WEBVTT

1
00:00:04.950 --> 00:00:05.640
Tracy Slatyer: I've just been to the

2
00:00:06.240 --> 00:00:07.980
Tracy Slatyer: So I apologize. The

3
00:00:08.340 --> 00:00:12.480
Tracy Slatyer: My speech flows, a little during this but um yeah so

4
00:00:14.340 --> 00:00:15.269
Tracy Slatyer: So let's begin.

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00:00:16.289 --> 00:00:19.980
Tracy Slatyer: So yesterday we talked about indirect searches for

6
00:00:21.150 --> 00:00:26.670
Tracy Slatyer: Photons and neutrinos. We talked about arrangement direct such as and we talked about

7
00:00:27.600 --> 00:00:36.510
Tracy Slatyer: We talked about how to compute a factors we talked about the different targets that you could look at and we talked about the constraints that we currently have from the searches that have actually been done.

8
00:00:37.470 --> 00:00:46.200
Tracy Slatyer: We also then at the end, talked a bit about how cosmic rays propagate through the galaxy. The picture around galaxy as a leaky box within which cosmic rays diffuse

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00:00:46.740 --> 00:00:58.980
Tracy Slatyer: And and gave a very quick sketch of how diffusion and energy losses of cosmic grapes, as they propagate through the galaxy. Change the observable spectrum of cosmic rays from what was injected

10
00:00:59.820 --> 00:01:11.820
Tracy Slatyer: So what I want to do today is first start out doing the thing that I wanted to at the end of last yesterday's lecture but didn't quite get to which is to go from there. To summarize the current limits that we have from cosmic rays, such as

11

00:01:12.930 --> 00:01:23.460
Tracy Slatyer: Then I want to turn to what might be called very indirect detection. Which way instead of looking directly for the annihilation or decay product we search for the

12
00:01:24.000 --> 00:01:27.270
Tracy Slatyer: Effects of those products over the history of the universe.

13
00:01:28.020 --> 00:01:39.150
Tracy Slatyer: So I want to walk through how you can estimate the size of these effects from energy injection from dark matter in the whole universe. And then I want to talk about some of the potential effects on the visible matter and radiation.

14
00:01:39.780 --> 00:01:50.730
Tracy Slatyer: So then we'll again summarize the limits that you can get these constraints and put together the picture of all right, what can what kind of document of scenarios that we currently constraining with indirect detection.

15
00:01:51.810 --> 00:02:03.210
Tracy Slatyer: And then, time permitting, I want to go on and talk about some I just fun stuff, which is the places where we currently have hints of signals that might possibly have something to do with dark matter.

16
00:02:03.510 --> 00:02:16.410
Tracy Slatyer: Now, I mean, I'll give you the caveat in advance that the odds are good that none of these signals are actually coming from Doc nado but it's worth keeping an eye on them as it is possible that one of them, turns out to be something interesting.

17
00:02:18.570 --> 00:02:23.070
Tracy Slatyer: Or, in many cases, they'll suddenly turned out to be something interesting as possible. The one will be connected with Matt.

18
00:02:24.030 --> 00:02:37.770
Tracy Slatyer: But alright so beginning with the continuum from from yesterday. So we talked about how roughly how cosmic rays behavior now galaxy. So now let's look at what limits we can use that to set what searches, people have done for cosmic rays originating from dark matter annihilation or

19
00:02:39.150 --> 00:02:52.110

Tracy Slatyer: So the the sort of leading experiment in the GV plus cosmic ray, such as is am so truth which is on the International Space Station. This is a picture.

20
00:02:53.580 --> 00:02:59.430
Tracy Slatyer: So and so, too, has measured a whole range of cosmic rays. The most abundant cosmic rays of protons.

21
00:03:00.360 --> 00:03:10.560
Tracy Slatyer: And electrons, but you could. They've also measured positrons, and he protons and a number of heavier nuclei and anti nuclei. The heavy and nuclei.

22
00:03:11.190 --> 00:03:17.670
Tracy Slatyer: Can be used to try to set constraints on how particles propagate through the galaxy as we said last time on

23
00:03:18.330 --> 00:03:28.140
Tracy Slatyer: Diffusion and losses modified the cosmic ray spectra that me and that means that secondary particles produced by the interactions of other particles have different spectrum in the primaries.

24
00:03:28.410 --> 00:03:40.860
Tracy Slatyer: There are pairs of cosmic grade nuclei. One is this produced as a secondary from the interactions of the other. And so by comparing this spectrum we can get some information on the propagation of the cosmic rays treat the galaxy.

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00:03:42.060 --> 00:03:52.110
Tracy Slatyer: So, um, but for the dark matter searches the strongest constraints today have generally come from the searches for anti protons and neutrons.

26
00:03:52.710 --> 00:04:01.830
Tracy Slatyer: It's worth noting that when looking at cosmic ray experiments. There's a distinction between experiments which have a magnet and those can be charged discrimination and experiments which not

27
00:04:02.160 --> 00:04:12.570
Tracy Slatyer: And so, too, has a magnet. That's, um, and so it can measure the spectrum of any particles separately from the particles. This makes it a pretty powerful instrument for dogma searches.

28
00:04:13.710 --> 00:04:25.590

Tracy Slatyer: Okay, so here's what the data looks like for am so true for anti protons and positrons, this is an anti pronouns on the left and positrons on the right. These are boys expressed as

29
00:04:26.070 --> 00:04:37.650
Tracy Slatyer: Ratios to the corresponding particles. So on the left, we're looking at the flux of empty protons divided by the flux of protons. And on the right, we're looking at the flux of positrons divided by the flux of positrons plus electrons.

30
00:04:38.670 --> 00:04:40.650
Tracy Slatyer: So this is, um,

31
00:04:41.760 --> 00:04:54.750
Tracy Slatyer: And on the left, you'll also see these bands which are the estimates of the range in theoretical expectations for this ratio varying a number of different parameters from this paper by GIS and that out in 2015

32
00:04:55.980 --> 00:05:02.700
Tracy Slatyer: So what you start a couple of things. The reason to look at ratios is because it cancels out or number of uncertainties.

33
00:05:04.200 --> 00:05:08.160
Tracy Slatyer: In both mental systematics to some degree in propagation

34
00:05:10.110 --> 00:05:29.160
Tracy Slatyer: You see the end the anti print on spectrum, at least in this plot, it looks like the results are pretty much in agreement with the with the modeling, although we'll come back to that later. Because there is a small bump in this MP4 in the latest 20% on data which may be interesting.

35
00:05:30.450 --> 00:05:39.300
Tracy Slatyer: There's as a potential document a signal on the right, the positron spectrum is not a theoretical band. This is because if we did your theoretical band, it would basically look

36
00:05:40.080 --> 00:05:56.190
Tracy Slatyer: Like this, hope you can all see my cousin, as we discussed last time, the expectation is secondaries have a soft disconnect from the primaries and positrons a thought possibly astrophysical background because McRae positrons, is that they're produced when protons interact with the

37

00:05:57.330 --> 00:06:04.890
Tracy Slatyer: interstellar medium and so they produce a secondary so we would expect the ratio to electrons to go down at high energies and as you see it does not do that.

38
00:06:05.760 --> 00:06:12.660
Tracy Slatyer: And that's something that's gotten a lot of interest over the years, but also complicates our ability to set constraint using this data set.

39
00:06:14.580 --> 00:06:15.840
Tracy Slatyer: So I'm

40
00:06:16.980 --> 00:06:29.550
Tracy Slatyer: Nonetheless, so, so there are so that that's the data. So what limits, can we set from them. So, in both cases. What we're going to do is have a model for the background cosmic rays have model for the dark matter injected cosmic rays propagate them.

41
00:06:29.730 --> 00:06:44.280
Tracy Slatyer: Using the methods that we discussed last time by solving a diffusion equation and then look at the expected flux at the neighborhood of the earth. So this point on the left is showing estimates of the limit for annihilation to

42
00:06:45.480 --> 00:06:50.850
Tracy Slatyer: To be the boss. This is a benchmark that we use when looking at the dwarf galaxy constraints, the other day.

43
00:06:51.270 --> 00:06:57.150
Tracy Slatyer: And everything about this blue line is rolled out. This is a measurement using the MS or two antiproton spectrum.

44
00:06:58.050 --> 00:07:07.200
Tracy Slatyer: They and the red line here is the comparison for the dwarf galaxies. You see that the scale that this intersects the

45
00:07:07.950 --> 00:07:24.210
Tracy Slatyer: 76543, you can see that this is the summer elec line is around two to three times 10 to the minus 26 so you see that if taken at face value this constraint can exclude some really cross sections up to masses of almost TV. So this is a very strong constraint.

46
00:07:24.840 --> 00:07:39.810

Tracy Slatyer: However, there are significant uncertainties in these constraints associated with cosmic ray propagation and production as well as instrumental offense, but at face value these if you understand cosmic ray propagation. These bands are potentially extremely sensitive

47
00:07:40.980 --> 00:07:51.840
Tracy Slatyer: The same that is similarly true for dark matter annihilating to leptons. I said last time that if dark matter and eyelids primarily two electrons in museums, then the photon that are produced.

48
00:07:52.950 --> 00:07:56.610
Tracy Slatyer: By radiative persistence by final state radiation and so on.

49
00:07:57.030 --> 00:08:11.700
Tracy Slatyer: A sub dominant and so they tend to those channels tend to be less constrained. This is how you constrain them, you go look for the electrons directly either the electrons produced by dark matter and I elation Oba decays nuance and it Mulan see such electrons and positrons

50
00:08:13.050 --> 00:08:22.590
Tracy Slatyer: And that allows you to set a limit, like this. This paper. So again, everything above the line is drill down and green band is an estimate of theoretical uncertainties.

51
00:08:23.010 --> 00:08:39.180
Tracy Slatyer: And you see that the claim is that for the electron final state. You can allow the femoral cross section up to a bit more than 100 GB which is significantly stronger than what you can do with any of the gallery constraints that I showed you last time, at least under conservative assumptions.

52
00:08:40.620 --> 00:08:48.090
Tracy Slatyer: So, and this green, of course, the concern is this green thing captures a lot of systematic uncertainties. The question is, have you fully bracket with them.

53
00:08:49.170 --> 00:08:56.610
Tracy Slatyer: But these constraints systematic uncertainties and propagation, but I'm potentially huge amount of sensitivity.

54
00:08:58.050 --> 00:09:10.320
Tracy Slatyer: So that's the story at higher and higher masses am so true can measure cosmic rays down to about the GV scale below the GV scale we run into an issue that we live in a solar system.

55
00:09:10.680 --> 00:09:18.180
Tracy Slatyer: And the solar wind deflect low energy cosmic rays from us. This makes it both harder to do theoretical predictions, because you have to model the effect of the sun.

