer: The annihilation rate of dogmatic indivisible particles is directly connected to the abundance of dogmatic CJ

19
00:02:27.240 --> 00:02:35.160
Tracy Slatyer: And so intimate relic models is a very predictive signal and the kinds of indirect so it shows that we're going to be talking about which will lead us to a national benchmark.

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00:02:35.490 --> 00:02:39.870
Tracy Slatyer: But inch it more broadly, moving away from where I like models moving away from

21
00:02:40.740 --> 00:02:52.710
Tracy Slatyer: You know the decay channel that only look for in general indirect detection provides a complimentary channel to other searches. It's for example, often very powerful for particularly high mass doc map.

22
00:02:53.340 --> 00:03:00.780
Tracy Slatyer: So let's, so I'm going to try to tell you about basically the current status of generic searches in two lectures.

23
00:03:01.140 --> 00:03:14.040
Tracy Slatyer: So today, where I want to start out as saying, just a little bit about benchmarks for dark matter annihilation decay. This will be pretty easy, since you already spent a lot of time talking about the thermal relic cross section which is the most standard annihilation benchmark.

24
00:03:14.790 --> 00:03:18.000
Tracy Slatyer: In the last lecture, and what I want to do today is talk you

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00:03:18.510 --> 00:03:24.870
Tracy Slatyer: Through the tools that you need to understand how these calculations are done, how we predict what signals we should expect to see

26
00:03:25.140 --> 00:03:38.340
Tracy Slatyer: And how constraints can be set on various mental models using these indirect such as. So we're going to talk about the annihilation product which travel directly from the point of annihilation or decay to ask it up.

27
00:03:38.550 --> 00:03:47.100
Tracy Slatyer: So I'm charged particles such as photons neutrinos are in this category. And in this case, there's a nice simple expression that you can write down, which tells us how bright

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00:03:47.610 --> 00:03:54.690
Tracy Slatyer: Do we expect signal to be to be anywhere in the sky, and then we can observe that with telescope. So we'll go through the calculation for this J factor.

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00:03:55.020 --> 00:04:02.520
Tracy Slatyer: Shoes. What are the parameters that describes the brightness of the signal. And then I want to talk through the car, the kinds of different searches that you can do.

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00:04:03.240 --> 00:04:08.070
Tracy Slatyer: Using photons and neutrinos what the current experiments are and what the current limits are.

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00:04:08.880 --> 00:04:16.890
Tracy Slatyer: And now for charged particles, things are a bit more complicated because we live in a galaxy galaxy has a magnetic field, the charged particles do not propagate and straight lines.

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00:04:17.220 --> 00:04:27.060
Tracy Slatyer: So I want to you at the end of this lecture to understand qualitatively how we characterize this diffuse of propagation of cosmic rays. Now galaxy where some of the major uncertainties come in.

33
00:04:27.360 --> 00:04:33.510
Tracy Slatyer: And the limits that we believe that we can set on dark matter annihilation and decay from current searches for these church cosmic Christ.

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00:04:34.380 --> 00:04:39.810
Tracy Slatyer: Okay, so let's begin by just talking about what kind of processes we might look for

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00:04:40.110 --> 00:04:47.670
Tracy Slatyer: So if you were to try to just ask, you know, very simply, what are the options for dogmatic particles to produce visible particles.

36
00:04:47.910 --> 00:04:56.370
Tracy Slatyer: One obvious possibility that comes to mind is when they collide together. You could make this full particles. So the picture here is that two or more dogmatic particles come in.

37
00:04:56.880 --> 00:05:01.080
Tracy Slatyer: And then some persons occurs, which you don't know. This is the new physics that you would like to prove

38
00:05:01.350 --> 00:05:10.530

Tracy Slatyer: And visible Standard Model particles are produced. Now, these could be quotes or leptons. Okay. He goes on to neutrinos. If they're not one of the stable particles at the standard model.

39
00:05:10.800 --> 00:05:22.620
Tracy Slatyer: Then they'll cascade, then they'll go through a decay cascade, which eventually leads to the stable Standard Model particles. So, these are electrons positrons neutrinos, protons anti protons and neutrons.

40
00:05:23.340 --> 00:05:28.890
Tracy Slatyer: And we understand this part of the of the process, the cascade engine on particles.

41
00:05:29.160 --> 00:05:41.520
Tracy Slatyer: So generally out indirect searches will be looking for some linear combination of those stable Standard Model particles. I guess I should add anti nuclear arms to the list as they can also new gloves and actually nucleus is they can also be stable.

42
00:05:42.270 --> 00:05:50.940
Tracy Slatyer: So the salient things about this process. We don't know that. Right. But the film early cross section gives us a possible benchmark talk about that in a moment.

43
00:05:51.390 --> 00:06:03.060
Tracy Slatyer: We expect this process to scale is the square of the document density. If it's the truth it persists. Now, that tells us, and that means that regions of high dogmatic density of particularly favorable as such as this.

44
00:06:03.690 --> 00:06:10.290
Tracy Slatyer: Process, you can have three body and higher annihilation processes which I even more peaked in regions of high documented density

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00:06:11.280 --> 00:06:17.640
Tracy Slatyer: This, for example, there's a significant literature on strongly directing massive particles with everybody annihilation to dominate the freaks out

46
00:06:18.090 --> 00:06:25.380
Tracy Slatyer: However, it turns out that in indirect searches in particular, three body annihilation is in the present day. I usually really, really tiny.

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00:06:25.590 --> 00:06:30.630
Tracy Slatyer: Compared to two buddy annihilation is just because documented densities and the present day are constrained to be rather law.

48
00:06:31.560 --> 00:06:37.200
Tracy Slatyer: So I'm going to assume I'm going to only show you constraints on to body processes going forward, but

49
00:06:37.620 --> 00:06:47.190
Tracy Slatyer: If you're interested in the three body constraints asked me, I can point you to a paper where we looked at how hard it was to see it, and concluded that acceptance and very limited cases the answer was really, really difficult.

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00:06:48.600 --> 00:06:58.710
Tracy Slatyer: Okay, so you heard in the previous lecture about the thermal relic scenario, the dark matter. So again, just to recap, the idea there is the doc medicine thermal equilibrium early on.

51
00:06:58.980 --> 00:07:05.160
Tracy Slatyer: And then it's depleted by annihilation. Now that naturally leads to a preferred scope and the dark matter of the

52
00:07:05.370 --> 00:07:18.420
Tracy Slatyer: Roughly the week scale to have roughly weeks ago and last week's call interactions, but that's not a requirement. You can get this on Morelli cross section with lots of different kinds of physics. If you assume that the present day if you're within the scenario and you assume that the

53
00:07:19.530 --> 00:07:24.690
Tracy Slatyer: Present day annihilation cross section is the same as the time of annihilation cross sections time of freaks out

54
00:07:25.020 --> 00:07:30.570
Tracy Slatyer: Then that fixes. Your annihilation rate to be roughly this sigma v, which is parametric we won over the

55
00:07:30.870 --> 00:07:40.050
Tracy Slatyer: Best times the temperature of matter radiation equality up to order one factors and when you put in the order one fact is comes out to be about two times 10 to the minus 26 centimeters. Keep the second

56
00:07:40.350 --> 00:07:47.070

Tracy Slatyer: So when I showed the femoral relic benchmark in future slides. That's, um, that's what I'm going to show. That's what I'm doing.

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00:07:47.820 --> 00:08:04.470
Tracy Slatyer: Now it's met again not going to talk about this in a lot of depth, but it's fast, it's worth noting that really what you constrained in somewhere like scenario is the annihilation cross section at free south. And guys, I think for hesitate said you

58
00:08:05.670 --> 00:08:10.740
Tracy Slatyer: Changes to the cosmology can can also be and change even that relationship to the lifetime of dominance

59
00:08:11.070 --> 00:08:16.080
Tracy Slatyer: But they can also be differences between the annihilation in the whole universe and the annihilation right at the present day.

60
00:08:16.380 --> 00:08:26.220
Tracy Slatyer: You can have the doc medico annihilating against a species, which isn't around anymore that suppresses the signal LA Times, you can have annihilation switch a velocity dependent either larger or smaller lifetimes.

61
00:08:26.520 --> 00:08:39.840
Tracy Slatyer: And then the only universe, and so on. The film or even if you have a film or Alex scenario. The somewhere else benchmark is not a guaranteed signal that you can look for. There are always ways around these constructs nonetheless it's a convenient.

62
00:08:42.240 --> 00:08:43.410
Tracy Slatyer: So what about

63
00:08:45.570 --> 00:08:55.830
Tracy Slatyer: So what about decaying doc meta so well. I said, you know, you could have a if you try to just write down the simplest possibilities, but how dogmatic would interact with the visible manner then

64
00:08:56.940 --> 00:09:04.860
Tracy Slatyer: You, you might say, well, what about collisions. Well, the other obvious possibility is that maybe you don't need to particles to produce Standard Model particles, maybe you can do it with just one

65
00:09:05.460 --> 00:09:15.480

Tracy Slatyer: Again, same picture. There's some physics that we don't understand the last with this decay that would produce Standard Model particles. These will subsequently cascade decay to the long lived no one particles.

66
00:09:16.020 --> 00:09:21.690
Tracy Slatyer: And it's these particles that we can search for the difference to the annihilation signature is because this is a

67
00:09:21.990 --> 00:09:30.150
Tracy Slatyer: One body persons, it only scales is one power of the document of density. This may. This may mean this regions with high documented density

68
00:09:30.900 --> 00:09:44.520
Tracy Slatyer: But low volume or less favorable for decay searches than for annihilation, such as, as I'll show you the lifetime for this decay what so we know from the fact that this does not matter. And today that lifetime has to be comparable to the age of the universe.

69
00:09:45.720 --> 00:09:54.390
Tracy Slatyer: We will see that the lifetime could actually be much, much longer than the has to be much, much longer than the age of the universe. If the decay is to any visible particles.

70
00:09:55.800 --> 00:10:00.780
Tracy Slatyer: Okay, so if we wanted to do a benchmark for decay similar for annihilation how we do that.

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00:10:02.130 --> 00:10:12.780
Tracy Slatyer: So this has been tricky because it can't. It's difficult for the decay of the dogmatic component today to set the abundance of dark matter and the whole universe, because of the dogmatic educate away at

72
00:10:13.050 --> 00:10:21.900
Tracy Slatyer: You at the time of freeze out then there wouldn't be any document left today, although it is possible for decay processes of other species to the doc meta, she said, The Dark Matter abundance

73
00:10:22.890 --> 00:10:27.960
Tracy Slatyer: But we could one thing that you can do if you want to sort of estimate decay lifetimes is do some kind of rough estimate

74
00:10:28.320 --> 00:10:36.750

Tracy Slatyer: But, back of the envelope estimate for plausible rates. So suppose we said the document. Suppose we guessed the dark matter and I lights through some high dimension operator.

75
00:10:37.860 --> 00:10:44.220
Tracy Slatyer: And let's assume that this is an assumption. It's not a guarantee or many, many other possibilities than this.

76
00:10:44.670 --> 00:10:59.100
Tracy Slatyer: But suppose I would say suppose I've got some model of week scale dark matter around the TV scale and it's decaying through some operator, which is suppressed by the scale of Grand Unified Theory. They got scale there's some you got scale physics. It allows the doc manager.

77
00:11:00.270 --> 00:11:05.850
Tracy Slatyer: Now then, broadly speaking, we can prioritize the kind of operators that can occur by the mass dimension.

78
00:11:06.720 --> 00:11:19.740
Tracy Slatyer: So, and this gives you naturally different scaling for the lifetime. So the lifetime has to scale like one of the mess just by dimensional analysis. We've got to mess skills and the problem the document of mess and the guts scale so

79
00:11:20.820 --> 00:11:30.150
Tracy Slatyer: We. So basically, the number of powers of the document masters in the Catskills was controlled by the operator dimension for dimension five operator, you have a

80
00:11:31.230 --> 00:11:44.250
Tracy Slatyer: Two powers of the heavy mass scale and you find that the lifetime should be avoided or point one second. So if the dark matter whole decade with a lifetime of appoint one second, the universe would look extremely different so that can't happen.

81
00:11:45.870 --> 00:11:59.340
Tracy Slatyer: Because there's a large mass hierarchy going to even the next operator up means that the natural lifetime would be about 10 to the 25 seconds, the age of the universe is about three times 10 to the age of the universe is

82
00:12:00.450 --> 00:12:10.560
Tracy Slatyer: Of order a few times 10 to 17 seconds so 10 to the 25 seconds is about eight orders of magnitude longer than the age of the universe. And that turns out to be interesting, but okay signals.

83
00:12:11.280 --> 00:12:20.250
Tracy Slatyer: The other hand, if you're suppressed by another couple of powers of the high mass scale than the lifetime would be 10 to the 51 seconds. And that turns out to be completely on observable.

84
00:12:20.550 --> 00:12:25.920
Tracy Slatyer: But so there is this sort of broad class of decaying document and models where there might be something interesting. The weekend see

85
00:12:27.420 --> 00:12:31.800
Tracy Slatyer: Okay, so these are the kinds of processes that I'm going to tell that we're going to try to constraint.

86
00:12:32.520 --> 00:12:45.750
Tracy Slatyer: So I've told you that what we're going to look for is the stable Standard Model particles. And so we can look forward the spectra, we can look for how many of these particles and produced as a function of position on the sky and it's a function of energy.

87
00:12:46.860 --> 00:12:57.810
Tracy Slatyer: So there are broadly three kinds of signal spectra that we will end up looking at actually for, I guess I didn't waste you go 100% neutrinos.

88
00:12:58.800 --> 00:13:06.840
Tracy Slatyer: On this, on this slide, if we think about what the possible standard model final states have many stellar model final states are colored particles.

89
00:13:07.770 --> 00:13:18.030
Tracy Slatyer: Or particles that can decay to colored particles. And so in these cases what tends to happen is that when these particles are produced, they probably had denies and decay.

90
00:13:18.330 --> 00:13:24.300
Tracy Slatyer: And the end of that decay chain includes pions. It can also, if the particles are heavy enough include anti protons.

91
00:13:24.600 --> 00:13:31.410
Tracy Slatyer: But as soon as you include any neutral plans at all which you generically have in any kind of hydroponic decay chain.

92
00:13:31.890 --> 00:13:35.130

Tracy Slatyer: Then those neutral pions decay producing a lot of gamma rays.

93
00:13:35.490 --> 00:13:45.390
Tracy Slatyer: So even if the document. It doesn't like to directly annihilate to vote on a given night lights to anything strongly interacting, usually the result of that is that you get quite a lot of photons out

94
00:13:45.870 --> 00:13:52.350
Tracy Slatyer: This get to a continuum sexual problems with a peak energy controlled by the document of mass, so that's

95
00:13:52.920 --> 00:14:03.810
Tracy Slatyer: One signal that you can look for kind of a bump in the spectrum measuring the position of that bump tells you both about what the annihilation final state was and what the mass of the original dogmatic particle was

96
00:14:04.650 --> 00:14:13.830
Tracy Slatyer: So that's what happens. For most standard model final state and the most standard model final states, the most sensitive probe is just going to be looking at the gamma ray production.

97
00:14:14.610 --> 00:14:18.540
Tracy Slatyer: But there are other or related things like the anti fraud on production.

98
00:14:19.020 --> 00:14:30.540
Tracy Slatyer: But there are some final states, we don't really work like that. If the annihilation or decay produces a lot of electrons on mute swans, then they do not decay producing photons not directly, although they can radiate photons.

99
00:14:31.080 --> 00:14:36.030
Tracy Slatyer: But that person is somewhat radioactively suppressed in that case the searches for the

100
00:14:37.110 --> 00:14:42.450
Tracy Slatyer: neutrinos that nuance produce when they decay over the electrons themselves over the electrons.

101
00:14:43.110 --> 00:14:48.210
Tracy Slatyer: Either produce directly annihilation of cacao produced by me on the cake me the most sensitive such channel.

102
00:14:48.870 --> 00:14:57.420
Tracy Slatyer: And then the third option is if there's a branching ratio to the document is to go into photons directly, then that's a really beautiful smoking gun signal.

103
00:14:58.050 --> 00:15:05.040
Tracy Slatyer: It would give us if you can have too dogmatic particles annihilated into two photons, then the phone on energy will be exactly the massive the document.

104
00:15:05.610 --> 00:15:21.900
Tracy Slatyer: That's basically a zero background signal if the document is heavy enough so that would be a great smoking gun signal with the branching ratio is expected to be small. So we can do searches for all of these different kinds of signals and I'll talk about here, what we see in the slides.

105
00:15:23.160 --> 00:15:36.240
Tracy Slatyer: Okay, so let me now. So having sort of introduced what we're going to look for what kinds of signals. We're going to see, um, let me now move on to how we do the calculations for neutral annihilation and decay products.

106
00:15:39.000 --> 00:15:50.100
Tracy Slatyer: I just want to know. I see. I'm okay. I just wanted to take a look at the chat. So yes, so please allow me, if there's anything that pops up in the chat that I need to know about. I need to respond to you.

107
00:15:52.680 --> 00:16:06.930
Tracy Slatyer: Okay, so I'll let ok so now I'm good. So for the moment. Now I'm going to specialize two photons and neutrinos to electrically neutral annihilation and K products we travel in a straight line from their point of origin to our telescopes.

108
00:16:08.640 --> 00:16:12.030
Tracy Slatyer: So now we might need to account for the fact that if these

109
00:16:12.360 --> 00:16:23.400
Tracy Slatyer: particles travel for long enough, they will reach if they will lose energy due to the expansion of the universe, and they might also get absorbed on the way she was so we might not see all of the particles that we originally that were originally emitted.

110

00:16:23.970 --> 00:16:36.900
Tracy Slatyer: But, um, that we don't have to worry about these particular trajectories bending in magnetic fields and that means this is very helpful because it means that when we look for a signal we can obtain two dimensional information on the source distribution.

111
00:16:37.320 --> 00:16:44.250
Tracy Slatyer: Certainly, two dimensional not 3D because we kind of waste, how, how far away the photons come from there are cases where you can get the 3D information.

112
00:16:45.150 --> 00:16:53.910
Tracy Slatyer: usually consisting of a spectral feature that has really shifted enough that you can see the change in frequency and that can tell you what redshift. It was admitted

113
00:16:54.750 --> 00:17:02.040
Tracy Slatyer: This is really helpful when you're trying to separate a document of signal from the from an astrophysical background because

114
00:17:02.370 --> 00:17:12.780
Tracy Slatyer: Everything that I've told you about high energy photons high energy charged particles high energy. She knows their astrophysical sources of all of these process of all of these objects.

115
00:17:13.050 --> 00:17:18.390
Tracy Slatyer: And so telling upon a document a signal from an astrophysical background is often quite challenging.

116
00:17:19.110 --> 00:17:24.360
Tracy Slatyer: So if we want to work out what the document a signal should look like, what the strength of the signal from a given source should be

117
00:17:24.570 --> 00:17:34.230
Tracy Slatyer: It's going to be controlled by the amount of dark metal in that regional by the dogmatic mc squared in the case of annihilation or cubed, or two before. In the case of higher body processes.

118
00:17:34.800 --> 00:17:44.640
Tracy Slatyer: And what parameters sizes that factor we called the J factor. So let's so the exercise we're going to do over the next few pages is imagine you have built a nice telescope

119
00:17:45.060 --> 00:17:52.440

Tracy Slatyer: I you want to know what appointed on the sky, you have some friends who will tell you where the regions are of high density in the sky.

120
00:17:52.950 --> 00:18:01.800
Tracy Slatyer: And you would like to know, you know, what is the optimal useful place to me to point my telescope highlight just signal should I expect from different regions at Sky.

121
00:18:03.270 --> 00:18:19.890
Tracy Slatyer: Okay, so how would I would say. So let's suppose, so we're at a telescope is it up, let's consider a volume element which are called DB at a distance away from us at all. And at that location of the volume element. The documented density is row.

122
00:18:21.570 --> 00:18:26.250
Tracy Slatyer: So let's do the annihilation cases, the decay case I'm translate to a pretty straightforward.

123
00:18:26.730 --> 00:18:33.000
Tracy Slatyer: So what I want to know is how many photons. Am I going to see it. Come on. Neutrinos. Am I going to see coming from that volume element.

124
00:18:33.300 --> 00:18:40.470
Tracy Slatyer: As a function of volume is a function of time. So the first ingredient is how many installations are occurring in that volume element of all the time.

125
00:18:41.250 --> 00:18:56.250
Tracy Slatyer: So this rate is given by the cross section and I'm going to assume identical dark metal particles here if they're not identical. It's just a factor of two. If they have if the bats. If the doc meta and the doc NT meta and not equal that have equal on it says

126
00:18:58.560 --> 00:19:07.710
Tracy Slatyer: Then the rate of annihilation of all the time is just going to go like the number density squared of the document of times the cross section times a factor of a half because they're identical particles.