56
00:09:19.230 --> 00:09:28.500
Tracy Slatyer: And it just makes it harder to see a signal. So it turns out that for sub GV cosmic rays. It turns out that the leading limits actually come from Voyager

57
00:09:29.010 --> 00:09:35.550
Tracy Slatyer: Which was quite surprising to me when I found out about it, especially as I've been working on limits in the strange and I was very happy with my

58
00:09:35.880 --> 00:09:41.640
Tracy Slatyer: World best limits and then somebody else without a paper that pointed out that we got beaten by a 1970s spacecraft

59
00:09:42.210 --> 00:09:49.830
Tracy Slatyer: So the reason that this is the Voyager one has a spectrometer that's capable of measuring low energy cosmic rays and Voyager one is now out beyond the helium oppose

60
00:09:50.490 --> 00:09:58.590
Tracy Slatyer: Which means that it can measure the interstellar cosmic spectrum and I connected the low energy cosmic rays before they get deflected by the sun.

61
00:09:59.760 --> 00:10:13.620
Tracy Slatyer: So the Voyager. This is a picture of Voyager it's still sending back data and it sets the best limits on dark matter between about the 10 me the scale and the GV scale if it decays two electrons and positrons

62
00:10:14.670 --> 00:10:24.300
Tracy Slatyer: It also says pretty stringent limits. If it, if it annihilate but we'll see that if that annihilation is independent of velocity, you can get better limits from the

63
00:10:24.780 --> 00:10:29.790
Tracy Slatyer: Us and we're going to talk about that next. But if the annihilation is very suppressed. A little the loss of these

64

00:10:30.360 --> 00:10:45.240
Tracy Slatyer: As will present in the universe. And these voyage limits are the strongest. So this is what I'm the Voyager bounds look like what different channels. So the solid lines here are the voyage of bounds. The thin lines of am so to

65
00:10:46.350 --> 00:10:56.130
Tracy Slatyer: Constraints left panel is for annihilating dark matter and the right panel is for decaying dark metal. So, you see that the MS so true constraints cut off.

66
00:10:56.640 --> 00:11:13.440
Tracy Slatyer: very sharply below about a GV but then Voyager takes over and can essentially roll out the test the thermal relic cross section and tests to K lifetimes around 10 to the 26 to 10 and 27 seconds, all the way down to document a mass of 10 Nev

67
00:11:15.330 --> 00:11:24.870
Tracy Slatyer: Okay, so that's the zero total picture of cosmic ray constraints. There are other instruments look doing cosmic ray measurements such as DMP and kelut

68
00:11:25.140 --> 00:11:41.130
Tracy Slatyer: Both provided nice recent measurements of the total cosmic ray like from plus positron spectrum, however dumpy and Kelly do not have the charge discrimination capabilities of am so true, which makes it challenging for them to do competitive constraints on dark matter annihilation.

69
00:11:42.720 --> 00:11:49.020
Tracy Slatyer: Okay, so that's what I wanted to say about cosmic ray. So just for the moment we'll circle back to it later when we talk about possible accesses

70
00:11:49.590 --> 00:11:57.120
Tracy Slatyer: But now let me move on to another class of constraints, where we're not looking for the particles from annihilation or decay directly, but we're

71
00:11:57.510 --> 00:12:11.610
Tracy Slatyer: exploiting the fact that if the sky annihilation of decay versus is happening, then they will have been most likely a steady trickle of energy from the mass stored in the doc meta into the Standard Model particles over the universe's whole history.

72
00:12:12.660 --> 00:12:20.400

Tracy Slatyer: So, for example, the presence of such particles. They can heat up the gas. They can ionized hydrogen gas. They can

73
00:12:21.900 --> 00:12:28.050
Tracy Slatyer: They can, they can add extra heat to the cosmic microwave background radiation and consequently distort it spectrum.

74
00:12:29.070 --> 00:12:40.230
Tracy Slatyer: So these only universe limits have the advantage that often they do not. They say, Well, generally not care about stuff like modeling the magnetic field around galaxy which is important because me Craig propagation

75
00:12:40.530 --> 00:12:47.460
Tracy Slatyer: If you look at early enough in the universe. They you may be able to make to say to a good approximation that the universe is homogeneous and

76
00:12:47.970 --> 00:12:56.430
Tracy Slatyer: The universe is fully homogeneous. There are no galaxies know stabs know clumps of document. Oh, so you can eliminate a lot of astrophysical uncertainties.

77
00:12:56.790 --> 00:13:06.180
Tracy Slatyer: By looking at these since you know we universe observations. The question of courses. So how do you tell what the universe was doing average of 10 or 15,000

78
00:13:08.040 --> 00:13:14.580
Tracy Slatyer: Okay. So let me first talk about the constraints that you can get from looking at dogmatic ionizing the hydrogen gas.

79
00:13:15.150 --> 00:13:24.540
Tracy Slatyer: So between a little cosmological history first between read tips of 10 hundred thousand. So when the universe was linearly, a factor of 10 to 1000 smaller than this today.

80
00:13:24.990 --> 00:13:27.870
Tracy Slatyer: The universe went through a phase where it was almost completely neutral.

81
00:13:28.650 --> 00:13:38.430
Tracy Slatyer: Which is called the cosmic Dark Ages. So this is after the cosmic microwave background was admitted the universe went from being

almost totally ionized almost totally neutral, but before the stars turned on.

82
00:13:38.700 --> 00:13:50.580
Tracy Slatyer: And produced ionizing radiation that reorganize the of us. So they'll see the photons of the cosmic microwave background stream to us through these cosmic Dark Ages. They were admitted at this edits beginning

83
00:13:52.110 --> 00:14:01.320
Tracy Slatyer: So they have to pass through the cosmic Dark Ages to get to us. That means that any free electrons produced during the cosmic Dark Ages act like a screen for those CMT photons.

84
00:14:01.680 --> 00:14:07.200
Tracy Slatyer: So if there is of course is going on the causes the hydrogen gas to be somewhat more ionized than it otherwise would.

85
00:14:07.410 --> 00:14:18.360
Tracy Slatyer: The CB actually gives us a very sensitive prob of small changes to the ionization history jury and hence of exotic enhance of energy injections that could I, and I guess during the Dark Ages period.

86
00:14:18.990 --> 00:14:25.170
Tracy Slatyer: So let's do a back of the envelope customer support is limited and I'm this is just going to be an energy document.

87
00:14:25.590 --> 00:14:37.770
Tracy Slatyer: Suppose I look at how much power that is in annihilating doc metal. And I want to know what fraction of dark matter what I need to annihilate to to ionized a significant fraction of the hyphen, the universe.

88
00:14:38.880 --> 00:14:45.930
Tracy Slatyer: So let's first ask, you know, if I were annihilating the hydrogen in the universe. How much would I need to iron eyes, how much would I need to annihilate

89
00:14:46.200 --> 00:14:59.520
Tracy Slatyer: To ionized hydrogen, the US. So that's just a matter of comparing the massive hydrogen to assign ization energy mass of the hydrogen atom is about one GB the ionization energy is 13.6 DB. So if I would have annihilate

90
00:14:59.940 --> 00:15:15.480

Tracy Slatyer: One hydrogen atom intend to the eight that would be enough energy to ionized all that hydrating the US, this will turn out is why this an ionization constraint is strong because you get to take advantage of this lodge hierarchy between the mass and the ionization energy.

91
00:15:16.650 --> 00:15:26.130
Tracy Slatyer: So, okay. So, but, of course, went on and I wait and hydrogen were annihilating the document. But this five times five or six times as much documentaries and hydrogen is there is by mass

92
00:15:26.700 --> 00:15:37.170
Tracy Slatyer: So what that tells us is that if wanting tend to the nine document of particles annihilate or the case away that provides enough power to iron is hot. The hydrogen in the universe. So

93
00:15:37.740 --> 00:15:47.280
Tracy Slatyer: And I'll just tell you in advance that the current level of cosmic microwave background observations we can constrain changes to the ionization fraction of hydrogen

94
00:15:47.640 --> 00:16:04.020
Tracy Slatyer: At the level of a few times 10 to the minus four, during the cosmic Dark Ages. So this is suggested that we have at least the potential to constrain annihilation at the level of one dot annihilation will decay at the level of one dogmatic particle in a trillion during this eBook.

95
00:16:06.450 --> 00:16:14.550
Tracy Slatyer: Okay, so find one in a trillion. But how does that actually compare to the annihilation and decay rates that were talking about, you might say, well, you know, maybe, maybe

96
00:16:14.880 --> 00:16:23.490
Tracy Slatyer: Double and annihilating doc meta only one in 10 to the 20 dogmatic particles is annihilating during this talk. So then there would be no constraints.

97
00:16:24.750 --> 00:16:31.470
Tracy Slatyer: So we can do a quick back of the envelope customer to figure out what this ratio should be. But some will annihilating documented.

98
00:16:32.520 --> 00:16:43.650
Tracy Slatyer: So let's ask what is the fraction of Dr Matta the nights and a Hubble time but thermal doc matter off to it freezes out. So the rate of

99
00:16:45.240 --> 00:16:54.030
Tracy Slatyer: So this rate is just the annihilation rate which is so the fraction of document of annihilate per unit time, which is enticing movie.

100
00:16:55.110 --> 00:16:57.390
Tracy Slatyer: Multiplied by the

101
00:16:59.520 --> 00:17:00.000
Tracy Slatyer: But

102
00:17:01.800 --> 00:17:08.790
Tracy Slatyer: Multiplied by the Hubble time. Sorry. I think my slide maybe need to an h to the minus one in here.

103
00:17:10.200 --> 00:17:15.270
Tracy Slatyer: So yeah, this, this should be, ah, the minus one. Sorry, I will fix it in the slides after the talk.

104
00:17:16.770 --> 00:17:26.880
Tracy Slatyer: So okay, so that's the ratio that we so that's the ratio that we want to look at. So just say this. Again, this is just a fraction annihilate per unit time multiplied by a whole time.

105
00:17:27.930 --> 00:17:42.990
Tracy Slatyer: So during radio during the radiation donate to the park. Ah skills like t squared for the implant. So it'd be important bit of the scaling. There is t squared. And the number density of doc meta scales like t cubed.

106
00:17:44.100 --> 00:17:57.690
Tracy Slatyer: So what this gives us is that this fraction of dogma as annihilate for Hubble time is going to scale like t cubed over t squared. So it scale. So it scales roughly proportionally to T. If the cross section doesn't depend on magic.