127
00:19:08.160 --> 00:19:13.500
Tracy Slatyer: We can rewrite this in terms of the document and mess density squared divided by the document and mass square

128

00:19:13.770 --> 00:19:17.970
Tracy Slatyer: We usually do this because the document of mass density is what it controls its gravitational pull.

129
00:19:18.180 --> 00:19:31.050
Tracy Slatyer: And that's what we have observational evidence for when you talk to your friends who map out the documented distribution by doing gravitational lensing or by looking at the orbits of stars or if you are one of those friends than what you are observing is row, not

130
00:19:32.760 --> 00:19:44.010
Tracy Slatyer: OK, so now. So that's how many particles annihilating in that region. So, but we need to know not just how many annihilation. There are, but how many photons neutrinos have reduced as a function of energy.

131
00:19:44.430 --> 00:19:51.240
Tracy Slatyer: At PR Annihilation. So, let's call that spectrum D amp D. This could be d&d your DM neutrinos D.

132
00:19:52.770 --> 00:20:02.670
Tracy Slatyer: So then to get the number of particles produced per energy been a volume per time. We just need to multiply the annihilation rate by this d amp D factor.

133
00:20:03.480 --> 00:20:12.750
Tracy Slatyer: So then we have this result. Okay, so that's the spectrum produced out of our PR volume per time. How many of these particles are going. Are we going to see

134
00:20:12.990 --> 00:20:17.370
Tracy Slatyer: And I'm going to ignore the expansion of the universe for the moment and I'll show you how to do that on the next page.

135
00:20:18.030 --> 00:20:25.620
Tracy Slatyer: Well, this is very easy. Then if we assume isotopic commission. So these particles are streaming out equally in all directions, then

136
00:20:26.280 --> 00:20:39.000
Tracy Slatyer: We know that at that we know that this spectrum will be spread out over an area of full pi r squared by the time it reaches us. So it's just a question of how much of that full pi r squared area. Can we see

137

00:20:39.510 --> 00:20:47.190
Tracy Slatyer: If we have a detector, a very A The answer is going to be that we can see a fraction A or before pie capital R squared.

138
00:20:48.180 --> 00:21:07.140
Tracy Slatyer: Of that region. So if we so so that. So if we just so I'm good. I put in the multiplication by the volume element here. So this is the contribution from the volume element dB to the spectrum of particles observed at our detector ignoring regifting for the month.

139
00:21:08.370 --> 00:21:21.870
Tracy Slatyer: And if we want to get the spectrum from a long line of sight or along the border region. We just need to integrate or a large number of volume elements. We just need to perform this volume integral and this row is a function of position.

140
00:21:23.490 --> 00:21:31.920
Tracy Slatyer: Okay, so let's work in circle polar coordinates. Let's assume for the moment that the center of the universe and working spherical Paul is centered on us.

141
00:21:32.370 --> 00:21:43.320
Tracy Slatyer: So that tells us that the observed spectrum of particles per unit detected area per unit time per unit energy is we just put together the factors from the previous page.

142
00:21:43.740 --> 00:21:51.660
Tracy Slatyer: As one of a pie MDM squared times the cross section, times the spectrum annihilation times this integral.

143
00:21:52.620 --> 00:22:00.690
Tracy Slatyer: Along the line of sight of the documented density squared. What's ok so this is the this is this is the integral over dB.

144
00:22:01.290 --> 00:22:07.710
Tracy Slatyer: Now typically, our scenario will be that we can see everything within some solid angle along the line of sight. So our

145
00:22:08.130 --> 00:22:16.860
Tracy Slatyer: Detector has some solid angle that we can look over and we may we may not be able to tell apart the photons coming from regions within that solid angle.

146
00:22:17.820 --> 00:22:26.670

Tracy Slatyer: So we when we perform this integral over the solid handle and this integral along the line of sight that we call that parameter the J factor.

147
00:22:27.240 --> 00:22:34.890
Tracy Slatyer: And you can see here that there's this nice separation in this equation between the terms that depends on the particle physics that depend on the cross section of

148
00:22:35.130 --> 00:22:43.650
Tracy Slatyer: The spectrum per annihilation depends on MDM so that you don't need to know anything about how the dark matter is distributed all you need to know is your theoretical model of the dogmatic candidate.

149
00:22:44.250 --> 00:22:49.800
Tracy Slatyer: And then this this J factor essentially parameters is how dark matter is distributed on the sky.

150
00:22:51.300 --> 00:23:04.380
Tracy Slatyer: So we can do the same exercise for an end this astrophysical factor in principle can be derived purely from the data just from looking at the gravitational pull of the documentary to map out row is a function of position.

151
00:23:05.460 --> 00:23:12.480
Tracy Slatyer: For decaying dark matter. We can do exactly the same thing. Everything looks the same, except now instead of the cross section we have

152
00:23:12.780 --> 00:23:20.850
Tracy Slatyer: One over the lifetime, whereas you make your lifetime as much longer than the age of the universe, which means that the decay rate per unit time is just one over town.

153
00:23:21.960 --> 00:23:30.690
Tracy Slatyer: There's no factor of two, because there's only one tactical involve t. And there's only one power of MDM and one power of road, not to because it's a one particle process. So, this

154
00:23:31.170 --> 00:23:36.720
Tracy Slatyer: Factor for the decay is sometimes called also called the J factor. And it's also sometimes called the de facto

155
00:23:37.560 --> 00:23:45.120

Tracy Slatyer: Just a question in the literature. Some sources, put the one who have a full pie factor as part of the de facto and some sources do not

156
00:23:45.900 --> 00:23:49.350
Tracy Slatyer: If in doubt, check the definition of the J factor.

157
00:23:49.650 --> 00:24:03.480
Tracy Slatyer: Because I know of at least one case where people set a constraint on annihilation and the constraint was a factor of 10 week have an effect or a full pie weaker than it should have been because they misunderstood the definition of the day factor and one of their references so so check

158
00:24:04.740 --> 00:24:12.900
Tracy Slatyer: Okay, so now we understand given about meta density distribution. We know how to figure out how many photos. When neutrinos. We're going to see from it.

159
00:24:13.710 --> 00:24:19.080
Tracy Slatyer: So what are the typical J factors for agents that we could look so we live inside a galaxy.

160
00:24:19.530 --> 00:24:30.540
Tracy Slatyer: And we expect the documented density to get larger towards the center of the galaxy. And we also observe clumps of documented and stars circulating our galaxy, which we call the dwarf satellite galaxies at the Milky Way.

161
00:24:31.200 --> 00:24:38.100
Tracy Slatyer: So dwarf satellites of the Milky Way typically have J factors about 10 to 17 to 20 GB square centimeter. The five

162
00:24:39.210 --> 00:24:45.000
Tracy Slatyer: You don't need to worry about the absolute value of these numbers so much, but, um, we can look at the comparisons between them.

163
00:24:45.510 --> 00:24:55.410
Tracy Slatyer: On the other hand, if we look at the galactic center region. And if you assume one of the classic density profiles, like in a very frank white profile which is is quite steeply was the galactic center.

164
00:24:55.710 --> 00:25:00.060

Tracy Slatyer: You find that the region within one degree of the Galactic Center has a factor of about 10 to the 22

165
00:25:00.420 --> 00:25:10.740
Tracy Slatyer: In these units. So at first glance, you might say. Uh huh. Okay, I know how did you, Doc, that as such as I should, at least for annihilation. I should always just point my telescope right at the galactic center.

166
00:25:12.390 --> 00:25:20.910
Tracy Slatyer: Um, so that assumes this Caspian of our first white profile which scales is one of our towards the galactic center. So there are two caveats here.

167
00:25:21.870 --> 00:25:37.440
Tracy Slatyer: One is that the profile may not actually be this Kospi towards the galactic center, we do not really have any good observational handles on what the dogmatic density profile of the Galactic Center does within a couple of geopolitics of the center

168
00:25:38.640 --> 00:25:48.420
Tracy Slatyer: It could be indications in some simulations that in galaxies of different sizes. The documented density profile, my flatten out within some distance of the Santo

169
00:25:49.560 --> 00:26:02.010
Tracy Slatyer: And no longer have this pronounced one of our costs if that happens in the Milky Way. It can really decrease the J factor within the in one degree by a lot but potentially by a couple of orders of magnitude.

170
00:26:02.970 --> 00:26:09.660
Tracy Slatyer: Now, my understanding of the current status of the simulations, is that there is not a lot of evidence. Either way, for

171
00:26:10.080 --> 00:26:18.180
Tracy Slatyer: Cause in Milky Way size halos. There is, there are some simulations that find sort of order KP sequel. There are other simulations that

172
00:26:18.780 --> 00:26:24.300
Tracy Slatyer: Don't find a call on a scale that can actually be measured within the simulation. So this is an uncertainty.

173
00:26:24.870 --> 00:26:34.650

Tracy Slatyer: And if we actually saw a signal, it wouldn't matter because then we could use the signal to measure the dogmatic density, but it means that setting constraints using the galactic center signal can be challenging.

174
00:26:35.430 --> 00:26:44.100
Tracy Slatyer: Because there is this logic uncertainty associated with the dark matter density per file associated with that row of affected the course energy into your J factor calculation.

175
00:26:44.700 --> 00:26:55.620
Tracy Slatyer: But let's take this at first, you know, at face value for the moment. Let's assume we really do have the full 10 to the 22 J factor. So documented and sneak keeps rising is one of our right into the center of the galaxy.

176
00:26:56.010 --> 00:27:09.060
Tracy Slatyer: Um, let's take the summer relic cross section that Tim talked about earlier as human hundred GB doc meta and suppose that we get one foot on produce per annihilation in the energy being of interest. So then how many phones will be see it from our calculation.

177
00:27:10.620 --> 00:27:20.760
Tracy Slatyer: So the rate of photos so just using the formula that we had before. We want to do one of a pie times MT M squared multiplied by sigma v multiply by the J factor.

178
00:27:21.750 --> 00:27:32.310
Tracy Slatyer: This you can put in the numbers for yourself. And I encourage you to do so, but this gives you a number of about 10 to the minus nine phones at a per square centimeter per second.

179
00:27:33.450 --> 00:27:41.670
Tracy Slatyer: So that sounds like a small number. At first glance, but the good news is we can build a take those that are a lot bigger than the square centimeter and last for a lot longer than the second

180
00:27:42.150 --> 00:27:49.560
Tracy Slatyer: So what this tells you is if we want to see one photon from annihilating dark matter with a film or La Crosse section 100 GB

181
00:27:50.400 --> 00:27:59.520
Tracy Slatyer: You need about a year of observations with the detective. That was 100 square centimeters. If you have a detector that is more like a square meter like funny and you have

182
00:27:59.820 --> 00:28:10.320
Tracy Slatyer: Like 10 years now. Now you're cooking. Now, you expect to see 10s of thousands of photons from this film relic from this summer eloquent with an F. W profile.

183
00:28:12.480 --> 00:28:23.190
Tracy Slatyer: Okay, so that's that that is basically the calculation that's going to go into all the constraints I show you people study a particular region of the sky, they get their best estimate of the dark matter density in the sky.

184
00:28:23.580 --> 00:28:33.270
Tracy Slatyer: They work out the J factor and the predicted signal they multiplied by the exposure of their experiment, they asked how many phones do we expect to see how many photons. Did we actually see

185
00:28:35.220 --> 00:28:42.120
Tracy Slatyer: Um, so the other complicating factor, of course, is it does not enough to see the photons are you have to be able to separate them from the background.

186
00:28:42.510 --> 00:28:51.510
Tracy Slatyer: So, and that's the other reason the galactic center may not be the best place to so get to that in a moment. But I just want to add one more point about the J factor calculation that we did.

187
00:28:52.440 --> 00:29:05.790
Tracy Slatyer: As written so far I assumed that there was no regifting that the energy of the phone. The source of the field, what the source was the same as the energy of the photo. And as mentioned now detectors. So, d amp D was just the same in both locations.

188
00:29:06.540 --> 00:29:14.040
Tracy Slatyer: And that and that is not a good assumption that if the photons or neutrinos come to us over cosmological distances.

189
00:29:14.520 --> 00:29:22.950
Tracy Slatyer: In that case, we need to do two things we need to take into account at the source spectrum needs to be evaluated at a different energy and the energy that we actually see

190
00:29:23.730 --> 00:29:37.920
Tracy Slatyer: So by a factor of one plus he was. He is the redshift. And the other thing that we need to take into account is that the photon

density is getting diluted by the expansion of the universe, not just, it's not just its outflow.

191
00:29:38.910 --> 00:29:52.320
Tracy Slatyer: So the easiest way to do this is to recast the integral that we did earlier in terms of redshift instead of distance. And if you do this, then this is the master formula that you went up with. So we see like the same behavior.

192
00:29:53.310 --> 00:30:06.960
Tracy Slatyer: As some so you know we see the same behavior as previously we see this raw squid dependence week to this, these three factors for manipulation and decay. But now the spectrum cannot be separated from the integral or

193
00:30:08.190 --> 00:30:23.370
Tracy Slatyer: What now now. So now this spectrum is explicitly a function of redshift. And so you can't just pull out the spectrum that as a pretty factor, you can get. So in this sense, the Particle Physics and Astrophysics

194
00:30:25.050 --> 00:30:29.580
Tracy Slatyer: More entangled in this case this can also happen. For example, if you have some

195
00:30:30.570 --> 00:30:37.290
Tracy Slatyer: Position dependency in your cross section. Say for example, your cross section for annihilation depends on the relative velocity of the particles.

196
00:30:37.500 --> 00:30:46.590
Tracy Slatyer: In that case, then sigma v will not be a constant that you can pull outside the integral over the line of sight. You have to keep it inside the interpretation. So in that case this J factor picture doesn't work. It simply

197
00:30:47.580 --> 00:30:54.690
Tracy Slatyer: But I'm given this result. It's again, straightforward to predict the signal that you would select from any document model.

198
00:30:55.920 --> 00:31:08.490
Tracy Slatyer: Given give if you know what target you're looking at if we wanted to include effects like not all the phones, make it to us. Some of them are absorbed, then we could add an absorption term inside this integral to account to that.

199
00:31:09.750 --> 00:31:10.050
Tracy Slatyer: Okay.

200
00:31:11.160 --> 00:31:21.330
Tracy Slatyer: So what targets. Can we look at. So these are sort of the classic targets for doc meta, such as the study today. We can look at what galaxies. We can look at the center of the galaxy. We can look at the galactic halo

201
00:31:21.660 --> 00:31:29.610
Tracy Slatyer: Which is sort of the, the whole halo of the Milky Way galaxy in which we live. We can look at other galaxies and clusters beyond our own

202
00:31:30.000 --> 00:31:41.070
Tracy Slatyer: We can we can try to look for sub halos of dark metal little clumps of document of the don't have any stars associated with them. Or we can just look at the whole sky and try to look at the extra galactic background radiation.

203
00:31:42.780 --> 00:31:51.900
Tracy Slatyer: So the advanced dwarf galaxies. There's reasons that the first on this list their high density clumps of dark matter so they can have a non negligible J factor.

204
00:31:52.290 --> 00:32:01.680
Tracy Slatyer: They really love background because they have few stars associated with them. So that's very nice. And they're relatively close to us because they are orbiting our Milky Way galaxy.

205
00:32:02.190 --> 00:32:11.460
Tracy Slatyer: So dwarf galaxies often give you the strongest constraint. Once you take into account the lodge uncertainties and backgrounds associated with the galactic center.

206
00:32:12.780 --> 00:32:23.490
Tracy Slatyer: The Galactic Center is your high signal region. If you're looking for a if you're looking for discovery potential for signals that can easily be just to distinguish from astrophysical backgrounds, such as

207
00:32:24.390 --> 00:32:32.160
Tracy Slatyer: A sharp gamma ray spectral line, then the galactic center is wet look but it does have a white background and it's sensitive to the presence of density customer calls

208
00:32:32.640 --> 00:32:38.790
Tracy Slatyer: That's it. There's still a decent possibility that if we see a document of signal the galactic center will be the first place we see

209
00:32:40.440 --> 00:32:49.980
Tracy Slatyer: The galactic halo. So we're embedded in the galaxy. We can look in all directions and see the document of Halo with the Milky Way. So this covers a large area on the sky.

210
00:32:50.700 --> 00:33:01.500
Tracy Slatyer: Your d omega in the integral can be very big that's favorable. But, and it's it's as nearby as you can get, since we're in it, but the backgrounds again can be somewhat complex

211
00:33:02.970 --> 00:33:09.720
Tracy Slatyer: We can look at other galaxies and clusters. So these have a large dogmatic content and often give you some of the strongest constraints on documented case.

212
00:33:09.750 --> 00:33:15.990
Tracy Slatyer: Just because documented case signals just scale is the integrated amount of documented density. And there's a lot of documented in the galaxy clusters.

213
00:33:17.130 --> 00:33:31.590
Tracy Slatyer: Galaxy clusters can be far enough away that the redshift information comes into play, which means that in principle you could look at signals from multiple clusters and see if their energies line up once you factor out the redshift, which gives you a check on instrumental

214
00:33:33.150 --> 00:33:43.380
Tracy Slatyer: systematics. The trick with galaxy clusters is that often, the expected signal in the galaxy cluster depends very strongly, at least for annihilation, not the decay.

215
00:33:43.710 --> 00:33:47.460
Tracy Slatyer: On how much substructure. There is within the cluster by which we made. How many

216
00:33:48.300 --> 00:33:55.800
Tracy Slatyer: Clumps of dark matter. There are within the cluster. How many galaxies. Does it have how many sub halos do those galaxies contain

217

00:33:56.190 --> 00:34:01.140
Tracy Slatyer: Because when we look at a cluster. What we're doing is integrating over the annihilation signal from all of those components.

218
00:34:01.410 --> 00:34:13.650
Tracy Slatyer: And there are plausible models to substructure where the signal from the substructure is about 1000 times larger than the signal from the galaxy cluster is called so when looking at cluster constraints. Look at what prescription people assumed for the substructure.

219
00:34:15.810 --> 00:34:22.500
Tracy Slatyer: We can try to look for doc meta halos themselves. There could be many of these things around the formation of structure in the whole universe.

220
00:34:22.770 --> 00:34:31.200
Tracy Slatyer: In principles that we believe start from the bottom up in a cold dark matter universe. There could be many called dense little clumps of dark metaphor very in the early in the universe floating around.

221
00:34:31.530 --> 00:34:40.950
Tracy Slatyer: And we don't see them because they don't attract much matter to them. Um, difficulty here is it's hard to predict the exact distribution of these objects and we don't know where to look.

222
00:34:41.790 --> 00:34:51.180
Tracy Slatyer: So in that case searches for that can involve, for example, looking for extended sources of gamma rays that don't seem to be associated with anything else.

223
00:34:52.410 --> 00:35:04.050
Tracy Slatyer: And there's the extra galactic background radiation. So this is now essentially integrating over the contributions from clumps of doc meta at all possible scales and all possible redshift. And I could also be pretty powerful.

224
00:35:05.940 --> 00:35:14.610
Tracy Slatyer: OK, so now. So that's the, that's what you need to know to understand these limits. So I now want to tell you what some of bounds actually are.

225
00:35:18.870 --> 00:35:26.280
Tracy Slatyer: Okay, so there are in galleries in photons. There are basically three classes of telescopes and the high energy band.

226
00:35:26.880 --> 00:35:35.220
Tracy Slatyer: That I'm particularly interesting. So for me, and also damping and color a space based telescopes, for me, is the

227
00:35:36.090 --> 00:35:46.320
Tracy Slatyer: Is the leading instrument for gamma rays in this energy range because it's space, paste it comes down to lower energies and the ground based instruments it essentially works by

228
00:35:46.950 --> 00:35:55.050
Tracy Slatyer: When a gamma ray hits the detector. It produces an electron positron pair, which can be traced back to infer the energy in the direction of the original photon.

229
00:35:56.280 --> 00:36:13.440
Tracy Slatyer: And its most sensitive to photons from an NGO around 180 me be up to the TV scale for me speed up in the sky. Since 2008 its data set it say to set is fully public they update as it gets updated on a regular on a very regular basis with more than once a day.

230
00:36:14.580 --> 00:36:16.320
Tracy Slatyer: And it's available for anyone to us.

231
00:36:17.760 --> 00:36:23.430
Tracy Slatyer: As we go to hire and now the limitation of funny is because its face face. It can't be too large. It's about a square meter.

232
00:36:23.940 --> 00:36:30.780
Tracy Slatyer: Is pretty substantial for a space telescope. But as we go to high energies. The gamma rays become Dara. Dara

233
00:36:31.350 --> 00:36:39.600
Tracy Slatyer: Both from hypothetical document. So aside from astrophysical sources. And if you want to see them. It would be really nice to have a Large Area Telescope.