107
00:17:59.730 --> 00:18:08.490
Tracy Slatyer: But, um, but at freeze out this ratio. Again, I think this should be this should be a minus one, I'm

108
00:18:09.120 --> 00:18:14.700
Tracy Slatyer: At freeze out this ratio is approximately equal to one. That's what defines freeze out. That's when the

109
00:18:15.000 --> 00:18:24.000
Tracy Slatyer: number density of document of stops changing rapidly from annihilation. So this fraction of documented annihilate bubble time becomes an older one number at freeze out

110
00:18:24.360 --> 00:18:36.060
Tracy Slatyer: So that tells you that during radiation domination. But after freeze out the fraction of document of the Nile is palpable time thermal Documenta is approximately going to be the temperature that later time, divided by the temperature freaks out

111
00:18:36.600 --> 00:18:41.700
Tracy Slatyer: first bullet point here tells you the scaling is one parity second bullet point just tells you how to normalize it.

112
00:18:43.080 --> 00:18:49.740
Tracy Slatyer: So that tells us that. So, suppose I had so many documented it freezes out at 100 Nev

113
00:18:51.660 --> 00:18:56.820
Tracy Slatyer: This cosmic microwave background is admitted at a temperature for about 4.1 TV.

114
00:18:57.300 --> 00:19:07.470
Tracy Slatyer: So that would give us a week. So, and most of that period from freeze out to recombination is during radiation domination. So these approximations will not be terrible.

115
00:19:08.100 --> 00:19:17.940
Tracy Slatyer: So this tells us that the level, the time of that if one in a billion document of particles what to annihilate the Hubble time which recall is what we said you needed to

116
00:19:18.990 --> 00:19:33.030
Tracy Slatyer: I and I have the hydrogen in the universe that corresponds more or less to somewhere else document of that, for example, 100 MVP. And if you freeze out earlier so of TF is larger, the sequel is smaller. If TF is smaller than the signal is launched them.

117
00:19:34.500 --> 00:19:41.880
Tracy Slatyer: So okay, so priests out of 100 I mean be, I don't know if you heard this in Professor Tate's lecture but freeze out typically happens in about a 10th.

118
00:19:42.240 --> 00:19:49.830
Tracy Slatyer: Of the mass of the document as one 20th of the mass of the doc map. So this would correspond to about to GV thermal doc.

119
00:19:50.520 --> 00:20:02.700
Tracy Slatyer: So what we've just said is, if we had to TV somewhere elec annihilating doc meta that's enough power being injected during the cosmic Dark Ages to iron is hot. The hydrogen us. That's a really, really big signal.

120
00:20:03.540 --> 00:20:15.240
Tracy Slatyer: If we think that we can actually constrain modifications, the ionization history 1000 times smaller than that, that suggests that we should be able to test order TV somewhere like doc. Now with this method.

121
00:20:16.290 --> 00:20:22.740
Tracy Slatyer: Now of course there are some big assumptions here. I assume that 100% of the power goes into ionization, that's not going to be true.

122
00:20:23.040 --> 00:20:31.710
Tracy Slatyer: In detail. So as you will see the answer ends up being weakened strict constrained more like 10 to 100 GB thermal dogma, but this is still a pretty powerful construct

123
00:20:33.090 --> 00:20:46.650
Tracy Slatyer: So here are the actual results. So doing the calculation in detail requires working out how when you inject high energy particles into the universe today cool down and lose the energy and what fraction of that power goes into ionization versus other things.

124
00:20:47.610 --> 00:20:58.650
Tracy Slatyer: I did this in a paper in 2016 which has large transfer functions available online that you can just download which will tell you if I inject a particle at some time.

125
00:20:59.310 --> 00:21:07.650
Tracy Slatyer: Then, how much of its power goes into the various channels as a function of time. There's also a new Python code called doc history that my students and I built

126
00:21:08.220 --> 00:21:15.990

Tracy Slatyer: We wrote a paper about it last year at and that will do this calculation for you in a way that is that works down to lower redshift.

127
00:21:16.770 --> 00:21:29.670
Tracy Slatyer: But, um, but, so just take my word for it. The moment that you can do this calculation in detail. So when you do this, you can put in the efficiency factor that tells you how much of your power actually goes into ionization, which is what you need to set strong limits.

128
00:21:30.840 --> 00:21:39.480
Tracy Slatyer: This is the result that you get for Annihilation. So, again, everything above the lines is ruled out by the, by observations of the CME be using with the plank satellite

129
00:21:40.200 --> 00:21:49.320
Tracy Slatyer: The, the different colored lines correspond to different standard model final states. The red line and the pink lines are annihilation directly to electrons and positron sort of photons.

130
00:21:49.590 --> 00:21:56.460
Tracy Slatyer: And then this band is every other standard more final state except neutrinos. There's also a constraint on neutrinos, but it's kind of up to

131
00:21:57.510 --> 00:22:09.210
Tracy Slatyer: The top of the wall so I'm the summer le client is this black dashed line and you can see that for electrons and protons. This excludes somewhere else documented below about

132
00:22:09.570 --> 00:22:15.690
Tracy Slatyer: 20 to 30 GB and for other channels that excludes it below somewhere in the ballpark of 10 GB

133
00:22:16.110 --> 00:22:24.570
Tracy Slatyer: And these lines just continue down with pretty much the slope almost same slope almost unchanged down to kV Dr Matta masses.

134
00:22:24.810 --> 00:22:39.030
Tracy Slatyer: With these are essentially color metric limits. They don't care very much about the spectrum particles that you're producing it basically just measuring total power into ionization, you can do the same exercise but decaying doc motto evaporating primordial black holes.

135
00:22:40.410 --> 00:22:51.060

Tracy Slatyer: What you find for for a decaying dark matter what you find is that if the decaying documented directly produces photons, then that's usually a stronger constraint.

136
00:22:51.540 --> 00:23:13.650
Tracy Slatyer: If it produces electrons in the energy range that Voyager can see then the Voyager Voyager MS can see then those constraints also usually stronger. But, um, for the but but for decay to electrons in a range where Voyager cannot see the signal. These are the strongest bounds that we have

137
00:23:15.090 --> 00:23:25.650
Tracy Slatyer: So this point on the left is just comparing to some of the decay constraints that we looked at last time from a range of photon telescopes looking for dogmatic came to electrons in the galactic halo

138
00:23:26.880 --> 00:23:41.430
Tracy Slatyer: These lines to the results for all those other telescopes. The black dog with the black process show the result from a single analysis of CMA data. So you can see the CMT is stronger than all of these bands, although if I put voyage on this plot those constraints would start

139
00:23:42.570 --> 00:23:46.170
Tracy Slatyer: At about 10 MTV and would be stronger at these high masses.

140
00:23:47.040 --> 00:23:57.030
Tracy Slatyer: The other thing that the CMU limits on the case do is they allow us that they allow us to constrain the possibility that there was another dogmatic component that decade away indivisible particles between

141
00:23:57.840 --> 00:24:07.950
Tracy Slatyer: The, the CMT epoch and the present day, we can say, for example, that if there was a species with a lifetime of around 10 to the 14 seconds, which means it decades to not business end was produced

142
00:24:08.250 --> 00:24:17.730
Tracy Slatyer: Then it had to have an abundance in mass that was less than 10 to the minus 11 of the document or abundance today so you can sit very stringent constraints in that case.

143
00:24:19.230 --> 00:24:29.430
Tracy Slatyer: I should know you know as especially for annihilation there a bit. Also if indicator of course ways to have a these

constraints. If you declare an elite to neutrinos, the bounds get much weaker.

144
00:24:29.700 --> 00:24:36.870
Tracy Slatyer: And go away completely, except for other high mass dark matter if the annihilation doesn't happen at late times because

145
00:24:37.170 --> 00:24:45.210
Tracy Slatyer: The dark metal was annihilating against another particle which is not presently universe, then that will stop these constraints as well as many other indirect detection constraints.

146
00:24:45.690 --> 00:24:54.930
Tracy Slatyer: And if the annihilation is suppressed upload velocities during the cosmic Dark Ages, the dark matter is pretty cold and slow moving it is expected to be

147
00:24:55.230 --> 00:25:02.640
Tracy Slatyer: At. And so consequently that could also suppress the sequel quite a lot, but for the simplest them were like scenarios. These CSV constraints are very powerful.

148
00:25:04.440 --> 00:25:12.810
Tracy Slatyer: Now we can look at other so I've just talked about. I and I station so far, but we can look at other possible effects on the universe as well. We've said that he wanted the ability

149
00:25:13.290 --> 00:25:23.850
Tracy Slatyer: To particles annihilated. It could is half the universe. So let's look at what that similar kind of energy and Jake do in terms of heating the universe or distorting the black body spectrum of the cosmic microwave background.

150
00:25:25.830 --> 00:25:37.800
Tracy Slatyer: So let's look a spectral distortion of the CSV file. So here, the idea is you're injecting extra photons into the universe as the son lives in equilibrate with the cosmic microwave background, what do we expect that to do to the spectrum to see me.

151
00:25:38.610 --> 00:25:47.130
Tracy Slatyer: So here's the answer. So here you can, you can, as a first glance, just look at, okay, how much can we energy are we injecting compared to the energy density in the CSV.

152
00:25:47.550 --> 00:25:53.790

Tracy Slatyer: Because the level at which we can constrain spiteful the solutions is about 10 to the minus five of the total energy in the end.

153
00:25:54.360 --> 00:26:07.890
Tracy Slatyer: So the radiation and Matta energy densities will equal but redshift to 3000 and the ratio scales, just as one power of redshift. So in the present data radiation is sub dominant to the democratic component in energy density by about a factor of 3000

154
00:26:08.970 --> 00:26:20.640
Tracy Slatyer: Um, so that tells us that if one in a billion fraction of the document of mass energy is liberated, then at the very most, that can distort the CME be at the level of one intended to six or less.

155
00:26:21.150 --> 00:26:31.140
Tracy Slatyer: Um, so, and remember, this was a case that is a honking great signal and I am a station. It's like extremely excluded if we injected this much power you and I and I have the universe.

156
00:26:31.530 --> 00:26:38.430
Tracy Slatyer: Um, so what this whereas in the CSV. It's a signal that is currently on observable. So what this tells us is, you know,

157
00:26:38.940 --> 00:26:45.330
Tracy Slatyer: If there's both and I integration signal and a CMT spectral distortion signal the ionization signal will usually be a lot easier to look for

158
00:26:46.260 --> 00:26:53.220
Tracy Slatyer: That said, there are cases where there's no ionization signal only a CNBC social distortion signal and those cases in those cases, it can be very powerful.

159
00:26:54.810 --> 00:26:57.060
Tracy Slatyer: So what about changes to the temperature of the gas.

160
00:26:57.420 --> 00:27:06.000
Tracy Slatyer: So a little bit more cosmological history. I've read your tire than 200 the cosmic microwave background and the ordinary meta a tightly coupled to each other in temperature.