234
00:36:39.960 --> 00:36:50.580
Tracy Slatyer: That's when we go to the ground based telescopes, such as has Farah test magic hawk and loss. So these are your ankles telescopes what they look for. So that has Veritas and magic.

235
00:36:51.090 --> 00:36:57.540

Tracy Slatyer: Is your income telescopes what they look for is when a high energy cosmic ray hits the atmosphere produces a shower of touring called ly

236
00:36:58.380 --> 00:37:13.500
Tracy Slatyer: Which these telescope race track this sensitive. They can't see true low energy cosmic rays to low energy gamma rays, just because they don't produce enough maturity of shower that sensitive down to energies about 100 GB and up to energies of 10s of TV.

237
00:37:14.670 --> 00:37:27.330
Tracy Slatyer: And then going to even higher energies. And so for me, is a full sky instrument it absorbs the whole sky once has Pharaoh's house and magic appointed instruments they have to pick a region of a few degrees to look at on the sky.

238
00:37:29.100 --> 00:37:36.930
Tracy Slatyer: You can also build ground based telescopes that so they the full sky and the water and club telescopes in this category.

239
00:37:38.250 --> 00:37:52.140
Tracy Slatyer: And so hawk is the current is that as the current exemplar of that that will still looking for sharing called showers, but using I'm using an array of water tanks, rather than imaging telescope

240
00:37:53.430 --> 00:37:58.950
Tracy Slatyer: And there's also the last or experiment in China, which is just getting started, which uses these technologies to

241
00:38:00.720 --> 00:38:02.160
Tracy Slatyer: Okay, so

242
00:38:03.030 --> 00:38:06.660
Tracy Slatyer: Let's talk about what happens when these telescopes, try to look at what galaxies.

243
00:38:06.810 --> 00:38:18.630
Tracy Slatyer: So in this case, what they do is they fit for localized gamma ray emission associated with the tool or the smooth background at the location of walk galaxies, and then they compare the observed and pretty key to have cameras signal into likelihood analysis.

244
00:38:19.050 --> 00:38:26.130
Tracy Slatyer: So the Fermi Gamma ray Space Telescope presented limits back in 2017 based on 45 for galaxies and candidate galaxies.

245
00:38:26.490 --> 00:38:33.750
Tracy Slatyer: And these are some of the strongest robust bounds that you can set on dogma of is lighter than about a TV and annihilate support on your channels.

246
00:38:34.200 --> 00:38:38.580
Tracy Slatyer: They provided the full likelihood functions which are available at this website.

247
00:38:38.940 --> 00:38:51.870
Tracy Slatyer: For the fluxes in each energy been so well they show results in the paper for specific annihilation channels like document or annihilating to be quotes or tell leptons. You can use this to set constraints on totally arbitrary spectrum.

248
00:38:53.790 --> 00:39:03.690
Tracy Slatyer: The ground based telescopes have also accepted wolf galaxies, and so they can supplement the foot me limits as you go to higher energies. So this is from an ISO analysis presented

249
00:39:04.170 --> 00:39:21.870
Tracy Slatyer: As a pre printed on the archive for this is from ICRC last year 2019 to these other panels are showing the results of a combined constraint analysis using flemmi quote has magic and Veritas so over telescopes that I just described is red. So this plot is the

250
00:39:22.890 --> 00:39:29.880
Tracy Slatyer: Annihilation cross section on the Y axis, this is for annihilation to be quotes annihilation, a tablet Tom's as to Representative channels.

251
00:39:30.180 --> 00:39:42.420
Tracy Slatyer: The red line choice of them were like cross section and the black line says that everything about this line is excluded to see that in both cases, the beak walks this analysis claims to rule out the femoral at cross section for

252
00:39:43.800 --> 00:39:52.350
Tracy Slatyer: For masses below about 200 GB and fatality tons below that 100 g. Now there is a caveat here, which is that

253
00:39:52.770 --> 00:40:02.820
Tracy Slatyer: So dwarfs figuring out the J factors can be pretty difficult because the way that we do it is by looking to the orbits of

stars around the dwarves and that on a lot of stars associated with us, which is why the Lord background.

254
00:40:03.300 --> 00:40:10.560
Tracy Slatyer: But, um, there were a couple of recent analyses that showed that if you change your prayers for how they're documented institution and the dwarf is treated

255
00:40:10.890 --> 00:40:19.830
Tracy Slatyer: Or you change your treatment if the line of sight full grounds, then it can move these constraints around by quite a bit. This is an example from one of those papers by endo Adele, the

256
00:40:20.190 --> 00:40:34.020
Tracy Slatyer: gray line is the sort of default analysis for annihilation to be cokes. And you see that it crosses the thermal relic line between about hundred and 200 GB. So that's similar to this combined analysis older I believe this group is using only Femi data.

257
00:40:35.190 --> 00:40:43.170
Tracy Slatyer: And then these other colored lines show what happens to the limit if you use alternative priors for the documented distribution within the dwarfs.

258
00:40:43.440 --> 00:40:52.770
Tracy Slatyer: And so you can see that that can reduce the constraint to only rolling out the femoral like benchmark at masses below about 20 or 30 TV.

259
00:40:53.250 --> 00:41:04.200
Tracy Slatyer: So keep this in mind with the adult constraints we expect to be able to prove some early cross section up to 10s of GB maybe hundreds of GV but the answer is somewhat sensitive to how much documented the residuals.

260
00:41:07.080 --> 00:41:15.900
Tracy Slatyer: So we can do the same kind of analysis for decay looking at 12 galaxies galaxy clusters extra galactic Emery backgrounds and the Milky Way Halo.

261
00:41:16.950 --> 00:41:24.690
Tracy Slatyer: And if we do that, if we combine those studies. Turns out, so this plot is now showing the document a lifetime versus the document a mess.

262

00:41:24.930 --> 00:41:35.190
Tracy Slatyer: This is the dogmatic came to be quotes. But as I explained earlier, the results will look usually fairly similar for anything that any I'm had chronic annihilation channel, any, any

263
00:41:35.610 --> 00:41:41.010
Tracy Slatyer: Any information any channel that leads to formation neutral pions we typically get fairly similar results.

264
00:41:41.460 --> 00:41:51.540
Tracy Slatyer: And these authors showed in 28 so now this is it a lifetime. So everything below the red line is ruled out a lifetime shorter than this and they showed that you could set bounds.

265
00:41:52.230 --> 00:42:01.080
Tracy Slatyer: On lifetimes of 10 to the 27 to 10 to 28 seconds off the document of masses in the range from 10 GB up to around 10 to the 10 GB

266
00:42:03.870 --> 00:42:18.090
Tracy Slatyer: Now if we go, you might say, Okay, and what about lower energies, so far I've just talked about, again, Maria telescopes that can probe the emission DV scales and higher. So there are also telescopes that look at lower energy photon emission

267
00:42:19.290 --> 00:42:19.710
Tracy Slatyer: The

268
00:42:22.410 --> 00:42:32.760
Tracy Slatyer: Once you adopt meta mask is much less than 100 MEP, it has limited pot options for annihilation is among the Standard Model particles, it can go to electrons and positrons photon so neutrinos.

269
00:42:33.300 --> 00:42:43.590
Tracy Slatyer: So this means that the photon spectrum is often predicted to be either a spectral line would it be a fairly hard spectrum, which is what happens when electrons and positrons radiate additional photos.

270
00:42:46.260 --> 00:43:00.090
Tracy Slatyer: So if the channels that produce abundant photons, the strongest limits on decay come from studying gamma rays from the Milky Way Halo which which has been studied by a range of telescopes that are listed here at one integral commonality grit and, more recently, funny.

271
00:43:01.290 --> 00:43:01.770
Tracy Slatyer: And

272
00:43:02.970 --> 00:43:14.340
Tracy Slatyer: The so so channels that produce a lot of photons. These give you the strongest constraints. If the annihilation is mostly into electrons or into neutrino is in this situation is harder for

273
00:43:15.210 --> 00:43:25.710
Tracy Slatyer: It turns out that for annihilation two electrons there a better constraints that we can do with the decay two electrons and positrons constraints from looking at the photons in the halo also pretty competitive.

274
00:43:26.460 --> 00:43:32.970
Tracy Slatyer: So this is what the data looks like from the galactic a law as a function of energy, the way that that

275
00:43:33.900 --> 00:43:42.630
Tracy Slatyer: The way that that converts into constraints. I'll show you in a couple of slides, but I just want to mention one cute sort of side point in this area, so far we've been talking about particle doc meta decay.

276
00:43:42.900 --> 00:43:54.990
Tracy Slatyer: But you can also have non political dogmatic candidates that produce very similar signatures for example primordial black holes are viable dogmatic candidates if they can be produced efficiently copiously during inflation.

277
00:43:55.860 --> 00:44:04.980
Tracy Slatyer: This plot is a review showing the current open space for black holes. The y axis is the fraction of document that they could constitute and the x axis is the mess.

278
00:44:05.310 --> 00:44:16.470
Tracy Slatyer: So the solid lines correspond everything above the solid lines is rolled out the solid lines correspond to pretty solid constraints, the dashed lines correspond to constraints that are more tenuous and have been questioned.

279
00:44:16.980 --> 00:44:28.290
Tracy Slatyer: And so there is this allowed window corresponding a massive about 10 to the 17 to 10 to the 23 grams for the primordial black holes in which they couldn't be potentially 100% of the document.

280
00:44:29.070 --> 00:44:37.950

Tracy Slatyer: at the low end of this mass range. The constraint is coming from a search for dogmatic okay well documented K in this sense means the black holes evaporate through Hawking radiation.

281
00:44:38.400 --> 00:44:50.670
Tracy Slatyer: The peak energy of that Hawking radiation at this boundary point is about 100 K be so you can again look for it in these observations which on this plot span the range from

282
00:44:51.750 --> 00:44:54.630
Tracy Slatyer: 10s of kV up to hundreds of G.

283
00:44:58.620 --> 00:45:08.040
Tracy Slatyer: So this is what the constraints on decaying annihilation look like from these channels for decay two photons. I'm going to tell you that this needs a slight update

284
00:45:08.550 --> 00:45:22.170
Tracy Slatyer: Shortly, but we see that you can generally constrained lifetimes of 10 to the 26 to 10 to the 27 seconds across a pretty across a pretty broad range for annihilation two electrons.