161
00:27:06.240 --> 00:27:12.360
Tracy Slatyer: Just Judah photon scattering of electrons. So that means that if you try to heat up the matter, you have to also heat up the CMT

162
00:27:12.840 --> 00:27:26.190
Tracy Slatyer: And the CME is a huge heat sink because it has so much energy stored in it. So then we get back to the same argument is respectful distortion and you can change the overall temperature by a factor of 10 to the minus six, but by one plus 10 to the minus six.

163
00:27:27.330 --> 00:27:37.290
Tracy Slatyer: So, um, but they just below 200 the gas temperature decoupled from the CMT temperature and then you can eat the gas without worrying about heating up the CSV.

164
00:27:38.490 --> 00:27:48.510
Tracy Slatyer: Since the barrier number density is nine orders of magnitude smaller than the CMT number density average use less than 200 the heat injection from the document is split among a much smaller number of particles.

165
00:27:49.020 --> 00:27:57.120
Tracy Slatyer: So again picking this benchmark. If we look at a one in a billion fraction of the document a mess energy being liberated. That's about

166
00:27:57.750 --> 00:28:16.320
Tracy Slatyer: That's about five dB of energy for every barium in the universe five up of energy corresponds to about a 50,000 Kelvin increase in temperature, a hydrogen. So again, this is a pretty big signal if we heat it up the entire universe by 50,000 Kelvin, then

167
00:28:17.400 --> 00:28:21.210
Tracy Slatyer: Leon, you know that that would potentially be a pretty big effect.

168
00:28:23.550 --> 00:28:34.230
Tracy Slatyer: So. So just to summarize those the CMT spectral distortion is a good way to probe physics that happens before the cosmic dark ages when the universe was fully ionized and adding extra ionization isn't going to do anything.

169
00:28:34.890 --> 00:28:45.270
Tracy Slatyer: Or processes that just don't transfer enough energy to ionized the guests, such as scattering of Dr Matta office particles. The CNBC spectral distortion conserve as appropriate that

170
00:28:46.770 --> 00:28:52.830

Tracy Slatyer: The guest temperature. The CMT is not very sensitive to that. But if we can measure the temperature of the gas that little red shift.

171
00:28:53.160 --> 00:28:59.820
Tracy Slatyer: Then we could potentially get pretty substantial heating effects from document or annihilation. Okay, so

172
00:29:00.810 --> 00:29:04.080
Tracy Slatyer: Let's follow that up. How do we measure the gas temperature at light times

173
00:29:04.560 --> 00:29:14.760
Tracy Slatyer: So one thing that we can do is we can look at atomic transmission lines and, in particular, there's a big experimental program to try to measure the 2170 to spin flip transition and mutual hydrogen in the US.

174
00:29:15.390 --> 00:29:29.670
Tracy Slatyer: So the picture here is that the universe is illuminated by the cosmic microwave background and as the C NB passes through the neutral hydrogen it we can get either emission lines or absorption lines.

175
00:29:30.750 --> 00:29:34.380
Tracy Slatyer: As the hydrogen gas is excited and D excited

176
00:29:35.430 --> 00:29:39.030
Tracy Slatyer: Out of the between these two spin configurations

177
00:29:40.560 --> 00:29:54.060
Tracy Slatyer: So now, of course, those admission absorption lines if that if they are produced at some redshift been their energy will read shift to the present day. So what we'll see in the present day is not a sharp line that is smeared out for our structure.

178
00:29:55.530 --> 00:30:04.080
Tracy Slatyer: So what controls the strength of this 21 centimeter signal we can talk about it in the in terms of a spin temperature, which basically just says how much

179
00:30:04.920 --> 00:30:12.630
Tracy Slatyer: Of the hydrogen is in the ground state of this transition versus the excited state, which just correspond to whether the electrons and protons fins are aligned or anti aligned

180
00:30:13.440 --> 00:30:24.240
Tracy Slatyer: So TS just means the temperature at which the observed ratio is what you would get from a gas in Evelyn at in equilibrium with this at that temperature

181
00:30:25.110 --> 00:30:38.730
Tracy Slatyer: So what that means is that if there's a lot of hydrogen in the excited state and the spin temperature is high. And if there's a lot of high fruit in the ground state, then the spin temperature is is low.

182
00:30:39.810 --> 00:30:56.910
Tracy Slatyer: So if the spin temperature is higher than the ambient radiation temperature. That means that there are more particles in the excited state, then you would expect from will pop. Sorry, more particles in the United States, and you would expect from

183
00:30:57.960 --> 00:31:06.810
Tracy Slatyer: The temperature of the of the photon field. And so consequently we see a lot of the excitation and we expect to see emission lines in the spectrum.

184
00:31:07.140 --> 00:31:16.560
Tracy Slatyer: If it's the other way around. If the temperature is lower than the radiation temperature, then there's a lot of hydrogen. The ground state compared to what you would expect from a full everyone with radiation. And so we would seem that absorption

185
00:31:17.160 --> 00:31:28.380
Tracy Slatyer: So this is the, this equation describes the 21 centimeter brightness temperature that we can look for. And you can see that there's this factor of one minus the radiation temperature divided by the same temperature

186
00:31:29.490 --> 00:31:36.780
Tracy Slatyer: So if we asked what we expect this signal to look like in the standard cosmology is a platform Valdez at all in 2017. This is the

187
00:31:37.380 --> 00:31:44.250
Tracy Slatyer: This is the brightness temperature difference red and orange means and negative value. So I met absorption and blue means and that emission value.

188
00:31:45.060 --> 00:31:48.690
Tracy Slatyer: So what's going on here is that when the first stars tunnel on that.

189
00:31:49.080 --> 00:32:01.410
Tracy Slatyer: They produce Lyman alpha photons which can efficiently couple of Sprint temperature to the actual physical temperature of the hydrogen gas. So now if we can measure the brightness temperature, which means measuring the skin temperature, then we can measure the hydrogen gas temperature

190
00:32:03.540 --> 00:32:08.010
Tracy Slatyer: So our expectation is that initially the hydrogen gas should be cooler than the CMT

191
00:32:08.340 --> 00:32:17.850
Tracy Slatyer: And that's basically because if we didn't have any stuff this one on the right shows what the temperature of the gas would look like compared to the sea and be that the same down to about redshift 200 but then

192
00:32:18.690 --> 00:32:28.860
Tracy Slatyer: They go, cool independently and non relativistic particles cool faster than relativistic particles and expanding us so we expect the gas to start out colder than the CMT

193
00:32:29.550 --> 00:32:38.310
Tracy Slatyer: But when the stars turned on. But then the stars also produce photons which heat up the gas. And so then at some point we expect the abortion say go to transition into animation signal.

194
00:32:38.910 --> 00:32:43.860
Tracy Slatyer: So possible signature of dark matter annihilation would be that we got an admission signal early on.

195
00:32:44.850 --> 00:32:50.610
Tracy Slatyer: In the period where you would normally expect absorption because the gas is getting heated to a level that's higher than this end.

196
00:32:51.330 --> 00:32:57.390
Tracy Slatyer: There are a number of current and future experiments and telescopes attempting to search for this 21 centimeter signal.

197
00:32:58.110 --> 00:33:08.430
Tracy Slatyer: There is a claim of the measurement from the edges telescope which would be really interesting is true. I'm not going to talk about that. But, you know, feel free to ask and follow up questions.

198
00:33:08.820 --> 00:33:20.730
Tracy Slatyer: If you want, but this is you know definitely something to keep an eye on over the next few years, because this would allow us potentially to do a measurement of guests temperature of the universe from some flight wrench in the range from like redshift 10 to 30

199
00:33:22.260 --> 00:33:22.560
Tracy Slatyer: Okay.

200
00:33:23.880 --> 00:33:24.630
Tracy Slatyer: So,

201
00:33:25.680 --> 00:33:29.730
Tracy Slatyer: So good. So that's one way. That's a forward looking way to measure the temperature

202
00:33:30.300 --> 00:33:36.870
Tracy Slatyer: Another way to measure the temperature, though, is to look at which we can do today is look at what's called the linemen alpha forest.

203
00:33:37.140 --> 00:33:43.710
Tracy Slatyer: To the 21 centimeter radiation signal requires you to have neutral hydrogen. When the university country ionized it lightly goes away.

204
00:33:44.580 --> 00:33:53.310
Tracy Slatyer: But after annotations mostly complete. They're so proud of you for hydrogen, the universe and like passing through these clouds produces absorption features in the spectrum.

205
00:33:53.670 --> 00:34:02.910
Tracy Slatyer: We can look at those absorption features and use them to map out the distribution of financial hydrogen clouds as a function of Reggie, and that's what the I'm an alpha forest and this

206
00:34:03.450 --> 00:34:14.130
Tracy Slatyer: These measurements have also been used to constrain won't matter to constrain the distribution of dark matter in the sky, but they also give us a measurement of just what is the gas temperature of the baryons

207
00:34:15.060 --> 00:34:21.810

Tracy Slatyer: As a function of time. So these two recent papers tried to do a try to use these Lyman alpha data.

208
00:34:22.170 --> 00:34:30.420
Tracy Slatyer: high in comparison with simulations to do a measurement of the temperature of the universe. So, Y axis here is the temperature of the universe in units of 10 to the full Kelton

209
00:34:30.660 --> 00:34:38.220
Tracy Slatyer: As a function of redshift. So the 21 centimeter. We were looking at. So great shifts tend to 30 now we're looking at much lower redshift read shifts of two to six.

210
00:34:38.730 --> 00:34:42.720
Tracy Slatyer: But we actually have data points here, which is which is very nice.

211
00:34:43.590 --> 00:34:59.580
Tracy Slatyer: So we can using this Python package doc history. Take our favorite classes documented decaying and annihilating models and figure out how that energy injection would change the temperature history of the universe and competitive these data points.

212
00:35:01.290 --> 00:35:09.480
Tracy Slatyer: So I did this in a paper that we put out like just a few weeks ago with my students when the queen and Greg, which was spiritually and my former student home on leave

213
00:35:10.170 --> 00:35:18.120
Tracy Slatyer: And this is what the, this is what the bounds look like. So this is on this on the king focus on this one. This is on decaying dark matter.

214
00:35:19.770 --> 00:35:28.080
Tracy Slatyer: Is the minimum lifetime based black line is the CME constraint on decaying dark matter that I showed you earlier. This dotted pink line is a voyage of constraint.

215
00:35:28.470 --> 00:35:35.010
Tracy Slatyer: I was mentioning earlier and then it higher energies. A MS comes in and the blue and red lines show

216
00:35:35.430 --> 00:35:48.000
Tracy Slatyer: The constraints from these temperature measurements at varying levels of consultants. So the blue line is the most conservative

treatment. And then as you allow for more astrophysical heating, we move up through these red and orange bands.

217
00:35:49.260 --> 00:35:55.740
Tracy Slatyer: The blue line is literally assuming that there is no astrophysical heating and the only source of heat in the universe is dark matter, which is probably quite realistic.

218
00:35:56.340 --> 00:36:03.060
Tracy Slatyer: So you can see that again down in this low mass range. These heating constraints can be pretty powerful can be stronger than the CMT

219
00:36:04.440 --> 00:36:16.890
Tracy Slatyer: And we can do the same thing. Similarly for velocity suppressed annihilation. I'd like times so heating on us ionization limits end up landing in around the same place for

220
00:36:18.060 --> 00:36:18.780
Tracy Slatyer: It for decades.

221
00:36:21.450 --> 00:36:37.800
Tracy Slatyer: Now what could we do with 21 centimeter with 21 centimeter, we could do a lot better if you consider a hypothetical 21 centimeter measurement that has a that finds a 21 centimeter value that is broadly consistent with the with with the standard model.

222
00:36:38.850 --> 00:36:44.250
Tracy Slatyer: Then we can estimate what we can estimate what limits we would be able to get

223
00:36:45.000 --> 00:36:53.880
Tracy Slatyer: With dark history. So this is assuming, like an order one uncertainty. If the expectation from the standard model is 10 Kelvin for the temperature average of 17

224
00:36:54.240 --> 00:37:00.300
Tracy Slatyer: Then you assume that your upper limit is going to be somewhere in that ballpark or not especially close to the Standard Model value.

225
00:37:01.560 --> 00:37:16.740
Tracy Slatyer: We computed the resulting limits for this using this code package dark history and the limits on light, dark matter decaying into

electrons could improve by two orders of magnitude with if we had this kind of detection. So

226
00:37:17.460 --> 00:37:24.390
Tracy Slatyer: We don't have this yet, unless you believe the edges result if you do believe the interest results and indeed the limit on became dogmatic can

227
00:37:24.660 --> 00:37:28.590
Tracy Slatyer: Get better by a couple of orders of magnitude in this mass range or bit with couple of caveats.

228
00:37:29.190 --> 00:37:37.050
Tracy Slatyer: Um, but, you know, optimistically, we could also hope that a future 21 centimeter experiment could see a strong heating signal.

229
00:37:37.920 --> 00:37:52.110
Tracy Slatyer: To close the methods that are currently rolled out who does it cross section decay rates that a 1% of what we are currently testing could still be visible in 21 centimeter observations. So this is a future direction to keep an eye on.

230
00:37:53.160 --> 00:37:57.600
Tracy Slatyer: So if we put all this together. I'm going to just focus on annihilation. For this example.

231
00:37:57.870 --> 00:38:05.820
Tracy Slatyer: If we put all this together and look at annihilation, so choose. And just asked. Okay, let's take the simplest one more Alex in our lives, as you know, the last the dependence in the cross section.

232
00:38:06.180 --> 00:38:12.030
Tracy Slatyer: Let's look at all possible standard line model final states, although I'm going to sit neutrinos aside for the moment, because that haha

233
00:38:12.810 --> 00:38:21.540
Tracy Slatyer: But let's assume that when not unlucky in the document. It doesn't have a huge doesn't have 100% branching ratio into neutrinos. Then what kind of women's can we set

234
00:38:22.590 --> 00:38:33.390
Tracy Slatyer: Then this green line shows the winner on the summer La Crosse section after marginalizing over step possible final state. So at every mass we take the least constrained final state.

235
00:38:34.710 --> 00:38:39.990
Tracy Slatyer: And what you see then is essentially that the case to

236
00:38:40.830 --> 00:38:48.120
Tracy Slatyer: final state to either had chronic final state or final stages of themselves have had chronic decays put you through to pilot, which in turn yield photons.

237
00:38:48.420 --> 00:39:02.070
Tracy Slatyer: And those photons searches are efficient at constraining most of the Standard Model final states the exceptions electrons and positrons ambulance and antibiotics can be efficiently tested by am so true. So at these at these higher messes. The

238
00:39:03.240 --> 00:39:14.130
Tracy Slatyer: Put me in a MS constraints contest. Pretty much any standard model channel except neutrinos, because we work with background constraints take over and masses below a few GB

239
00:39:14.430 --> 00:39:23.640
Tracy Slatyer: And test again essentially every channel except neutrinos very efficiently, all the way down to the kV scale the least constraint channel overall

240
00:39:24.330 --> 00:39:37.200
Tracy Slatyer: is dark matter and Eileen to me ones with a large branching ratio, just because that's moderately hard to see. And for me, because it doesn't produce a ton of photons and in a MS or to the spectrum of particles produced is

241
00:39:37.860 --> 00:39:48.450
Tracy Slatyer: Less us peaky unless distinctive the narrative annihilation two electrons. So if you have a dominant branch ratio and to me once, then you can have the thermal really cross section down the masses around 20 GB

242
00:39:49.350 --> 00:40:02.760
Tracy Slatyer: But in general, if you want to document it will be a thermal relic and to be lighter than about 20 GB you either need a large branching ratio to neutrinos, or you want to or you need a way to suppress the annihilation in Malaya us

243
00:40:03.390 --> 00:40:14.670

Tracy Slatyer: Out, but if I delete universe. I mean, essentially everything off to the CMT a pop. There are multiple ways to do that. So this is not a no go theorem. It's just, but you do need some extra ingredients to do some relic like

244
00:40:17.310 --> 00:40:26.670
Tracy Slatyer: Okay. So just to recap, the current constraints and then all my last 15 minutes I'll go on and talk about some some some possible signals.

245
00:40:27.240 --> 00:40:33.450
Tracy Slatyer: We have searched for the visible products of dark matter annihilation and k in a broad range of experiments and looking at a broad range of target regions.

246
00:40:33.810 --> 00:40:42.660
Tracy Slatyer: But most of the final states we can place pretty stringent limits on the femoral cross sections or document masses below and up to around 10 to 100 GB

247
00:40:43.800 --> 00:40:53.460
Tracy Slatyer: Limit on annihilation to neutrinos. It typically a few orders of magnitude in somewhere like cross section across the whole range. So if you want to make sure we get those umbrella cross section about the orange.

248
00:40:54.360 --> 00:41:06.150
Tracy Slatyer: We can also constrained to K lifetimes. We to avoid attend to the 25 to 28 seconds for document a message, all the way from kV mess scales up to 10 to the 10 GV using a combination of

249
00:41:07.200 --> 00:41:16.320
Tracy Slatyer: The CSV early universe heating photon and you train on data, the least constraint channels here again, not counting neutrinos.

250
00:41:16.620 --> 00:41:31.470
Tracy Slatyer: Are pretty low, low mass dark matter and isolating leptons Lee, but the early universe. The combination of Voyager and the early universe constraints can already set pretty strong grounds in that region. And if we can get 21 centimeter observations fan belt test this region, even though

251
00:41:33.330 --> 00:41:38.700
Tracy Slatyer: Okay, so if you take like one thing about indirect detection. Take that status report away.

252
00:41:39.870 --> 00:41:47.730
Tracy Slatyer: Okay, so that's those limits on those isn't all results, but there are various um

253
00:41:48.210 --> 00:41:57.510
Tracy Slatyer: Excesses are anomalies or possible signals of the data. So let me just give you a quick rundown of those in the last in the last 15 minutes so

254
00:41:58.350 --> 00:42:09.030
Tracy Slatyer: We start out at the low mass end at the x ray range back in 2014 mobile at all. And boy ASCII it out both observed that when they looked at a stack sample of galaxy clusters.

255
00:42:09.300 --> 00:42:20.760
Tracy Slatyer: They saw what looked to be a spectral lines signal and energy of 3.5 KB both cases the significance was about four sigma. So, this is not massively significant, but um

256
00:42:21.450 --> 00:42:31.560
Tracy Slatyer: But you know, it's also not a true. It's also not true sigma. It's not easy to dismiss as a statistical fluctuation. They. Furthermore, they saw that the

257
00:42:32.130 --> 00:42:41.190
Tracy Slatyer: Significance when we if they just combine the signals from different clusters. Now you believe, but when they reach scale them. But when they have shifted the signal that account for regifting

258
00:42:41.370 --> 00:42:52.080
Tracy Slatyer: Properly assuming that this signal is truly coming from the clusters, then they got a significant signal. So, you know, that's that argues against it simply being some kind of instrumental affect

259
00:42:53.070 --> 00:43:02.850
Tracy Slatyer: Us that it's actually something coming from the cost is in question. Now there are possible non dogmatic contributions at 3.5 KB. There are other atomic spectral lines in that vicinity

260
00:43:03.390 --> 00:43:10.290
Tracy Slatyer: So aligned signal is not necessarily a document a smoking gun at these energies, whereas in the gamma rays. It would be a smoking gun.

261

00:43:12.030 --> 00:43:18.780
Tracy Slatyer: So they're like, so there are lines that could potentially contribute their tragic change reactions between heavy nuclei and neutral gas.

262
00:43:19.020 --> 00:43:26.310
Tracy Slatyer: Which could produce a structure of lions those energies which could be mistaken for a single line by experiments with the current level of energy resolution.

263
00:43:27.060 --> 00:43:34.770
Tracy Slatyer: But if you do want to explain it with document at the simplest way to do it is to say, right, we have the seven K be sterile neutrino. It's came to a photon plugin nutrient on

264
00:43:35.280 --> 00:43:42.750
Tracy Slatyer: There are significantly more complicated and Tesla's predictive dark matter and dark matter explanations as well. But that's the one that's getting the most attention.

265
00:43:43.560 --> 00:43:55.260
Tracy Slatyer: Now that explanation is extremely predictable because it's it because now you know exactly what the spectrum is you know what the masses. The only thing that controls your sequel your J factor is how much document of areas in any given system.

266
00:43:55.710 --> 00:44:00.270
Tracy Slatyer: So the first thing that people did was went and took a look at a bunch of other systems to see if they could see a signal.

267
00:44:01.740 --> 00:44:10.380
Tracy Slatyer: And they, there have been claimed observations of this 3.5 KB line and a number of other signals, including towards the center of the Milky Way galaxy.

268
00:44:10.740 --> 00:44:14.580
Tracy Slatyer: So this plot on the right, which is from a review by Kevin Sachi and in 2017

269
00:44:15.120 --> 00:44:30.630
Tracy Slatyer: summarizes a parent detections of the of this line, assuming a sterile neutrino scenario. So this one x. This is the mixing angle between the sterile neutrino and the visible neutrinos, which is directly relate, which essentially dramatizes the lifetime.

270

00:44:31.650 --> 00:44:32.250
Tracy Slatyer: Of this thing.