285
00:45:23.220 --> 00:45:34.500
Tracy Slatyer: On you can you can constrain cross sections below the summer relic value, but there are better constraints which is what this black line is showing

286
00:45:35.160 --> 00:45:44.700
Tracy Slatyer: For decay of dark matter to electrons. You can constrain lifetimes around 10 to the 24 to 10 to the 25 seconds by looking at the photons that those electrons radiate

287
00:45:46.260 --> 00:46:02.640
Tracy Slatyer: And for annihilation into of dogmatic into photons. You can set you can again set a boundary that is well below the femoral a cross section and is the strongest bound in these MTV mass scales.

288
00:46:04.950 --> 00:46:10.440
Tracy Slatyer: Now for decay two photons. This was the original analysis from a bicycle and 20

289
00:46:11.280 --> 00:46:18.900
Tracy Slatyer: And 2013. It turns out there's some green line is a bit overestimated. So in a paper that my colleagues and I put out recently.

290
00:46:19.260 --> 00:46:25.350
Tracy Slatyer: This gray line shows this low gray line shows the corrected constraint, the dash gray line here is the original constraint.

291
00:46:25.680 --> 00:46:34.020
Tracy Slatyer: But it's still the broad picture. I mean, it's true. You can constrain lifetimes of 10 to the 27th 28 seconds 10 orders of magnitude longer than the age of universe.

292
00:46:34.380 --> 00:46:46.020
Tracy Slatyer: Across this whole range and the primordial black holes case we can use this integral data to rule out primordial black holes less than about two times 10 to the 17 grams as 100% of the document.

293
00:46:48.330 --> 00:46:55.230
Tracy Slatyer: As we go down to even lower energy scales and low mass scales we can look at x ray limits on dark matter.

294
00:46:55.740 --> 00:47:03.060
Tracy Slatyer: And this is a paper by Rochelle from 2019 which is a nice compilation of constraints from you stuff on dark matter annihilation.

295
00:47:03.510 --> 00:47:09.060
Tracy Slatyer: The annihilation. Again, the limits are a long way to load the somewhere else cross section of the strange. So you're typically probing models.

296
00:47:09.360 --> 00:47:13.470
Tracy Slatyer: That I'm not produced in that way. They get their abundance through a different mechanism.

297
00:47:14.160 --> 00:47:21.630
Tracy Slatyer: So decay. There's a theoretically interesting scenario in this strange, which is on mute style neutrino document indicating to a neutrino plus photon.

298
00:47:21.990 --> 00:47:30.570
Tracy Slatyer: Again down this strange, we see that we can using x ray experiments we can control constrained lifetimes, as long as about 10 to the 28 seconds so

299
00:47:30.990 --> 00:47:46.530
Tracy Slatyer: Really generically for almost all channels, except to care annihilation except decayed neutrinos. We can use in lifetimes of 10 to

the 27 to 10 to 28 seconds from document of masses of the kV scale up to the 10 to the 10 GB scale.

300
00:47:48.300 --> 00:48:00.660
Tracy Slatyer: When we look at neutrinos. We can look at. So if the neutrinos. We have a range of experiments there is to become your candy, which covers a few MTV to TV scale and Tyrese

301
00:48:01.350 --> 00:48:08.850
Tracy Slatyer: Which covers the hundred GB 100 TV scale and ice cube which again starts at 100 GB and co op can go up to very high energies.

302
00:48:09.330 --> 00:48:24.270
Tracy Slatyer: So neutrino experiments can search for the neutrinos from any and I always tell in general, it's usually easier to see the photons or the charged particles in the neutrinos. If there are any photons charged particles produced in the interaction.

303
00:48:25.350 --> 00:48:30.720
Tracy Slatyer: But these searches have unique sensitivity. If you treat knows the main annihilation okay products.

304
00:48:32.010 --> 00:48:41.190
Tracy Slatyer: So this is a nice review by well said I'll from late last year, which shows the constraint on dark matter annihilation to neutrinos across a very wide range of energies.

305
00:48:41.880 --> 00:48:57.210
Tracy Slatyer: Is the experiments that I mentioned on ice cube and and Tyrese and super Kevin your candy low into cheese. You see that these constraints. It's very challenging to get down to the symbol relic cross section for annihilation to neutrinos, but the parameter spaces and totally often

306
00:48:58.740 --> 00:48:59.460
Tracy Slatyer: We can

307
00:49:00.870 --> 00:49:13.290
Tracy Slatyer: Also yet. We could also look at non neutrino channels that still produce neutrinos, such as dark matter. And I always tell leptons. This example is showing here. So these black lines of the

308
00:49:14.010 --> 00:49:23.310
Tracy Slatyer: Gamma ray observations of the galactic center that I was telling you about this black dotted line is gamma observations. The wolf

galaxies, which are perhaps more trustworthy than this galactic center line.

309
00:49:23.730 --> 00:49:35.070
Tracy Slatyer: And this green line is a observation us using a combined observations from Antares and ice cube. So as you get to a very high message the neutrino limits can start to become competitive.

310
00:49:37.020 --> 00:49:44.070
Tracy Slatyer: Okay, so that's what I wanted to say about mutual states. Now, I know I have five minutes left in today's lecture. So some of this may be

311
00:49:44.460 --> 00:49:58.350
Tracy Slatyer: So I'm going to read, Eric, some of this material to tomorrow's lecture, which is fine. I had left space in tomorrow's lecture for the spirituality. So let me just say a little bit to you about how challenged particles propagate through our galaxy.

312
00:50:00.360 --> 00:50:06.960
Tracy Slatyer: So as I've already said charged particles are affected by galactic magnetic fields that trajectories. Don't point back towards this sources.

313
00:50:07.260 --> 00:50:11.670
Tracy Slatyer: And so that makes it a lot harder to tell the signal from the background. We can't do what we did.

314
00:50:12.090 --> 00:50:23.190
Tracy Slatyer: Where we say, Oh, we're just going to look at the dwarf galaxies. There's no way for us to just look at the cosmic ray particles that are coming from dwarf galaxies, only instead we get an integral over the whole galaxy.

315
00:50:24.360 --> 00:50:27.240
Tracy Slatyer: So our options, then we can look for

316
00:50:28.740 --> 00:50:35.460
Tracy Slatyer: We can look for channels where we expect there to be very low astrophysical background. So it's just the anti nuclear I fall into this category.

317
00:50:35.850 --> 00:50:45.630

Tracy Slatyer: But if we're looking for, say, electrons or positrons or anti protons out mean observable really is just going to be the energy spectrum of the particles that we can measure it in the neighborhood.

318
00:50:47.040 --> 00:50:54.270
Tracy Slatyer: So the separation from background is hotter and modeling the expected signal is also quite a lot more complicated than photons neutrinos.

319
00:50:54.720 --> 00:51:07.890
Tracy Slatyer: The uncertainties and how particles propagates through our galaxy and what the magnetic field of our galaxy is affects both the signal in the background, but let me give you a quick sketch of how that propagation calculation walks in practice this calculation is usually done numerically.

320
00:51:08.910 --> 00:51:16.650
Tracy Slatyer: So essentially what we do is we model our galaxy is a sea of cosmic rays diffusing through the Galactic magnetic field and losing energy as they propagate.

321
00:51:17.520 --> 00:51:28.710
Tracy Slatyer: So to study this we can solve the diffusion equation for the cosmic ray propagation. So what we're going to do is say, okay, let the spectrum of cosmic rays at a given point.

322
00:51:29.160 --> 00:51:43.410
Tracy Slatyer: This d amp D spectrum be this function side. So it's a function of time and position and energy and species. So this holds true for each species of cosmic ray, then we can have our equation will generally have this diffusion term.

323
00:51:44.460 --> 00:51:56.940
Tracy Slatyer: A an energy loss term and and a source term. This is the simplest version, you can do you can add additional terms to this equation. So our strategy, more or less, is going to be to try to

324
00:51:58.290 --> 00:52:09.450
Tracy Slatyer: To try to predict the source term and energy last term and the diffusion term through a combination of theoretical modeling and fitting two observations of the cosmic ray data.

325
00:52:10.170 --> 00:52:14.430
Tracy Slatyer: I, in practice, use numerical so with such as God profit tracking it is

326
00:52:15.420 --> 00:52:22.110
Tracy Slatyer: So the simple approaches you model the galaxy is a cylindrical slab. So this is the differential equation we do invoice boundary conditions as well.

327
00:52:22.230 --> 00:52:30.510
Tracy Slatyer: The simplest version of the boundary conditions is that you just say, Okay, once the cosmic rays reach a certain distance from disk of the galaxy. They just free streaming away and completely escape.

328
00:52:31.620 --> 00:52:39.930
Tracy Slatyer: Simple version again is Hume's isotopic and homogeneous diffusion and you model this diffusion coefficient is just some Pamela function of energy.

329
00:52:40.560 --> 00:52:47.190
Tracy Slatyer: All of those assumptions can be modified and the authors of gal profit have done a lot of work in recent years to try to allow for other

330
00:52:47.790 --> 00:52:58.800
Tracy Slatyer: For modifications those assumptions, such as and isotopic diffusion and to add allow the addition of more terms to this equation, such as to account for conviction of the cosmic rays acceleration of the cosmic rays.

331
00:52:59.310 --> 00:53:05.250
Tracy Slatyer: Fig. What's your soup and over eminence fragmentation of cosmic rays of cosmic nuclei and so on.

332
00:53:06.810 --> 00:53:13.260
Tracy Slatyer: So I can say I already said what what each of the sound. So I'm going to use these colors to reference these things generically.

333
00:53:14.970 --> 00:53:23.250
Tracy Slatyer: Okay, so, but if we interested in dark matter annihilation and decay is our source. Specifically, we don't expect this to be a one off fancy and event we expect it to be a steady source.

334
00:53:23.460 --> 00:53:34.950
Tracy Slatyer: So what we're actually going to observe is not the spectrum for a particular annihilation. We're going to look at this steady state spectrum this steady state sigh of at the position of the earth.

335
00:53:36.420 --> 00:53:38.040
Tracy Slatyer: As a, as a function of energy.

336
00:53:39.450 --> 00:53:43.500
Tracy Slatyer: So if we set aside time independent and just to a quick

337
00:53:44.160 --> 00:53:52.170
Tracy Slatyer: For quick idea of how things scale. Let's treat site as having a power low energy dependence. It's going to be a powerful spectrum in energy. This is a

338
00:53:52.410 --> 00:54:05.700
Tracy Slatyer: This can be really bad approximation. If you're injecting particles with one specific energy. But let's assume that has a powerful energy independence. So that means that differentiating with respect to energy is basically just going to give you factors, one of the

339
00:54:06.840 --> 00:54:19.380
Tracy Slatyer: In the equation. And let's write this diffusion term this we shook hands on crowd squid sigh as just sigh divided by some link scale asked when so that we can call the diffusion line.