271
00:44:33.270 --> 00:44:41.700
Tracy Slatyer: And you see that there's this range of apparent detections, most of which are all, most of which many of which are consistent with 03 sigma

272
00:44:42.330 --> 00:44:52.620
Tracy Slatyer: But see, which seemed very broadly in the same ballpark. But there are also we're independent observations which didn't see a signal and which look at first glance to be in at least some tension with this apparent detection.

273
00:44:53.310 --> 00:44:59.430
Tracy Slatyer: Is a recent analysis by desert at out which are claims to set a new constraint which

274
00:44:59.910 --> 00:45:11.040
Tracy Slatyer: Is which appears to pretty cleanly rule out the region that is most favored by the author observation. There's an ongoing argument going on about these limits and whether they really strong.

275
00:45:11.490 --> 00:45:24.420
Tracy Slatyer: And I encourage you. This GitHub link I had presents a simplified version of the analysis, which is enough to see why the constraints are as strong as they are so you curious about this. I encourage you to, you know, go play around with it and form your own opinion.

276
00:45:26.010 --> 00:45:30.300
Tracy Slatyer: So that's the 3.5 KB line, the resolution to that one is

277
00:45:31.410 --> 00:45:41.550
Tracy Slatyer: Is likely going to be if we can get an x ray instrument that has better energy resolution, then we would be able to see exactly if the light that we will be able to measure the width of the line. Ideally,

278
00:45:41.940 --> 00:45:51.630
Tracy Slatyer: And if it's coming from document, there should be a width associated with the Doppler shift from the movement of data within the galaxy which if it could be measured would be a pretty great smoking gun.

279
00:45:54.420 --> 00:46:00.540

Tracy Slatyer: Okay, so next access am so to aunty protons. I mentioned earlier that

280
00:46:01.650 --> 00:46:11.700
Tracy Slatyer: There was perhaps a little bump in the MS surgery antiproton nexus that little bump on his, um, yeah. So, this this low o'clock on the right.

281
00:46:12.240 --> 00:46:26.820
Tracy Slatyer: Is showing the full spectrum and the size of the claimed bump. And you can see that it's a pretty. It's a pretty small signal. So it's only possible to detect this at all because MS claims, very tiny Airbus, the data.

282
00:46:27.750 --> 00:46:33.120
Tracy Slatyer: The nominal significance of this in the original papers was about four and a half sigma

283
00:46:33.780 --> 00:46:42.510
Tracy Slatyer: The best fit dogmatic parameters is shown in this right plot it corresponds to a document of massive between about 40 and 130 GV M.

284
00:46:43.440 --> 00:46:53.910
Tracy Slatyer: With a week fishes. That's assuming annihilation of equals, but there are similar masses for all the channels as well. And the cross section very conveniently is right around the somewhere like value.

285
00:46:54.300 --> 00:47:05.430
Tracy Slatyer: That you would need. So that's some so that's interesting, the challenges, though, as I said before, there are significant uncertainties in the modeling of how the any protons, of course, produced how they propagate.

286
00:47:06.120 --> 00:47:13.320
Tracy Slatyer: Both through the galaxy. And then in the neighborhood of the sun and the instrumental effects of am so cheap in particular.

287
00:47:14.400 --> 00:47:19.680
Tracy Slatyer: If you take a look. The MS or two error bars, it becomes immediately clear that they cannot be uncorrelated.

288
00:47:20.010 --> 00:47:27.210

Tracy Slatyer: Between beans because the scattered between Airbus and neighboring beings is much smaller than you would expect from just statistical fluctuations.

289
00:47:28.050 --> 00:47:40.680
Tracy Slatyer: But Amazon has not released a full covariance matrix for these error bars. There have been a couple of recent papers that have tried to put in ad hoc models for the correlations between and achievements and

290
00:47:41.700 --> 00:47:51.030
Tracy Slatyer: One group that did this found that the significance went up to five sigma and another group using a different model found that it went down to 0.5 sigma. So,

291
00:47:51.720 --> 00:47:59.850
Tracy Slatyer: My view of this access at the moment is that it's pretty interesting. But, um, this is a small signal were relying very heavily on understanding

292
00:48:00.600 --> 00:48:11.340
Tracy Slatyer: On understanding our uncertainties and at the moment. I don't think we have a good enough handle on the uncertainties to really be able to say whether this is significant, but that is a again a direction to keep an eye on.

293
00:48:13.650 --> 00:48:21.090
Tracy Slatyer: The positron channel. This is an older access. This is much bigger access. So I mentioned this early on that the ratio of drums

294
00:48:21.900 --> 00:48:29.610
Tracy Slatyer: Drums goes up with energy at high energies which is not what you would expect from expectations of positrons produced from protons hitting the gas.

295
00:48:30.120 --> 00:48:42.120
Tracy Slatyer: So this has been extensively discussed as possible seamless of dark matter annihilation or decay, but it requires very large cross sections, much higher than normal. And that's in some tension with the other measurements that we have looked at

296
00:48:43.890 --> 00:48:52.770
Tracy Slatyer: So that was it. So really what this empirically suggests is that there is some kind of source of primary source of positrons out there.

297
00:48:53.220 --> 00:48:57.840
Tracy Slatyer: And the argument for a long time has been. Could this be pulsars or could it

298
00:48:58.260 --> 00:49:14.070
Tracy Slatyer: Be dogmatic annihilating in recent years, the pulse our explanation has gotten a bit of a boost because the hawk telescope detected extended gamma ray emission around to nearby pulse us, which suggests that they are indeed producing a large amounts of high energy electrons and positrons

299
00:49:15.090 --> 00:49:21.870
Tracy Slatyer: And these recent papers argued that these measurements suggests pretty strongly that poses provide a dominant contribution.

300
00:49:22.080 --> 00:49:32.250
Tracy Slatyer: To the aim. So to posit comes in this plot on the right is an example model of the spectrum that you would expect from positron from these pulses scenario compared to the am so true data.

301
00:49:32.700 --> 00:49:44.430
Tracy Slatyer: I should say that there are still quite a lot of knobs to turn to get this model any particular this explanation doesn't require that I'm diffusion of electrons and protons within the galaxy is pretty highly in homogeneous.

302
00:49:44.640 --> 00:49:47.070
Tracy Slatyer: That there is going to the NPC yes

303
00:49:47.820 --> 00:49:48.480
Lisa Kaufman: minutes left.

304
00:49:48.810 --> 00:49:49.560
Lisa Kaufman: Yeah, good.

305
00:49:49.680 --> 00:49:49.950
Lisa Kaufman: Thanks.

306
00:49:50.460 --> 00:49:58.200
Tracy Slatyer: That there is going to be impeded diffusion around the pulse house. So that seems like a good possible explanation without the moment

307

00:49:58.650 --> 00:50:09.330
Tracy Slatyer: And so, too, has just well they haven't published this yet, as far as I know, but has recently reported something even more surprising, which is that they have been looking for.

308
00:50:09.960 --> 00:50:20.070
Tracy Slatyer: Anti nuclei and low energy anti nuclei a thought to be essentially non existent from astrophysical person says this part here is showing the expected flux of

309
00:50:21.570 --> 00:50:25.620
Tracy Slatyer: As showing the expected. Okay. The explosive showing the expected flux of anti helium.

310
00:50:26.160 --> 00:50:34.680
Tracy Slatyer: For all my doc meta from a document or annihilation model and from astrophysical processes. The blue and green lines of the astrophysical processes.

311
00:50:34.980 --> 00:50:42.180
Tracy Slatyer: And this career each and off here is a and so choose expected five years so Tinea sensitivity and you can see that the Astro

312
00:50:42.570 --> 00:50:47.550
Tracy Slatyer: And so to is expected to be background free in this channel. Unfortunately, it's also expected to be signal free

313
00:50:48.420 --> 00:50:55.890
Tracy Slatyer: Plausible document of models. The same is the same is true for anti Judah Ron's the upcoming gaps experiment is a dedicated NT tutor on search

314
00:50:56.520 --> 00:51:02.490
Tracy Slatyer: But am so true claims to have observed eight events that have consistent with an empty helium signal.

315
00:51:03.120 --> 00:51:16.440
Tracy Slatyer: So that's very surprising given this flow and it may well still be an instrumental error on the AMA. So two people I've talked to a very, you know, cautious about really describing this to cause to astrophysical anti helium.

316
00:51:17.730 --> 00:51:23.310
Tracy Slatyer: That's it. There's been some recent book by Winkler in London, just a month or two ago, the suggested that

317
00:51:23.640 --> 00:51:34.950
Tracy Slatyer: When computing the anti helium yield from dark matter annihilation. It's important to take into account the production of Lamb to be anti baryons because these indicator helium to empty helium with a high rate.

318
00:51:35.430 --> 00:51:45.030
Tracy Slatyer: And this is a point where they're a very difficult period for a week to give pretty different predictions. But what the yield should be that they claim is that if you tune

319
00:51:45.390 --> 00:51:57.600
Tracy Slatyer: In the right way to properly take into account this production of fun to bury homes, then you can potentially get a signal that is launching a famous so to say. So again, that's something to keep an eye on potentially interesting

320
00:51:59.520 --> 00:52:07.770
Tracy Slatyer: So the last access which you know in three minutes. I'm just going to give you to give you the highlights. But yeah, I'm happy to answer more questions about it later.

321
00:52:08.040 --> 00:52:15.540
Tracy Slatyer: Is another long standing one. This has been around for about this, but if we look towards the center of the galaxy. There is a glow of gamma rays around the galactic center.

322
00:52:16.170 --> 00:52:21.840
Tracy Slatyer: Which looks roughly like a fuzzy blog, there's debate ongoing as to whether

323
00:52:22.110 --> 00:52:33.600
Tracy Slatyer: The access looks more like the Galactic bhogal more like something spiritual if it really looks like the Galactic bullish that would suggest is still origin, if it looks more spherical that might be more consistent with the document or explanation.

324
00:52:34.080 --> 00:52:40.530
Tracy Slatyer: These a gamma ray photons peaking at energies of one to three GB mostly in the region within about 10 degrees of the galactic center.

325
00:52:40.860 --> 00:52:50.520

Tracy Slatyer: Called the galactic center access. This was supposed discovered by good enough and Hooper in 2009 and confirmed by many other groups. Subsequently, including the funny collaboration in 2016

326
00:52:51.540 --> 00:52:54.540
Tracy Slatyer: The simple stock better explanation is still a relic document is

327
00:52:55.680 --> 00:53:03.240
Tracy Slatyer: Dark Matter annihilating hydroponically and way to make neutral pylons and then photons with a mass scale between about 10 and 100 GB it's

328
00:53:03.750 --> 00:53:13.620
Tracy Slatyer: The cross section that you need is bang on the film or relic value. So this is also quite consistent with that am so to anti fraud on ACCESS THE ONE OF debatable significance.

329
00:53:14.280 --> 00:53:23.010
Tracy Slatyer: Um, but, so this plot is showing the spectrum of the access these statistical errors only these data points. So this is powerful over and make interval versus energy

330
00:53:23.340 --> 00:53:26.220
Tracy Slatyer: The black line is a document model that's been fitted to the data.

331
00:53:26.580 --> 00:53:36.600
Tracy Slatyer: But another possible explanation for this is encompassed by these dashed and dotted lines which are the specter of observe pulse have observed millisecond, Paul says in the front me data.

332
00:53:37.260 --> 00:53:46.050
Tracy Slatyer: So the leading non dark matter explanation has been the what we've actually discovered here is a large new population of Paul says in this region of the galaxy.

333
00:53:49.170 --> 00:53:57.000
Tracy Slatyer: So this so the arguments against this week, the argument for being dark matter is essentially the spectrum looks like what you the spectrum and the great

334
00:53:57.270 --> 00:54:04.890

Tracy Slatyer: Looks like what you would expect from somewhere relic doc Matta 10s of GB annihilating hydroponically the arguments against it, that

335
00:54:05.220 --> 00:54:10.530
Tracy Slatyer: Some of them you were analyses find that the spatial will follow G looks more like the stone cold, then why something circle.

336
00:54:11.010 --> 00:54:20.280
Tracy Slatyer: There out I'm hesitant. I'm a little hesitant about these analyses, just because the result can be very since this result can be pretty sensitive to how you move the backgrounds and the choice of region of interest.

337
00:54:21.960 --> 00:54:27.930
Tracy Slatyer: And how you model the other points horses in the region, but if confirm this would be a good argument against the dark matter scenario.

338
00:54:28.380 --> 00:54:34.260
Tracy Slatyer: There are constraints from other searches the limits from two galaxies initially a PhD in some tension with this document or explanation.

339
00:54:34.530 --> 00:54:42.150
Tracy Slatyer: But the recent studies that I mentioned yesterday, looking at the uncertainties and the dwarf J factors have found that actually there's not really a lot of tension, then

340
00:54:43.110 --> 00:54:52.950
Tracy Slatyer: The third argument against the dark matter interpretation which I would talk more about if I have more time, but I want to you because I'm basically out of time is to look at the code on statistics of the excess

341
00:54:53.460 --> 00:55:06.300
Tracy Slatyer: So I'm just going to give you the zero code a summary of what's happened in the last few years on this. So in 2016 my collaborators and I and several other people developed a new statistical techniques to try to look for

342
00:55:06.900 --> 00:55:18.150
Tracy Slatyer: How clumpy the galactic center access was because if it was very clunky that might suggest it was coming from a relatively small number of points offices as opposed to something like dark matter annihilation, which would expect to be mostly

343
00:55:18.600 --> 00:55:27.360
Tracy Slatyer: We run the analysis and we found that the access seem to really want to be very funky. So we said okay that's evidence that is points also we've discovered Posada in the galaxy went down.

344
00:55:28.560 --> 00:55:38.280
Tracy Slatyer: But last year I revisited this analysis with Rebecca lean, who was a postdoc at MIT at the time and we found off. There's a bit of an issue with this analysis.

345
00:55:38.580 --> 00:55:50.700
Tracy Slatyer: If you add a document a signal to the real data and run the analysis. Again, it still says it's all point to losses and it continues to say this until you inject a signal that's about five times larger than the access itself.

346
00:55:51.150 --> 00:55:58.080
Tracy Slatyer: So that custom data on the initial statement that what the baseline accesses points horses.

347
00:55:59.310 --> 00:56:10.830
Tracy Slatyer: Then my colleagues at Michigan and Berkeley and Princeton showed in a couple of papers late last year early this year that this bad behavior that the

348
00:56:12.090 --> 00:56:25.680
Tracy Slatyer: That the Fitch, Miss attributes A document a signal to point sources with an equivalent way of saying that is that it actually would prefer to give the document a single very negative flux in the original fit.

349
00:56:26.430 --> 00:56:34.830
Tracy Slatyer: That that appears to be a problem with the background model and that if you use a better background model than that bad behavior goes away.

350
00:56:35.220 --> 00:56:45.180
Tracy Slatyer: And then the evidence points horses drops down a lot from about six or seven sigma down to about three sigma, but there's still appears to be some preference of points also is there, but then

351
00:56:46.380 --> 00:56:59.460
Tracy Slatyer: Earlier this year, Rebecca Lee and then I showed that there's another issue which is that it turns out that the method were

using can very easily confused, just giving the fifth the wrong model for the signal with having point sources.

352
00:57:00.450 --> 00:57:08.700
Tracy Slatyer: So I'm just going to show you one slide and then I'll wrap up because we've been come two minutes over. So, this

353
00:57:09.660 --> 00:57:16.440
Tracy Slatyer: So just looking at these plots these top plots are result of an analysis on the real data. This on

354
00:57:17.070 --> 00:57:23.580
Tracy Slatyer: This first panel is showing the posterior probability distribution. So the flux associated with the smooth GC in red.

355
00:57:23.880 --> 00:57:33.660
Tracy Slatyer: And a GC made a point sources in blue. So this is the result that says the GC looks like it's 100% made of points horses with very small smooth component

356
00:57:34.350 --> 00:57:46.200
Tracy Slatyer: And it in fuzz and the number of sources that you have as a function of flux. That's what the plot on the right is showing the blue line shows how many sources you infer as a function of flux for the galactic center access now.

357
00:57:46.710 --> 00:57:59.580
Tracy Slatyer: The little clock is based on simulated data. And in that simulated data, the galactic center access is 100% smooth, but there's a difference in the brightness of the access between the northern hemisphere in the southern hemisphere.

358
00:58:00.210 --> 00:58:06.840
Tracy Slatyer: And it turns out that that difference in brightness is actually preferred in the fit to the real data. But this, this is just a simulation.

359
00:58:07.290 --> 00:58:16.920
Tracy Slatyer: So we've simulated that completely smooth Galactic Center access brighter in the north and the south we run the same analysis that people have been wanting to try to detect point sources.

360
00:58:17.340 --> 00:58:23.370
Tracy Slatyer: And this is what happens. And you see that again. The fit is like, Yep, no smooth component. Hundred percent point sources.

361
00:58:23.940 --> 00:58:31.230
Tracy Slatyer: And the on on the right, we see the reconstructed flexes, we see the reconstructed number of sources as a function of flux

362
00:58:31.950 --> 00:58:35.550
Tracy Slatyer: But these different components and it looks exactly like the real data.

363
00:58:36.060 --> 00:58:46.110
Tracy Slatyer: So this is an example that you can mimic the behavior in the real data extremely well with the galactic center access that is 100% smooth. If you guys morphology somewhat wrong.

364
00:58:46.410 --> 00:59:00.210
Tracy Slatyer: So I would not at this point tape very, um, wait, very heavily the evidence that the galactic center access has made a point sources. That doesn't mean it's made of dark matter, but don't throw away the non points also explanations.

365
00:59:01.500 --> 00:59:12.720
Tracy Slatyer: Okay, so I'm going to wrap up there. So I hope I've convinced you that indirect detection is telling us interesting things, and that there are some interesting possible signals to keep an eye on.

366
00:59:13.410 --> 00:59:22.590
Tracy Slatyer: Looking forward to the future. We their improvement student may be modeling the signal as we get better understanding of how documentaries distributed in our galaxy and beyond.

367
00:59:23.250 --> 00:59:35.820
Tracy Slatyer: Their improvements to be made a modeling the backgrounds as a message to continues to measure the cosmic rays as we understand the cultural population of our galaxy better, we will get a better handle on some of these backgrounds.

368
00:59:36.750 --> 00:59:51.330
Tracy Slatyer: There a future missions CTA looking for high energy gamma rays amigo proving that MTV to GV gamma ray band gaps which will touch because and create anti Judah runs the 21 centimeter experiments and see me stage for going off to the whole universe and many more.

369
00:59:53.580 --> 00:59:59.490
Tracy Slatyer: Which will hopefully give us more enriched data sets to continue this search into the future. Thanks very much.

370
01:00:01.740 --> 01:00:06.360
Lisa Kaufman: Thank you, Tracy for that really nice talk. Okay, we'll turn it over to Q AMP a

371
01:00:07.560 --> 01:00:10.830
Lisa Kaufman: 10 minutes rich will moderate questions for you.

372
01:00:12.450 --> 01:00:15.240
Richard Partridge: Okay. Hi, Tracy, thanks a lot for wonderful

373
01:00:16.560 --> 01:00:21.540
Richard Partridge: The first question I here. Actually, there were several questions that were pretty similar.

374
01:00:25.200 --> 01:00:32.490
Richard Partridge: And so let me just pick out one of these usually cosmic rays should give rise to a plus b minus equal rates. Right.

375
01:00:32.820 --> 01:00:33.120
Tracy Slatyer: Yep.

376
01:00:33.210 --> 01:00:40.230
Richard Partridge: They come from protest pair producing and why are positrons a sensitive probe for dark matter.

377
01:00:41.010 --> 01:00:49.110
Tracy Slatyer: Good. Yeah, so, um, most of the cosmic rays that we, our hypothesis is that most of the high energy cosmic rays that we see.

378
01:00:51.090 --> 01:01:03.090
Tracy Slatyer: Coming from electrons and protons that get accelerated in high energy supernovae. So these are not electrons that are made by peppered auction. These are like just the electrons that are floating around our galaxy all the time.

379
01:01:03.870 --> 01:01:07.320
Tracy Slatyer: In the supernova sharks. They get accelerated up to high energies.

380
01:01:07.560 --> 01:01:11.910
Tracy Slatyer: And then we see them it up so that the asymmetry between electrons and protons is

381
01:01:12.090 --> 01:01:22.800
Tracy Slatyer: You know, reflective of the asymmetry between electronic sorry the asymmetry between electrons and positrons or protons and anti protons is reflective of the asymmetry in our universe between matter and antimatter so Paul says,

382
01:01:24.060 --> 01:01:32.730
Tracy Slatyer: So, you know, Paul says do produce electrons and positrons by production, as you said, I'm in a production cascade. So that's why the pulse cell signal.

383
01:01:33.780 --> 01:01:45.150
Tracy Slatyer: Which produces can act as an abundant primary source of positron similar to dark matter annihilation and potentially explain the extra positrons in am so true at high energies.

384
01:01:48.720 --> 01:01:49.050
Richard Partridge: Right.

385
01:01:50.280 --> 01:01:53.340
Richard Partridge: The next question is on

386
01:01:54.630 --> 01:01:55.950
Richard Partridge: Slide for

387
01:01:58.770 --> 01:02:08.640
Richard Partridge: And the question read minimal model and data are in very, very consistent for the highest energy points. Is there any possible concern about overfitting.