340
00:54:20.370 --> 00:54:30.150
Tracy Slatyer: Then since we're looking at the steady state solution. We're going to set Deep sigh DT to zero. And then we going to have a relationship between the diffusion of a loss and the source jump.

341
00:54:31.380 --> 00:54:40.560
Tracy Slatyer: Which looks like this. So, it will often be the case that one of these two tons either diffusion of losses dominates over the other. So if

342
00:54:41.160 --> 00:54:53.550
Tracy Slatyer: One of these is one of these terms is much larger than the other than the straightforward solution is just to say that okay sigh is whatever your source term was multiplied by one over the appropriate term here.

343
00:54:54.060 --> 00:55:08.100
Tracy Slatyer: So if we're in the diffusion dominated regime, we can think of size just being source term multiplied by an energy dependent diffusion time if we're in the last dominated energy, we can think of Psy as being the source term multiplied by an energy dependent last time.

344

00:55:12.000 --> 00:55:21.420
Tracy Slatyer: So if we then put in this estimate that the diffusion coefficient is a is a power law. This is based on this. This is based on a simulation on

345
00:55:22.320 --> 00:55:34.620
Tracy Slatyer: Analog estimates we expect the diffusion coefficient to roughly be a power and energy with the index being roughly or point 3.7 this corresponds to, like, come over versus Kraken diffusion

346
00:55:35.280 --> 00:55:43.260
Tracy Slatyer: So that tells us that in the diffusion dominated regime, the effect of the diffusion is basically going to be to soften the spectrum.

347
00:55:44.100 --> 00:55:52.980
Tracy Slatyer: By a factor of either the minus delta. So, whatever your injected source spectrum was you essentially diffusion essentially just multiply that by a parallel

348
00:55:53.850 --> 00:56:02.070
Tracy Slatyer: In the last dominated regime. The, the main cooling mechanisms cooked our high energy positrons and electrons, which is where this mostly applies.

349
00:56:02.400 --> 00:56:09.990
Tracy Slatyer: Have losses that scale like energy squared. So that follows from the equation on this side. Tell us the CEO VP.

350
00:56:10.440 --> 00:56:15.030
Tracy Slatyer: This tells us that the steady state spectacle look like this. So spectrum multiplied by one of the

351
00:56:15.420 --> 00:56:21.990
Tracy Slatyer: So, in both cases, you take whatever your source factories, you multiply by some energy dependent function and that gives you your final spectrum.

352
00:56:22.770 --> 00:56:31.740
Tracy Slatyer: If diffusion is dominant, for some energies, but last is dominant. The other energies and that will give rise to non trivial features in the spectrums like breaks in your power law.

353
00:56:32.670 --> 00:56:41.220

Tracy Slatyer: Diffusion and losses typically make the spectra softer, or they make features sport and exercise that you can do, which is quite nice to sort of to go back to this original differential equation.

354
00:56:42.150 --> 00:56:49.110
Tracy Slatyer: And try like putting in a delta function in in time. So it does all the function in that energy as your source tongue.

355
00:56:49.440 --> 00:57:00.630
Tracy Slatyer: And then seeing what that does to advance hitting this deep sigh VT to zero and seeing what that does to the steady state solution and you will see that the spectrum that you get out is very much not a delta function in cheap anymore.

356
00:57:01.440 --> 00:57:05.850
Tracy Slatyer: And so this gives us a couple of sort of general features the spectra of particles.

357
00:57:06.630 --> 00:57:11.880
Tracy Slatyer: After they diffuse or lose energy should be somewhat softer, they should have less power at high energies.

358
00:57:12.300 --> 00:57:25.860
Tracy Slatyer: And consequently, if those particles scatter on the gas and make more secondary particles those particles have a softer softer spectrum, then they're presented as did so they should also be softer have less power at high end cheese. Okay.

359
00:57:26.340 --> 00:57:41.100
Tracy Slatyer: So next time I will use those ideas and those insights to show you what the current results look like from cosmic rays from charge cosmic ray experiments and what limits we can currently set

360
00:57:41.610 --> 00:57:45.750
Tracy Slatyer: I'll tell you about some hints of possible excesses in those channels as well.

361
00:57:46.740 --> 00:58:00.240
Tracy Slatyer: I also want to tell you about ways to do indirect detection using observations in the variable universe. And then at the end, I'll circle back to the gamma rays and you trios, and tell you a bit about some excesses.

362
00:58:00.510 --> 00:58:02.970
Tracy Slatyer: In photons and a cosmic rays.

363
00:58:03.240 --> 00:58:10.020
Tracy Slatyer: That have been seen it and not yet fully resolved and which could potentially have something to do with Doc metal, although we have no

364
00:58:10.440 --> 00:58:11.580
Tracy Slatyer: Strong country.

365
00:58:13.350 --> 00:58:19.980
Tracy Slatyer: Okay. So I will stop there, since I'm a time and I guess we can move on to the Q AMP a thank you very much.

366
00:58:21.660 --> 00:58:29.460
dong su: Thank you very much for a super nice lecture. And so we now turn over to Tom going to take over for the nice

367
00:58:30.930 --> 00:58:38.820
thomas rizzo: Thanks a lot. Tracy, that was great. There's a huge number of questions. Let's start from sort of the beginning of your talk. Slide five

368
00:58:39.750 --> 00:58:40.290
Okay.

369
00:58:43.230 --> 00:58:53.700
thomas rizzo: So the question is, how does the coldness or warmness of dark matter particles today affect the thermal relic benchmark.

370
00:58:55.170 --> 00:59:05.100
Tracy Slatyer: I'm good. Okay. So the question is, yeah. OK. So the standard. Good. Okay.

371
00:59:07.830 --> 00:59:21.120
Tracy Slatyer: So this sort of very standard thermal win scenario where you say, Okay, we've got 100 GB doc Matta so it freezes out at a temperature about one 20th of its mass

372
00:59:21.360 --> 00:59:31.650
Tracy Slatyer: So that might be like five GB for 100 GB particle that tends to predict very cold, dark metal. So if you're anywhere around that regime.

373

00:59:32.100 --> 00:59:45.510
Tracy Slatyer: Whether the document of froze out at five TV or one GB or you know 400 MTV tends to make very little difference to that to that film or like benchmark. Once you're up at these

374
00:59:45.870 --> 00:59:57.720
Tracy Slatyer: Up at this sort of why GV and plus hi mess regime. The summer like benchmark berries very mildly with mass between about two and three times 10 to the minus 26 centimeters cute per second.

375
00:59:58.860 --> 01:00:10.350
Tracy Slatyer: Now right ok but so if you're down in the regime where people usually talk about warm dark matter, you're thinking about sort of kV so kV scale dark matter.

376
01:00:10.740 --> 01:00:24.690
Tracy Slatyer: That was in thermal contact with the visible matter is expected to have a high enough temperature that it would be observable as one dark matter today that you could be the same. No negligible effects in the matter power spectrum today.

377
01:00:25.770 --> 01:00:26.130
Tracy Slatyer: I'm

378
01:00:27.360 --> 01:00:41.400
Tracy Slatyer: That you usually have to come up with some mechanism that is not just straight up simplest possible thermal freeze out to get your to get your corrective maintenance, um,

379
01:00:42.210 --> 01:00:53.940
Tracy Slatyer: So, and those mechanisms can have a wide variety of things that they predict for annihilation or decay signals in the present day. So where this benchmark is so

380
01:00:55.260 --> 01:01:02.460
Tracy Slatyer: Yeah so. So another way. Yeah, so I guess like where this benchmark is

381
01:01:03.480 --> 01:01:14.190
Tracy Slatyer: Most useful is it high masses in there. It's pretty stable I yeah so if you if you do carefully the calculation for, like, what is the film a relic cross section for

382
01:01:14.520 --> 01:01:18.930

Tracy Slatyer: kV doc meta. So, like, what do you then, then I can imagine it would be

383
01:01:19.320 --> 01:01:30.000
Tracy Slatyer: I mean, I think the calculation will actually still be pretty similar. And you're naive them are like cross section will still look pretty similar to what it is in these scenarios. Just because that still cart.

384
01:01:30.780 --> 01:01:38.190
Tracy Slatyer: Once you start once that still corresponds to freeze out you know before close to matter radiation equality, which is the thing that could make a

385
01:01:39.570 --> 01:01:48.750
Tracy Slatyer: Well, yeah, so I right so sorry. I think I'm I guess the in warmed up in the one that right so sorry I said something a little misleading that I'm

386
01:01:49.260 --> 01:01:56.820
Tracy Slatyer: One of the things to the things that distinguish one that animals that we can look for as one. One is that they tend to be one mass related to that is that they're freezing out while they're still

387
01:01:57.240 --> 01:02:16.650
Tracy Slatyer: Mostly while they're still somewhat relativistic. And so in that case the suppression. So in that case, the suppression of the documented density is much less severe than if they freeze out while they're fully relativistic but I

388
01:02:17.430 --> 01:02:19.170
Tracy Slatyer: Think it's still just

389
01:02:20.100 --> 01:02:28.500
Tracy Slatyer: So, so yeah, so I don't actually know exactly what cross section, you need to get down to the observed abundance, um,

390
01:02:29.010 --> 01:02:43.290
Tracy Slatyer: With those with those scenarios if the calculation goes through exactly the same or not. But I think, like, in general, if you're thinking about realistic models like kV scale won't matter, you usually need a different kind of reaction mechanism anyway.

391
01:02:46.590 --> 01:02:47.640
Tracy Slatyer: But that answers the question.

392
01:02:49.740 --> 01:02:53.190
thomas rizzo: So. Thanks, Tracy and slide seven

393
01:02:55.710 --> 01:03:08.520
thomas rizzo: Except for the dark matter decay time having to be inversely proportional with the some mass scale dimensionally. What determines the powers of the gut and dark matter mass scales in the higher dimension operators.

394
01:03:09.660 --> 01:03:19.440
Tracy Slatyer: So it's more or less so. So when we talk about if you think about, um, what the look around cheon looks like. So that, so the this is again just to

395
01:03:19.770 --> 01:03:28.050
Tracy Slatyer: Like justice justice sketch, you should not take this too seriously because there are many documented models that can lead to decaying dogmatic, this is just sort of a parametric estimate

396
01:03:28.710 --> 01:03:39.060
Tracy Slatyer: But, um, but if you think about what the term in the loop raunchy and should look like what we mean when we say a dimension five operator is that the mass dimensions of all the field operators.