388
01:02:10.710 --> 01:02:19.050
Tracy Slatyer: I'm okay that yeah so good that minimal model is like just on in the right hand panel. I assume this means

389
01:02:19.650 --> 01:02:24.720
Tracy Slatyer: That mental model is like just a numerical fit to to the data. It's not a theoretical model.

390
01:02:24.960 --> 01:02:36.930
Tracy Slatyer: On the theoretical model for what the signal would be from your secondaries, as I said would basically be aligned that went down here, I would not agree with the data at all. But, um, so, so, yeah. I mean, but

391
01:02:38.040 --> 01:02:46.950
Tracy Slatyer: So, so I mean like, yes, it's probably a defeated. It's just, just move function that they have made to go through the data points, but it's worth noting that I'm

392
01:02:47.550 --> 01:02:57.300
Tracy Slatyer: Am so two data points, especially at the lower energies have less scatter than you would expect from a statistical on Sunday, only because these aerosols include systematic concerned. He's as well as statistical

393
01:02:58.080 --> 01:03:02.010
Tracy Slatyer: Although I think at the highest energies. If it's statistics dominated

394
01:03:02.550 --> 01:03:13.920
Tracy Slatyer: But I'm busy systematic component that systematic component is correlated between bins understanding those correlations becomes really important when, if you see like a localized bump and you want to understand how significant it really is.

395
01:03:14.130 --> 01:03:24.150
Tracy Slatyer: Which is the situation and anti protons and which is why it's still not really clear if that it for it on access that I talked about as a one secure access or five similar access because it all depends on the between correlations

396
01:03:25.290 --> 01:03:28.890
Richard Partridge: OK, the next question is how Slide seven

397
01:03:31.710 --> 01:03:45.810
Richard Partridge: Oh, why do cross session limits for dark matter decay annihilation and g plus or minus display spiky features between one Tony V and 50 maybe around 10 GB

398
01:03:47.160 --> 01:03:51.930
Tracy Slatyer: That's a, that's a good question. So, um,

399
01:03:53.520 --> 01:04:02.520
Tracy Slatyer: I would, yeah that's that's a good question and one to which I do not know the answer offhand, often those spiky features or something along the lines of the

400

01:04:02.970 --> 01:04:11.340
Tracy Slatyer: The experiment has like several energy chat has effectively like several energy bins that reported data in and if your signal is pretty so the

401
01:04:11.730 --> 01:04:19.800
Tracy Slatyer: electron positron signal, even after diffusion. The signal is still pretty peeps, so it can be localized to one energy been so with the energy being that it's in

402
01:04:20.520 --> 01:04:33.540
Tracy Slatyer: So as you dial the mass of the dark matter, the energy been in which the signal peaks will change. And if you know a Jason energy bins had somewhat different up a women's then that can cause a feature in the

403
01:04:34.650 --> 01:04:42.690
Tracy Slatyer: Yes, that that goes a feature in the constraint which channels that are not electrons and positrons, the spectrum of cosmic rays is generally considerably smoother.

404
01:04:42.990 --> 01:04:52.320
Tracy Slatyer: Because so direct annihilation that you plus C Minus is the initial spectrum before propagation is a delta function like all the electrons and positrons just have the energy of the document of mass

405
01:04:52.740 --> 01:05:01.230
Tracy Slatyer: And so, even after propagation is still pretty steep, whereas if for example you made me want to make a two electrons that spectrum will be much broader diffusion will smooth it out further

406
01:05:01.470 --> 01:05:06.570
Tracy Slatyer: And so the constraint will generally be coming from multiple energy bins and that sort of average it out the

407
01:05:07.800 --> 01:05:21.030
Tracy Slatyer: That, that, sort of, yeah. Just, just like averages out the variations from being to being um so my guess would be that that's what's going on, but I actually do not remember if that's exactly what's going on in the Voyager paper, but that would be my guess.

408
01:05:22.050 --> 01:05:26.580
Richard Partridge: Okay, so we jumped up to slide 14

409
01:05:30.330 --> 01:05:33.750

Richard Partridge: And the question is an insight 14

410
01:05:36.120 --> 01:05:45.510
Richard Partridge: Question is why does the minus nine of the dark matter, getting annihilated Cortana to a one minus six distortion in the CSV spectrum.

411
01:05:47.250 --> 01:05:51.450
Tracy Slatyer: So it's just this argument that I gave here that I'm so

412
01:05:52.650 --> 01:06:01.920
Tracy Slatyer: I mean this is it's 10 to the minus six, at most, so suppose you liberated one pot in 10 to the minus nine of the energy stored in the document at matter radiation equality so redshift.

413
01:06:02.430 --> 01:06:04.350
Tracy Slatyer: Average of 3000 or so.

414
01:06:04.860 --> 01:06:13.380
Tracy Slatyer: And then it's matter radiation equality, so total energy density in the CMT as the same as the total energy density and matter which is approximately the end if you don't see in dark metal

415
01:06:13.560 --> 01:06:22.530
Tracy Slatyer: So if I liberate 10 to the minus nine. If the energy in the dark matter, that means I'm changing the energy density in the CM e by 10 to the minus nine as well. Now,

416
01:06:23.130 --> 01:06:31.050
Tracy Slatyer: When now not at Richard 3000 anymore. But at red shift zero. So the universe has expanded by a factor of 3000 since then.

417
01:06:31.350 --> 01:06:33.990
Tracy Slatyer: And the energy density and the CM be relative to matter.

418
01:06:34.230 --> 01:06:44.580
Tracy Slatyer: Has dropped by a factor of 3000 so like in the present day right at the moment the energy then seeing the CMT is about a factor of 3000 below the energy density and dark matter. So if we're right in the present day.

419
01:06:44.970 --> 01:06:54.450

Tracy Slatyer: I took 10 to the minus nine of the energy in the dark matter and converted it to energy in the C NB that would be roughly 10 to the minus six effect just 3000 times 10 to the minus nine.

420
01:06:55.740 --> 01:07:04.950
Tracy Slatyer: But that's all the annihilation happened today, whereas you know most of the most of the conversion was really had that we can look for what's happening. Earlier in the universe is history.

421
01:07:05.370 --> 01:07:10.320
Tracy Slatyer: And so in reality the signal will be below 10 to the minus six. If you do a detailed study

422
01:07:11.160 --> 01:07:19.290
Tracy Slatyer: Of models that are not yet rolled out by ionization, which again 10 to the minus nine is like a huge signal in ization

423
01:07:19.620 --> 01:07:23.070
Tracy Slatyer: And the real constraint is more like down at 10 to the minus 11 so

424
01:07:23.370 --> 01:07:33.660
Tracy Slatyer: If you ask what is the CMT spectral distortion for models that are on the boundary of being rolled out by the ionization signal for dark matter annihilation my memories. It's between 10 to the minus nine and 10 to the minus 10

425
01:07:37.440 --> 01:07:39.750
Richard Partridge: Jobs for decide 24

426
01:07:42.900 --> 01:07:49.110
Richard Partridge: And the question is, could the seven K TV sterile neutrino also explain the LM s amp D anomaly.

427
01:07:51.390 --> 01:08:01.020
Tracy Slatyer: I think that's really the wrong mass range for the lesson D anomaly. I haven't worked as much on the lesson D anomaly, but my understanding is that a reply as much like a sterile neutrinos.

428
01:08:04.230 --> 01:08:04.650
Richard Partridge: And

429
01:08:06.630 --> 01:08:09.720

Richard Partridge: Dark matter. I'm going to leave the case with species in the dark.

430
01:08:10.860 --> 01:08:16.320
Richard Partridge: Is there any experimental way still to determine its nature, apart from the gravitational one

431
01:08:17.070 --> 01:08:21.300
Tracy Slatyer: Um, so it depends what the stuff in the doc sector to case do if the

432
01:08:21.840 --> 01:08:29.010
Tracy Slatyer: If the stuff in the doc sector to case back to the standard model, then you can use a lot of these constraints. It's just the spectrum of your final states changes a little bit

433
01:08:29.520 --> 01:08:35.910
Tracy Slatyer: Um, but, you know, most of broadly the constraints would roughly carry across if it decays probably back to the standard model.

434
01:08:36.510 --> 01:08:43.140
Tracy Slatyer: If it the case back to the standard model with a long lifetime, then that changes the constraints by a bit more. But usually you can still constrain it

435
01:08:43.470 --> 01:08:49.470
Tracy Slatyer: If it doesn't take it back to the standard model at all. And it's just like documented decaying say to some doc radiation component

436
01:08:50.310 --> 01:09:05.490
Tracy Slatyer: Then, then you're mostly reduced to gravitational cosmological constraints. But so, for example, you can look for evidence of changes to the expansion history of the universe and the doc radiation component. You can look at

437
01:09:06.000 --> 01:09:10.710
Tracy Slatyer: And changes to document a structure formation from the presence of the doc radiation component

438
01:09:11.250 --> 01:09:18.060
Tracy Slatyer: And I mean like there are constraints from this CM be on from structure formation that basically say that no more than 4%

439

01:09:18.390 --> 01:09:29.220
Tracy Slatyer: Of the dogmatic and decay into invisible doc radiation between the CME in the present day. But still, I mean, you can see how much seeing the visible signals buys you you know we can we can say

440
01:09:30.540 --> 01:09:38.850
Tracy Slatyer: You. We've seen that with with that with the K to stand and mobile particles, you can sort of test the hypothesis that one pod intend to the 10 or 10 to the 11

441
01:09:39.090 --> 01:09:49.230
Tracy Slatyer: Of the doc Matta decays away between the CMT epoch in the present day. And as soon as you say, well, actually, it came to something totally invisible. It's just doc radiation than the limit becomes more like

442
01:09:49.710 --> 01:09:59.160
Tracy Slatyer: We can say that up to 4% of the dark matter put two k away. So it's a it's like you know it's it's the eight orders of magnitude in a constraint.

443
01:10:01.500 --> 01:10:05.460
Tracy Slatyer: See there are some things you could do. But it would definitely be nice to have it. The case indivisible stuff.

444
01:10:08.340 --> 01:10:08.970
Richard Partridge: Timing so

445
01:10:10.770 --> 01:10:11.640
Lisa Kaufman: We're at time

446
01:10:13.980 --> 01:10:20.460
Lisa Kaufman: So I guess we'll have to answer the rest of the questions offline Tracy, thank you so much and

447
01:10:22.500 --> 01:10:25.770
Tracy Slatyer: Thank you all for all the great questions and I hope you enjoy the rest of us. So

448
01:10:26.790 --> 01:10:27.300
Lisa Kaufman: Thank you.

449
01:10:28.800 --> 01:10:29.160
Lisa Kaufman: Will have

450
01:10:29.820 --> 01:10:34.290
Lisa Kaufman: stop the recording and then we'll have a 10 minute break before our final talk of the day.