397
01:03:39.630 --> 01:03:48.450
Tracy Slatyer: Add up to five. So that means that there has to be some other you know that I mentioned a little bit Thompson little grouchy and has to be four. So that means that there needs to be a one or 2am

398
01:03:48.780 --> 01:03:56.430
Tracy Slatyer: happy that the effect of coupling that operator in the logger on G and needs to be dimensional. So, and it needs to have dimensions of one of the mass

399
01:03:56.730 --> 01:04:06.840
Tracy Slatyer: So when I say the operator is suppressed by a high mass scale. The got scale. What I mean is that parametric Lee that dimension full coupling is one over the high mass scale.

400
01:04:07.170 --> 01:04:13.020
Tracy Slatyer: Okay, so we're dimension five operator. It's that coupling the coupling effectively is one of them got

401

01:04:13.470 --> 01:04:24.660
Tracy Slatyer: And so that's a coupling. But if I'm looking at a cross section I typically have to square the coupling. So the matrix element might go like one of it and got but the cross section would go like one of it and got squid. If it's a tree level.

402
01:04:25.110 --> 01:04:26.640
Tracy Slatyer: You persist through that operator.

403
01:04:27.330 --> 01:04:35.850
Tracy Slatyer: And so that's what gives you. So that's that. So the decay rate skills like one of them got squid. That means that the decay lifetime skills like him got squared.

404
01:04:36.030 --> 01:04:40.710
Tracy Slatyer: And if the only on the scale and the problem is the document a master, it will make up the author, in fact, is

405
01:04:41.190 --> 01:04:50.340
Tracy Slatyer: If we want to dimension six operated. That means that the effective coupling that appears and little grungy and has to have messed I mentioned one of the mess squid. So if we say

406
01:04:50.670 --> 01:05:03.150
Tracy Slatyer: The operator is suppressed by the high five, high mass scale than what we mean is that the coupling is parametric Lee, one of the MC squared with him is the high mass scale. And so then the great the great ends up going like, I'm

407
01:05:03.240 --> 01:05:04.440
Tracy Slatyer: One of them. So the fourth

408
01:05:04.710 --> 01:05:20.220
Tracy Slatyer: That timescale, the fourth, which means the lifetime goes like massive the high skill to the full. Um, and so on, does that. So yeah, so that's the, that's the relationship between the message I mentioned of the operator and these scaling is in the decay rate.

409
01:05:23.070 --> 01:05:25.740
thomas rizzo: Okay, thanks. On slide 11

410
01:05:27.540 --> 01:05:32.340
thomas rizzo: How safe is it to assume that the dark matter annihilate is a tropical

411
01:05:33.600 --> 01:05:36.360
Tracy Slatyer: A good that's a, that's a good question. So

412
01:05:36.840 --> 01:05:45.120
Tracy Slatyer: In any given interaction, it's probably not very safe at all. Well, I mean that there. You have to metal particles coming into each other.

413
01:05:45.330 --> 01:05:54.420
Tracy Slatyer: That you know sets up an access, there is no reason at all to think the spectrum of the annihilation products up is a topic about those that access and lights, it's generally not but

414
01:05:55.620 --> 01:05:59.700
Tracy Slatyer: If you have many, many document of particles annihilating in your volume element.

415
01:06:00.450 --> 01:06:08.700
Tracy Slatyer: Then if the velocity distribution of the document of particles is roughly isotopic than you would expect these

416
01:06:09.060 --> 01:06:15.030
Tracy Slatyer: These anisotropy effects on the level of individual collisions to cancel out when you ever you ever enough document of particles.

417
01:06:15.630 --> 01:06:23.730
Tracy Slatyer: So the exception might be like say there's some, you know, big like stream of dogmatic coming in such little the dogmatic particles going in the same direction.

418
01:06:24.060 --> 01:06:33.810
Tracy Slatyer: Then, then I could imagine such that, and they're encountering dogmatic particles in the halo of the system that they're encountering such that all the collisions are in a particular direction.

419
01:06:34.140 --> 01:06:46.020
Tracy Slatyer: Then I can imagine that even the average spectrum might not be fully isotopic but if you're thinking about a sort of steady state equilibrated serialized system then to a pretty good approximation, the document of particles.

420
01:06:47.340 --> 01:06:57.180

Tracy Slatyer: bouncing around in the cloud. There's a broadly isotopic in the Galactic frame velocity distribution and john I you expect the

421
01:06:57.810 --> 01:07:09.750
Tracy Slatyer: And I said trophies. In the event individual collisions to largely average out when you when you integrate over a sufficiently large DE DE and pretty much any astrophysical TV is going to be a sufficiently large DE DE If you're dying. That is actually a particle

422
01:07:13.020 --> 01:07:26.550
thomas rizzo: Okay. On slide 18, could you motivate a little bit more where we get the J factor. I'm afraid I don't see where it comes from, or how it comes in and how it's connected to the previous slide.

423
01:07:32.820 --> 01:07:37.050
Tracy Slatyer: Okay, so. Okay, good. So, I mean, the

424
01:07:38.220 --> 01:07:51.000
Tracy Slatyer: OK, so the point about the J factors here is just as we discussed, you need to J factor in order to set a limit. Okay, you need if you if I want to set a limit on the particle physics of dark matter on this sigma v d amp D.

425
01:07:52.440 --> 01:07:54.870
Tracy Slatyer: That I have been my J factor calculation.

426
01:07:57.480 --> 01:07:59.760
Tracy Slatyer: So if I want to set a limit on the particle physics.

427
01:07:59.790 --> 01:08:05.190
Tracy Slatyer: side of this equation, I need to know what this J factor is what the astrophysics piece is

428
01:08:06.360 --> 01:08:17.100
Tracy Slatyer: So then the question becomes, okay. What if I'm trying to infer information about what signally can I constrain, then one of my uncertainties on this arm astrophysical contribution.

429
01:08:17.940 --> 01:08:27.090
Tracy Slatyer: And I talked about uncertainties in the J factor of the galactic center because we don't know how around how Kospi a halo is but the

430
01:08:27.900 --> 01:08:36.180

Tracy Slatyer: End because we don't have good observational constraints. So for dwarf galaxies. We have some direct observational constraints on what the J factors are

431
01:08:36.480 --> 01:08:45.030
Tracy Slatyer: They come from looking at stars that are orbiting around the dwarf galaxies and using that to try to infer the documented density as a function of position.

432
01:08:45.390 --> 01:08:57.150
Tracy Slatyer: And and then squaring that info dogmatic distribution to to go into the integral of the de facto but the situation he especially for very faint to also the background is very low.

433
01:08:58.320 --> 01:09:07.590
Tracy Slatyer: Which are good targets for that reason is that they usually that on a ton of stars and figuring out which stars exactly which set of stars is associated

434
01:09:07.830 --> 01:09:23.100
Tracy Slatyer: With the wolf and what they are doing is quite a non trivial problem. So you just have you have limited data and you're trying to figure out the full distribution of doc meta within this to a payload that often people

435
01:09:23.160 --> 01:09:23.940
Tracy Slatyer: Sort of take

436
01:09:25.200 --> 01:09:29.430
Tracy Slatyer: In for a central value and infer an error, about which is used to be Gaussian

437
01:09:29.760 --> 01:09:39.900
Tracy Slatyer: What this arm and what our paper recently did was, okay, look, let's try to like really and also this hour, is that all paper was tried said, Okay, let's try to really take into account.

438
01:09:40.260 --> 01:09:48.600
Tracy Slatyer: The so the average people looked at the tails in the prize of the J factor as well as the modeling of the background that comes from

439
01:09:48.600 --> 01:09:50.940
Tracy Slatyer: Just stuff that is on the line of sight between

440

01:09:50.940 --> 01:10:08.820
Tracy Slatyer: Us and the dwarf even if it's not associated with the dwarf itself and and and what else tried looking at using prize to how the documentaries distribution. The tool based on simulations of document of structure formation and and and feeding that into the Stella data.

441
01:10:08.850 --> 01:10:17.370
Tracy Slatyer: To inform and EJ factors, but the dwarfs. And what they found was that in all these cases, it makes a pretty big difference to the constraints that you can go from

442
01:10:17.700 --> 01:10:25.860
Tracy Slatyer: Apparently rolling out the femoral at cross section at 200 GV to only being able to roll out the femoral a cross section of 20 or 30

443
01:10:26.160 --> 01:10:35.700
Tracy Slatyer: Chief eight or in terms of sensitivity between, you know, between this great line and this blue line can be you know getting close to an order of magnitude. So

444
01:10:36.450 --> 01:10:44.550
Tracy Slatyer: It's not multiple orders of magnitude. But again, the point of this slide was just to say, here are the dwarf limits you know they're beautiful. They're robust, but

445
01:10:44.850 --> 01:11:01.140
Tracy Slatyer: If you want to keep one caution in mind about the dwarf limits. It is that the extraction of the J factors which is a key ingredient. And this is I'm a bit challenging, just because the number of trace of particles that we have is stars in this case is pretty small.

446
01:11:03.960 --> 01:11:04.170
Thanks.

447
01:11:05.640 --> 01:11:08.760
dong su: Thomas crazy. I think you unfortunately run out of time.

448
01:11:10.800 --> 01:11:11.640
Tracy Slatyer: I'm happy to

449
01:11:14.430 --> 01:11:21.600
Tracy Slatyer: I'm happy to. I don't have you want to do this you i'm happy if you if you send me the questions, I'm happy to answer other questions by email or to you.

450
01:11:21.600 --> 01:11:26.280
dong su: Know post I will happen will send you the compile the possible the rest of passions, your

451
01:11:27.360 --> 01:11:27.690
Tracy Slatyer: Great.

452
01:11:28.860 --> 01:11:29.160
Okay.

453
01:11:30.540 --> 01:11:30.750
thomas rizzo: Thank

454
01:11:31.170 --> 01:11:31.710
Tracy Slatyer: You very much.

455
01:11:32.010 --> 01:11:35.220
Tracy Slatyer: Thank you very much for the great questions. Everyone

456
01:11:35.280 --> 01:11:40.200
Tracy Slatyer: And I will look forward to reading the others that's green belts and I'll see you all again tomorrow. So talk to

457
01:11:41.970 --> 01:11:42.780
dong su: Okay, thank you.

458
01:11:52.770 --> 01:11:54.150
Tracy Slatyer: Sorry, just trying to figure out